Outline

Gravitational waves

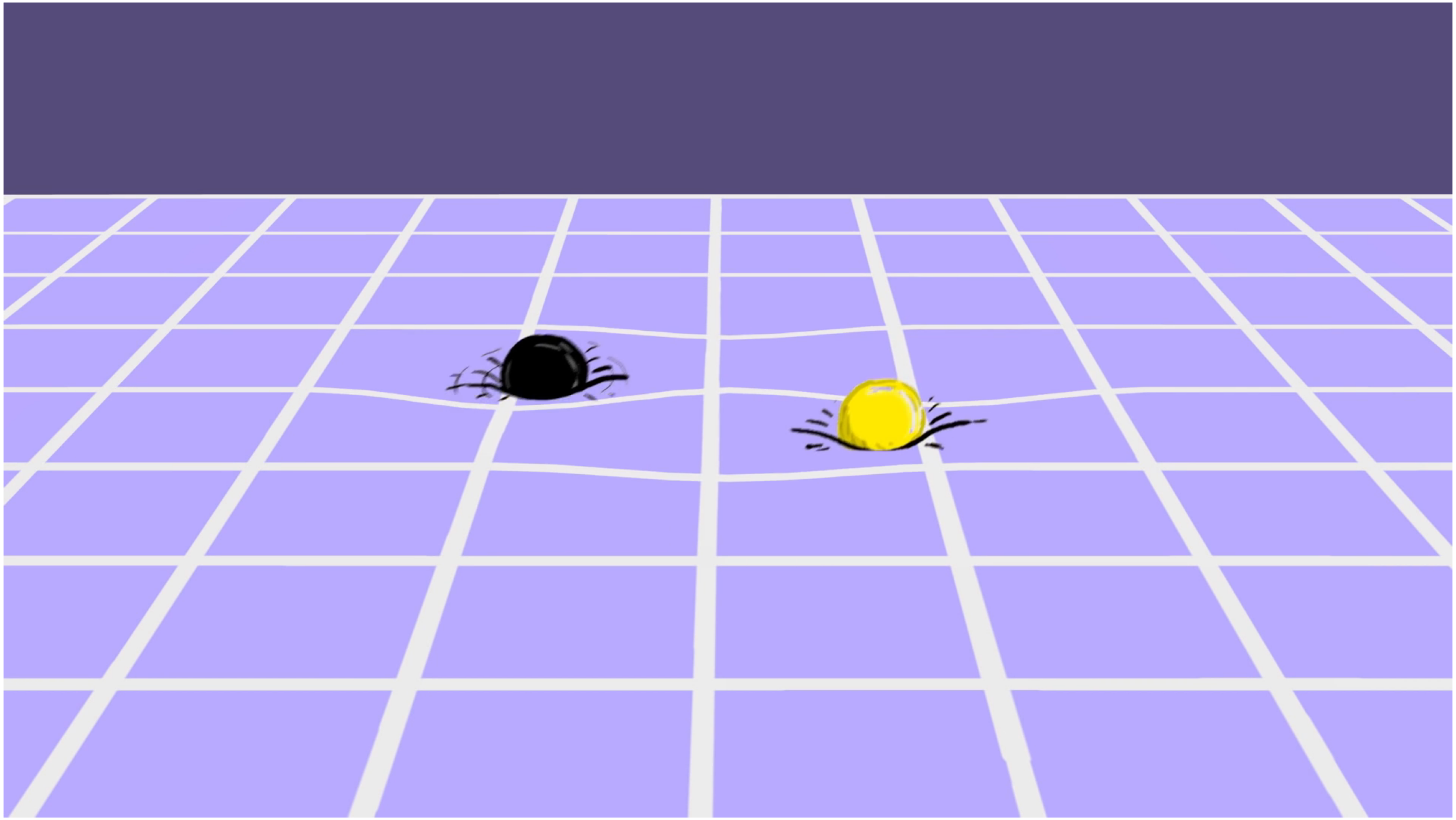
EMGW: GW170817 and results

Lessons learnt

Daksha

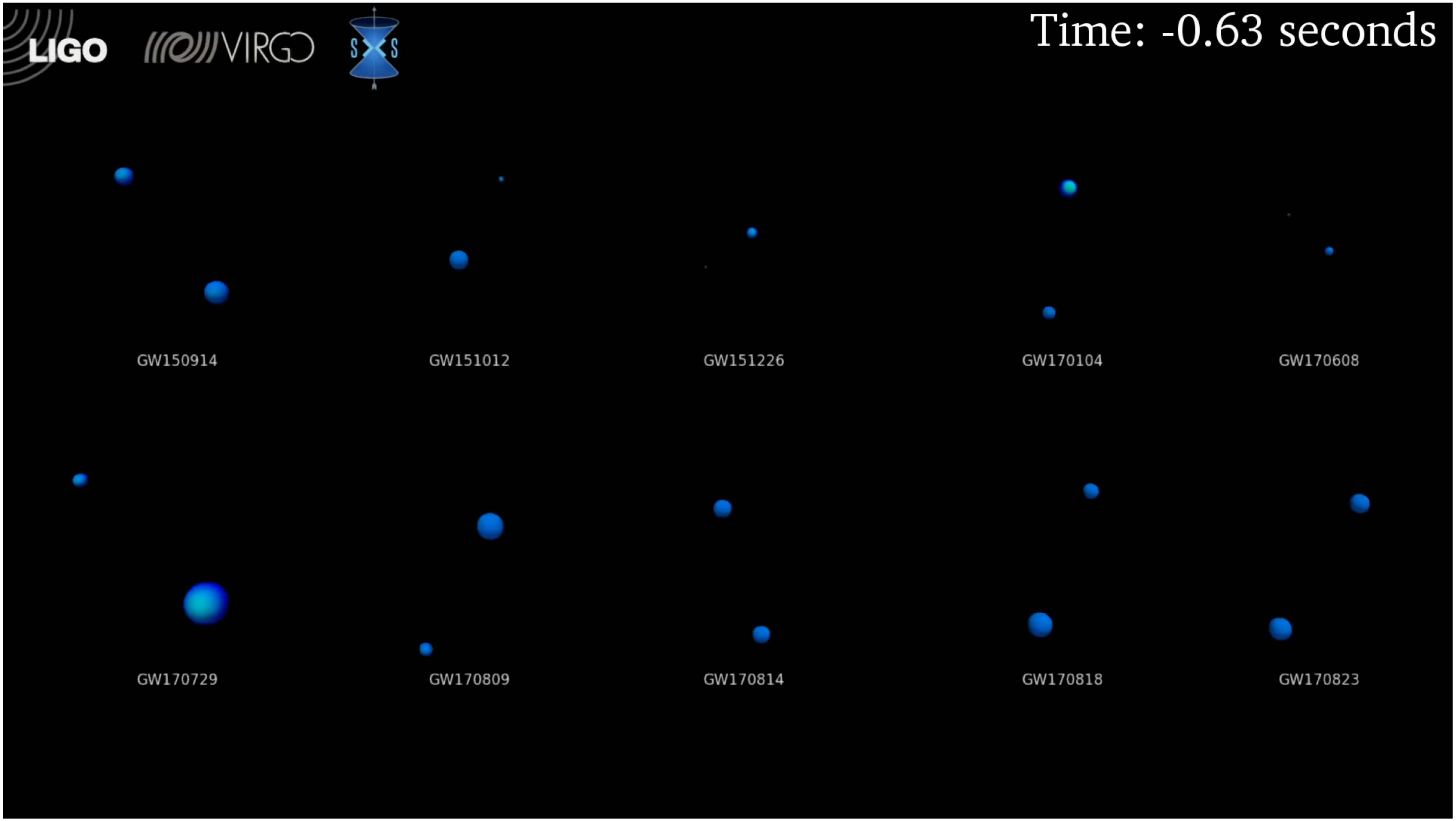
Gravitational Waves

Ripples in spacetime

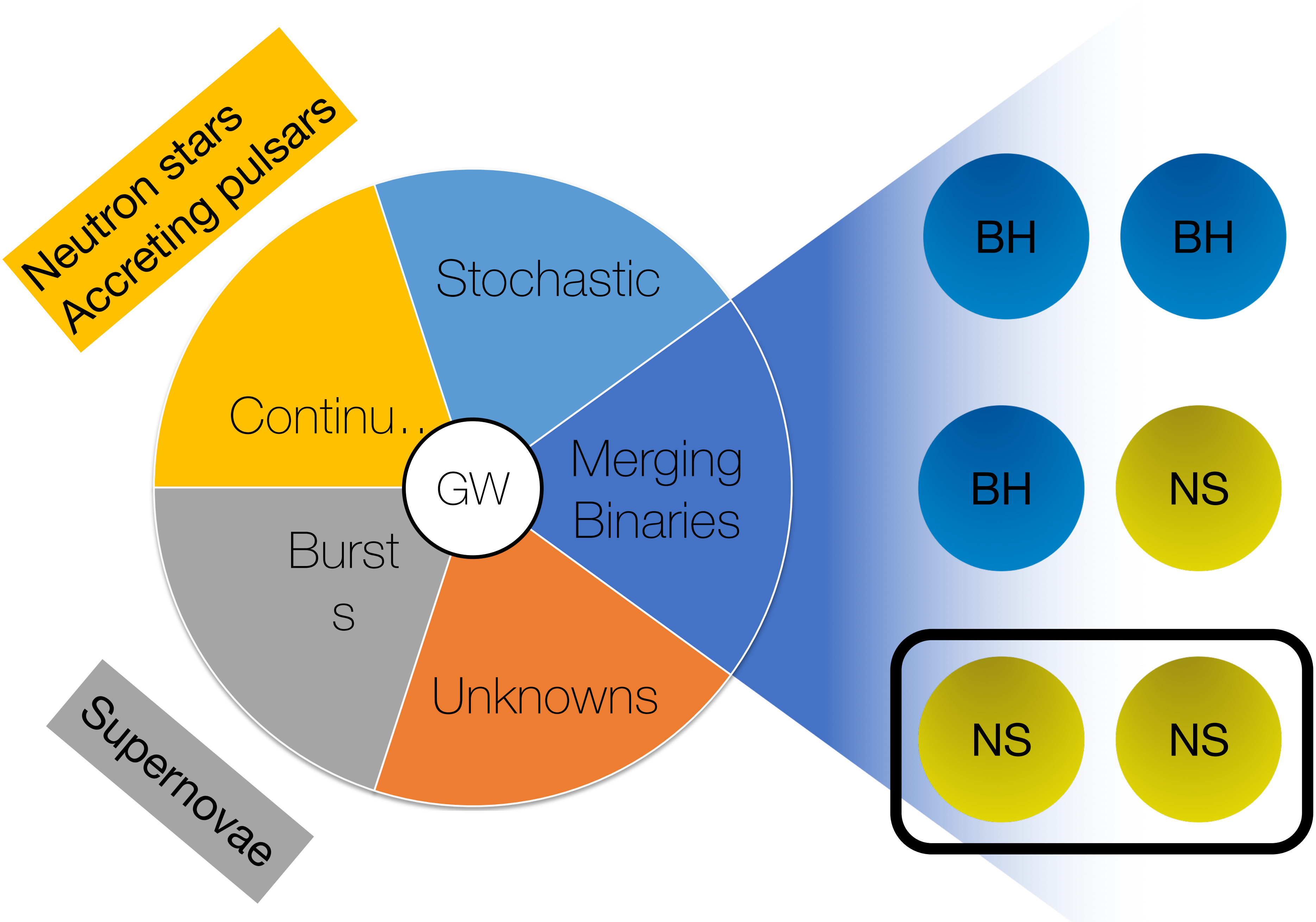


Gravitational wave detectors

Gravitational waves



Credit: Teresita Ramirez / Geoffrey Lovelace / SXS Collaboration / LIGO Virgo Collaboration



Neutron stars
Accreting pulsars

Stochastic

Continu..

GW

Merging Binaries

Burst
s

Unknowns

Supernovae

BH BH

BH NS

NS NS

Complementary information

GW

- Masses
- Spins
- Geometric properties
  - » Position
  - » Distance
  - » Inclination angle…

EM

- Precise location
- Nucleosynthesis
- Ejecta properties
  - » Beaming
  - » Mass
  - » Velocity…
- Cosmology

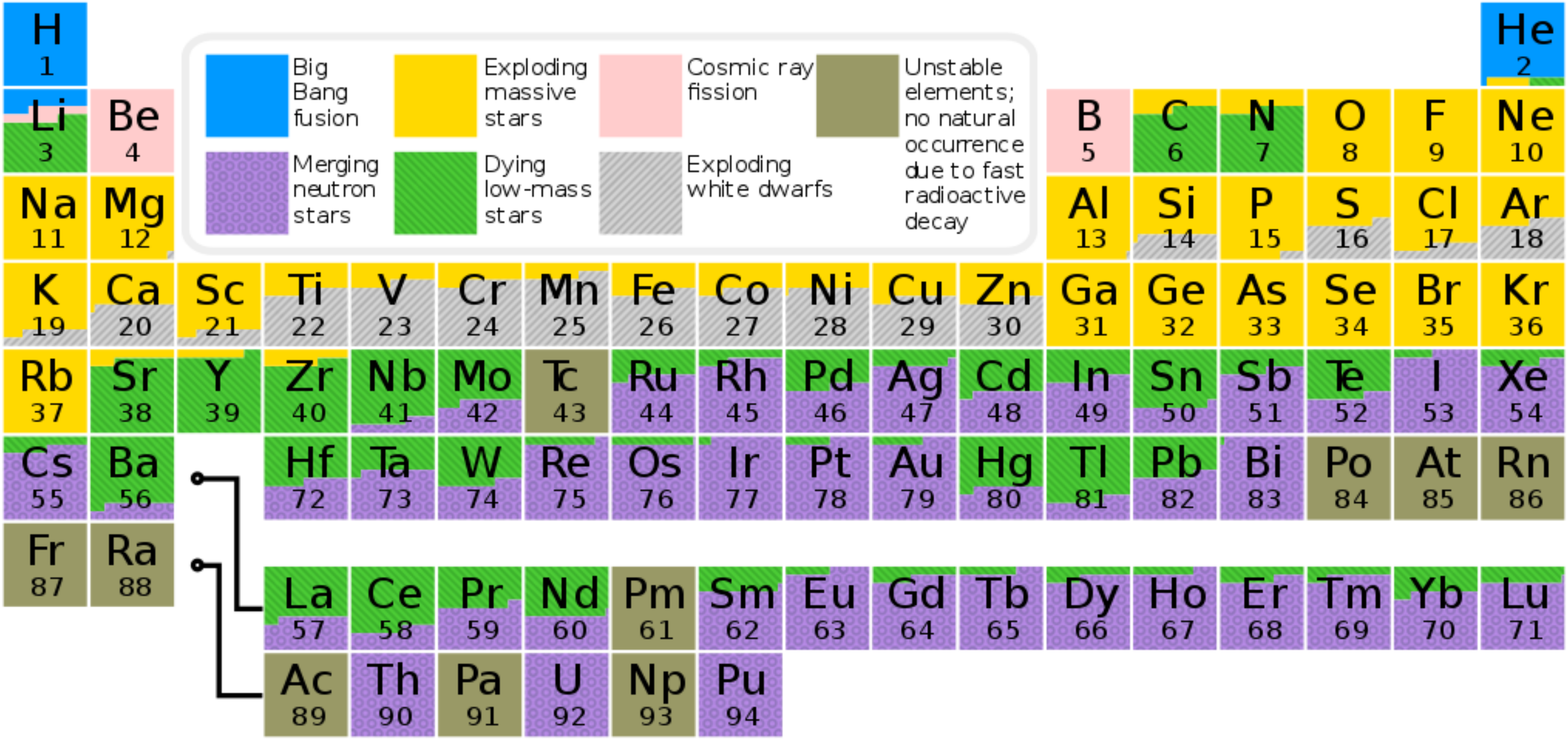
Complete astrophysical picture

Astrophysics

Where are all the heavy metals in the universe formed?

What is the Equation of State of ultra-dense matter?

Nucleosynthesis



By Geckzilla [CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)], from Wikimedia Commons

Credit: NASA/GSFC

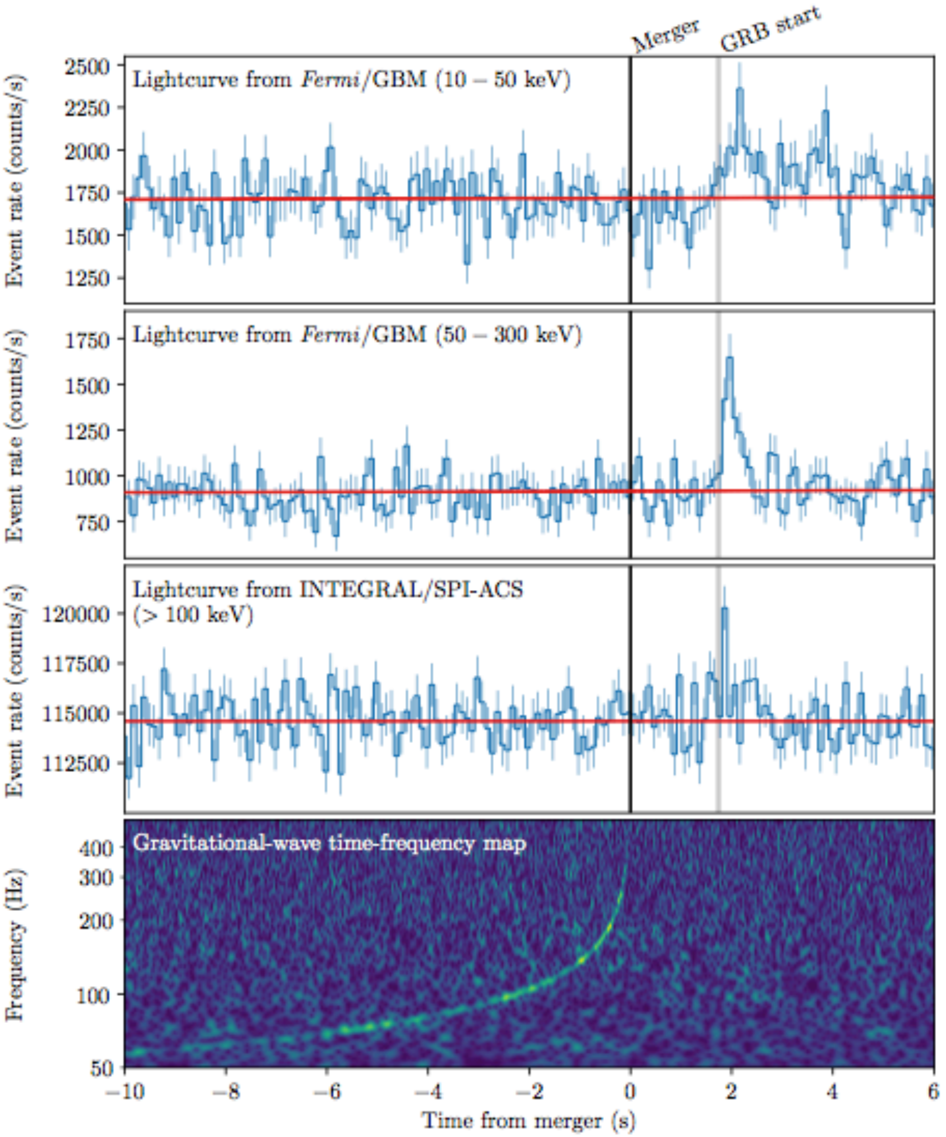
GW170817

GW170817

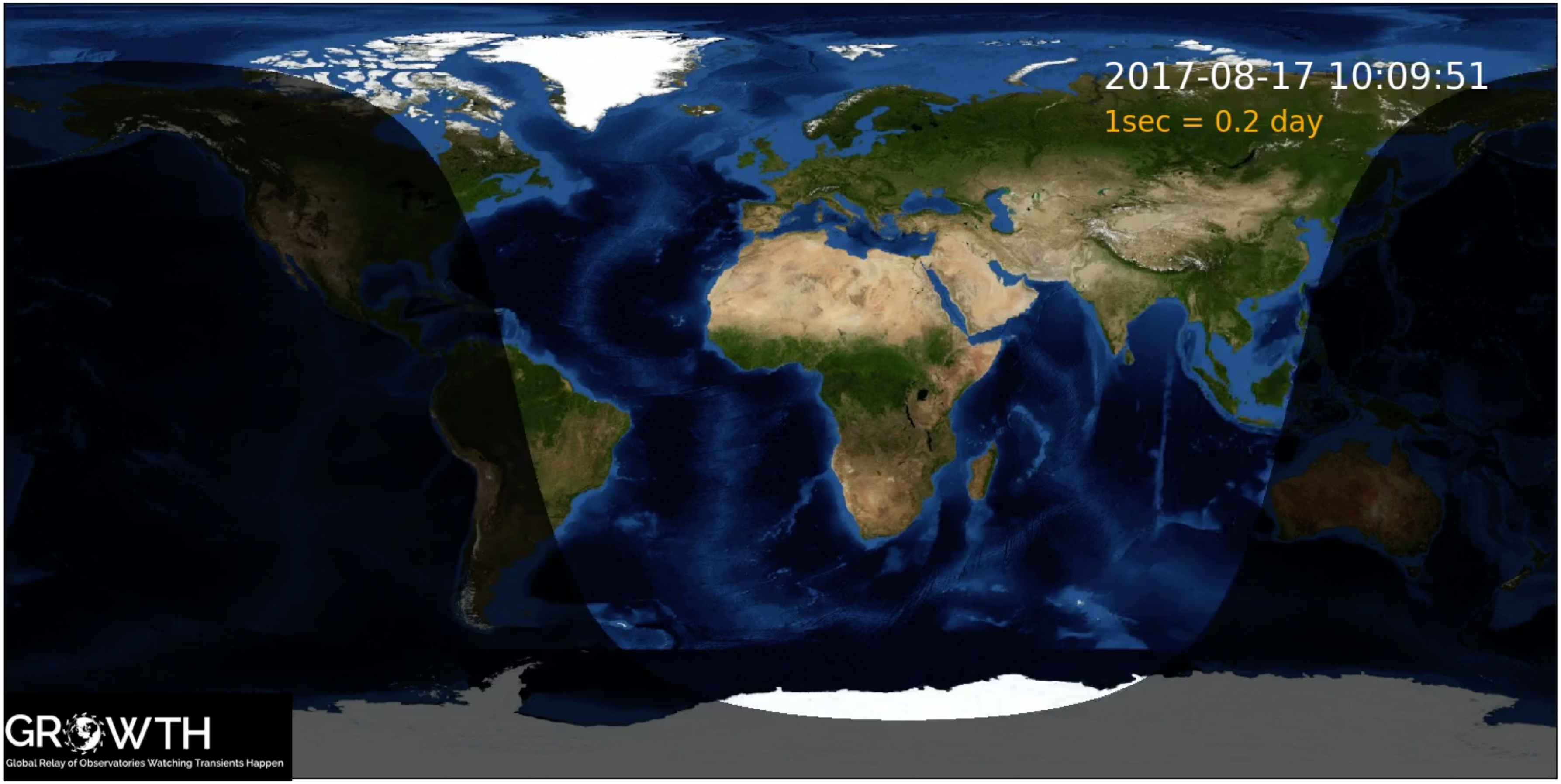
First direct detection of gravitational waves from merging binary neutron stars

40 Mpc (130 million light years)

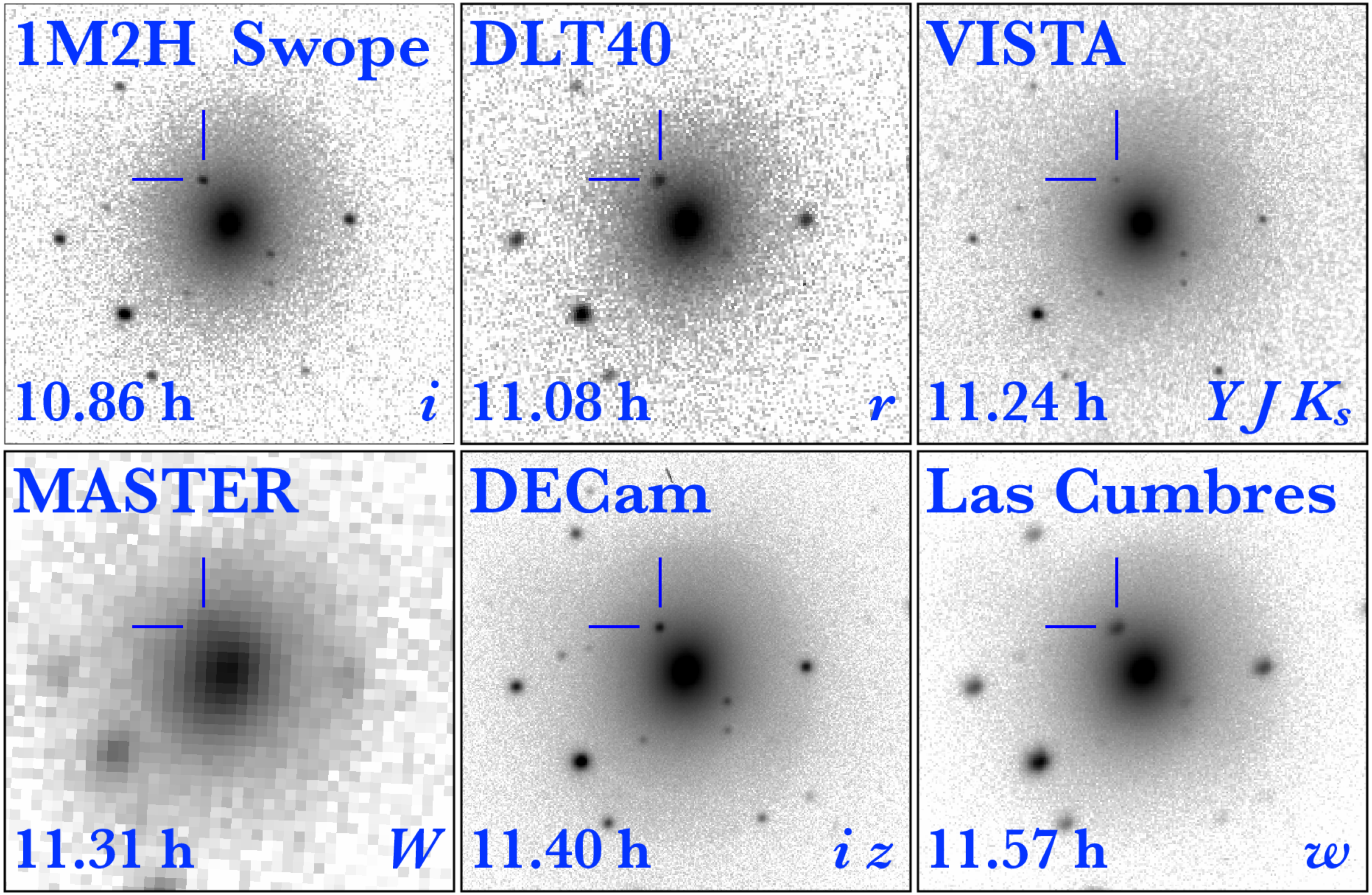
"This is a big deal…"



Observing frenzy

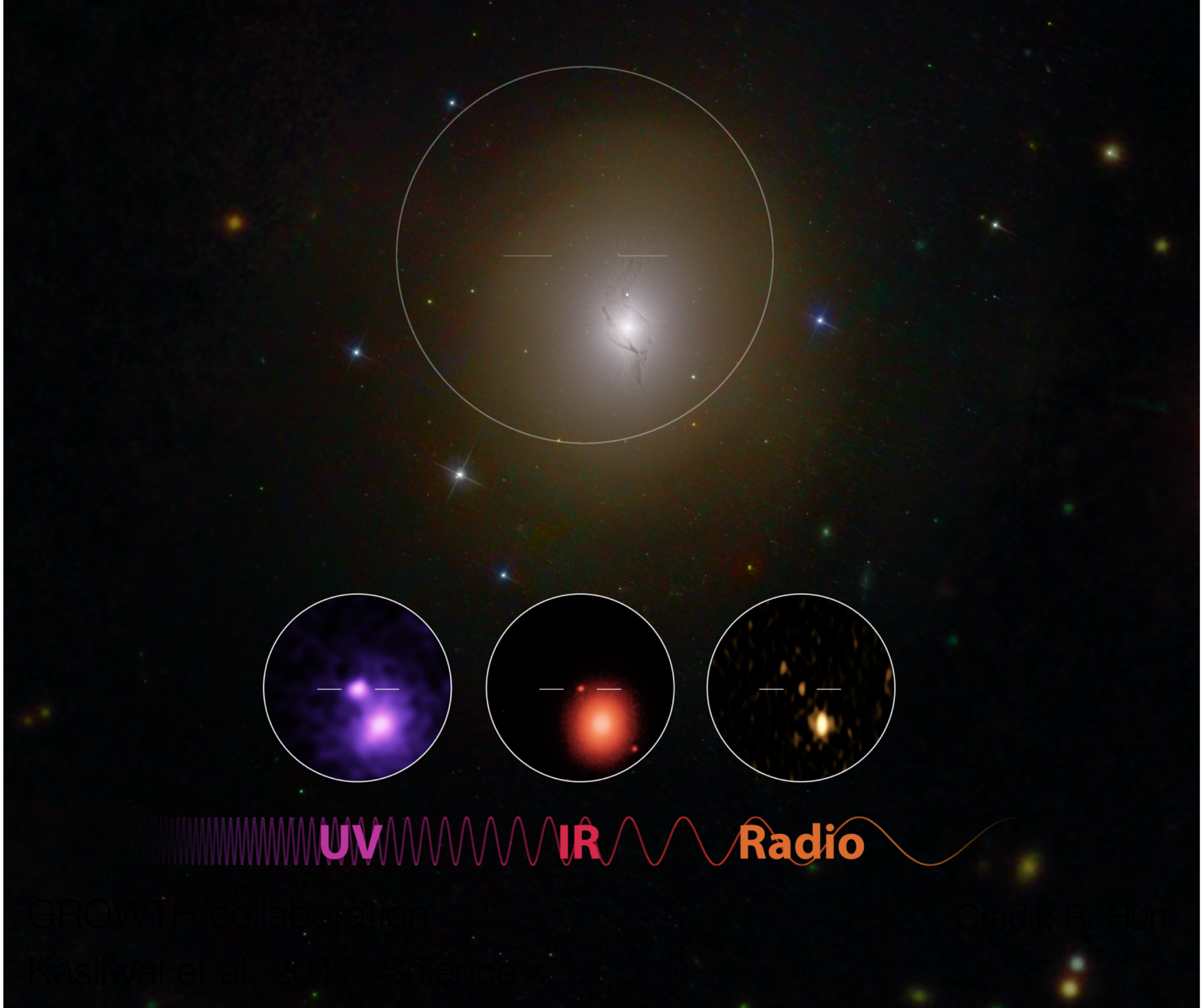


Credits: Pavan Hebbar, Varun Bhalerao (IITB), David Kaplan (UW Milwaukee),
Mansi Kasliwal (Caltech), GROWTH collaboration



Credit: LSC et al, 2017, ApJL

Counterpart!

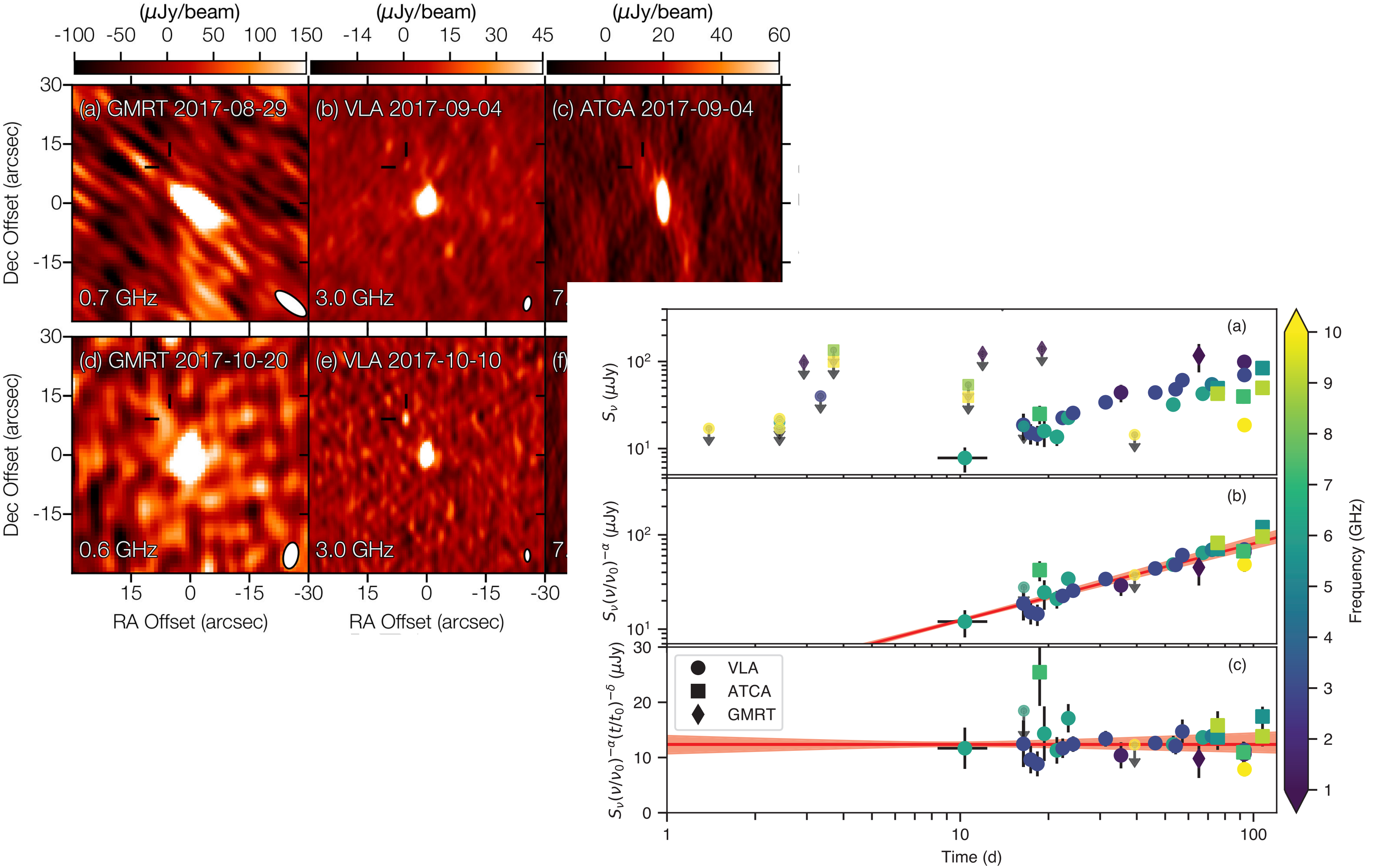


GROWTH collaboration

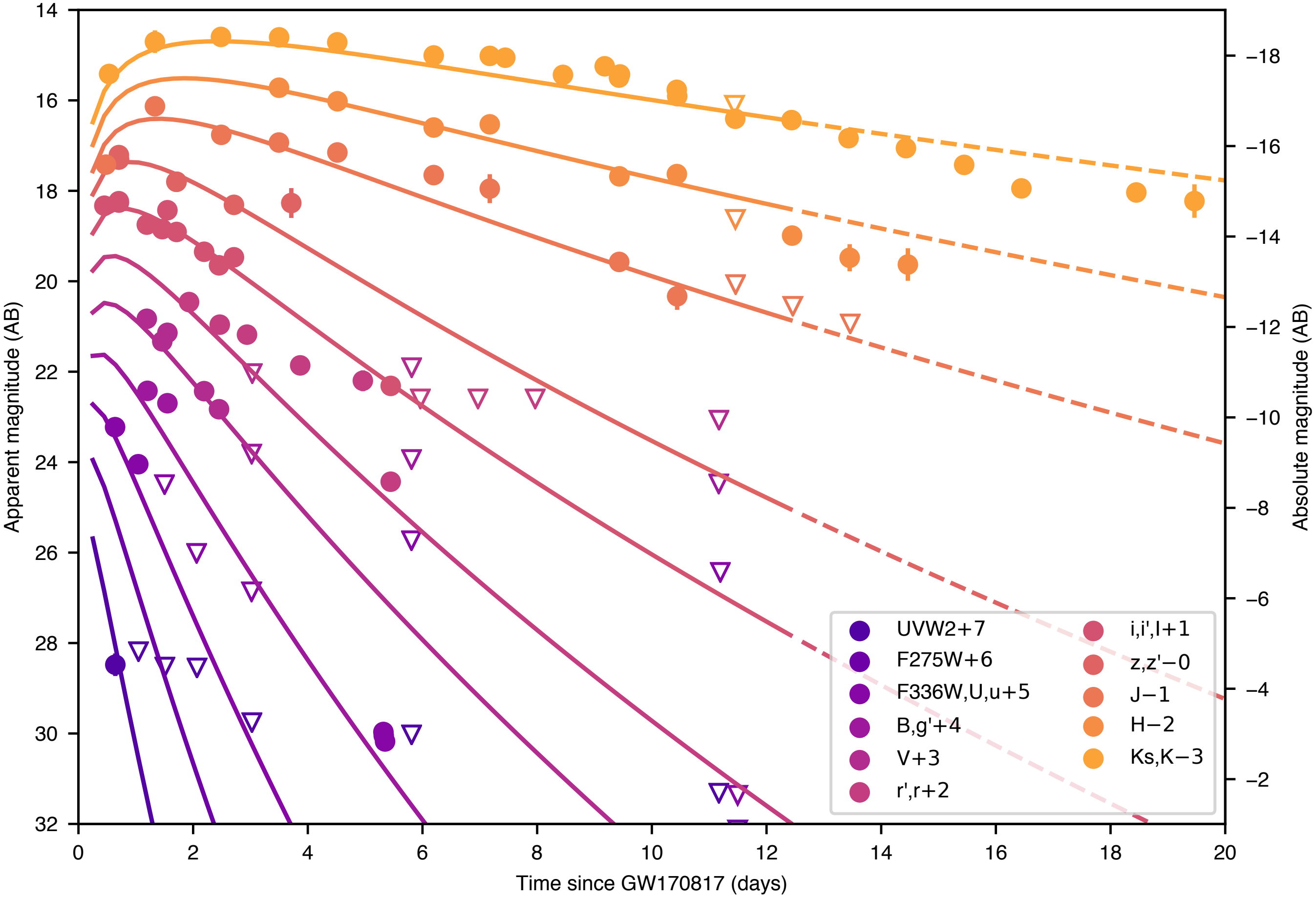
Kasliwal et al. 2017, Science

Credit: R. Hurt

GW170817: GMRT



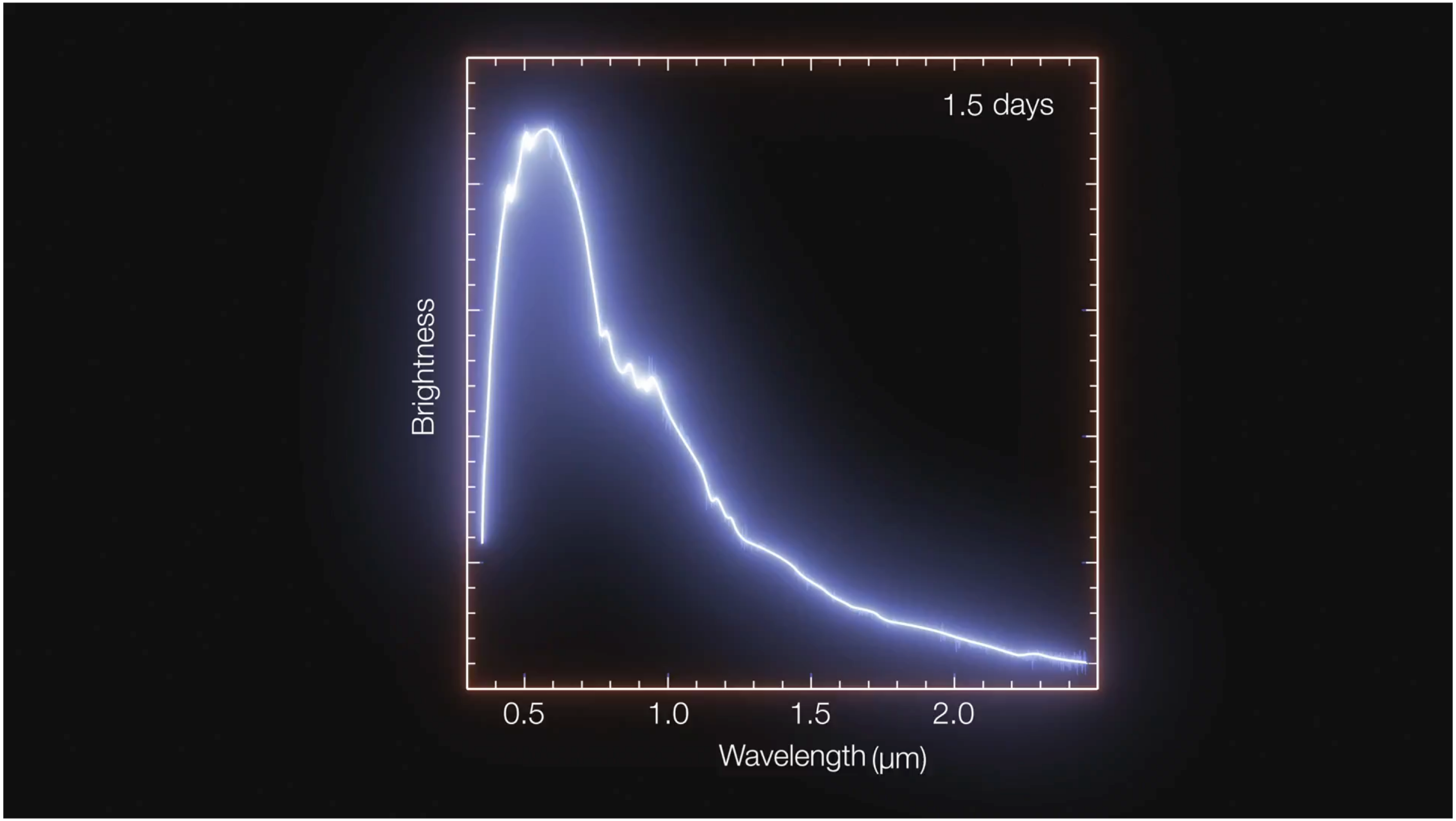
UVOIR Lightcurve



See also:
Andreoni et al. 2017
Arcavi et al. 2017
Cowperthwaite et a. 2017
Coulter et al. 2017
Drout et al. 2017
Lipunov et al. 2017
Lyman et al. 2017
Pian et al. 2017
Soares-Santos et al. 2017
Smartt et al. 2017
Tanvir et al. 2017
Utsumi et al. 2017
Villar et al. 2017

Evans et al. 2017, Kasliwal et al. 2017c

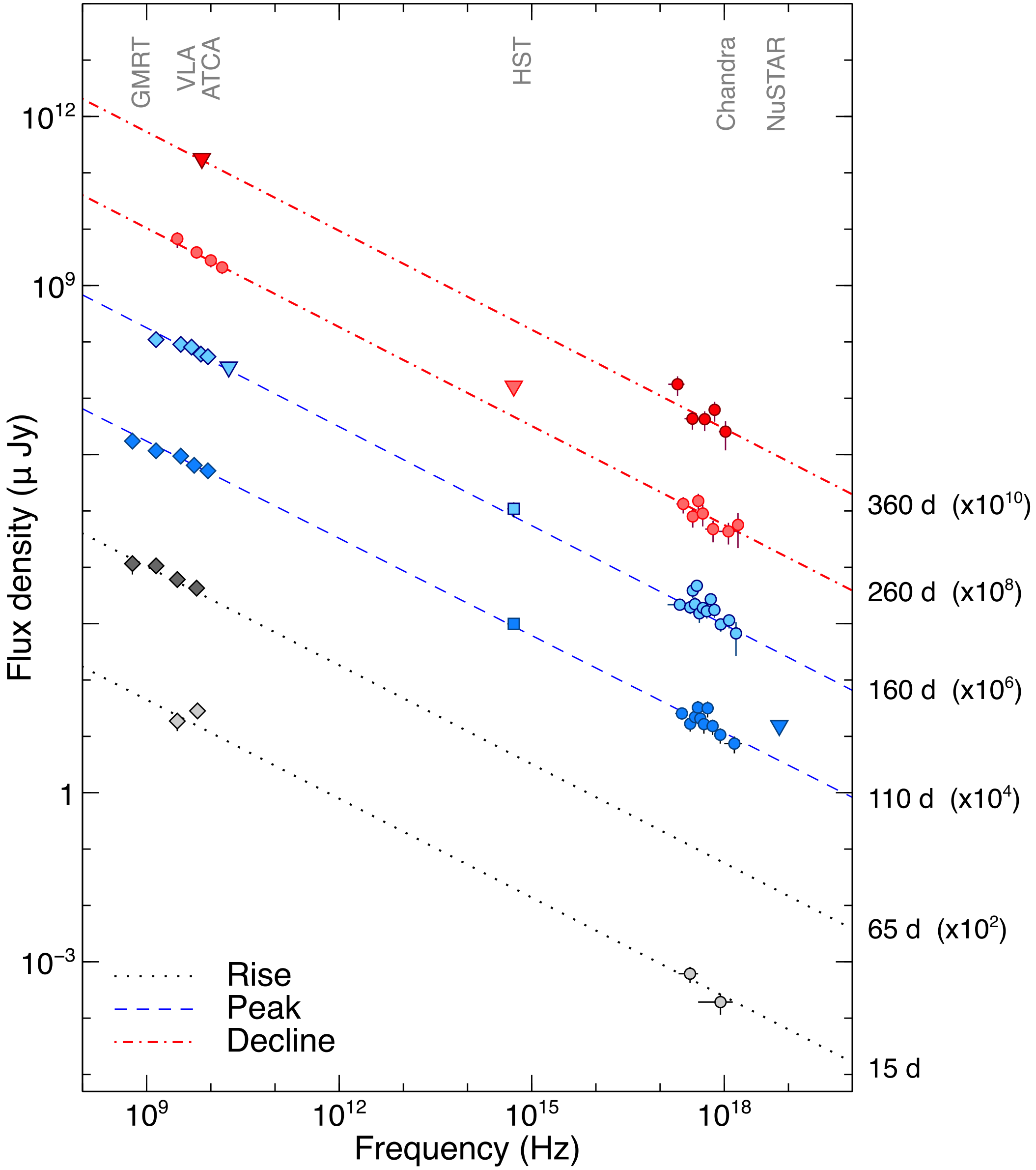
Hot source, cool source



Credit: ESO/E. Pian et al./S. Smartt & ePESSTO/L. Calçada

The afterglow spectrum

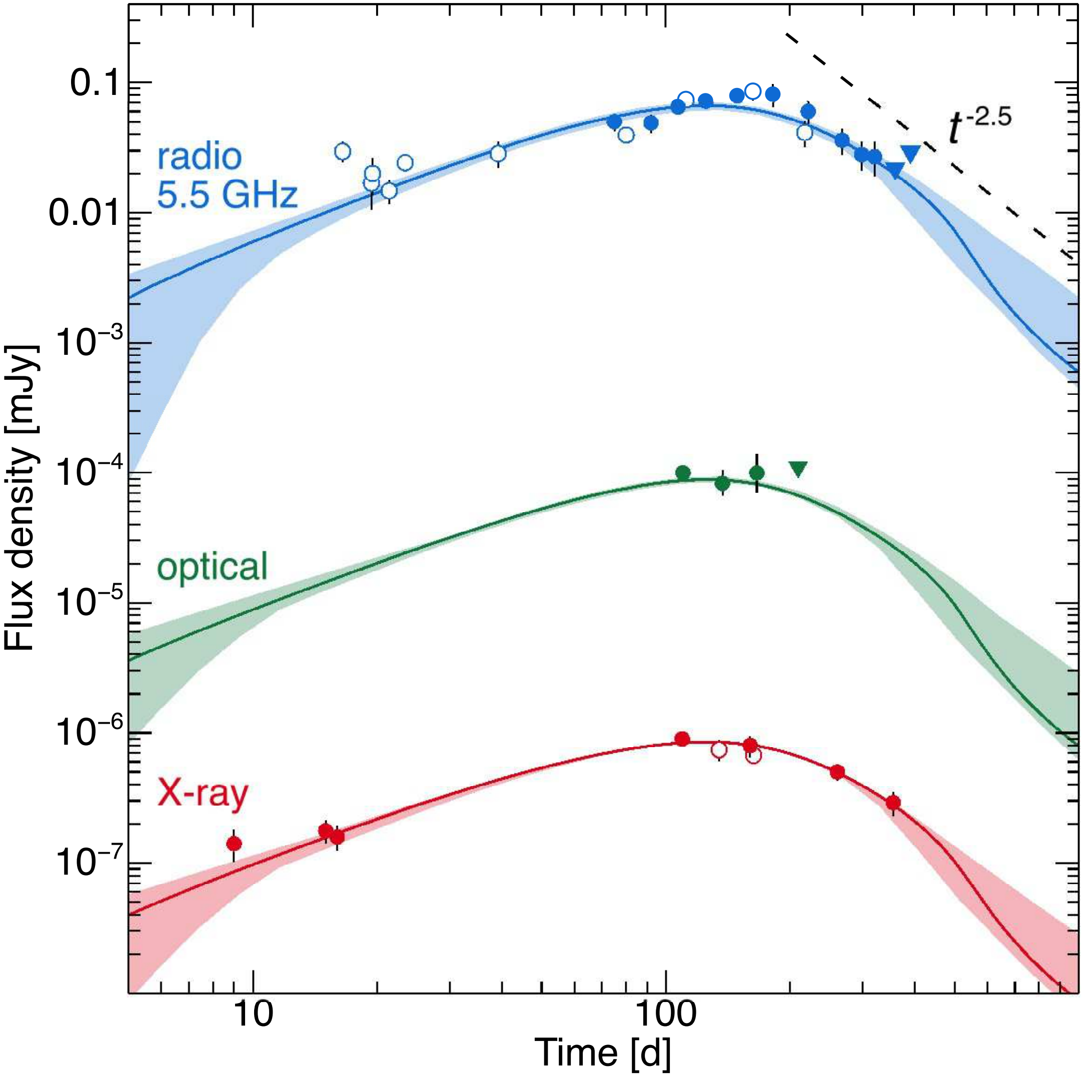
- Consistent with a constant slope, $\beta=0.585\pm0.005$
- No intrinsic absorption (only MW)
- Consistent with synchrotron (p=2.17)
- ν_c > 1 keV (90% cl) at 260 d, ν_c > 0.1 keV at 360 d.
- Troja et al., 2019 (arXiv:1808.06617)



Lightcurve evolution

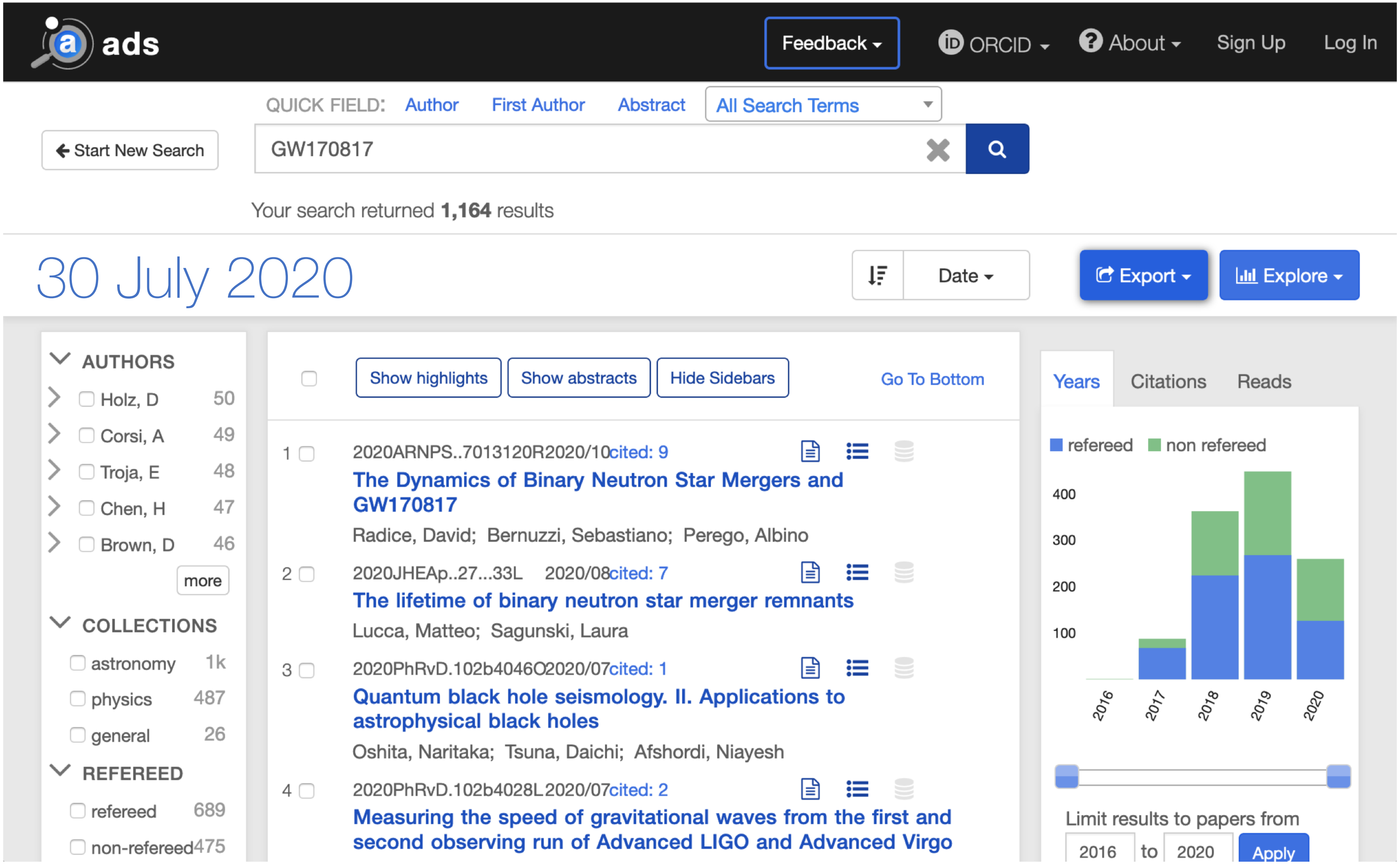
- Slow rise, now rapid decline
- Consistent with a Gaussian jet viewed off-axis
- Far off-axis viewers may see more absorption

Troja et al., 2019 (arXiv:1808.06617)



So, what did we learn?

1078 days, 1164 papers…



30 July 2020

GW170817

Your search returned **1,164** results

AUTHORS

Holz, D	50
Corsi, A	49
Troja, E	48
Chen, H	47
Brown, D	46

more

COLLECTIONS

astronomy	1k
physics	487
general	26

REFEREED

refereed	689
non-refereed	475

1 2020ARNPS..7013120R2020/10cited: 9

The Dynamics of Binary Neutron Star Mergers and GW170817

Radice, David; Bernuzzi, Sebastiano; Perego, Albino

2 2020JHEAp..27...33L 2020/08cited: 7

The lifetime of binary neutron star merger remnants

Lucca, Matteo; Sagunski, Laura

3 2020PhRvD.102b4046O2020/07cited: 1

Quantum black hole seismology. II. Applications to astrophysical black holes

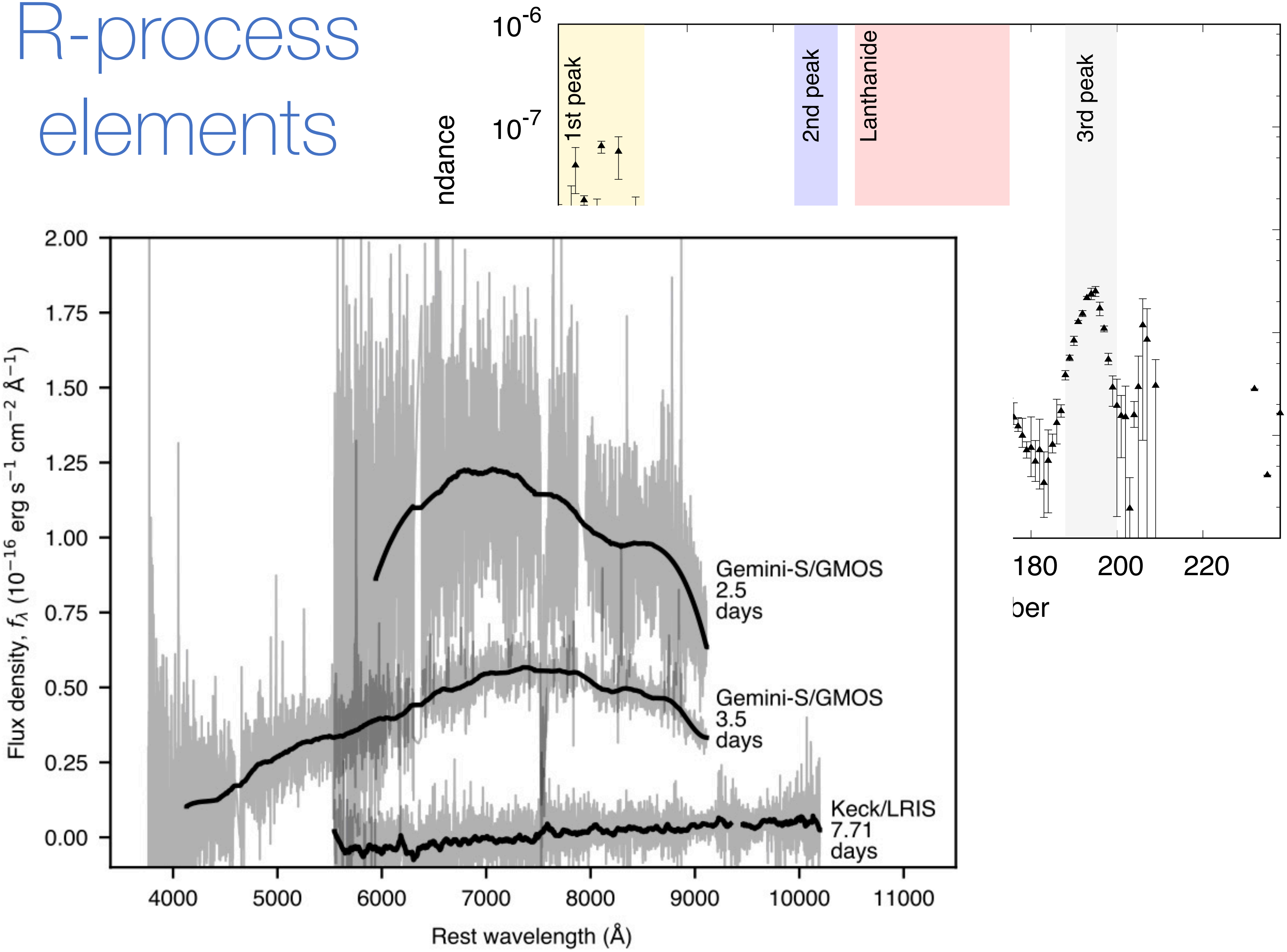
Oshita, Naritaka; Tsuna, Daichi; Afshordi, Niayesh

4 2020PhRvD.102b4028L2020/07cited: 2

Measuring the speed of gravitational waves from the first and second observing run of Advanced LIGO and Advanced Virgo

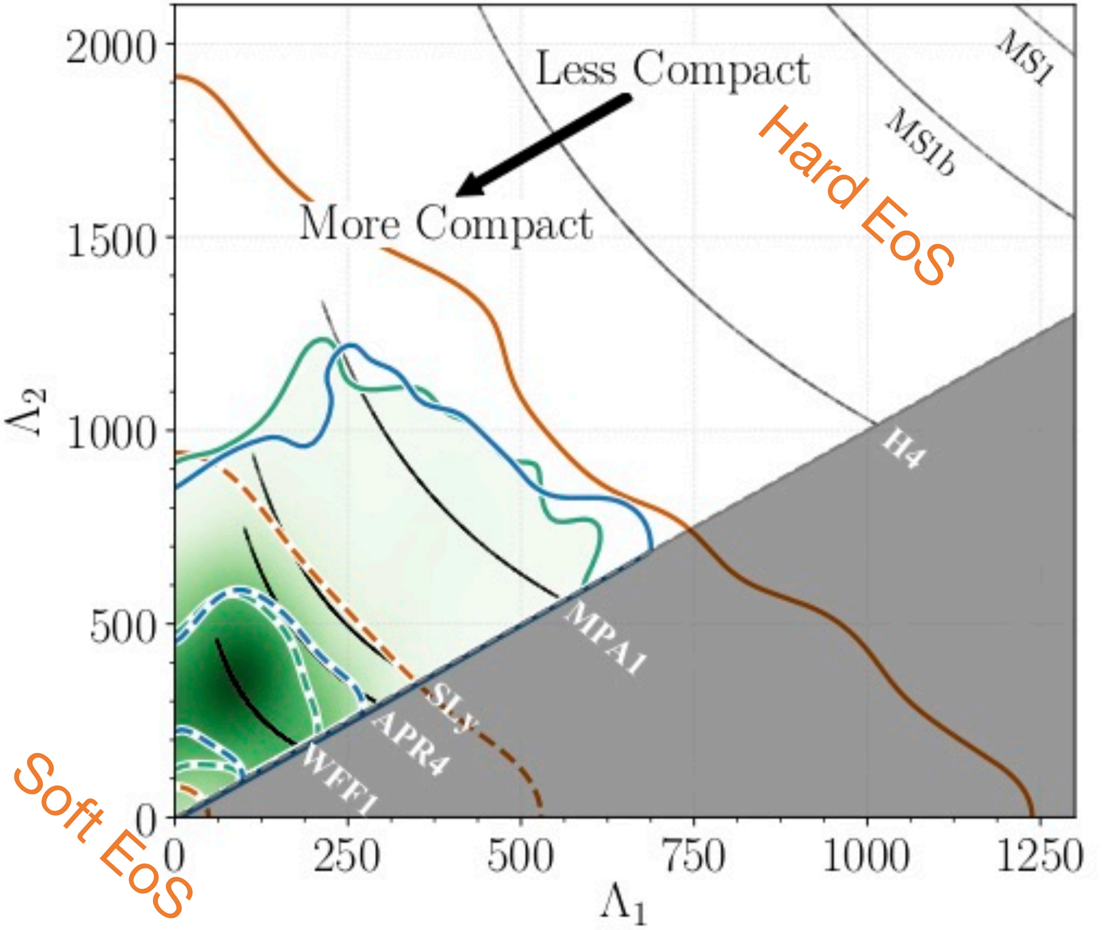
Limit results to papers from 2016 to 2020

R-process elements



Equation of state

- Increase the pre
    - » Density change
    - » Density hardly c
- What was know
    - » Heavy neutron s
- What's new:
    - » EoS is not too hard!

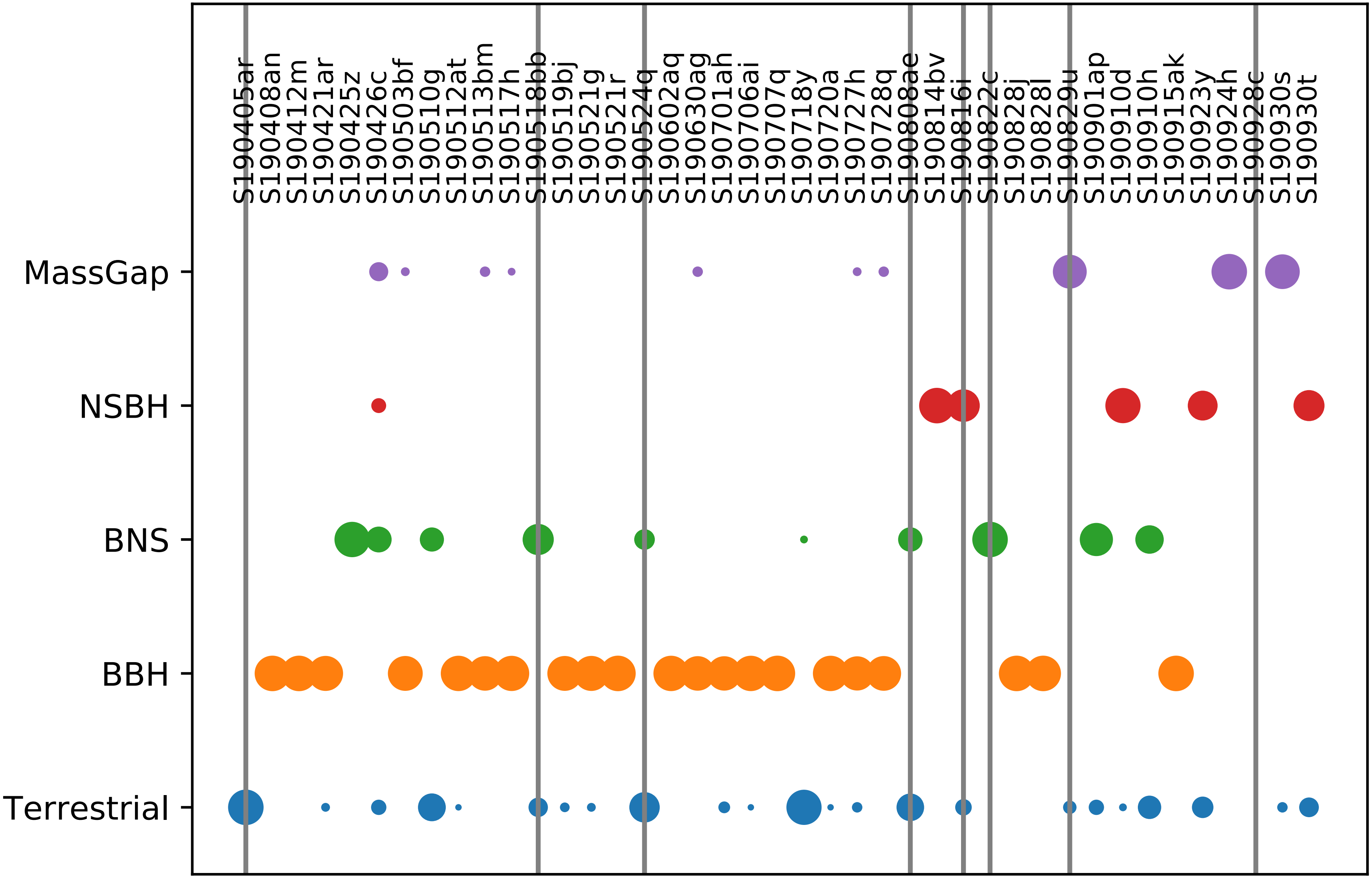


Hard EoS

Soft EoS

ArXiv:1805.11581

O3 candidates



https://gracedb.ligo.org/superevents/public/O3/

O3 NS candidates

Name	Type	Distance (Mpc)	90% area (sq deg)	Counterpart
S190425z	99% BNS	156 ± 41	7461	No
S190426c	49% BNS, 13% NSBH, 24% Gap, 14% Terrestrial	377 ± 100	1131	No
S190510g	42% BNS, 58% Terrestrial	227 ± 92	1166	No
S190718y	2% BNS, 98% Terrestrial	227 ± 165	7246	No
S190814bv	100% NSBH	267 ± 52	23	No
GW170817	100% BNS	41	31	Yes

GW170817-like scaling

Name	Type	Distance (Mpc)	90% area (sq deg)	Optical	IR (Ks)	X-ray (10 keV-1000 keV)
S190425z	99% BNS	156 ± 41	7461	20	21	5e-8
S190426c	49% BNS	377 ± 100	1131	22	23	9e-9
S190510g	42% BNS	227 ± 92	1166	21	22	2e-8
S190718y	2% BNS, 98% Terrestrial	227 ± 165	7246	21	22	2e-8
S190814bv	100% NSBH	267 ± 52	23	21	22	2e-8
Fake event	100% BNS	500	–	22	23	5e-9
GW170817	100% BNS	41	31	17	18	7e-7

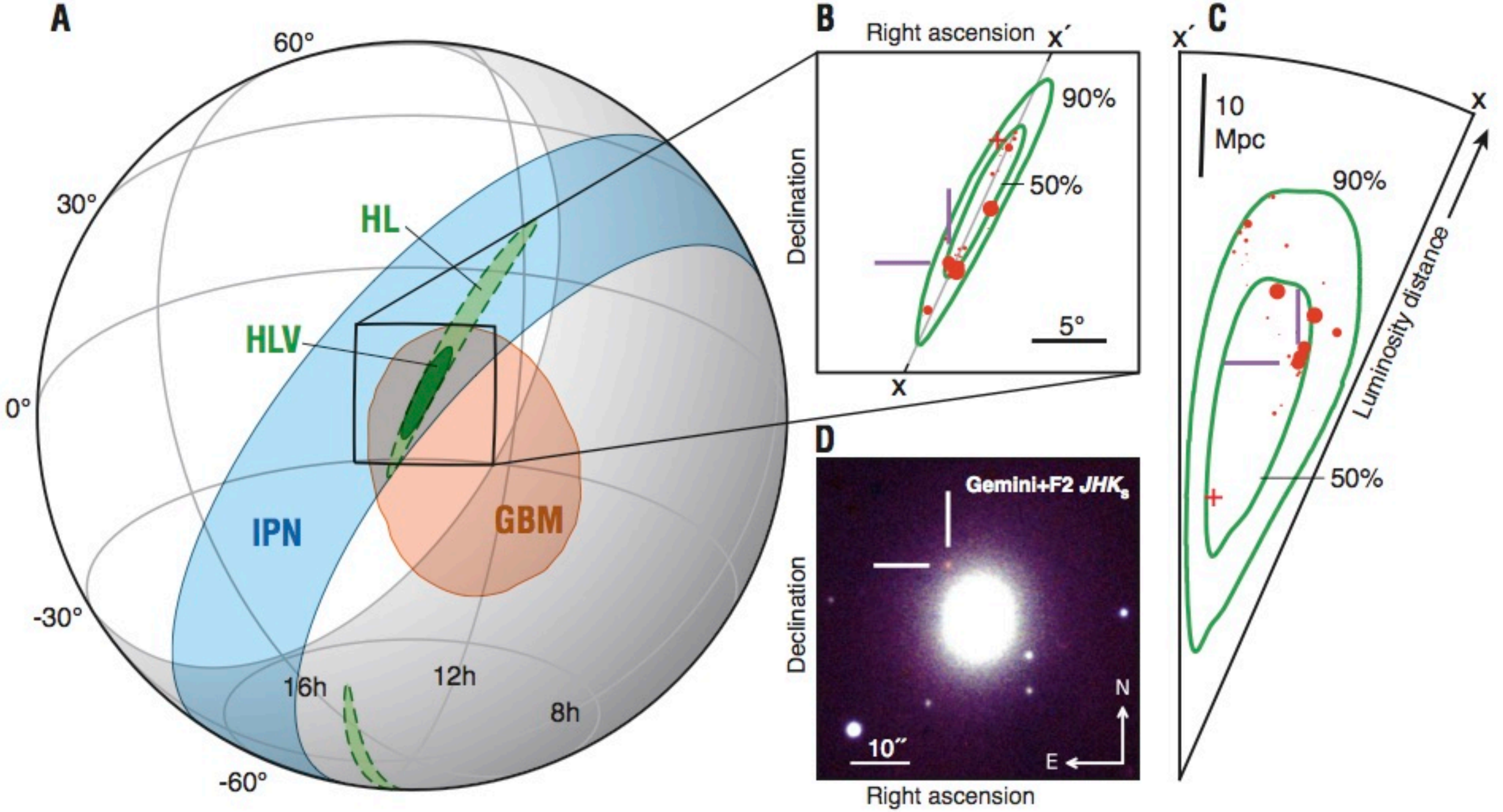
Scaling from Kasliwal et al. (2017) and Abott et al 2017 (Fermi + Integral +LVC)

Typical optical surveys reach ~21 mag (ZTF, PanSTARRs), ~23 DECam
IR ~ 17.5 (Gattini), X-ray / Gamma ray ~ few e-7

What’s next?

Lessons from GW170817 + O3

GW170817: AstroSat



Lesson 1

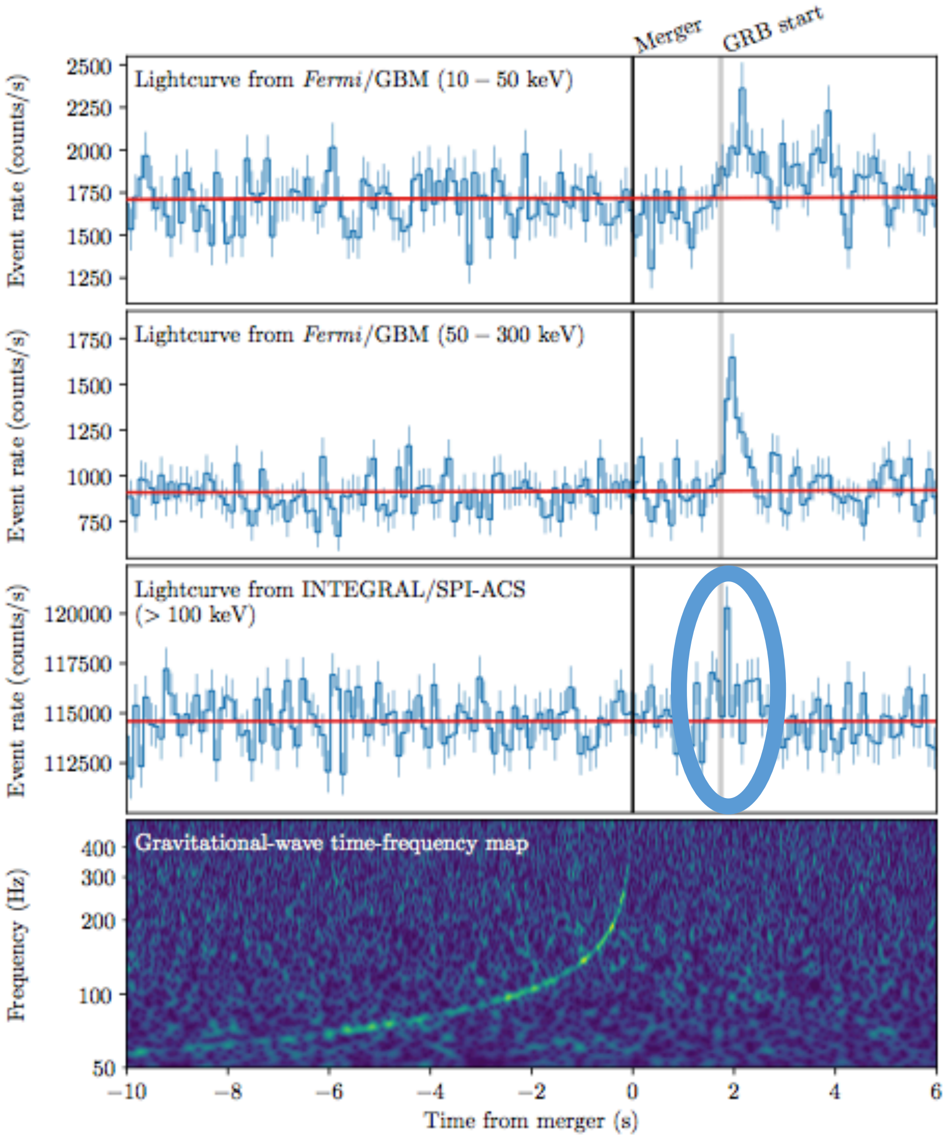
Look at the entire sky at all times

GW170817

Signal is very faint

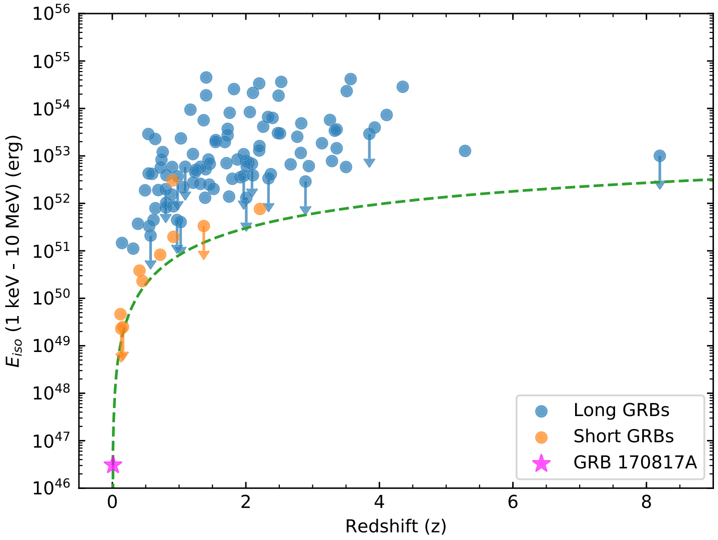
30% fainter, and it would have been missed…

(LSC et al 2017, discovery paper)

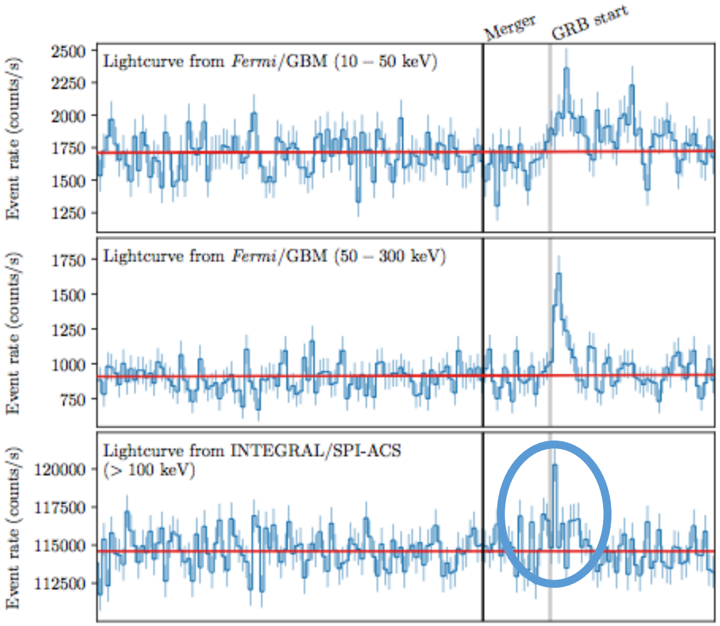


New class of bursts !

- GRB was very faint: 3-4 orders of magnitude lower than SGRBs
  next will be fainter!



- Broadband: seen from few keV to hundreds of keV
- Missed by Swift, AstroSat, CALET…



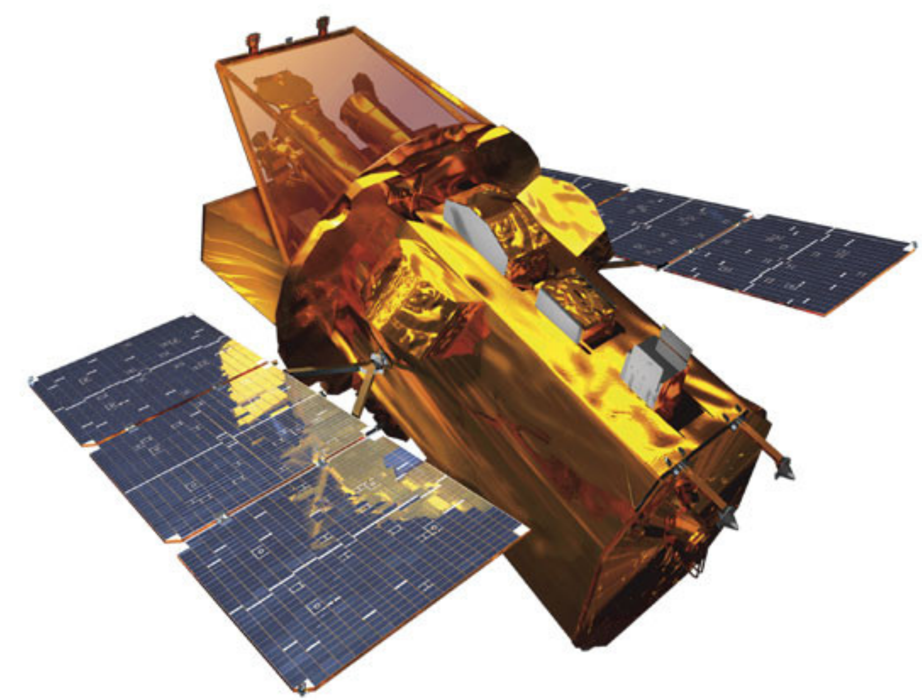
Lesson 2

Need 10x higher sensitivity
as compared to current missions

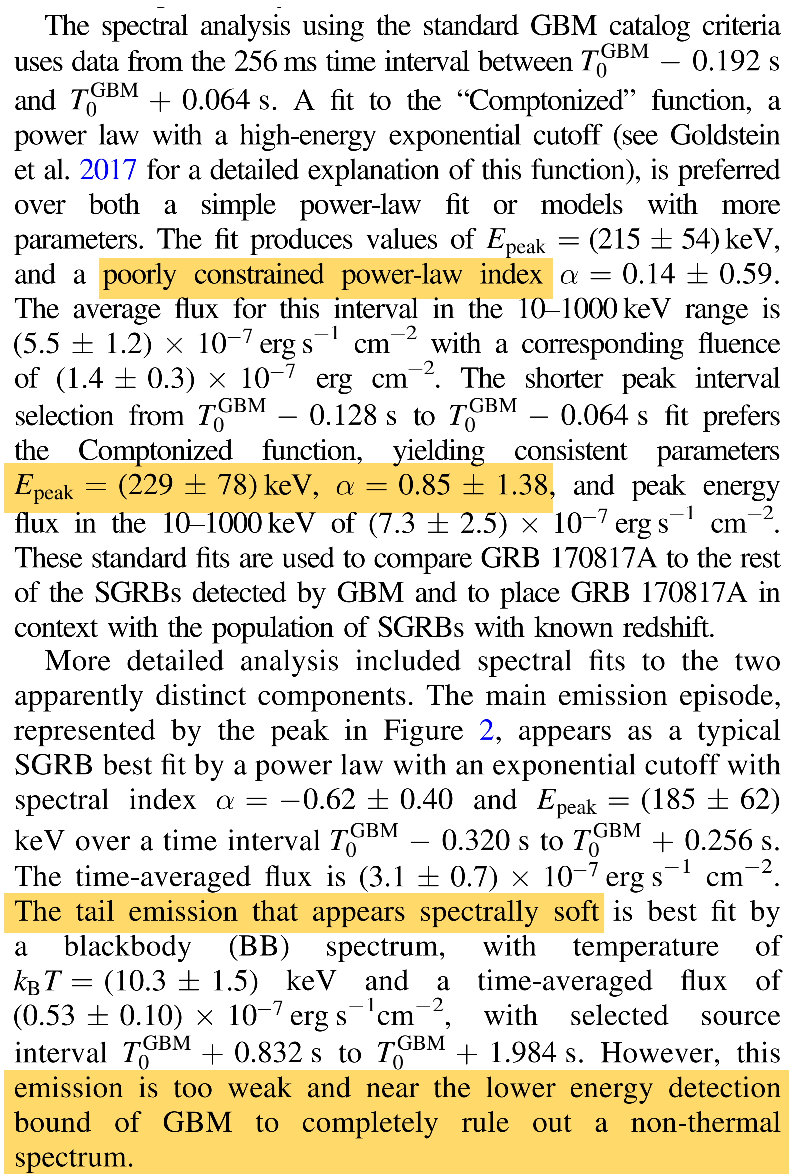
Current missions

Fermi: NASA + Europe

Neil Gehrels Swift Observatory
NASA



Saw it. So what?



The spectral analysis using the standard GBM catalog criteria uses data from the 256 ms time interval between $T_0^{\mathrm{GBM}} - 0.192$ s and $T_0^{\mathrm{GBM}} + 0.064$ s. A fit to the "Comptonized" function, a power law with a high-energy exponential cutoff (see Goldstein et al. 2017 for a detailed explanation of this function), is preferred over both a simple power-law fit or models with more parameters. The fit produces values of $E_{\mathrm{peak}} = (215 \pm 54)$ keV, and a poorly constrained power-law index $\alpha = 0.14 \pm 0.59$. The average flux for this interval in the 10–1000 keV range is $(5.5 \pm 1.2) \times 10^{-7}$ erg s^{-1} cm^{-2} with a corresponding fluence of $(1.4 \pm 0.3) \times 10^{-7}$ erg cm^{-2}. The shorter peak interval selection from $T_0^{\mathrm{GBM}} - 0.128$ s to $T_0^{\mathrm{GBM}} - 0.064$ s fit prefers the Comptonized function, yielding consistent parameters $E_{\mathrm{peak}} = (229 \pm 78)$ keV, $\alpha = 0.85 \pm 1.38$, and peak energy flux in the 10–1000 keV of $(7.3 \pm 2.5) \times 10^{-7}$ erg s^{-1} cm^{-2}. These standard fits are used to compare GRB 170817A to the rest of the SGRBs detected by GBM and to place GRB 170817A in context with the population of SGRBs with known redshift.

More detailed analysis included spectral fits to the two apparently distinct components. The main emission episode, represented by the peak in Figure 2, appears as a typical SGRB best fit by a power law with an exponential cutoff with spectral index $\alpha = -0.62 \pm 0.40$ and $E_{\mathrm{peak}} = (185 \pm 62)$ keV over a time interval $T_0^{\mathrm{GBM}} - 0.320$ s to $T_0^{\mathrm{GBM}} + 0.256$ s. The time-averaged flux is $(3.1 \pm 0.7) \times 10^{-7}$ erg s^{-1} cm^{-2}. The tail emission that appears spectrally soft is best fit by a blackbody (BB) spectrum, with temperature of $k_B T = (10.3 \pm 1.5)$ keV and a time-averaged flux of $(0.53 \pm 0.10) \times 10^{-7}$ erg $\mathrm{s}^{-1}\mathrm{cm}^{-2}$, with selected source interval $T_0^{\mathrm{GBM}} + 0.832$ s to $T_0^{\mathrm{GBM}} + 1.984$ s. However, this emission is too weak and near the lower energy detection bound of GBM to completely rule out a non-thermal spectrum.

(LSC et al 2017, discovery paper)

Poorly constrained power law index

$E_{\mathrm{peak}} = 229 \pm 78$ keV, $\alpha = 0.85 \pm 1.38$

…tail emission *appears* spectrally soft…

However, this emission is too weak and near the lower energy detection bound of GBM to completely rule out a non-thermal spectrum.

Lesson 3

Wide spectral band

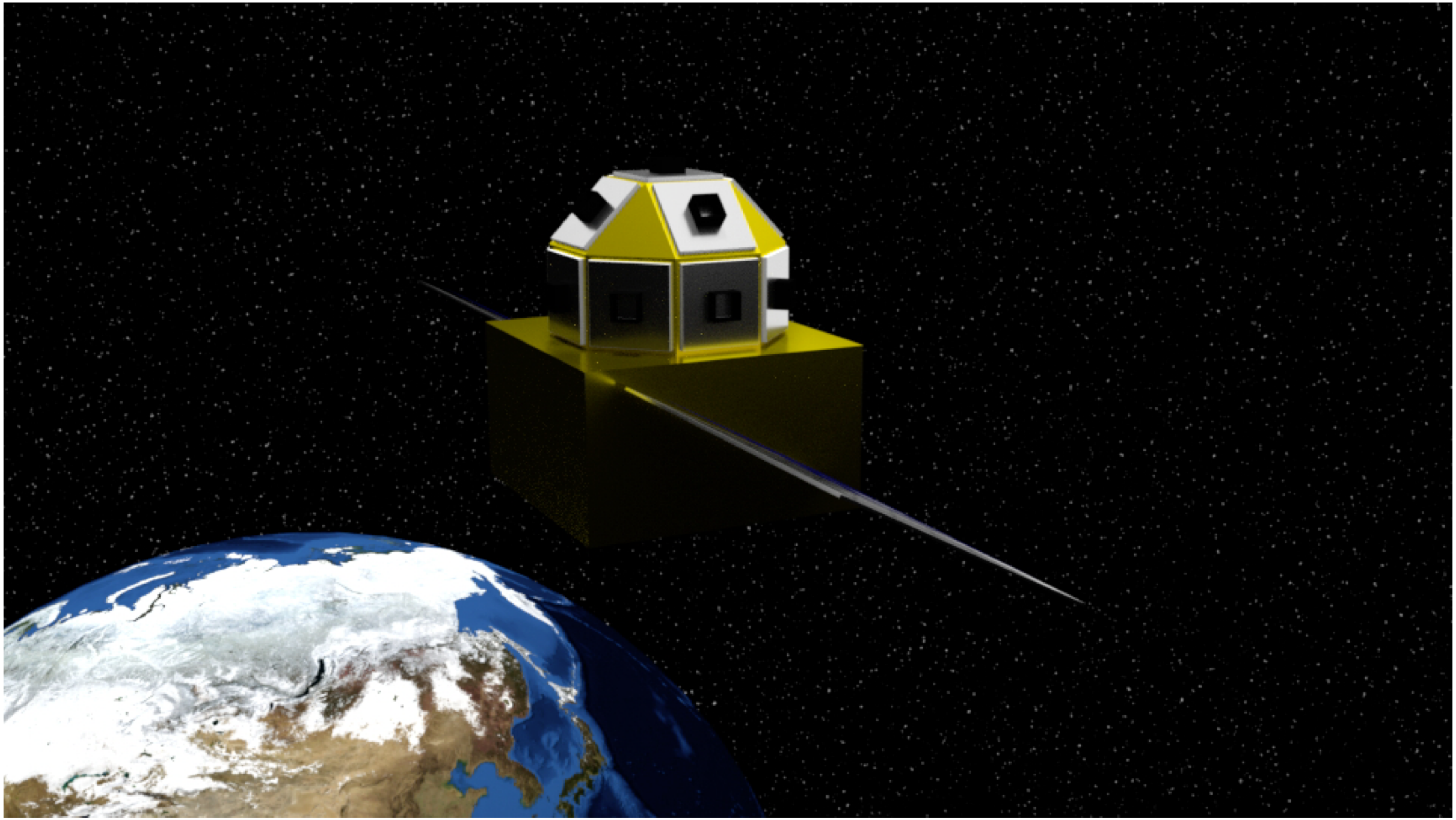
Requirements

Order of magnitude higher sensitivity
(Large area, lower noise, background rejection)

Wide spectral band
(1 keV to >1 MeV)

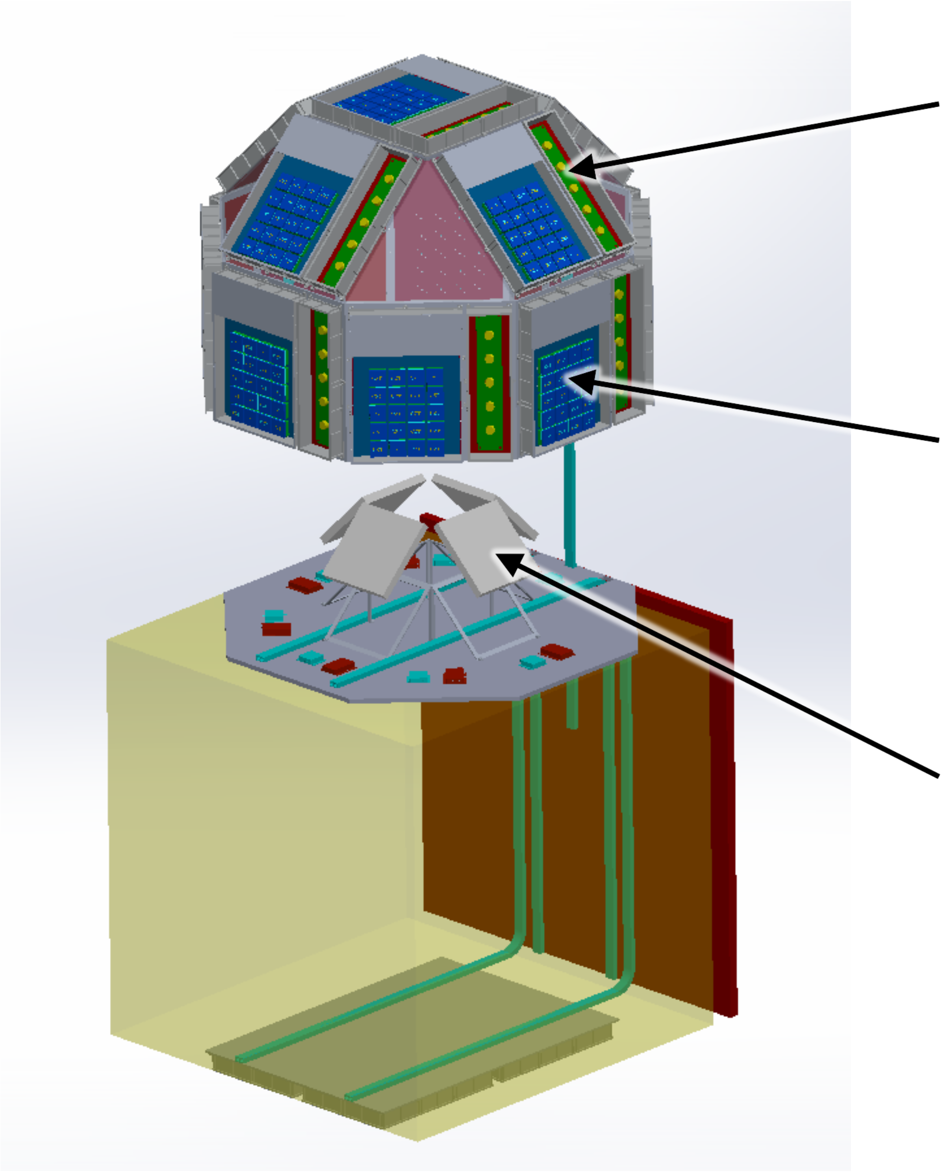
Continuous all-sky coverage
(Two satellites)

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

Advantage Daksha

- Effective area (2 satellites): 1700 cm^2
  - Fermi: ~100 cm^2 individual, ~300 cm^2 total
- Sky coverage:
  - 71% individual, ~100% two satellites
  - BAT: ~11%
- Energy range: 1 keV to > 1 MeV
  - BAT 15 – 150 keV, Fermi GBM > 8 keV

Daksha results – 1

- Detect dozens of BNS mergers per year
  - Also ~1000 on-axis GRBs per year
- Localisation:
  - ~10 degrees on board
  - ~5 degrees ground processing
- Broadband prompt spectra
  - Only mission to give prompt soft spectra
- Hard X-ray polarimetry

Daksha results – 2

- Provide time and direction of burst
  - » Lower FAR for GW searches
  - » Lower detection statistic!

- **Increase LIGO detections by 2x – 3x !**

Huge discovery space

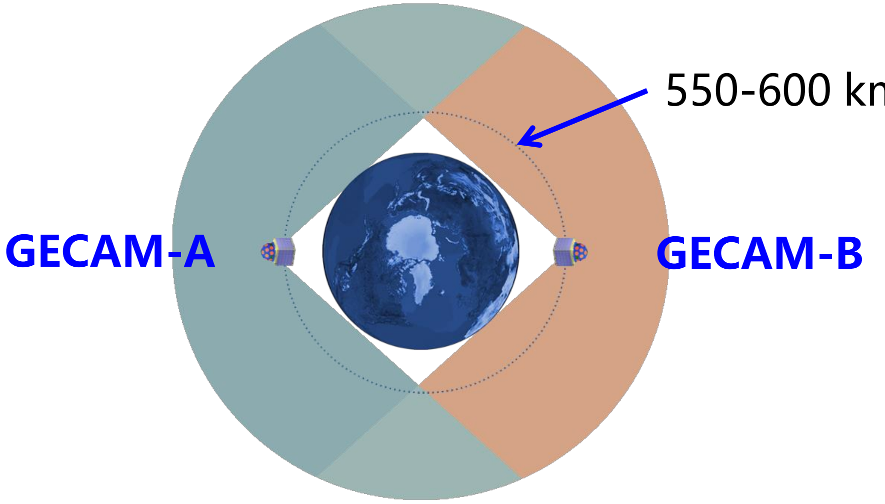
Other Future Missions

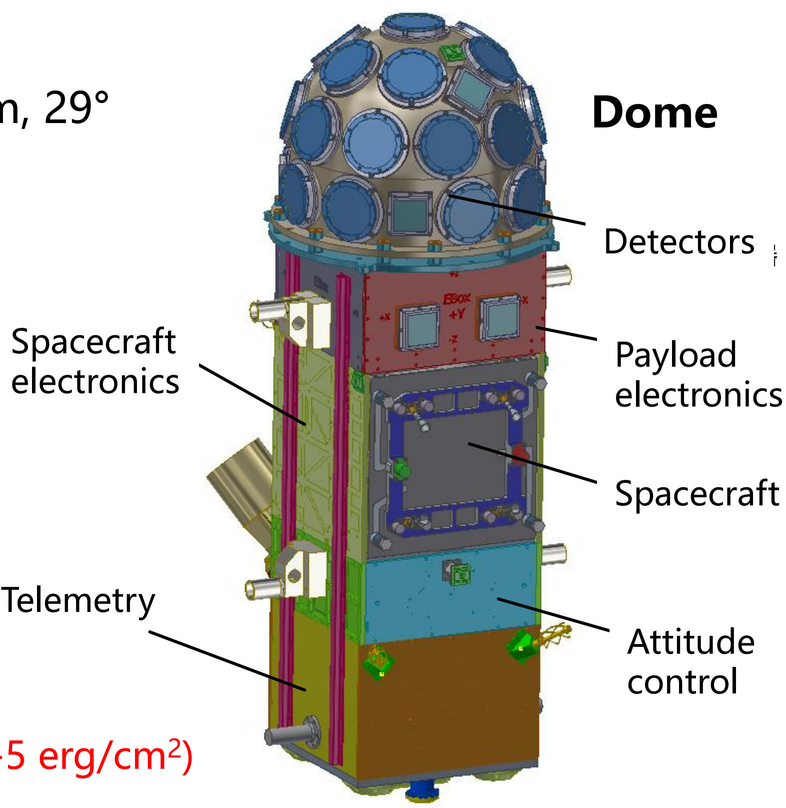
Small satellites and survey missions

- BurstCube (NASA GSFC ++)
  - 1/20 collecting area (52 cm^2)
  - CsI: 10 keV – 1 MeV
  - Launch: 2022/23
- HERMES (Italy)
  - 1/20 collecting area (50 cm^2)
  - CsI / LaBr3: 3 keV – 50 MeV
  - Unfunded
- Few lobster-eye concepts (ISS-TAO, China, Theseus)

GECAM

Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor





GECAM satellite (~140 kg for each)

- **Characteristics**
  - **FOV:** 100% all-sky
  - **Sensitivity:** ~2E-8 erg/cm^2/s
  - **Localization:** ~1 deg (1-σ stat., 1E-5 erg/cm^2)
  - **Energy band:** 6 keV – 5 MeV
- **Planned to launch by the end of 2020**
  - since LIGO will reach the design sensitivity around 2020 to 2021

Slide from Shaolin XIONG, Institute of High Energy Physics (IHEP), Chinese Academy of Sciences (CAS)

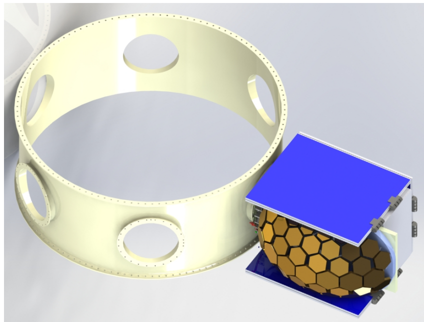
Slide from Eric Grove

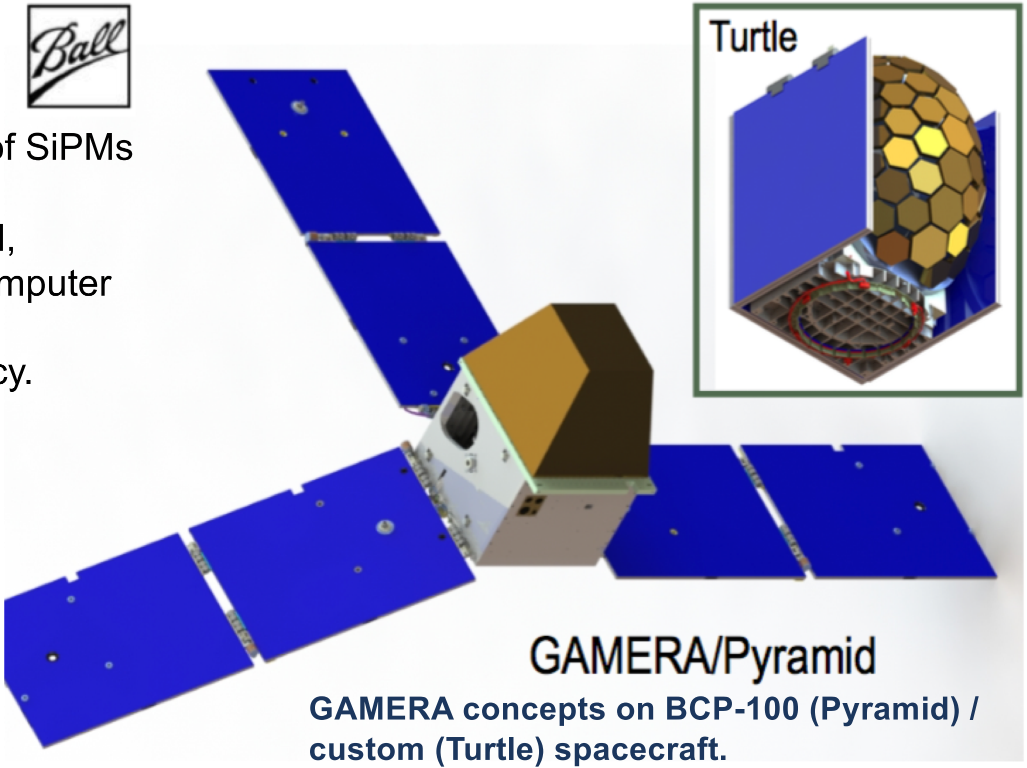
GAMERA Mission Concept – Instrument

GAMERA/Pyramid truncated pyramid CsI array (base 60x50 cm, height 40 cm). Dimensions fill ESPA volume and mass limit and are compatible with a standard SmallSat bus. Total instrument masses are ~70 kg.

GAMERA/Turtle ellipsoidal dome array spanning the longer ~90x60 cm dimensions of the ESPA volume. More efficiently exposes detector area to the sky, but requires a modified spacecraft bus layout.

- Scintillator modules read out with an array of SiPMs digitized by a multichannel analyzer.
- Time-tagged pulse-height data are collected, processed, and stored by a single-board computer that interfaces with the spacecraft bus.
- GPS provides absolute time with μs accuracy.





GAMERA concepts on BCP-100 (Pyramid) / custom (Turtle) spacecraft.

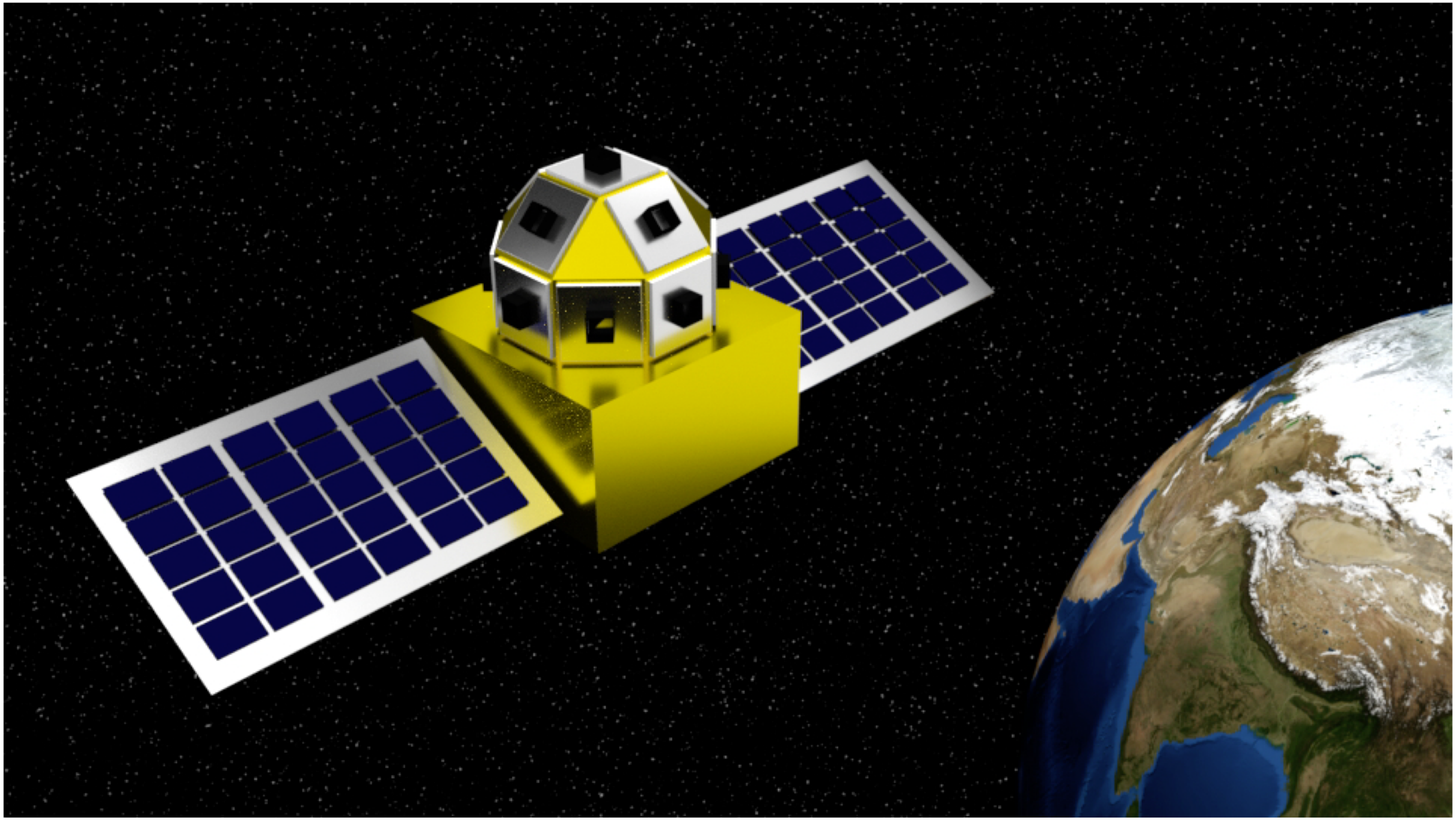
Building Daksha

- Lead institute: IIT Bombay
- Jointly with PRL, TIFR, IUCAA, RRI, ISRO

- Currently active sub-teams:
  - » Science
  - » Detectors and electronics
  - » Design and fabrication

- Current status: *Seed funding has been provided to demonstrate a proof-of-concept!*

Daksha



On alert for high energy transients