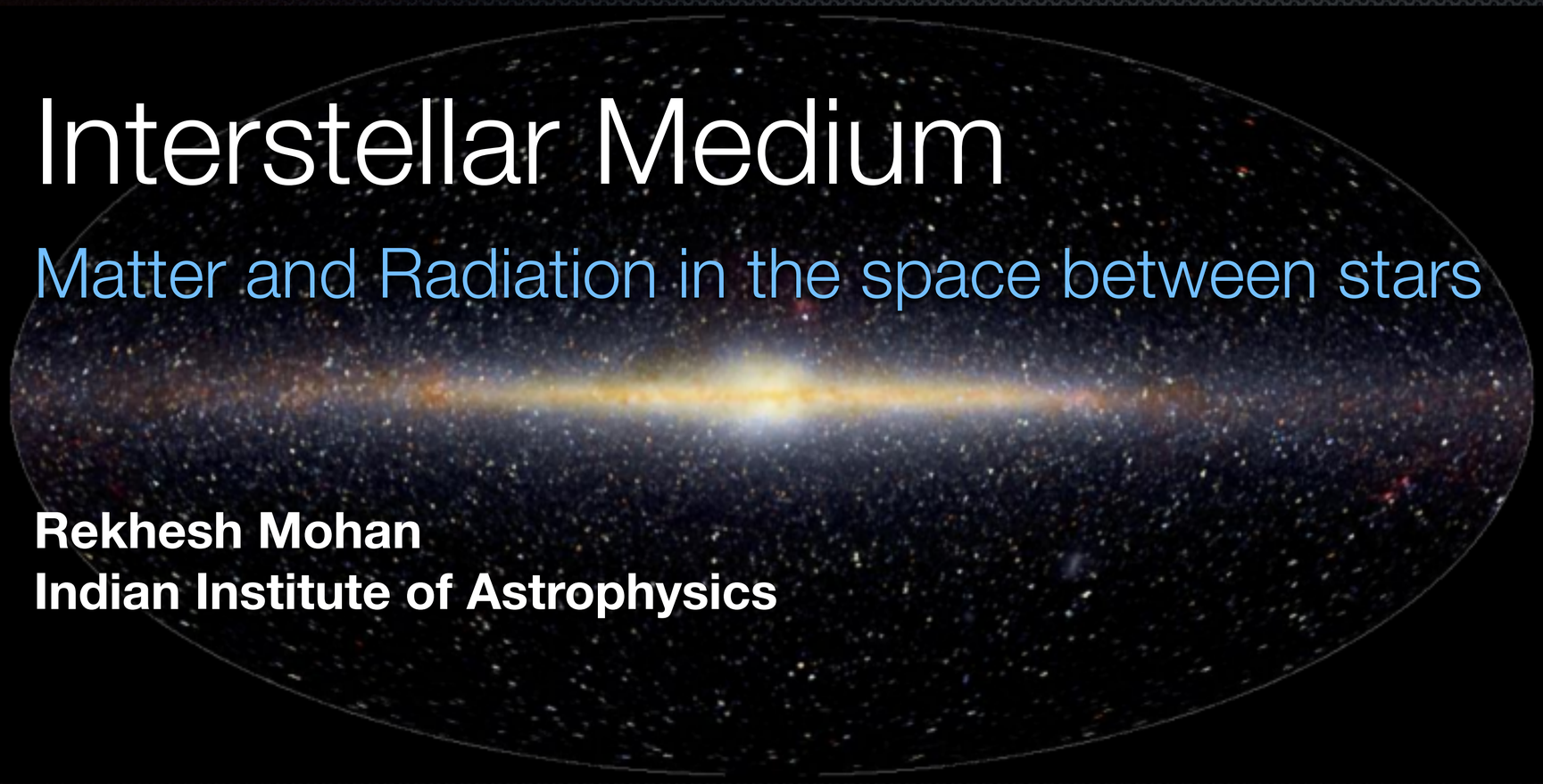
Interstellar Medium

Matter and Radiation in the space between stars



Rekhesh Mohan
Indian Institute of Astrophysics

ISM: What can we see?

Stuff between the stars - scatter starlight

Picture: An amateur photograph of the direction towards the Galactic centre

→ Scattered star light,
Blocked star light..

Bernard (1900s: Deep Images of the sky)

ISM: What can we see?

Stuff between the stars - scatter starlight

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Bernard (1900s: Deep Images of the sky)

Bernard68 (from VLT/ESO)
APOD 2020-11-02

ISM: What can we see?

Stuff between the stars - scatter starlight

~~Picture: An amateur photograph of the direction towards the Galactic centre~~

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Bernard (1900s: Deep Images of the sky)
Interstellar Extinction, Reddening
Dust!

Bernard68 (from VLT/ESO)
APOD 2020-11-02

ISM: Dust

0.2% of total mass of ISM. Size ~0.5 - 300 nm
ices, graphites, silicates, metals, ...

→ Made of C, Fe, Si, Mg,O
mixed with or coated with water

Average dust-dust separation: 150 m

Need to understand dust distribution to correct for extinction, reddening.

Horsehead Nebula
APOD 2013-12-31

ISM: Gas

Hartmann, 1904: Spectroscopic study of binary star δ-orionis

→ Narrow absorption lines that do not follow orbital motion of stars

Narrow line -> Cooler regions

Adams, 1948: Number of narrow absorption lines ∝ distance to stars

Orion's Belt
APOD 2009-02-10

ISM: Hydrogen

Atomic hydrogen (HI) : spin quantum number of proton and electron (+1/2, +1/2) or (+1/2, -1/2) - slightly different energy levels : 5.9 μeV

→ λ ~ 21.1 cm (1.420 GHz, radio)

Predicted 1944 (Van De Hulst, Oort).
Observed in 1951(Ewin & Purcell .. Muller & Oort)

Hydrogen is ubiquitous. It is everywhere.
21cm mapping of sky in 1950s - Spiral structure of our Galaxy

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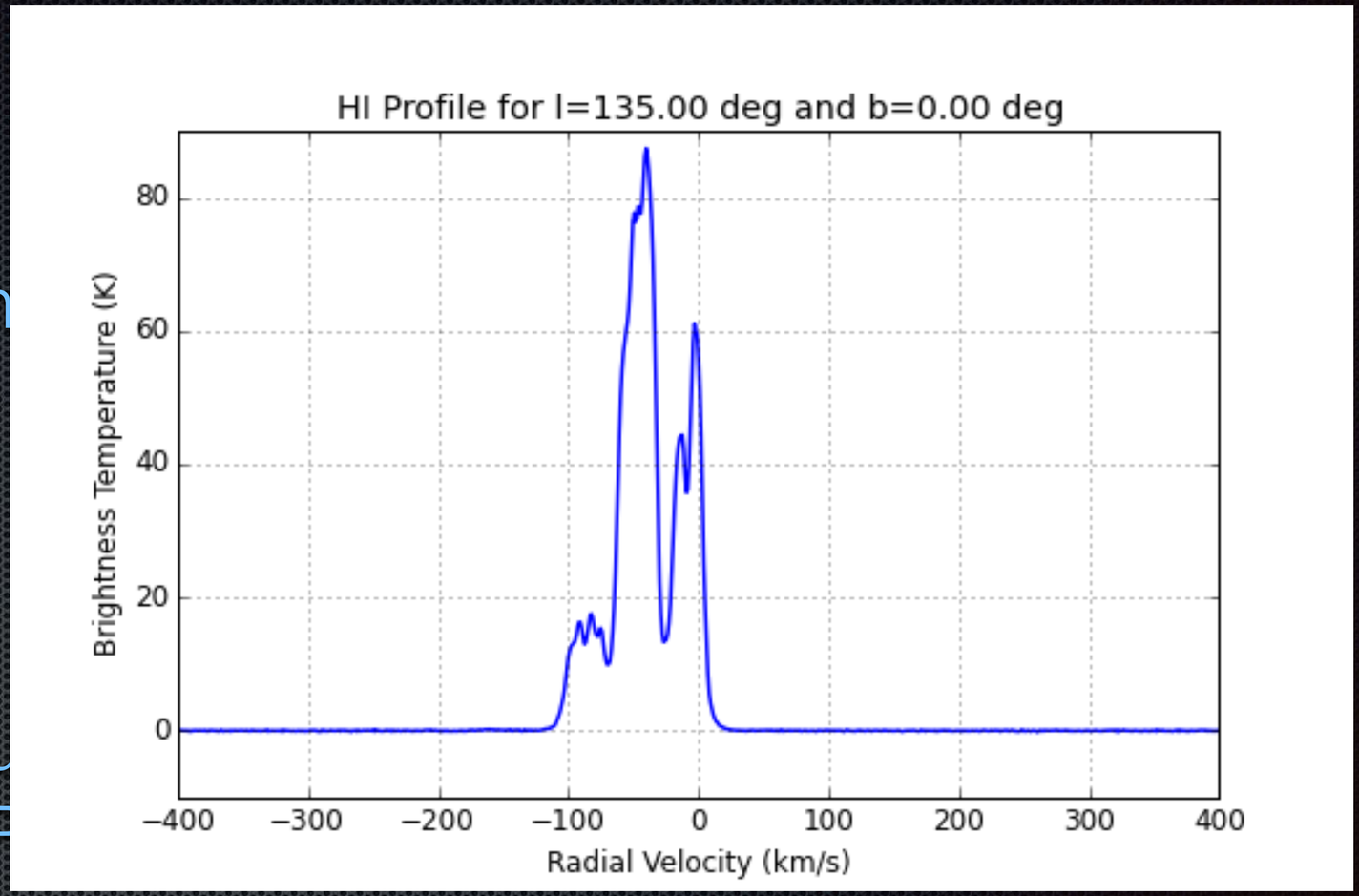

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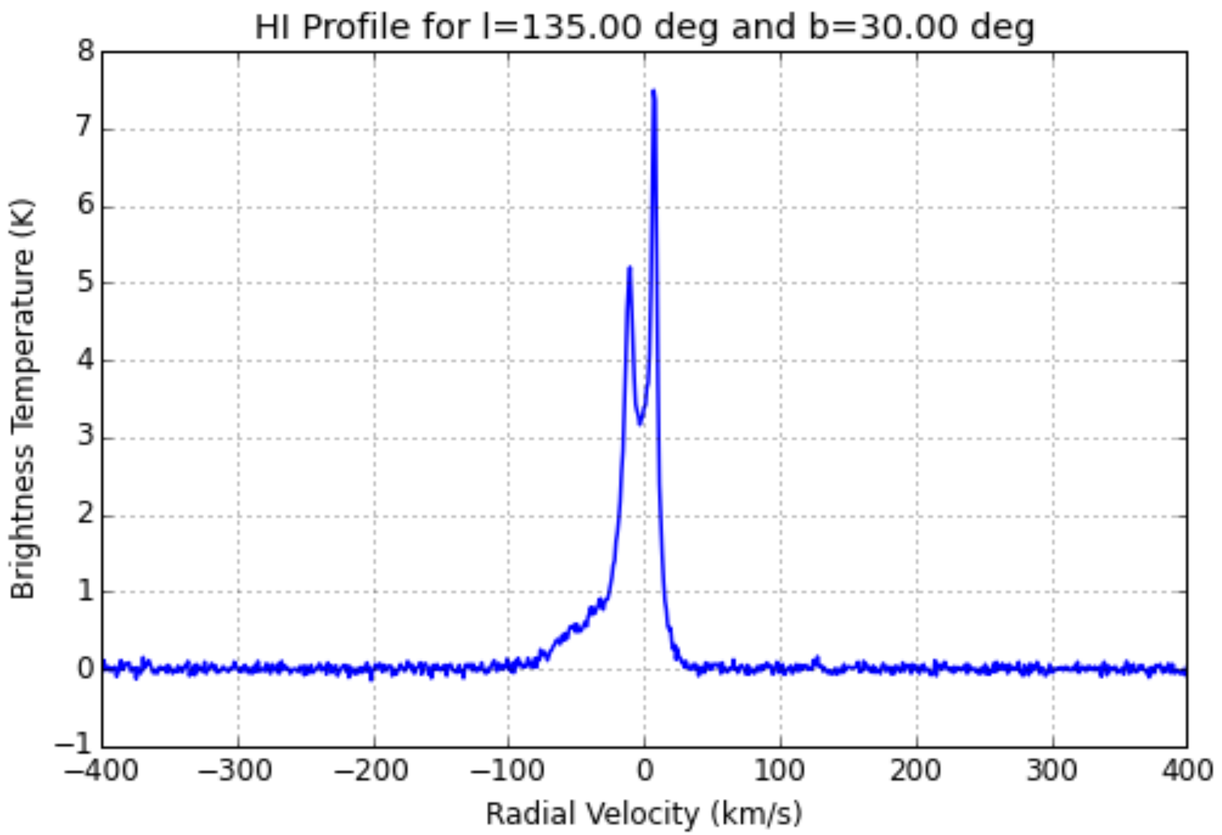
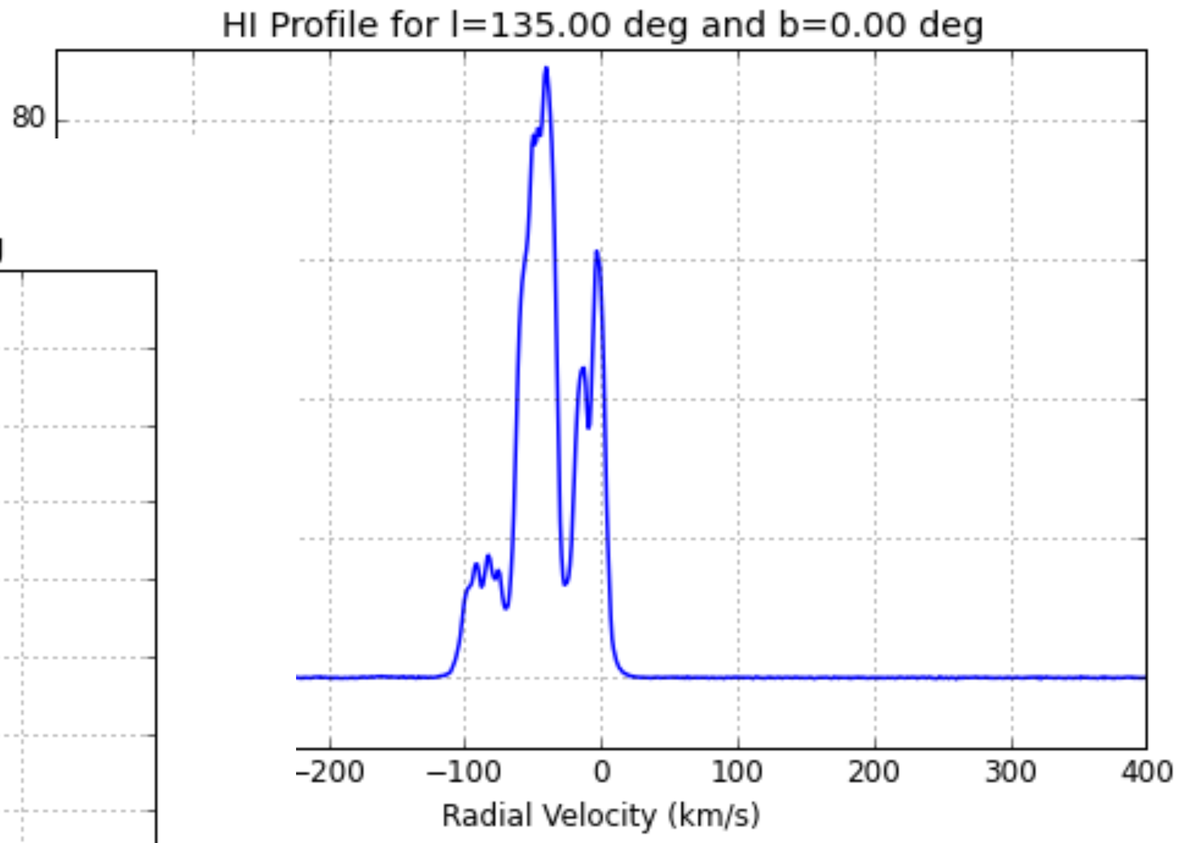
ISM: Hydrogen





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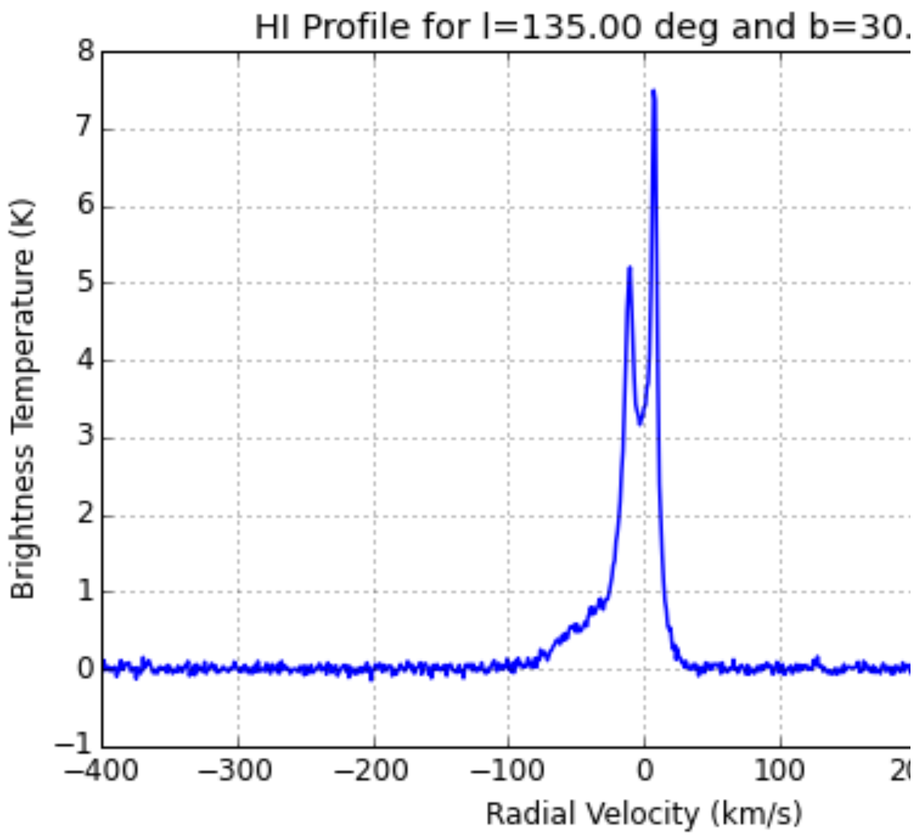
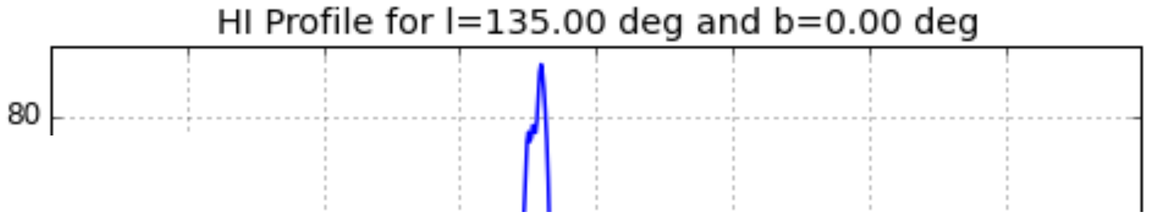
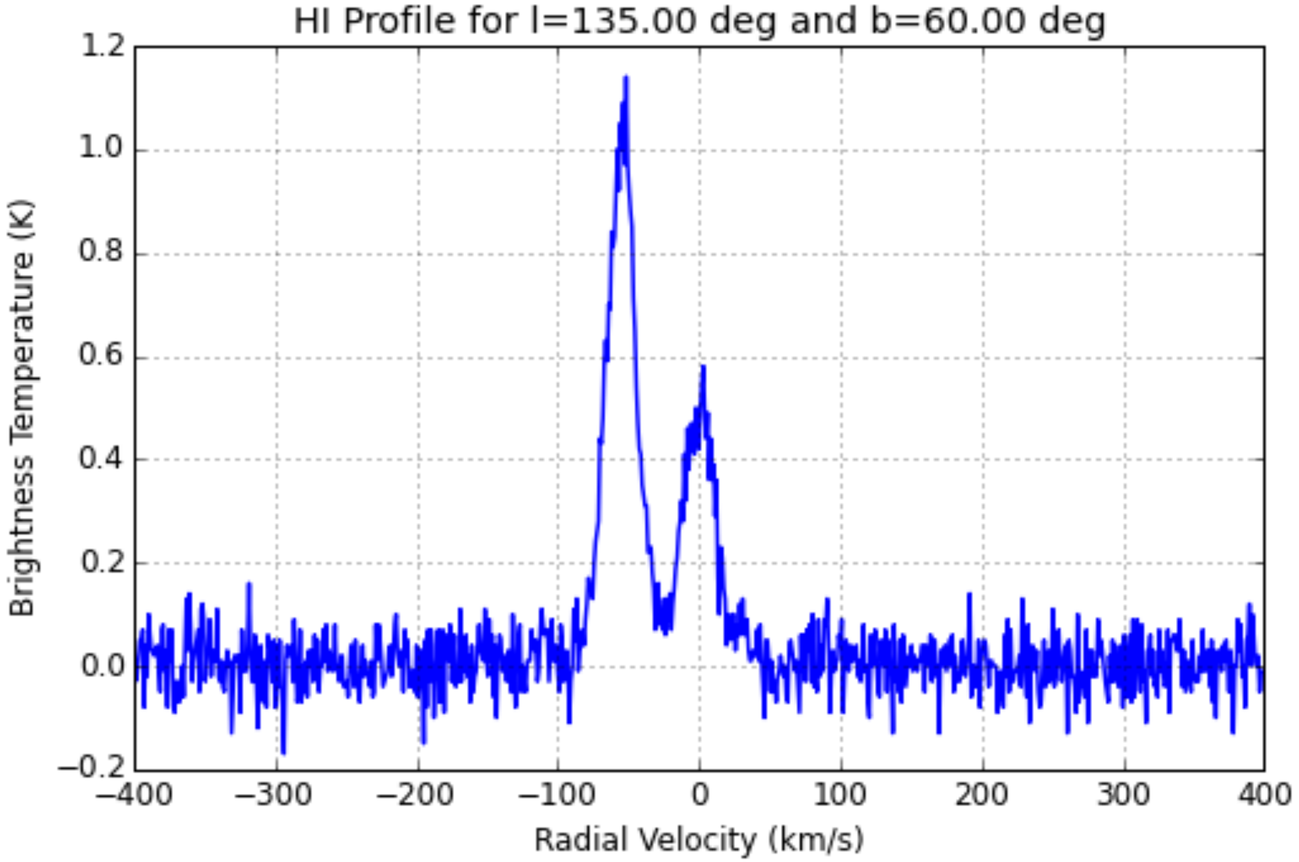
21cm mapping of sky in 1960s - Spiral structure of our Galaxy

ISM: Hydrogen







21cm mapping of sky in

ISM: Global properties

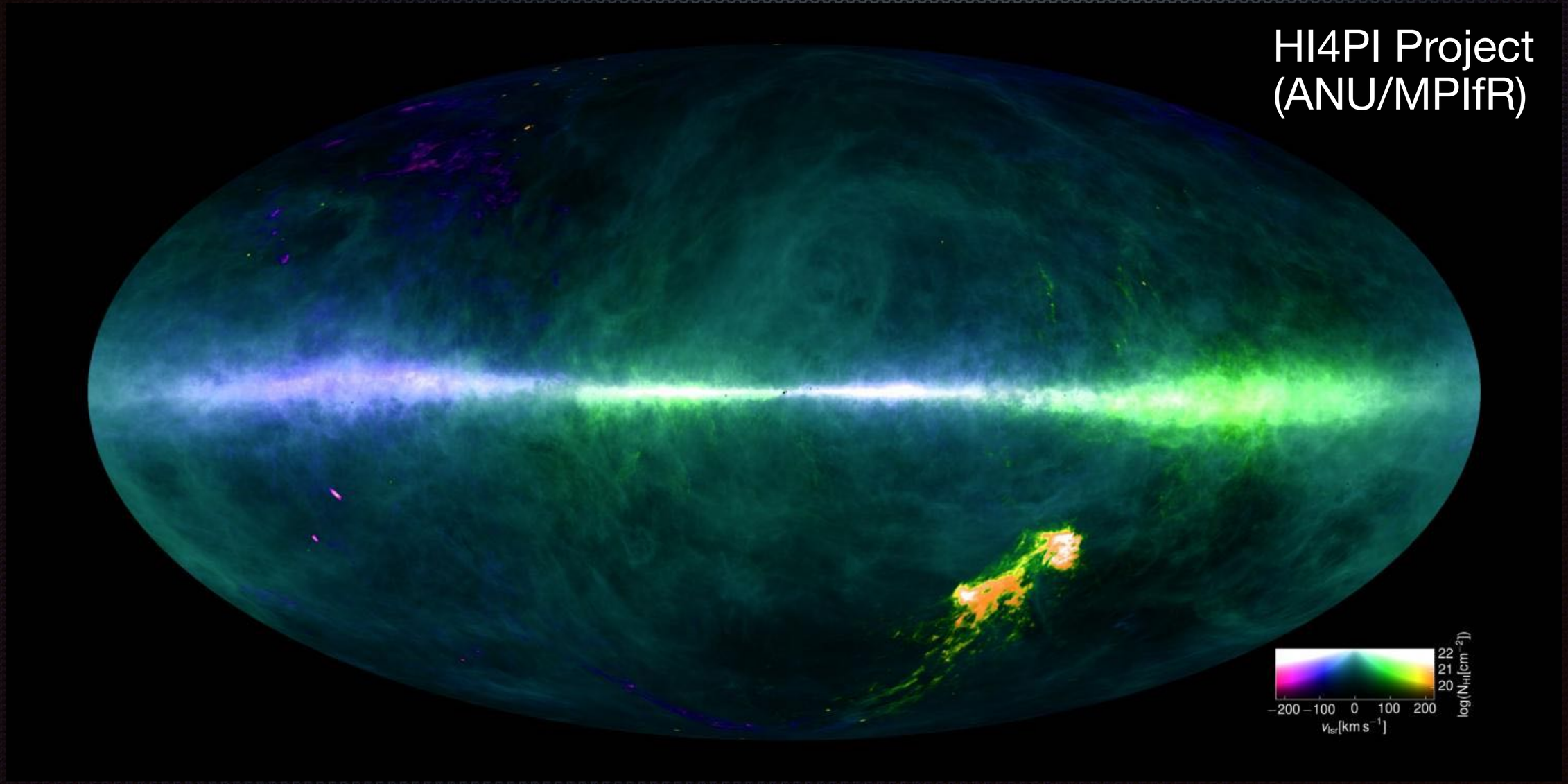
- Mostly hydrogen
  - warm (WNM) : T ~ 10,000 K, n_H ~ 1/cc
  - cool (CNM) : T ~ 30 - 100 K, n_H ~ 100 - 300/cc
  - cold : < ~ 10 - 30 K
  - Warm Ionized gas : ~10^4 K, n_H ~ 0.1 - 1/cc
  - coronal gas : ~10^6 K n_H ~ 0.001/cc
  - Molecular Clouds
  - Giant Molecular Clouds (GMCs)

} $n_1 T_1 = n_2 T_2$

Field, Goldsmith, Habing (1969)
McKee & Ostriker (1977)
Wolfire et al, 2003

Source of Energy: Supernovae

ISM: Global properties



ISM: Global properties

Hydrogen : ~70.5 % of mass (half of it in molecular form)

Helium : 28%

Metals/heavier elements (C, N, O, Mg, Si, Fe) : 0.1 to 1.5%

Complex molecules : Poly Aromatic Hydrocarbons..
H_2CO formaldehyde, CH_3CH_2OH ethyl alcohol,
CH_3CH_2CN ethyl cyanide, water.

ISM: Magnetic Fields

Polarization studies of starlight - Dust grains aligned by magnetic fields! (Davis & Greenstein, 1951).
Galaxy's magnetic field: B ~ 3 micro Gauss..

Origin: Not clearly understood..

Charged particles - cosmic rays, ionized gas.. moving in magnetic field: synchrotron emission

Radio continuum mapping of the sky: provides spatial distribution

ISM: Galactic Structure

Galactic structure as seen in HI 21cm line studies.

Let us do it together today afternoon in the tutorial session!

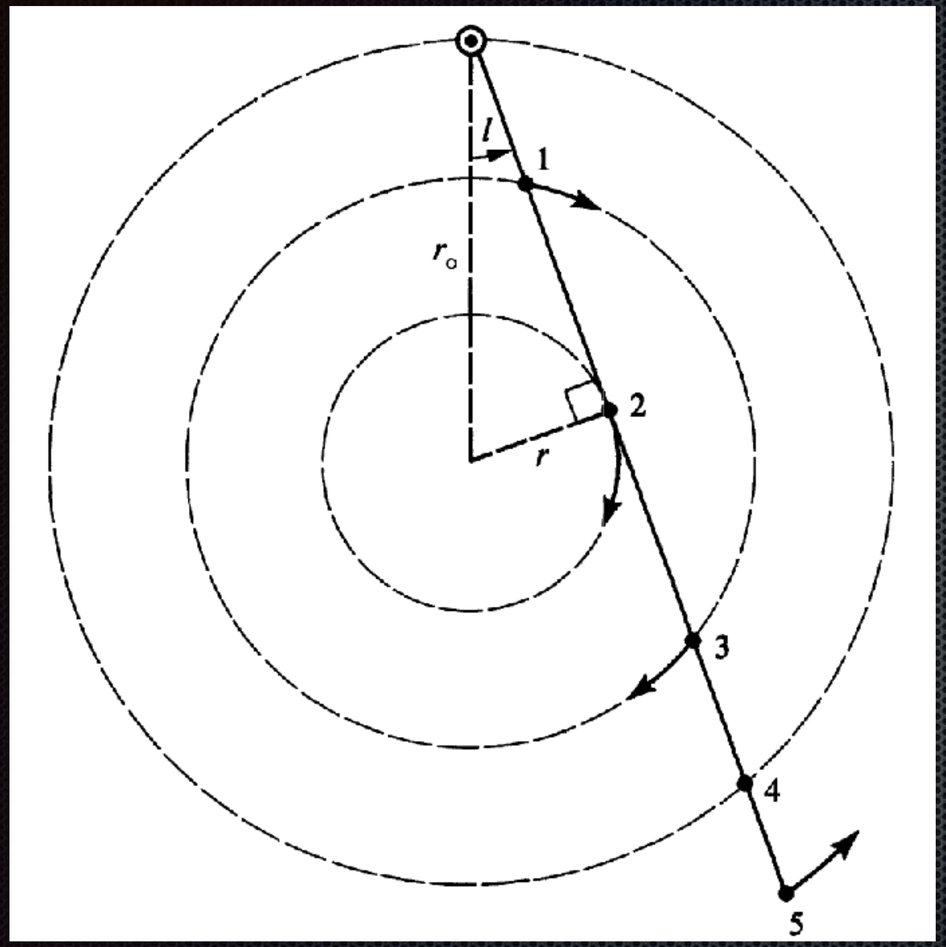
ISM: Galactic Structure - Tutorial

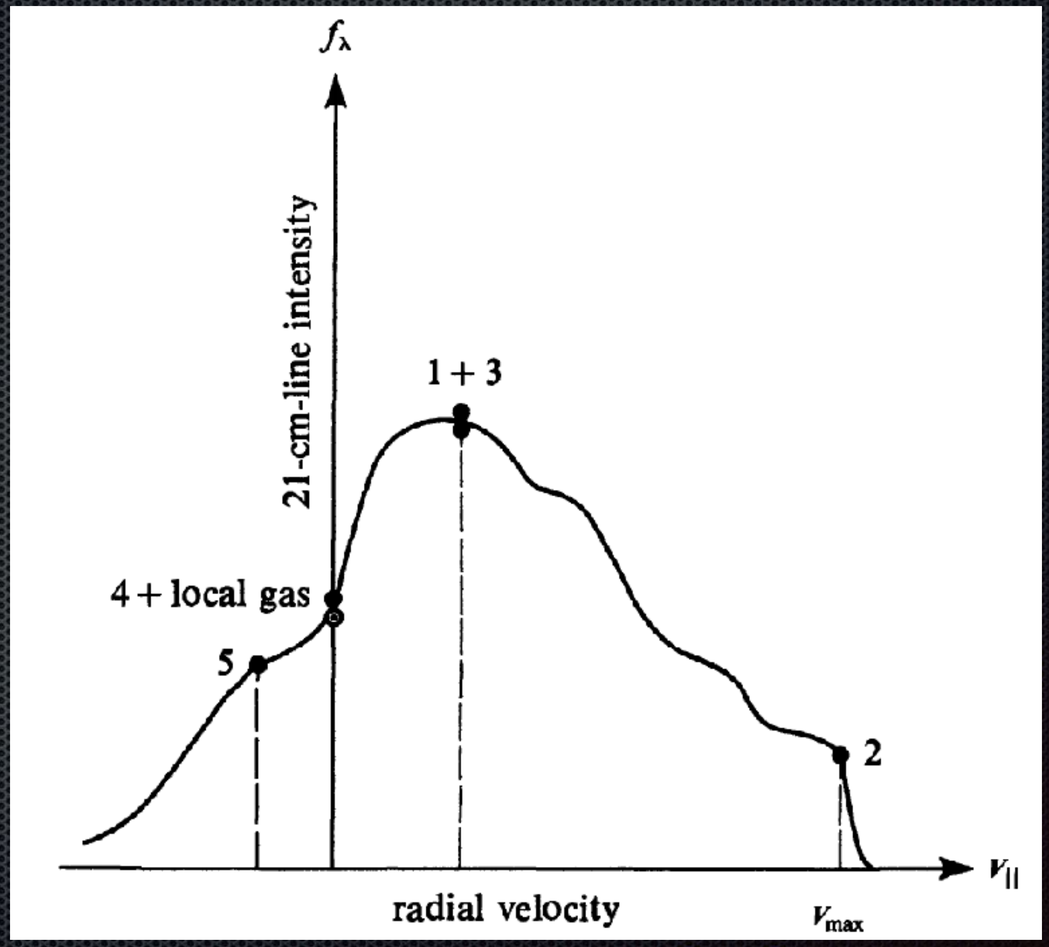
- Galaxy: Early images show flat structure, not spherical.
  - Spheres : can be sustained by random orbits
  - Disk : Requires rotation to sustain

- Before the discovery of 21cm line - Nearby stars:
  - spectroscopic studies: line of sight velocity component
    Systematic rotation of galaxy + random movement
  - Variable stars (Cepheids, RR lyrae): Standard candles.
  - Map position v/s doppler velocity

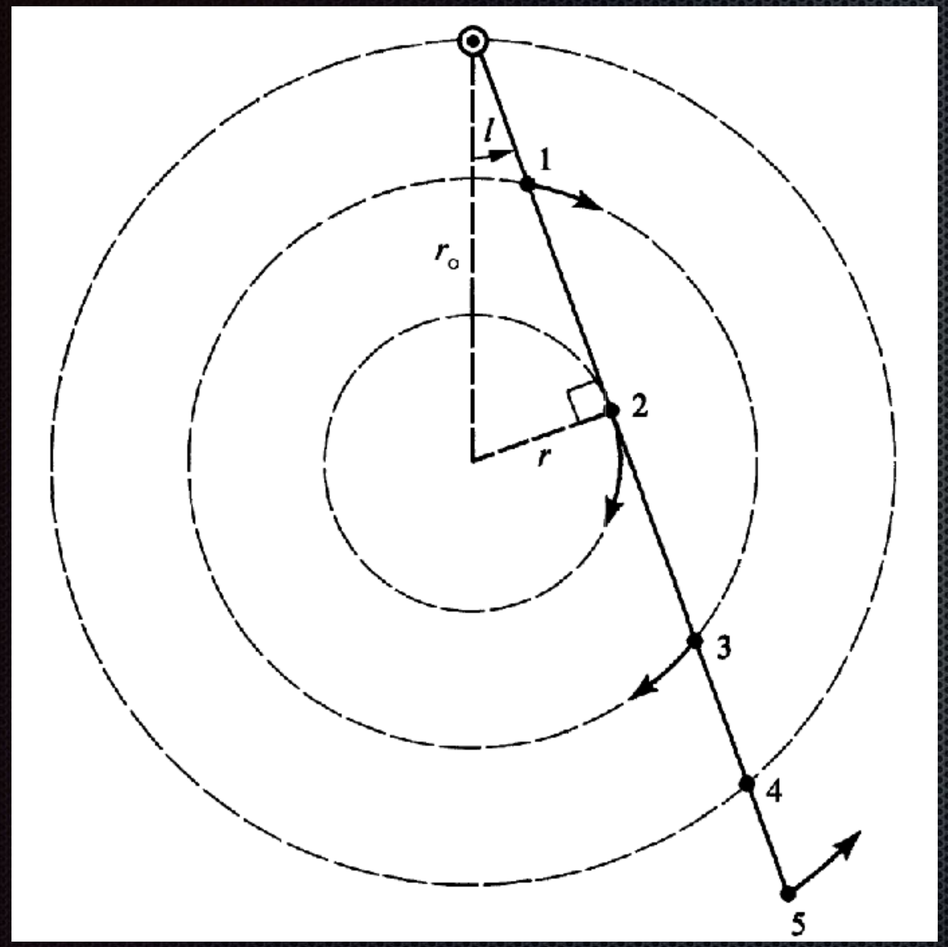
- Oort’s study: parametrize the whole thing based on 2 constants

ISM: Galactic Structure - Rotation Curve





ISM: Galactic Structure - Rotation Curve



For any of these “orbits” in inner galaxy, rotation velocity = radial component at the tangent point [2]

To plot the rotation velocity v/s distance: span different longitudes 0 to 90 deg. at b = 0 and find v_max.

We also need “r”. Look at the right angle Triangle here. $r = r_\odot sin(l)$.

$r_\odot$ = 8.5 KPc

ISM: Galactic Structure - Rotation Curve

Line profiles

www.astro.uni-bonn.de/hisurvey/euhou/LABprofile/

- Use the form:
  - select “coordinate system = galactic coordinates”
  - Give b = 0, l = 0, 10, 20 .. 90 deg, one at a time
  - Leave the rest of inputs untouched.

For each value of l, download the ascii data, open it with a text editor, find the peak flux value near the maximum velocity.

ISM: Galactic Structure - Rotation Curve

Line profiles

www.astro.uni-bo

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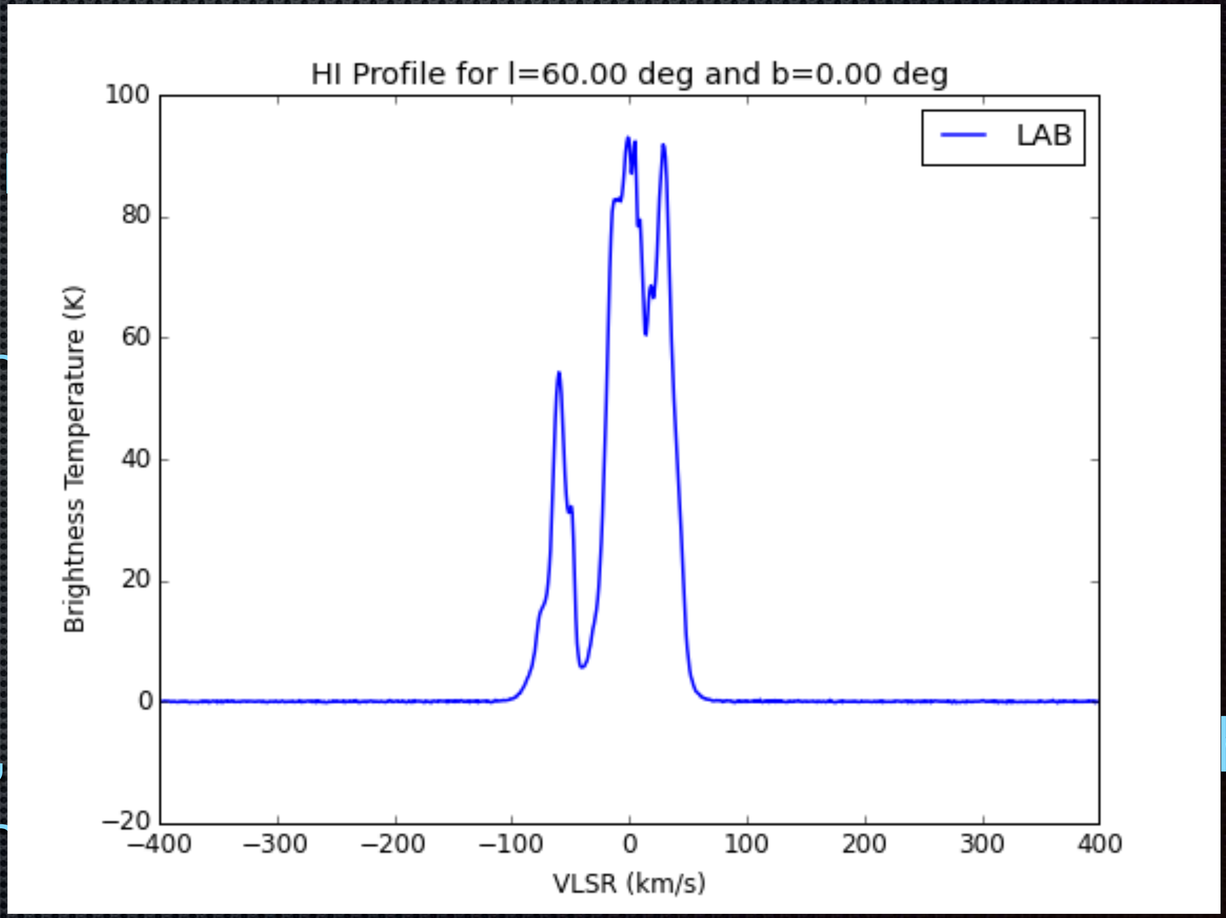

ISM: Galactic Structure - What else?

Line profiles

www.astro.uni-bonn.de/hisurvey/euhou/LABprofile/

- Try plotting the peak flux at same longitude (l), but different latitudes (b: -90 to +90). What do you see?

ISM: Galactic Structure - What else?

Line profiles

www.astro.uni-bonn.de/hisurvey/euhou/LABprofile/

- Why is the spectrum so weird in the direction towards the Galactic centre (l = 0, b = 0)?
  - Compare it with the profile towards anticentre direction (l = 180^{o})