TEXAS TECH UNIVERSITY™

Radio counterparts of GWs

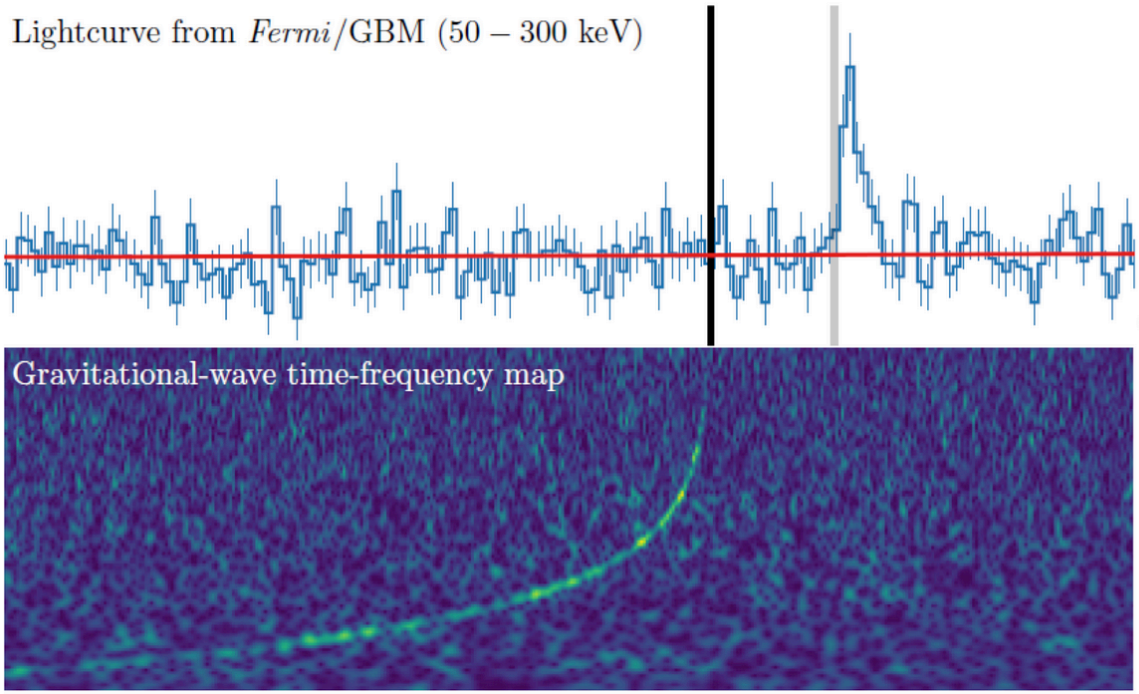
Alessandra Corsi

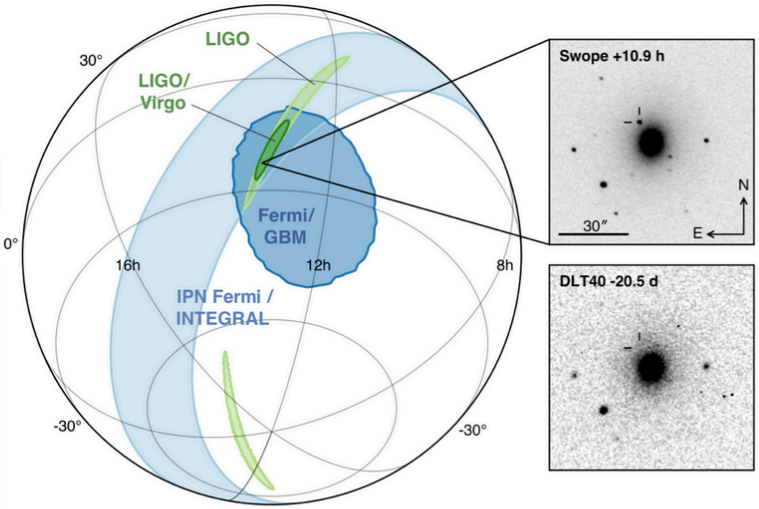
Physics & Astronomy Department
Texas Tech University

VULCANO WORKSHOP 2018
Frontier Objects in Astrophysics and particle Physics

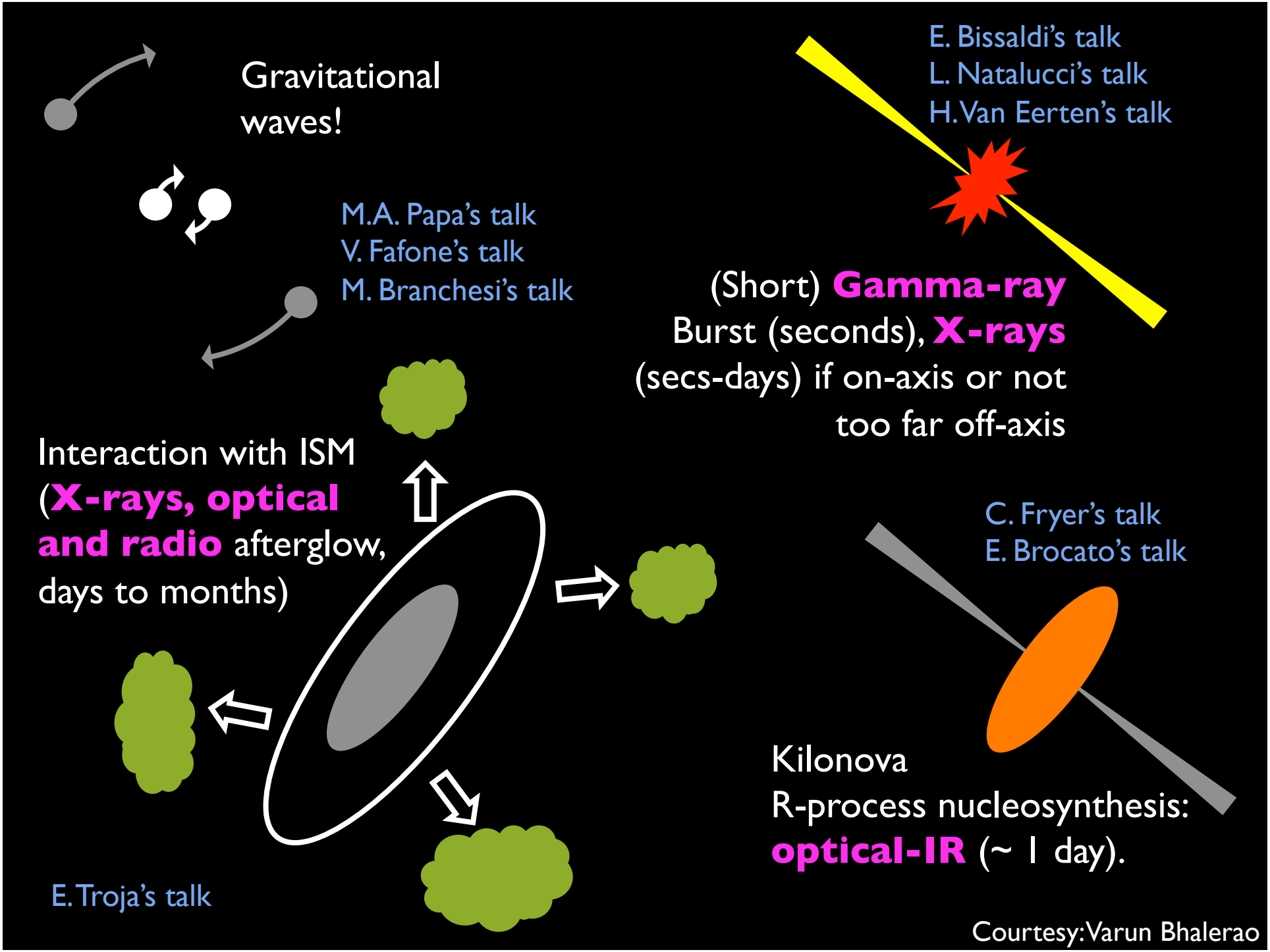
Welcome to the era of GW astrophysics!

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

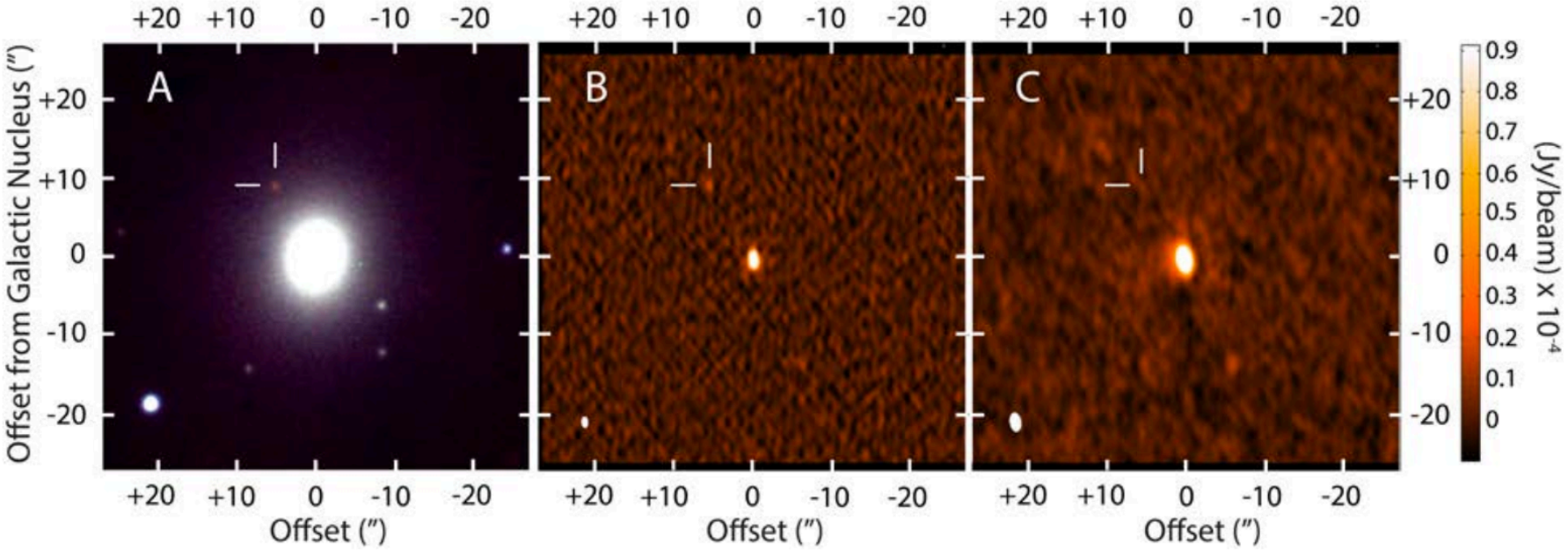




GW170817: e.g., Abbott et al. 2017, PRL, 119, 1101; Abbott et al. 2017, ApJ, 848, L12; Abbott et al. 2017, ApJ, 848, 13; Goldstein et al. 2017, ApJL, 848,2; references therein (AND MANY MORE!)

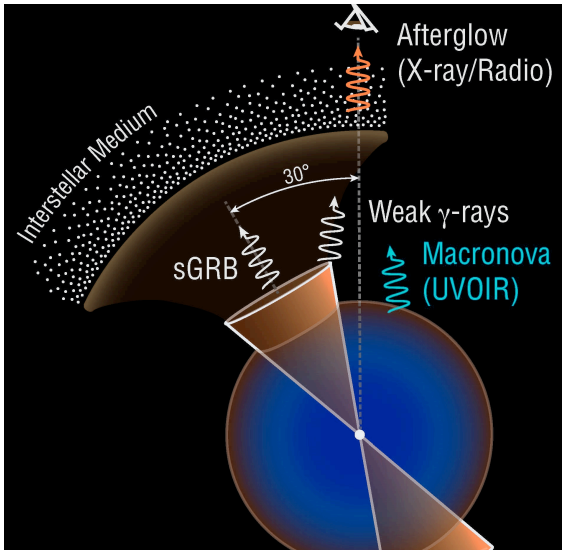

Gravitational waves!
M.A. Papa's talk
V. Fafone's talk
M. Branchesi's talk
E. Bissaldi's talk
L. Natalucci's talk
H. Van Eerten's talk
(Short) Gamma-ray Burst (seconds), X-rays (secs-days) if on-axis or not too far off-axis
Interaction with ISM (X-rays, optical and radio afterglow, days to months)
C. Fryer's talk
E. Brocato's talk
Kilonova
R-process nucleosynthesis: optical-IR (~ 1 day).
E. Troja's talk
Courtesy: Varun Bhalerao

Discovery of a delayed radio glow

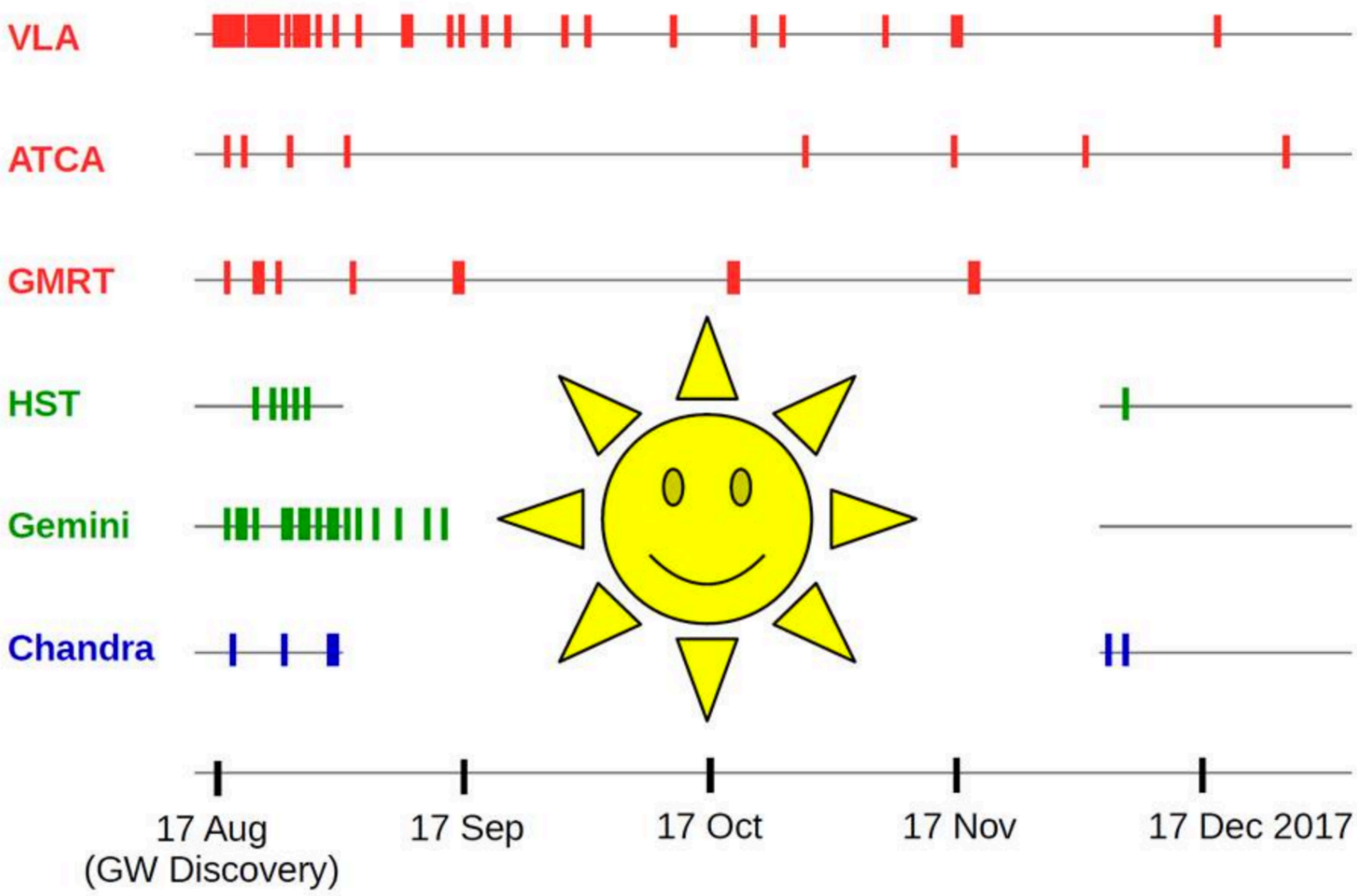


Hallinan, Corsi, et al. 2017, Science, 358, 1579

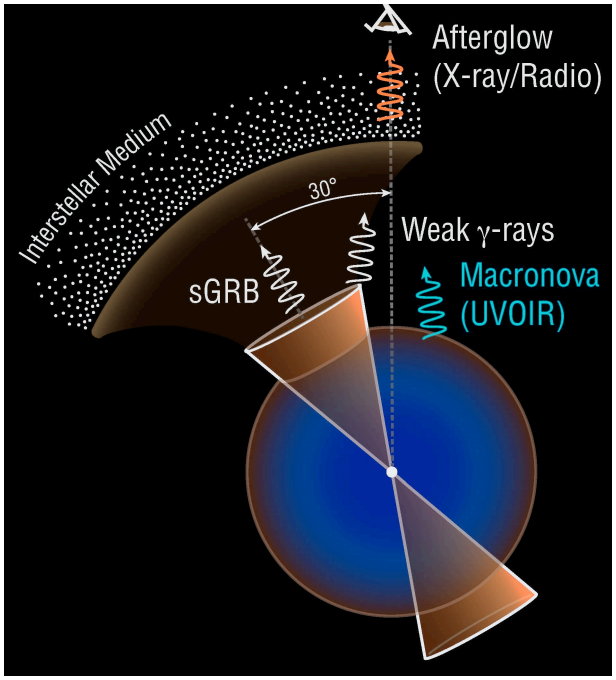
Kasliwal et al., Science, 2017, 358.1559



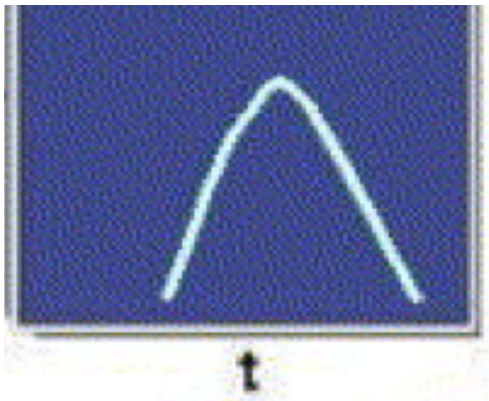
No Sun constraints in the radio



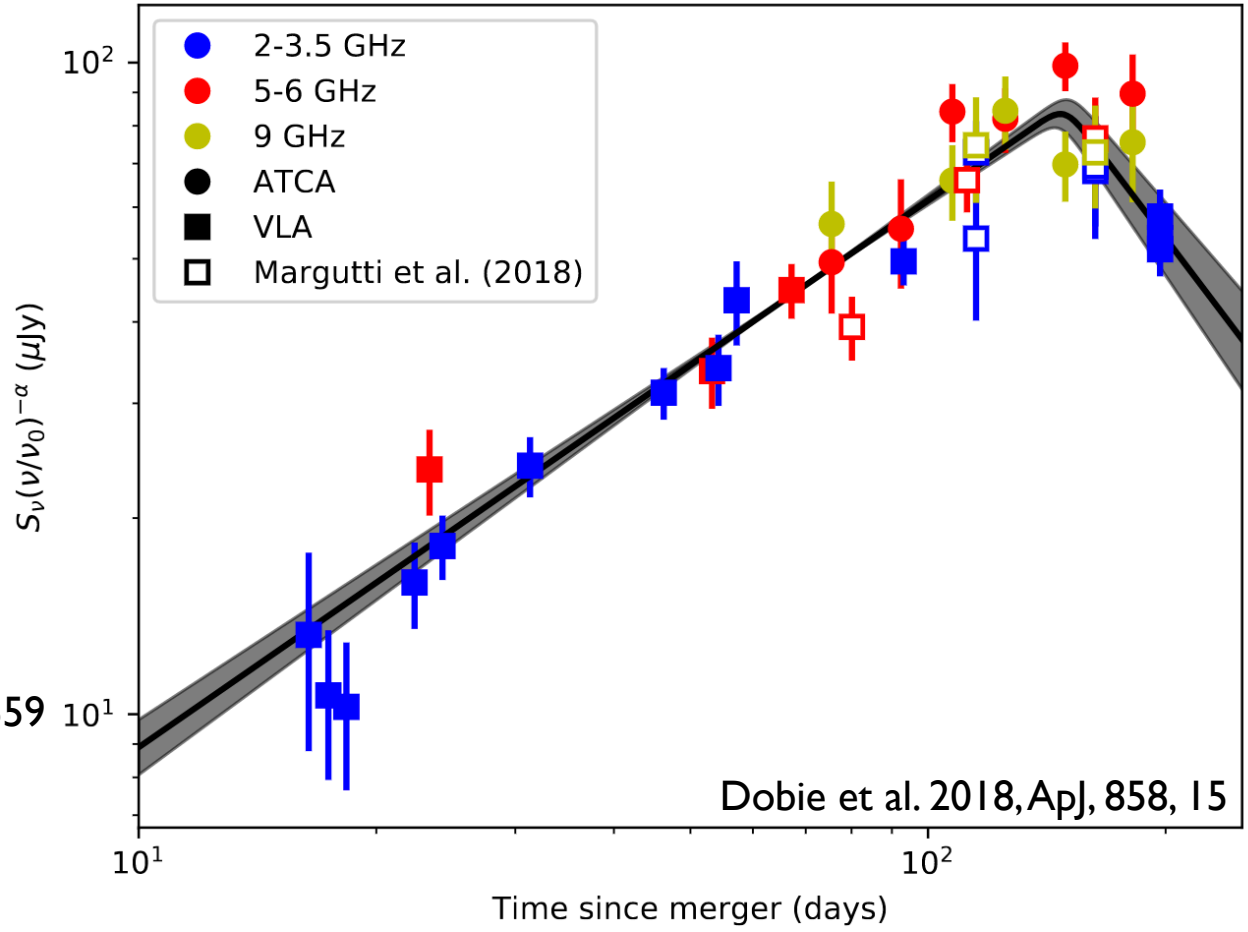
Ruling out a top-hat off-axis jet



Kasliwal et al., Science, 2017, 358, 1559

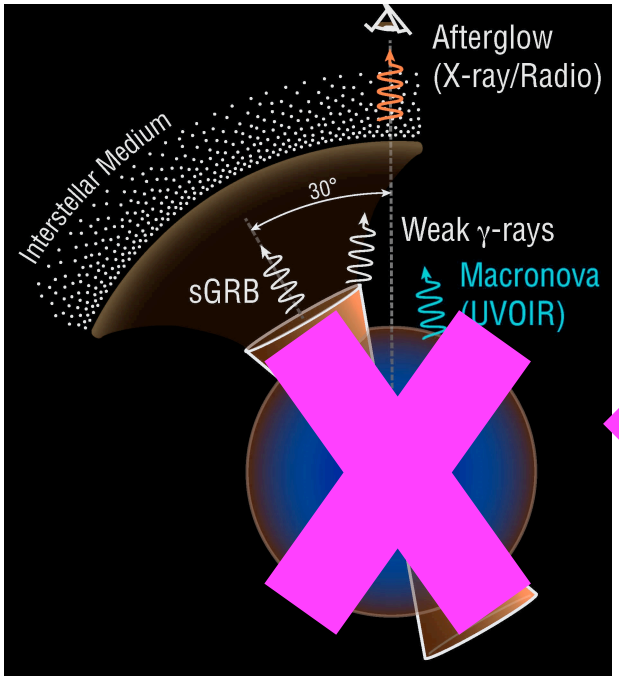


Nakar & Piran 2003

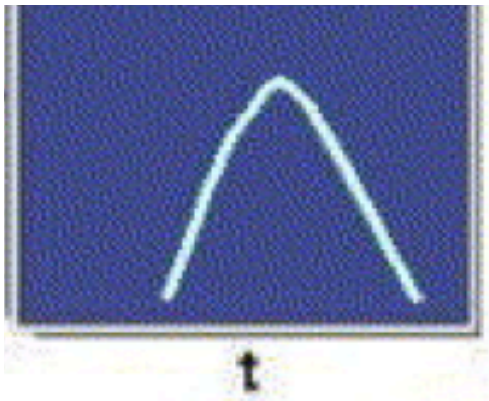


See also:
Mooley et al.. 2018, Nature, 554, 207
Troja et al. 2017, Nature, 551, 71

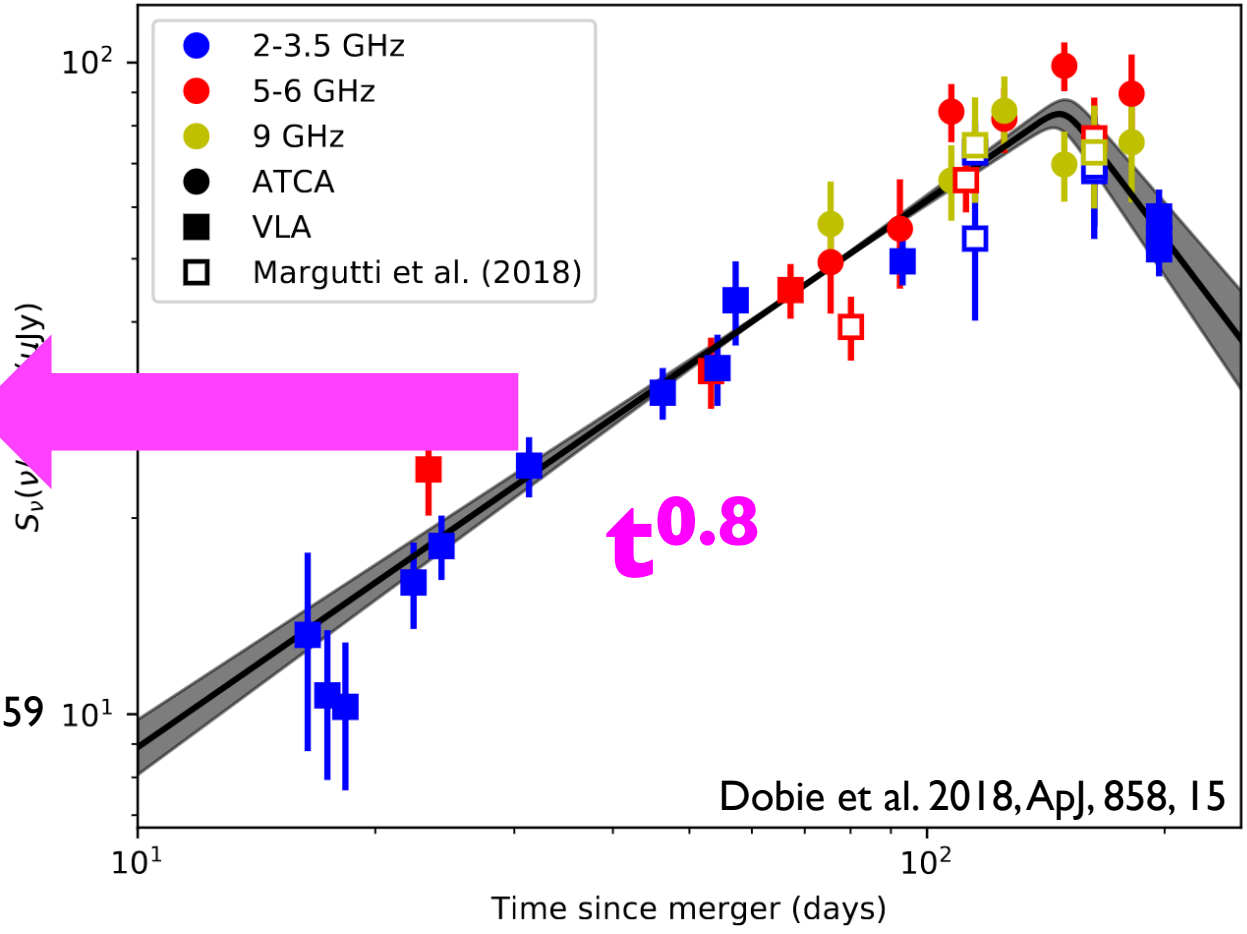
Ruling out a top-hat off-axis jet



Kasliwal et al., Science, 2017, 358, 1559

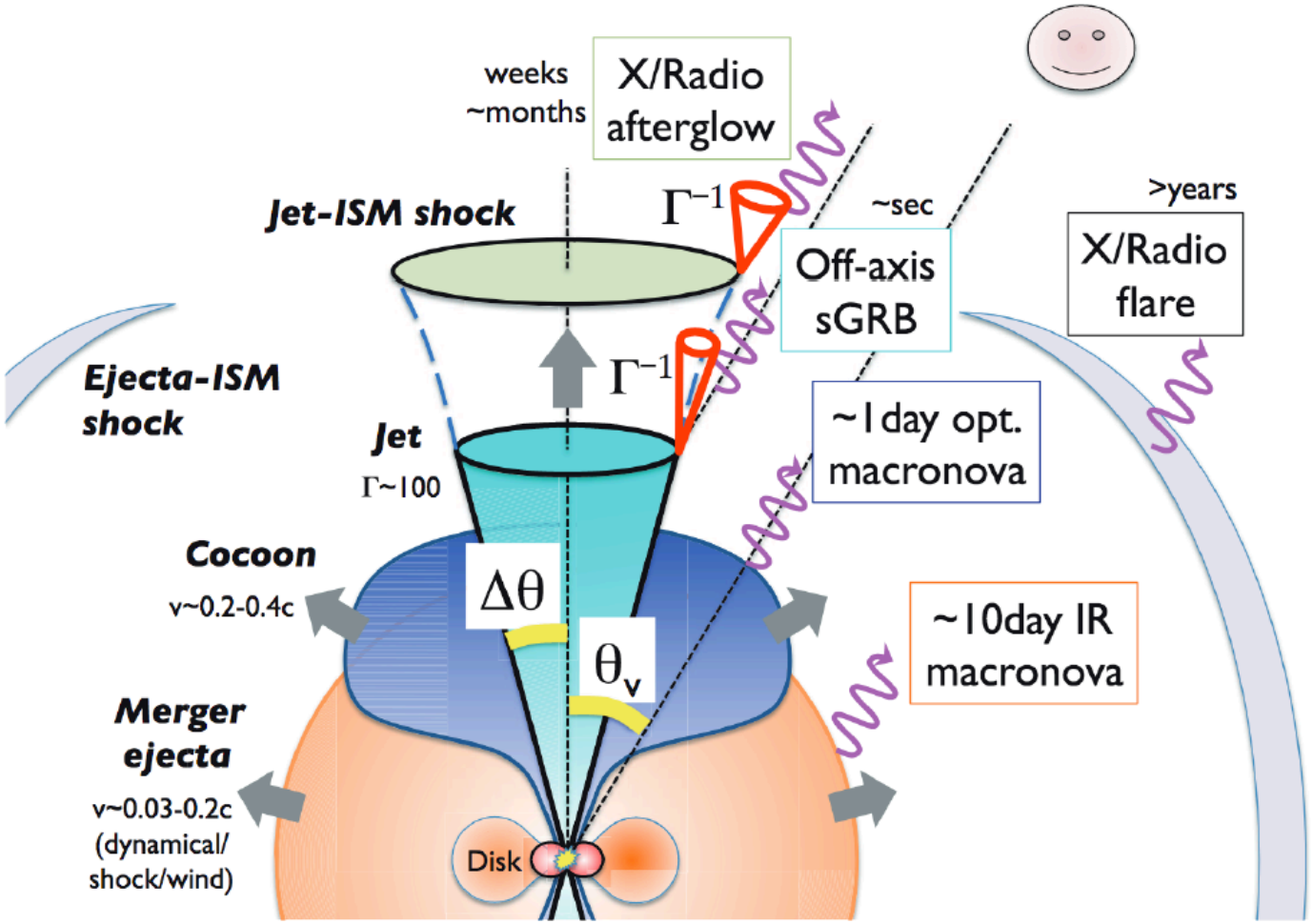


Nakar & Piran 2003

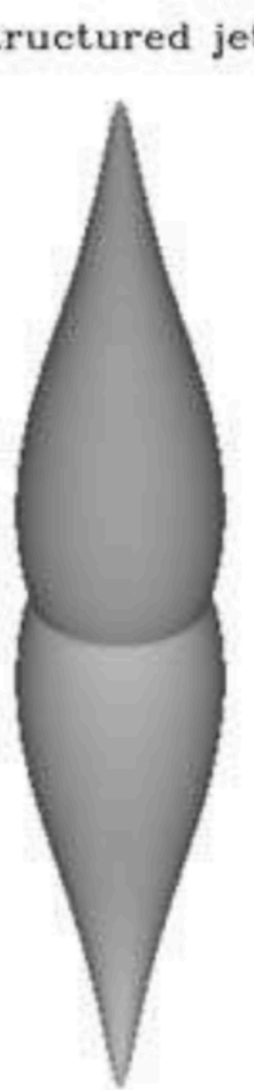


See also:
Mooley et al.. 2018, Nature, 554, 207
Troja et al. 2017, Nature, 551, 71

Morphology of GW170817 outflow



Ioka & Nakamura 2017, arXiv:171005905



Rossi et al. 2004, MNRAS, 354, 86

Why do we care? Geometry matters!

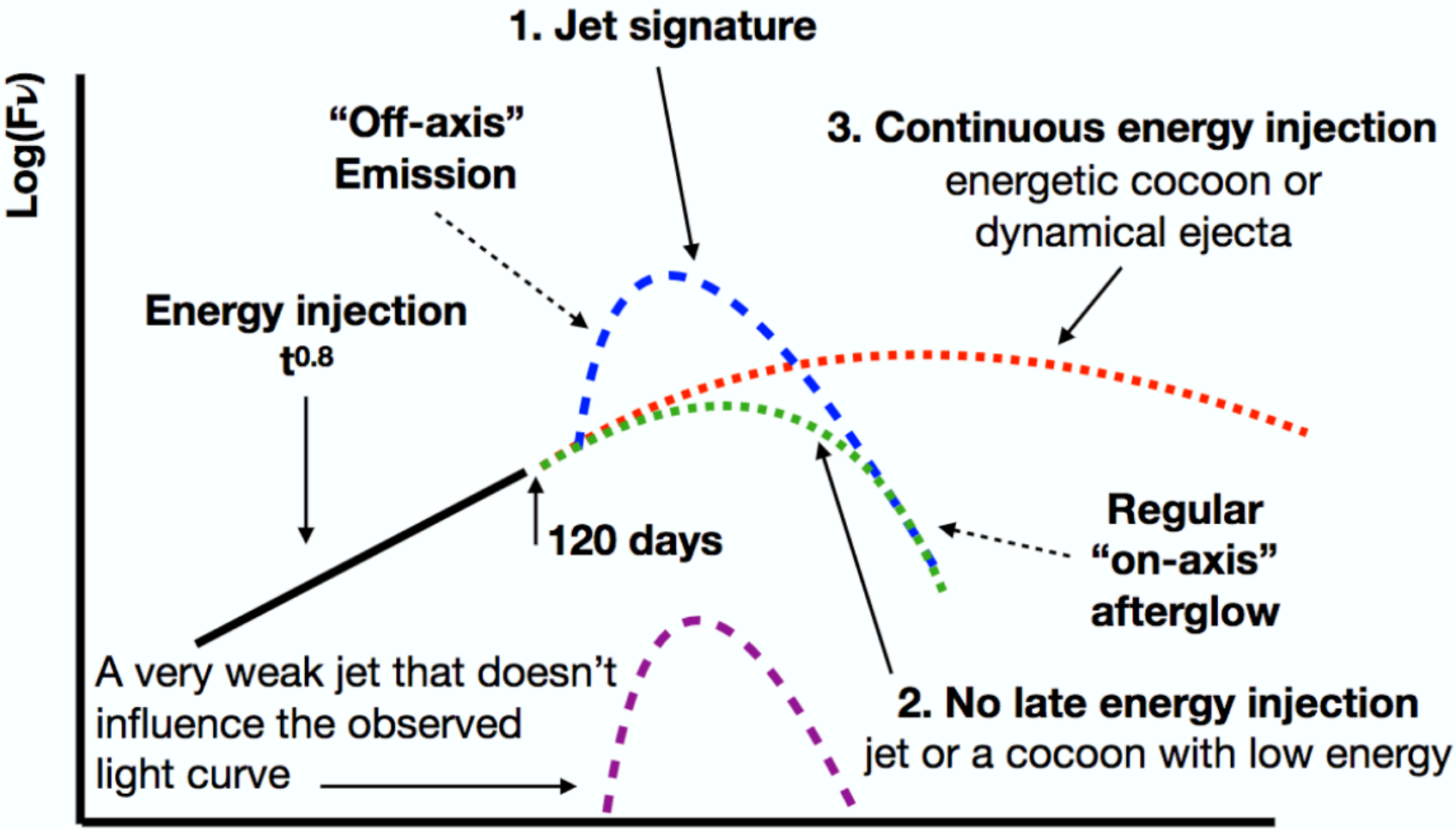
Successful structured jet (jet+cocoon)

- After yrs of circumstantial evidence, we now have **direct proof** that **sGRBs are NS-NS mergers**.
- After 20 years of searching, we have found an **off-axis GRB jet**.
- **sGRB rate** traces NS/NS rate.
- Viewing angle constrains orbital inclination → Helps break degeneracies in GW studies…

Cocoon only (choked jet)

- Establishes **diversity of central engine outcomes**. Some launch jets, others fail.
- Short GRB rate < **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?

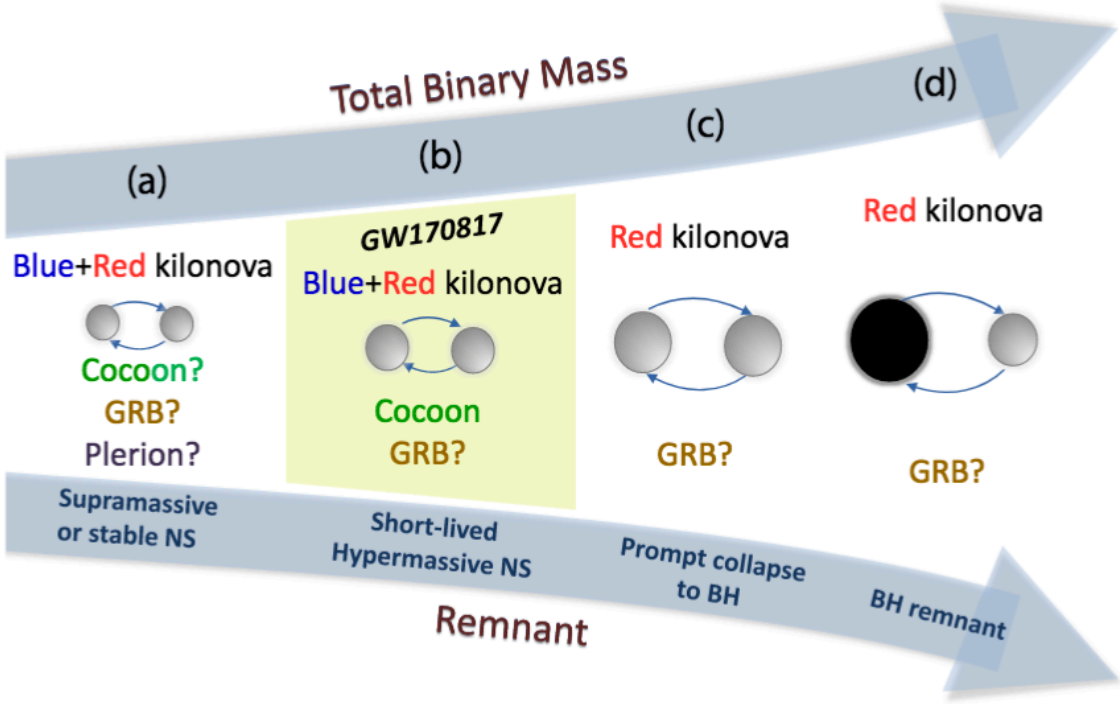
Radio light curve monitoring alone will likely not break all model degeneracies



Nakar & Piran 2018, arXiv:1801.09712

How common is GW170817?

Is relativistic outflow launched in the absence of BH collapse?



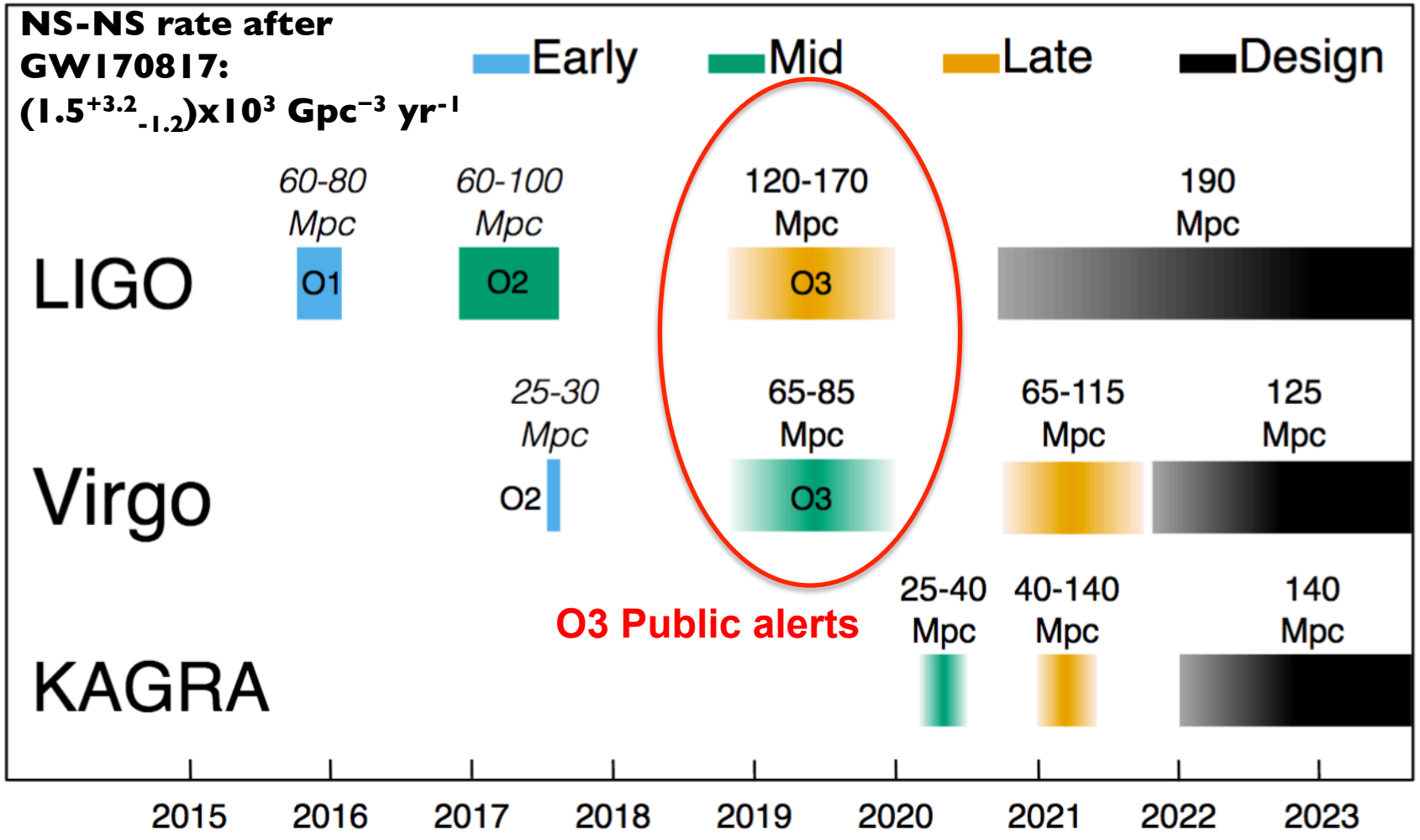
GW170817-like events: blue and red kilonovae and cocoon. Fraction of such mergers where the jets escape through the polar ejecta yet to be determined.

Prompt collapse to BH may suppress blue kilonova (due to lack of neutrino flux which prevents formation of heavy r-process elements)?

Possibly, relativistic jets escape cleanly without interacting with polar ejecta, precluding cocoon formation?

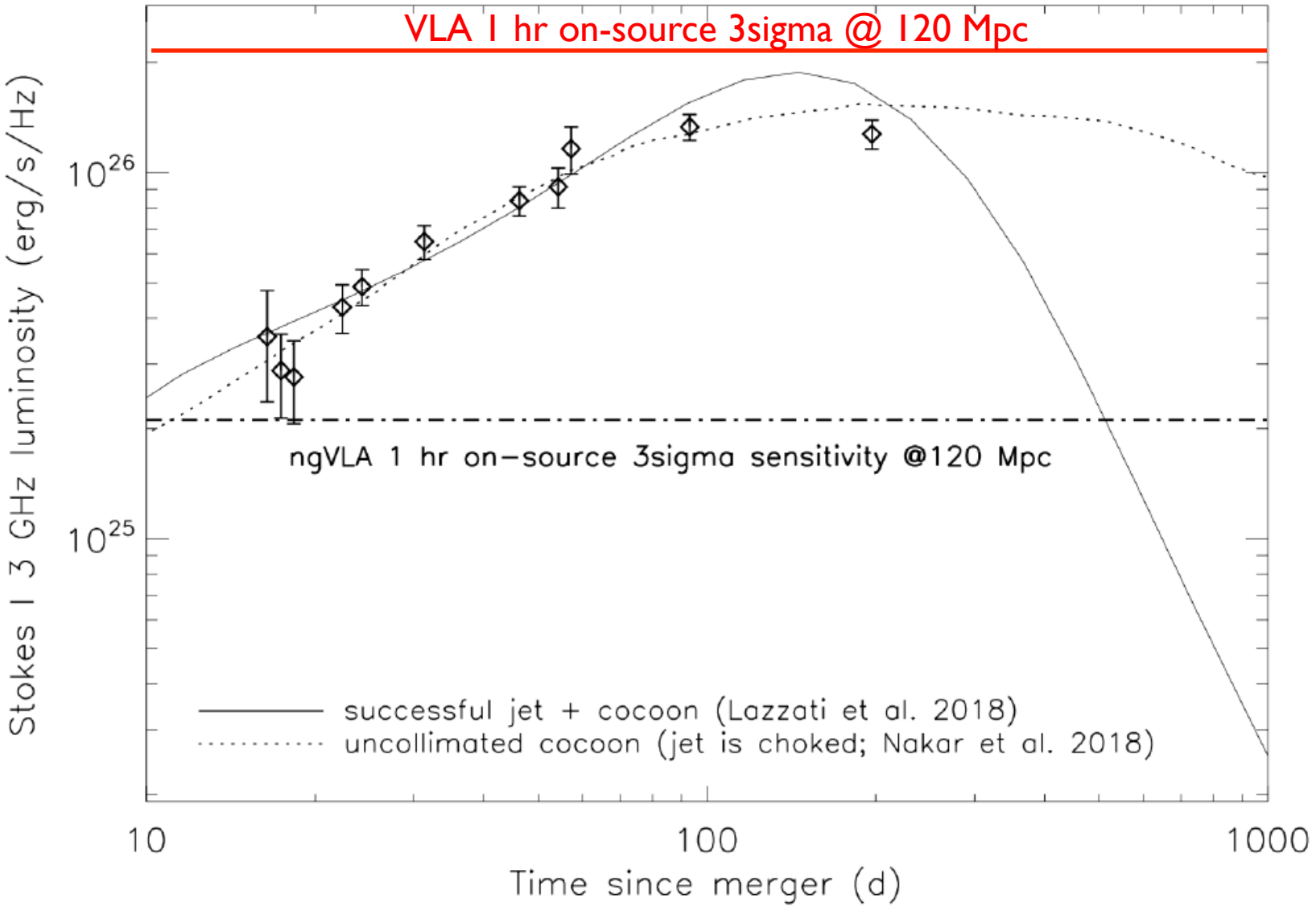
Credit: JAGWAR team

Advanced detectors expected progress

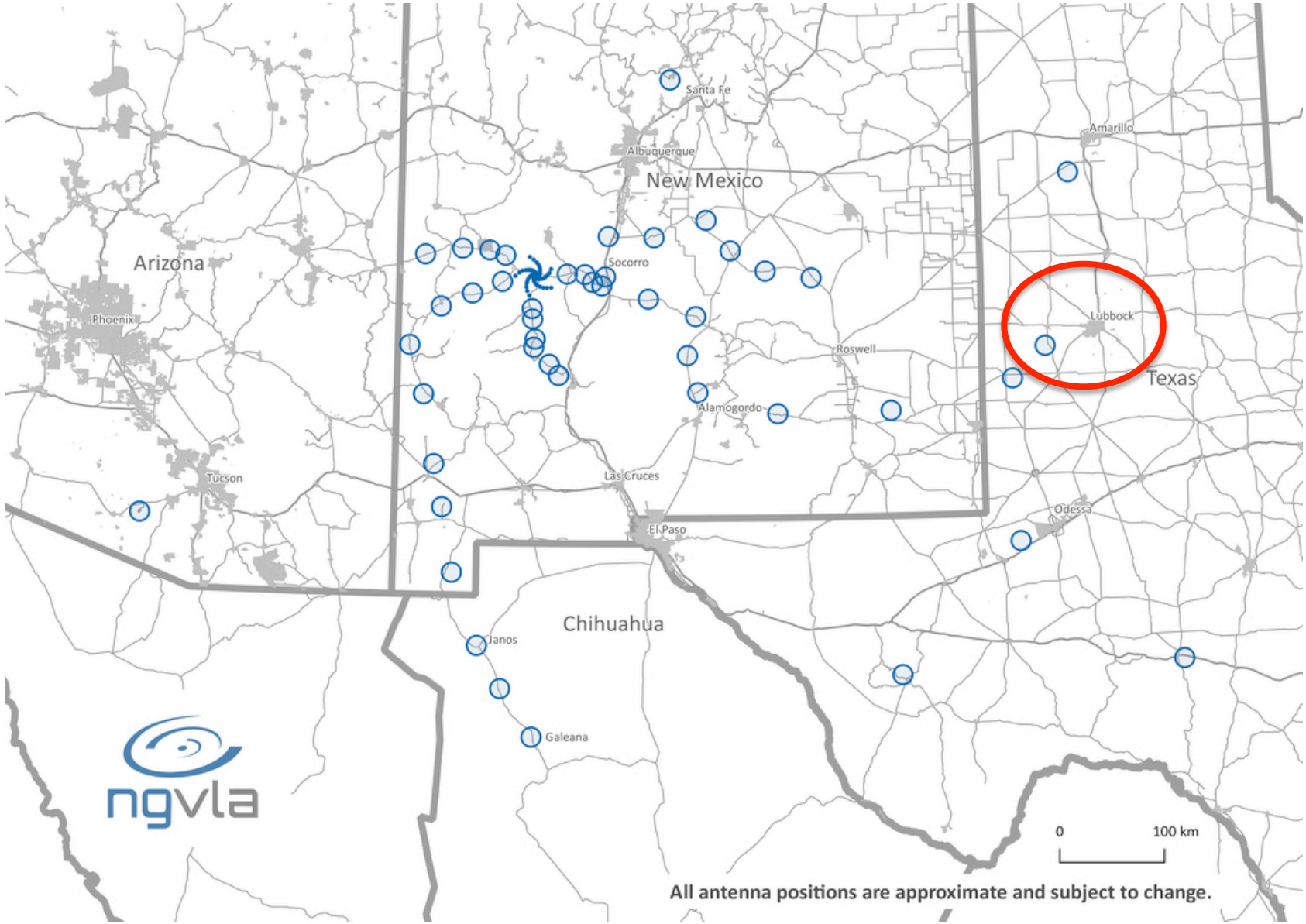


Abbott et al., Living Reviews in Relativity 19, 1 (2016)

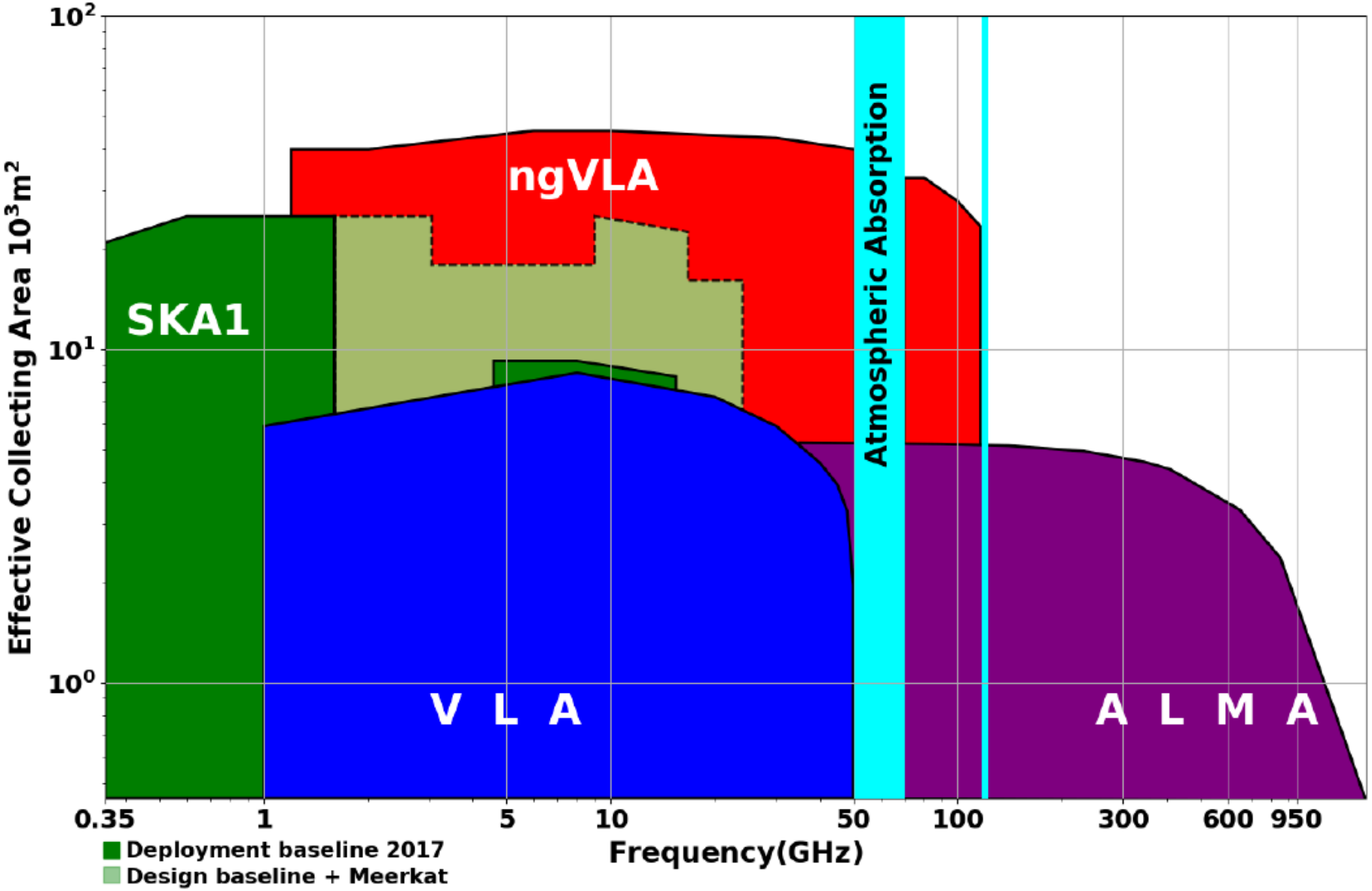
GW170817-like transient @ 120 Mpc: We need the next generation VLA!



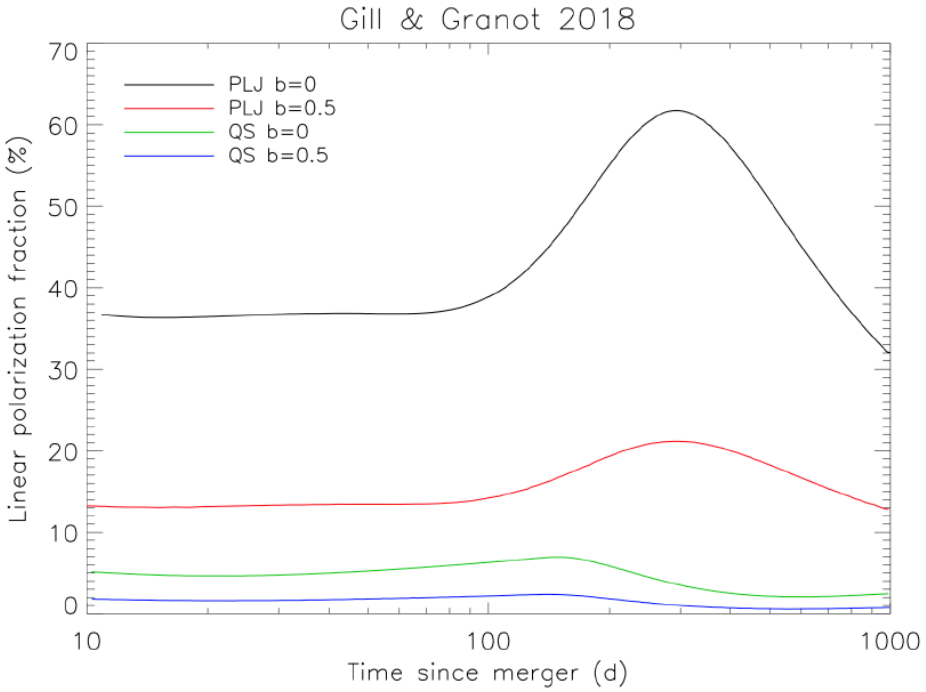
The next generation VLA (ngVLA)



The ngVLA projected sensitivity

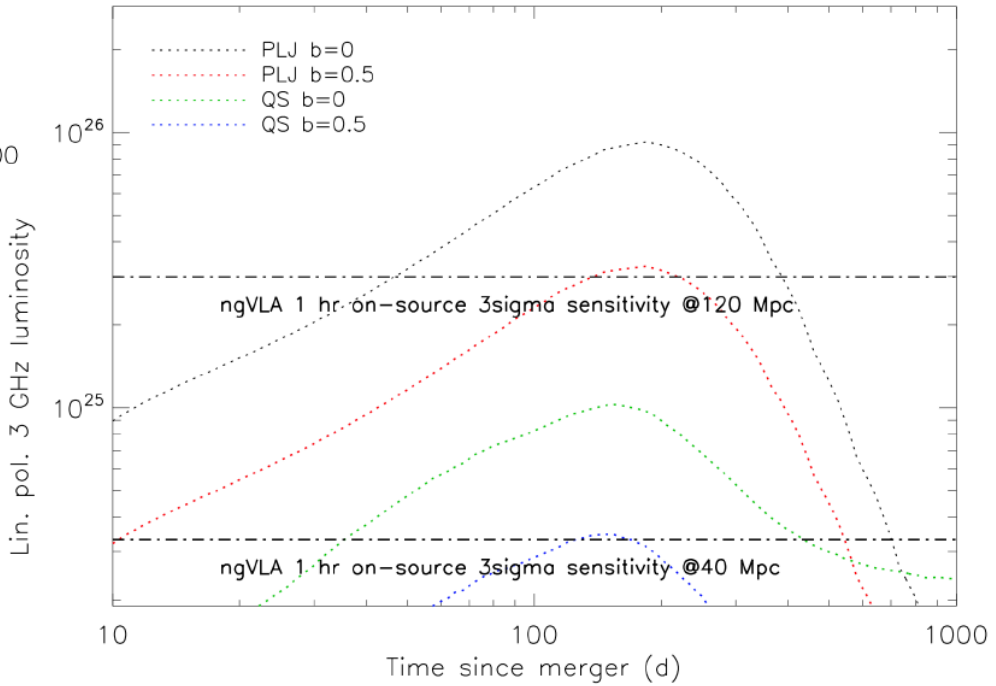


Prospects for radio polarization studies

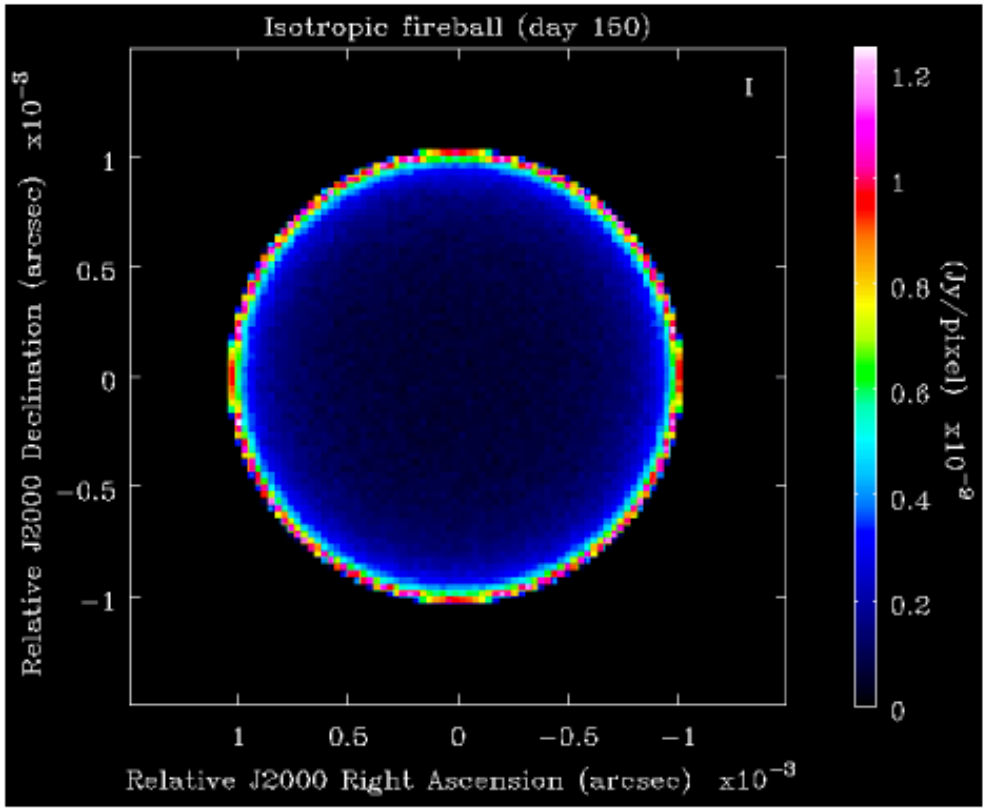


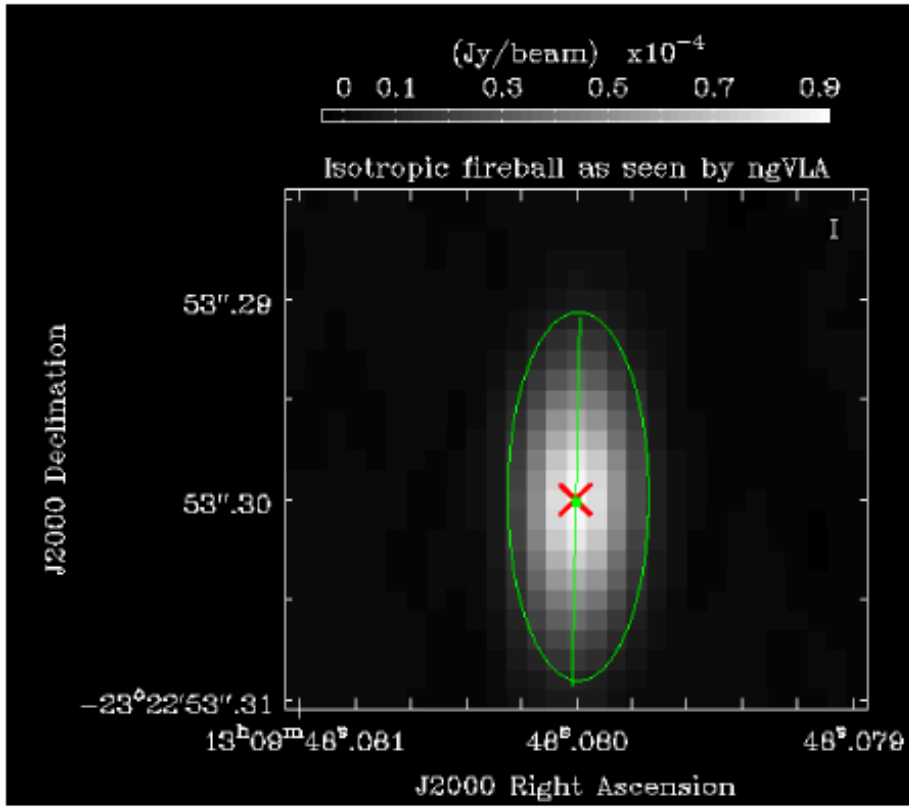
- Structured jet: energy and speed of ejecta components depend on polar angle → Emitting surface asymmetric for misaligned observers.

- Magnetic field appears to have some degree of "order" →appreciable degree of linear polarization.



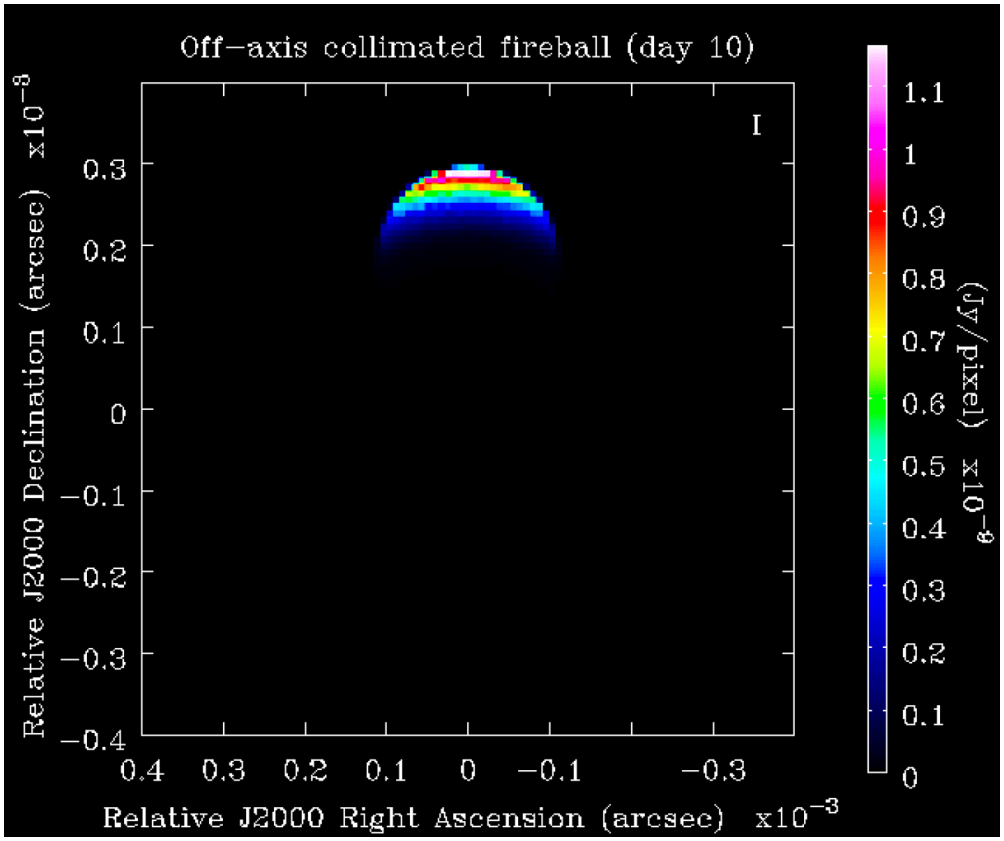
ngVLA+VLBA imaging: on-axis jet @150d

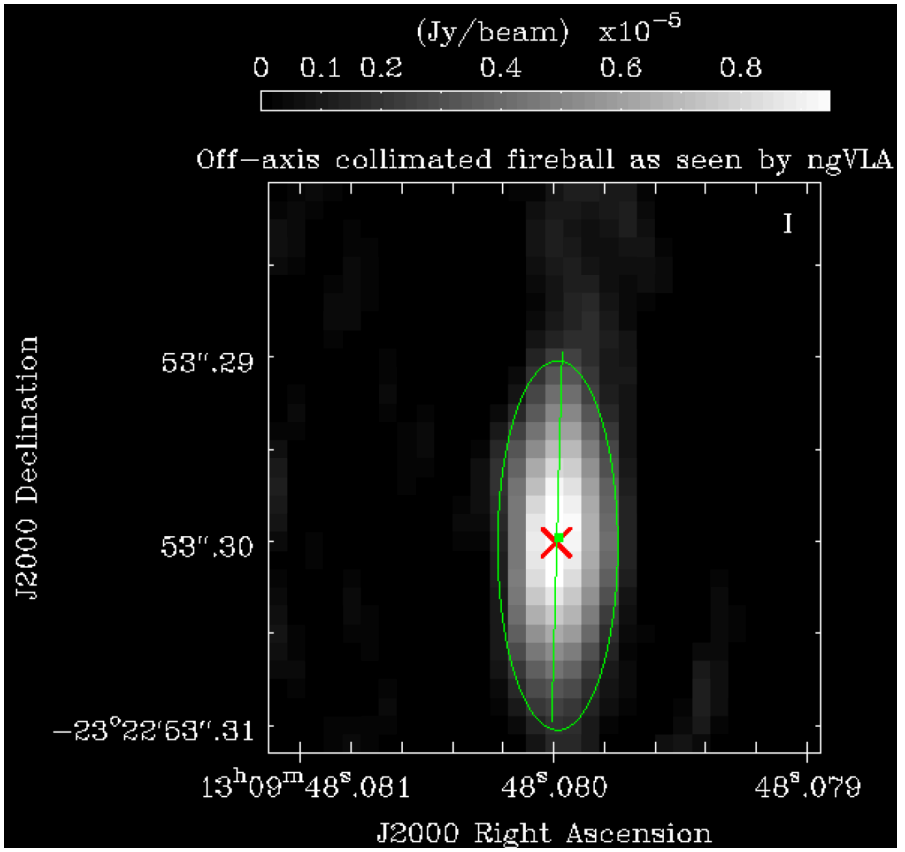




Corsi et al., ngVLA science book chapter
Model images credit: Davide Lazzati

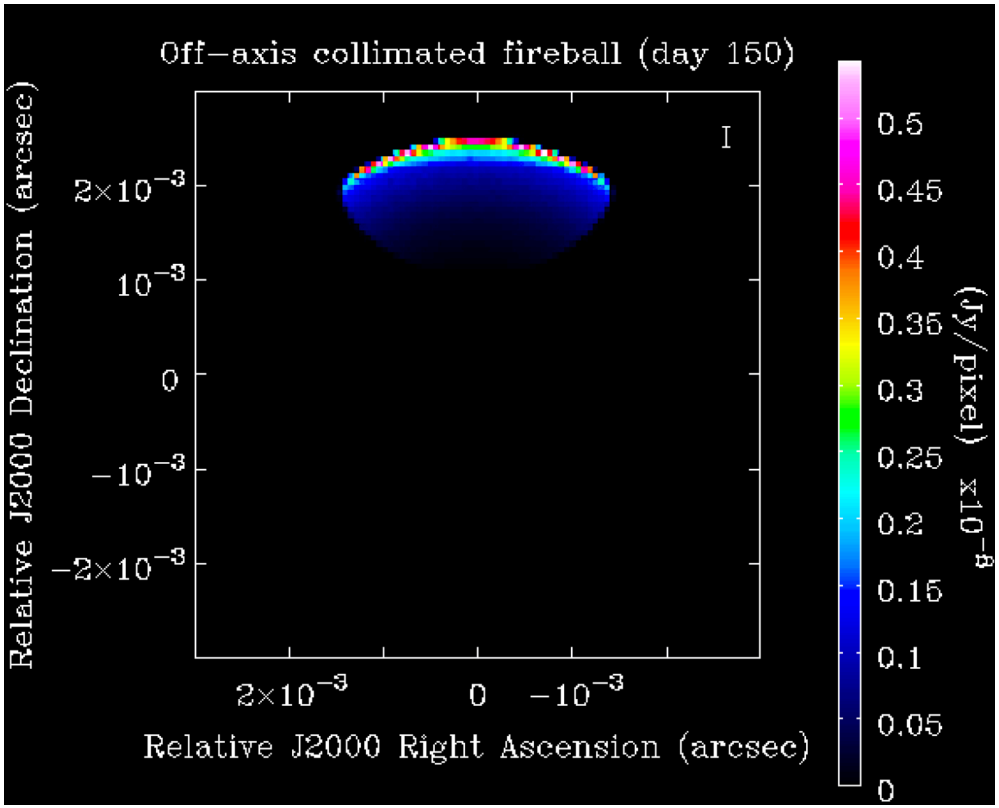
ngVLA+VLBA imaging: off-axis jet @10d

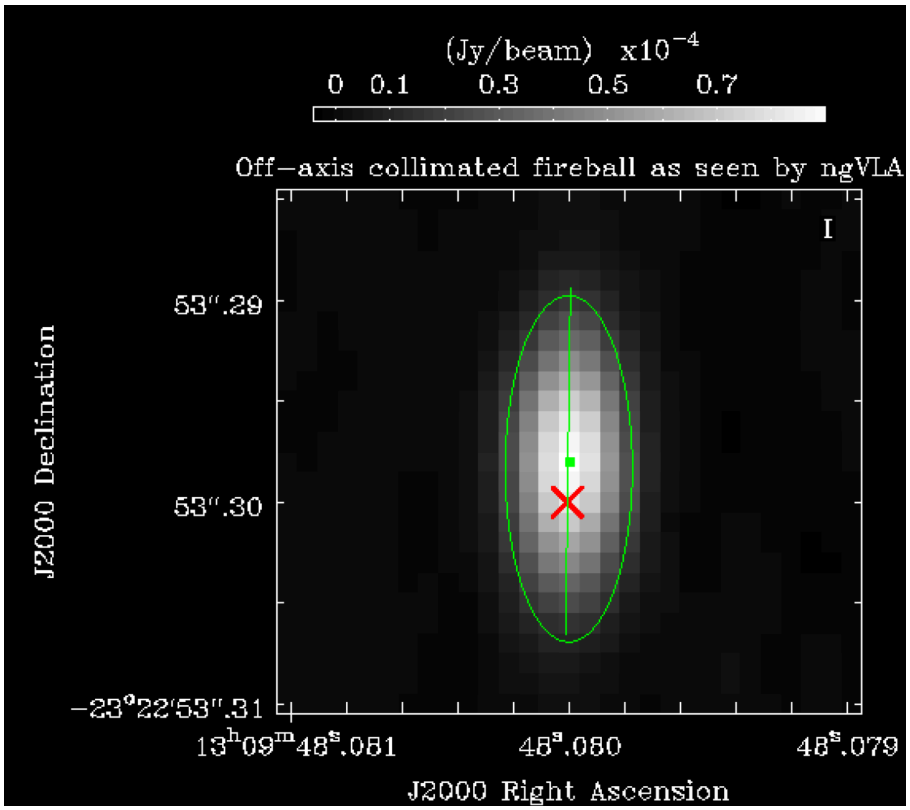




Corsi et al., ngVLA science book chapter
Model images credit: Davide Lazzati

ngVLA+VLBA imaging: off-axis jet @150d





Corsi et al., ngVLA science book chapter
Model images credit: Davide Lazzati

Conclusion and future prospects

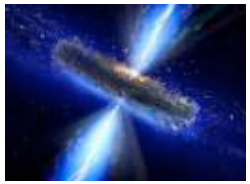
- LIGO-Virgo have made first direct measurements of GWs!
- Merging binary black hole and neutron star systems have been observed for the first time!
  'a scientific revolution'
- Plans are underway to improve LIGO (and Virgo) sensitivity for O3 and beyond.
- Don't forget to also improve radio facilities!

STAY TUNED!

TEXAS TECH UNIVERSITY™

TEXAS TECH UNIVERSITY
From here, it's possible.

TEXAS TECH UNIVERSITY
Graduate Study in Physics and Astrophysics Research



TO APPLY AND FOR MORE INFO:

http://www.depts.ttu.edu/phas/Academics/Graduate_Program/Prospective_Students/index.php

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

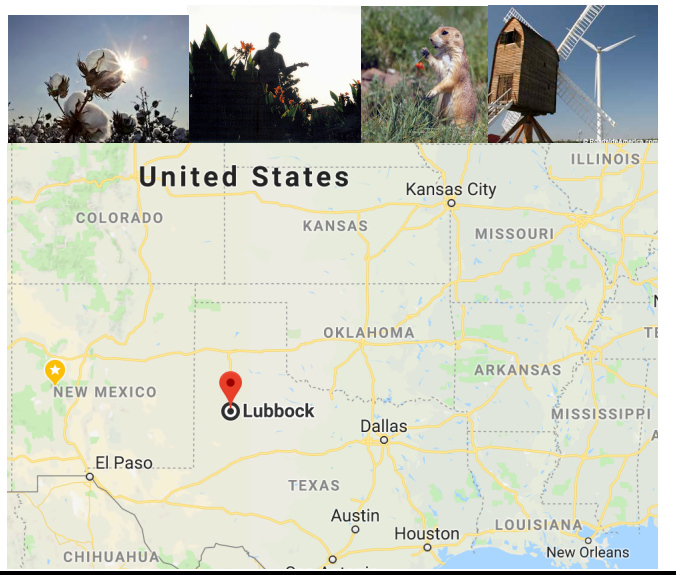
Stellar Populations in Nearby Galaxies
- X-ray binary populations of nearby galaxies.

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

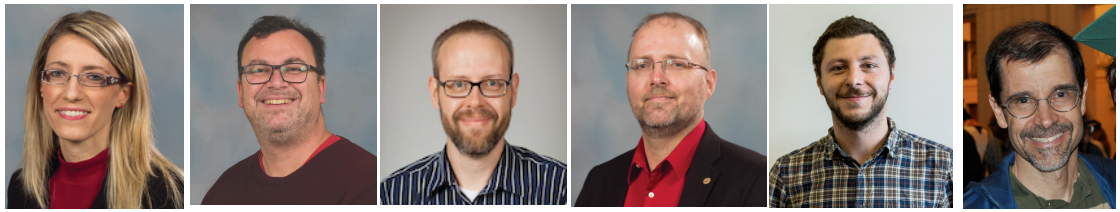
Instrumentation and Collaborations
- STROBE-X – X-ray Timing and Spectroscopy on Dynamical Timescales from Microsecs to Yrs.
- Small telescopes for photometric follow-up of targets from exoplanet transit surveys.
- We are part of: CTA, DLT40, GROWTH, LIGO, ngVLA.

LSC LIGO Scientific Collaboration

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

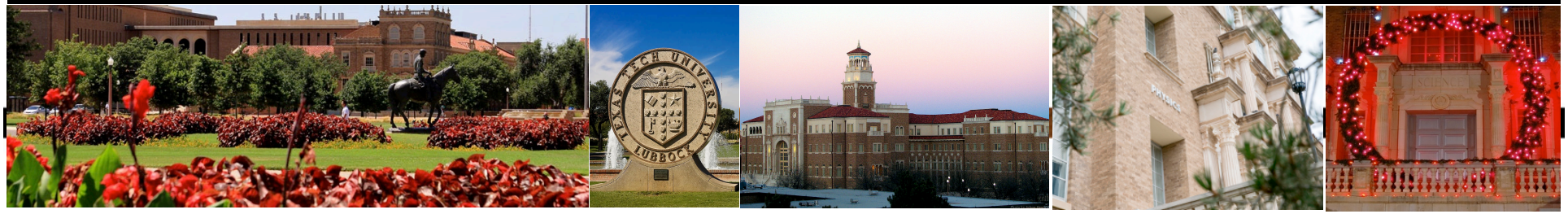


QUESTIONS? *Contact us:*

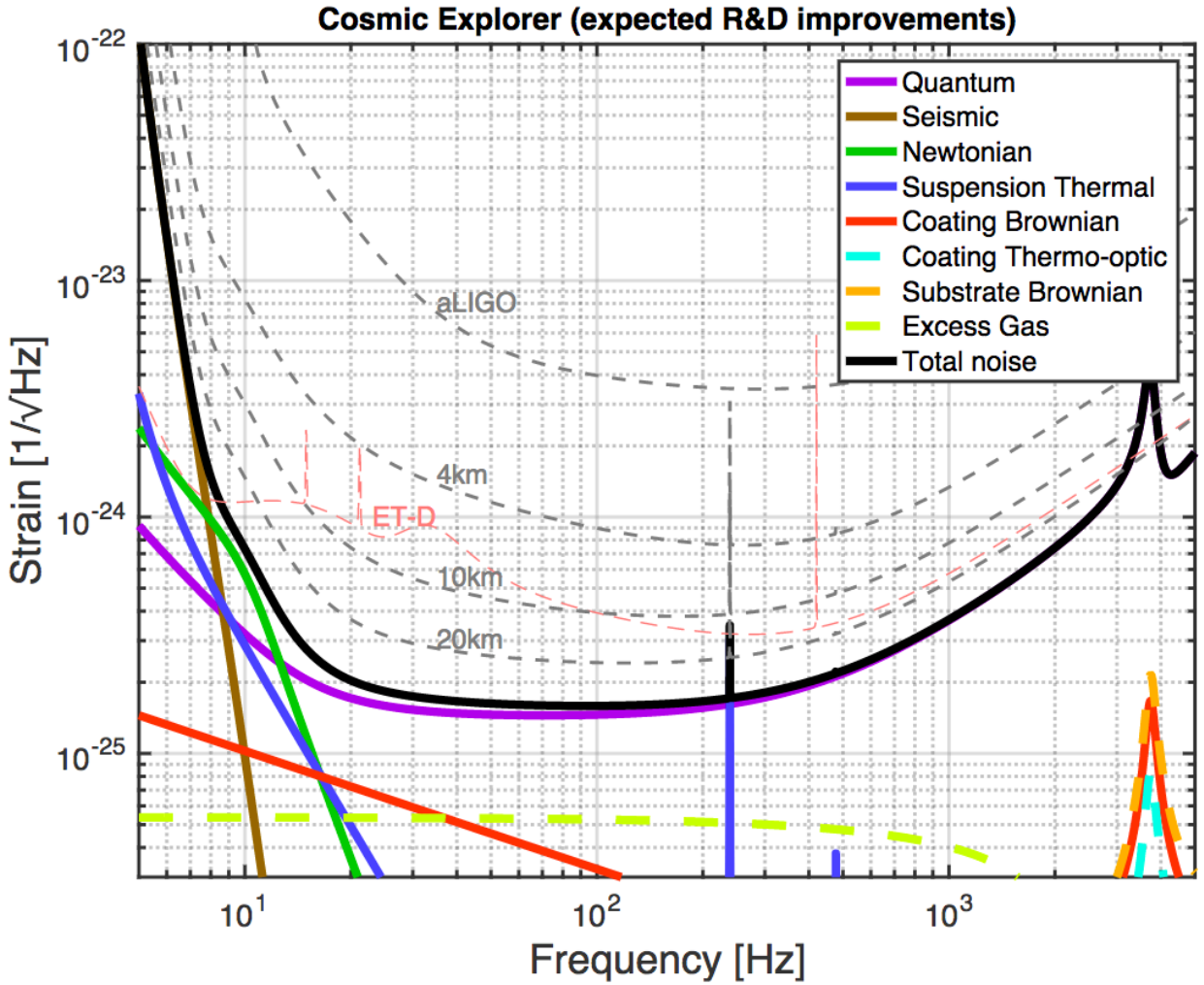


A. Corsi | T. Maccarone | R. Morehead | B. Owen | S. Scaringi | J. Romano

"Easily one of the ten most beautiful campuses" (Stewart Mandel) - "Most beautiful west of the Mississippi until you get to Stanford" (James A. Michener)

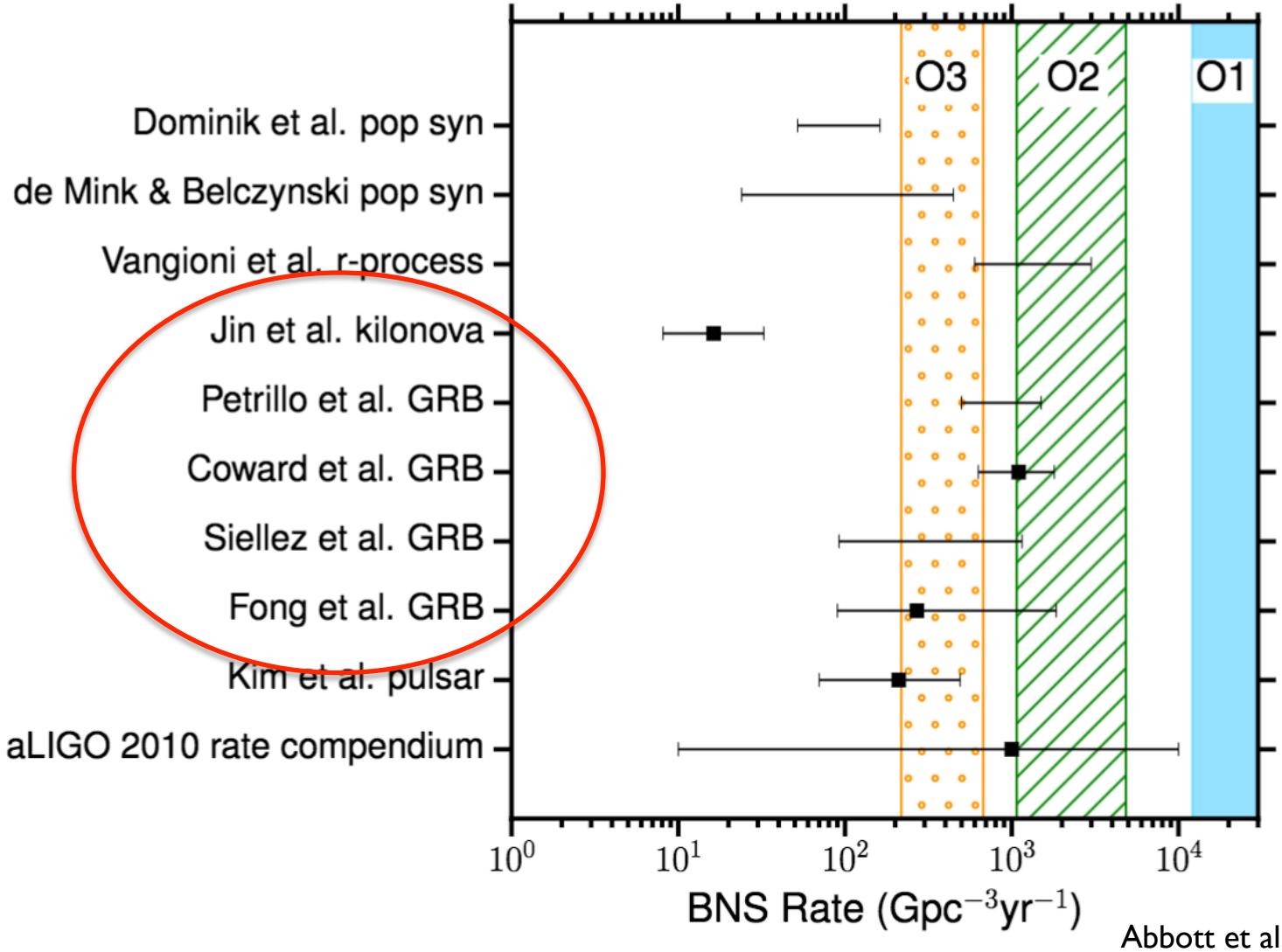


Future of ground-based GW astronomy



- Technology expected to be operational 10-15 yrs from now.
- Abbott et al. 2017, CQG, 34, 4001A

Expectations for NS-NS rates

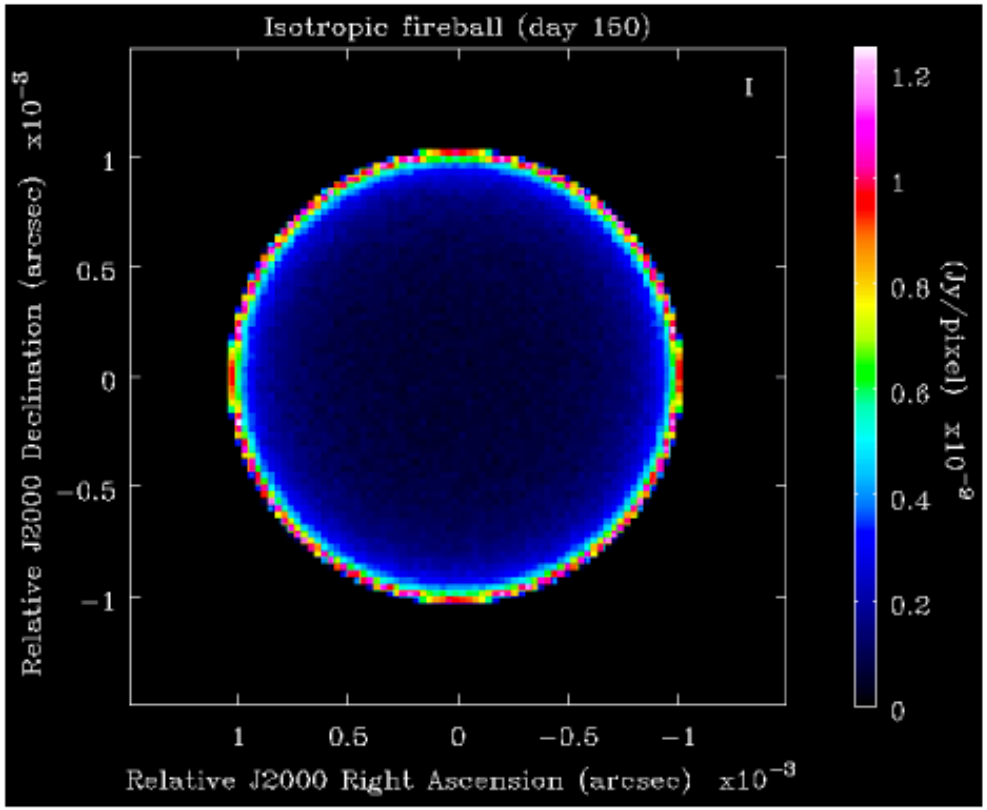


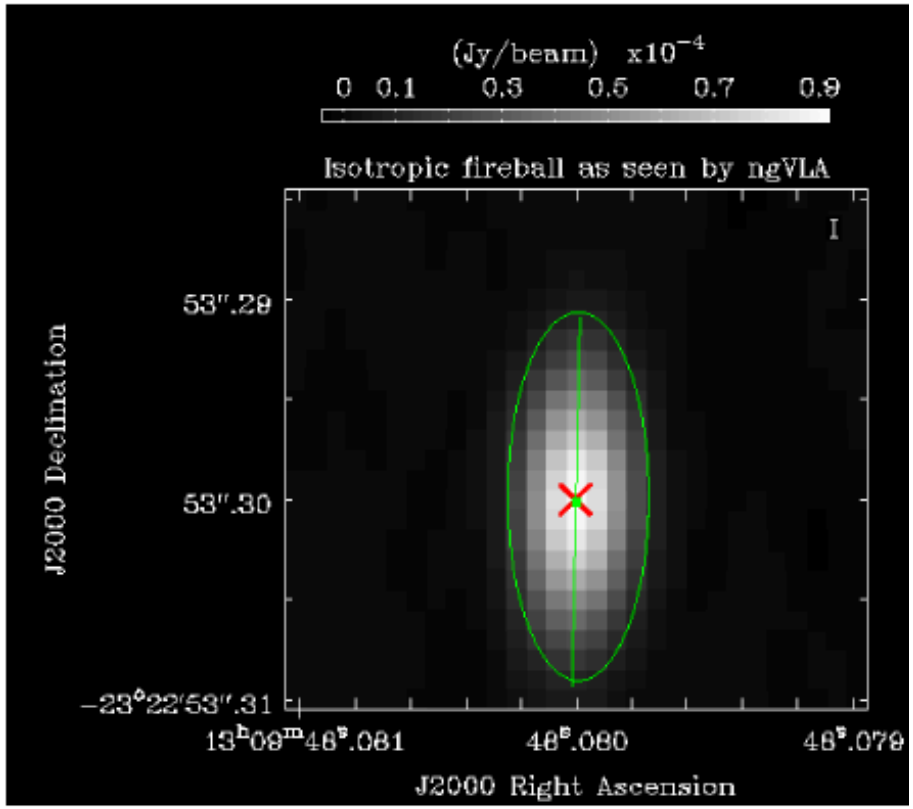
NS-NS rate after GW170817: $(1.5^{+3.2}_{-1.2})\times10^3$ Gpc^{-3} yr^{-1}

BBH rate:
2–213 Gpc^{-3} yr^{-1}

Abbott et al. 2016, ApJ, 832, L21

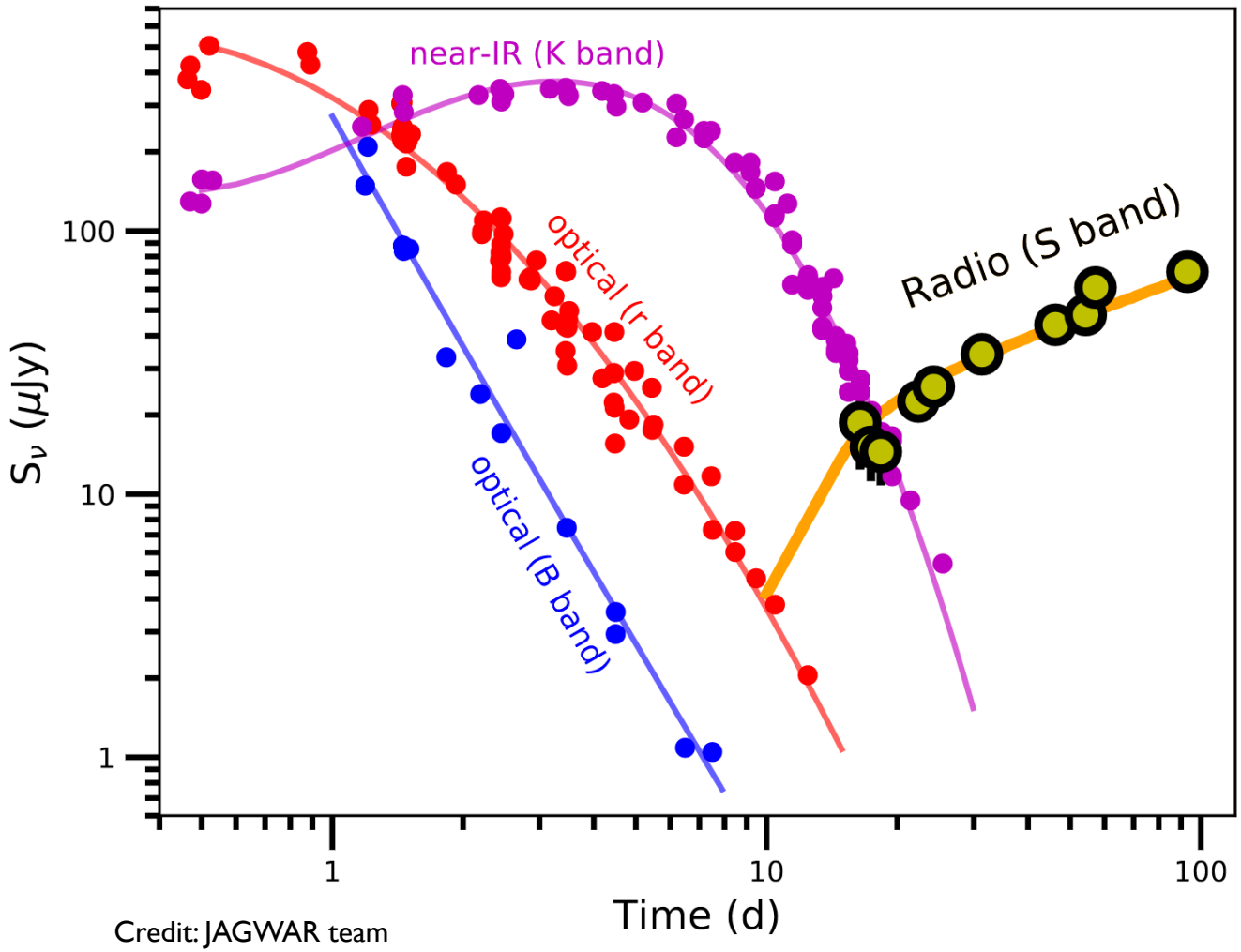
Prospects for ngVLA+VLBA imaging: isotropic fireball





Corsi et al., ngVLA science book chapter
Model images credit: Davide Lazzati

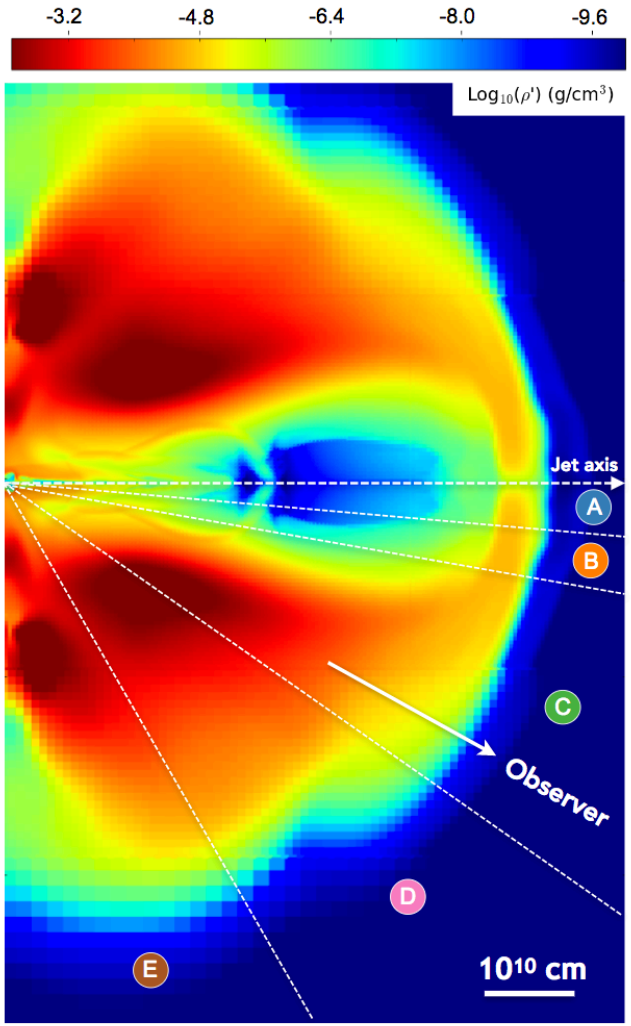
A puzzling EM counterpart



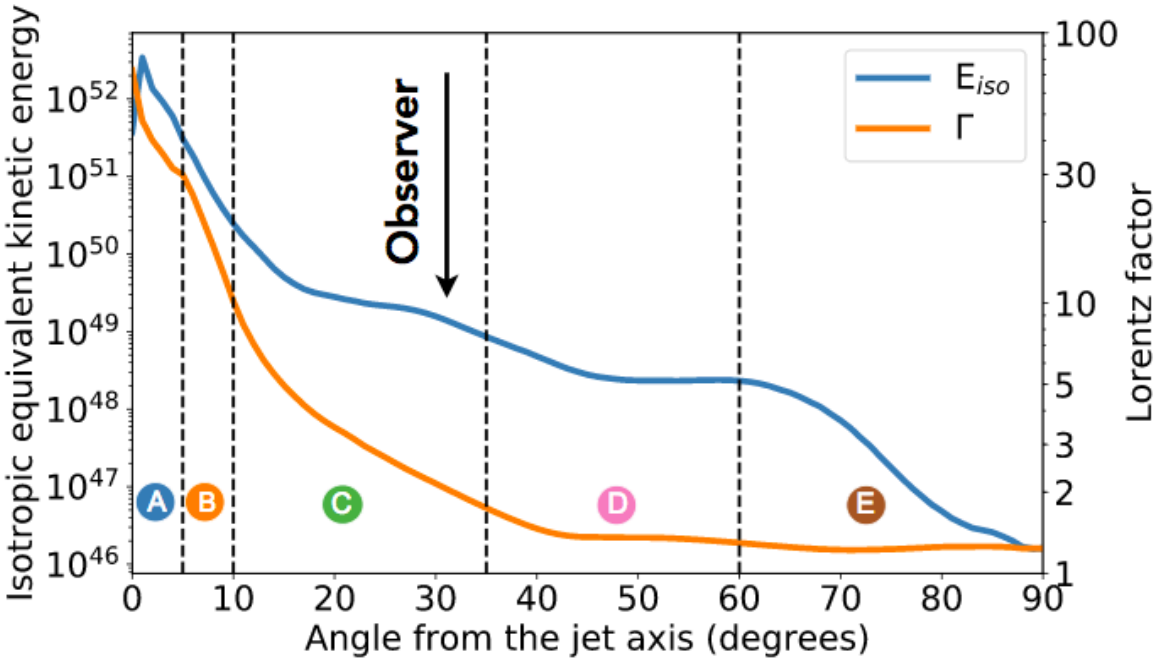
Credit: JAGWAR team

Instead of bright γ-rays from an on-axis relativistic jet, just a red kilonova, and a relatively prompt radio/X-ray afterglow, we saw **γ-rays a factor of ~1000 weaker** than for ordinary short GRBs, an **early blue kilonova**, and **late radio/X-ray** emission.

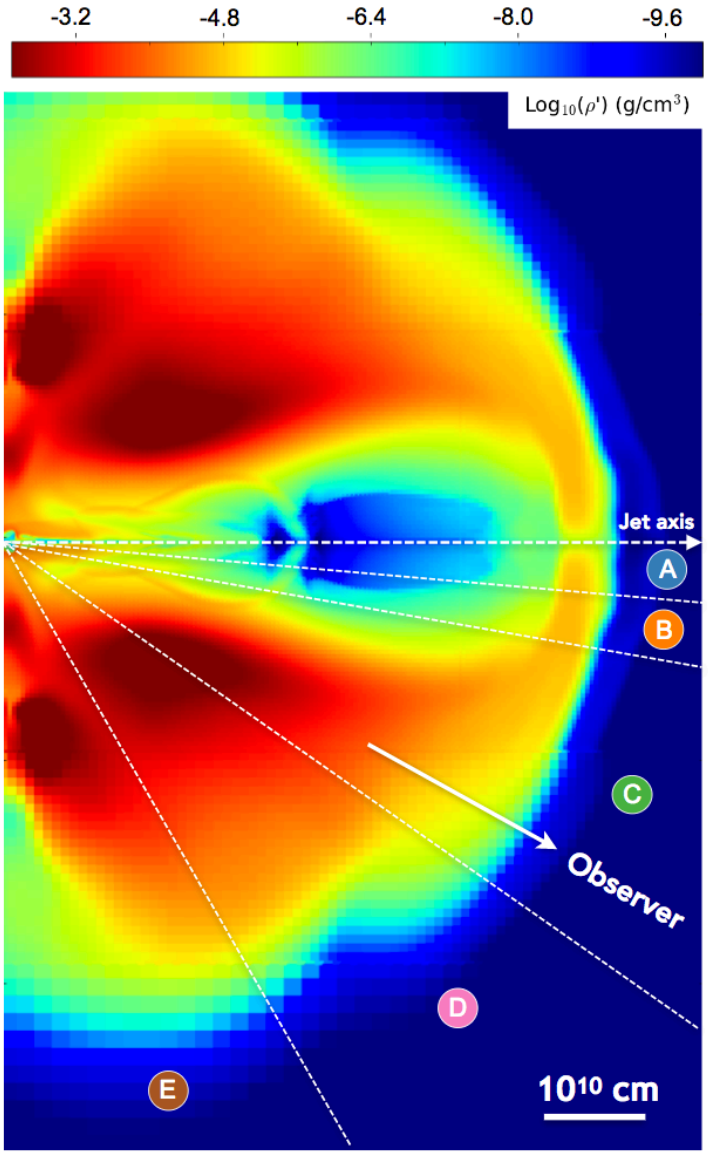
A successful structured jet - continued



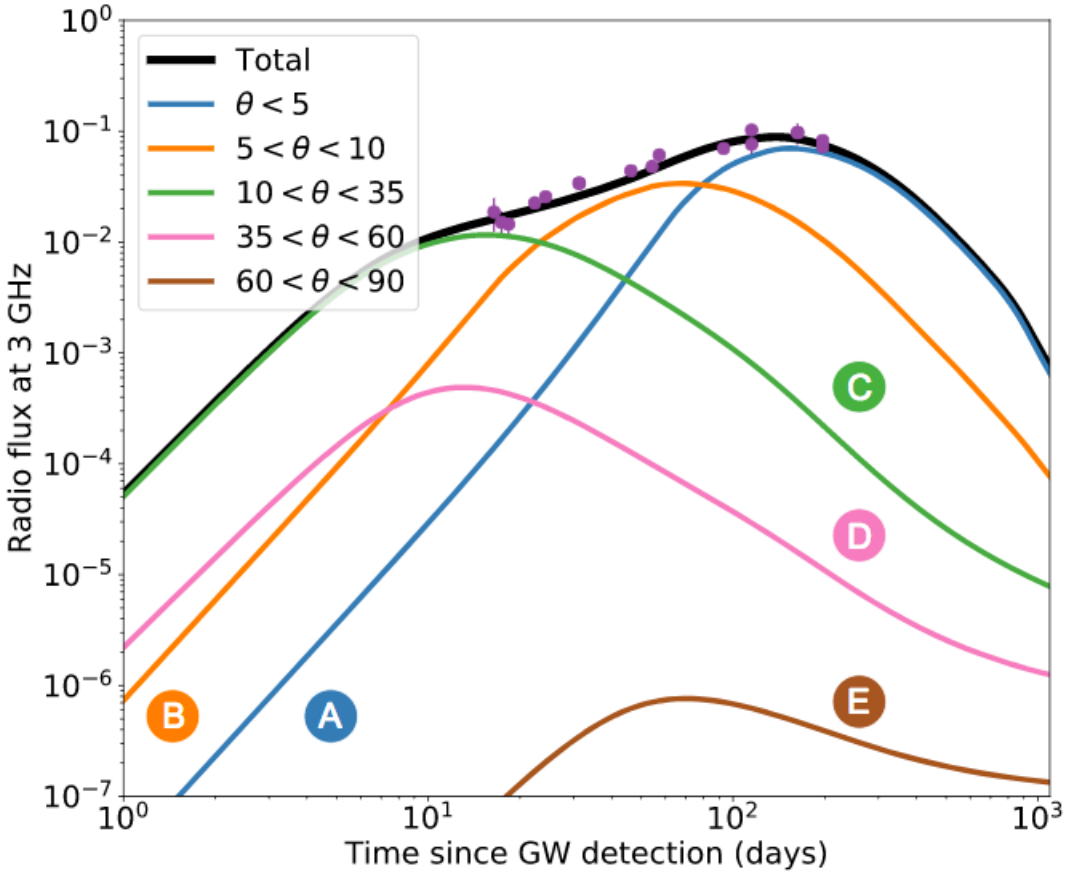
Lazzati et al. 2017, arXiv:1712.03237



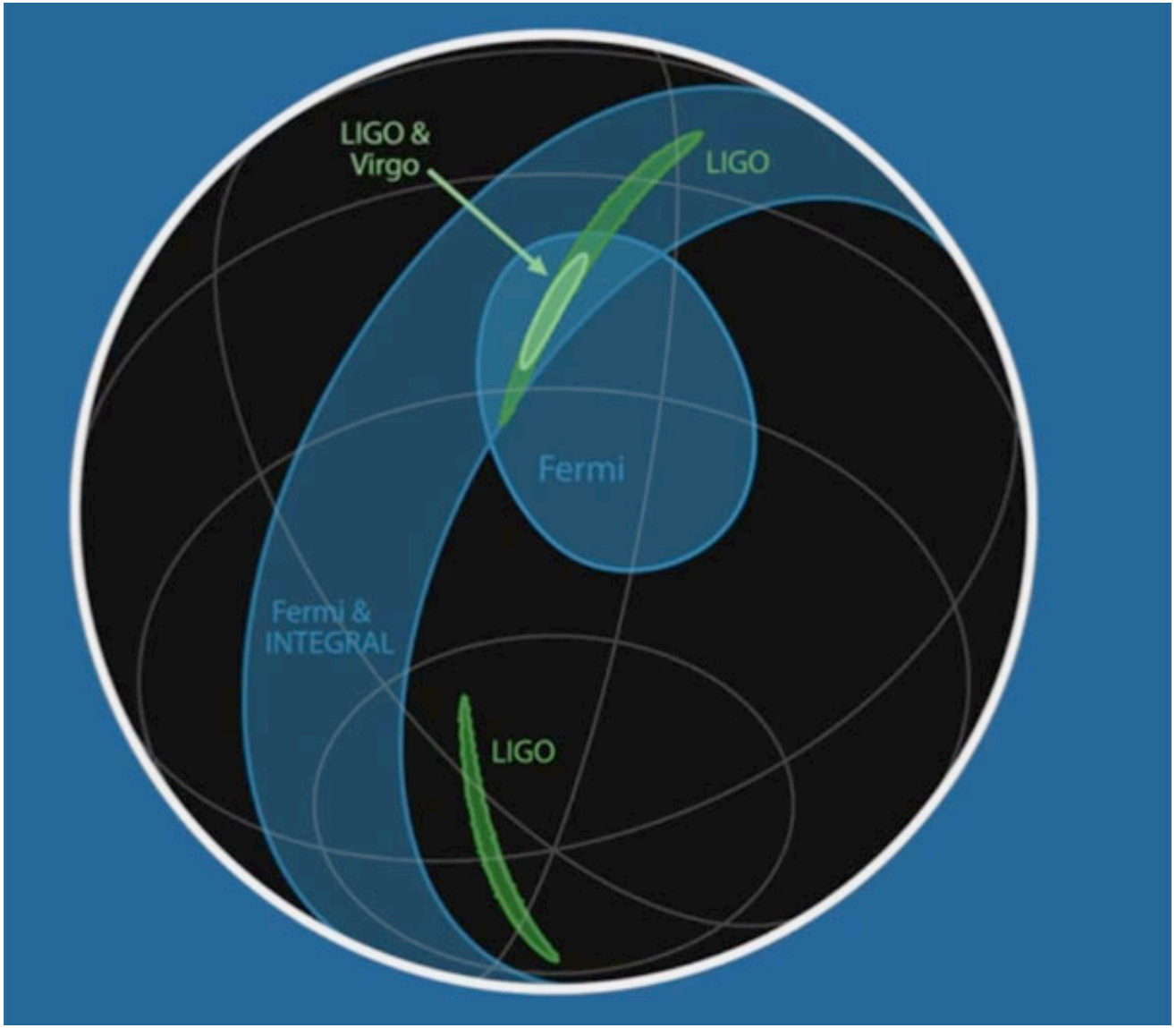
A successful structured jet



Lazzati et al. 2017, arXiv:1712.03237



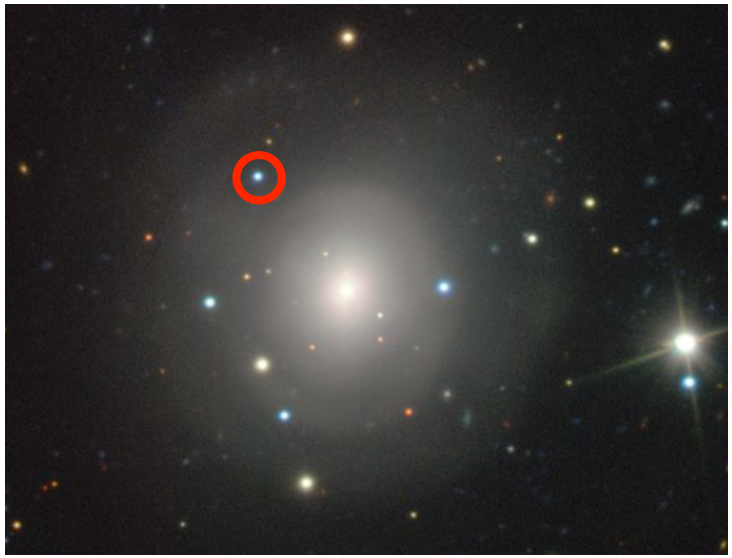
GW170817: Sky localization



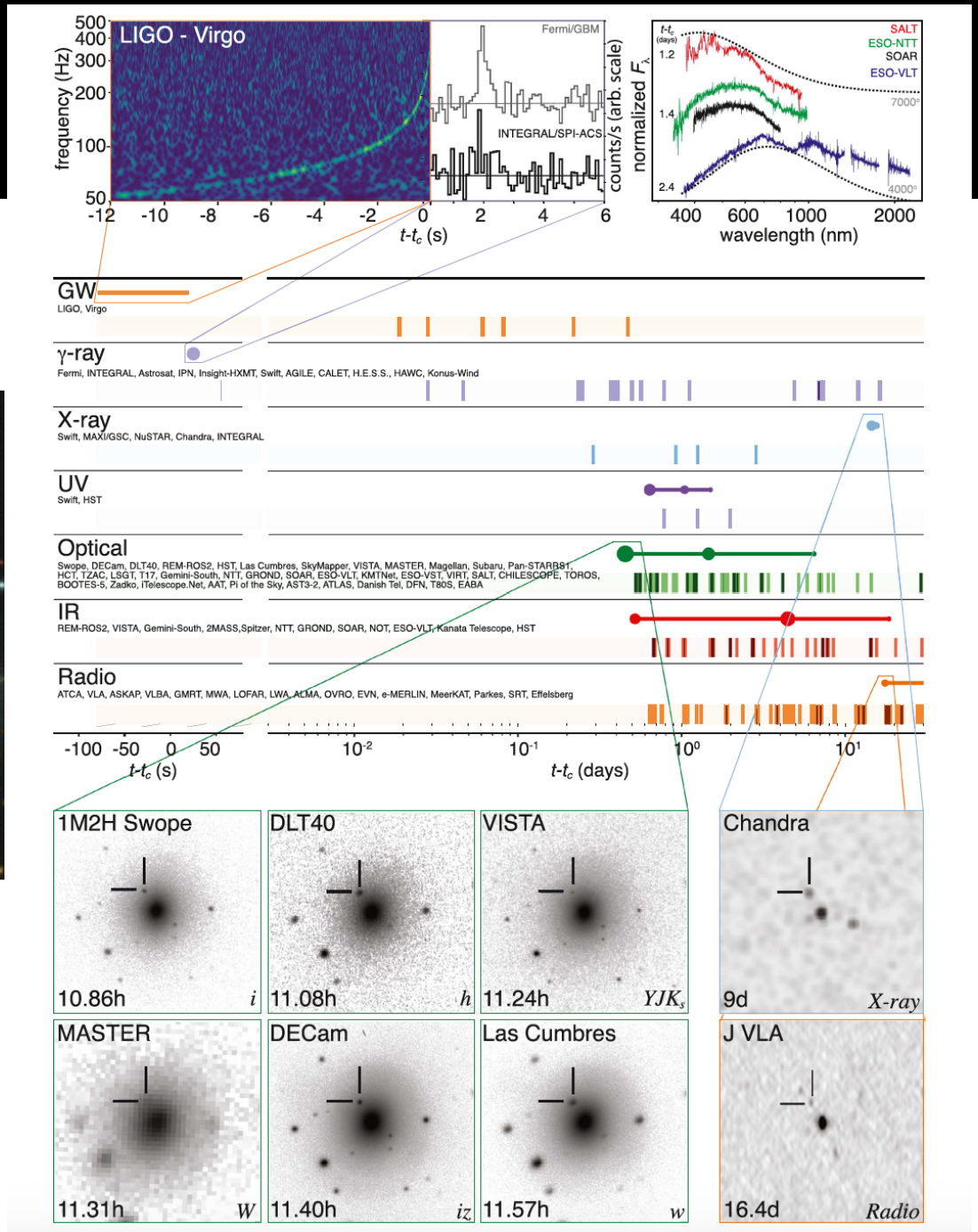
Combination of LIGO, Virgo, Fermi, and Integral localizations for GW170817: final patch is about 30 sqr deg in area.

Credit: LIGO / Virgo

NS-NS merger @ 40 Mpc

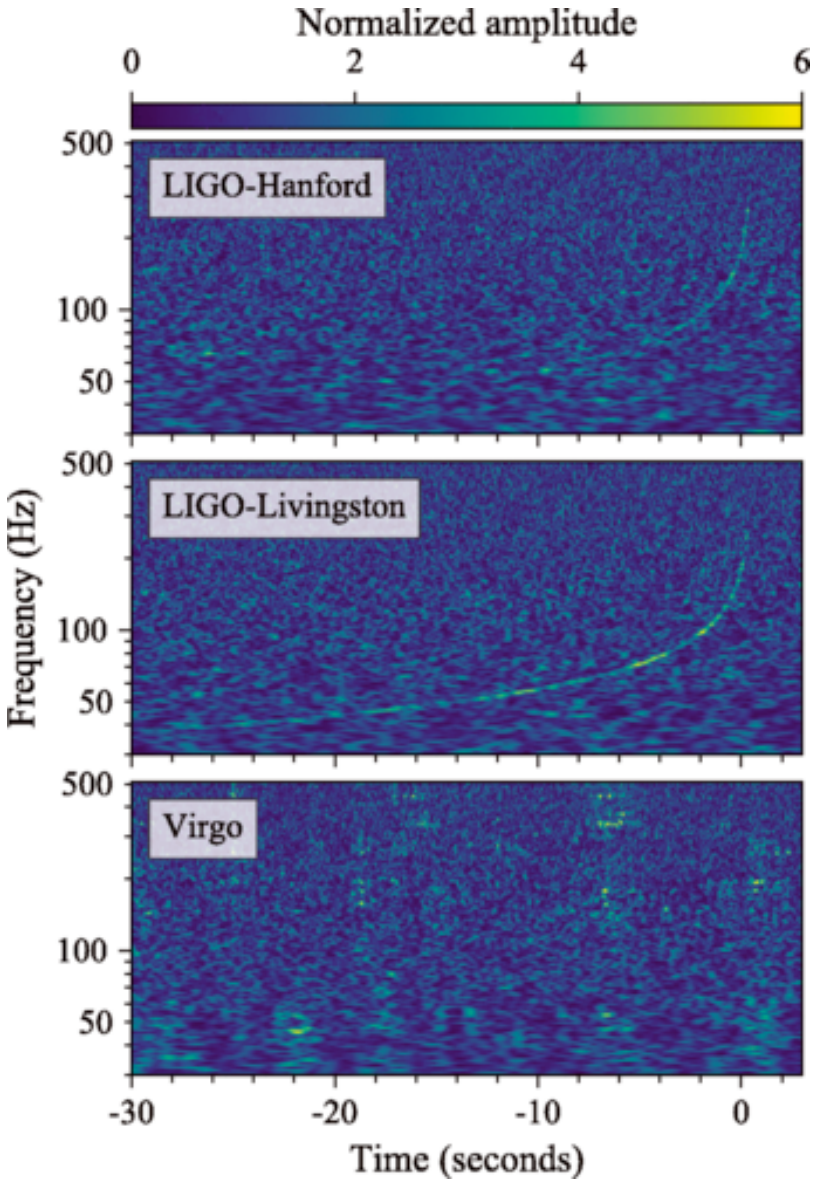


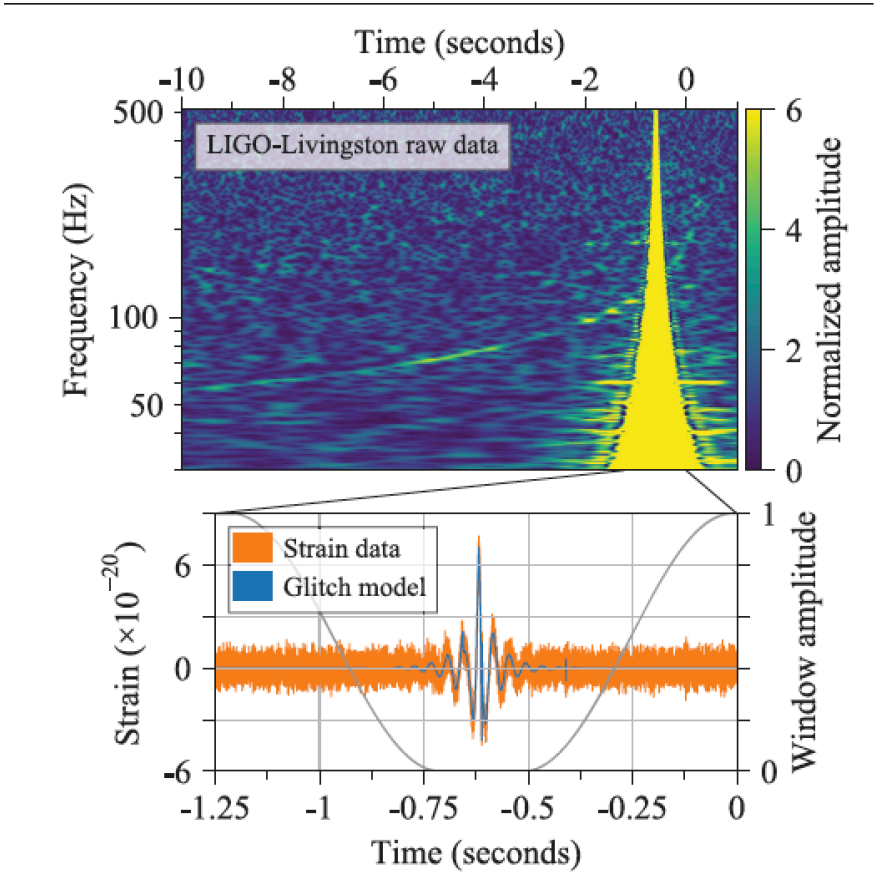
Credit: European Southern Observatory
Very Large Telescope



Abbott et al., ApJL, 848:L12, 2017

GW170817: 1st LIGO-Virgo NS merger





The gravitational-wave strain amplitude of GW170817 is of the order of 10^{-22} and so is not visible in the bottom panel

Abbott et al. 2017, PRL, 119, 1101