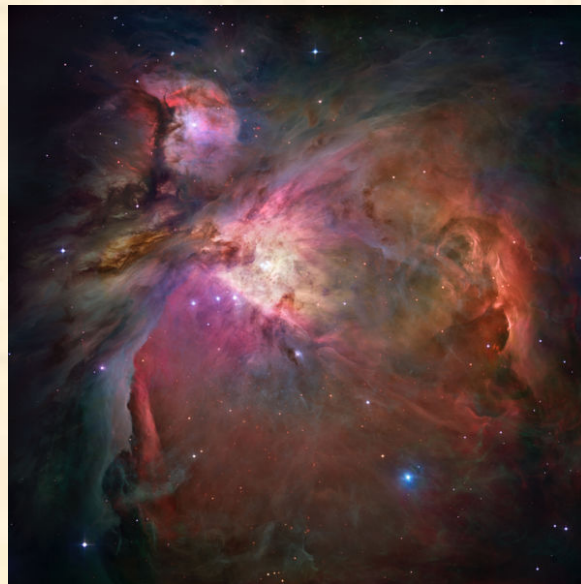


H II Regions

(What are they good for?)

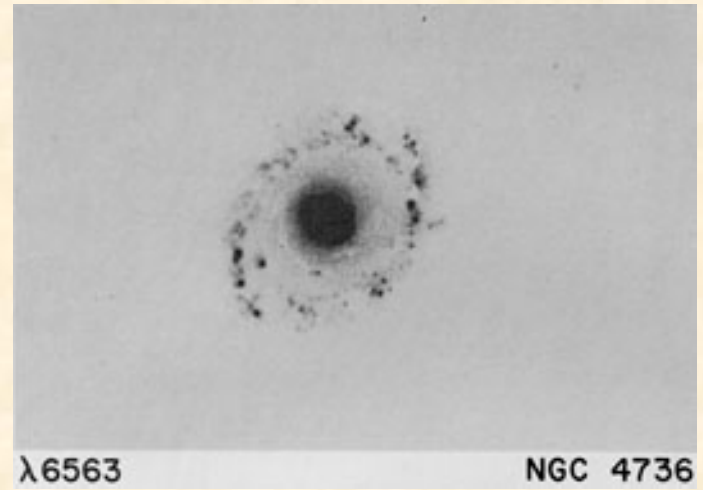
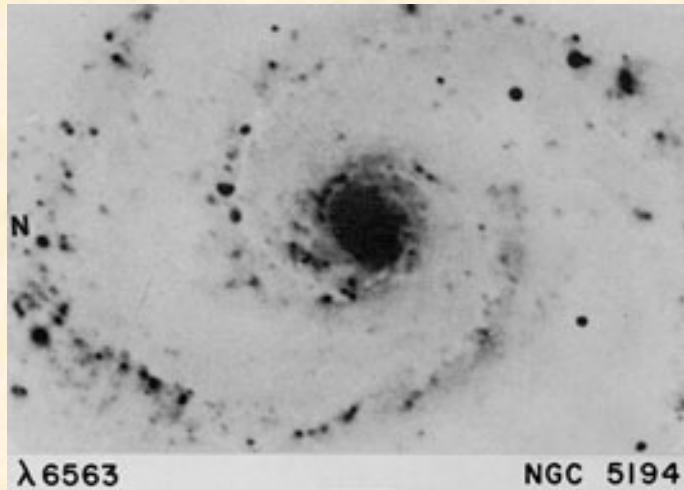
- Distribution of hot stars and ionized gas in our Galaxy and other galaxies.
- Abundances (including abundance gradients across other galaxies).
- Rotation curves in other galaxies
- Star formation rates and processes
- H II Region structure and photodissociation regions (PDRs)



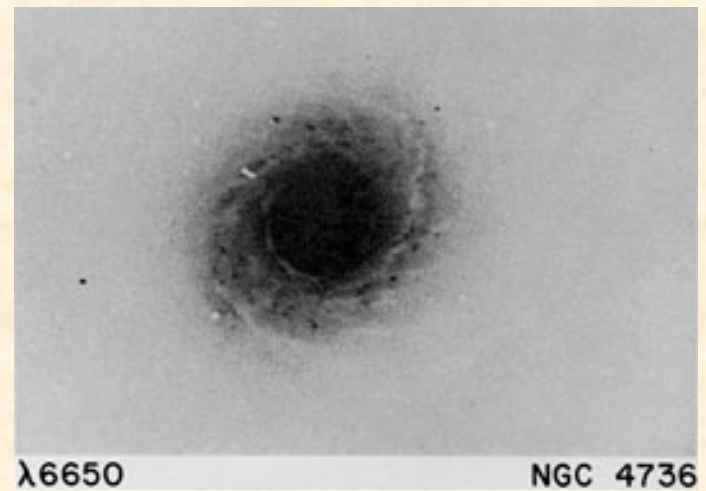
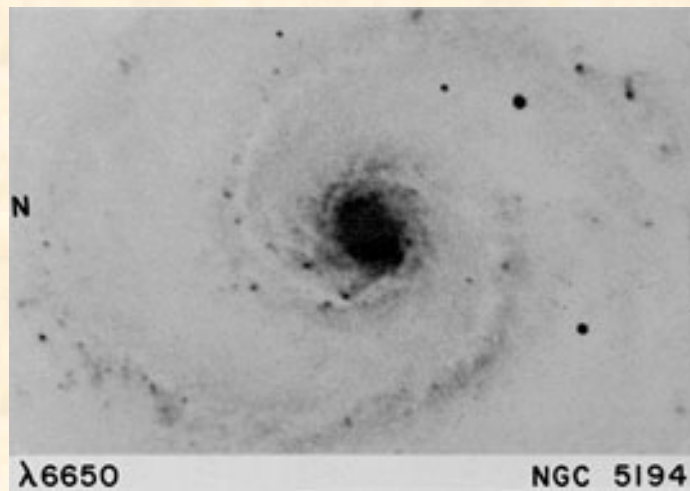
H II Regions in Other Galaxies

- Optical Surveys: narrow-band filters centered on $H\alpha + [N II]$
 - typically brighter than $H\beta + [O III]$ 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
 - $\sim 10\%$ of spirals show active star formation and large H II regions in their nuclei \rightarrow “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

H α narrow-band filter:



Red continuum filter:



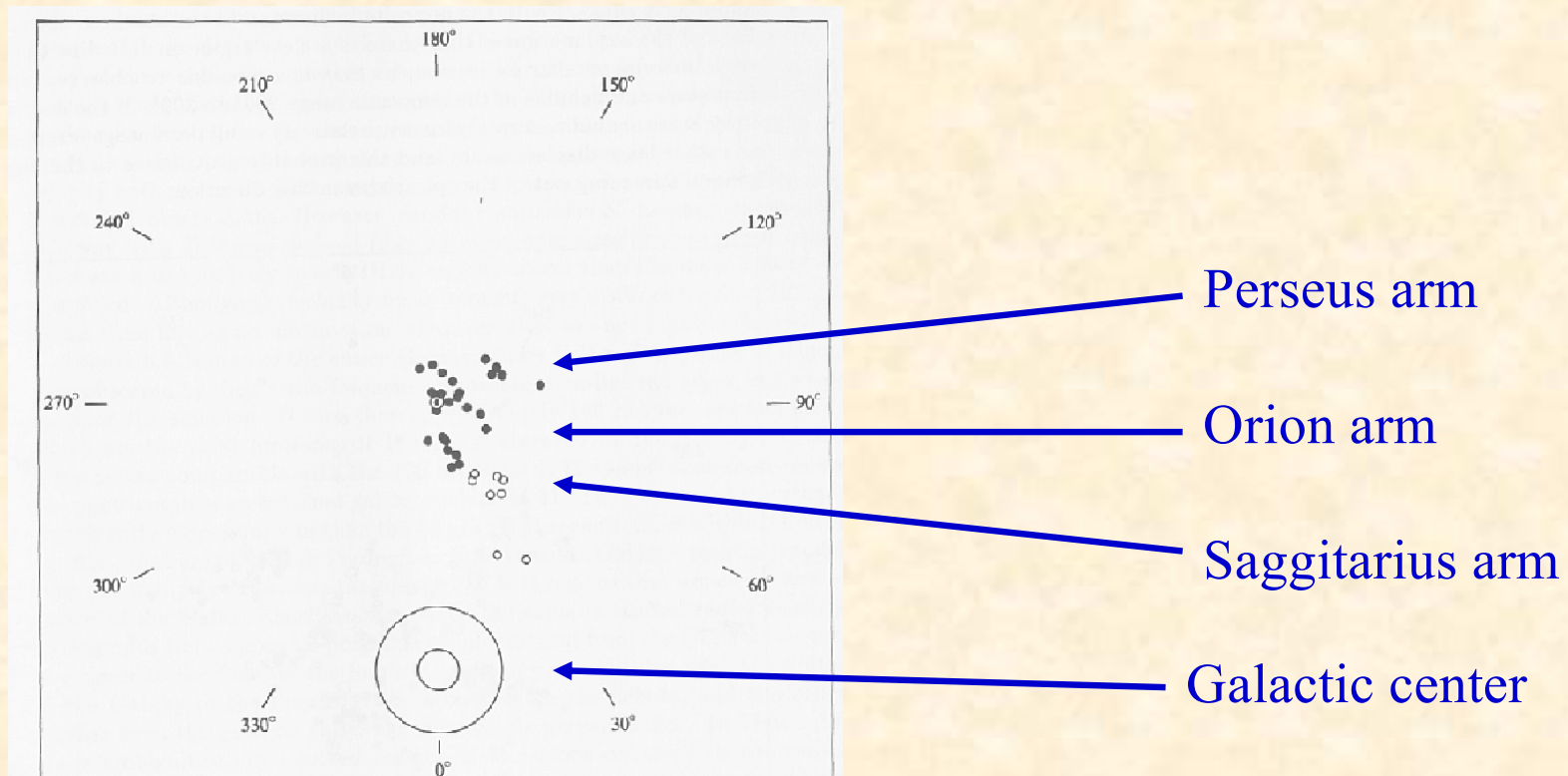
(Lynds, B. 1974, ApJS, 28, 391)



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

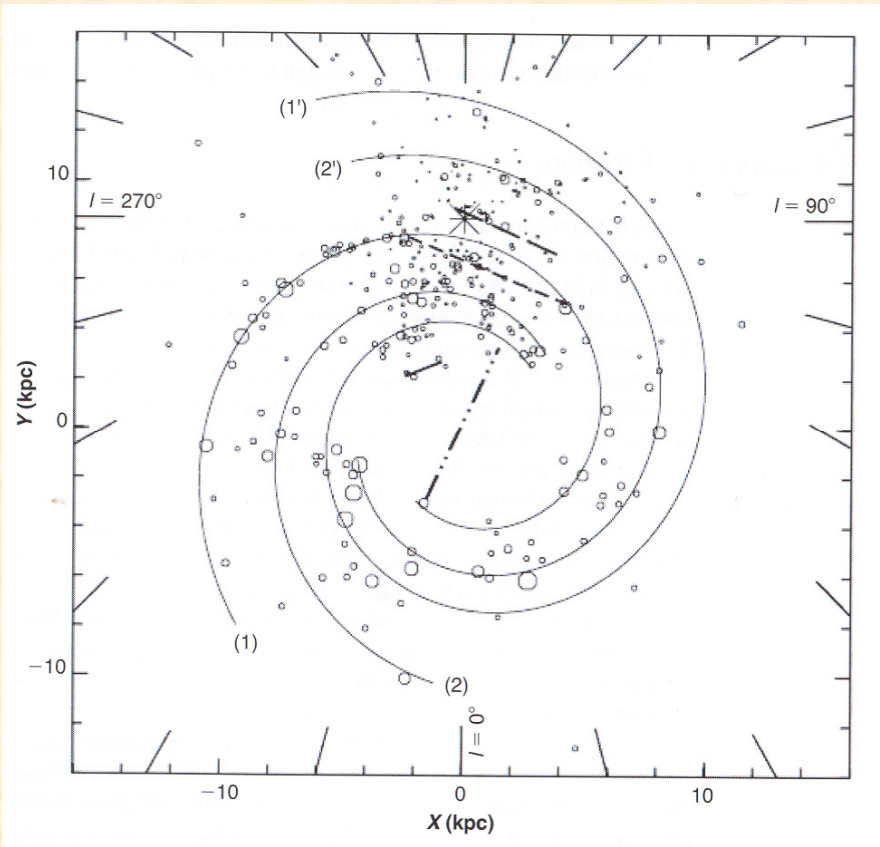
Distribution of H II Regions in our Galaxy

- Optical: nearby H II regions identified by optical narrow-band filters centered on H α λ 6563 + [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 ≤ 2 kpc by extinction in Galactic plane.



(Osterbrock 1st edition)

- Radio: use high-order recombination lines
 - Ex) $n = 110$ to $n=109$ gives $H109\alpha$ 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 $\lambda 21$ -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:

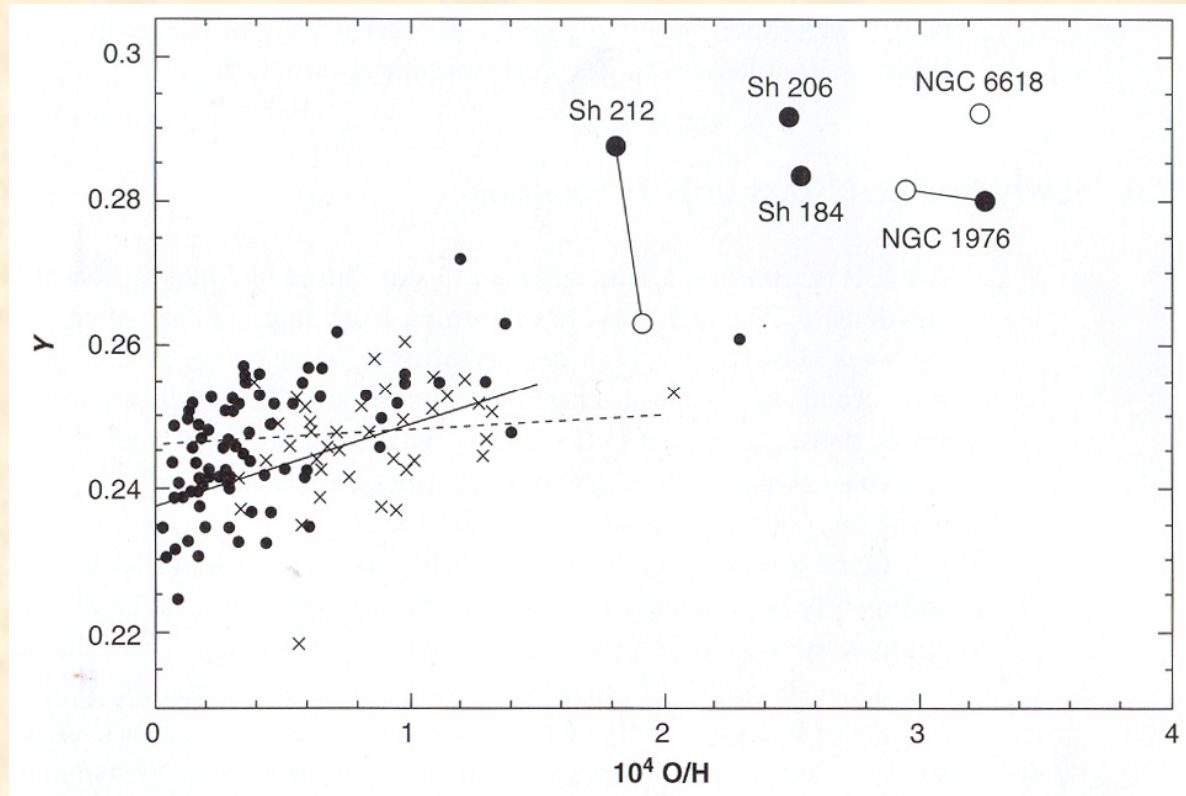
$$I_{\text{H}\beta} = \int n_p n_e h\nu_{\text{H}\beta} \alpha_{\text{H}\beta}^{\text{eff}} (\text{H}^0, T) ds$$

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

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

(Osterbrock & Ferland, p. 142)

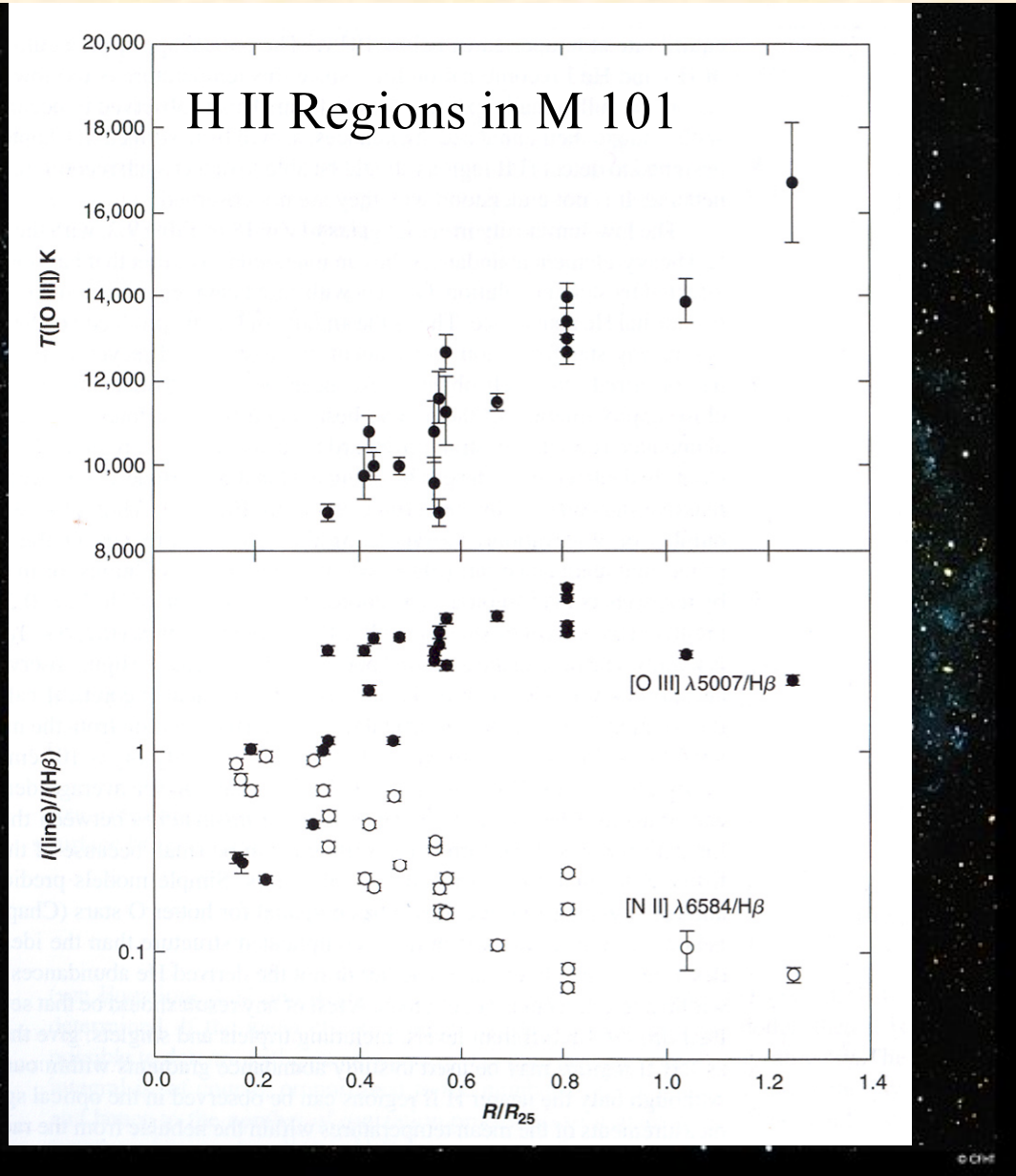
- He /H ratios are only weak functions of density and temperature, and **therefore sensitive to the He abundance**.
- The He abundance is given by number relative to H, or by mass fraction: $Y = \text{mass (He)} / \text{total mass of the elements}$.
- Y should scale roughly with Z (mass fraction of heavy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



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)

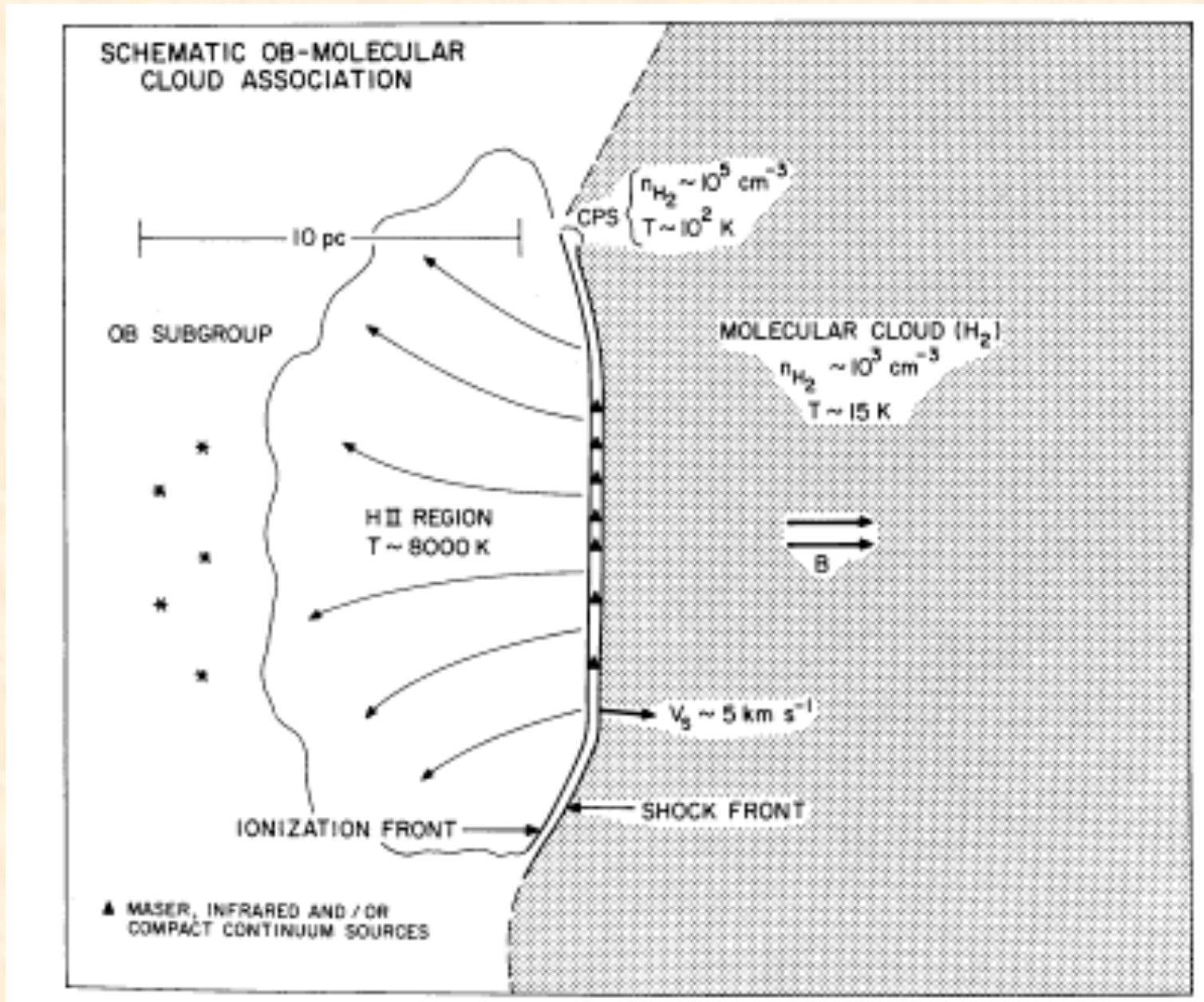
$[\text{O III}]/\text{H}\beta$ **increases** outward: lower O abundance leads to higher temperatures, so $[\text{O III}]/\text{H}\beta$ increases to help cool gas.

$[\text{N II}]/\text{H}\beta$ **decreases** outward: higher temperatures do not compensate for lower abundance

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 H₂O 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.

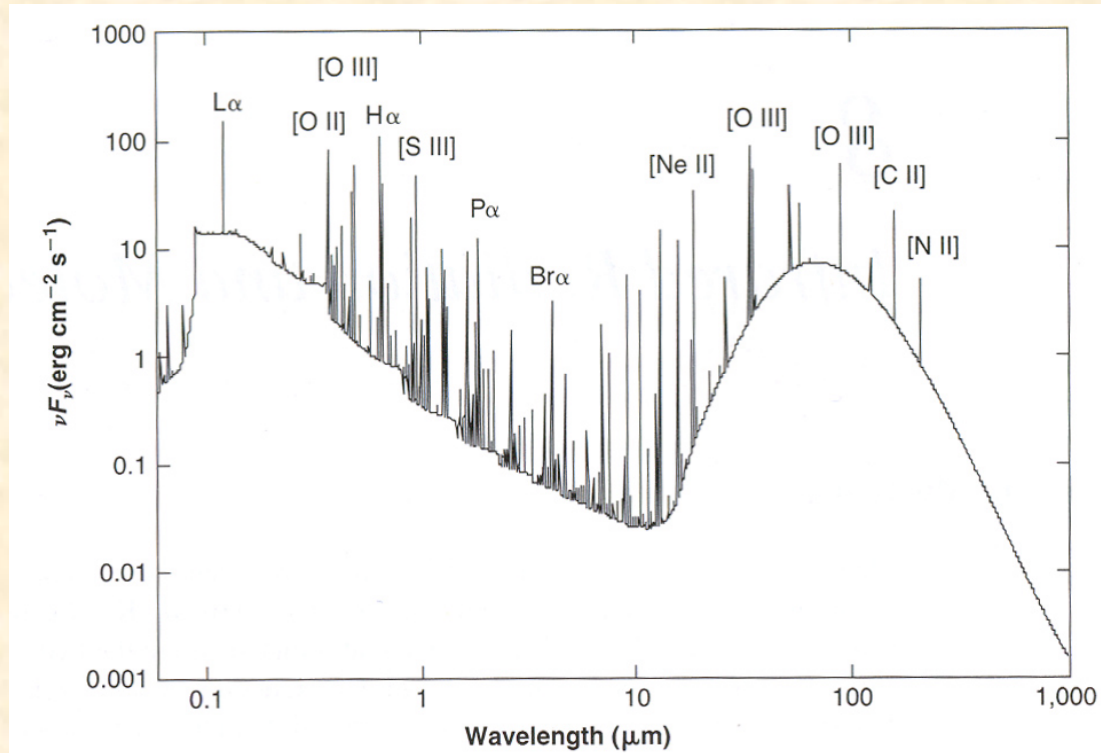
H II Regions and Induced Star Formation



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

Photodissociation Regions (PDRs)

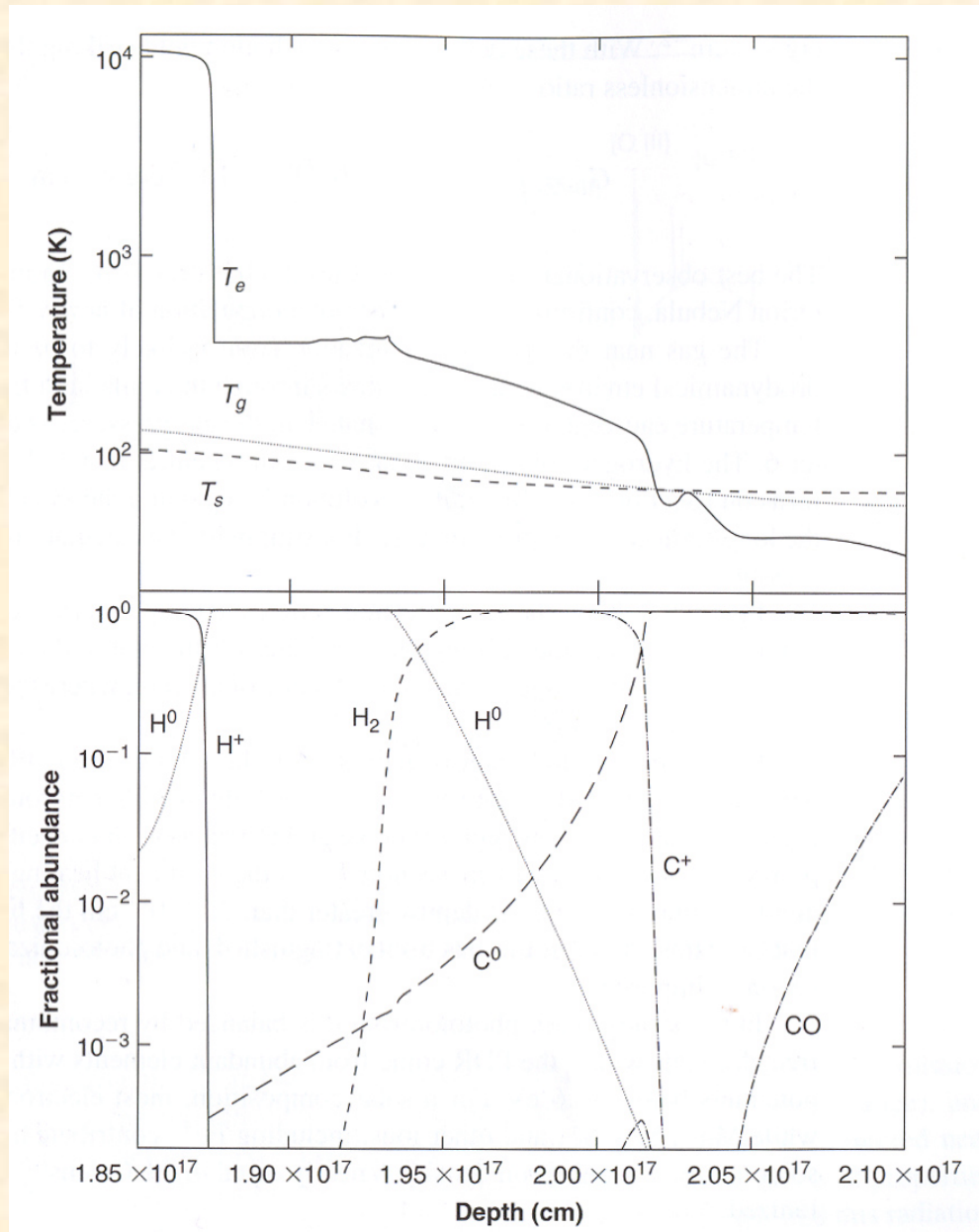
H II region flux transmitted into molecular cloud:



Osterbrock & Ferland, p. 208

- UV, optical, and IR radiation at $\lambda > 912 \text{ \AA}$ 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. $\text{C I} \rightarrow \text{C II}$)
- The transition region between H II region and molecular cloud is the PDR.

PDR Model



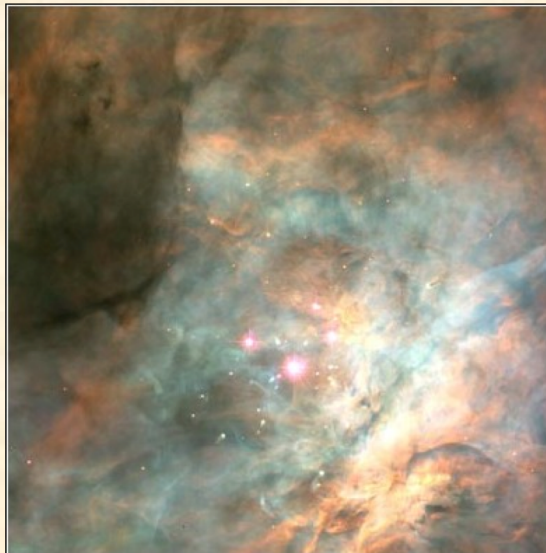
- Most of the heating at shallow depths is by photoionization of grains.
- At larger depths, heating is due to dust absorption.
- Cooling is by dust radiation and IR fine-structure lines.
- PAH's are excited by UV and optical radiation, and reradiate emission features in the mid-IR
→ Excellent tracers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

Orion Nebula (M42, NGC 1976)



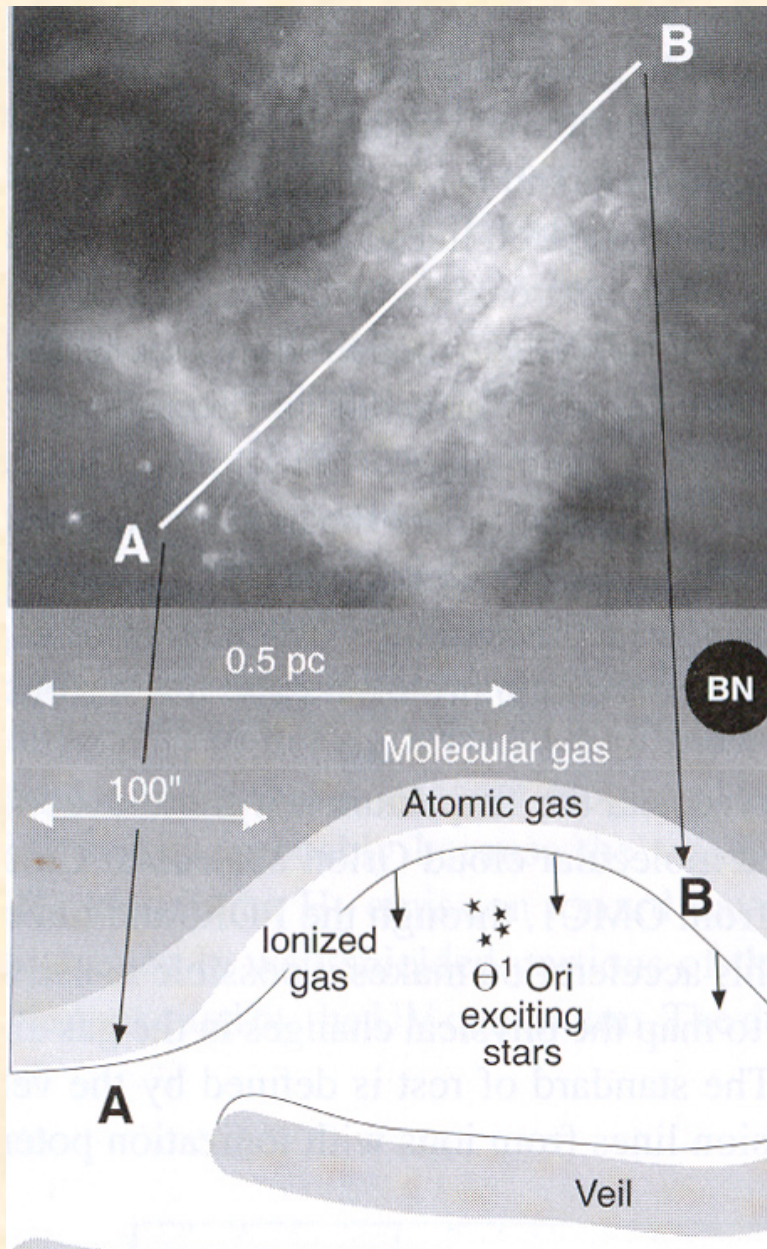
Huygens Region

Trapezium
(optical)



Trapezium
(IR)

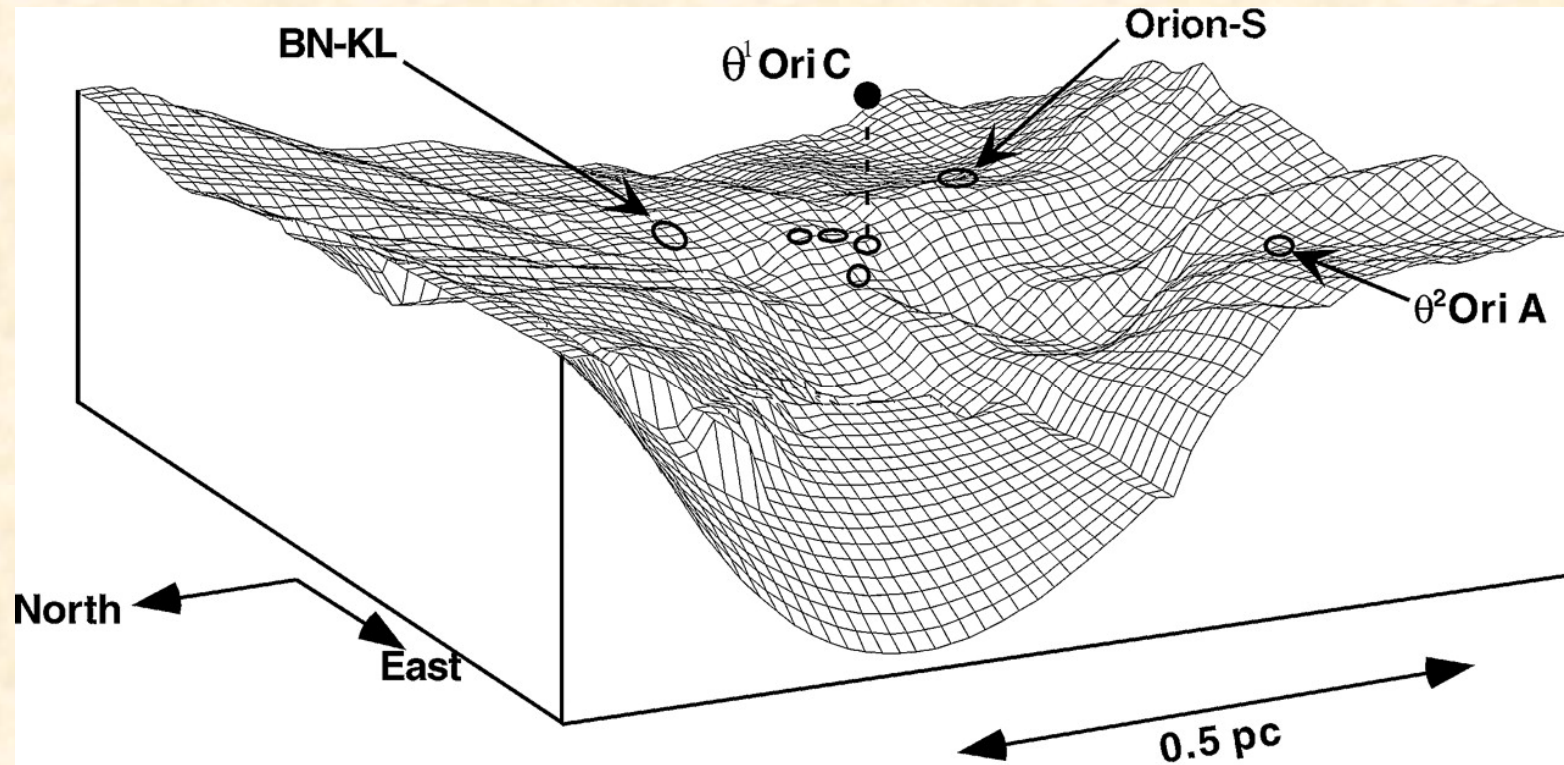
Structure of the Orion Nebula



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

