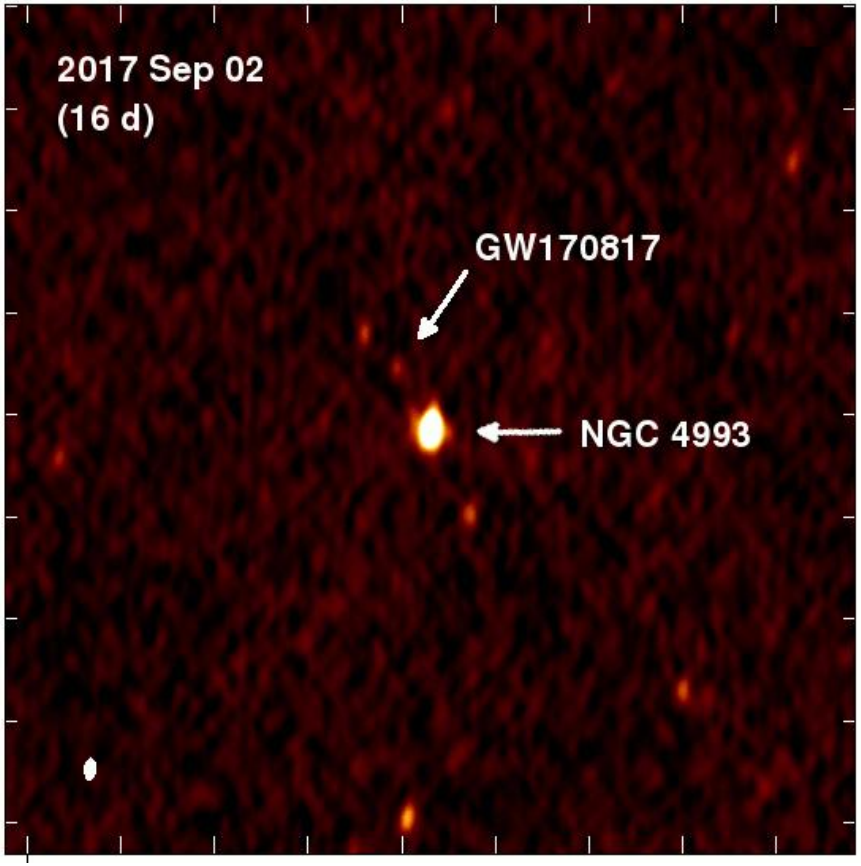
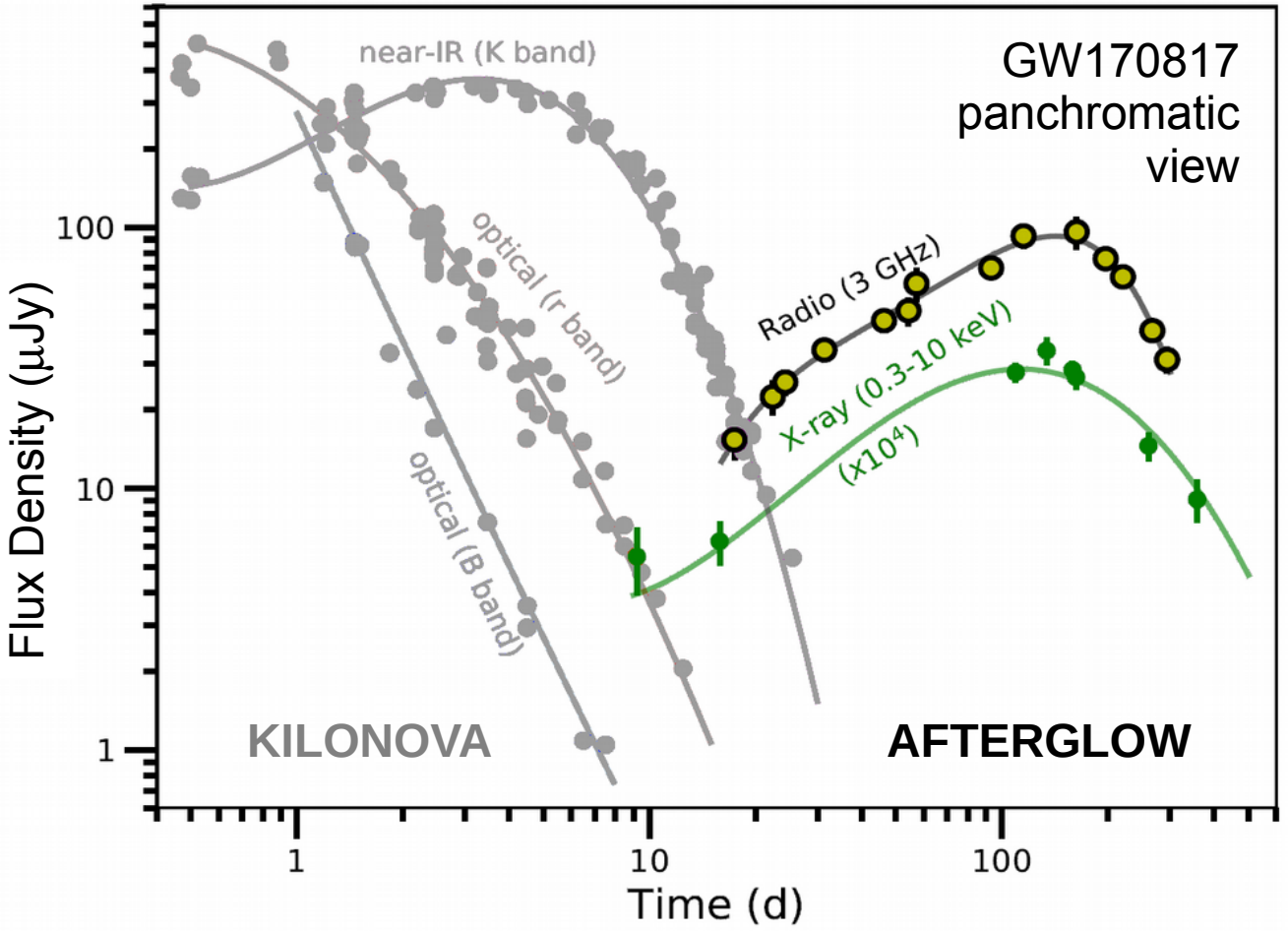
The Radio Afterglow of GW170817



Kunal P. Mooley (Jansky Fellow, NRAO, Caltech); Gregg Hallinan; Adam Deller; Alessandra Corsi; Ore Gottlieb; Ehud Nakar; Kenta Hotokezaka; Dale Frail; Mansi Kasliwal; Stephen Bourke; Assaf Horesh; Kishalay De; Dougal Dobie; David Kaplan; Poonam Chandra; Fernando Camilo; Rob Fender; Sharmila Goedhart; Ian Heywood; Shri Kulkarni; Davide Lazzati; Emil Lenc; Christine Lynch; Sphe Makhatini; Eric Murphy; Tara Murphy; Steven Myers; Samaya Nissanke; Tsvi Piran; Javed Rana; Leo Singer; Oleg Smirnov; Keith Bannister; Varun Bhalerao; Dario Carbone; Patrick Woudt (**JAGWAR Collaboration**)

Outline



GROWTH

1. **DISCOVERY**
   Hallinan et al. 2017, *Science*, 358, 1579

2. **SLOW RISE**
   Mooley et al. 2018a, *Nature*, 554, 207

3. **TURNOVER**
   Dobie et al. 2018, *ApJ Letters*, 858, 15

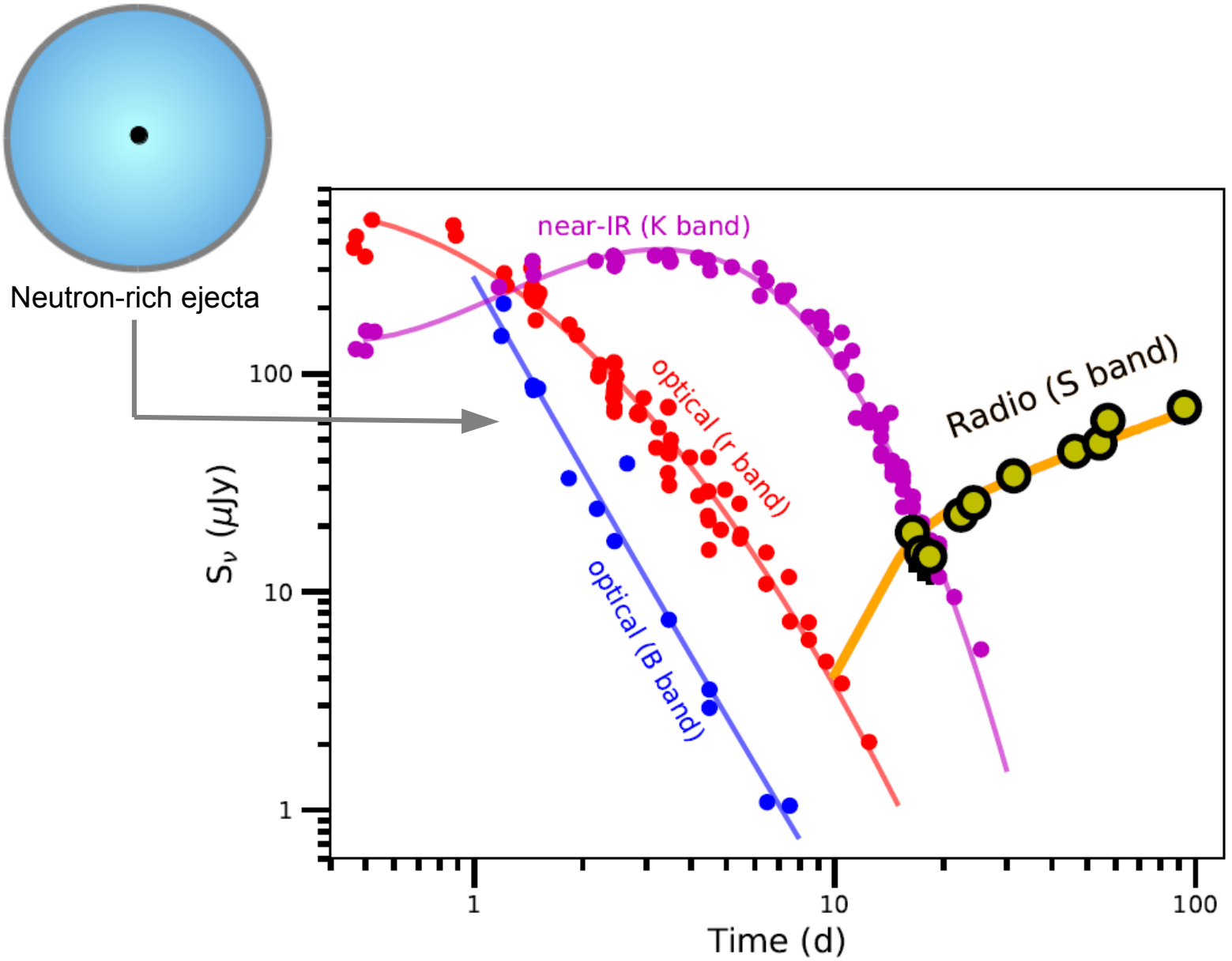
4. **POLARIZATION**
   Corsi et al. 2018, *ApJ Letters, 861, 10*

5. **VLBI**
   Mooley et al. 2018b, *Nature*, 561, 355

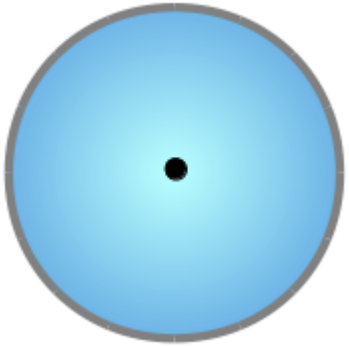
6. **DECLINE**
   Mooley et al. 2018c, *ApJ Letters,* 868, 11

Also see poster by Dougal Dobie

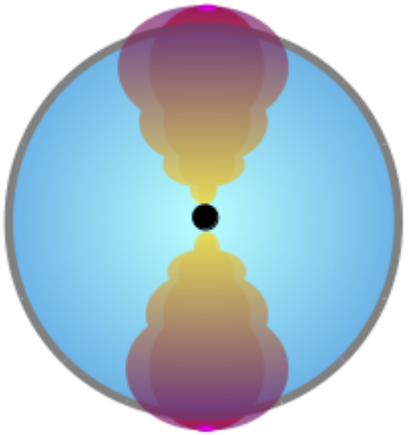
GW170817 Panchromatic View



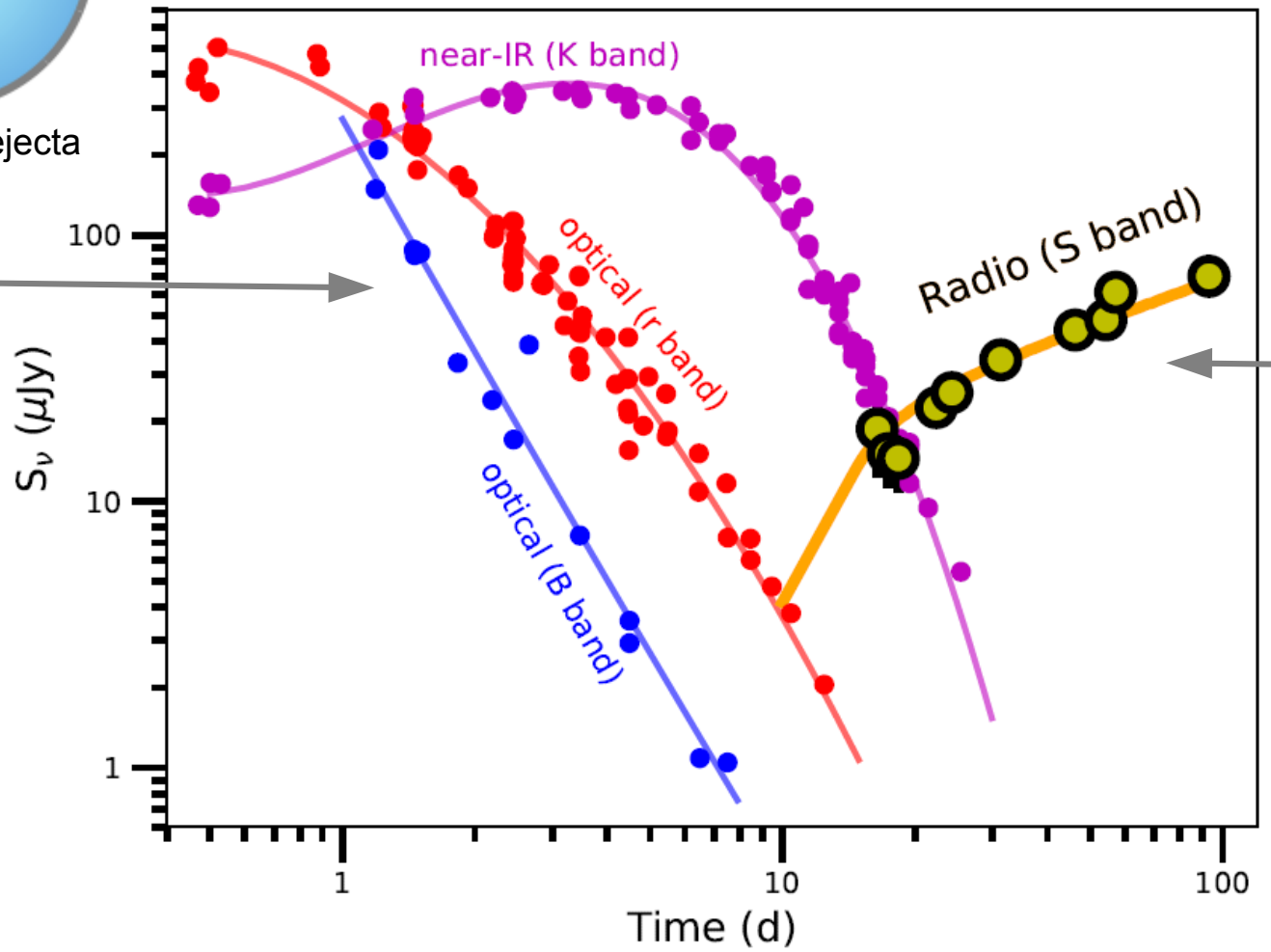
GW170817 Panchromatic View



Neutron-rich ejecta



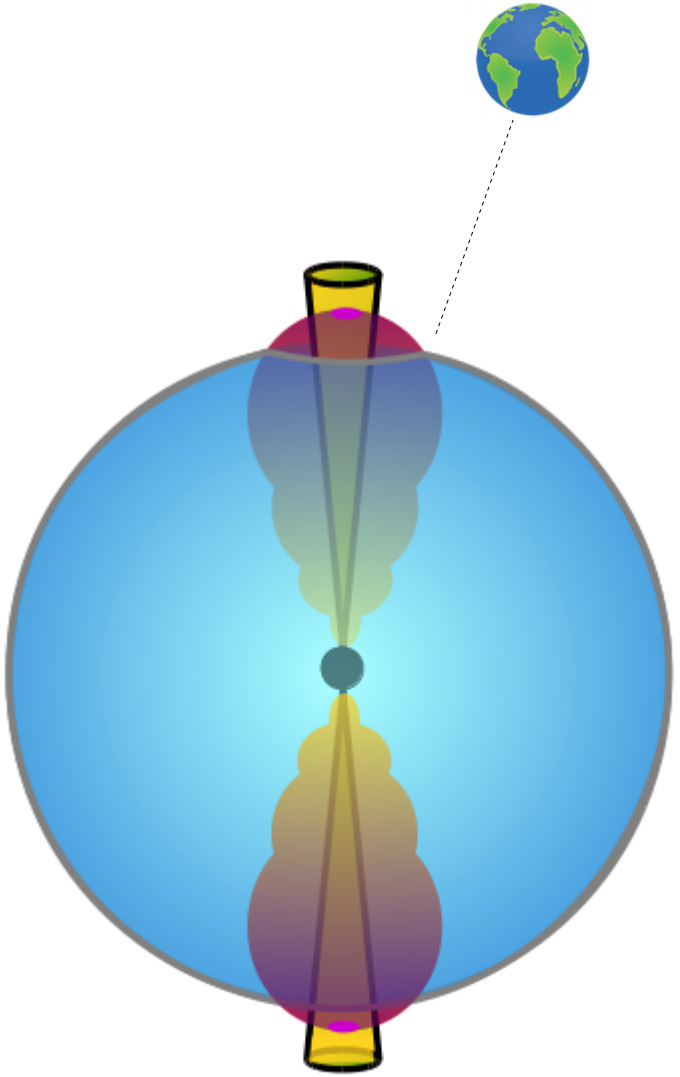
Wide-angle outflow



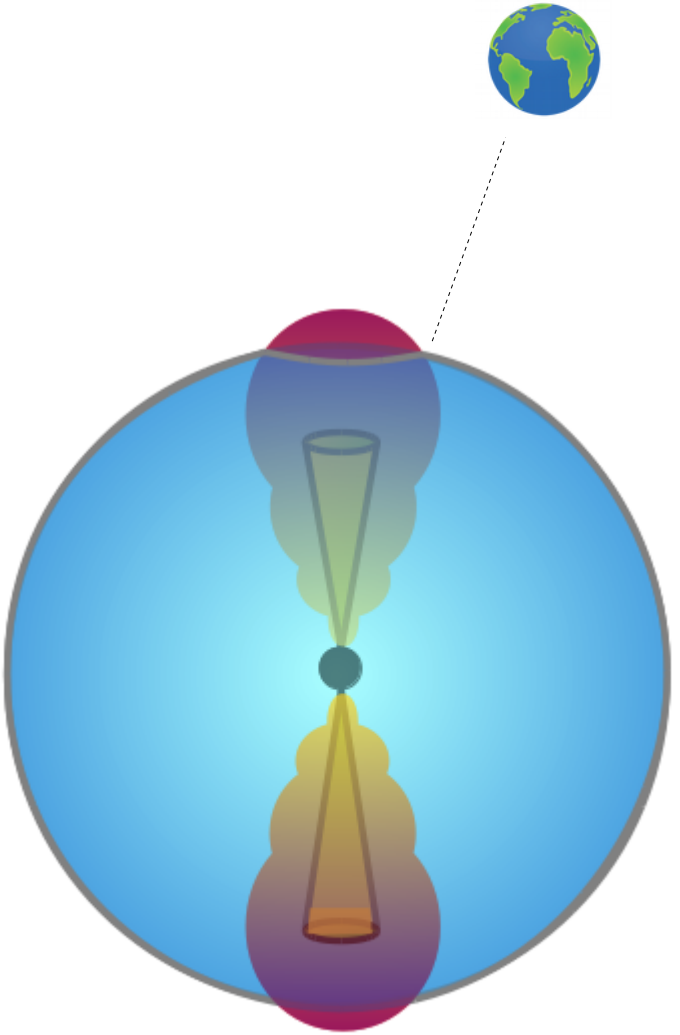
Mooley et al. 2018a (Nature)

Also see Margutti et al. 2018, Ruan et al. 2018, D'Avanzo et al. 2018, Troja et al. 2018a, Resmi et al. 2017 etc.

Did GW170817 launch a Successful Jet?



(A)
Successful jet + cocoon
(a.k.a. structured jet)

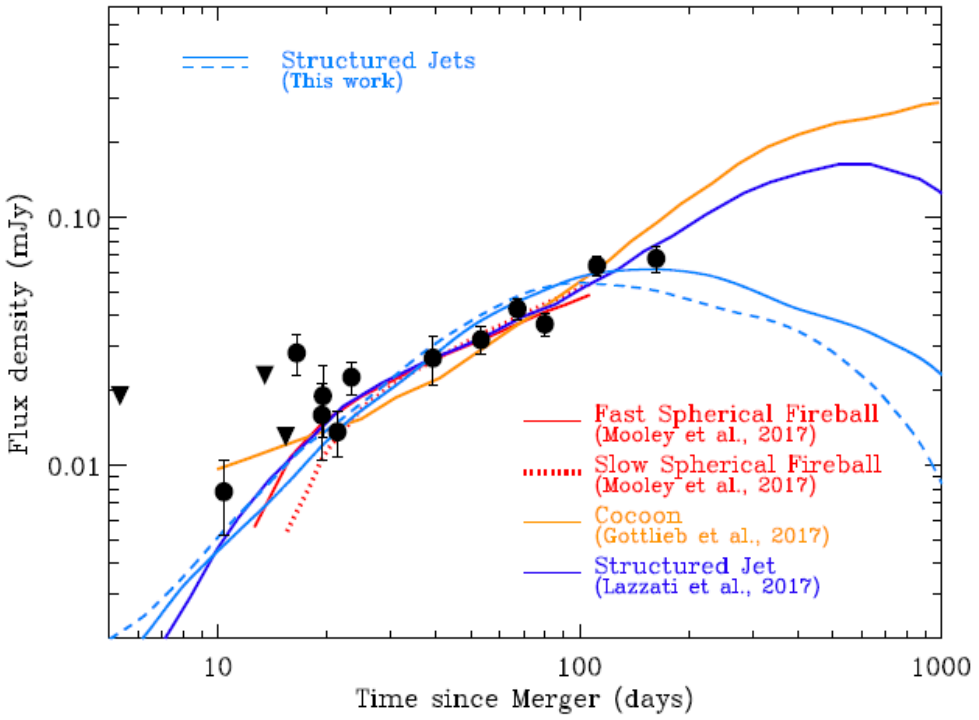


(B)
Choked jet + cocoon
(misnomer: cocoon model)

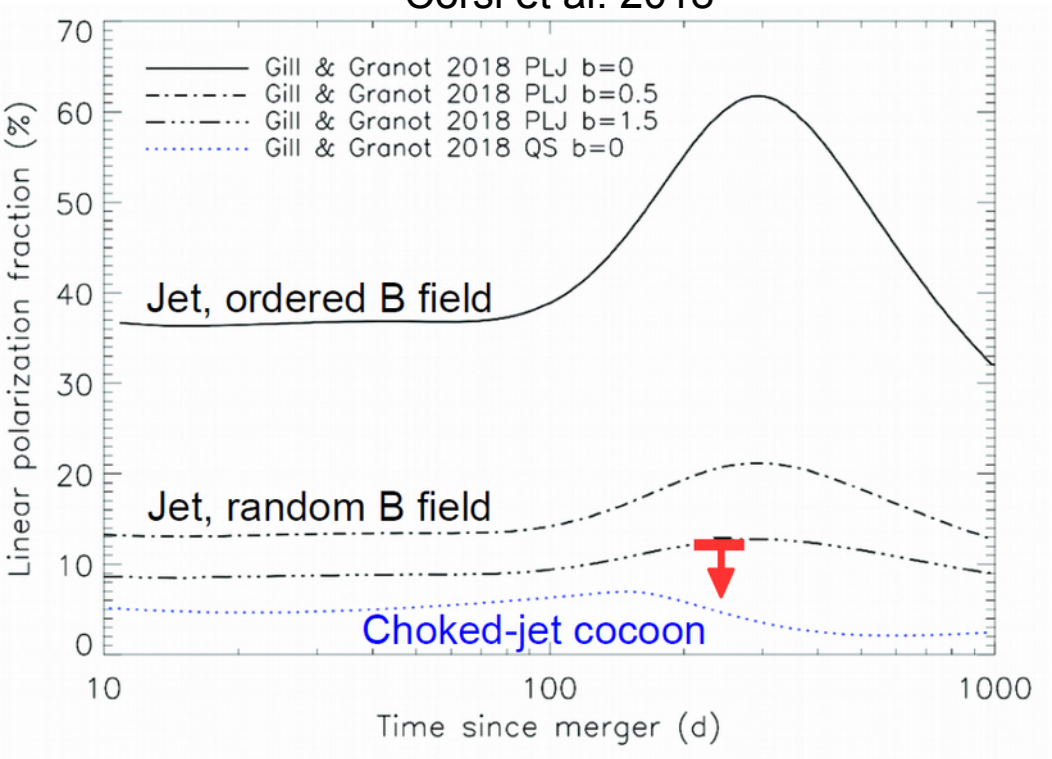
e.g. Kasliwal et al. 2017, Gottlieb et al. 2018, Hallinan et al. 2017, Mooley et al. 2018, D'Avanzo et al. 2018, Lamb et al. 2018, Gill & Granot 2018, Lazzati et al. 2018, Margutti et al. 2018, Resmi et al. 2018, Dobie et al. 2018, Alexander et al. 2018, Ruan et al. 2018, Troja et al. 2018, Corsi et al. 2018

No useful constraints from the light curve and polarization

Margutti et al. 2018



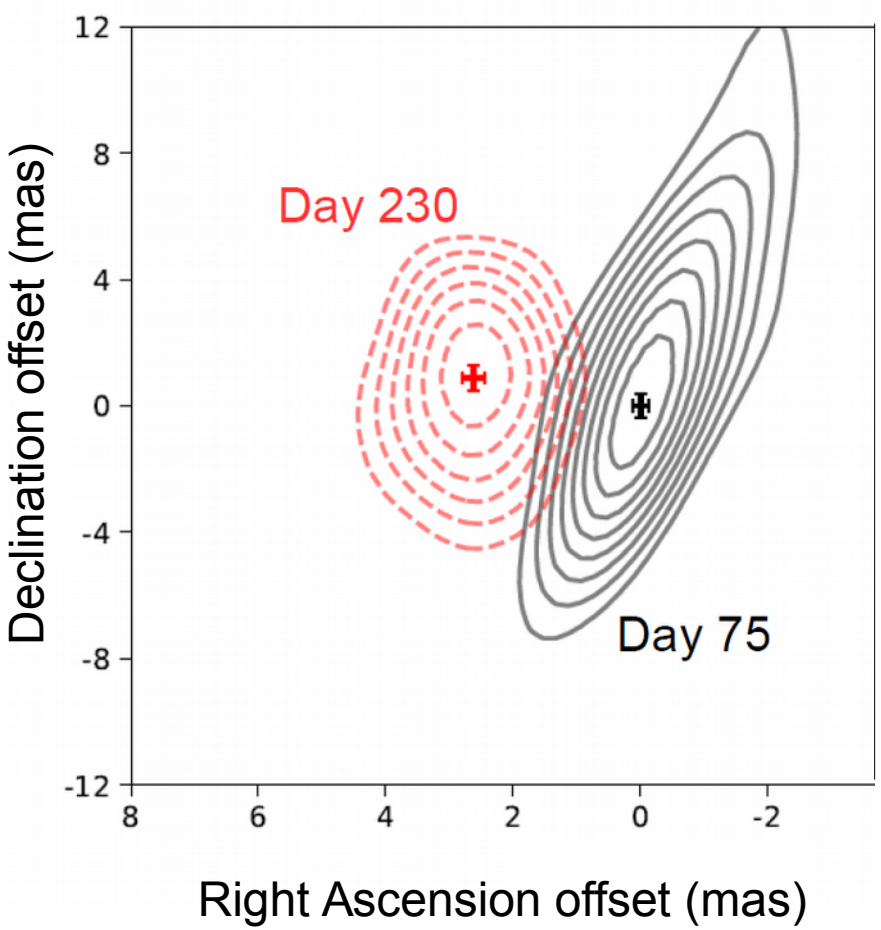
Corsi et al. 2018



Also see Dobie et al. 2018, Alexander et al. 2018, Nynka et al. 2018, D'Avanzo et al. 2018, Troja et al. 2018a

Successful-/choked-jet controversy resolved with VLBI

Successful-/choked-jet controversy resolved with VLBI

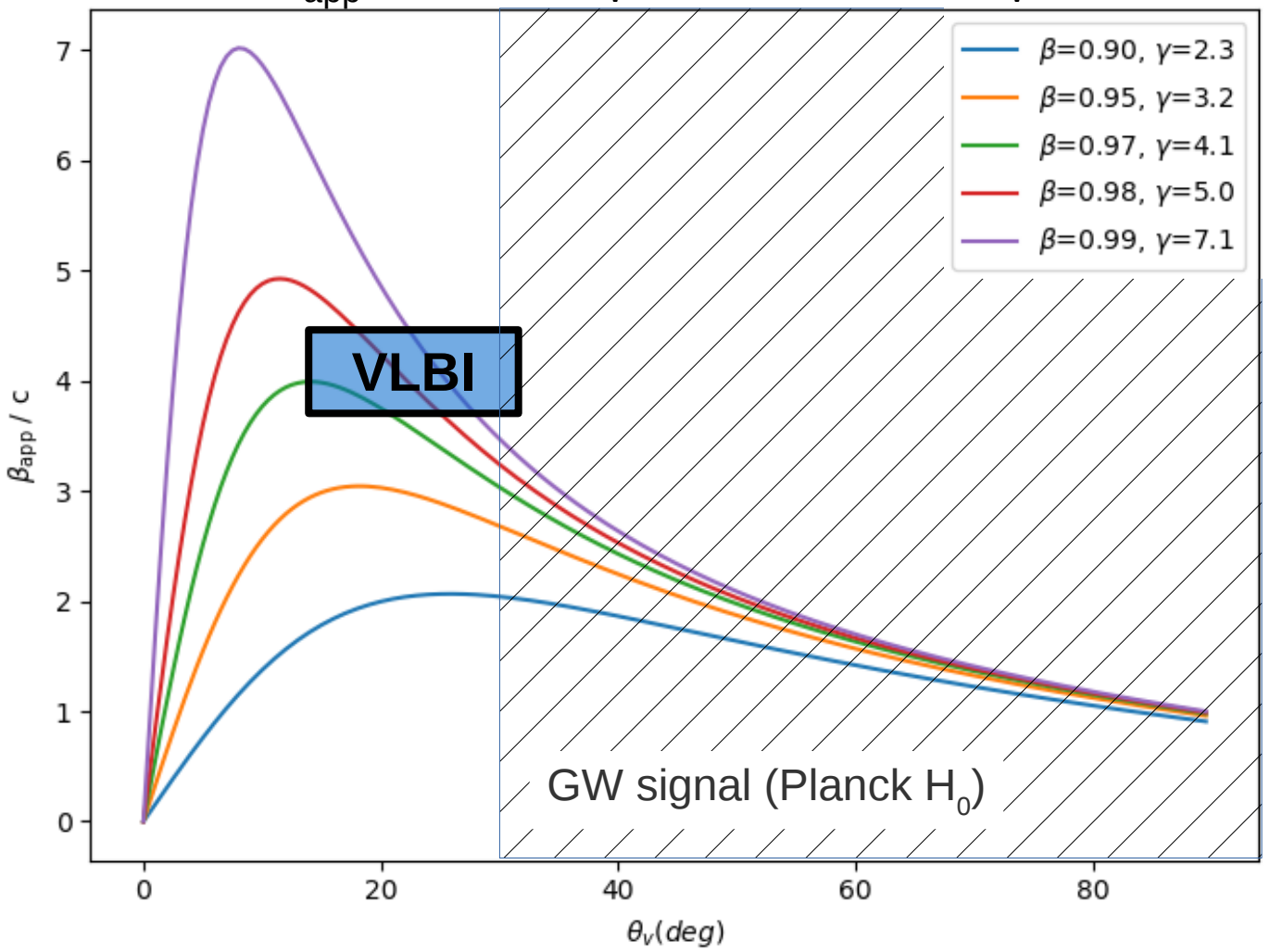


- Radio emitting region moved 2.7 mas over 155 days.
- Superluminal motion! $\beta_{app} \approx 4$
- One of the strongest observational evidences linking BNS mergers and short GRBs

Mooley, Deller, Gottlieb et al. 2018 (Nature)

VLBI constrains the geometry of GW170817

$$\beta_{app} = \beta \sin(\theta_v) / (1 - \beta \cos(\theta_v))$$

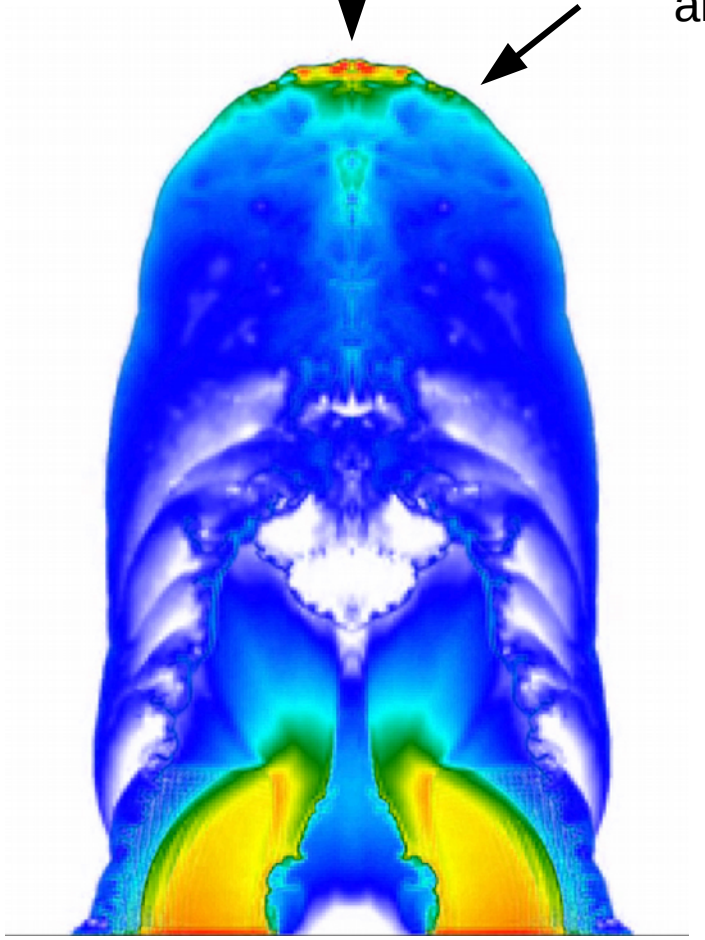


Mooley, Deller, Gottlieb et al. 2018 (Nature)

Best constraints on the geometry, jet and ISM parameters

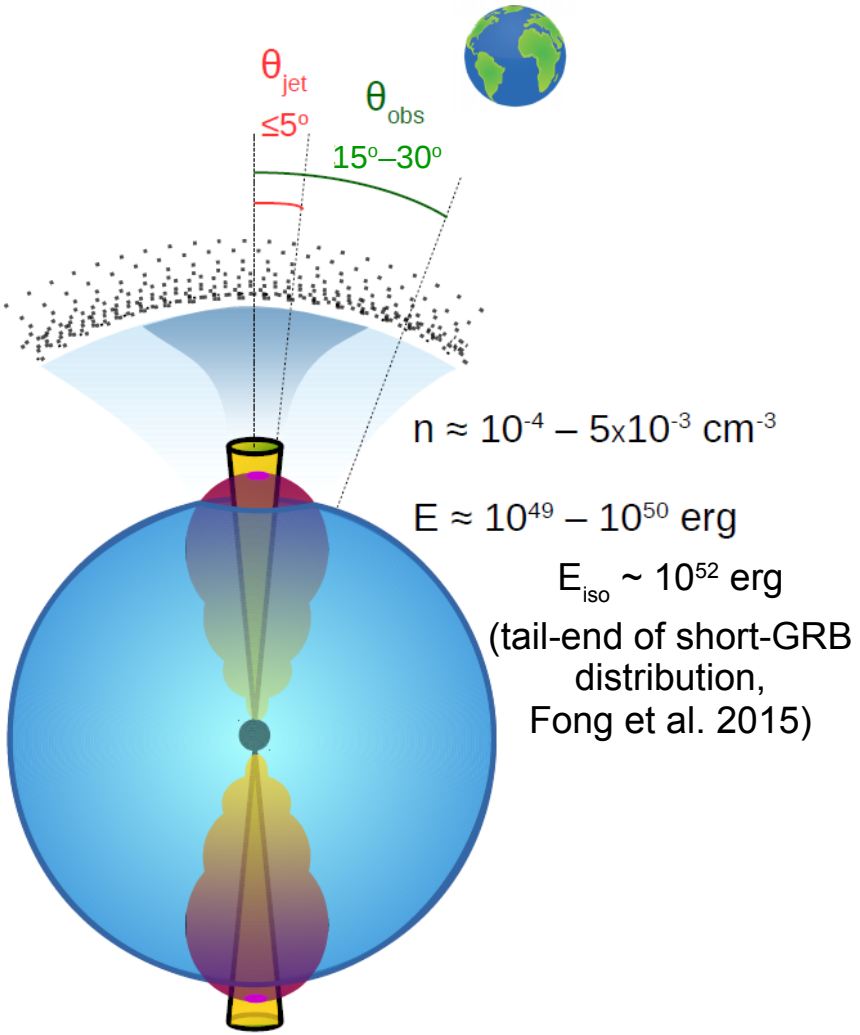
Successful Jet
(unshocked jet core)

Cocoon
(shocked ejecta and jet)



Hydrodynamical simulations

(By E. Nakar and graduate student O. Gottlieb)

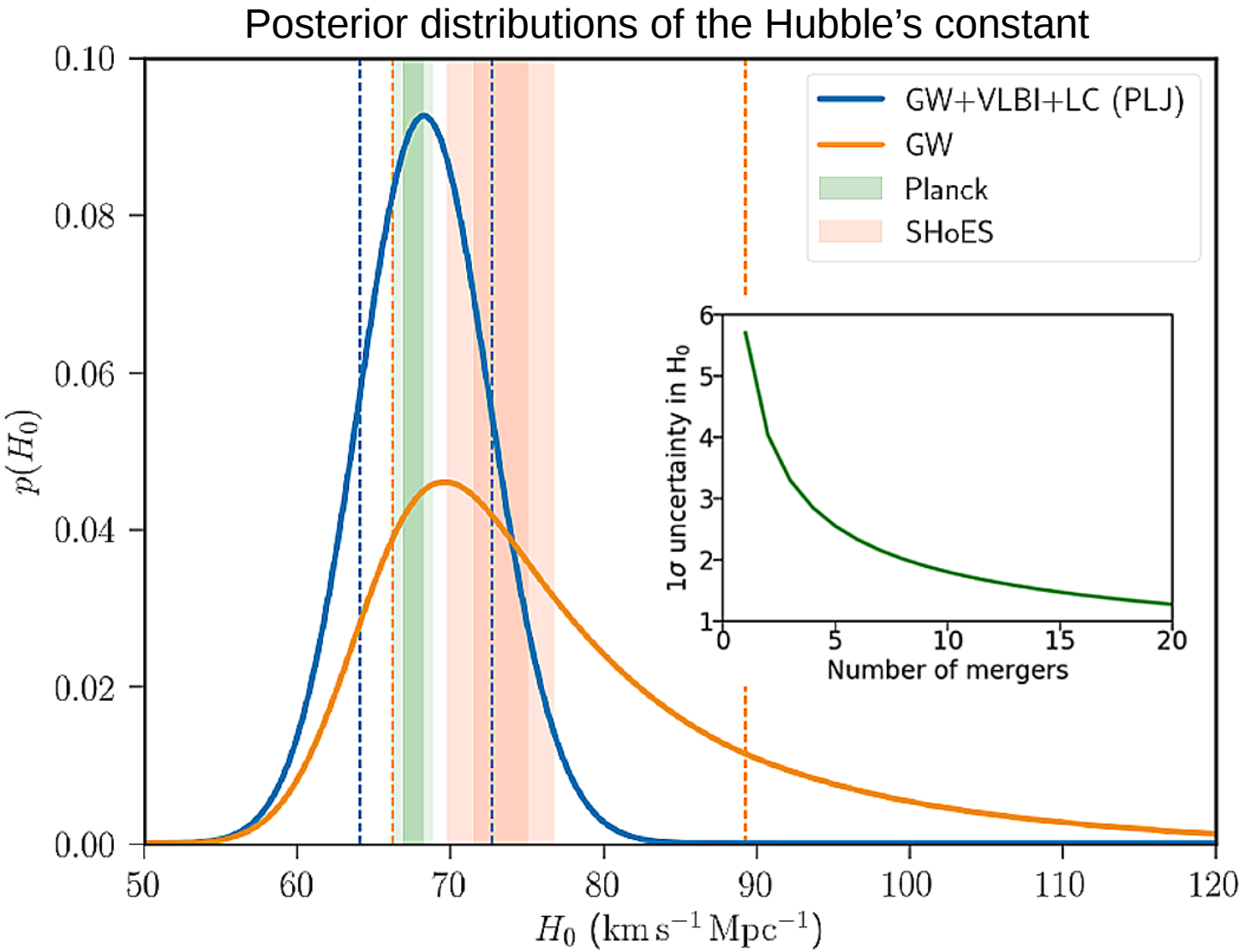


Cartoon representation

Mooley, Deller, Gottlieb et al. 2018 (Nature)

Standard Siren Measurements of H_0

(Hotokezaka et al. 2019, Nature Astronomy)



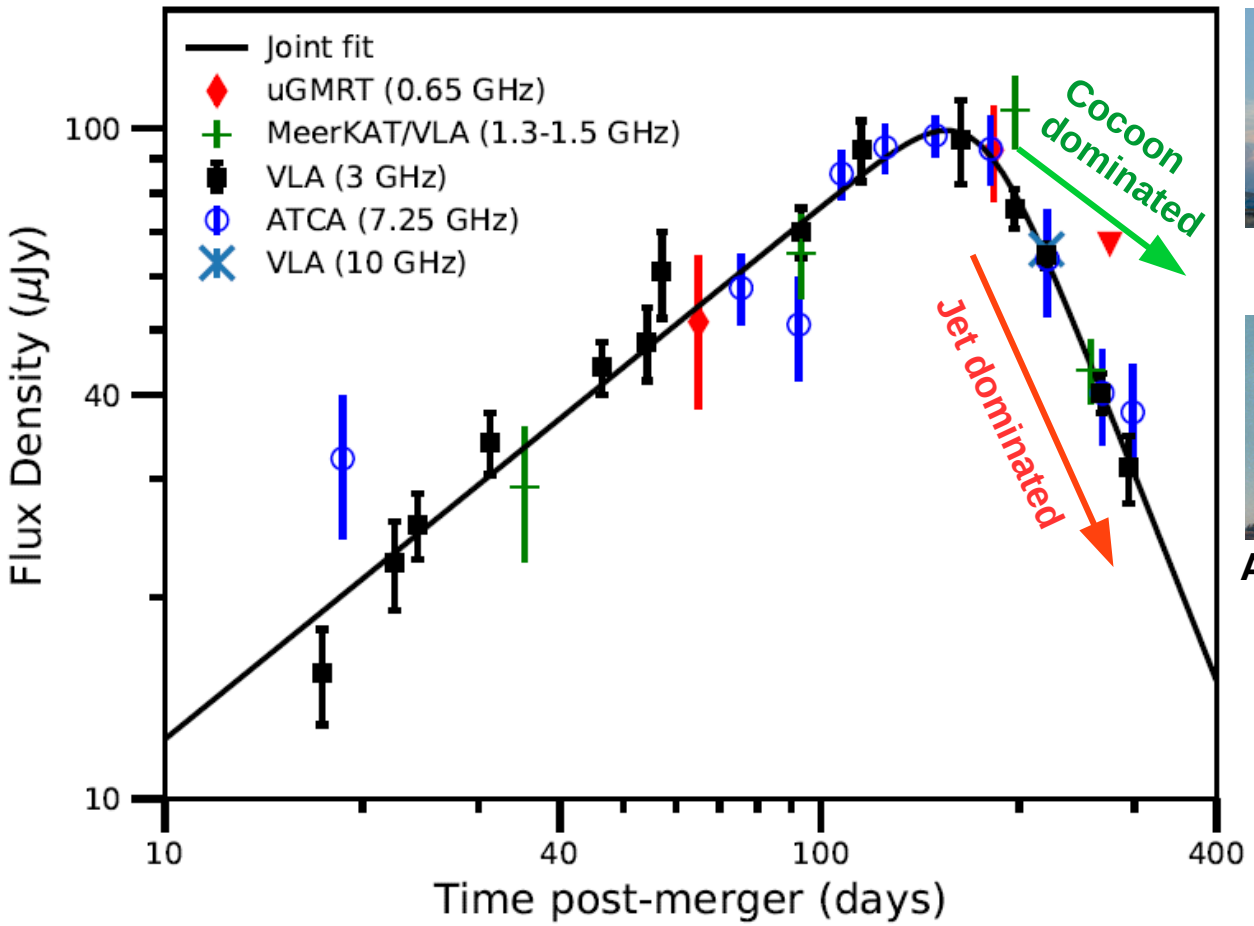
GW+EM:
74^{+16}_{-8} km/s/Mpc

GW+EM+VLBI:
70.3±5.3 km/s/Mpc

See also Abbott et al. 2017 (Nature)

A Strong Jet Signature from the Light Curve of GW170817

(Mooley et al. 2018c, ApJL)



VLA (USA)

GMRT (India)

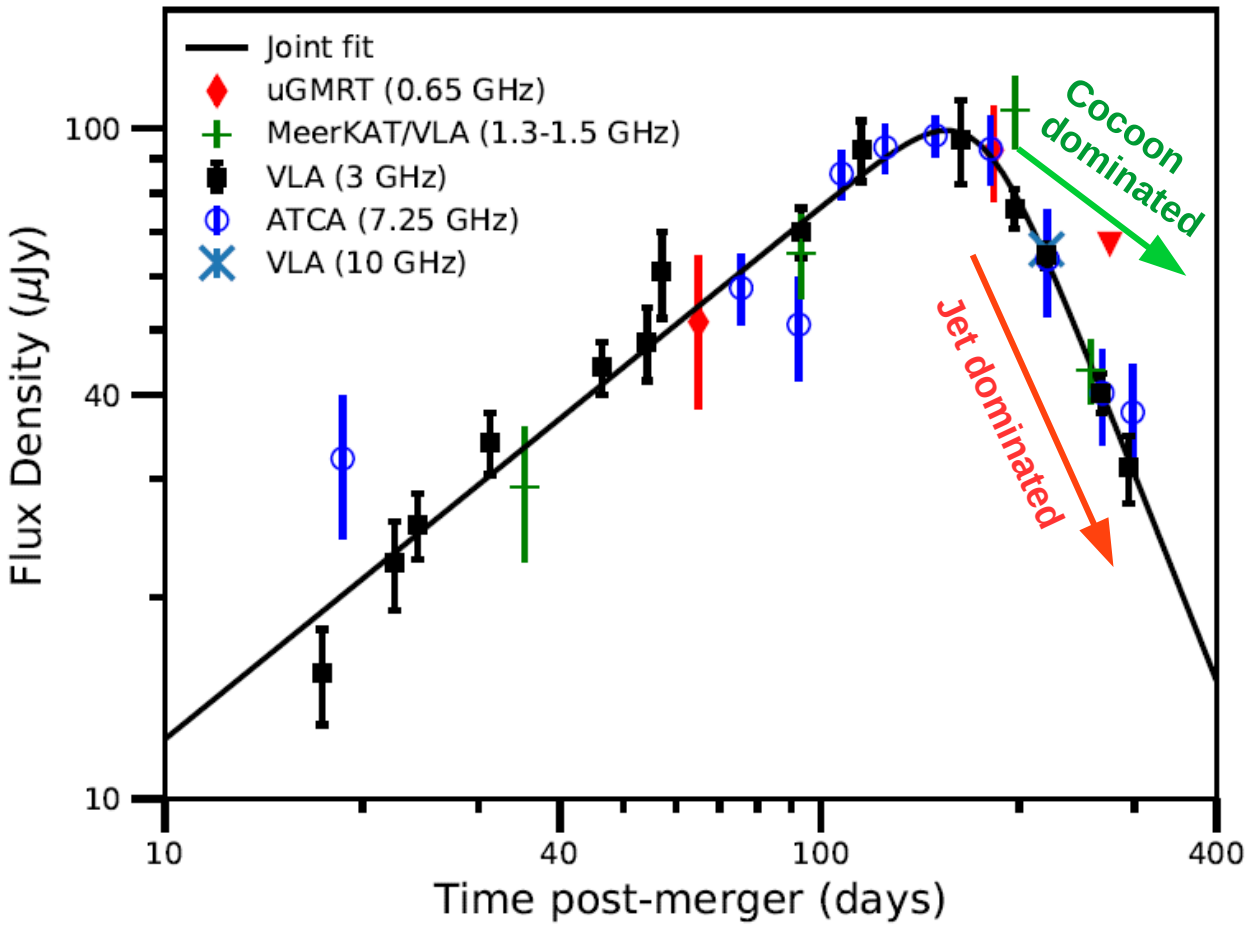
ATCA (Australia)

MeerKAT (South Africa)

Also see Troja et al. 2018b, Lamb et al. 2019, Hajela et al. 2019

A Strong Jet Signature from the Light Curve of GW170817

(Mooley et al. 2018c, ApJL)

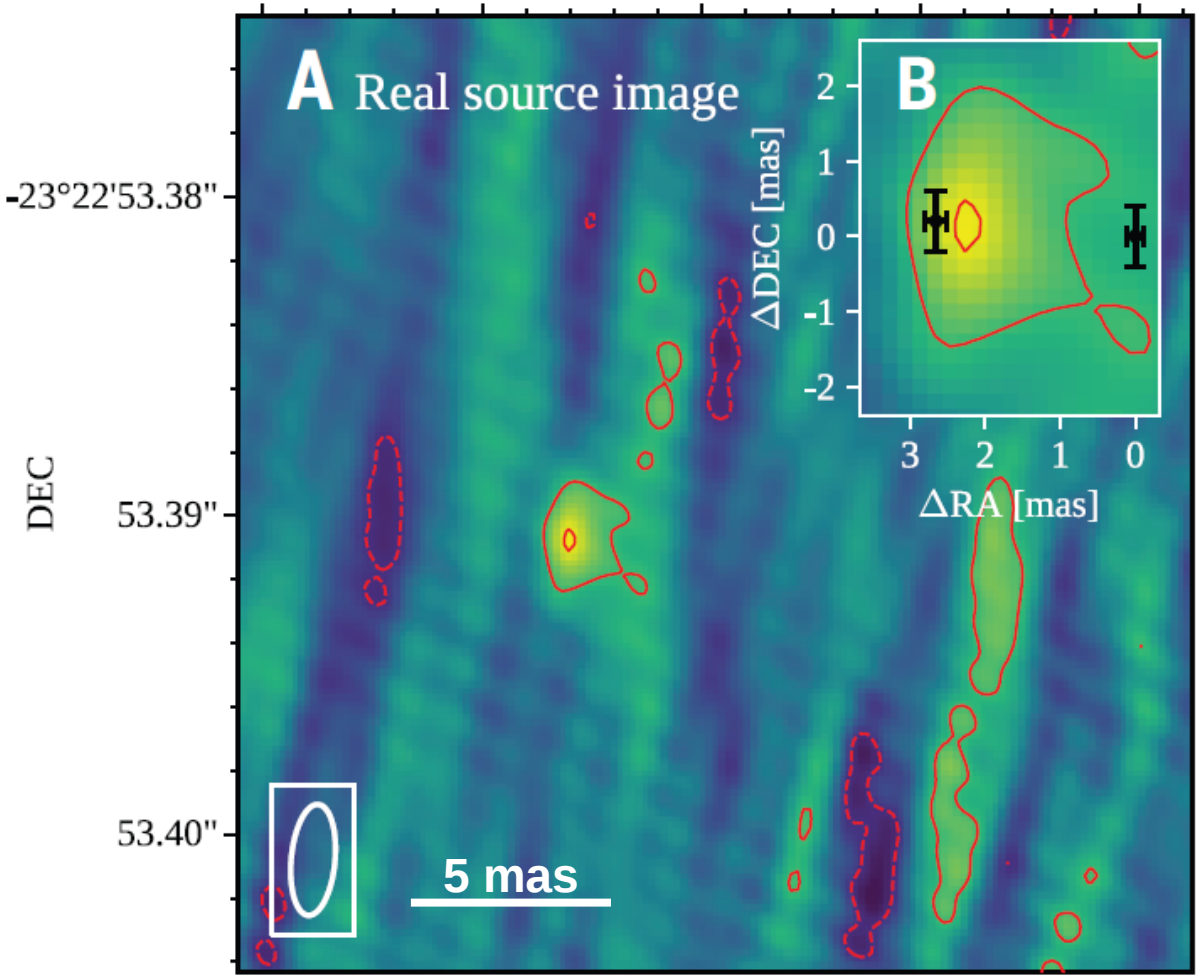


- Late time radio light curve reveals narrow peak and fast decline
- Implies:
  - Narrow energetic jet
  - Relativistic phase
  - Laterally expanding jet
- Analytical calculation implies:
  - viewing angle ~ 15 deg
  - jet opening angle < 5 deg

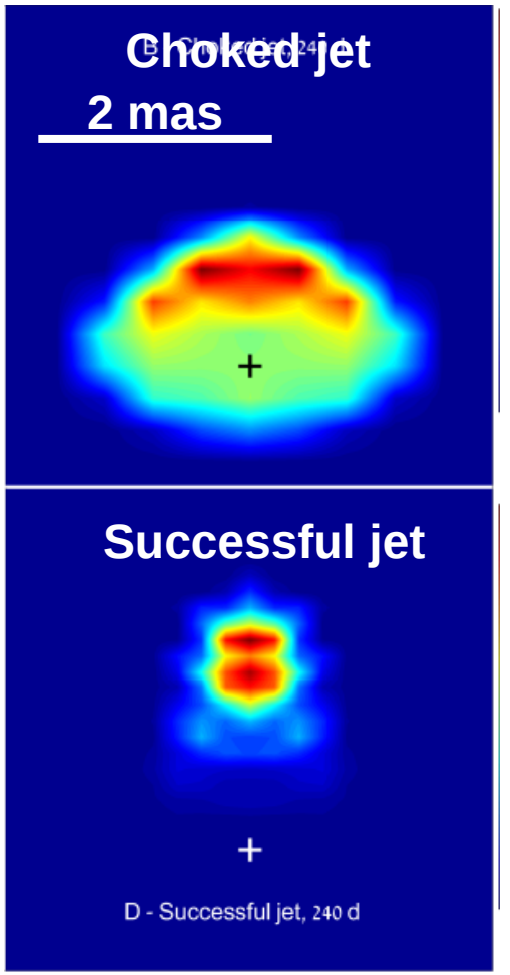
Also see Troja et al. 2018b, Lamb et al. 2019, Hajela et al. 2019

Confirmation of Successful Jet

Global VLBI image
(Ghirlanda et al. 2019)



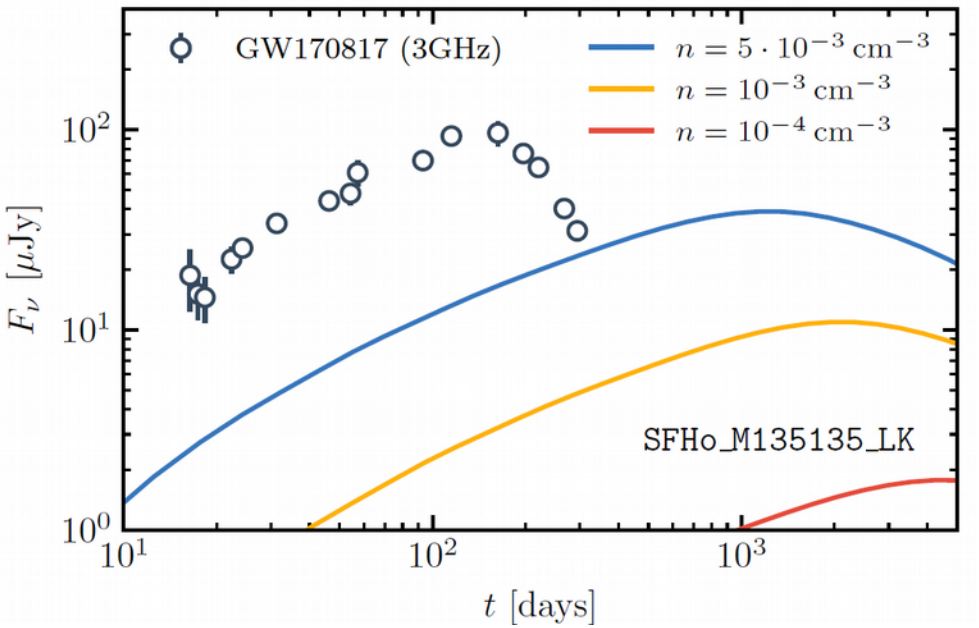
Simulated images
(Nakar et al. 2018)

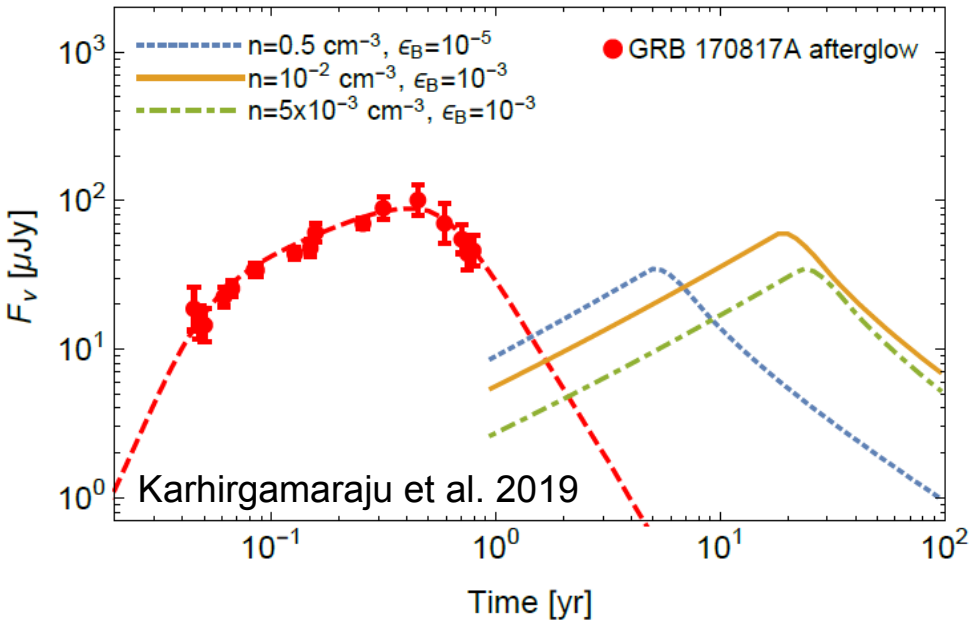


What comes next for GW170817?

- The relativistic jet-cocoon fading rapidly
- Kilonova/dynamical ejecta also have kinetic energy
  - 0.05 Msun at ~0.1c-0.3c
  - deceleration timescale ~ yrs
  - synchrotron emission
- Search is on for rising radio (and X-ray) component

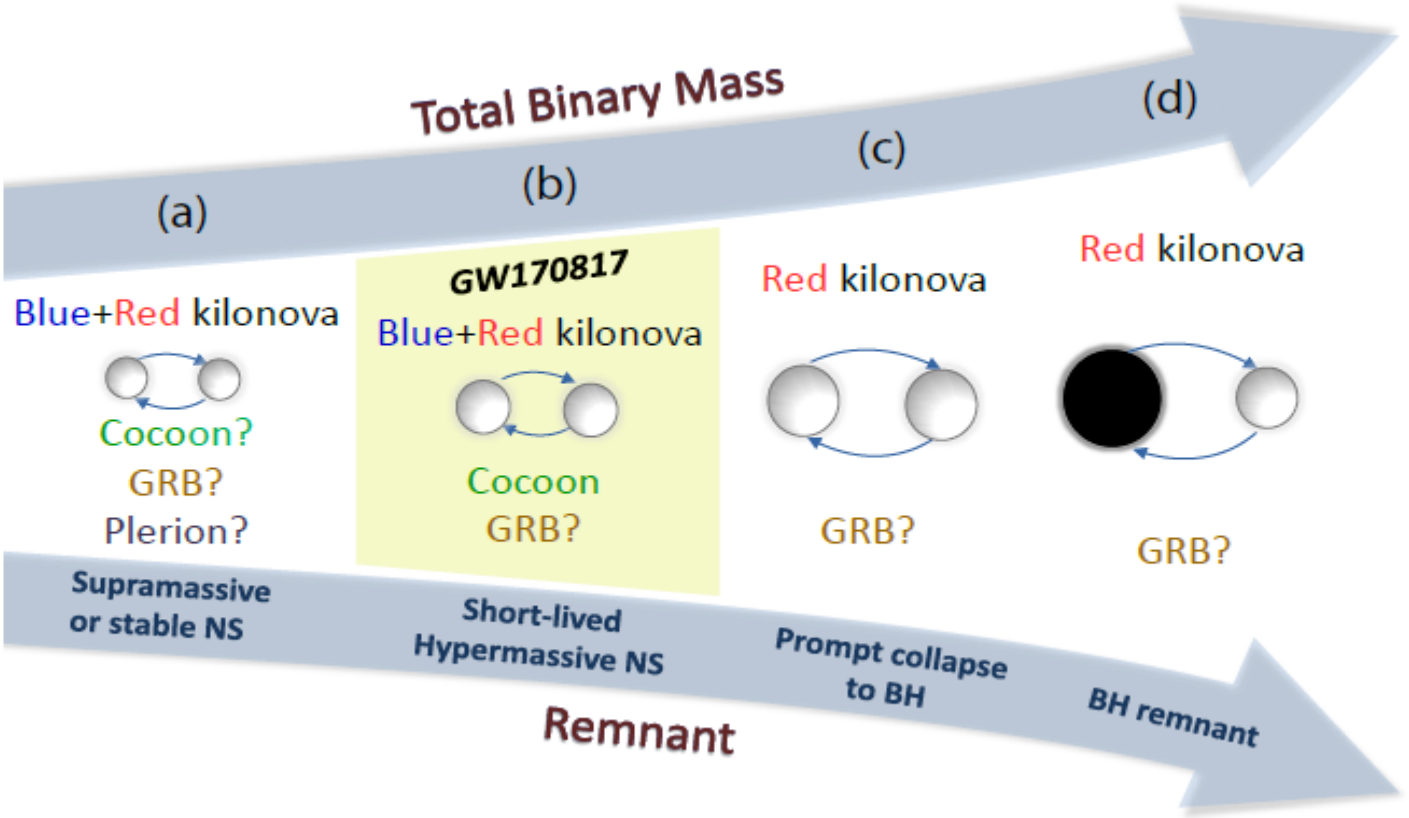
Radice et al. 2018





Also see Nakar & Piran 2011, Rosswog et al. 2013, Hotokezaka & Piran 2015

Diverse Outcomes of Mergers and the Radio Advantage



+ Radio may be the only way to detect many of mergers (especially NS-BH)
+ Daytime sky and dust obscured environments are accessible
+ Radio afterglow timescales are long (months~years)
+ Prompt radio emission: exciting possibility!

Image credit: Gregg Hallinan

JAGWAR and VLBI programs: O3 and beyond

+

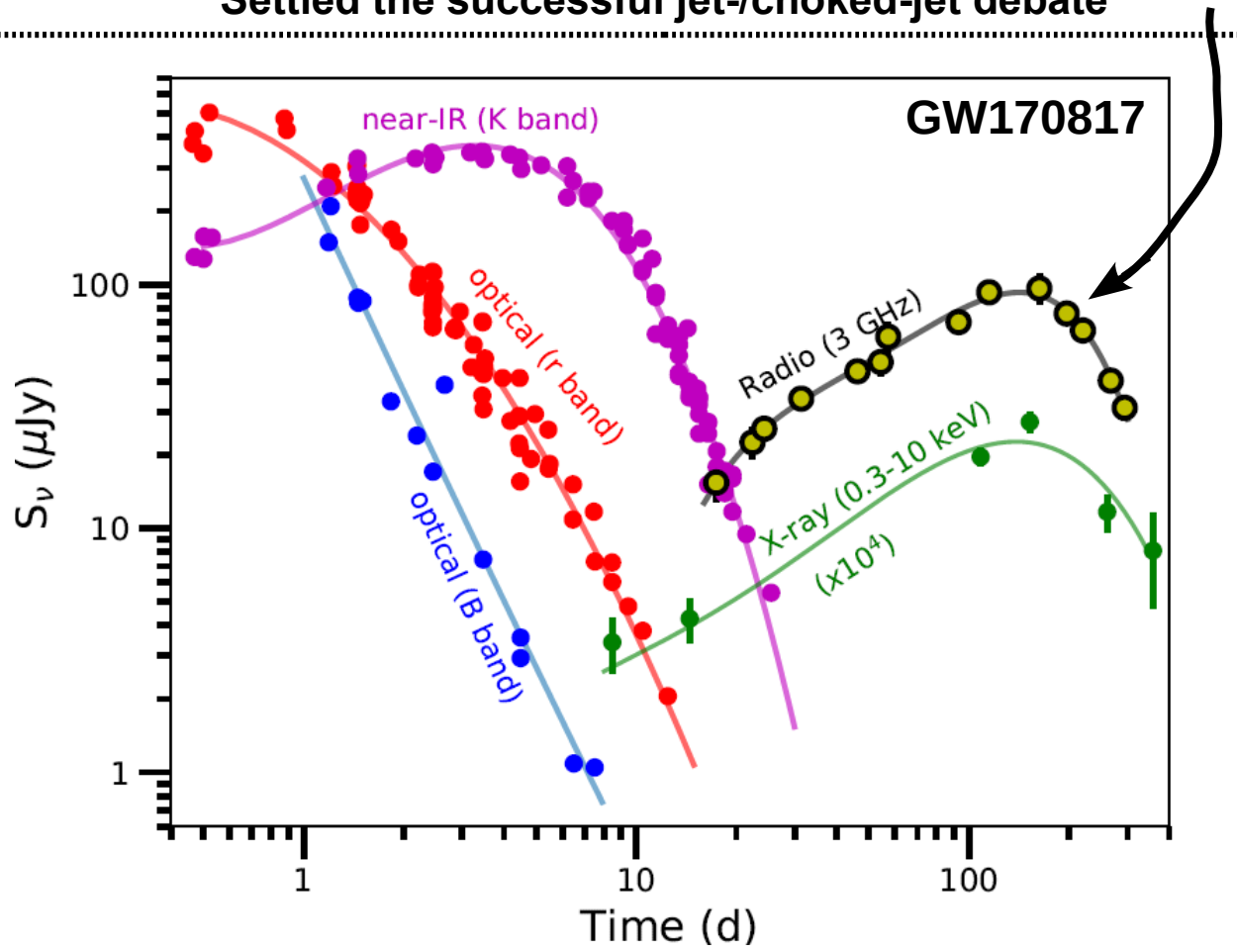
GROWTH

Global Relay of Observatories Watching Transients Happen

Summary

Radio afterglow revealed energetics, environment, geometry and ejecta morphology

Settled the successful jet-/choked-jet debate



Radio observations will play a key role in understanding the (astro)physics of mergers

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