Lecture 18

The Material Between the Stars

Outline of Lecture 18

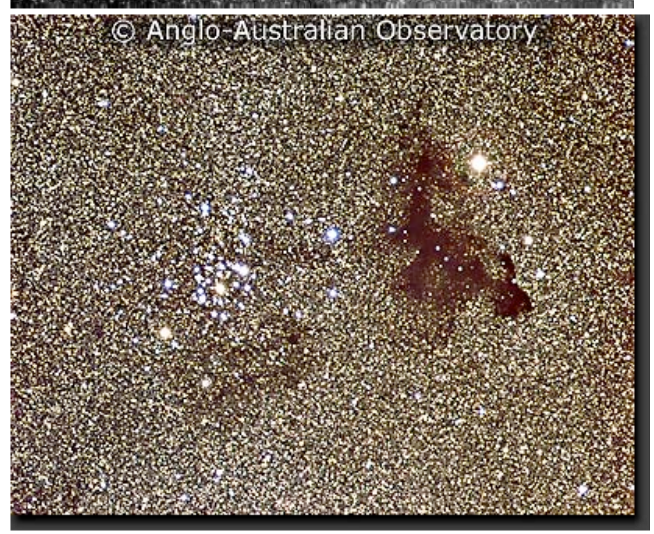
- Interstellar *dust* causes *extinction and reddening* of optical light from background stars, as well as *reflection nebulae* around embedded or nearby stars;
- Interstellar *gas* is observed in optical, infrared, and radio radiation as *emission nebulae*, with the emission arising from *thermal processes* in ionized nebulae (*H II regions*) and *planetary nebulae*.
- In *supernova remnants*, emission in X-rays can arise from very hot shocked gas ($T > 10^6$ K), or from the *nonthermal process* of *synchrotron radiation* of *relativistic electrons* gyrating wildly in *magnetic fields*.

Why Interstellar Medium is Interesting

- ISM is not empty; it contains
  - small solid particles = dust grains,
  - gas, atomic and molecular, as well as plasma,
  - relativistic particles = cosmic rays,
  - magnetic fields.
- ISM is kept active by interactions with stars:
  - Luminous stars provide continuous source of energy in form of starlight, especially UV light.
  - Dying stars provide source of processed matter as well as input of kinetic energy.
  - ISM provides the cradles of star birth, supplying the raw material for new generations of stars and planets.
  - The last two processes provide the explanation for the differences between Population I and Population II stars.

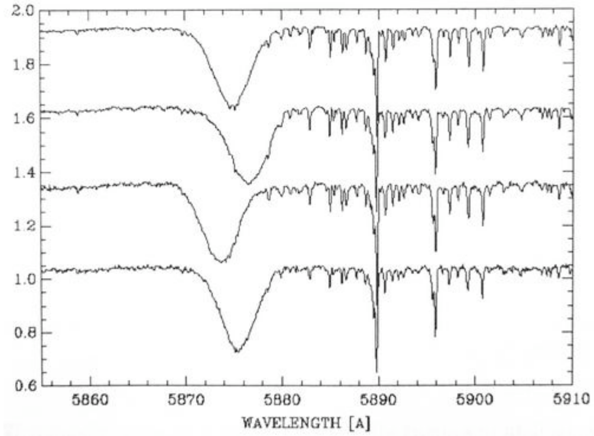
Herschel's "Holes in the Sky"

- In 1785, Sir William Herschel (1738-1822), a professional musician and astronomer, the discoverer of Uranus, aided by his sister, Caroline, discovers what he thought were "holes" in rich star fields.
- Caroline later urges his son, John, to study this strange phenomenon.
- It later becomes apparent that rather than holes (which would be quickly filled in by random motions of the stars), the true explanation must lie in foreground obscuration.

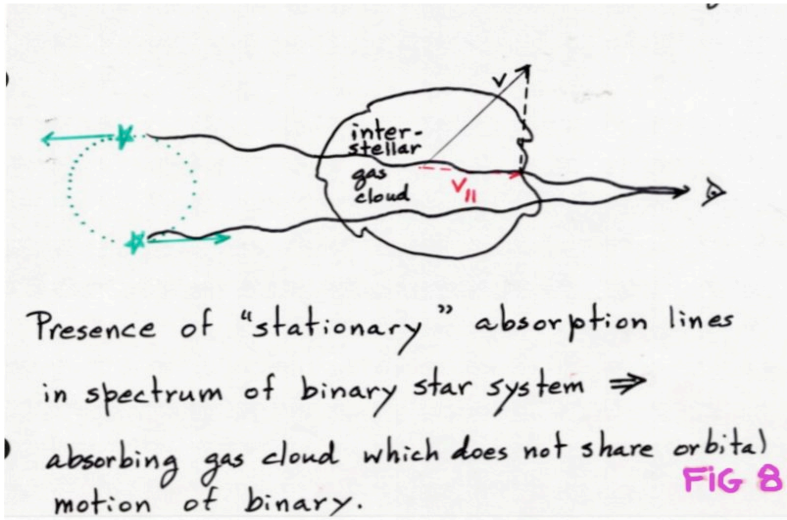


Discovery of Interstellar Gas by Johann Hartmann (1865-1936)

- The fourth brightest star in Orion, δ Orionis, is actually a binary.
- In addition to the broad absorption lines that move by the Doppler effect with the binary orbit, there are narrow, "stationary," absorption lines.
- Conclude that there must be cool gas between us and the stars.
- There is not enough gas, however, to cause the obscuration associated with Herschel's "holes in the sky."

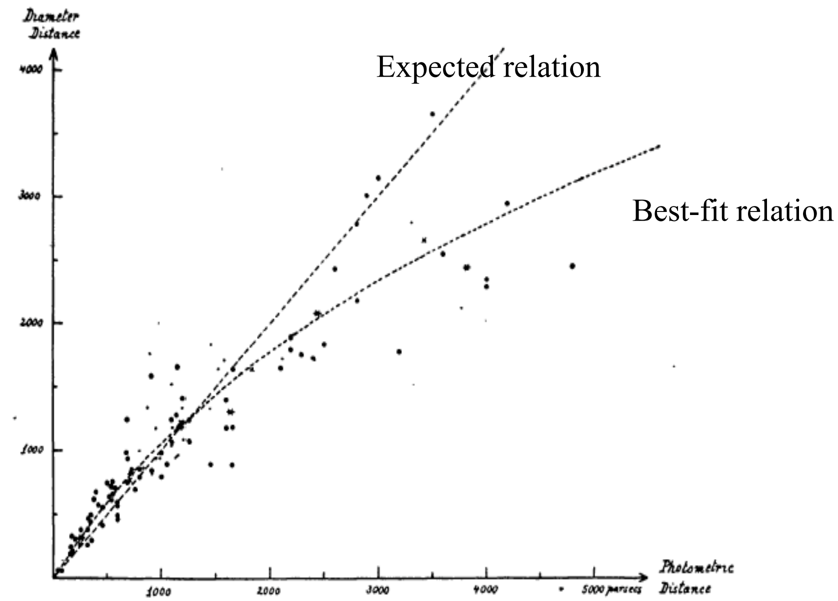


Guenther (2000) as cited by H. Zinnecker



Discovery of Interstellar Dust by Robert J. Trumpler (1886-1956)

- Working at Lick Observatory, Trumpler studies H-R diagram of open star clusters (Lecture 17).
- He notices something peculiar about the apparent brightness *f* and the angular diameter θ of the clusters.
- If he defines a photometric distance by $r = (L/4\pi f)^{1/2}$, and a diameter distance by $r = (D/\theta)$, then he expects the two distances to be equal on average, assuming that open clusters have on average similar diameters *D* and the same luminosity *L* of stars on the main-sequence (for the same effective temperatures).
- Instead, Trumpler finds the expected equality to hold for nearby clusters, but not for far ones.
- Either clusters must get smaller with distance from the Sun (to seem to yield too great a diameter distance), or they must be fainter than they should be for the actual (diameter) distance (because of foreground extinction).
- Unless, we are in a privileged position, the second interpretation must be the correct one.



Dimming per kpc (3260 lt-yr) is too much to be associated with interstellar gas. Must be due to interstellar dust, small particulates about the size of the wavelength of visible light. The latter interpretation, due originally to Pannokoek, is consistent with Trumpler's correlation of interstellar extinction with interstellar reddening.

Dark Clouds Seen Against Bright Background of Emission Nebula (H II Region)

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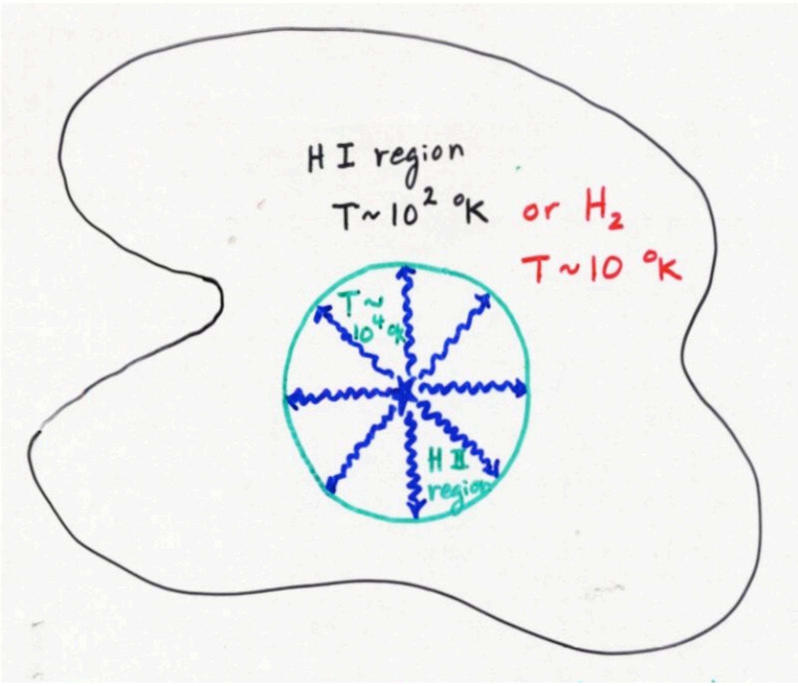
Analogy for Interstellar Reddening: Blue Sky and Reddening of Sun at Sunset & Sunrise

Reflected Starlight Looks Bluer Than Illuminating Stars

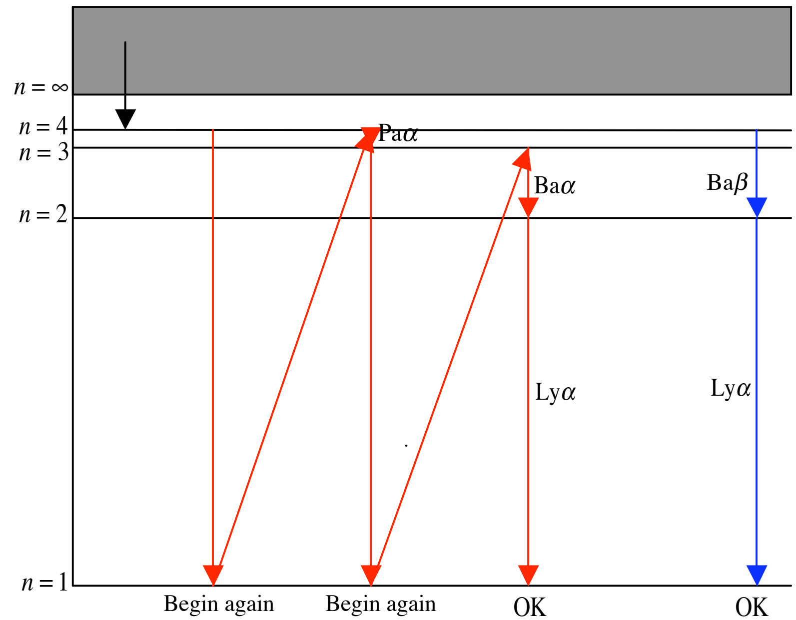
Hot Young Stars Ionize Surrounding Material, Producing Ionized Hydrogen (H II) Regions



Orion nebula in middle of sword of Orion.

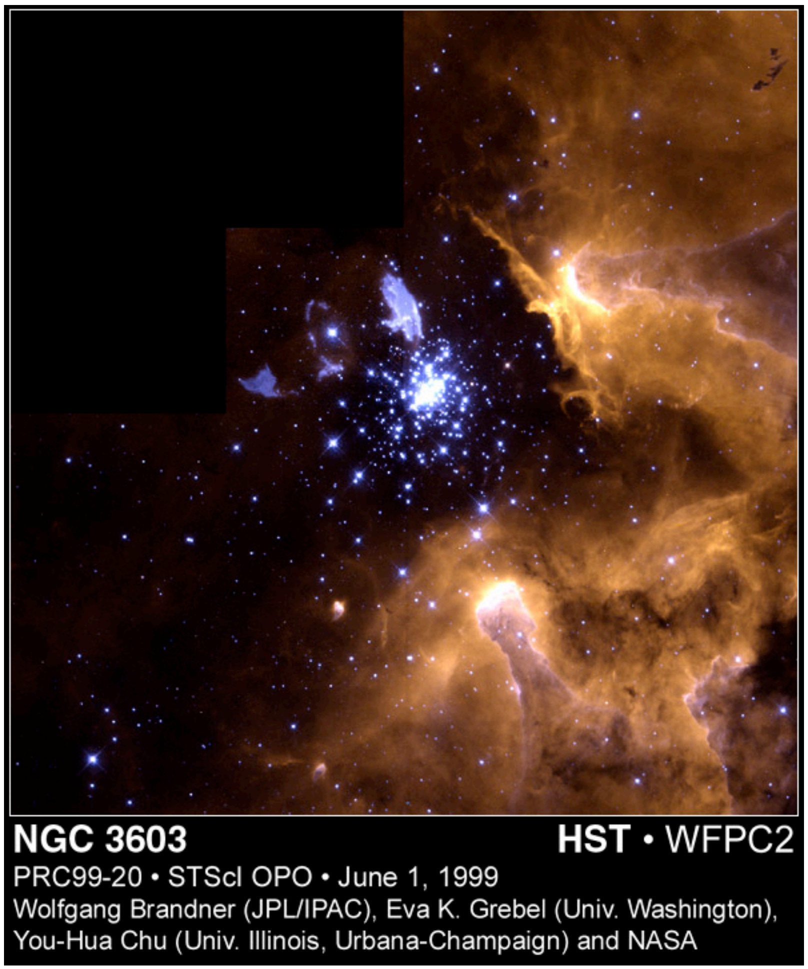
- Central star emits ultraviolet radiation, which the H II region degrades by fluorescence into visible and infrared radiation.

H II Regions Show Characteristic Red Light of Fluorescing H (extra material)



In interstellar space, most atoms, including recombining H, are in ground electronic state. This explains recombination cascade, where every ionizing ultraviolet photon is broken down into a Lyman alpha photon plus a Balmer photon plus other photons. The ample presence of Balmer alpha (Hα) photons gives H II regions their red hue in color photographs.

Star Clusters at Birth Are Closely Associated with Gas and Dust



Panorama showing interaction of gas, dust, and newly-born stars in the region of the Horsehead nebula.

Supernova Remnants Produce Both Thermal and Nonthermal Emission Nebulae

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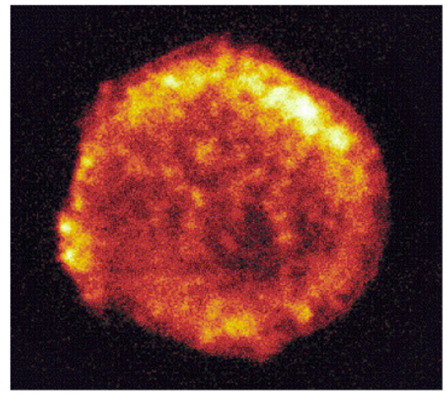

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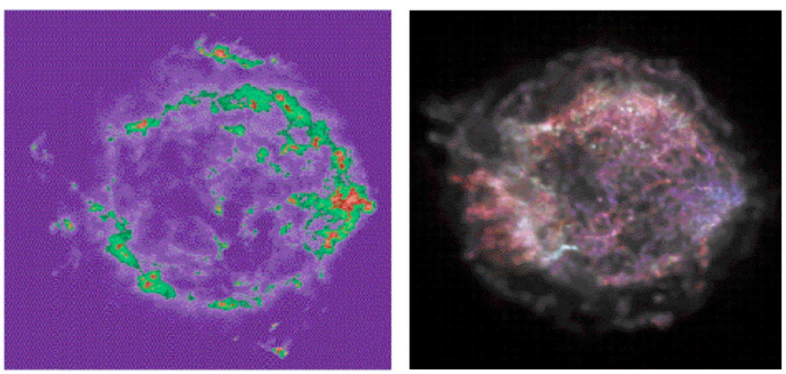

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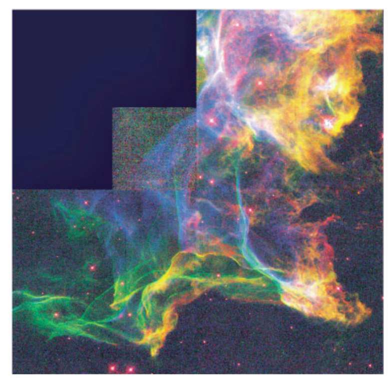

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Nonthermal Continuum Emission = Synchrotron Emission