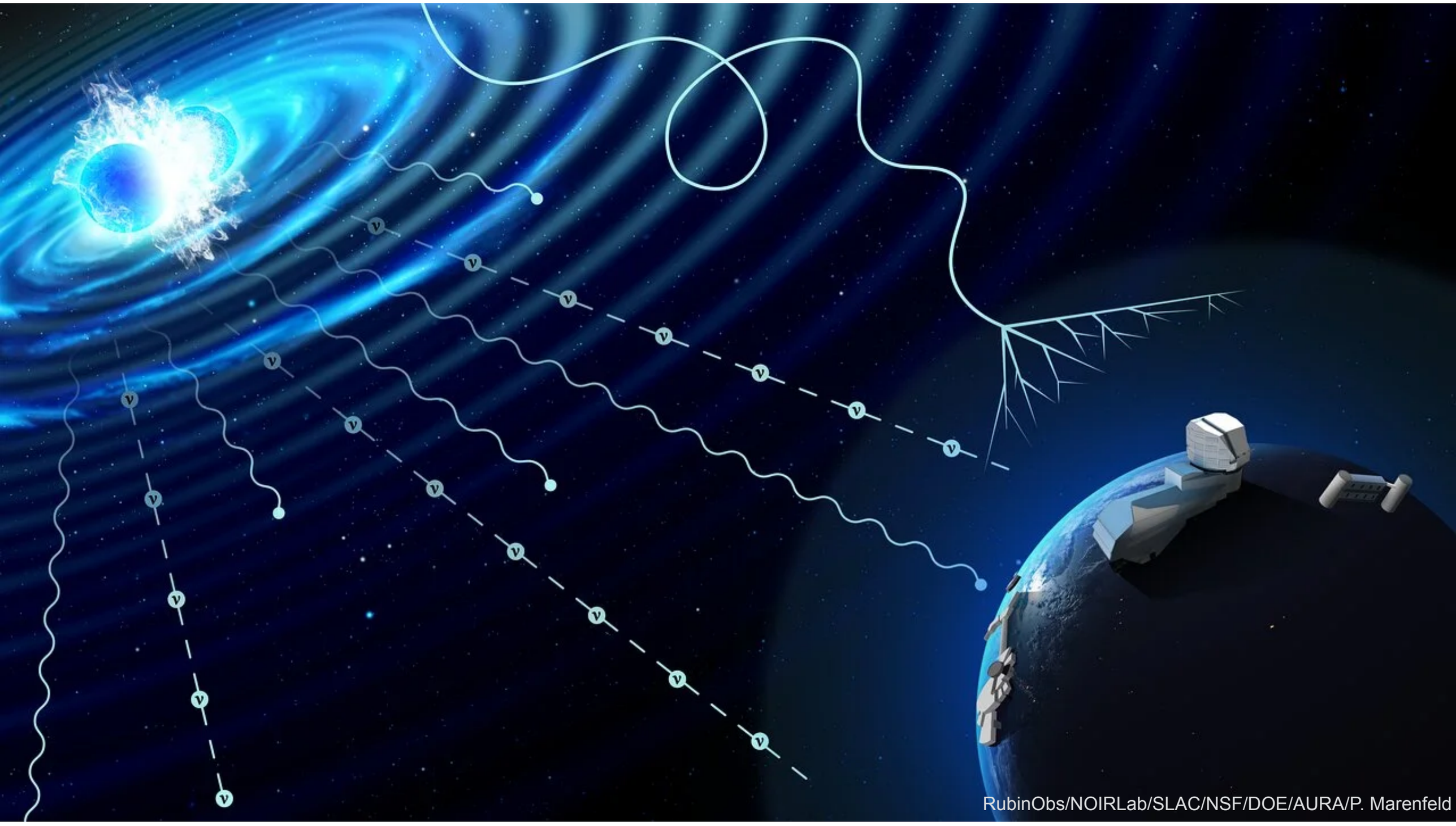
Multi-messenger astroparticle physics



Fabian Schüssler

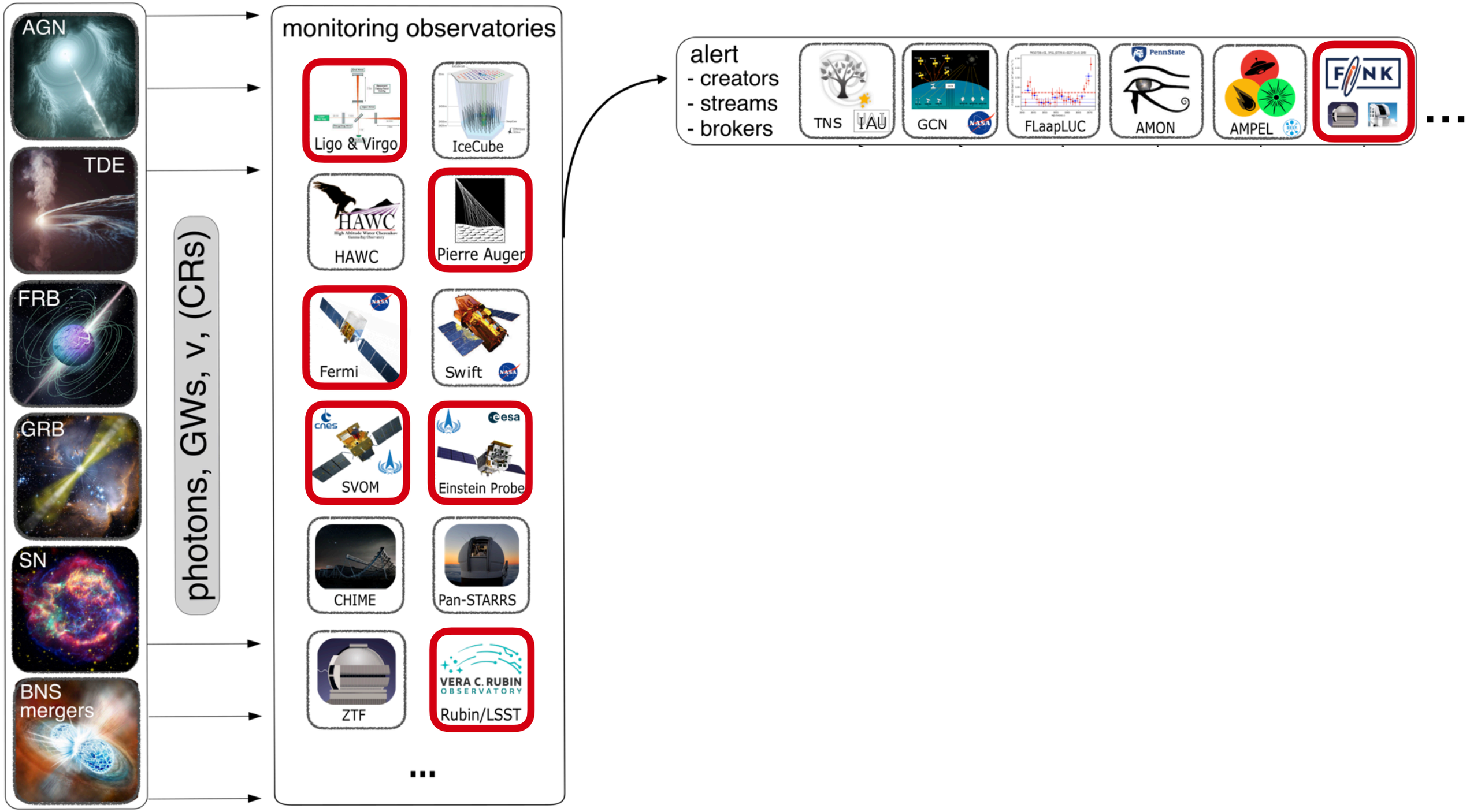
November 26, 2025

Detection of transient phenomena

- *Identification* of new phenomena in real-time
- Typically via a single messenger (and wavelength)
- *Characterisation* of the phenomenon via (multi-messenger and multi-wavelength) follow-up observations
  - Efficient filtering and target selection
  - Comparison with archival information
  - Real-time alerts + automatic reactions

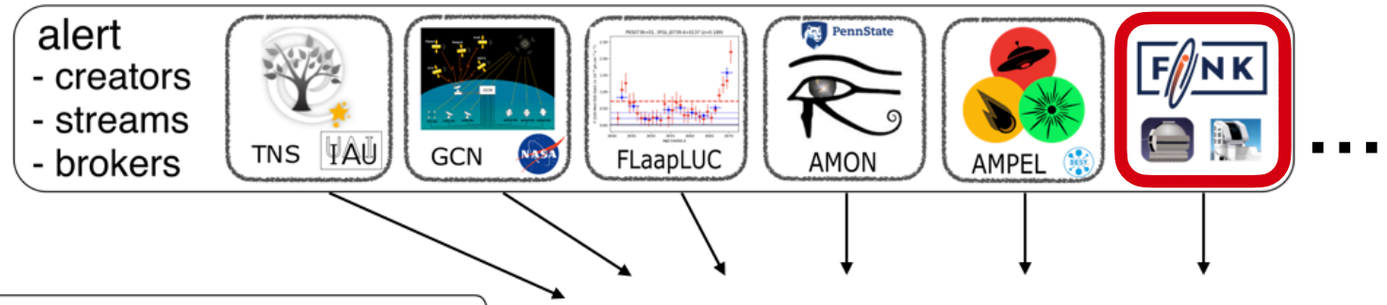
Paris-Saclay

Detection of transient phenomena



Paris-Saclay

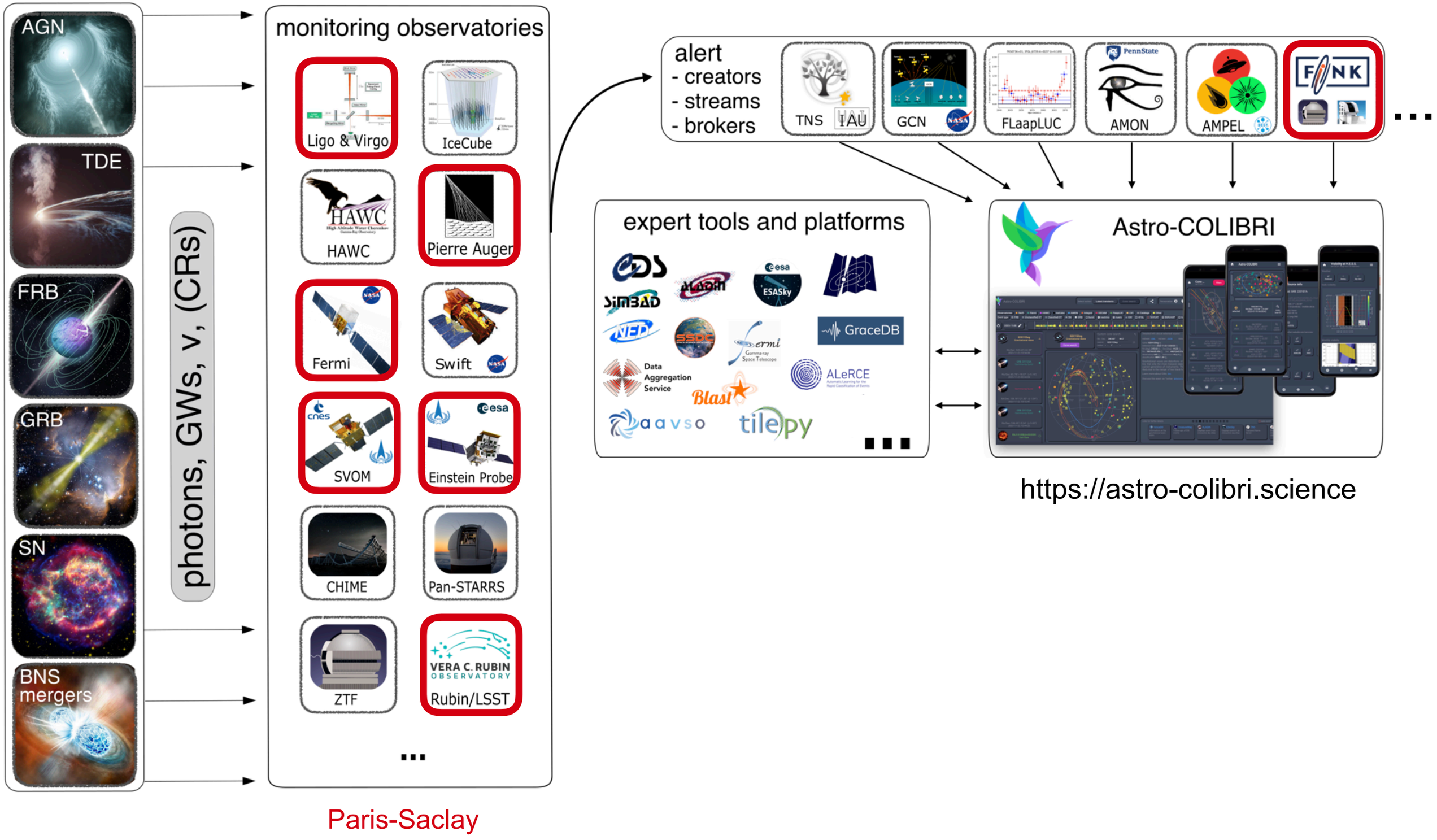
Detection of transient phenomena



- Very different data formats
- Very different distribution protocols (limited access)
- Partial correlation between streams
- Partial connections with existing services

Paris-Saclay

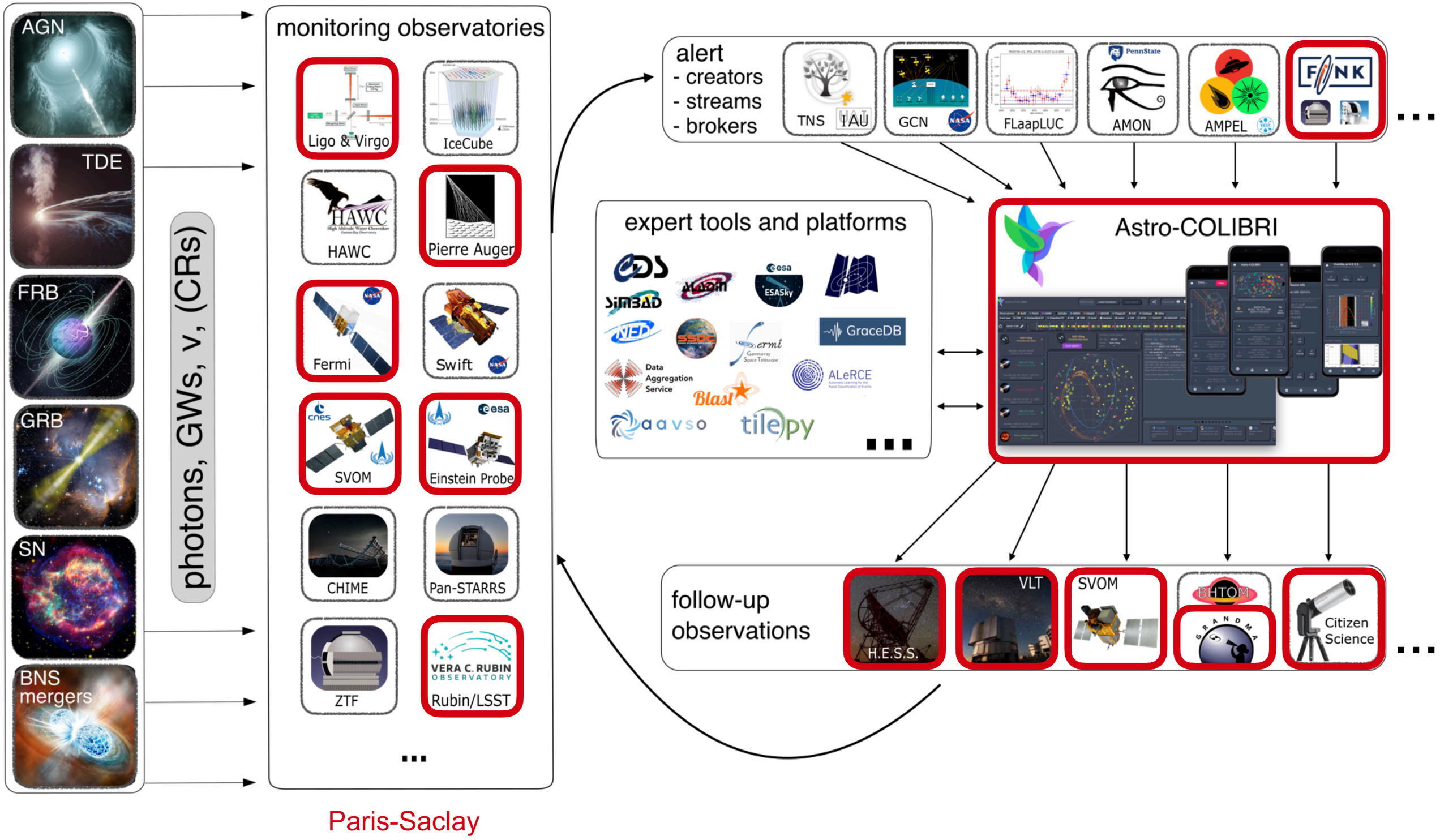
Detection of transient phenomena



https://astro-colibri.science

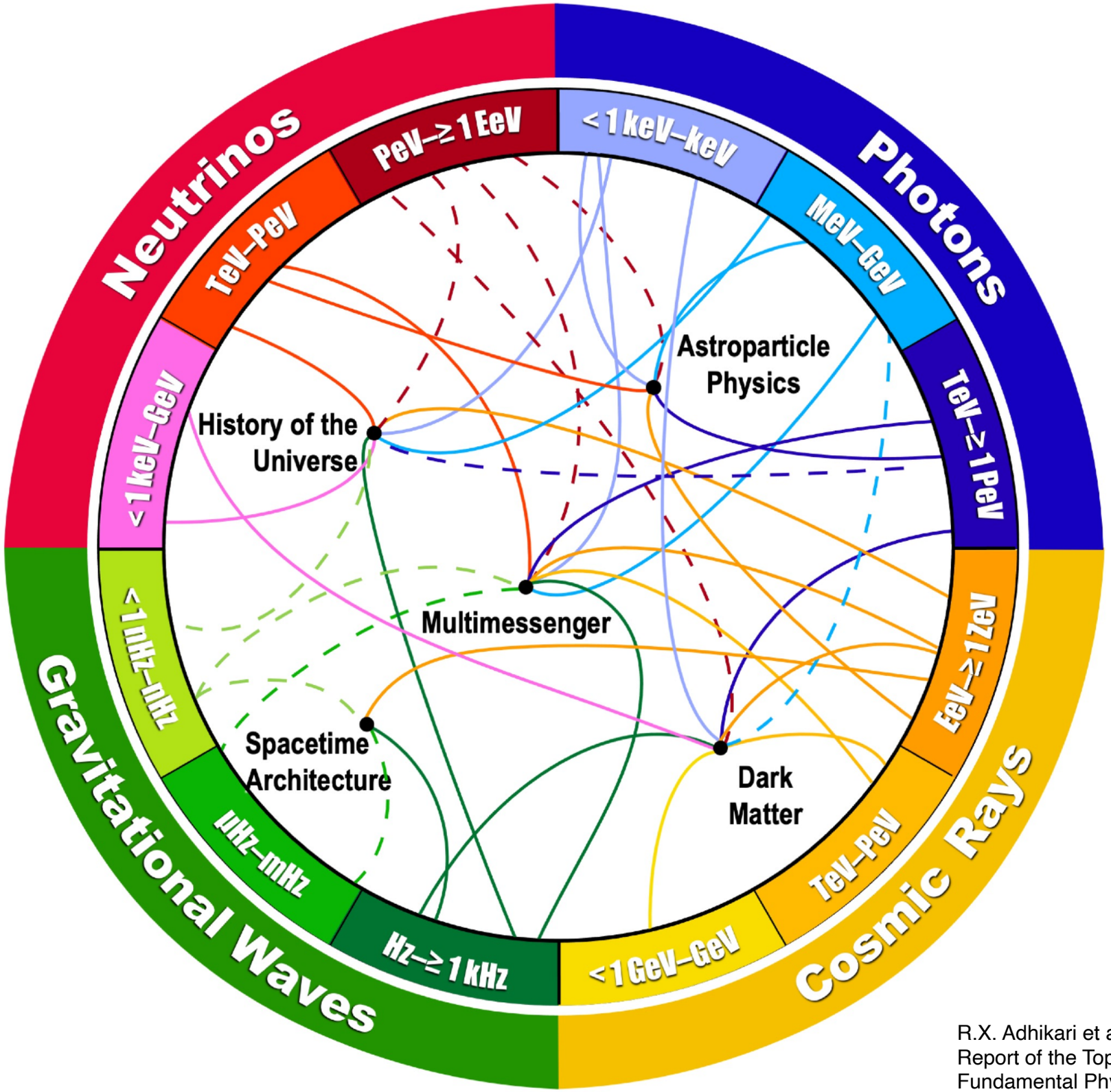
Paris-Saclay

Detection of transient phenomena



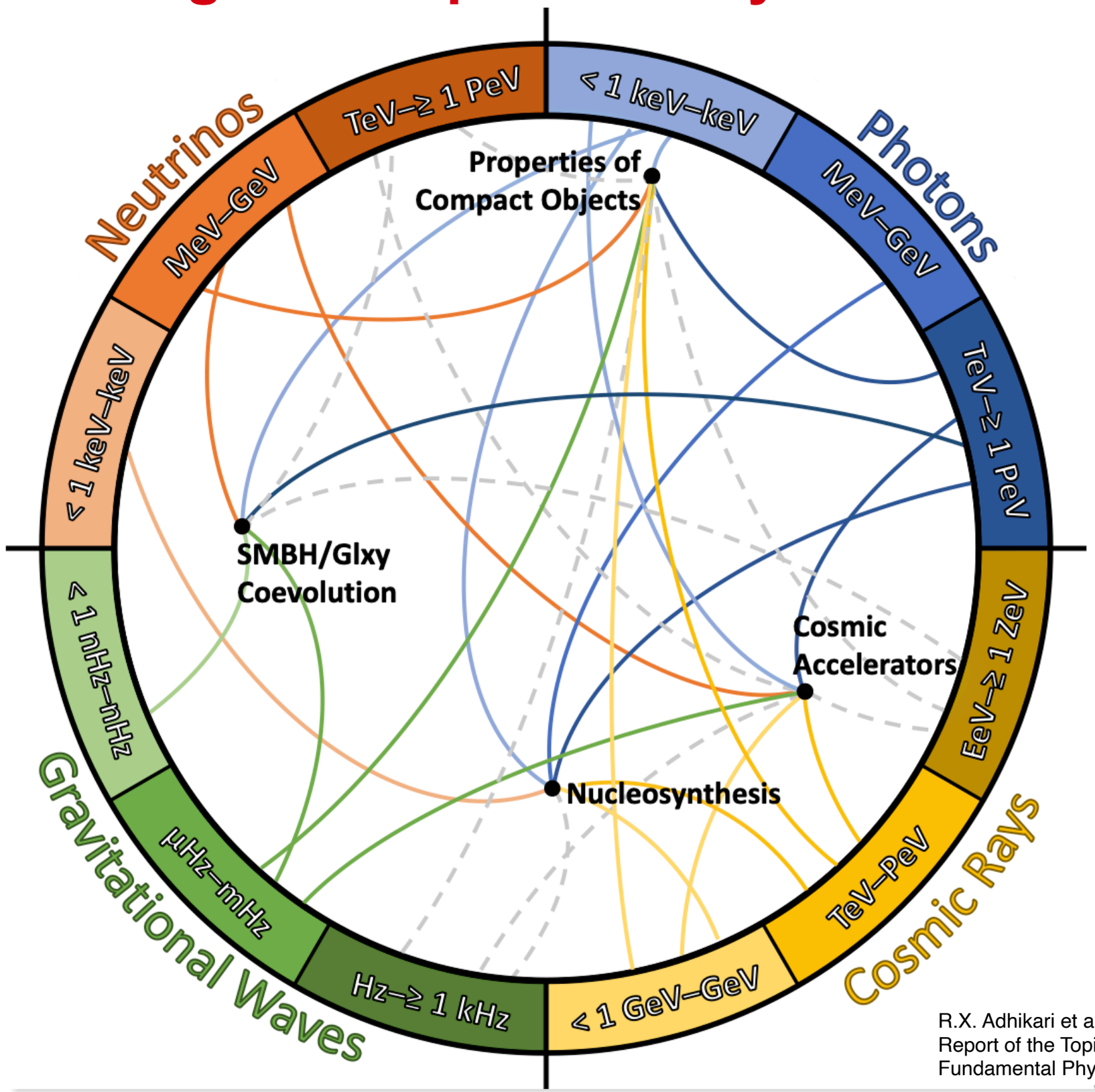
Paris-Saclay

MULTI-Messenger Astroparticle Physics



R.X. Adhikari et al - arXiv:2209.11726
Report of the Topical Group on Cosmic Probes of Fundamental Physics for for Snowmass 2021

MULTI-Messenger Astroparticle Physics



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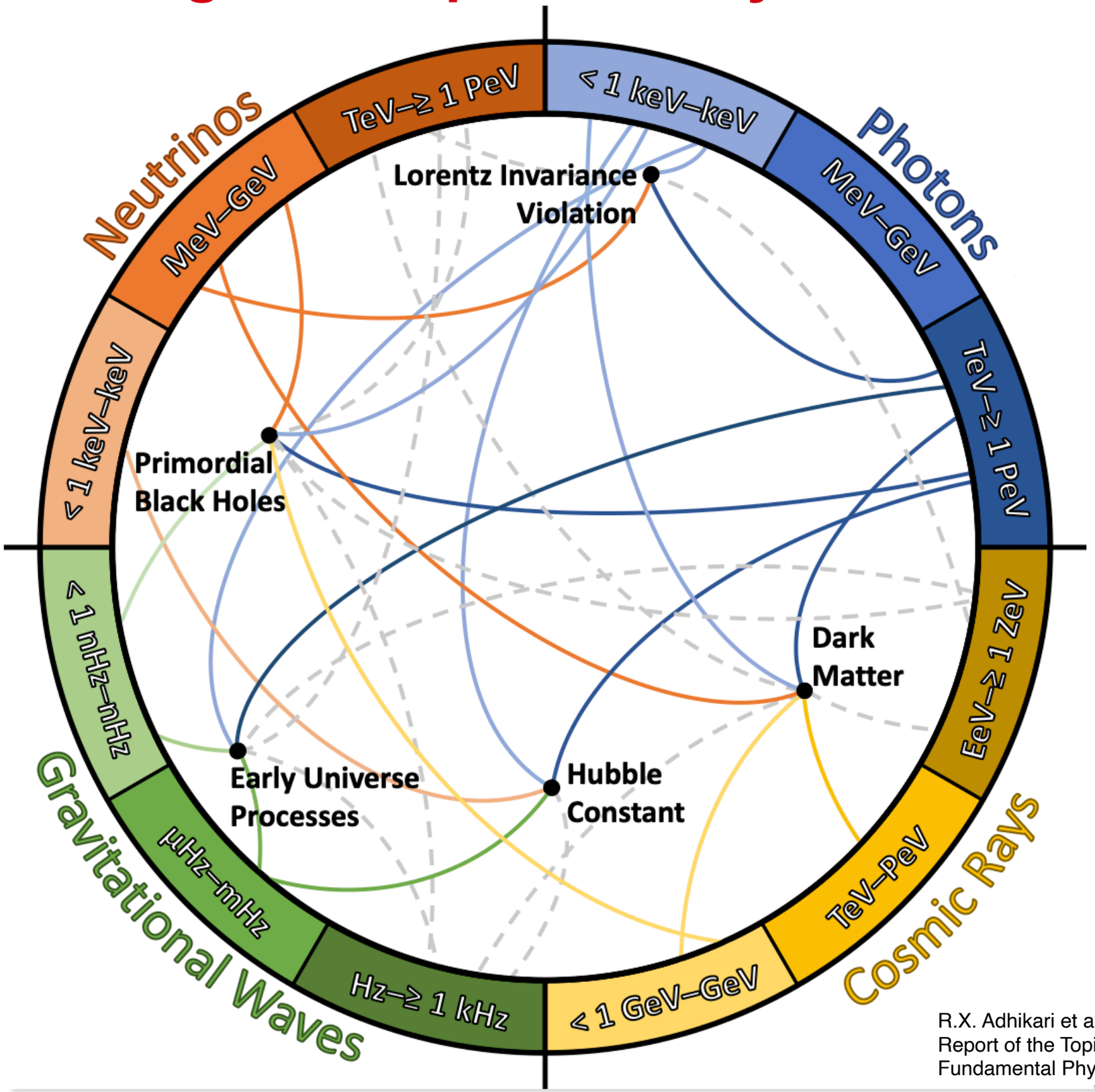

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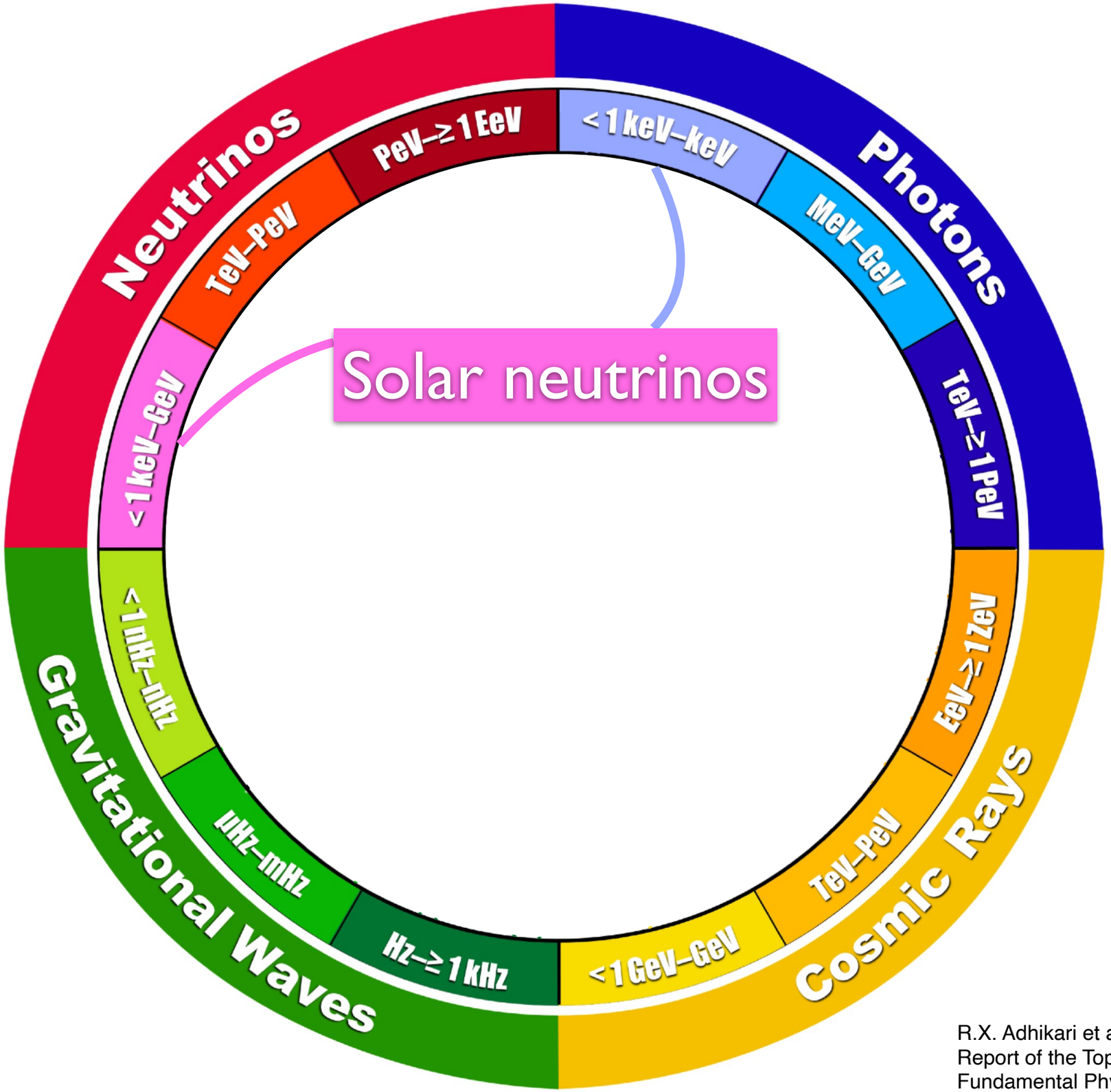

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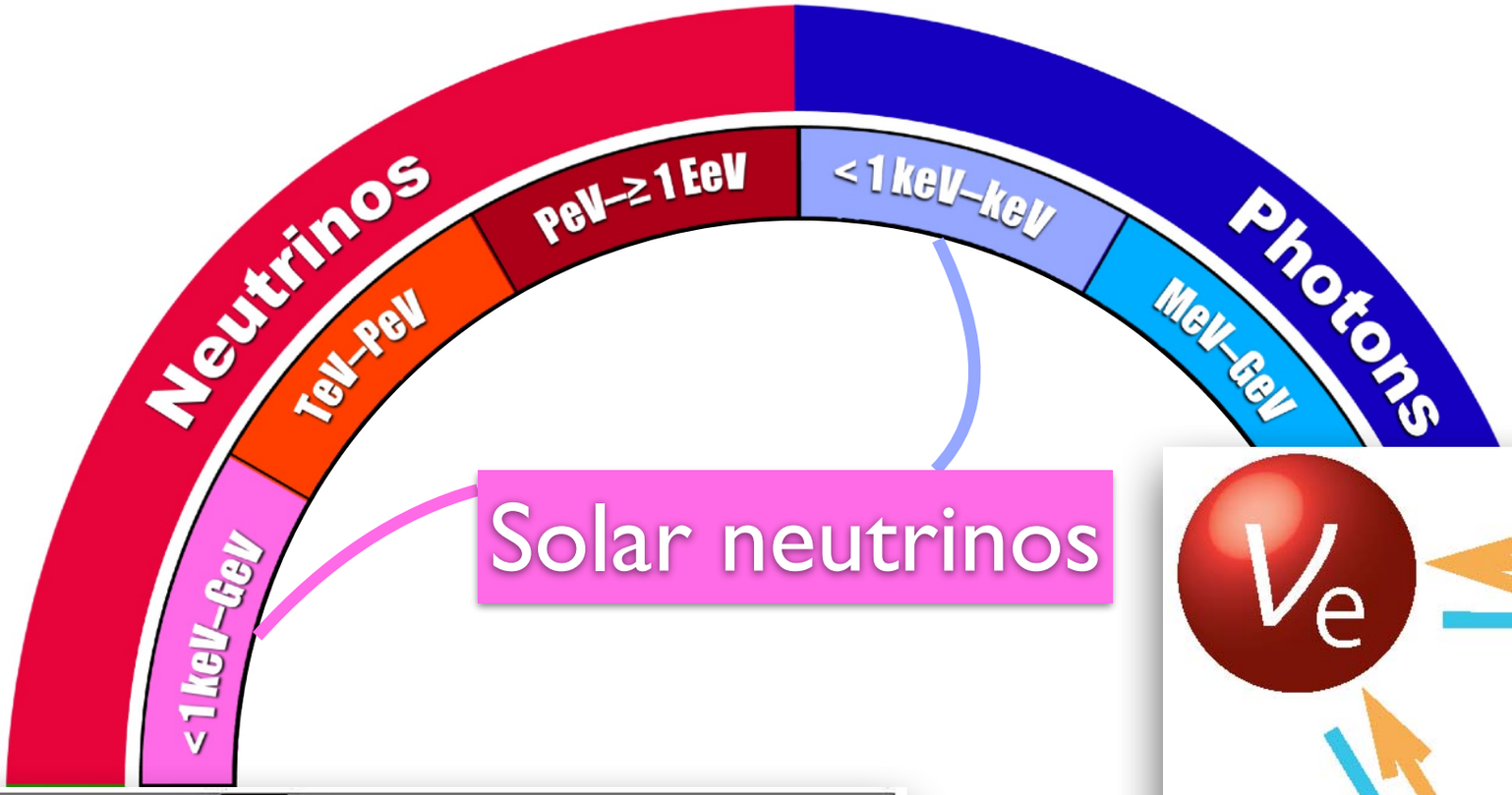
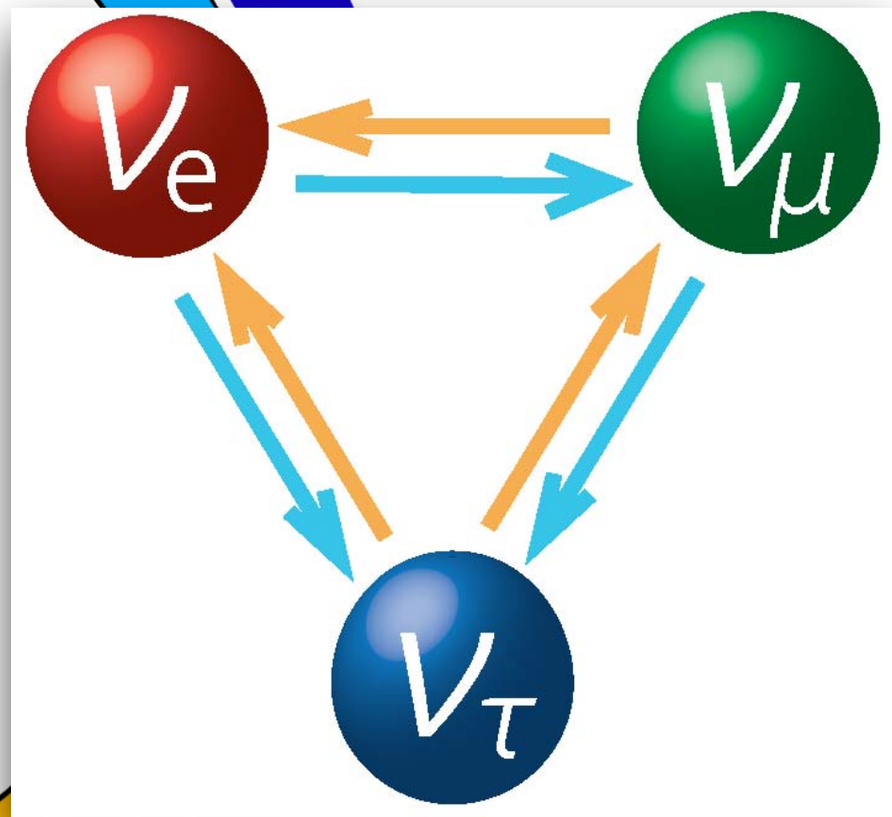
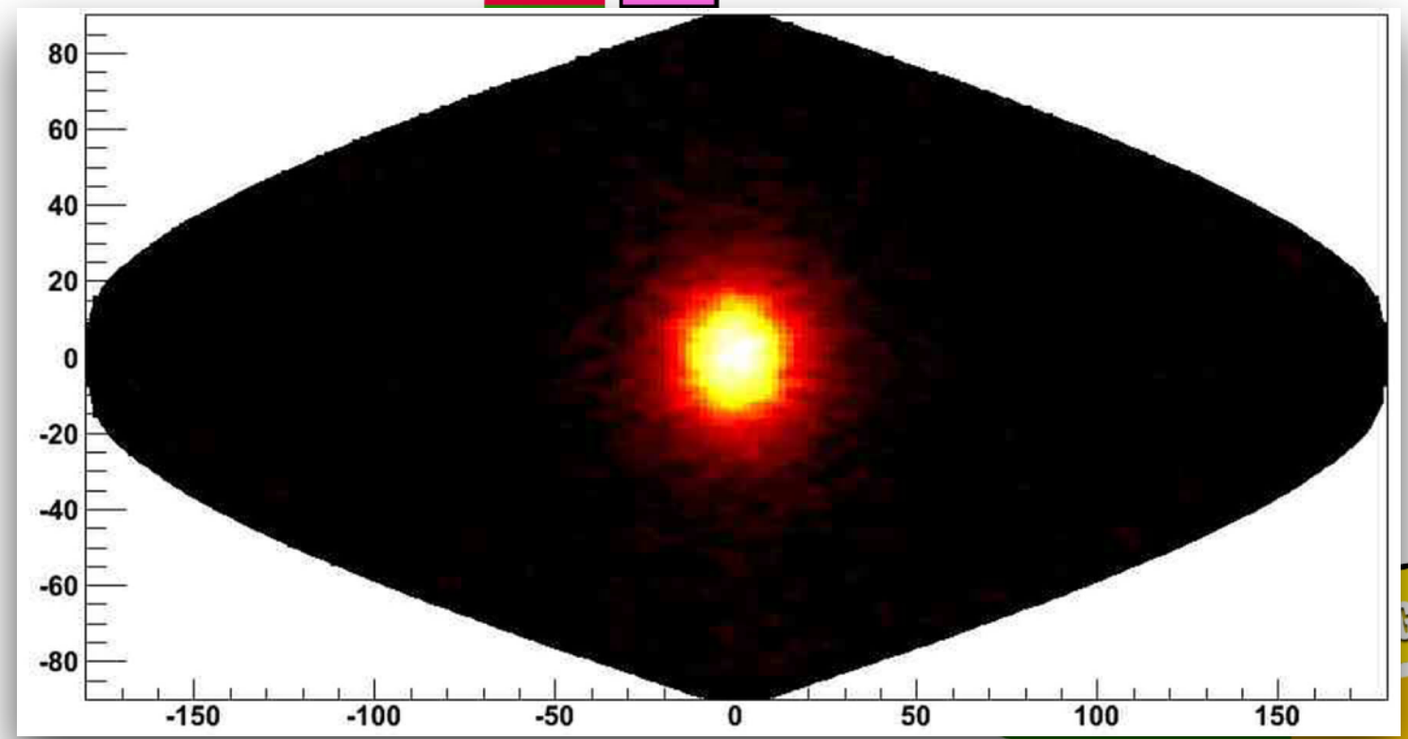




SuperK (1996-2018)



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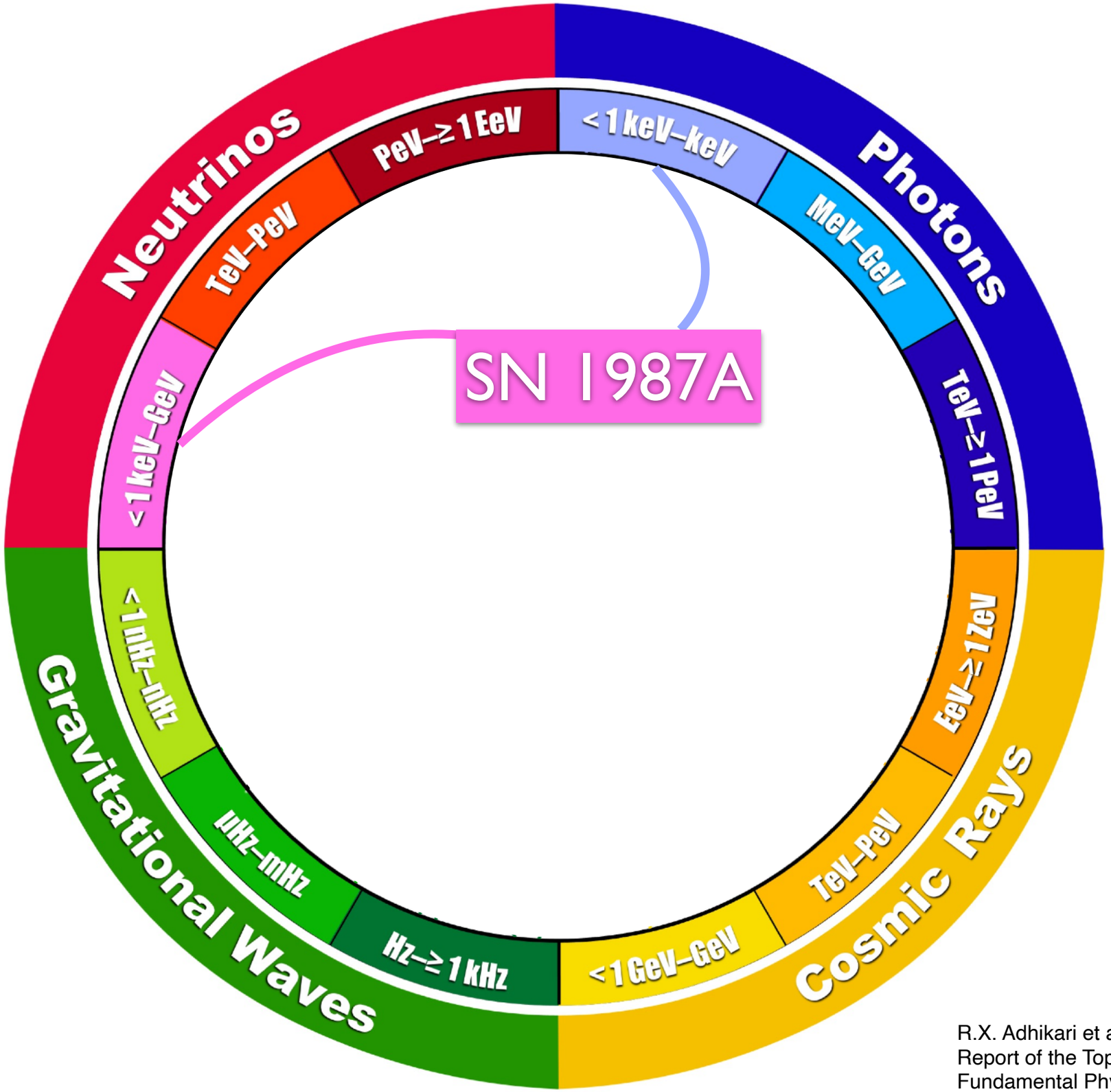

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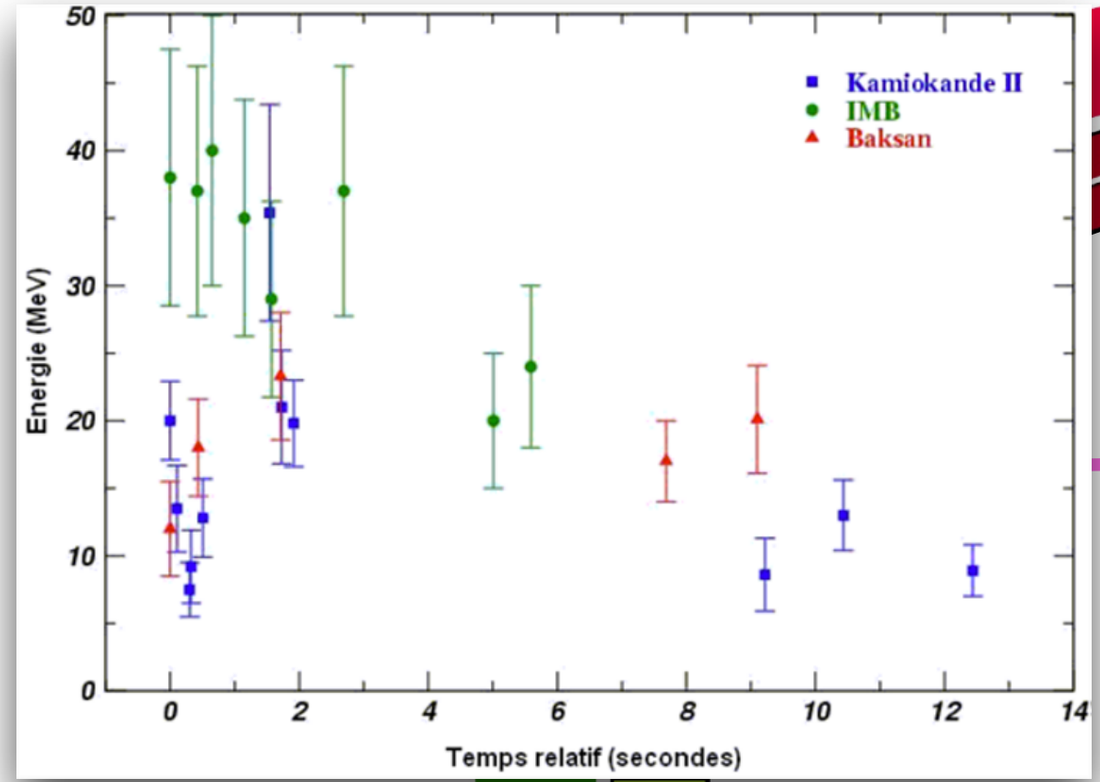

SN 1987A

HST

R.X. Adhikari et al - arXiv:2209.11726
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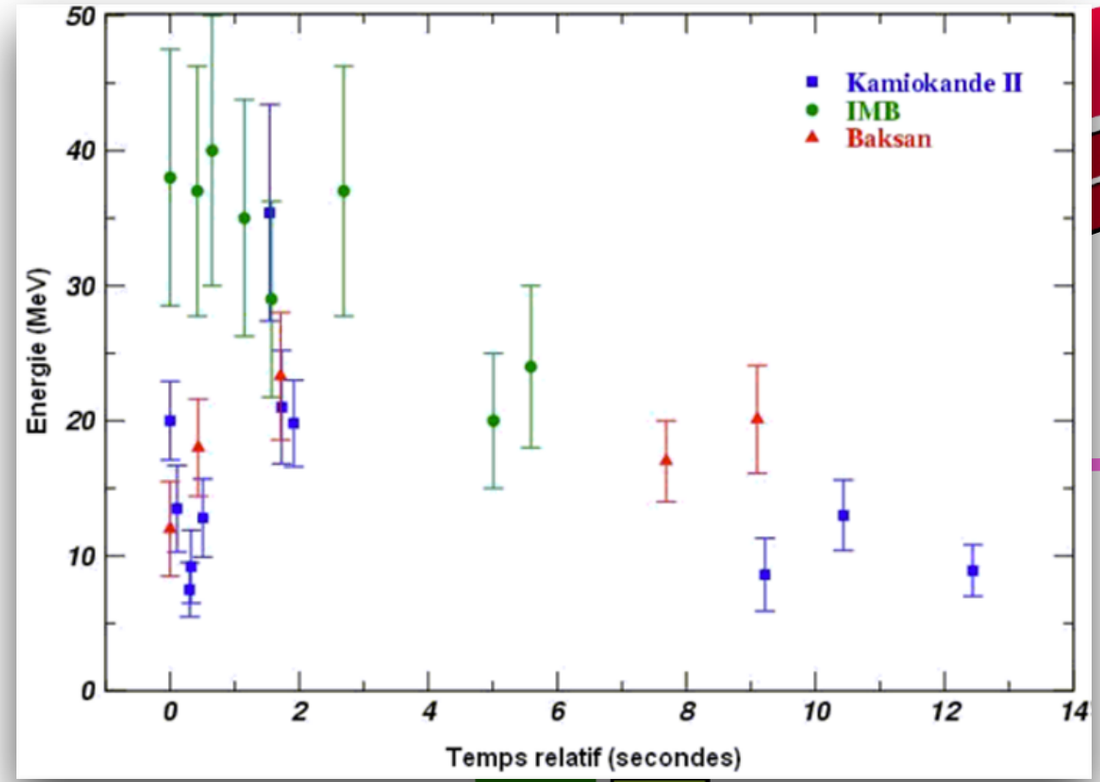
MULTI-Messenger Astroparticle Physics



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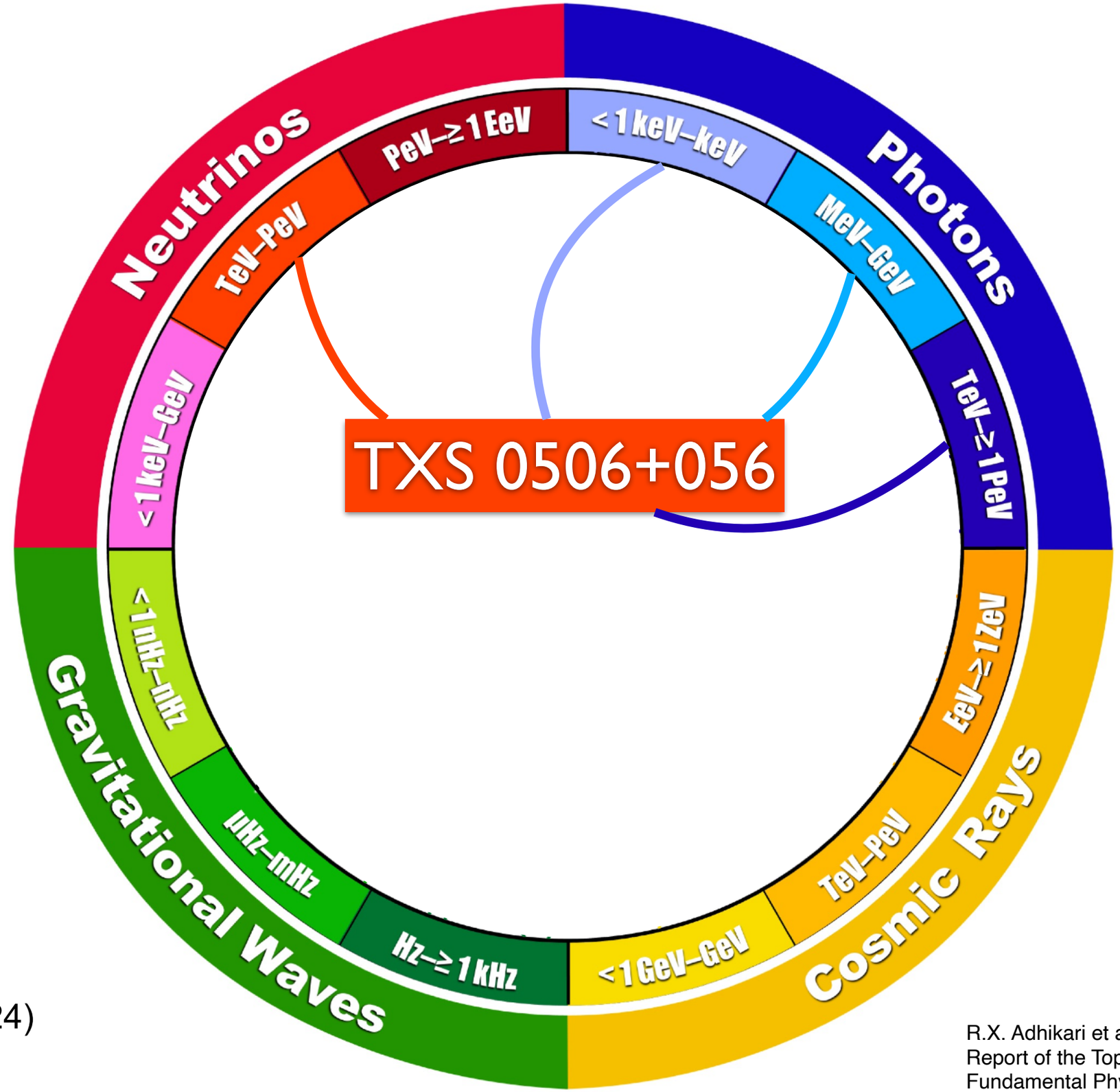
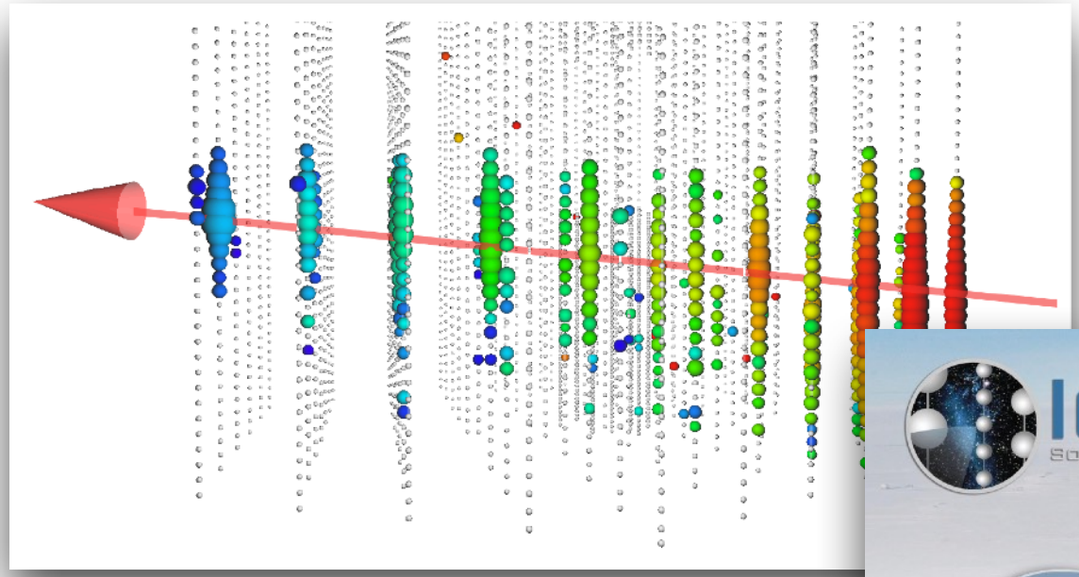
MULTI-Messenger Astroparticle Physics



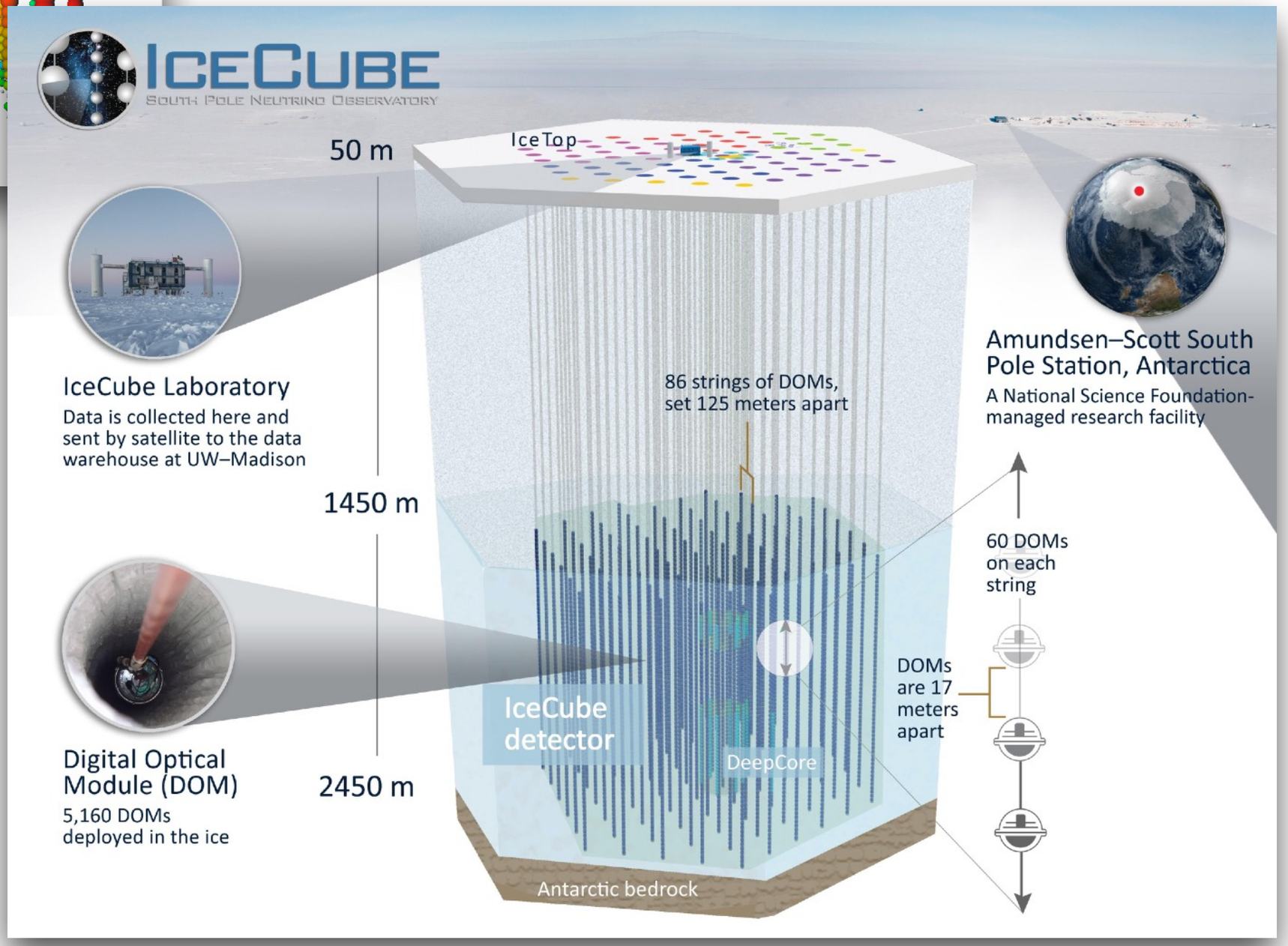
F. Bradascio
(Journée P2I 2024)

R.X. Adhikari et al - arXiv:2209.11726
Report of the Topical Group on Cosmic Probes of Fundamental Physics for for Snowmass 2021

IC-170922A

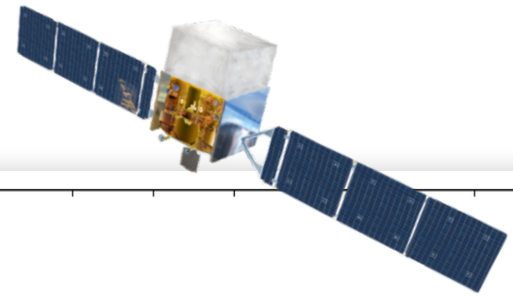


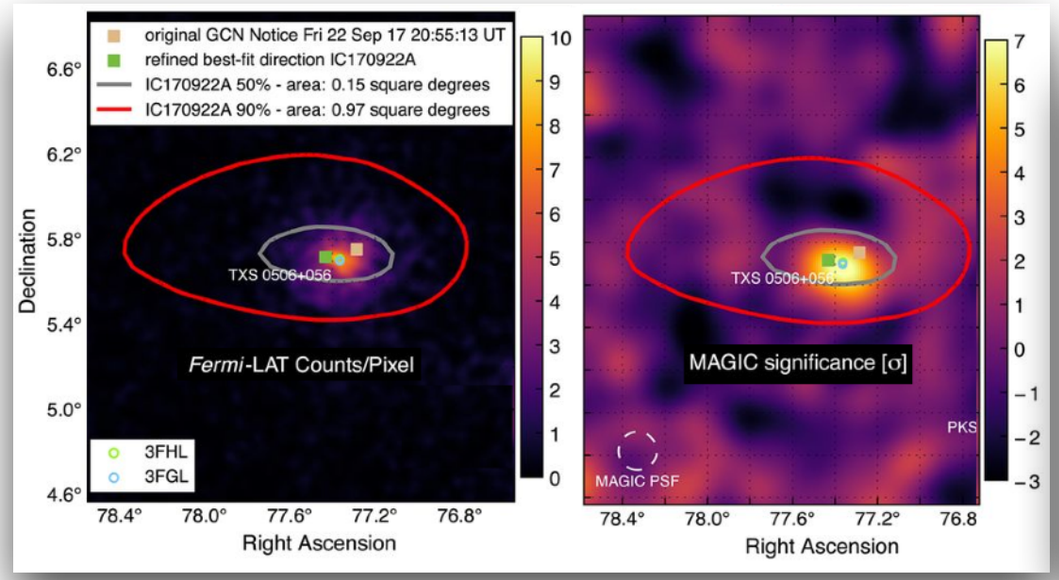
Science 361, 147–151 (2018)

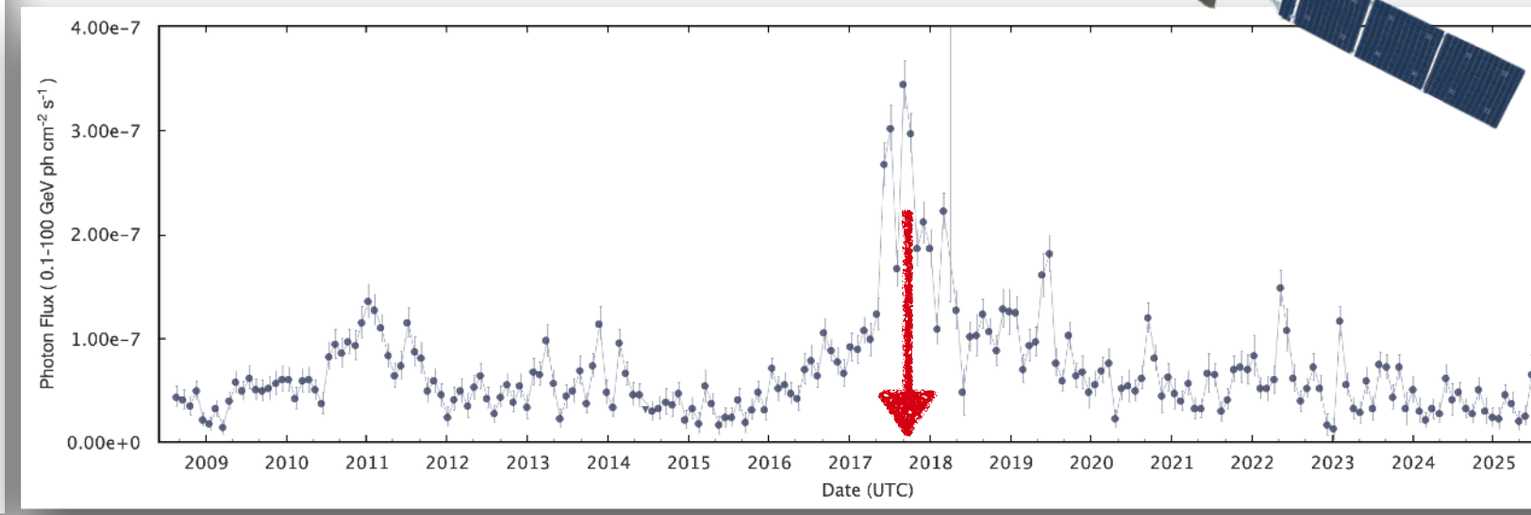


F. Bradascio
(Journée P2I 2024)

IC-170922A + flaring blazar TXS 0506+056



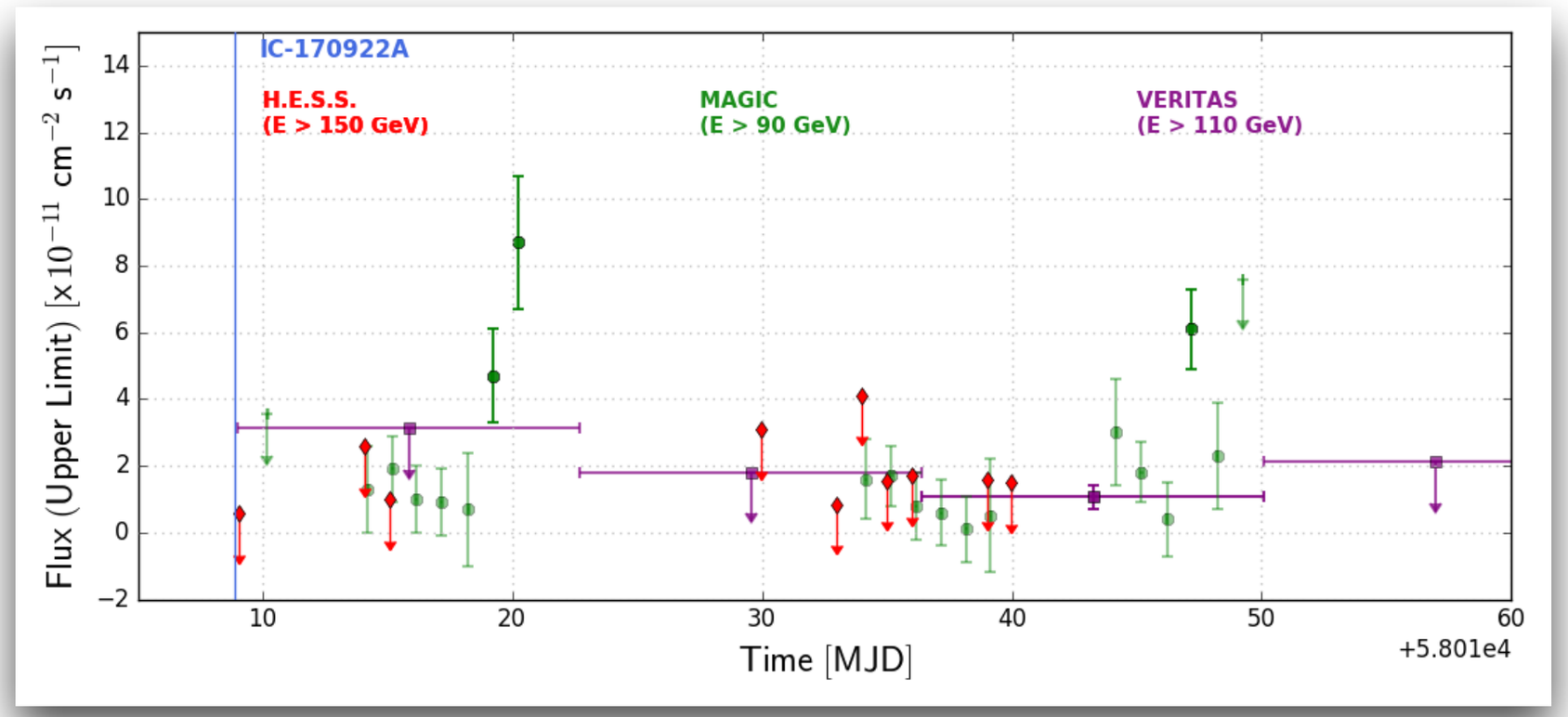




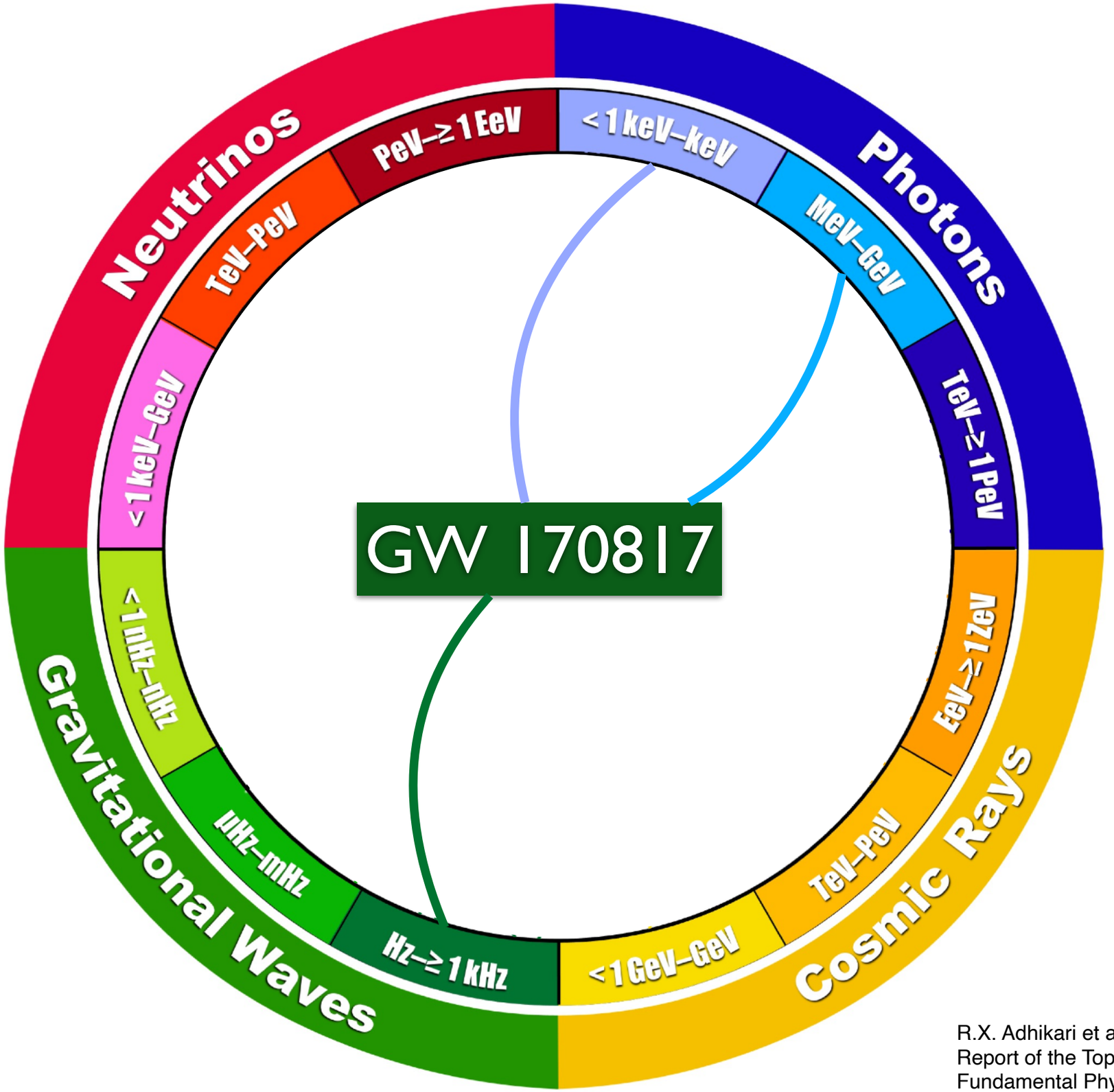
Science 361, eaat1378 (2018)

FS et al. (TevPA 2018)

F. Bradascio
(Journée P2I 2024)

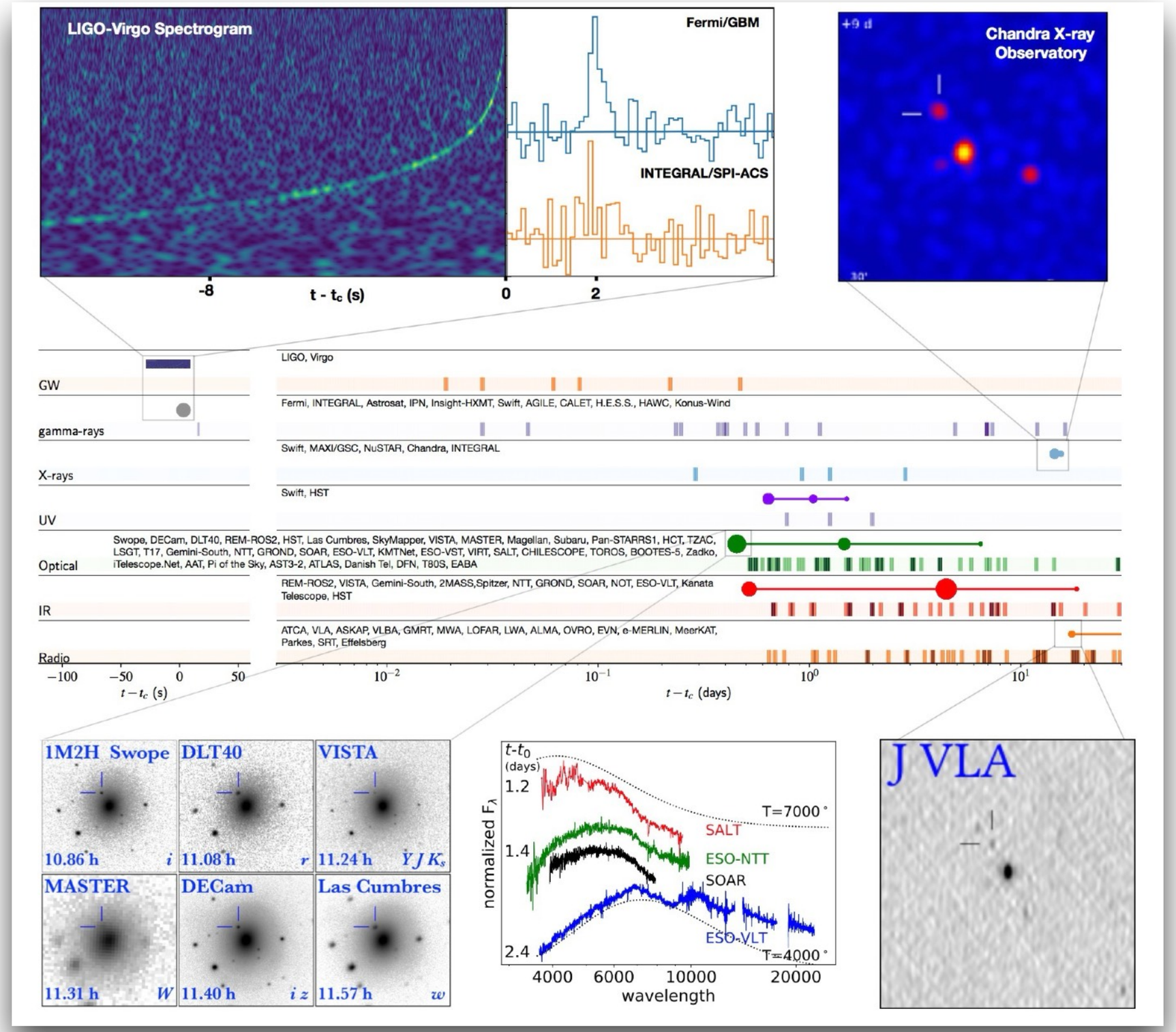


MULTI-Messenger Astroparticle Physics



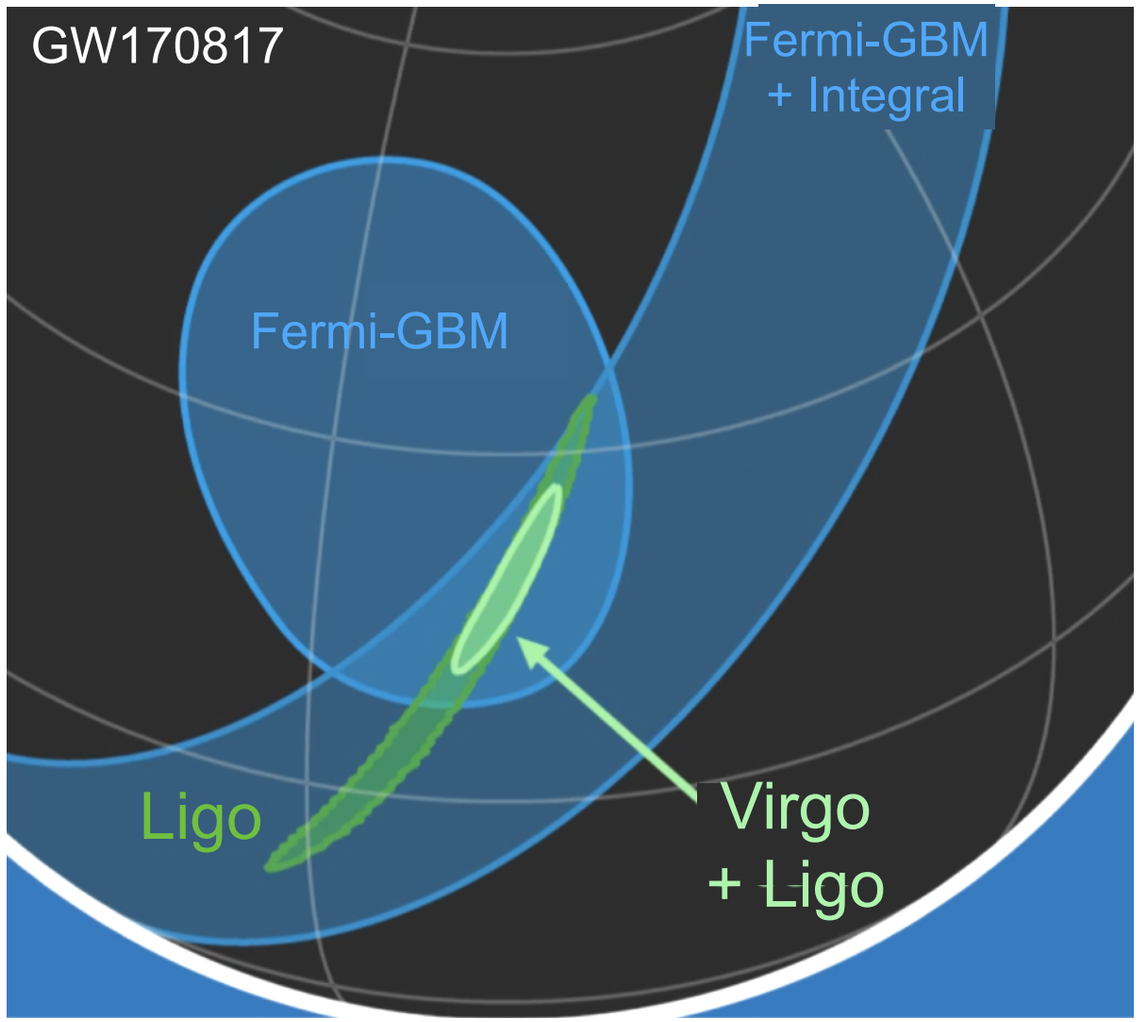
R.X. Adhikari et al - arXiv:2209.11726
Report of the Topical Group on Cosmic Probes of Fundamental Physics for for Snowmass 2021

Gravitational waves + Gamma-Ray Burst + Kilonova

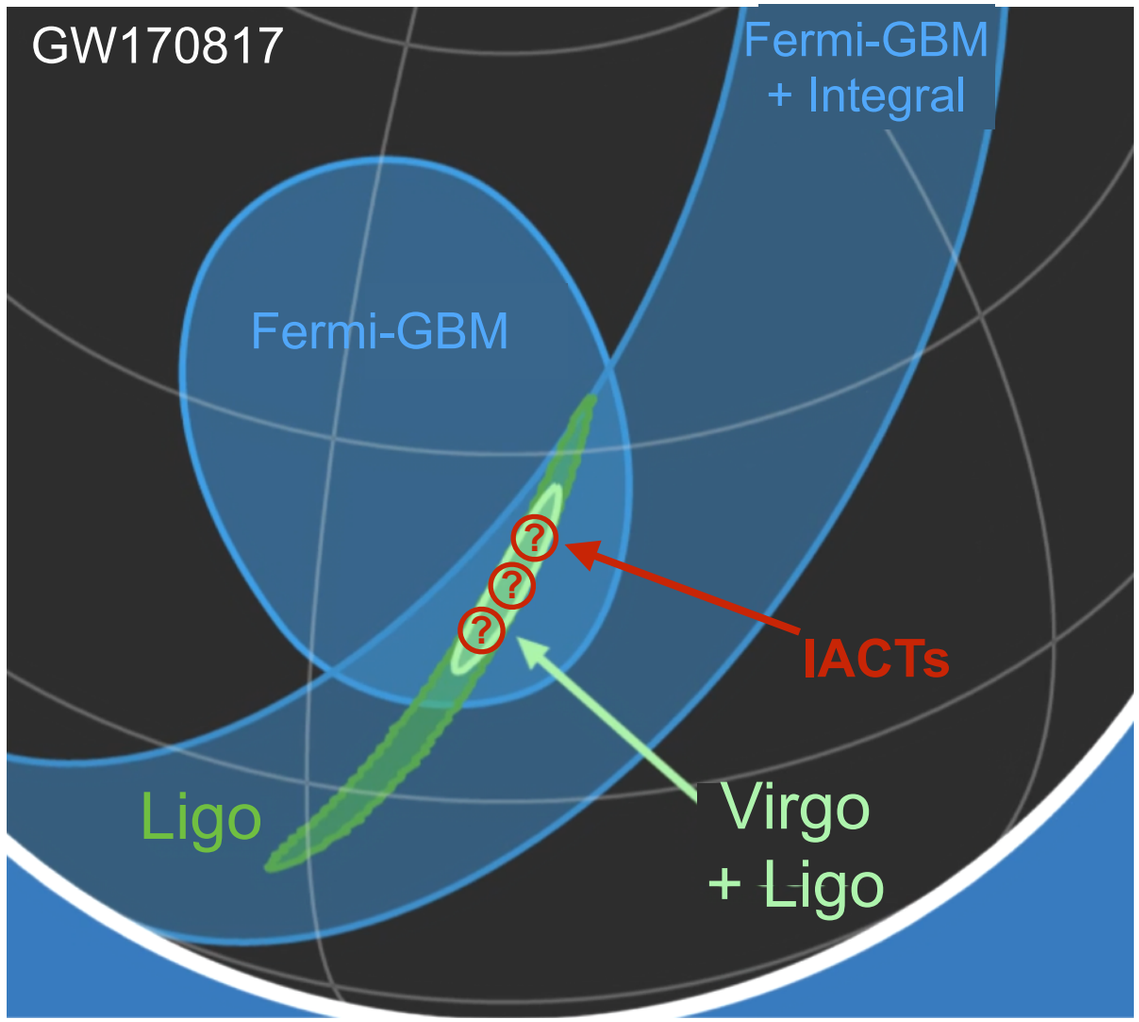


Abbott, B.P. et al 2017 ApJL 848 L12

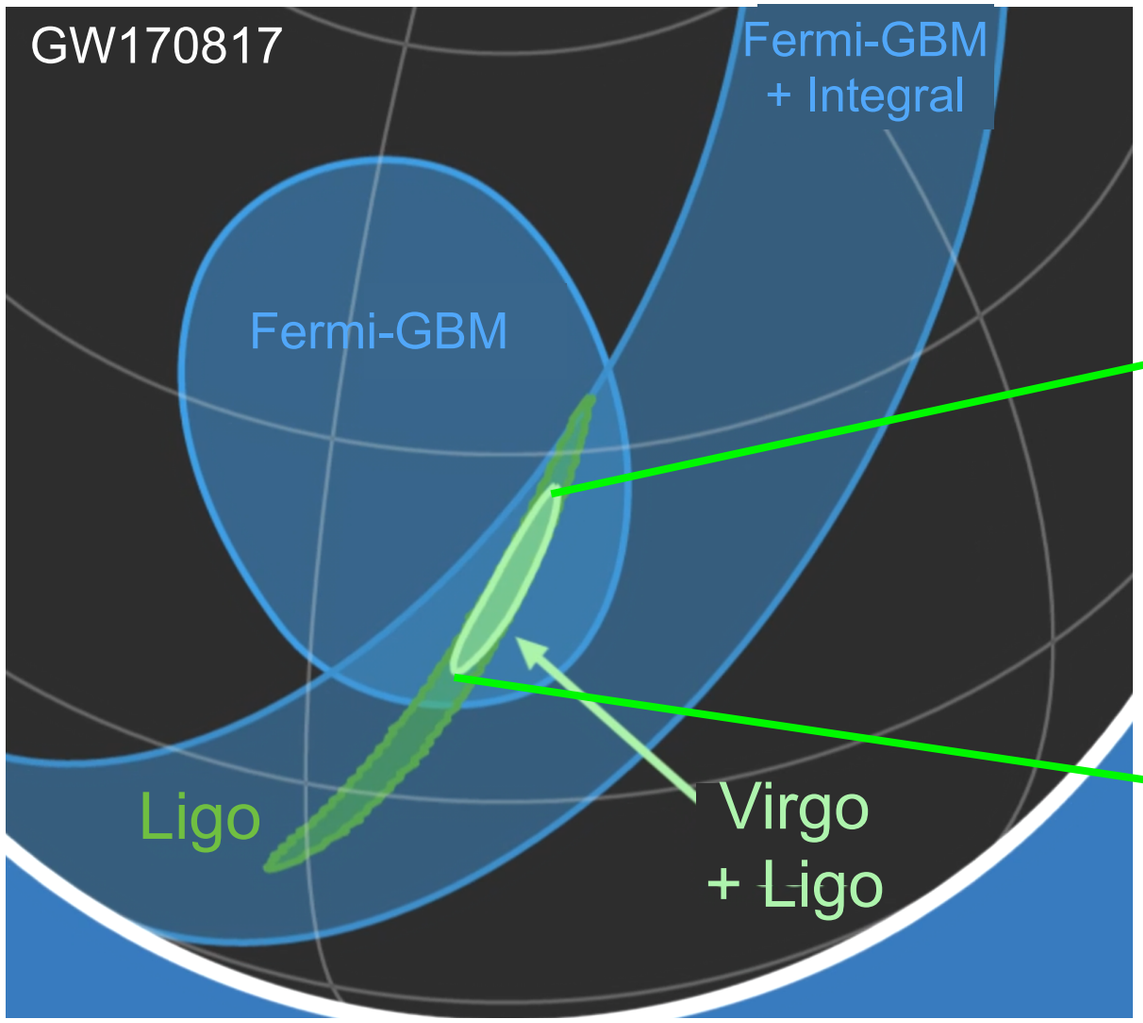
Scheduling and pointing strategy

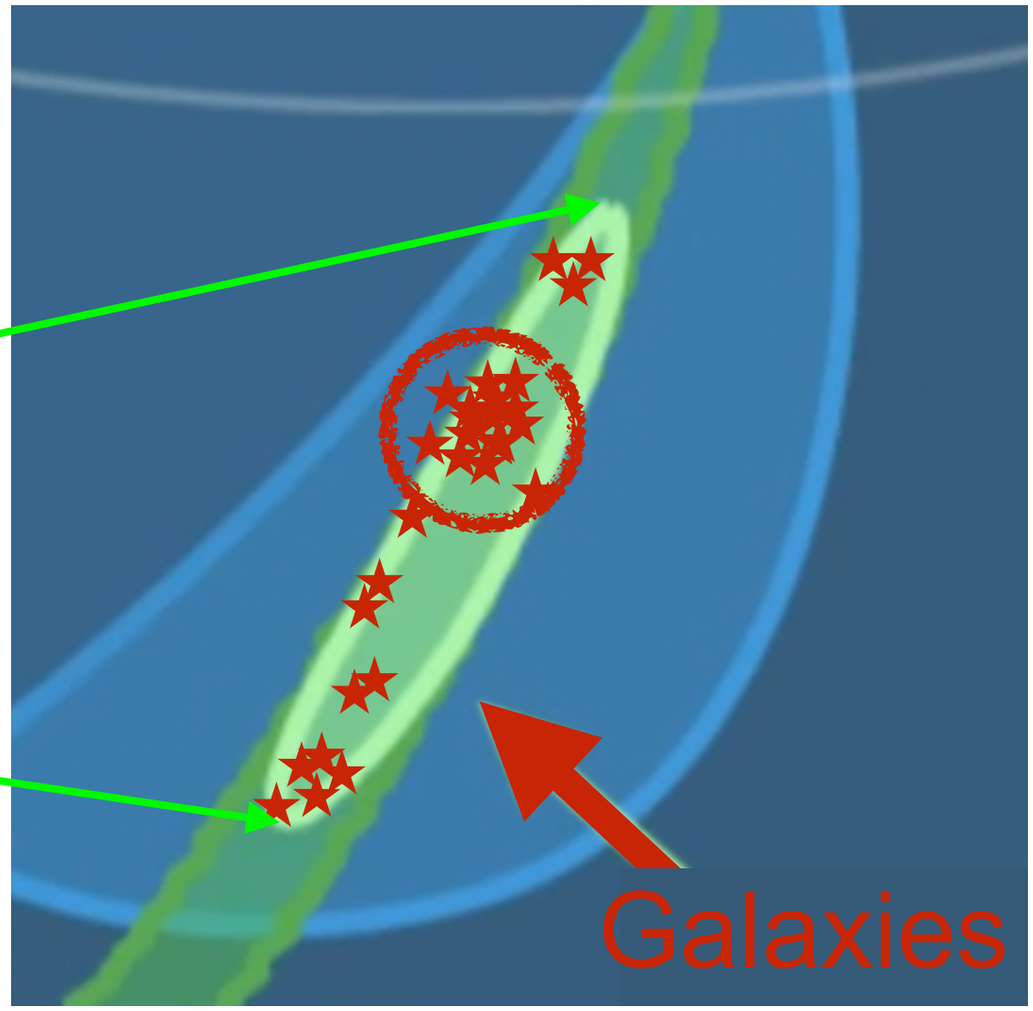


Scheduling and pointing strategy



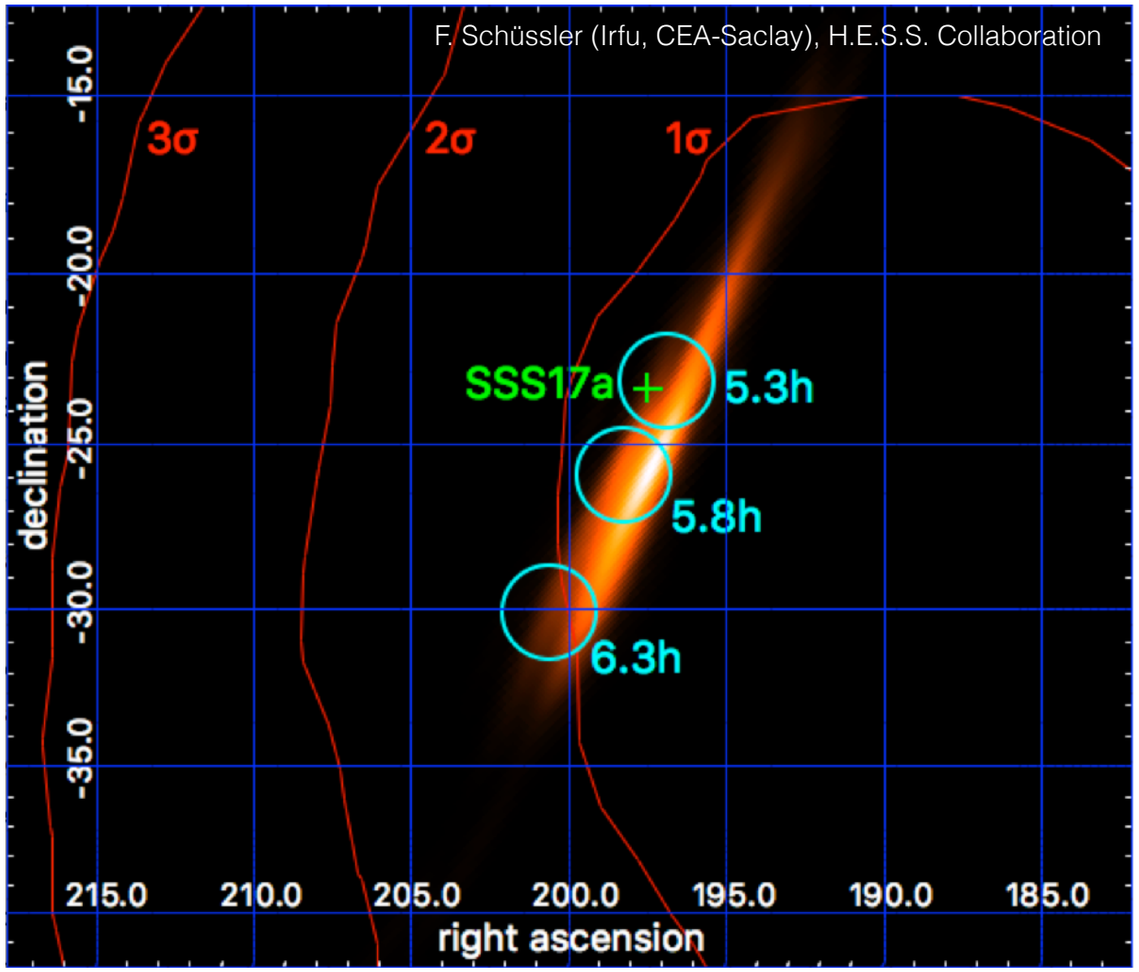
Scheduling and pointing strategy





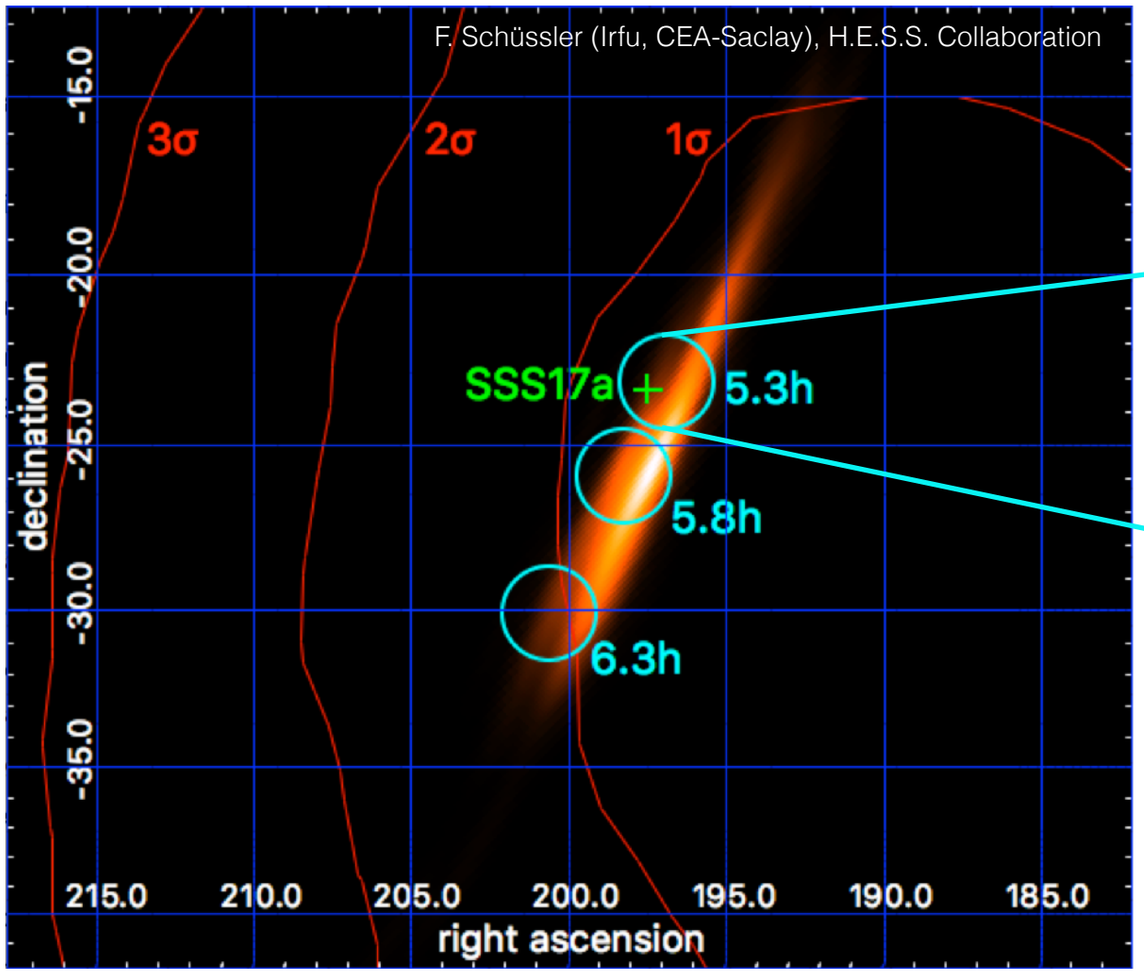
- automatic selection of regions of interest
  - correlation with galaxy catalog(s) in 3 dimensions
  - dedicated algorithms for the different possibilities (e.g. BNS, BBH, bursts, etc.)

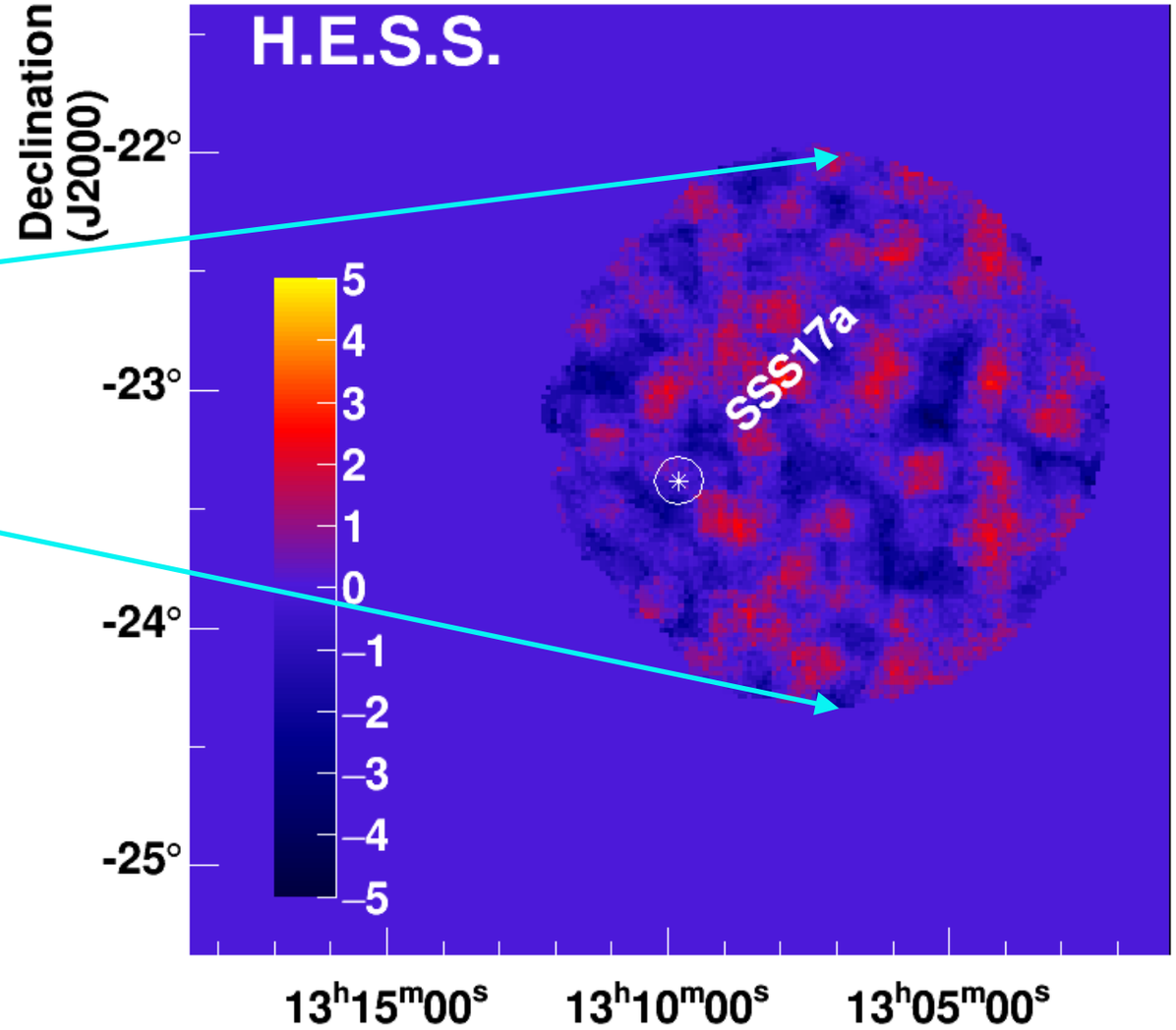
H.E.S.S. rapid follow-up of GW170817



- First observations of a ground-based pointing instrument
  - 5.3 hours after GW170817
  - 5 minutes after the GCN circular announcing the LIGO+Virgo localisation

H.E.S.S. rapid follow-up of GW170817



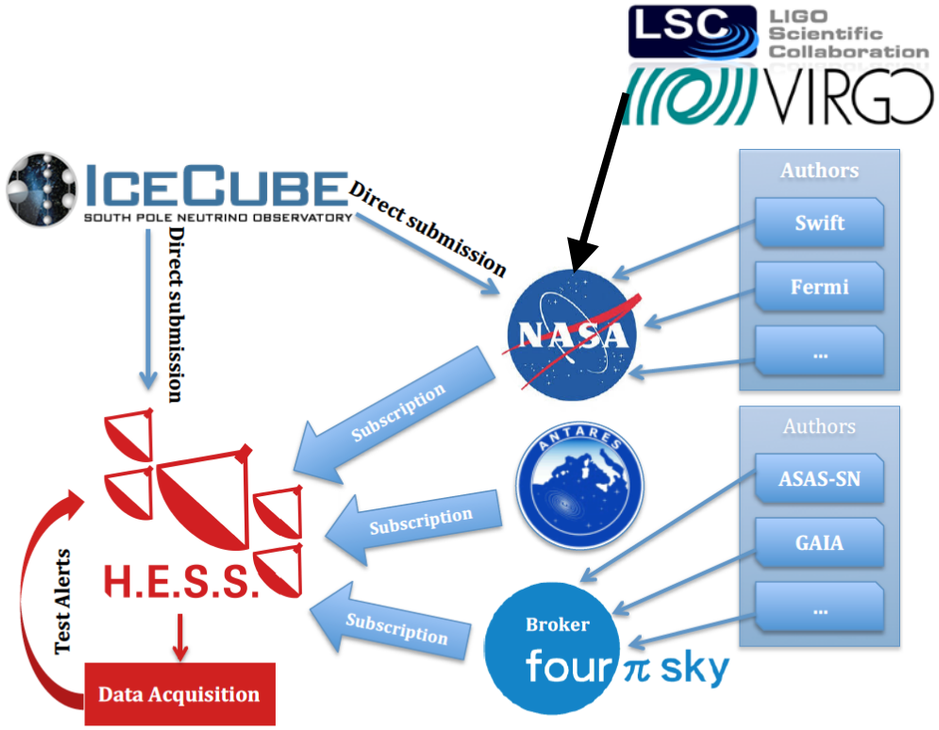


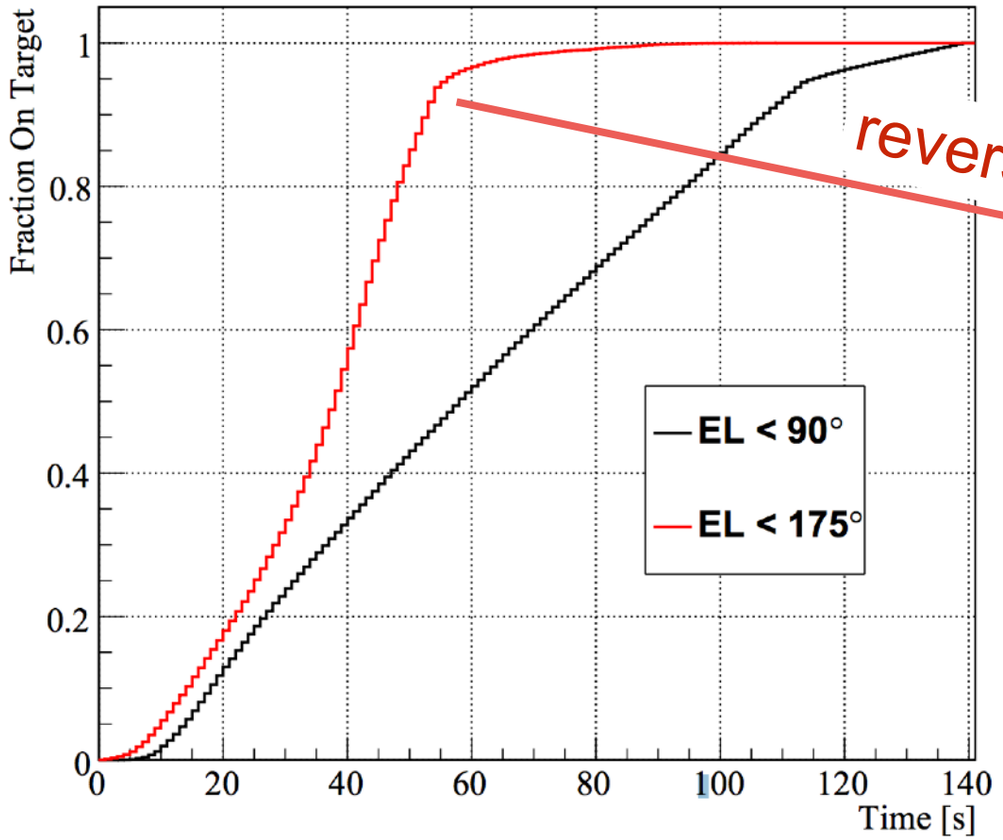
- First observations of a ground-based pointing instrument
  - 5.3 hours after GW170817
  - 5 minutes after the GCN circular announcing the LIGO+Virgo localisation
  - no significant signal: Φ (0.28 < E [TeV] < 2.31) < 3.9 x 10^{-12} erg cm^{-2} s^{-1}
  - monitoring campaign over 5 nights + extensive campaign covering the radio maximum

H. Abdalla et al. (H.E.S.S.), ApJL 855:L22 (2017) + ApJL 894:L16 (2020)

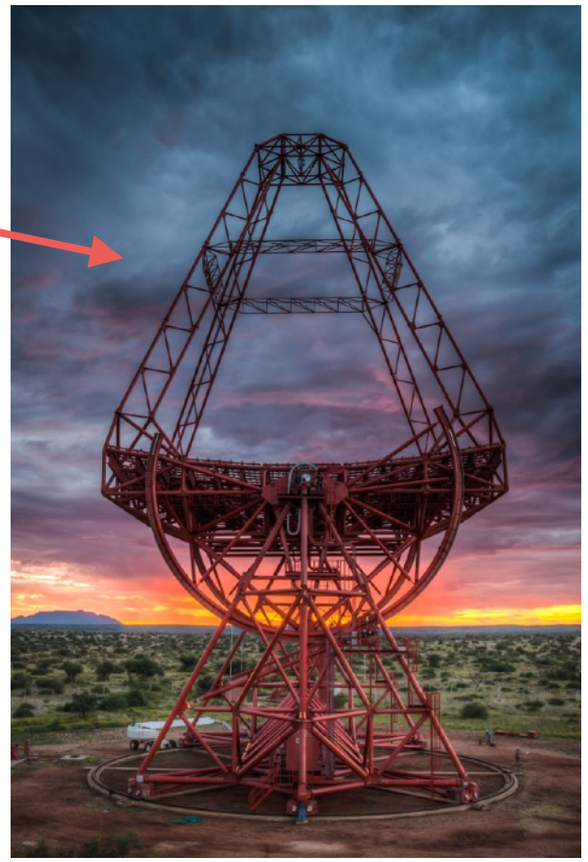
The H.E.S.S.-II response to ToOs

- main design principles of the H.E.S.S. 28m telescope
  - large photon collection area (614 m² mirror area; largest IACT worldwide)
  - **rapid response time**
  - **flexible + fully automatized alert system**



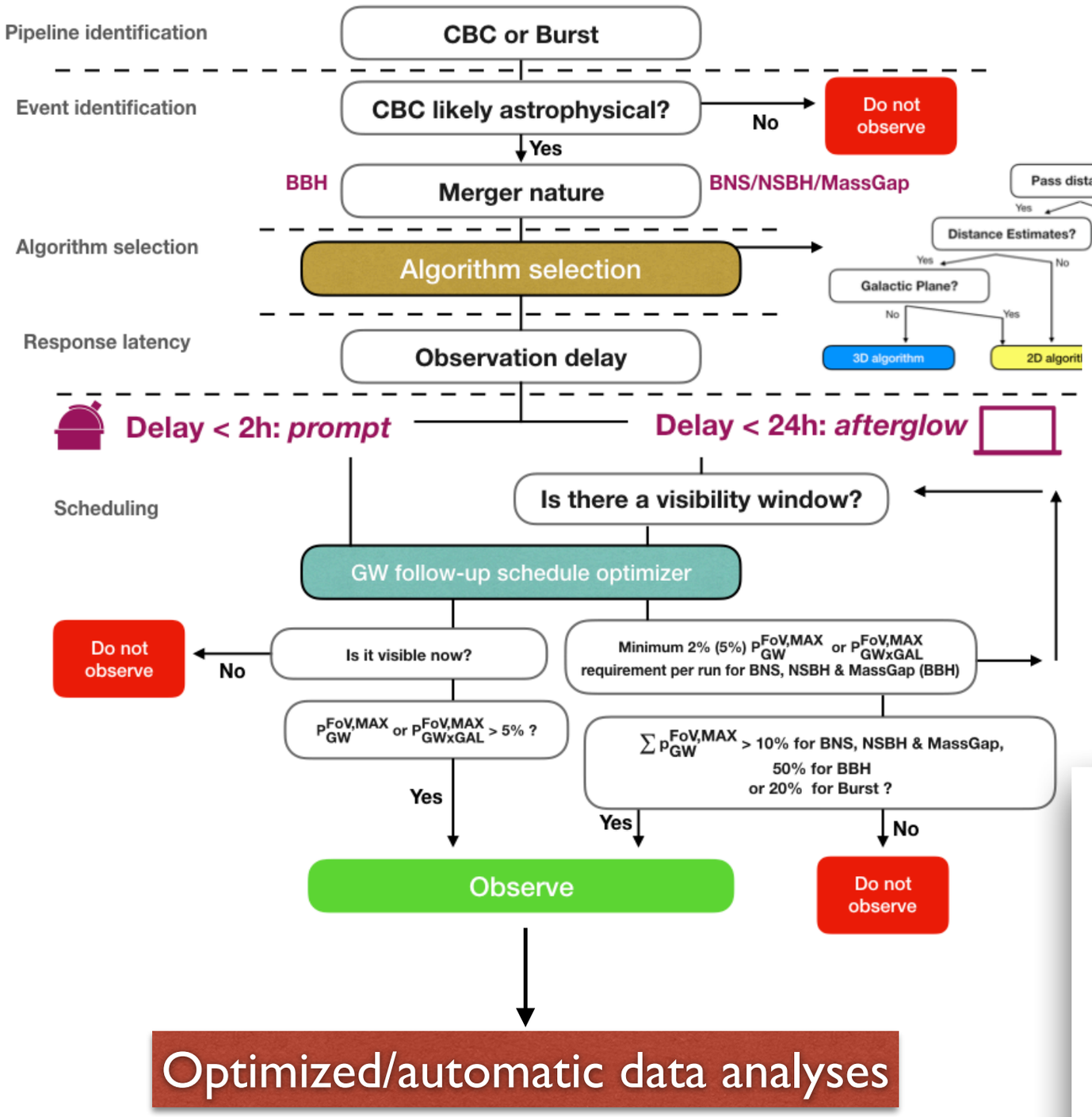


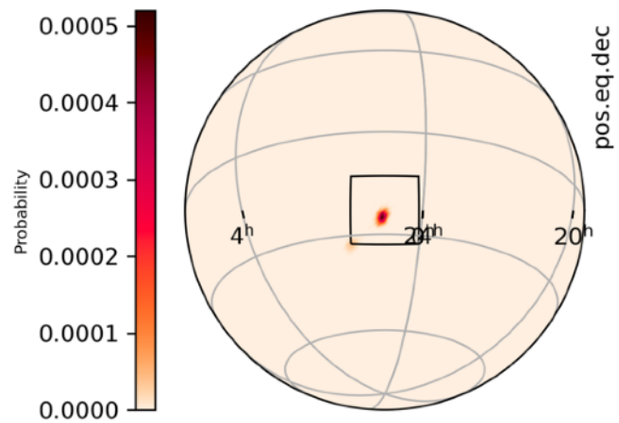
reverse tracking

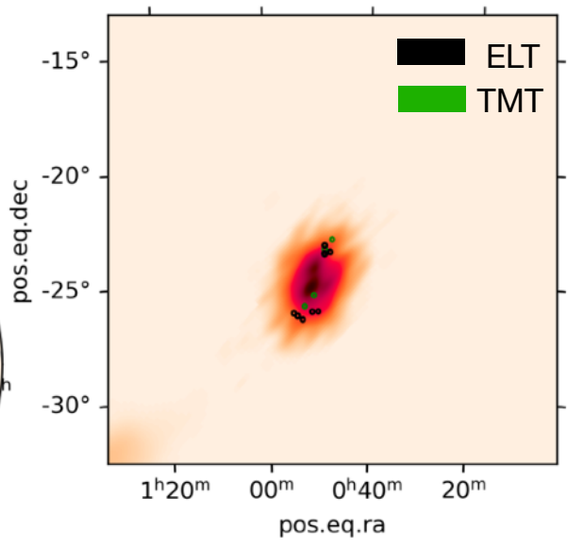


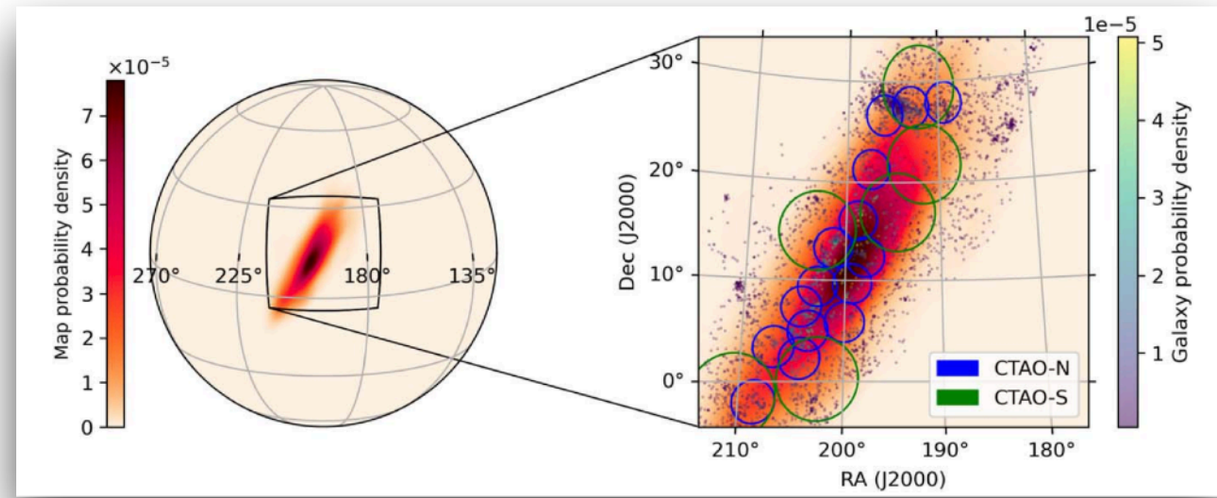
Hofverberg et al., ICRC 2013

Scheduling and pointing strategies





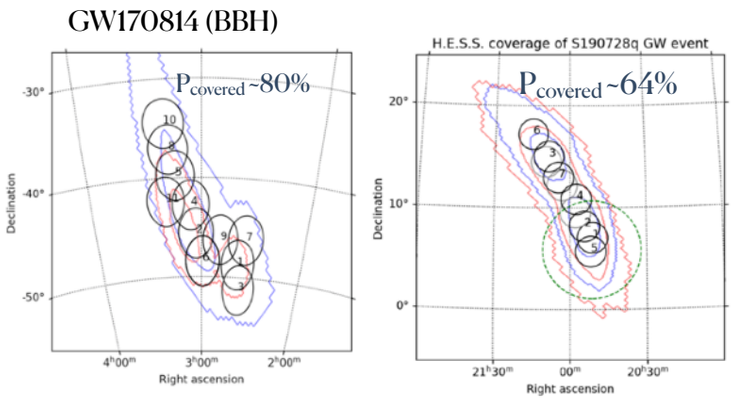




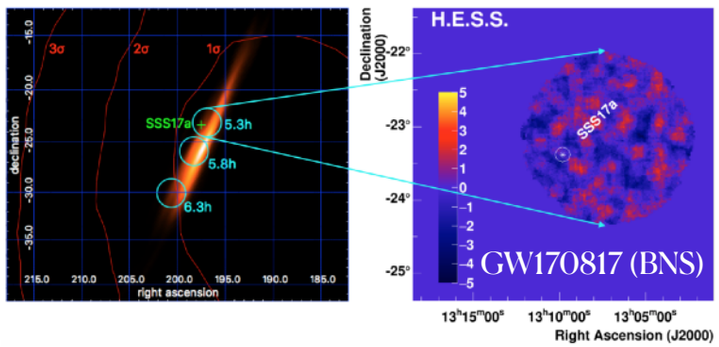
H. Ashkar et al., “The H.E.S.S. Gravitational Wave Rapid Follow-up Program”, JCAP03(2021), 45

tilepy

- Scheduling: **H.E.S.S**

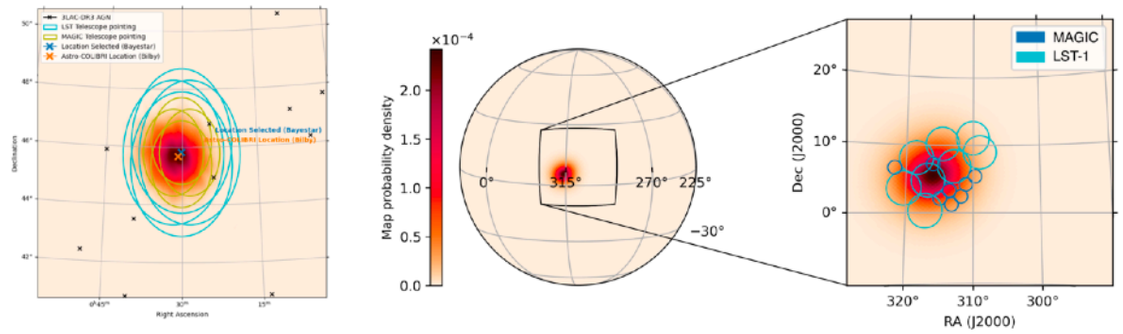


H.E.S.S. Collaboration, ApJ, 923, 109 (2021)



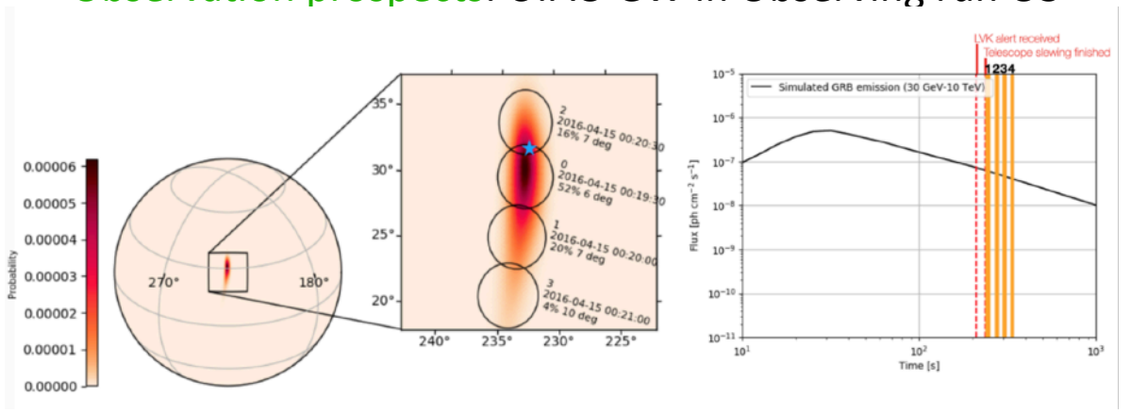
H.E.S.S. Collaboration, ApJL 850 (2017) L22

- Scheduling: CTAO/**Large Sized Telescope-1 + MAGIC**



M. Seglar-Arroyo, e*t al* [CTAO/LST Collaboration] (ICRC2025) 841

- Observation prospects: CTAO GW in Observing run O5



B. Patricelli, e*t al* [CTAO Collaboration] (ICRC2021) 998

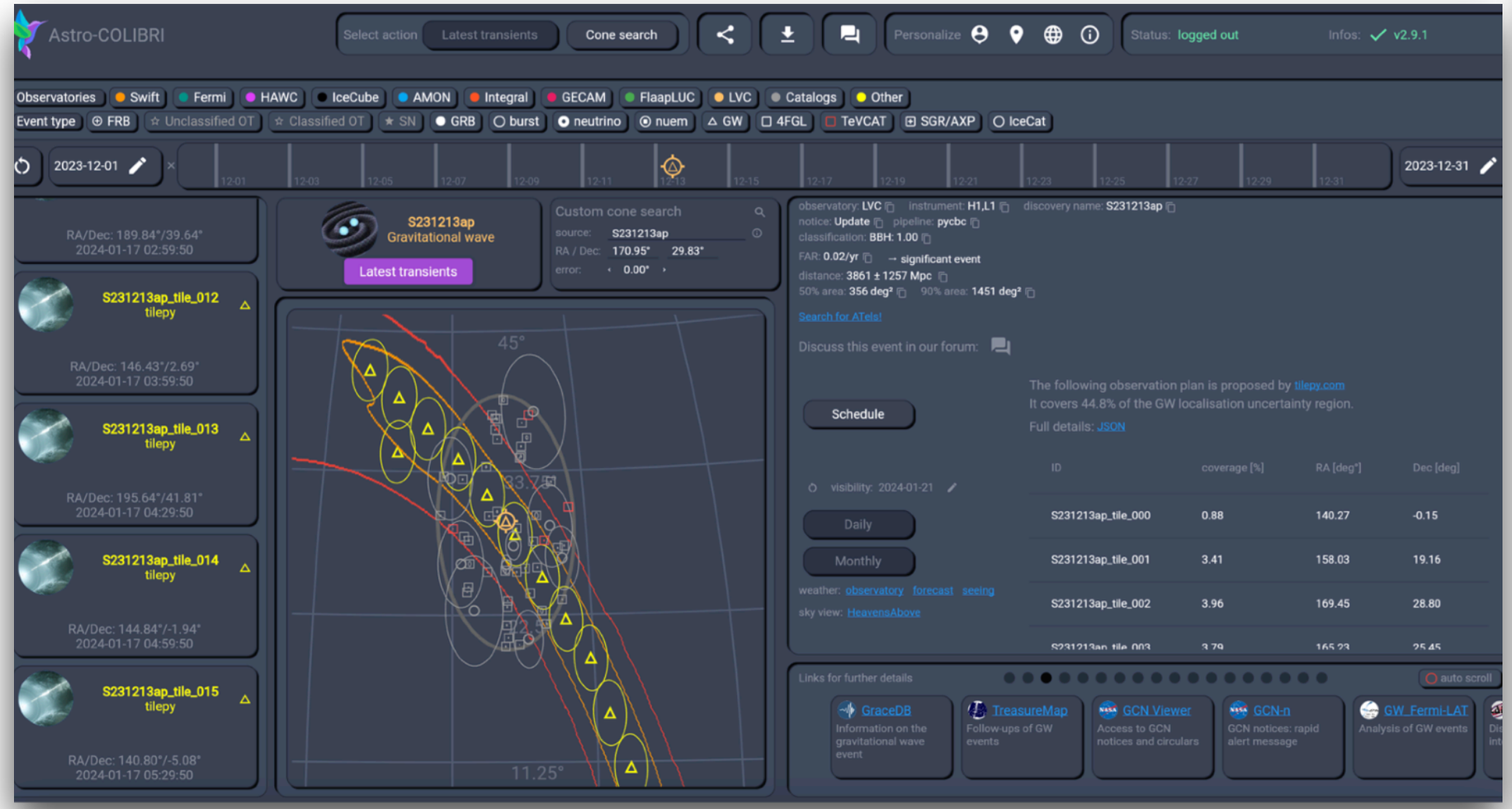
- Scheduling: CTAO (ACADA Transient-Handler)

- **GitHub: github.com/astro-transients/tilepy**
- **PyPI: pypi.org/project/tilepy/**
- **Doc: tilepy.readthedocs.io**
- **API at tilepy.com**

Tilepy integration in Astro-COLIBRI

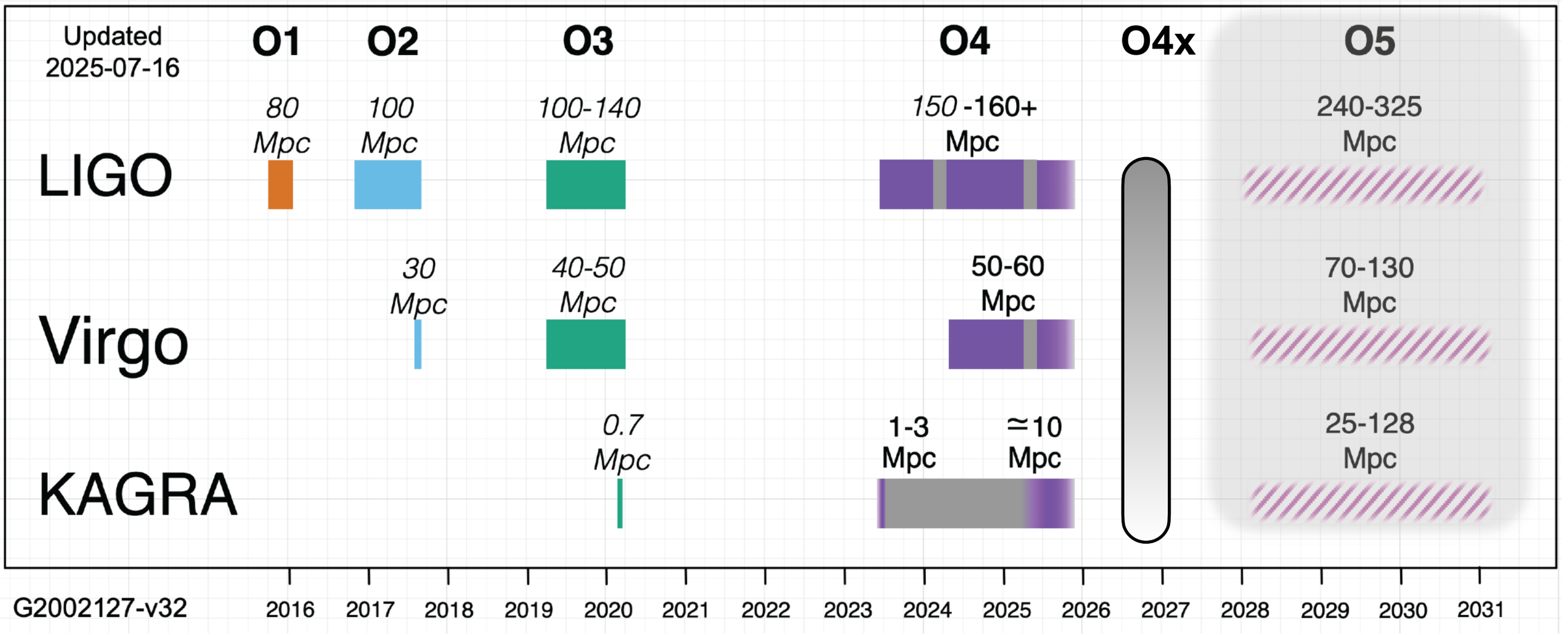
- Optimal observation plans with the click of a button
- Support for other poorly localised transients coming soon!

https://astro-colibri.science



Overview: O1 + … + O4 + …

The last observation run (O4) ended last Tuesday (Nov. 18) without another BNS merger detection



We currently envision a six month observing run to begin in the late summer/early fall of 2026, with detectors participating as available.

From: https://observing.docs.ligo.org/plan/

MULTI-Messenger Astroparticle Physics

- **Many years of preparation coming to fruition**
  - automatic alert systems + dedicated data analysis tools + novel platforms + …

- **Neutrinos + electromagnetic emissions**
  - Most promising route towards discovery of the source of ultra-high energy cosmic rays
  - Time domain studies help to reduce chance coincidences

- **Gravitational waves + Gamma Ray Bursts**
  - major breakthroughs over the last years (GW170817, GRB190114C, GRB190829A, etc.)

- Multi-messenger observations allow for a large range of fundamental studies
- Groups at **P2I** with major contributions to most of the crucial observatories
- Incl. large range of future observatories: CTAO, SKAO, (KM3NeT + IceCube-Gen2), Einstein Telescope, THESEUS, …