# Gamma-Ray Burst Afterglows

Kev Abazajian

NASA/Fermilab Theoretical Astrophysics

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Fermi National Accelerator Laboratory

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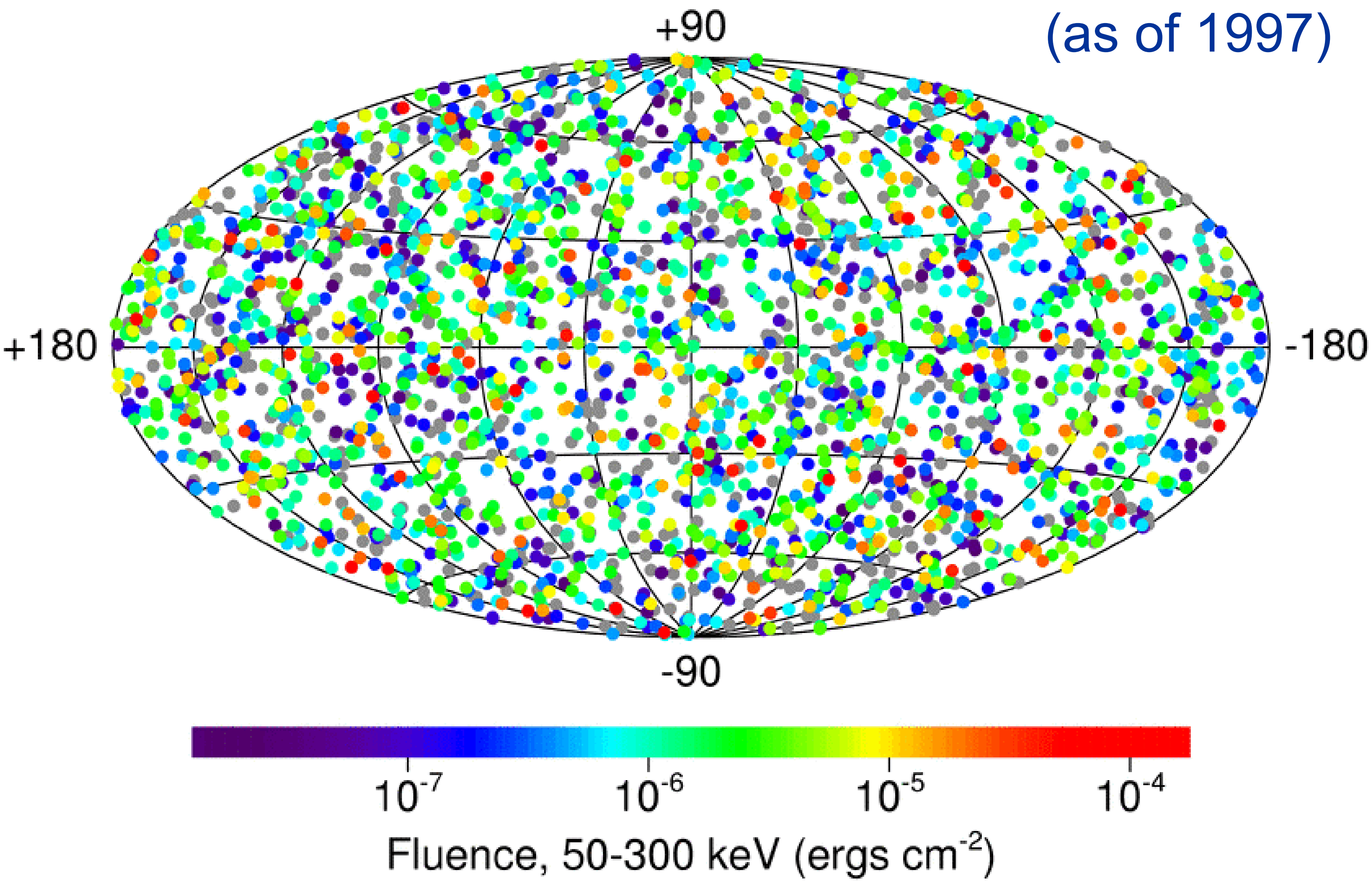
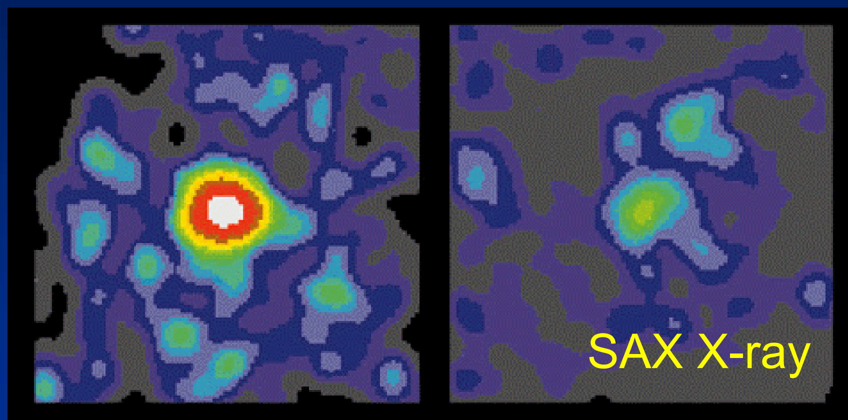
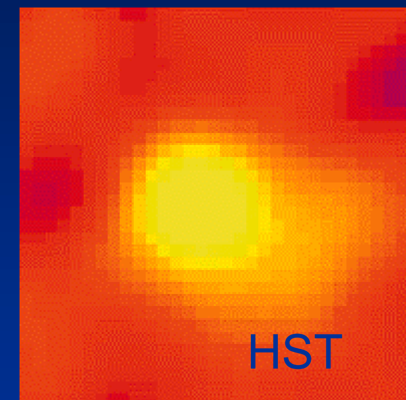
# 2704 BATSE Gamma-Ray Bursts



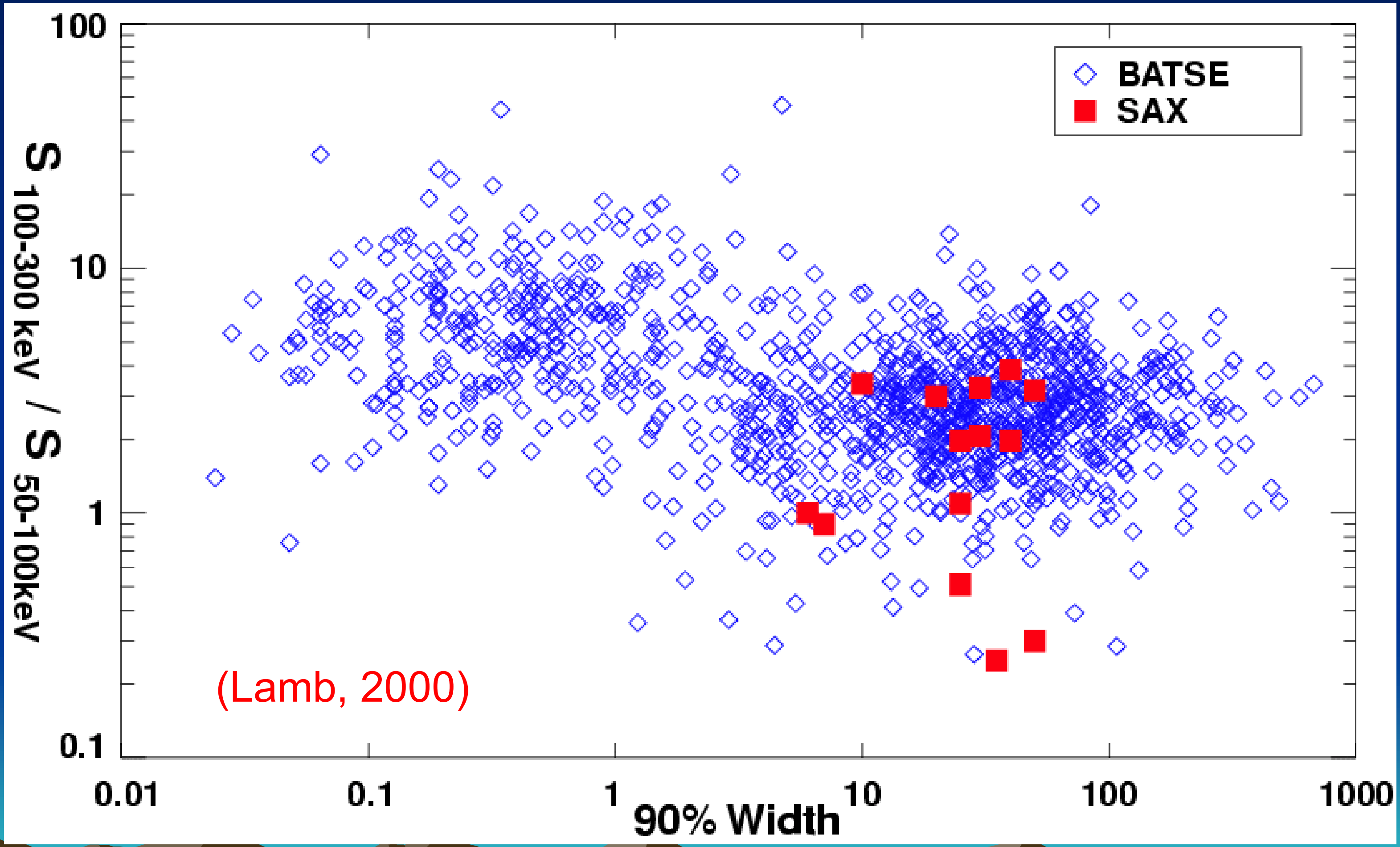
# Beppo-SAX Satellite



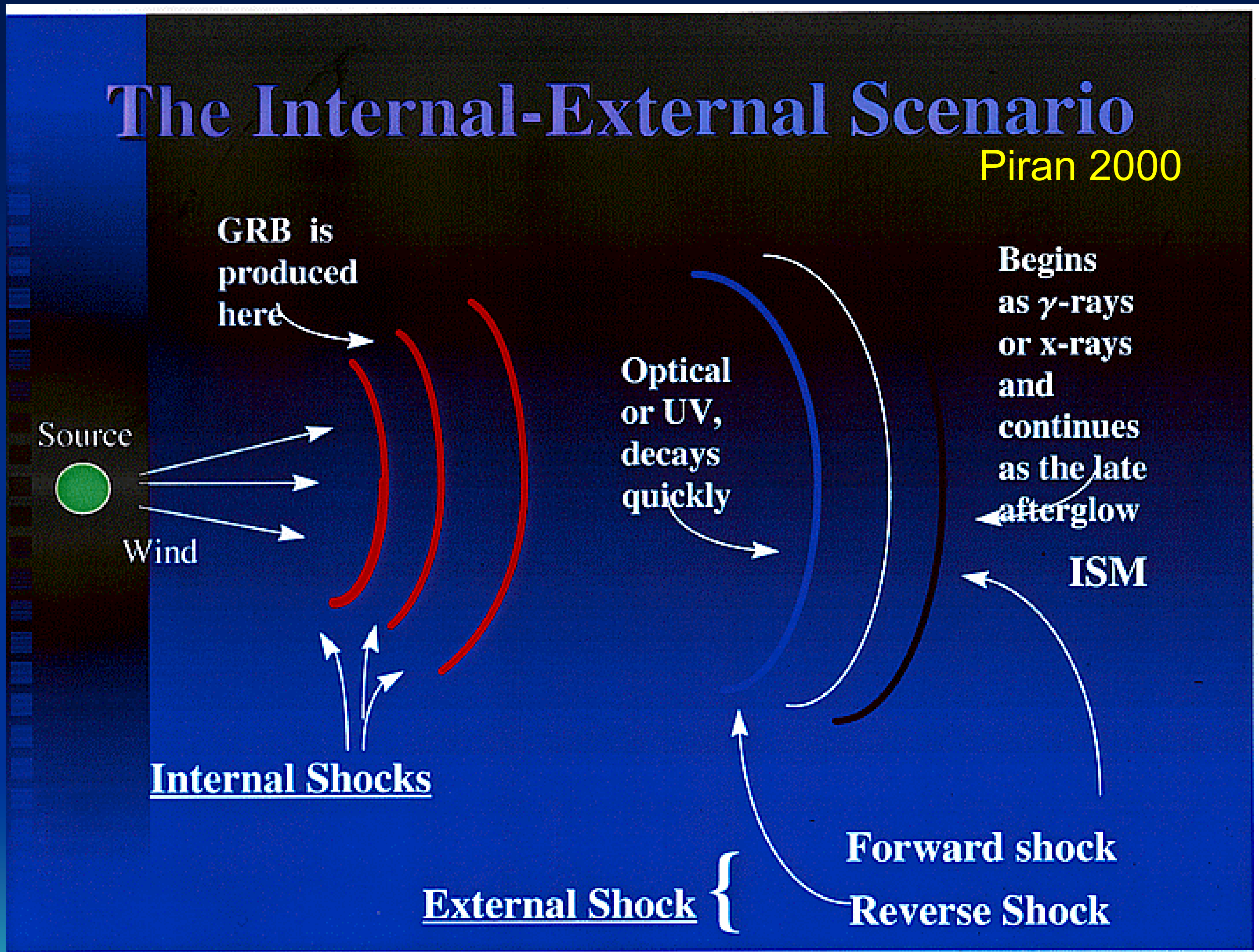




- Revolutionized GRB physics – GRB 970228 viewed March 3, 1997:  first burst to be localized, viewed in multiband, and measured redshift
- Since then: ~20 bursts have been localized by BeppoSAX

# Two classes: Fluence (S) vs. Duration

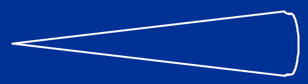


# The *Blastwave* Model

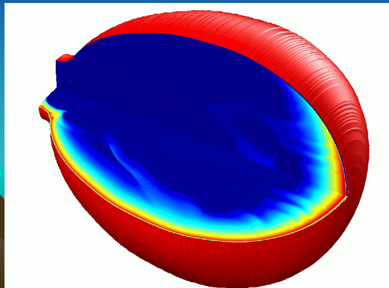


# Levels of Sophistication in Modeling GRB Afterglow Fireballs (Blastwave Model)

- Spherical fireball expanding adiabatically emitting radiation via synchrotron radiation of shock accelerated electrons (Blandford & McKee, 1976)
  - Homogeneous shocked matter
  - Electron energy distribution $N(E_e) \propto E_e^{-p}$
  - Single point on expanding front (Meszaros, Rees & Papathanassiou, 1994; Sari & Piran 1995; Dalal, Griest & Pruet, 2002)
  - Shocked material is spherical with finite opening angle
    - (Panaitescu & Kumar, 2002)



  - Integrated evolution over the surface (Granot, Piran & Sari, 1998)
- Two Dimensional hydrodynamics of an expanding relativistic jet
  - (Granot et al, 2001)

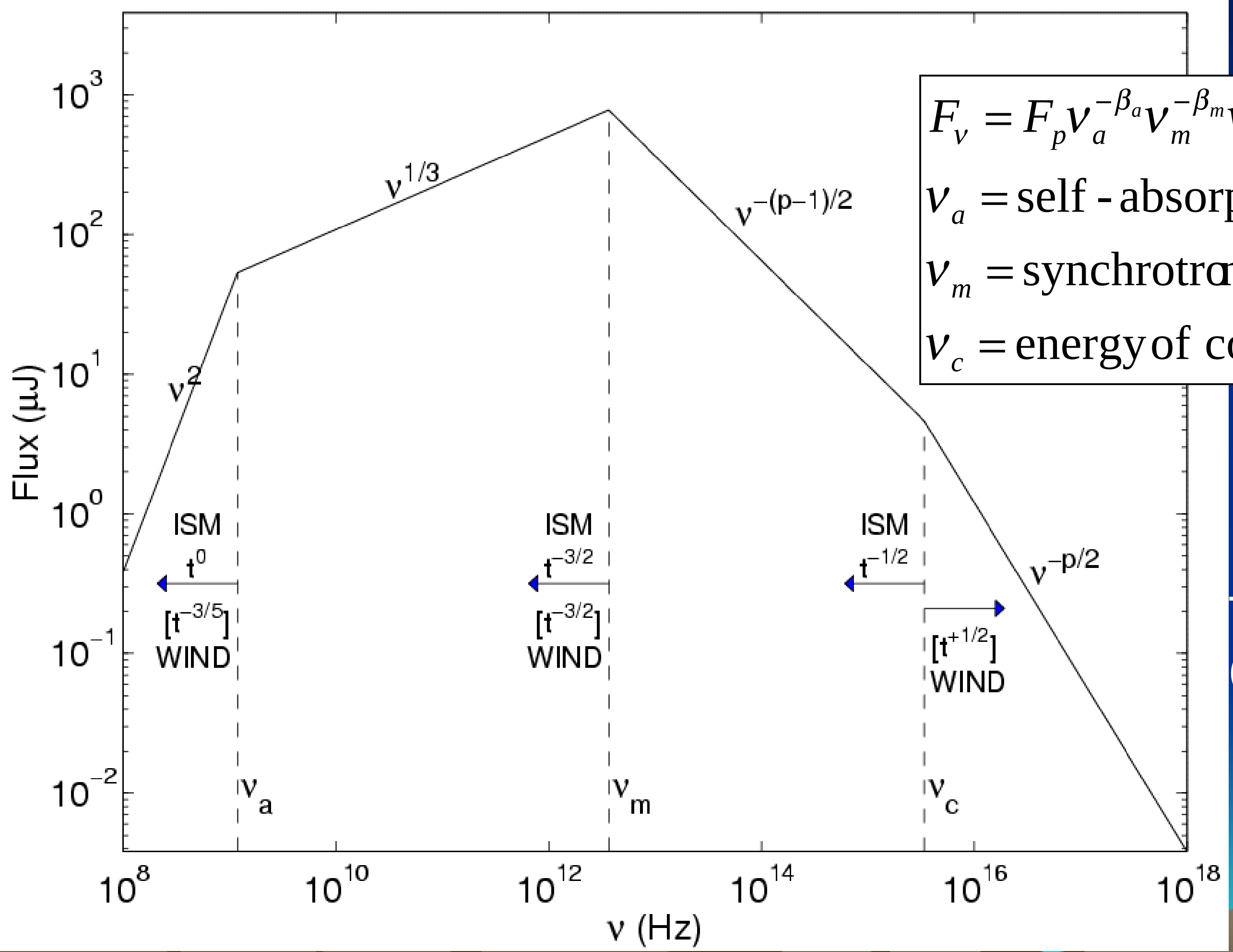


# Competing “Cannonball” Model

- Ultrarelativistic cloudlets (“cannonballs”) emitted from Type Ib/c supernovae (Dar & De Rujula 2000)
- produce the GRB signal via collision with SN shell
- Similar to blastwave model, the cloudlets decelerate upon hitting interstellar medium, emitting synchrotron radiation to produce afterglow
- Successful qualitative fits to X-ray and optical afterglows

# Afterglow Spectral Evolution (Blastwave Model)

Spectrum evolves according to properties of the plasma




$$F_\nu = F_p \nu_a^{-\beta_a} \nu_m^{-\beta_m} \nu_c^{-\beta_c} \nu^{\beta_a+\beta_m+\beta_c}$$

$\nu_a$ = self-absorption frequency

$\nu_m$ = synchrotron peak/electron minimum energy

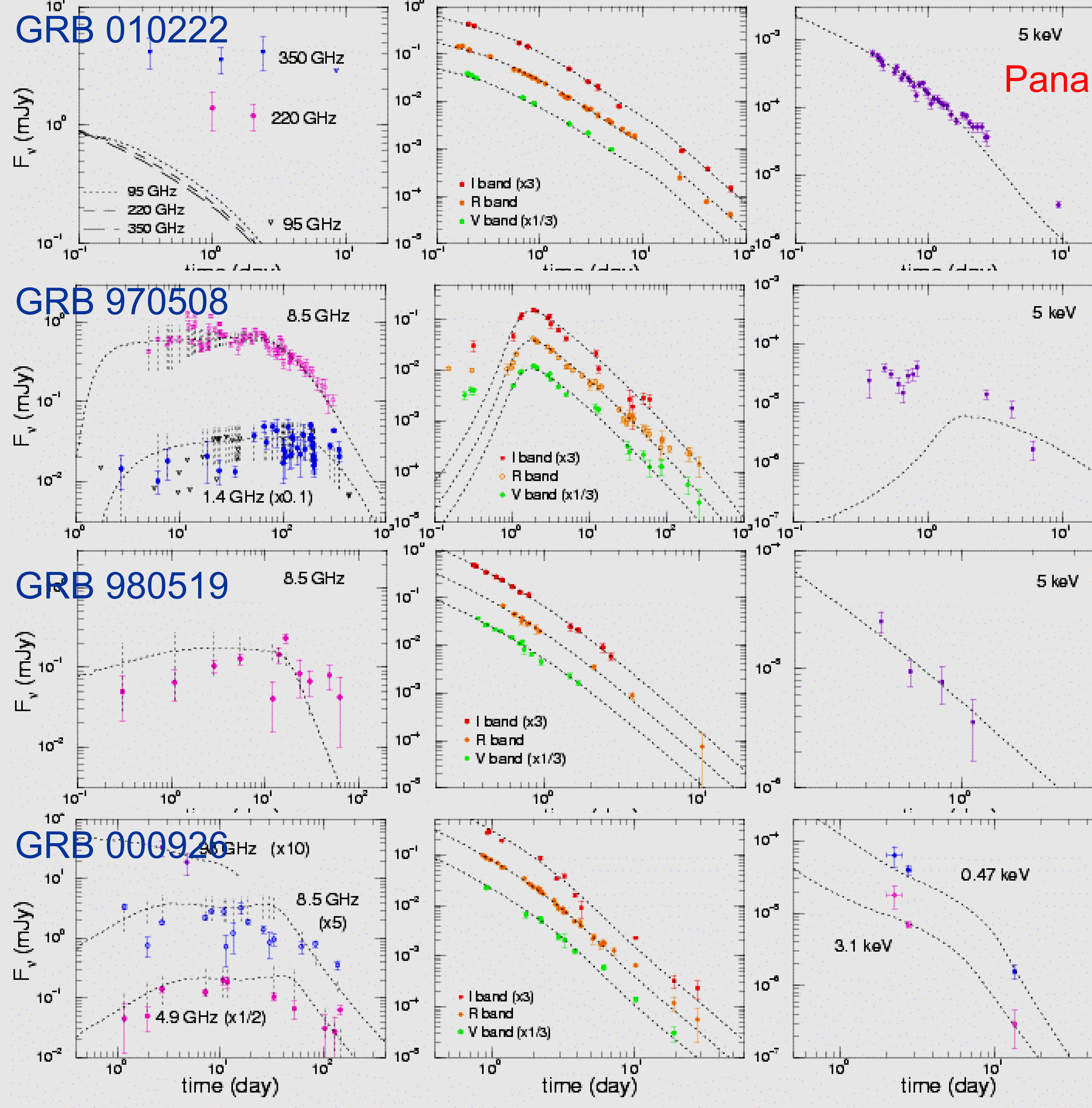
$\nu_c$ = energy of cooled electrons

(Sari, Piran, Narayan 1998)

Time Dependency:
(Rhoads, 1999;
Sari Piran Halpern, 1999)

$$F_\nu \propto \nu^\beta t^\alpha$$

Panaitescu & Kumar 2002



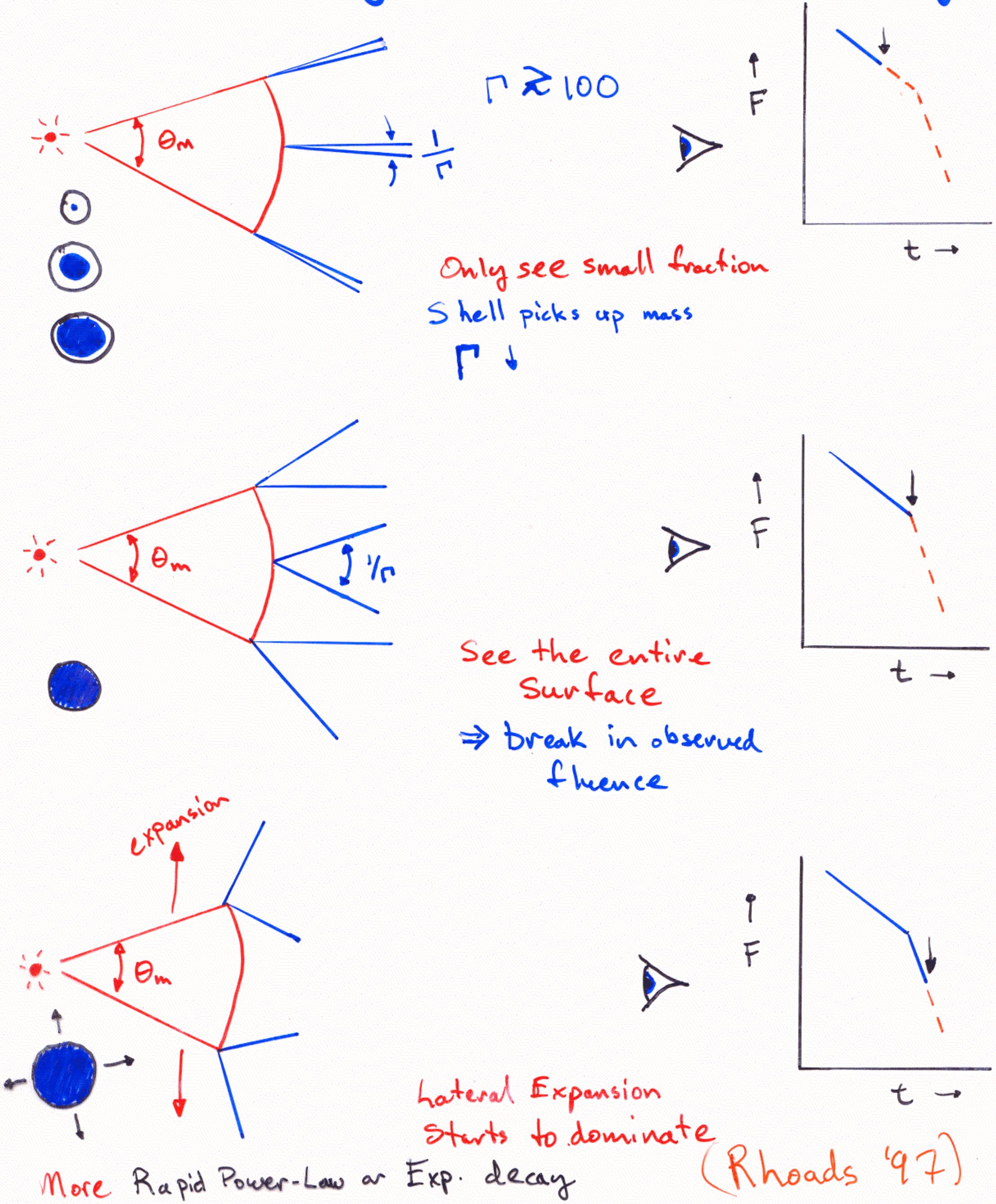

Multidimensional 8 parameter fits of the a uniform jet with homogeneous shock electron distribution

Obvious physical constraints on $\theta_b$, $E_{tot}$, n, $t_{break}$

Effective description of the afterglow dynamics, but incomplete

Favor homogeneous ISM over Wind environ.

# Beaming and Afterglow Decay

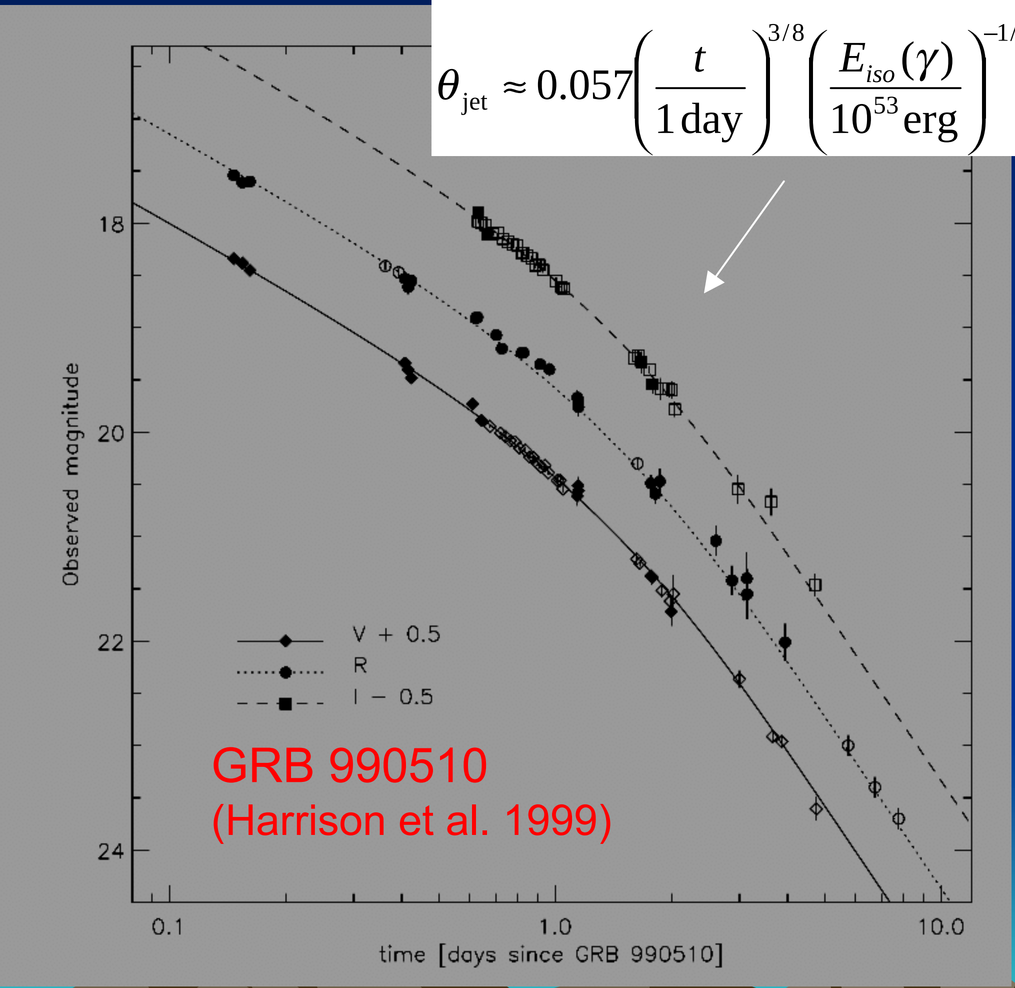


# Jets & Breaks

$$F_\nu \propto \nu^{\beta} t^{\alpha}$$

$\Rightarrow$ break in light curve

$$\theta_{\rm jet} \approx 0.057 \left( \frac{t}{1\,\rm day} \right)^{3/8} \left( \frac{E_{iso}(\gamma)}{10^{53}\,\rm erg} \right)^{-1/8}$$




- Achromatic Breaks in power-law decay of afterglow (Harrison et al. 1999; Stanek et al. 1999)
- varied beaming angles $\theta \sim 2° - 25°$
- Inferred $\gamma$ energy is within one magnitude (Freedman & Waxman 2001; Frail et al. 2001)

$$E_\gamma \sim 5 \times 10^{50} \;\; \rm erg$$

- Inferred total fireball energy

$$E_0 \sim 10^{50} - 3 \times 10^{51} \;\; \rm erg$$

- Inferred total GRB progenitor rate (Frail et al)

$$R_{GRB}(z=0) \approx 250\,\rm Gpc^{-3}\;\; yr^{-1}$$

# "Orphan Afterglows" - Predictions and Constraints

- A 2D or 3D jet model generally emits lower frequencies to a broader fraction of the sky as the jet decelerates and broadens (Rhoads 1997)

- Use afterglow searches to find "untriggered" GRB counterparts in lower frequencies via supernova searches, deep surveys

- Naïvely: 2 frequencies should give observed rates $N_1/N_2=\Omega_1/\Omega_2$

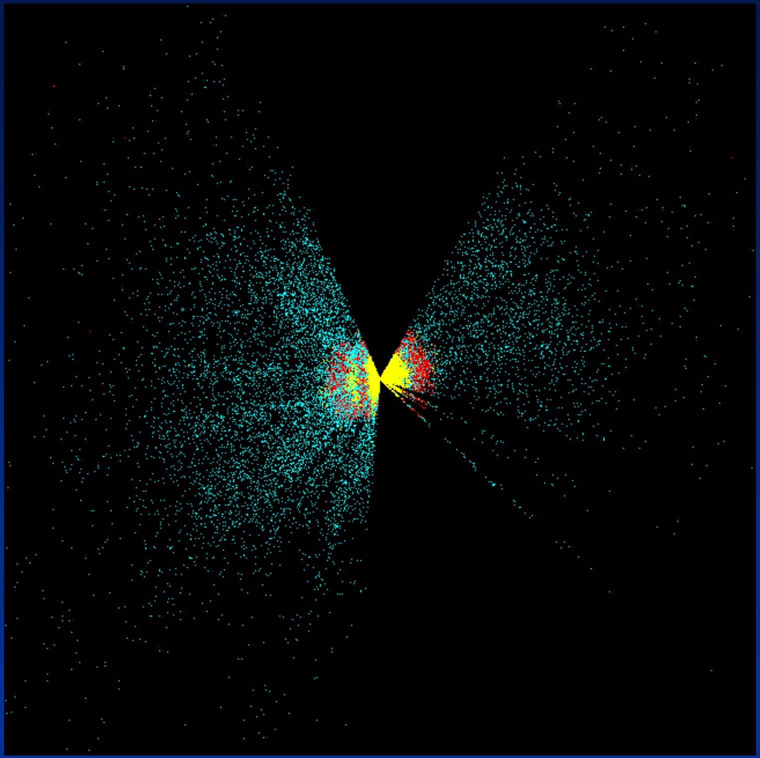
- There may be secondary blastwaves emitting only at sub-gamma ray frequencies, and detectable (Rhoads, 1999)

# Constraints on Beaming from Afterglows

- Radio Surveys: The predicted number of radio sources that fade cannot be larger than those observed (~ 3%) Since $N_{radio} \sim \theta_b^2$, $\theta_b > 6°$ ($\theta_b$ = $\gamma$-ray beaming) (Perna & Loeb, 1998)

- Lack of unidentified X-ray transients: places constraints on X-ray beaming (Grindlay 1999; Greiner et al. 2000)

- *Can use large optical surveys to provide identification or constraints on optical "orphan" afterglows (Vanden Berk et al., 2001; Rhoads 2001)*



# Sloan Digital Sky Survey

¼ of sky

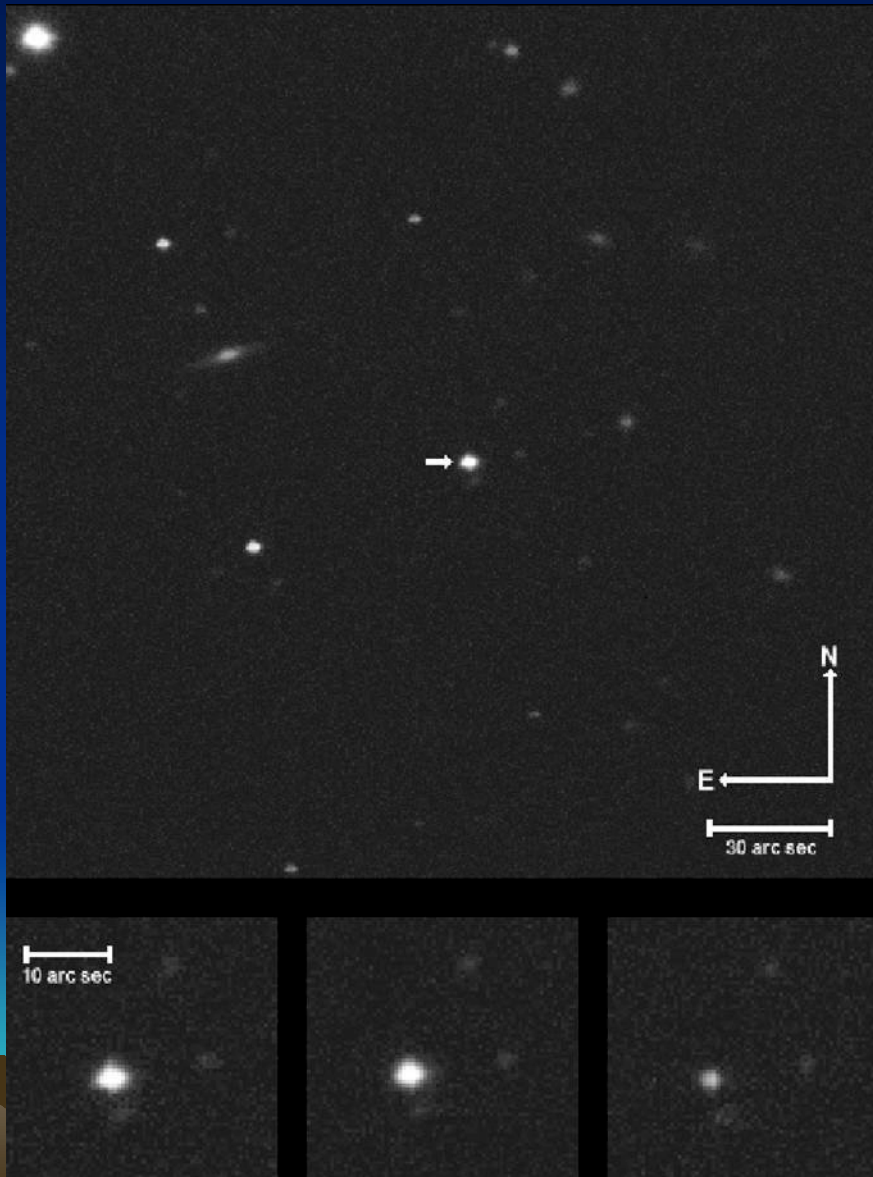
Distance of $10^6$ galaxies, $10^5$ quasars

The primordial (inflationary) power spectrum

Number of “contaminant” GRB afterglows (given SFR and survey’s selection effects) (Vanden Berk et al., 2001):

$$N \approx 5 f_{opt}$$

# Candidate Orphan Afterglow: SDSS J124602.54+011318.8




Vanden Berk et al. 2001

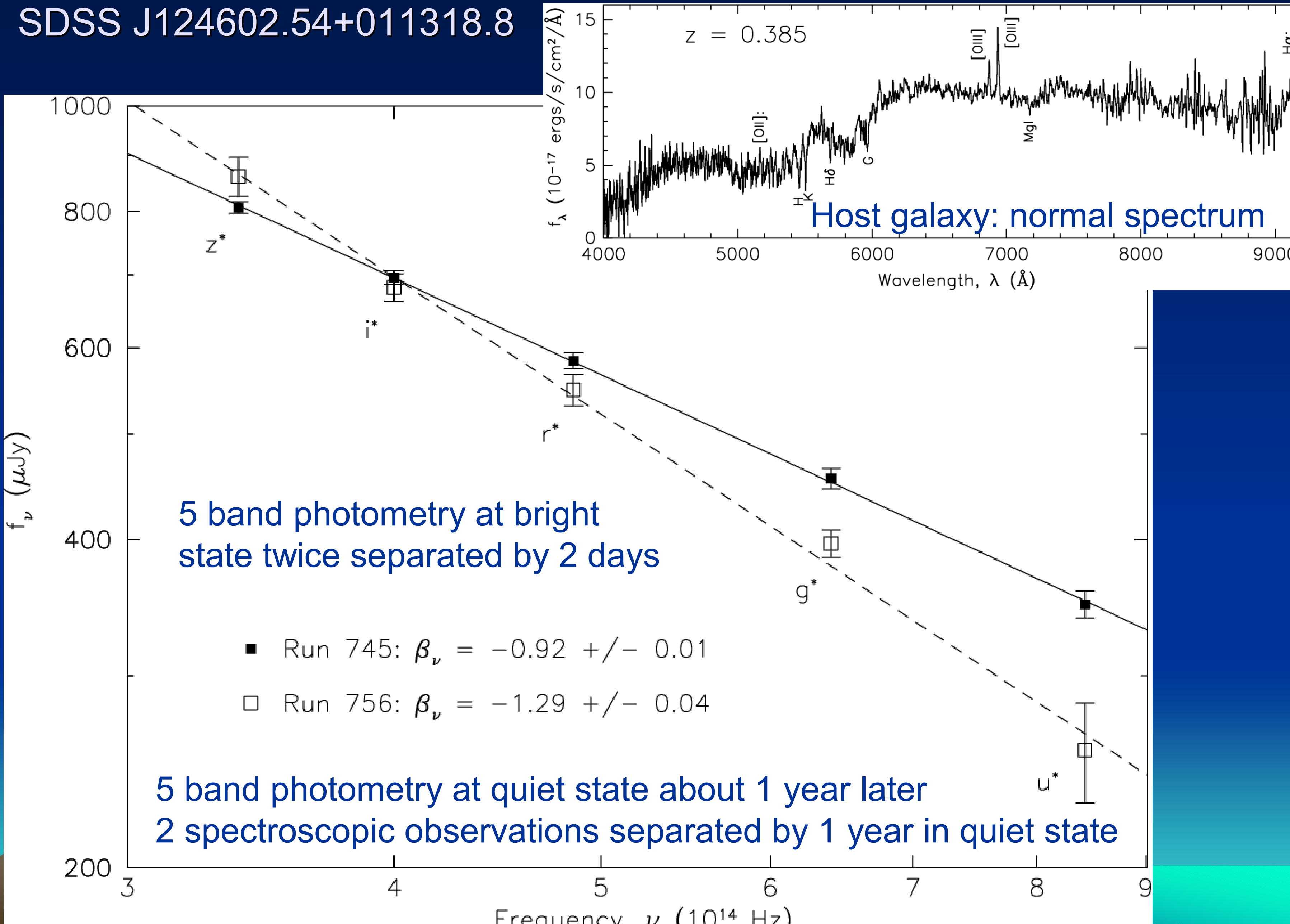
All spectroscopic objects are looked at twice (once photometrically, once spectroscopically)

Some fields overlap

SDSS J1… targeted as quasar for spectroscopy

Object is found to have the spectrum of a normal galaxy

# SDSS J124602.54+011318.8




Host galaxy: normal spectrum

5 band photometry at bright state twice separated by 2 days

5 band photometry at quiet state about 1 year later

2 spectroscopic observations separated by 1 year in quiet state

# Rare Optical AGN, not afterglow

- Gal-Yam et al. (2002) observed SDSS J124602.54+011318.8 this January and found it again in a relatively bright state, with strong H-alpha emission indicative of AGN activity

- SDSS event is most varying optically active AGN found

# SDSS Future

- The lack of detections in current SDSS 1500 sq° favors non-isotropic optical emission from GRB progenitors (but, this is small number statistics)

- *Only 10% of the SDSS survey has been searched!*

$$N_{events} \approx 10\left(\frac{f_{opt}}{0.02}\right)$$

- Expect ~10 to ~100 afterglows in entire SDSS north

# Current and Future Optical Afterglow Searches

- SDSS – north survey and southern strip
- Subaru Telescope (Japan) – current wide-field afterglow search
- SuperNova Acceleration Probe (SNAP) – proposed to use its deep, wide field of view for afterglow searches
- LSST telescope

# Conclusions

- Jets are inferred from breaks and rapid declines in the optical afterglow magnitude
- Homogeneous jet model is effective in describing the observed “triggered” afterglows
- If all of the progenitor’s blastwave is confined to a jet, untriggered orphan afterglows will be seen about ten times more frequently then GRBs
- Searches for GRB counterparts in radio constrain total GRB beaming
- Searches for GRB counterparts in optical can constrain the off-jet-axis behavior of the progenitor (which is still unknown)