



Argelander-
Institut
für
Astronomie



HI

Milky Way rotation from 21cm line profiles

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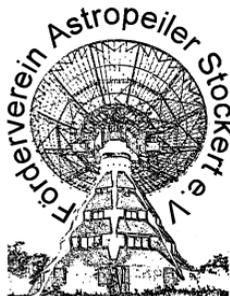
Argelander-Institut für Astronomie Bonn

Astroteiler Stockert e.V.



Education and Culture DG

Lifelong Learning Programme

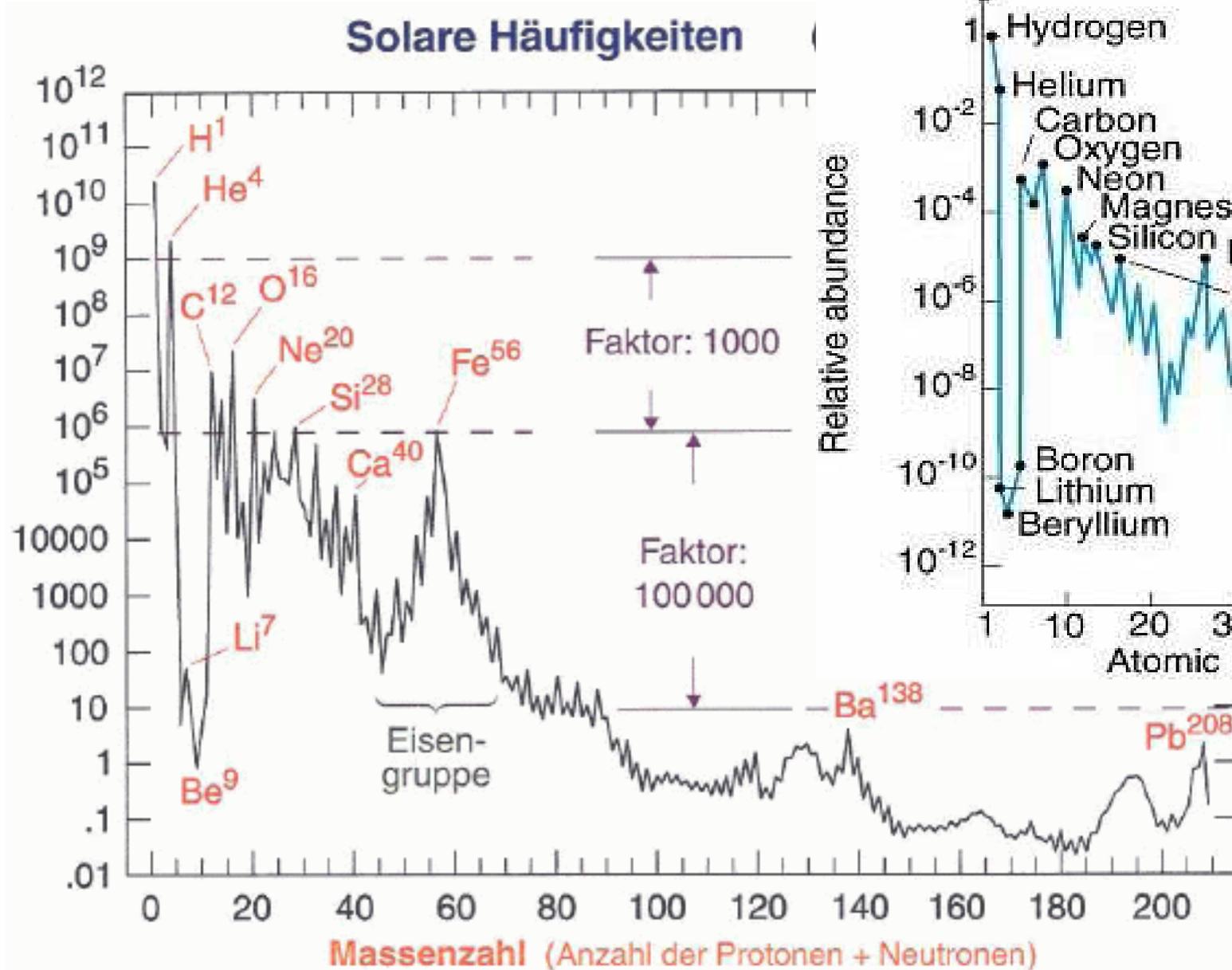


universität**bonn**

Why is HI important?

- Hydrogen is the most abundant element
- Neutral hydrogen (HI) fills most of the space between the stars
- Because of the Doppler effect HI lines supply kinematical information for the observed HI clouds (center velocities), even information about internal motions (profile width)

Element abundance, Solar & Cosmic



Hydrogen is by far the most abundant element

- Very basic ideas:
 - Assuming that the hydrogen atoms are uniformly distributed throughout the galaxy, we might expect to find hydrogen for each line of sight
 - Stars are expected to be born out of gas condensations but some gas should have been left over (the interstellar medium, ISM)
 - Hydrogen is a gas and free to move. This gas however should have settled in the gravitational potential (caused by the stellar disk). In analogy to planetary atmospheres we even might expect to find a “Galactic atmosphere” around the disk.
 - Line emission would be best for a diagnosis
 - Each of the observed lines would be Doppler shifted. Hence, one could be able to see the rotation of the Milky.
 - Radio lines would be important since they would not be obscured by dust

The quest for a hydrogen line (1944)

- Oort (Professor in Leiden) had spent many years studying the rotation and structure of the Galaxy using optical means. He was frustrated by the extensive clouds of dust lying in the galactic plane, which block visible light. But radio waves will penetrate the dust and show us the galactic center and indeed the opposite side of the galaxy. One can then study the differential rotation of the galaxy and estimate distances to gas clouds, and thus map the distribution of matter in the galaxy.
- Radio science has in 1944 advanced to a promising field after detections of radio emission from the Milky Way by Jansky and Reber.
- Oort assigned his student, H.C. Van de Hulst, the job of figuring out what radio spectral lines might exist and what their frequencies would be. Since hydrogen is the most abundant element in the universe, he started his studies with hydrogen. He found that a "hyperfine" transition in the ground state of neutral hydrogen would produce radiation in the radio range, at a frequency of 1420 MHz, or about 21 cm wavelength.

1944: Van der Hulst reports about the H I line... van de Hulst & Oort

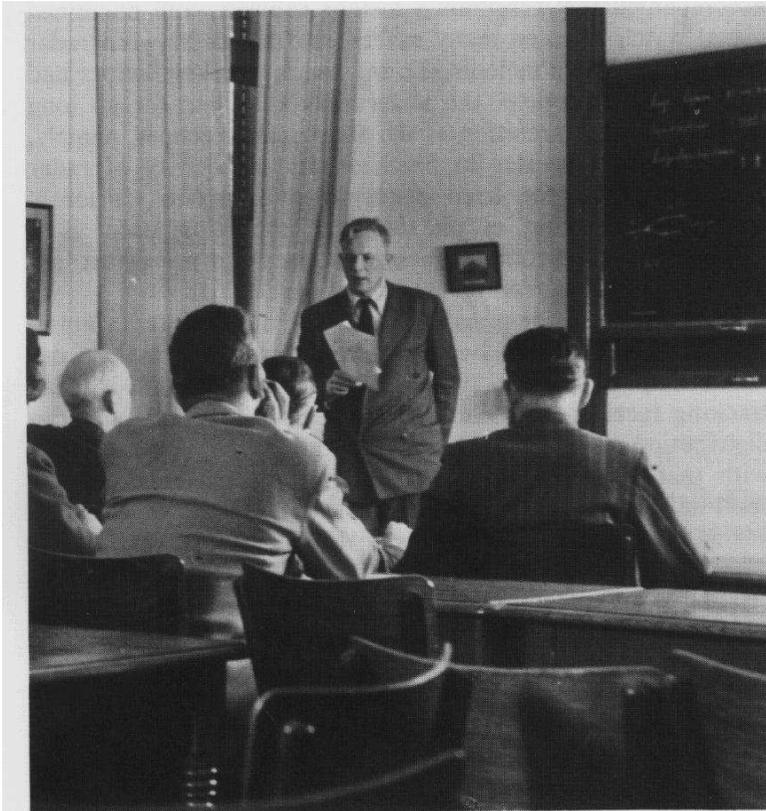
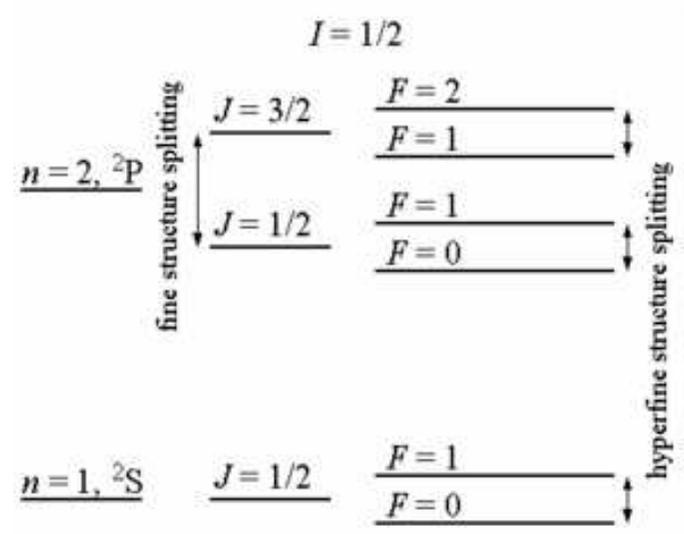
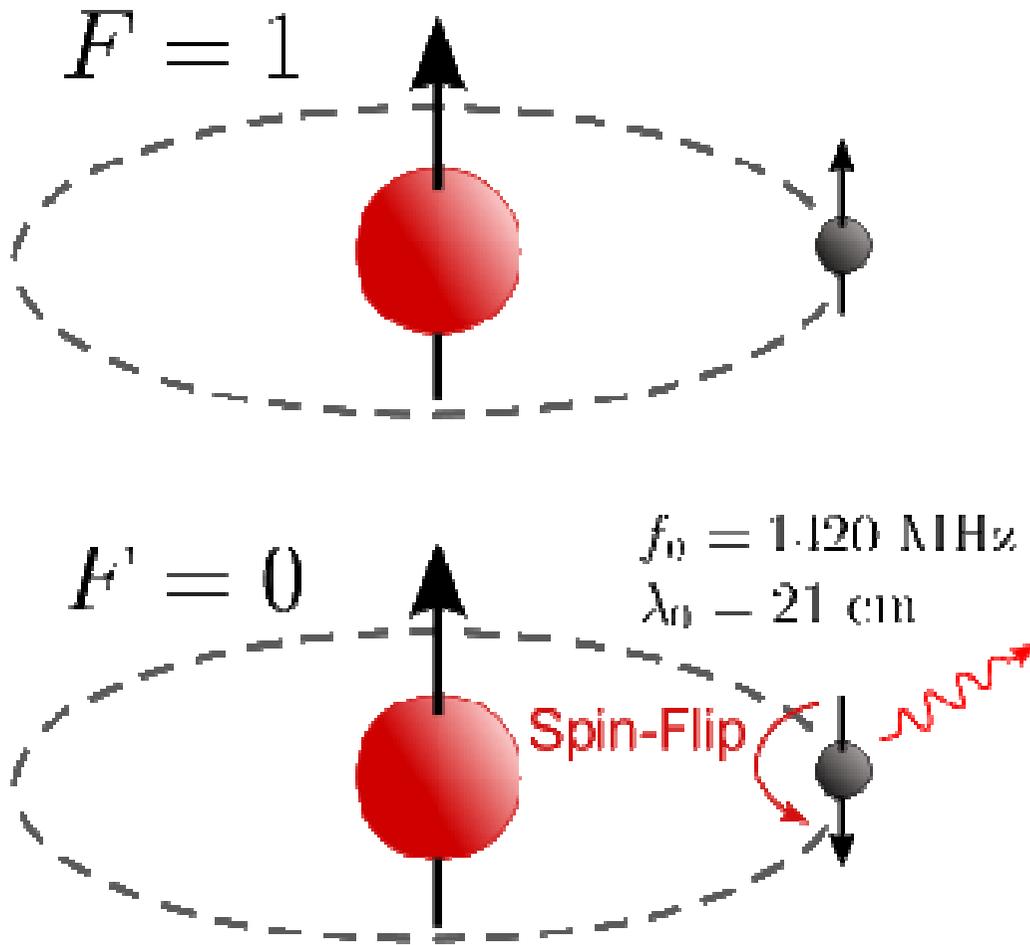


Plate 1.6 Van de Hulst reading his paper on the 21 cm hydrogen line. (This photograph taken in 1955 is a reconstruction of the 1944 meeting).
(By courtesy of H. C. van de Hulst, Leiden)



<http://www.gb.nrao.edu>

The hyperfine splitting of the ground state 2S is the source of the 21 cm hydrogen line.



Frequency 1420.40575177 MHz

Properties of the HI 21-cm line

- Magnetic dipole emission is a “forbidden” transition. This means, the transition probability is extremely low.
- The lifetime of an excited state can be derived from the Einstein coefficient A_{10}
 - $\tau = 1/A_{10} \sim 3.5 \cdot 10^{14} \text{ s} \sim 11 \text{ million years}$
 - The frequency is extremely well defined
- Observed line reflects motion of the gas (Doppler effect)
 - Center velocity - rotation curve – radial motion
 - Line width - temperature and turbulence in the ISM
- Excitation by collisions
- Line detected 1951 in US, Australia, and the Netherlands

“Doc” Ewen – receiver and feed (1951)

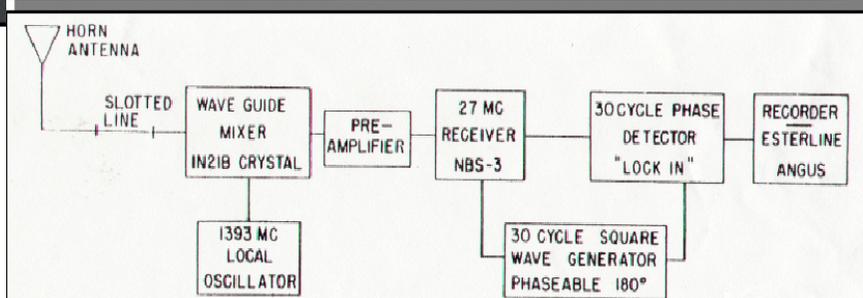
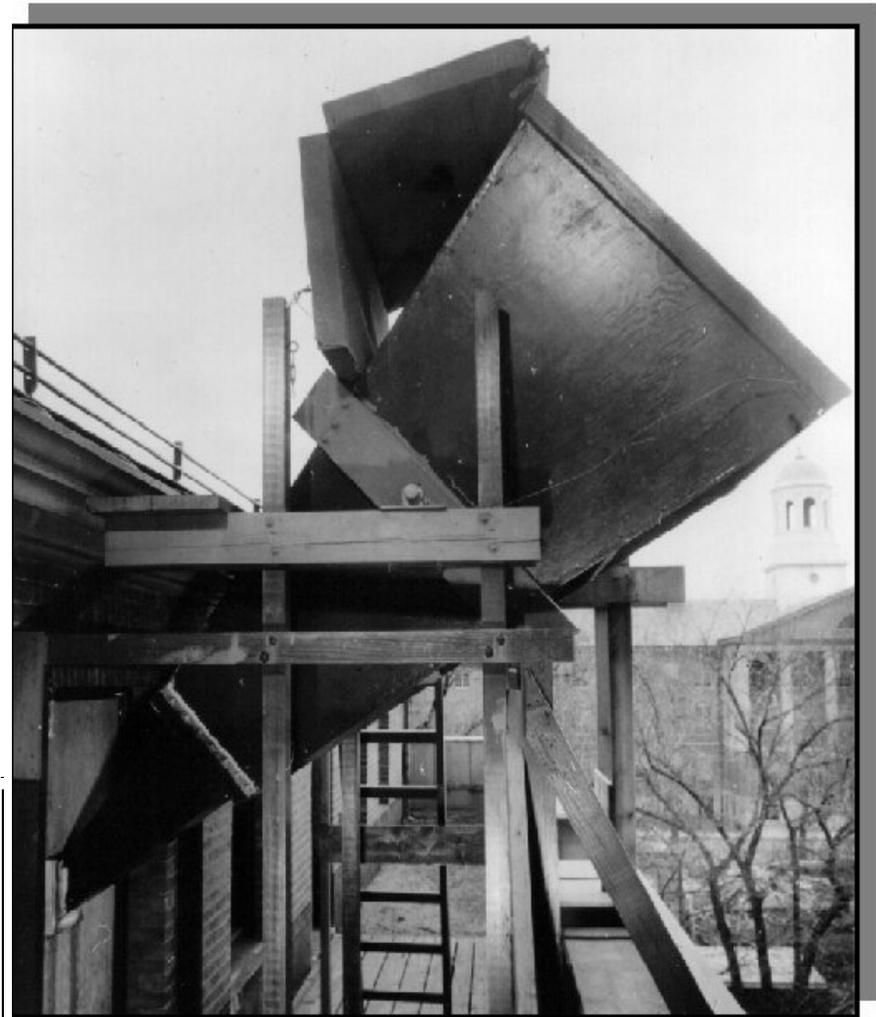
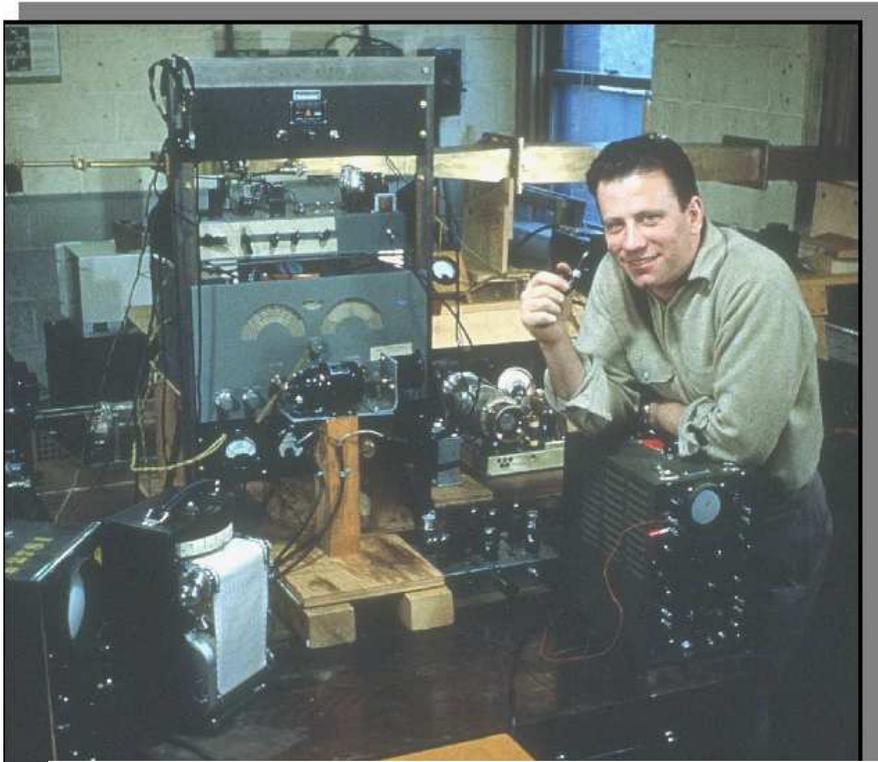


Figure 1. Block diagram of the equipment.

The potential of 21-cm line data for 3D studies of the Milky Way was realized first by Oort

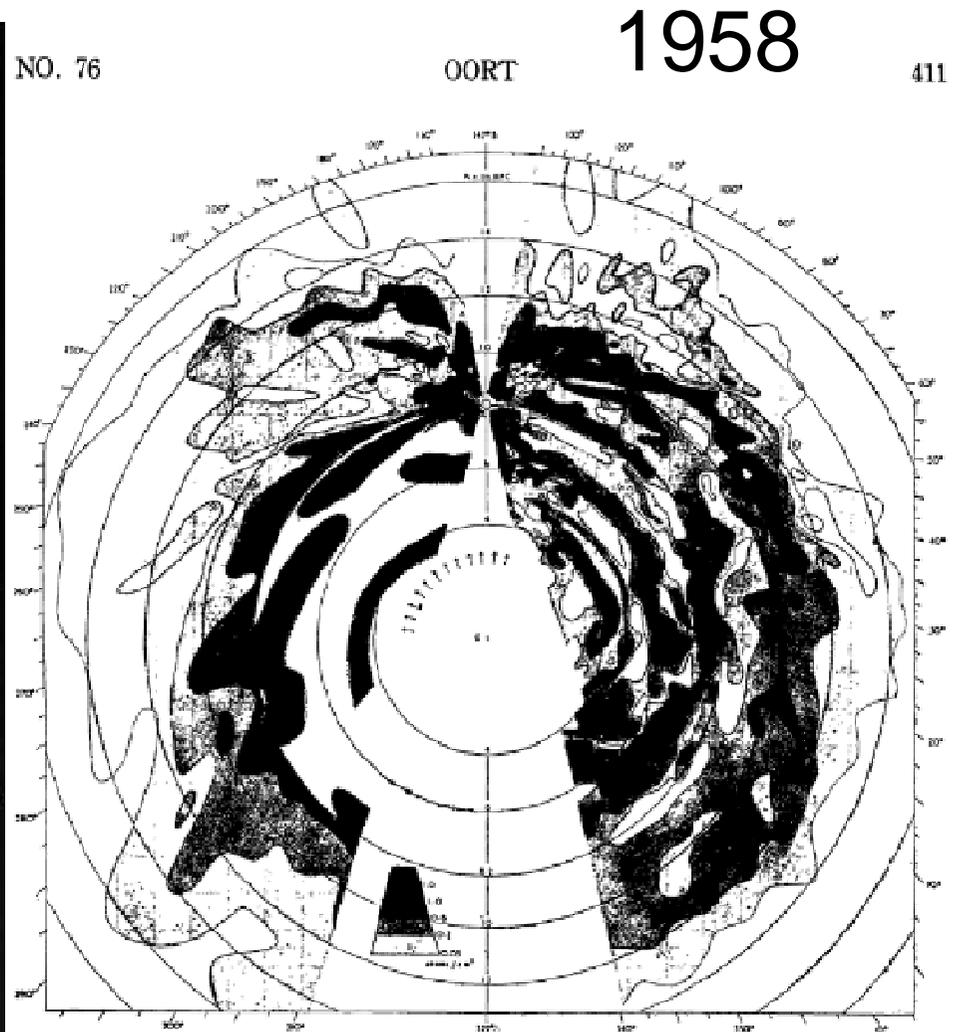
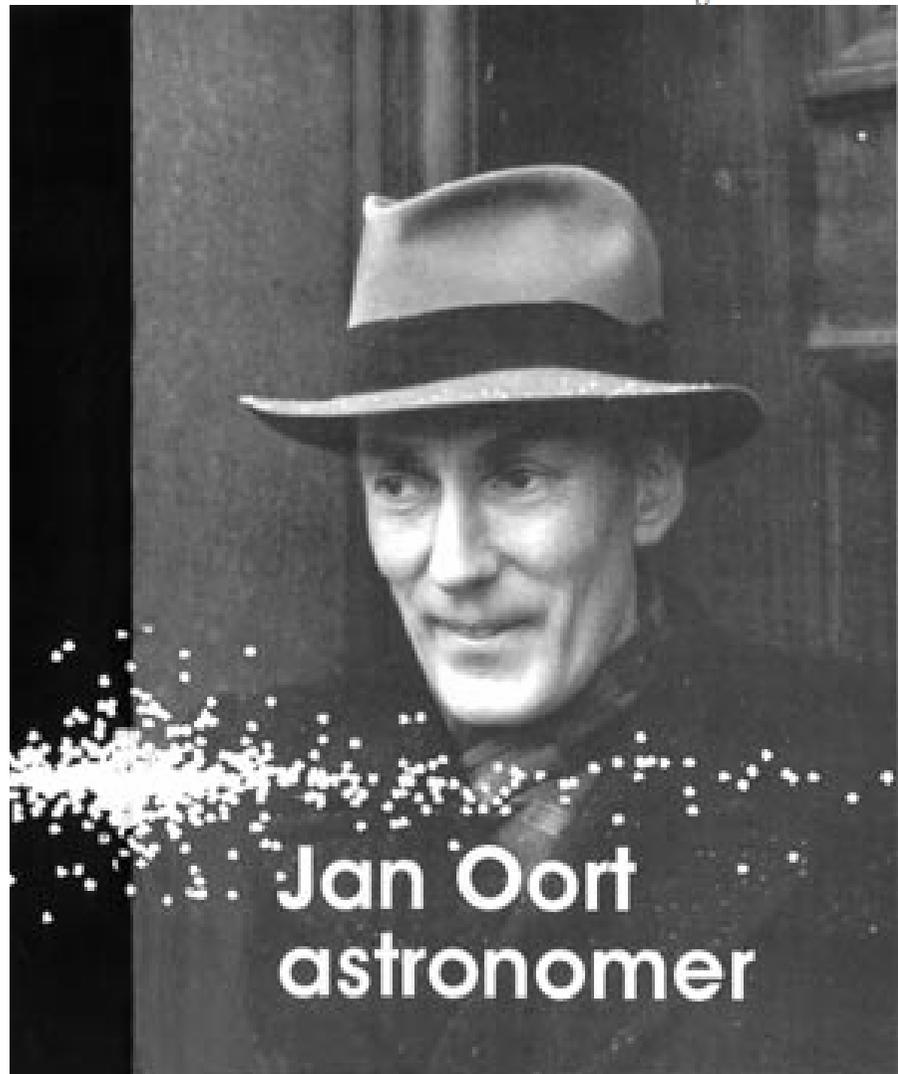
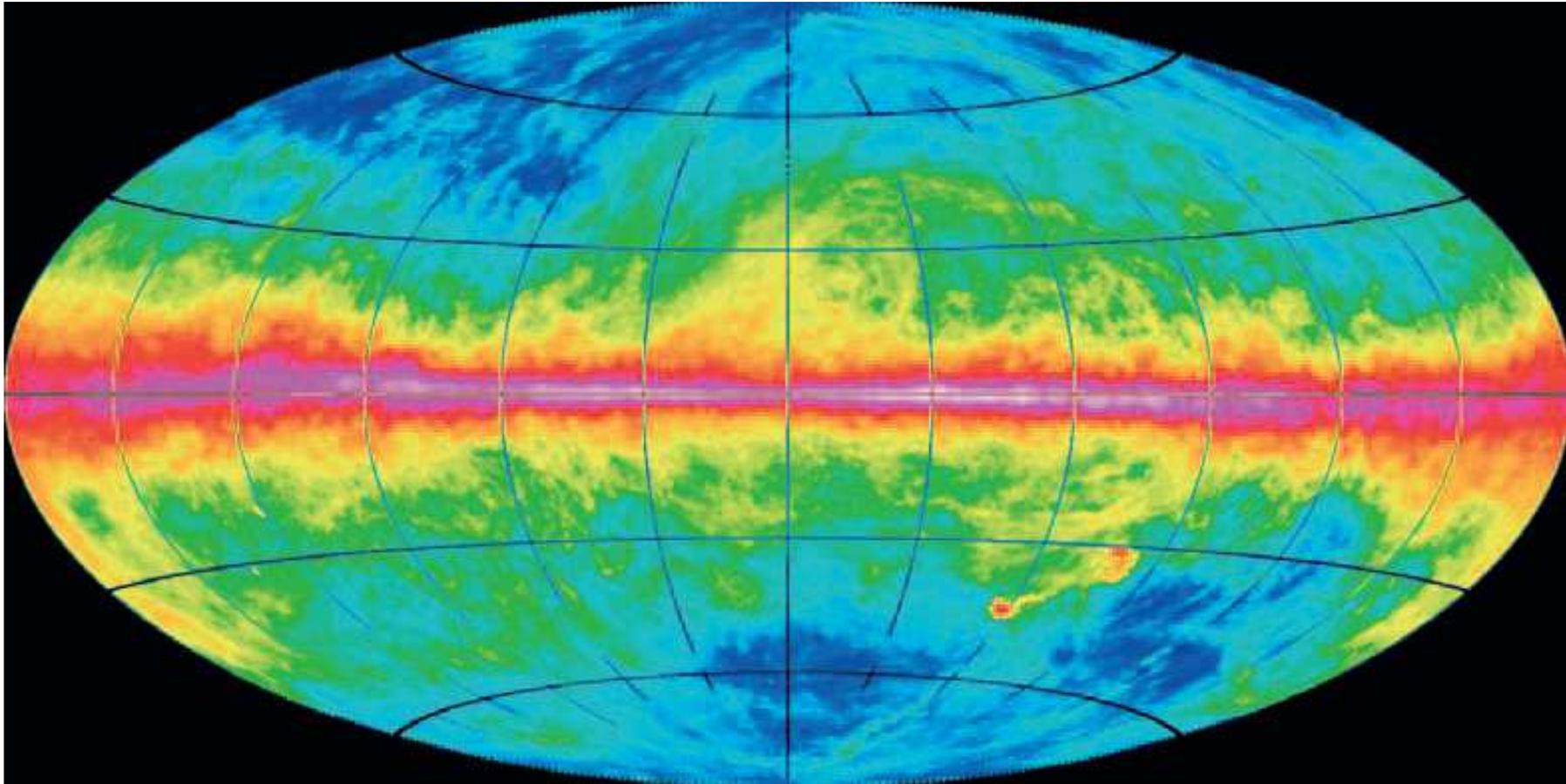


FIG. 1. Distribution of neutral hydrogen in the galactic system.

Today it is easy to browse HI data



Data access through AlfA web interface

<http://www.astro.uni-bonn.de/hisurvey/euhou/>

EU-HOU Connecting classrooms to the Milky Way

AifA HI Survey Server

Welcome to the Survey server of the Argelander-Institut für Astronomie in Bonn!

This server was set up for the EU grant is 510308-LLP-1-2010-1-FR-COMENIUS-CMP.

Leiden Argentine Bonn (LAB) Survey



[Hi profiles](#)

Access to profiles and to the rotation curve

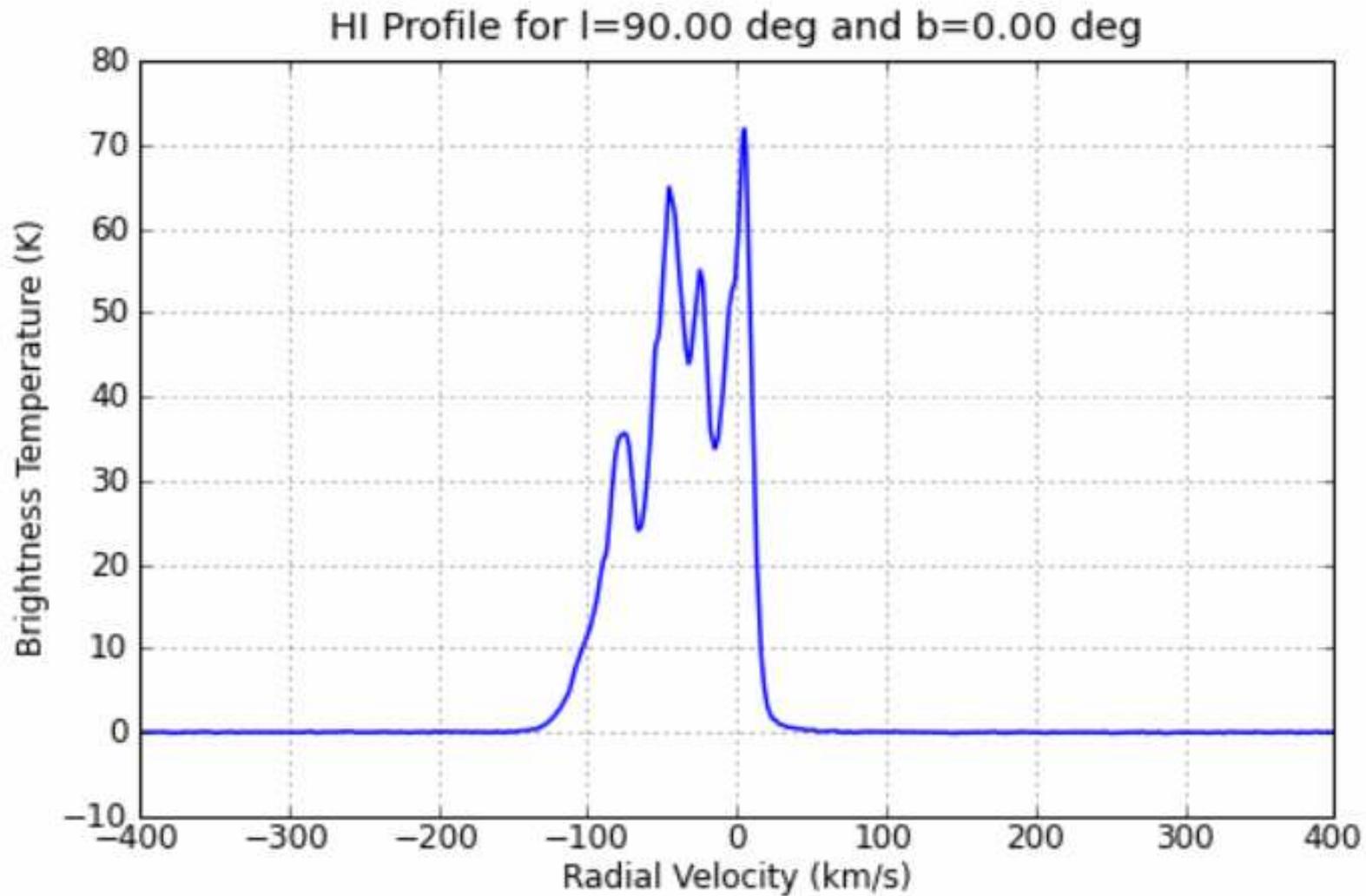
How to get profiles

Simply select a position in equatorial or Galactic coordinates

Example: $l = 90^\circ$, $b = 0^\circ$ in Galactic coordinates

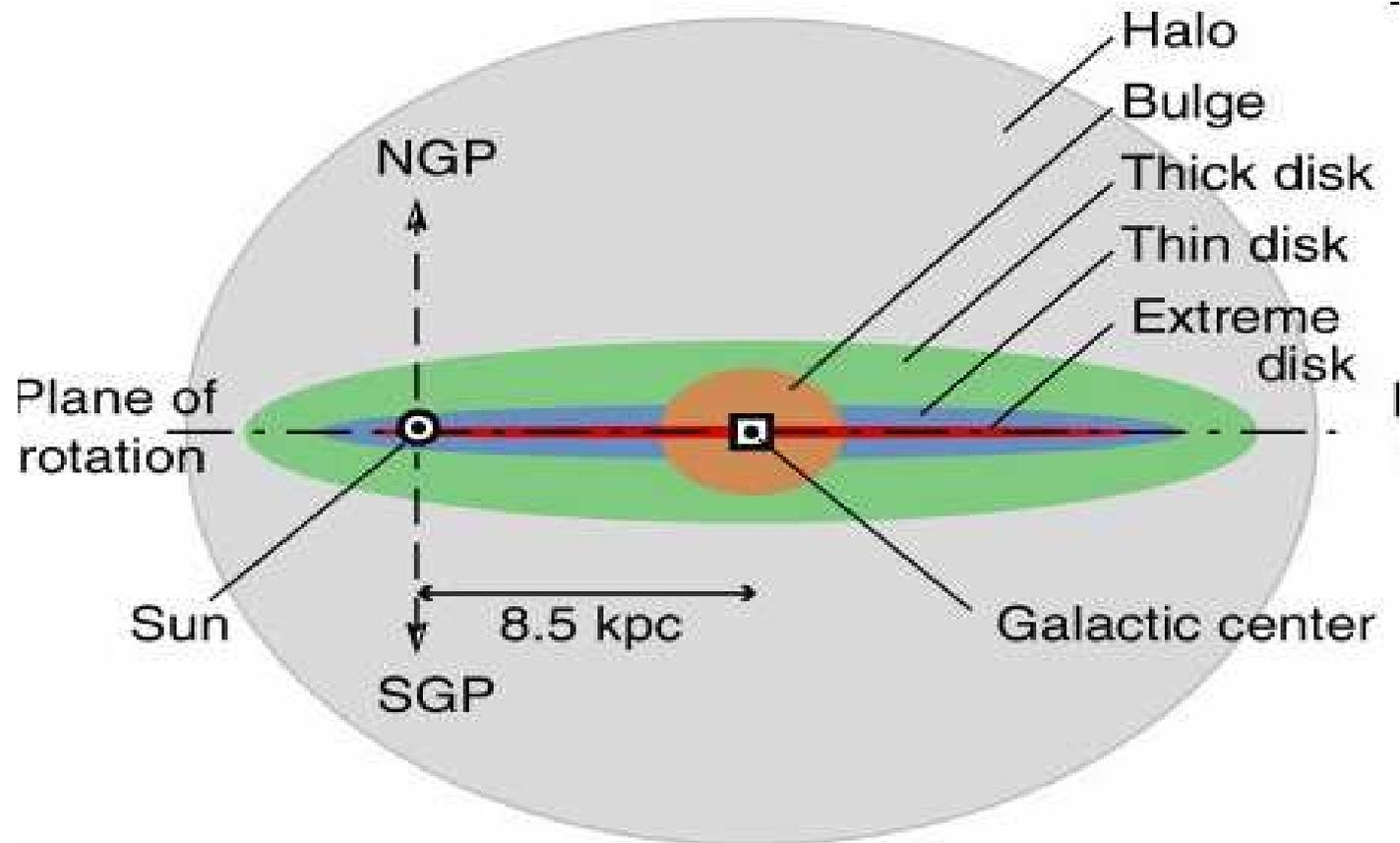
| Select Position | | |
|--|-------------------------------|---------|
| Coordinate system | Galactic coordinates (l, b) ▼ | |
| Position | RA [h m s]/ l [°] | 90 |
| | DEC [±° ' "]/ b [°] | 0 |
| Effective beamsize FWHM [°] | 0.60 | |
| Velocity Window for display | Minimum [km/s] | -400.00 |
| | Maximum [km/s] | 400.00 |
| <input type="button" value="Search data"/> | | |

You get the observed HI profile



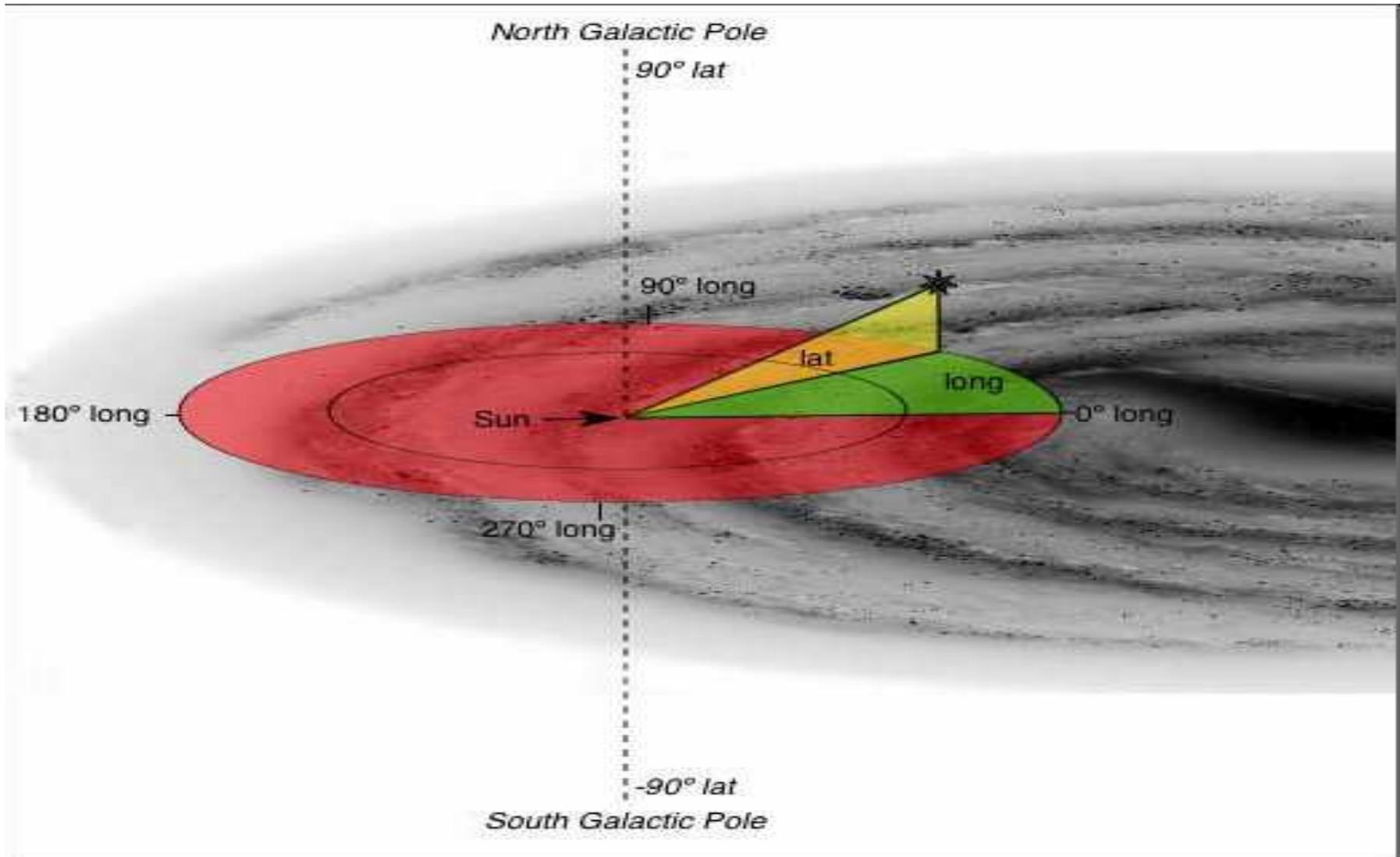
Now you may explore the Milky Way in HI

But: you need to take the geometry into account
The Sun is offset from the Galactic center

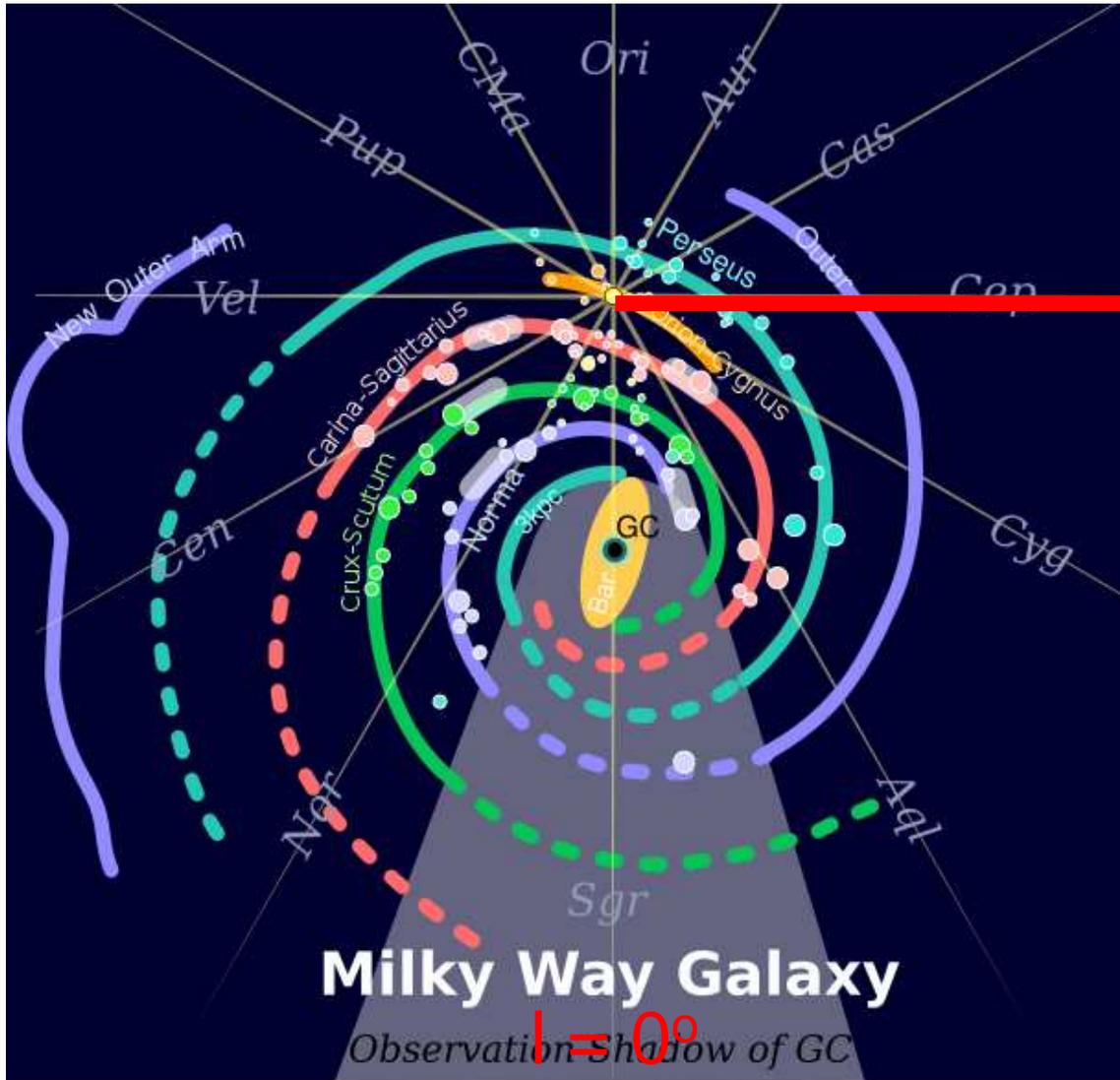


http://c2h2.ifa.hawaii.edu/Tutorial/pages/gal_components.htm

Galactic coordinates in longitude l and latitude b



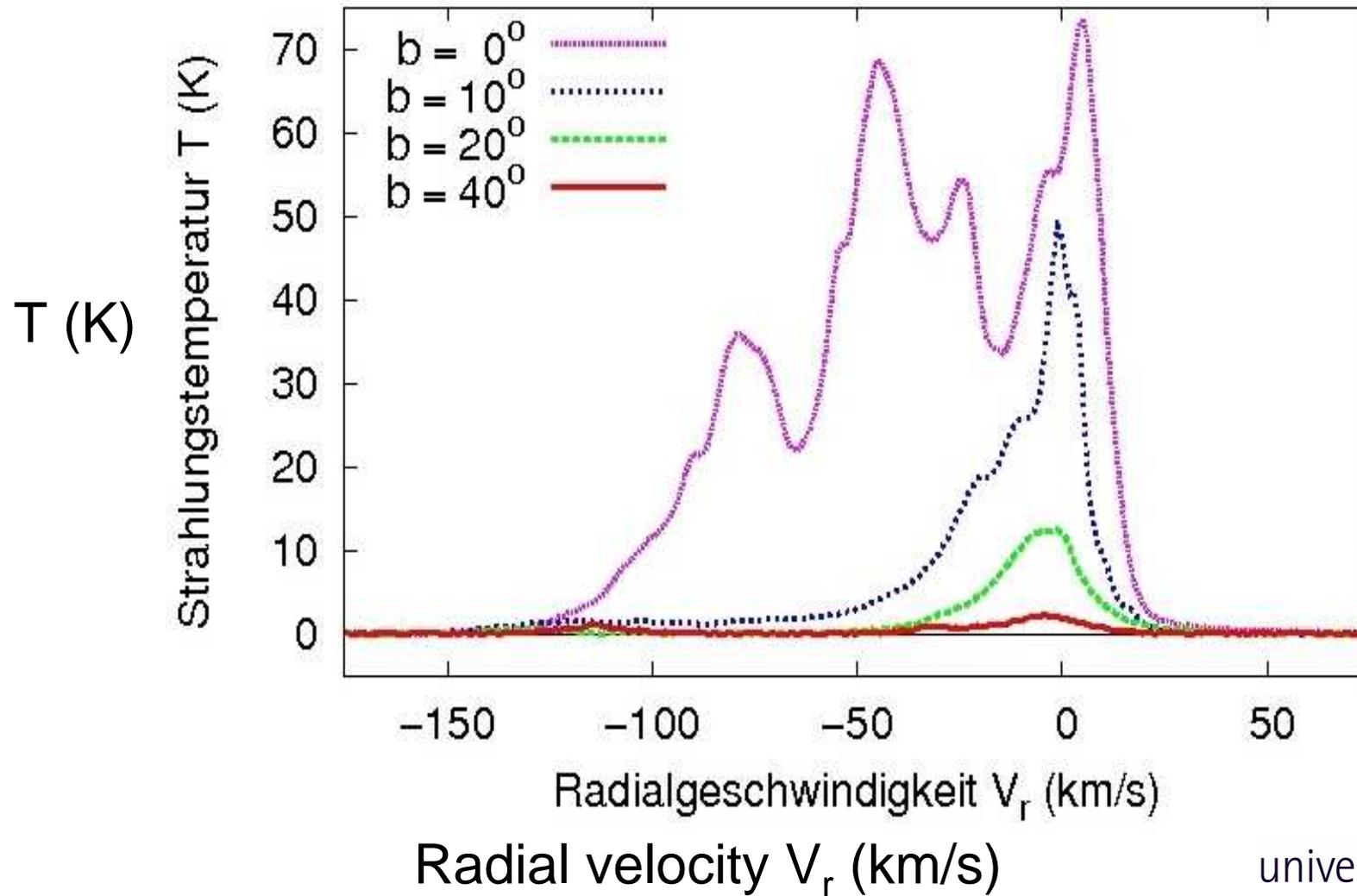
$l = 90^\circ$, $b = 0^\circ$, we look in direction Cepheus



$l = 0^\circ$
Sag A

The thin disk - looking perpendicular to the disk

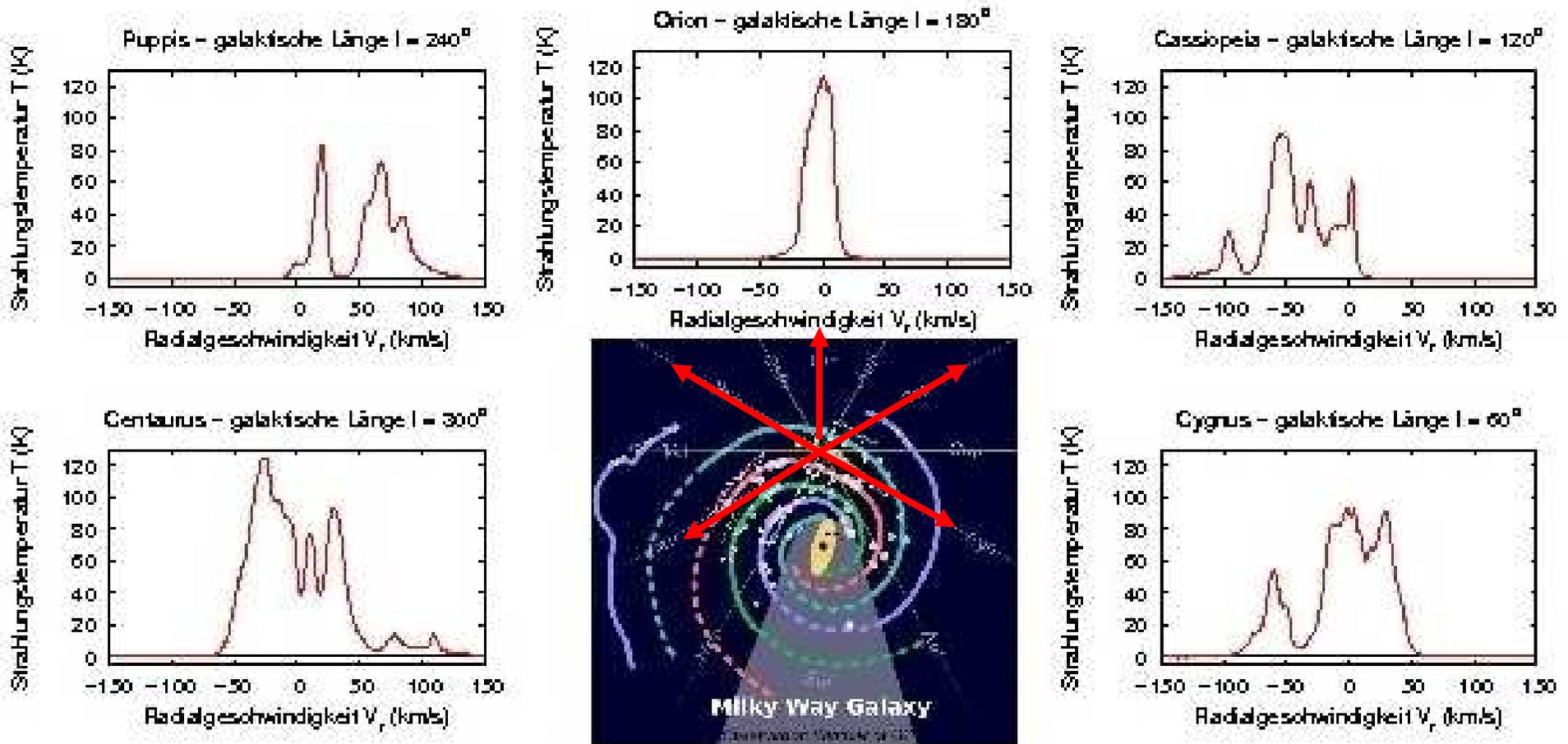
Cepheus – galaktische Länge $l = 90^\circ$



Exercise

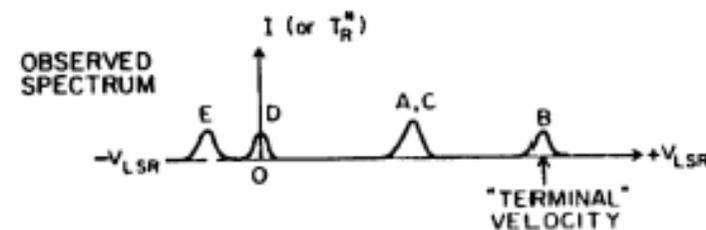
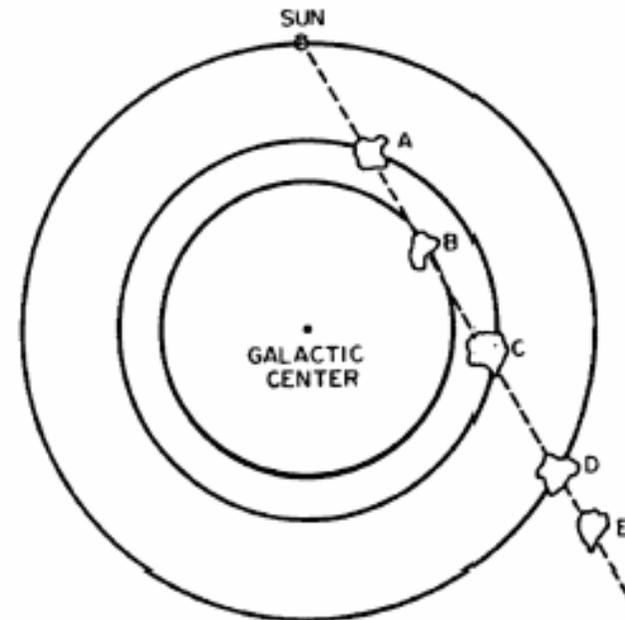
- Select several positions in the Galactic plane ($l = 0^\circ$)
 - For each constant longitude vary the latitude b and compare profiles and calculated column densities
 - Plot the observed column densities as function of latitude $|b|$
 - Explain the result
 - What causes the emission around $v = 0$ km/s?
 - What is the reason for the other lines?
 - Can you find a function that fits best to the observed column densities?

Rotation - looking around in the disk



HI in differential rotation

- For a rotating disk we expect different velocities for clouds along the line of sight.
- Assuming circular rotation, the distance of HI clouds from the Galactic center (or from the Sun) could then be calculated.
- The rotation curve needs to be known.
- In the inner Galaxy the rotation at the tangent points is unambiguous (terminal velocity).



van Dishoek lecture 8

Calculate observed radial velocity for cloud at M

From

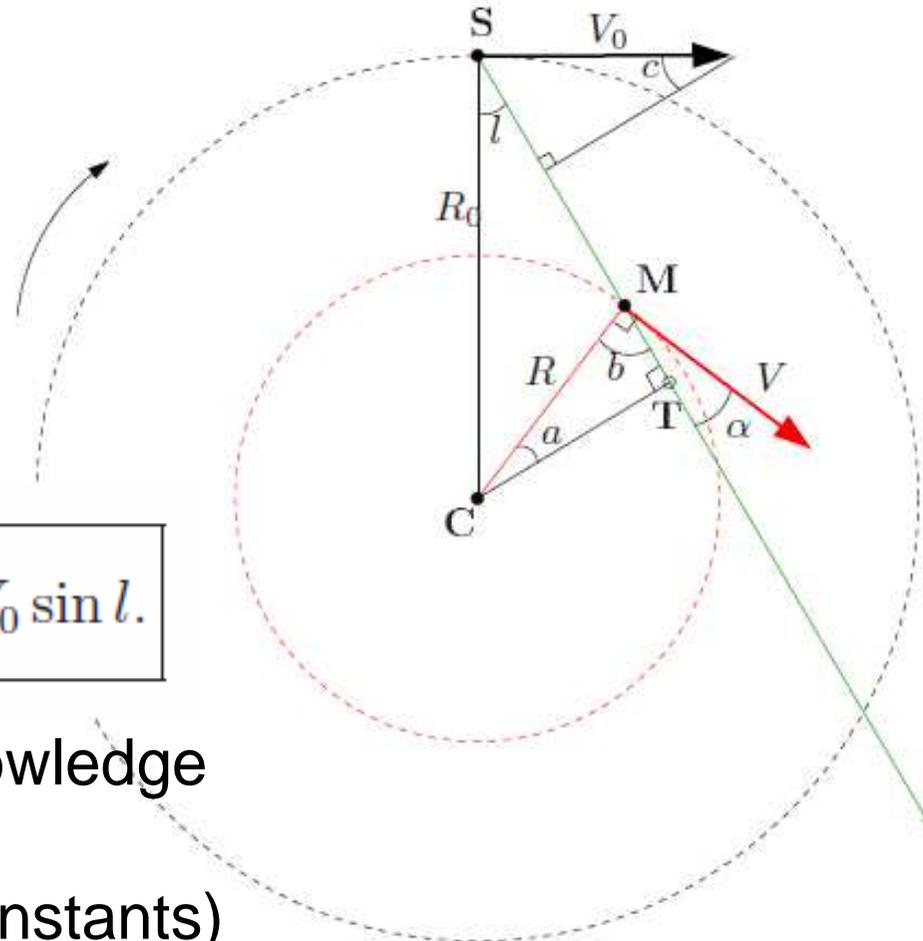
$$V_r = V \cos \alpha - V_0 \sin c.$$

with

$$CT = R_0 \sin l = R \cos \alpha$$

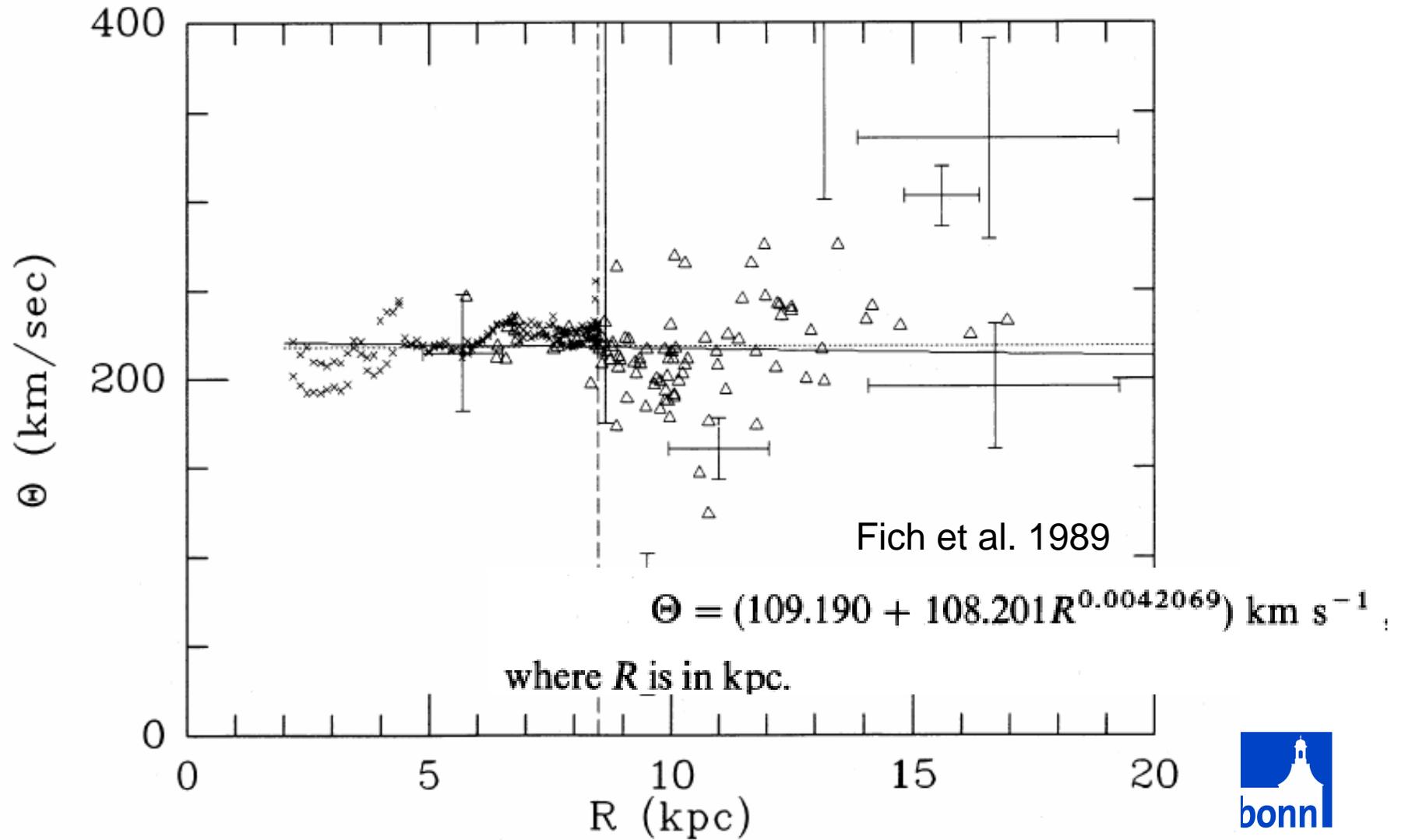
one gets:

$$V_r = V \frac{R_0}{R} \sin l - V_0 \sin l.$$

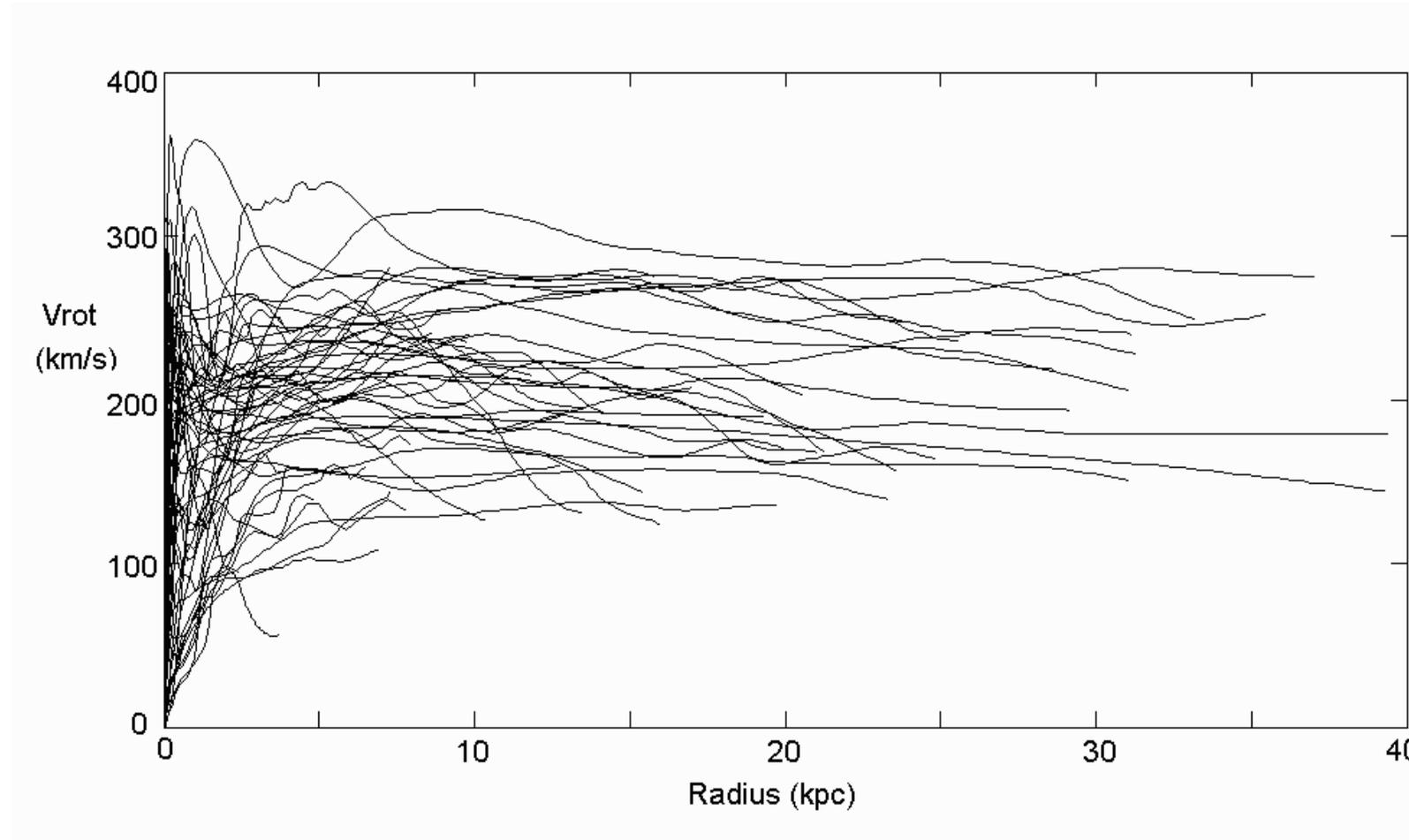


Most important is the knowledge of the Galactic constants R_0 and V_0 (called Oort constants)
A good approximation is $V = V_0$ (flat rotation curve)

Rotation curve of the Milky Way

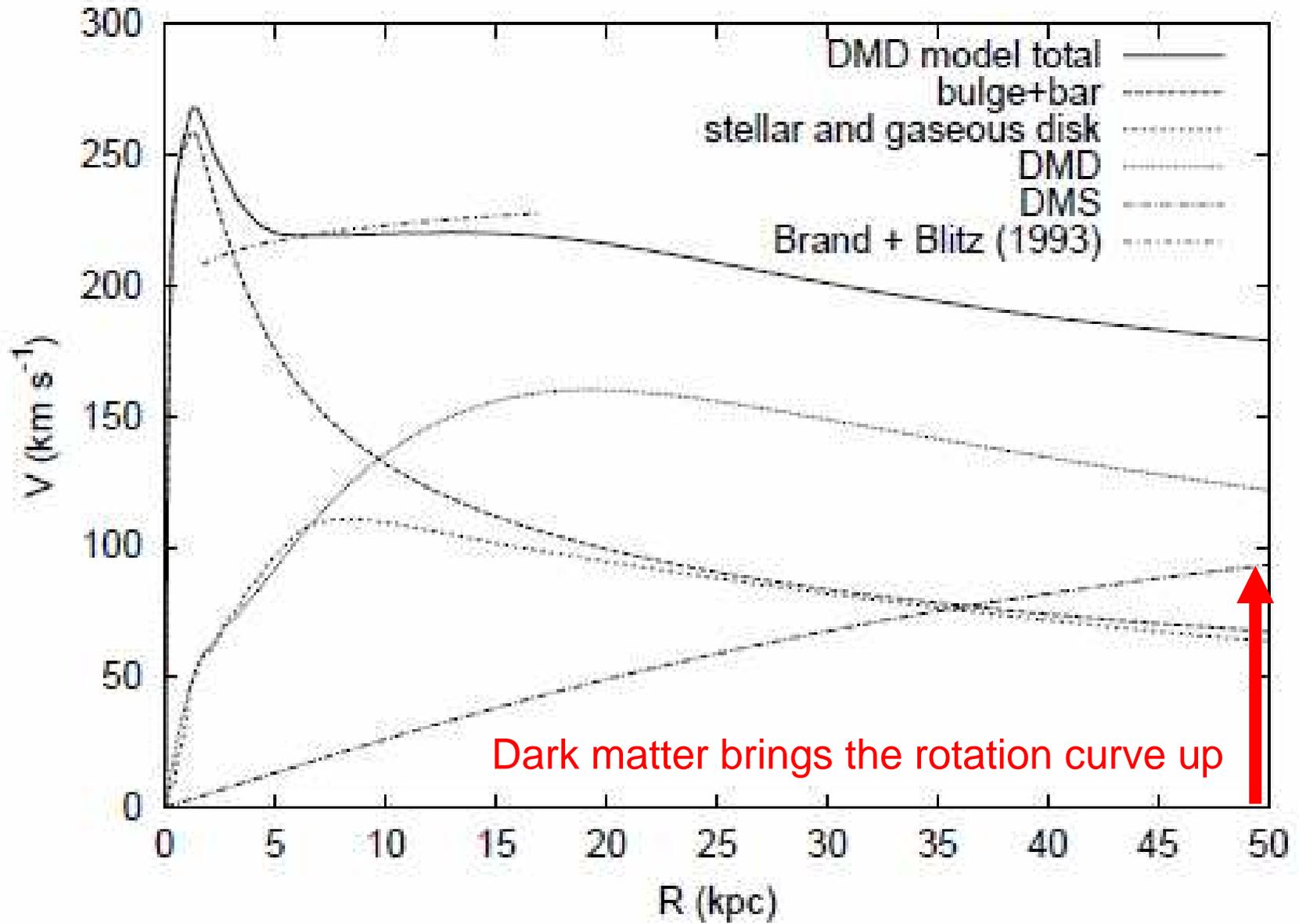


Rotation curves of a few other galaxies: flat



Flat rotation inconsistent with Kepler law
Implies Dark Matter

MW rotation decomposition: Dark Matter needed



Search for spiral arms

- Spiral arms cause density enhancements in the HI distribution
- Such enhancements are observable as peaks in the HI line, hence peaks may indicate spiral structure
 - Caution: gas along a long distance can be "crowded" into a small velocity interval, mimicking also spiral structure

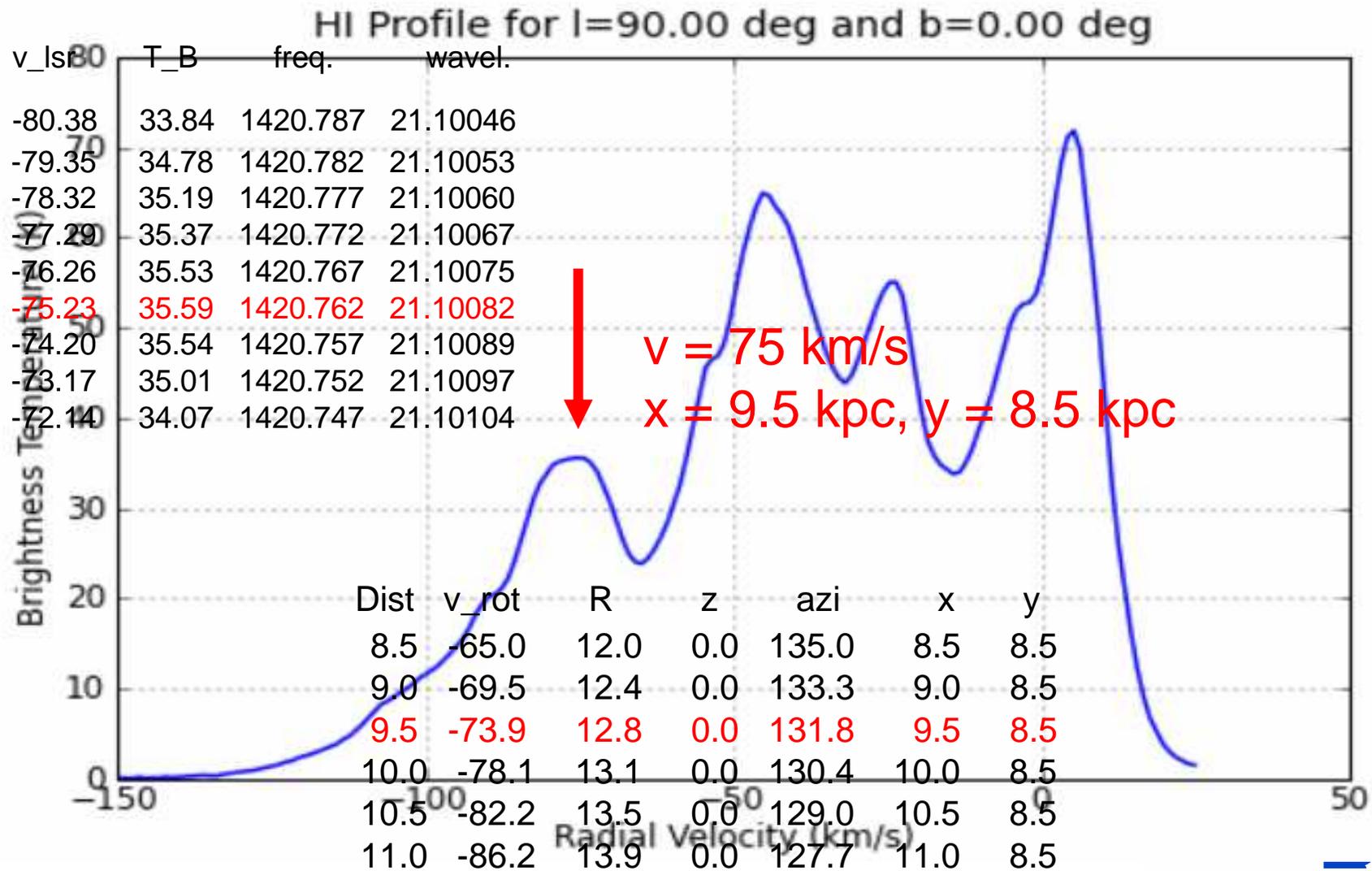
Exercise

- Search for HI peaks in profiles at latitude $b = 0^\circ$
- Determine their velocities and positions according to the rotation curve
 - Use ASCII tables provided by the web interface
- Plot positions found
 - Use the [Galactic grid](#)
- Trace spiral arm features in longitude
- Can you also trace spiral arms in latitude?

Step by step

- Select profile (e.g. $l = 90^\circ$, $b = 0^\circ$)
- Check velocity of a peak in the profile
 - [Download HI profile as ASCII file](#) (For Windows use wordpad)
 - Read off velocity
- From rotation curve get corresponding position in x, y
 - [Download rotation curve as ASCII file](#) (For Windows use wordpad)
 - Read x, y
- Plot position and think about a new position.....

How to - using ASCII data for $l=90^\circ$, $b=0^\circ$



Astrofische : Annika, Juliane, Kra, Franzi, Tina, Selina

EU Hands-On Universe exercise

<http://www.astro.uni-bonn.de/hisurvey/euhou>

mm paper is available at:

http://www.astro.uni-bonn.de/hisurvey/euhou/xy_galactic_grid.pdf

[kpc]

25

20

15

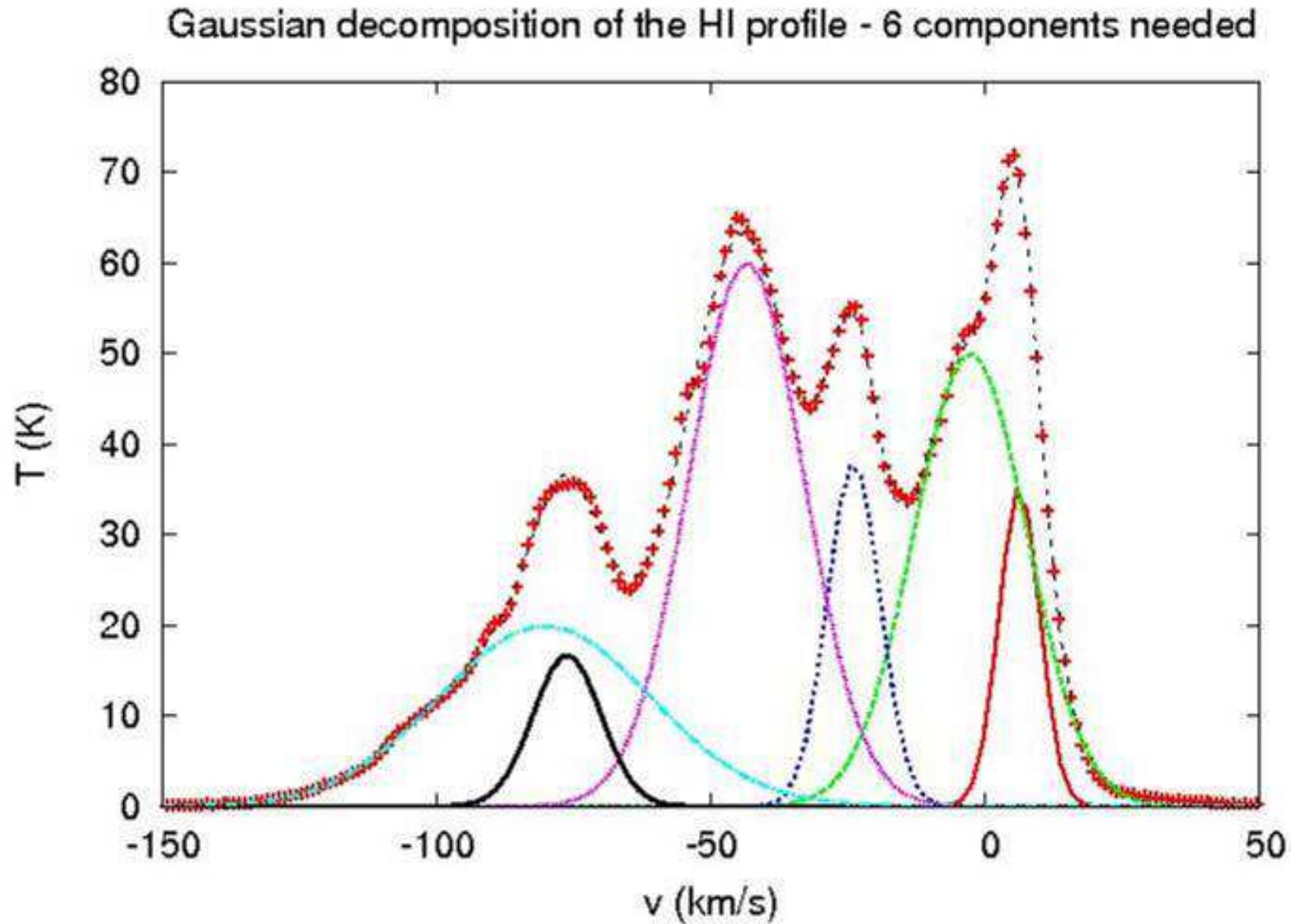
Sonne

Persus Arm

Galaktisches Zentrum



More accurate fitting with Gaussians



Fitted Parameters (gnuplot fit, 6 components)

Final set of parameters

=====

Asymptotic Standard Error

=====

| | | | | | |
|----|---|----------|-----|---------|-----------|
| a1 | = | 35.1037 | +/- | 0.828 | (2.359%) |
| v1 | = | 6.10903 | +/- | 0.06736 | (1.103%) |
| s1 | = | 3.73012 | +/- | 0.0891 | (2.389%) |
| a2 | = | 49.9281 | +/- | 0.572 | (1.146%) |
| v2 | = | -2.81713 | +/- | 0.1982 | (7.035%) |
| s2 | = | 10.2931 | +/- | 0.1194 | (1.16%) |
| a3 | = | 37.9548 | +/- | 0.9601 | (2.53%) |
| v3 | = | -24.1013 | +/- | 0.0942 | (0.3908%) |
| s3 | = | 4.82079 | +/- | 0.1146 | (2.377%) |
| a4 | = | 59.9751 | +/- | 1.073 | (1.789%) |
| v4 | = | -43.6551 | +/- | 0.18 | (0.4123%) |
| s4 | = | 10.5102 | +/- | 0.2965 | (2.821%) |
| a5 | = | 16.7286 | +/- | 1.439 | (8.6%) |
| v5 | = | -76.383 | +/- | 0.2554 | (0.3343%) |
| s5 | = | 6.18121 | +/- | 0.3675 | (5.945%) |
| a6 | = | 19.8456 | +/- | 1.284 | (6.471%) |
| v6 | = | -80.443 | +/- | 1.815 | (2.256%) |
| s6 | = | 19.2644 | +/- | 0.7706 | (4%) |

The $v = -75$ km/s estimate was not too bad!

The Milky Way spiral pattern, artist impressions

Radio
Early data 1958

Infrared
Spitzer Space Telescope

1959IAUS...9...409O

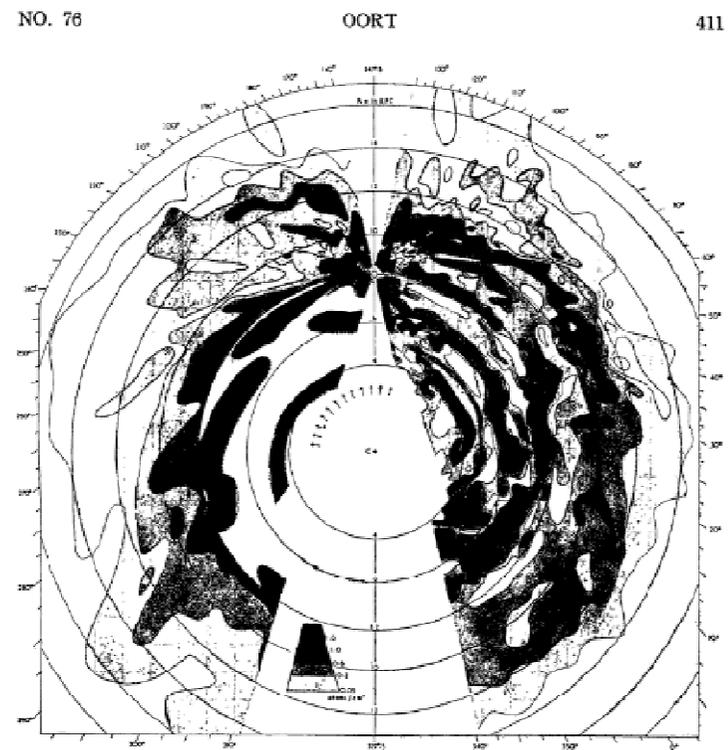
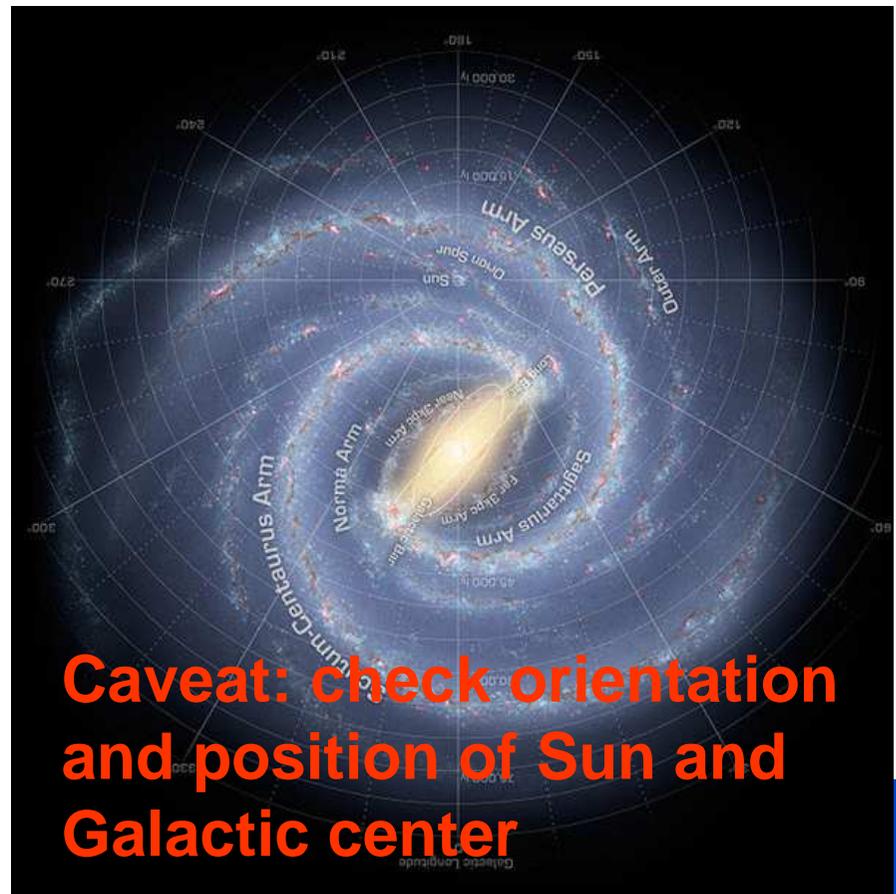
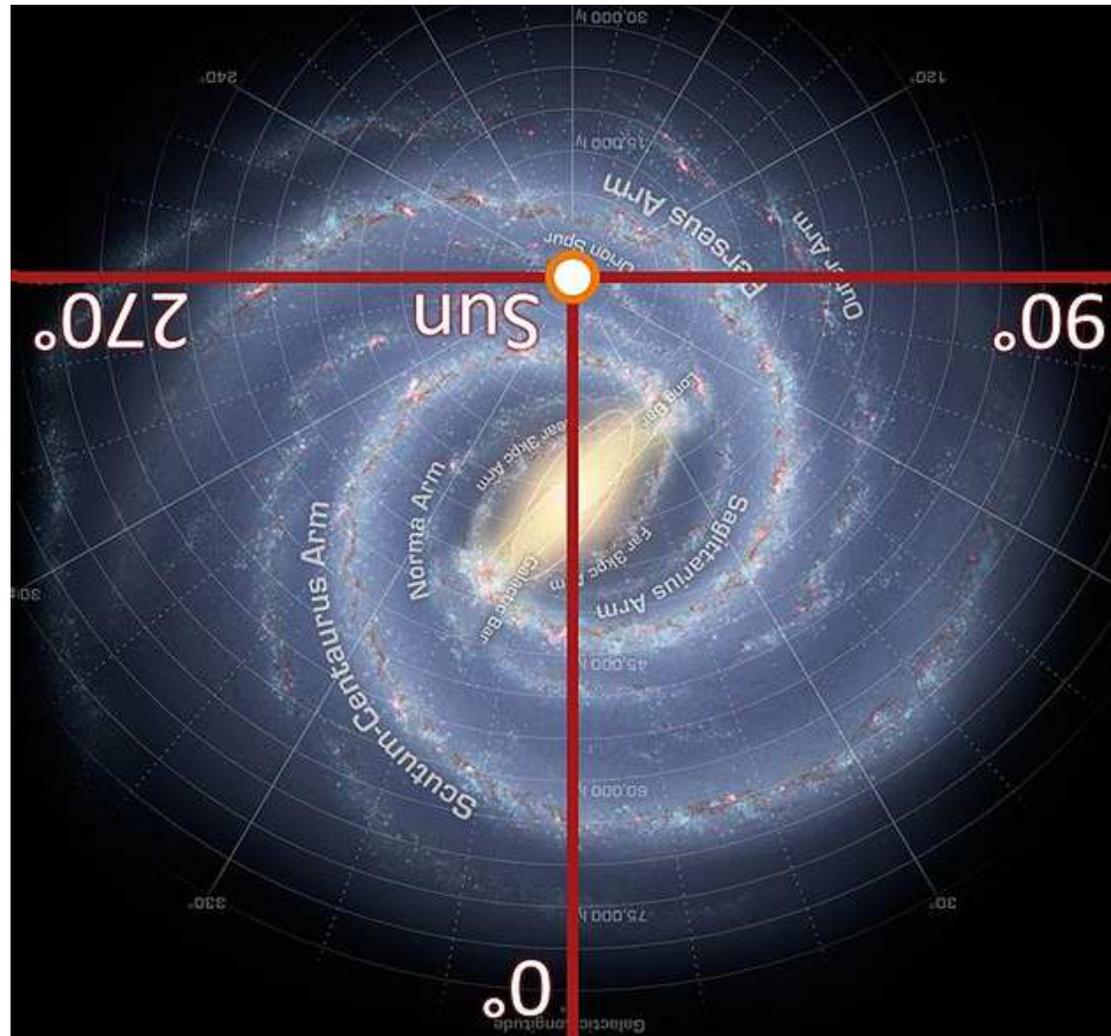


FIG. 1. Distribution of neutral hydrogen in the galactic system.



Caveat: check orientation and position of Sun and Galactic center

Care about astronomical conventions.....



http://en.wikipedia.org/wiki/Milky_Way

Spitzer presentation

- **Missing Spiral Arms:** Following the demotion of Pluto, it seems that rewriting the nature of the Universe has become part and parcel of an astronomer's job. Well, now scientists working with the Spitzer Space Telescope have removed two arms from the Milky Way Galaxy. Hello, I'm Daniel Brennan.
<http://legacy.spitzer.caltech.edu/features/podcasts/transcripts/20080613transcript.pdf>
- Also putting the Galaxy upside down, great!
- For critical discussion see
<http://galaxymap.org/drupal/node/171>

**This might be a better MW spiral model
(in agreement with asymmetries found in HI)**

