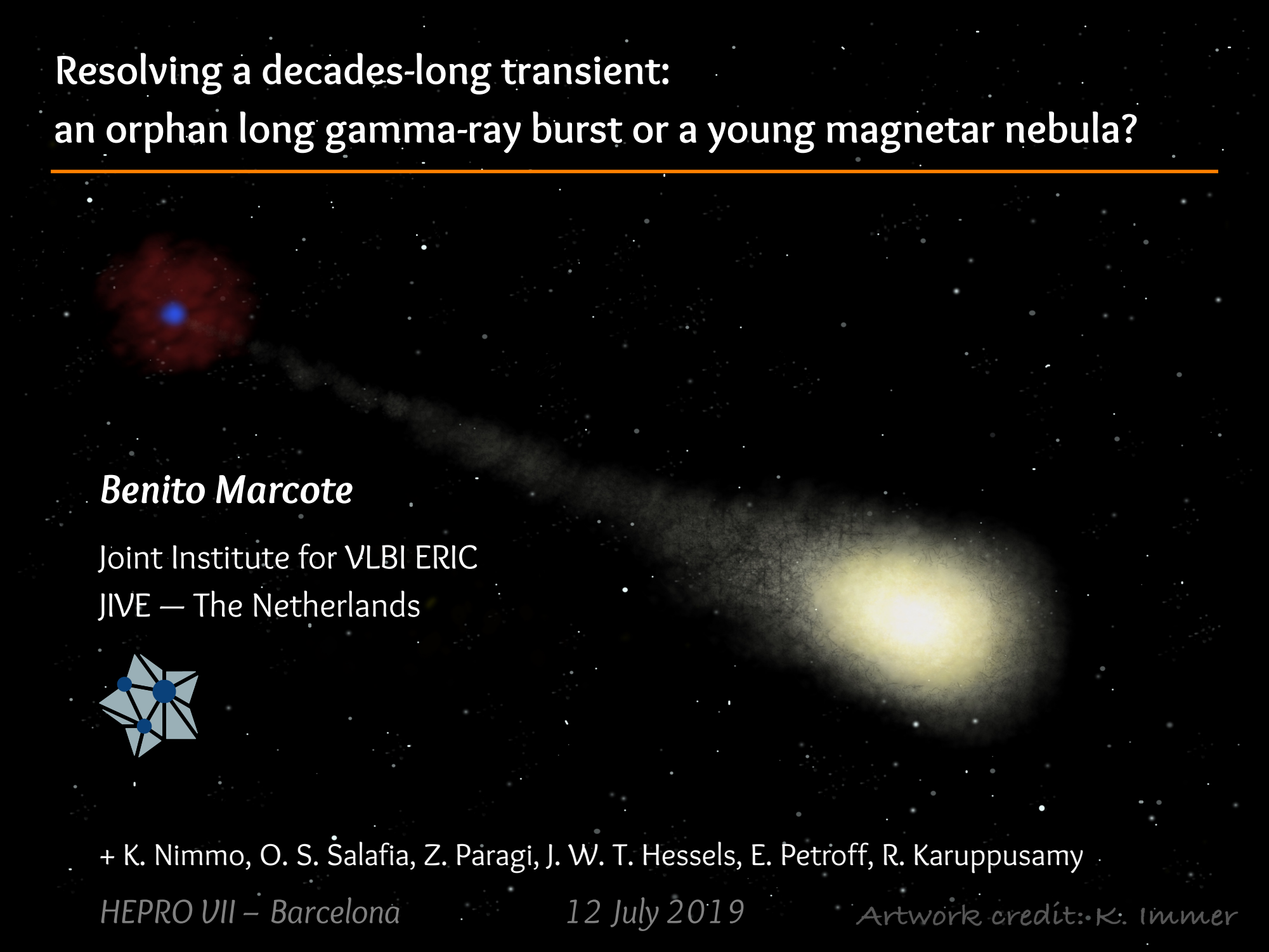
Resolving a decades-long transient: an orphan long gamma-ray burst or a young magnetar nebula?



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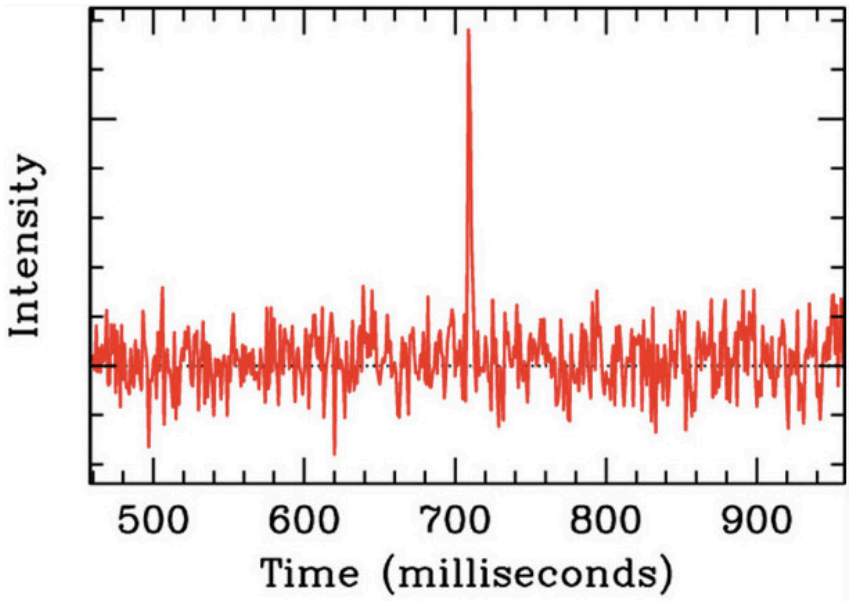
HEPRO VII – Barcelona *12 July 2019*

Artwork credit: K. Immer

It was all about Fast Radio Bursts (FRBs)...

- **Fast Radio Bursts (FRBs)**
- Duration of a few milliseconds
- Bright: $\sim$ 0.1–100 Jy
- At GHz radio frequencies
- Discovered by Lorimer et al. (2007)
- Tens/hundreds of them reported (Petroff et al. 2016)



FRB 140514

It was all about Fast Radio Bursts (FRBs)…

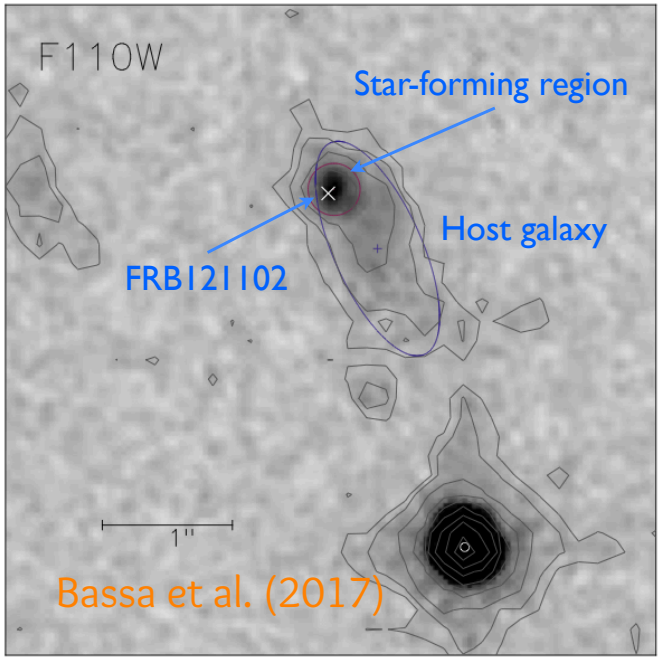
- The first repeater **FRB 121102**, the only* precise localization
  Spitler et al. (2014,2016)

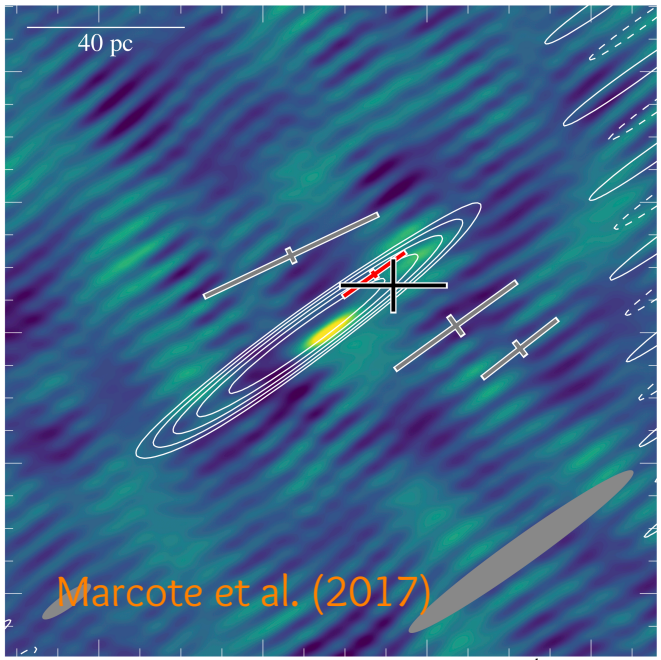
- Low-metallicity star-forming region in a dwarf galaxy at 972 Mpc

- Compact radio source (< 0.7 pc)

- Superluminous Supernova?
  Massive Black Hole?

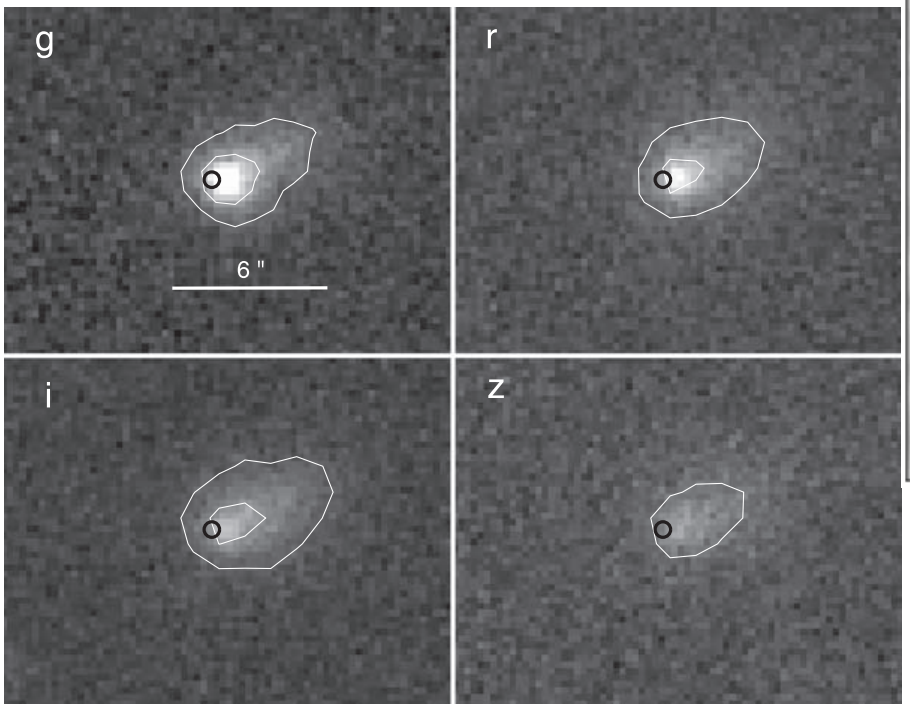
  Chatterjee et al., Marcote et al.,
  Tendulkar et al., Bassa et al. (2017)

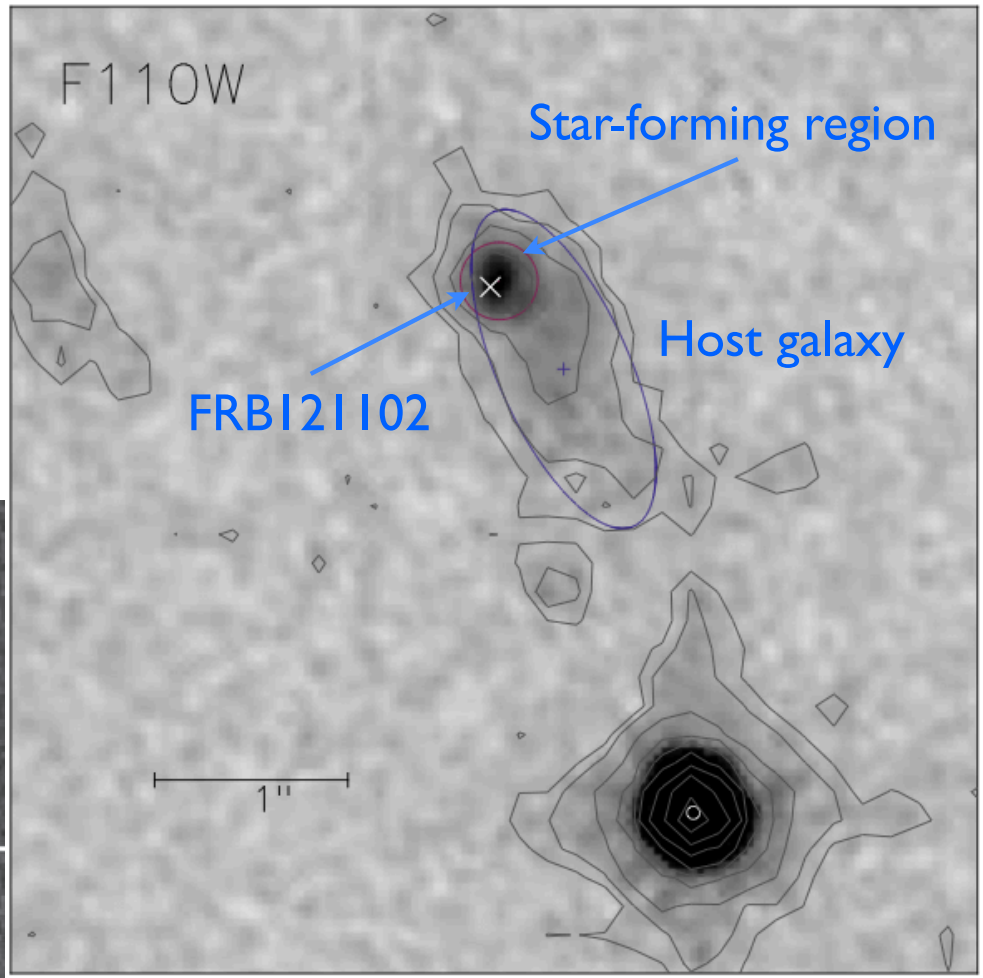




Searching for new Fast Radio Bursts…

- Searching for similar sources: Compact radio sources in dwarf galaxies (Ofek 2017)
- FIRST J1419+3940 (Law et al. 2018)





A decaying radio transient: FIRST J1419+3940

Decaying radio light-curve for the last 30 years

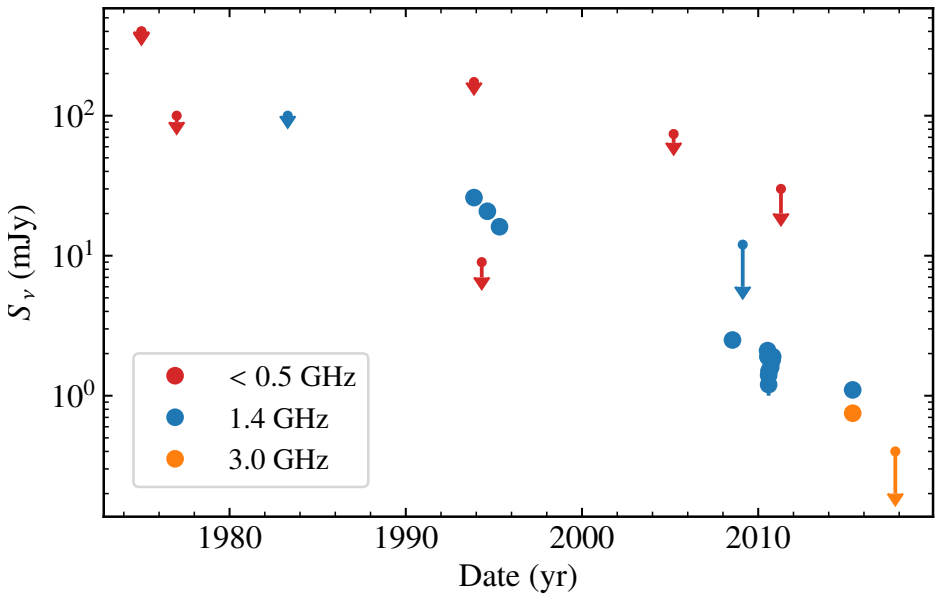
Located at 87 Mpc

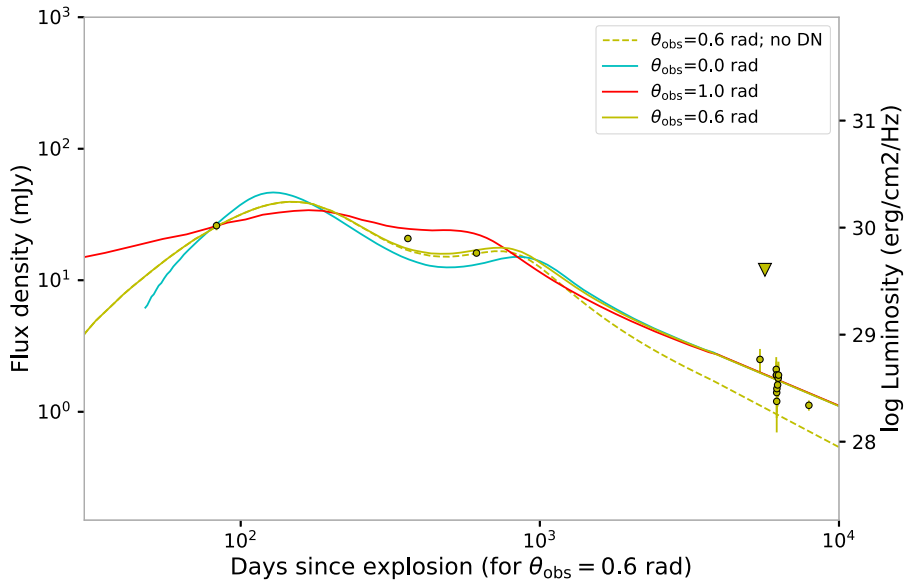
Consistent with:

- Long GRB afterglow:

  $E_{iso} \sim 10^{53}$ erg,
  $\theta_{obs} \sim 30°$

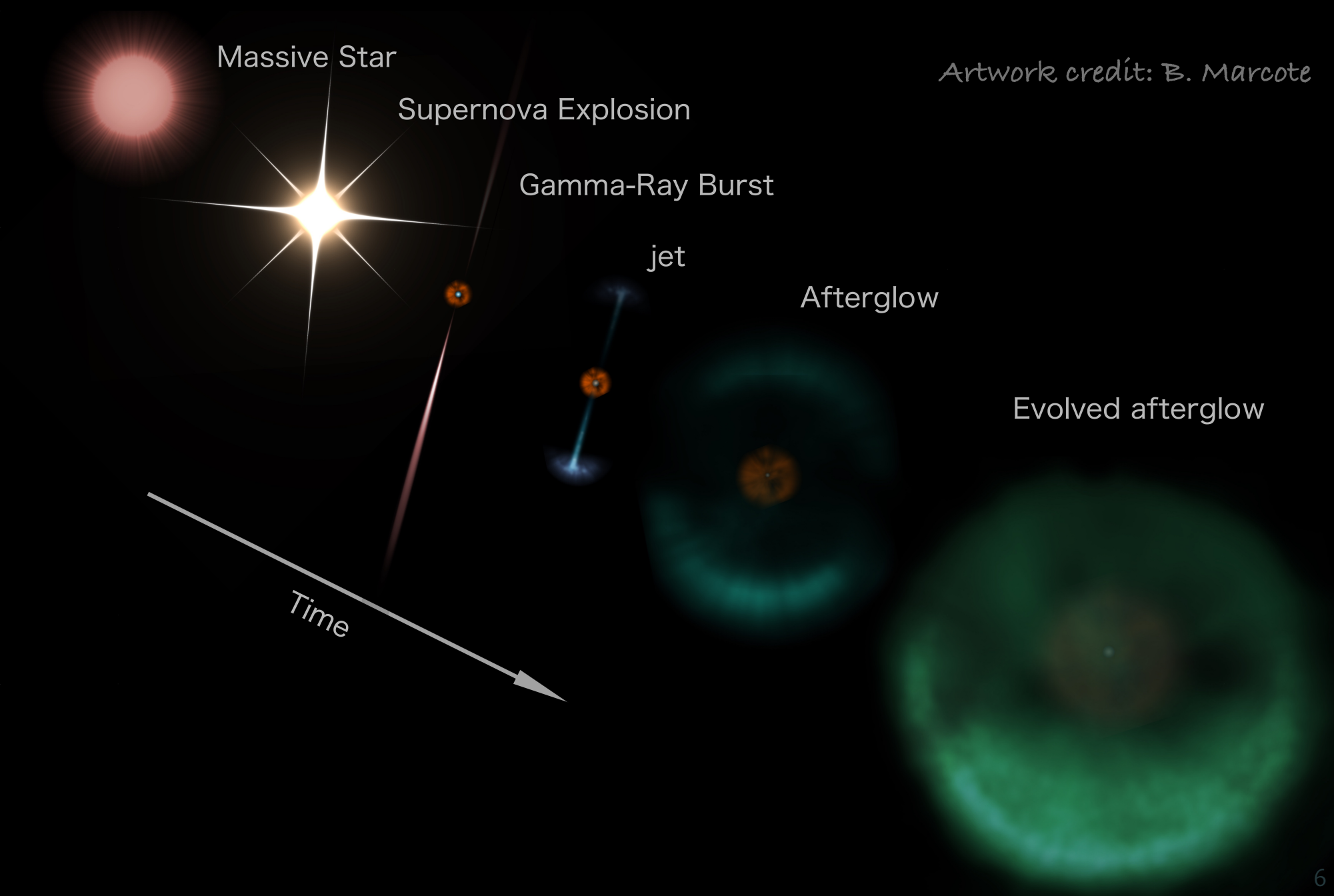
- Magnetar wind nebula





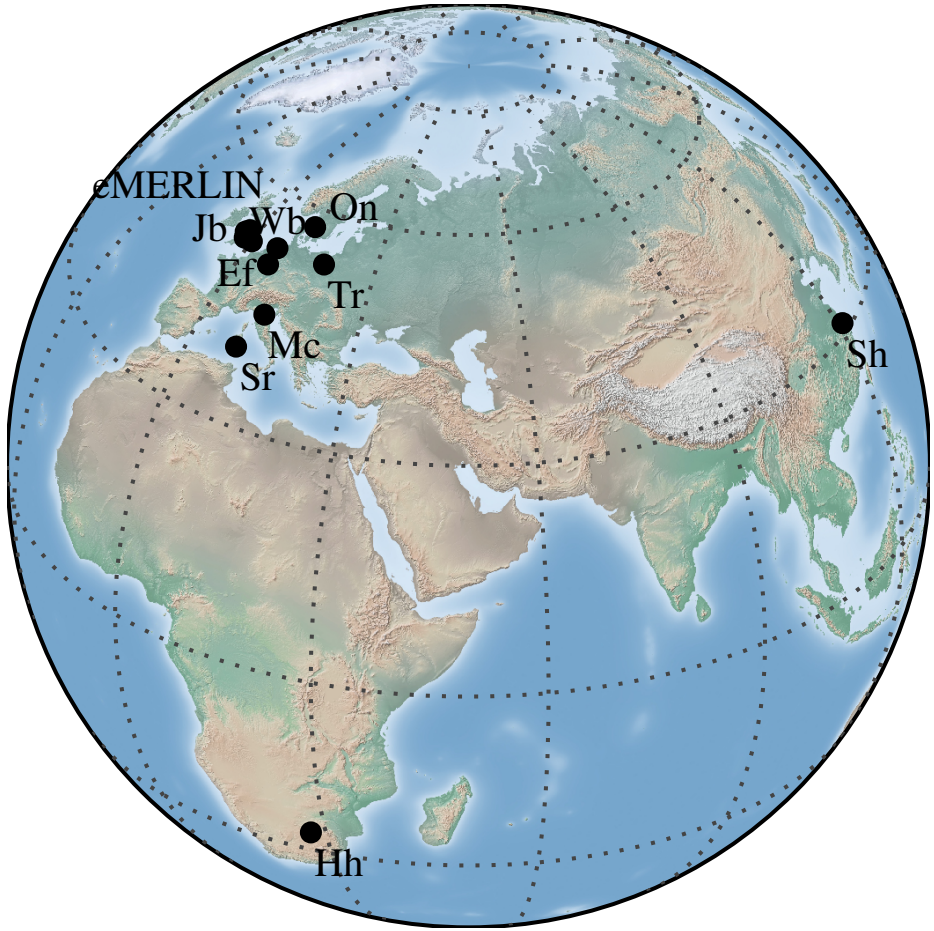
Law et al. (2018, ApJL, 866, L22)

Long Gamma-Ray Bursts (GRBs)



European VLBI Network (EVN) observations

- **e-EVN ToO at 1.6 GHz**
- 2018 September 18
- $\sim$ 4.5 h on target
- 12 antennas:
  9 EVN + 3 e-MERLIN



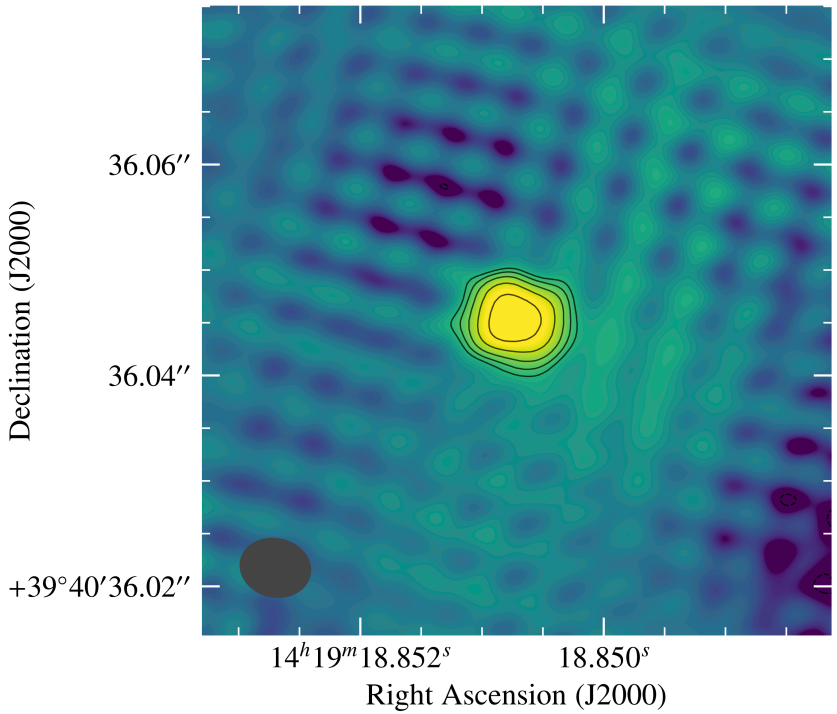
- **Effelsberg PSRIX data**
- 40.96 µs, 0.2438 MHz
- DM trials 0–1210.8 pc cm^{-3}

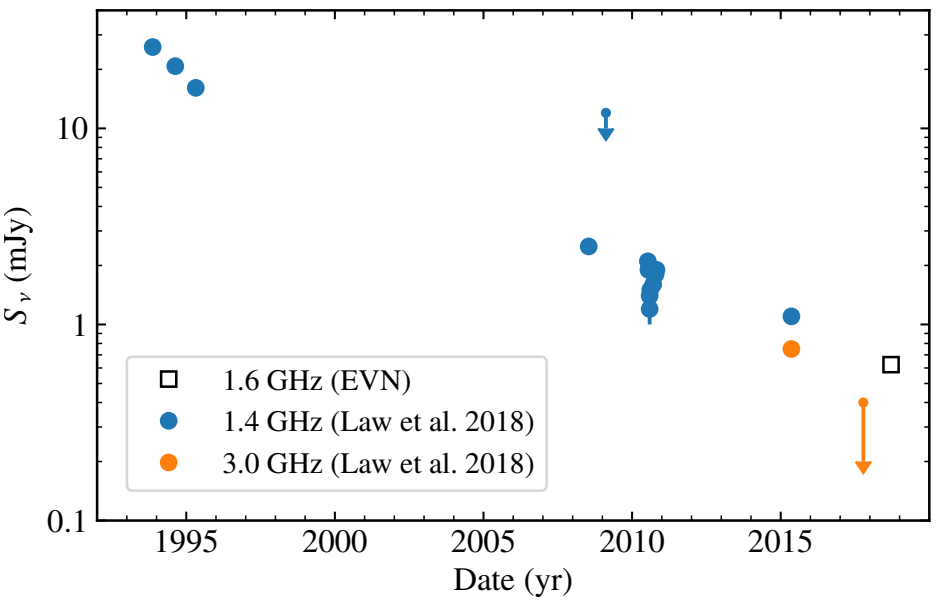
Marcote et al. (2019, ApJL, 876, L14)

FIRST J1419+3940 on milliarcsecond scales

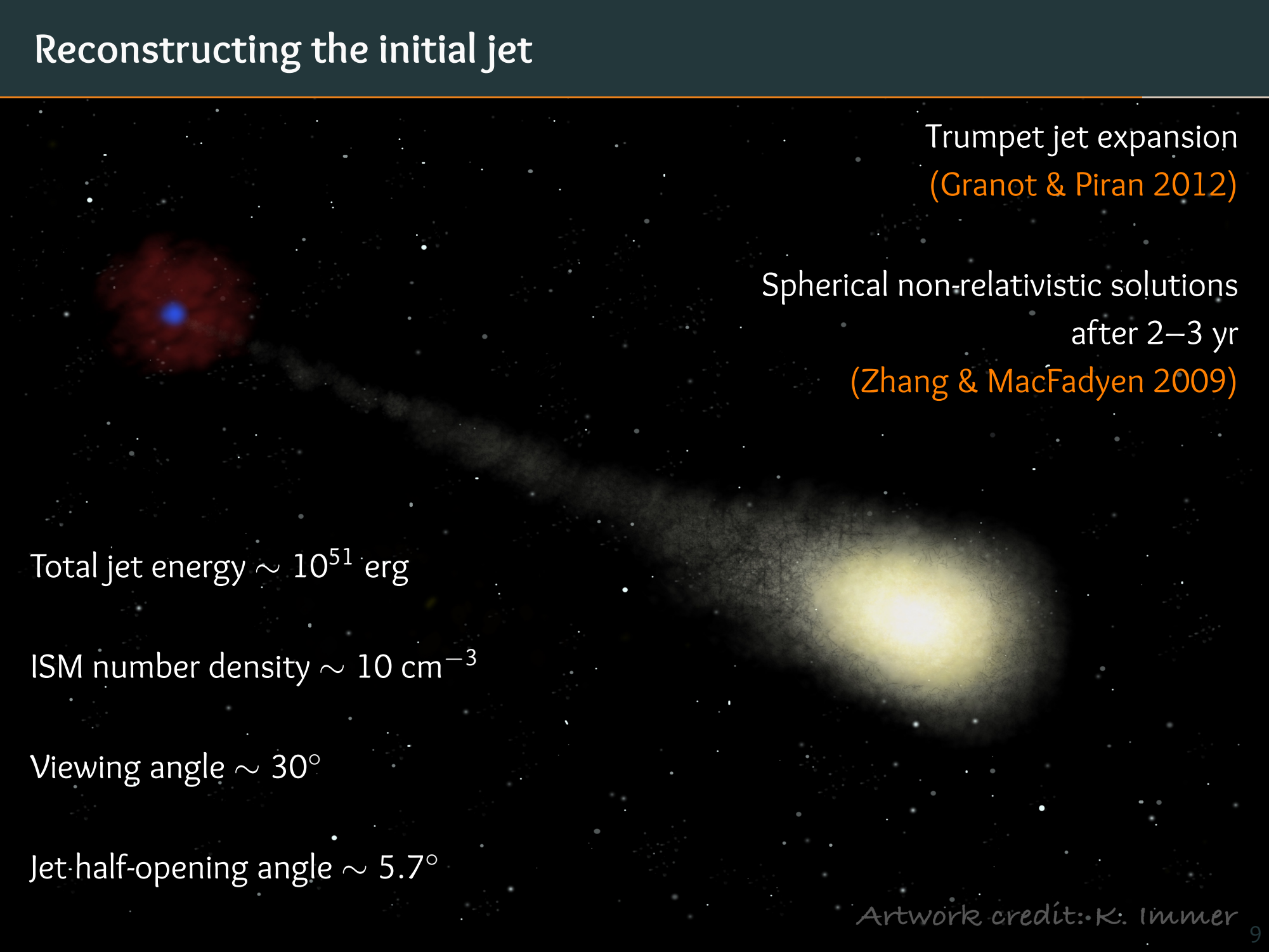
- Flux density: 620 ± 20 μJy at 1.6 GHz
- $\nu L_\nu = (9.4 \pm 0.3) \times 10^{36}$ erg s^{-1}
- Spectral index $\lesssim -0.62$
- Size: 3.9 ± 0.7 mas: **1.6 ± 0.3 pc**
- Synthesized beam: 6×5 mas^2
- Average expansion (30 yr): **$(0.11 \pm 0.02)c$**
- No bursts were detected.

Marcote et al. (2019, ApJL, 876, L14)





Reconstructing the initial jet



Trumpet jet expansion
(Granot & Piran 2012)

Spherical non-relativistic solutions
after 2–3 yr
(Zhang & MacFadyen 2009)

Total jet energy $\sim 10^{51}$ erg

ISM number density $\sim 10\ \mathrm{cm}^{-3}$

Viewing angle $\sim 30°$

Jet half-opening angle $\sim 5.7°$

Artwork credit: K. Immer

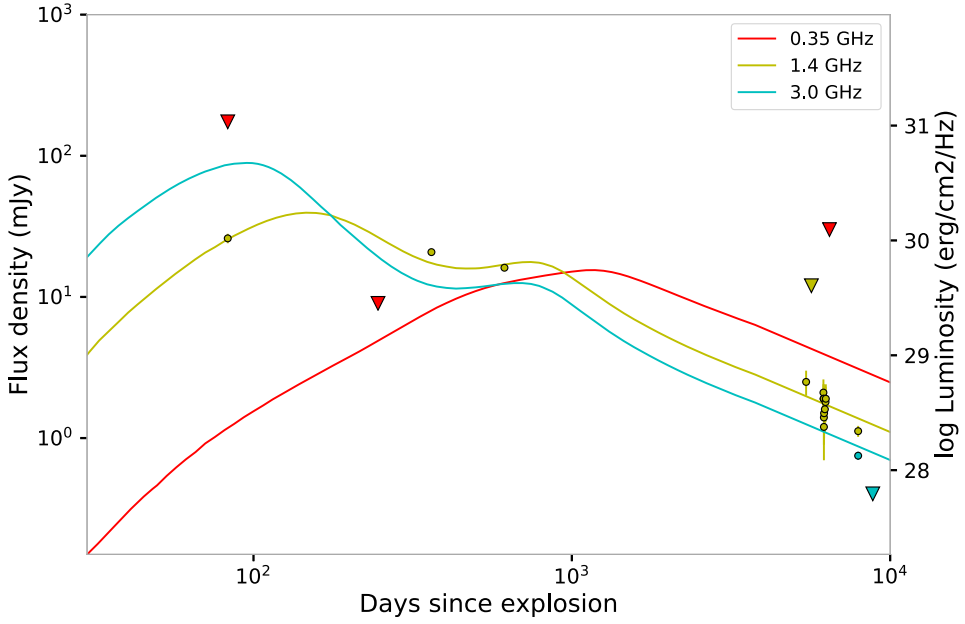
Conclusions

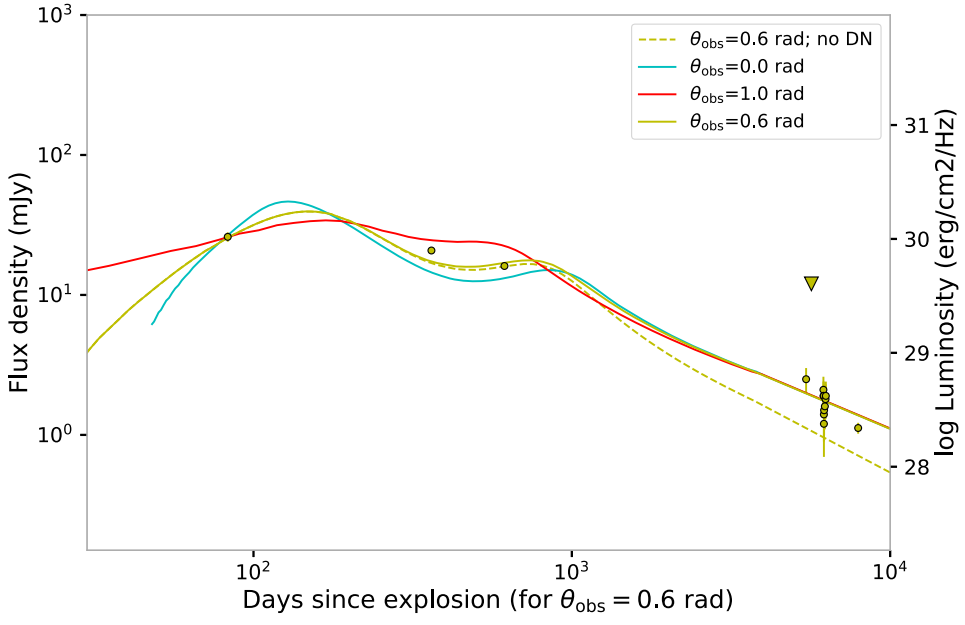
- FIRST J1419+3940 exhibits a size of 1.6 ± 0.3 pc (in Sep. 2018).
- Mildly relativistic average expansion velocity of $\sim 0.11c$.
- Faster declining during the last years.
- Consistent with an (orphan) afterglow of a putative long GRB.
- Radio transients to find missing GRBs?
- Source properties different from FRB 121102.
- No FRBs detected during the observations. *But...*

Marcote et al. (2019, ApJL, 876, L14)

Thank you!

Expected light-curves from GRB models (Law et al. 2018)





Discussion II

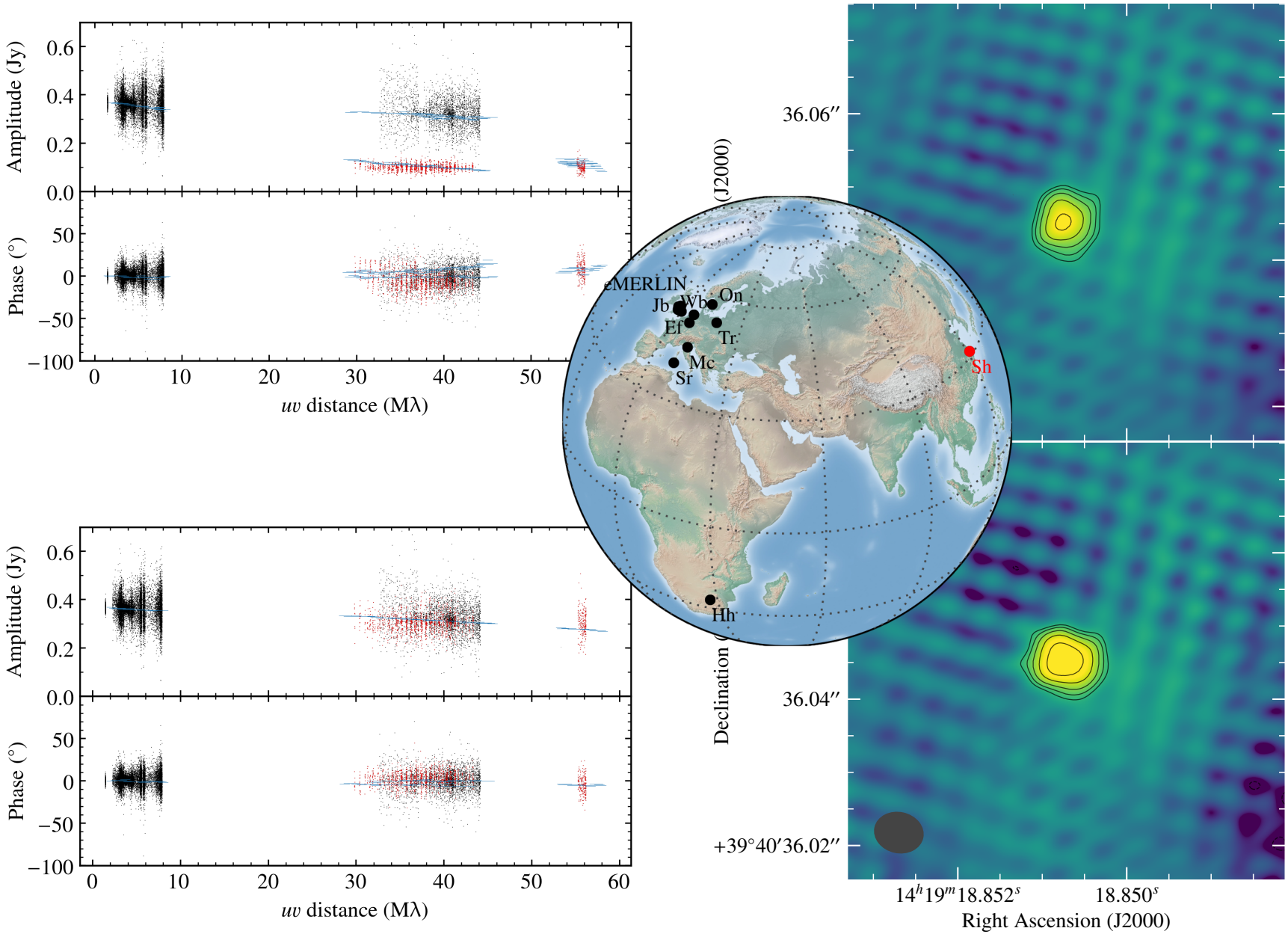
Comparison with FRB 121102

- Similar luminosities ($\sim 10^{38}$ erg s^{-1})
- Declining light-curve. Younger? ($\sim$ 30 vs 50–100 yr)
- Larger size. Consistent with ejecta speeds of 10^{3-4} km s^{-1} (Margalit & Metzger 2018; Piro & Gaensler 2018)
- Fluences $>$ 2.5 Jy ms would be expected

Comparison with PTF10hgi

- Radio source coincident with SLSN (Eftekhari et al. 2019)
- Comparable $E_{\rm iso} \sim 3 \times 10^{53}$ erg, $n \sim 10$ vs 10^{-3}–10^{2} cm^{-3}

FIRST J1419+3940 on milliarcsecond scales



FIRST J1419+3940 on milliarcsecond scales

- **Source size** (circular Gaussian):

  3.9 ± 0.7 mas

  1.6 ± 0.3 pc

- $T_b \sim 1.1 \times 10^7$ K

- **Mean expansion velocity:**

  $(3.2 \pm 0.6) \times 10^4$ km s^{-1}

  $(0.11 \pm 0.02)c$

  Mildly relativistic