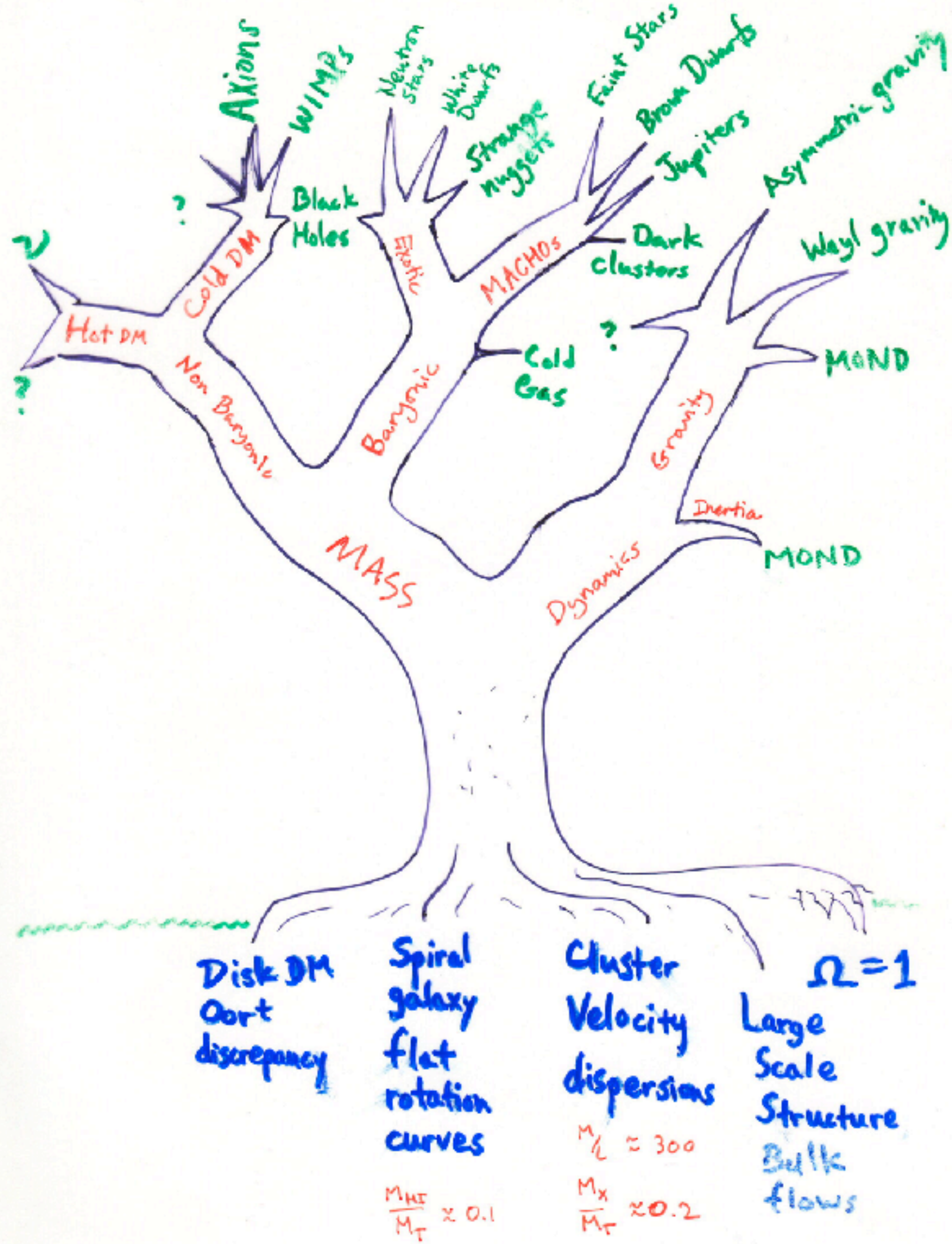
Dark Matter

ASTR 333/433
Spring 2016
T R 4:00-5:15pm
Sears 552

TODAY

- Interstellar medium
  - Atomic gas (HI)
  - Molecular gas (H2)
  - Ionized gas (HII)
  - Dust
- Galactic Structure
  - Galactic Constants
  - Kinematics

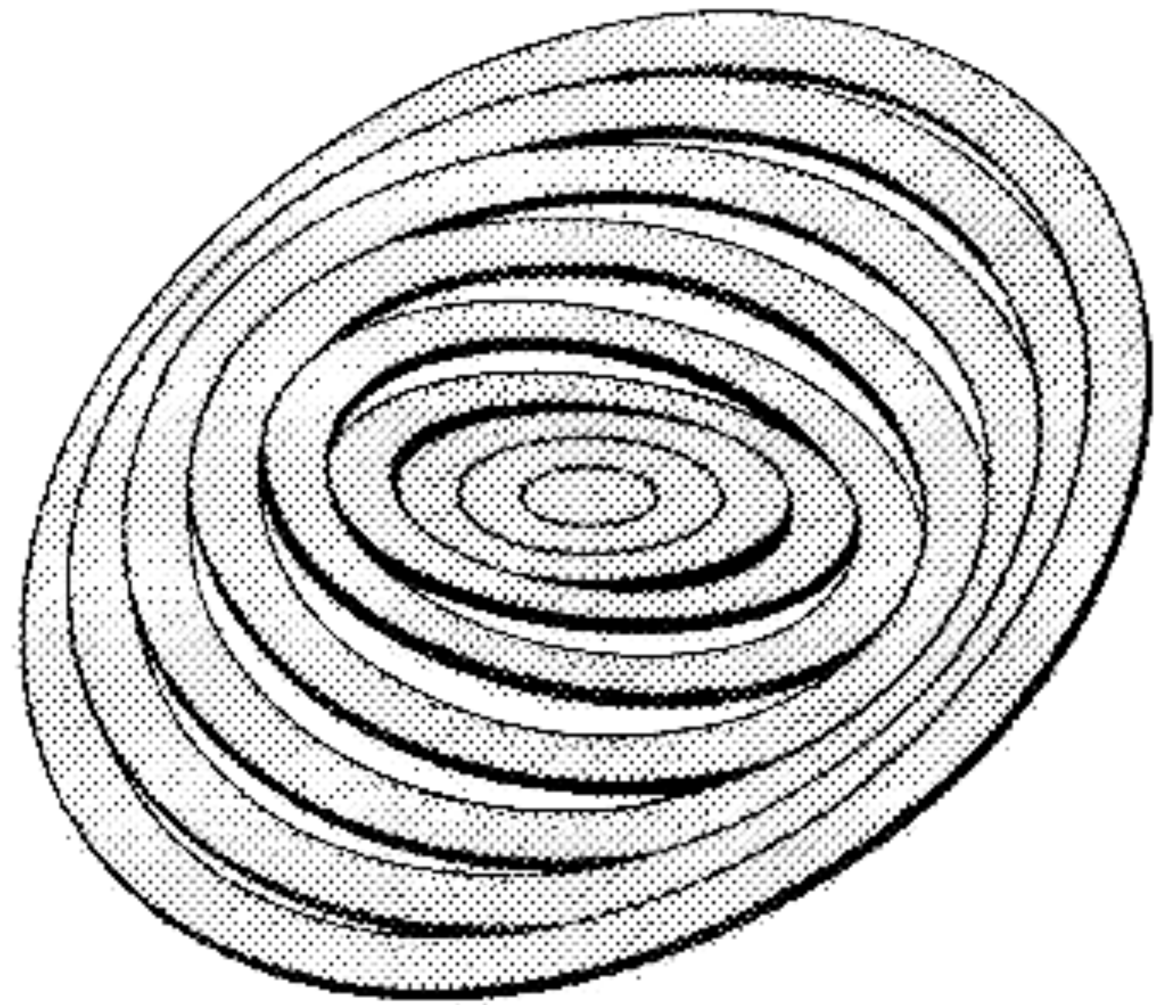
Homework 1
DUE Next Time

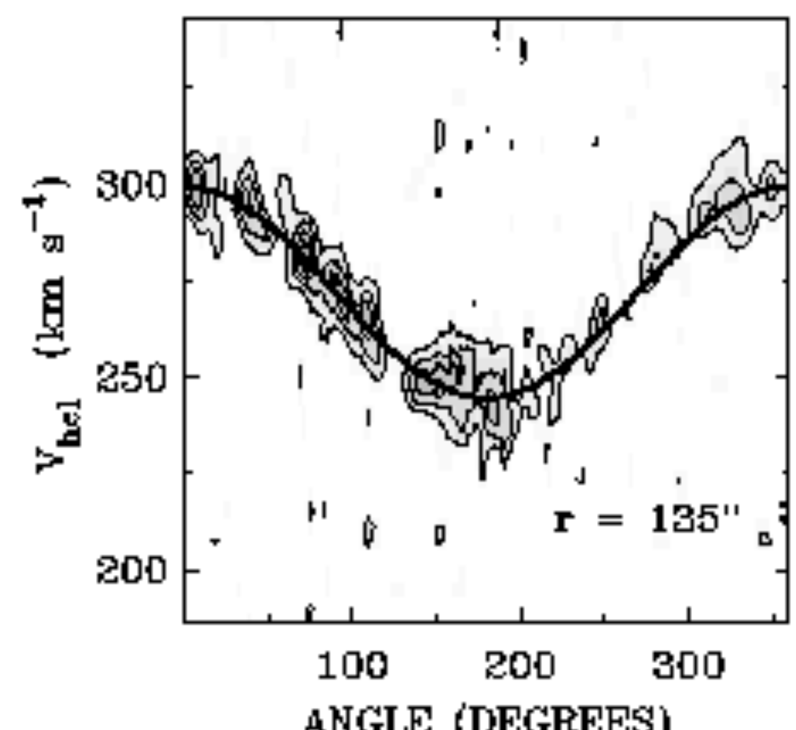


Rotation curves extracted using "tilted ring" fits

Fit ellipses that most closely match the circular velocity at a given radius. In principle, get ellipse center, position angle, axis ratio, inclination, and rotation velocity. In practice, usually have to fix some of these parameters.

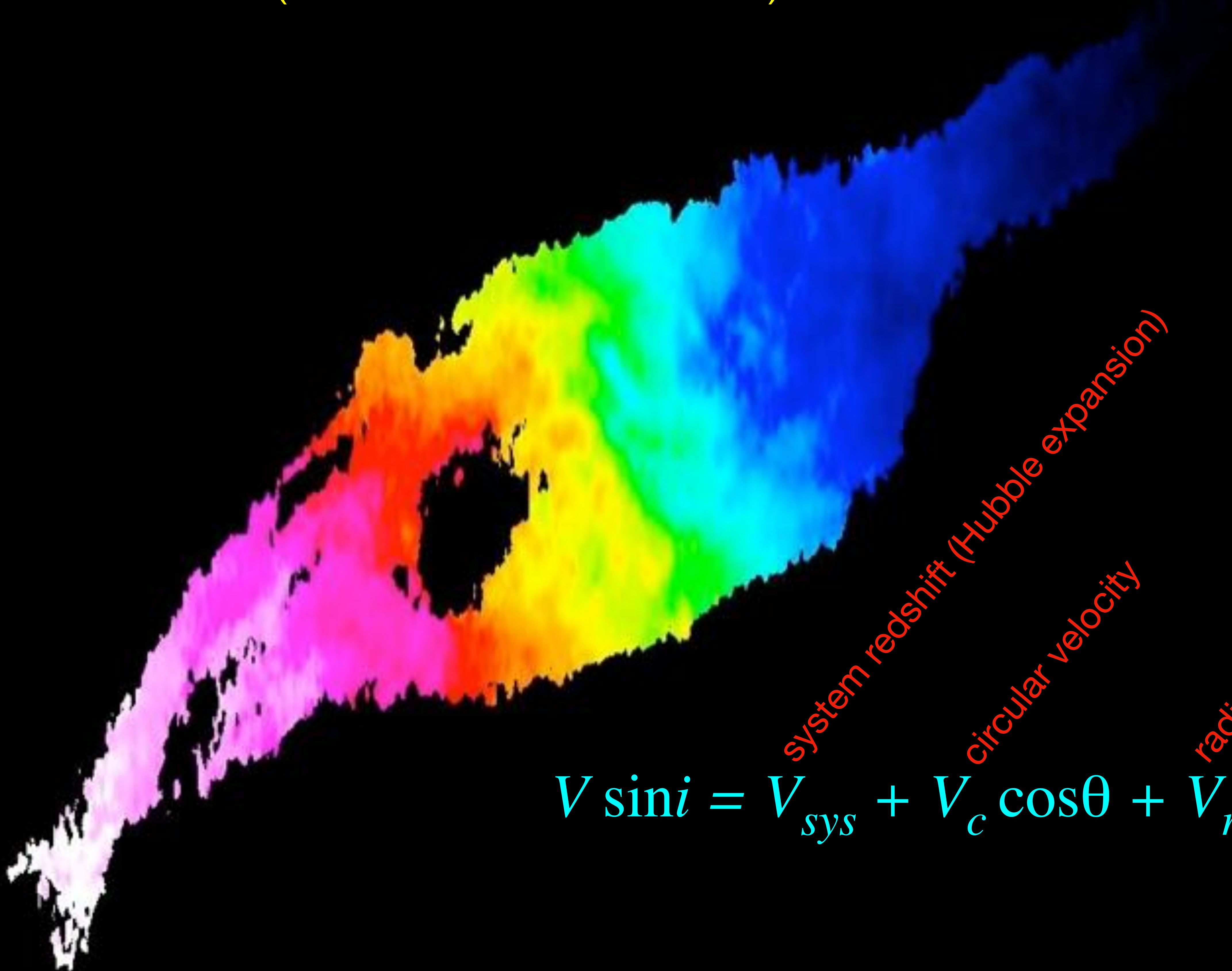
titled ring model





velocity variation along ring

NGC 6822 (Weldrake & de Blok 2003)



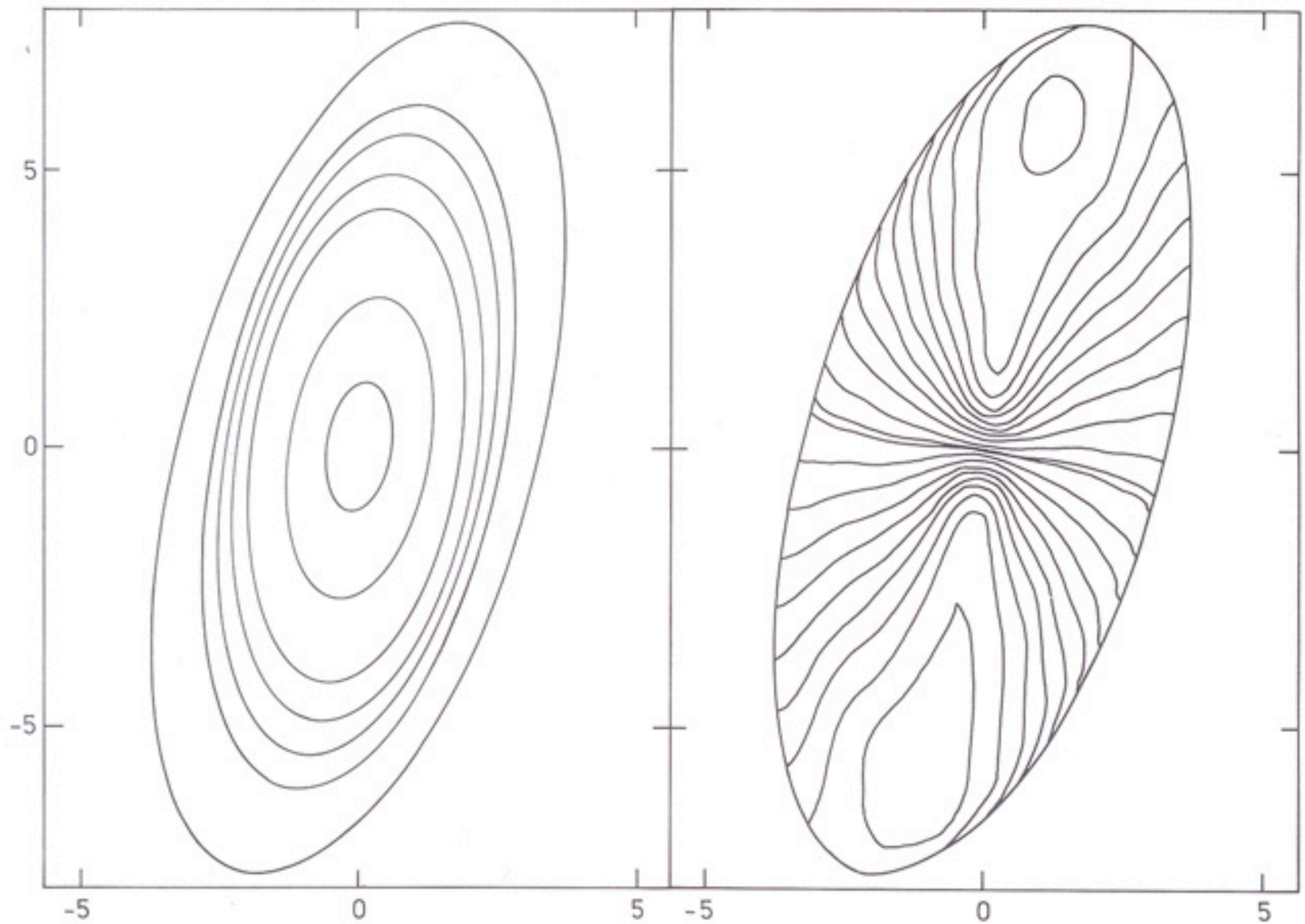
system redshift (Hubble expansion)

circular velocity

radial velocity

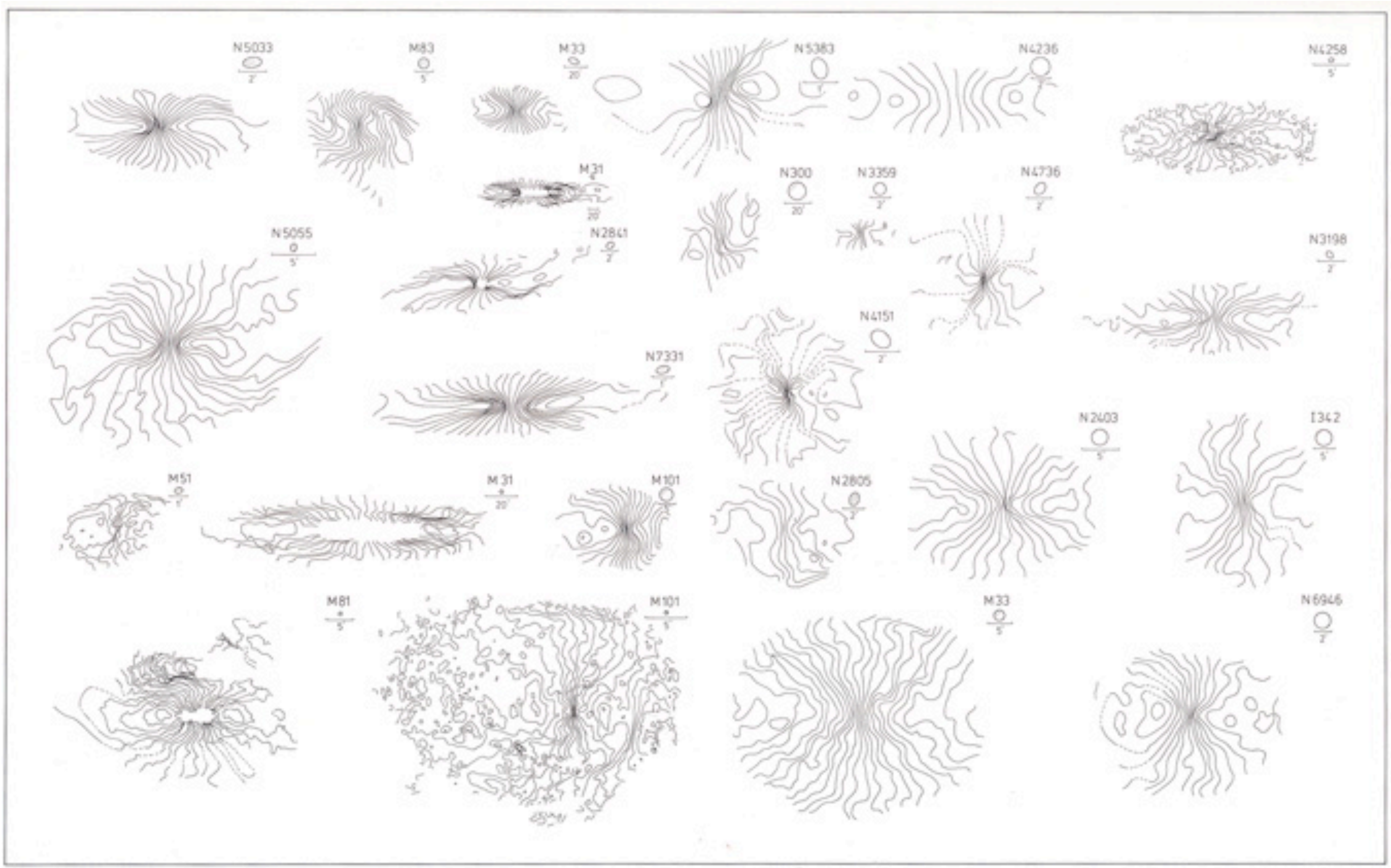
$$V \sin i = V_{sys} + V_c \cos\theta + V_r \sin\theta$$

titled ring model



isovelocity contours

observed velocity fields

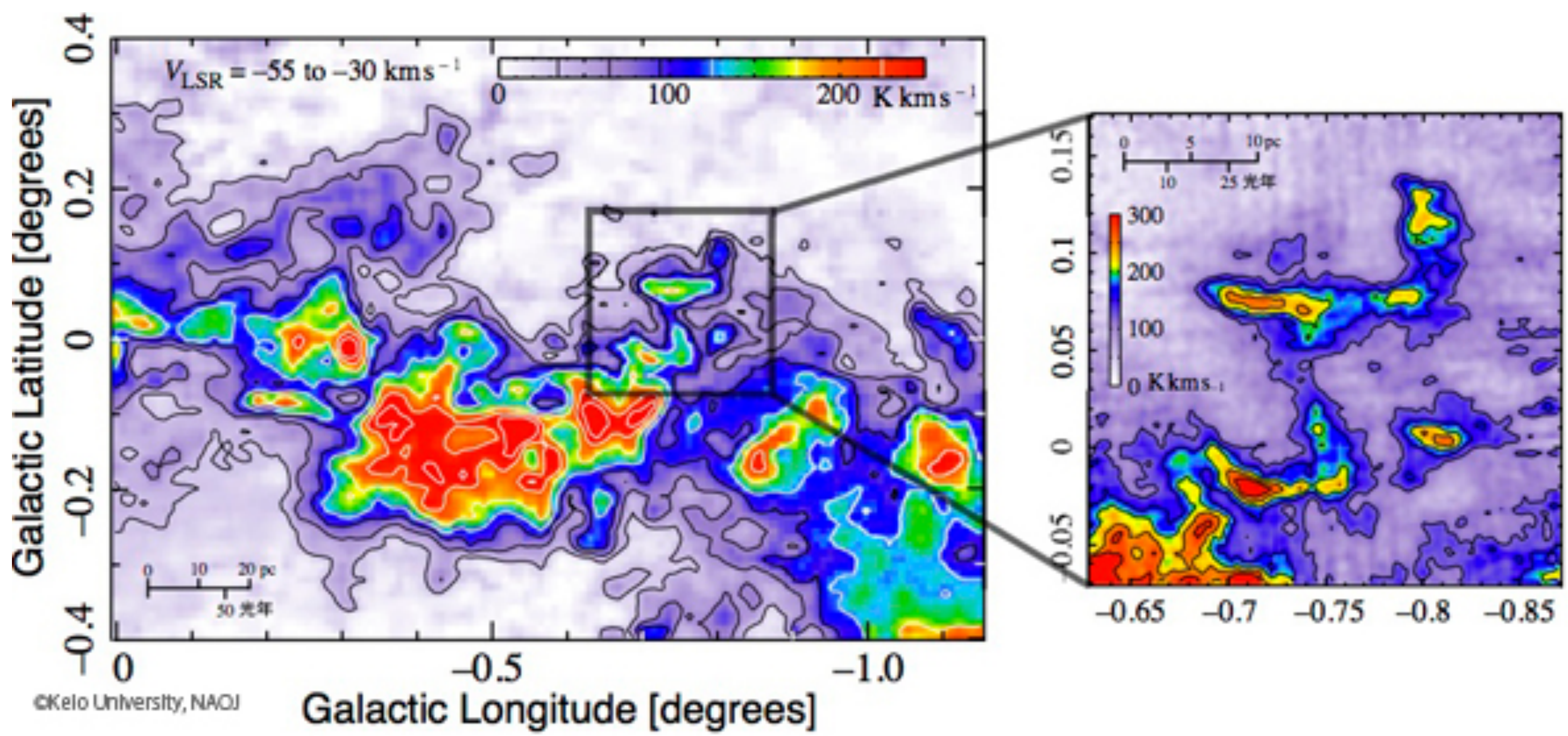


Bosma (1981)

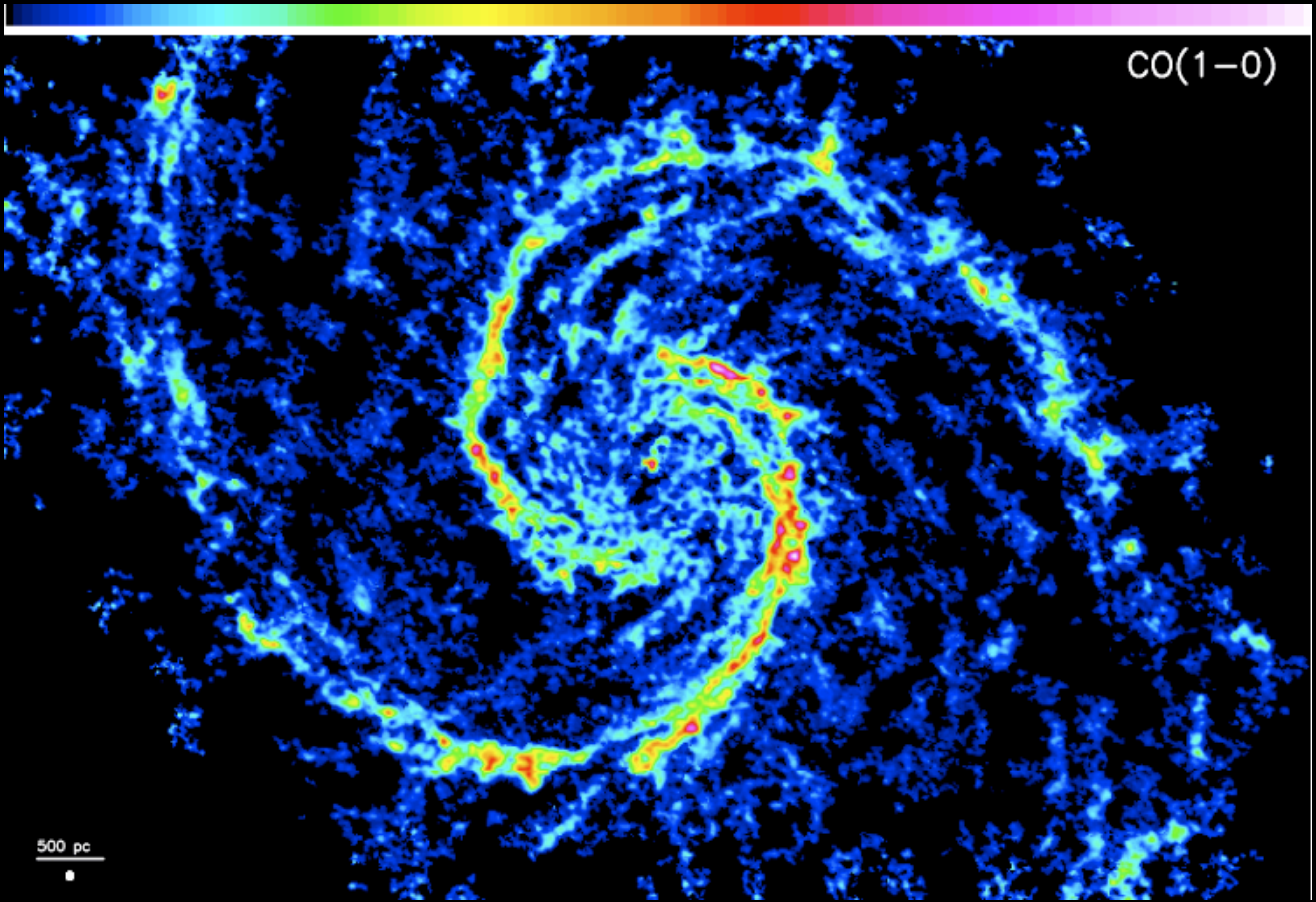
Molecular ISM

Cold (~ 30 K), "dense" (> 100 molecules/cc) phase of interstellar medium

Very clumpy, with low filling factor - much of the H_2 mass is in Giant Molecular Clouds (~10^6 $M_\odot$) This is where stars form.



M51 in CO



Diatomic molecules (H_2, N_2, O_2) boring - or at least hard to excite, as they have no dipole moment.

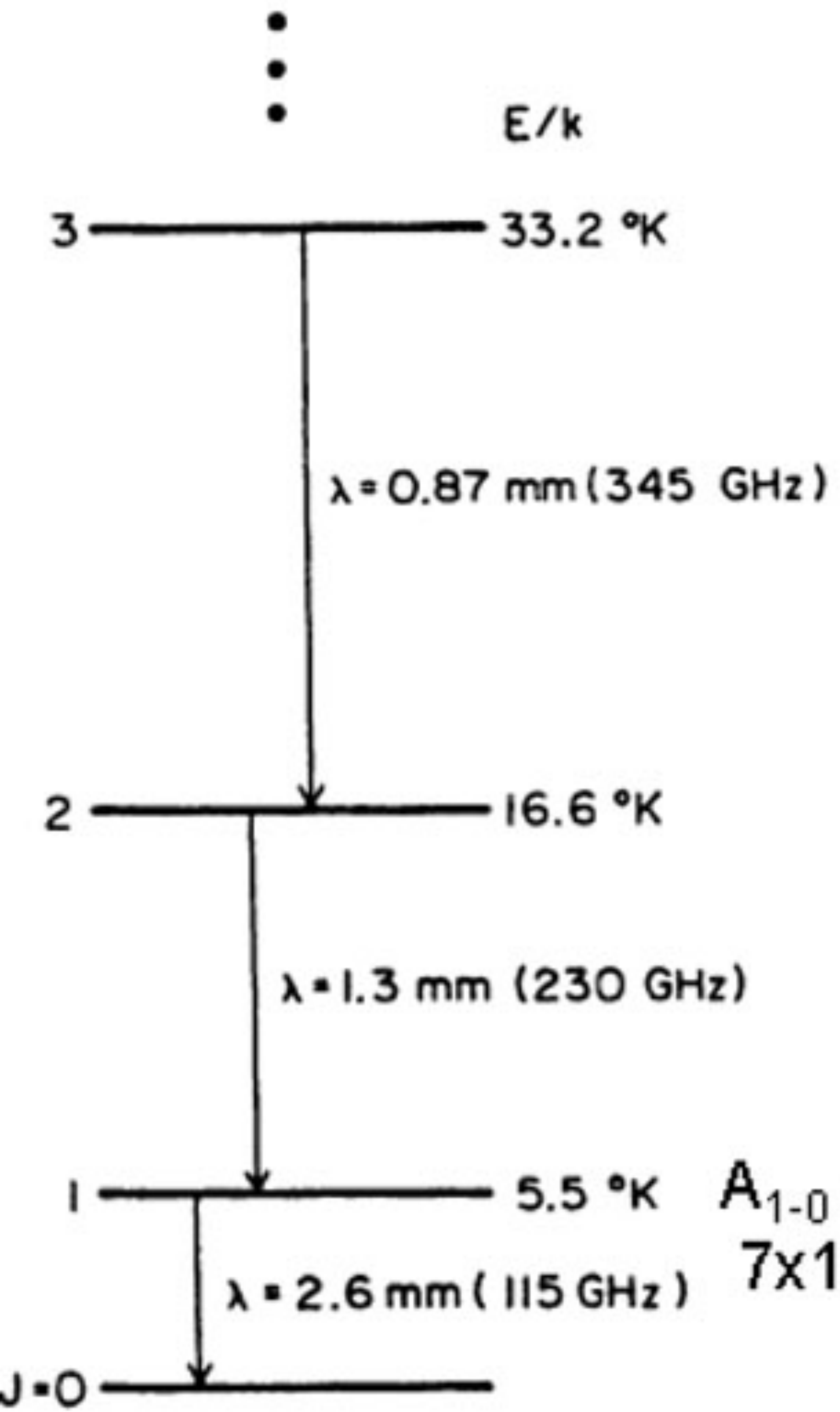
Polar molecules (esp. CO) have a permanent dipole moment thanks to asymmetry so have a rich rotational spectrum (typically in the mm or cm wavelengths).

$$E_{rot} = \frac{J(J+1)\hbar^2}{2I}$$

$$M_{H_2} = 1.1 \times 10^4 D^2 F_{CO}$$

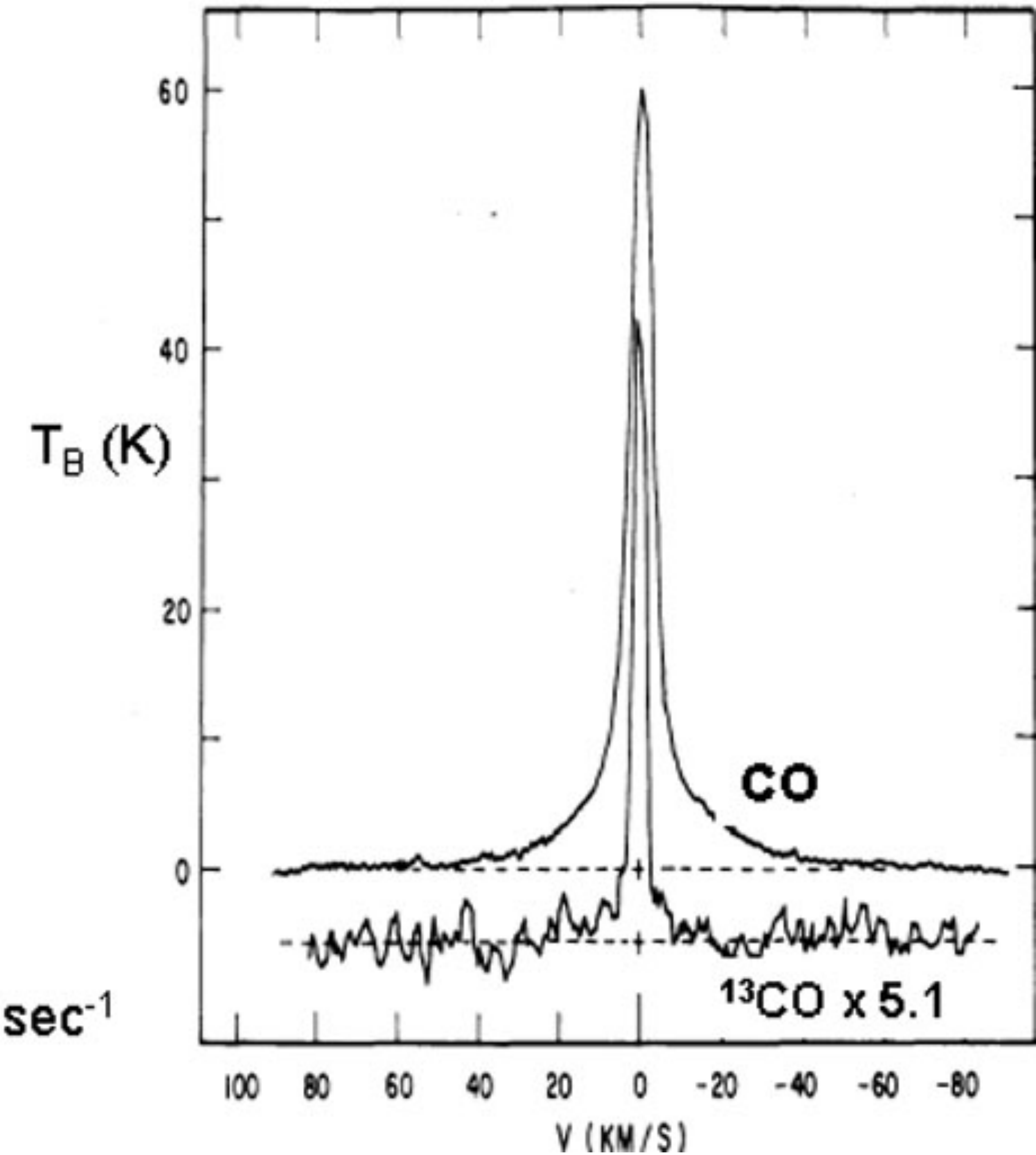
$$X_{CO} = 2.8 \times 10^{20} \mathrm{cm}^{-2} (\mathrm{K\ km/s})^{-1}$$

CO Rotational Levels



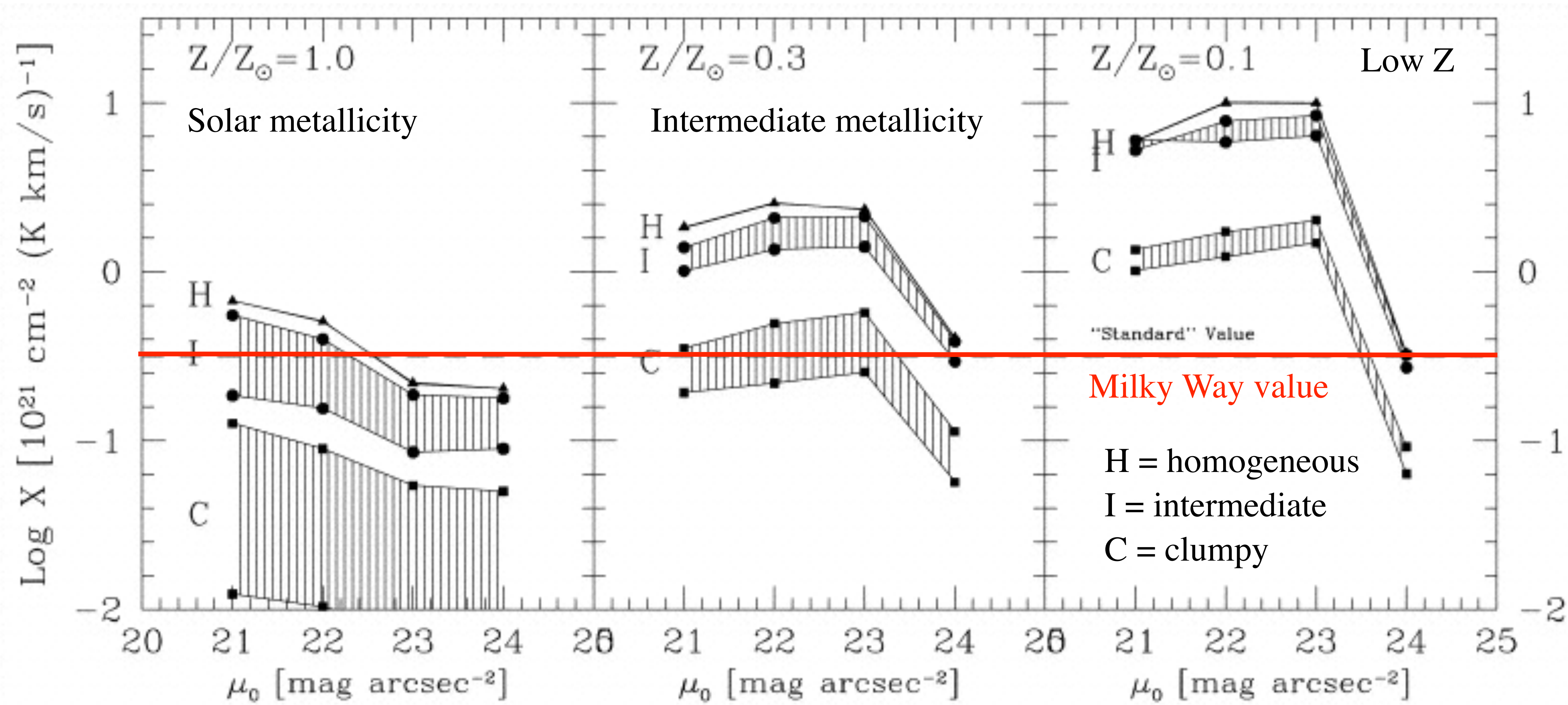
$A_{1-0} = 7\times10^{-8}\ \text{sec}^{-1}$

CO (J=1-0) in Orion KL Nebula



X: CO-to-H_2 conversion factor

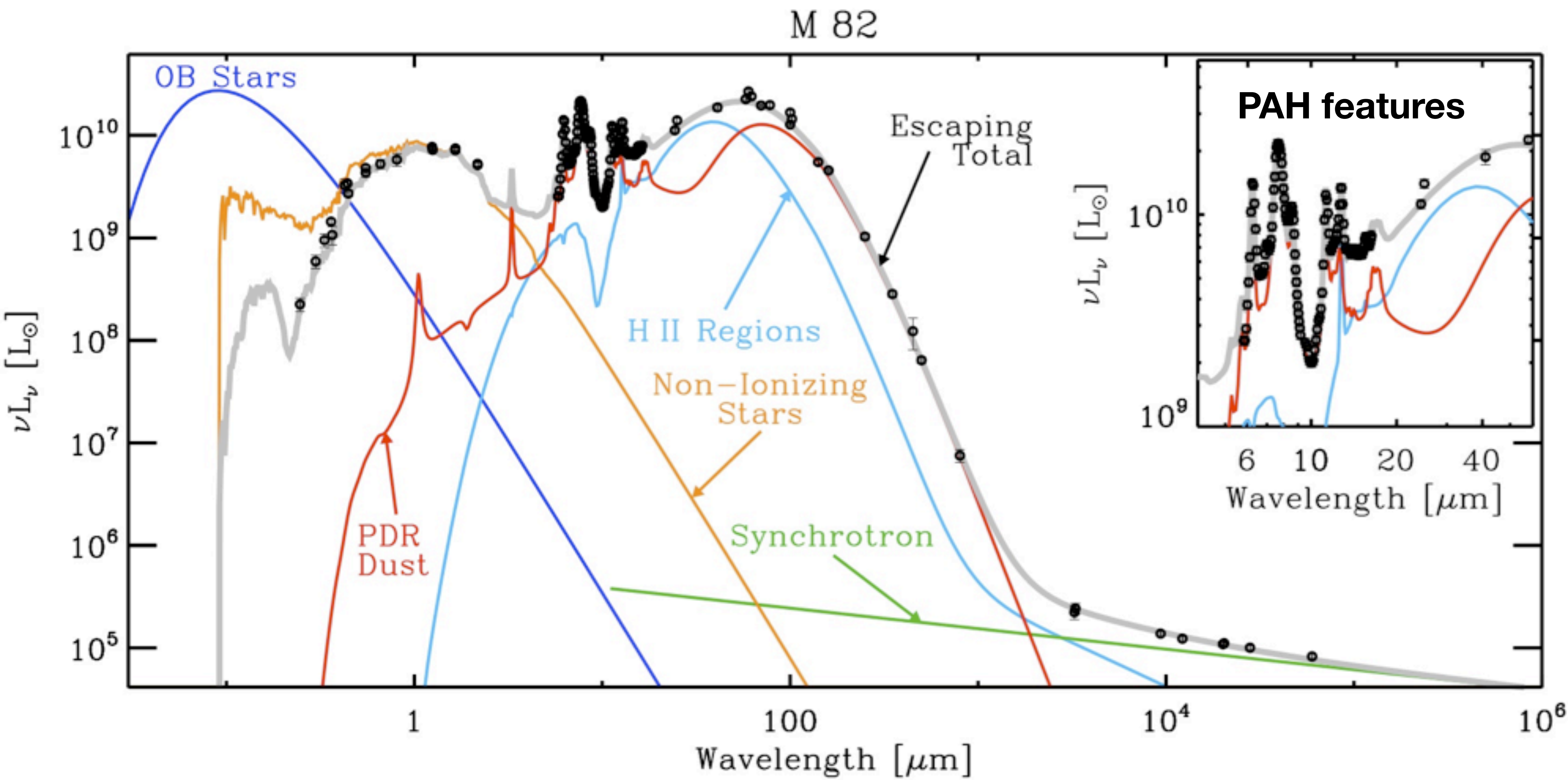
(Mihos, Spaans, & McGaugh 1998)



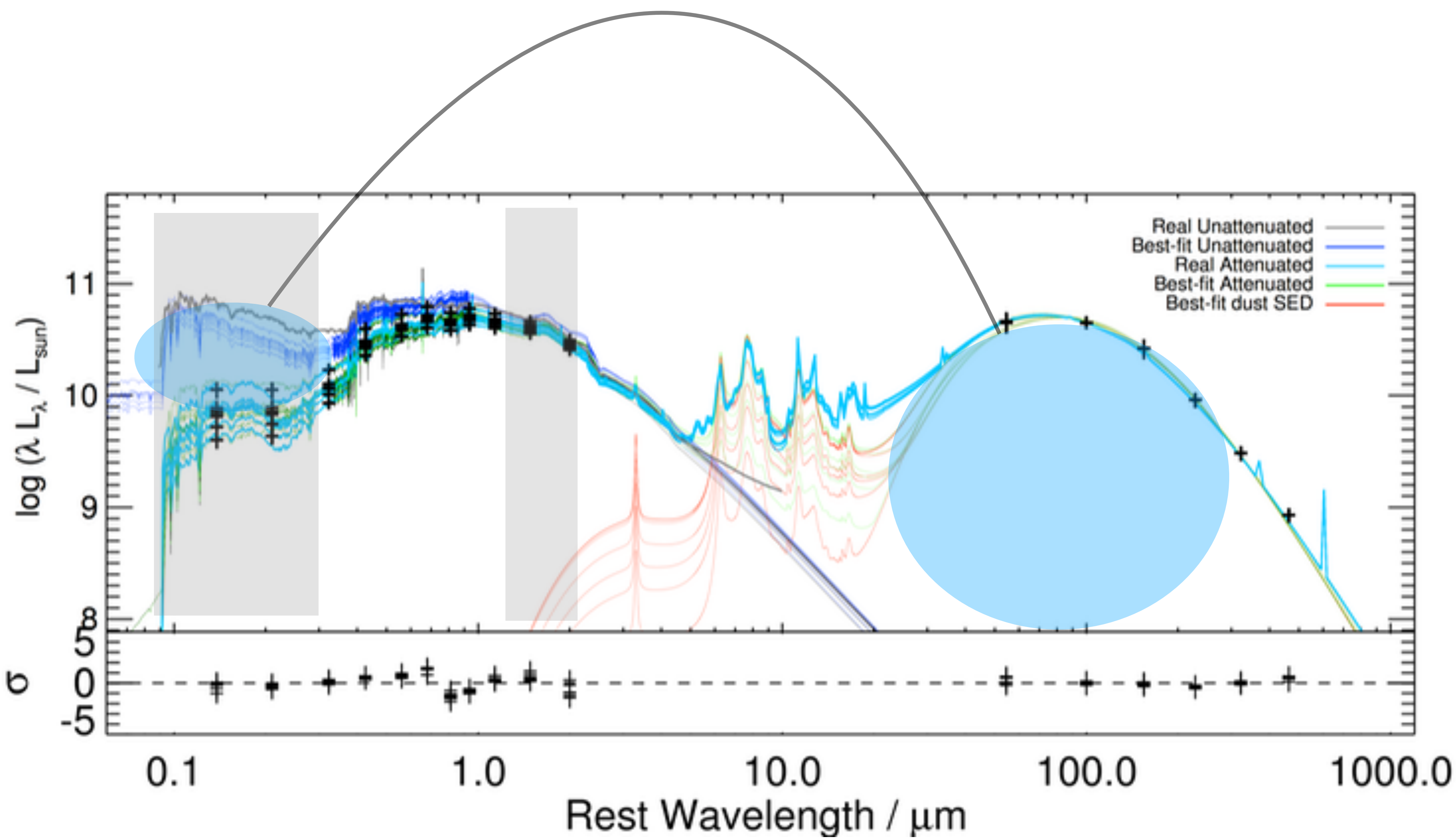
X should depend on the metallicity, the radiation field, the density of the gas, and how dusty and clumpy it is. So we usually just assume it is constant.

Dust

Scatters optical light
Absorbs UV; reradiates in IR
typically 60 - 100 microns



Dust-absorbed UV & optical radiation re-emitted in the IR



Lousy spot for measuring stellar mass - blue & UV wavelengths

Sweet spot for measuring stellar mass near-IR: 2-4 microns

Some galaxies are “ultraluminous” in the IR
Most are not

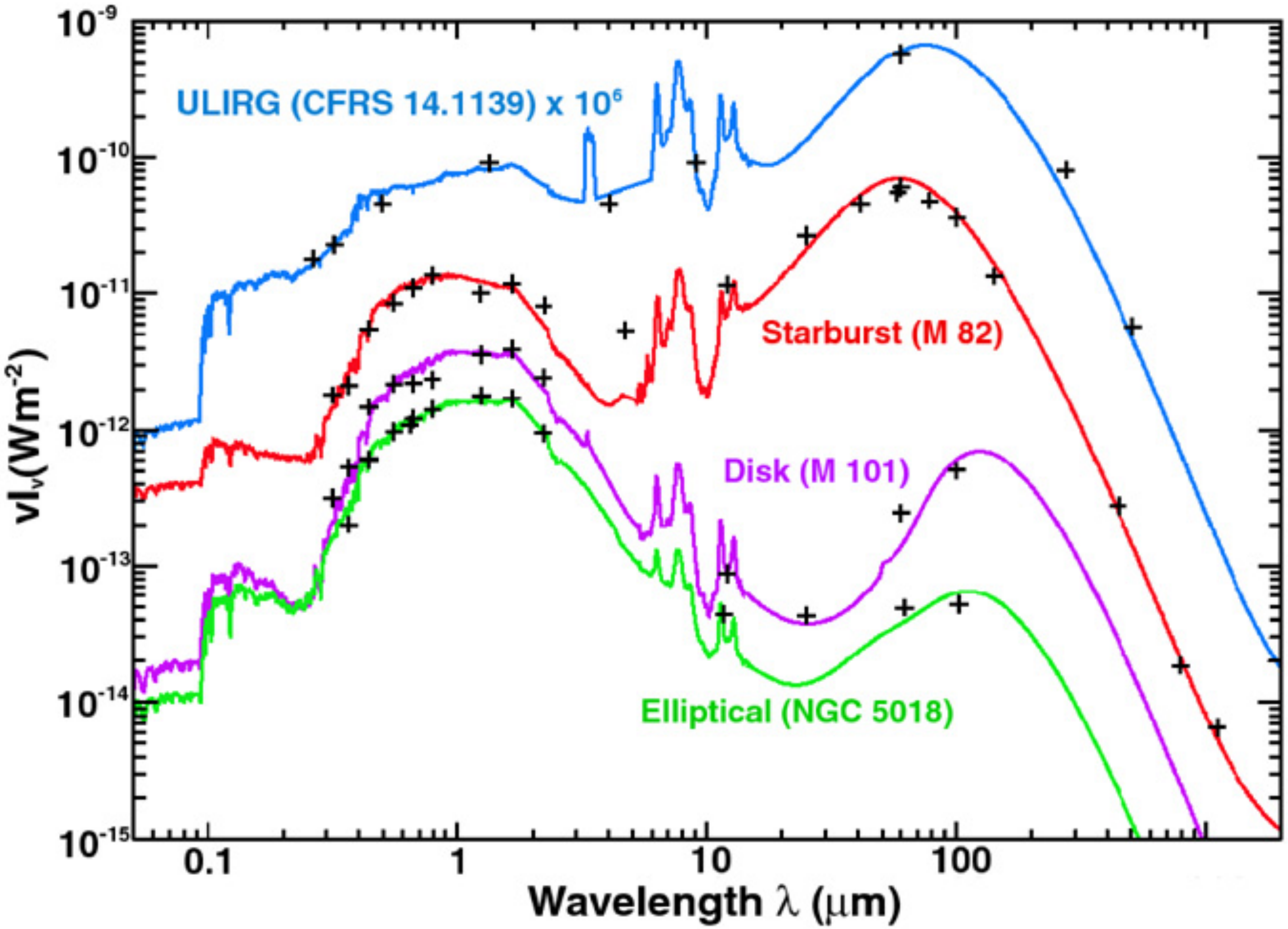


Fig 7.7 (P. Chanial, G. Lagache) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Galactic Kinematics

Galactic constants

$$R_0 \; \Theta_0 \; A \; B$$

$$\Omega < \kappa < \nu_z$$

Local Standard of Rest

Epicycle approximation

Galactic Coordinates

from solar system | from Galactic Center

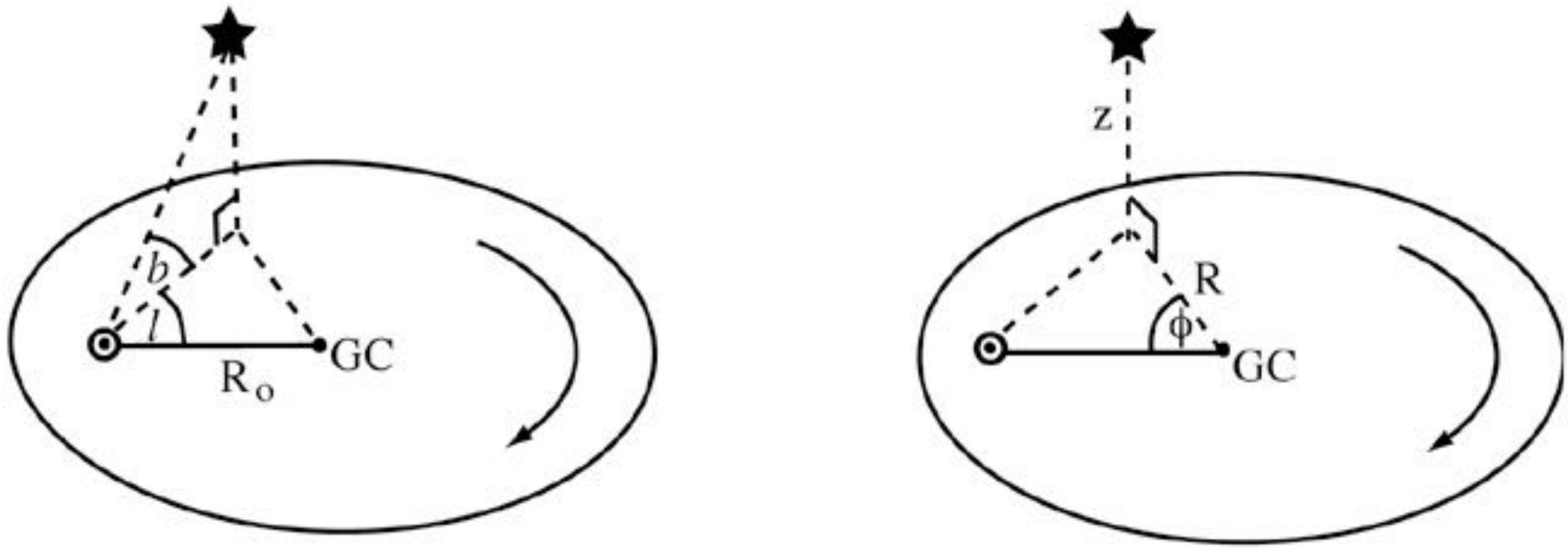


Fig 1.10 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

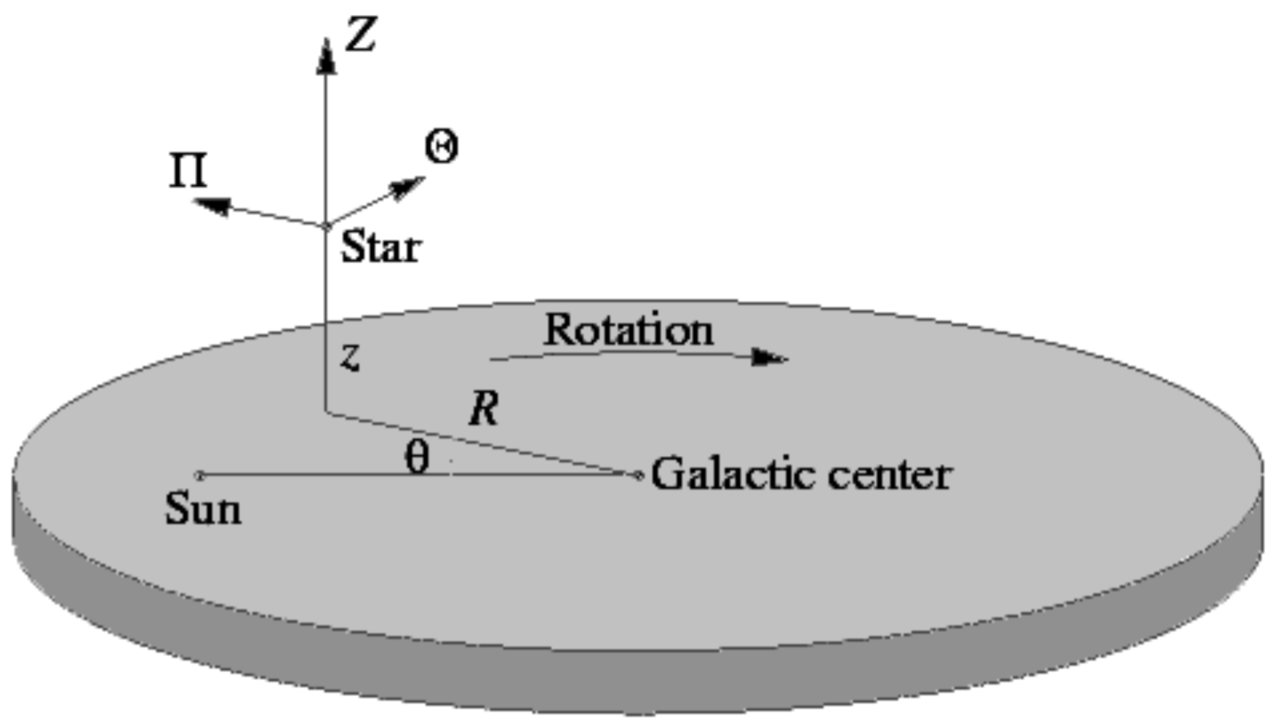
longitude & latitude

$$\ell, b$$

$$R, \phi, z$$

The Local Standard of Rest

Let's define a coordinate system:



$$\text{Position} : (R, \theta, z) \quad \text{Velocity} : (\Pi, \Theta, Z)$$

- R = galactocentric distance
- theta = azimuthal coordinate
- z = height above/below the plane

- Pi = velocity in/out from center
- Theta = tangential velocity
- Z = velocity up and down

LSR - local standard of rest

Define a point in space that is moving on a perfectly circular orbit around the center of the galaxy at the Sun's galactocentric distance. We measure all velocities of stars relative to this point, which is known as the **Local Standard of Rest**.

The velocity of the Local Standard of Rest (LSR) is then given by

$$\Pi_{LSR} = 0$$

$$\Theta_{LSR} = \Theta_0$$

$$Z_{LSR} = 0$$

More generally, if the Galactic potential is not axis-symmetric (e.g., because of the Galactic bar), then the LSR orbit is oval.

R_0 distance to Galactic Center

Θ_0 orbital velocity of LSR

$$\Omega_0 = \frac{\Theta_0}{R_0}$$ angular velocity of LSR

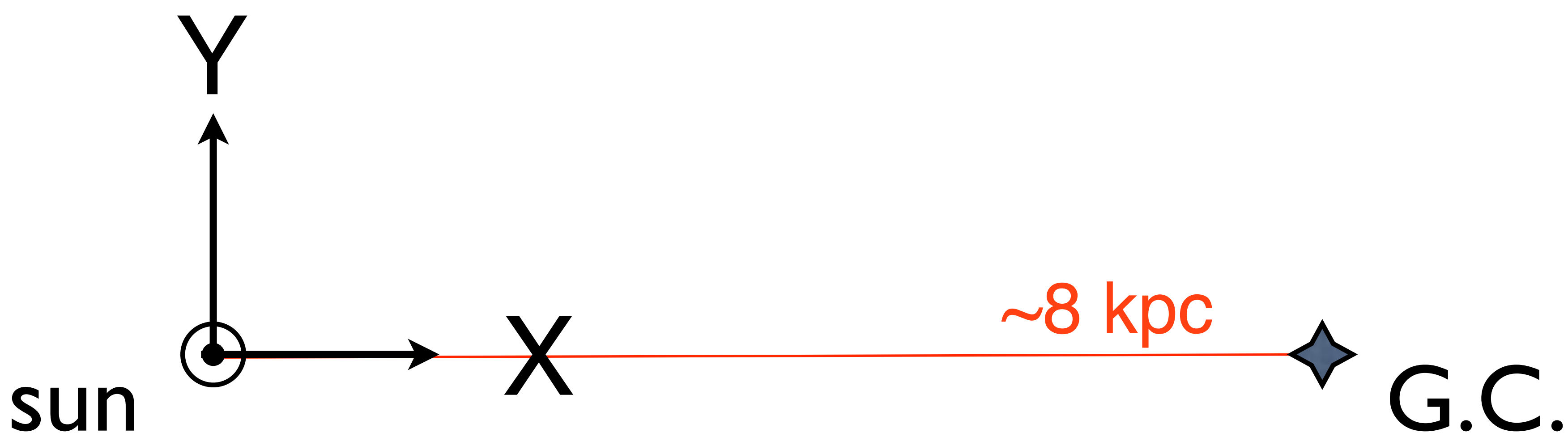
A Oort constant A

B Oort constant B

Local Galactic Coordinates

Cartesian coordinates centered on solar system

As opposed to Galactic Center. Beware sign conventions



X, Y, Z:

X points towards the Galactic Center

Y points in direction of the sun’s orbital motion

Z is perpendicular to the Galactic Plane

U, V, W are velocities in these directions

Solar Motion

The residual solar motion wrt the average of local stars is

radial $U_\odot = 10\,\mathrm{km\,s^{-1}}$

azimuthal $V_\odot = 12\,\mathrm{km\,s^{-1}}$

vertical $W_\odot = 7\,\mathrm{km\,s^{-1}}$

Some say V = 5 km/s, some say 15 km/s!

The Sun is moving

- a bit towards the galactic center
- faster than the LSR
- northward out of the galactic plane

Currently we are near the mid-plane

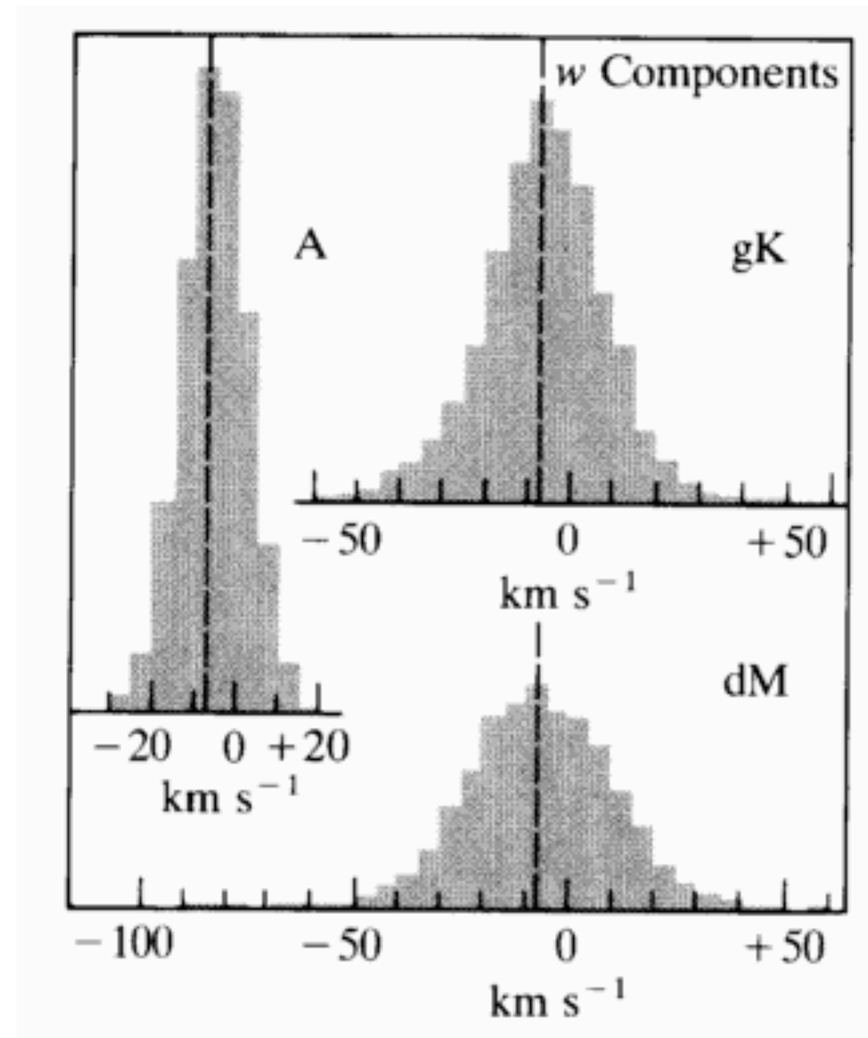
(Remember this doesn't account for the rotation of the disk!)

The Velocity Distribution of Stars

Make a histogram of the Z (up/down) velocities of stars of different spectral type:

- A stars ("A")
- K giants ("gK")
- M dwarfs ("dM")

(what is different about these groups of stars?)



The spread in velocities -- called the **velocity dispersion** and calculated as the standard deviation of the distribution -- is different for each group:

Stars	Dispersion (km/s)
A	9
gK	17
dM	18
white dwarfs	25

$$\sigma_z = \sqrt{\sum W_i^2}$$