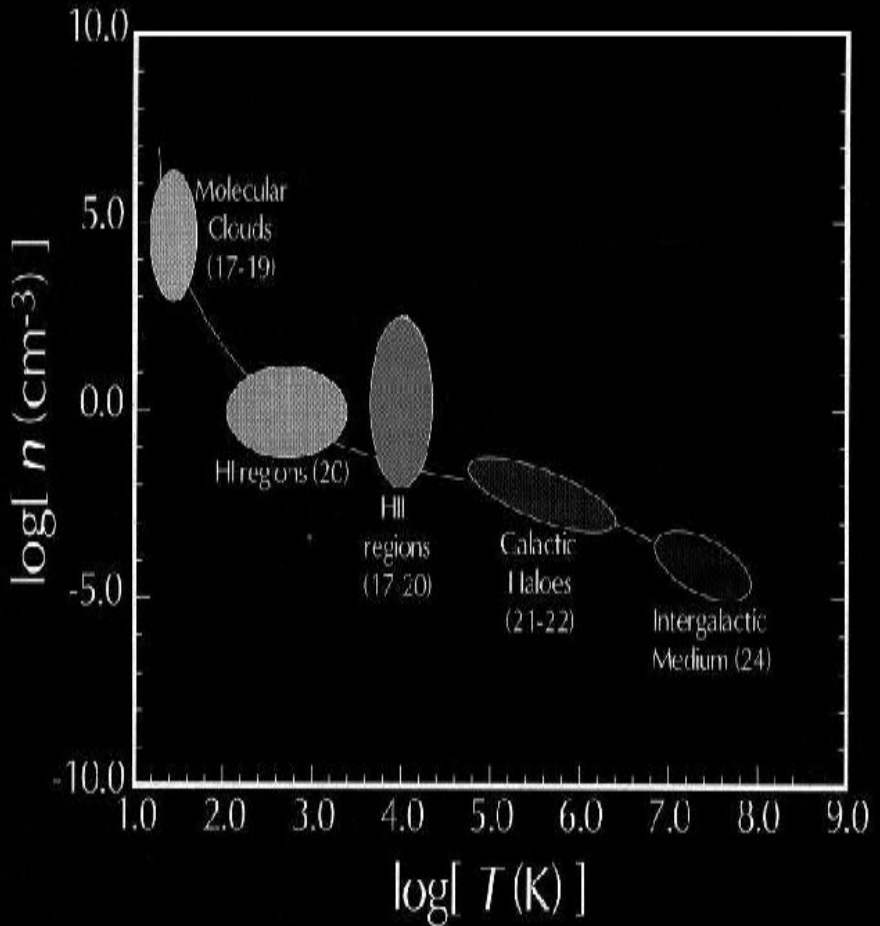
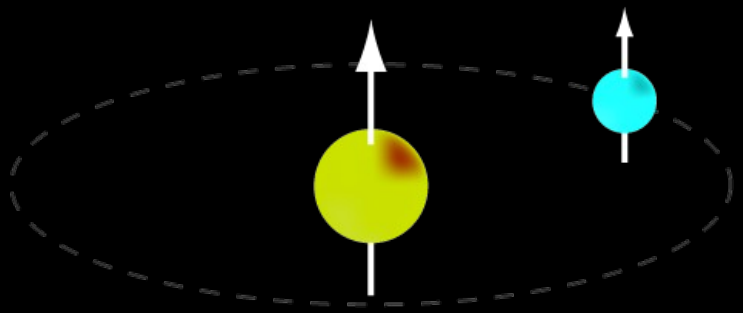
The Interstellar Medium

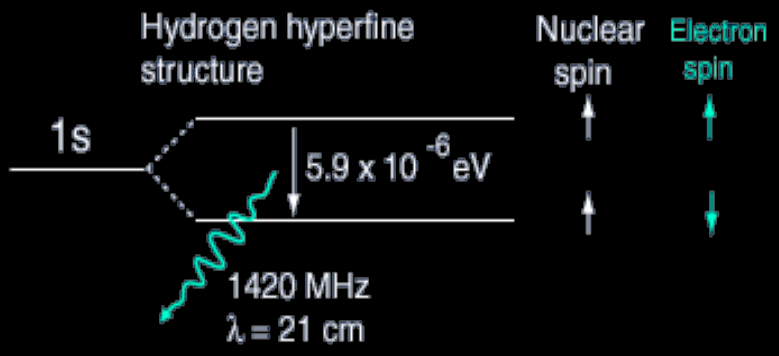
The 5 phases of the Interstellar matter



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

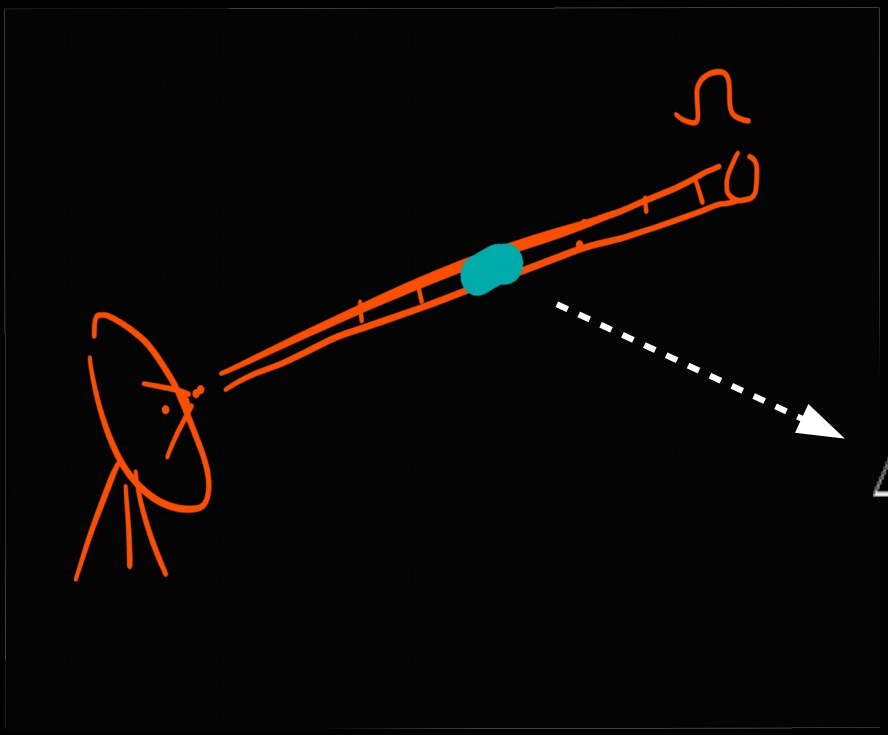
F = J + I = 0,1

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



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

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

Neutral Hydrogen Survey

Leiden-Dwingeloo survey at 21 cm

(Hartmann et al 1997)

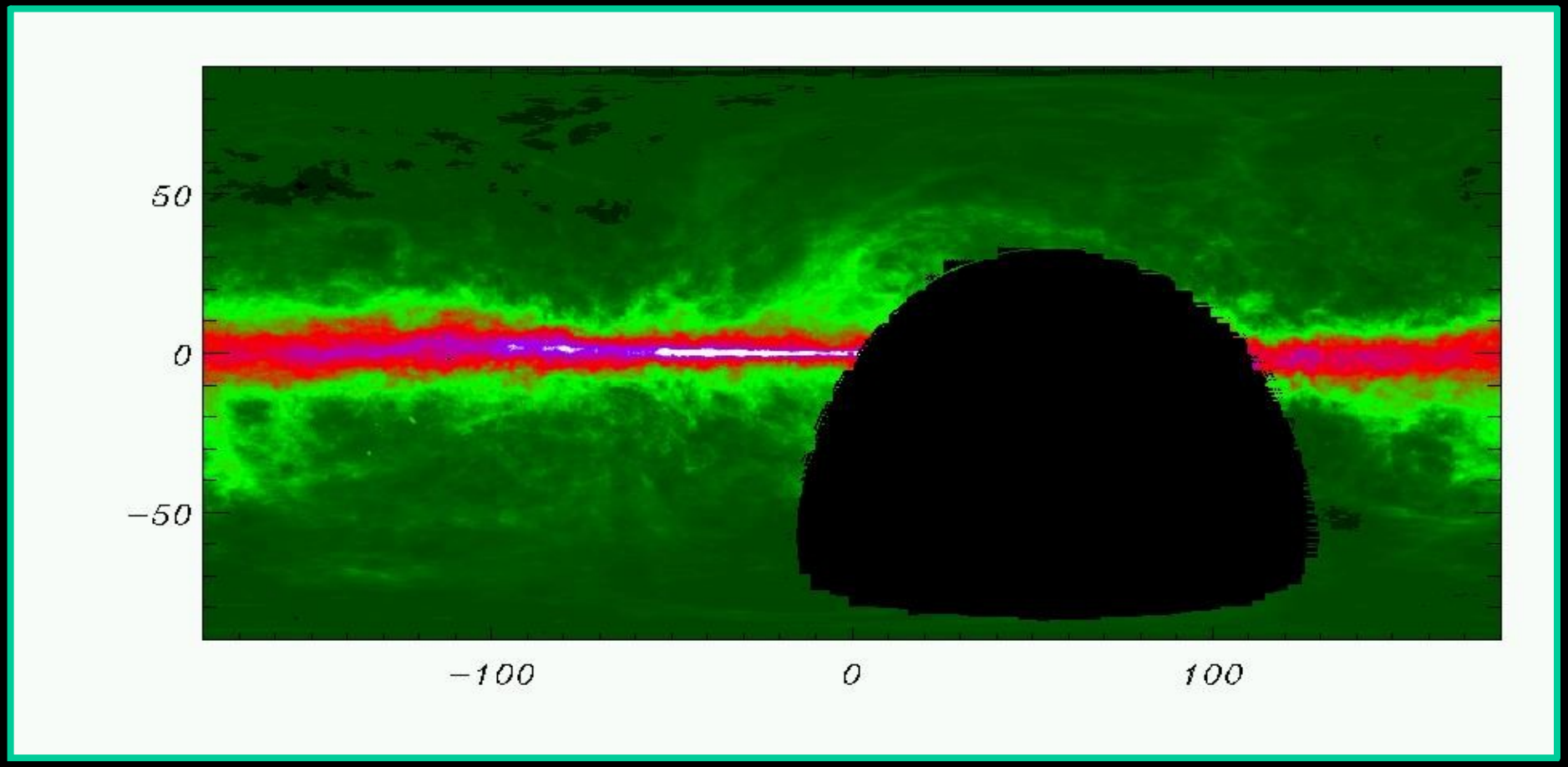
Spatial resolution: 30’

Velocity resolution: 1.03 km/s

Velocity range: -450,400 km/s

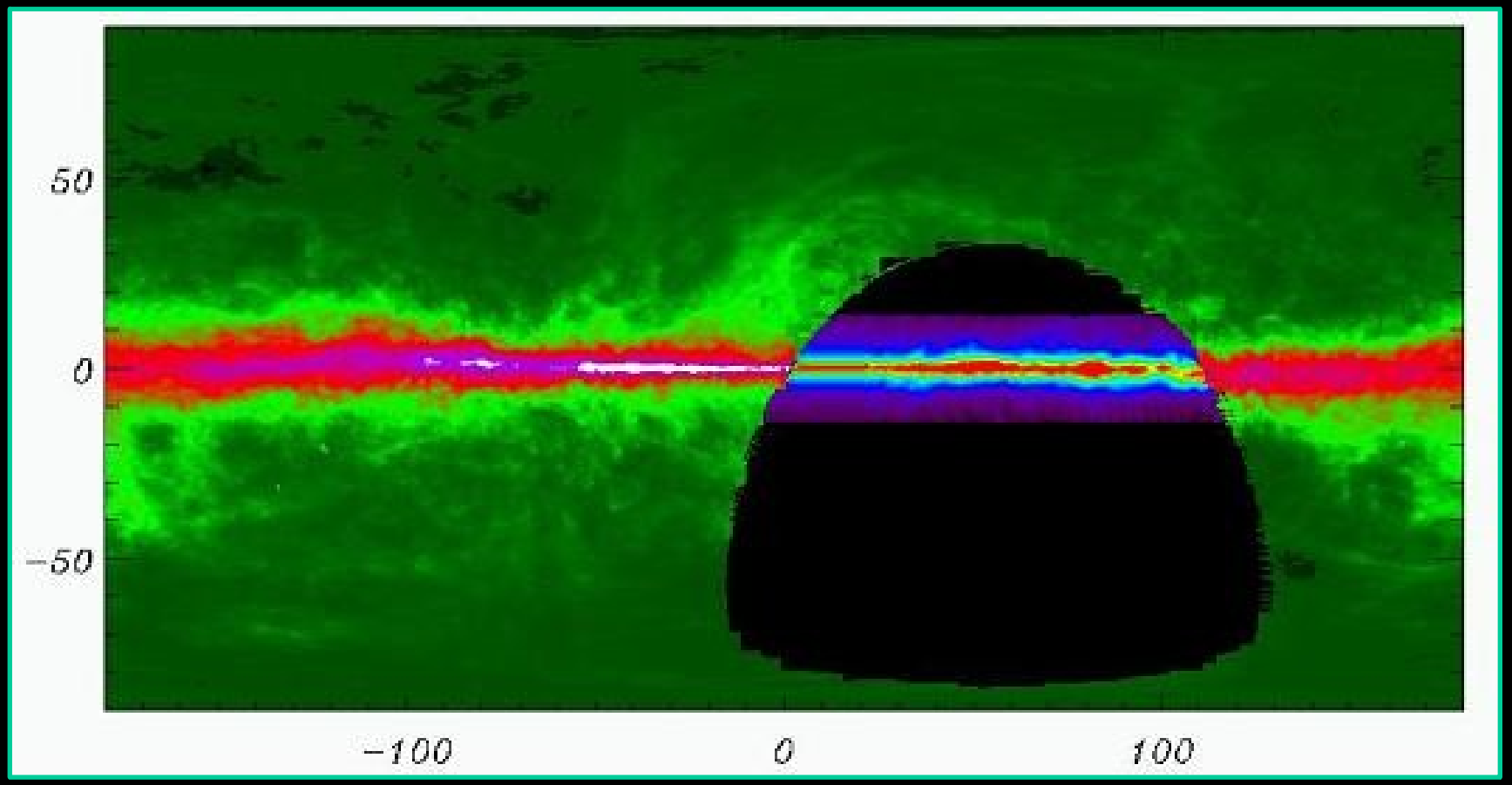
Sensitivity: 0.07° K

Neutral Hydrogen



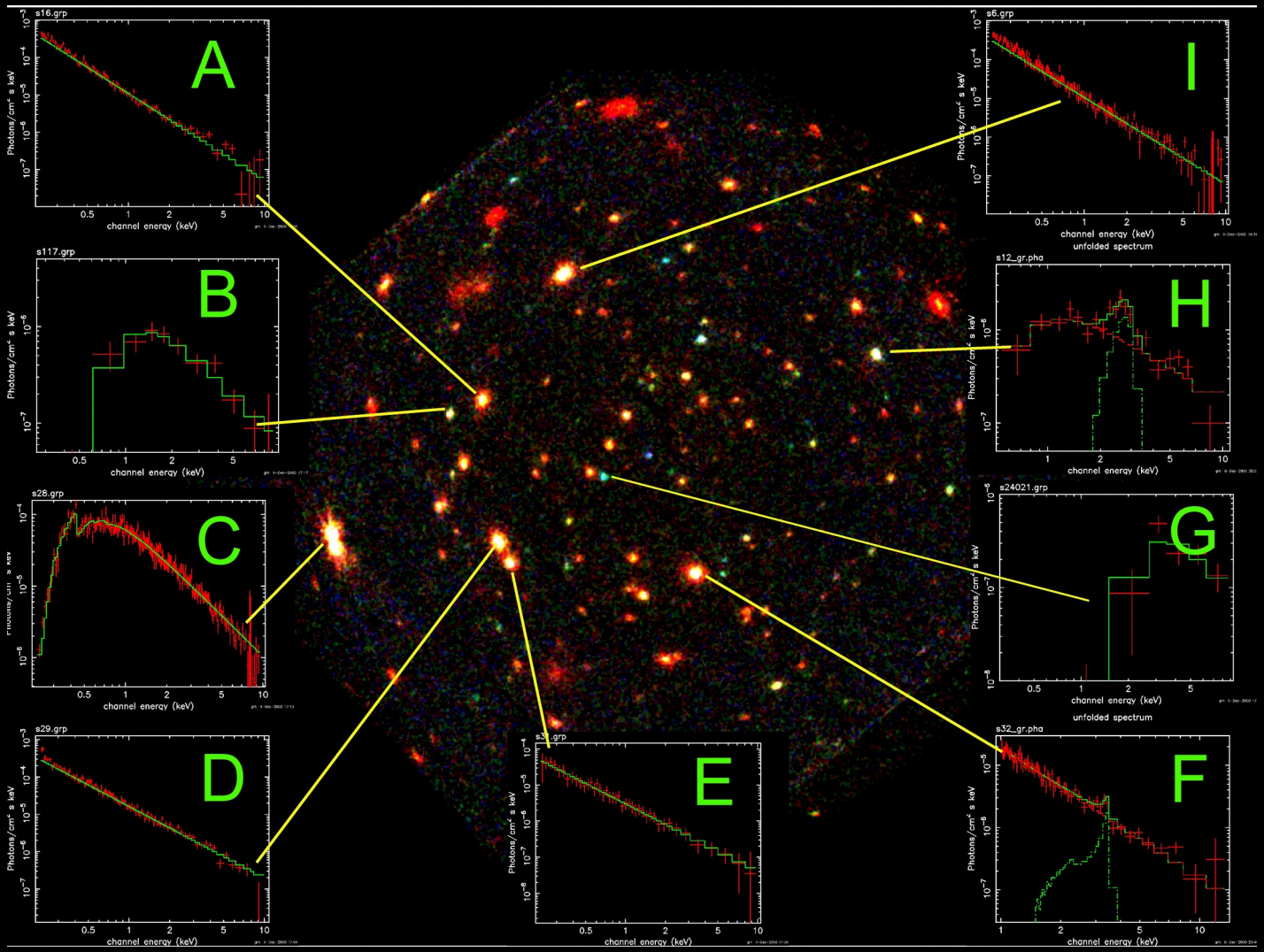
Leiden-Dwingeloo survey at 21 cm (Hartmann et al 1997)

Neutral Hydrogen

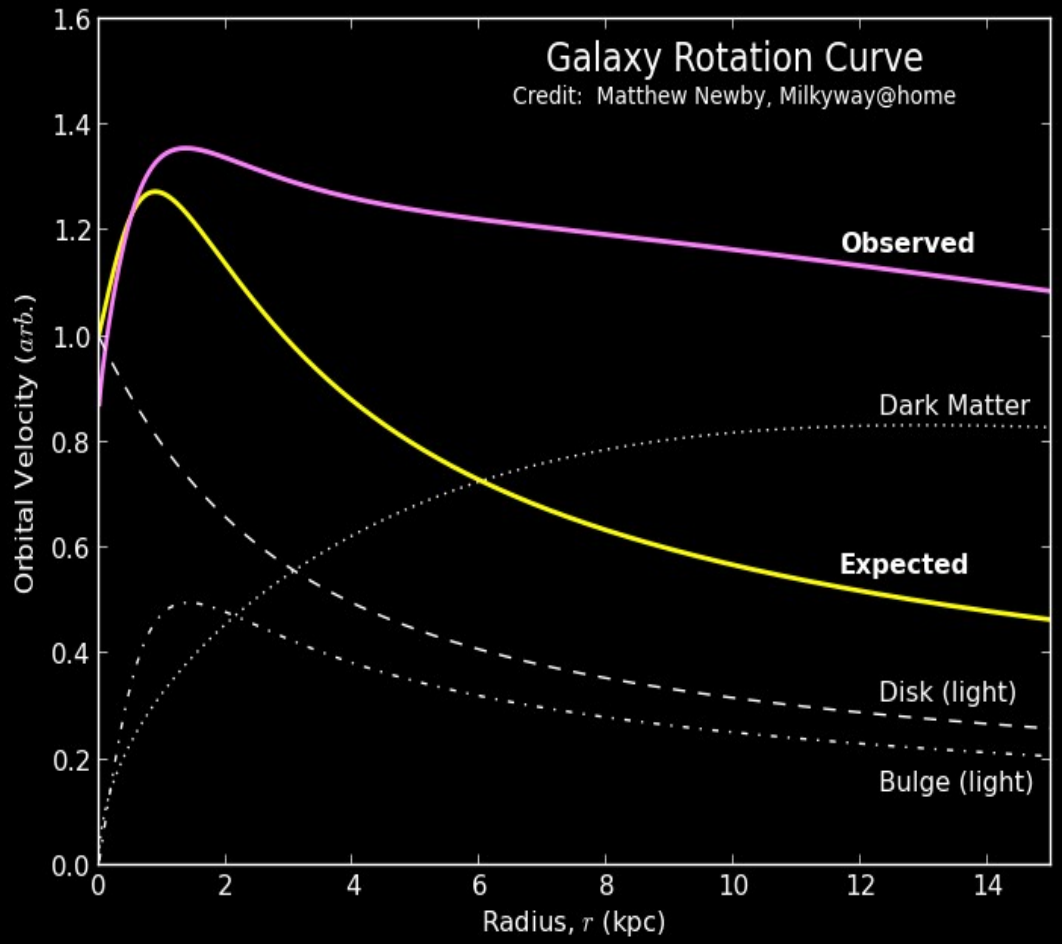


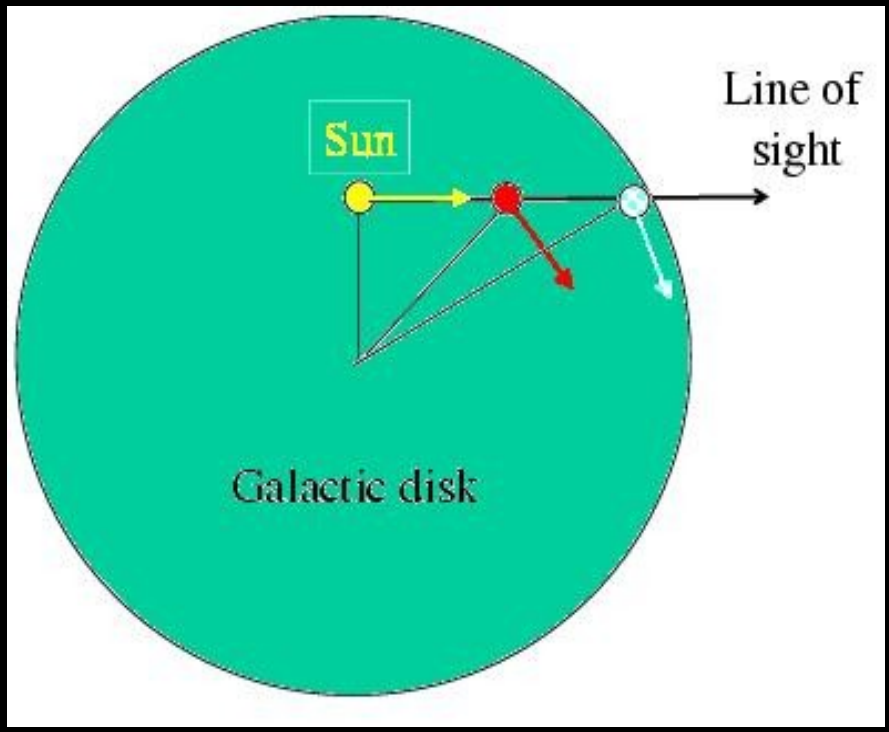
Leiden-Dwingeloo survey + Parkes (Kerr et al 1986)

Lockman Hole

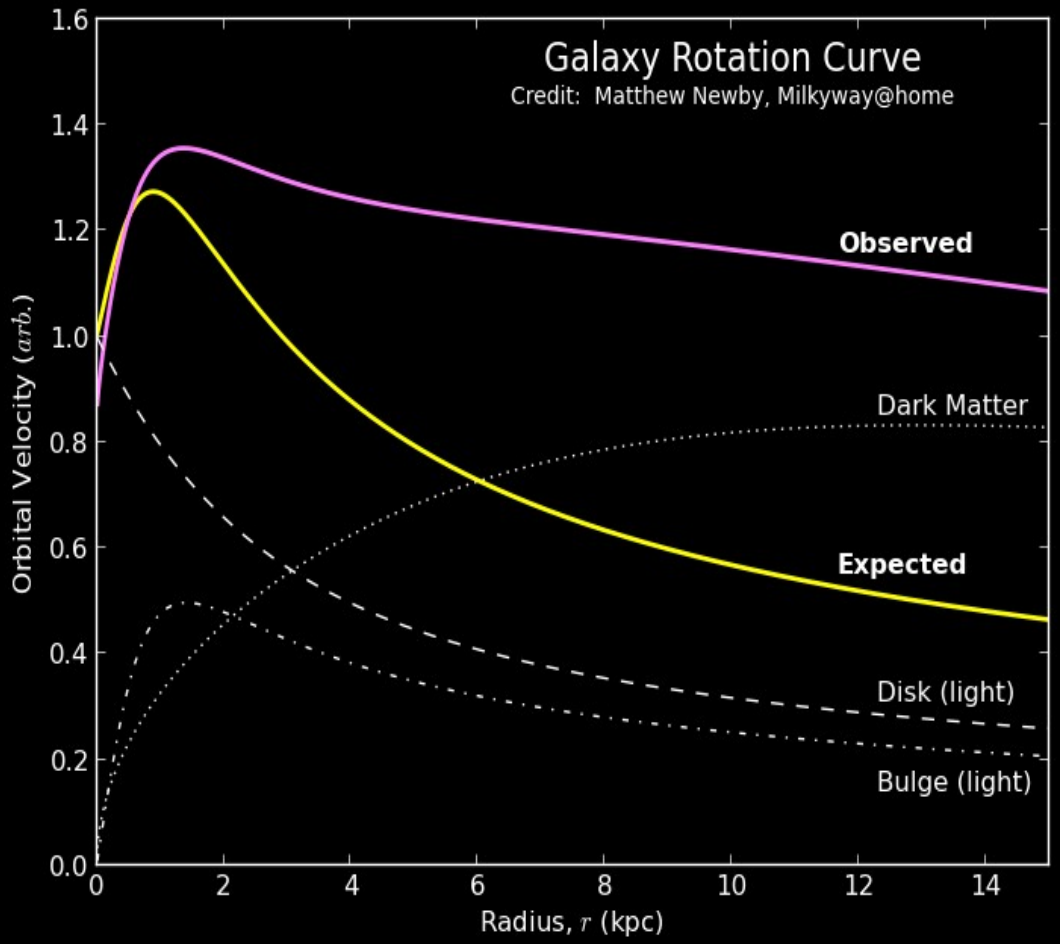


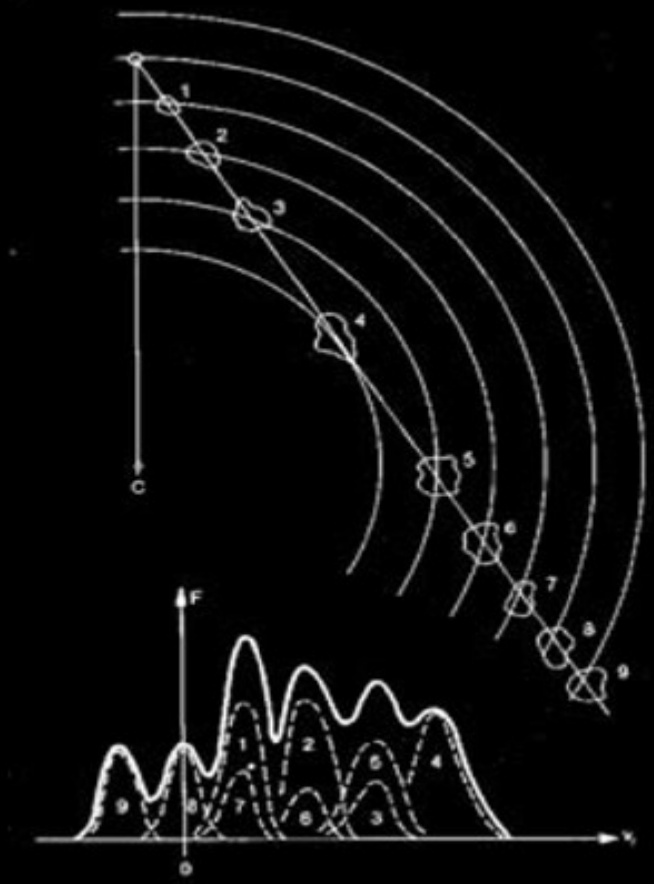
Radio Data deprojection



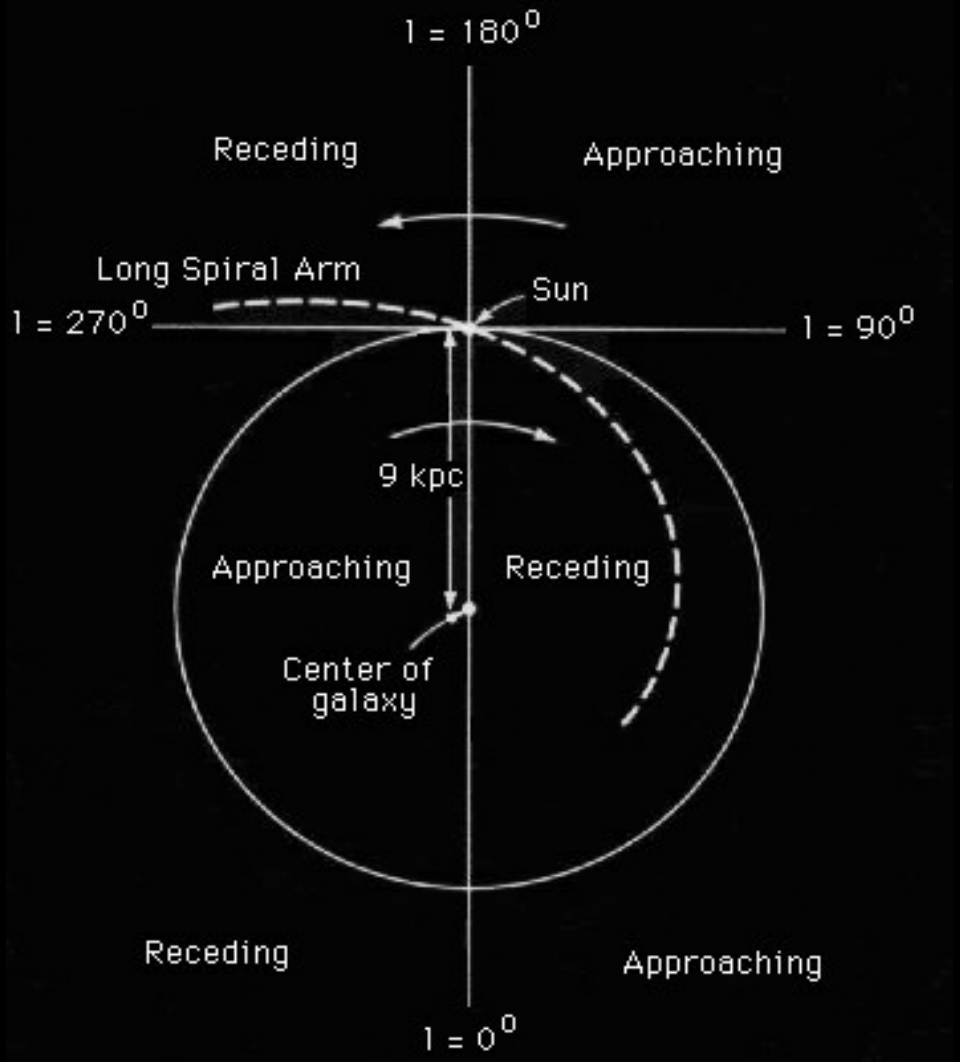


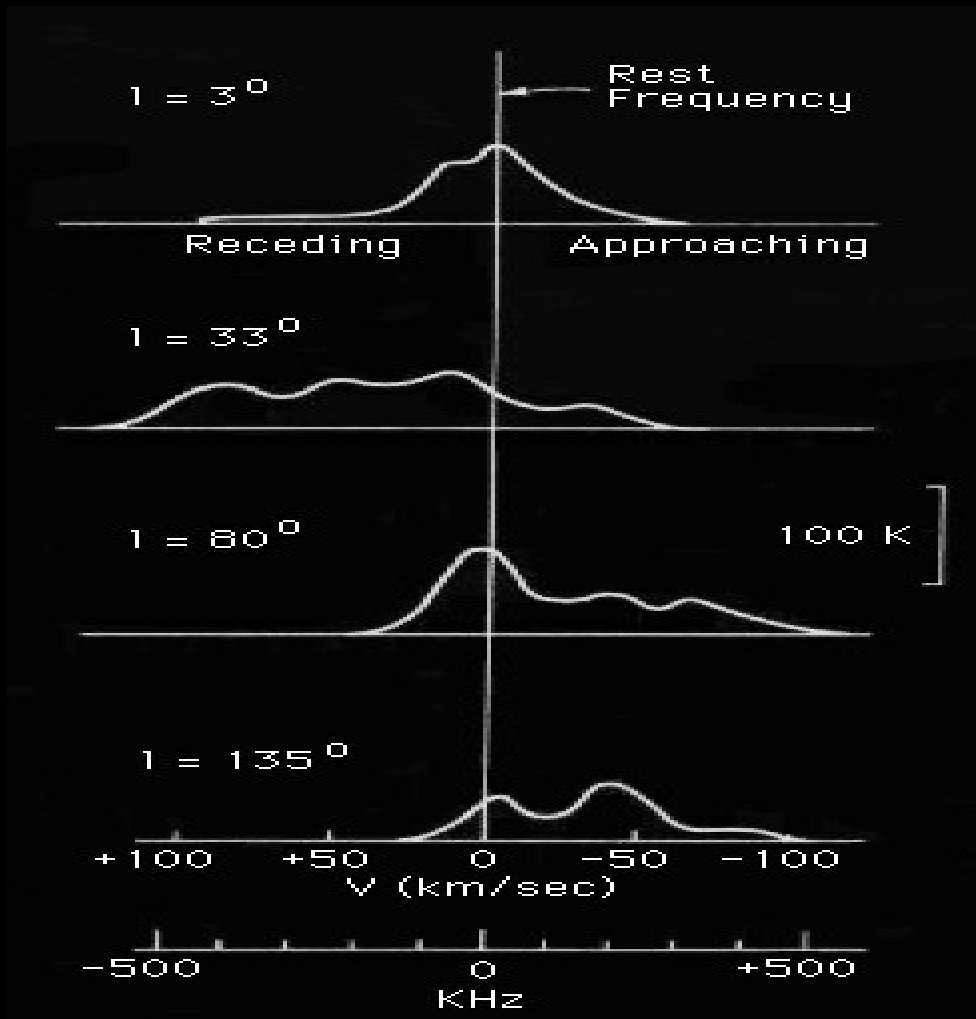
Radio Data deprojection



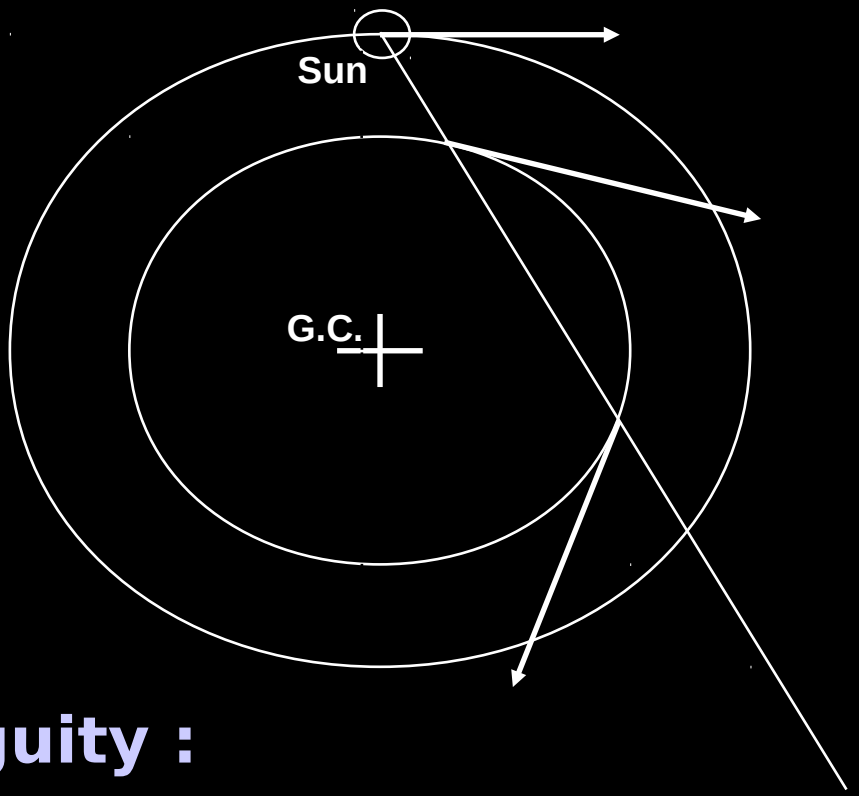


Radio Data deprojection





Near-Far distance ambiguity:



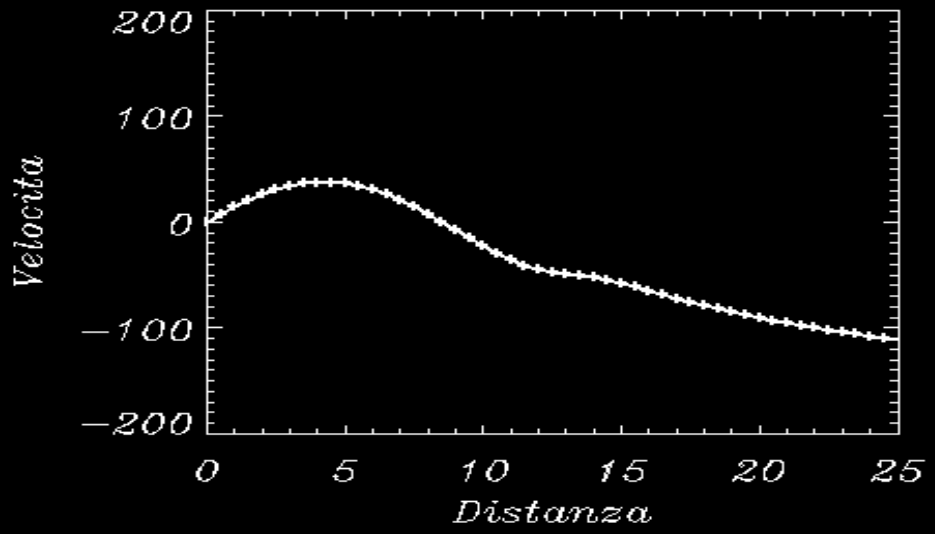
Dinamical ambiguity :

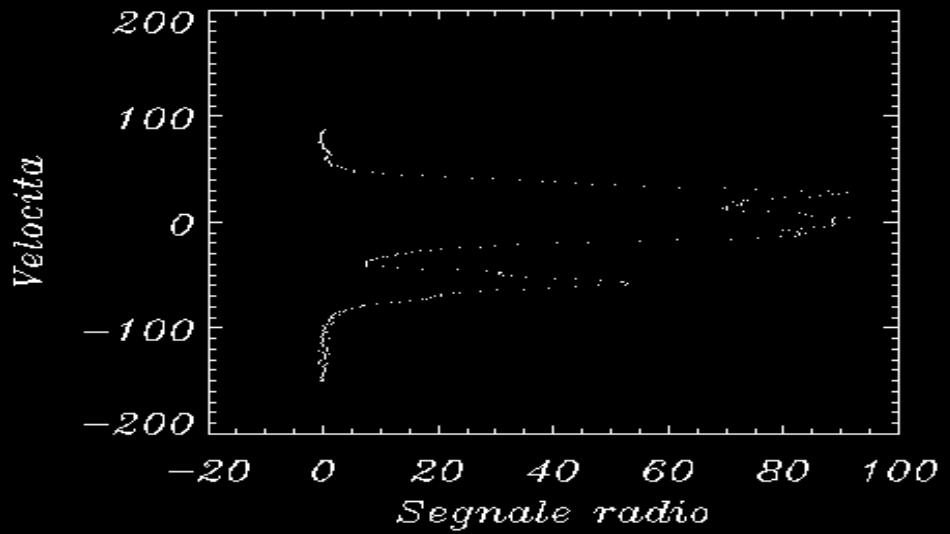
$$w.f. \propto e^{-\frac{1}{2}\frac{z}{Z_{gas}}}$$

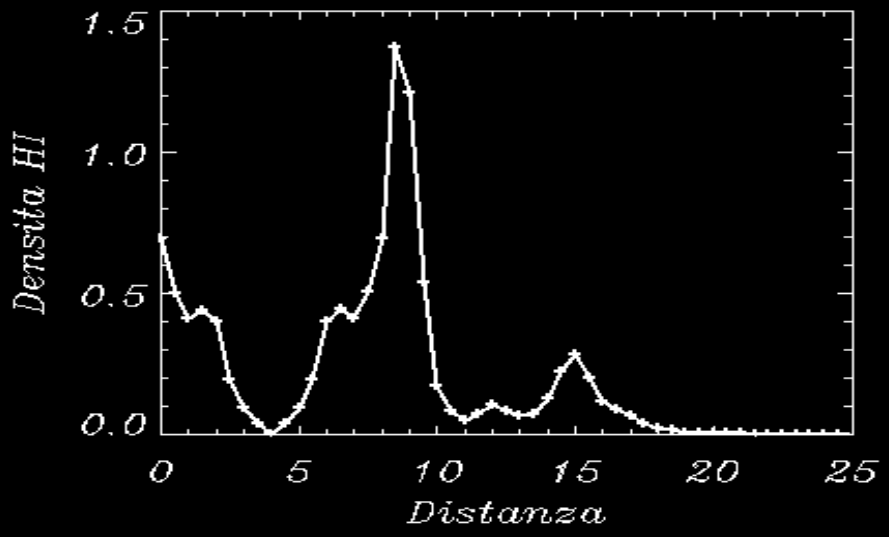
Z_{gas} = 100 *pc* for HI

Z_{gas} = 60 *pc* for H_2

Radio Data deprojection







Lat. 0.00000

Long. 60.0000

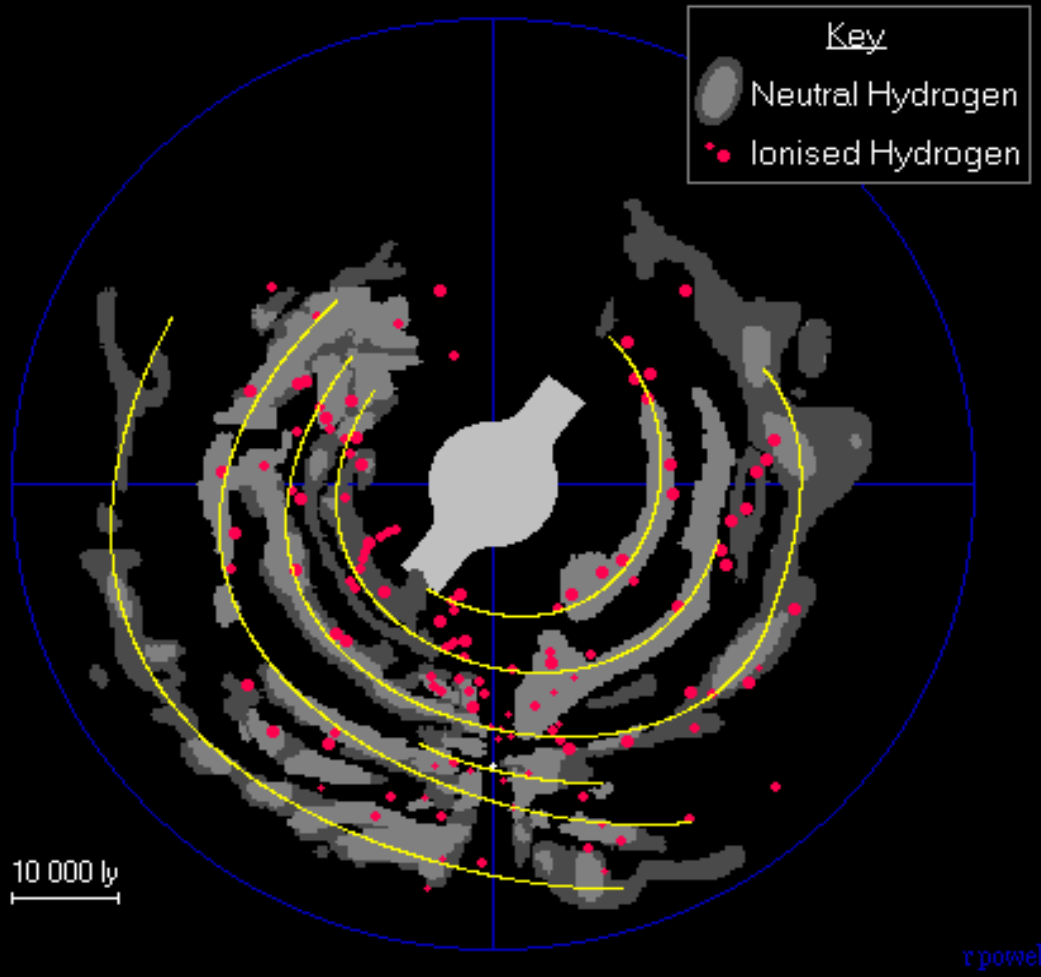
Absorbed HI

HI density :

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

$T_S = 125\ K$

Neutral Hydrogen (HI)



Two phase medium in pressure balance

Cold (100 K)

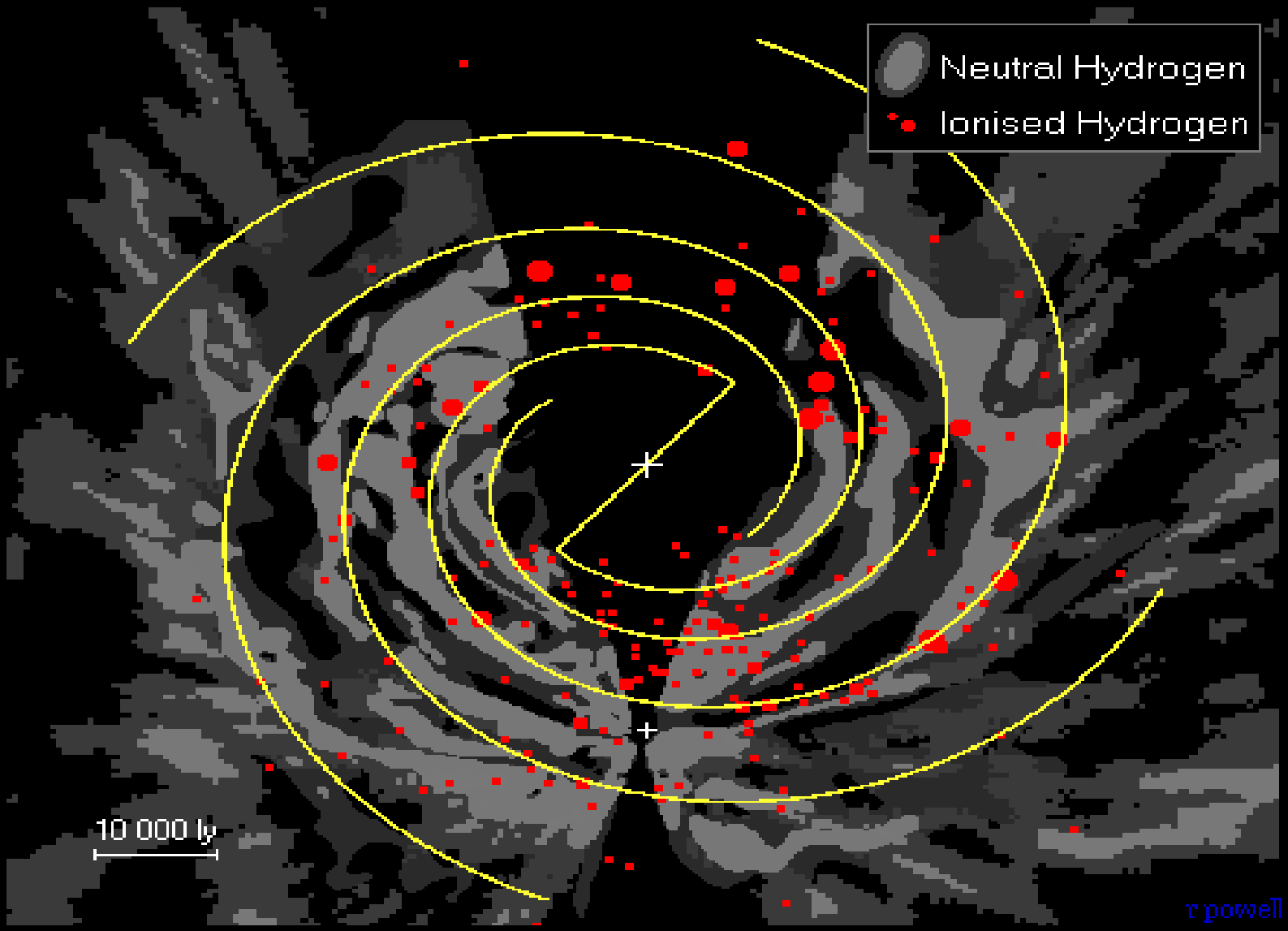
Mass

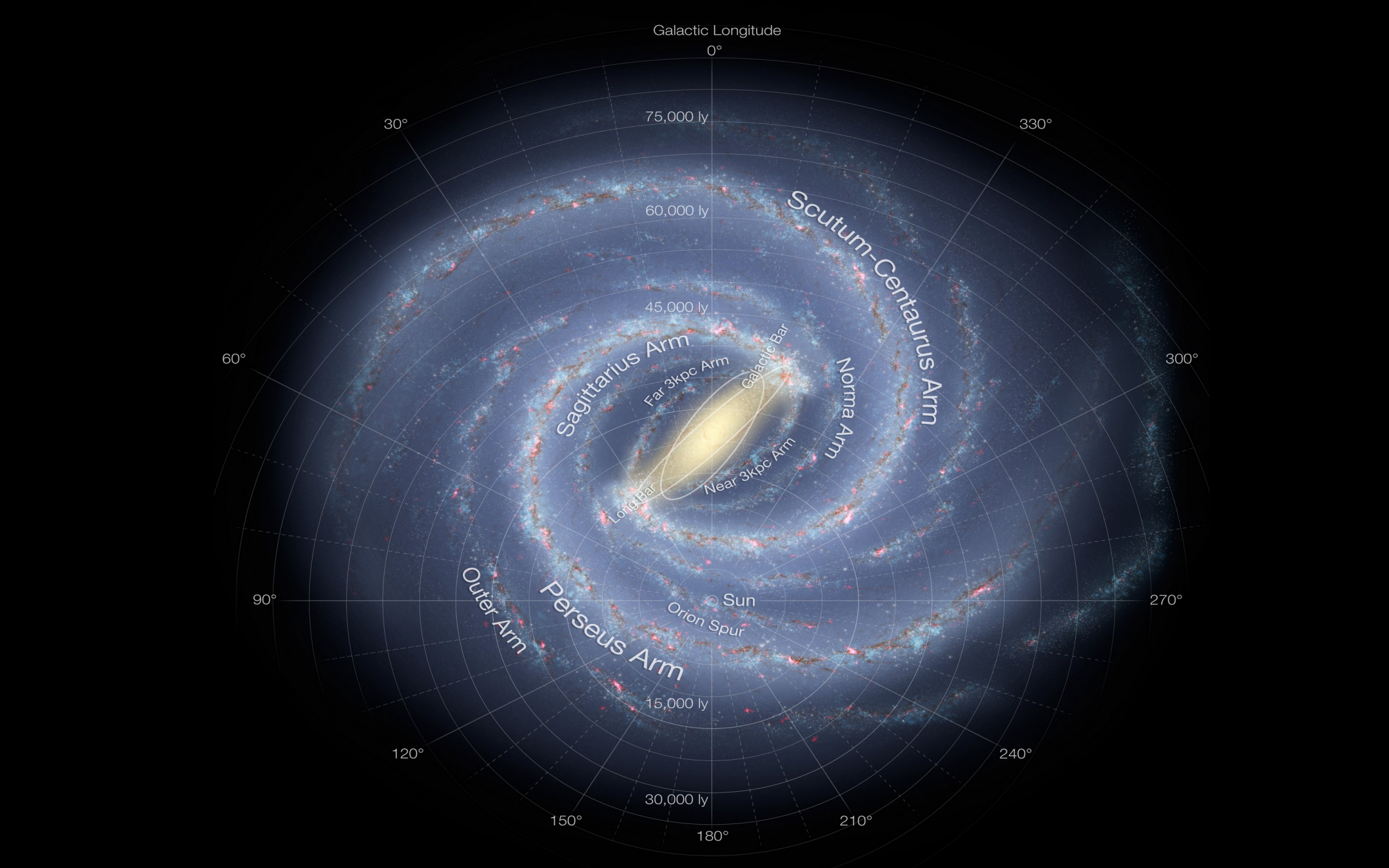
Dense sheet

No grav. Bound

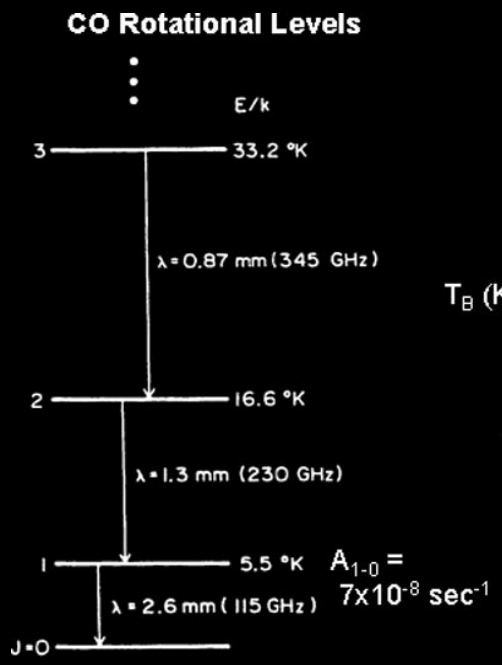
n = 20–60 cm^{-3}

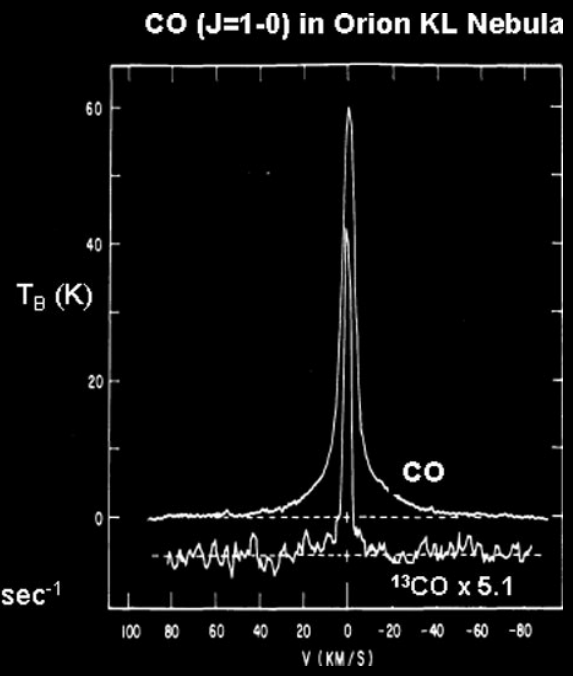
Warm (6000 K)


Neutral Hydrogen
Ionised Hydrogen
10 000 ly
r powell


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

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}

Molecular Hyd. density :

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

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

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

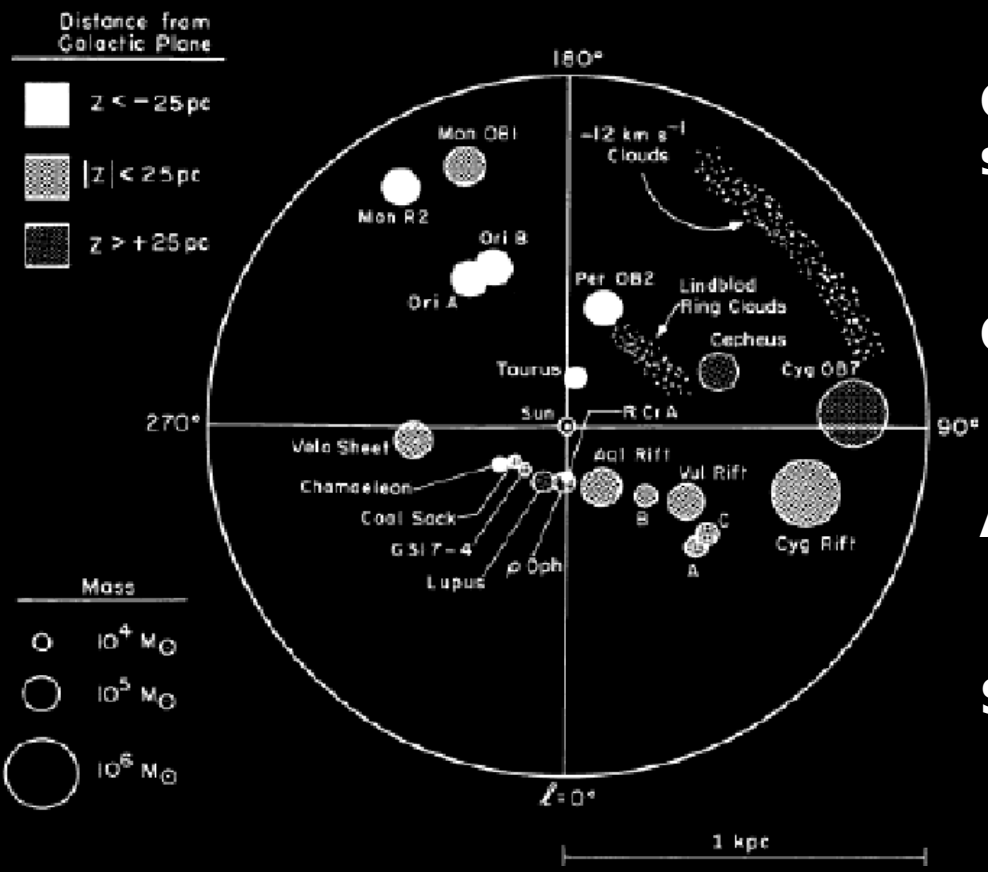
Sensitivity: 0.62° K

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

CO Survey →Molecular Clouds

CO Survey →Molecular Clouds

The molecular clouds

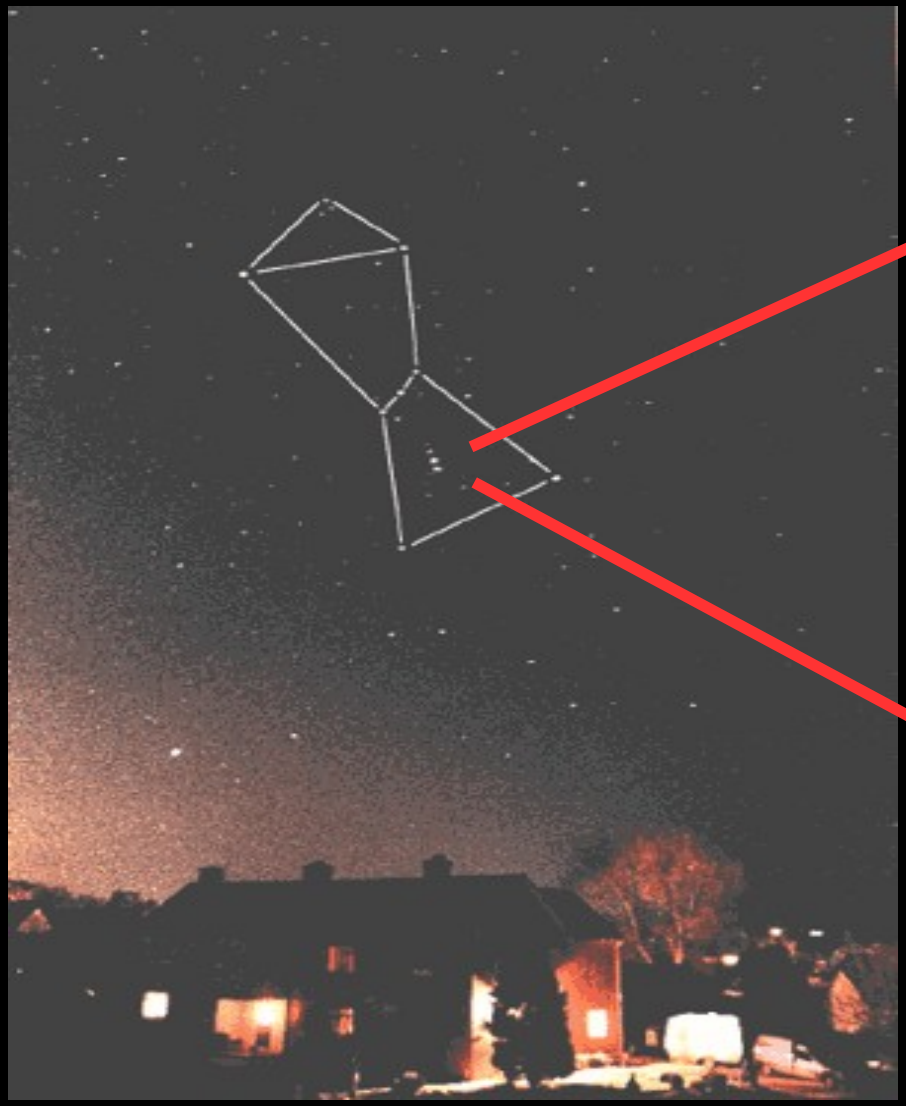


Concentrated in *Giant Clouds* (10^3 -10^7 Msol) self graviting with n > 10^3 cm^{-3}

Optically thick (dust, H_2)

Along spirala arms

Small scale thickness (120 pc)



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**

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

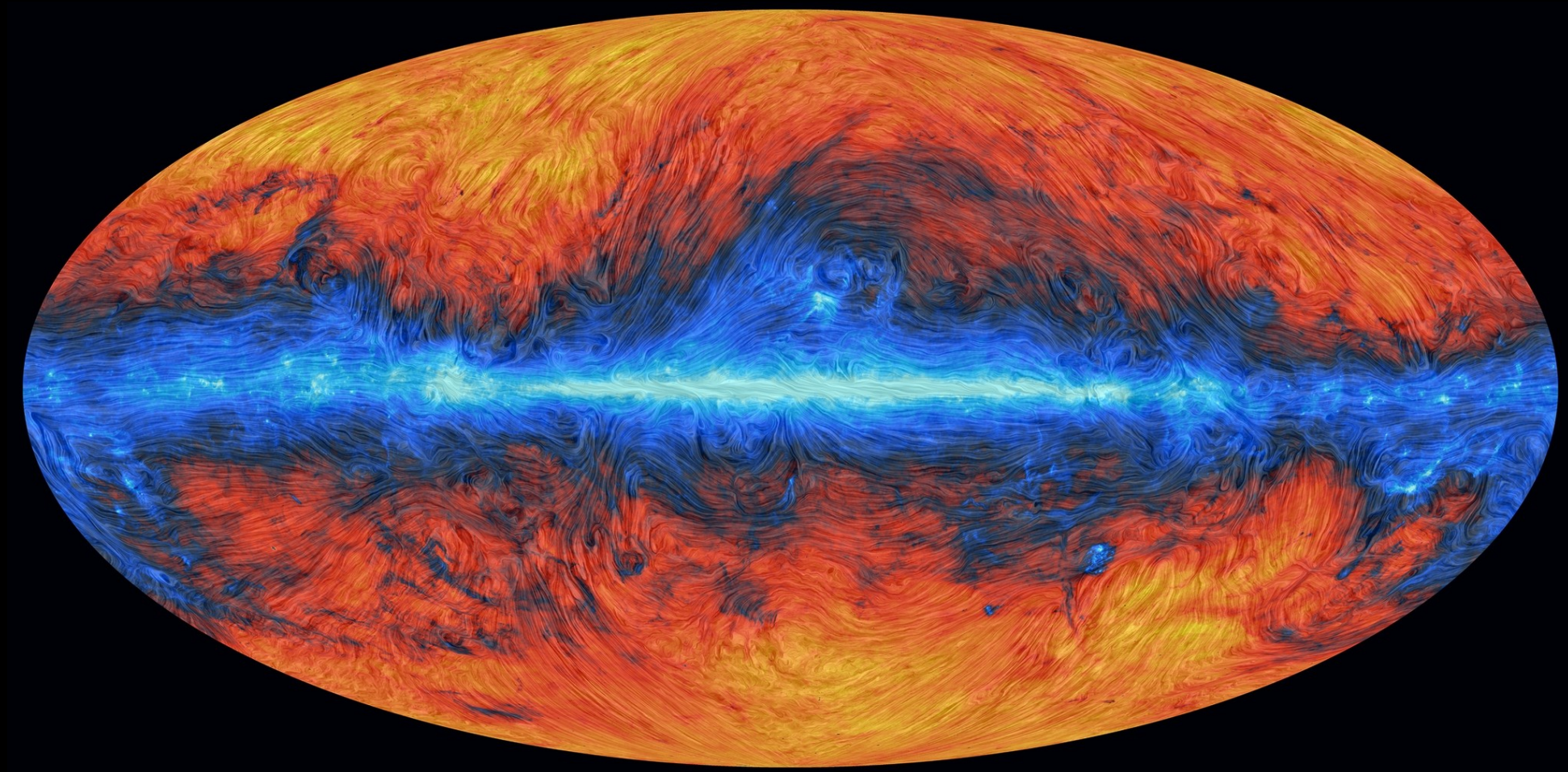
The magnetic field

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

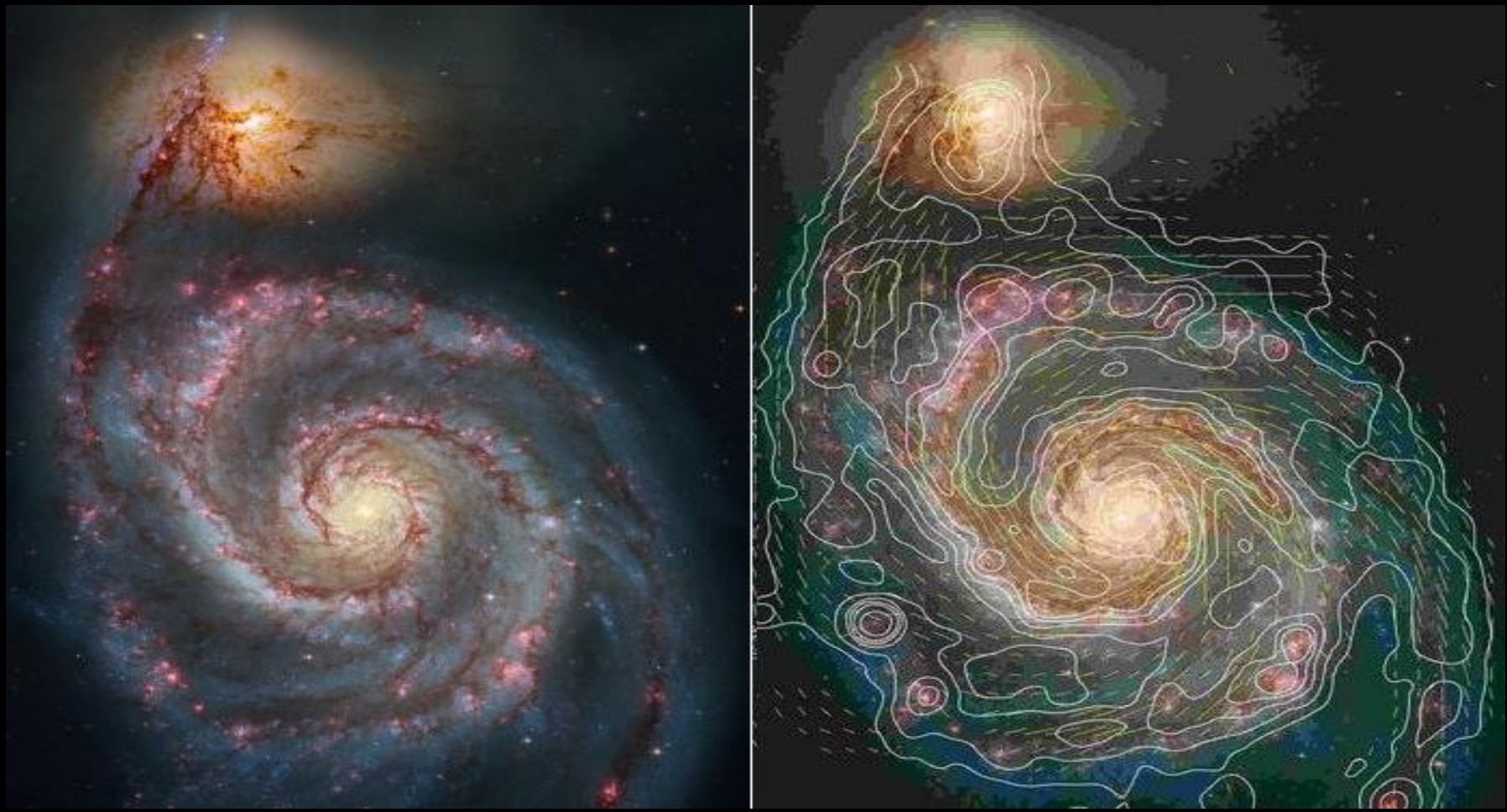
Explored with:

- **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)

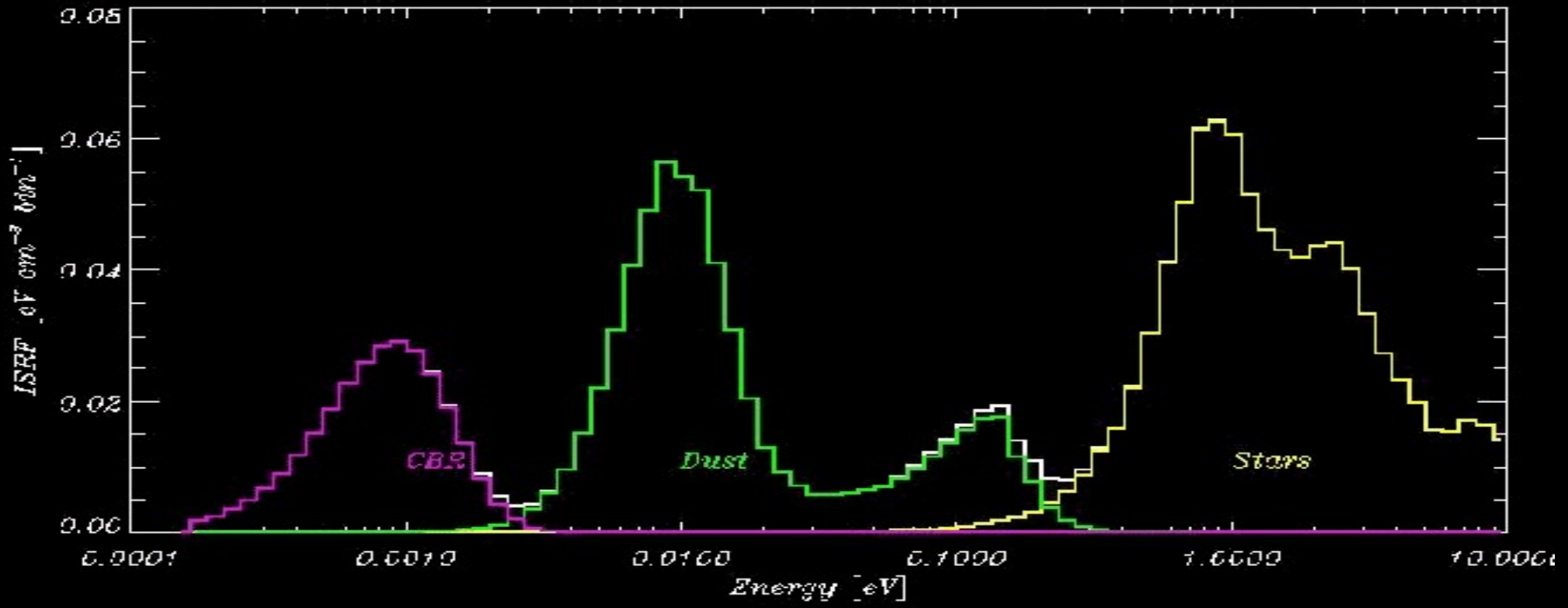
$$ISRF(\vec{r},\nu)=\int_{MW}\frac{\varepsilon(\vec{r}',\nu)}{|\vec{r}-\vec{r}'|^2}\,e^{-\int k(\vec{r}',\nu)\,ds}\,dV'$$

ISRF model :

ε from COBE/DIRBE emissivities + detailed stellar model

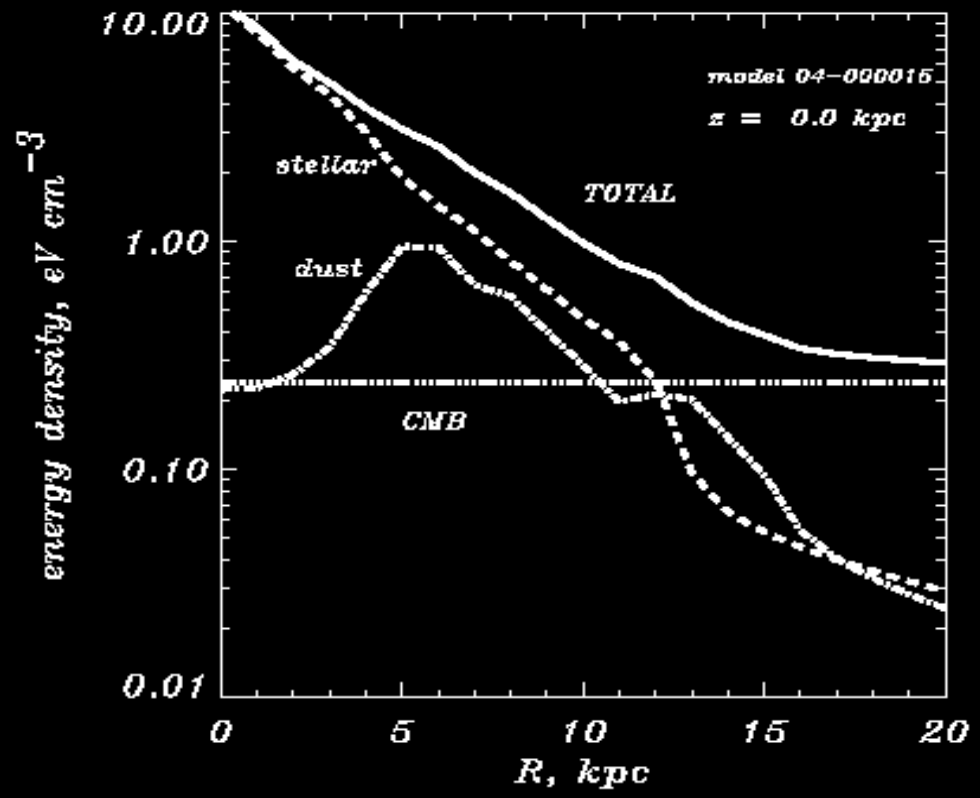
k from extinction curves, grain albedo

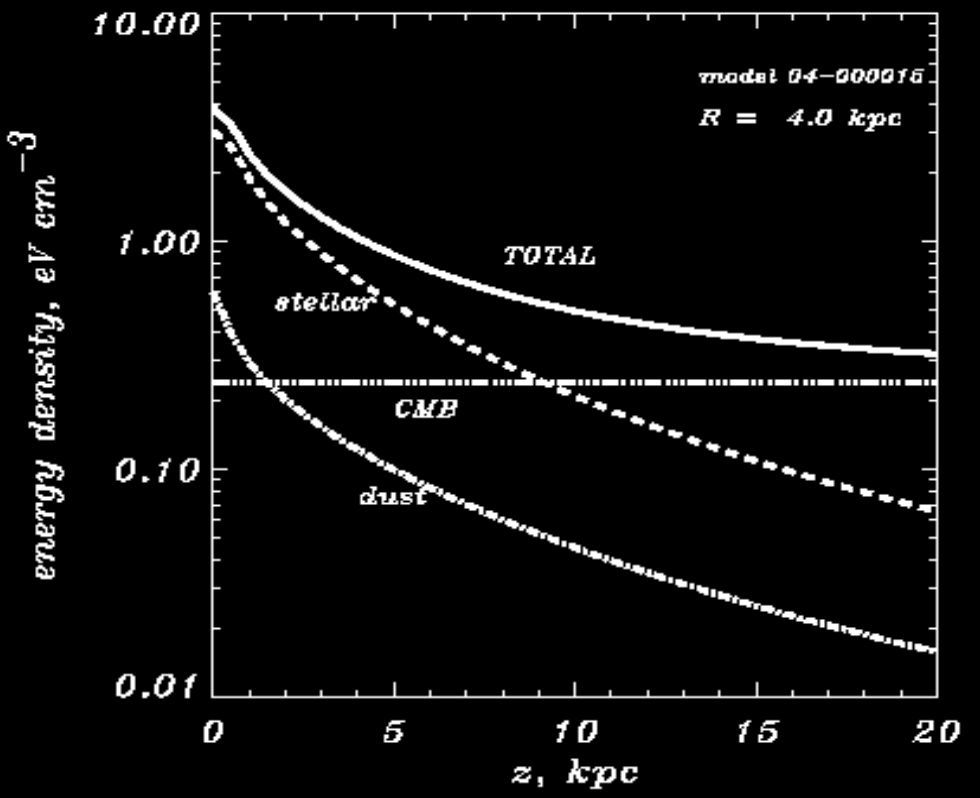
The Interstellar Radiation Field



Strong, Moskalenko, & Reimer (2000)

The Interstellar Radiation Field





Strong, Moskalenko, & Reimer (2000)