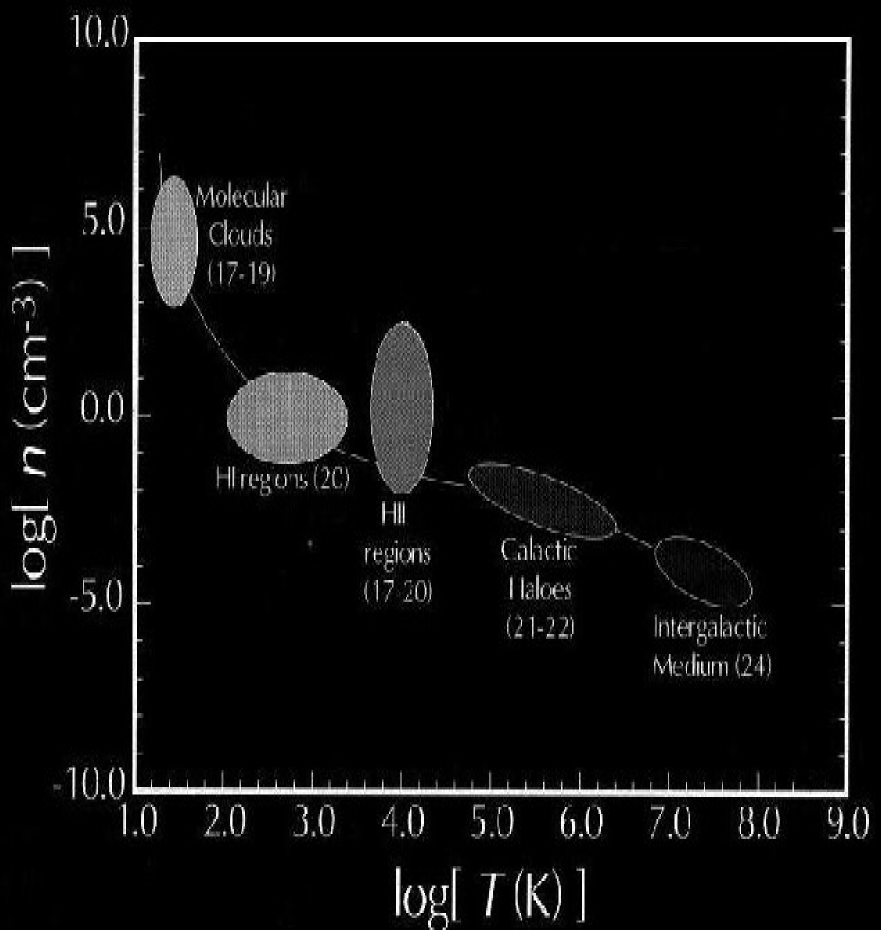
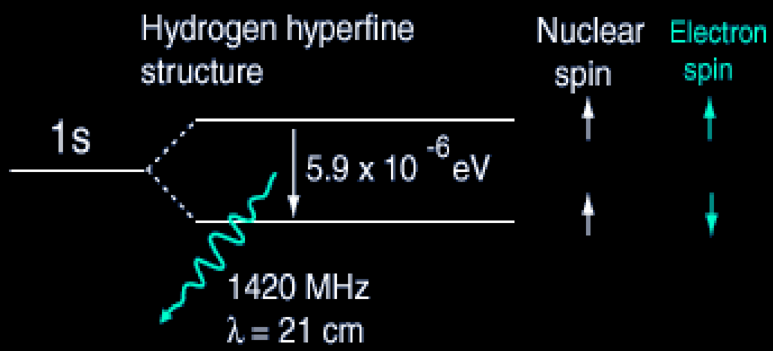
# The 5 phases of the Interstellar matter




| Regions | Density ($cm^{-3}$) | T (K) | ISM Mass Fraction |
|---|---|---|---|
| Molecular clouds | $10^3$ | 10 – 30 | 40-50% |
| HI cold | 1-100 | 80 | 40-50% |
| warm | 0.3-1 | 6000 | 4-6% |
| HII warm | 0.1 – 1 | 6000-12000 | 0.1% |
| hot | 10-2 | $10^6$ | |

# Neutral Hydrogen (HI)




**Ground level of neutral hydrogen ($1^2S_{1/2}$) is split into two sublevels**

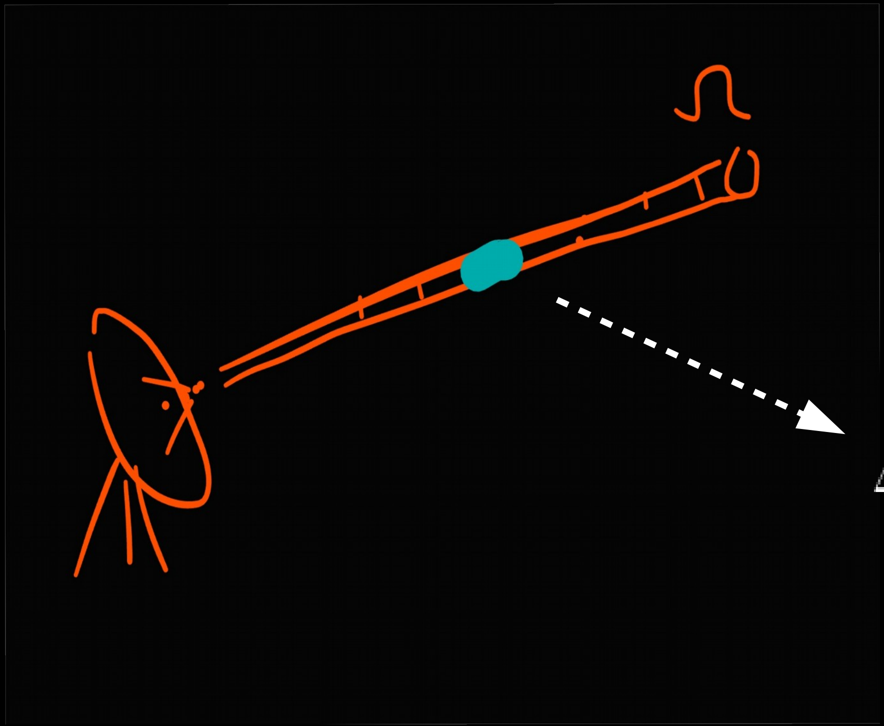
**F = J + I = 0,1**

**Tiny energy separation (t = 1.1 $10^7$ years)**

**Radio emission at 1420.4 MHz or 21 cm**

**Spin temperature $T_S$**

# Intensity vs column density



$$\Delta F = \frac{\Delta L}{4\pi r^2} = \frac{\epsilon(r)\,\Delta V}{4\pi r^2} = \frac{\epsilon(r)\,\Omega r^2\,dr}{4\pi r^2} = \epsilon(r)\,\frac{\Omega}{4\pi}\,dr$$

$$I = \frac{F}{\Omega} = \frac{1}{4\pi}\int_0^\infty \epsilon(r)\,dr = \frac{3}{16\pi\,\tau}\int_0^\infty n_{HI}(r)\,dr$$

# Hydrogen distribution

**HI density :**

$$n_{HI} = -\frac{1.83}{\Delta r} \int_{\Delta v} T_S \ln\left[1 - \frac{T_b(v)}{T_S}\right] dv \qquad atom\ cm^{-3}$$

$T_S = 125\ K$

**Molecular Clouds density :**

$$n_{H_2} = \frac{2X}{\Delta r} \int_{\Delta v} T_b(v)\, dv \qquad atom\ cm^{-3}$$

$X = 1.8\ 10^{20}\ H_2 cm^{-2} (K\ km\ s^{-1})^{-1}$

# Neutral Hydrogen Survey

Leiden-Dwingeloo survey at 21 cm

(Hartmann et al 1997)

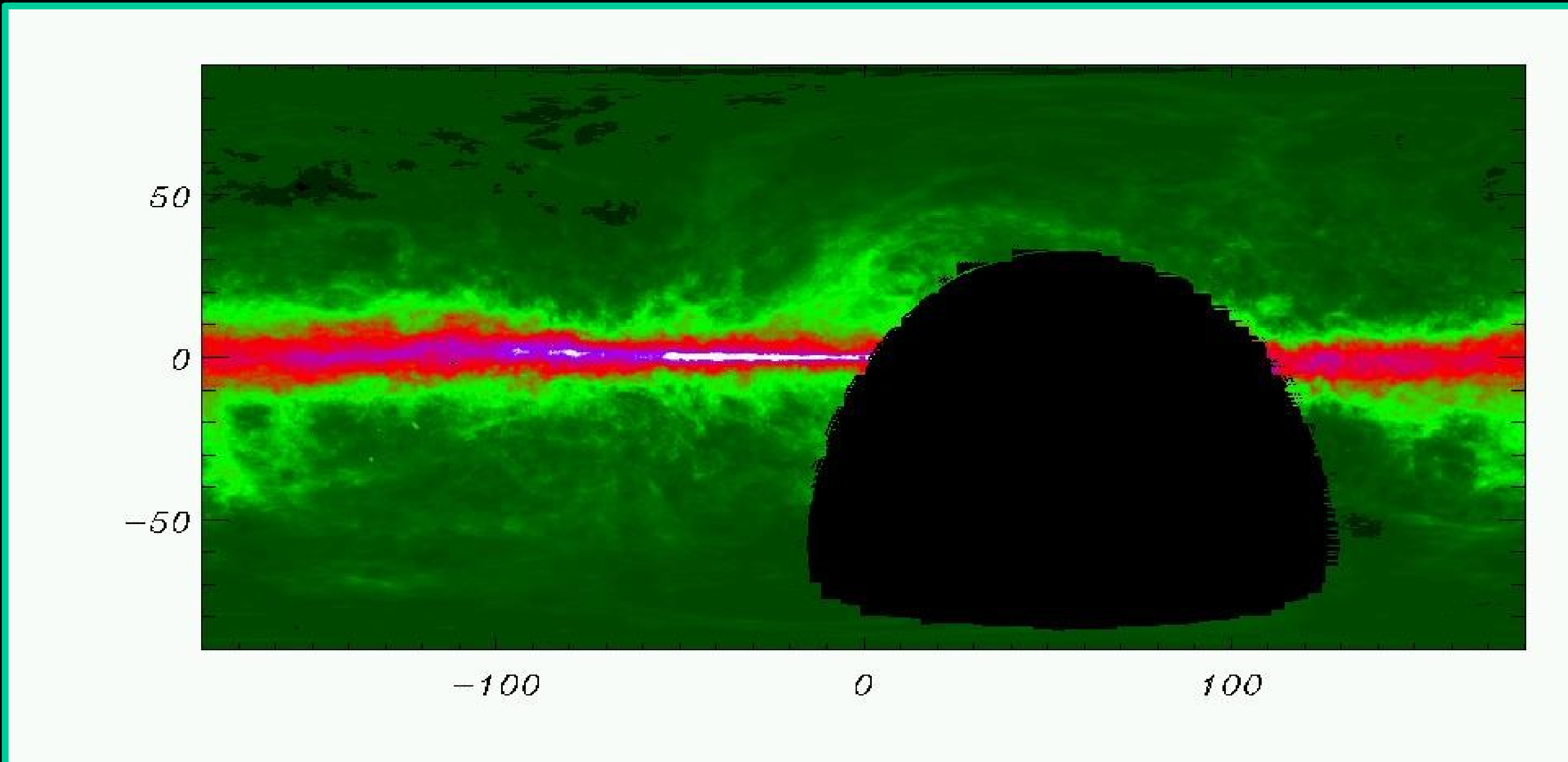
Spatial resolution: 30’

Velocity resolution: 1.03 km/s

Velocity range: -450,400 km/s

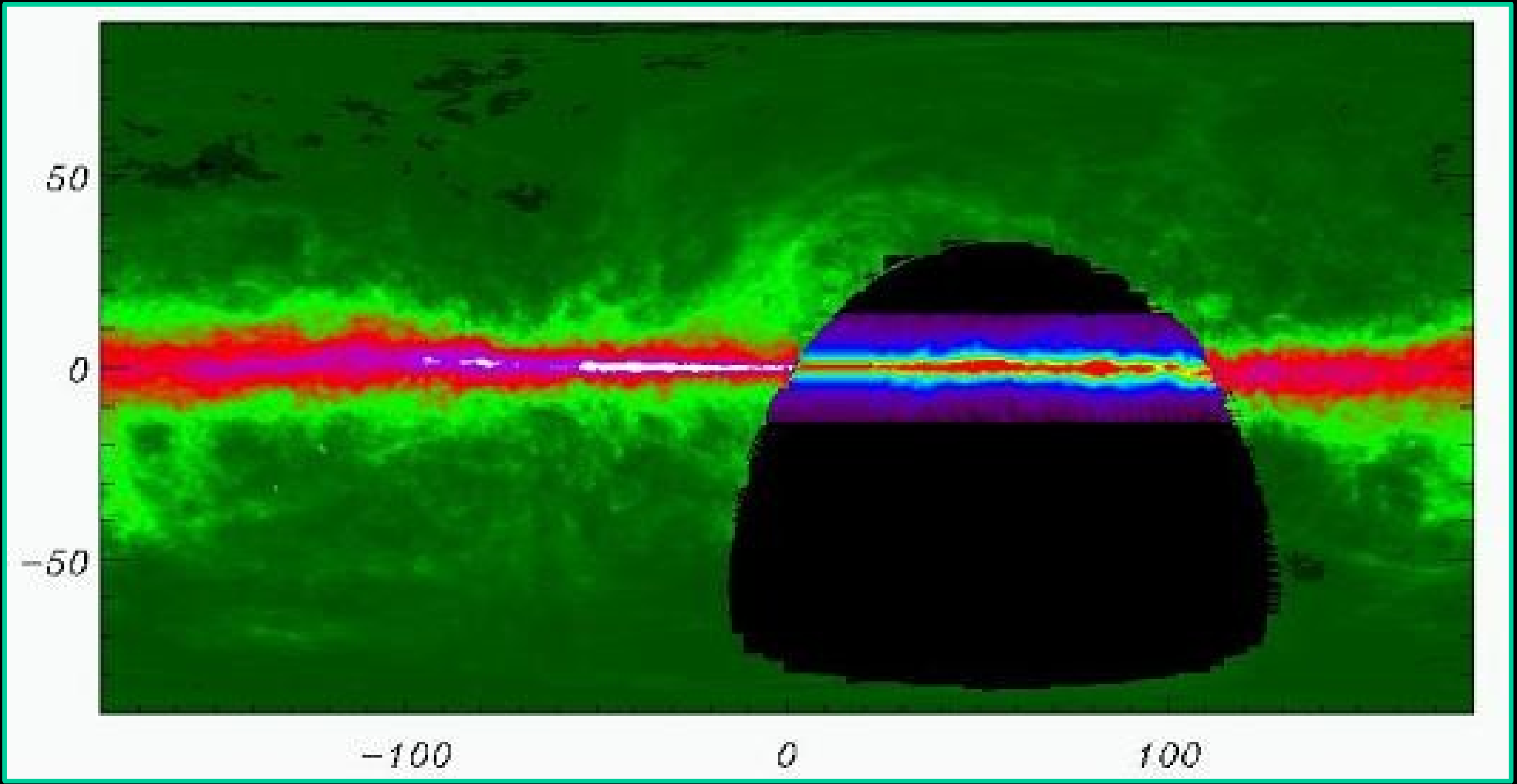
Sensitivity: 0.07° K

# Neutral Hydrogen



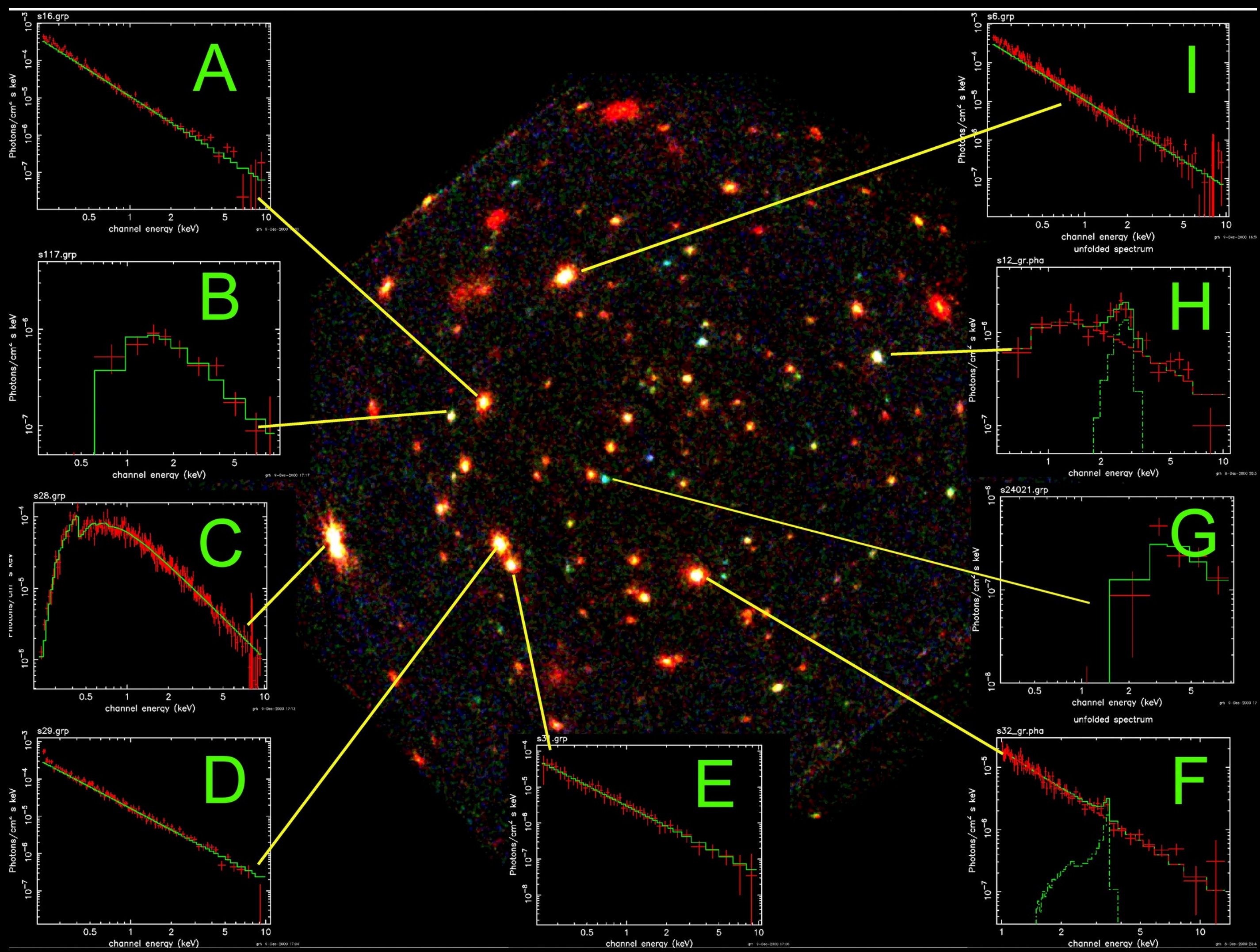

Leiden-Dwingeloo survey at 21 cm (Hartmann et al 1997)

# Neutral Hydrogen

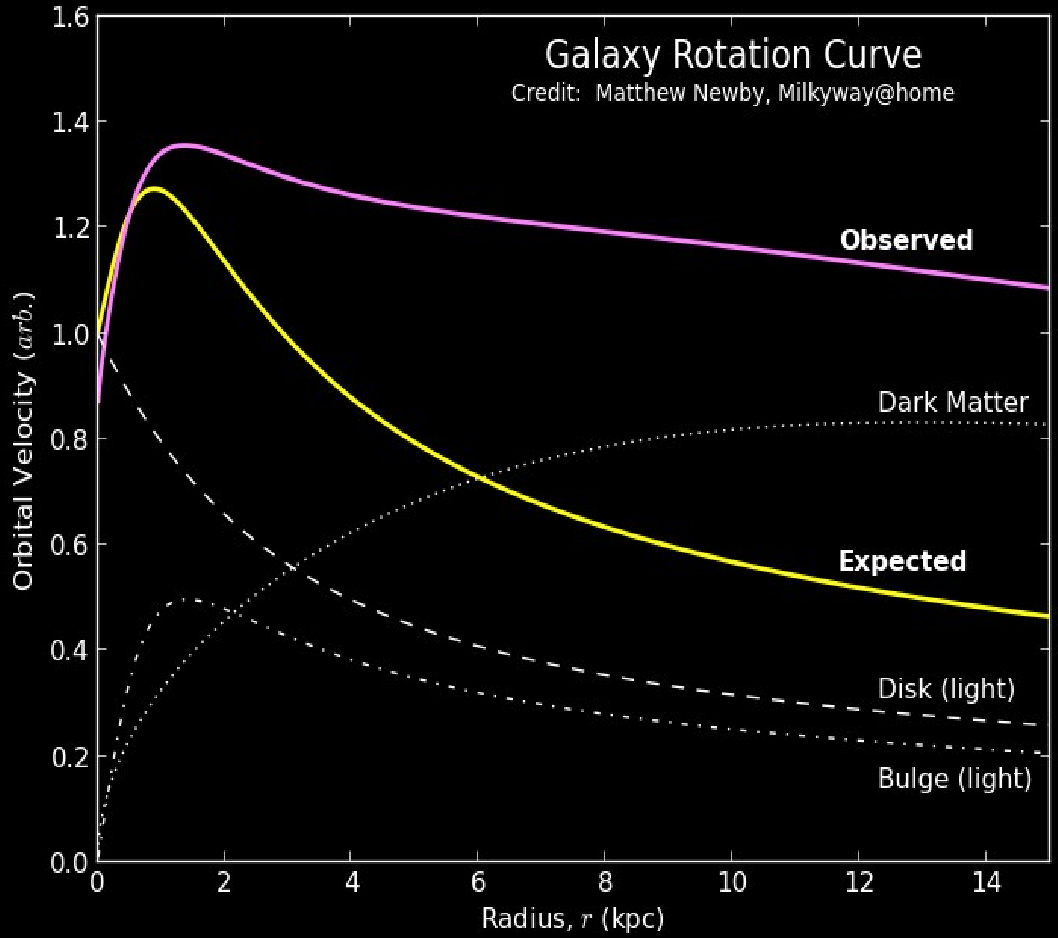


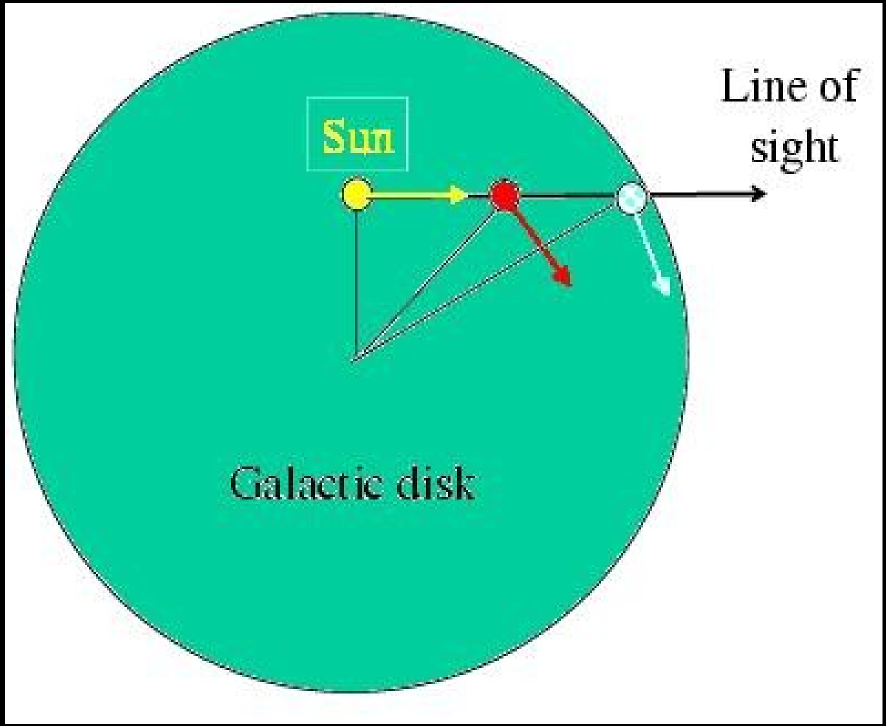

Leiden-Dwingeloo survey + Parkes (Kerr et al 1986)

# Lockman Hole

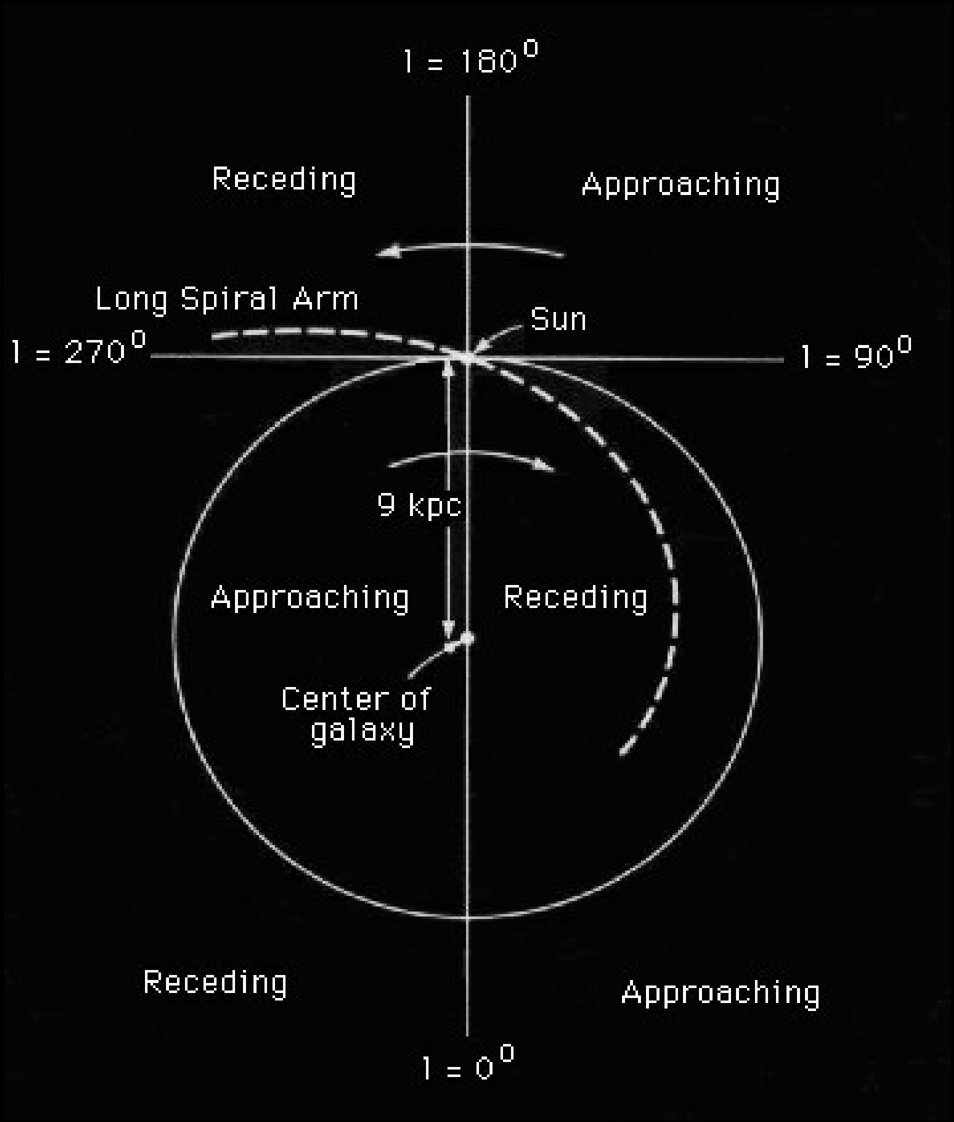


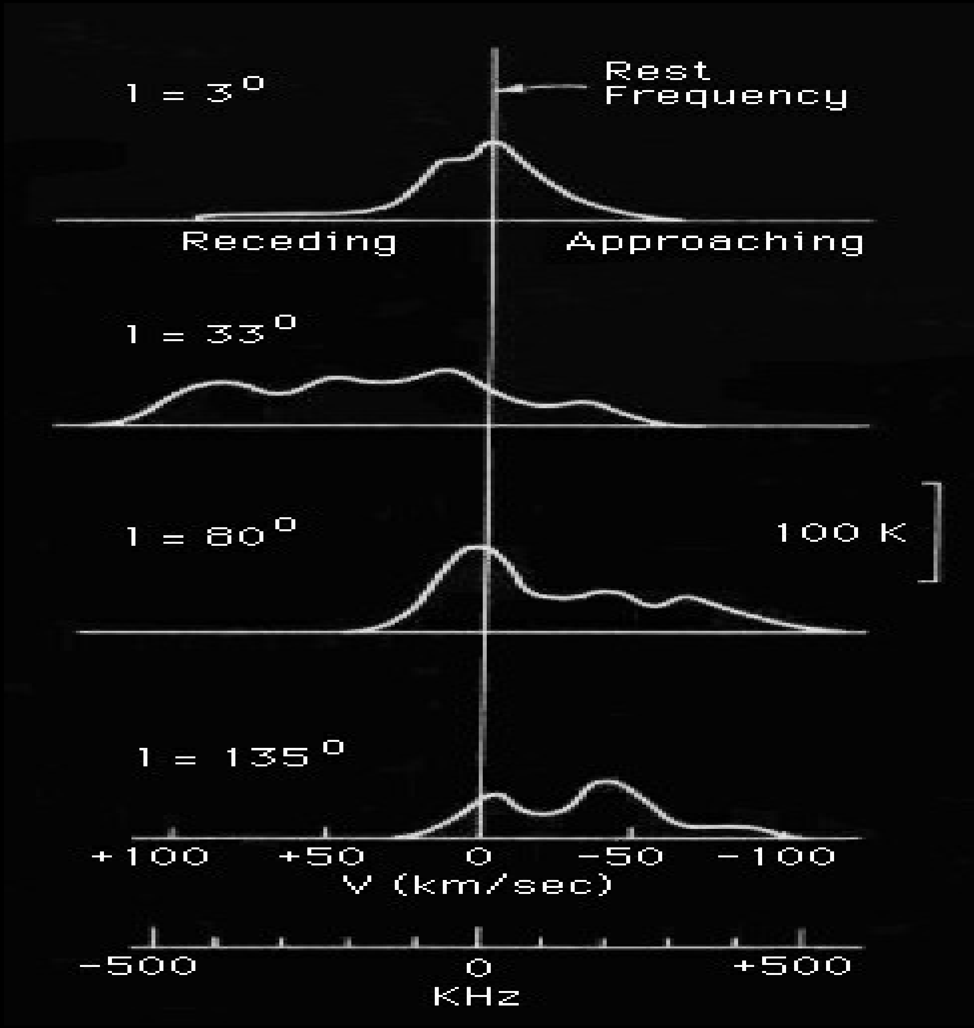
# Radio Data deprojection



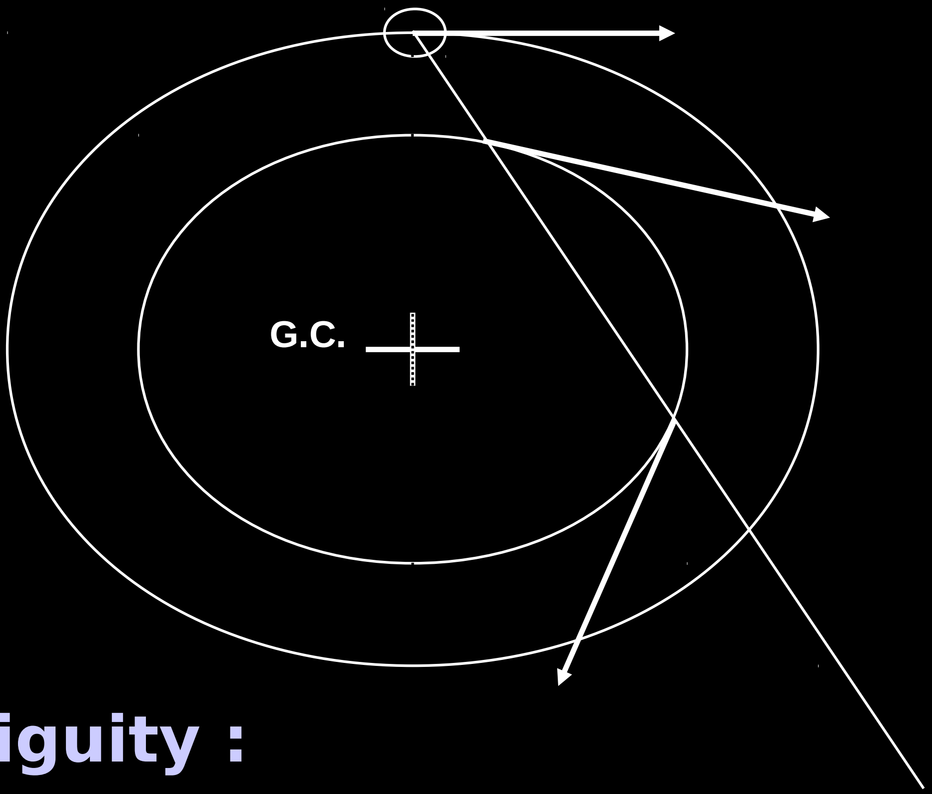



# Radio Data deprojection



# Near-Far distance ambiguity:



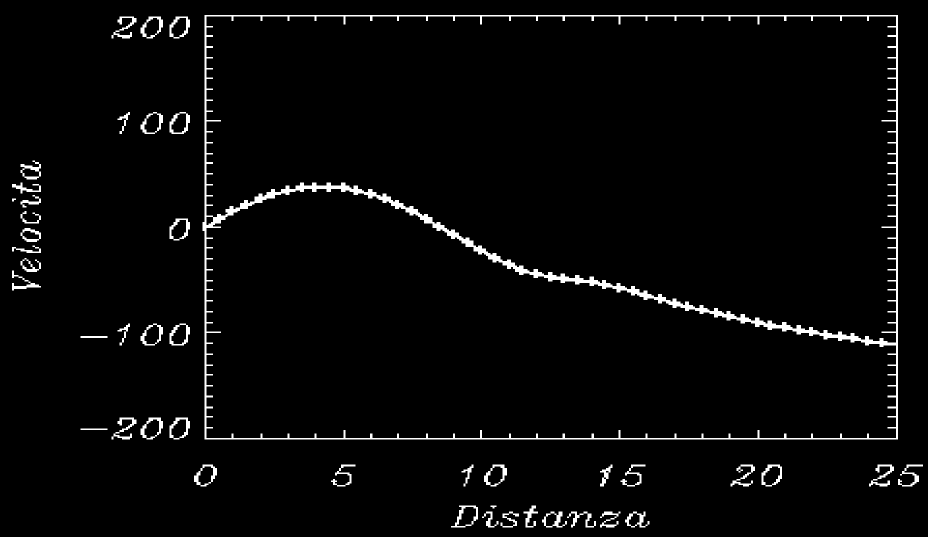

**Dinamical ambiguity :**

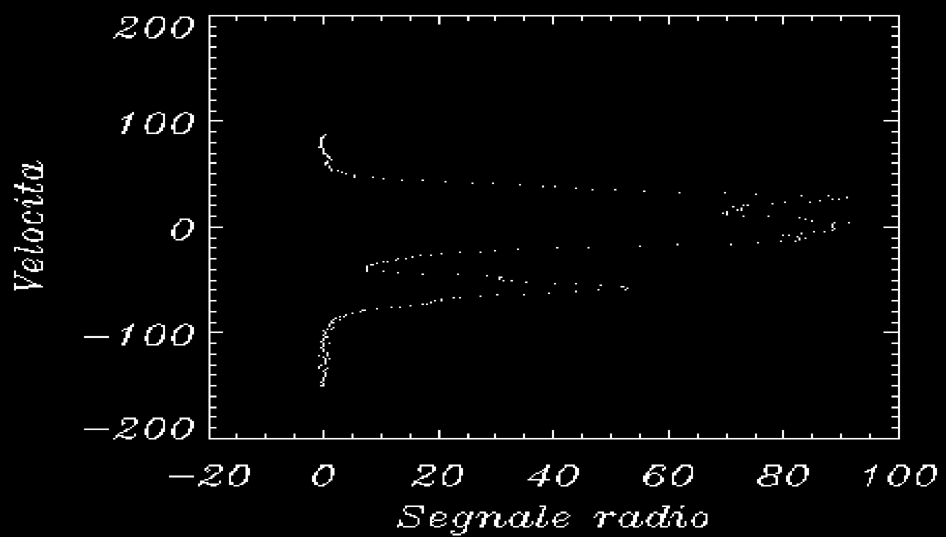
$$w.f. \propto e^{-\frac{1}{2}\frac{z}{Z_{gas}}}$$

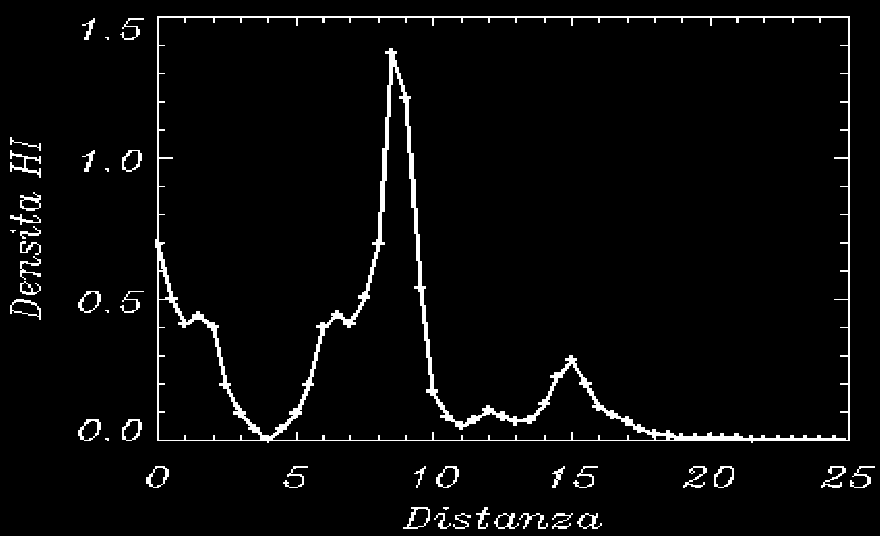
$Z_{gas} = 100\ pc$ for HI

$Z_{gas} = 60\ pc$ for $H_2$

# Radio Data deprojection



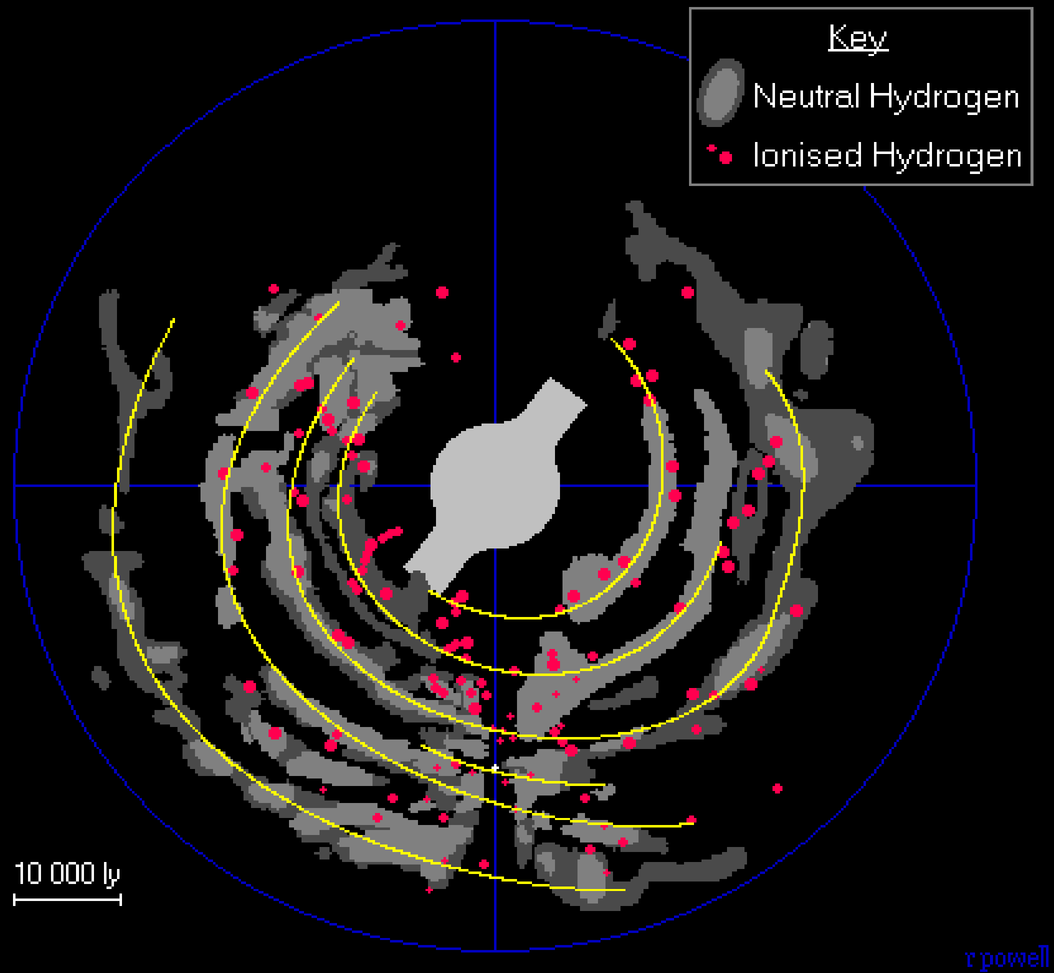




Lat. 0.00000

Long. 60.0000

# Neutral Hydrogen (HI)




**Two phase medium in pressure balance**

**Cold (100 K)**

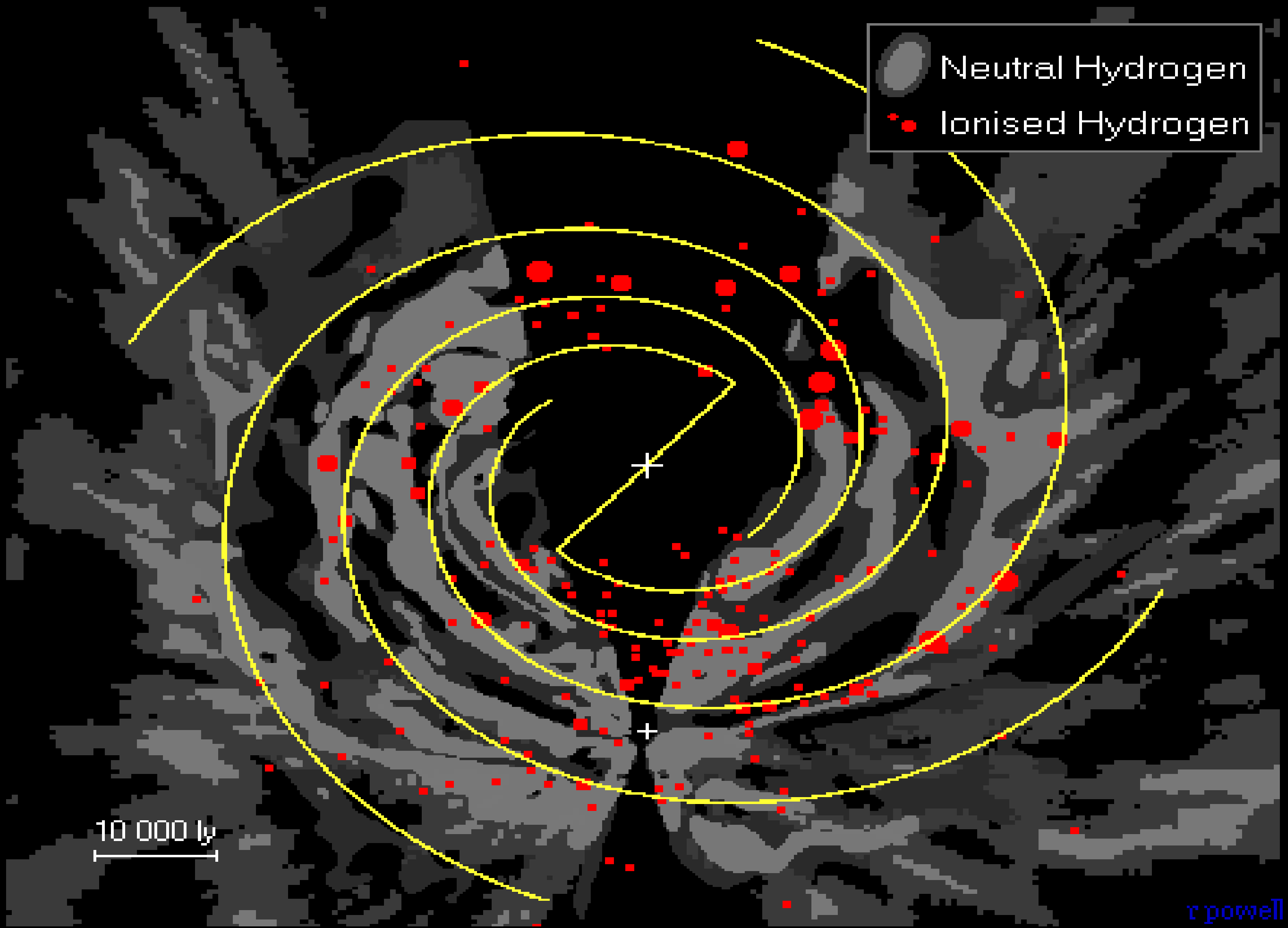
**Mass**

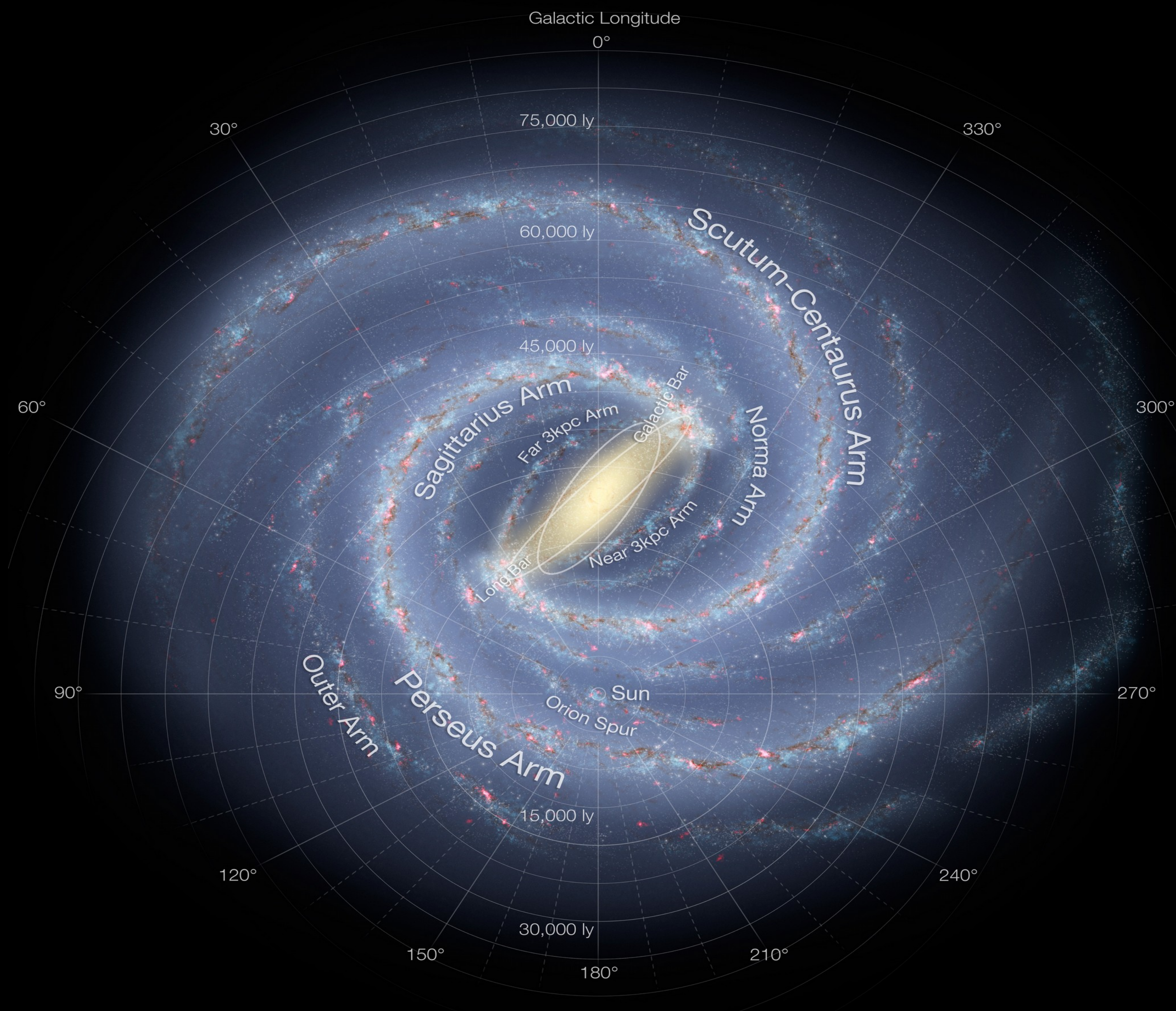
**Dense sheet**

**No grav. Bound**

**n = 20–60 cm$^{-3}$**

**Warm (6000 K)**


Neutral Hydrogen
Ionised Hydrogen
10 000 ly
r powell


Galactic Longitude
0°
30°
330°
60°
300°
90°
270°
120°
240°
150°
210°
180°
75,000 ly
60,000 ly
45,000 ly
15,000 ly
30,000 ly
Scutum-Centaurus Arm
Sagittarius Arm
Far 3kpc Arm
Galactic Bar
Norma Arm
Near 3kpc Arm
Long Bar
Outer Arm
Perseus Arm
Sun
Orion Spur

# Ionized Hydrogen (HII)

**Two phase medium in pressure balance**

**Warm (6000-12000 K)**

**Photoionized by hot young stars**

**$n = 1\ cm^{-3}$**

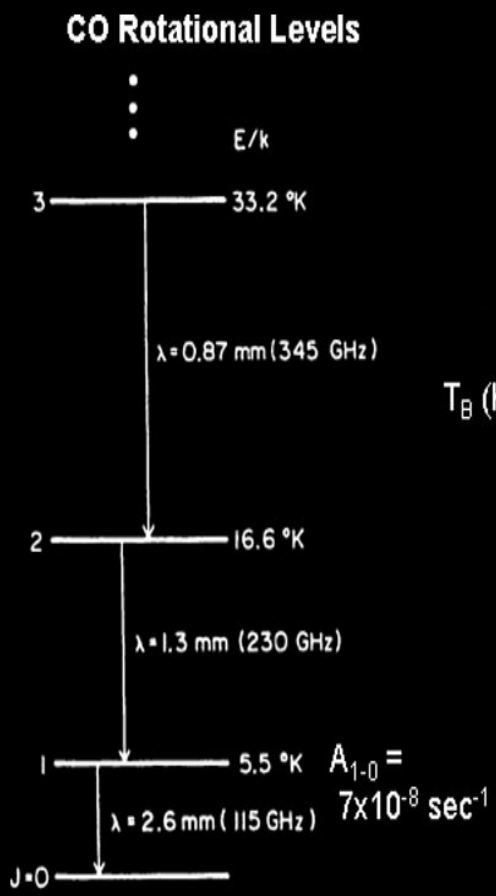
**Hot ($10^6$ K)**

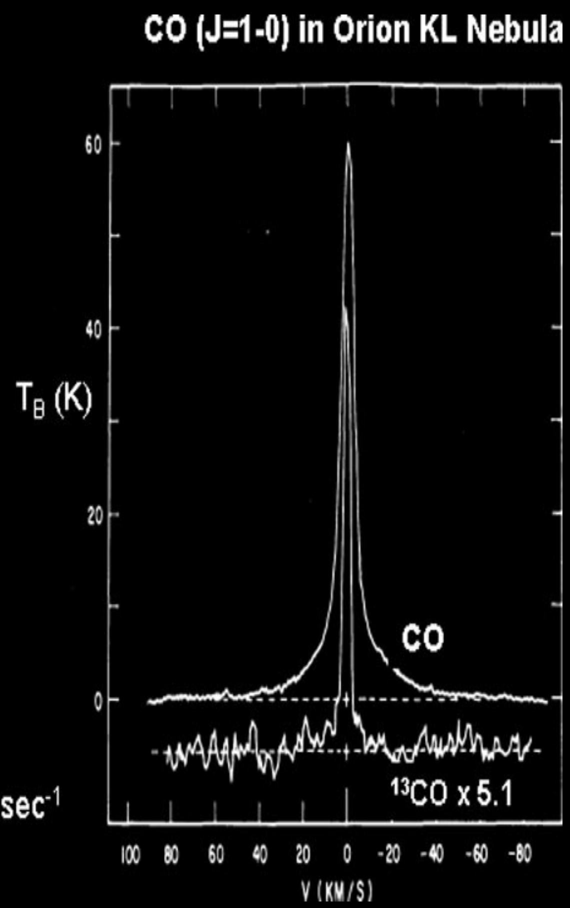
**$n = 10^{-2}\ cm^{-3}$**

**Buoyancy**

**Local bubble**

# CO emission




**$H_2$ is homopolar → No vibrational or rotational emission**

**CO is the abundant molecule after $H_2$**

**CO emits strong line radiation at 2.6 mm (J 1→0)**

**CO tracer of $H_2$**

**$n_{H2}$ proportional to $L_{CO}$**

# CO Survey

(Dame et al.  2001)

CO observation

J 1→0  115 GHz

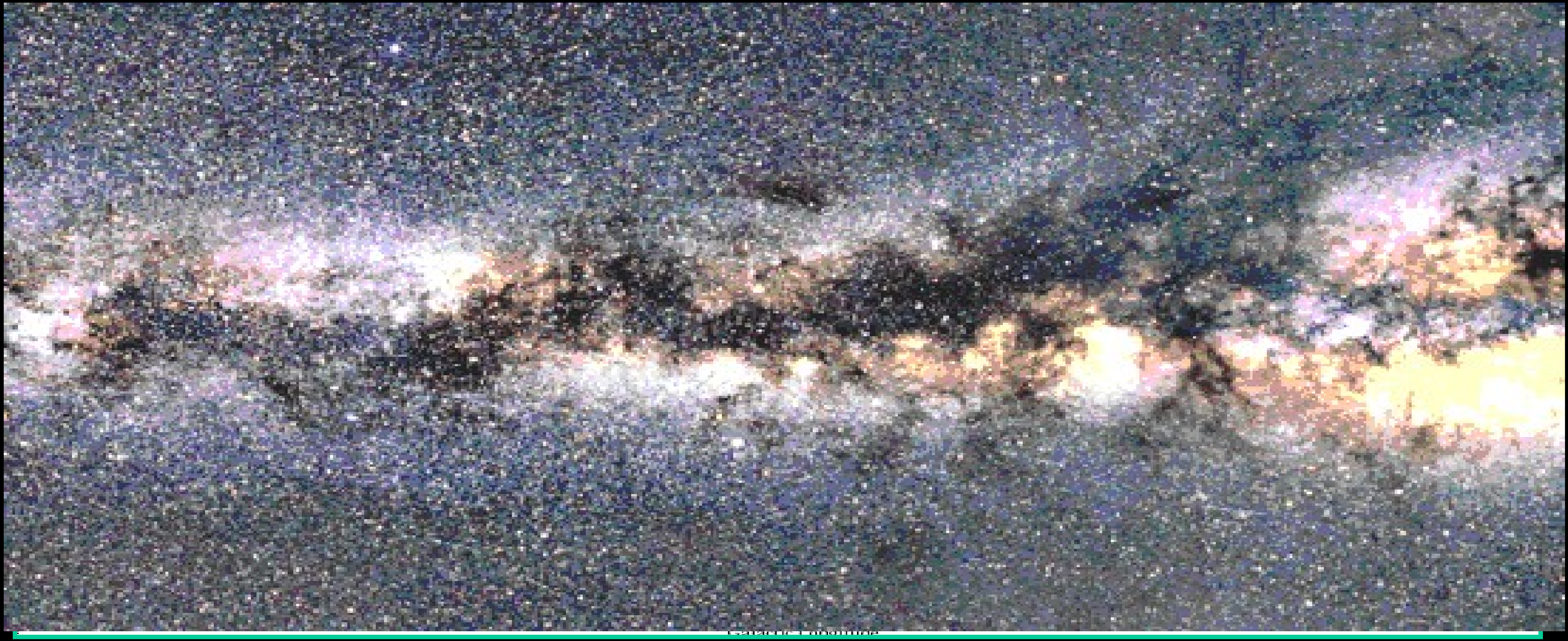
31 survey combined

Spatial resolution: 12’ or more
Velocity resolution: 0.65 km/s

Sensitivity: 0.62° K

$X = n_{HI} / I_{CO} = 1.8\ 10^{20}\ cm^{-2}\ K^{-1}\ km^{-1}\ s$

# CO Survey →Molecular Clouds



# Hydrogen distribution

**HI density :**

$$n_{HI} = -\frac{1.83}{\Delta r} \int_{\Delta v} T_S \ln\left[1 - \frac{T_b(v)}{T_S}\right] dv \qquad atom\ cm^{-3}$$

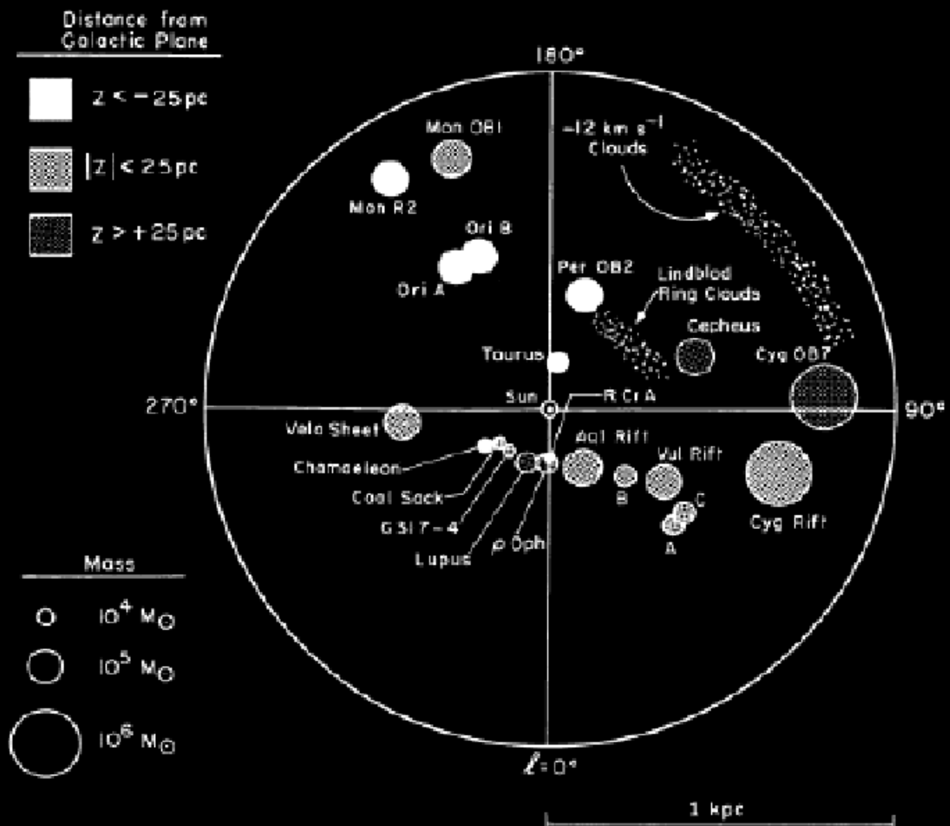
$T_S = 125\ K$

**Molecular Clouds density :**

$$n_{H_2} = \frac{2X}{\Delta r} \int_{\Delta v} T_b(v)\, dv \qquad atom\ cm^{-3}$$

$X = 1.8\ 10^{20}\ H_2 cm^{-2} (K\ km\ s^{-1})^{-1}$

# The molecular clouds




**Concentrated in *Giant Clouds* ($10^4$ -$10^8$ Msol) self graviting with n > $10^3$ $cm^{-3}$**

**Optically thick (dust, $H_2$)**

**Along spirala arms**

**Small scale thickness (120 pc)**

# CO Survey →Molecular Clouds

# DUST

**Cold Dust (15-25 K)** associated to the HI regions and molecular clouds. Heated by both old and young stellar population

**Warm dust (30-40 K)** associated to HII regions. Heated by OB stars

**Hot dust (250-500 K)**

very small grains ( 5 A) heated by ISRF

normal grains (1 micron) heated by M giants

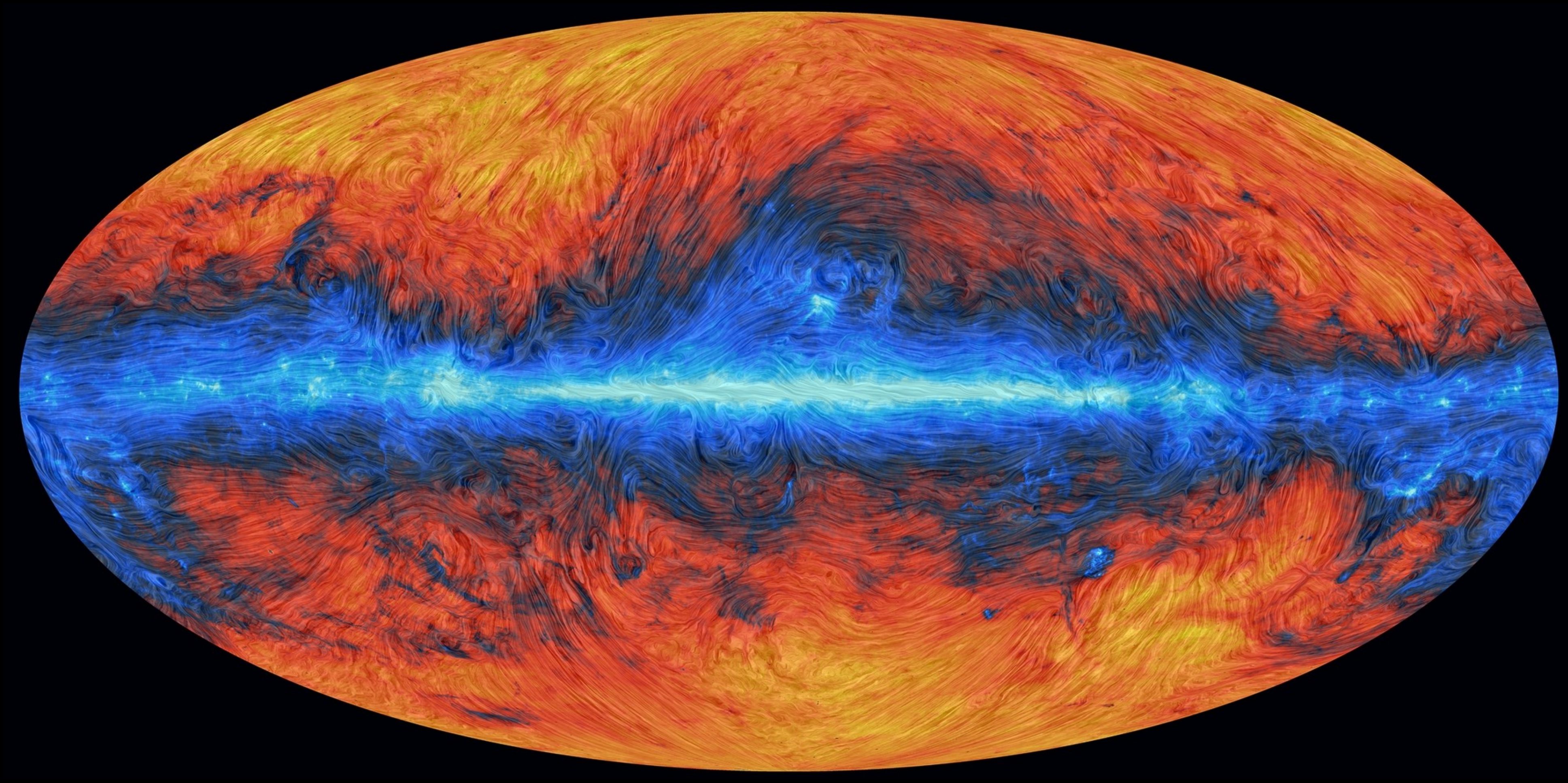
# The magnetic field

**Ordered, large-scale magnetic field**
**B  =  2 - 6 microGauss**

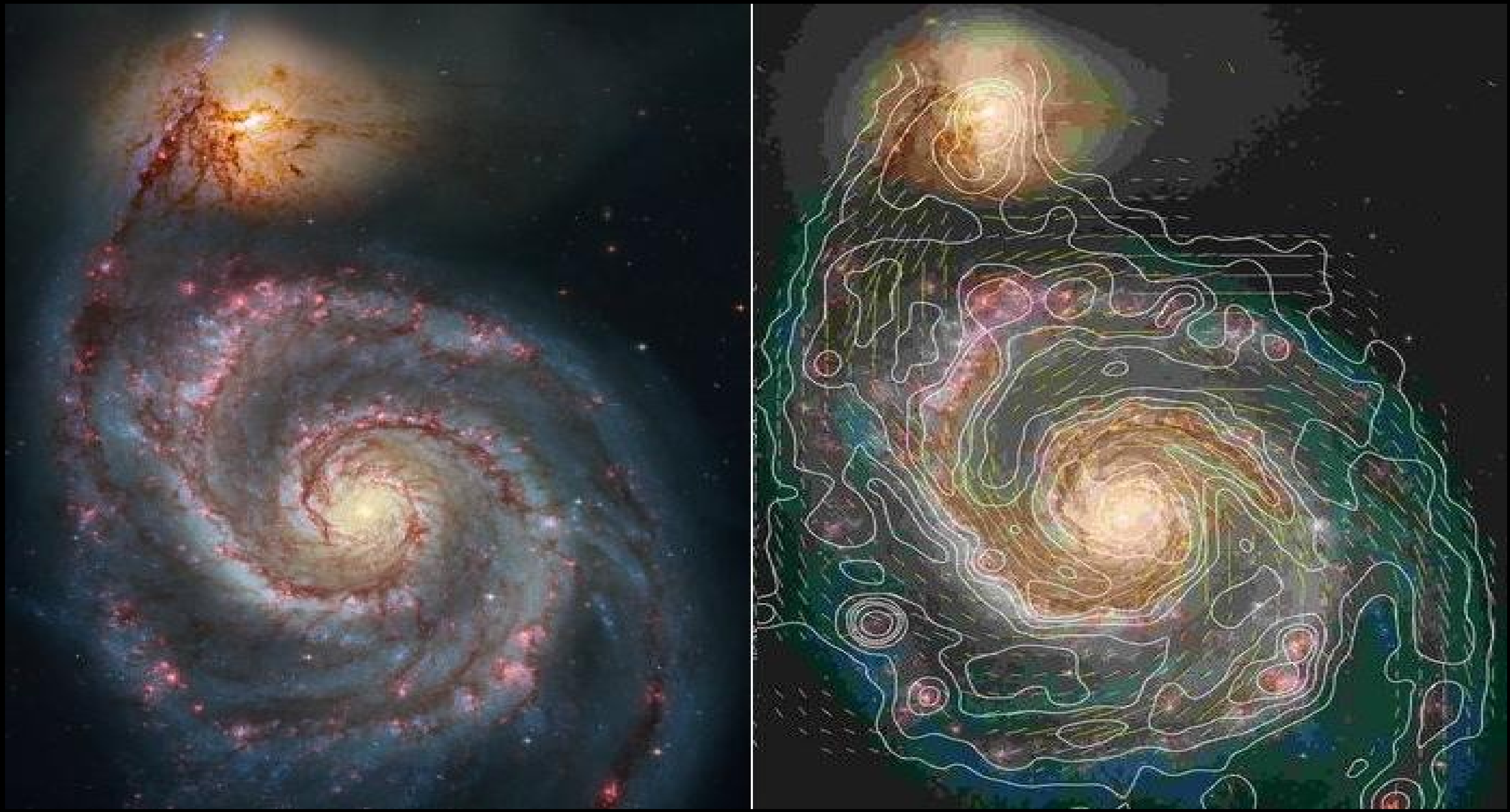
**Explored with:**

- **Radio continuum**
- **Starlight polarization**
- **Faraday Rotation**
- **Zeeman splitting**

# The magnetic field



# The magnetic field



# Interstellar Radiation Field

## Cosmic Background Radiation

## *Model* of the Interstellar Radiation Field

**Far Infrared (dust)**

**Near Infrared (late stars)**

**Optical/UV (OB stars)**

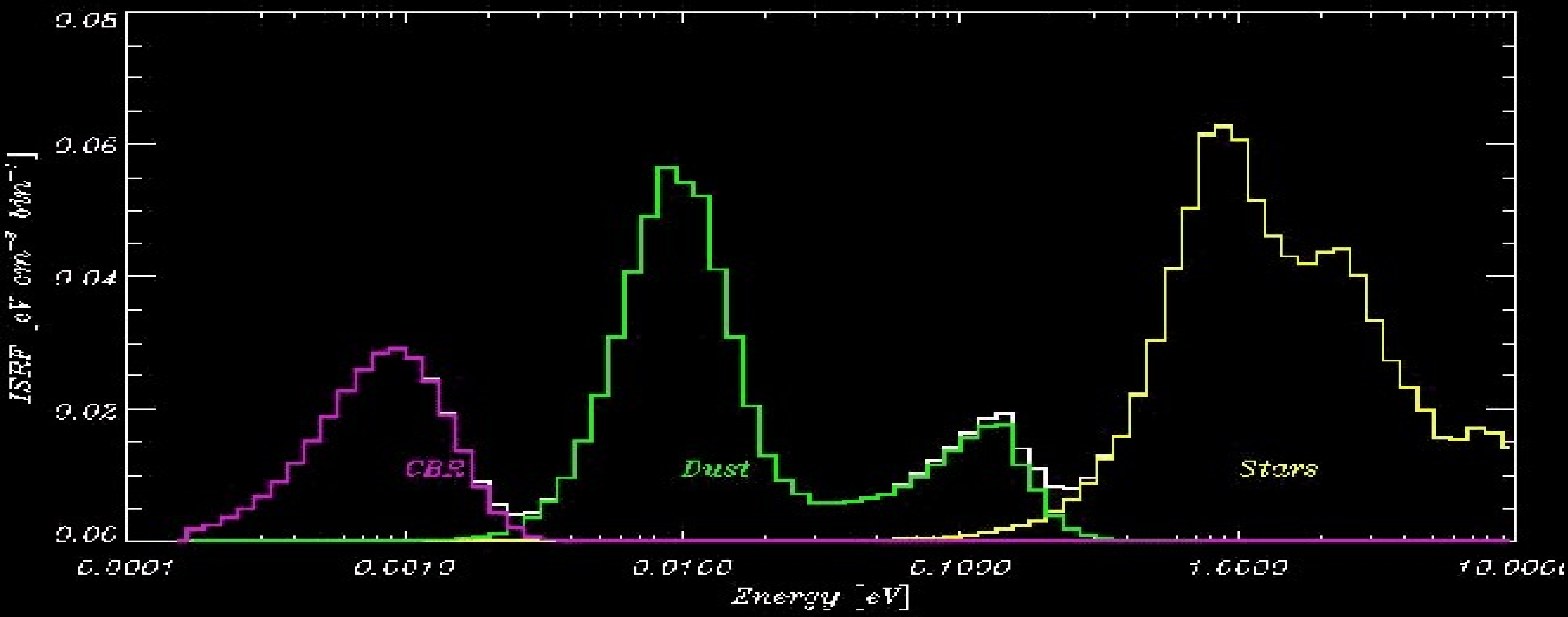
$$ISRF(\vec{r},\nu) = \int_{MW} \frac{\varepsilon(\vec{r}\,',\nu)}{|\vec{r}-\vec{r}\,'|^2}\, e^{-\int k(\vec{r}\,',\nu)\,ds}\, dV'$$

ISRF model :

**ε** from COBE/DIRBE emissivities + detailed stellar model

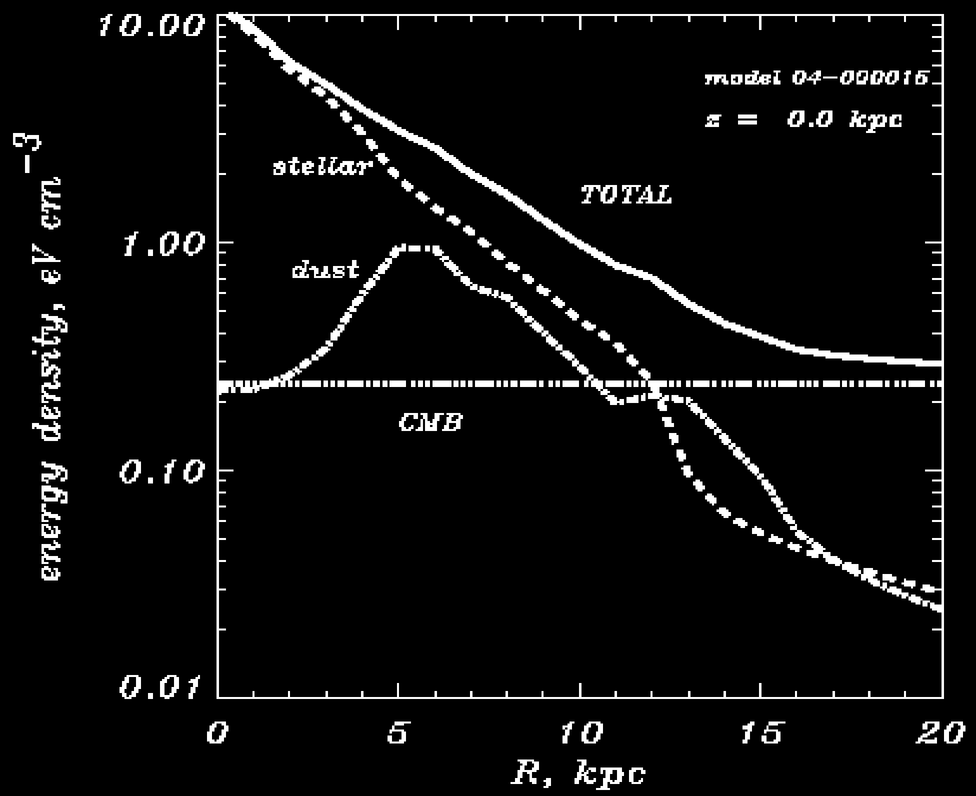
*k* from extinction curves, grain albedo

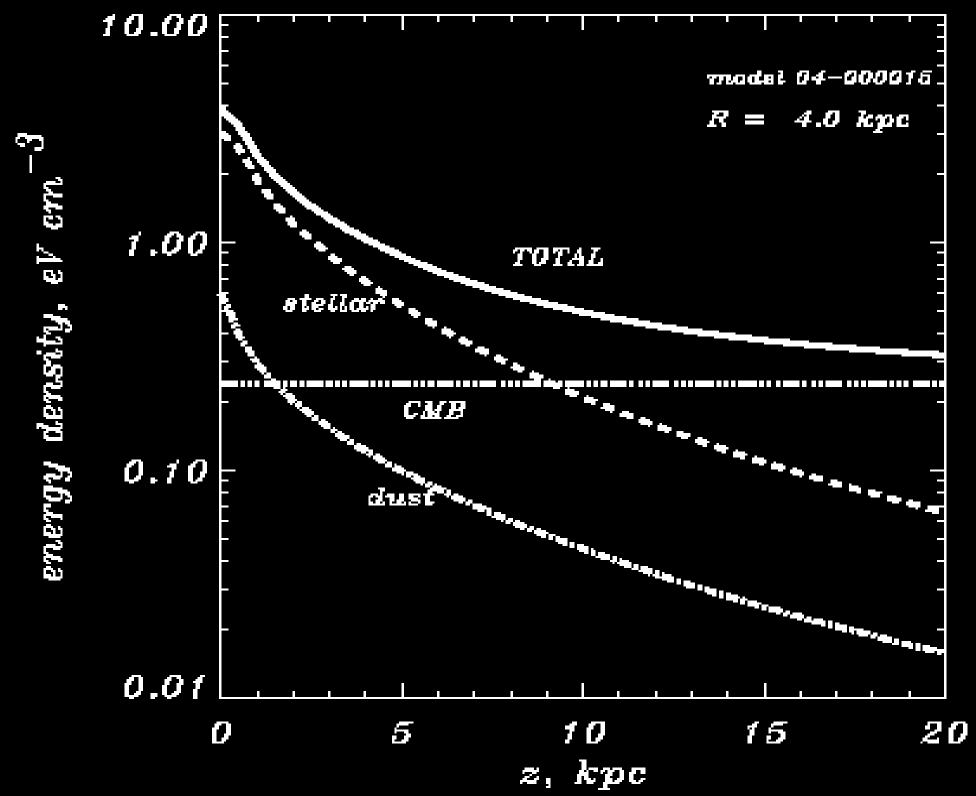
# The Interstellar Radiation Field




Strong, Moskalenko, & Reimer (2000)

# The Interstellar Radiation Field




Strong, Moskalenko, & Reimer (2000)