Pre-workshop MMA-CADO, Aug 30th 2026

Multi-messenger astronomy Global emergence and Japan

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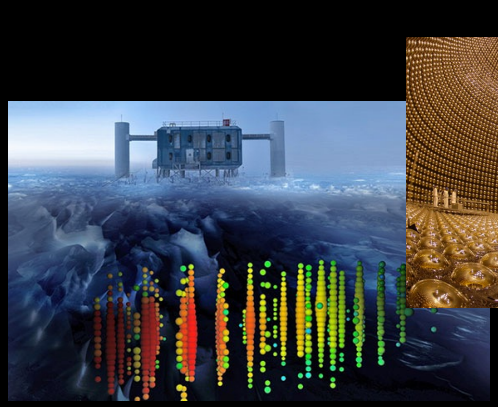
Image credit: NASA/ESA

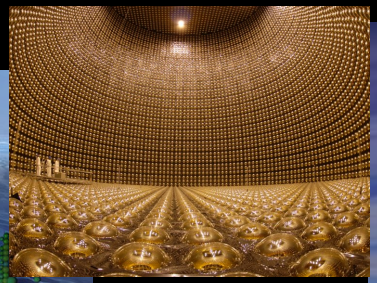
Multi-messenger astronomy

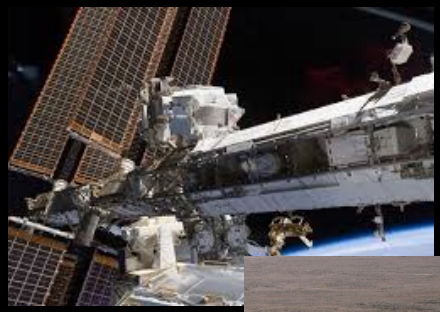
Utilize the strengths of each cosmic messenger:

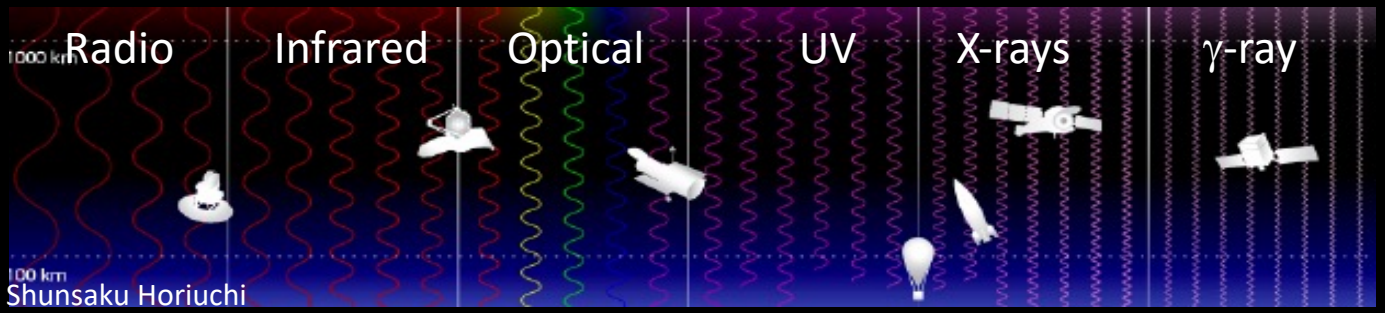
Photons	Extensive infrastructure & detailed data sensitivity
Cosmic rays	Huge energy range, composition information
Neutrinos	Penetrating, huge energy range, huge FOV
Gravitational waves	Penetrating, huge FOV

When combined, the whole is stronger than the sum of its parts









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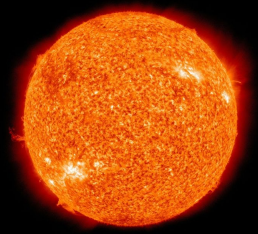
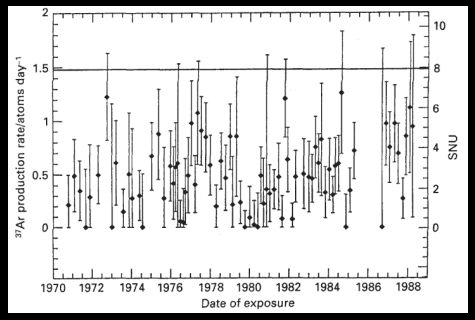
Why should one care?

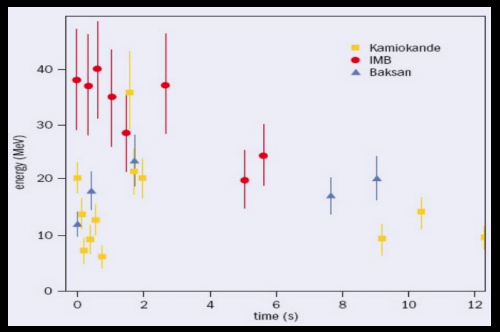
Solar neutrinos





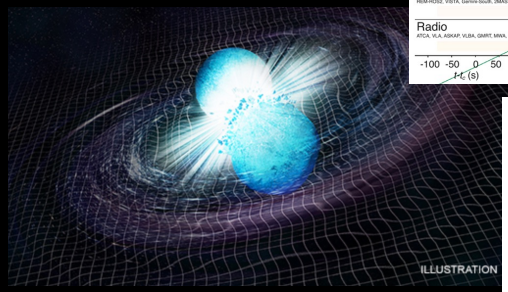
Photons + neutrinos
→ Neutrino oscillation, many others

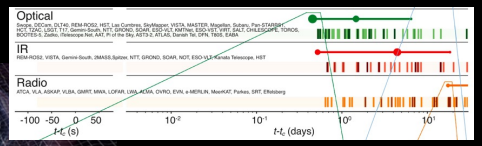
SN1987A, TXS 0506+056, NGC 1068, ...

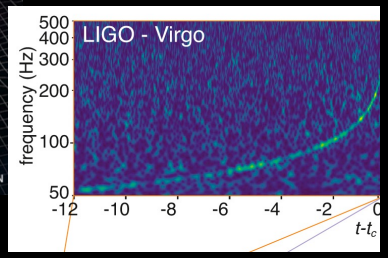


Photons + neutrinos
→ Weak interactions, CRs, many others

GW170817



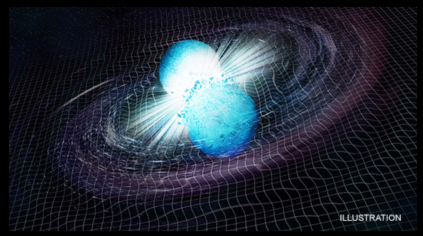


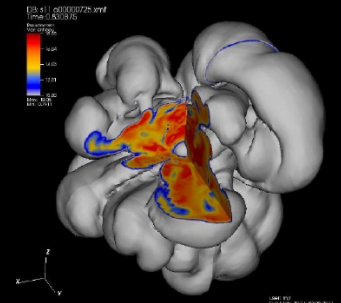


Photons + grav. waves
→ Origin of elements, many others

Ongoing & future

- Increasingly more detectors
- Increasingly important how messengers are combined



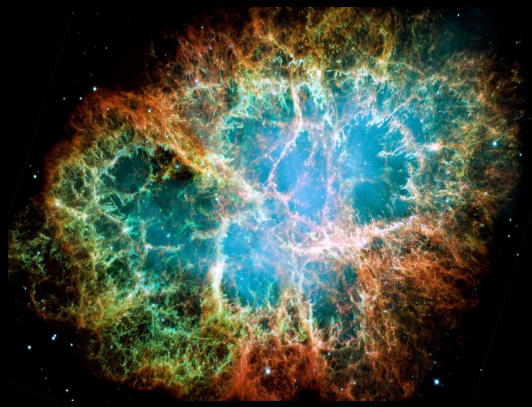


Many sources & open questions

Many sources and open questions to be investigated

Supernovae

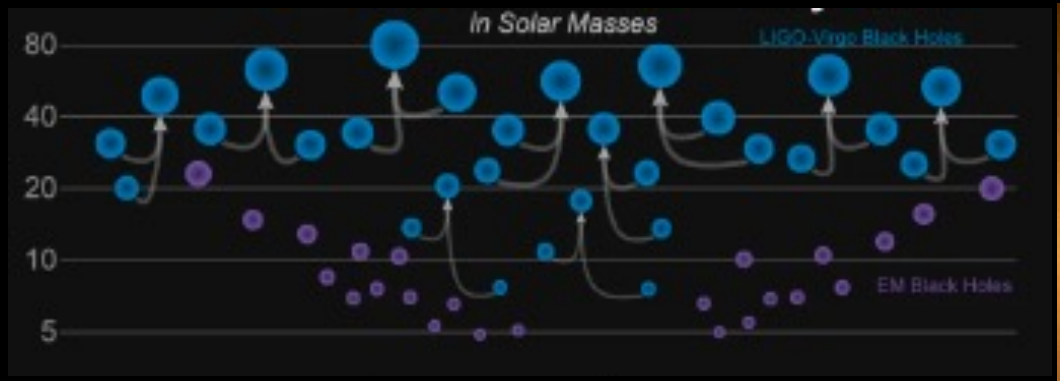
Supernova remnants



Compact objects

Dark matter

Compact object mergers



Black holes

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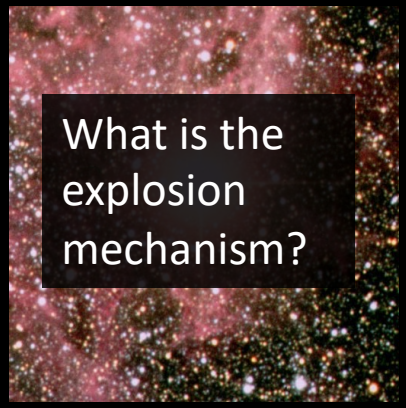
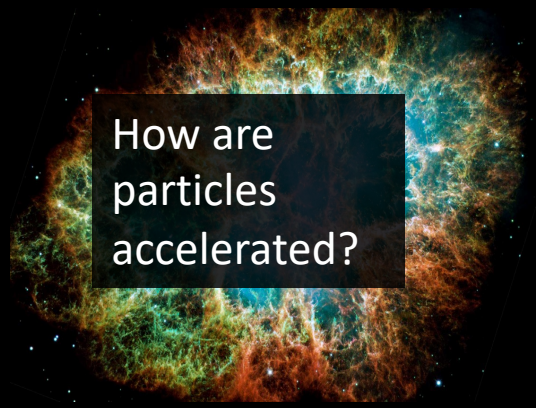


Supernova remnants



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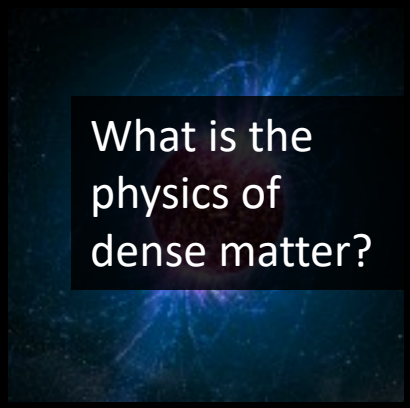

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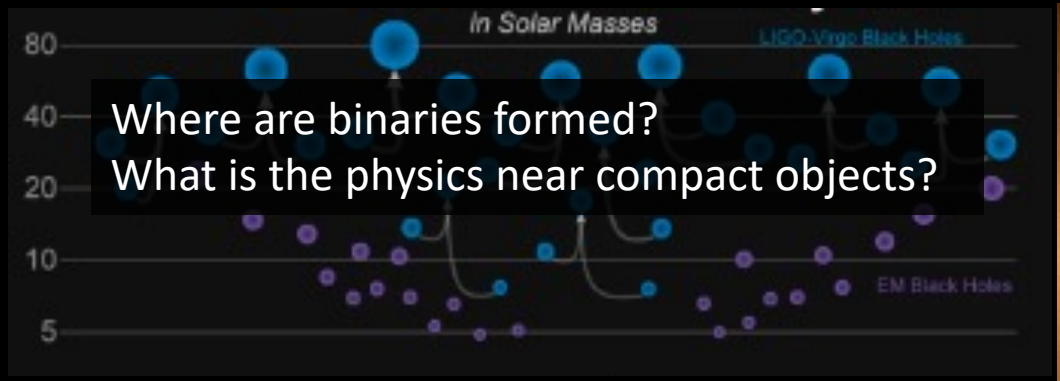

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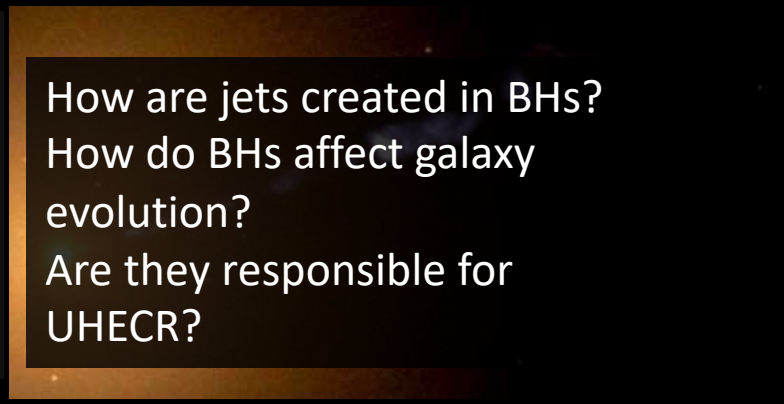
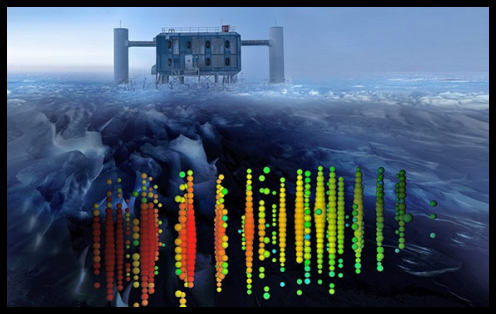
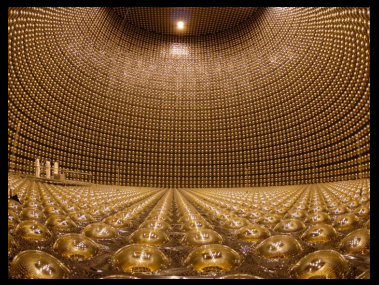


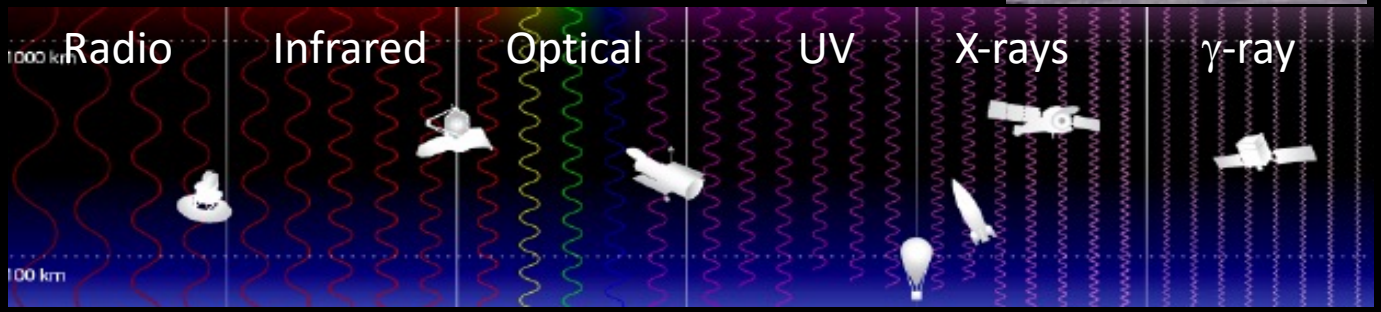
➔ **Revealing new source physics and new fundamental physics**

Multi-messenger astro pre-reqs

Many fields, methods, techniques, and limitations....







... must all come together for multi-messenger astronomy

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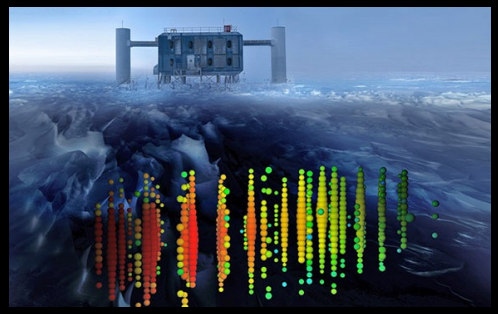
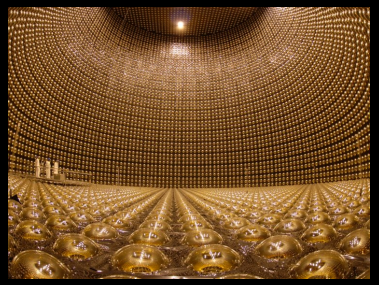
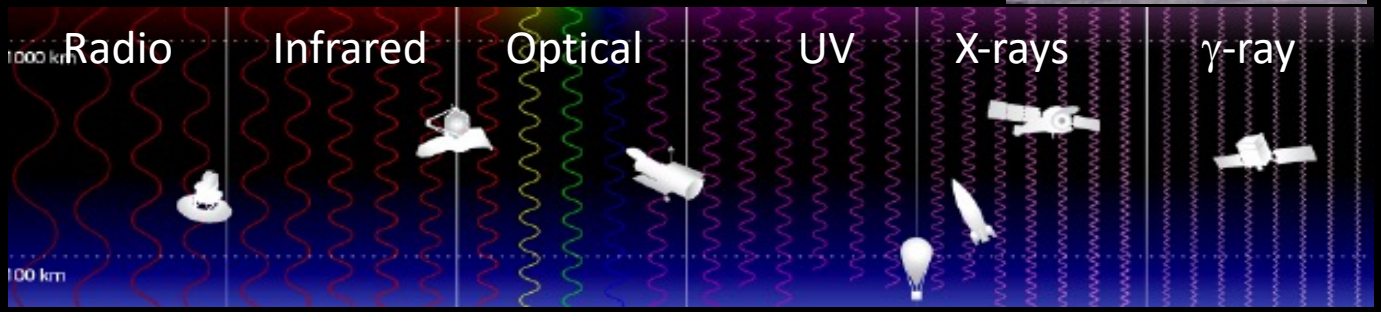






... must all come together for multi-messenger astronomy

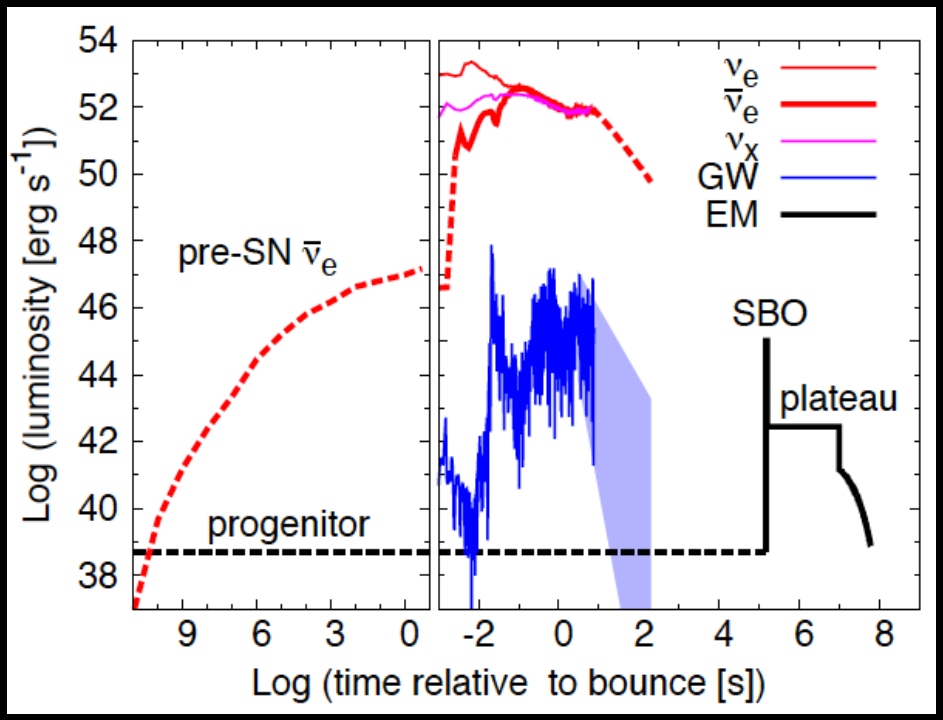
Needs:

- Dedicated information exchanges & understanding
- Communication and team building/work
- Training, open to failures
- Funding & resources for interdisciplinary research

Example: open questions

What is the explosion mechanism of supernovae?

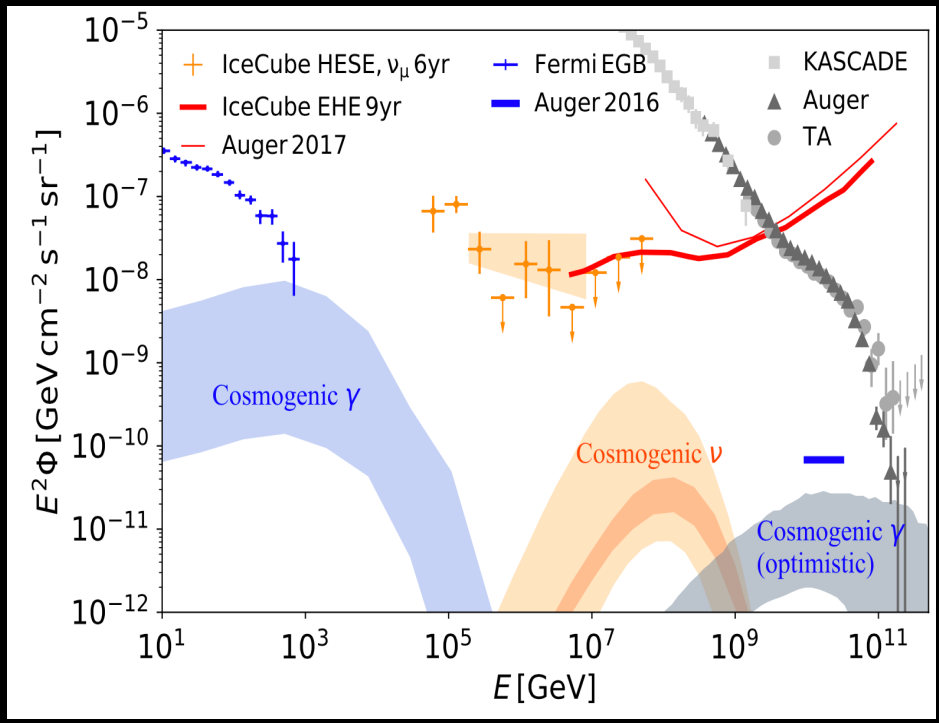
- Long history: complex numerical problem involving all forces of nature
- Several models: always emits neutrinos, usually light, and gravitational waves (depending)



Nakamura et al (2016)

What are the sources of (ultra-high energy) cosmic rays?

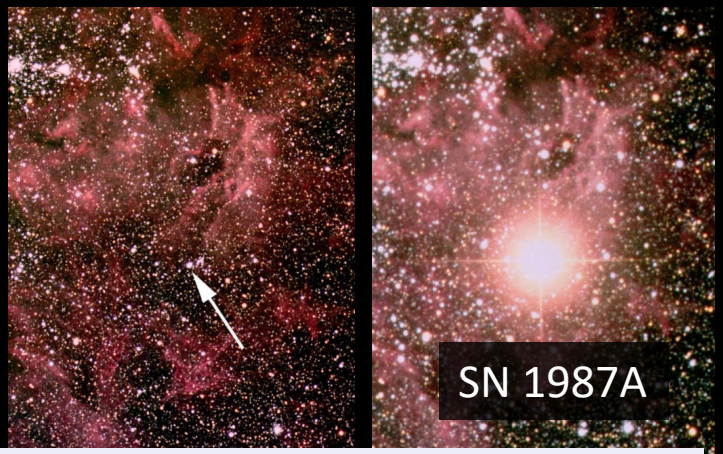
- Long history: complex numerical problem involving wide energies and processes
- Many source classes, interactions produce neutrinos and light

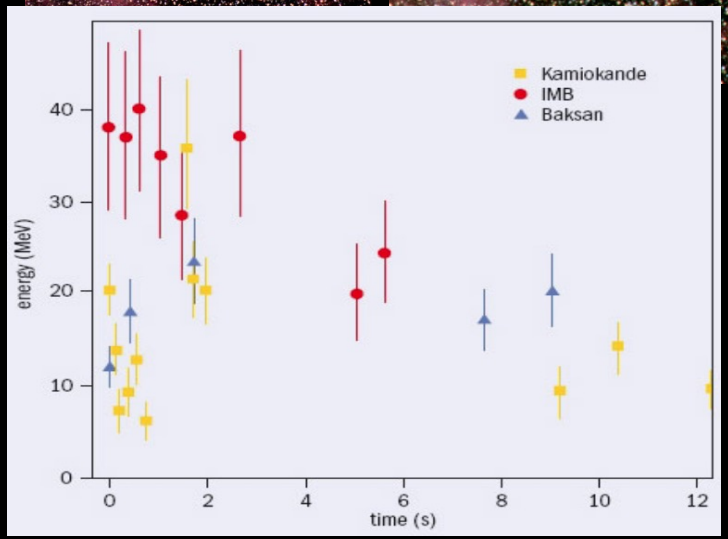


Batista et al (2019)

Emergence of neutrino astronomy

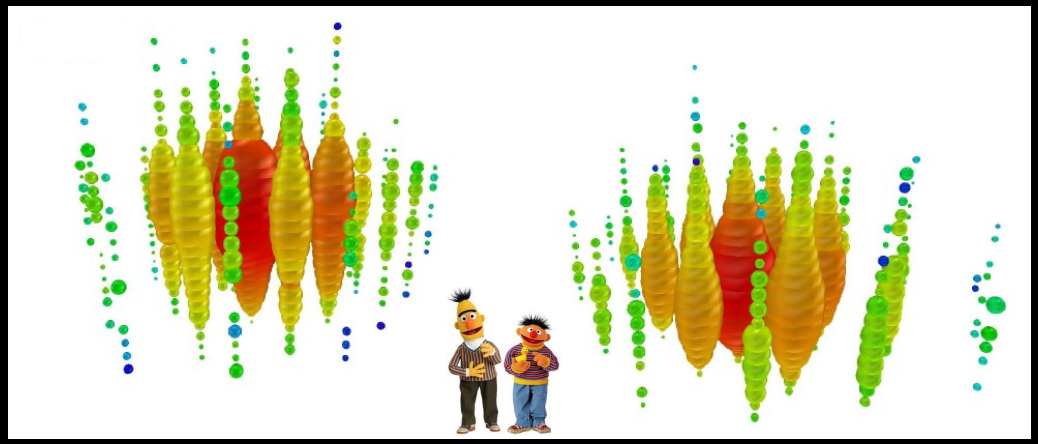
Thermal (low-energy) neutrinos





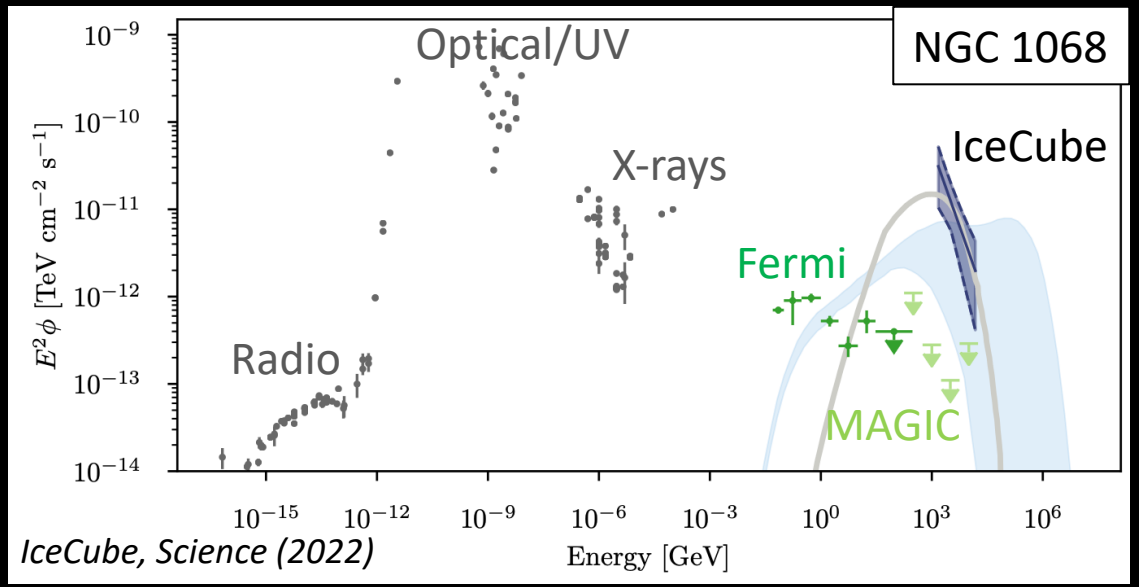
And 2.6σ hint of diffuse supernova neutrino background by SuperK-Gd *(Neutrino 2026)*

Non-thermal (high-energy) neutrinos



IceCube, PRL (2013), Science (2013)

Detailed diffuse, TXS 0506+056, NGC1068, Galactic



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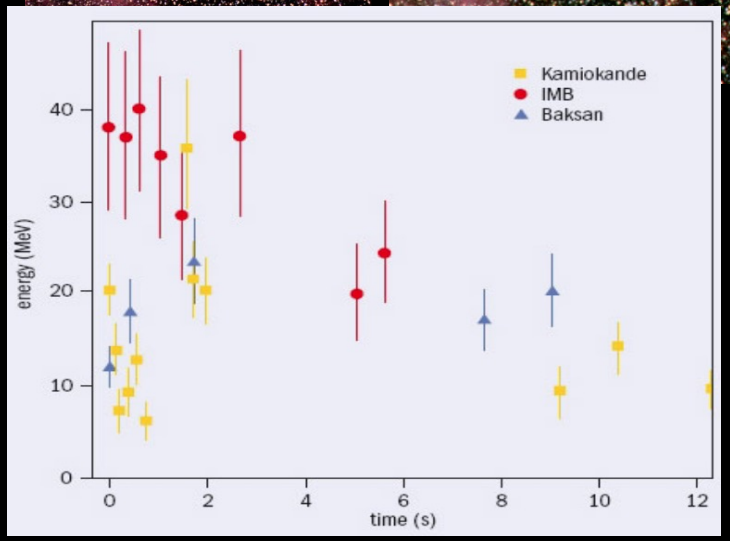

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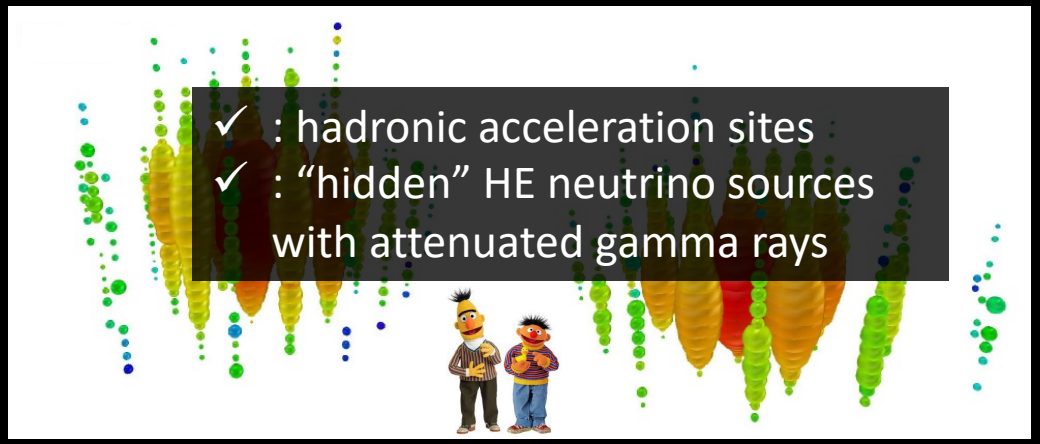

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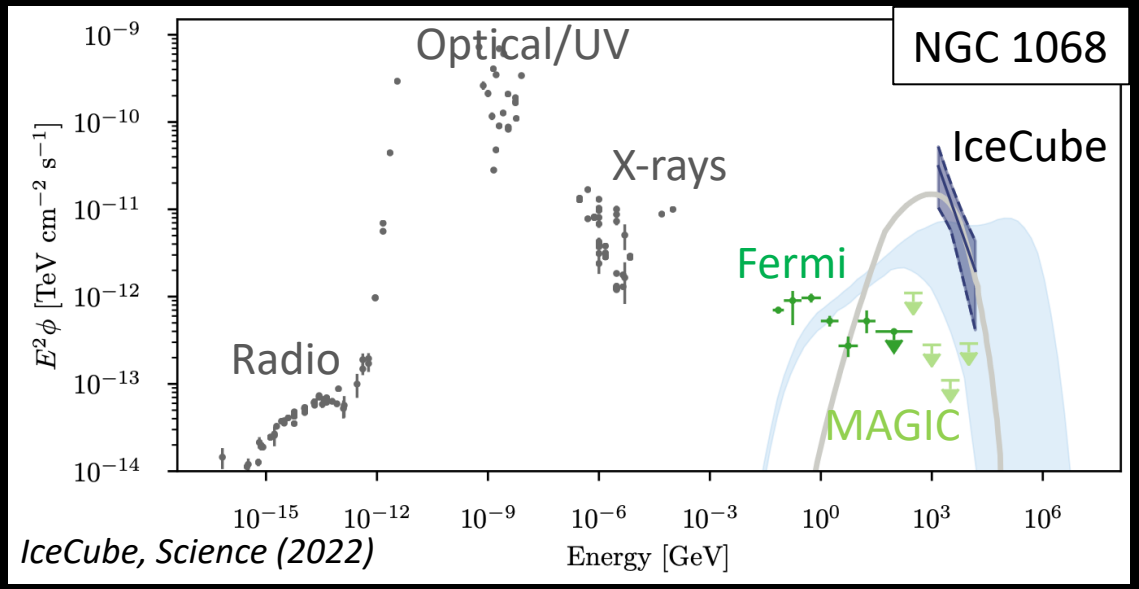
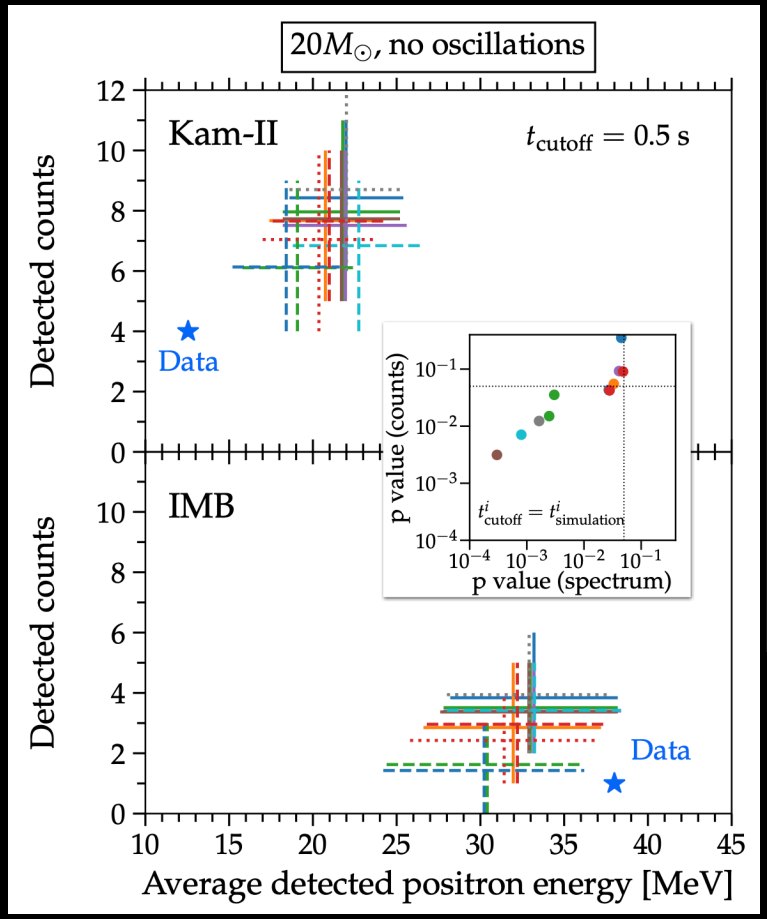


IceCube, Science (2022)

Implications

What is the explosion mechanism of supernovae?

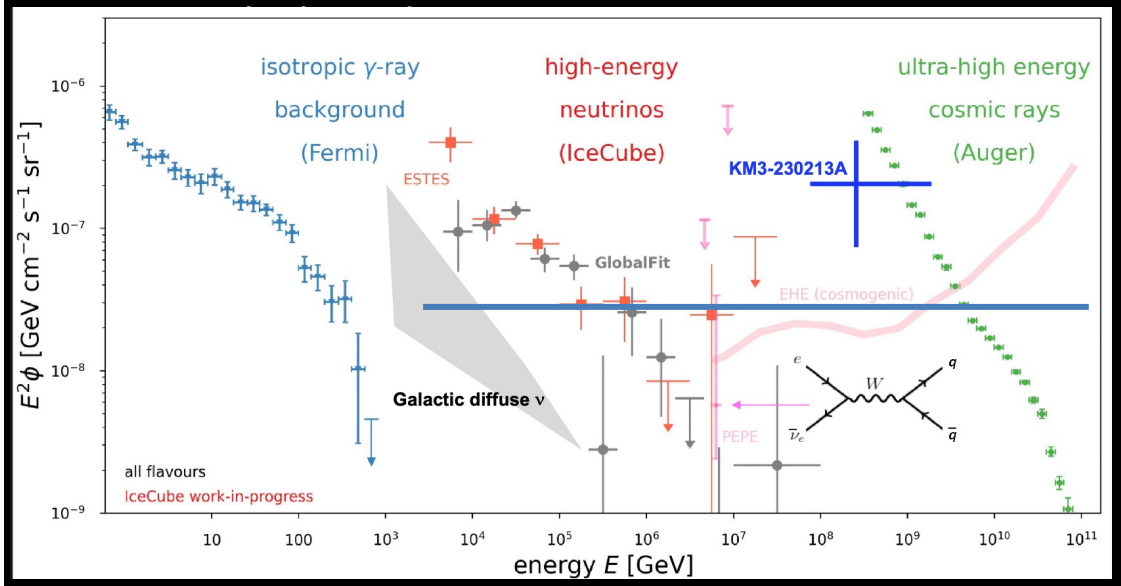
Modern models disagree with data



Li et al (2023), but see Fiorillo et al (2023)

What are the sources of (ultra-high energy) cosmic rays?

Measurements are above model fluxes and Waxmann-Bahcall bound



IceCube (2024)

➔ Open questions + new question: what is the origin of diffuse HE neutrinos?

Towards future

What are the sources of (ultra-high energy) cosmic rays and diffuse HE neutrinos?

- ✓ Detect more events
- ✓ Transients: detail on one object, triggers & followups crucial

Sky coverage and monitoring

Timing for coincident

Pointing for follow-up

Prompt and automated alerts

- Trigger: often neutrino, gravitational waves (large FOV, penetrating, early signal), but can be photons (eg large FOV instruments, or specific source clases to study, etc)
- Followup: sensitivive, smaller FOV observations for detailed scrutiny

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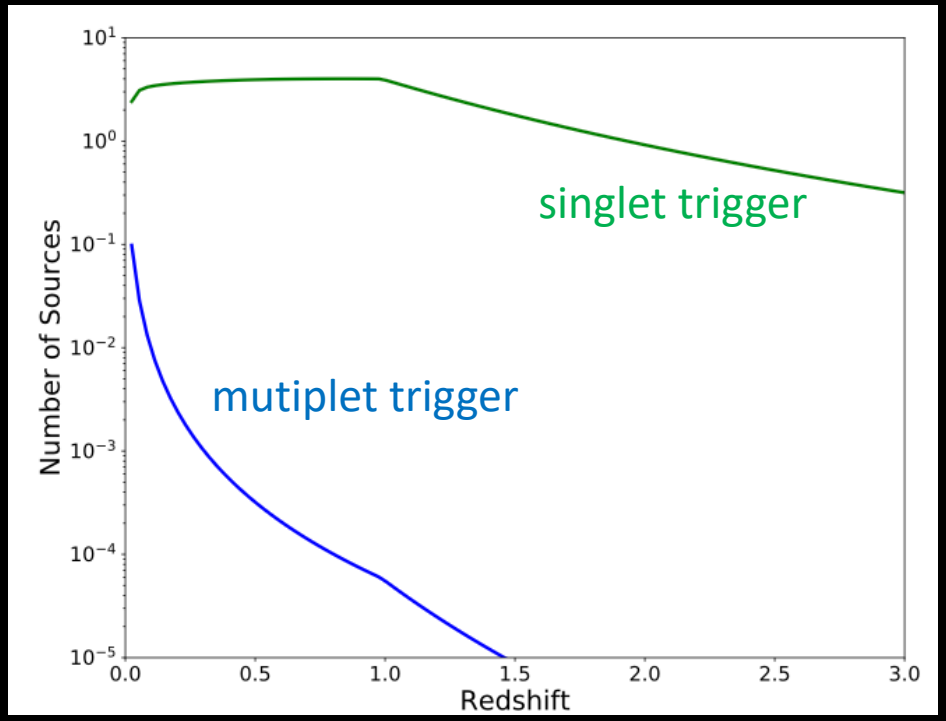

Yoshida et al (2022)

Potential HE sources: many models with high rates (supernovae, LL GRB, jet-driven supernova, TDE, ...)

How to probe?

Trigger: neutrino
But neutrino siglet followups have large number of chance coincidence
→ Use multiplet neutrino triggers
→ Reduce chance coincidence and find true source(s)

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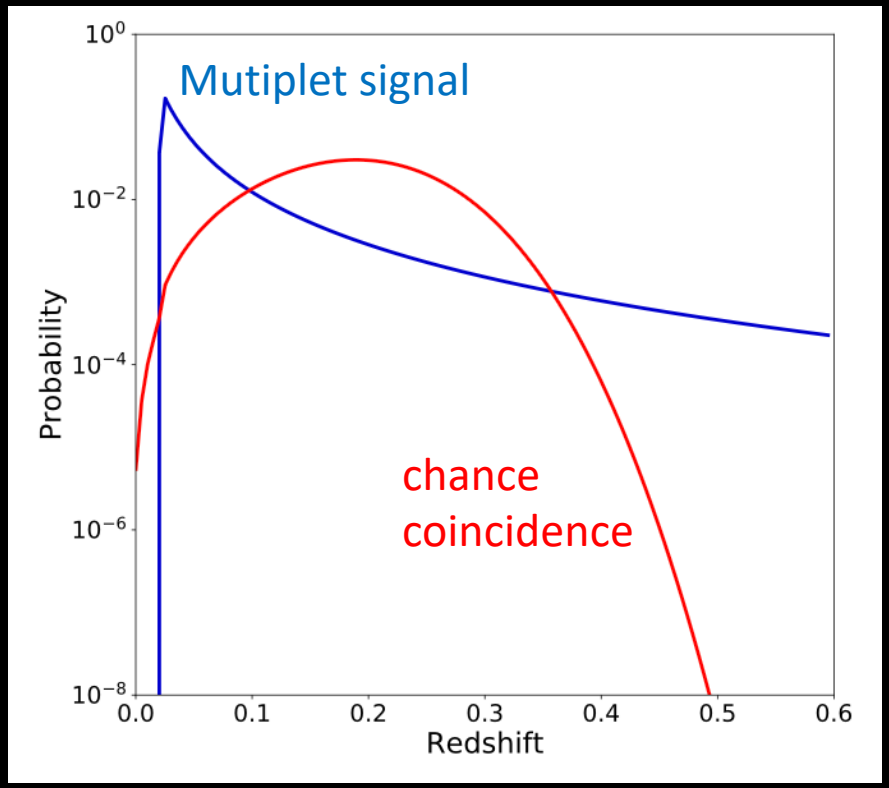


Yoshida et al (2022)

Search HE sources: many models with high rates (supernovae, LL GRB, jet-driven supernova, TDE, ...)

← PDF of source redshift

Trigger: neutrino multiplets
Followup: electromagnetic

- opt/IR [ID, redshift]
- X-ray [MAXI,etc]

Observatories with strong Japanese involvement

ν

SuperK gadolinium
Hyper-Kamiokande
IceCube

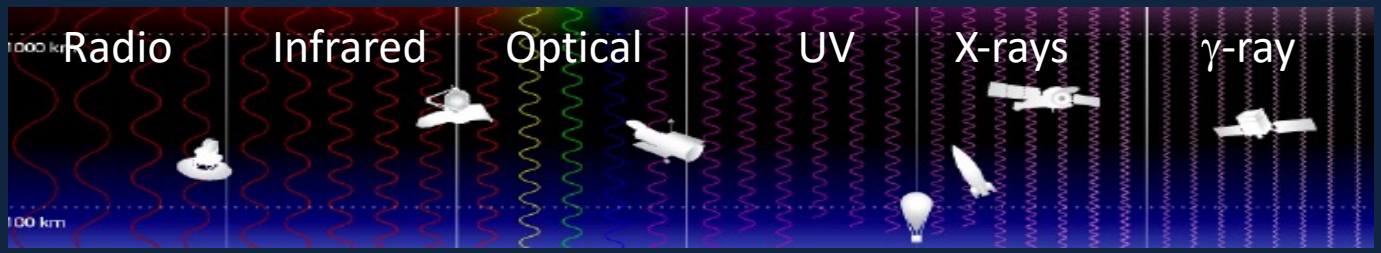
CR

Telescope array
TIBET-ASG
ALPACA

GW

KAGRA
LIGO

γ



ALMA

Subaru
TAO
Seimei
Kiso
Kanata

MAXI
KOYOH
XRISM/NICER

Fermi
CTA

**most definitely an incomplete list

Shunsaku Horiuchi

Multi-messenger: future

- ✓ Multiple messengers: neutrinos, cosmic rays, photons, gravitational waves
- ✓ Stragetic searches: go beyond simple ‘looking’ with messenger detectors. Identify suitable triggers, motivate followup searches, and interpretations (even null observations - theory guidance).
- ✓ Multiple detectors: not only about having the “most sensitive” but having the “most coverage” in both space & time

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Bunch ball (thanks Danny Milisavljevic)

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Football gold

A lot to look forward to! – thank you.