

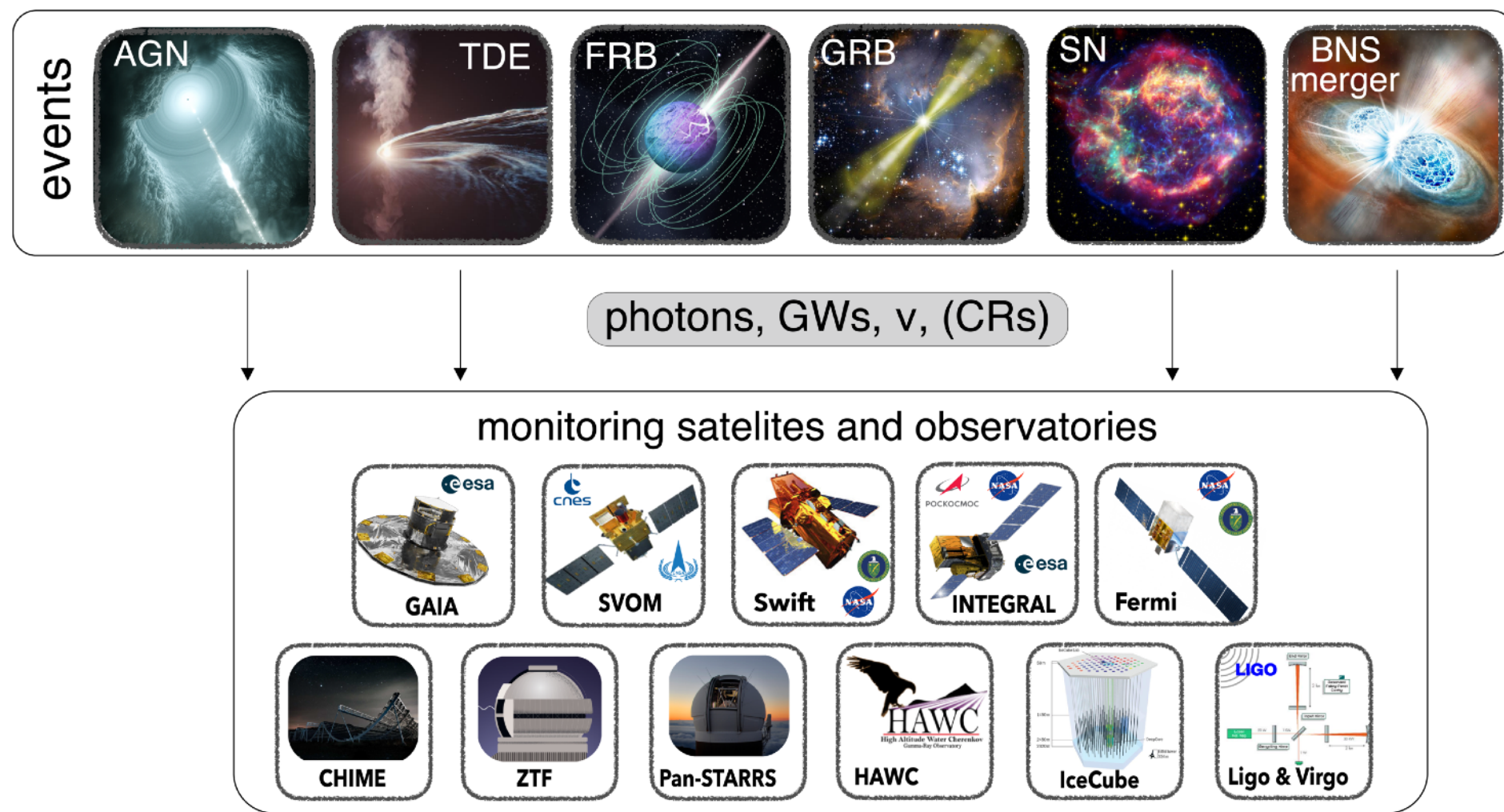
The Landscape of Multi-Messenger Astrophysics Infrastructures



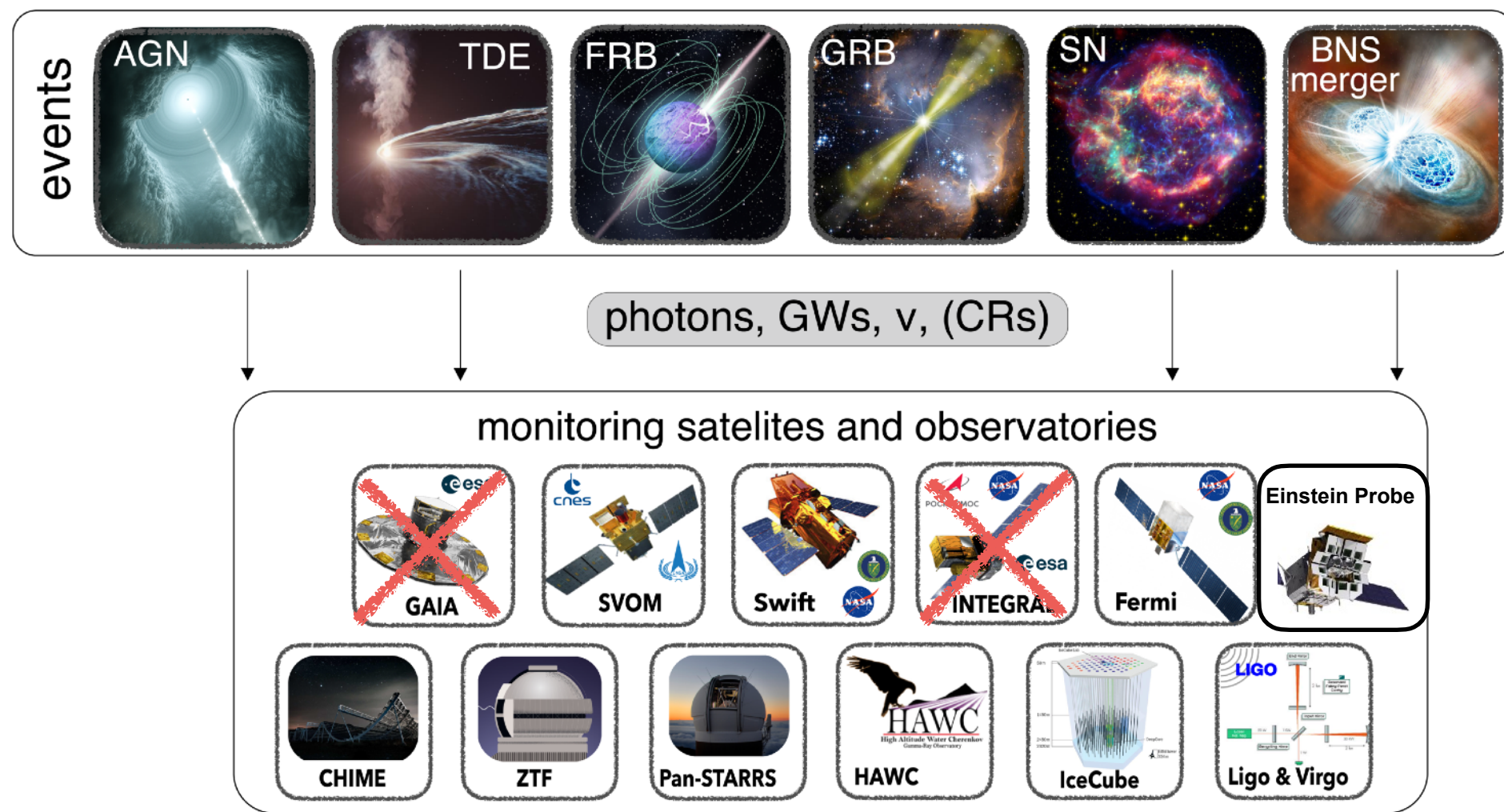
How can we improve multi-messenger astrophysics ?

- **Efficient and rapid detections**
 - Including MM/MWL correlations
 - Including (real-time) sharing of information/data
- **Efficient and rapid follow-up observations**
 - Including sharing of information/data
- **Efficient and rapid interpretation**
 - Guiding further observations
 - Detailed, joint analyses
- **Requirements**
 - Full adoption of open data principles
 - Integration and interconnection of tools and platforms



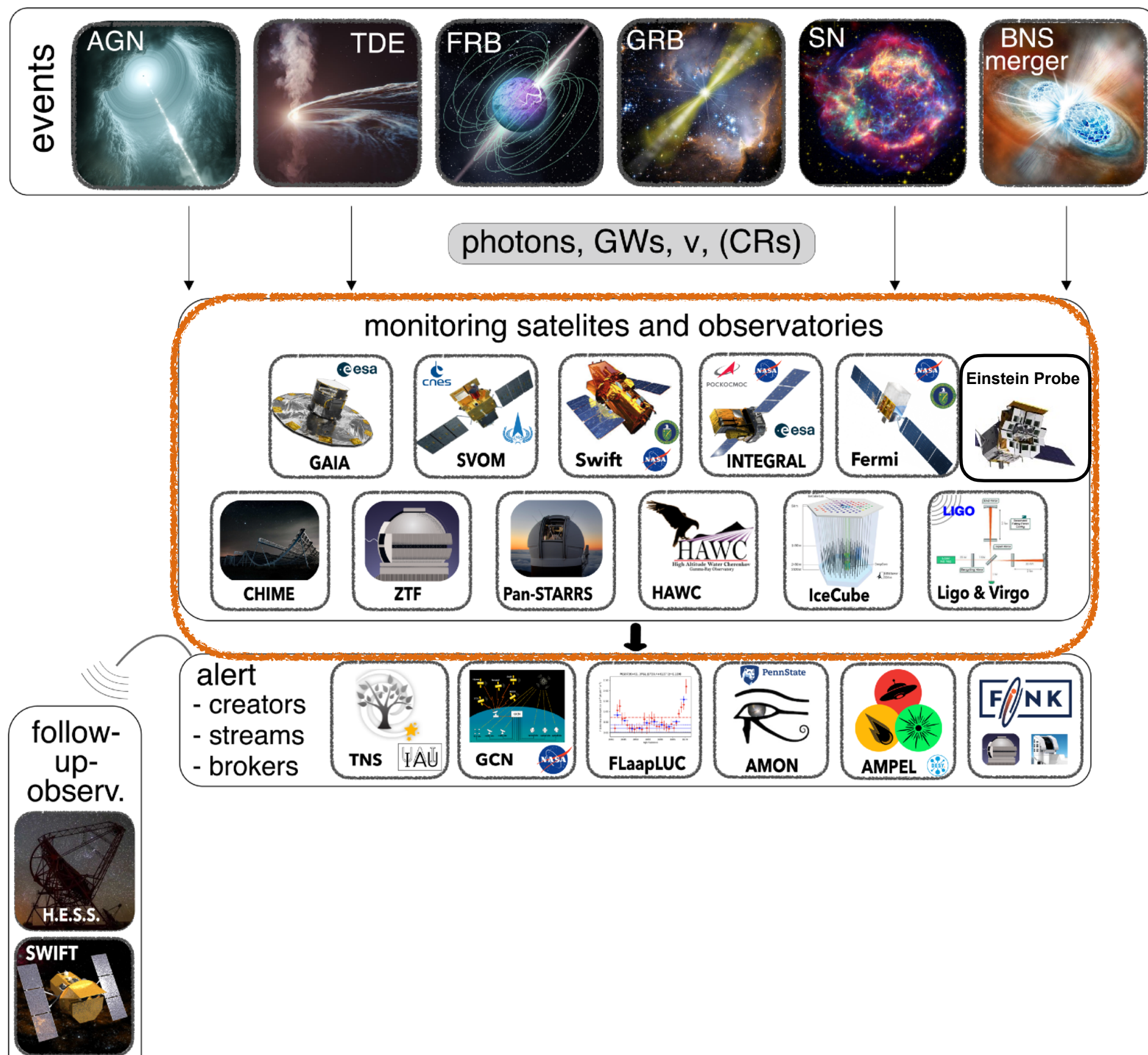


Detection: monitoring instruments



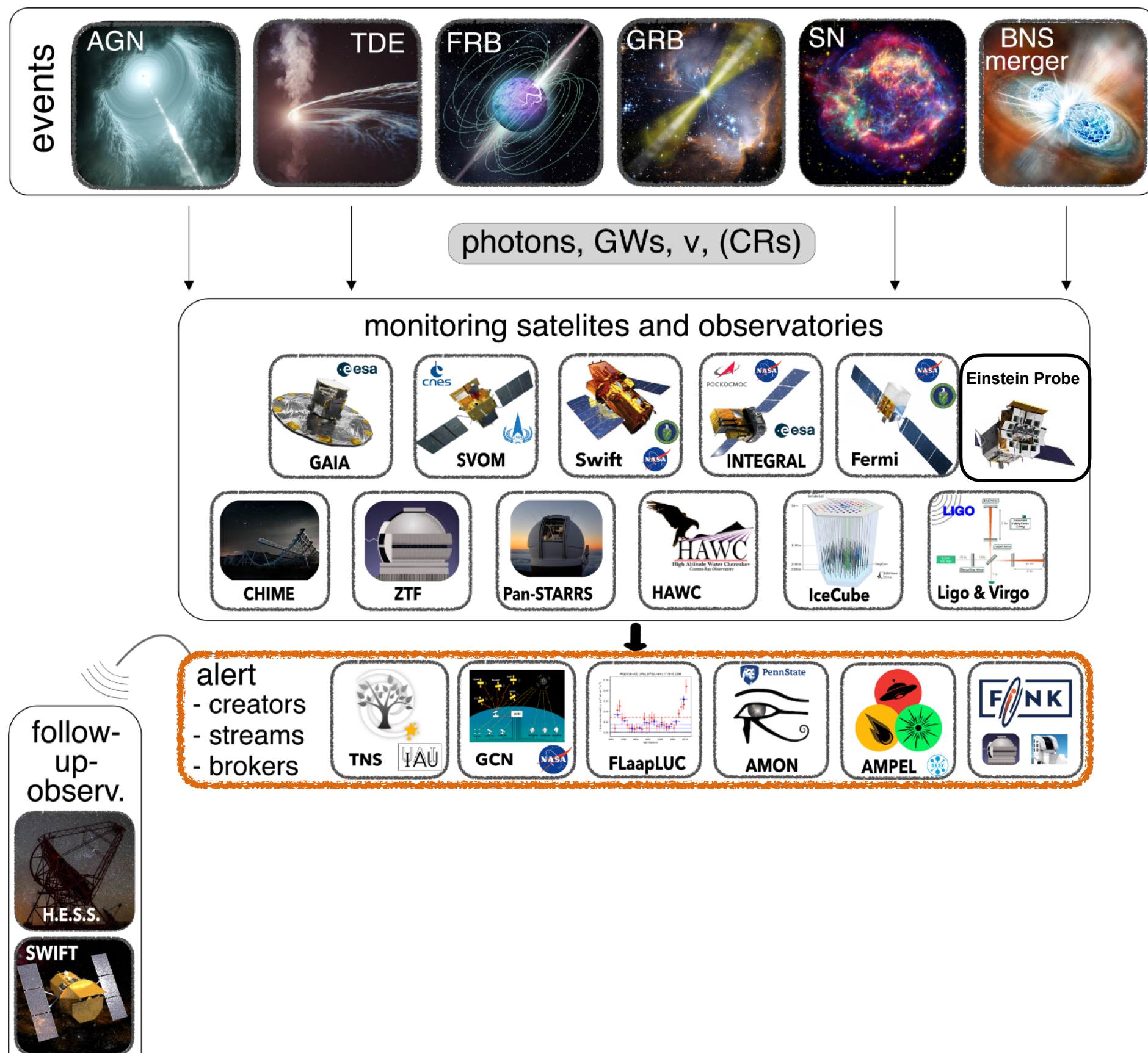
Detection: monitoring instruments

	Large FoV	Small FoV
Monitoring (+ duty cycle)		
Sensitivity		
Resolution		




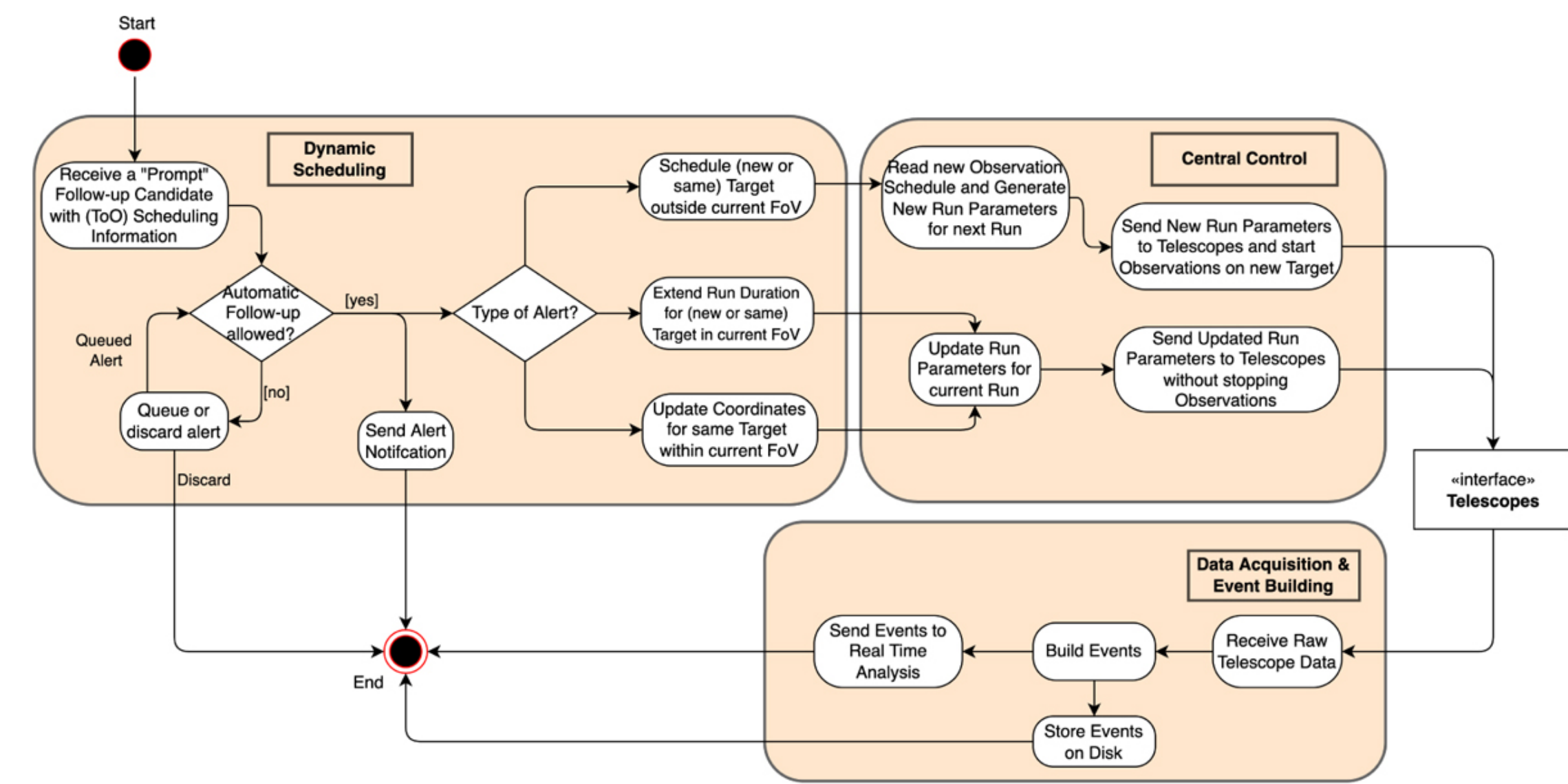
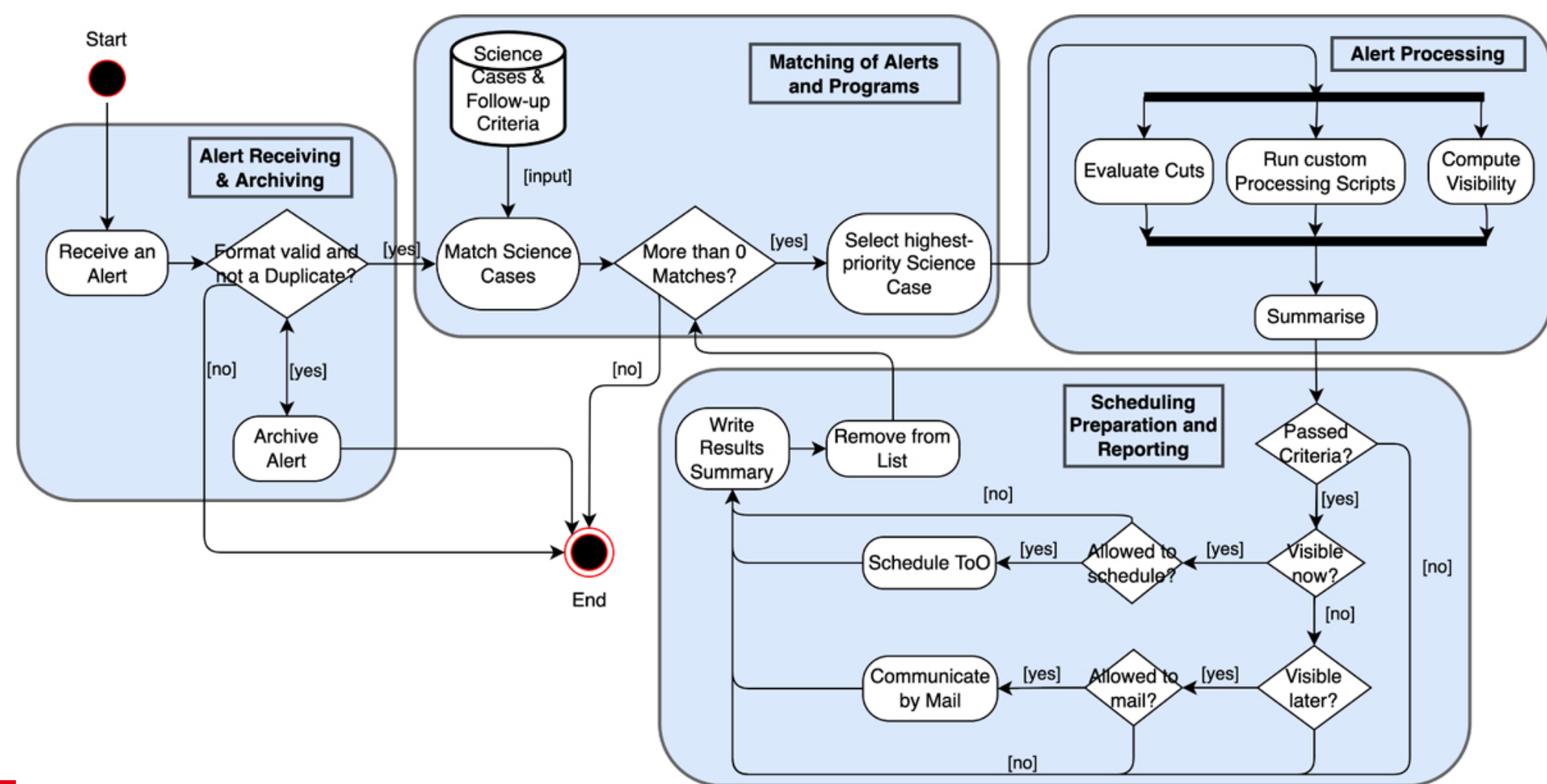
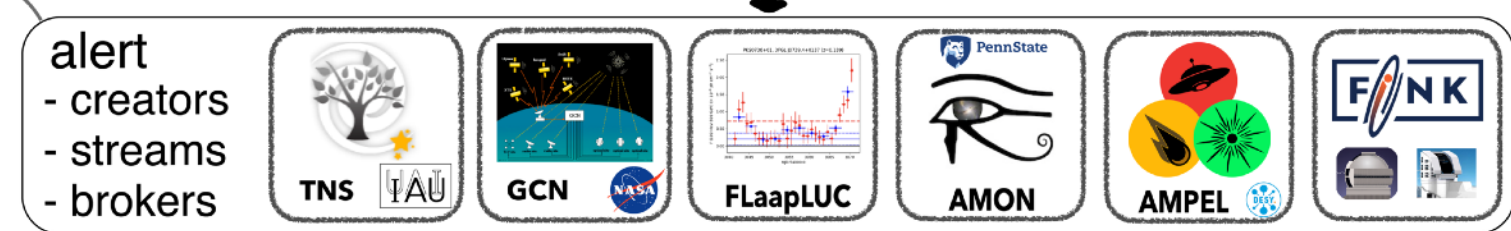
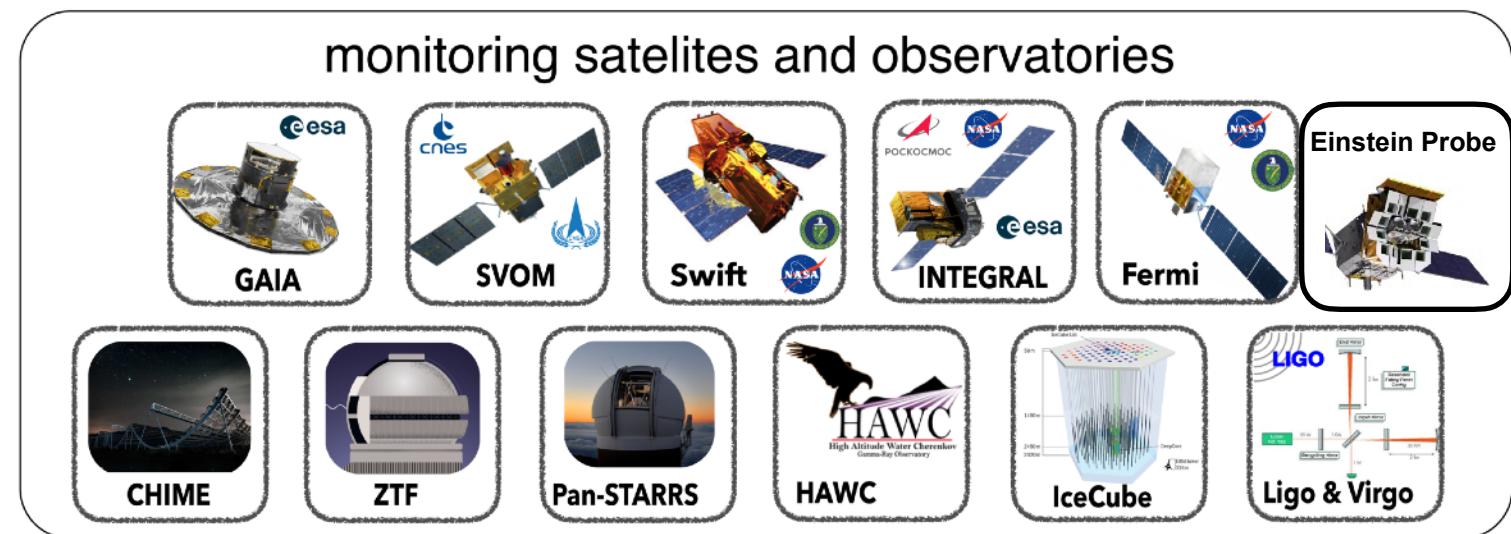
Real-time information sharing + alerts

- Requires real-time data analysis and alert publication
 - Examples:
 - LVK public alerts (incl. early warnings)
 - IceCube public alerts
 - Fermi/Swift/SVOM/EP/etc.
 - CHIME FRB alerts
 - Rubin/LSST 🤖
 - ...



Information/alert distribution

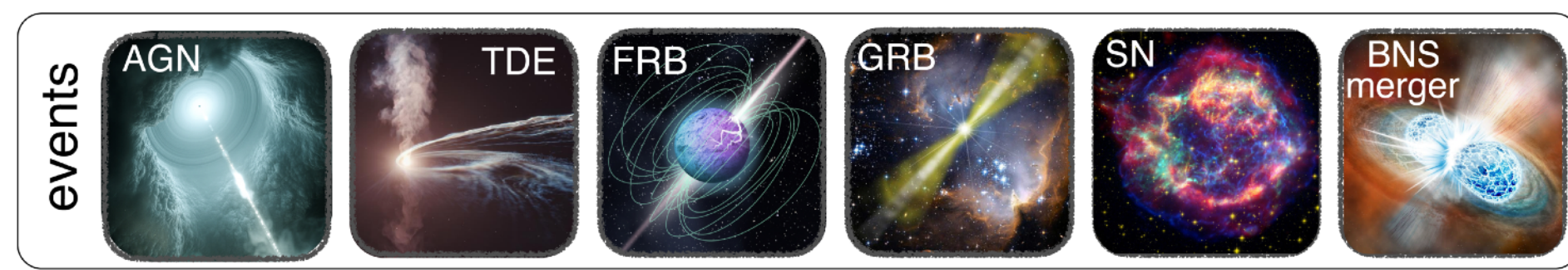
- Increasing number of distribution channels + brokers
 - Multiple classification + characterization of the same data
 - => European Broker Initiative 
- Increasing number of data transmission protocols (VoEvent, Kafka, emails, websites, etc.)
- Increasing number of data schema and serializations (VoEvent vs. GCN; XML vs. JSON vs. Avro, etc.)



Automatic follow-up observations

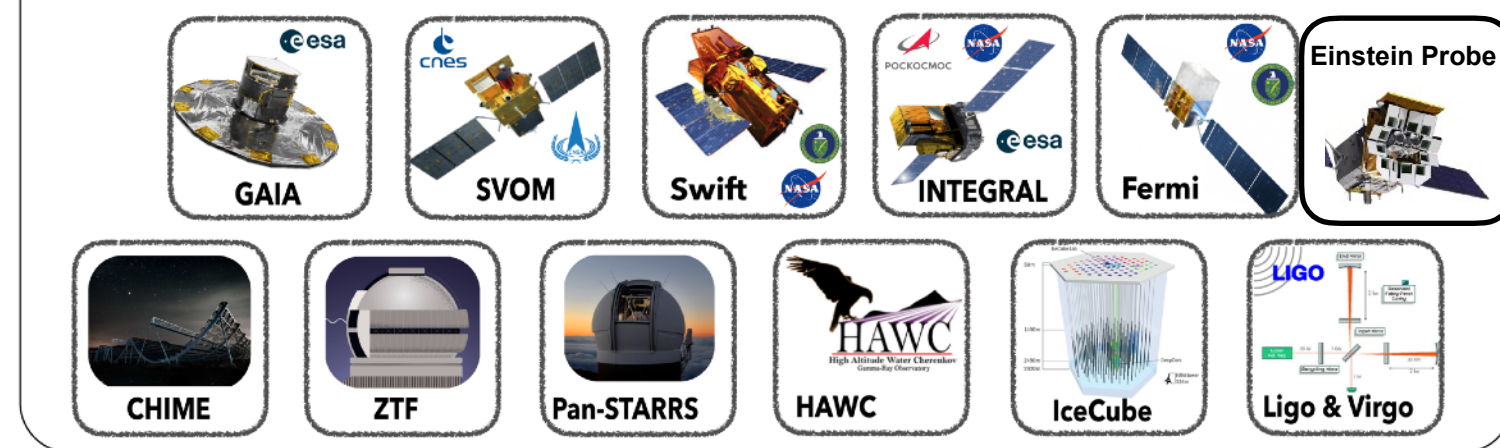
- Proposal preparation/submission/etc.
- Automatic alert filtering + selection
 - Caveat: you'll typically only trigger on known phenomena/features
- Triggering of follow-up observations
 - Integration with observatory/telescope software

C. Hoischen et al., A&A 666, A119 (2022)

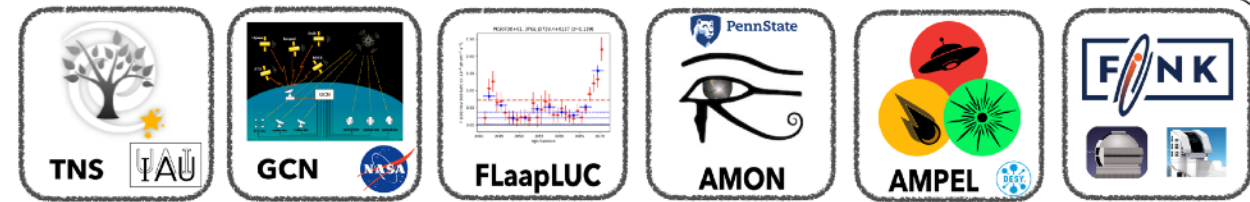


photons, GWs, ν , (CRs)

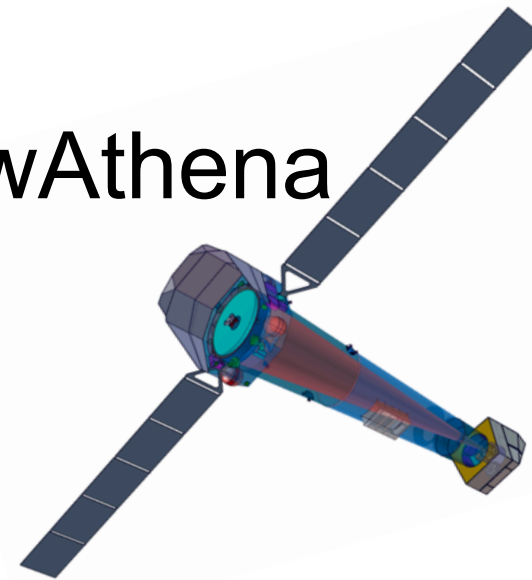
monitoring satellites and observatories



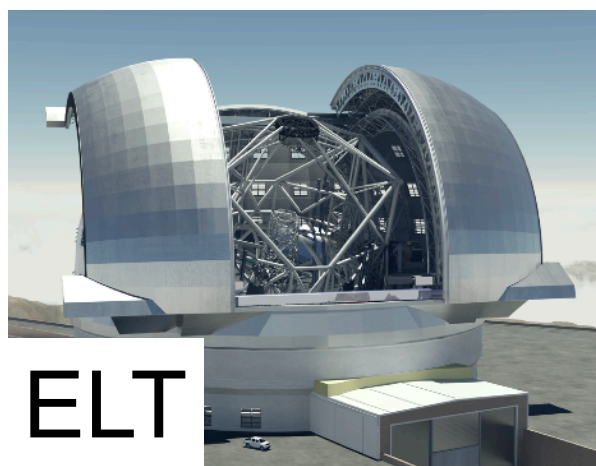
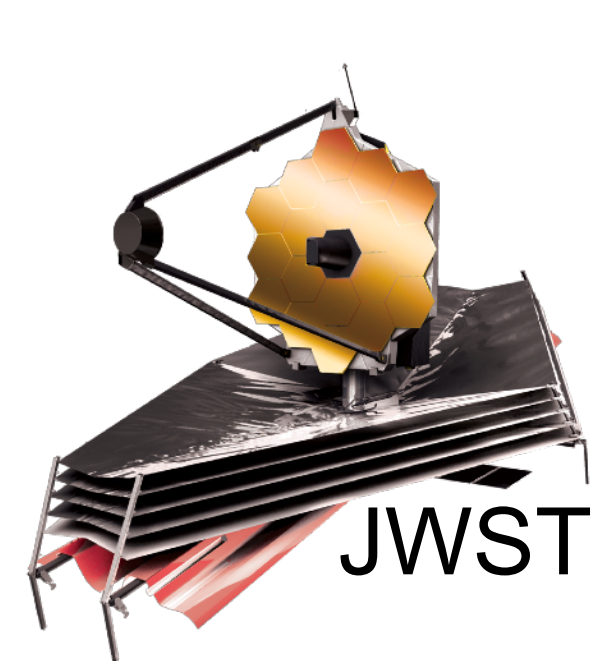
alert
- creators
- streams
- brokers



NewAthena



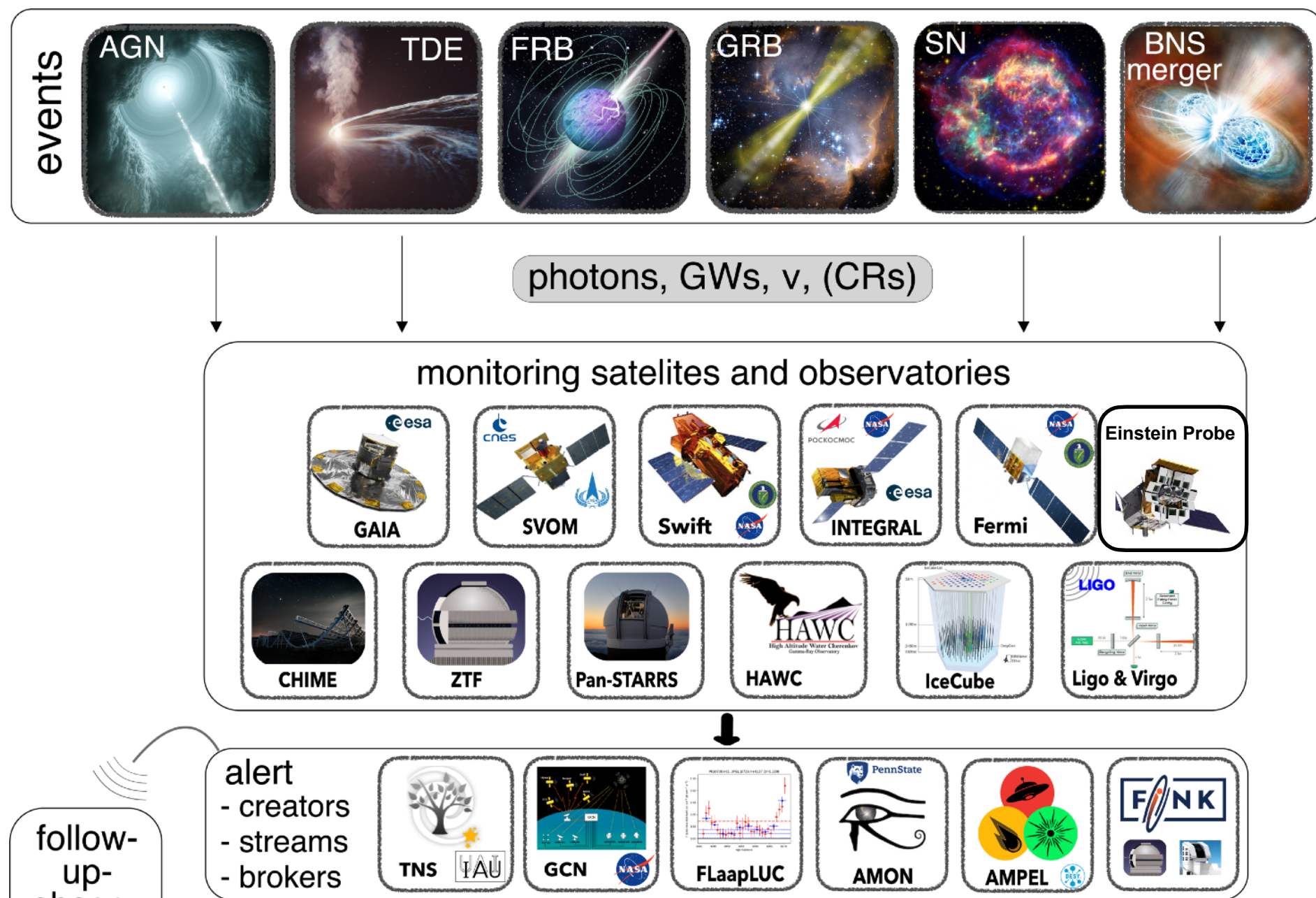
JWST



Follow-up observatories

	Large FoV	Small FoV
Monitoring (+ duty cycle)	✓	✗
Sensitivity	✗	✓
Resolution	✗	✓

- Localisation (e.g. GRB afterglows, kilonovae, ...)
- Classification + characterization
 - Spectroscopy + Polarimetry + ...
- Strong competition for time at major facilities
 - Increasing fraction of non-classified transients



Manual follow-up observations

- Proposal preparation/submission/etc.
- Find **interesting** targets
 - Increasing number of transient detections
 - MWL/MM context scattered across multiple platforms
 - ...

The following new classification/s were reported on:

```

2021grk RA=16:31:36.210, DEC=+13:38:14.93, Classification=SN II, Redshift=0.026, Time received: 2022-03-23 18:56:17, Classifier: T. Moore, S. Sr
group: ePESSTO+
2022dkw RA=14:35:50.295, DEC=+24:40:58.20, Classification=SN IIn, Re
group: ePESSTO+
2022dfl RA=13:24:06.914, DEC=-00:41:34.50, Classification=SN Ia-91T-II
Source group: ePESSTO+
2022dsu RA=14:05:30.767, DEC=+15:43:15.52, Classification=SN Ia-91b
Source group: ePESSTO+
2022efg RA=16:41
group: ePESSTO+
2022ehu RA=20:1
group: ePESSTO+
2022eml RA=10:2
group: ePESSTO+
2022enc RA=14:4
group: ePESSTO+
  
```

Recurrent Nova M31N 2008-12a: Discovery of the 2024 eruption

ATel #16942; Jingyuan Zhao (Xingming Observatory), A. W. Shafter, J. C. Horst, R. M. Quimby (SDSU), M. J. Darnley, M. W. Healy-Kalesh (LJMU), K. L. Page (U. Leicester), on behalf of the 12a Collaboration on 13 Dec 2024; 04:31 UT Distributed as an Instant Email Notice Novae Credential Certification: Allen W. Shafter (ashafter@sdsu.edu)

GCN Circular 38568

Subject GRB 241209B: SVOM/VT optical continuous fading
Date 2024-12-14T06:11:47Z (4 hours ago)
From Chao Wu at NAOC <cwu@nao.cas.cn>
Via Web form

SVOM/VT commissioning team: Y. L. Qiu, H. L. Li, L. P. Xin, C. Wu, X. H. Han, J. Wang, W. J. Xie, H. B. Cai, Y. Xu, Y. J. Xiao, P. P. Zhang, J. S. Deng, L. Lan, X. M. Lu, R. S. Zhang, D. H. Zhao (NAOC), J. Zhang, L. J. Dan, G. Y. Zou, C. J. Wang, Y. F. Du, C. Huang (XIOPM), H. Zhou (PMO), C. Plasse (CEA)

SVOM JSWG: Jian-Yan Wei (NAOC), Bertrand Cordier (CEA), Shuang-Nan Zhang (IHEP), Stéphane Basa (LAM), Arnaud Claret (CEA), Zi-Gao Dai (USTC), Frédéric Daigne (IAP), Jin-Song Deng (NAOC), Olivier Godet (IRAP), Andrea Goldoni (APC), Diego Götz (CEA), Xu-Hui Han (NAOC), Cyril Lachaud (APC), En-Wei Liang (GXU), Yu-Lei Qiu (NAOC), Susanna Vergani (Obs.Paris), Jing Wang (NAOC), Chao Wu (NAOC), Li-Ping Xin (NAOC), Shao-Lin Xiong (IHEP), Bing Zhang (UNLV)

report on behalf of the SVOM team:

SVOM/VT revisited GRB 241209B (Xie et al., GCN 38478) since 2024-12-10T15:07:15 UT with a total exposure time of 8750 seconds. The optical counterpart (Qiu et al. GCN 38516) was continuously fading, reaching a magnitude of 23.70 +/- 0.30 in VT_R. Nothing was seen down to limiting magnitude of 23.80 (3 sigma) in simultaneous channel VT_B.

The Space Variable Objects Monitor (SVOM) is a China-France joint mission led by the Chinese National Space Administration (CNSA, China), National Center for Space Studies (CNES, France) and the Chinese Academy of Sciences (CAS, China), which is dedicated to observing gamma-ray bursts and other transient phenomena in the energetic universe. VT was jointly developed by Xi'an Institute of Optics and Precision Mechanics (XIOPM), CAS and National astronomical observatories (NAOC), CAS.

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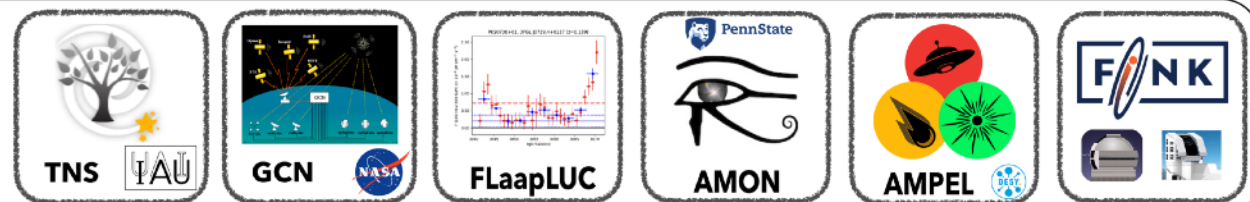


photons, GWs, ν , (CRs)

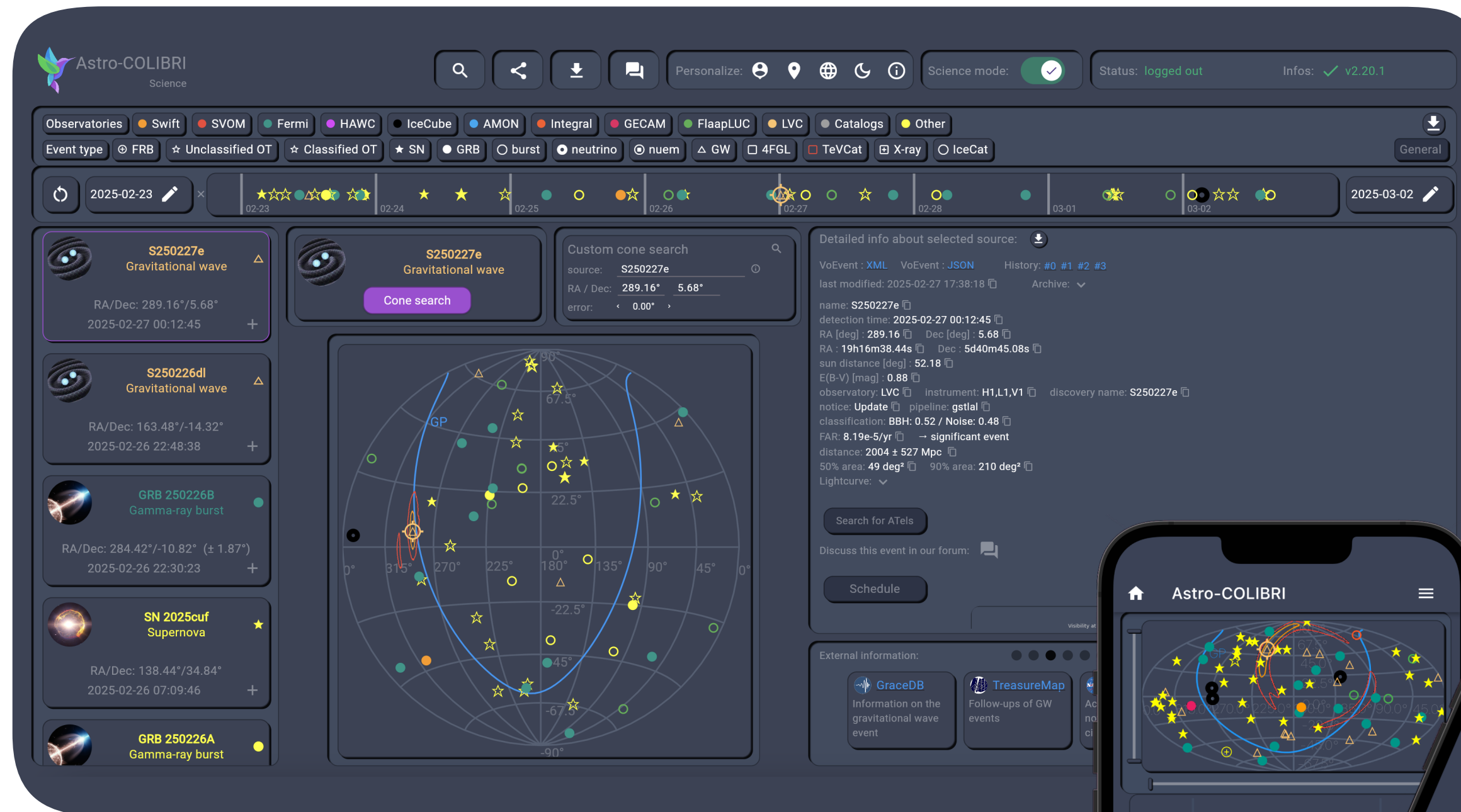
monitoring satellites and observatories



alert
- creators
- streams
- brokers

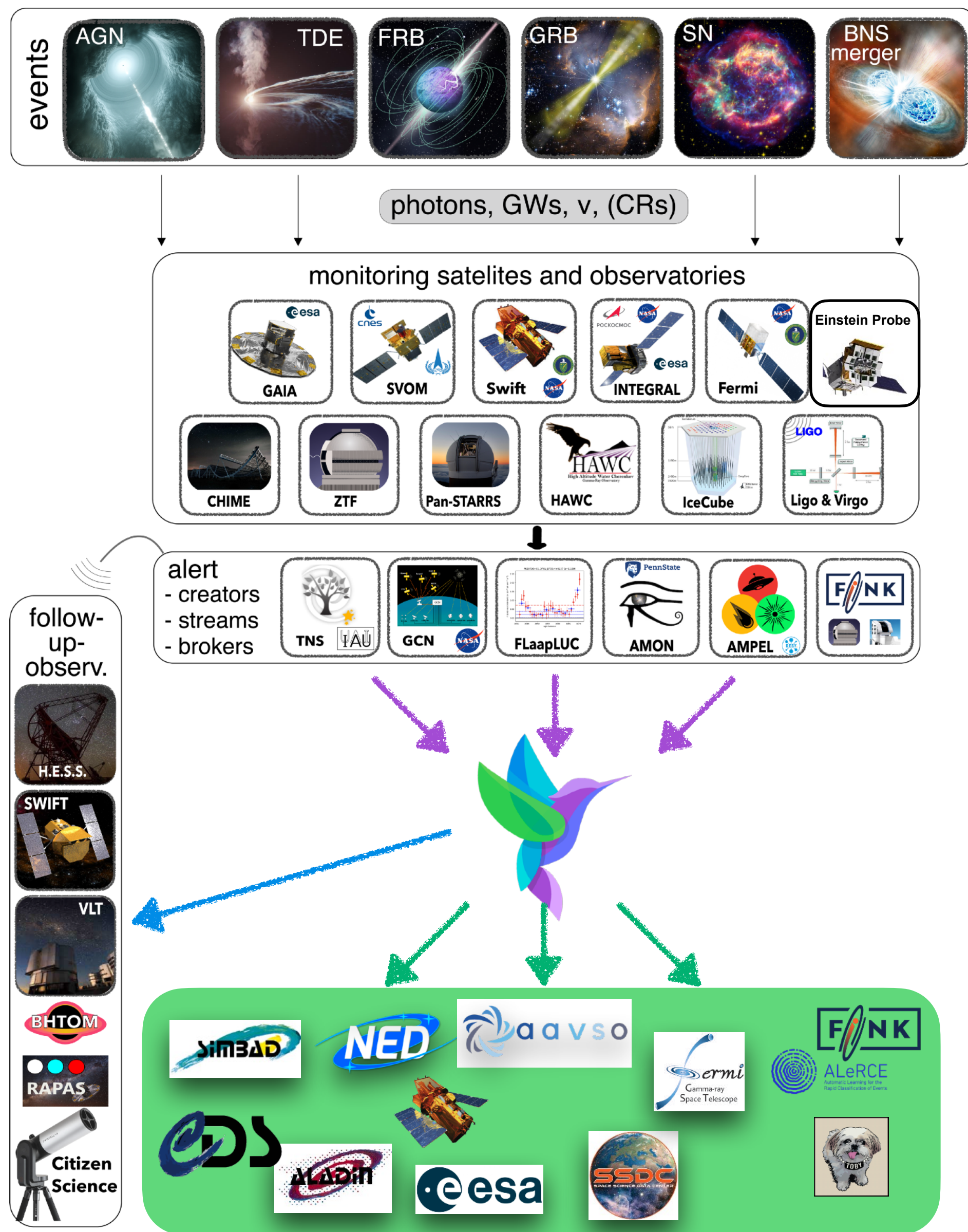


Astro-COLIBRI



<https://astro-colibri.science>





MWL/MM context

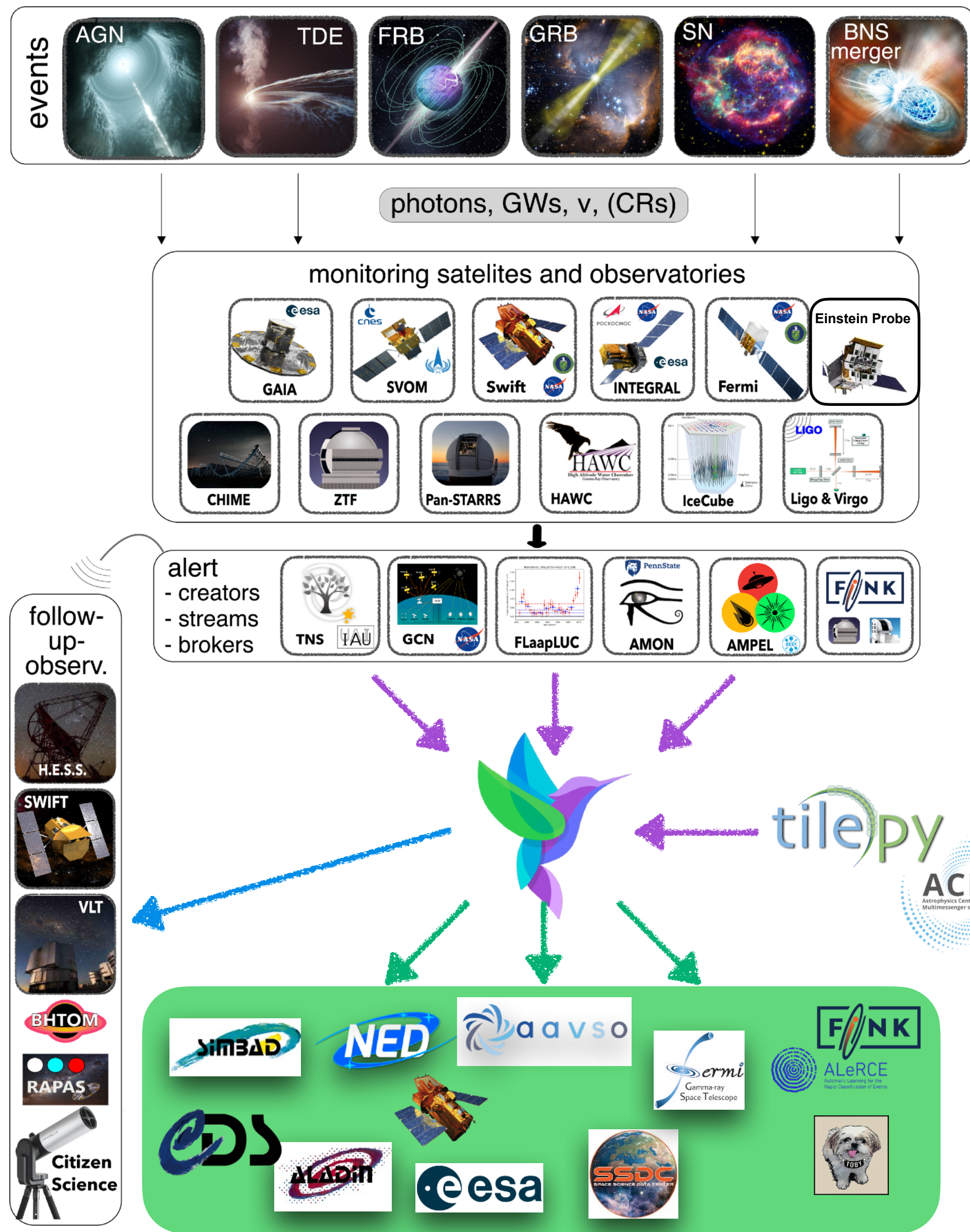
■ Additional information

- MWL context, archival information + related MWL/MM transients
 - Aggregated information and direct links to MWL/MM platforms
 - Lightcurves (ASAS-SN + ATLAS + ZTF; Swift-XRT; Fermi LCR, ...)
 - Realtime context: GraceDB, brokers, TNS, LSXPS, ...
 - Archival context (IceCat-1, 4FGL, TeVCat, ...)
 - Simbad, Aladin, ESASky, NED, SSDC, ...
 - ...

■ Coordination with colleagues and the community

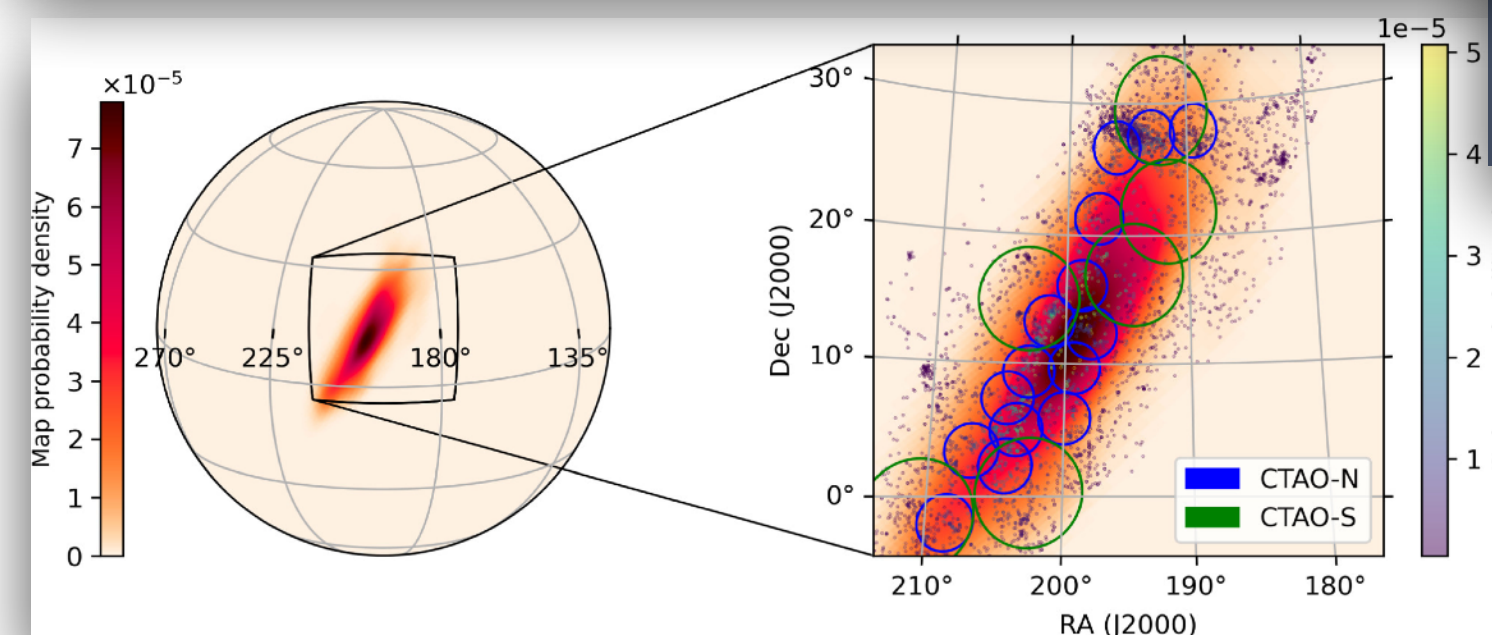
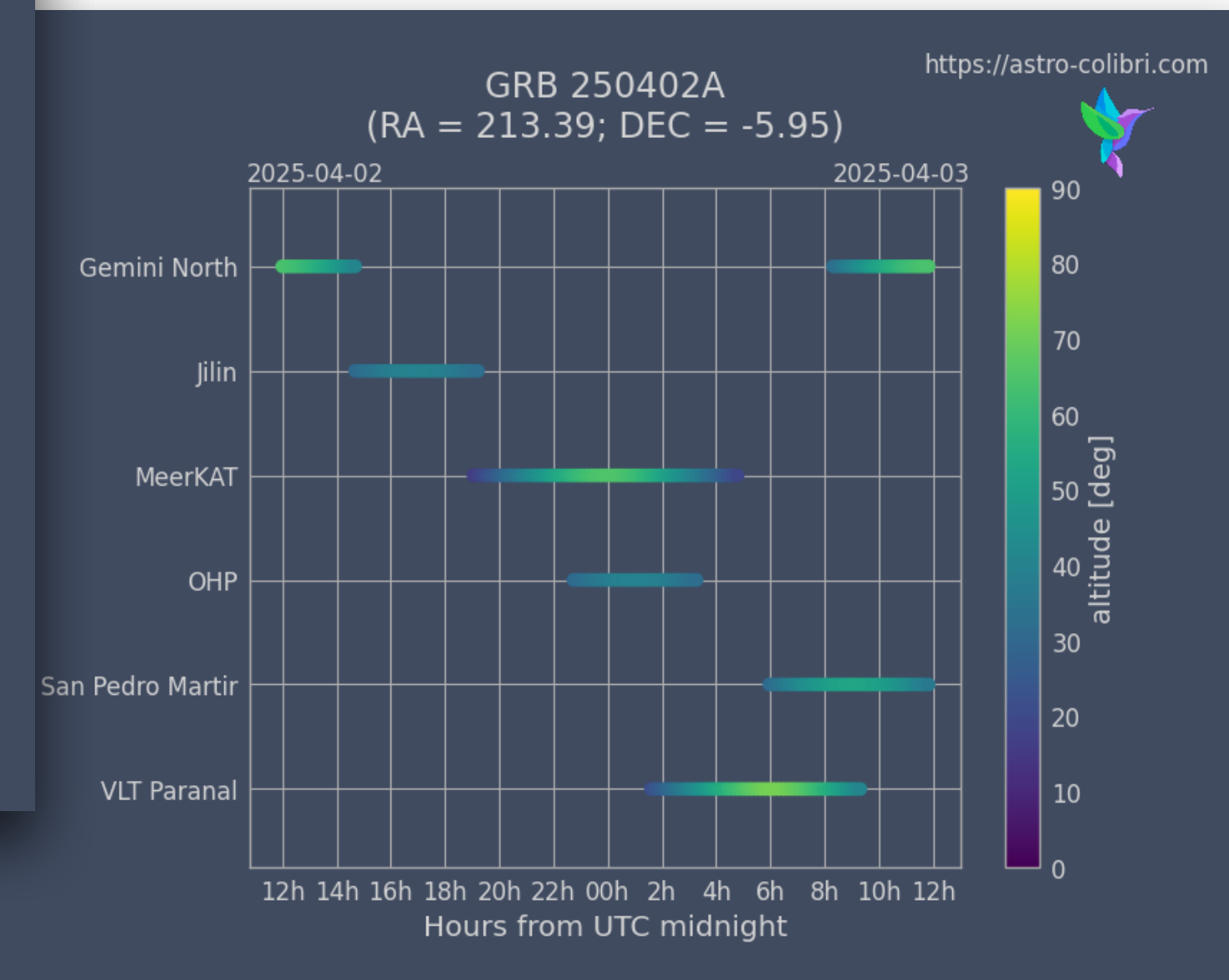
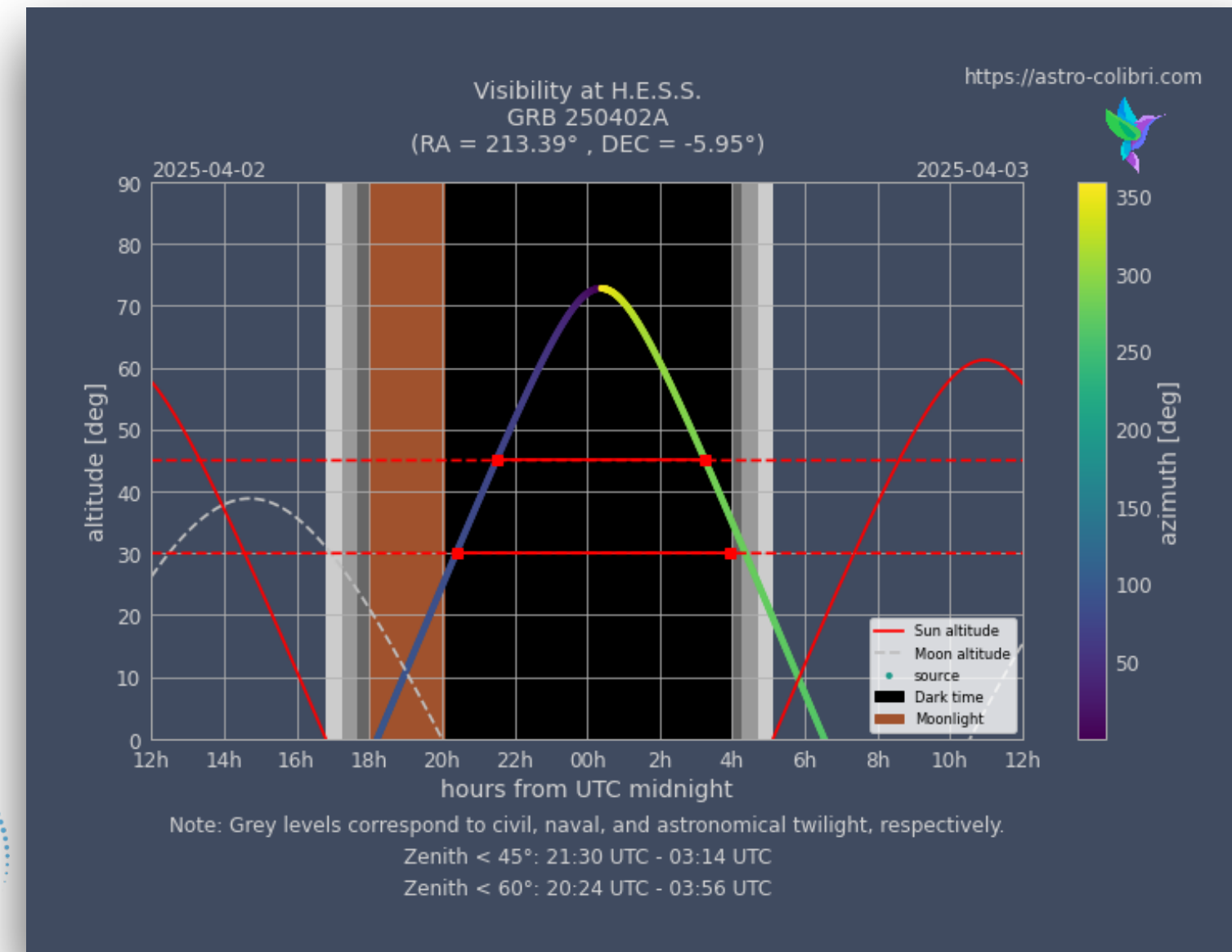
- Sharing of events
- Discussion forum
- ...

<https://astro-colibri.science>

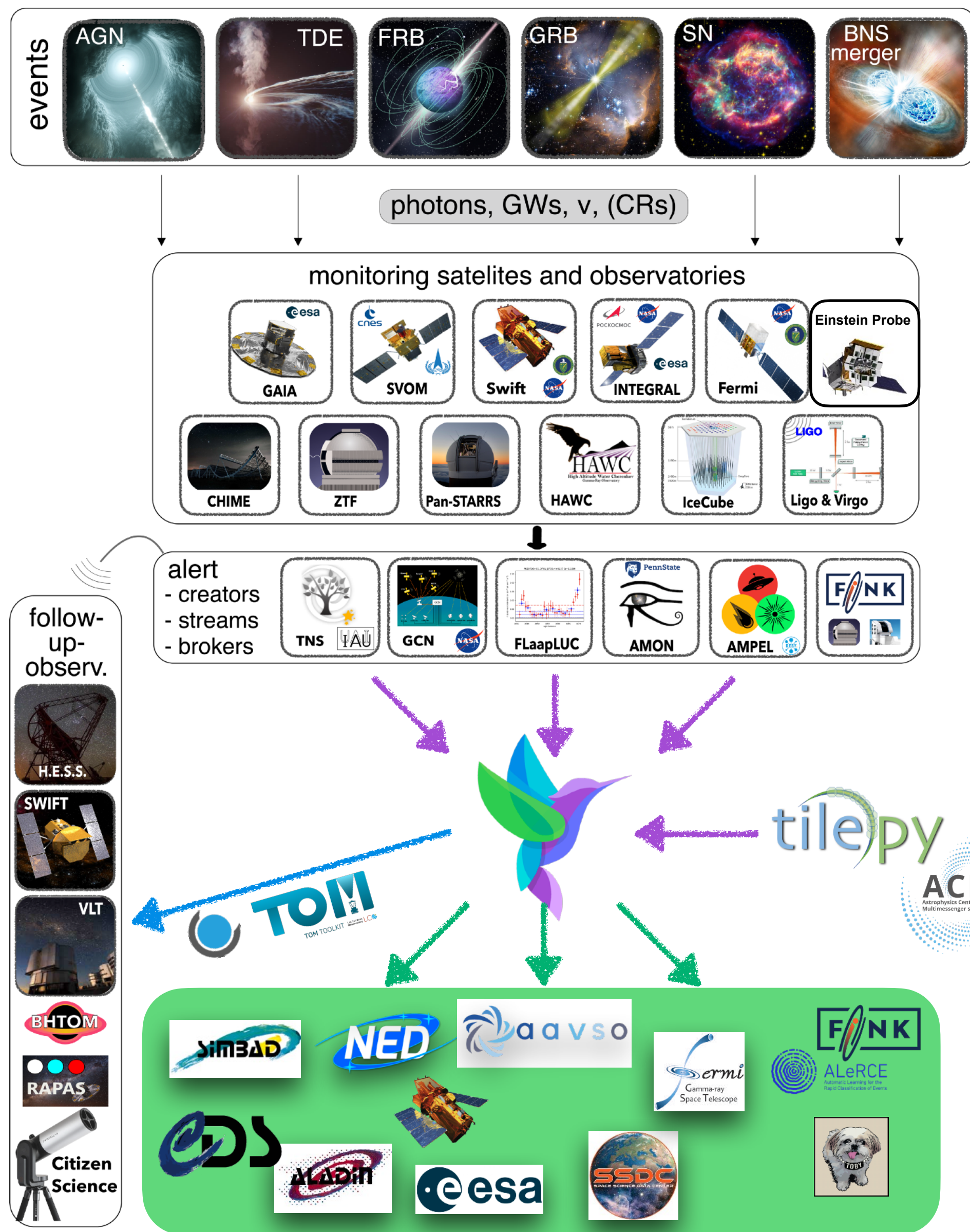


Observation planning

- Observation planning
 - (Multi-observatory) observability assessment
 - Optimized observation plans (e.g. Tilepy integration)

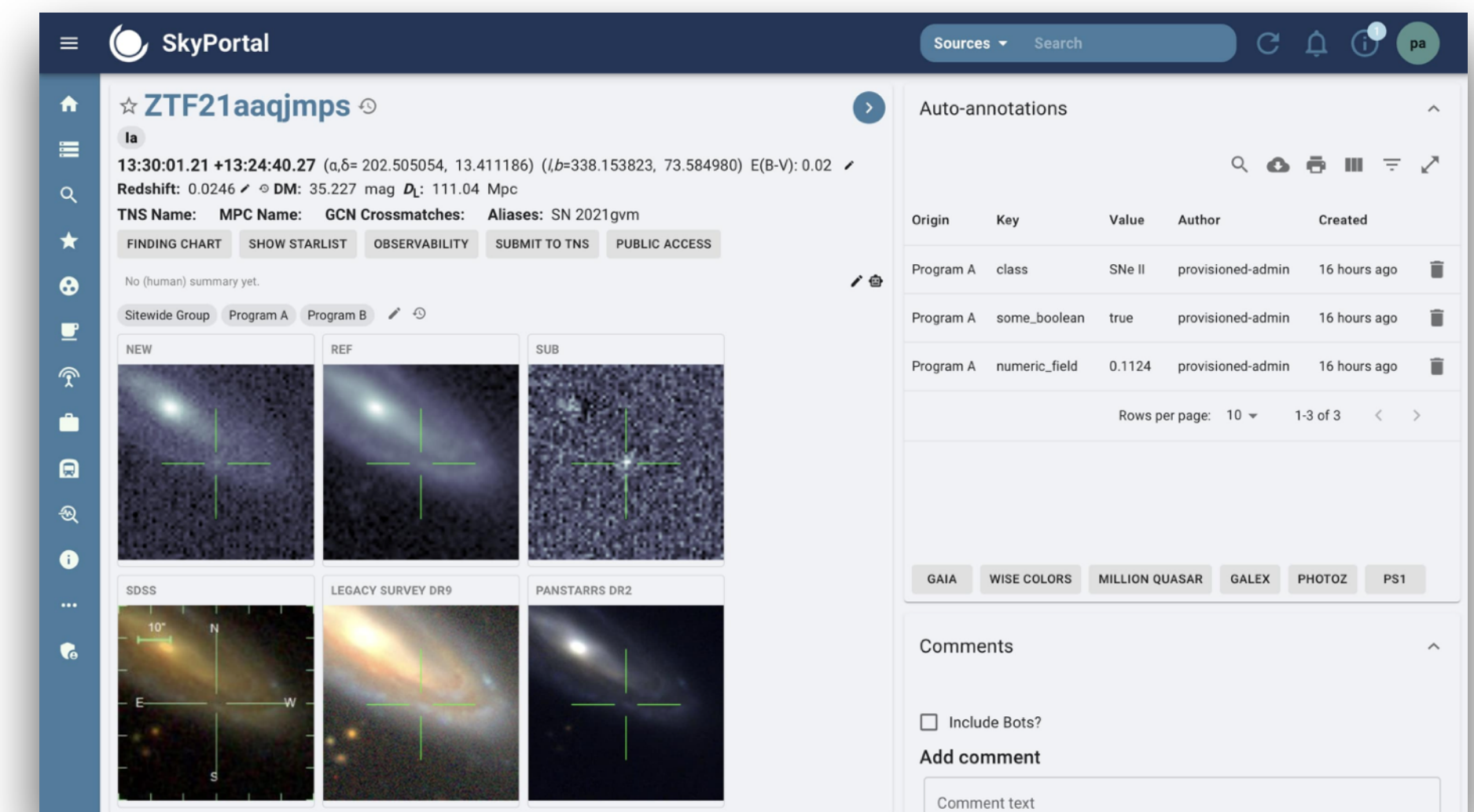


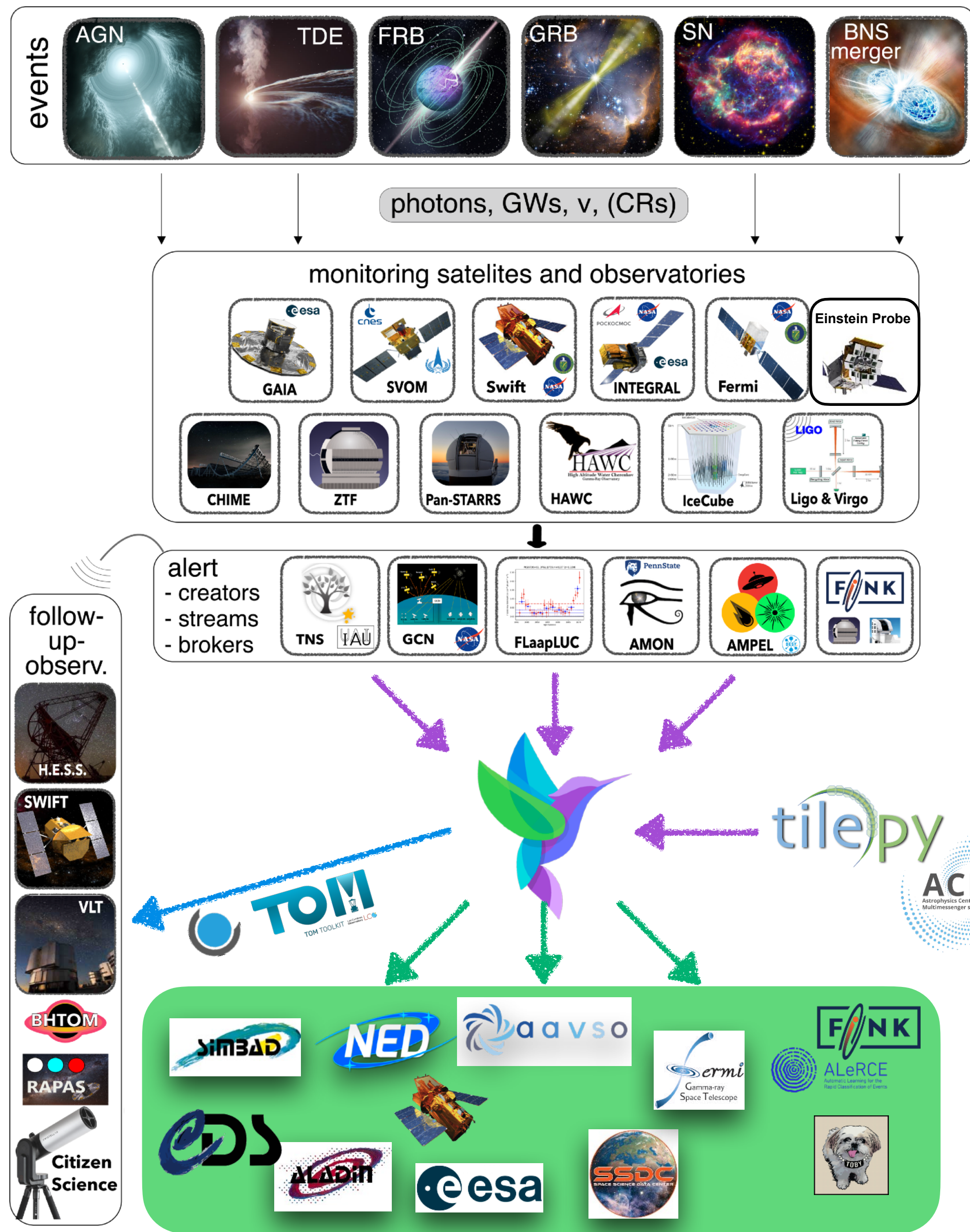
M. Seglar-Arroyo et al., ApJS 274 (2024) 1



Follow-up observations

- Triggering of follow-up observations
 - Dedicated tools: TOM toolkit + SkyPortal
 - Connection with amateur astronomers + citizen scientists





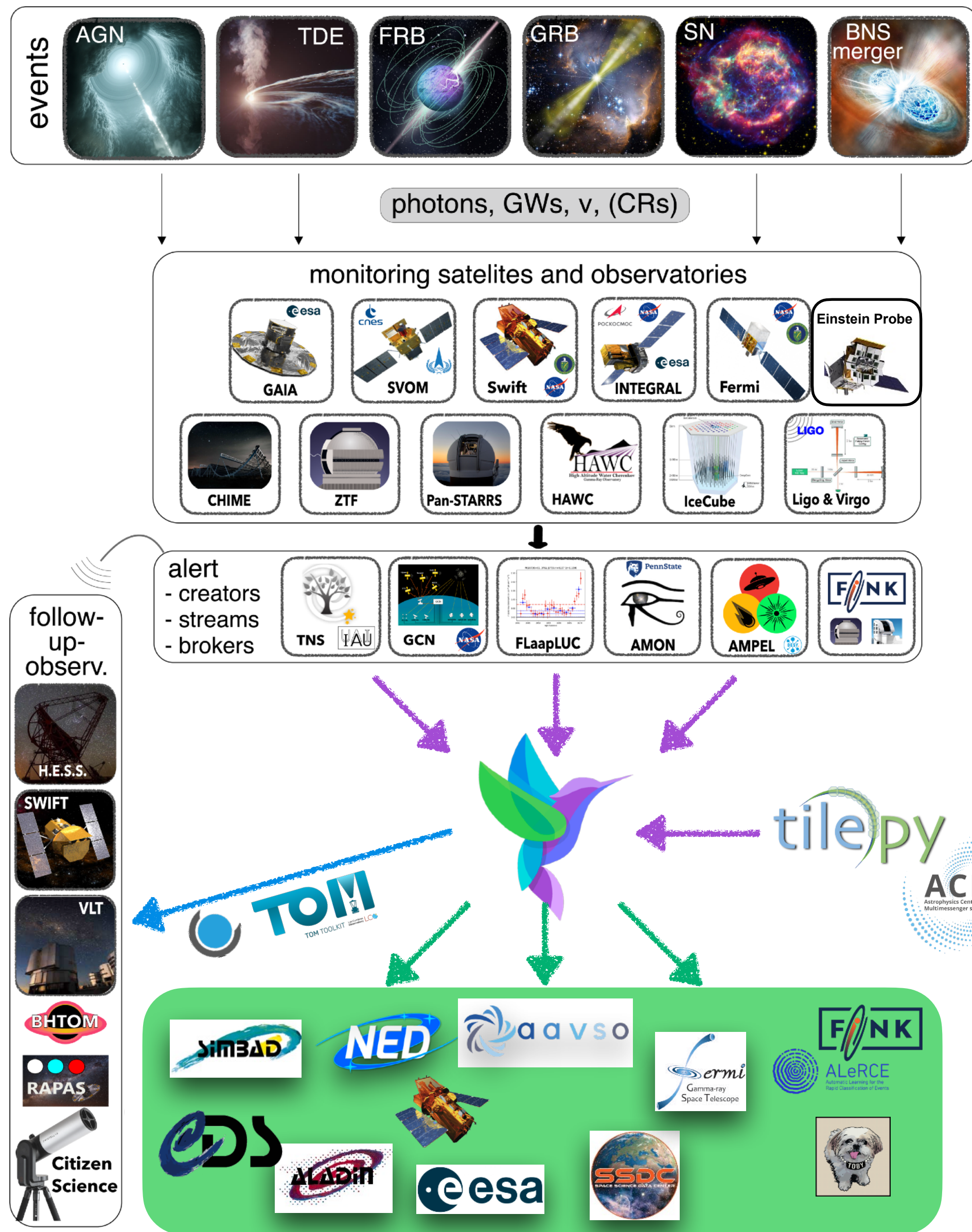
Coordinated follow-up observations

- Gravitational waves: TreasureMap.space



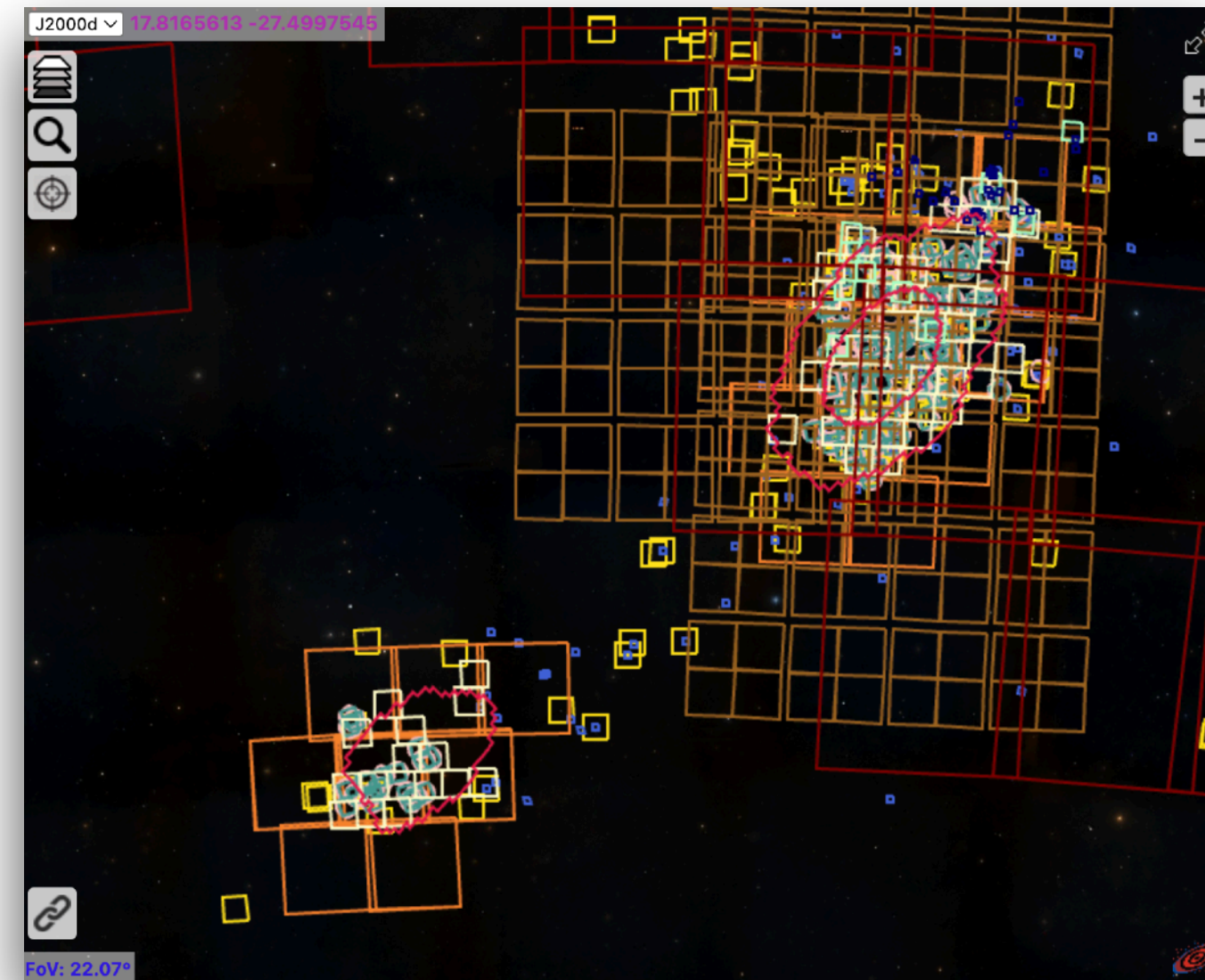
S190814bv

Well-localized NS-BH merger

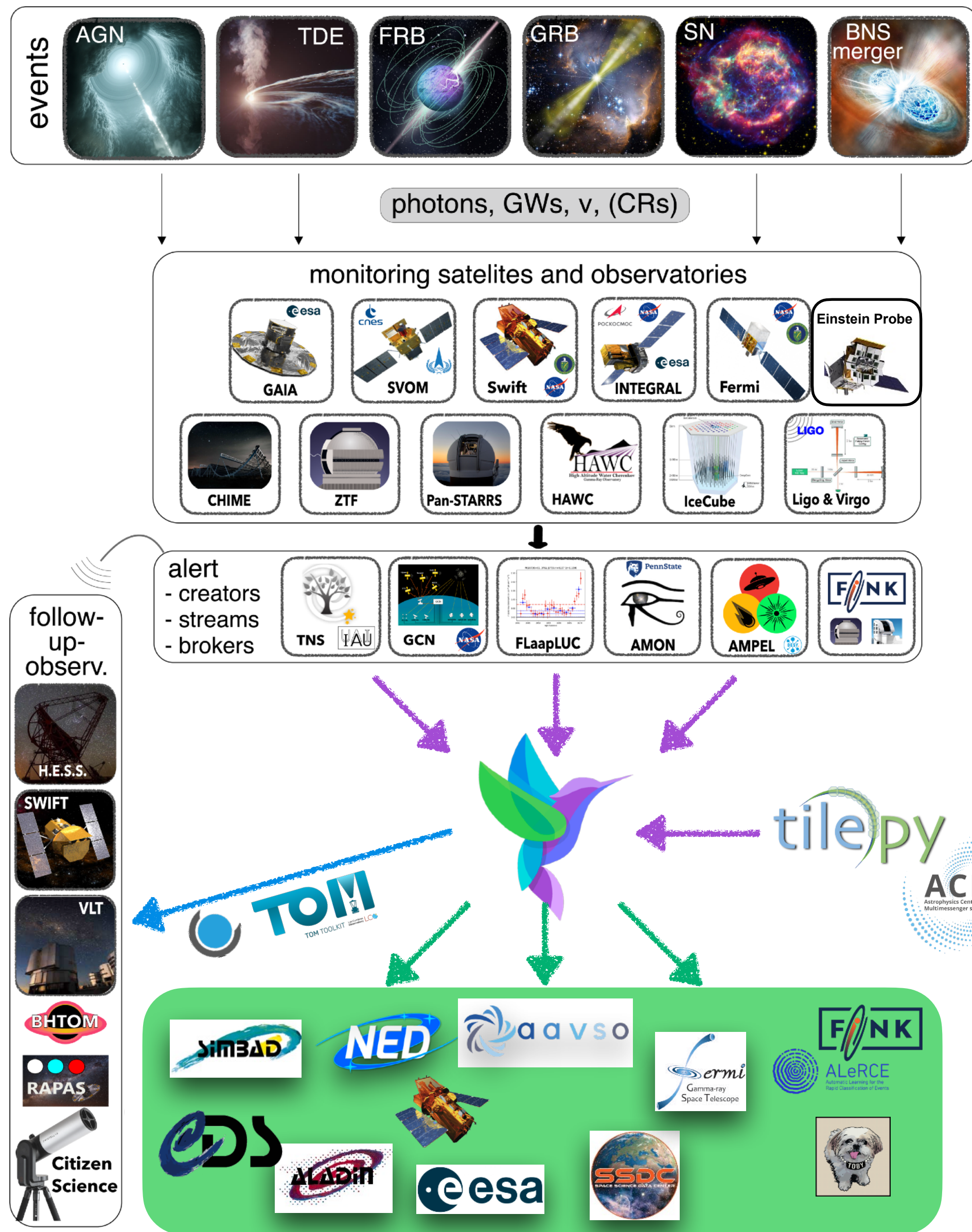


Coordinated follow-up observations

- Gravitational waves: TreasureMap.space

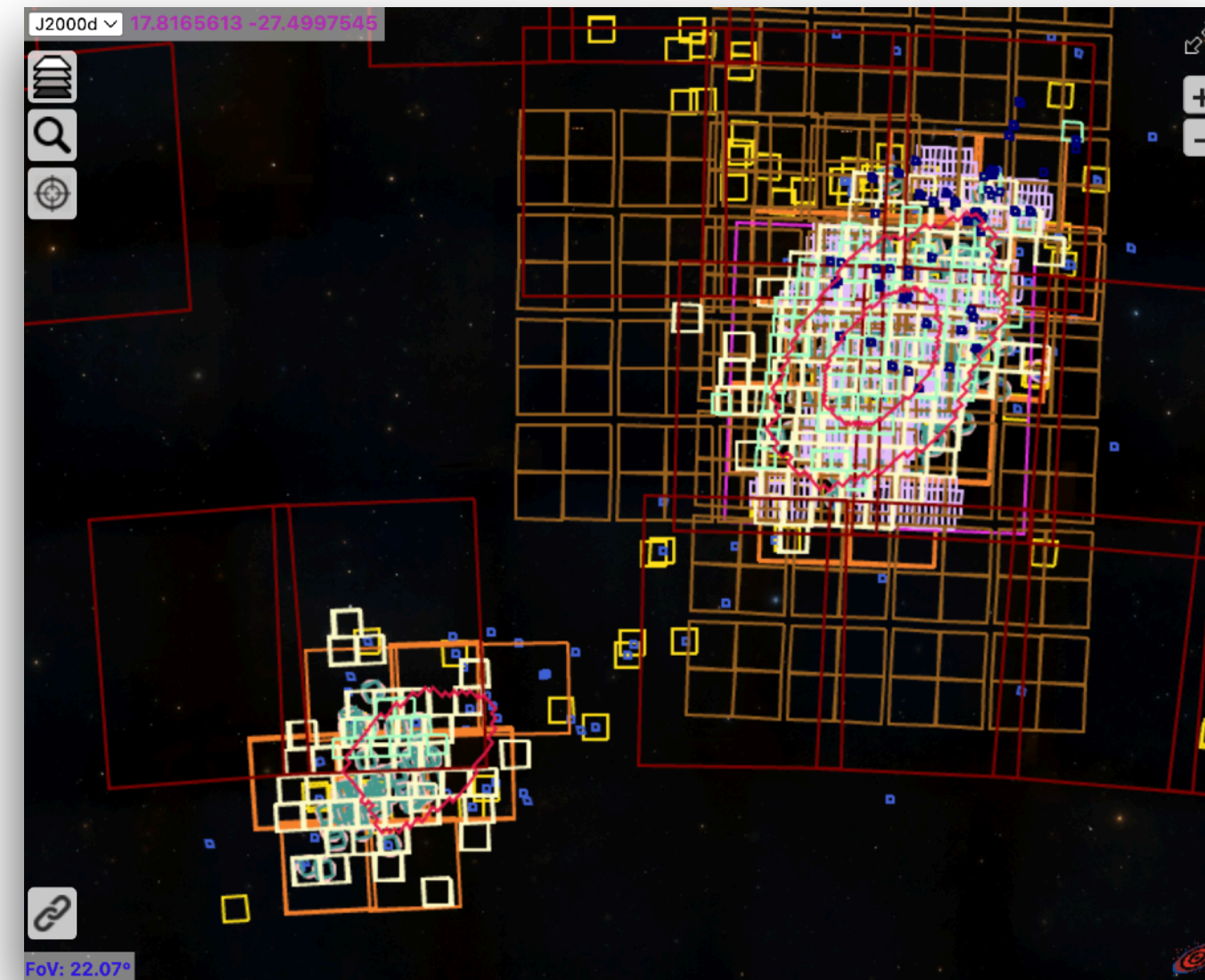


S190814bv
Well-localized NS-BH merger

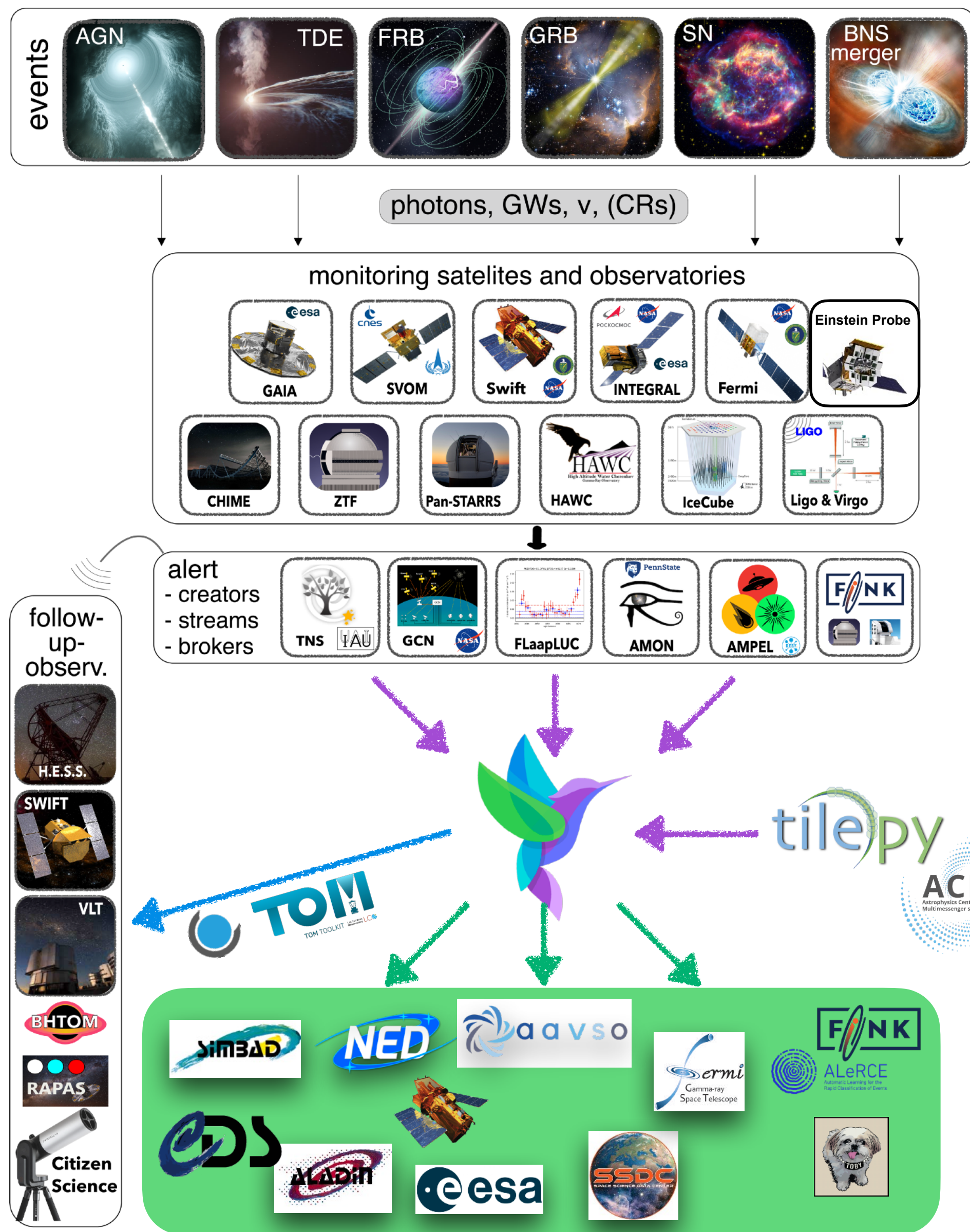


Coordinated follow-up observations

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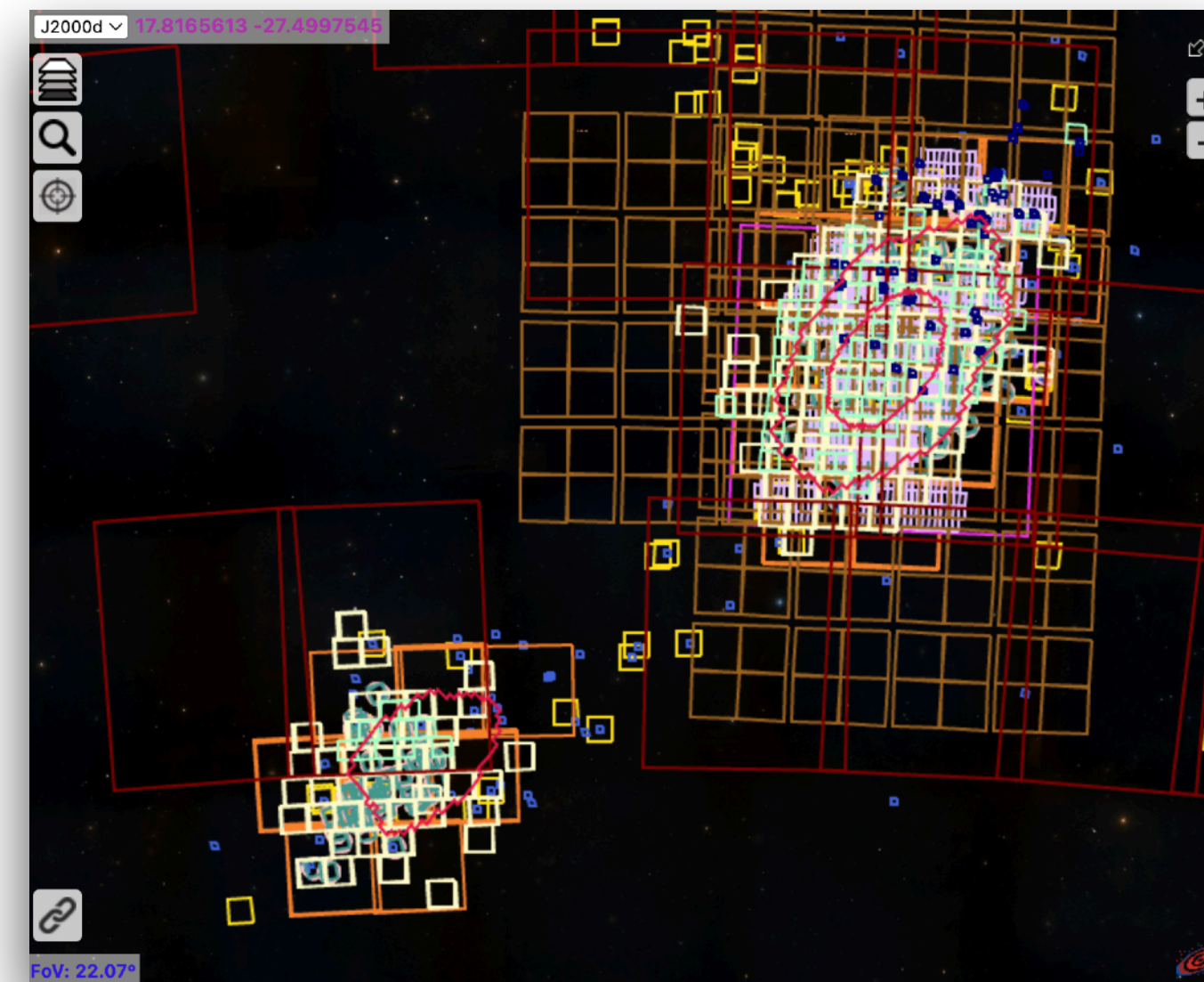


S190814bv
Well-localized NS-BH merger



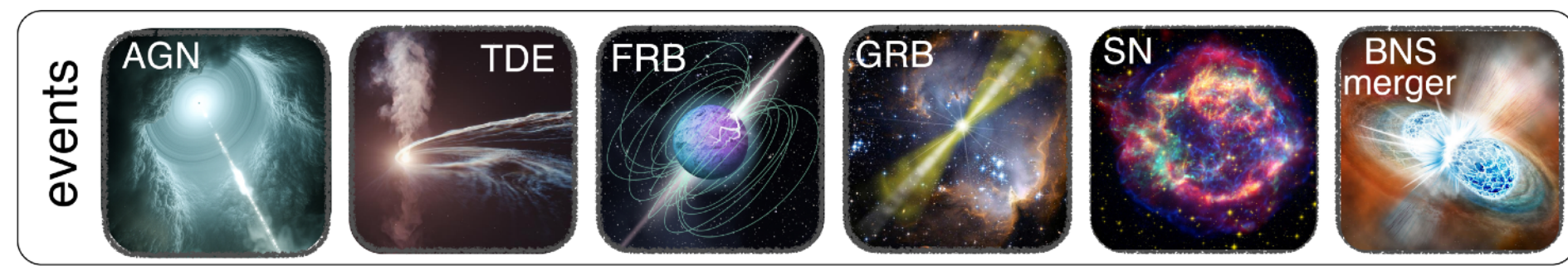
Coordinated follow-up observations

- Gravitational waves: TreasureMap.space

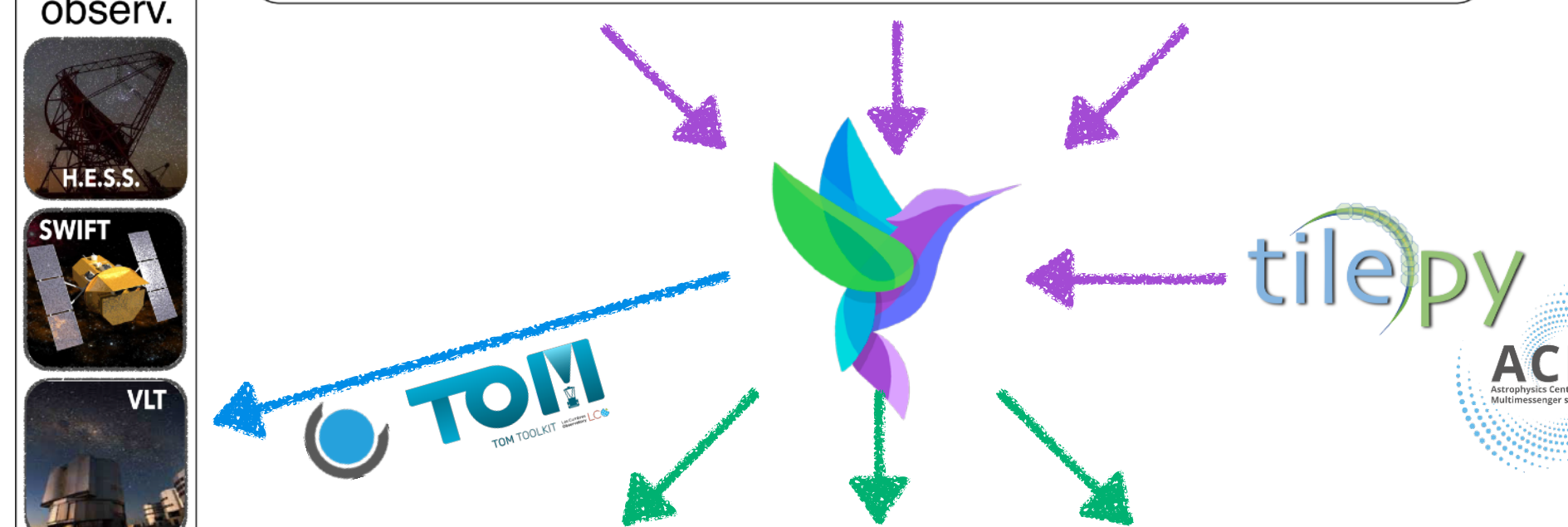
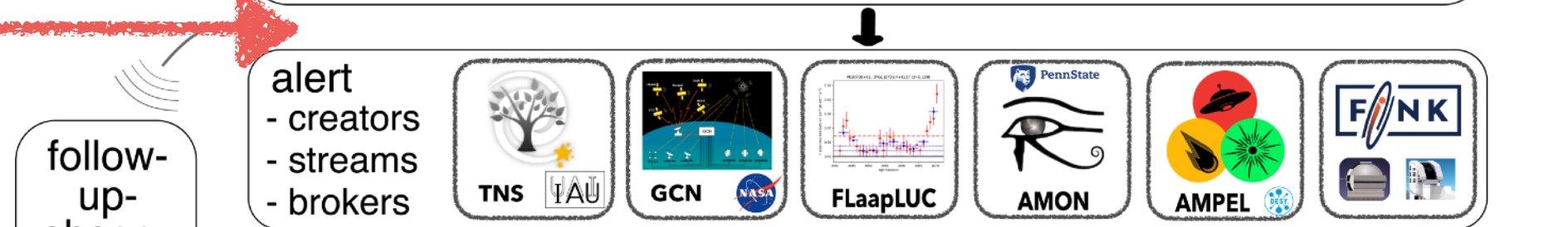
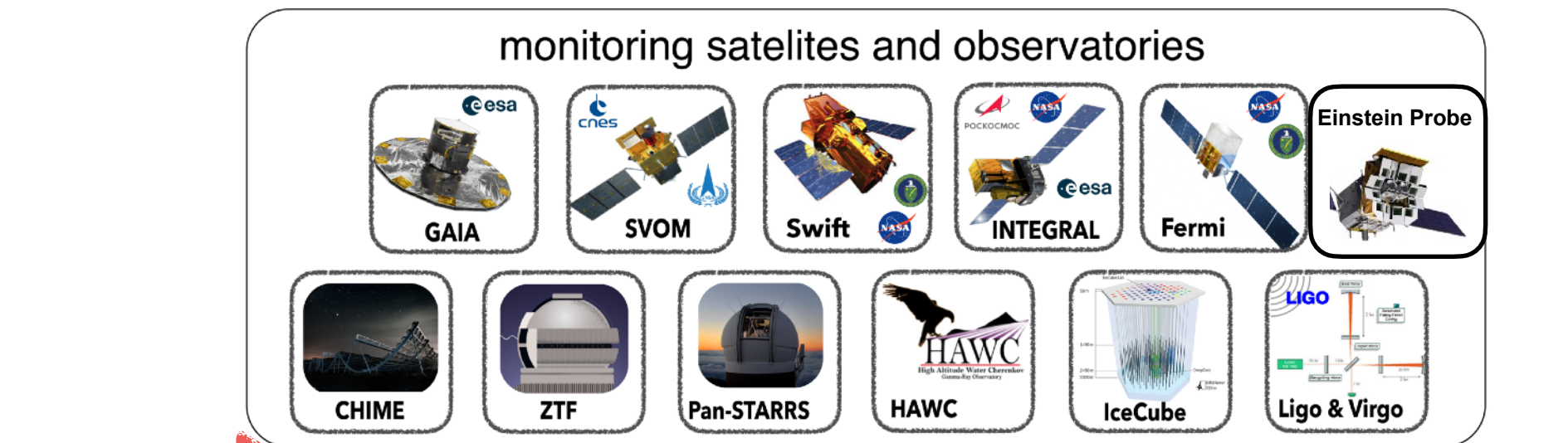


S190814bv
Well-localized NS-BH merger

- Public schedules
 - ObsLocTAP services (e.g. TOBY)
 - Individual observatories
 - Example: H.E.S.S. GRB follow-up schedule (<https://grbhess.github.io/>)



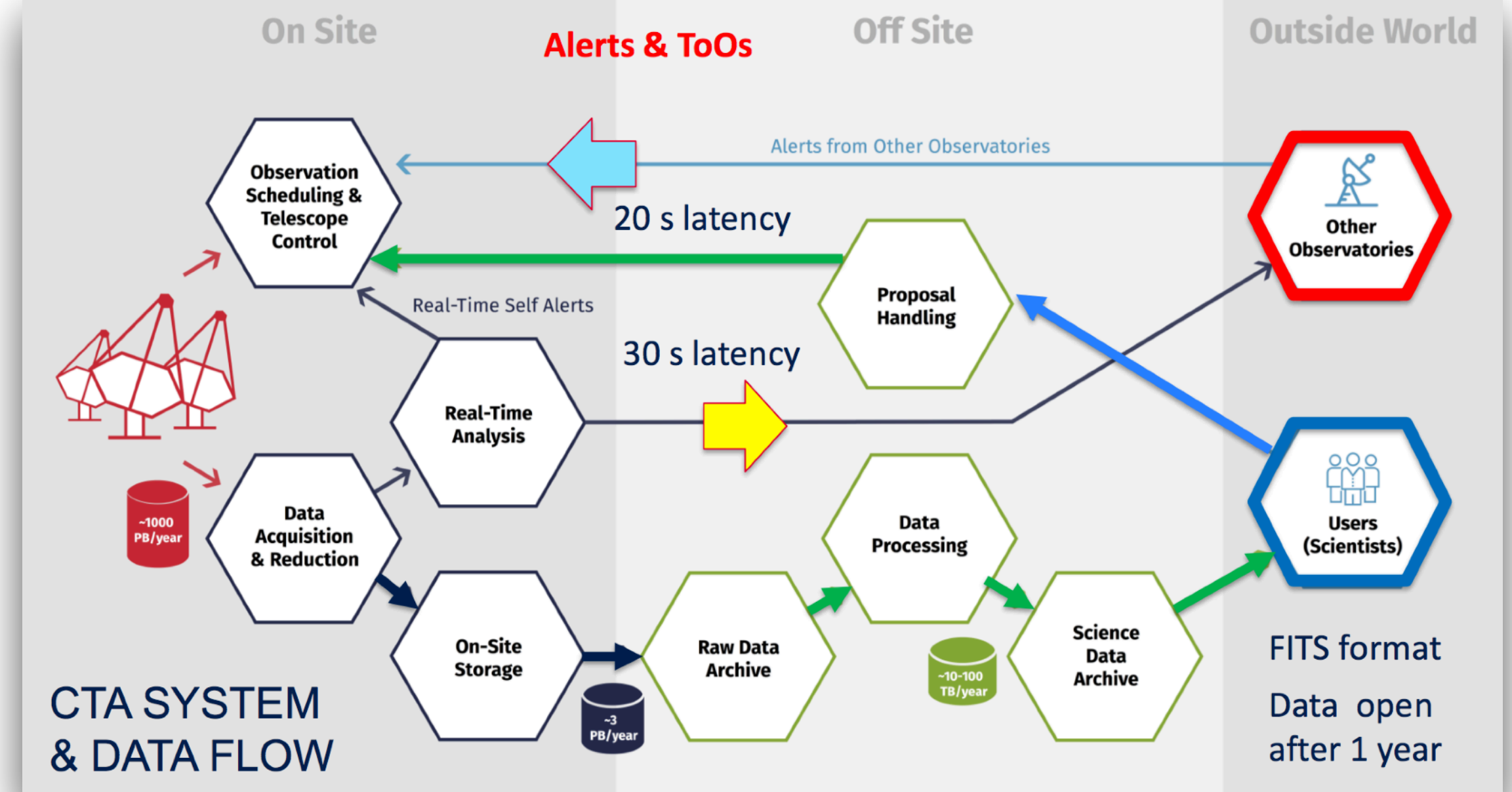
photons, GWs, ν , (CRs)



Rapid data analysis + dissemination

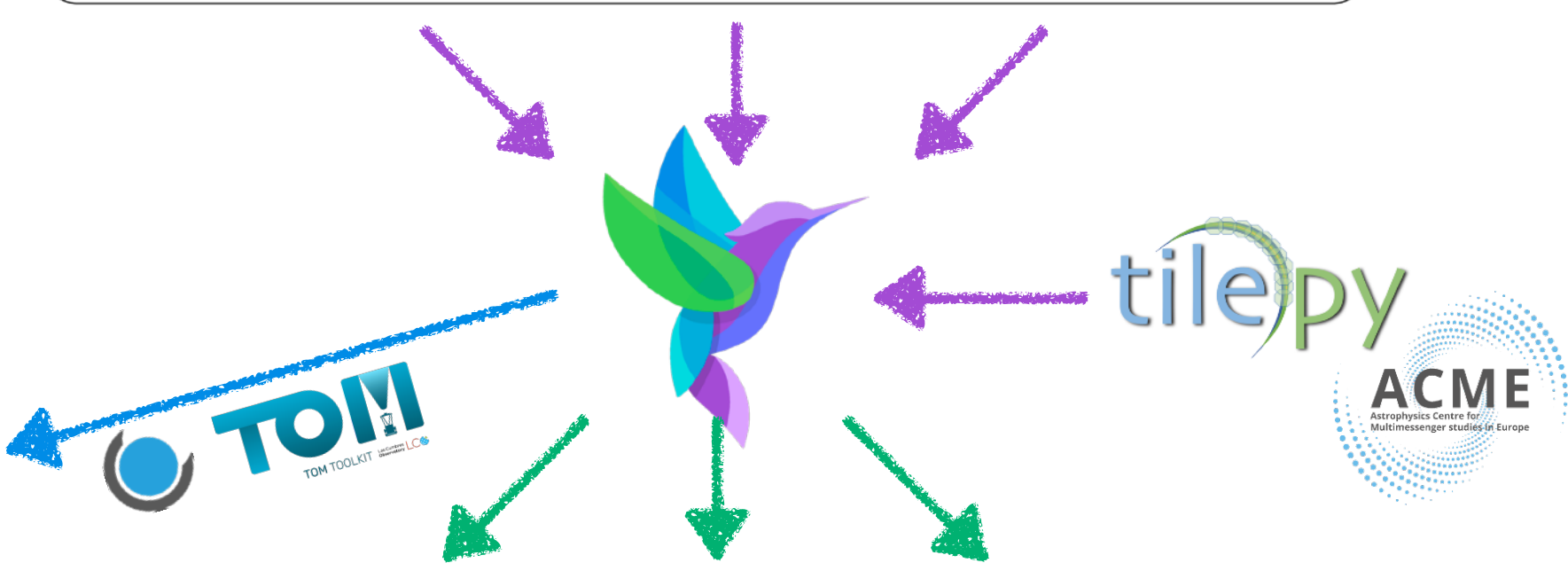
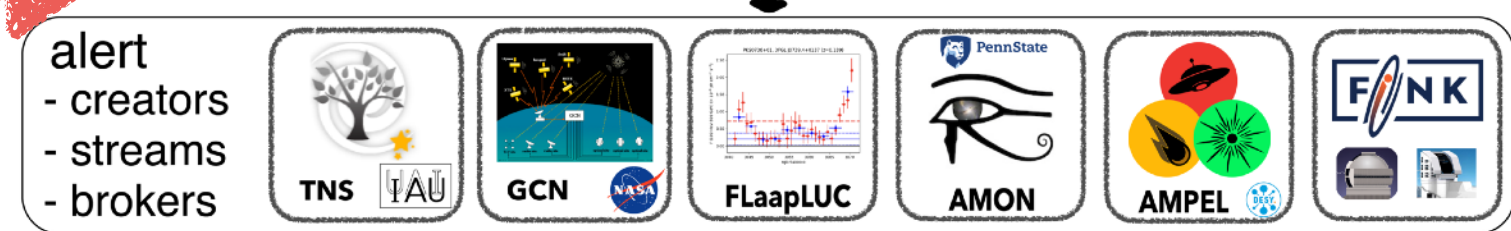
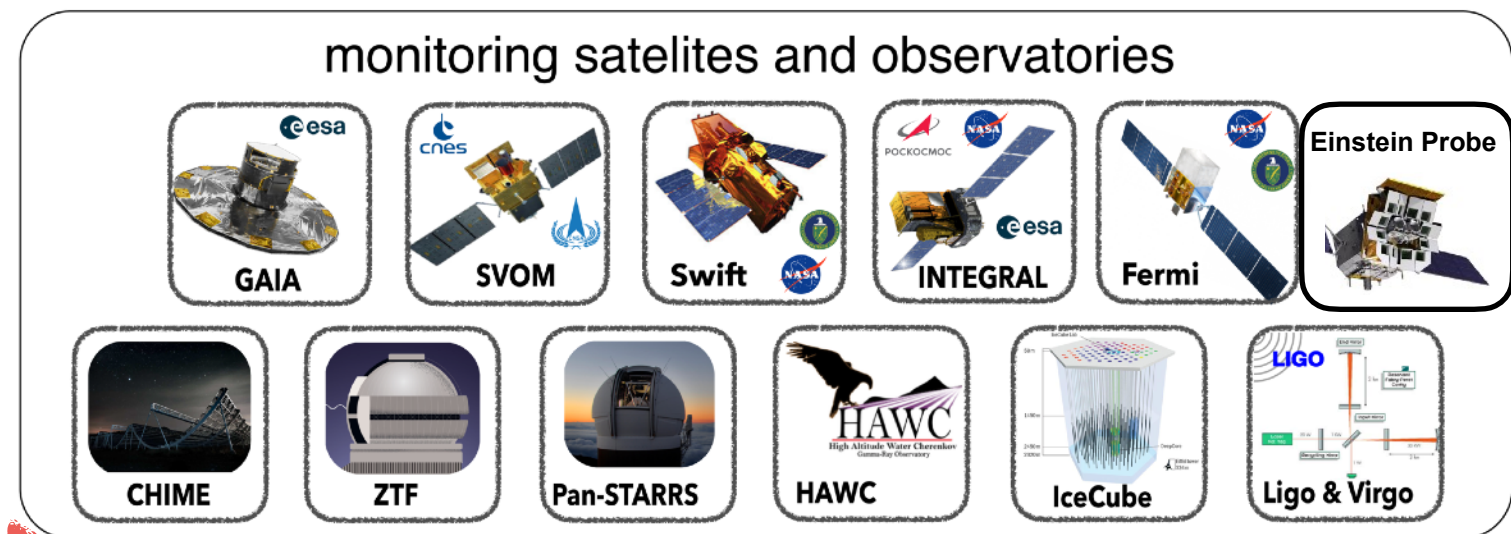
- (realtime) data analyses => guide further observations

Example: CTAO





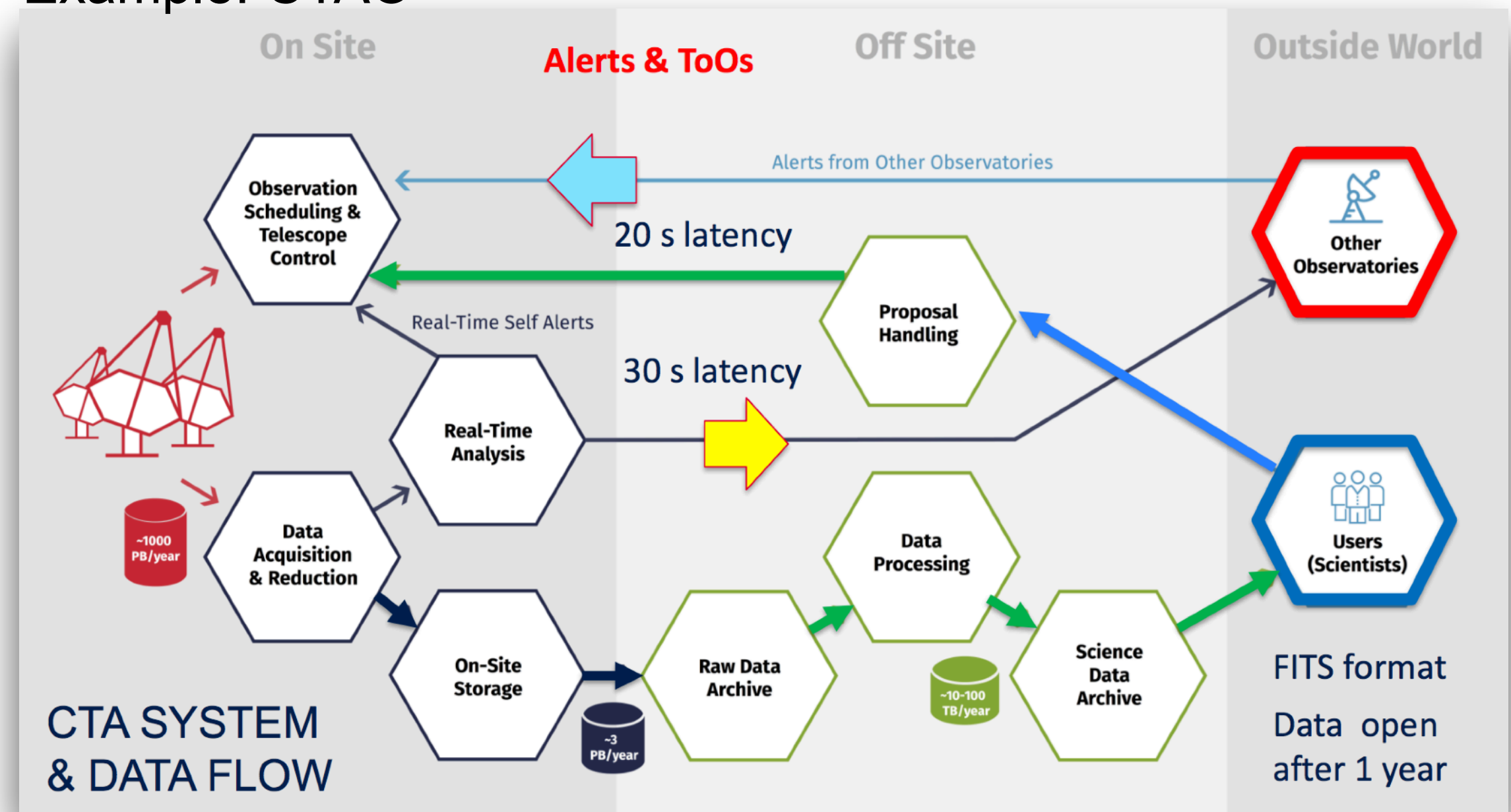
photons, GWs, ν, (CRs)



Rapid data analysis + dissemination

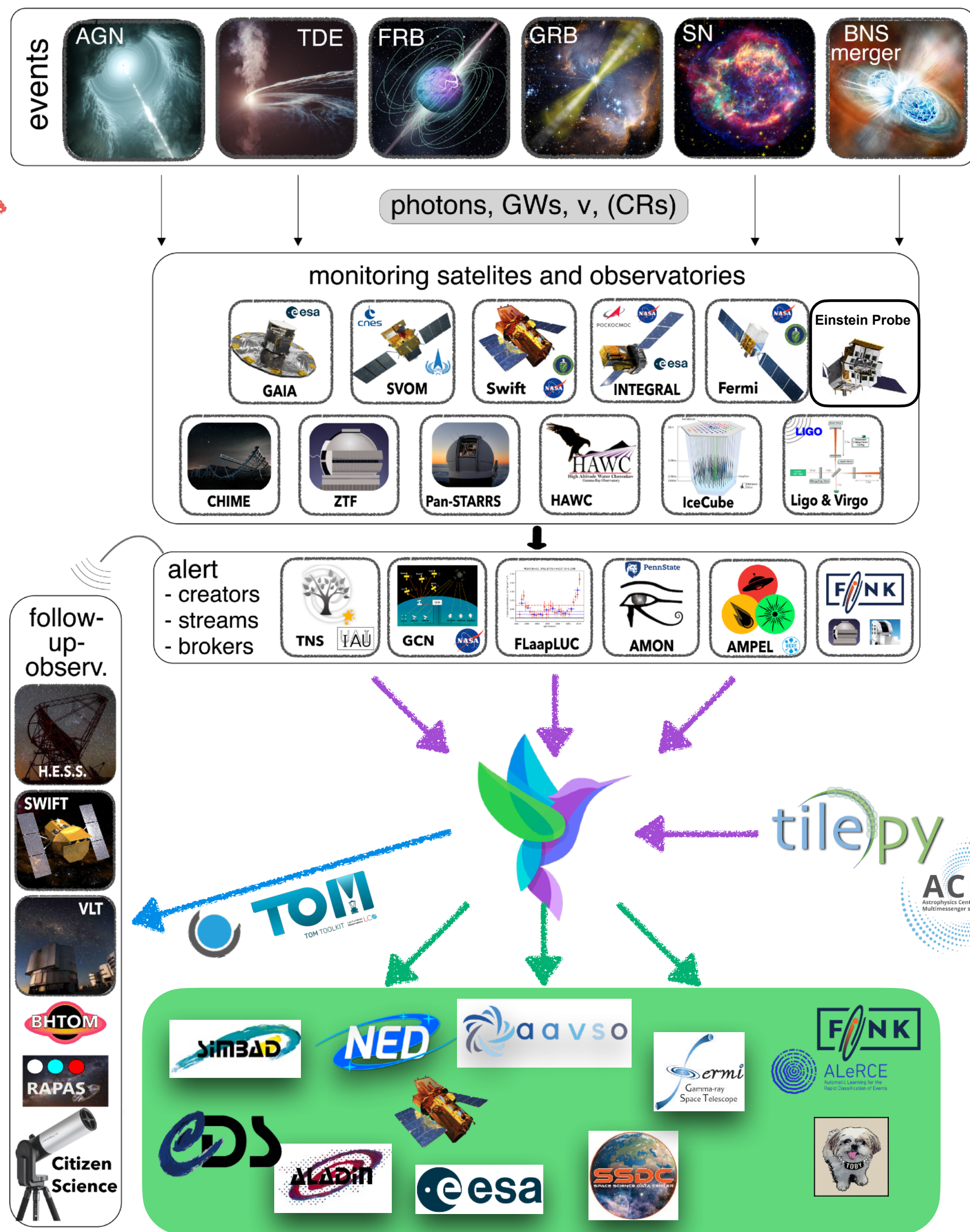
- (realtime) data analyses => guide further observations

Example: CTAO



- Rapid publication of follow-up results
 - Classification + characterization => increased efficiency
 - Comparable results (e.g. BHTOM)



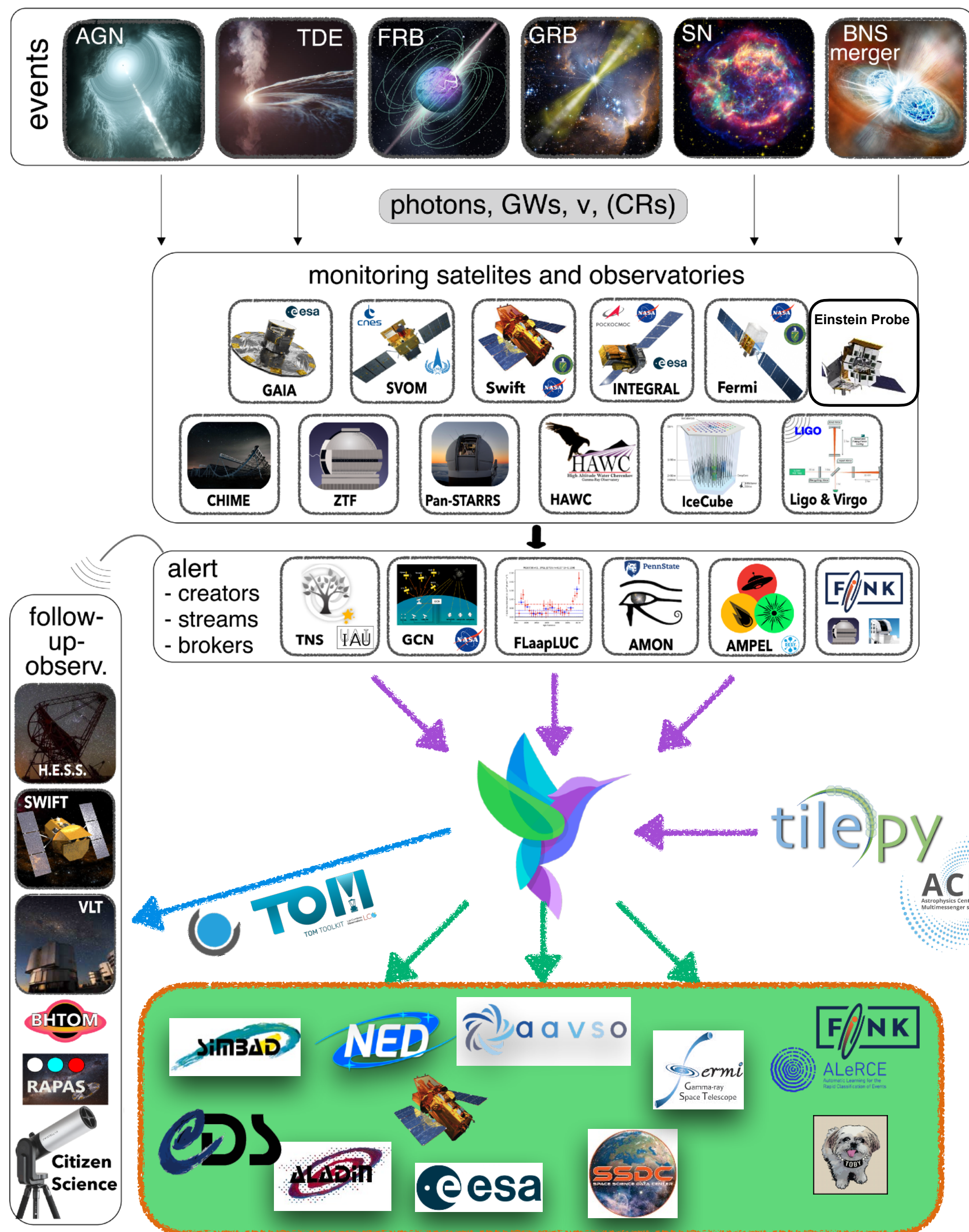


Global, joint MWL/MM analyses

- Complete picture of (transient) phenomena
- Rapid publication + data releases
- Finding data: global information database of available datasets ?
- MWL/MM + multi-instrument data analysis tools

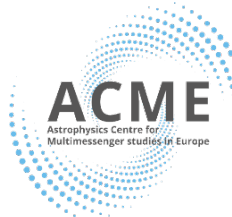
$\gamma\pi$ A **Python** package for **gamma-ray** astronomy

...



FAIR data archives

■ FAIR data archives

- Comprehensive archives of MWL/MM data
- Association with computing resources: facilitate reproducibility of analyses
 - e.g. MMODA 
- Common interfaces to allow for easy integration
 - e.g. connection to realtime decision making processes

Summary

- (Transient) multi-wavelength and multi-messenger observations are challenging
- We already have an enormous set of increasingly sophisticated tools at our disposal
- Further automatization and integration is necessary to cope with the increasing number and complexity of MWL/MM data.
- The Astrophysics Center for Multimessenger studies in Europe aims to advance this process
- Many open questions
 - How sustainable is the current landscape of tools and platforms in the mid/long-term? Single point failures?
 - What role will AI play?
 - Extract information from human written observation reports (e.g. GCN Circulars, ATEs, Astronotes)
 - Decision making processes: event classifiers as first step => agents ingesting all available data and take autonomous decisions on follow-ups ?
 - How can we further leverage contributions from citizen scientists?
 - ...