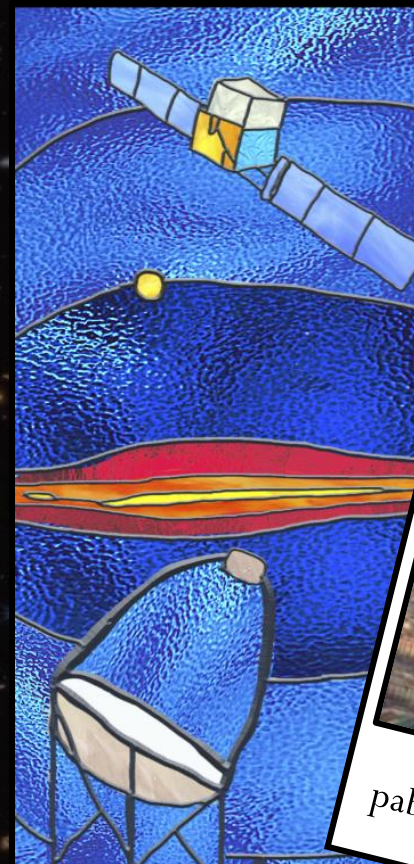


PARTICLE ASTROPHYSICS

Pablo Martinez-Mirave on behalf of

Markus Ahlers, Mauricio Bustamante, D. Jason Koskinen,
Oleg Ruchayskiy, Shashank Shalgar & Irene Tamborra





PARTICLE ASTROPHYSICS

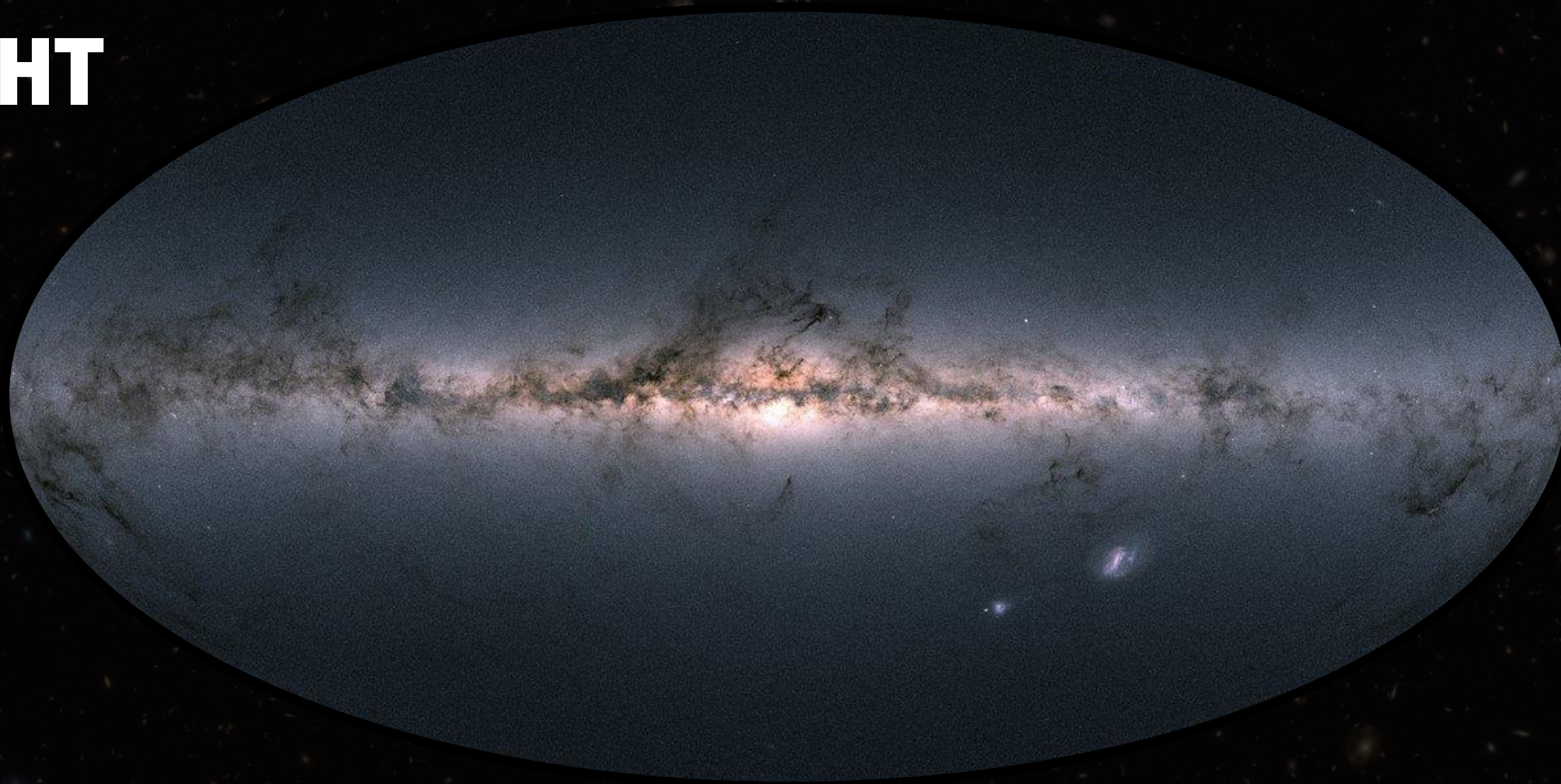
Pablo Martinez-Mirave on behalf of

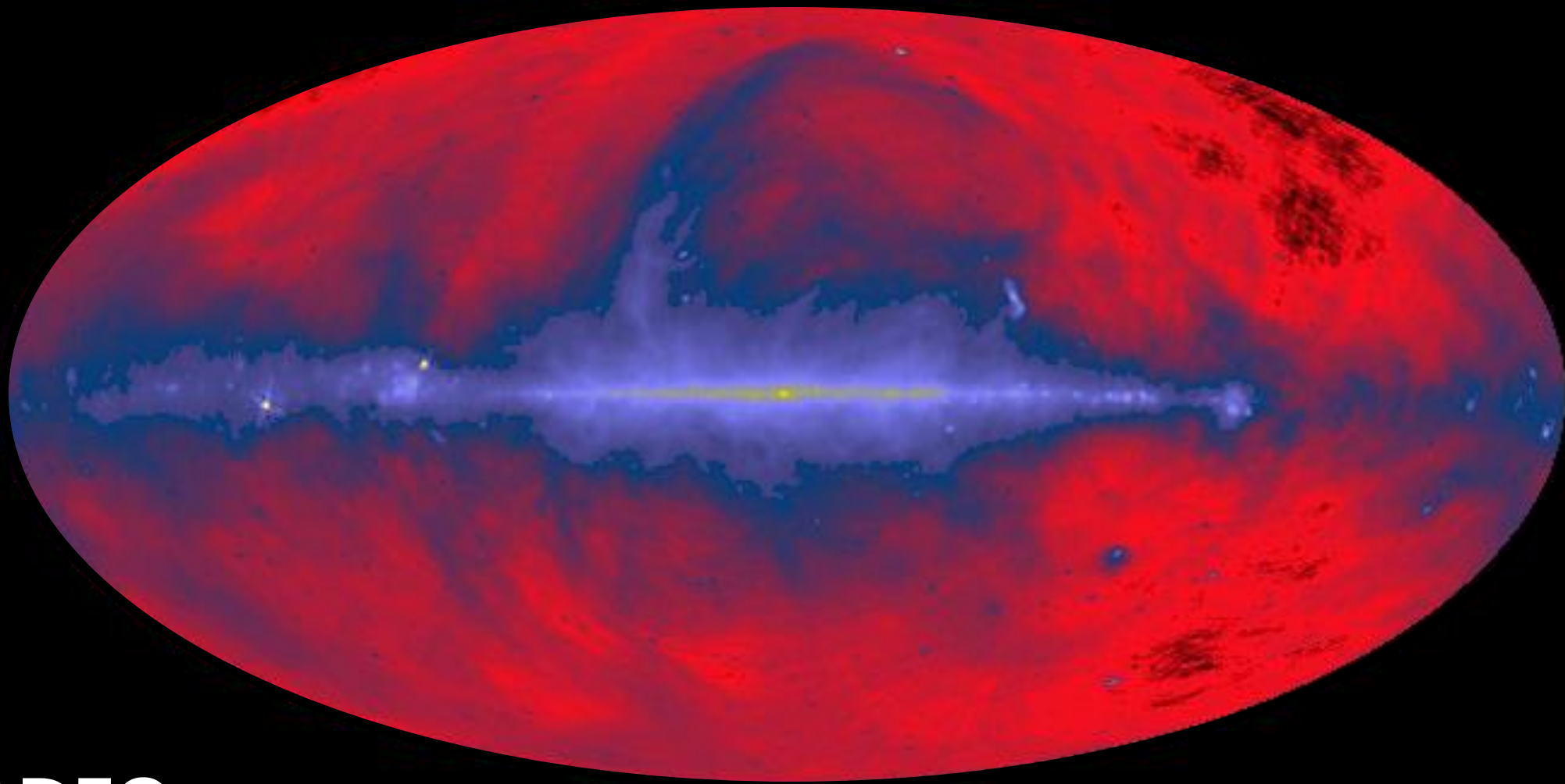
Markus Ahlers, Mauricio Bustamante, D. Jason Koskinen,
Oleg Ruchayskiy, Shashank Shalgar & Irene Tamborra



The Niels Bohr
International Academy

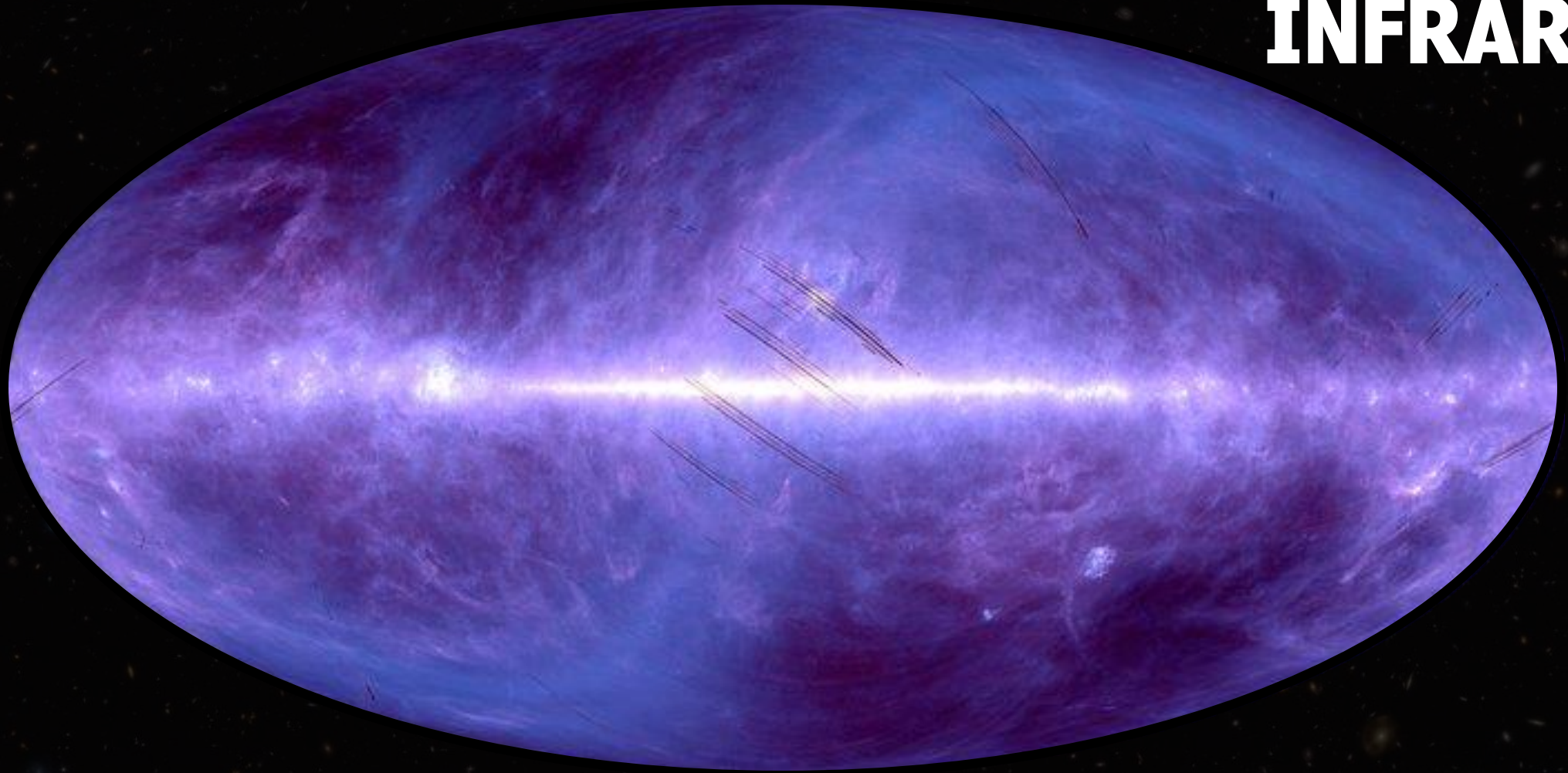
OPTICAL LIGHT

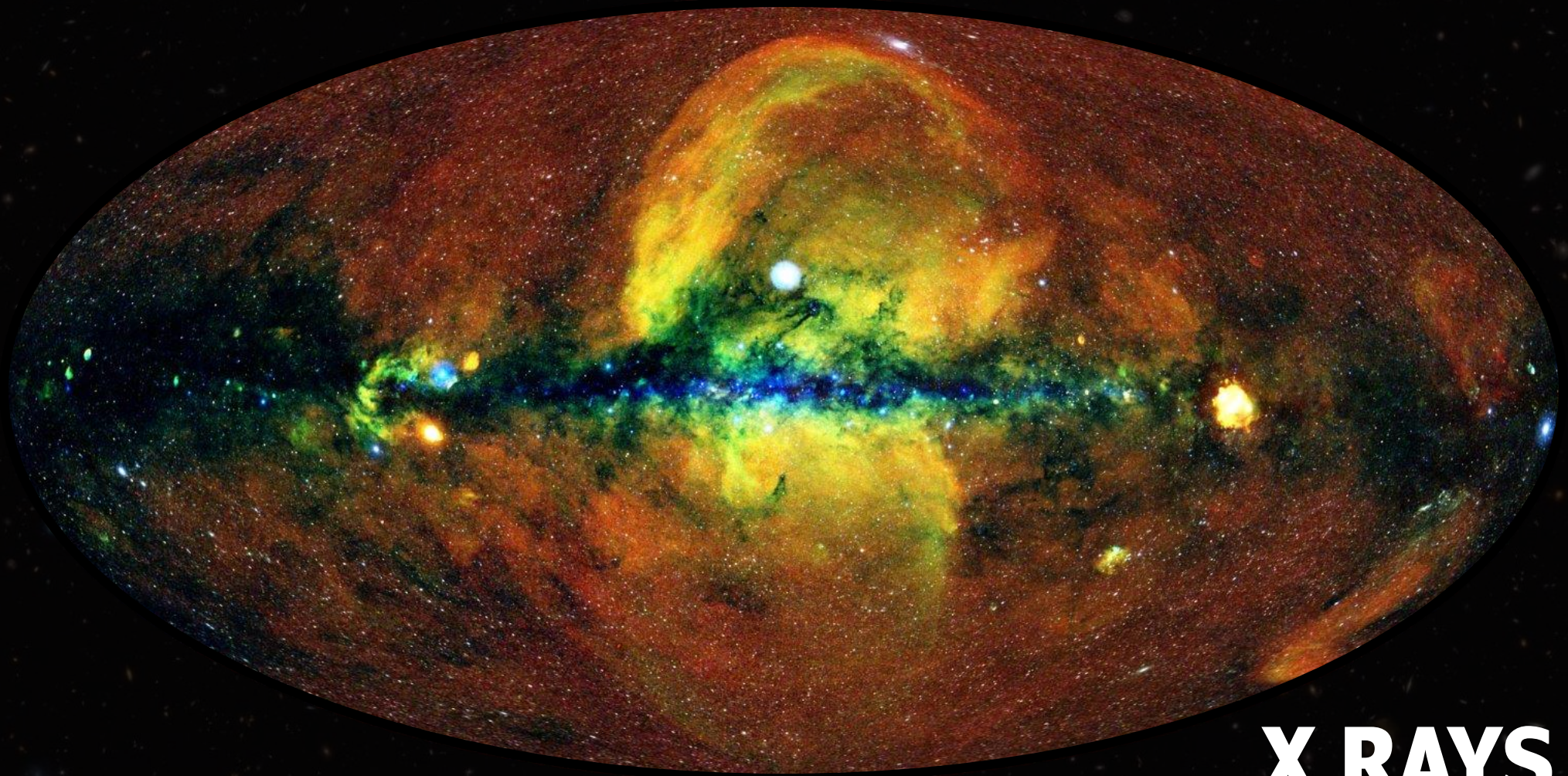




RADIO

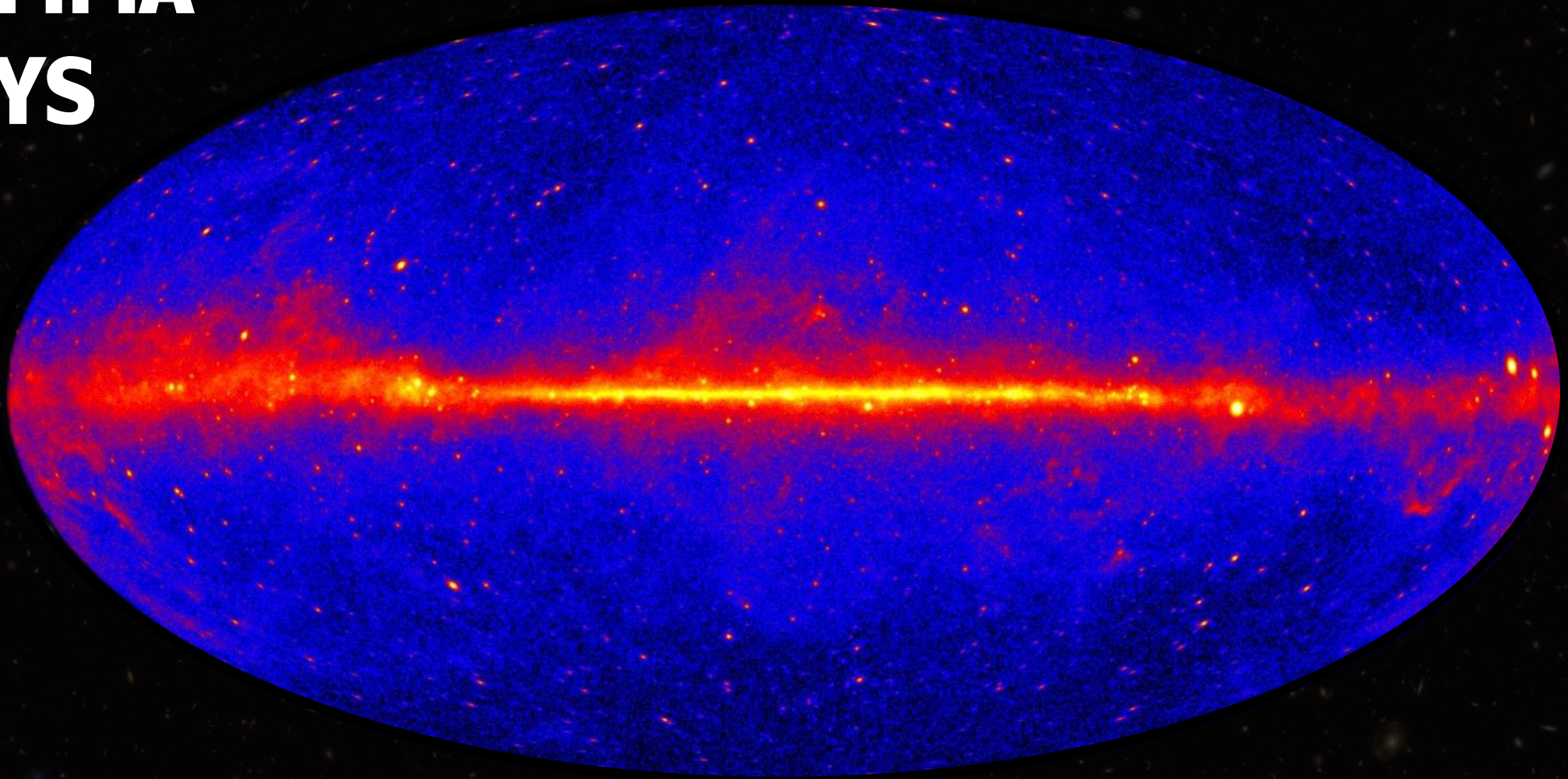
INFRARED

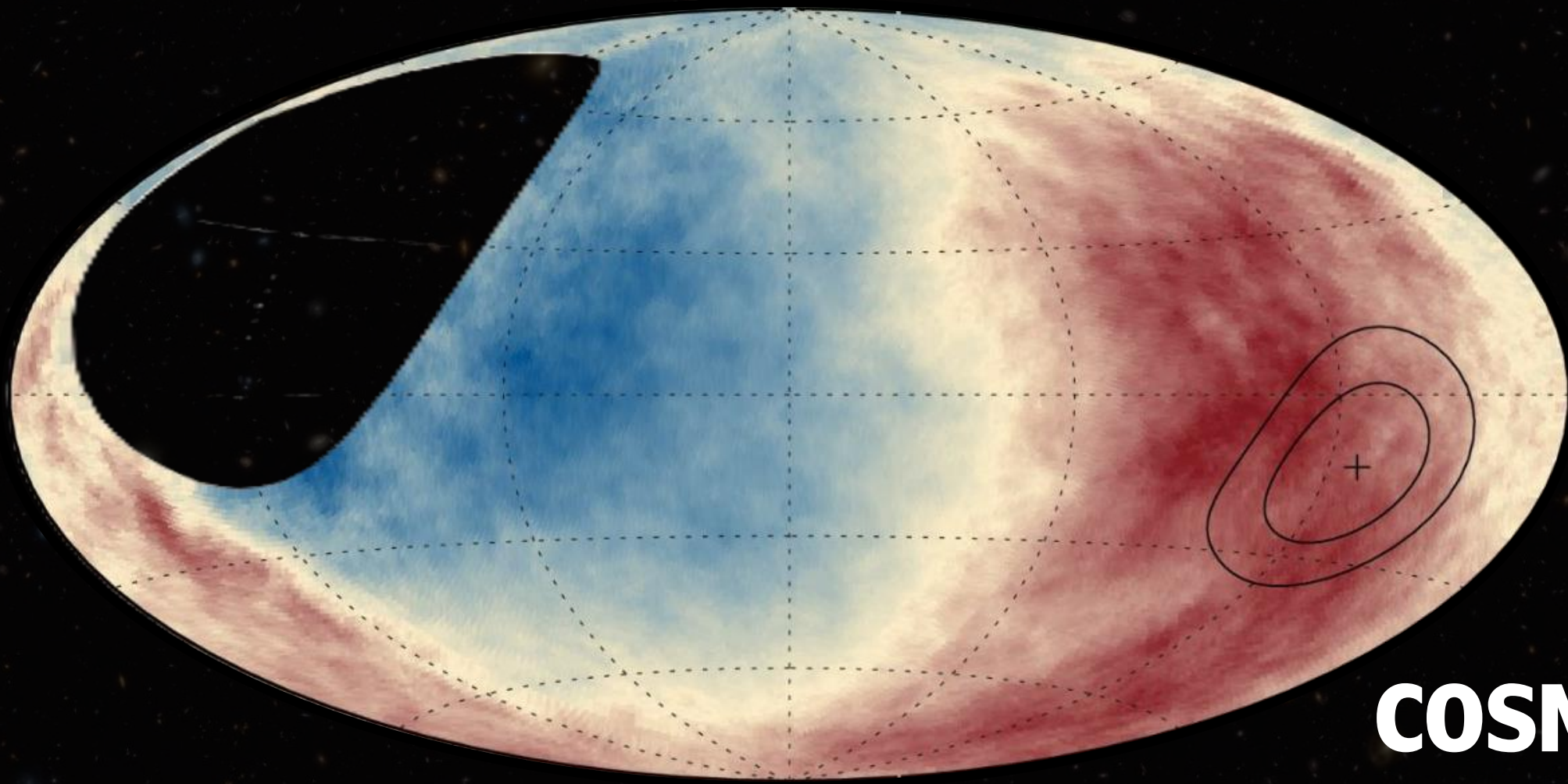




X RAYS

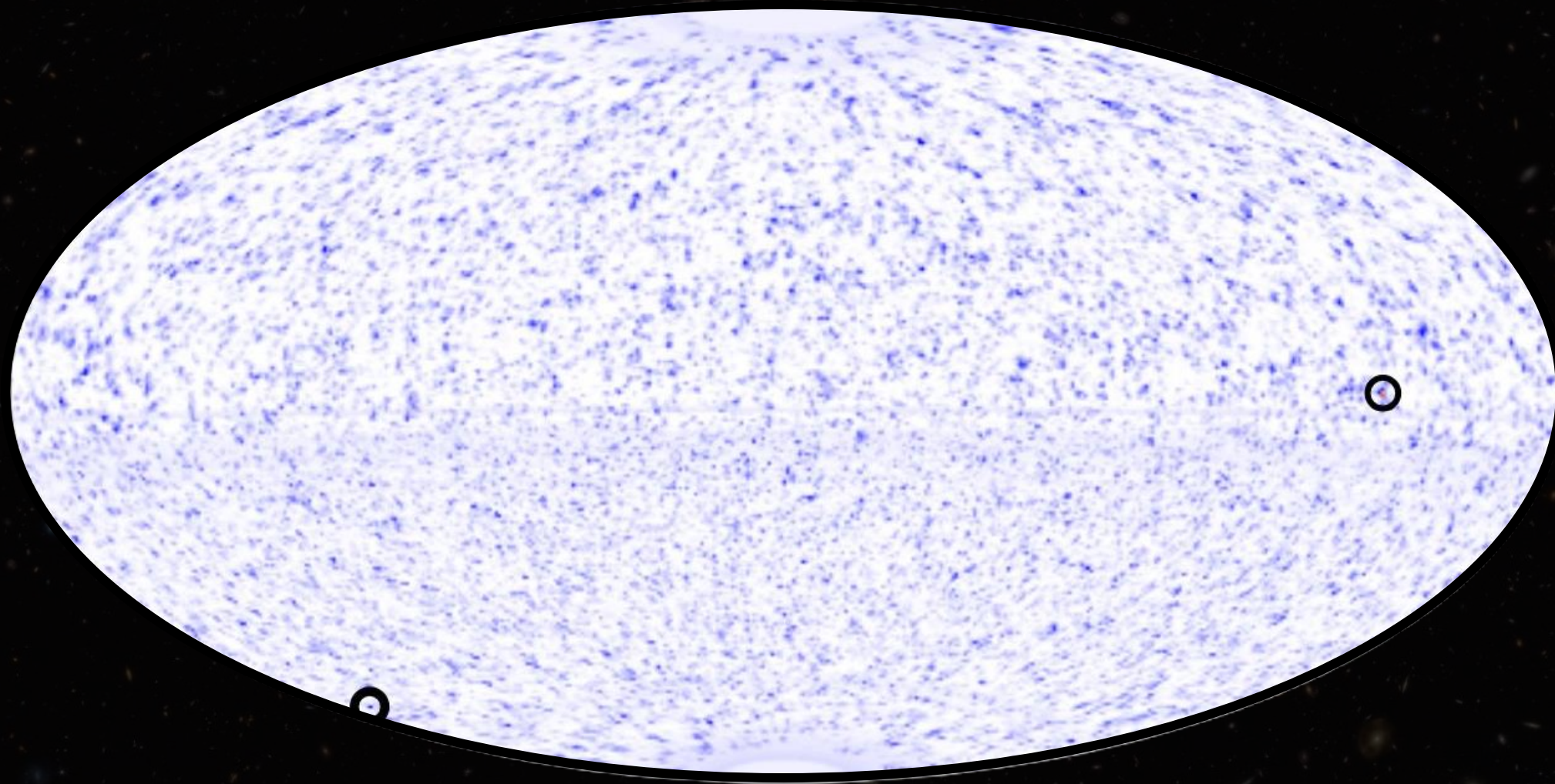
GAMMA RAY



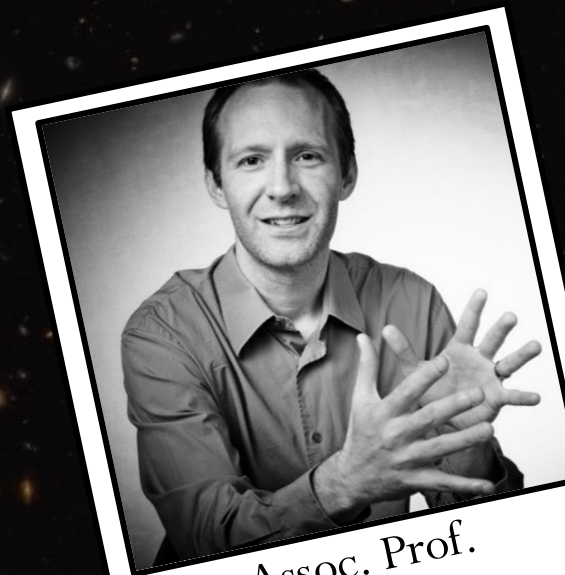


**COSMIC
RAYS**

NEUTRINOS



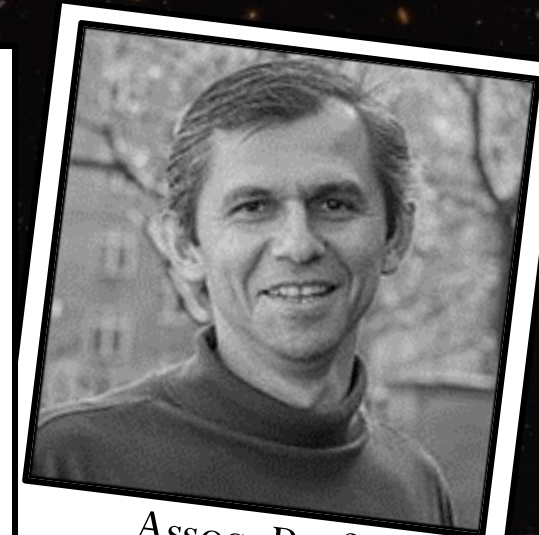
WHO ARE WE?



Assoc. Prof.
D. Jason Koskinen



Prof. Irene Tamborra



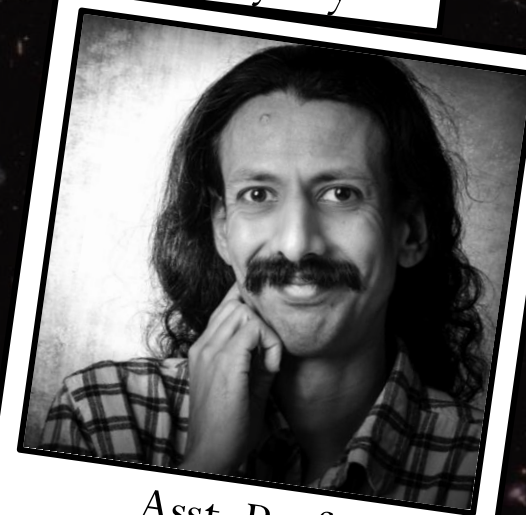
Assoc. Prof.
Oleg Ruchayskiy



Assoc. Prof.
Markus Ahlers



Asst. Prof.
Mauricio Bustamante



Asst. Prof.
Shashank Shalgar

WHO ARE WE?



koskinen@nbi.ku.dk



tamborra@nbi.ku.dk



Oleg.Ruchayskiy@nbi.ku.dk



markus.ahlers@nbi.ku.dk



mbustamante@nbi.ku.dk

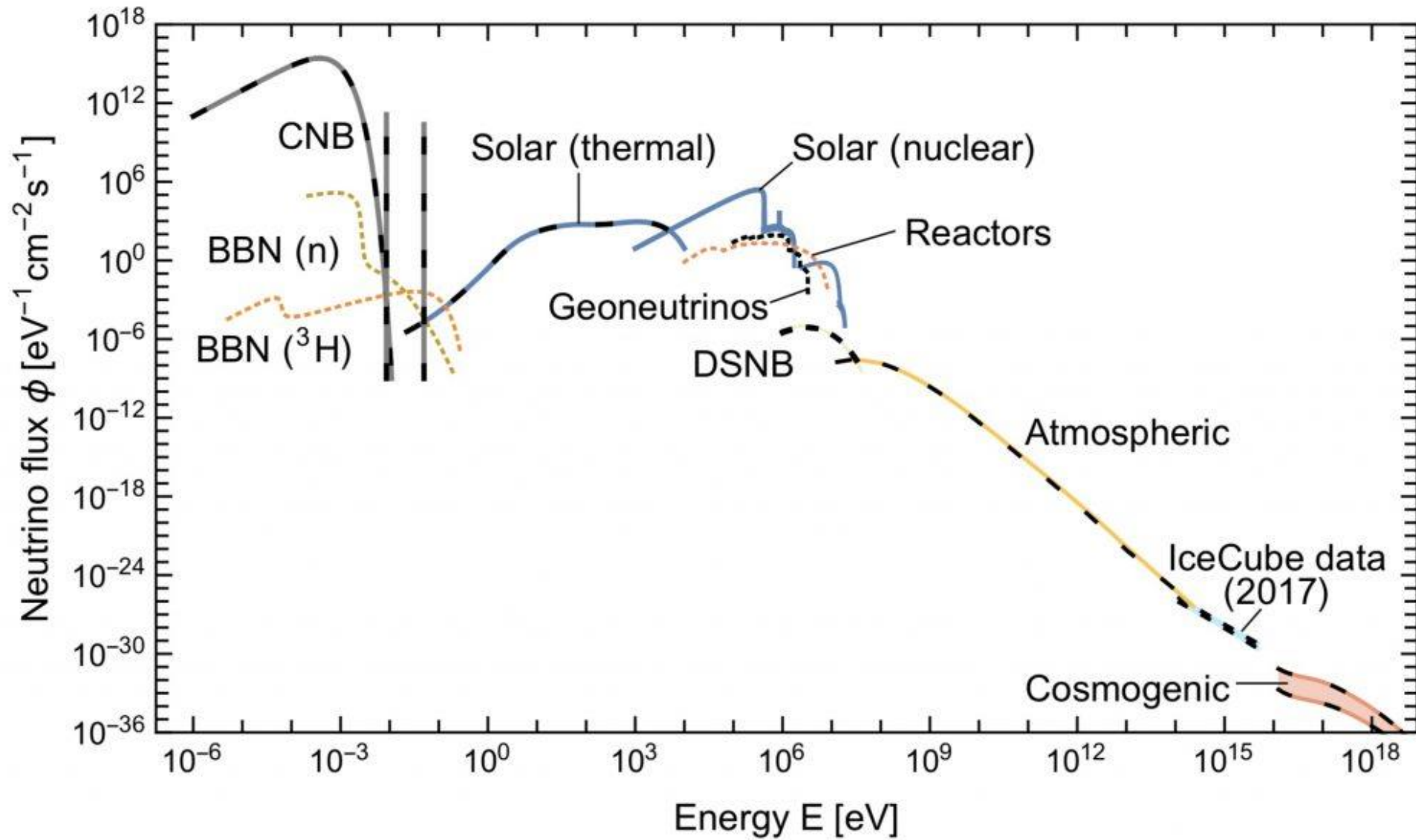


shashank.shalgar@nbi.ku.dk

The image features a dense field of distant galaxies, appearing as small, colorful specks (blue, orange, and white) against a black background. The galaxies are scattered across the frame, with some showing distinct spiral or elliptical shapes. In the center of the image, the word "NEUTRINOS" is written in a large, bold, white, sans-serif font.

NEUTRINOS

NEUTRINOS ARE EXTREMELY ABUNDANT





ABUNDANT

NEUTRINOS

ν
 ν ν ν ν
ABUNDANT
 ν ν ν ν



ELEMENTARY

NEUTRINOS

ν ν ν ν ν
ABUNDANT
 ν ν ν ν



ELEMENTARY

NEUTRINOS



NEUTRAL



ν ν ν ν ν
ABUNDANT
 ν ν ν ν



ELEMENTARY

NEUTRINOS



**WEAKLY
INTERACTING**



NEUTRAL



ABUNDANT

ELEMENTARY



NEUTRINOS

WEAKLY INTERACTING



LIGHT



NEUTRAL



ABUNDANT

ELEMENTARY



NEUTRINOS

WEAKLY INTERACTING



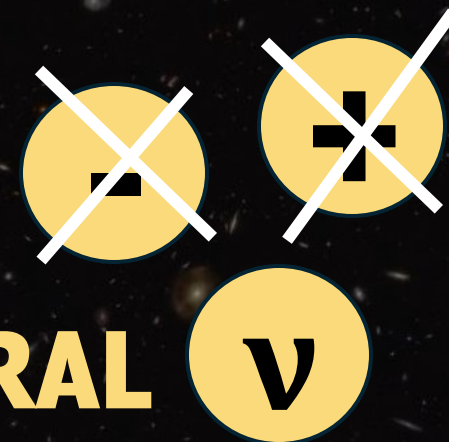
LIGHT



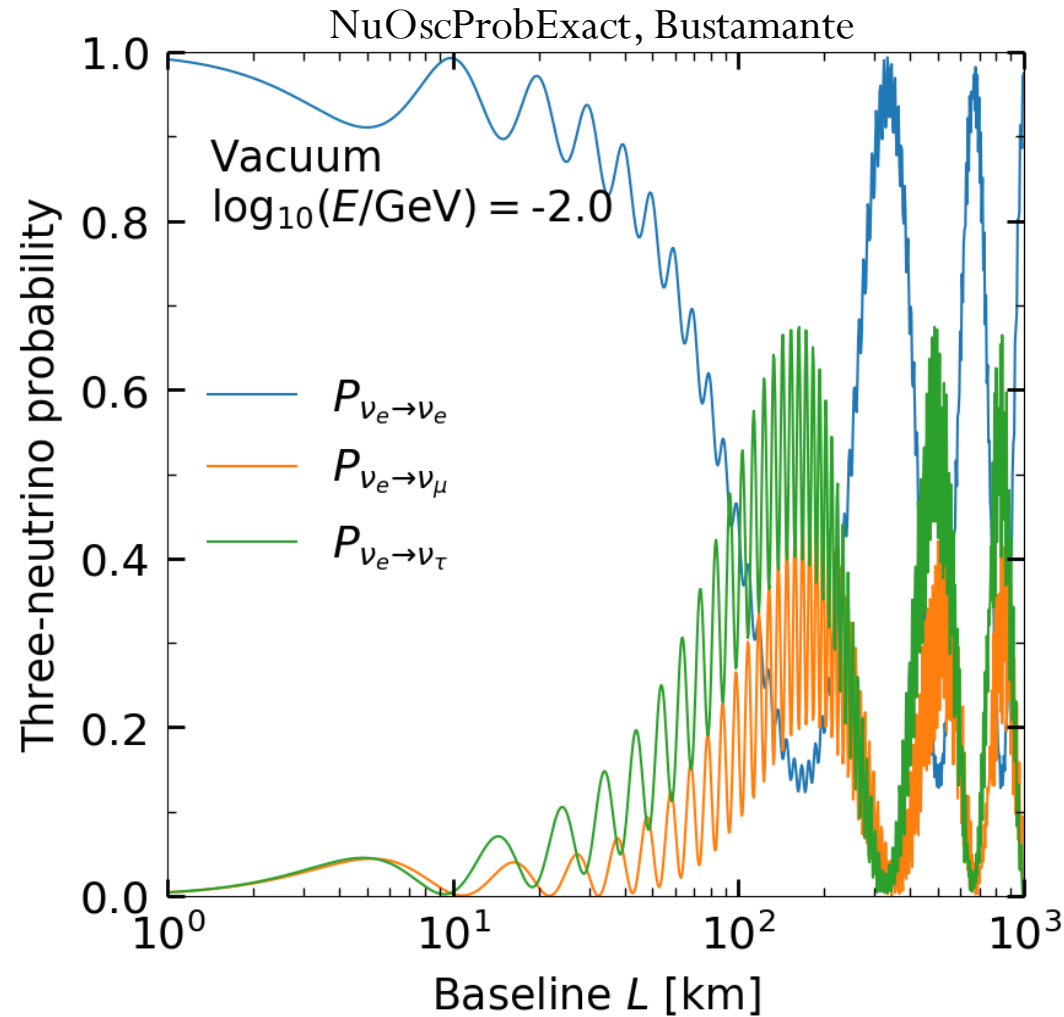
CHANGE FLAVOUR



NEUTRAL



NEUTRINOS CHANGE FLAVOUR



Neutrinos oscillate between flavours while they propagate (depending on their **energy** and the **distance** travelled).

- 'Survival' probability
- 'Transition' probability
- 'Transition' probability

contact:
Koskinen

ABUNDANT

ELEMENTARY



NEUTRINOS

WEAKLY INTERACTING



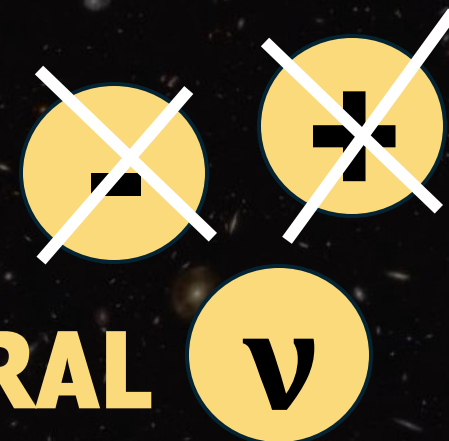
LIGHT



CHANGE FLAVOUR



NEUTRAL



ABUNDANT

ELEMENTARY

NEUTRINOS

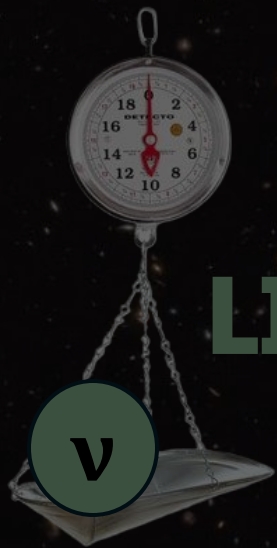
are excellent cosmic messengers

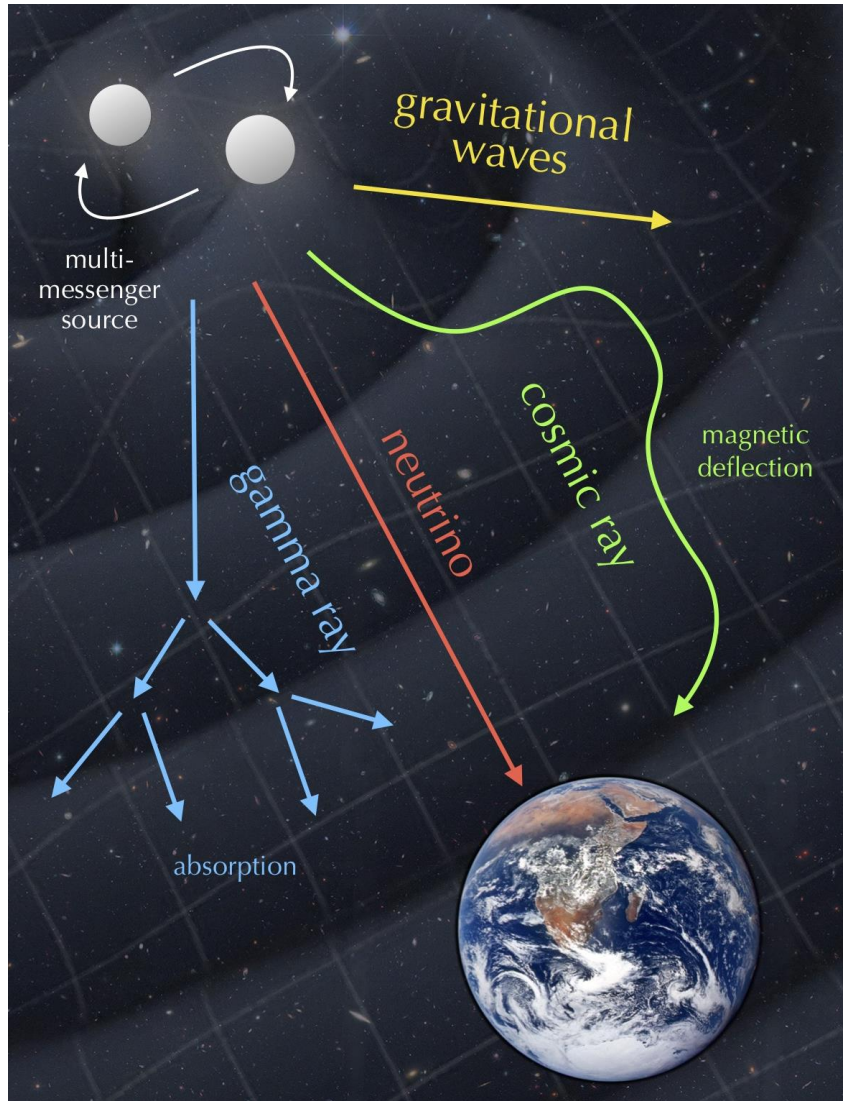
WEAKLY INTERACTING

LIGHT

CHANGE FLAVOUR

NEUTRAL





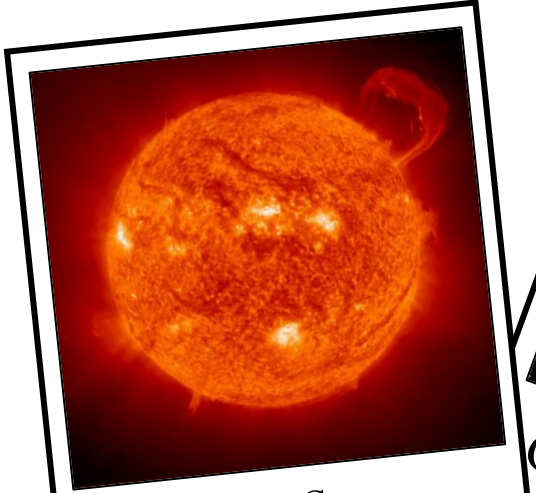
NEUTRINOS

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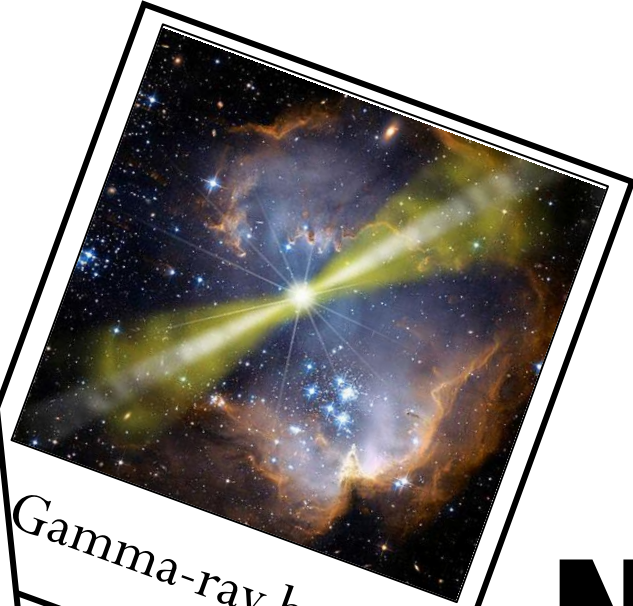
not absorbed or deflected by magnetic fields

smoking-gun of unknown sources of cosmic rays

coincident with gamma rays and gravitational waves



The Sun



Gamma-ray bursts



Active galaxies

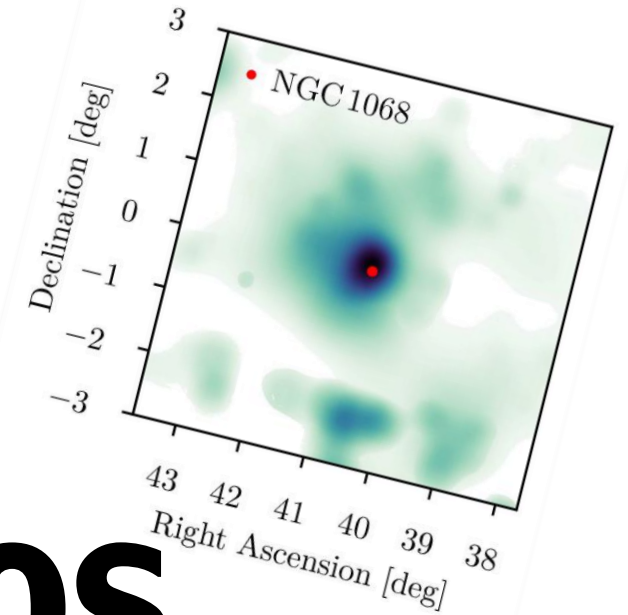
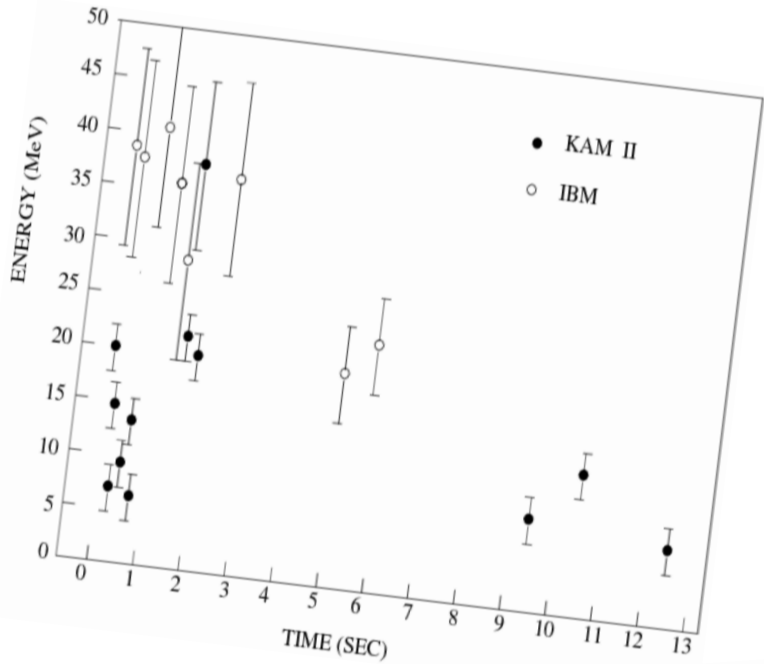


Supernovae

NEUTRINOS

are excellent cosmic messengers

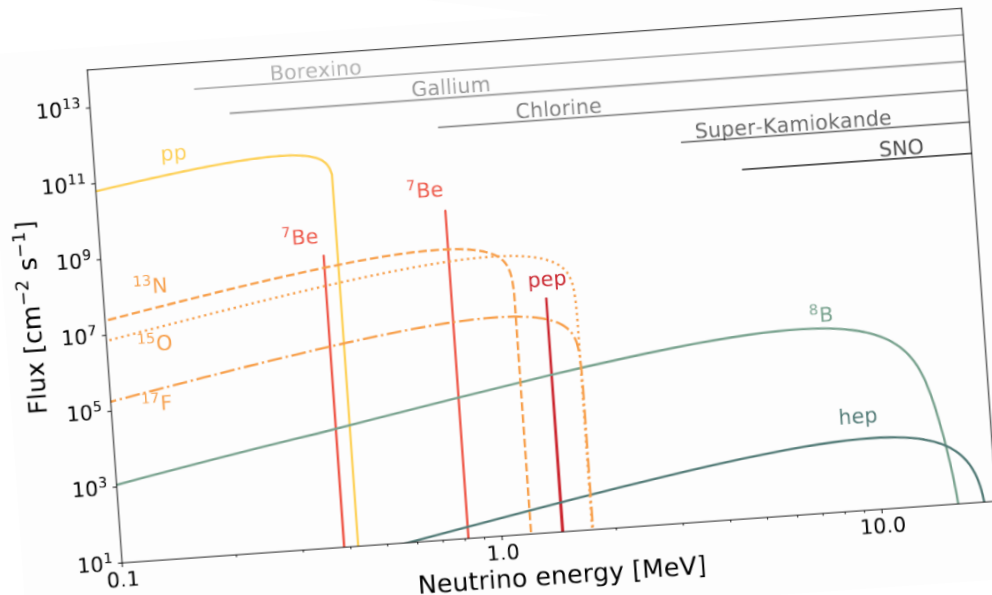
Neutrinos are copiously produced in **astrophysical sources**.

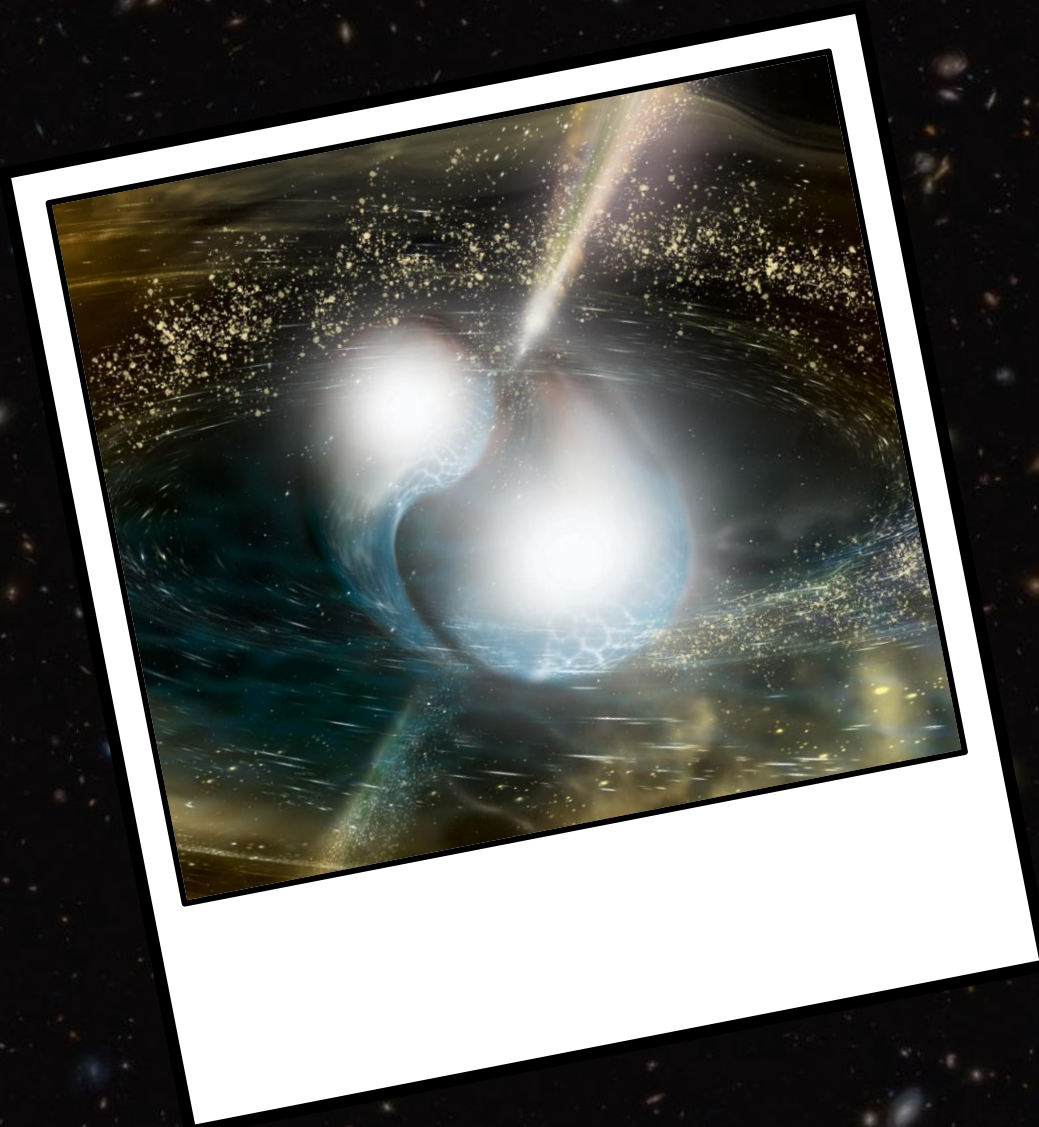


NEUTRINOS

are excellent cosmic messengers

Neutrinos provide us with **energy, time, flavour and directional information.**

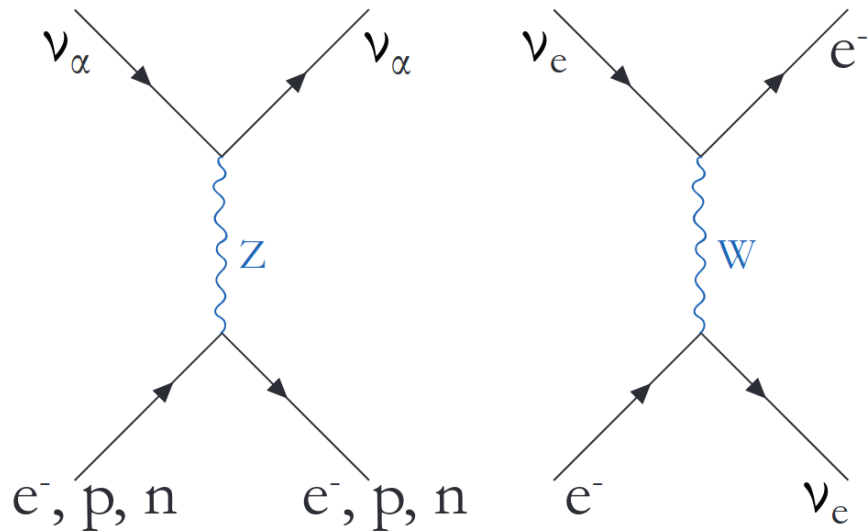




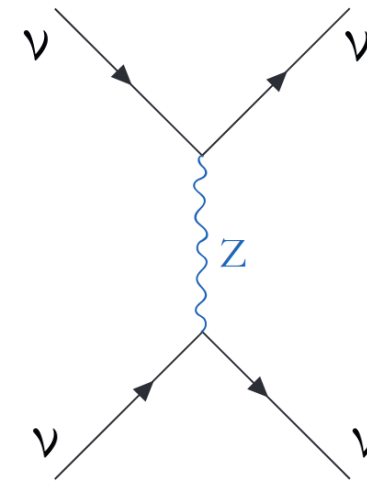
NEUTRINOS

in Supernovae and Mergers

NEUTRINO INTERACTIONS



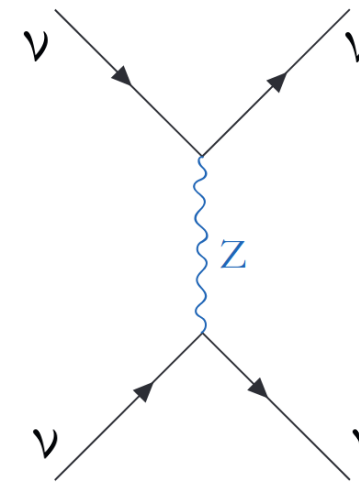
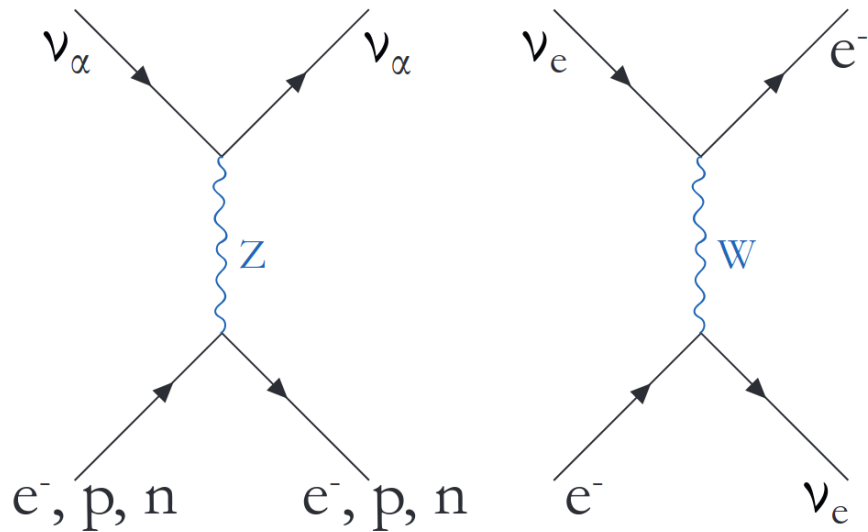
Neutrino interactions with protons, electrons, and neutrons in matter are well understood.



But we still need to learn a lot about **neutrino-neutrino interactions!**
This is a **non-linear phenomenon!**

NEUTRINO INTERACTIONS

contact:
Tamborra



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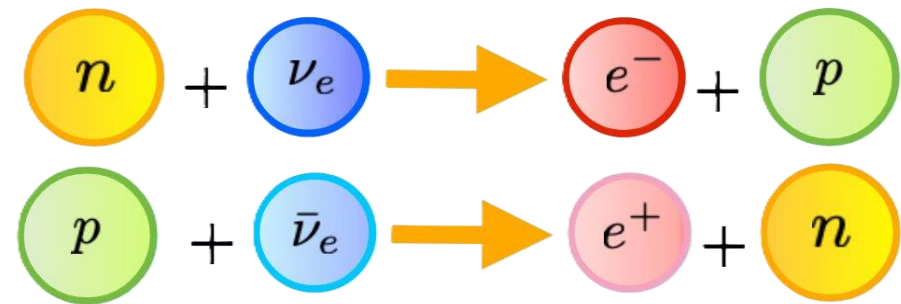
But we still need to learn a lot about **neutrino-neutrino interactions!**
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STELLAR NUCLEOSYNTHESIS

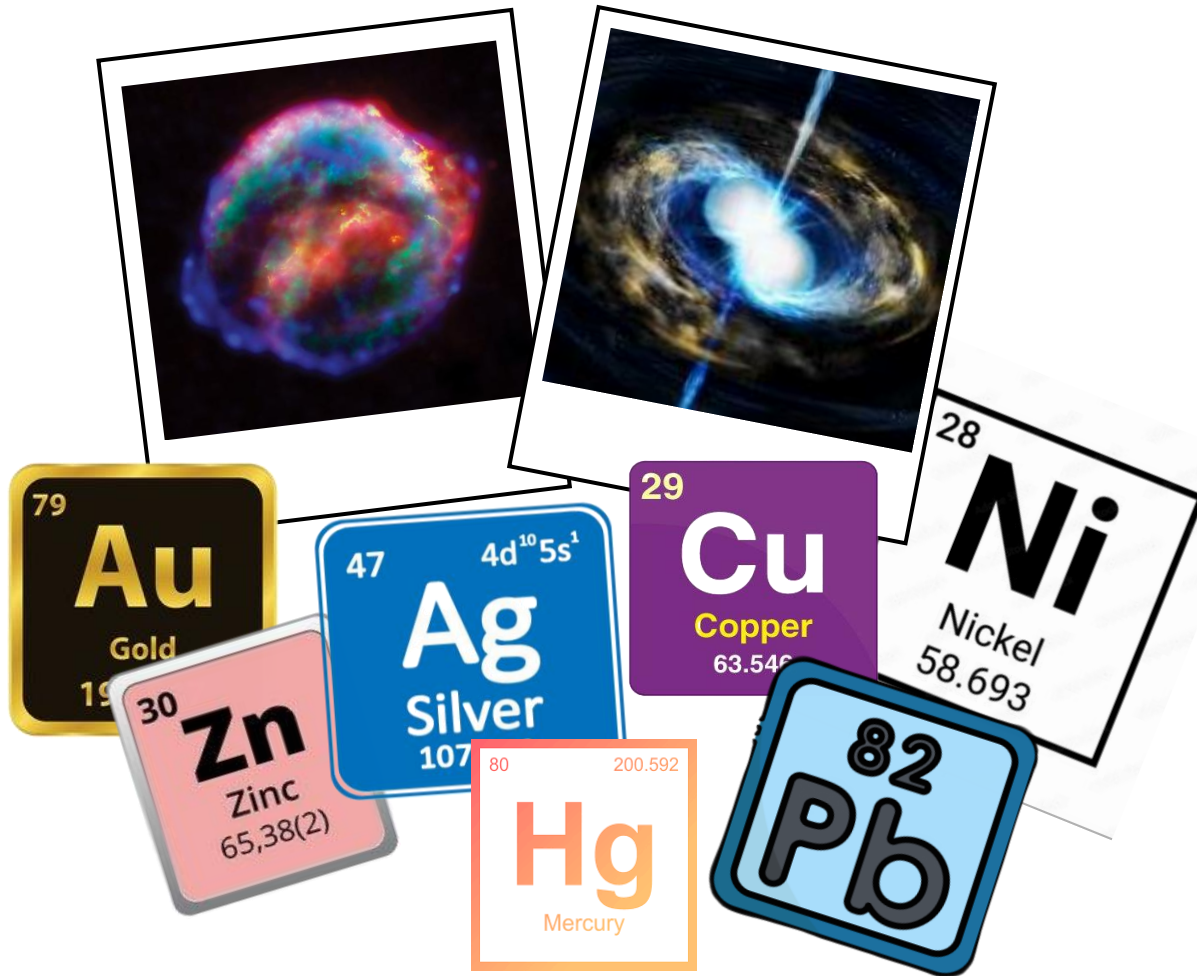


Elements heavier than iron are born in supernovae and neutron-star mergers.

Synthesis of new elements could not happen without **neutrinos**.



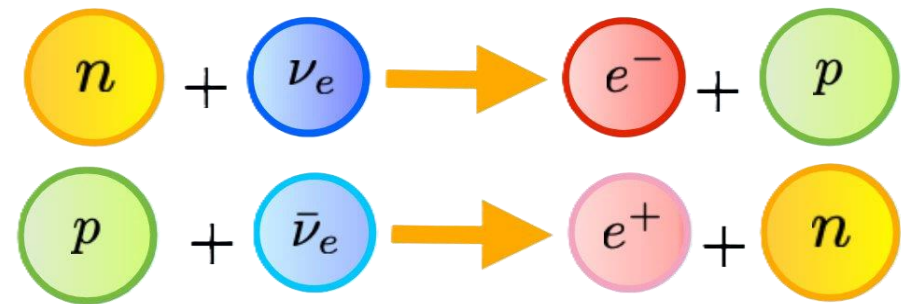
STELLAR NUCLEOSYNTHESIS



contact:
Tamborra

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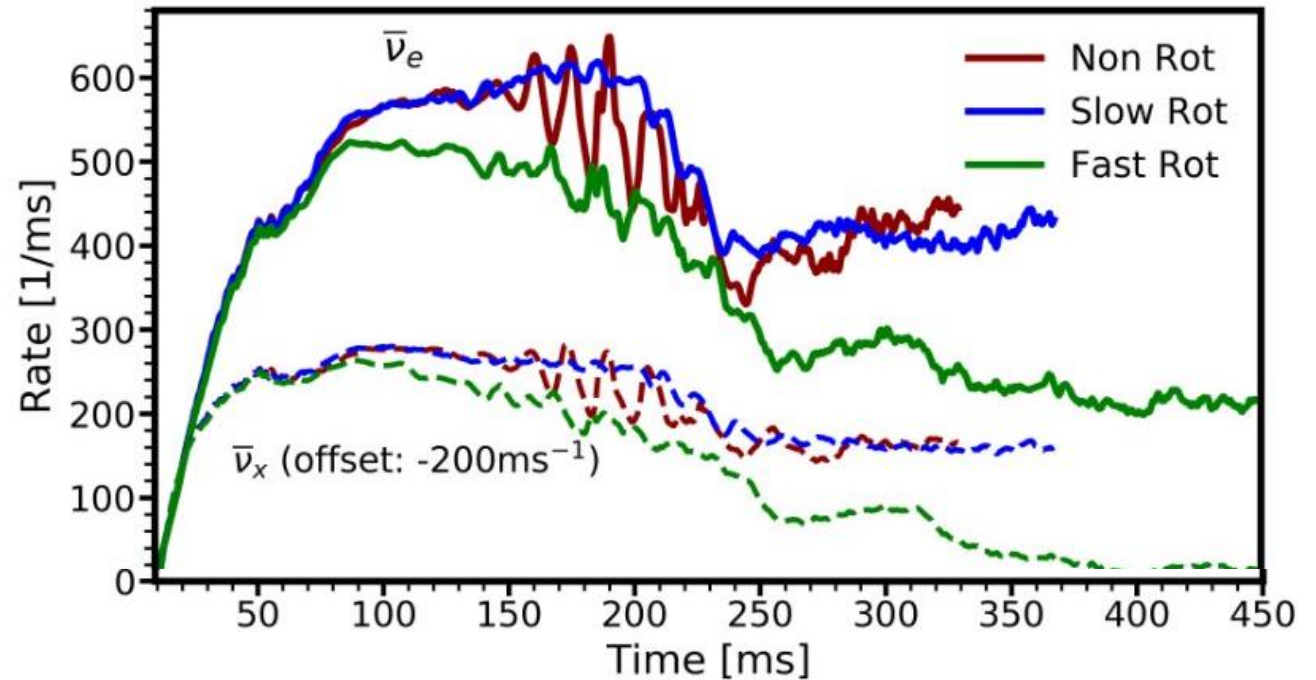
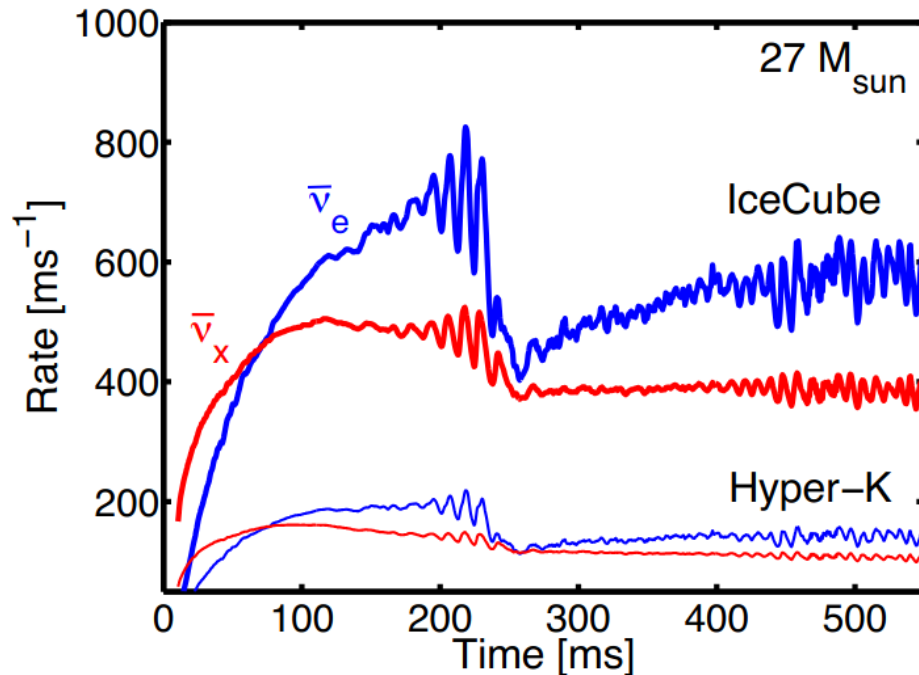


PROBE OF SUPERNOVA DYNAMICS

Tamborra et al.

Phys.Rev.D 98 (2018) 12, 123001

Phys.Rev.D 90 (2014) 4, 045032



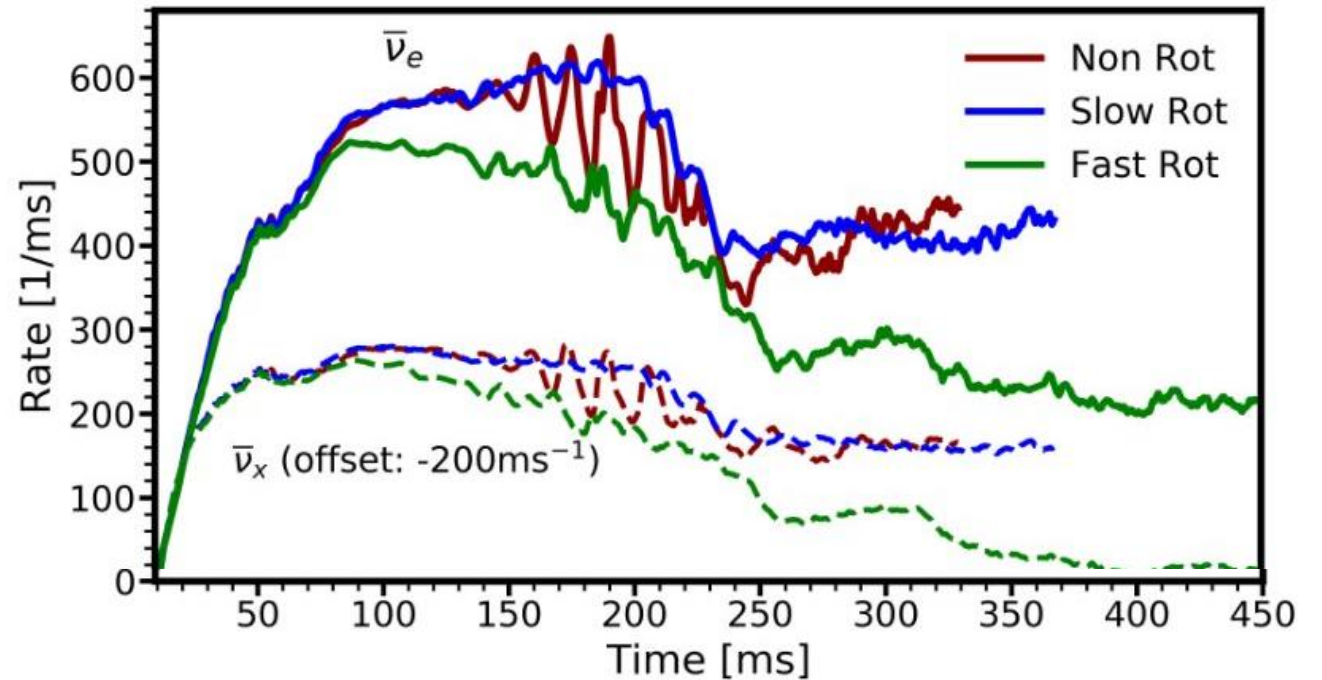
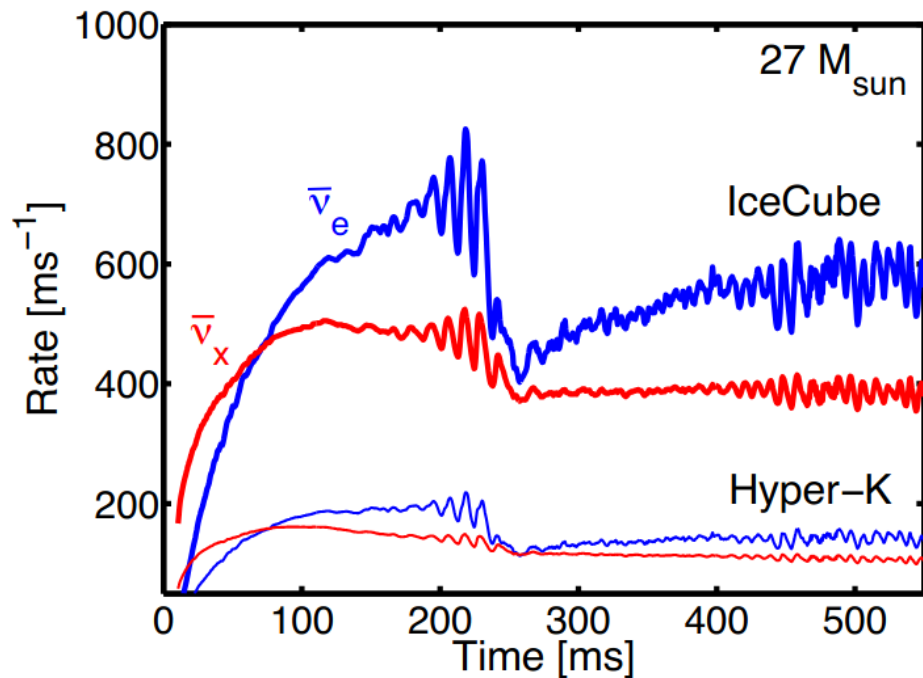
Neutrinos probe **explosion mechanism** of a supernova and its **rotation**.

Complementary information from detection of gravitational waves.

PROBE OF SUPERNOVA DYNAMICS

Tamborra et al.
Phys.Rev.D 98 (2018) 12, 123001
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contact:
Tamborra



Neutrinos probe **explosion mechanism** of a supernova and its **rotation**.
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NEUTRINOS

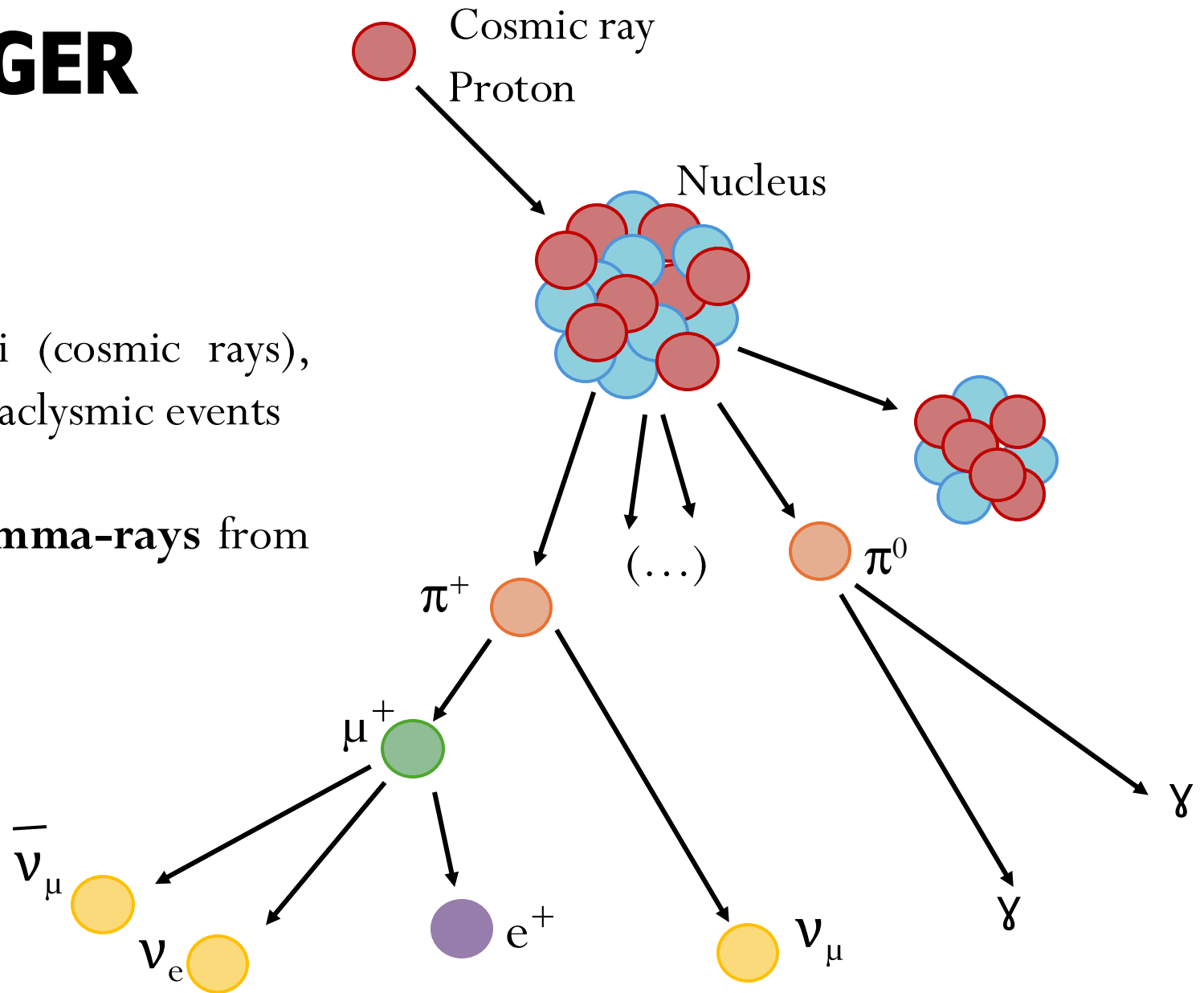
in and from cosmic accelerators



MULTI-MESSENGER ASTRONOMY

Acceleration of charged nuclei (cosmic rays), especially in the aftermath of cataclysmic events

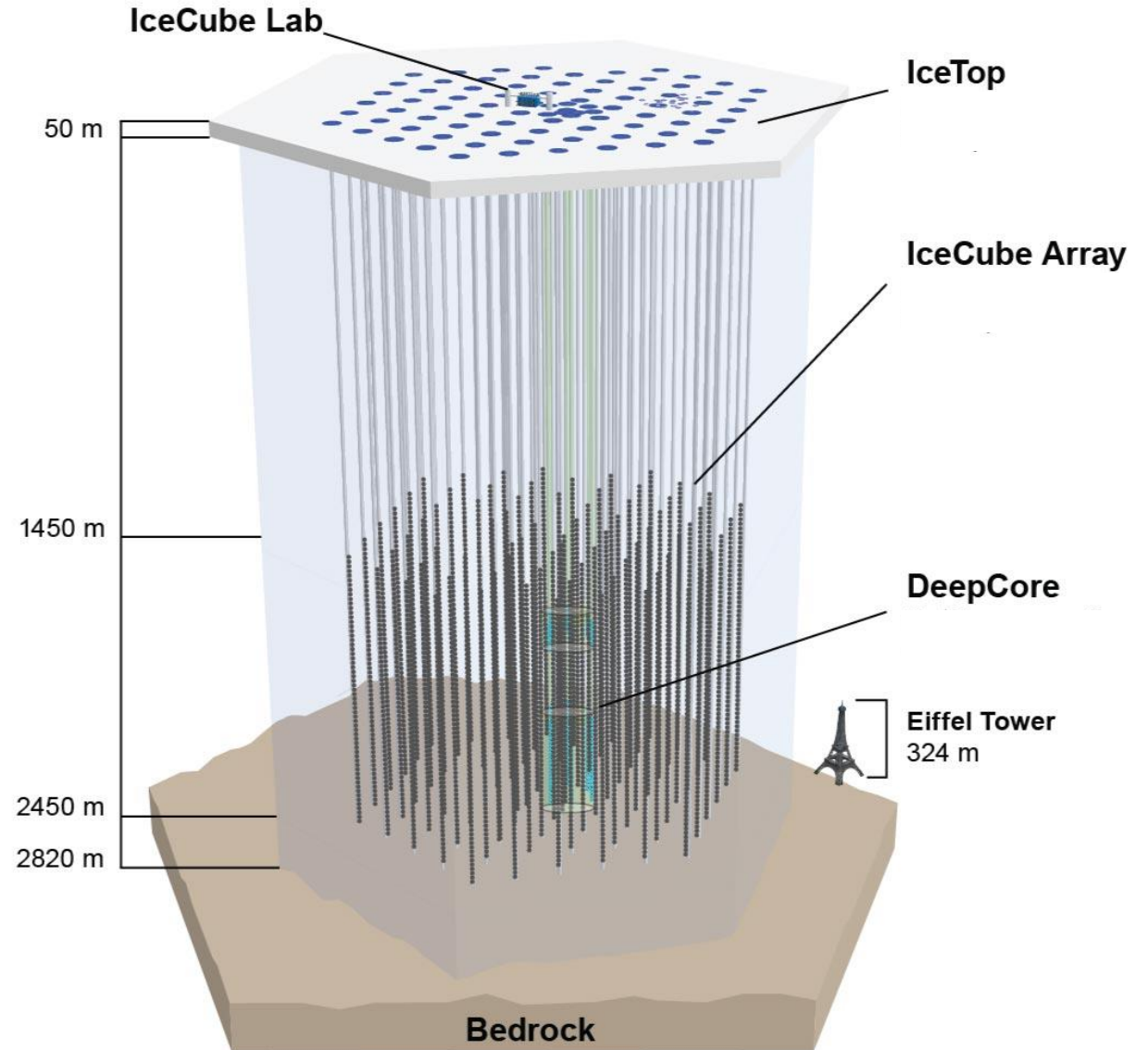
Secondary **neutrinos** and **gamma-rays** from pion decays.



ICECUBE OBSERVATORY

Giga-ton Cherenkov telescope at the **South Pole**. Collaboration of about **300 scientists** at 53 international institution.

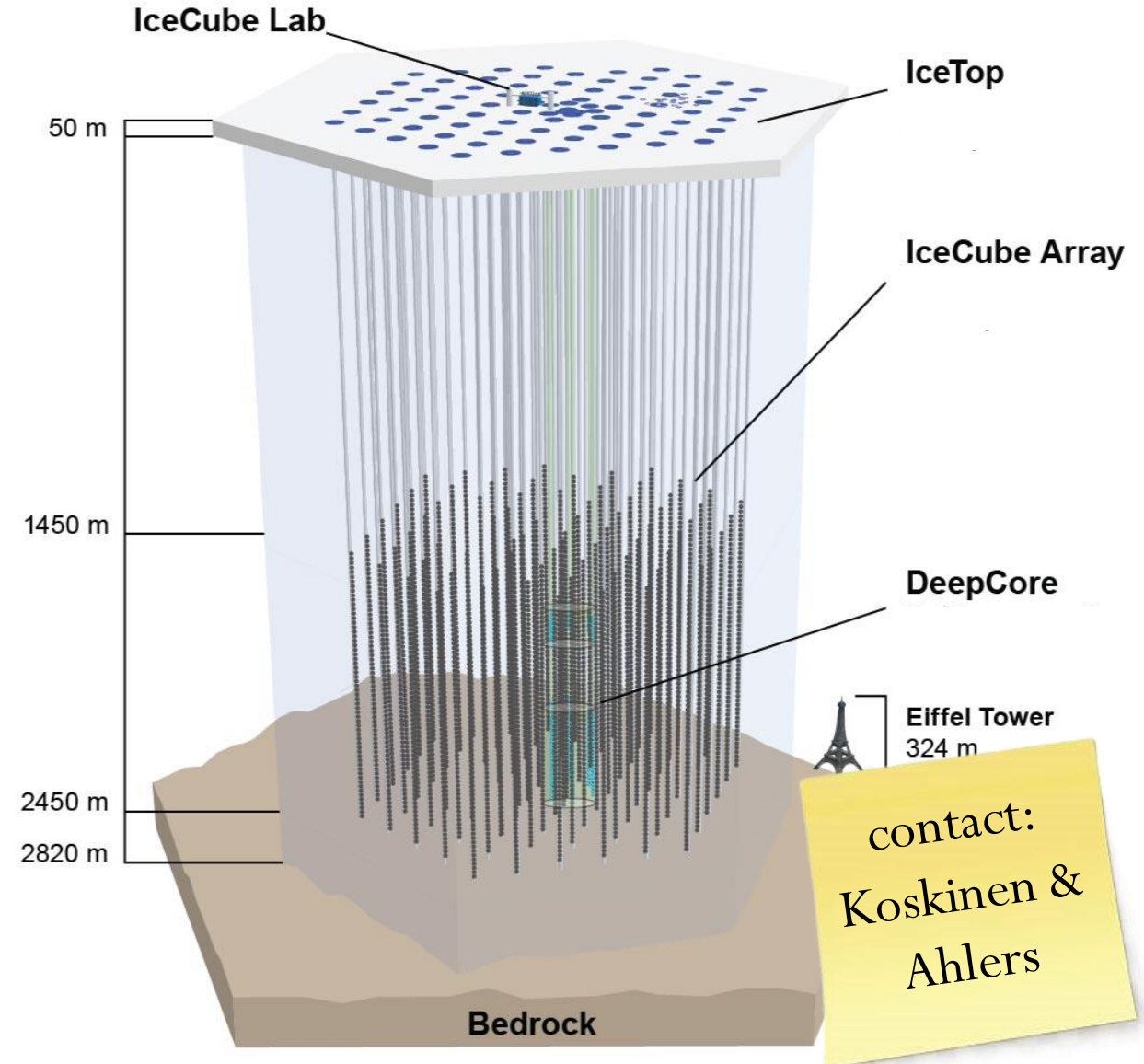
- **60 digital optical modules (DOMs)** attached to strings
- **86 IceCube strings** instrumenting **1km³** of clear glacial ice
- **81 IceTop stations** for cosmic ray shower detections



ICECUBE OBSERVATORY

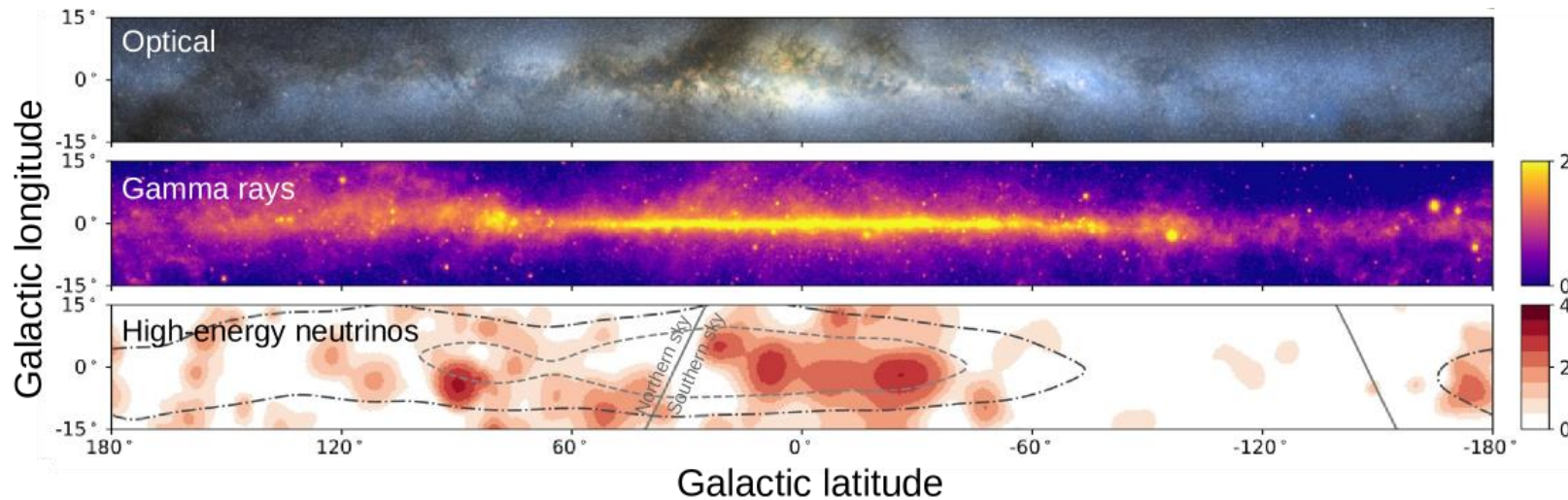
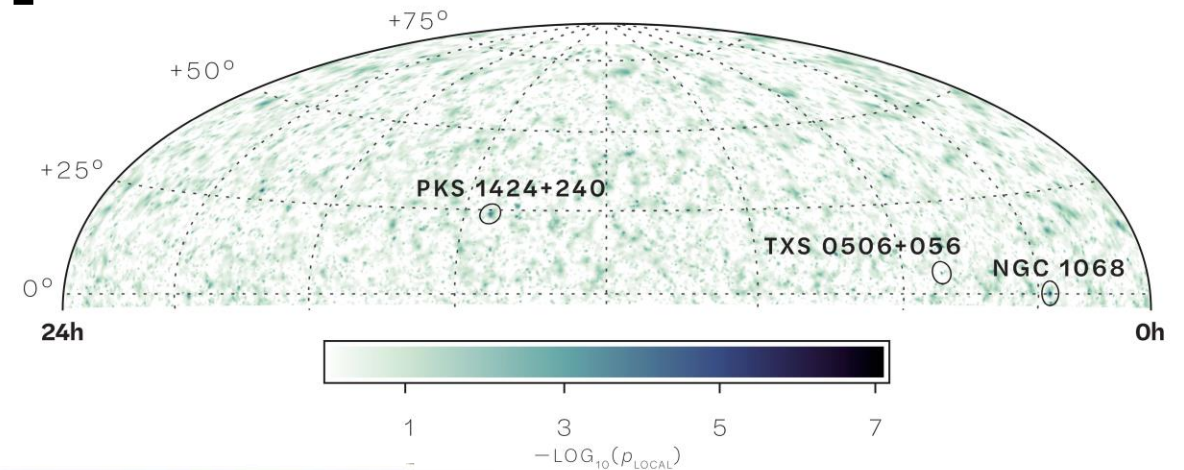
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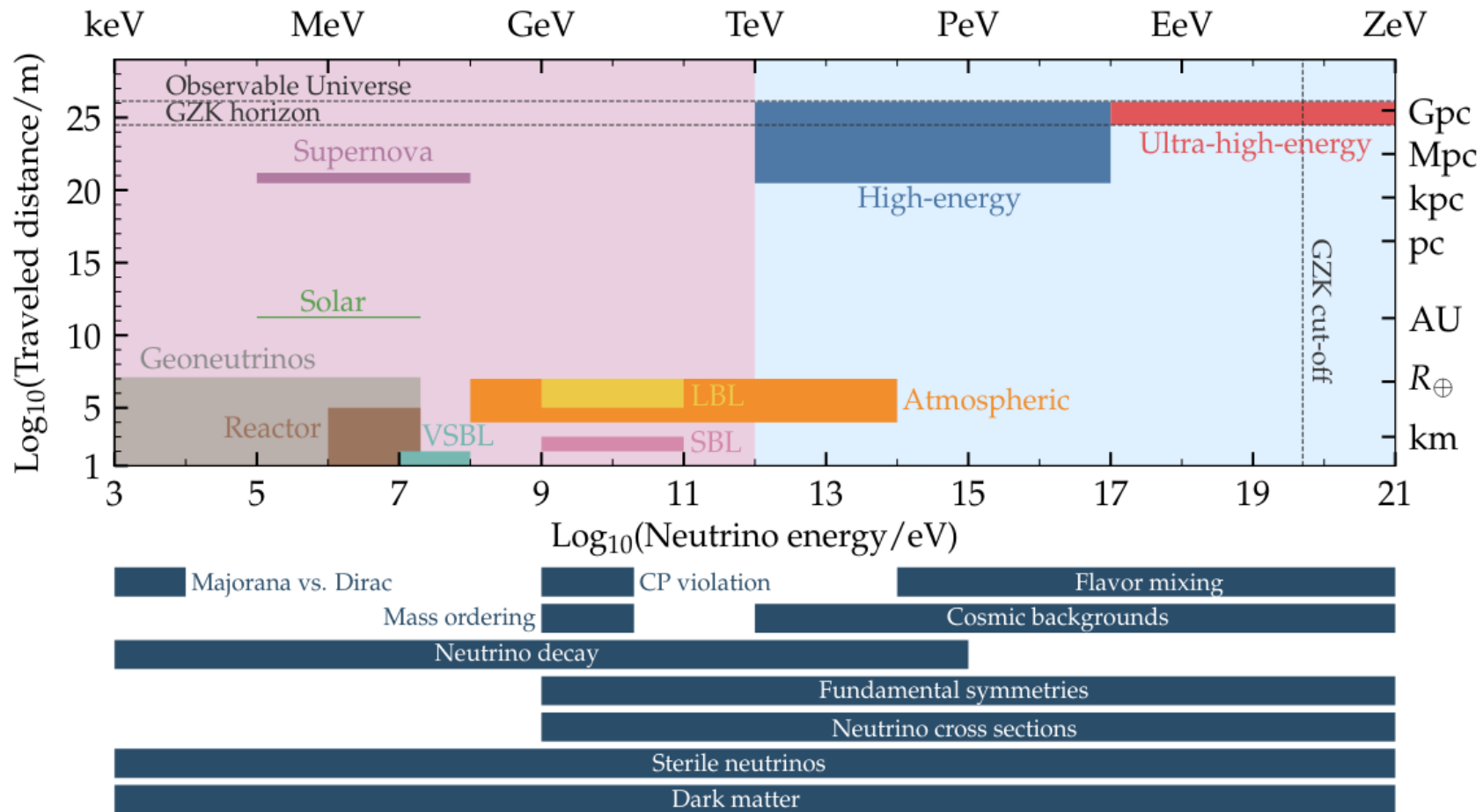
STATUS OF NEUTRINO ASTRONOMY

IceCube has found evidence of high-energy neutrino emission from **NGC 1068** (an active galaxy)...



... and from the Milky Way.

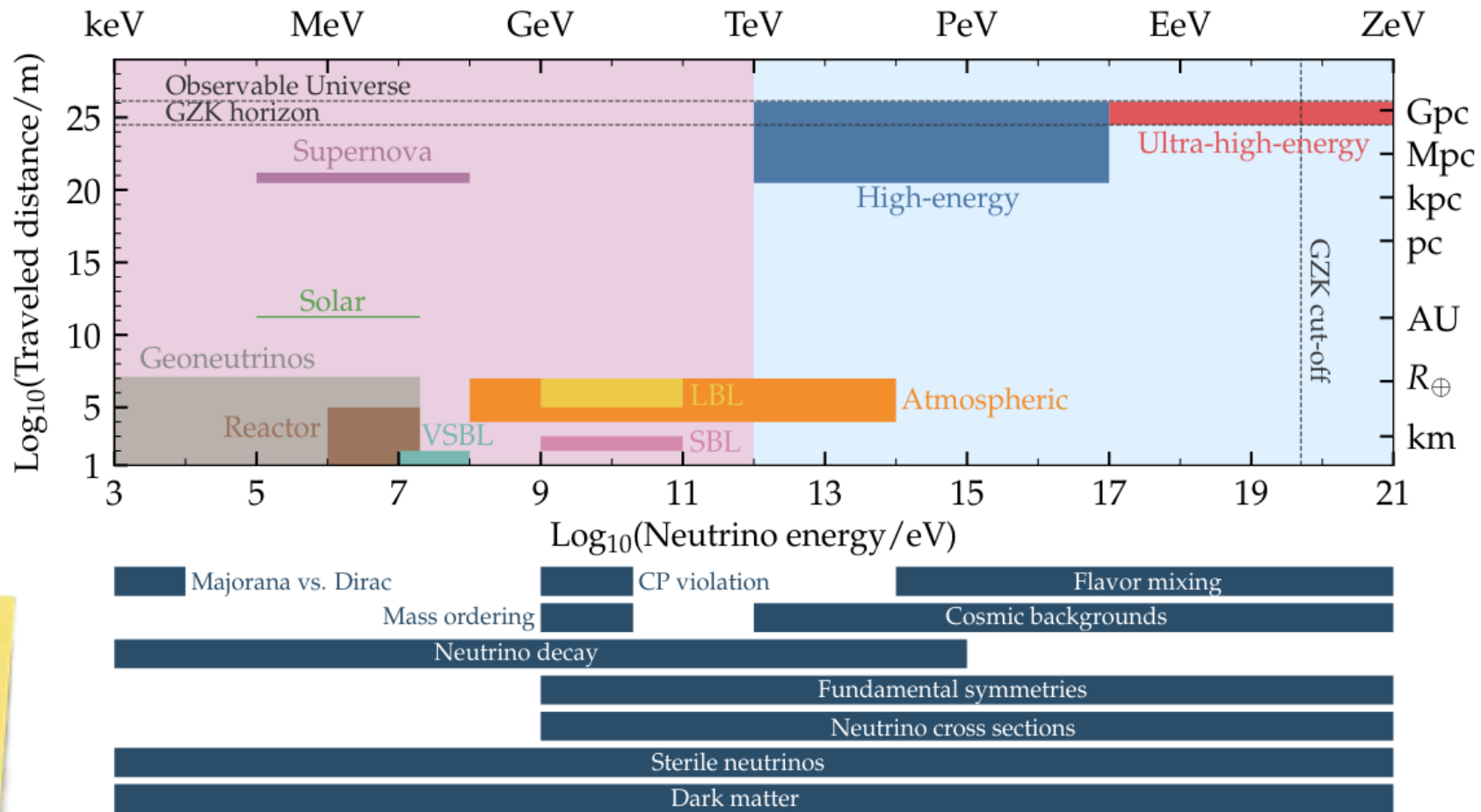
PROBE OF FUNDAMENTAL PHYSICS



Ahlers, Bustamante, et al.
 Bull.Am.Astron.Soc. 51 (2019) 215

Astrophysical neutrinos travel over enormous distances and their energies span many orders of magnitude.

PROBE OF FUNDAMENTAL PHYSICS



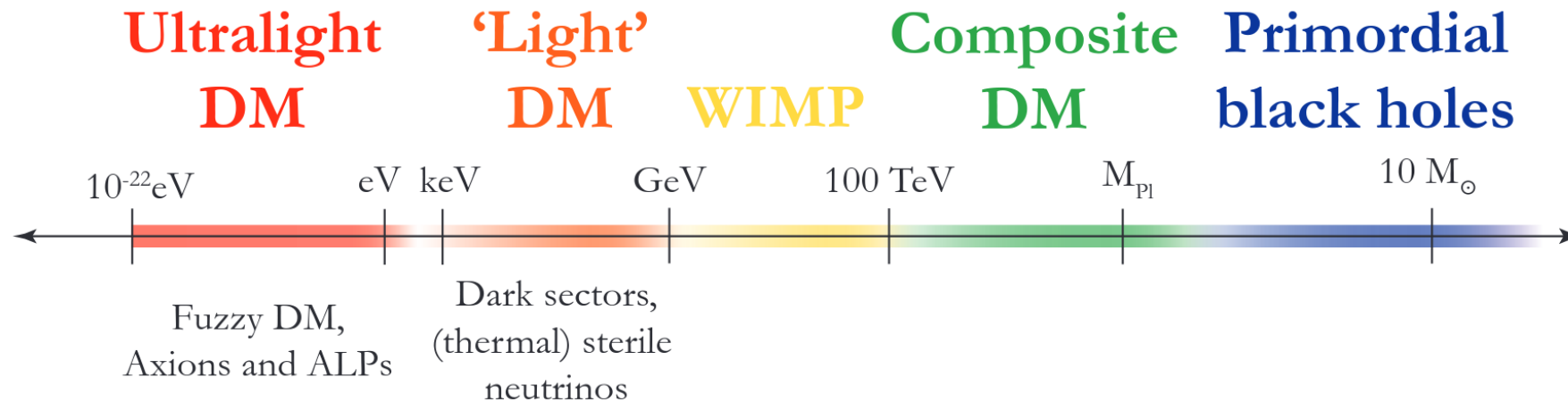
contact:
Ahlers,
Bustamante,
Tamborra

Astrophysical neutrinos travel over enormous distances and their energies span many orders of magnitude.

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Bull.Am.Astron.Soc. 51 (2019) 215

NEW PARTICLES, NEW PROBES

What is dark matter? Are there other particles?

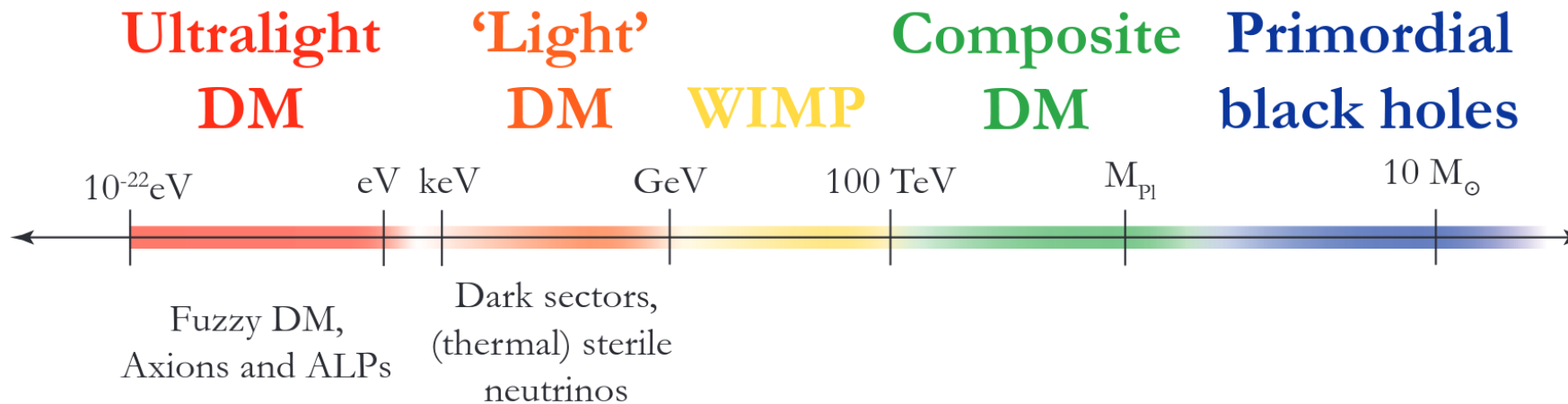


How can we probe the existence of **new particles** ('hidden' sector) at **colliders**, **neutrino experiments** and through their impact in **astrophysical sources** and **cosmology**?

NEW PARTICLES, NEW PROBES

contact:
Ruchayskiy,
Bustamante,
Tamborra

What is dark matter? Are there other particles?



How can we probe the existence of **new particles** ('hidden' sector) at **colliders**, **neutrino experiments** and through their impact in **astrophysical sources** and **cosmology**?



NEUTRINOS

are fundamental in most **energetic phenomena** in our Universe

are ideal **messengers**

affect **element formation** in astrophysical sources

carry imprints of engine and population of **extreme transients**

their **flavour conversions** are crucial but yet to be fully grasped

The impact of neutrinos
on **stellar** evolution

Neutrinos as probes of
astrophysical
environments

M.Sc. projects in
Particle Astrophysics
can cover various aspects:

Neutrinos as direct
probes of the origin
of **cosmic rays**

Observation in
neutrino **telescopes** or
experiments

Fundamental
neutrino properties