



High energy follow-up of transient sources with H.E.S.S.

Bernardo Cornejo, CEA / IRFU - DPhP



1. General introduction

- Transient astrophysics
- Gamma astronomy



2. GRB & GW follow-up with H.E.S.S.

- GRBs & GWs in VHE
- Observation strategy
- External tools



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What are transient sources?





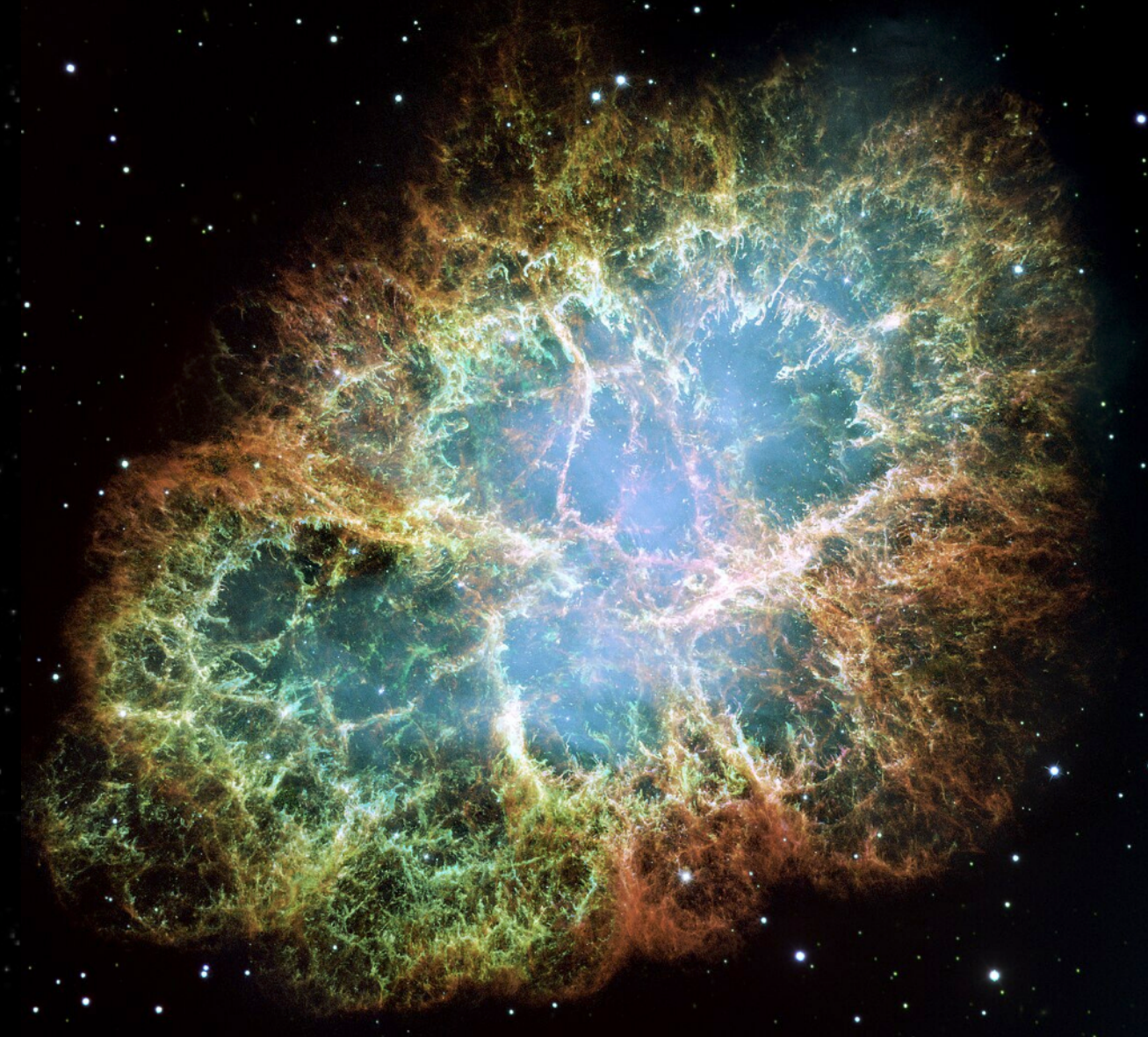
What are transient sources?

Energetic phenomena which appear suddenly, stay “briefly” (seconds to days) and fade away



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Crab Nebula - Hubble Space Telescope

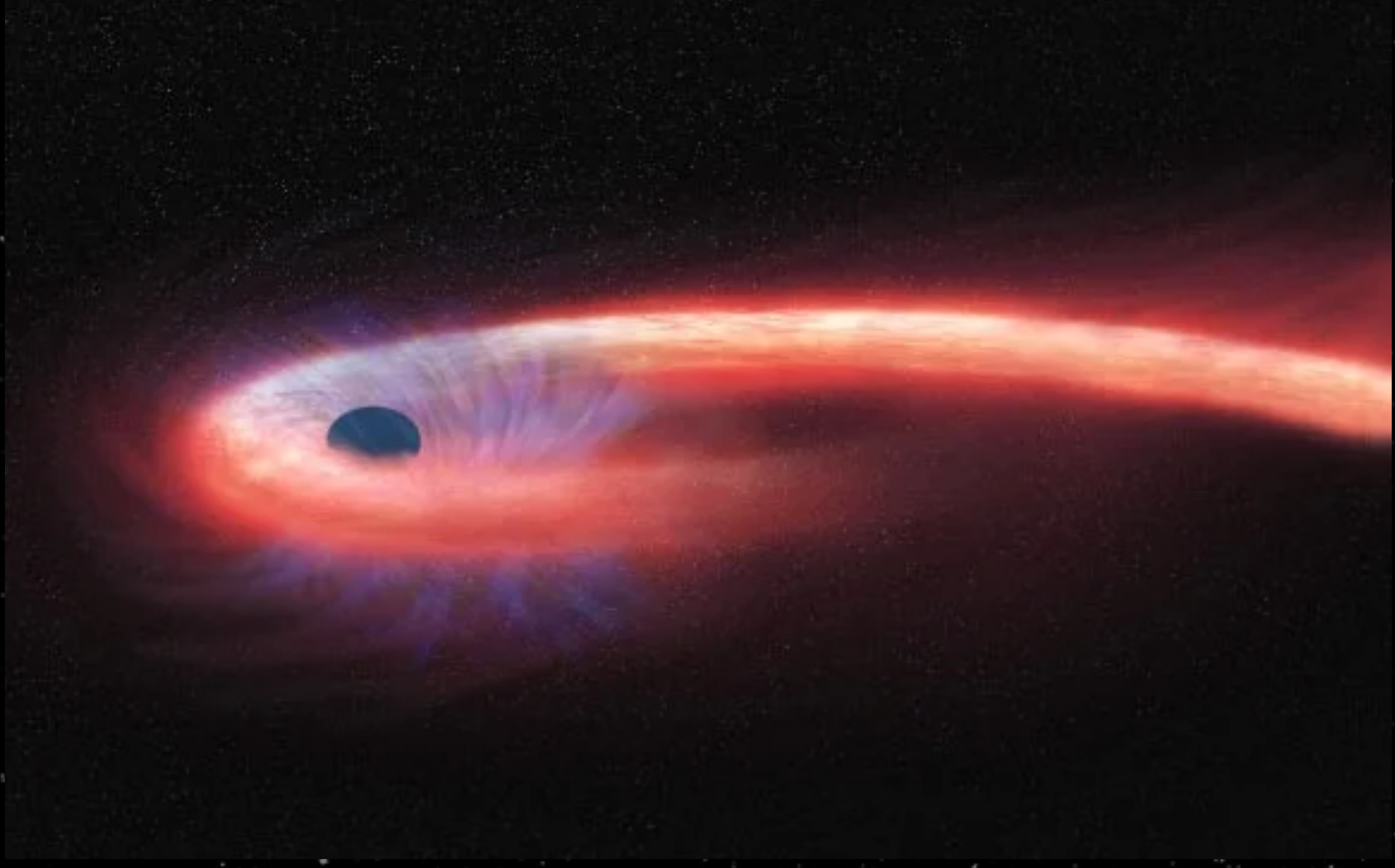
Supernova

Explosion of a star at the end of its lifetime



What are transient sources?

Energetic phenomena which appear suddenly, stay “briefly” (seconds to days) and fade away



Tidal Disruption Event

Supermassive black hole shredding a passing star

Artist's representation of a TDE - NASA / CXC / M. Weiss





What are transient sources?

Energetic phenomena which appear suddenly, stay “briefly” (seconds to days) and fade away



VLA Radio Image of Hercules A - NASA

AGN Flares

A short-term, stochastic surge in the brightness of an Active Galactic Nucleus

 **Go see Julian & Anastasiia's talk**

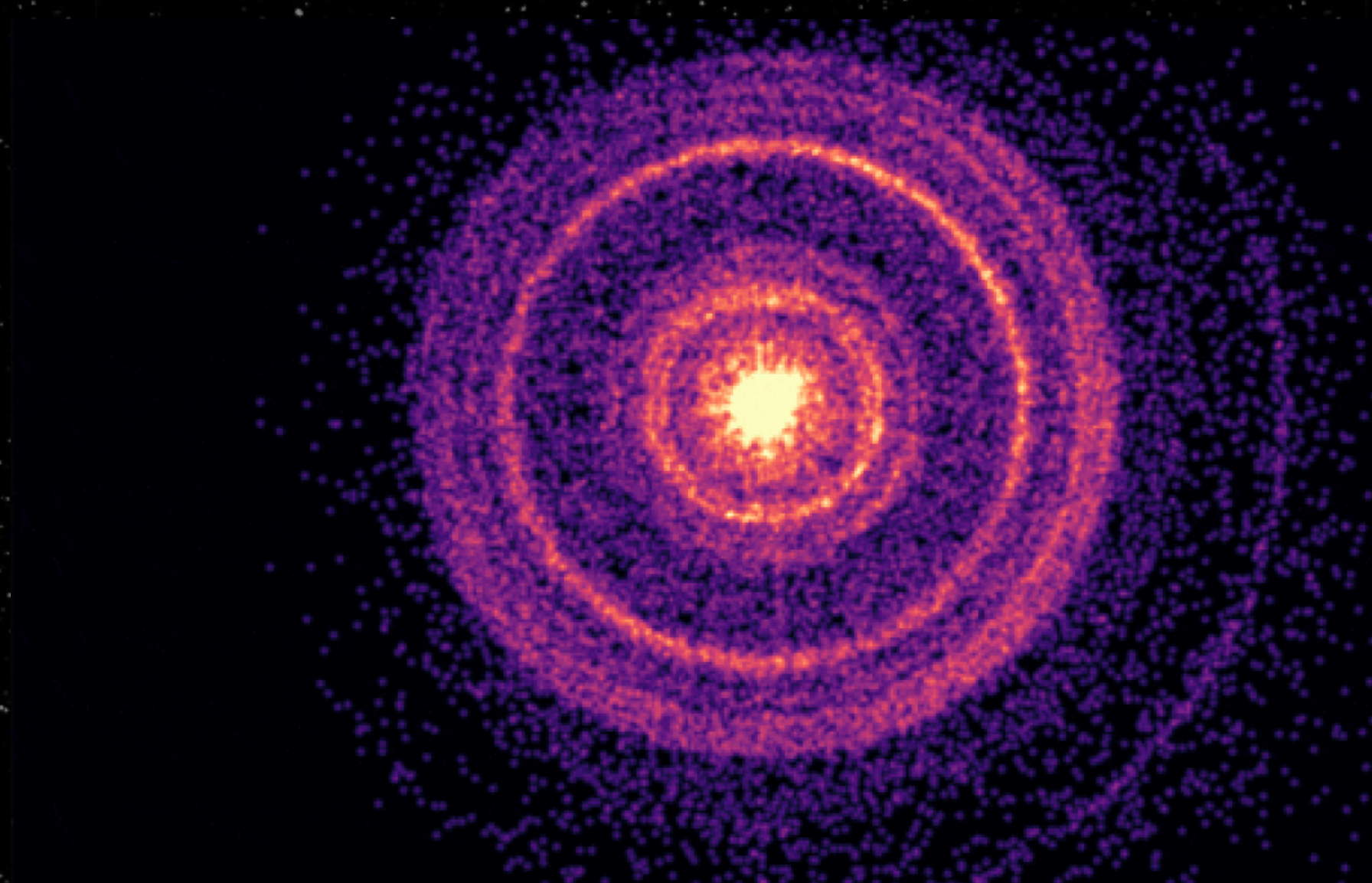




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Gamma-Ray Bursts



SWIFT Time lapse animation of the brightest GRB - NASA

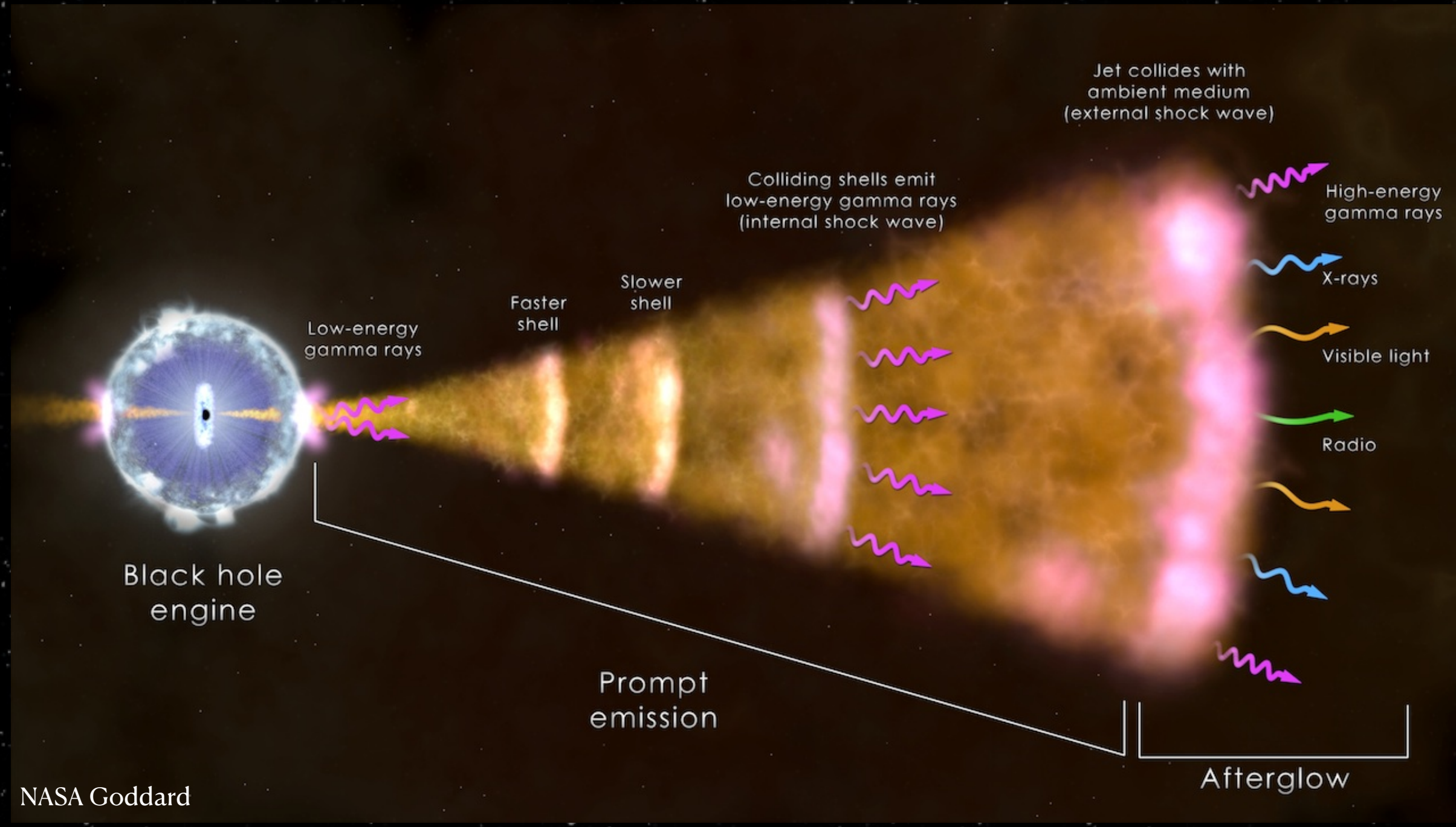




Gamma-Ray Bursts

Inmensly energetic jetted explosions, described as “the most powerful class of explosions of the Universe”

- Two emission phases : **Prompt emission** & **Afterglow** emission



Multiple wavelengths emitted



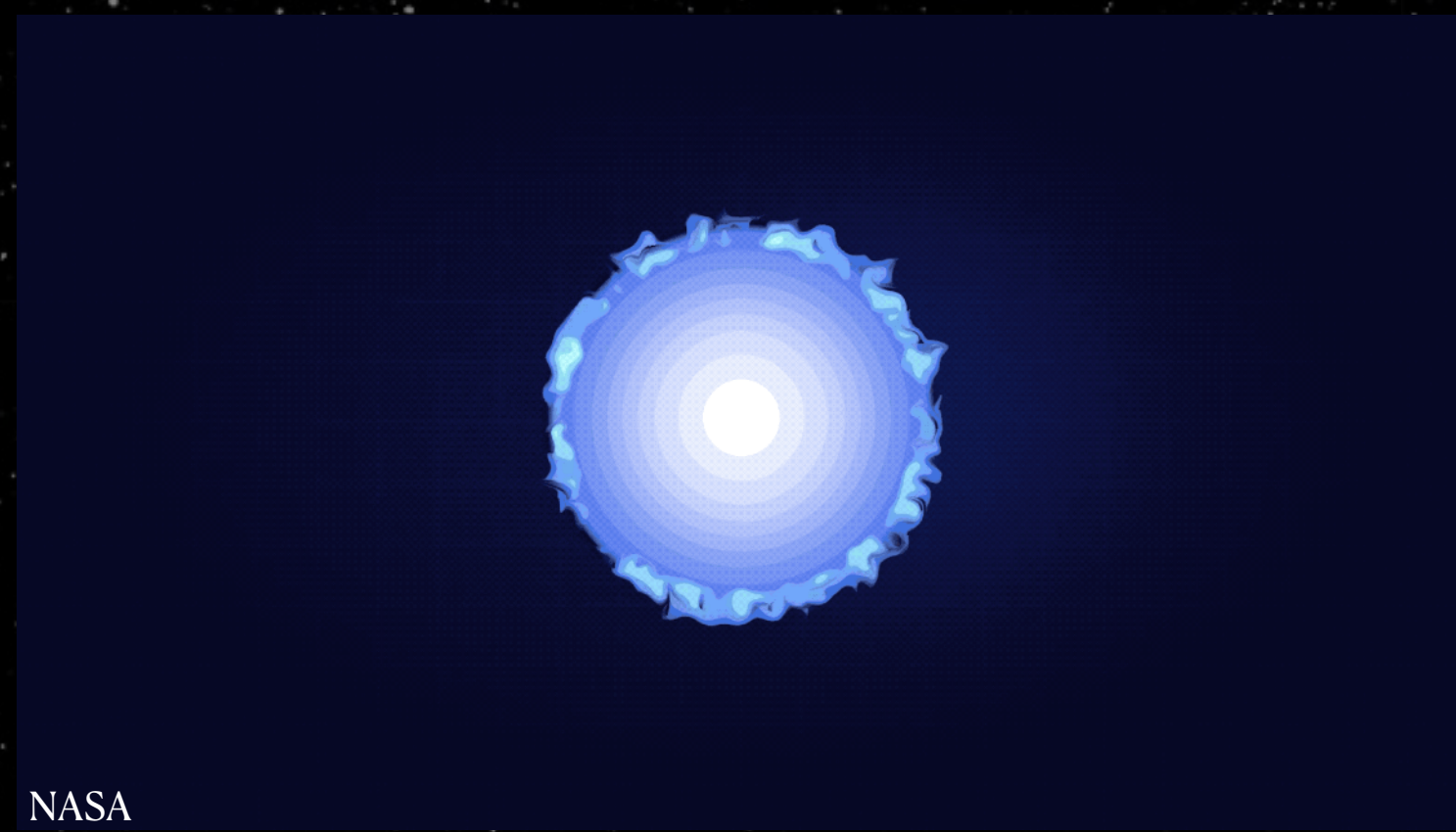


Gamma-Ray Bursts

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- Two main classes :

Long (prompt up to minutes)



NASA



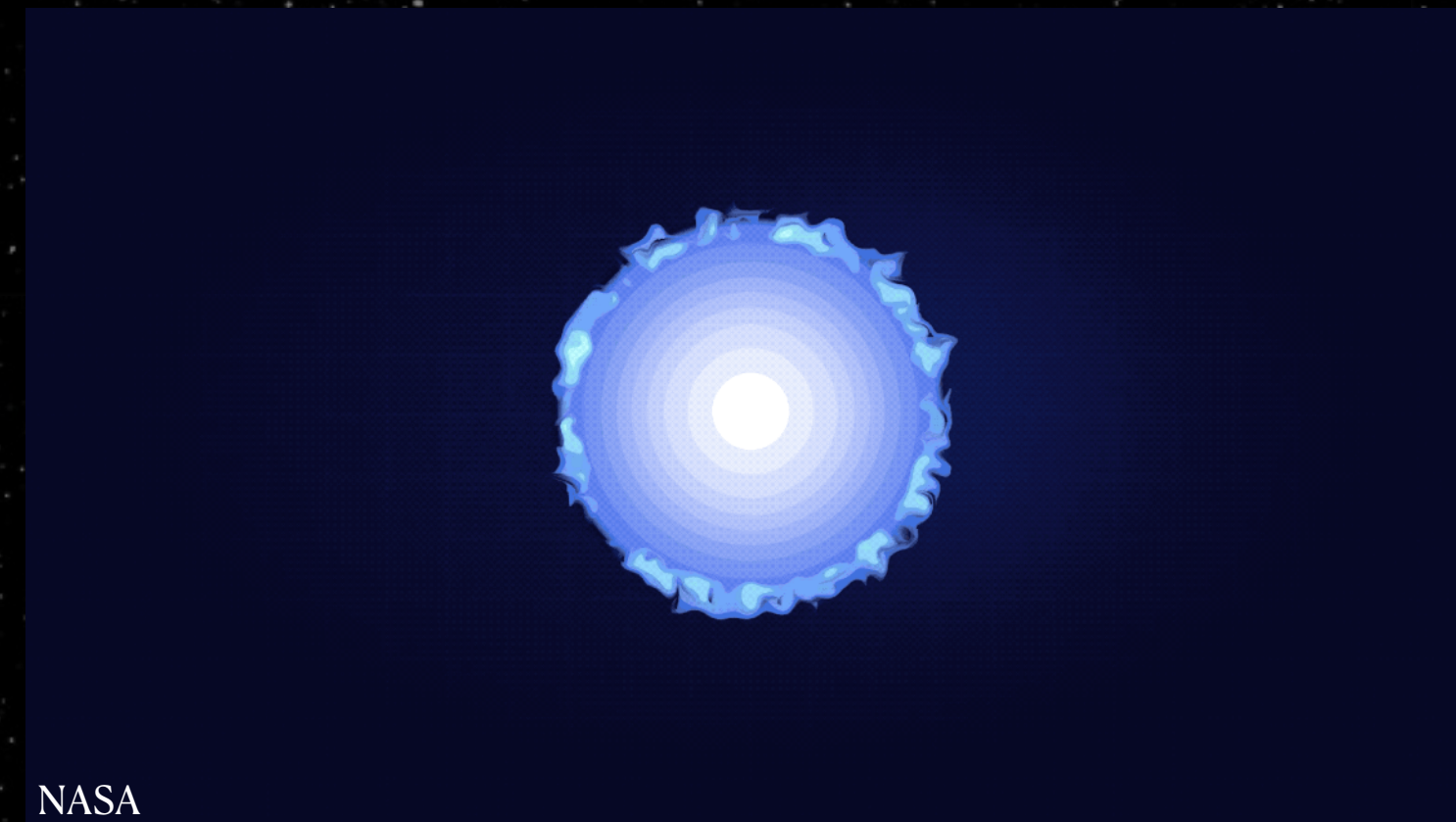


Gamma-Ray Bursts

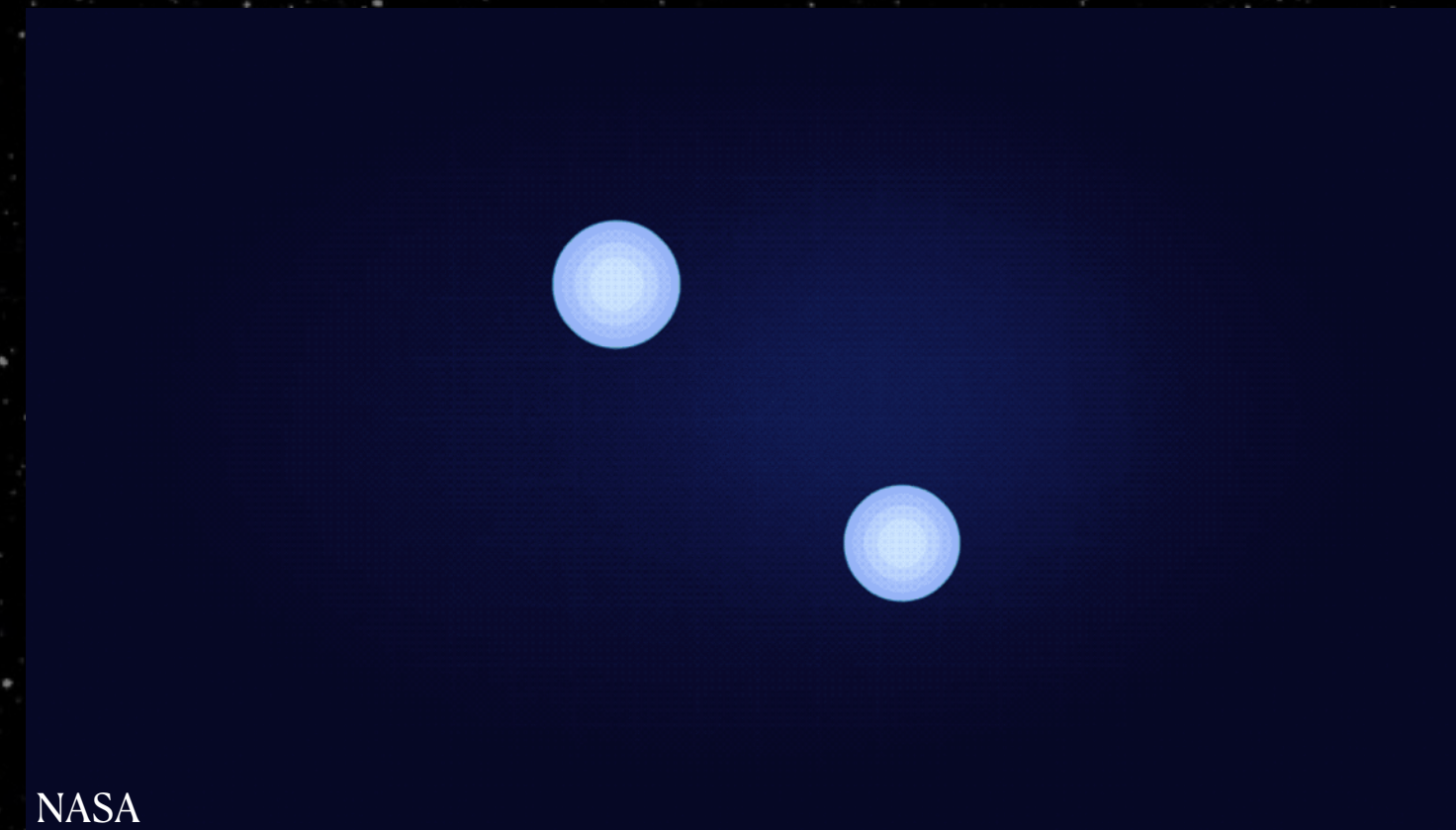
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Short (prompt < 2 s)



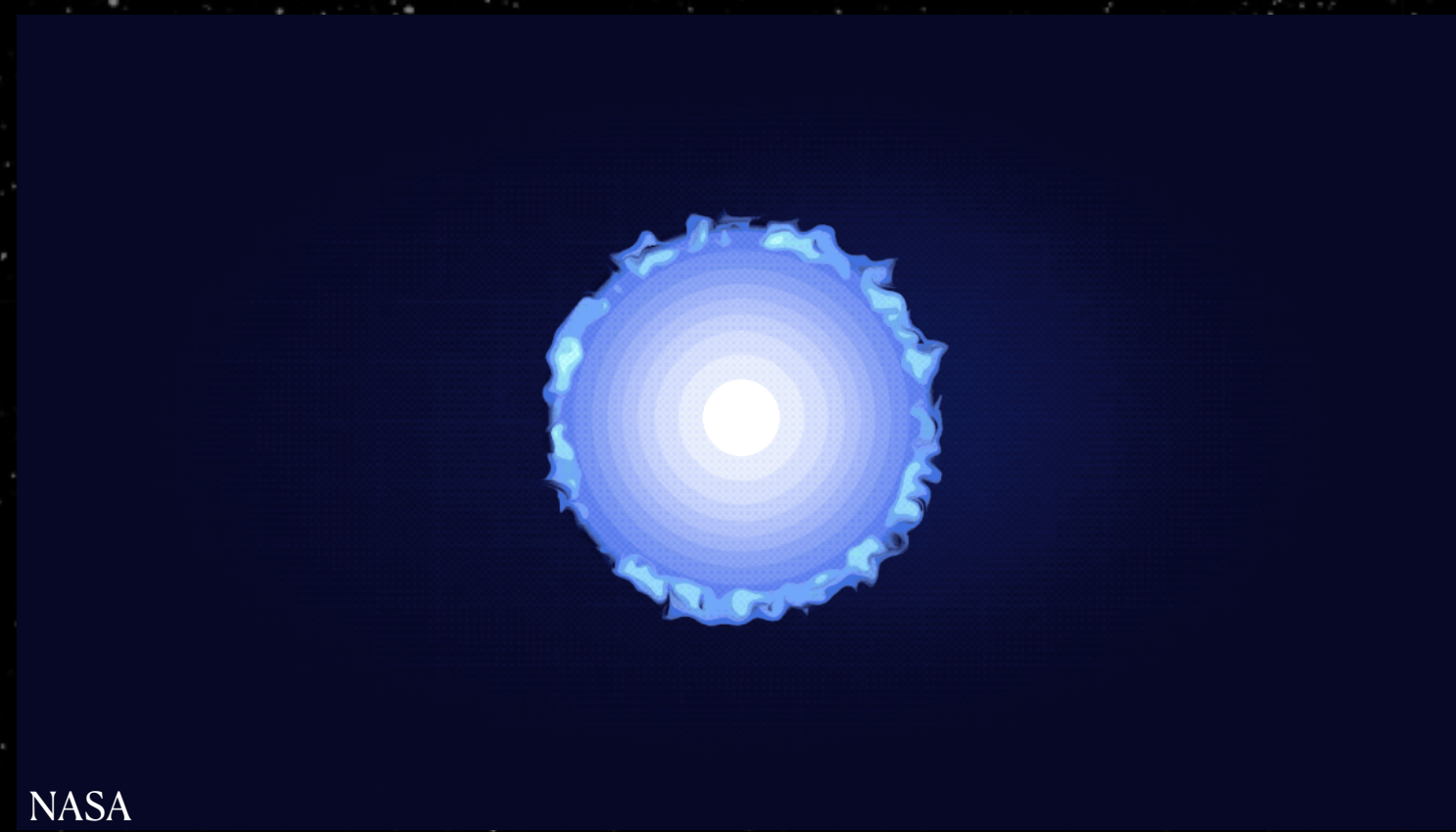


Gamma-Ray Bursts

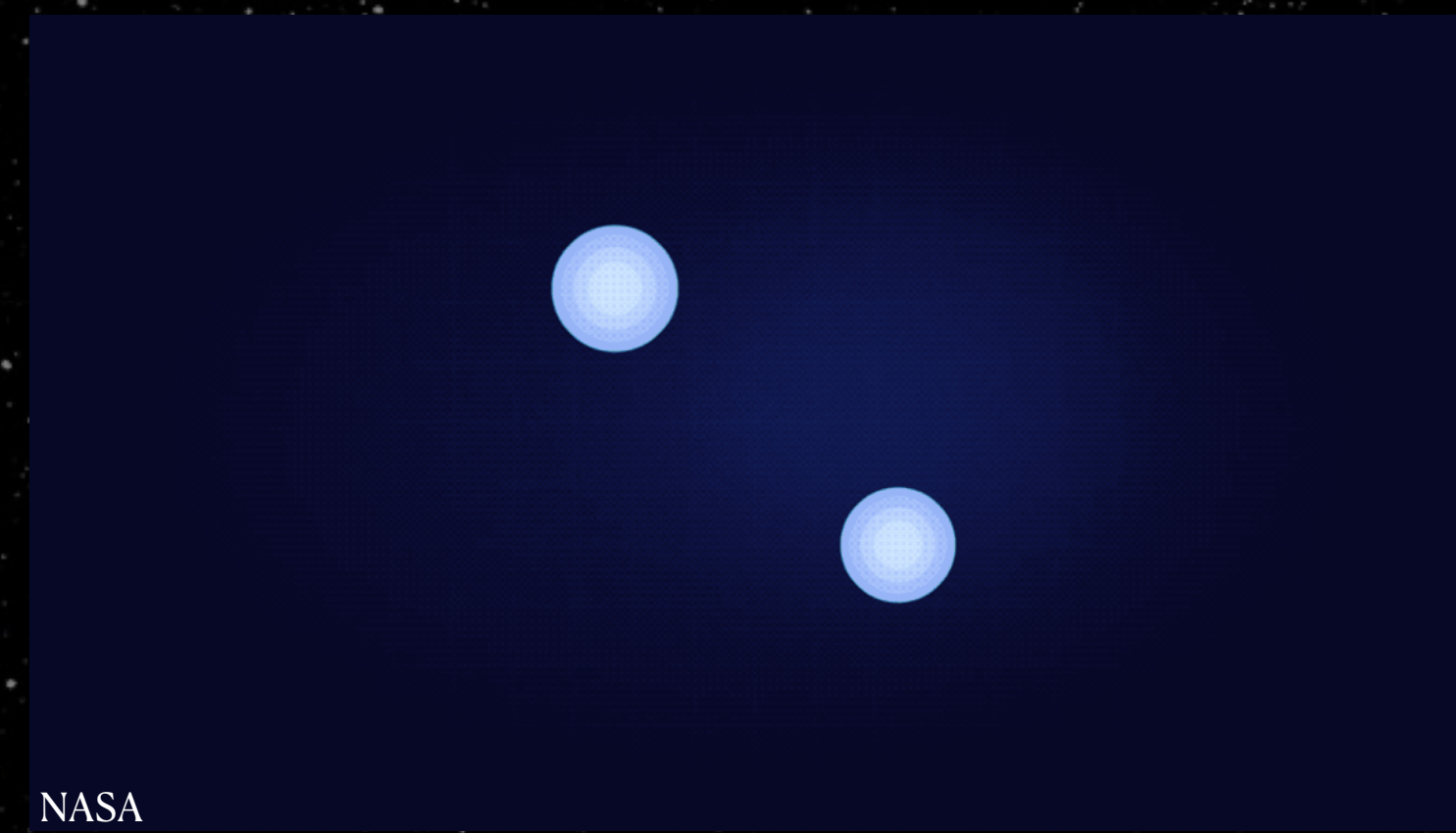
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GW emitter!



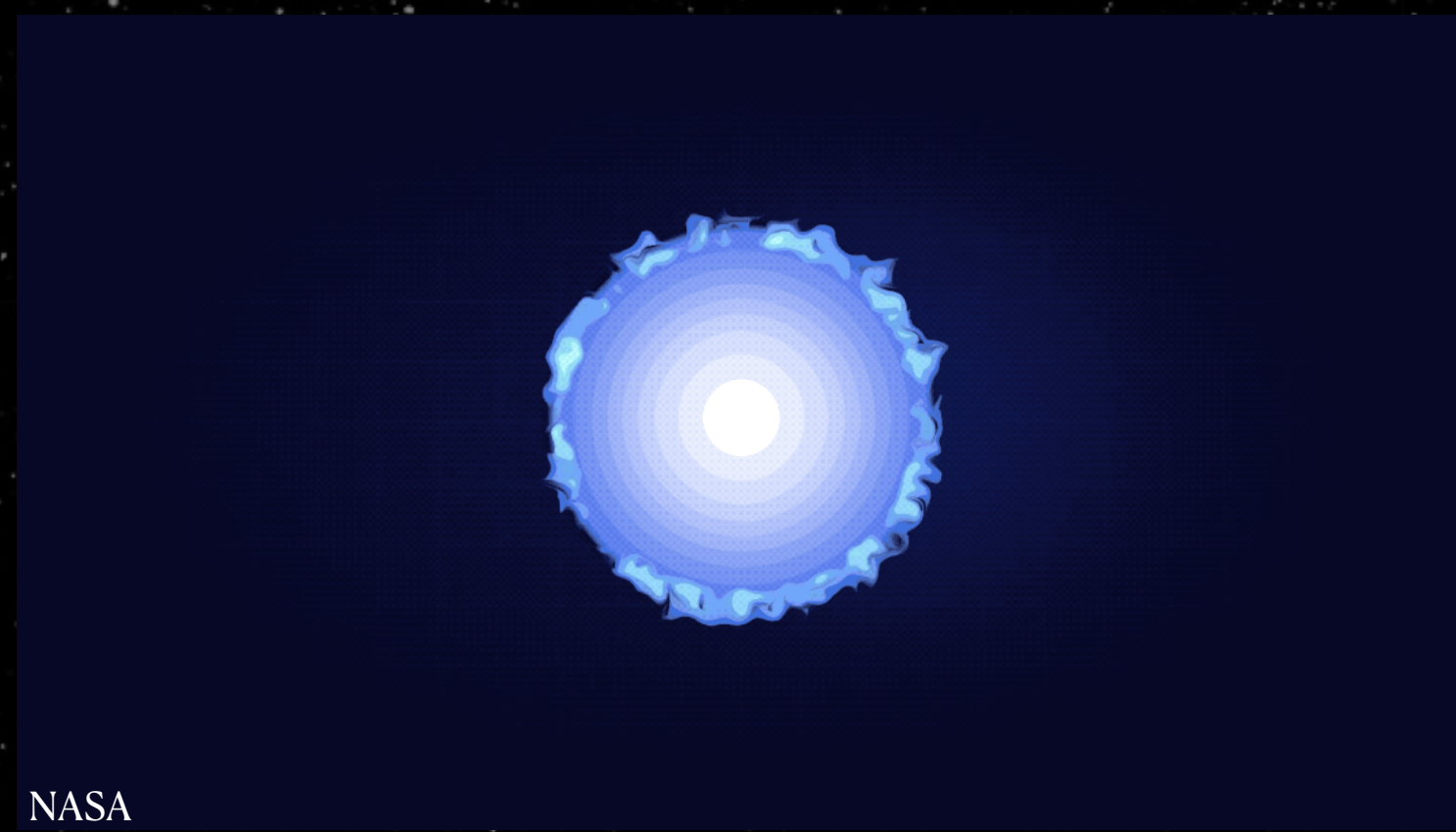


Gamma-Ray Bursts

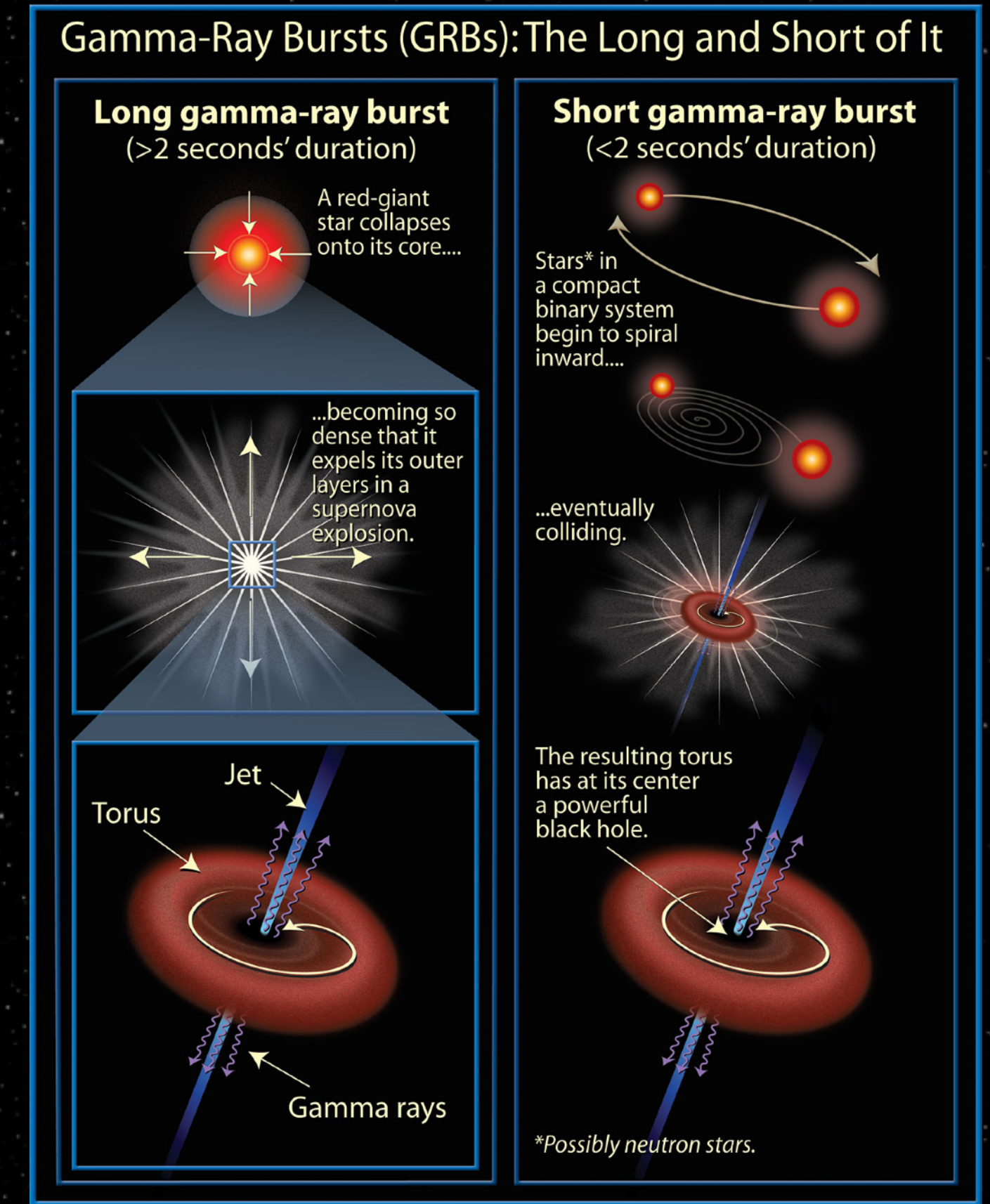
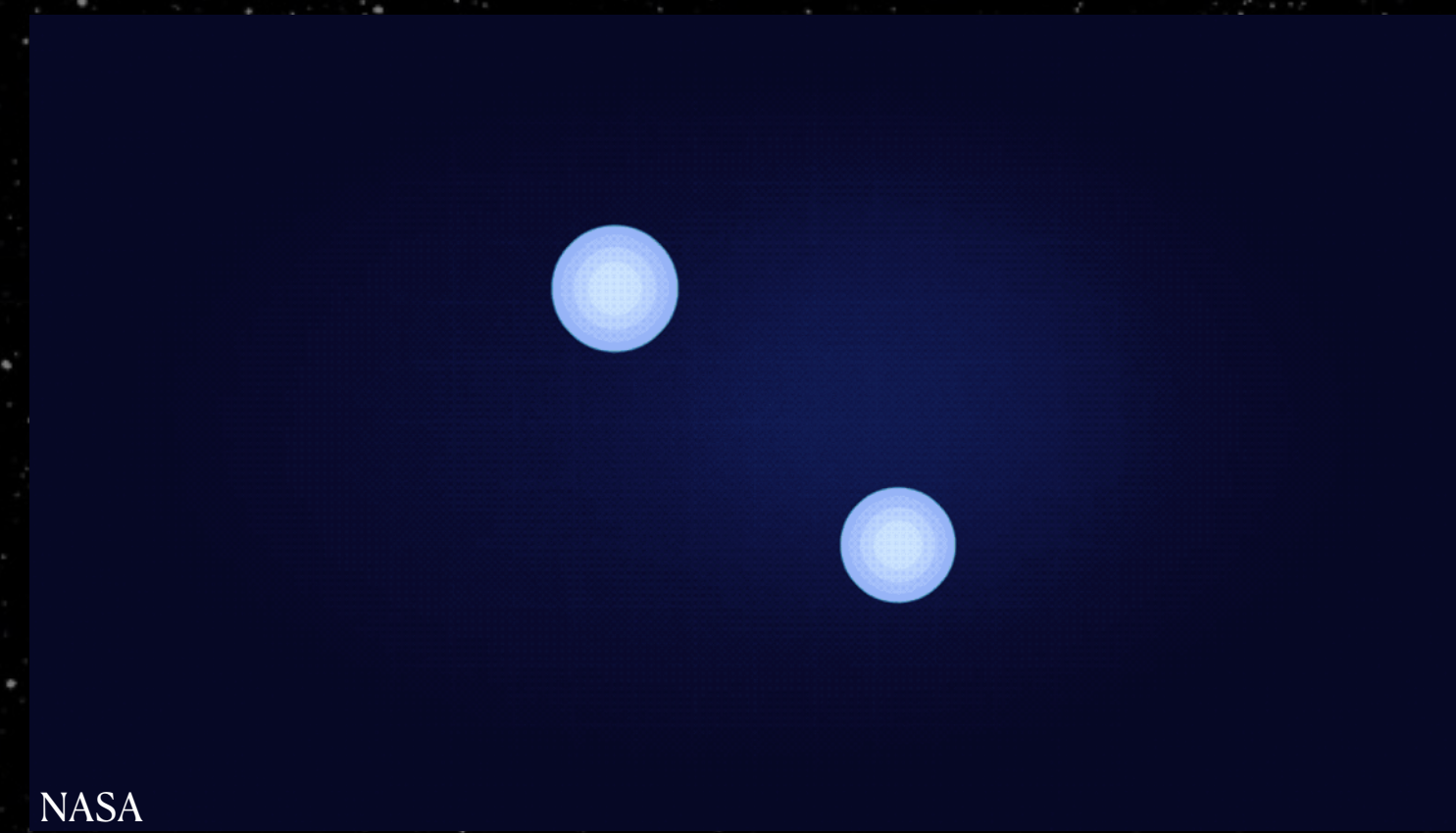
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NASA and E. Feild

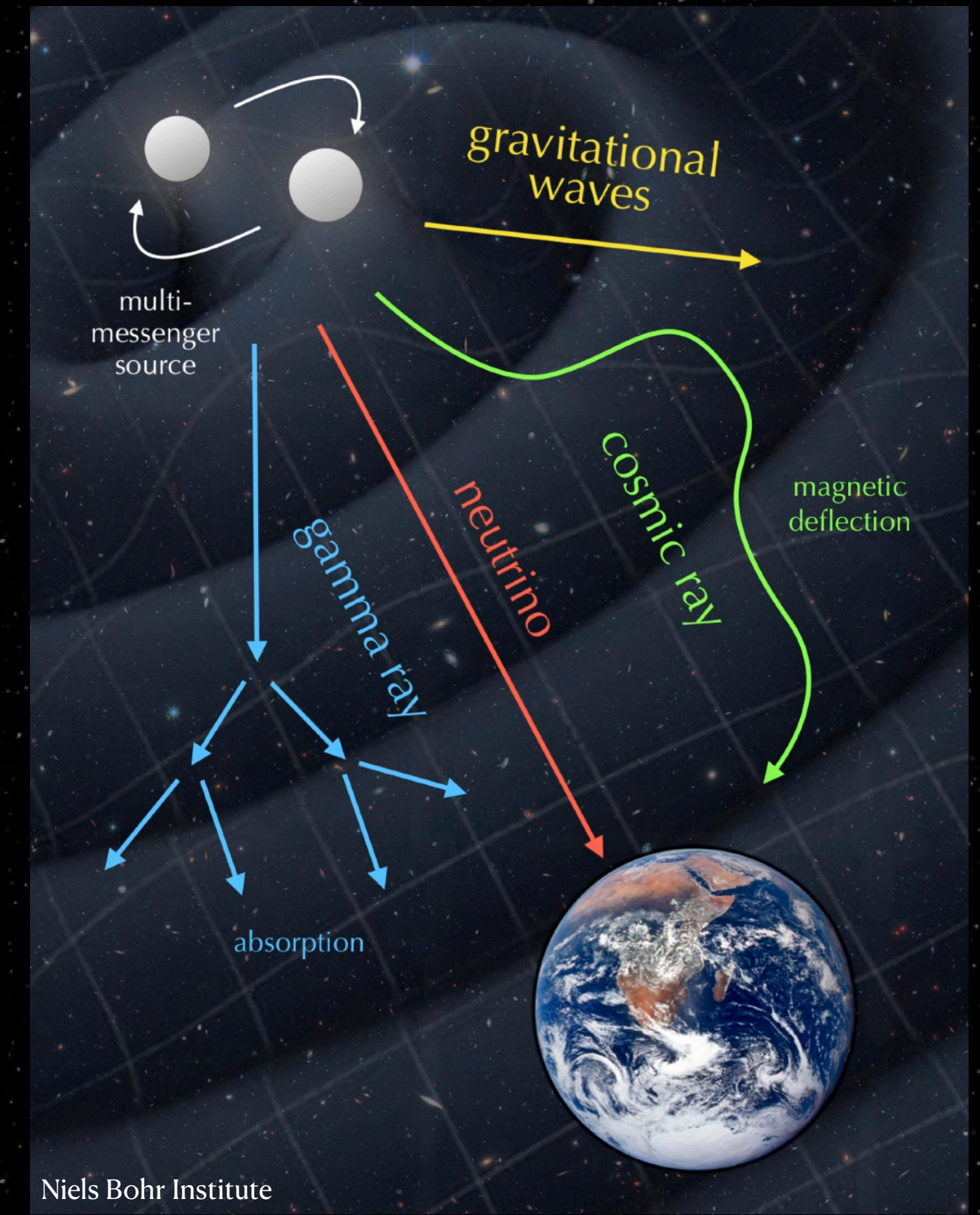




Multi-messenger (& wavelength) astronomy

Transient sources emit one or often many “cosmic messengers”

- **Cosmic Rays:** Deflected by galactic and extra-galactic magnetic fields
- **Electromagnetic Waves:** Emission in every wavelength
- **Neutrinos**
- **Gravitational Waves**





How to observe transients?

Wide Field-of-View (FoV) observatories, all sky-survey but low resolution in position and energy



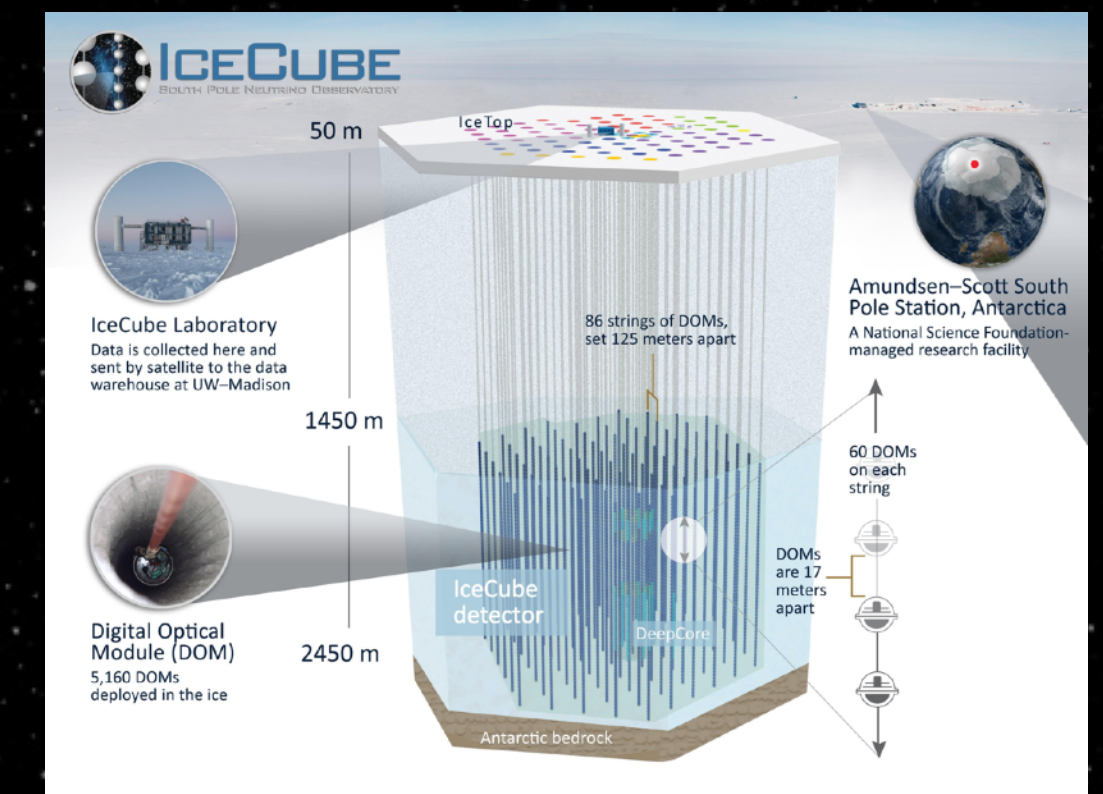
CHIME



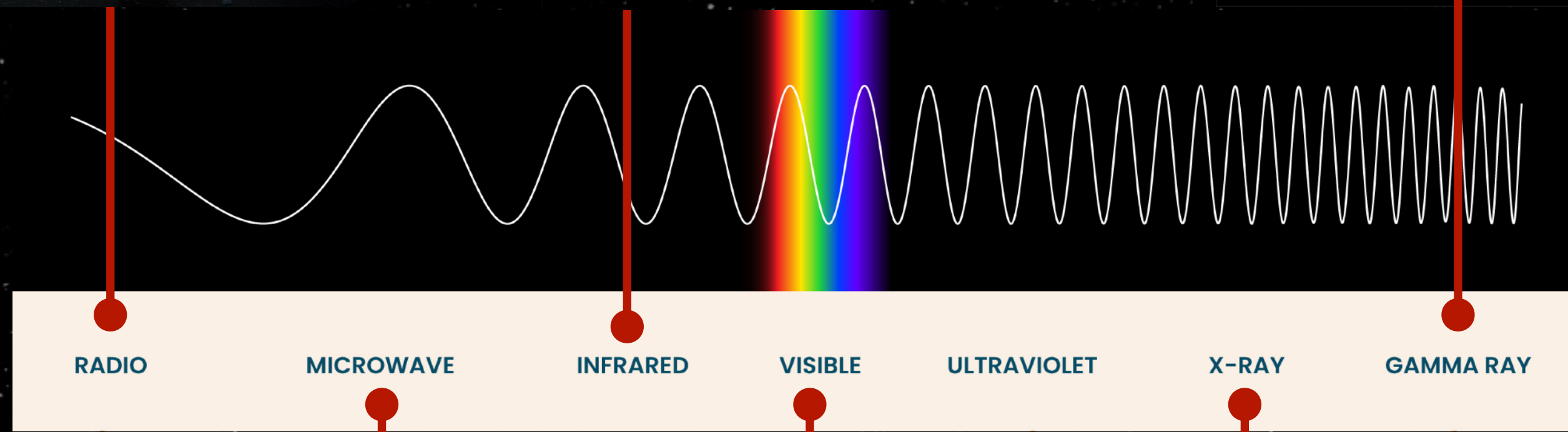
WISE



SVOM



IceCube



RADIO

MICROWAVE

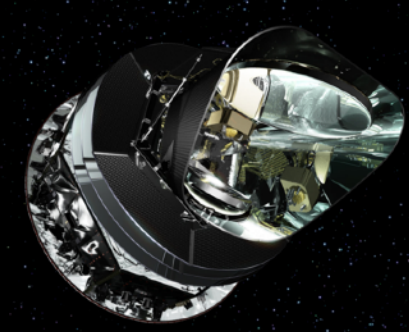
INFRARED

VISIBLE

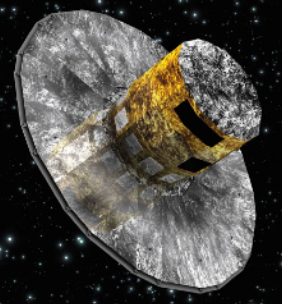
ULTRAVIOLET

X-RAY

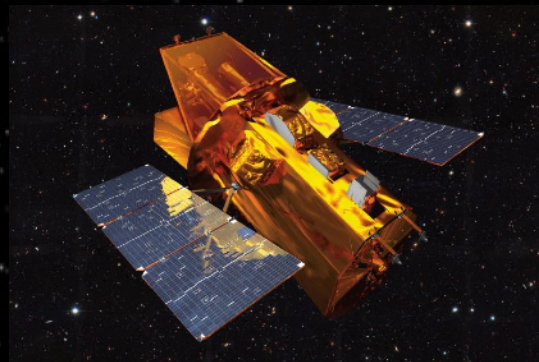
GAMMA RAY



Planck



Gaia



Swift-BAT



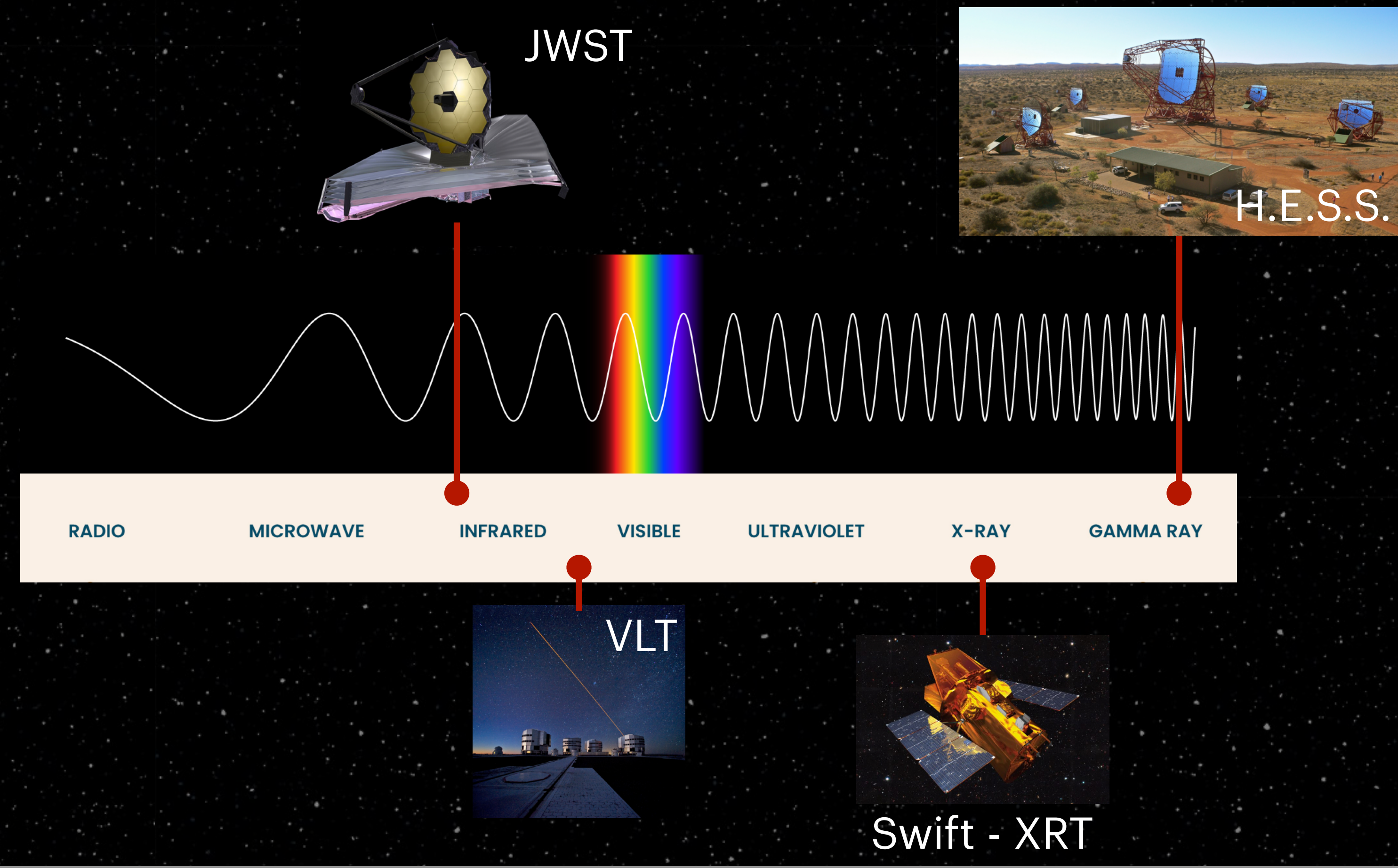
Ligo/Virgo/Kagra





How to observe transients?

Small FoV observatories, **pointed** instruments but **good resolution** in position and energy



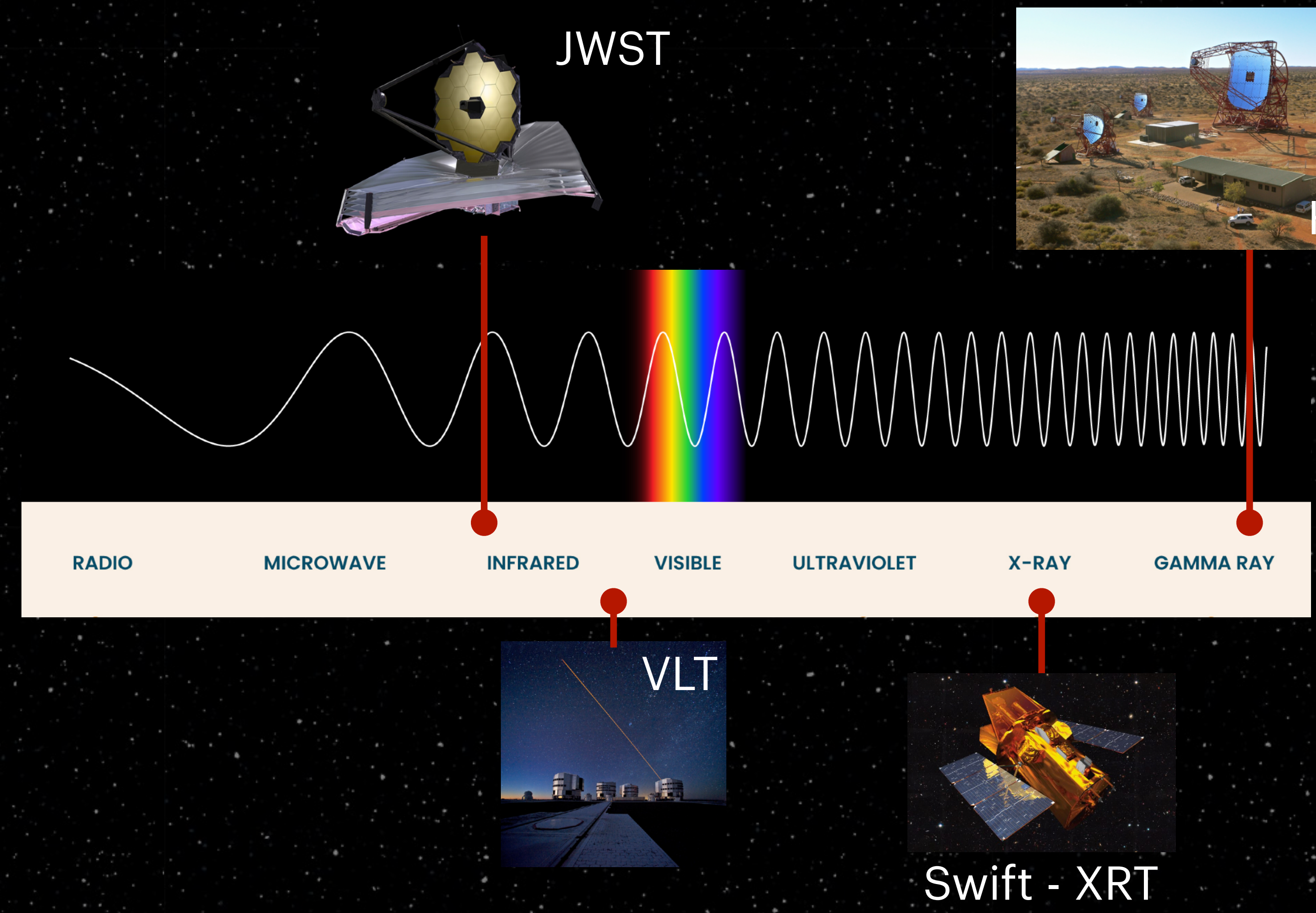
NASA





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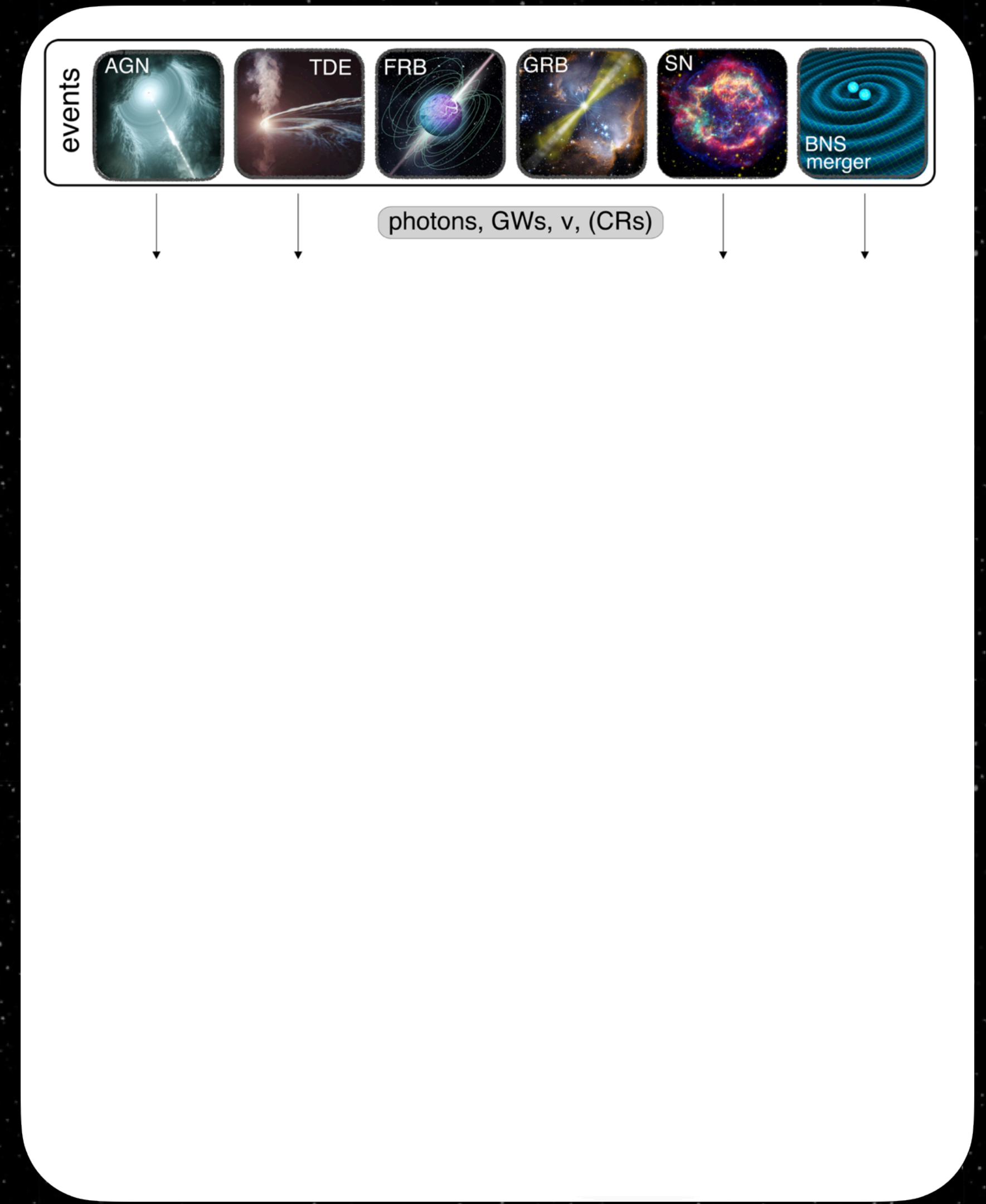
Where I work!

NASA





How to observe transients?



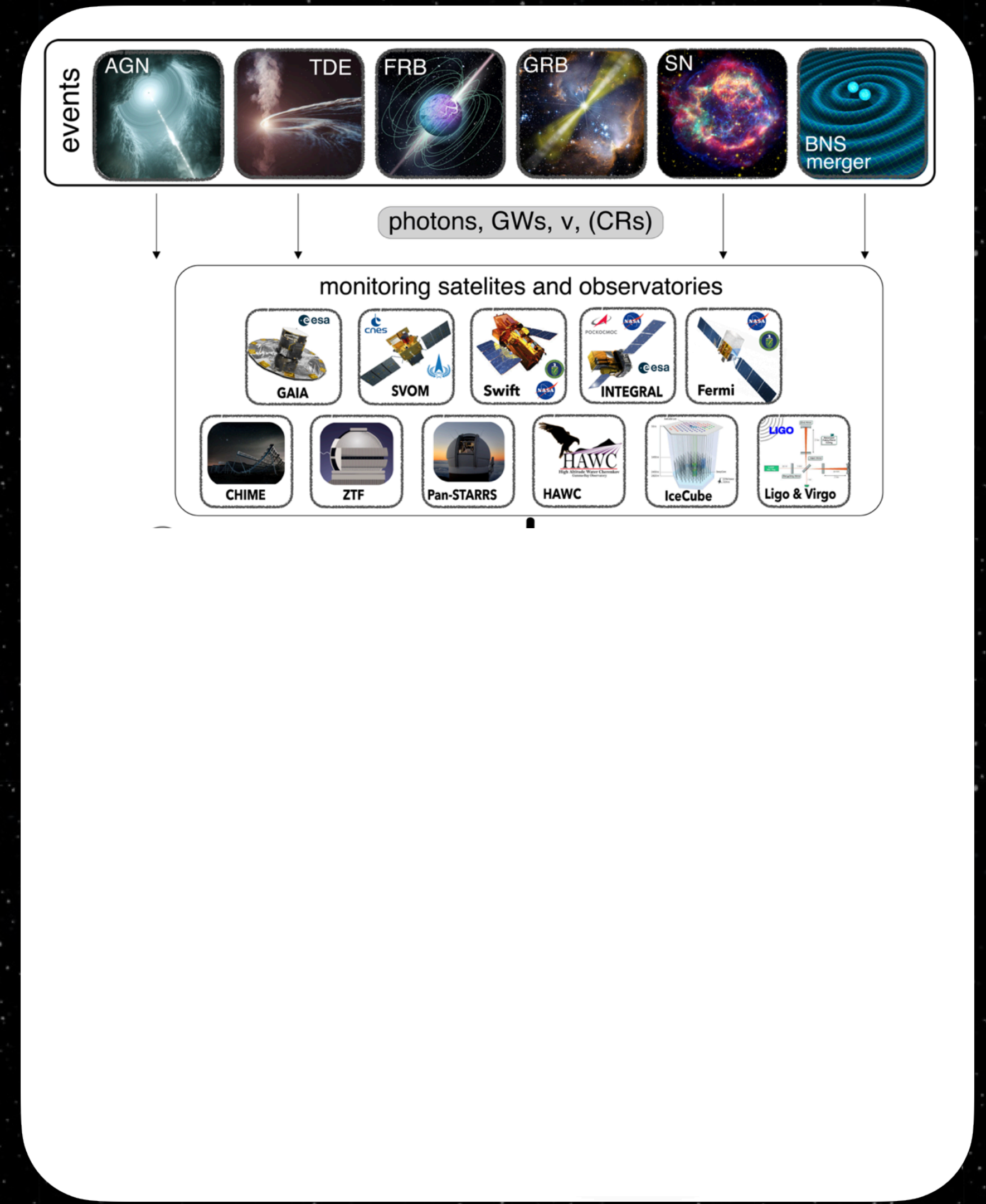
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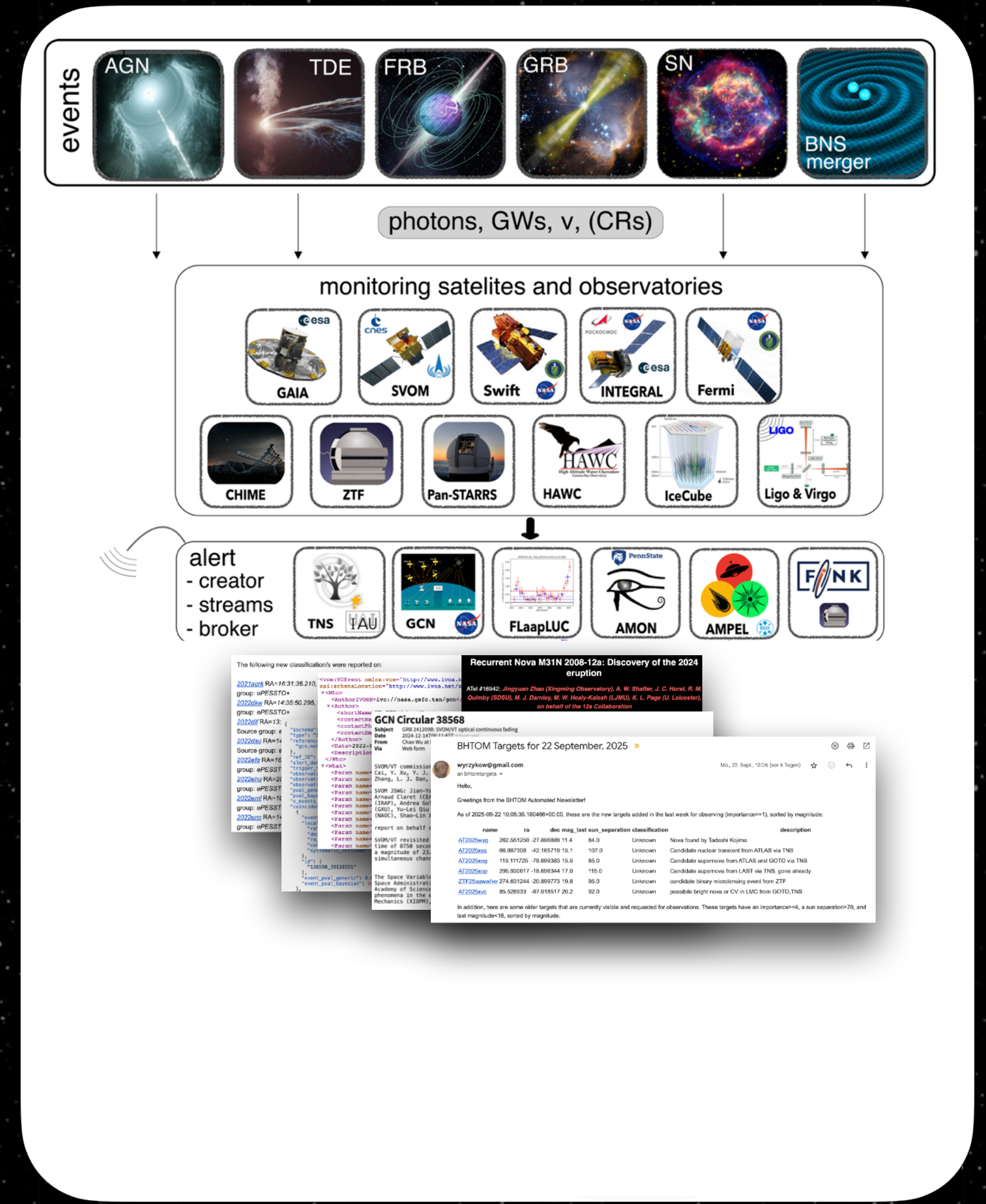
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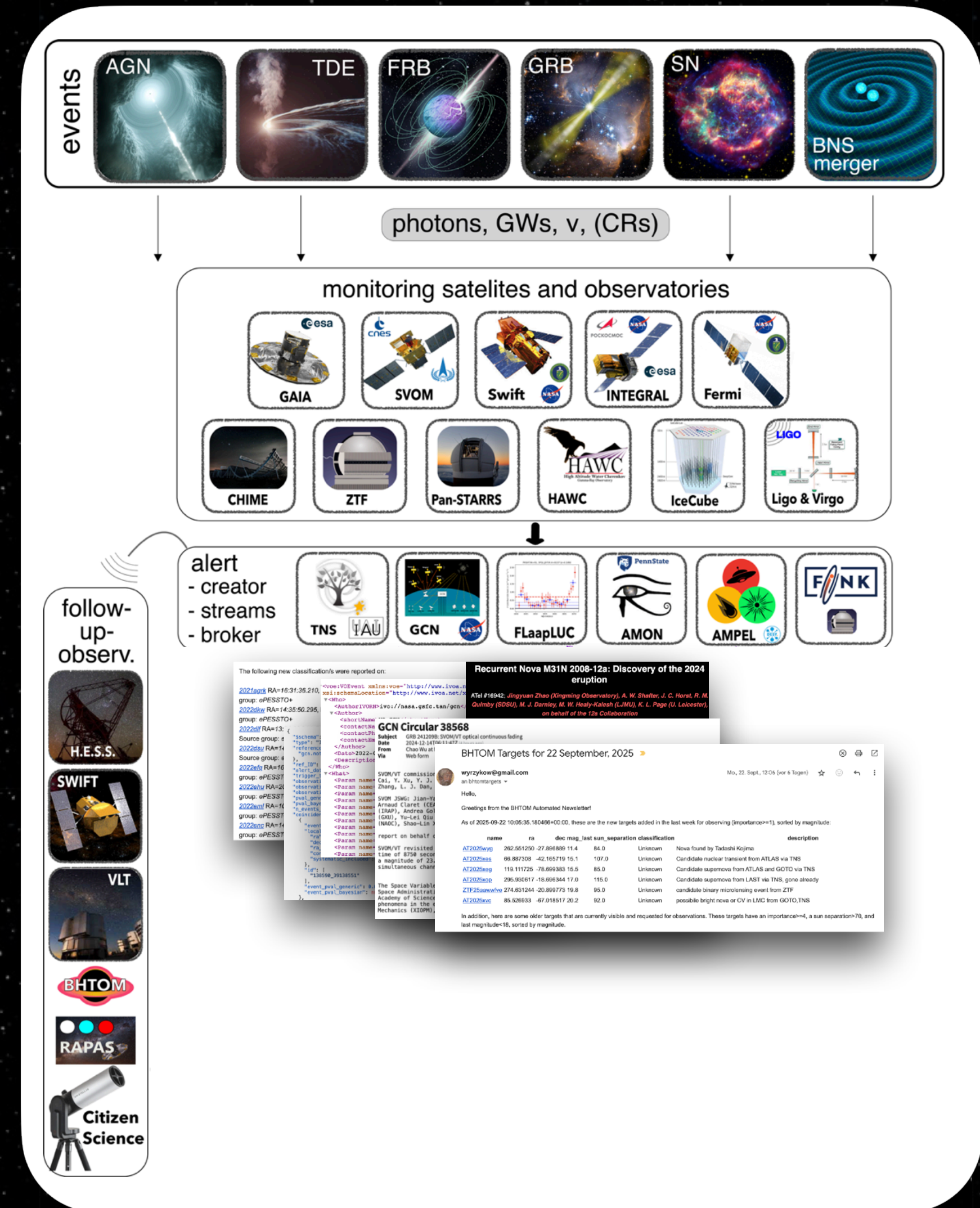
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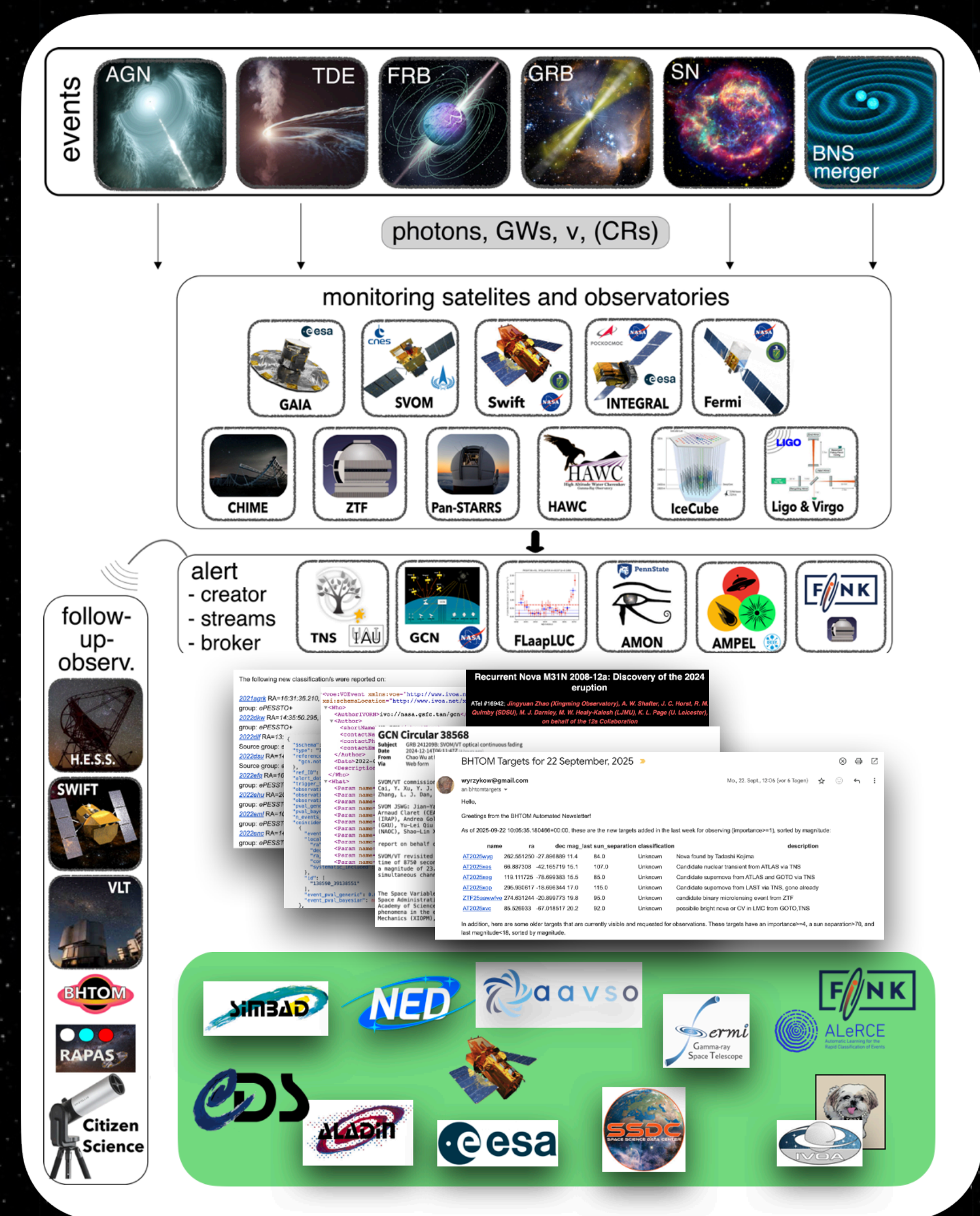
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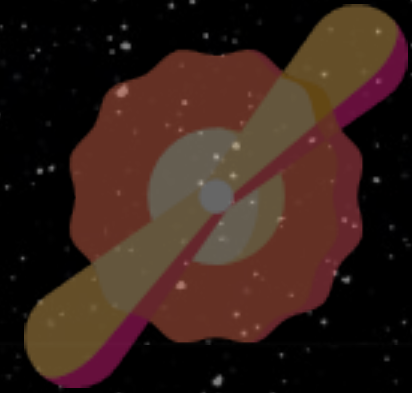


VHE astronomy with H.E.S.S.

Imaging Air Cherenkov Telescope (IACT) w/:

- *Khomas Highland, Namibia* (altitude: 1800m)
- Four 12m telescopes + one 28m telescope
- Field of view: $\sim 2.5^\circ$
- Energy sensitivity: ~ 100 GeV - 100 TeV
- Duty cycle: $\sim 15\%$
- Energy resolution: $\sim 15\%$
- Angular resolution: 0.1°





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GRBs & GW in VHE

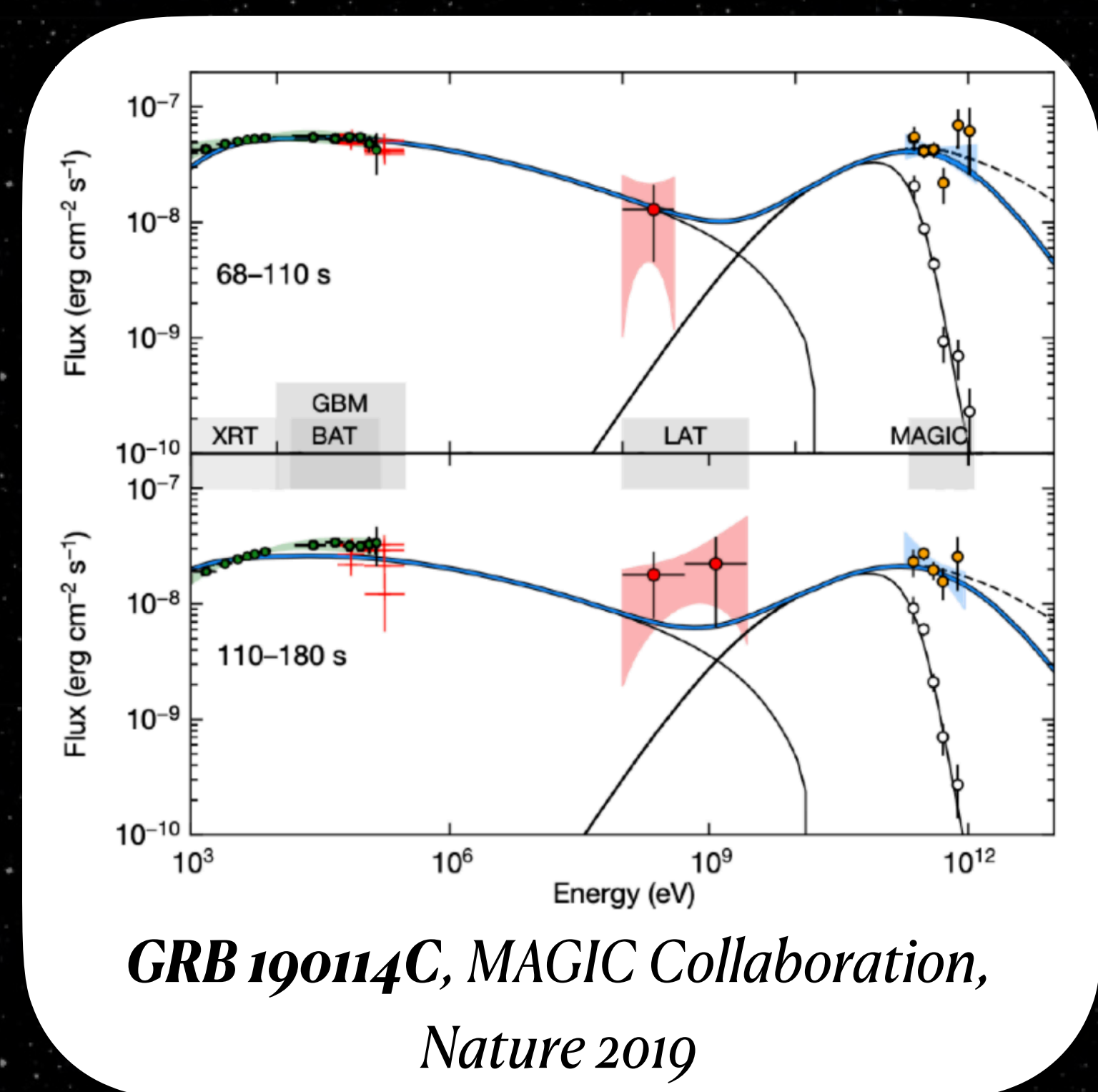
Very High Energy (VHE) detections of GRB and GW counterparts are essential to:

- Understand acceleration and radiation processes at energies unreachable on Earth
- Constrain jet composition and magnetic field structure
- Explore compact object physics and the nature of progenitors
- Test Lorentz invariance
- Study the EBL and intergalactic magnetic fields
- Measure cosmological parameters



GRBs & GW in VHE

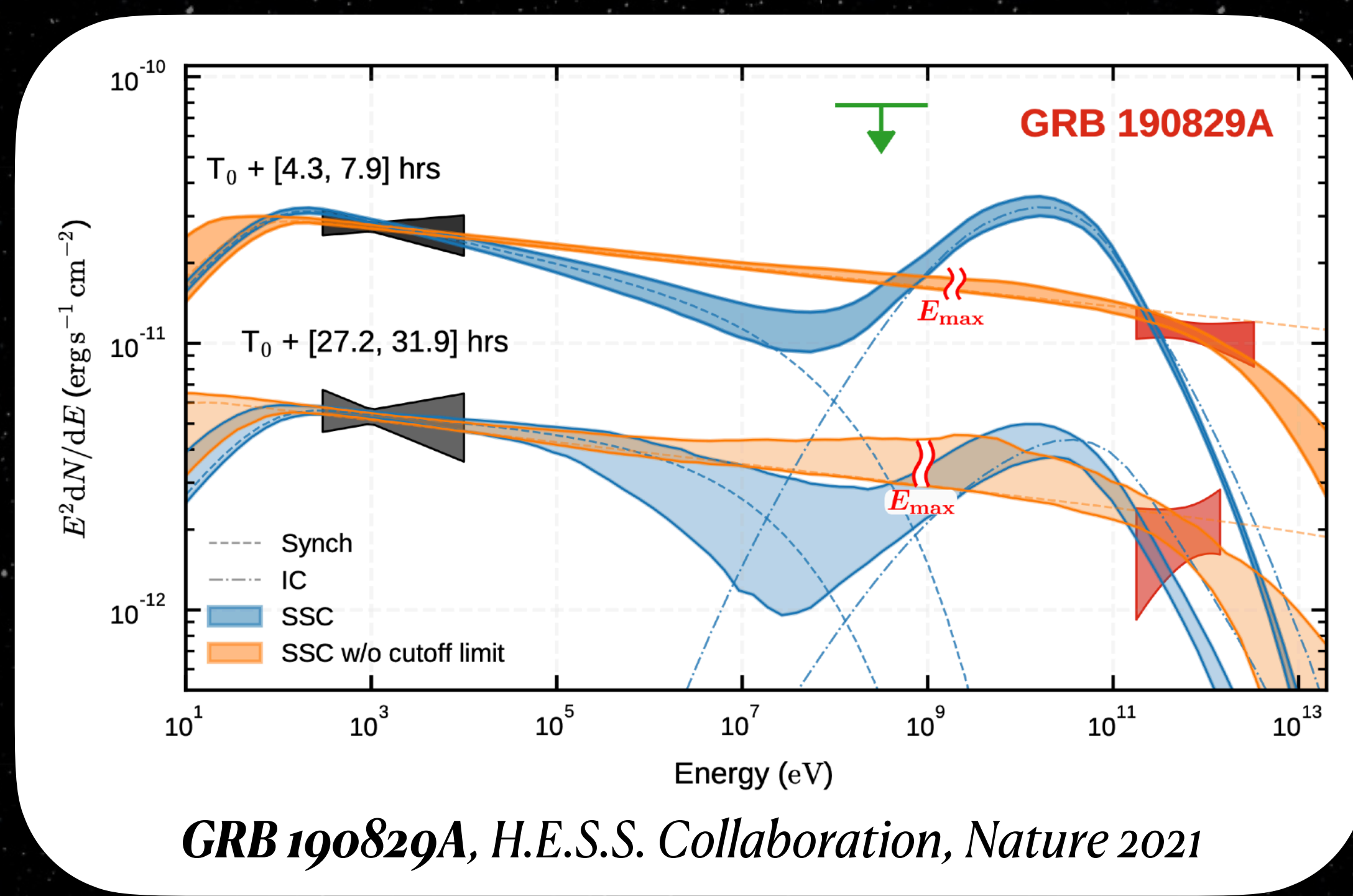
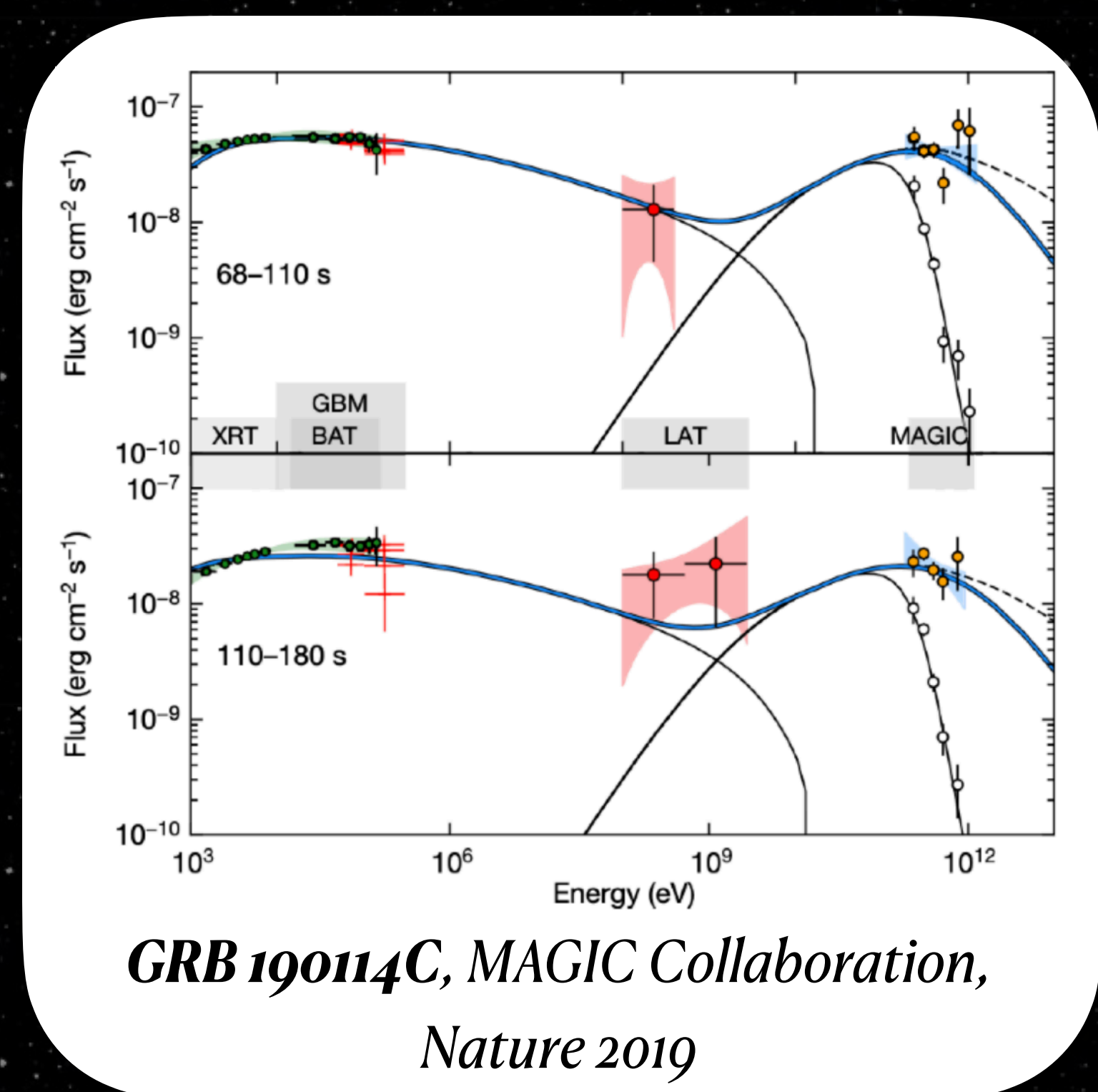
Previous detections of GRBs in VHE





GRBs & GW in VHE

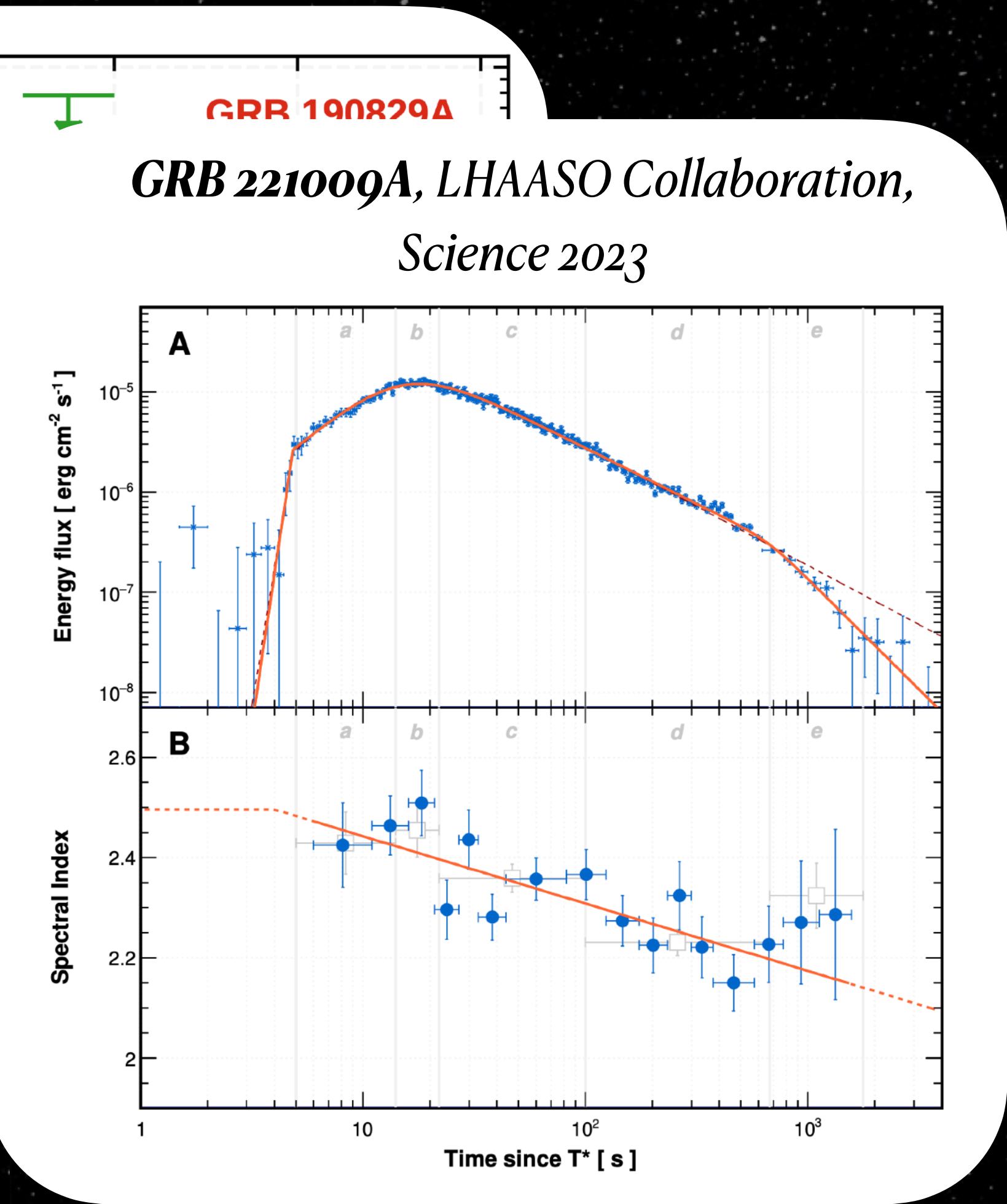
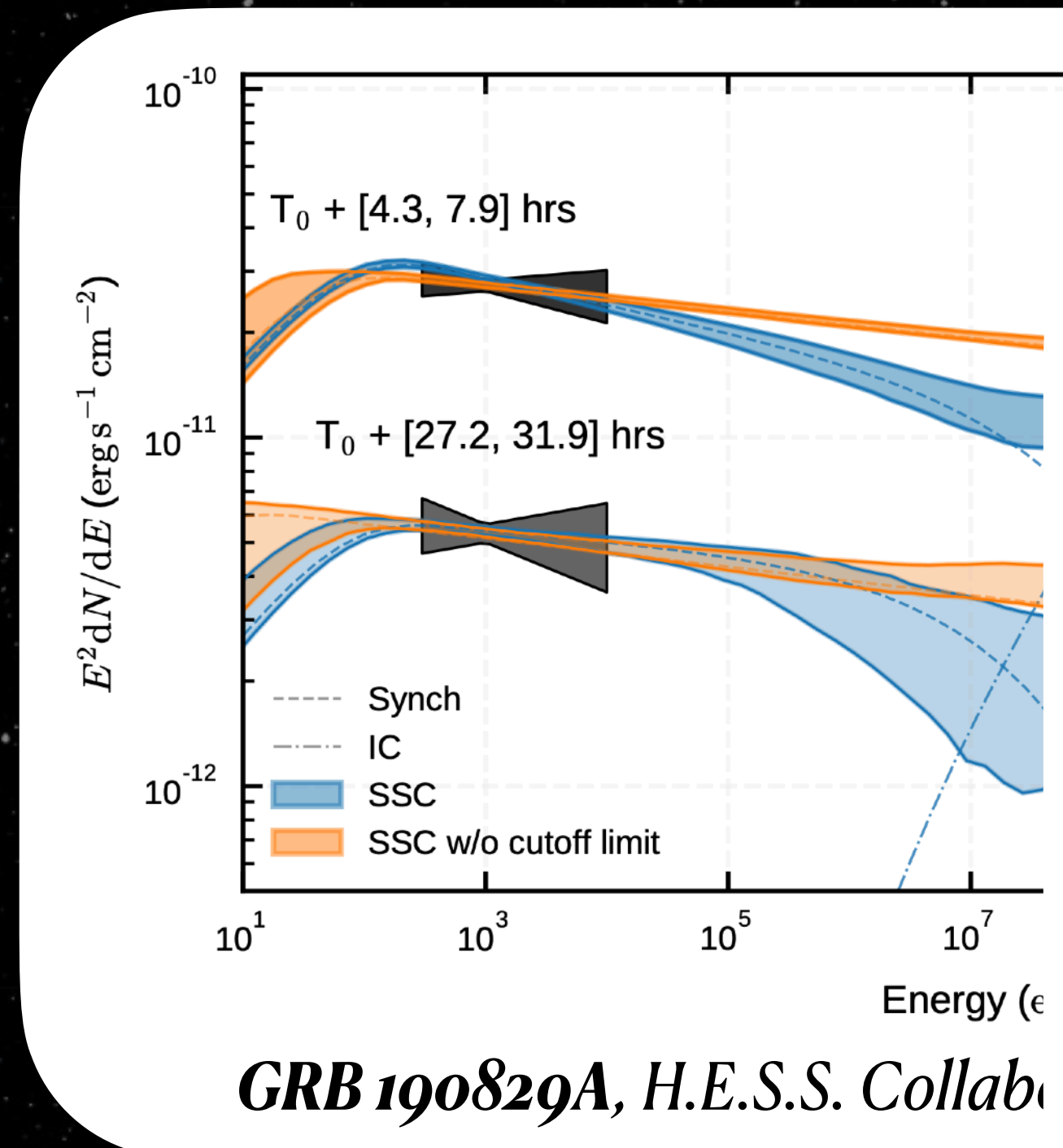
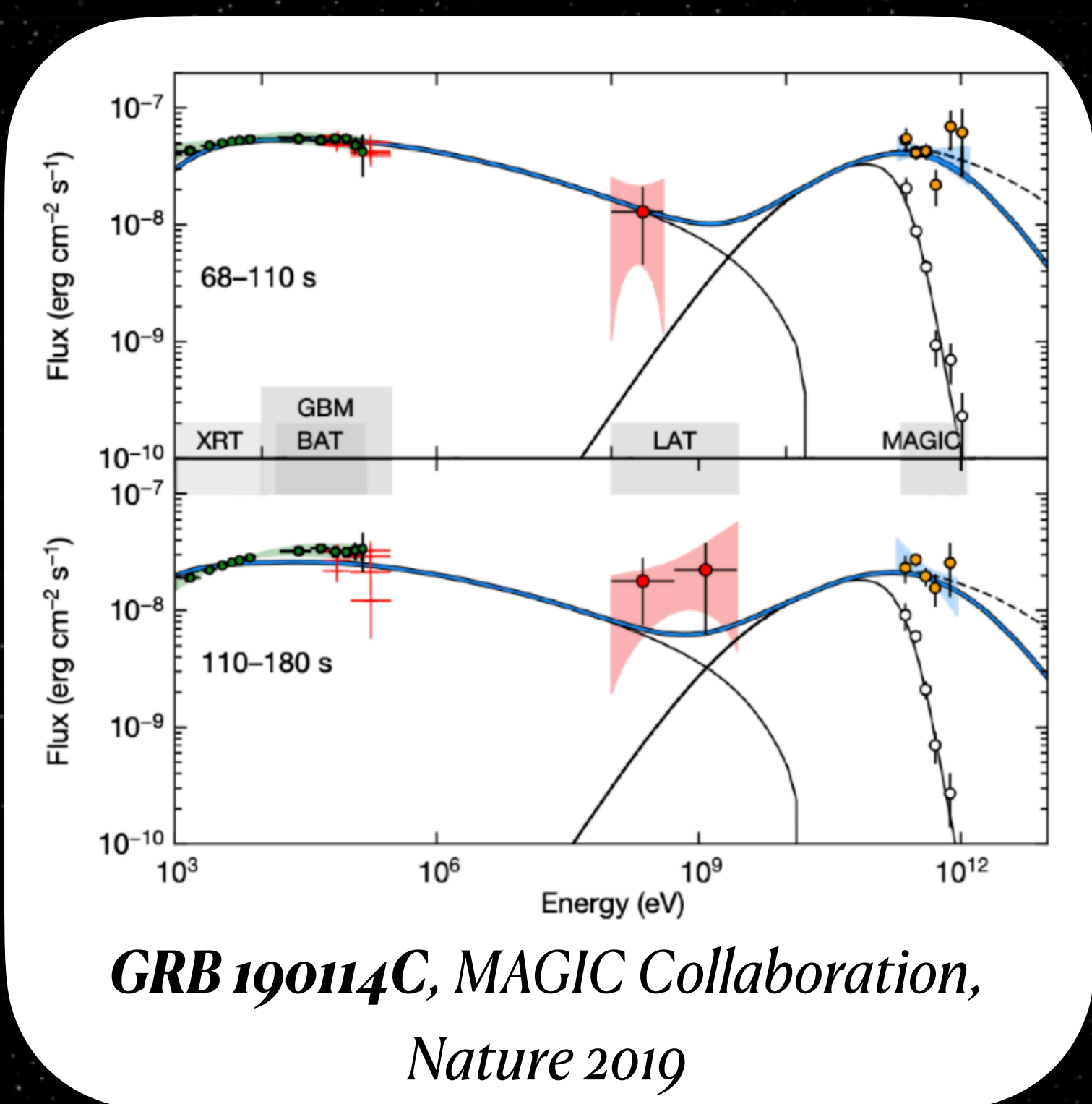
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GRBs & GW in VHE

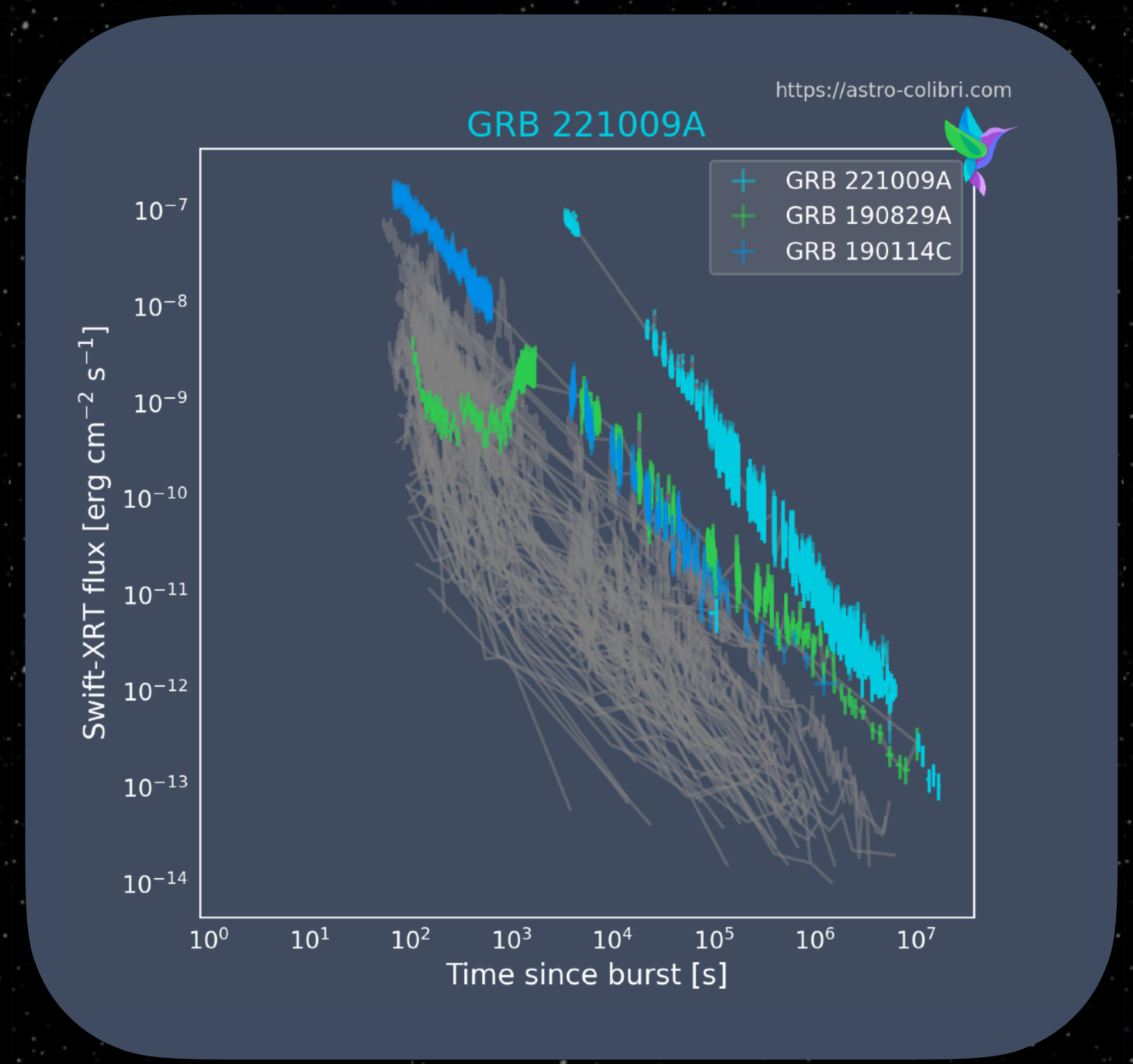
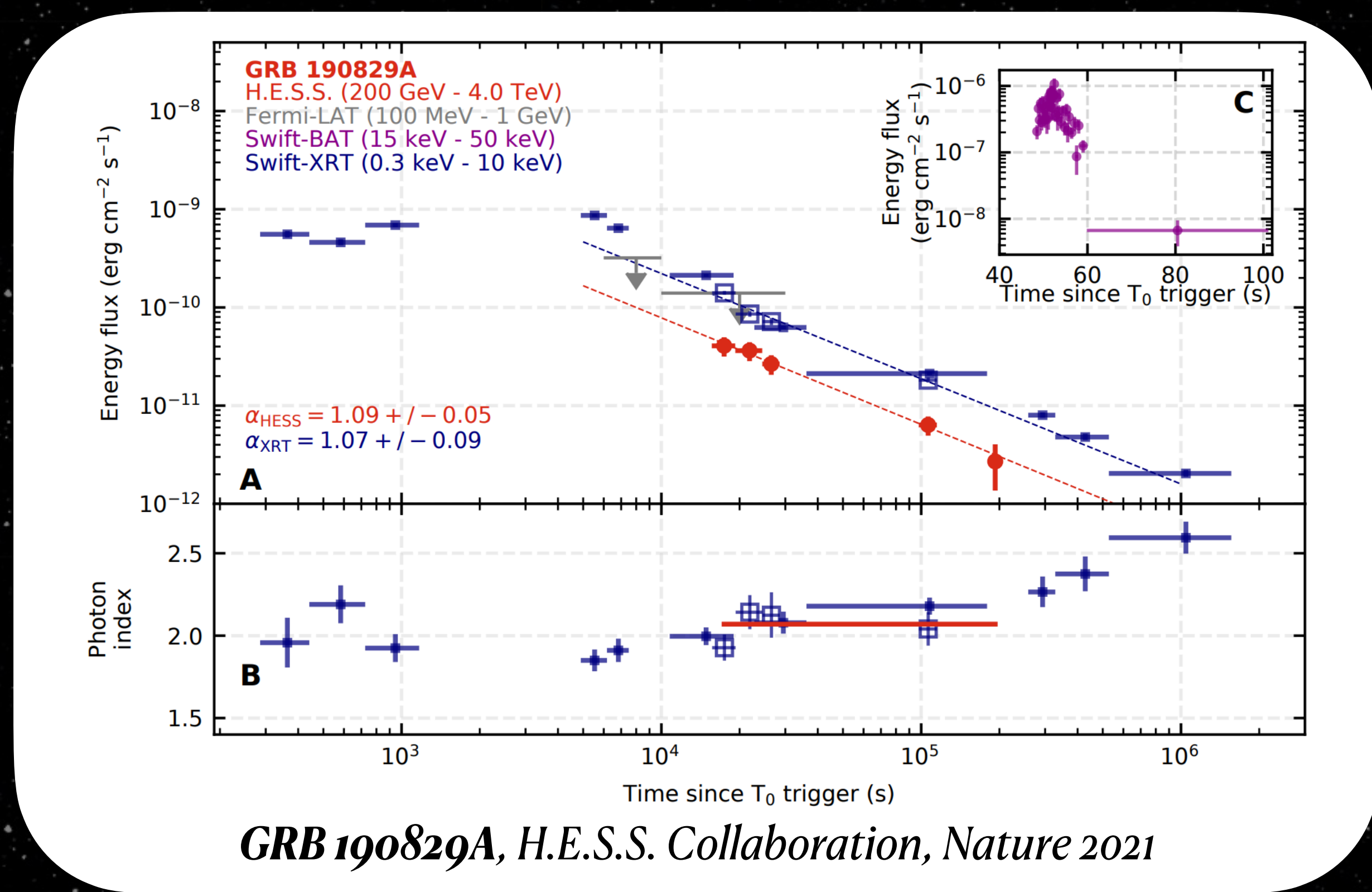
Previous detections of GRBs in VHE





GRBs & GW in VHE

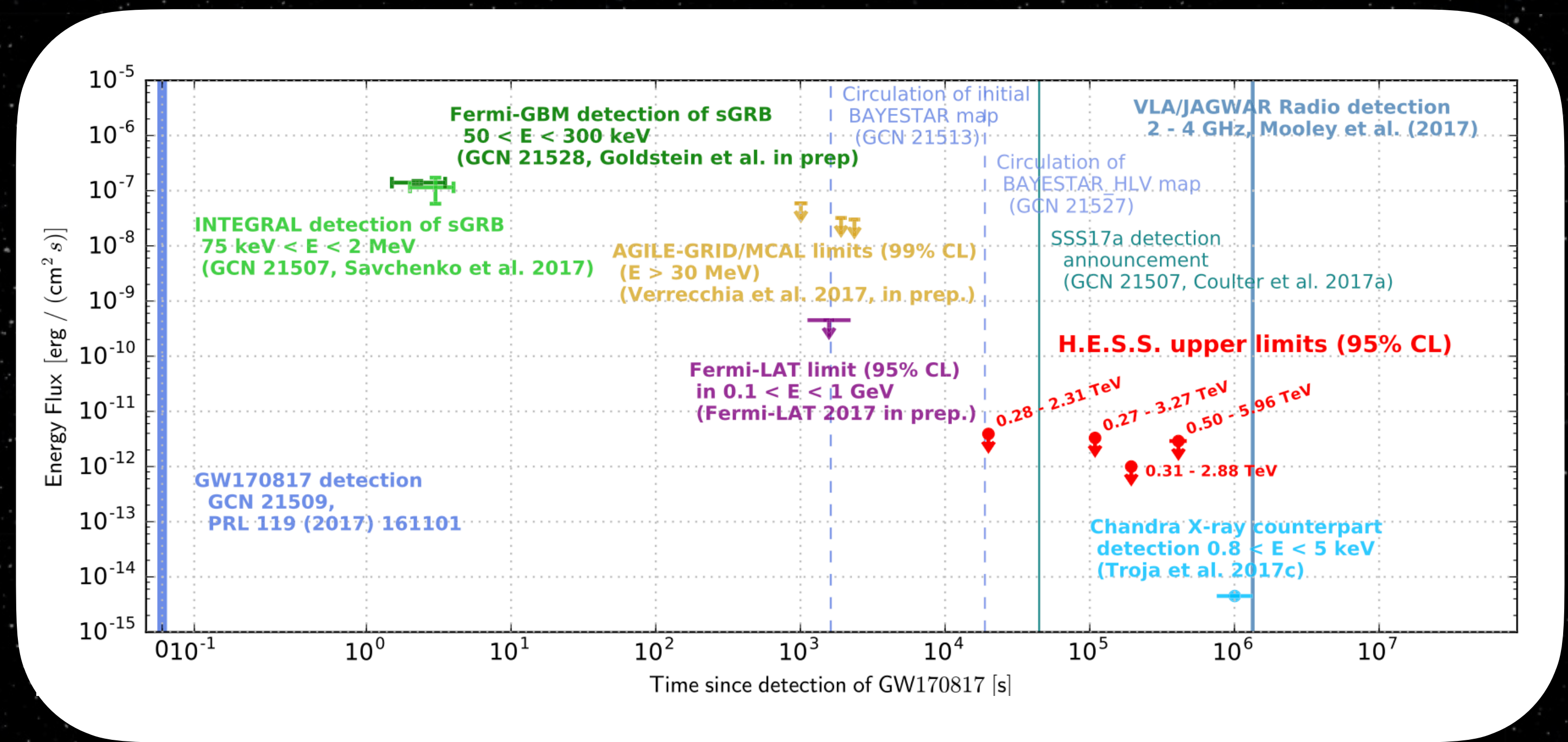
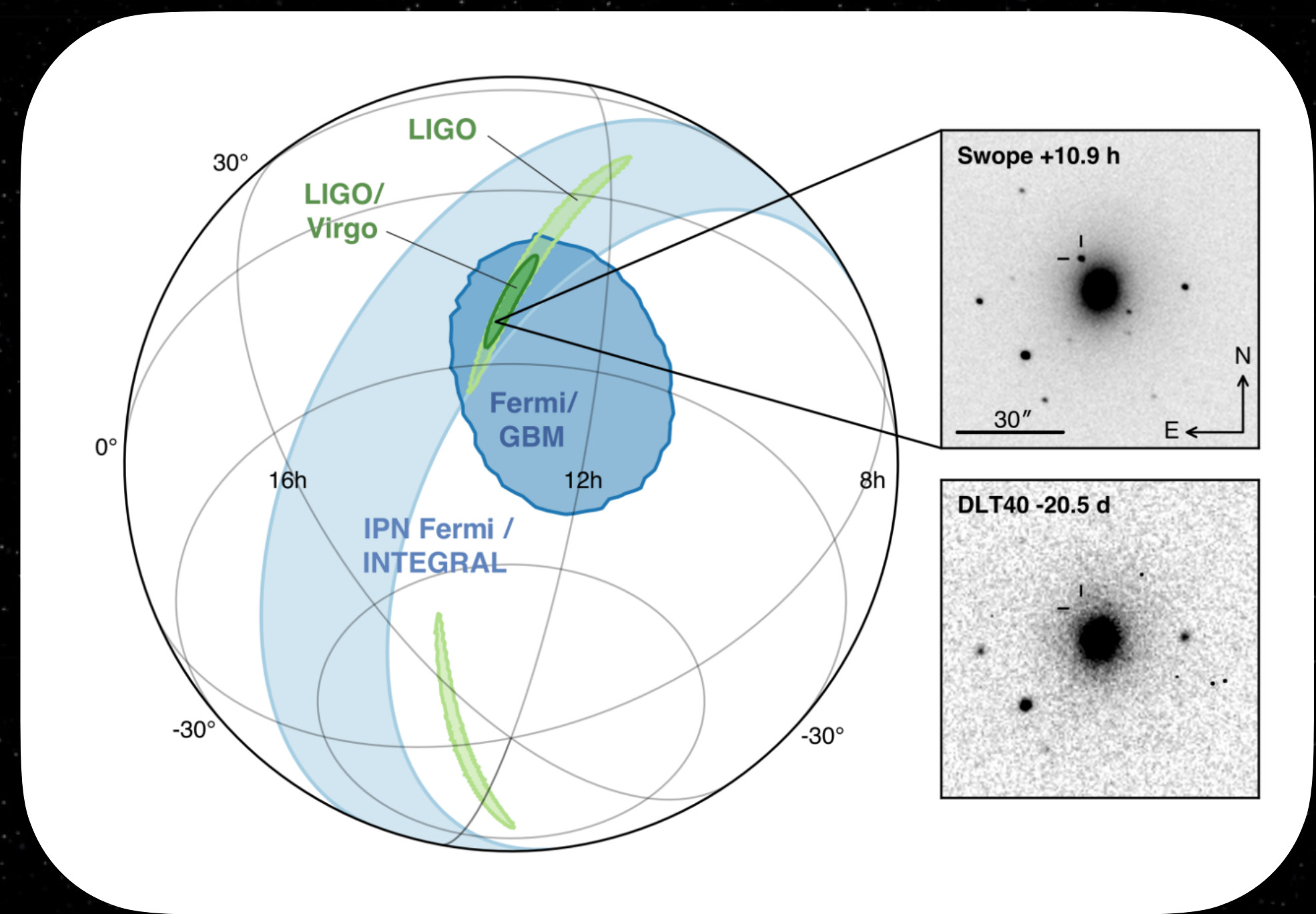
Previous detections of GRBs in VHE





GRBs & GW in VHE

The “holy grail” in multi-messenger astrophysics: GW170817



LIGO Collaboration (and many more), APJL 2017

H.E.S.S. Collaboration, APJL 2017





GRBs & GW in VHE

Cool! So GRB & GW counterpart detections in VHE are extremely useful and we had detections in just a couple years. Now in almost 2026 we should have many more, right?



GRBs & GW in VHE

Cool! So GRB & GW counterpart detections in VHE are extremely useful and we had detections in just a couple years. Now in almost 2026 we should have many more, right?

RIGHT?



GRBs & GW in VHE

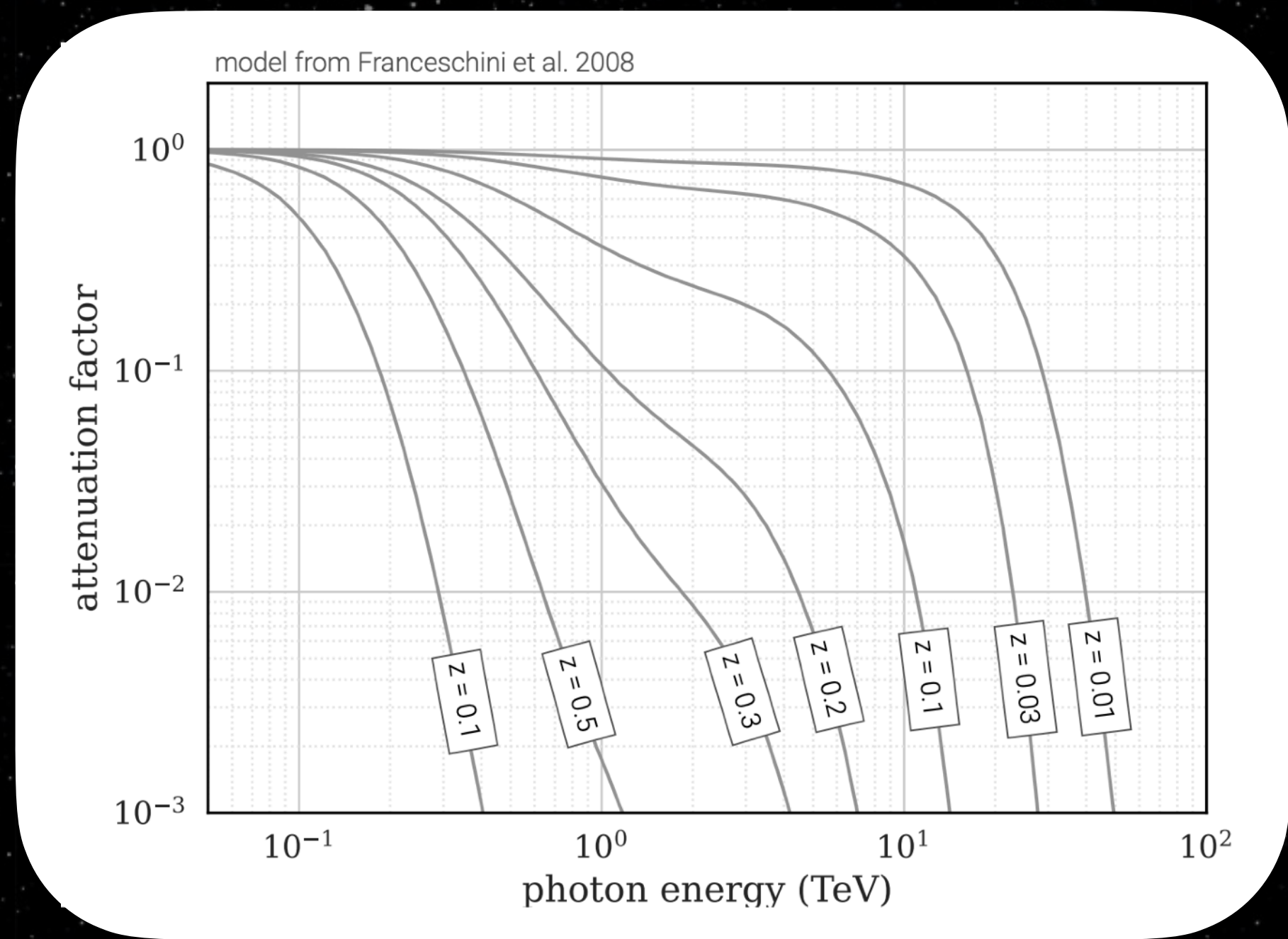
Cool! So GRB & GW counterpart detections in VHE are extremely useful and we had detections in just a couple years. Now in almost 2026 we should have many more, right?

NO!



GRBs & GW in VHE

Many observational constraints for IACTs + bright close GRBs are rare (EBL absorption) + high energy emission from GRBs could be rare?



From Sylvia Zhu



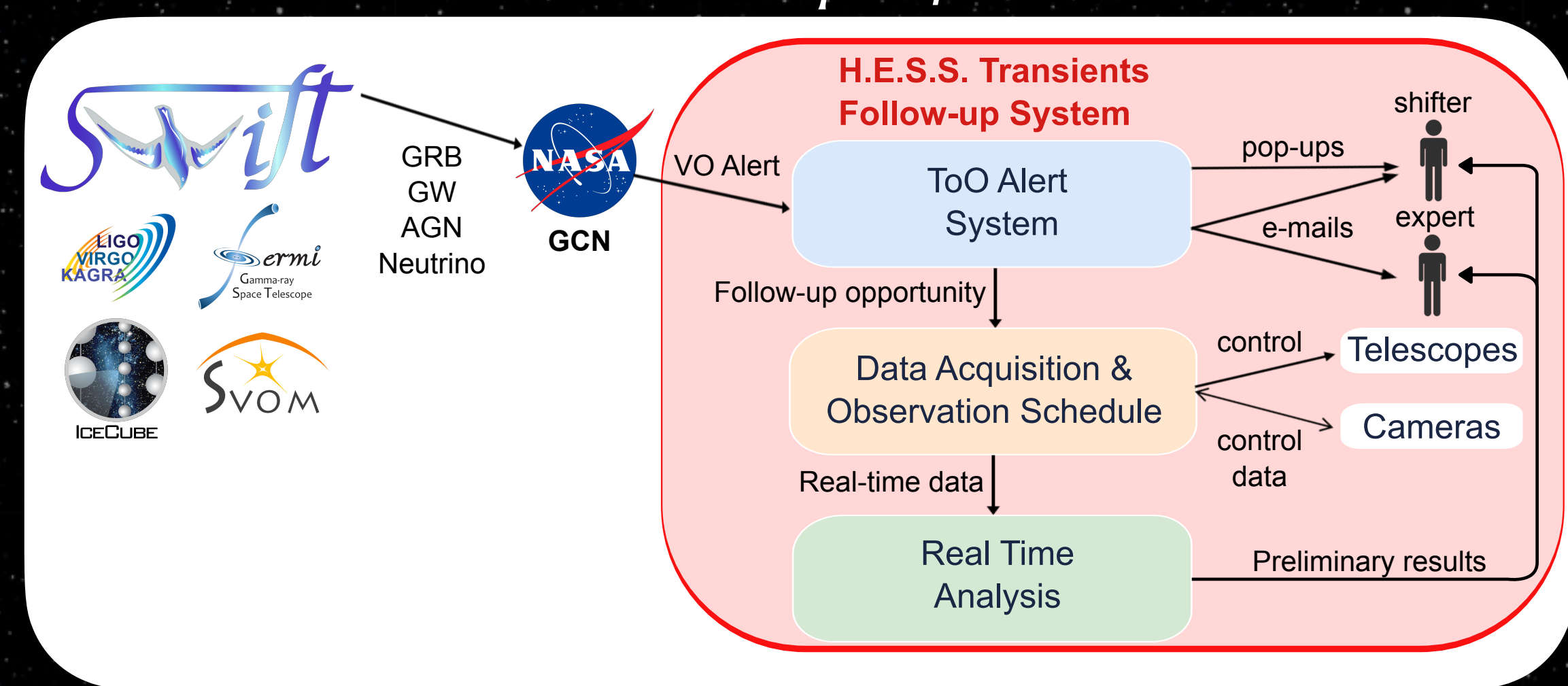


The H.E.S.S. response system

H.E.S.S. has an **automatic** response system allowing for **fast follow-up** of transient sources

1. Incoming public alerts filtered following event-dependant criteria and visibility conditions
2. If visible, an automatic response is triggered. If not, strategy is discussed within each group
3. During observations, real-time analysis has to be monitored
4. After observations, an offline analysis is performed and further strategy is discussed

Adapted from Ashkar H. et al. 2021



Semi-automatic
We need a human on the loop!



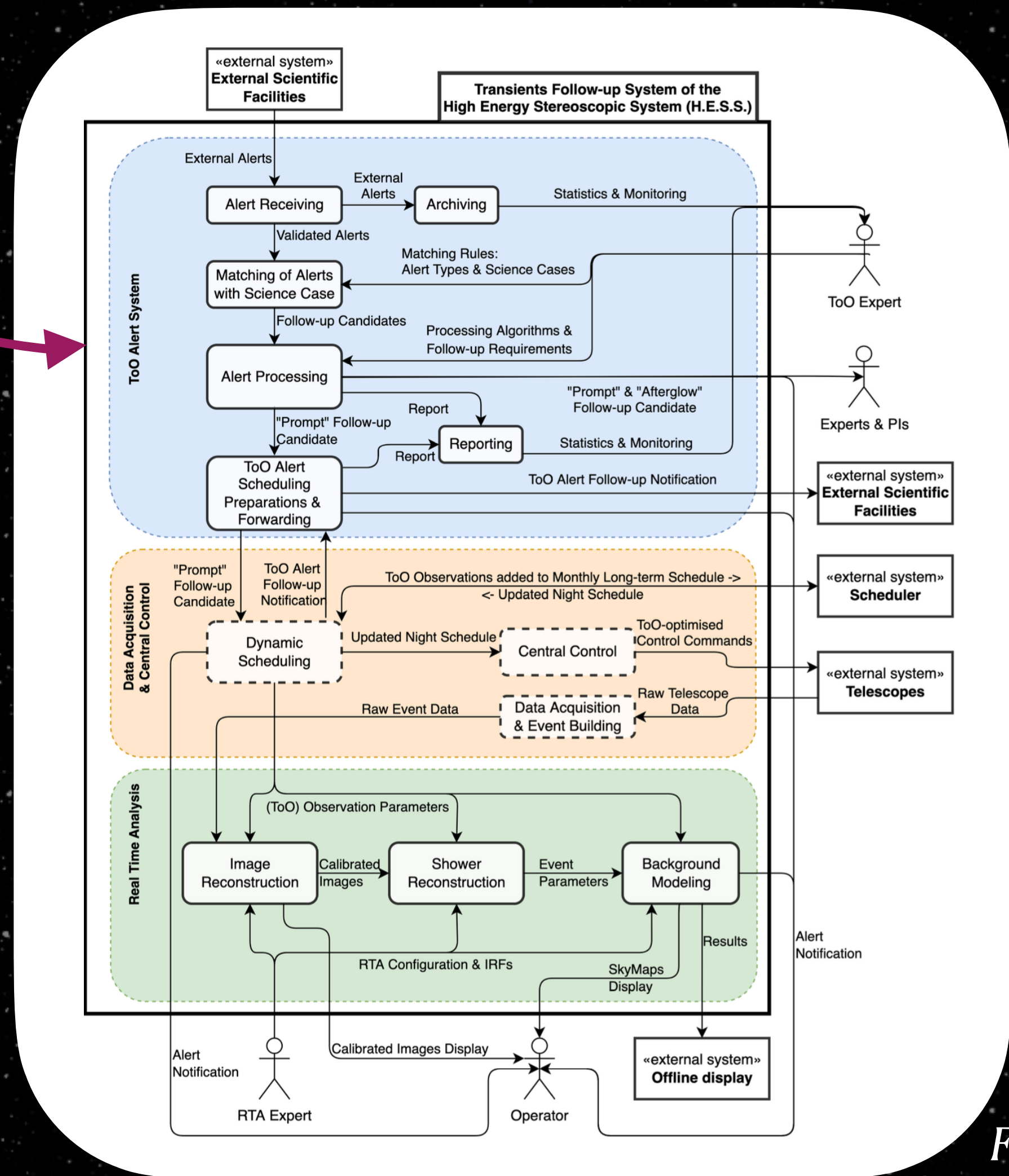


The H.E.S.S. response system

Responsible for this part

+

Many BA shifts



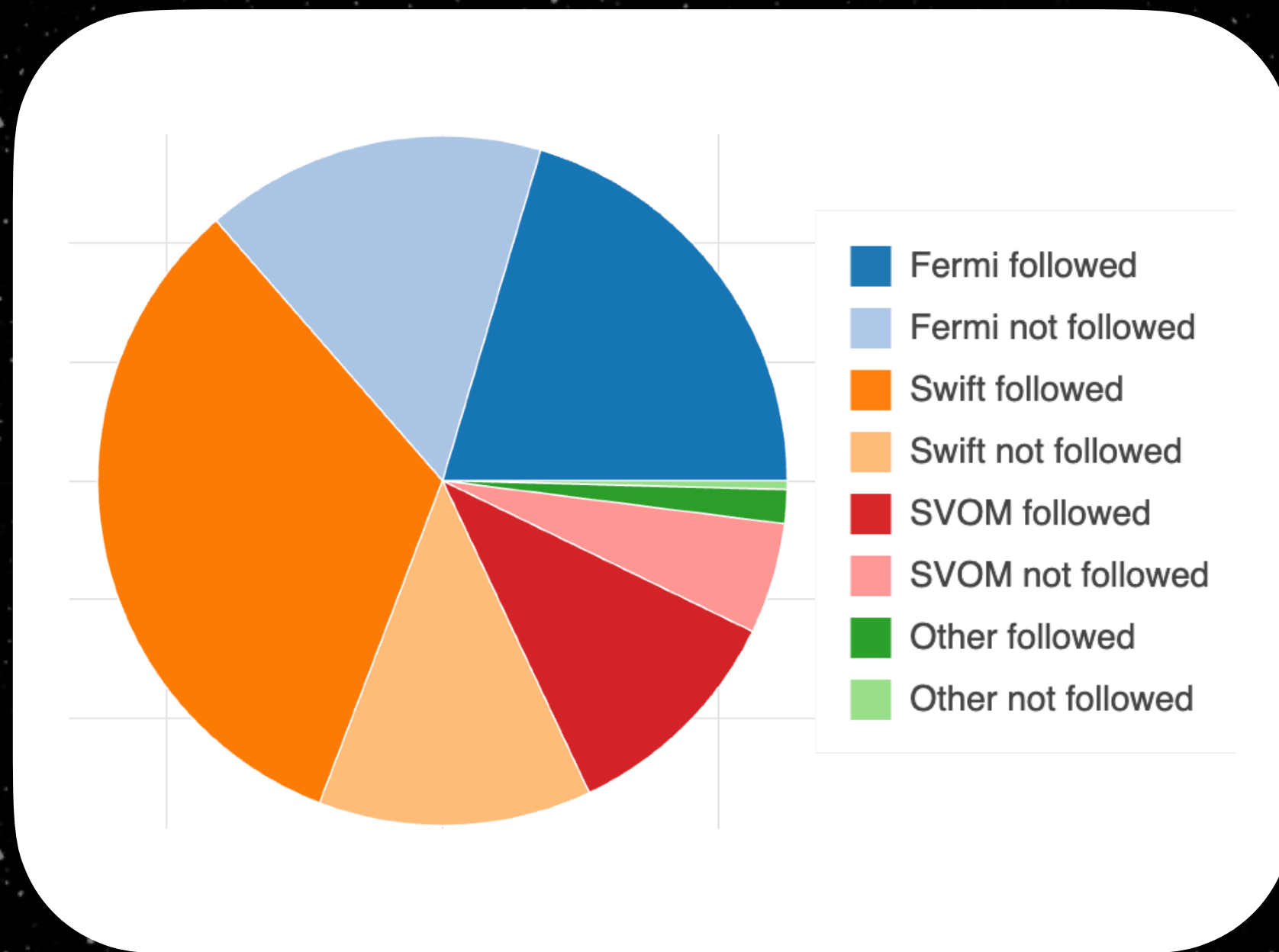
From Hoischen C. et al. 2022



The H.E.S.S. GRB & GW follow-up program

Co-task leader for the GRB & GW follow-up effort within H.E.S.S.. Responsible for **current follow-ups** and **archival data from 2020 onwards**. H.E.S.S. follow-up information is available [here](#).

GRBs:



- 2230 GRB alerts*
- 250 passed our observation criteria (~11%)
- 164 were actually followed (~7%)
- 49 of the followed ones have a redshift

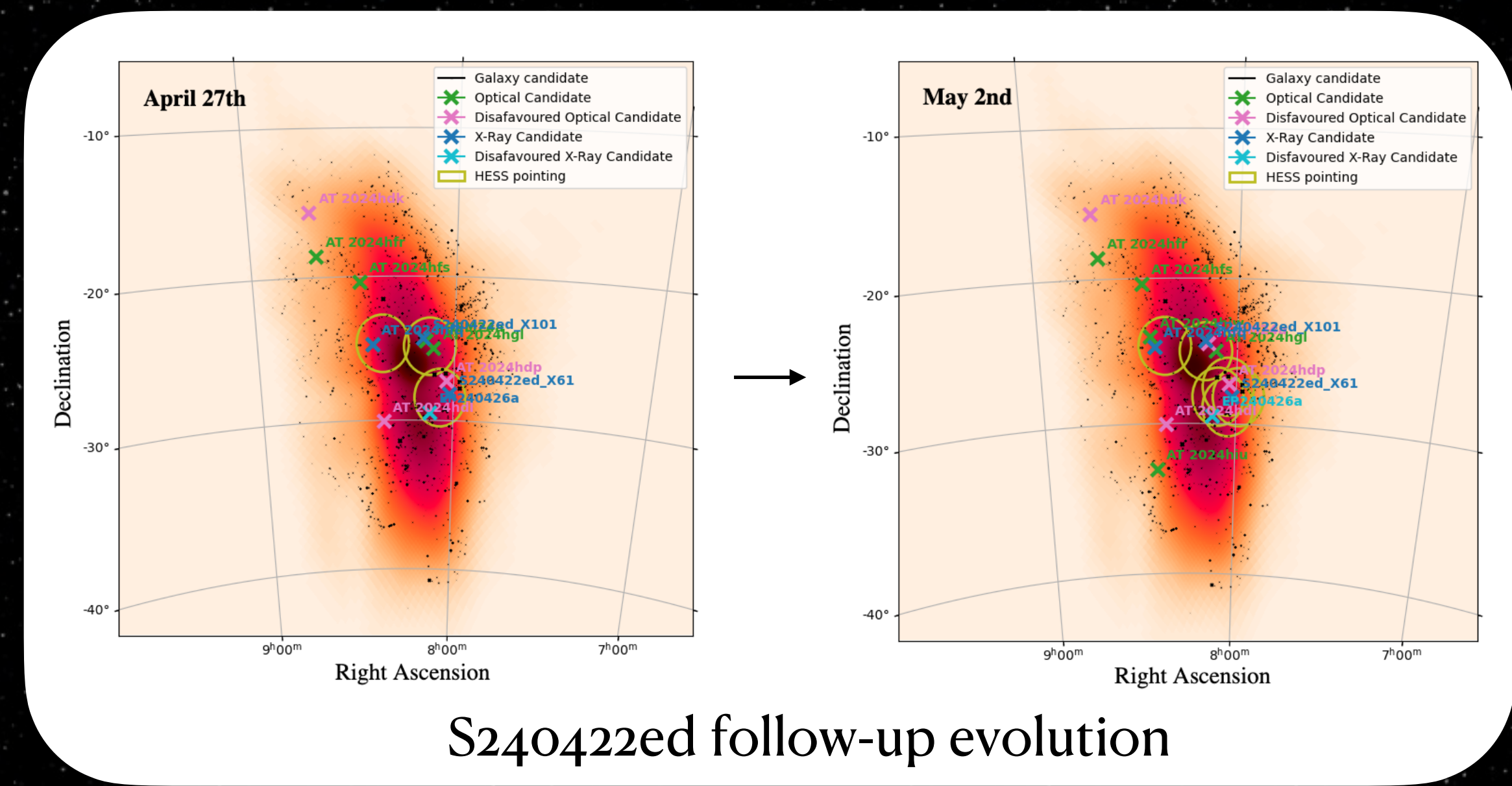
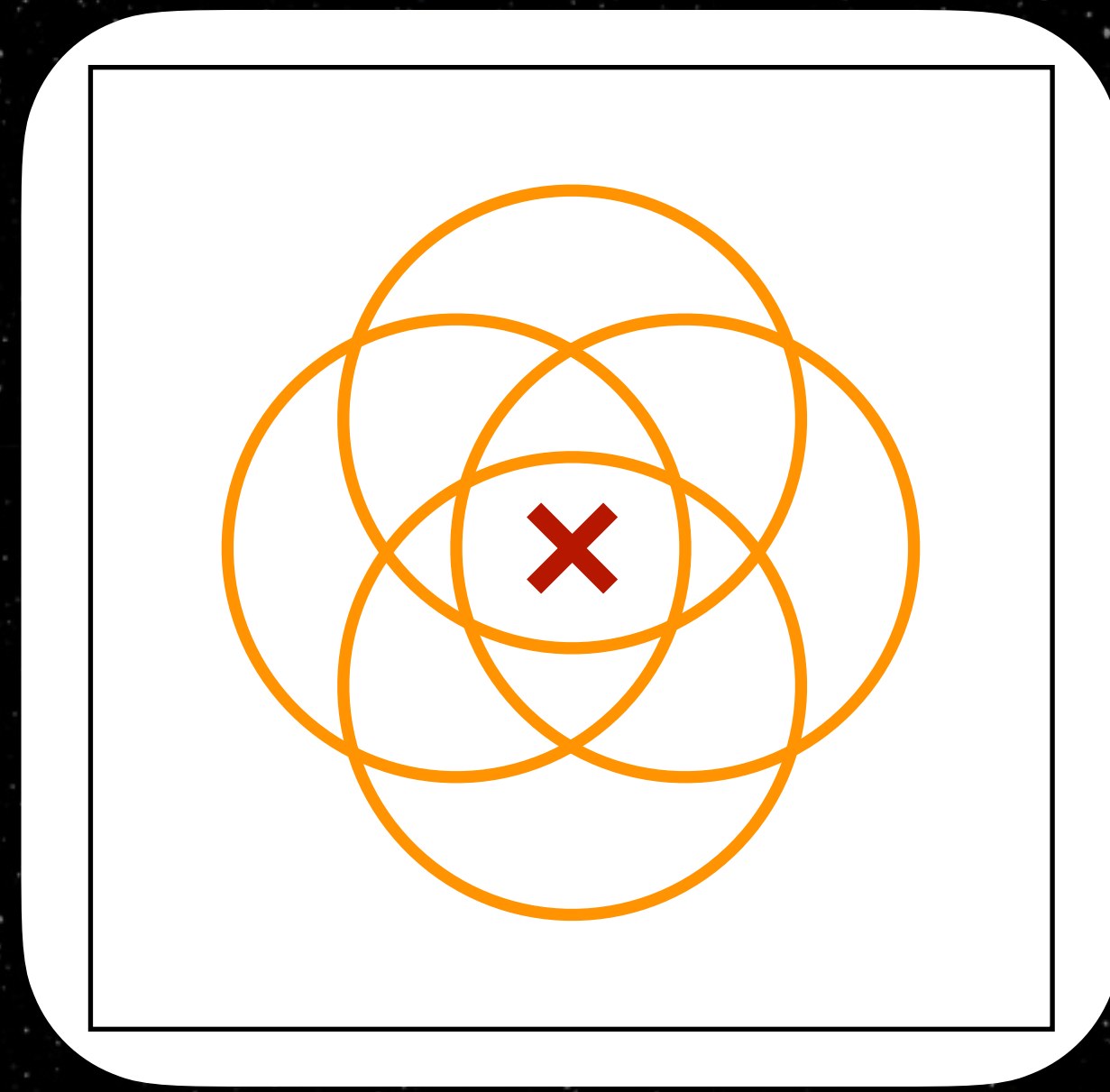


* from [GRBWeb](#)



The H.E.S.S. GRB & GW follow-up program

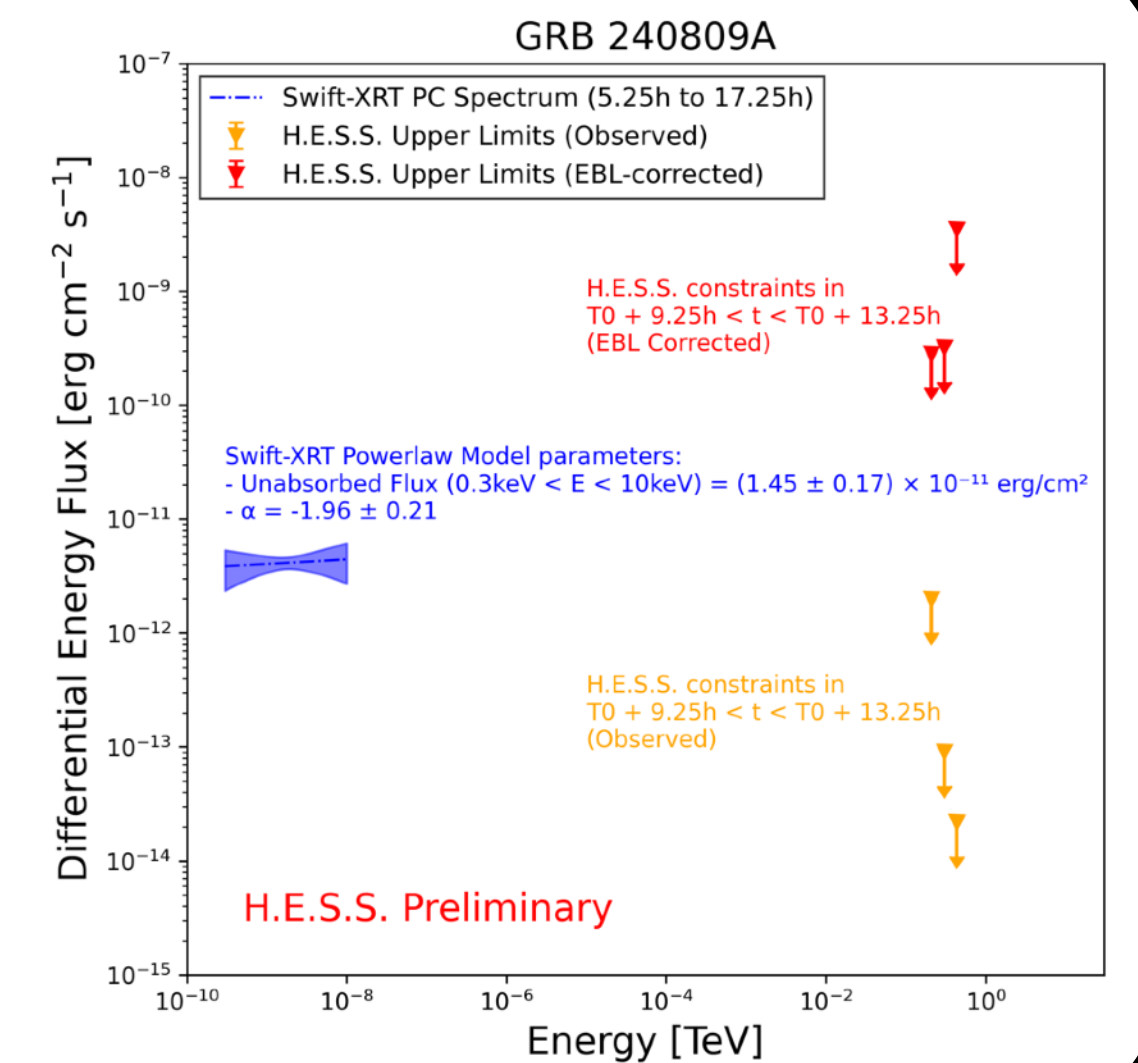
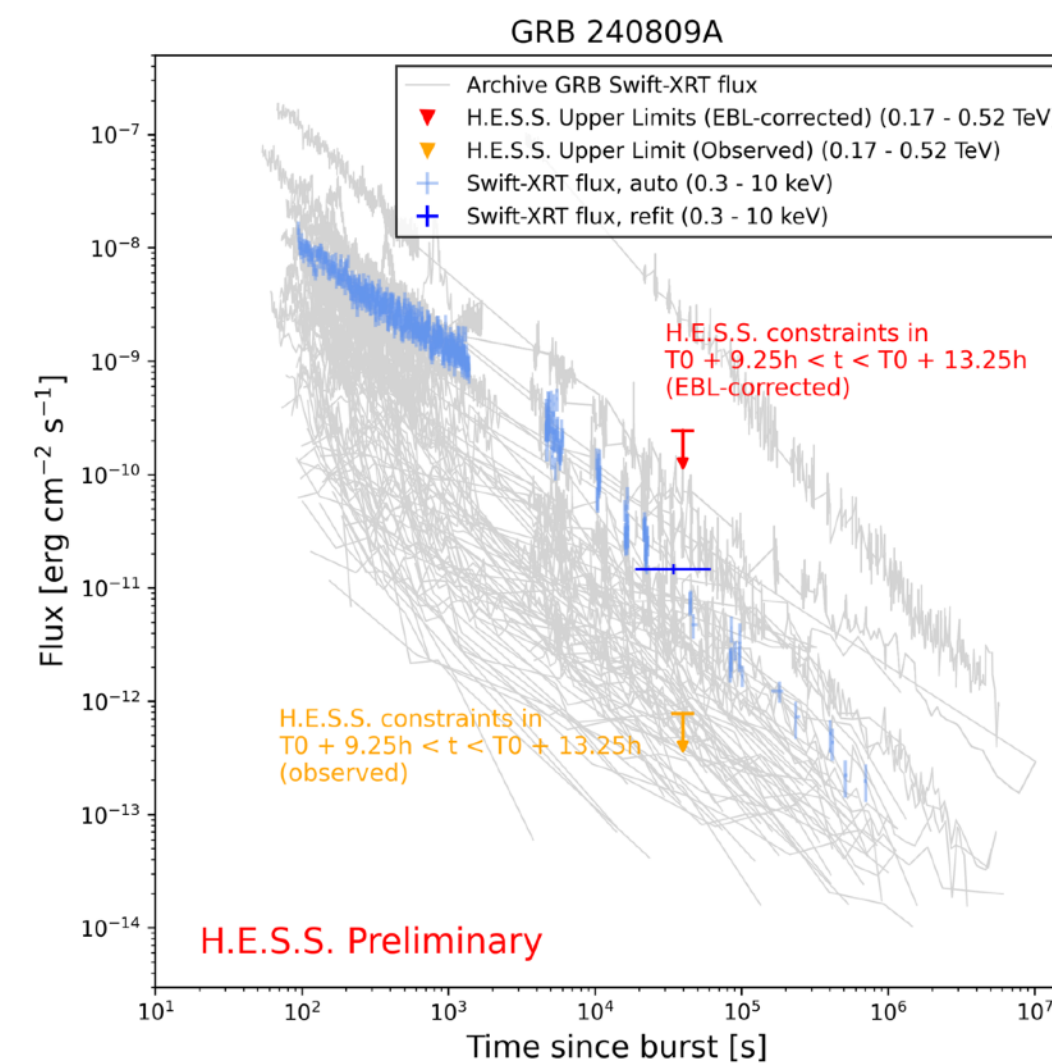
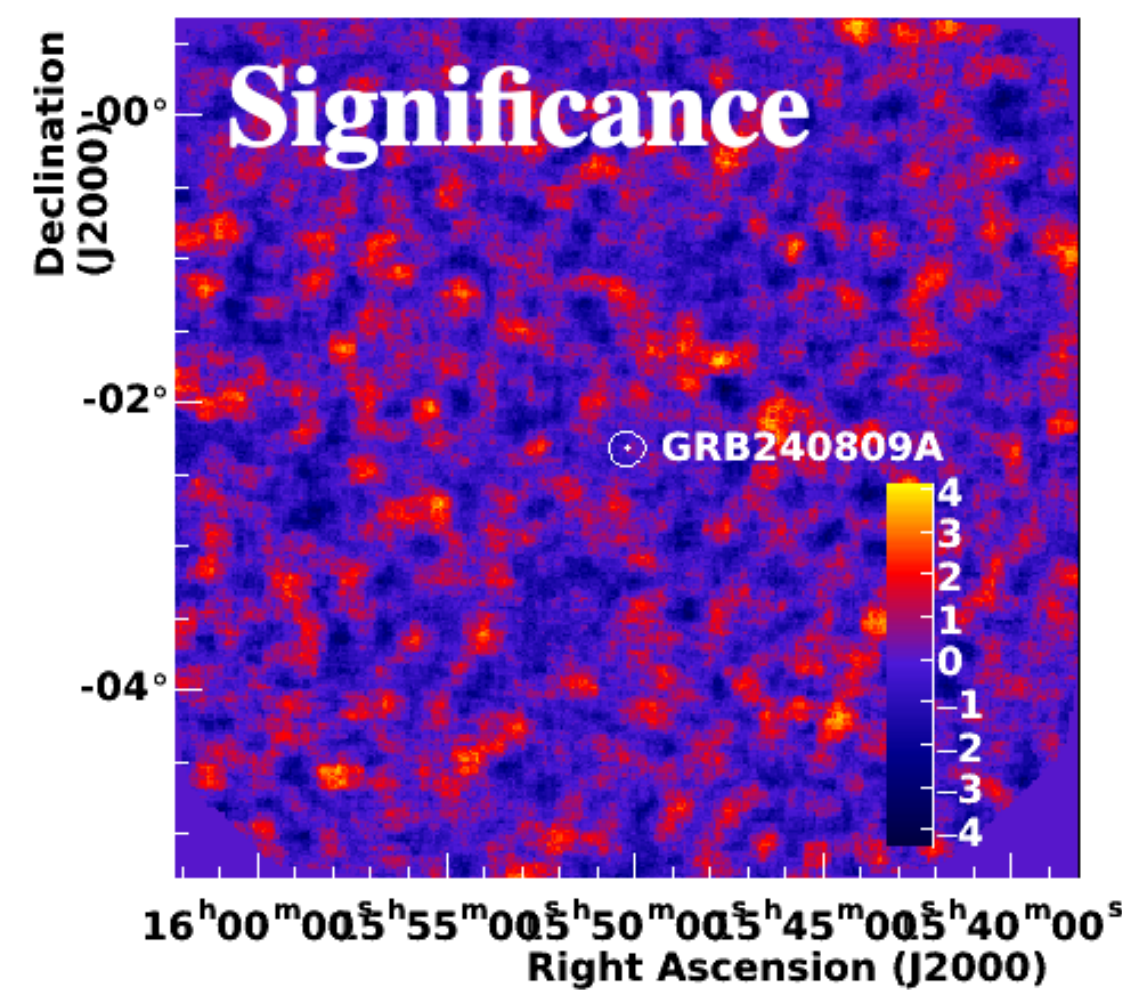
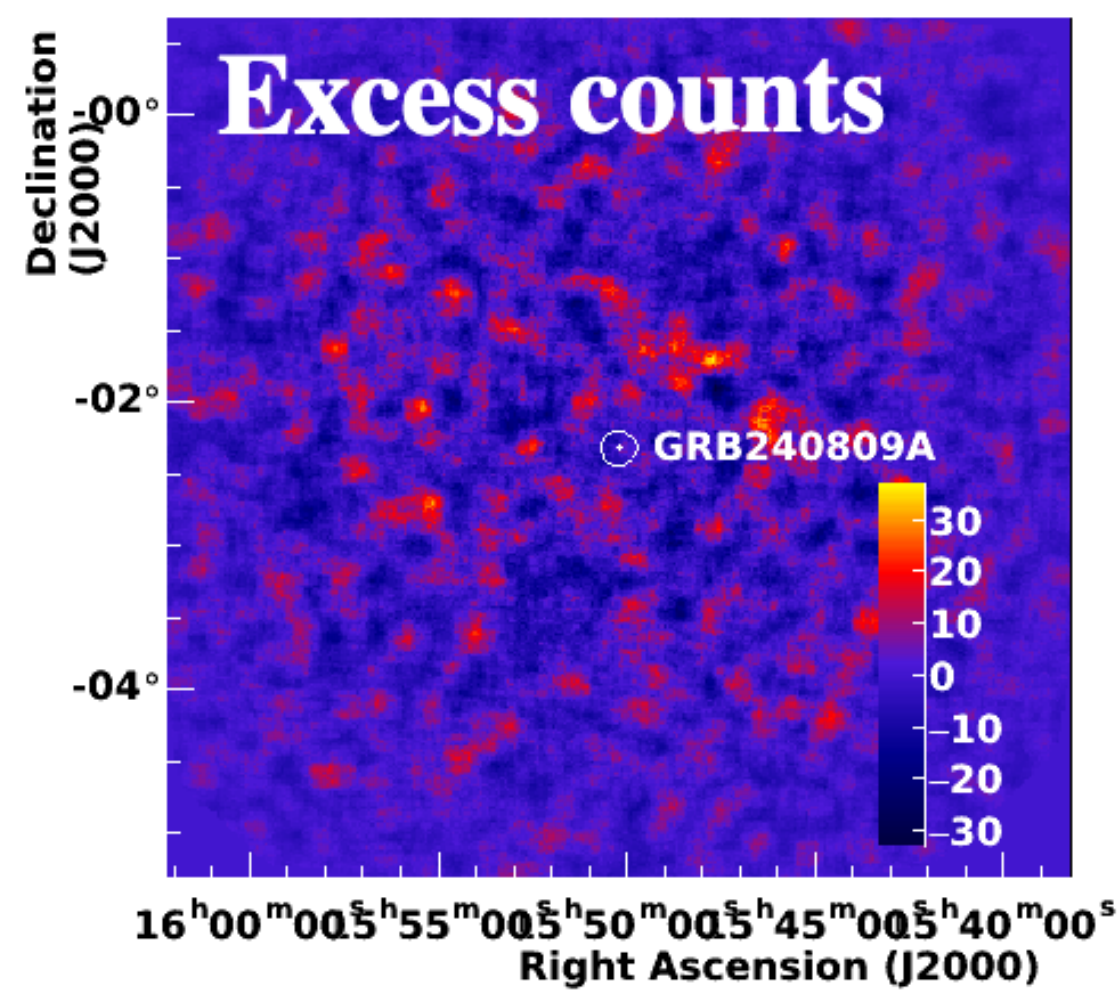
Typical examples of Target-of-Opportunity (ToO) follow-ups. If the alert is well-localized, we wobble around the source position. If not, we tile the uncertainty area with as many runs as we can with the time available. Strategies heavily depend on alert updates and change overtime





The H.E.S.S. GRB & GW follow-up program

Typical example of a GRB follow-up analysis, including **excess and significance maps, lightcurve** and **spectral energy distribution** into a **multi-wavelength context**. GRB 240809A with $z = 1.494$





The H.E.S.S. GRB & GW follow-up program

Present and future work:

For GRBs : VHE detected GRBs are X-ray bright and nearby -> Look into the archive of H.E.S.S. follow-ups for alerts of X-ray bright GRBs with a “small” redshift. Analyze this dataset in order to study the relationship between X-ray and gamma emission

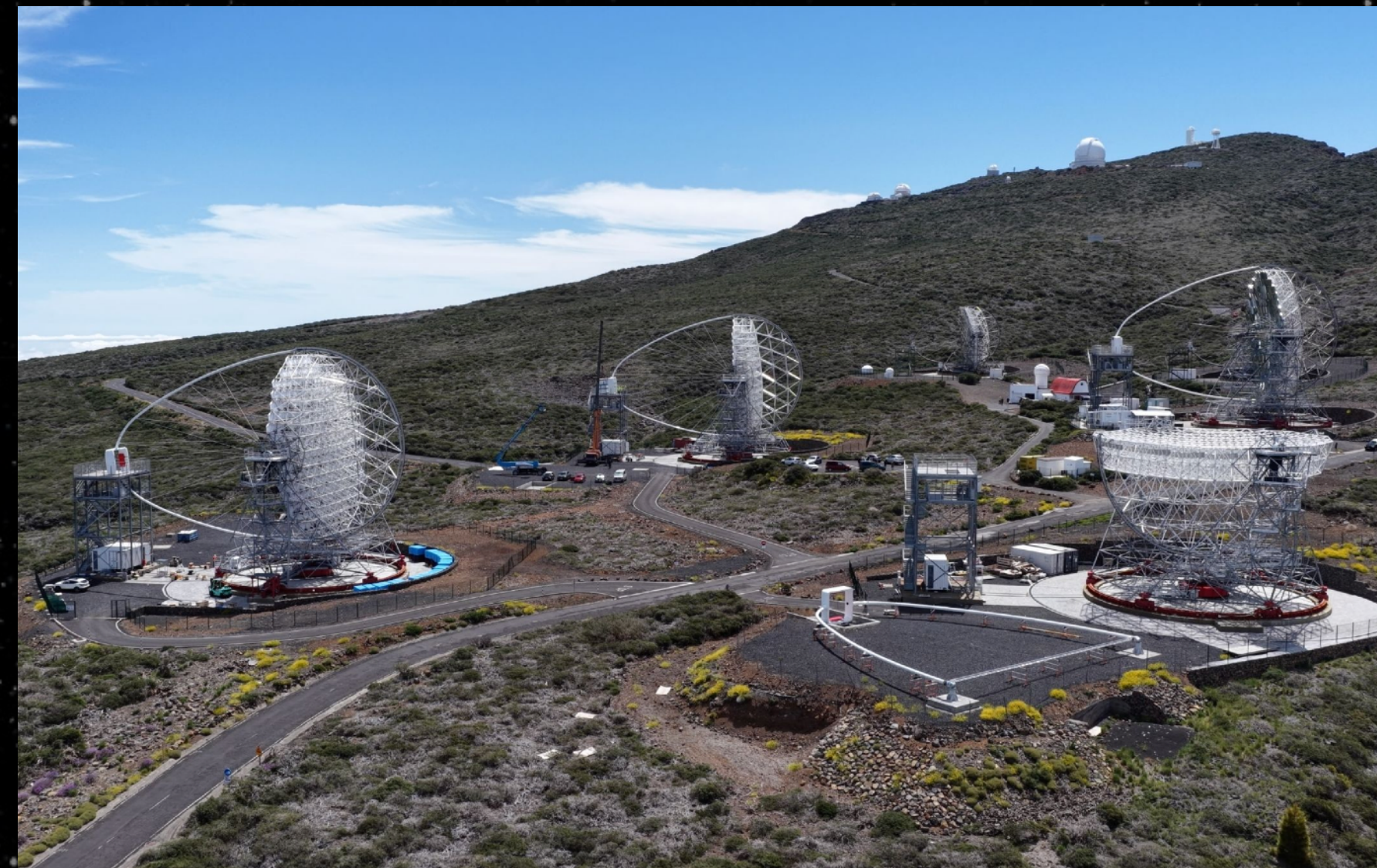
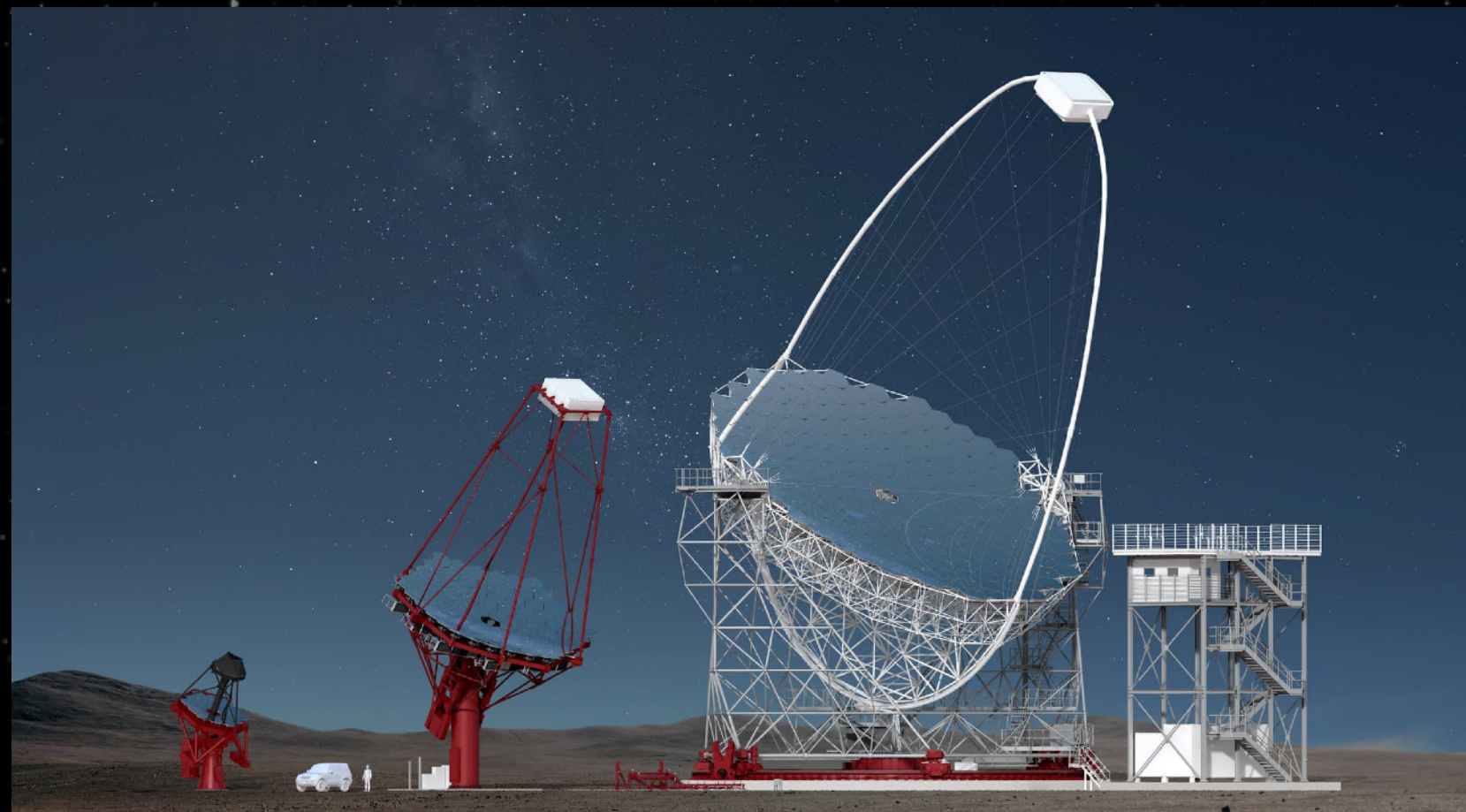
For GWs: Run O₄ of LVK has just come to an end -> Analyze the H.E.S.S. dataset on GW follow-up from this period



Future of VHE follow-ups

Transient follow-ups need a **rapid-response time** ensured by an efficient internal strategy and architecture supported by the right use of external tools. A **lower energy threshold** would allow us to reach for dimmer and further events (**bigger arrays!**).

Future **Cherenkov Telescope Array Observatory (CTAO)**:



Energy threshold
~20 GeV

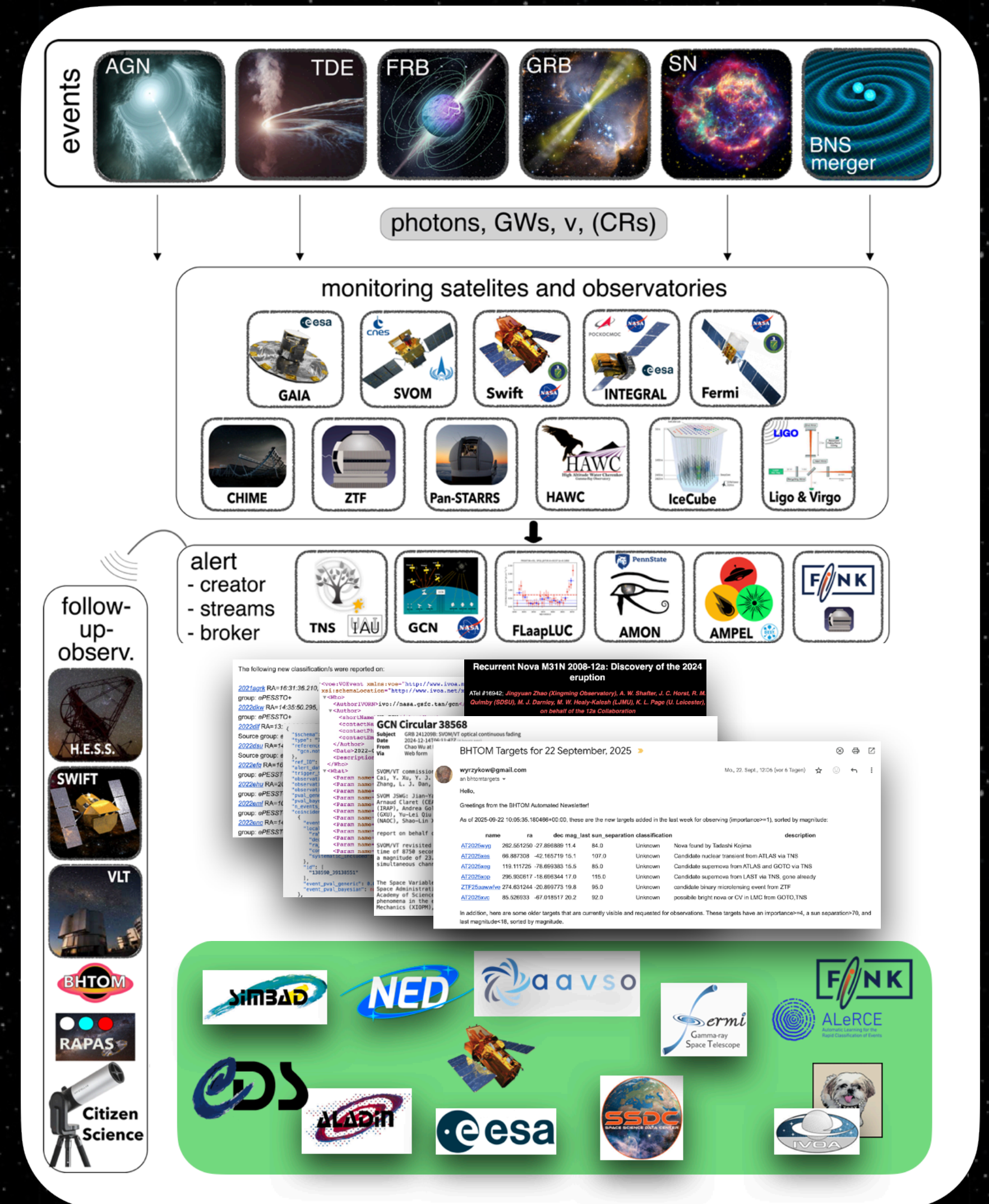
Sensitivity
x10 current generation





Astro-COLIBRI

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2. Wide FoV observatories and satellites detect one of this messengers
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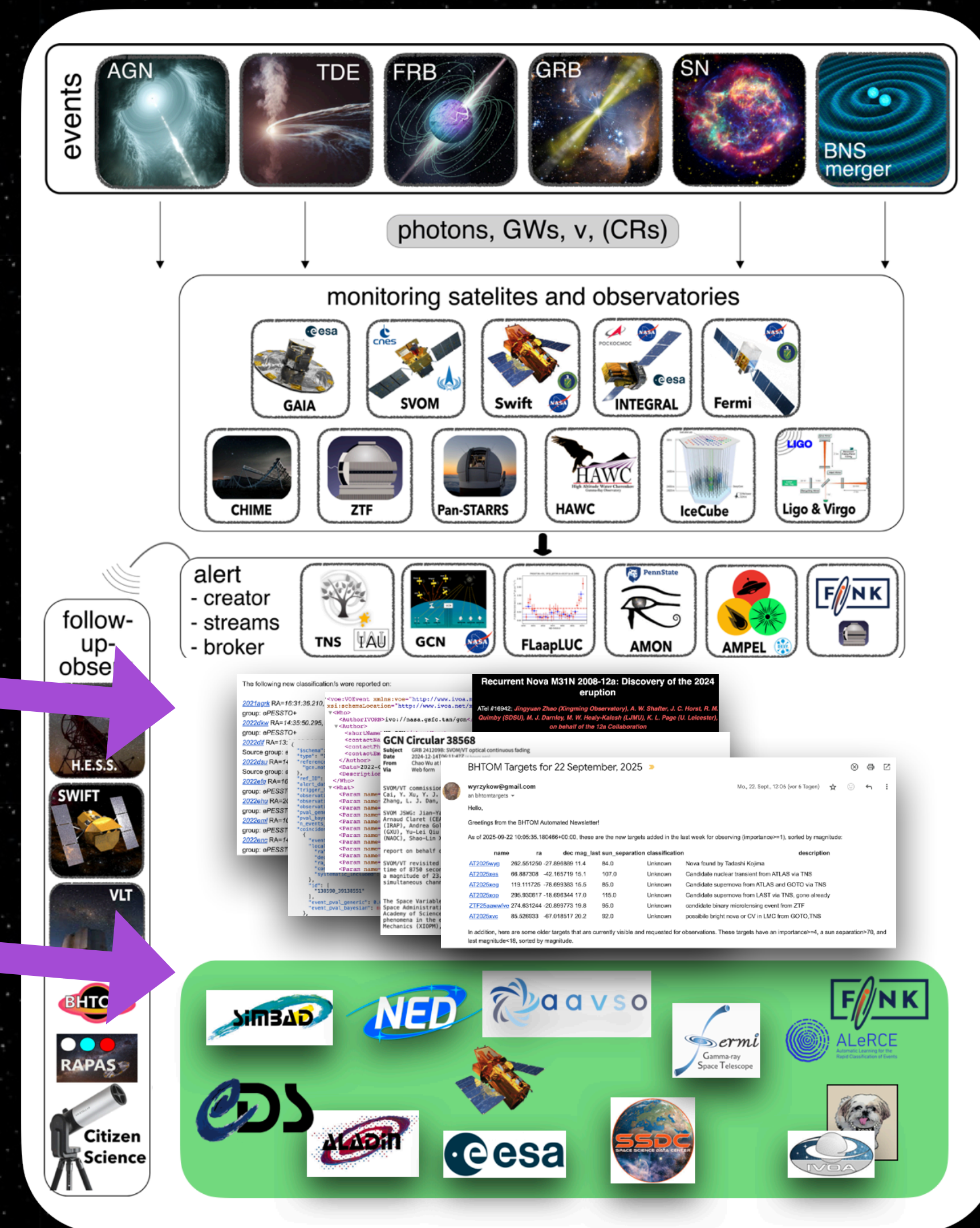
Astro-COLIBRI

What if the follow-up is not fully automated?

What about amateur astronomers? And the general public?

Many different information streams and data formats

Information scattered in many useful pages



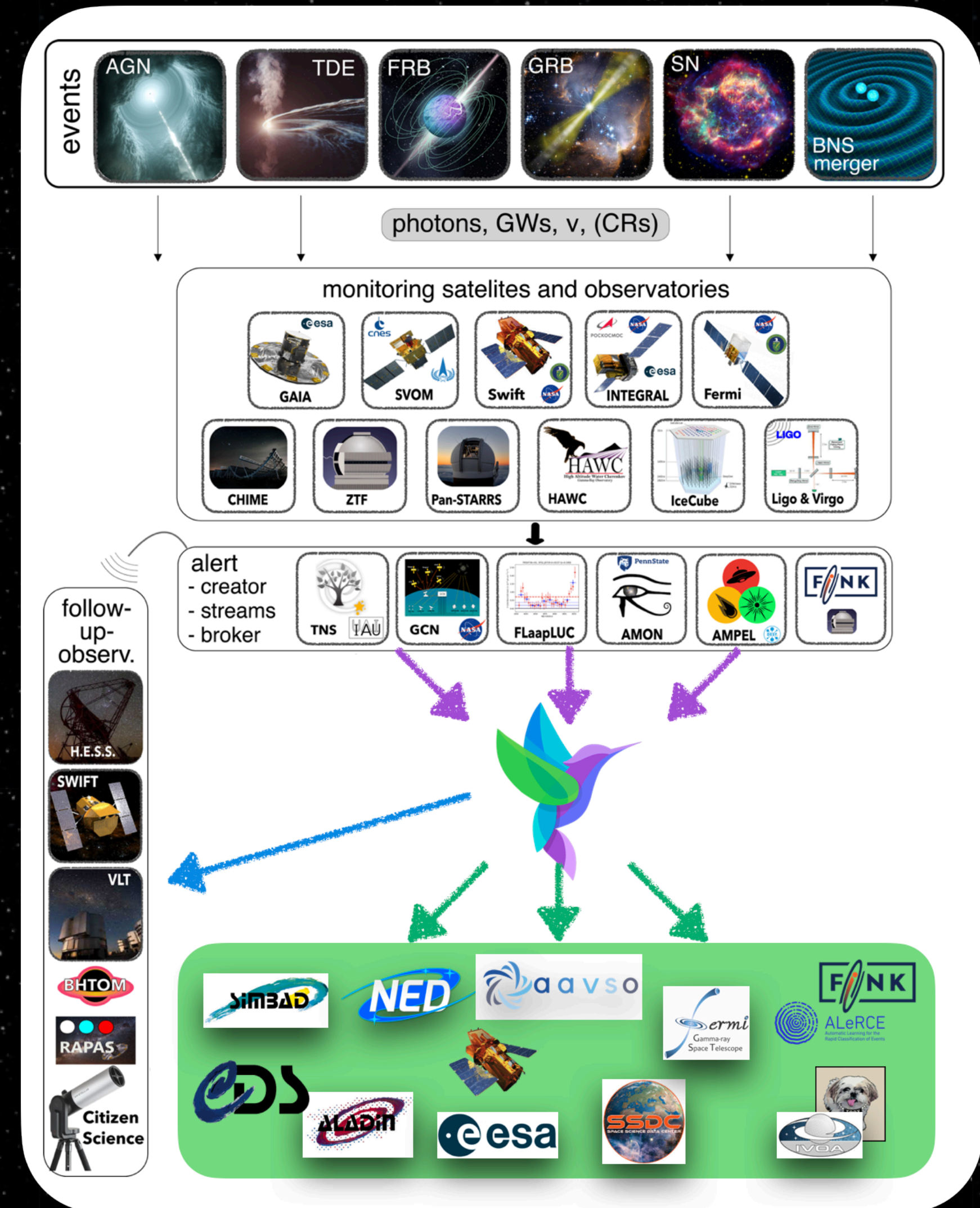


Astro-COLIBRI

- All of the information from an alert in **one place**
- **User-friendly** interface
- **External links** to all the useful astrophysical pages
- Fully **customizable** to see just what you are interested in
- **Pop-up notifications** to never miss an alert

Astro-COLIBRI 22:12
SVOM GRB alert (ECLAIRs)
Coords are RA=176.77 deg,
Dec=29.88 deg (err=0.15 deg), slew:
no

Updated SVOM GRB 22:17
Coords are RA=176.79 deg,
Dec=29.83 deg (err=0.0053 deg), sl...





Astro-COLIBRI





Summary

- Very High Energy observation of Gamma-Ray Bursts are fundamental to understanding the mechanisms of acceleration of their progenitors
- Many observational constraints for IACTs concerning this type of events, including not only alert handling but also big uncertainty regions, sources with a big redshift, ...
- We are improving strategies and tools to maximise VHE GRB/GW counterpart detection chances with H.E.S.S.
- GW counterpart detection is not only a new way to detect GRBs but also gives crucial information on the pre-merger system and post-merger energetics and particle acceleration processes
- CTAO is coming... but H.E.S.S. remains the only IACT in the south until CTAO-south is built



Thank you!
Any questions?

