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

5 Years at 5 GHz

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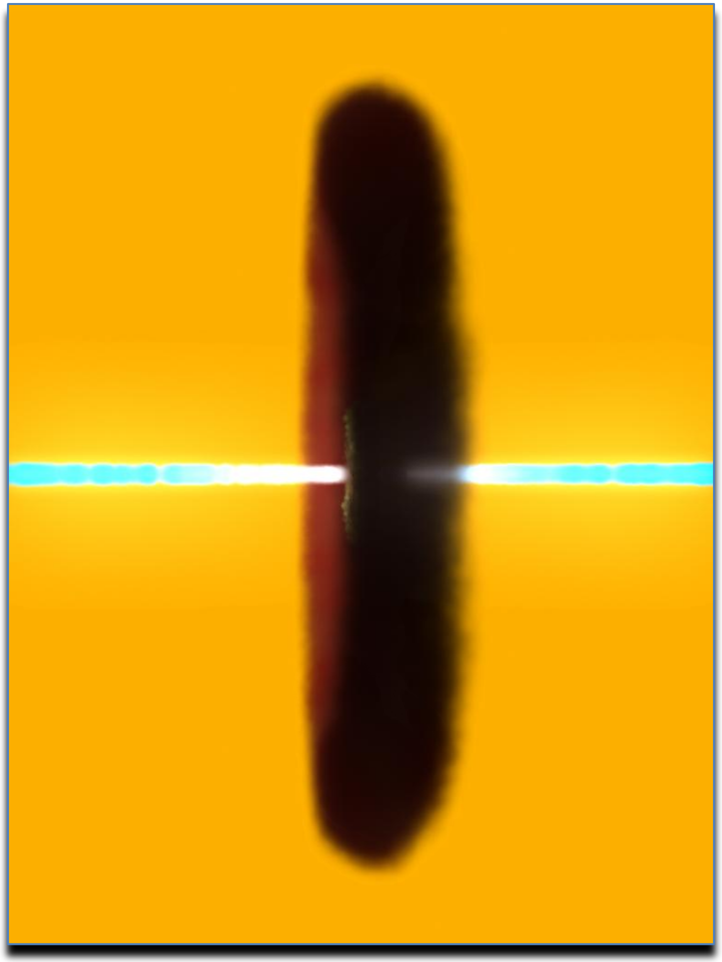
Talk Outline

- 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

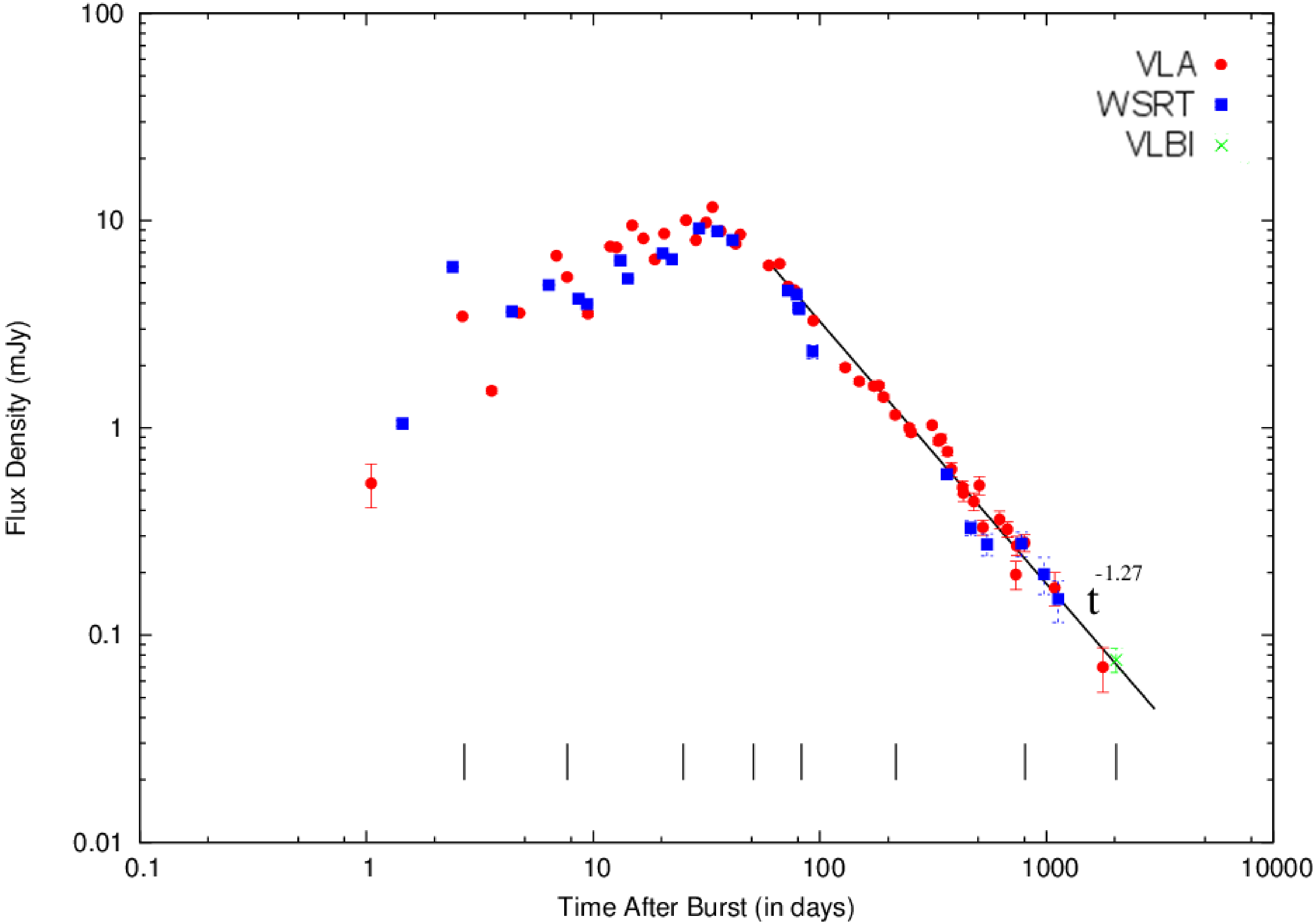
- Brightest radio afterglow ever detected at radio frequencies (55 mJy at 43 GHz)
- Relatively close to Earth
  - $z = 0.1685$
  - $d = 587$ Mpc
- Only GRB to ever be resolved with VLBI
- Detectable at 5 GHz by VLA through 2008

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



Estimating the Density Profile from the 5 GHz Light Curve

- The density profile can be calculated from the temporal index α and the spectral index β
- Density profile is assumed to be of the form

$$\rho(r) \propto r^{-k}$$

- The power law k can be found using

$$k = \frac{5\alpha - 15\beta + 3}{\alpha - 4\beta + 2}$$

$$k = 1.1 \pm 0.2$$

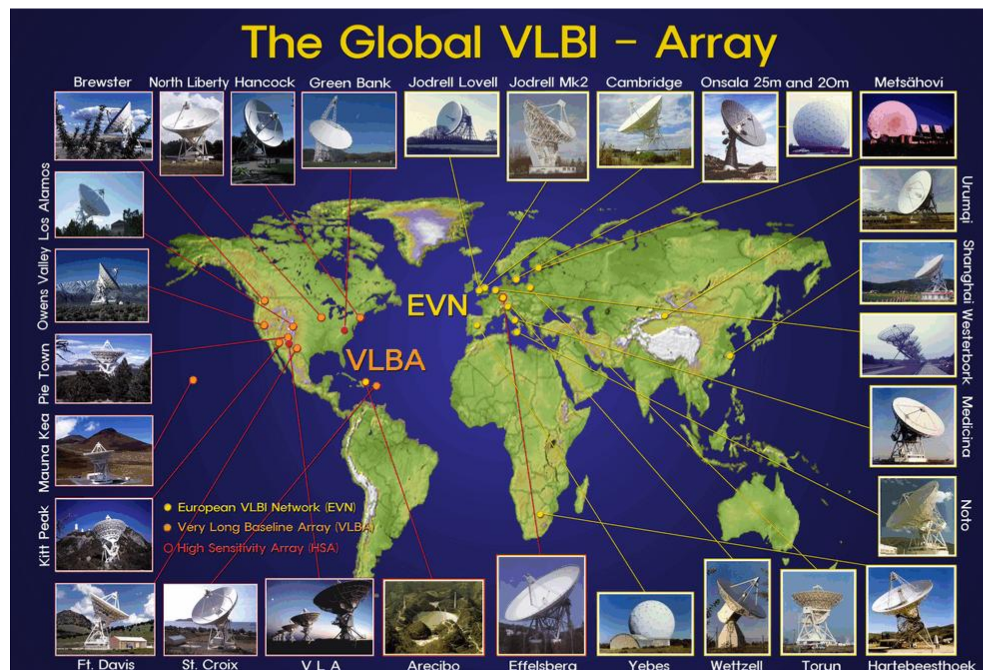
$$\beta = 0.54 \pm 0.2 \text{ (van der Horst et al. 2008)}$$

- This method is highly-dependent upon the choice of tNR, and can only provide an estimate of the circumburst medium density profile

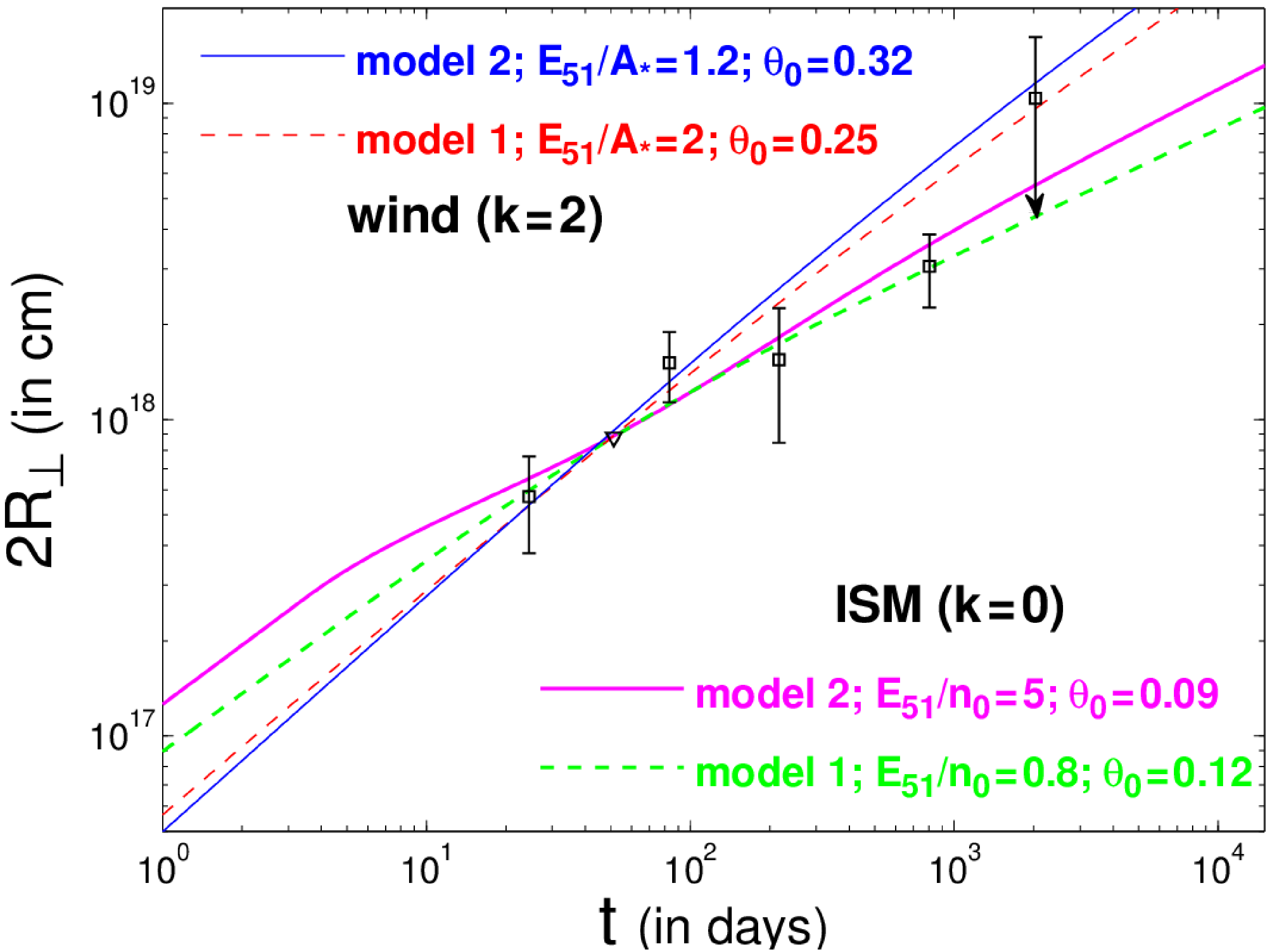
VLBI Observations

- 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

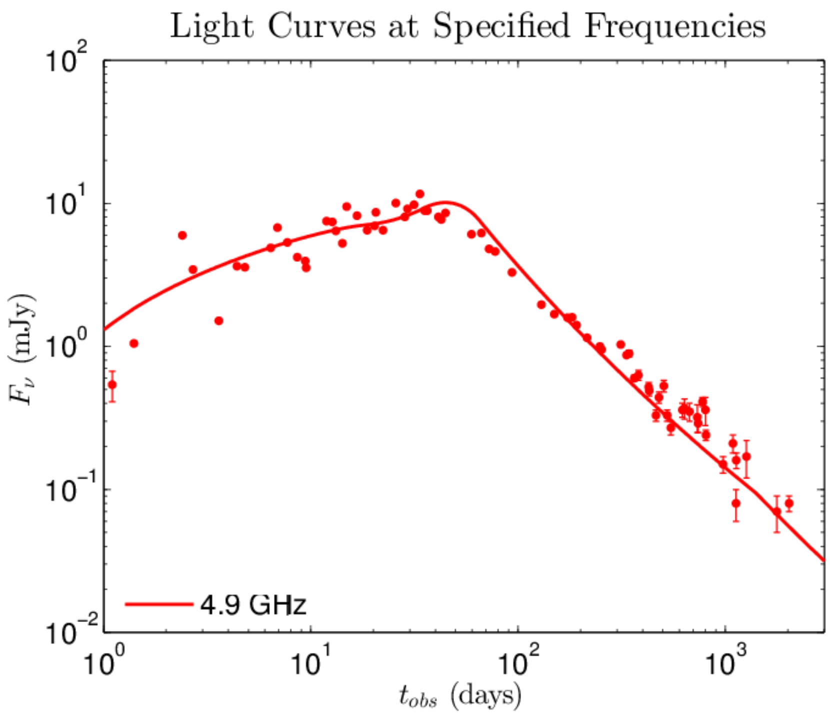


Comparison with the Models

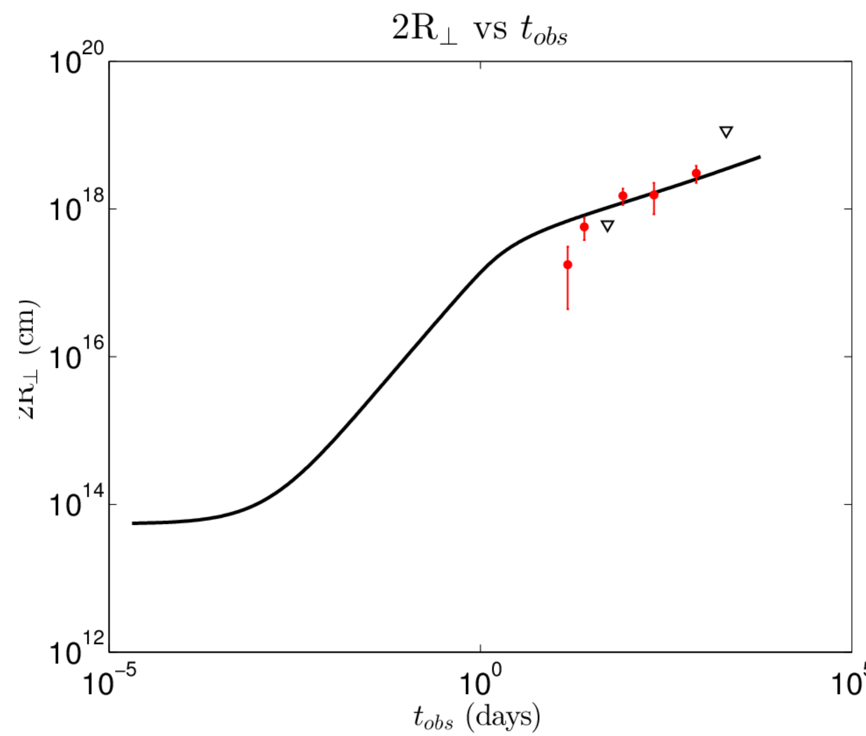


Burst Calorimetry

- 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



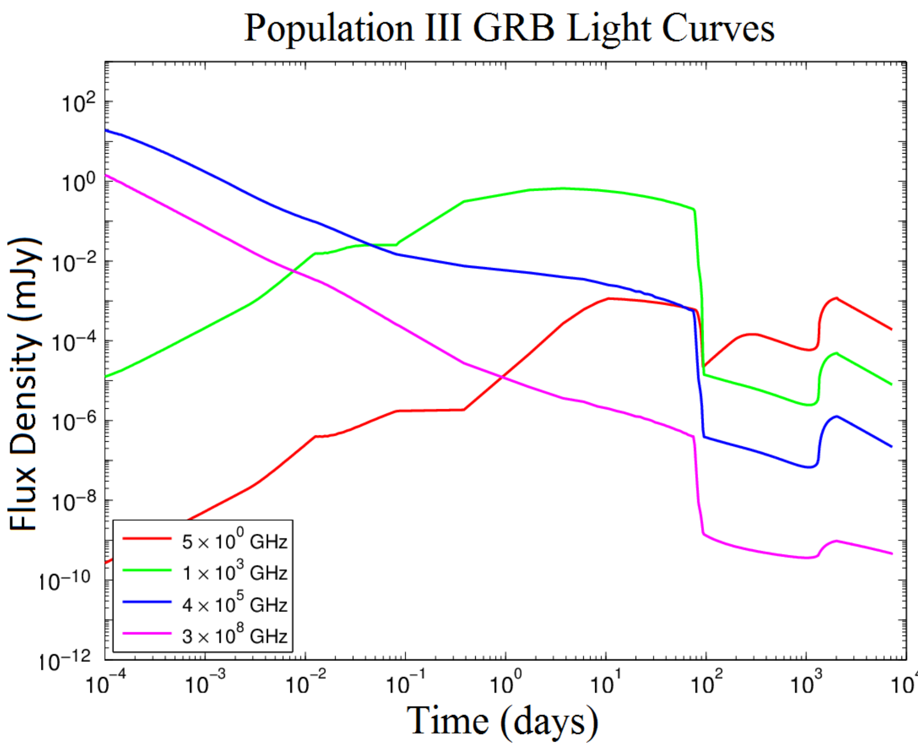
Light Curves at Specified Frequencies
10^2
10^1
10^0
10^{-1}
10^{-2}
F_ν (mJy)
4.9 GHz
10^0
10^1
10^2
10^3
t_{obs} (days)



$2R_\perp$ vs t_{obs}
10^{20}
10^{18}
10^{16}
10^{14}
10^{12}
$2R_\perp$ (cm)
10^{-5}
10^0
10^5
t_{obs} (days)

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?

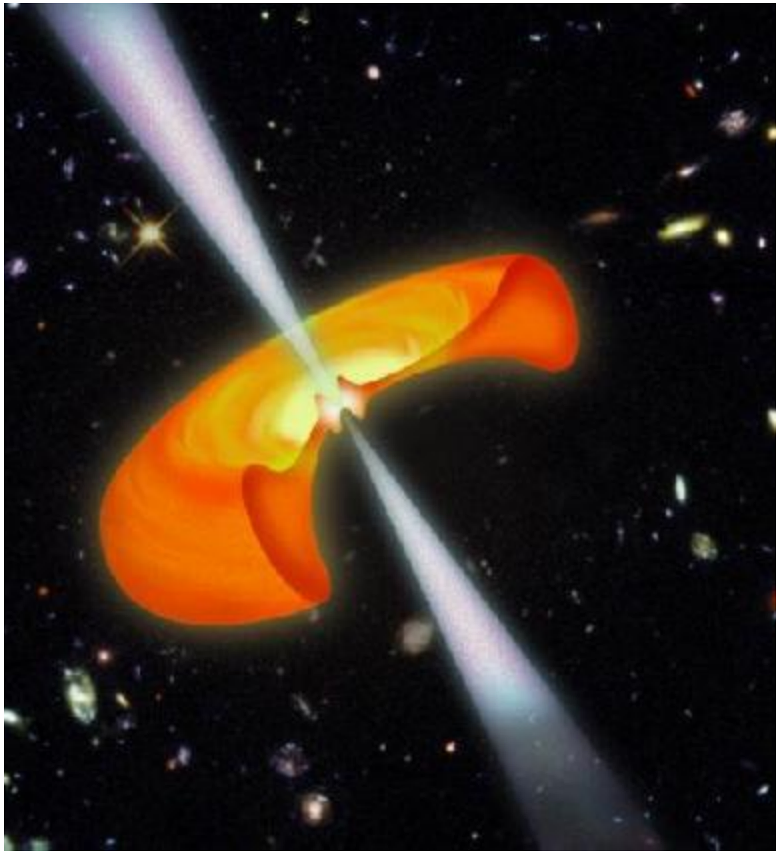


Acknowledgements

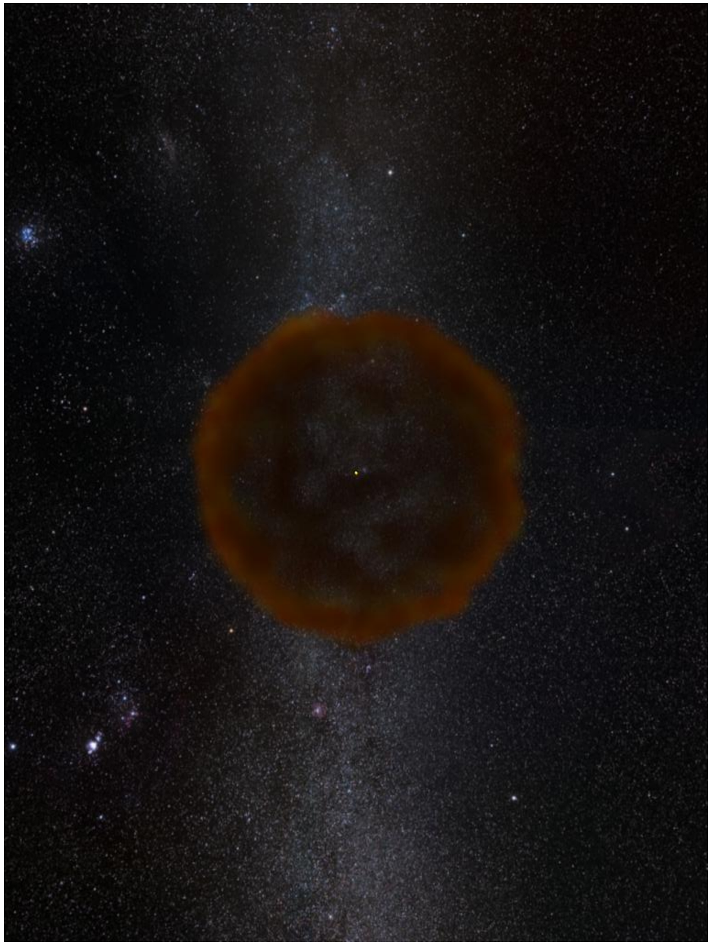
- Ylva Pihlström
- Greg Taylor
- Jonathan Granot

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

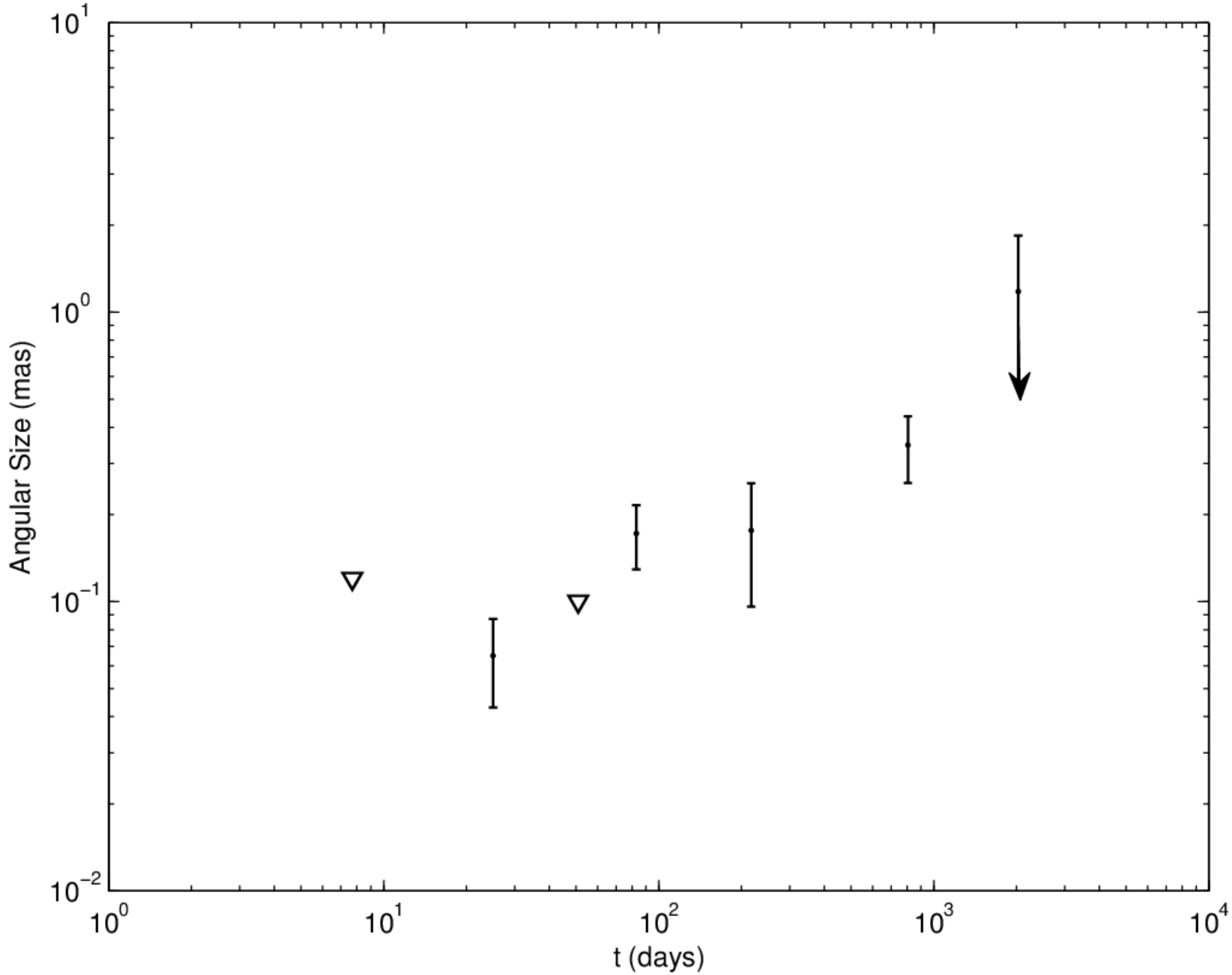


Density Profiles

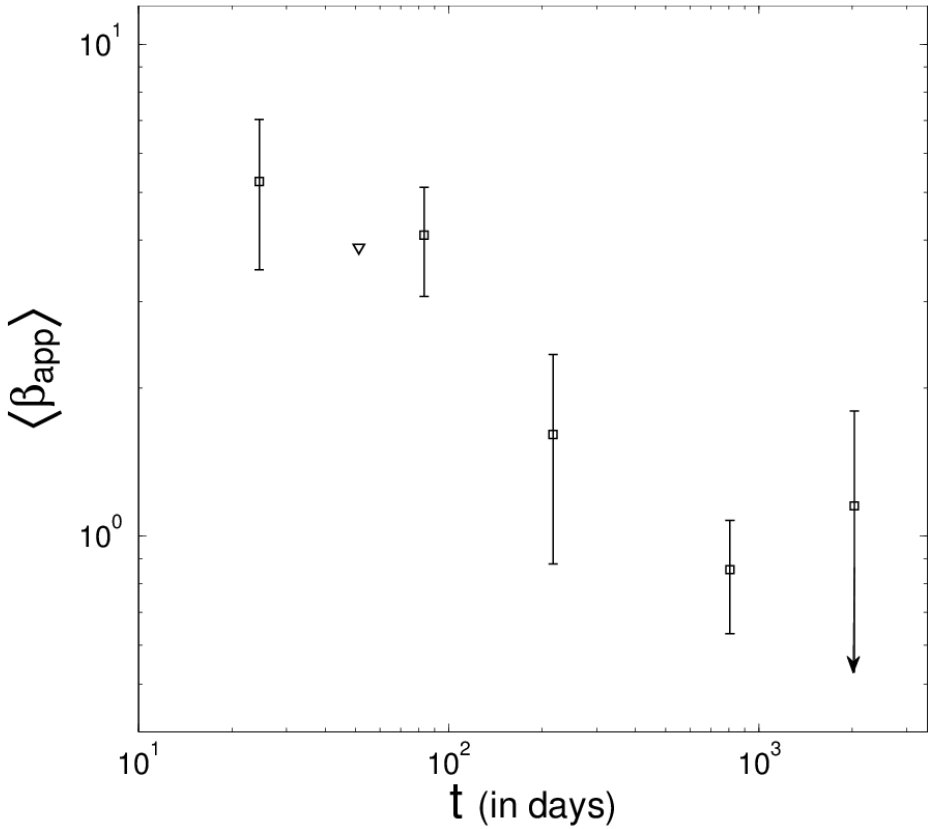


- Wind-like Medium
  - Stellar wind from evolved star blows bubble into ISM
  - Density within bubble is characteristic of r^{-2} density wind
- Uniform Density Medium
  - Characteristic of the ISM
  - Not expected for a stellar-type progenitor

GRB 030329 Afterglow Angular Size



Afterglow Expansion Rate



- All data points are direct measurements
- Assumes Gaussian surface brightness profile

$$\langle \beta_{app} \rangle = \frac{(1+z)\, R_{\perp}}{ct}$$