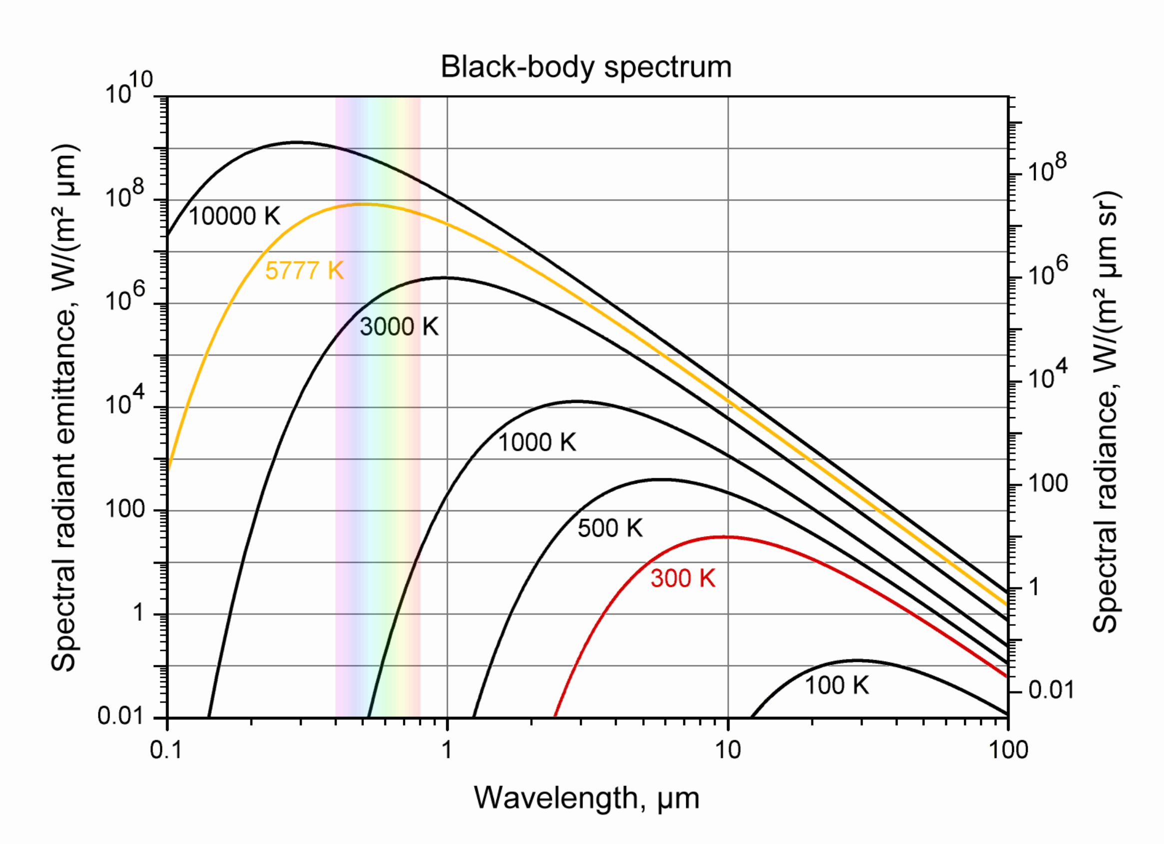
Emission lines spectra and novae

OHP Spectro Party 2012 - August 15
Ivan De Gennaro Aquino

Some cheap atomic physics - 1



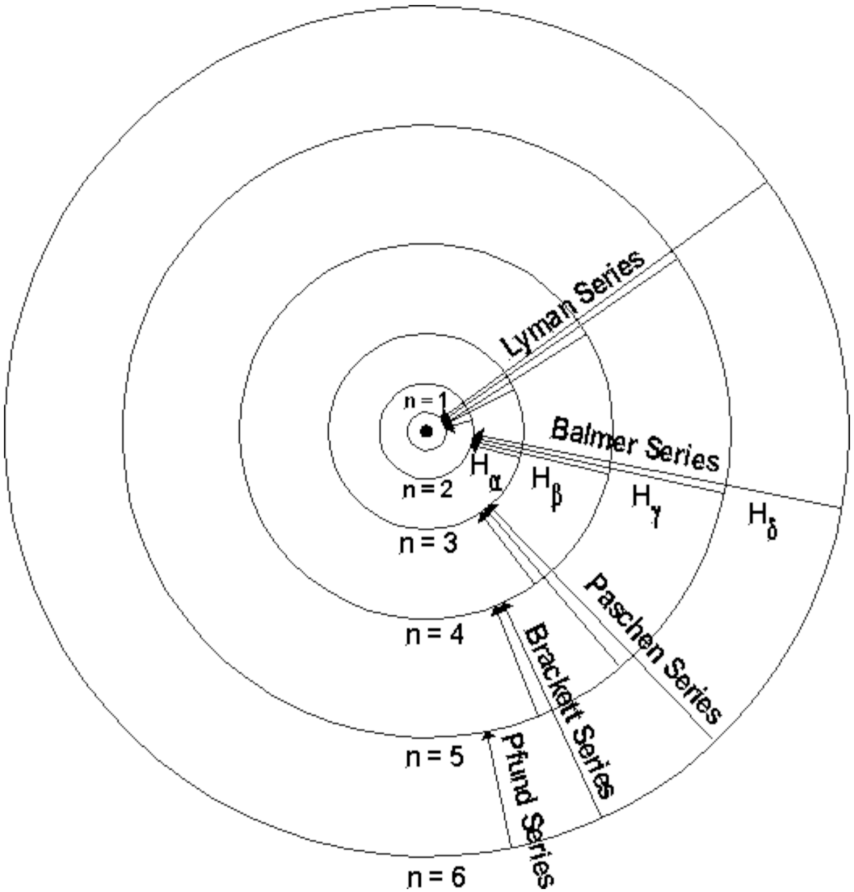
The black body spectrum (Planck sp.)

Some cheap atomic physics - 2

Niels Bohr atomic model works! Defined states populated by electrons. A precise set of quantum number per state.

Many processes determine the atomic states populations:

- Absorption
- Spontaneous emission
- Stimulated emission
- Collisions
- Ionization
- Recombination



Some cheap atomic physics - 3

Local thermal equilibrium (LTE): atomic states are strongly coupled with colliding electrons and radiation is coupled to.

A gas in LTE is fully described by one single parameter: temperature.

- Atomic states populations follow Boltzmann distribution
- Ionization and recombination rates are balanced (Saha Equation)
- Radiation? Black body

Some cheap atomic physics - 4

Every process involving atomic transitions has its own probability (it's a quantum world).

A "bound-bound" transition (an electron going from a certain state *j* to another *k*) is said to be allowed when the *dipole approximation* and the *selection rules* work fine.

For this process, probability (A_{jk}) is high, so radiative (de)-excitation happens fast.

Some cheap atomic physics - 5

We said "allowed"...and "not allowed"?

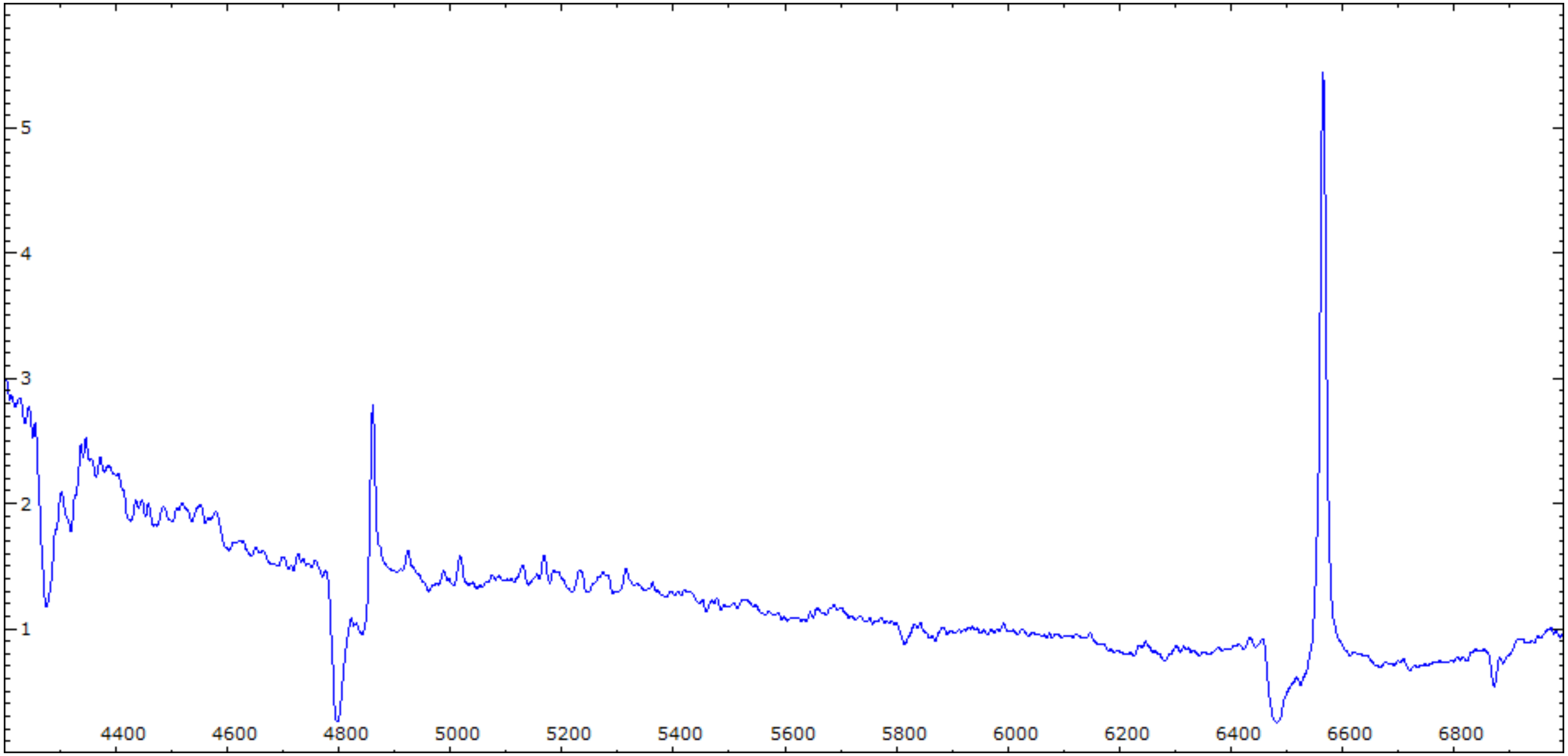
In the quantum world, "not allowed" only means "very improbable", and in laboratories it means "we have never seen it".

So what about transitions that do not respect those rules? They will have a very low transition probability, low A_{jk}.

Some cheap atomic physics - 6

We get our instruments working properly and we see something like this...should we panic?

v604 Mon



Some cheap atomic physics - 7

What is going on there?

We see <u>absorption lines</u>: a **dilute** gas is stealing photons.

We see <u>emission lines:</u> to which elements\molecules\processes are related? Before answering, remember: there is a **dilute** gas somewhere.

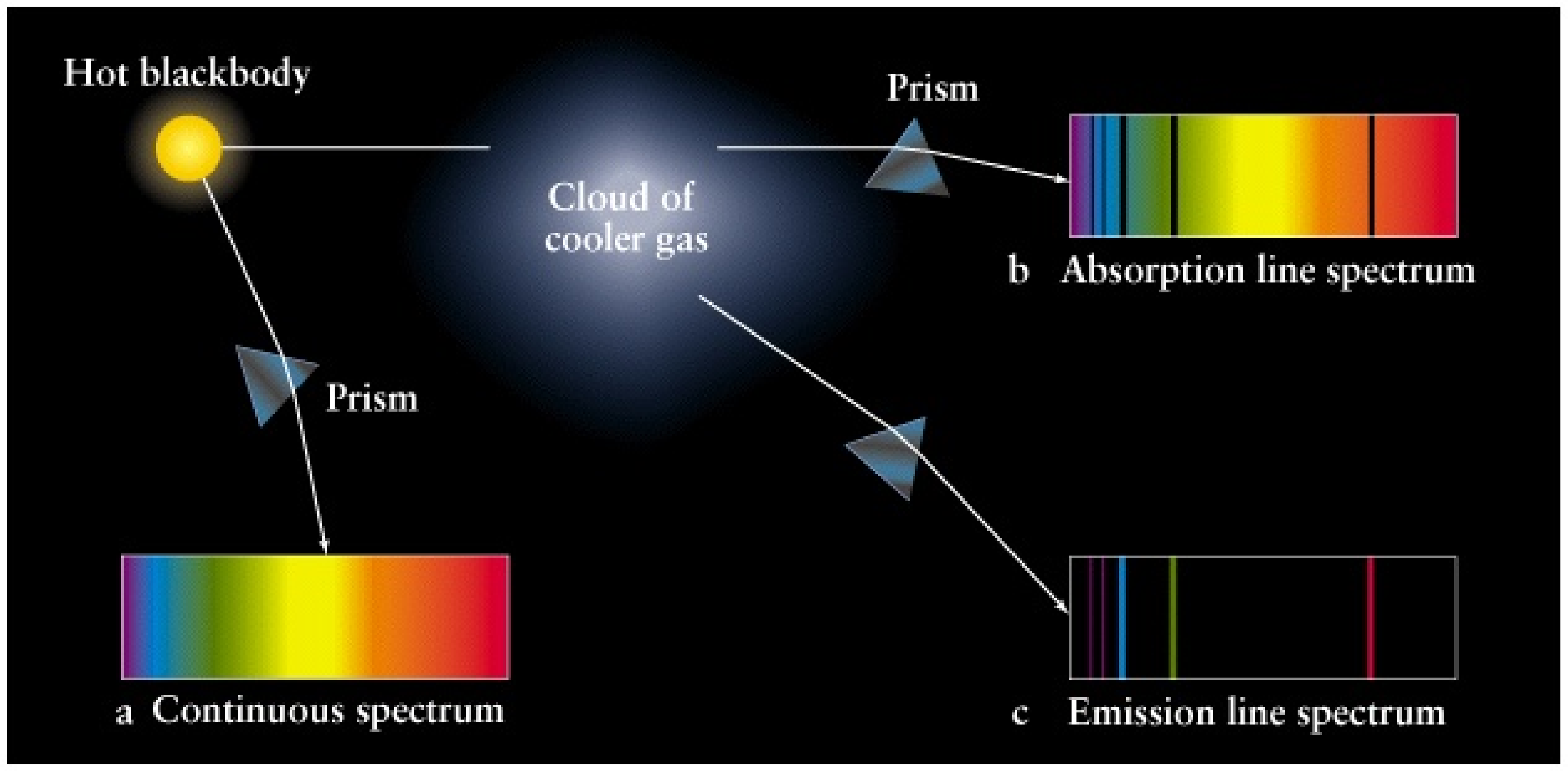
Some cheap atomic physics - 8

What does dilute really mean? What happens when a gas rarefies?

First guess: the typical distances between atoms (the *mean free path*) will get bigger, so collisions will be less frequent.

Will LTE approximation work properly?

Emission line spectra - 1



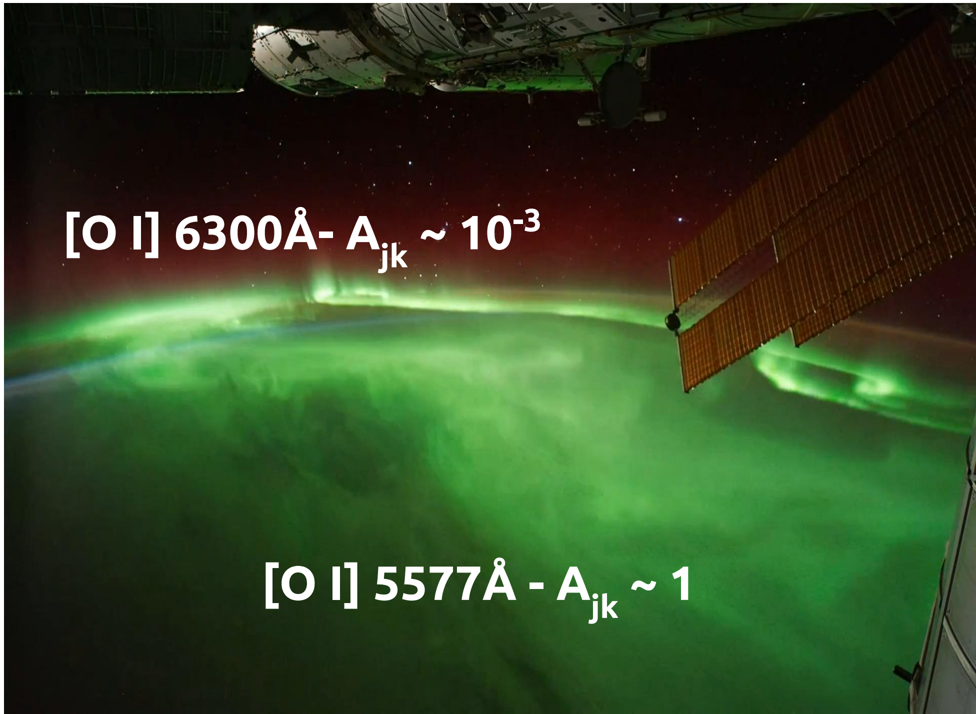
A nice picture interlude.

Emission line spectra - 2

Emission spectra objects are quite familiar, lamps for example, but Earth atmosphere is pretty nice too.

Line absorption features by Earth atmosphere?

What are does green and red lights? Aurorae, emission from a dilute gas.



Emission line spectra - 3

Our friends in atomic physics laboratory told us about the Balmer series. We see those lines in emission on a spectrum.

Recombination!

However, our friends in the laboratory didn't tell us about many emission lines we see.

Forbidden lines!

Emission line spectra - 4

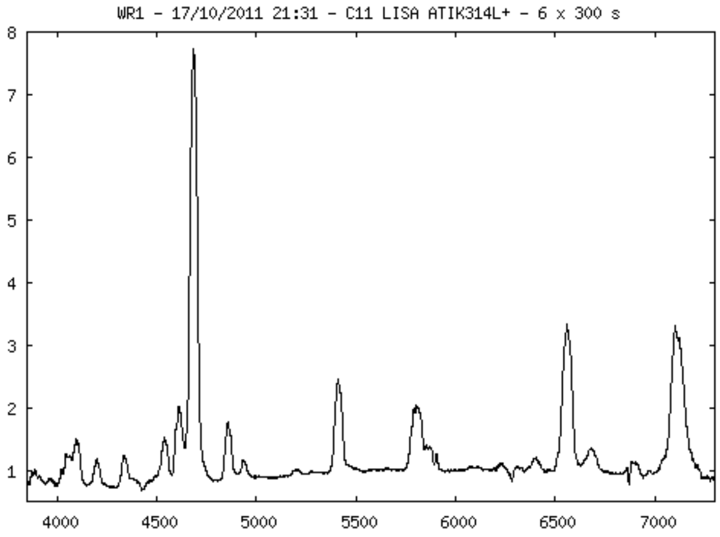
One single forbidden line in a spectrum is a signature of non-LTE conditions.

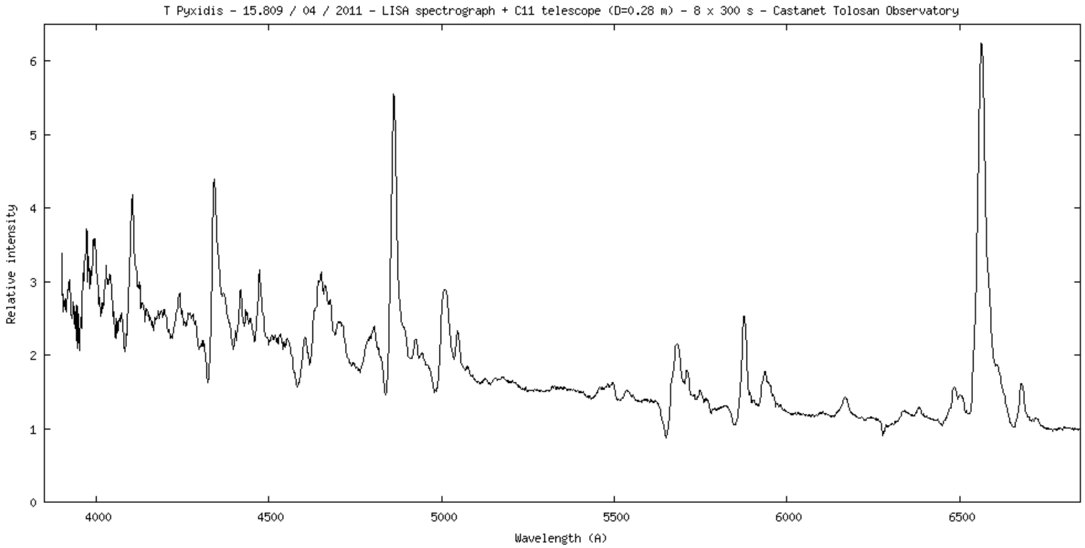
Let's go back to the aurora: high energy electrons from space kick oxygen electrons to stable, metastable states or ionize.

But collisions are rare: metastable states (which are collisionally (de)-excited in LTE) now de-excite radiatively, emitting "forbidden photons".

Emission line spectra - 5

A fistful of examples

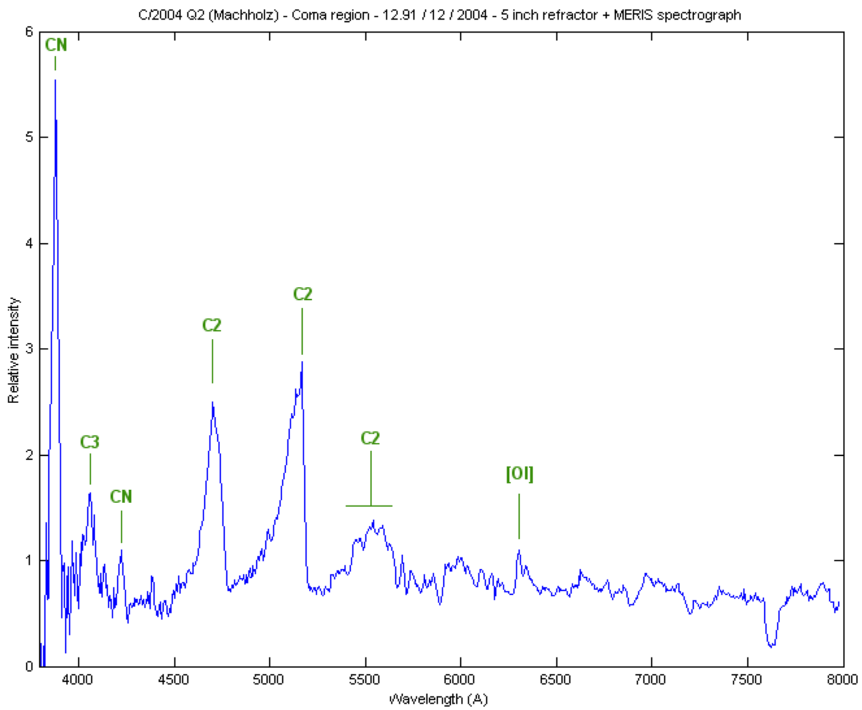




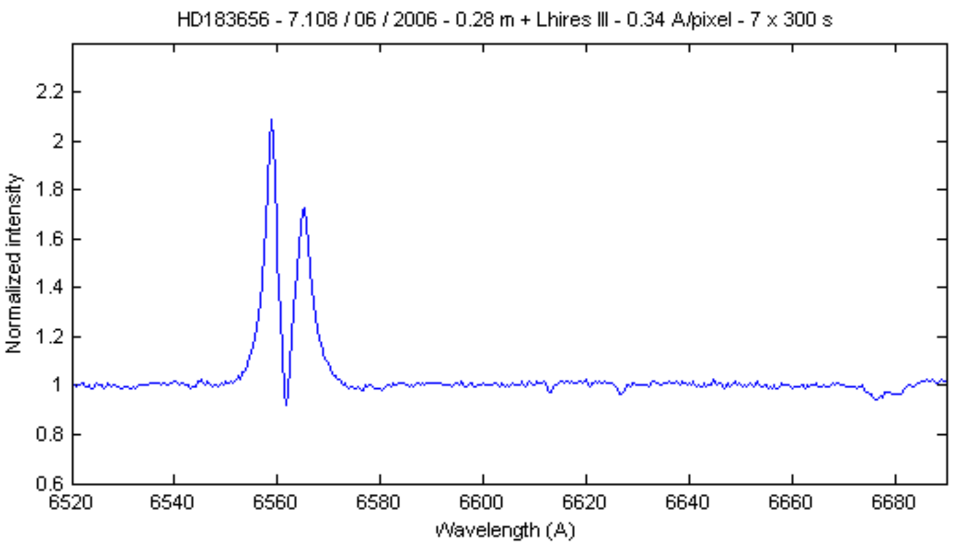
Wolf-Rayet stars

Novae

Emission line spectra - 5.1

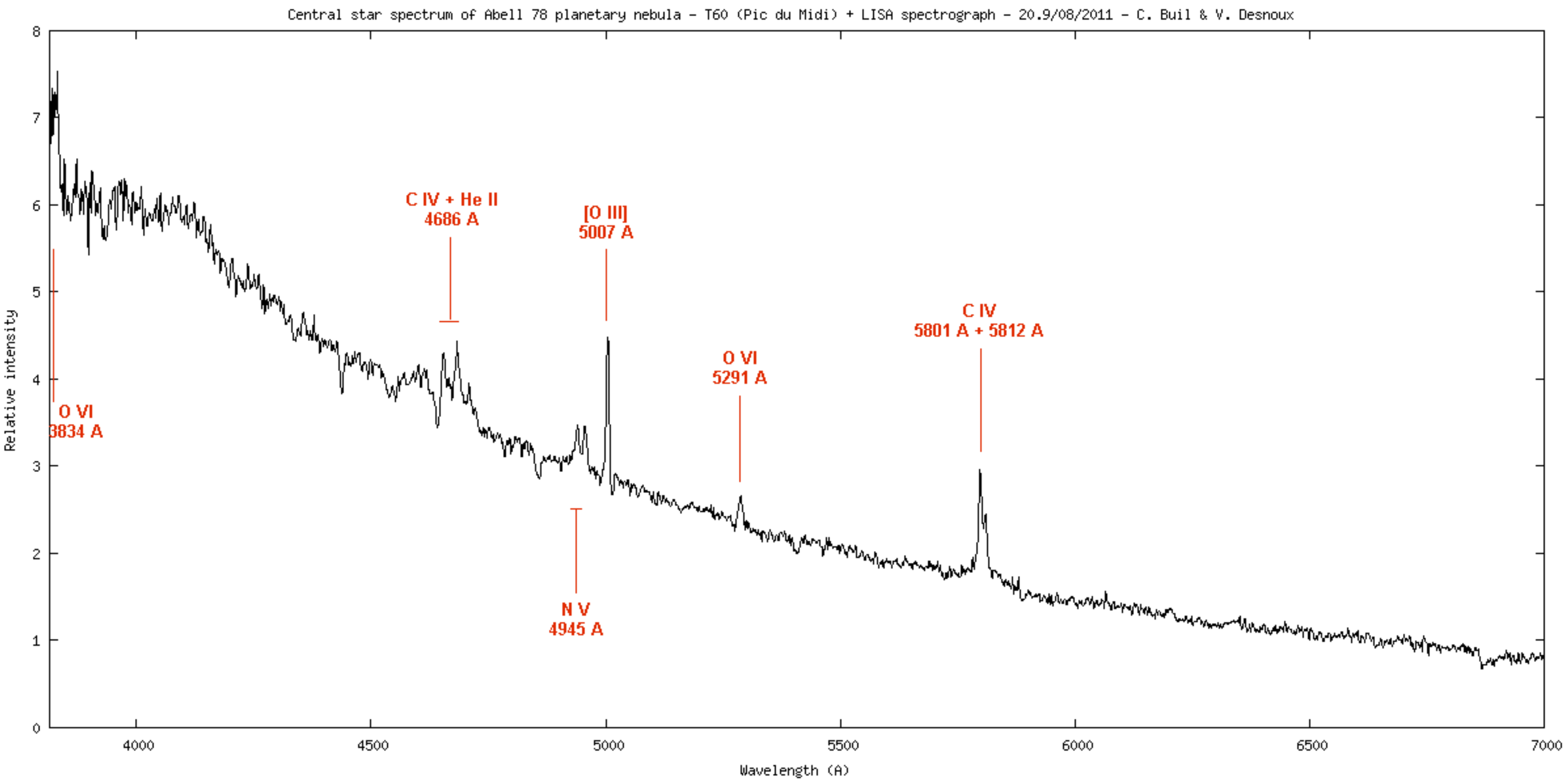


Comets



Be stars

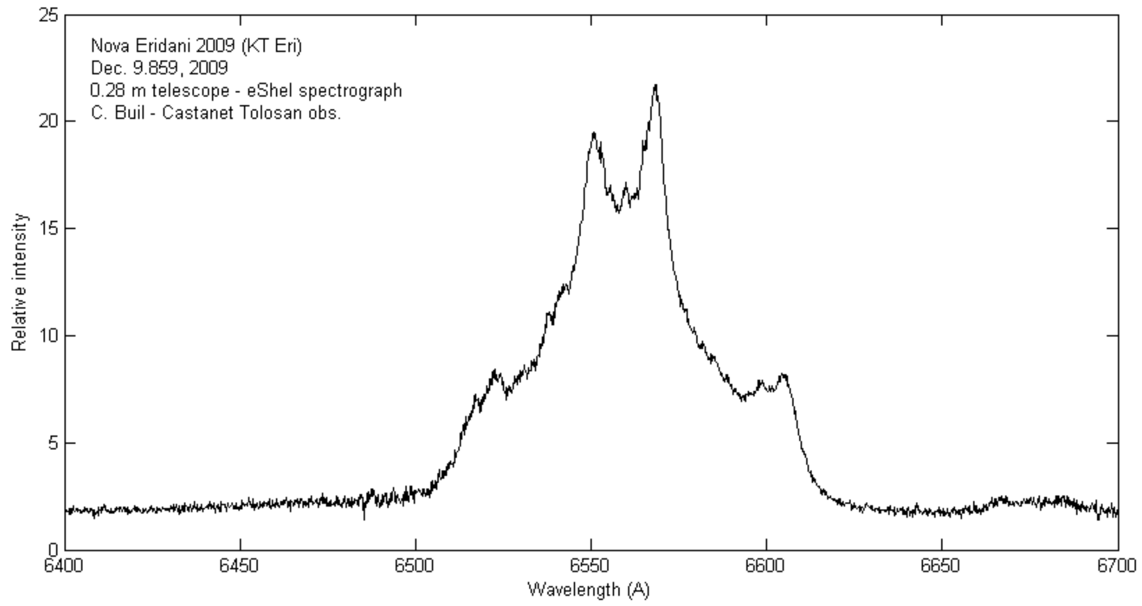
Emission line spectra - 5.2



Planetary nebulae

Emission line spectra - 6

We see some Balmer emission lines, associated with recombination.
We can understand some physical properties of the system (velocity, geometry) just looking at them...



Emission line spectra - 7

We use emission line intensity ratios for specific elements because...theory works.

$$R = I_{jk}/I_{mn} = N_k / N_n * A_{jk} / A_{mn} * \lambda_{mn} / \lambda_{jk}$$

k and n are the upper states.

Ratios for Balmer lines are useful for determining the ISM extinction (**reddening**) thanks to hydrogen "simple" physics.

Emission line spectra - 8

We see lines associated to not allowed transitions.

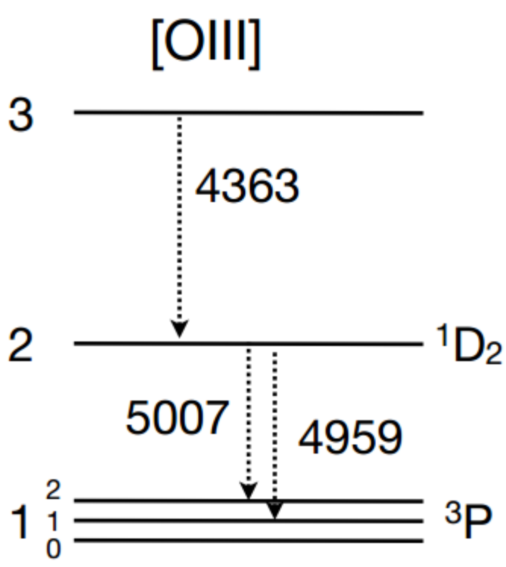
There are different categories

- Intercombination transitions: only SR violated, so higher probability then...
- Magnetic dipole transitions
- Electric quadrupole transitions

We can use forbidden lines from a specific element as good diagnostic tools for Te and Ne in low density systems.

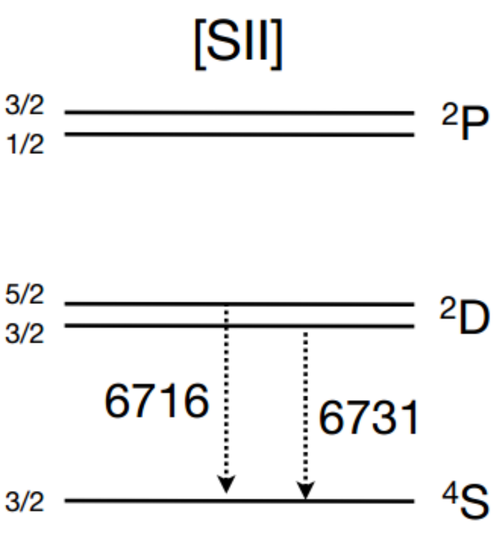
Emission line spectra - 9

[O III] good for Te: transitions involved are related to states with different energy, so populations difference will be sensitive to temperature.



[OIII] 5007+4959 / 4363

[S II] for Ne: states with similar energies but different transition probabilities, so one collisionally de-excite faster, so it's Ne sensitive.



[SII] 6716 / 6731

Emission line spectra - 10

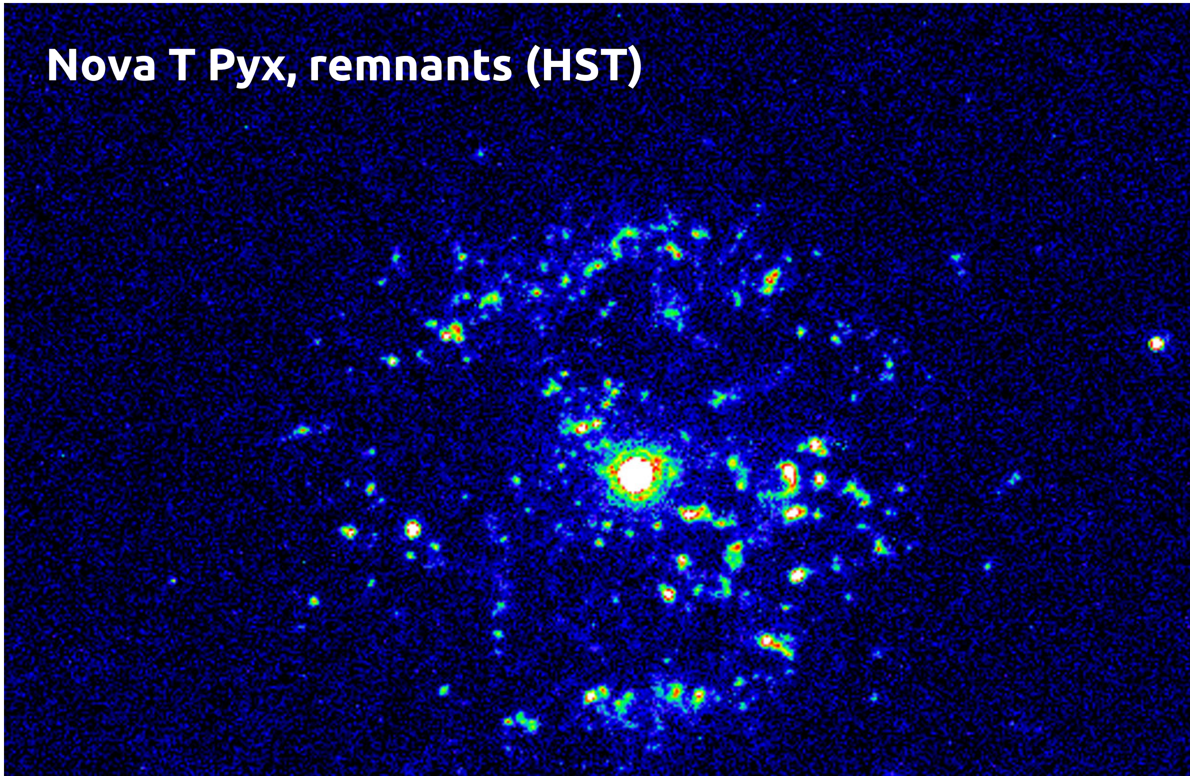
Are you interested in details as I am?

- It is possible to see Balmer series lines and only neutral heavier elements lines thanks to a little difference in ionization potential for CNO.
- Emission lines do not necessarily mean non-LTE conditions.
- Forbidden transitions physics is quite complex: to have a complete description one needs good knowledge of (at least) UV and IR transitions.

Novae - 1

Observational facts:

- Many novae per year (roughly 10/y)
- Increase in brightness of order 10 mag from quiescence to maximum
- Decay timescale from weeks to months
- Almost unique spectral evolution sequence (with subtypes)



Novae - 2

Nowadays accepted picture for classical novae.

"The outbursts of novae are caused by nuclear reactions on the surface of a degenerate white dwarf which has accreted gas from the Roche-lobe overflow of a secondary companion in a close binary system."

Williams, R.E.

Novae - 3

Few details more.

<u>The outburst</u>

Hydrogen-rich gas in a thin layer on the surface of the white dwarf reacts with heavy elements (CNO) when temperature at bottom reaches a critical value (10^7 K).
Everything is very fast, tens of seconds.

WD mass and composition is important here!

Novae - 4

The ejected gas

Ejected mass is assumed to be constant after outburst.

The expansion velocity (always order of 10^3 km/s is

$V \sim V_{max} * r$ (Hubble flow)

The density than decrease

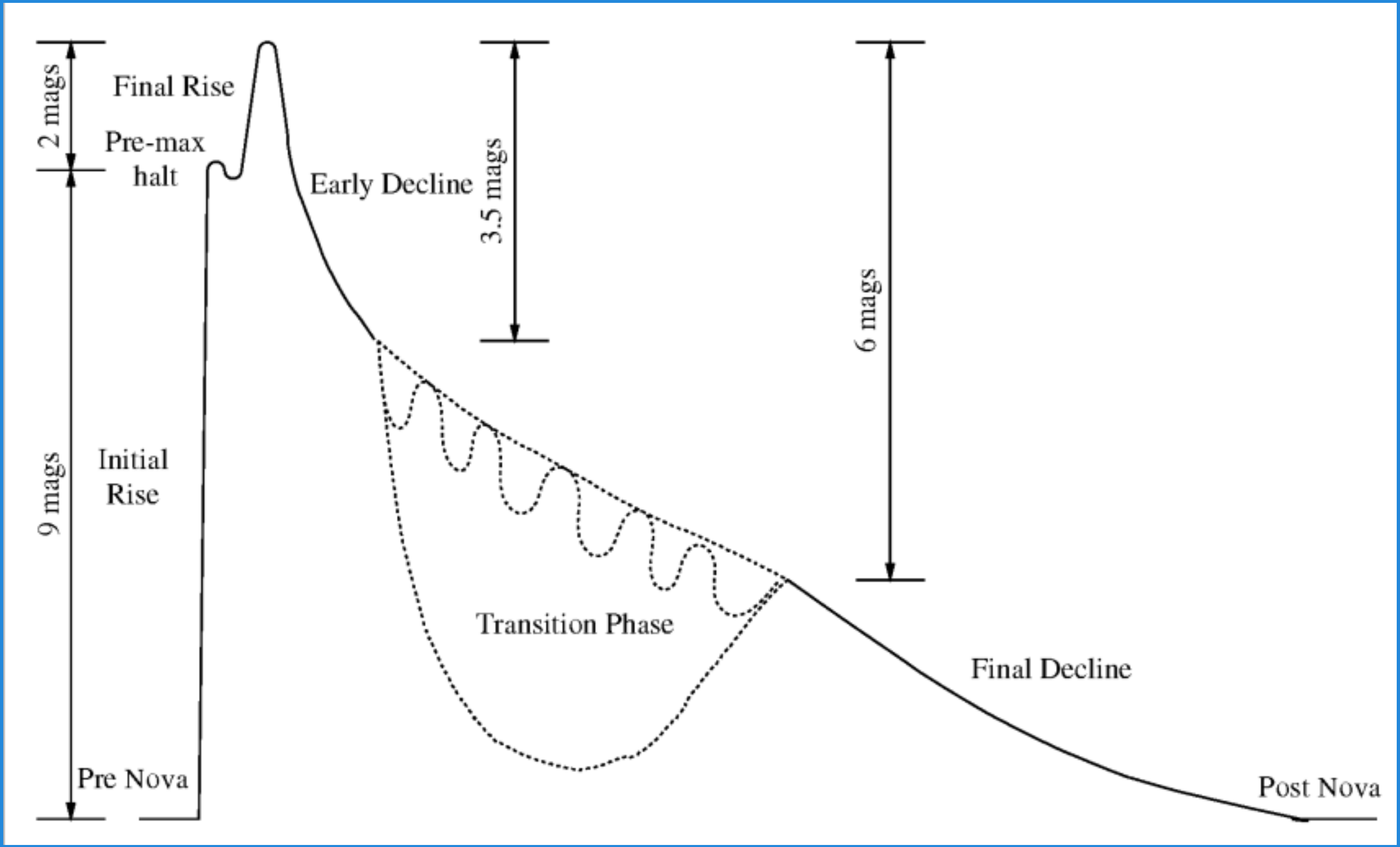
$\rho \sim t^{-3}$

During the initial stage, density is so high that makes the gas optically thick.

Novae - 5

Light curve evolution of CN can be divided into several stages:

1. Initial rise: 2 mag before maximum (increase of 8-9 mag).
2. Pre-maximum halt and final rise to max.
3. First decline phase: 3.5 mag below max.
4. Transition phase. somewhere between 3.5 and 6 mag below max.
5. Final decline phase.
6. Post nova.



An "ideal" light curve (McLaughlin)

Novae - 6

Astronomers like groups and types and classes. Novae suffer a heavy classification process.

Based on the light curve only, Payne-Gaposchkin introduced the concept of ***speed class***.

- t_2 is the time for 2mag decrease from max
- t_3 for 3mag and so on

An observational evidence: brighter novae belong to higher speed classes (McLaughlin).

Novae - 7

The spectroscopic evolution of CN follows the dynamics of the ejected gas, which rarefies and cools with time.

Small differences in the physical properties of the binary system, composition and mass of the WD, ejected mass etc can significantly change the spectra appearances.

Novae - 8

Everytime we take a CN spectrum, Balmer lines are strong, so we use non-Balmer lines to classify the spectra development.

Fe II: prominent P Cyg and absorption in Fe lines; narrower profiles; low speed; first forbidden lines to appear are low excitations ones.

He/N: prominent He and N lines; broader profiles; higher excitation forbidden lines.

Novae - 9

Spectral development groups have not to be confused with abundance taxonomy classes defined through a complete study of the nova in UV, visible and IR. The mass and composition of the WD is the key.

CO: diverse light curve behaviour; enhanced CNO abun.; He/H near solar; dust formation is notable (not exclusive).

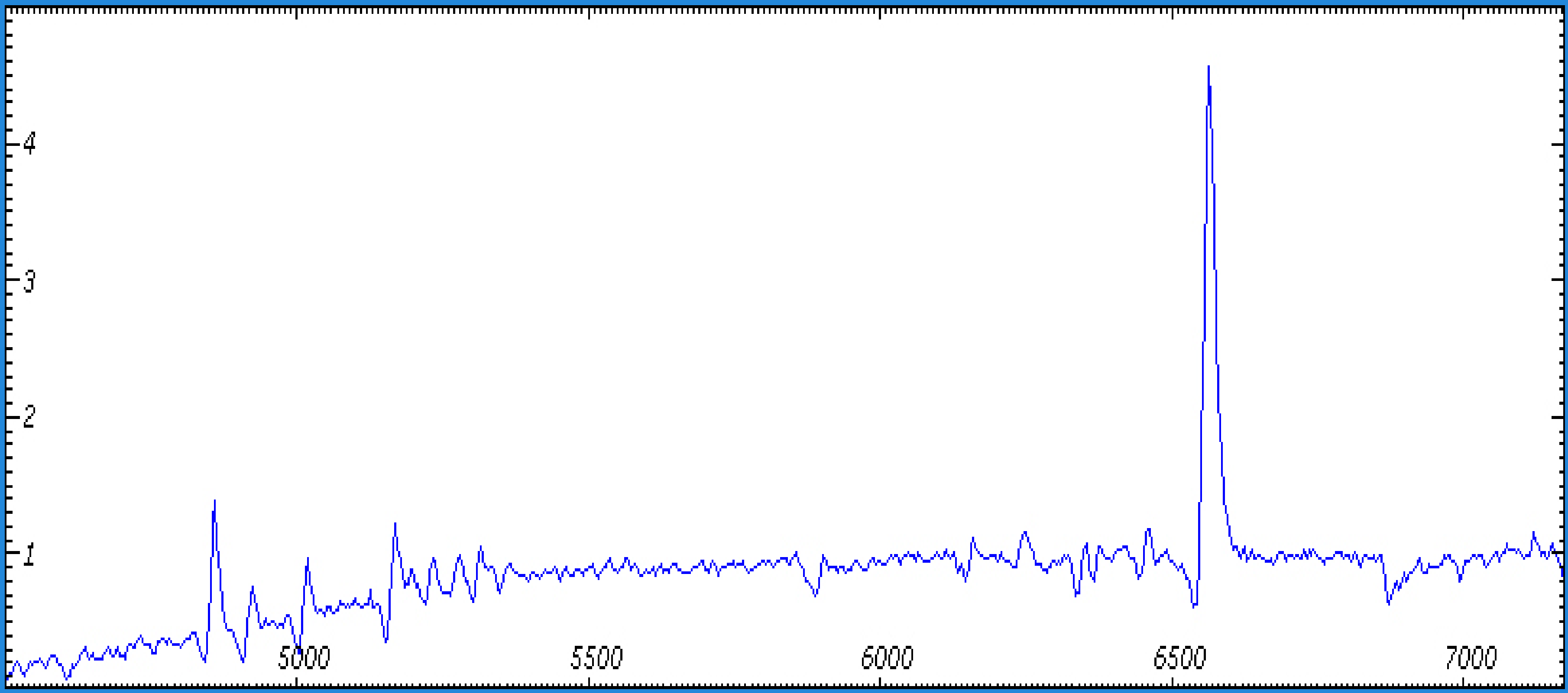
ONe: early [Ne II] 12.8μm marker; usually C depleted, O an Ne higher relative to solar.

Novae - 10

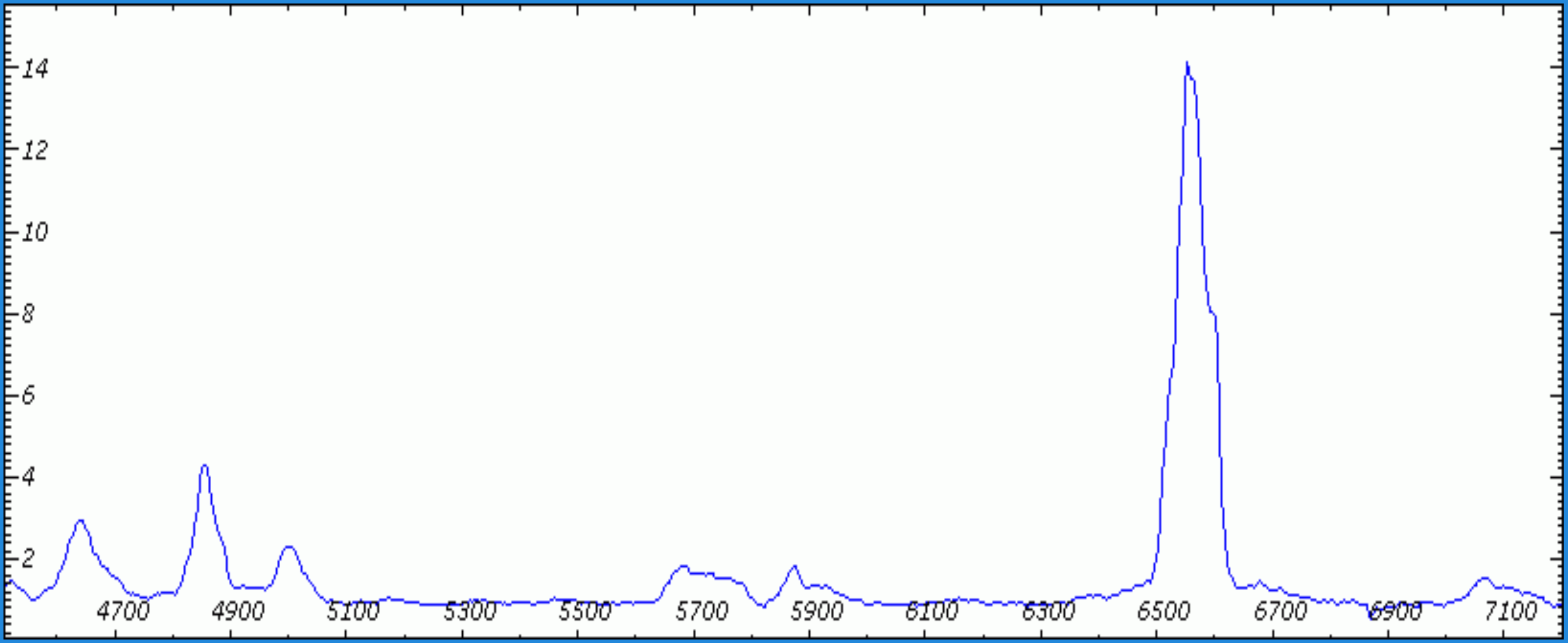
About the initial rise phase we have almost none spectral information.

At maximum we see the so-called **principal spectrum**: it looks like a A or F supergiant with enhanced CNO.

Observational evidence: higher speed class develops broader absorption features (always McLaughlin).



Fe II type principal spectrum of Nova Sct 2009



He/N type principal spectrum of Nova Eri 2009

Novae - 11

Sometimes (mainly in CO type) an **enhanced diffuse spectrum** appears, 1-2mag after max, showing broader lines and blueshifted peaks.

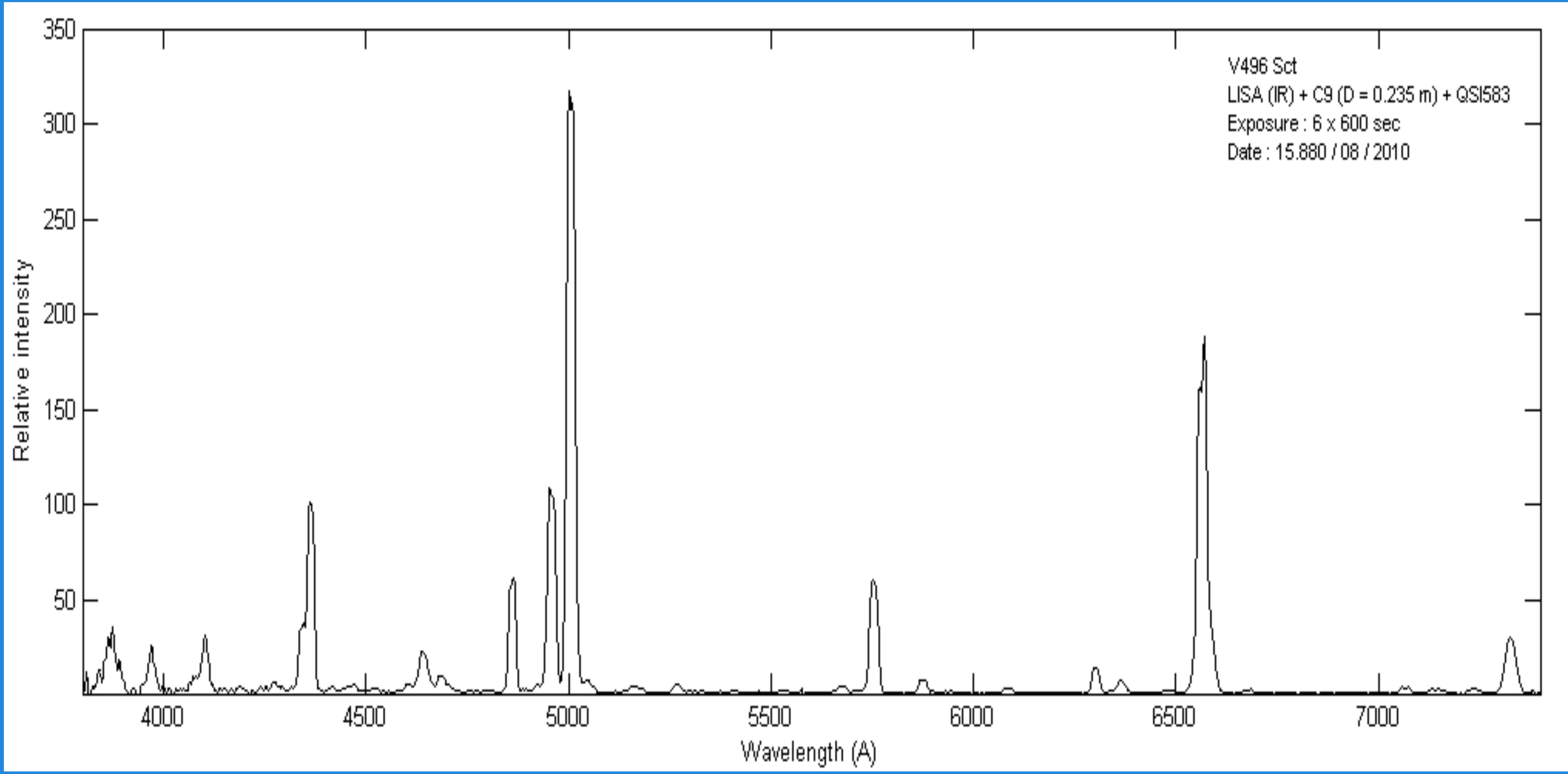
The **Orion spectrum** phase follows, showing some weak (for now) forbidden low excitation lines, [O II], [N II].

Novae - 12

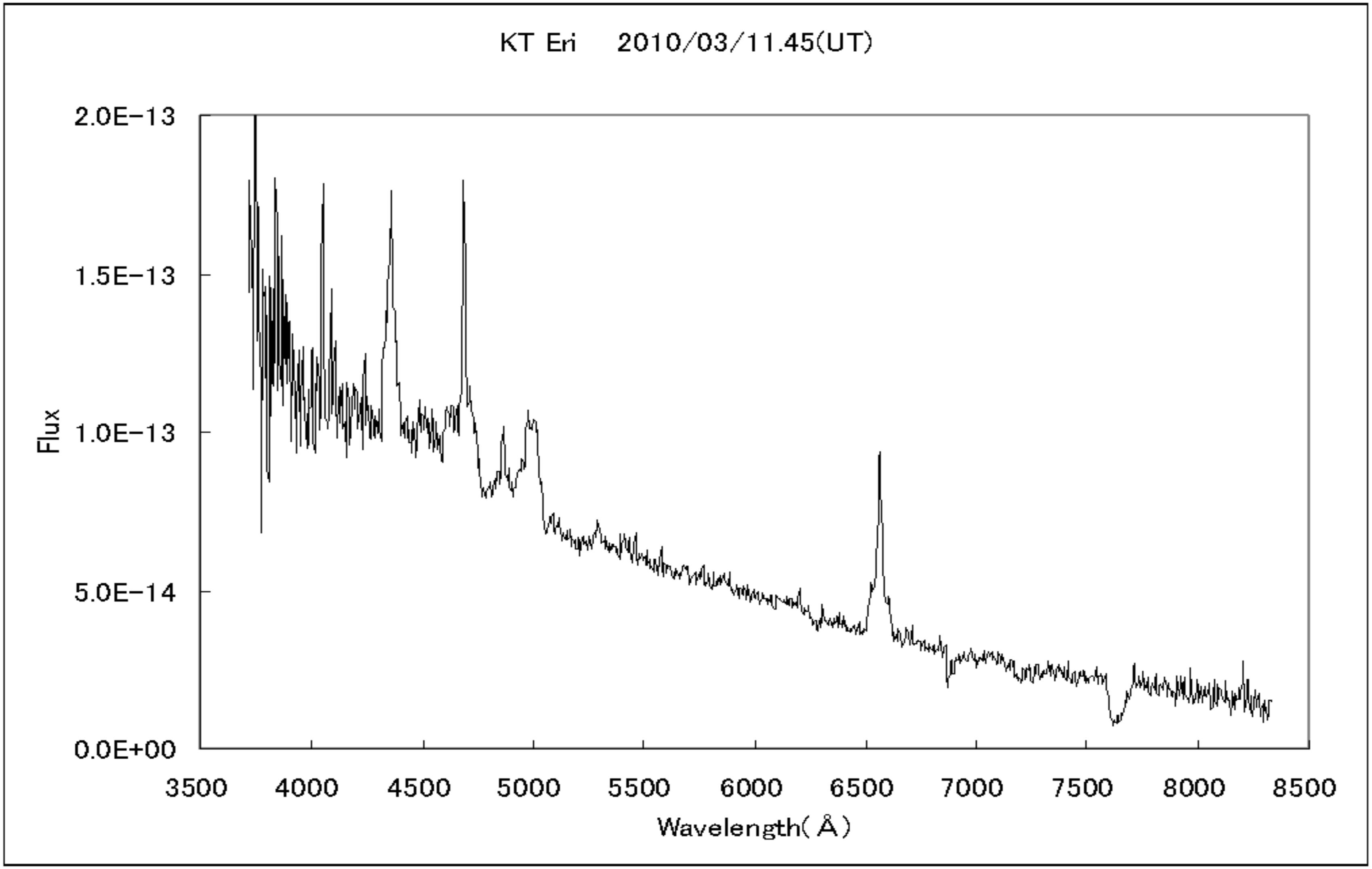
The **nebular spectrum** appears ~3mag after max, and is characterized by strong forbidden lines, increasing in strength.

At this stage, spectra resemble a PN.

Very high excitation lines visible, like coronal lines [Fe X] 6347A or [Fe XIV] 5303A.



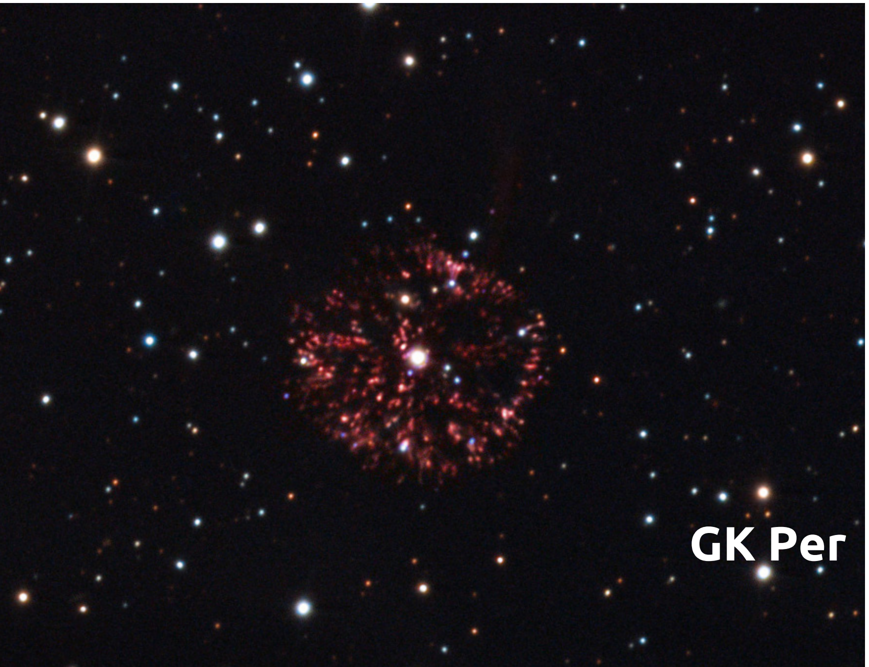
Fe II type nebular spectrum of Nova Sct 2009

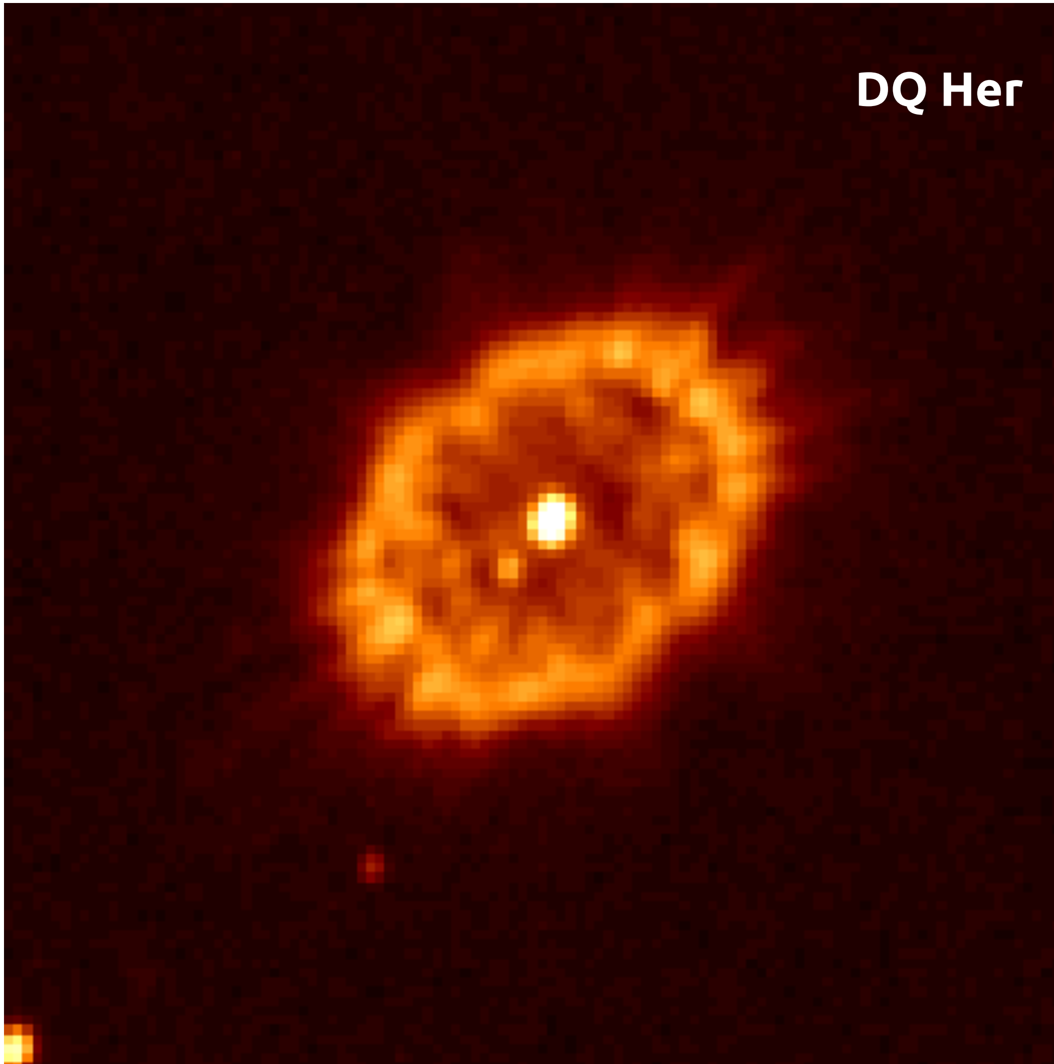


He/N type Nova Eri 2009 entering nebular phase

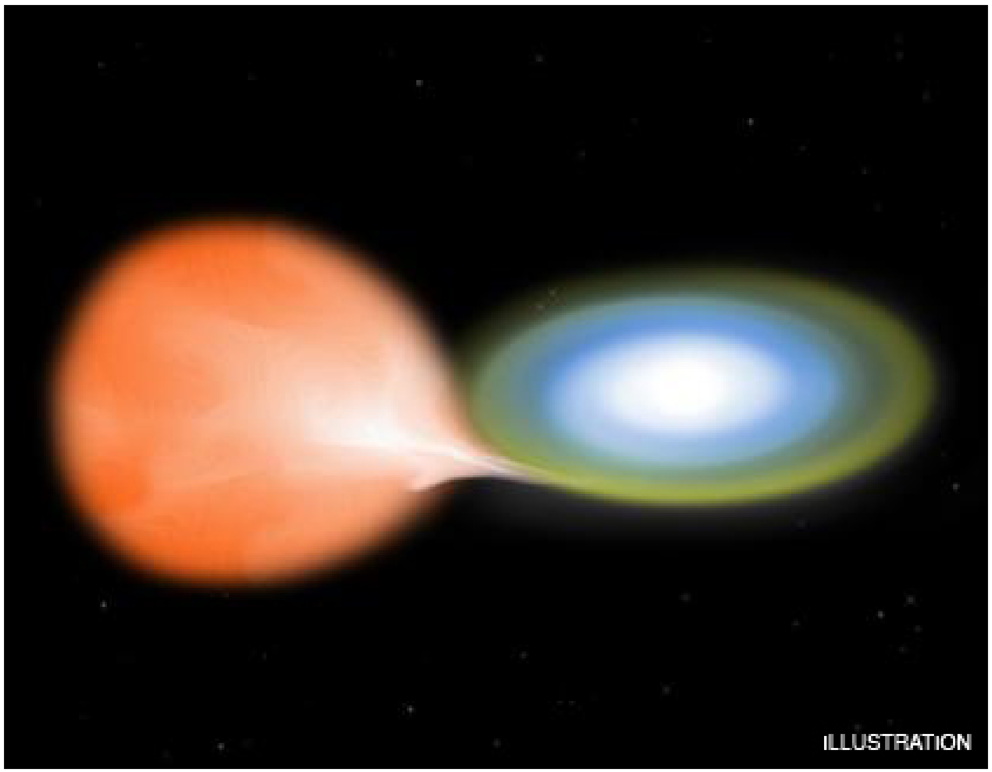
Novae - 13

If we are very patient, we can be lucky enough to see resolved nebular remnants.





Novae - 14



For a single nova, we have many physical aspects to clear up.

- Distance!!!
- Binary system
- Mass accreted
- Mass blown-out
- Ejecta composition
- Ejecta structure

Novae - 15

Astrozoology going wild!

- Hybrid N: interesting behaviour, transitions between Fe II and He/N spectral types.
- Recurrent N (RS Oph, T Pyx, U Sco etc): it is warmly accepted that all CN lived\are living\will live a recurrency phase, with the period they prefer.
- Dwarf N (Z Cam, SU UMa, U Gem subtypes): outburst (2-5 mag increase) caused by release of gravitational energy due to increase in accretion from a disk.
- Symbiotic N (RS Oph, V407 Cyg etc): the WD in symbiotic system erupt (slower than CN) and spectra clearly show the presence of the peculiar environment observed (!!) in quiescence.

Novae - Conclusions

The general picture is well understood, but there are still interesting long-standing puzzles and each new nova brings new gifts, that's why an excellent time coverage is needed ;-)

Few open questions and problems: dust formation, Lithium synthesis, atmosphere advanced modeling, recurrency, geometry of the ejecta, novae in close galaxies, SN Ia progenitors.

Let's take a look at Nova Mon 2012!

Really quick analysis of the first spectra