Explosion of Cosmic Explosions

S. R. Kulkarni
California Institute of Technology
Pasadena

''Reports that say that something that has not happened is always interesting to me...

The message is that there are known knowns, there are things we know that we know.

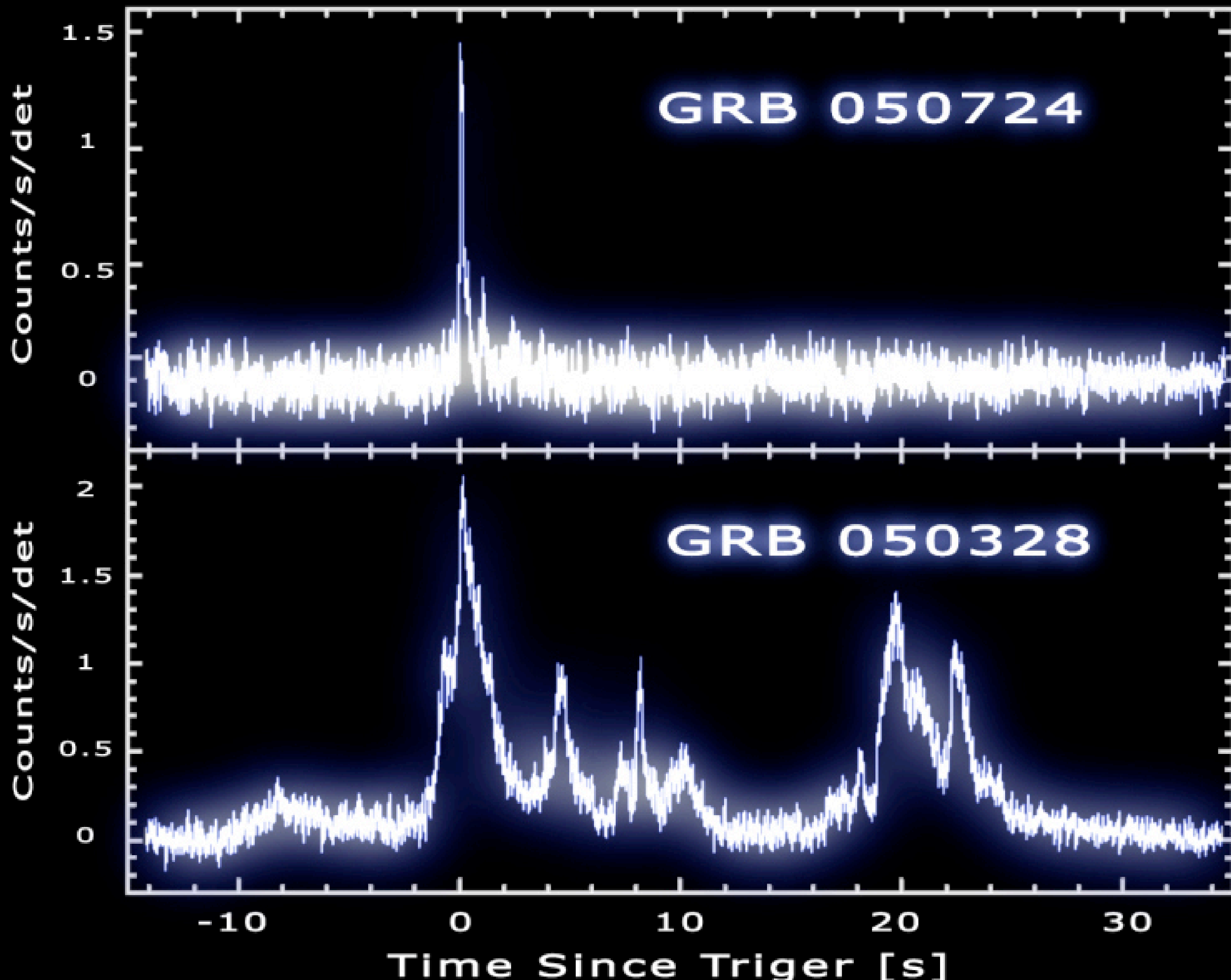
There are known unknowns, that is to say there are things that we now know we don't know.

But there are also unknown unknowns, there are things we do not know we don't know and each year we discover a few more of the unknown unknowns.''

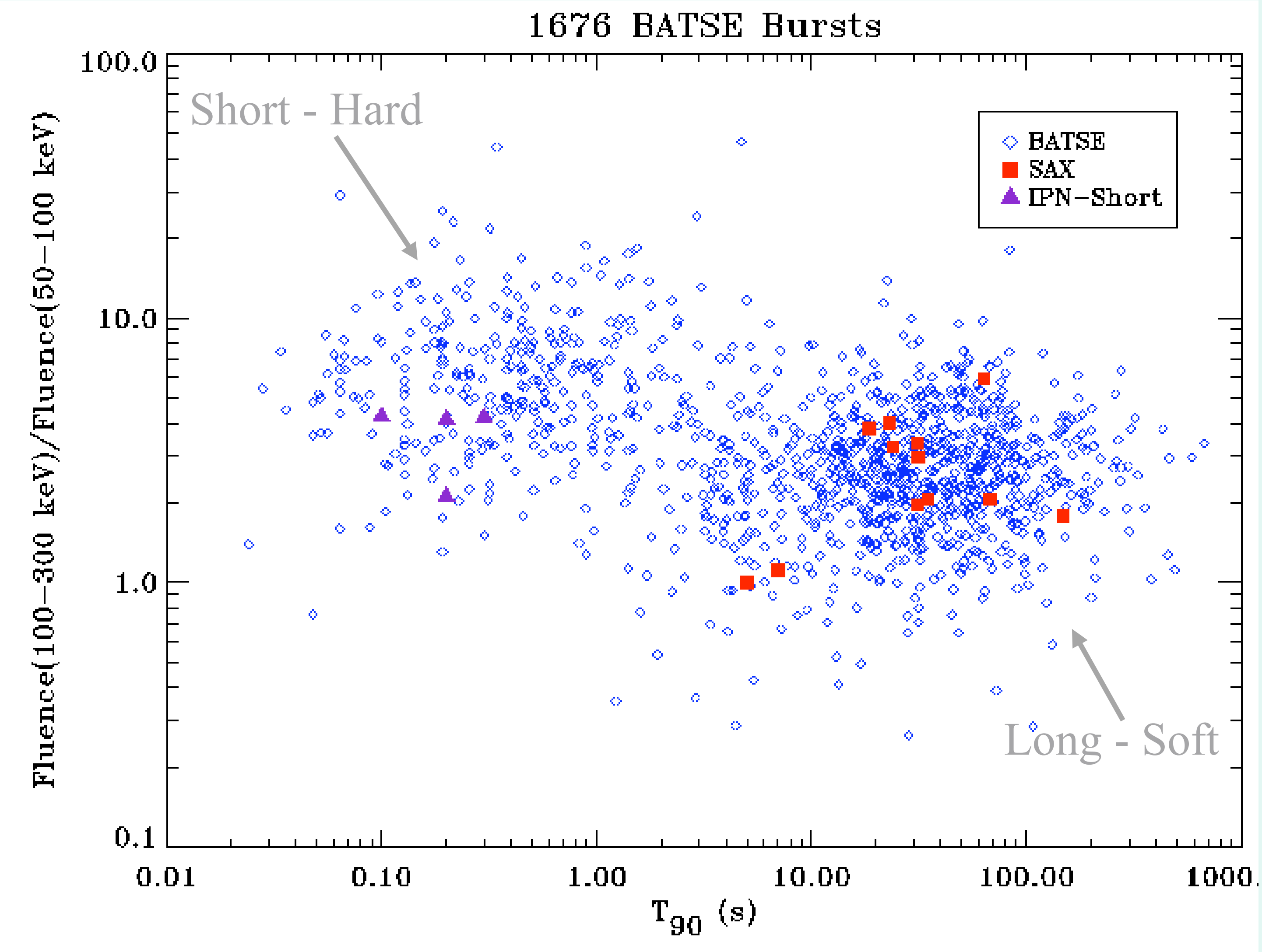
Mr. Donald Rumsfeld, Department of Defense new briefing

The Great Debate

Long & Short


GRB 050724
GRB 050328
Counts/s/s/det
Counts/s/s/det
1.5
1
0.5
0
2
1.5
1
0.5
0
-10
0
10
20
30
Time Since Triger [s]

Two classes of GRBs



Long Duration Bursts:

Kulkarni et al.
Bloom et al.
Frail et al.
Berger et al.
Soderberg etal

Collapsar Model: Woosley, Heger, MacFadyen

Collapsar: The Movie

A Hollywood-Bollywood Production

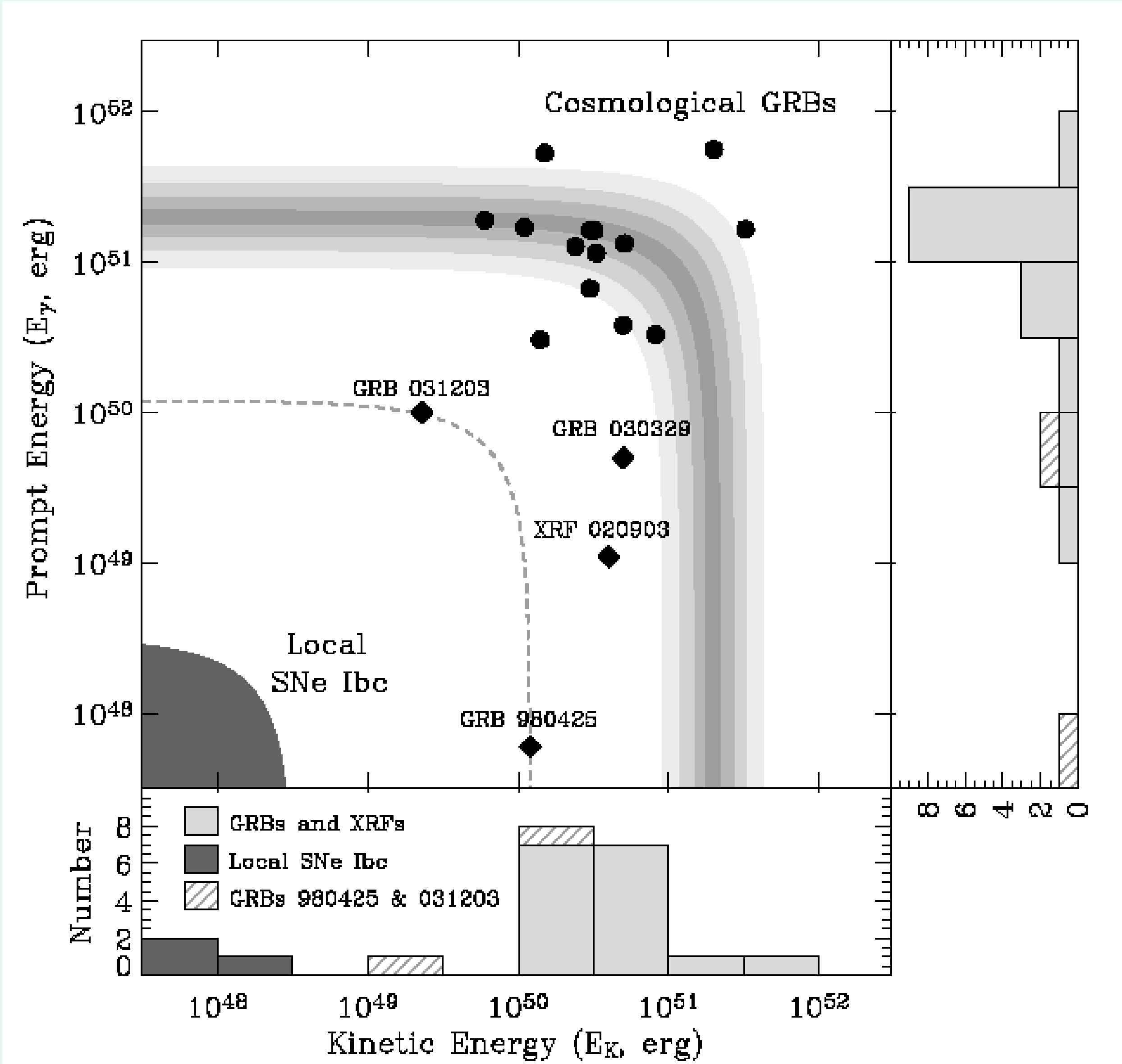
From Bogus Enterprise,

A Division of General Propaganda

Long Duration GRBs: Questions

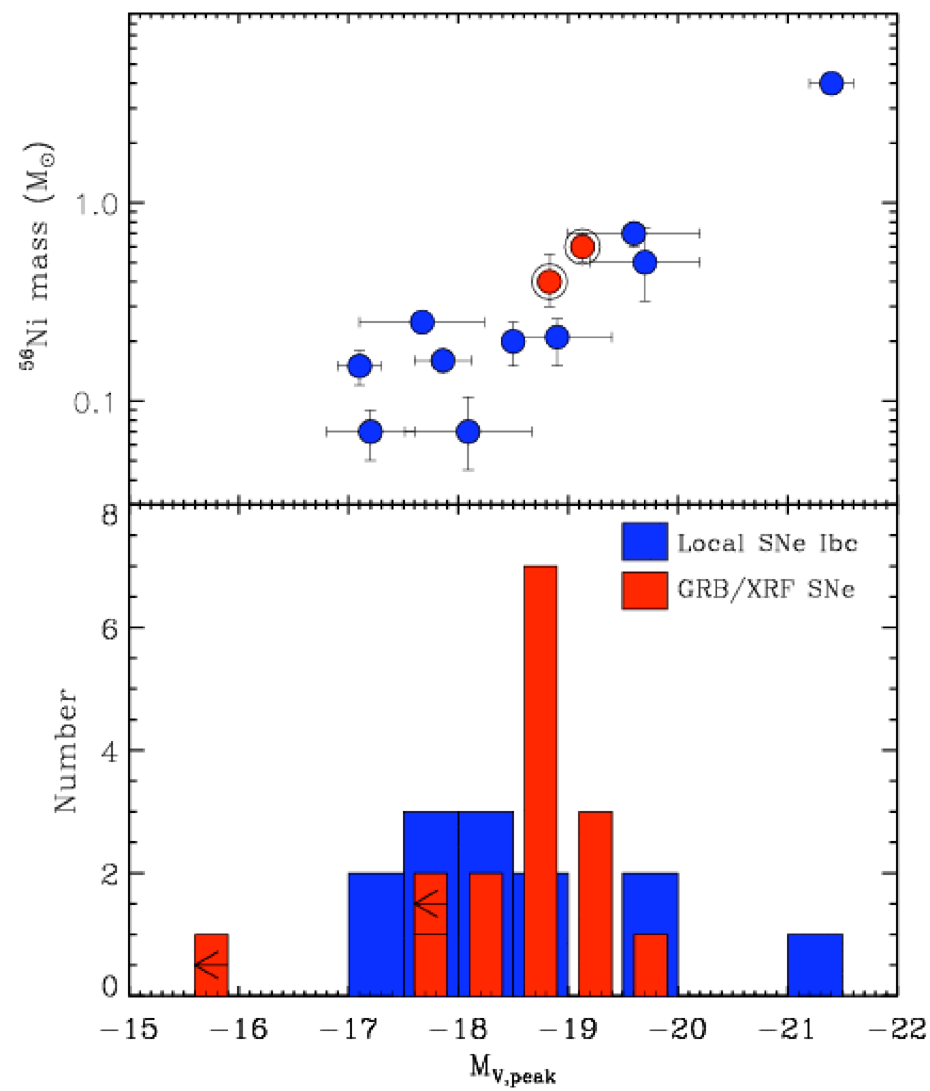
- Core Collapse: Bimodal or Continuum
  - Bimodal: Engine dominated vs pure collapse
  - Continuum: an engine is always present
- Production of Radioactive Nickel:
  - Only one channel: spherical shock
  - Two channels: spherical shock & jets

A New Family of Cosmic Explosions:



Soderberg

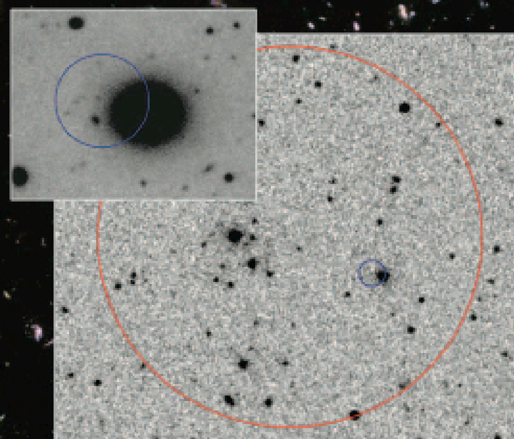
SUMMARY: Peak SN magnitudes



(Soderberg et al. 2005b)

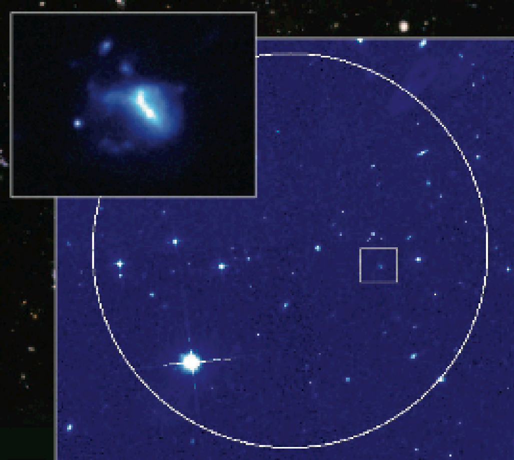
6 October 2005 | www.nature.com/nature | $10
THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE

nature



SHORT GAMMA-RAY BURSTS

The birth of a black hole seen in the stars



INFLUENZA PANDEMIC

Genome sequence of the 1918 virus

SEX PHEROMONES

A glint in the eye

EARTHQUAKES

Pulling the trigger

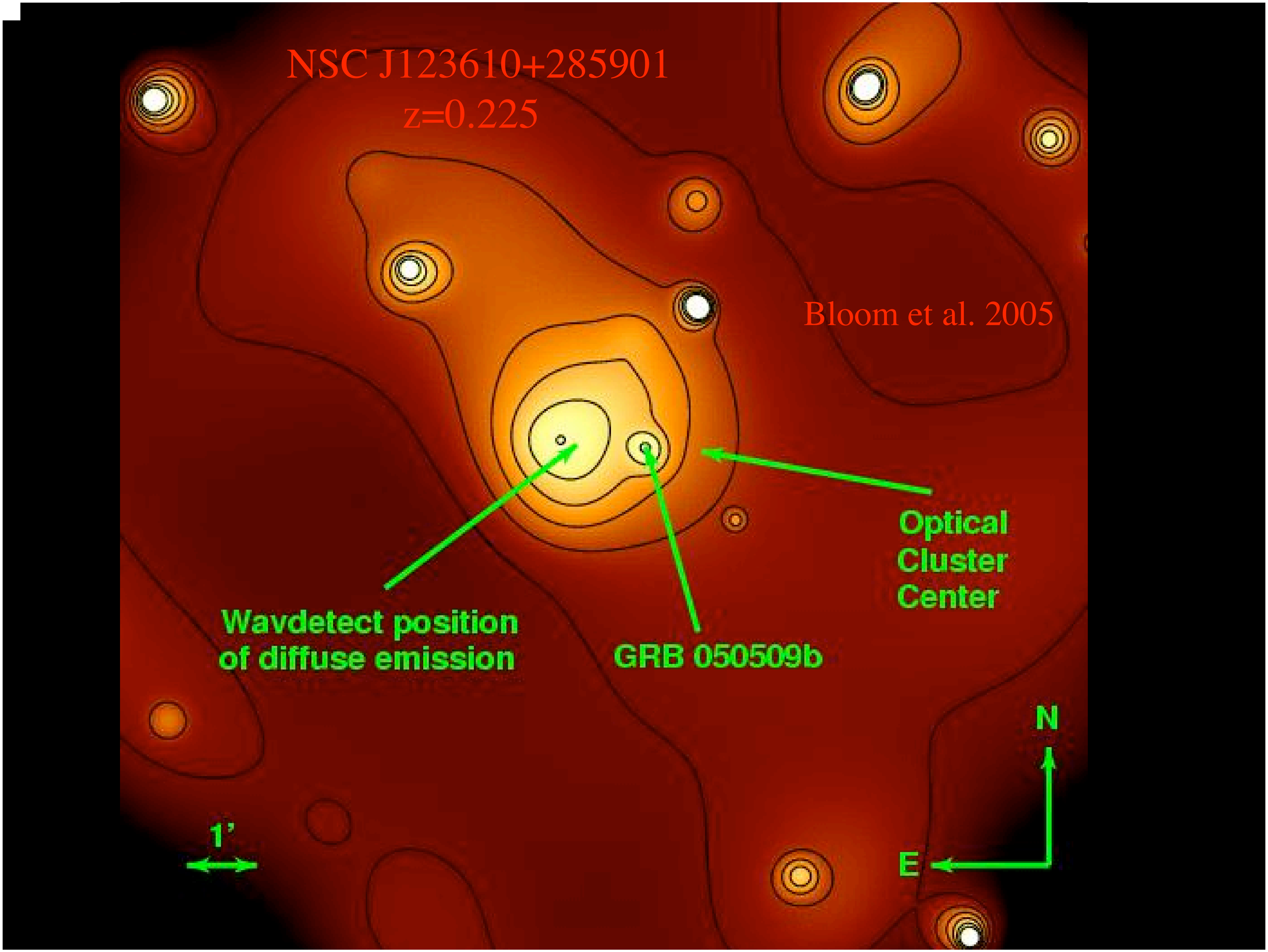
NATUREJOBS

$10.00US $12.99CAN

Toward the SHB Progenitor: Redux

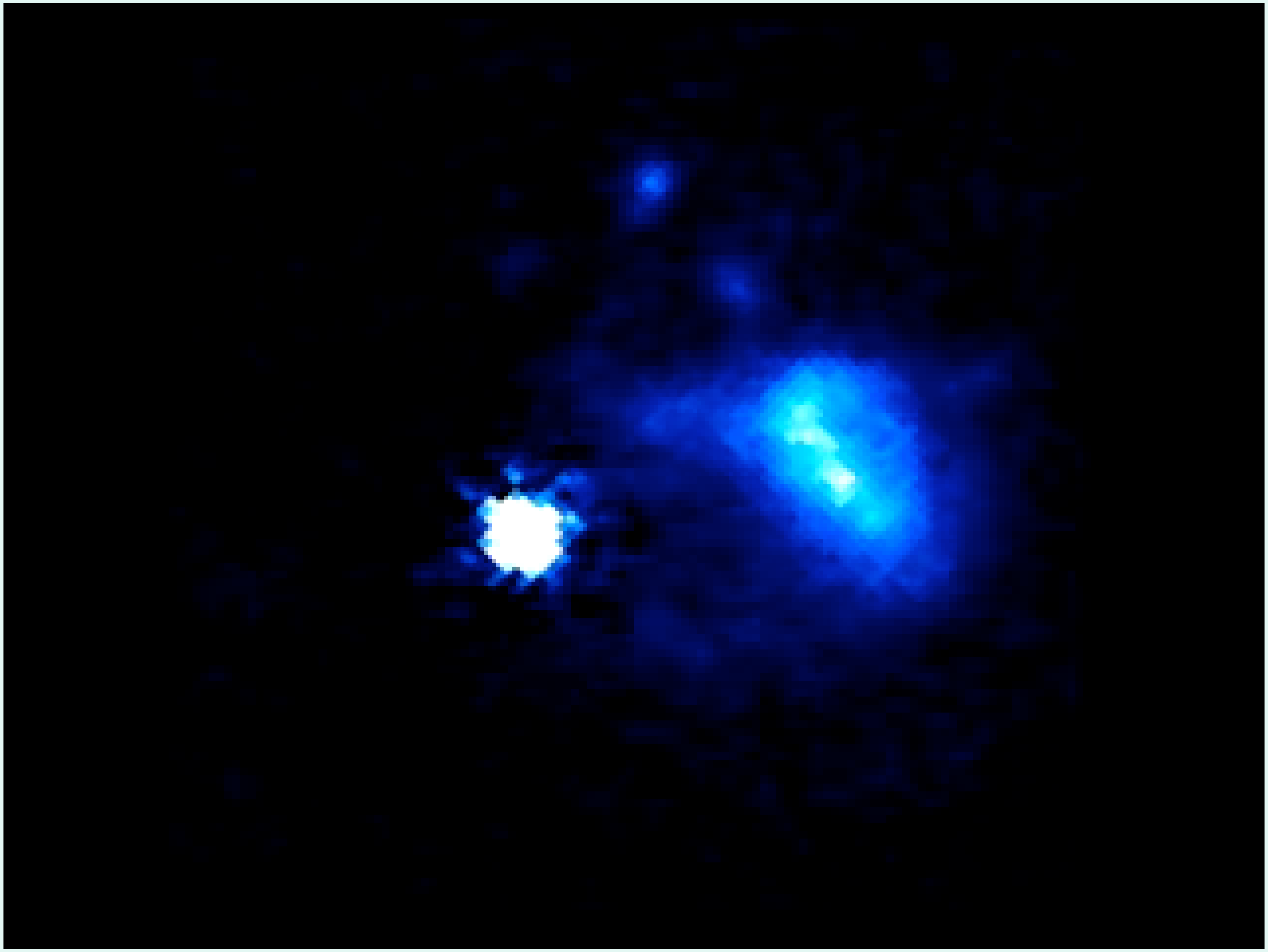
- How far away are they?
- How much energy do they release?
  - is the energy release isotropic or collimated?
  - are the central engines long or short-lived?
  - Is there associated non-relativistic ejecta?
- What are the progenitors?
  - Clue (macro) = host galaxy + offset
  - Clue (micro) = circumburst environment

The key to answering these questions has been the <u>precise positions</u> enabled by the discovery of long-lived afterglows.



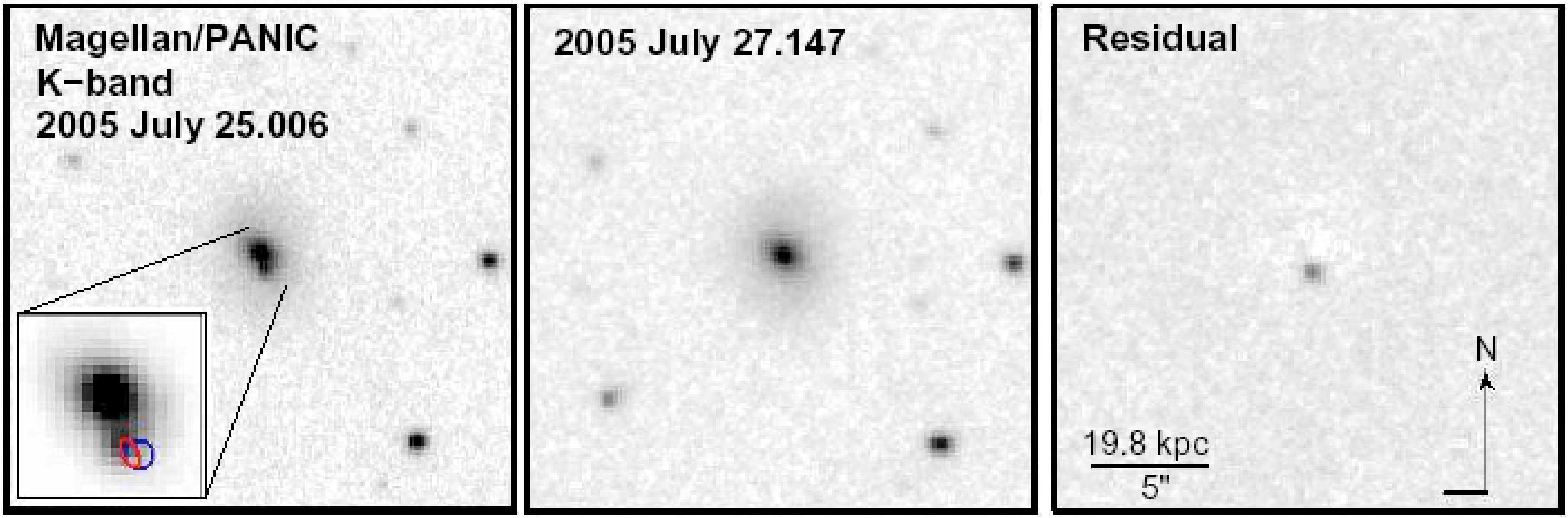
NSC J123610+285901
z=0.225
Bloom et al. 2005
Optical
Cluster
Center
Wavdetect position
of diffuse emission
GRB 050509b
1'
N
E

HST imaging & search for supernova explosion



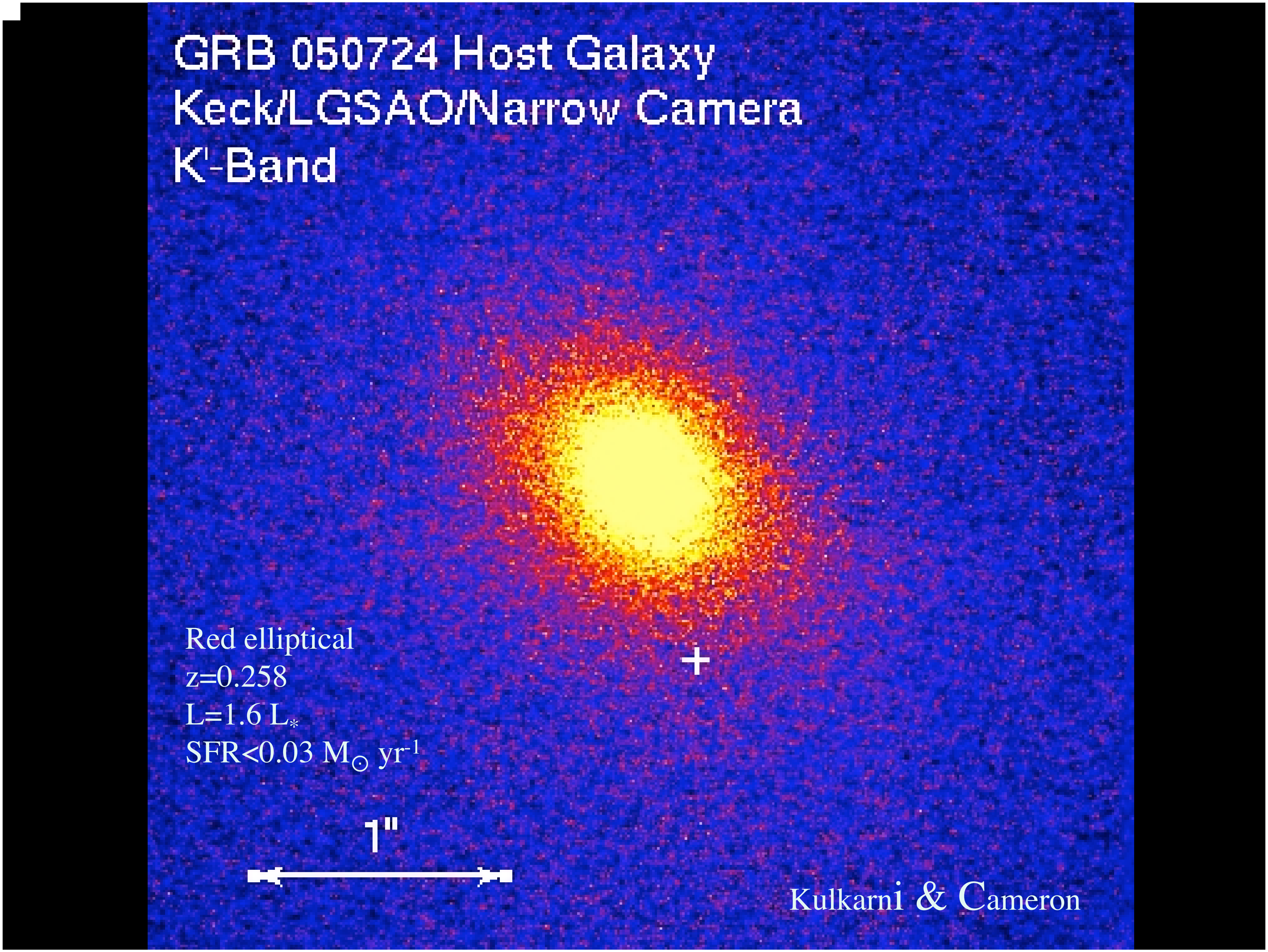
Fox et al. 2005

GRB 050724: *Swift*



Berger et al. 2005

Keck Laser Guide Star AO


GRB 050724 Host Galaxy
Keck/LGSAO/Narrow Camera
K'-Band
Red elliptical
z=0.258
L=1.6 L_*
SFR<0.03 $M_\odot$ yr^{-1}
1"
Kulkarni & Cameron

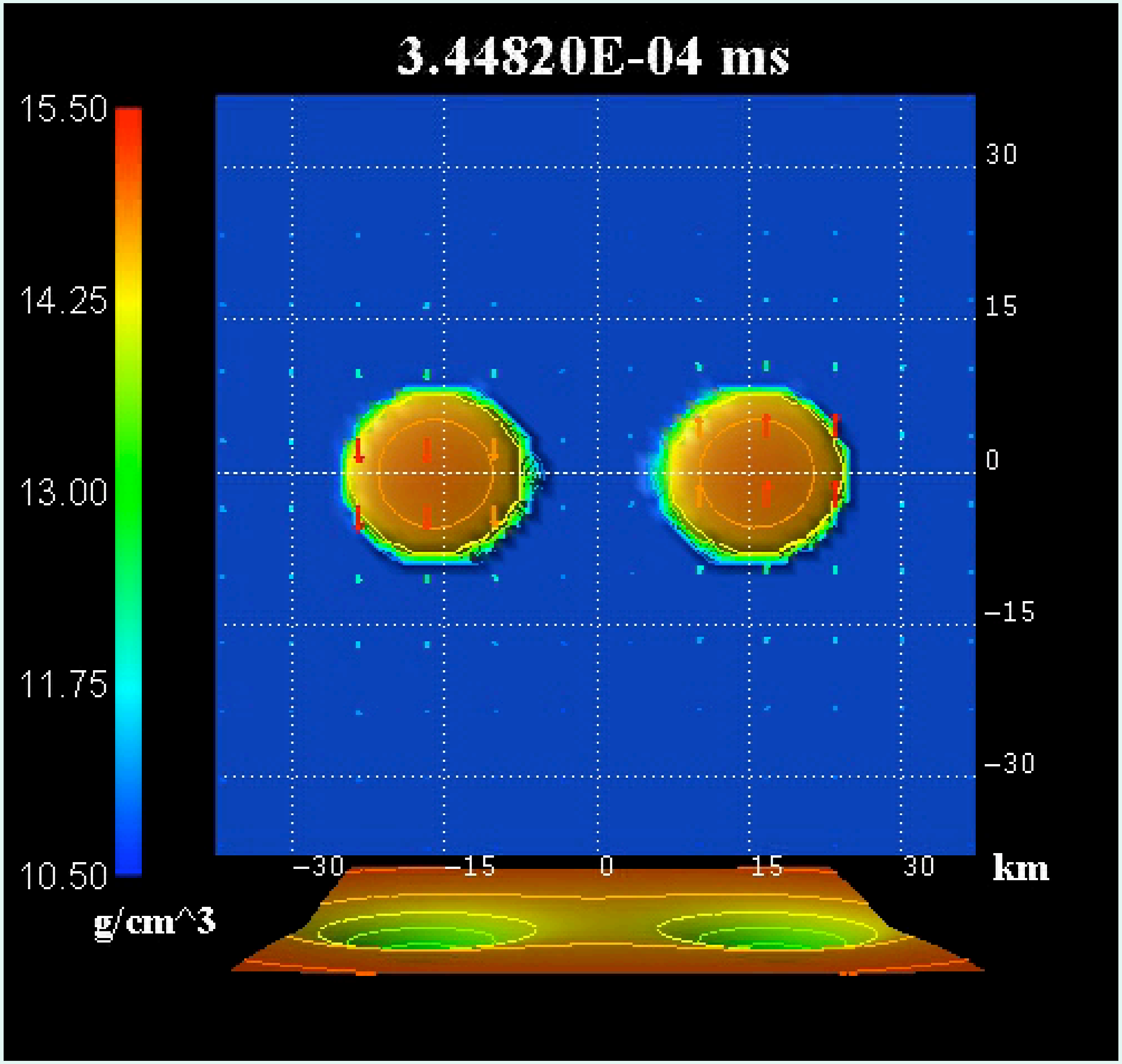
Toward the SHB Progenitor

- How far away are they?
  - At least some short bursts are z ~ 0.2
- How much energy do they release?
  - About 10^{49} to 10^{50} erg
  - Evidence for ``jets''
- Is there an associated supernova explosion?
  - Supernova, if any, are faint ($M_v > -13$)
- What are they?
  - Both elliptical and star-forming host galaxies

Holy smokes, he is dead?!!

Ph: Glendinning

Coalescence of Neutron Stars (Shibata)



Macronova

- Is there a sub-relativistic explosion accompanying short hard bursts?

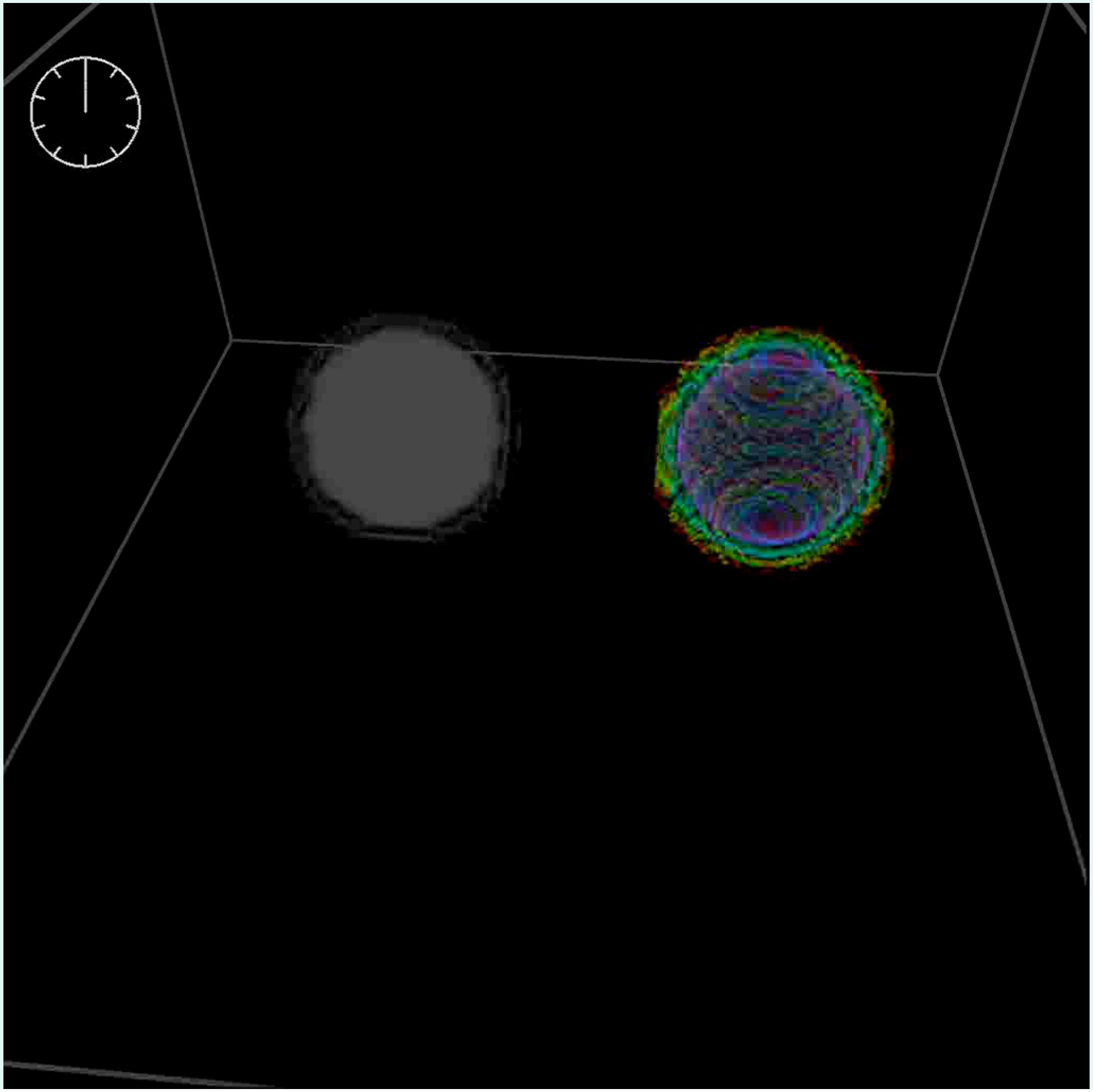
Li & Paczynski 1998

- If so, (observationally)
  - $>$ Nova
  - $<$ Supernova

=> “*Mini*-**super**nova” or “*Macronova*”

Kulkarni 2005

Black Hole-Neutron Star (Rupert, Janka)



Macronova Model

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

The total heat of the system is due to the electrons (density, n_e), ions (density, n_i) and photons:

$$E/V = \frac{3}{2}n_i(Z+1)kT + aT^4, \tag{2}$$

where $V = 4\pi/3R^3$, $N_i = M_{\rm ej}/(Am_H)$, $n_i = N_i/V$, $n_e = Zn_i$ and m_H is the mass of a hydrogen atom. For future reference, the total number of particles is $N = N_i(Z+1)$. This heat store has gains and losses described by

$$\dot{E} = \varepsilon(t) - L(t) - 4\pi R(t)^2 P v(t) \tag{3}$$

where $L(t)$ is the luminosity radiated at the surface. P is the total (electron, ion and photon) pressure and is

$$P = n_i(Z+1)kT + aT^4/3. \tag{4}$$

As explained earlier, the ejecta gain speed rapidly from expansion (the $4\pi R^2 P v_s$ work term). Thus, following the initial acceleration phase, the radius can be expected to increase linearly with time:

$$R(t) = R_0 + v_s t; \tag{5}$$

With this (reasonable) assumption of coasting we avoid solving the momentum equation.

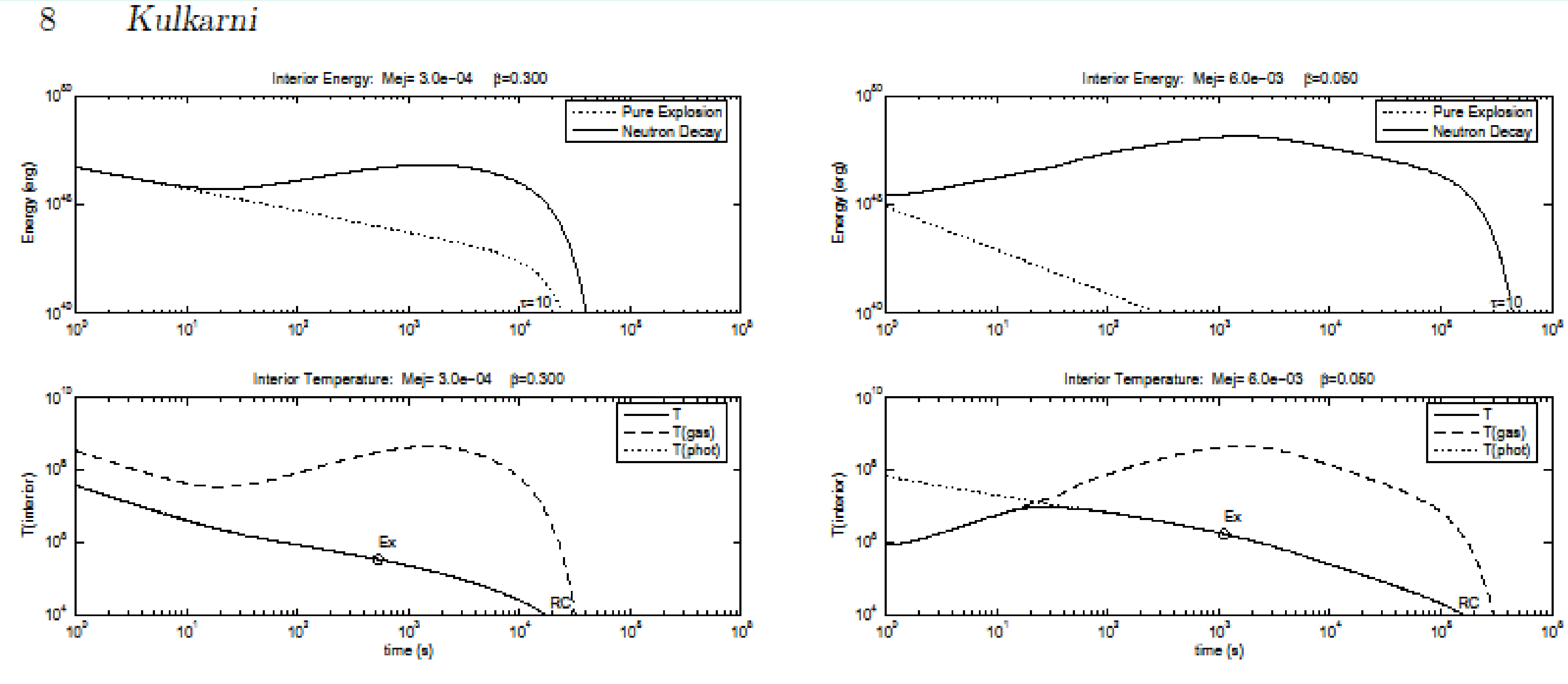
Heating by Decay of Neutrons

heating rate is

$$\varepsilon(t) = 5.4 \times 10^{14}\,\mathrm{erg\,gm^{-1}\,s^{-1}}. \tag{10}$$

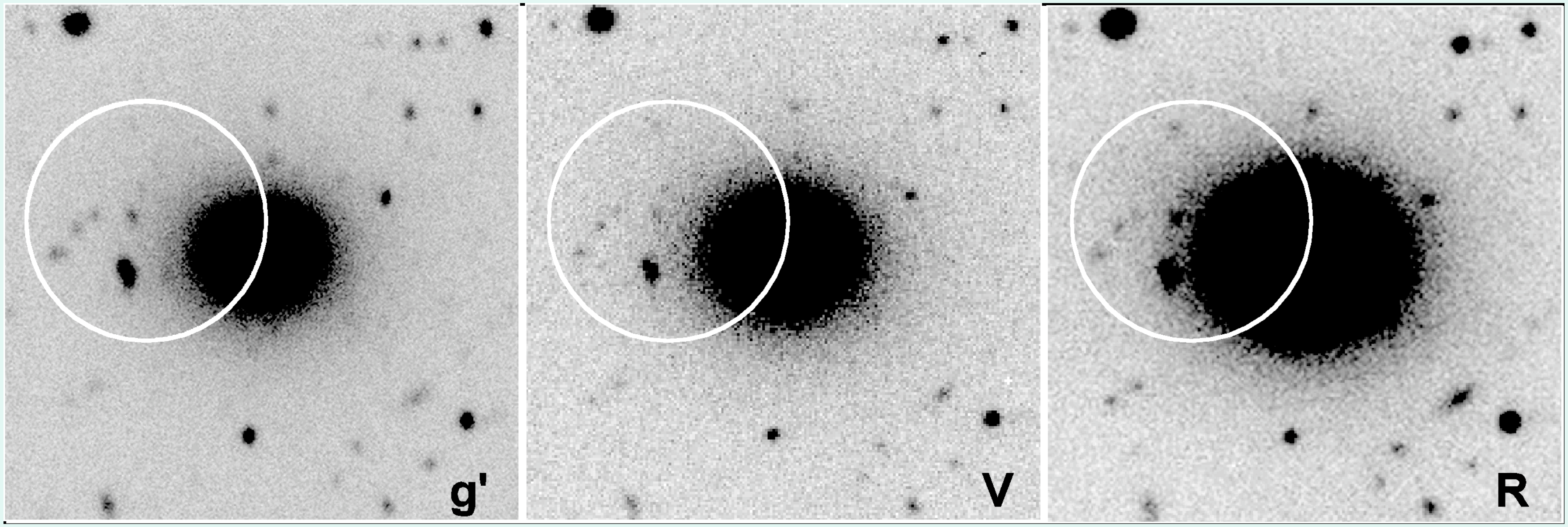
Even though half life is 10 minutes, neutron heating results in detectable signals.

Heating by Neutron Decay



Problem: Initial photons radiated away

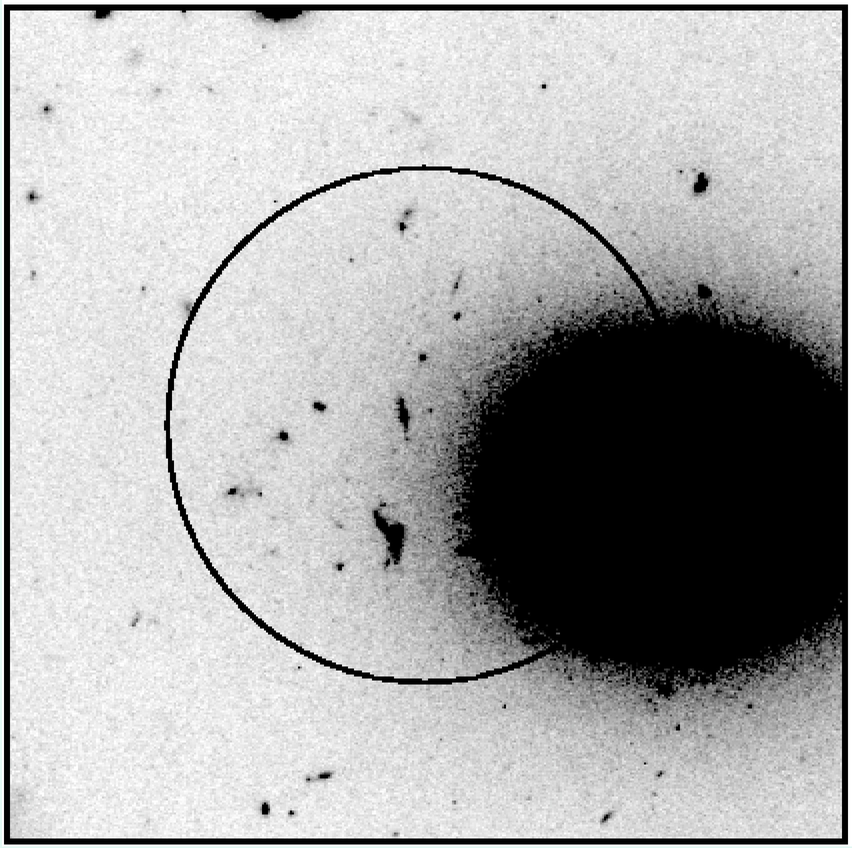
GRB 050505B: Keck/Subaru

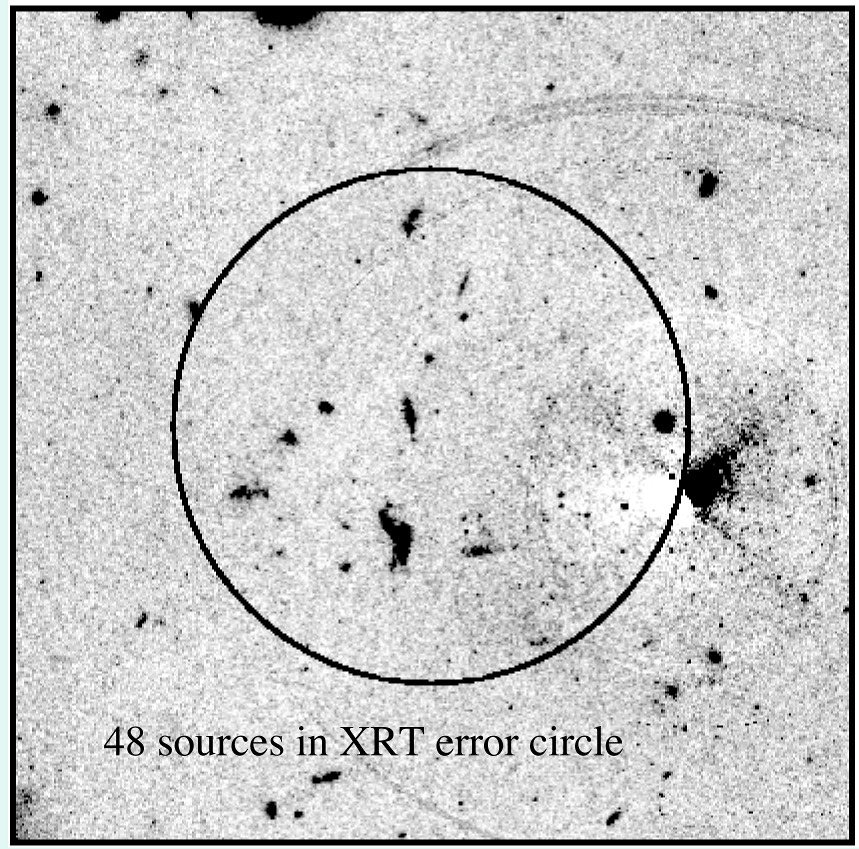


Error radius = 9.3 arcsec

Kulkarni et al. 2005

HST Imaging: No Supernova



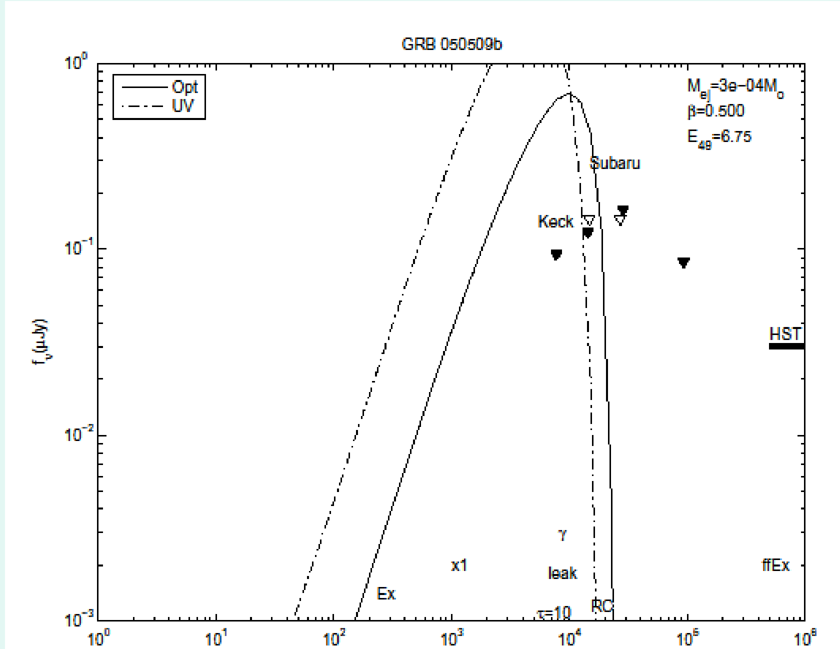


Error radius = 9.3 arcsec
4 HST Epochs
May 14 to June 10

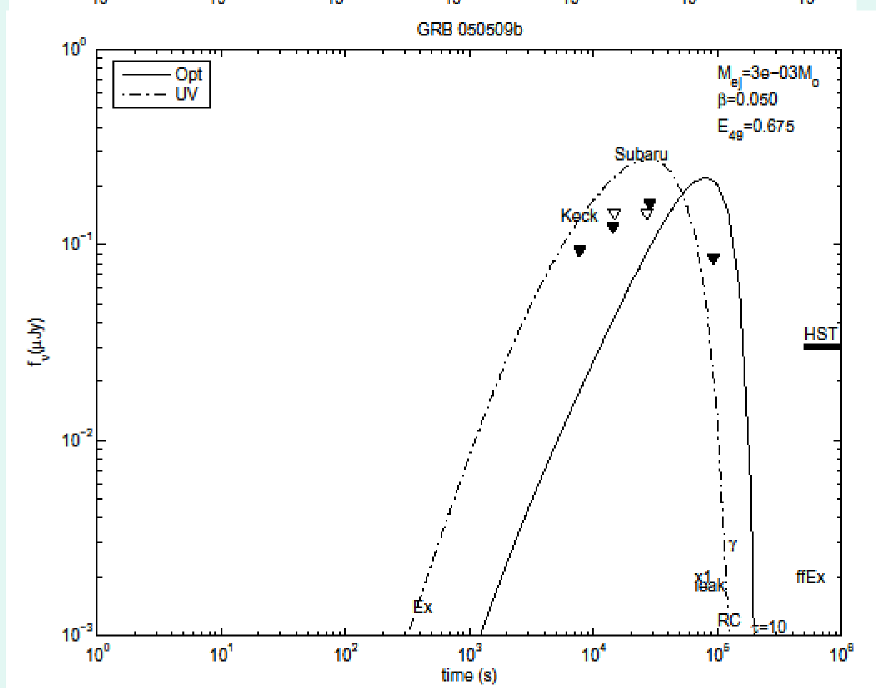
Giant elliptical Bloom et al
$L=1.5L_*$
$SFR<0.1\ M_\odot\ yr^{-1}$

Kulkarni et al. 2005

Comparison to Data (GRB 050509b)



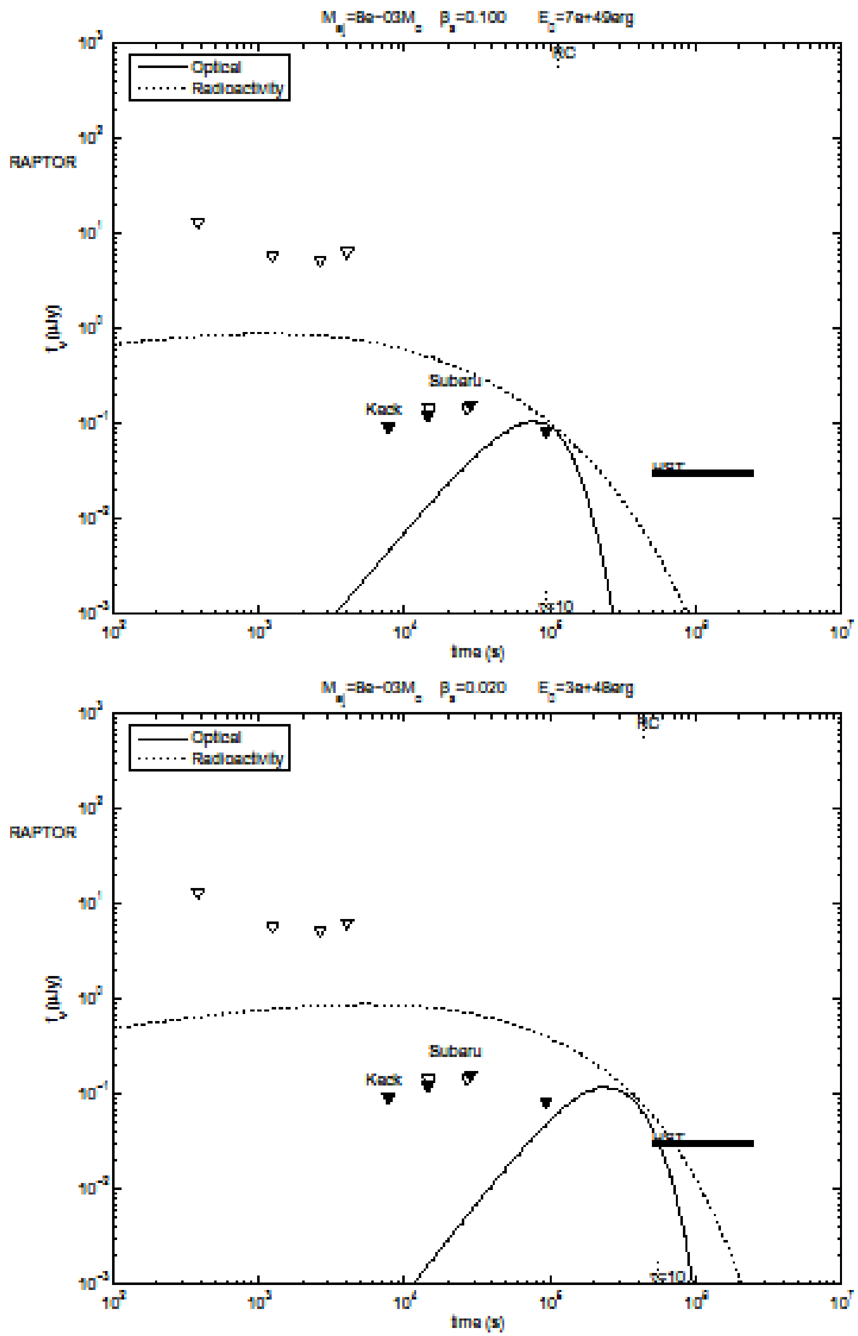
β=0.5



β=0.05

Heating by Decay of Ni^{56}

- Nickel decay results in 1.72 MeV gamma-rays.
- A few scatterings are needed to transfer bulk of the energy to electrons
- Unlike ordinary SN, the ejecta become transparent to gamma-rays before 6 days.


M_ej=8e-03M_⊙ β_s=0.100 E_c=7e+49erg
Optical
Radioactivity
RAPTOR
Keck
Subaru
HST
time (s)
M_ej=8e-03M_⊙ β_s=0.020 E_c=3e+48erg
Optical
Radioactivity
RAPTOR
Keck
Subaru
HST
time (s)

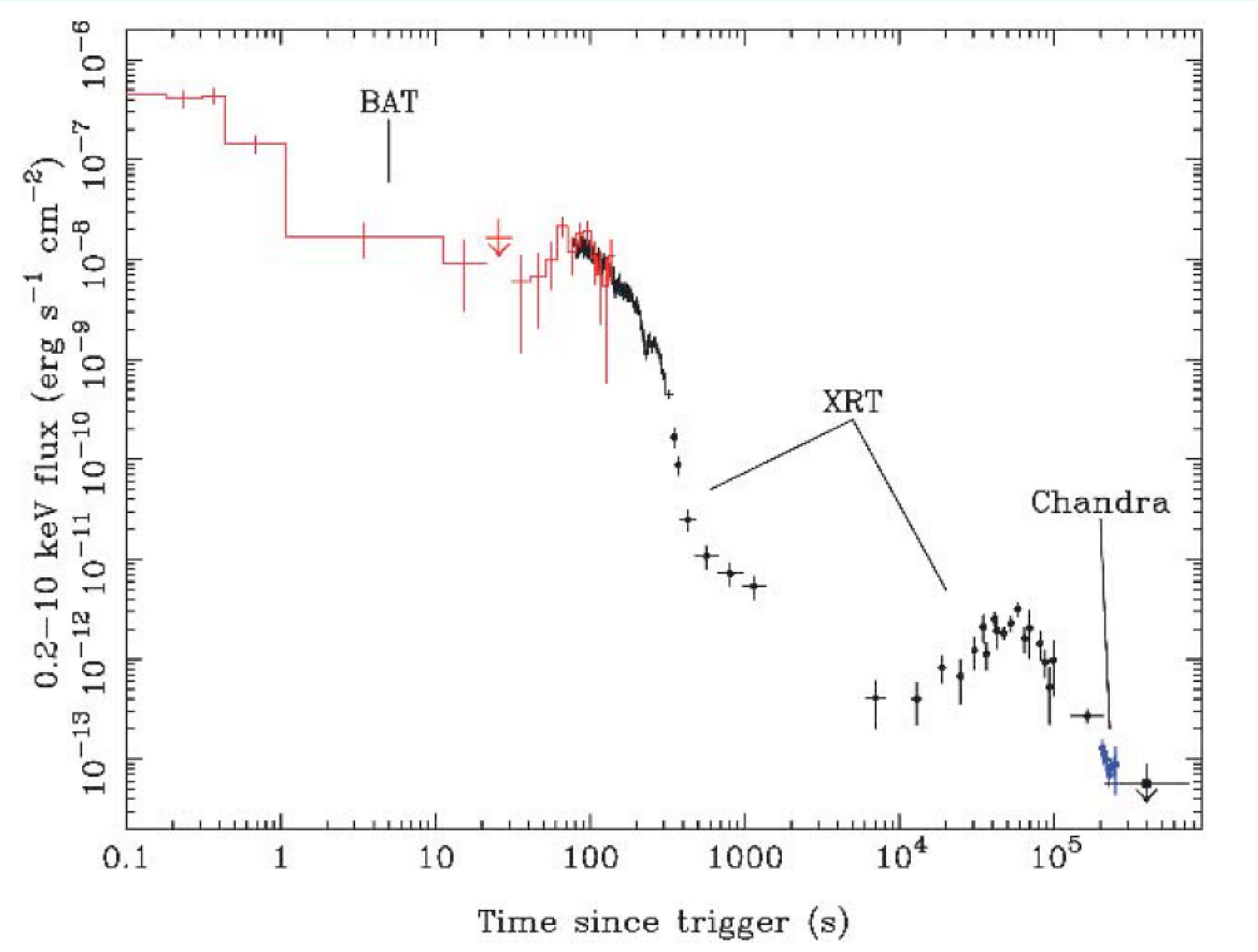
β=0.1

β=0.05

The Macronova as a reprocessor

- Long lived central soure (e.g. magnetar)
- Long lived accretion disk

There are already indications of tremendous late time activity.



Barthelmy al. 2005

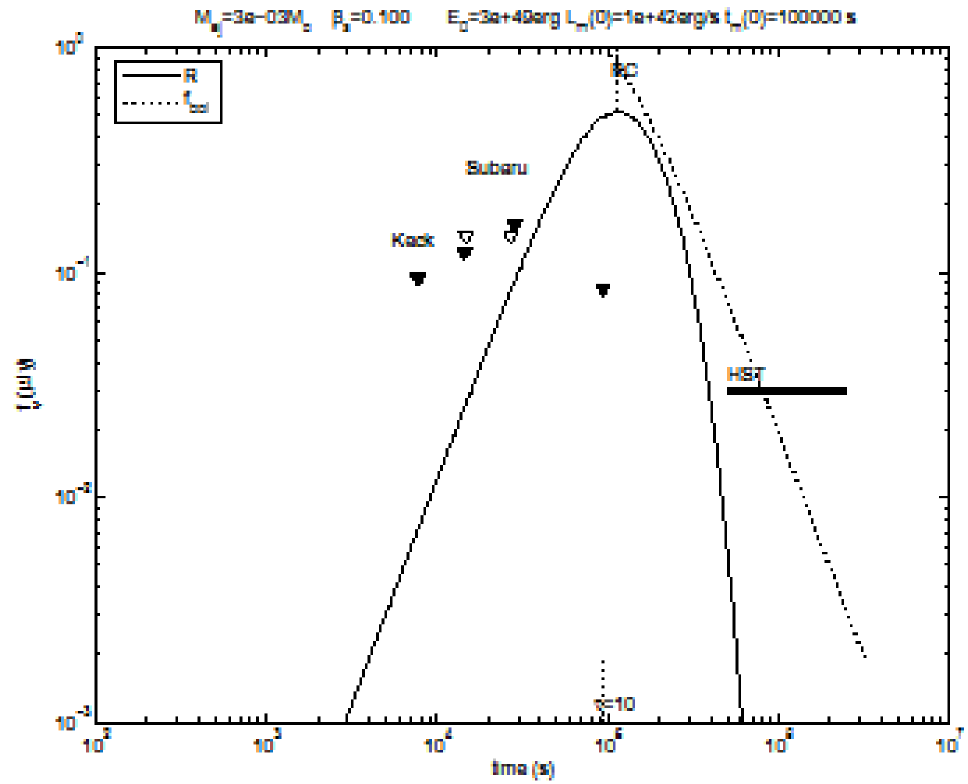


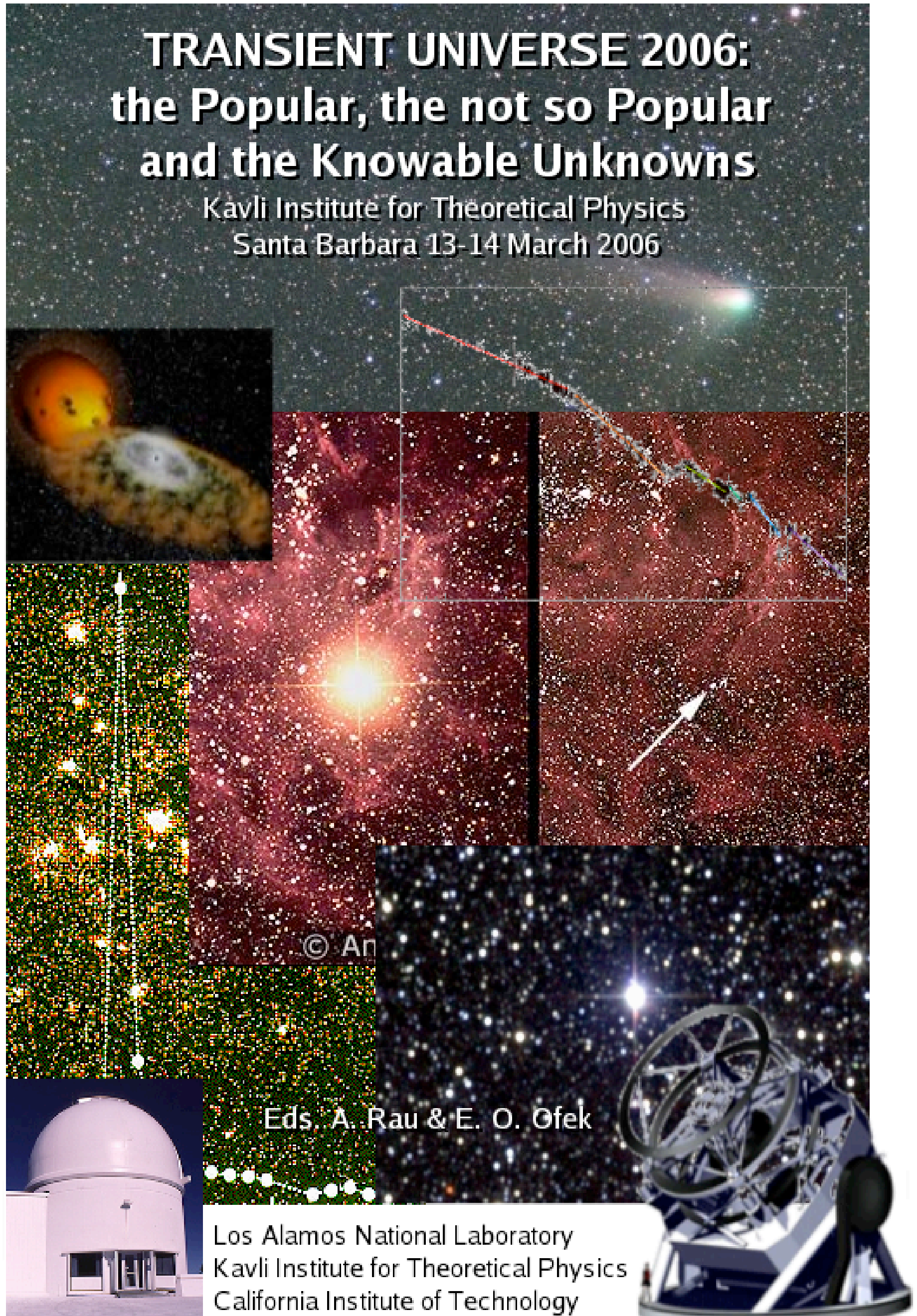
Figure 8.

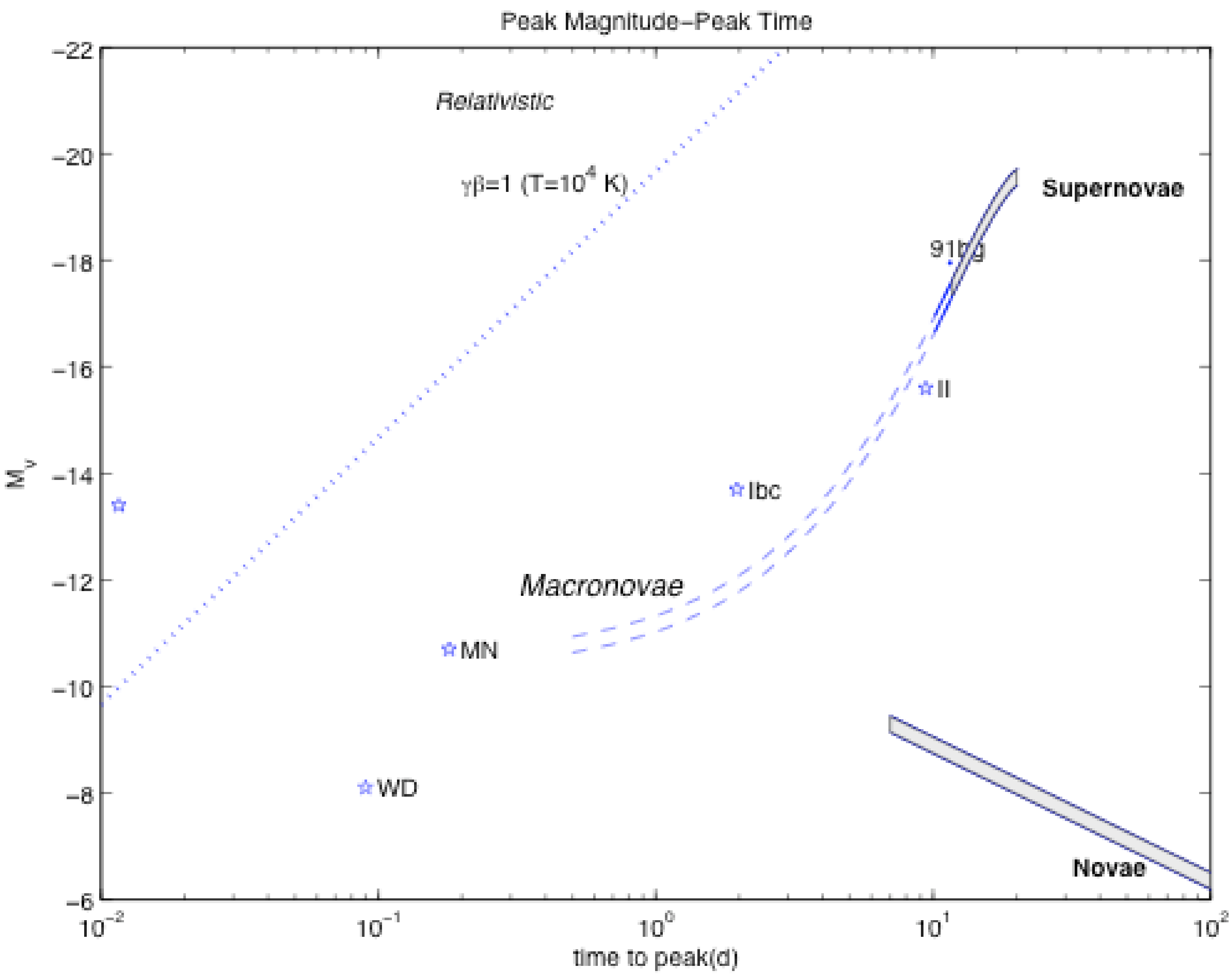
angular frequency and P is the rotation period. For $B = 10^{15}\,\mathrm{G}$, $R_n = 16\,\mathrm{km}$ we obtain $dE/dt \sim 10^{42}(P/100\,\mathrm{ms})^{-4}\,\mathrm{erg\ s^{-1}}$ and the characteristic age is $5 \times 10^4\,\mathrm{s}$ (Fig. 8).

Caveat: assumes no funnel geometry

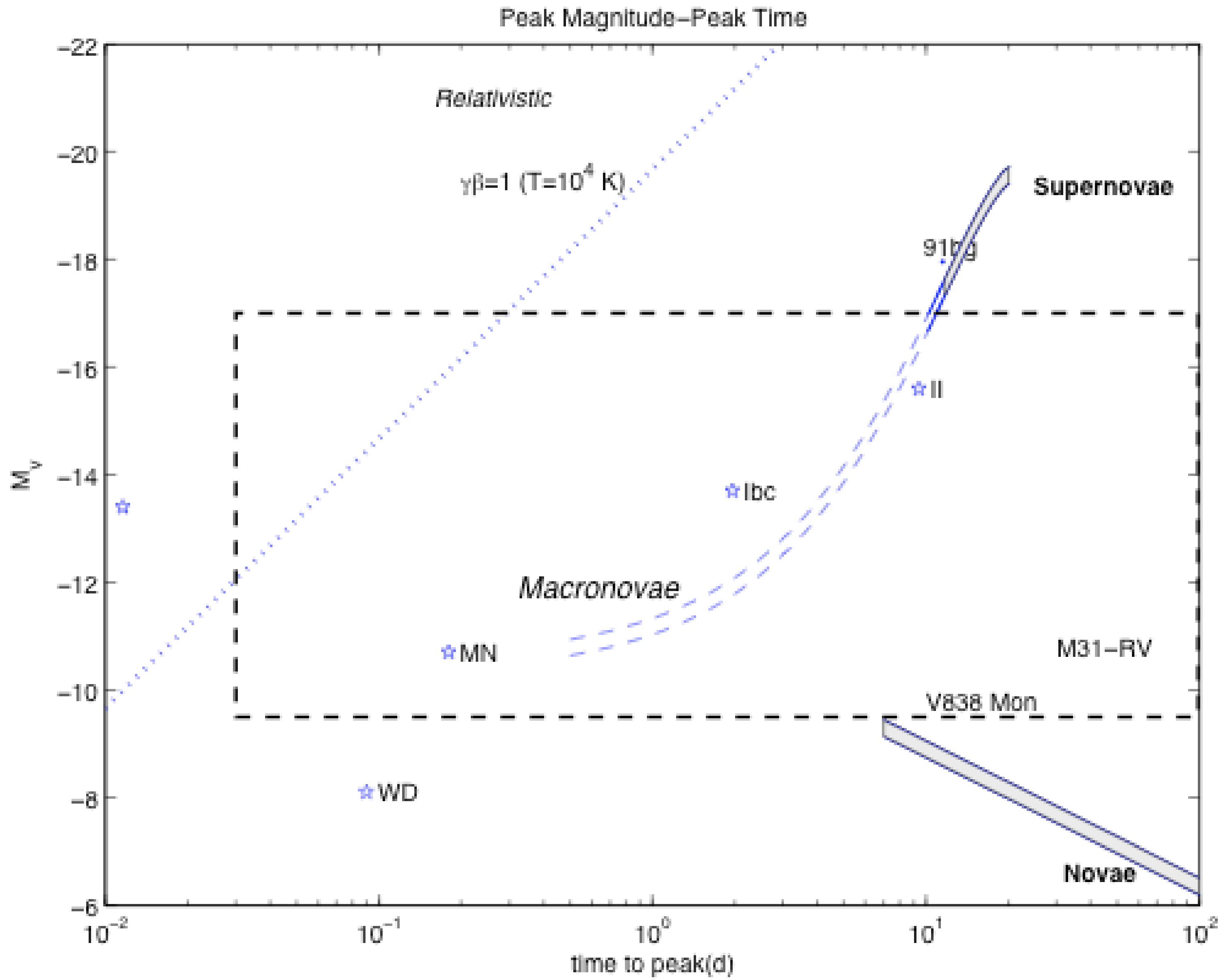
Bottom Line

- Neutron decay: Keck/Subaru data (2 hr-26 hr) constrain, over the velocity range 0.05c to 0.5c,
  - Kinetic energy of the macronova to be less than 10^{49} erg, comparable to $E\gamma$(isotropic)
- Nickel decay: Keck+HST constrain Nickel mass to be $<10^{-2}$ Msun
- Continued activity/flares but constrained to be less than 10^{41} erg/s on timescales of hours to days

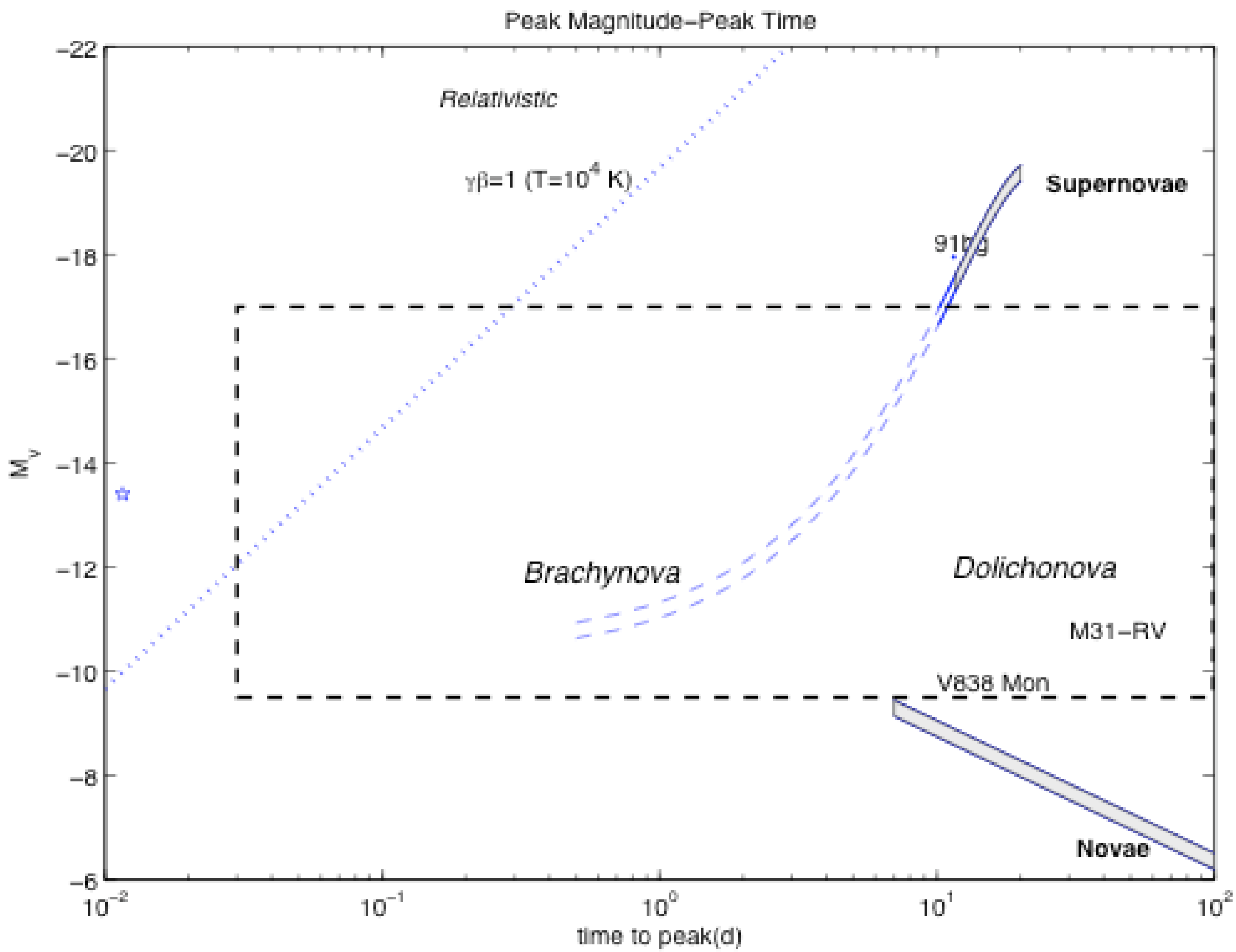

TRANSIENT UNIVERSE 2006:
the Popular, the not so Popular
and the Knowable Unknowns
Kavli Institute for Theoretical Physics
Santa Barbara 13-14 March 2006
Eds. A. Rau & E. O. Ofek
Los Alamos National Laboratory
Kavli Institute for Theoretical Physics
California Institute of Technology



Peak Magnitude−Peak Time
Relativistic
γβ=1 (T=10^4 K)
Supernovae
91bg
II
Ibc
Macronovae
MN
WD
Novae
M_V
time to peak(d)
−22
−20
−18
−16
−14
−12
−10
−8
−6
10^−2
10^−1
10^0
10^1
10^2



Peak Magnitude−Peak Time
Relativistic
γβ=1 (T=10^4 K)
Supernovae
91bg
II
Ibc
Macronovae
MN
M31−RV
V838 Mon
WD
Novae
−22
−20
−18
−16
−14
−12
−10
−8
−6
M_V
10^−2
10^−1
10^0
10^1
10^2
time to peak(d)



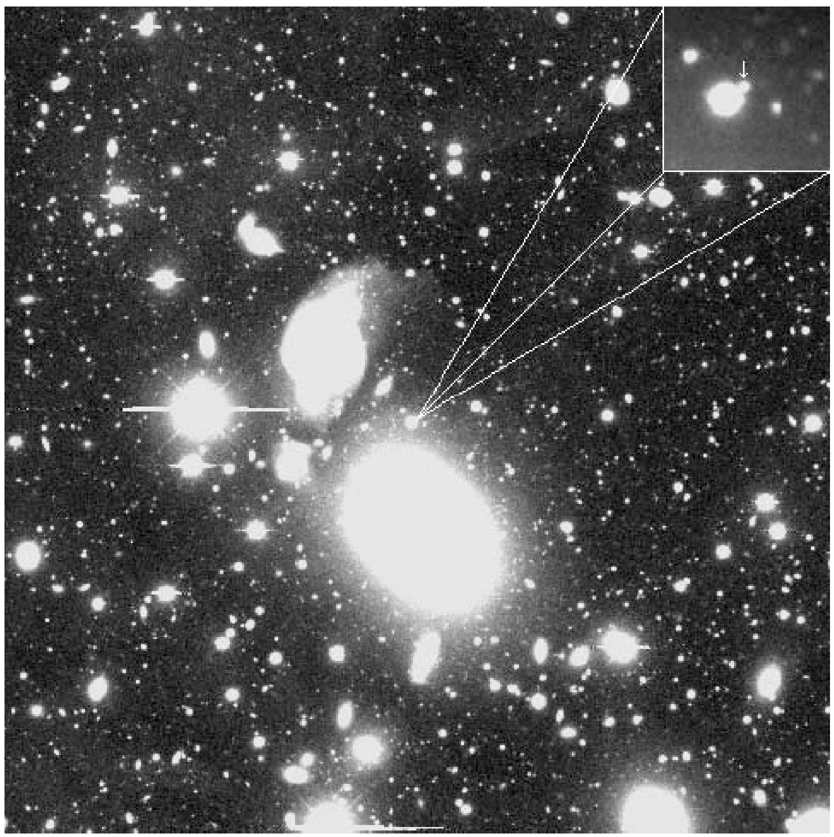
Dolicho: long
Brachy: short

Finding Brachynova ain't easy

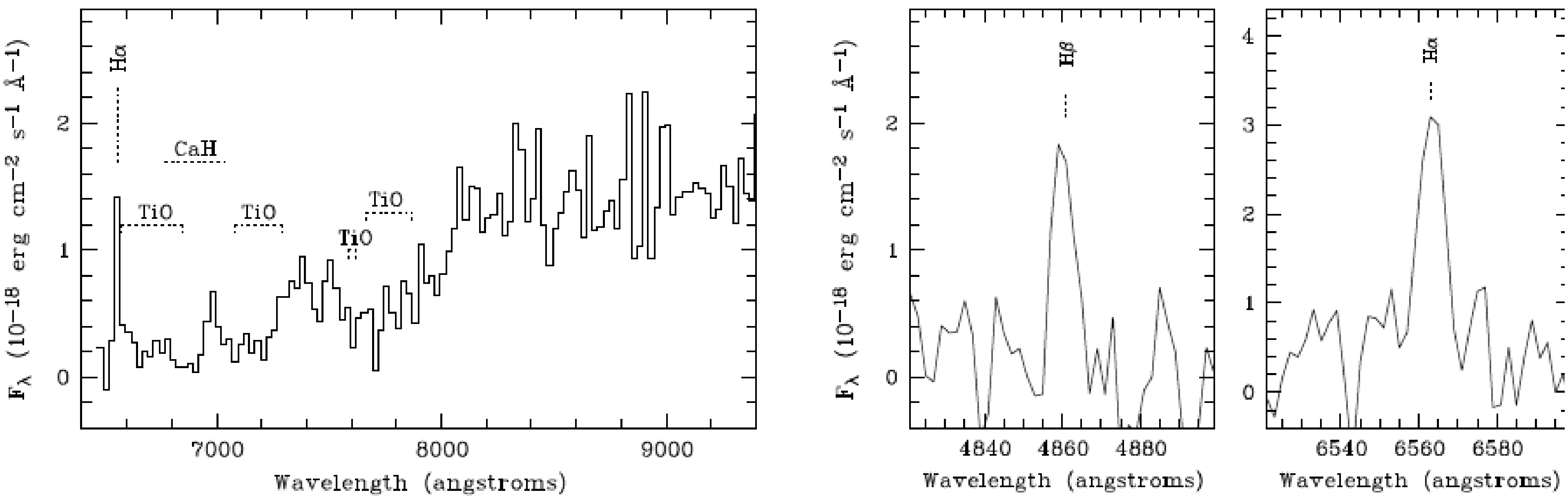
THE DEEP LENS SURVEY TRANSIENT SEARCH. I. SHORT TIMESCALE AND ASTROMETRIC VARIABILITY

A. C. Becker,[1,2,3] D. M. Wittman,[1,4] P. C. Boeshaar,[4,5] A. Clocchiatti,[6] I. P. Dell'Antonio,[7] D. A. Frail,[8] J. Halpern,[9]
V. E. Margoniner,[1,4] D. Norman,[10] J. A. Tyson,[1,4] and R. A. Schommer[11]

Received 2004 March 4; accepted 2004 April 19



A Foreground Fog of Flares

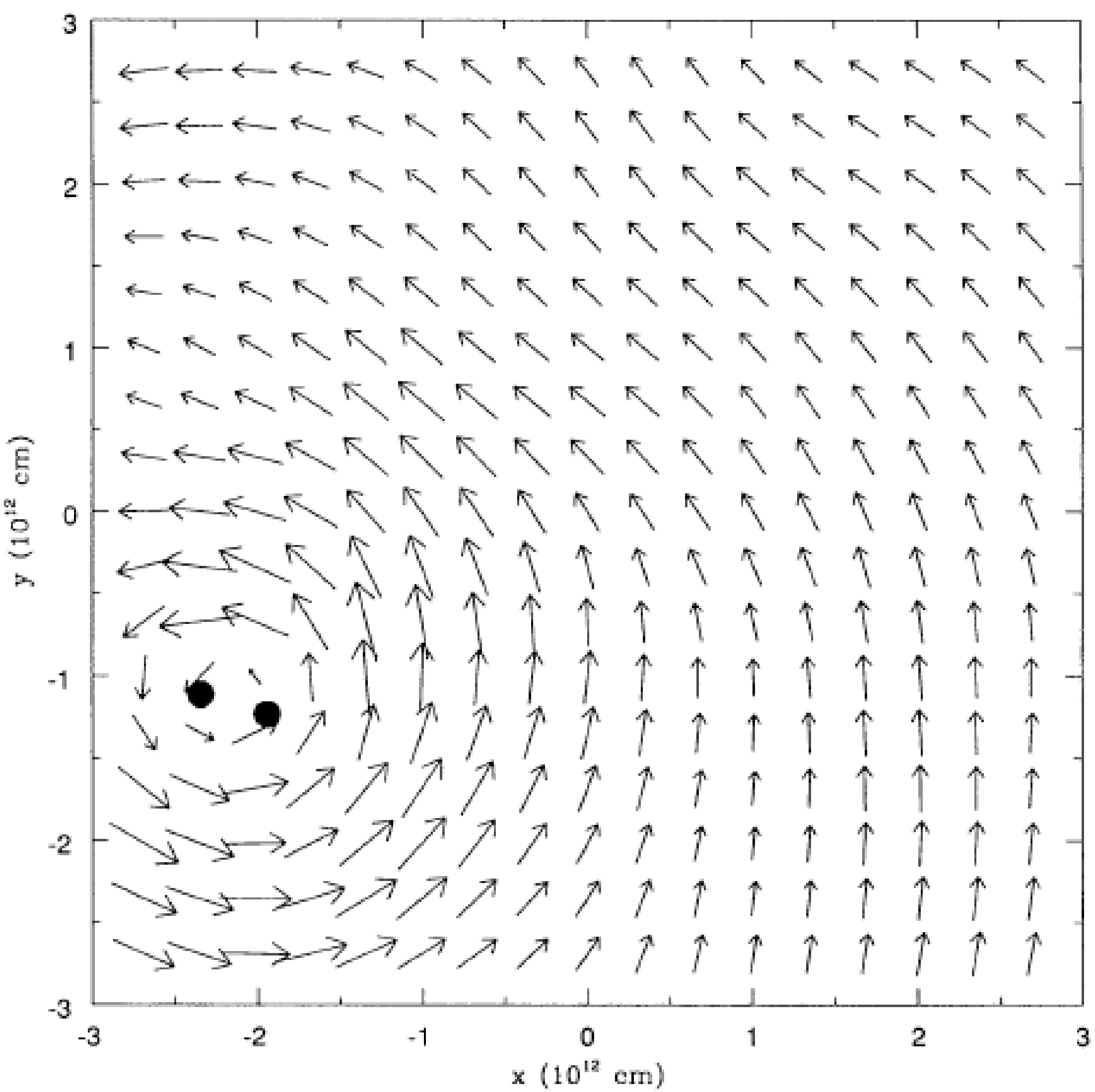


Kulkarni & Rau (2006)

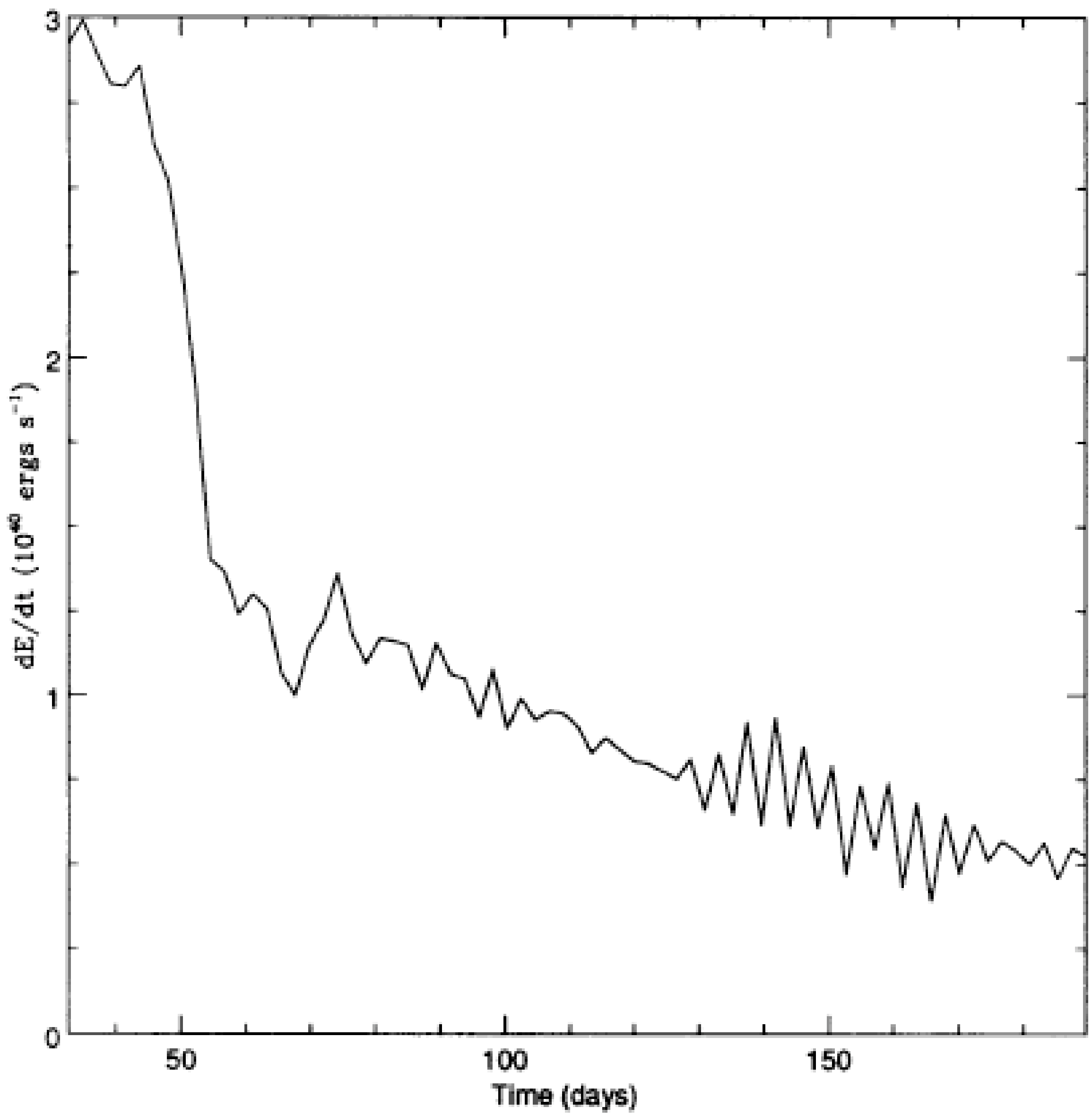
Dolichonova?

- Stellar mergers are common
  - 51 Peg-B like companion
  - Stellar companion -> Common envelope
- What does a stellar merger look like?
  - Is it an explosive transient?
  - Is it a very long lived transient?

Mergers (aka common envelope) can be explosive



Ternam, Taam & Hernquist



dE/dt (10^{40} ergs s^{-1})
Time (days)
0
1
2
3
50
100
150

Dolichonova?

Finding Dolichonova is easy

- V838 Mon, V4332 Sgr and M31-RV -- found serendipitously
- Long life means that the survey can be done leisurely
- Super Eddington is the best criterion to filter out novae

=> *A survey of nearby mass concentrations is likely to pay off*

(as we go to press …)

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