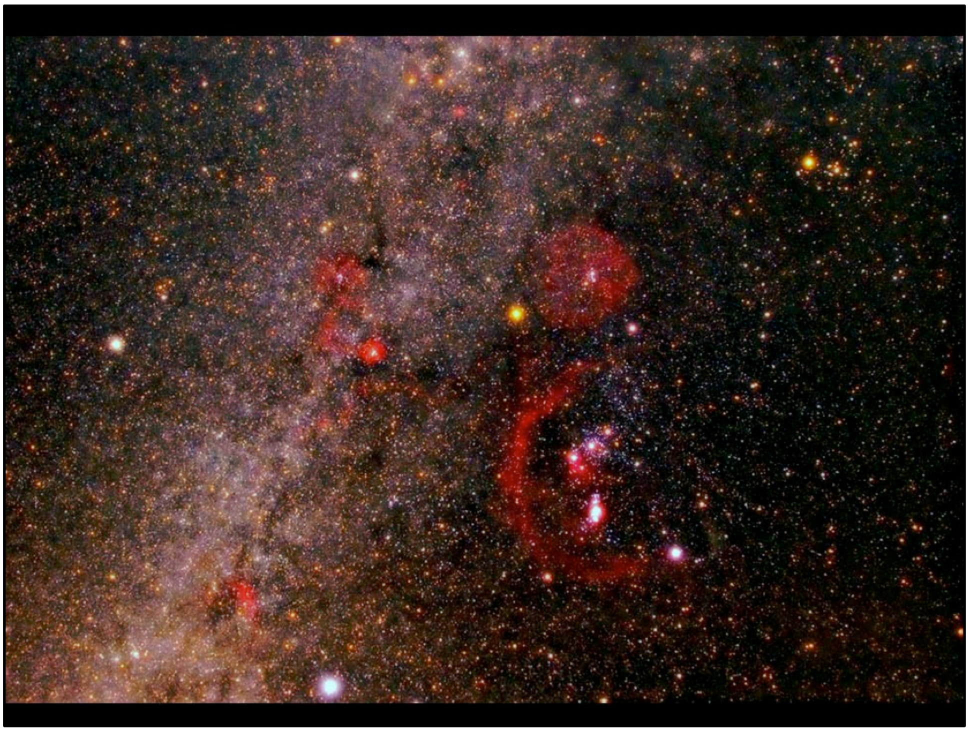
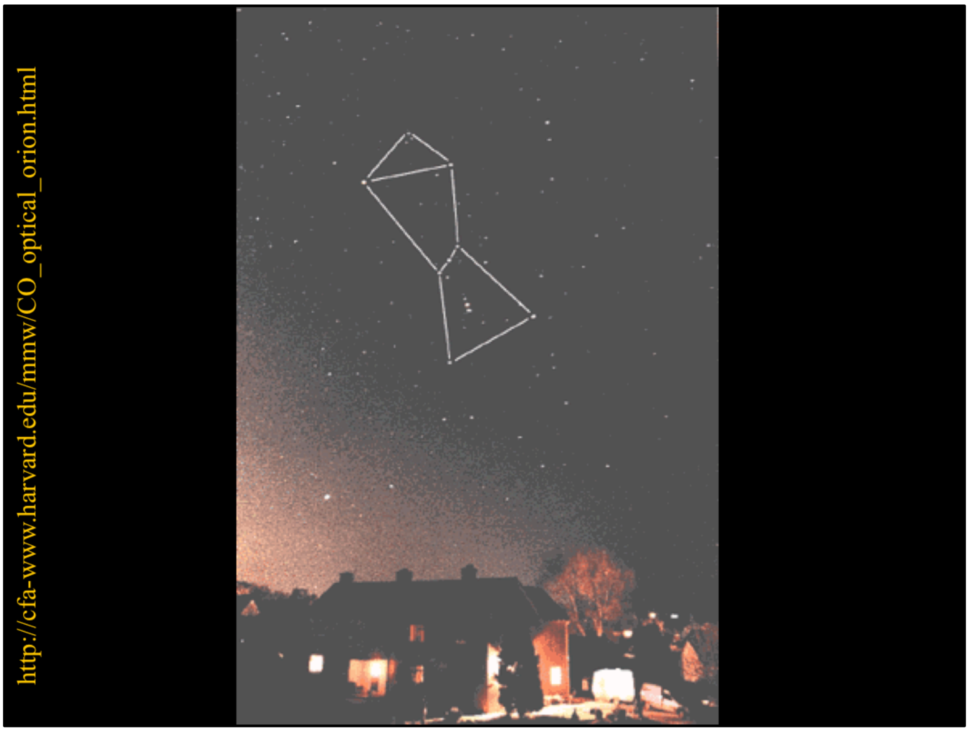
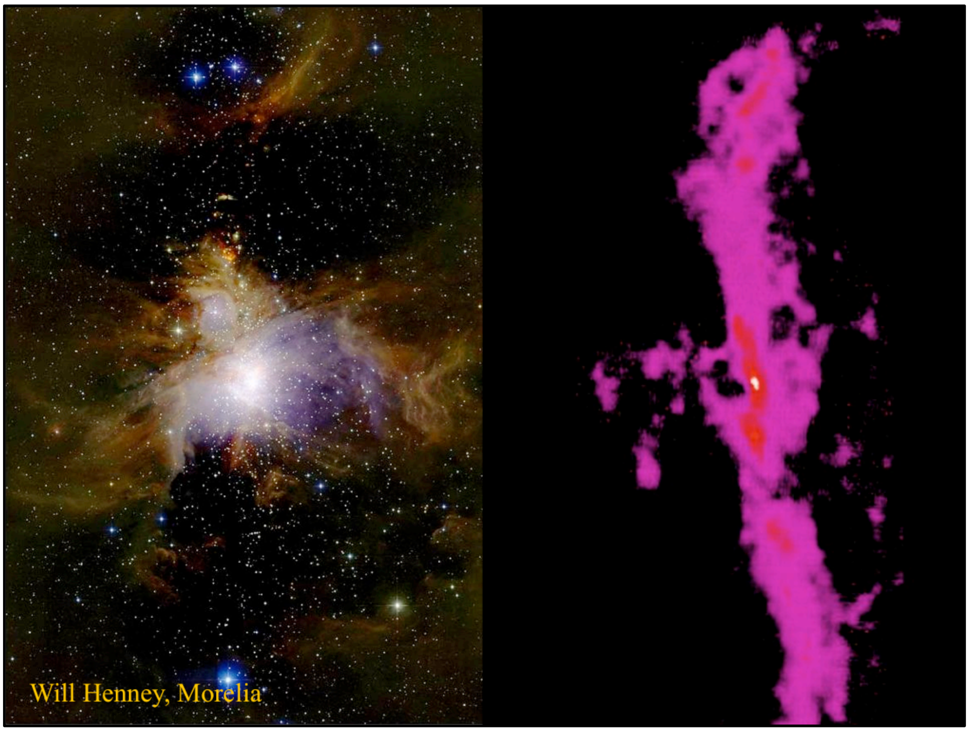

Cloudy summer school, 2012
Welcome!!

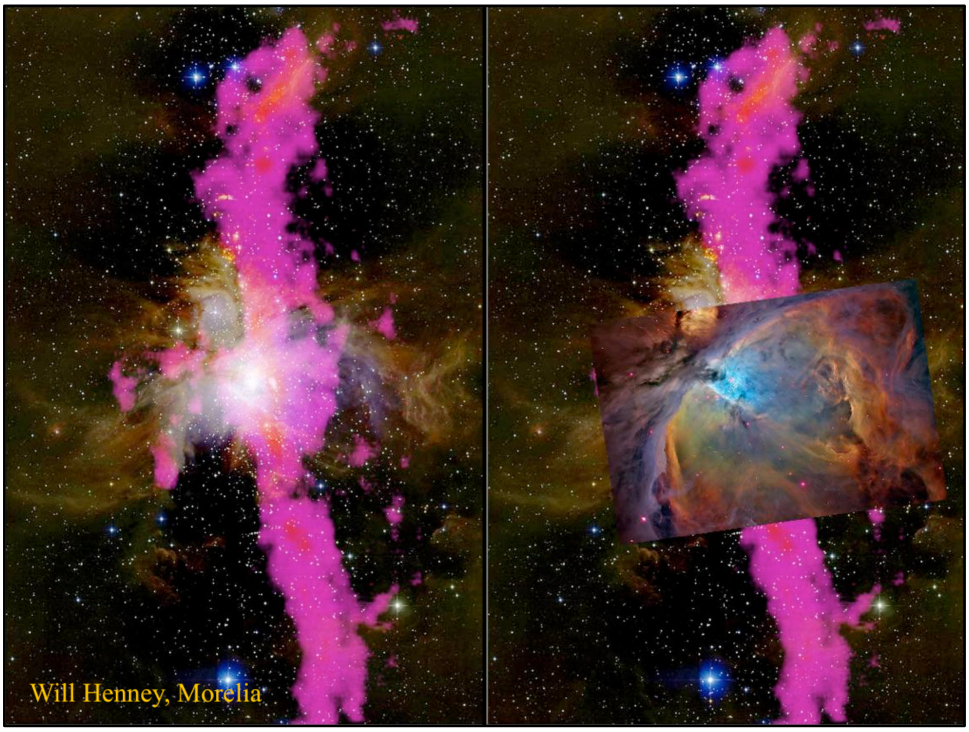


Active star formation – bernard’s loop – windblown bubble, stars forming within last 1e6 yrs old
Not in plane of milky way
Outline molecular clouds, total mass, actual associations about 500 pc away



Tom Dame


Will Henney, Morelia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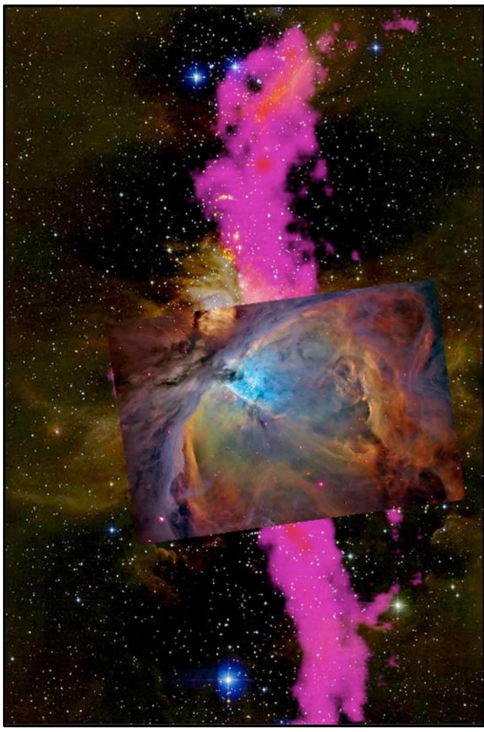
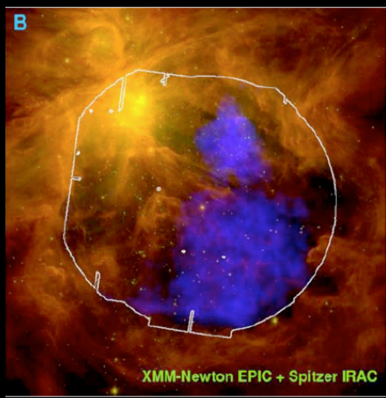
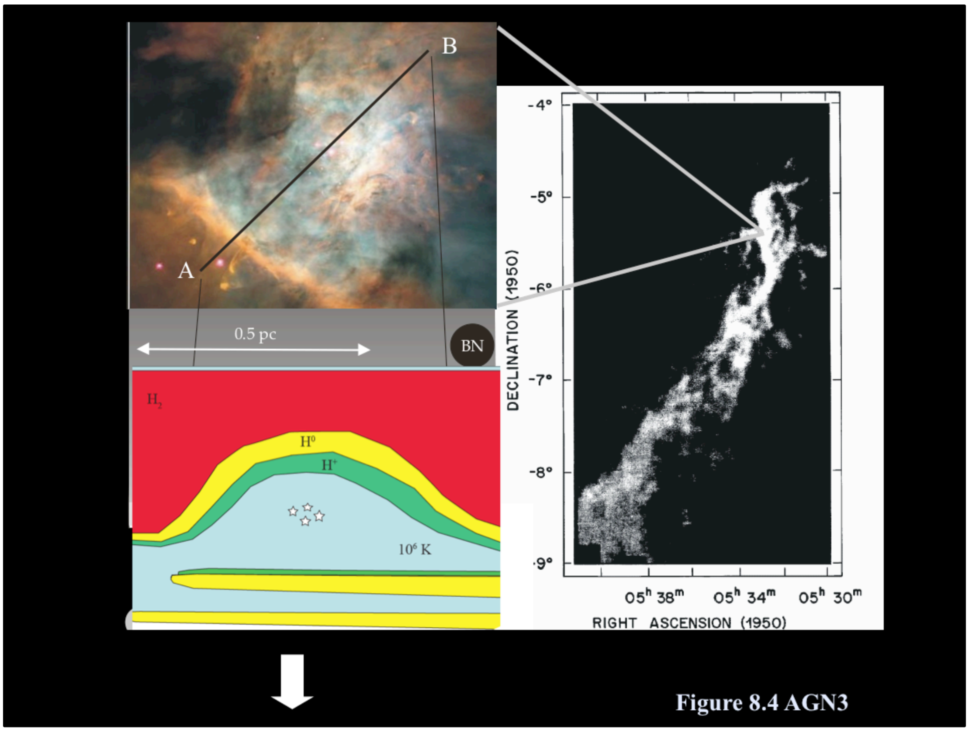
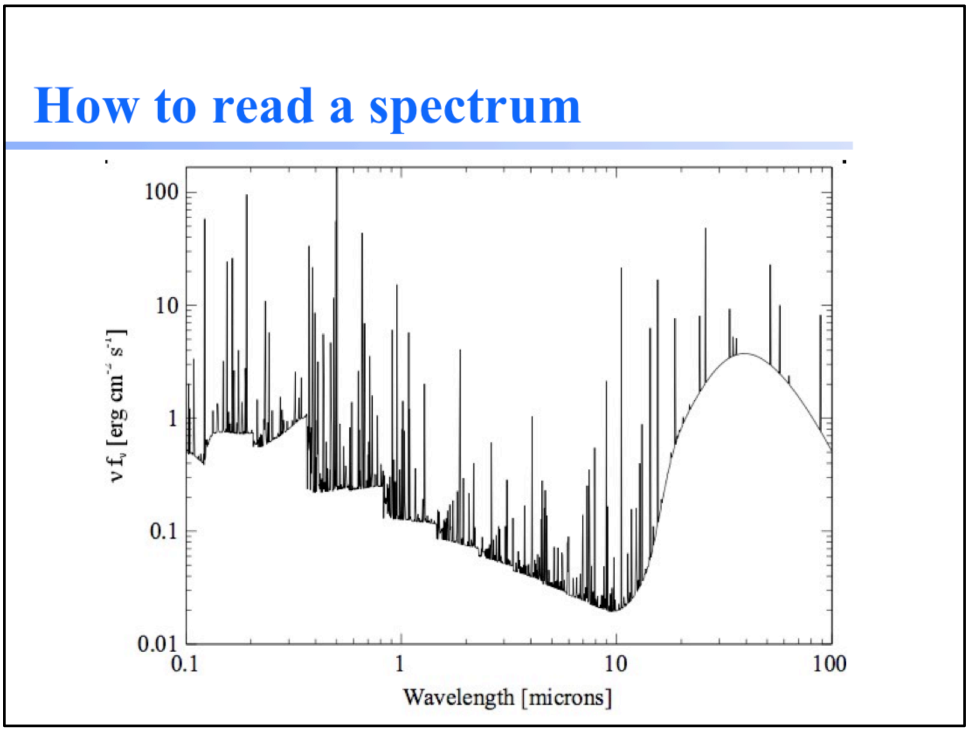




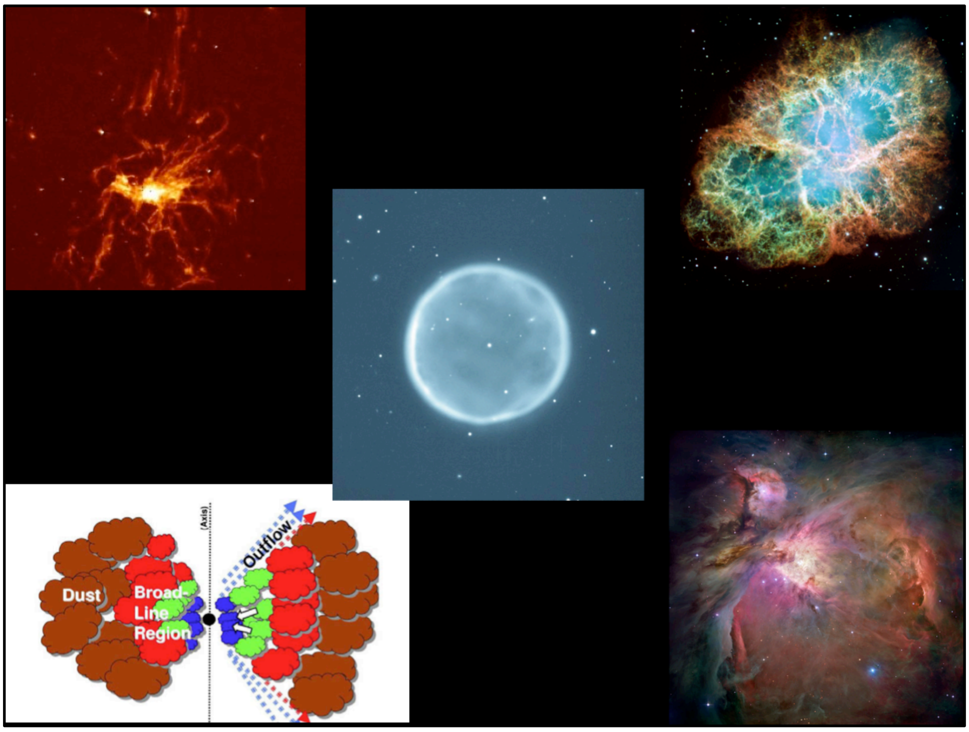
Guedel+ 2008 Science 319, 309



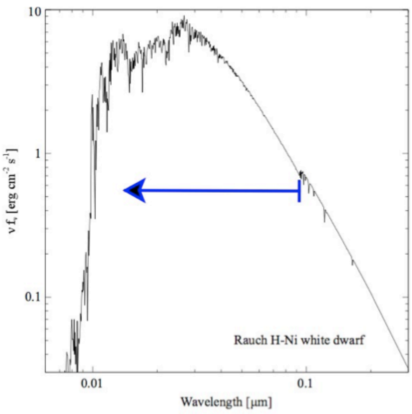
Geometry, extinction is in the veil – here emphasize the veil



Contains dust
Most gas is hydrogen
Temperature is around 1e4 K

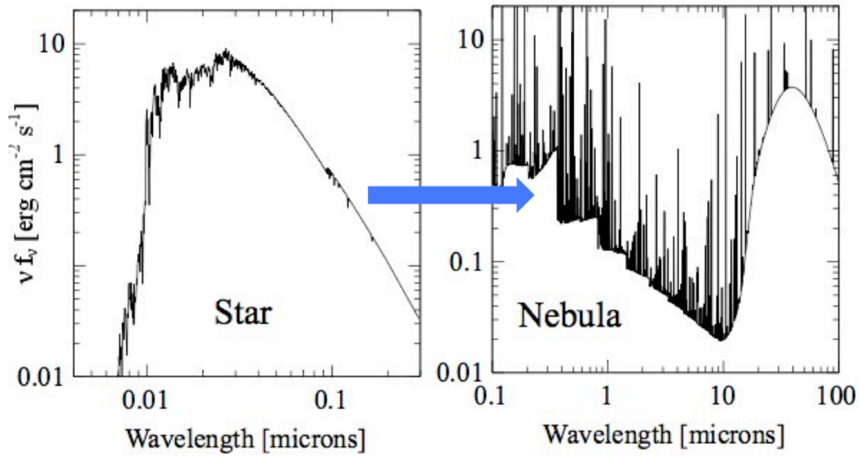

Dust
Broad-
Line
Region
(Axis)
Outflow

The primary mechanism



2012 Cloudy workshop

Energy is conserved



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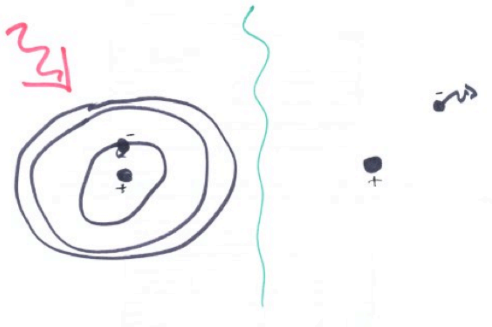
Some jargon – AGN3, Appendix 1

- **Mean intensity *J* (AGN3 eq A1.5)**
  - Mostly deal with $4\pi J$, [erg s^{-1} cm^{-2}]
- **Emissivity *j* (AGN3 Sec A1.7)**
  - Emission per unit volume, [erg s^{-1} cm^{-3}]
- **Luminosity L**
  - $L = 4\pi j \times$ Volume (if optically thin) [erg s^{-1}]
- **Opacity κ**
  - Absorption per unit length [cm^{-1}]
- **Optical depth τ**
  - $\kappa \times$ Length, with attenuation $\exp(-\tau)$

More jargon – H I vs H^0

- H^0 is atomic hydrogen, a proton and an electron, H^+ is its ion, H_2 its molecule
- H I is the spectrum emitted by H^0. H I is a collection of photons
- It is not correct to speak of the H I column density, although an H I absorption line does measure the H^0 column density
- In an ionized gas recombining H^+ also makes H I lines, so an H I emission line indicates the H^+ column density
- There is no such thing as H II

Photoionization AGN3 2.2



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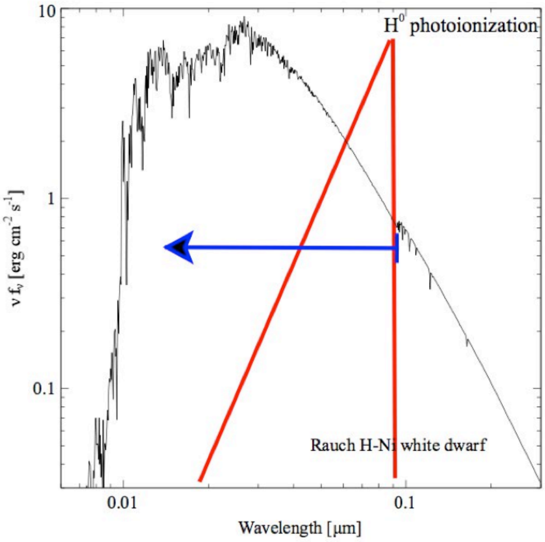
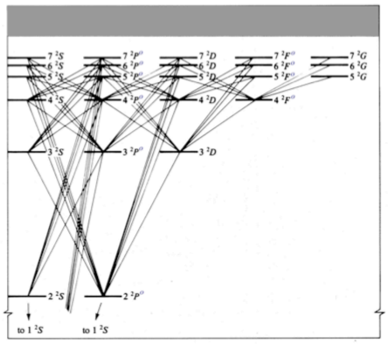
Photoionization



Recombination



Photoioization balance

- **AGN3 eq 2.1**

$$\text{recombination} = \text{ionization}$$

$$n_e n_p \alpha_B(T) = n(H^0) \int_{\nu_0}^{\infty} \frac{4\pi J_\nu}{h\nu} a_\nu d\nu = n(H^0)\varphi(H)\bar{a}[\text{cm}^{-3}\text{s}^{-1}],$$

Number of ionizing photons

- **Total emitted into 4π**

5.14 Q(H) = 56.789 [range...]

This is the log of the total number of ionizing photons emitted by the central object [s^{-1}]

$$Q(\mathrm{H}) = 4\pi R_{star}^2 \int_{\nu_1}^{\nu_2} \frac{\pi F_\nu}{h\nu} d\nu. \tag{5.7}$$

The default energy range is 1 Ryd to 7.354×10^6 Ryd and the **range** option can be used to change the energy bounds ν_1 and ν_2. The photon flux (the number of photons per unit area of cloud surface) can be specified with the **phi(H)** command[3].

- **Photons per sq cm**

5.13 phi(H) = 12.867 [range...]

This command specifies the log of $\Phi(\mathrm{H})$, the surface flux of hydrogen-ionizing photons [$\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$] striking the illuminated face of the cloud. It is defined as

$$\Phi(\mathrm{H}) \equiv \frac{Q(\mathrm{H})}{4\pi r_0^2} = \frac{R_{star}^2}{r_0^2} \int_{\nu_1}^{\nu_2} \frac{\pi F_\nu}{h\nu} d\nu [\mathrm{cm}^{-2}\ \mathrm{s}^{-1}] \tag{5.6}$$

and is proportional to the optical depth in excited lines, such as the Balmer lines (Ferland et al., 1979; AGN3). The range option can be used to change the default energy range, given by the values of ν_1 and ν_2.

Photoionization balance

- Photoionization rate set by radiation field, not related to temperature
- Recombination depends on temperature, $\alpha \sim T^{-1}$
  - Tables in Ch 2, Appendix 5; discussed in Appendix 4

Photoionization balance

- **AGN3 eq 2.1**

$$\varphi(H)\, n(H^0) \langle \sigma \rangle = n_p n_p \alpha$$

$$\frac{n_p}{n(H^0)} = \frac{\varphi(H)}{n_e} \frac{\langle \sigma \rangle}{\alpha}$$

$$\langle \sigma \rangle \sim 10^{-18}\ \mathrm{cm}^{-2}$$

$$\langle \sigma \rangle \sim 10^{-13}\ \mathrm{cm}^{3}\ \mathrm{s}^{-1}$$

Ionization parameter

- **AGN eq 14.7**

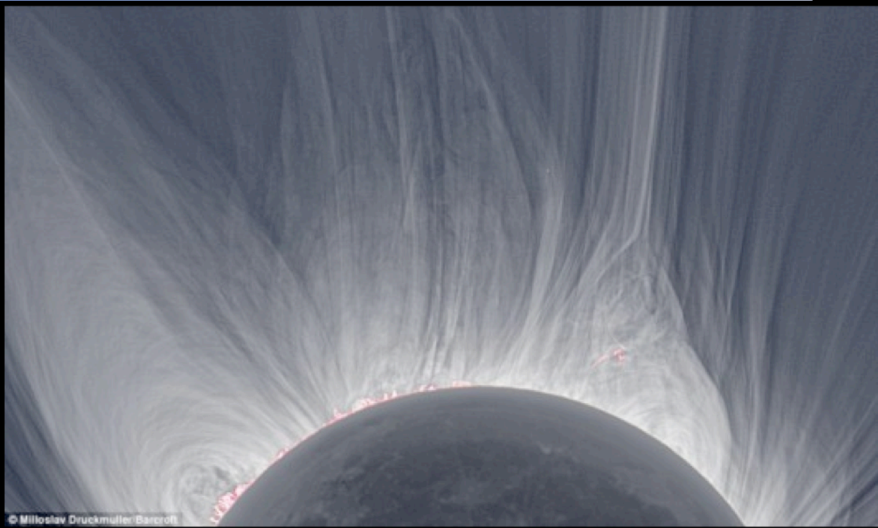
5.8 ionization parameter = −1.984

The ionization parameter is the dimensionless ratio of hydrogen-ionizing photon to total-hydrogen densities. It is defined as

$$U \equiv \frac{Q(\mathrm{H})}{4\pi r_0^2 n(\mathrm{H})\, c} \equiv \frac{\Phi(\mathrm{H})}{n(\mathrm{H})\, c} \tag{5.4}$$

(AGN3, equation 14.7, page 357). Here r_o is the separation [cm] between the center of the source of ionizing radiation and the illuminated face of the cloud, $n(\mathrm{H})$ [cm^{-3}] is the total[1] hydrogen density (ionized, neutral, and molecular), c is the speed of light, $Q(\mathrm{H})$ [s^{-1}] is the number of hydrogen-ionizing photons emitted by the central object, and $\Phi(\mathrm{H})$ [$\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$] is the surface flux of ionizing photons. The number is interpreted as the log of U unless the keyword **linear** appears. The ionization parameter is a useful quantity in plane-parallel, low-density, constant-density, models, because of homology relations between models with different photon and gas densities but the same ionization parameter (see Davidson, 1977).

Coronal equilibrium



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Coronal (Collisional) ionization

- q_{ion} – **collisional ionization rate coefficient**
- **Rate set by gas temperature & ionization potential of a species**
  - Radiation field does not matter
- **AGN3 eq 12.6, 12.7**

$$n(H^0)\, n_e\, q_{ion} = n_p\, n_e\, \alpha$$

$$q_{ion} \sim K \exp(-T_{ion}/T_{gas})$$