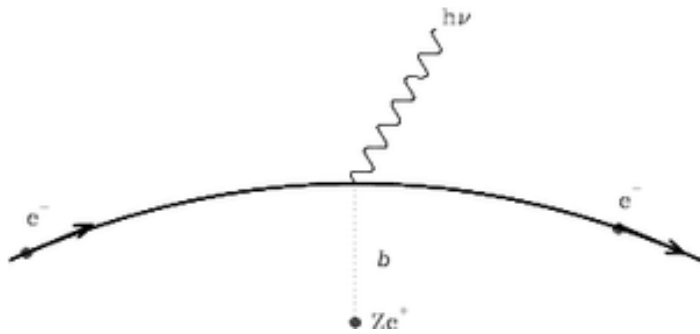
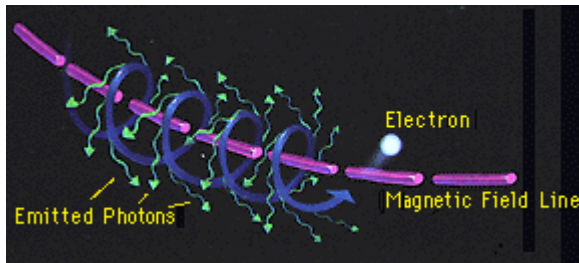
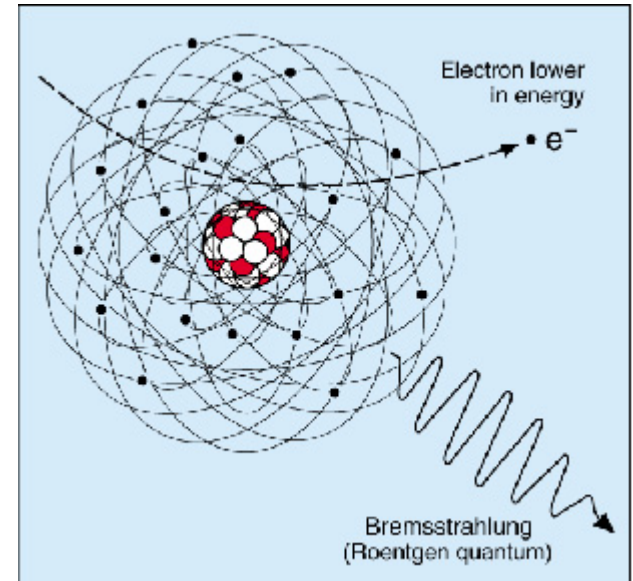


Thermal Emission

Hot, low-density plasma (e.g., HII regions, PNe, SNRs)
→ thermal radio emission



<http://www.astro.utu.fi/~cflynn/>



c.f.
Synchrotron
Radiation



Emission lines $\rightarrow T_e \sim 10^4$ K, so in radio wavelengths

$$h\nu \ll kT \text{ and } B_\nu \approx \frac{2kT\nu^2}{c^2}$$

$$\text{f-f emission } j_\nu \approx \frac{n_e n_i}{T_e^{1/2}} \longrightarrow \kappa_\nu = j_\nu / B_\nu \approx \frac{n_e n_i}{T_e^{3/2} \nu^2}$$

Emission Spectrum

$$j_\nu^{ff} = 6.8 \times 10^{-38} Z^2 n_e n_i T^{-1/2} e^{-h\nu/kT} \bar{g}_{ff} \text{ ergs s}^{-1} \text{ cm}^{-3} \text{ Hz}^{-1}$$

Where \bar{g}_{ff} : velocity averaged Gaunt factor ~ 1

$$\text{Total Emission Power (Volume Emissivity)} = \int j_\nu^{ff} d\nu$$

$$j^{ff} = 1.4 \times 10^{-27} Z^2 n_e n_i T^{-1/2} \bar{g}_B \text{ ergs s}^{-1} \text{ cm}^{-3}$$

Where \bar{g}_B : frequency average of the velocity averaged Gaunt factor $\sim 1.1-1.5$

Considering the Gaunt factor, $G \sim \ln(T/\nu)$

$$\tau = \int \kappa_\nu ds = \frac{8.235 \times 10^{-2}}{T_e^{1.35} \nu^{2.1}} \text{ EM}$$

where $\text{EM} = \int n_e n_i ds$ [$\text{cm}^{-6} \text{ pc}$], ν in GHz

That is, low τ (long λ) \rightarrow

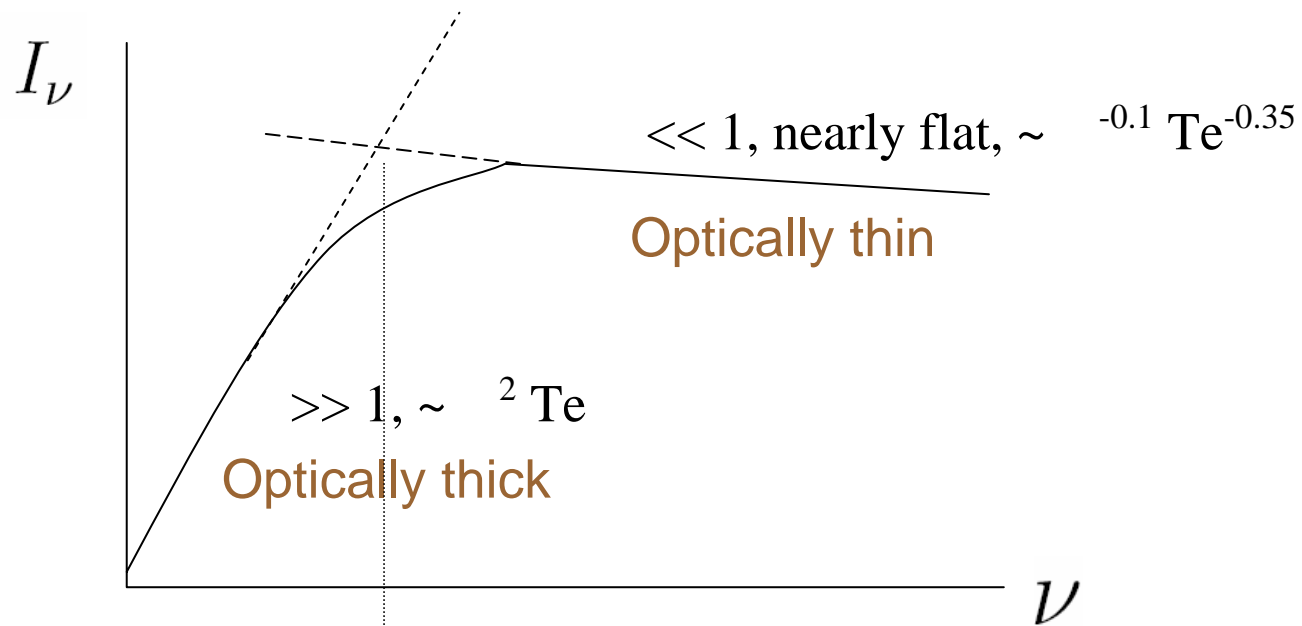
Plasma is transparent at high frequencies

At high freq. $\tau \ll 1$,

$$I_\nu = B_\nu \tau \propto \frac{2kT\nu^2}{c^2} \frac{\text{EM}}{T^{3/2}\nu^2} \propto \frac{\text{EM}}{T^{1/2}} \quad \leftarrow \times \rightarrow \nu$$

At low freq. $\tau \gg 1$

$$I_\nu = B_\nu = \frac{2kT\nu^2}{c^2} \quad \text{Blackbody} \quad \leftarrow \times \rightarrow n_e$$



$$\tau = 1, \text{ at } \nu_{\text{critical}} = 0.3 \left(\frac{n_e^2 L}{T^{1.35}} \right) \text{ GHz}$$

Obs at $\gg 1 \rightarrow$ get $T \longleftrightarrow$ Obs at $\ll 1$
 \rightarrow Get n_e

Adv. of radio observations: less extinction; measures T directly at low freq.

In general, I or $S \sim \nu^{-\alpha}$, where α is the spectral index.

For H II regions, if optically thin $\alpha = 0$
 if optically thick $\alpha = +2$

For synchrotron radiation, $I \sim \nu^{-0.8}$ or $T_B \sim \nu^{-2.8}$



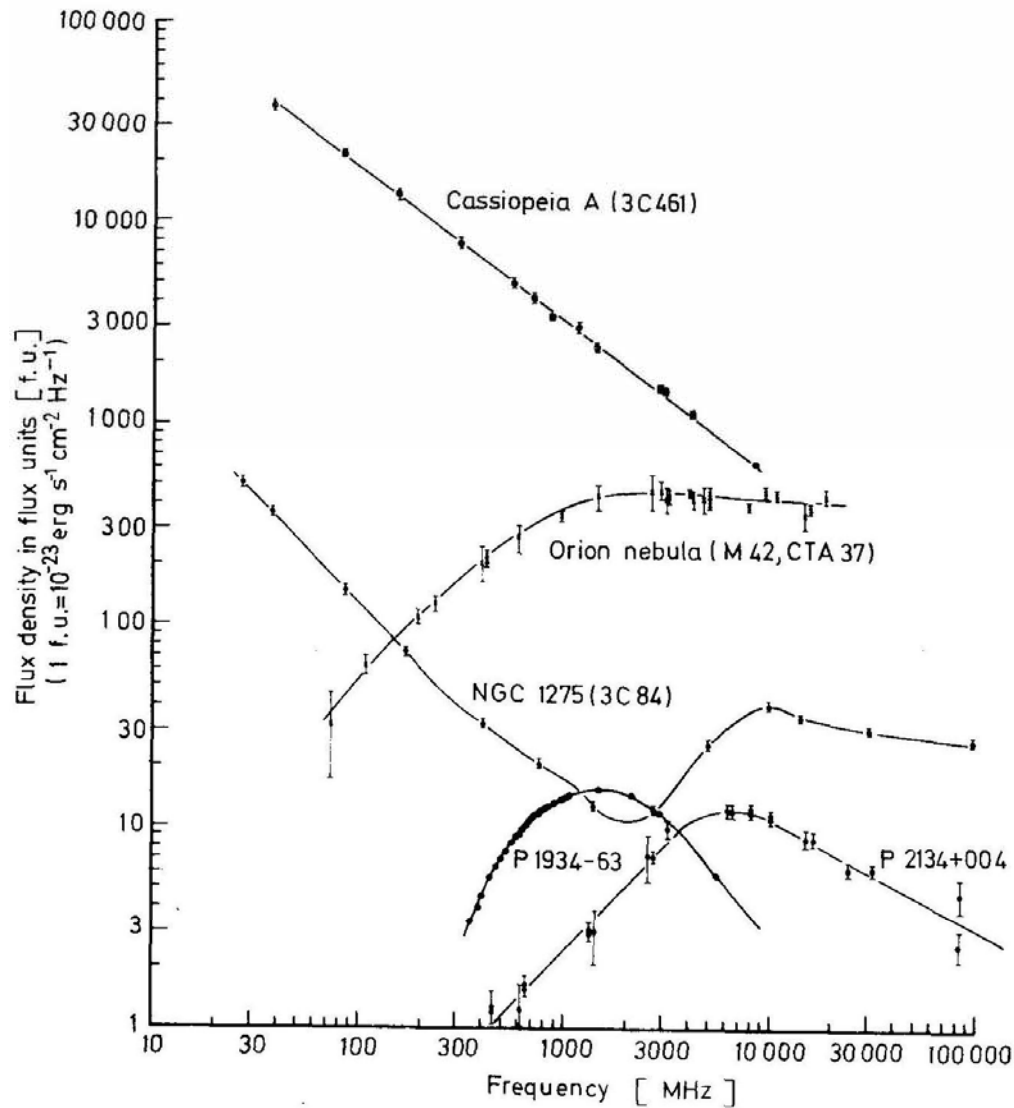
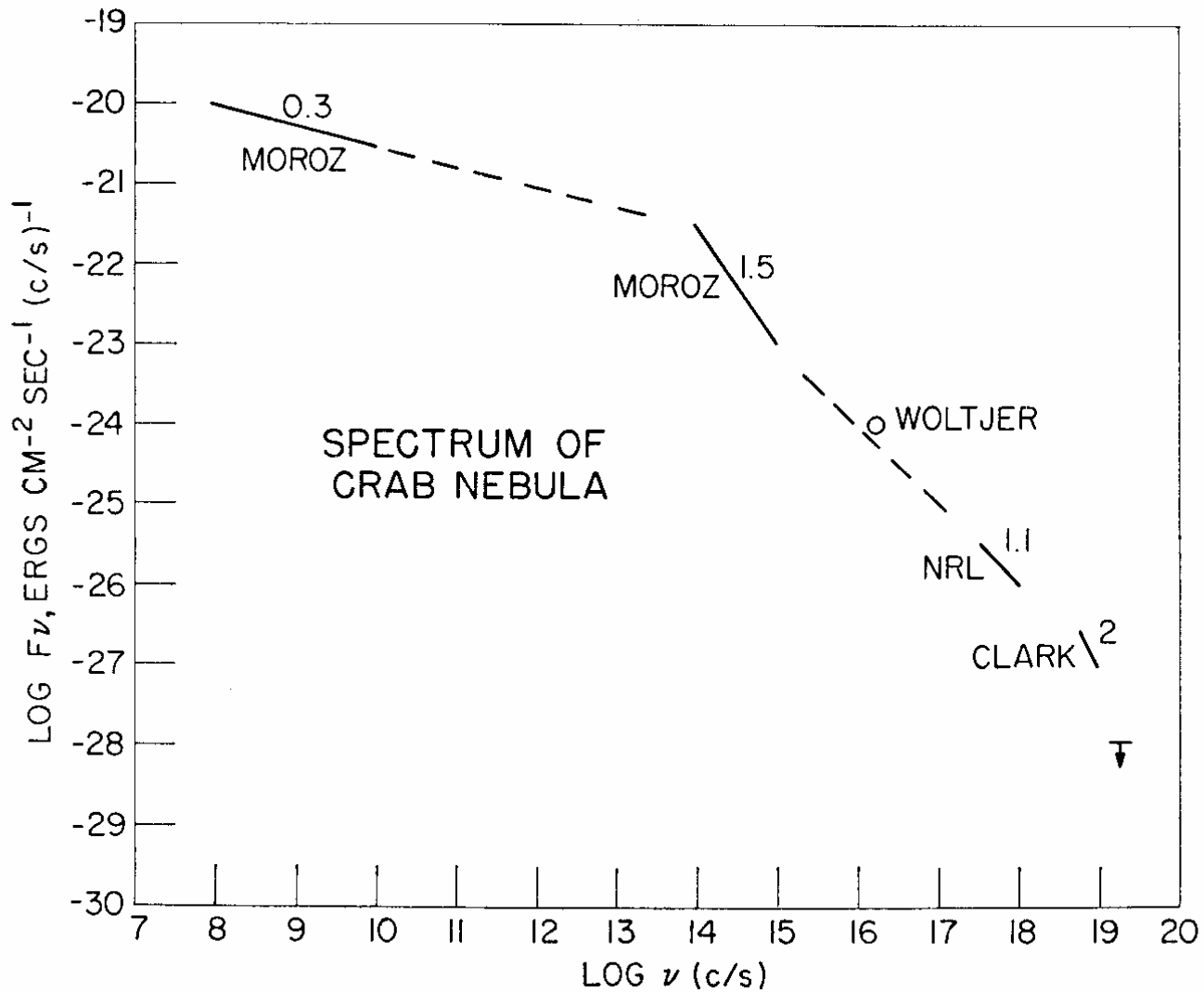
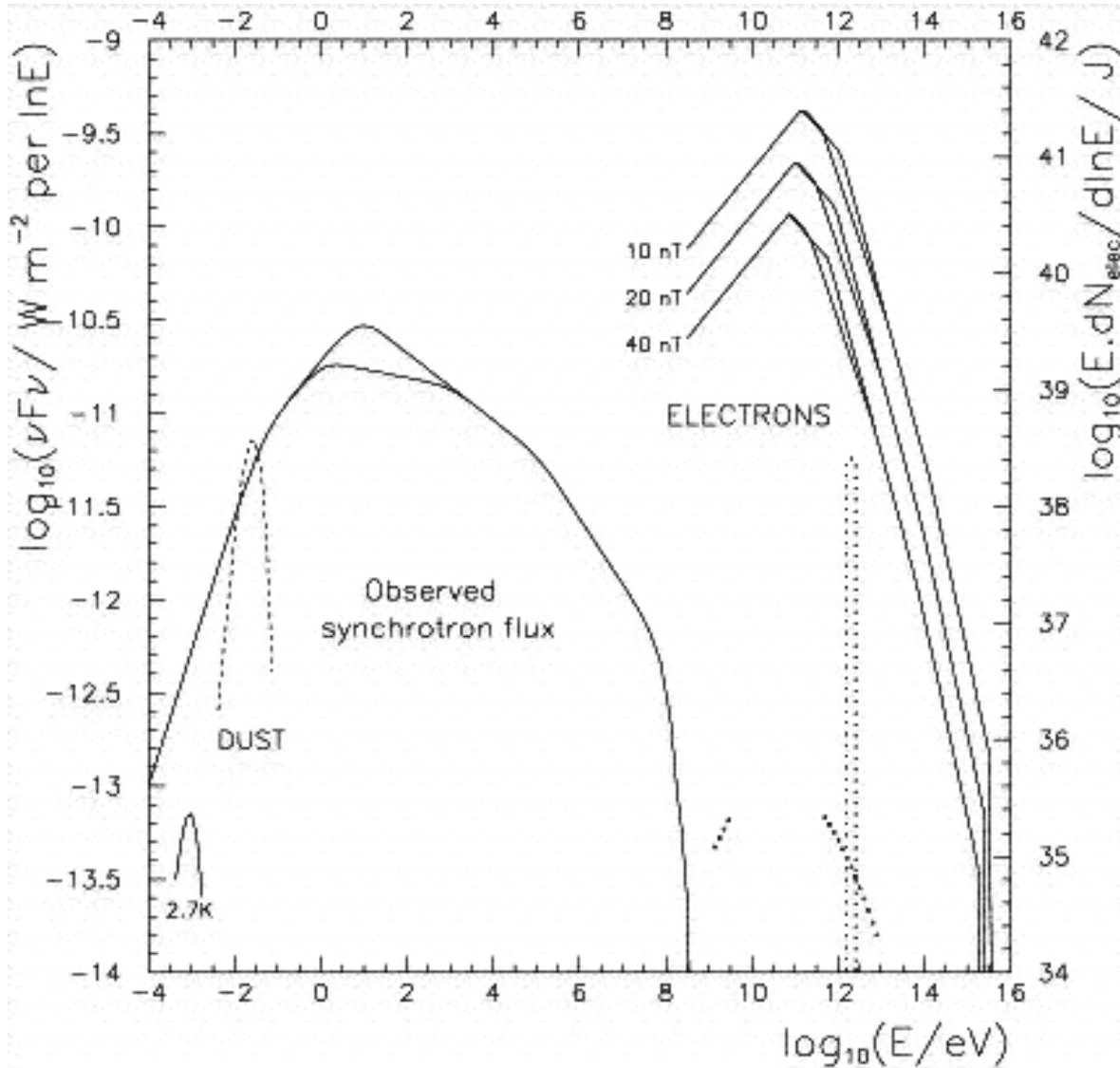


Fig. 4. Radiofrequency spectra of sources exhibiting the power law spectrum of synchrotron radiation (Cassiopeia A), the flat spectrum of thermal bremsstrahlung radiation with low frequency self absorption (Orion Nebula), unusual high frequency radiation (NGC 1275), and low frequency absorption processes (P 1934-63 and P 2134+004). The data for P 2134+004 are from E. K. CONKLIN, and the other data are from KELLERMANN (1966), HJELLMING, and CHURCHWELL (1969), TERZIAN and PARRISH (1970), KELLERMANN, PAULINY-TOTH, and WILLIAMS (1969), and KELLERMANN *et al.* (1971)

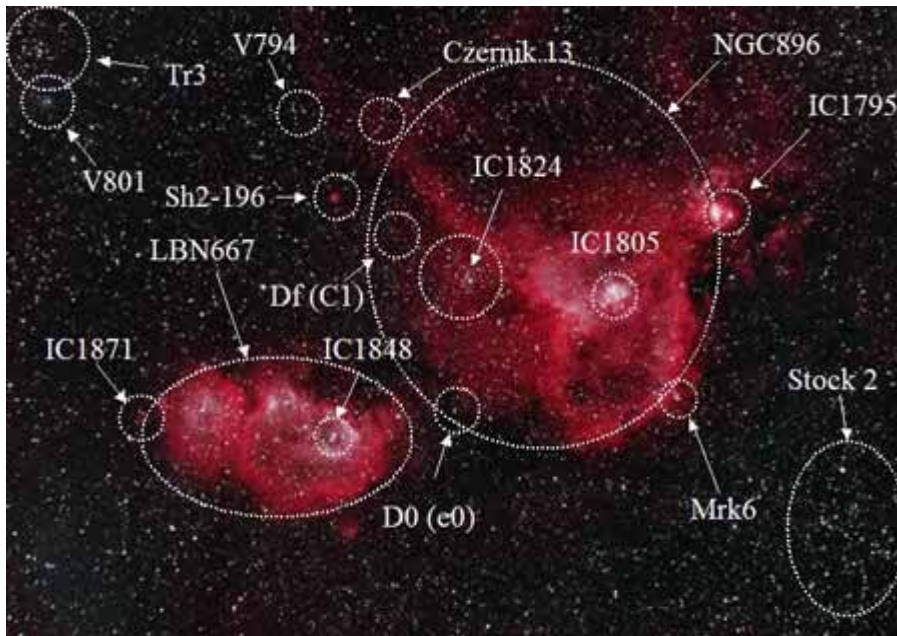


Spectrum of Crab Nebula from radio to X-ray wavelengths
(Middlehurst & Aller)



Spectrum of the Crab over a very wide range of energies. The emission is dominated by synchrotron radiation, and at very high energies (10¹⁰-12 eV) there may be an inverse-Compton component.
Source

Hillas (1998), ApJ, 503, 744



W3= IC 1795

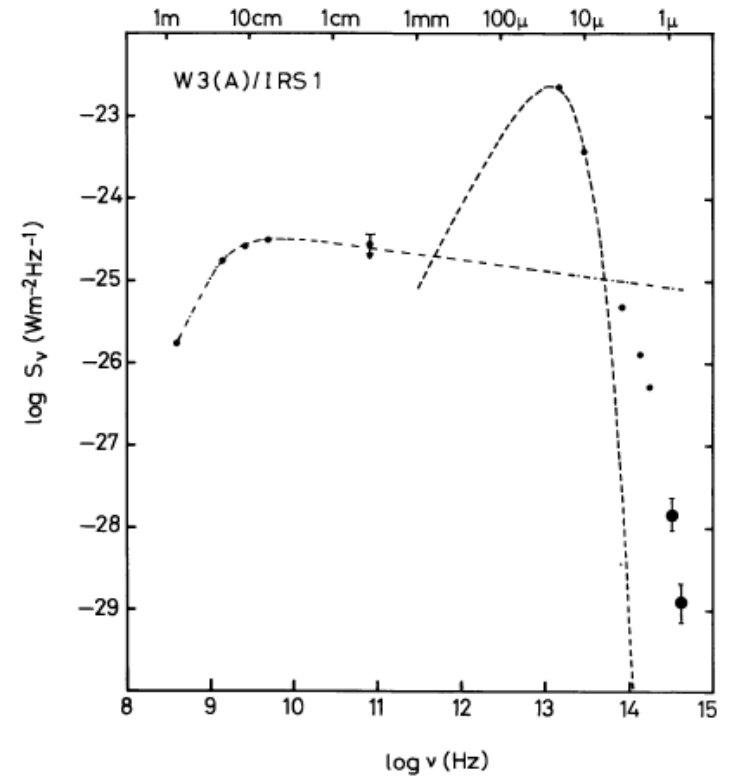


Fig. 2. Energy distribution of IRS 1 according to Wynn-Williams *et al.* (•) together with flux densities in *J* and *R* (●). Dashed lines: Predicted free-free emission from ionized hydrogen and thermal infrared radiation of dust, represented by Planck-curve with temperature $T = 200$ K

