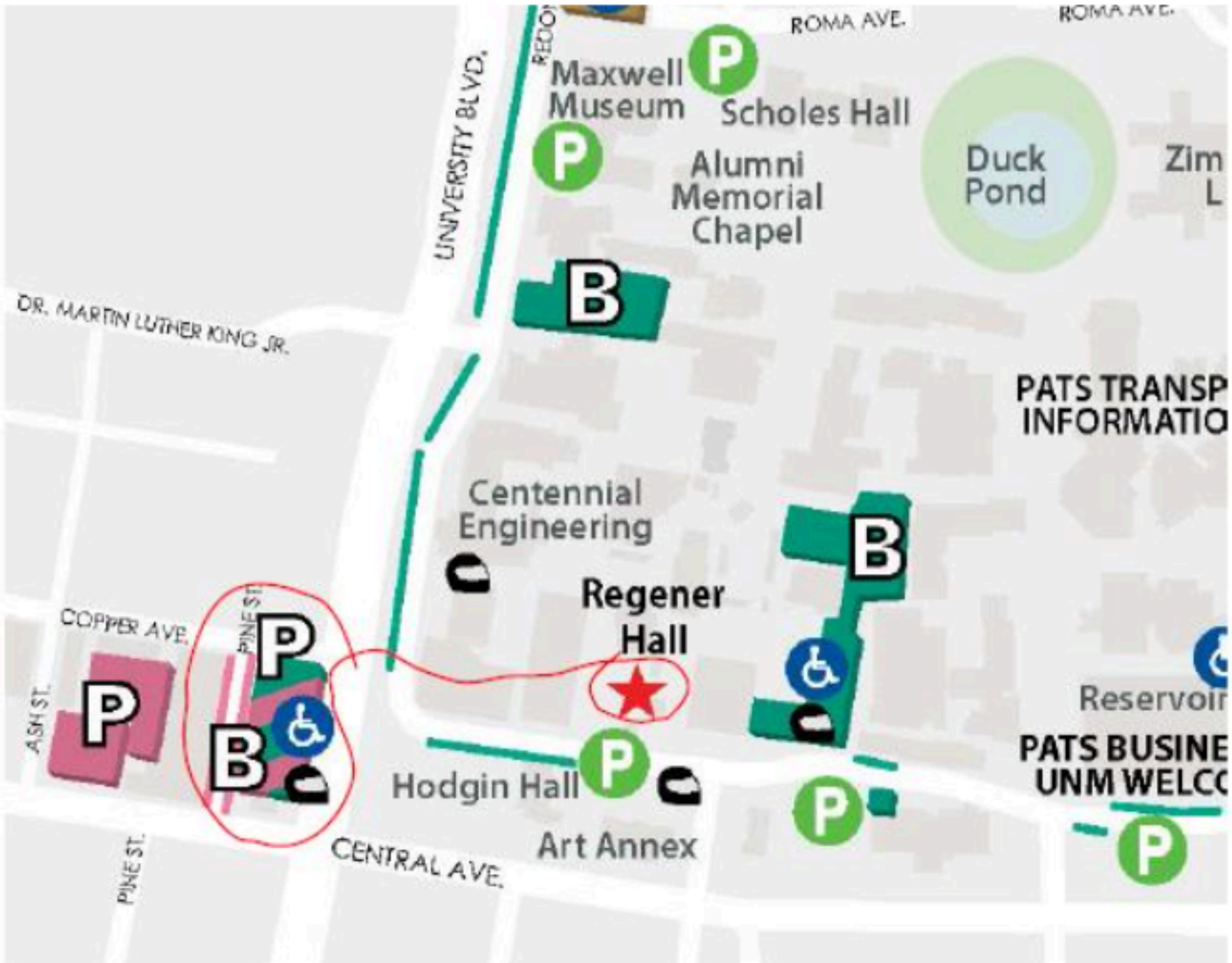
The UNM Department of Physics and Astronomy

Fall Lecture Demonstration Show

Wednesday November 2, 2016, 7-8 pm

THE UNIVERSITY of NEW MEXICO



AFTER 6 PM THERE IS FREE PARKING IN "B/P-LOT"

ON THE NORTHWEST CORNER OF UNIVERSITY BLVD AND CENTRAL AVE, 0.2 MILES FROM REGENER HALL

Cosmic Explosions

- Novae (detonations on the surface of a star)
- Supernovae (detonations of a star)
- Gamma Ray Bursts (formation of a black hole)

Energy

mosquito lands on your arm = 1 erg

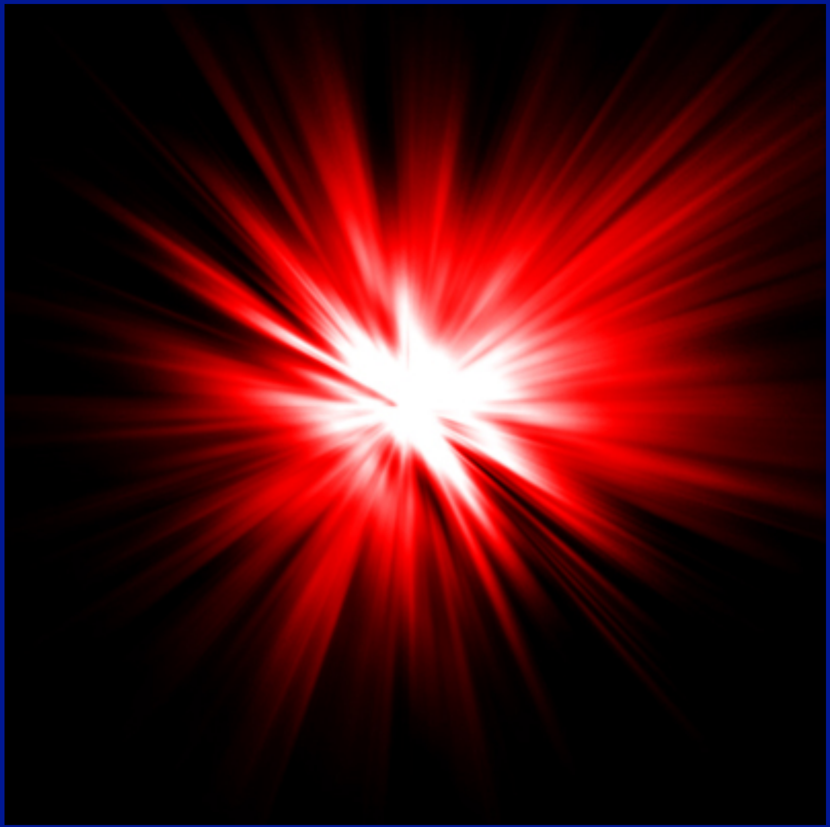
Planet cracker = 1×10^{32} ergs

Luminosity of the sun = 4×10^{33} ergs/sec

Nova explosion = 1×10^{44} ergs

Supernova explosion = 1×10^{50} ergs

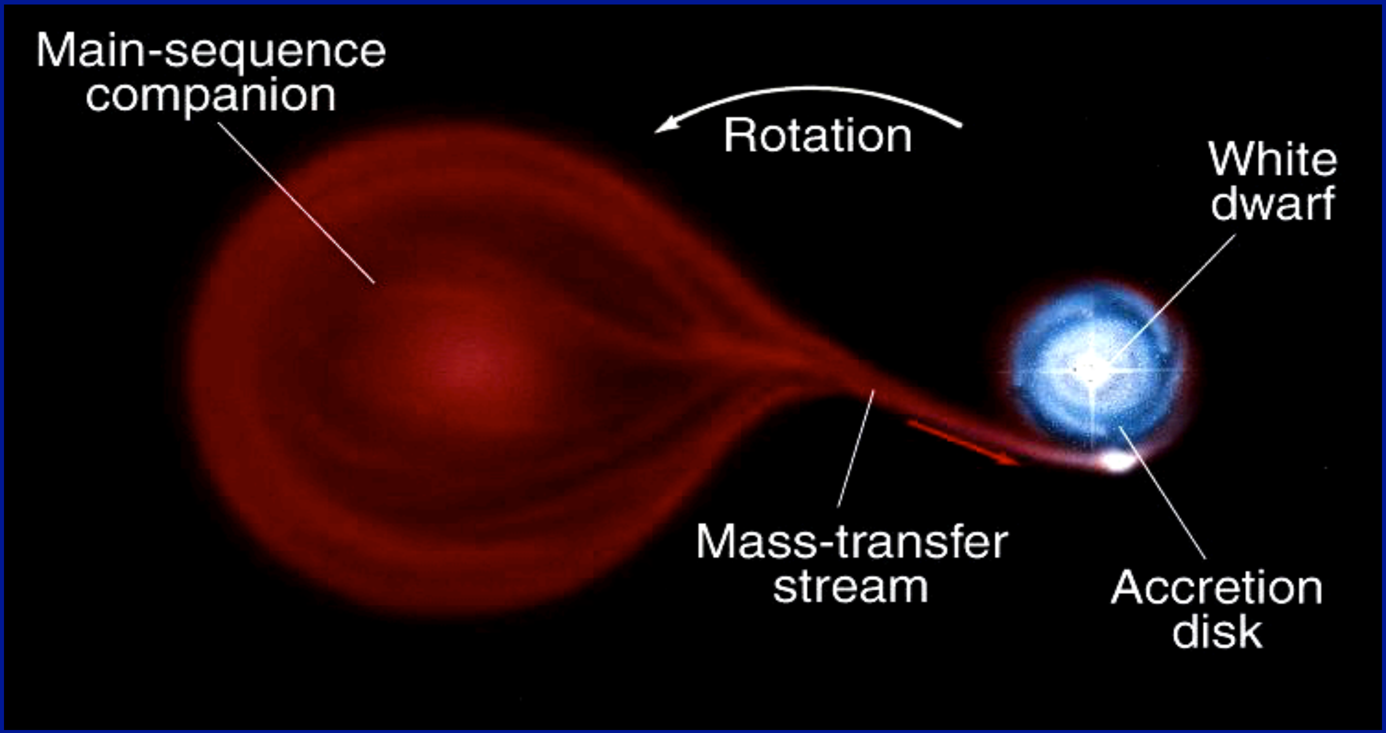
Hypernova explosion = 1×10^{52} ergs
(and highly beamed)



Stellar Explosions

Novae

White dwarf in close binary system

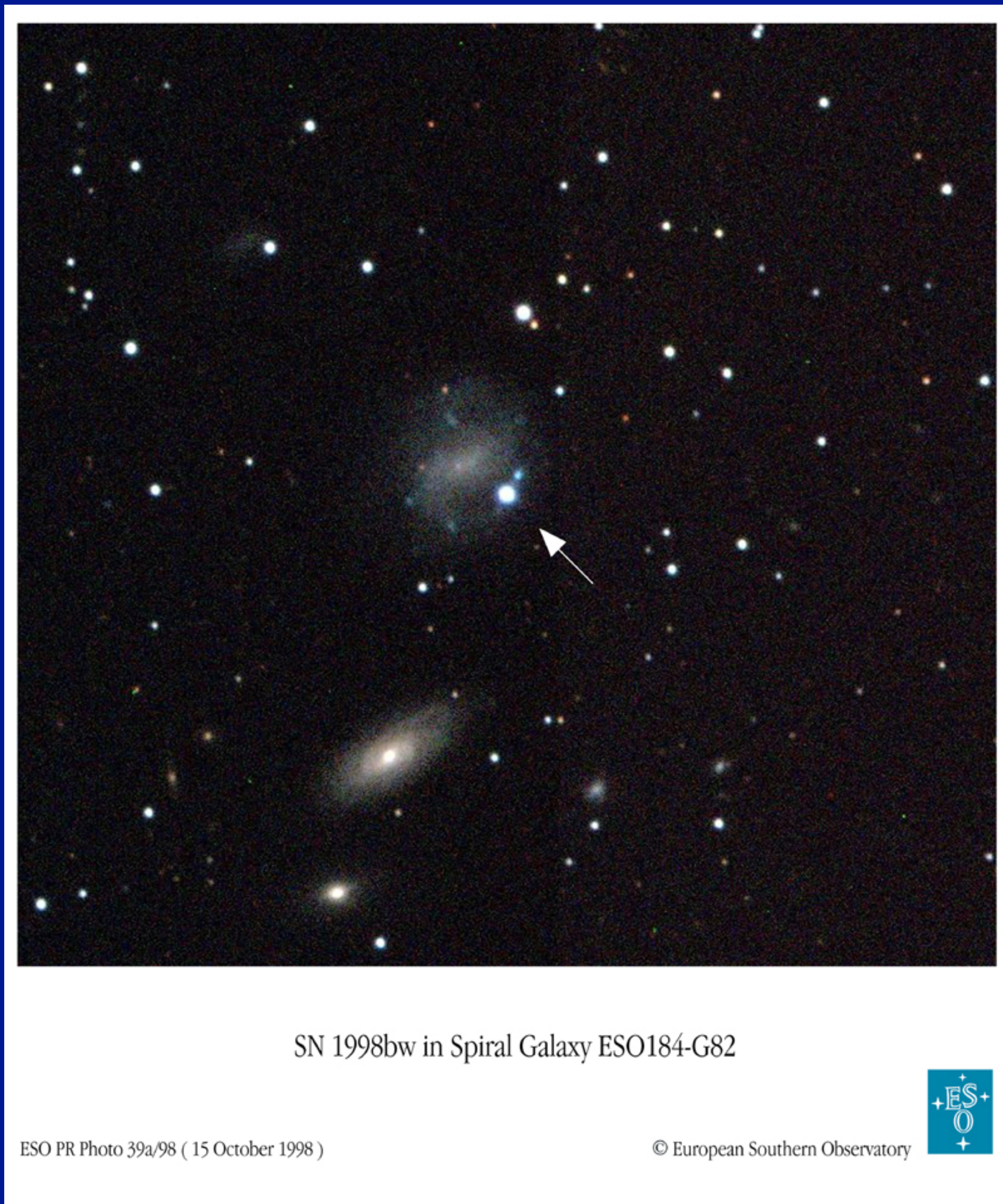


WD's tidal force stretches out companion, until parts of outer envelope spill onto WD. Surface gets hotter and denser. Eventually, a burst of fusion. Binary brightens by 10'000's! Some gas expelled into space. Whole cycle may repeat every few decades => recurrent novae.

Nova V838Mon with Hubble,
May – Dec 2002

4.2 pc

七色絵巻のよう!


SN 1998bw in Spiral Galaxy ESO184-G82
ESO PR Photo 39a/98 (15 October 1998)
© European Southern Observatory
ESO


七色絵巻のよう

Death of a High-Mass Star

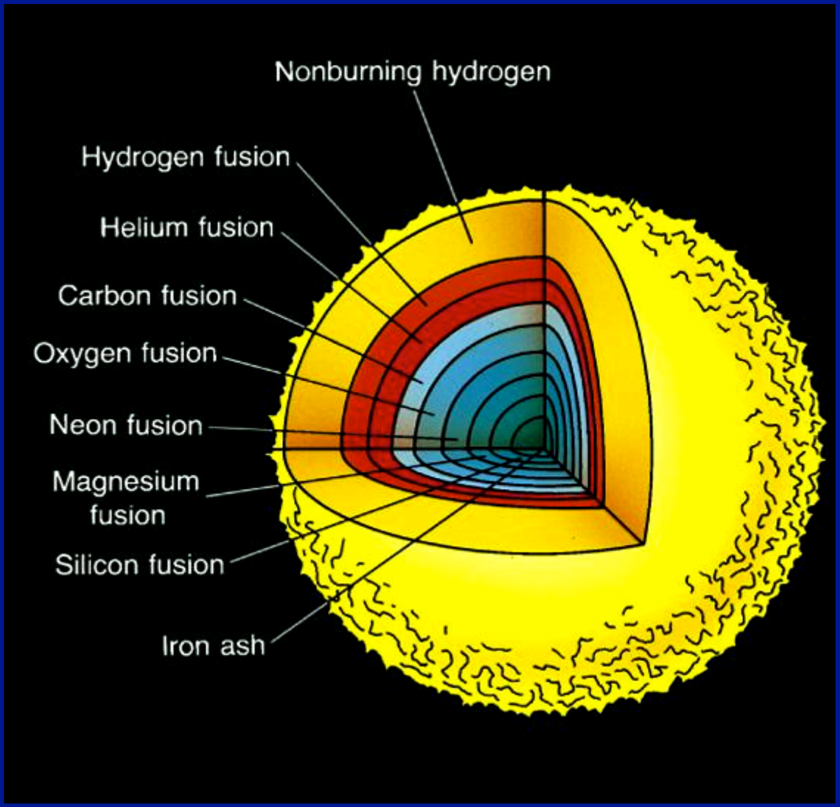
$M > 8\ M_{Sun}$

Iron core

Iron fusion doesn't produce energy (actually requires energy) => core shrinks and heats up

$T \sim 10^{10}$ K, radiation disrupts nuclei,

p + e => n + neutrino



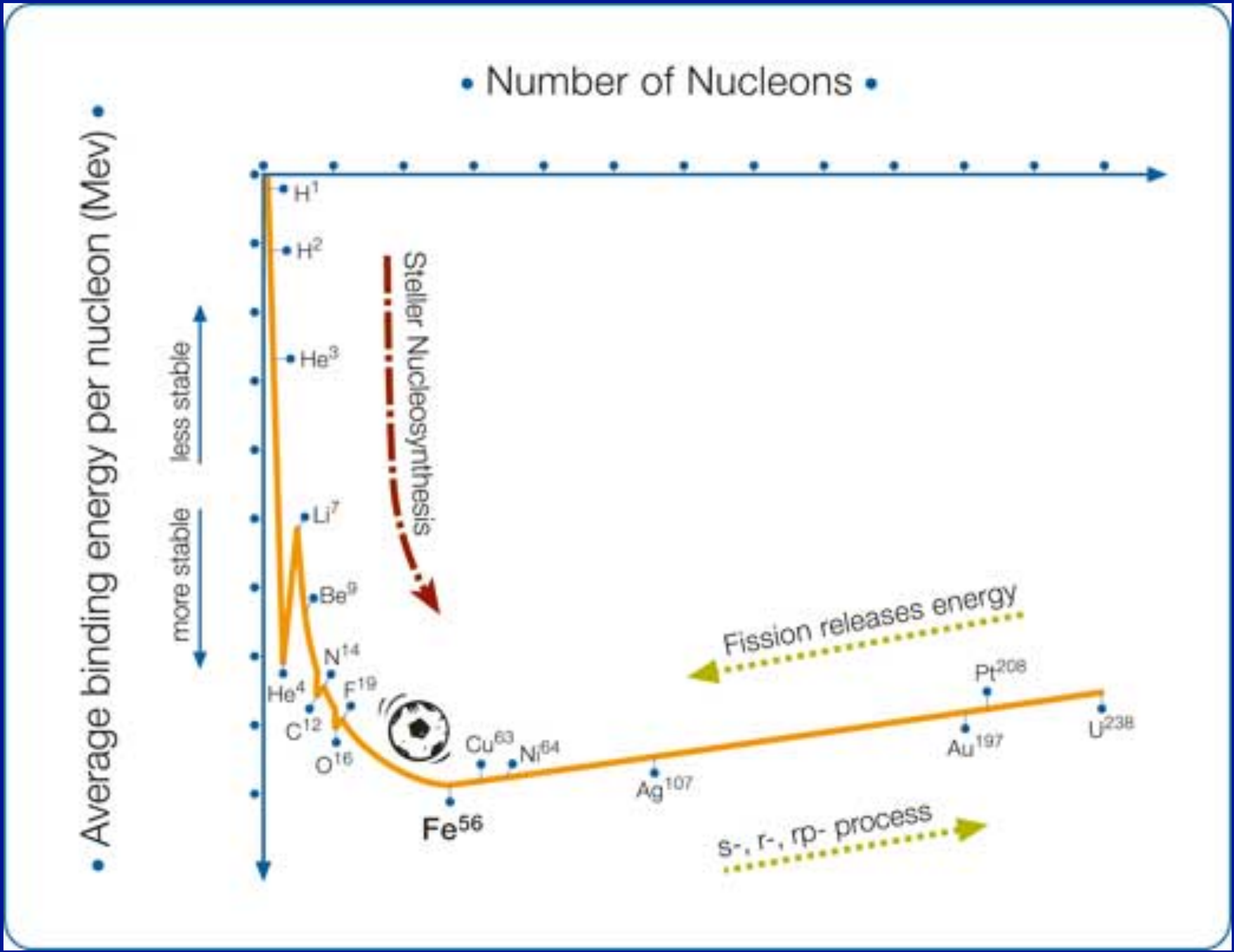
Collapses until neutrons come into contact. Rebounds outward, violent shock ejects rest of star => A Core-collapse or Type II Supernova

Ejection speeds 1000's to 10,000's of km/sec! (see DEMO)

Such supernovae occur roughly every 50 years in Milky Way.

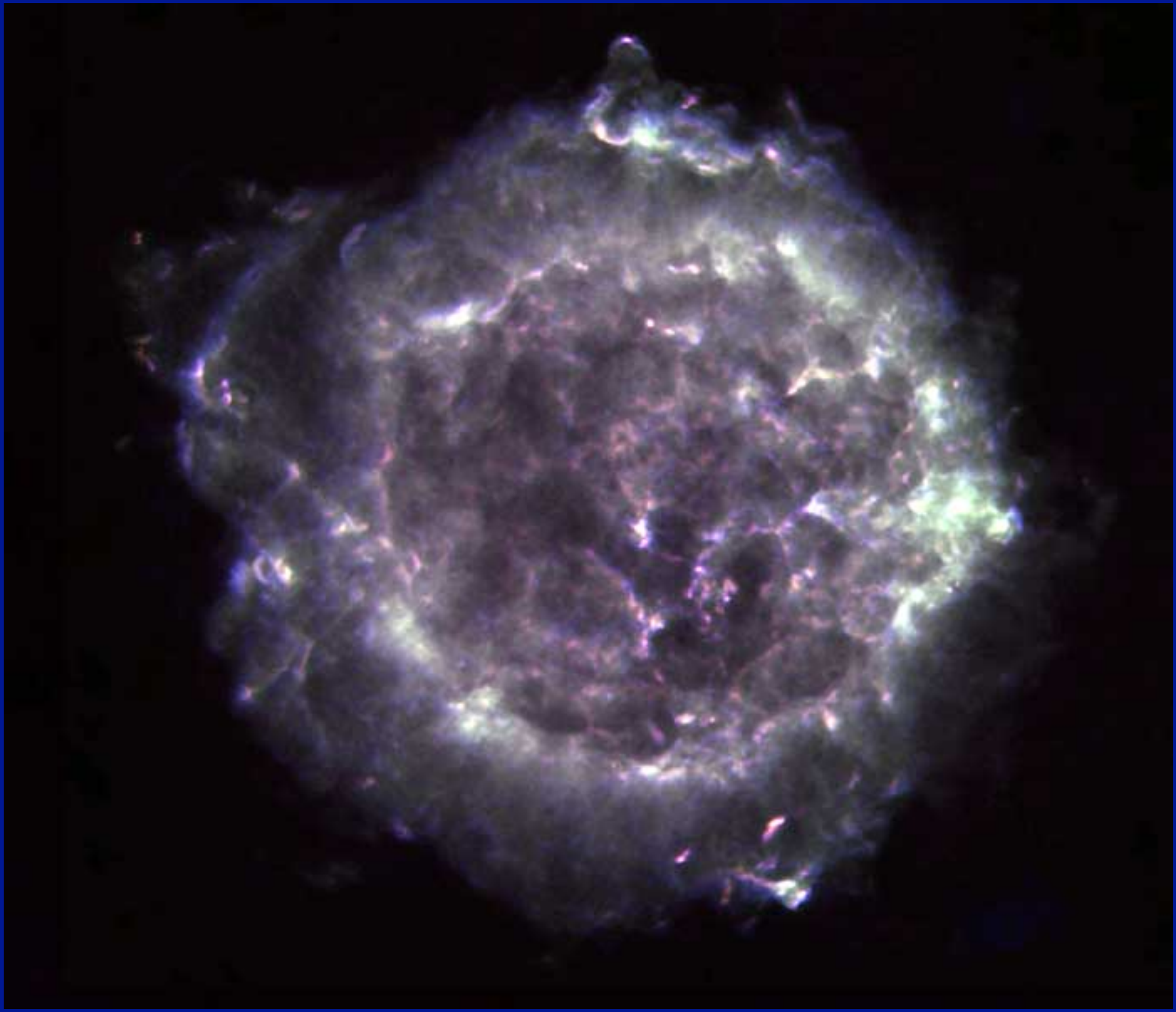
Remnant is a “neutron star” or “black hole”.

Binding Energy per nucleon



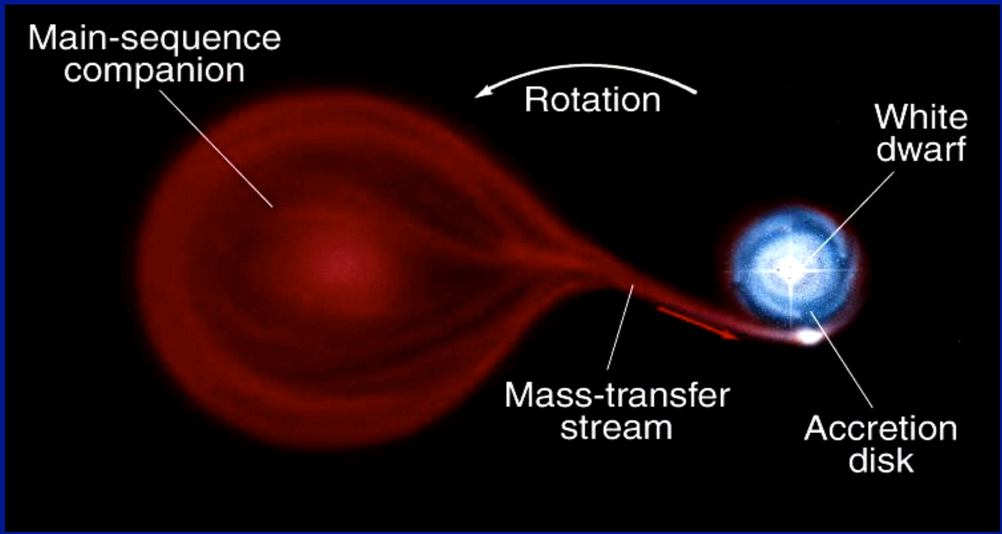
Example Supernova: 1994D in NGC 4526

Cassiopeia A: Supernova Remnant



A Carbon-Detonation or "Type Ia" Supernova

Despite novae, mass continues to build up on White Dwarf.

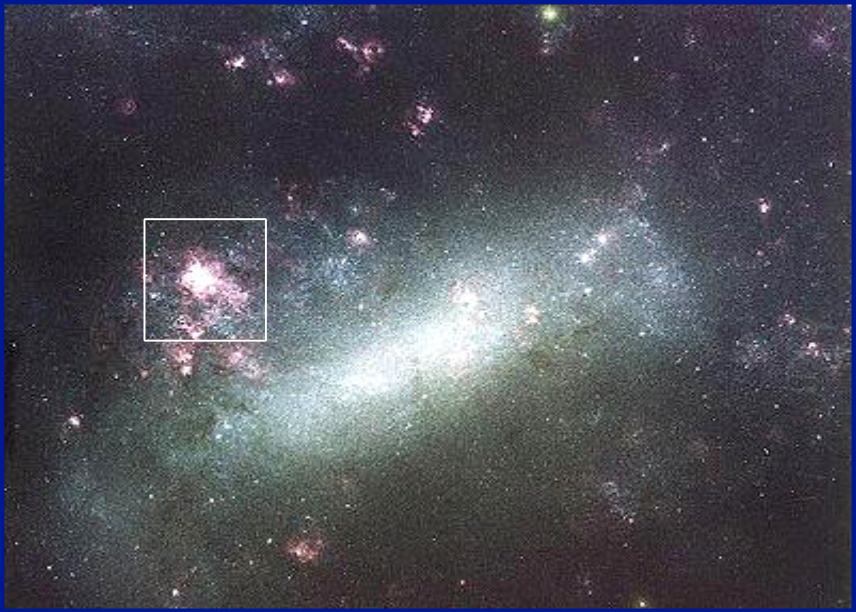


If mass grows to 1.4 M_{Sun} (the "Chandrasekhar limit"), gravity overwhelms the Pauli exclusion pressure supporting the WD, so it contracts and heats up.

This starts carbon fusion everywhere at once.

Tremendous energy makes star explode. No core remnant.

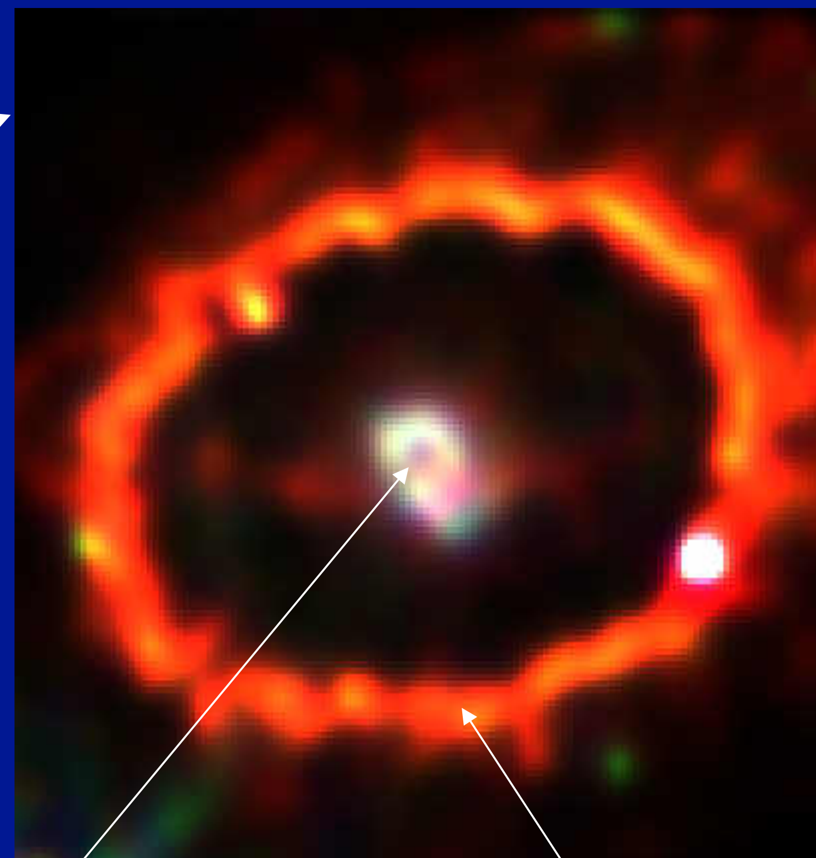
Supernova 1987A in the Large Magellanic Cloud



SN 1987A is evolving fast!

1994

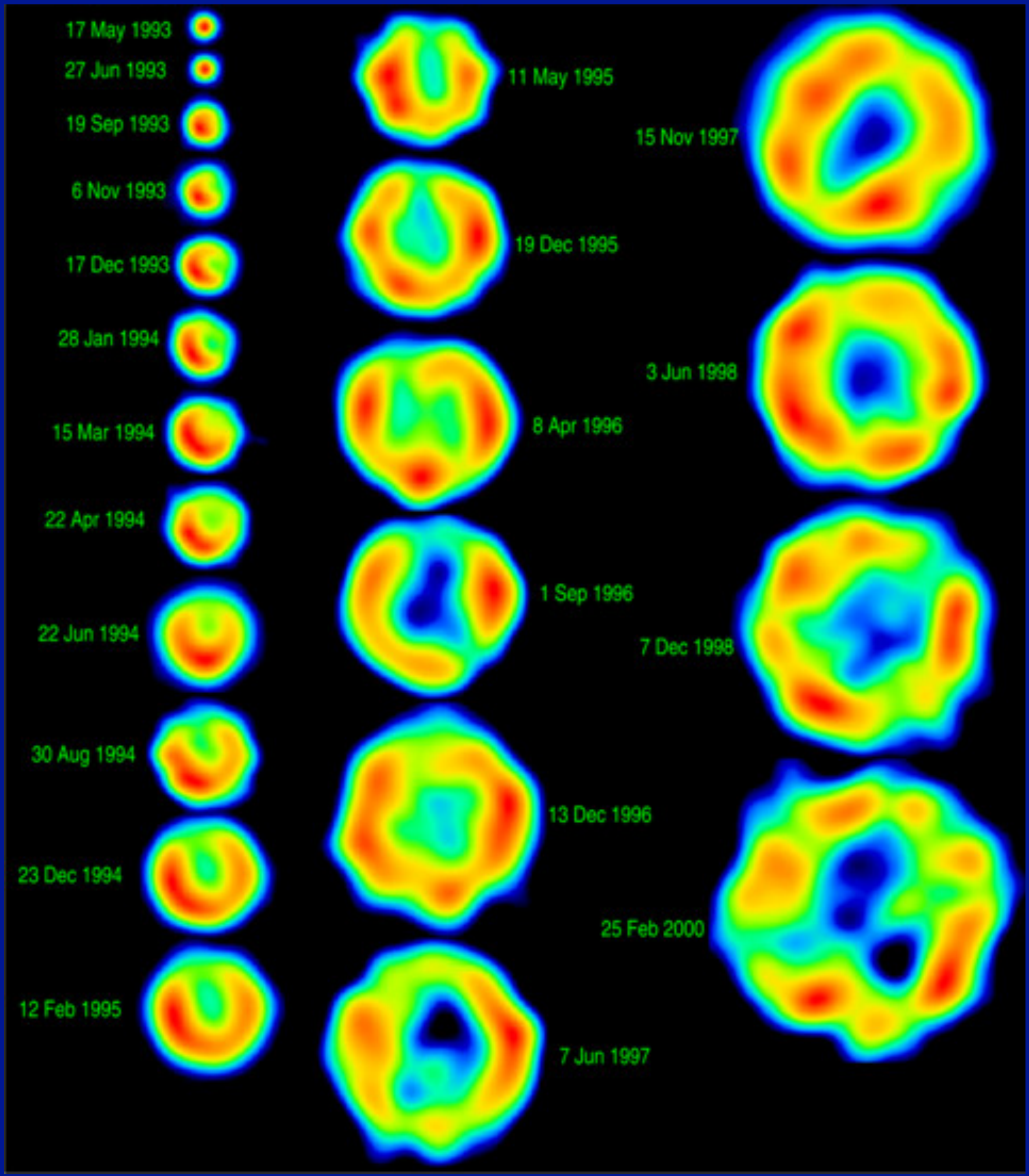
1998



Expanding debris from star. Speed almost 3000 km/sec!

Light from supernova hitting ring of gas, probably a shell from earlier mass loss event.

A Young Supernova



SN 1993J
Rupen et al.

In 1000 years, the exploded debris might look something like this:

2 pc

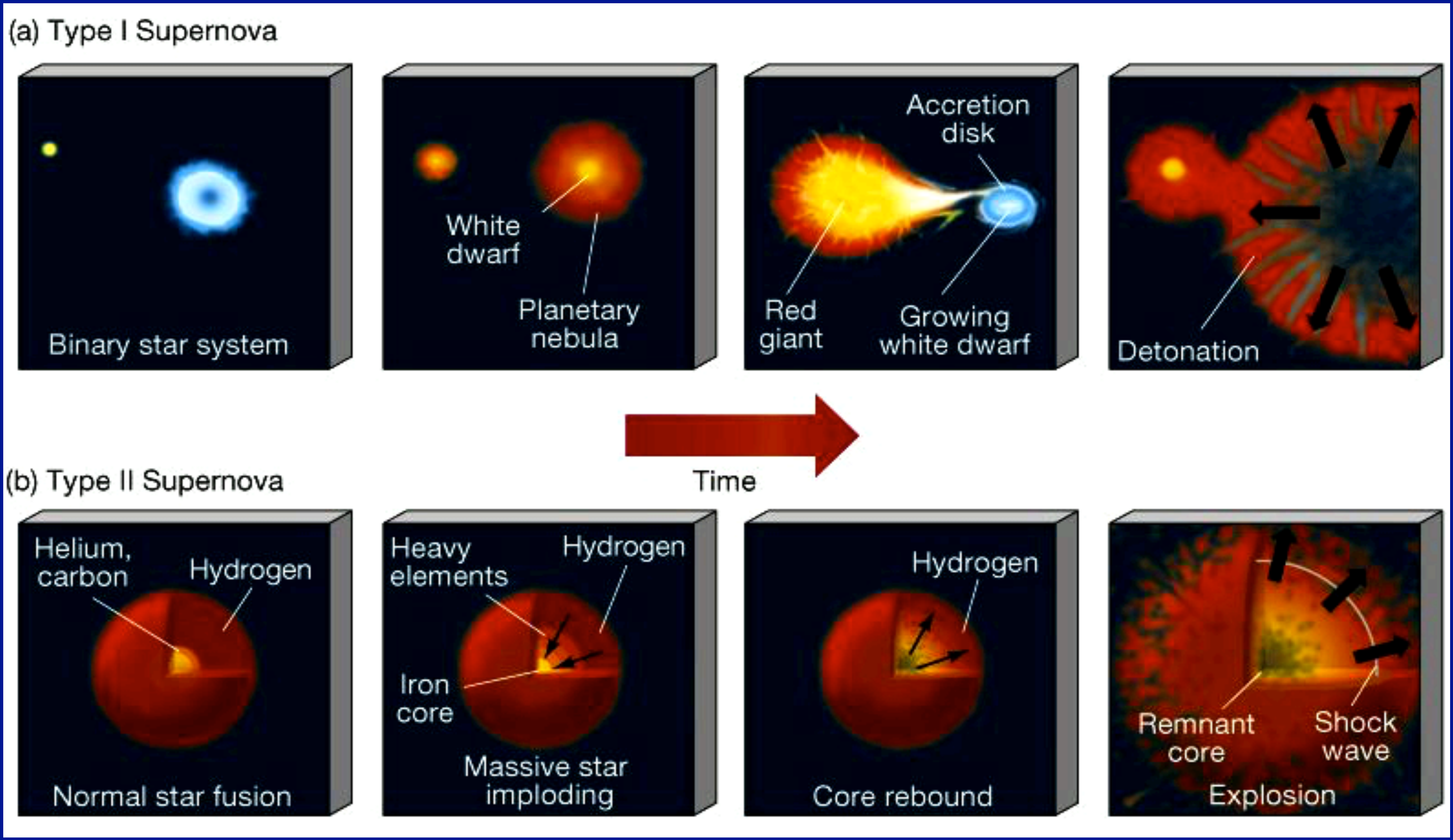
Crab Nebula: debris from a stellar explosion observed in 1054 AD.

Or in 10,000 years:

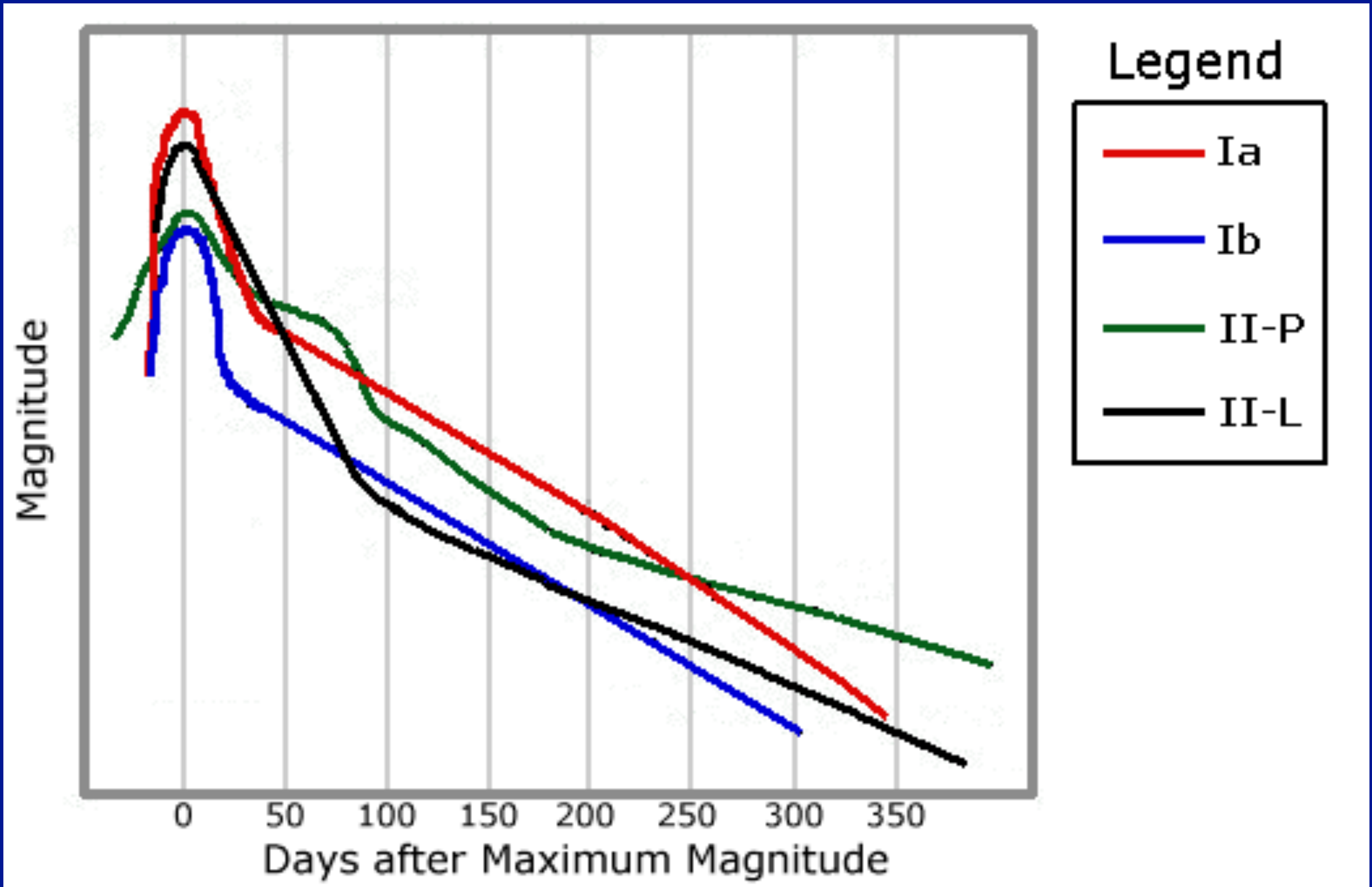
50 pc

Vela Nebula: debris from a stellar explosion in about 9000 BC.

Remember, core collapse (Type II) and carbon-detonation (Type I) supernovae have very different origins



Supernova light curves



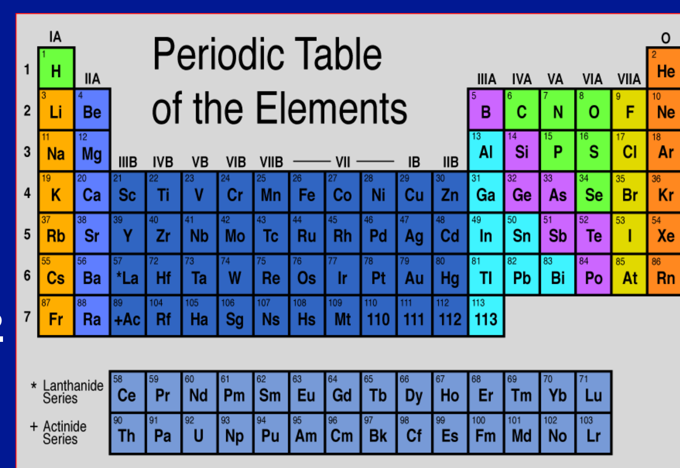
Making the Elements

Universe initially all H (p's and e's). Some He made soon after Big Bang before stars, galaxies formed. All the rest made in stars, and returned to ISM by supernovae.

Solar System formed from such "enriched" gas 4.6 billion years ago. As Milky Way ages, the abundances of elements compared to H in gas and new stars are increasing due to fusion and supernovae.

Elements up to iron (^{56}Fe, 26 p + 30 n in nucleus) produced by steady fusion (less abundant elements we didn't discuss, like Cl, Na, made in reactions that aren't important energy makers).

Heavier elements (such as lead, gold, copper, silver, etc.) by "neutron capture" in core, even heavier ones (uranium, plutonium, etc.) in supernova itself.



Clicker Question:

What is the remnant left over from a Type Ia (carbon detonation) supernova?

A: a white dwarf + expanding shell

B: a neutron star + expanding shell

C: a black hole + expanding shell

D: no remnant, just the expanding shell

Clicker Question:

What is the heaviest element produced by steady fusion in the core of a massive star?

A: Hydrogen

B: Carbon

C: Iron

D: Uranium

Clicker Question:

All of the following atoms have a total of 4 nucleons (protons or neutrons). Which of the following has the smallest mass?

A: 4 hydrogen atoms

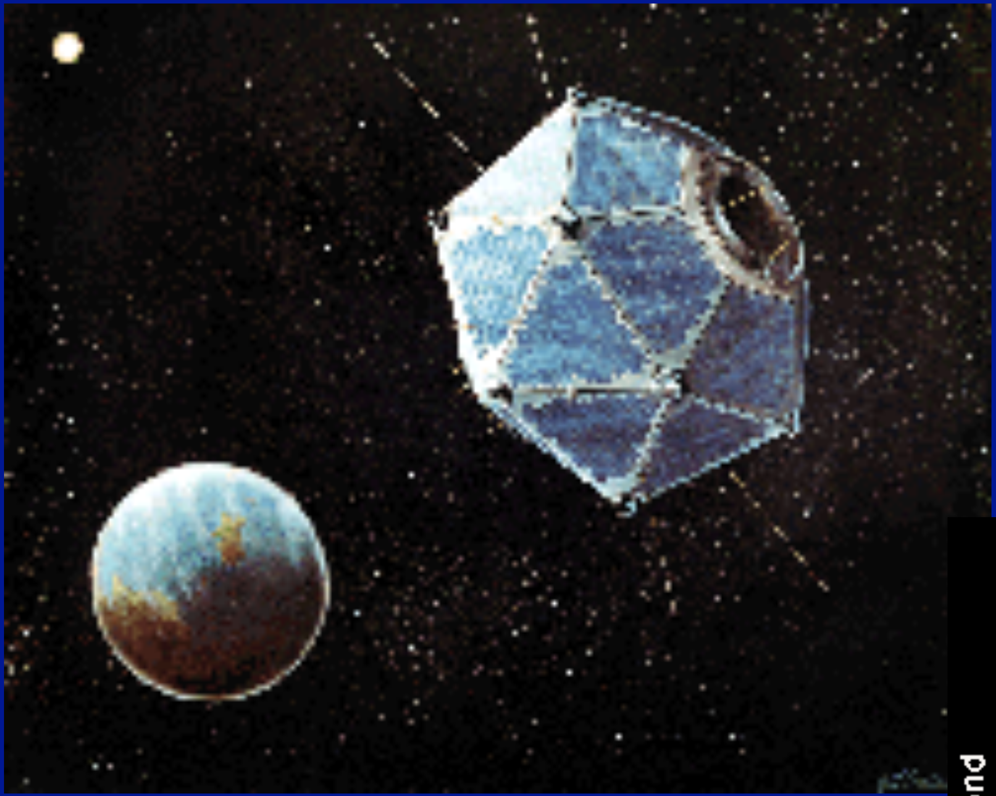
B: 2 deuterium atoms

C: 1 tritium atom and 1 hydrogen atom

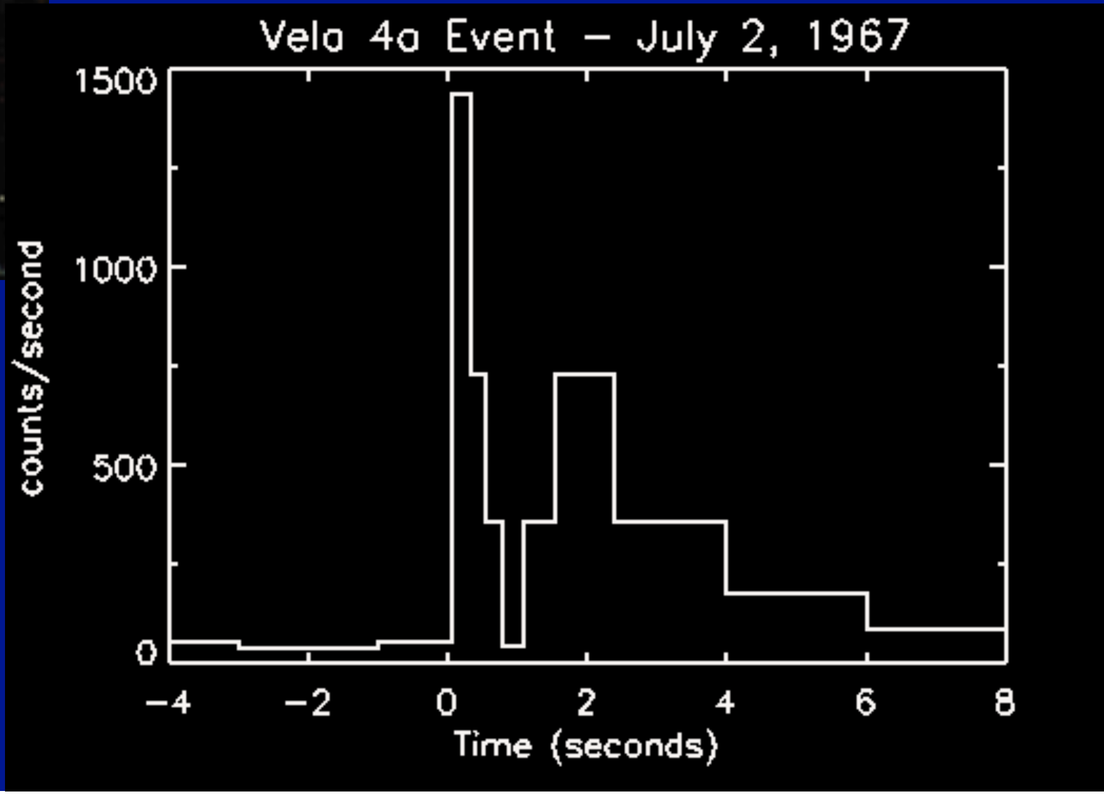
D: 1 Helium atom

E: None of the above, they all have the same total mass

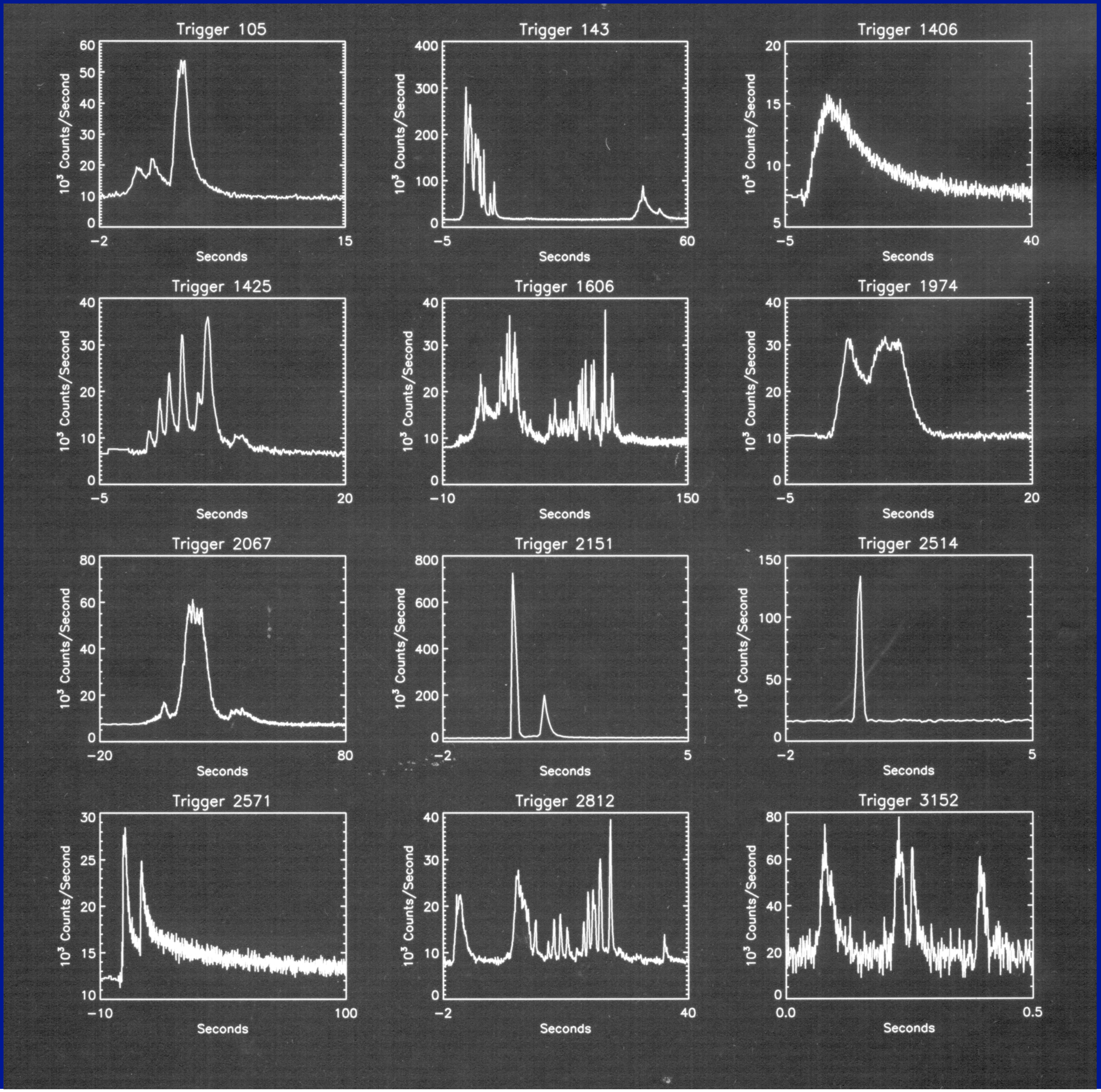
An early gamma ray-burst

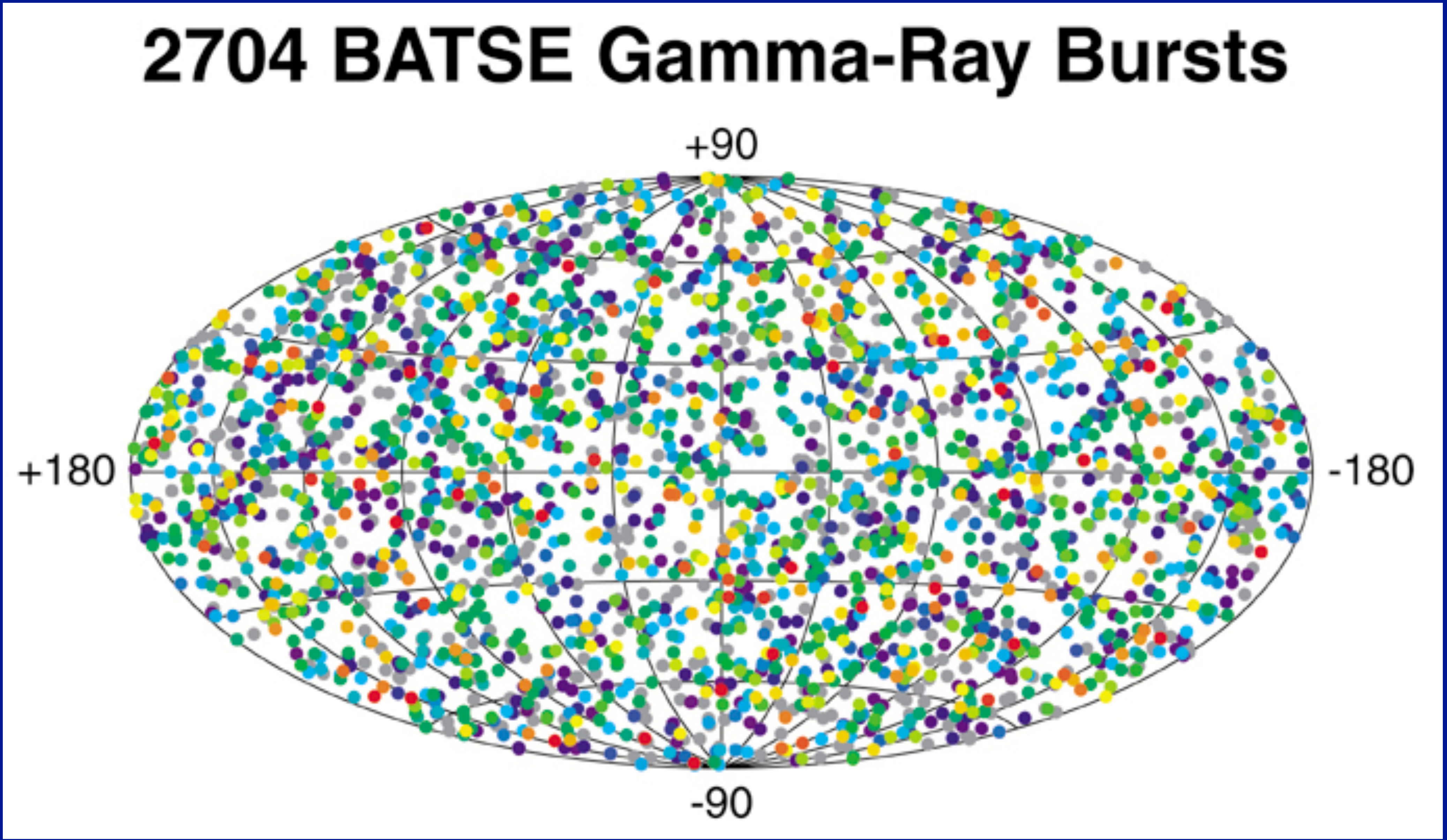


Vela satellite



A Gamma Ray Burst Sampler

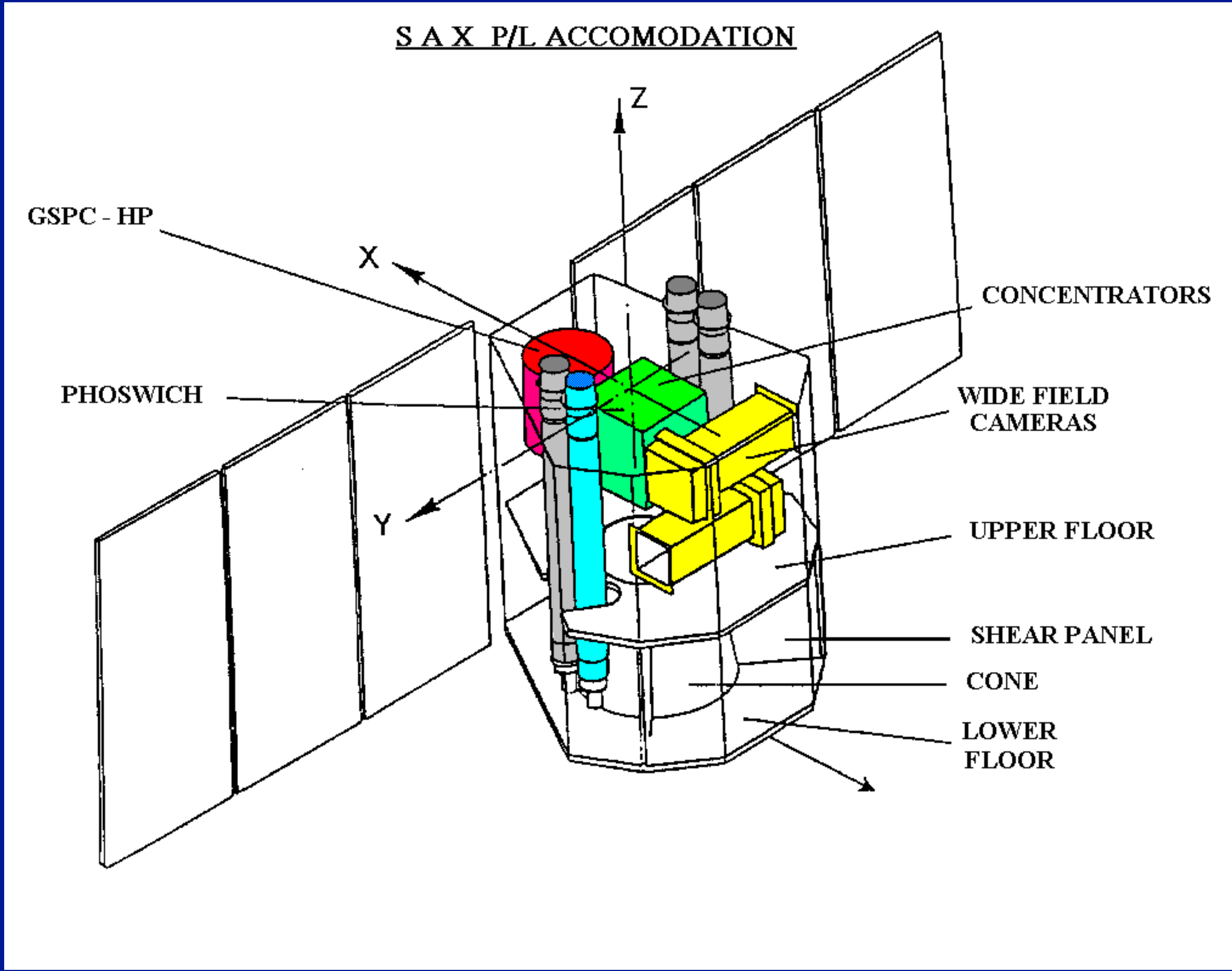




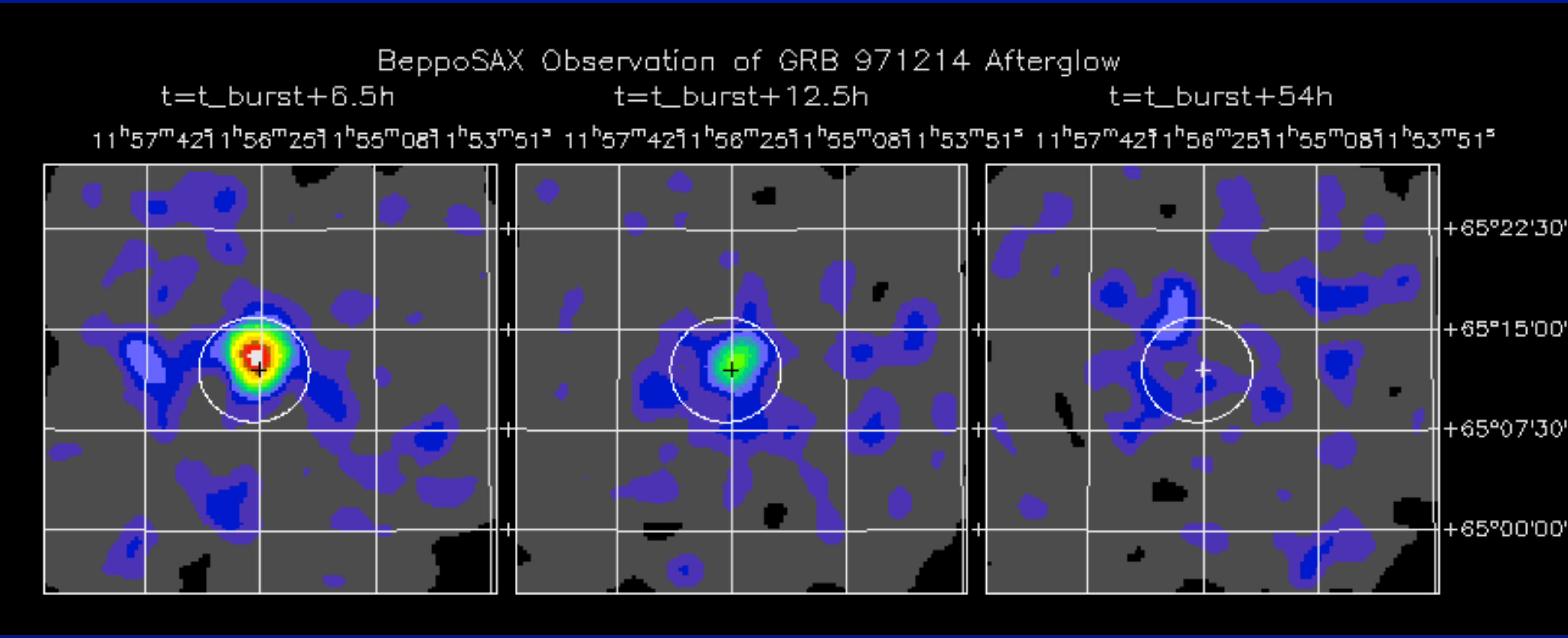
Great debate: 1967-1997

Bepposax Satellite

GRBM: 40-600 keV
WFC: 2-30 keV
NFI: 2-10 keV

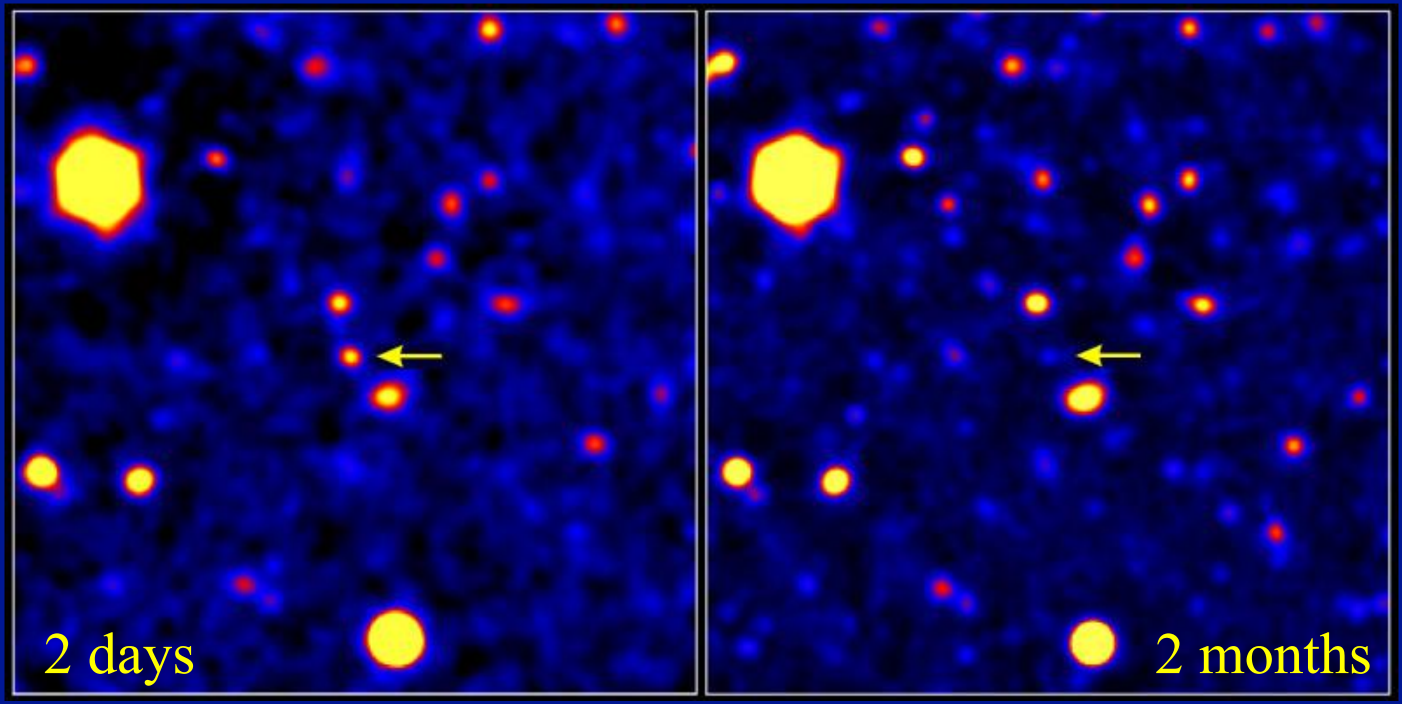


X-Ray Afterglow from GRB 971214

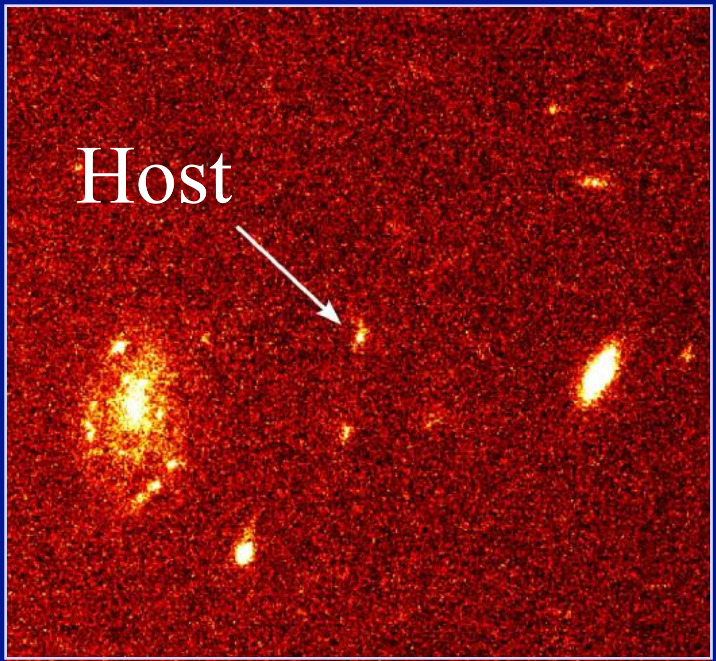


t=6.5 hrs t=12.5 hrs t=54 hrs

Optical Afterglow from GRB 971214



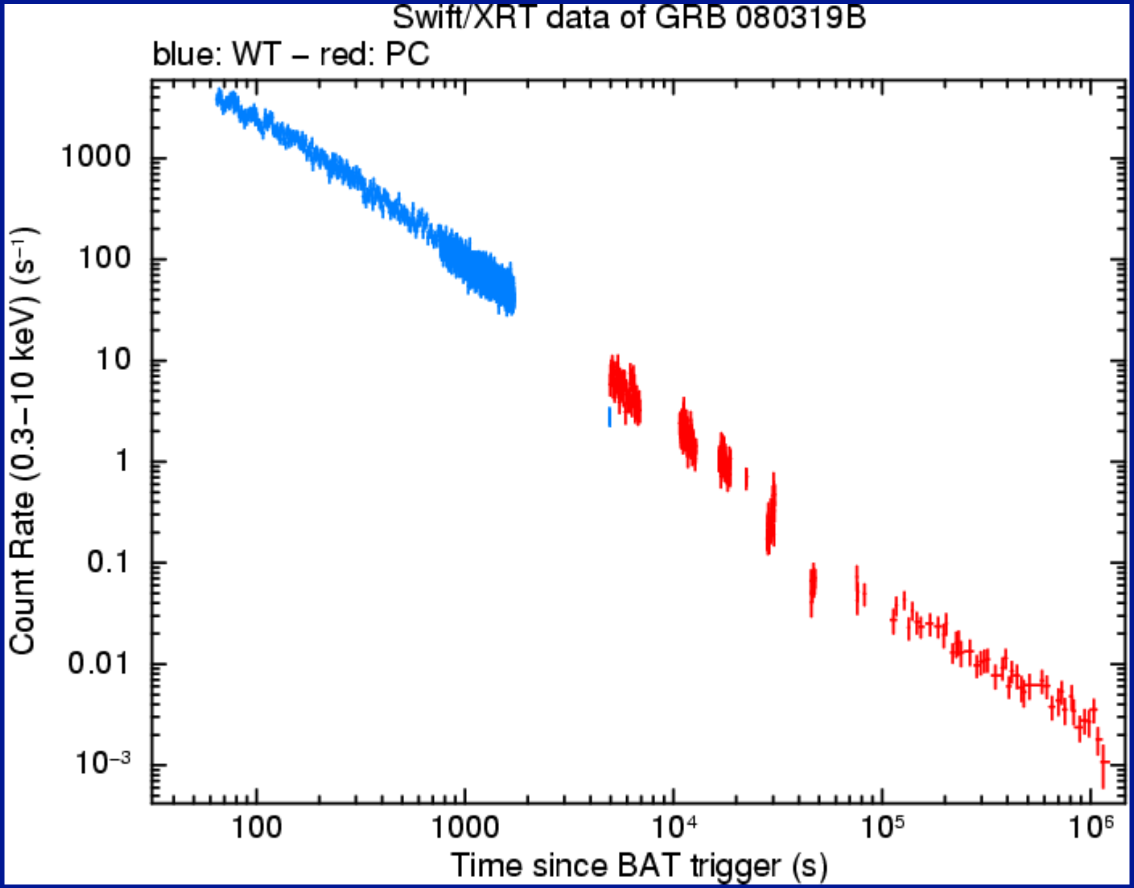
Keck Images



HST Image

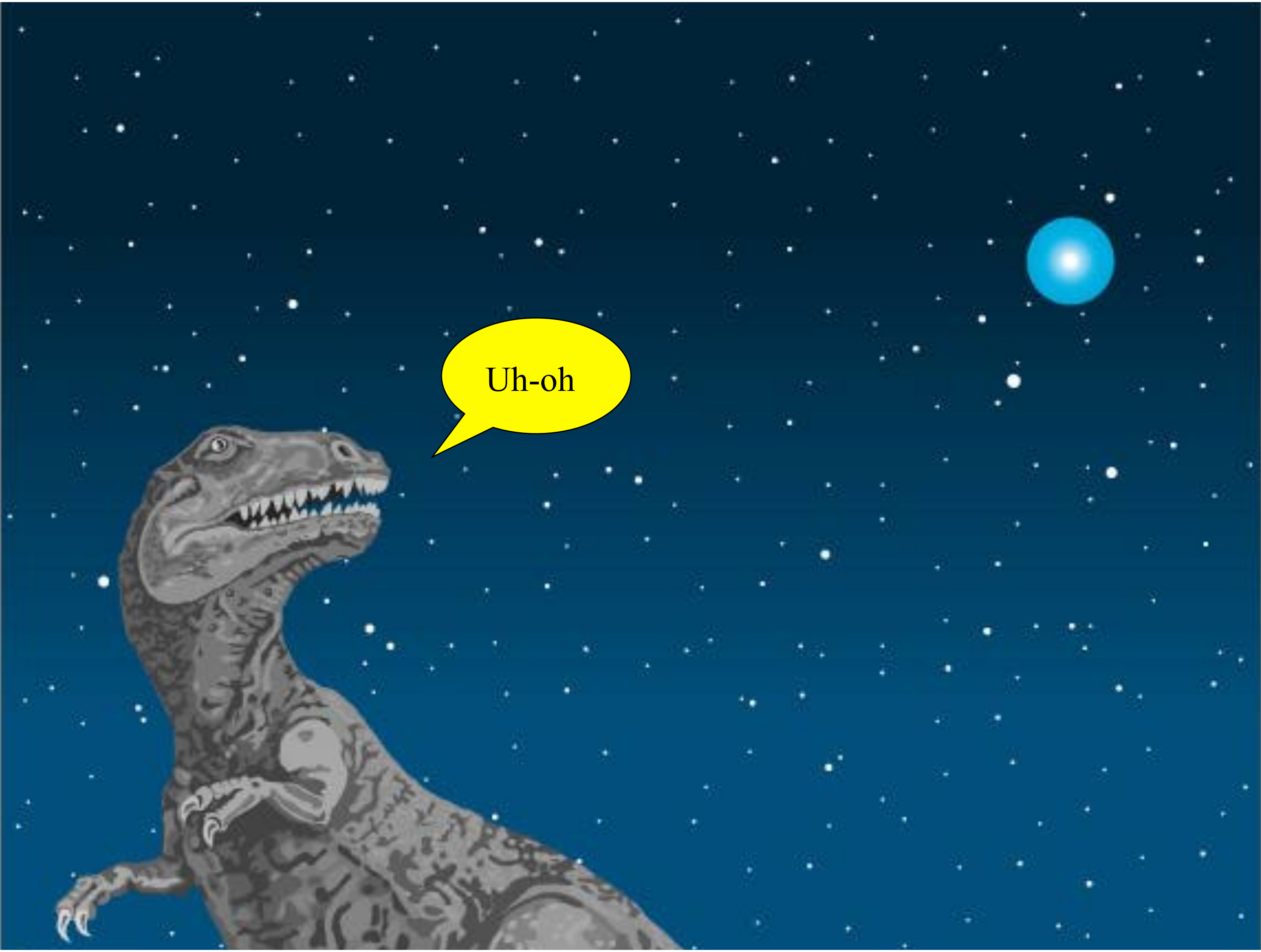
Optical Afterglow from GRB 080319b

Swift Image

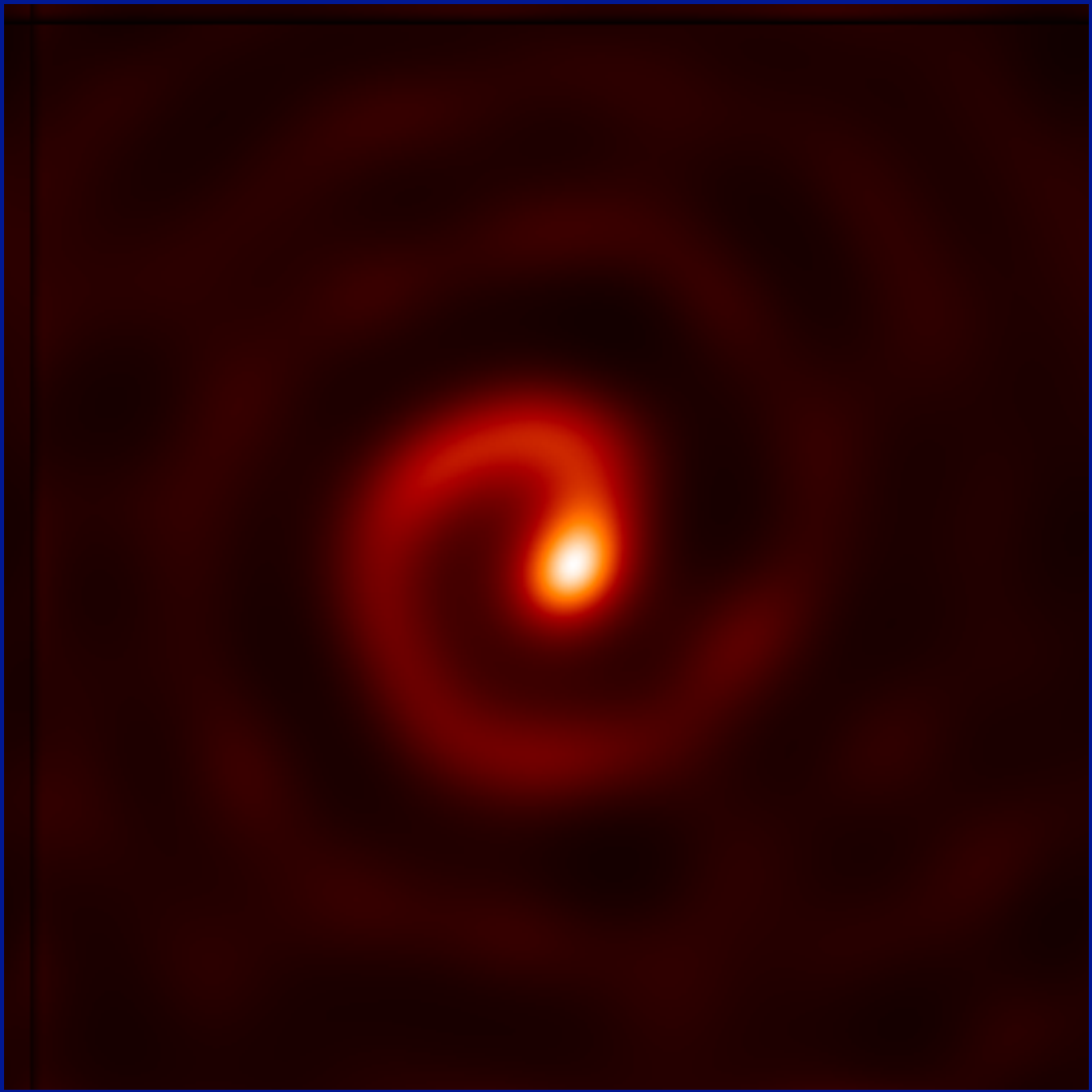


Light Curve

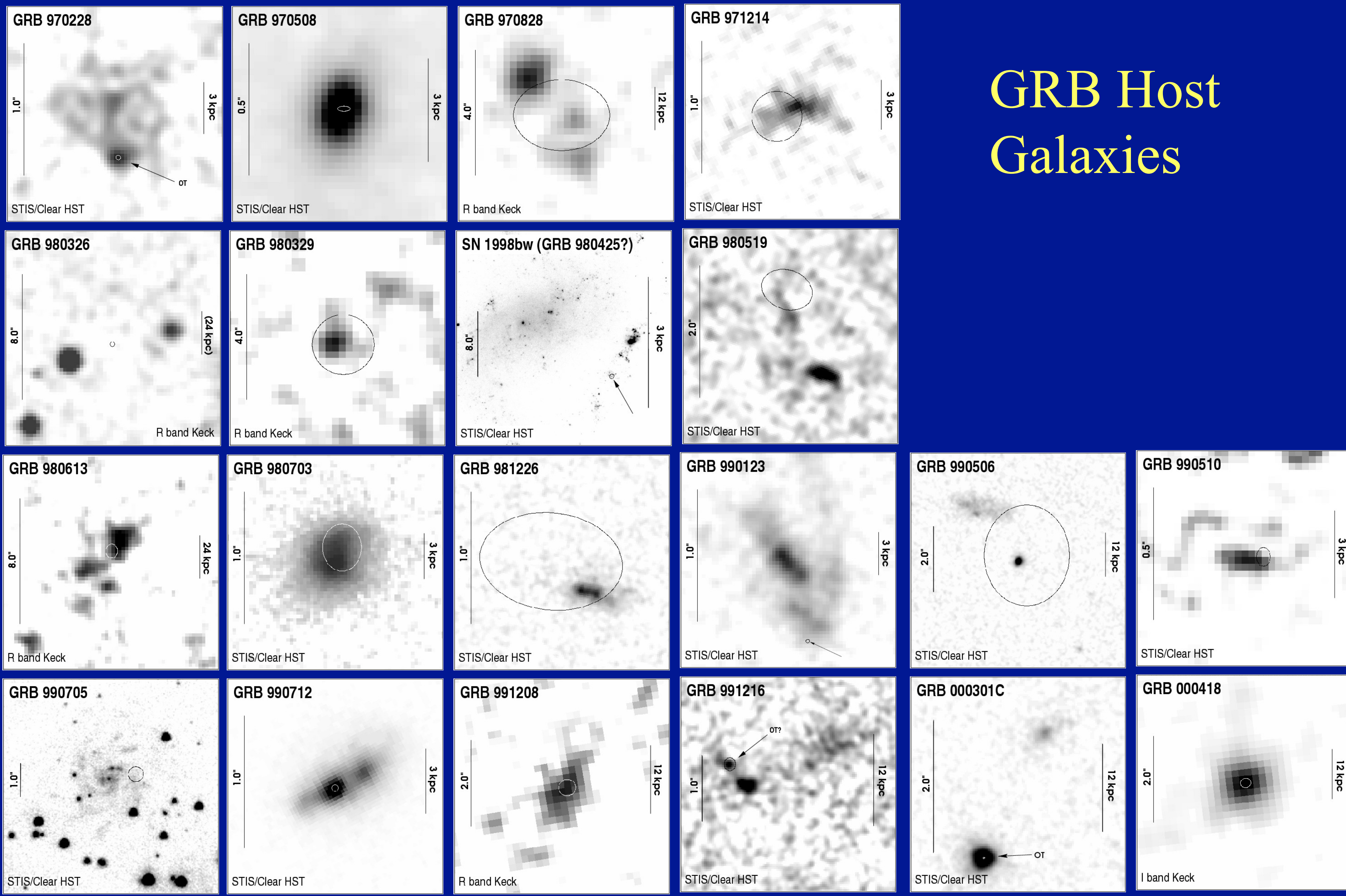
Naked-eye visible for ~30 sec. Distance = 7.5 billion ly


Uh-oh

WR104 - Looking Down the Barrel of a GRB system 8000 lt-years from us



GRB Host Galaxies

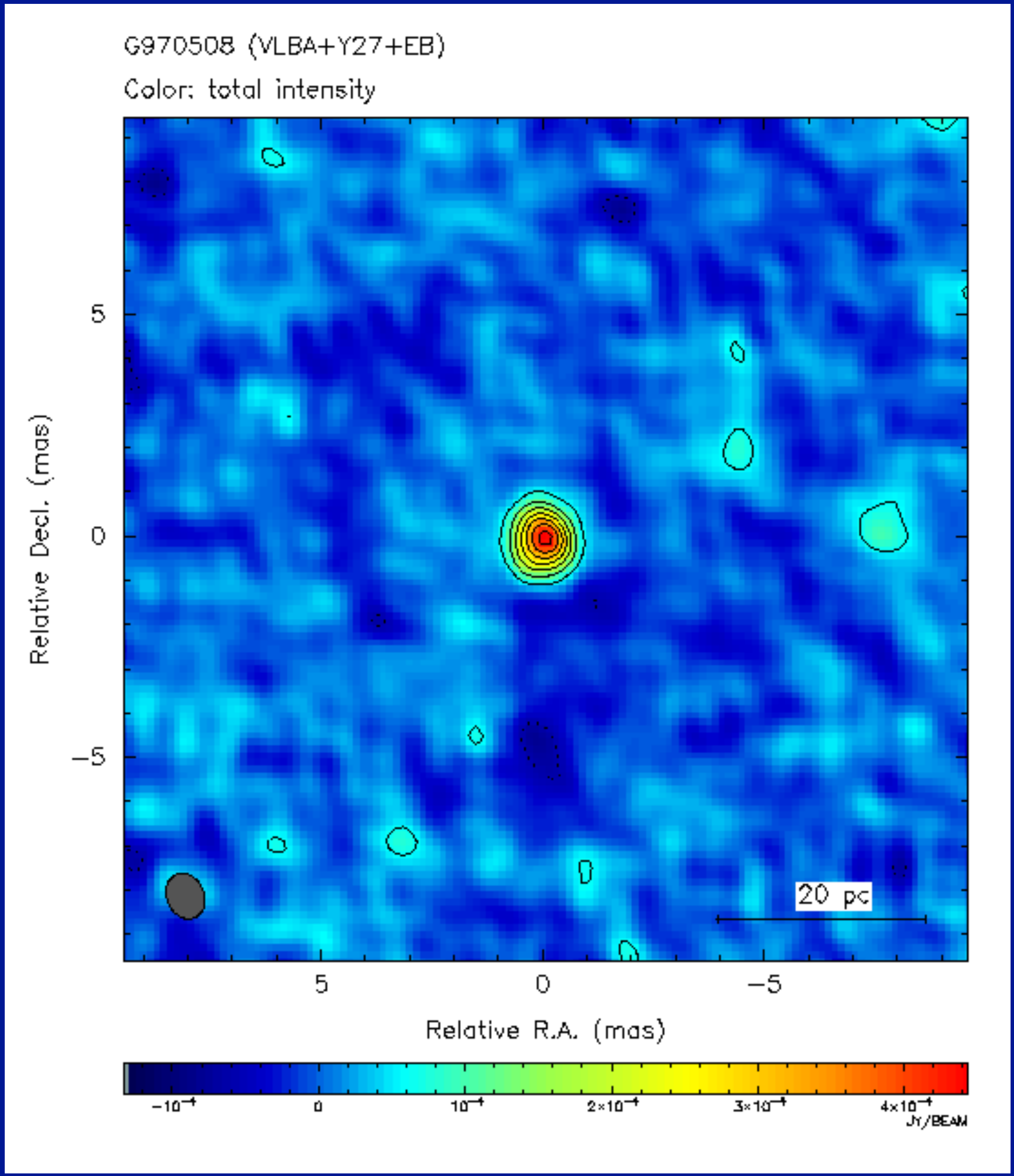


Bloom et al. 2002

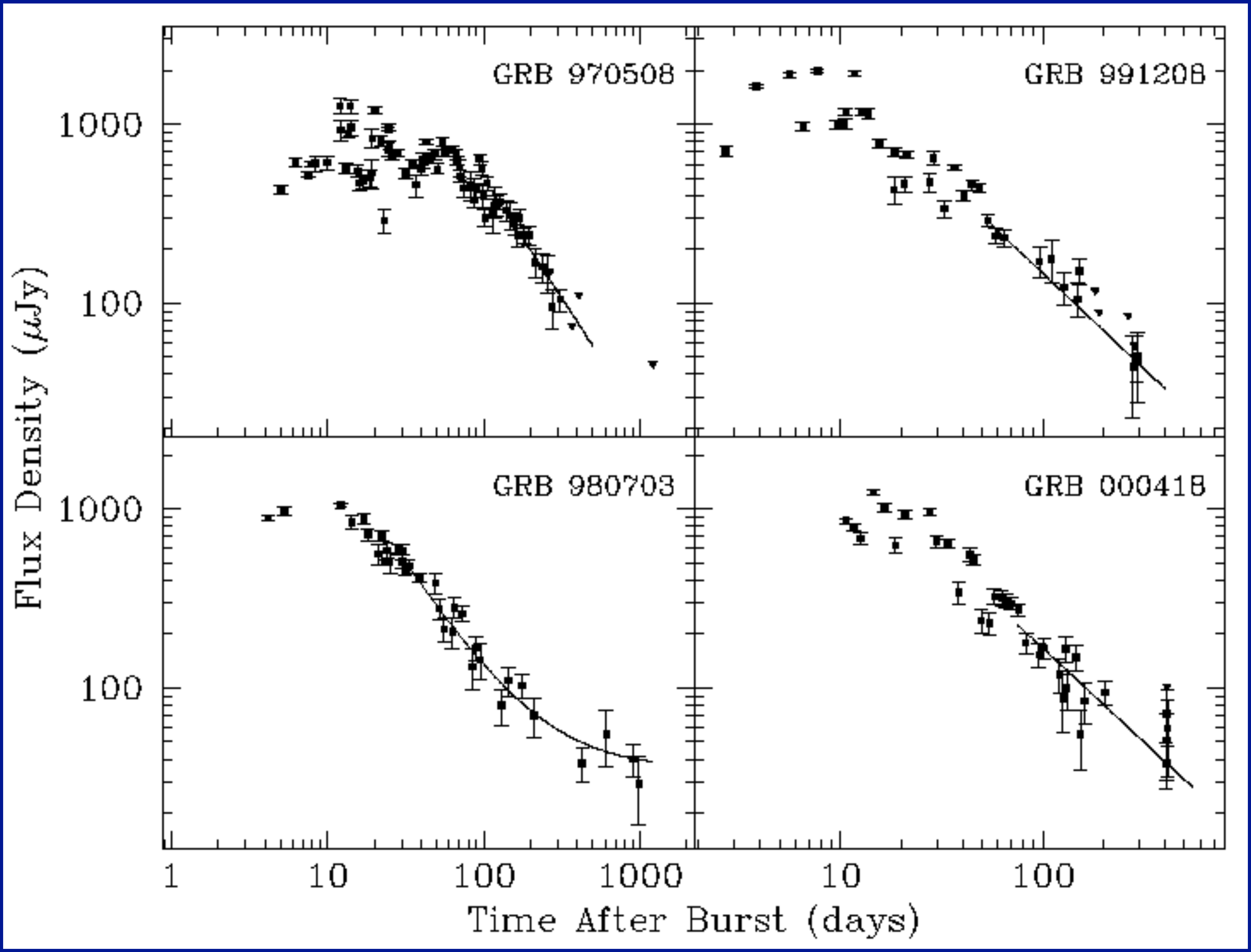
GRB 970508

- First VLBI detection of a GRB Afterglow
- absolute position to < 1 mas
- Size < 10^19 cm (3 lt years)
- Distance > 10000 lt years

Taylor et al 1997



Radio Light Curves from long GRBs



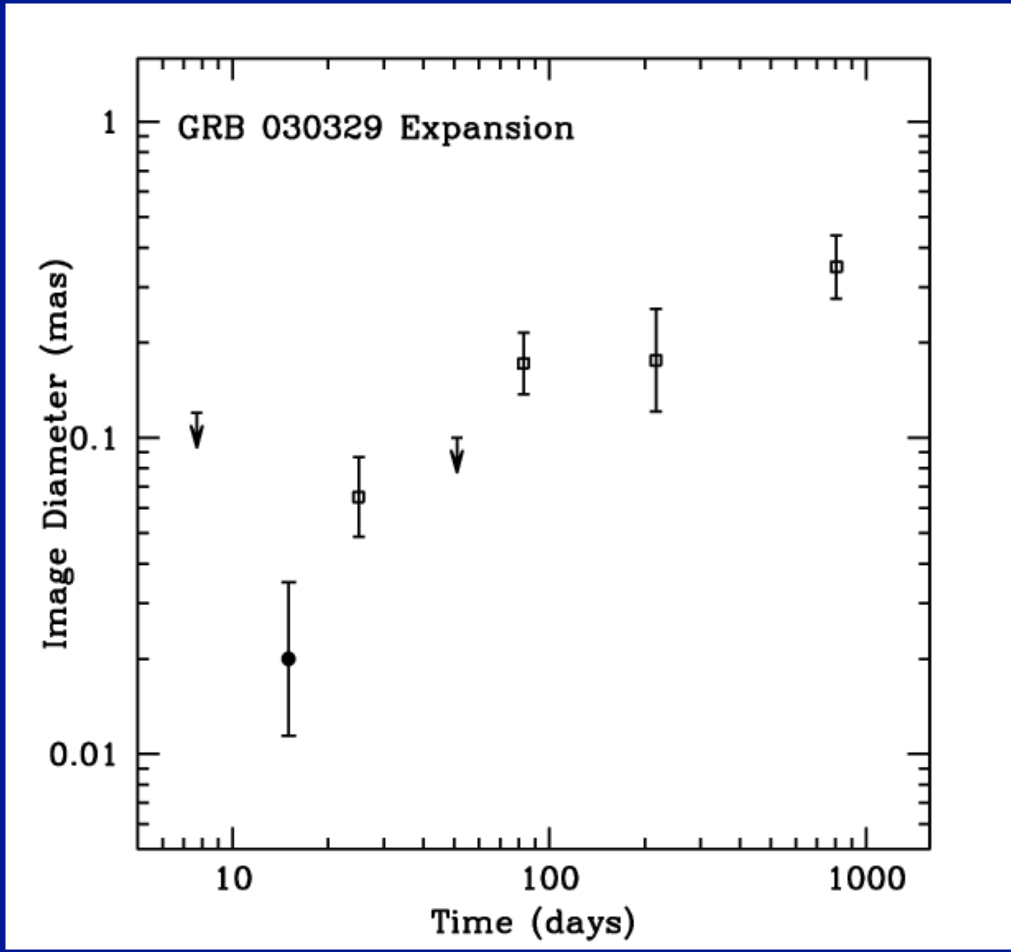
GRB Expansion

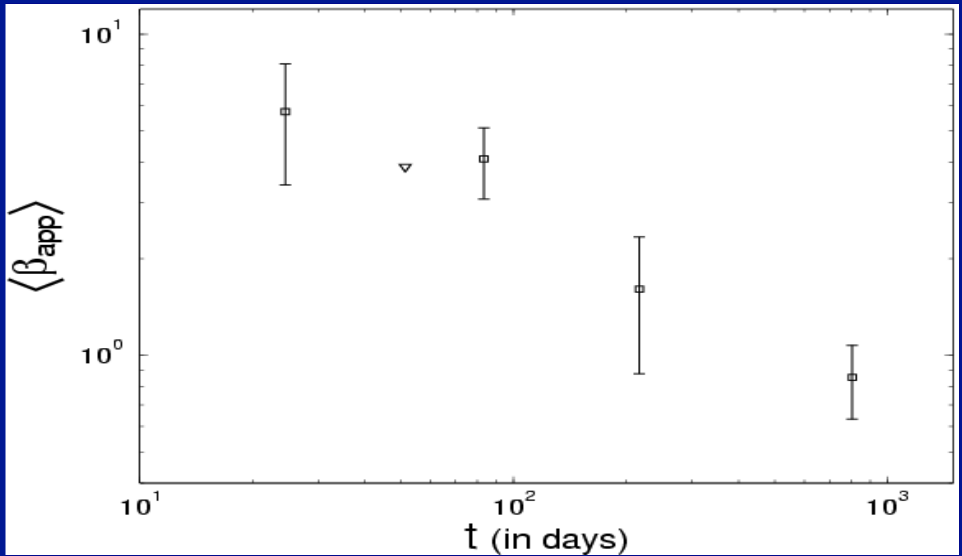
Relativistic
Expansion v ~ 0.96c

E ~ 10^53 ergs
(isotropic
equivalent)

R ~ (E/n)^1/8

Taylor et al 2004
Pihlstrom et al 2007





GRBs are a type of Supernova "Hypernova"

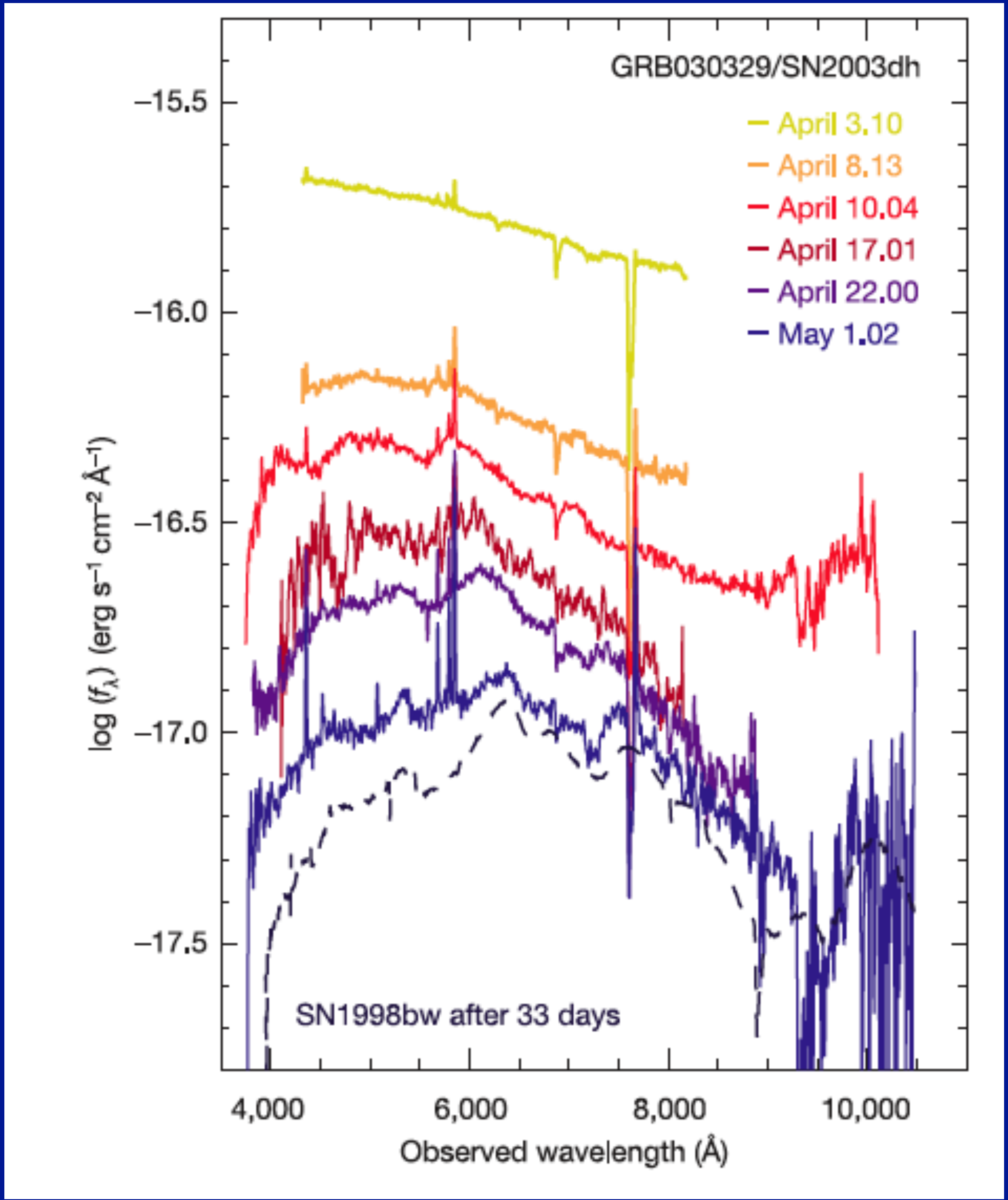
- Peak toward low end of gamma-ray, complex gamma-ray light curves
- Often have bright afterglows
- Evidence for a relativistic explosion
- Energy required of ~ 10^{53} ergs (isotropic)
- Associated with regions of star formation in distant galaxies (out to edge of observable universe)
- Sometimes obscured by dust
- Plus …

Example Hypernova: 1998bw

SN 1998bw in Spiral Galaxy ESO184-G82

ESO PR Photo 39a/98 (15 October 1998)

Long GRBs clearly connected to Supernovae



Hjorth et al 2003

Final States of a Star

1. White Dwarf
   If initial star mass $< 8\ M_{Sun}$ or so

   No Event + PN

2. Neutron Star
   If initial mass $> 8\ M_{Sun}$ and $< 25\ M_{Sun}$

   Supernova + ejecta

3. Black Hole
   If initial mass $> 25\ M_{Sun}$

   GRB + Hypernova + ejecta

Clicker Question:

What is the remnant left over from a GRB?

A: a white dwarf + expanding shell

B: a neutron star + expanding shell

C: a black hole + expanding shell

D: no remnant, just the expanding shell

Clicker Question:

Where do most long duration GRBs occur:

A: in globular clusters

B: in star forming regions

C: in old open clusters

D: in the Oort cloud

Clicker Question:

What was the subject of the great debate about GRBs that went on for ~30 years?

A: If they were produced by Supernovae or colliding stars.

B: If they were galactic or extragalactic in origin.

C: If they were of terrestrial or extraterrestrial in origin?

D: If a nearby GRB killed off the dinosaurs.

Relativistic Jets From Collapsars

S.E. Woosley's Group

Inital Model: he15

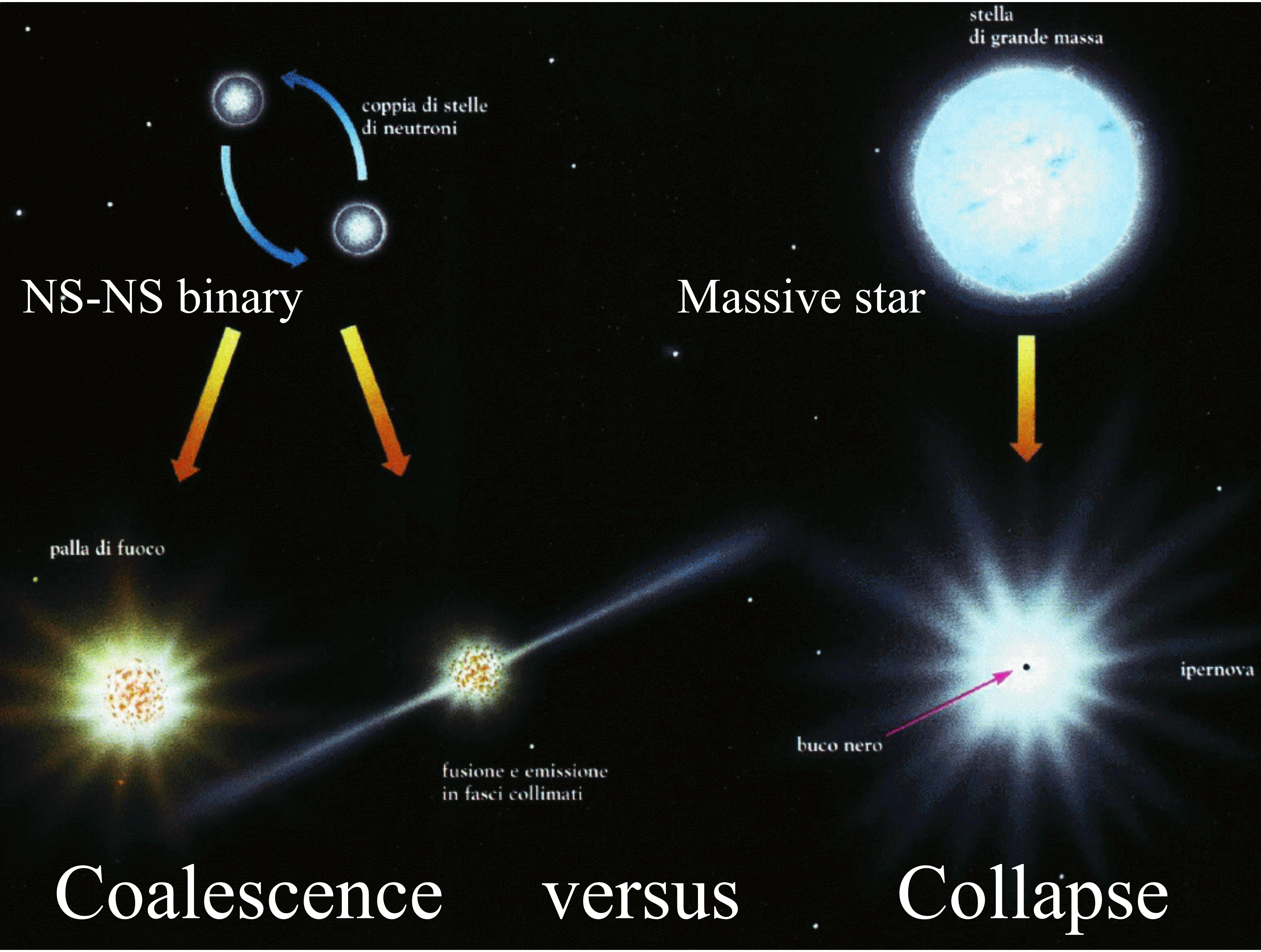
480 radial zones, 200 angular zones

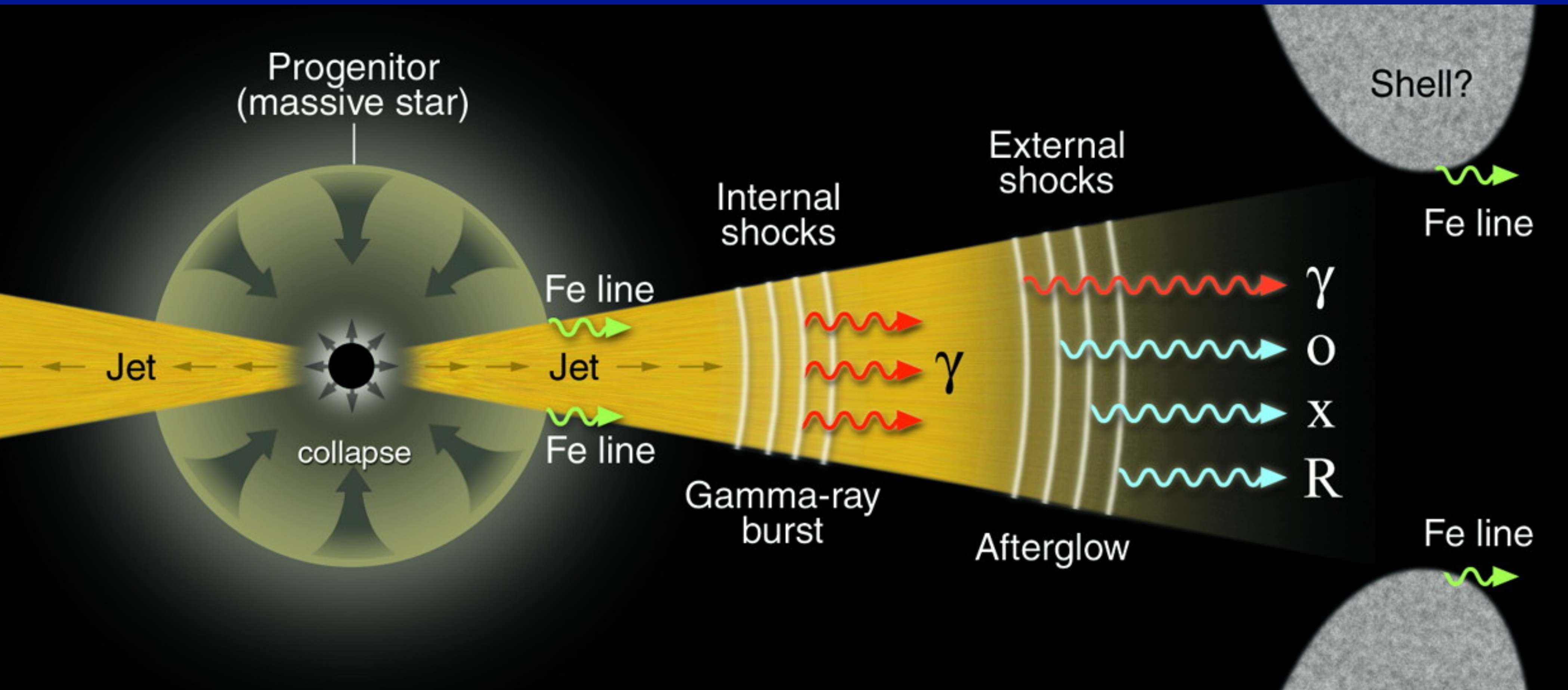
Energy Deposition Rate: 10^{51} ergs/s

Half Opening Angle: 20

$f_e(E_{th}/E_{tot})$: 0.67

Lorentz Factor: 50


coppia di stelle
di neutroni
stella
di grande massa
NS-NS binary
Massive star
palla di fuoco
fusione e emissione
in fasci collimati
buco nero
ipernova
Coalescence versus Collapse



$\Gamma \approx 100$
$r \approx 10^{15}$ cm

$\Gamma \approx 10 \rightarrow 1$
$r \approx 10^{17}$ cm