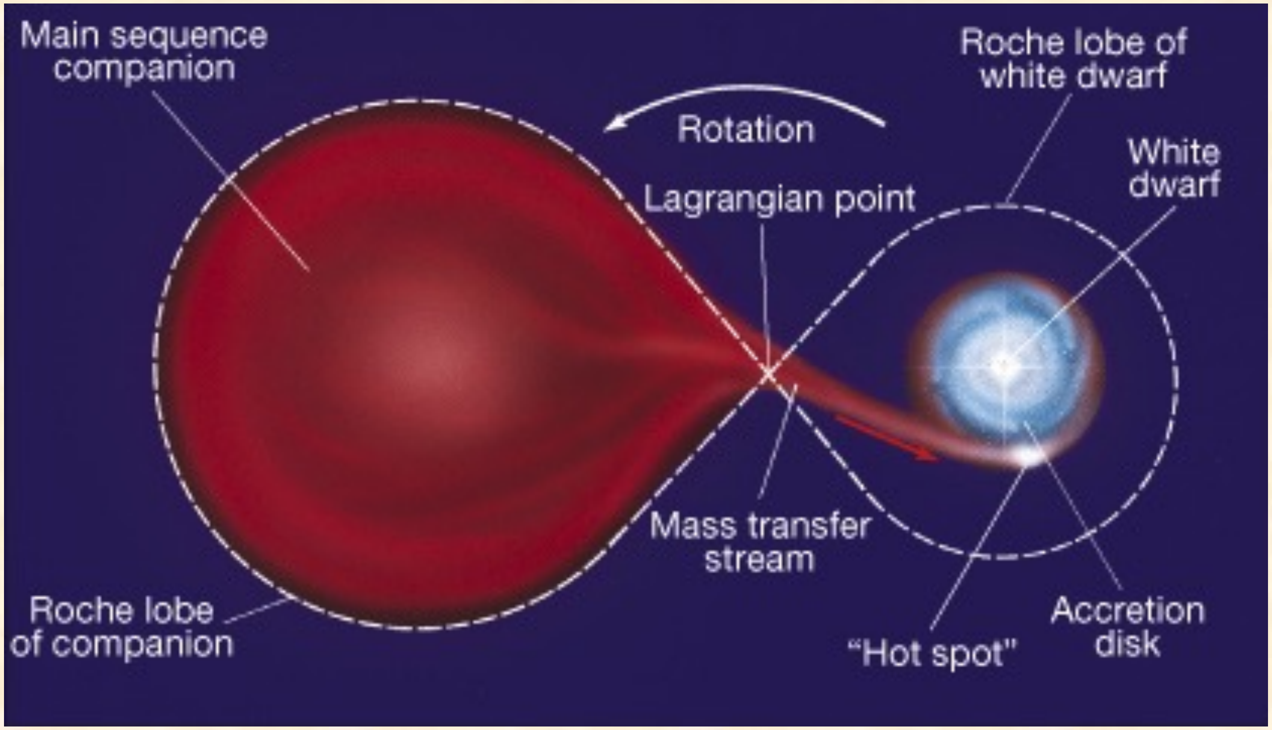
# Novae

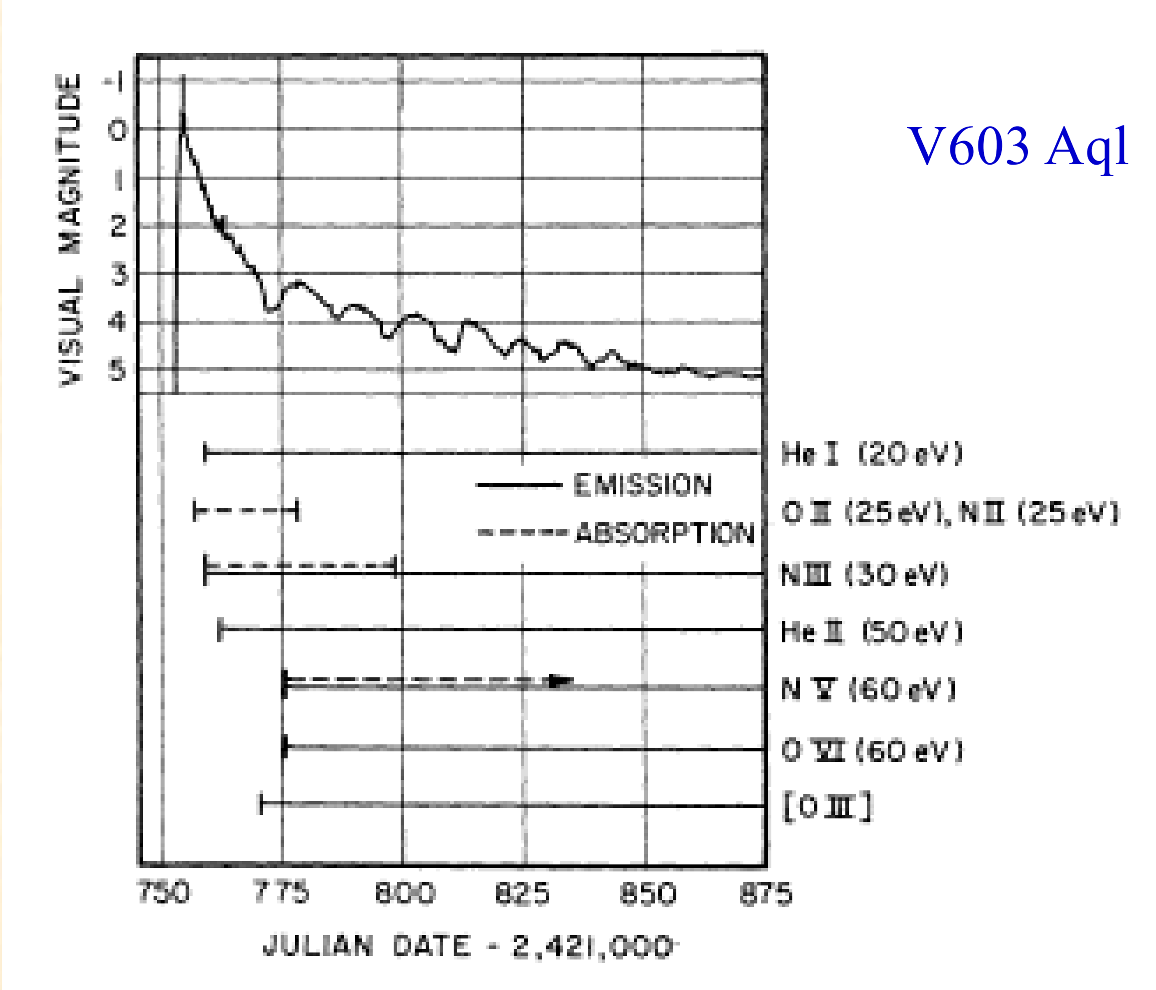
- Basics, types
- Evolution
- Spectra (days after eruption)
- Nova shells (months to years after eruption)
- Abundances



# Cataclysmic Variables (CVs)

- M.S. dwarf or subgiant overflows Roche lobe and transfers mass onto a nearby companion white dwarf.
- 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




V603 Aql

(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

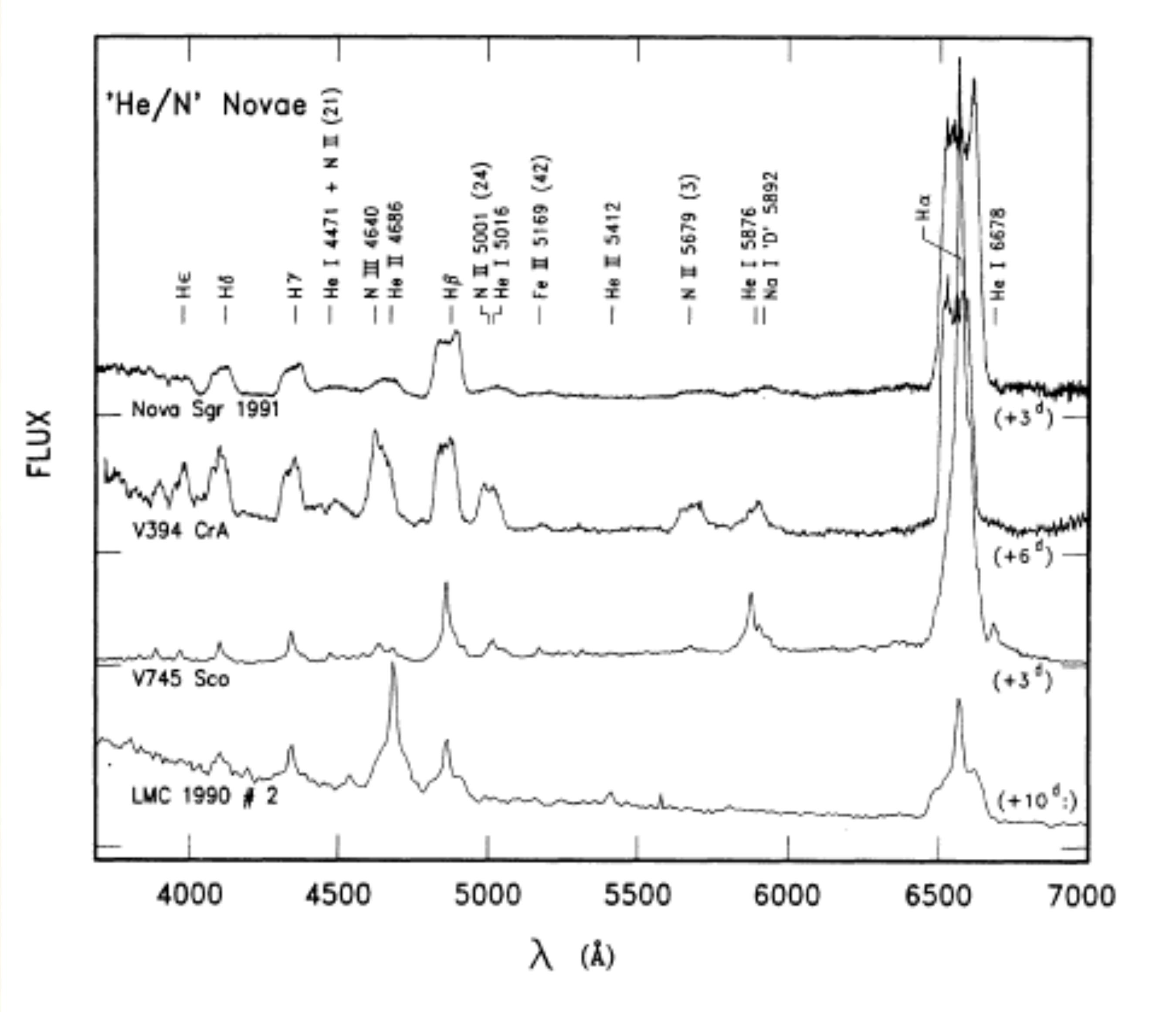
# Nova Evolution

- 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 ~ $10^8$K.
- Thermonuclear runaway (TNR): capture of protons by heavy elements (CNO cycle), happens in seconds

# Novae: Spectral Evolution

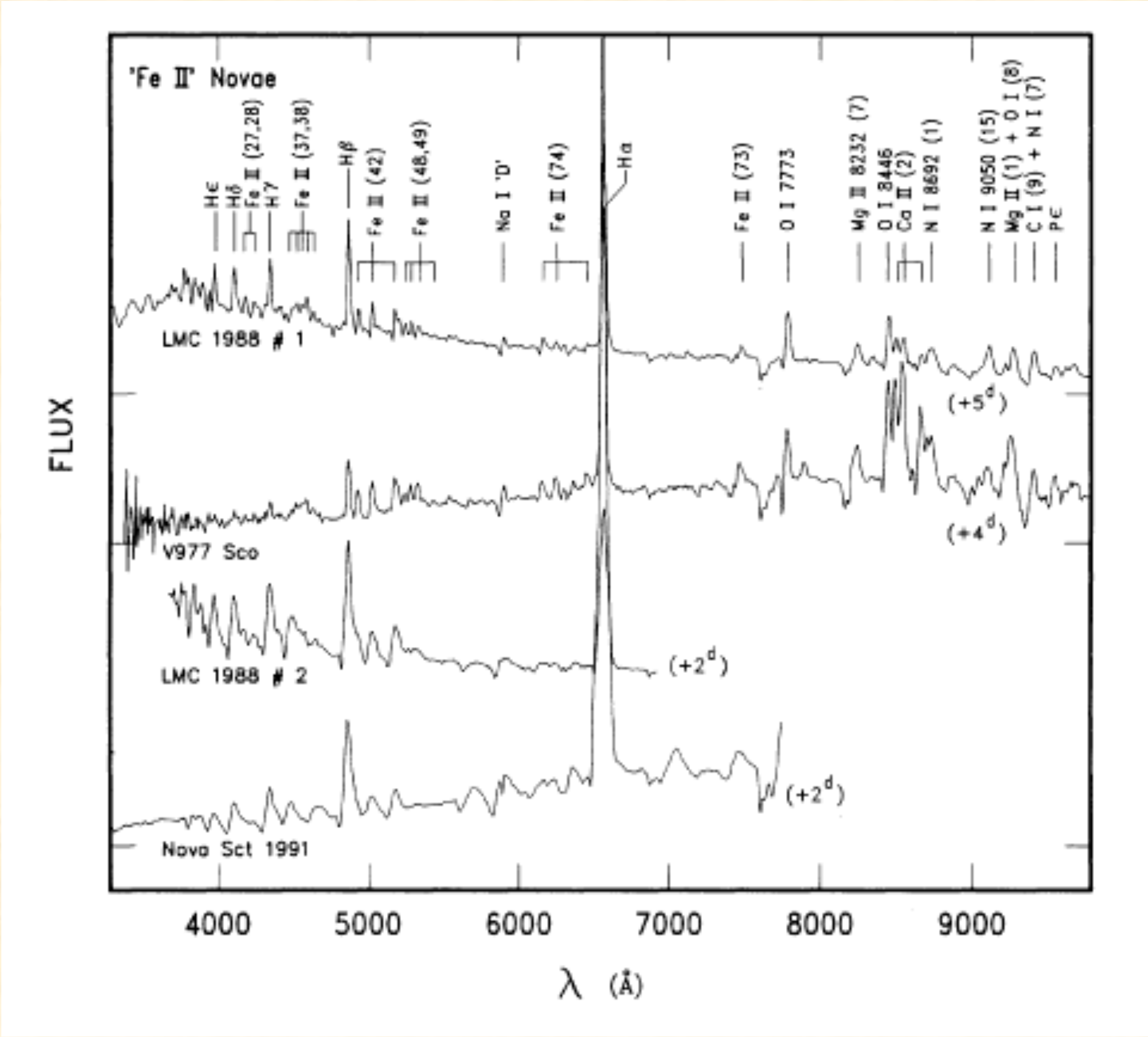
- At maximum light – Blueshifted absorption lines (resembling A - F supergiants) from expanding photosphere.
- After few days – broad permitted emission lines (densities too high for most forbidden lines)
- Two classes of novae at this time (days): He/N, Fe II
- The class depends on dominance of outer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



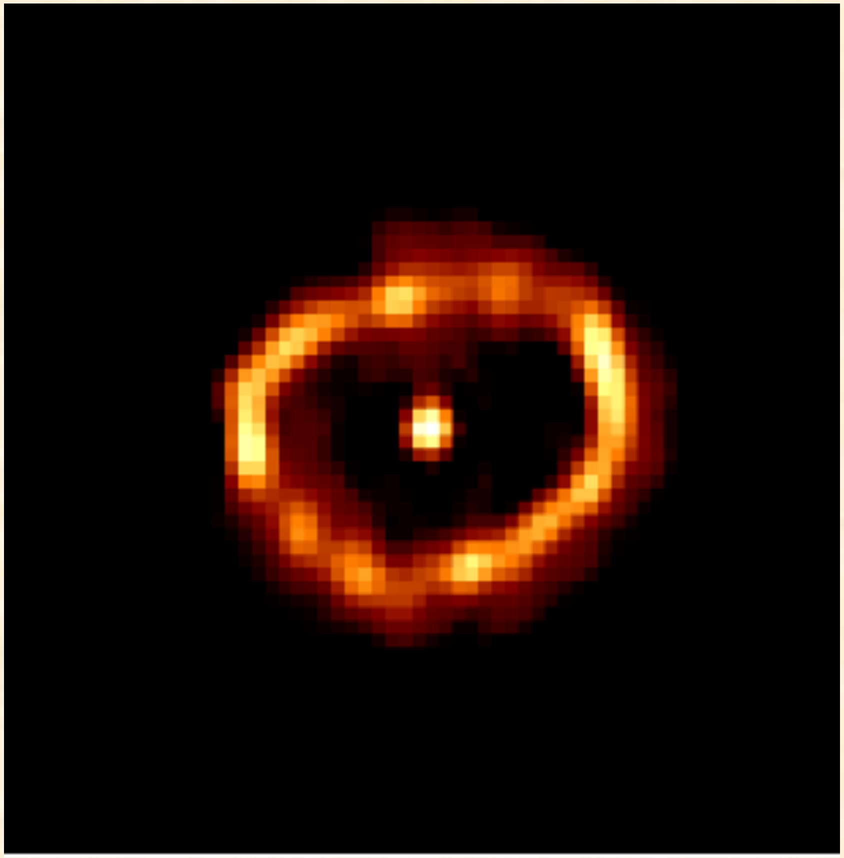

(Williams, R.E. 1992, AJ, 104, 725)

# Fe II Novae - Spectra

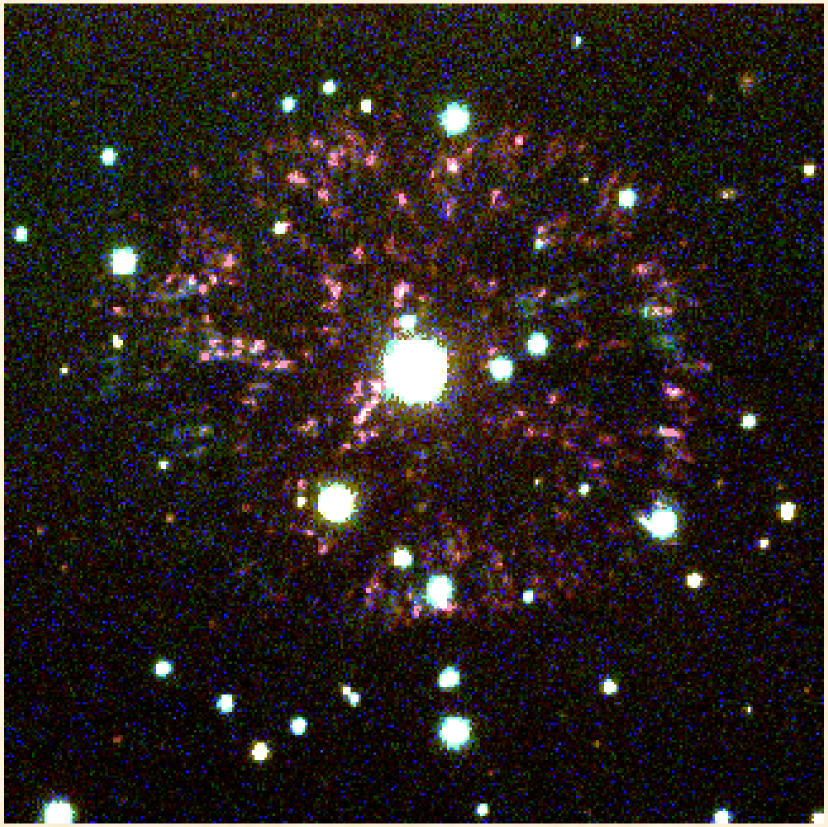



(Williams, R.E. 1992, AJ, 104, 725)

# Nova Shells



Nova Cygni 1992 (HST image)



GK Per - erupted 1901

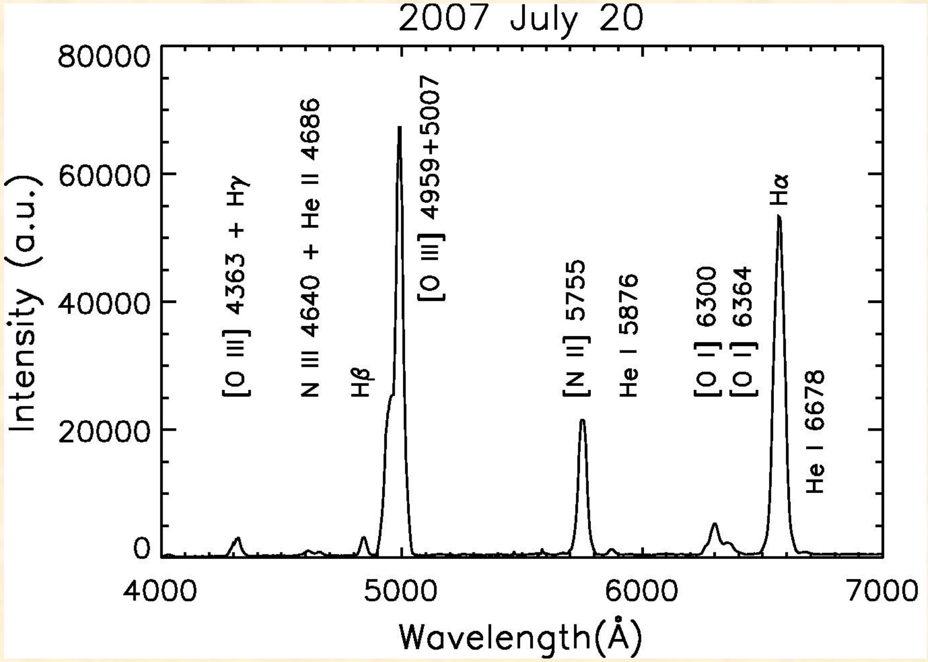
- A nova shell is typically resolvable as an equatorial ring or limb-brightened shell (sometimes elliptical) after a few months to years
- Dominance of ring/shell depends on original WD rotation.
- Distance can be calculated from radial velocity, proper motion of shell

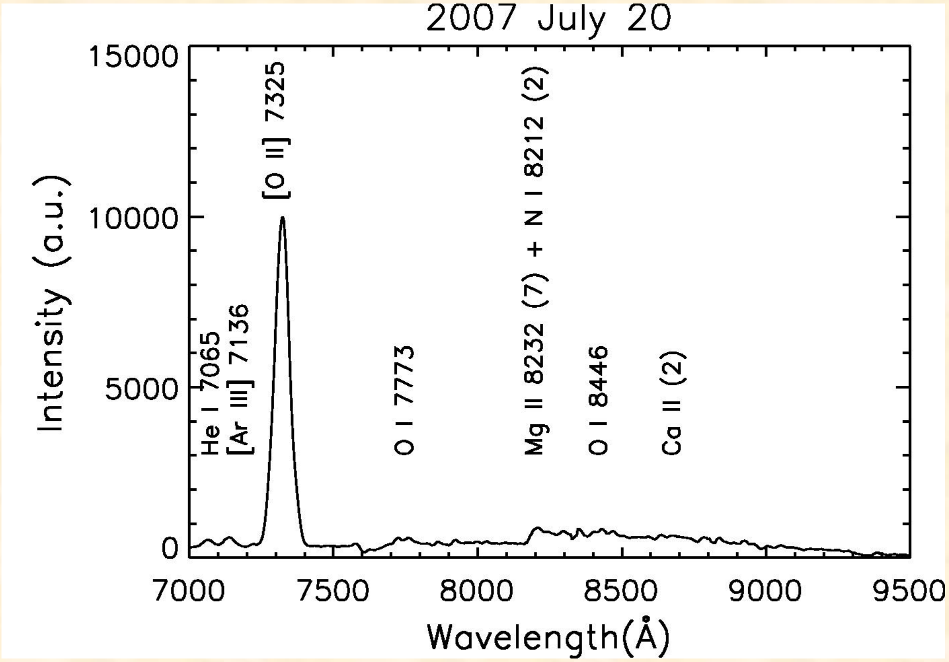
# Nova Shells

- 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 x $10^4$ $cm^{-3}$).

  - 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

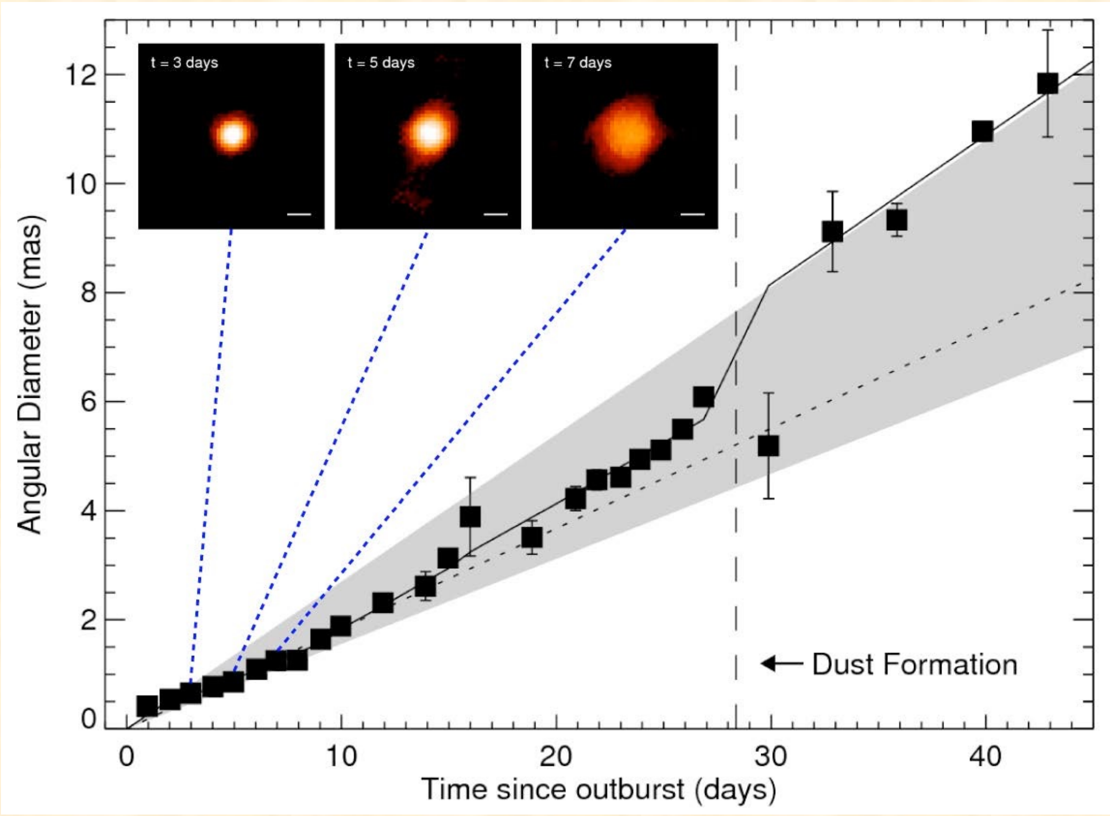
| | | Major axis | | Minor axis | |
|---|---|---|---|---|---|
| Ion | λ (Å) | Observed | Model | Observed | Model |
| H I | 4861 | 100 | 100 | 100 | 100 |
| H I | 6563 | — | 512 | — | 333 |
| $\nu F_\nu$(BaC) | 3646 | 250 | 190 | 220 | 250 |
| He I | 4471 | 9 | 9 | — | 8 |
| He II | 4686 | 12 | 12 | — | 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+ | $\leq 10$ | 3 | — | 4 |
| $T$(K) | | | 750 | | 100 |
| $n_H$(cm$^{-3}$) | | | 82 | | 880 |
| He/H | | | 0.15 | | 0.15 |
| C/H | | | $1.0 \times 10^{-2}$ | | $1.8 \times 10^{-2}$ |
| N/H | | | $4.0 \times 10^{-2}$ | | $7.7 \times 10^{-2}$ |
| O/H | | | $4.4 \times 10^{-2}$ | | $5.1 \times 10^{-2}$ |

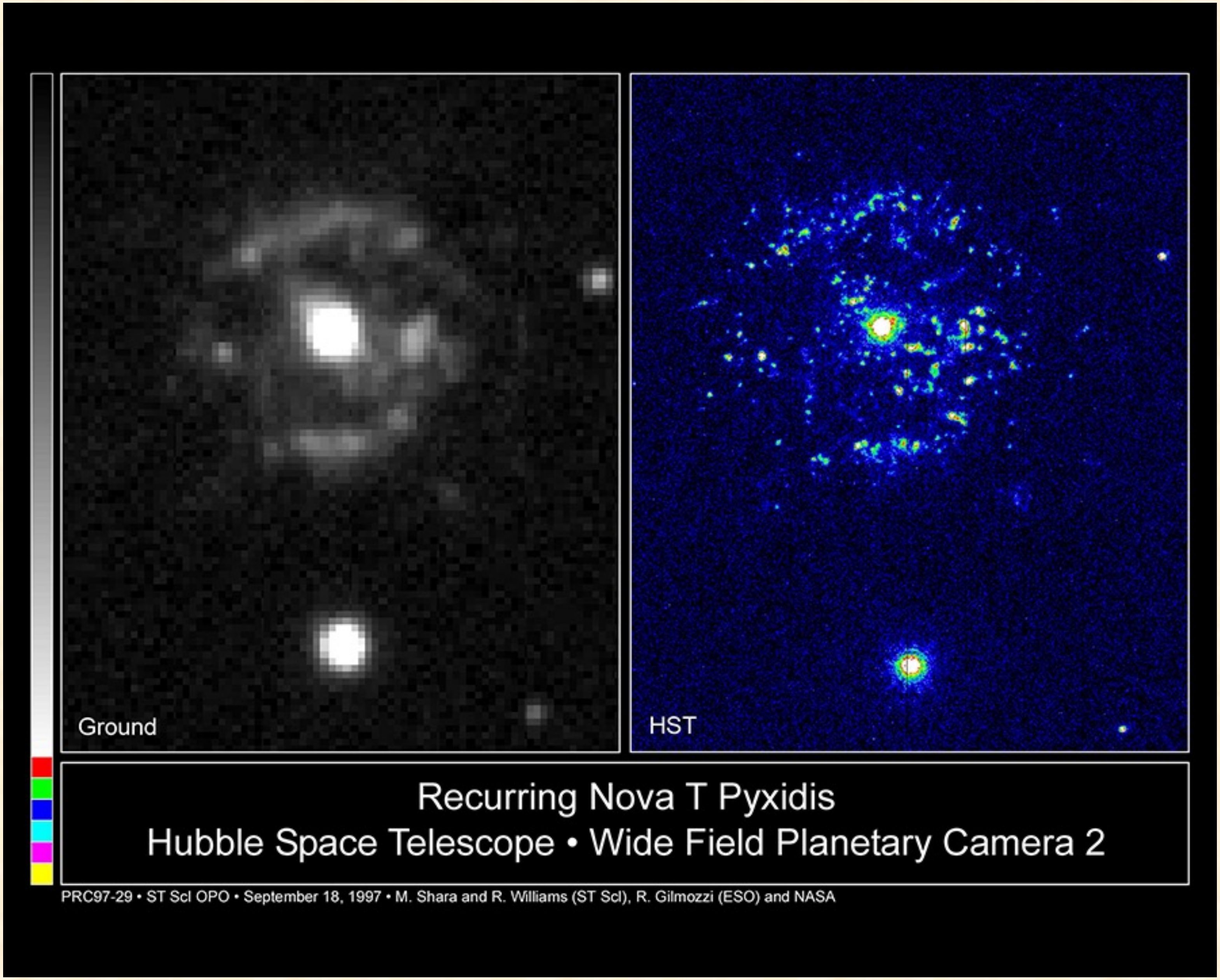
(Osterbrock & Ferland, p 298)

- Slightly enriched He, very high CNO abundances
- There are ~25 novae in the Galaxy per year, contribute ~$2.5 \times 10^{-3}$ $M_\odot$/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.




Ground
HST
Recurring Nova T Pyxidis
Hubble Space Telescope • Wide Field Planetary Camera 2
PRC97-29 • ST Scl OPO • September 18, 1997 • M. Shara and R. Williams (ST Scl), R. Gilmozzi (ESO) and NASA