ISSN 2427-4577

BULLETIN N° 254
ACADÉMIE EUROPÉENNE INTERDISCIPLINAIRE DES SCIENCES
INTERDISCIPLINARY EUROPEAN ACADEMY OF SCIENCES

Lundi 7 février 2022 (en format mixte présence-distance) :

15h : Hommage à notre regretté collègue Claude Maury
15h 30 : Conférence :
"***L'apport des sciences de l'environnement, de l'évolution et de la socio-écologie face au risque futur de pandémies***"
Par la Pr. Delphine DESTOUMIEUX-GARZÓN
Directrice de Recherche au CNRS
Directrice d'Unité Adjointe
Laboratoire Interactions Hôtes-Pathogènes-Environnements (IHPE)
UMR 5244 CNRS/Université de Montpellier/ Ifremer/Université de Perpignan

Notre Prochaine séance aura lieu le lundi 7 mars 2022 de 15h30 à 18h00
Salle Annexe Amphi Burg
Institut Curie, 13 rue Lhomond - 75005 Paris

Elle aura pour thème :

15h30 : Conférence
'La matière noire à la croisée des chemins de deux modèles standards"

Par notre Collègue **Gilles Cohen-Tannoudji**
Chercheur émérite au Laboratoire de recherche sur les sciences de la matière (LARSIM - CEA - Saclay)
Conseiller scientifique de la Direction de la recherche fondamentale au CEA

Académie Européenne Interdisciplinaire des Sciences
Siège Social : 5 rue Descartes 75005 Paris
Nouveau Site Web : http://www.science-inter.com

ACADÉMIE EUROPÉENNE INTERDISCIPLINAIRE DES SCIENCES
INTERDISCIPLINARY EUROPEAN ACADEMY OF SCIENCES

Février 2022

N°254

TABLE DES MATIERES

<u>Prochaine séance : lundi 7 mars 2022 de 15h30 à 18h00</u>

15h30 : Conférence
"La matière noire à la croisée des chemins de deux modèles standards"

Par notre Collègue **Gilles Cohen-Tannoudji**
Chercheur émérite au Laboratoire de recherche sur les sciences de la matière (LARSIM - CEA - Saclay)
Conseiller scientifique de la Direction de la recherche fondamentale au CEA

ACADÉMIE EUROPÉENNE INTERDISCIPLINAIRE DES SCIENCES

INTERDISCIPLINARY EUROPEAN ACADEMY OF SCIENCES

Séance du Lundi 7 février 2022 mixte présentiel-distanciel

La séance est ouverte à 15h, **sous la Présidence de Victor MASTRANGELO**

- **Étaient présents physiquement nos Collègues membres titulaires** : Gilbert BELAUBRE, Jean BERBINAU, Éric CHENIN, Gilles COHEN-TANNOUDJI, Françoise DUTHEIL, Michel GONDRAN, Irène HERPE-LITWIN, Jean-Pierre TREUIL
- **Étaient connectés à distance nos Collègues** : Jean-Louis BOBIN, Anne BURBAN, Jean-Félix DURASTANTI, Abdel KENOUFI, Édith PERRIER, Jacques PRINTZ, Jean SCHMETS

I. Hommage à notre Collègue Claude MAURY

À la suite de la disparition de notre très regretté Collègue Claude MAURY le 5 janvier 2022, notre Président Victor MASTRANGELO et nos Collègues Gilbert BELAUBRE, Irène HERPE-LITWIN, Edith PERRIER, Jean Pierre TREUIL ont prononcé un discours rappelant pour certains leurs liens personnels, pour d'autres leurs liens scientifiques, philosophiques, épistémologiques avec notre très regretté Collègue Claude MAURY qui avait été jusqu'à l'issue de sa maladie un membre très actif de notre société savante.

Après leurs discours, une minute de silence a été observée.

Voici les textes des discours communiqués :

1. Victor MASTRANGELO

HOMMAGE de notre société savante à notre Collègue Claude MAURY
décédé le 5 janvier 2022

Je vais d'abord délivrer quelques propos et ensuite donner la parole à des collègues qui ont eu des moments d'échanges privilégiés avec lui. Je vais donc demander successivement à Irène, Edith, Jean-Pierre et Gilbert de bien vouloir intervenir sachant que nous devons normalement terminer cet hommage pour 15h30, heure du début d'intervention de notre conférencière.

Claude est donc décédé le mercredi 5 janvier 2022 à l'âge de 79 ans.

Il est passé par l'Ecole Polytechnique (promotion 1961) et l'Ecole des Mines de Paris qui l'a conduit à intégrer le Corps des Mines.

Il a assuré successivement la direction technique de l'école des Mines de Nancy, la direction des relations extérieures de l'Ecole Polytechnique et enfin au Ministère de l'Industrie il a dirigé la cellule qui a en charge la tutelle des écoles d'ingénieurs qui dépendent de ce ministère. Il s'est beaucoup impliqué dans la définition des programmes scientifiques des écoles d'ingénieurs au sein du CEFI – Comité d'études sur les formations d'ingénieurs. Il a terminé sa carrière comme Ingénieur général des Mines.

Après cette brillante carrière, il a demandé en toute modestie son adhésion à notre société savante comme membre titulaire le 7 avril 2014.
En plus de ses connaissances scientifiques et techniques étendues, il avait un intérêt tout particulier pour développer une démarche philosophique dans les cercles scientifiques écrivait-il. Je voudrais rappeler un texte important qu'il avait produit et intitulé *Les théories dans* lequel, il écrivait je cite « Les théories apparaissent selon les cas avoir une dimension utilitaire et pragmatique lorsqu'elles nous permettent surtout de prévoir, ou une dimension cognitive lorsqu'elles nous apportent interprétations et compréhension. On

peut, si on est philosophe, se concentrer (sur) la dimension formelle qu'elles donnent à un discours supposé faire le pont entre l'esprit humain et la réalité… »

Mes collègues vont certainement parler des nombreuses contributions de Claude au sein de notre société savante.
Je voudrais pour terminer ce propos vous relater une qualité particulière qu'avait Claude : un sens aigu du devoir accompli qui m'a a posteriori impressionné ! Lors de notre dernier colloque des 28 et 29 octobre derniers, il avait été programmé pour être le modérateur de la quatrième session du vendredi après-midi. Le jeudi du colloque j'ai noté qu'il n'était pas du tout en forme mais je n'ai pas cherché plus loin. Le vendredi matin il est arrivé en costume et en apparence en forme.

L'après-midi j'ai compris que cela n'allait pas du tout, je me suis empressé de lui proposer de l'aider dans sa tâche de modérateur. Il m'a répondu qu'il allait assumer ce rôle qu'il avait l'habitude. Ce qu'il a fait. Quelques jours après Jean-Pierre Treuil était informé de la maladie incurable de Claude qui allait l'emporter rapidement, il m'en informa aussitôt. J'ai appelé Claude nous avons échangé comme si de rien n'était. Je lui ai tenu des propos de circonstance et lui ai dit que nous étions à sa disposition et en particulier moi-même.

2. **Gilbert BELAUBRE** (*texte rédigé à partir de l'enregistrement audio*)

Gilbert BELAUBRE a connu Claude MAURY lors de son entrée à l'AEIS en 2014. Ils se sont rapprochés comme d'anciennes connaissances. CLAUDE MAURY a trouvé à l'AEIS un milieu qui lui a permis de s'exprimer. Il avait une perception de la science comme le résultat d'un *système adaptatif complexe* (SAC).

GILBERT BELAUBRE met en regard de cette vision *épistémologique de la science* la *vision neurologique de la fabrication de la science* par le cerveau à la suite de l'extraordinaire livre de Stanislas DEHAENE « Face à face avec son cerveau » paru en septembre 2021 peu de temps avant que CLAUDE MAURY ne sombre dans la maladie. Selon cet ouvrage tout le déroulement de l'accession à la connaissance est aujourd'hui accessible via l'immense instrument installé à Neurospin. Ainsi l'homme se voit en train de penser et il sait ce qui se passe en visant les circuits qui se mettent en route dans son cerveau, ce qui est extraordinaire. Cette époque nous a apporté des certitudes quant à la capacité des molécules à former de grosses molécules, à former de l'ARN et de l'ADN, à former de grosses couches qui se ferment sur elles-mêmes pour former des cellules qui contiennent de l'ADN et tout cela se produisant dans une édification quasi automatique à partir du moment où les conditions de concentration, de température …sont réunies. La vie devient en somme prévisible, inéluctable et elle existe probablement partout où ces conditions sont réunies… Sous quelle forme ? Peut-être pas tout à fait la même partout puisque l'évolution n'est qu'une histoire.

Telles étaient leurs discussions scientifiques …Ils ne pensaient pas tout à fait de la même façon puisque CLAUDE MAURY était fasciné par la notion de *hasard* tandis que pour GILBERT BELAUBRE le *hasard* était une notion dénuée de sens.

Mais en réalité leurs relations étaient ailleurs… Elles se sont formées lors de leurs rencontres dans la résidence secondaire de GILBERT BELAUBRE à Montreuil aux Lions où ils discutaient de leurs émotions. Ils partageaient le goût de la musique, de la peinture, de la poésie … Selon GILBERT BELAUBRE la règle corrige l'émotion et l'émotion corrige la règle..

Avec CLAUDE MAURY GILBERT BELAUBRE a donc eu cette relation très particulière et privilégiée tout en revenant alternativement aux sujets scientifiques, épistémologiques. GILBERT BELAUBRE déclare que « la vérité est ce que je crois devoir croire aujourd'hui » et cite une phrase de Paul VALERY relative à la clarté , selon laquelle « Tout ce qui est clair est faux, mais tout ce qui n'est pas clair est inutile. » .

Voilà ce qu'a été CLAUDE MAURY pour GILBERT BELAUBRE.

3. Irène HERPE-LITWIN

C'est avec une très grande tristesse que j'ai appris la disparition le 5 janvier 2022 de notre Collègue Claude MAURY qui avait rejoint l'AEIS le en tant que membre titulaire le 7 avril 2014. Notre Collègue était très assidu à nos séminaires mensuels ainsi qu'à nos colloques où il avait accepté l'animation de sessions

Très épris d'épistémologie, après notre fameux colloque de 2016 sur « Ondes, Matière et Univers », il nous avait proposé de faire un colloque sur « Science et Hasard » en 2018. Son projet était fort bien étayé, le hasard avait été très présent dans de nombreux domaines de la science, mais une autre thématique intéressante, à savoir, « Les Signatures de la Conscience » avait été retenue. Cela ne l'aurait pas empêché de présenter à nouveau son sujet très intéressant …Malheureusement la maladie ne lui pas accordé cette possibilité.

Je regretterai donc toujours la disparition d'un collègue chaleureux, amical et épris d'épistémologie.

4. Edith PERRIER

Notre président Victor vient de nous dire que Claude avait fait acte de candidature à l'AEIS le 7 avril 2014. J'ai vérifié, je suis donc de la même promotion AEIS14 que Claude. Moins prestigieux que « même promotion X61" comme pour Jean-Pierre Treuil, mais j'en suis malgré tout très honorée. Et surprise. Car pour moi Claude Maury était membre de l'AEIS depuis , disons… « très longtemps »… Je l'ai toujours vu présent à nos réunions depuis les toutes premières auxquelles il m'a été donné de participer, je l'ai souvent vu intervenir avec humour et intelligence, et me souviens très bien de sa proposition d'un projet de colloque sur le hasard, et j'avais d'ailleurs voté pour sa proposition . Cet homme me plaisait, mais de fait je ne le connaissais pas. Je l'ai vraiment rencontré à la suite de mon exposé de juin 2021, qui consistait en un plaidoyer pour la reconnaissance de l'incertitude dans la démarche scientifique, car il y a réagi, y compris par écrit, de façon à fois critique et constructive. Nous avons échangé des idées, nous avons même déjeuné ensemble près du Luxembourg un jour de soleil avant une réunion d'un Lundi AEIS où il repartait chez lui assister à distance à cause des quotas de présence en temps de Covid. Il m'a envoyé des textes de son cru sur le sens de la Science que j'ai trouvés extrêmement intéressants. Il réfléchissait beaucoup et écrivait très bien. Plutôt que de m'appesantir sur la profonde tristesse que me cause sa disparition, avec un décès que je n'ai pas absolument pas vu venir malgré les problèmes de santé qu'il l'avait annoncés lors de notre dernier colloque et que j'ai trop pris à la légère, je me contenterai de vous encourager à lire son projet d'article sur la science et l'actualité qu'il avait mis en ligne à me demande sur la Dropbox de l'AEIS, et vous lire la dernière version la conclusion de ce papier , car les hommes passent et l'essentiel est sans doute intemporel, et laisse donc la parole à Claude avec son dernier Mail du 12 octobre 2021 intitulé nouvelle conclusion de mon papier

Mieux saisir la nature de la science

On peut revenir, à la lumière de ces analyses, sur la question de la nature de la science, sans que se dégage sur ce sujet une certitude totale .

La science se constitue d'abord, et surtout, comme la mise en œuvre d'un projet de connaissance du Monde, développé spontanément, en réponse à nos curiosités, mais de plus en plus collectivement parce qu'il nous assure un pouvoir d'action sur le Monde. Le fait extraordinaire est que cette entreprise se révèle miraculeusement possible : la science, c'est au fond ce que nous faisons pour connaître une nature qui se révèle à nous comme connaissable… (ce qui peut légitimer d'introduire un Dieu des philosophes!)

On peut, pour aller plus loin, observer que la science se développe à trois grands niveaux:

- *À celui d'un repérage et d'une identification et d'une classification des phénomènes (et des objets) avec une exigence forte de véracité*

• Au niveau de la construction d'explications reconnues mobilisant un principe causal accepté comme absolu, rendant intelligibles les enchaînements observés,

• Celui de la proposition de relations formalisées, sous forme mathématique, par des lois, équations d'état ou modèles, apportant des capacités prédictives.

Le fait scientifique passe par l'accumulation de ces trois exigences, celle d'un respect des faits et de leur véracité, celle de l'élaboration de schémas compréhensibles et enfin, celle d'une pertinence des modèles.

Ce tableau ne donne place à aucun moment l'idée d'une vérité essentielle, même si nous en restons fascinés par le concept et que nous ressentons le besoin de nous y référer.

On peut tout juste appuyer le discours scientifique :

• Sur une référence aux faits (factualité scientifique)

• Sur des sentiments d'évidence scientifique (la terre n'est pas plate, le monde vivant est issu d'une évolution sur des millions d'années…) par mobilisation d'éléments généraux de compréhension,

• Sur une qualité de prévisions des modèles, par eux-mêmes et dans leur usage.

Dans ce cadre, il est difficile, et même déplacé, d'évoquer une "vérité" scientifique, même si celle-ci participe à notre construction de l'image des productions scientifiques.

Ces qualités marquent la valeur du discours scientifique vis à vis de toute alternative, qui prendrait des libertés avec les faits, nous imposerait des schémas explicatifs extravagants ou n'aurait qu'une faible valeur prédictive…

5. Jean-Pierre TREUIL

Lorsque j'avais proposé, en 2015 je crois, de compléter les comptes-rendus de nos conférences mensuelles par des rapports détaillés, Claude Maury avait accepté de faire partie de la commission des synthèses scientifiques créée pour ce faire.

L'une de ses contributions est ainsi le rapport qu'il avait rédigé à la suite de la conférence de Jean-Philippe Uzan sur les effets de lentilles gravitationnelles faibles et leur utilisation en cosmologie. Lorsqu'on relit son texte, on se rend compte à quel point il cherchait à trouver un juste milieu entre un apport trop général pour faire passer le message scientifique et des développements techniques accessibles uniquement à ceux qu'ils les avaient déjà pratiqués : rendre compte de l'historique scientifique de la question, de la théorie dans laquelle cette question prend sens, des outils mathématiques utilisés pour y répondre, des résultats obtenus, en ne débordant pas de ce qu'il supposait être le niveau de culture scientifique générale de son lectorat.

Qu'est-ce que comprendre ? Qu'est-ce que faire comprendre ? Comment faire comprendre ? A qui ? pourquoi ? Tels sont quelques-uns des problèmes auxquels il réfléchissait.

Dans cette perspective, prenaient place plusieurs de ses interrogations ; l'une nous concernant directement, puisqu'elle avait trait aux objectifs de notre association, la forme et le contenu que de nos colloques et de nos publications, le public auxquelles elles s'adressaient.

D'autres interrogations, plus fondamentales, concernaient les rôles respectifs dans les sciences, de l'observation de l'expérimentation d'une part, de l'imagination – l'élaboration de concepts et de théories – et aussi de postulats implicites, d'autre part ; mais aussi les rapports entre comprendre et convaincre, et au-delà, entre connaissances et croyances. Pour un être humain engagé dans l'action, devant prendre des décisions, comprendre et convaincre sont tous deux nécessaires ; et l'on ne peut vraiment convaincre que si l'on admet l'existence de points de vue, de rationalités multiples, que si l'on a pris conscience que sa seule logique propre ne suffit pas. Il m'avait ainsi communiqué une réflexion qu'il avait menée sur les invariants culturels de la formation des polytechniciens, emprunt du positivisme du 19éme siècle, dont il faisait une évaluation critique. Un des points qu'il abordait dans cet article, c'est le flou de la séparation entre connaissances et croyances. Pour le positivisme, écrivait-il, la séparation était nette, et les croyances, assimilées à de la superstition, devaient être combattues. Dans l'état actuel des sciences, avec toute la complexité du réel qu'elles mettent en évidence, comprendre quelque chose mélange obligatoirement une part de certitude acquise par une compréhension détaillée de l'expérience et des concepts, et une part admise comme vraie par confiance envers ceux que l'on en juge digne.

Il est sûr que la pensée de Claude sur la place des sciences dans nos sociétés était très riche, exigeante, et d'une grande actualité.

II. Conférence de la Pr Delphine DESTOUMIEUX -GARZON

1. Présentation de la Conférencière par notre président Victor MASTRANGELO

Delphine DESTOUMIEUX-GARZÓN

Directrice de Recherche au CNRS

2007	**Habilitation à Diriger des Recherches.** Univ. Paris 6. Obtenue le 7 mai 2007. Les peptides antimicrobiens, effecteurs de l'immunité innée et des compétitions microbiennes. Jury - G. Bœuf (Président), G. Mitta, F. Le Roux, S. Rebuffat, et E. Bachère.
1998	**Doctorat.** Univ. Montpellier 2**.** Obtenu le 10 décembre 1998**. Avec la mention très honorable et les** Félicitations du Jury. Caractérisation et analyse de l'expression des pénaeidines, peptides antimicrobiens isolés chez la crevette pénéide *Penaeus vannamei* (Crustacea, Decapoda). Jury - G. Lefranc (President), G. Bœuf, K. Söderhäll, P. Bulet, P. Nicolas, P. Roch, et E. Bachère.
1995	**DEA de Microbiologie et Biotechnologies.** Univ. Paul Sabatier, Toulouse. Mention Très Bien. Etude de la régulation des gènes de fixation de l'azote dans une association symbiotique plante-microorganisme.

Delphine DESTOUMIEUX-GARZON est actuellement directrice adjointe du Laboratoire

Interactions Hôtes-Pathogènes-Environnements (IHPE)

UMR 5244 CNRS, Université de Montpellier, Ifremer, Université de Perpignan

Au cours de ces dernières années, elle a dirigé l'équipe « Interactions et Adaptation en Milieu Marin » au sein du laboratoire Interactions Hôtes-Pathogènes-Environnements IHPE.
Au cours de sa carrière, elle avez étudié l'immunité et les maladies infectieuses émergentes chez les invertébrés marins.
ELLE a également décrit les mécanismes d'adaptation et de résistance des bactéries du genre *Vibrio* aux défenses de leurs hôtes.
Elle a présidé depuis 2016 des conférences internationales sur les peptides antimicrobiens (AMP2016, http://amp2016.univ-perp.fr/ , prochaine conférence Gordon sur les peptides antimicrobiens, https://www.grc.org/antimicrobial-peptides-conference/2021/).
De 2017 à 2021, elle a été chargée de mission au CNRS en charge de la Recherche pluridisciplinaire sur le nexus Santé - Environnement (cadre One Health).
Au cours de sa carrière, elle a publié une série d'articles prenant en compte les multiples traits des hôtes et des pathogènes convergeant pour l'expression de la maladie, sous influence environnementale.

Elle est l'auteur de 83 publications dans des revues à comité de lecture
Elle a encadré 12 thèses et 2 post-doctorats

IHPE développe des recherches intégratives sur les interactions entre les animaux, leurs agents pathogènes et leurs environnements.

Il regroupe des personnels issus de quatre institutions : le CNRS, l'Ifremer, L'université de Montpellier et l'Université de Perpignan.

Les changements globaux, la mondialisation des échanges et de l'échange, l'industrialisation des systèmes de production alimentaire, ainsi que le mouvement migratoire des animaux, micro-organismes et les humains sont à l'origine d'importantes modifications des écosystèmes.
Ces changements environnementaux rapides sont liés à l'émergence et à la réémergence de maladies infectieuses et non infectieuses chez l'homme, et chez la faune exploitée et non exploitée. Le risque de pandémies a considérablement augmenté avec des risques accrus des transmissions des pathogènes de l'animal à l'homme (zoonoses). En d'autres termes, les maladies sont désormais reconnues comme résultant d'un dysfonctionnement des écosystèmes, caractérisés par leurs interactions complexes.

La santé humaine est étroitement liée à la santé animale et à la santé environnementale, résumées sous la formule « Une Planète – Une Santé – Un Océan ».
Nos efforts de recherche sont dirigés vers une compréhension intégrale des mécanismes conduisant à l'apparition d'agents infectieux, leur dynamique de l'évolution, leur émergence et leur extinction dans les milieux naturels. Dans ce cadre, nous appliquons des approches de biologie intégrative et de biologie des systèmes en utilisant des méthodologies holistiques, multidisciplinaires et à multi-échelles.

Notre recherche se concentre sur trois thèmes principaux :
i) les maladies tropicales négligées ii) l'aquaculture iii) les récifs coralliens

Conférence de la Pr Delphine DESTOUMIEUX -GARZON

Voici le résumé en français de la conférence de la Pr Delphine DESTOUMIEUX-GARZON :

L'apport des sciences de l'environnement, de l'évolution et de la socio-écologie face au risque futur de pandémies

Delphine Destoumieux-Garzón

Directrice adjointe du laboratoire Interactions Hôtes-Pathogènes-Environnements. CNRS, Ifremer, Université de Montpellier, Université de Perpignan. Montpellier. France.

Les agents infectieux peuvent provoquer des épidémies, épizooties et des zoonoses menaçant la santé animale, humaine et la stabilité mondiale. L'incidence des maladies infectieuses émergentes a augmenté au cours des dernières décennies et menace d'augmenter dans un avenir proche. En effet, les activités humaines, le changement climatique et l'érosion de la biodiversité sont des facteurs connus de l'émergence de maladies infectieuses (IPBES, 2020). Afin de transformer en actions de recherche les multiples appels des scientifiques en faveur une approche plus intégrée de la santé (One Health, Planetary Health), nous avons cartographié des domaines de recherche prioritaires. L'accent a été mis sur les besoins de recherche en socio-écologie et sciences de l'évolution, qui sont des aspects clés mais encore négligés de la recherche actuelle sur les épidémies. Nous incluons également des aspects éthiques, philosophiques, sociétaux et transformationnels, afin de mieux prévenir et contrôler les pandémies actuelles et futures. Les domaines de recherche identifiés doivent permettre de mieux comprendre l'émergence des maladies infectieuses, de caractériser les causes et moteurs des futures pandémies et de mettre en œuvre des moyens de prévention au travers d'approches multidisciplinaires et participatives. Des installations opérationnelles sont proposées, telles que des **observatoires en écologie de la santé** et des **laboratoires vivants** implantés dans les territoires, pour soutenir la recherche proposée. Ceux-ci pourraient être reliés par un réseau mondial de centres de recherche en soutien à la prévention de futures pandémies, facilitant l'échange et la validation de données, l'interopérabilité et l'applicabilité des outils informatiques. Ce travail de prospective a été réalisé dans le cadre du projet HERA (www.HERAresearchEU.eu) qui vise à définir les priorités d'un agenda de recherche sur l'environnement, le climat et la santé dans l'Union Européenne en adoptant une approche systémique face aux problèmes environnementaux mondiaux. Ce travail coordonné par des membres du laboratoire IHPE (UMR5244) a réuni des chercheurs du CNRS, du CIRAD, de l'INRAe, de l'INSERM, des Universités de Montpellier, Perpignan, Utrecht (Hollande), Texas A&M (USA), Thessalonique (Grèce), du Centre Helmholtz de Munich (Allemagne), et du Muséum des Sciences Naturelles de Berlin (Allemagne).

Destoumieux-Garzón, D., Matthies-Wiesler, F., Bierne, N., Binot, A., Boissier, J., Devouge, A., et al. (2022) Getting out of crises: Environmental, social-ecological and evolutionary research is needed to avoid future risks of pandemics. *Environ. Int.* **158**:106915**.**

M. Dujon, A., Brown, J.S., Destoumieux-Garzón, D., Vittecoq, M., Hamede, R., Tasiemski, A., et al. (2021) On the need for integrating cancer into the One Health perspective. *Evol. Appl.* **14**: 2571–2575.

Barouki, R., Kogevinas, M., Audouze, K., Belesova, K., Bergman, A., Birnbaum, L., et al. (2021) The COVID-19 pandemic and global environmental change: Emerging research needs. *Environ. Int.* **146**: 106272.

Destoumieux-Garzón, D., Mavingui, P., Boetsch, G., Boissier, J., Darriet, F., Duboz, P., et al. (2018) The one health concept: 10 years old and a long road ahead. *Front. Vet. Sci.* **5**: 1–13.

Un compte-rendu rédigé par un membre de l'AEIS sera prochainement disponible sur le site de l'AEIS http://www.science-inter.com.

REMERCIEMENTS

Nous tenons à remercier vivement M. Jean-Louis DUPLOYE et M. Yann TRAN et Mme Annabelle POIRIER de l'Institut Curie pour la qualité de leur accueil.

Documents

Pour illustrer ter la conférence de Mme Delphine DESTOUMIEUX-GARZON nous vous proposons :

P 12 : un article de Delphine Destoumieux intitulé « The One Health Concept 10 Years Old and a Long Road Ahead » paru dans la revue *Frontiers in Veterinary Science* | www.frontiersin.org février 2018

Pour préparer la conférence de notre Collègue Gilles COHEN-TANNOUDJI, nous vous proposons :

P 25: Un article intitulé « Cold Dark Matter: A Gluonic Bose–Einstein Condensate in Anti-de Sitter Space Time» de notre Collègue Gilles Cohen-Tannoudji paru dans la revue *Universe 2021, 7, 402*

frontiers in Veterinary Science

REVIEW
published: 12 February 2018
doi: 10.3389/fvets.2018.00014

The One Health Concept: 10 Years Old and a Long Road Ahead

Delphine Destoumieux-Garzón[1†], Patrick Mavingui[2,3*†], Gilles Boetsch[4,5], Jérôme Boissier[6], Frédéric Darriet[7], Priscilla Duboz[4,5], Clémentine Fritsch[8], Patrick Giraudoux[8,9], Frédérique Le Roux[10], Serge Morand[11,12], Christine Paillard[13], Dominique Pontier[14,15], Cédric Sueur[16] and Yann Voituron[17*]*

[1] CNRS, Interactions Hôtes-Pathogènes-Environnements (IHPE), UMR5244, Université de Perpignan Via Domitia, Université de Montpellier, Ifremer, Montpellier, France, [2] Université de La Reunion, UMR PIMIT (Processus Infectieux en Milieu Insulaire Tropical), INSERM 1187, CNRS 9192, IRD 249, Sainte-Clotilde, La Réunion, France, [3] UMR Ecologie Microbienne, CNRS, INRA, VetAgro Sup, Claude Bernard University Lyon 1, Université de Lyon, Villeurbanne, France, [4] UMI 3189 "Environnement, Santé, Sociétés", Faculty of Medicine, Cheikh Anta Diop University, Dakar-Fann, Senegal, [5] Téssékéré International Human-Environment Observatory Labex DRIIM, CNRS and Cheikh Anta Diop University, Dakar, Senegal, [6] Université de Perpignan Via Domitia, Interactions Hôtes-Pathogènes-Environnements (IHPE), UMR5244, CNRS, Ifremer, Université de Montpellier, Perpignan, France, [7] Institut de Recherche pour le Développement, Maladies Infectieuses et Vecteurs, Ecologie, Génétique, Evolution et Contrôle (MIVEGEC), IRD, CNRS, Université de Montpellier, Montpellier, France, [8] Laboratoire Chrono-Environnement, UMR 6249 CNRS/Université Bourgogne Franche-Comté Usc, INRA, Besançon, France, [9] Institut Universitaire de France, Paris, France, [10] Ifremer, Unité Physiologie Fonctionnelle des Organismes Marins, Plouzané, France, [11] Institut des Sciences de l'Évolution (ISEM), UMR 5554, CNRS, Université de Montpellier, CIRAD, IRD, EPHE, Montpellier, France, [12] UPR ASTRE, CIRAD, Montpellier, France, [13] Laboratoire des Sciences de l'Environnement Marin (LEMAR), Institut Universitaire Européen de la Mer, Université de Bretagne Occidentale, UMR 6539, CNRS, UBO, IRD, Ifremer, Plouzané, France, [14] Laboratoire de Biométrie et Biologie Evolutive UMR5558, CNRS, Université de Lyon, Université Claude Bernard Lyon 1, Villeurbanne, France, [15] LabEx Ecofect, Eco-Evolutionary Dynamics of Infectious Diseases, University of Lyon, Lyon, France, [16] Université de Strasbourg, CNRS, IPHC, UMR 7178, Strasbourg, France, [17] Laboratoire d'Ecologie des Hydrosystèmes Naturels et Anthropisés, UMR 5023, CNRS, Université Claude Bernard Lyon1, Université de Lyon, Villeurbanne, France

OPEN ACCESS

Edited by:
Sandra C. Buttigieg,
University of Malta, Malta

Reviewed by:
Monique Sarah Léchenne,
Swiss Tropical and Public Health Institute, Switzerland
Barry McMahon,
University College Dublin, Ireland

***Correspondence:**
Delphine Destoumieux-Garzón
ddestoum@ifremer.fr;
Patrick Mavingui
patrick.mavingui@cnrs.fr;
Yann Voituron
yann.voituron@univ-lyon1.fr

[†]These authors have contributed equally to this work.

Specialty section:
This article was submitted to Veterinary Epidemiology and Economics, a section of the journal Frontiers in Veterinary Science

Received: 26 August 2017
Accepted: 22 January 2018
Published: 12 February 2018

Citation:
Destoumieux-Garzón D, Mavingui P, Boetsch G, Boissier J, Darriet F, Duboz P, Fritsch C, Giraudoux P, Le Roux F, Morand S, Paillard C, Pontier D, Sueur C and Voituron Y (2018) The One Health Concept: 10 Years Old and a Long Road Ahead. Front. Vet. Sci. 5:14. doi: 10.3389/fvets.2018.00014

Over the past decade, a significant increase in the circulation of infectious agents was observed. With the spread and emergence of epizootics, zoonoses, and epidemics, the risks of pandemics became more and more critical. Human and animal health has also been threatened by antimicrobial resistance, environmental pollution, and the development of multifactorial and chronic diseases. This highlighted the increasing globalization of health risks and the importance of the human–animal–ecosystem interface in the evolution and emergence of pathogens. A better knowledge of causes and consequences of certain human activities, lifestyles, and behaviors in ecosystems is crucial for a rigorous interpretation of disease dynamics and to drive public policies. As a global good, health security must be understood on a global scale and from a global and crosscutting perspective, integrating human health, animal health, plant health, ecosystems health, and biodiversity. In this study, we discuss how crucial it is to consider ecological, evolutionary, and environmental sciences in understanding the emergence and re-emergence of infectious diseases and in facing the challenges of antimicrobial resistance. We also discuss the application of the "One Health" concept to non-communicable chronic diseases linked to exposure to multiple stresses, including toxic stress, and new lifestyles. Finally, we draw up a list of barriers that need removing and the ambitions that we must nurture for the effective application of the "One Health" concept. We conclude that the success of this One Health concept now requires breaking down the interdisciplinary barriers that still separate human and veterinary medicine from ecological, evolutionary, and environmental sciences. The development of integrative approaches should be promoted by linking the study of factors underlying stress responses to their consequences on ecosystem functioning and evolution. This knowledge is required for the development of novel control strategies inspired by environmental mechanisms leading to desired equilibrium and dynamics in healthy ecosystems and must provide in the near future a framework for more integrated operational initiatives.

Keywords: One health, EcoHealth, infectious disease, non-communicable disease, multifactorial disease, ecotoxicology, interdisciplinary research, public health

INTRODUCTION

Human population increase, industrialization, and geopolitical problems accelerate global changes causing significant damage to biodiversity, extensive deterioration of ecosystems, and considerable migratory movement of both mankind and species in general. These rapid environmental changes are linked to the emergence and re-emergence of infectious and non-infectious diseases (**Figure 1**). Over recent years, certain zoonoses, such as bird flu or the Ebola and Zika viral epidemics, have illustrated this fact to the whole world demonstrating the interdependence of human health, animal health, and ecosystem health. Coming from the "One Medicine" concept (1) that advocates a combination of human medicine and veterinary medicine in response to zoonoses (2), the "One World - One Health" concept[1] was created in 2004. The novelty was the incorporation of the ecosystem health, including that of wild fauna. The "One Health" initiative[2] therefore constitutes a global strategy highlighting the need for an approach that is holistic and transdisciplinary and incorporates multisector expertise in dealing with the health of mankind, animals, and ecosystems (3) (**Figure 2**).

[1] www.oneworldonehealth.org.

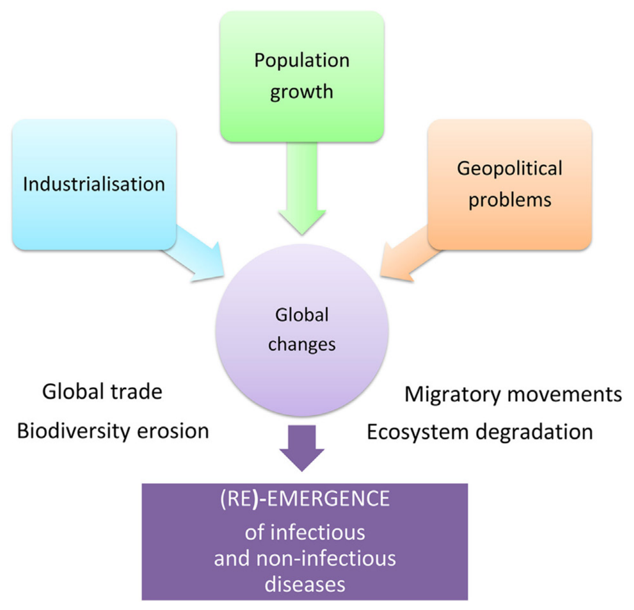

FIGURE 1 | Global changes favor the (re)-emergence of infectious and non-infectious diseases.

When one considers the multiple factors at play and the complexity of public health issues, it is clear that the "One Health" holistic approach (4) cannot be disassociated from the notion of ecological health (EcoHealth). The underlying premise is that the health and well-being of the human population will be more and more difficult to maintain on a polluted planet suffering from social or political instability and ever-diminishing resources. Supporting that view, the European ministers responsible for health and the environment as well as the World Health Organization (WHO) regional director for Europe met on June 15, 2017 in Ostrava, Czech Republic for the sixth ministerial conference on Environment and Health. They recognized that "environmental factors that could be avoided and/or eliminated cause 1.4 million deaths per year" in the WHO European Region. They declared that "public authority shares the common responsibility for safeguarding the global environment and for promoting and protecting human health for all environmental hazards across generation and in all policies." Paving the way for ambitious integrative initiatives in the One Heath framework, researchers in "Ecohealth" and its practitioners implement systemic and integrated practices to promote sustainable ecosystemic services linked to the concept of health (human, animal, and ecosystem) and to social stability. Thus, the One Health concept provides a way of looking at complex systems and approaching processes leading to undesirable effects such as disease emergence, etc. It thus encourages and promotes the interdependence, coexistence, and evolution of living beings and their environment, which is itself in a state of constant transformation (5).

However, after just over 10 years in existence, the "One Health" concept, which predicted the integration of the interface with ecosystems in the "One Medicine" concept, has not quite completed its transformation (6). The documents and publications on the "One Health" approach, and the strategic framework developed around it, have largely focused on the battle against emerging zoonoses originating in domestic (7) or wildlife (8) and/or their interactions (9), without really considering the role of inclusive ecosystems (10). Thus, a quick review of scientific investigations claiming to adhere to the "One Health" concept clearly reveals

[2] www.onehealthinitiative.com.

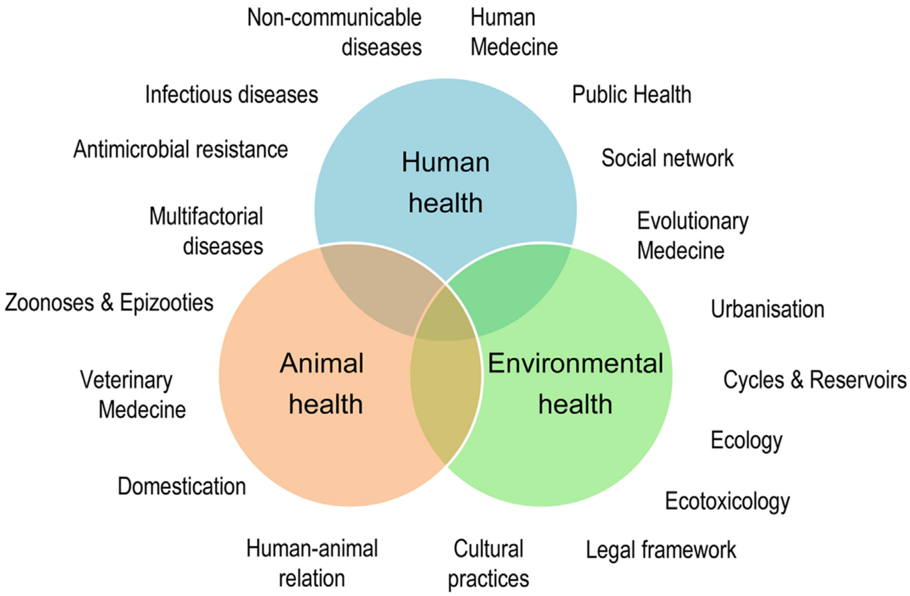

FIGURE 2 | The One Health concept: a holistic, transdisciplinary, and multisectoral approach of Health.

that they only mention the environment and its biotic and abiotic components as the scene of transmission, often reduced to global planetary changes or the Anthropocene. Very few studies deal effectively with the ecology of transmission and the ecology of health meaning developing an ecological and progressive epidemiology linked to components of biodiversity, ranging from physiological stresses on populations to changes in habitat, or linked to ecosystem processes (11, 12, 13).

One of the major challenges in the successful integration of the environment alongside human and animal health in the "One Health" triptych is the capability to define the state of health of our ecosystems. Ecology researchers face a growing demand from administrators for detailed, relevant information on the health and desired equilibrium or dynamics of multifunction ecosystems to guide decision-making on sustainable development, species conservation, and human, animal, and plant health (14). This calls for the definition of shared indicators for ecosystem health (biodiversity, ecosystem services, desired "equilibrium", and "evolutions" on relevant space–time scales, etc.).

When the "One Health" concept was conceived, initial collaboration between human medicine and veterinary medicine resulted in an inevitable research bias toward zoonotic diseases (15), temporarily ignoring the important question of chronic non-infectious diseases, which are the leading cause of global human mortality. Nowadays, the "One Health" concept hopes to extend to other fields, such as antimicrobial resistance, ecotoxicology, or health in urban environments.

In this review article, we discuss the need of incorporating ecological, evolutionary, and environmental sciences into One Health approaches for an innovative and effective control of both infectious and multifactorial non-communicable diseases. We next provide examples in which the integration of the ecosystemic component of the One Health concept enabled deciphering the processes underlying disease emergence and re-emergence. Finally, we discuss operational brakes that still limit the application of the concept, its ambitions, and future challenges.

INFECTIOUS DISEASES

Ecosystem Dynamics and Imbalances

The emergence and re-emergence of infectious diseases are closely linked to the biology and ecology of infectious agents, their hosts, and their vectors (16). Therefore, a comprehensive understanding of ecosystem dynamics that informs on the processes leading to the occurrence or the recurrence of infectious agents, and their dissemination and extinction in natural habitats, is essential in assessing the risk of infection. The genomes of parasitic organisms, in the widest sense of the term (virus, prokaryotes, and eukaryotes), evolve in their natural environment through mutation, recombination, horizontal transfer, and hybridization. These "genetic entities" respond differently to selective environmental filters, and some genotypes are selected. These genotypes may express new phenotypes and colonize new hosts. They can also cause damage to the hosts they colonize, thereby becoming pathogens. Above and beyond the need for a comprehensive understanding of the life cycles of pathogens, transmission pathways, and transgression of species barriers, further research is required to (i) explore pathogen dynamics in natural habitats and (ii) develop models of infection close to natural systems. Developments that have been achieved for certain models, such as pathogenic vibrios in mollusks (17, 18) or pathogenic *Leptospira* in many vertebrates (19, 20), open up the possibility of a better understanding of pathogen dynamics in microbiota, interacting with a host species or a community of hosts.

Understanding ecosystem dynamics allows us to assess the degree to which the alterations caused by anthropogenic forcing lead to the development of large-scale infectious events. Historically, the domestication of animals has indirectly mediated the transfer of infectious agents between wildlife and humans (7). The majority of emerging infectious diseases considered to be significant in terms of public health also have a zoonotic origin (21), and almost three-quarters originate in wild animals (22). The study of ecological factors affecting the transmission of infectious agents in wildlife is therefore essential in understanding the mechanisms involved in transgression of species barrier (also referred to as host-switching, host-jumping, or host-shifting) and emergence in human populations. For example, the density and diversity of hosts, migration, environmental persistence, and interaction within communities of infectious agents have been identified as determining factors in the emergence of direct and vector-borne transmission agents (23, 24). Assessing the risk of the emergence of zoonoses in human populations therefore requires the analysis of interaction networks between infectious agents, their hosts, and the environment in which they evolve [for an instance of transmission of malaria between macaques and humans, see Huffman et al. (25)].

Habitat destruction and fragmentation, environmental pollution, and climate change have a confirmed catalyst effect on the occurrence and geographic distribution of infectious agents (26, 27, 28). Recent examples of epizootics, particularly destructive epidemics or zoonoses (bird flu, coronavirus, Ebola, chikungunya, dengue, and Zika) indicate that this spread was in many cases assisted by global changes. Thus, by altering the repartition of pathogens, their vectors and their reservoirs, global warming is responsible for the appearance of new diseases at northern latitudes that have previously never been affected (29–31). Particularly, noteworthy examples are the cases of schistosomiasis (32) and chikungunya emergence (33) in the European continent. The recent Ebola epidemic in Western Africa recalls that epidemics are not only limited to the circulation of viruses or knowledge of contamination principles but also strongly influenced by history, political contexts, economic inequalities, and cultural phenomena (34, 35).

In the same vein, the globalization of trade and exchange and the industrialization of agriculture, aquaculture, and agribusiness have occurred in a very short period of time when viewed on an evolutionary scale (36, 37). These trends are responsible for increased movement of humans, plants, and animals with their accompanying infectious agents, who have been able to colonize new territories. Industrialization, which has fostered intensive breeding and farming practices, has also generated stress in organisms, which in turn has created an environment that is conducive to the spread of infectious agents.

The industrialization of agriculture and farming is also responsible for the widespread and often abusive use of pesticides, fertilizers, and antibiotics, which have selected on the one hand resistance to insecticides in mosquitoes that transmit pathogens (etiological agents of malaria, arboviruses, filarioses, etc.) (38–40) and on the other hand resistance to antibiotics in bacteria (41). The selection of antibiotic-resistant strains has occurred in the same way, through abusive and poorly considered use of antibiotics in human health care. This issue now represents one of the most serious threats to global health, food security, and development for the WHO. Antimicrobial resistance is a global health crisis with multiple dimensions. Using a "One Health" approach connecting medicine with some of the well-established key concepts in eco-evolutionary dynamics is urgently needed for developing novel approaches to bacterial infection therapy for which resistance is less quick to evolve (42). Beyond research, the examples of resistance to antimicrobials and pesticides are indicative of the need to develop a policy framework that is common to public health, agriculture, and farming (43).

Resilience, Restoration, and Eco-Inspired Control

The concept of resilience emerged in the ecological literature in 1960s and 1970s to describe the response of ecosystems to disturbances (44). In socioecology, resilience is defined as the capacity of a socio-ecosystem to absorb disturbance and to maintain particular properties such as function, structure, identity, and feedback (45). Resilience should be viewed in a dynamic way, as it allows an ecosystem to shift between different steady states, each of them possessing different sets of processes allowing functions to be maintained. On one hand, it has been advocated that an integrated One Health approach addressing the potential health effects at the human/animal/environment interface will enhance the resilience of local communities (46) through better disease prevention (47). On the other hand, the concept of resilience plaids for system-based thinking and holistic approaches, which for the "One Health" concept means to take into account the importance of diversity (from genes to species), redundancy, and adaptability of the socio-ecosystem to better face, for example, health sanitary crises.

Thus, the spread of infectious agents can be controlled by biological diversity, with predation, competition, and host–symbiont interactions, all playing a role in holobiont fitness and their dynamics, i.e., hosts and their associated microbiota. However, processes by which biodiversity can dilute or amplify disease transmission are still poorly known and are both scale- and context-dependent (48). "Demoresilience" associated with progresses in prevention and simple hygiene has not eliminated old scourges, such as plague, tuberculosis, etc., which are still infecting people and communities, but has led to a continuous decrease in epidemics, this far before vaccines and antibiotics were made available (49).

Nature can help provide viable solutions that use and deploy the properties of natural ecosystems and the services they provide. Thus, eco-inspired innovative strategies have been developed to control infectious diseases. Phages are natural predators of bacteria, controlling bacterial behavior and dynamics in the environment (50). Similarly, antimicrobial peptides, effectors of innate immunity in metazoans, and competition in prokaryotes can also influence pathogen dynamics (51, 52), vector-borne transmission (53), and may allow alternative routes of transmission in the natural environment (54). These natural control mechanisms are real sources of inspiration for the development of new anti-infectious strategies. New methods of fighting vector-borne transmission based on microbial symbiosis represent an area of research that is being promoted and encouraged on a global level by the WHO [Bourtzis et al. (55)[3]]. Likewise, just as the specter of the post-antibiotic era appears before us (56), research into alternative anti-infectives has become an international priority, once again backed by the WHO, who recommends a global action plan based on "One Health" principles (57).

We now need to evaluate the capacity of these alternatives to induce resistance and define its molecular basis in order to assess the risk. Indeed, the challenge over future years will be to identify new anti-infectious strategies likely to generate less resistance and having reduced impact on non-target organisms and the environment (58). Studies in this particular field are already underway and indicate a definite advantage to using phage cocktails (59) or antimicrobial peptides from metazoans (60) as an alternative to antibiotics. There are also promising leads opening up with the development of immunomodulatory peptides derived from antimicrobial peptides (61), whose risk of inducing resistance is extremely low.

If research is called upon to find innovative and ambitious solutions to control infectious diseases, then society, for its part, must not forget that for many extremely destructive infectious diseases, hygiene and prevention are far more effective control solutions than the use of anti-infectives or vaccines, if they exist. This also applies to various vector-borne diseases, for which education and information are the key to avoiding exposure to vectors and the pathogens they transmit.

MULTIFACTORIAL AND NON-COMMUNICABLE CHRONIC DISEASES

Toxic Risk

Complexity and Ambitions of Ecotoxicology

The toxic risk is implicated on many levels in the issues surrounding the "One Health" concept because of direct harmful effects of contaminants and their impact on the physiology, immune, and endocrine responses of organisms, biodiversity, and the transmission of pathogens. Contaminants and toxins can also impact host–pathogen interactions, by directly affecting the pathogens (62). However, toxins and pollutions are to a certain extent part of nature, and toxicity does not mean the same for all organisms. For example, Lake Natron (Kenya) is an unhospitable place for most species, but some have adapted to this environment (like flamingos, *Spirulina*, and invertebrates adapted to caustic waters they live on). As a consequence, the occurrence of toxicants *per se* might not be problem, and there is certainly a lot to learn from the adaptive mechanisms evolved by species living in such "toxic" environments.

Environmental pollution is *a worldwide concern*. The toxic risk is particularly high in environments where the human population is very dense, such as coastal areas, where species are subjected to multiple toxins and pollutants including natural toxins (e.g., paralytic shellfish poisoning toxins synthesized by certain harmful microalgae), emerging pollutants (e.g., micro- and nanoplastics) and diffuse pollution linked to multiple anthropogenic releases (63, 64). However, even remote areas without high anthropogenic activities such as polar areas are also contaminated, with a long list of legacy or emerging organic and inorganic compounds involved (65). The recent and global nature of environmental pollution is even reflected by marked differences in Holocene signatures in stratigraphic records showing unprecedented combinations of various anthropogenic substances (66). Wildlife and domestic animals are currently exposed to numerous contaminants at levels endangering their survival and health, their ability to reproduce and capability to cope with other stressors such as pathogens, and this represents a threat on biodiversity and ecosystem functioning which is now acknowledged (67–71).

The widescale development of *multifactorial diseases* affecting both invertebrates (bees, corals, and oysters) (72–75) and vertebrates (amphibians, cetaceans, and chiropterans) (76–79) is increasingly recognized thanks to the development of tools in genomic medicine and epidemiology that facilitate their study. As a consequence, diseases of complex etiologies are receiving increasing attention. Multifactorial diseases often emerge in organisms whose defense capacities have been reduced by changes in nutrition, temperature, salinity, pH, exposure to pollutants, toxins, radiations, etc. Through cumulative and long-term effects, toxins have significant impact on morbidity caused by both pathogens and other toxic substances (cocktails). Toxicants increase the risk of infectious diseases when the immune system is directly or indirectly affected (67, 71, 80–83). Immunotoxic effects do not only have a direct effect on human health and the viability of human and animal populations, but also affect the broader functioning of ecosystems and promote the transmission of zoonotic diseases by increasing the prevalence of pathogens in animal reservoirs or intermediary hosts. Therefore, the major threat posed by pollutants to biodiversity has currently undetermined consequences on biotic interactions (**Figure 3**). As a result of changes in species abundance and food web topology (extinction of "regulatory" predators, role of "super-predator," consumptive competition, effects on keystone species, biological invasion, increase in resistant disease reservoir species, density effects dependent on emergence of epizootics or zoonotic diseases, etc.), pollution further significantly increases the risk of disease.

The occurrence of some *chronic non-communicable diseases* is currently soaring in southern countries, highlighting the globalization of sanitary risks (84). Part of it is due to significant advances in combating infectious diseases, which have greatly reduced mortality and as a consequence modified the occurrence of non-infectious diseases. However, environmental changes, and particularly exposure to toxic substances, were shown to play an important role in the occurrence of serious chronic non-infectious diseases in humans (respiratory, cardiovascular, neurological, and metabolic diseases, obesity, diabetes, and cancer), the prevention of which is a major challenge for our society, both for the present and the future generations. Transgenerational effects of environmental stress (85) transmitted by epigenetic mechanisms (86) have been described in various species. There is no reason to think that humans should be exception to this rule, and indeed a comparable picture emerges for wildlife from

[3] http://www.eliminatedengue.com/program.

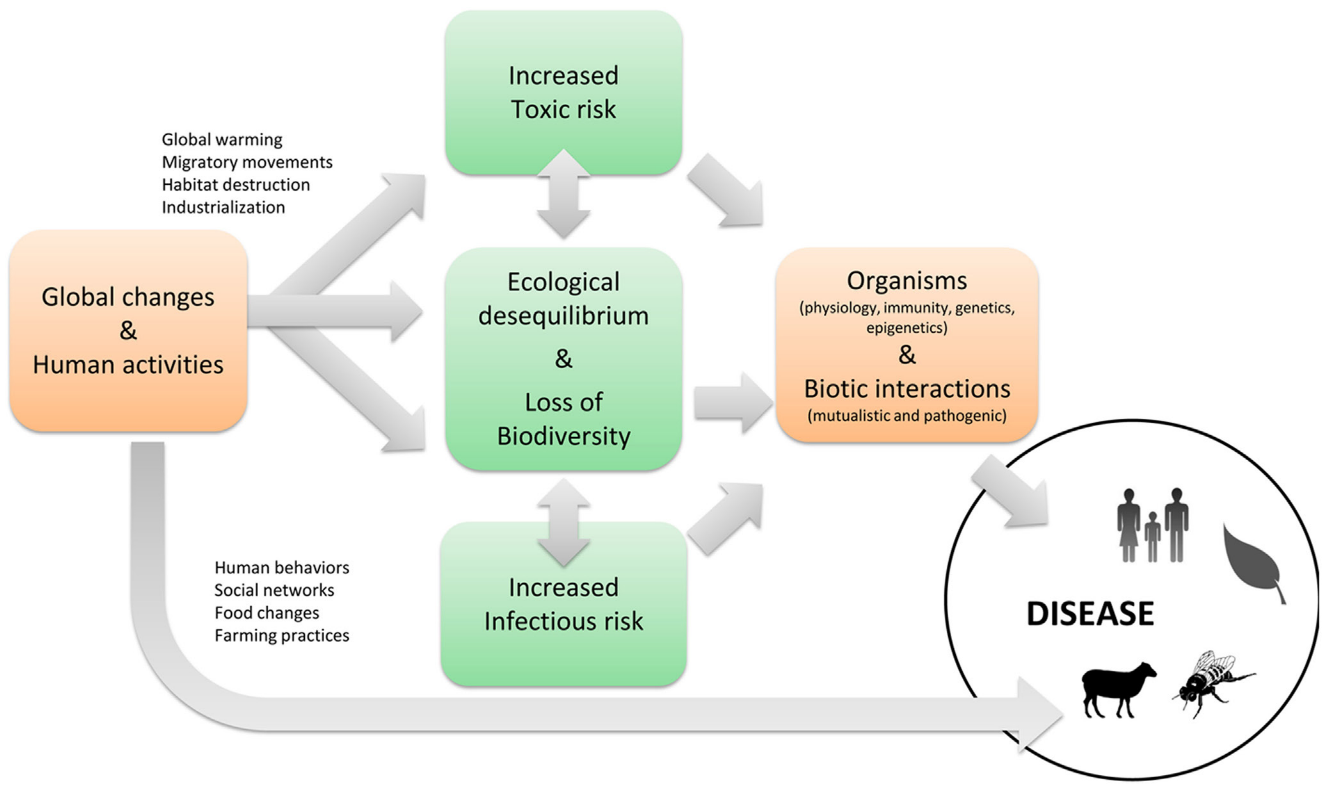

FIGURE 3 | The infectious and toxic risks and their interactions.

many case reports worldwide (70). This indicates the importance of the man–animal–ecosystem interface in determining the evolution and emergence of chronic diseases in humans, just as in other species. For this reason, human and veterinary medicine is often developing a reductionist and frequently reductive approach that needs reviewing in the context of the current situation. Prevention and control, which are increasingly accessible, have a great potential for tackling such complex disease dynamics.

Building a Harmonized Framework for Biological and Chemical Contaminants

Over the past two decades, a few articles called for a transdisciplinary harmonization of ecotoxicology as a component of "Ecosystem Health" and the encompassing "One Health" (81). Evidence, examples, and opportunities for cooperation have been detailed (26, 27, 81, 87–89). However, studies incorporating chemical contaminants and environmental quality in a "One Health" framework are still marginal (87). Addressing simultaneously the needs of "Ecosystem Health" and "One Health" with their inherent trade-offs is a required step forward that would undoubtedly help achieving the goal of better health for people, animals, and our environment.

Beyond integration of environmental pollution as one of the anthropogenic disturbances impairing environmental health, consideration of toxicants for their role in immunity and endocrine system would benefit from a unified framework merging the theoretical and applied contexts of eco-epidemiology, ecophysiology, and ecotoxicology (90). Pathogenic organisms and chemical pollutants have their own specificities. However, many common ecological, physiological, and biological processes rule the transmission of biological and chemical contaminants on the one hand and the exposure and responses of organisms and ecosystems on the other hand. System studies on both pathogens and toxicants not only require specialists but also joint expertise to assess impacts, manage risk, and apply therapeutic care. For instance, similar tools in mathematical modeling can be shared for trophically transmitted parasites and pollutants. This calls for more cooperation between human and veterinary medicine, functional and evolutionary ecology, institutional health-care and wildlife management, as well as socioeconomics and regulatory issues.

Furthermore, interactions between pathogenic organisms and chemical toxicants have a high interest in itself. Thus, evaluating the impacts of massive use of biocides and xenobiotics has become a priority to anticipate the consequences of such delivery on the whole ecosystem. Integrating ecotoxicological issues of biocidal substances in "One Health" should help refining the chemical control of pathogen vectors (e.g., mosquitoes) or parasites (antihelminthic, acaricide, etc.). As a first step, the development of "adaptive monitoring" approaches dealing with co-exposure to pollutants and pathogens is absolutely crucial (91–93). The challenge is to assess exposure and organism response on both an individual level and at the population level through relevant and appropriate approaches for both wildlife and human (91, 92). A further challenge consists in defining spatial and temporal scales, types of sample, biomarkers, and end points (92, 94).

Toward Integrated Multiscale Approaches

The ecotoxicological impact of diffuse pollution, phycotoxins, and contaminants of emerging concern, as well as their modulation by environmental factors, needs assessing today using an integrated approach that encompasses the different scales of organization of living beings (macroscopic, cellular, biochemical, and molecular) and includes studies in both controlled environments and *in situ*. The study of population response to multiple stress factors and the genetic and epigenetic bases of their capacity to adapt to these stress factors are currently priority fields of research in order to anticipate future sanitary crises that may influence the fate of species.

Urbanization and Health

Urbanization, associated with ground and air pollution, and its role in lifestyle changes (energy-dense diets with ready-made foods that are rich in lipids, reduced physical activity, more sedentary lifestyles, etc.) represents a major environmental change for man. Since 2010, towns and cities have been the living environment of more than half of humanity (95). Our increasingly urban lifestyle leads to exposure to multiple stress factors (exposome), the health impact of which we do not yet fully understand, especially among the more fragile members of society.

The way in which people are connected and our towns constructed has an enormous impact on health, and particularly its evolution with age. A person's social network will influence both his propensity to being infected by directly transmissible pathogens (without an intermediary host) (96) and to being affected by non-infectious diseases such as obesity (97) or blood cholesterol. However, we do not yet know exactly how urbanization, mobility, or social network nurture or hinder good health. This will require significant research. New portable detectors such as GPS or accelerometers make it possible to record extensive and precise data pertaining to people's mobility and activity (98). The combination of this type of approach with social network measurements opens up new ways of measuring and understanding epidemics and health inequalities (96, 99). The development of statistical methods, graph theory, and multiagent simulation would make it possible to (i) identify which urban environment or social network properties influence well-being and activity and (ii) provide concrete recommendations to improve urbanization plans and public health strategies.

The notion of ecological, epidemiological, sanitary, and demographic transition seems to be a particularly federative idea in the "One Health" approach, because it allows for both the implementation of concrete interdisciplinary research (ecologists, doctors, anthropologists, biologists, demographers, etc. can work together on the changes observed) and because it is also very closely associated with the environmental change represented by urbanization, making it possible to address the subject of the etiology and prevention of chronic non-communicable diseases and infectious disease in a new and innovative manner.

ONE HEALTH CONCEPT SUCCESSES IN THE INTEGRATION OF ITS ECOSYSTEMIC COMPONENT

Some key examples illustrate the degree to which the adoption of a "One Health" approach is both consensual and particularly effective in deciphering the processes underlying the emergence and re-emergence of diseases.

Optimizing Land Use to Control Pathogen Transmission

In 1960s, the European agriculture common policy encouraged French farmers to specialize in milk production. Farmlands from the Jura Mountains were then converted into permanent grasslands. With the destruction of hedges and increased productivity, this shifted the regional ecosystems toward large-scale small mammal pest surges with a cascade of direct and indirect consequences in agriculture, conservation, and public health, including exacerbating the transmission of *Echinococcus multilocularis*, a deadly parasite of public health concern (100). In China, similar effects came from deforestation and agriculture encroachments during 1980s (101). In such a context, research and disease regulation were necessarily considered together with the other issues. Researchers provided knowledge on ecological processes that helped stakeholders to discuss and select, in a system approach, the inherent trades off between seemingly divergent sectoral interests (102).

Deciphering the Emergence of Infectious Diseases through Holistic and Multiple Scale Approaches

In 2013 and 2015, two independent outbreaks of Schistosomiasis occurred in southern Europe (Corsica Island, France) with around 300 estimated cases (103, 104). The occurrence of this tropical disease in higher latitude was unanticipated and caught scientists and health authorities unprepared. At the beginning of the outbreak the locals were worried, the communication was not controlled, the local physicians were not trained to diagnose this tropical disease, and the ecologists were unprepared to consider this parasite in temperate zone. Moreover, the hybrid status of the parasite, a cross between a human and an animal schistosome, made the epidemiological situation much more complex. A collaborative effort between physicians, veterinaries, biologists, ecologists, and public health institutions was set up to identify the origin of the outbreak and control it (32). The biologists identified the intermediate host implicated, defined the hybrid status of the parasite and its Senegalese origin; veterinarians proved the absence of ruminant reservoir hosts; and physicians and health authorities improved diagnostic tools, addressed the clinical characteristic of the patients, and measured the extent of the outbreak.

Modeling Diseases in Social Networks

As the growing worldwide population becomes more mobile and urbanized the risk of epidemics is constantly increasing. Studying animal interactions and the coevolution between emerging social networks and pathogen transmission may help to predict outbreaks and develop strategies avoiding epidemics and epizootics. Network studies, especially in non-human primates, suggest not only that the position of an individual in a group affects the risk of being infected and infecting conspecifics (105) but also that the shape of interaction networks independently from individuals affects pathogen transmission (106). Over the past few years, concepts such as efficiency, resilience, and nestedness (107, 108) have been used to understand the evolution of ecological and social networks facing to environmental changes. Modeling epidemic spread in social networks should help target animals as well as humans according to their social position in the network in order to vaccine them and better manage outcome of epidemic outbreaks. Integrating ecological pressures and intra- and interspecific relationships in these models could also bring new understanding about how these networks are robust to changes and could act as buffers between the environment and animals, including humans.

Those examples illustrate how the application of the "One Health" approach to infectious risk needs to be systematically reinforced with ecobiology expertise. Similarly, the toxic risk needs to be enriched with ecotoxicology expertise. Further understanding of the risk presupposes asking a certain number of questions which may be presented in the same way for both risks (see **Table 1**). This knowledge of ecosystem processes must generate the signposts to guide the sustained exchange effort required from ecologists, epidemiologists, evolutionists, and human and animal health-care specialists with other activity sectors.

OPERATIONAL BRAKES ON THE "ONE HEALTH" CHALLENGE AND RECOMMENDATIONS

Major barriers to the effective integration of "One Health" need to be removed (i) for the systematic implementation of a "One Health" strategy and (ii) for the development of operational solutions that both respect environmental health and its future and are realistic in the face of the urgency of medical care for patients.

A major barrier to the development of "One Health" approaches is very clearly the lack of communication between human and veterinary medicine, agronomy and ecological, environmental, and evolutionary science. Removing this major impediment implies the integration of sufficient understanding of other disciplines, multidisciplinary approaches, and the aims and conditions of their implementation. This can be formulated at different levels.

From a *training* point of view, it is essential to include ecology and evolution in any medical, veterinary, and agronomic training (109, 110). Although relatively recent, a number of these training courses are currently being developed around evolutionary medicine. This initiative should be supported and strengthened in the future.

From a *research* point of view, improved *scientific cooperation* requires the development of collaborative national and international research networks (including within Europe). The integration of southern countries, with their diverse intertropical ecosystems and biodiversity hot spots, is absolutely vital as they represent genuine natural laboratories for the implementation of the "One health" concept in the face of demographic and sanitary transition resulting from global changes. Networks must also include a maximum number of key players in research, representing various disciplines and specializing in different levels of organization of living beings, and spatial and temporal scales. They must work together toward the implementation of shared training programs, tools, and protocols with a shift from research generating basic and isolated knowledge to translational research leading to systems and implicational knowledge. This certainly needs a mentality change not only from researchers but also—and even more importantly—from research funding bodies. Scientific

TABLE 1 | Exploring the infectious and toxic risks through ecobiology and ecotoxicology expertise.

	Infectious risk		Toxic risk
	Case of pathogen emergence	**Case of antibiotic resistance**	**Case of emerging toxins and recurrent toxicants**
Ecosystem processes	How does a commensal infectious agent become a pathogen?	What is the ecological role of antibiotics and of their resistance genes?	What is the ecological role of toxins produced by microorganisms?
	How do infectious agents alter certain hosts?	How do antibiotics and their resistance genes operate?	How do toxins alter certain hosts?
	How do infectious agents proliferate within the microbiota of their hosts?	How do antibiotic production systems and their resistance genes proliferate?	How do organisms adapt to toxicants?
	How are infectious agents controlled in a natural environment?	How are antibiotic-producing or resistance gene-carrying populations controlled?	How are toxins controlled?
Anthropogenic alterations	How do global changes/anthropic activities impact on environments affect biodiversity and the emergence of pathogens?	How do global changes/anthropic activities impact on environments affect the emergence of antibiotic-resistant bacteria?	How do global changes/anthropic activities impact on environments affect toxic risk?
	How does the synergy between infectious and toxic factors multiply the effects and complexity of responses?		
Solutions	Which innovative control solutions are inspired by the ecobiology of infectious agents, their hosts, and their vectors?	How can we develop anti-infectives that generate less resistance?	Which control solutions are inspired by the ecology of emerging toxins?

This table summarizes questions to be addressed for understanding the risks and develop innovative solutions.

cooperation also needs better access to knowledge, which is currently partially blocked (intellectual property, patents), thereby depriving certain key players of diagnostic criteria or fundamental knowledge (81). *Observation tools and data management programs* should also be supported. Long-term monitoring of transmission or exposure systems must be organized and supported by appropriate means and measures, including outside peaks of visible emergence, taking into consideration the different spatial and temporal scales relevant to the organisms in question (e.g., multiannual demographic variations of organisms, landscape changes, practice changes, rearrangement of communities in response to these factors, etc.). This requires the implementation of policies to collect, capitalize, secure, and make available the data derived from ambitious research (database management, observatories, etc.). In addition, promoting *multidisciplinary integrative approaches* is needed for the development of a progressive health (human and animal) ecology, which is based on acquired expertise and methodology in immunoecology and endocrine-epidemiology (111) and links the study of proximal factors (mechanisms) to their ongoing evolutionary consequences (112, 113). It is also necessary to support work into the *definition of ecosystem services* for the regulation of infectious or toxic risk (contributing to the requests of the, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services).

From a *political* point of view, it would appear necessary to implement a gradual *reinforcement of biosecurity* including production, transport, and transformation of biological resources. It is additionally absolutely essential to *break down the sectoral partitioning* that exists between public health, agronomy policy, and other sectors of activity (27). Indeed, current sectoral partitioning trends foster infectious risk. For instance, to date the agriculture/public health interface does not come under the competences of farmers nor vector control services, which increases the development of insect vectors resistant to agricultural insecticides. The synergy of a partnership between scientists, farmers, and the vector control services would initiate pluridisciplinary research programs whose goal would be to protect the crops while reducing the populations of vectors as much as possible. Similarly, sectoral partitioning increases the emergence and the spread of microorganisms that are antibiotic-resistant as a result of spreading slurry from farms using antibiotics or by the increase in size of host populations of pathogenic agents. It is therefore clear that a comprehensive review of industrial agriculture and farming practices is vitally urgent. Overall, significant efficacy gains can be achieved through intersectoral cooperation in a "One Health" approach. This should include a control at source, which is often more cost-effective than fighting a disease. This supposes (i) cooperation in terms of monitoring and diagnosis for a quicker and more precise diagnosis; (ii) cooperation in terms of preventative measures, such as vaccination, to increase coverage; and (iii) a detailed and immediate communication to reduce the number of cases (114).

Remarkably, a purely *economic* view also calls for a global approach of Health that relies on both "prevention at source" for animals and "control" for humans (115). It has been estimated that this two-sided approach would cost between 1.9 and 3.4 billion dollars per year to implement and optimize this approach, a sum which is far below the annual average of 6.7 billion dollars of economic losses historically suffered as a result of epidemics (114). These methods will require the consolidation of regional, national, and international approaches to biosecurity for the control of human, animal, and plant diseases and the implementation of an integrated, interdisciplinary, intersectoral approach to the monitoring of and investigation into diseases common to man and animal. A first necessary step is the development of a database that includes a corpus of essential statistics on demography, the sanitary situation, health determinants (human, animal, and ecosystem), and risk factors. These multi- and intersectoral collaborations, nourished by the results of relevant research, are also essential in identifying the bio-economically, socially, and ecologically acceptable compromises between (sometimes) contradictory management objectives (food production, health, biodiversity preservation, etc.).

In addition to prevention, ecology today must be able to offer the authorities *innovative solutions* to vector control (antivector fight) and pathogenic infectious agents (remediation) that are more ambitious and less destructive to biodiversity and ecosystems than those currently deployed. With regard to antibiotic resistance, research programs working on the identification of new anti-infectives must henceforth consider the risk of resistance emergence from the moment that new therapeutic agents are developed.

CHALLENGES AND AMBITIONS FOR THE "ONE HEALTH" CONCEPT

The insufficient consideration of certain key components in the implementation of the "One Health" concept can be highlighted. Particularly, the wildlife component and numerous related ecological issues (community ecology and evolutionary ecophysiology) are still neglected (116), as are certain environmental science components (soil and climate) (117). Additionally, social, legal, and economic sciences are similarly marginalized (118).

However, social sciences play a major role in the construction of the problems facing "One Health" research. The understanding of infectious or toxic risks cannot simply be reduced to its biological or chemical components. It is also essential to take into consideration the vulnerability, variability, and susceptibility of human societies as well as the different ways they interact with animals and ecosystems. The "One Health" concept, which promotes an interdisciplinary and intersectoral approach, must therefore engage at different levels of health governance, from a global level right down to a local level, by encouraging participative approaches that bring together communities, scientific experts, administrations, and other key players (NGOs, industry, legal experts, etc.). Infectious and toxic risks must also be addressed through their perceptions and impacts to contribute to the improvement of surveillance and prevention systems and the resilience of societies in the face of sanitary crises.

The issue of plant health as a full component of "One Health" concept is a challenge to be urgently resolved (119). In fact, human health and animal health are directly or indirectly dependent on plant health, as the latter is essential as food resources, phytomedecine, land management, etc. In terms of basic knowledge, investigations in plant ecology and epidemiology have provided useful data for understanding the mechanisms of virulence and adaptation of pathogens in humans and animals. A renowned example is the discovery by botanists of interfering RNA as a key component in gene regulation, including host–pathogen interactions (120). While some plant pathogens may pass the species barrier and cause nosocomial diseases, such as the *Burkholderia* complex bacteria responsible for human cystic fibrosis (121), others belonging to enteric bacteria (*Salmonella, Escherichia coli*, *Shigella*, etc.) are plant inhabitants that can cause food contaminants that are harmful to human (122). Thus, raising the concept of "One Health" to a realization requires also access to a good plant health through a productive (yield, quality, nutritional value, and biosafety) and sustainable (reducing pesticides and chemical fertilizers, encouraging culture rotation practice, biofertilization, etc.) agriculture.

The question of ethics should also be more widely integrated into the "One Health" concept. If ethics are referred to essentially through bioethics and the ethics of animal health, other components are often neglected. This is the case for environmental and biodiversity ethics, social science ethics, and the ethics of various legal concepts, such as human rights, the rights of indigenous people, environmental justice, and animal rights. The Nagoya Protocol to the Convention on Biological Diversity is one of the ethical and legal frameworks which are legally binding on scientific research, generating new consequences on the access to and sharing of microorganisms, human, animal and plant samples, data, and traditional and local knowledge and skills. Far from being a new constraint, it is an opportunity to reflect on the role of scientific research in our societies (123).

CONCLUSION

This review illustrates how crucial it is to consider ecological, evolutionary, and environmental sciences in (i) understanding the emergence and re-emergence of infectious and non-communicable chronic diseases and (ii) in creating innovative control strategies. However, the actual organization of research and the sectoral allocation of resources in our societies still limit the development of transdisciplinary approaches and integrated operational actions. Removing the interdisciplinary barriers that still separate ecological, environmental, and evolutionary sciences from human and animal medicine is a major challenge to the implementation of the "One Health" concept, which moves beyond science and impacts politics (health, agriculture, aquaculture, land management, urbanism, and biological conservation), law, and ethics. There is a need to provide evidence on the added value of "One Health" approach for governments, researchers, funding bodies, and stakeholders (124). Finally, promoting the integrative benefits expected of the "One Health" concept requires a new interface with human, social, and legal sciences that remains to be built.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

ACKNOWLEDGMENTS

The issues discussed in this article have been debated during the prospective days of the National Institute of Ecology and Environment (INEE) from the French National Center for Scientific Research (CNRS), February 22–24, 2017, Bordeaux, France.

FUNDING

We warmly thank the National Institute of Ecology and Environment (INEE) from the French National Center for Scientific Research (CNRS) for financial support.

REFERENCES

1. Schwabe C. *Veterinary Medicine and Human Health*. Baltimore: Williams & Wilkins (1984). 713 p.
2. Zinsstag J, Schelling E, Waltner-Toews D, Tanner M. From "one medicine" to "one health" and systemic approaches to health and well-being. *Prev Vet Med* (2011) 101:148–56. doi:10.1016/j.prevetmed.2010.07.003
3. One Health Initiative Task Force. *One Health: A New Professional Imperative*. Schaumburg, IL: American Veterinary Medical Association (2008).
4. Zinsstag J, Schelling E, Waltner-Toews D, Tanner M, editors. *One Health, the Theory and Practice of Integrated Health Approaches*. CABI (2015). doi:10.1079/9781780643410.0000
5. Lebov J, Grieger K, Womack D, Zaccaro D, Whitehead N, Kowalcyk B, et al. A framework for One health research. *One Health* (2017) 3:44–50. doi:10.1016/j.onehlt.2017.03.004
6. Gibbs EPJ. The evolution of One Health: a decade of progress and challenges for the future. *Vet Rec* (2014) 174:85–91. doi:10.1136/vr.g143
7. Day MJ. One health: the importance of companion animal vector-borne diseases. *Parasit Vectors* (2011) 4:49. doi:10.1186/1756-3305-4-49
8. Dantas-Torres F, Chomel BB, Otranto D. Ticks and tick-borne diseases: a One Health perspective. *Trends Parasitol* (2012) 28:437–46. doi:10.1016/j.pt.2012.07.003
9. Mencke N. Future challenges for parasitology: vector control and "One health" in Europe: the veterinary medicinal view on CVBDs such as tick borreliosis, rickettsiosis and canine leishmaniosis. *Vet Parasitol* (2013) 195:256–71. doi:10.1016/j.vetpar.2013.04.007
10. Papadopoulos A, Wilmer S. *Introduction au concept "Une seule santé"*. Centre de collaboration nationale en santé environnementale (2011). p. 1–10. Available from: www.ccnse.ca/sites/default/files/Un_seule_sante_nov_2011.pdf
11. Morand S, Figuié M. *Émergence de maladies infectieuses. Risques et enjeux de société*. Versailles: Quae (2016).
12. Morand S, Lajaunie C. *Biodiversity and Health. Linking Life, Ecosystems and Societies*. London: Elsevier, ISTE Press (2017). 300 p.
13. Cantor M, Pires MM, Marquitti FM, Raimundo RL, Sebastián-González E, Coltri PP, et al. Nestedness across biological scales. *PLoS One* (2017) 12(2):e0171691. doi:10.1371/journal.pone.0171691
14. Giraudoux P. Équilibre écologique et santé des écosystèmes: entre mythe biologique et consensus social. *Nature ou Culture, Les colloques de l'Institut Universitaire de France*. Saint Etienne: de l'Université de St Etienne (2014). p. 129–42.
15. Dhama K. One world, one health-veterinary perspectives. *Adv Anim Vet Sci* (2013) 1:5–13.
16. Vittecoq M, Roche B, Prugnolle F, Renaud F, Thomas F. *Les maladies infectieuses*. Paris: de Boeck Solal (2015).

17. Le Roux F, Wegner KM, Polz MF. Oysters and *Vibrios* as a model for disease dynamics in wild animals. *Trends Microbiol* (2016) 24:568–80. doi:10.1016/j.tim.2016.03.006
18. Paillard C, Jean F, Ford SE, Powell EN, Klinck JM, Hofmann EE, et al. A theoretical individual-based model of brown ring disease in Manila clams, *Venerupis philippinarum*. *J Sea Res* (2014) 91:15–34. doi:10.1016/j.seares.2014.03.005
19. Lagadec E, Gomard Y, Le Minter G, Cordonin C, Cardinale E, Ramasindrazana B, et al. Identification of *Tenrec ecaudatus*, a wild mammal introduced to Mayotte Island, as a reservoir of the newly identified human pathogenic *Leptospira mayottensis*. *PLoS Neg Trop Dis* (2016) 10:e0004933. doi:10.1371/journal.pntd.0004933
20. Picardeau M. Virulence of the zoonotic agent of leptospirosis: still terra incognita? *Nat Rev Microbiol* (2017) 15:297–307. doi:10.1038/nrmicro.2017.5
21. Taylor LH, Latham SM, Woolhouse ME. Risk factors for human disease emergence. *Philos Trans R Soc Lond B Biol Sci* (2001) 356:983–9. doi:10.1098/rstb.2001.0888
22. Woolhouse MEJ, Haydon DT, Antia R. Emerging pathogens: the epidemiology and evolution of species jumps. *Trends Ecol Evol* (2005) 20:238–44. doi:10.1016/j.tree.2005.02.009
23. Keesing F, Belden LK, Daszak P, Dobson A, Harvell CD, Holt RD, et al. Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature* (2010) 468:647–52. doi:10.1038/nature09575
24. Telfer S, Lambin X, Birtles R, Beldomenico P, Burthe S, Paterson S, et al. Species interactions in a parasite community drive infection risk in a wildlife population. *Science* (2010) 330:243–6. doi:10.1126/science.1190333
25. Huffman MA, Satou M, Kawai S, Maeno Y, Kawamoto Y, Tuyen N, et al. New perspectives on the transmission of malaria between macaques and humans: the case of Vietnam. *Folia Primatol* (2013) 84:288–9.
26. Daszak P, Cunningham AA, Hyatt AD. Anthropogenic environmental change and the emergence of infectious diseases in wildlife. *Acta Trop* (2001) 78:103–16. doi:10.1016/s0001-706x(00)00179-0
27. Patz JA, Daszak P, Tabor GM, Aguirre AA, Pearl M, Epstein J, et al. Unhealthy landscapes: policy recommendations on land use change and infectious disease emergence. *Environ Health Perspect* (2004) 112:1092–8. doi:10.1289/ehp.6877
28. Levy S. Warming trend: how climate shapes *Vibrio* ecology. *Environ Health Perspect* (2015) 123:A82–9. doi:10.1289/ehp.123-A82
29. Travers MA, Basuyaux O, Le Goïc N, Huchette S, Nicolas JL, Koken M, et al. Influence of temperature and spawning effort on *Haliotis tuberculata* mortalities caused by *Vibrio harveyi*: an example of emerging vibriosis linked to global warming. *Glob Change Biol* (2009) 15:1365–76. doi:10.1111/j.1365-2486.2008.01764.x
30. Bebber DP. Range-expanding pests and pathogens in a warming world. *Ann Ren Phytopathol* (2015) 53:335–56. doi:10.1146/annurev-phyto-080614-120207
31. Vezzulli L, Grande C, Reid PC, Hélaouët P, Edwards M, Höfle MG, et al. Climate influence on *Vibrio* and associated human diseases during the past half-century in the coastal North Atlantic. *Proc Natl Acad Sci U S A* (2016) 113:E5062–71. doi:10.1073/pnas.1609157113
32. Boissier J, Grech-Angelini S, Webster BL, Allienne J-F, Huyse T, Mas-Coma S, et al. Outbreak of urogenital schistosomiasis in Corsica (France): an epidemiological case study. *Lancet Infect Dis* (2016) 16:971–9. doi:10.1016/S1473-3099(16)00175-4
33. Rezza G, Nicoletti L, Angelini R, Romi R, Finarelli AC, Panning M, et al. Infection with chikungunya virus in Italy: an outbreak in a temperate region. *Lancet* (2007) 370:1840–6. doi:10.1016/S0140-6736(07)61779-6
34. Ezenwa VO, Prieur-Richard AH, Roche B, Bailly X, Becquart P, García-Peña GE, et al. Interdisciplinarity and infectious diseases: an ebola case study. *PLoS Pathog* (2015) 11:e1004992. doi:10.1371/journal.ppat.1004992
35. Mwangi W, de Figueiredo P, Criscitiello MF. One Health: addressing global challenges at the nexus of human, animal, and environmental health. *PLoS Pathog* (2016) 12:e1005731. doi:10.1371/journal.ppat.1005731
36. Stoate C, Boatman N, Borralho R, Carvalho CR, Snoo GR, Eden P. Ecological impacts of arable intensification in Europe. *J Environ Manage* (2001) 63:337–65. doi:10.1006/jema.2001.0473
37. Stoate C, Báldi A, Beja P, Boatman ND, Herzon I, van Doorn A, et al. Ecological impacts of early 21st century agricultural change in Europe – a review. *J Environ Manage* (2009) 91:22–46. doi:10.1016/j.jenvman.2009.07.005
38. Duvallet G, Fontenille D, Robert V. *Entomologie médicale et vétérinaire*. Marseille, Versailles, France: Coédition IRD, Quae éditions (2017).
39. Chouaïbou MS, Fodjo BK, Fokou G, Allassane OF, Koudou BG, David JP, et al. Influence of the agrochemicals used for rice and vegetable cultivation on insecticide resistance in malaria vectors in southern Côte d'Ivoire. *Malar J* (2016) 15:426. doi:10.1186/s12936-016-1481-5
40. Tantely ML, Tortosa P, Alout H, Berticat C, Berthomieu A, Rutee A, et al. Insecticide resistance in *Culex pipiens* quinquefasciatus and *Aedes albopictus* mosquitoes from Réunion Island. *Insect Biochem Mol Biol* (2010) 40:317–24. doi:10.1016/j.ibmb.2010.02.005
41. Holmes AH, Moore LS, Sundsfjord A, Steinbakk M, Regmi S, Karkey A, et al. Understanding the mechanisms and drivers of antimicrobial resistance. *Lancet* (2016) 387:176–87. doi:10.1016/S0140-6736(15)00473-0
42. Read AF, Woods RJ. Antibiotic resistance management. *Evol Med Public Health* (2014) 2014:147. doi:10.1093/emph/eou024
43. Darriet F. *Des moustiques et des hommes. Chronique d'une pullulation annoncée. Editions de l'IRD*. Marseille, France: Collection Didactiques (2014).
44. Holling CS. Resilience and stability of ecological systems. *Annu Rev Ecol Syst* (1973) 4:1–23. doi:10.1146/annurev.es.04.110173.000245
45. Walker B, Holling CS, Carpenter SR, Kinzig A. Resilience, adaptability and transformability in social-ecological systems. *Ecol Soc* (2004) 9(2):5. doi:10.5751/ES-00650-090205
46. Ruscio BA, Brubaker M, Glasser J, Hueston W, Hennessy TW. One Health – a strategy for resilience in a changing arctic. *Int J Circumpolar Health* (2015) 74:27913. doi:10.3402/ijch.v74.27913
47. Heymann DL, Jay J, Kock R. The One Health path to infectious disease prevention and resilience. *Trans R Soc Trop Med Hyg* (2017) 111:233–4. doi:10.1093/trstmh/trx052
48. Randolph SE, Dobson ADM. Pangloss revisited: a critique of the dilution effect and the biodiversity-buffers-disease paradigm. *Parasitology* (2012) 139:847–63. doi:10.1017/S0031182012000200
49. Gualde N. *L'épidémie et la démorésilience*. Paris: L'Harmattan (2011).
50. Argov T, Azulay G, Pasechnek A, Stadnyuk O, Ran-Sapir S, Borovok I, et al. Temperate bacteriophages as regulators of host behavior. *Curr Opin Microbiol* (2017) 38:81–7. doi:10.1016/j.mib.2017.05.002
51. Sassone-Corsi M, Nuccio SP, Liu H, Hernandez D, Vu CT, Takahashi AA, et al. Microcins mediate competition among *Enterobacteriaceae* in the inflamed gut. *Nature* (2016) 540:280–3. doi:10.1038/nature20557
52. Destoumieux-Garzón D, Rosa RD, Schmitt P, Barreto C, Vidal-Dupiol J, Mitta G, et al. Antimicrobial peptides in marine invertebrate health and disease. *Philos Trans R Soc Lond B Biol Sci* (2016) 371:1695. doi:10.1098/rstb.2015.0300
53. Aoyagi KL, Brooks BD, Bearden SW, Montenieri JA, Gage KL, Fisher MA. LPS modification promotes maintenance of *Yersinia pestis* in fleas. *Microbiology* (2015) 161:628–38. doi:10.1099/mic.0.000018
54. Easterday WR, Kausrud KL, Star B, Heier L, Haley BJ, Ageyev V, et al. An additional step in the transmission of *Yersinia pestis*? *ISME J* (2012) 6:231–6. doi:10.1038/ismej.2011.105
55. Bourtzis K, Dobson SL, Xi Z, Rasgon JL, Calvitti M, Moreira LA, et al. Harnessing mosquito-*Wolbachia* symbiosis for vector and disease control. *Acta Trop* (2014) Suppl:S150–63. doi:10.1016/j.actatropica.2013.11.004
56. Czaplewski L, Bax R, Clokie M, Dawson M, Fairhead H, Fischetti VA, et al. Alternatives to antibiotics – a pipeline portfolio review. *Lancet Infect Dis* (2016) 16:239–51. doi:10.1016/S1473-3099(15)00466-1
57. World Health Organization. *Global Action Plan on Antimicrobial Resistance*. Geneva: WHO Press (2015). p. 1–28.
58. Perron GG, Inglis RF, Pennings PS, Cobey S. Fighting microbial drug resistance: a primer on the role of evolutionary biology in public health. *Evol Appl* (2015) 8:211–22. doi:10.1111/eva.12254
59. Yen M, Cairns LS, Camilli A. A cocktail of three virulent bacteriophages prevents *Vibrio cholerae* infection in animal models. *Nat Commun* (2017) 8:14187. doi:10.1038/ncomms14187
60. Rodríguez-Rojas A, Makarova O, Rolff J. Antimicrobials, stress and mutagenesis. *PLoS Pathog* (2014) 10:e1004445. doi:10.1371/journal.ppat.1004445
61. Hancock REW, Haney EF, Gill EE. The immunology of host defense peptides: beyond antimicrobial activity. *Nat Rev Immunol* (2016) 16:321–34. doi:10.1038/nri.2016.29
62. Lafferty K. Environmental parasitology: what can parasites tell us about human impacts on the environment? *Parasitol Today* (1997) 13:251–55. doi:10.1016/S0169-4758(97)01072-7
63. Harvell CD, Kim K, Burkholder JM, Colwell RR, Epstein PR, Grimes DJ, et al. Emerging marine diseases – climate links and anthropogenic factors. *Science* (1999) 283:1505–10. doi:10.1126/science.285.5433.1505

64. Burge CA, Mark Eakin C, Friedman CS, Froelich B, Hershberger PK, Hofmann EE, et al. Climate change influences on marine infectious diseases: implications for management and society. *Ann Rev Mar Sci* (2014) 6(1):249–77. doi:10.1146/annurev-marine-010213-135029
65. Rockström J, Steffen W, Noone K, Persson A, Chapin FS, Lambin E, et al. Planetary boundaries: exploring the safe operating space for humanity. *Ecol Soc* (2009) 14:33. doi:10.5751/ES-03180-140232
66. Waters CN, Zalasiewicz J, Summerhayes C, Barnosky AD, Poirier C, Ga uszka A, et al. The Anthropocene is functionally and stratigraphically distinct from the Holocene. *Science* (2016) 351:aad2622. doi:10.1126/science.aad2622
67. Acevedo-Whitehouse K, Duffus ALJ. Effects of environmental change on wildlife health. *Philos Trans R Soc Lond B Biol Sci* (2009) 364:3429–38. doi:10.1098/rstb.2009.0128
68. Clements WH, Rohr JR. Community responses to contaminants: using basic ecological principles to predict ecotoxicological effects. *Environ Toxicol Chem* (2009) 28:1789–800. doi:10.1897/09-140.1
69. Guitart R, Croubels S, Caloni F, Sachana M, Davanzo F, Vandenbroucke V, et al. Animal poisoning in Europe. Part 1: farm livestock and poultry. *Vet J* (2010) 183:249–54. doi:10.1016/j.tvjl.2009.03.002
70. Kendall RJ, editor. *Wildlife Toxicology: Emerging Contaminant and Biodiversity Issues*. Boca Raton, FL: CRC Press (2010).
71. Marcogliese D, Pietrock M. Combined effects of parasites and contaminants on animal health: parasites do matter. *Trends Parasitol* (2011) 27:123–30. doi:10.1016/j.pt.2010.11.002
72. de Montaudouin X, Paul-Pont I, Lambert C, Gonzalez P, Raymond N, Jude F, et al. Bivalve population health: multistress to identify hot spots. *Mar Pollut Bull* (2010) 60:1307–18. doi:10.1016/j.marpolbul.2010.03.011
73. Mondet F, de Miranda JR, Kretzschmar A, Le Conte Y, Mercer AR. On the front line: quantitative virus dynamics in honeybee (*Apis mellifera* L.) colonies along a new expansion front of the parasite *Varroa destructor*. *PLoS Pathog* (2014) 10:e1004323. doi:10.1371/journal.ppat.1004323
74. Petton B, Bruto M, James A, Labreuche Y, Alunno-Bruscia M, Le Roux F. *Crassostrea gigas* mortality in France: the usual suspect, a herpes virus, may not be the killer in this polymicrobial opportunistic disease. *Front Microbiol* (2015) 6:686. doi:10.3389/fmicb.2015.00686
75. Barneah O, Ben-Dov E, Kramarsky-Winter E, Kushmaro A. Characterization of black band disease in Red Sea stony corals. *Environ Microbiol* (2007) 9:1995–2006. doi:10.1111/j.1462-2920.2007.01315.x
76. Bossart GD. Marine mammals as sentinel species for oceans and human health. *Vet Pathol* (2011) 48:676–90. doi:10.1177/0300985810388525
77. Grogan LF, Berger L, Rose K, Grillo V, Cashins SD, Skerratt LF. Surveillance for emerging biodiversity diseases of wildlife. *PLoS Pathog* (2014) 10:e1004015. doi:10.1371/journal.ppat.1004015
78. Kannan K, Yun SH, Rudd RJ, Behr M. High concentrations of persistent organic pollutants including PCBs, DDT, PBDEs and PFOS in little brown bats with white-nose syndrome in New York, USA. *Chemosphere* (2010) 80:613–8. doi:10.1016/j.chemosphere.2010.04.060
79. Rohr JR, Schotthoefer AM, Raffel TR, Carrick HJ, Halstead N, Hoverman JT, et al. Agrochemicals increase trematode infections in a declining amphibian species. *Nature* (2008) 455:1235–9. doi:10.1038/nature07281
80. Abi-Khalil C, Finkelstein DS, Conejero G, Du Bois J, Destoumieux-Garzón D, Rolland JL. The paralytic shellfish toxin, saxitoxin, enters the cytoplasm and induces apoptosis of oyster immune cells through a caspase-dependent pathway. *Aquat Toxicol* (2017) 190:133–41. doi:10.1016/j.aquatox.2017.07.001
81. Beasley V. "One toxicology", "ecosystem health" and "one health". *Vet Ital* (2009) 45:97–110.
82. Hégaret H, da Silva PM, Wikfors GH, Lambert C, De Bettignies T, Shumway SE, et al. Hemocyte responses of Manila clams, *Ruditapes philippinarum*, with varying parasite, *Perkinsus olseni,* severity to toxic-algal exposures. *Aquat Toxicol* (2007) 84:469–79. doi:10.1016/j.aquatox.2014.05.002
83. Lafferty KD, Kuris AM. How environmental stress affects the impacts of parasites. *Limnol Oceanogr* (1999) 44:925–31. doi:10.4319/lo.1999.44.3_part_2.0925
84. World Health Organization. *Global Status Report on Noncommunicable Diseases*. Geneva: World Health Organization (2014).
85. Lane M, Robker RL, Robertson SA. Parenting from before conception. *Science* (2014) 345:756–60. doi:10.1126/science.1254400
86. Duncan EJ, Gluckman PD, Dearden PK. Epigenetics, plasticity, and evolution: how do we link epigenetic change to phenotype? *J Exp Zoolog B Mol Dev Evol* (2014) 322:208–20. doi:10.1002/jez.b.22571
87. Aguirre AA, Beasley VR, Augspurger T, Benson WH, Whaley J, Basu N. One health-transdisciplinary opportunities for SETAC leadership in integrating and improving the health of people, animals, and the environment. *Environ Toxicol Chem* (2016) 35:2383–91. doi:10.1002/etc.3557
88. Buttke DE. Toxicology, environmental health, and the "one health" concept. *J Med Toxicol* (2011) 7:329–32. doi:10.1007/s13181-011-0172-4
89. Rumbeiha WK. Toxicology and "One Health": opportunities for multidisciplinary collaborations. *J Med Toxicol* (2012) 8:91–3. doi:10.1007/s13181-012-0224-4
90. Martin LB. Stress and immunity in wild vertebrates: timing is everything. *Gen Comp Endocrinol* (2009) 163:70–6. doi:10.1016/j.ygcen.2009.03.008
91. Rabinowitz PM, Gordon Z, Holmes R, Taylor B, Wilcox M, Chudnov D, et al. Animals as sentinels of human environmental health hazards: an evidence-based analysis. *Ecohealth* (2005) 2:26–37. doi:10.1007/s10393-004-0151-1
92. Van der Schalie WH, Gardner HS Jr, Bantle JA, De Rosa CT, Finch RA, Reif JS, et al. Animals as sentinels of human health hazards of environmental chemicals. *Environ Health Perspect* (1999) 107:309–15. doi:10.1289/ehp.99107309
93. Woodruff TJ. Bridging epidemiology and model organisms to increase understanding of endocrine disrupting chemicals and human health effects. *J Steroid Biochem Mol Biol* (2011) 127:108–17. doi:10.1016/j.jsbmb.2010.11.007
94. National Academies of Sciences, Engineering, and Medicine. *Approaches to Understanding the Cumulative Effects of Stressors on Marine Mammals*. Washington, DC: The National Academies Press (2016).
95. United Nations, Department of Economic and Social Affairs, Population Division. *World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352)* (2014).
96. Finger F, Genolet T, Mari L, de Magny GC, Manga NM, Rinaldo A, et al. Mobile phone data highlights the role of mass gatherings in the spreading of cholera outbreaks. *Proc Natl Acad Sci U S A* (2016) 113:6421–6. doi:10.1073/pnas.1522305113
97. Christakis NA, Fowler JH. The spread of obesity in a large social network over 32 years. *N Engl J Med* (2007) 357:370–9. doi:10.1056/NEJMsa066082
98. Kestens Y, Chaix B, Gerber P, Desprès M, Gauvin L, Klein O, et al. Understanding the role of contrasting urban contexts in healthy aging: an international cohort study using wearable sensor devices (the CURHA study protocol). *BMC Geriatr* (2016) 16:96. doi:10.1186/s12877-016-0273-7
99. Sueur C. *Analyse des réseaux sociaux appliquée à l'éthologie et l'écologie*. Paris, France: Editions Matériologiques (2015). 514 p.
100. Giraudoux P, Craig PS, Delattre P, Bao G, Bartholomot B, Harraga S, et al. Interactions between landscape changes and host communities can regulate *Echinococcus multilocularis* transmission. *Parasitology* (2003) 127:121–31. doi:10.1017/S0031182003003512
101. Giraudoux P, Raoul F, Afonso E, Ziadinov I, Yang Y, Li L, et al. Transmission ecosystems of *Echinococcus multilocularis* in China and Central Asia. *Parasitology* (2013) 140:1655–66. doi:10.1017/S0031182013000644
102. Delattre P, Giraudoux P. *Le Campagnol terrestre: prévention et contrôle des pullulations*. Versailles: QAE (2009).
103. Boissier J, Moné H, Mitta G, Bargues MD, Molyneux D, Mas-Coma S. Schistosomiasis reaches Europe. *Lancet Infect Dis* (2015) 15:757–8. doi:10.1016/S1473-3099(15)00084
104. Noël H, Ruello M, Maccary A, Pellat C, Sommen C, Boissier J, et al. Large outbreak of urogenital schistosomiasis acquired in Southern Corsica: monitoring the early signs of the endemicization. *Clin Microbiol Infect* (2017). doi:10.1016/j.cmi.2017.06.026
105. Romano V, Duboscq J, Sarabian C, Thomas E, Sueur C, MacIntosh AJJ. Modeling infection transmission in primate networks to predict centrality-based risk. *Am J Primatol* (2016) 78:767–79. doi:10.1002/ajp.22542
106. Griffin RH, Nunn CL. Community structure and the spread of infectious disease in primate social networks. *Evol Ecol* (2012) 26:779–800. doi:10.1007/s10682-011-9526-2
107. Fushing H, Wang H, VanderWaal K, McCowan B, Koehl P. Multi-scale clustering by building a robust and self correcting ultrametrictopology on data points. *PLoS One* (2013) 8:e56259. doi:10.1371/journal.pone.0056259
108. Pasquaretta C, Levé M, Claidière N, van de Waal E, Whiten A, MacIntosh AJJ, et al. Social networks in primates: smart and tolerant species have more efficient networks. *Sci Rep* (2014) 4:7600. doi:10.1038/srep07600

109. Nesse RM, Bergstrom CT, Ellison PT, Flier JS, Gluckman P, Govindaraju DR, et al. Making evolutionary biology a basic science for medicine. *Proc Natl Acad Sci U S A* (2010) 107:1800–7. doi:10.1073/pnas.0906224106
110. Guégan JF, Constantin de Magny G, Durand P, Renaud F. Écologie de la santé: le macroscope, un nouvel outil! In: Thomas F, Guégan JF, Renaud F, editors. *Ecologie et évolution des systèmes parasités*. Bruxelles: De Boeck (2012). p. 303–42. Licence Maitrise Doctorat Biologie.
111. Martin LB, Ghalambor CK, Woods HA. *Integrative Organismal Biology*. Hoboken, New Jersey: John Wiley and Sons, Inc (2015).
112. Paun A, Danska JS. Immuno-ecology: how the microbiome regulates tolerance and autoimmunity. *Curr Opin Immunol* (2015) 37:34–39. doi:10.1016/j.coi.2015.09.004
113. Chemaitilly W, Cohen LE. Diagnosis of endocrine disease: endocrine late-effects of childhoood cancer and its treatments. *Eur J Endocrinol* (2017) 176:R183–R203. doi:10.1530/EJE-17-0054
114. Institute of Medicine. *Sustaining Global Surveillance and Response Systems for Emerging Zoonotics Diseases*. Washington, DC: National Research Council (2009).
115. The World Bank. *People, Pathogens and Our Planet, Vol 2. The Economics of One Health*. Washington (2012). Report No. 69145-GLB.
116. Hall DC, Le QB. Monitoring and evaluation of one health projects; lessons from Southeast Asia. *Procedia Soc Behav Sci* (2015) 186:681–3. doi:10.1016/j.sbspro.2015.04.070
117. Barrett MA, Bouley TA. Need for enhanced environmental representation in the implementation of one health. *Ecohealth* (2015) 12:212–9. doi:10.1007/s10393-014-0964-5
118. Lapinski MK, Funk JA, Moccia LT. Recommendations for the role of social science research in one health. *Soc Sci Med* (2015) 129:51–60. doi:10.1016/j.socscimed.2014.09.048
119. Fletcher J, Franz D, LeClerc E. Healthy plants: necessary for a balanced 'One Health' concept. *Vet Ital* (2009) 45:79–95.
120. Agrawal N, Dasaradhi PVN, Mohammed A, Malhotra P, Bhatnagar RK, Mukherjee SK. RNA interference: Biology, mecahnism, and applications. *Microbiol Mol Biol Rev* (2003) 67:657–85. doi:10.1128/MMBR.67.4.657-685.2003
121. Mahenthiralingam E, Urban TA, Goldberg JB. The multifacious, multireplicon *Burkholderia cepacia* complex. *Nat Rev Microbiol* (2005) 3:144–56. doi:10.1038/nrmicro1085
122. Brandl MT. Fitness of human enteric pathogens on plants and implications for food safety. *Annu Rev Phytopathol* (2006) 44:367–92. doi:10.1146/annurev.phyto.44.070505.143359
123. Lajaunie C, Morand S, Huan TB. Barcoding, biobanking, ebanking for "One Health" projects in South-East Asia: considering ethics and international law. *Eubios J Asian Int Bioeth* (2014) 24:129–31.
124. Rüegg SR, McMahon BJ, Häsler B, Esposito R, Nielsen LR, Ifejika Speranza C, et al. A blueprint to evaluate One Health. *Front Public Health* (2017) 5:20. doi:10.3389/fpubh.2017.00020

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

universe

MDPI

Article

Cold Dark Matter: A Gluonic Bose–Einstein Condensate in Anti-de Sitter Space Time †

Gilles Cohen-Tannoudji [1,‡] and Jean-Pierre Gazeau [1,2,*,‡]

[1] Laboratoire de Recherche sur les Sciences de la Matière, LARSIM CEA, Université Paris-Saclay, F-91190 Saint-Aubin, France; Gilles.Cohen-Tannoudji@cea.fr
[2] Université de Paris, CNRS, Astroparticule et Cosmologie, F-75013 Paris, France
* Correspondence: gazeau@apc.in2p3.fr
† This paper is an extended version from the proceeding paper: Jean-Pierre Gazeau, Gilles Cohen-Tannoudji. The Realization of Some Cosmological Experiments Seems to Favor the Ideas of Sakharov. In Proceedings of the 1st Electronic Conference on Universe, online, 22–28 February 2021.
‡ These authors contributed equally to this work.

Abstract: In the same way as the realization of some of the famous gedanken experiments imagined by the founding fathers of quantum mechanics has recently led to the current renewal of the interpretation of quantum physics, it seems that the most recent progress of observational astrophysics can be interpreted as the realization of some cosmological gedanken experiments such as the removal from the universe of the whole visible matter or the cosmic time travel leading to a new cosmological standard model. This standard model involves two dark components of the universe, dark energy and dark matter. Whereas dark energy is usually associated with the cosmological constant, we propose explaining dark matter as a pure QCD effect, namely a gluonic Bose–Einstein condensate, following the transition from the quark gluon plasma phase to the colorless hadronic phase. Our approach not only allows us to assume a Dark/Visible ratio equal to 11/2 but also provides gluons (and di-gluons, viewed as quasi-particles) with an extra mass of vibrational nature. Such an interpretation would support the idea that, apart from the violation of the matter/antimatter symmetry satisfying the Sakharov's conditions, the reconciliation of particle physics and cosmology needs not the recourse to any ad hoc fields, particles or hidden variables.

Keywords: cosmological constant; dark matter; dark energy; de Sitter; anti-de Sitter; quark gluon plasma; gluon Bose–Einstein condensate

Citation: Cohen-Tannoudji, G.; Gazeau, J.-P. Cold Dark Matter: A Gluonic Bose–Einstein Condensate in Anti-de Sitter Space Time. *Universe* **2021**, *7*, 402. https://doi.org/10.3390/universe7110402

Received: 23 September 2021
Accepted: 20 October 2021
Published: 25 October 2021

1. Introduction

The *new cosmological standard model* model involves two dark components of the universe, dark energy [1] and dark matter [2]. Whereas dark energy is commonly associated with the cosmological constant, both of us, Gilles Cohen-Tannoudji [3,4], and Jean-Pierre Gazeau [5], have independently tried to address the challenging issue of the dark matter component in the cosmological energy density.

The approach of GC-T [3,4] aimed at interpreting dark matter as a component of the cosmological energy density, which, together with dark energy, would constitute the *world matter*, namely what, according to de Sitter, must be added to the visible matter in order for a cosmological theory to obey the principle of the relativity of inertia. On the other hand, the interpretation by J-PG in [5] in terms of a pure vibration energy due to positive curvature was partially based on mass formulae in terms of energy and spin in de Sitter and/or Anti-de Sitter spacetimes, which are established in the quantum context with the reasonable assumption that the proper mass of an elementary system (in the Wigner [6,7] sense) is independent of the space-time metric.

In the present paper, we explain how our two approaches are complementary in proposing the value $11/2 = 5.5$ for the Dark/Visible ratio (the observed one is currently estimated to be $27/5 = 5.2$) and interpreting (cold) dark matter as a gluonic Bose–Einstein Condensate (BEC) that is a relic of the quark period. These proposals were already present in [4], but the BEC interpretation is here given a firmer basis thanks to the quantum features of elementary systems in Anti-de Sitter spacetime, whose description was given in [5].

In Section 2, we review the history of the new cosmological standard model, known as ΛCDM, from the Einstein–de Sitter debate at the onset of modern cosmology to its current assets. We recall that Λ stands for the cosmological constant and CDM for cold dark matter.

Section 3 is devoted to the key concept of a *(normal- or anti-) de Sitter comoving world matter density*, with which we intend to fill the gaps between our two approaches.

In Section 4, we conjecture, as a merging of our two approaches, that the cold dark matter, identified with the gravitational potential induced by matter, is affected by a Bose–Einstein condensation mechanism.

Finally, in Section 5, we compare our approach with other schemes that also assume a Bose–Einstein mechanism but involve unknown particles.

2. The New Standard Model of Cosmology, the Performance of the Critical Cosmological Gedanken Experiment, and Its Qualitative Results

2.1. The Einstein–De Sitter Debate

Our common starting point is the history of the debate that was raised between Einstein [8] and de Sitter [9] at the onset of modern cosmology. This debate was about a critical cosmological gedanken experiment, one that would consist of "removing all the visible matter from the universe" in order to decide whether or not an isolated particle acting as a test body would have inertia. The answer to this question refers to what is known as *Mach's principle* or what Einstein and de Sitter named *the principle of the relativity of inertia*. It is summarized in the following quoted statement by de Sitter [9], in which he introduces the concept of *world matter*:

> *To the question: If all matter is supposed not to exist, with the exception of one material point which is to be used as a test-body, has then this test-body inertia or not? The school of Mach requires the answer No. Our experience however decidedly gives the answer Yes, if by 'all matter' is meant all ordinary physical matter: stars, nebulae, clusters, etc. The followers of Mach are thus compelled to assume the existence of still more matter: the* world-matter. [1]

The debate of Einstein and de Sitter concerned three possible cosmological models: the first one was Einstein's closed, static model consisting of large masses sent at spatial infinity, a model that Einstein abandoned following the criticism of de Sitter; in the second model, which de Sitter calls "system A", Einstein re-introduces the "cosmological term", involving the cosmological constant that he had ignored in previous attempts, leading to a sort of repulsive force (negative pressure) preventing the universe from collapsing under its own gravitation, and which de Sitter assimilates to a world matter insuring the validity of the postulate of the relativity of inertia; and the third one, "system B" according to de Sitter consists of a universe that is empty except for the cosmological term. About these last two models, de Sitter summarizes the debate in a postscript added to Reference [9] and quoted here:

> *Prof. Einstein, to whom I had communicated the principal contents of this paper, writes 'to my opinion, that it would be possible to think of a universe without matter is unsatisfactory. On the contrary the field $g^{\mu\nu}$* must be determined by matter, without which it cannot exist *[underlined by de Sitter]. This is the core of what I mean by the postulate of the relativity of inertia'. He therefore postulates what I called above the logical impossibility of supposing matter not to exist. I can call this the "material postulate" of the relativity of inertia. This can only be satisfied by choosing the system A, with its world-matter, i.e., by introducing the constant λ, and assigning to the time a separate position amongst the four coordinates. On the other hand, we have the 'mathematical postulate' of the relativity of inertia, i.e., the postulate that the $g^{\mu\nu}$ shall*

be invariant at infinity. This postulate, which, as has already been pointed out above, has no physical meaning, makes no mention of matter. It can be satisfied by choosing the system B without a world-matter, and with complete relativity of the time. However, here also we need the constant λ. The introduction of this constant can only be avoided by abandoning the postulate of the relativity of inertia altogether [underlined by us].

By revisiting the Einstein–de Sitter debate about the concept of inertia, one can notice a perplexing irresolution concerning the position of that constant λ or Λ in the left-hand side (as a fundamental constant) or in the right-hand side (as a phenomenological world matter term) in the Einstein Equation [10]. This is also the insistent "little music" pervading the content of the present contribution.

2.2. The Performance of the Gedanken Experiment with ΛCDM

The more and more precise measurements of the cosmic microwave background (CMB) radiation by the COBE, WMAP, and Planck experiments allowed the performance of the above-mentioned gedanken experiment leading to the assets of ΛCDM, the new standard model of cosmology, namely:

- The rediscovery of the cosmological constant that, as mentioned above, is essential for the validity of the foundational principle of the relativity of inertia.
- The replacement of the Big Bang singularity, which prevented any causal description of the early universe, by an inflation mechanism that remains conjectural but can explain quantitatively the primordial fluctuations observed in the CMB.
- The discovery of two non-visible components of the cosmological energy density, which together amount to about 95% of the full content of the universe: the *dark energy*, is commonly associated with the cosmological constant, and the *dark matter*, which raises theoretical questions, some of which are addressed in the present paper.

3. A Possible Kinematics in Quantum Cosmology: Desitterian/Anti-Desitterian Comoving World-Matter Densities

In this section, we first review the Friedmann–Lemaitre model involving density and pressure of the material content of the universe before describing the consequences on the kinematic symmetry of space time if one decides to view pressure as an effective curvature.

3.1. A Reminder about the Cosmological Formalism ($c = 1$)

In an isotropic and homogeneous cosmology, the solution of the Einstein's equation

$$\mathsf{R}_{\mu\nu} - \frac{1}{2} g_{\mu\nu} \mathsf{R} = 8\pi G_N T_{\mu\nu} + \Lambda g_{\mu\nu} \tag{1}$$

is the Robertson metric

$$\mathrm{d}s^2 = \mathrm{d}t^2 - R^2(t)\left(\frac{\mathrm{d}r^2}{1-kr^2} + r^2(\mathrm{d}\theta^2 + \sin^2\theta\,\mathrm{d}\phi^2\right) \tag{2}$$

depending on the time-dependent radius of the universe $R(t)$ and a curvature index k. The coordinate r is dimensionless; the dimension is carried by $R(t)$, which is the cosmological scale factor which determines proper distances in terms of the comoving coordinates. These quantities obey the Friedmann–Lemaître equations of a perfect fluid with which is phenomenologically modeled the material content of the universe.

$$H^2 \equiv \left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi G_N \rho}{3} - \frac{k}{R^2} + \frac{\Lambda}{3} \tag{3}$$

$$\frac{\ddot{R}}{R} = \frac{\Lambda}{3} - \frac{4\pi G_N}{3}(\rho + 3P)\,, \tag{4}$$

and a third equation expressing energy conservation,

$$\dot{\rho} = -3H(\rho + P)\,. \tag{5}$$

In these equations, the density ρ and isotropic pressure P express the stress energy momentum of the perfect fluid:

$$T_{\mu\nu} = -Pg_{\mu\nu} + (P + \rho)u_\mu u_\nu\,. \tag{6}$$

The cosmological term is taken to the right-hand side of the Einstein's equation and may be interpreted as a contribution to the stress energy tensor that reduces to minus the pressure multiplying the metric $g_{\mu\nu}$ (the density and the pressure sum to zero). This represents a quantitative expression of what de Sitter called world matter in their debate with Einstein. Let us note that according to the sign of the pressure one can talk of a de Sitter world matter (Λ positive, pressure negative) or an anti-de Sitter world matter (Λ negative, pressure positive).

3.2. Dark Matter as an Anti-de Sitter World Matter

In the measurement of the CMB radiation, it is crucial to get rid of the light that is emitted in the foreground in order to obtain the original map of the CMB radiation. This can be done using known technics, but once this is done, one is faced with the problem of the gravitational lensing possibly distorting the path of light between its emission and its arrival at the detector. To solve this problem, it has been possible to use a technique that has been already used to get information about the dark matter present in some very heavy super clusters of galaxies: such clusters may induce a gravitational lensing potential distorting (and possibly multiplying) the image of a galaxy situated far behind the cluster; correlating the distorted observations one has been able to produce a map of the dark matter present in the cluster or in its halo that induces the lensing. The success of this technique has been considered as a proof of the presence of dark matter at extra galactic scales. Using this technique for the full sky distribution of the CMB with both the measurements of the temperature and of the polarization of the radiation, the Planck experiment has been able to yield two outcomes essential for the establishment of the cosmological standard model: on the one hand, the original map of the CMB, not distorted by the lensing, that can be used as the input data in simulations, and, on the other, a full sky map of the gravitational lensing potential, which is tentatively interpreted in [3,4] as the (anti-de Sitter) world matter identified with dark matter.

3.3. Simulation, a Gedanken Cosmological Experiment Algorithmically Peryformed

The results of simulation, which can be considered as an algorithmic performance of the final stage of the cosmological gedanken experiment [11], are particularly spectacular. Figure 1 can be interpreted as showing the complex topology of the spacetime of the dark universe: a web of dark filaments that are tensionless dark strings freely moving in a void space (the white regions in the figure) with negative curvature related to the cosmological constant, whereas the spacetime inside the filaments has a positive curvature.

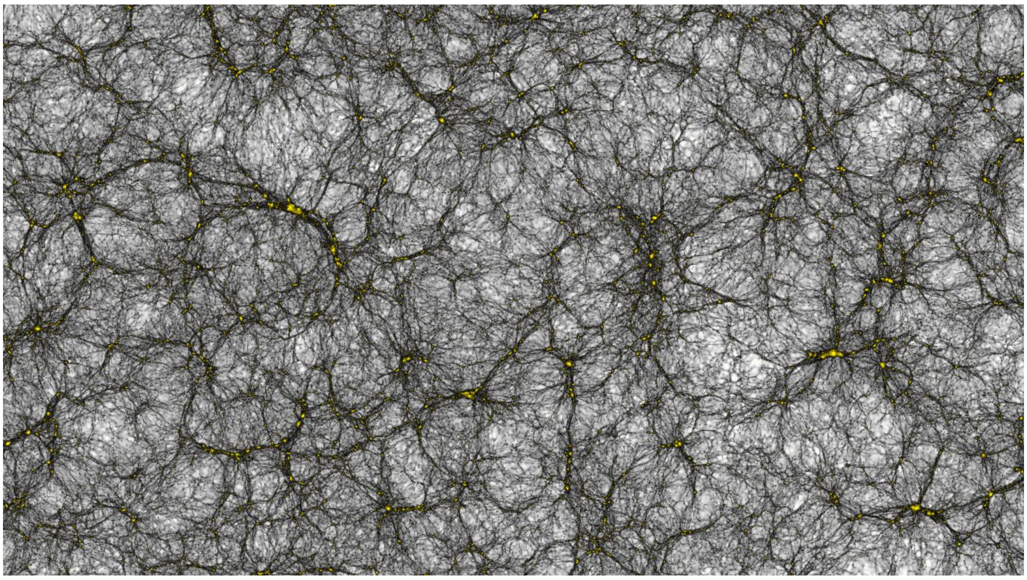

Figure 1. A section of the largest virtual universe ever simulated. From [11].

3.4. dS/AdS Quantum Elementary Systems in Wigner's Sense

3.4.1. dS and AdS Geometries

Here we abandon the cosmological conception of Λ as a part (pressure or density) of the right side of the Einstein equation to instead adopt the fundamental constant point of view according to which the place of Λ should lie on the left of the Einstein equation, as was discussed in [10]. Minkowski, de Sitter (dS) and anti-de Sitter (AdS) space-times are maximally symmetric. dS and AdS symmetries are one-parameter deformations [12] of Minkowski symmetry. In terms of the cosmological constant Λ we, respectively, have (in this dS/AdS context c is restored)

- dS negative curvature $-\sqrt{\Lambda_{\text{dS}}/3}$,
- AdS positive curvature $\sqrt{|\Lambda_{\text{AdS}}|/3}$.

The corresponding kinematical groups are the proper orthochronous Poincaré group $\mathbb{R}^{1,3} \rtimes \mathrm{SO}_0(1,3)$ (or $\mathbb{R}^{1,3} \rtimes \mathrm{SL}(2,\mathbb{C})$) the dS $\mathrm{SO}_0(1,4)$ (or $\mathrm{Sp}(2,2)$) and AdS $\mathrm{SO}_0(2,3)$ (or $\mathrm{Sp}(4,\mathbb{R})$) groups.

dS space-time is conveniently represented by the one-sheeted hyperboloid embedded in the 5d Minkowski space $\mathsf{H}_{\text{dS}} \equiv \{x \in \mathbb{R}^5;\ x^2 = \eta_{\alpha\beta}\, x^\alpha x^\beta = -\Lambda_{\text{dS}}/3\},\ \alpha,\beta = 0,1,2,3,4,$ where $\eta_{\alpha\beta} = \mathrm{diag}(1,-1,-1,-1,-1)$.

AdS is represented by the one-sheeted hyperboloid embedded in $\mathbb{R}^5$ equipped with the metric: $\mathsf{H}_{\text{AdS}} \equiv \{x \in \mathbb{R}^5;\ x^2 = \eta_{\alpha\beta}\, x^\alpha x^\beta = |\Lambda_{\text{AdS}}|/3\},\ \alpha,\beta = 0,1,2,3,5,$ where $\eta_{\alpha\beta} = \mathrm{diag}(1,-1,-1,-1,1)$.

The Lie algebras of groups dS and AdS group are generated by the ten Killing vectors $\mathrm{K}_{\alpha\beta} = x_\alpha \partial_\beta - x_\beta \partial_\alpha$.

There exists a crucial difference between dS and AdS with regard to the question of time. While there is no globally time-like Killing vector in dS, there is one in AdS, namely K_{50}. This fact has heavy consequences for attempting to properly define "energy at rest" in dS, as is shown below.

3.4.2. Compared Classifications of Poincaré, dS and AdS UIR's for Quantum Elementary Systems

In a given unitary irreducible representation (UIR) of dS and AdS groups, their respective generators map to self-adjoint operators in Hilbert spaces of spinor-tensor valued fields on dS and AdS, respectively:

$$\mathrm{K}_{\alpha\beta} \mapsto \mathrm{L}_{\alpha\beta} = \mathrm{M}_{\alpha\beta} + \mathrm{S}_{\alpha\beta}\,,$$

with orbital part $M_{\alpha\beta} = -\mathrm{i}(x_\alpha\partial_\beta - x_\beta\partial_\alpha)$ and spinorial part $S_{\alpha\beta}$ acting on the field components.

The physically relevant UIRs of the Poincaré, dS and AdS groups are denoted by $\mathcal{P}^{>}(m,s)$ ("$>$" for positive energies), $U_{\mathrm{dS}}(\varsigma_{\mathrm{dS}}, s)$, and $U_{\mathrm{AdS}}(\varsigma_{\mathrm{AdS}}, s)$, respectively. These UIRs are specified by the spectral values $\langle\cdot\rangle$ of their quadratic and quartic Casimir operators. The latter define two invariants, the most basic ones being predicted by the relativity principle, namely proper mass m for Poincaré and ς_{dS}, ς_{AdS} for dS and AdS, respectively, and spin s for the three cases (details on their respective ranges are given in [5]).

- For Poincaré the Casimir operators are fixed as

$$\begin{aligned} Q^{(1)}_{\text{Poincaré}} &= P^\mu\, P_\mu = P^{0^2} - \mathbf{P}^2 = m^2\, c^2\,, \\ Q^{(2)}_{\text{Poincaré}} &= W^\mu W_\mu = -m^2\, c^2\, s(s+1)\hbar^2,\ W_\mu := \frac{1}{2}\epsilon_{\mu\nu\rho\sigma}J^{\nu\rho}P^\sigma\,. \end{aligned} \tag{7}$$

- For de Sitter,

$$\begin{aligned} Q^{(1)}_{\mathrm{dS}} &= -\frac{1}{2}L_{\alpha\beta}L^{\alpha\beta} = \varsigma^2_{\mathrm{dS}} - \left(s-\frac{1}{2}\right)^2 + 2 \equiv \langle Q^{(1)}_{\mathrm{dS}}\rangle\,, \\ Q^{(2)}_{\mathrm{dS}} &= -W_\alpha W^\alpha = \left(\varsigma^2_{\mathrm{dS}} + \frac{1}{4}\right)s(s+1)\,, \quad W_\alpha := -\frac{1}{8}\epsilon_{\alpha\beta\gamma\delta\eta}L^{\beta\gamma}L^{\delta\eta}\,. \end{aligned} \tag{8}$$

- For Anti-de Sitter,

$$\begin{aligned} Q^{(1)}_{\mathrm{AdS}} &= -\frac{1}{2}L_{\alpha\beta}L^{\alpha\beta} = \varsigma_{\mathrm{AdS}}(\varsigma_{\mathrm{AdS}}-3) + s(s+1) \equiv \langle Q^{(1)}_{\mathrm{AdS}}\rangle\,, \\ Q^{(2)}_{\mathrm{AdS}} &= -W_\alpha W^\alpha = -(\varsigma_{\mathrm{AdS}}-1)(\varsigma_{\mathrm{AdS}}-2)s(s+1\,,\ W_\alpha := -\frac{1}{8}\epsilon_{\alpha\beta\gamma\delta\eta}L^{\beta\gamma}L^{\delta\eta}\,. \end{aligned} \tag{9}$$

While the relation between mass and energy in Minkowski is not ambiguous, these notions in de Sitterian/Anti-de Sitterian geometry have to be devised from a flat-limit viewpoint, i.e., from the study of the contraction limit $\Lambda \to 0$ of these representations. In this respect, a mass formula for dS has been established by Garidi [13]:

$$m^2_{\mathrm{dS}} := \frac{\hbar^2\Lambda_{\mathrm{dS}}}{3c^2}(\langle Q^{(1)}_{\mathrm{dS}}\rangle - 2) = \frac{\hbar^2\Lambda_{\mathrm{dS}}}{3c^2}\left(\varsigma^2_{\mathrm{dS}} + \left(s-\frac{1}{2}\right)^2\right). \tag{10}$$

This definition should be understood through the contraction limit of representations:

$$\text{dS UIR} \longrightarrow \text{Poincaré UIR}\,.$$

More precisely, with

$$\Lambda_{\mathrm{dS}} \to 0 \quad \varsigma_{\mathrm{dS}} \to \infty\,, \quad \text{while fixing} \quad \varsigma_{\mathrm{dS}}\hbar\sqrt{\Lambda_{\mathrm{dS}}}/\sqrt{3}c = m_{\text{Poincaré}} \equiv m\,. \tag{11}$$

we have

$$U_{\mathrm{dS}}(\varsigma_{\mathrm{dS}}, s) \underset{\substack{\Lambda_{\mathrm{dS}}\to 0\,,\,|\varsigma_{\mathrm{dS}}|\to\infty \\ |\varsigma_{\mathrm{dS}}|\sqrt{\Lambda_{\mathrm{dS}}}/\sqrt{3} = \frac{mc}{\hbar}}}{\longrightarrow} c_{>}\mathcal{P}^{>}(m,s) \oplus c_{<}\mathcal{P}^{<}(m,s)\,. \tag{12}$$

This result was proved in [14] and discussed in [15]. One should notice the possible breaking of dS irreducibility into a direct sum of two Poincaré UIR's with positive and negative energy, respectively. To some extent, the choice of the factors $c_<$, $c_>$, is left to a "local tangent" observer. In particular, one of these factors can be fixed to 1, while the other one is forced to vanish. This crucial dS feature originates from the dS group symmetry mapping any point $(x^0, \mathsf{P}) \in \mathsf{H}_{\mathrm{dS}}$ into its mirror image $(x^0, -\mathsf{P}) \in \mathsf{H}_{\mathrm{dS}}$ with respect to the x^0-axis. Under such a symmetry the four dS generators L_{a0}, $a = 1,2,3,4$, (and particularly

L_{40}, which contracts to the energy operator) transform into their respective opposite $-\mathrm{L}_{a0}$, whereas the six L_{ab}'s remain unchanged.

Concerning AdS, a mass formula similar to (10) has been given in [10,16]:

$$\begin{aligned} m^2_{\mathrm{AdS}} &= \frac{\hbar^2|\Lambda_{\mathrm{AdS}}|}{3c^2}\left(\langle Q^{(1)}_{\mathrm{AdS}}\rangle - \langle Q^{(1)}_{\mathrm{AdS}}|_{\varsigma_{\mathrm{AdS}}=s+1}\rangle\right) \\ &= \frac{\hbar^2|\Lambda_{\mathrm{AdS}}|}{3c^2}\left[\left(\varsigma_{\mathrm{AdS}}-\frac{3}{2}\right)^2 - \left(s-\frac{1}{2}\right)^2\right]. \end{aligned} \tag{13}$$

One here deals with the AdS group representations $U_{\mathrm{AdS}}(\varsigma_{\mathrm{AdS}}, s)$ with $\varsigma_{\mathrm{AdS}} \geq s+1$ (discrete series and its lowest limit), and their contraction limit holds with no ambiguity

$$U_{\mathrm{AdS}}(\varsigma_{\mathrm{AdS}}, s) \underset{\substack{\Lambda_{\mathrm{AdS}}\to 0,\, \varsigma_{\mathrm{AdS}}\to\infty \\ \varsigma_{\mathrm{AdS}}\sqrt{|\Lambda_{\mathrm{AdS}}|/3}=\frac{mc}{\hbar}}}{\longrightarrow} \mathcal{P}^{>}(m,s)\,. \tag{14}$$

Now, the contraction Formulae (12) and (14) give us the freedom to write

$$m_{\mathrm{dS}} = m_{\mathrm{AdS}} = m\,, \tag{15}$$

which agrees with the Einstein position that the proper mass of an elementary system should be independent of the geometry of space-time, or equivalently there should not exist any difference between inertial and gravitational mass.

Let us now disclose a property of AdS that is essential for our interpretation of dark matter in our universe. Since the invariant ζ_{AdS} is the lowest value of the discrete spectrum of the AdS time generator, we define the positive rest energy as

$$E^{\mathrm{rest}}_{\mathrm{AdS}} := \hbar c\sqrt{\frac{|\Lambda_{\mathrm{AdS}}|}{3}}\,\zeta_{\mathrm{AdS}}\,. \tag{16}$$

This results from Equation (13):

$$E^{\mathrm{rest}}_{\mathrm{AdS}} = \left[m^2c^4 + \hbar^2\omega^2_{\mathrm{AdS}}\left(s-\frac{1}{2}\right)^2\right]^{1/2} + \frac{3}{2}\hbar\omega_{\mathrm{AdS}}\,, \tag{17}$$

with frequency $\omega_{\mathrm{AdS}} := \sqrt{\frac{|\Lambda_{\mathrm{AdS}}|}{3}}\,c$. Hence, to the order of $\hbar$, an AdS elementary system in the Wigner sense is a deformation of both a relativistic free particle with rest energy mc^2 and a 3d isotropic quantum harmonic oscillator with ground state energy $\frac{3}{2}\hbar\omega_{\mathrm{AdS}}$ and with excited states, which, apart from degeneracy, are spaced at equal energy intervals of $\hbar\omega_{\mathrm{AdS}}$. A complete proof of this feature in the $1+1$ AdS case is given in [17].

We do not find such a limpid result with dS. Nevertheless, let us formally define

$$E^{\mathrm{rest}}_{\mathrm{dS}} := \hbar c\sqrt{\frac{\Lambda_{\mathrm{dS}}}{3}}\,\zeta_{\mathrm{dS}}\,, \tag{18}$$

which can assume any real value. The counterpart of (17) reads:

$$E^{\mathrm{rest}}_{\mathrm{dS}} = \pm\left[m^2c^4 - \hbar^2c^2\frac{\Lambda_{\mathrm{dS}}}{3}\left(s-\frac{1}{2}\right)^2\right]^{1/2}. \tag{19}$$

There is a noticeable simplification in both cases for spin $s = 1/2$:

$$\text{for dS}: \quad E^{\mathrm{rest}}_{\mathrm{dS}} = \pm mc^2\,, \tag{20}$$

$$\text{for AdS}: \quad E^{\mathrm{rest}}_{\mathrm{AdS}} = mc^2 + \frac{3}{2}\hbar\omega_{\mathrm{AdS}}\,. \tag{21}$$

The choice $E_{\rm dS}^{\rm rest} = mc^2$ should be privileged for obvious reasons. Moreover, in the massless case and spin s, we have

$$\text{for dS}: \quad E_{\rm dS}^{\rm rest} = \pm \mathrm{i}\hbar\sqrt{\frac{\Lambda_{\rm dS}}{3}}c\left(s - \frac{1}{2}\right), \tag{22}$$

$$\text{for AdS}: \quad E_{\rm AdS}^{\rm rest} = \hbar\sqrt{\frac{|\Lambda_{\rm AdS}|}{3}}c(s+1)\,. \tag{23}$$

Therefore, while for dS the energy at rest makes sense only for massless fermionic systems and is just zero, on the contrary, for AdS the energy at rest makes sense and is strictly positive for any spin, and in particular for spin 1 massless bosons, we get

$$E_{\rm AdS}^{\rm rest} = 2\hbar\omega_{\rm AdS}\,. \tag{24}$$

One should add that in the AdS massless cases with $s > 0$ Gupta–Bleuler and gauge structures have to be introduced in the description of quantum states. The spectrum of the time generator L_{05} is still of the harmonic type, but there are possible different degeneracies. Moreover, the concept of helicity in AdS has to be reconsidered in terms of conformal symmetry. Details are given in [18–20]. One important point to notice is that the quantum states in the massless cases $\zeta_{\rm AdS} = s+1$ are described in holographic terms of vector-valued functions on the three-dimensional Shilov boundary of the Cartan classical domain $\mathcal{R}_{IV}$ of the fourth type [21], whereas the massive cases $\zeta_{\rm AdS} > s+1$ are described in terms of holomorphic functions in $\mathcal{R}_{IV}$. The latter is diffeomorphic to the left group coset $\mathrm{Sp}(4,\mathbb{R})/\mathrm{K}$, where K is the maximal compact subgroup $\mathrm{S}(\mathrm{U}(1)\times\mathrm{SU}(2))$. Its Shilov boundary is diffeomorphic to $[0,\pi]\times\mathbb{S}^2$ ("Lie sphere"), or equivalently to the null cone in $\mathbb{R}^5$ equipped with the $(+,-,-,-,+)$ metric. The latter can be viewed as the future horizon of the AdS space time.

The existence of a strictly positive at-rest energy for massless systems in AdS should not be misinterpreted. For instance, the energy in (24) might be viewed as a kind of "mass gap". However, the gluons, like all AdS elementary systems for which $\zeta_{\rm AdS} = s+1$ and so $\langle \mathrm{Q}^{(1)}_{\rm AdS}\rangle = 2(s^2-1)$, are rigorously massless and propagate on the light cone, as proved for instance in the appendix of [22]. Even though the ground state energy that they acquire in that AdS environment may be assimilated to that mass gap or/and energy gap, they remain conformally coupled and do not experience any decay.

3.4.3. From the Elementary Quantum Context to the Quantum Cosmological Context

All that has been done in the present section in the elementary quantum context can be transposed in the cosmological context by coming back to the standard conception considering the cosmological term as a part of the right-hand side of Einstein's equation. The phenomenological description of the matter content of the universe in terms of a perfect fluid characterized by a density and a pressure involves, in a four-dimensional Minkowskian spacetime, a thermodynamical interpretation of the Friedman Lemaître differential equations that assimilates the boundaries in the far future (point ω in Figure 2 below, in which the Hubble radius $L(a) = H^{-1}(a)$ is plotted versus the scale factor $a(t)$ in logarithmic scale) and the remote past (point α in Figure 2) implied by the Hubble expansion to *event horizons with quantum properties* [23]. The future event horizon occurs in the region where the dark energy (attributed to CC) dominates, which leads us to call it a *de Sitter horizon*; and, for reasons that that will appear clearer below, we call the past event horizon an *anti-de Sitter horizon*.

The methodology underlying this phenomenological description is one of the *effective theories* according to which, if there are parameters that very large or very small with respect to the quantities of physical interest (with the same dimensions), one can integrate out the very small and/or very large parameters and obtain a simpler, approximate description (said semi-classical) of the phenomena in terms of a family of effective theories depending only on finite but *variable* effective parameters (said running or comoving); so, in our interpretation, the de Sitter and anti-de Sitter world matter densities are meant to be *effective co-moving world matter densities*.

4. Matching the Standard Models of Particle Physics and Cosmology

4.1. Our Interpretation of the Assets of Λ*CDM*

4.1.1. From Time-Dependent Densities to Effective Co-Moving Densities

The way how we interpret the assets of ΛCDM in terms the co-moving de Sitter and anti-de Sitter world matter densities is illustrated by Figure 2.

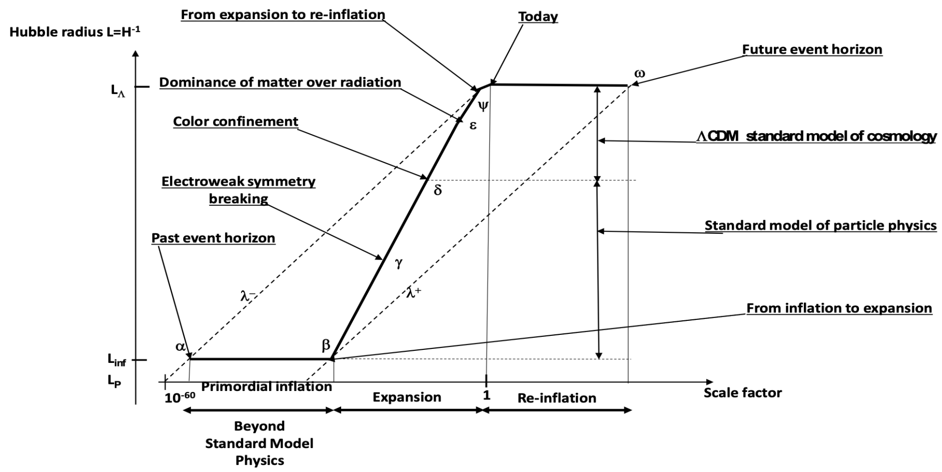

Figure 2. Hubble radius $L(a) = H^{-1}(a)$ $(c = 1)$ is plotted versus the scale factor $a(t)$ in logarithmic scale (from [3]).

The cosmic evolution is schematized on the thick line, on which the cosmic time, which is proportional to the logarithm of the scale factor, is made implicit, which allows it somehow to solve the "problem of time in cosmology" by replacing all dimensioned quantities depending on the local time t, by "effective co-moving densities" that are scaled by the scale factor depending on a global time, denoted τ, which is said to be *thermal* [24] because it depends through the Unruh's constant $U = \dfrac{h}{k_B c}$ on the temperature at a power corresponding to their dimensions.

In particular, this means that the dS and AdS curvatures discussed above in the quantum elementary context have to be replaced, in the quantum cosmological context by effective co-moving curvatures. For instance, the Hubble radius between β and ϵ behaving like a^2 must be rescaled by a factor a^{-1} because it is a length. The boundary of the Hubble 3-sphere is a *co-moving horizon*. So, *the comoving Hubble radius behaves like the comoving radius of the universe*, which means, in terms of densities, that the number of degrees of freedom in the bulk equals the number of degrees of freedom on the boundary. It turns out that this "holographic" relation can be extended to the whole region between ϵ and ψ in which pressure-less matter dominates over radiation in such a way that holography is at work in the full expansion region from β to ψ.

4.1.2. Our Interpretation of the Flatness Sum Rule

All quantum fluctuations exit from the co-moving horizon in the primordial inflation phase, enter it in the expansion phase, and re-exit it in the late inflation phase. No information-carrying quantum fluctuation with a wavelength smaller than λ^- on the left of the *past informational* α (this is the reason why we called it above an anti-de Sitter horizon), or with a wavelength larger than λ^+ on the right of the *future informational, or de Sitter event horizon* ω enters the co-moving horizon. Note that the scenario of a bouncing phase taking place at the point α has been proposed in recent works co-authored by one of us (see the review [25] and references therein).

The interpretation of the holographic relation, which is at work in the full expansion phase from point β to point ψ, is particularly clear at point ψ that marks the transition from the expansion phase to the re-inflation phase at which the function $R(t)$ presents an inflection point ($\ddot{R} = 0$), which, through the second Friedman Equation (4), leads to the total bulk energy, or total active mass, equating with the contribution of the cosmological constant (CC). It is clear, since the pressure associated with Λ is negative, that this cannot be realized without a contribution with a positive pressure, which is with an anti-de Sitter world matter $\rho^{\text{ind}}_{\text{AdS}}(\psi)$, which exactly cancels at point ψ the contribution of CC. Such an anti-de Sitter world matter can be interpreted as the constant of integration result of integrating out the wavelengths smaller than λ^-, namely beyond the anti-de Sitter horizon. When applied in the full expansion phase, the cancellation of CC by this anti-de Sitter world matter amounts to replacing in our quantum cosmology the local time t by the global time τ. One could say that considering these two times amounts to a complexification of the time, and that t and τ are complex conjugate variables: if the densities in our quantum cosmology are analytic functions depending on the global time τ, they do not depend on its complex conjugate, namely the local time. We shall come back to this idea of the complexification of time in our contribution to the incoming book [26] on *Time in Science*.

More generally, the flatness sum rule that expresses the vanishing of the spatial curvature [4] equates the sum of the visible energy density ρ_{vis} (the baryonic ρ_{b} and radiative ρ_{R} energy densities), the dark energy density, and the dark matter energy density, which amounts to nothing but the total active mass in the effective comoving dark universe with a radius equal to its Hubble radius, to the so-called critical density $\rho_{\text{c}} = \dfrac{3H^2}{8\pi G_{\text{N}}}$. The latter is the energy density at the boundaries in the far past and in the far future of the Hubble horizon in the absence of any integration constant and any spatial curvature. More precisely, this flatness sum rule reads as:

$$\rho_{\text{vis}} + \rho_{\text{DM}} + \rho_{\text{DE}} - \rho_{\text{c}} = 0\,, \tag{25}$$

with

$$\rho_{\text{vis}} = \rho_{\text{b}} + \rho_{\text{R}}\,, \quad \rho_{\text{DE}} = \frac{\Lambda}{8\pi G_N}\,. \tag{26}$$

Our interpretation is inspired by the seminal work of Brout, Englert, and Gunzig [27] which states

> *Cosmology, because it is concerned with the variation of $g_{\mu\nu}$ within a distribution of matter and not without, is described—at least in the mean—by only that part of $g_{\mu\nu}$ which is its determinant that may be represented by a scalar field ϕ in Minkowski space .*

This leads us to equate in Equation (25) the critical density ρ_{c} to the energy density ρ_ϕ of the so-called *dilaton*, i.e., the covariant (comoving) quantum field ϕ, representing the determinant of the Friedman, Robertson, Walker (FRW) metric of the effective comoving dark universe. According to our methodology of effective field theory, ϕ has the equation of state $W_\phi = P_\phi/\rho_\phi = -1/3$. Thus, $\rho_{\text{c}} = \rho_\phi = -3P_\phi$ and this insures the vanishing of the total active mass of the vacuum, the zero point of energy: with

$$\rho_{\text{vis}} + \rho_{\text{DM}} \equiv \rho_{\text{M}} = \frac{1}{2}\rho_{\text{DE}} = -P_\phi\,, \tag{27}$$

Equation (25) becomes, with all densities and pressures (including ρ_{DE}) being rescaled at time τ,

$$\rho_{\text{vis}} + \rho_{\text{DM}} + \rho_{\text{DE}} = -3P_\phi = \rho_\phi\,. \tag{28}$$

This means that the dark matter density and the dark energy sum, to which must be added to the visible matter density in order, for the total matter–energy density, to satisfy the principle of the relativity of inertia $\rho_{\text{M}} + P_\phi = 0$, or the vanishing of the spatial curvature $\rho_\phi + 3P_\phi = 0$.

An important remark is in order here: it may look puzzling that, whereas the equations of states (EoS) of both dark matter and dark energy are equal to -1, the EoS of the effective comoving dark universe is equal to $-1/3$. However, in [28], F. Melia solved this puzzle: the EoS of energy densities (that are not true scalar energy densities) are frame-dependent: when the active mass does not vanish, a comoving frame does not, in general, coincide with a free fall frame (which may happen only at one particular position), but "in FRW, the comoving and free-falling frames are supposed to be identical at every spacetime point" .

4.1.3. The Primordial Inflation and the Minimal "beyond the Standard Model" (BSM) Assumption

In ΛCDM, the primordial inflation phase occurs at a Hubble radius of about 10^3 to 10^4 Planck's lengths, which is clearly a domain of physics beyond the standard model (BSM) and supposedly relies on quantum gravitational effects. It is generally admitted that, although it does not resolve completely the cosmological singularity problem (the singularity is sent behind an event horizon), the primordial inflation phase helps correcting the well-known defects of the "simple Big Bang model", namely the absence of monopoles, the vanishing of the spatial curvature and the particle-horizon problem. It ends with the emission of particles with a mass of about 2.5 meV, which could be neutrinos, and which, as is frequently assumed, we associate with the cosmological constant and thus to the dark energy. The scale at which it occurs has long been associated with the grand unification symmetry breaking or supersymmetry breaking, but the fact that it corresponds to the zero point of the energy strongly suggests that it has rather to be associated with the matter/antimatter symmetry breaking: the rhs of Equation (27), half of the dark energy density, is nothing but the missing dark energy, the one of the anti-matter that has been "integrated out". We remind that if matter would reduce to visible matter (which is supposed to be pressure-less), there would be no negative pressure to insure the principle of the relativity of inertia. It is the addition of the dark matter density that may insure the validity of this principle. We shall see below that this feature is an essential key point of our paper.

To link the scales of the primordial inflation, of the cosmological constant, of the neutrino masses and of the matter/antimatter symmetry breaking is indeed very appealing. To explore the possible consequences of such an association, one must discuss the problem of the neutrino masses per the Brout–Englert–Higgs (BEH) mechanism. It is well known that the standard model using the BEH mechanism is compatible with massless neutrinos. In fact, right-handed neutrinos, which would be necessary to generate mass through the Yukawa coupling of the BEH boson to the right-handed and left-handed neutrinos, have quantum numbers that make of them *SM sterile* particles (zero weak isospin, zero charge and zero weak hypercharge). So, the SM is completely compatible with massless neutrinos. If neutrinos are massive, as they seem to be, their mass is thus highly likely a signal of BSM physics. The simplest assumption is that there do exist sterile right-handed neutrinos. The problem is that if one gives the neutrinos Dirac masses through the Yukawa couplings to the BEH boson, one does not understand why these masses are much smaller than the Dirac masses of the charged fermions. The way out of this difficulty comes from the fact that the right-handed neutrinos can have a Majorana mass on their own. If the Majorana mass is exceptionally large, one can manage, with a "seesaw" mechanism to get, by diagonalizing the mass matrix, a physical neutrino which would be a linear combination of the normal left-handed neutrino plus a small anti-right-handed neutrino component. With a Majorana mass of the order of the primordial inflation scale, one can have neutrino masses in the milli-eV range in possible agreement with the results of neutrino oscillations experiments. Furthermore, this mechanism has the advantage that through their Yukawa couplings, the sterile right-handed neutrinos can decay into standard model particles (a BEH boson plus a lepton) thus providing a mechanism of lepton number non-conservation (leptogenesis) (see for instance [29,30]). Now, through the so-called "sphaleron" mechanism, the breaking of lepton number can lead to the breaking of baryon number (baryogenesis) at the primordial inflation scale, thus satisfying one of the Sakharov's conditions for the origin of matter [31].

We thus adopt this assumption which can be considered as the minimal BSM assumption about the initial condition of quantum cosmology.

4.2. The Dark Matter Induced by QCD

If one wants to match the standard models of cosmology and particle physics, one has to move on the thick line of Figure 2, either "bottom up", ψ to point δ that marks the transition from the QCD quark gluon plasma to the colorless hadronic phase, or, "top down" from point β and through point γ, the electroweak symmetry breaking per the BEH mechanism, to point δ, which represents the low-energy frontiers of the standard model of particle physics and the high-energy frontiers of the one of quantum cosmology. Our idea is thus to interpret $\rho^{\text{ind}}_{\text{AdS}}$ as a comoving density that, when evaluated at point δ, would plays the role of the anti-desitterian world matter, induced by QCD, to cancel the contribution of the comoving CC at point δ. Now, it turns out that following an idea of Sakharov [32] and the work of Adler [33], such a contribution can be rigorously evaluated (or at least estimated) [34,35]. The idea of Sakharov was that the non-renormalizable Einstein–Hilbert action would be an effective theory resulting from the coupling of a renormalizable gauge theory to a renormalizable gravitational theory quadratic in the curvature. The aim of Adler was to use the methodology of effective theories to evaluate the cosmological term induced by integrating out, in the effective action, the quantum fields of the standard model:

$$-\frac{1}{2\pi}\frac{\Lambda_{\text{ind}}}{G_{\text{ind}}} = \frac{\int \mathrm{d}\{\Phi\}\, e^{\mathrm{i}S[\{\Phi\},\eta_{\mu\nu}]}T(0)}{\int \mathrm{d}\{\Phi\}\, e^{\mathrm{i}S[\{\Phi\},\eta_{\mu\nu}]}}, \tag{29}$$

where $T(0)$, the trace anomaly, can be evaluated in terms of the flat space time vacuum expectations of renormalized products of gauge and matter fields (called condensates). In QCD, these condensates involve a mass scale parameter $M(g,\mu) = \mu\exp(-1/b_0 g^2)$, where μ is the renormalization scale and $b_0 = \left(11N_c - 2N_f\right)$, where N_c is the number of colors and N_f the number of quark flavors, that plays, in QCD, the same role as the scale parameter $a(\theta)$, where θ is the temperature. The mass scale parameter presents an essential singularity at $g^2 = 0$, so the induced cosmological term cannot be evaluated perturbatively. In any case, if one can use some non-perturbative technique such as the lattice gauge quantization, one can expect all the condensates contributing to the trace anomaly to be proportional, with a negative factor, to the constant b_0. For instance, the contribution of the di-gluons, through what is called in [33] the *gluon pairing amplitude* to the trace anomaly reads

$$\left\langle T^{\mu}{}_{\mu}\right\rangle_0 = -\frac{1}{8}\left[11N_c - 2N_f\right]\left\langle \frac{\alpha_s}{\pi}\left(F^a_{\mu\nu}F^{a\mu\nu}\right)^r\right\rangle_0. \tag{30}$$

In the following quote from [4], it was argued:

> *The minus sign in the right hand side shows that when the constant* $b_0 = \left(11N_c - 2N_f\right)$ *is positive, all the QCD condensates contribute negatively to the energy density, which means that the QCD world-matter is globally an anti-de Sitter world-matter (dominance of an anti-de Sitter world-matter over a smaller de Sitter world-matter).*
>
> *The multiplicative factor* b_0 *allows reading, thanks to the well-known property that boson and fermion loops contribute in quantum field theory with opposite signs, see Figure 3, the relative contributions of the components of the QCD vacuum to the full world-matter:*
>
> - *the bosonic (gluon) loops, proportional to* N_c*, contribute to the anti-de Sitter world matter that represents the contribution of the bulk of free gluons to the total active mass in the effective dark universe, and*
> - *the fermionic (quark) loops, proportional to* N_f*, contribute to the normal de Sitter world matter, which, per our interpretation, represents the kinetic energy den-*

sity of the quarks which have survived to the global annihilation of fermions and antifermions, namely the constituents of the baryonic matter.

This quotation of a previous work includes an expression of free gluons that we will not retain in the present paper because it is misleading: the gluons in the quark gluon plasma that can be considered as free before the hadronization transition have to be "integrated out" (see Equation (29)) to form, in the colorless hadronic phase, the non-interacting world matter induced by QCD that will be interpreted below (Section 4.3) as Bose–Einstein condensate of di-gluons.

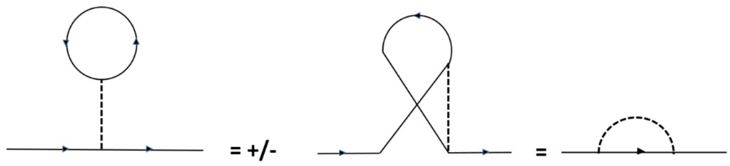

Figure 3. A "tadpole" diagram in which a boson (resp. fermion) exchanges a virtual dilaton with a vacuum loop involving a particle identical to it, is transformed trough the interchange of identical particles, into a positive, i.e., increasing the mass (resp. negative, i.e., increasing the energy) self-energy diagram.

Now, since the transition from the Quark Gluon Plasma (QGP) to the colorless hadronic phase occurs in the region of expansion in which we use the methodology of effective theories, we assimilate the full content of the universe at point δ to an "effective dark universe" for which the radius of the universe is equal to the Hubble radius. This means that we have (by thought) changed the baryonic matter at the Hubble horizon, made of its energy density, into a de Sitter world matter. This is the key point of [4]: the term in Equation (30) proportional to N_f is a de Sitter world matter that represents, at point δ, the kinetic energy of the quarks, called "valence quarks" that constitute the baryonic matter, whereas the term proportional to N_c is an anti-de Sitter worldmatter that represents the active mass of the gluons, namely the dark matter. At point δ, N_c is equal to 3, and N_f, which is not the number of quark flavors, but rather the number of fermions that constitute a nucleon, is also equal to 3. Equation (30) thus allows us to conjecture the value of the Dark/Visible ratio to be equal to $11/2$, at point δ but also since pure numbers do not need to be rescaled. This is the main outcome of [4] that we now confront with the results of the Planck experiment: in Table 2 of [36], these results are compared with the expectations from the so-called "base LambdaCDM" standard model. In the last column of this table, we can read the 68% limits on the parameters based on "Planck TT,TE,EE,+lowE+lensing": for Ω_Λ we read 0.6889 ± 0.0056, for Ω_{M} (which stands for $\Omega_{\mathrm{vis}} + \Omega_{\mathrm{DM}}$), we read 0.3111 ± 0.0056. Now, according to our model, we expect

$$\Omega_\Lambda - \Omega_{\mathrm{vis}} = \Omega_\Lambda - \frac{2}{11}\Omega_{\mathrm{M}} = 2\Omega_{\mathrm{M}} \Rightarrow \Omega_{\mathrm{M}} = \frac{11}{24}\Omega_\Lambda \approx 0.3157\,, \tag{31}$$

to be favorably compared with 0.3111 ± 0.0056.

4.2.1. Baryons as "Chromo-Magnetic" Monopoles

A superconductor analogy was used in [37] by Nielsen and Olesen, who proposed a suggestive model of the QCD vacuum involving unconfined chromo-magnetic monopoles moving freely along magnetic flux lines. The interpretation of baryons as color magnetic monopoles [2] was proposed by Ed. Witten [38] in the following quote (where N has to be replaced by N_c):

Indeed, the baryon mass is of order N, which can be written as $1/(1/N)$. However, $1/N$ is the "coupling constant" of the strong interactions, which characterizes the interaction among mesons. $1/N$ plays in QCD roughly the role that α plays in spontaneously broken *gauge theories of the weak and electromagnetic interactions. The fact that the baryon mass is of order* $1/(1/N)$ *is analogous to the fact that the Polyakov-'t Hooft monopole mass is of order* $1/\alpha$.

4.2.2. Magnetic Flux Lines as Dark Matter Filaments

In [37], Nielsen and Olesen have argued that "one gains energy by separating a monopole and an anti-monopole". It is thus reasonable to interpret the color magnetic flux lines (a pure QCD effect) as filaments of a world matter (that is, a component of the universe with no interaction other than gravitational), that is, filaments of dark matter connecting monopoles to anti-monopoles. Now, since we can assume that anti-monopoles have been integrated out, in giant black holes at the center of galaxies or galaxy clusters, we expect that in simulations of the distribution of galaxies, the filaments must close at the points where the heavy black holes are located. Furthermore, this is precisely what is seen in Figure 1.

4.3. Bose–Einstein Condensation in the Cosmological Context

Since 1999 there has been experimental evidence (RHIC, LHC) of the quark–gluon plasma as a super-liquid that is produced in ultra-relativistic heavy ion collisions; see, for instance, [39,40] and the recent comprehensive historical account [41]. Measurements indicate that quarks, antiquarks, and gluons flow independently in this liquid. On the other hand the universe at its quark epoch, i.e., from 10^{-12} s to 10^{-6} s, with temperature $T > 10^{12}$ K, was uniformly filled with QGP, which once the Universe cooled below evaporated into a gas of hadrons. This corresponds to the point δ in Figure 2. As explained above, an effective AdS with curvature provided by Λ is present at this period.

Returning to our approach to elementary systems in dS or AdS space-times, Equation (21) tells us that the energy at rest of a fermion in an AdS background decomposes into a "visible" mass part, like in Minkowski, and a "dark" part, which is like the ground state energy of a quantum three-dimensional isotropic harmonic oscillator with frequency equal to $\sqrt{\frac{|\Lambda_{\rm AdS}|}{3}}c$. This feature led one of us in [5] to infer that at the point δ , i.e., at the hadronization phase transition, "chemical freeze-out" temperature $T_{cf} \gtrsim 1.8 \times 10^{12}$ K, the ratio "dark/visible" $r := \frac{3}{2}\frac{\hbar\omega_{\rm AdS}}{mc^2}$ for light quarks u (mass $m_u \approx 2.2$ MeV$/c^2$) and d ($m_d \approx 4.7$ MeV$/c^2$) are given by $r(u) \approx 108$ and $r(d) \approx 49$, respectively. In Reference [5], it was suggested that dark matter originated from this supplementary mass granted to (anti-)quarks by the ADS environment. In the present paper, we instead explain the existence of dark matter as holding its origin from the gluonic component of the QGP. On the same footing, we tentatively explain dark matter by asking a simple question: what becomes the huge amount of gluons after the transition from QGP period to hadronization?

Equation (24) tells us that the energy at rest of a spin 1 massless boson in an AdS background is purely "dark" and is twice the elementary quantum $\hbar\omega_{\rm AdS}$. Hence the QGP gluons in the AdS background at the point δ acquire an effective mass $2\hbar\omega_{\rm AdS}$. The latter is qualitatively determined through the equipartition $k_B T_{cf} \approx \hbar\omega_{\rm AdS}$. Hence, $2\hbar\omega_{\rm AdS}/c^2 = 144 \times m_u \approx 317$ MeV$/c^2$. One should notice that this gluonic effective mass is about $4/3$ times the effective mass acquired by quarks and antiquarks in that QGP-AdS environment.

Now, it is tempting to establish a parallel between dark matter and CMB, since the latter is viewed as the emergence of the photon decoupling, precisely when photons started to travel freely through space rather than constantly being scattered by electrons and protons in plasma. Hence, one may assert that a (considerable) part of the gluonic component of the quark epoch freely subsists after hadronization, within an effective AdS environment, as an assembly of a large number, say N_G, of non-interacting entities that are not individual free gluons, but rather decoupled gluonic colorless systems, which are assumed to form a grand canonical Bose–Einstein ensemble. As said above, in Section 4.1.2, the holographic relation that holds in the expansion phase, from point β to point ψ in Figure 2, cannot be satisfied without an anti-de Sitter world matter density that can compensate (see Equation (30)) the contribution of CC in Equation (4). The simplest purely gluonic system of this type, susceptible to form a Bose–Einstein condensate is a di-gluon whose contribution is the one of the gluon pairing amplitudes of Equation (30). The di-gluons can be called "dark matter quasi-particles", which, with an AdS rest mass equal to $\sqrt{\Lambda}$ form a Bose–Einstein condensate because their Compton wavelength as well as their mean relative distances equal with the Hubble radius. Let us remind the reader that, according to the methodology of effective theories, all dimensioned quantities such as the rest mass of a quasi-particle are rescaled, i.e., depend on the global thermal time τ (see above Section 4.1.2).

Actually, the "effective dark universe", which, as said above, is supposed to provide the cosmological standard model with a quantum vacuum or a ground state, cannot be thought of as an "empty spacetime" in which some objects would move, but rather as a medium in which vacuum polarization events occur, which Gürsey [42] calls scintillation events [43] [3], namely events each consisting in the virtual creation of a particle–antiparticle pair, followed, a short time later, by its annihilation. If the particles of the pair are fermions, such event would contribute to a negative curvature (normal de Sitter) world matter, a sort of a *baryonic Fermi–Dirac sea*, at the exterior of the Hubble horizon, and if they are bosons, the event would contribute to a positive curvature (anti-de Sitter) world matter, a *gluonic Bose–Einstein condensate*, at the interior of the Hubble horizon.

Therefore, we consider an assembly of these N_G dark matter di-gluons viewed as quasi-particles in an AdS environment with individual energies $E_n = E^{\text{rest}}_{\text{AdS}} + n\hbar\omega_{\text{AdS}}$, where $E^{\text{rest}}_{\text{AdS}}$ is the expression (17) taken at $m = m_G$ (can be zero or negligible) and $s = 0$, and degeneracy $g_n = (n+1)(n+3)/2$ [18]. Consequently, those remnant entities are analogous to isotropic harmonic oscillators in 3-space. They are assumed to form a grand canonical Bose–Einstein ensemble whose the chemical potential μ is fixed by the requirement that the sum over all occupation probabilities at temperature T yields [44,45]

$$N_G = \sum_{n=0}^{\infty} \frac{g_n}{\exp\left[\frac{\hbar\omega_{\text{AdS}}}{k_B T}(n+\nu_0-\mu)\right]-1}, \quad \nu_0 := \frac{E^{\text{rest}}_{\text{AdS}}}{\hbar\omega_{\text{AdS}}}. \tag{32}$$

Since this number is very large, one expects that this Bose–Einstein gas condensates at temperature

$$T_c \approx \frac{\hbar\omega_{\text{AdS}}}{k_B}\left(\frac{N_G}{\zeta(3)}\right)^{1/3} \approx 1.18\times 10^{-3}\times\sqrt{|\Lambda_{\text{AdS}}|}\,N_G^{1/3} \tag{33}$$

to become the currently observed dark matter. The above formula involving the value $\zeta(3) \approx 1.2$ of the Riemann function is standard for all isotropic harmonic traps (see for instance [44]; however, one should not be misled by the latter term: there is no harmonic trap here, it is the AdS geometry that originates the harmonic spectrum on the quantum level). To support this scenario, and as explained in [46], it has been shown, thanks to the physics of ultra-cold [4] atoms, that Bose–Einstein condensation can occur in non-condensed matter but also in gas, and that this phenomenon is not linked to *interactions* but rather to the *correlations implied by quantum statistics*.

Although we do not precisely know at which stage beyond the point δ in Figure 2 the gluonic Bose–Einstein condensation takes place, let us see if Equation (33) yields reasonable orders of magnitude by putting T_c equal to the current CMB temperature, $T_c = 2.78$ K, and $|\Lambda_{\text{AdS}}| \approx \frac{5.5}{6.5}\times\frac{11}{24}\times\Lambda_{\text{dS}} = 0.39\times\Lambda_{\text{dS}}$, with $\Lambda_{\text{dS}} \equiv$ present CC $\Lambda = 1.1\times 10^{-52}$ m^{-2}. We then derive from (33) the following estimate of the number of di-gluons in the condensate:

$$N_G \approx 5\times 10^{88}. \tag{34}$$

This estimate already seems reasonable since the gluons are around 10^9 times the number of baryons, and the latter is estimated to be around 10^{80}. Keeping this number in Equation (33) allows us to estimate the scaling factor defined by

$$\sigma_c := \frac{\Lambda_{\rm dS}}{T_c^2} \approx 1.85 \times 10^6 \times N_G^{-2/3} \approx 1.36 \times 10^{-53}\,. \tag{35}$$

Hence, having T_c of the order of "Matter-dominated era" temperature, say 10^4 K, i.e., at the point ε in Figure 2, yields the following value for $\Lambda_{\rm dS}$:

$$\Lambda_{\rm dS}(\varepsilon) \approx 1.36 \times 10^{-44}\,{\rm m}^{-2}\,. \tag{36}$$

Some years ago, it has been shown that Bose–Einstein condensation of dark matter can solve the core/cusp problem in the rotation curves of dwarf galaxies [47,48] with dark matter particles of mass in the meV range. [5] In these motivating articles, the exact nature of the BEC particles is not made precise, but strong interaction between them is assumed, and dark matter is viewed as a non-relativistic, Newtonian Bose–Einstein gravitational condensate gas, whose density and pressure are related by a barotropic equation of state. Some observed properties of dwarf galaxies appear to fit well with this scenario. More recently, the interpretation of dark matter in terms of a Bose–Einstein condensate has drawn interest in the framework of the so called "fuzzy dark matter" (FDM) model [49]. Originated from the idea that the dark matter particle is an ultralight particle [50], the *axion*, this model intends to solve the small scale shortcomings of the cold dark matter (CDM) [51] model ("cuspy" dark matter halo profiles and an abundance of low mass halos). In the FDM model, their mass of the would-be dark matter particle must be of the order of 10^{-22} eV in order for its wave nature to be significant at astrophysical scales. For testing the ability of such a model to account for observations, it was necessary to use simulations. Such high-precision simulations were done in [52], and they confirm the expected order of magnitude of 10^{-22} eV for the mass of the dark matter particle. Whereas such small masses seem highly unrealistic for particles to be considered in particle physics, we think that our scalar covariant quantum "dilaton" field ϕ, which is not a "dark matter particle" but rather, using a terminology of condensed matter physics, a "*dark matter quasi-particle, or a collective excitation*" viewed as a di-gluon , can have a temperature-dependent mass gap of this order of magnitude.

5. Discussion

In this concluding discussion section, we would like, on the one hand, to see in which way the present paper could fill the gaps between our two former approaches and, on the other hand, to propose new arguments in favor of their common aim, namely the aim of reconciling the standard models of particle physics and cosmology. The starting point of the approach of GC-T was, as explained above, to associate dark matter with a gravitational lensing potential and thus to assimilate it to an anti-de Sitter world matter. This approach was lacking a firmer theoretical ground, which we think has been provided by the approach of J-PG. The idea of this approach is that, apart from the ordinary mass, elementary quantum systems can acquire in an anti-de Sitter space time a supplement of mass, of purely geometric origin, that could be a candidate, in the cosmological context, that is, as explained in Section 3.2, when the cosmological term in the Einstein's equation is put back in the right hand side in terms of world matter densities, to constitute the dark matter.

Actually, the link between the two approaches can be provided by what we call the "*dilaton*" field ϕ, that is a scalar *covariant* quantum field that is given by *non-perturbative* effects of the gauge theories of the standard model, at each cosmic event of emergence of masses, a "Higgs like" potential (with a Mexican hat shape) that can be interpreted as a world-matter energy density. This is indeed true at the electroweak symmetry breaking at point γ in Figure 2, but also at the QCD hadronization transition at point δ in Figure 2. Let us note that, in [51], the authors attribute to the *axion* the potential provided by the non-perturbative QCD effects, whereas we attribute it to the *dilaton field*, which, as explained above looks much more reasonable.

In particle physics, the frontier of the standard model is essentially due to non-perturbative effects such as instantons or monopoles that can be encountered in the cosmological context [53]. Fortunately, as explained in Section 4.1.2, it turns out that cosmology at extra-galactic scales may be because it depends only on the determinant of the metric, easier to deal with than at smaller scales. The question of whether the filament structure that appears in the distribution of dark matter at extra-galactic scales is also present at smaller scales is still an open question. For instance, it is often claimed that, at galactic scales, dark matter is rather distributed in the halo of ordinary matter. However, we think that this feature cannot be considered an argument against our approach, because our interpretation of dark matter as a Bose–Einstein condensate, precisely aimed to correct the defects of the conventional cold dark matter model, has been some how confirmed, as shown above, by the fuzzy dark matter paradigm. On the other hand, it seems that a very recent work, based on deep learning, has shown the existence of a local web of dark matter at galactic scales [54].

Author Contributions: Both authors contributed equally to this work: conceptualization, methodology, validation, formal analysis, investigation, writing and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors thank V.B. (Thalès) and M.K. Director of Virtual Institute of Astroparticle Physics, for insightful comments and suggestions.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

CMB	Cosmic microwave background
BEC	Bose–Einstein condensate
dS	de Sitter
AdS	Anti-de Sitter
QGP	quark gluon plasma

Notes

1 The proper mass is predicted by special relativity if we adopt Wigner's point of view of elementary system [6,7]. Its existence results from the symmetry of empty Minkowski, de Sitter, and Anti-de Sitter space-times as being one of the two invariants (the other one being the spin) of the representations of their respective kinematical groups. This point is developed in Section 3.4.

2 As a special tribute to Georges Lochak (1930–2021), French physicist known for their work on magnetic monopoles.

3 The mass scintillation model imagined by Gürsey is comparable with the steady state cosmology of Bondy [43] in which the creation, at constant density of matter- -energy, induces the expansion of the universe.

4 As a side remark, one could propose naming the cosmological standard model ΛUCDM (UCDM for Ultra Cold Dark Matter).

5 We would like to acknowledge the anonymous referee who let us know these references.

References

1. Peebles, P.J.E.; Ratra, B. The cosmological constant and dark energy. *Rev. Mod. Phys* **2003**, *75*, 559–606. [CrossRef]
2. Arbey, A.; Mahmoudi, F. Dark matter and the early Universe: A review. *Prog. Part. Nucl. Phys.* **2021**, *119*, 103865. [CrossRef]
3. Cohen-Tannoudji, G. Lambda, the Fifth Foundational Constant Considered by Einstein. *Metrologia* **2018**, *55*, 486–498. [CrossRef]
4. Cohen-Tannoudji, G. The de Broglie universal substratum, the Lochak monopoles and the dark universe. *Ann. Fond. Louis Broglie* **2019**, *44*, 187–209.
5. Gazeau, J.-P. Mass in de Sitter and Anti-de Sitter Universes with Regard to Dark Matter. *Universe* **2020**, *6*, 66. Available online: https://www.mdpi.com/2218-1997/6/5/66 (accessed on 22 September 2021).
6. Wigner, E.P. On unitary representations of the inhomogeneous Lorentz group. *Ann. Math.* **1939**, *40*, 149–204. [CrossRef]
7. Bargmann, V.; Wigner, E.P. Group theoretical discussion of relativistic wave equations. *Proc. Natl. Acad. Sci. USA* **1948**, *34*, 211–223. [CrossRef]
8. Einstein, A. Cosmological considerations about the general theory of relativity, Preussische Akademie des Wissenschaften. *Sitzungsberichte* **2012**, *1917*, 142–152; In French, Albert Einstein, oeuvres choisies, Tome 3, Relativités. p. 91 Le Seuil, Paris (1993).
9. de Sitter, W. On the relativity of inertia. Remarks concerning Einstein's latest hypothesis, *KNAW Proc. Royal Acad. Amst.* **1917**, *19*, 1217–1225.
10. Gazeau, J.-P.; Novello, M. The Nature of Λ and the Mass of the Graviton: A Critical View. *Int. J. Mod. Phys. A* **2011**, *26* 3697–3720. [CrossRef]
11. Potter, D.; Stadel, J.; Teyssier, R. PKDGRAV3: Beyond trillion particle cosmological simulations for the next era of galaxy surveys. *Comput. Astrophys.* **2017**, *4*, 2–13. [CrossRef]
12. Bacry, H.; Lévy-Leblond, J.-M. Possible Kinematics. *J. Math. Phys.* **1968**, *9*, 1605. [CrossRef]
13. Garidi, T. What is mass in de Sitterian Physics? *arXiv* **2003**, arXiv:hep-th/0309104.
14. Mickelsson, J.; Niederle, J. Contractions of representations of de Sitter groups. *Commun. Math. Phys.* **1972**, *27*, 167–180. [CrossRef]
15. Garidi, T.; Huguet, E.; Renaud, J. de Sitter waves and the zero curvature limit. *Phys. Rev. D* **2003**, *67*, 124028. [CrossRef]
16. Gazeau, J.-P.; Novello, M. The question of mass in (anti-) de Sitter spacetime. *J. Phys. A Math. Theor.* **2008**, *41*, 304008. [CrossRef]
17. Gazeau, J.-P.; Renaud, J. Relativistic harmonic oscillator and space curvature. *Phys. Lett. A* **1993**, *179*, 67. [CrossRef]
18. Fronsdal, C. Elementary particles in a curved space. IV. Massless particles. *Phys. Rev. D* **1975**, *12*, 3819–3830. [CrossRef]
19. Binegar, B.; Fronsdal, C.; Heidenreich, W. de Sitter QED. *Ann. Phys.* **1983**, *149*, 254–272. [CrossRef]
20. Gazeau, J.-P.; Hans, M.; Murenzi, R. Invariant bilinear forms on 3 + 2 de Sitter space. *Class. Quantum. Grav.* **1989**, *6*, 329–348. [CrossRef]
21. Hua, L.K. Harmonic analysis of functions of several complex variables in the classical domains. In *Translations of Mathematical Monographs*; American Mathematical Society: Providence, RI, USA, 1963; Volume 6.
22. Flato, M.; Fronsdal, C.; Gazeau, J.-P. Masslessness and light-cone propagation in 3 + 2 de Sitter and 2 + 1 Minkowski spaces. *Phys. Rev. D* **1986**, *33*, 415–420. [CrossRef]
23. Padmanabhan, T.; Patel, A. Role of Horizons in Semiclassical Gravity: Entropy and the Area Spectrum. *arXiv* **2013**, arXiv:gr-qc/0309053.
24. Connes, A.; Rovelli, C. Von Neumann Algebra Automorphisms and Time-Thermodynamics Relation in General Covariant Quantum Theories. *Class. Quant. Grav.* **1994**, *11*, 2899–2918. [CrossRef]
25. Bergeron, H.; Czuchry, E.; Gazeau, J.-P.; Małkiewicz, P. Quantum Mixmaster as a Model of the Primordial Universe. *Universe* **2020**, *6*, 7. [CrossRef]
26. Lestienne, R.; Harris, P. (Eds.) *Time in Science*; World Scientific: Singapore, 1967.
27. Brout, R.; Englert, F.; Gunzig, E. The Creation of the Universe as a Quantum Phenomenon. *Ann. Phys.* **1978**, *115*, 78–106. [CrossRef]
28. Melia, F. The Zero Active Mass Condition in Friedmann-Robertson-Walker Cosmologies. *Front. Phys.* **2017**, *12*, 129802. [CrossRef]
29. Ramond, P. Neutrinos: Precursors of new physics. *Comptes Rendus Phys.* **2005**, *6*, 719–728. [CrossRef]
30. Buchmuller, W.; Peccei, R.D.; Yanagida, T. Leptogenesis as the origin of matter. *Ann. Rev. Nucl. Part. Sci.* **2005**, *55*, 311–355. [CrossRef]
31. Sakharov, A. Violation of CP Invariance, C asymmetry, and baryon asymmetry of the universe. *JETP Lett.* **1967**, *5*, 24–27.
32. Sakharov, A. Vacuum quantum fluctuations in curved space and the theory of gravitation. *Dok. Akad. Nauk. SSR* **1967**, *177*, 70.
33. Adler, S.L. Einstein gravity as a symmetry breaking effect in quantum field theory. *Rev. Mod. Phys.* **1982**, *54*, 729. [CrossRef]
34. Brindejonc, V.; Cohen-Tannoudji, G. An effective strong gravity induced by QCD. *Mod. Phys. Lett. A* **1995**, *10*, 1711. [CrossRef]
35. Brindejonc, V. Einstein–Yang-Mills black hole solutions in three dimensions. *Class. Quant. Grav.* **1998**, *15*, 3599–3608. [CrossRef]
36. Aghanim, N.; Akrami, Y.; Ashdown, M.; Aumont, J.; Baccigalupi, C.; Ballardini, M.; Banday, A.J.; Barreiro, R.B.; Bartolo, N.; Basak, S.; et al. Planck 2018 Results–VI. Cosmological parameters. *A&A* **2020**, *A6*, 641.
37. Nielsen, H.B.; Olesen, P. A Quantum Liquid Model for the QCD Vacuum. *Nucl. Phys. B* **1979**, *160*, 380–396. [CrossRef]
38. Witten, E. Baryons in the $1/N$ expansion. *Nuclear Phys. B* **1979**, *160*, 57–115. [CrossRef]
39. Pasechnik, R.; Šumbera, M. Phenomenological Review on Quark-Gluon Plasma: Concepts vs. Observations. *Universe* **2017**, *3*, 7. [CrossRef]
40. Andronic, A.; Braun-Munzinger, P.; Redlich, K.; Stachel, J. Decoding the phase structure of QCD via particle production at high energy. *Nature* **2018**, *561*, 321–330. [CrossRef] [PubMed]

41. Rafelski, J. Discovery of Quark-Gluon Plasma: Strangeness Diaries. *Eur. Phys. J. Spec. Top.* **2020**, *229*, 1–140. [CrossRef]
42. Gürsey, F. Reformulation of General relativity in accordance with Mach's principle. *Ann. Phys.* **1963**, *21*, 211–242. [CrossRef]
43. Bondi, H.; Gold, T. The Steady-State Theory of the Expanding Universe. *Mon. Not. R. Astron. Soc.* **1948**, *108*, 252–270. [CrossRef]
44. Grossmann, S.; Holthaus, M. On Bose–Einstein condensation in harmonic traps. *Phys. Lett. A* **1995**, *208*, 188–192. [CrossRef]
45. Mullin, W.J.; Bose–Einstein, W.J. Condensation in a Harmonic Potential. *J. Low Temp. Phys.* **1997**, *106*, 615–641. [CrossRef]
46. Cohen-Tannoudji, C.; Dalibard, J.; Laloë, F. La condensation de Bose Einstein dans les gaz. In *Einstein Aujourd'hui, Savoirs Actuels*; EDP Sciences/CNRS: Paris, France, 2005; pp. 87–127.
47. Böhmer, C.G.; Harko, T. Can dark matter be a Bose–Einstein condensate? *J. Cosmol. Astropart. Phys.* **2007**, *2007*, 025. [CrossRef]
48. Harko, T. Bose–Einstein condensation of dark matter solves the core/cusp problem. *J. Cosmol. Astropart. Phys.* **2011**, *5*, 022. [CrossRef]
49. Hu, W.; Barkana, R.; Gruzinov, A. Cold and Fuzzy Dark Matter. *Phys. Rev. Lett.* **2000**, *85*, 1158–1161. [CrossRef] [PubMed]
50. Lam Hui, L.; Ostriker, J.P.; Tremaine, S.; Witten, E. Ultralight scalars as cosmological dark matter. *Phys. Rev. D* **2017**, *95*, 043541.
51. Duffy, L.D.; van Bibber, K. Axions as Dark Matter Particles. *New J. Phys.* **2009**, *11*, 105008. [CrossRef]
52. Schive, H.-Y.; Chiueh, T.; Broadhurst, T. Cosmic structure as the quantum interference of a coherent dark wave. *Nat. Phys.* **2014**, *10*, 496–499. [CrossRef]
53. Weinberg, S. *The Quantum Theory of Fields, Volume II Modern Applications, Chapter 23 Extended Field Configurations*; Cambridge University Press: Cambridge, UK, 1996; p. 421.
54. Hong, S.E.; Jeong, D.; Hwang, H.S.; Kim, J. Revealing the Local Cosmic Web from Galaxies by Deep Learning. *Astrophys. J.* **2021**, *913*, 76. [CrossRef]