Multi-messenger exploration of the transient radio sky

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Texas Tech University

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TEXAS TECH UNIVERSITY

From here, it's possible.

NRAO ALMA AUI NSF New Mexico Tech SCIENCE · ENGINEERING · RESEARCH · UNIVERSITY The University of New Mexico New Mexico CONSORTIUM

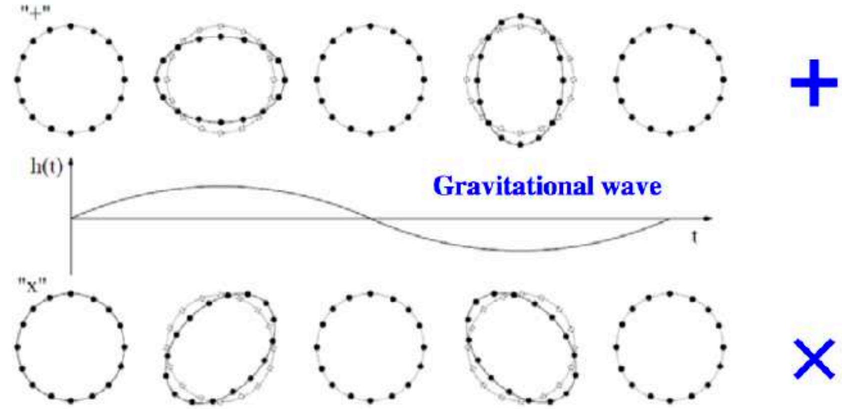
Transient Astronomy

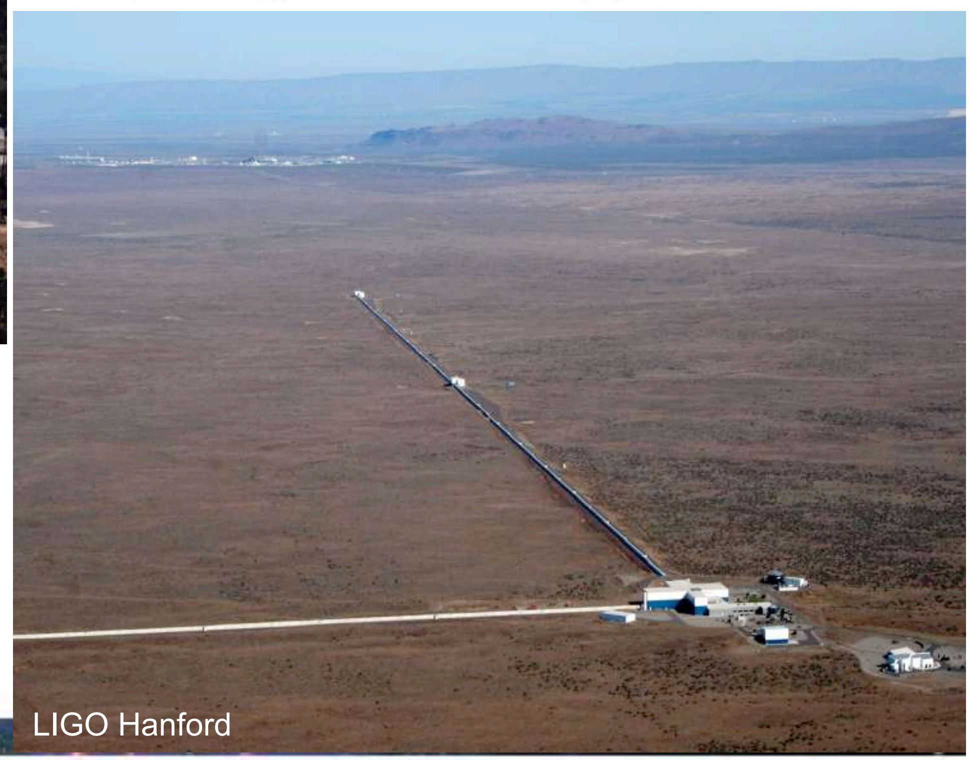
- A **transient** astronomical event is an astronomical object or phenomenon whose **duration may be from seconds to days, weeks or even several years**.

- These timescales are much shorter than the millions or billions of years during which galaxies and their component stars in our universe have evolved.

- I will focus on transient astronomy in connection with **ground-based** GW detectors, and on electromagnetic (EM) counterparts of **"CATASTROPHIC" events marking the birth of NSs or BHs**.

Laser Interferometer GW Observatory (LIGO)





$$h \sim \frac{G}{c^4} \frac{\epsilon E}{d} \sim \frac{\Delta L}{L}$$

~10^{-43} !

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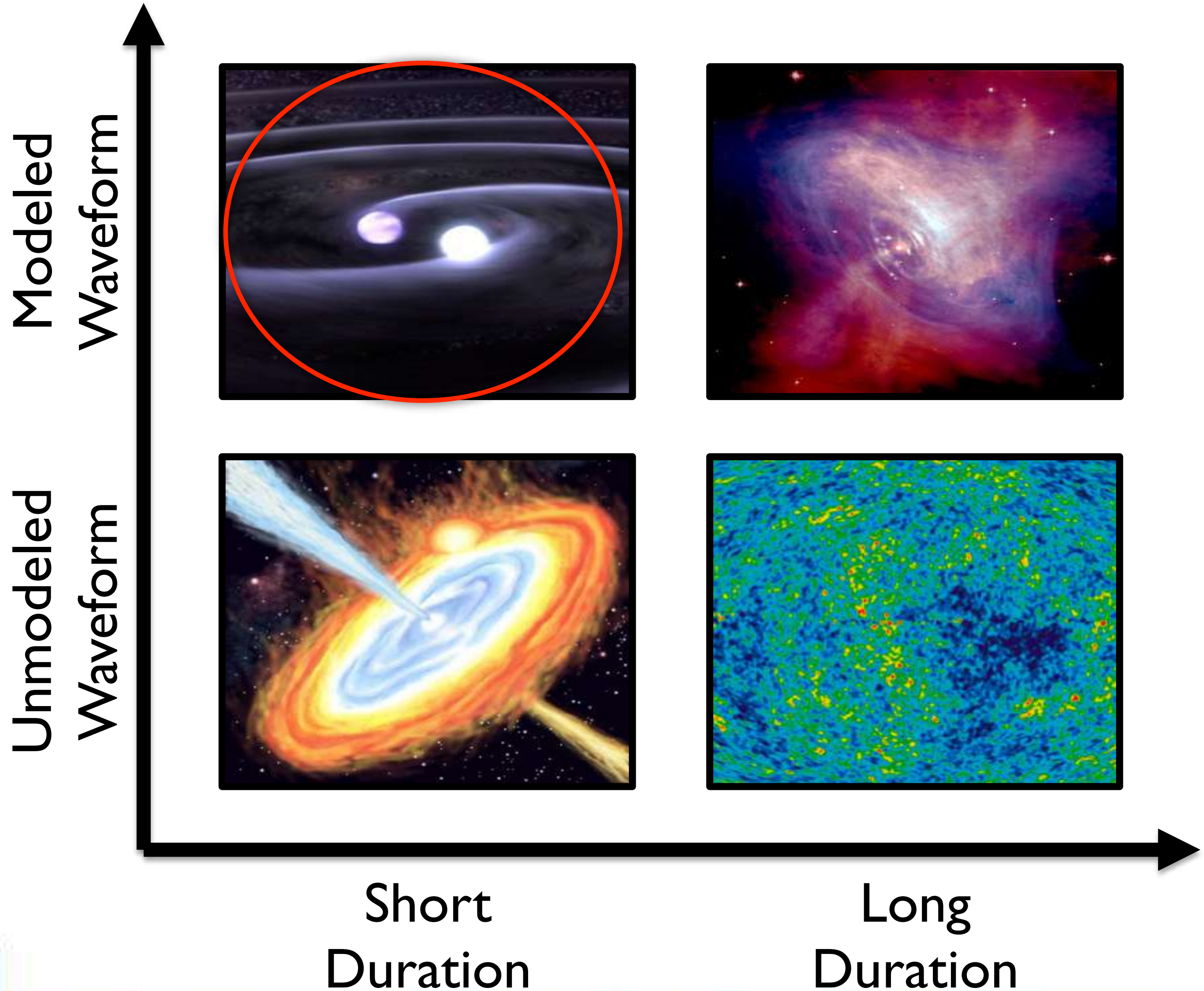
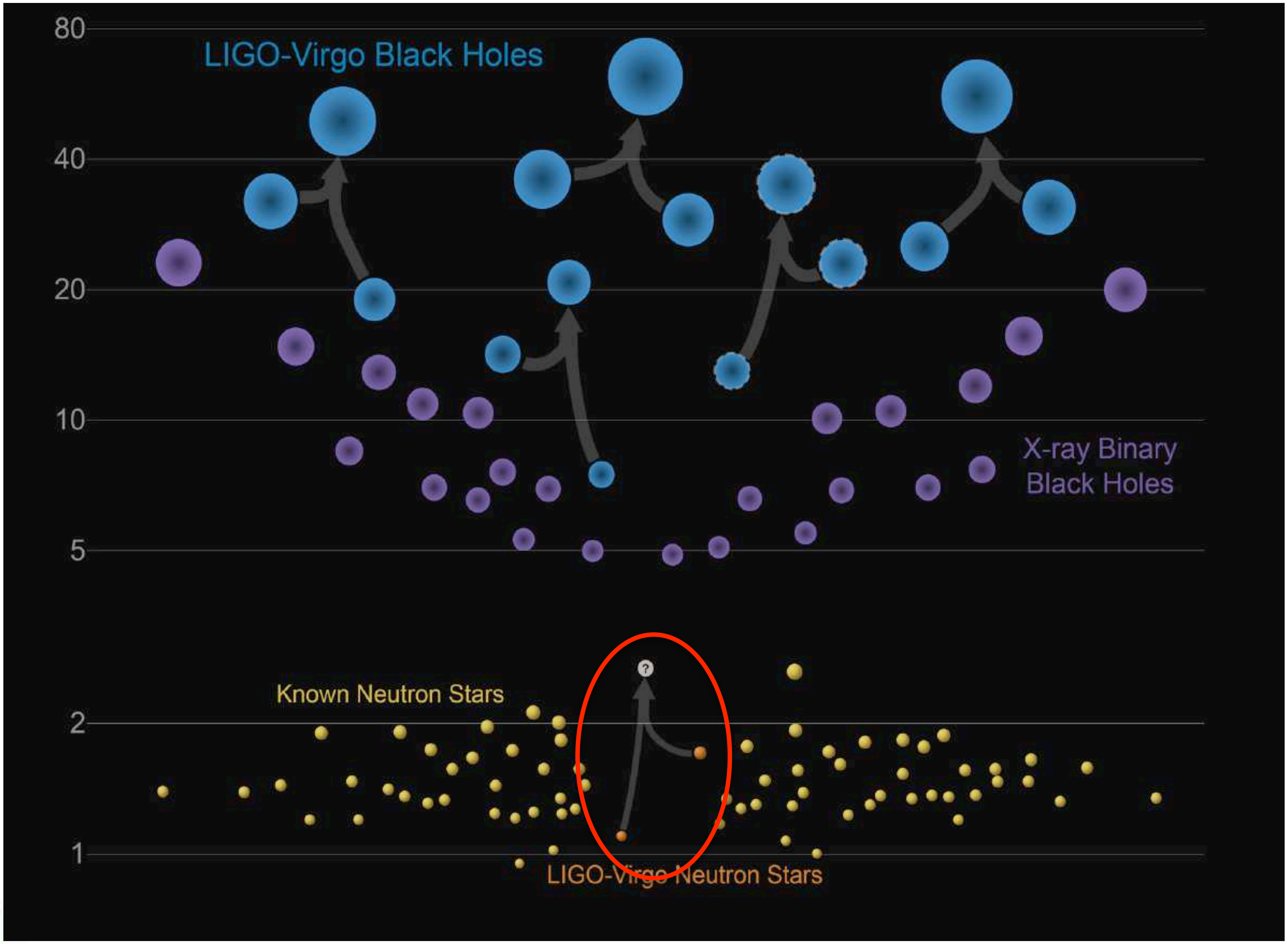
A ZOO of GW sources

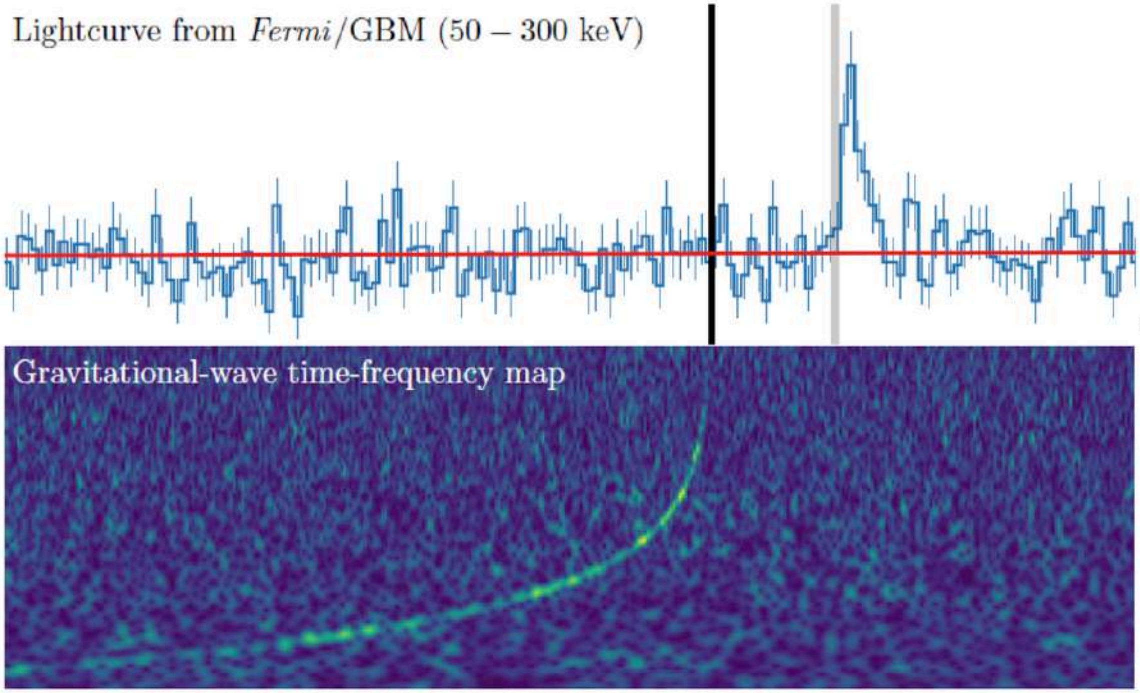


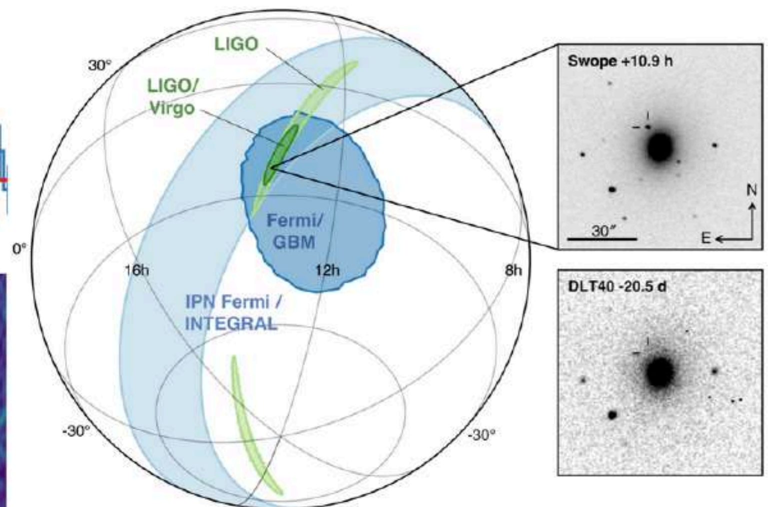
BBHs are nice but NS matter…



Welcome to the era of GW astrophysics!

LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars





GW170817: e.g., Abbott et al. 2017, PRL, 119, 1101; Abbott et al. 2017, ApJ, 848, L12; Abbott et al. 2017, ApJ, 848, 13; Goldstein et al. 2017, ApJL, 848,2; and references therein AND MANY MORE!

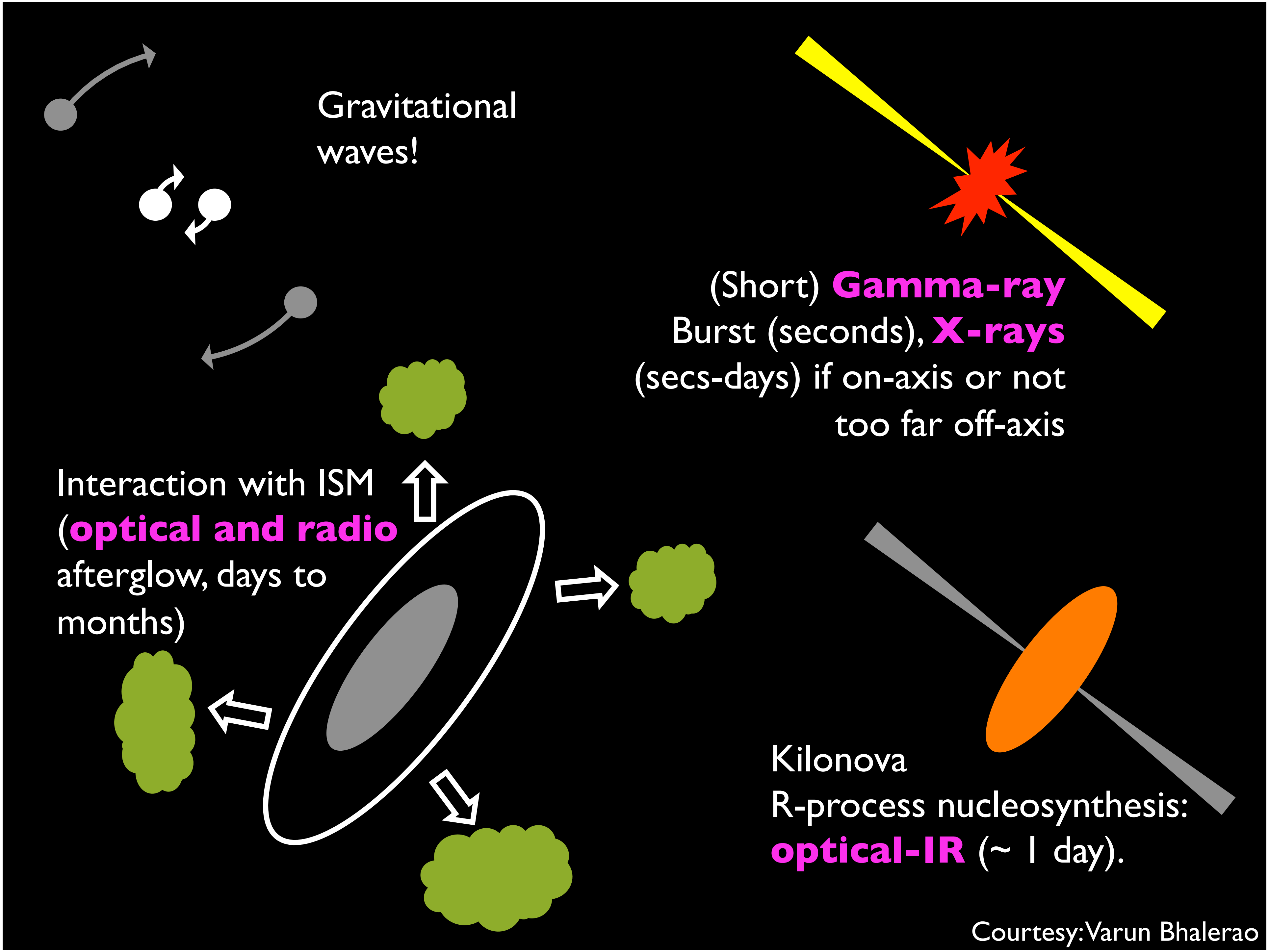
Why multi-messenger astrophysics?

GWs

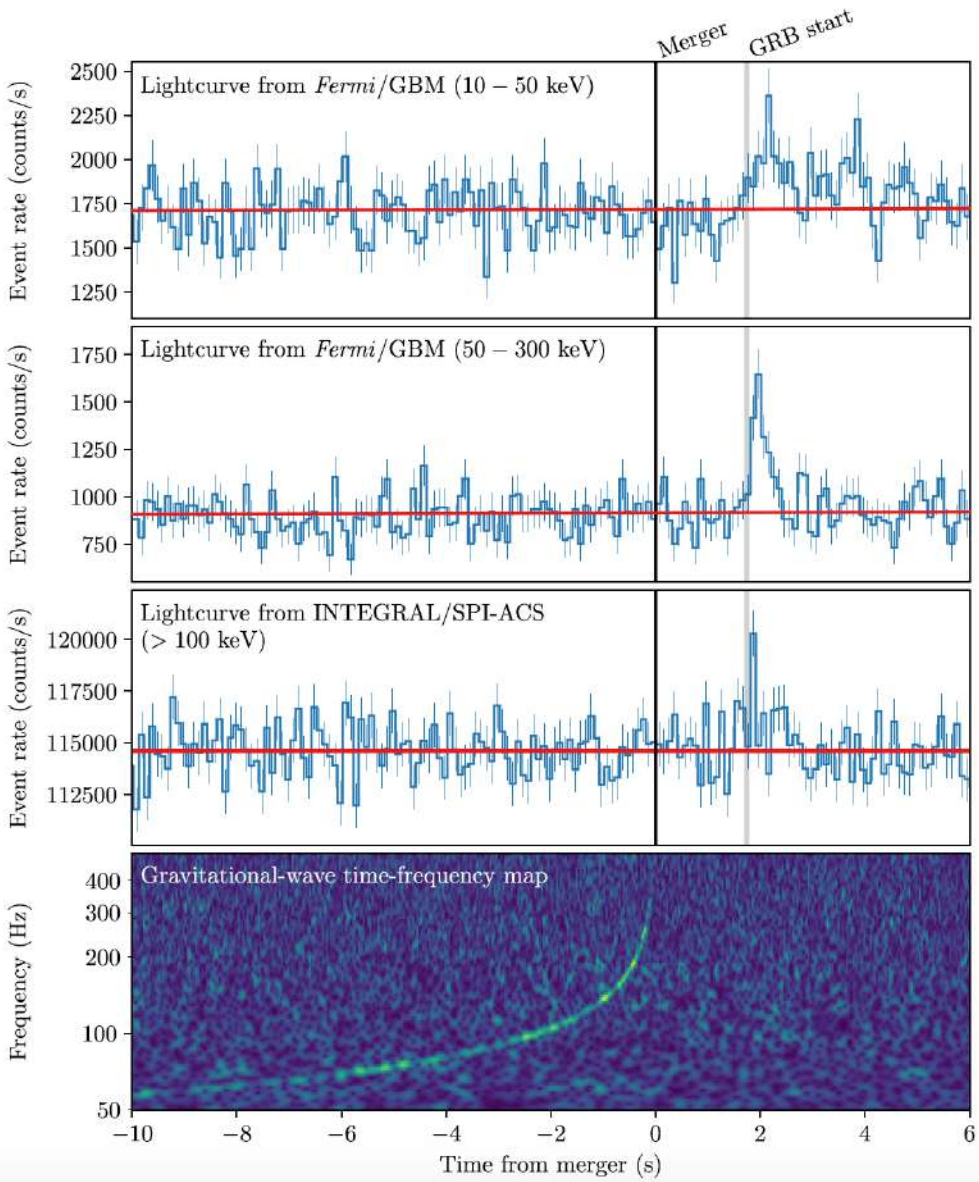
- Directly probe progenitors!
- Masses.
- Spins.
- Rates and implications on progenitor formation scenarios.
- Geometric properties of the progenitor:
  - "Position"
  - Distance
  - Inclination angle
  - …

EM

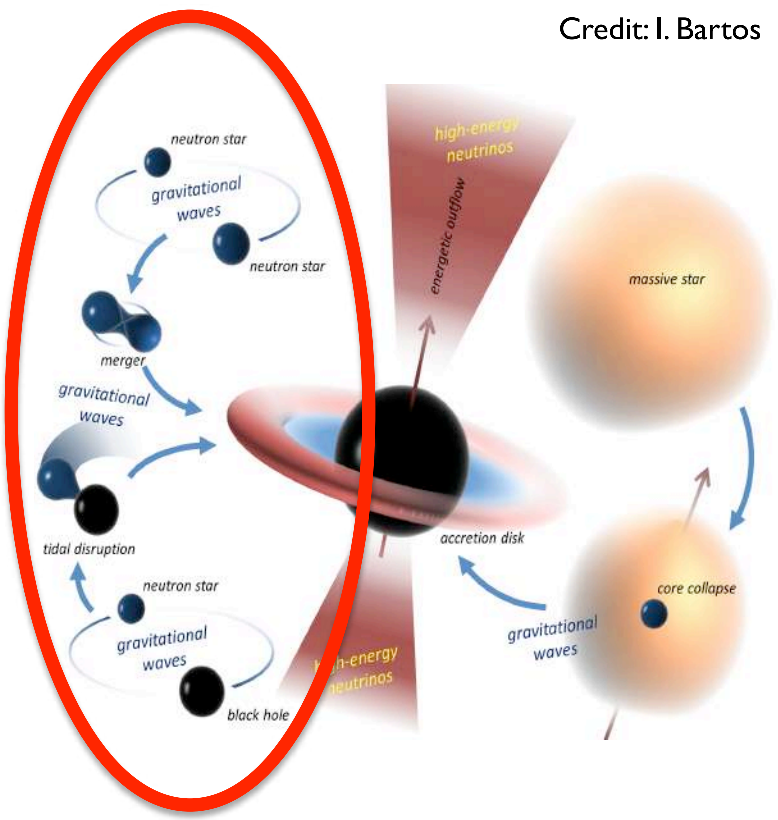
- Nucleosynthesis.
- Ejecta properties:
  - Energetics
  - Velocity
  - Geometry
- Redshift.
- Environment properties (especially density).
- Enhance confidence of low-SNR GW detections
- …


Gravitational
waves!
(Short) Gamma-ray
Burst (seconds), X-rays
(secs-days) if on-axis or not
too far off-axis
Interaction with ISM
(optical and radio
afterglow, days to
months)
Kilonova
R-process nucleosynthesis:
optical-IR (~ 1 day).
Courtesy: Varun Bhalerao

GW astronomy makes the BIG leagues!



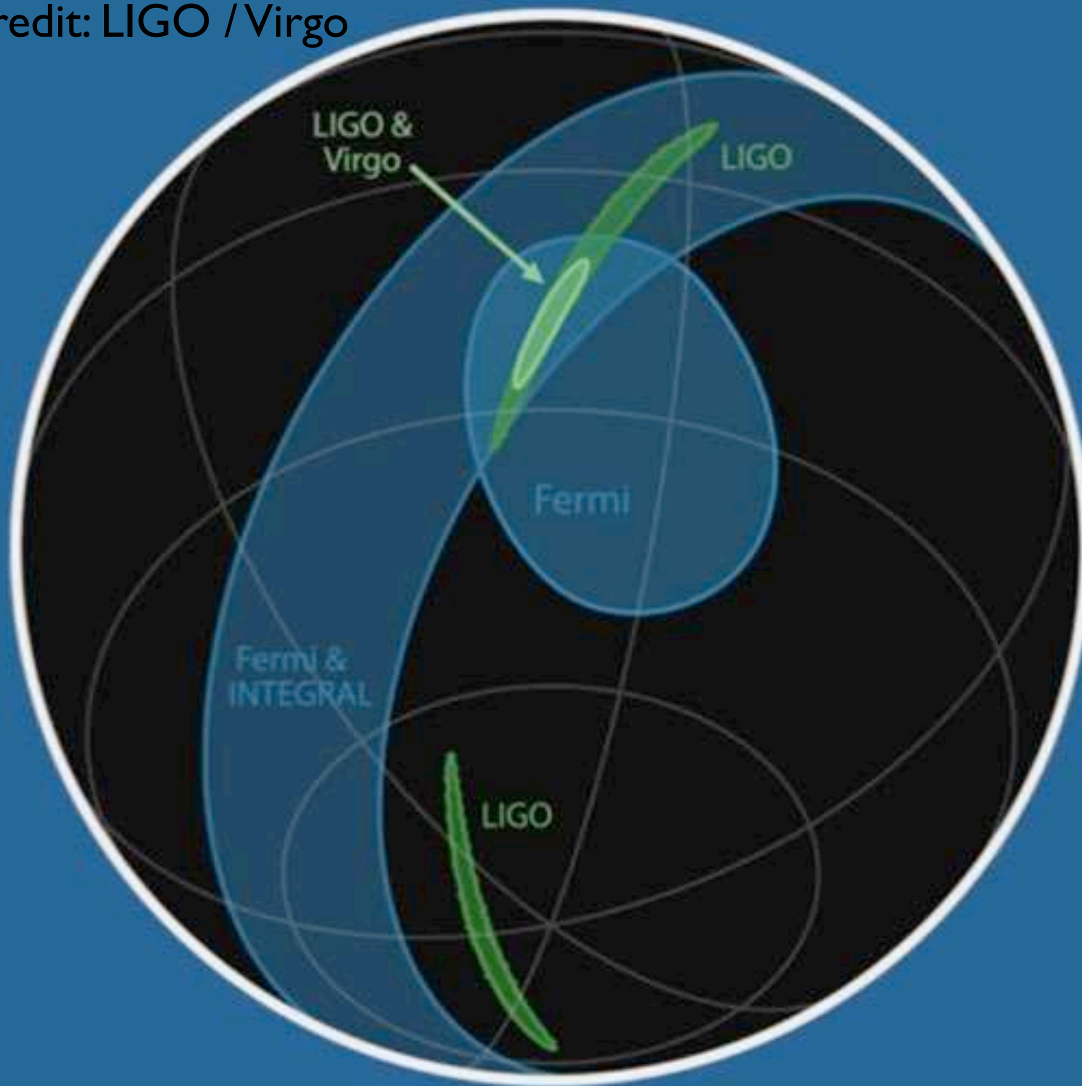
Credit: I. Bartos



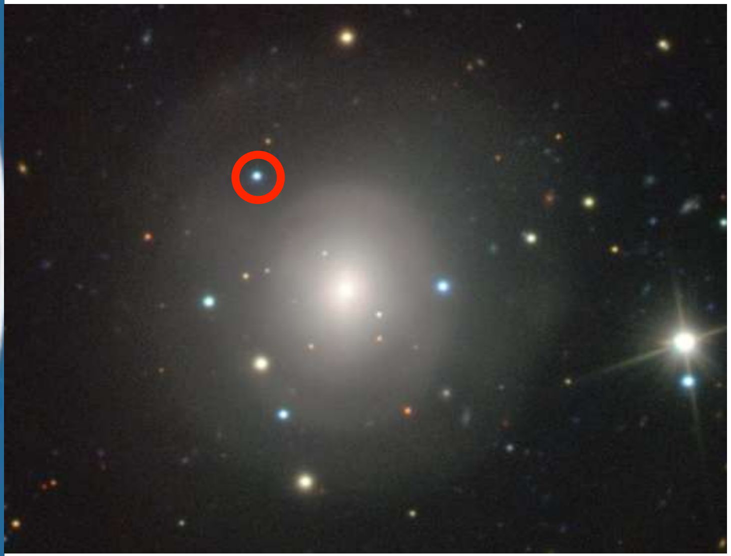
Abbott et al., ApJL, 848:L13, 2017

GW170817 localization

Credit: LIGO / Virgo



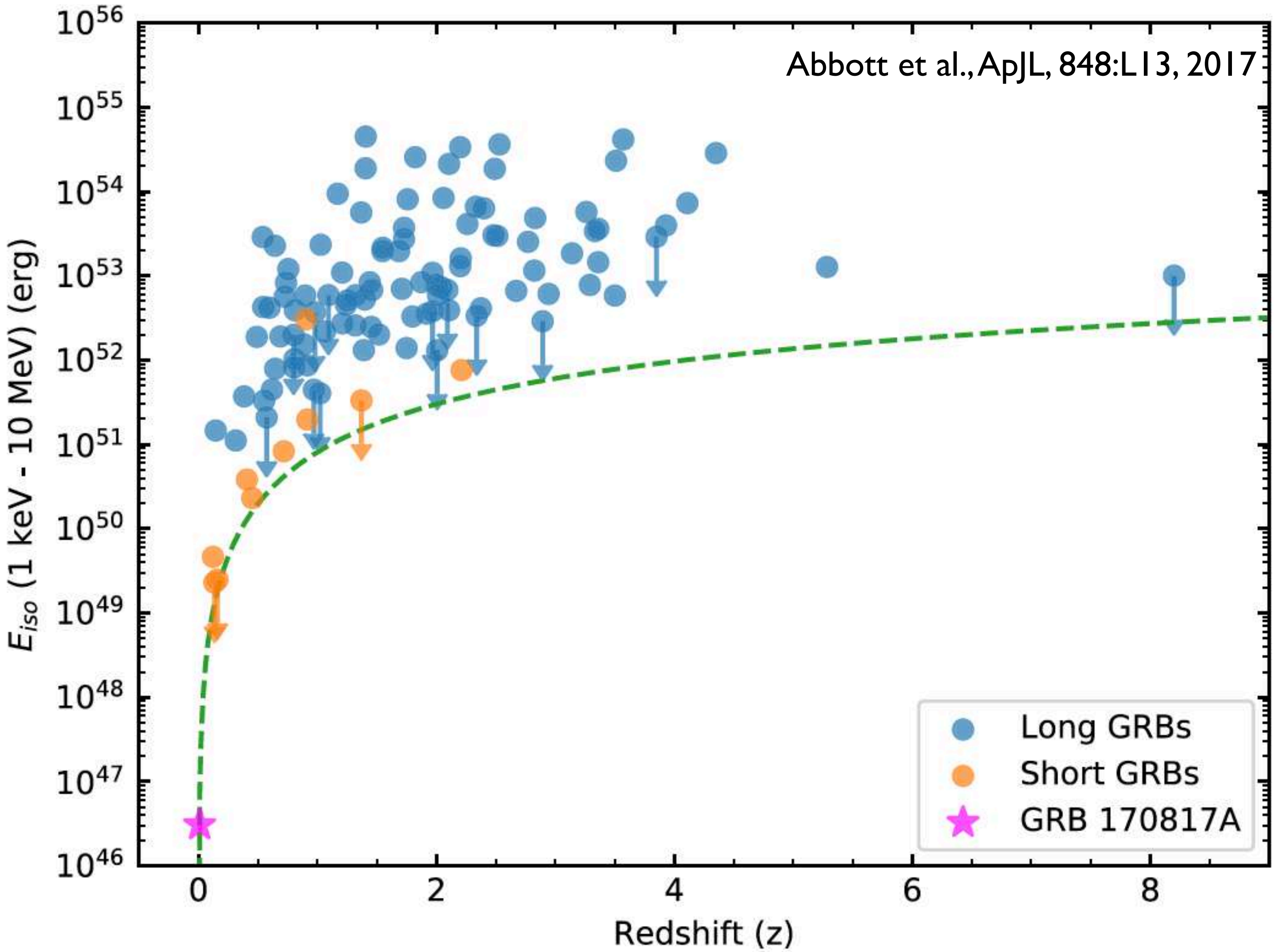
Combination of LIGO, Virgo, Fermi, and Integral localizations for GW170817: ~30 deg^2 in area.



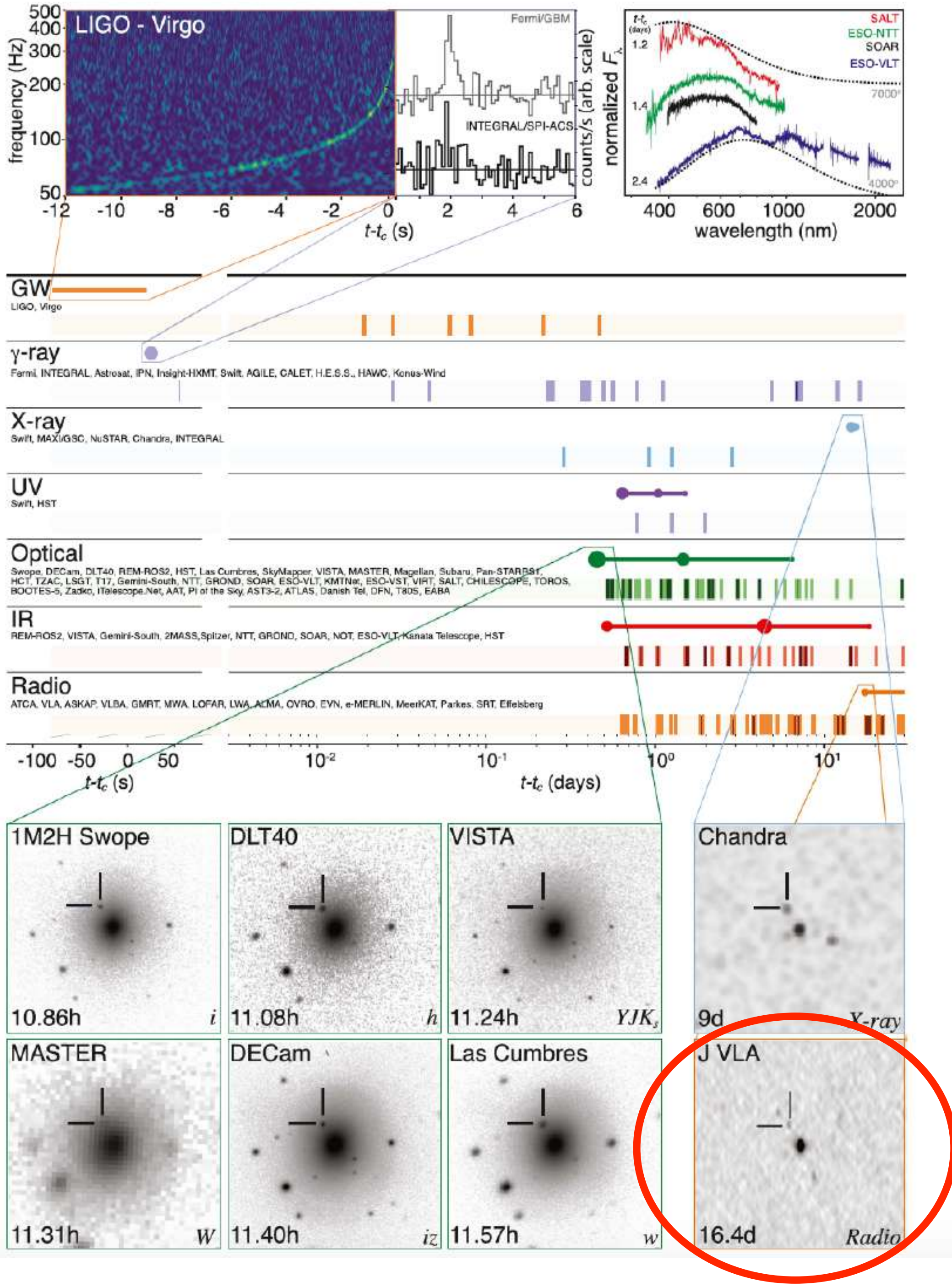
Credit: European Southern Observatory VLT

Optical observations reveal a host galaxy @ 40 Mpc!

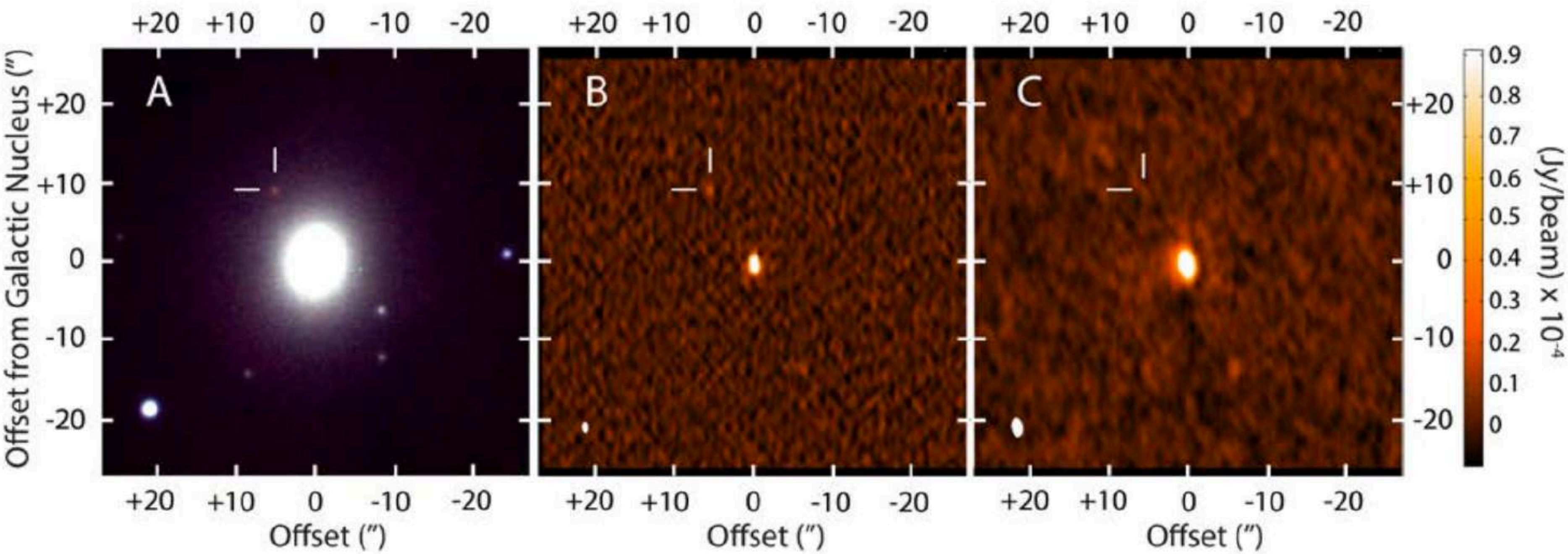
OH, hang on, this is kind of dim??



Abbott et al. 2017, ApJL, 848:L12

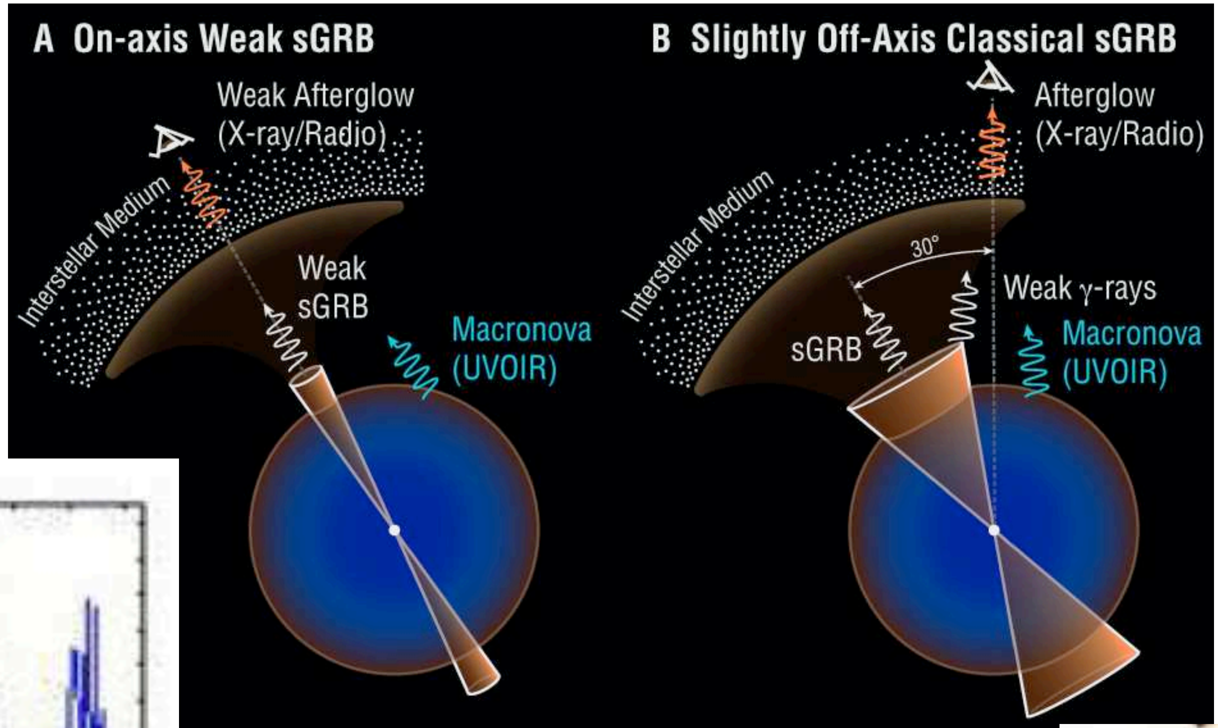


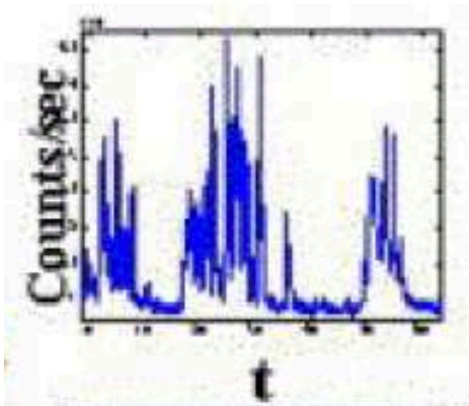
Discovery of a delayed radio glow



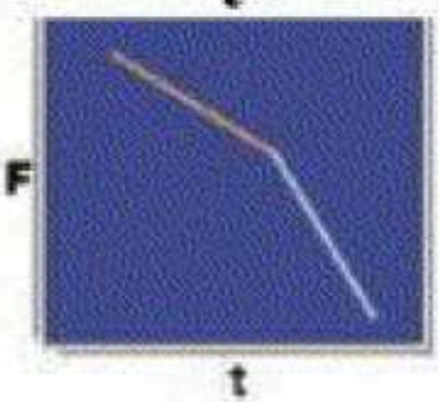
Hallinan, Corsi et al. 2017, Science, 358, 1579
Mooley et al. 2018, Nature, 554, 207
Hotokezaka et al. 2016, ApJ, 831, 190
Gottlieb et al. 2018, MNRAS, 473, 576
Lazzati et al. 2017, arXiv1712.03237
Margutti et al. 2018, arXiv1801.03531
Dobie et al. 2018, arXiv:1803.06853

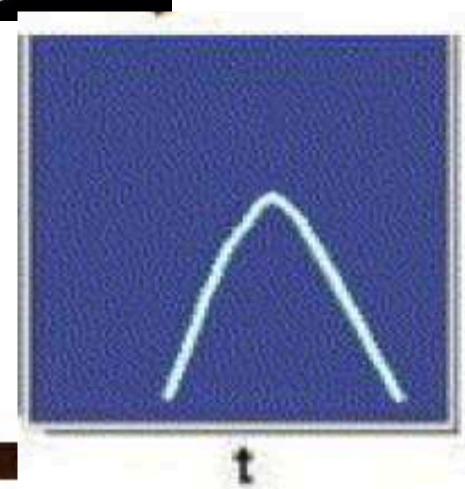
An off-axis "top-hat" jet?





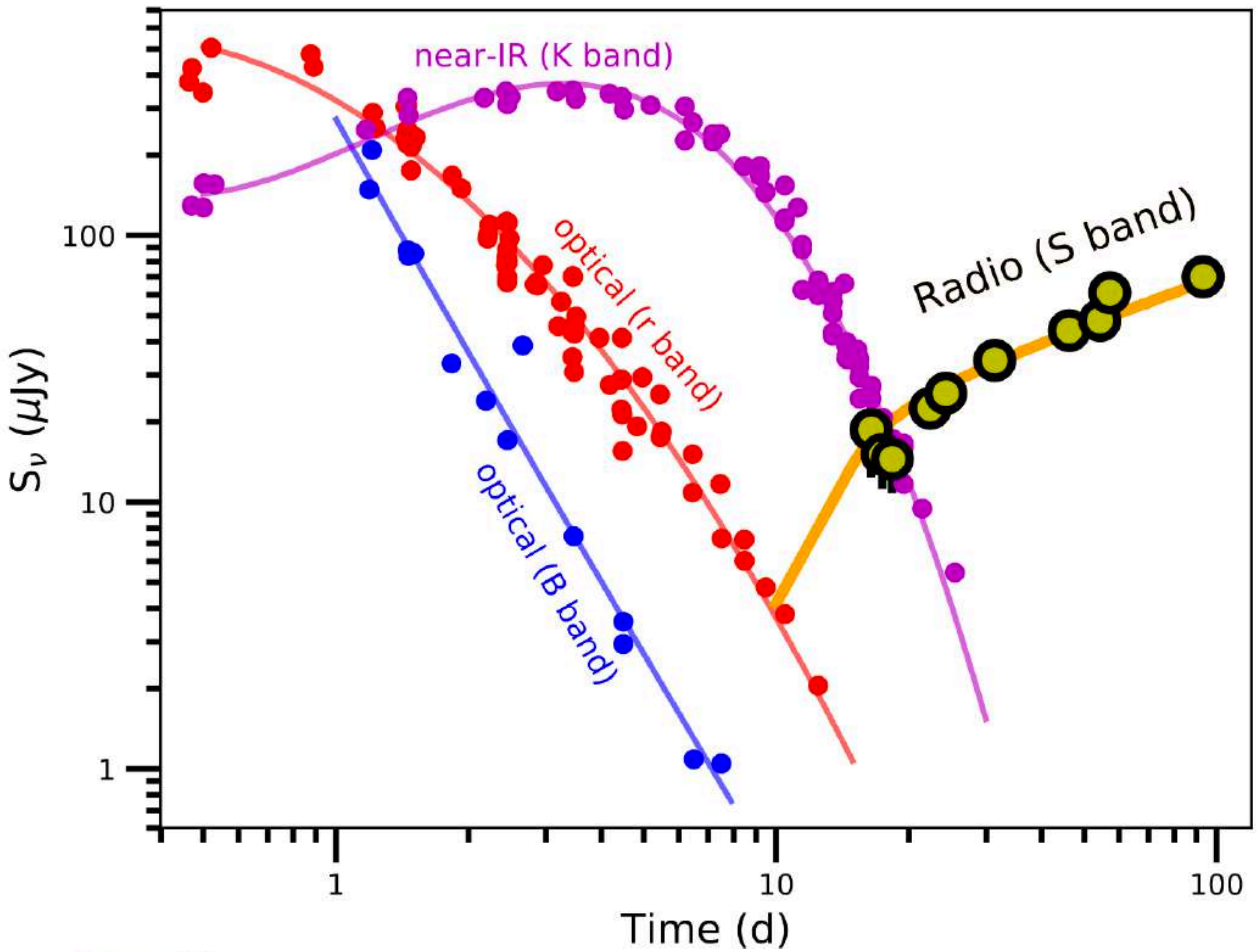
Kasliwal et al., Science, 2017, 358.1559





Nakar & Piran 2003

OH, hang on, radio light rises too slowly!



Instead of bright gamma-rays from an on-axis relativistic jet, just a red kilonova, and a relatively prompt radio/X-ray afterglow, we saw:

- gamma-rays ~10^3 times weaker than ordinary short GRBs;
- early blue kilonova;
- late radio/X-ray emission.

Credit: JAGWAR team

Credit: JAGWAR team

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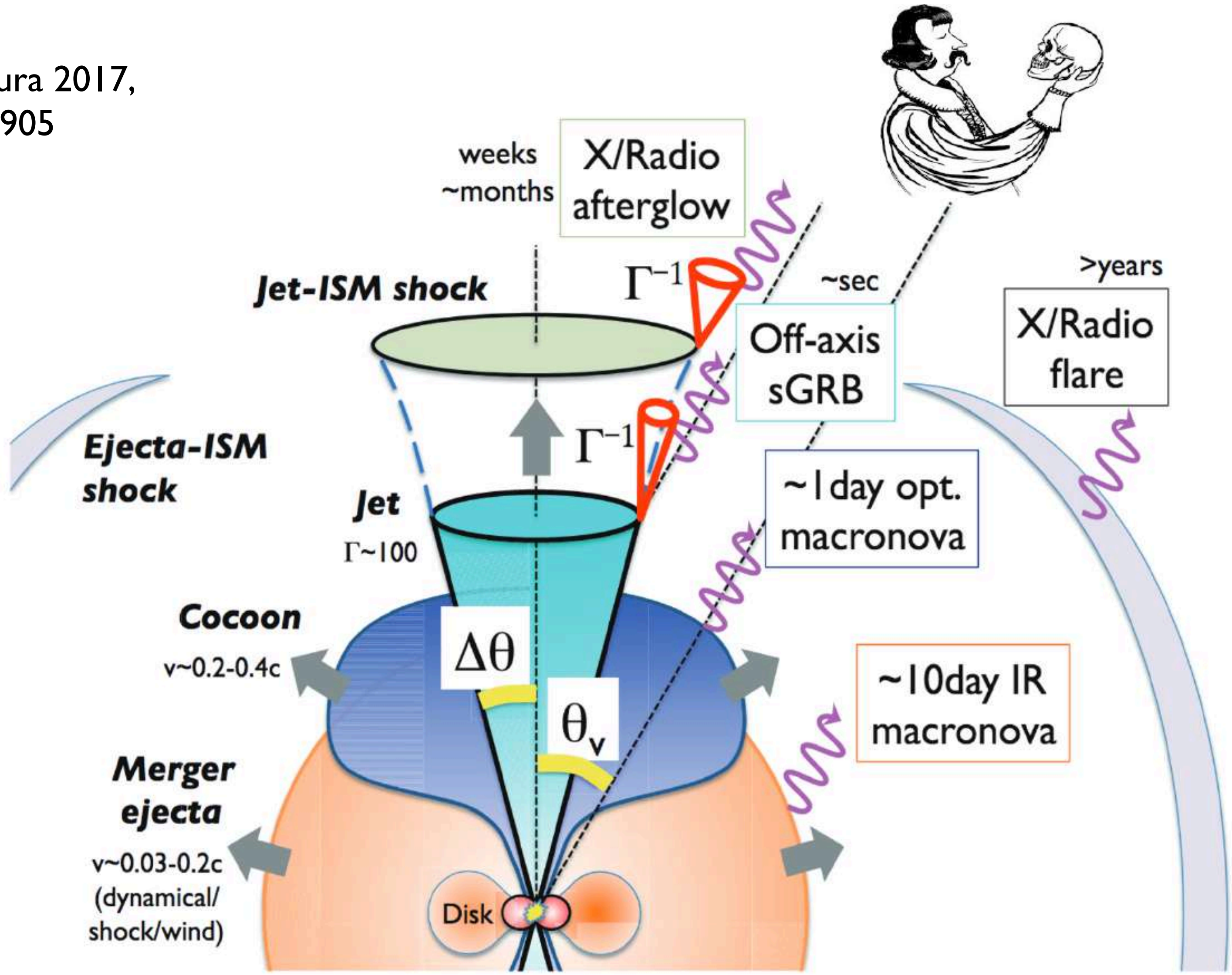
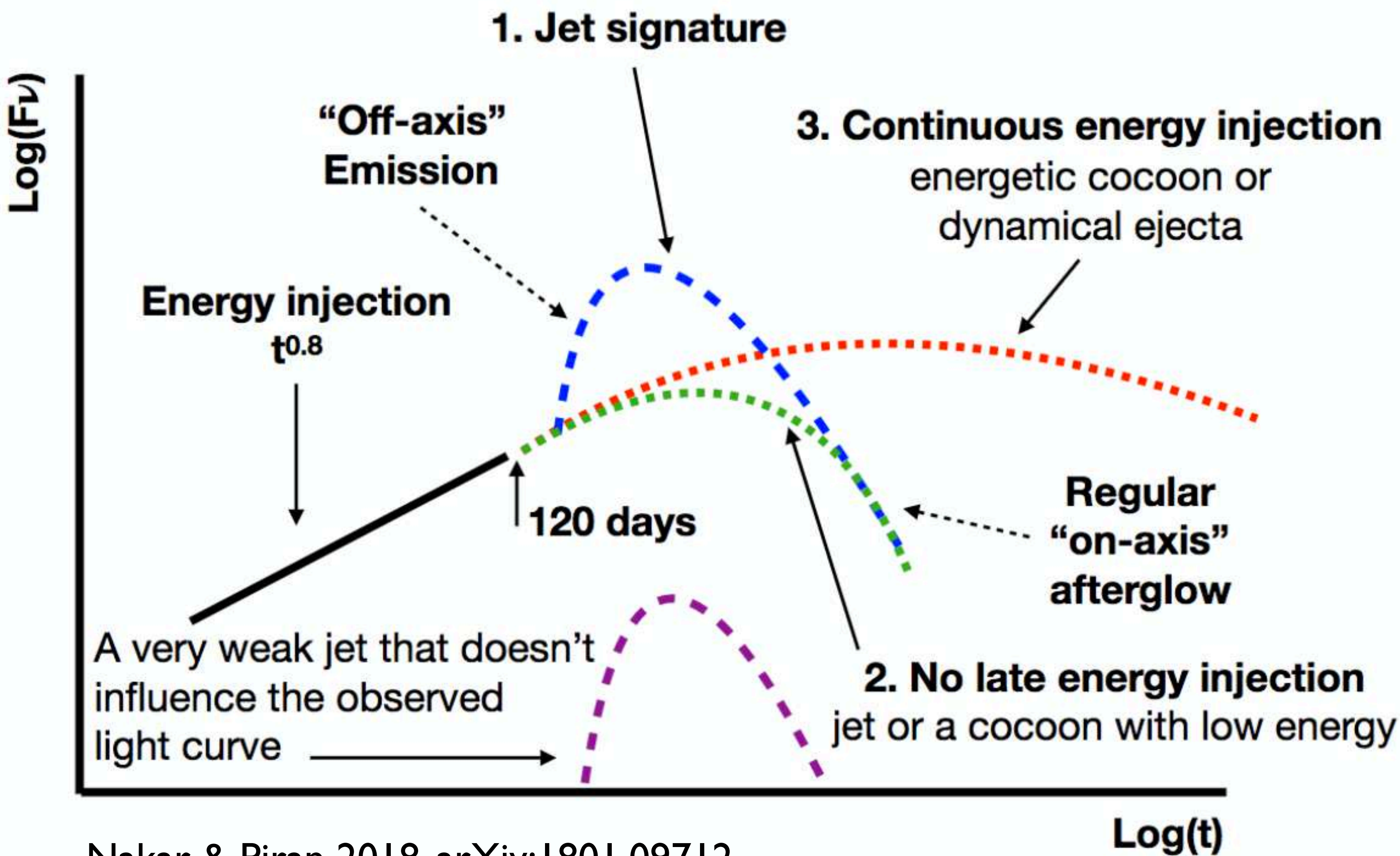
A more complex outflow: to jet or not to jet?

Ioka & Nakamura 2017,
arXiv:1710.05905

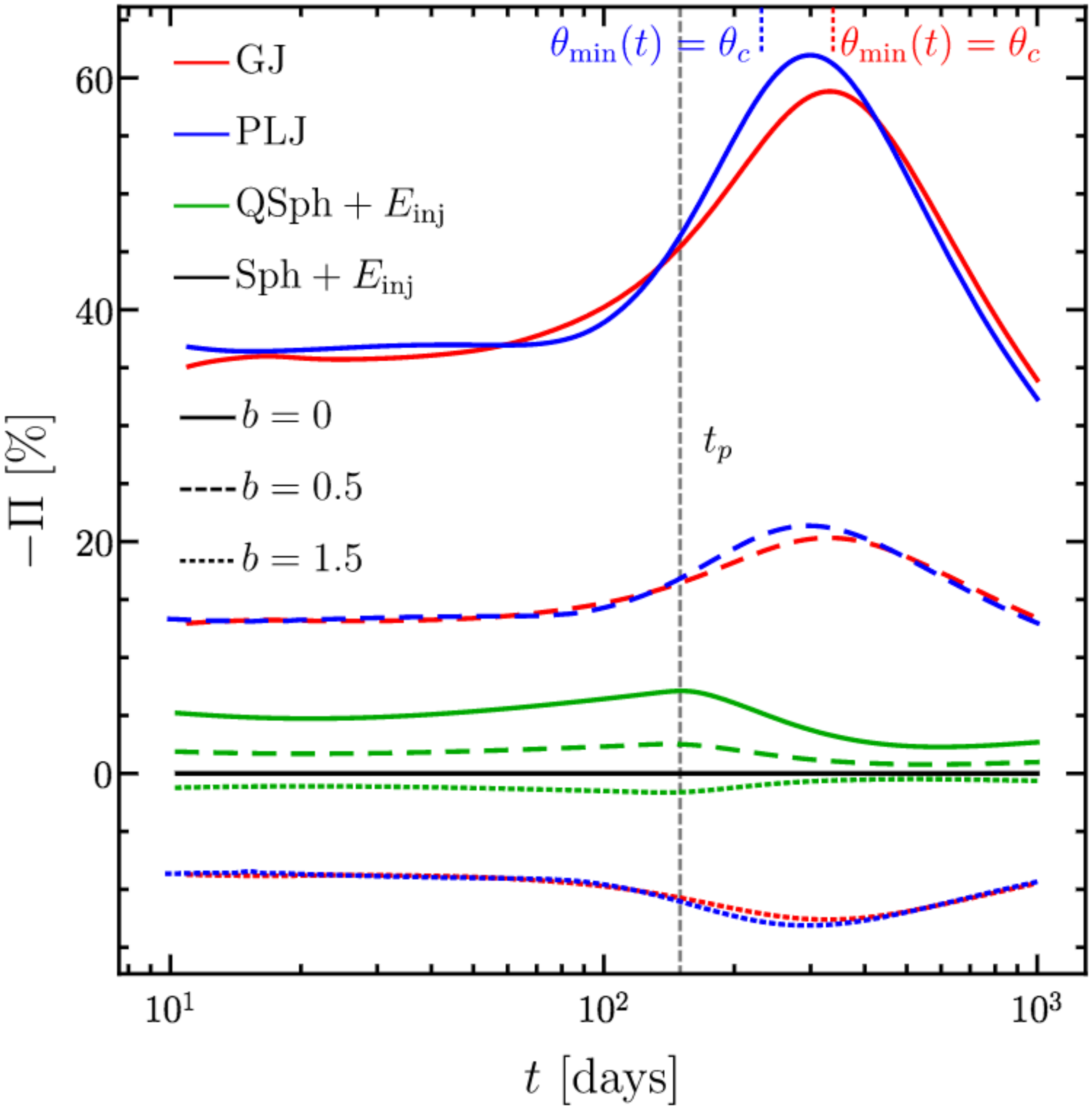


Anatomy of NS-NS outflows: Stokes I radio continuum



Nakar & Piran 2018, arXiv:1801.09712

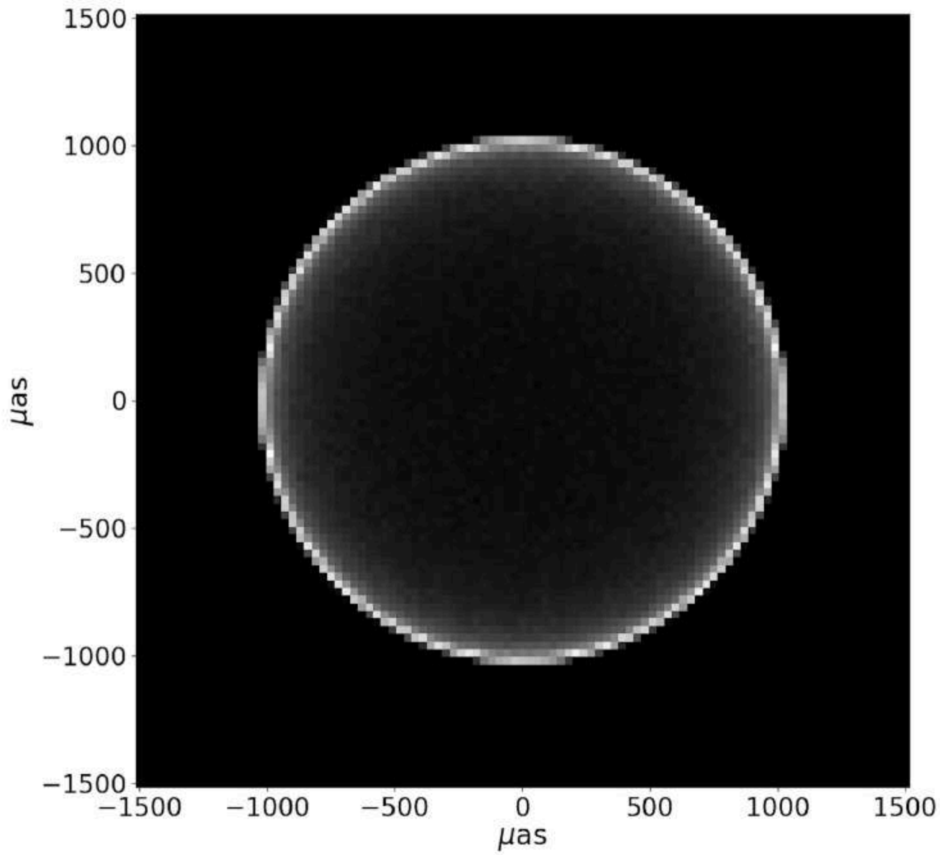
Anatomy of NS-NS outflows: Linear polarization

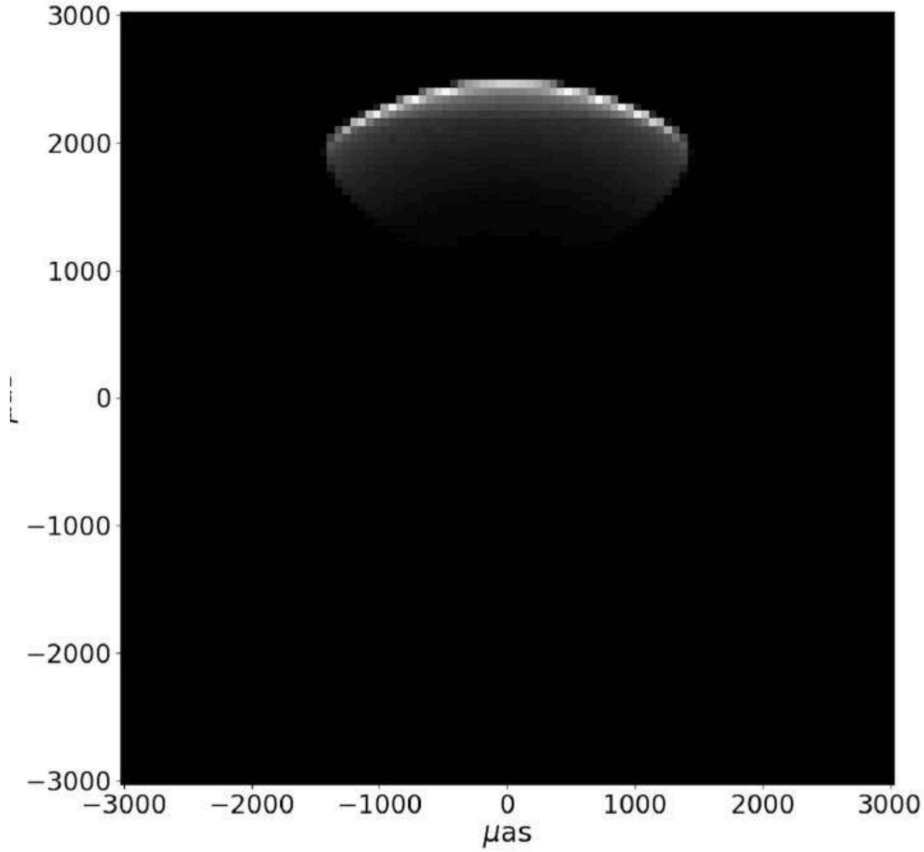


- In a structured jet model, the required asymmetry is built into the jet structure: energy and speed of ejecta components depend on polar angle.
- Emitting surface never completely symmetric for misaligned observers: magnetic field appears to have some degree of "order" or alignment, resulting in an appreciable degree of polarization in the received radiation.

Gill & Granot, arXiv: 1803.05892

Anatomy of NS-NS outflows: VLBI mapping





Credit: Davide Lazzati

Why do we care? Geometry Matters

Successful jet+cocoon

(a.k.a. structured jet)

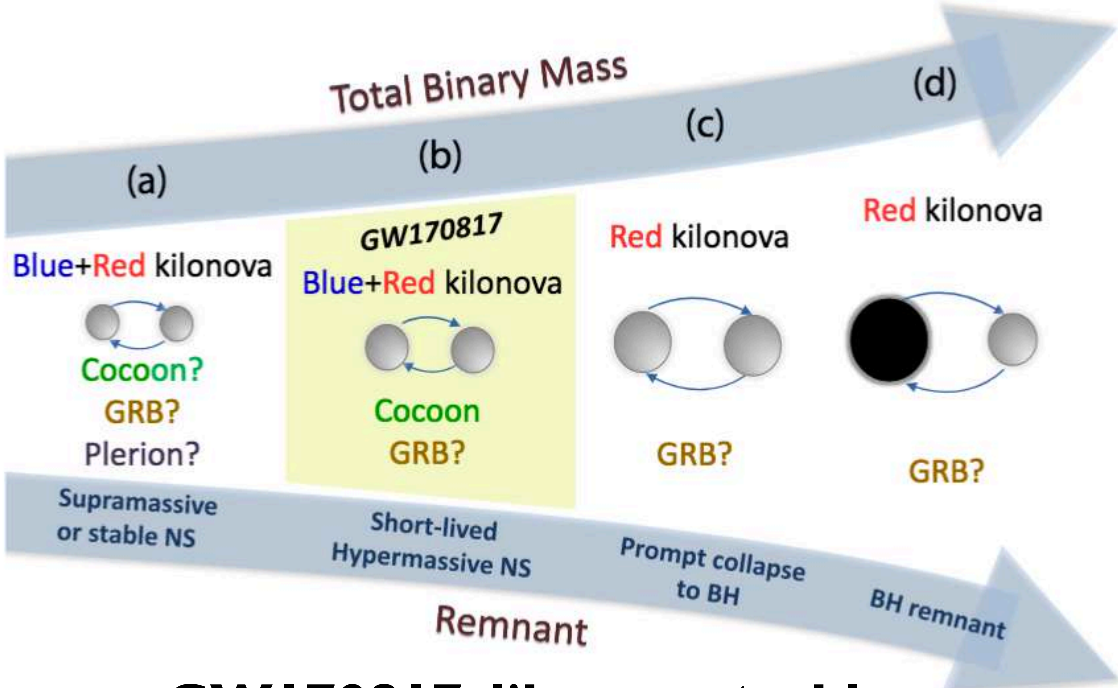
- After years of circumstantial evidence, we now have direct proof that short GRBs are related to binary NS mergers.
- After 20 years of searching, we have found an off-axis GRB jet.
- Rate of short GRBs traces NS/NS rate.
- Viewing angle constrains orbital inclination → Breaks H_o degeneracy!

Cocoon only (choked jet)

- There is a diversity of central engine outcomes. Some launch jets, others fail.
- Rate of short GRBs < NS/NS rate.
- Expect a larger number of EM counterparts than off-axis jet:
  - Wide-angle ejecta are visible over a wider solid angle.
  - Cocoon may boost early UV/ blue kilonova brightness.

How common is GW170817?

Is relativistic outflow launched in the absence of BH collapse?

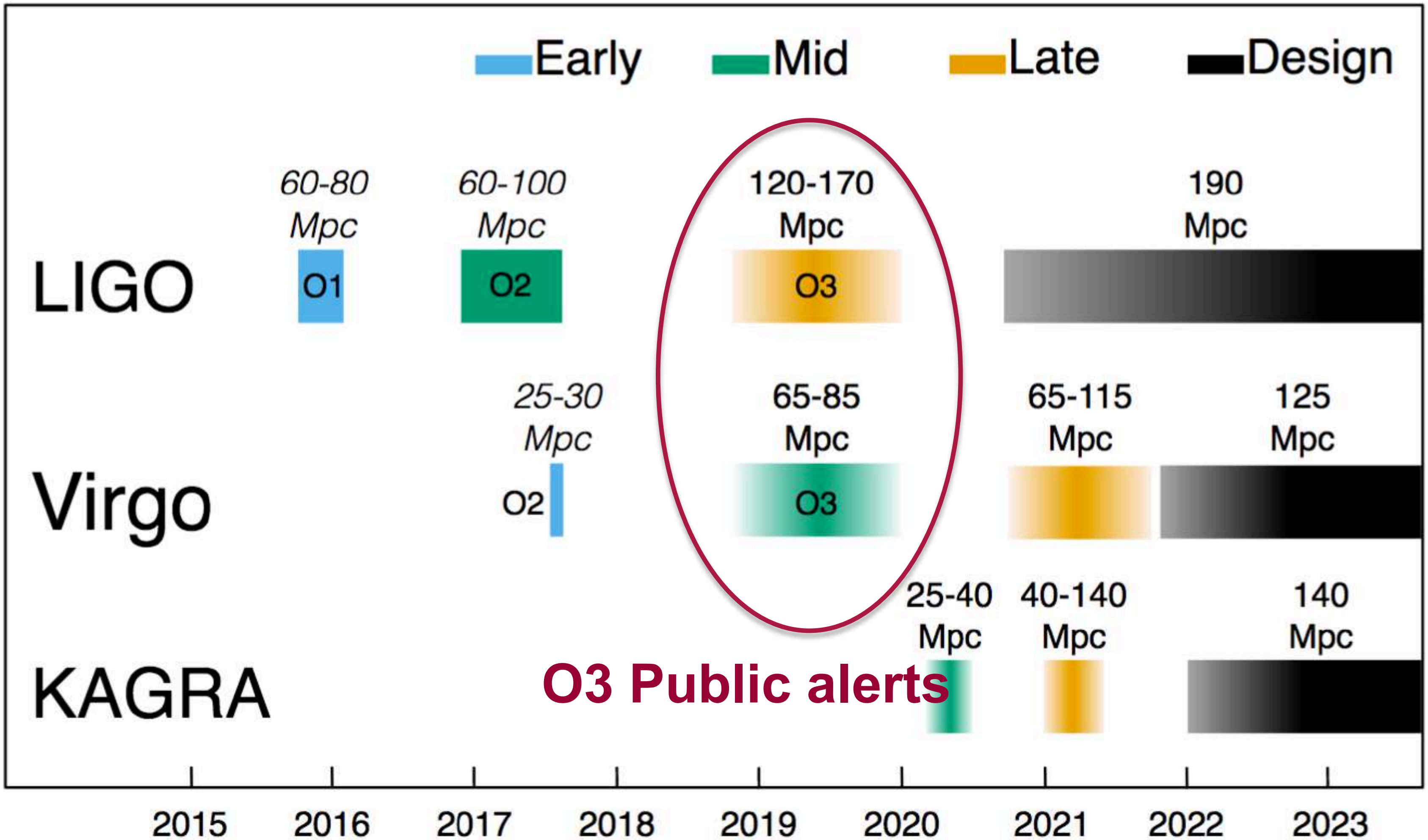


Prompt collapse to BH may suppress blue kilonova (due to lack of neutrino flux preventing formation of heavy r-process elements)? Possibly, relativistic jets escape cleanly without interacting with polar ejecta, precluding cocoon formation?

GW170817-like events: blue and red kilonovae and cocoons. Fraction of such mergers where the jets escape through the polar ejecta yet to be determined.

Credit: JAGWAR team

What's next?



Abbott et al., Living Reviews in Relativity 19, 1 (2016)

Conclusion

- LIGO-Virgo have made first measurements of GWs!
- Merging binary black hole and neutron star systems have been observed for the first time!

  'a scientific revolution'

- Plans are underway to improve LIGO's sensitivity for O3 and beyond.

STAY TUNED!

TEXAS TECH UNIVERSITY

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TEXAS TECH UNIVERSITY
Graduate Study in Physics and Astrophysics Research

Extreme and Explosive Astrophysics
- Radio/X-ray follow-up of core-collapse supernovae and other transients.
- Observational studies of dynamics of dense star clusters.
- Accretion onto black holes and neutron stars, jets, GRBs.

Stellar Populations in Nearby Galaxies
- X-ray binary populations of nearby galaxies.

Gravitational-Wave Physics and Astronomy
- Gravitational waves from GRBs, pulsars, magnetars with LIGO.
- Radio, optical, and X-ray follow-up of gravitational waves.
- Theoretical studies of neutron stars and black holes.

Instrumentation and Collaborations
- STROBE-X – X-ray Timing and Spectroscopy on Dynamical Timescales from Microsecs to Yrs.
- Small telescopes for photometric follow-up of targets from exoplanet transit surveys.
- We are part of: CTA, DLT40, GROWTH, LIGO, ngVLA, ZTF.

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QUESTIONS? *Contact us:*


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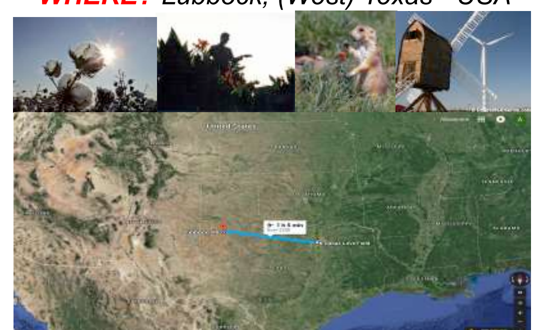
WHERE? *Lubbock, (West) Texas - USA*



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