

Resolving Jets from Gamma-Ray Bursts

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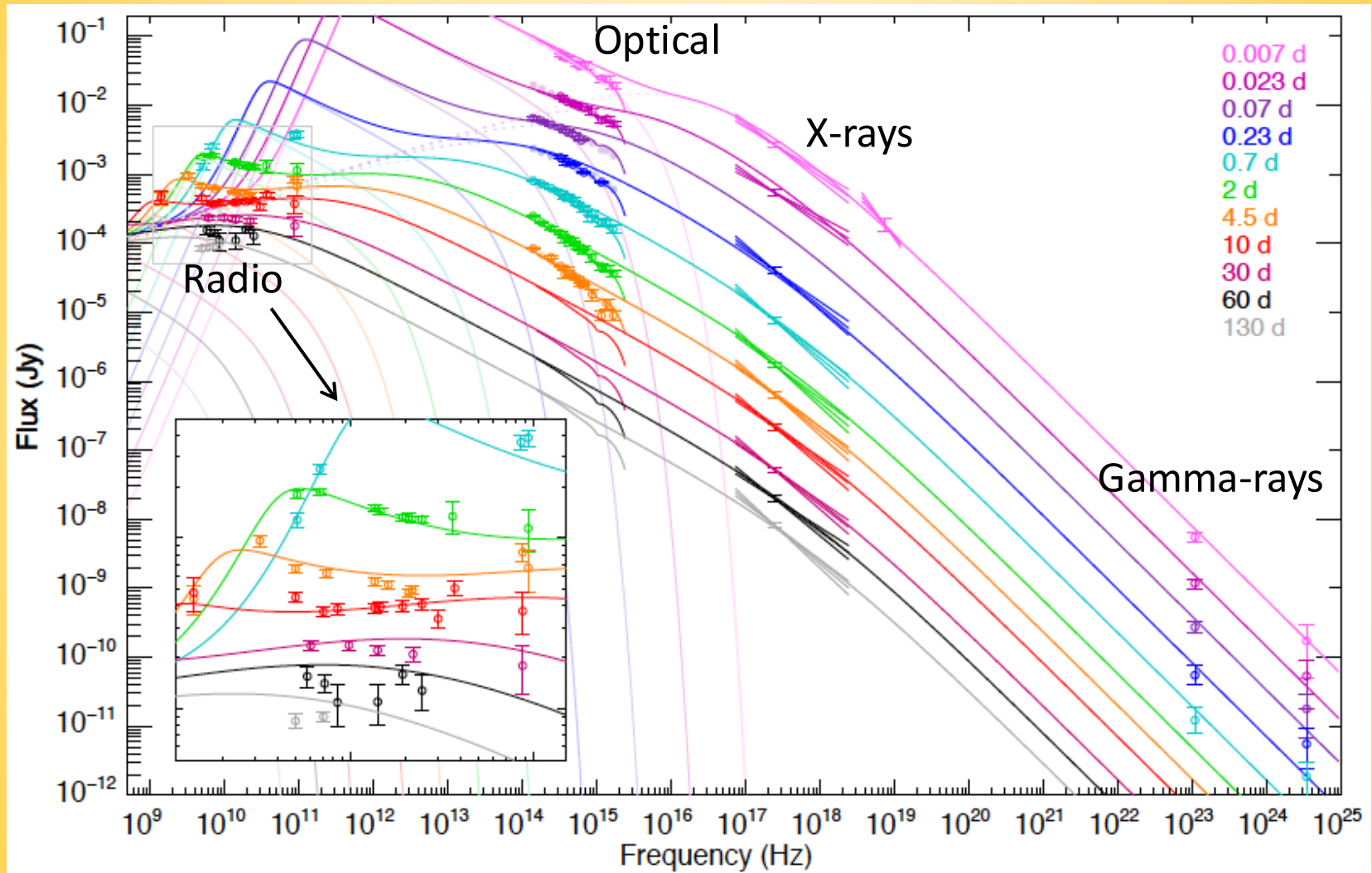
WASHINGTON, DC

247th AAS Meeting

Phoenix – 7 January 2026

The Highest Angular Resolution Frontier

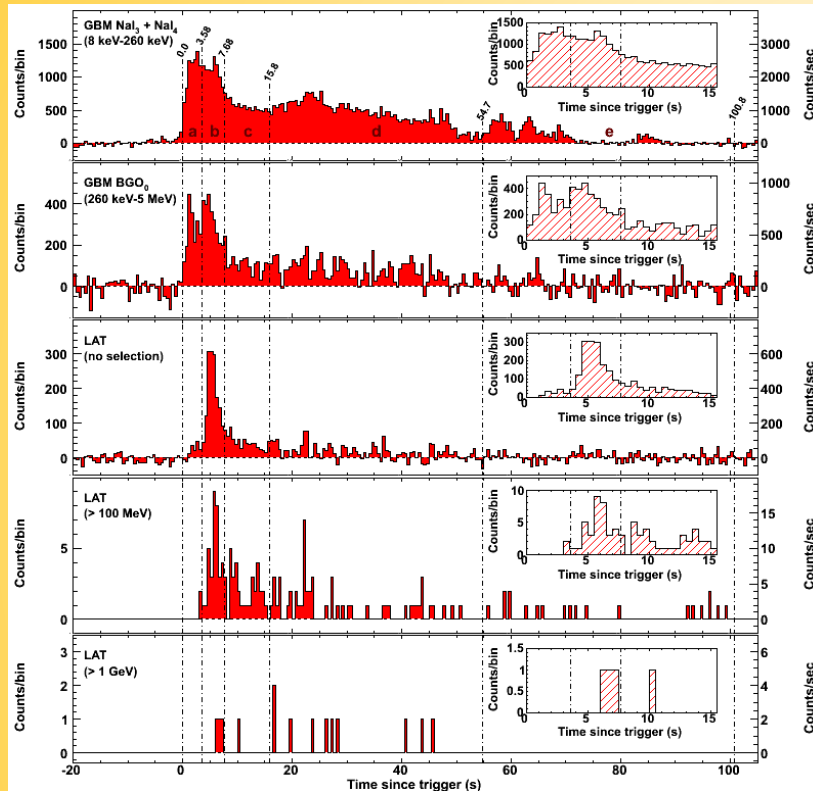
GRBs: Multi-Wavelength Transients



GRB 130427A (Perley et al. 2014)

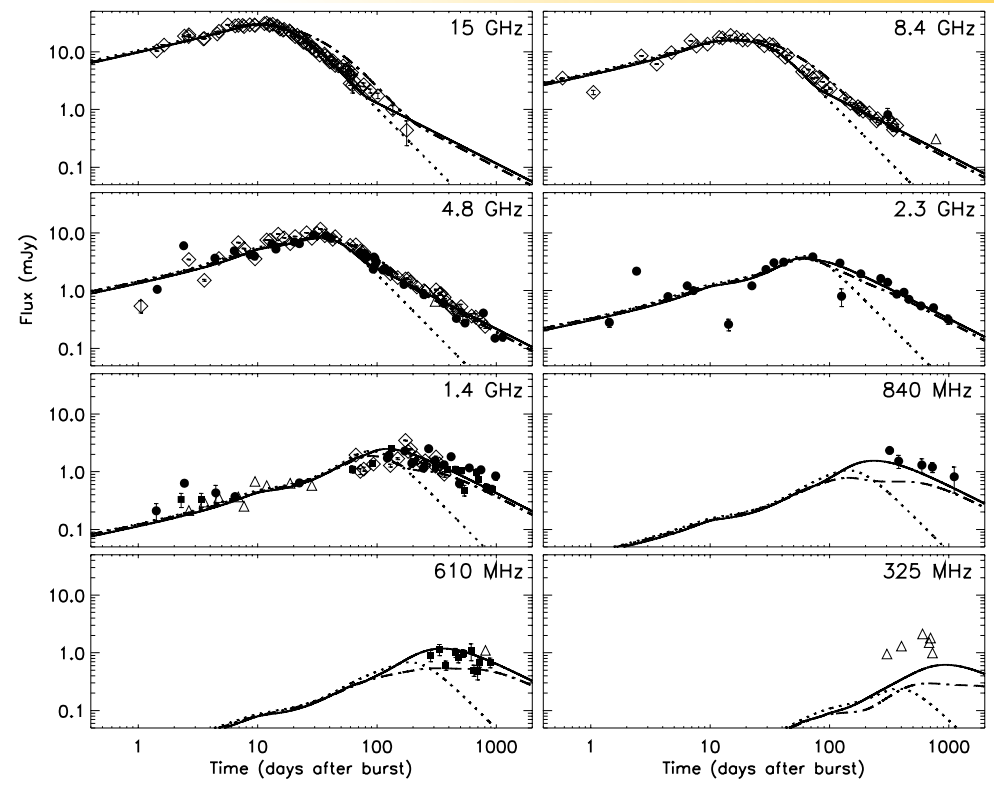
Multi-Wavelength & Multi-Timescale

GRB 080916C (Abdo et al. 2009)



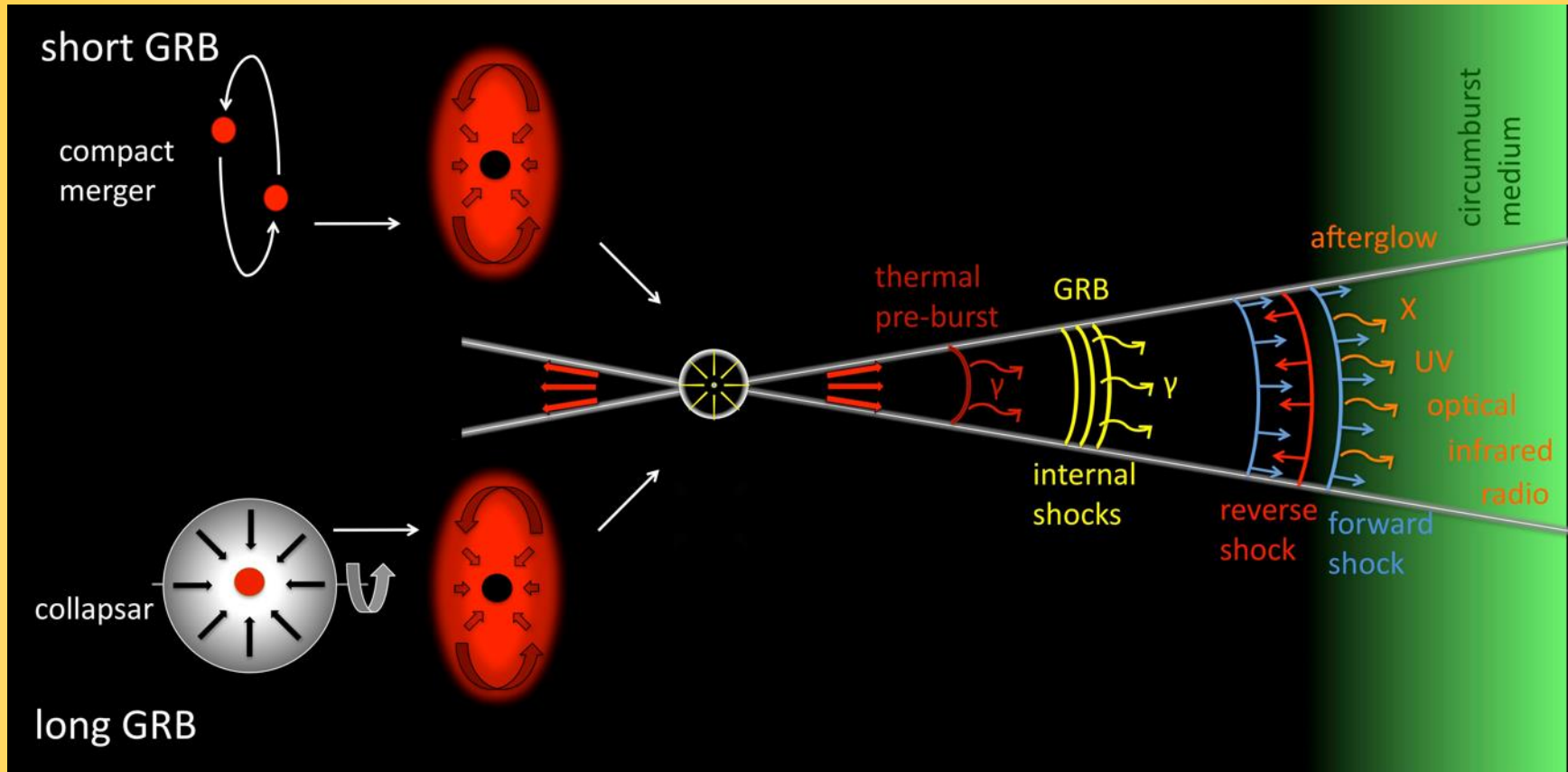
↑
GeV – GHz →

← Seconds – Years



GRB 030329 (AJvdH et al. 2008)

Relativistic Blast Wave Model

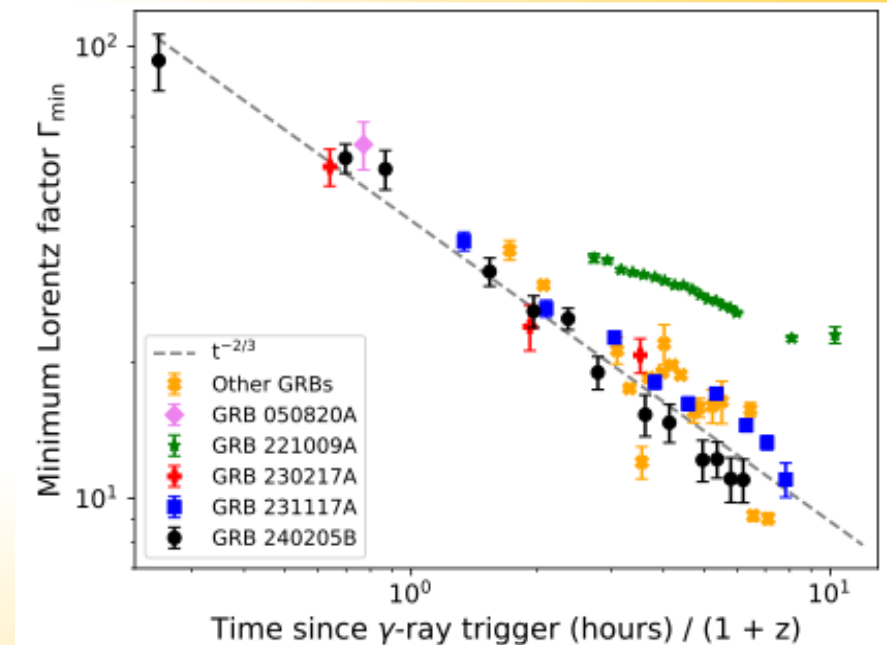
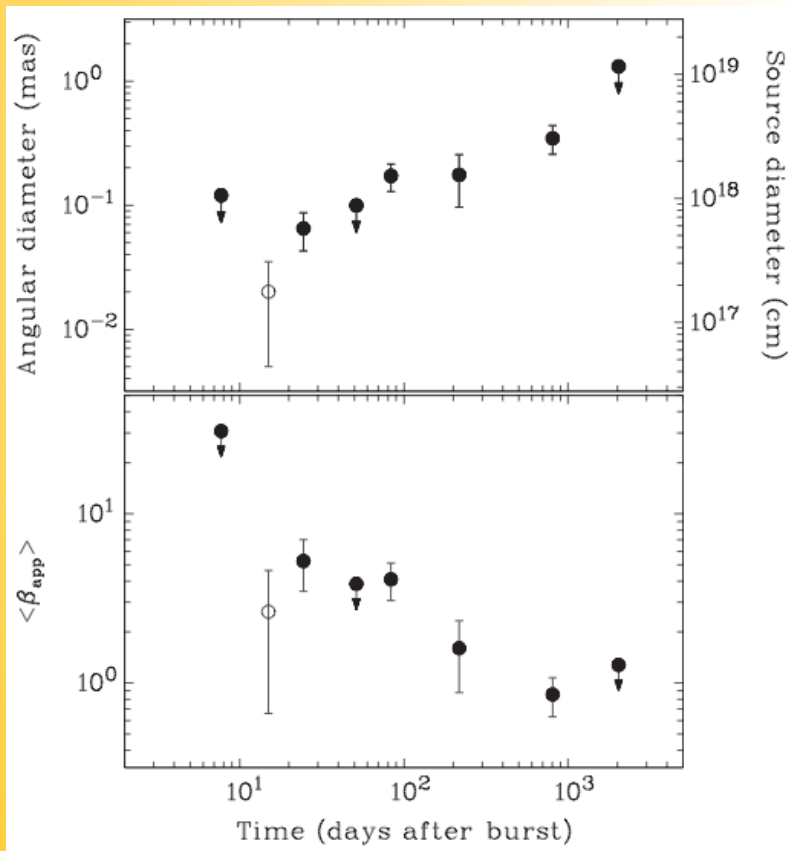


Meszaros & Rees 1992; Rees & Meszaros 1992 (Figure: Gomboc 2012)

- Afterglow synchrotron emission $\rightarrow$ relativistic beaming: $\vartheta_{\text{rel}} = 1/\Gamma$
- Collimated relativistic outflow $\rightarrow$ jet opening angle: ϑ_0
- Initially $\vartheta_{\text{rel}} \ll \vartheta_0$, but blast wave decelerating

Evidence for Relativistic Jets in Radio

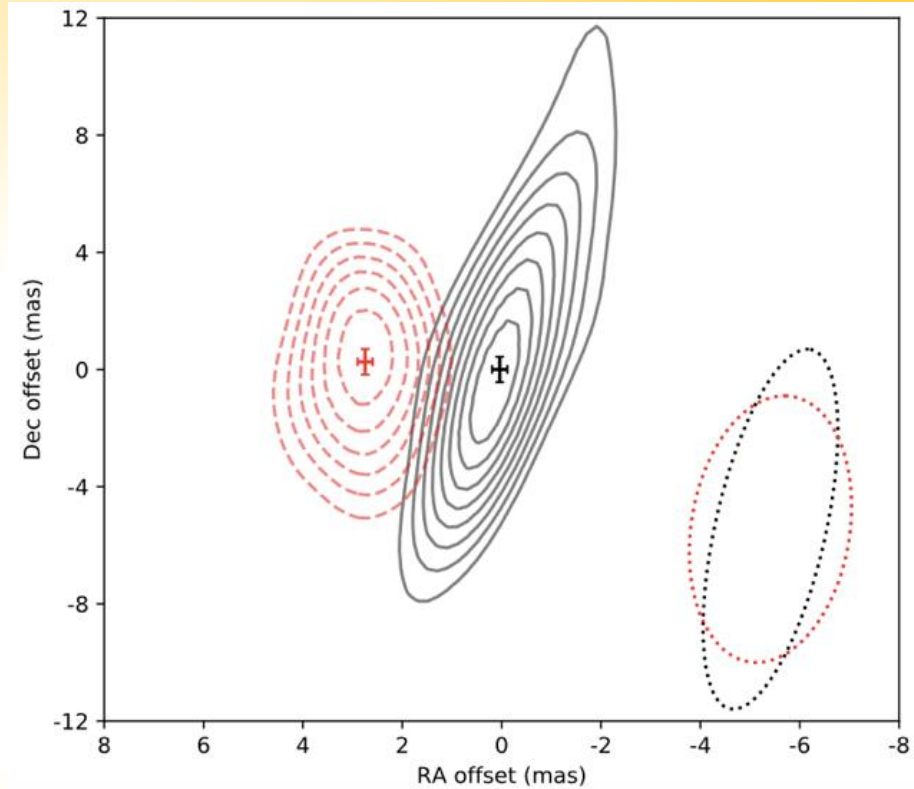
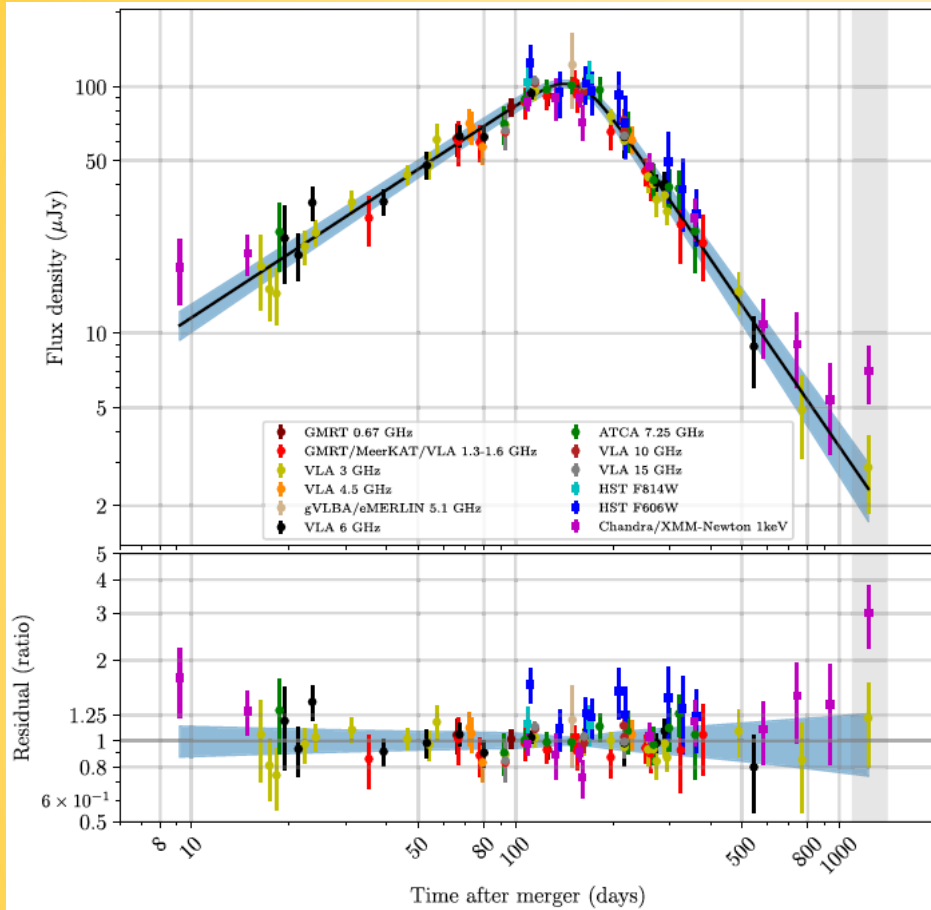
- Radio scintillation $\rightarrow$ relativistic expanding outflow
- Direct imaging of source expansion with VLBI
- Brightness temperature $\rightarrow$ minimum Lorentz factor



Chastain, Anderson, AJvdH et al. 2025;
see also iPoster 176.05 (AJvdH et al.)

GRB 030329 (Taylor et al. 2004, 2005; Pihlstrom et al. 2007; Granot & AJvdH 2014)

Afterglow of GW 170817 / GRB 170817A



Mooley et al. 2018; Ghirlanda et al. 2019

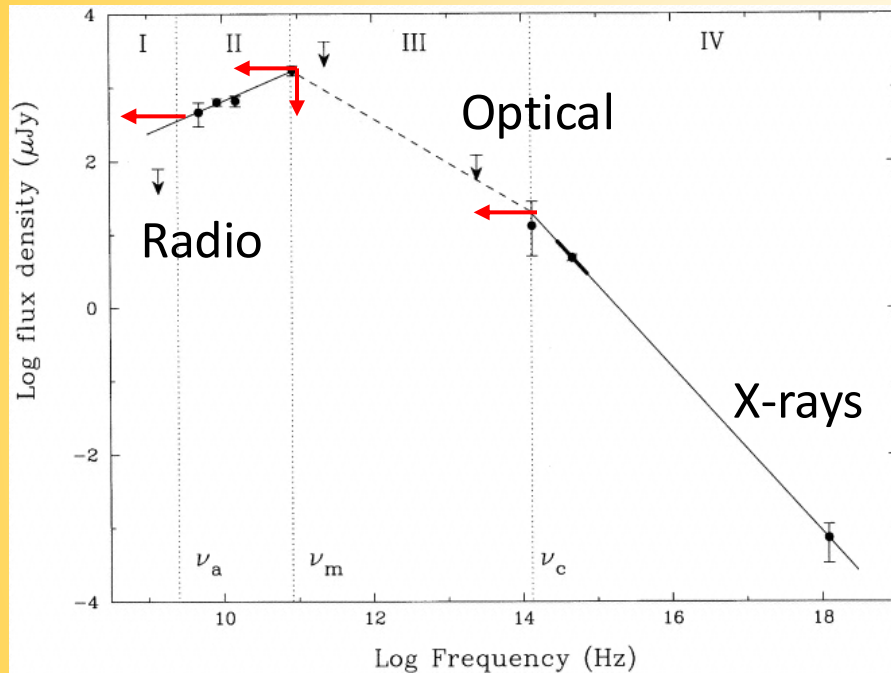
Troja et al. 2017, 2018, 2019; Hallinan et al. 2017; Alexander et al. 2018; Lyman et al. 2018; Margutti et al. 2018; Mooley et al. 2018; Resmi et al. 2018; Fong et al. 2019; Lamb et al. 2019; Piro et al. 2019; Balasubramanian et al. 2021

Modeling Spectra & Light Curves

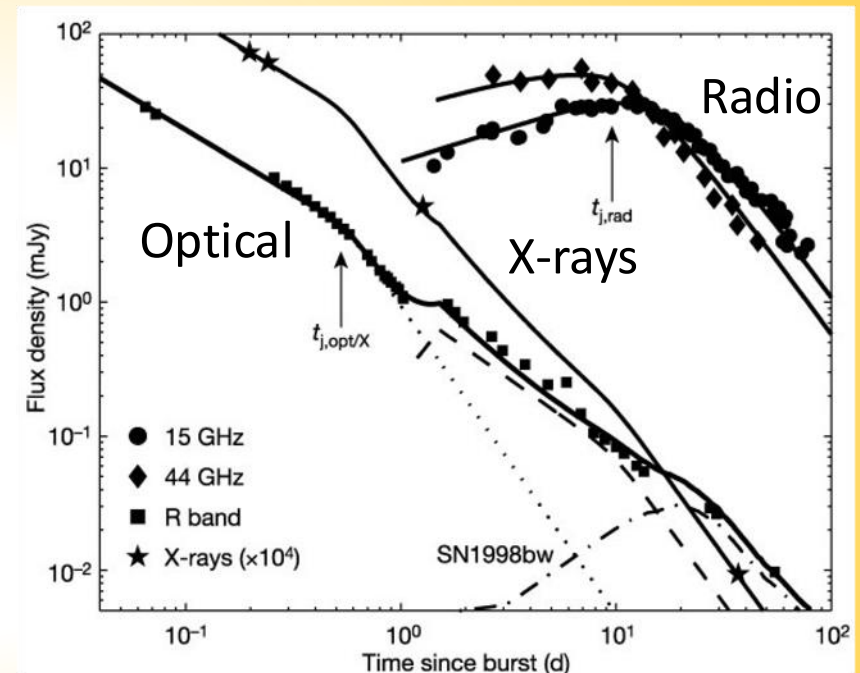
Evolving spectrum



Light curves



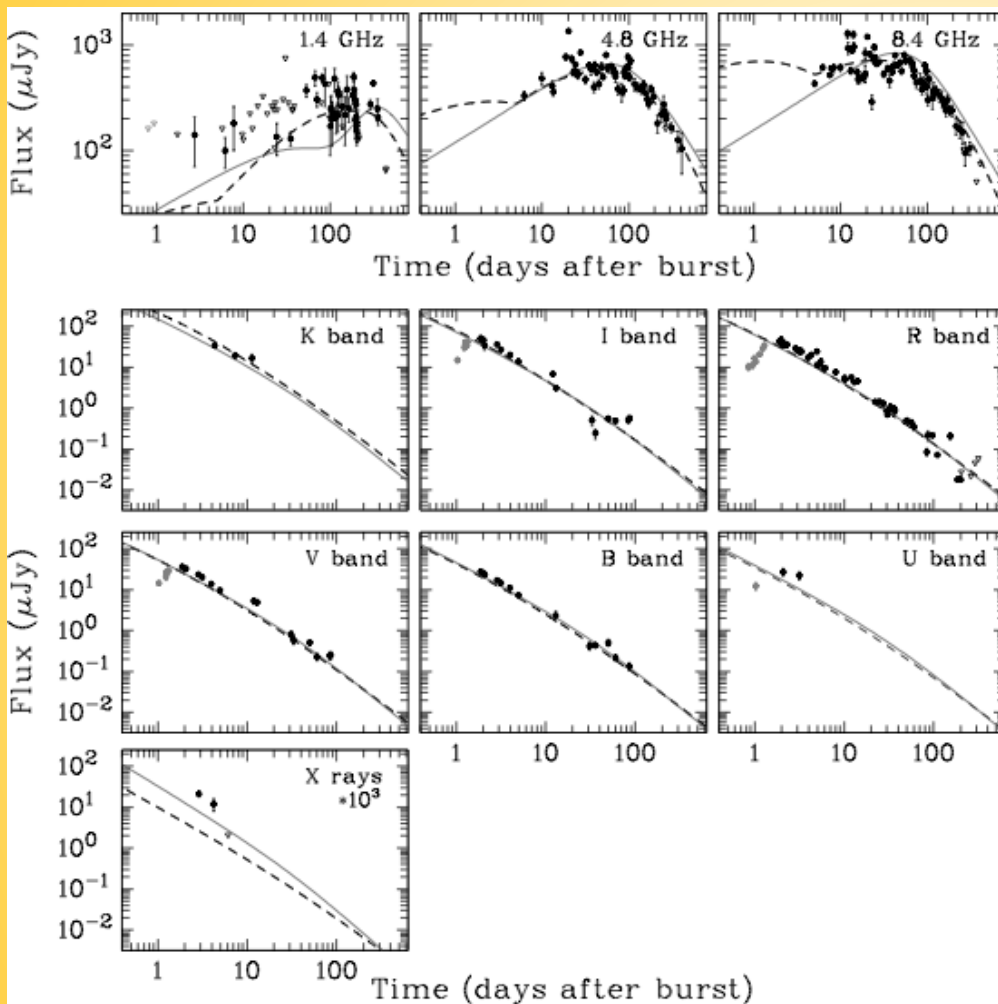
GRB 970508 (Wijers & Galama 1999)



GRB 030329 (Berger et al. 2003)

- Radio crucial: pin down evolution of peak flux, peak frequency, self-absorption frequency
- Scintillation: source size constraints, but with caveats

Physical Parameters

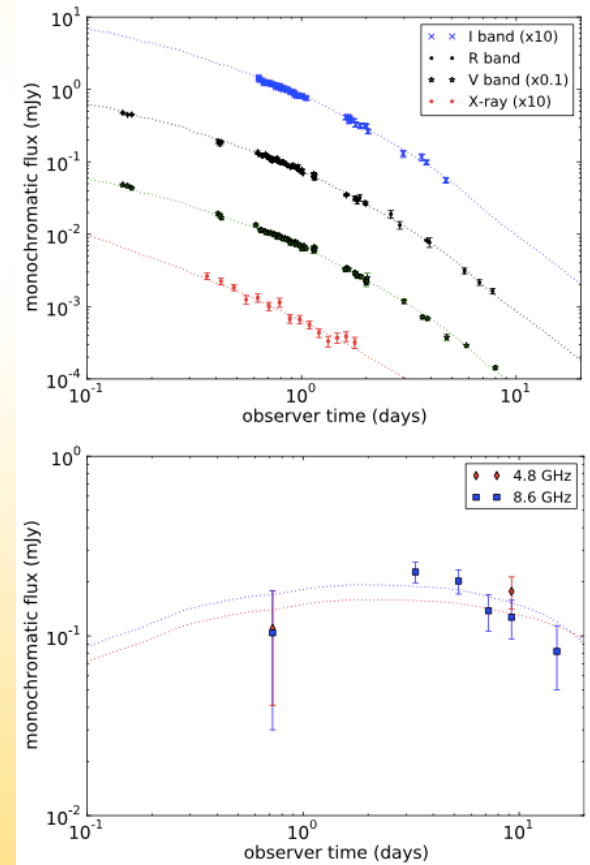
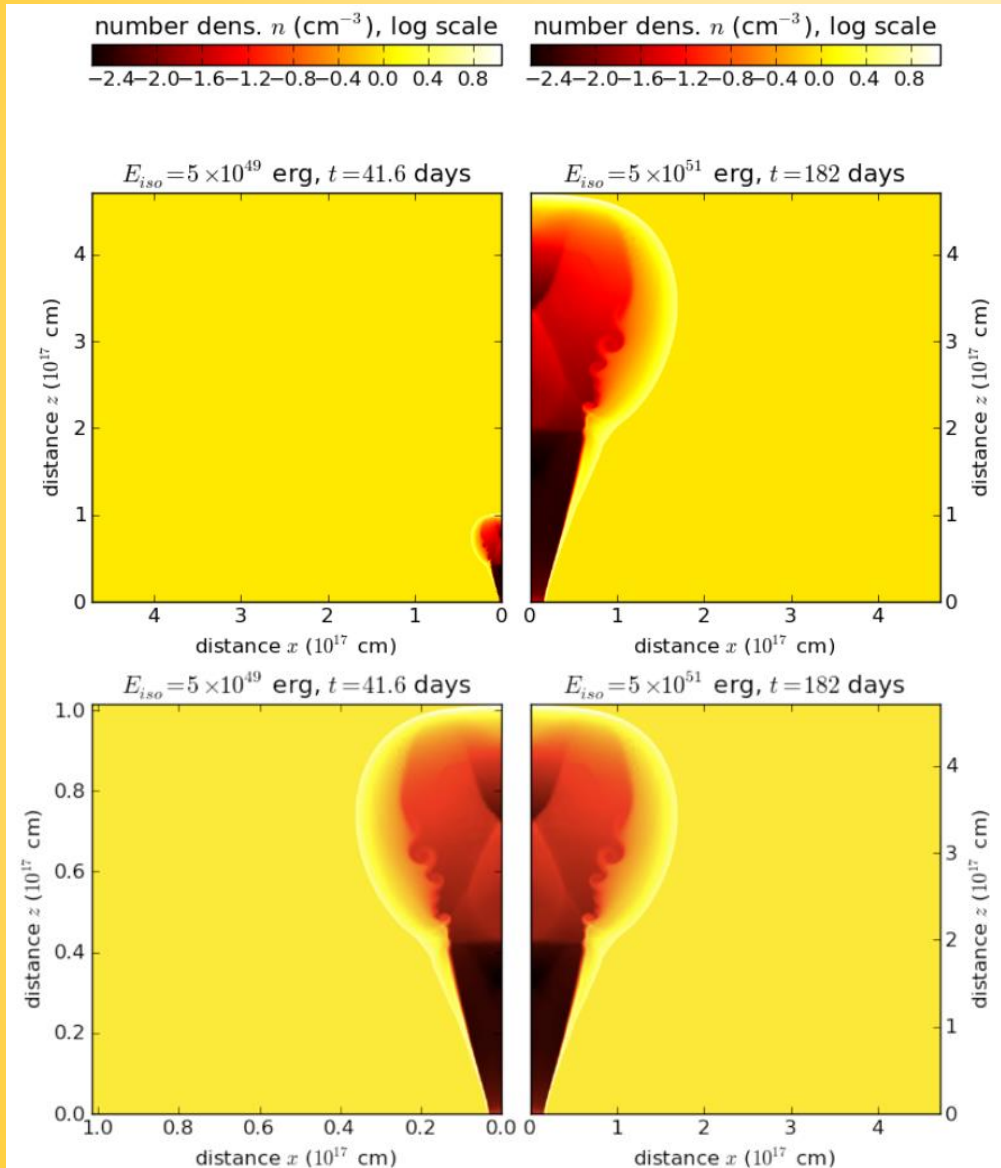


GRB 970508 (Leventis, AJvdH et al. 2013)

- Explosion parameters
 - Blast wave energy
 - Density of ambient medium
 - Structure of ambient medium
 - Jet opening angle
- Radiation parameters
 - Electron energy distribution
 - Energy in electrons
 - Accelerated electron fraction
 - Energy in magnetic field
- Observer parameters
 - Observing angle
 - Redshift & luminosity distance
 - Observer time & frequency

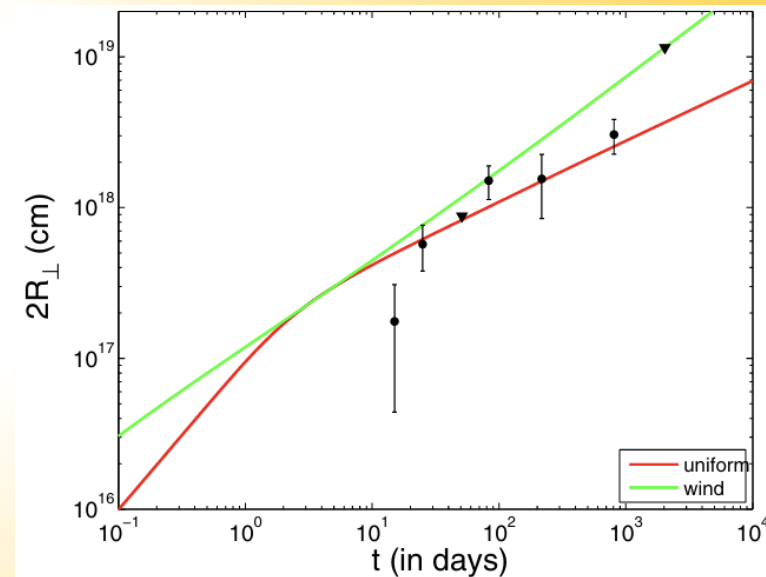
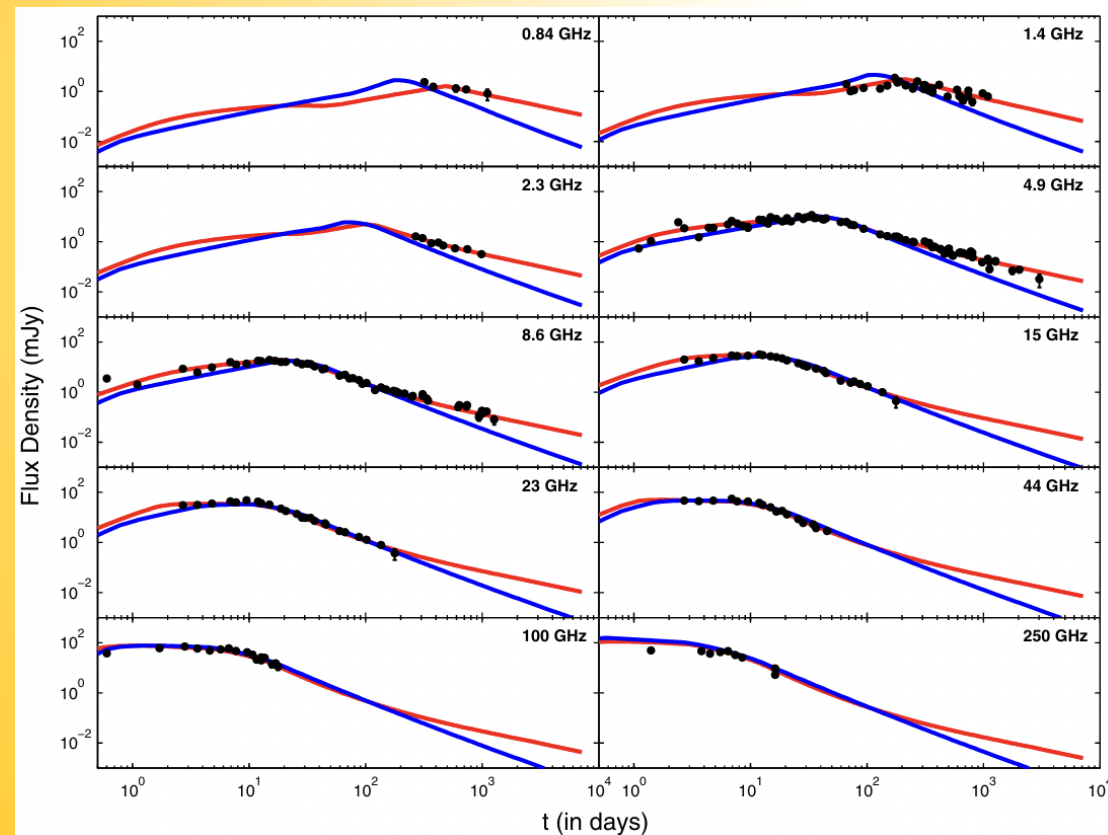
Breakthroughs in Modeling

- Modeling based on 2D hydrodynamic simulations
- 2D dynamics scale invariant
- Valid for entire evolution



Broadband Modeling & Imaging

- Many physical parameters $\rightarrow$ modeling degeneracies
- Questions regarding jet evolution / lateral expansion
- Direct imaging $\rightarrow$ addressing degeneracies & physics questions



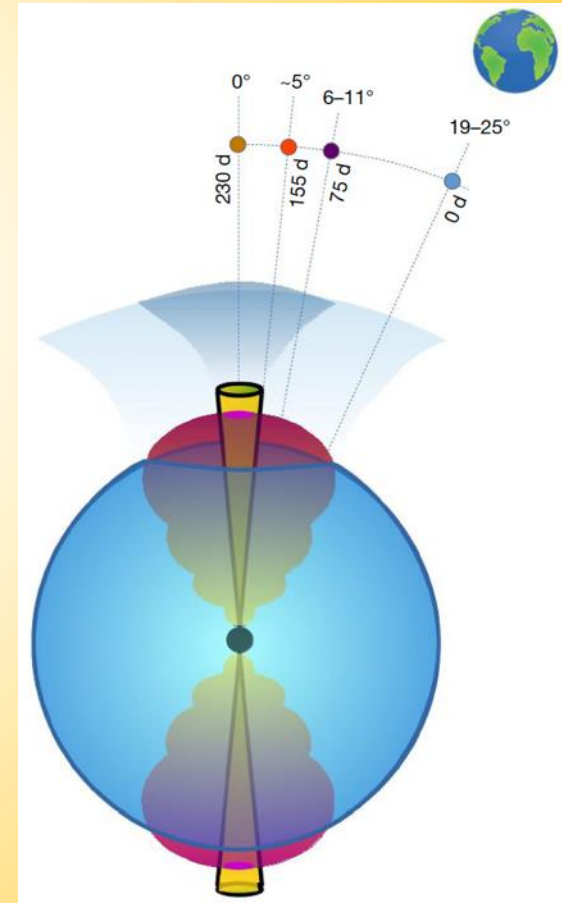
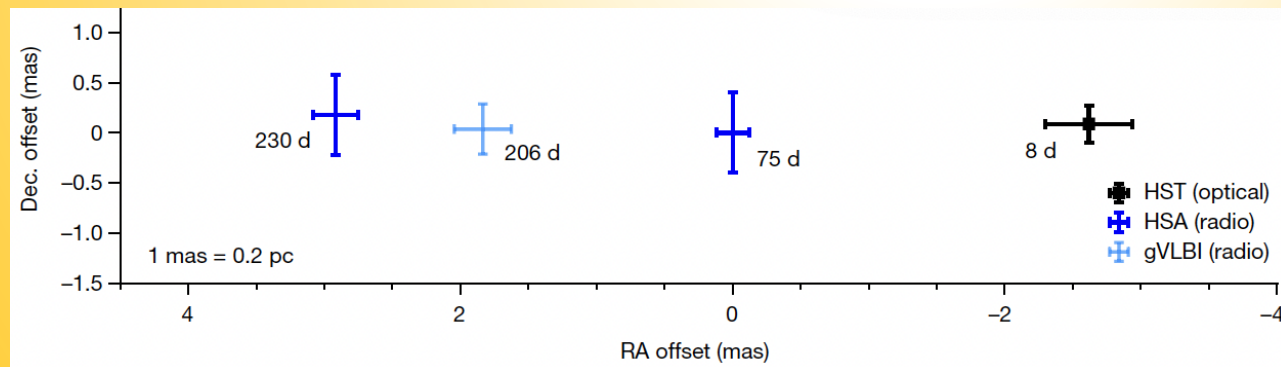
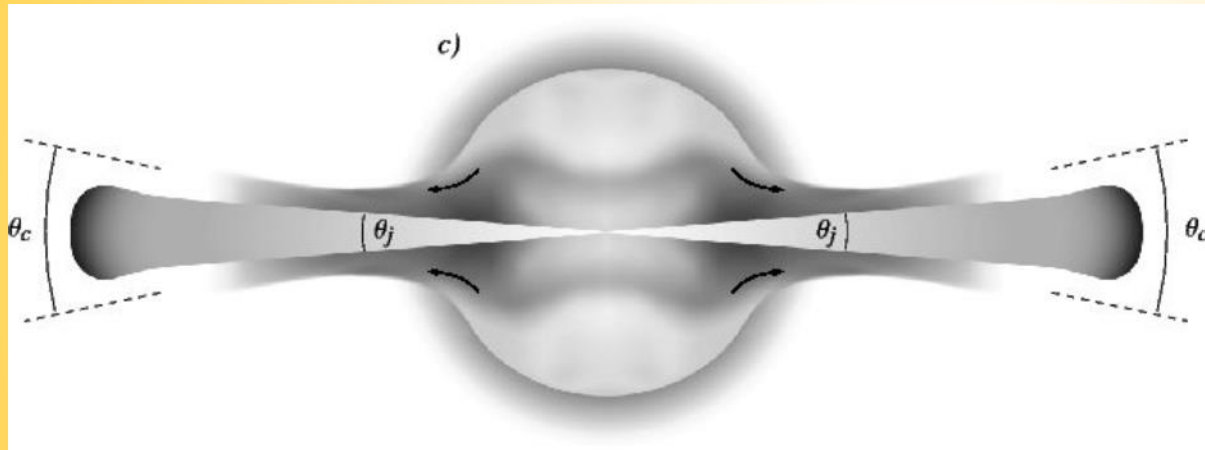
GRB 030329

(Mesler & Pihlstrom 2013)

Jet Structure

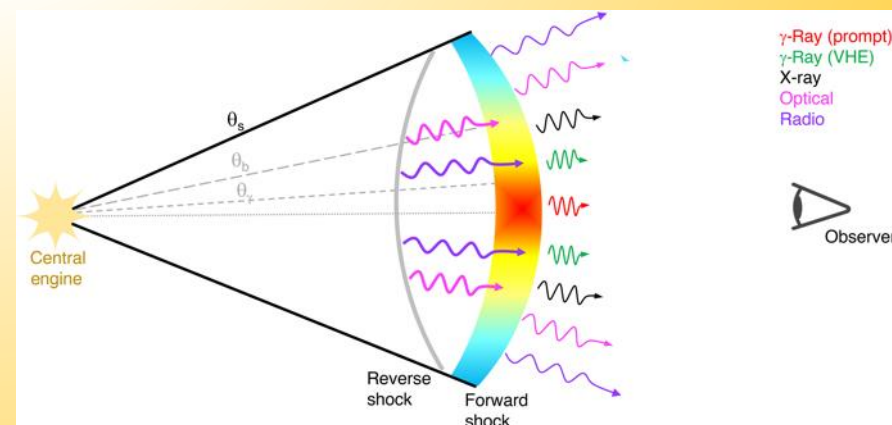
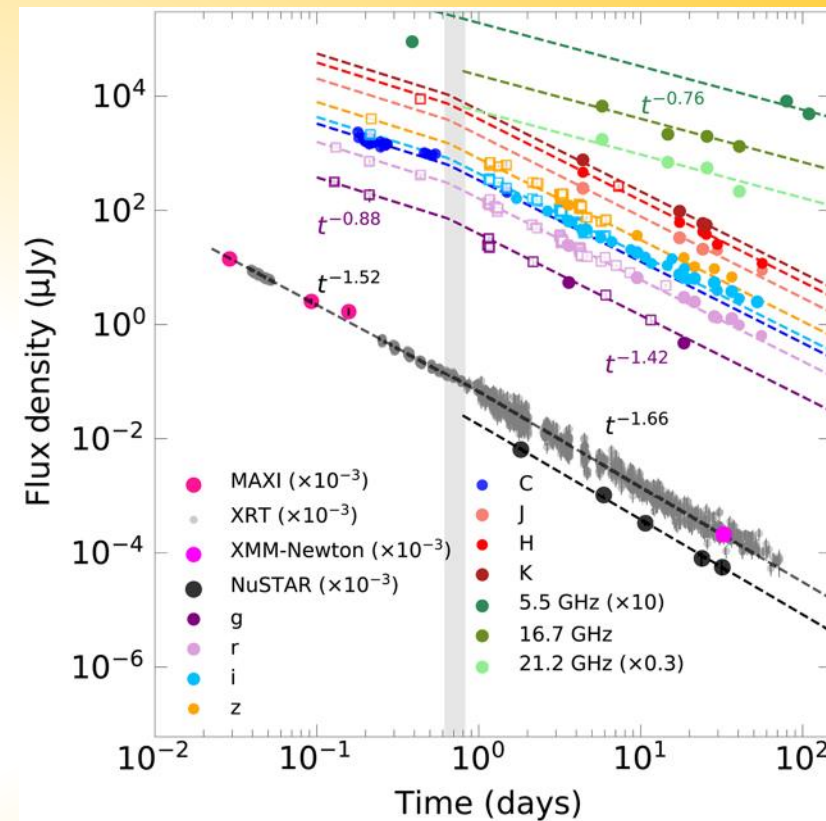
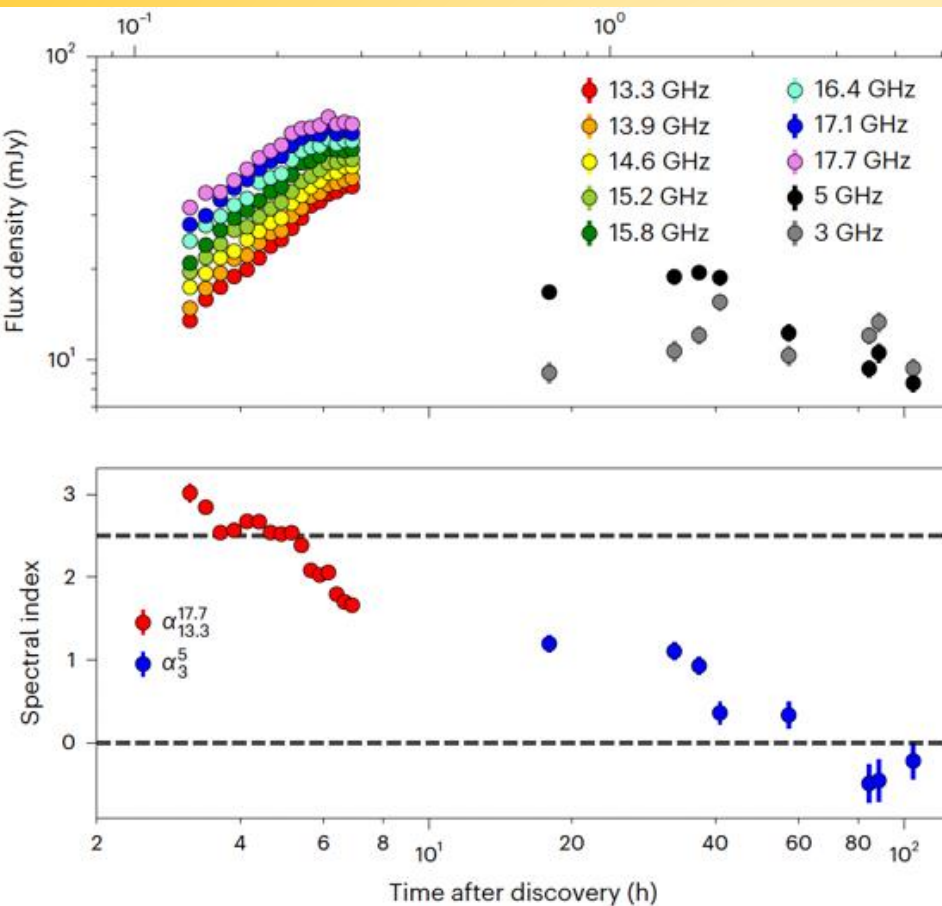
- GRB jets are structured: overall energy/velocity structure, core & wings / cocoon, etc. → direct imaging important

Ramirez-Ruiz et al. 2002



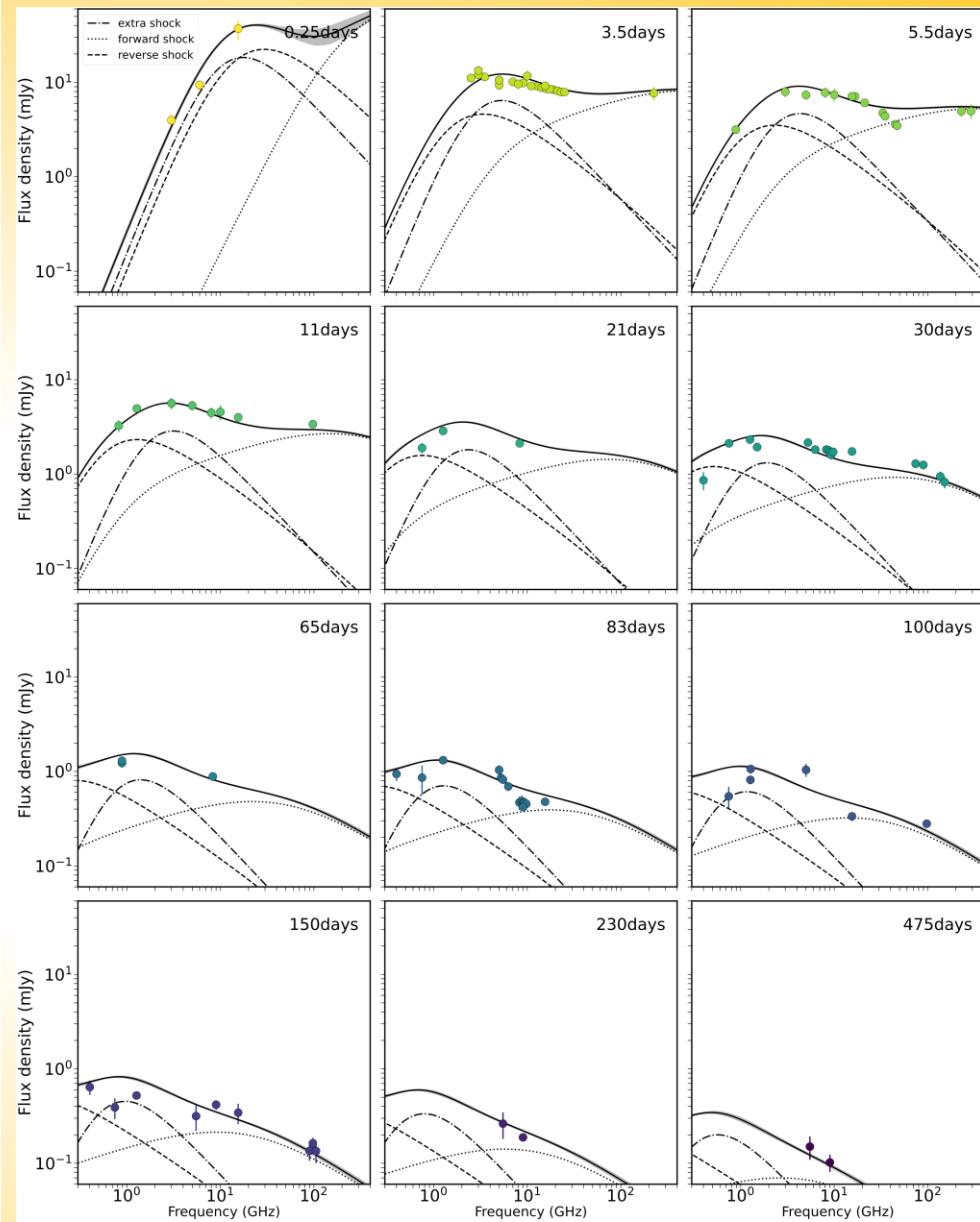
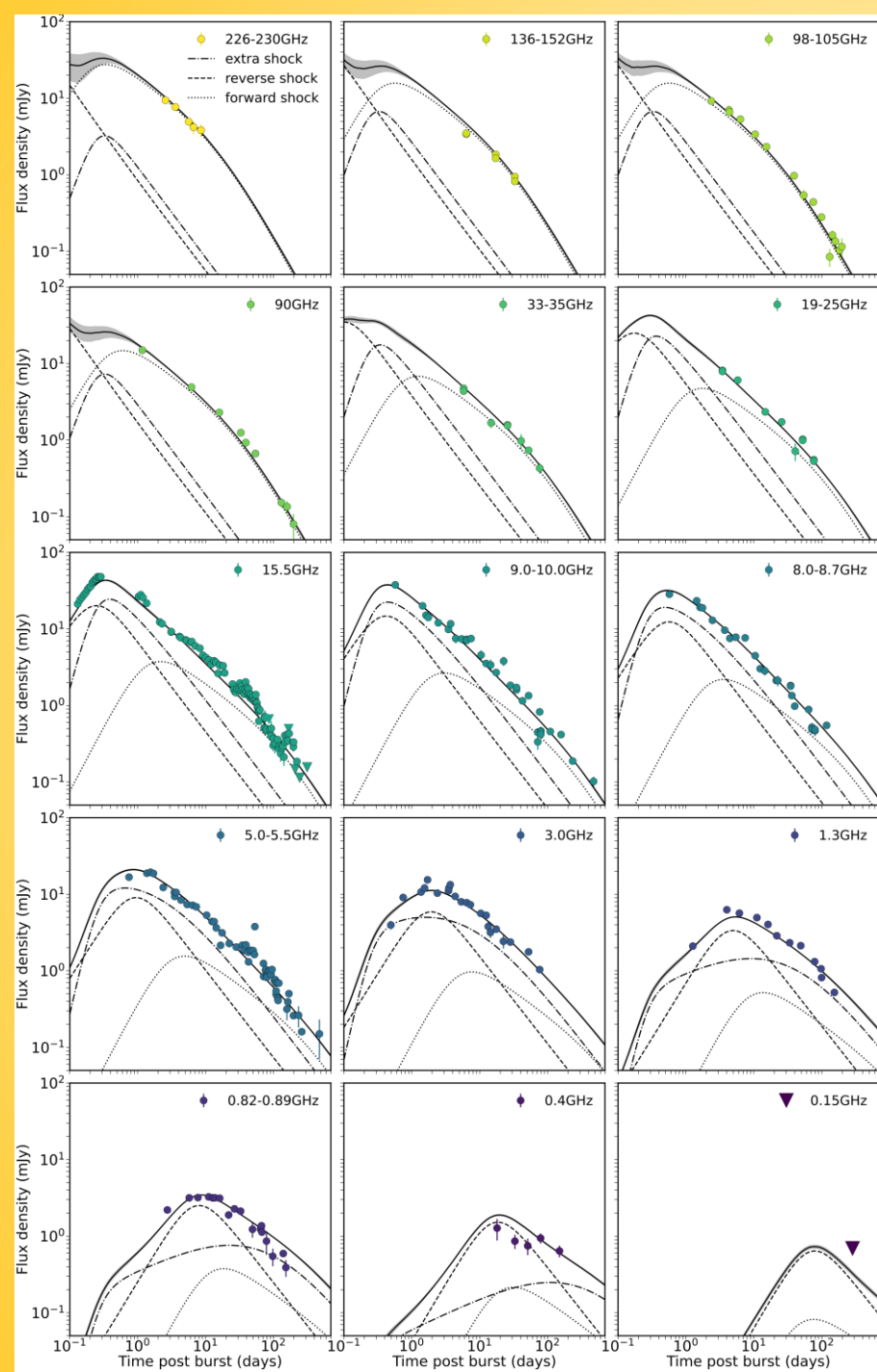
GW 170817 / GRB 170817A (Mooley, Anderson & Lu 2022)

The BOAT: GRB 221009A



Bright, Rhodes et al. 2023

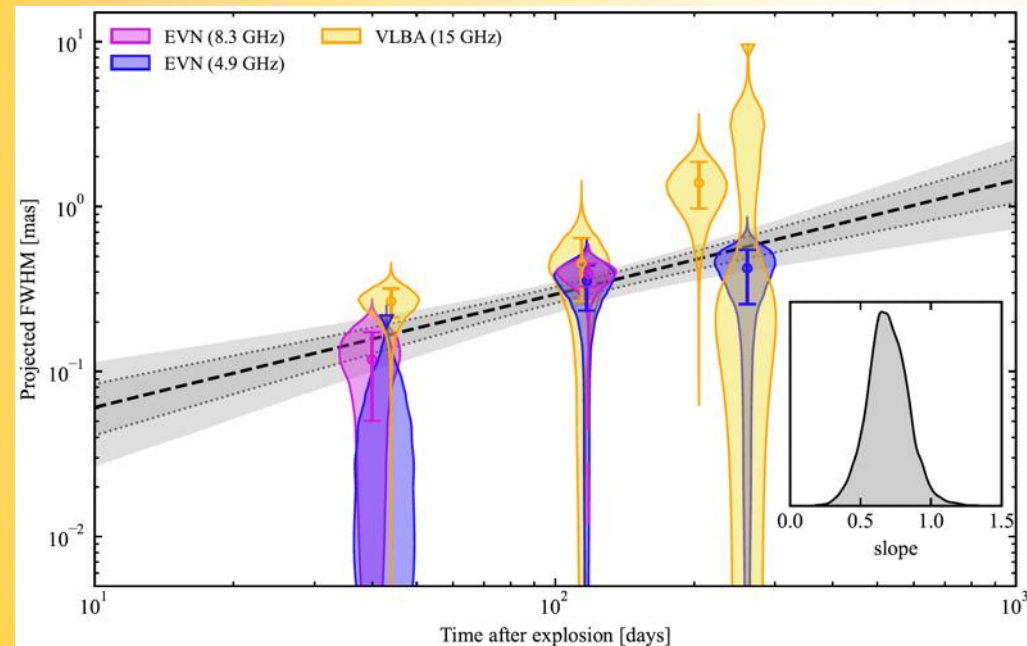
O'Connor, Troja et al. 2023



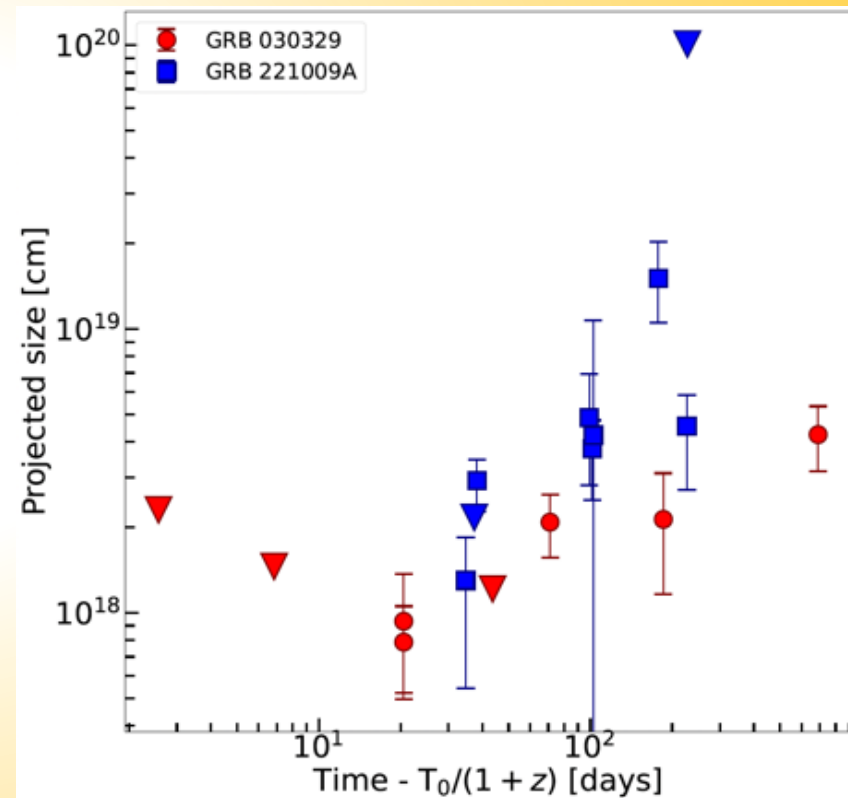
GRB 221009A (Rhodes, AJvdH et al. 2024)

Imaging GRB 221009A

- Superluminal expansion rate, varying between frequencies
- Forward & reverse shock at different frequencies & times



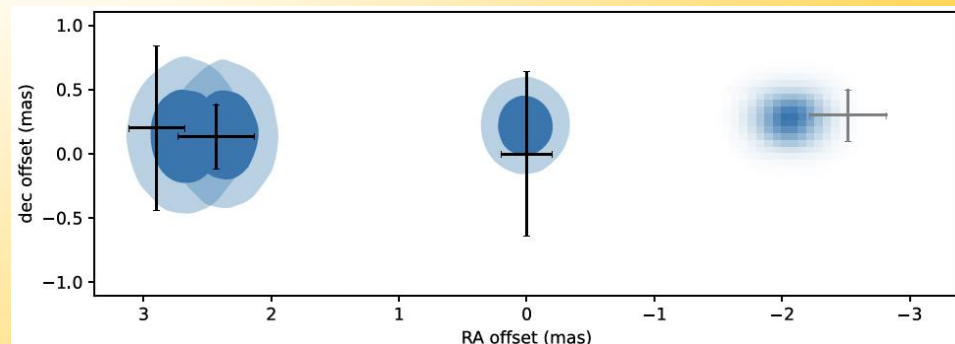
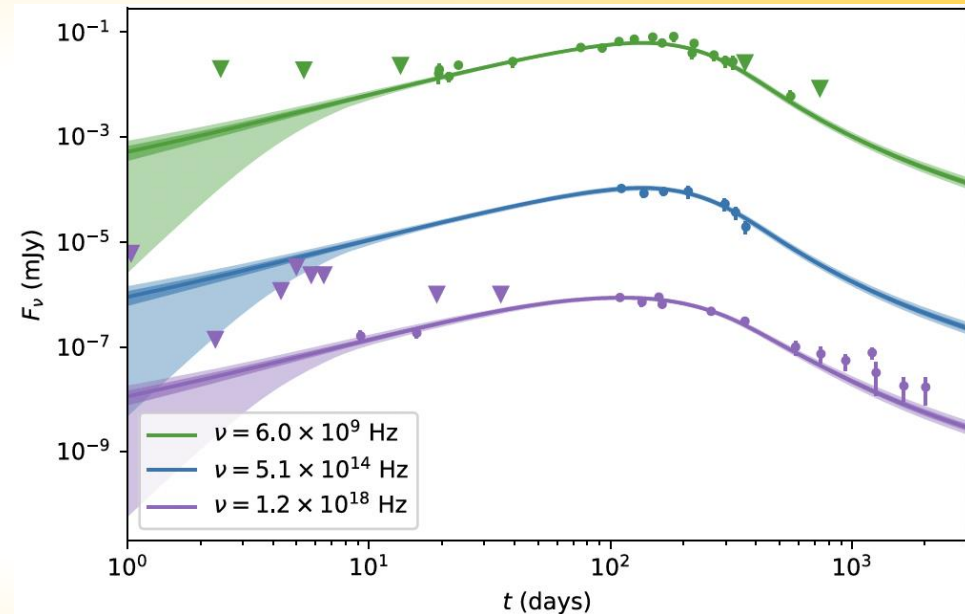
VLBI (Giarratana, Salafia et al. 2024)



ngVLA Photometry & Imaging

- High-resolution imaging results to date: compact object binary merger at 40 Mpc; collapsars at redshifts 0.15 & 0.17
- ngVLA resolution + sensitivity → significant sample increase for collapsars
- ngVLA & next-generation GW observatories → significant sample increase for compact object binary mergers
- ngVLA will have large impact on GRB jet physics!

GW 170817 / GRB 170817A
(Ryan, van Eerten et al. 2024)



Conclusions

- Gamma-ray bursts: multi-timescale, multi-wavelength, and multi-messenger
- Recent developments in observations & modeling
 - Better spectral & temporal coverage
 - TeV detections & automated early radio observations
 - Fitting hydrodynamics simulations to broadband data
 - Observations & modeling pushing each other forward
- Highest angular resolution frontier
 - Imaging jet expansion / evolution
 - Addressing modeling degeneracies & uncertainties
 - Pin down jet structure, opening & observing angle, etc.

ngVLA resolution & sensitivity → large impact on GRB jet physics