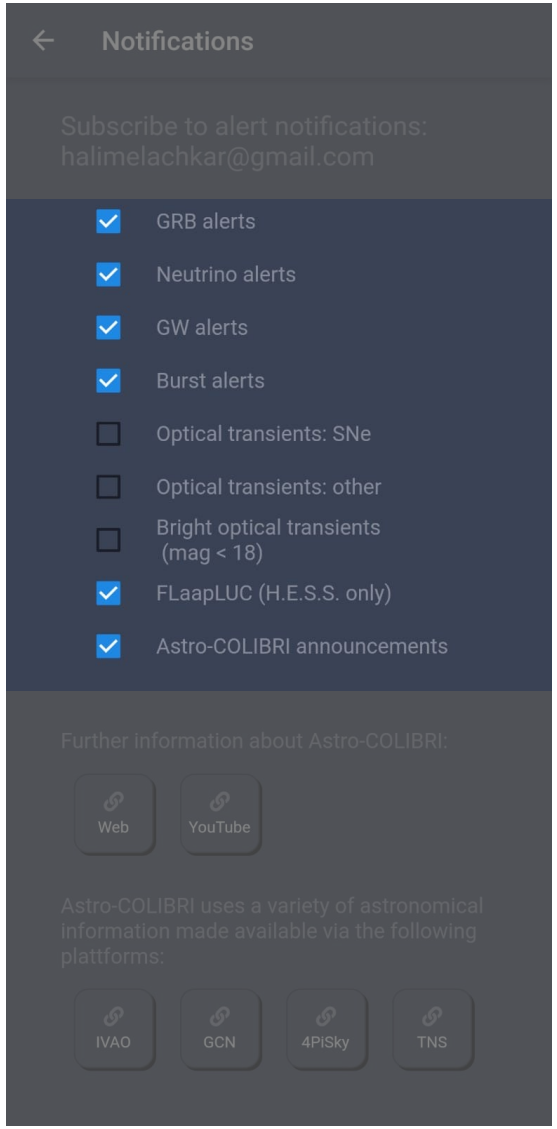
IACT transients follow-up systems

Halim ASHKAR

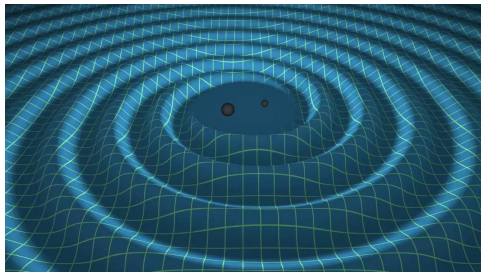
1st Astro-COLIBRI multi-messenger astrophysics workshop

26 September 2022 – Bochum, Germany

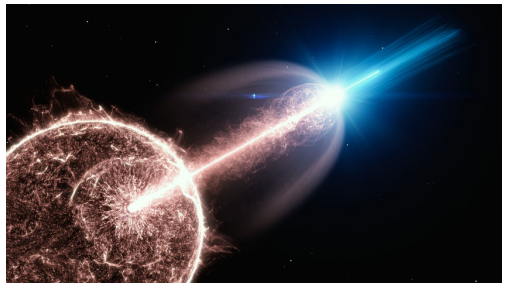
Transients



GW



GRB

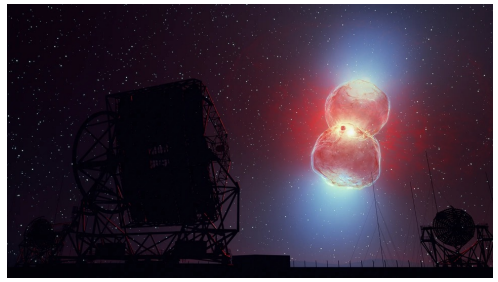


Neutrino

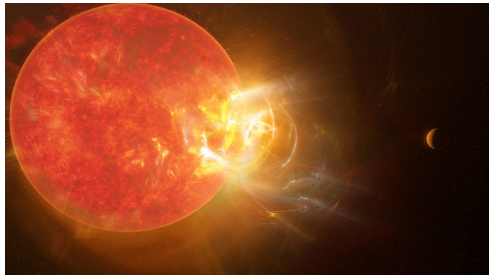
FRB

SGR

Nova

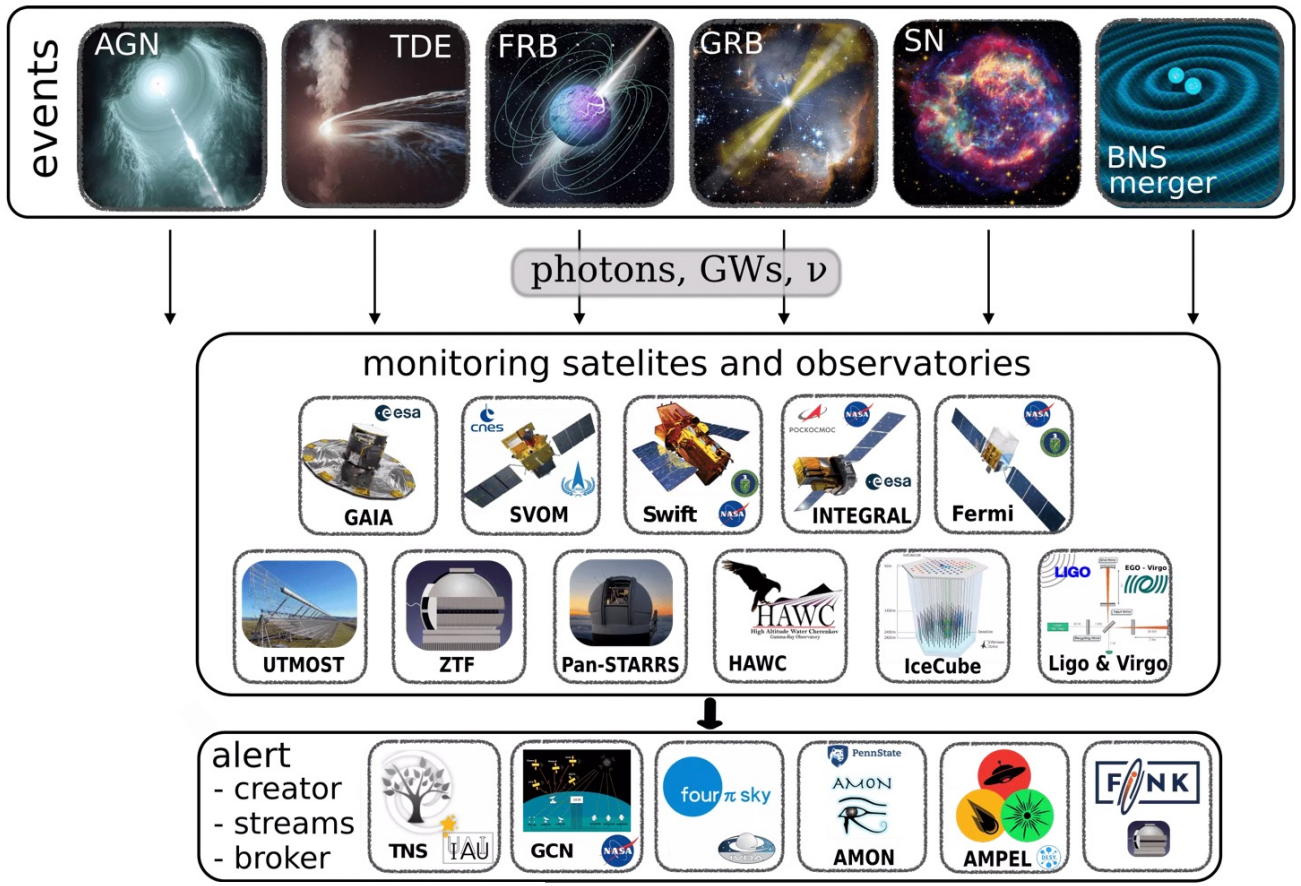


Flaring stars



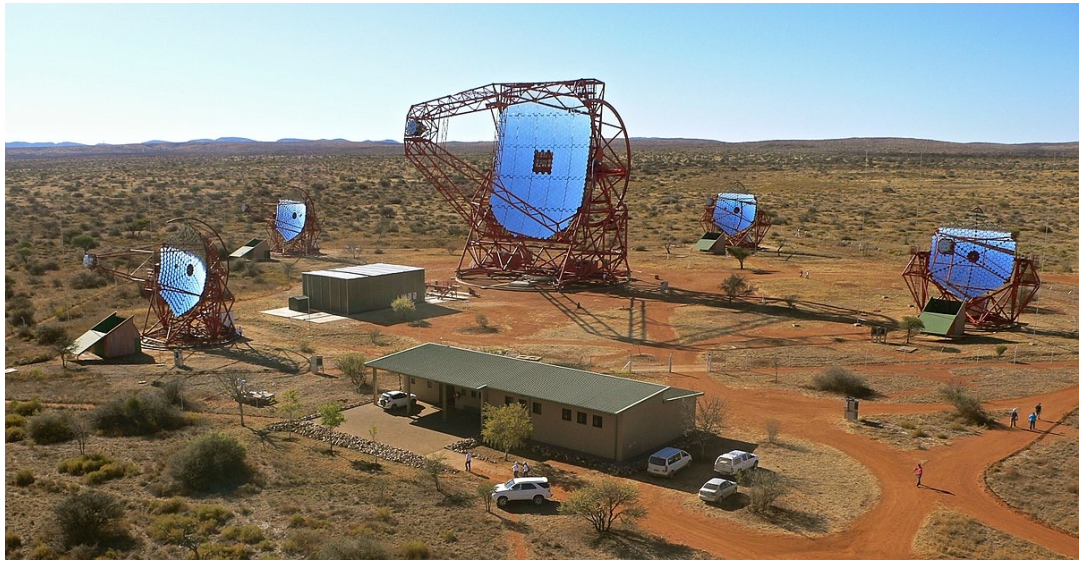
AGN flares

TDE

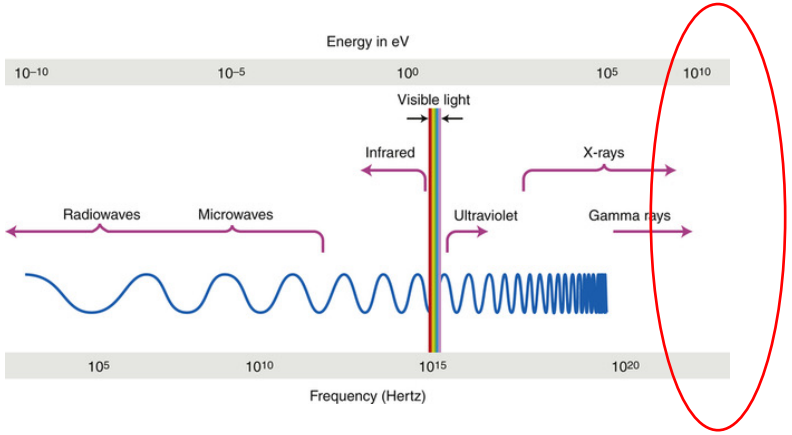


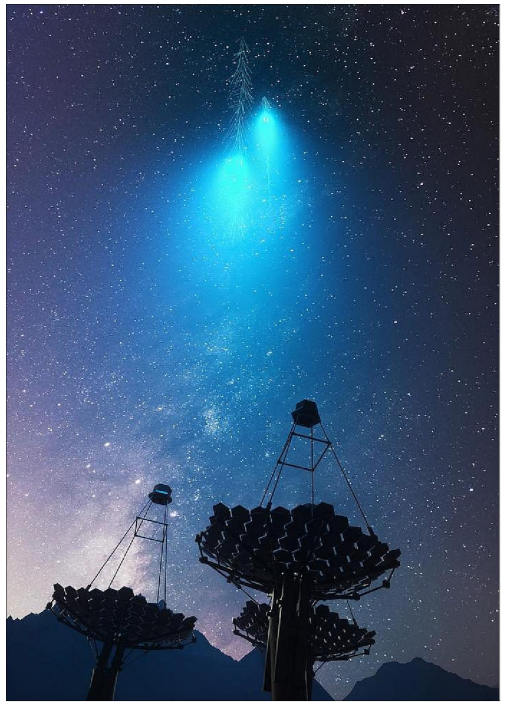
P. Reichherzer, (2021), 256, 5

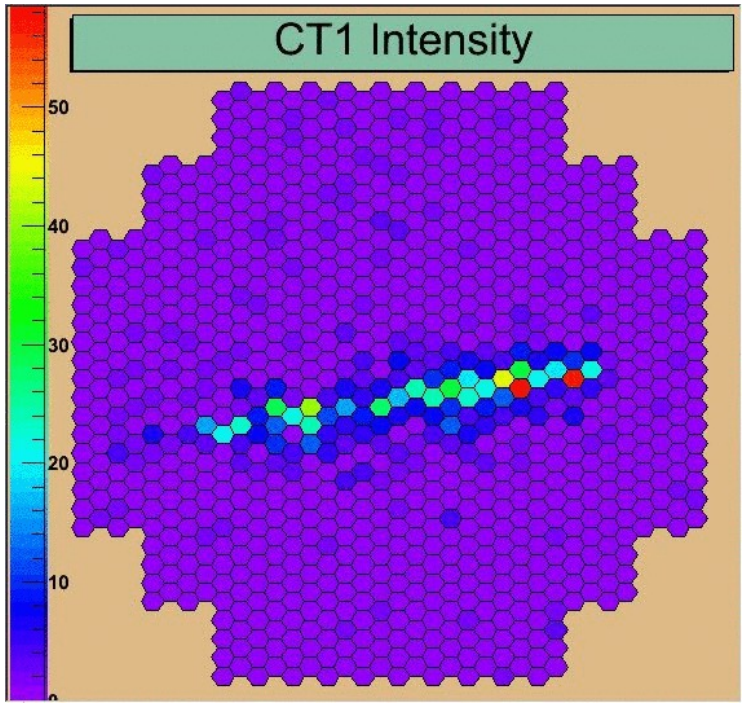
IACTs: Imaging Atmospheric Cherenkov Telescopes

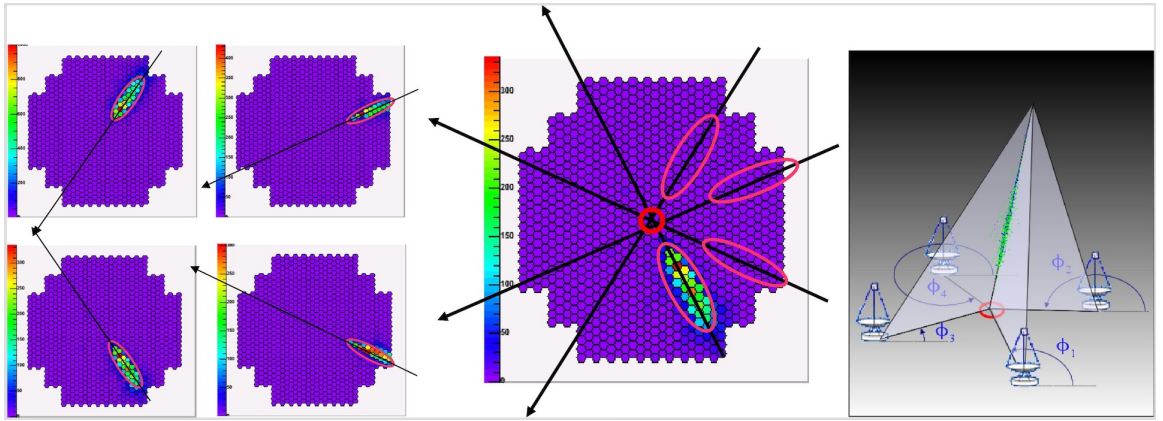


Detection of VHE Gamma-rays with IACTs

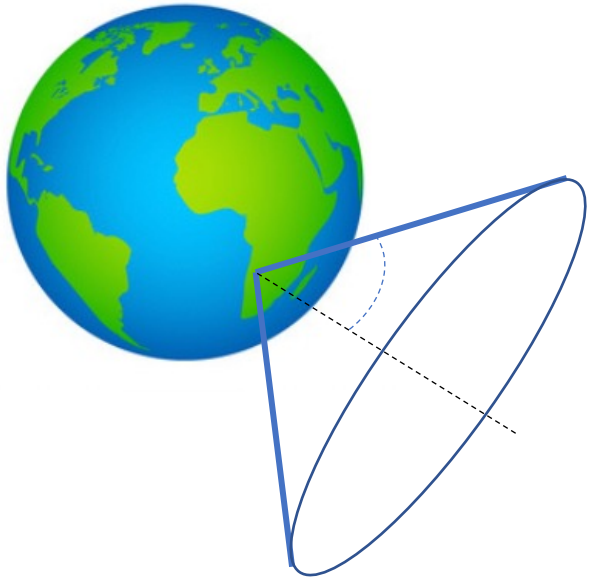






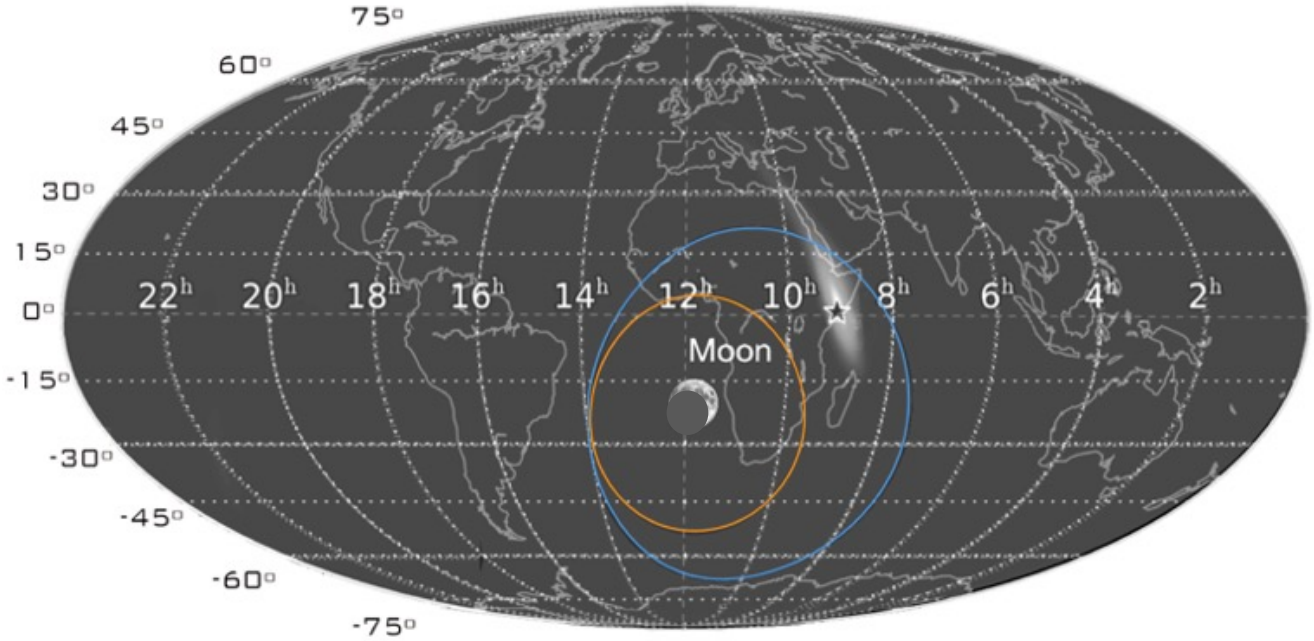


Considerations for IACTs

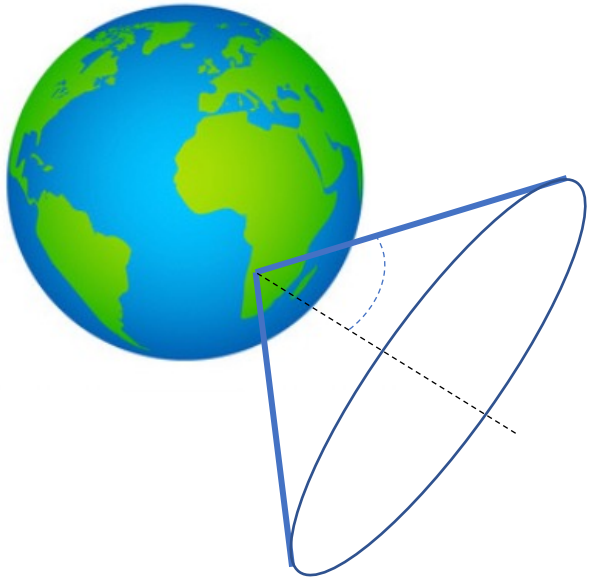


- Visibility conditions :
  - Position of the telescopes (lon , lat)
  - Maximum zenith angle possible

- Observation conditions :
  - Sun and Moon position
  - Moon phase



Considerations for IACTs



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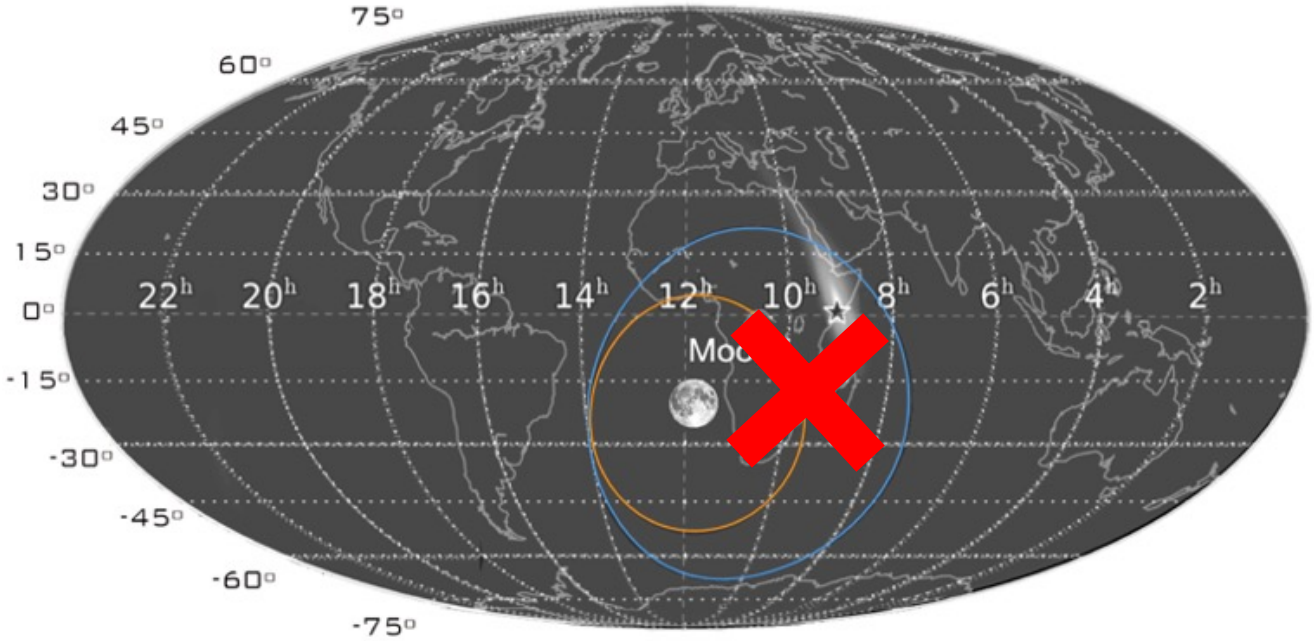
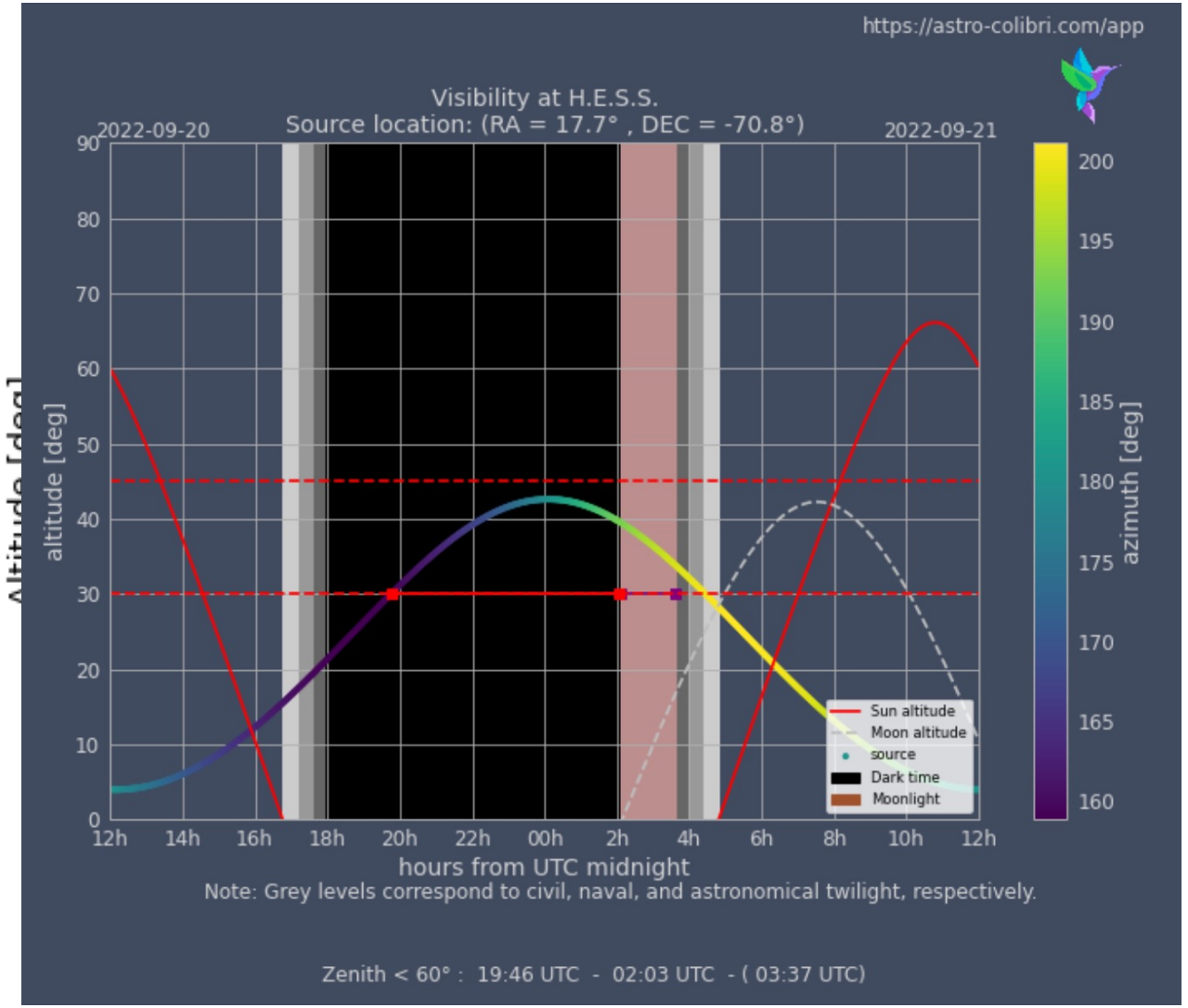
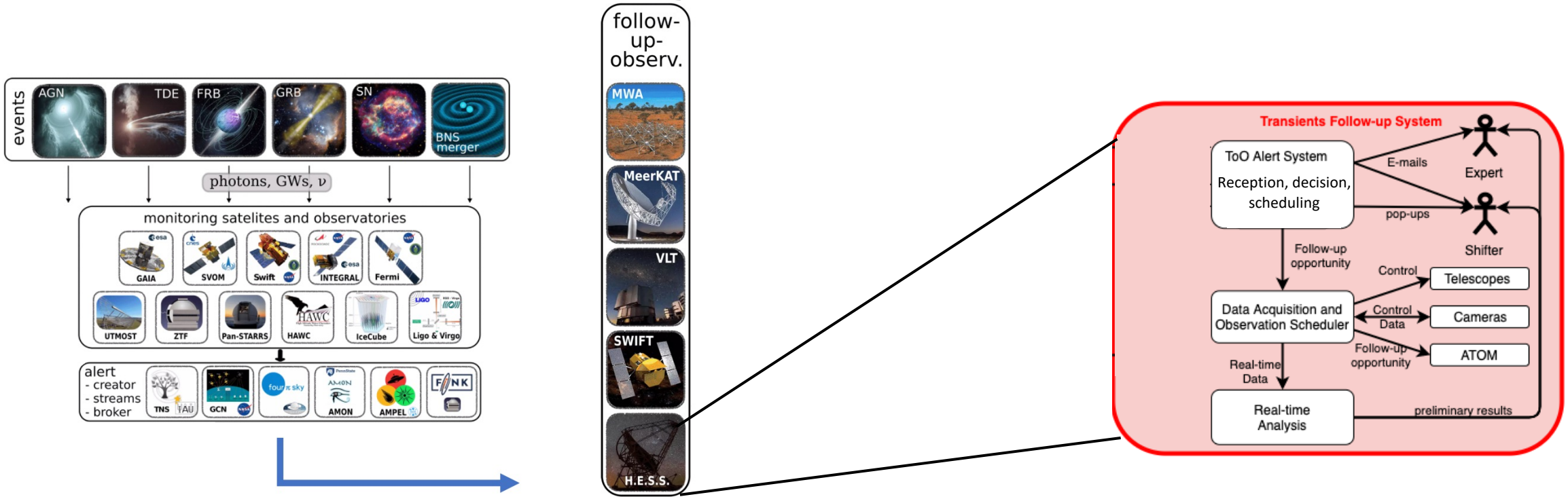


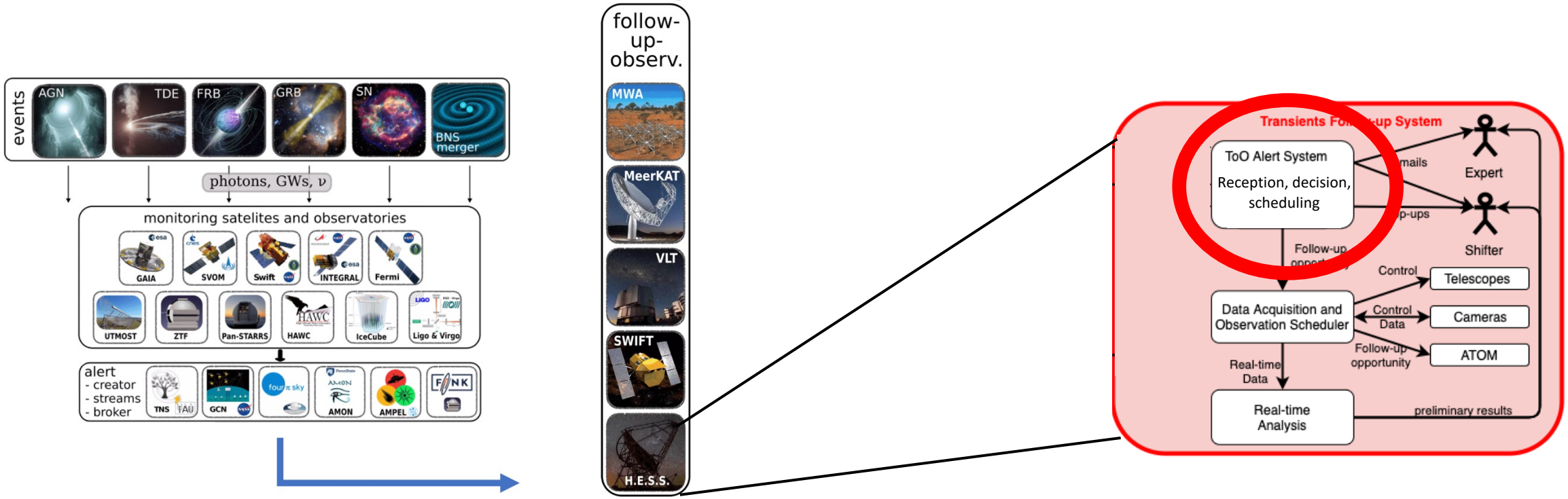
Considerations for IACTs



Transient follow-up systems



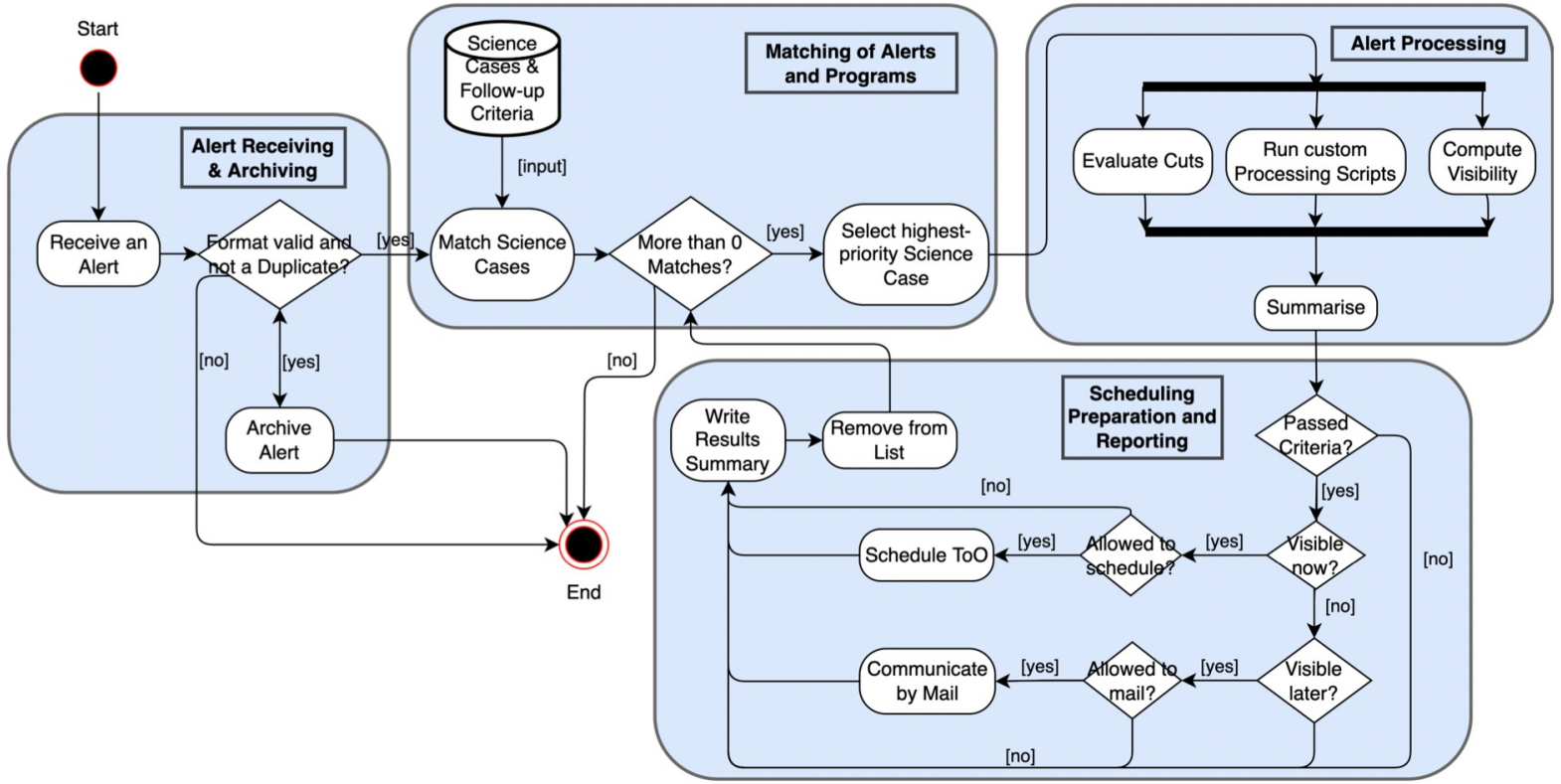
Transient follow-up systems



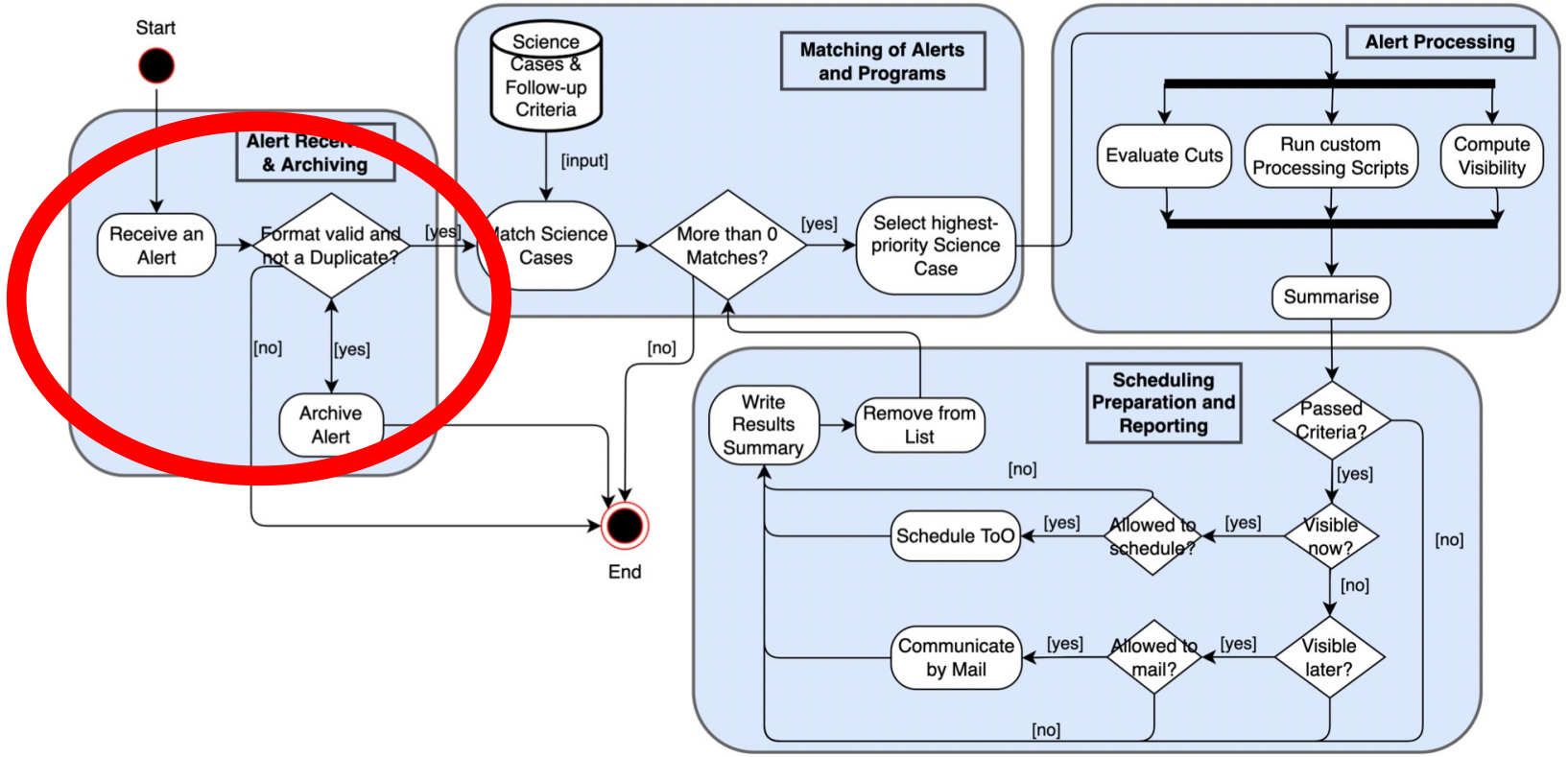
ToO alert systems

C. Hoischen, (2022). A&A

Brokers: GCN, 4pisky
Facilities: IceCube, Antares



ToO alert systems



Burst BNS BBH

LVC GW

Early, Preliminary, Initial,
Update, Retraction

SGR

FRB

Test alerts

Neutrino

Gold, Bronze

LAT GRB

Swift GRB

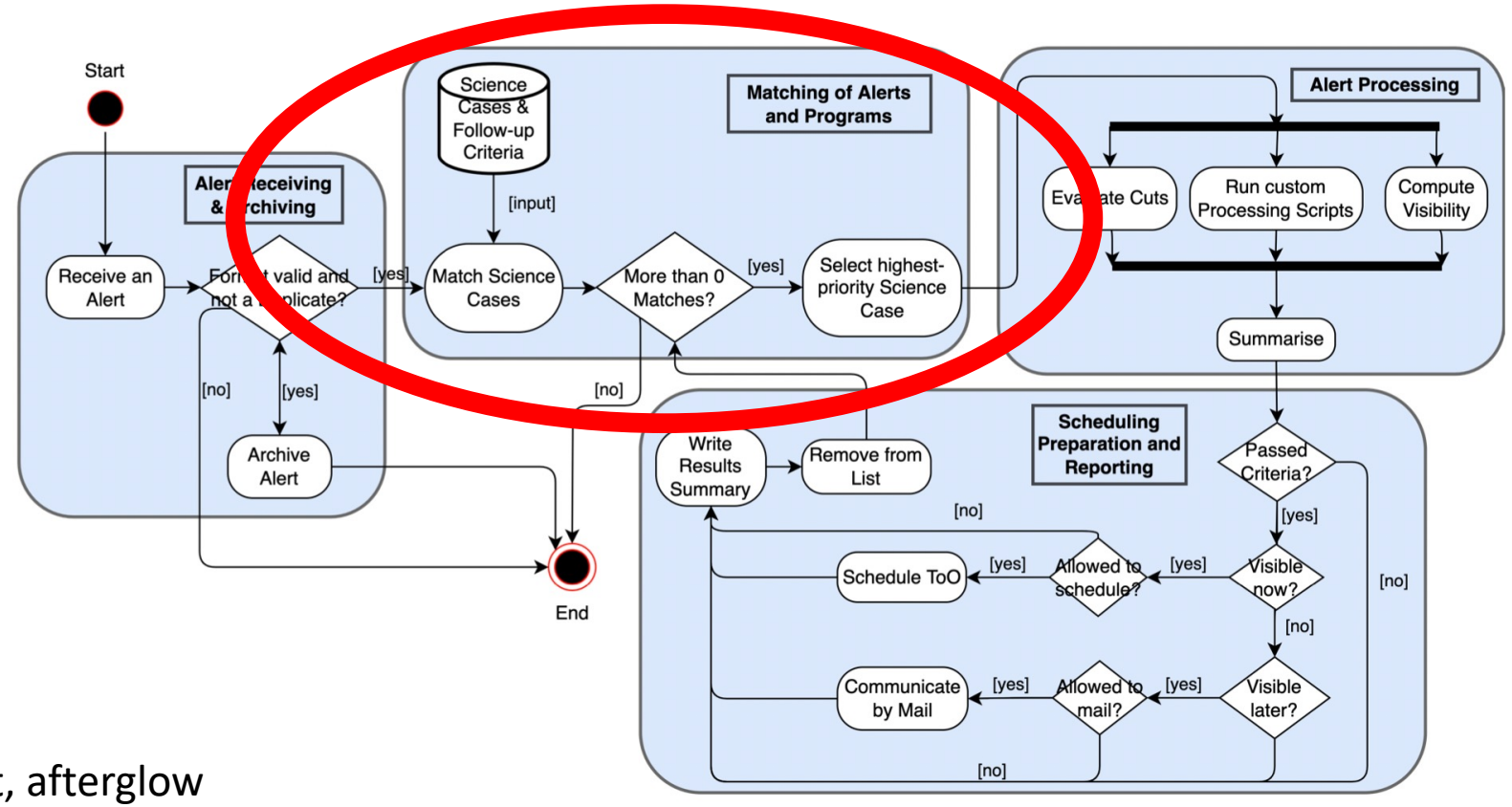
GBM GRB

FLT, GnD, Final

Flaring star

GBM GRB

Slew alerts



Prompt, afterglow

Priorities

GBM GRB

LAT GRB

Neutrino Gold

SGR

Swift GRB

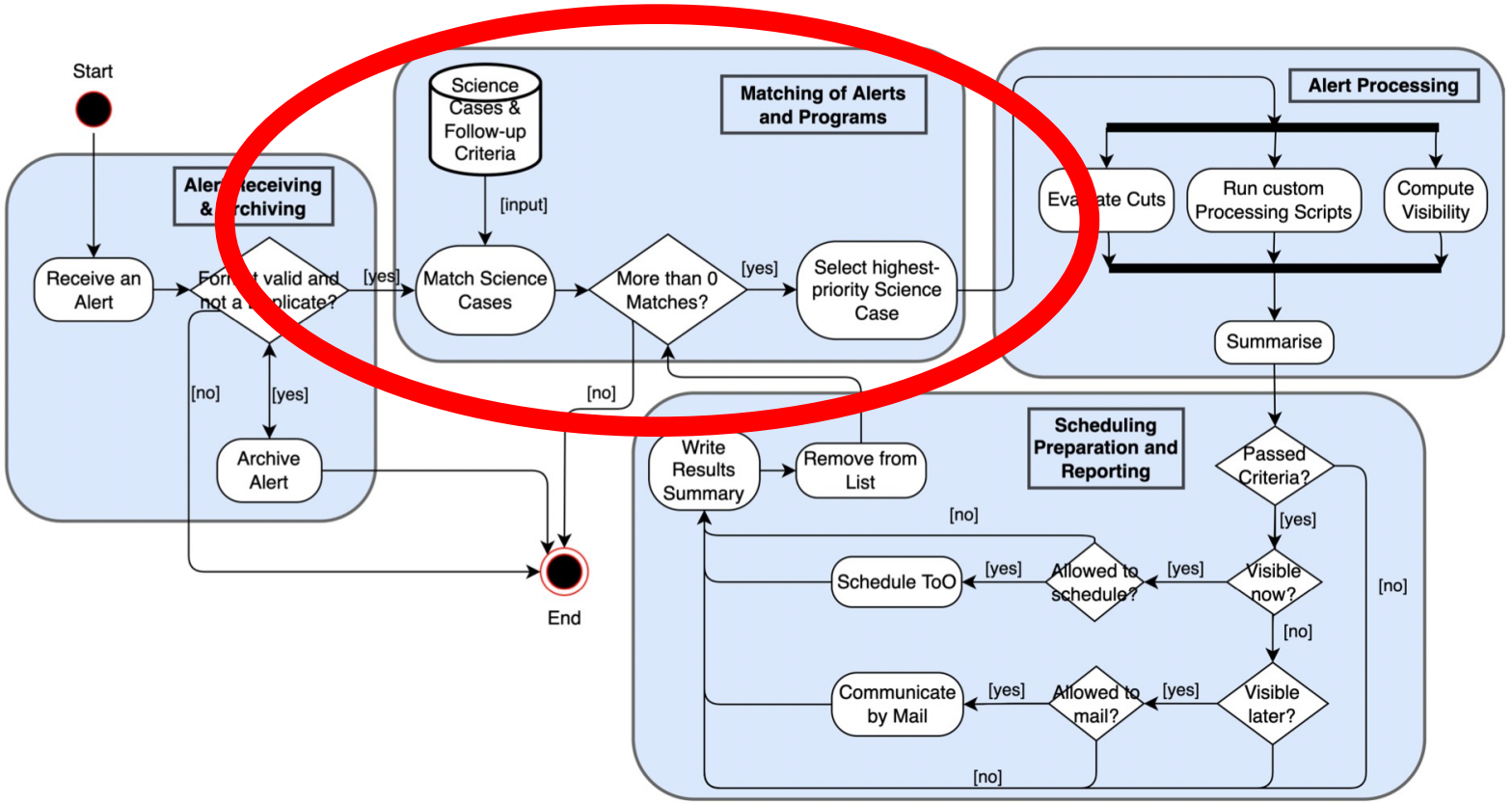
Flaring stars

BNS

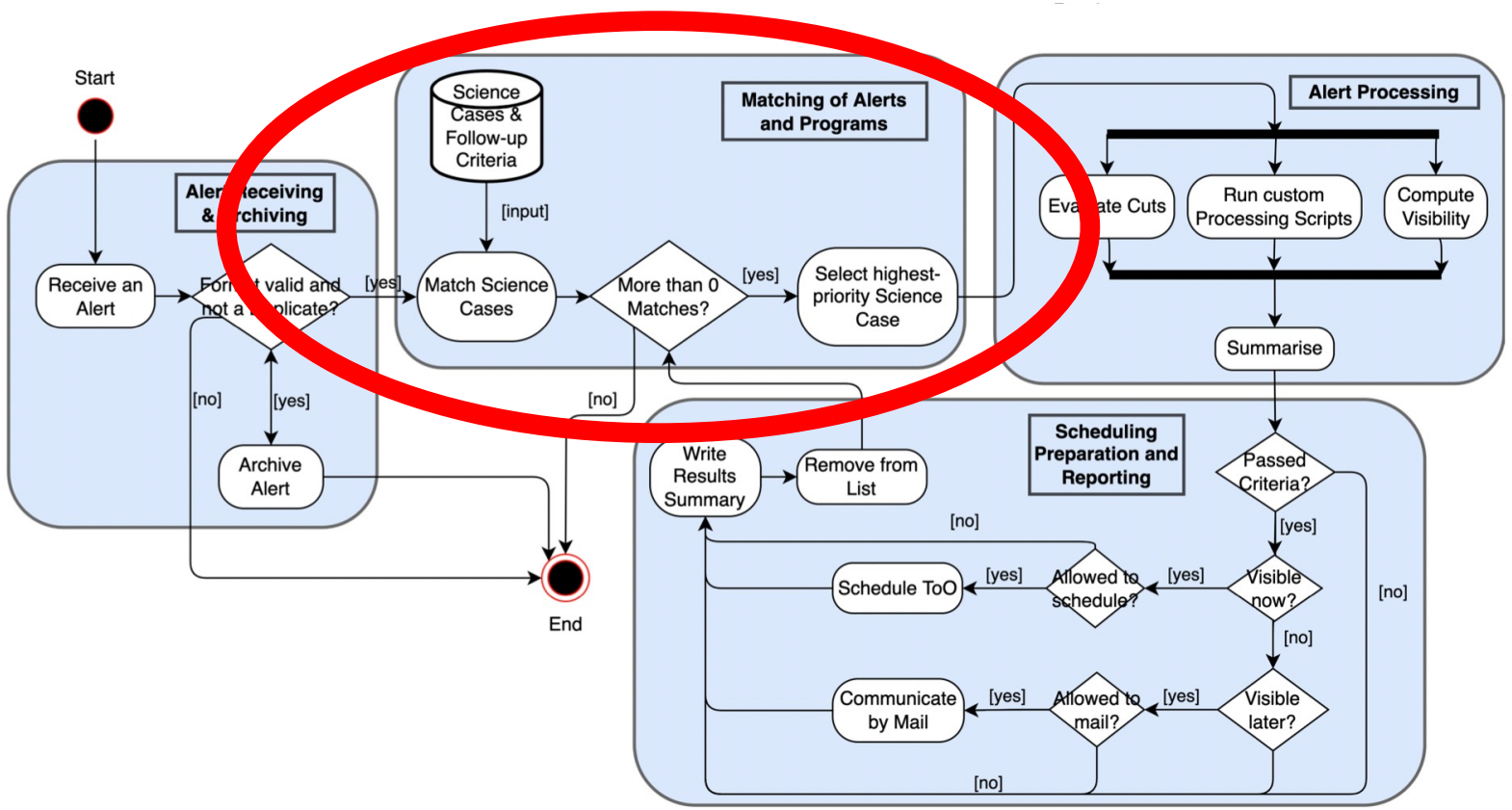
BBH

FRB

Burst



Priorities



LAT GRB

BNS

Swift GRB

SGR

GBM GRB

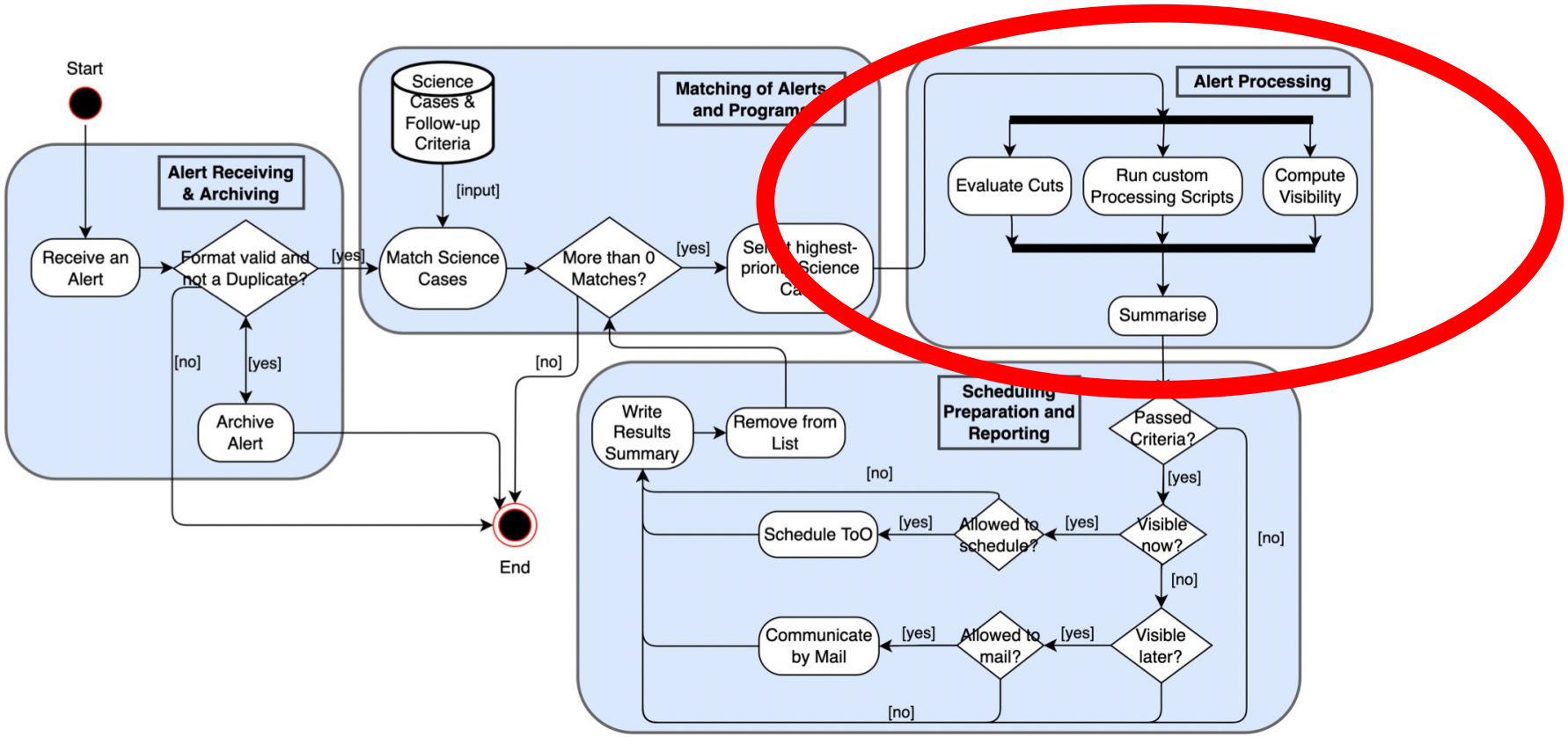
Neutrino Gold

Burst

BBH

FRB

Flaring stars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Alert Receiving & Archiving
Receive an Alert
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Science Cases & Follow-up Criteria
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Matching of Alerts and Programs
Match Science Cases
More than 0 Matches?
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[no]
Alert Processing
Evaluate Cuts
Run custom Processing Scripts
Compute Visibility
Summarise
Scheduling Preparation and Reporting
Passed Criteria?
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Visible now?
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Allowed to schedule?
[yes]
Schedule ToO
Visible later?
[yes]
[no]
Allowed to mail?
[yes]
Communicate by Mail
[no]
Write Results Summary
Remove from List
End

Cut evaluation

General cut examples:

- GRBs:
  - Errors on the localization region
  - Known source
- SGRs:
  - Number of counts
- Neutrinos:
  - Signalness
- FRBs:
  - DM
  - S/N
- GWs:
  - Terrestrial probability
  - BNS, BBH or other….

Custom processing

If needed:

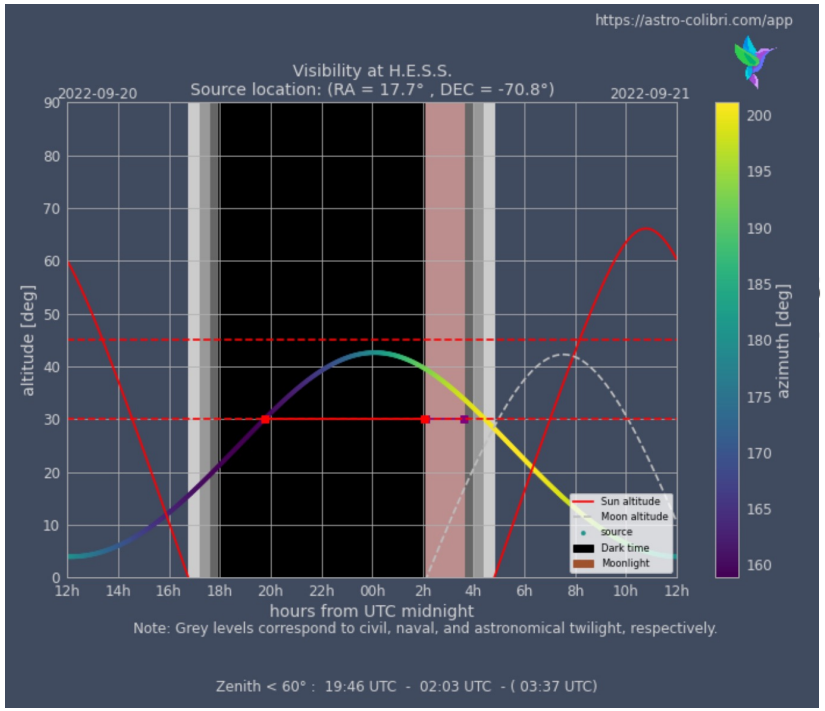
- Alerts that require special treatment
- Extra calculations and computations

Special cases:

Matches with source catalogues: SGR and flaring stars

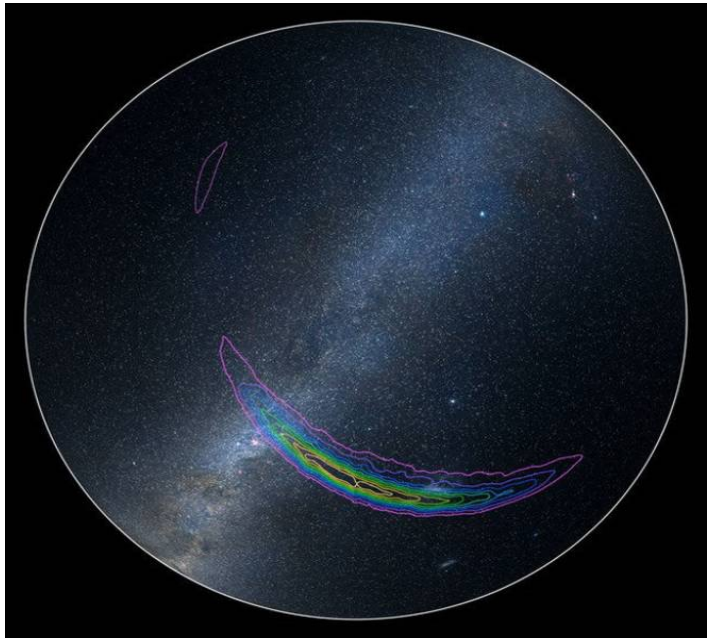
Poorly localized alert (GW, GBM GRBs)

Visibility computation

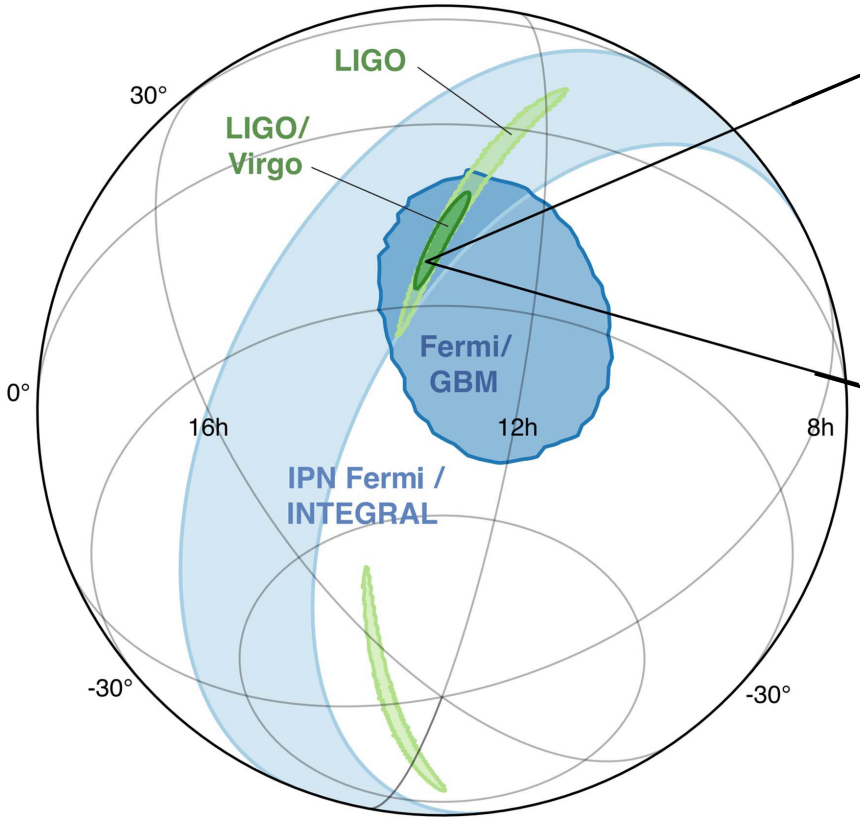


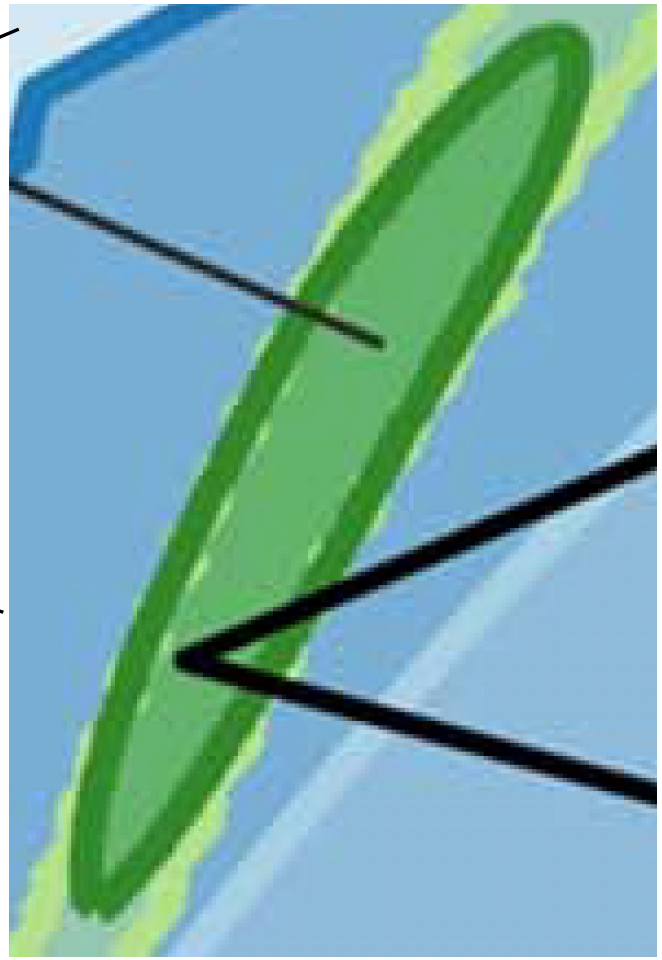
- Relatively well localized events
- Position is reported as coordinate + small uncertainties
- Standard evaluation

- Relatively poorly localized events
- Position is reported as coordinate + large uncertainties
- + Localization maps
- GWs, GBM GRBs, Neutrinos…
- Special treatment



Gravitational Wave event localization





GW 90% region: 31 deg^2

Moon: 0.5 deg^2

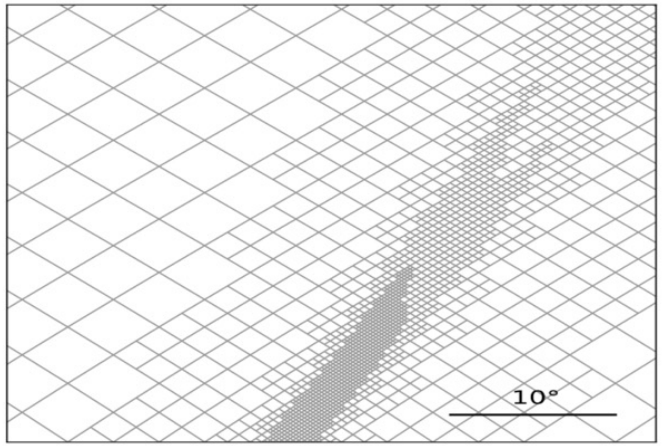
Ingredients for the solution

1. GW localization/probability map

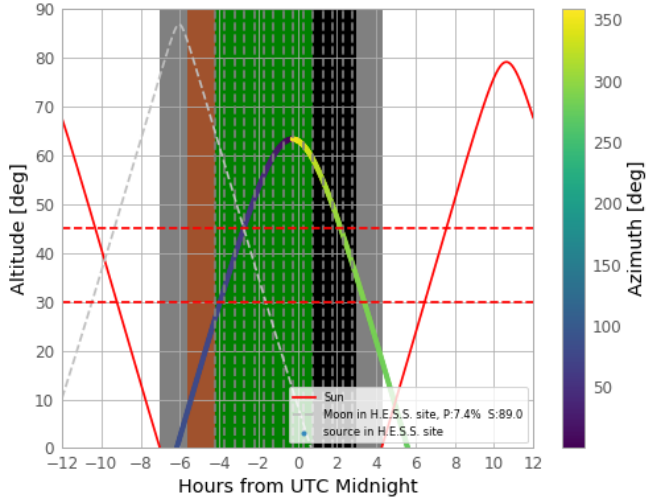
HEALPix format: Pixel indices + 4 layers

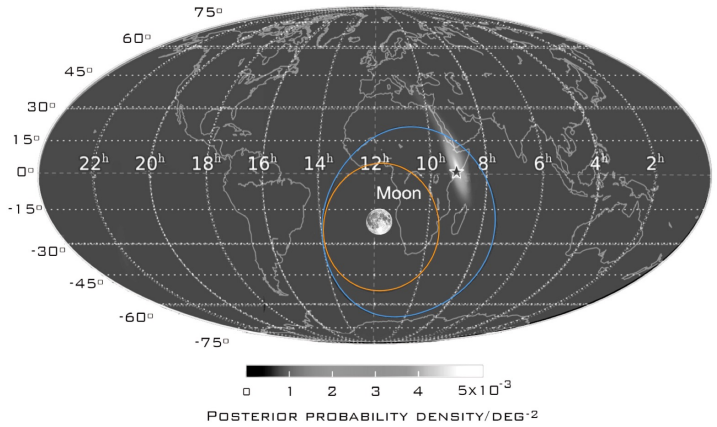
1. Prob: Posterior Probability

- If has 3D info:
  2. distance average
  3. distance error
  4. distance normalization



2. Telescope visibility and observation constraints



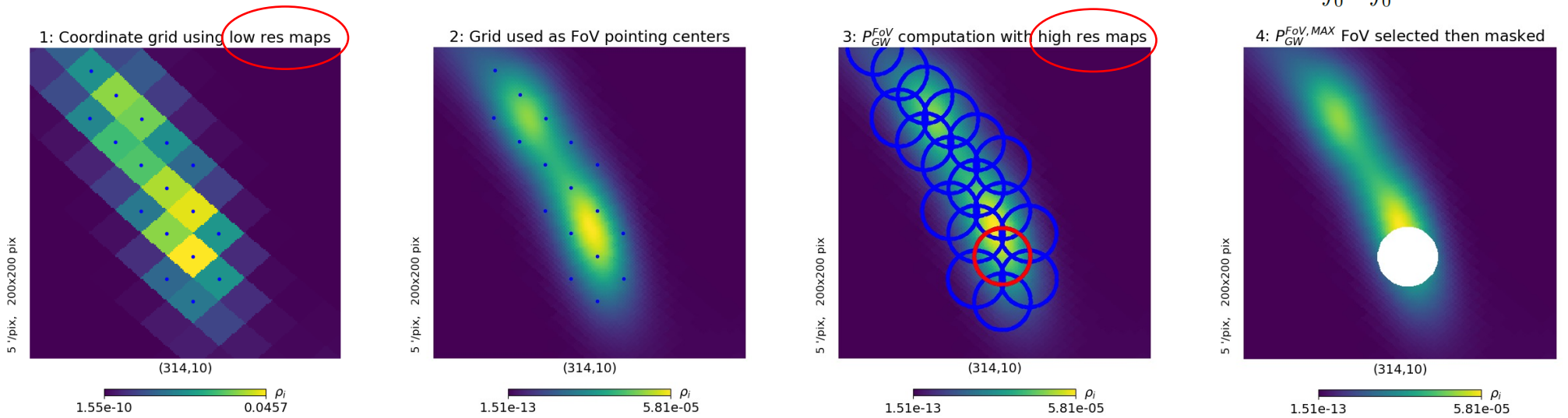


2D solutions

Ashkar, H. et al. (2021) *JCAP*, JCAP2021(03), 45

$$P_{GW}^{FoV,i} = \int_0^{2\pi} \int_0^{r_{FoV}} \rho(r,\phi)\, \mathrm{d}r\mathrm{d}\phi,$$

Strategy 1:
2D **FoV-targeted** search with coordinate grid **(PGWinFoV)**

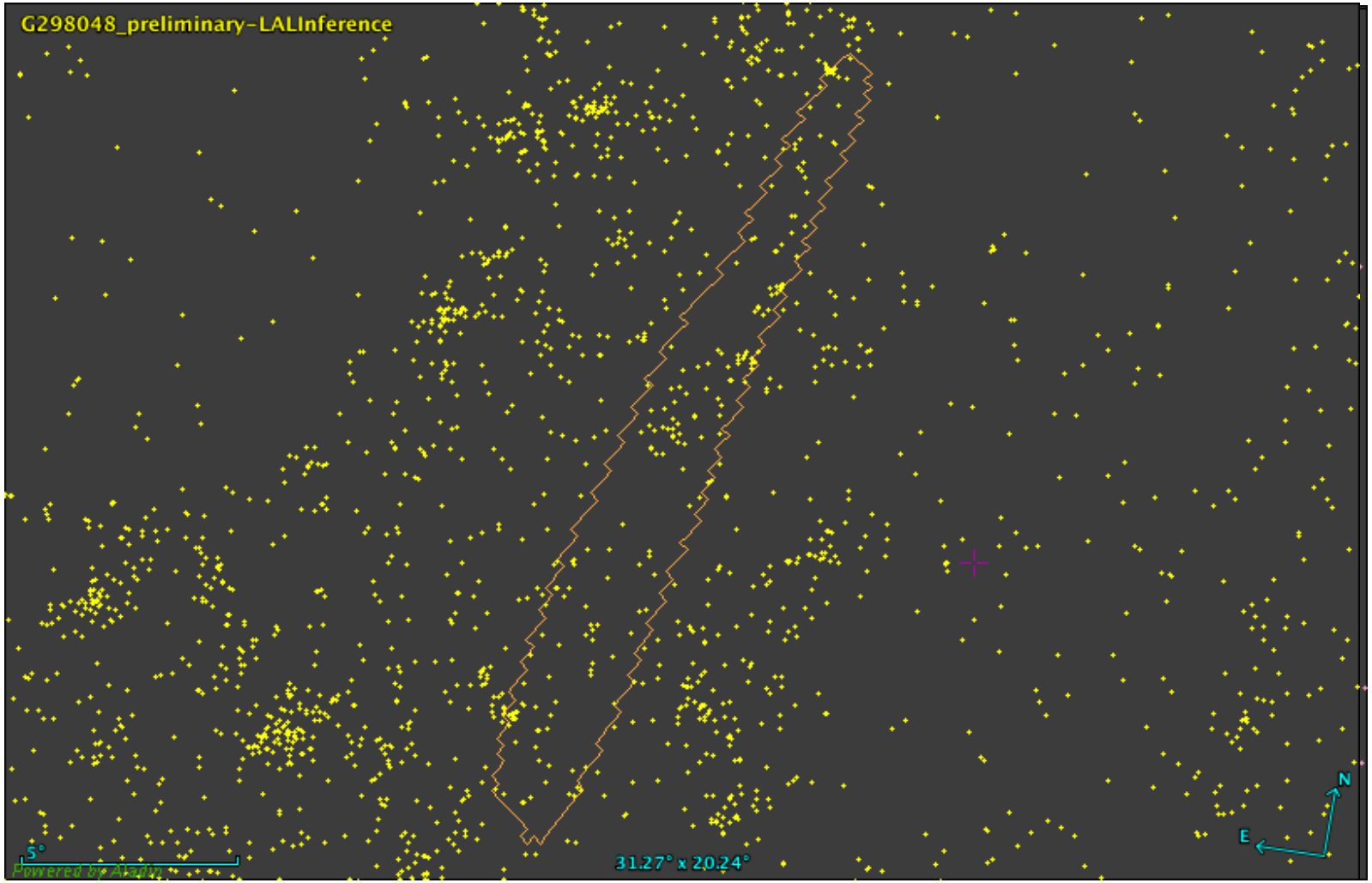


Re-do for next window

Gravitational Waves: distance is important

GW170817 at 40 Mpc

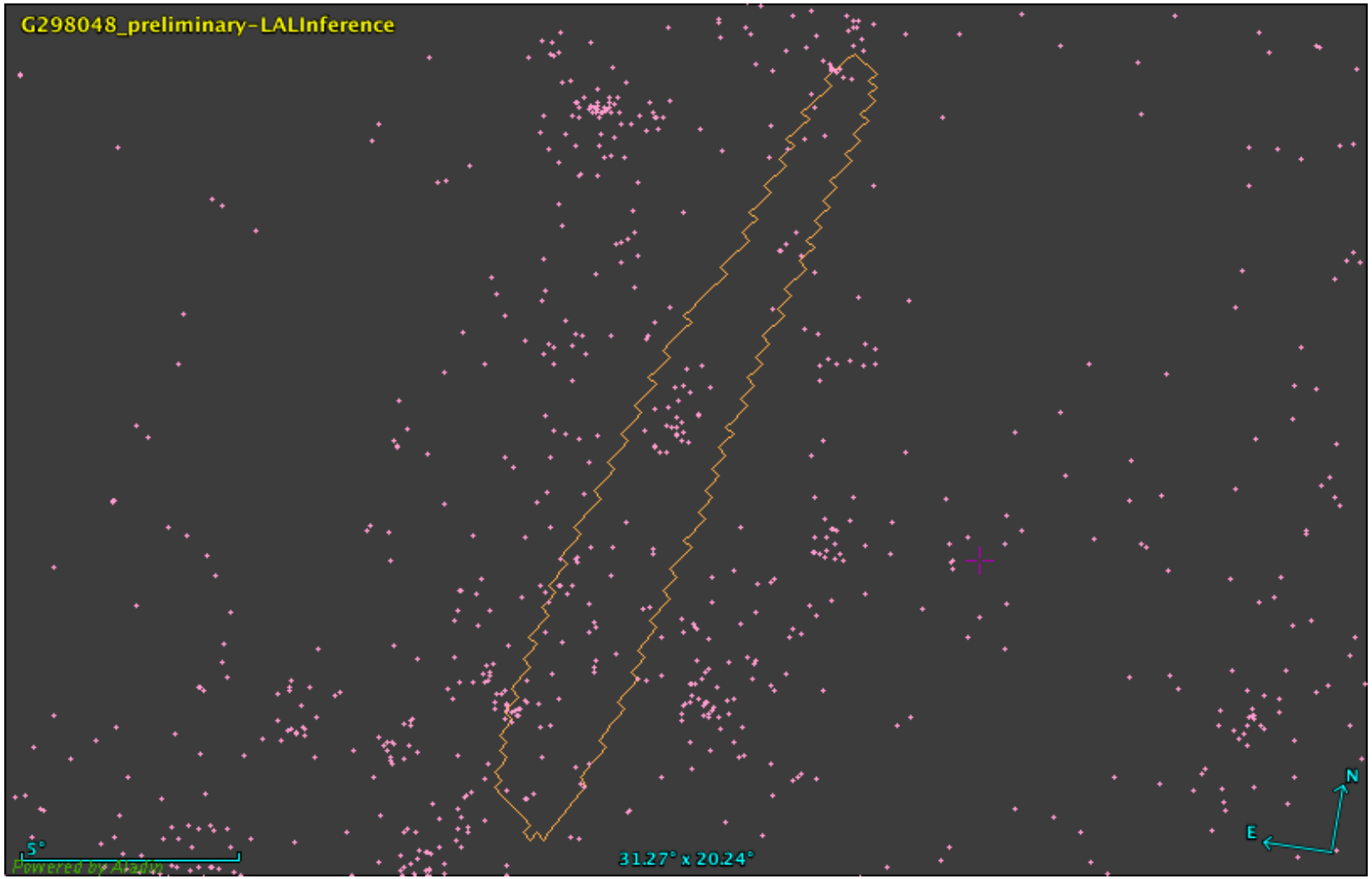
0 Mpc < Distance < 100 Mpc



Gravitational Waves: distance is important

GW170817 at 40 Mpc

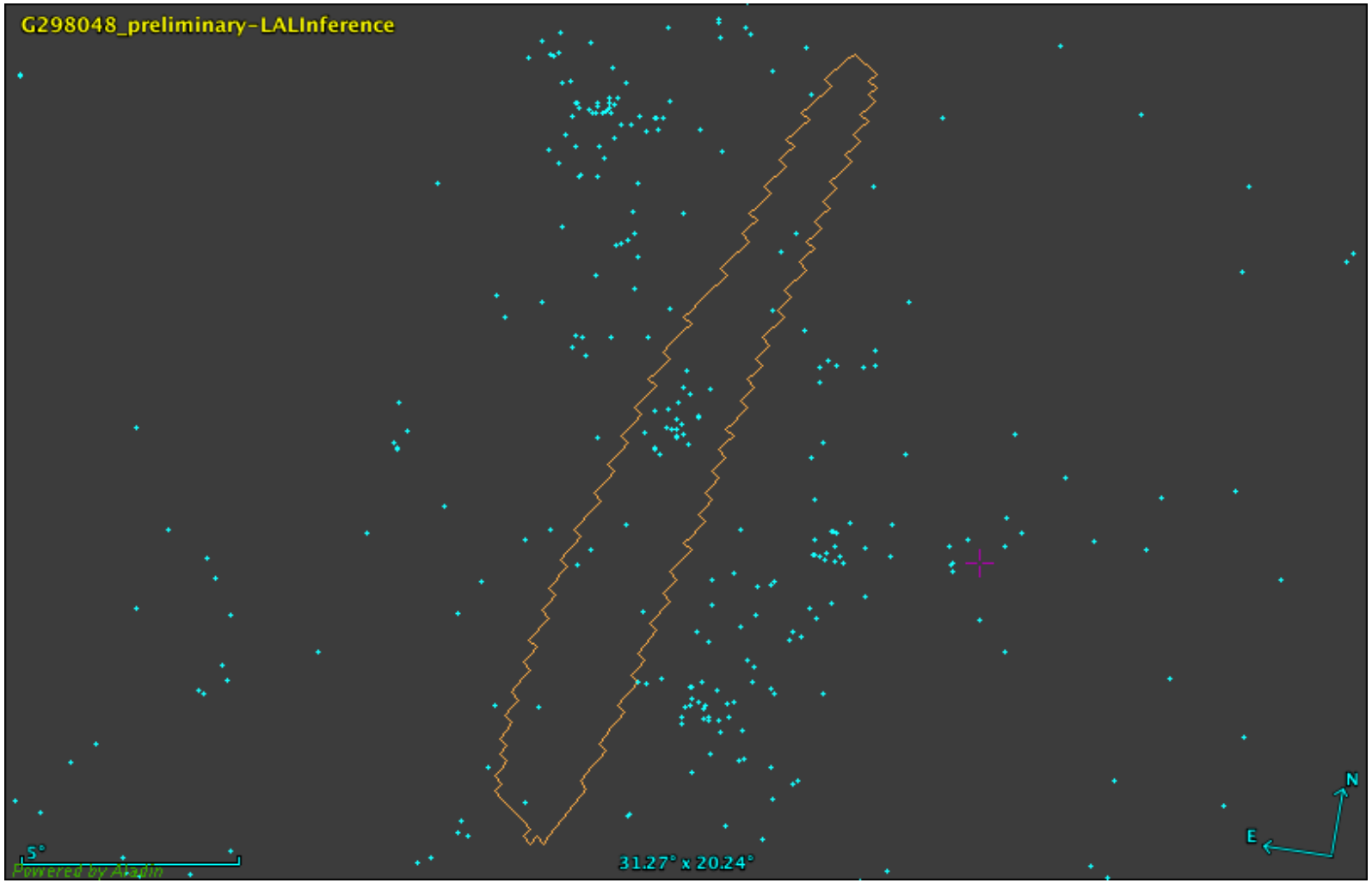
20 Mpc < Distance < 60 Mpc



Gravitational Waves: distance is important

GW170817 at 40 Mpc

32Mpc < Distance < 48 Mpc



3D solutions

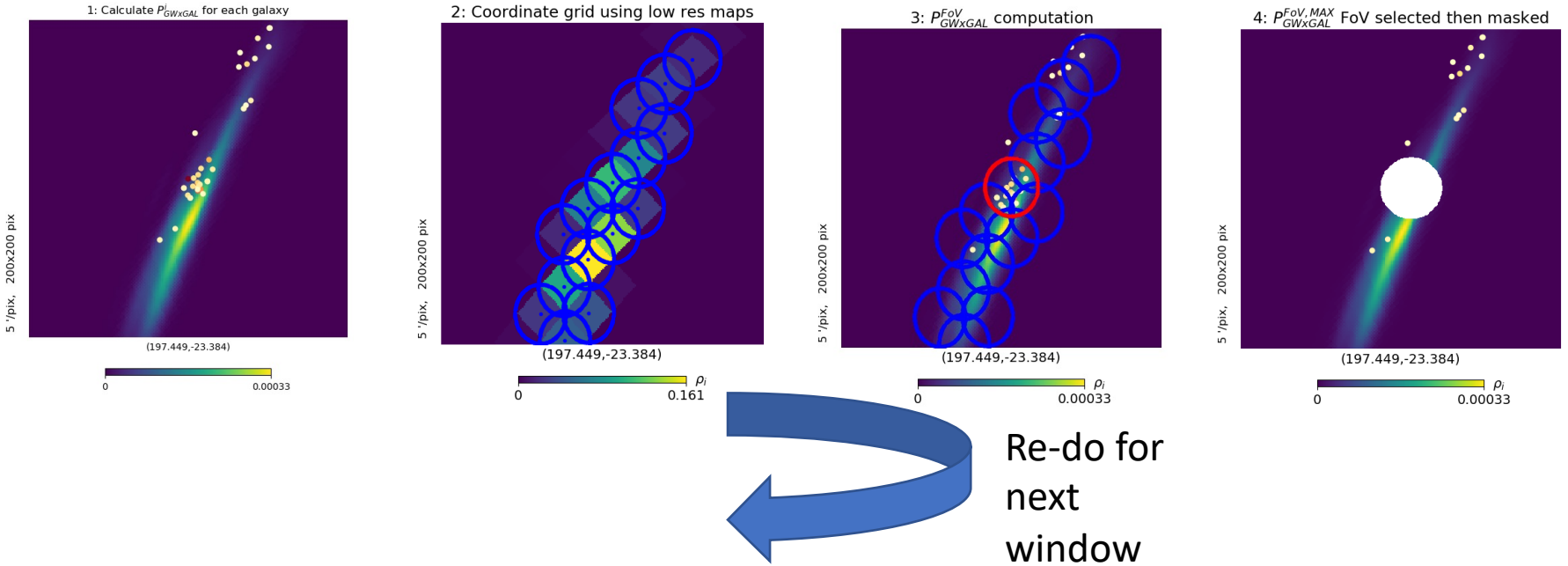
Assign probabilities for galaxies (Singer et al. 2016)

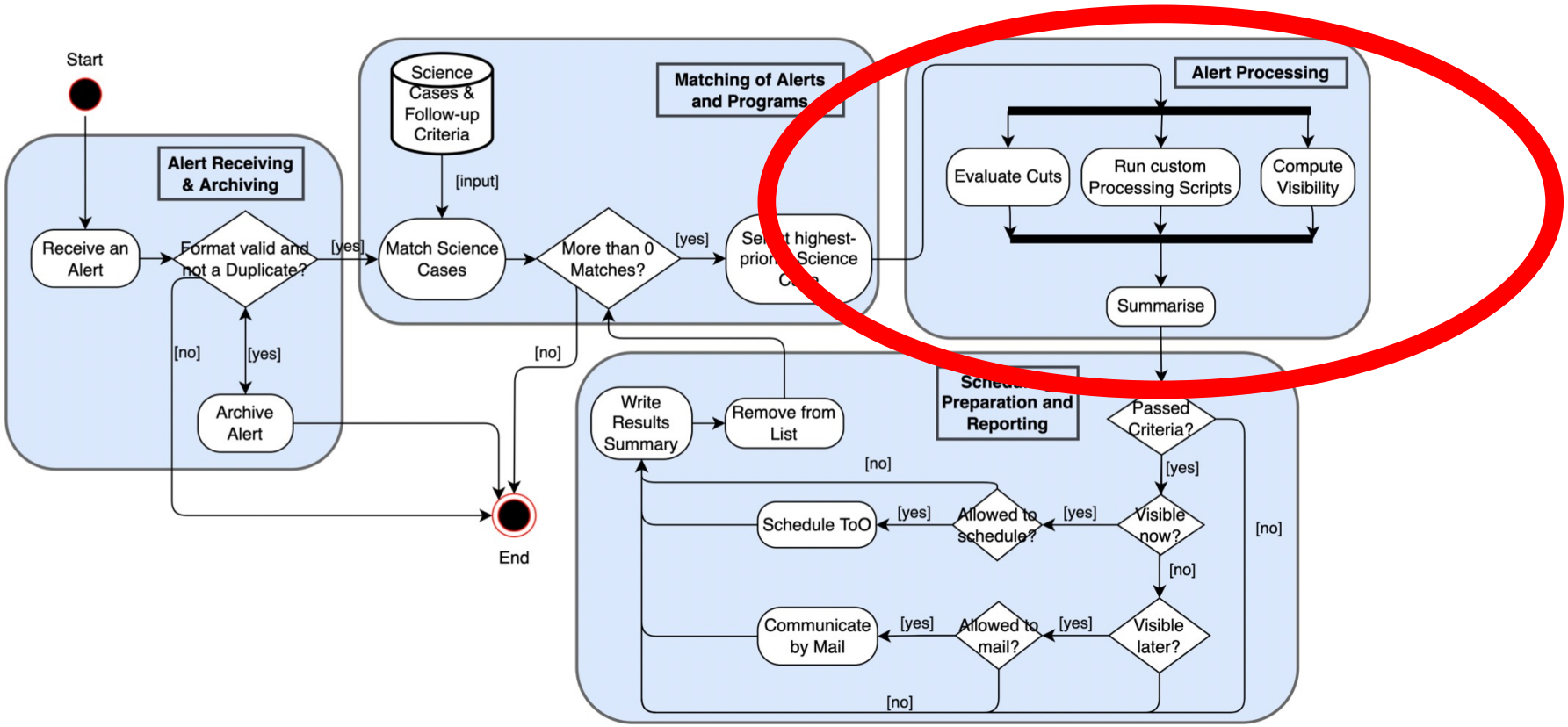
$$\frac{\mathrm{d}P}{\mathrm{d}V} = \rho_i \frac{N_{\mathrm{pix}}}{4\pi} \frac{\hat{N}_i}{\sqrt{2\pi}\hat{\sigma}_i} \exp\left[-\frac{(z-\hat{\mu}_i)^2}{2\hat{\sigma}_i^2} \right]$$

$$P^i_{GW\times GAL} = \frac{\mathrm{d}P^i/\mathrm{d}V}{\sum_j \mathrm{d}P^j/\mathrm{d}V} \qquad \sum_i P^i_{GW\times GAL} = 1.$$

$$P^{FoV,i}_{GW\times GAL} = \int_0^{2\pi}\int_0^{r_{FoV}} P^i_{GW\times GAL}(r,\phi)\,\mathrm{d}r\mathrm{d}\phi.$$

Strategy 2:
3D FoV-targeted search with coordinate grid **(PGALinFoV-PixRegion)**

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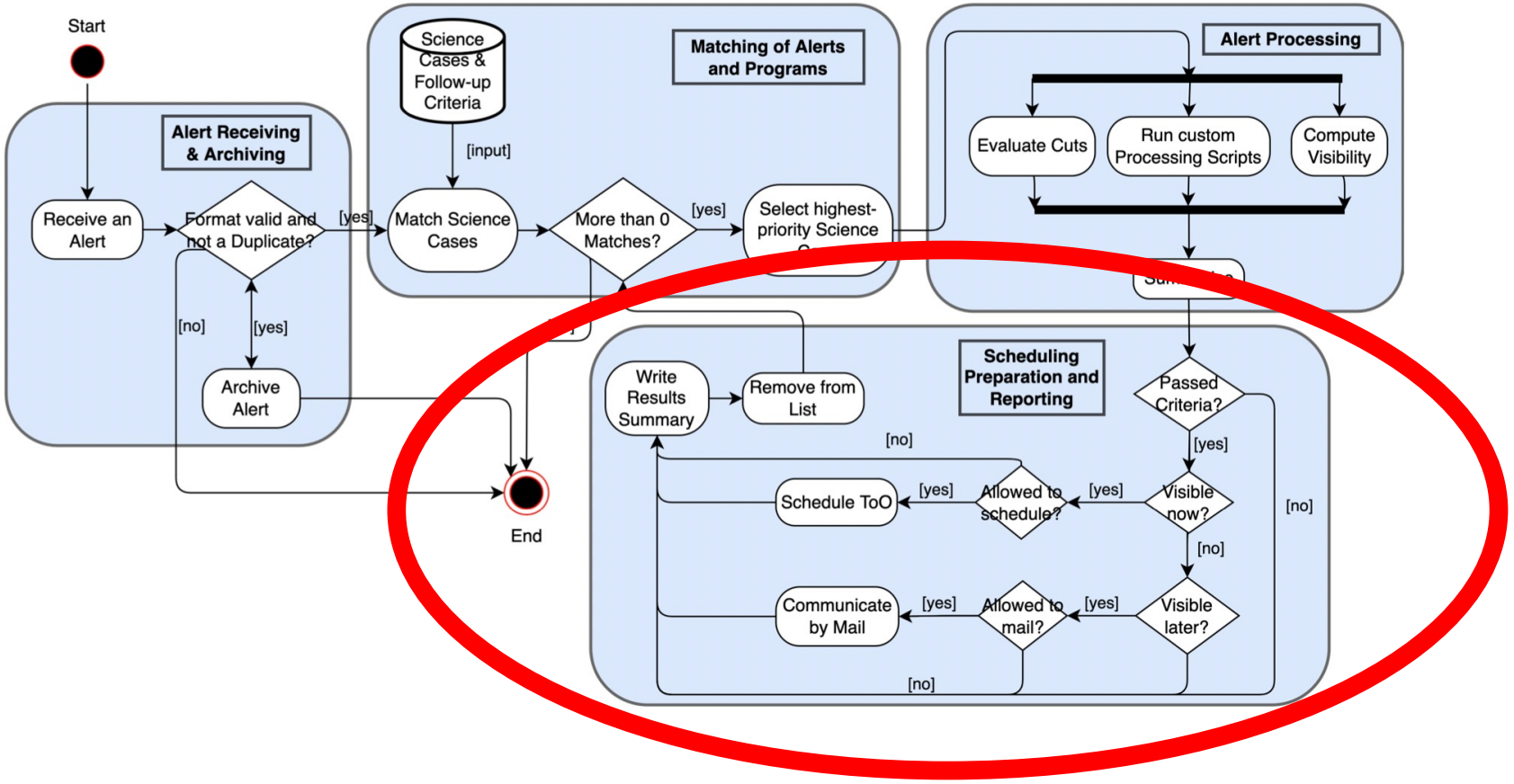
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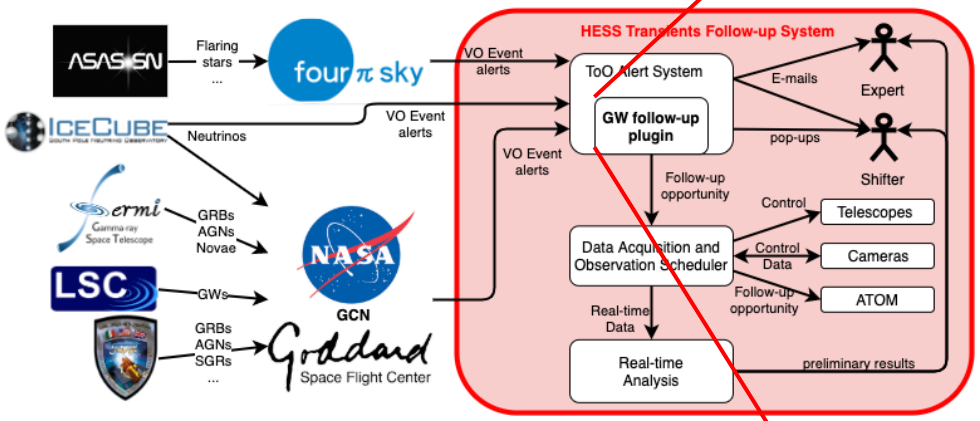
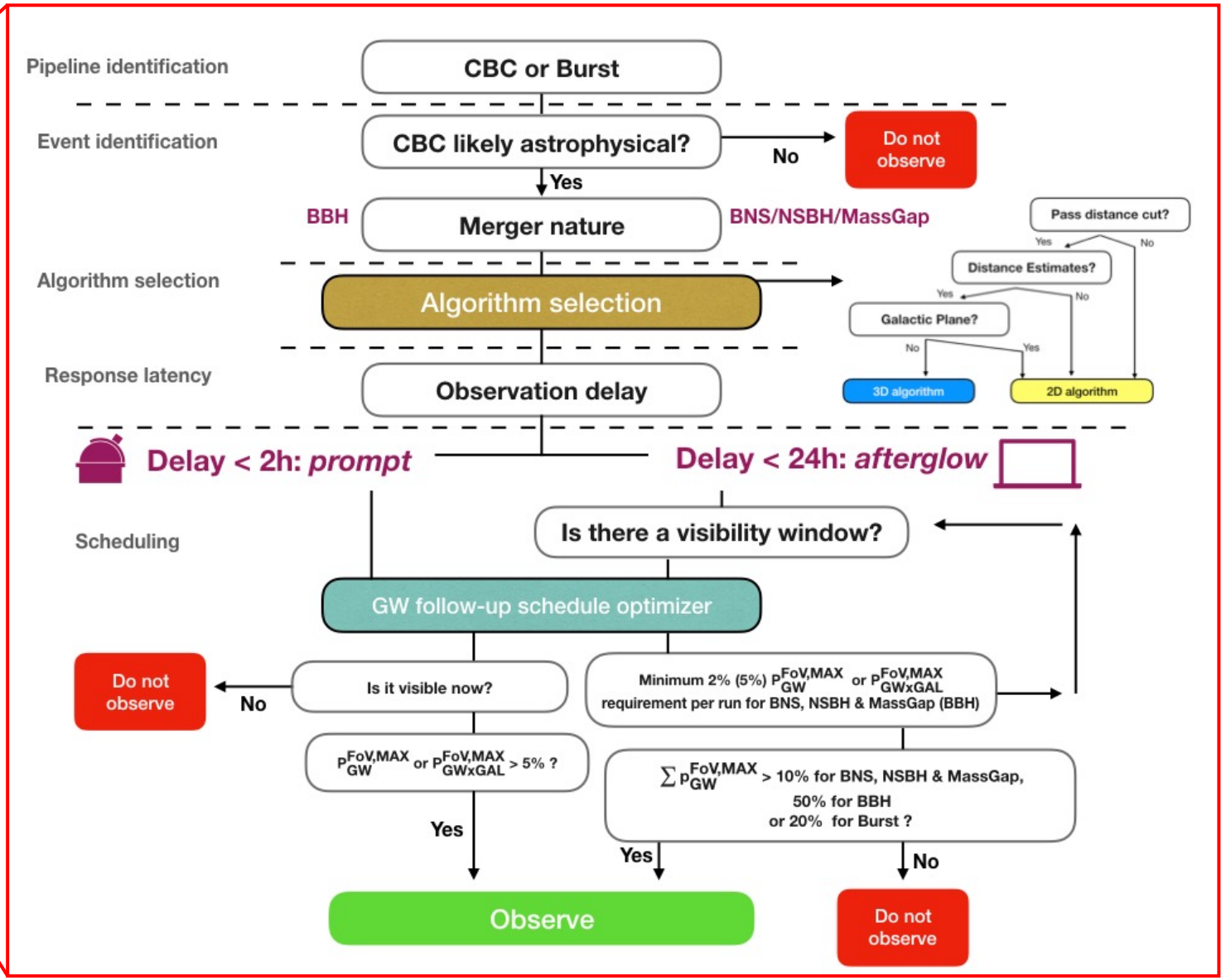
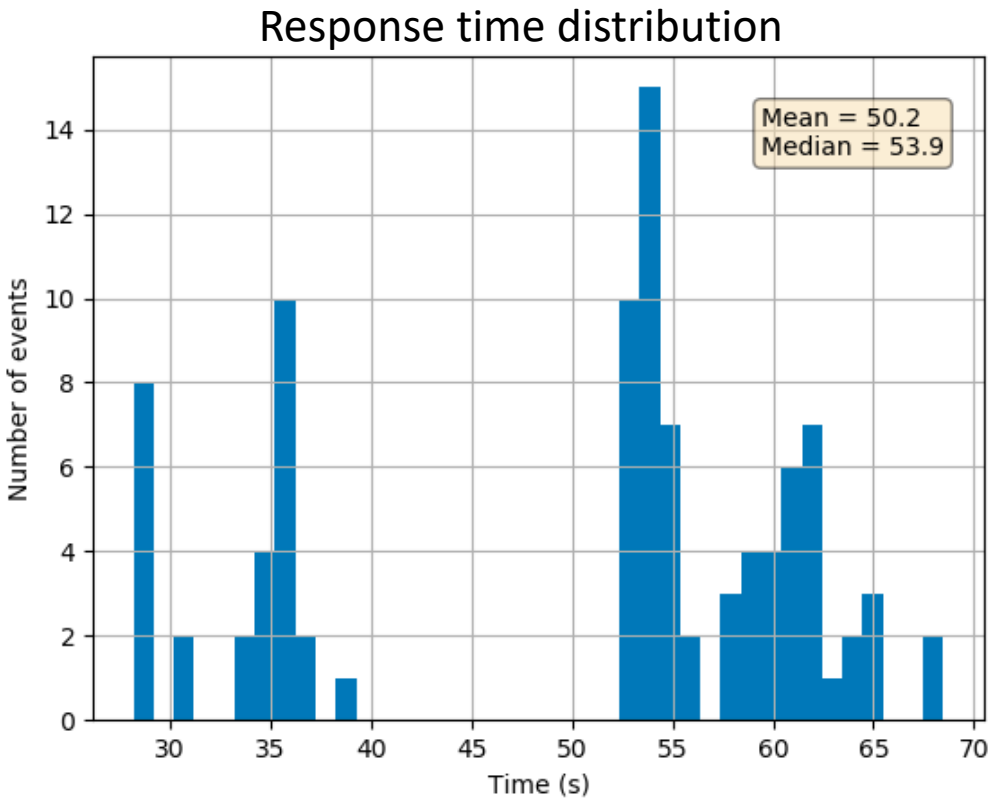
GW automatic response – H.E.S.S. example



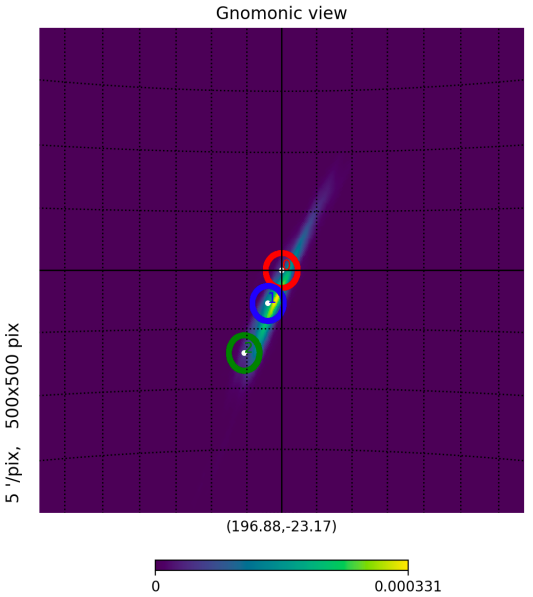
Ashkar, H. et al. (2021)
JCAP, JCAP2021(03), 45



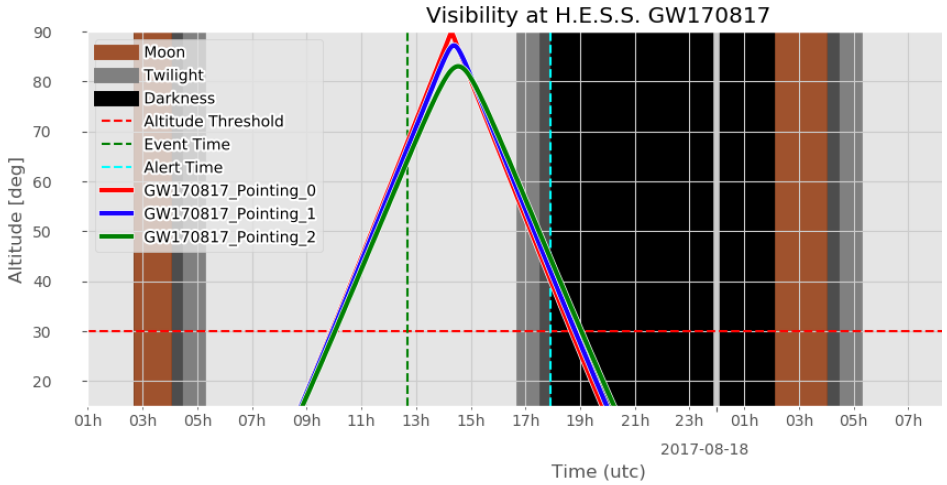
H.E.S.S. response to GW alerts



[Ashkar, H. et al. (2021) *JCAP*, JCAP2021(03), 45]



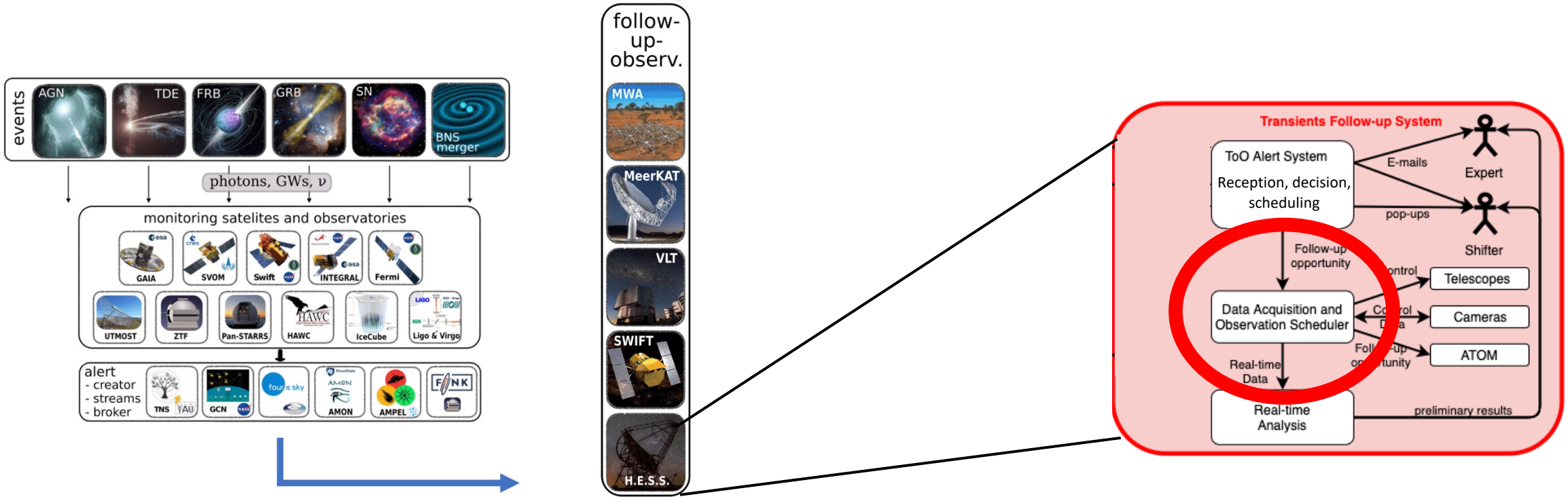
Output



Start time	Ra	Dec	PGAL	Observation window	Priority
2017-08-17 17:59	196.88	-23.17	0.72	2017-08-17 17:55 → 2017-08-17 18:39	0
2017-08-17 18:27	198.19	-25.98	0.16	2017-08-17 17:55 → 2017-08-17 18:48	1
2017-08-17 18:56	200.57	-30.15	0.05	2017-08-17 17:55 → 2017-08-17 19:01	2

Taking into consideration only alerts that pass requirements + adding telescope slewing time: **response time is less than 1 minute for most cases and less than 2 minutes for all cases.**

Transient follow-up systems



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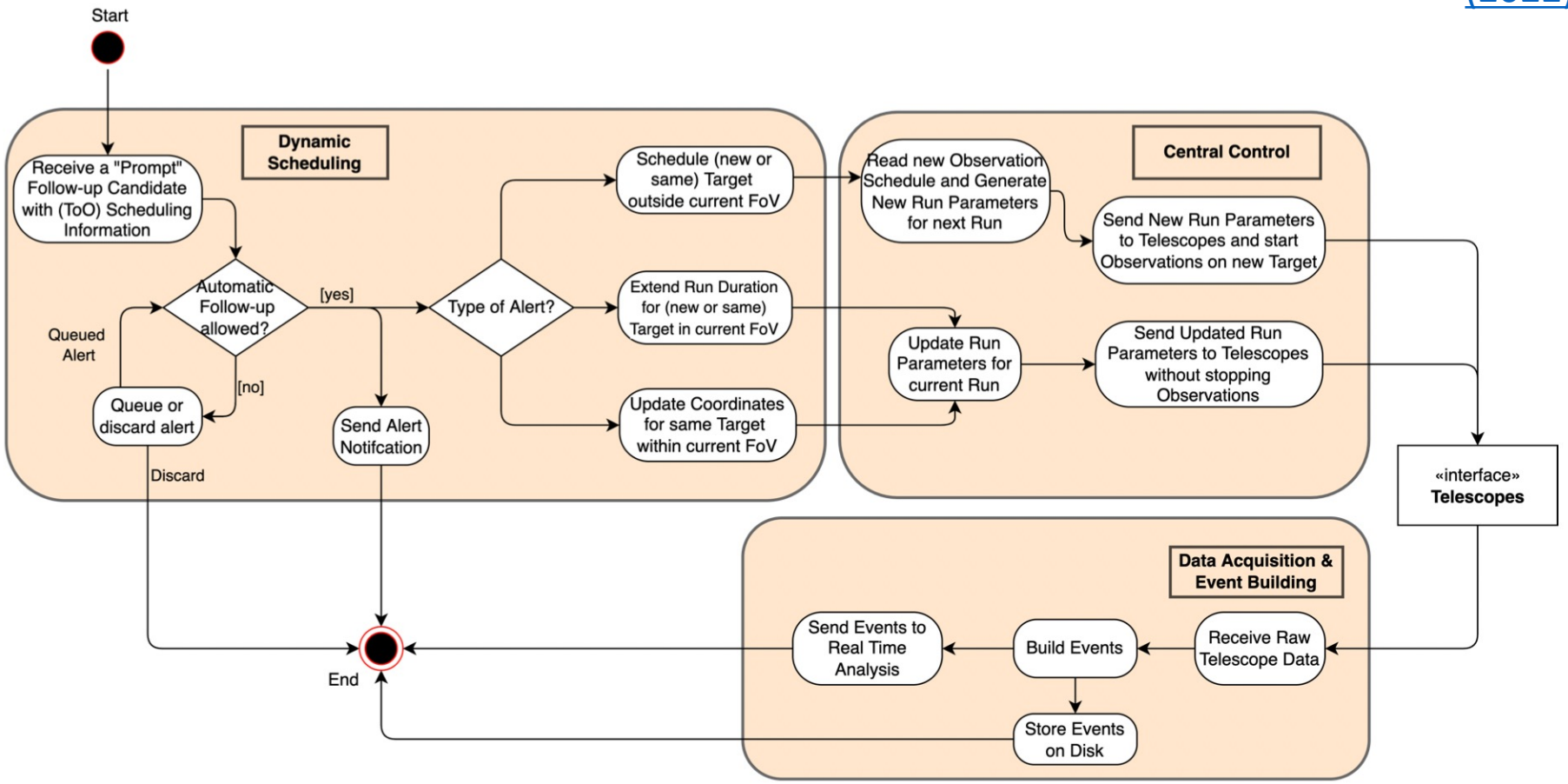
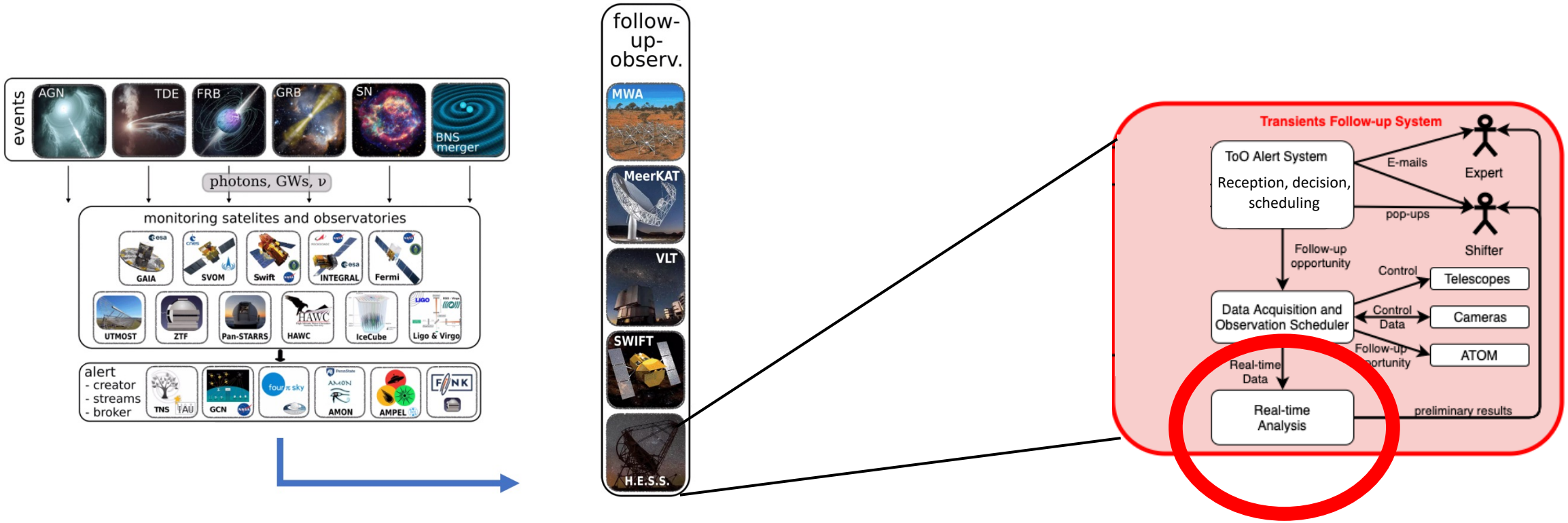
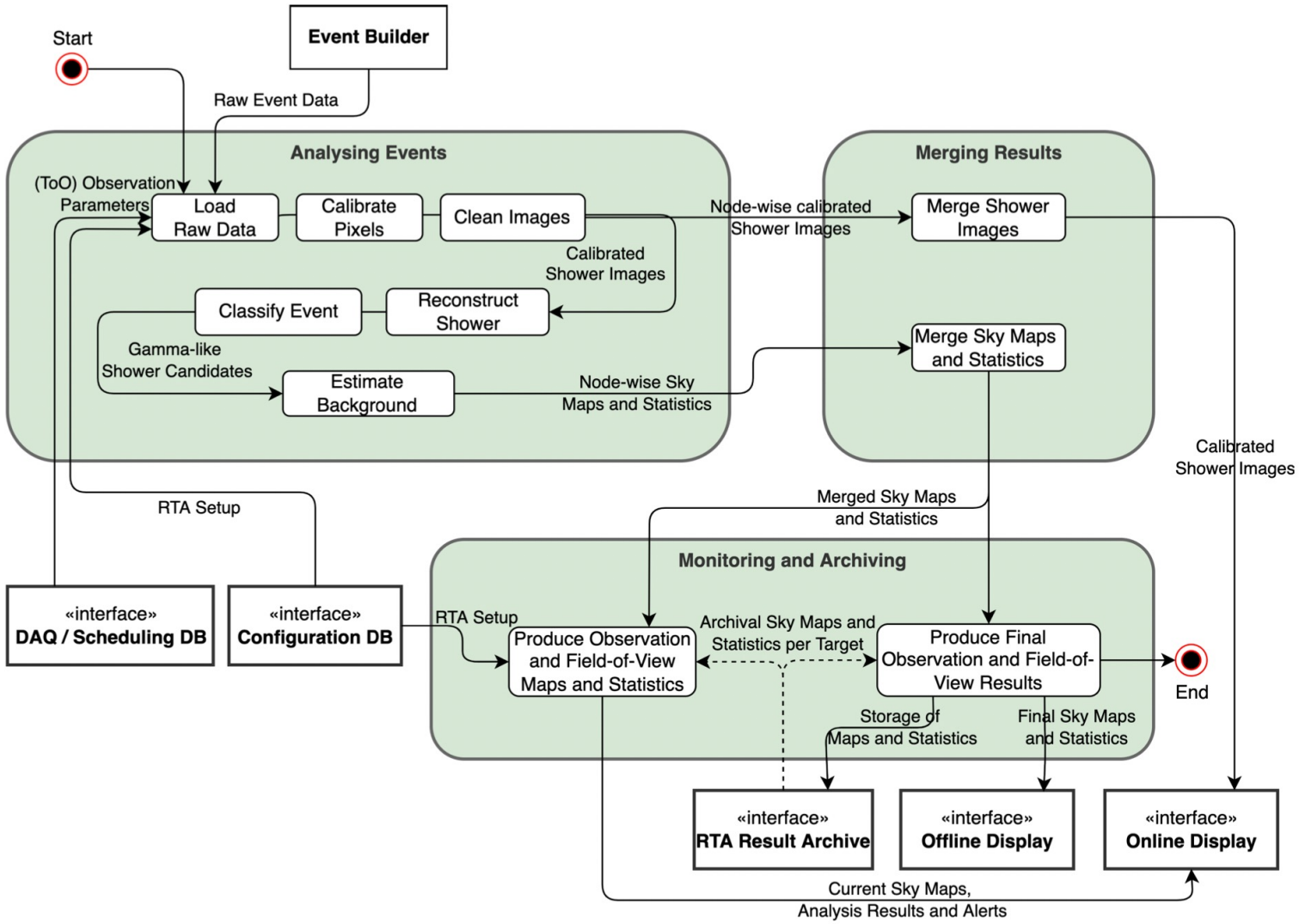


Transient follow-up systems

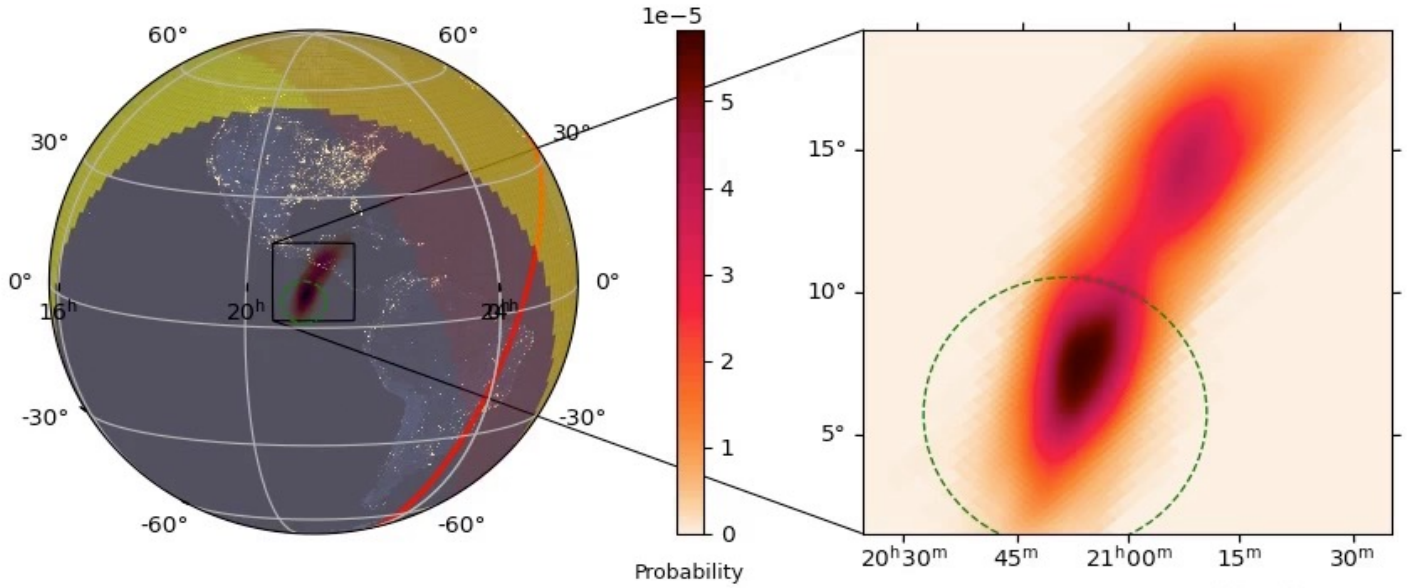




C. Hoischen, (2022). A&A

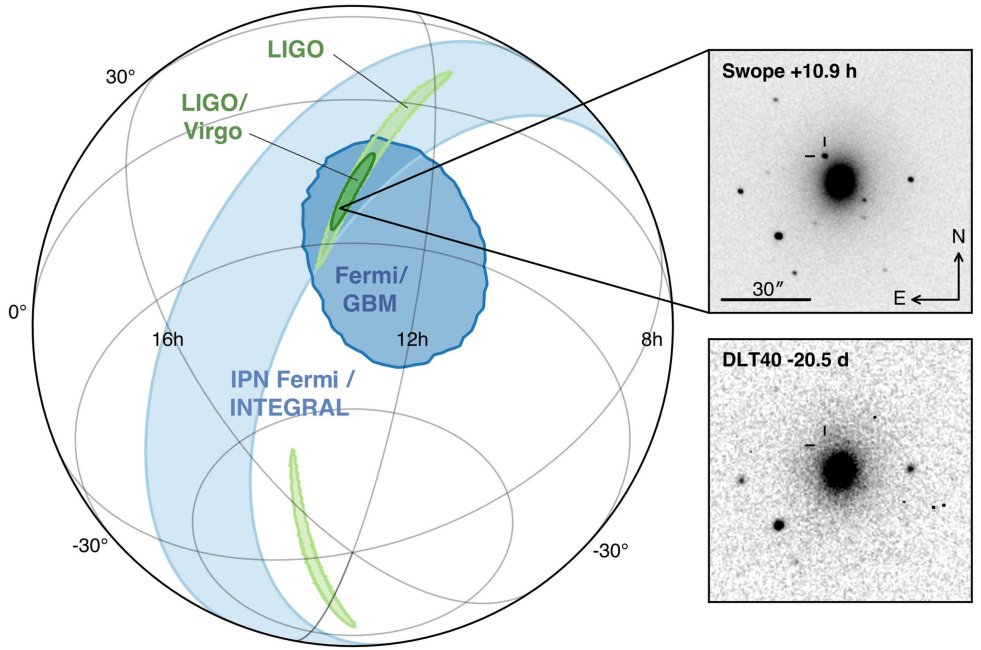
RTA results might be used to trigger external facilities. Example ATCA (for GRBs)

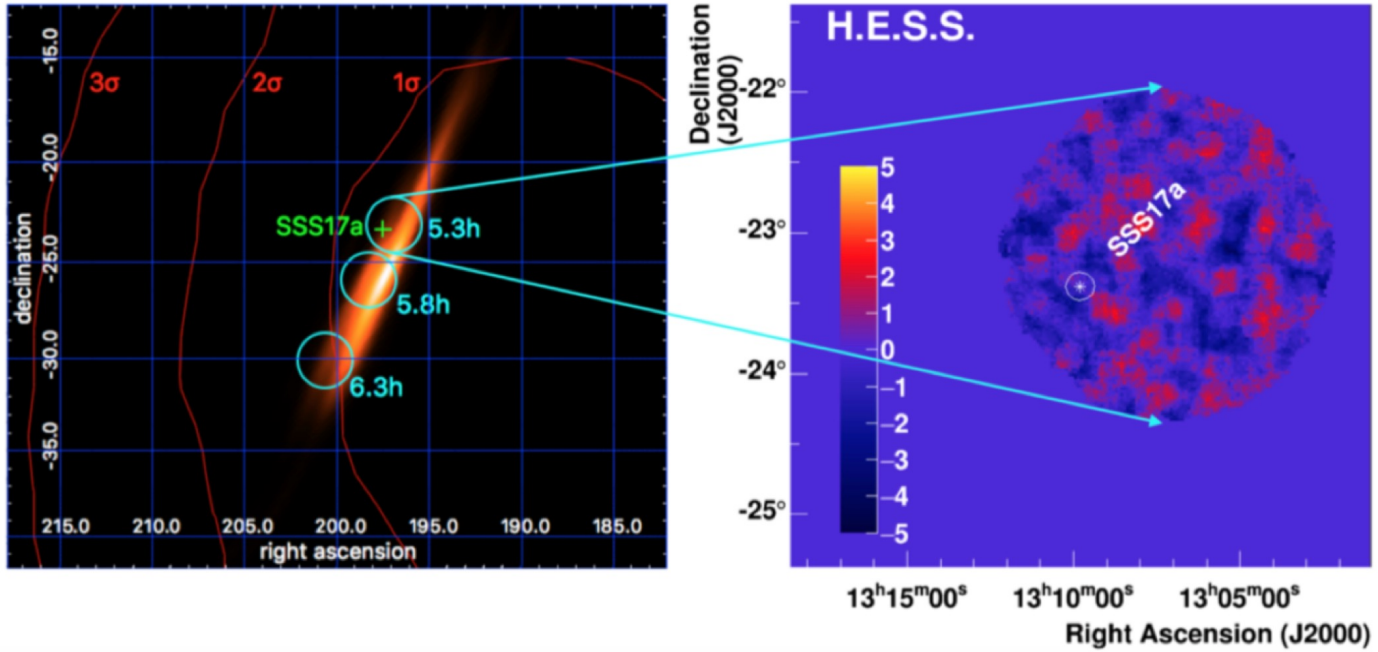
GW follow-up observations – BBH example (GW190728)



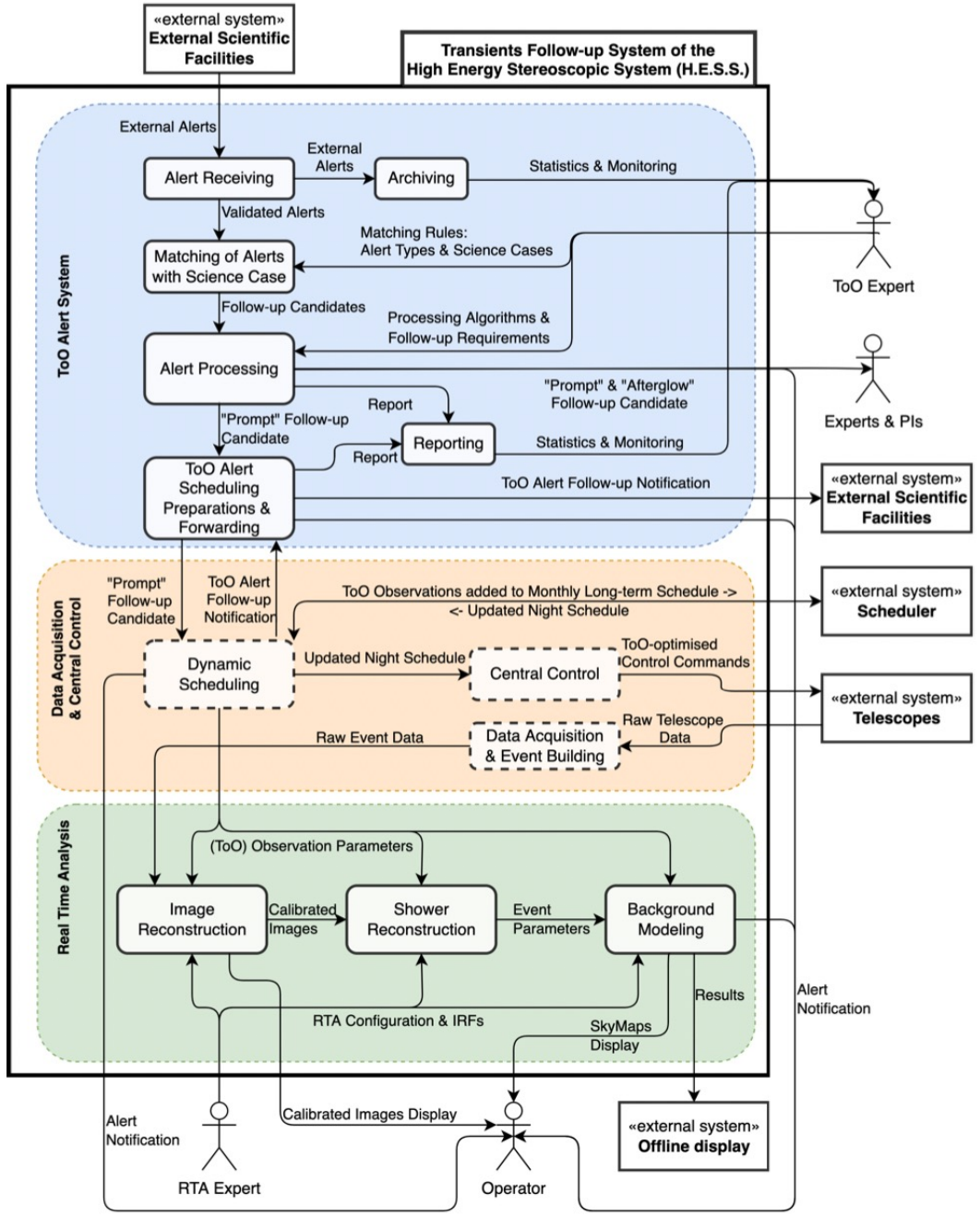
H.E.S.S. and GW170817

H.E.S.S. was the first ground based facility to get on target (**before the EM counterpart detection**)





Summary


«external system»
External Scientific Facilities
Transients Follow-up System of the High Energy Stereoscopic System (H.E.S.S.)
ToO Alert System
External Alerts
Alert Receiving
External Alerts
Archiving
Statistics & Monitoring
Validated Alerts
Matching Rules:
Alert Types & Science Cases
Matching of Alerts with Science Case
Follow-up Candidates
Processing Algorithms & Follow-up Requirements
Alert Processing
"Prompt" & "Afterglow" Follow-up Candidate
Report
"Prompt" Follow-up Candidate
Reporting
Statistics & Monitoring
Report
ToO Alert Scheduling Preparations & Forwarding
ToO Alert Follow-up Notification
ToO Expert
Experts & PIs
«external system»
External Scientific Facilities
Data Acquisition & Central Control
"Prompt" Follow-up Candidate
ToO Alert Follow-up Notification
ToO Observations added to Monthly Long-term Schedule ->
<- Updated Night Schedule
«external system»
Scheduler
Dynamic Scheduling
Updated Night Schedule
Central Control
ToO-optimised Control Commands
«external system»
Telescopes
Raw Event Data
Data Acquisition & Event Building
Raw Telescope Data
Real Time Analysis
(ToO) Observation Parameters
Image Reconstruction
Calibrated Images
Shower Reconstruction
Event Parameters
Background Modeling
Results
Alert Notification
RTA Configuration & IRFs
SkyMaps Display
Alert Notification
RTA Expert
Calibrated Images Display
Operator
«external system»
Offline display