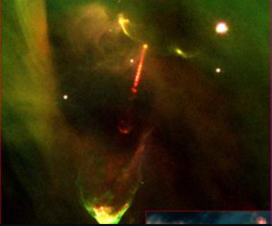
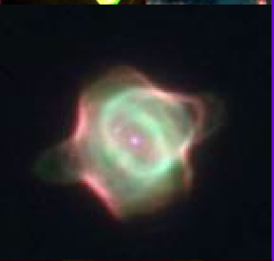
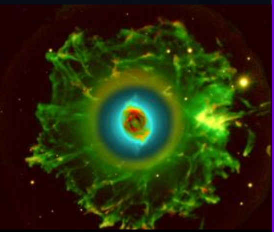
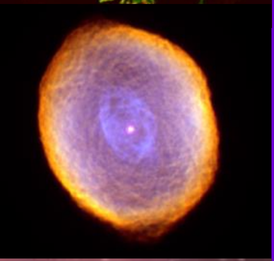
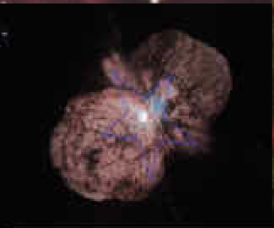







NEBULATOM

Emission line objects in the Universe

Lecture 1

An introduction to ionized nebulae and their spectra

Grażyna Stasińska

Observatoire de Paris

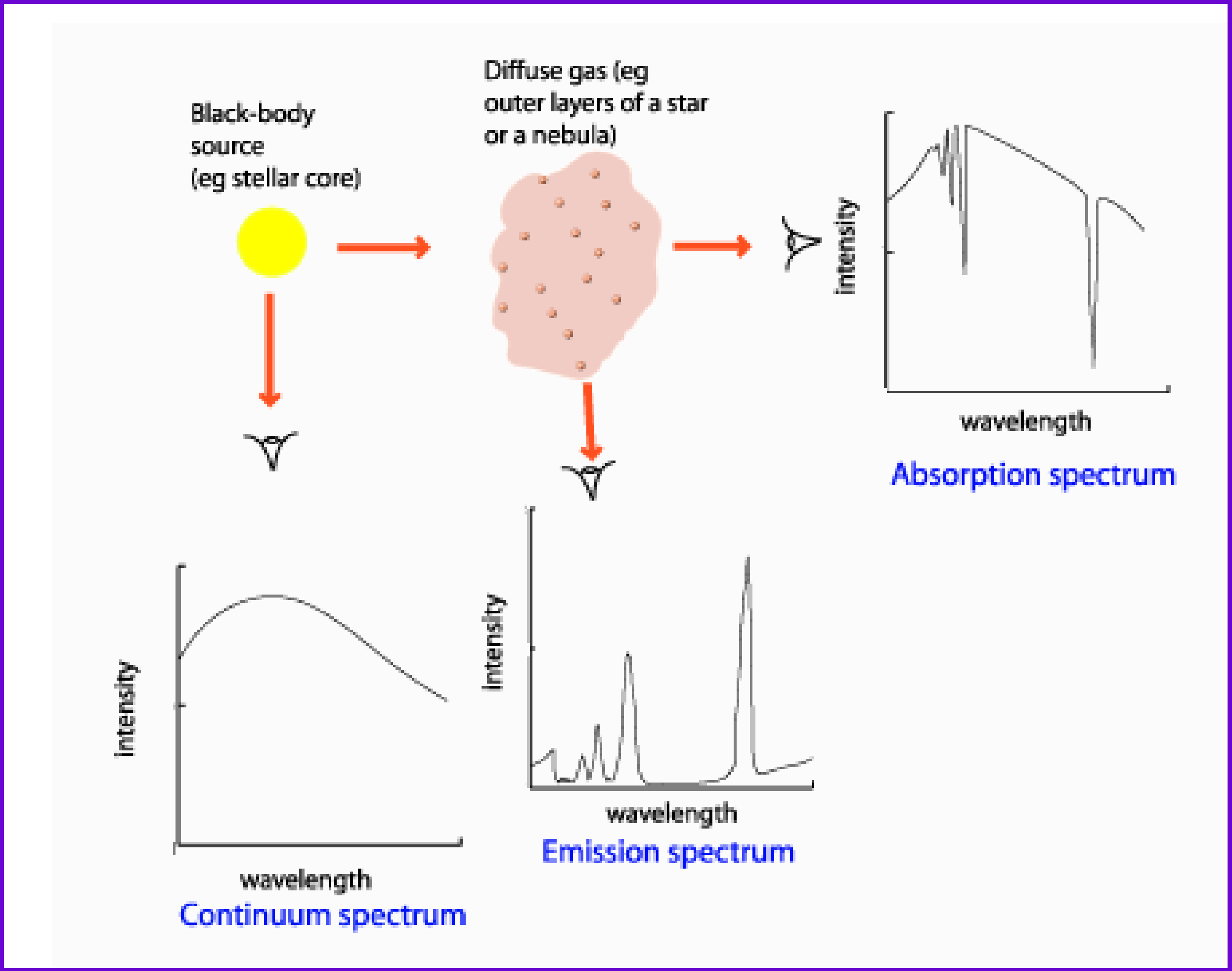






Types of astronomical spectra

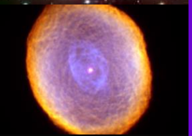
Kirchhoff 1860



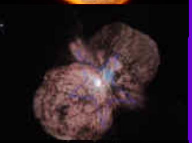
how continuous, emission and absorption spectra can be produced from same source

The different types of emission-line objects

- HII regions



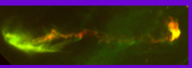
- Planetary nebulae (PNe)



- Ejecta from massive stars

- Supernovae

- Novae



- Young stellar objects

- Star forming galaxies

- Active galactic nuclei (AGNs) and quasars

The interest of emission lines

The mere presence of emission lines indicates

- the existence of gas
  - eg emission line galaxies contain gas in large amounts while
  - galaxies showing only a continuum with absorption features do not

- the existence of an ionizing agent (most emission lines come from ionized species)
  - hot star(s)
  - active nucleus
  - (shocks) …

Emission lines are easy to detect and provide (easy) information on

- The gas chemical composition
- The nature of the ionizing source
- The gas dynamics ($v=d\lambda/\lambda$)
- The redshift ($z=d\lambda/\lambda$)

HII regions in brief

- HII regions are signposts of recent star formation
  (less than 10^7 yr ago)

- They are powered by one, a few, or a cluster of massive stars (depending on the resolution at which one is working)

- The nebulae have complex shapes resulting from the complex structure of the parent molecular clouds

- At late sages, stellar winds leave their imprint on the nebular morphologies

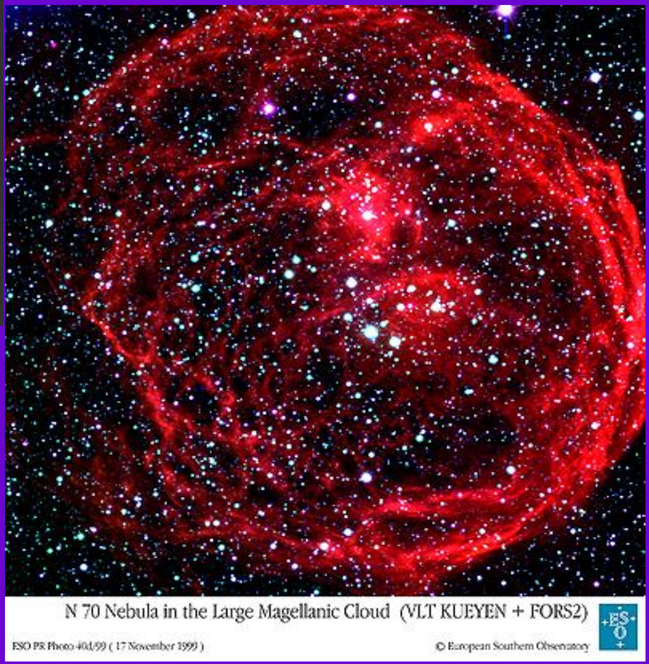
- The temperatures T* of the ionizing stars are between 35000- 55000K

- The gas density is typically 10^3-10^5 cm^{-3} for compact HII regions,
  and 10^2 cm^{-3} for giant extragalactic HII regions (GHRs)

- The velocity dispersions range from 10-20 km/sec to ~100 km/sec for GHRs

Examples of HII regions

M8 a bright HII region in the Milky Way



N70 a Wind blown HII region in the LMC

NGC 3603 a giant star forming region in the Milky Way

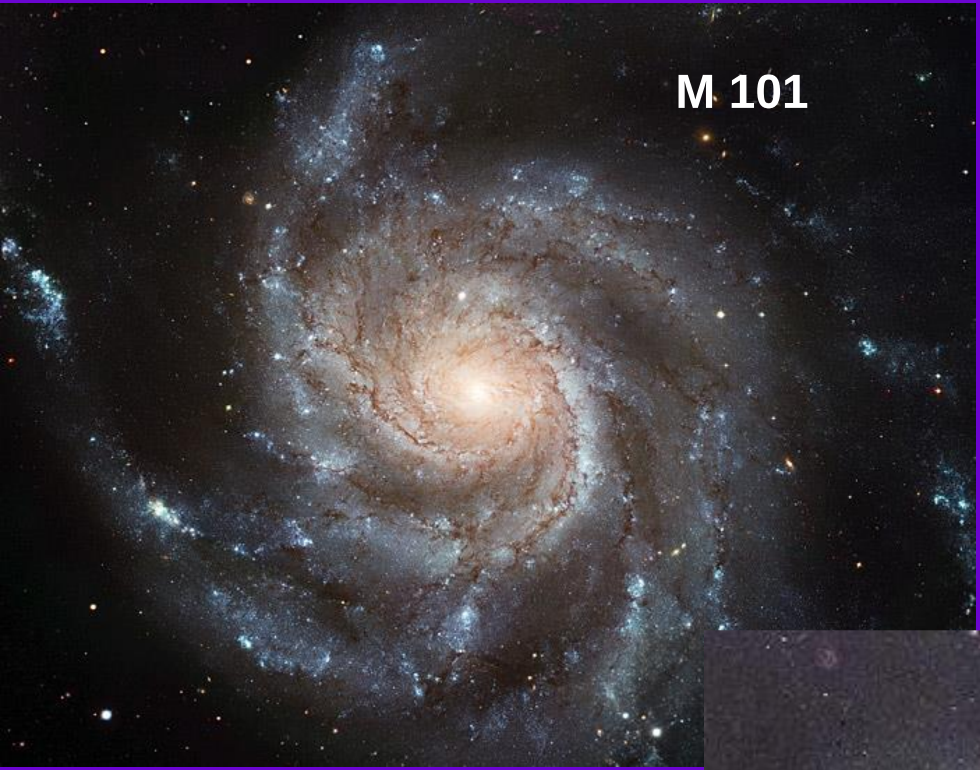
HII regions close ups

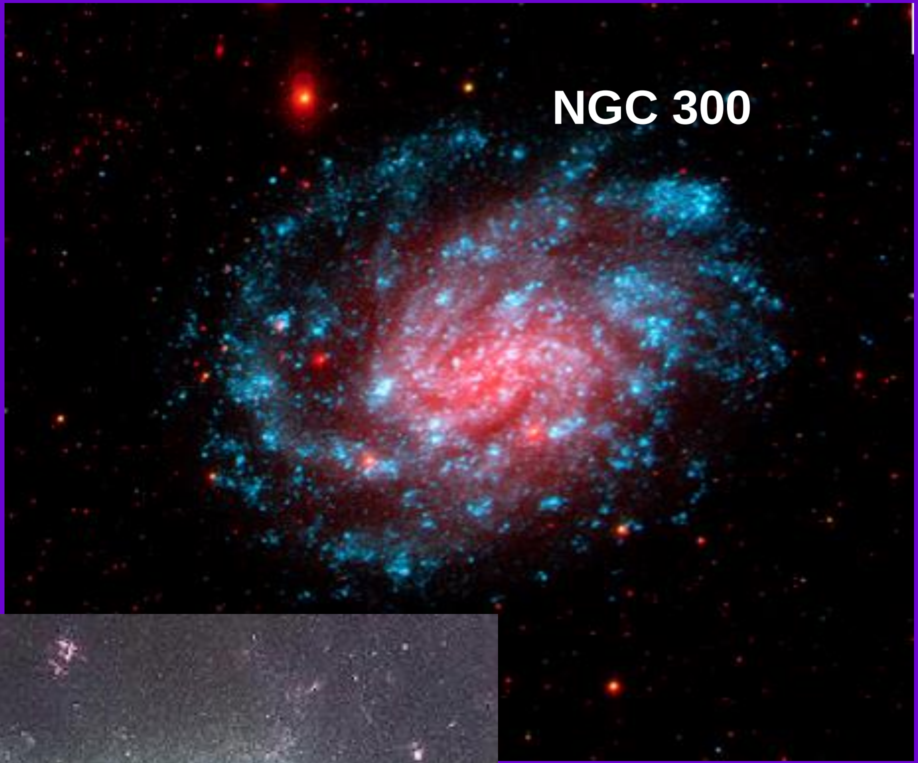
the Orion nebula

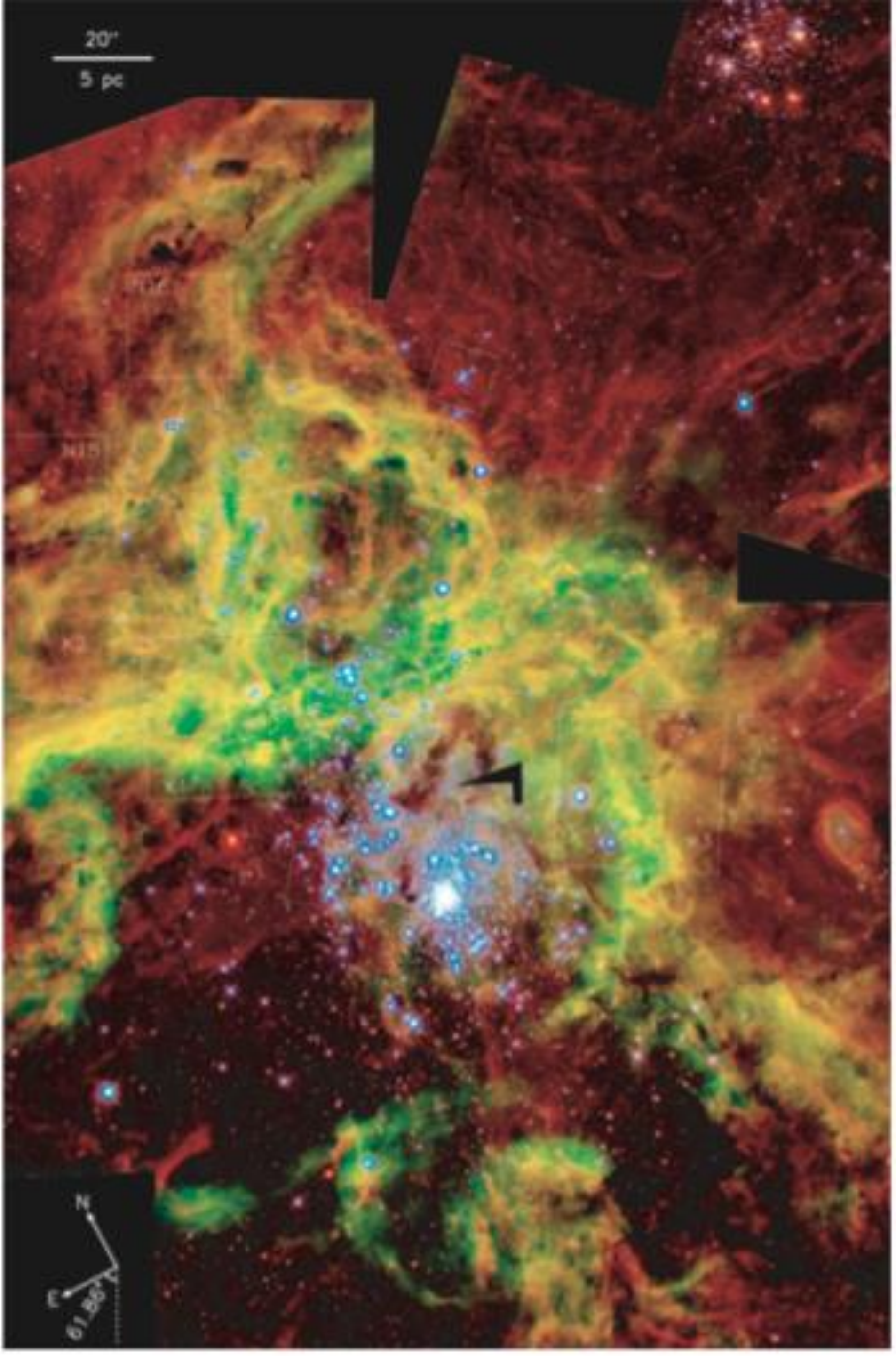
the internal dynamics of HII regions is extremely complicated

3D reconstruction of the Orion nebula

HII regions in galaxy context

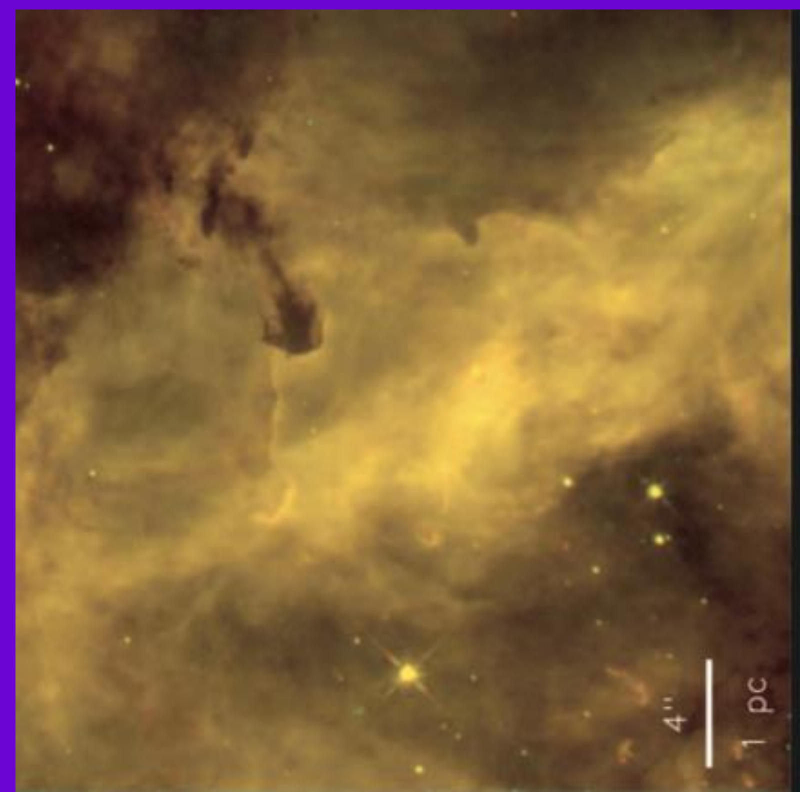






Extragalactic HII region close-up

30 Dor in the LMC

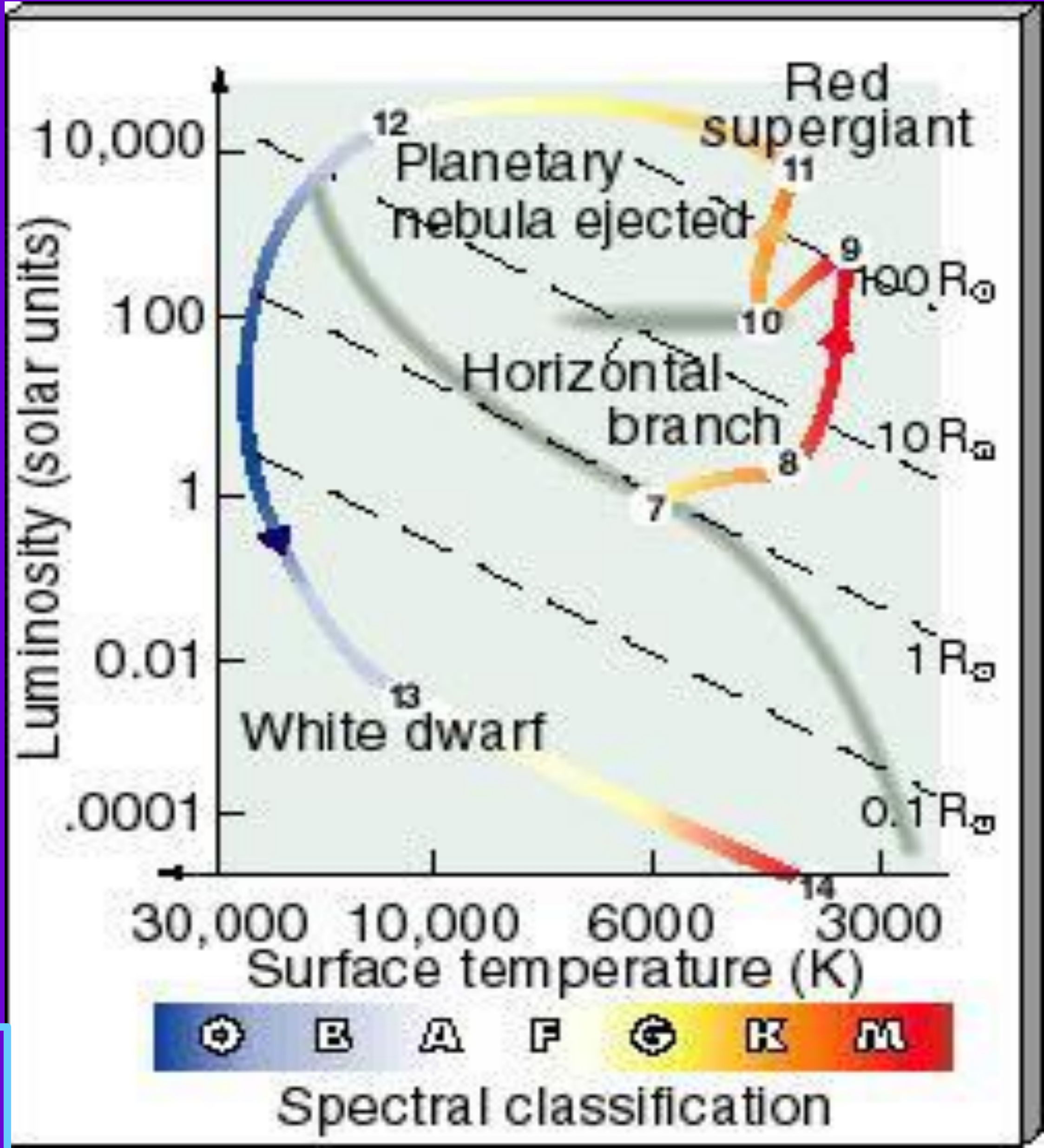


Planetary Nebulae (PNe) in brief

- PN shapes have a rather large degree of symmetry
- Often, the amount of nebular gas is not sufficient to completely trap the stellar ionizing radiation (PNe are often density-bounded)
- The temperatures T* of the ionizing stars are between 35000- 200000K
- The lifetimes of PN are of about 10^4 yr
- but PNe originate from stars which were born more than 10^8 yr ago (up to ~10^{10}yr)
- The gas density is typically 10^3-10^5 cm^{-3} , but PN of lower density also exist
- The chemical composition of the PN envelopes is not identical to that of the cloud out of which the progenitor star was born
- The expansion velocities are typically of 15 - 40 km/sec

The evolution of low & intermediate mass stars 1-8 $M_\odot$

- Planetary nebulae result from the evolution of such stars
- all along the AGB, the star looses mass
- At the tip of the AGB a strong mass-loss episode occurs. The satr is cool and luminous
- A PN appears when the star gets sufficiently hot to ionize the surrounding gas
- it expands and gradually fades into the interstellar medium
- while the central star becomes a white dwarf

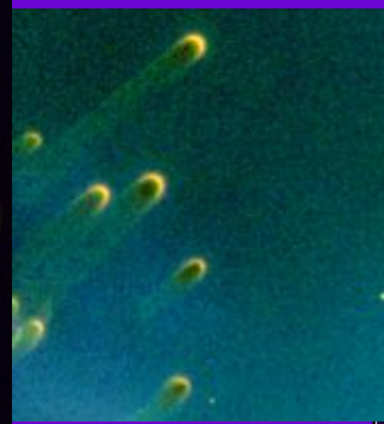


Evolution track of a 5$M_\odot$ star in the HR diagram

planetary nebulae morphologies

can be round

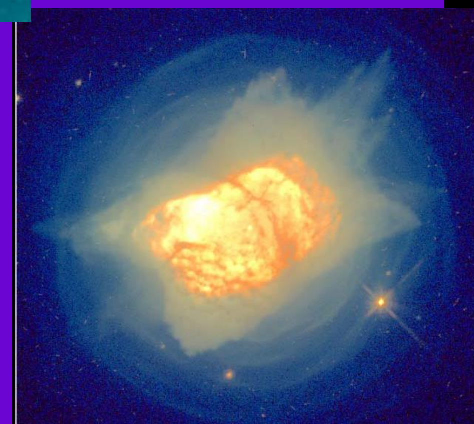
but not necessarily

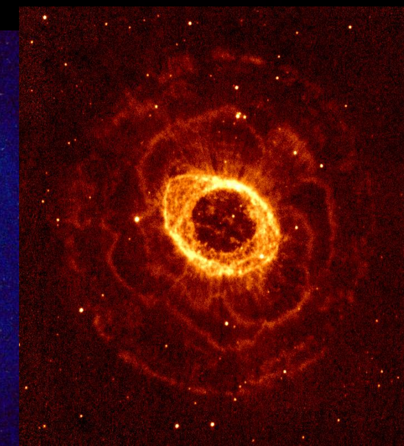


they can show blobs or microstructures

and

extended haloes





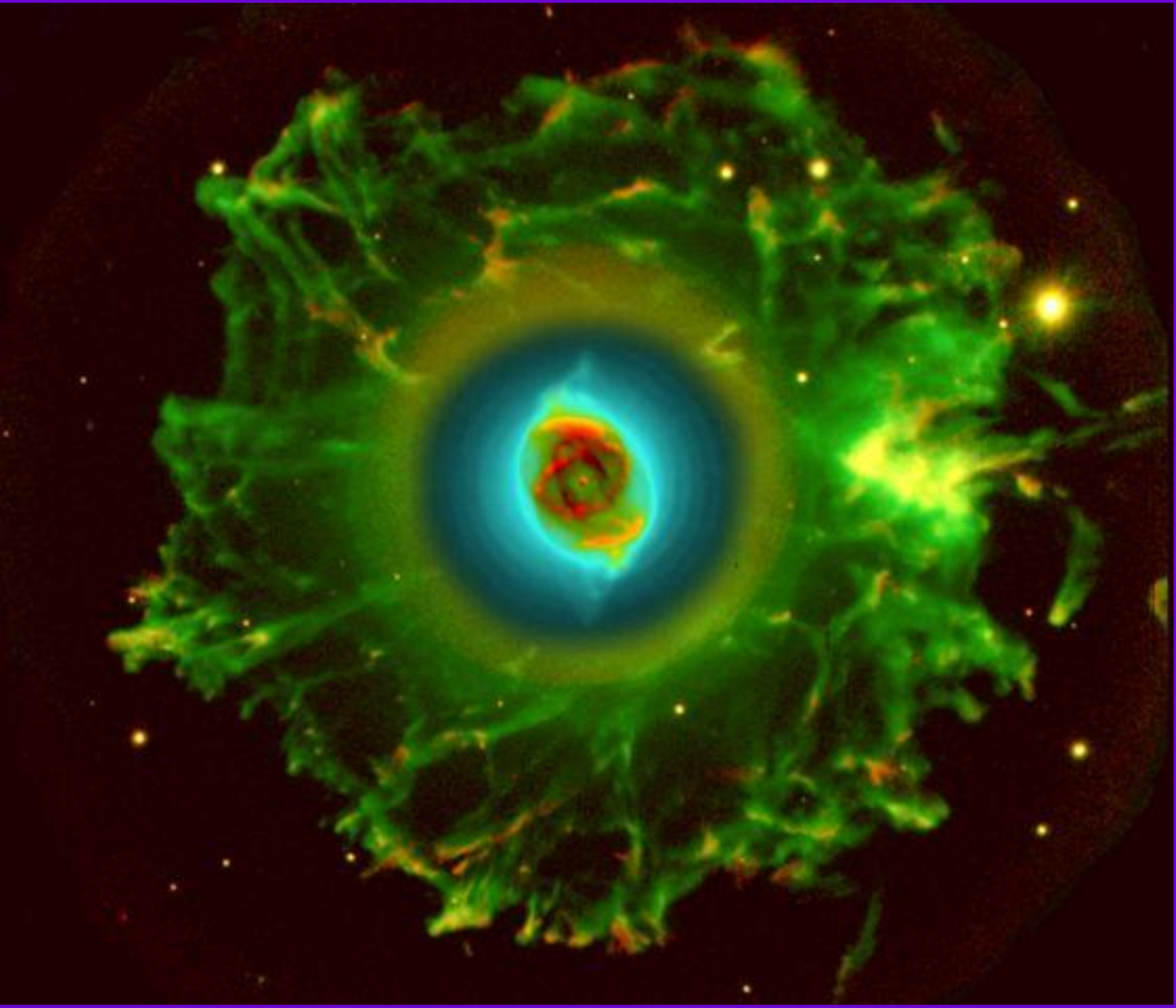
NGC 6543

HST image of the bright core of the «cat eye » planetary nebula

NGC 6543

its bright core and spherical halo

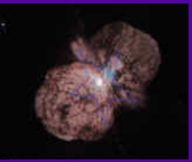
NGC 6543



its bright core
its spherical halo
and its fluffy halo

The Helix planetary nebula

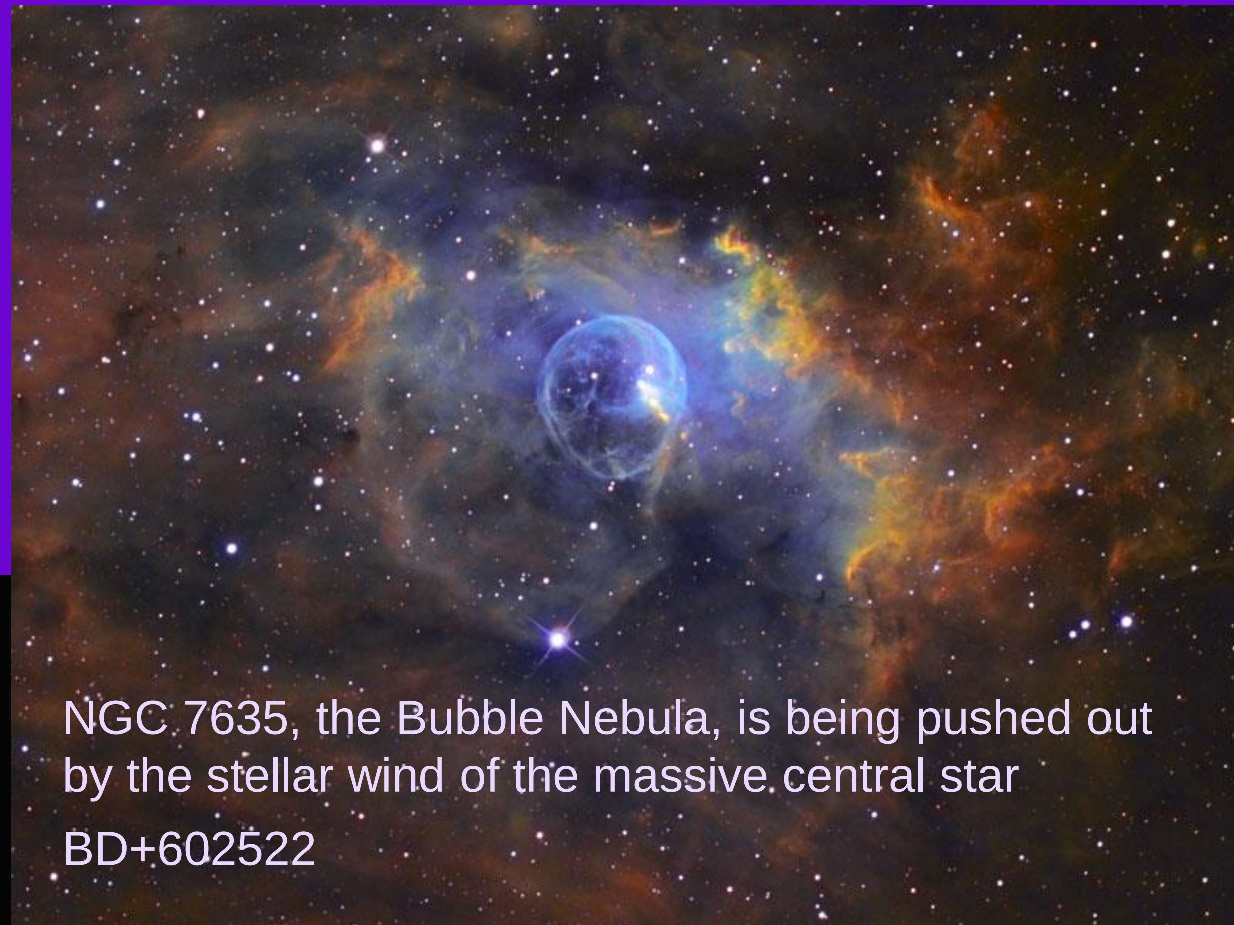
3D reconstitution



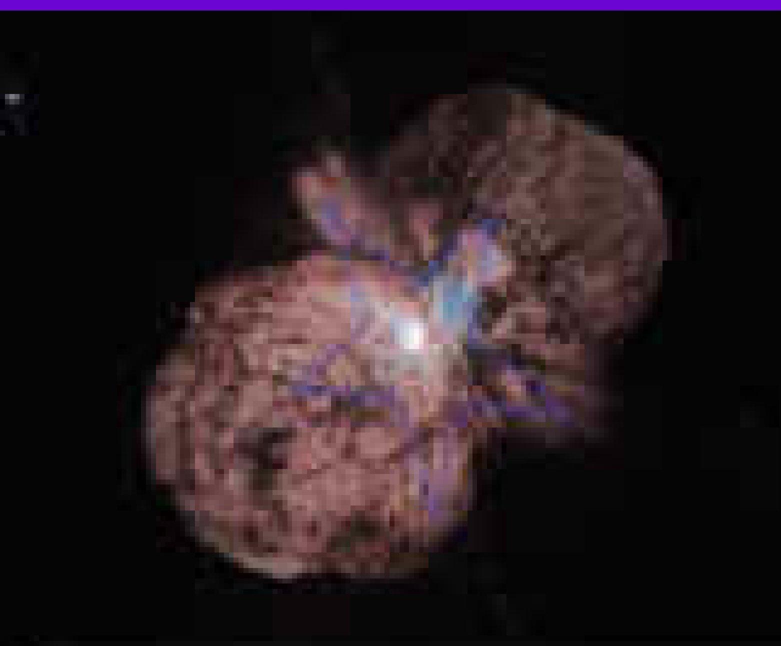
Ejecta from massive stars

- They are in many respects similar to planetary nebulae but they arise fom massive stars (mainly Wolf-Rayet stars)
- They are far less numerous than PNe (the number of massive stars is *** times less than that of intermediate mass stars), the duration of the strong mass-loss phenomenon is about 1 Myr
- They are confined to the thin Galactic disk, so their study is difficult
- Their chemical composition is that of the stellar ejecta but it can also be dominated by that of the swept-up interstellar medium
- It is not always easy to distinguish a nebula arising from a massive star from a PN

Ejecta from massive stars



NGC 7635, the Bubble Nebula, is being pushed out by the stellar wind of the massive central star BD+602522



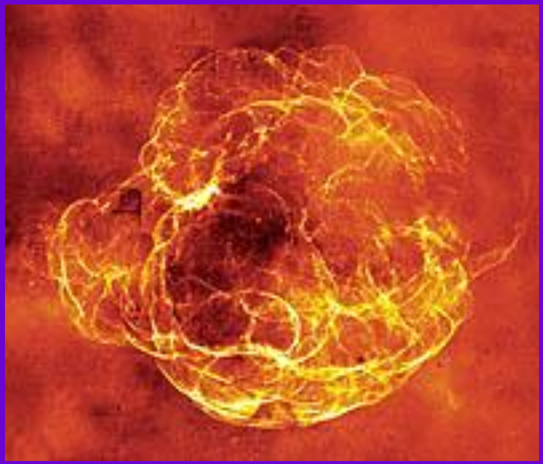
the Eta Carinae nebula

Supernova remnants

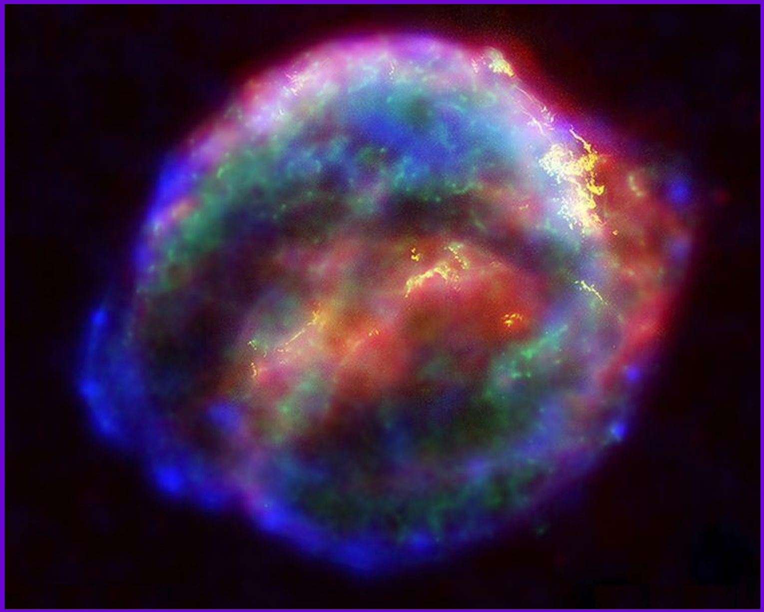
- Are remainings from the explosion of stars in a supernova event
  - Type II SNe result from the core collapse of massive stars into a neutron star or a black hole
  - Type Ia SNe occur when a accreting white dwarf has reached a mass larger than $1.4M_{\odot}$ and suddenly collapses into a neutron star
- They contain nuclearly processed material from the stellar interior
- Their expansion velocities can be of thousands of km/sec
- They are most often shock ionized
- They emit a lot in X-rays

Supernova remnants

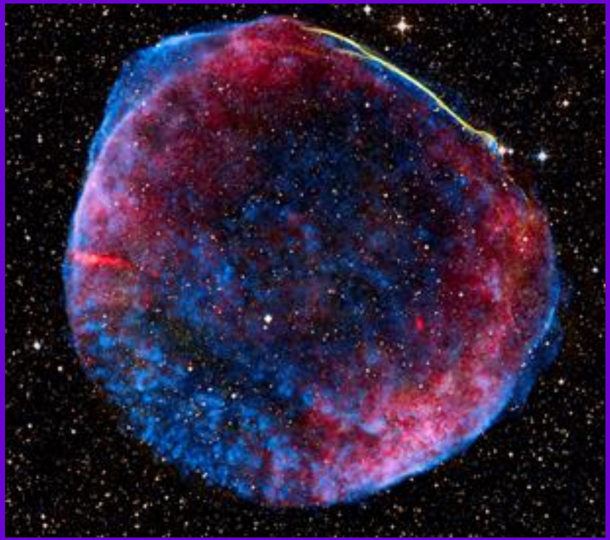
Puppis A in IR (WISE)



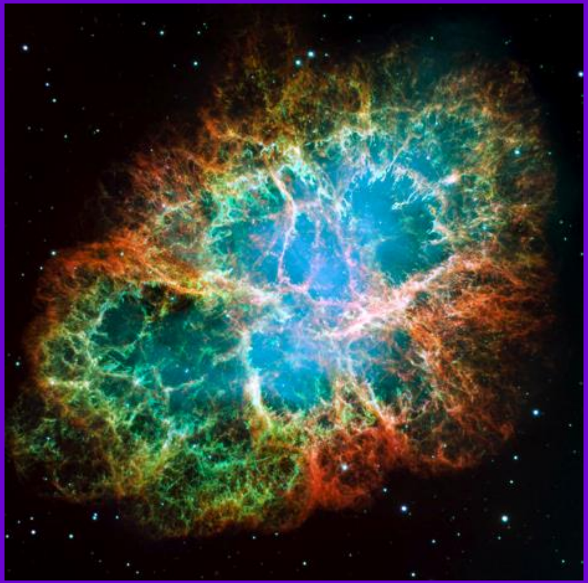
S147 in Hα



Composite image of Kepler's SN
X-ray (4-6 keV), Chandra
X-ray (0.3-1.4 keV), Chandra
Optical, HST
IR, Spitzer

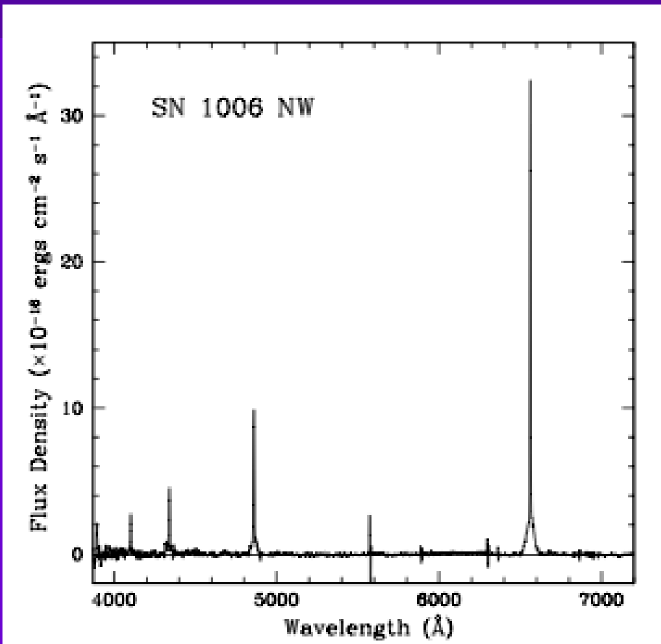


SN 1006 in X-rays (Chandra)

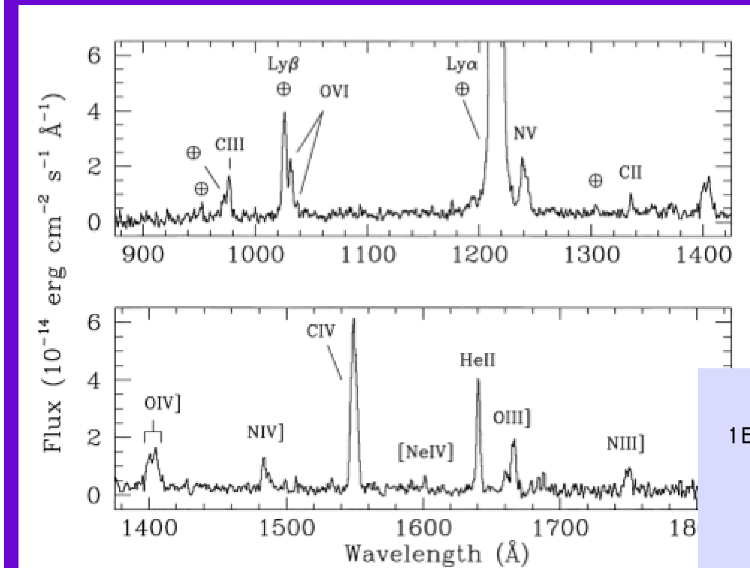


the Crab nebula Optical (HST)

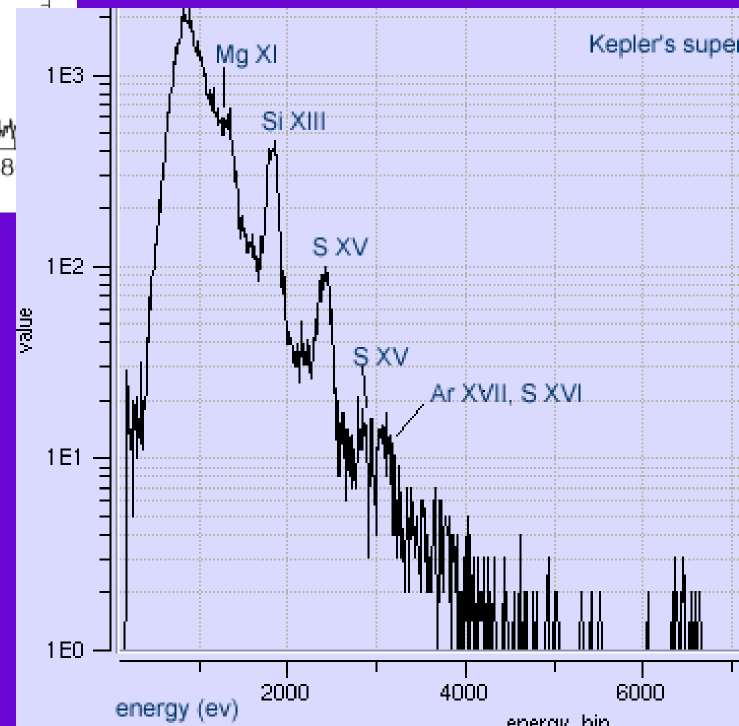
Supernova remnant spectra



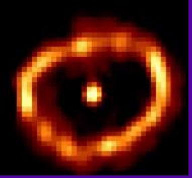
Optical spectrum of SN 1006



UV spectrum of Pup A



Chandra spectrum of Kepler's SN



Novae and related objects

- Are due to explosions occuring in the accretion disc of a close binary system containing an accreting whte dwarf.
- After the explosion, a nebula is seen, and quickly fades away (order of years)
- The masses are very small, the densities rather high
- It contains highly processed nuclear material

Nova V 603 Aquilae

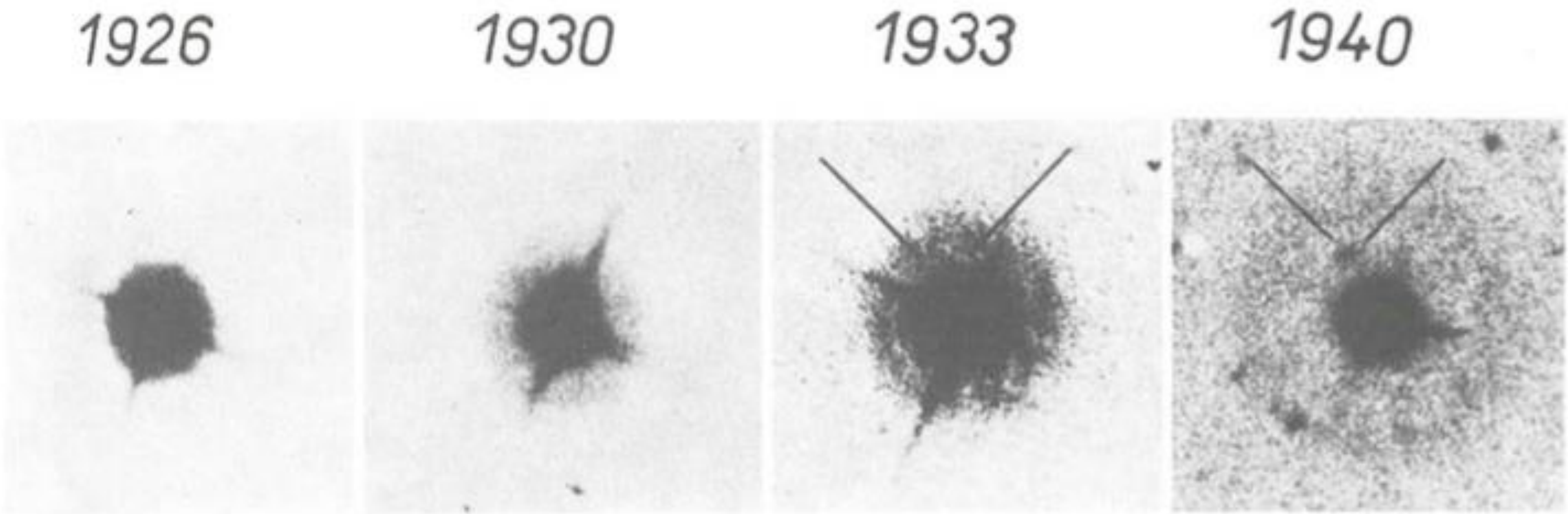
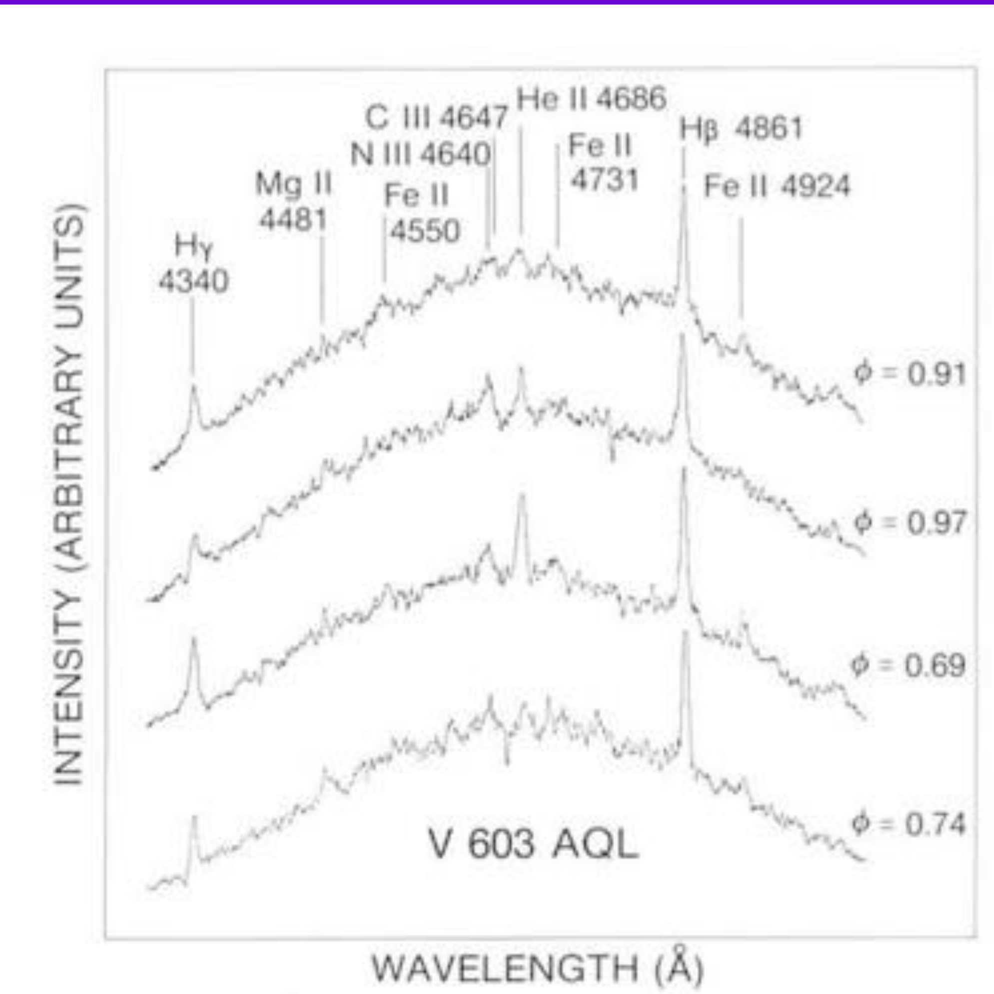


Fig. 1: *Photographs of the expanding envelope around the old nova V 603 Aquilae, taken at Mt. Wilson Observatory (from Mustel and Boyarchuk, 1970).*

Nova V 603 Aquilae spectra



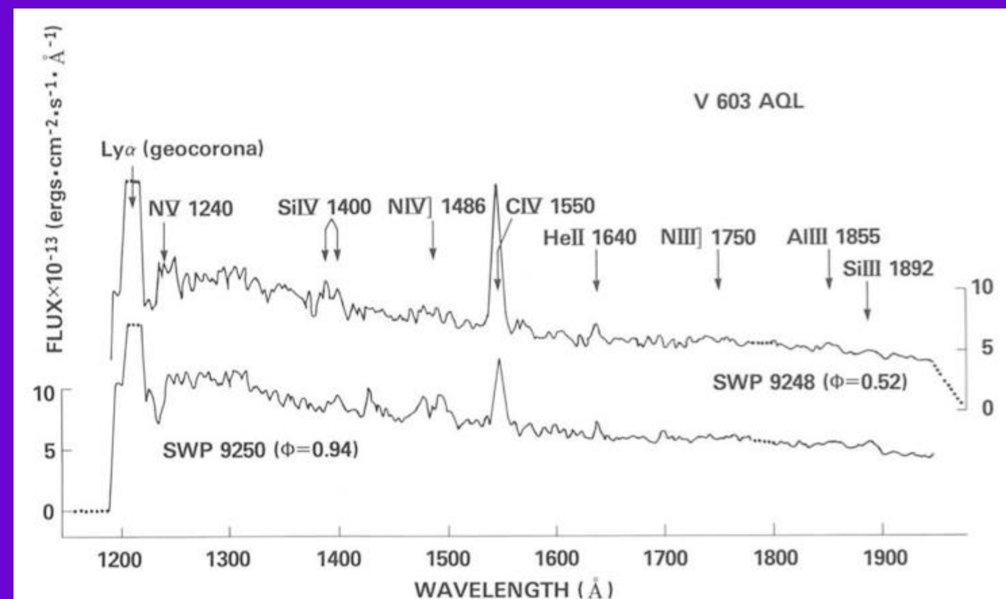
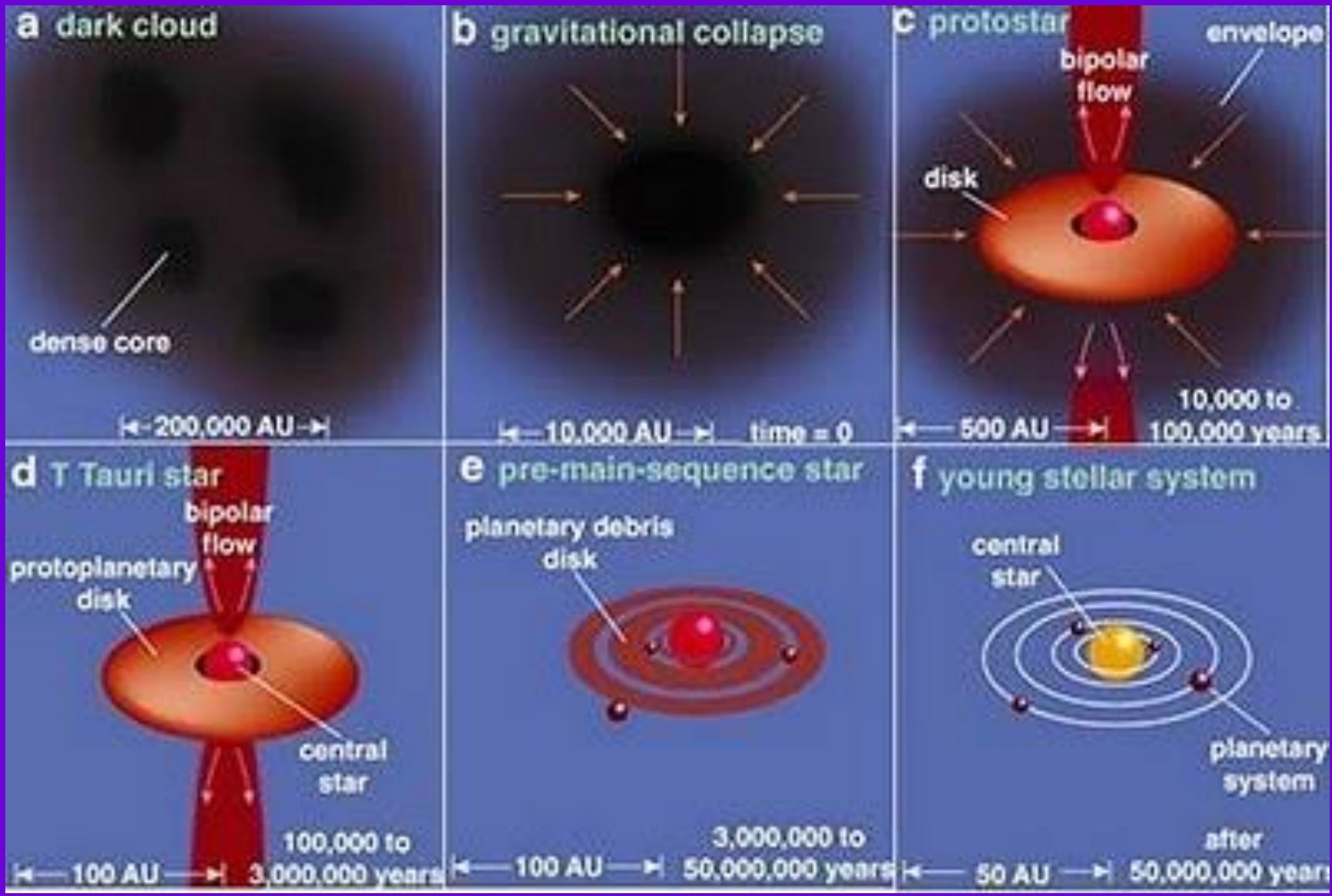


Fig. 3: *Two selected IUE short wavelength spectrograms of V 603 Aql obtained at orbital phase 0.52 and during the eclipse at phase 0.94. Pronounced variations of the strengths of C IV (1550), Si IV (1400) and He II (1640) as well as of N IV] (1486) — but in an opposite sense — are clearly noticeable.*

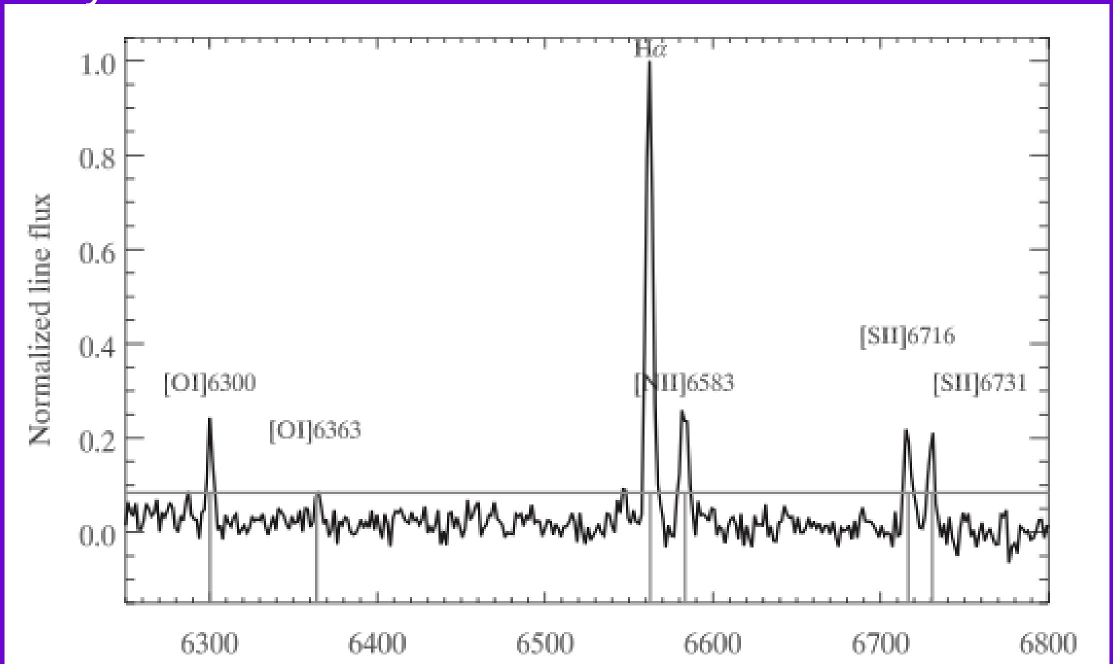
Protostars

- There are several phases in the lives of protostars where emission lines can be seen
  - Herbig-Haro objects
  - T-Tauri objects



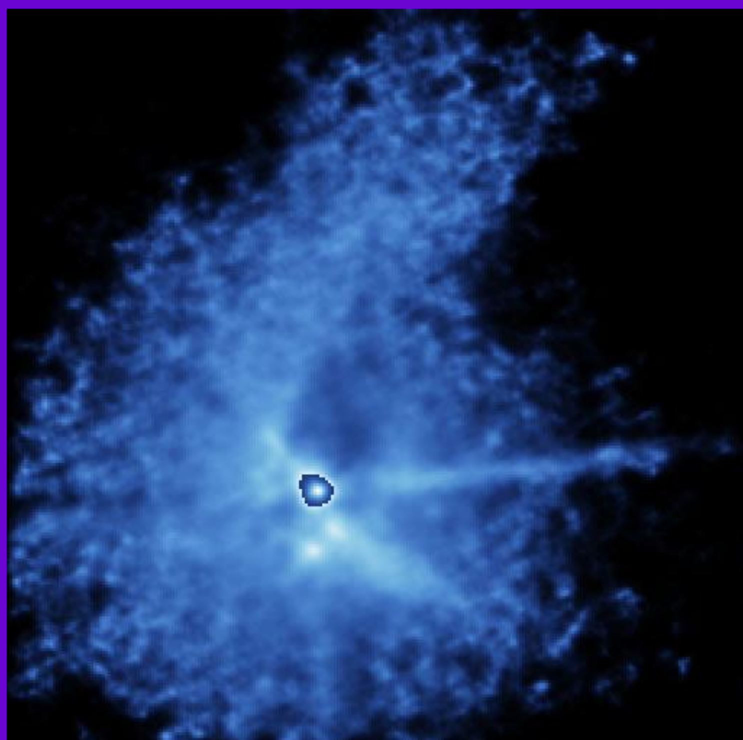
Protostars: Herbig-Haro objects

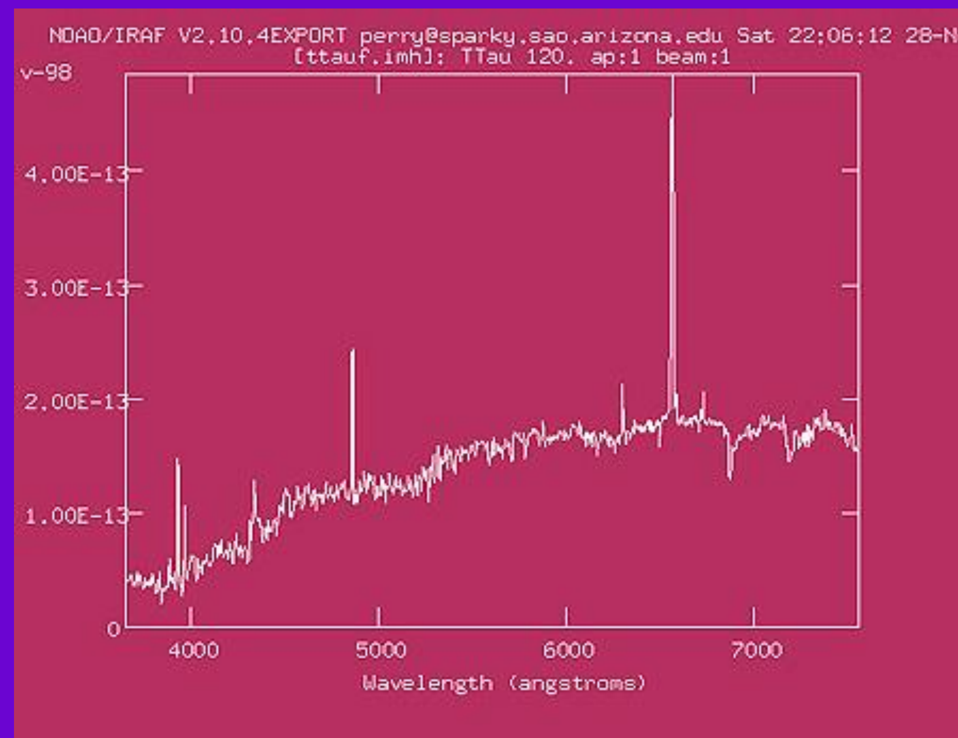
- Emission from HH objects is caused by shock waves when they collide with the interstellar medium
- Velocities of hundreds of km/sec
- The new nebula in LDN 1415 - A cry from the cradle of a low-luminosity source



Protostars: T Tauri objects

- Age between 10^5 and 10^8 yr
- Mass 0.5 to 3.0 $M_{\odot}$
- losing mass via stellar winds with typical v_{exp} = ~100 km/s.





Star forming galaxies

- They are galaxies containing either HII regions or an active nucleus (or both)
- They can be either

- small mass galaxies dominated by one or a few giant HII regions (HII galaxies, blue compact galaxies). In this case they are of low « metallicity » (downsizing)

- Normal spiral galaxies containing many giant HII regions. The integrated spectrum of such galaxies is dominated by the giant HII regions in the inner zone, where the « metallicities » are moderate to large

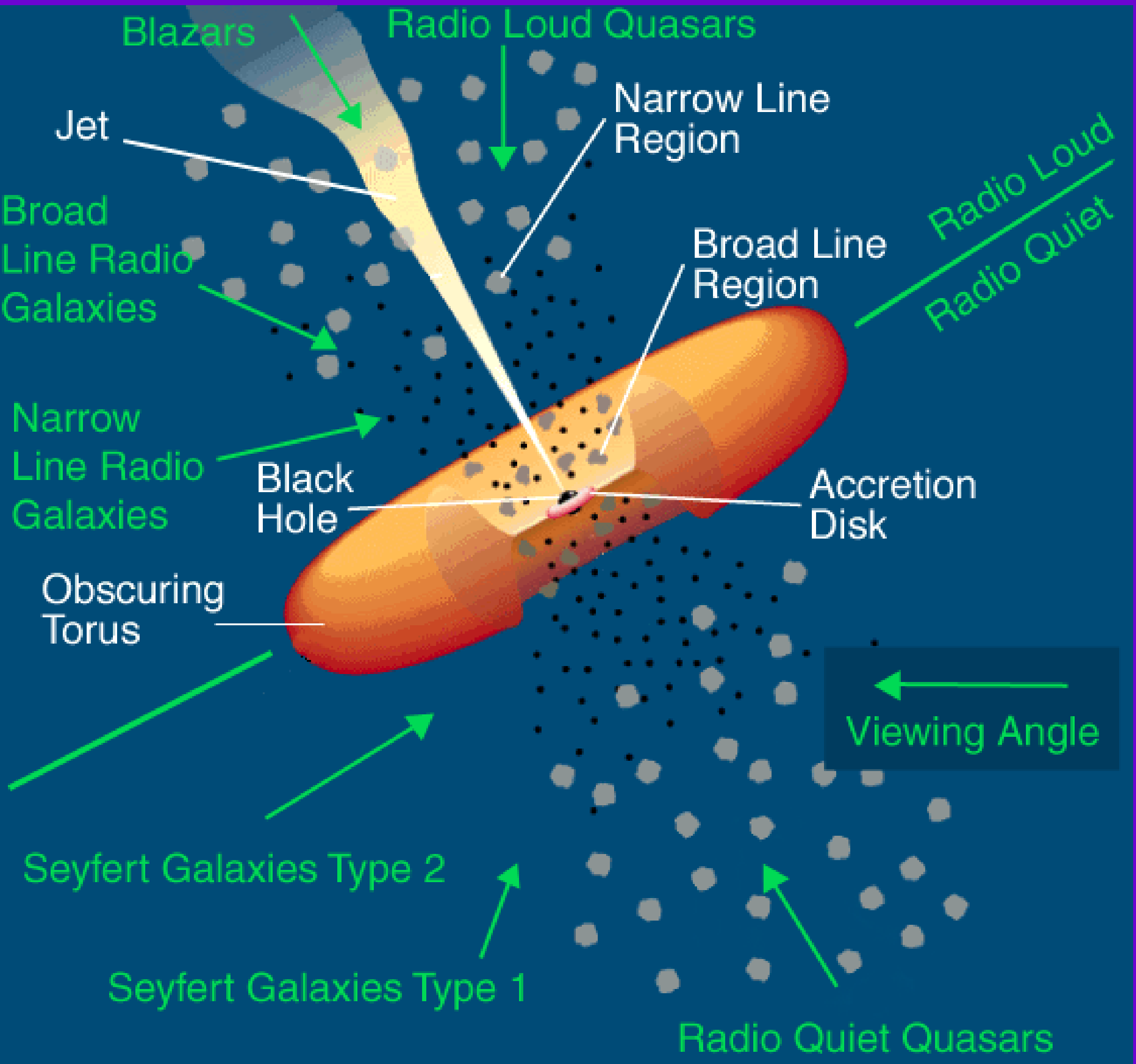
- Spiral galaxies containing an active nucleus

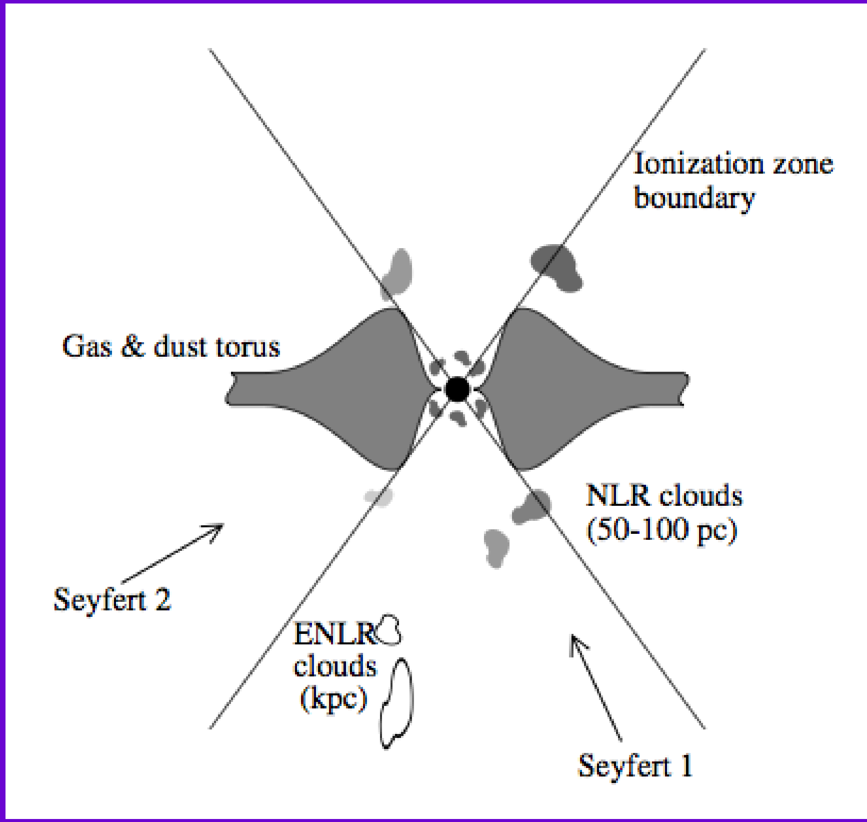
Active galactic nuclei and quasars

- They are galaxies containing either HII regions or an active nucleus (or both
- They can be either
  - small mass galaxies dominated by one or a few giant HII regions (HII galaxies, blue compact galaxies). In this case they are of low « metallicity » (downsizing)
  - Normal spiral galaxies containing many giant HII regions. The integrated spectrum of such galaxies is dominated by the giant HII regions in the inner zone, where the « metallicities » are moderate to large
  - Spiral galaxies containing an active nucleus

Active galactic nuclei (AGN) and quasars

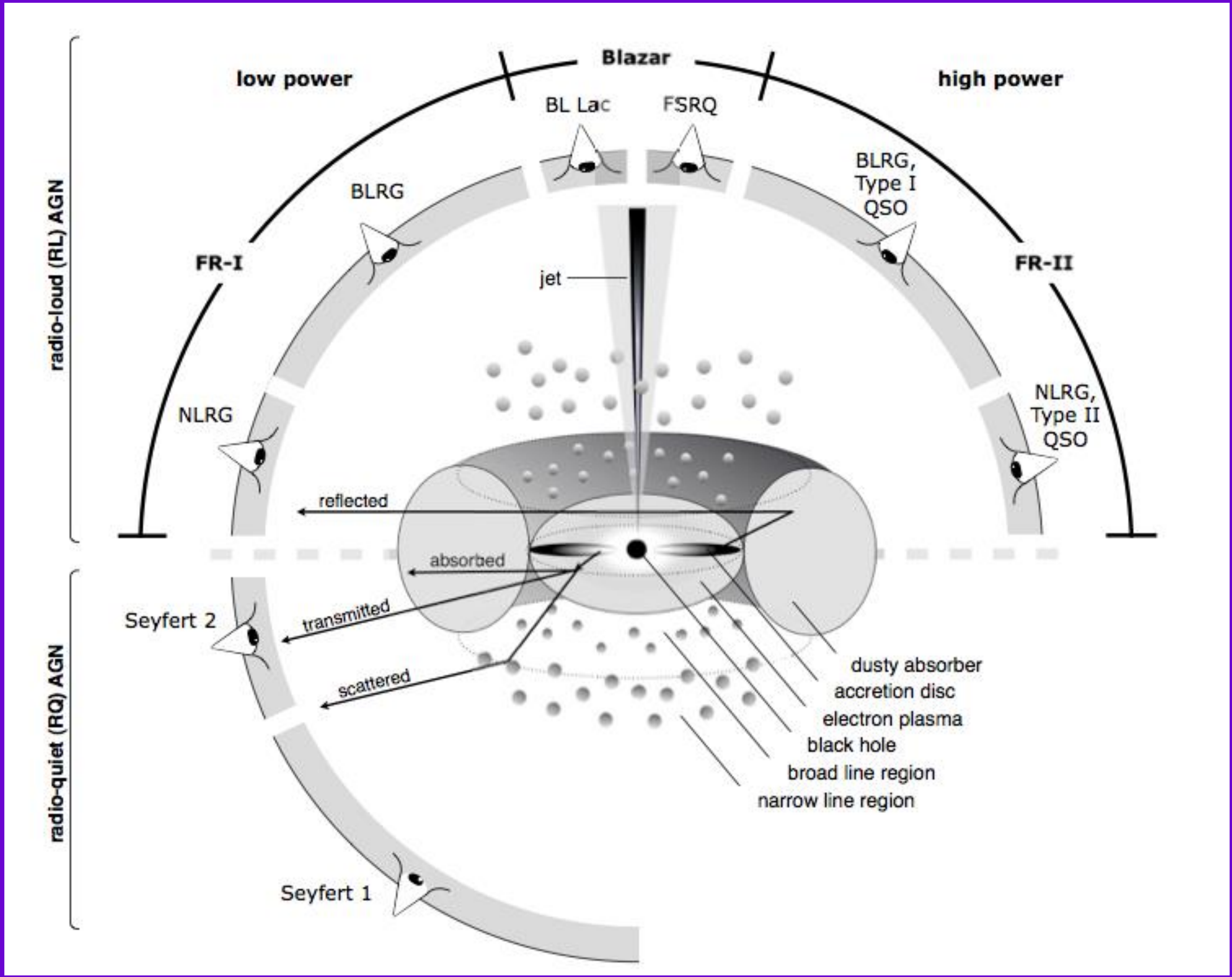
The unified model





the unified scheme of AGNs

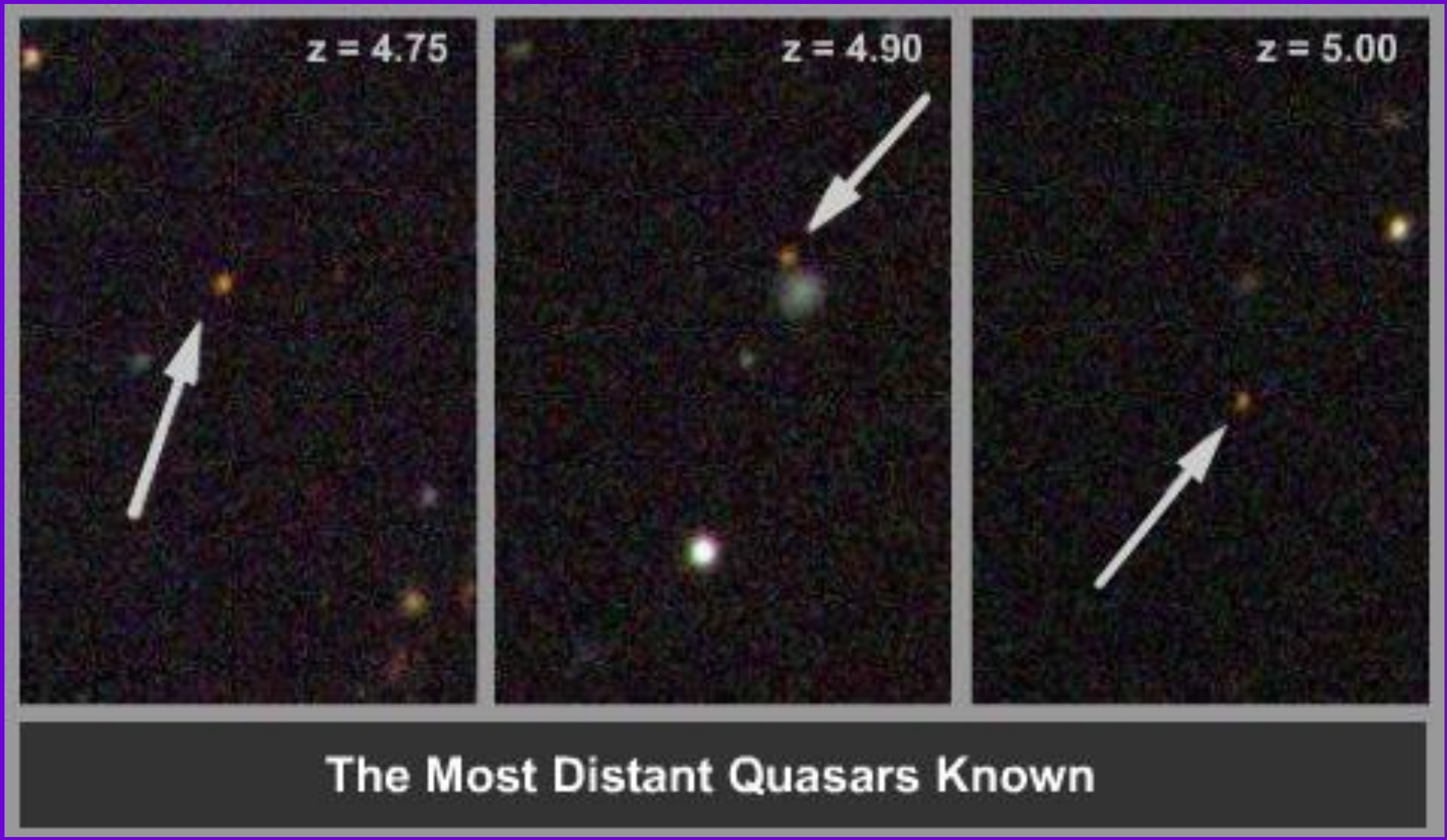
Active galactic nuclei (AGN) and quasars



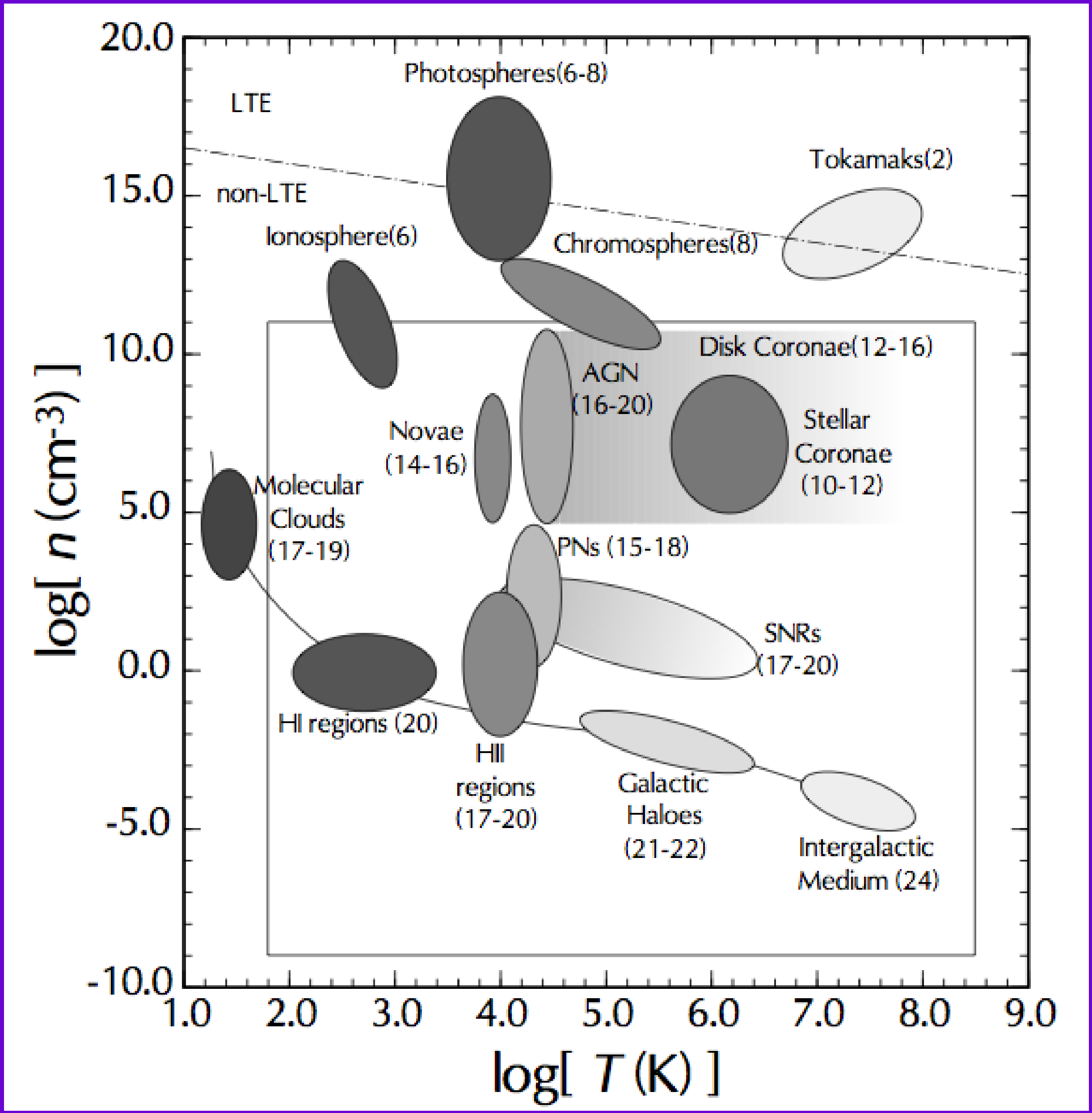
active galactic nuclei (AGN) and quasars

the nucleus of M87,
a giant elliptical galaxy

NGC 7742 a spiral galaxy
with an active nucleus



Temperatures, densities and sizes of diffuse astrophysical plasmas in the universe



Dopita & Sutherland 2003
Astrophysics of the Diffuse Universe