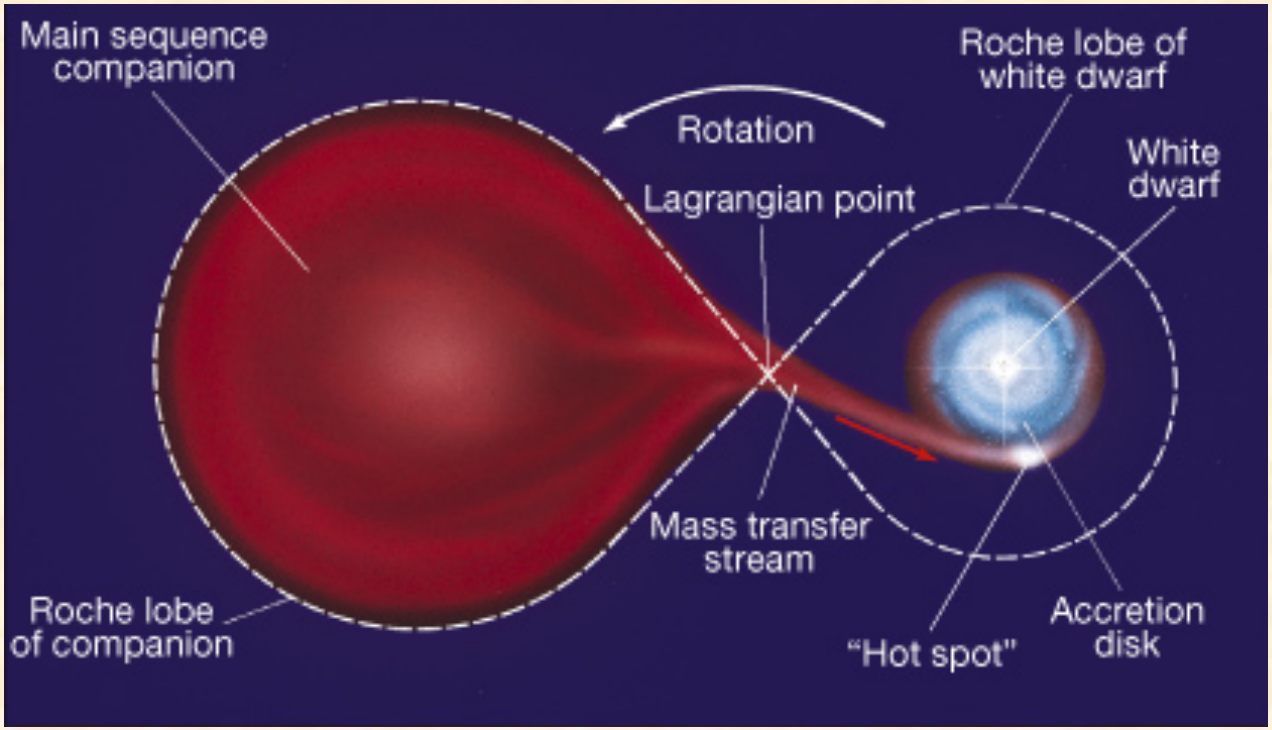
Novae

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

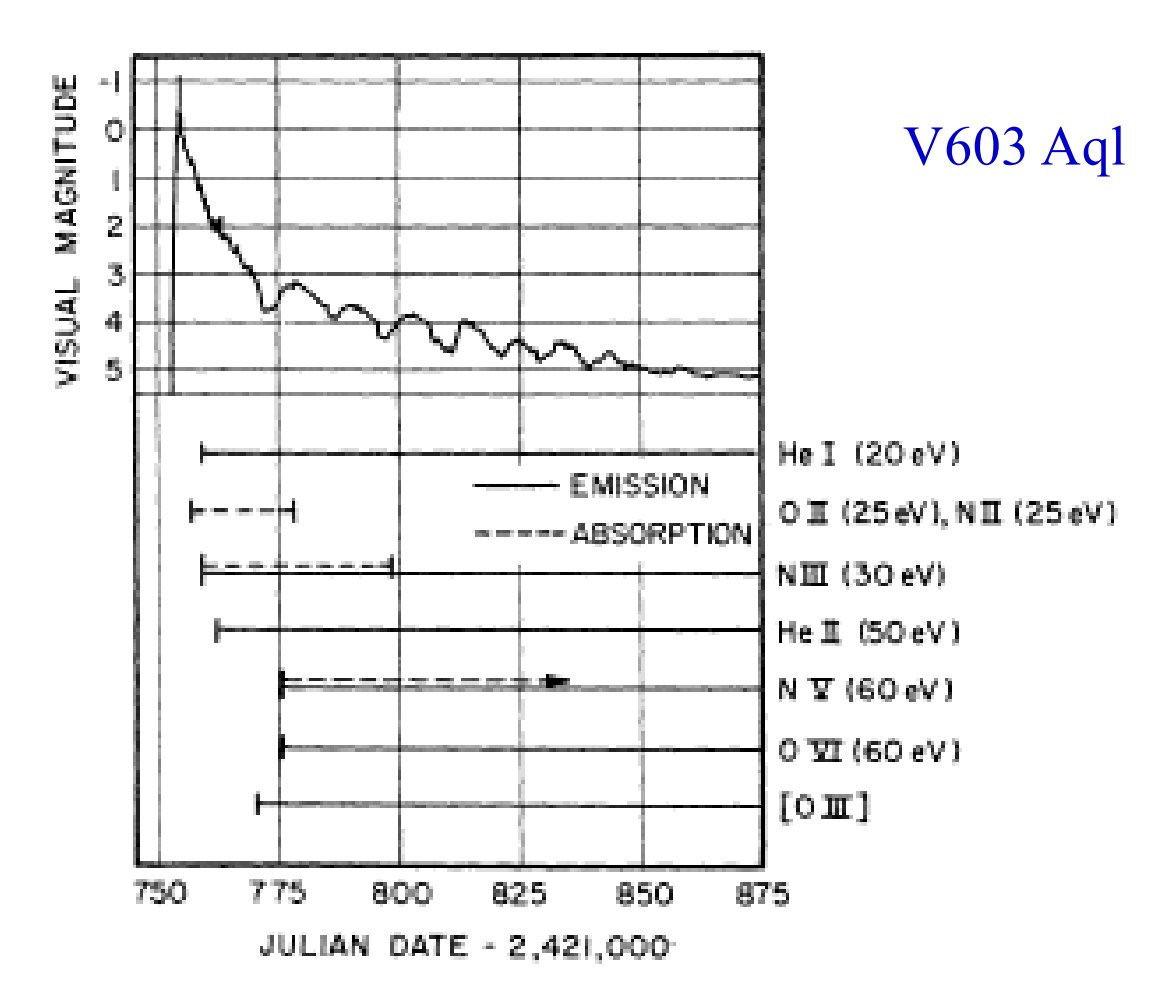


Cataclysmic Variables (CVs)

- 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 ~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



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

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

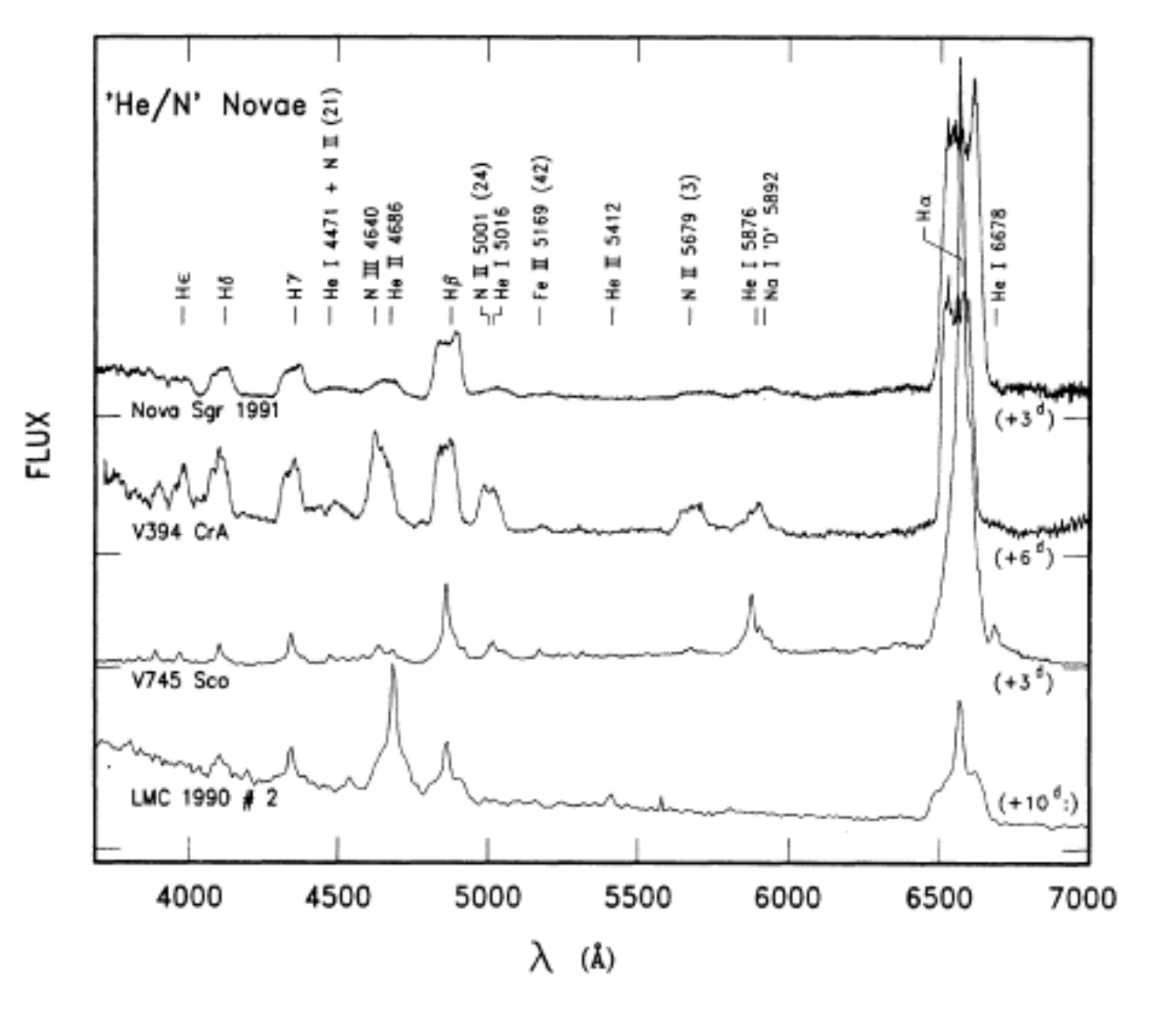
Nova Evolution

- 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

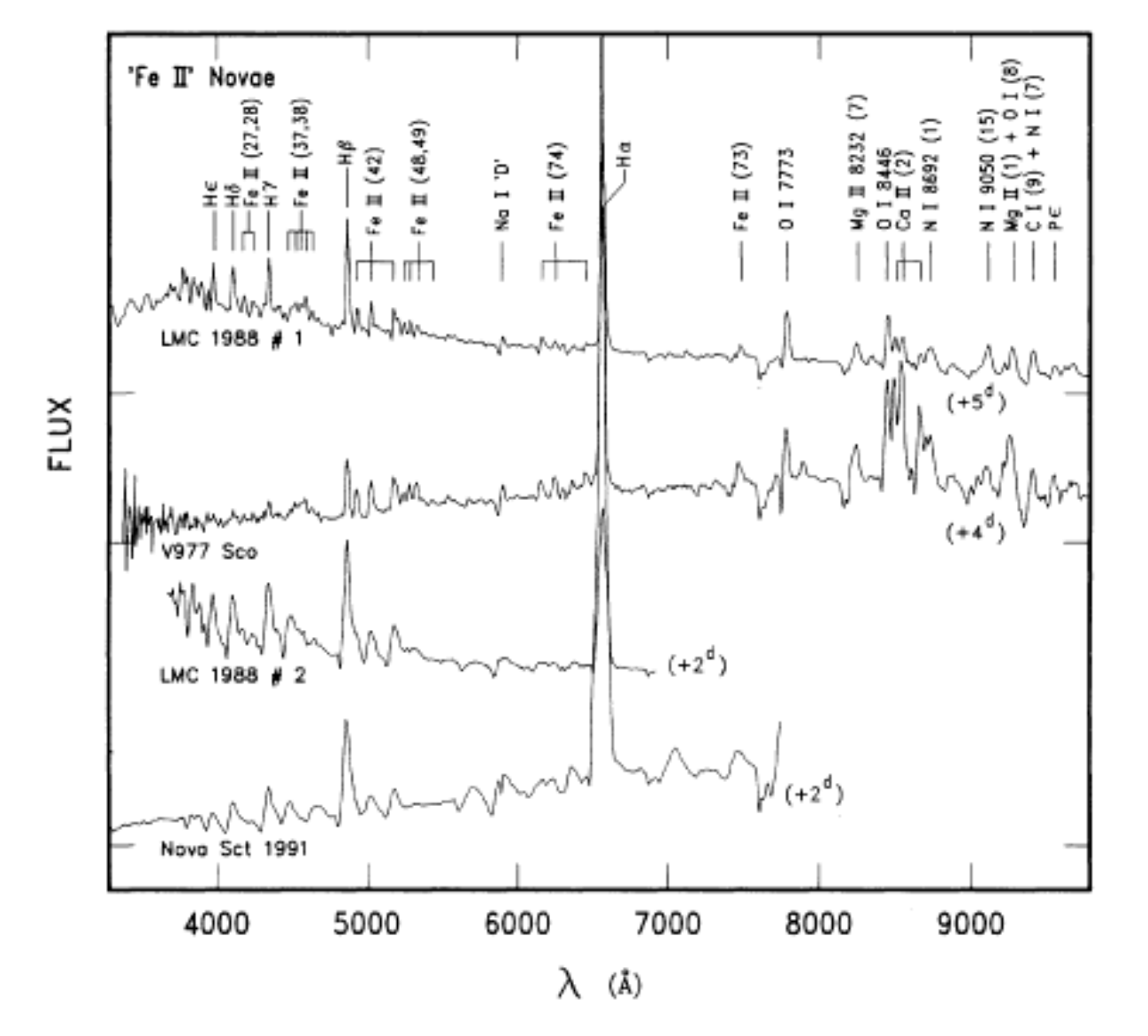
- At maximum light – Blueshifted absorption lines (resembling A - F supergiants) from expanding photosphere.
- After few days – broad permitted emission lines (densities too high for most forbidden lines)
- Two classes of novae at this time (days): He/N, Fe II
- The class depends on dominance of outer 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



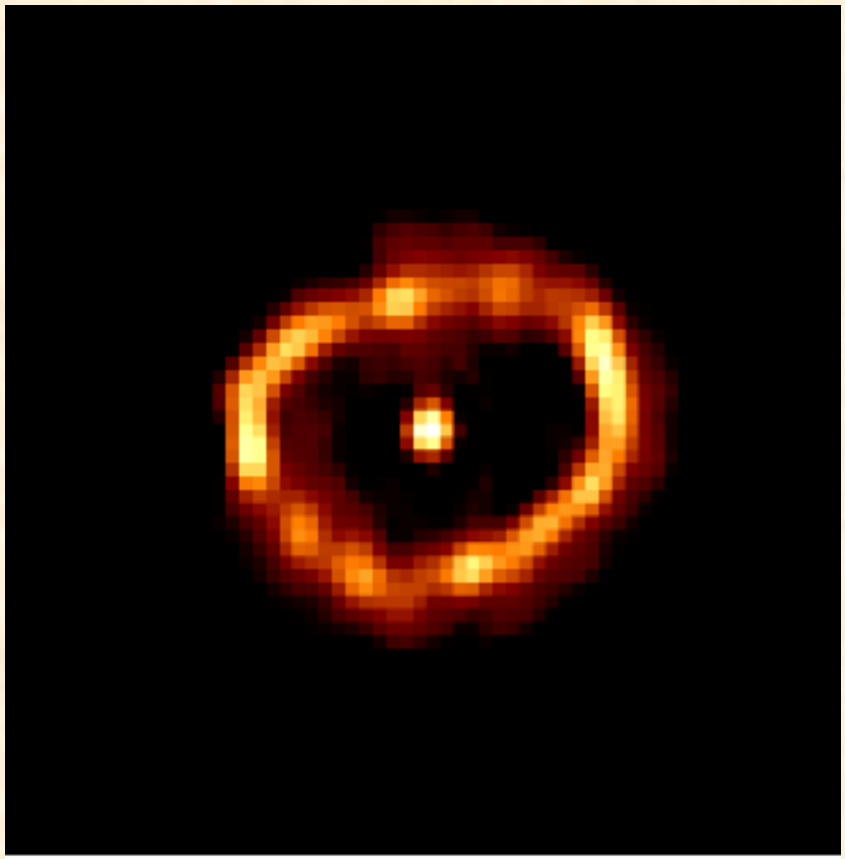
(Williams, R.E. 1992, AJ, 104, 725)

Fe II Novae - Spectra

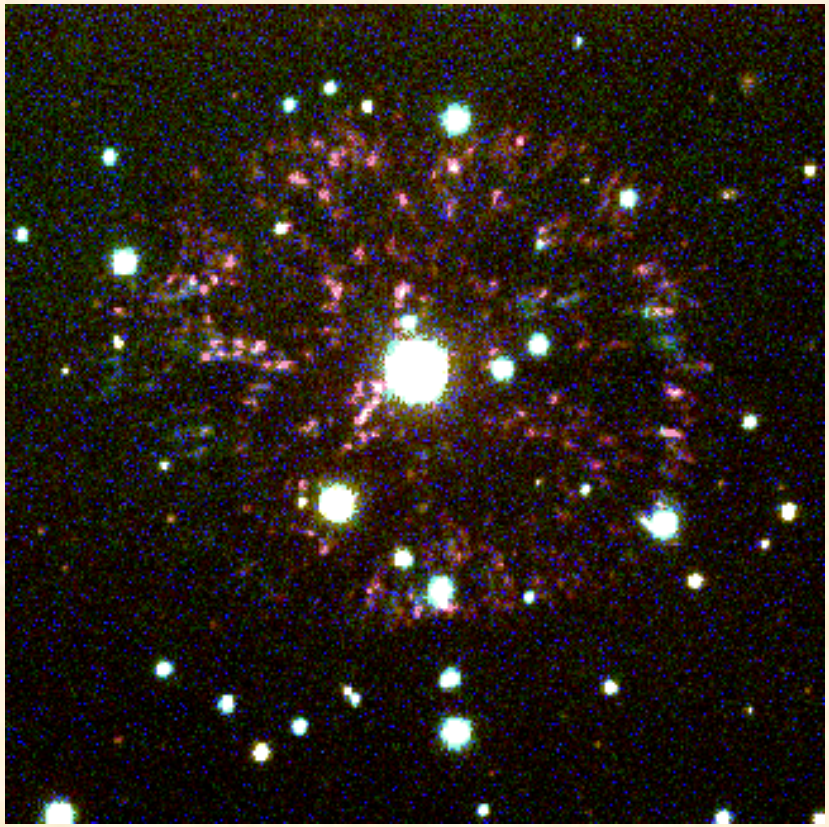


(Williams, R.E. 1992, AJ, 104, 725)

Nova Shells



Nova Cygni 1992 (HST image)



GK Per - erupted 1901

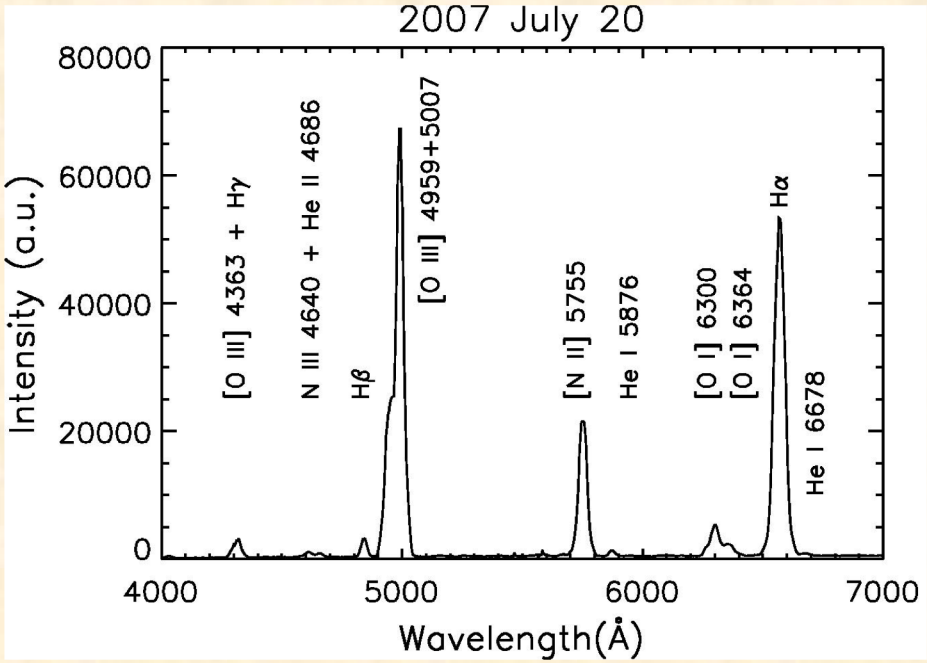
- A nova shell is typically resolvable as an equatorial ring or limb-brightened shell (sometimes elliptical) after a few months to years
- Distance can be calculated from radial velocity, proper motion of shell

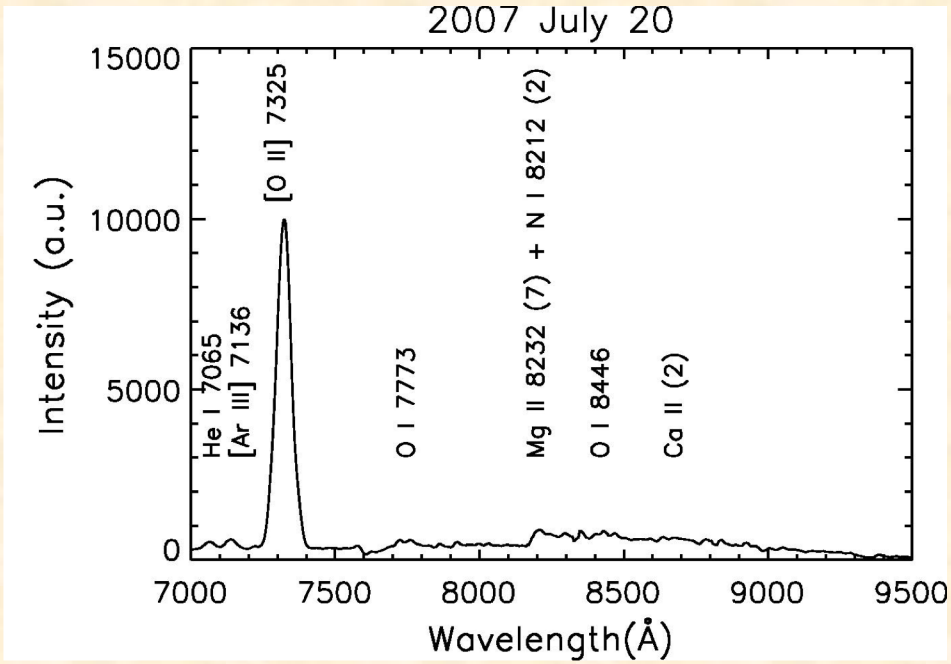
Nova Shells

- 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 (8.6×10^4 cm^{-3}).

  - due to low level of ionizing flux and thus low temperatures (not enough electron velocity to collisionally excite most levels): $T_{gas} \leq 3000K$
- 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

Observed and predicted line strengths in DQ Her

		Major axis		Minor axis	
Ion	λ (Å)	Observed	Model	Observed	Model
H I	4861	100	100	100	100
H I	6563	—	512	—	333
νF_ν(BaC)	3646	250	190	220	250
He I	4471	9	9	—	8
He II	4686	12	12	—	3
C II	4267	26	27	18	10
C II	1335	270:	40	270:	223
C III]	1909	40::	12	40::	9
[N II]	6583+	80	38	220	209
N II	5005	25	25	16	9
[O II]	3727	110	107	110	128
O II	4651	40	40	20	22
[O III]	5007+	≤ 10	3	—	4
T(K)			750		100
n_H(cm^{-3})			82		880
He/H			0.15		0.15
C/H			1.0×10^{-2}		1.8×10^{-2}
N/H			4.0×10^{-2}		7.7×10^{-2}
O/H			4.4×10^{-2}		5.1×10^{-2}

(Osterbrock & Ferland, p 298)

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

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 ~ 4.54 kpc.