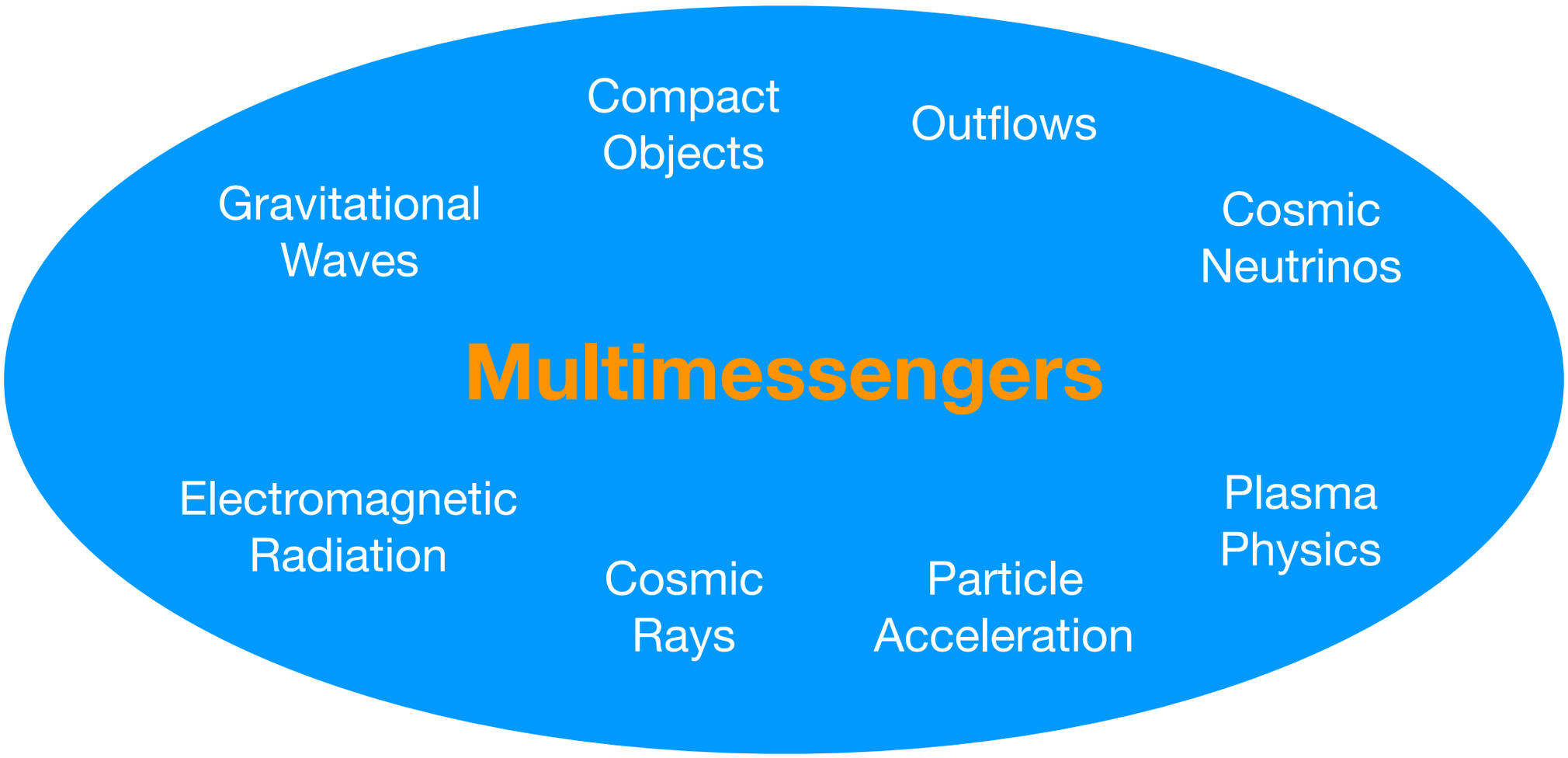
# THAT @ DESY — Strategy update

## THeoretical Astro(particle) physics - Theory



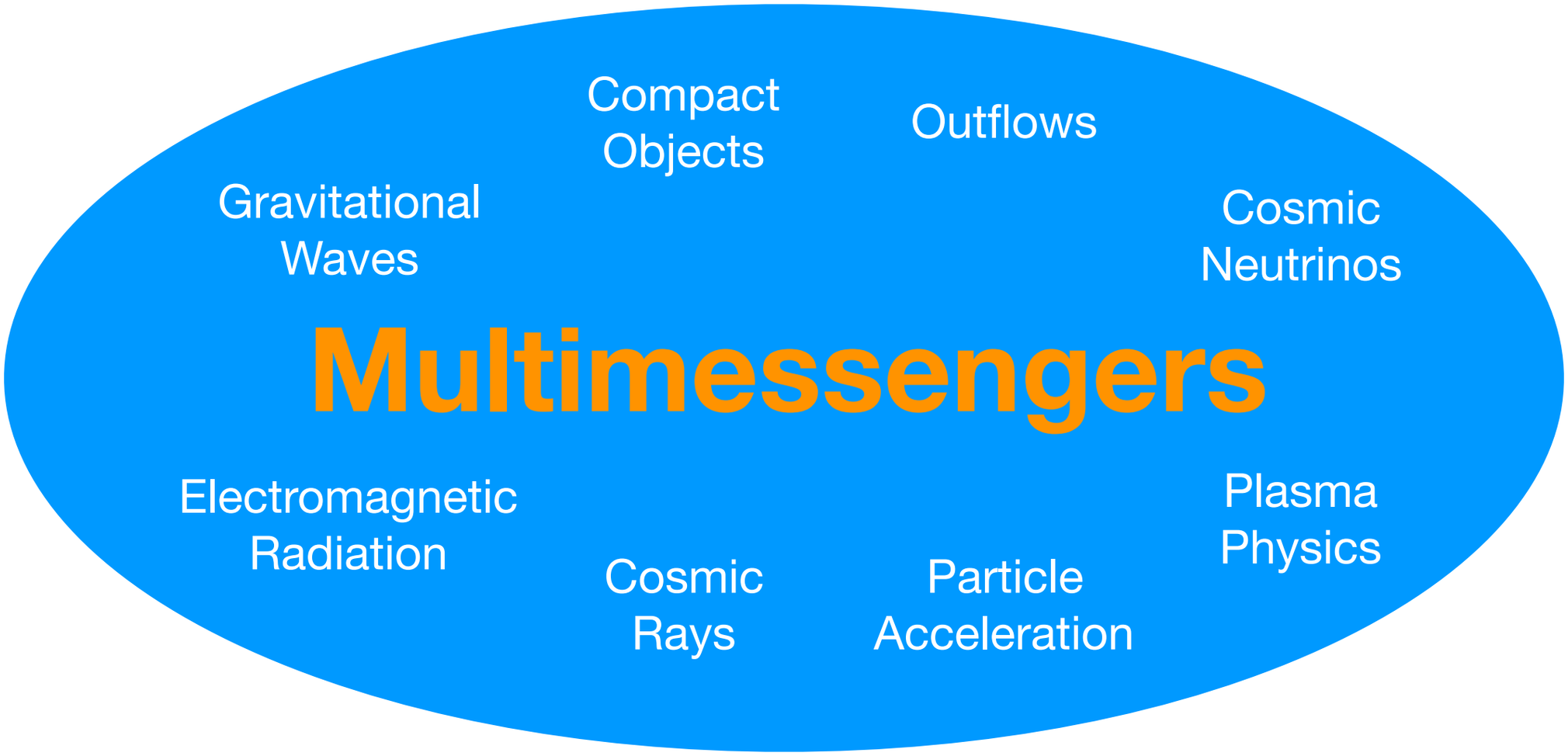

Martin Pohl, Rafael Porto, Andrew Taylor, Walter Winter, Huirong Yan

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

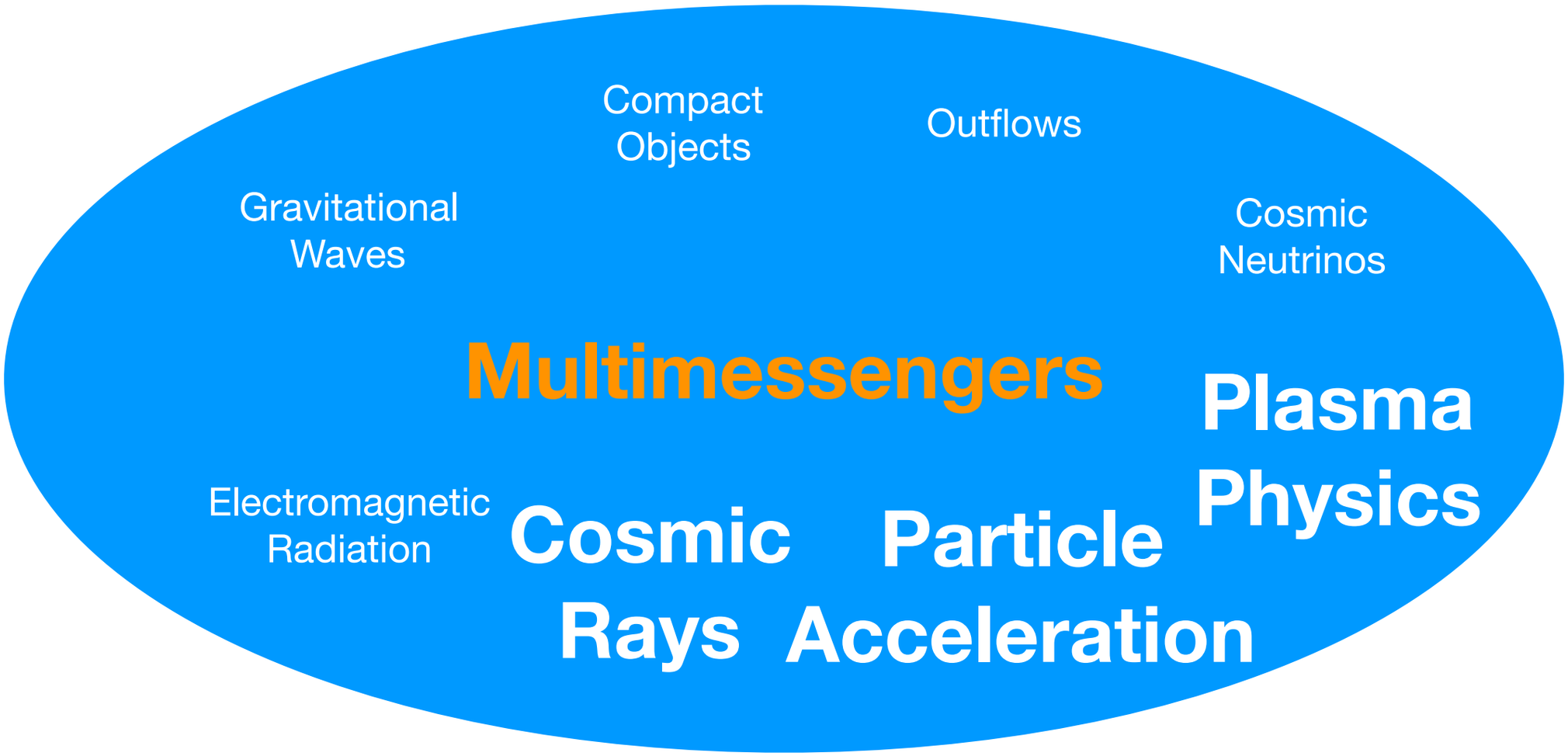
# THAT @ DESY — Strategy update

## THeoretical Astro(particle) physics - Theory




- The underlying theme of the **THAT** group is the **multi-messenger** approach to probing the ***extreme Universe*** — highly energetic events communicated via cosmic rays, neutrinos and electromagnetic/gravitational-wave radiation

# THAT @ DESY — Highlights

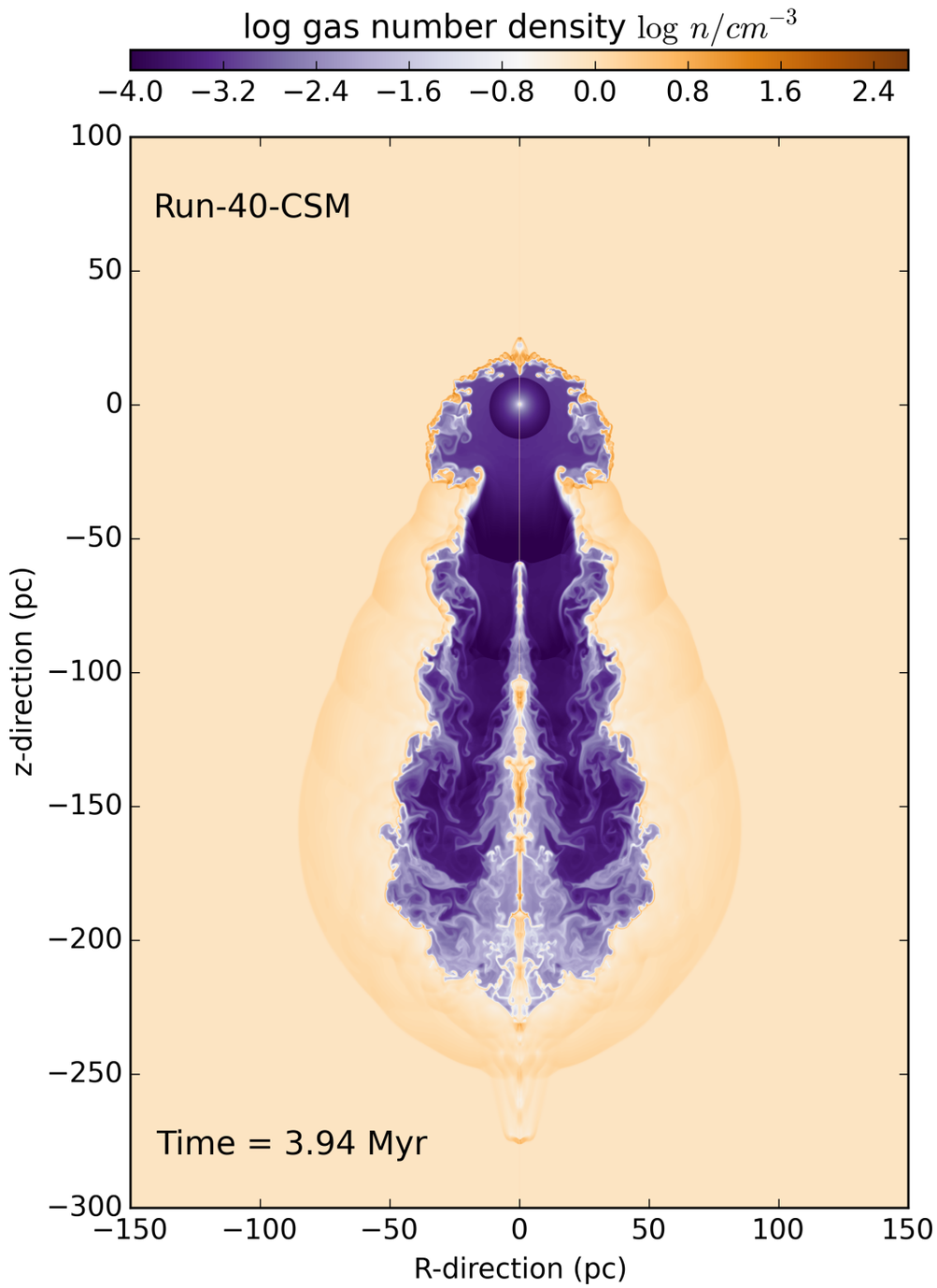



Martin Pohl,

# THAT @ DESY — Highlights

[Slide by Martin Pohl]

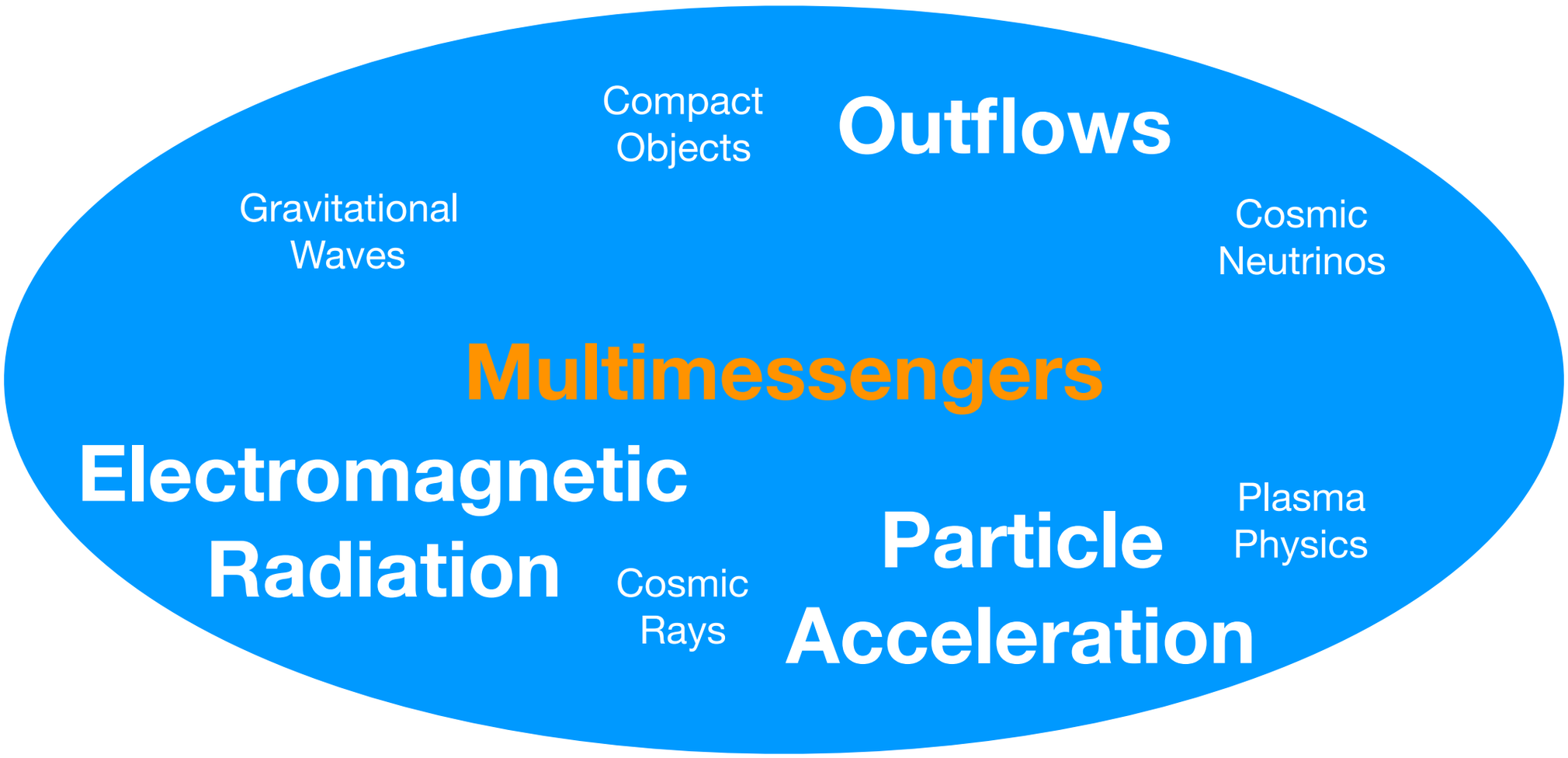
Density structure in a stellar wind bubble before a supernova goes off.




Calculated the acceleration and release of cosmic rays in these systems, including elemental composition

2020MNRAS.493.3548M
2020MNRAS.496.3906M

# THAT @ DESY — Highlights




Andrew Taylor,

# THAT @ DESY — Highlights

[Slide by Andrew Taylor]

Article | Published: 17 June 2020

## Resolving acceleration to very high energies along the jet of Centaurus A

The H.E.S.S. Collaboration

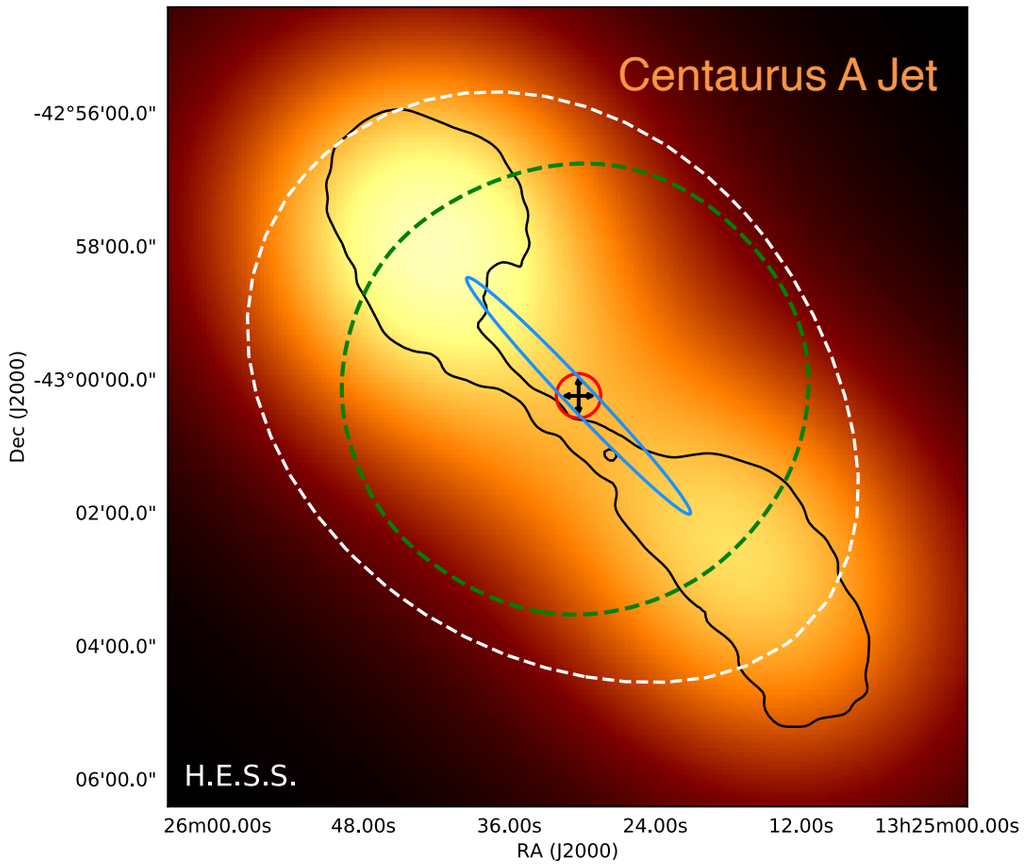
*Nature* **582**, 356–359(2020) | Cite this article



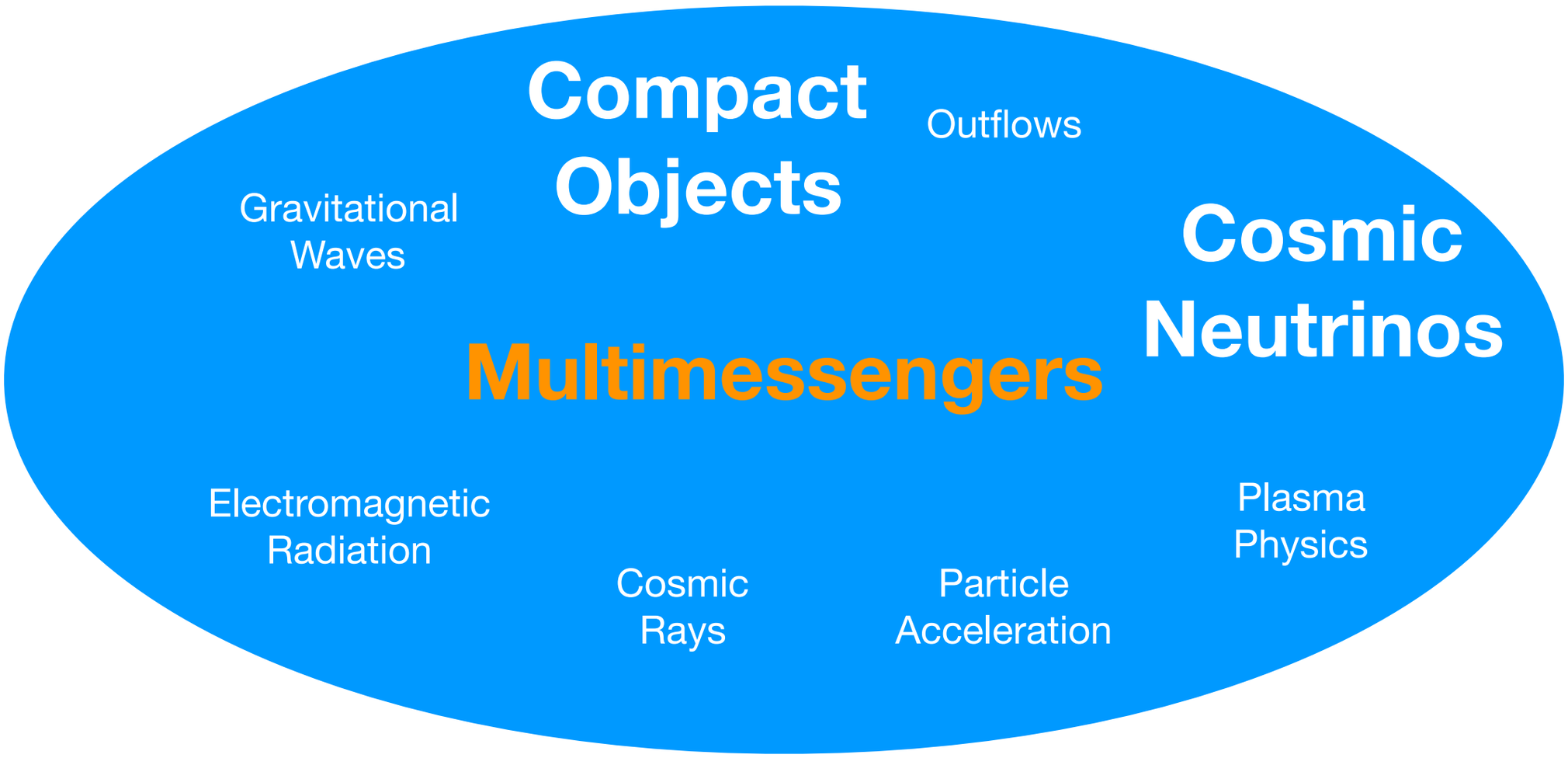
HESS gamma-ray observations complement previous X-ray observations, resolving previous ambiguity on the required maximum energy.

Acceleration of ultrarelativistic electrons along the kpc length jet is demonstrated to be required.

This suggests that a delocalised acceleration process (such as shear acceleration) is at play.



# THAT @ DESY — Highlights

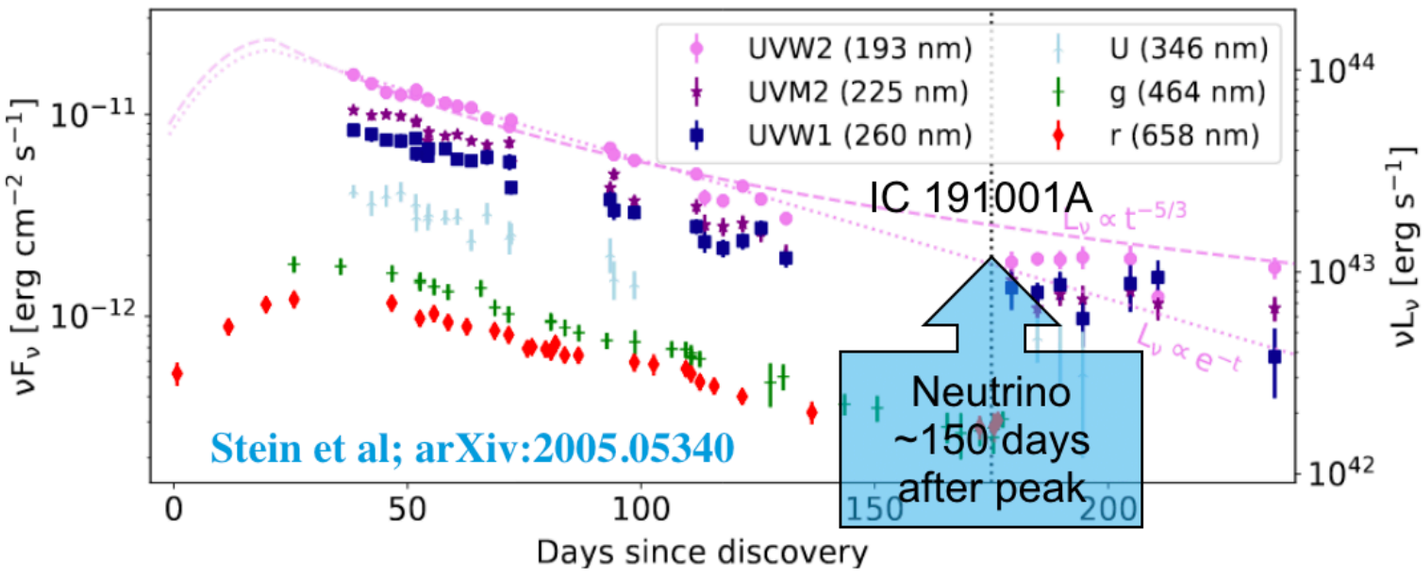


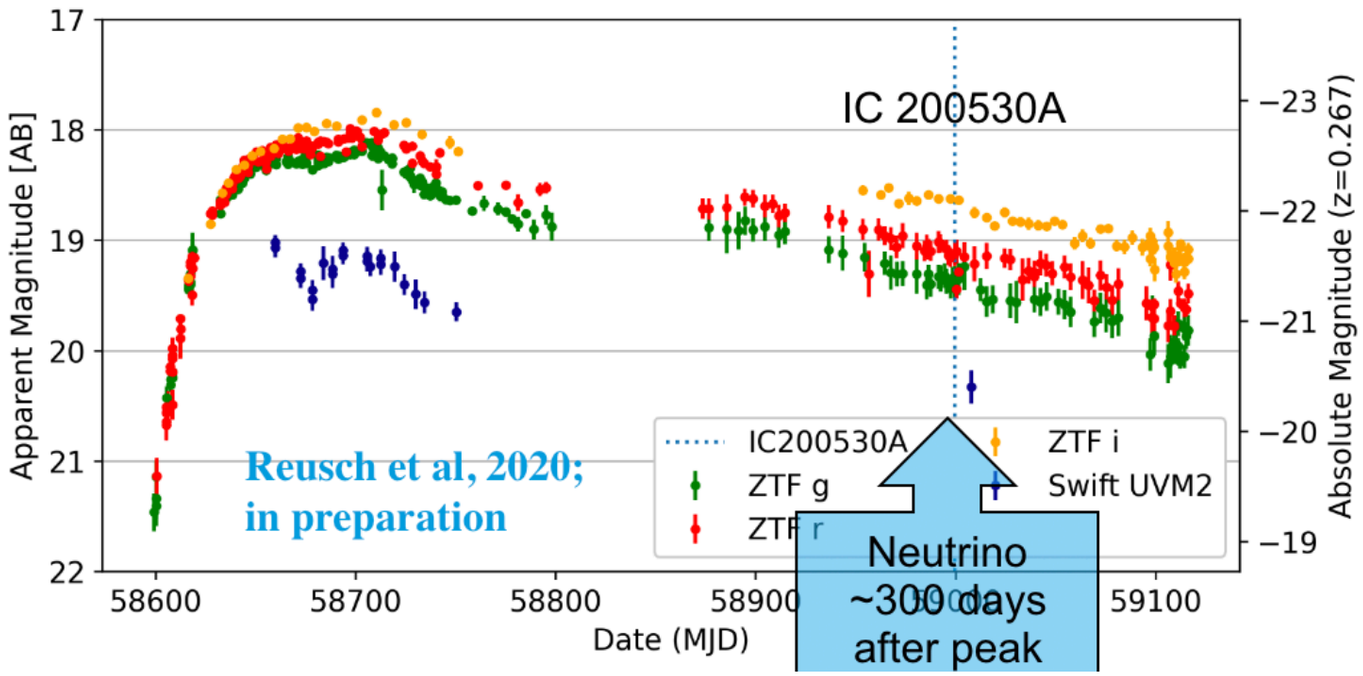

Walter Winter,

# THAT @ DESY — Highlights

[Slide by Walter Winter]

## Neutrinos from the Tidal Disruption of massive stars?



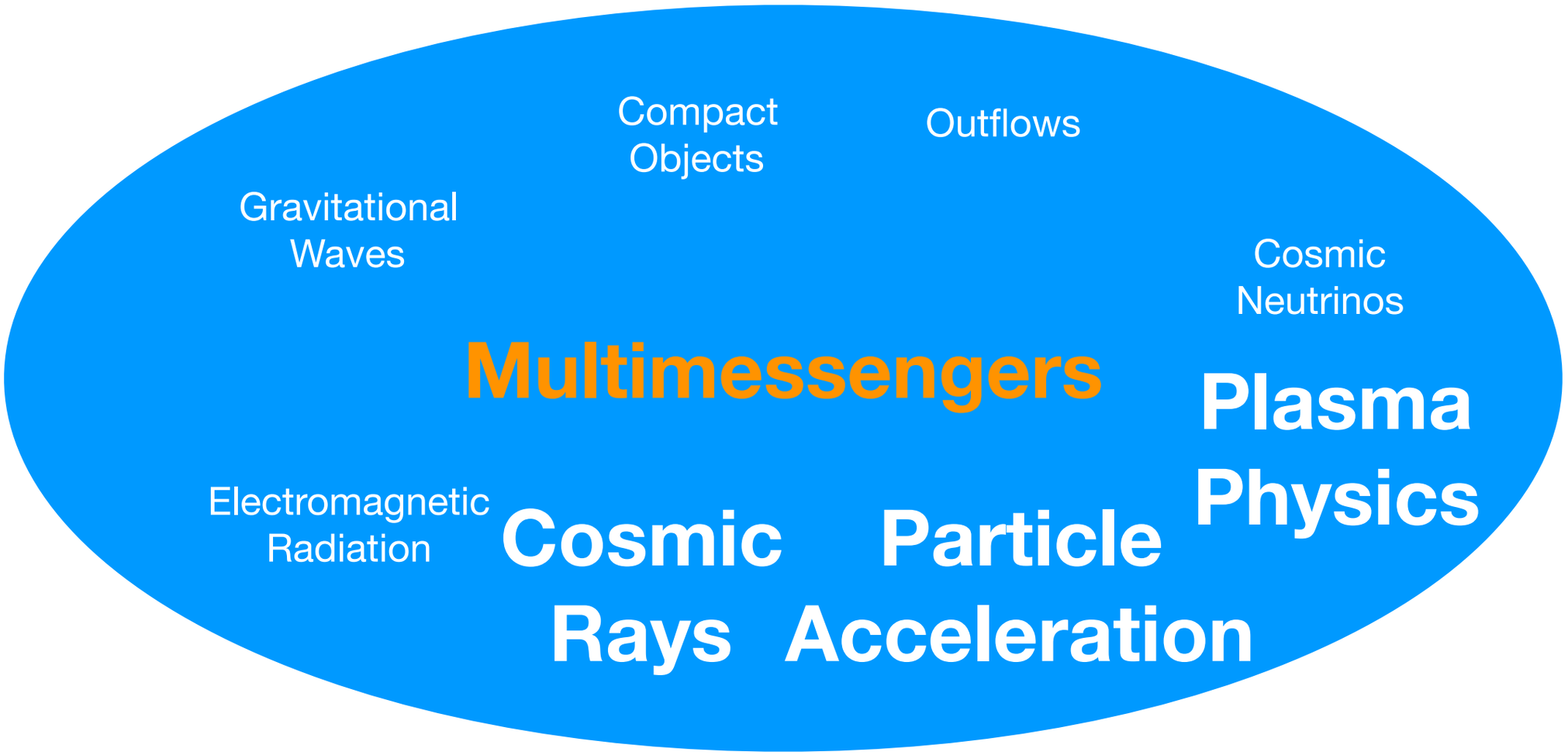




Is that a coincidence? Driven by Zeuthen experimental neutrino group!

**Ongoing theoretical modeling:** Why do these neutrinos come about half a year after the peak?

**Winter comes...**

# THAT @ DESY — Highlights




Huirong Yan

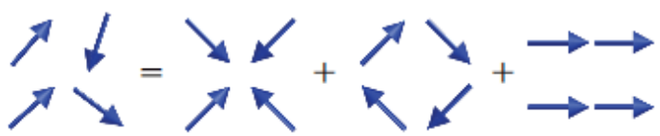
# THAT @ DESY — Highlights

[Slide by Huirong Yan]

## Energy fraction in each plasma mode

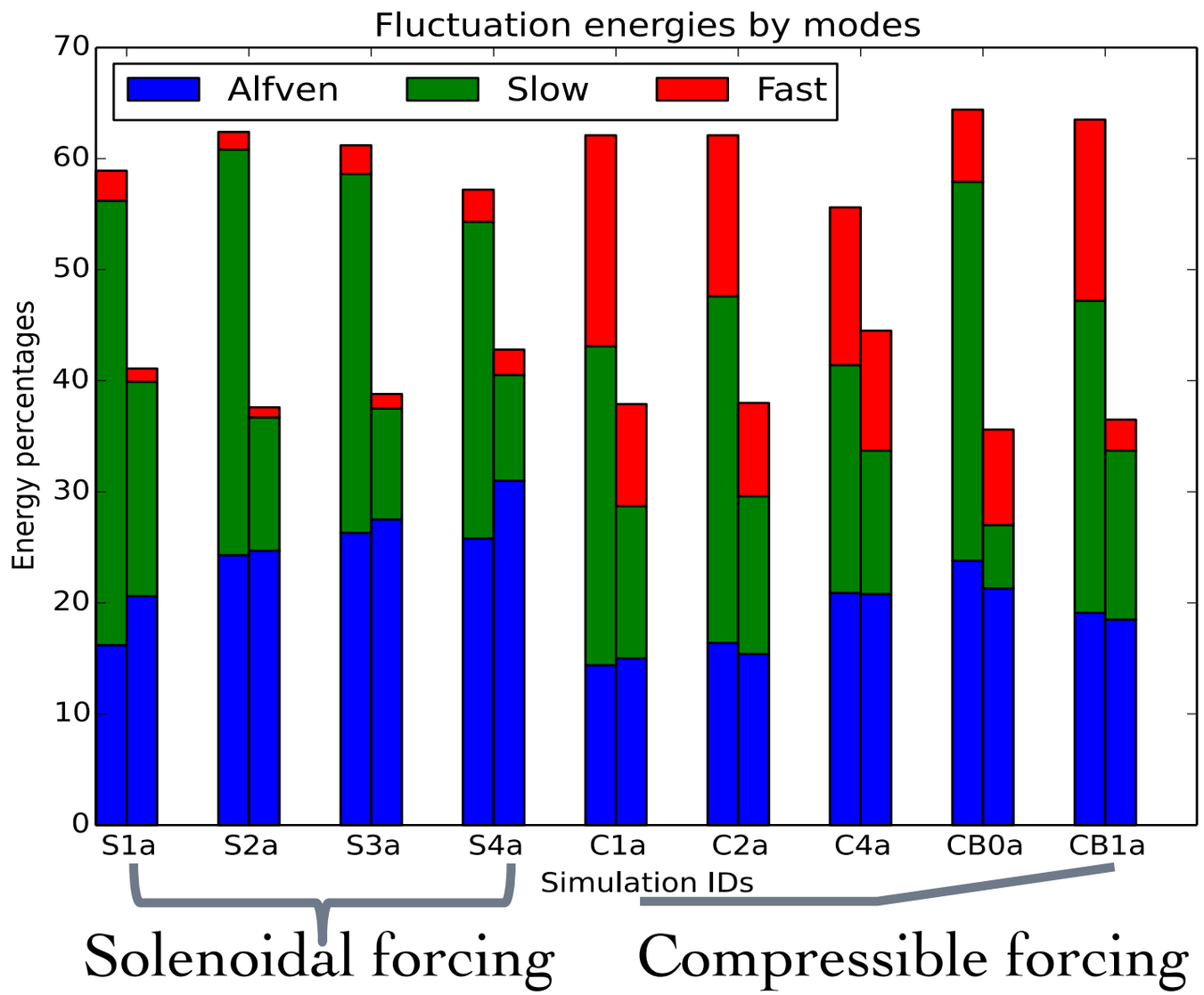
from Makwana & HY 2020, PRX

*Fundamental theorem of vector fields*



$$\vec{f} = \vec{f}_c + \vec{f}_s + \vec{f}_h$$

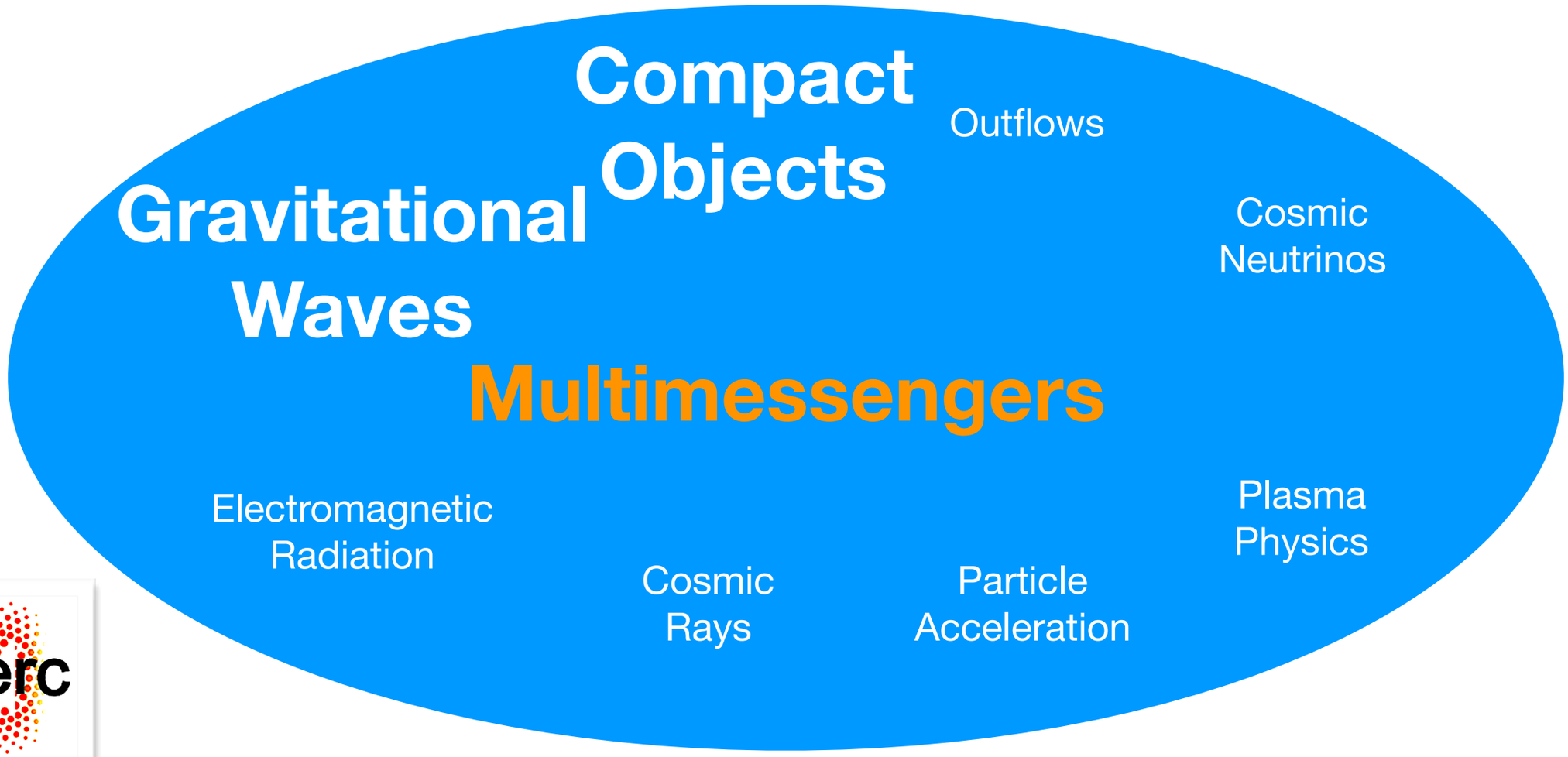
$$\vec{\nabla} \times \vec{f}_c = \vec{0} \qquad \vec{\nabla} \cdot \vec{f}_s = 0 \qquad \nabla^2 \vec{f}_h = \vec{0}$$



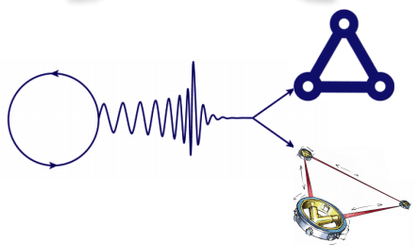

Composition of MHD turbulence depends on driving. Compressible driving leads to more significant fraction of fast modes, the dominant modes for comic ray scattering.

# GWAT @ DESY

## Gravitational Wave Astro(particle) physics - Theory

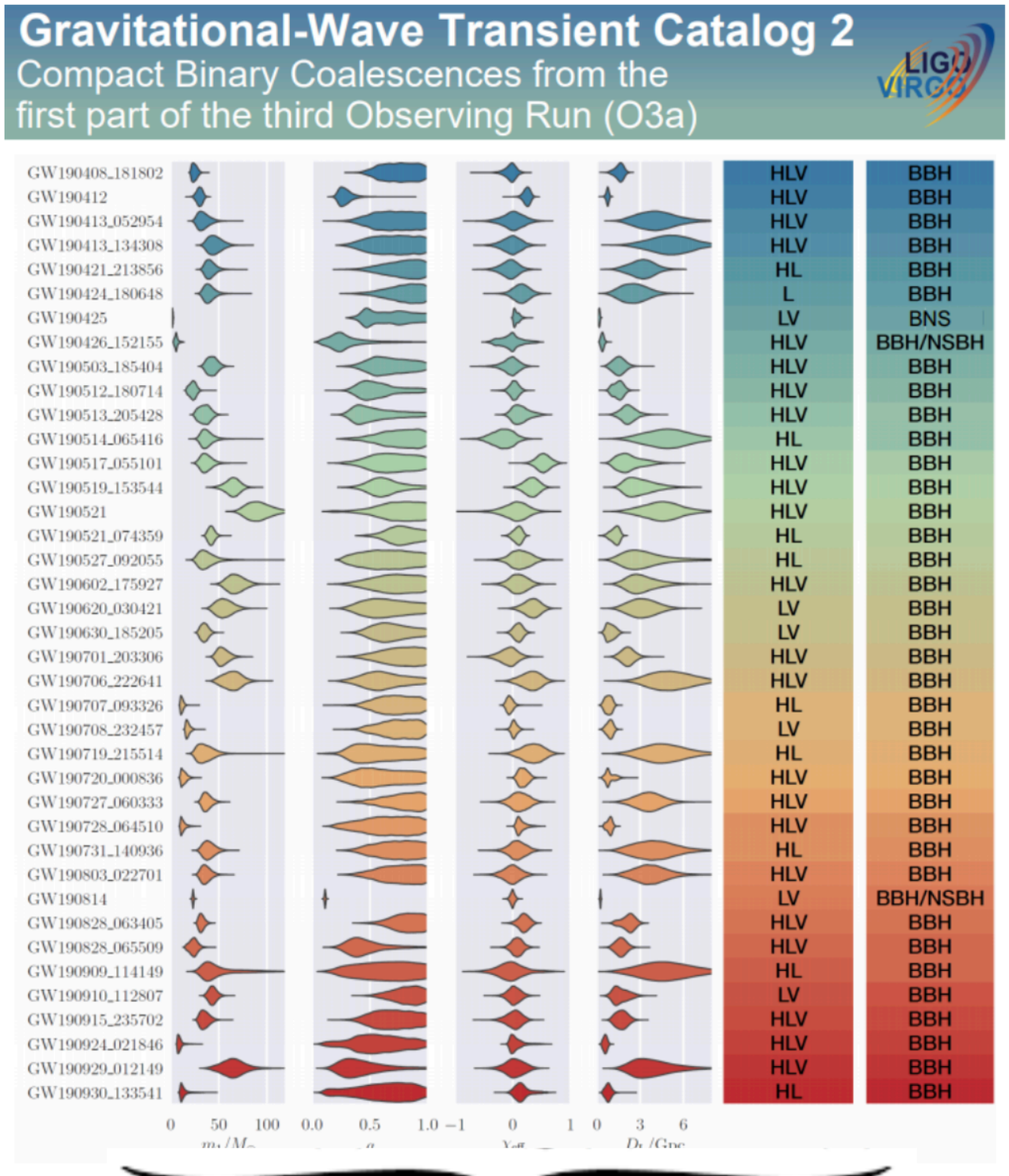



erc



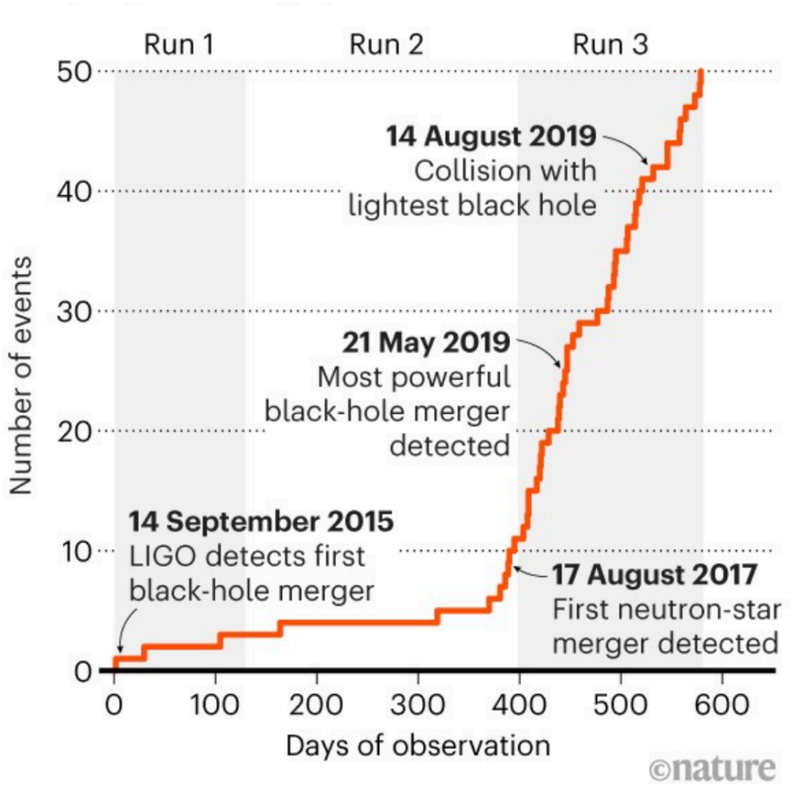
**LHCtoLISA(ET)**

Rafael Porto,

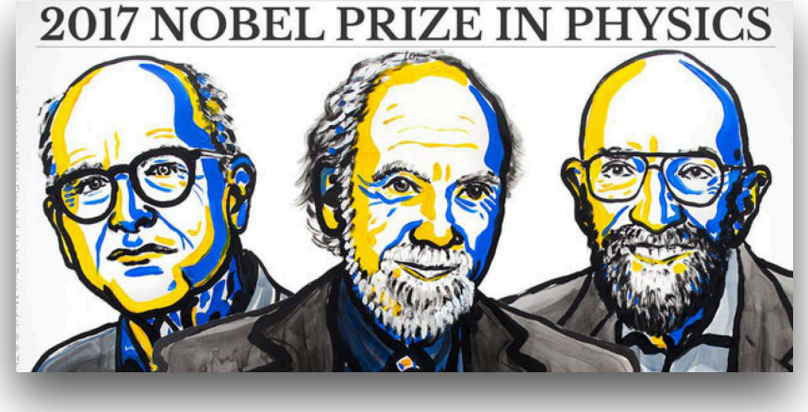


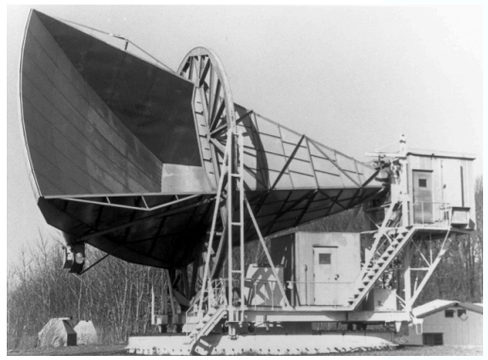

**39 more events!**

**100s of events/year at design-sensitivity!**





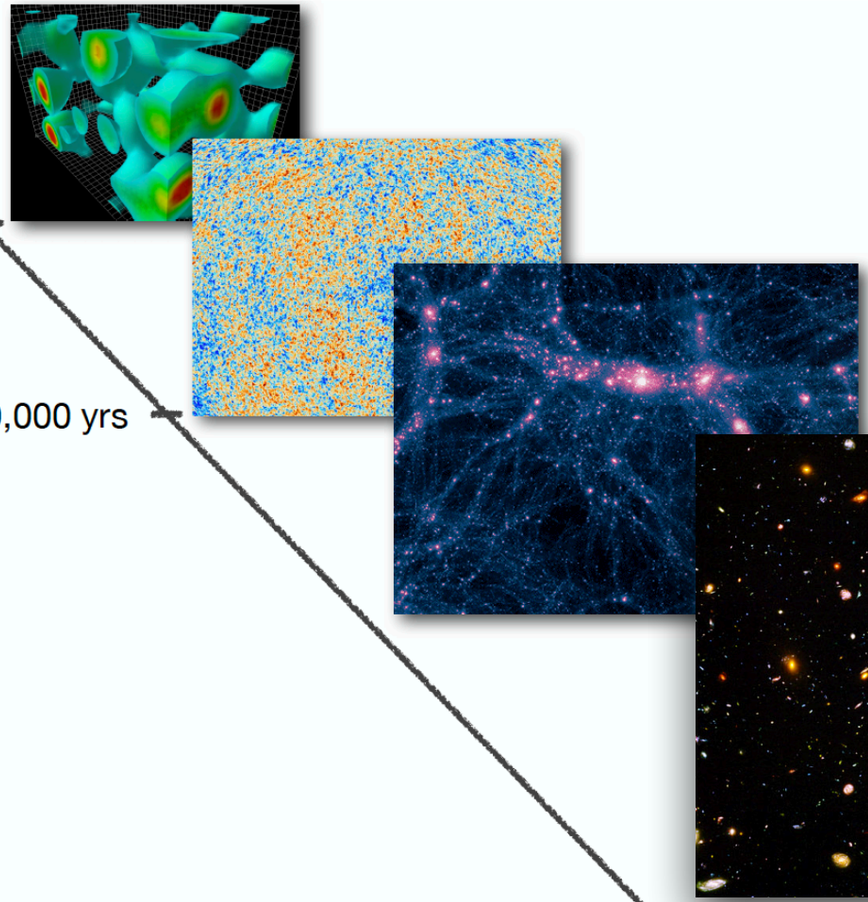


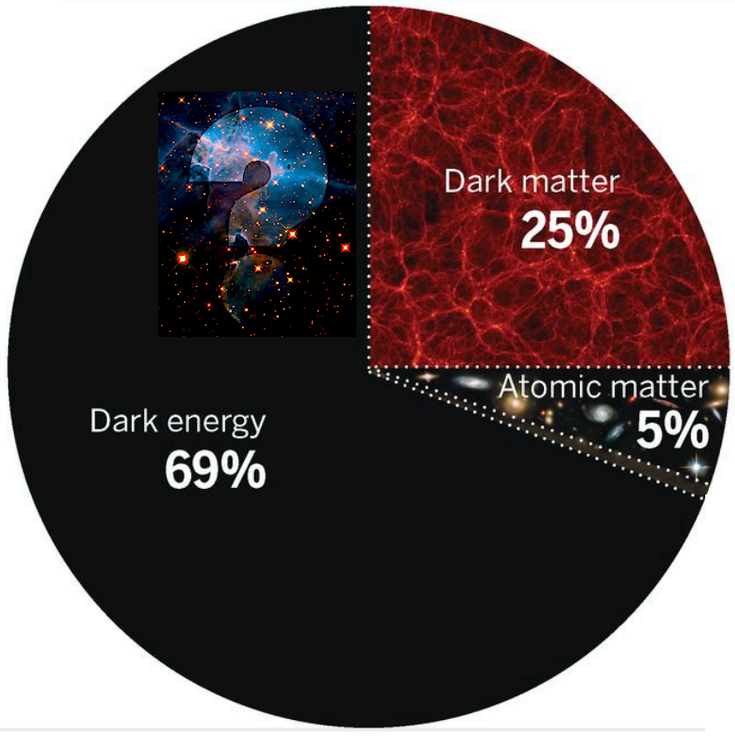



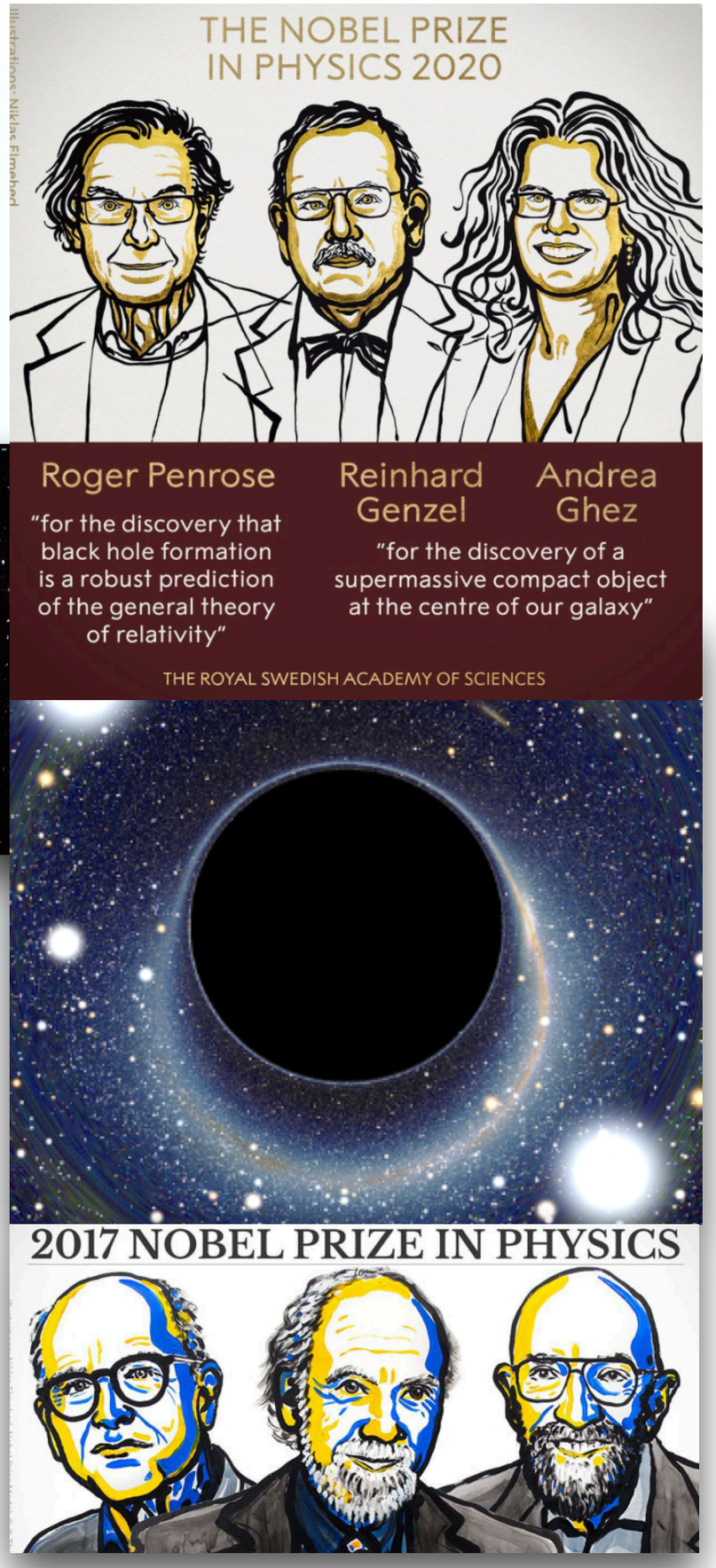
THE NOBEL PRIZE
IN PHYSICS 2019

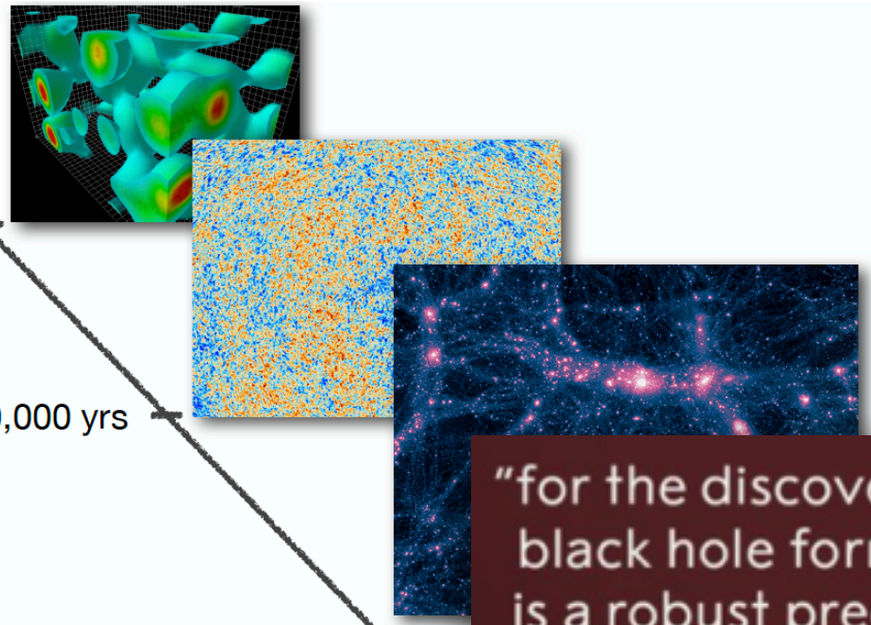
James Peebles

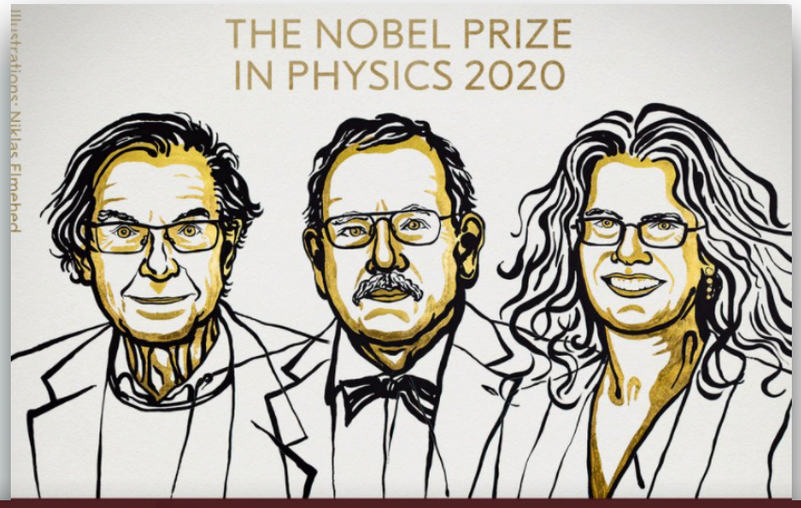
"for theoretical discoveries in physical cosmology"



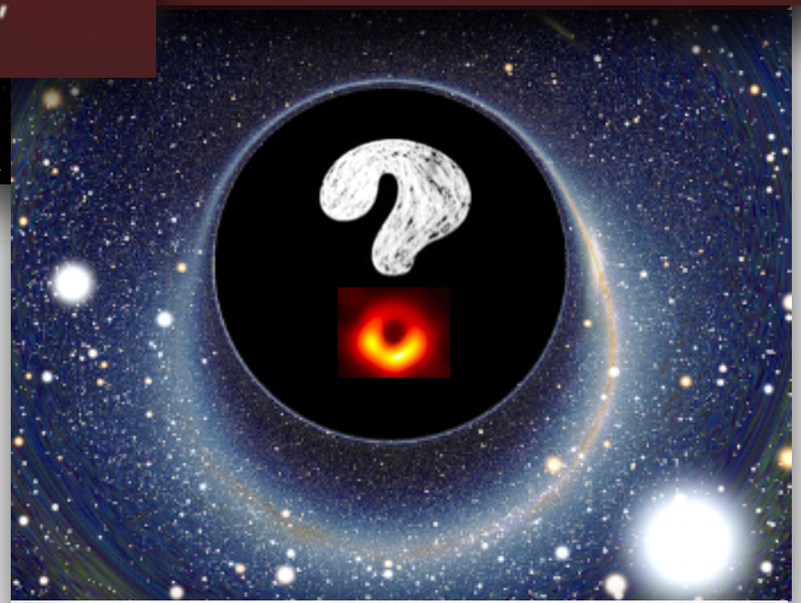



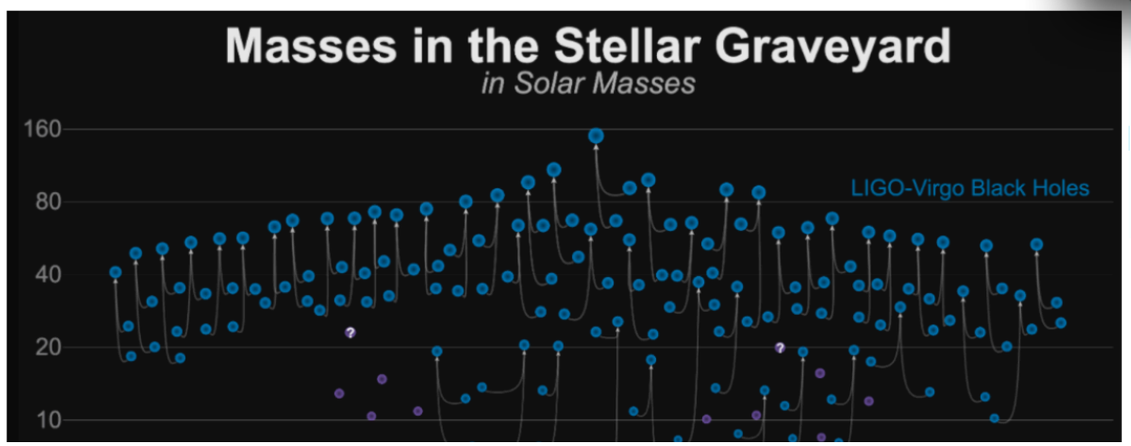

"for the discovery that black hole formation is a robust prediction of the general theory of relativity"

"for the discovery of a supermassive compact object at the centre of our galaxy"

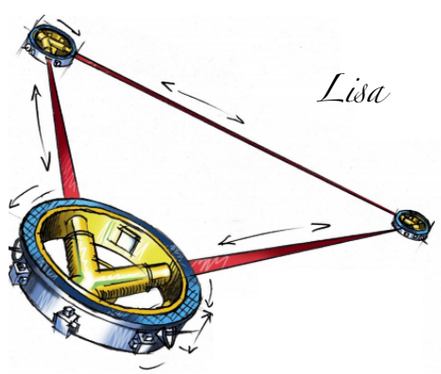
**Same BHs! (but smaller so far)**

ion yrs

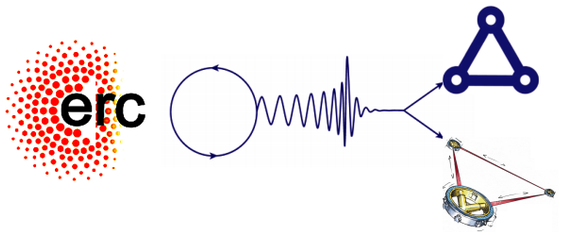








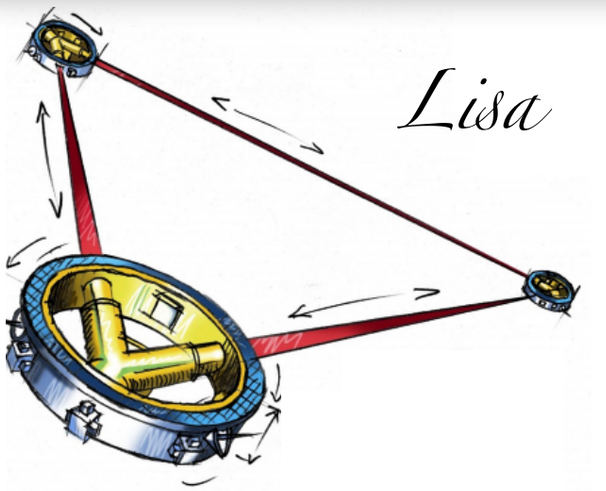

1993



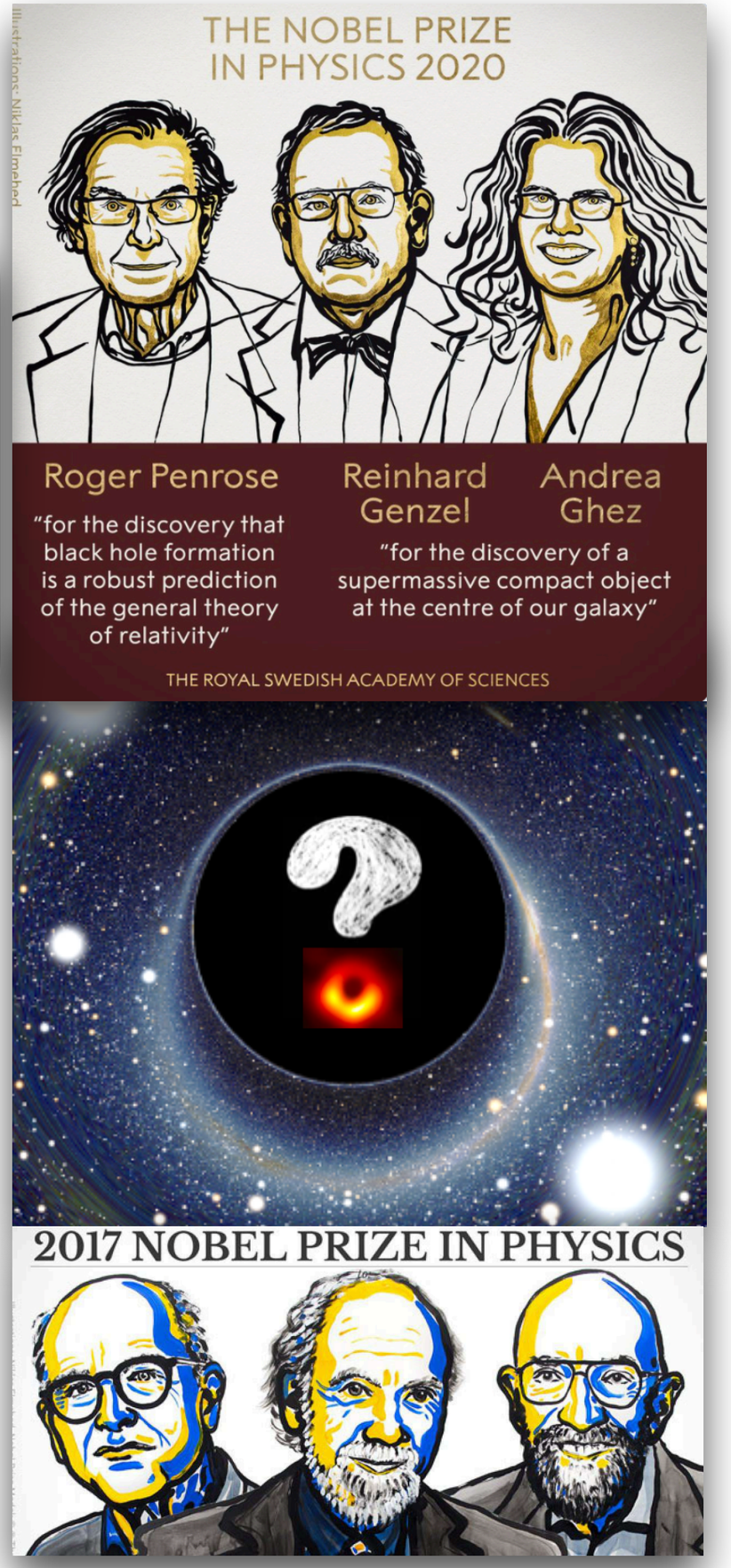

# Discovery Potential =

## ***Precise Theoretical Predictions***

*"Waveforms will be far more complex and carry more information than expected. Improved modeling will be needed for extracting the gravitational wave's information"*



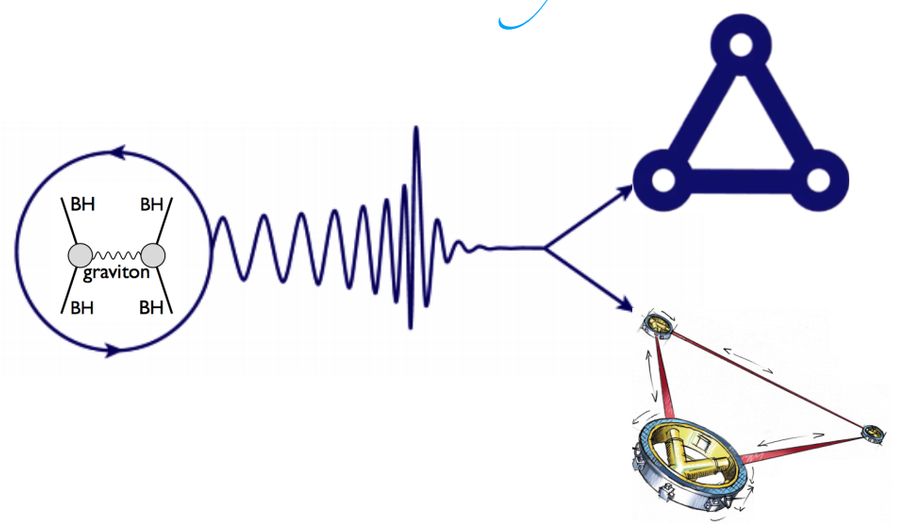




## GWAT in a nutshell:

*Effective field Theory*

*(Particle Physics)*




*Scattering Amplitudes*

*("String theory")*

*Gravitational Waves*

*(General Relativity)*

erc

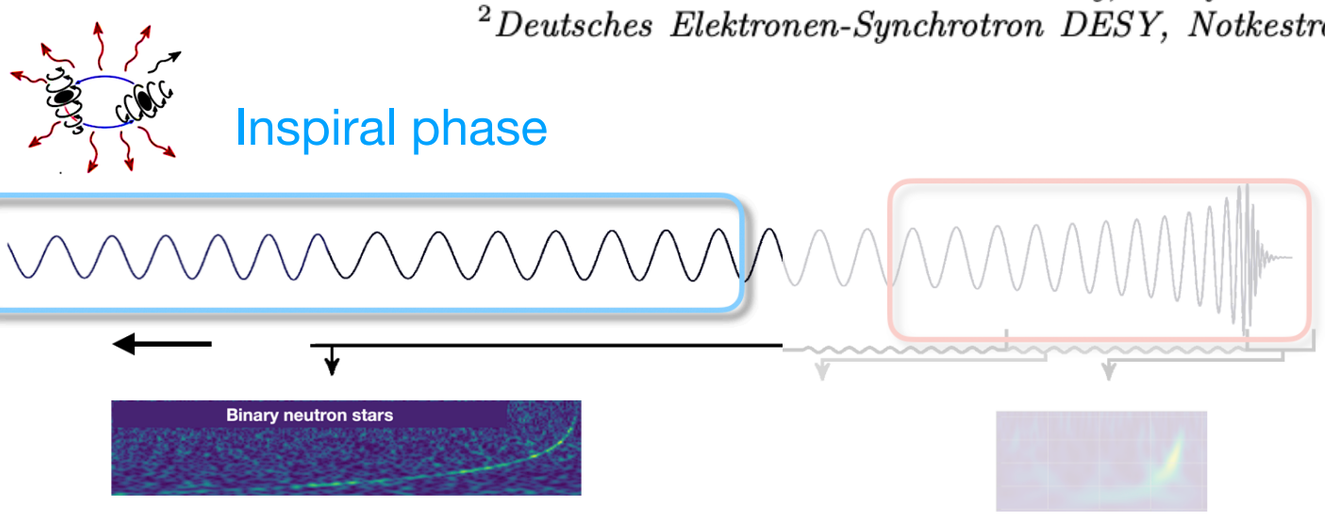
LHCtoLISA 18'

-2020 **Conservative Dynamics of Binary Systems to Third Post-Minkowskian Order from the Effective Field Theory Approach**


Gregor Kälin,[1] Zhengwen Liu,[2] and Rafael A. Porto[2]

[1] *SLAC National Accelerator Laboratory, Stanford University, Stanford, CA 94309, USA*

[2] *Deutsches Elektronen-Synchrotron DESY, Notkestrasse 85, 22607 Hamburg, Germany*


Scattering Amplitudes from LHC to LIGO and Beyond

Lance Dixon

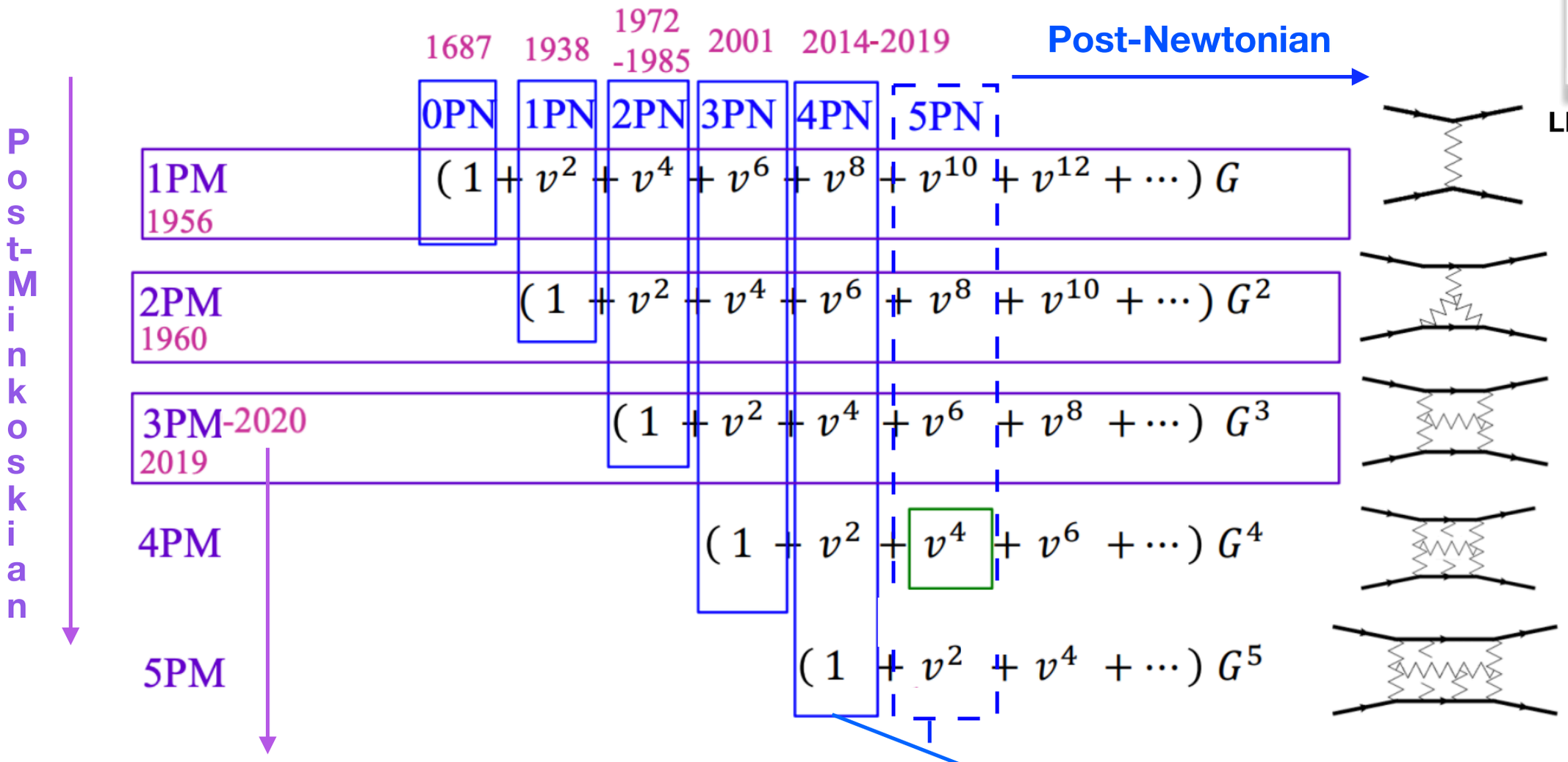
SLAC NATIONAL ACCELERATOR LABORATORY

"Quantum Universe" Colloquium

DESY and University of Hamburg

23 June 2020

Caveat: Only ***conservative***




LHCtoLISA 18'

**Conservative Dynamics of Binary Systems to Third Post-Minkowskian Order from the Effective Field Theory Approach**


Gregor Kälin,[1] Zhengwen Liu,[2] and Rafael A. Porto[2]

[1] *SLAC National Accelerator Laboratory, Stanford University, Stanford, CA 94309, USA*
[2] *Deutsches Elektronen-Synchrotron DESY, Notkestrasse 85, 22607 Hamburg, Germany*


Lots of room for synergy between **PPT** and **GWAT**!


PHYSICAL REVIEW D **100,** 024048 (2019)


**Conservative dynamics of binary systems to fourth post-Newtonian order in the EFT approach. II. Renormalized Lagrangian**

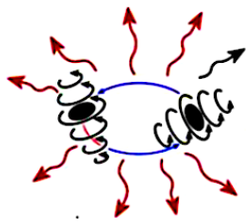

Stefano Foffa,[1] Rafael A. Porto,[2,3] Ira Rothstein,[4] and Riccardo Sturani[5]


**The fifth-order post-Newtonian Hamiltonian dynamics of two-body systems from an effective field theory approach: potential contributions**


J. Blümlein[a], A. Maier[a], P. Marquard[a], and G. Schäfer[b]

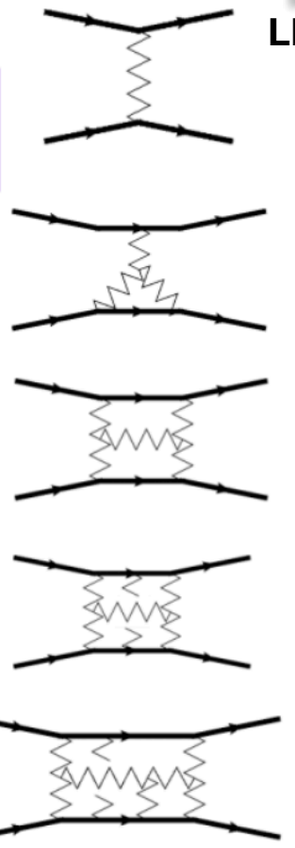

**ZPPT**-2020

## *Must include radiation too!*



LHCtoLISA 18'

| | 1687 | 1938 | 1972 -1985 | 2001 | 2014-2019 | | |
|---|---|---|---|---|---|---|---|
| | 0PN | 1PN | 2PN | 3PN | 4PN | 5PN | |
| 1PM 1956 | $(1$ | $+v^2$ | $+v^4$ | $+v^6$ | $+v^8$ | $+v^{10}$ | $+v^{12}+\cdots)\,G$ |
| 2PM 1960 | | $(1$ | $+v^2$ | $+v^4$ | $+v^6$ | $+v^8$ | $+v^{10}+\cdots)\,G^2$ |
| 3PM-2020 2019 | | | $(1$ | $+v^2$ | $+v^4$ | $+v^6$ | $+v^8+\cdots)\,G^3$ |
| 4PM 2021 | | | | $(1$ | $+v^2$ | $+v^4$ | $+v^6+\cdots)\,G^4$ |
| 5PM 2022-2023 | | | | | $(1$ | $+v^2$ | $+v^4+\cdots)\,G^5$ |



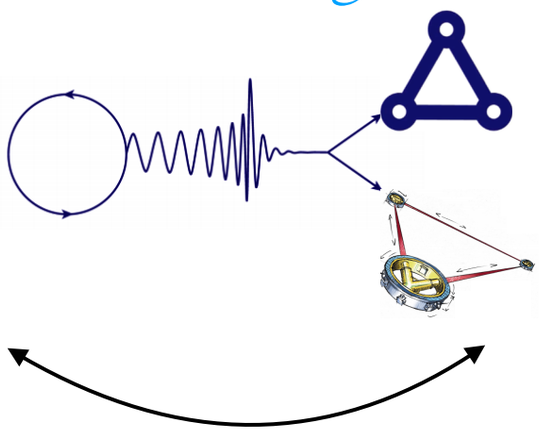
*Effective field Theory (Particle Physics)*

**Gregor Kalin (Postdoc/ERC)**

**Zhengwen Liu (Postdoc/Th)**

**Zixin Yang (Postdoc/ERC)**

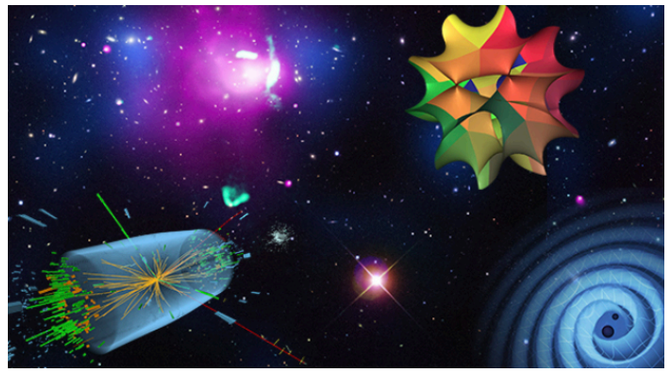
**Gihyuk Cho (Postdoc/ERC)**

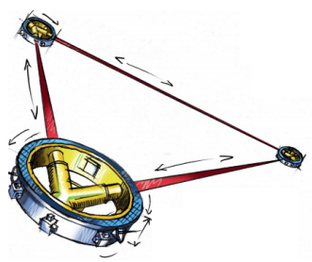


*Scattering Amplitudes ("String theory")*

*Gravitational Waves (General Relativity)*

# NEW frontier in particle physics





Fortschr. Phys. 64, No. 10, 723–729 (2016) / DOI 10.1002/prop.201600064

**The tune of love and the *nature(ness)* of spacetime**

*Rafael A. Porto**

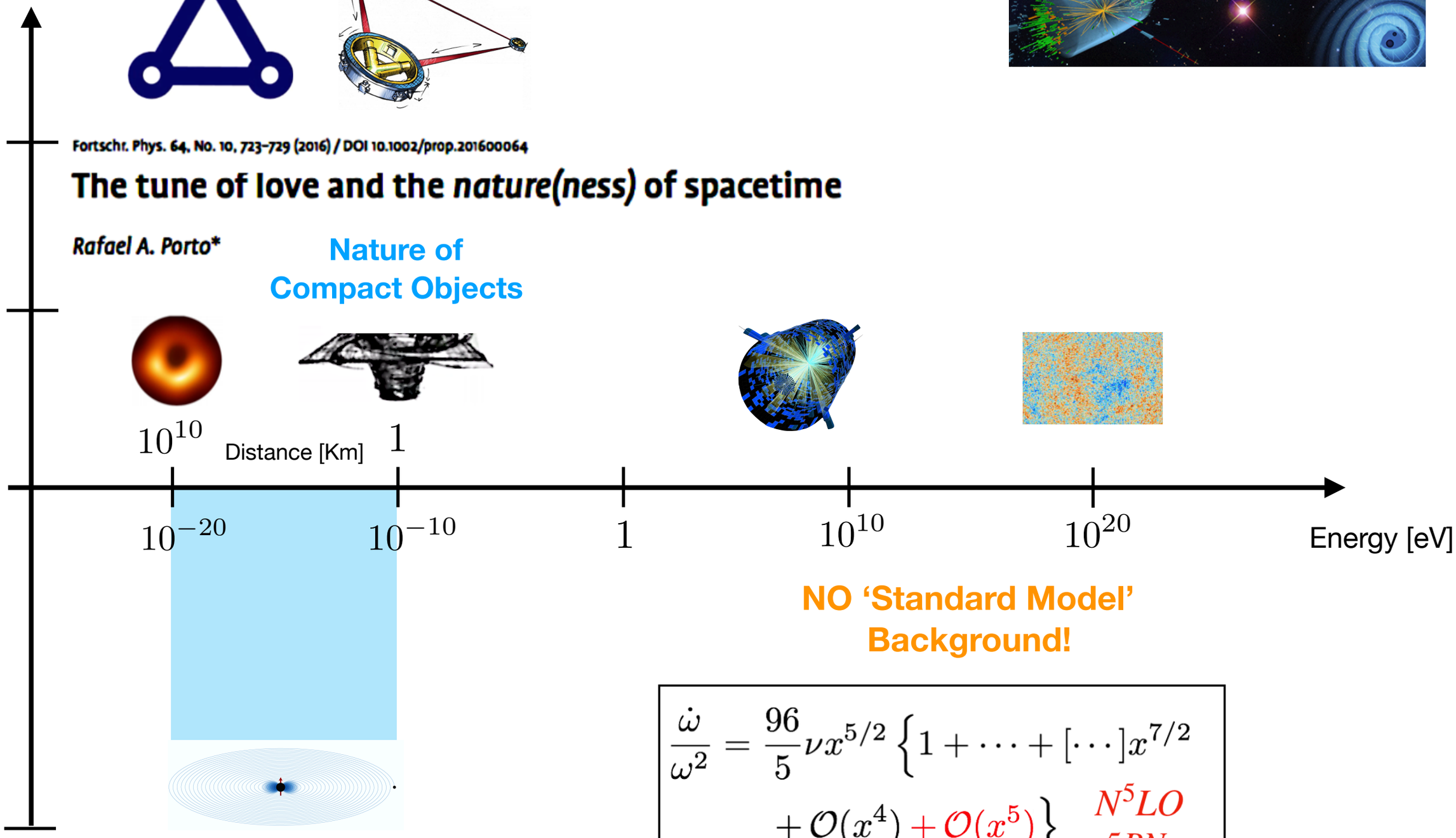
**Nature of Compact Objects**












**NO 'Standard Model' Background!**

$$\frac{\dot{\omega}}{\omega^2} = \frac{96}{5}\nu x^{5/2}\Big\{1 + \cdots + [\cdots]x^{7/2} + \mathcal{O}(x^4) + \mathcal{O}(x^5)\Big\} \qquad N^5LO \quad 5PN$$

$$\Psi(v) = \Psi_{\rm PP}(v) + \Psi_{\rm tidal}(v)$$

Gravitational collider physics

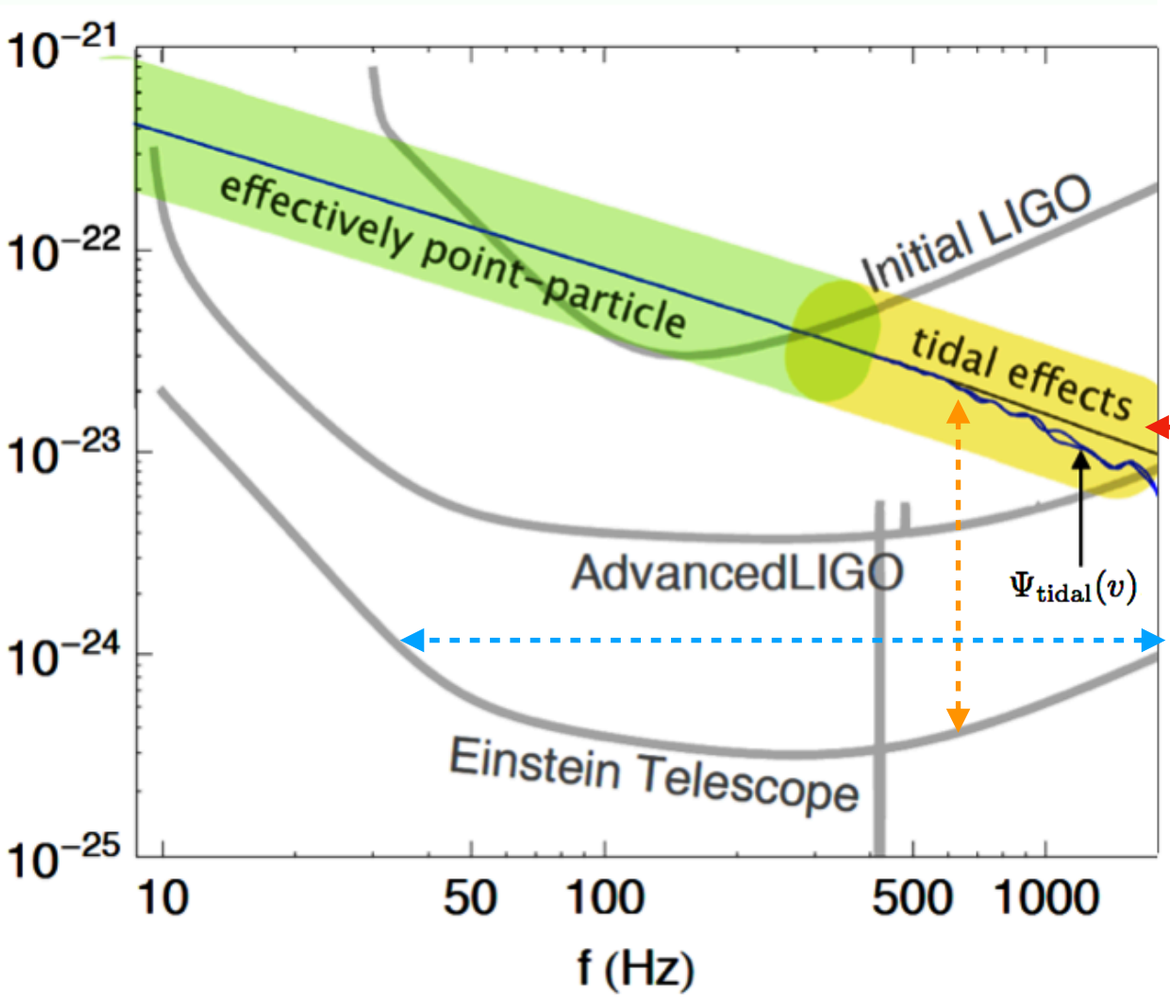
Daniel Baumann, Horng Sheng Chia, Rafael A. Porto, and John Stout
Phys. Rev. D **101**, 083019 – Published 15 April 2020

*"Waveforms will be far more complex and carry more information than expected. Improved modeling will be needed for extracting the GW's information"*

Kip Thorne 'Last 3 minutes' **1993**

**20+ years prior to first detection!**

# 3G = More 'luminosity/sensitivity' at 'short/long distances'



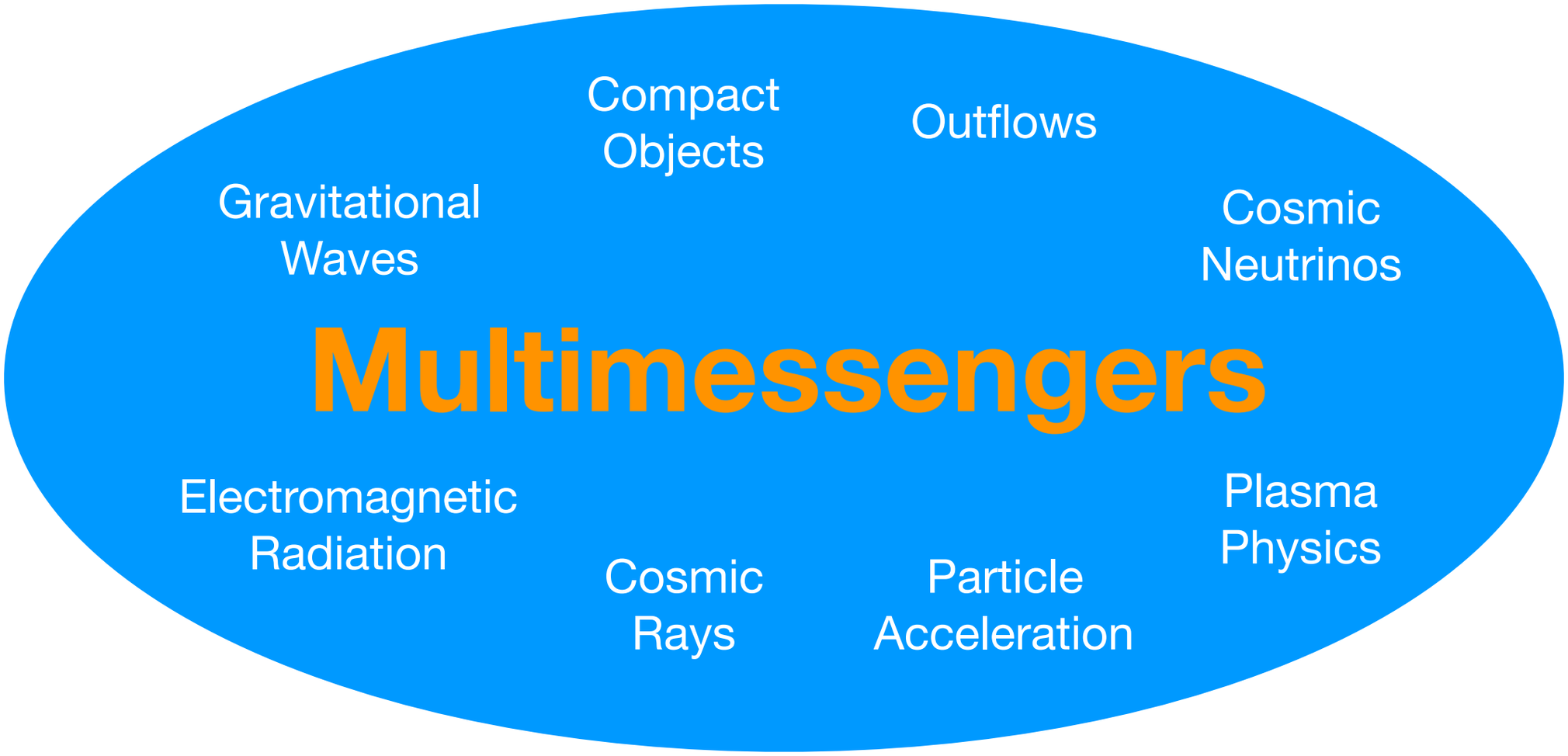


**'New Physics Threshold'**

- **Energy/Frequency Frontier**
- **Luminosity Frontier**

# THAT @ DESY — Strategy update

## THeoretical Astro(particle) physics - Theory




- The unifying theme of **THAT** researchers is the **multi-messenger** approach to probing the ***extreme Universe*** — highly energetic events communicated via cosmic rays, neutrinos and electromagnetic/gravitational-wave radiation

# **THAT @ DESY** — Strategy update
# **TH**eoretical **A**stro(particle) physics **- T**heory

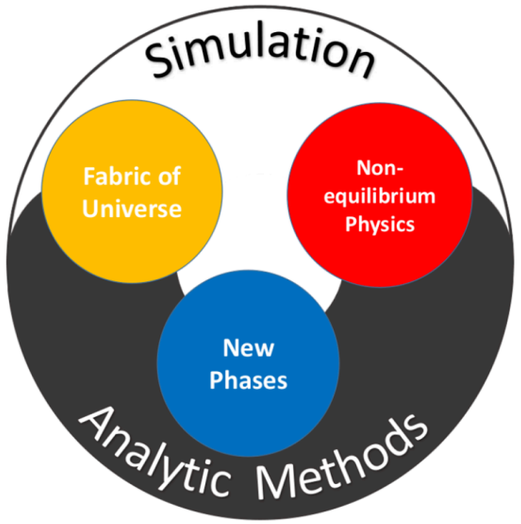
- Continue providing counsel and direct contributions to existing high-energy gamma-ray and neutrino experiments, e.g. **VERITAS, HESS gamma-ray telescope.**

- Provide input for the conception & development of future experiments, e.g. **CTA, SWGO, E-Astrogam, OST, IceCube-Gen2 and *the Einstein Telescope.***

- A new member specialized in general relativistic MHD astrophysics would ***fill the gap between multi-messenger models and the gravitational physics of compact objects.***

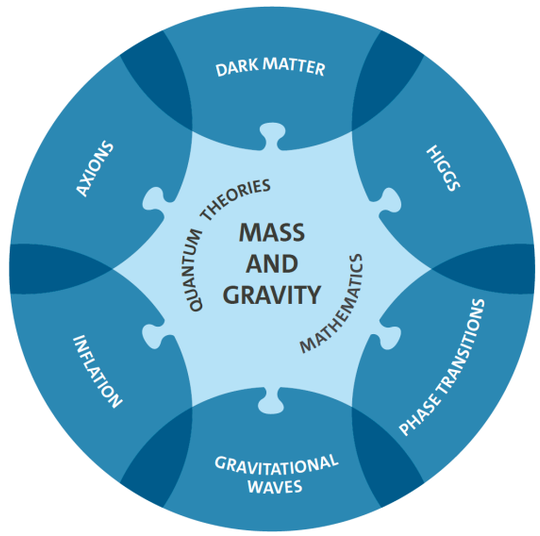
# THAT @ DESY — Strategy update
# THeoretical Astro(particle) physics - Theory

- Continue to build bridges with other theory (experimental) divisions at DESY. In particular to strengthen connection between **PPT** and **THAT** in Hamburg & Zeuthen.
  ***Through the recruitment of a staff scientist at ZPPT.***




- We welcome the **WPC** in Hamburg **(2 PIs in THAT)** to foster interaction between research areas.
  ***The connection to Zeuthen is under development.***

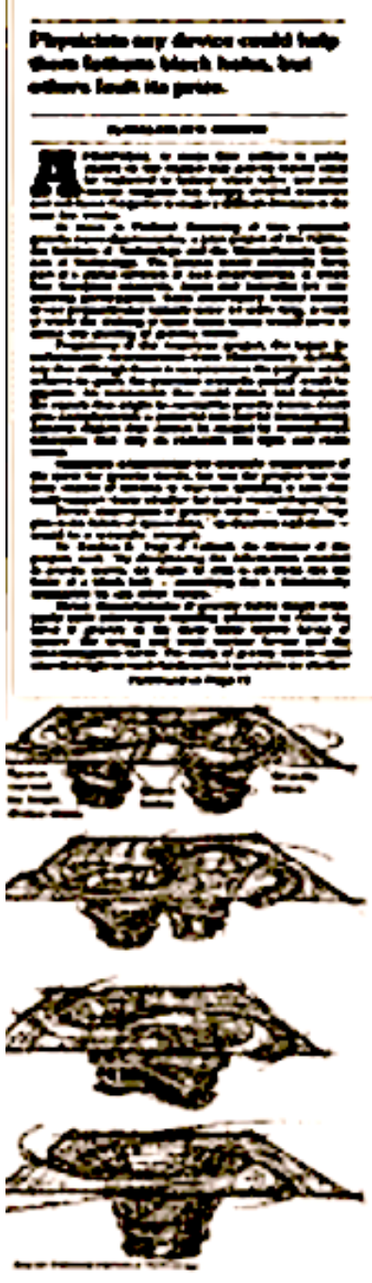
- One PI (R. Porto) in the “Quantum Universe” cluster at the University of Hamburg, others as ‘key researchers’. Discussions ongoing for the new phase (and *Porto’s position at UHH*) aiming at ***strengthening the link between the QU cluster and GWAT.***



NYT 1991

# Experts Clash Over Project To Detect Gravity Wave

**Physicists say device could help show bottom black holes, but others fault its price.**



# Die Ziet

*no.203.078* — *01.01.203X*

# *E*ins*T*ein reloaded*!*

**New era of foundational investigations established through Multi-messenger Precision Data.**

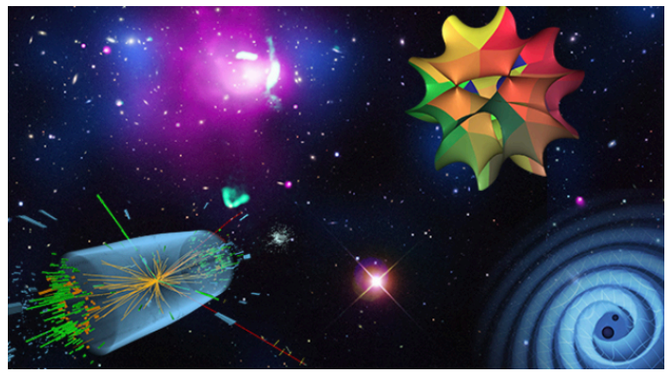
# More synergy
# Z/HPPT/QU
# & GWAT!

Featured in Physics  Editors' Suggestion

## Signals of a Quantum Universe

Daniel Green and Rafael A. Porto
Phys. Rev. Lett. **124**, 251302 – Published 24 June 2020

PHYSICS See synopsis: A Quantum Signature for the Cosmos





euclid

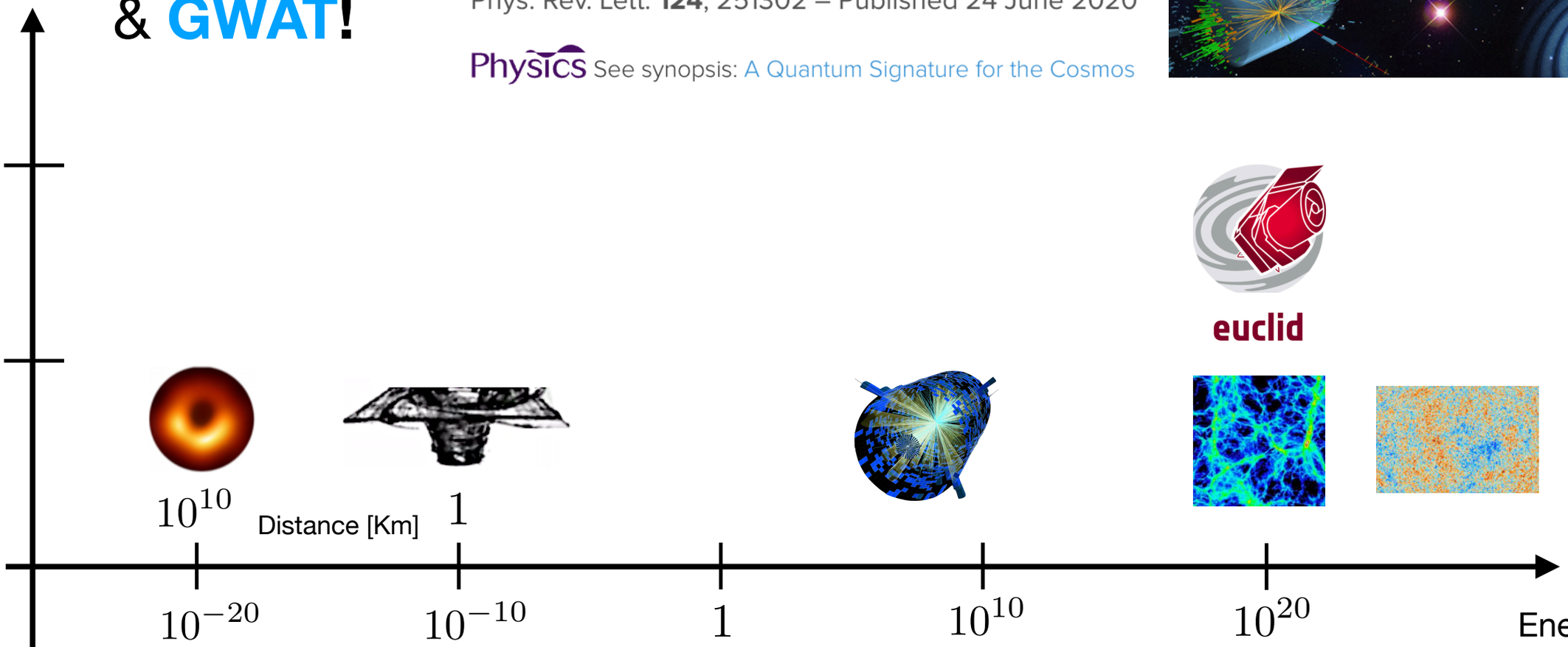












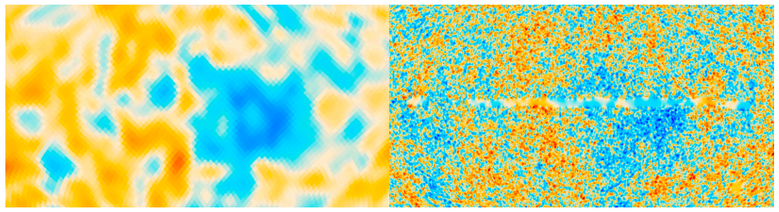

## Did Galaxies Grow from Quantum Static?

SCIENTIFIC AMERICAN

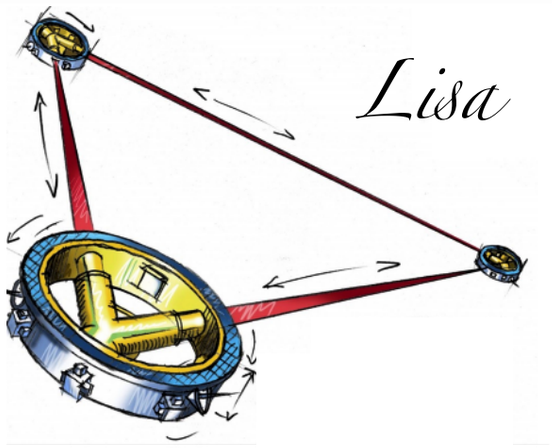
Porto agrees. “There’s lots of data,” he says, and “lots of work to do.” Researchers who want to unravel the evolution of the universe can now bring tools from particle physics, data science and the search for gravitational waves. When you put it all together, Porto says, “this is the most exciting time to be.”

# Are we ready for the future

‘Ligo/Virgo’ ‘LISA/ET’ (+20)



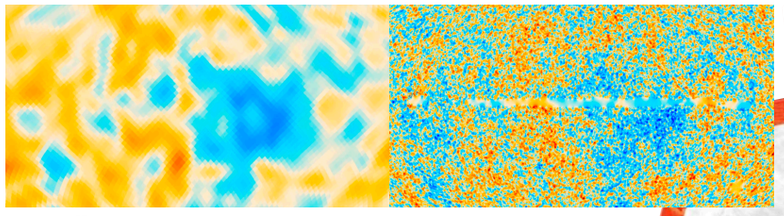
Cobe (92) Planck (13)





# Are we ready for the future

‘Ligo/Virgo’ ‘LISA/ET’ (+20)



Cobe (92) Planck (13)