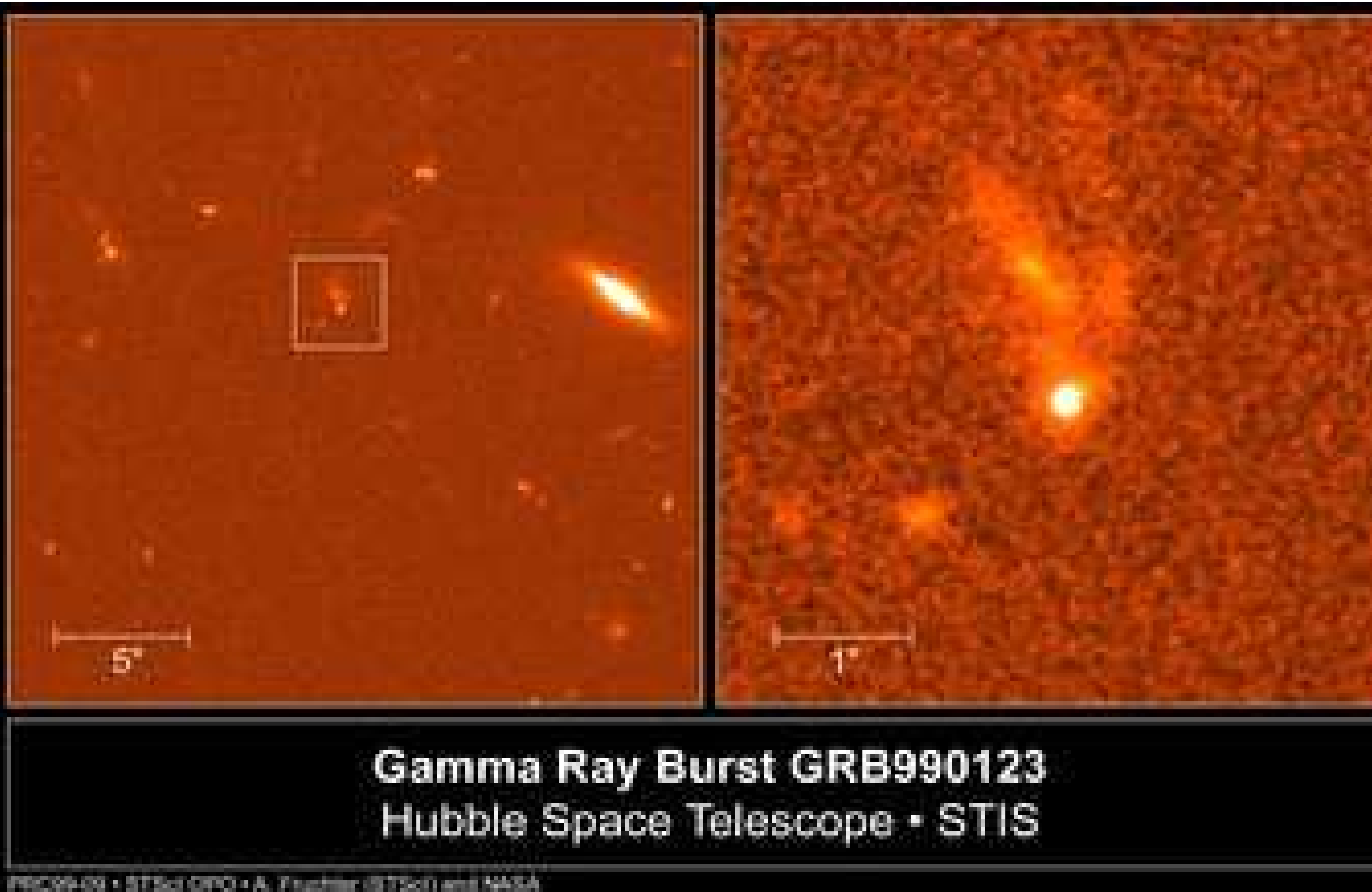
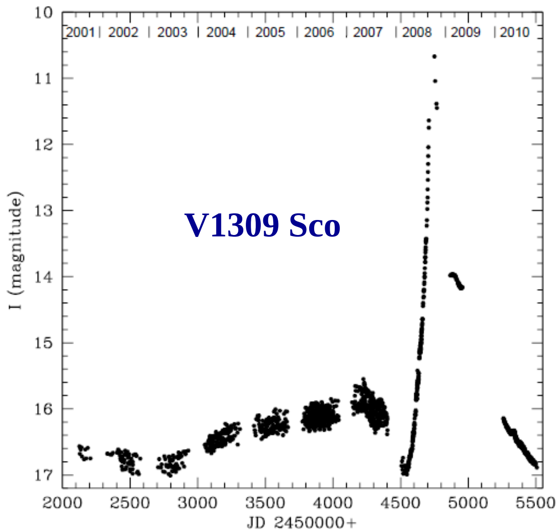
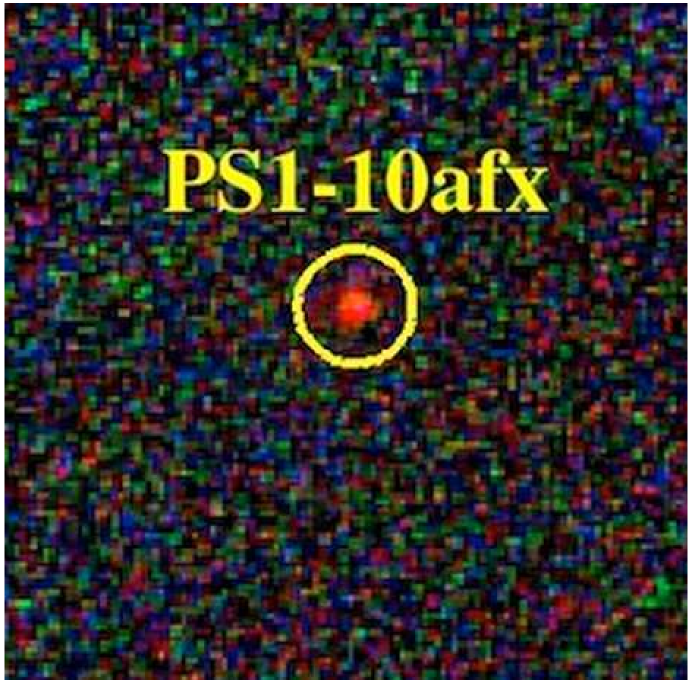

5"
1"
Gamma Ray Burst GRB990123
Hubble Space Telescope • STIS

Transients

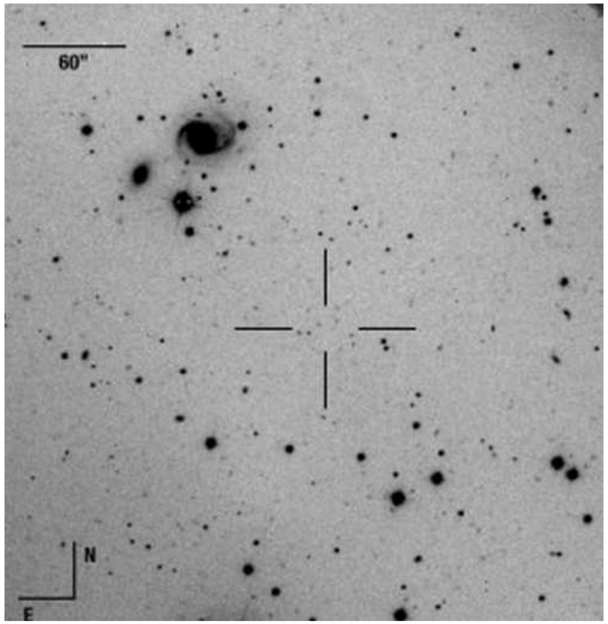


Stellar Mergers

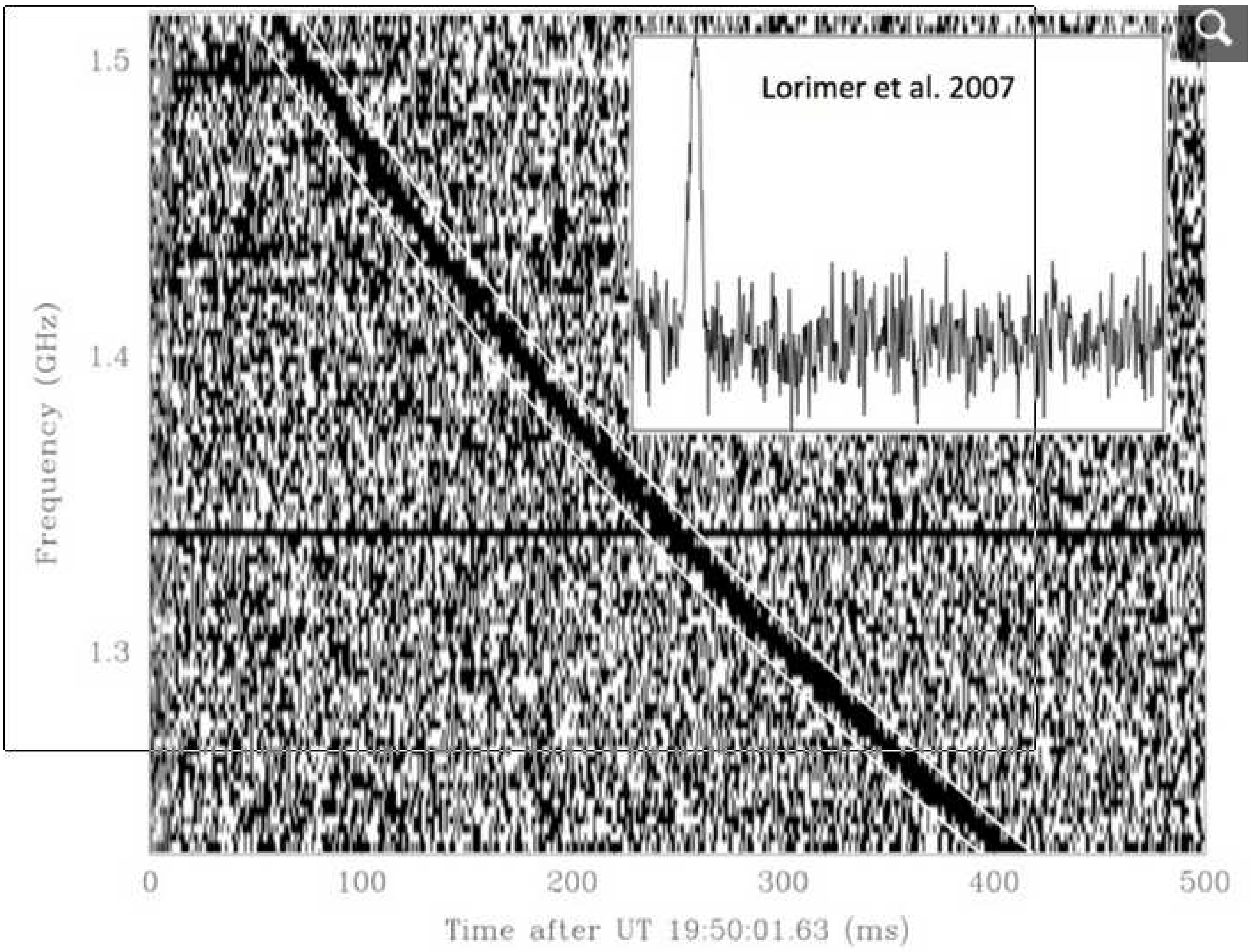
V838 Mon



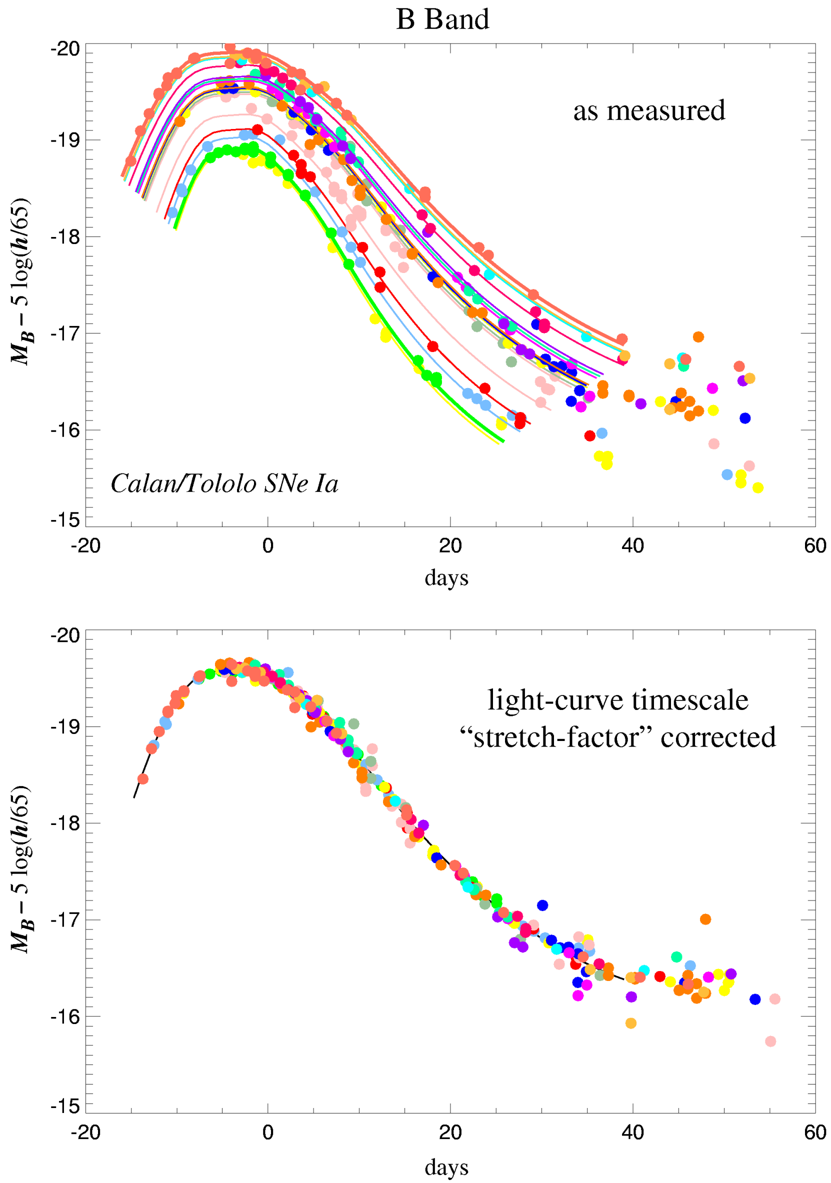
Superluminous Supernovae (Pan−STARRS)



SNe in the middle of nowhere
(SN PTF10ops, Maguire)



Fast Radio Bursts (FRBs, Lorimer 2007)



Kim, *et al.* (1997)

TYPE IA SUPERNOVAE

- late 90s: Type Ia supernovae have been used to measure the acceleration of the Universe
- Type Ia supernovae are like standard distance candles!
  - ▷ more distant supernovae are fainter than expected from ‘standard’ expansion of the Universe
  - → expansion must have accelerated
  - → need unknown source of energy → Dark Energy

→ Nobel Prize in 2011 for Schmidt, Riess, Perlmutter

caveat: the progenitors of Type Ia supernovae are not known

Metallicity as a second parameter of SN Ia lightcurves

- the lightcurve is powered by the radioactive decay of ^{56}Ni to ^{56}Co ($t_{1/2} = 6.1\,\mathrm{d}$)

$\rightarrow$ $L_{\mathrm{peak}} \propto M_{56\mathrm{Ni}}$

- the lightcurve width is determined by the diffusion time
  - ▷ depends on the opacity, in particular the total number of iron-group elements (i.e. ^{56}Ni, ^{58}Ni, ^{54}Fe)

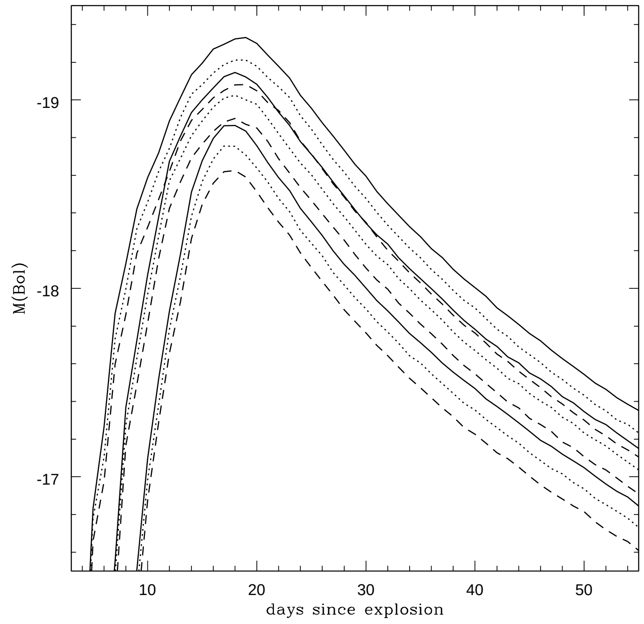
  $\rightarrow$ $t_{\mathrm{width}} \propto M_{\mathrm{iron-group}}$
  - ▷ ^{54}Fe, ^{58}Ni are non-radioactive $\rightarrow$ contribute to opacity but not supernova luminosity

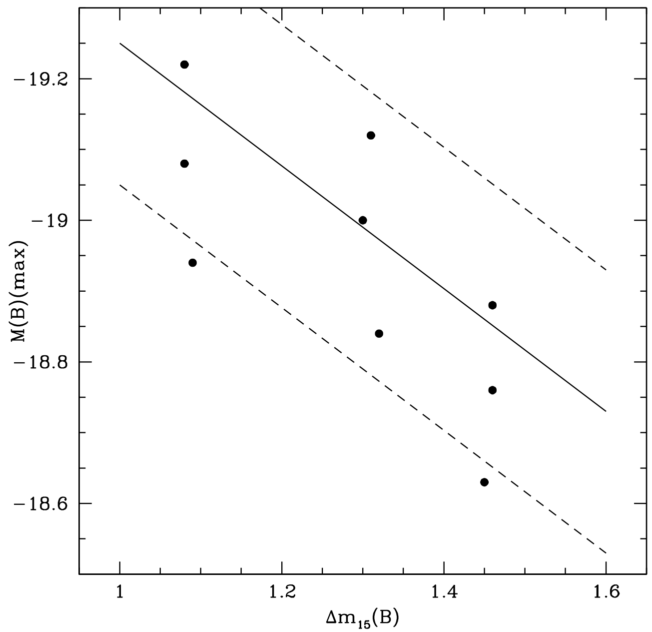
$\rightarrow$ necessary second parameter

- the relative amount of non-radioactive and radioactive Ni depends on neutron excess and hence on the initial metallicity (Timmes et al. 2003)
- variation of 1/3 to 3 $Z_{\odot}$ gives variation of 0.2 mag

The Second SN Ia Parameter: (^{54}Fe + ^{58}Ni)/ ^{56}Ni

(Mazzali and Podsiadlowski 2006)





Podsiadlowski, Mazzali, Lesaffre, Förster (2006)

- metallicity *must* be a second parameter that at some level needs to be taken into account
- cosmic metallicity evolution can mimic accelerating Universe

but: metallicity evolution effects on their own *appear* not large enough to explain the supernova observations without dark energy (also independent evidence from WMAP, galaxy clustering)

- it will be difficult to measure the equation of state of dark energy with SNe Ia alone without correcting for metallicity effects

Measuring the Equation of State

Linder (2003)

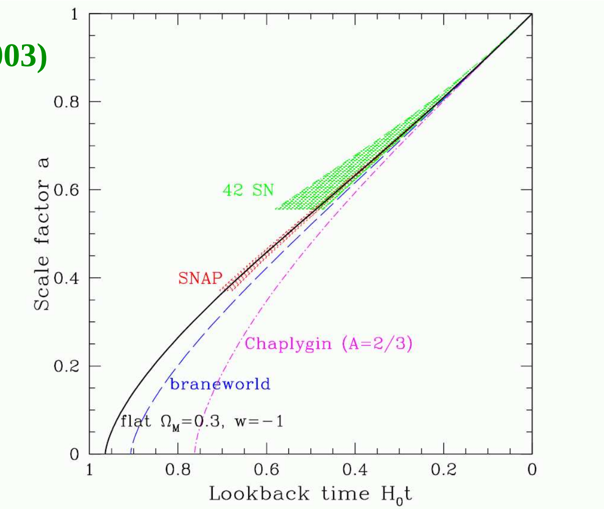
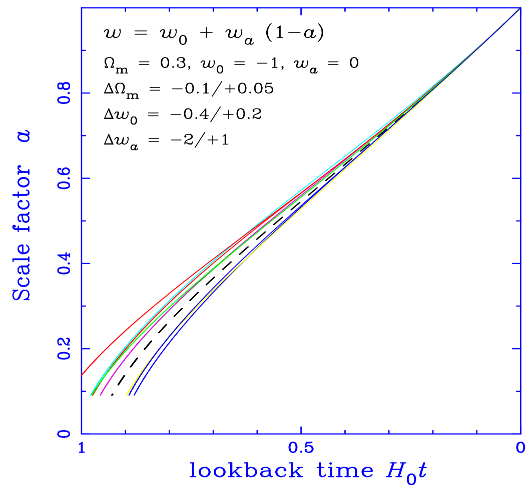


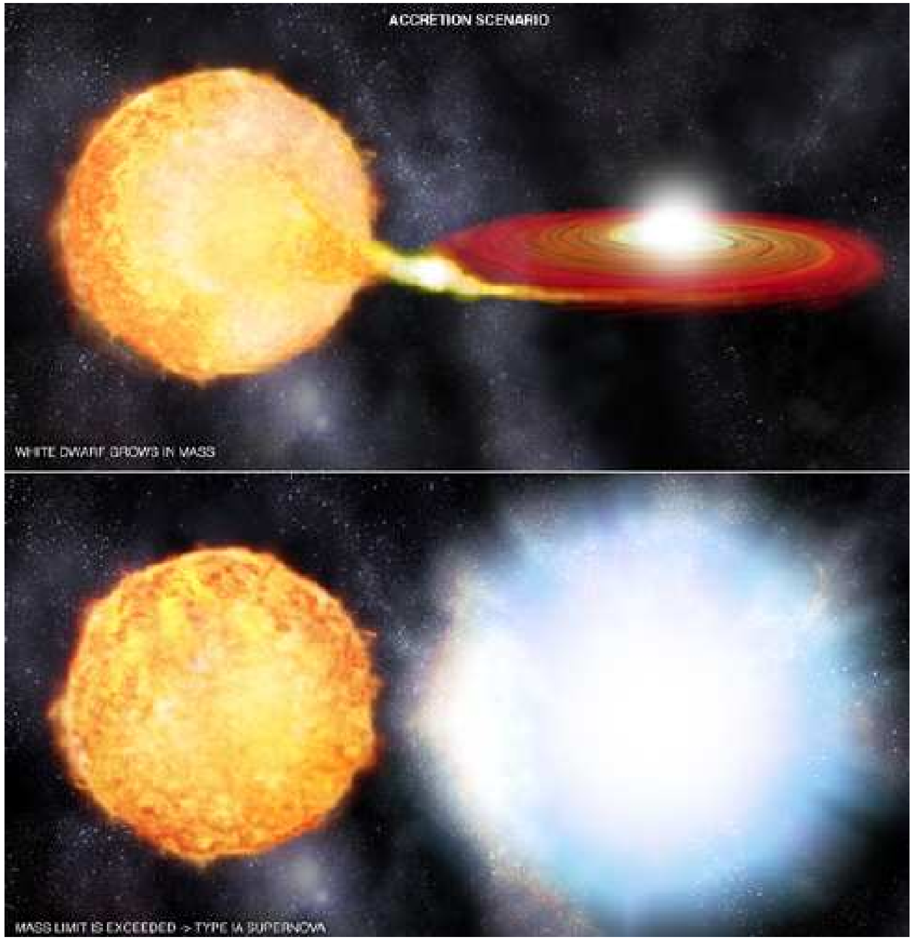
FIG. 1: Mapping the expansion history through the supernova magnitude-redshift relation can distinguish the dark energy explanation for the accelerating universe from alternate theories of gravitation, high energy physics, or higher dimensions. All three models take an $\Omega_M = 0.3$, flat universe but differ on the form of the Friedmann expansion equation.

The effect of metallicity evolution

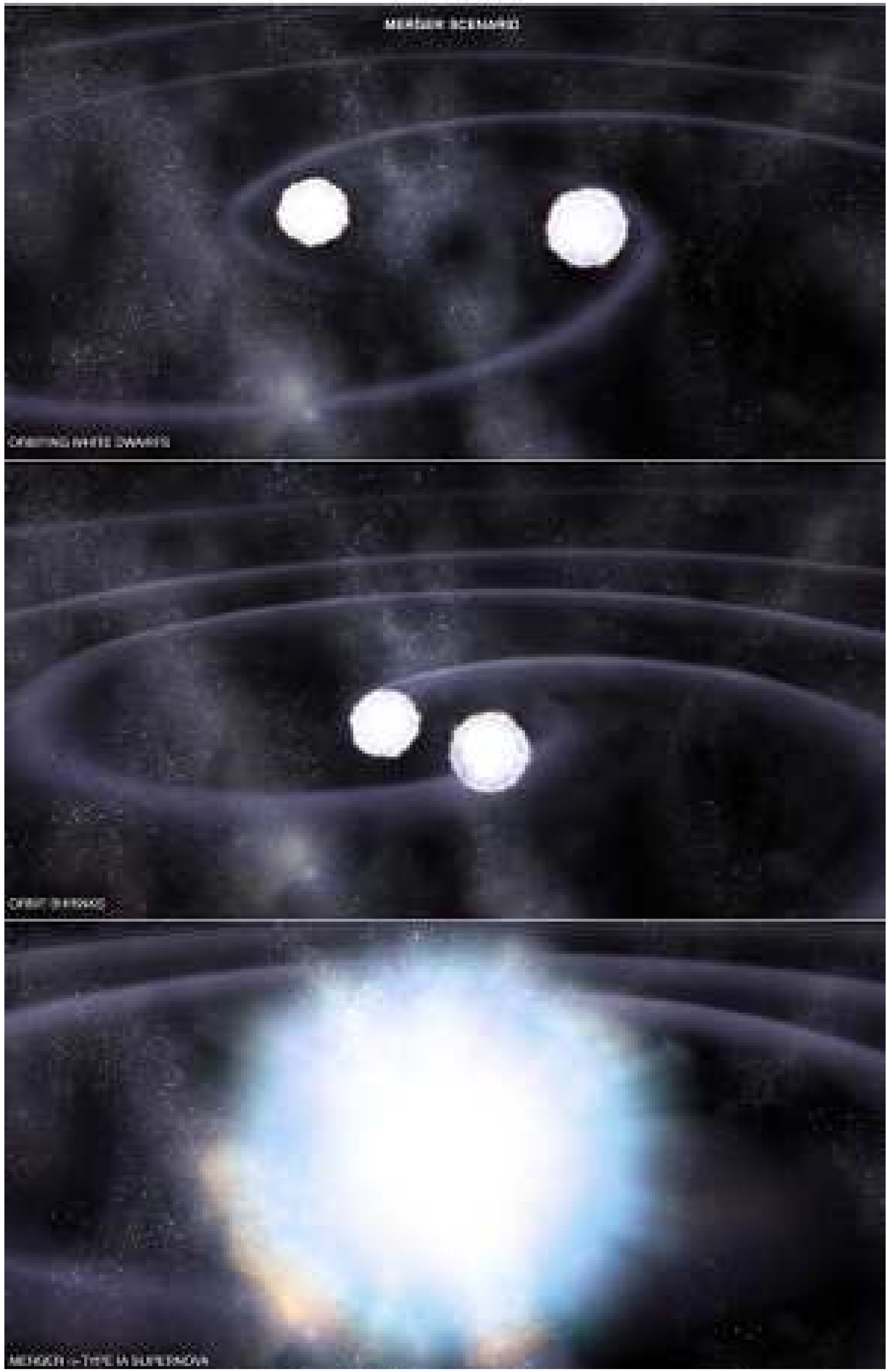


(based on PMLWF 2006)

Accretion Model



Merger Model



The Progenitor of SN 1987A

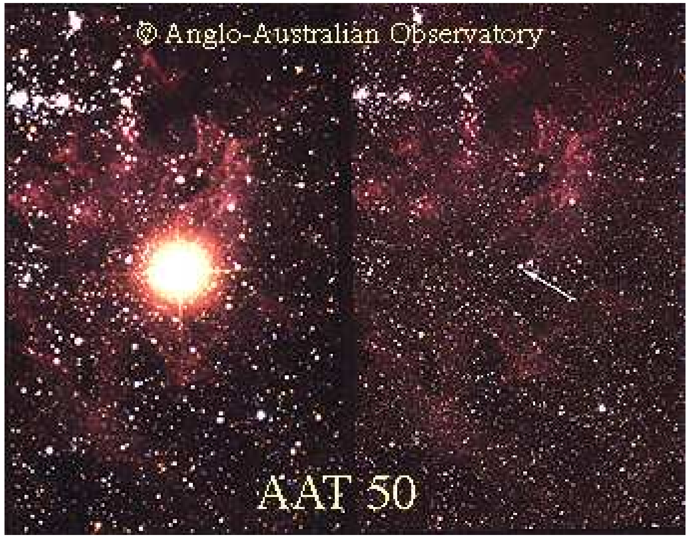
Thomas Morris (Oxford/MPA), Ph.P.

SN 1987A: an anomalous supernova

- progenitor (SK $-69°202$): blue supergiant with recent red-supergiant phase (10^4 yr)
- chemical anomalies:
  - ▷ helium-rich (He/H$\sim$ 0.25, N/C$\sim$ 5, N/O$\sim$ 1)
  - ▷ CNO-processed material, helium dredge-up
  - ▷ barium anomaly ($5 - 10$ solar)
- the triple-ring nebula

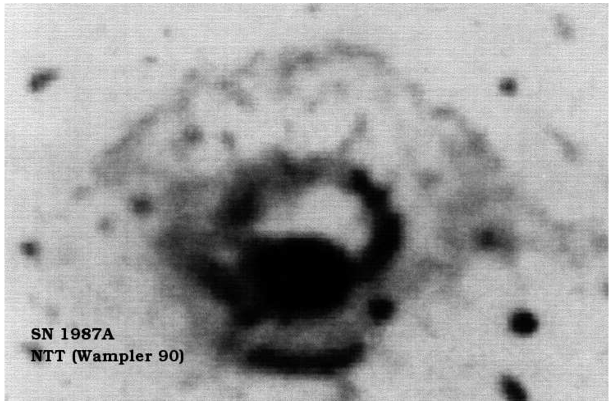
→ axi-symmetric, but highly non-spherical

→ signature of rapid rotation



The Triple-Ring Nebula

- discovered with NTT (Wampler et al. 1990)



- HST image (Burrows et al. 1995)
- not a limb-brightened hourglass, but physically distinct rings
- axi-symmetric, but highly non-spherical

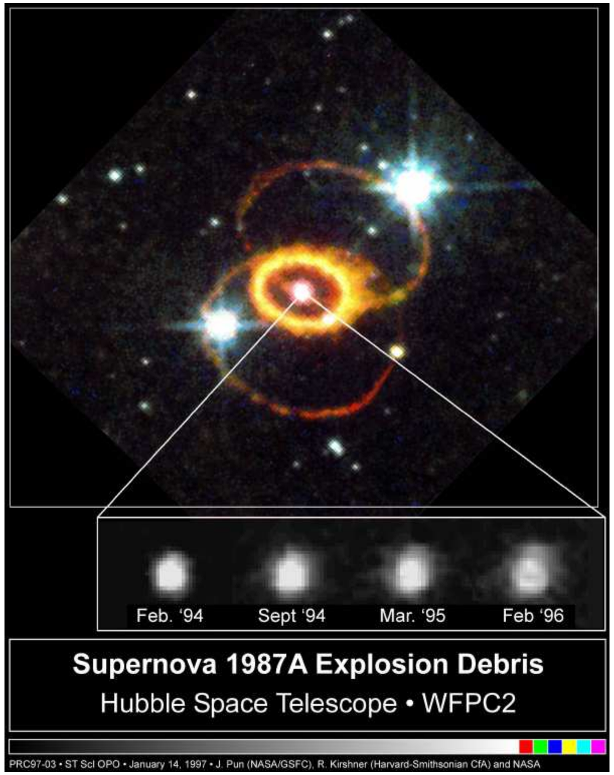
  $\rightarrow$ signature of rapid rotation?

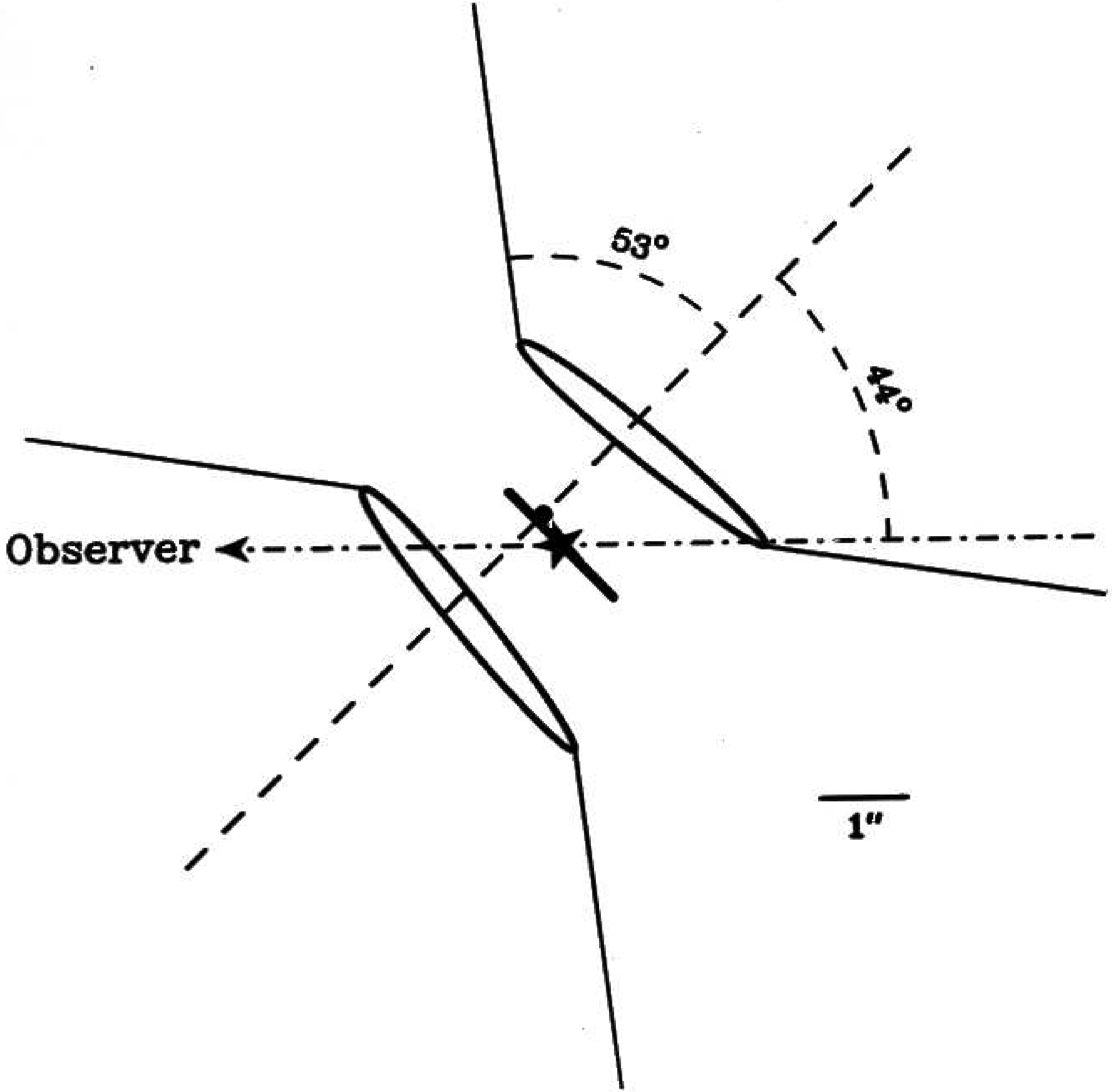
  ▷ not possible in simple single-star models (angular-momentum conservation!)

  ▷ supernova is at the centre, but outer rings are slightly displaced

  ▷ dynamical age: $\sim 20,000\,\mathrm{yr}$

all anomalies linked to a single event a few 10^4 yr ago, most likely the merger of two massive stars

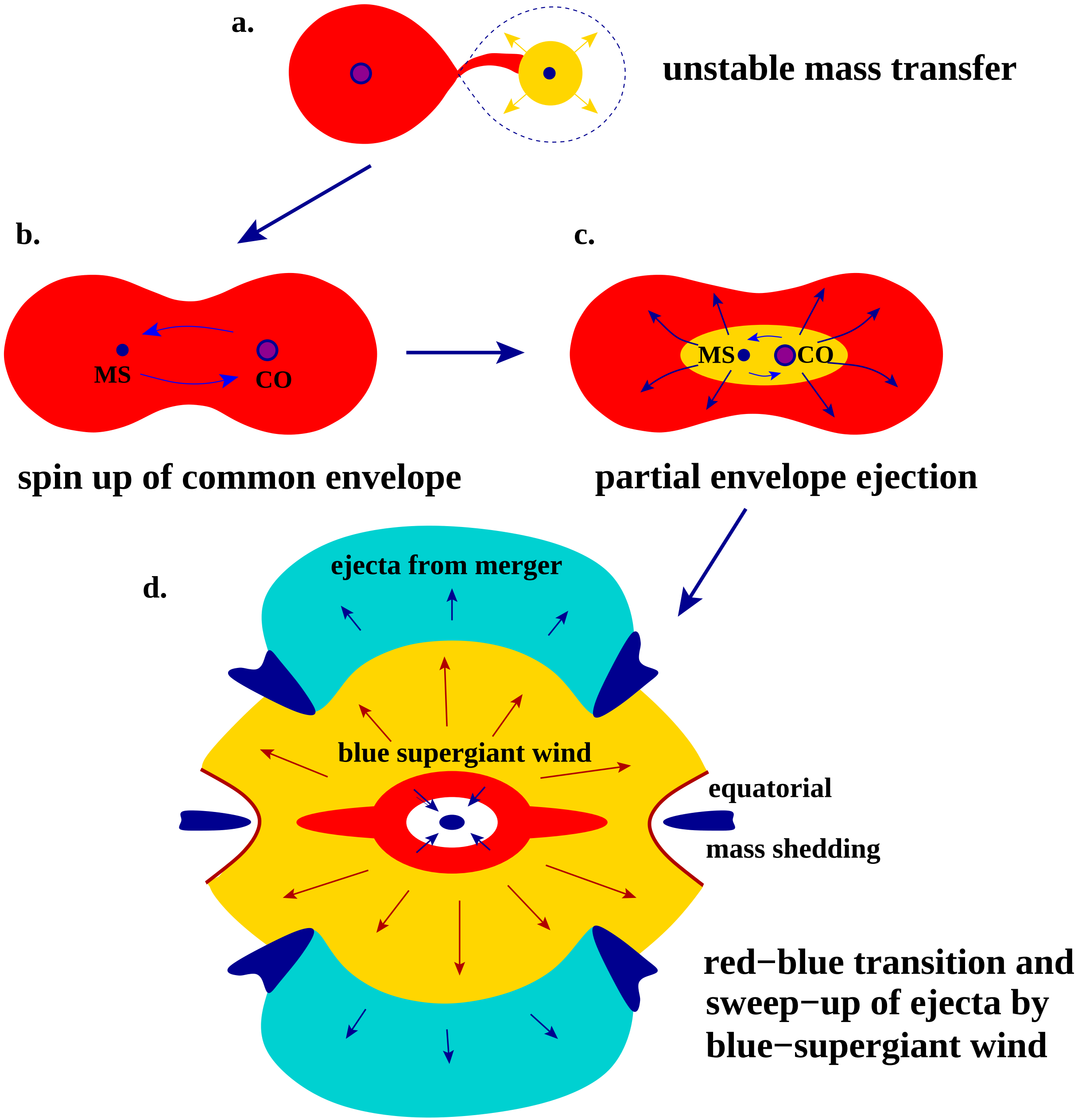


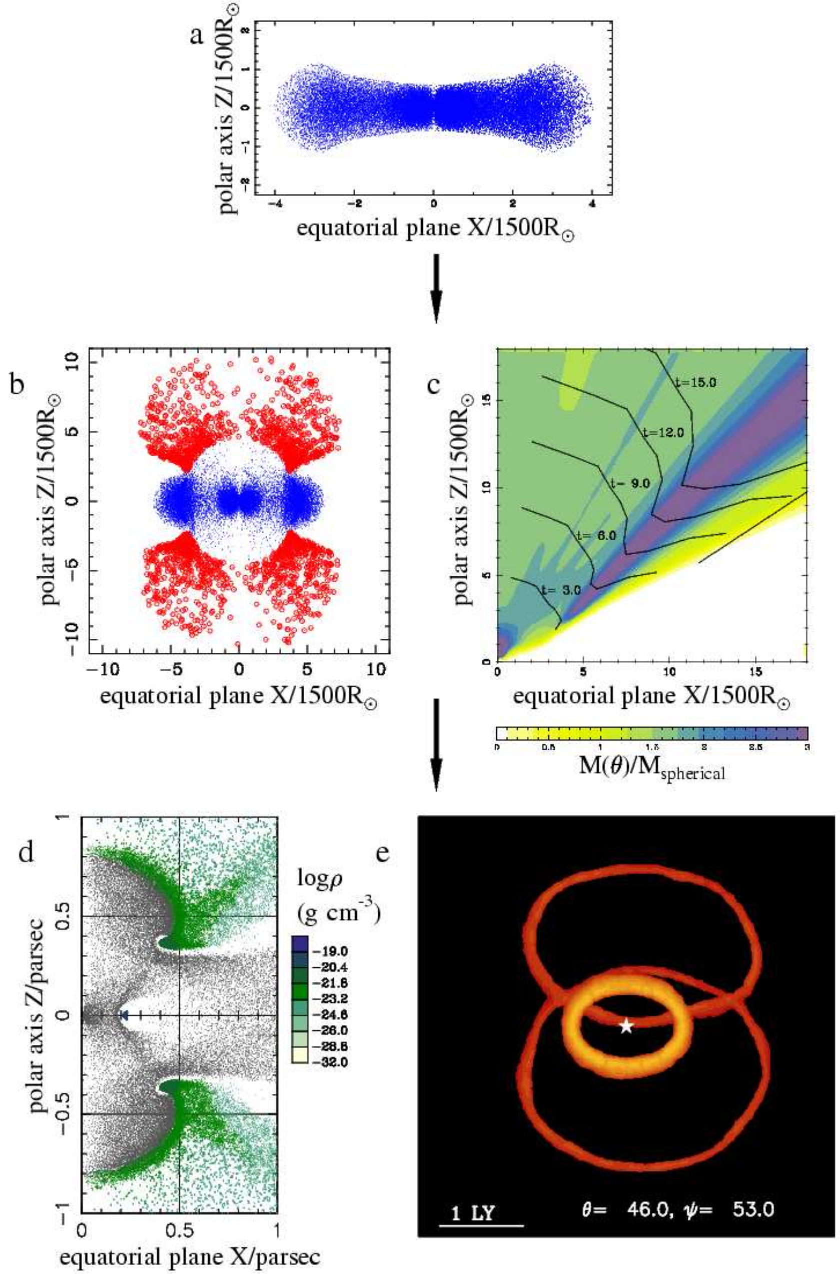


53°
44°
Observer
1″

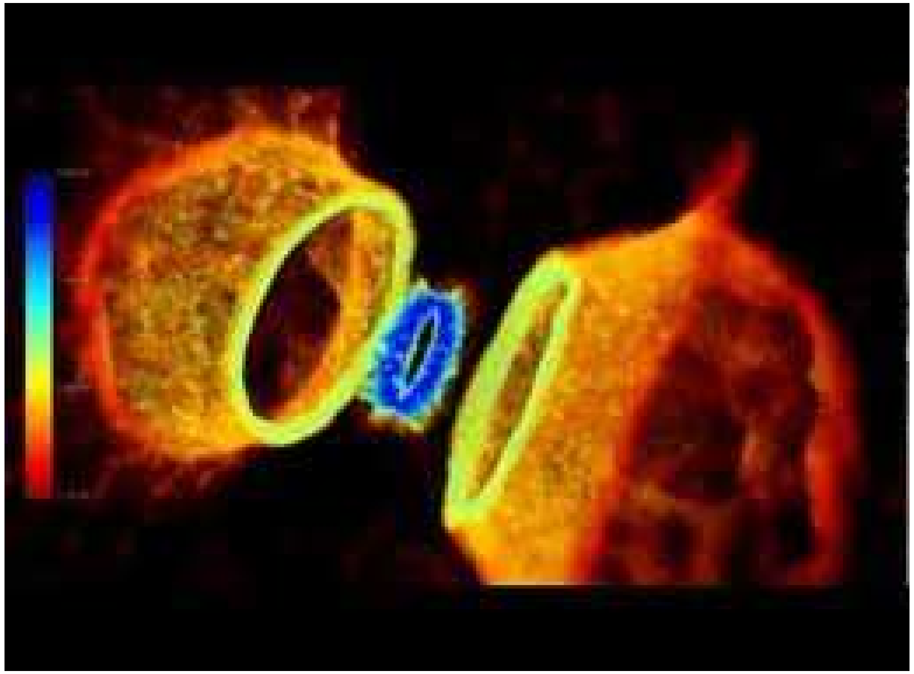
Formation of the Triple-Ring Nebula

(Podsiadlowski, Morris, Ivanova)

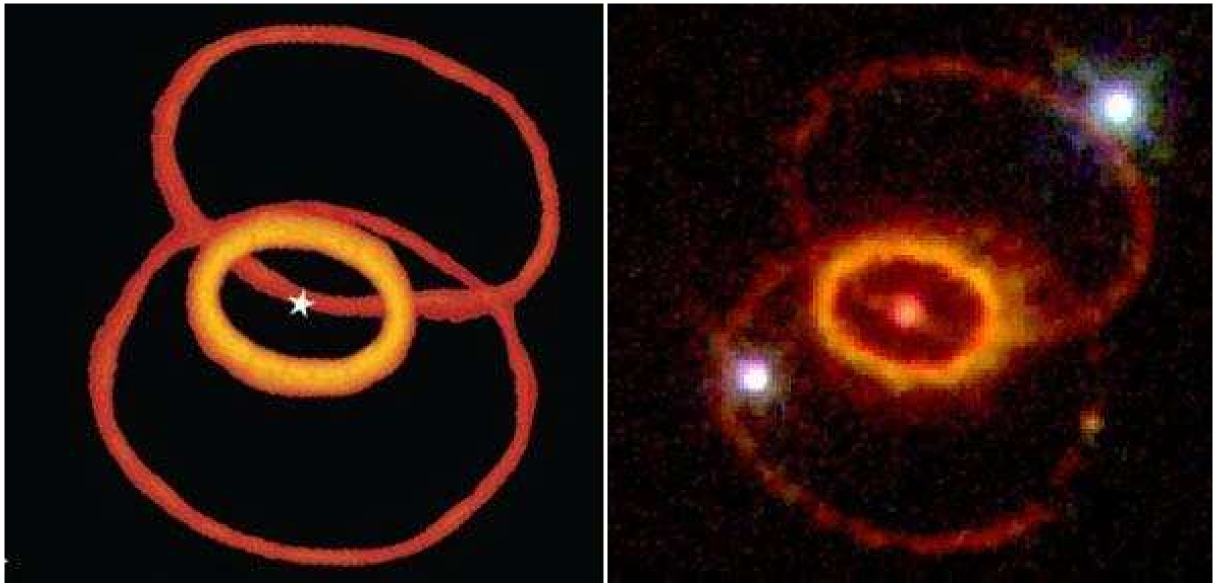



a
polar axis Z/1500R⊙
equatorial plane X/1500R⊙
b
polar axis Z/1500R⊙
equatorial plane X/1500R⊙
c
polar axis Z/1500R⊙
equatorial plane X/1500R⊙
t= 3.0
t= 6.0
t= 9.0
t=12.0
t=15.0
M(θ)/M_spherical
d
log ρ
(g cm^-3)
-19.0
-20.4
-21.8
-23.2
-24.6
-26.0
-28.8
-32.0
polar axis Z/parsec
equatorial plane X/parsec
e
1 LY
θ= 46.0, ψ= 53.0

Final Structure

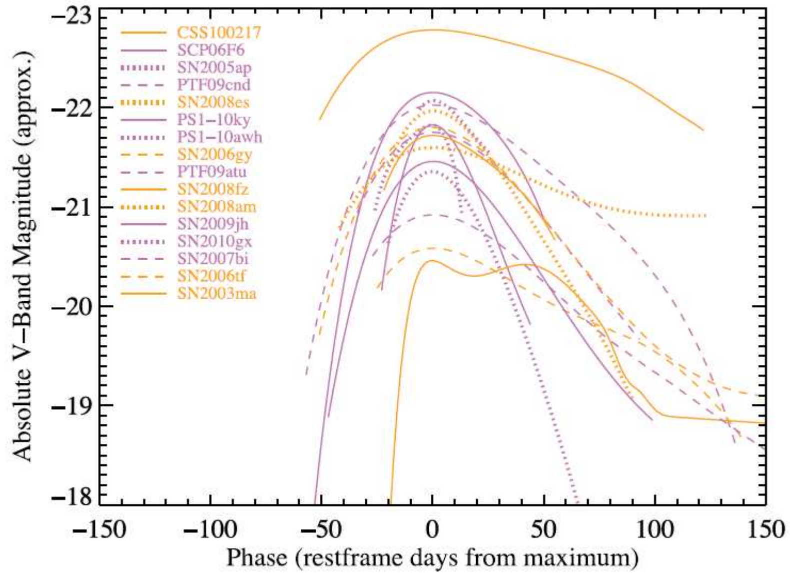


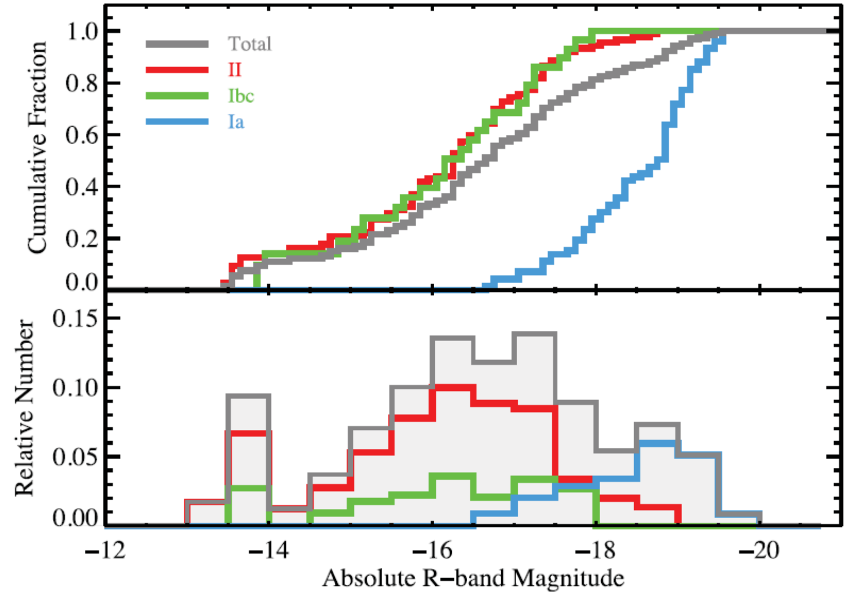
Rings: Theory vs. Observations



Superluminous Supernovae

- recently discovered class of extremely luminous supernovae ("Quimbies")
- a factor up to 100 brighter than normal supernovae
- rare events: 1 in 10^4 core-collapse SNe
- can be seen to high redshift (record: $z = 3.9$, Cooke et al. 2012)
- total photon energy not necessarily $> 10^{51}$ erg
- theoretical model suggestions
  - ▷ pair-instability supernovae (example: SN 07bi)
  - ▷ magnetar-powered
  - ▷ interaction SNe (due to recently ejected shell)





Quimby (2012)

Causes of Supernova Diversity

- binarity
  - ▷ supernova appearance (mass loss/accretion, merging)
  - ▷ core structure
- metallicity
  - ▷ appearance (mass loss, compactness)
  - ▷ core evolution
- rotation/magnetic fields
  - ▷ important in early evolutionary phases (only?), e.g. through mixing (magnetic fields prevent rapidly rotating evolved cores (Spruit))
- dynamical environment
  - ▷ e.g. in dense clusters → dynamical interactions → different final products (dynamical mergers → more HNe?)

Supernova Diversity

Theory

- explosion mechanisms
- supernovae
- stars/binaries

Explosion Mechanisms

- iron−core collapse
- e−capture collapse
- thermonuclear
- pair−instability
- collapsar
- magnetar
- shell detonation

Host Galaxies

- progenitor constraints
- IMF
- starbursts

Binary Evolution

- envelope properties
- supernova sub−type
- final fate

Rotation/Magnetic Fields

- core rotation
- mixing
- mass loss

Metallicity

- mass loss
- rotation rate
- nuclear burning

Supernova Observations

- surveys/rates
- new supernova types
- individual supernovae
- supernova diagnostics

Dynamical Interactions

- stellar collisions
- runaway mergers

Cosmology

- cosmological parameters
- star−formation probes

The Fireworks Initiative