INTERSTELLAR MEDIUM

- Stefano Bovino -

The interstellar radiation field

Energy sources in the ISM

- ISM is a semi-open medium: weak interaction with external world
- Its energy sources are mainly:
  - Stellar radiation
  - High-energy particles (CRs)
  - Mechanical energy from SNe
  - Stellar winds

Interaction matter-radiation

- Determines
  - the physical state of interstellar gas (phase transitions)
  - its chemical and ionization state (photochemistry)
  - its thermal state (photoelectrons)
  - re-radiation of energy at longer wavelengths (dust)
  - radiation pressure (dynamical effects)

Interstellar Radiation Field

- Galactic synchrotron radiation from relativistic electrons
- The cosmic microwave background radiation
- FIR and IR from dust grains heated by starlight
- Plasma emission (10^4 K) free-free, free-bound, and bound-bound
- Starlight
- X-ray emission from hot plasma (10^5 to 10^8 K)

$$u_\nu(\Omega) = \frac{1}{c} I_\nu$$

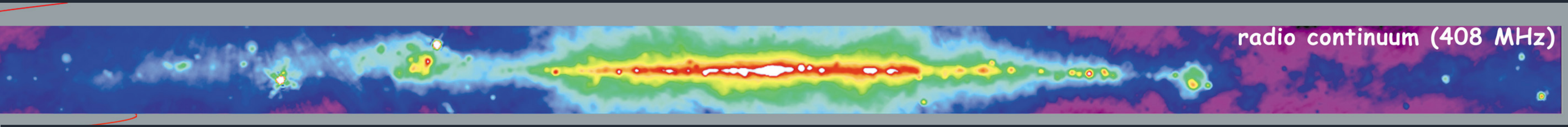
Energy density per solid angle
units [erg/cm^3/Hz/sr]

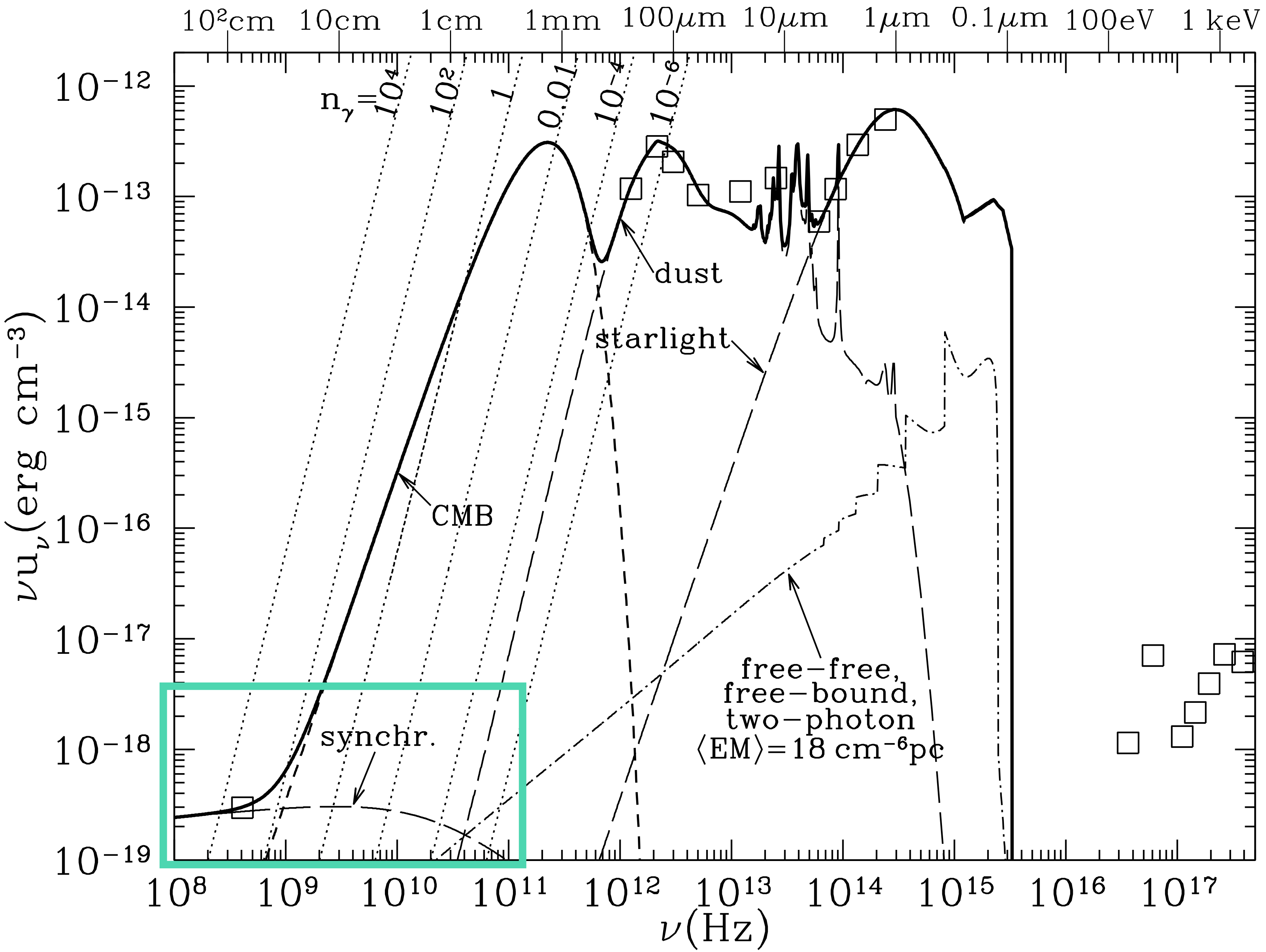
$$u_\nu = \frac{1}{c} \int I_\nu d\Omega$$

Energy density
units [erg/cm^3/Hz]

Galactic synchrotron radiation

- Relativistic electrons emit synchrotron radiation when deflected by magnetic field
- This dominates @ frequencies < 1 GHz
- Spatially variable: large near SNR
- Synchrotron radiation:

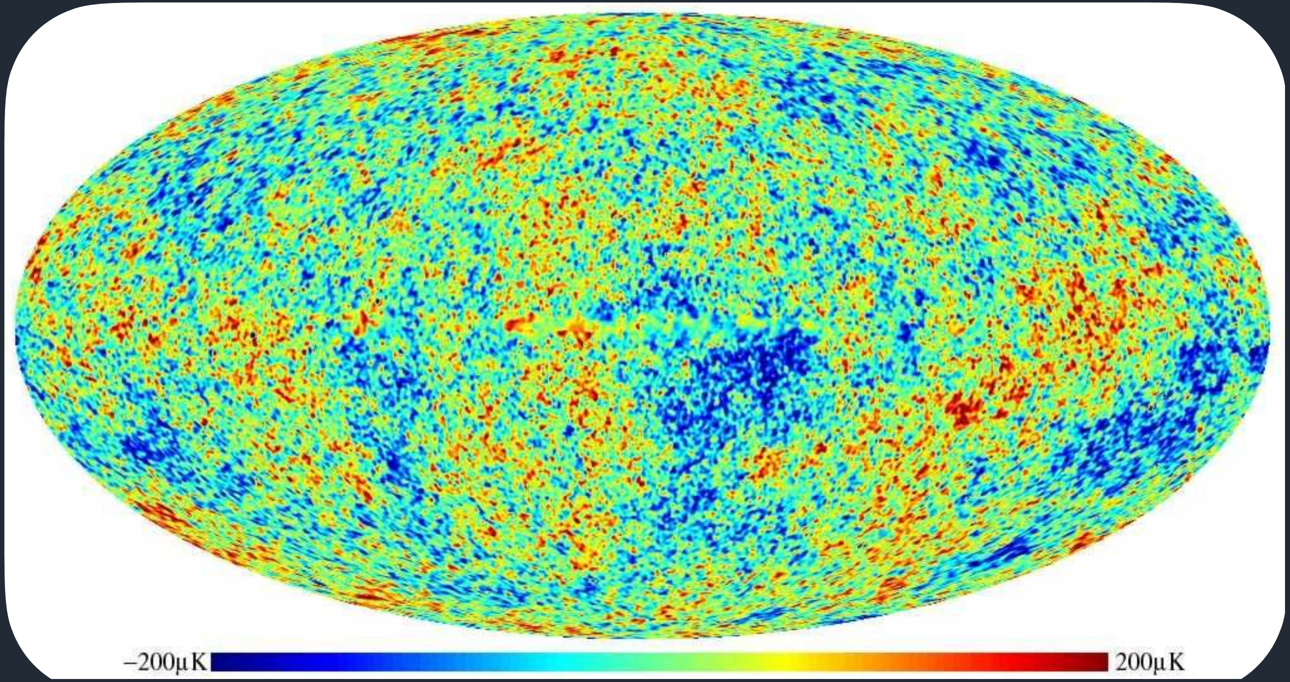


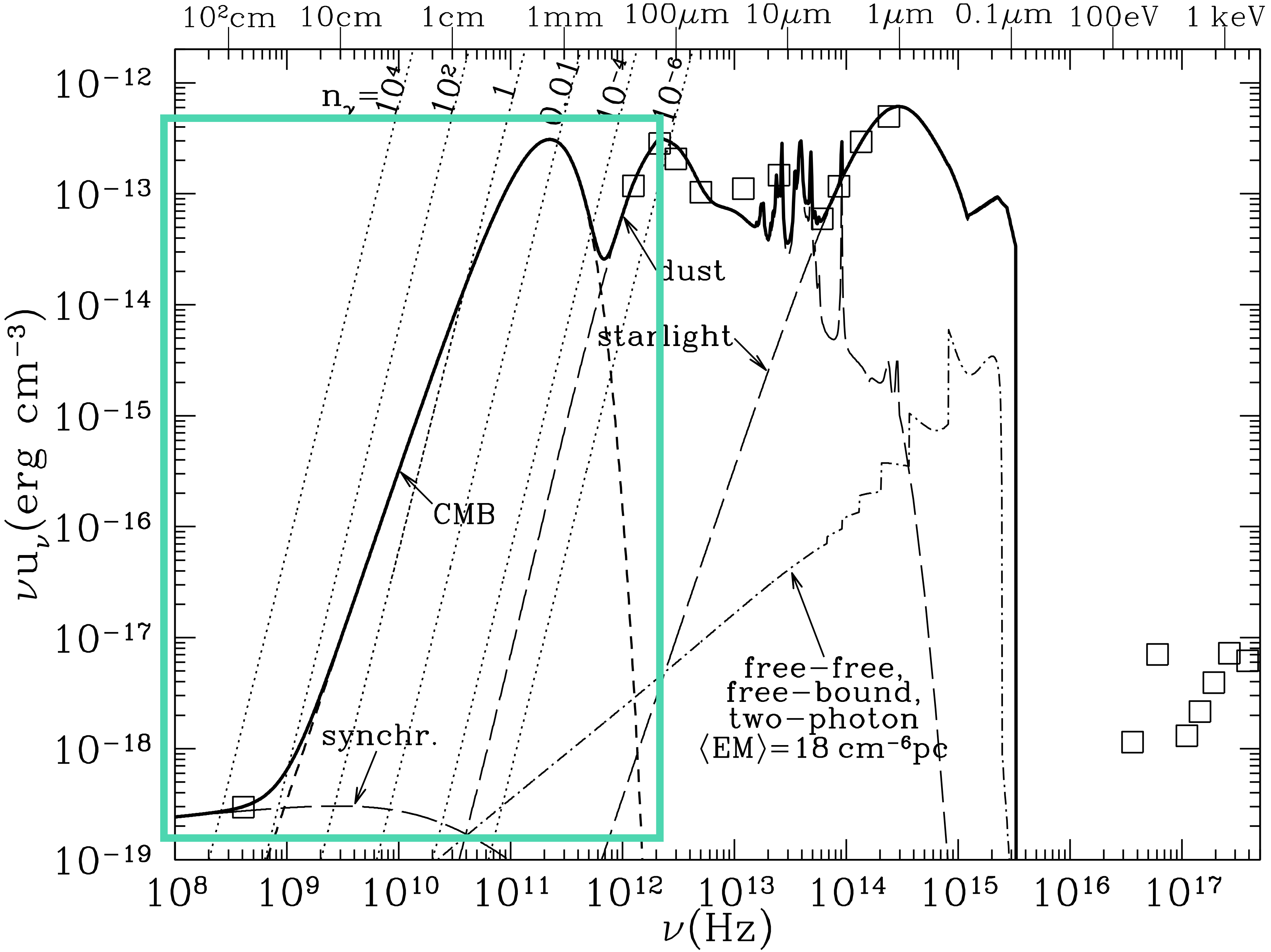


10²cm 10cm 1cm 1mm 100μm 10μm 1μm 0.1μm 100eV 1 keV
n_γ = 10⁴ 10² 1 0.01 10⁻⁴ 10⁻⁶
dust
starlight
CMB
synchr.
free−free,
free−bound,
two−photon
⟨EM⟩=18 cm⁻⁶pc
νu_ν(erg cm⁻³)
ν(Hz)

Cosmic microwave background

- Radiation almost BB at 2.7255 K (Fixsen 2009)
- Isotropic (almost)
- CMB exceeds Galactic synchrotron at freq > 1 GHz





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10^{-12}
10^{-13}
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10^{-17}
10^{-18}
10^{-19}
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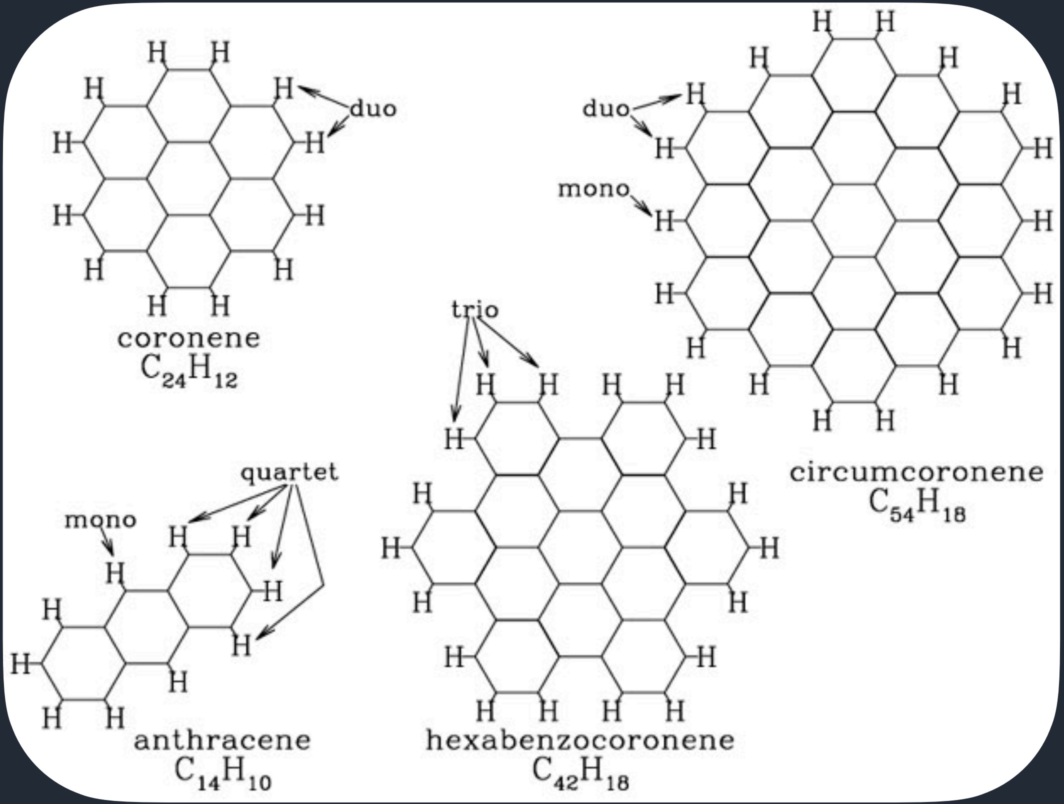
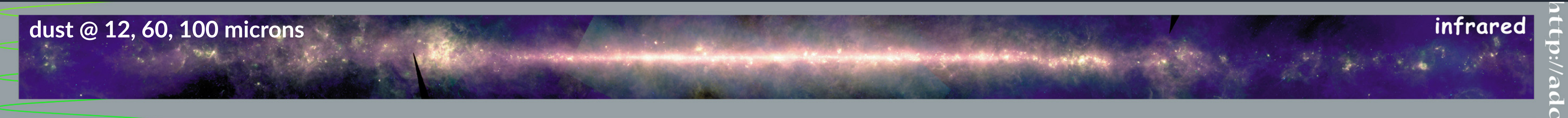
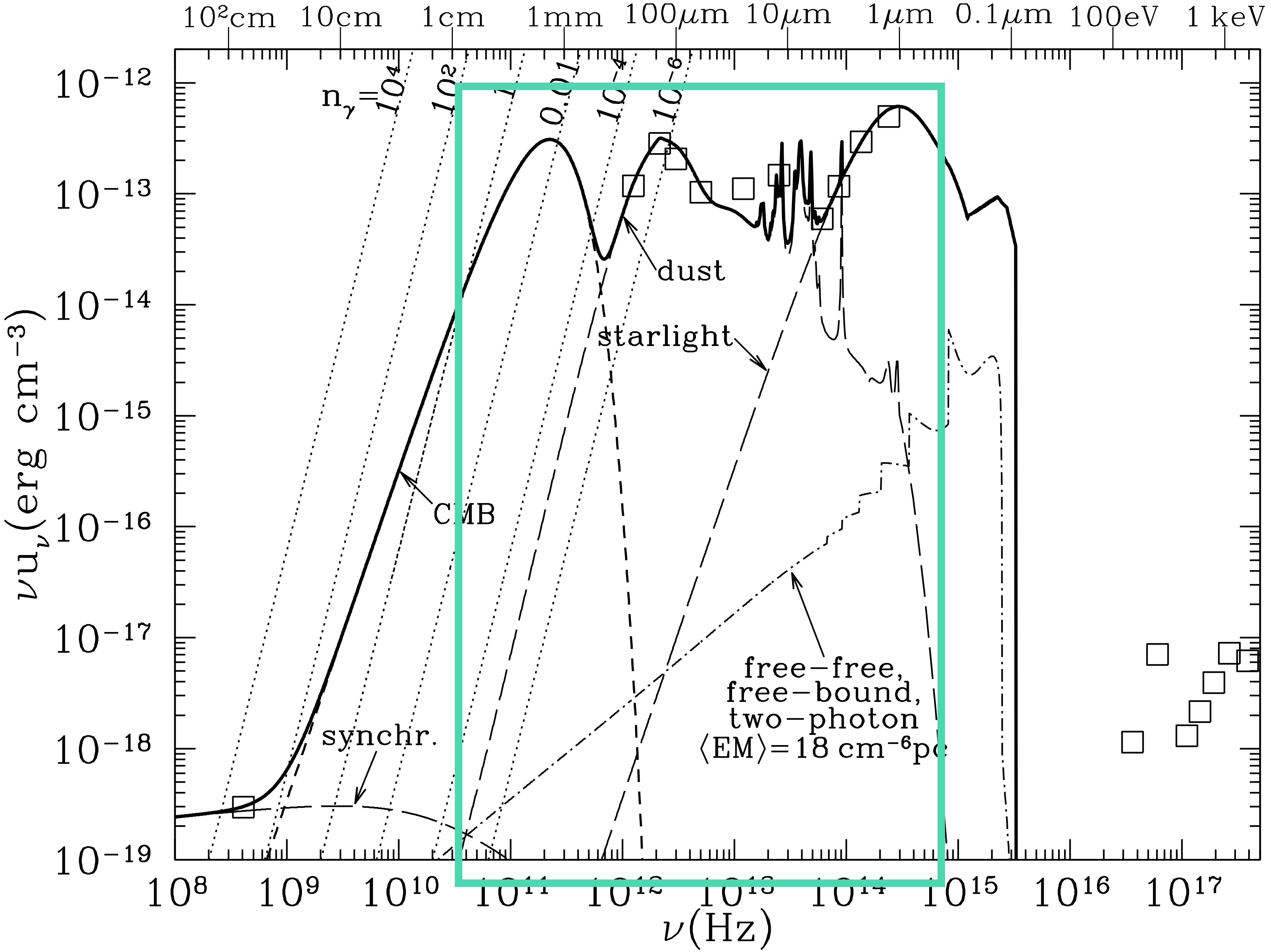
10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17}
ν(Hz)

IR emission from dust

- Dominates in between 500 GHz (600 micron) and 6 x 10^{13} Hz (5 micron)
- 2/3 radiated at wavelength larger than 50 micron, thermal emission from dust grains at T ~ 17 K
- 1/3 vibrational emission bands at 3.3, 6.2, 7.7, 8.6, 11.3 and 12.7 micron (PAHs)







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10cm
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100μm
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n_γ=10⁴
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νu_ν(erg cm⁻³)
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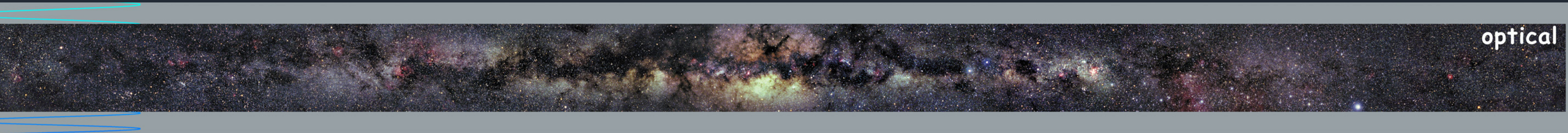
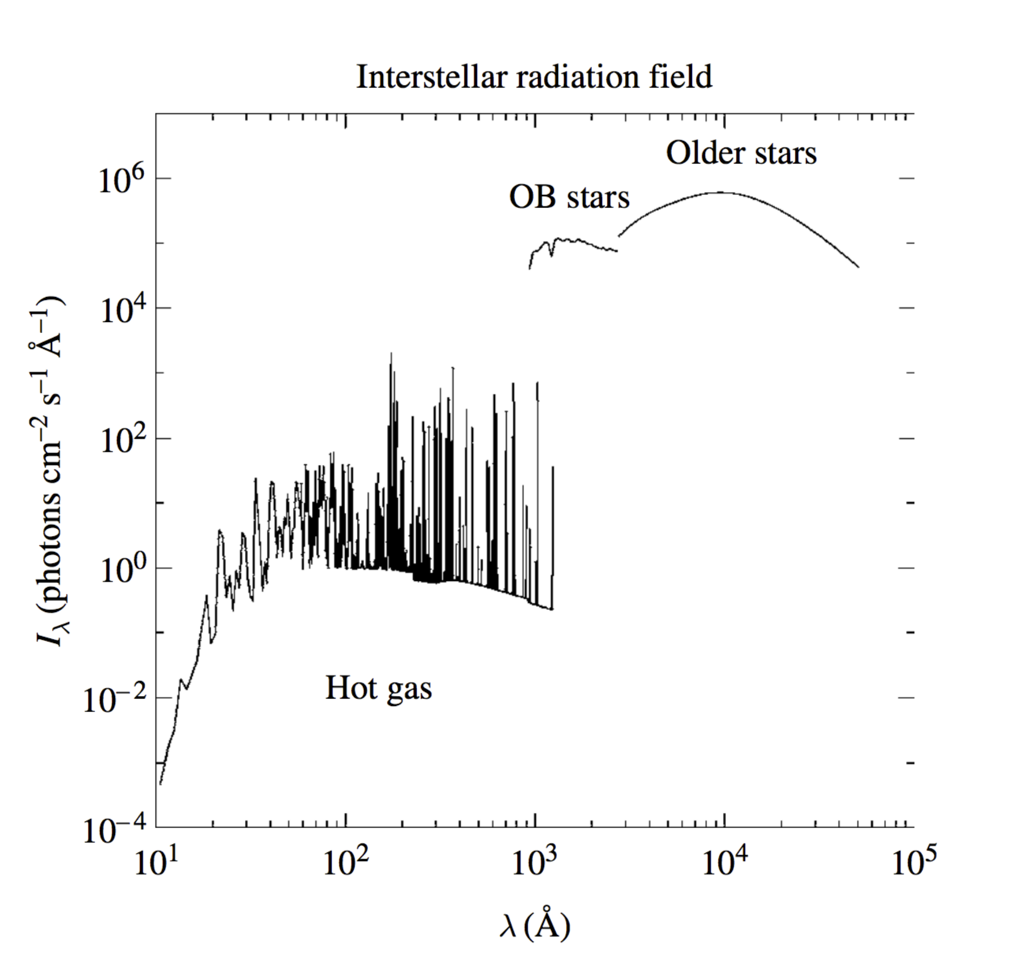
Starlight

- HI regions radiation is mainly emitted below 13.6 eV
- Photons in between 13.6 and 100 eV are strongly absorbed by H and He
- FUV radiation very important in the neutral ISM
  - Photoexcitation, photodissociation (particularly H_2)
  - Photoionization of heavy elements
  - Ejection of photoelectrons from dust grains



FUV

- Almost everywhere in the Galaxy the radiation field is truncated below the Lyman limit @ 912 Angstrom
- Atomic hydrogen (HI) completely absorbs radiation
- In HII regions FUV radiation can propagate



Starlight

- Habing (1968) early estimate of the intensity of UV radiation
- 4×10^{-14} erg cm^{-3} at 1000 Angstroms, i.e. E = 12.4 eV
- I ~ 1.3×10^{-4} erg s^{-1} sr^{-1}

$$\chi \equiv \frac{(\nu u_\nu)_{1000\,\text{Å}}}{4 \times 10^{-14}\,\text{erg cm}^{-3}}$$

Starlight

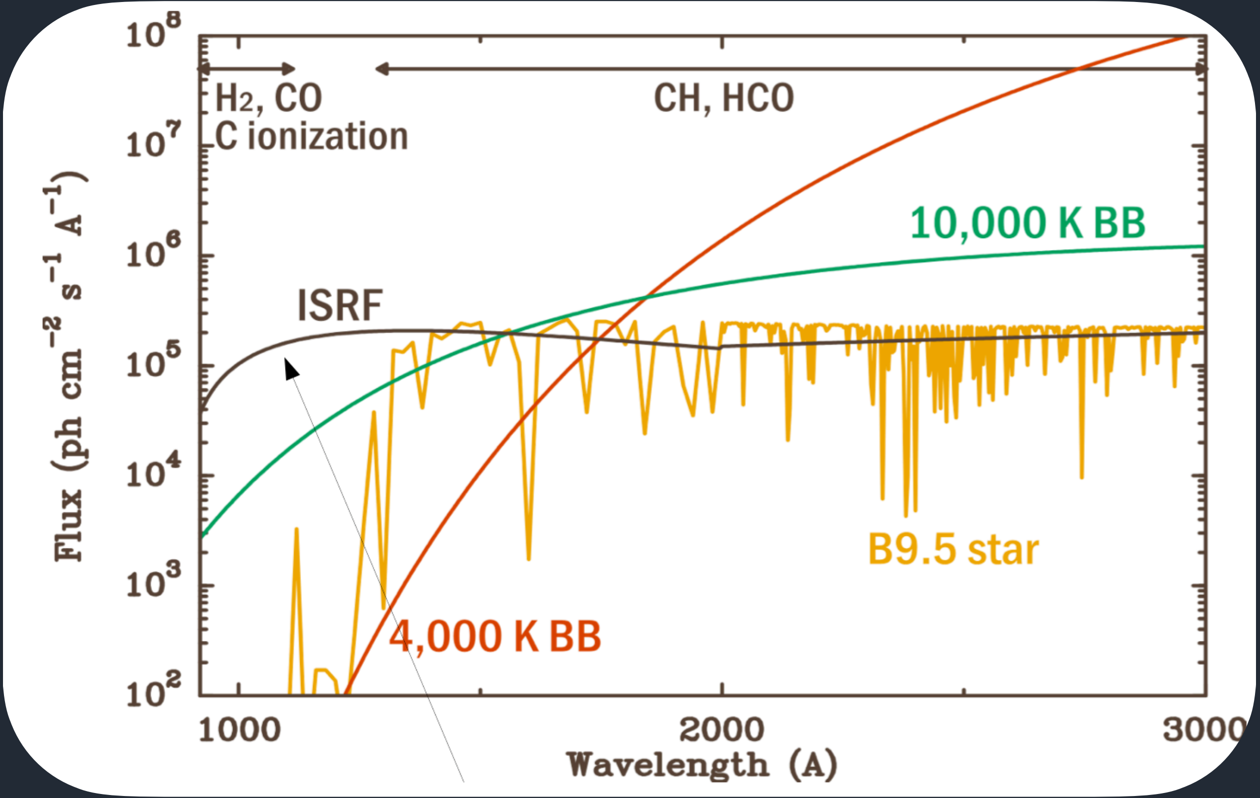
- Habing flux is good in between 10-13.6 eV
- If we integrate the Habing's UV spectrum in between 6 and 13.6

$$u_{\rm Hab}(6 - 13.6\,{\rm eV}) = 5.29 \times 10^{-14}\,{\rm erg\,cm^{-3}}$$

$$G_0 \equiv \frac{u(6 - 13.6\,{\rm eV})}{5.29 \times 10^{-14}\,{\rm erg\,cm^{-3}}}$$

Standard Interstellar Radiation Field

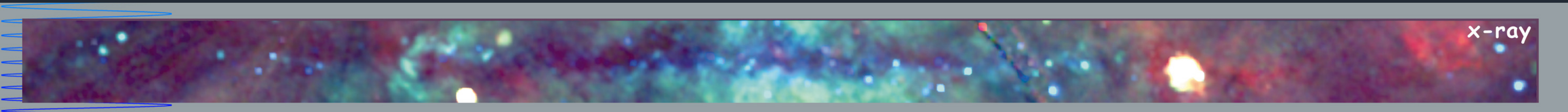
- It is the standard UV field measured in the solar vicinity
- With energy < 13.6 eV



$$\mathcal{N}_{ISRF} = 8.530 \times 10^{-5}\lambda^{-1} - 1.376 \times 10^{-1}\lambda^{-2} + 5.495 \times 10^{1}\lambda^{-3}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{Hz}^{-1}\mathrm{sr}^{-1}$$

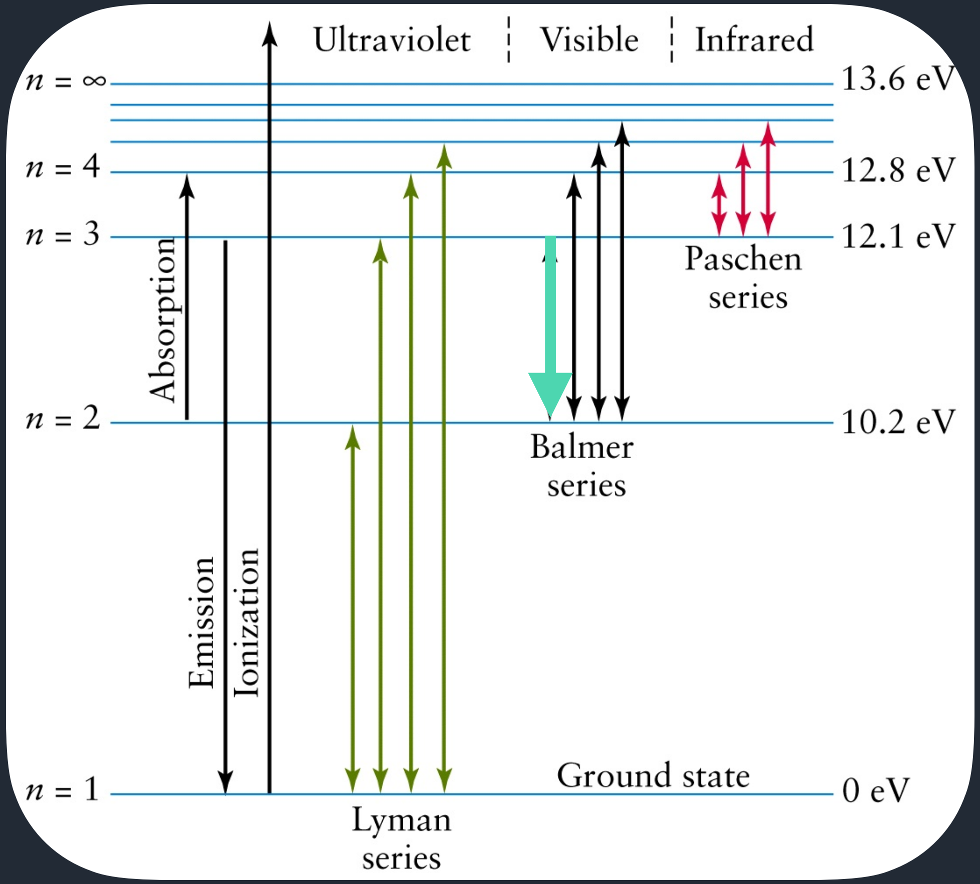
X-Rays

- SNe inject 10^{51} erg/100 yr in the ISM
  - Produce hot plasma
  - Accelerate nuclei and electrons to ultra relativistic energies
- Kinetic energy goes into thermal plasma and radiates as X-ray or EUV
- The low energy (EUV and soft-Xray) photons can be absorbed by neutral gas, which means highly variable within the galaxy
- 10^{-6} a small portion of the total radiation field

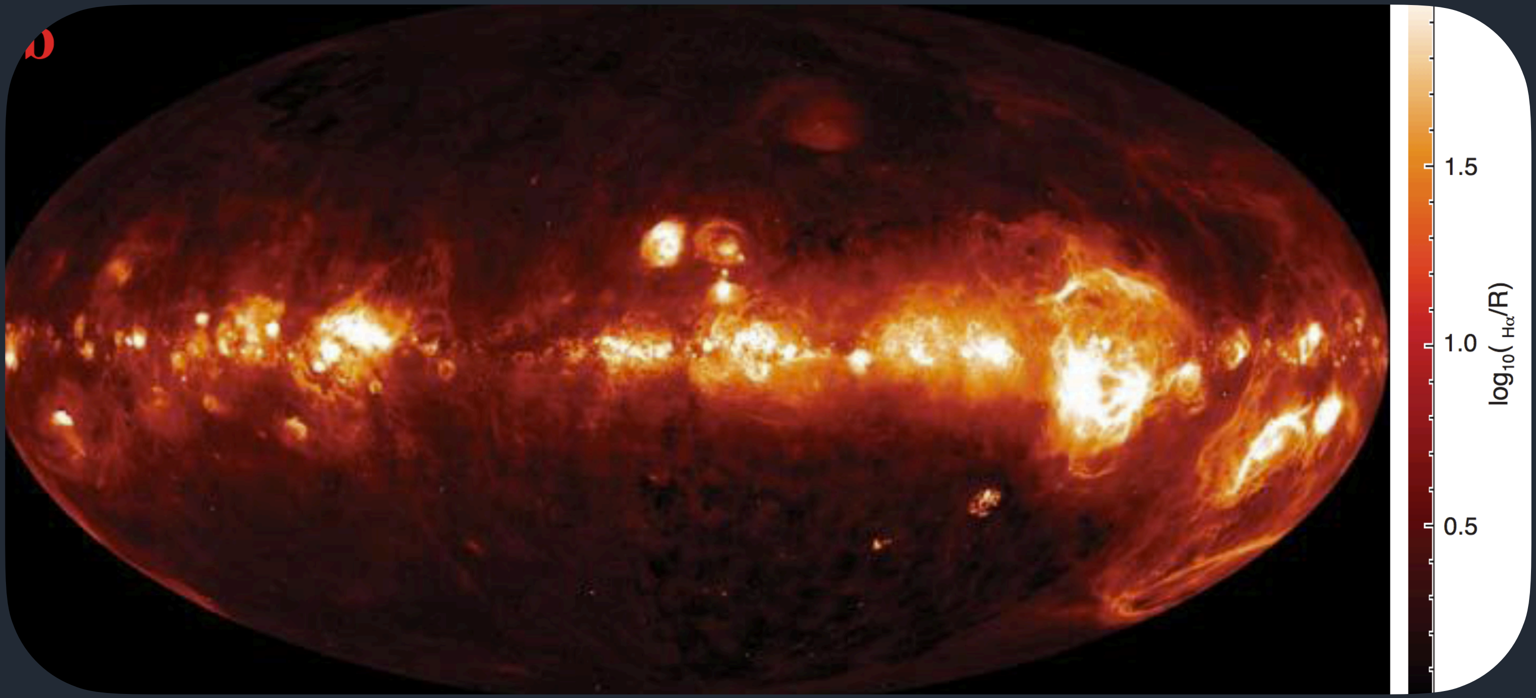


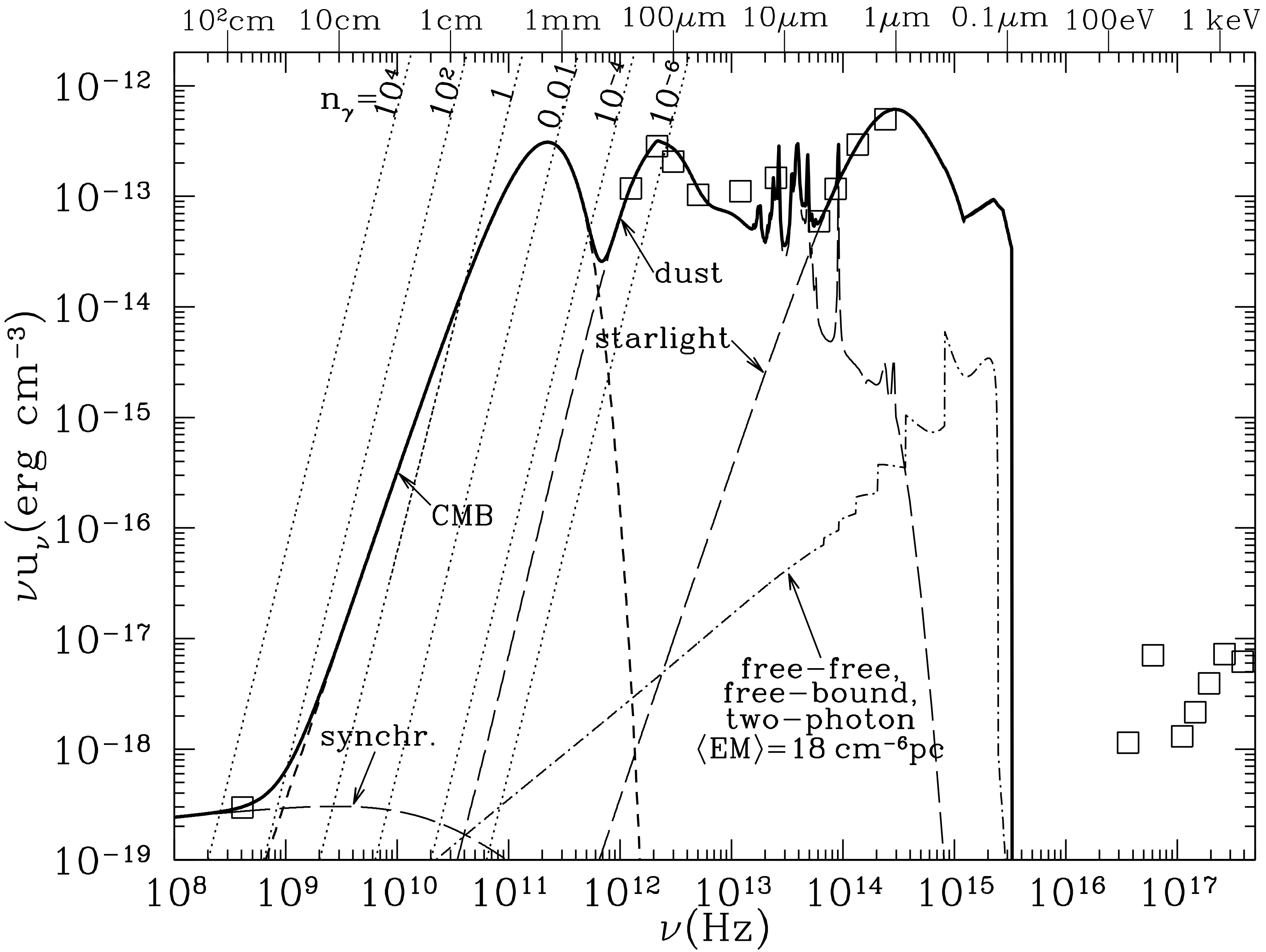
Plasma emission (T ~ 8000 K)

- Example: H-alpha (Balmer series)



Finkbeiner, 2003





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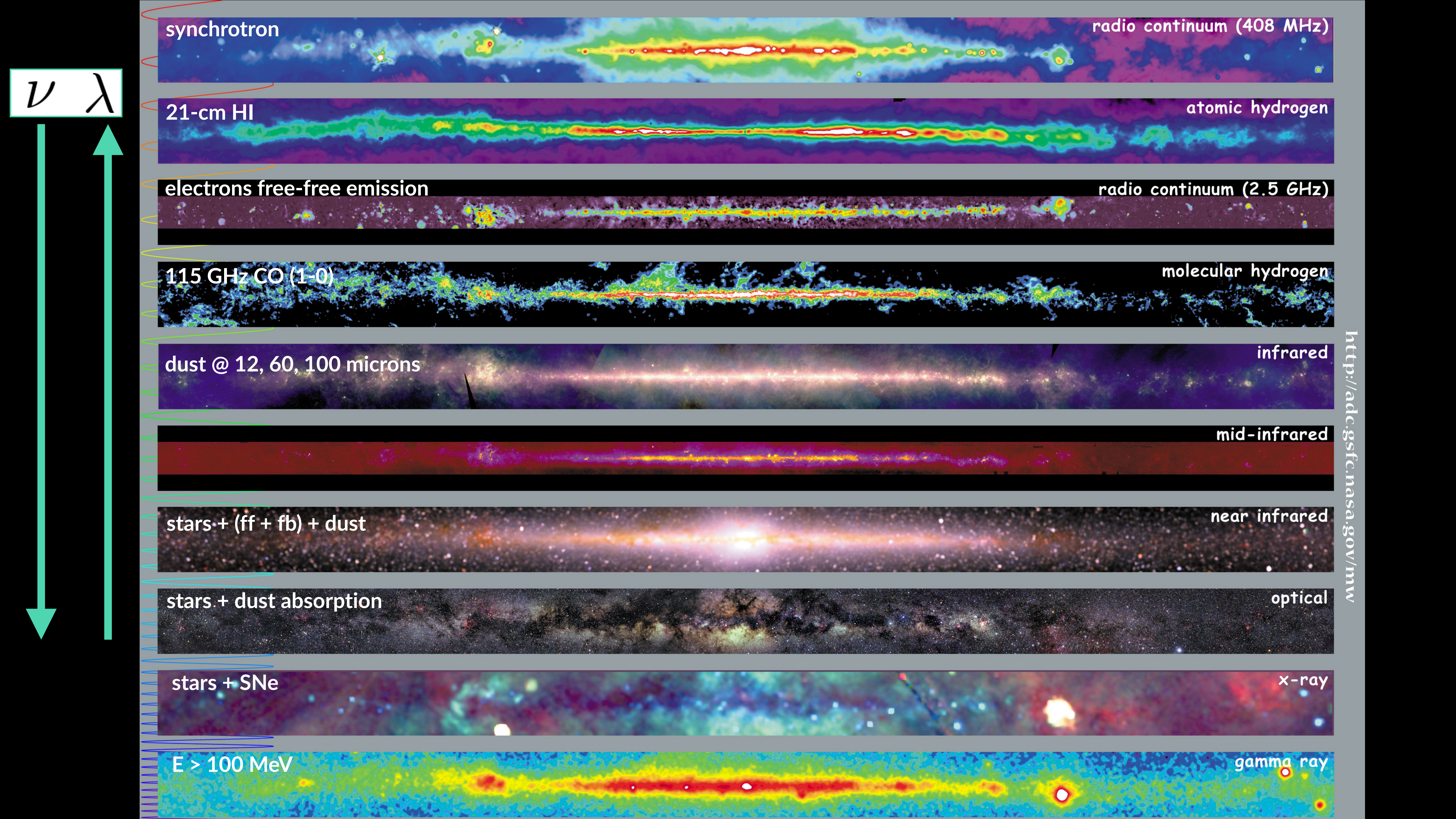
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁸
10⁹
10¹⁰
10¹¹
10¹²
10¹³
10¹⁴
10¹⁵
10¹⁶
10¹⁷
ν(Hz)

Table 12.1 Interstellar Radiation Field (ISRF) Components

Component		u_{rad} (erg cm^{-3})
Radio synchrotron [Eq. (12.2)]		2.7×10^{-18}
CMB, $T = 2.725$ K		4.19×10^{-13}
Dust emission		5.0×10^{-13}
Free–free,free–bound,two-photon		4.5×10^{-15}
Starlight: $T_1 = 3000$ K, $W_1 = 7 \times 10^{-13}$	4.29×10^{-13}	
$T_2 = 4000$ K, $W_2 = 1.65 \times 10^{-13}$	3.19×10^{-13}	
$T_3 = 7500$ K, $W_3 = 1 \times 10^{-14}$	2.29×10^{-13}	
$\lambda < 2460$ Å UV (Eq. 12.7)	7.11×10^{-14}	
Starlight total		1.05×10^{-12}
Hα		8×10^{-16}
Other $\lambda \geq 3648$ Å H lines = $1.1 \times$ Hα:		9×10^{-16}
$0.1 - 2$ keV x rays		1×10^{-17}
ISRF total		2.19×10^{-12}

Extragalactic sources

- The radiation originating in other galaxies and in the IGM is very weak
- Its energy density is around 2.7×10^{-14} erg cm^{-3}
- 2/3 is in the MIR and FIR (wavelengths > 6 micron)


ν λ
synchrotron
radio continuum (408 MHz)
21-cm HI
atomic hydrogen
electrons free-free emission
radio continuum (2.5 GHz)
115 GHz CO (1-0)
molecular hydrogen
dust @ 12, 60, 100 microns
infrared
mid-infrared
stars + (ff + fb) + dust
near infrared
stars + dust absorption
optical
stars + SNe
x-ray
E > 100 MeV
gamma ray
http://adc.gsfc.nasa.gov/mw

Summary with M51 example