Novae

Progenitor system survives the explosion

All progenitor systems of novae are close binaries with one WD

Distinguish 4 types:

- Classical novae: WD + MS [RG] ⇒ Roche-lobe overflow
- Symbiotic novae: WD + RG ⇒ Wind
- Recurrent novae: More than one nova from a system since recording. Typical delays: 10 - 100 years, prob. open end
- Neon novae: Show significant amount of Ne in spectra (~30%)

Good sources:

Book "Classical Novae" Ed. by M. F. Bode & A. Evans 2008
Cambridge Astrophysics Series

Gehrz et. al. "Nucleosynthesis in Classical Novae and Its Contribution to the Interstellar Medium"
PASP 1998

arXiv: 1301.1249v1

White Dwarfs (WDs)

Final state of stars with initial mass $M_{ini} \lesssim 8 M_\odot$

Stellar evolution:

- Driving force: Gravity
- Stars loose energy by radiation. This energy will be replaced by:
  - nuclear fusion (hydrostatic burning)
  - gravitational binding energy (contraction, central density AND temperature increase)

- Phases of nuclear burning a separated in space and time → onion structure
- ashes of one phase are fuel for the next phase
- If an additional burning phase will take place depends on the temperature that is reached in the center of the star → The number of burning phases depends only on the total mass of the star
- For $M \gtrsim 8 M_\odot$ all possible phases are realized (up to Fe)

Burning phase:	fuel	$T_{ignition}$	Ash	M_{star}
H	^1H	$2 \cdot 10^7 K$	^4He, ^{14}N	$M \gtrsim 0.08 M_\odot$
He	^4He	$2 \cdot 10^8 K$	^{12}C, ^{16}O, ^{22}Ne	$M_{He} \gtrsim 0.35 M_\odot$
C	^{12}C	$8 \cdot 10^8 K$	^{20}Ne, ^{24}Mg, ^{16}O, ^{23}Na	$M_C \gtrsim 0.9 M_\odot$
Ne, O, Si				

If the central temperature is not high enough to ignite nuclear burning again → further contraction

Contraction is halted eventually when the electrons become **degenerate**.

→ Degeneracy pressure counteracts gravity

Uncertainty principle: $\Delta p \cdot \Delta x \approx \hbar$

$$\Rightarrow E_{k,\,\text{electrons}} \approx \frac{N(\Delta p)^2}{2m} \approx \frac{N \hbar^2 n^{2/3}}{2m} \approx \frac{M^{2/3} N^{5/3} \hbar^2}{2m R^2}$$

(E_{k}: Energy per unit mass; N: # electrons per unit mass; $2m$: non-relativistic; n: number density of electrons, $\Delta x \sim n^{-1/3}$)

$$E_g \approx \frac{GM}{R} \overset{!}{=} E_k \Rightarrow R \approx \frac{N^{5/3} \hbar^2}{2m\, G M^{1/3}} \sim M^{-1/3}$$

→ More massive WD's are smaller

Relativistic case:

$$M^{\text{limit}} = M_{CH} = 5.76\, Y_e^2\, M_\odot$$

symmetric matter ($N = Z$, i.e. ^4He, ^{12}C, ^{16}O): $Y_e = 0.5$

$$\Rightarrow M_{Ch} = 1.44\, M_\odot$$

Isolated WD's are inert objects! They cool down by black-body radiation forever.

3 Types of WDs:

He - WDs ($M \lesssim 0.45\, M_\odot$)
CO WDs ($M \lesssim 1.2\, M_\odot$) when formed!
ONe(Mg)-WDs ($M \gtrsim 1.2\, M_\odot$)

[Brown dwarfs: H - WD's]

WD's:

$M \sim 0.1\, M_\odot - 1.44\, M_\odot$

$R \sim 10^8 - 10^9\, cm$ (earth size)

$\rho \sim 10^6 - 10^9\, g/cm^3$

$T_{surface} \sim 1\text{-}3 \cdot 10^4 K$ (but hotter inside)

Typical mass $\sim 0.6\, M_\odot$

$L \sim 10^{-4} L_\odot - 1 L_\odot$

$v_{esc} \sim 1000 \frac{km}{s} \approx 10^8 \frac{cm}{s}$

Energy injection into degenerate matter:

- non-degenerate: Energy injection ⇒ temperature rises ⇒ pressure rises ⇒ expansion ⇒ cooling
- degenerate: energy injection ⇒ temperature rises ⇒ no pressure reaction until degeneracy is lifted

Interacting binaries

MS WD

O . → MS evolves

→ Mass transfer, WD accretes H from MS star

Depending on $\frac{dM}{dt}$ (mass accretion rate):

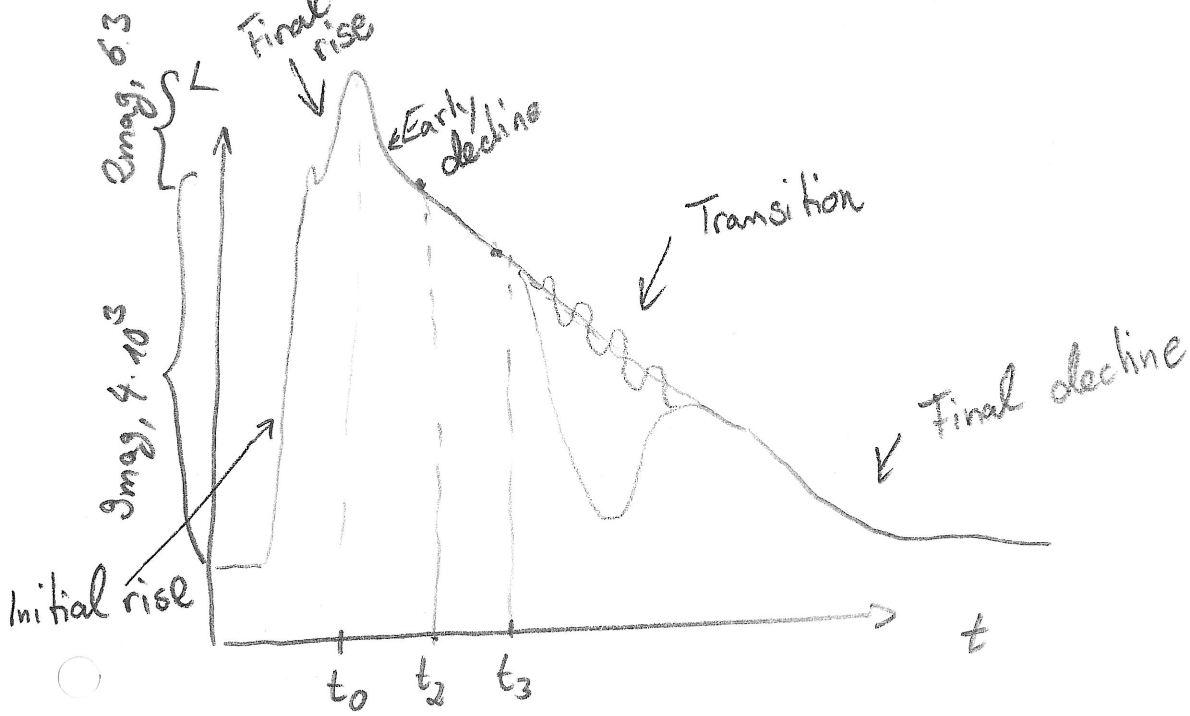
$\dot{M} \gtrsim 10^{-8} \frac{M_\odot}{yr}$: stable H-burning on surface

$\dot{M} \lesssim 10^{-8} \frac{M_\odot}{yr}$: accumulation of H in a shell

When M_{shell} increases, the material that has been accreted earlier is compressed (and mixed with some WD material)
→ H becomes degenerate at the bottom of the shell and density/pressure increase further
Once a critical pressure is reached at the bottom, H ignites pycnonuclear burning (triggered by high density/pressure).
→ Sudden increase of Temperature, but no expansion (degeneracy)
→ Strong increase of reaction rates, even higher temperatures
Eventually: Temperature so high, that degeneracy is lifted and parts of the shell are ejected ($\sim 10^{-4} M_\odot$)
Only a few % of H are burned! $v \sim 10^{3} \frac{km}{s}$, $E \sim 10^{45}$ erg
→ H-burning on the surface (now non-degenerate) continues until there is no H left!
Blows wind from the surface of WD
→ Accretion starts again.

Timescales depend on M_{WD} (larger WD mass
→ higher density on surface, smaller shell mass needed for explosion)

General optical nova light curve: ~~(visual)~~



t_2: time until nova fades by 2 mag from peak

t_3: –"– 3 –"–

t_2: ranges from < 10 d (very fast) to 150 - 250 d (very slow).
Mostly depends on M_{WD}, brighter novae have more massive WD's.

More extreme version: Replace WD with NS

⇒ Type I X-ray bursts

- Initial rise: Takes 1-3 days
  expanding Ejecta are optically thick → Increase in brightness from increase in radius of the „photosphere" ← spectrum of thick expanding shell
  (Spectrum looks like hot supergiant star)
  but enhanced in CNO
  ↓
- After maximum: Constant L_{bol}, powered by
  1-20 days continuous nuclear burning
  „Photosphere" recedes to smaller radii and higher T
  → Flux shifted to UV, away from optical (wind spectrum)
- Transition region: possible dust formation and destruction,
- Final decline: Energy production stopped, system returnes to pre-nova state, ejecta become transparent