Discovery of the X-ray Counterpart to GW170817: Our Understanding at at 1, 25, and 120 days

Alan M. Watson
Instituto de Astronomía
Universidad Nacional Autónoma de México

on behalf of

E. Troja

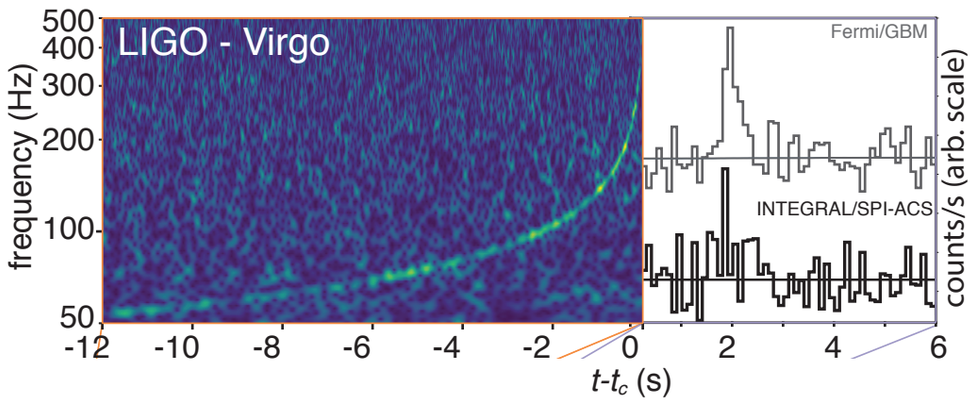
and

L. Piro, H. van Eerten, R. T. Wollaeger, M. Im, **O. D. Fox**, N. R. Butler, S. B. Cenko, T. Sakamoto, C. L. Fryer, R. Ricci, A. Lien, R. E. Ryan, Jr, O. Korobkin, S.-K. Lee, **J. M. Burgess**, W. H. Lee, C. Cho, S. Covino, P. D'Avanzo, C. J. Fontes, J. Becerra González, H. G. Khandrika, J. Kim, S.-L. Kim, C.-U. Lee, H. M. Lee, A. Kutyrev, G. Lim, R. Sánchez-Ramírez, S. Veilleux, M. H. Wieringa & Y. Yoon

15 December 2017

At 1 day

- GRB 170817A coincident in time (2s) and 2D space
- SSS17a (AT 2017gfo) in NGC 4993 coincident in time (20d < *t* < 10h) and 3D space.
- No XRT emission from SSS17a. Not a standard on-axis SGRB.
- Questions
  - Is the SSS17a related to the GRB and GW transient? Is it a SN? Is it an unrelated transient?
  - If we can show that they are related, what can we learn?



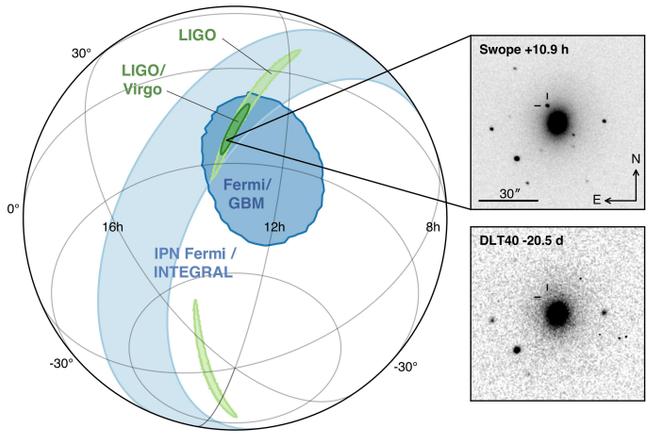
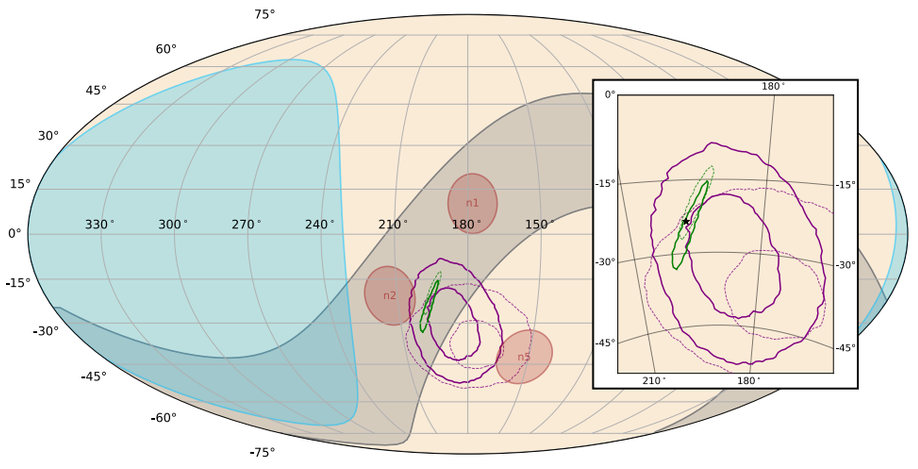
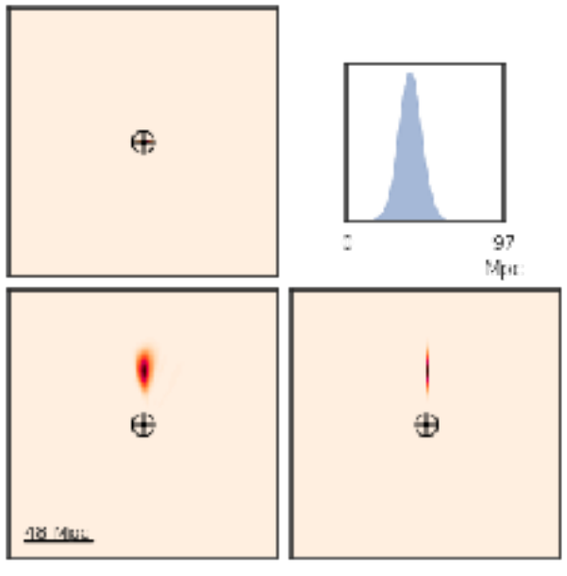


Figure 1. Localization of the gravitational-wave, gamma-ray, and optical signals. The left panel shows an orthographic projection of the 90% credible regions from LIGO (190 deg^2, light green), the initial LIGO-Virgo localization (31 deg^2, dark green), IPN triangulation from the time delay between *Fermi* and *INTEGRAL* (light blue), and *Fermi* GBM (dark blue). The inset shows the location of the apparent host galaxy NGC 4993 in the Swope optical discovery image at 10.9 hours after the merger (top right) and the DLT40 pre-discovery image from 20.5 days prior to merger (bottom right). The reticle marks the position of the transient in both images.

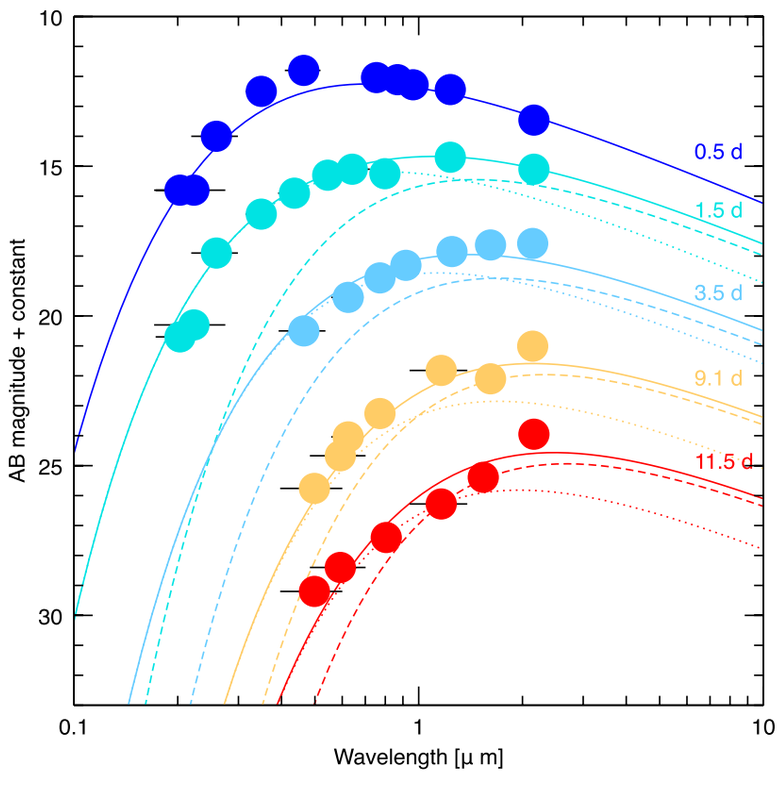




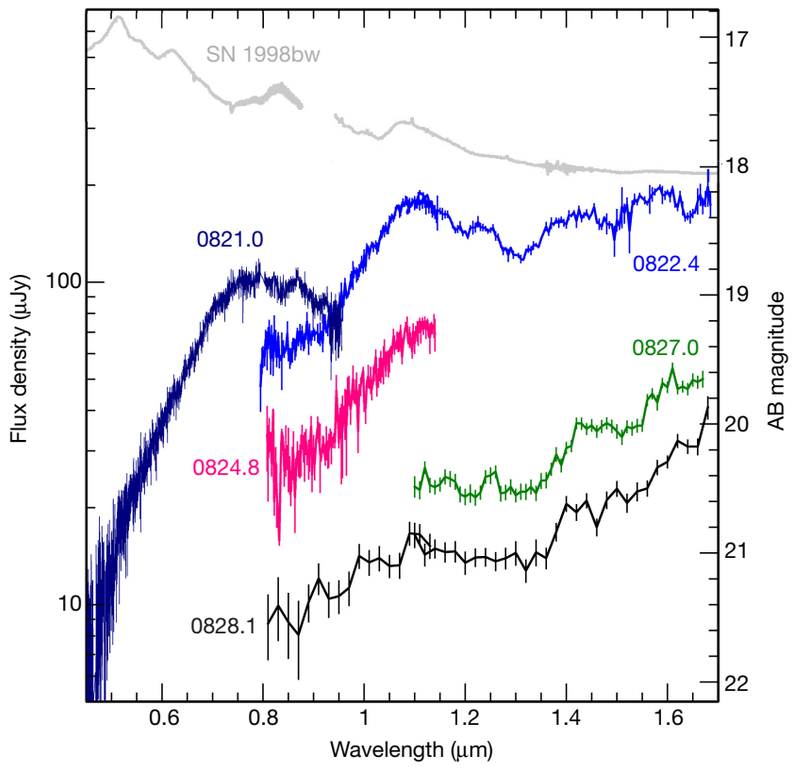
Our contribution

- Many observations with ground and space telescopes.
  - *Chandra* — discovery of X-ray emission at 9d
  - Gemini-S — photometry and optical spectroscopy
  - *HST* — photometry and infrared specterscopy
  - ATCA — upper limits
- Modeling of the kilonova and jet.
- Understanding to 25d published as Troja et al. (2017) in *Nature* and in the MMO paper

Optical and Infrared



- Photometry and spectroscopy with Gemini and HST
- Peak $M_V \approx -16$; too faint for any normal SN
- Initially blue but fading and red. Simple BB fits suggest T = 3000-10000 K and expansion at v ≈ 0.3c
- Spectra unlike any SN, but show many broad bands in red and infrared.



Credit: Troja et al. (2017)

OIR: Kilonova Models

Detailed modeling and fitting to OIR photometry gives a reasonable match with

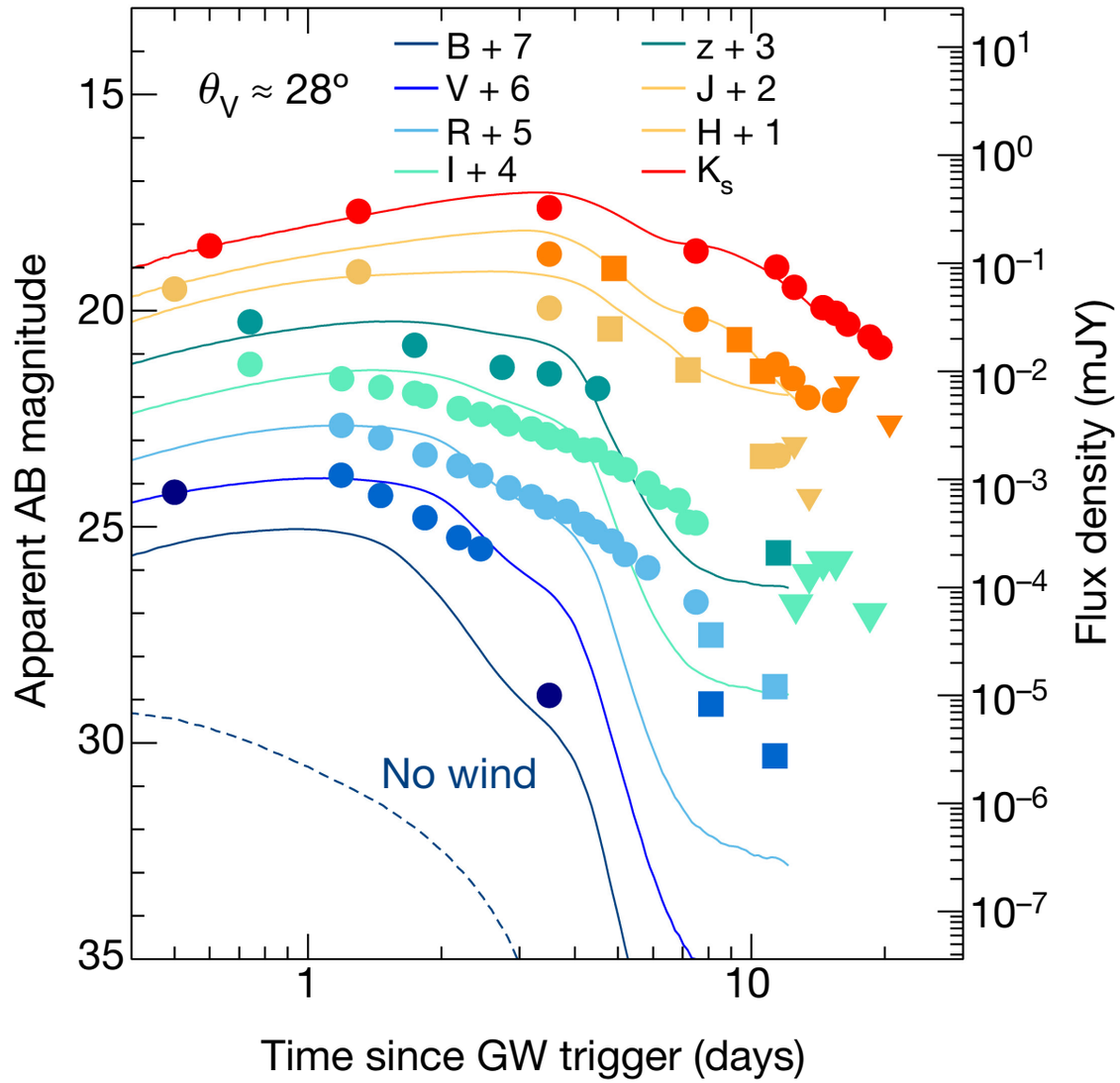
i = 28 deg (20-60 deg)

Red, fast ejecta:

0.002 solar mass
0.2*c*

Blue, slow wind:

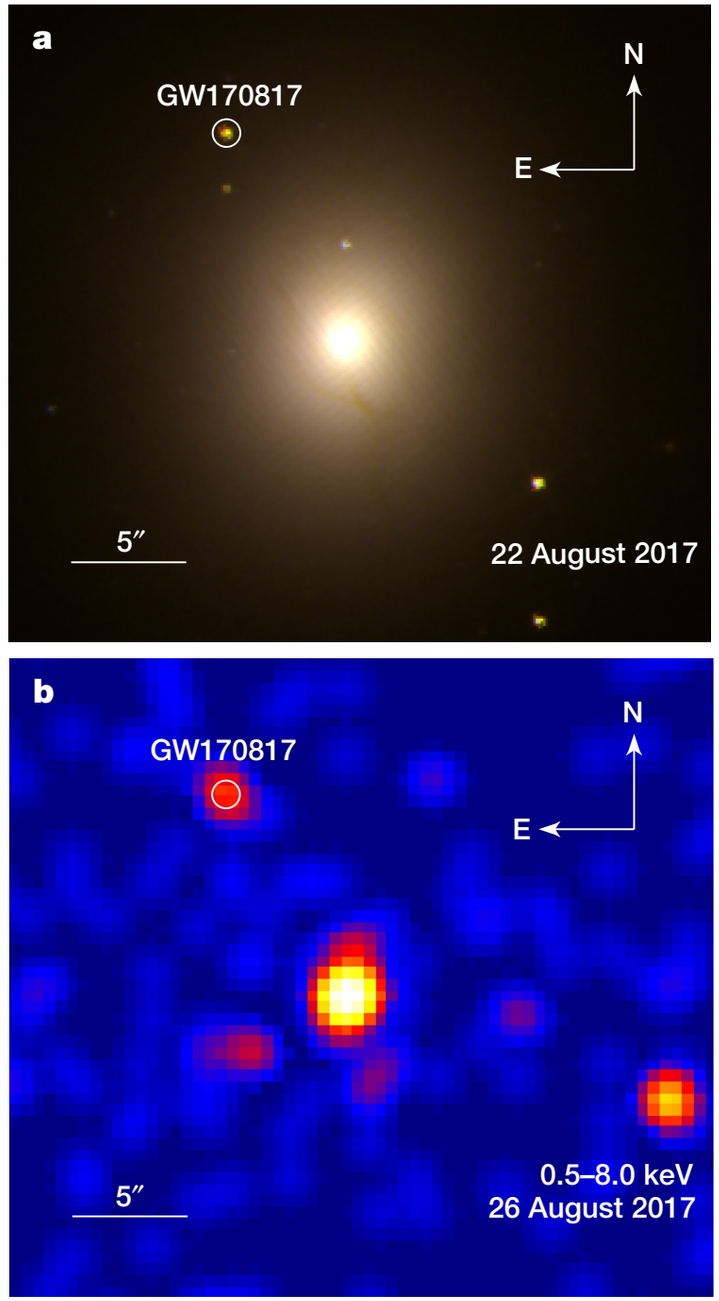
0.015 solar mass
0.08*c*



Credit: Wollaeger, Fryer, Korobkin, & Fontes in Troja et al. (2017)

X-Rays

- No detections with
  - Swift/XRT at 0.6d (Evans et al. 2017)
  - NuSTAR at 0.7d (Evans et al. 2017)
  - Chandra at 2.2d (Margutti et al., GCN 21648)
  - INTEGRAL up to 6d (Savchenko et al. 2017).
- Not standard on-axis SGRB.
- Detection with Chandra at 8.9d by our group (Troja et al., GCN 21765).
- 12 photons / 34 authors = 0.35 photons/author
- Subsequent early monitoring with Chandra at 15.1d (Troja et al., GCN 21787) and 16.1d (Haggard et al., GCN 21798).



Credit: Troja et al. (2017)

What It’s Not

- **On-Axis SGRB.** Not standard on-axis SGRB. X-rays too late and too faint compared to OIR.

- **Dynamical Ejecta.** Shocks between dynamical ejecta and CSM could produce X-rays, but this would require $n > 10^3$ cm^{-3}. There is no evidence for such high densities in the photometry or spectroscopy.

- **Magnetar.** If the merger product is a rapidly rotating magnetized NS, it could produce X-rays, but it is unlikely to be able to sustain them for 2 weeks.

- **Fall-Back Accretion. C**ould produce X-rays, but probably not radio.

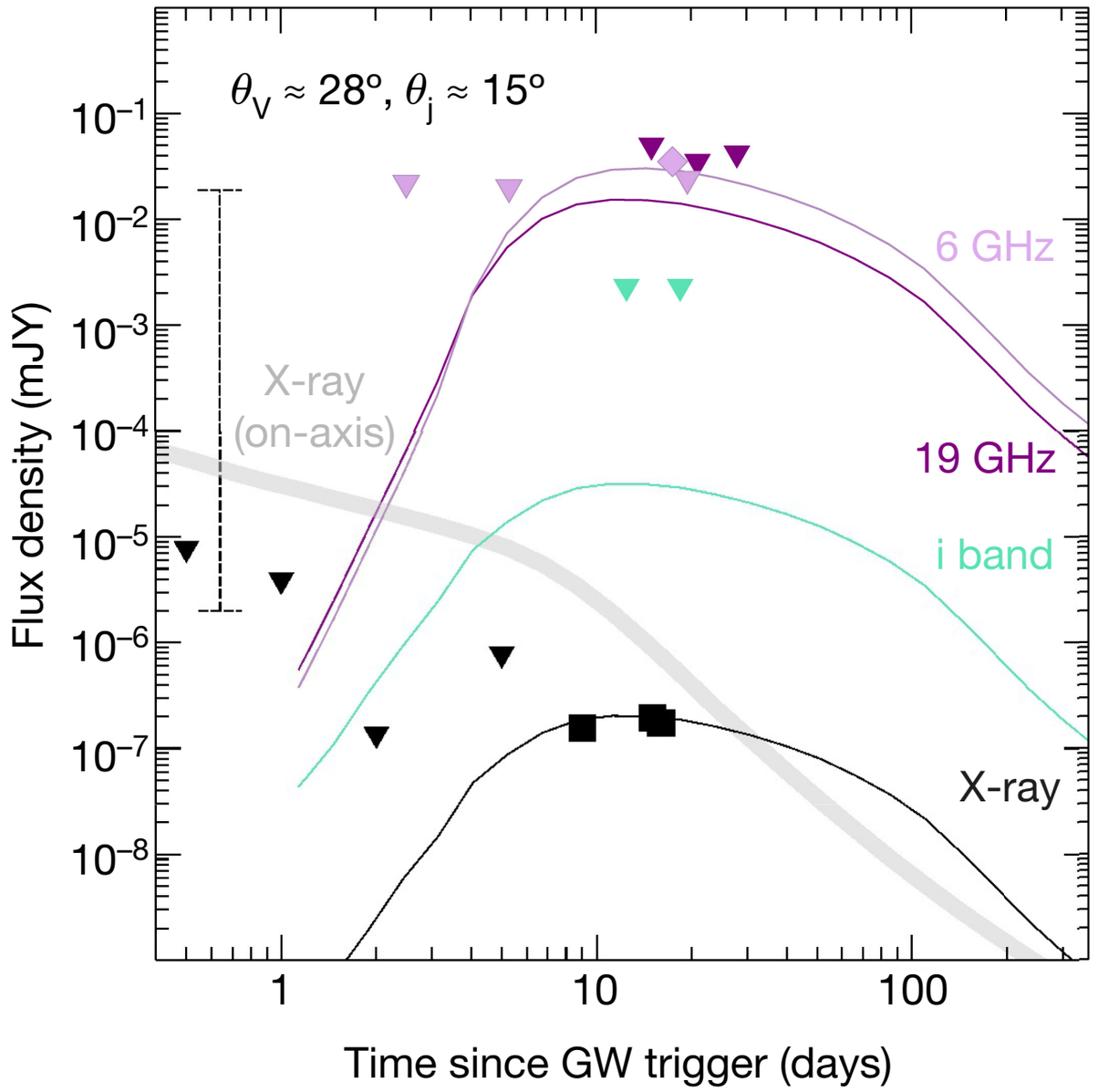
Early X-Ray and Radio Data: Consistent with Off-Axis Afterglow

- Off-axis **top-hat** jet can explain the early X-rays and radio, but gives a GRB that is too faint.

- GRB from precursor or cocoon or …

- Off-axis **gaussian structured** jet works better. Can explain early X-rays and radio and the GRB.

- A **cocoon** might might work too. Not surprising: empirically is similar to a structured jet, even if the physical origin may well be different.



Credit: Troja et al. (2017)

At 25 days

- OIR consistent with kilonova with wind
- GRB , X-ray, and radio consistent with off-axis structured jet or cocoon.
- So, astrophysics strengthens the argument that

GW170817 = GRB 170817A = SSS17a (AT 2017gfo)

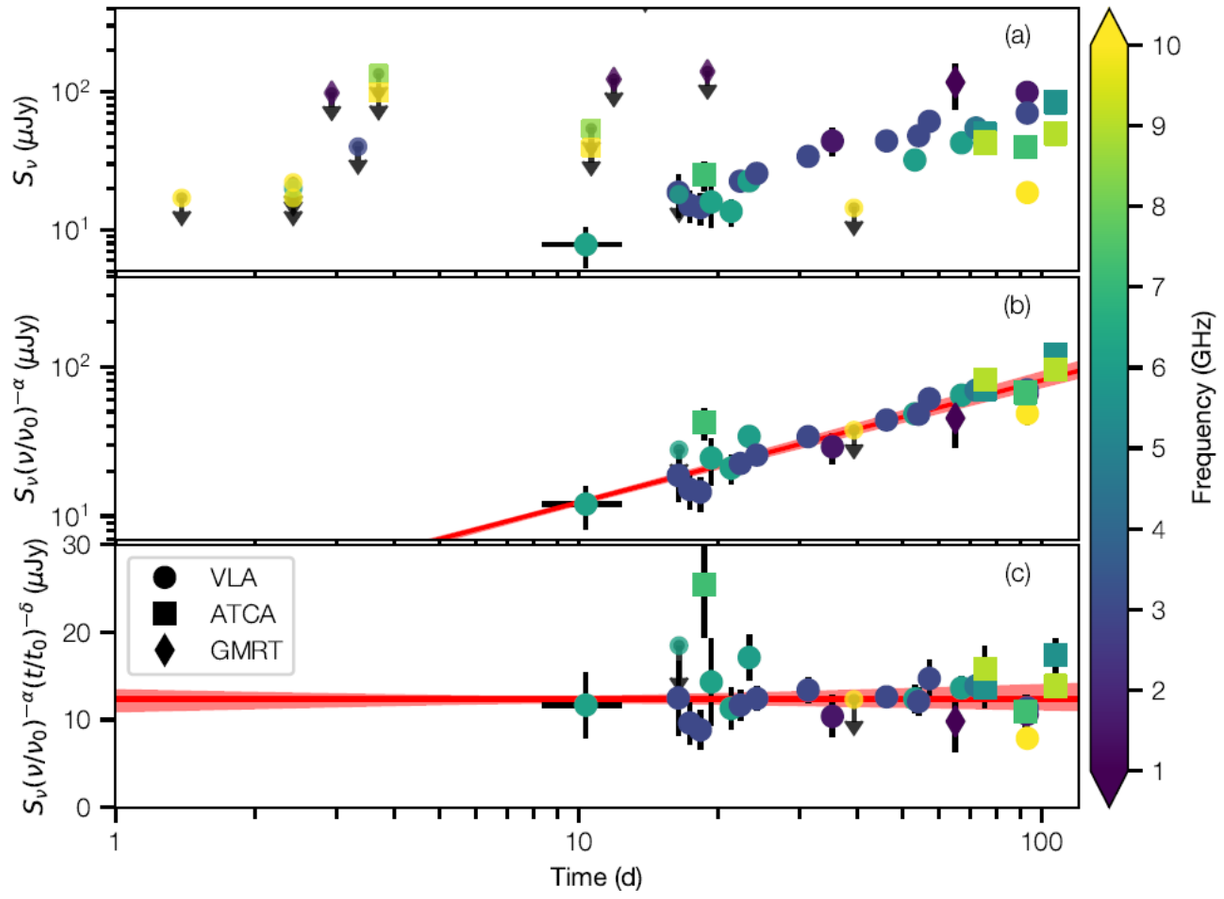
Late Radio Data: Keeps Rising

- Mooley et al. (2017) present monitoring with the VLA, ATCA, and uGMRT.

- $S_\nu \propto \nu^{-0.6} t^{+0.8}$

- Modelled as a blastwave with a falling mass-velocity profile.

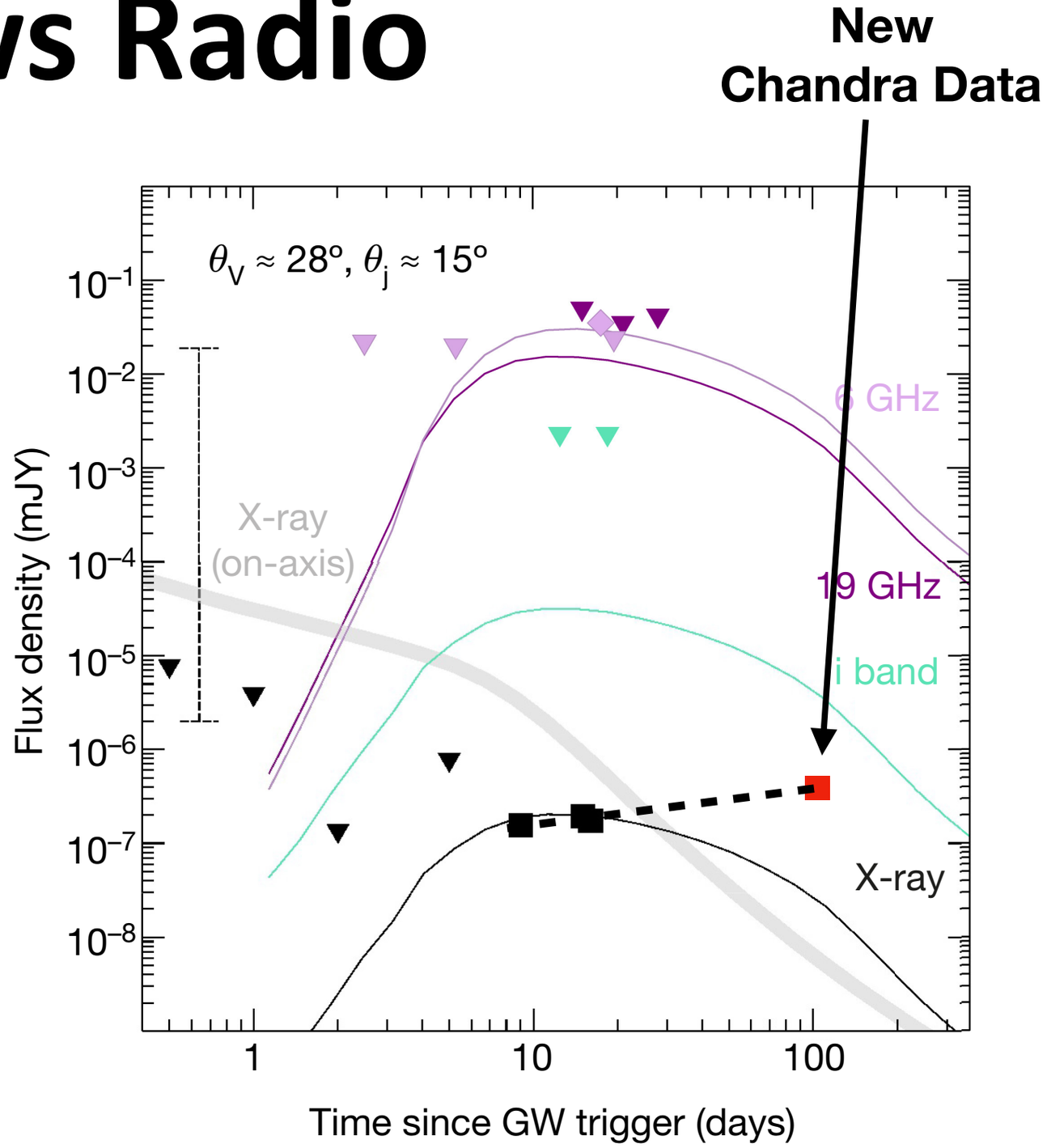
- Stated as being more consistent with a cocoon.



Credit: Mooley et al. (2017)

Late X-Ray Data: Follows Radio

- Late monitoring with Chandra at 108d and 111d by our group and others (Troja et al., GCN 22201; Margutti et al., GCN 22203; Haggard et al., GCN 22206)
- Flux had increased by about a factor of three compared to 16d.
- Continues to rise like the radio data.
- Predicted by Mooley et al. 2017

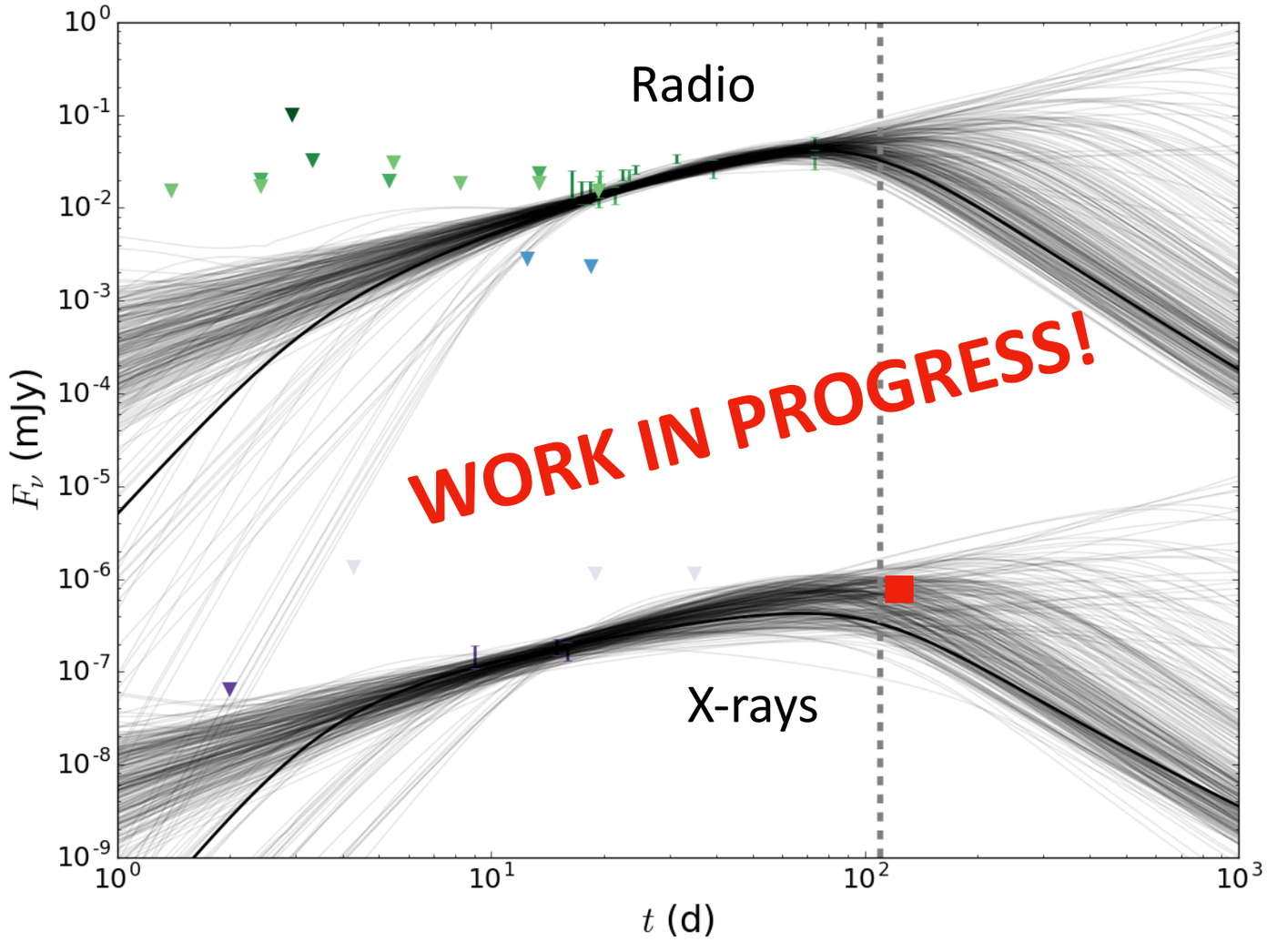


Credit: Troja et al. (2017)

Explanations?

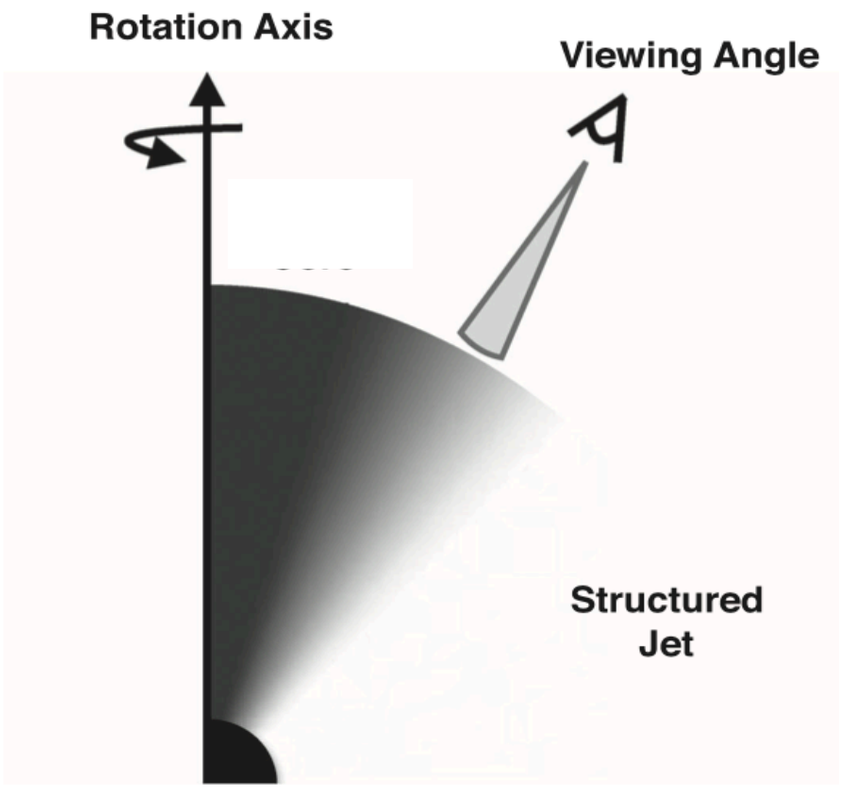
- Mooley et al. (2017) propose a revised cocoon model with continuous energy injection.
- Lazzati yesterday.
- Work in progress by Geoffrey Ryan and Hendrik van Eerten suggest a structured jet still works.

Structured jet models

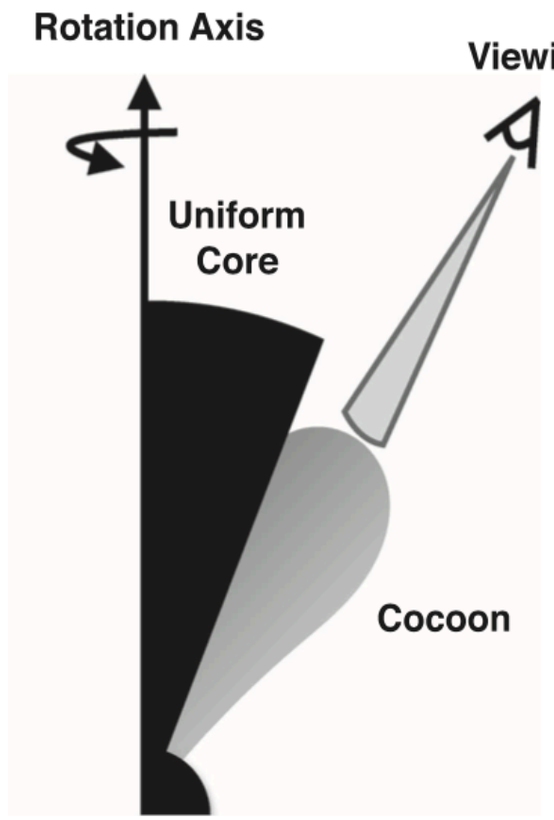


Current Possibilities

Structured Jet



Top-Hat Jet plus Cocoon



At 120 days

- X-ray, radio, and GRBs **STILL** seems to be most consistent with a structured jet or jet-driven cocoon.
- Early OIR **STILL** consistent with kilonova.
  - Need to consider possibility of a cocoon in OIR modeling and reconsider whether we have need a wind.
- Need to work on understanding the relation between GW170817 and classical SGRBs.
- More GW sources will help understand what is common and what is unique.

Outlook

RATIR

COATLI

- Rate observed to be 1 event in 14 months (5 mo O1 + 9 mo O2). O3 expected to start in summer 2018. Sensitivity improving. We expect to see more events!
- If the next NS-NS merger is observable from the north, the UNAM transients group and collaborators will be all over it:
  - DDOTI (Mexican and France): unbiased search and early optical photometry with few minute cadence
  - RATIR: *riZYJH* imaging of galaxies and candidates
  - COATLI: optical imaging of galaxies with few minute cadence

DDOTI

Thank you!

Questions?