H II Regions

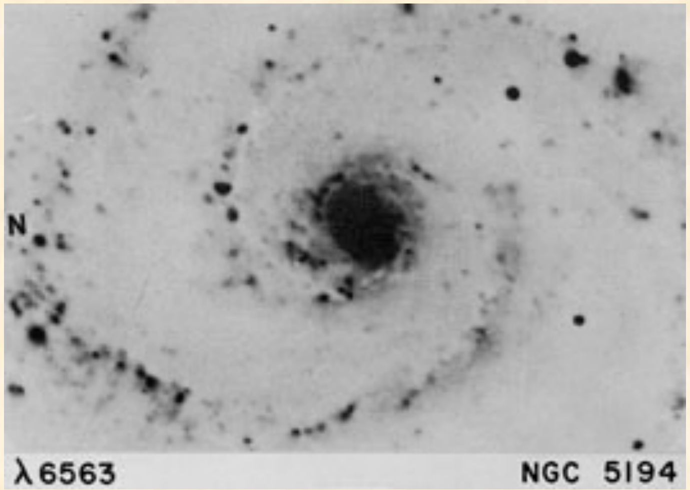
(What are they good for?)

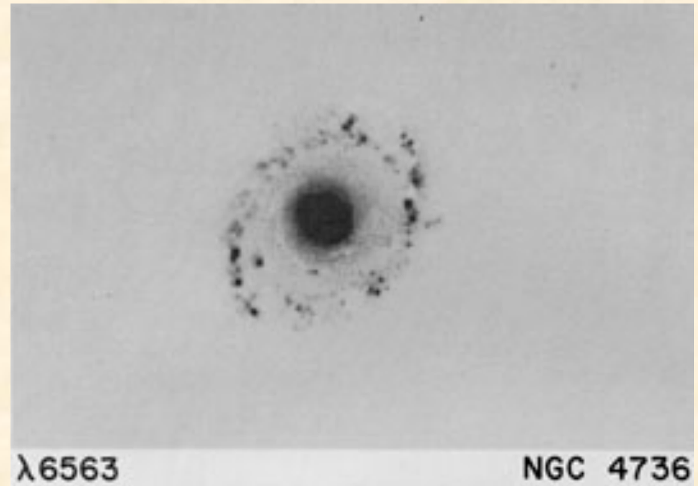
- Distribution of hot stars and ionized gas in our Galaxy and other galaxies.
- Abundances (including abundance gradients across other galaxies).
- Rotation curves in other galaxies
- Star formation rates and processes
- H II Region structure and photodissociation regions (PDRs)

H II Regions in Other Galaxies

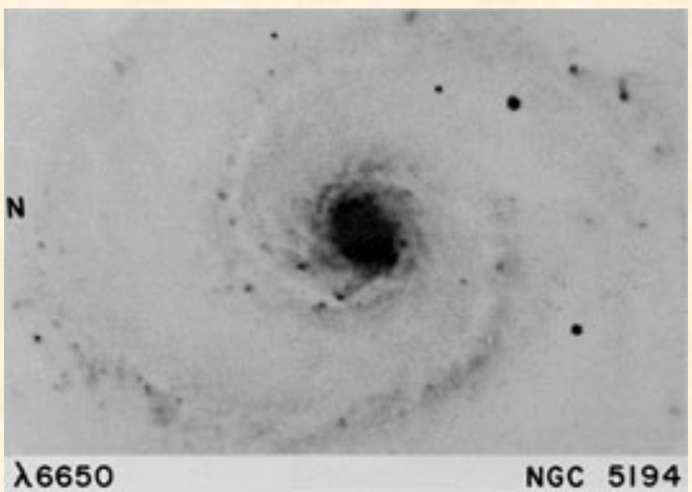
- Optical Surveys: narrow-band filters centered on Hα + [N II]
  - typically brighter than Hβ + [O III] and less affected by dust
  - previously on photographic plates; now with modern detectors (e.g., CCDs)
- Spirals: H II regions concentrated along arms in disk
  - most spirals lack H II regions in their nuclei
  - ~10% of spirals show active star formation and large H II regions in their nuclei → "H II or starburst galaxies"
- Irregulars: H II regions usually asymmetrically distributed
  - some show features resembling spiral arms or bars (LMC)
- Ellipticals and SOs: almost never show H II regions.
  - no hot stars
- H II regions are very luminous in a few spectral lines, and the lines show low velocity dispersions
  - perfect for radial velocity curves of galaxies

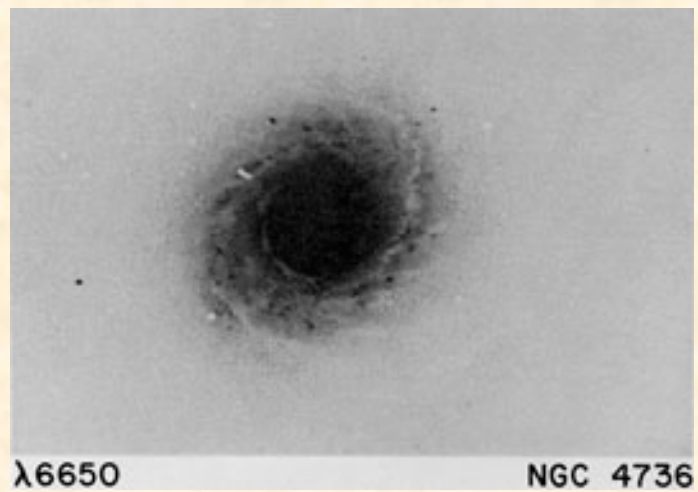
Hα narrow-band filter:





Red continuum filter:



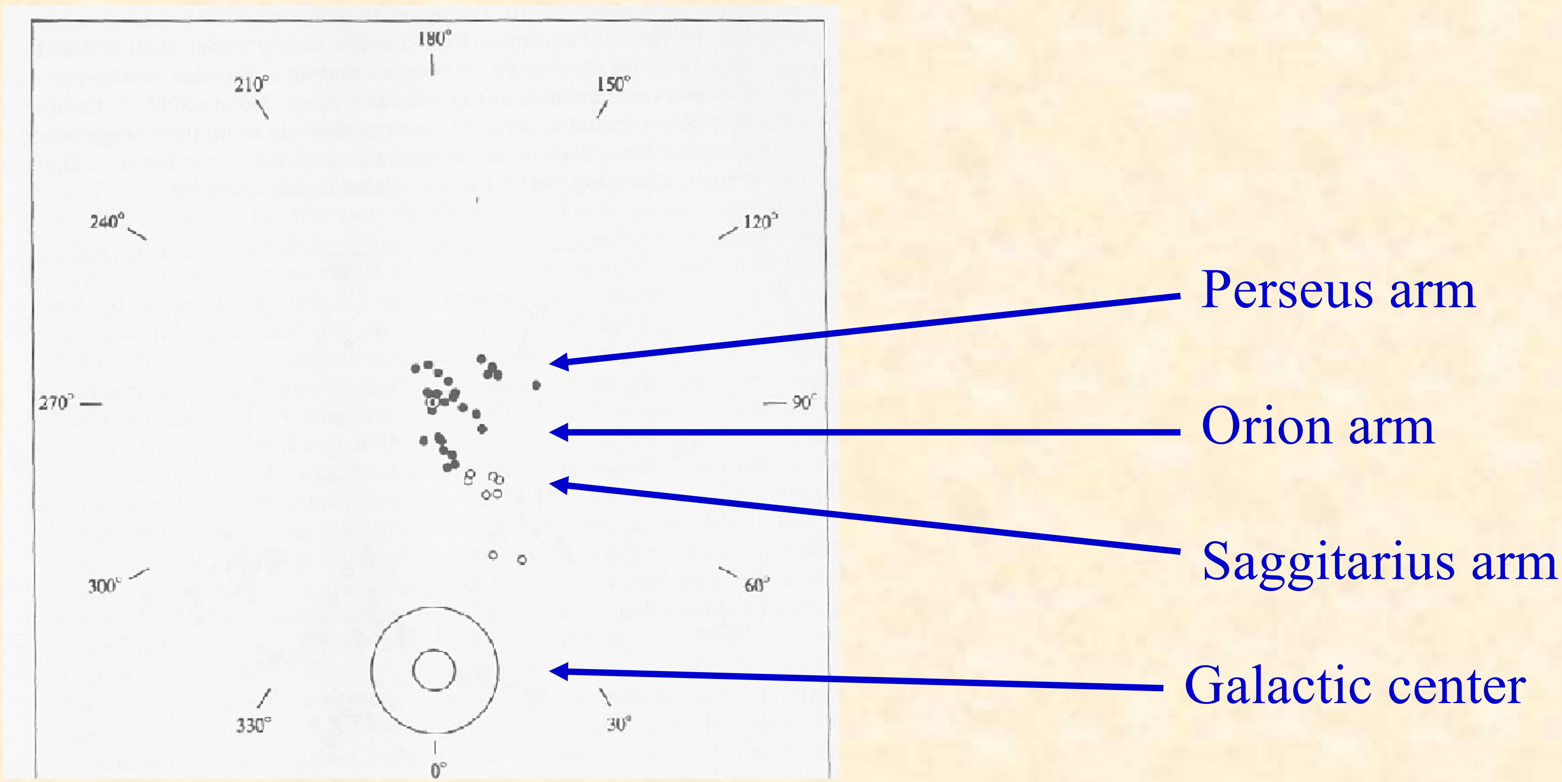


(Lynds, B. 1974, ApJS, 28, 391

HST image of M51:
- Hot stars and H II regions on leading edge of spiral arms
- Dust lanes on trailing edge

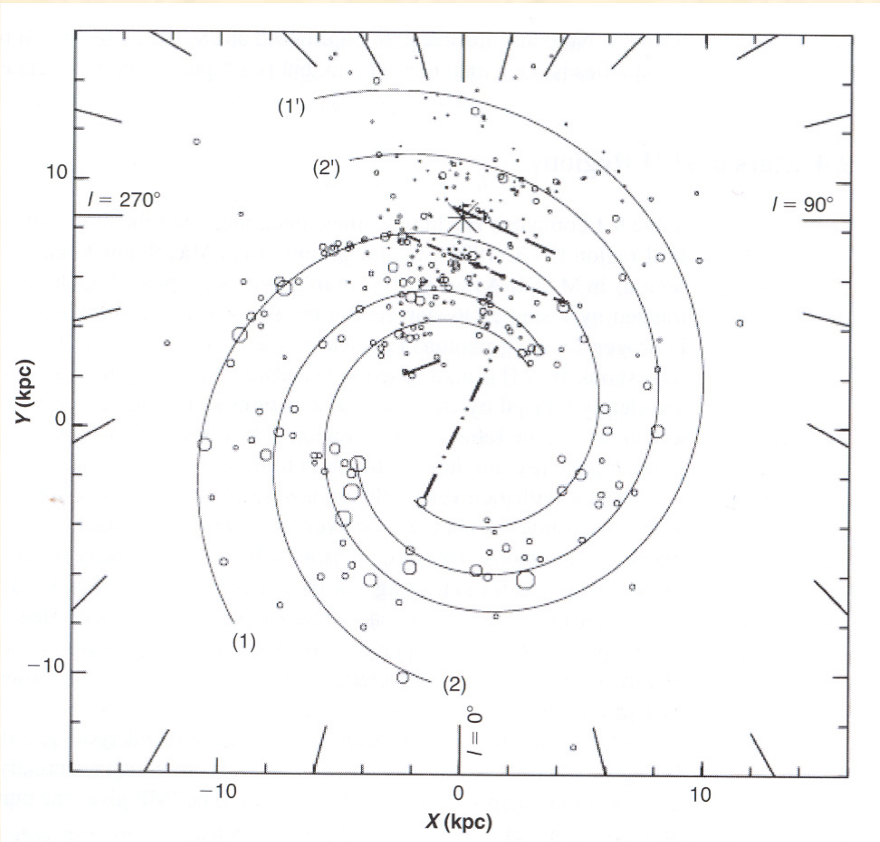
Distribution of H II Regions in our Galaxy

- Optical: nearby H II regions identified by optical narrow-band filters centered on Hα λ6563 + [N II] $\lambda\lambda$ 6548, 6583 .
  - If ionizing stars can be identified, distances can be determined by spectroscopic parallax of O and B stars.
  - Limited to distances $\leq$ 2 kpc by extinction in Galactic plane.



(Osterbrock 1st edition)

- Radio: use high-order recombination lines
  - Ex) n = 110 to n=109 gives H109α at $\lambda = 5.99$ cm
  - not affected by dust in Galactic plane
- No direct measurement of distance (O and B stars are not detectable at large distances due to dust)
  - must rely on radial velocity measurements and Galactic velocity curves from HI λ21-cm to get distances



(Osterbrock & Ferland, p. 229)

- ~100 luminous H II regions detected in Milky Way, similar to other large spiral galaxies
- H II regions are in the Galactic disk, and are concentrated in spiral arms (defined by H I 21 cm emission)

Abundances

H II regions are important for determining He abundances.

Surface brightnesses:

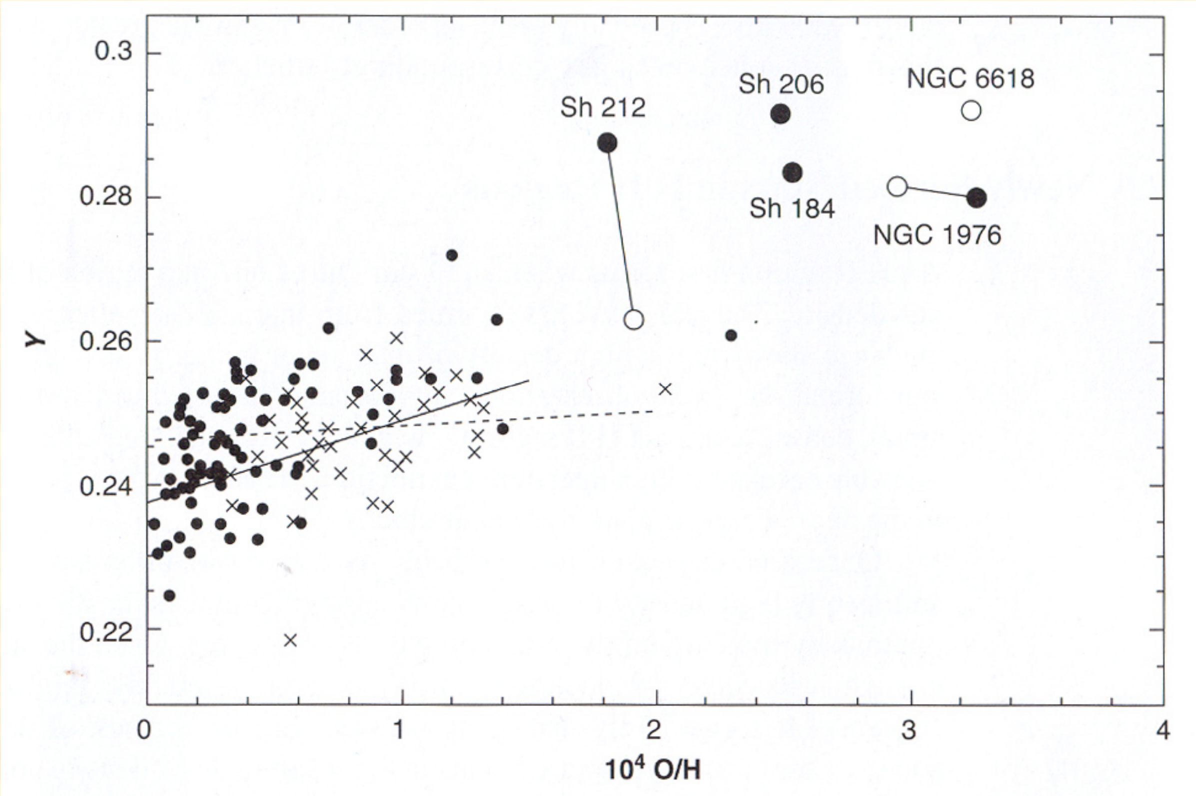
$$I_{H\beta} = \int n_p n_e \, h\nu_{H\beta} \, \alpha^{eff}_{H\beta} \, (H^0, T) \, ds$$

$$I_{He\ I\ \lambda 5876} = \int n_{He^+} n_e \, h\nu_{5876} \, \alpha^{eff}_{5876} \, (He^0, T) \, ds$$

$$I_{He\ II\ \lambda 4686} = \int n_{He^{++}} n_e \, h\nu_{4686} \, \alpha^{eff}_{4686} \, (He^+, T) \, ds$$

(Osterbrock & Ferland, p. 142)

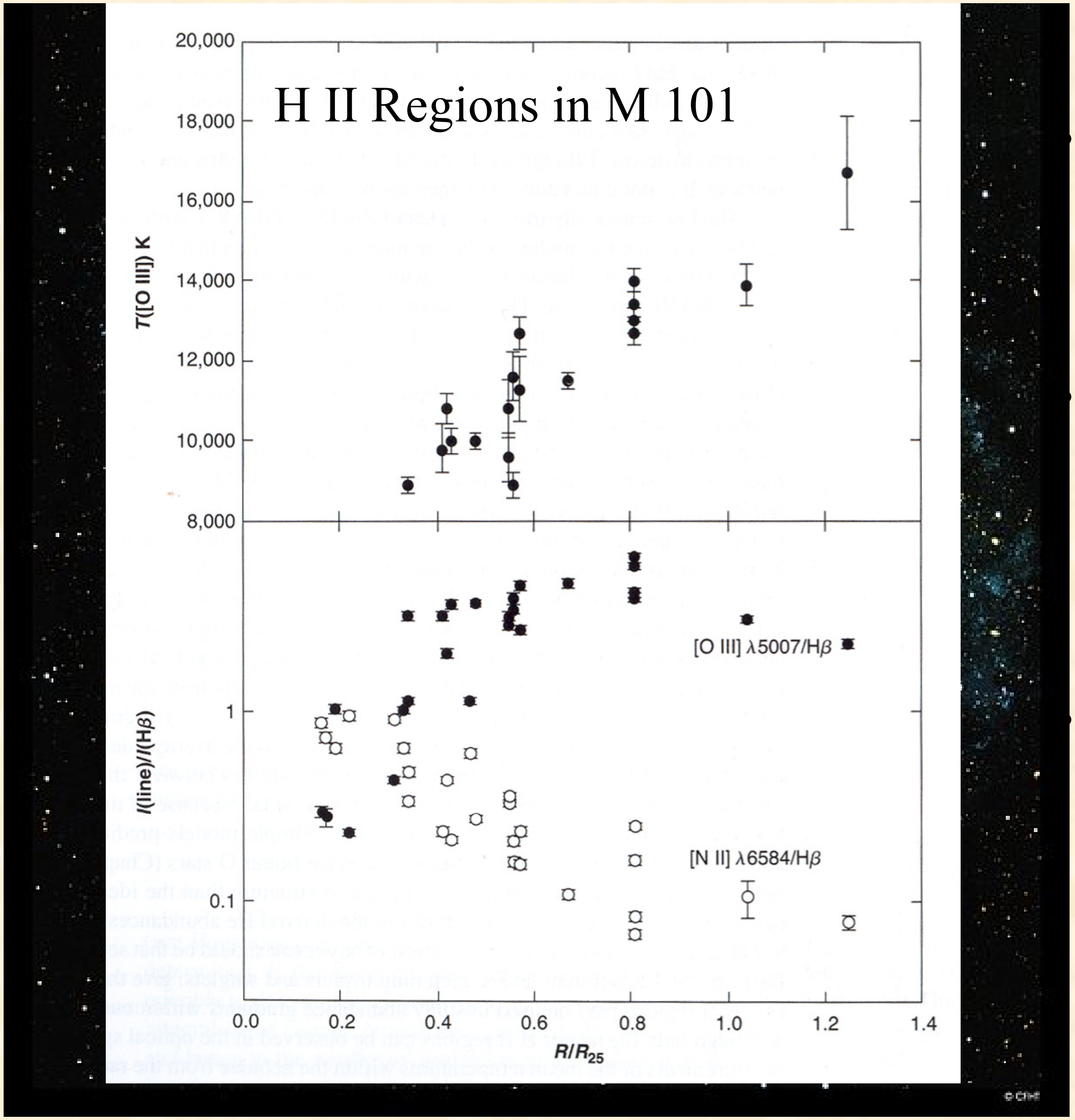
- He /H ratios are only weak functions of density and temperature, and therefore sensitive to the He abundance.
- The He abundance is given by number relative to H, or by mass fraction: Y = mass (He) / total mass of the elements.
- Y should scale roughly with Z (mass fraction of heavy elements), due to nucleosynthesis (X = mass fraction of H).



Osterbrock & Ferland, p. 239

- Numbered points: H II regions in our Galaxy
- Other points: H II regions in irregular and blue compact dwarf galaxies
  - less processed material, lower star formation rates in the past
- Y-intercept gives primordial mass fraction of He:
  $0.225 < Y_0 < 0.255$ (current Big Bang models give 0.235)
- Puzzle: Orion nebula and other H II regions have similar Y and Z compared to the Sun - shouldn't these nebula have more processed stuff?

Other Abundances



- Spiral galaxies: abundances decrease with increasing distance from nucleus (temperature increases)
- [O III]/Hβ increases outward: lower O abundance leads to higher temperatures, so [O III]/Hβ increases to help cool gas.
- [N II]/Hβ decreases outward: higher temperatures do not compensate for lower abundance

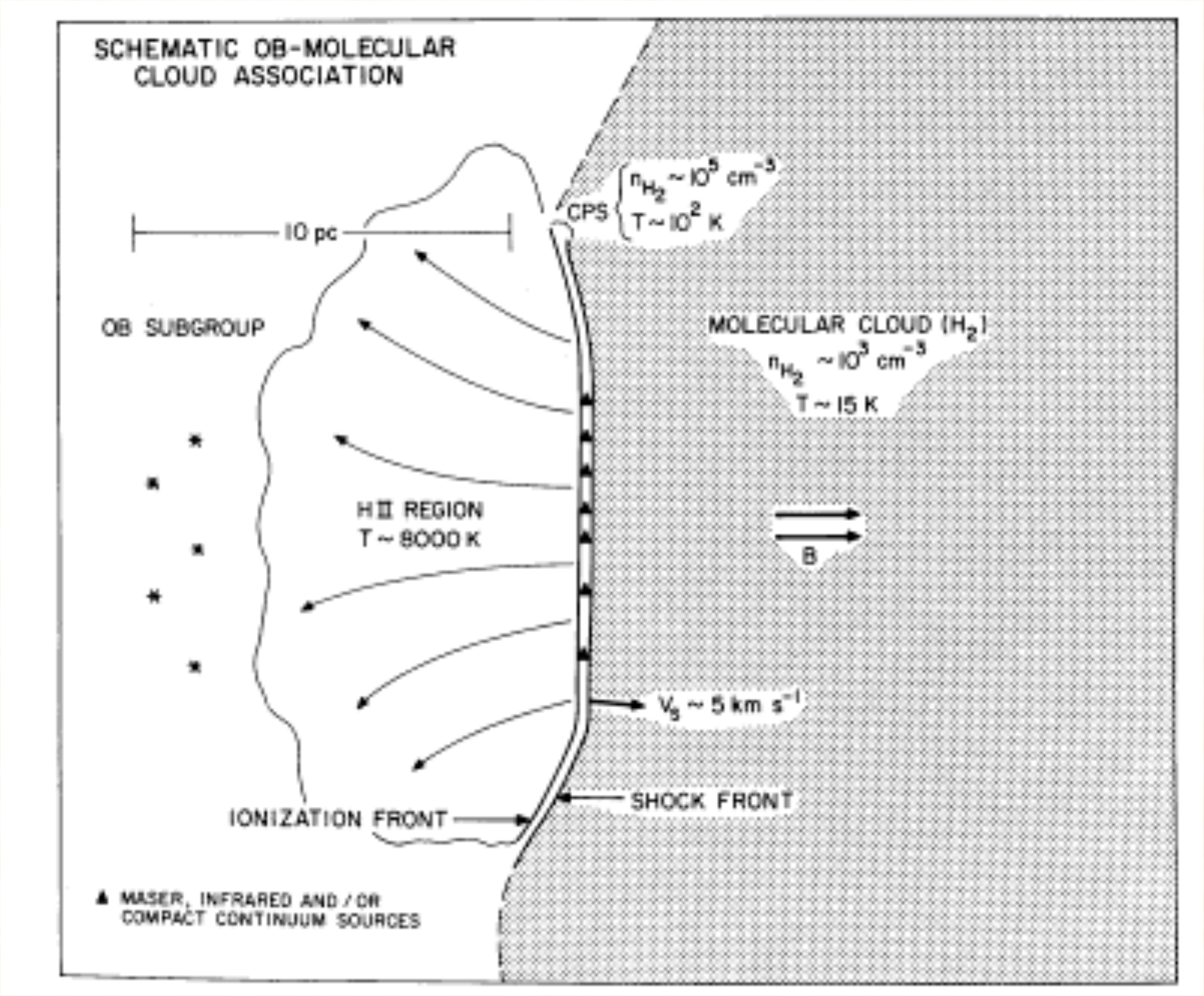
Osterbrock & Ferland, p. 237

H II Region Structure - "Blister" Model

- OB group is located near a large molecular cloud
- Ionizing radiation creates an H II region.
- An ionization shock-front propagates into the cloud.

  (travels 10 – 15 pc in 2 million years)
- Material is swept up into a thin layer, becomes gravitationally unstable, and collapses
- New stars are formed. They are obscured in the optical by their dusty surroundings. However, they are visible as IR sources, or H_2O and OH masers.
- The new O and B stars clear out the surrounding material in about ½ million years.
- A new H II region is created, which starts the process over again.

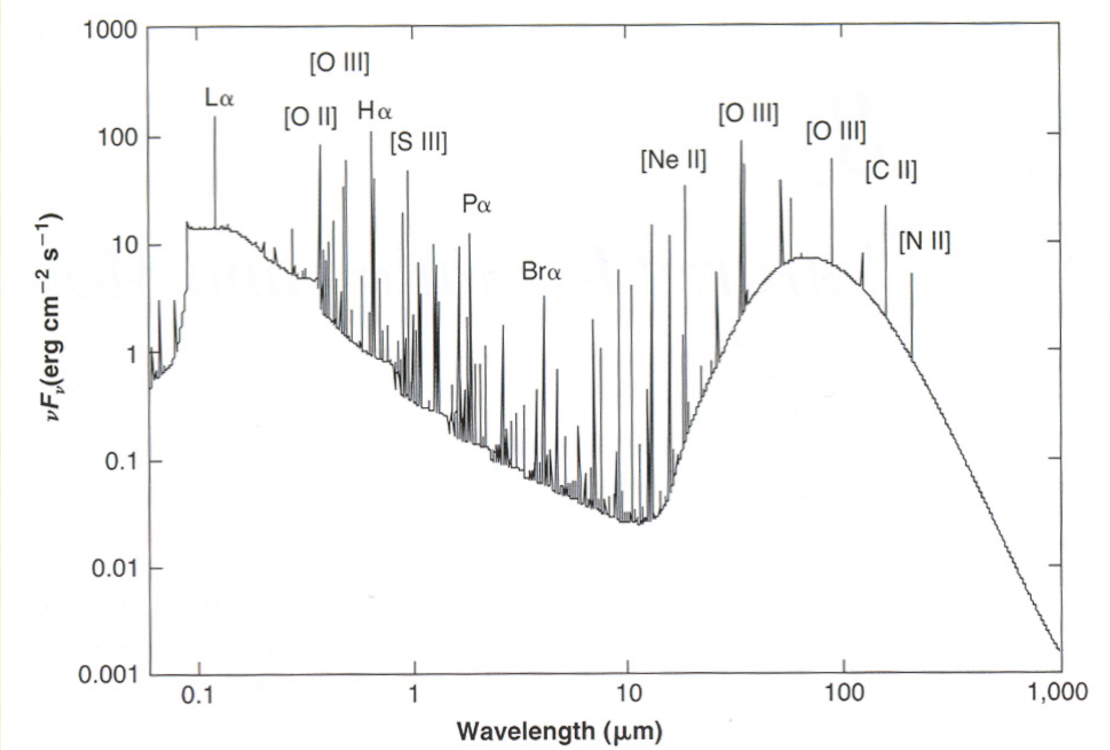
H II Regions and Induced Star Formation



(Elmegreen and Lada, 1977, ApJ, 214, 725)

Photodissociation Regions (PDRs)

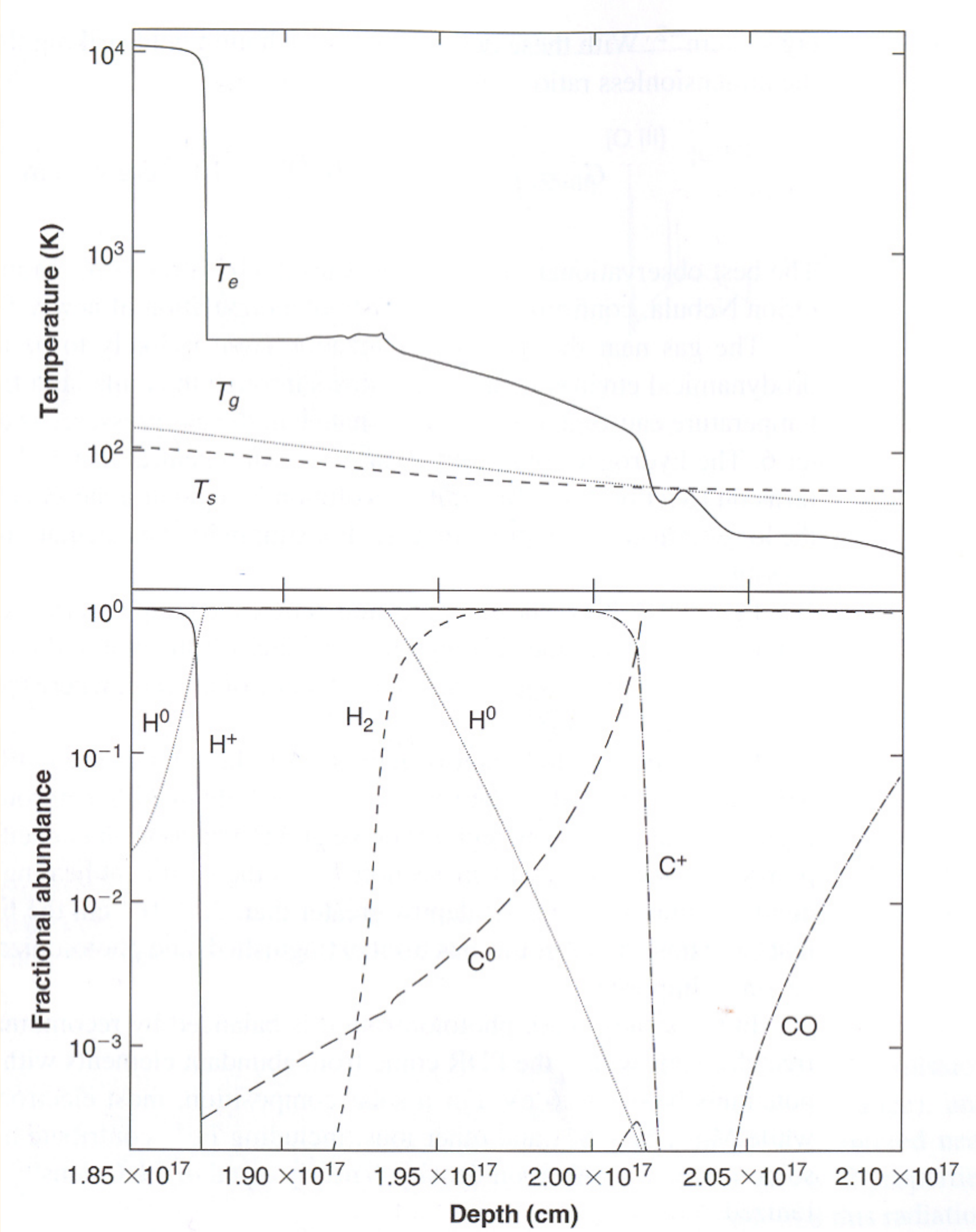
H II region flux transmitted into molecular cloud:



Osterbrock & Ferland, p. 208

- UV, optical, and IR radiation at $\lambda > 912$ Å from stars, recombination continuum, and heated dust in the H II region penetrate molecular cloud.
- Molecules are dissociated. The gas is atomic and neutral, or singly ionized for atoms with ionization potentials less than 13.6 ev (e.g. C I → C II)
- The transition region between H II region and molecular cloud is the PDR.

PDR Model



Osterbrock & Ferland, p. 210

- Most of the heating at shallow depths is by photoionization of grains.
- At larger depths, heating is due to dust absorption.
- Cooling is by dust radiation and IR fine-structure lines.
- PAH's are excited by UV and optical radiation, and reradiate emission features in the mid-IR
  →Excellent tracers of starburst activity in other galaxies

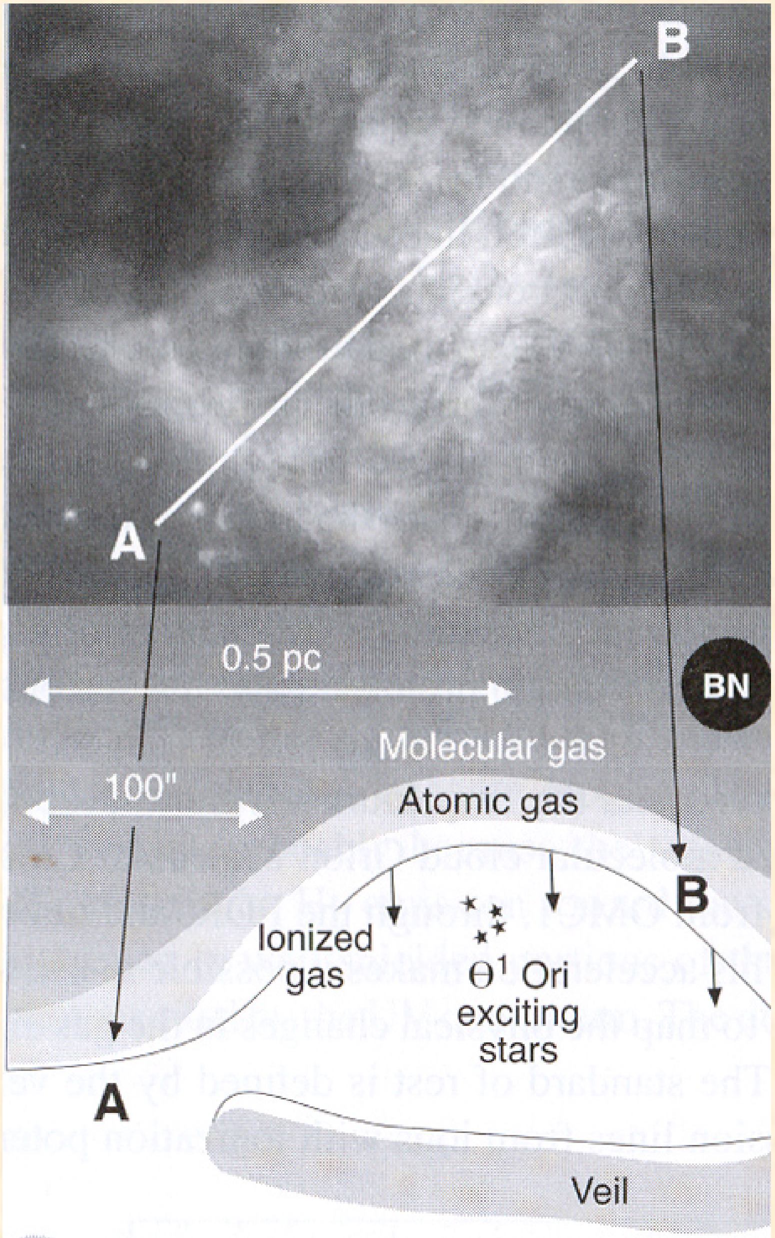
Orion Nebula (M42, NGC 1976)

Huygens Region

Trapezium (optical)

Trapezium (IR)

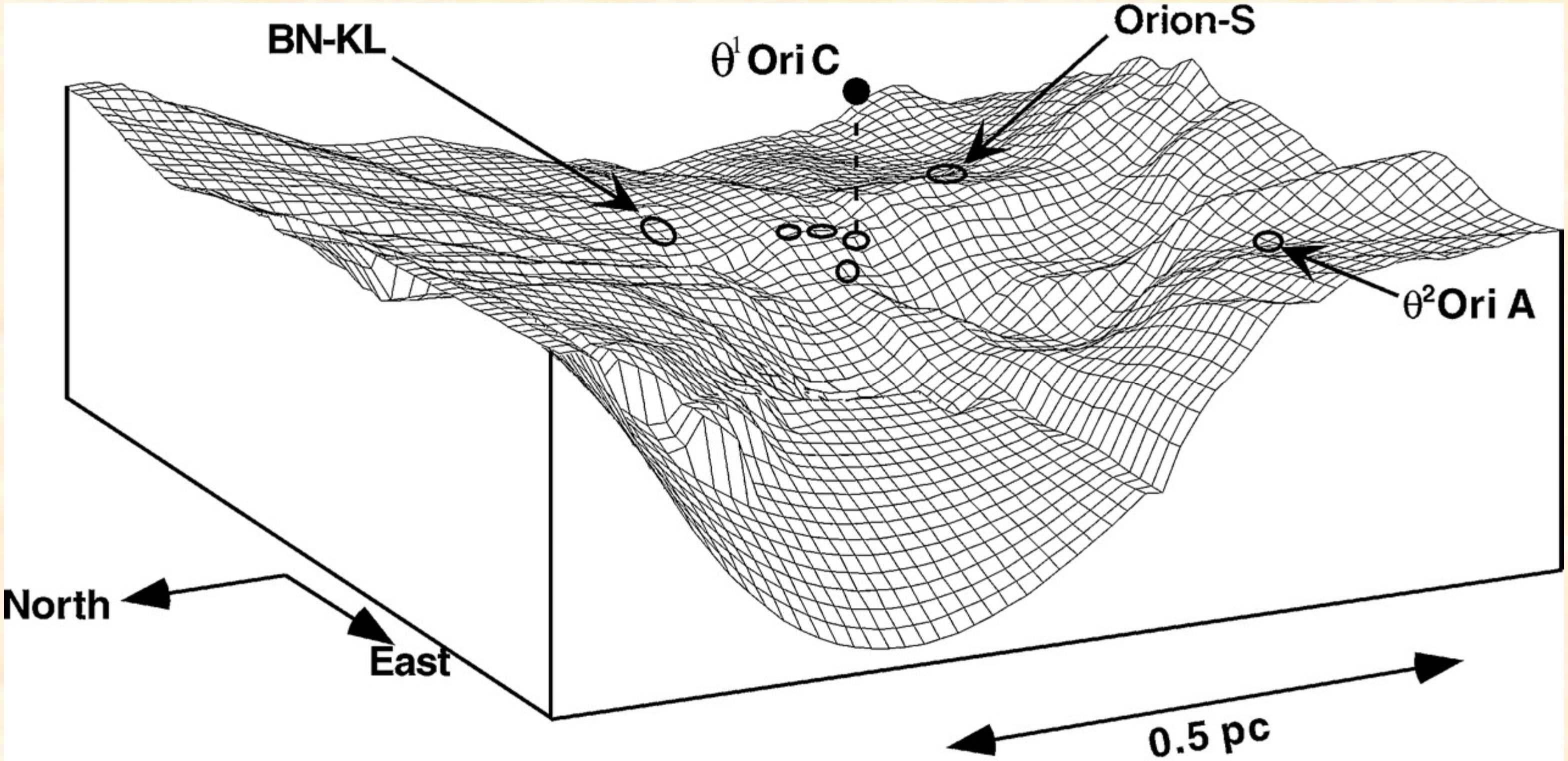
Structure of the Orion Nebula



Osterbrock & Ferland, p. 217

- Distance of M42 is ~450 pc.
- The nebula is a thin, concave "blister" on the molecular cloud OMC-1, facing us.
- The blister is ~1 pc in extent and only ~0.1 pc thick (the extended nebula is ~10 pc across).
- Ionization is dominated by θ^1 Ori C (O6 V star)
- The "atomic gas" is the PDR.
- A slow shock + ionization front is moving into the cloud.
- Ionized gas is outflowing towards the ionizing stars at ~10 km s^{-1}.
- The Veil is neutral gas responsible for most of the extinction.

3D Structure of the Orion Nebula



(O' Dell, C.R. 2001, ARAA, 39, 99)

- Determined from surface brightness and density along the line of sight.
- Sun is along the z axis at a distance of 450 pc.
- Ionization front is ~0.25 pc from θ^1 Ori C.

3D Movie