

Gamma-ray burst-SN connection

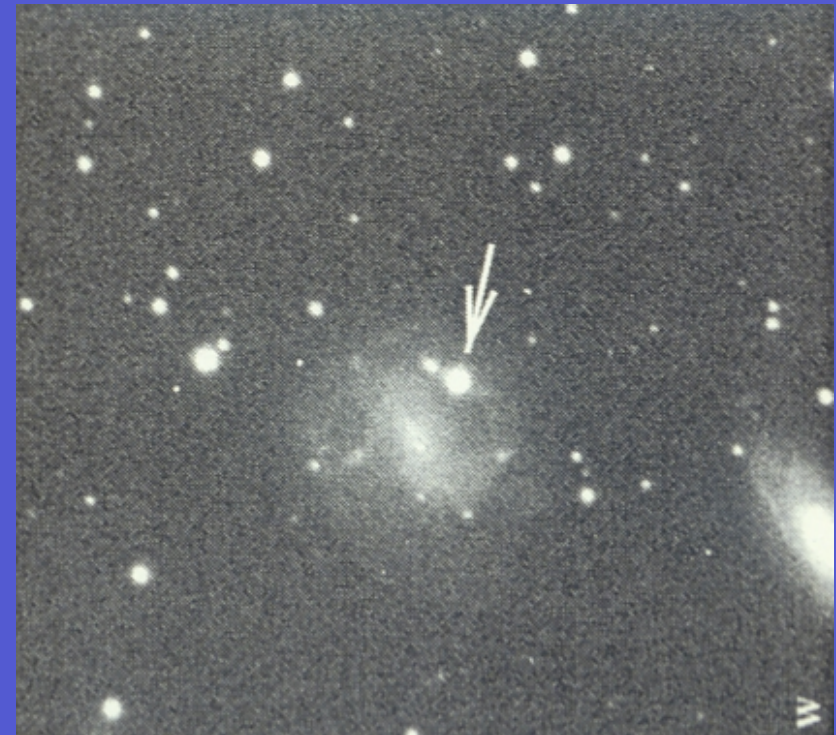
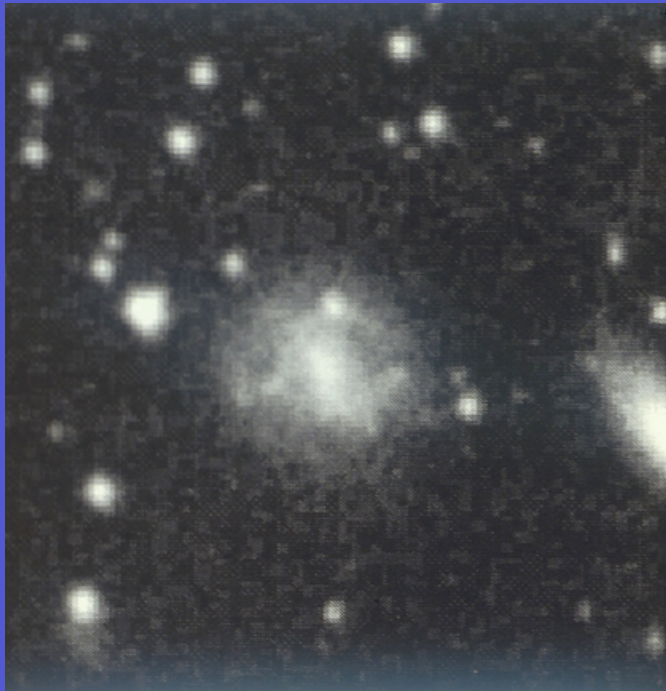
(What we have learnt since GRB980425/SN1998bw)

S. R. Kulkarni & A. M. Soderberg

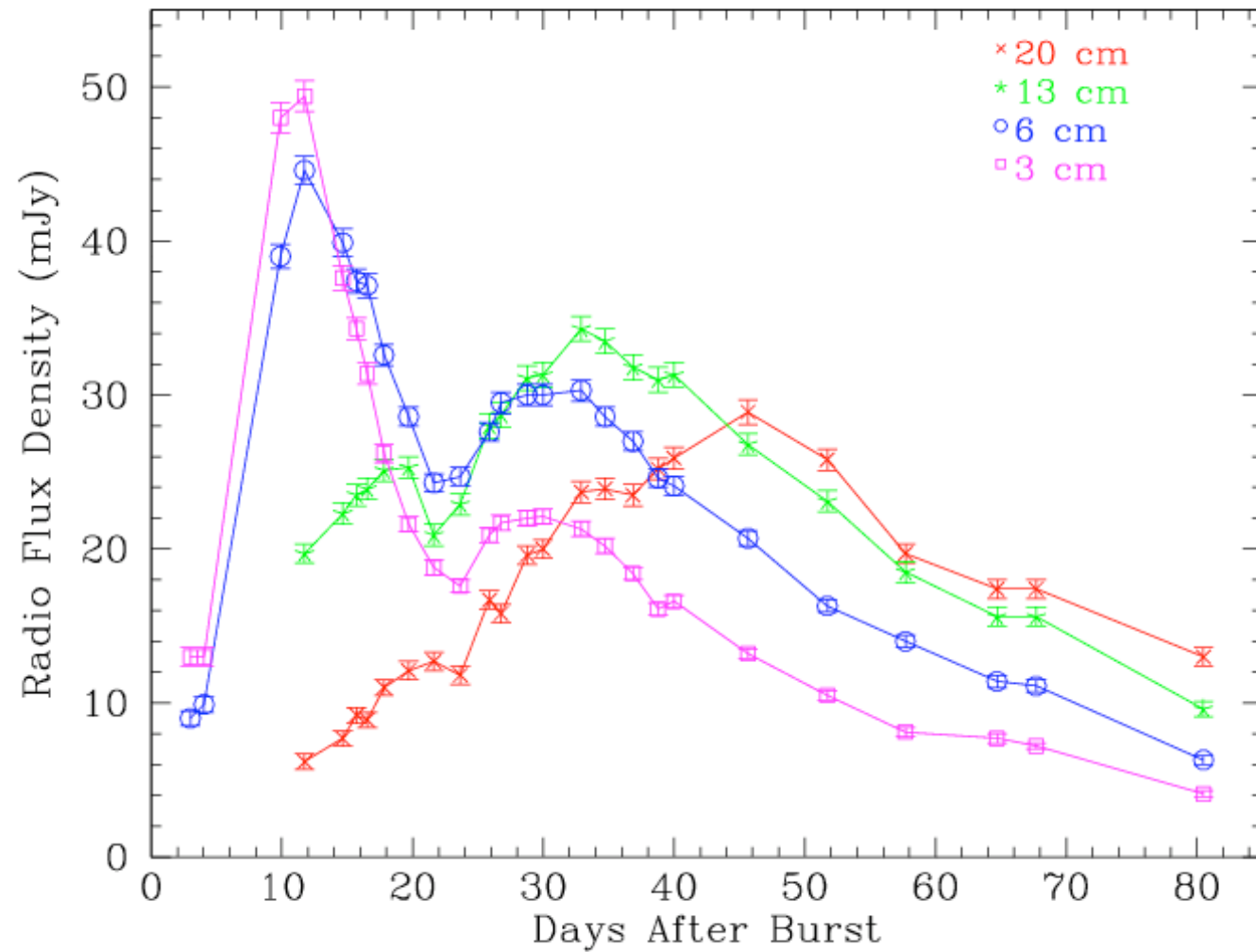
California Institute of Technology

Pasadena

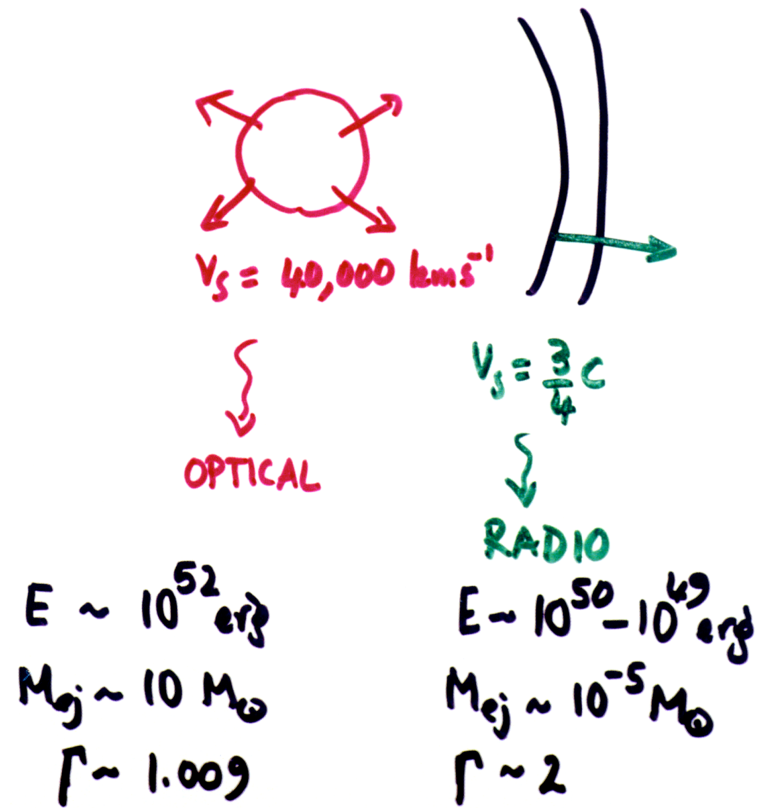
SN 1998bw/GRB 980425



Radio Emission from SN 1998bw



Clue 3: Mildly Relativistic Ejecta in SN 1998bw

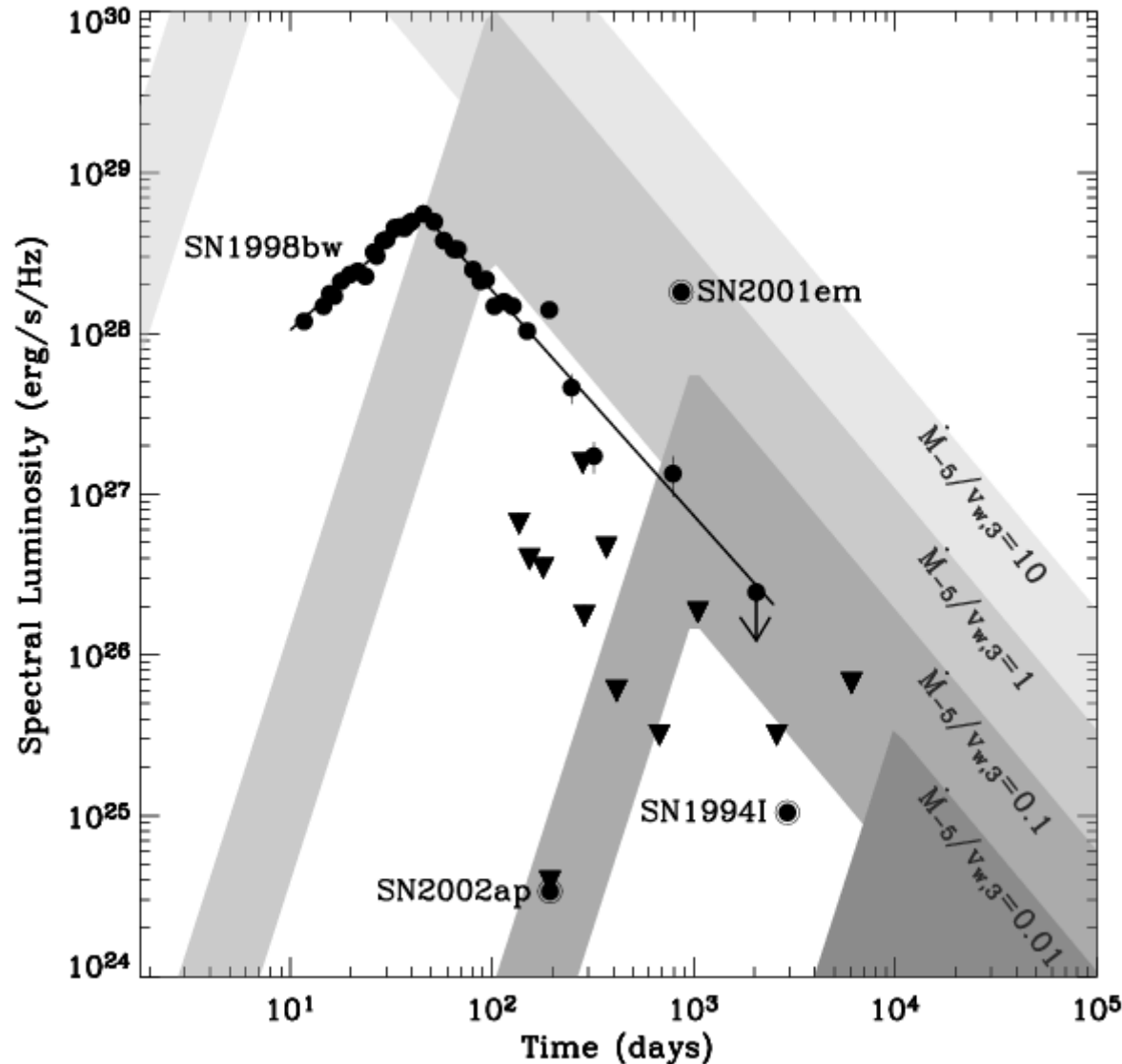


Kulkarni et al

What was GRB 980425/SN 1998bw?

- An off-axis “normal” GRB (B. Wagon et al)
- An off-axis “hypernova” (B. Wagon, Iwamoto)
 - Broad optical lines
- A most common but peculiar GRB
 - Not particularly beamed (low E_γ event)
 - Dominated by mildly relativistic ejecta
 - A high local rate (cf Seyfert vs Quasars)

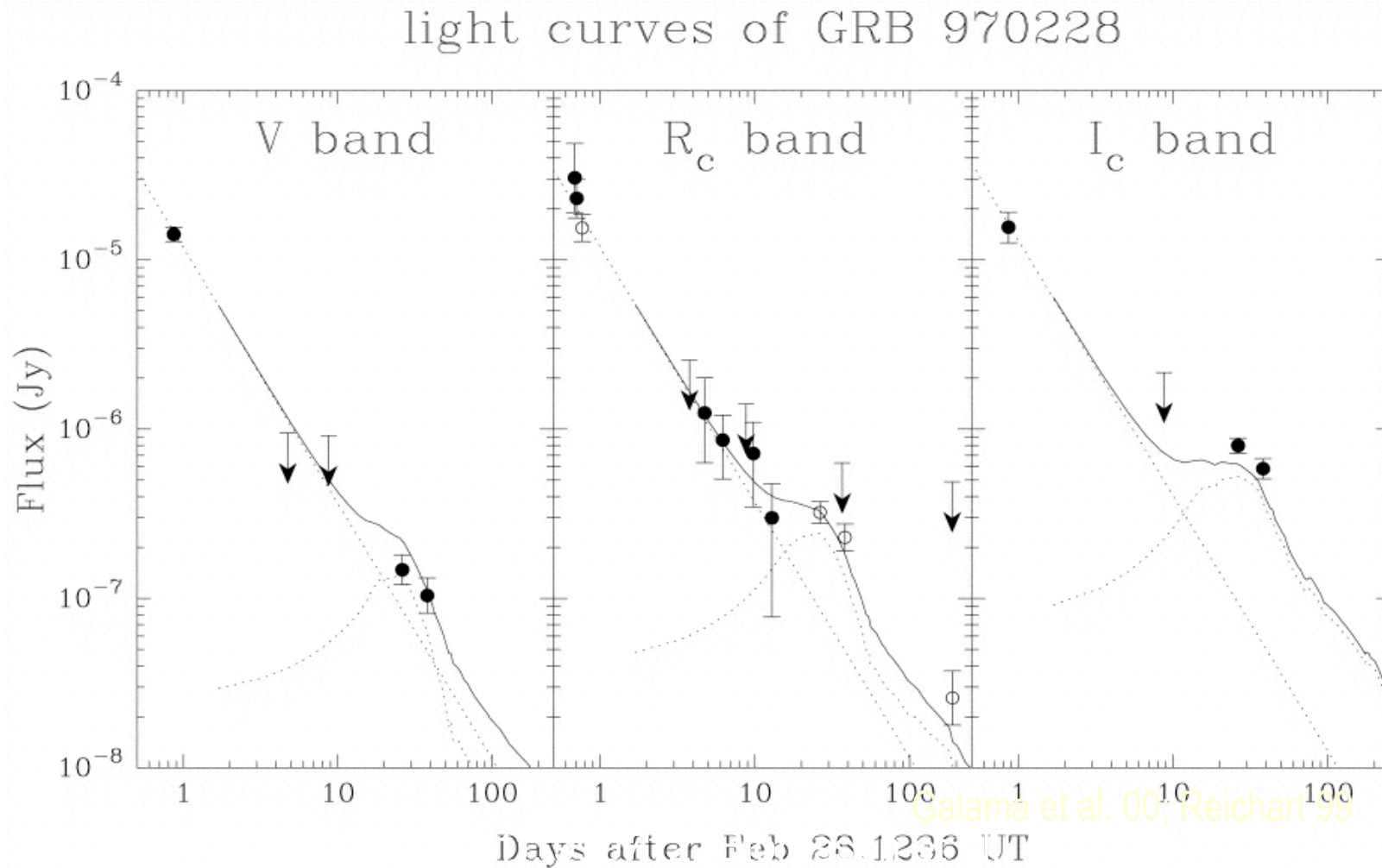
Six years of radio monitoring: No off-axis energy seen



(Legalese) *Off-axis jet (if present) requires a very low mass rate: $A_* \sim 0.03$, not consistent with inferred density*

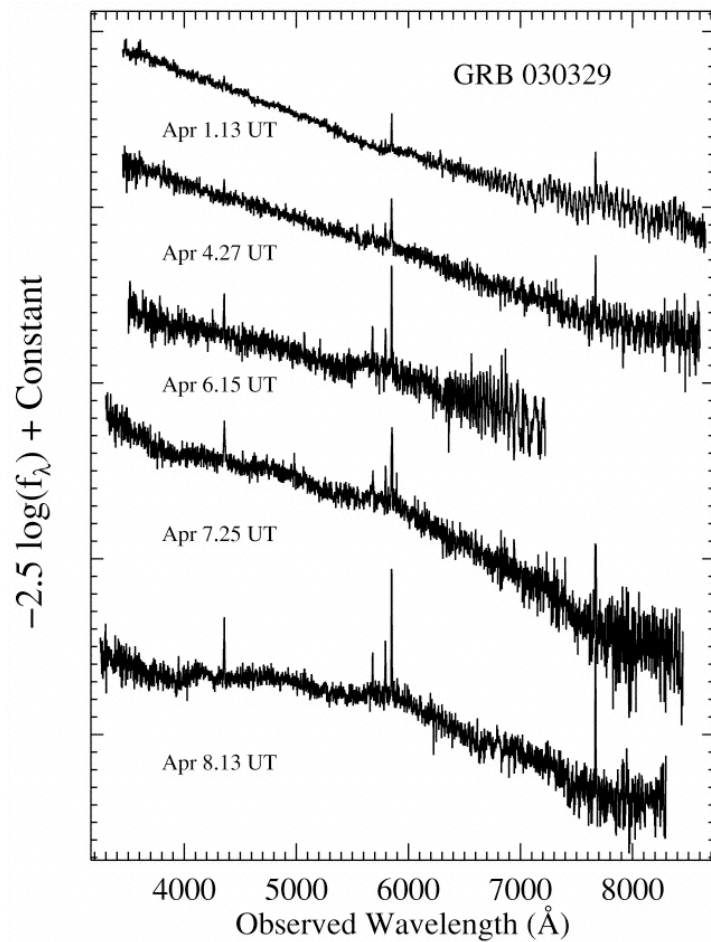
(Soderberg, Frail, Wieringa 2004)

Bumps in the middle of the night: 980326, 970228, 010921, 011121,...

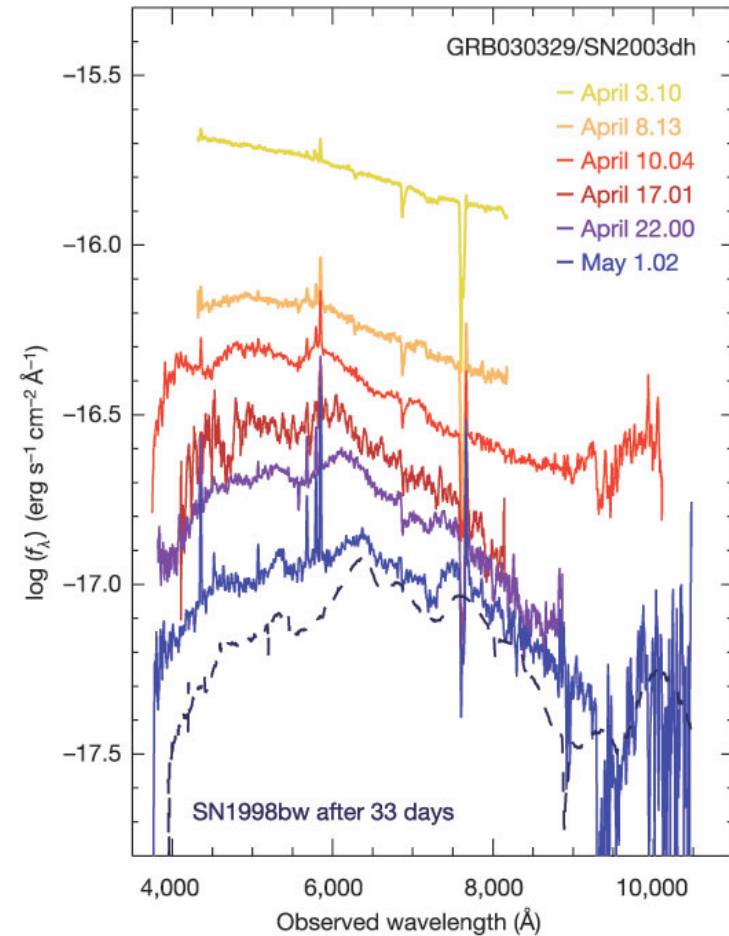


$z = 0.695$ Bloom et al. 01

Direct Spectroscopic Evidence: GRB 030329



MMT (Staneck et al)



VLT (Hjorth et al)

GRB 060218 & SN 2006

- Shock breakout, WR progenitor Campana et al.
- Low mass progenitor inferred Mazzali et al.
- Event not hyperkinetic nor hypernova Pian et al
- Low energy events dominate over cosmological events Soderberg et al.
- Suggestion of an engine active (5 days)

Supernovae --> GRBs

(Soderberg Thesis)

- Do some local SNe house a hidden GRB?
 - Relativistic ejecta
 - Collimated explosion
 - Non-negligible energy from engine
- How does one diagnose hidden engines?
 - Radio emission
 - Optical line width
 - Optical polarization

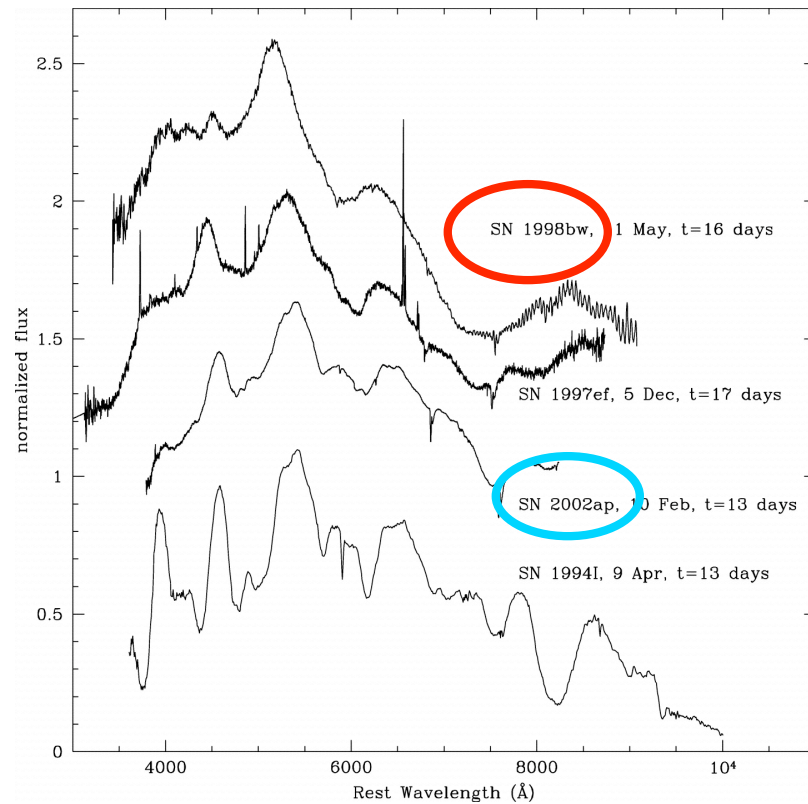
Line widths: poor proxy

SN2002ap was spectroscopically identical to **SN 1998bw**

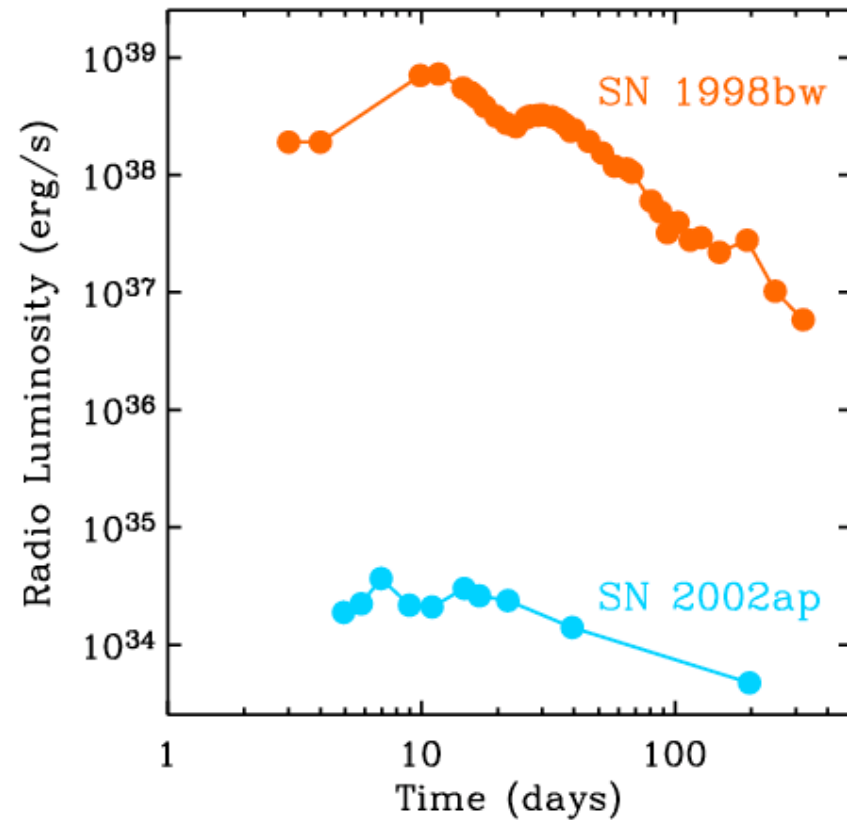
$L_{\text{opt}} \sim 0.2 \times 98\text{bw}$

BUT

$L_{\text{radio}} \sim 10^{-4} \times 98\text{bw}$

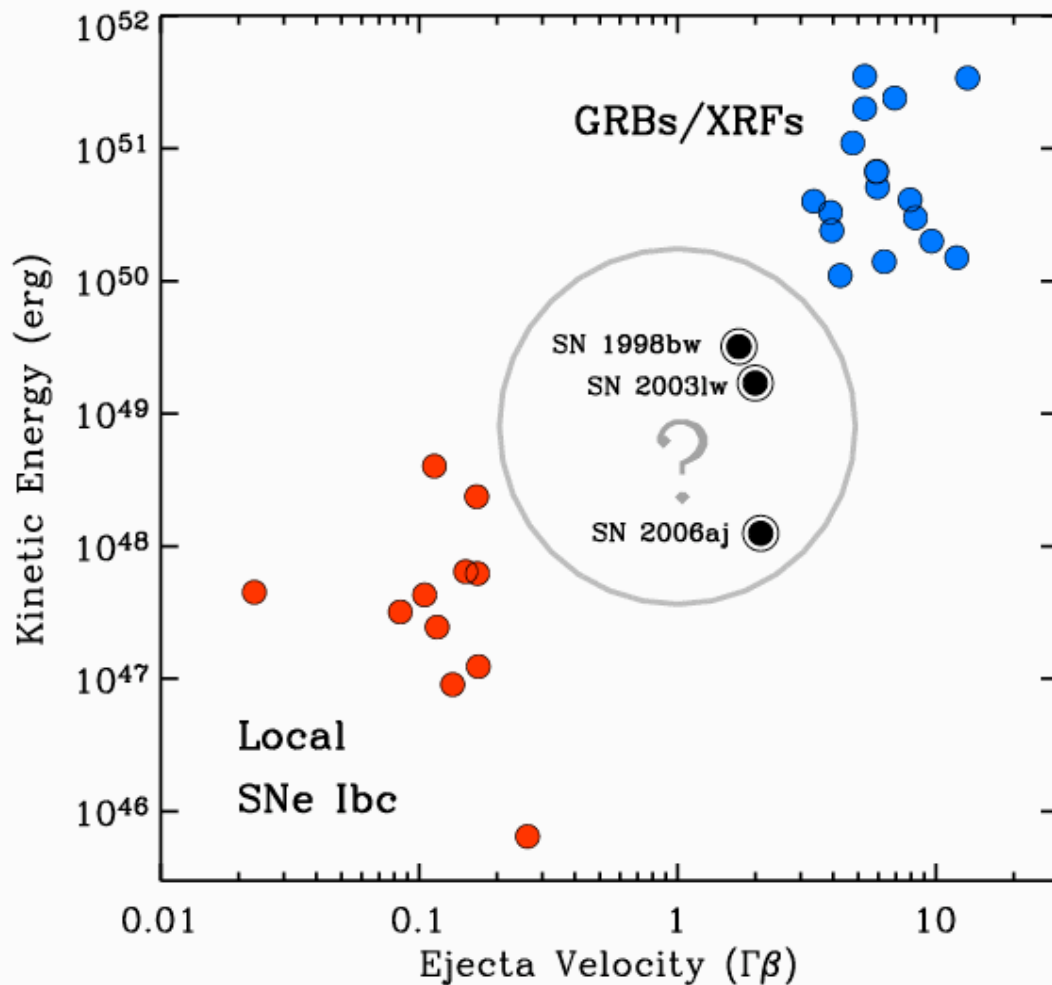


(Mazzali et al 2002)



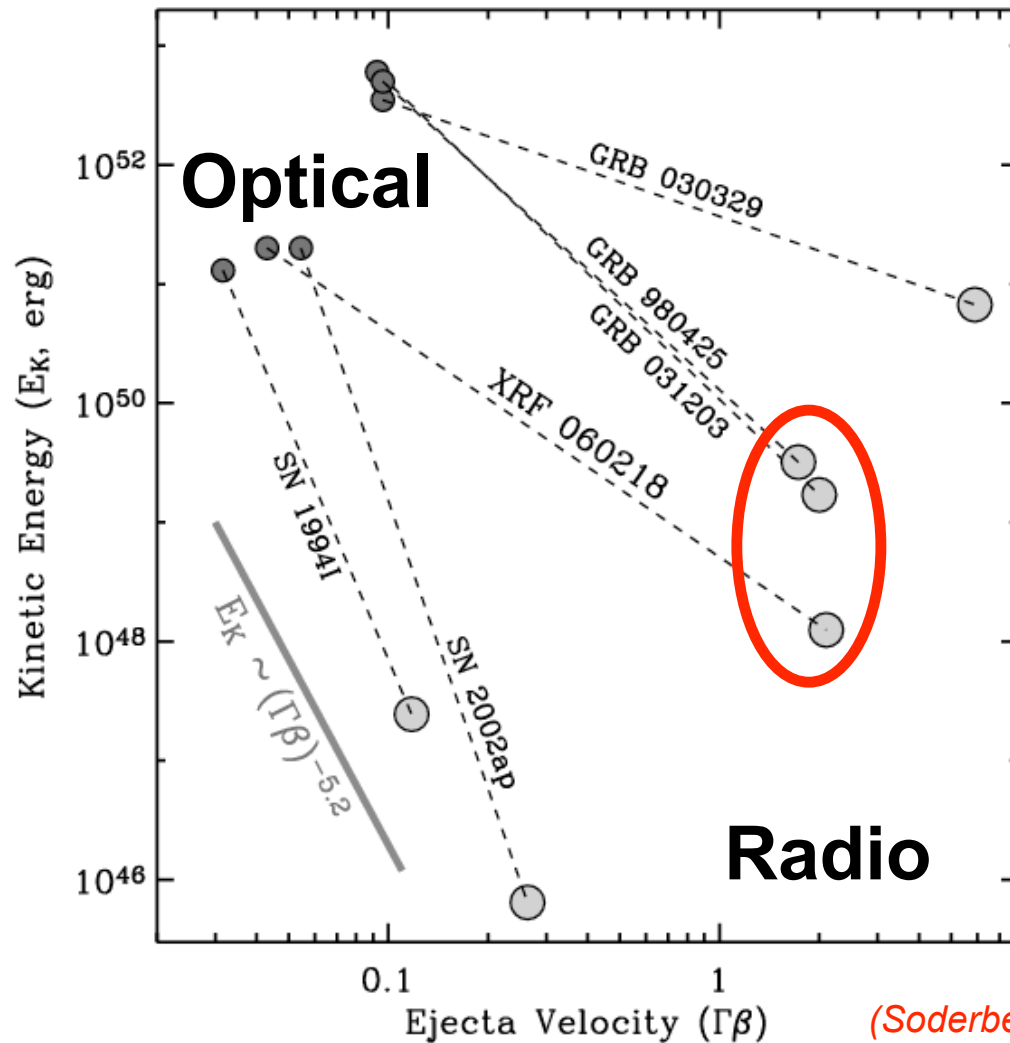
(Kulkarni et al 1998, Berger 2002)

I. Radio Diagnostics: Three classes of supernovae



Along the sequence:
+ Collimation increases
+ Relativistic Energy increases

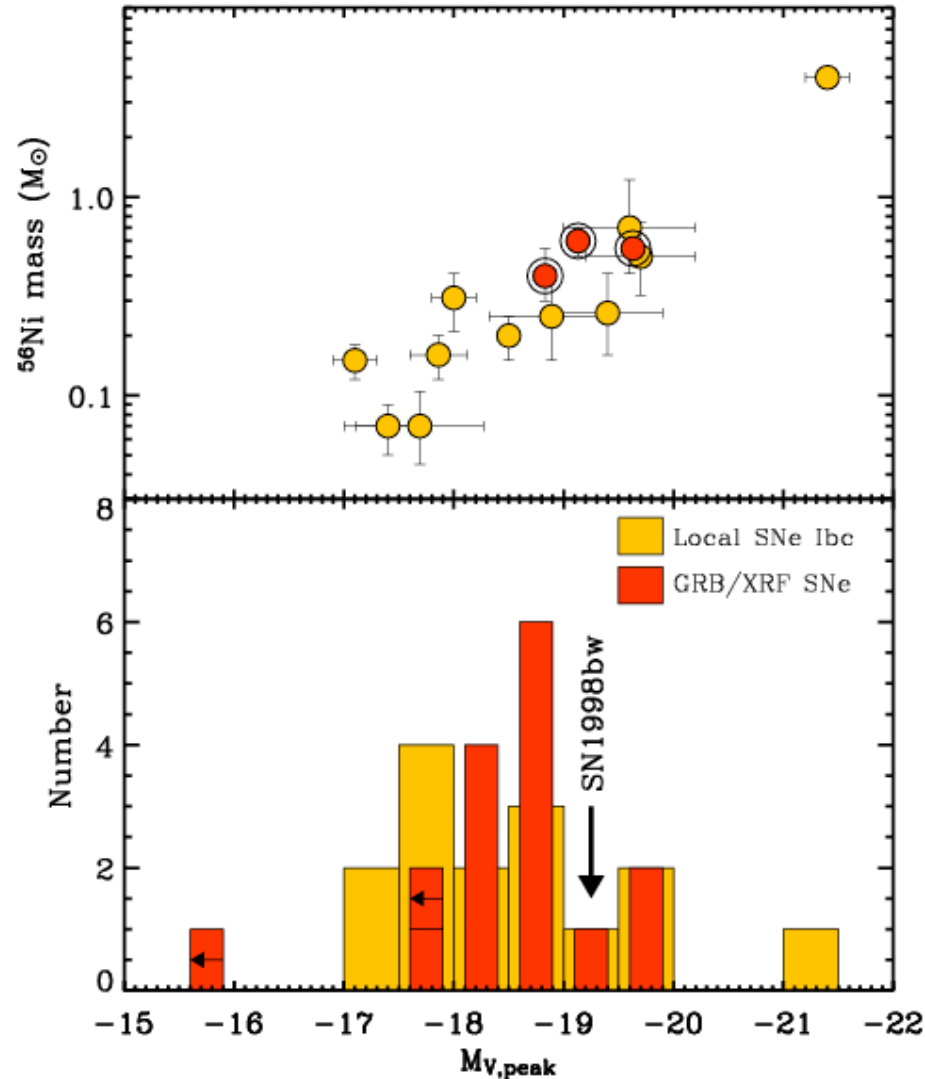
II: Velocity Profile is the Key



In the local sample of 155 supernovae including 10 “hypernovae” less than 3% have such profiles

(Soderberg, 2006, Nature)

III. Nickel production in SNe & GRBs

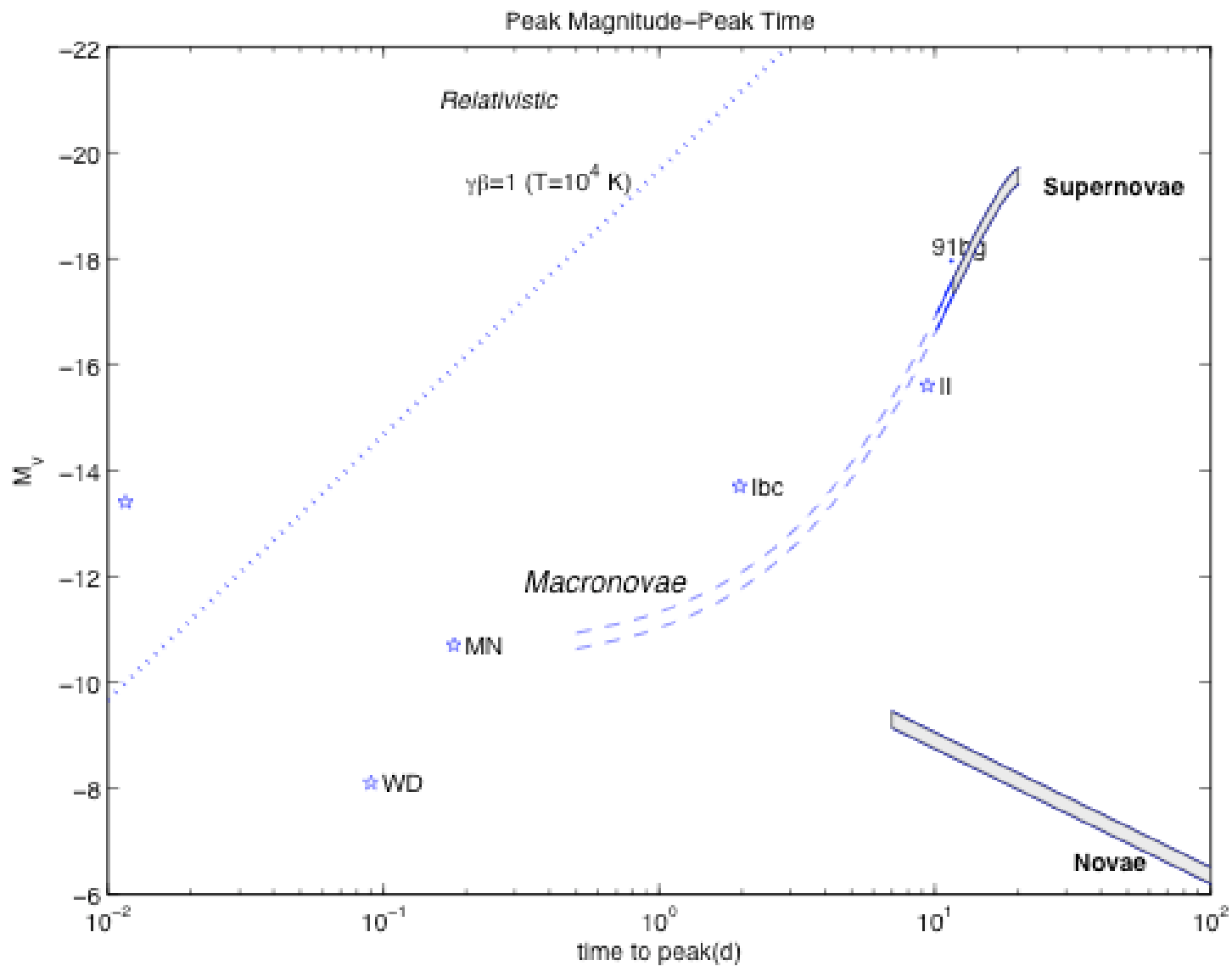


M_V a rough proxy for ^{56}Ni

1. M_V distⁿ are similar
2. SN1998bw is **NOT** the brightest event
3. Broad-lined SNe (5% of local popⁿ) are not overluminous.

Vanishing Supernovae

- Associated supernovae can be vanishingly small (e.g. black hole advects all ejecta)
- GRB 060614, a long burst, has no detectable supernovae
- Short hard bursts have little ejecta and so expect very low luminosity supernovae

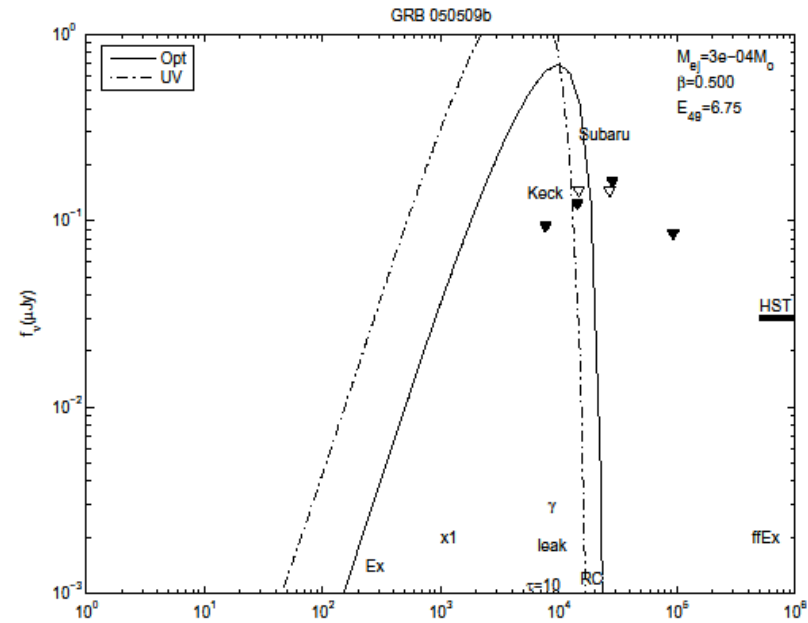


Macronova Model

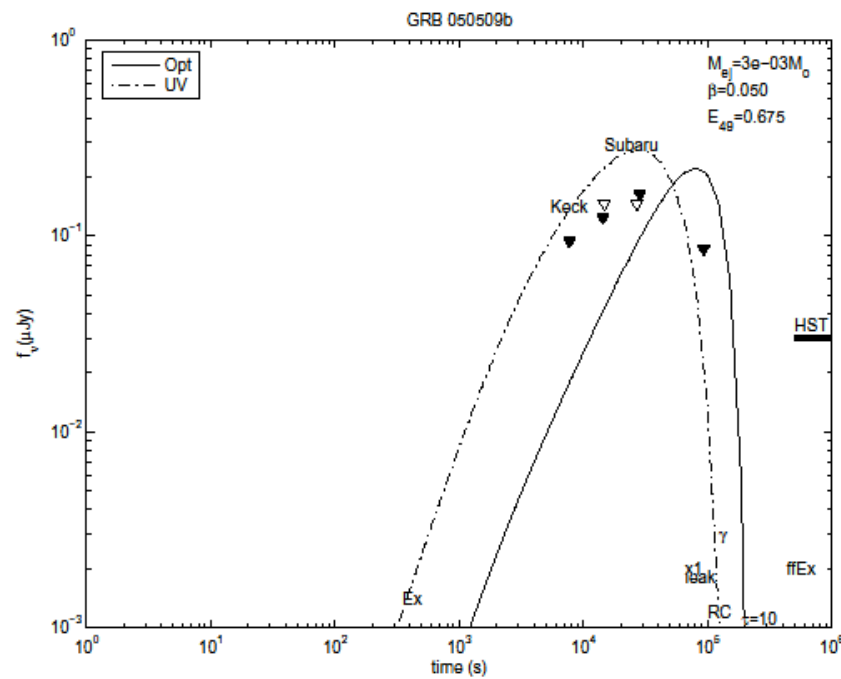
- Parameters: M_{ejecta} & $v = \beta c$
- Injection of energy (post explosion) is essential for macronova to shine
- Composition matters
 - + Free Neutrons
 - + Radioactive Nickel
 - Neutron Rich Material (non-radioactive)

Kulkarni 2005

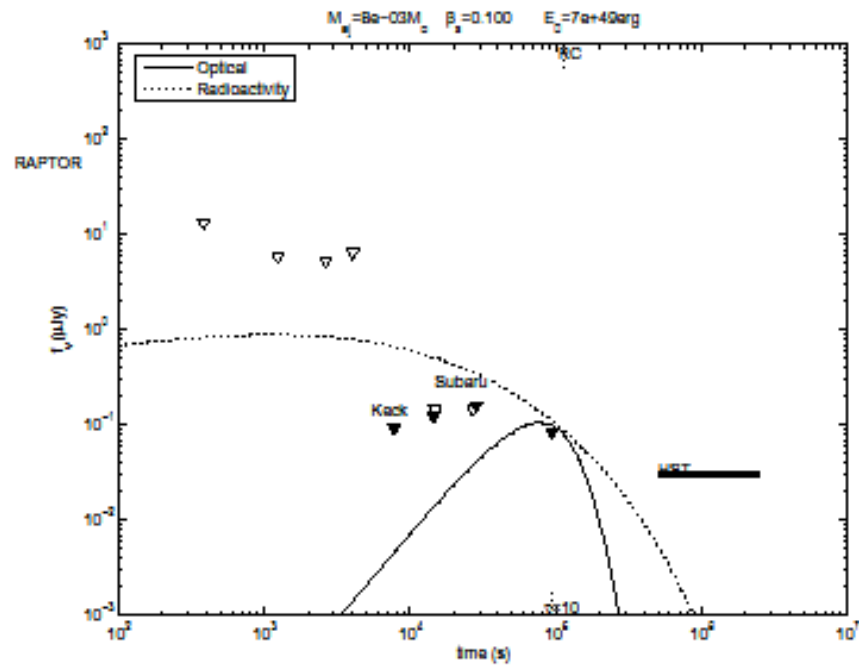
Comparison to Data (GRB 050509b)



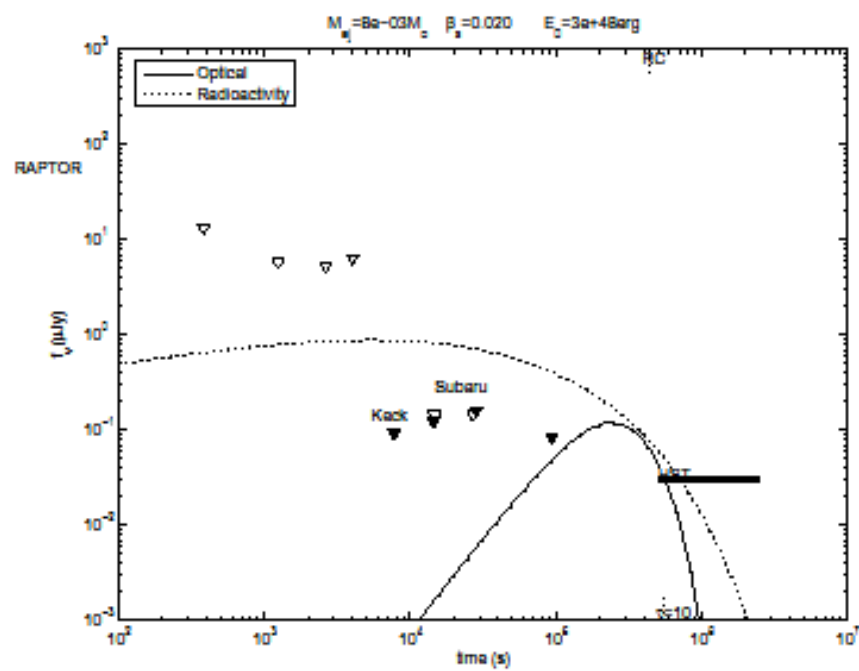
$\beta=0.5$



$\beta=0.05$

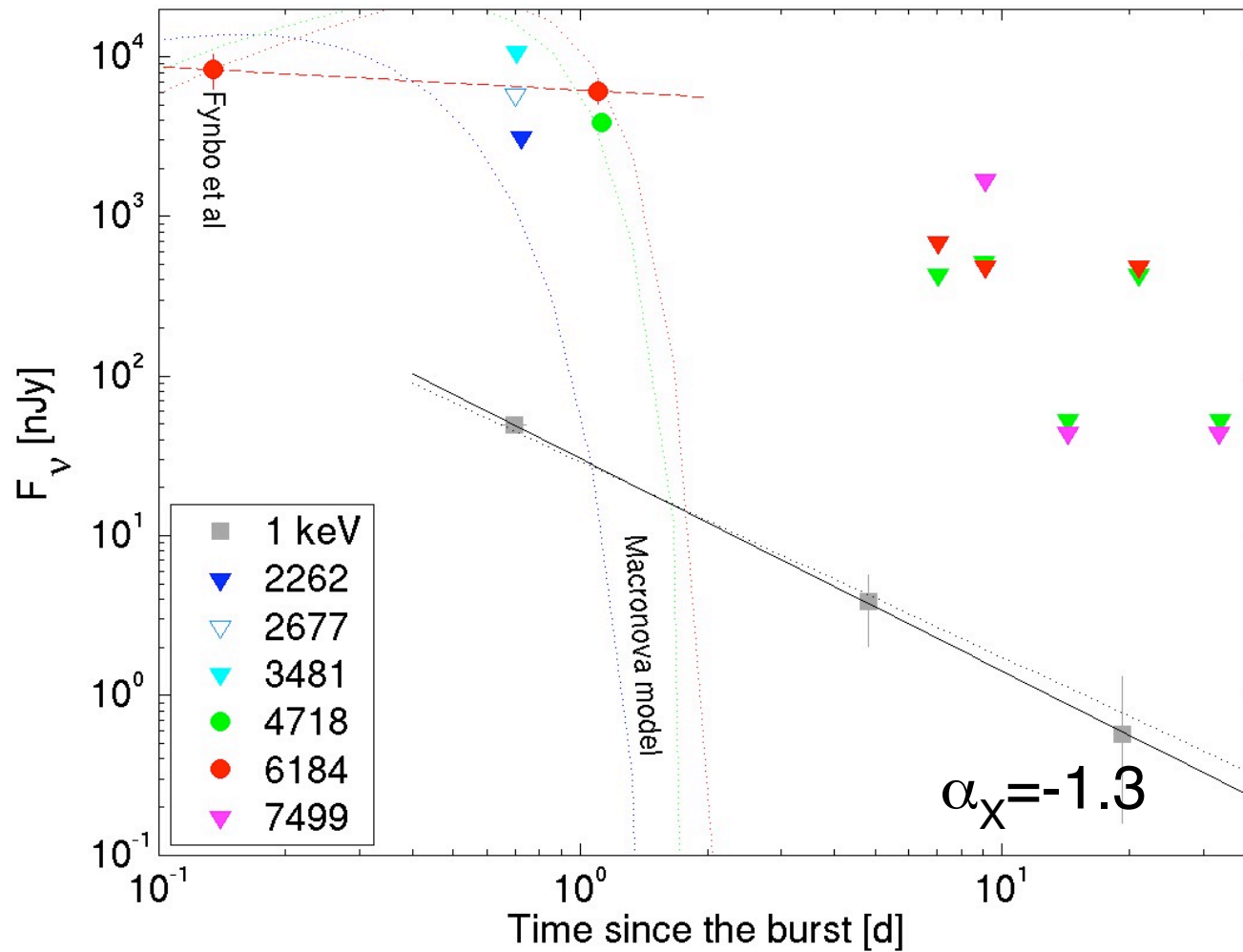


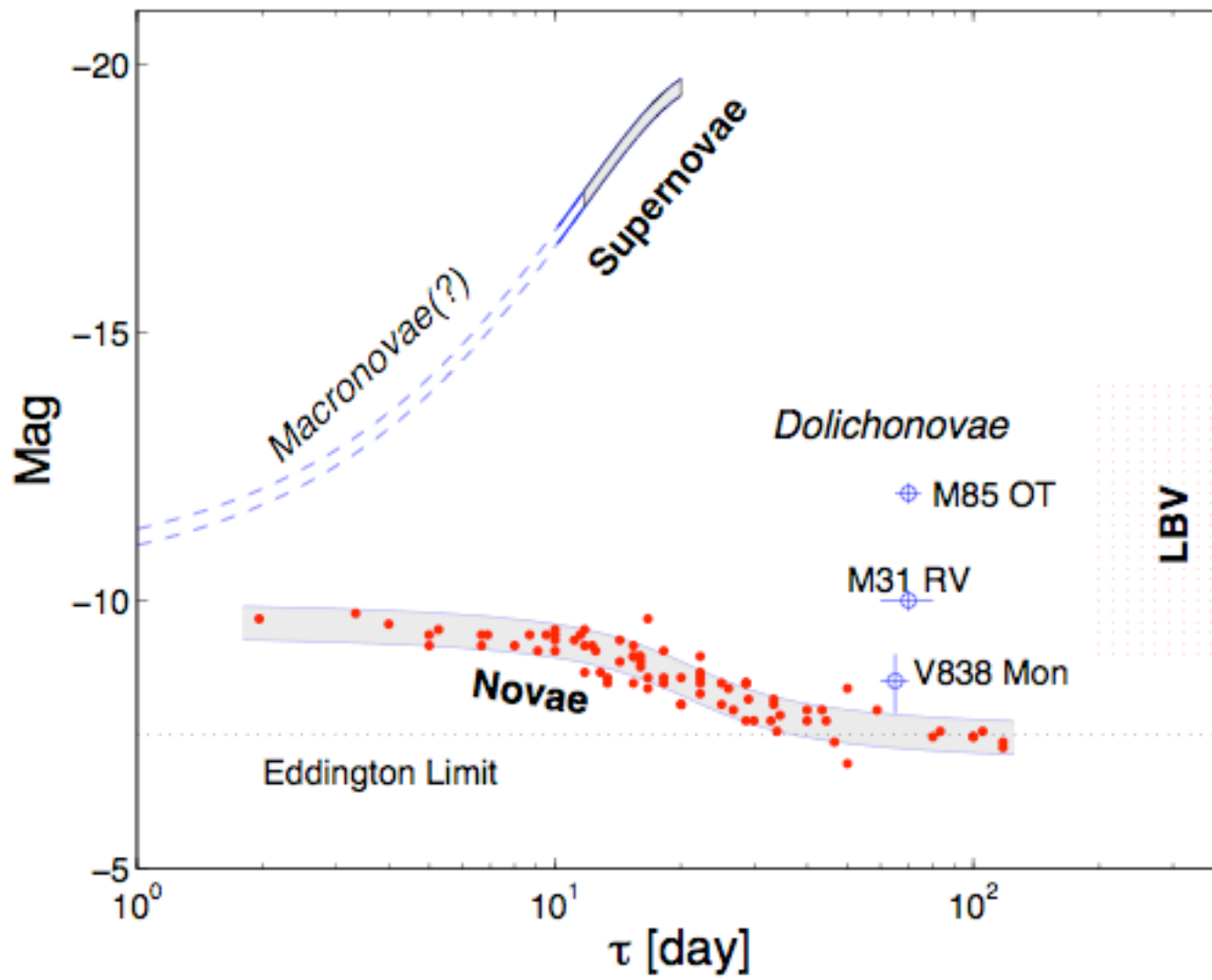
$\beta=0.1$



$\beta=0.05$

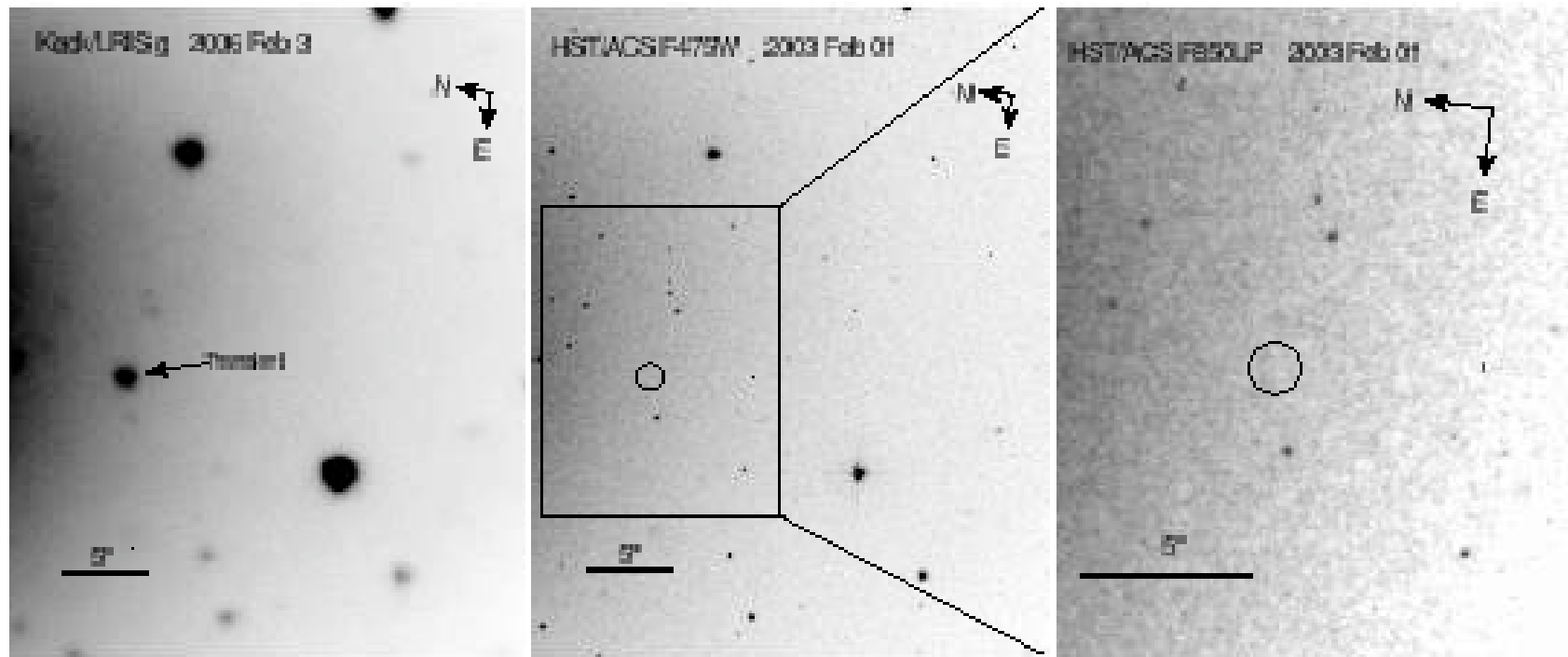
GRB 060505 – Light curve



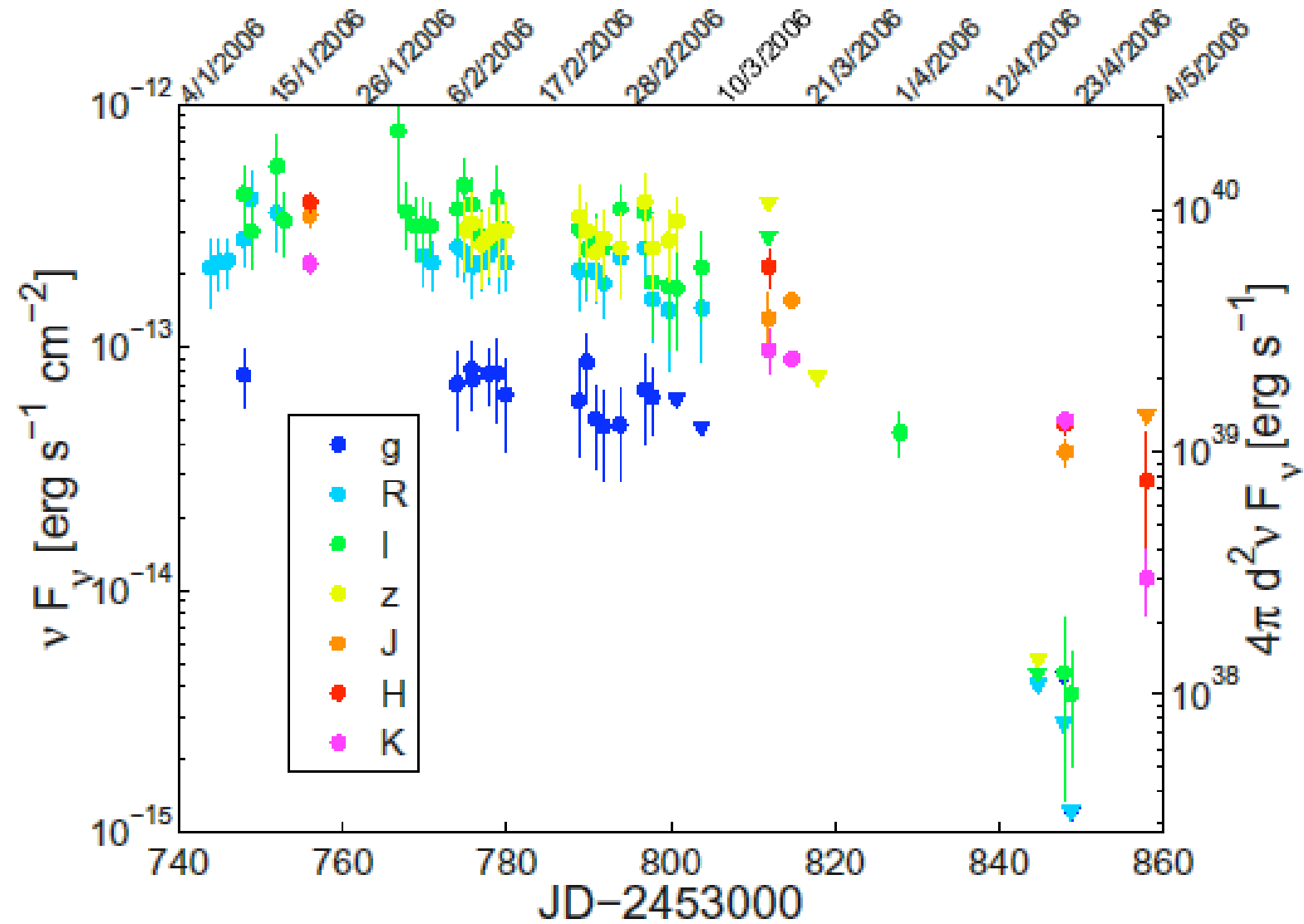


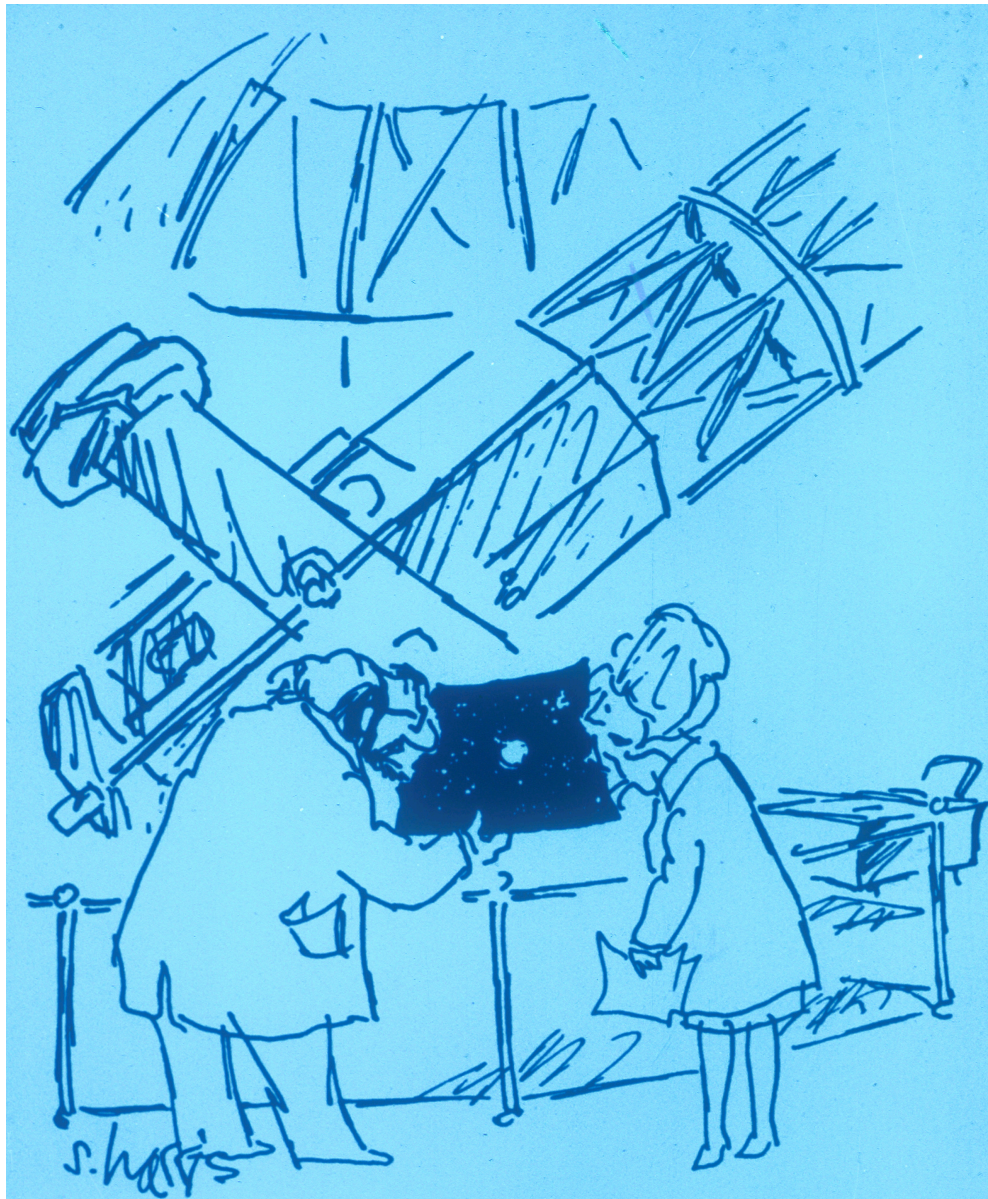
A brilliant event in M85

Brilliant transient in Messier 85



Hyper-Eddington Red Nova





**'It's somewhere between a nova and a supernova
... probably a pretty good nova.'**