VLBI and Archival VLA and WSRT Observations of the GRB 030329 Radio Afterglow

5 Years at 5 GHz

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Talk Outline

• Introduction
• GRB 030329
  – VLA/WSRT Light Curve Monitoring
  – VLBI
  – Size Evolution
• Burst Calorimetry
• Future Work
  – Pop III GRBs
  – Other GRB afterglows?
The Fireball-Shock Model

• The Model
  – Material in a black hole accretion disk is expelled in twin polar jets
  – Jets are highly relativistic, implying strong beaming
  – \( \sim 10^{51} \) erg is released in a few minutes or less
  – Jets propagate into surrounding medium
  – Jets slow as they sweep up material, decreasing the importance of beaming
  – Observed image expands due to decrease in beaming and then lateral expansion of the jet

• Typical properties of a GRB afterglow
  – Power law spectrum separated by breaks
  – Break frequencies time dependent, can lead to breaks in the light curve
  – Temporal index of light curves dependent upon the density profile of the circumburst medium
GRB 030329

- Brightest radio afterglow ever detected at radio frequencies (55 mJy at 43 GHz)
- Relatively close to Earth
  - $z = 0.1685$
  - $d = 587$ Mpc
- Only GRB to ever be resolved with VLBI
- Detectable at 5 GHz by VLA through 2008
VLA/EVLA and WSRT Observations

• Source observed at 5 GHz from 59 – 1828 days after the burst
• Peak flux at 5 GHz was 11.6 mJy
  – Brightest GRB ever recorded at this frequency
  – Unusual intensity allowed radio afterglow to be detectable by EVLA through at least 2008

• Source decays with clear power law with $\alpha = -1.27 \pm 0.03$
5 GHz Radio Light Curve

Flux Density (mJy) vs. Time After Burst (in days)

- \( t \approx 1.27 \)
Estimating the Density Profile from the 5 GHz Light Curve

- The density profile can be calculated from the temporal index $\alpha$ and the spectral index $\beta$
- Density profile is assumed to be of the form
  \[ \rho(r) \propto r^{-k} \]
- The power law $k$ can be found using
  \[ k = \frac{5\alpha - 15\beta + 3}{\alpha - 4\beta + 2} \]
  \[ k = 1.1 \pm 0.2 \]
  \[ \beta = 0.54 \pm 0.2 \text{ (van der Horst et al. 2008)} \]
- This method is highly-dependent upon the choice of tNR, and can only provide an estimate of the circumburst medium density profile
VLBI Observations

- Models of linear size at early times
  - Source unresolved until day 83
  - Estimate of angular size attained through model-dependent estimation of the quenching of the scintillation
  - Large uncertainties due to reliance on imperfectly understood properties of the ISM

- Direct measurements of linear size
  - Proximity to Earth make this the only GRB to ever be resolved by VLBI
  - Direct observations put much-needed constraints on the models
Comparison with the Models

wind (k=2)

ISM (k=0)

- model 2; $E_{51}/A_*=1.2; \theta_0=0.32$
- model 1; $E_{51}/A_* = 2; \theta_0 = 0.25$
- model 2; $E_{51}/n_0 = 5; \theta_0 = 0.09$
- model 1; $E_{51}/n_0 = 0.8; \theta_0 = 0.12$
Burst Calorimetry

• A semi-analytic method is in development for producing synthetic light curves for GRB afterglows

• Broadband afterglow observations and direct size measurements can be used simultaneously to find a best-fit model and determine the burst parameters
Future Work

- Can we detect GRBs produced by Population III stars?
  - Doing so would provide first direct evidence of Pop III stars
  - MHD / emission model can handle arbitrarily complicated density profiles
- VLBI observations of another GRB
  - Right now our sample size is exactly one
  - Wishful thinking?
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Gamma Ray Burst Emission

• Prompt Emission
  – Predominantly gamma rays
  – Short duration (a few minutes or less)
  – Internal shocks

• The Afterglow
  – X-rays, UV, optical, IR, and radio
  – Long duration (days to years)
  – External shocks (collisionless)
  – Synchrotron
Density Profiles

• Wind-like Medium
  – Stellar wind from evolved star blows bubble into ISM
  – Density within bubble is characteristic of $r^{-2}$ density wind

• Uniform Density Medium
  – Characteristic of the ISM
  – Not expected for a stellar-type progenitor
GRB 030329 Afterglow Angular Size
Afterglow Expansion Rate

All data points are direct measurements

Assumes Gaussian surface brightness profile

\[ \left\langle \beta_{app} \right\rangle = \frac{(1 + z) R_\perp}{ct} \]