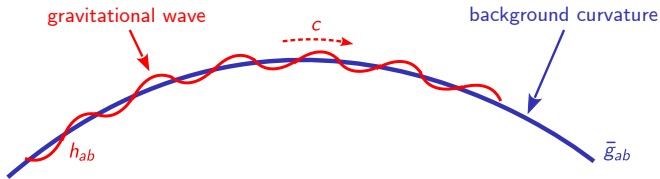


What is a gravitational wave ?

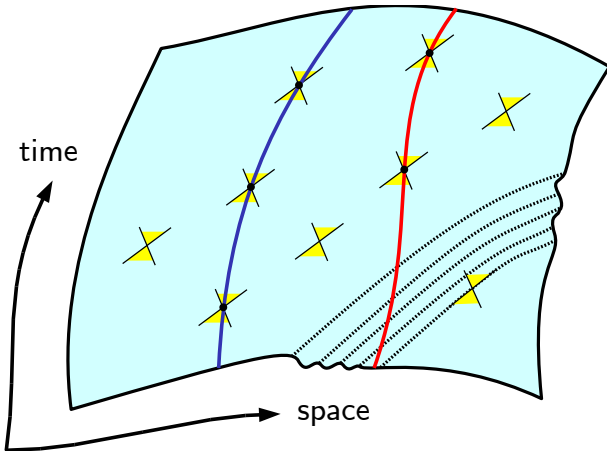
A **gravitational wave** is a tiny ripple in the **curvature of spacetime** that propagates at the vacuum speed of light



$$\square h_{ab} + 2\bar{R}_{abcd}h^{cd} = -16\pi T_{ab}$$

Key prediction of Einstein's general theory of relativity

What is a gravitational wave ?



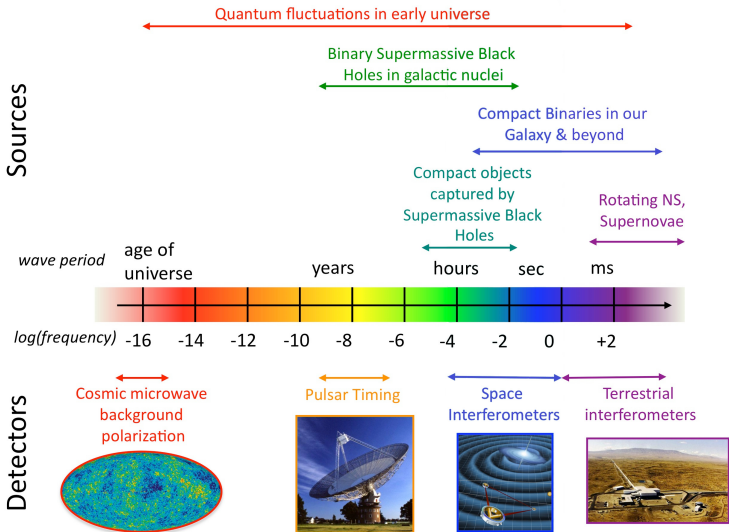
(Credit: E. Gourgoulhon)

Electromagnetic vs gravitational waves

	Electromagnetic waves	Gravitational waves
Origin	electromagnetic field	spacetime curvature
Nature	waves <i>in</i> spacetime	waves <i>of</i> spacetime
Sources	accelerated charges	accelerated masses
Wavelength	\ll size of source	\gtrsim size of source
Structure	dipolar	quadrupolar
Coherence	low	high
Interaction	strong	weak
Detection	power	amplitude
Analogy	vision	audition

Complementary sources of information about the Universe

The gravitational-wave spectrum



Gravitational-wave science

Astrophysics

- Formation and evolution of compact binaries
- Origin and mechanisms of γ -ray bursts
- Internal structure of neutron stars

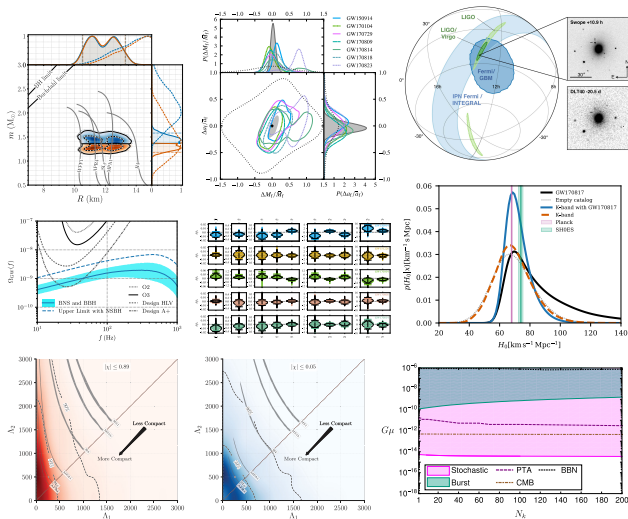
Cosmology

- Cosmography and measure of Hubble's constant
- Origin and growth of supermassive black holes
- Phase transitions during primordial Universe

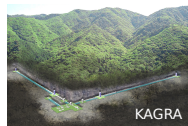
Fundamental physics

- Strong-field tests of GR
- Black hole no-hair theorem
- Cosmic censorship conjecture
- Dark energy equation of state
- Alternatives to general relativity

The beginnings of gravitational-wave science

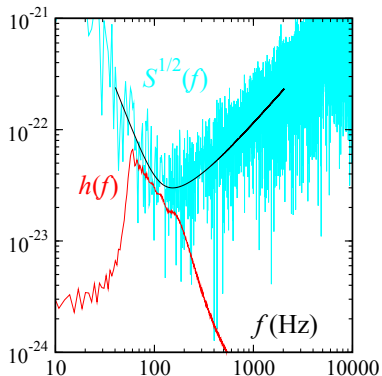
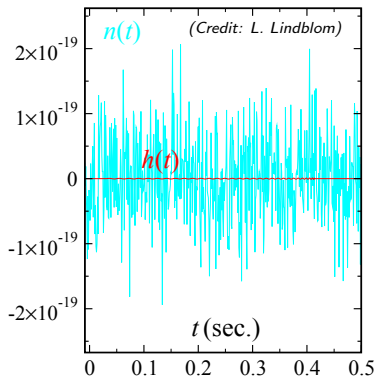


Science with gravitational-wave observations



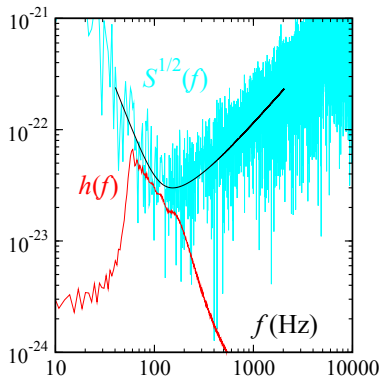
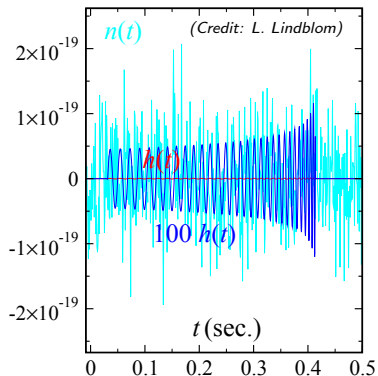
Detectors

Need for accurate template waveforms



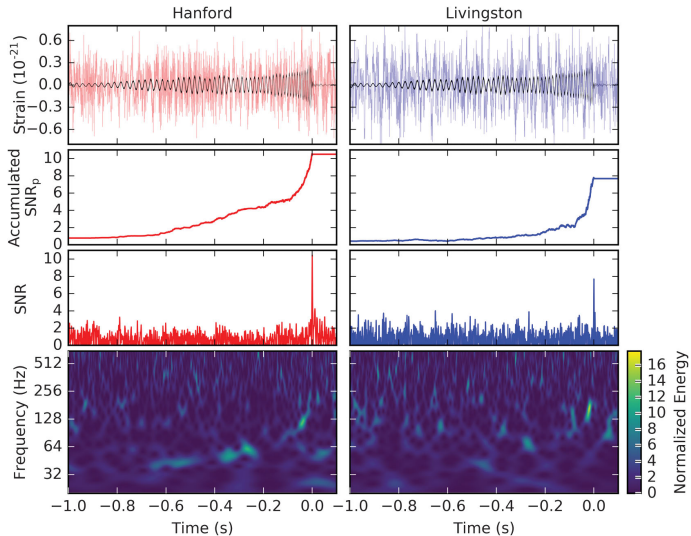
If the expected signal is *known in advance* then $n(t)$ can be filtered and $h(t)$ recovered by **matched filtering** → **template waveforms**

Need for accurate template waveforms

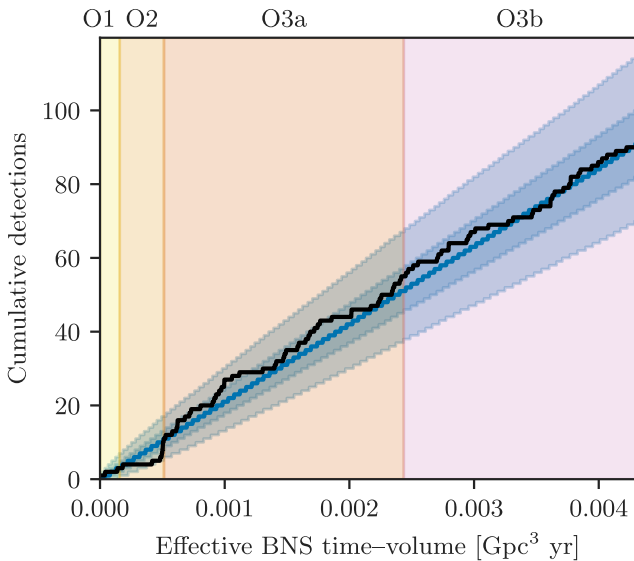


If the expected signal is *known in advance* then $n(t)$ can be filtered and $h(t)$ recovered by **matched filtering** \rightarrow **template waveforms**

An example: the event GW151226



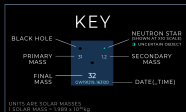
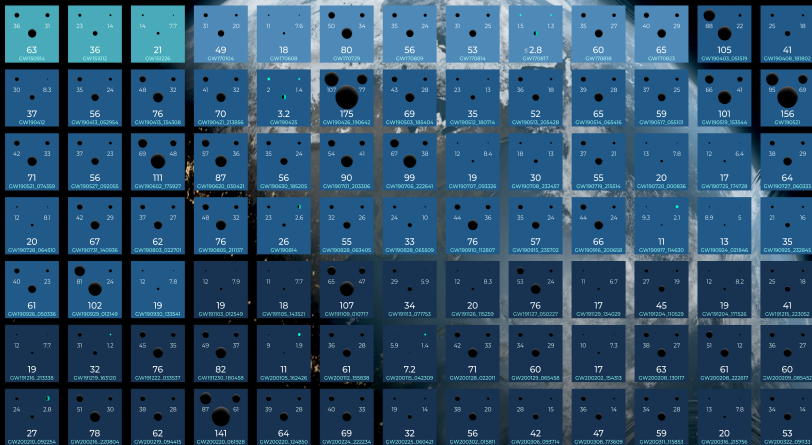
Current gravitational-wave detections



OBSERVING
01
2015 - 2016

02
2016 - 2017

03a+b
2019 - 2020

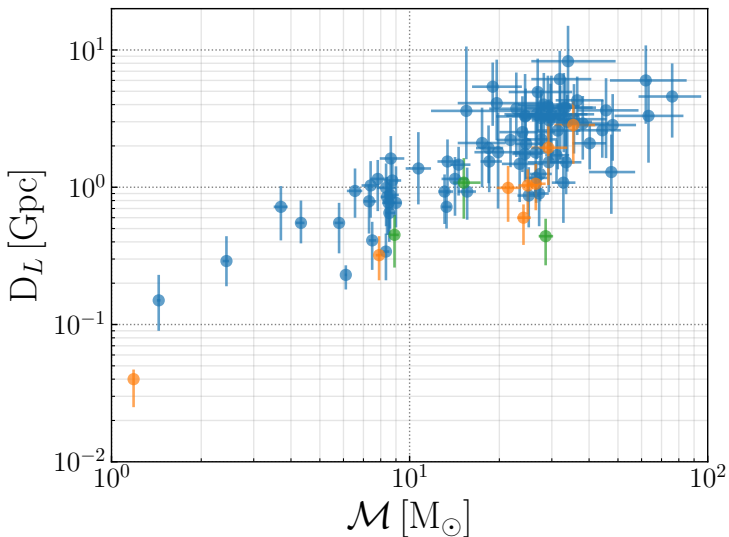


GRAVITATIONAL WAVE MERGER DETECTIONS

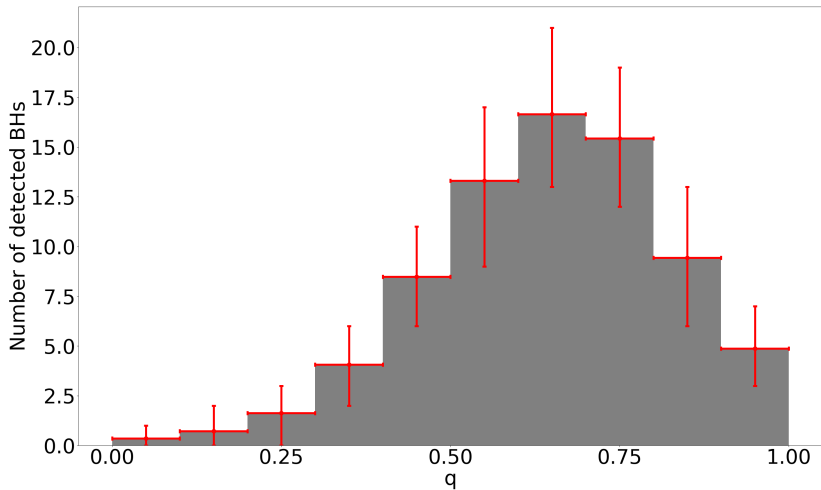
SINCE 2015



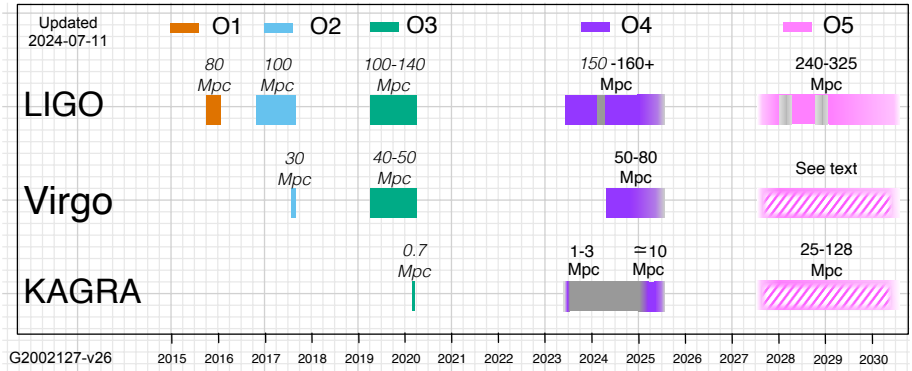
Properties of observed compact binaries



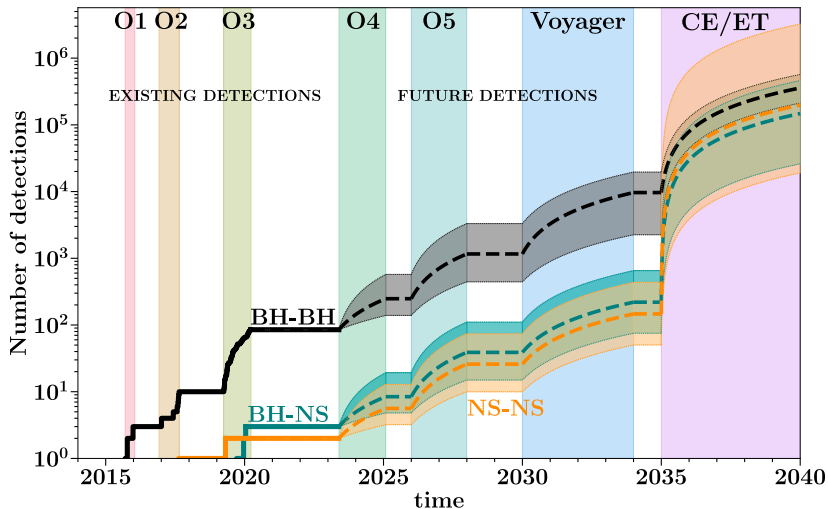
Properties of observed compact binaries



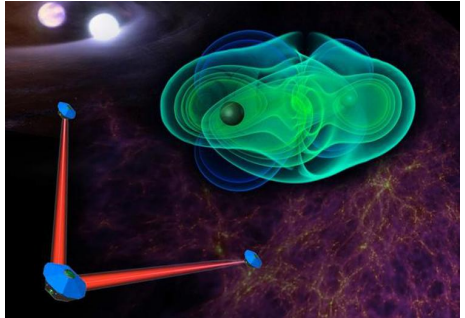
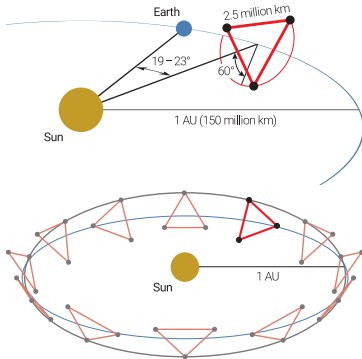
Roadmap for ground-based detectors



Roadmap for ground-based detectors

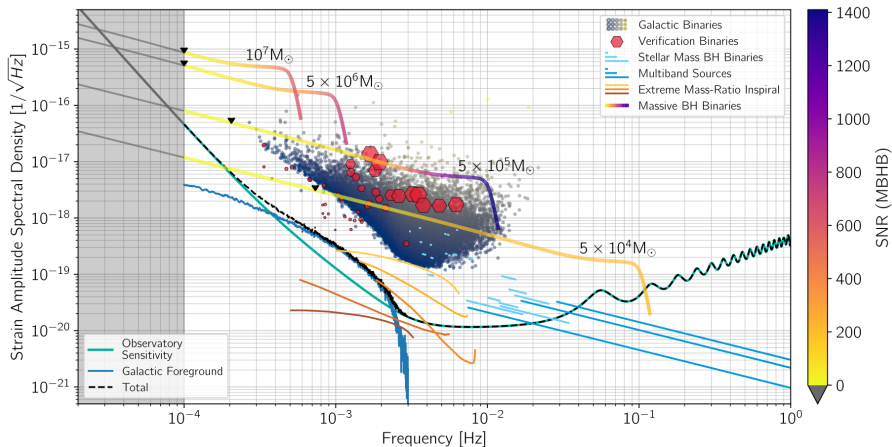


LISA: a gravitational antenna in space



The **LISA mission** was officially adopted/approved by ESA in 2024, with a launch planned for **2035**

LISA sources of gravitational waves



More than half of data deficient species predicted to be threatened by extinction

Jan Borgelke¹, Martin Dorber¹, Marthe Aines Heiberg¹ & Francesca Veronesi¹

PNAS

PERSPECTIVE

OPEN ACCESS



Climate Endgame: Exploring catastrophic climate change scenarios

Luke Kemp^{1,2}, Chi Xu¹, Joanna Depledge¹, Kristie L. Ebi³, Goodwin Gibbs¹, Timothy A. Kohler^{4,5}, Johan Rockström¹, Marten Scheffer⁶, Hans Joachim Schellnhuber⁷, Will Steffen⁸, and Timothy M. Lenton⁹

Accelerated modern human-induced species losses: Entering the sixth mass extinction

Gerardo Caballero¹, Paul R. Ehrlich², Anthony D. Barnosky³, Andrés García⁴, Robert M. Pringle⁵, Todd M. Palmer⁶

Underestimating the Challenges of Avoiding a Ghastly Future

Corey J. A. Bradshaw^{1,2}, Paul R. Ehrlich³, Andrew Beattie⁴, Gerardo Caballero⁵, Eileen Crist⁶, Joan Diamond⁷, Rodolfo Dirzo⁸, Arne H. Ehrlich⁹, John Hart¹⁰, Mary Ellen Hart¹¹, Graham Pyke¹², Peter H. Raven¹³, William J. Ripple¹⁴, Frédéric Sauter¹⁵, Christine Turnbull¹⁶, Mathis Wackernagel¹⁷ and Daniel F. Burslem^{18,19}

Global risk of deadly heat

Camilo Mora¹, Bénédicte Dousset², Iain R. Caldwell³, Farrah E. Powell⁴, Rollan C. Geronimo⁵, Coral R. Bielecki⁶, Chelsie W. W. Counsell⁷, Bonnie S. Dietrich⁸, Emily T. Johnston⁹, Leo V. Louis¹⁰, Matthew P. Lucas⁶, Marie M. McKenzie¹¹, Alessandra G. Shea¹², Han Tseng¹³, Thomas W. Giambelluca¹⁴, Lisa R. Leon¹⁵, Ed Hawkins¹⁶ and Clay Trauernicht¹⁷

RESEARCH ARTICLE

CLIMATE CHANGE

Exceeding 1.5°C global warming could trigger multiple climate tipping points

David I. Armstrong McKay^{1,2,3}, Aisling Staal^{4,5}, Jesse F. Abrams⁶, Ricardo Wehbehuysen^{6,7}, Boris Samkoev⁸, Siva Luthar⁹, Inga Fetisov¹⁰, Sarah E. Cornell¹¹, Johan Rockström¹², Timothy M. Lenton¹³

Viewpoint

World Scientists' Warning of a Climate Emergency

WILLIAM J. RIPPLE, CHRISTOPHER WOLF, THOMAS M. NEWSOME, PHOEBE BARNARD, WILLIAM R. MOOMAW, AND 11,258 SCIENTIST SIGNATORIES FROM 153 COUNTRIES (LIST IN SUPPLEMENTAL FILE S1)

REVIEW

Scientists' warning on climate change and insects

Jeffrey A. Harvey^{1,2} | Kévin Tougeron^{3,4} | Rieta Gols⁵ | Robin Heinen⁶ | Mariana Abarca⁷ | Paul K. Abram⁸ | Yves Basset^{9,10} | Matty Berg¹¹ | Carol Boggs^{12,13} | Jacques Brodeur¹⁴ |

Approaching a state shift in Earth's biosphere

Anthony D. Barnosky^{1,2}, Elizabeth A. Hadly³, Jonell Bascompte⁴, Eric L. Berlow⁵, James H. Brown⁶, Mikael Fortelius⁷, Wayne M. Getz⁸, John Hart⁹, Alan Hastings¹⁰, Pablo A. Marquet^{11,12,13}, Nao D. Martinez¹⁴, Arne Moores¹⁵, Peter Roopnarine¹⁶, Coenraad Vermeij¹⁷, John W. Williams¹⁸, Rosemary Gillespie¹⁹, Ines Kitzes²⁰, Charles Marshall²¹, Nicholas Matlack²², David P. Mindel²³, Ekoy Revilla²⁴ & Adam R. Smith²⁵

Article Worldwide occurrence records suggest a global decline in bee species richness

Eduardo E. Zattara^{1,2,3,4,5,6,7} and Marcelo A. Aizen^{4,8}

More than 75 percent decline over 27 years in total flying insect biomass in protected areas

Caspar A. Hofmann¹, Martin Sorg², Eelke Jongejans³, Henk Siespel⁴, Nick Hofland⁵, Heinz Schwant⁶, Werner Stenmans⁷, Andreas Müller⁸, Hubert Sumser⁹, Thomas Hören¹⁰, Dave Goulson¹¹, Hans de Kroon¹²

Viewpoint

World Scientists' Warning to Humanity: A Second Notice

WILLIAM J. RIPPLE, CHRISTOPHER WOLF, THOMAS M. NEWSOME, MAURO GALETTI, MOHAMMED ALAMGIR, EILEEN CRIST, MAHMOUD I. MAHMOUD, WILLIAM F. LAURANCE, and 15,364 scientist signatories from 184 countries

ECOLOGICAL MONOGRAPHS

REVIEW

Scientists' warning to humanity on tree extinctions

Malin Rivers¹ | Adrian C. Newton² | Sara Oldfield³ | Global Tree Assessment Contributors⁴

Review

Further evidence for a global decline of the entomofauna

Francisco Sánchez-Bayo^{1,2} & Kris A G Wyckhuys^{2,3,4}

Plants People Planet PPF

Co-extinctions annihilate planetary life during extreme environmental change

Giovanni Strona¹ & Corey J. A. Bradshaw²

The quiet crossing of ocean tipping points

Christoph Haas^{1,2}, Thoreten Blenckner³, Helena Martins⁴, Dagmara Rudacka^{5,6}, Raff Döschner⁶, Martin Gribben⁷, Niklas Graber⁸, Elizabeth Hubbard⁹, Dymitr How¹⁰, Fortunat Jaub¹¹, John Brian Robin Matthew¹², Raf Radwan¹³, and Simon Wilson¹⁴

Outside the Safe Operating Space of a New Planetary Boundary for Per- and Polyfluoroalkyl Substances (PFAS)

Jan T. Cousins¹, Jana H. Johansson, Matthew E. Salter, Bo Sha, and Martin Scheringer

Un état des lieux biophysique

Énergie

- Combustibles **fossiles** et “impulsion du carbone”
- **Pic du pétrole** conventionnel passé en 2008 (AIE)
- **Additions** et **synergies** énergétiques et matérielles

Climat

- Réchauffement climatique d'origine **anthropique**
- Boucles de rétroaction et **points de bascule**
- Risque d'un **emballement** climatique

Écologie

- Érosion accélérée de la **biodiversité**
- Effondrement des **populations** d'espèces
- Début de la sixième **extinction de masse**
- **Déficit écologique** global depuis ~ 1970
- Nombreuses **limites planétaires** dépassées

Où va-t-on ?

Un exercice de réflexivité à Royaumont ?

Quelques questions au-delà de l'exercice de comptabilité carbone attendu des tutelles:

- Quel est le **sens** (individuel et collectif) de notre activité ?
- Quelle **rôle** jouons-nous, en tant que scientifiques, dans le désastre en cours ?
- Quelle recherche en astrophysique à l'ère des **conséquences** ?