Novae

- Basics, types
- Evolution
- Spectra (days after eruption)
- Nova shells (months to years after eruption)
- Abundances
Cataclysmic Variables (CVs)

- M.S. dwarf or subgiant overflows Roche lobe and transfers mass onto a nearby companion white dwarf. (if secondary is a red giant, then it’s a symbiotic variable)
- H-rich material builds up on white dwarf surface until it explodes outward due to nuclear fusion.
- Novae radiate primarily in the UV to X-ray region.
- Types:
  - **Classical Novae**: only one eruption observed (timescales of $10^3 - 10^5$ years), $\Delta m > 9$ mag (Nova Cygni 1992)
  - **Dwarf** (or recurrent) Novae: periodic eruption every $\sim 100$ days, $\Delta m \sim 5$ mag (SS Cygni)
  - **Polars**: magnetic field = 10 - 100 MegaGauss - prevents formation of accretion disk, rotation periods = orbital period (AM Her)
  - **Intermediate Polars**: B field = 1 - 10 MG, accretion disk disrupted close to the WD (DQ Her), strong hard X-ray sources like polars
  - **Nova-like variables**: roughly constant mass transfer (SW Sex, SU UMa)
- We will concentrate on classical novae, to study the nova shells
Classical Novae

\( V603 \text{ Aql} \)

(Gallagher & Starrfield, 1978, ARAA, 16, 171)

- Peak lum. = \(10^4 \ L_\odot\), Mass ejected = \(10^{-4} \ M_\odot\), Max. velocity = \(10^3 \ \text{km s}^{-1}\)
- Increasing ionization during optical decline:
  - “photosphere” expands outward much more slowly than nova material
Nova Evolution

- The red star overflows its Roche lobe at the inner Lagrange point and forms an accretion disk around the WD.
- The accreting gas hits the disk at the “hot spot”.
- The H-rich gas accretes onto the surface of the WD. The energy of accretion onto this compact object raises the temperature to $T \sim 10^7$ K, sufficient for slow H burning.
- “Flickering” in the quiescent state is due to slight variations in accretion.
- The H-rich material mixes with WD (CNO) material.
- Eventually, the temperature is hot enough for explosive fusion. For classical novae, this happens on a time scale of $10^3 – 10^5$ years (depending on $M_{WD}$, accretion rate, etc.)
- The temperature rises at the base of the accreted matter to $\sim 10^8$ K.
- **Thermonuclear runaway (TNR):** capture of protons by heavy elements (CNO cycle), happens in seconds.
Novae: Spectral Evolution

• At maximum light – Blueshifted absorption lines (resembling A - F supergiants) from expanding photosphere.
• After few days – broad permitted emission lines (densities too high for most forbidden lines)
• Two classes of novae at this time (days): He/N, Fe II
• The class depends on dominance of outer shell vs. wind
• Outer shell dominant – He/N : higher ionization, broader lines (> 5000 km/sec), rapid evolution (days), initial forbidden lines are “coronal” – [Fe VII], [Ne V], etc.
• Wind dominant – Fe II: lower ionization, lower velocities (<5000 km/sec), initial forbidden lines are “auroral” – [N II], [Ne III], etc.
• Some hybrids exist, confirming this basic picture
He/N Novae - Spectra

Fe II Novae - Spectra

Nova Shells

Nova Cygni 1992 (HST image)  
GK Per - erupted 1901

- A nova shell is typically resolvable as an equatorial ring or limb-brightened shell (sometimes elliptical) after a few months to years
- Distance can be calculated from radial velocity, proper motion of shell
Nova Shells

• Gas is ejected in two phases: discrete shell and wind
  – **Discrete shell**: from initial blast on surface, lasts ~ 10 sec
  – **Hot wind**: due to continued burning of H on WD surface over months
• Initially the ejecta are very optically thick – “expanding photosphere”
  – continuum plus absorption lines
• As the ejecta expand and become optically thin in the outer regions, the visible photosphere shrinks by comparison
  - temperature of photosphere increases, as you see closer in
• The ejecta undergo some recombination, but are kept photoionized by the hot photosphere/ nuclear burning on the white dwarf surface
• The ejecta are characterized by decreasing ionization and density over the following months to years
• Eventually, the ejecta merge with the ISM. IR observations indicate dust shells are often formed in the ejection (Gherz, 1988, ARAA 26, 377).
Novae Shells - Spectra (Nova Cygni 2006)
Old Novae Shells - Spectra

- Shell photoionized by low-level nuclear burning on W.D., accretion disk UV radiation
- Emission-line spectrum dominated by permitted lines in the optical plus [N II], [O II]. Why?
  - low ionization not due to high density, since [N II] critical density is relatively low ($8.6 \times 10^4$ cm$^{-3}$).
  - due to low level of ionizing flux and thus low temperatures (not enough electron velocity to collisionally excite most levels): $T_{\text{gas}} \leq 3000$K
- Strong CNO permitted lines – due to recombination
- Balmer continuum jump is present and relatively sharp, which confirms low temperature (very few electrons recombining at high velocities)
- Relatively strong IR lines (collisionally excited) are expected; recent observations confirm these.
Photoionization Models

- Slightly enriched He, very high CNO abundances
- There are \( \sim 25 \) novae in the Galaxy per year, contribute \( \sim 2.5 \times 10^{-3} \) \( M_\odot/\text{yr} \)
- Novae are the major source of \(^{15}\text{N}\) and \(^{17}\text{O}\) in the Galaxy.

(Osterbrock & Ferland, p 298)
CHARA Observations of Nova Delphini 2013

- Results published in *Nature* (Schaefer et al., 2014)
- CHARA observations started one day after explosion.
- Elliptical light distribution (prolate or bipolar).
- Apparent changing expansion rate due to optical depth changes.
- Distance from angular radius, radial velocity $\sim 4.54$ kpc.