Astronomy 537

Lecture 4: Gas in The Milky Way Galaxy

Key concepts:

Gas in the Milky Way
High Velocity Clouds

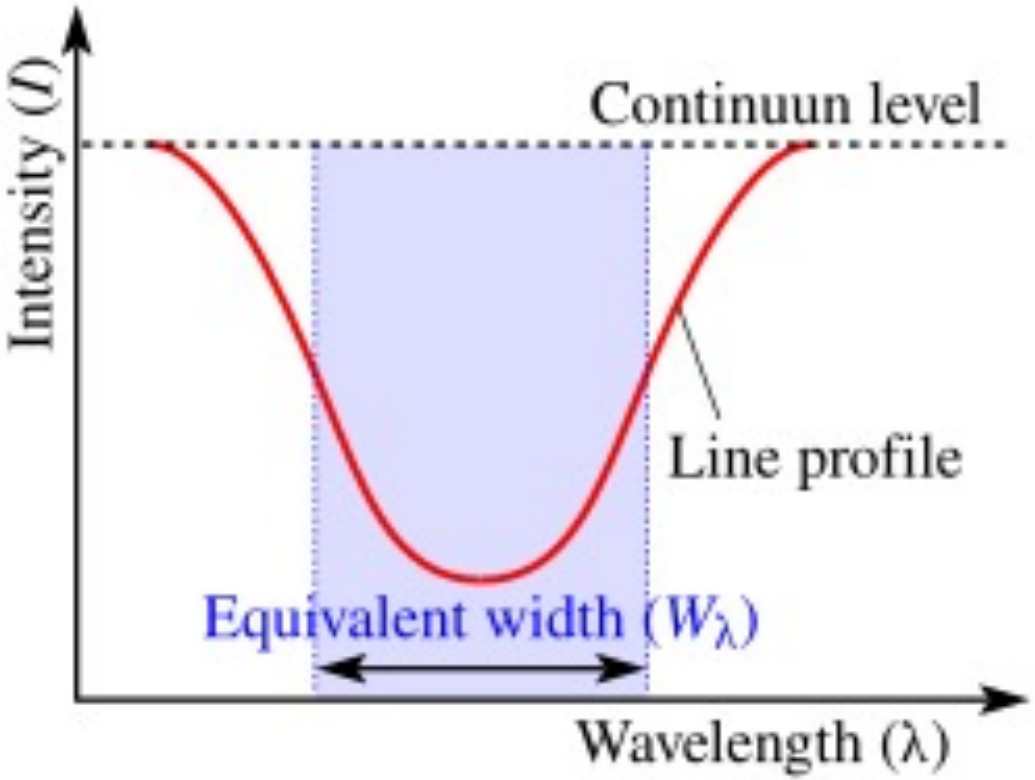
Journal Class

- **The debris of the ‘last major merger’ is dynamically young**

Donlon et al. 2024

Discussion leader: **Izabela Pavel**

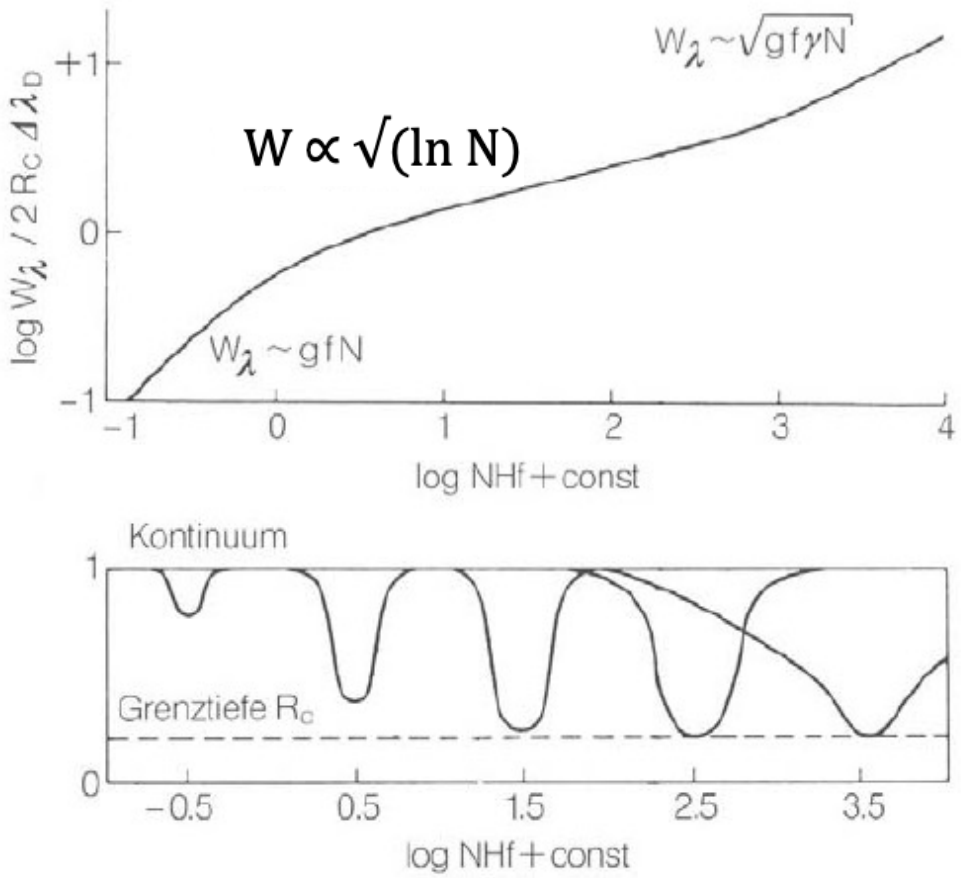
Equivalent Width



$$W_\lambda = \int \frac{F_c - F_s}{F_c} d\lambda = \int (1 - F_s/F_c) d\lambda.$$

Curve of growth; examples

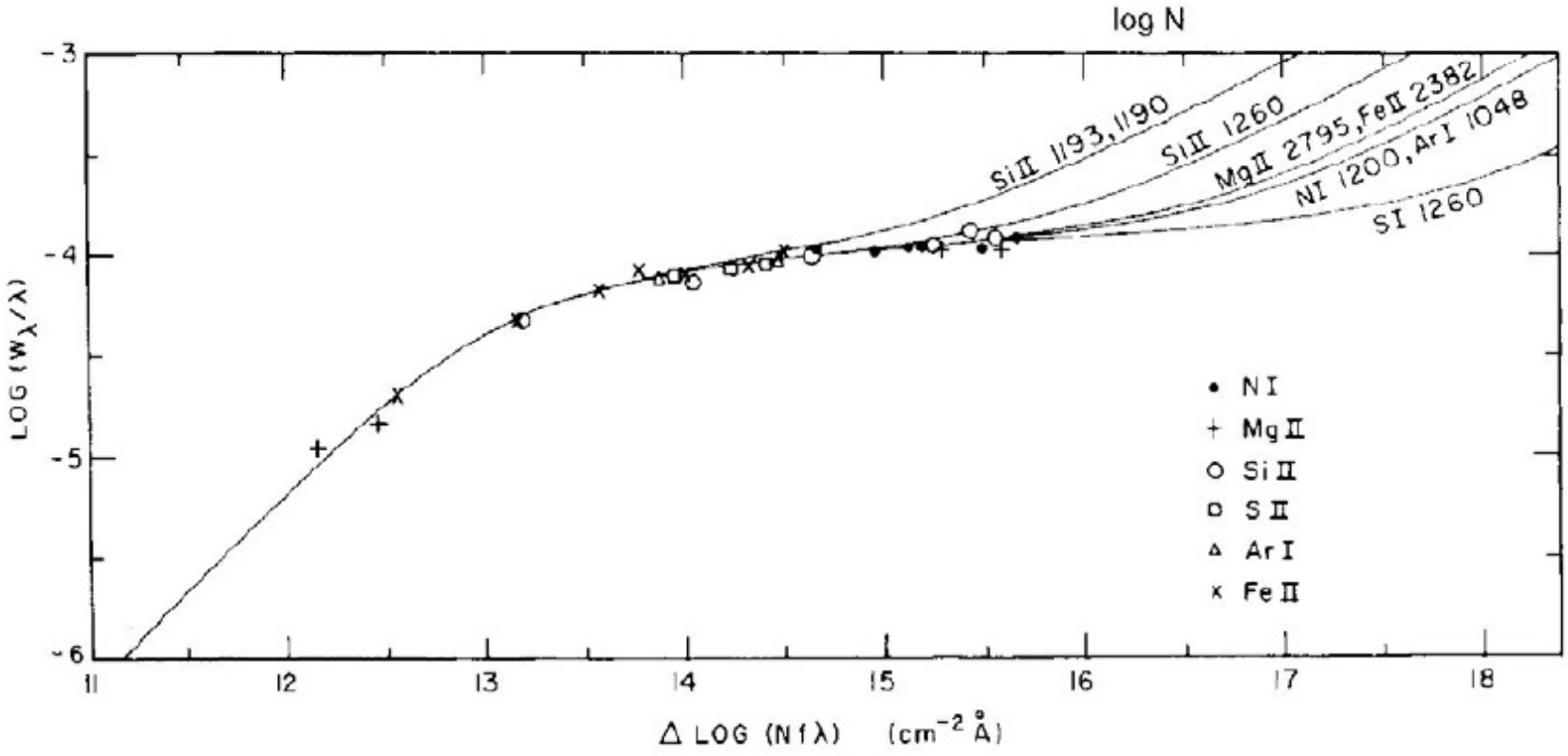
How the curve grows alongside the absorption line development as N is increasing.



van der Hulst

Curve of growth; examples

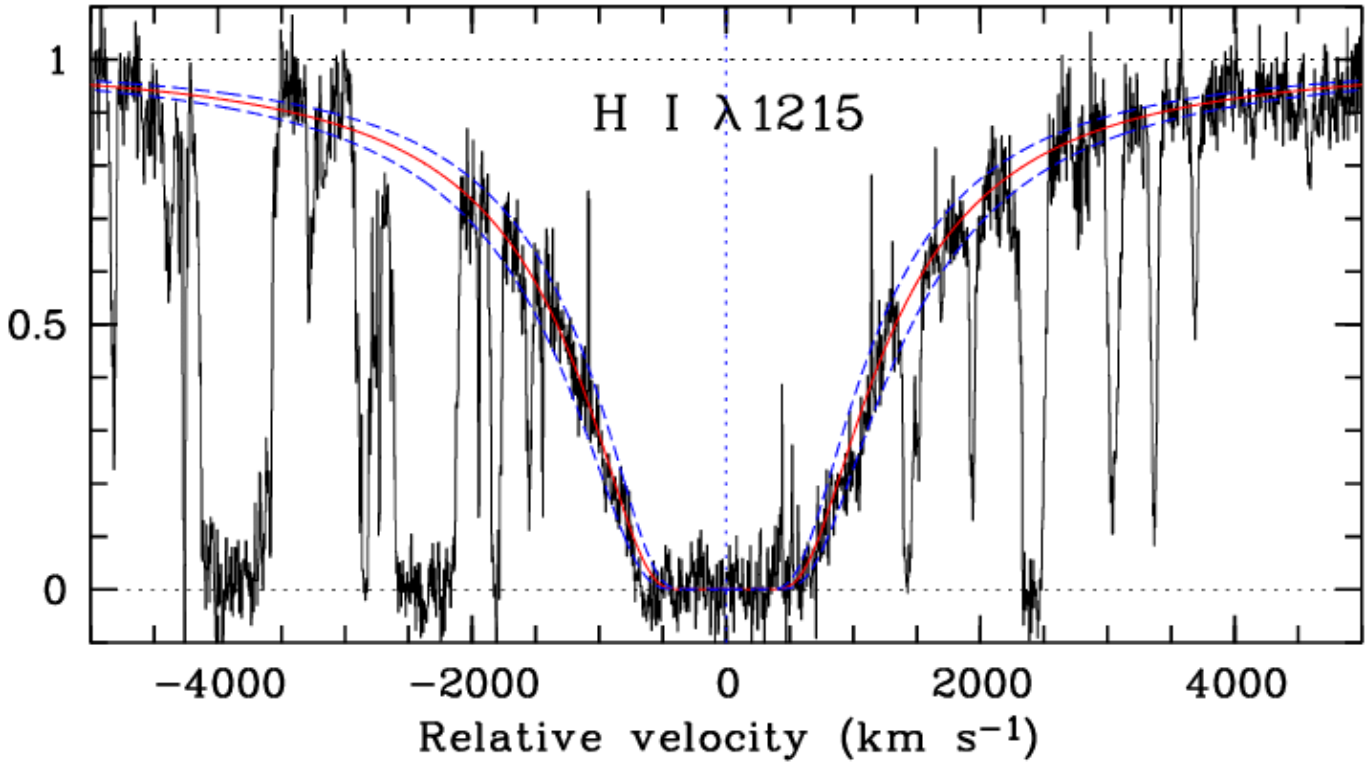
Example of absorption lines coming from a region with the same broadening (doppler determined width).



van der Hulst

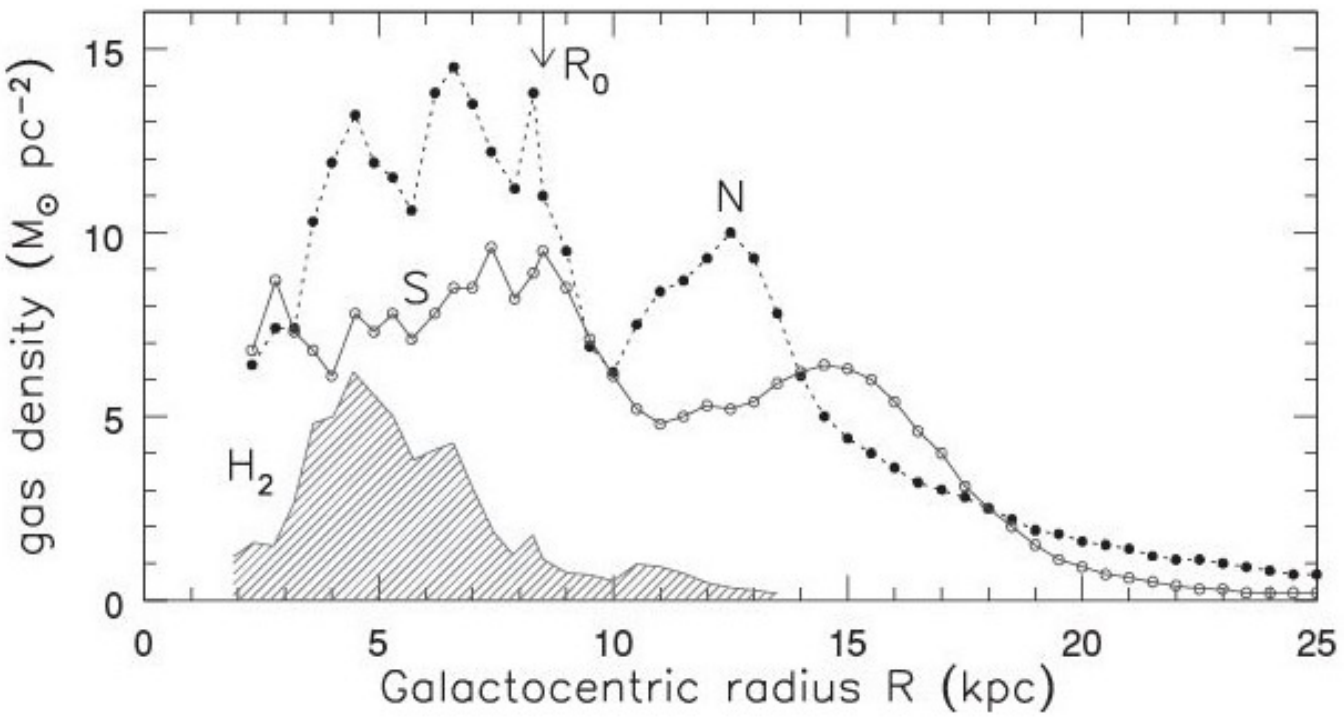
Example of the damped region of the curve of growth.

- VLT spectrum showing the damped Lyman-α line at z abs = 1.962 toward Q 0551−366. The best Voigt-profile fitting, N (HI) = (3.2 ± 0.6) × 10^{20} cm^{-2} , is superimposed.



Noterdaeme et al. 2007

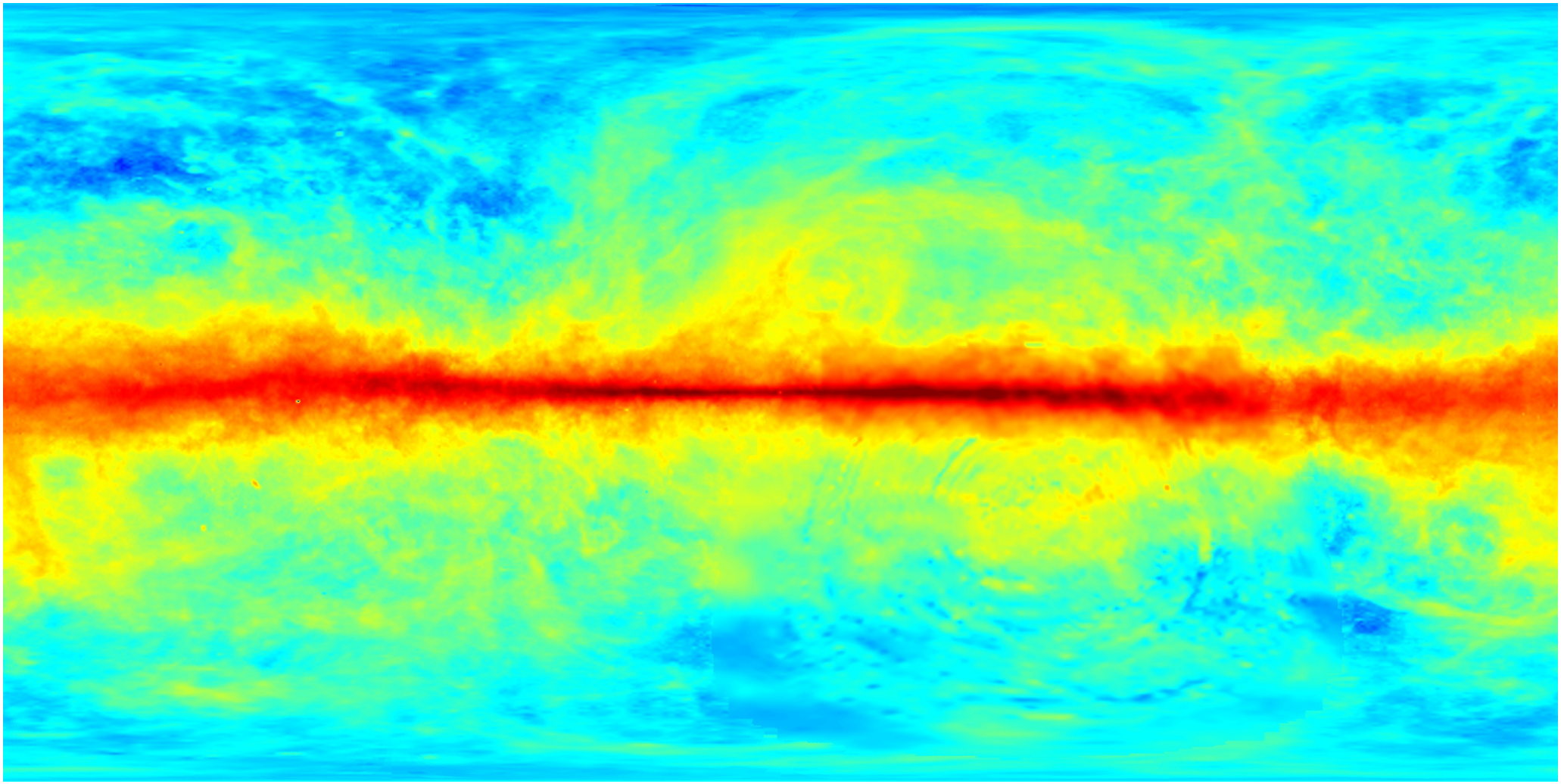
Gas in the Milky Way



Points are Hydrogen in northern and southern halves of the MW. Shaded region is the molecular gas density.

The Milky Way contains about 4-8 billion solar masses of neutral H and about half that much in molecular gas.

Estimated column density of HI in the Milky Way, assuming optically thin conditions when the 21cm emission is directly proportional to the column density:



Observations of HI clouds in the MW

- Two main stable phases, the CNM (T<300K) and the WNM (T>5000K)
  - Embedded in a hot ionized medium
  - Estimates give ~50% in the unstable region in between

- HI mainly in the disk and extends to much larger radii than the stars
  - Used to trace the Galactic mass distribution
  - HI mass: $8 \times 10^9 M_\odot$ (WIM $2 \times 10^9 M_\odot$, molecular gas $2.5 \times 10^9 M_\odot$, DM $1.8 \times 10^{11} M_\odot$)

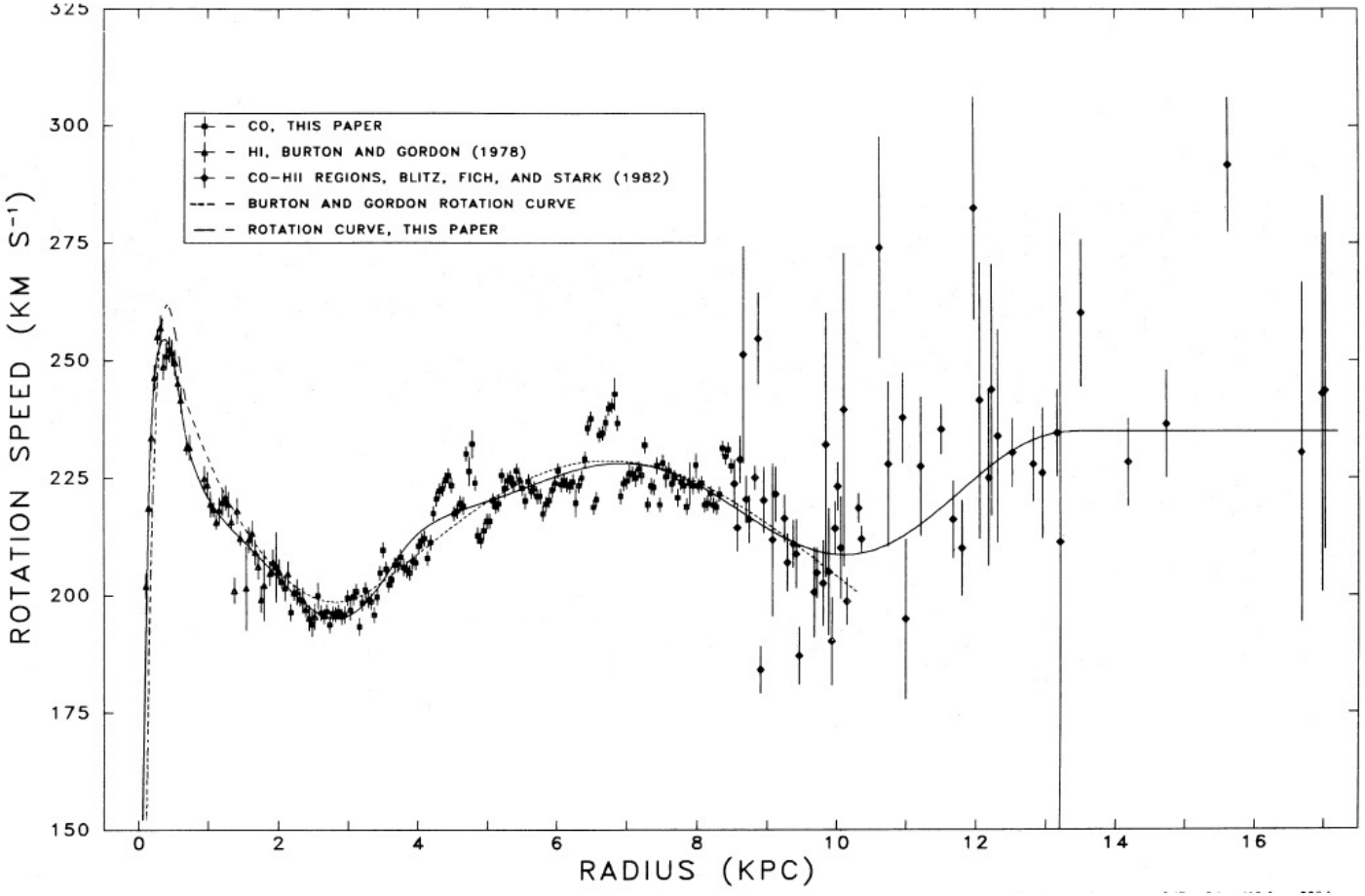
- The distribution of HI in the galaxy is derived by adopting a rotation curve, and thereby determining the distance to the HI cloud.
  - Feeds back into the rotation curve model, too.

Kalberla 2009

HI velocities to derive a rotation curve

- Differential rotation of the gas in the disk means that regions at different distances from the Sun will have different radial velocities.

- For an assumed Galactic rotation curve, the 21cm intensity versus radial velocity can be used to understand the distribution of gas in the Galaxy.

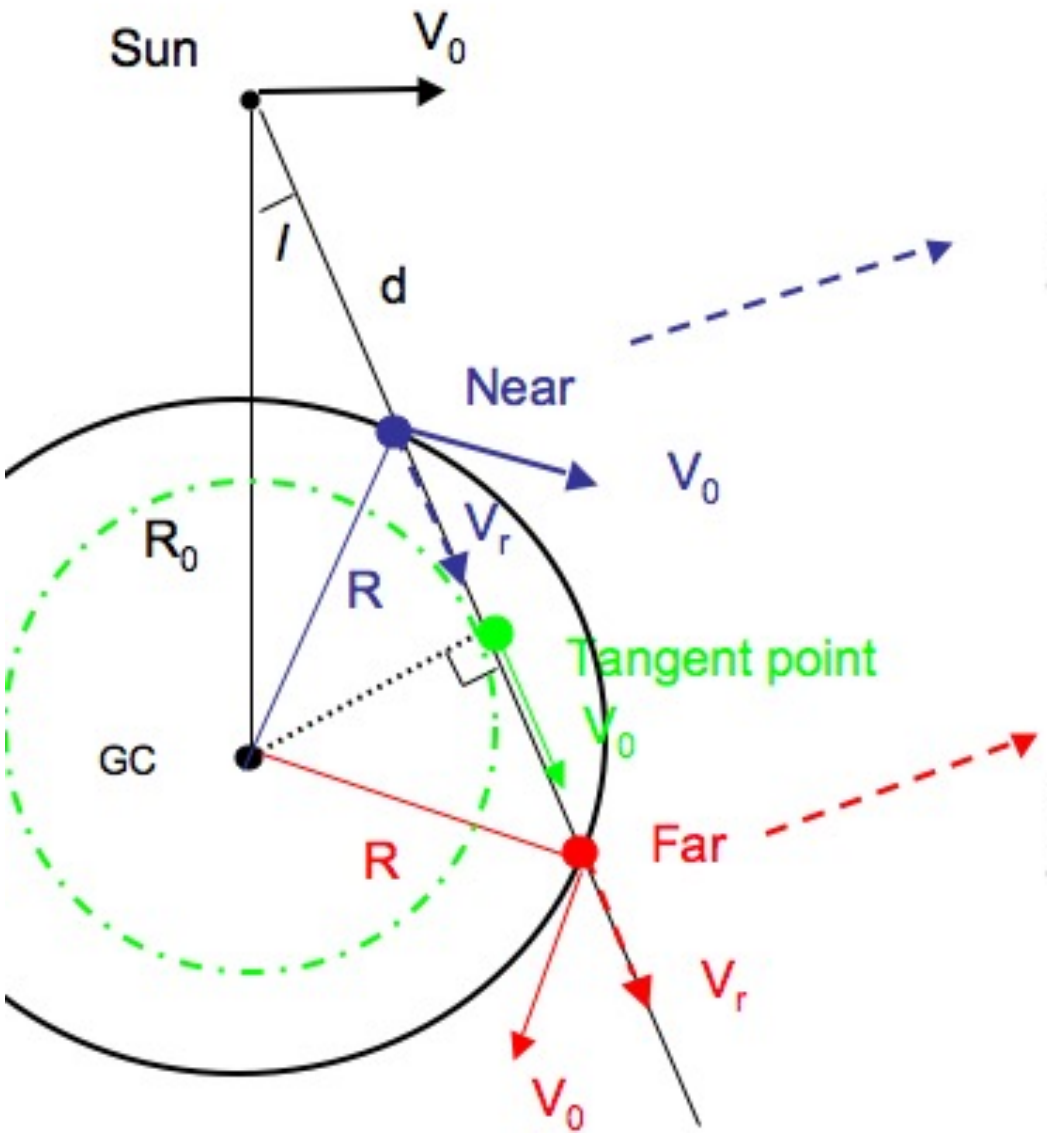


Clemens 1985

- In the inner Galaxy (90°<*l*<-*90°*) there is a distance ambiguity since there are two distances corresponding to the same radial velocity

- Maximum velocity component at tangent point.

- The gas often has non-circular motions, so there is a large uncertainty in the distance inferred.



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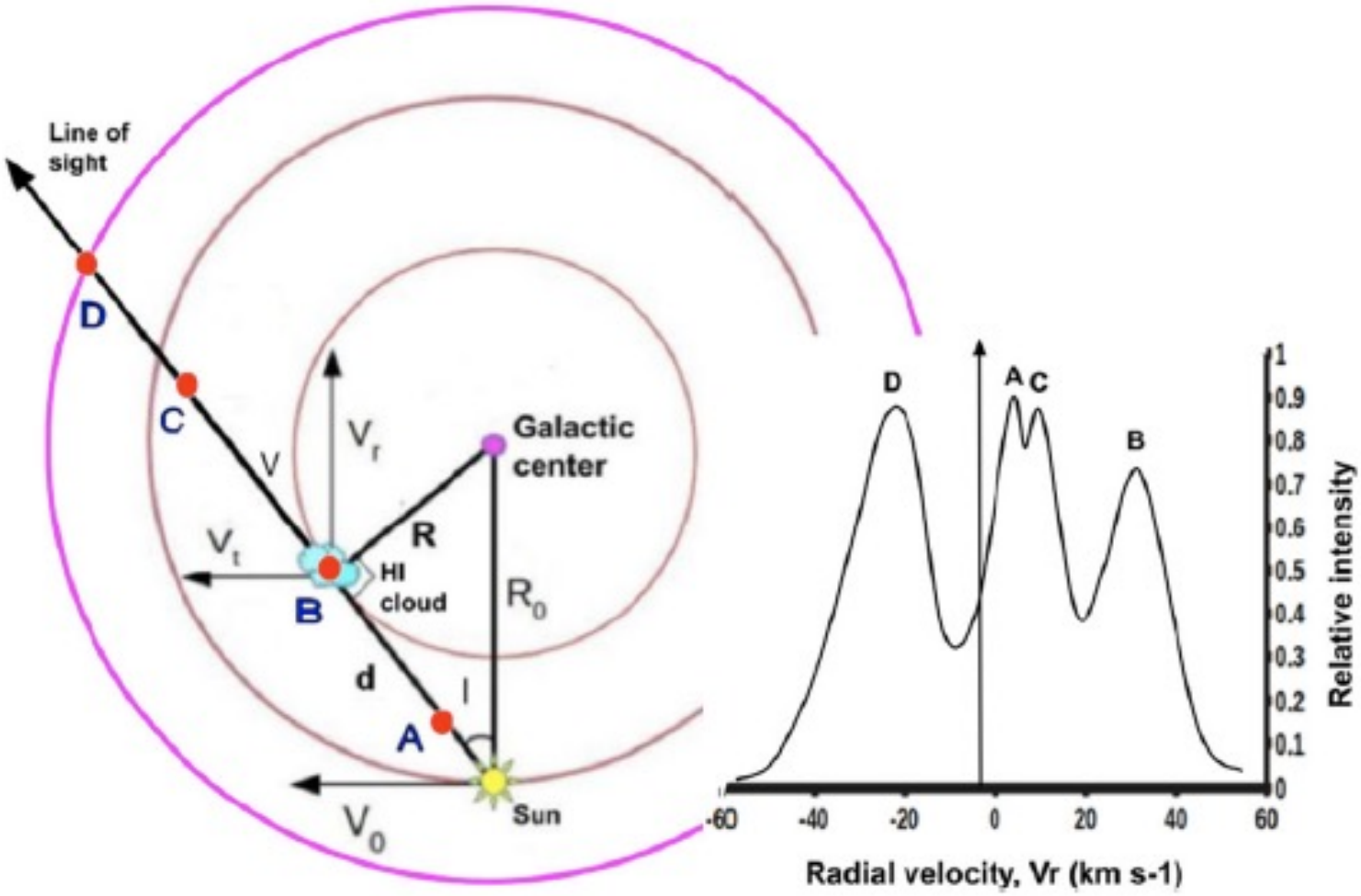
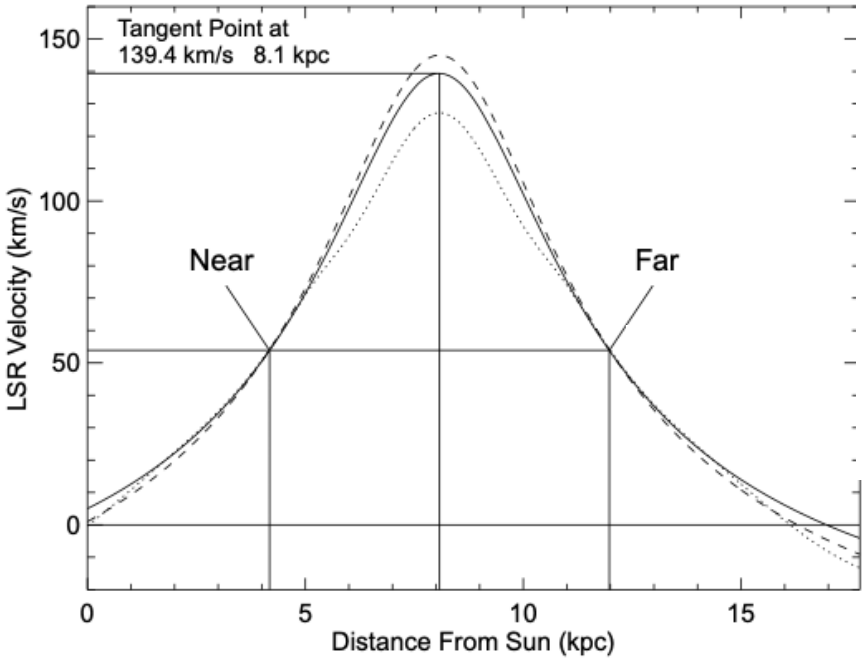
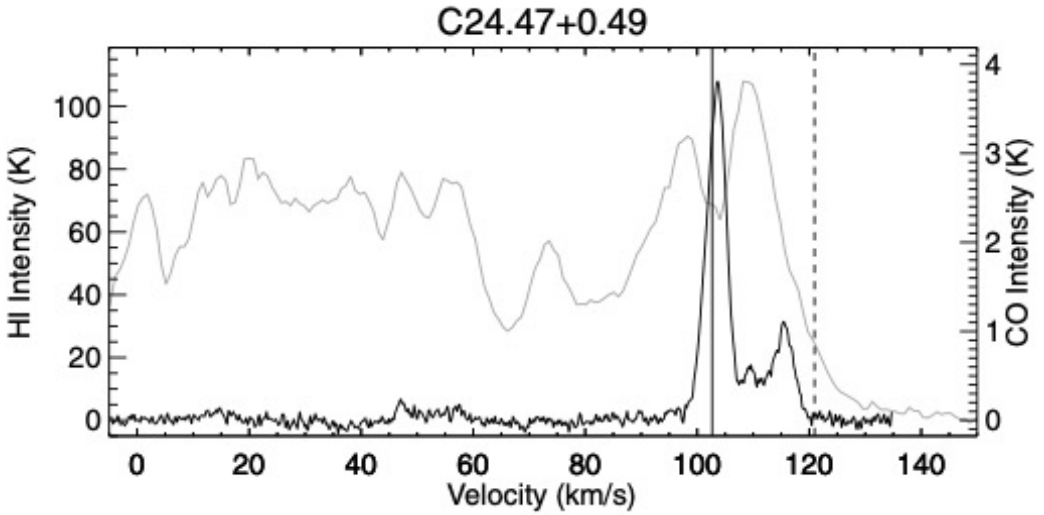


Pandian et al 2022





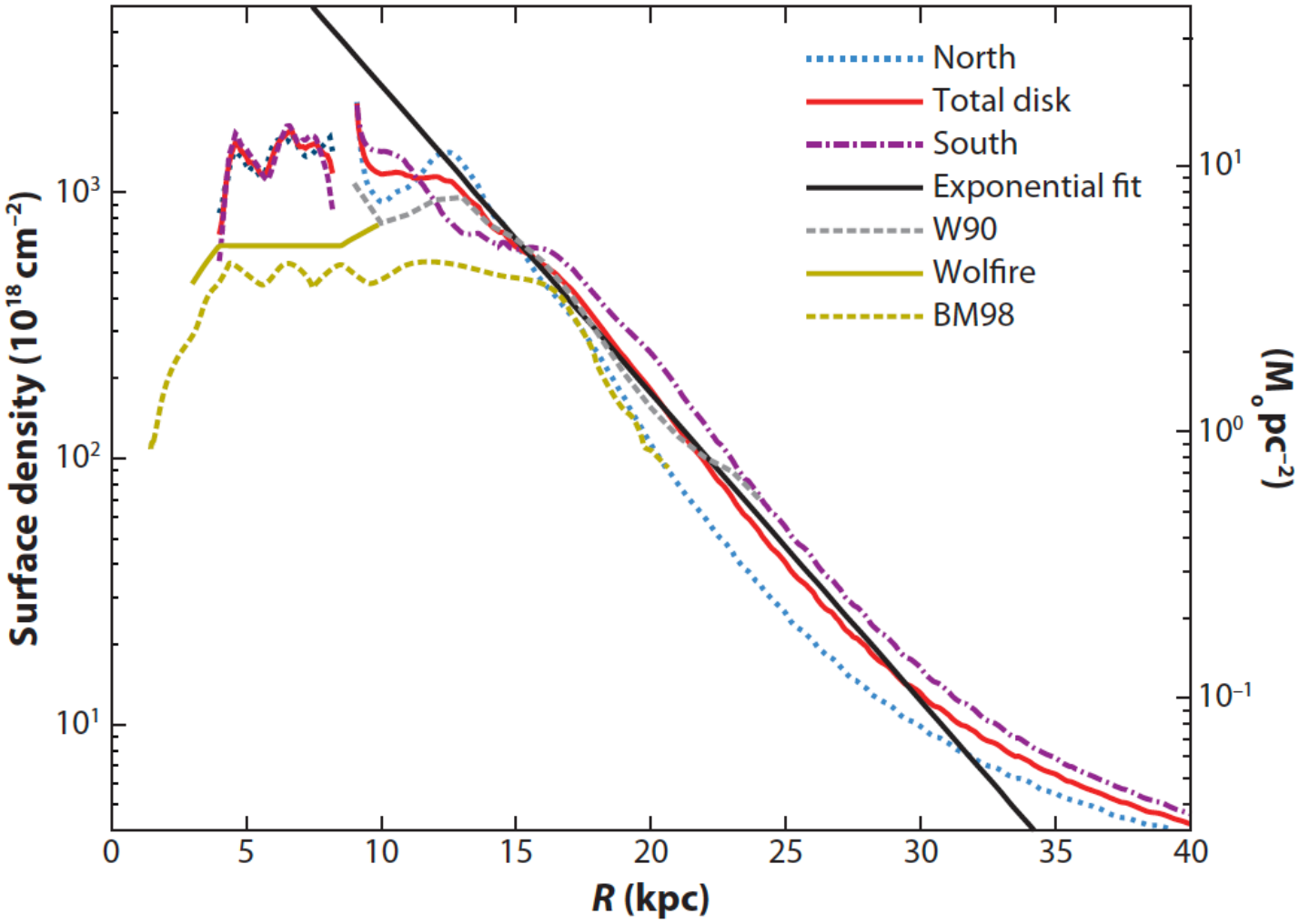
HII region CO emission studies. Grey line is HI, black is ^{13}CO. Near kinematic distance. How do we know?

If HII region is at the near kinematic distance, there will be no absorption from more distant and usually at larger absolute velocities, but absorption at and below the source velocity.

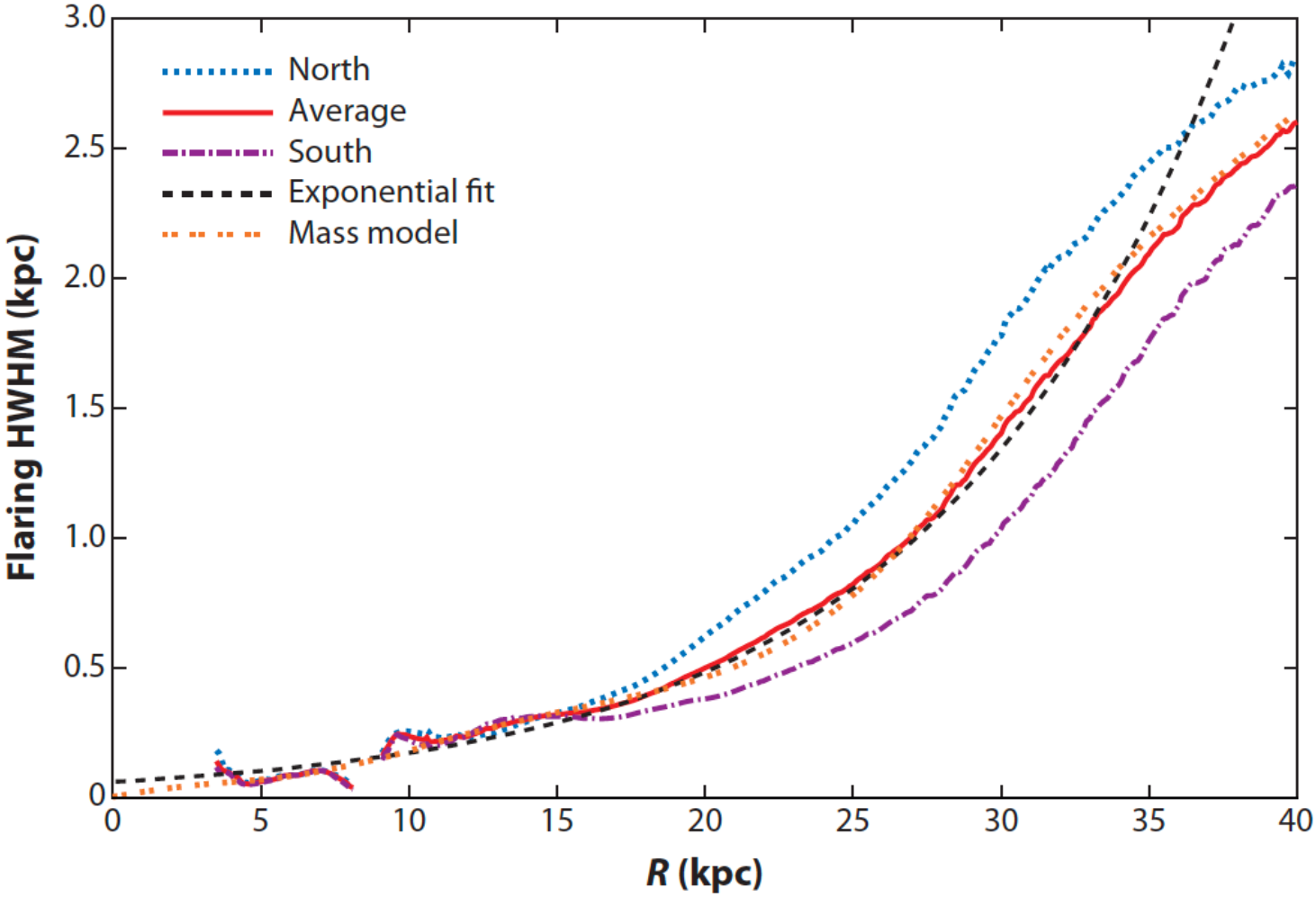
Conversely, if absorption features are seen at larger velocities than the H II region, it is likely to be located at the far kinematic distance.

Anderson & Bania 2009

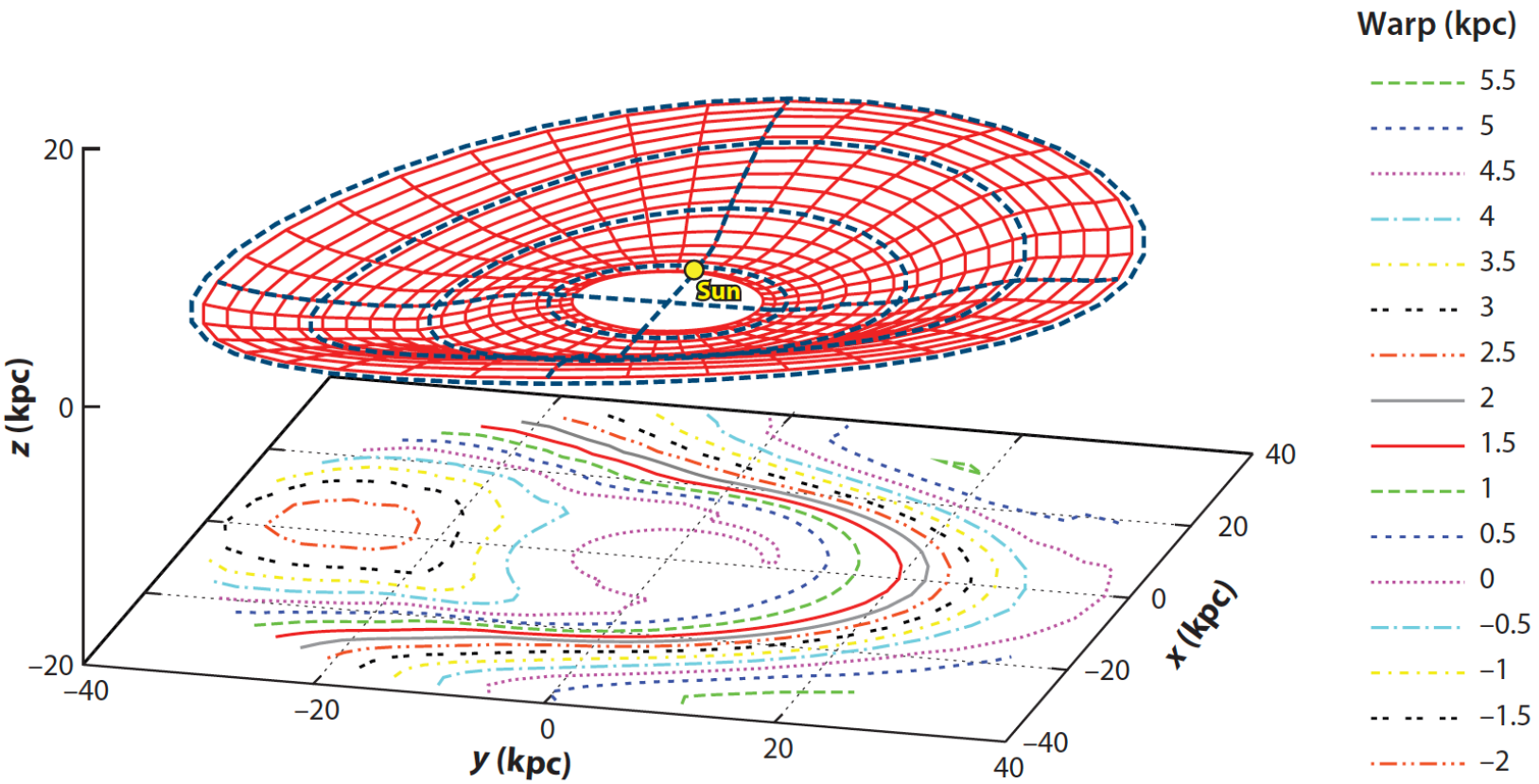
Radial distribution of HI (Kalberla & Kerp 2009)



Vertical distribution of HI (Kalberla & Kerp 2009)



The disk is warped (common in galaxies)



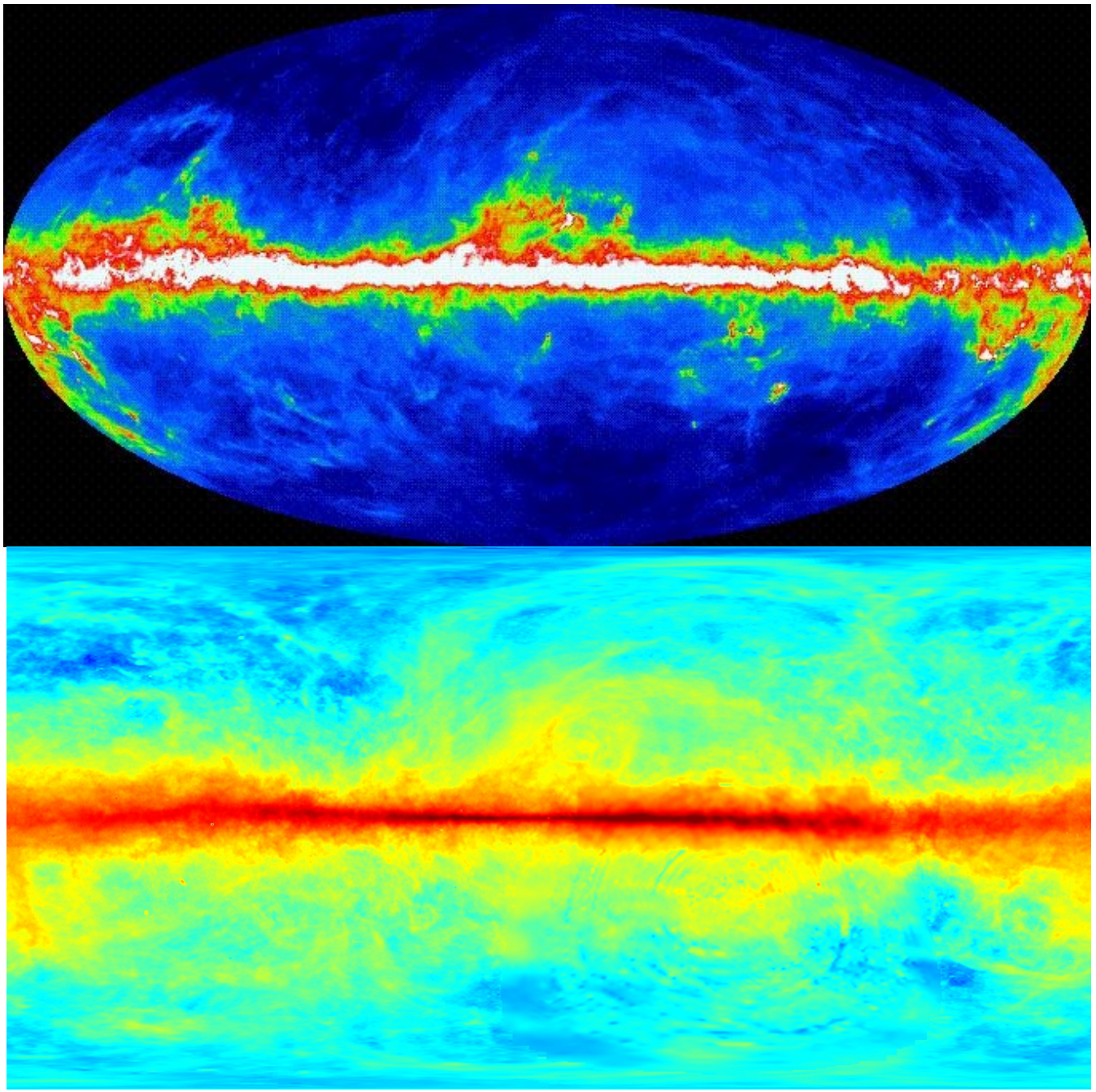
Infrared emission and neutral gas:

Plenty of dust mixed with the HI, so IR emission can also be used to investigate the neutral component of the gas.

- At high Galactic latitudes dust is heated by diffuse starlight, and dust temperatures are expected to be quite uniform between different regions
  - If the dust to gas ratio is constant, we'd expect the IR emission to be proportional to the 21cm emission

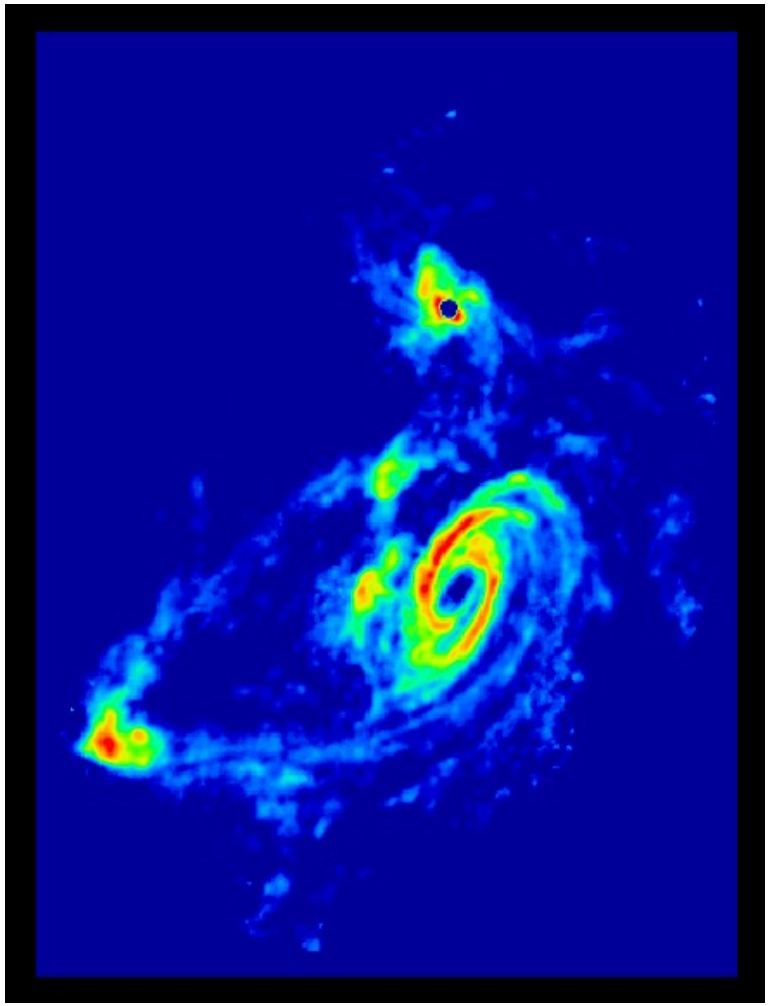
- The Diffuse Infrared Background Experiment (DIRBE) on the COBE satellite made an all-sky map of the 100μm emission
  - Correlation between this and 21cm agrees with assumption that HI and dust are well mixed, and that starlight heating is quite uniform

IRAS 100μm emission, and N(HI).



HI in galaxies

HI measures column density, the neutral atomic gas mass, and gas temperatures in interstellar clouds. Shows connections between interacting galaxies.

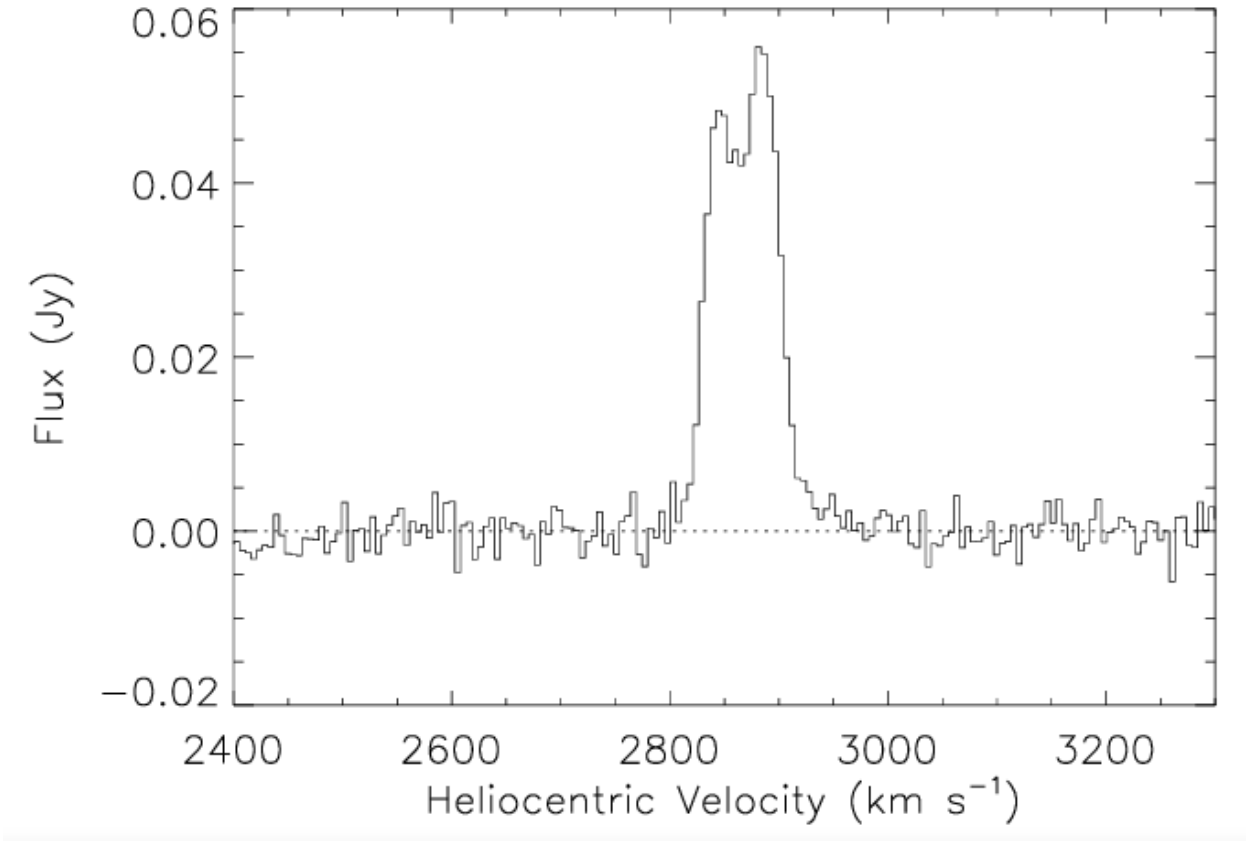


HI mainly in the disk, and has a typical extent of 3 x stellar distribution in galaxies

Used to trace the Galactic mass distribution.

HI in galaxies

Double-horned profile indicates a rotating disk.



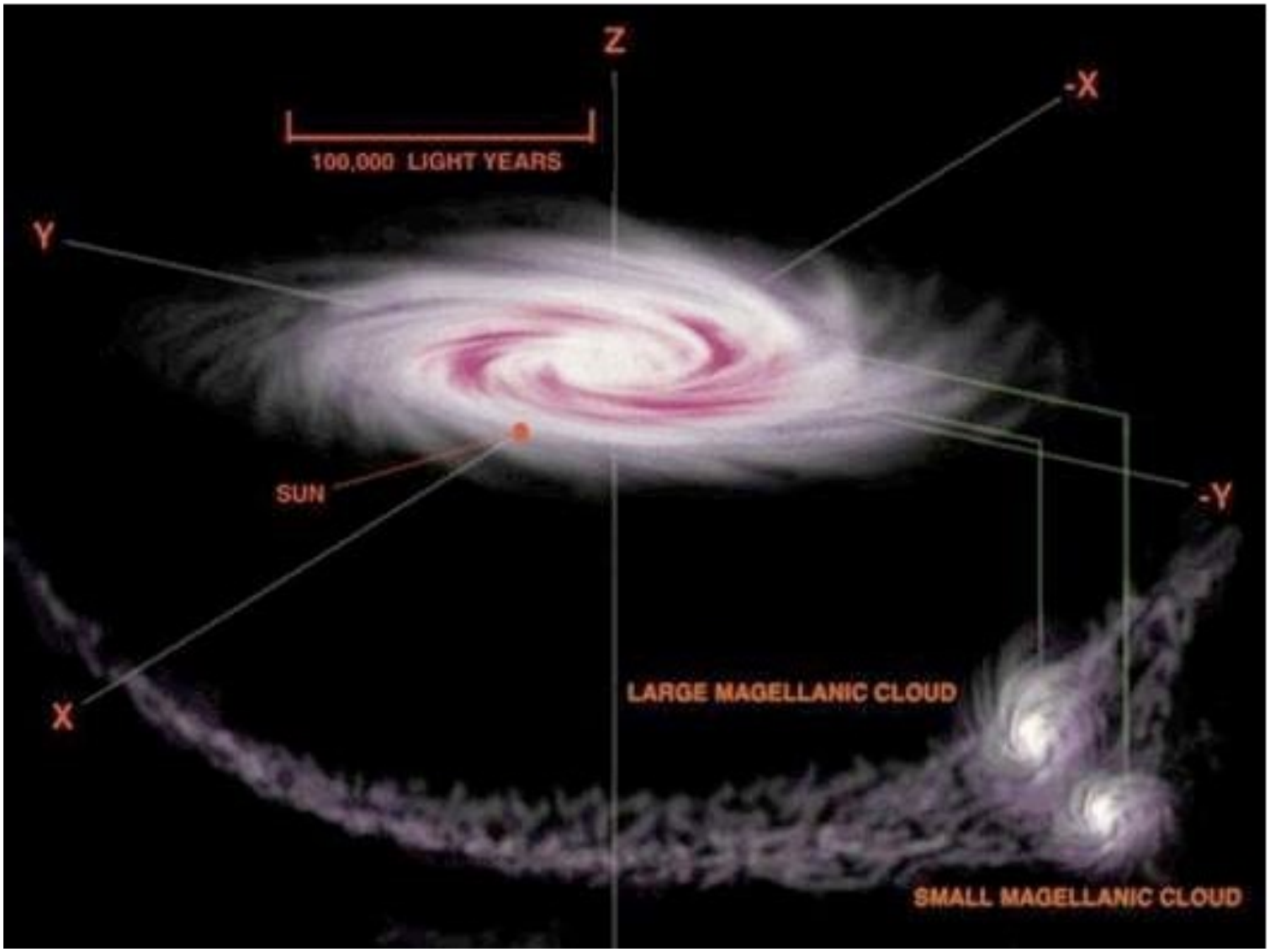
High Velocity Clouds

- V_LSR > 90 km/s (generally)
- Not consistent with an origin in the disk (velocity differs by more then 50 km/s from simple galactic rotation)
- First detected by Muller (1963)
- Depending on distance, could make up 10% of all HI:
  - M = 10^4 M_sun D_{kpc}^2

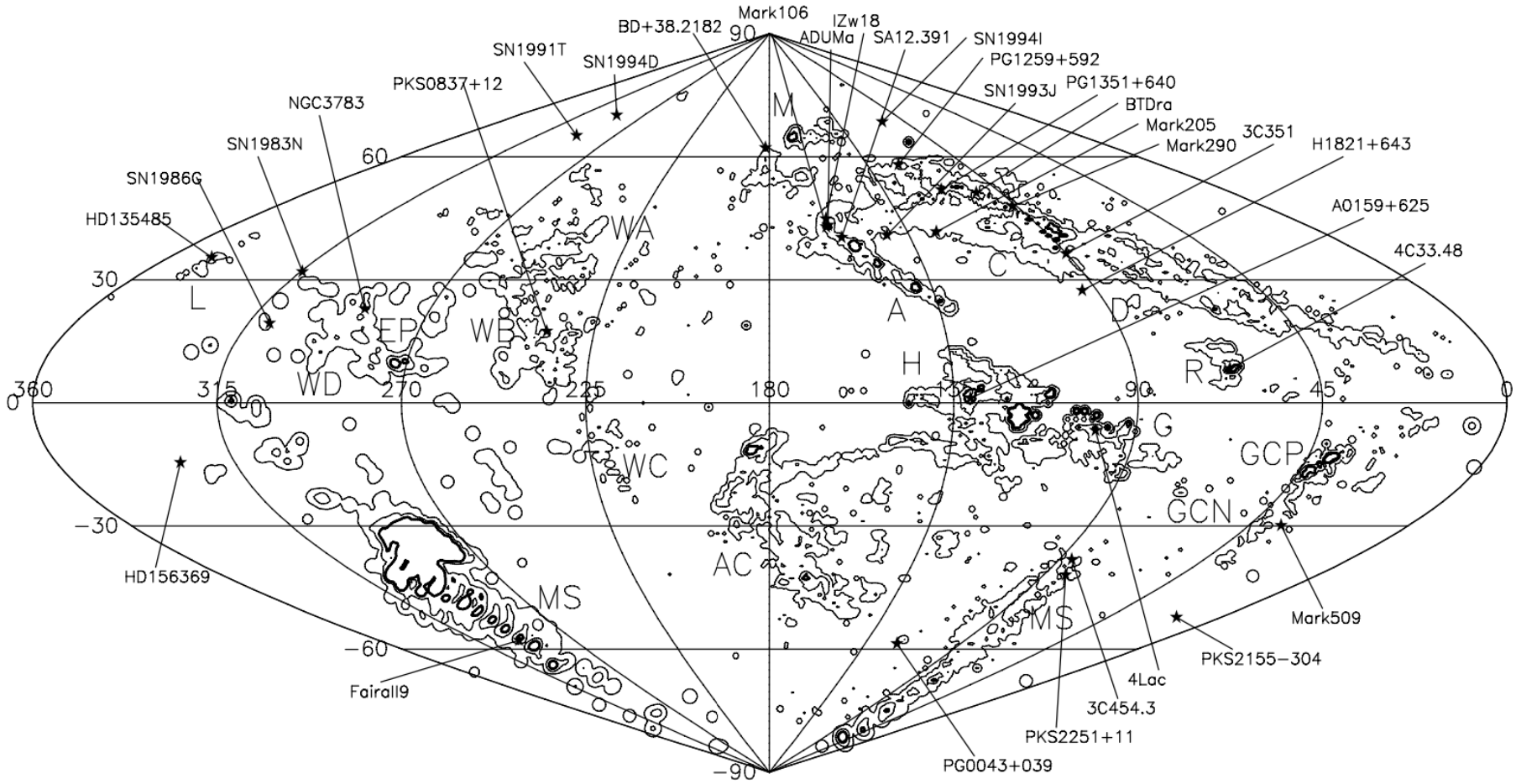
Magellanic stream

21cm emission, about 180 deg across. Tidal debris tail. Gas falling into the Milky Way

Could be as much as 0.4 Msun/year(van Woerden et al. 2004)



High Velocity Clouds



Wakker et al. 1997

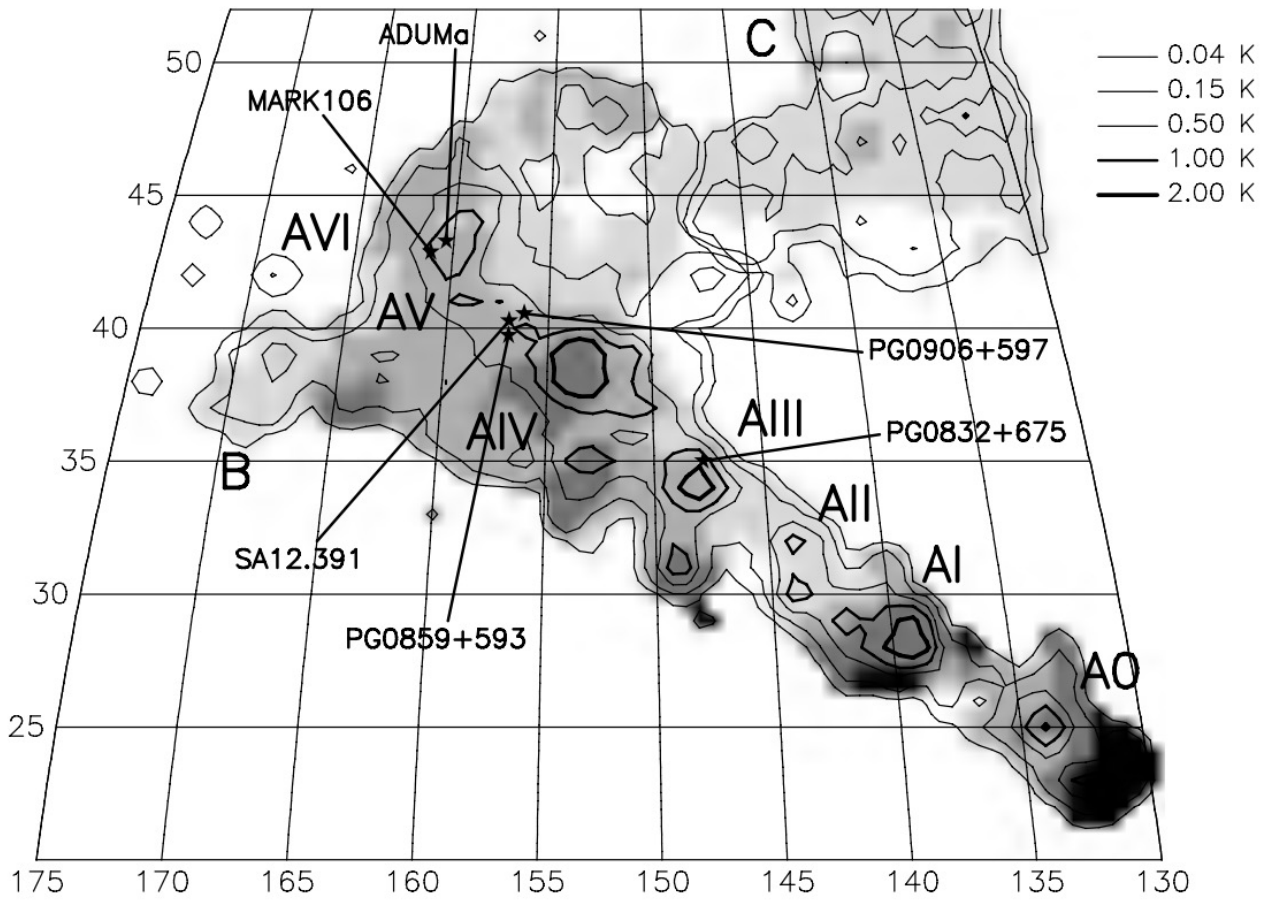


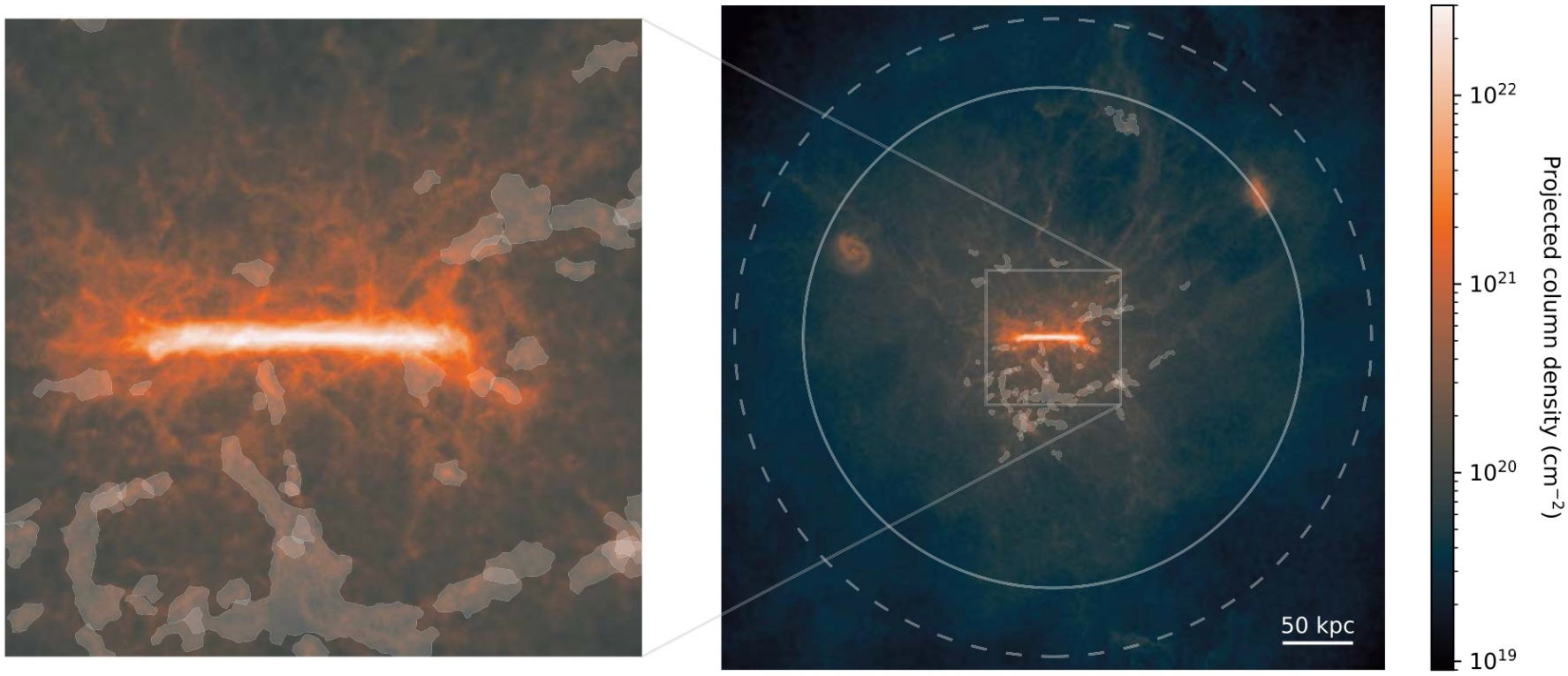
Figure 2 Brightness temperature (contours) and velocity field (greyscale) of complex A. The darkest greyscale is for velocities less than −190 km/s. It changes at −170, −150, and −130 km/s. Shown are the objects used to derive a distance (Section 4). In the top right corner, part of complex C is included to show the bridge between A and C. Separate contours were drawn for A and C, to show where the artificial boundary was put.

Wakker et al. 1997

High Velocity Clouds

- Distance is the key unknown – estimates range from 100 pc to 100 kpc
- Sometimes seen in absorption to distant stars, giving a limit.
- HVC A complex must be between 2.5 and 6.5 kpc, M~10^6 M_sun
- Highly ionized species in HVCs like CIV indicate a hot galactic halo
- Some HVCs also seen in nearby spirals like M101
- HVCs still not fully understood
- HVCs are probably a combination of gas stripped from merging galaxies and a galactic fountain

High Velocity Clouds



Simulation of a disk galaxy with HVCs

Luchini et al. 2024

High Velocity Clouds