

Astrophysical Dynamics, VT 2010

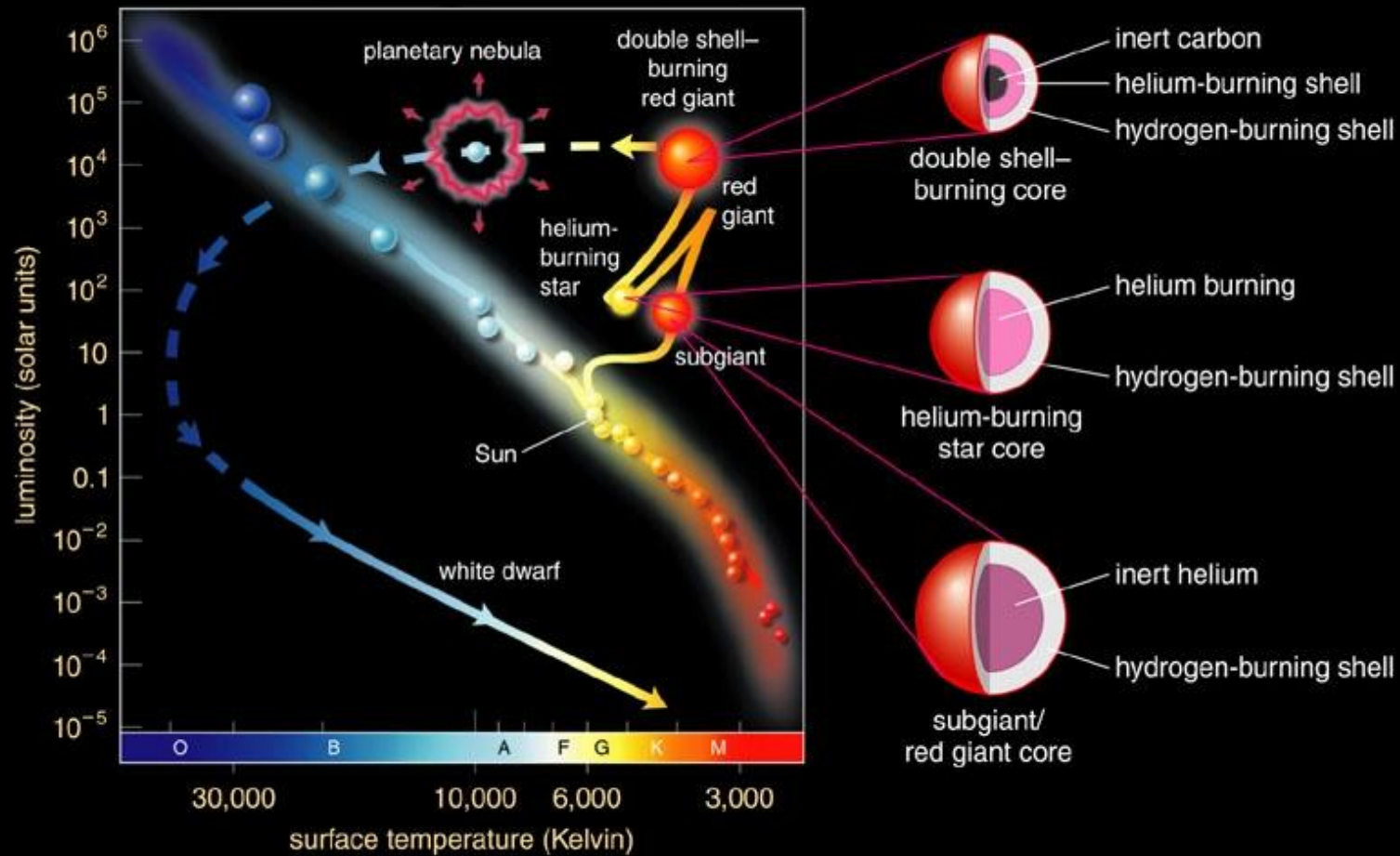
Stellar Winds and Supernova Remnants: Interaction with the ISM



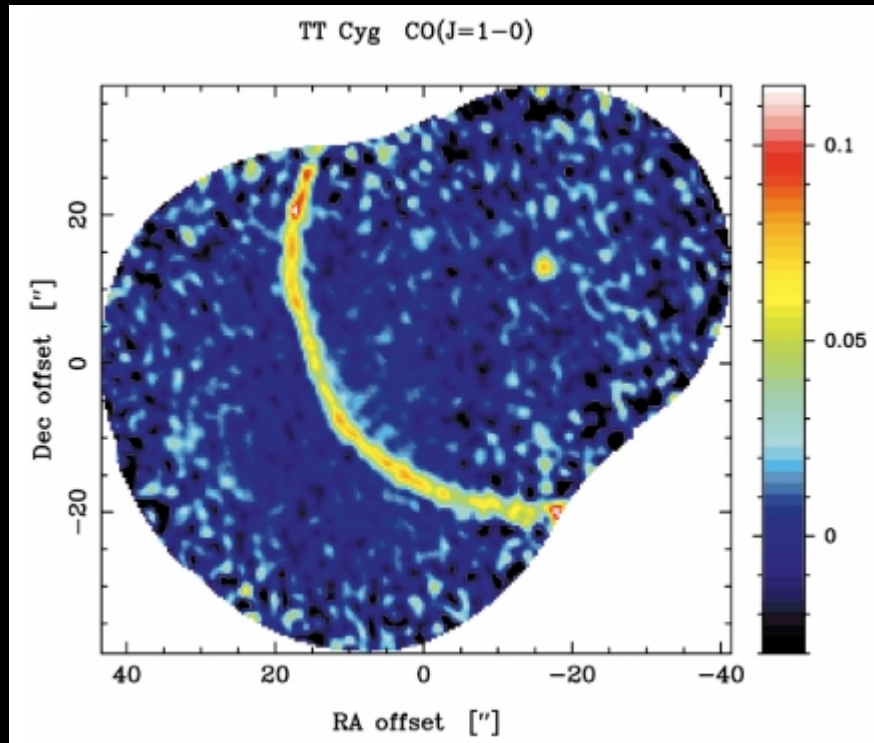
Susanne Höfner

Susanne.Hoefner@fysast.uu.se

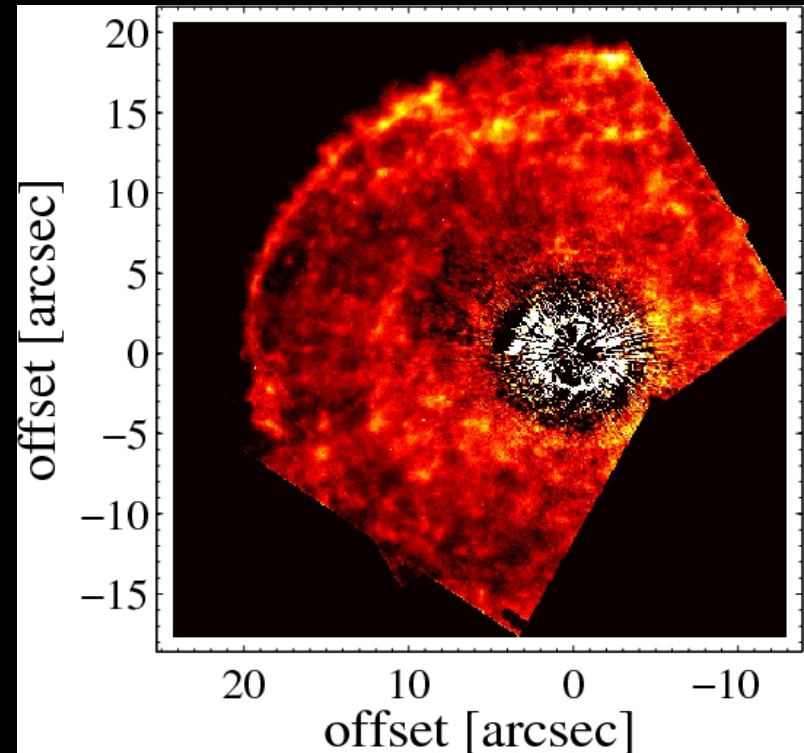
Stellar Evolution: Low Mass Stars



Observations of detached shells

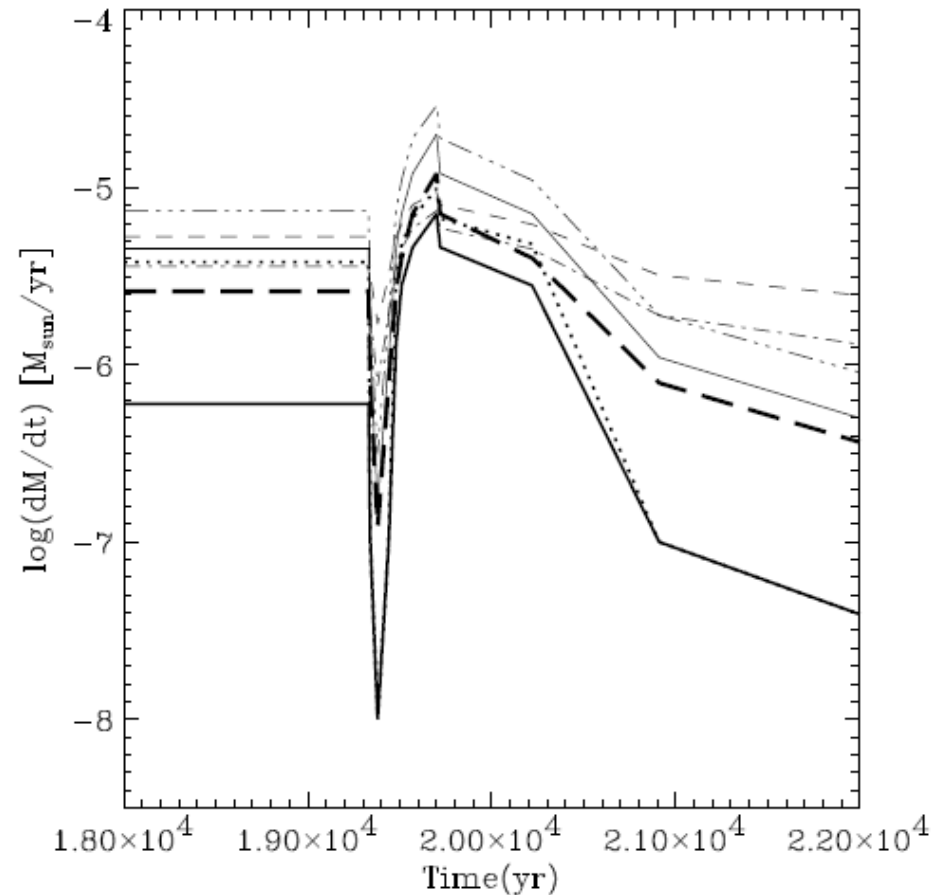
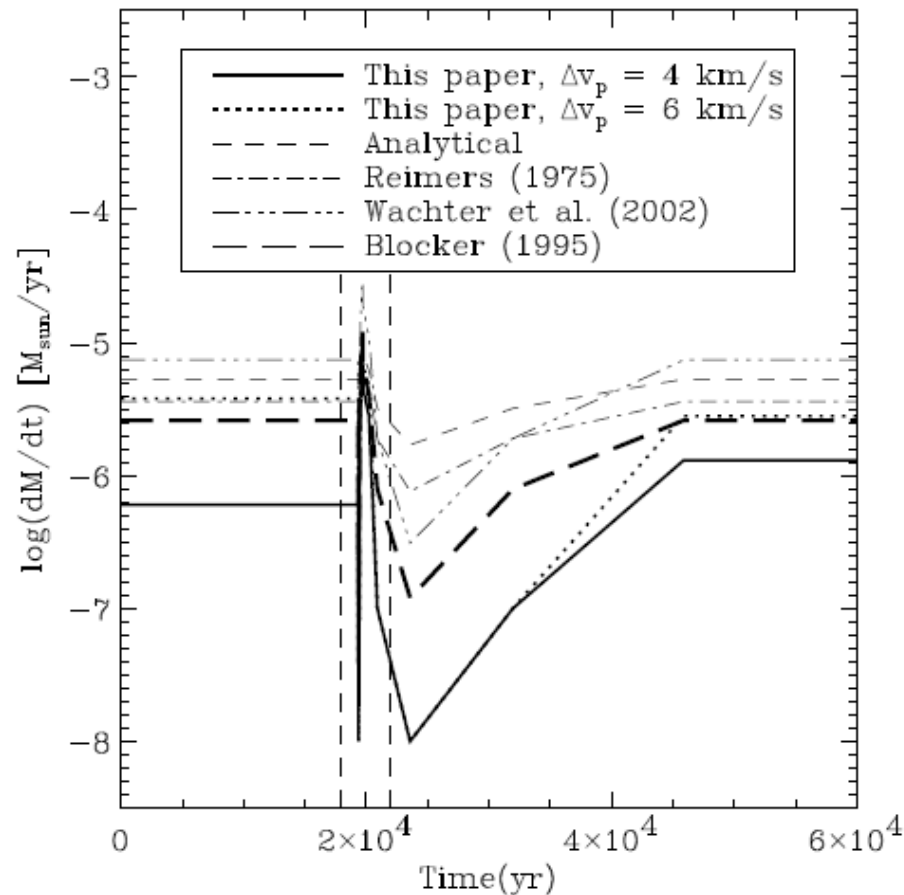


Thin molecular shell around
TT Cyg (Olofsson et al. 1998)



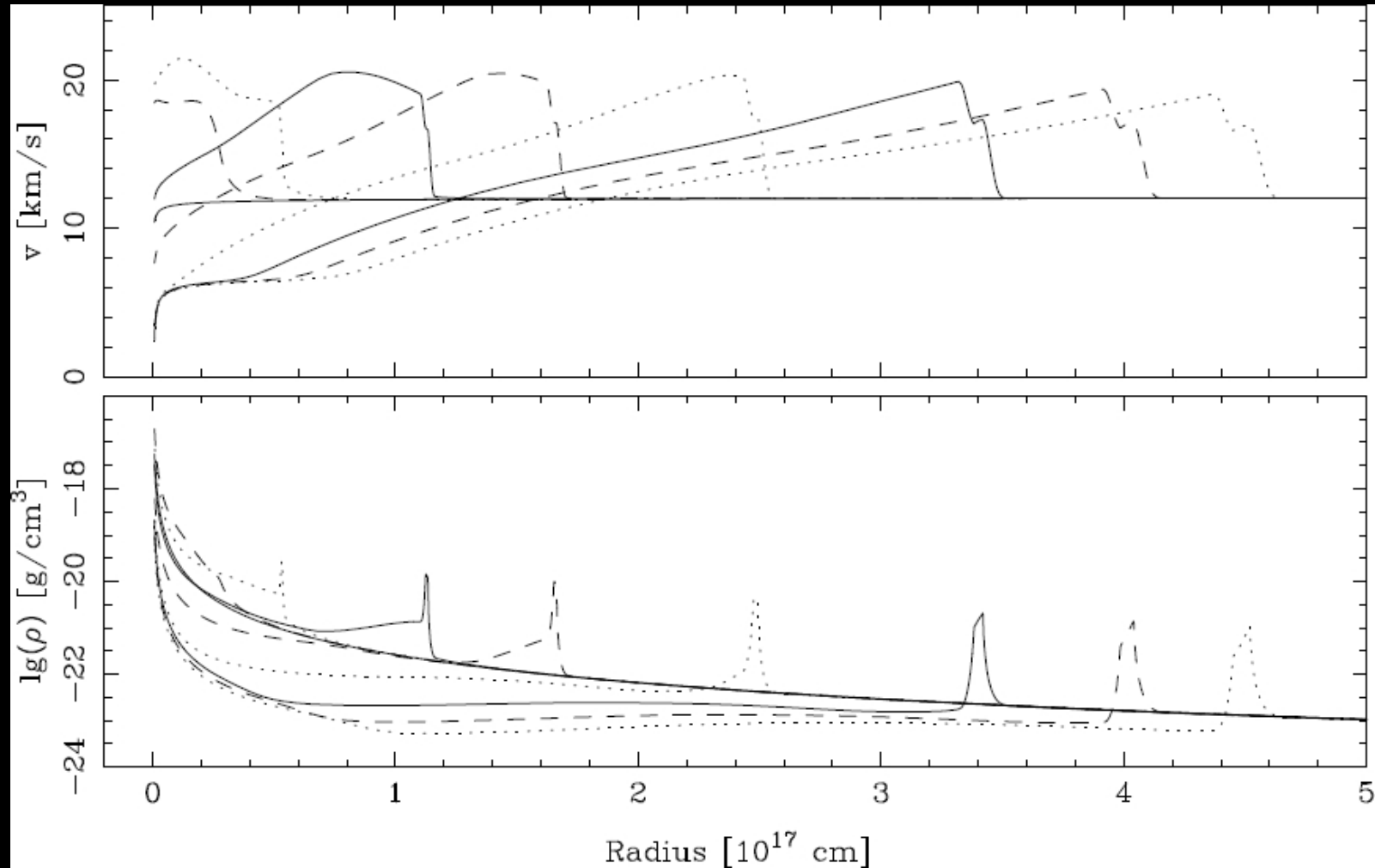
Circumstellar envelope of
R Scl (Olofsson et al. 2010)

Mass loss during a He-shell flash



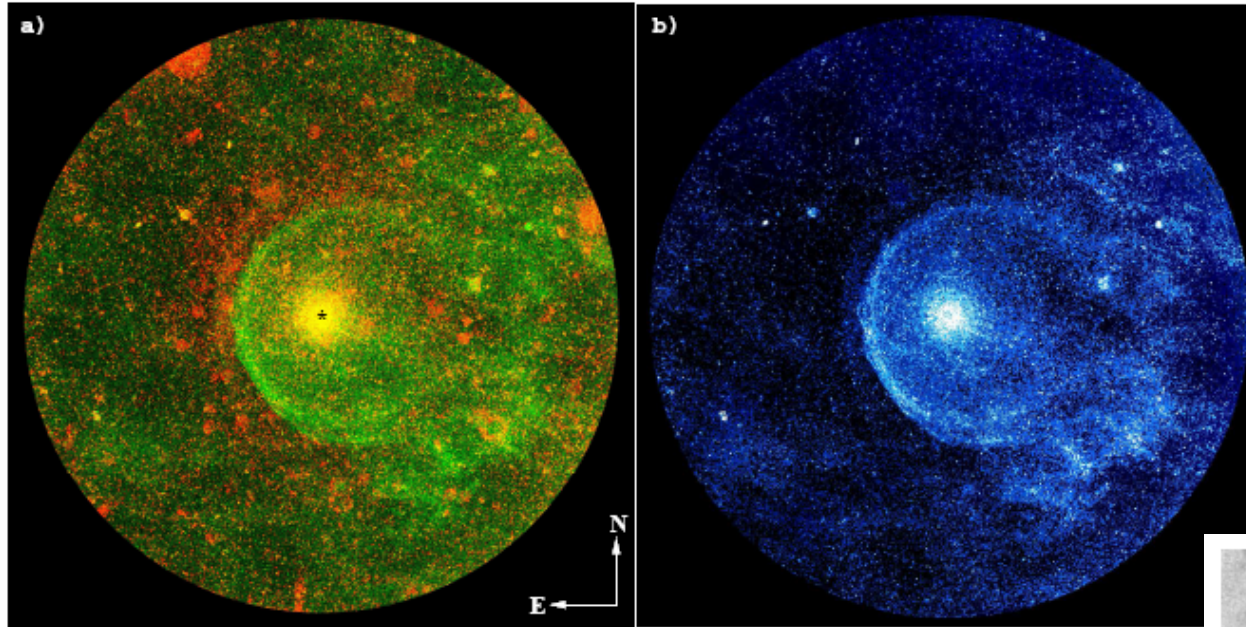
variation of mass loss during a He-shell flash: comparison of models
(Mattsson, Höfner & Herwig 2007)

Mass loss during a He-shell flash



variation of wind properties leading to the formation of a detached shell:
snapshots of velocity (top) and density (bottom) (Mattsson et al. 2007)

Large-scale structure of the CSE

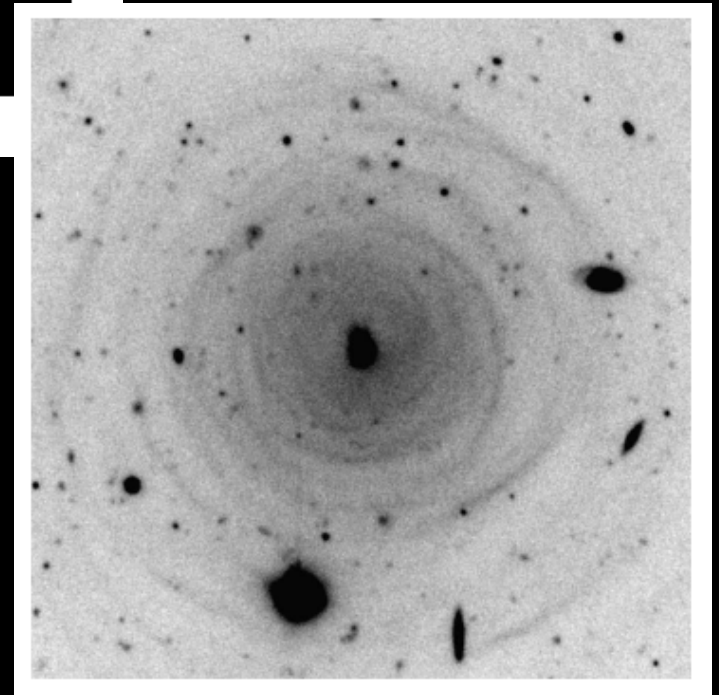


V-band image of IRC+10216 showing shell-like structures in the circumstellar envelope (90"x 90")

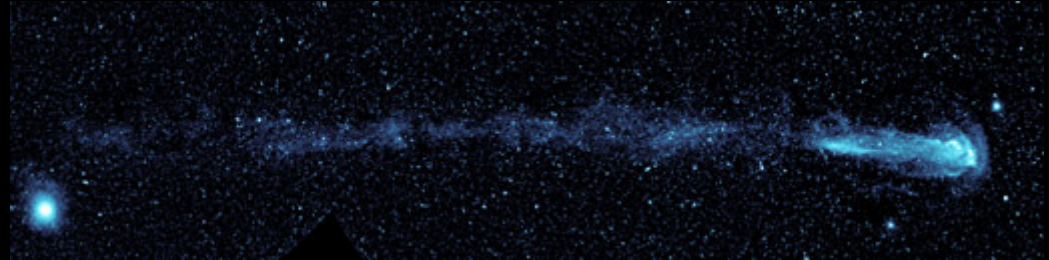
Mauron & Huggins (2010)

GALEX images of IRC+10216 (left: composite NUV+FUV, right: FUV) showing wind - ISM interaction (field of view 62'x 62')

Sahai & Chronopoulos (2010)



Wind of Mira interacting with ISM

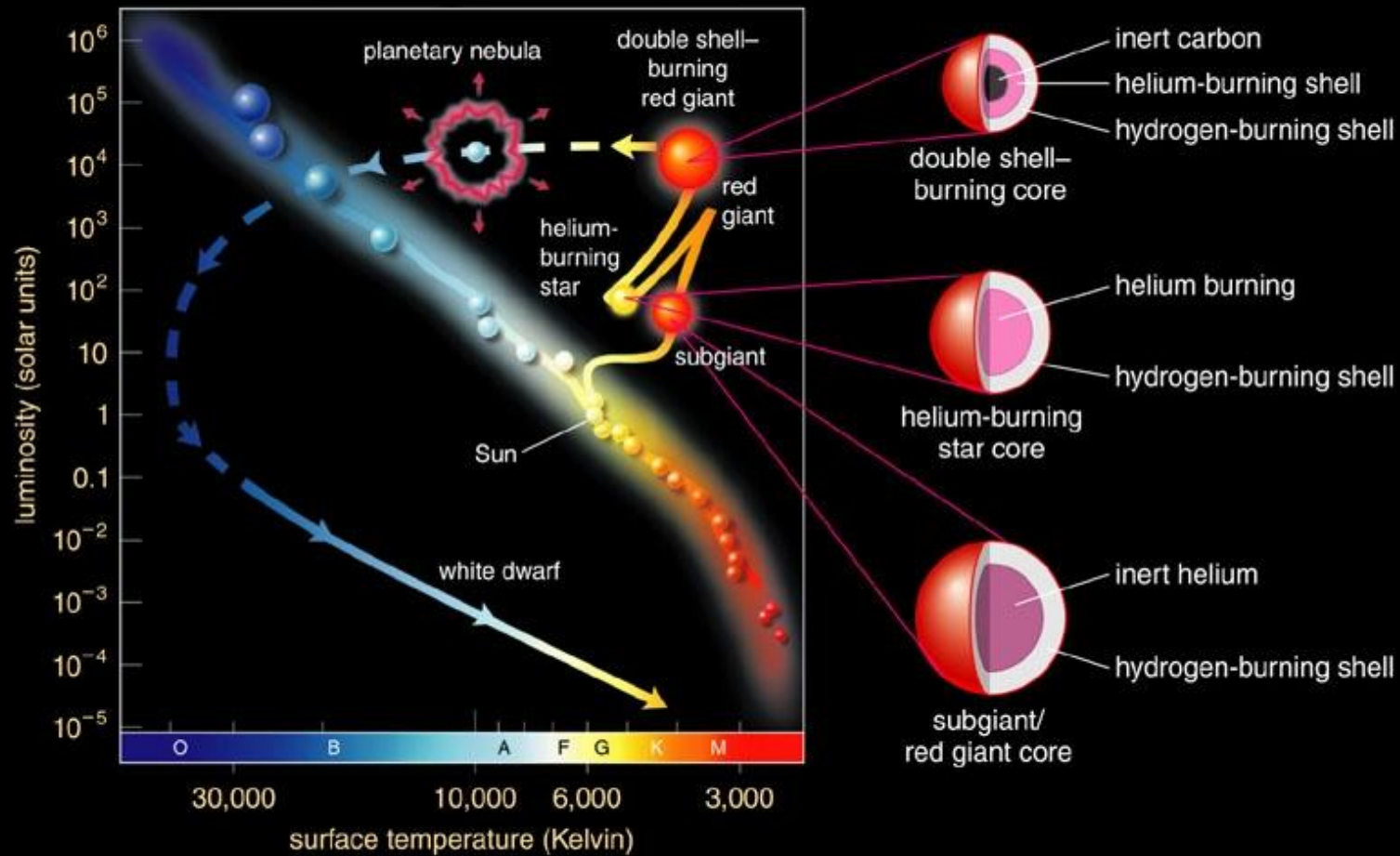


First periodic variable
star
ever discovered!

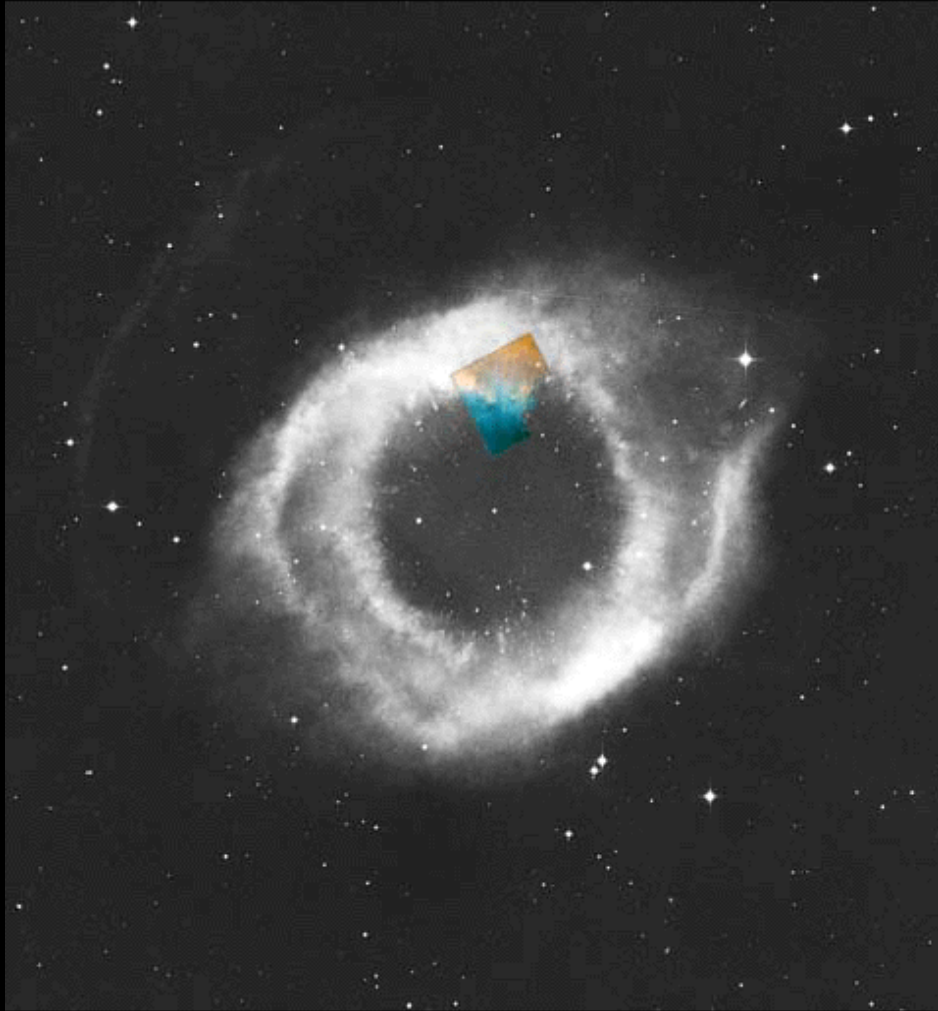


NASA's Galaxy Evolution Explorer (GALEX) discovered an exceptionally long (13 light years) tail of material trailing behind the cool giant star Mira (o Ceti). The tail is only visible in ultraviolet light (top left), and does not show up in visible light (bottom left).

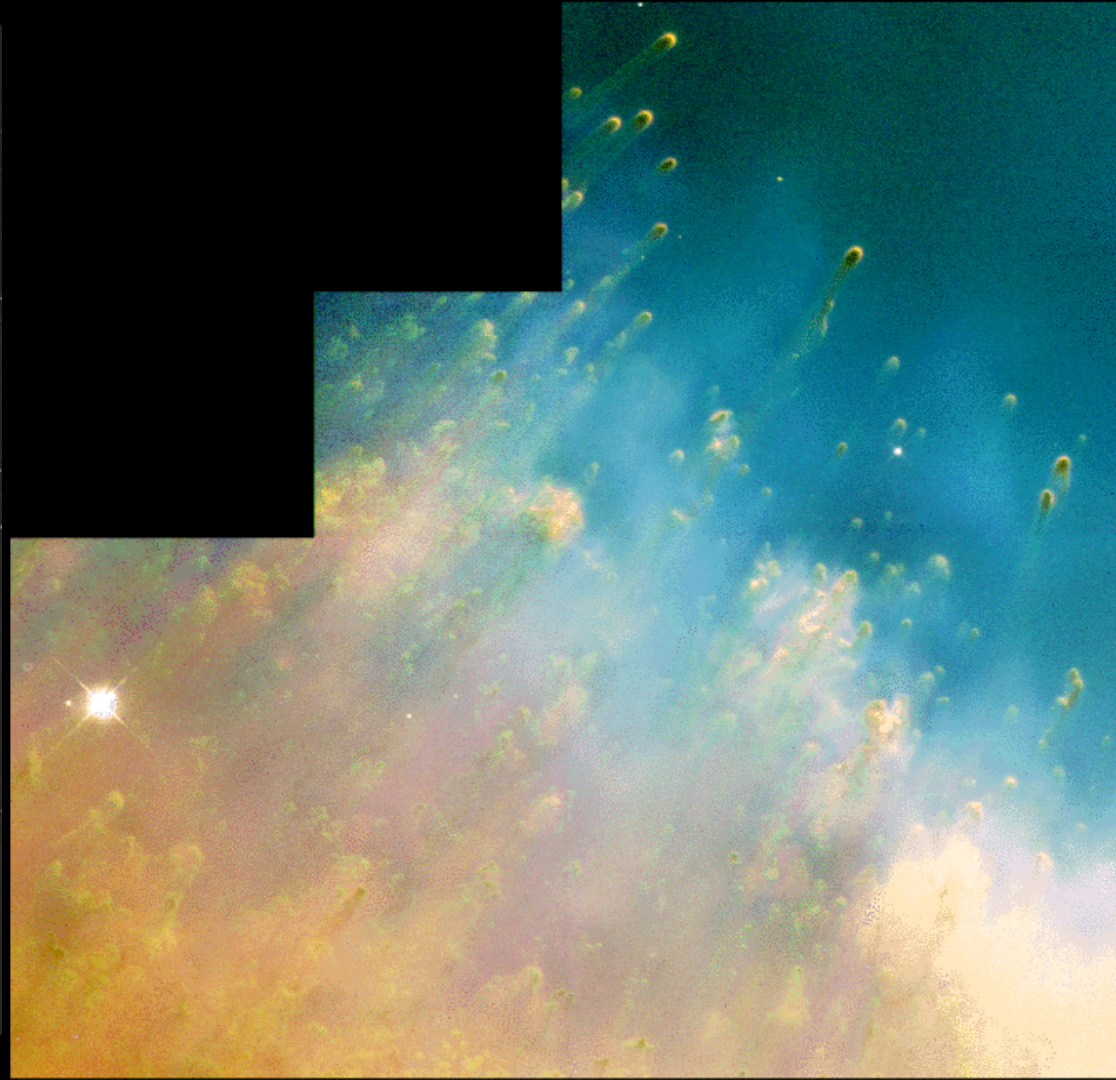
Stellar Evolution: Low Mass Stars



PN: mass loss made visible



Helix Nebula • NGC 7293 • Las Campanas Observatory and HST
Black & White: J. Bedke (CSC/STScI), Carnegie Institution of Washington
Color Inset: C.R. O'Dell (Rice Univ.), NASA

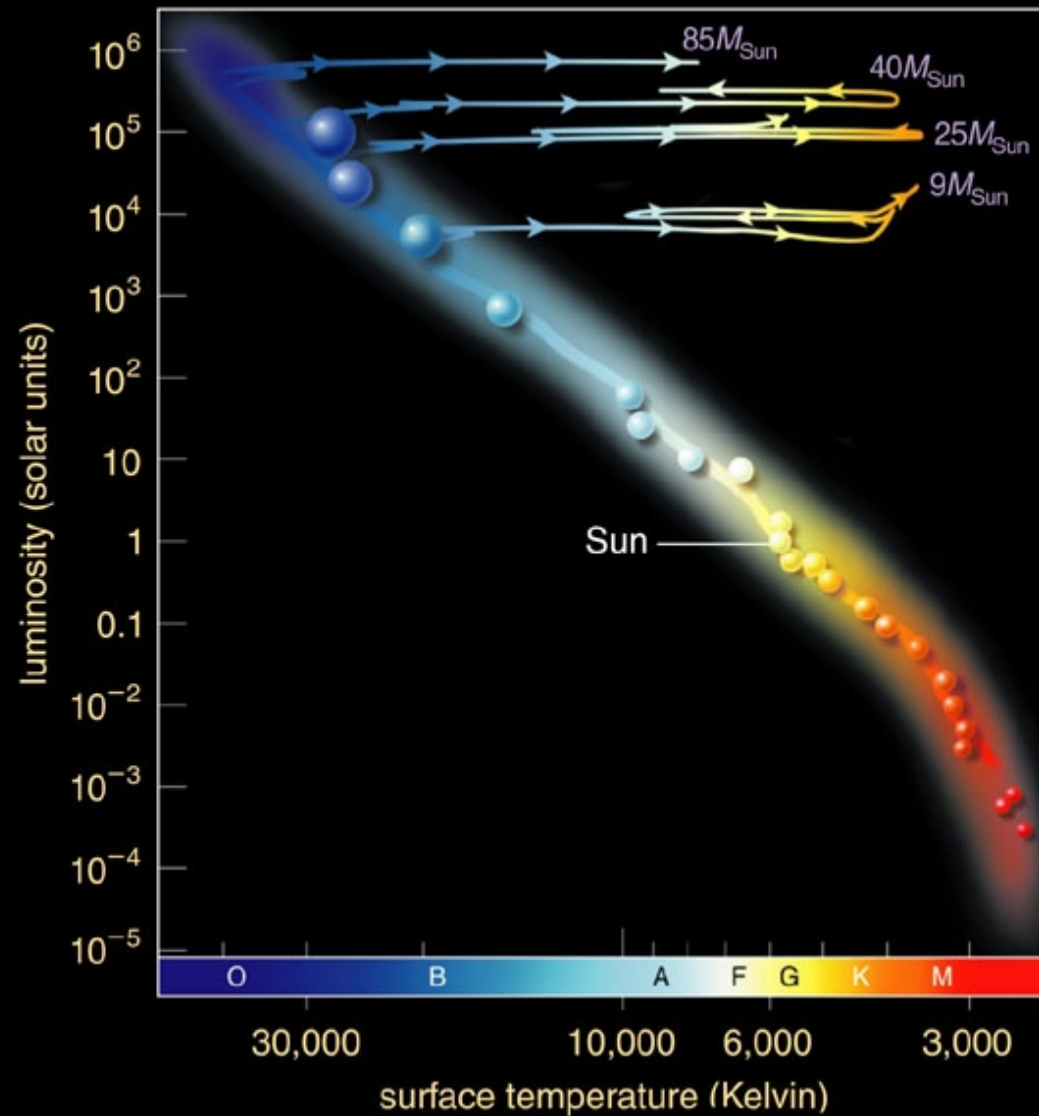


Helix Nebula • NGC 7293

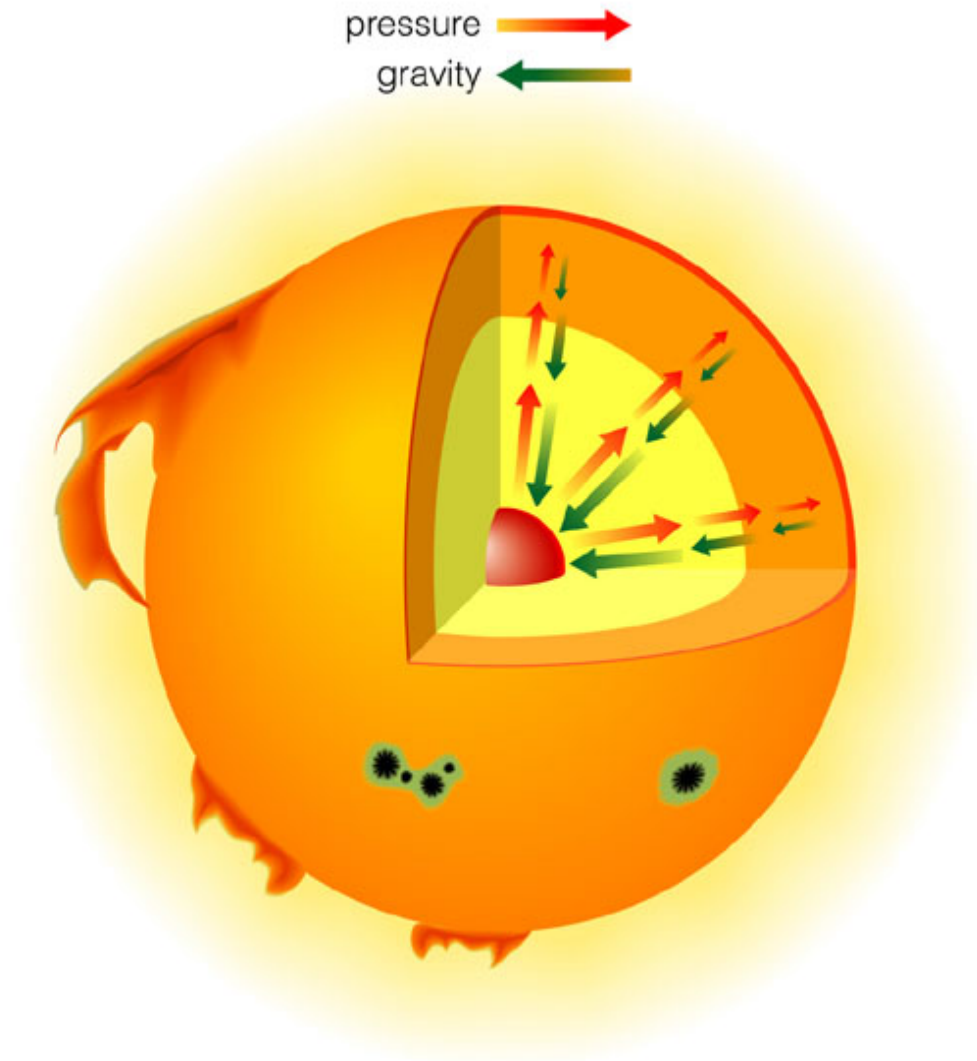
HST • WFPC2

PRC96-13a • ST ScI OPO • April 15, 1996 • C.R. O'Dell (Rice Univ.), NASA

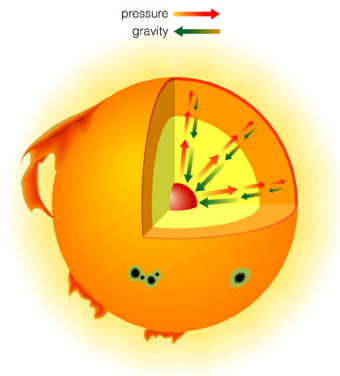
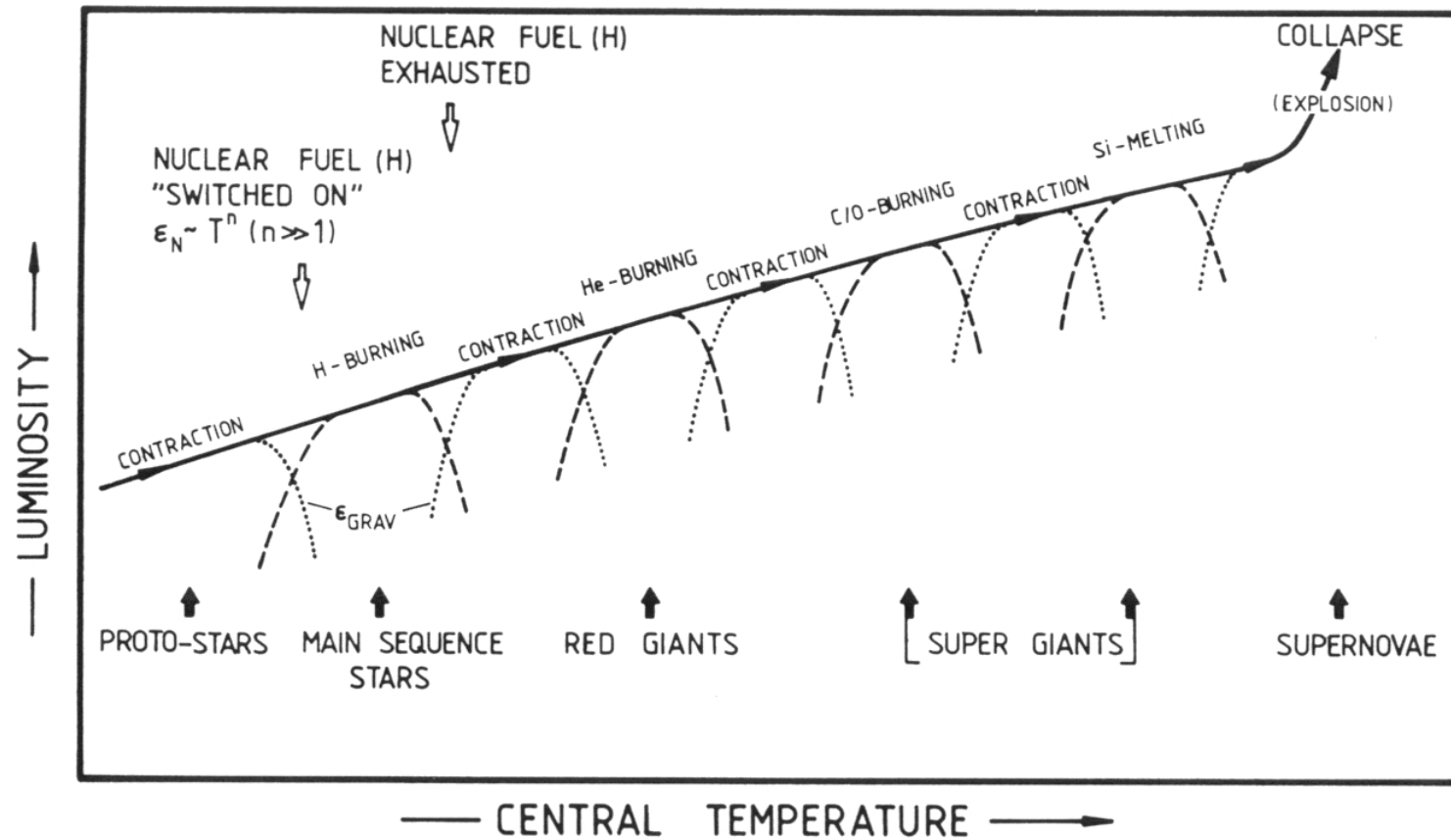
Stellar Evolution: High Mass Stars



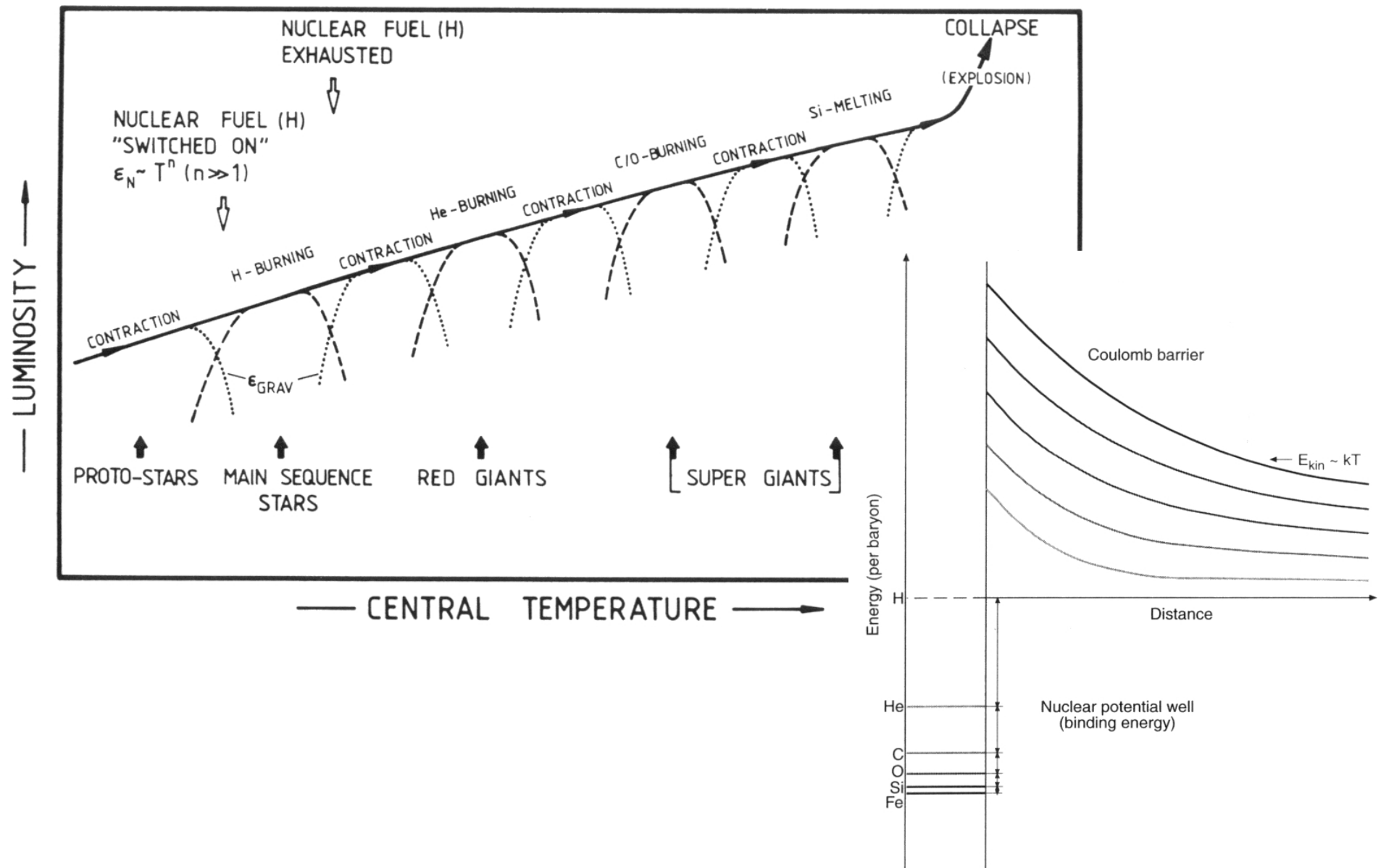
Stellar Structure: Pressure vs. Gravity



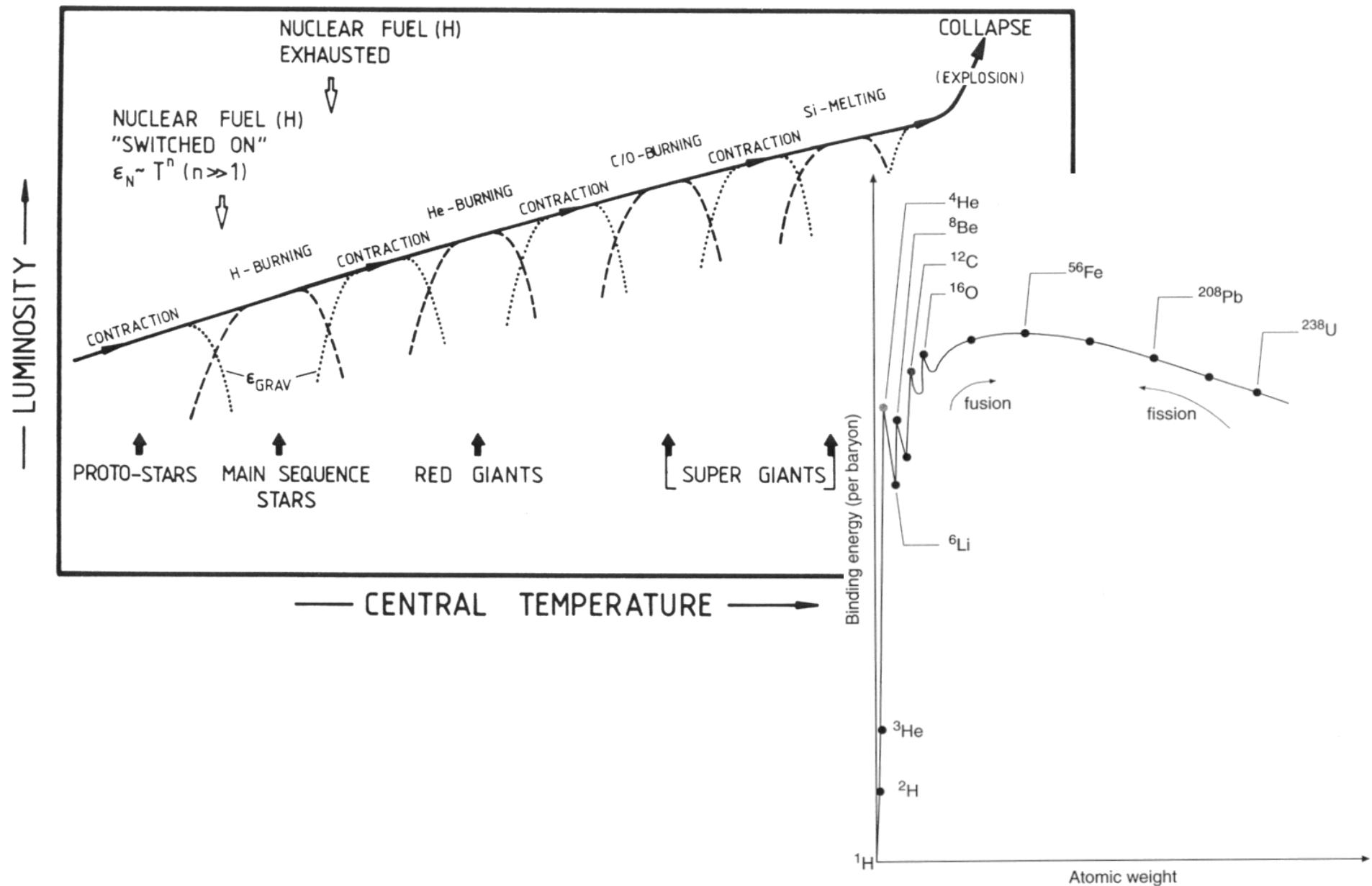
Stellar Evolution: Burning Phases



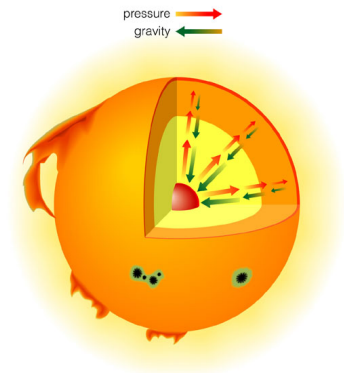
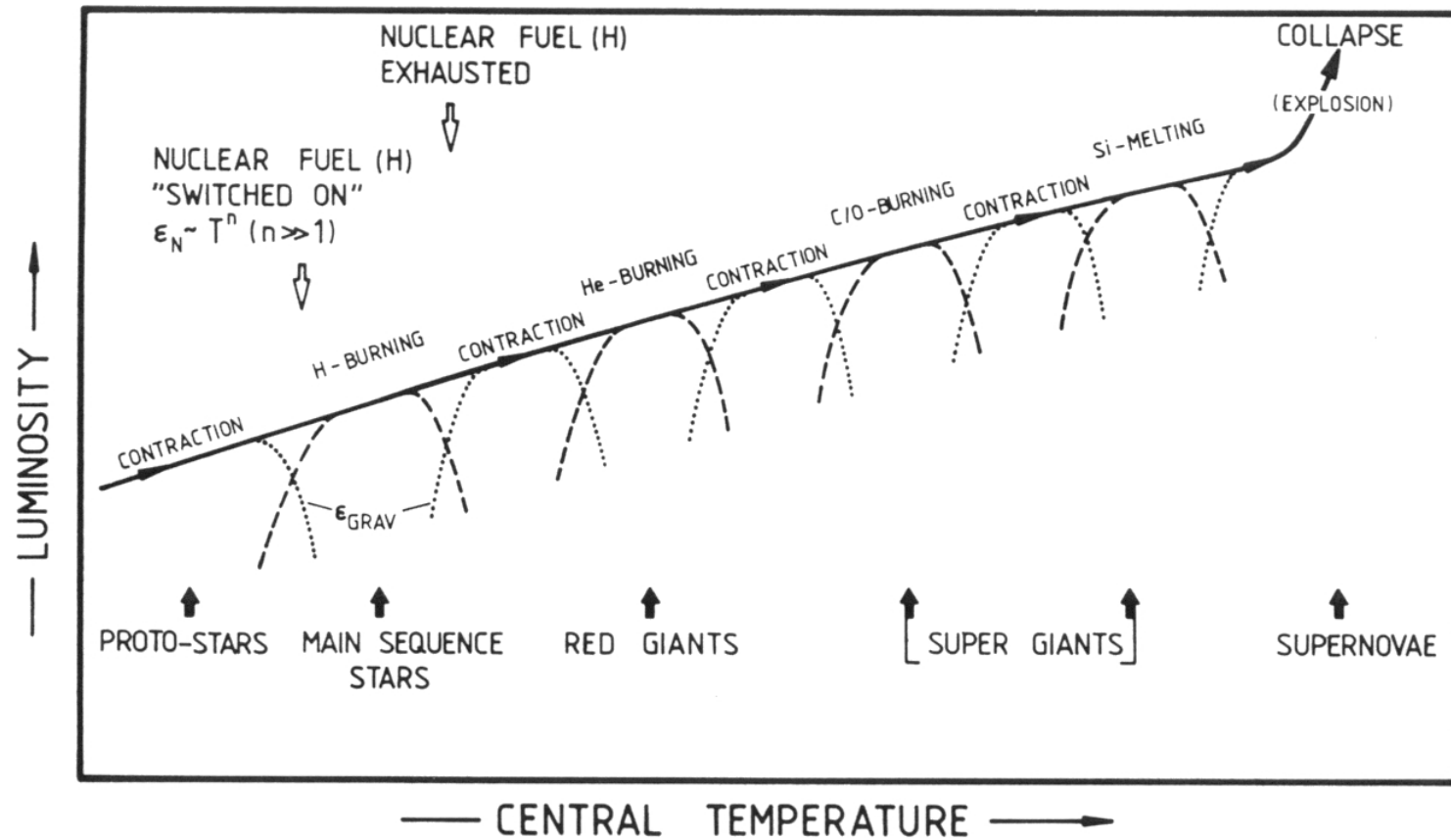
Stellar Evolution: Burning Phases



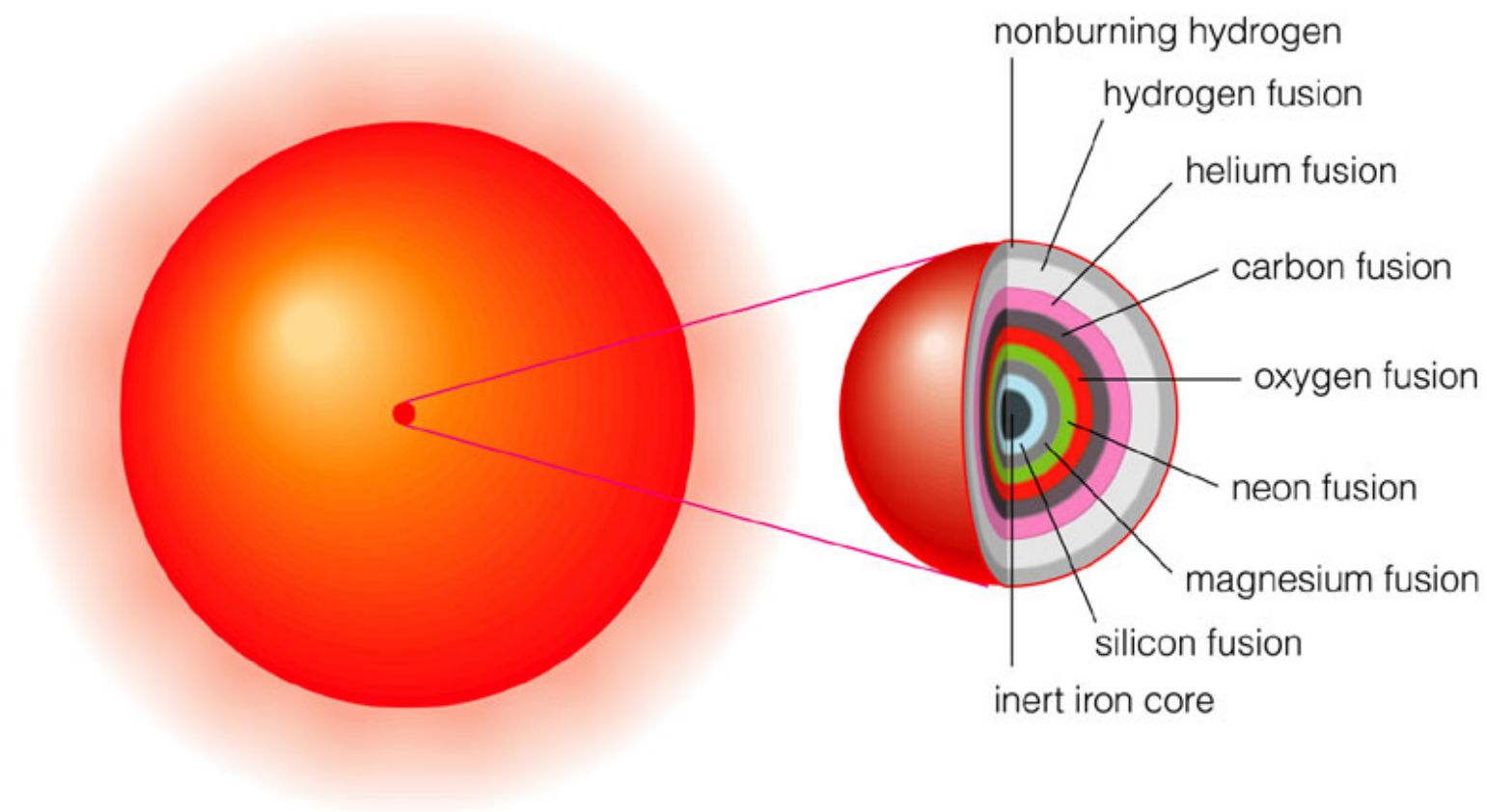
Stellar Evolution: Burning Phases



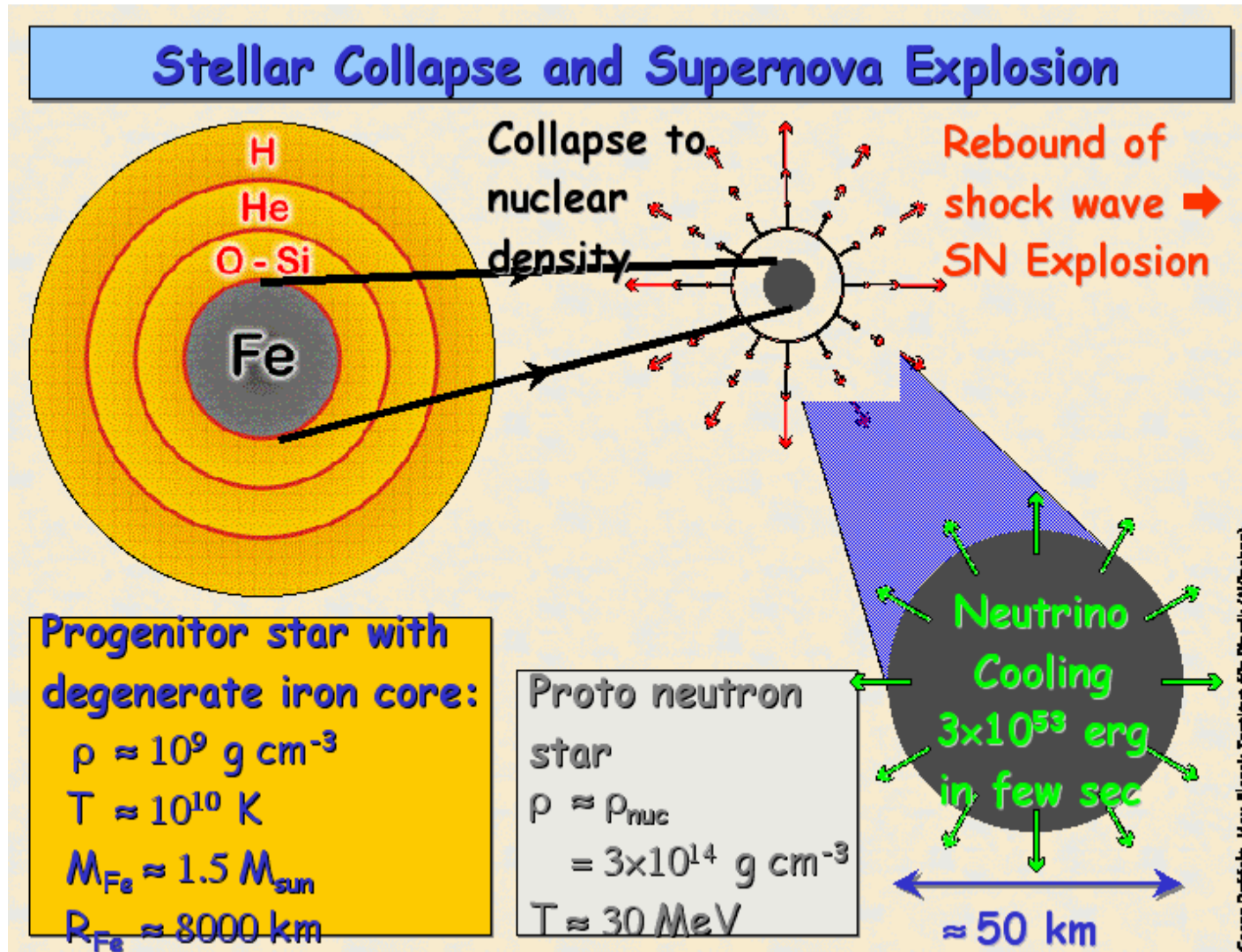
Stellar Evolution: Burning Phases



Stellar Evolution: High Mass Stars



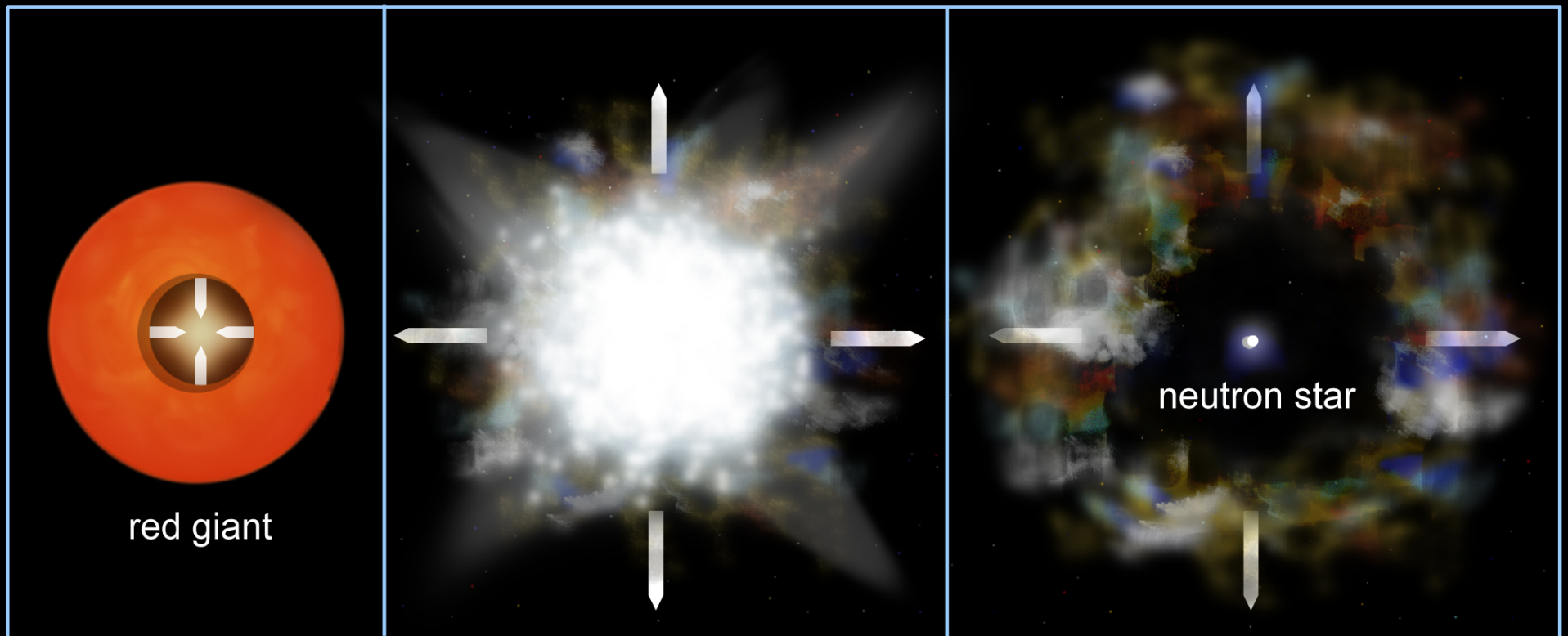
Stellar Evolution: High Mass Stars



Formation of a SNR

Birth of a Neutron Star and Supernova Remnant

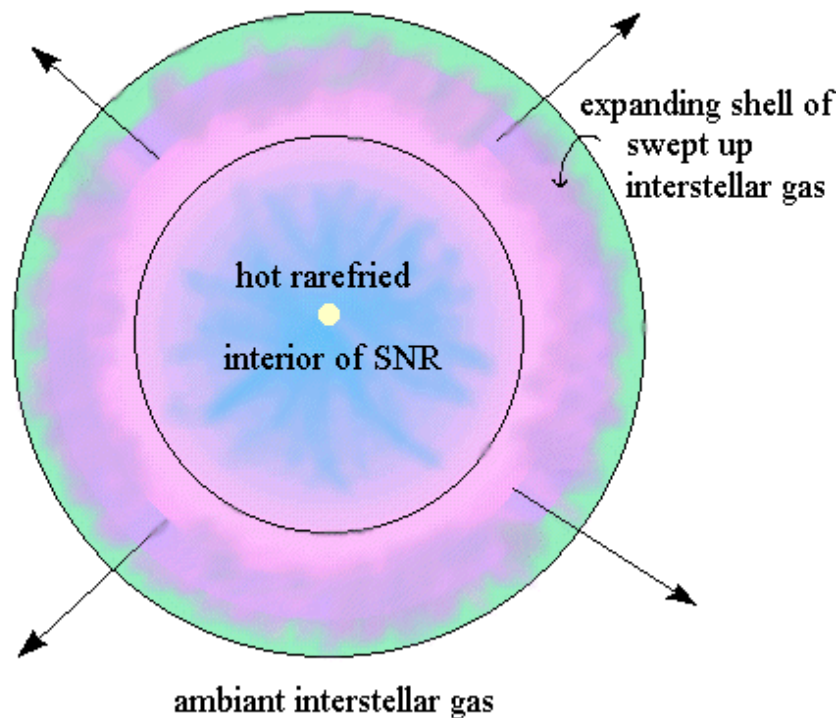
(not to scale)



Core Implosion → **Supernova Explosion** → **Supernova Remnant**

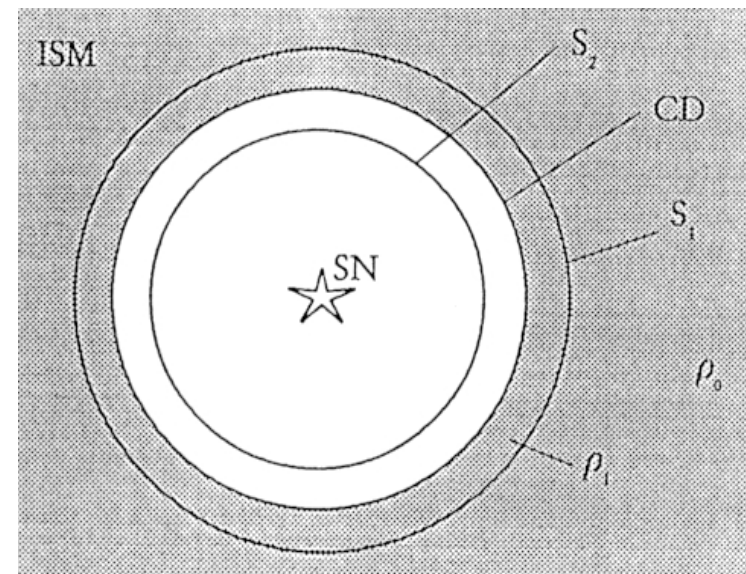
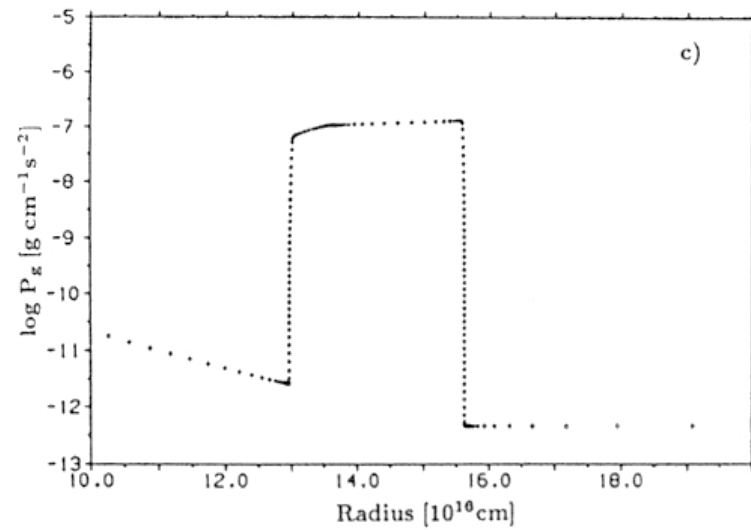
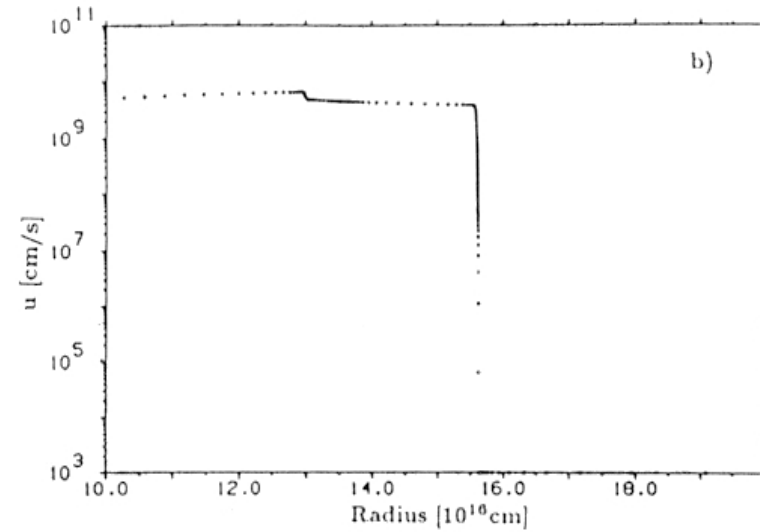
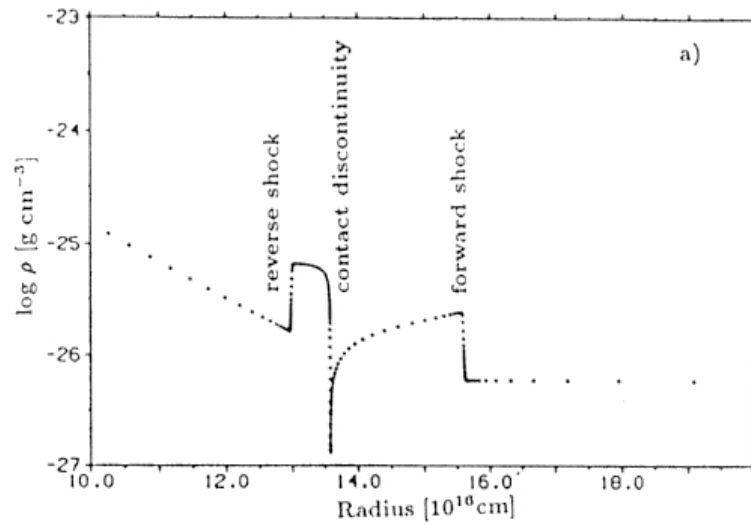
SNR: Expansion & Interaction with ISM

Supernova Remnant (SNR) - Snowplow



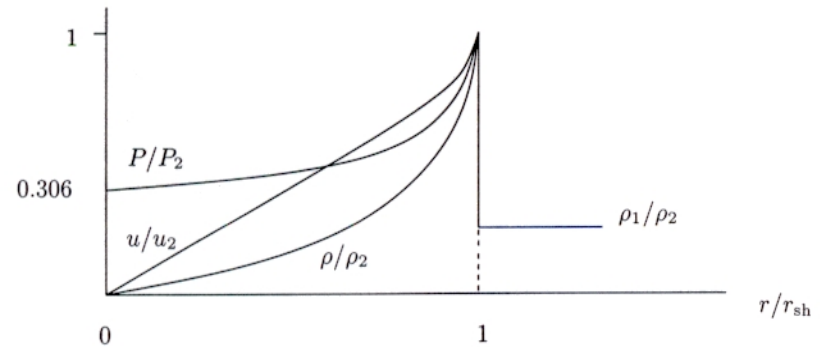
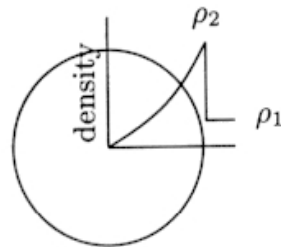
- How fast will the SNR expand, and on which typical timescales ?
- What are the dominant physical processes ?
- What are typical temperatures and densities ?
- How will the SNR interact with the surrounding ISM ?

SNR: Free Expansion Phase

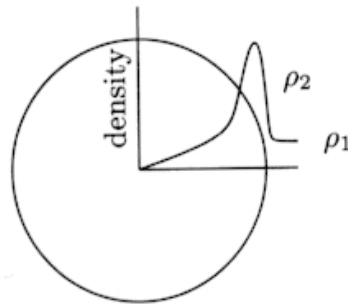


SNR: Expansion & Interaction with ISM

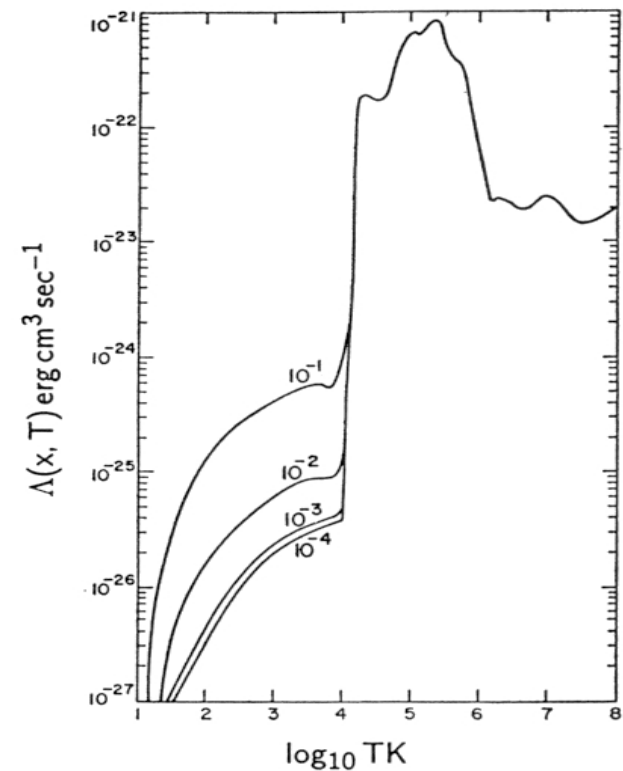
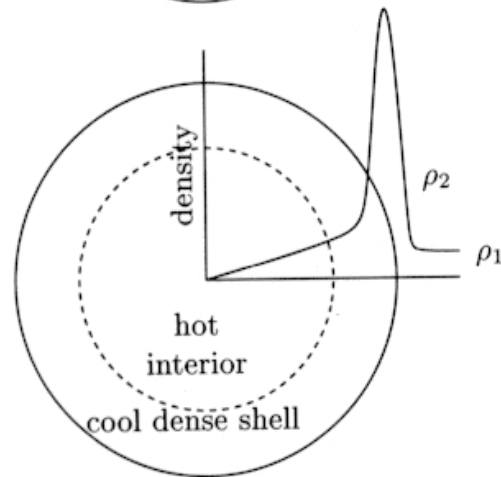
blast wave
(energy conserving)



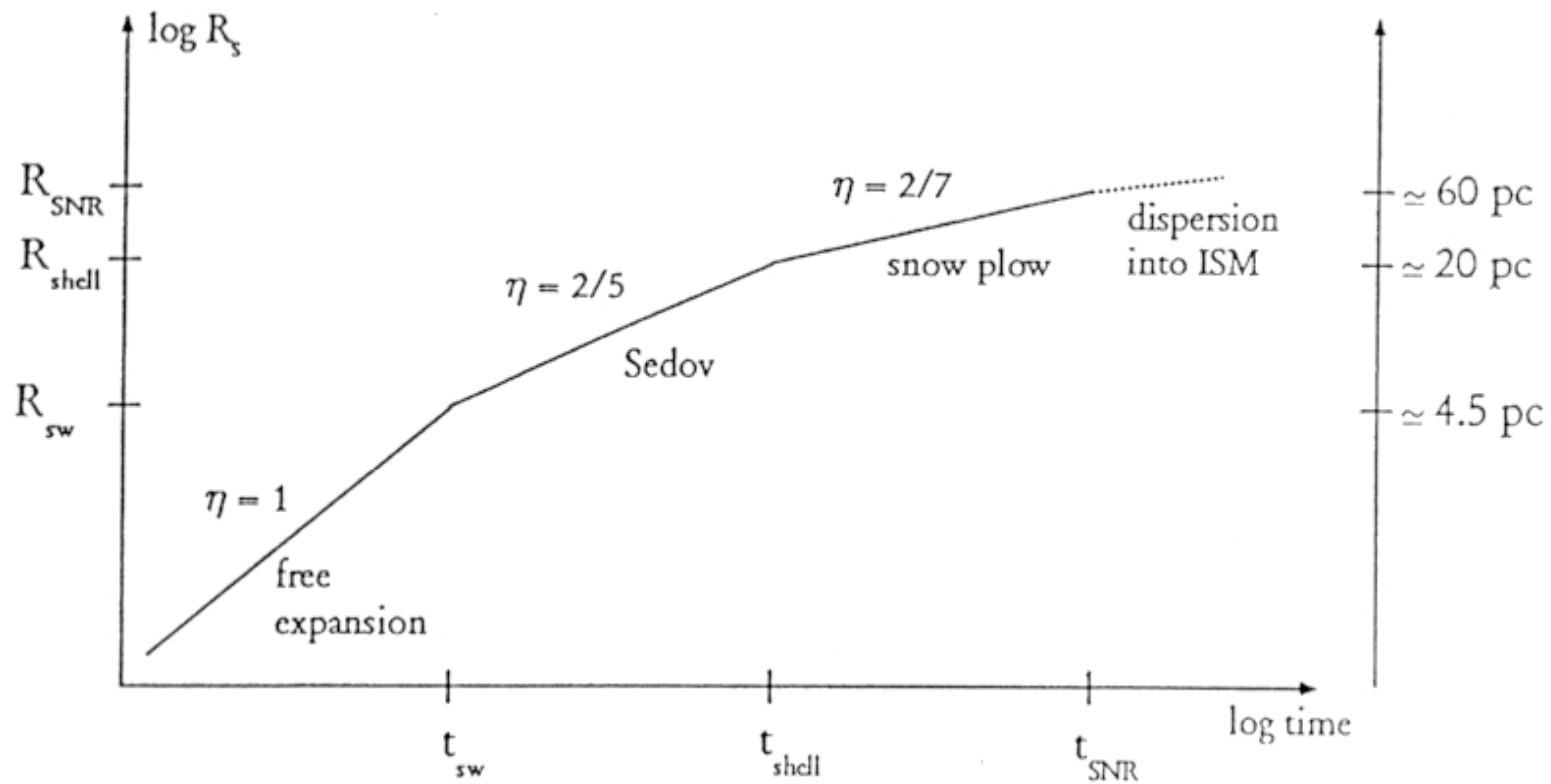
shell formation
(radiative losses $\lesssim E$)



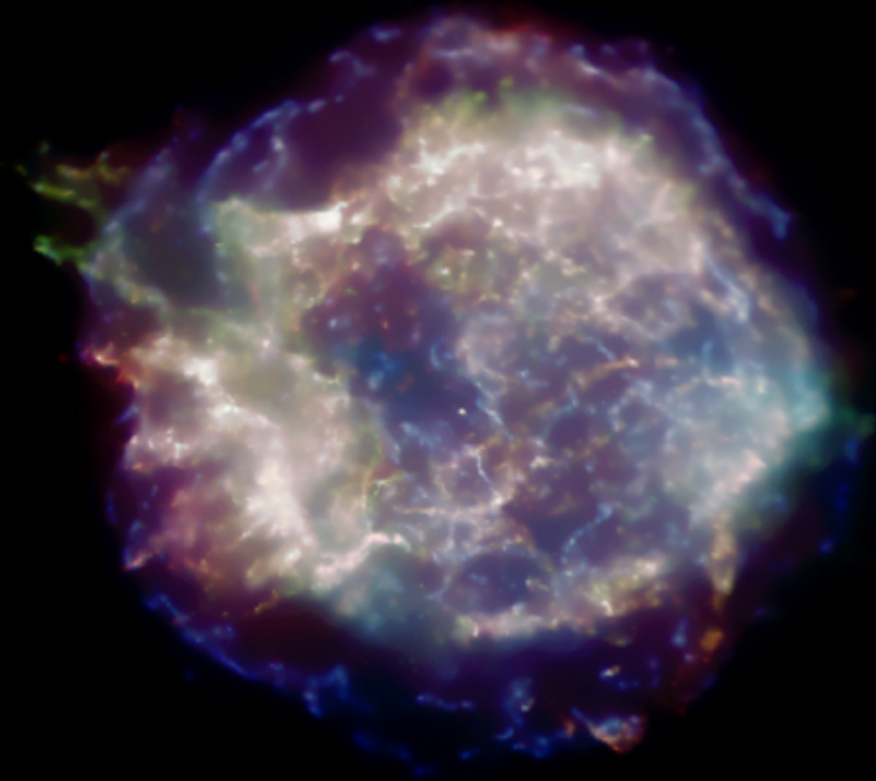
snow plow
(momentum conserving)



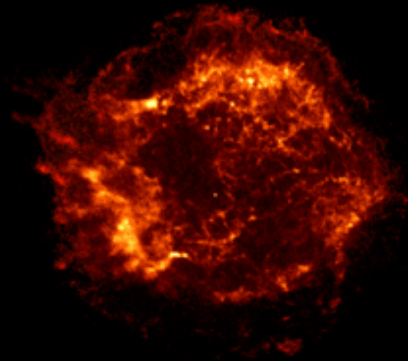
SNR: Expansion & Interaction with ISM



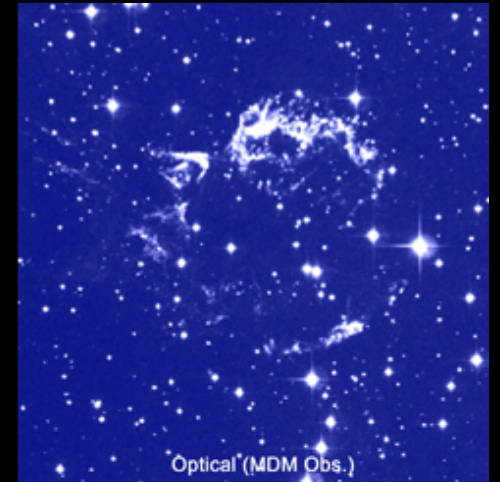
Example: Cas A SNR



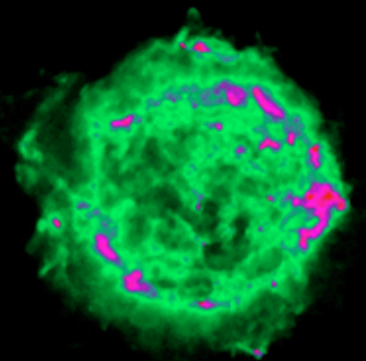
Chandra image (X-rays)



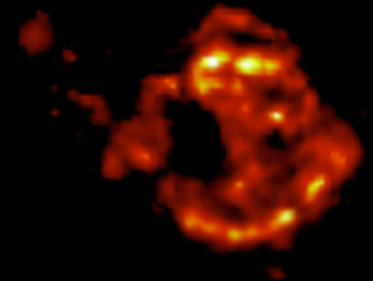
X-Ray (NASA/CXC/SAO)



Optical (MDM Obs.)

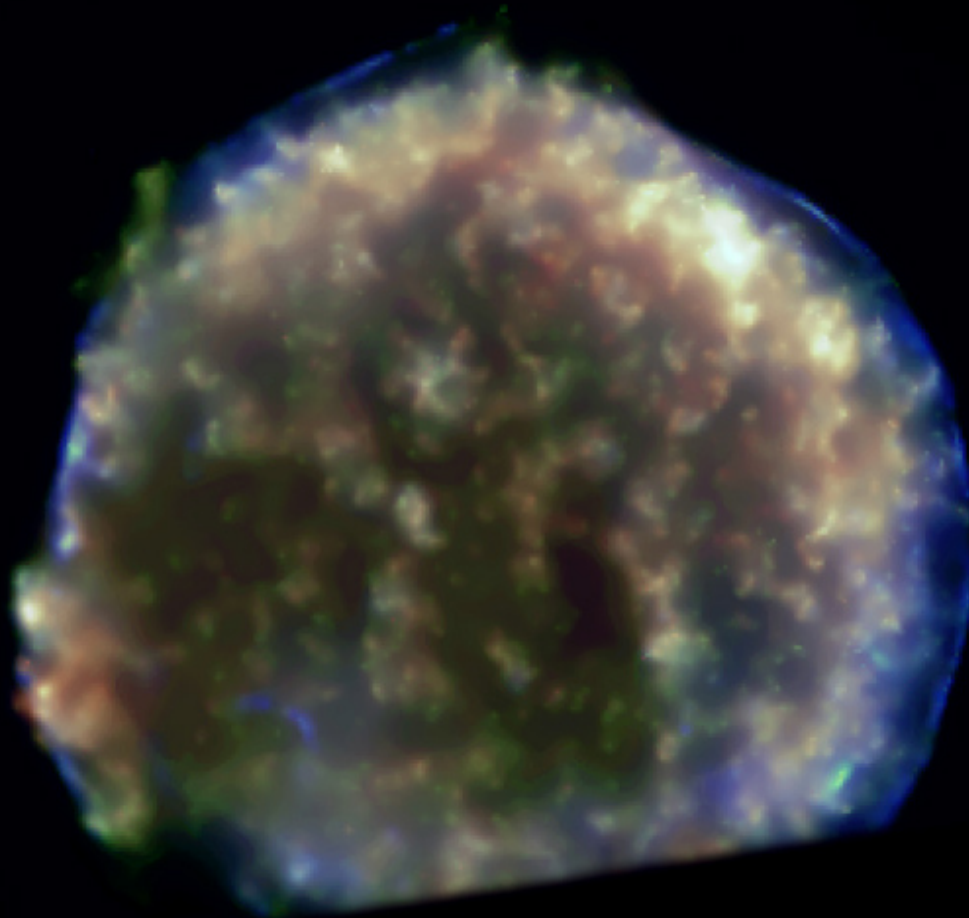


Radio (VLA)



Infrared (ISO)

Example: Tycho's SNR



SN event observed by
T. Brahe in 1572

no stellar remnant:
SN type Ia

Chandra image:

- X-rays
- colours: diff. energies
- blue rim:
shock, 20 million K
- fingers: stellar debris,
10 million K

Classification of Supernovae

Type	Ia	Ib	Ic	II
Spectrum	No Hydrogen			Hydrogen
	Silicon	No Silicon		
		Helium	No Helium	
Physical mechanism	Nuclear explosion of low mass star	Core collapse of evolved massive star (may have lost its hydrogen or even helium envelope during red-giant evolution)		
Light curve	Reproducible	Large Variations		
Neutrinos	Insignificant	~ 100 x Visible energy		
Compact Remnant	None	Neutron star (typically appears as pulsar) Sometimes black hole ?		
Rate/h ² SNu	0.36 ± 0.11	0.14 ± 0.07		0.71 ± 0.34
Observed	Total ~ 2000 as of today (nowadays ~200/year)			

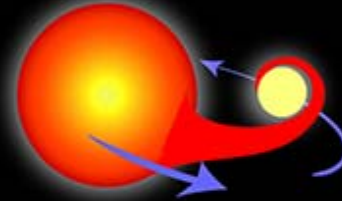
The progenitor of a Type Ia supernova



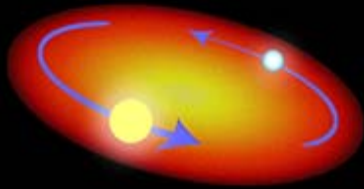
Two normal stars are in a binary pair.



The more massive star becomes a giant...



...which spills gas onto the secondary star, causing it to expand and become engulfed.



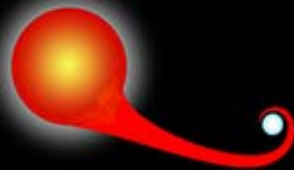
The secondary, lighter star and the core of the giant star spiral inward within a common envelope.



The common envelope is ejected, while the separation between the core and the secondary star decreases.



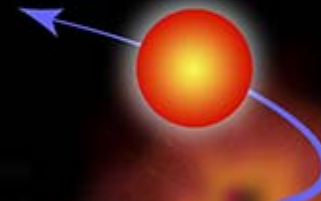
The remaining core of the giant collapses and becomes a white dwarf.



The aging companion star starts swelling, spilling gas onto the white dwarf.



The white dwarf's mass increases until it reaches a critical mass and explodes...



...causing the companion star to be ejected away.

Example: SN 1987A

Supernova 1987A 1994-2003

HST • WFPC2 • ACS



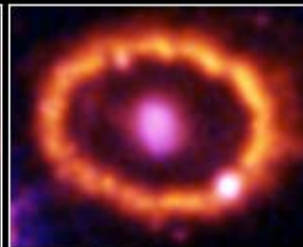
September 24, 1994



March 5, 1995



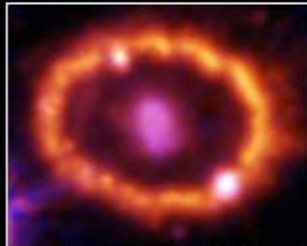
February 6, 1996



July 10, 1997



February 6, 1998



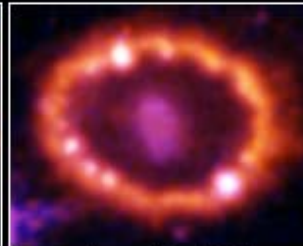
January 8, 1999



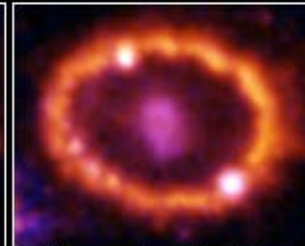
April 21, 1999



February 2, 2000



June 16, 2000



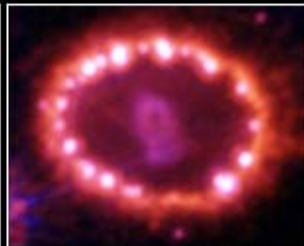
November 14, 2000



March 23, 2001



December 7, 2001



January 5, 2003



August 12, 2003



November 28, 2003

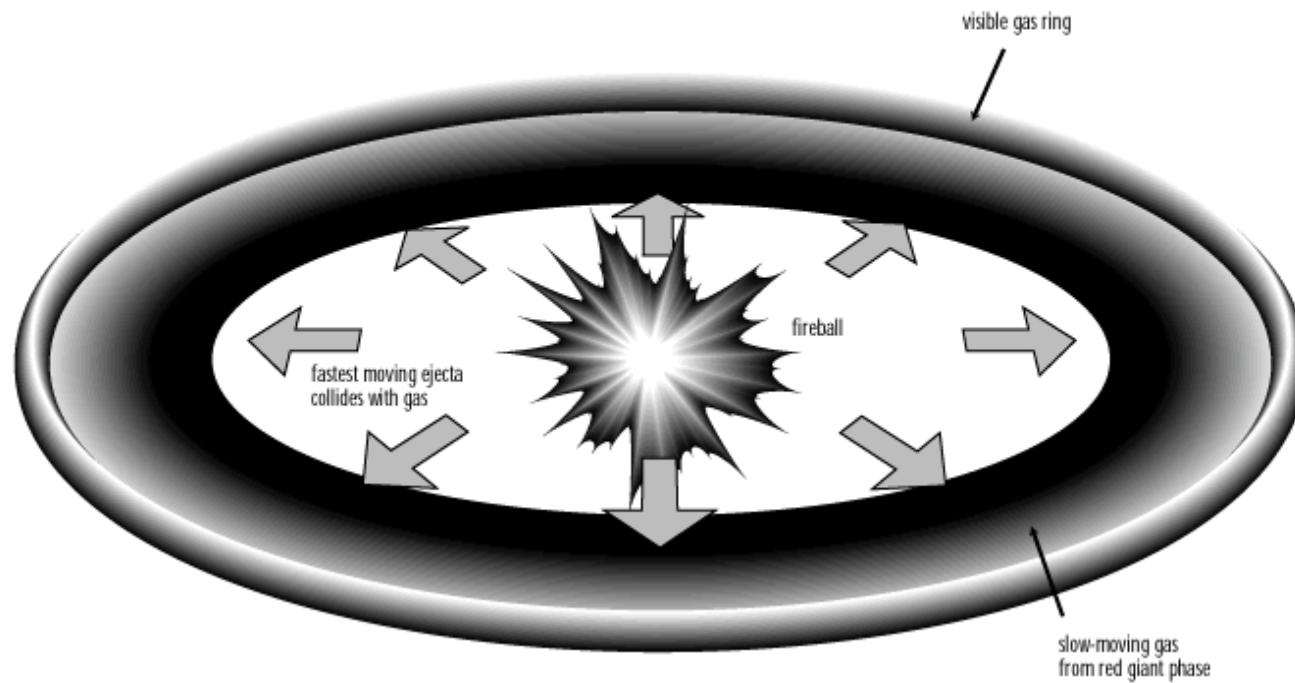
NASA and R. Kirshner (Harvard-Smithsonian Center for Astrophysics)

STScI-PRC04-09

Example: SN 1987A

Supernova 1987A

Collision Between Explosion
Ejecta and Slower Moving Gas



Example: Cygnus Loop

Cygnus Loop
HST • WFPC2

SN explosion took place
about 15 000 years ago

HST picture shows only a
small part of the SNR

the shock wave (moving left
to right) is hitting denser IS
gas

blue: O (doubly ionized)
hot gas behind shock
red: S (singly ionized)
cooler gas
green: H
directly behind shock

