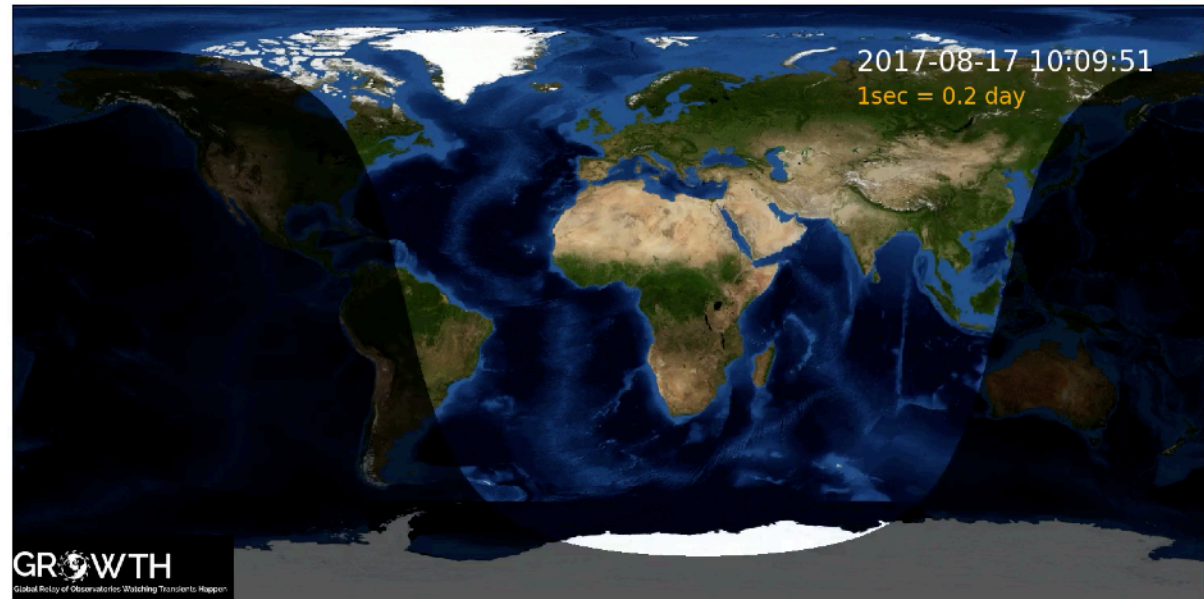


GW170817

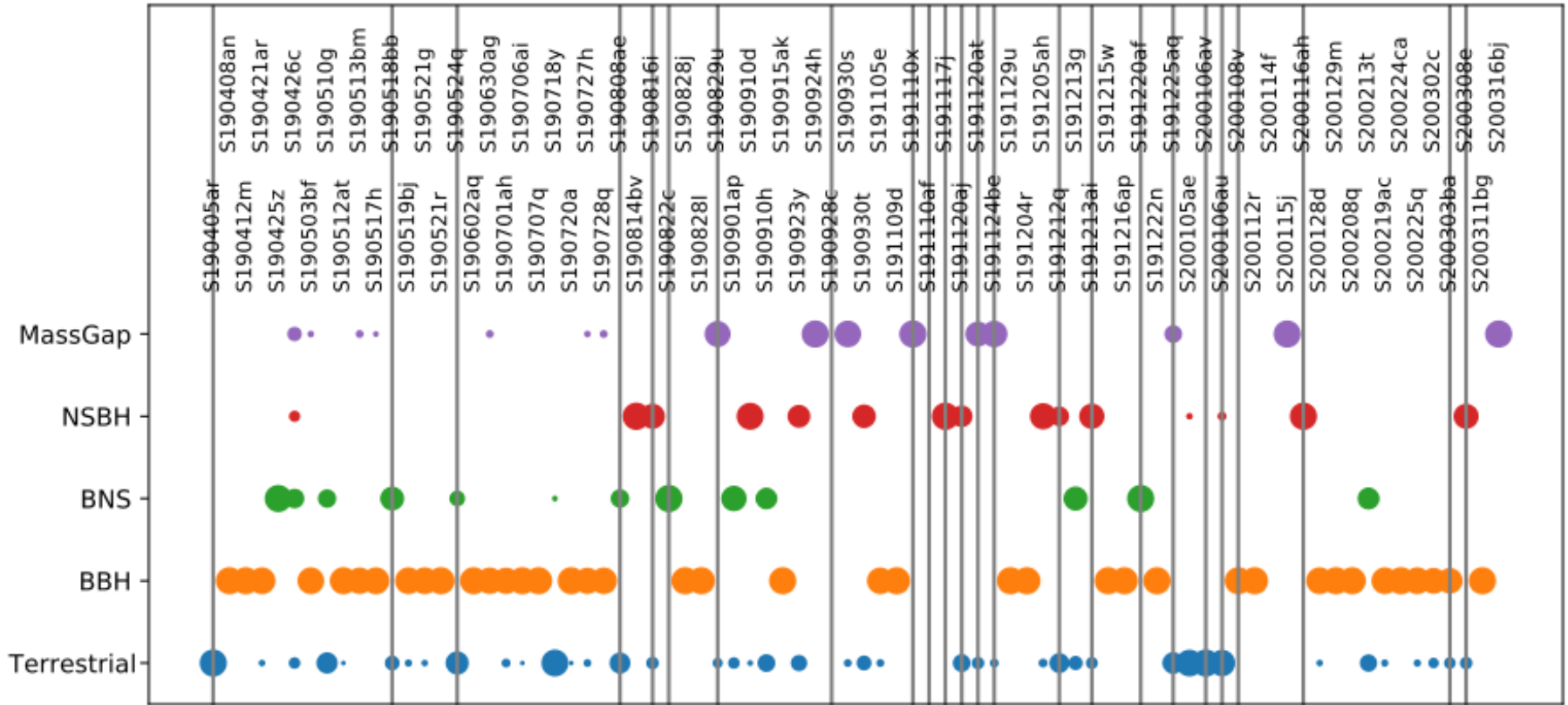
Still going strong:
1637 days
>1520 papers

Credit: NASA / GSFC

Credit: Pavan Hebbar /
Varun Bhalerao /
GROWTH Collaboration

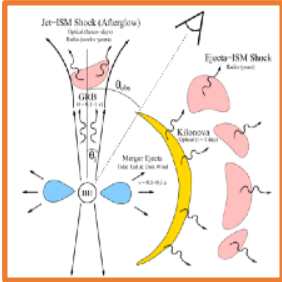


O3 GW candidates



Data: <https://gracedb.ligo.org/superevents/public/O3/>

What can we learn?



Observables

- Luminosity
- Spectrum
- Lightcurve
- Delay

$$L = \frac{\sigma_T}{\pi c^2} \frac{L_{\gamma, \text{iso}}}{E_p \delta t}$$

$$t_{\text{bo}} \sim \frac{R_{\text{bo}}}{2c\gamma_{f, \text{bo}}^2}$$

$$\delta t_{\text{jet}} \approx \frac{\beta_{s, \text{bo}}}{\beta_{s, \text{bo}}(1 - \beta_{s, \text{bo}})}$$

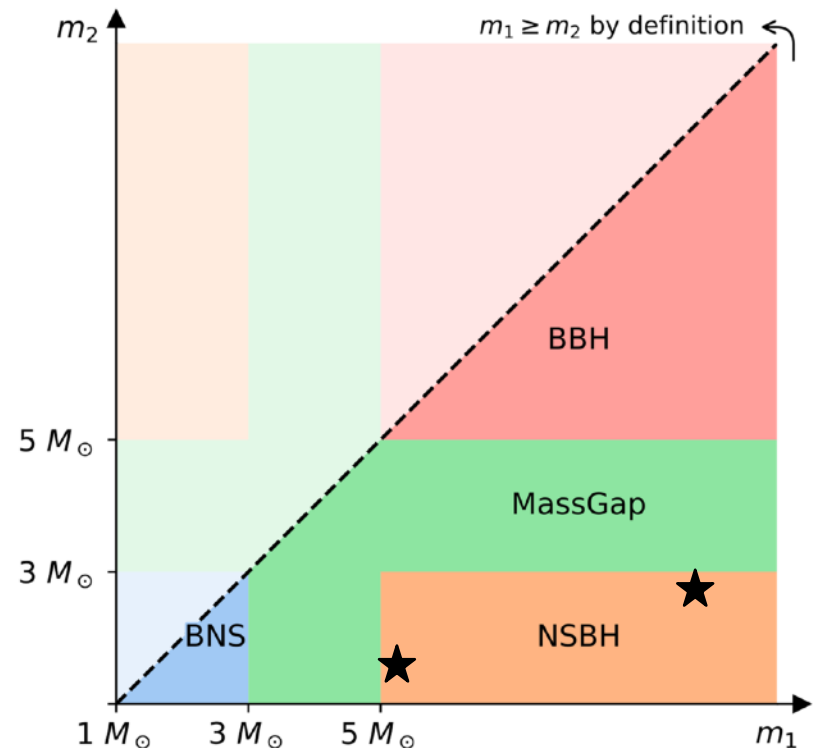
Inferences

- Emission Physics
- Inclination
- Local environment
- Cosmology

Was there a neutron star?

- GW190426: $5.7_{-2.3}^{+4.0} M_{\odot}$, $1.5_{-0.5}^{+0.8} M_{\odot}$
- GW190814: $23.2_{-1.0}^{+1.1} M_{\odot}$, $2.59_{-0.09}^{+0.08} M_{\odot}$

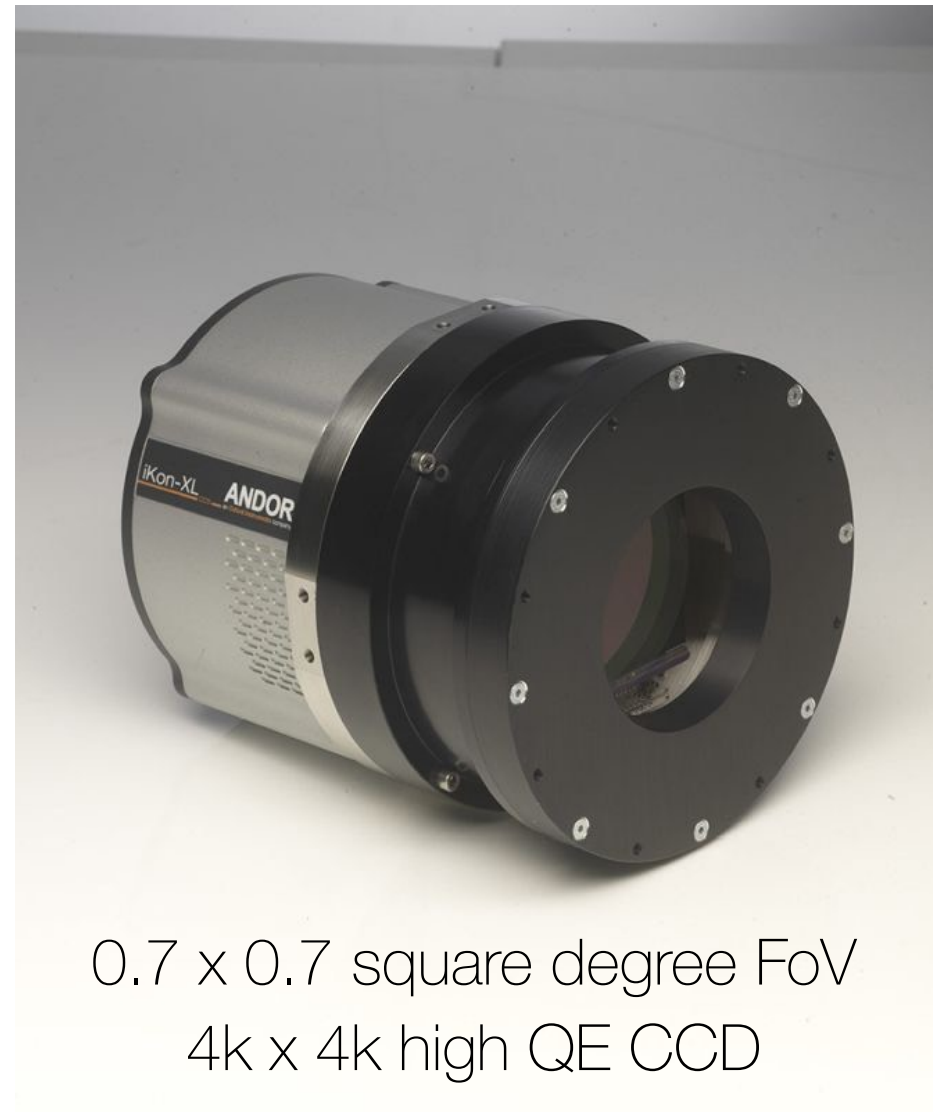
- Can MassGap objects emit EM radiation?
- S1909030s, S190924h, S200115j, S200316bj

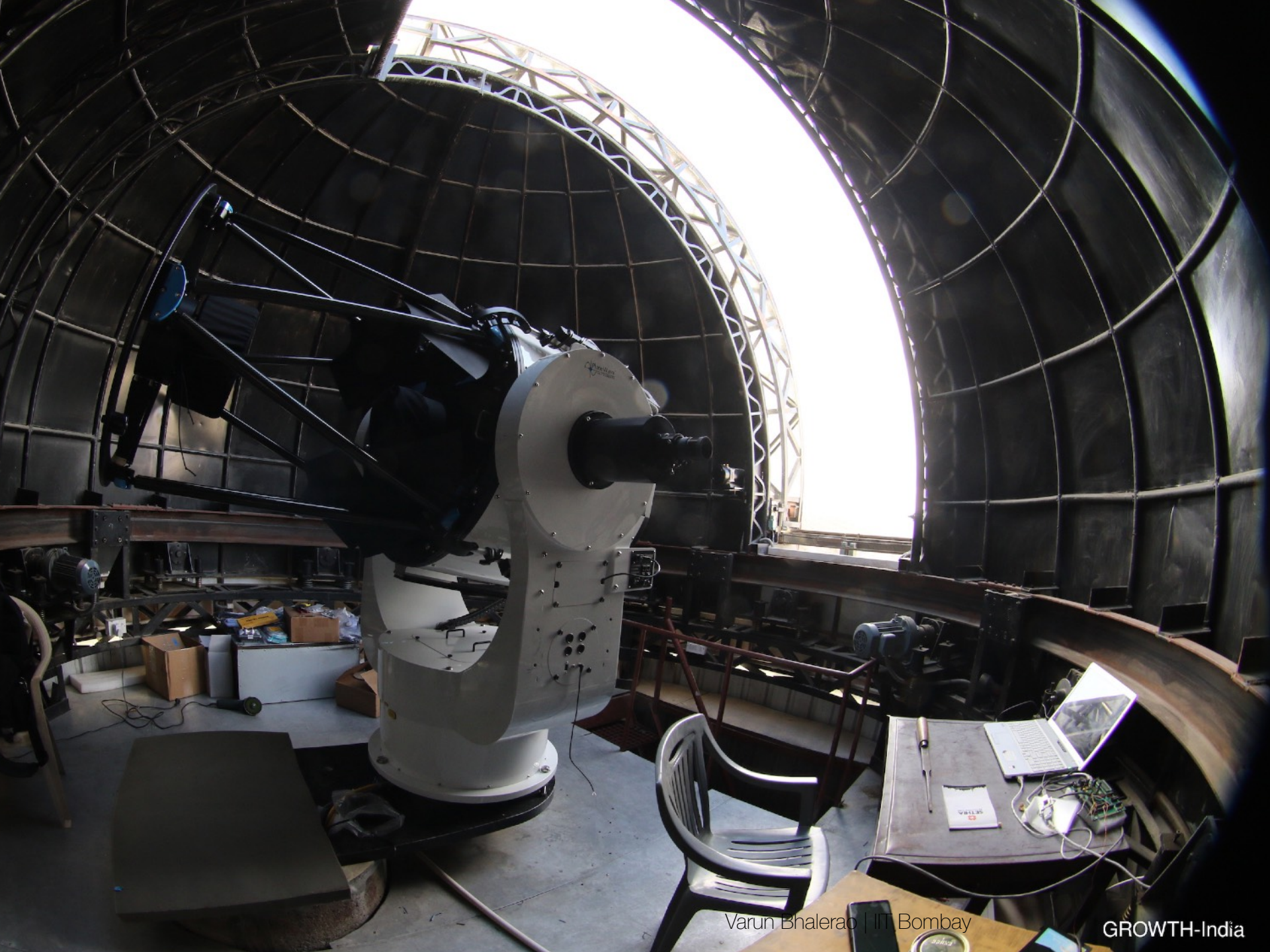


GROWTH India



GROWTH-India: Robotic telescope





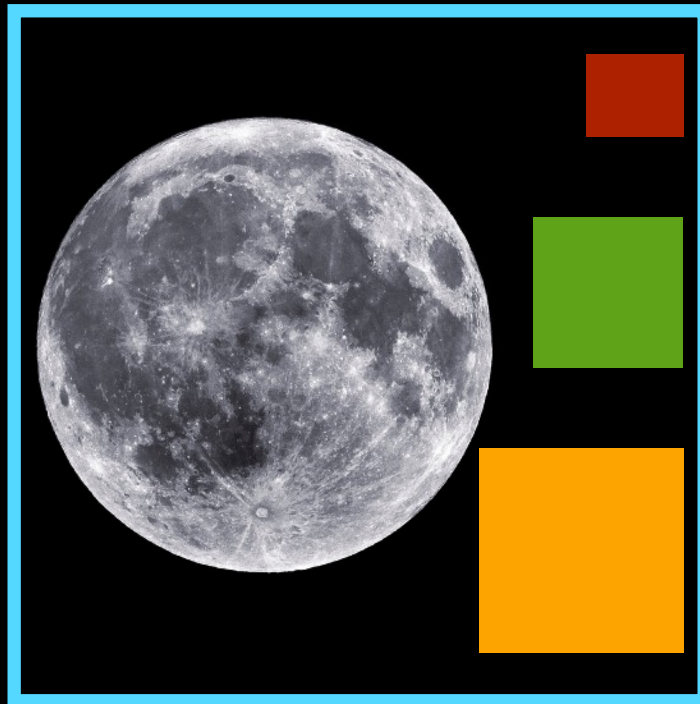


First light: June 2018

M16: “Eagle Nebula”
Pillars of Creation

<https://sites.google.com/view/growthindia/first-light>

VIEWING THE SKY



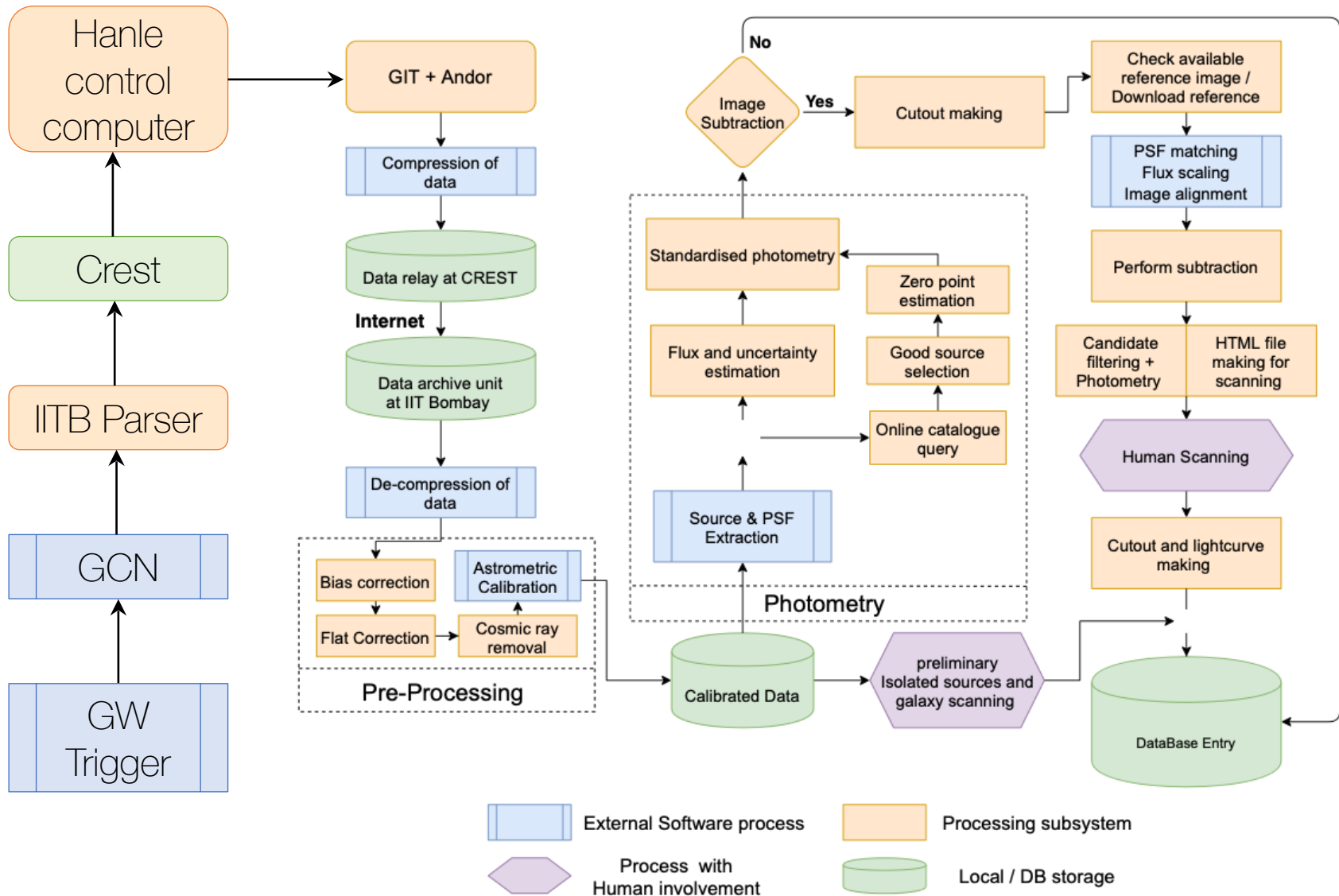
1.2m Mount Abu
Telescope (NICS)

2m Himalayan Chandra
Telescope (HFOSC)

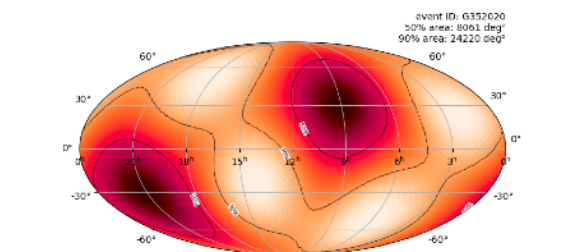
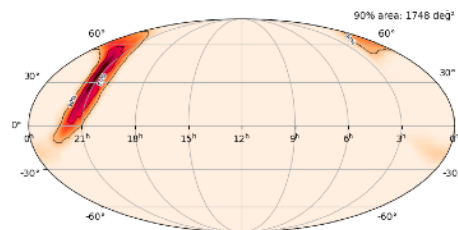
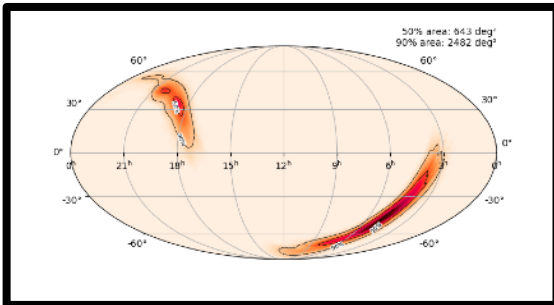
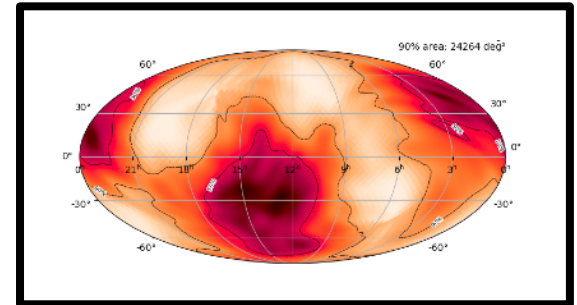
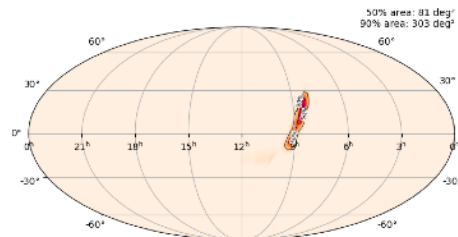
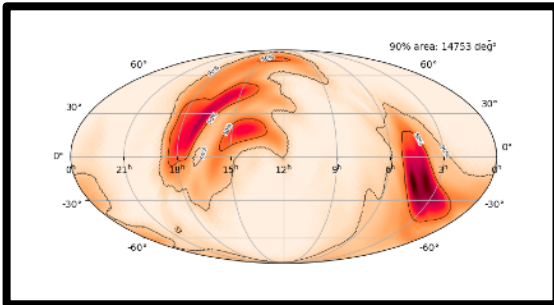
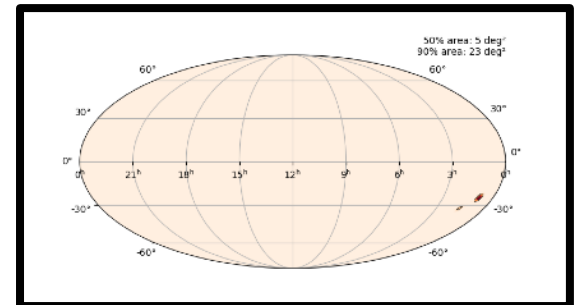
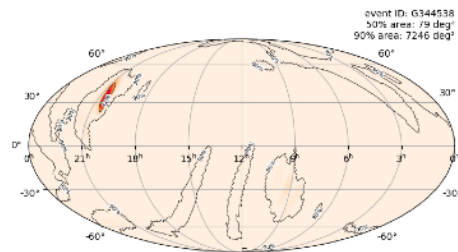
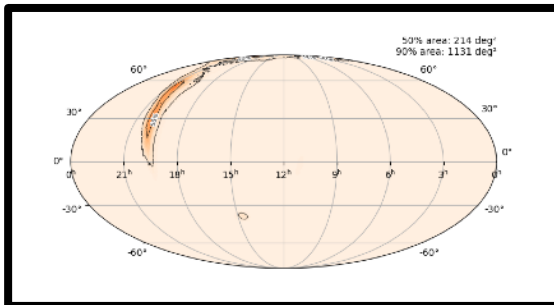
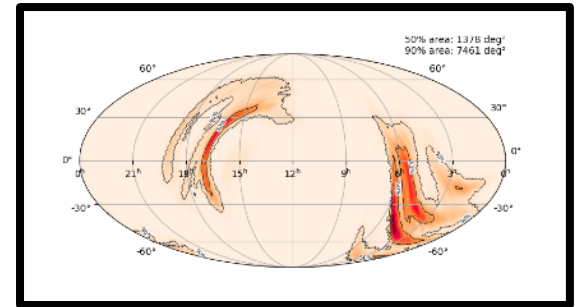
3.6m Devasthal Optical
Telescope (ADFOSC)

0.7m GROWTH-India Telescope

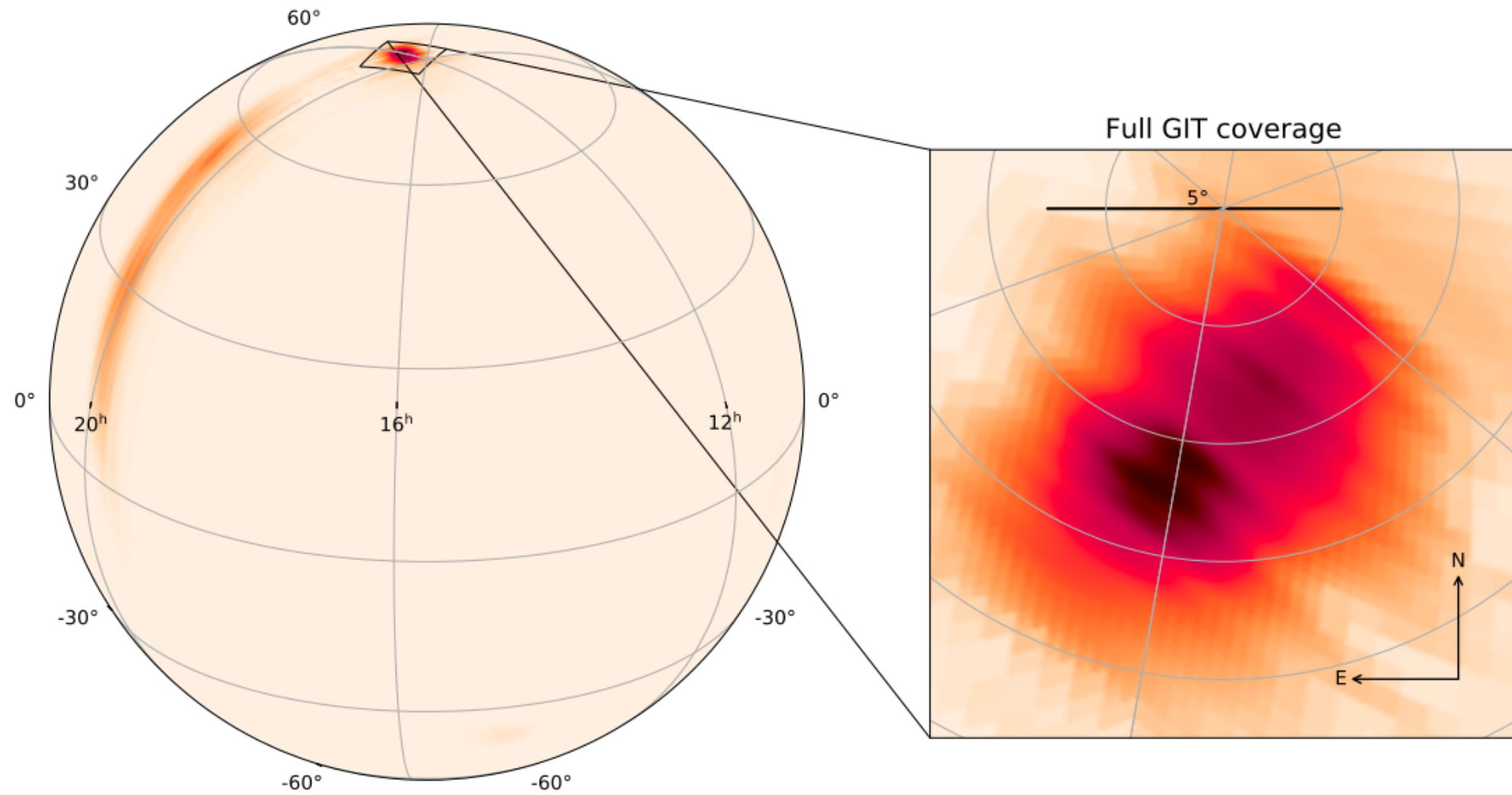
Workflow



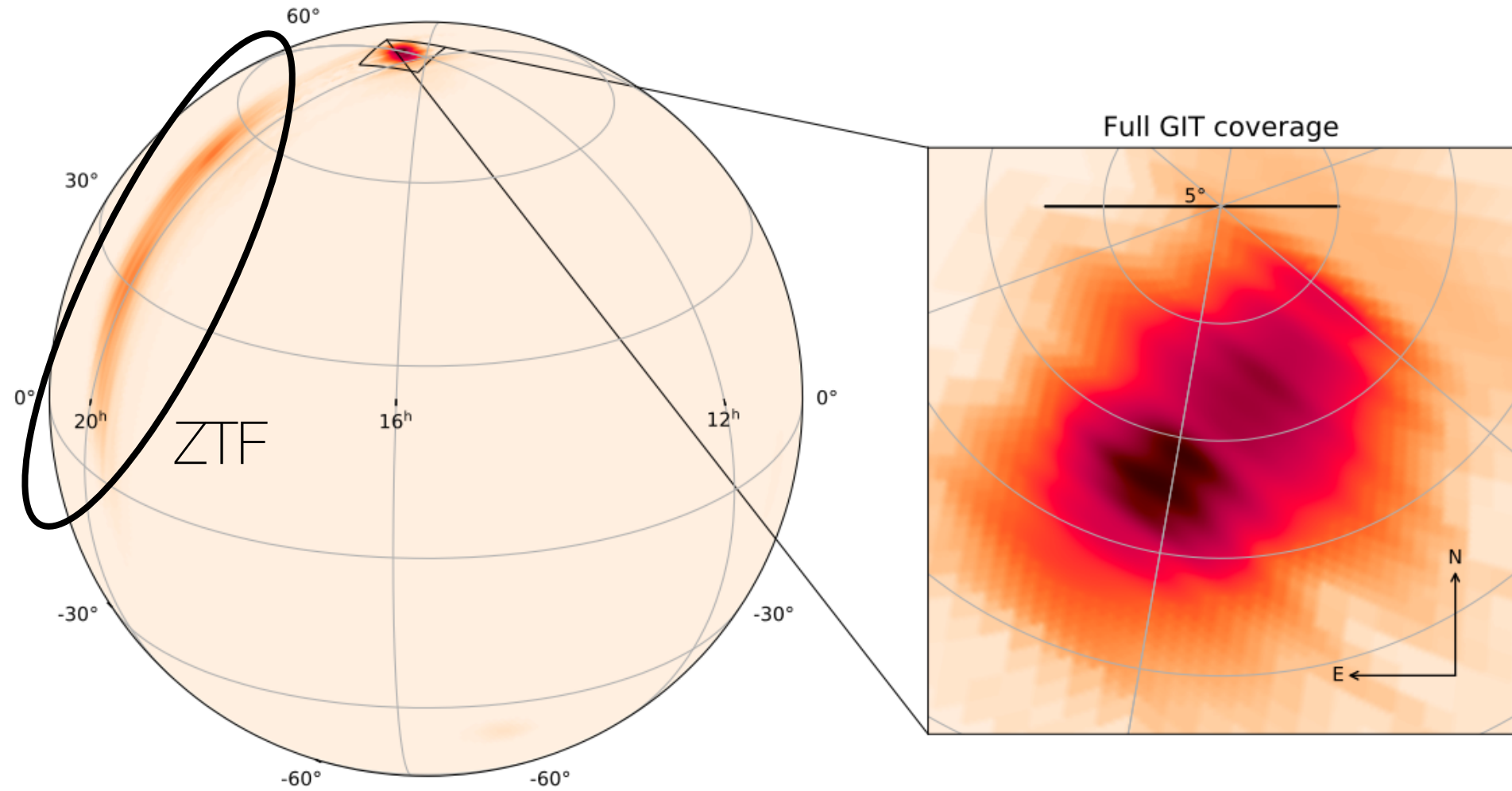
LIGO O3a and GROWTH India



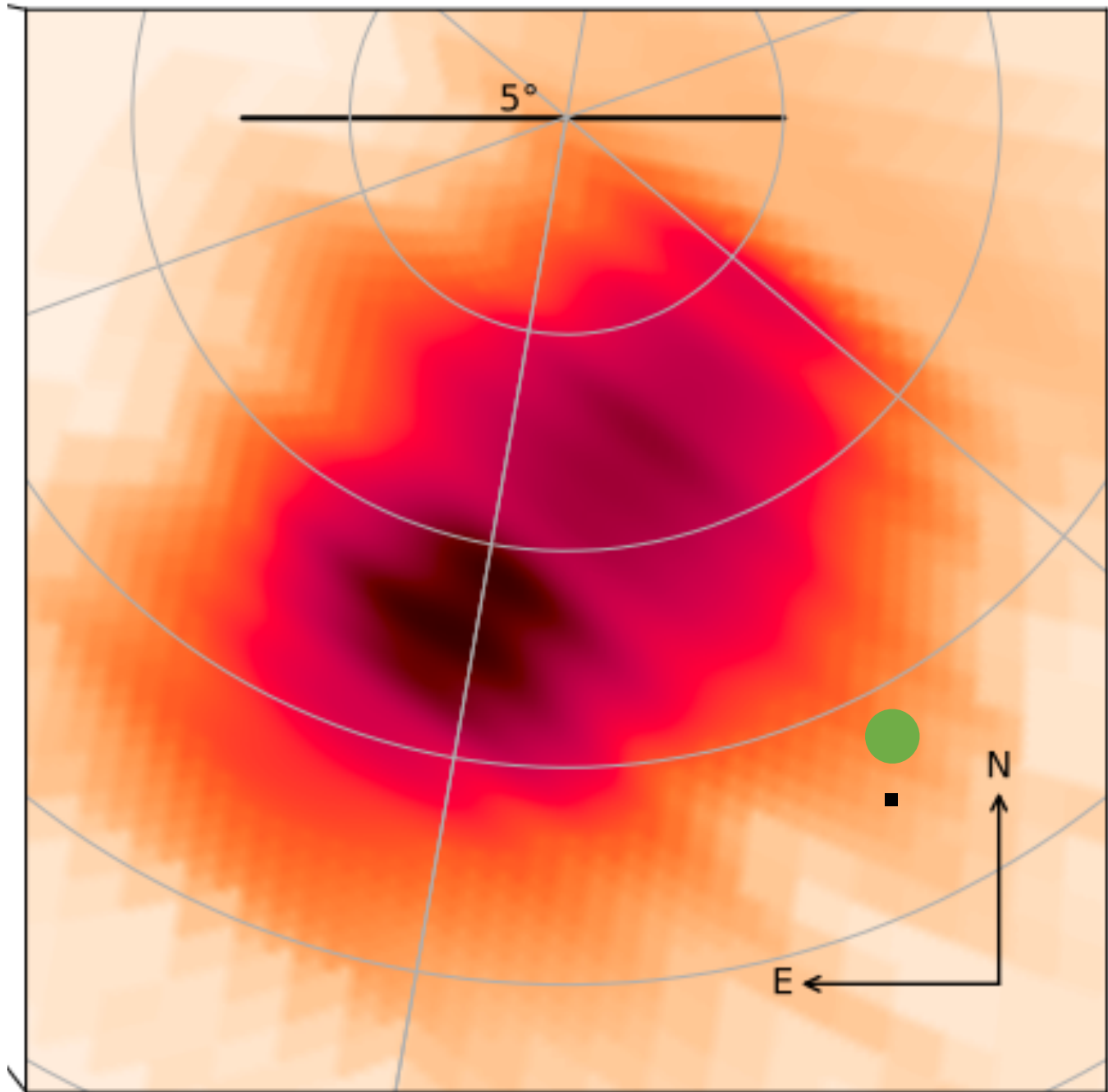
S190426C: covering the pole



S190426C: covering the pole

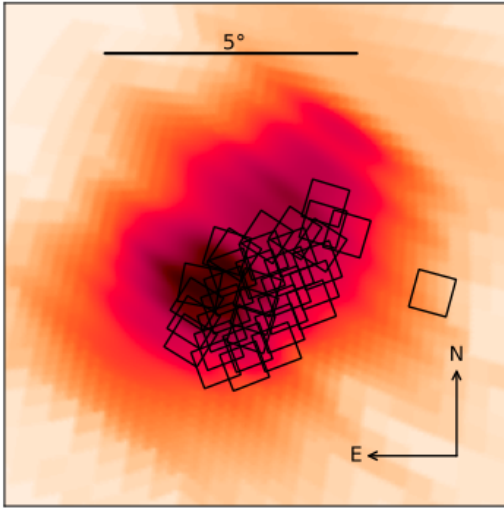


Wide-field

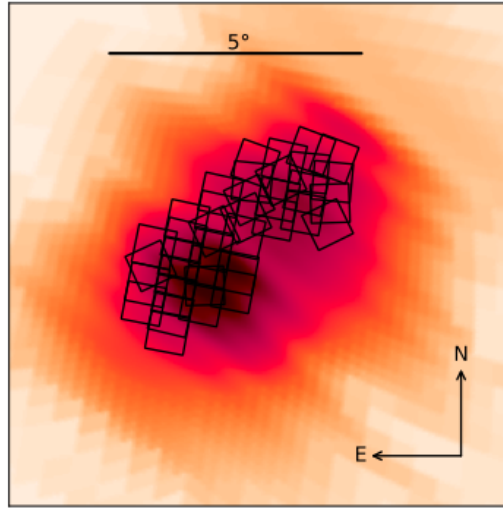


Coverage

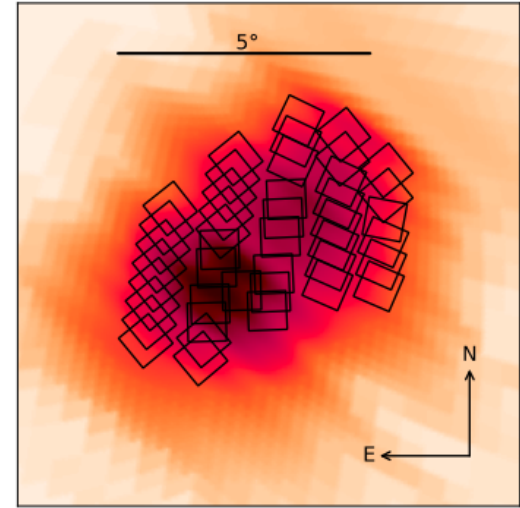
20190426



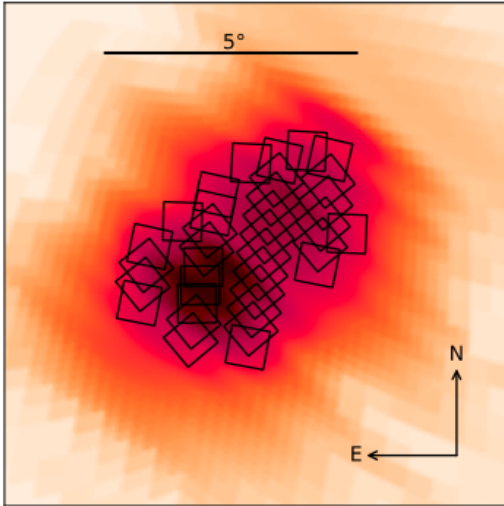
20190427



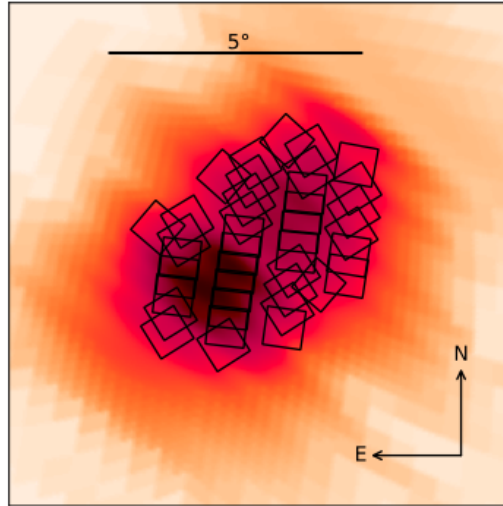
20190428



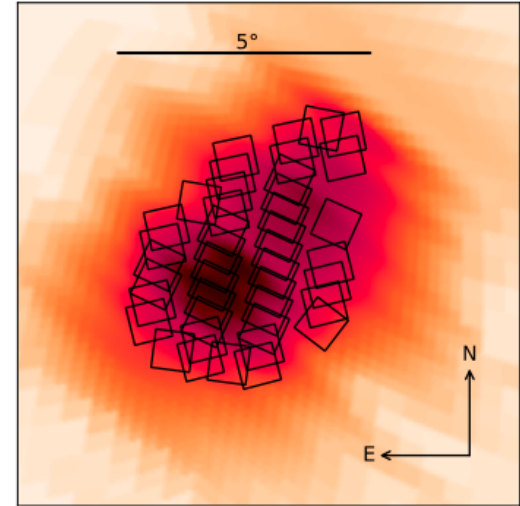
20190503



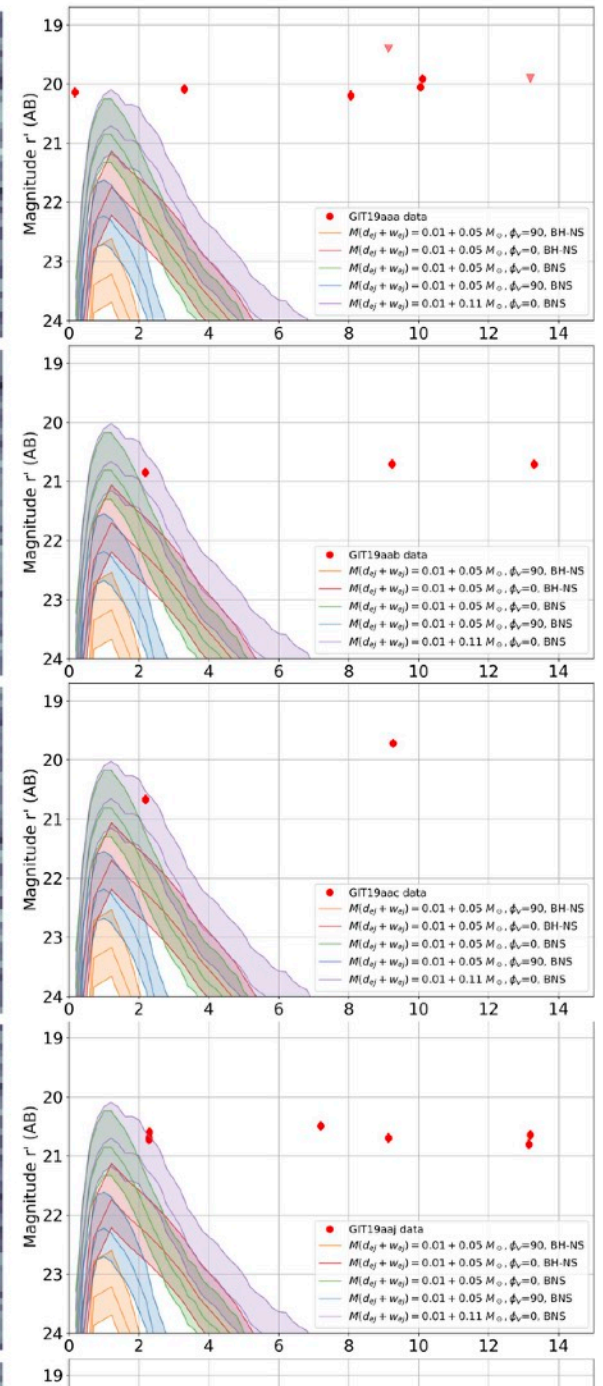
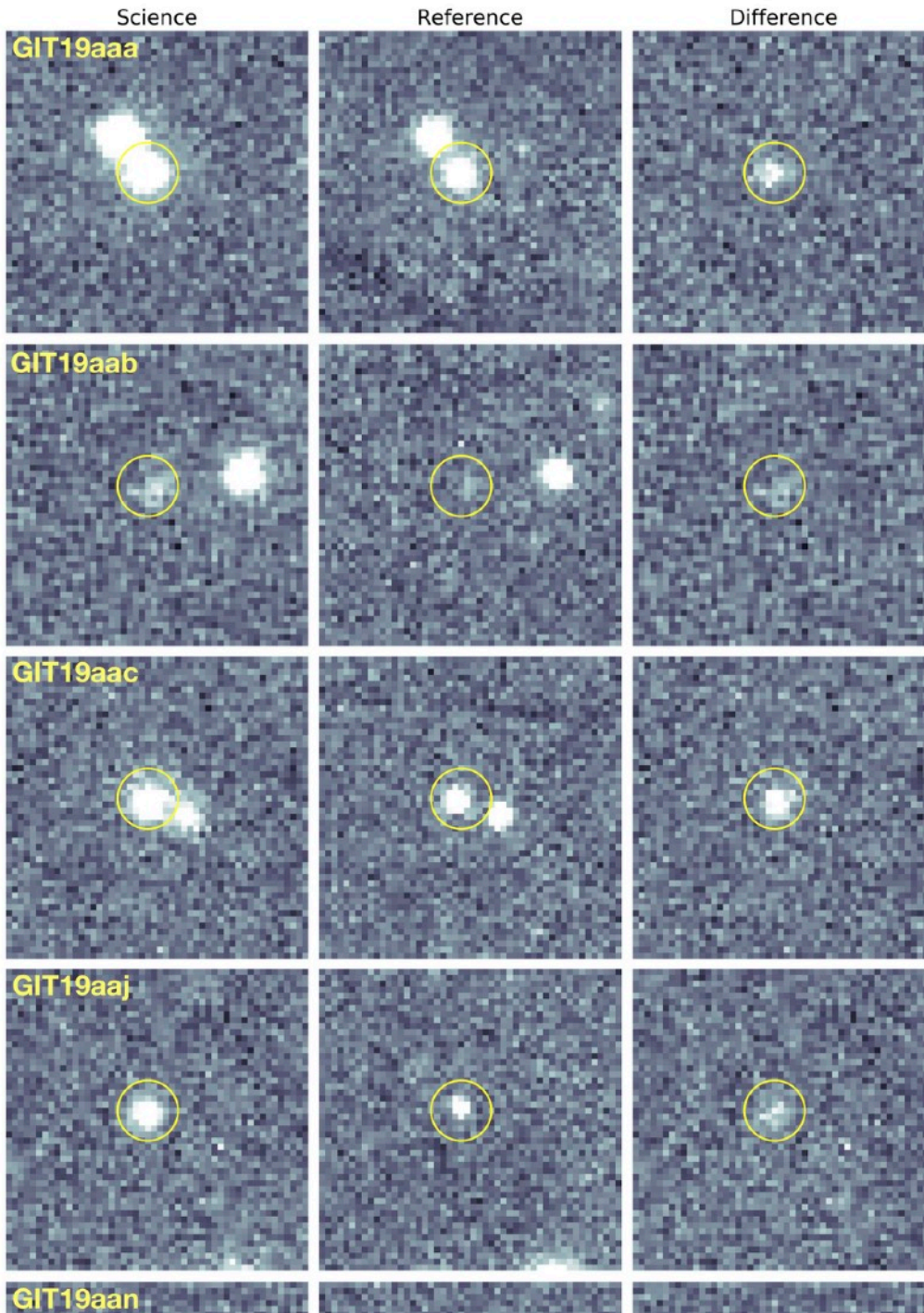
20190504



20190505

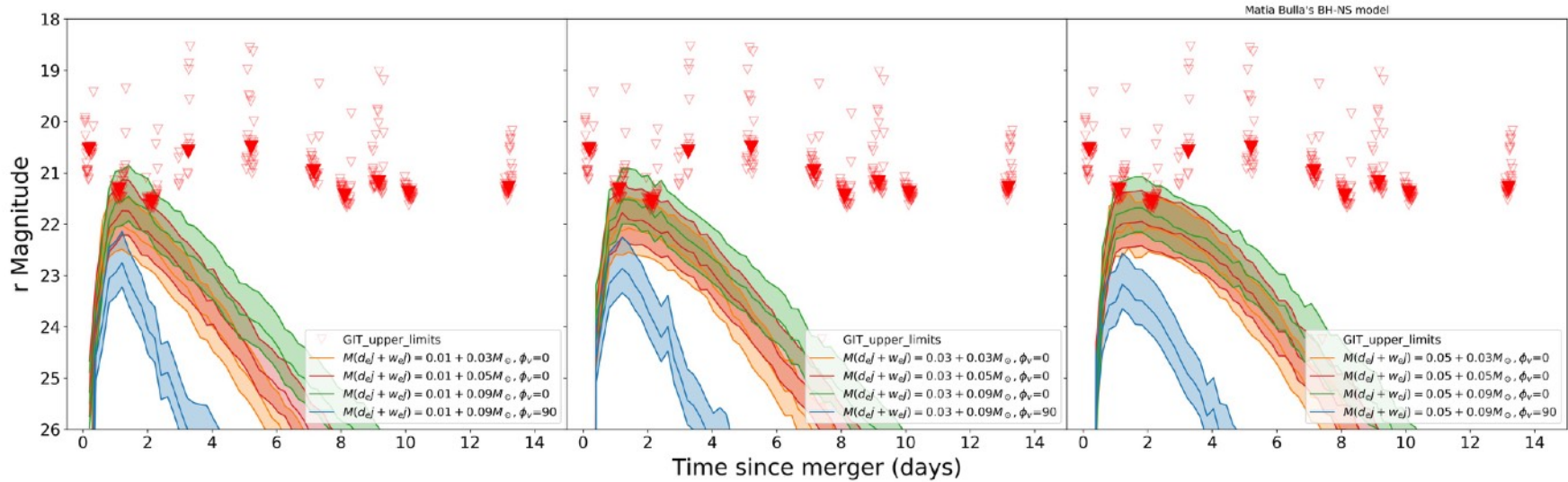


What we found

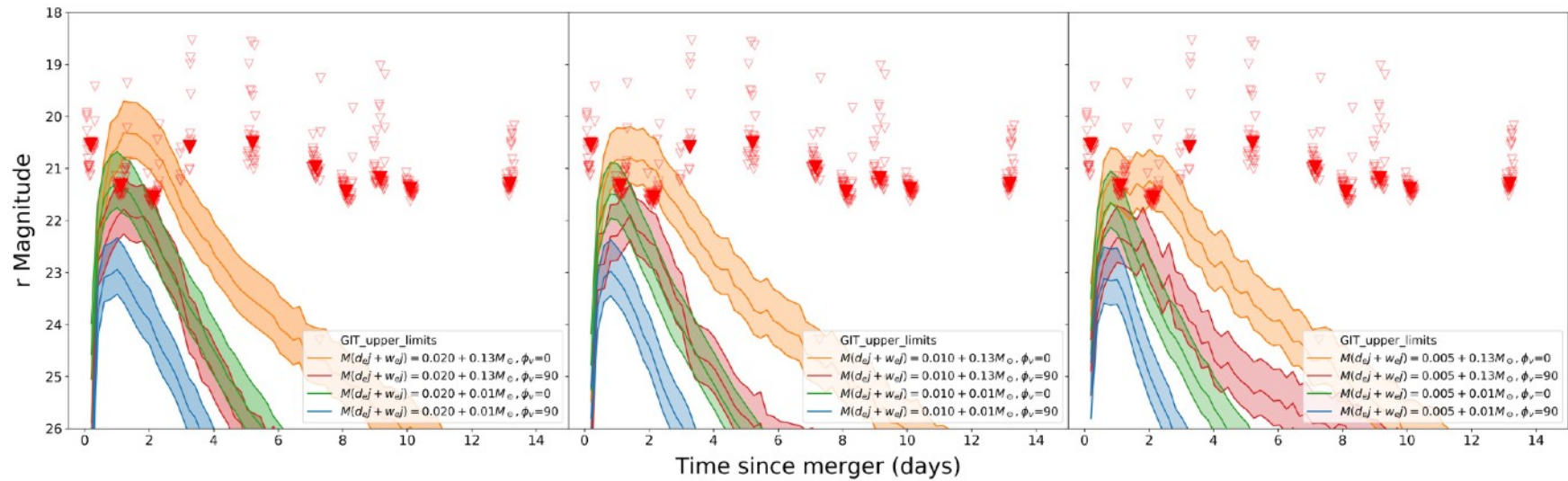


Even non-detections matter!

BH + NS



NS + NS

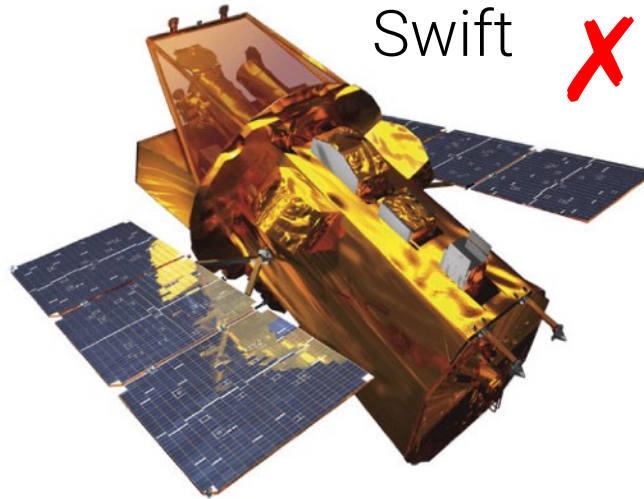
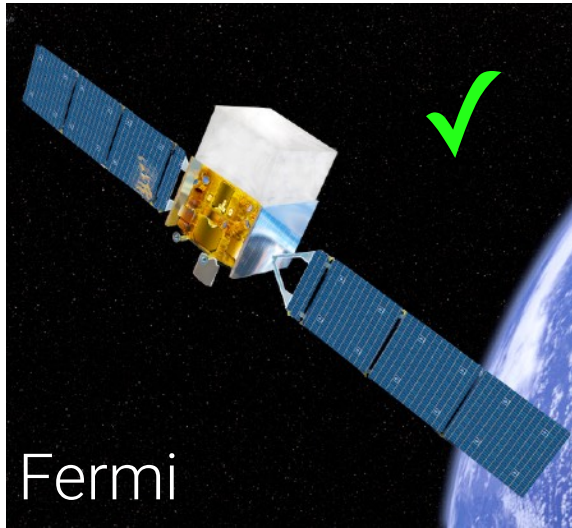
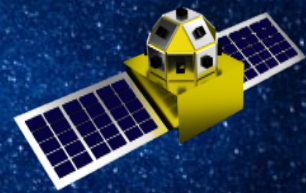


High energy follow up

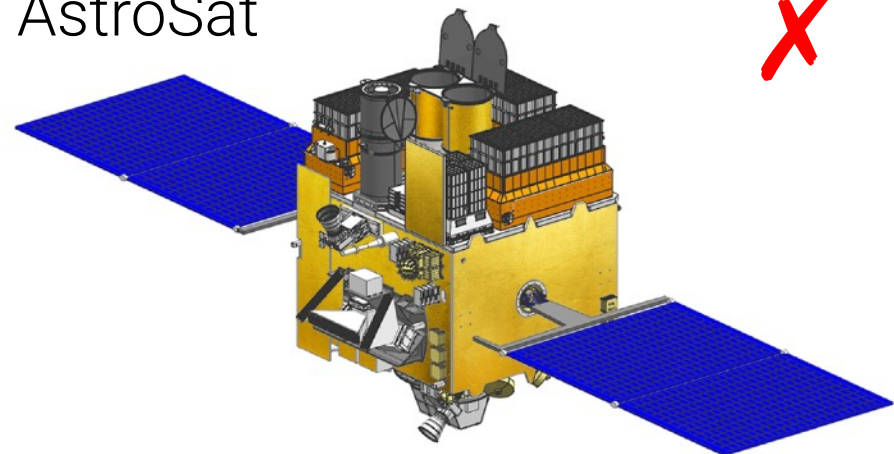
Who's keeping watch?



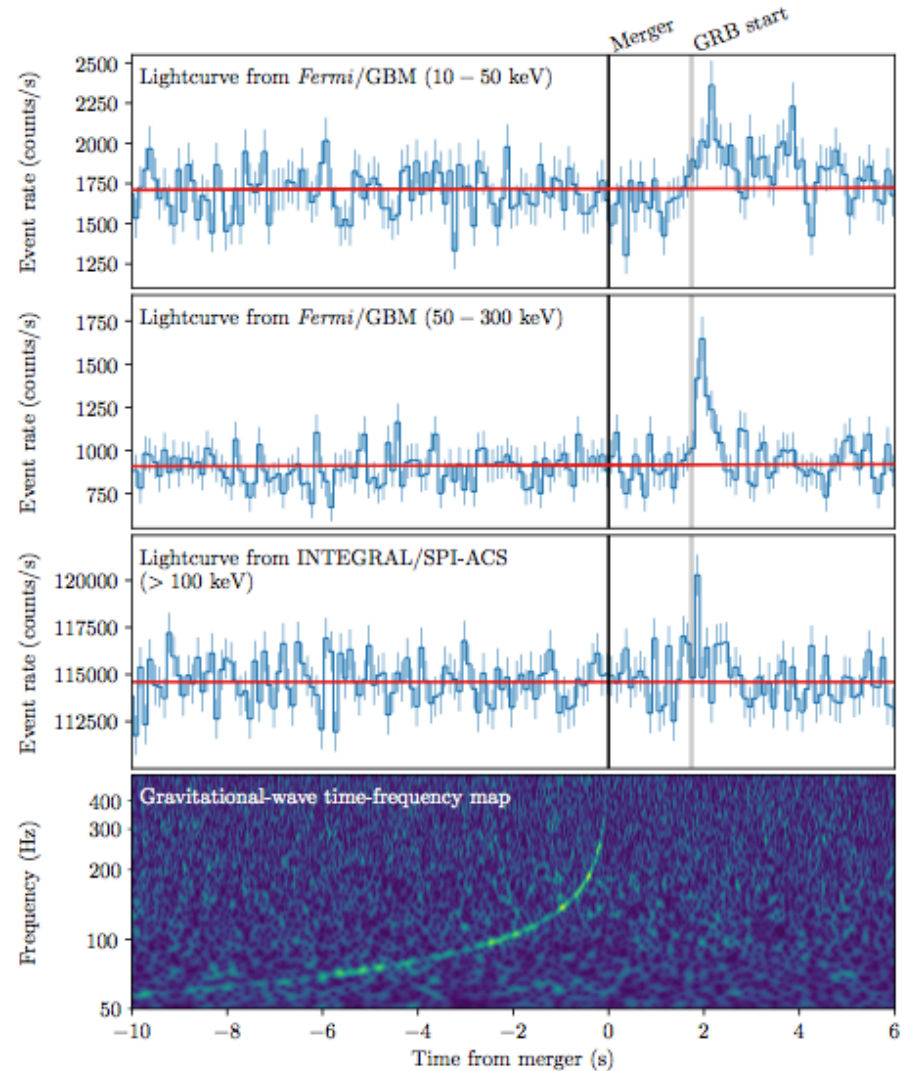
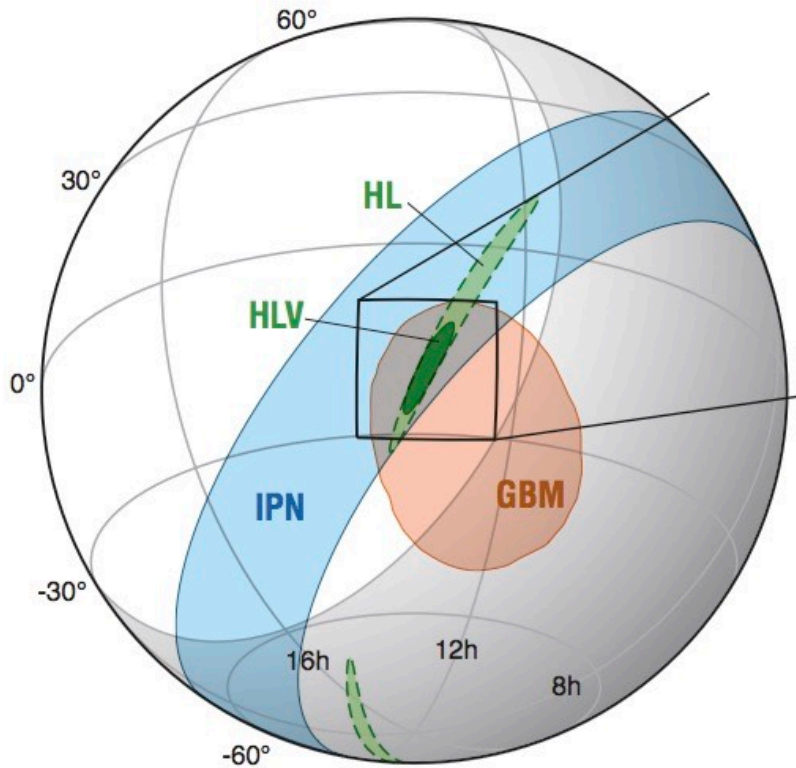
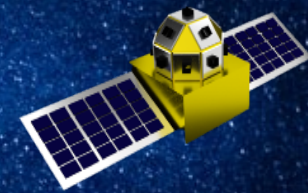
Who's keeping watch?



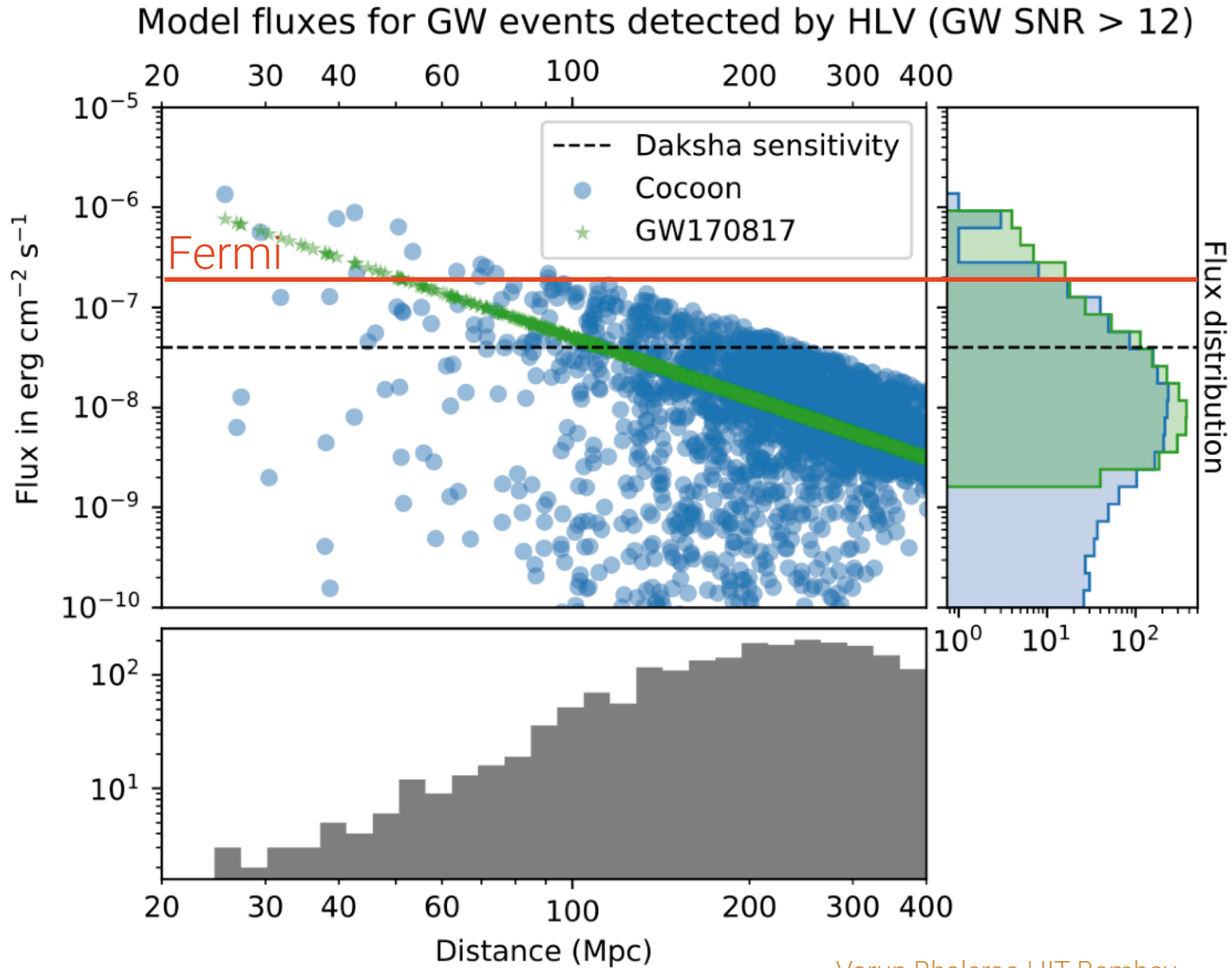
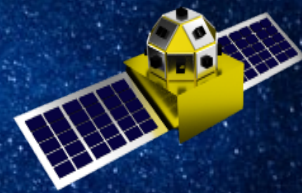
AstroSat



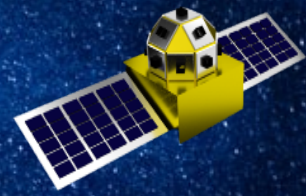
AstroSat and GW170817



High Energy Fluxes



Lessons from 03



1. Don't blink

- All the sky, all the time

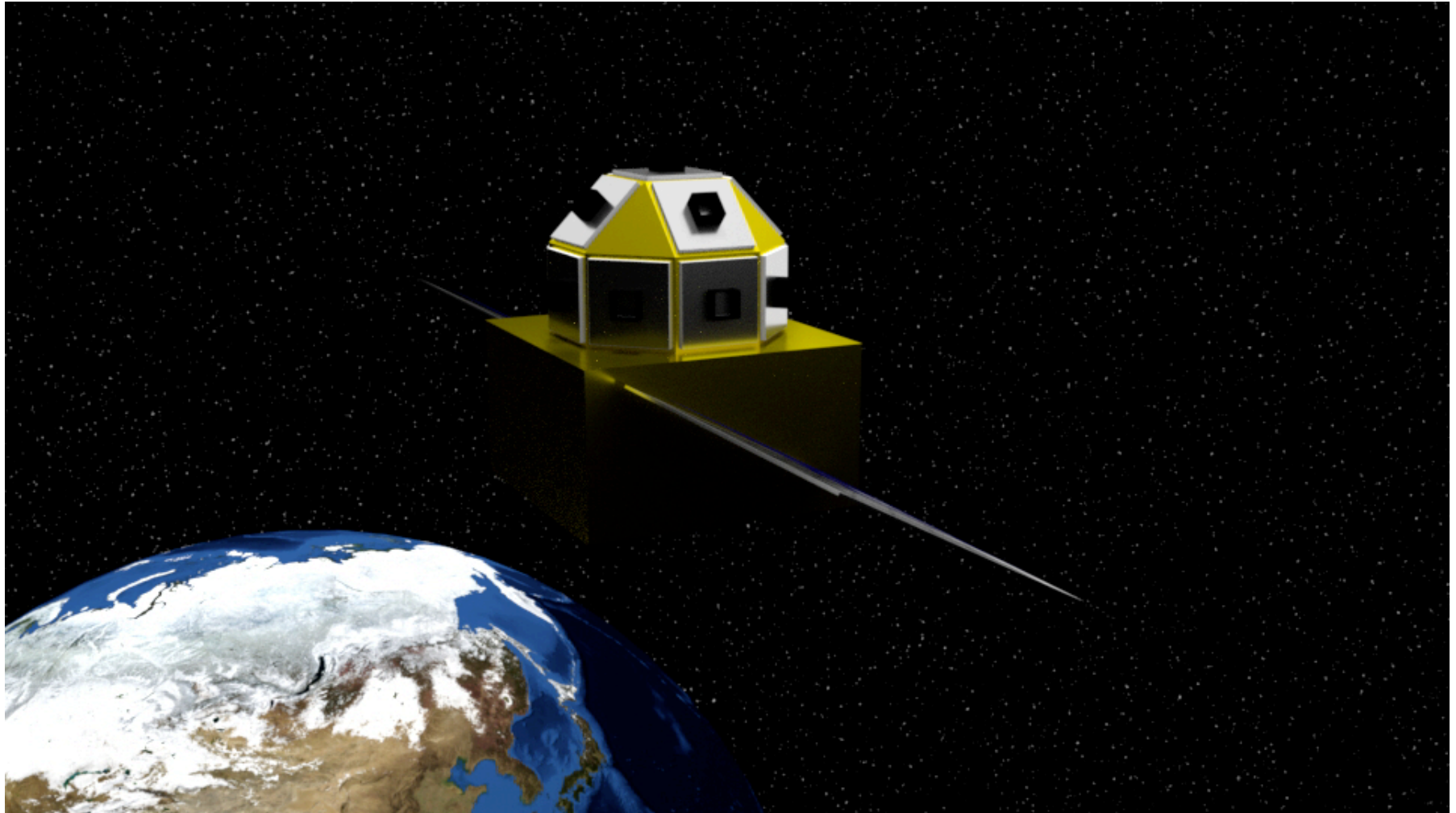
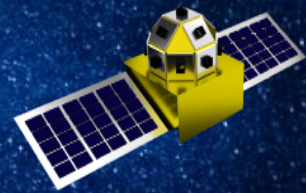
2. More sensitivity

- Order of magnitude more grasp

3. Broadband

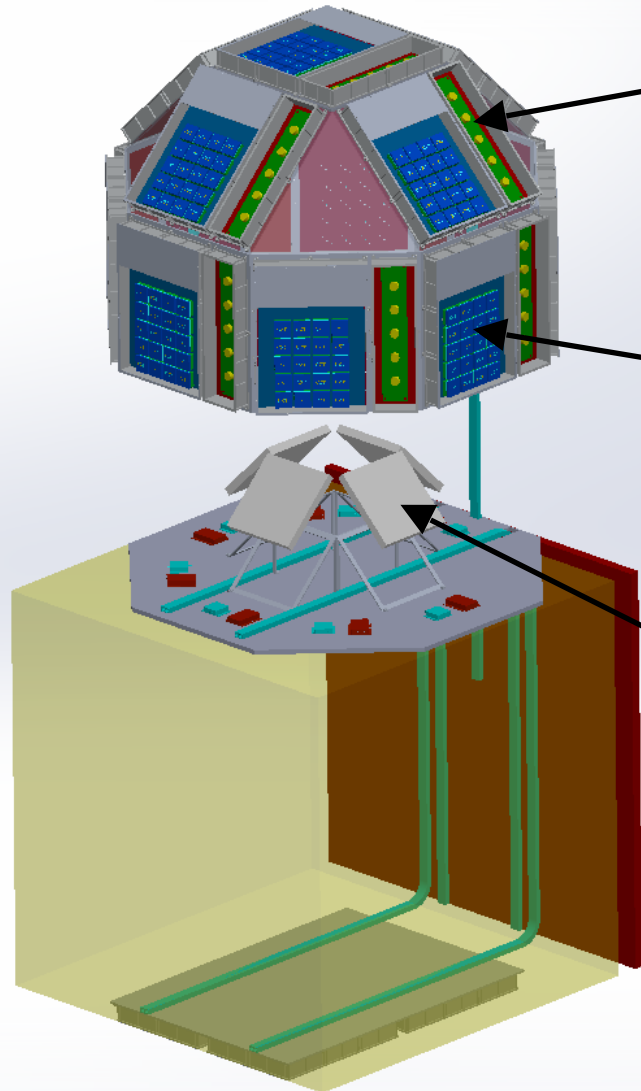
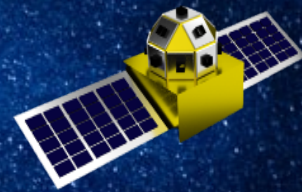
- Detect → Characterize → Interpret

Introducing Daksha



On Alert for High Energy Transients

Daksha



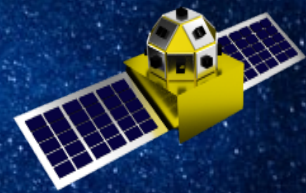
Low Energy: SDDs
1-25 keV

Medium Energy: CZT
20-200 keV

High Energy: Scintillator
100-1000 keV

Two satellites

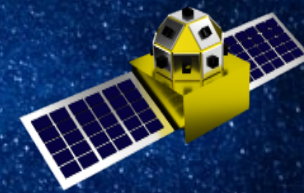
Daksha: vital statistics



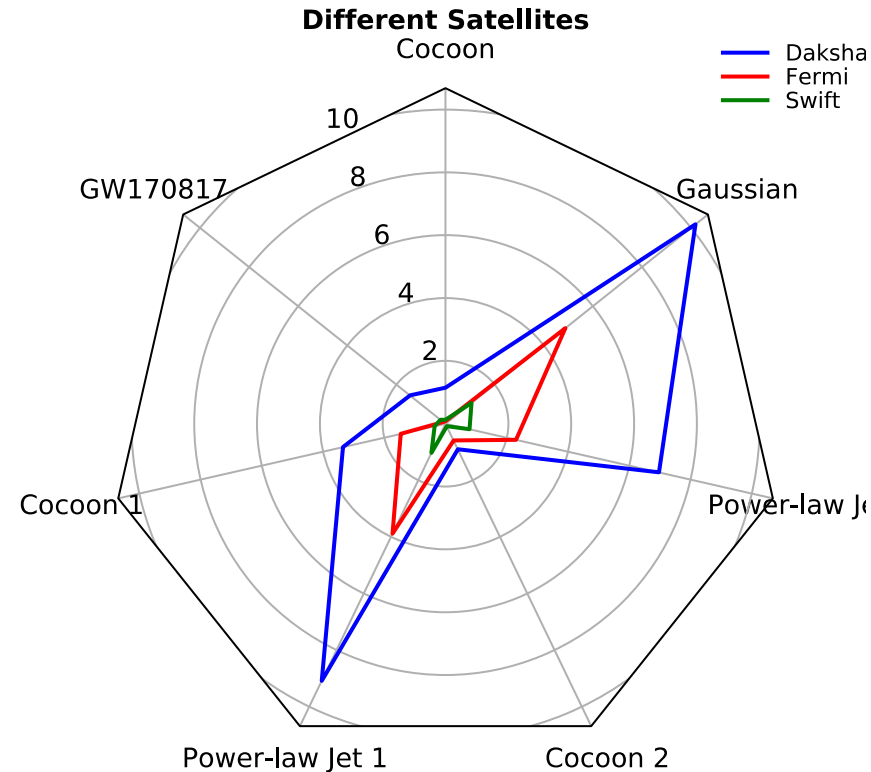
- Broadband energy coverage: 1 keV to > 1 MeV
- Median effective area: 1300 cm^2 (single sat)
- Sky coverage: 1 satellite $\sim 50\%$, two $\sim 87\%$
- Event alert within ~ 1 minute

- Downlink all event mode data – offline searches possible

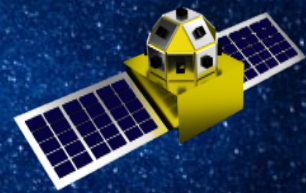
Daksha + EMGW



- Rates: ~ 4 events / year
 - Range 1–11/year
 - 3–10 \times Fermi, 10 \times Swift
 - Most will be EM + GW
- Subthreshold events
 - Increase LIGO rates!
 - Few / year

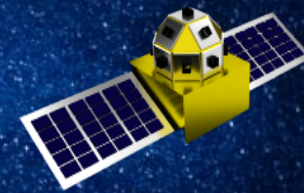


Daksha science



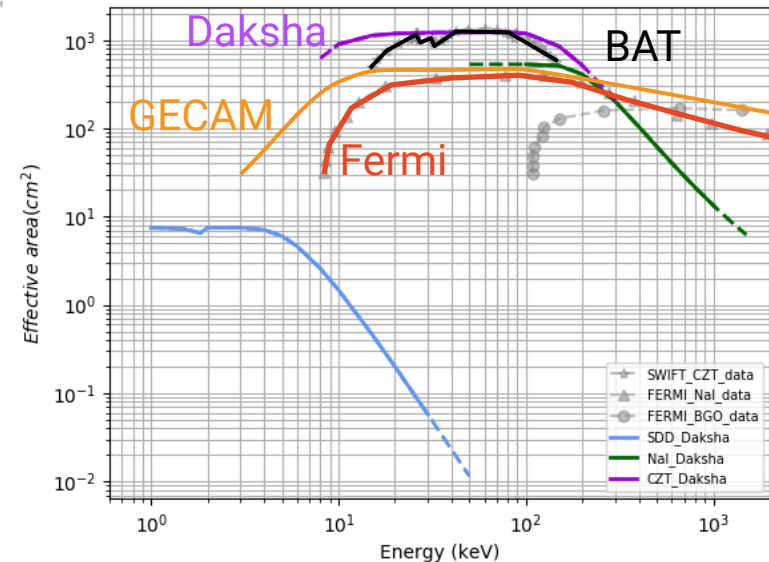
- Gamma-ray bursts
 - High-redshift GRBs
 - GRB polarisation
 - Fine time-resolved spectroscopy
 - Prompt soft spectroscopy
- Other science
 - TGFs, XRFs, Solar flares, FRBs
 - Earth-occultation imaging
 - Pulsars
 - Compton imaging

Comparing missions

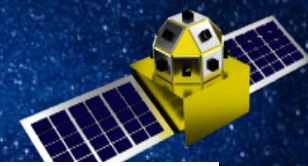


Mission	Energy range	Effective area	FoV		Grasp	Sensitivity (1-s, 5 σ)	
name	(keV)	(cm ²)	Sky fraction	(sr)	(cm ² sr)	erg cm ⁻² s ⁻¹	ph cm ⁻² s ⁻¹
<i>Daksha</i> (single)	20–200	1300	0.7	8.8	11435	4→10 ⁻⁸	0.6
<i>Daksha</i> (two)	20–200	1700	1	12.6	16336	4→10 ⁻⁸	0.6
<i>Swift</i> -BAT	15–150	1400	0.11	1.4	1960	3→10 ⁻⁸	0.5
<i>Fermi</i> -GBM	50–300	420	0.7	8.8	3695	20→10 ⁻⁸	0.5
GECAM-B	6–5000	480	0.7	8.8	4222	9→10 ⁻⁸	—
<i>SVOM</i> /ECLAIRs	4–150	400	0.16	2	800	4→10 ⁻⁸	0.8
<i>THESEUS</i> /XGIS	2–30	500	0.16	2	1000	1.7→10 ⁻⁸	—
<i>THESEUS</i> /XGIS	30–150	500	0.16	2	1000	5→10 ⁻⁸	—
<i>THESEUS</i> /XGIS	150–1000	1000	0.5	6.2	6200	45→10 ⁻⁸	—

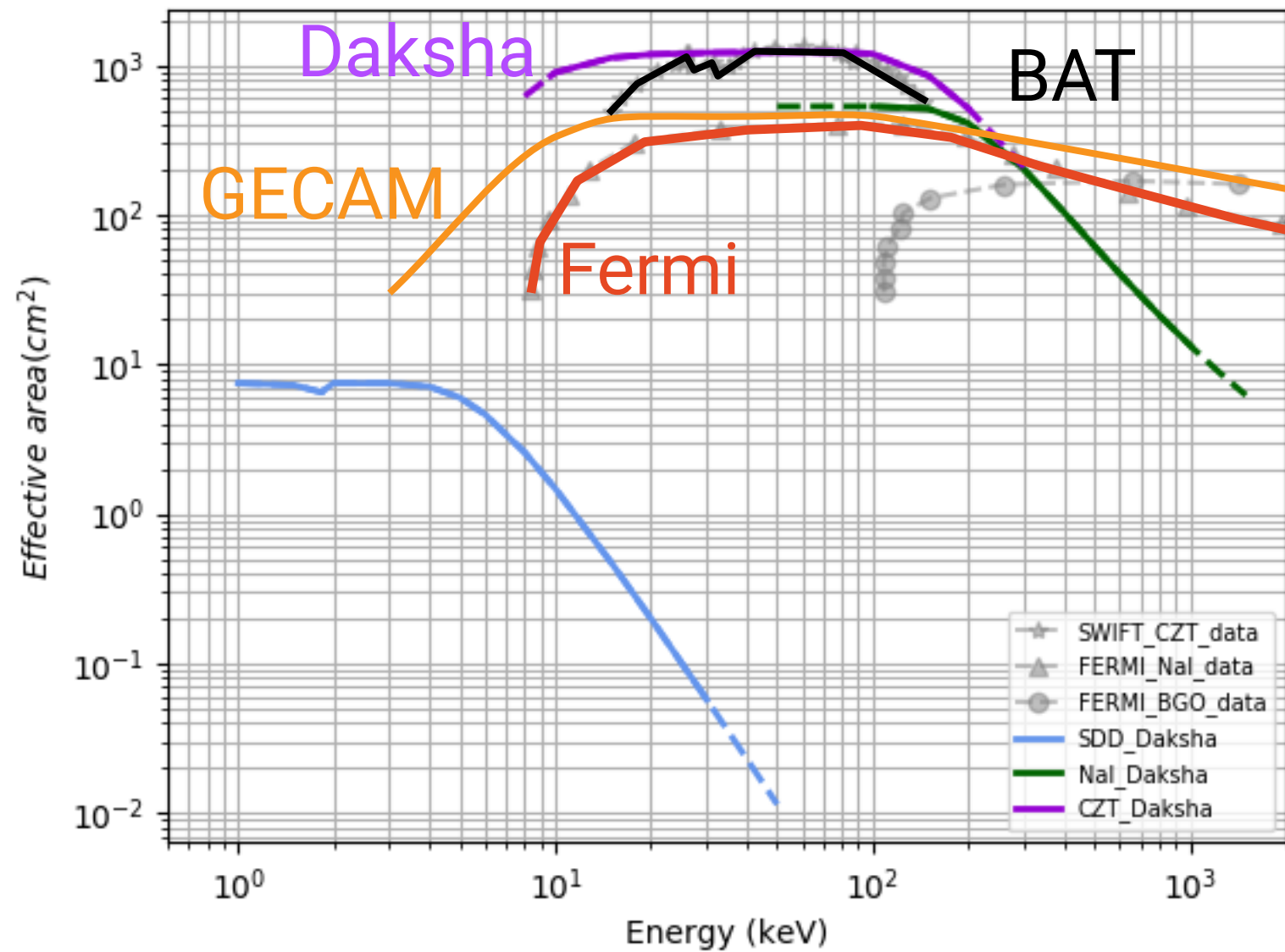
- Daksha has the highest grasp of any mission
- BAT-like sensitivity over the entire sky
- Wider spectral band



Comparing missions

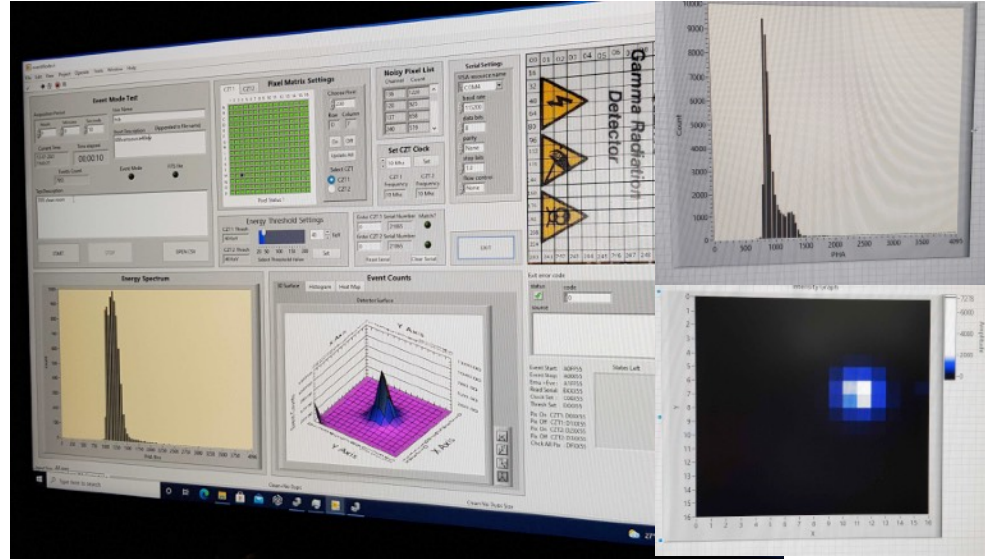
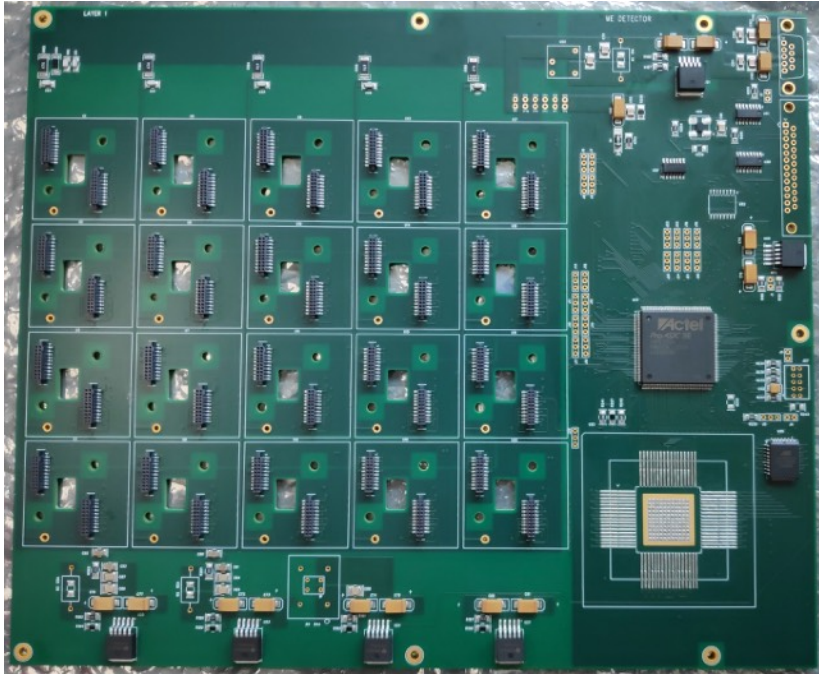
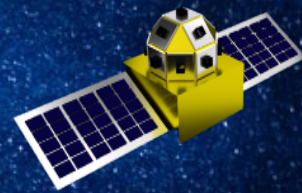


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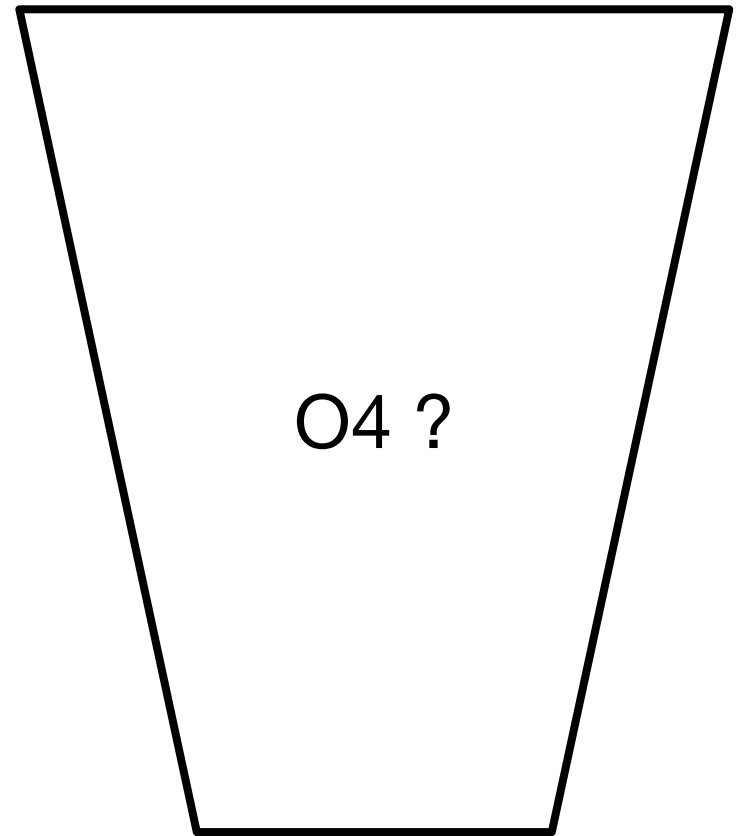
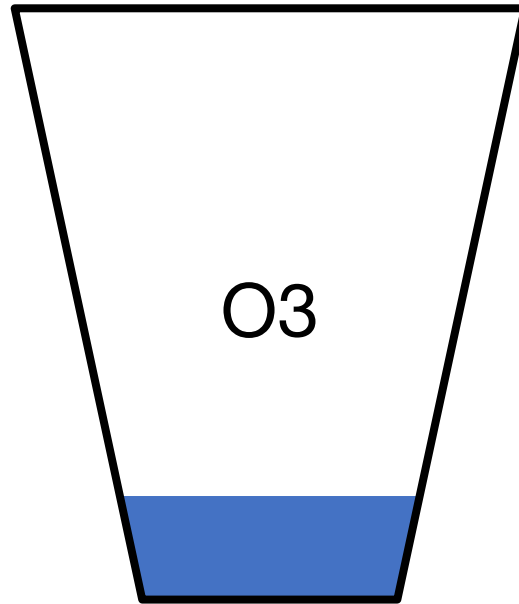


-1
-1

Daksha Status



What's next?



NS events in O3

Event	Event probabilities	Dist (Mpc)	Area (sq deg)
S190425z	99% BNS	157 ± 43	9881
S190426c	49% BNS, 13% NSBH	377 ± 107	1393
S190814bv	100% NSBH	241 ± 26	19
S190901ap	86% BNS	241 ± 79	14753
S190910d	98% NSBH	632 ± 186	2482
S190910h	61% BNS	230 ± 88	24264
S190923y	68% NSBH	438 ± 133	2107
S190930t	74% NSBH	108 ± 38	24220
S191205ah	93% NSBH	385 ± 164	6378
S191213g	77% BNS	201 ± 81	4480
S200213t	63% BNS	201 ± 80	2326

Scaling to GW170817

Event	Dist (Mpc)	Area (sq deg)	Optical (r)	IR (Ks)	X-ray (10^{-8} cgs) (10 – 1000 keV)
S190425z	157 ± 43	9881	24	25	5
S190426c	377 ± 107	1393	28	29	0.8
S190814bv	241 ± 26	19	26	27	2
S190901ap	241 ± 79	14753	26	27	2
S190910d	632 ± 186	2482	31	32	0.3
S190910h	230 ± 88	24264	26	27	2
S190923y	438 ± 133	2107	29	30	0.6
S190930t	108 ± 38	24220	22	23	10
S191205ah	385 ± 164	6378	28	29	0.8
S191213g	201 ± 81	4480	25	26	3
S200213t	201 ± 80	2326	25	26	3

O4 and beyond

- High energy: Daksha
- AstroSat: approved EMGW program
- Optical rapid response: Small telescopes for search (GIT, GOTO...), big for follow-up
- Next generation:
 - » Replicate GROWTH-India?
(~3.5 cr ₹ / 500 k\$ / 350 k£)
 - » 100-telescope array?
 - » Small satellites?