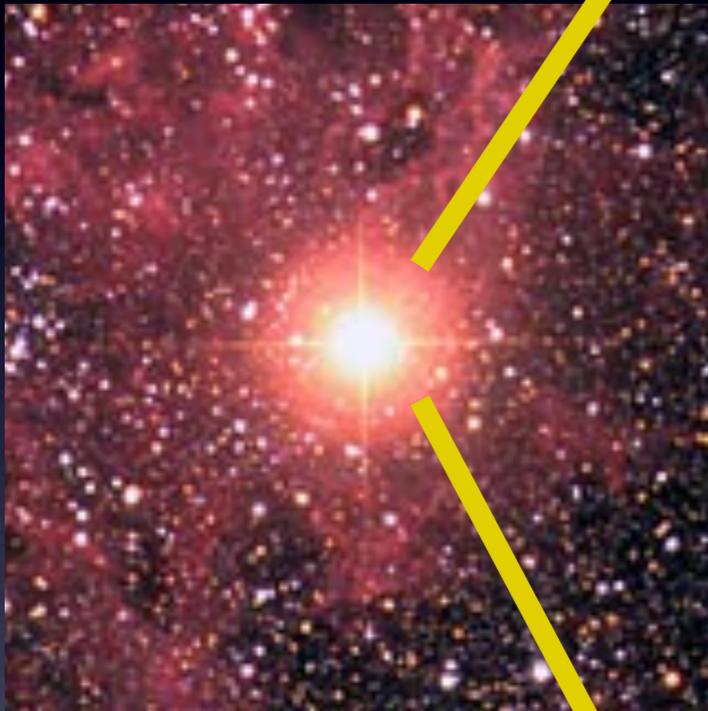


Three-Dimensional View of Supernovae

Masaomi Tanaka

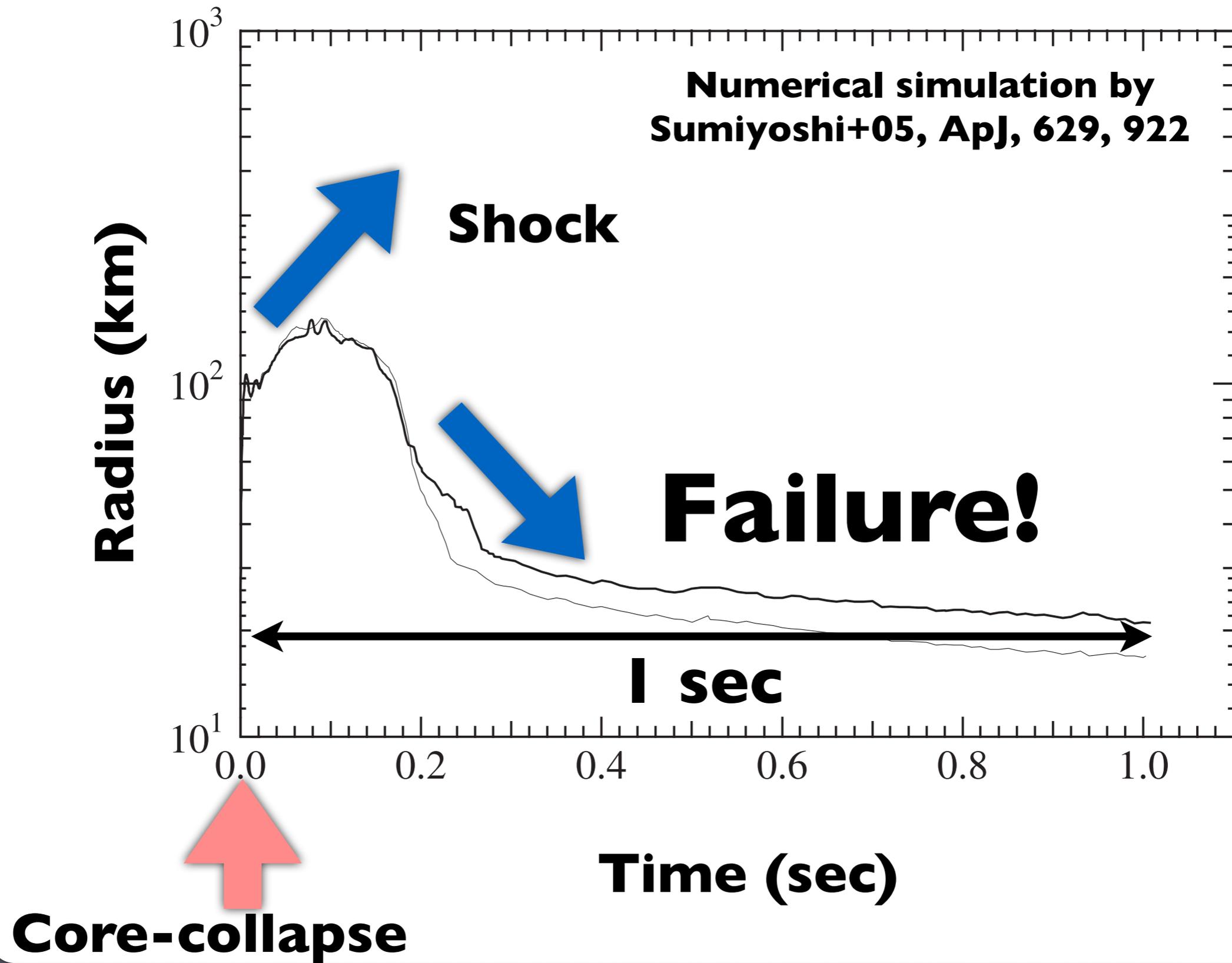
(National Astronomical Observatory of Japan)

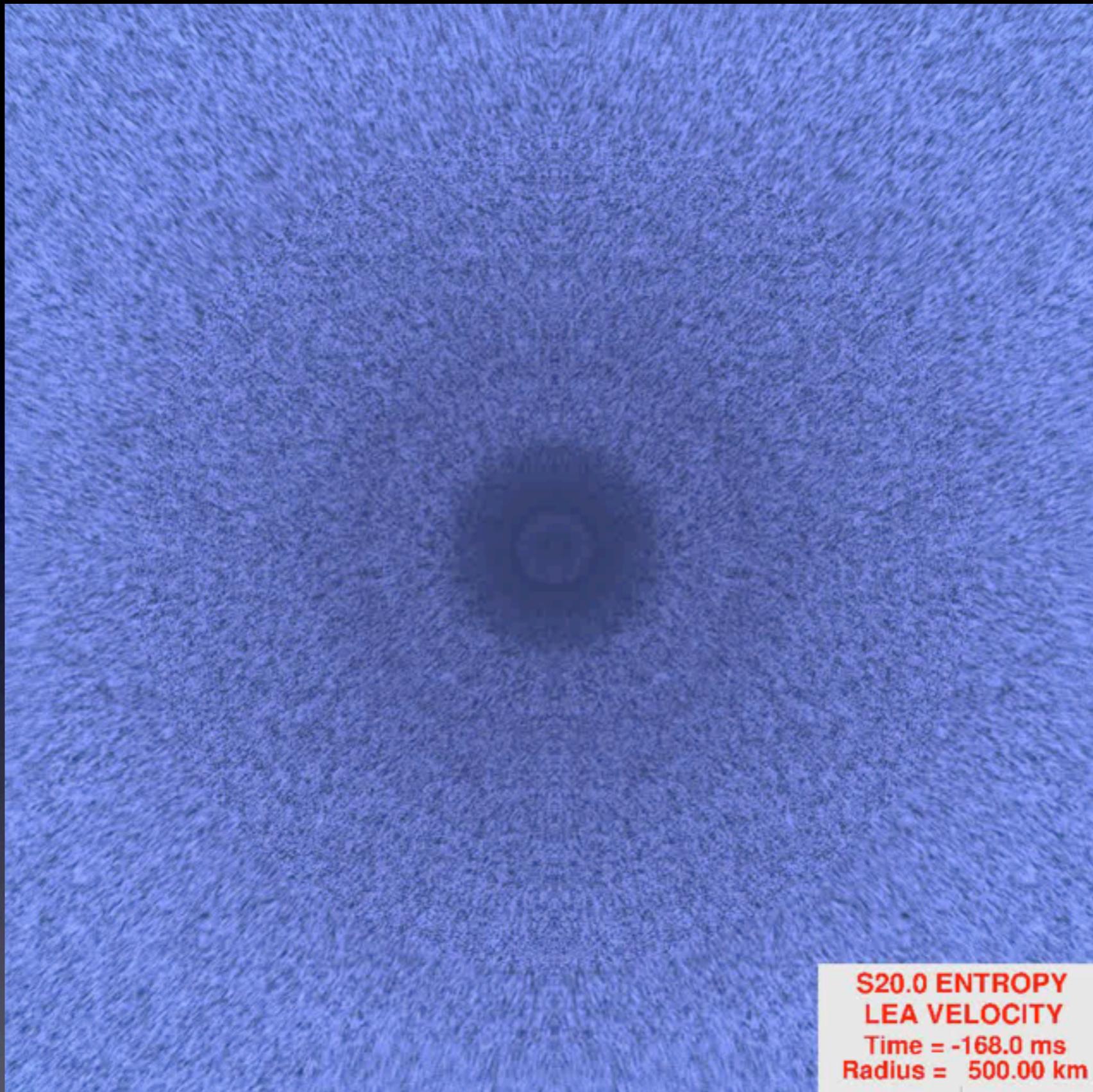
Supernova



- **End point of stellar life**
- **Origin of elements**
 - **Stellar nucleosynthesis**
 - **Explosive nucleosynthesis**
- **Huge kinetic energy**
 - **Injection to ISM**
 - **Cosmic ray acceleration**
- **Gravitational wave source**
- **Neutrino source**
 - **SN 1987A (in LMC)**

Big mystery in astrophysics

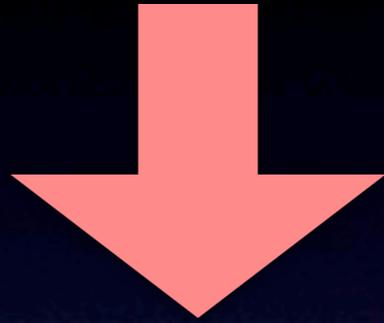




**A. Burrows
(Princeton)**

- **Neutrino mechanism: Germany, US, Japan, ...**
- **Magneto-rotational mechanism: Russia, US, Japan, ...**
(after **Bisnovatyi-Kogan 1970**)

Observations of supernovae



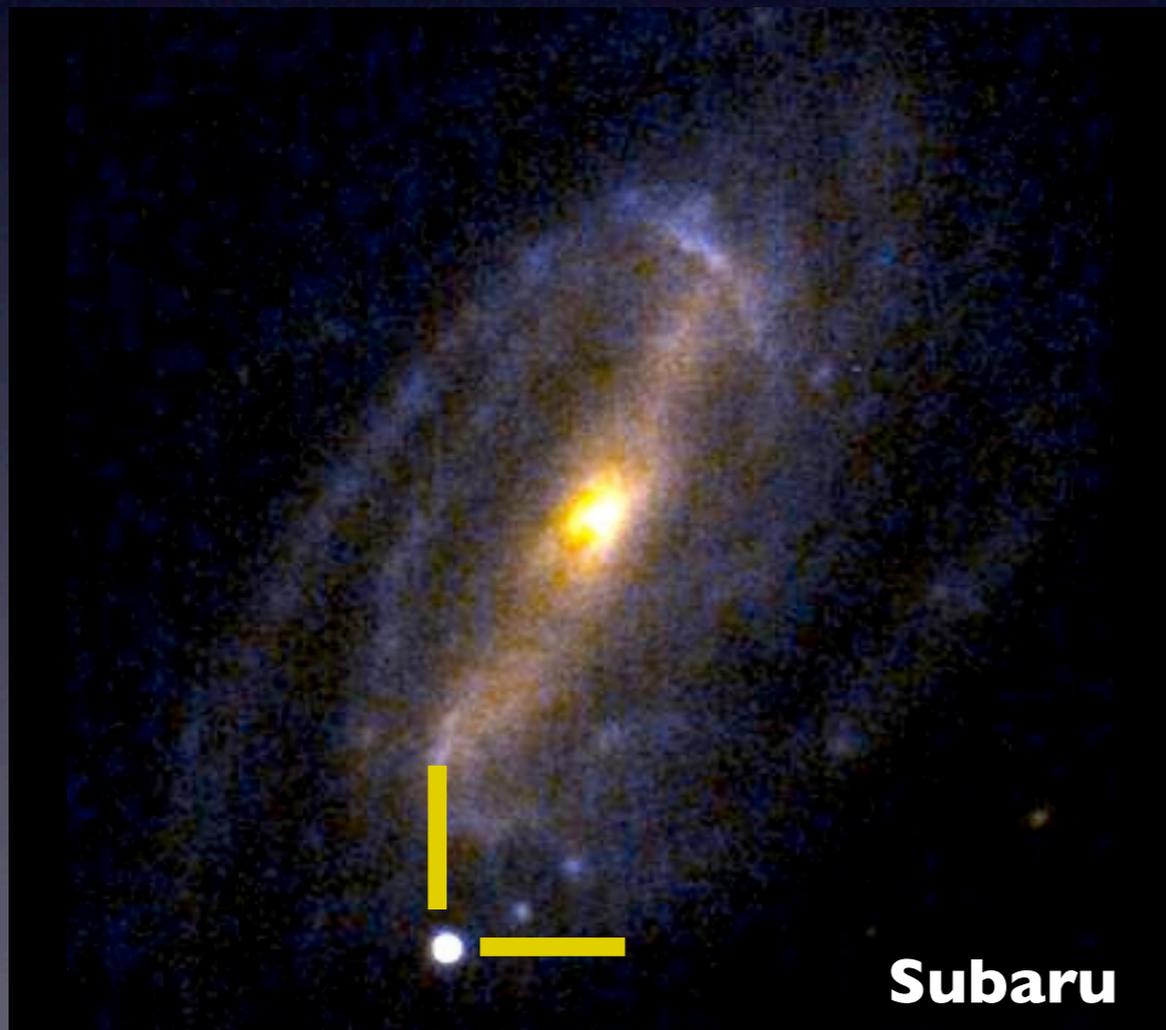
**Three-dimensional geometry
of supernovae**



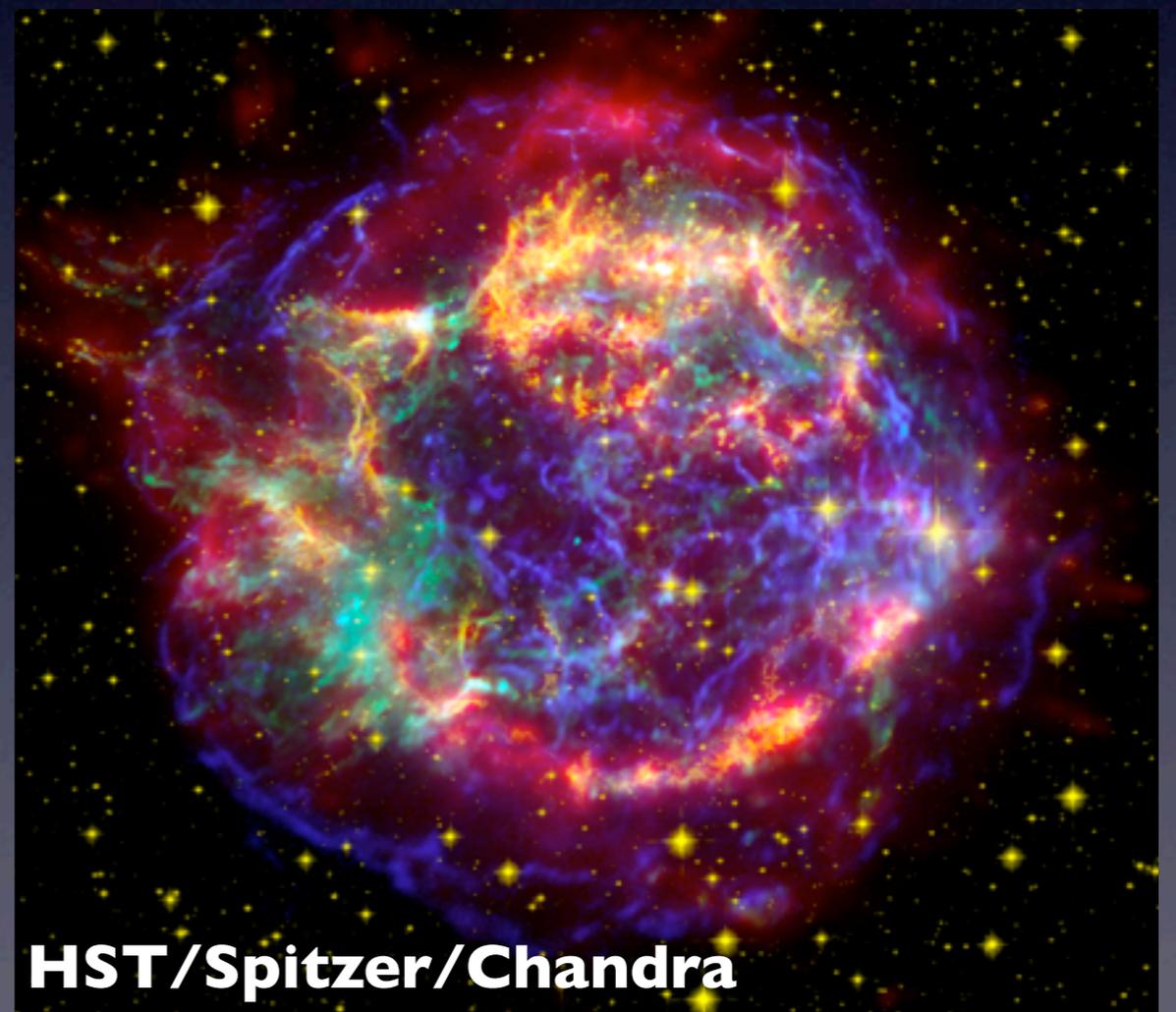
Mechanism of the explosion

Observations of supernovae

**Young supernovae
($< 2-3$ yr)**

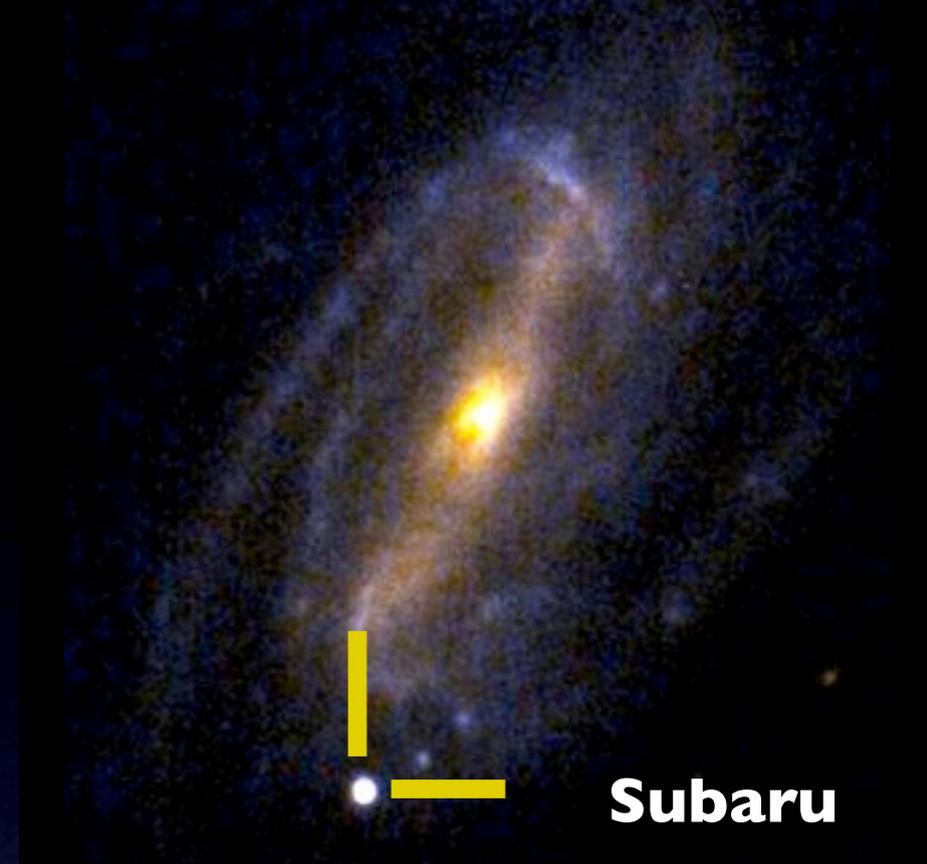


**Supernova remnants
(> 300 yr)**

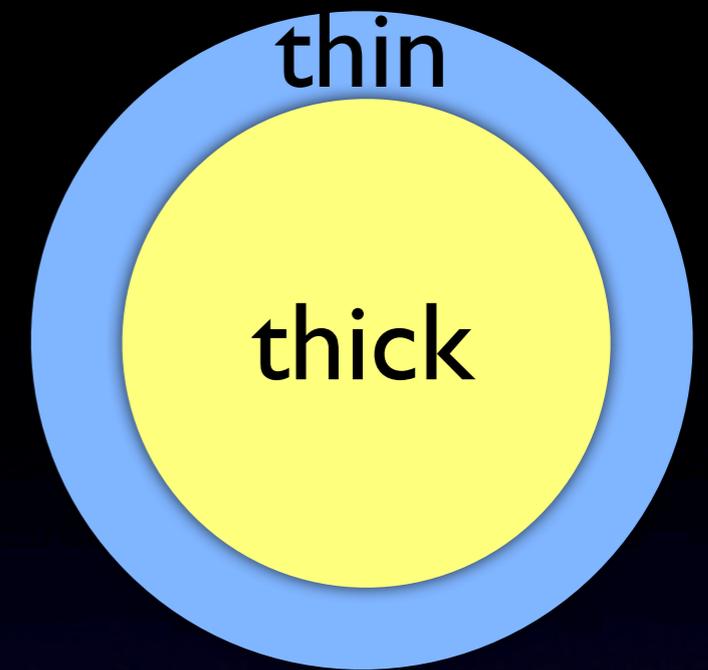
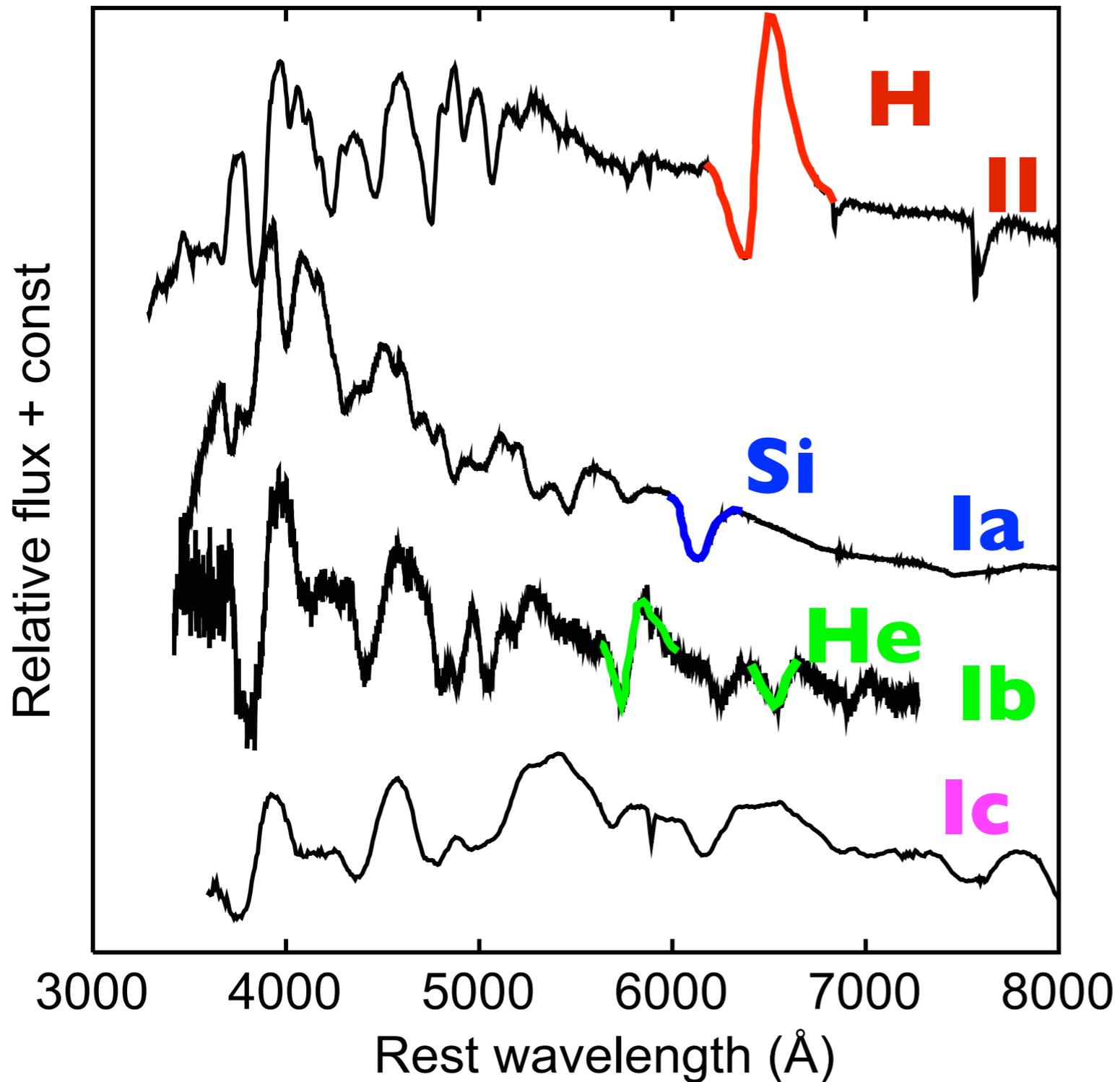


Extragalactic Supernova

- **Velocity** $\sim 10,000$ km/s
- **Radius** $\sim 2 \times 10^{15}$ cm ~ 0.001 pc @ 30d
- $\tau \sim n_e \sigma R \sim 10^2 (t/10 \text{ days})^{-2}$
optically thick \Rightarrow thin (~ 1 yr)
- **Distance** ~ 30 Mpc ($\sim 10^{26}$ cm ~ 100 Mly)
- **Angular size** $\sim 10^{-6}$ arcsec @ 30d
Point source!



Spectrum



Type II: Hydrogen

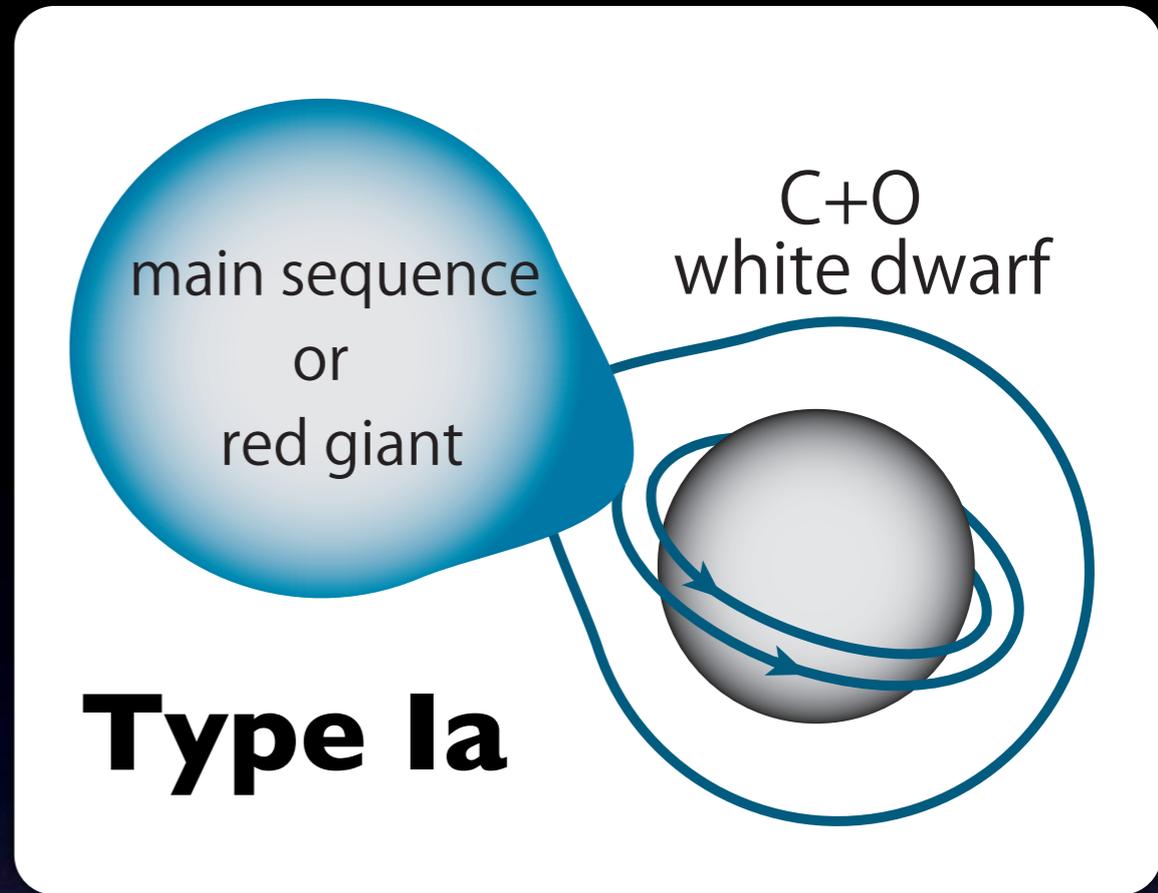
Type I: No hydrogen

Ia: Strong Si

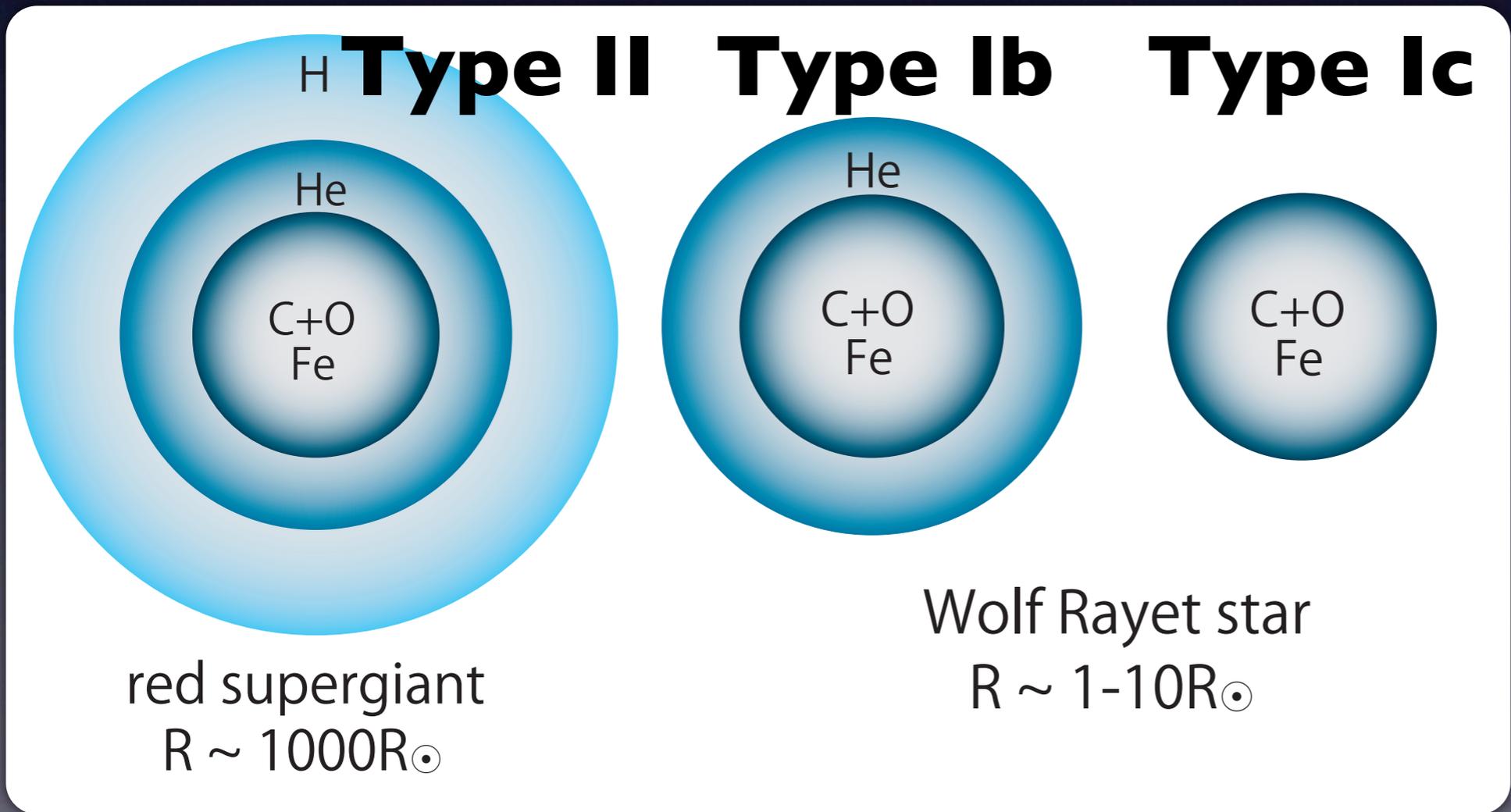
Ib: Strong He

Ic: No strong Si/He

Progenitors of supernovae



Massive stars

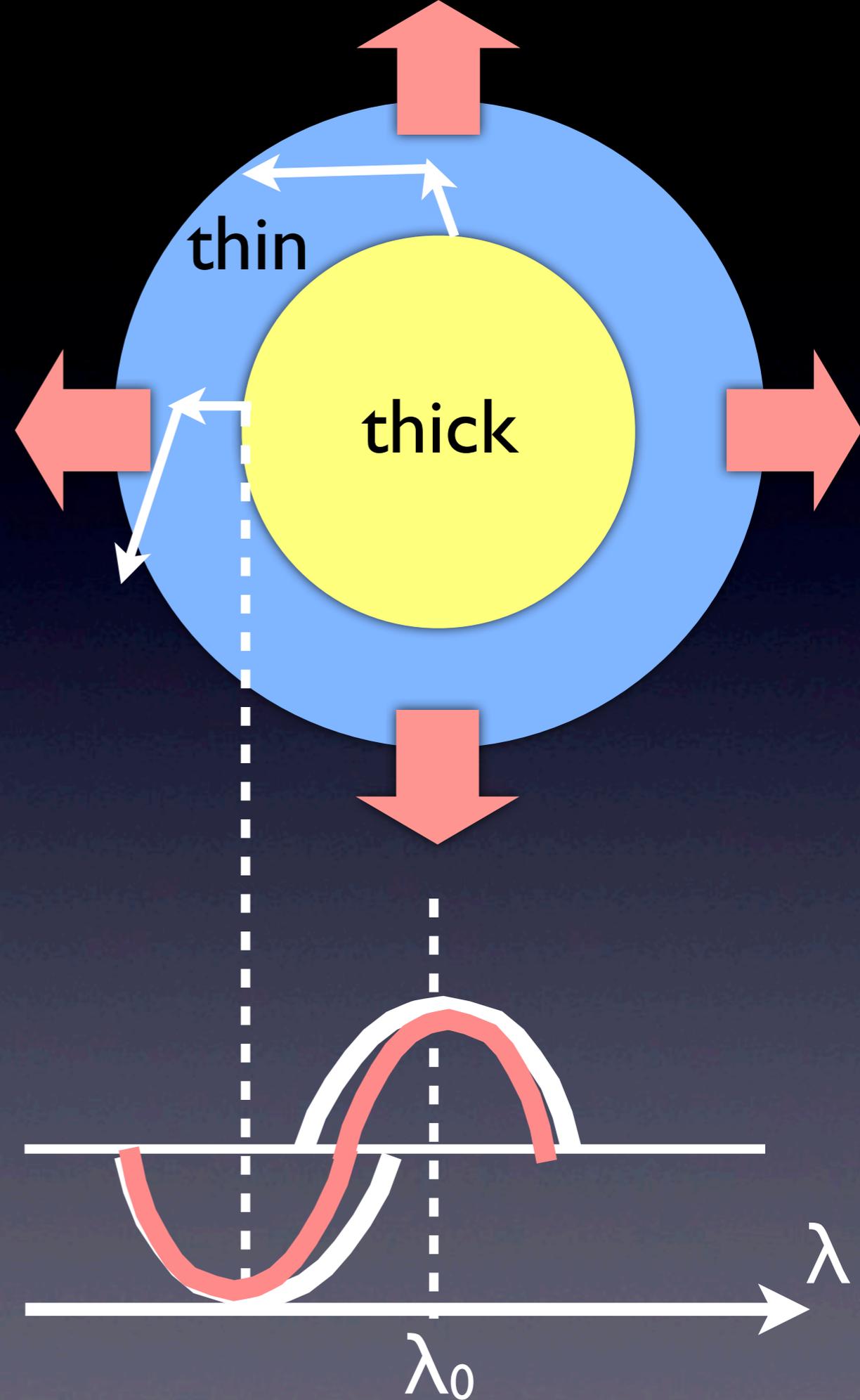


White dwarfs

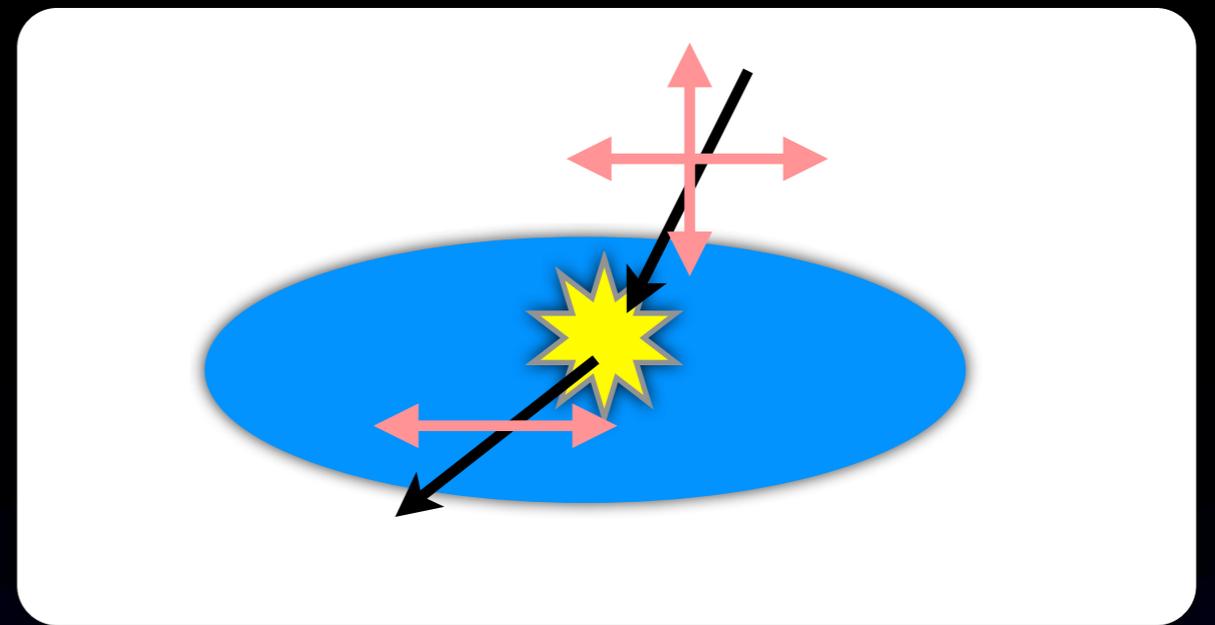
“P-Cygni” profile

Element abundance
&
Expansion velocity
 $v \sim 10,000 \text{ km/s}$

No information
of geometry



Power of polarization

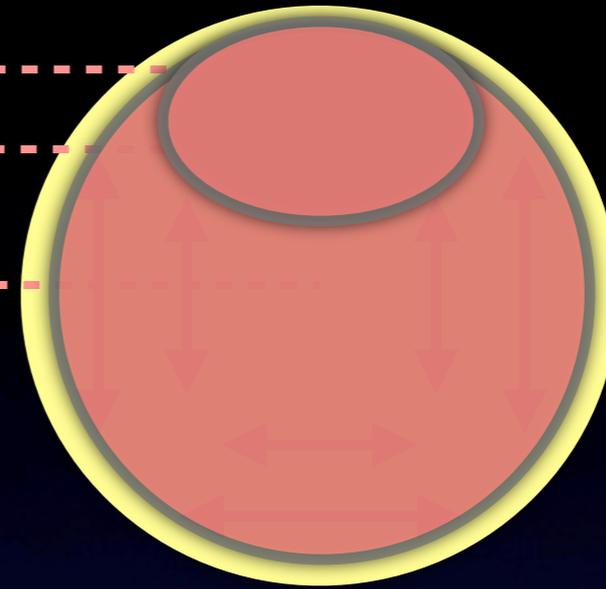
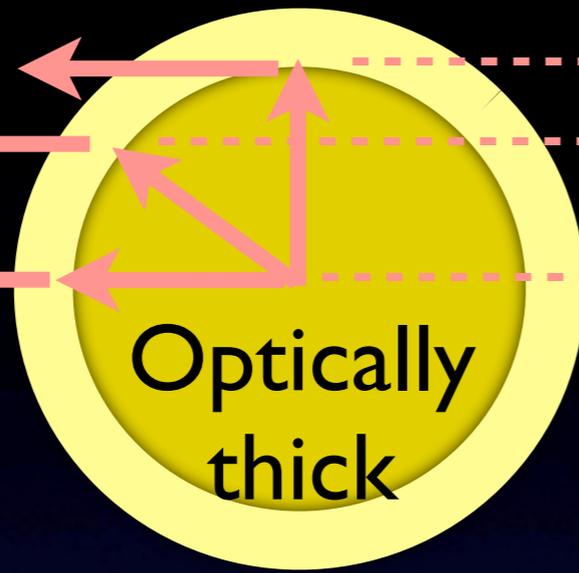


**With
polarization filter
(cutting )**

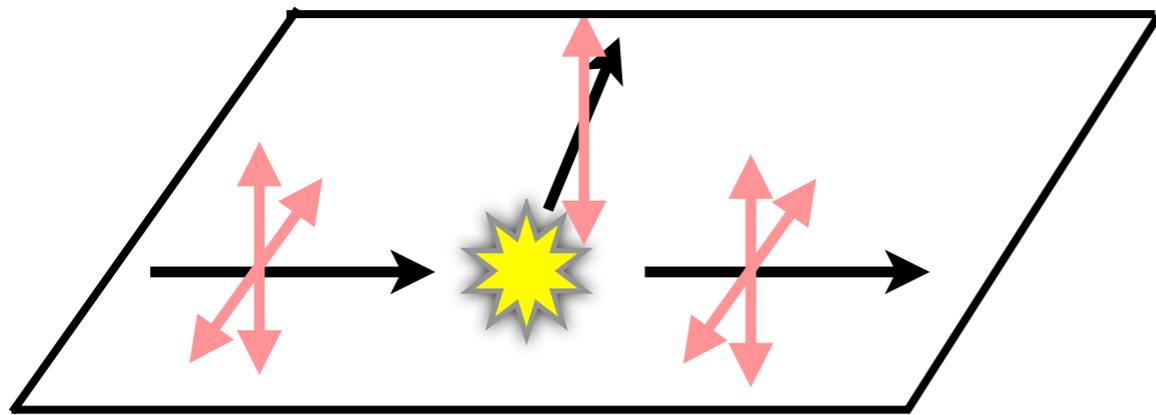
From the side

On the sky

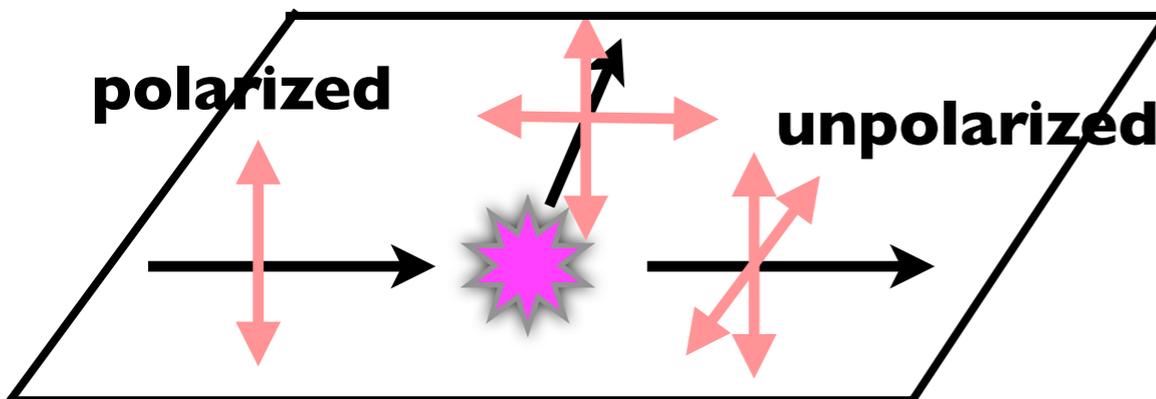
Observer



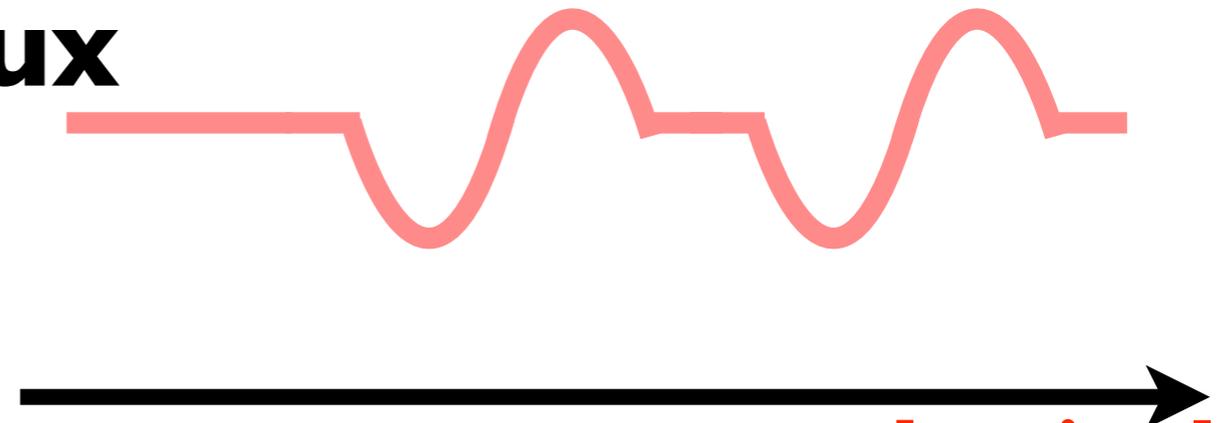
Electron scattering



Line scattering

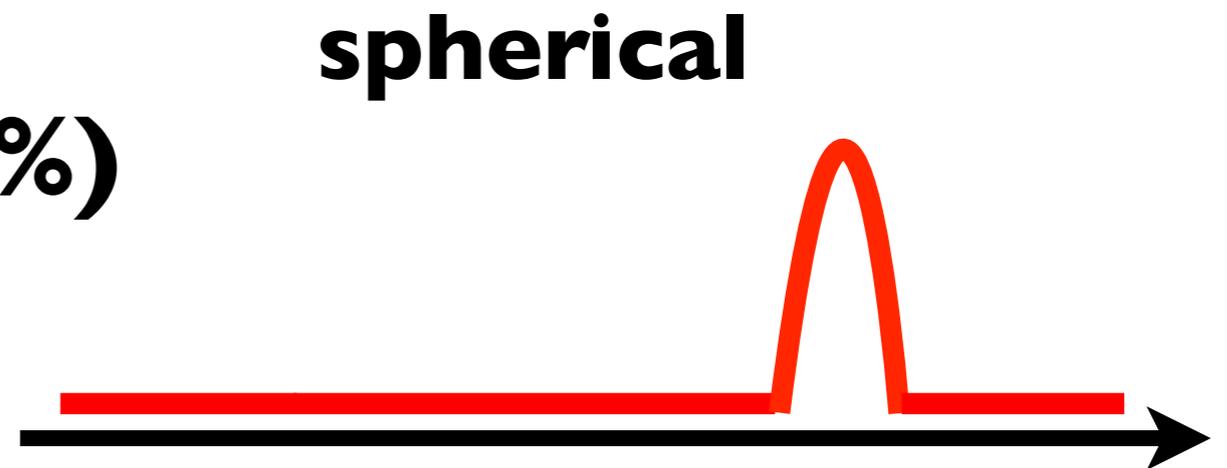


Flux

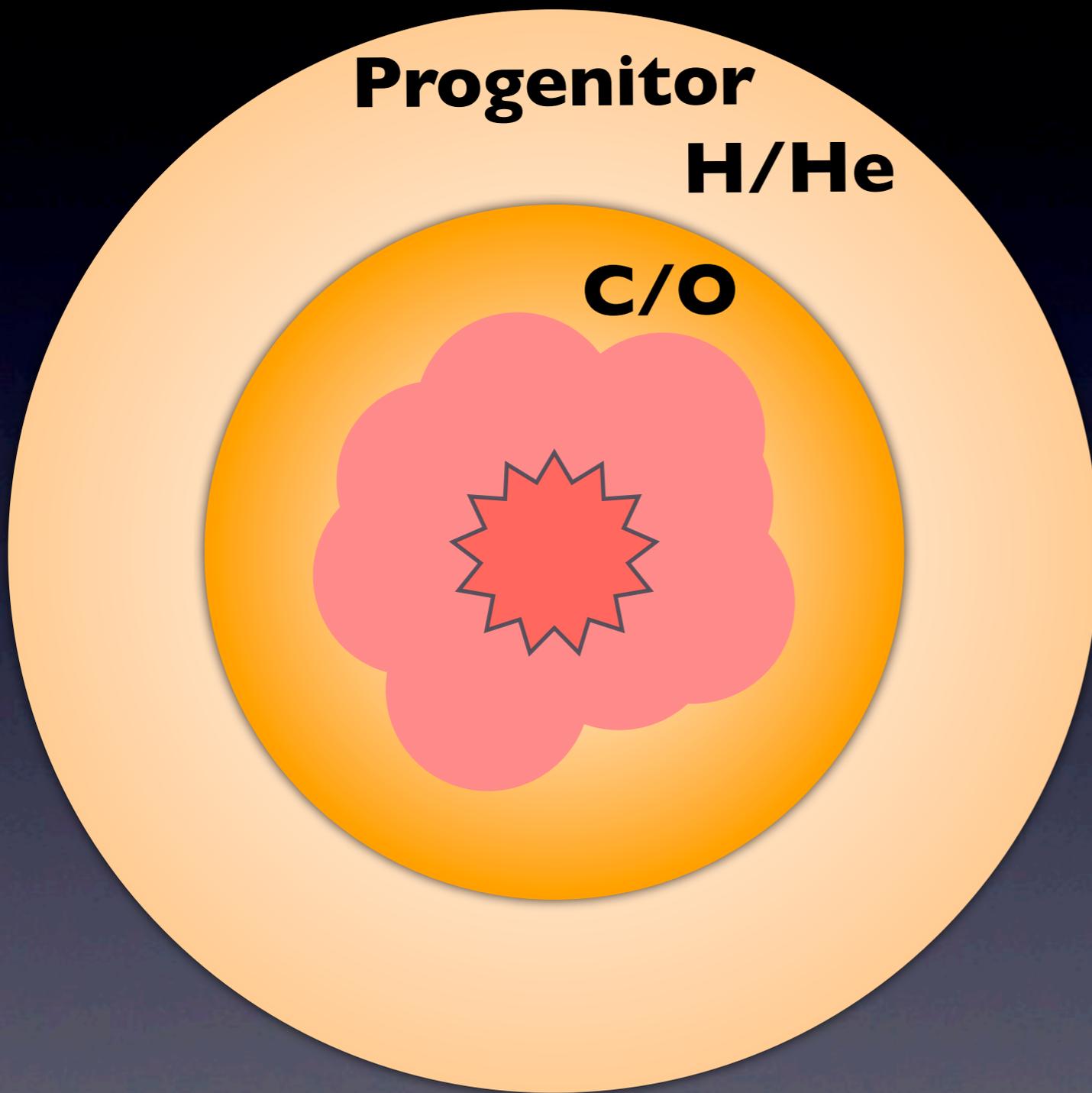


aspherical

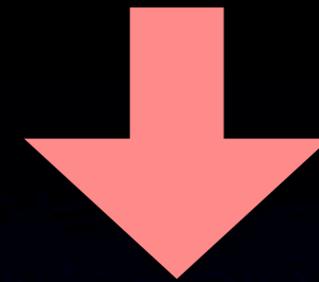
P(%)



spherical



Explosion



Nucleosynthesis



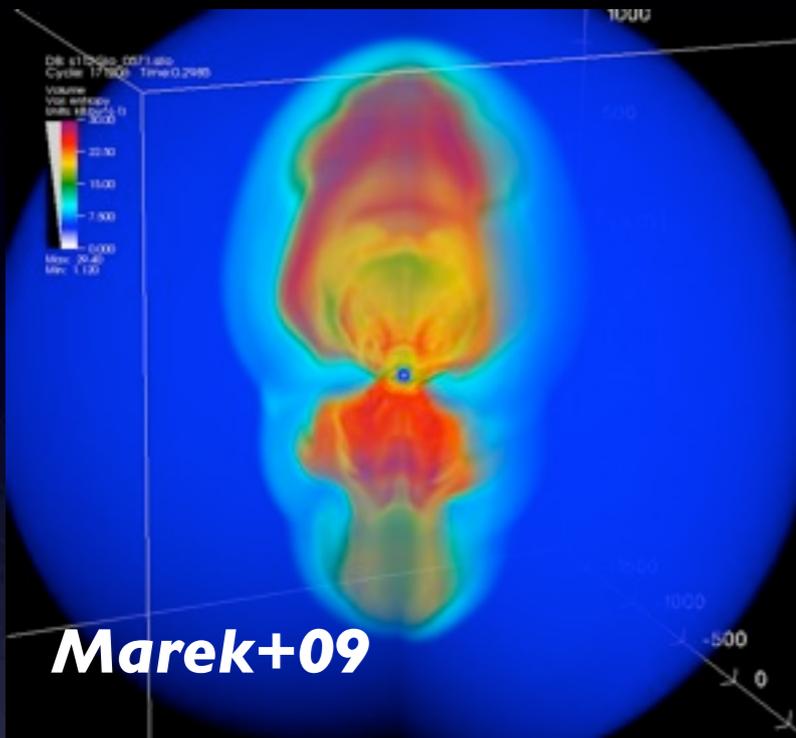
Absorption line
(progenitor/explosive)



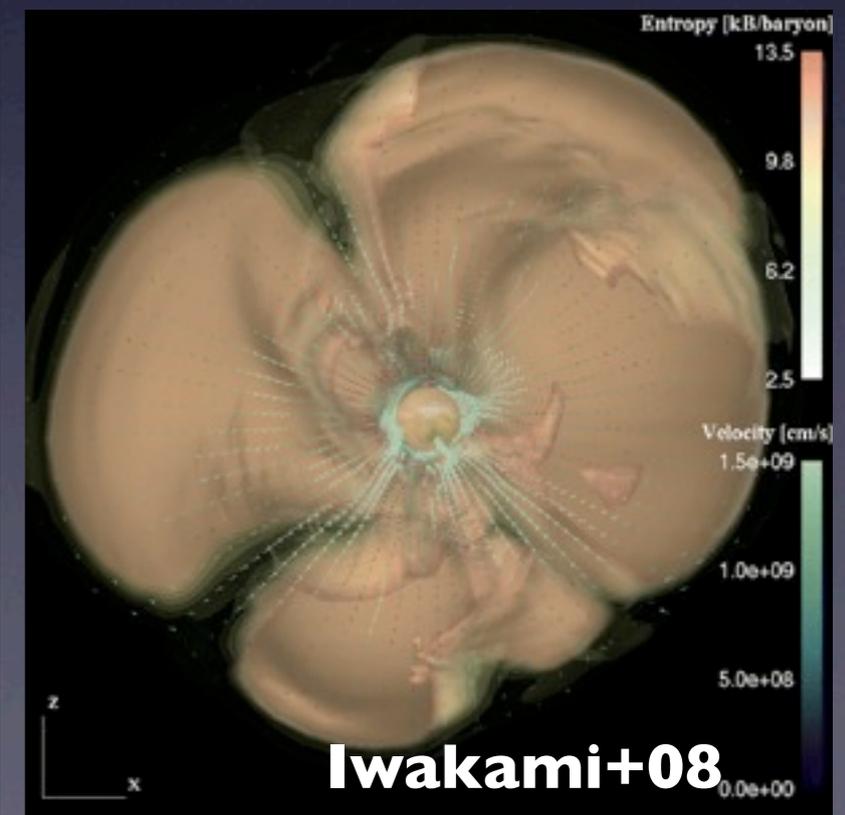
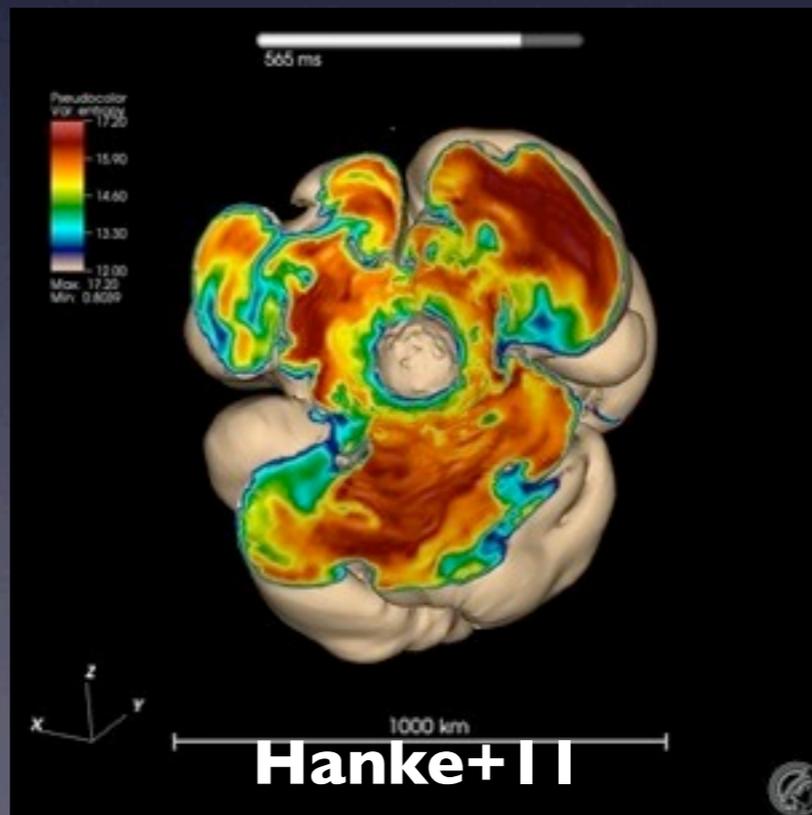
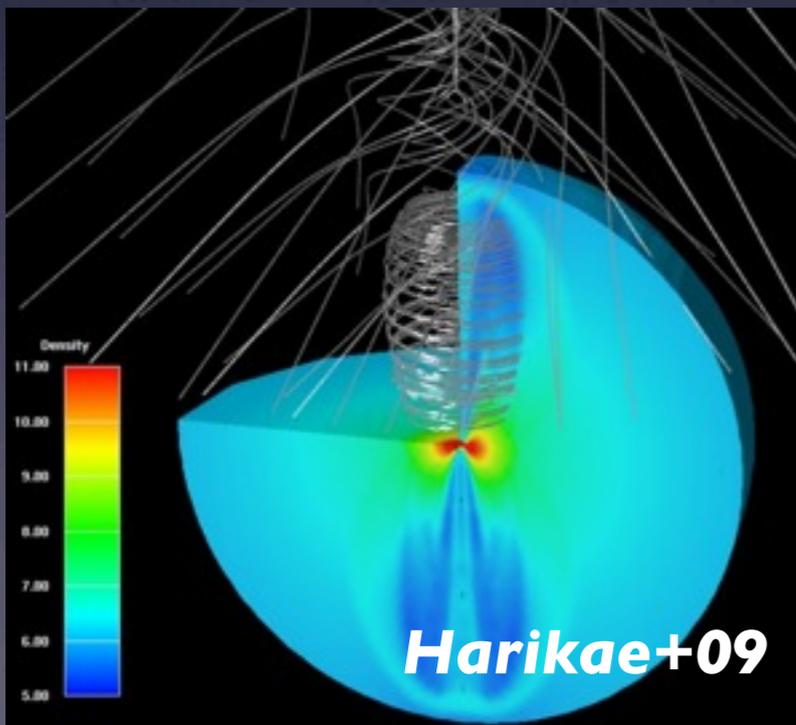
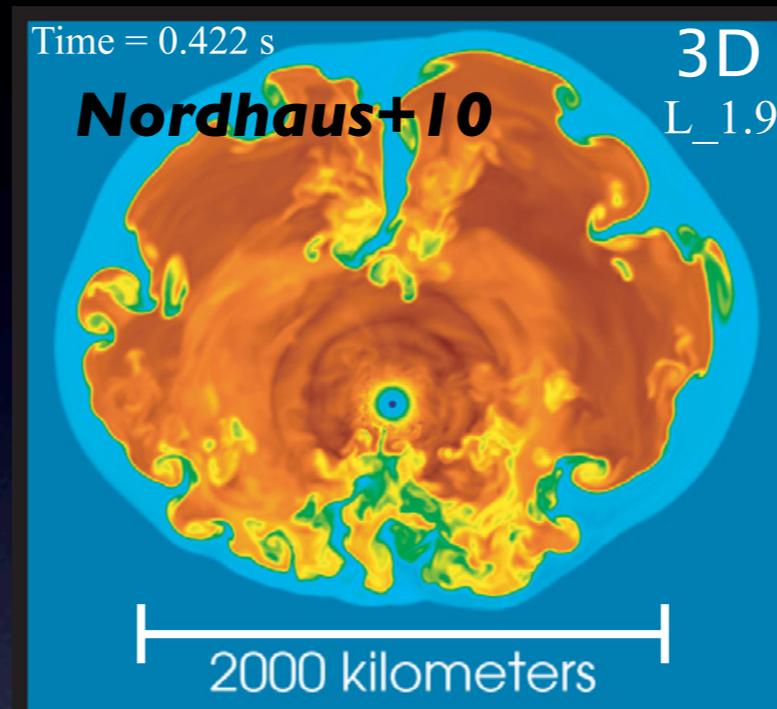
Line polarization
Type Ibc (w/o H)

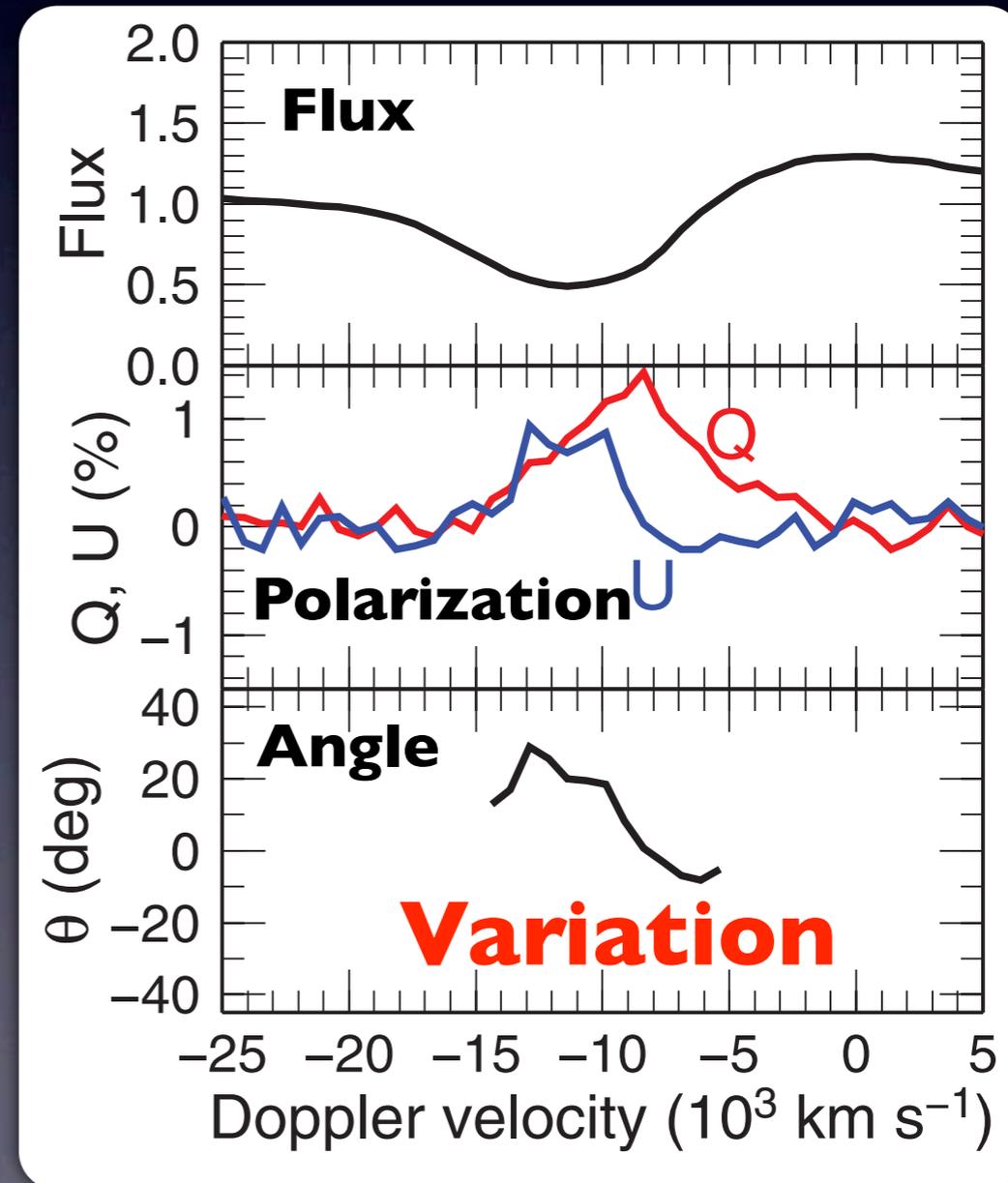
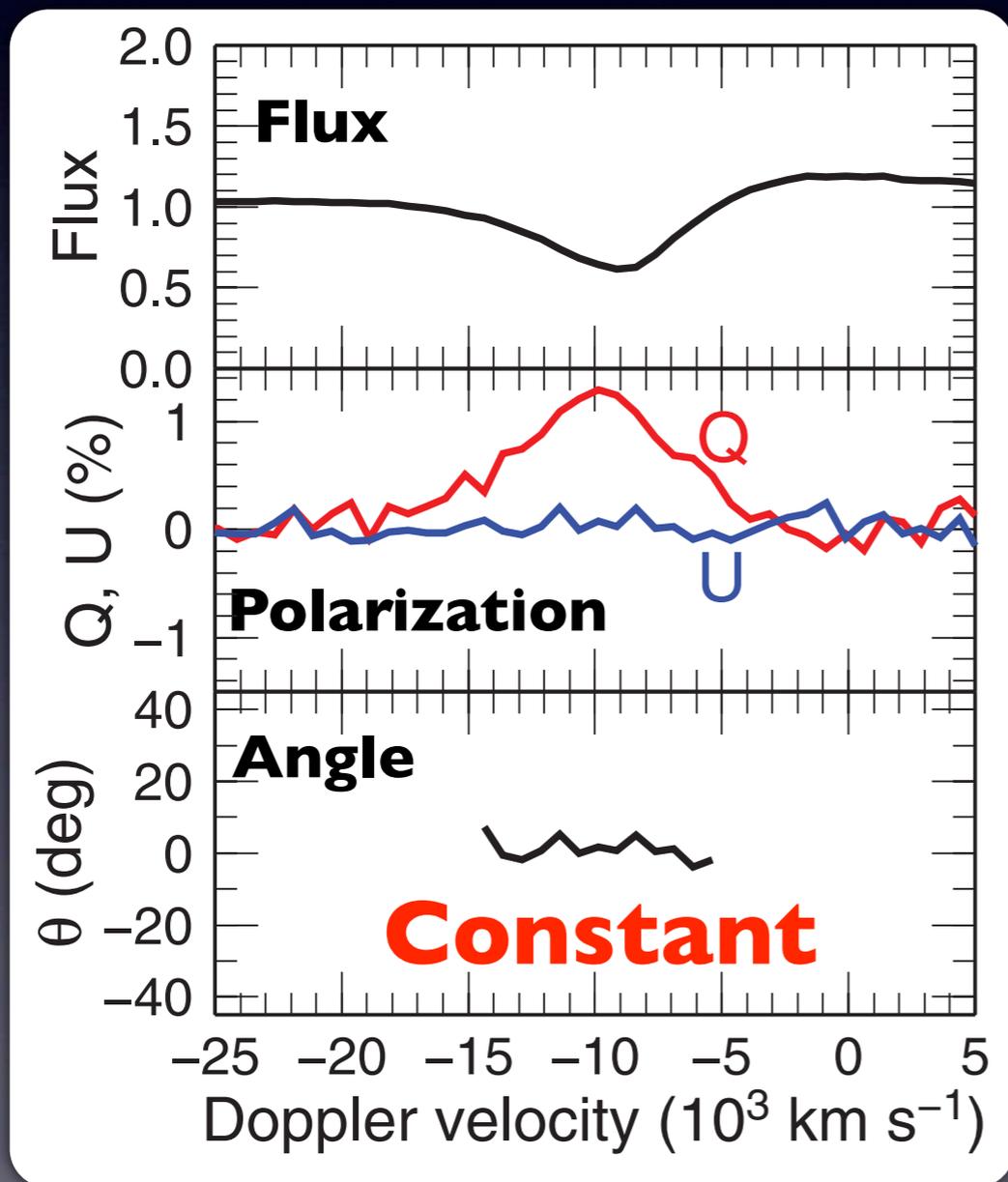
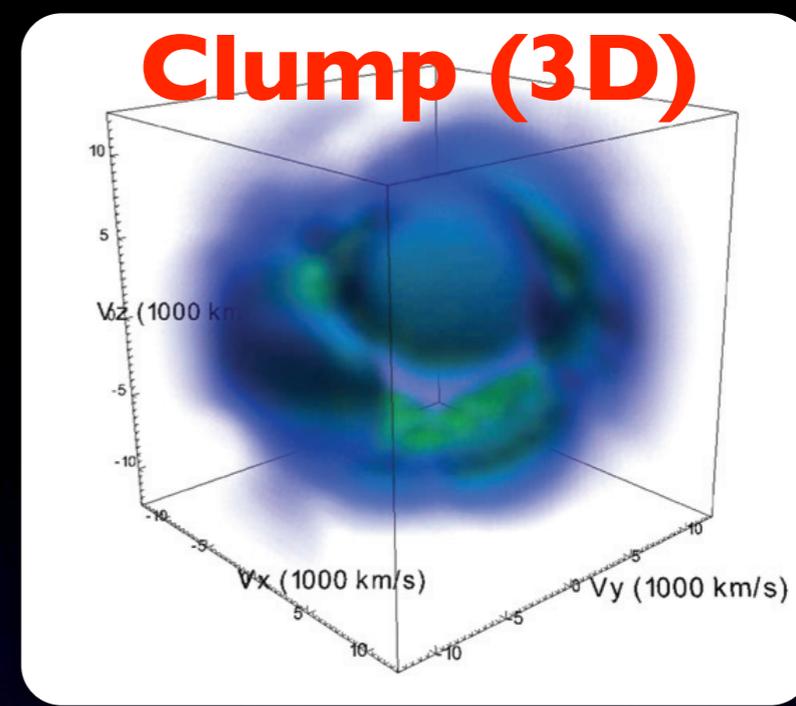
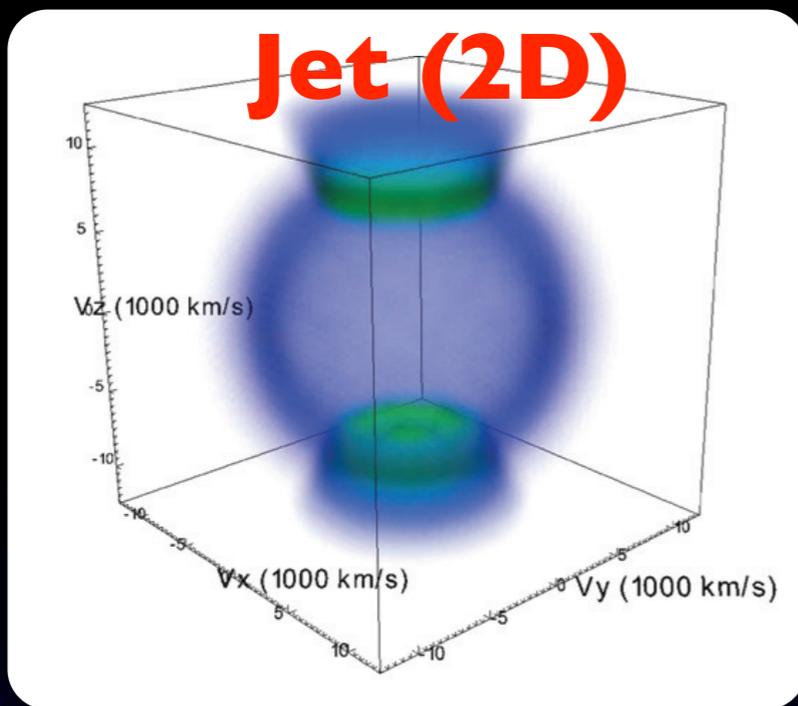
Diagnostic of the Geometry?

2D bipolar flow ?



3D convection?





Polarization ~ 1 %
Measurement error ~ 0.1 %

SN
with ~16 mag

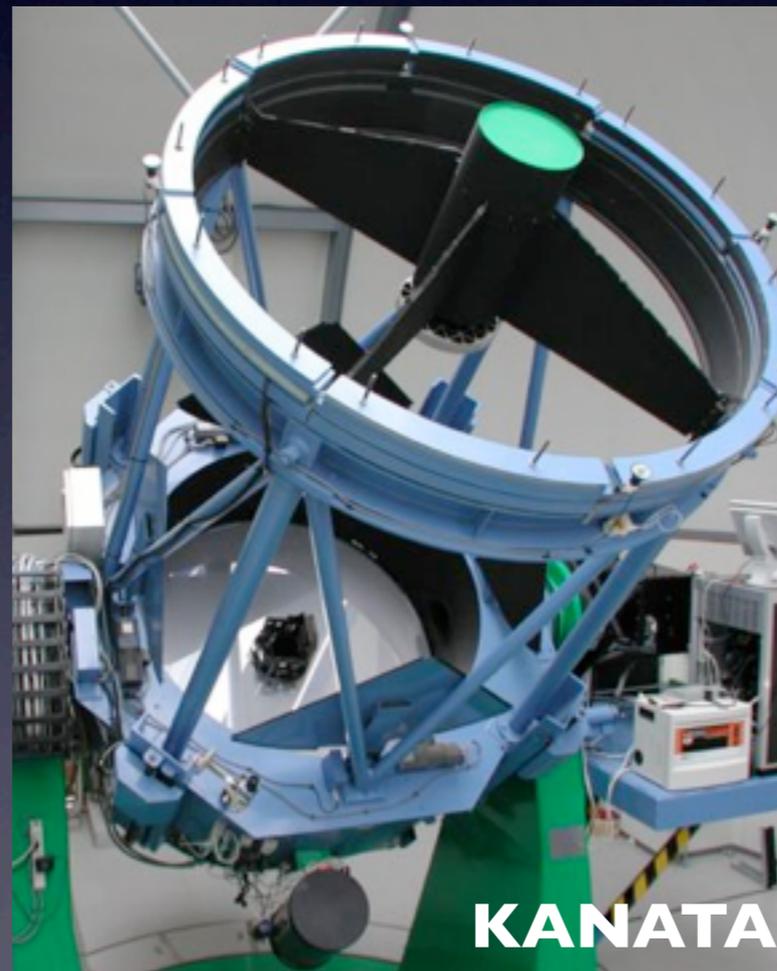
Spectro-
polarimetry

Spectroscopy

Imaging



0.5-1 m

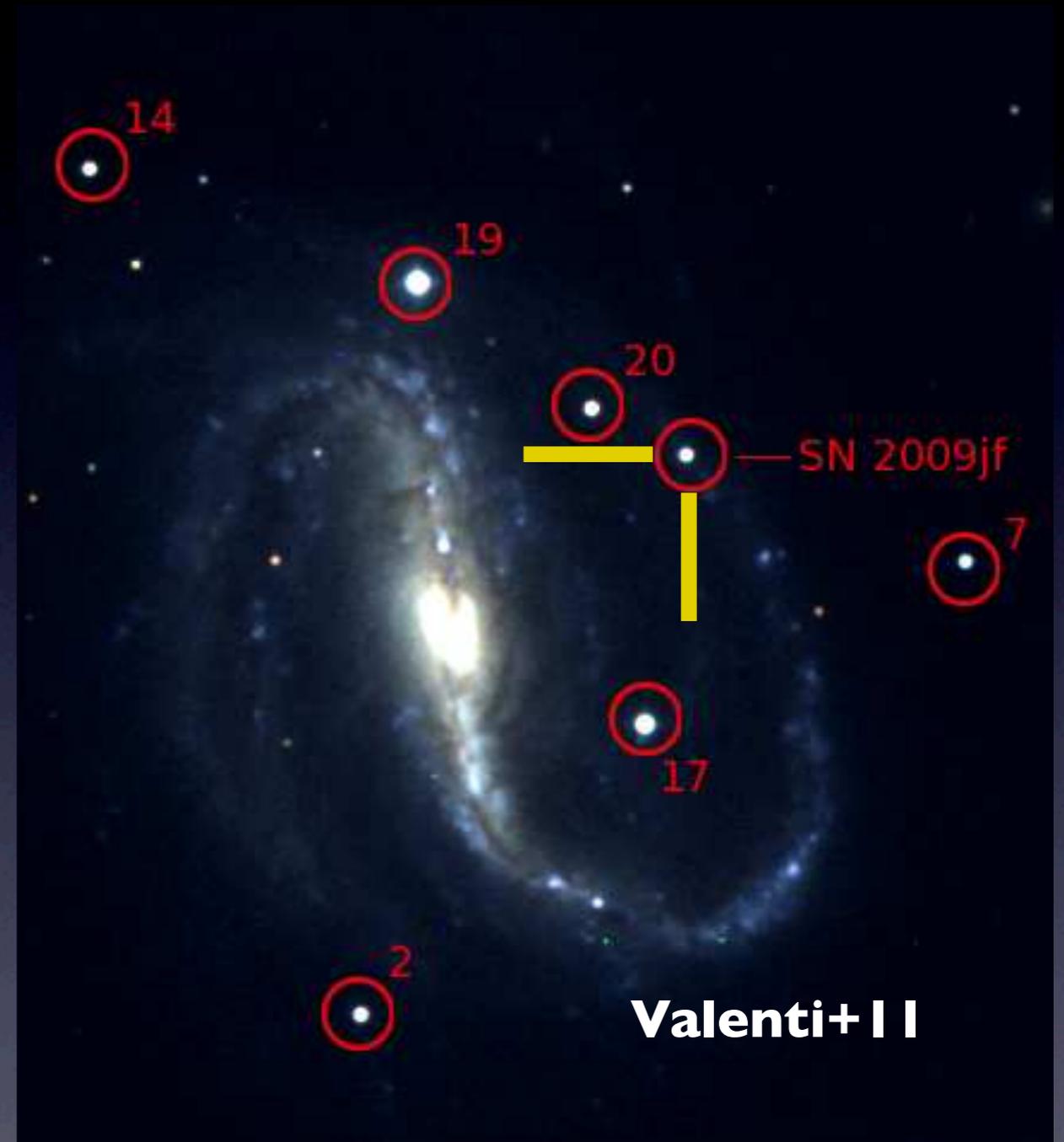
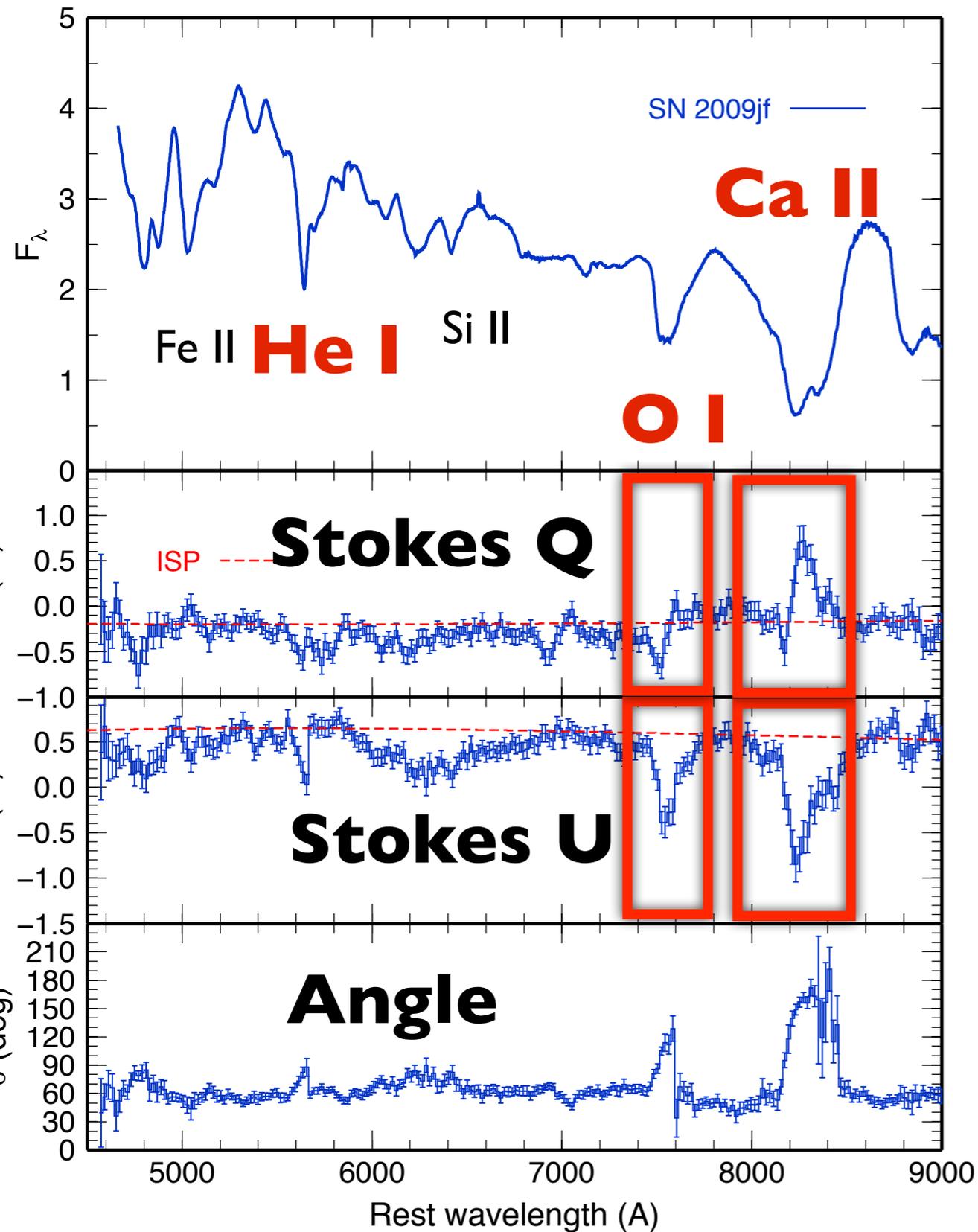


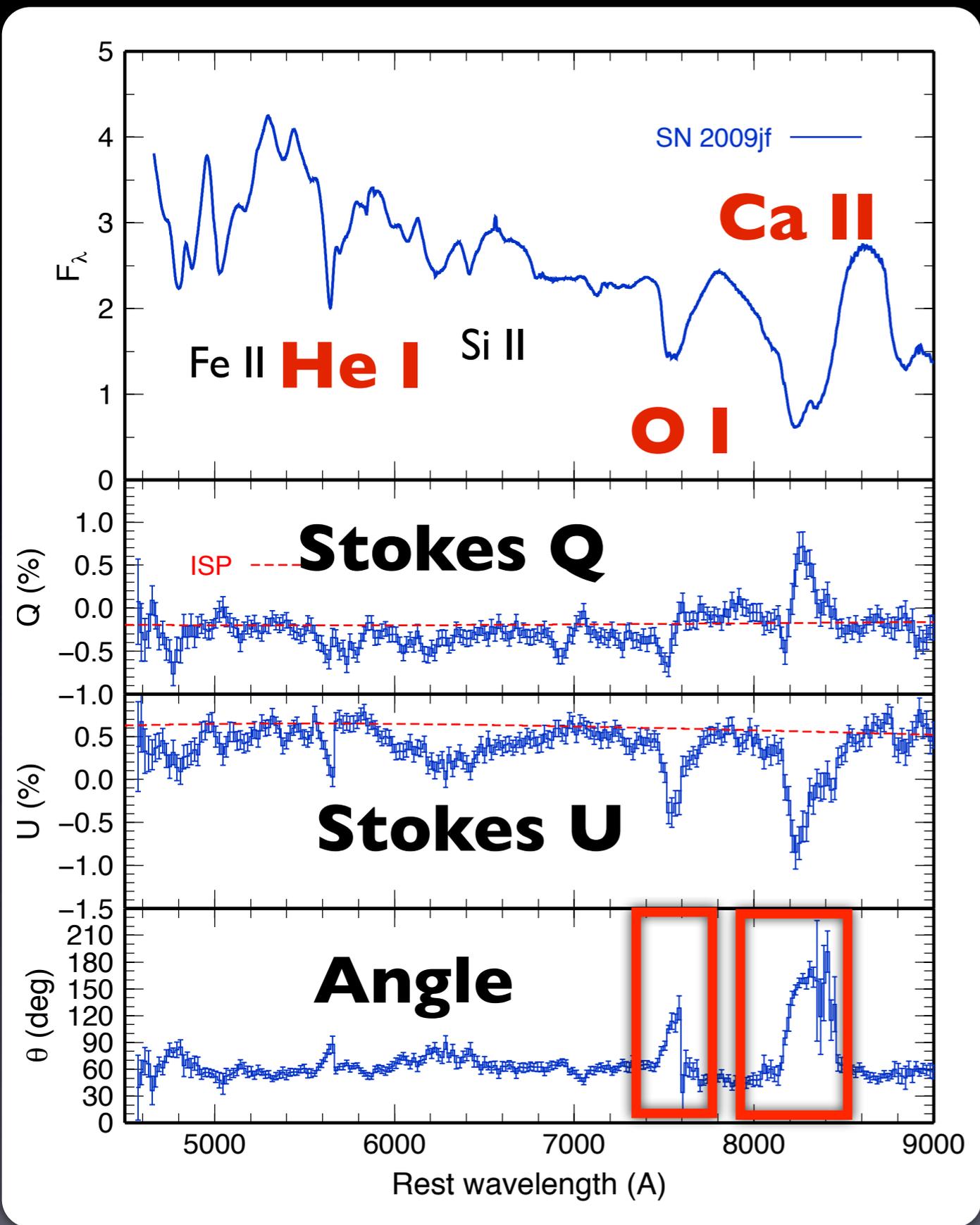
1-4 m



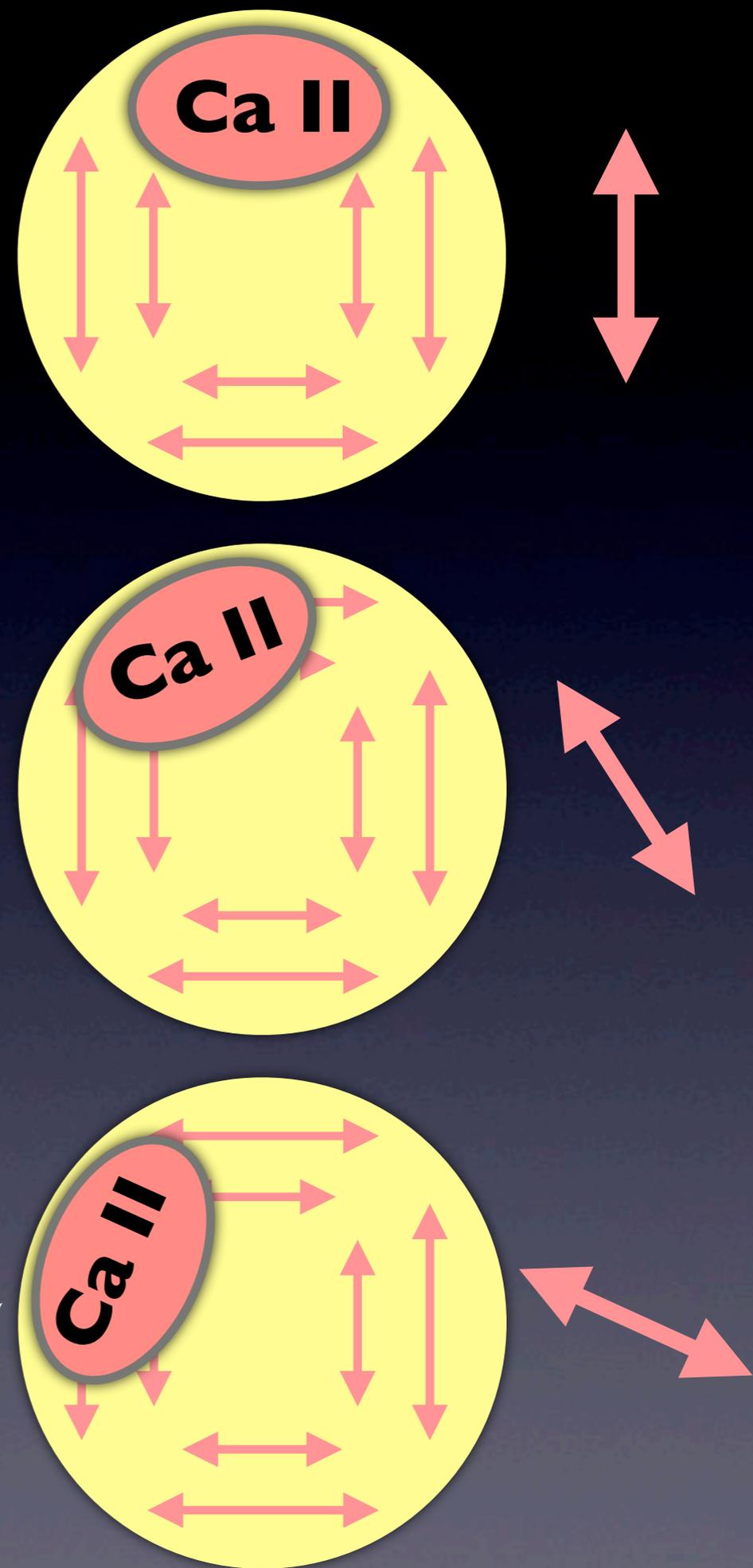
8-10 m

SN 2009jf (Ib)

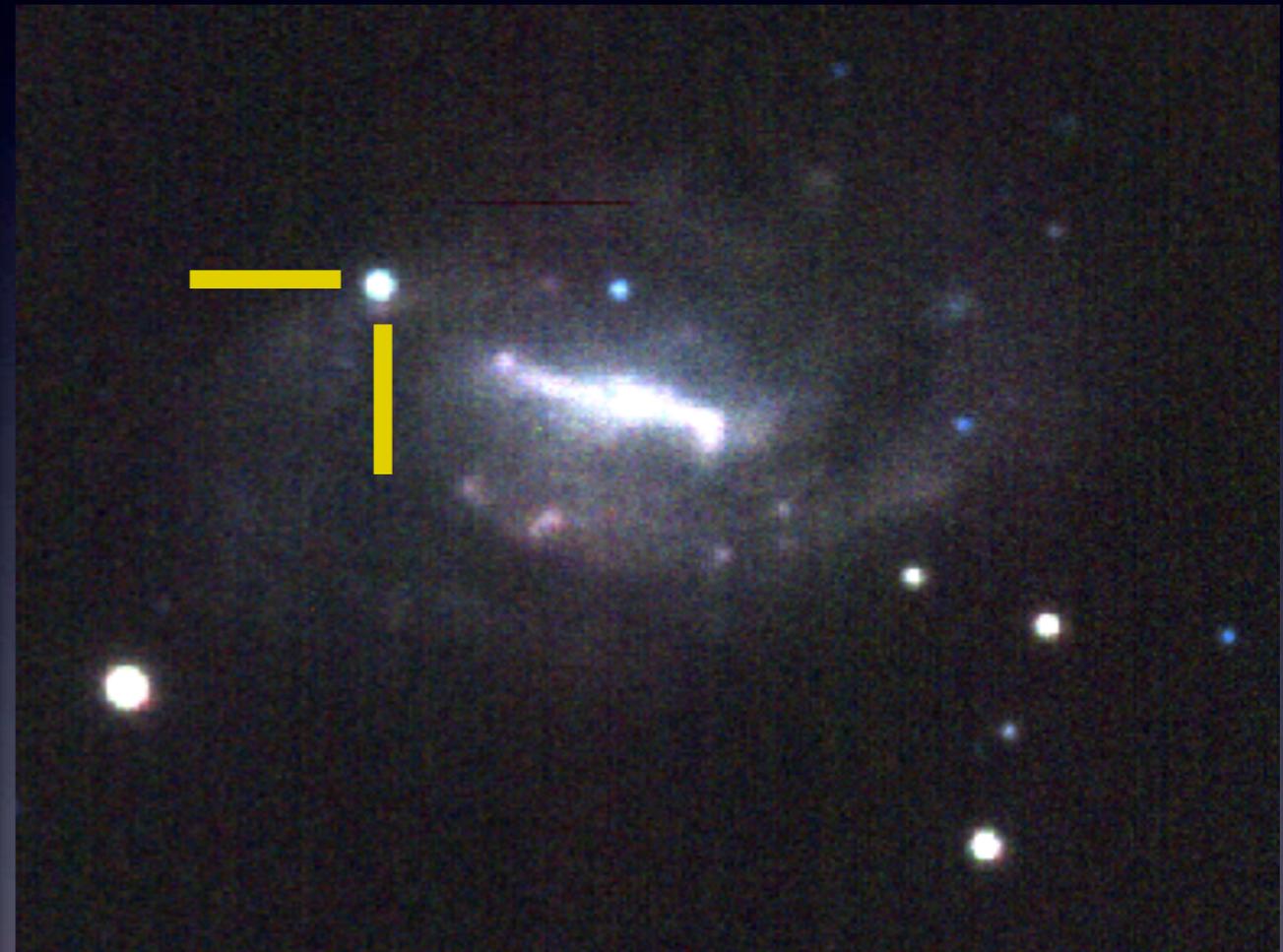
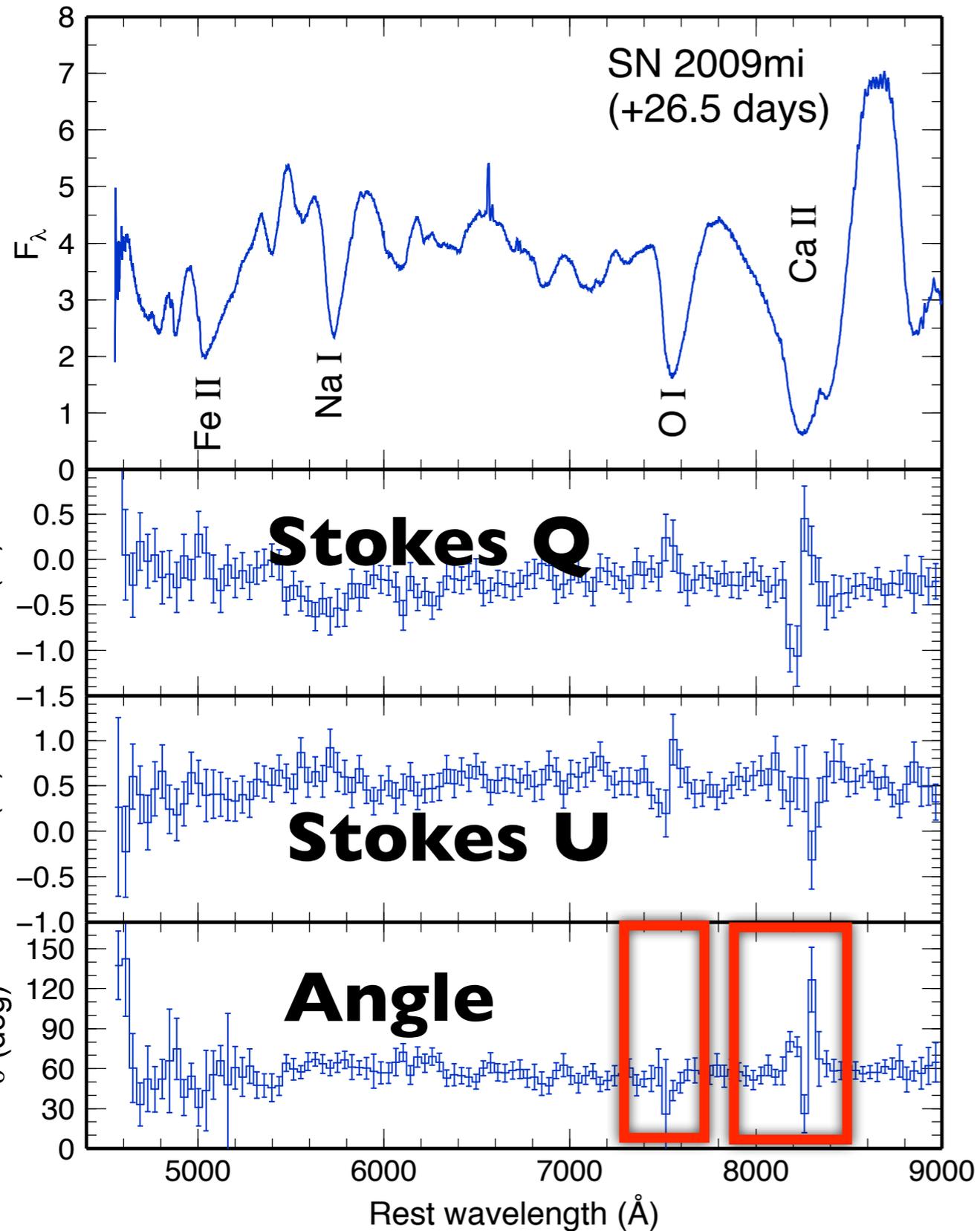




Depth (Doppler velocity)



SN 2009mi (Ic)



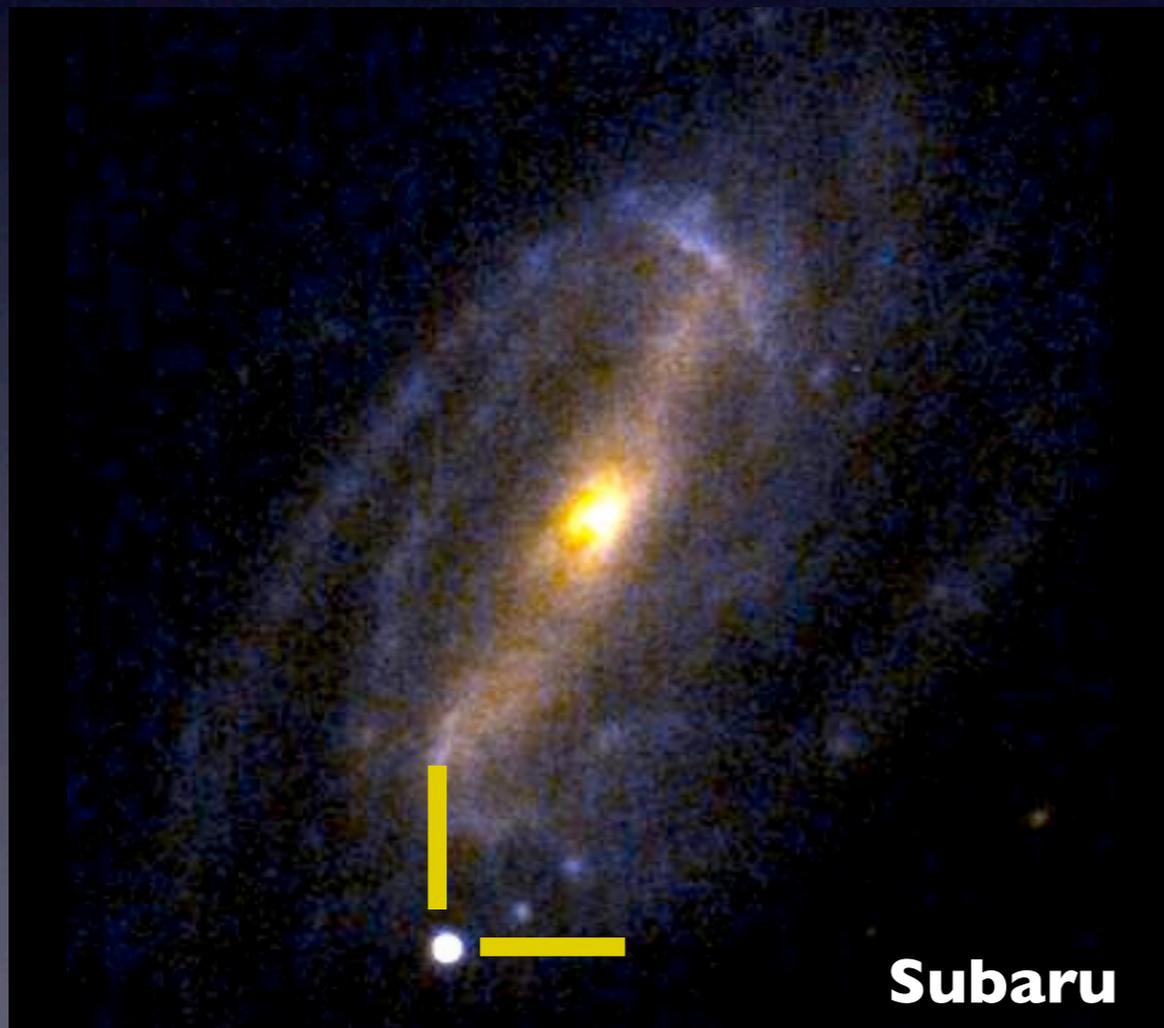
Object	Type	3D?	Ref.
SN 2002ap	Ic broad	YES	Kawabata+02, Leonard+02, Wang+03
SN 2005bf	Ib	YES	Maund+07, MT+09
SN 2007gr	Ic	No	MT+08
SN 2008D	Ib	YES	Maund+09
SN 2009jf	Ib	YES	MT+12
SN 2009mi	Ic	YES	MT+12

Non-axisymmetric signature is common

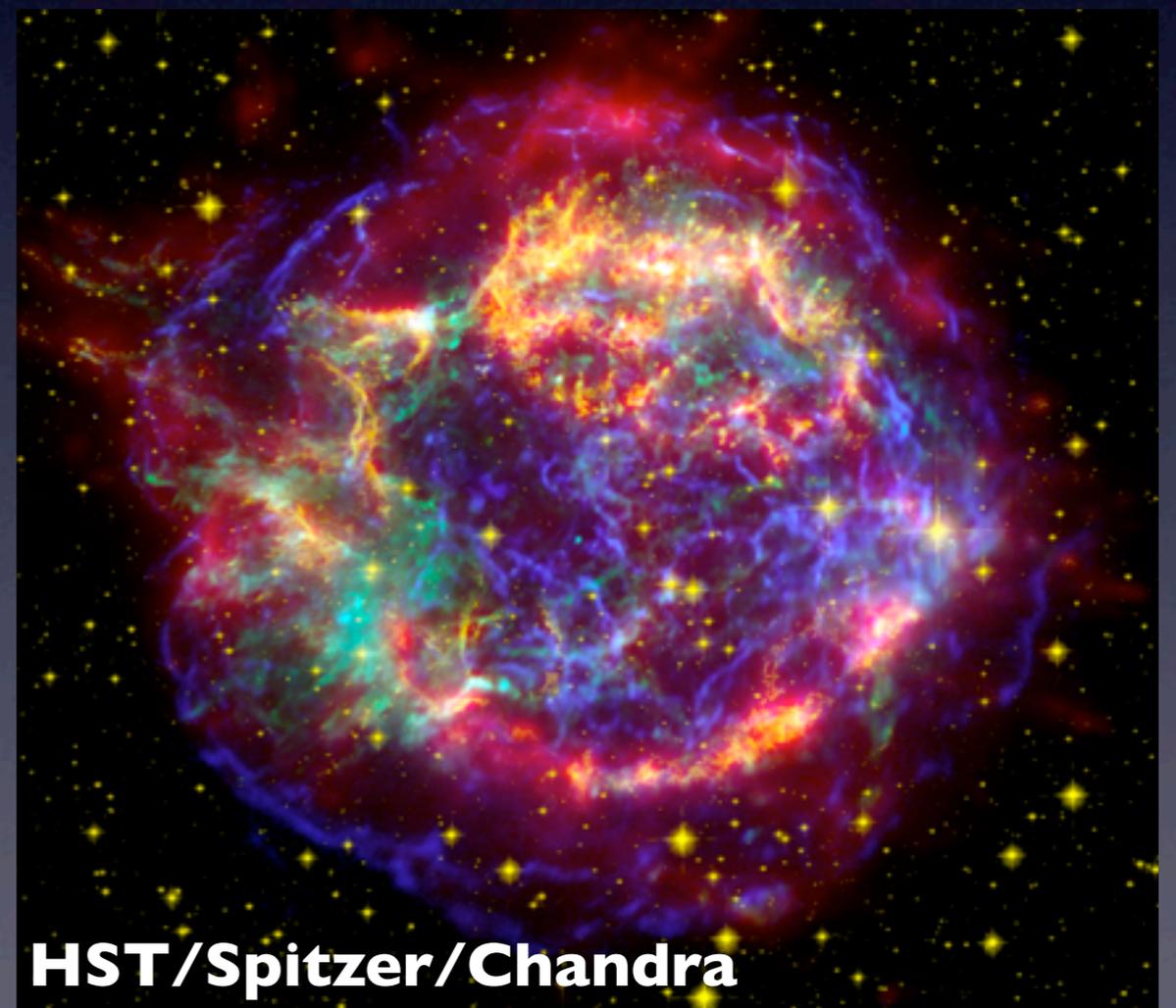
Tanaka+2012, ApJ, 754, 63

Observations of supernovae

**Young supernovae
($< 2-3$ yr)**

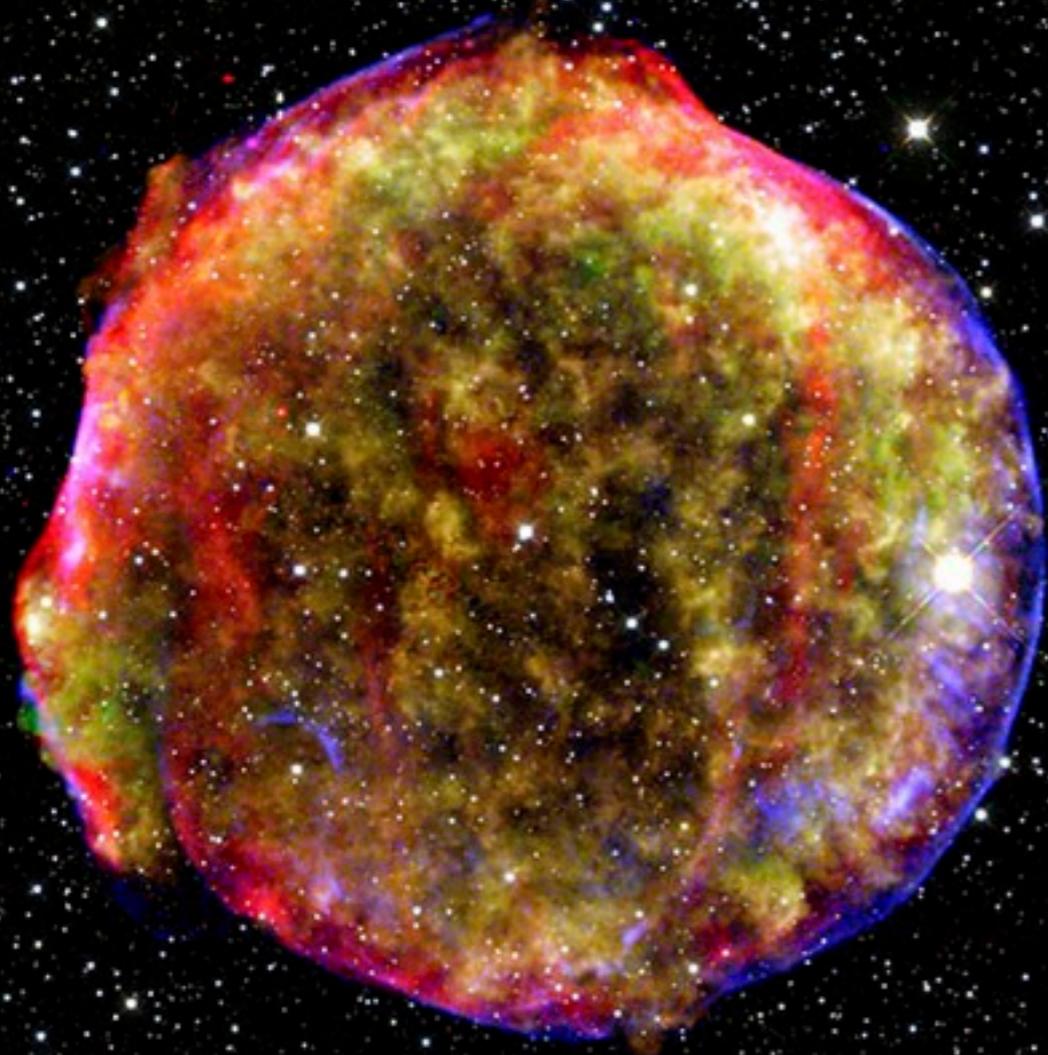


**Supernova remnants
(> 300 yr)**





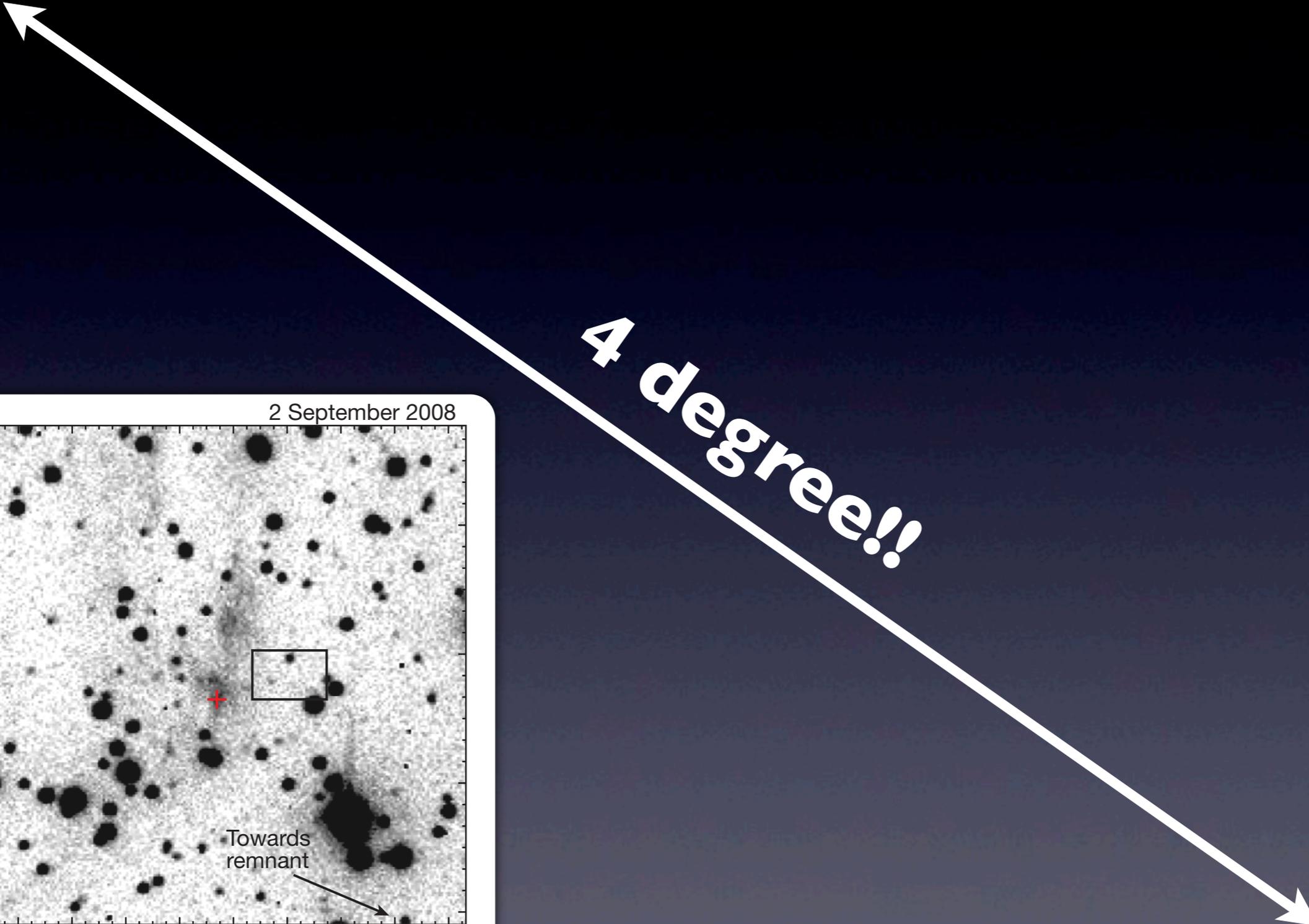
C: NASA/Chandra/MPIA



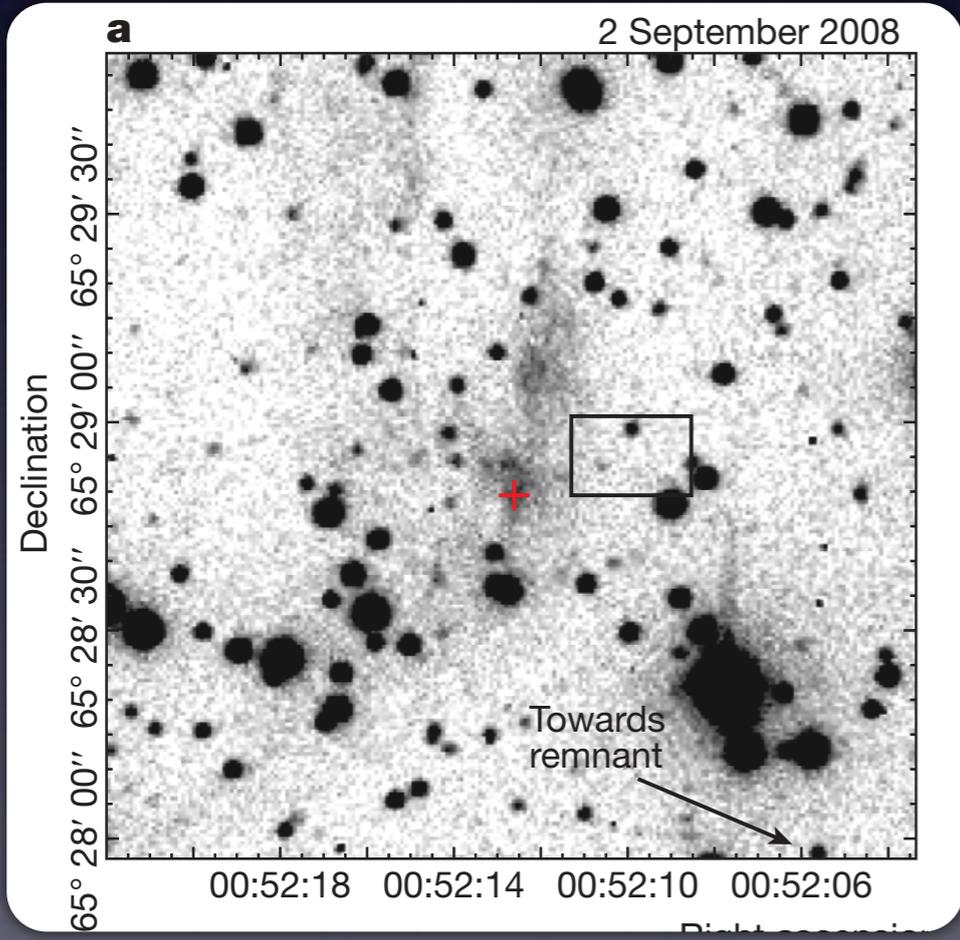
1572



**“Astronomie Populaire”
by Camille Flammarion (Paris, 1884)**



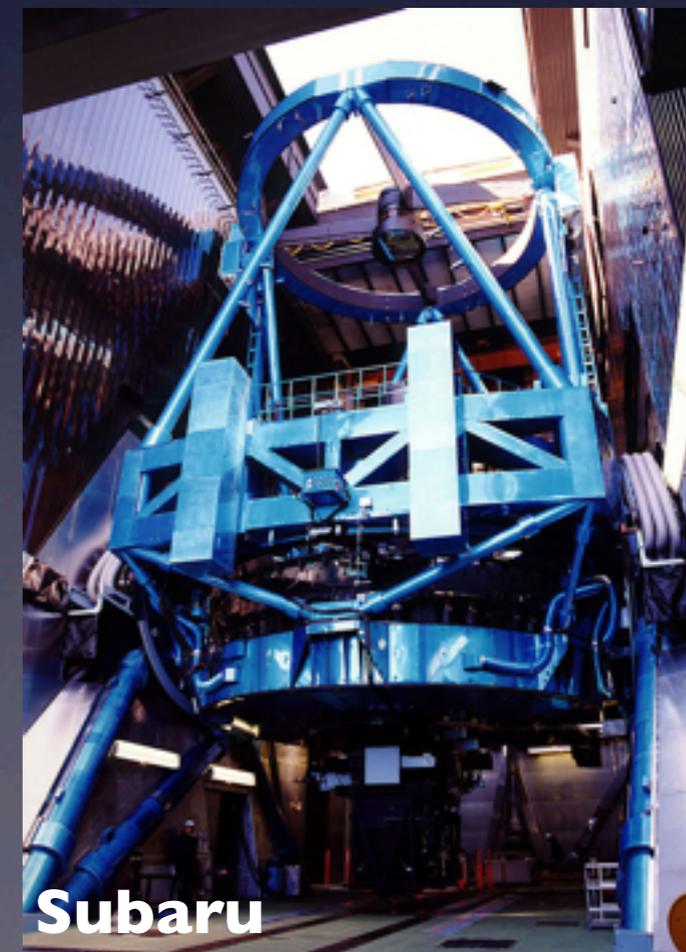
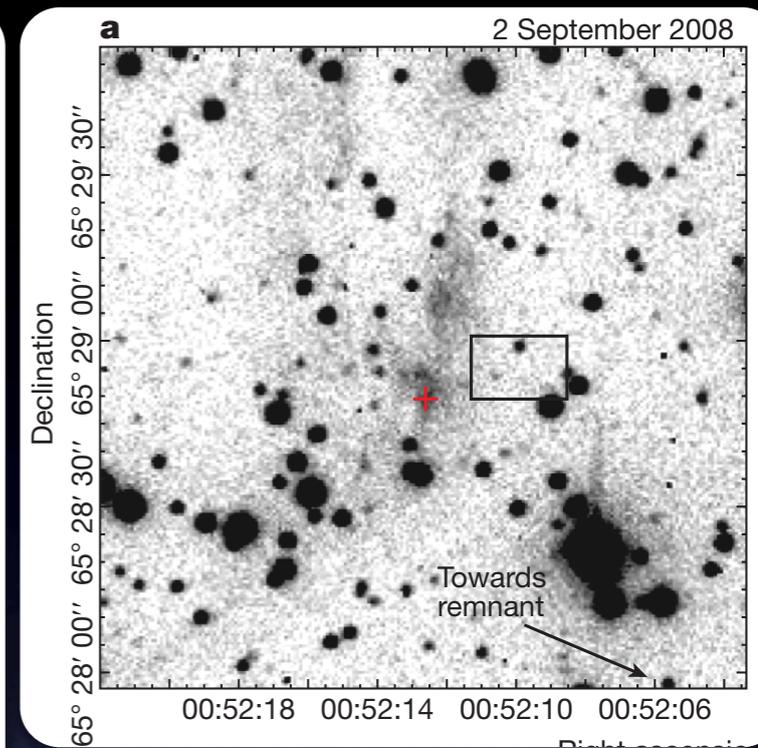
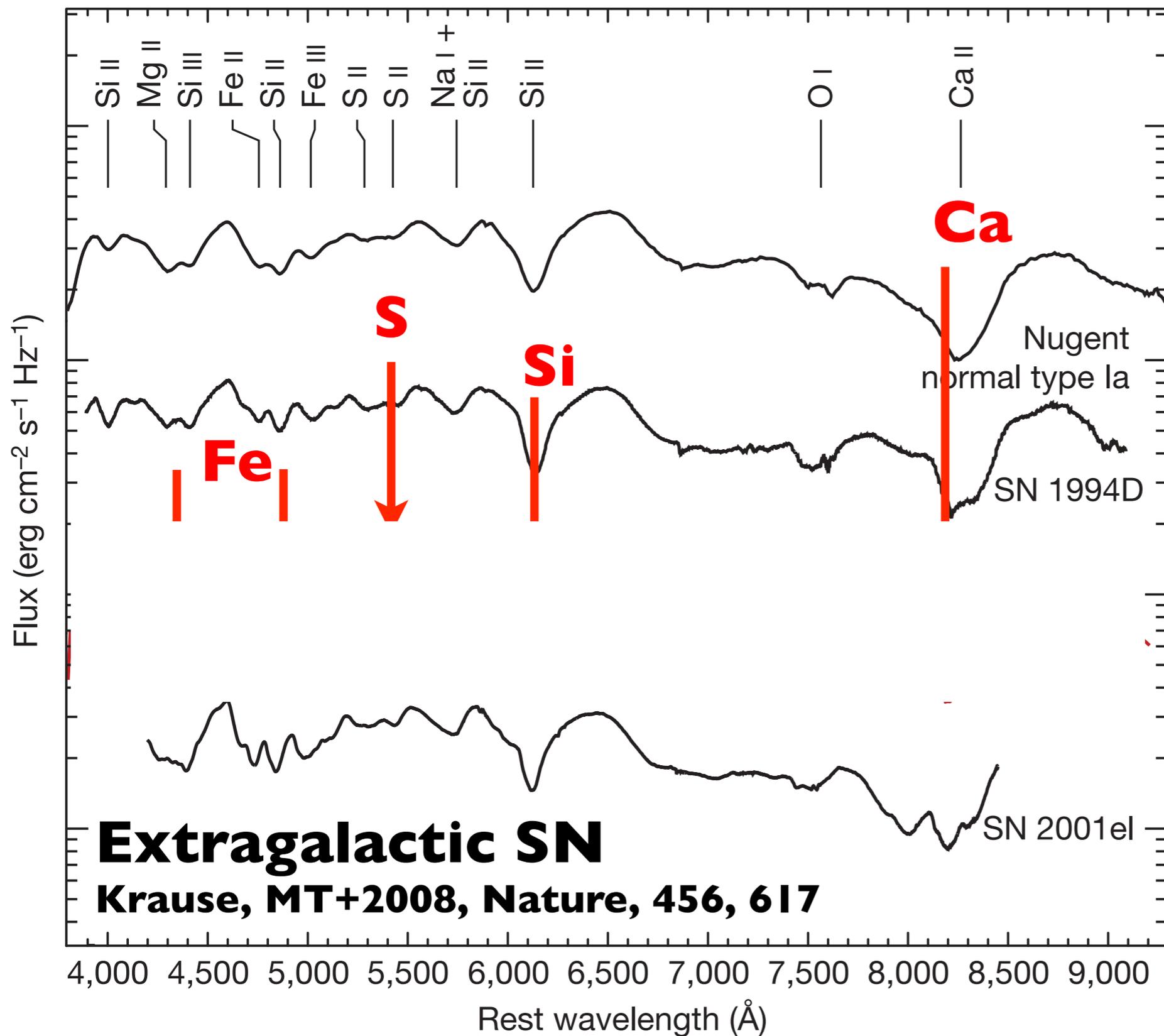
4 degree!!



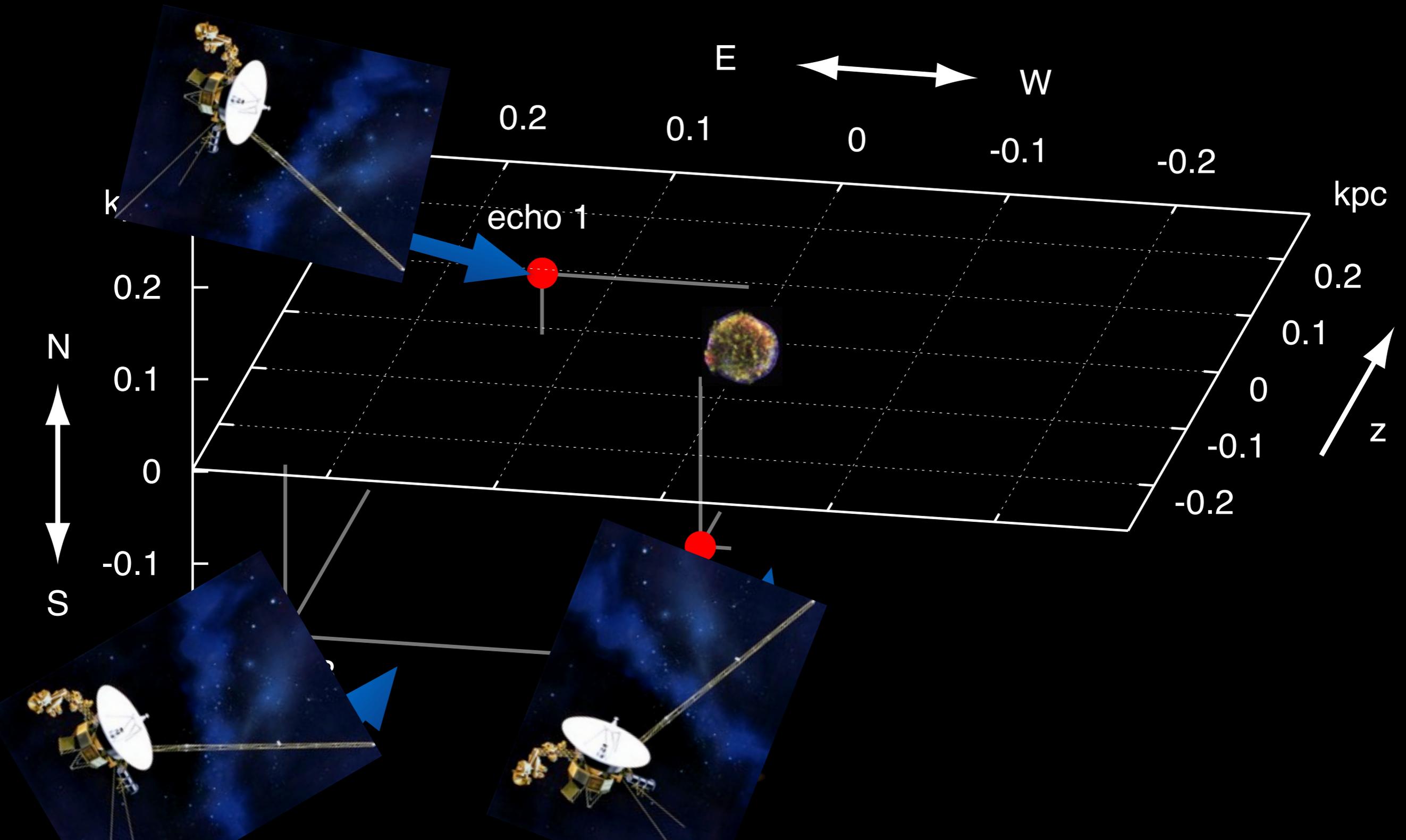
0.1 deg



Tycho's SNR = Type Ia!!



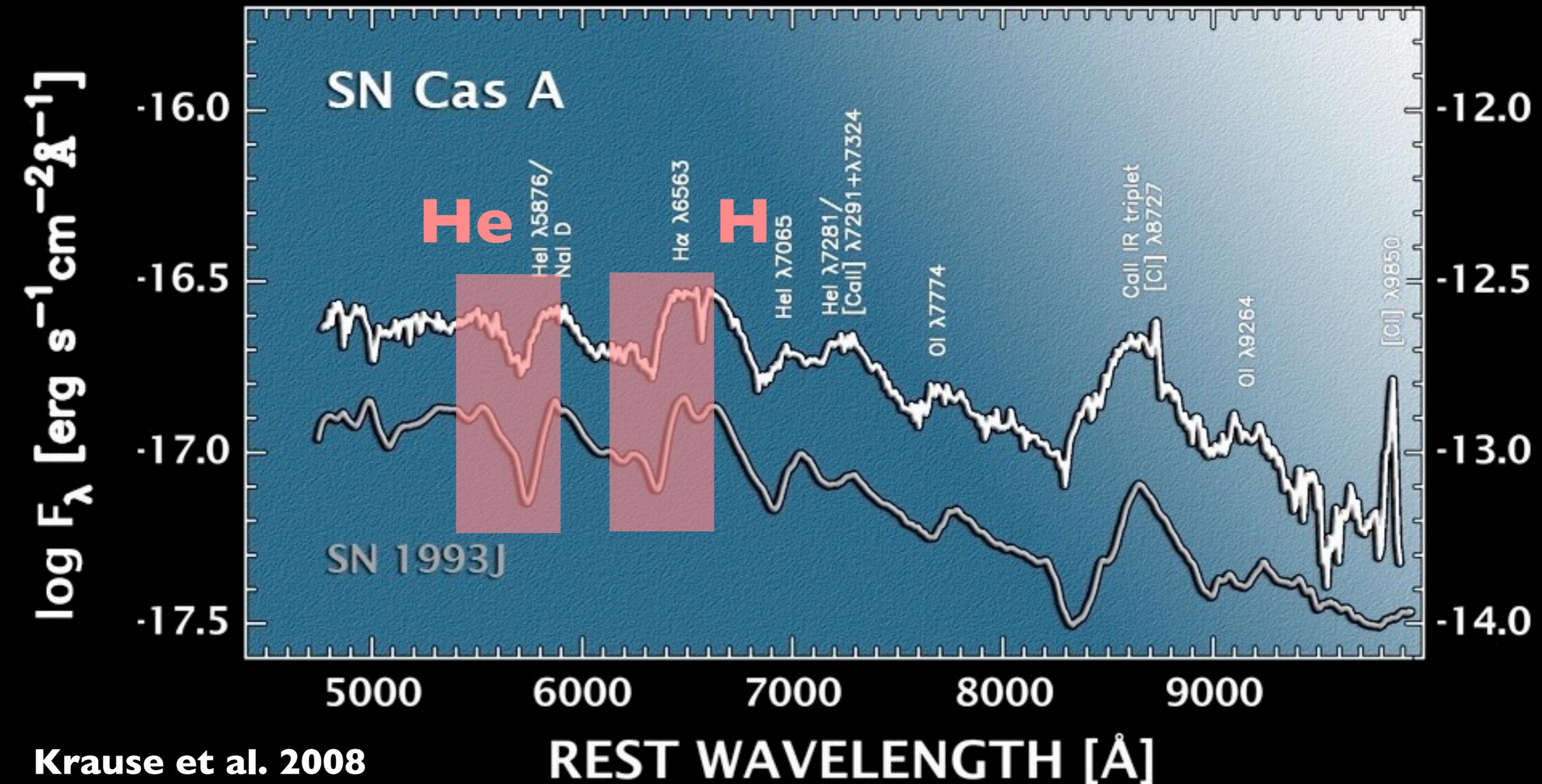
3D View of Tycho



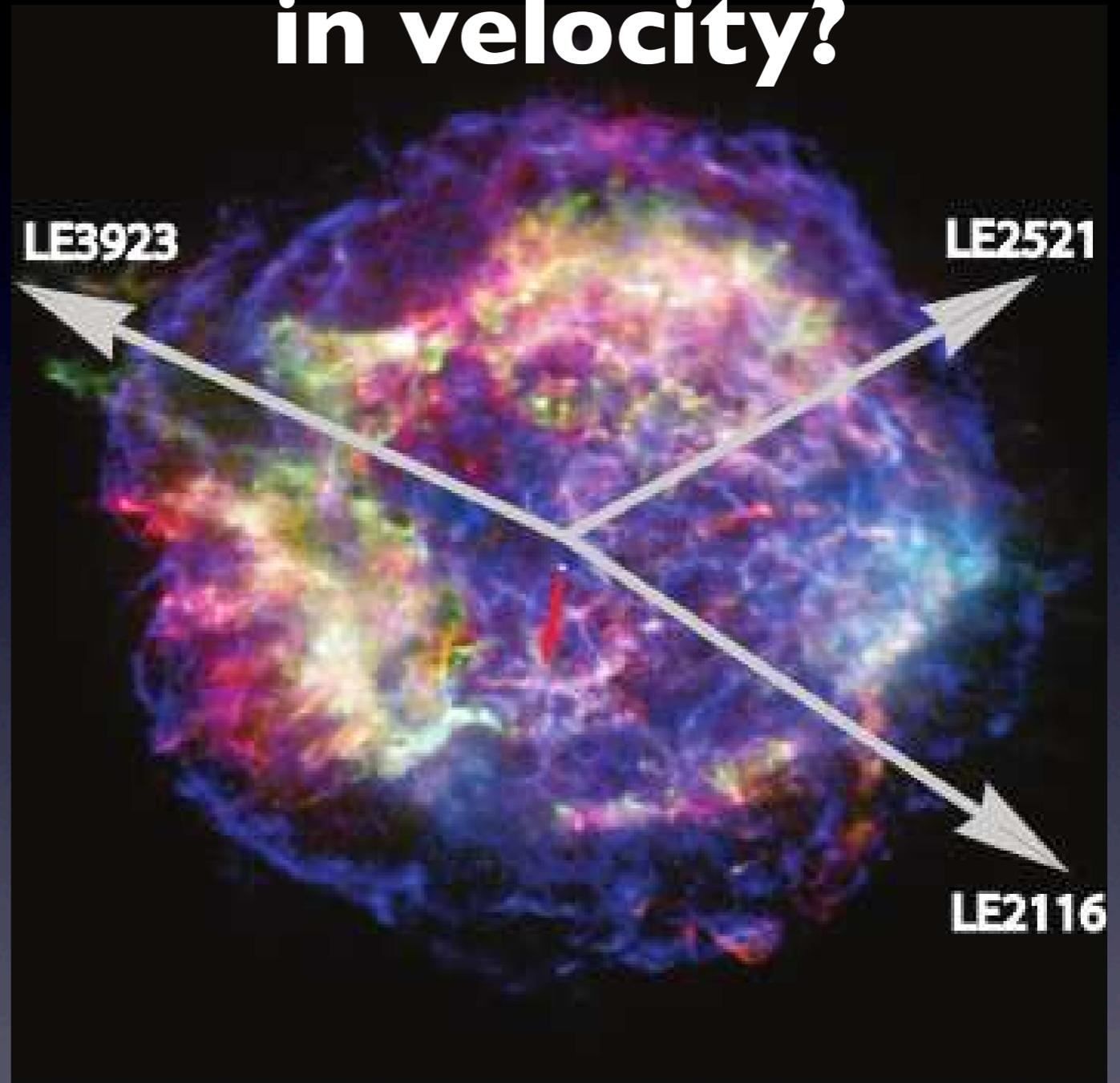
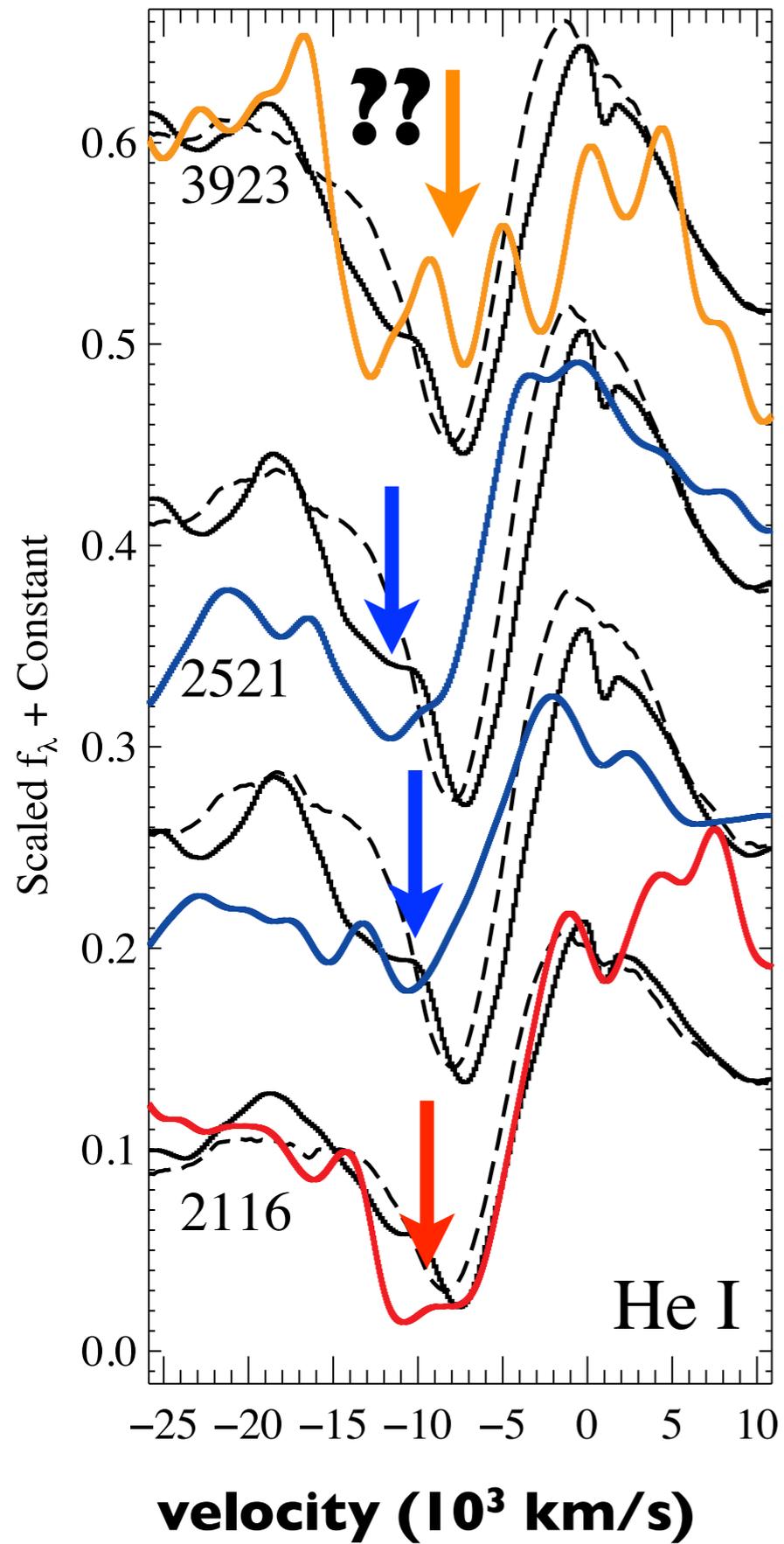


Cas A = Type IIb (Type Ib with small H)

HST/Spitzer/
Chandra



Cassiopeia A Possible variation in velocity?



Rest+10

Future opportunity with TMT

Thirty Meter Telescope

- **2014**
Start construction
- **2022**
First light



Caltech-UC-Japan-Canada-India-China

Summary

- **Mechanism of supernova is not yet understood**
 - **Multi-dimensional geometry is a key**
- **Three-dimensional geometry of SN is becoming apparent**
 - **extragalactic supernovae \leq polarization**
 - **Galactic supernova remnants**
 - **Light echo (with different angle)**
- **More opportunities with TMT**