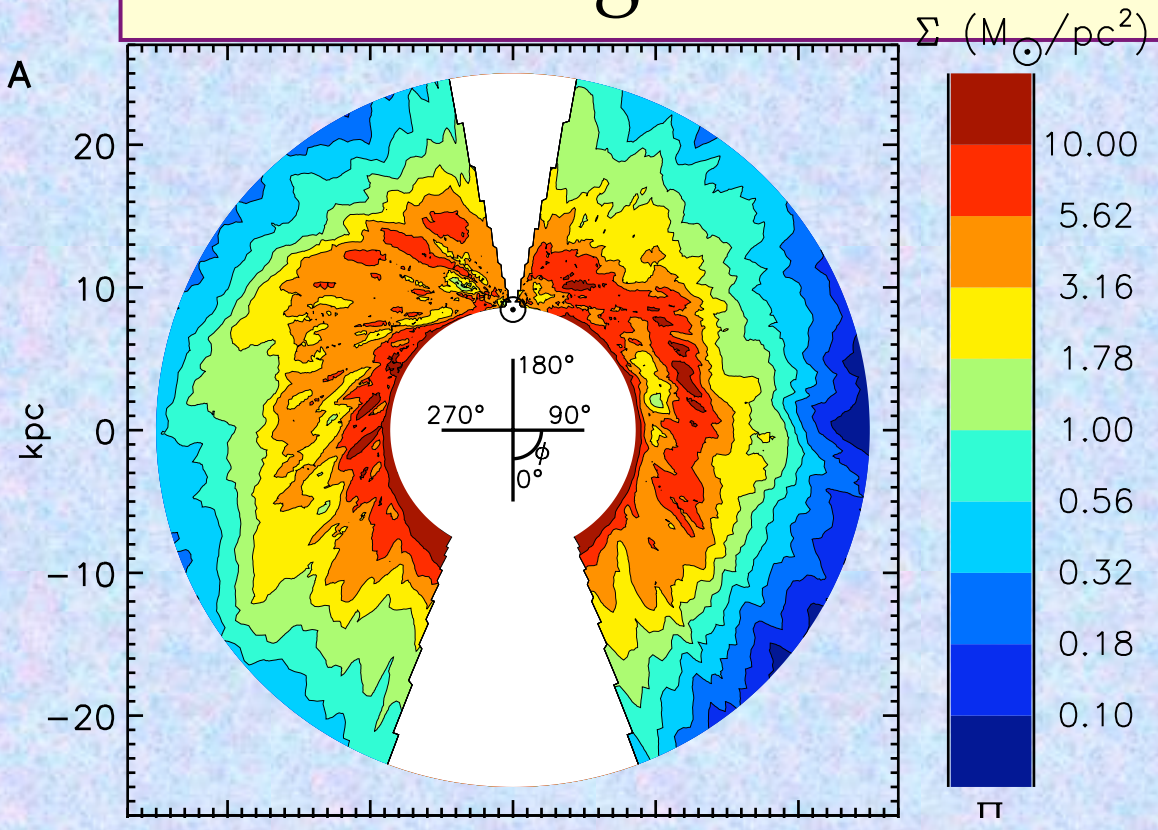
Neutral Gas in the Milky Way: Some Things We've Learned and Some Things We'd Still Like to Know



Leo Blitz

Carl Heiles

Chanda Jog

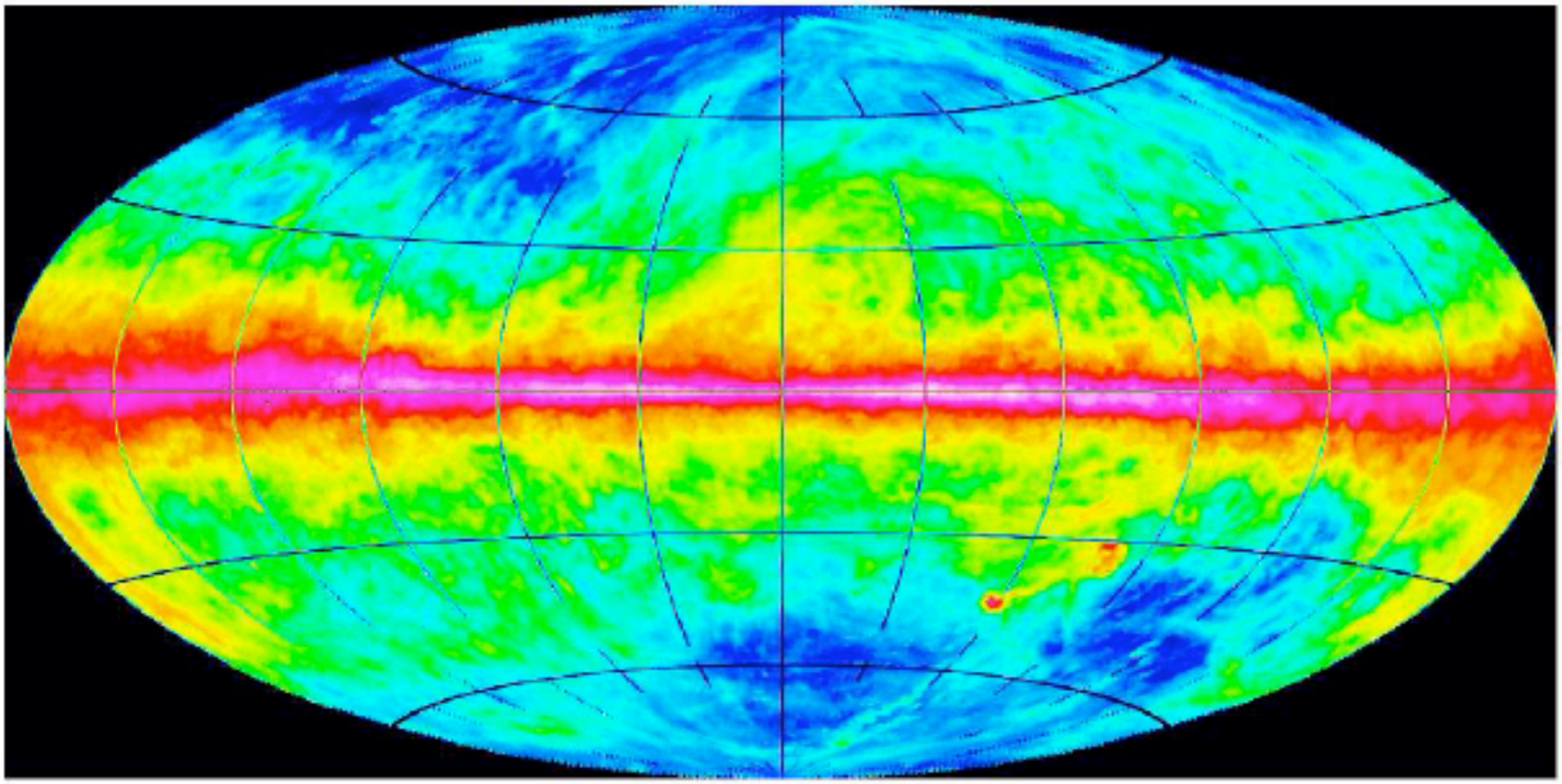
Evan Levine

Kanak Saha

Martin Weinberg

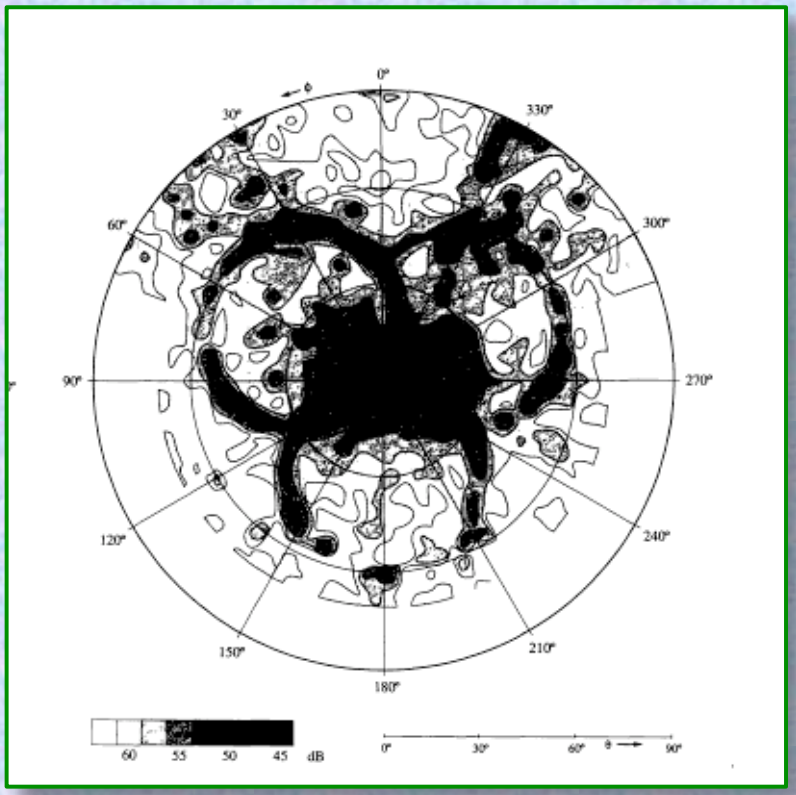
Santa Barbara September 30, 2008

Leiden/**A**rgentina/**B**onn Survey of Galactic HI

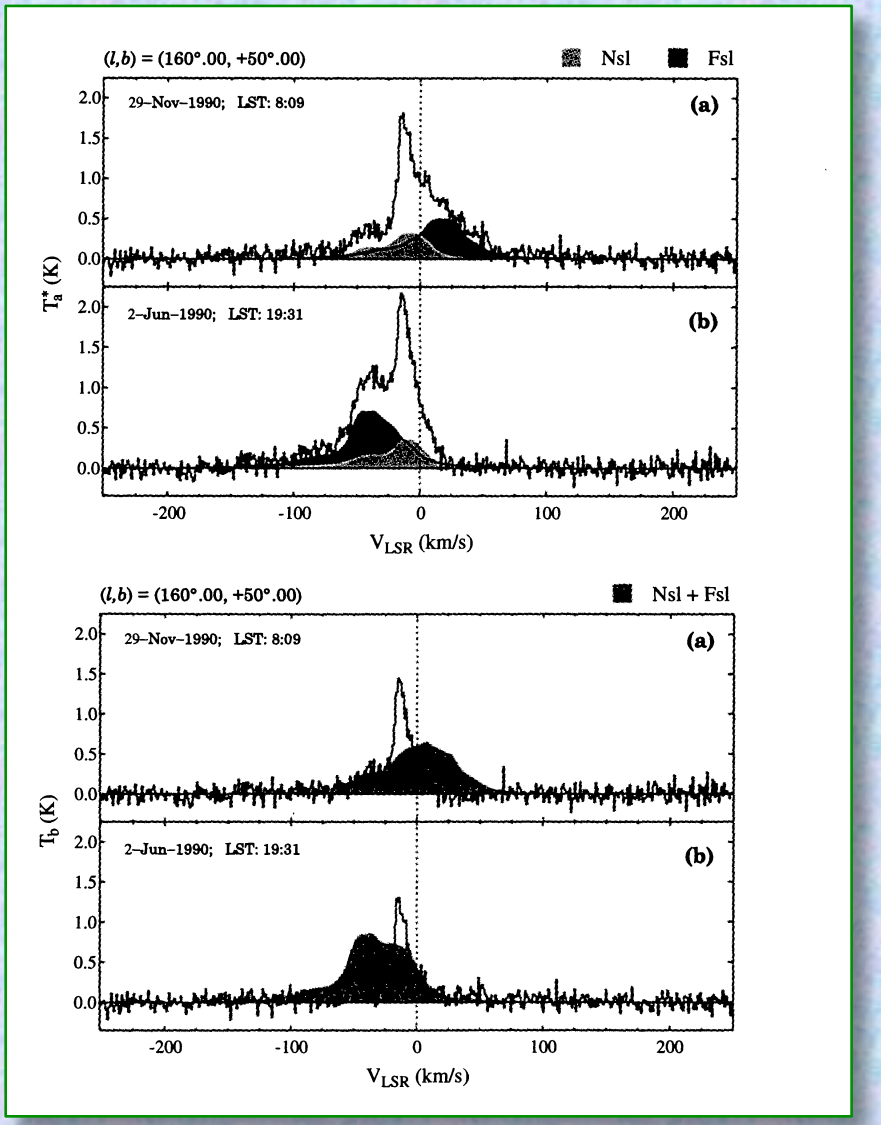


Kalberla, et al. 2006

Sidelobe Removal



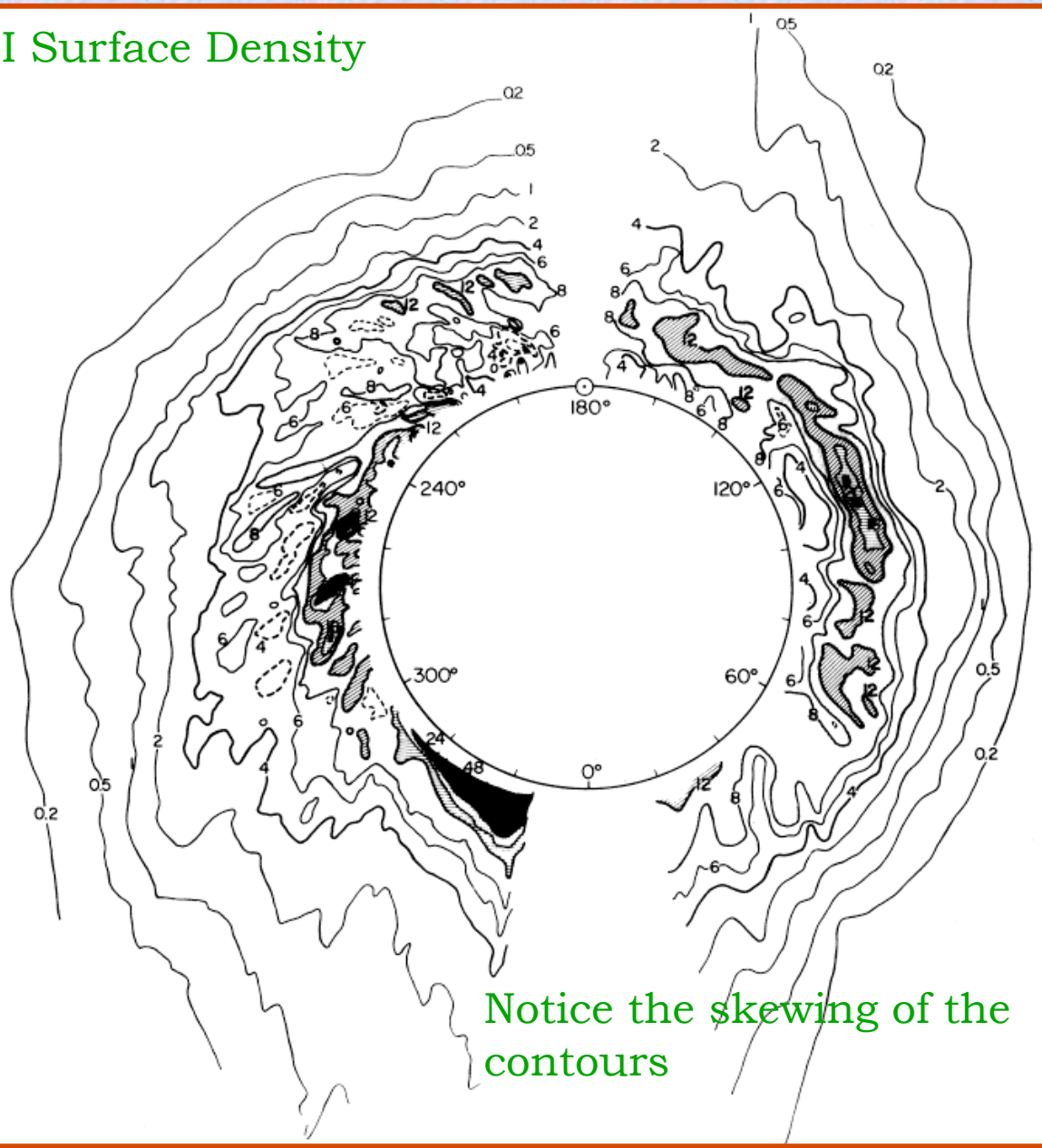
Hartmann, et al. 1996
Hartmann 2000



Motivation for New MW Analysis

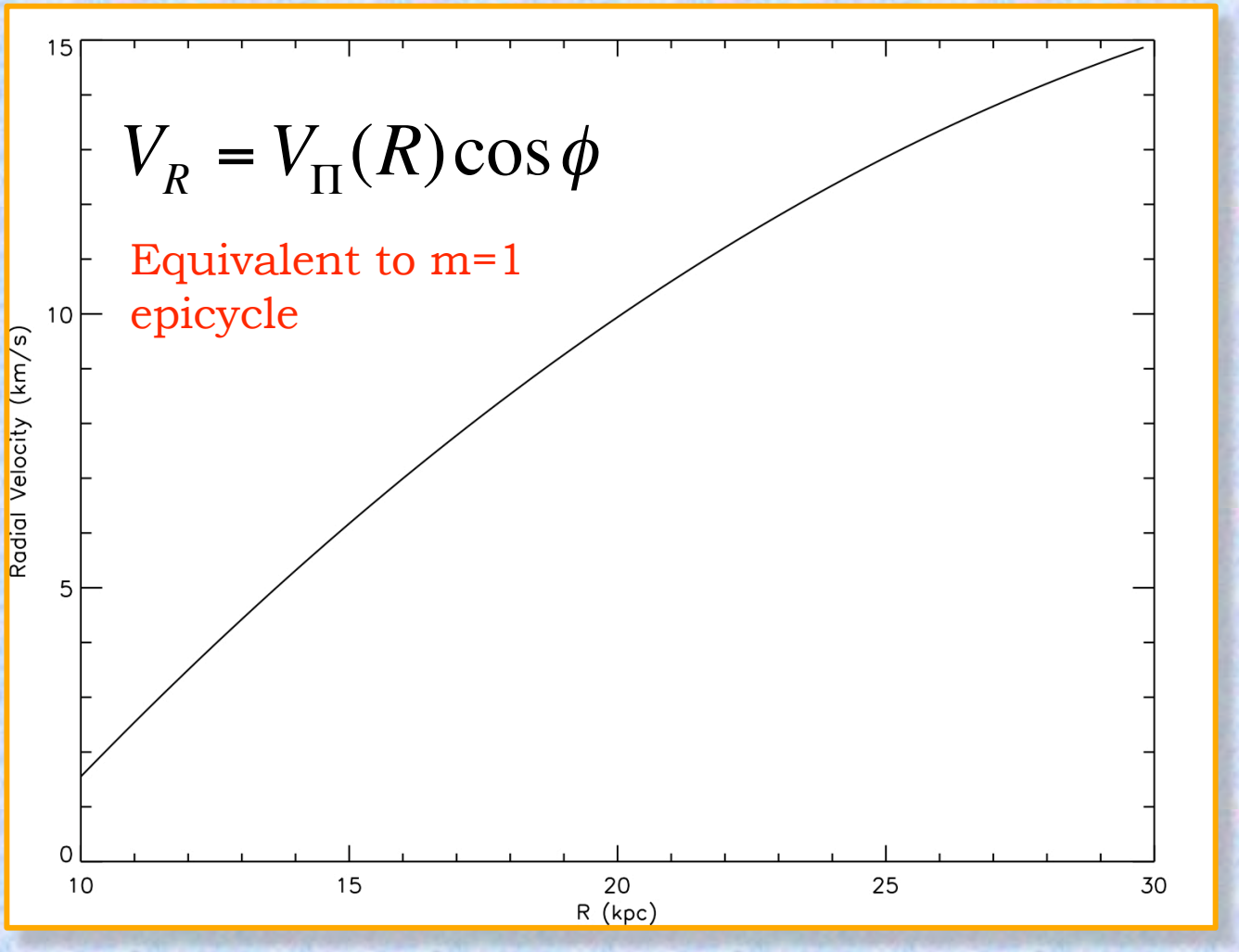
- There are ~60 - 70 dwarfs total down to magnitude limit observed
- M_{halo} ~10^7 $M_\odot$
- But Via Lactea predicts ~1000 halos with M > 10^7 $M_\odot$. Where are the rest?
- Are there dark galaxies with HI only?
- Can one find naked halos by their interaction with the gas in MW disk?

HI Surface Density



Notice the skewing of the contours

Henderson, Jackson & Kerr 1982

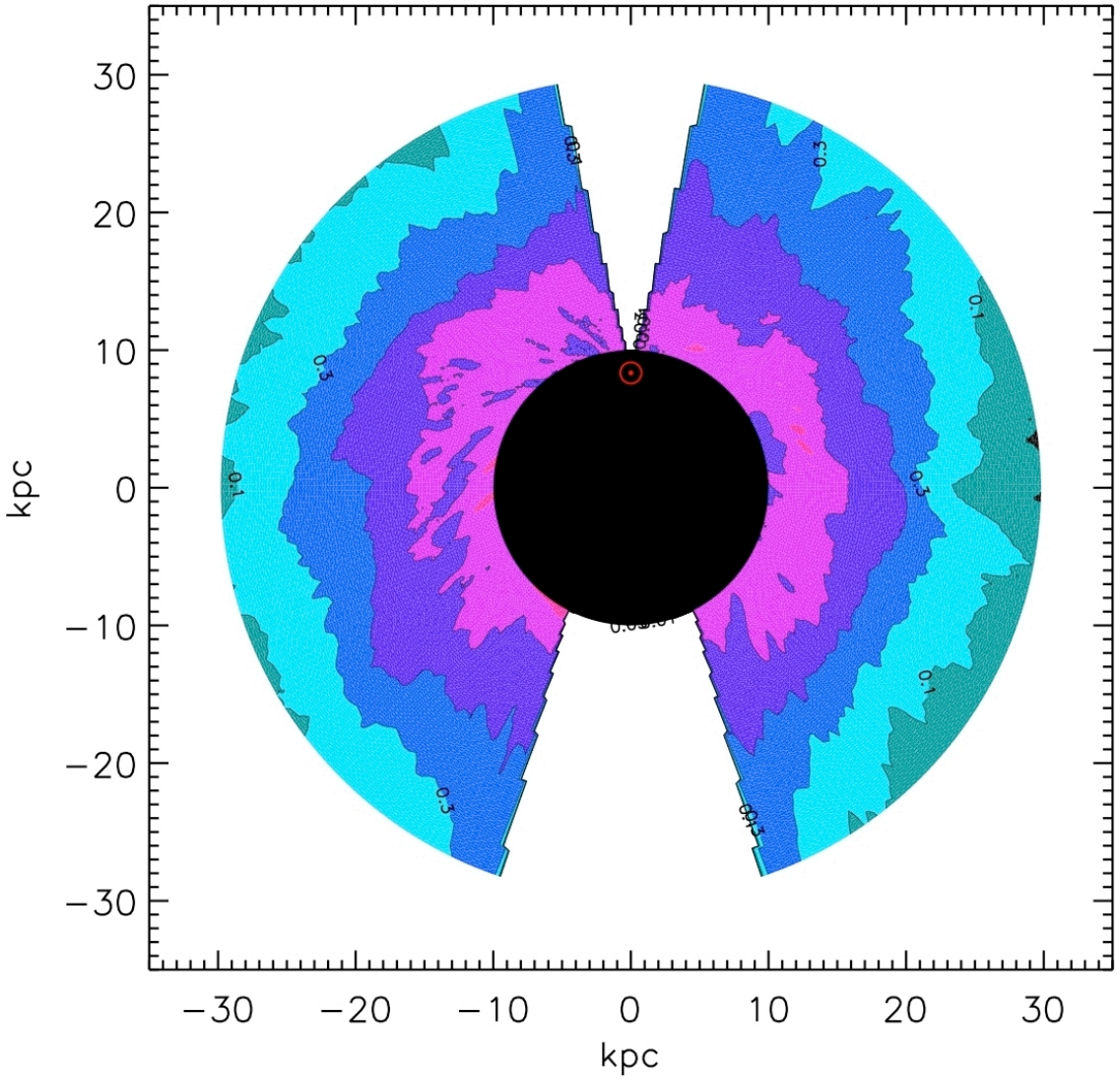

$V_R = V_\Pi(R)\cos\phi$
Equivalent to m=1 epicycle
Radial Velocity (km/s)
R (kpc)
0
5
10
15
10
15
20
25
30

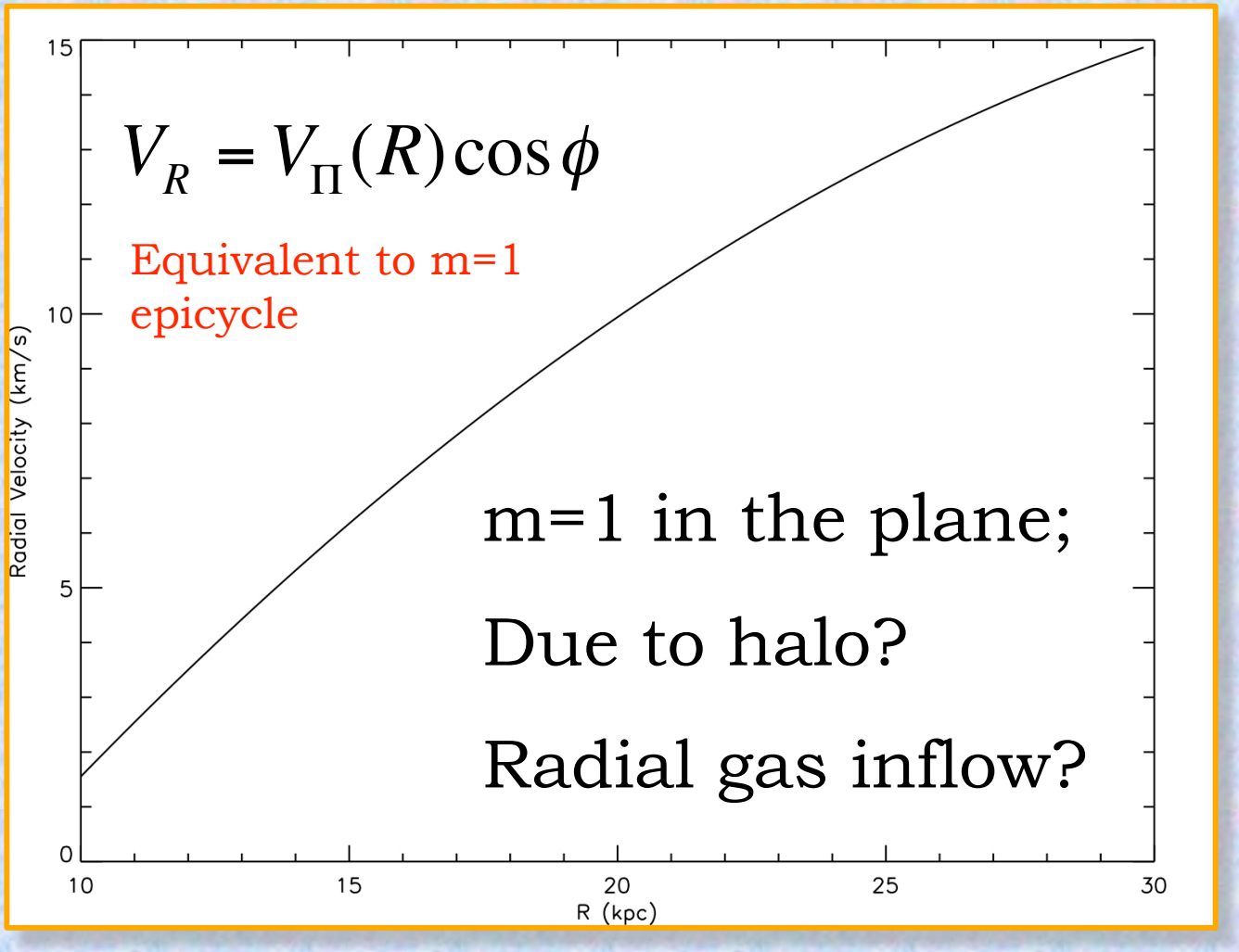
HI Surface Density

By adding a small radial component to the gas relative to the LSR, at various distances, the azimuthal discontinuity in the HI can be removed.

What keeps gas velocity dispersion nearly constant with Galactic radius?

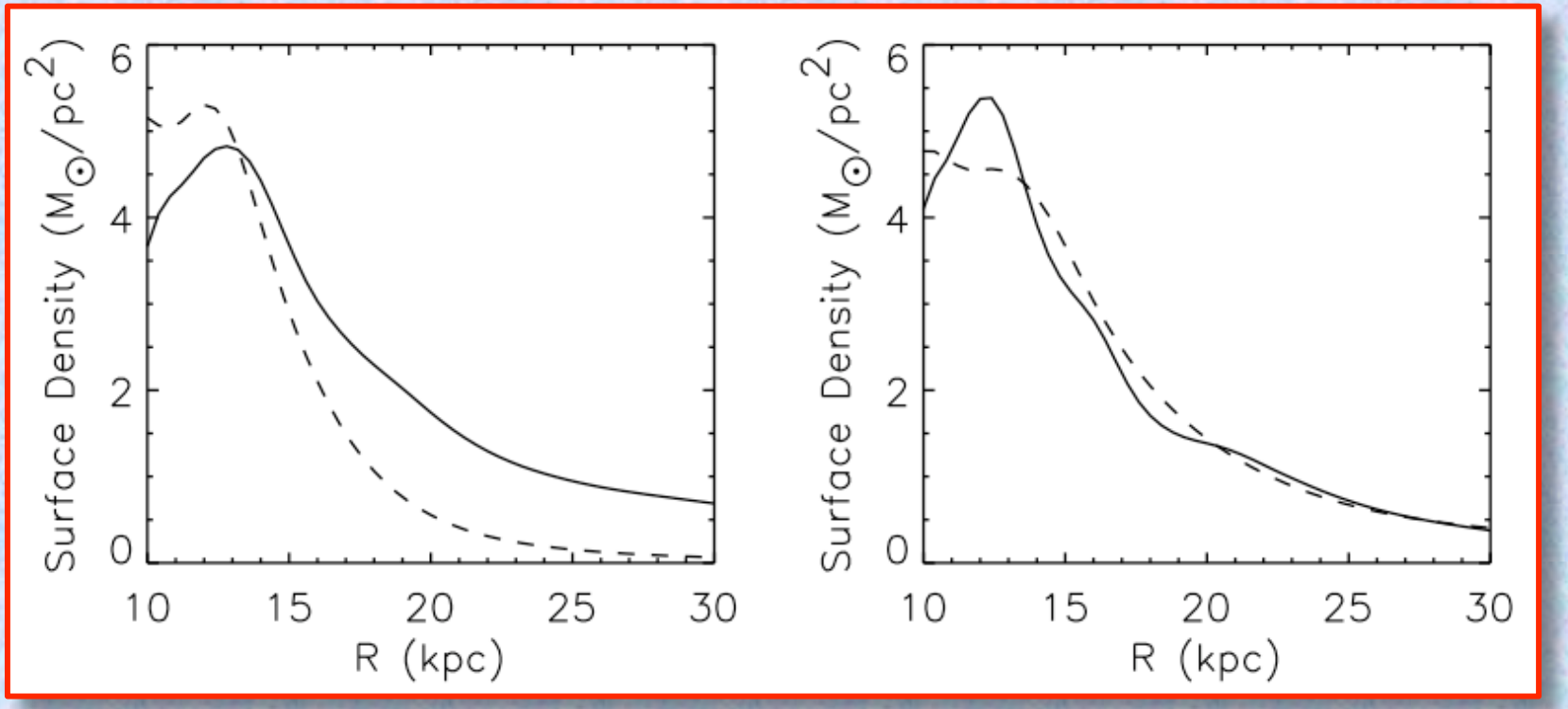
Can You Spot the Spiral Arms?





Real component of gas motion if we are to avoid Σ(HI) discontinuities

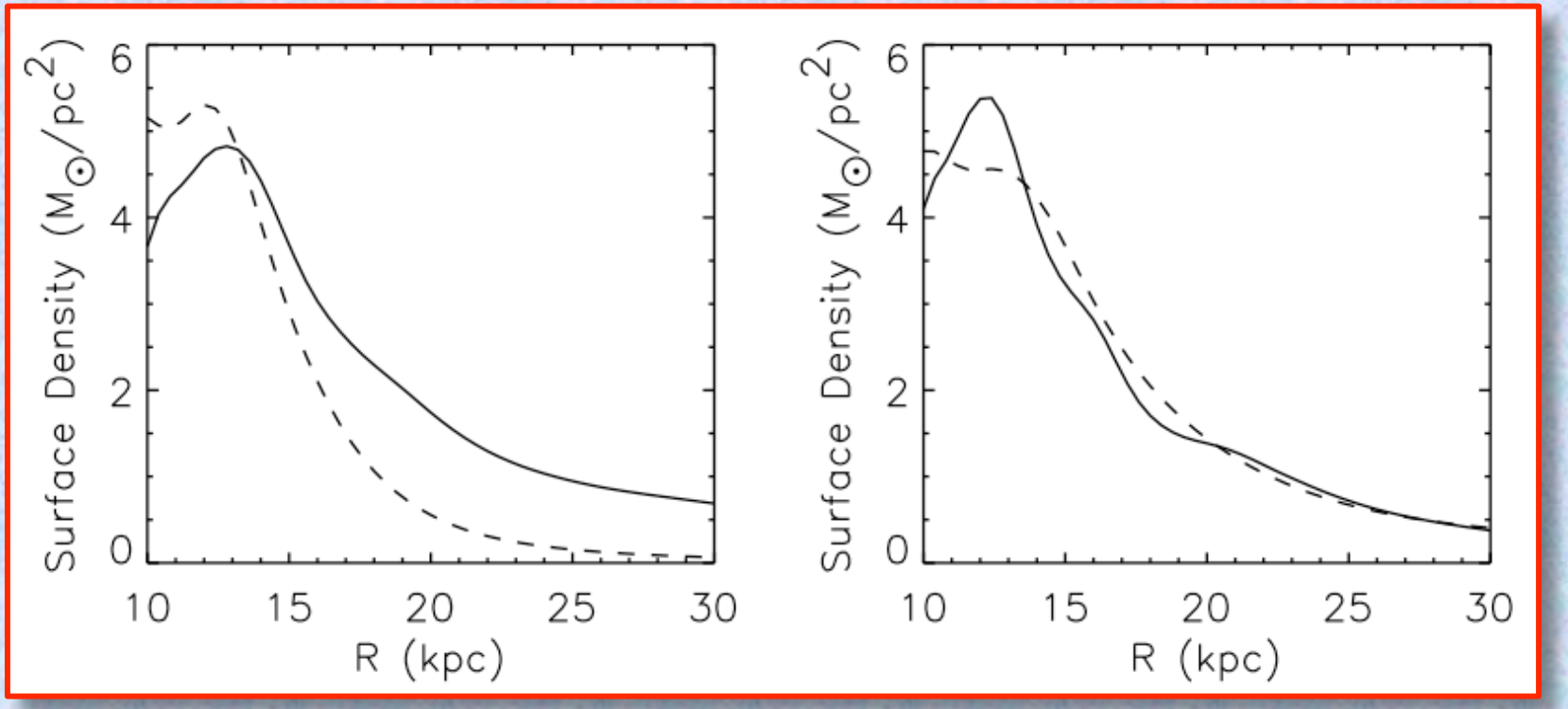
Surface Density Comparison



No V_Π correction

With V_Π correction

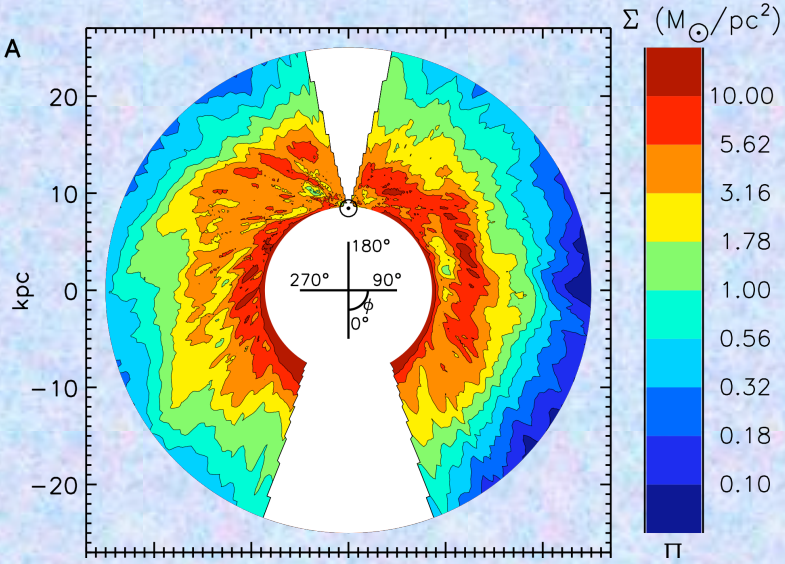
Surface Density Comparison



No V_Π correction

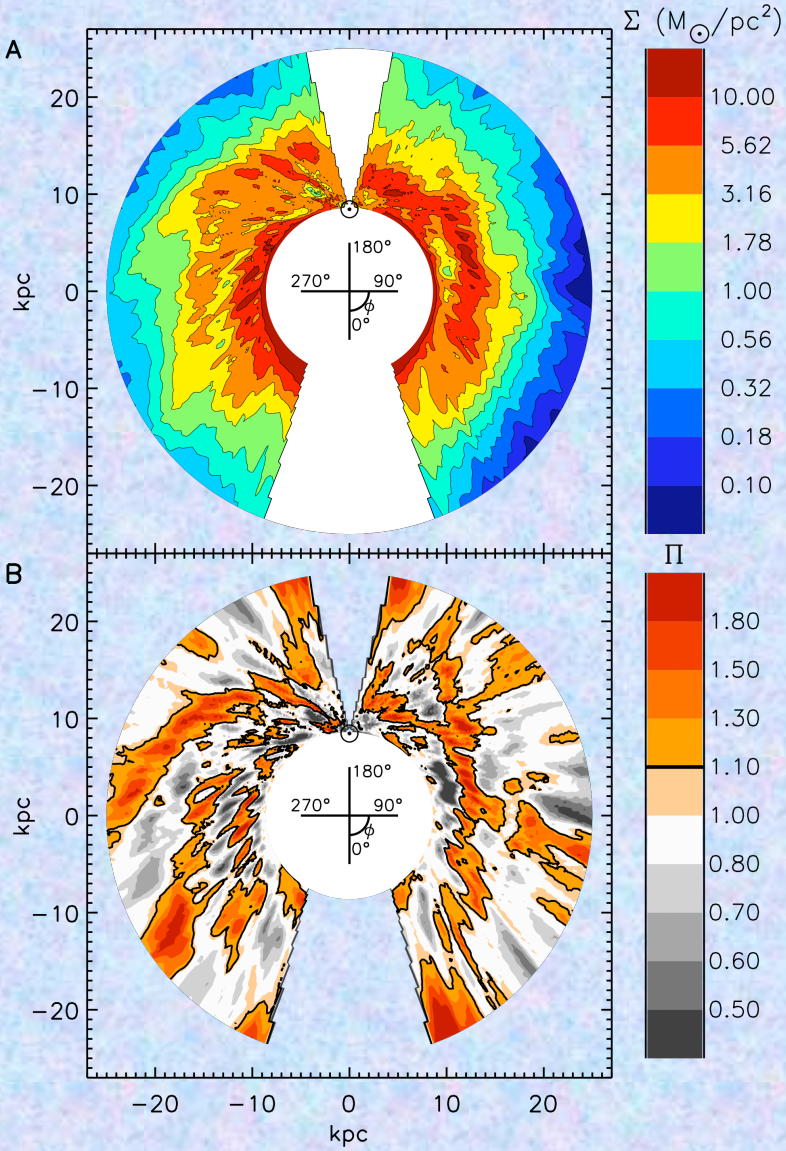
With V_Π correction

Early Spiral Structure Maps



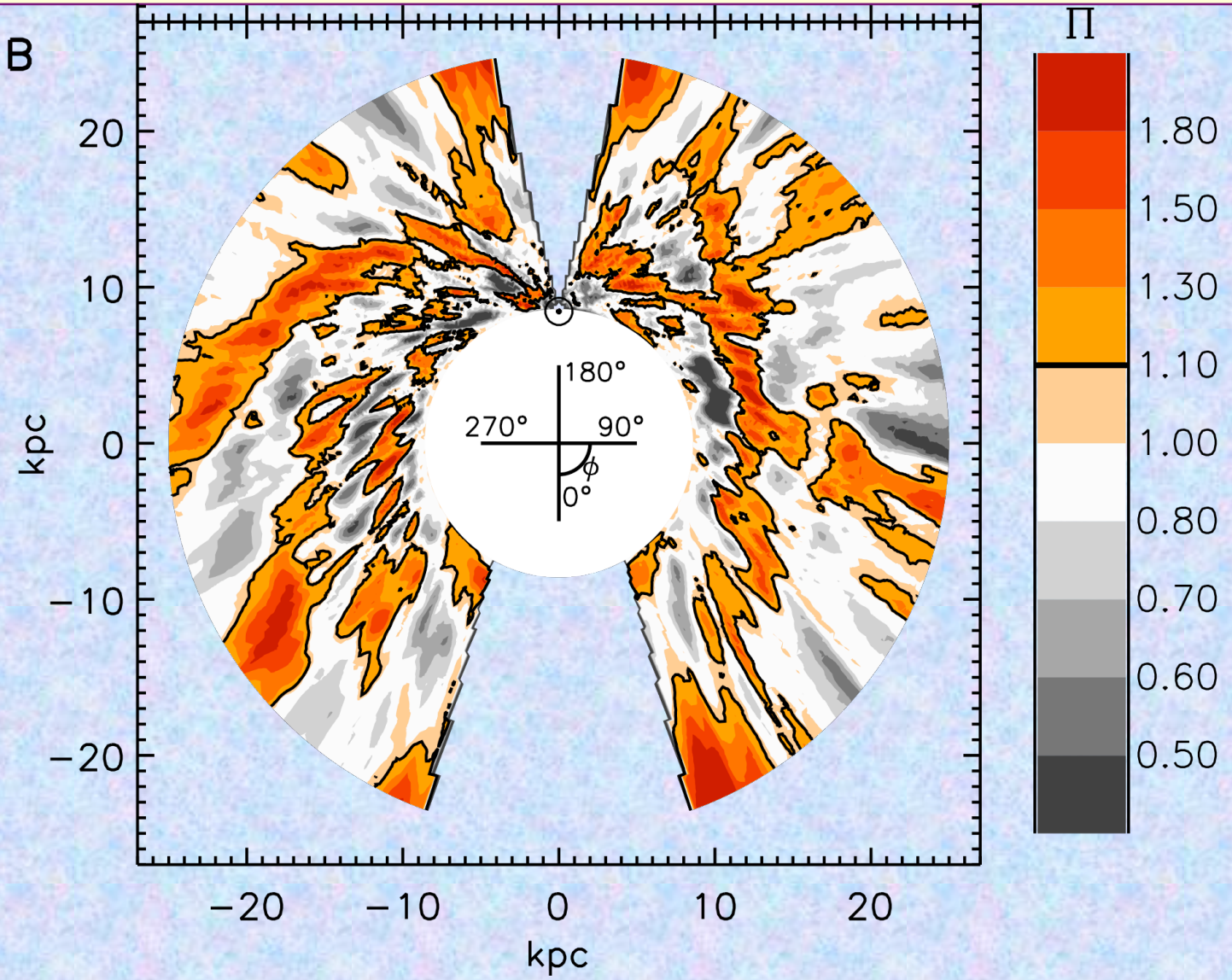
Current Spiral Structure Maps

Unsharp masked HI map



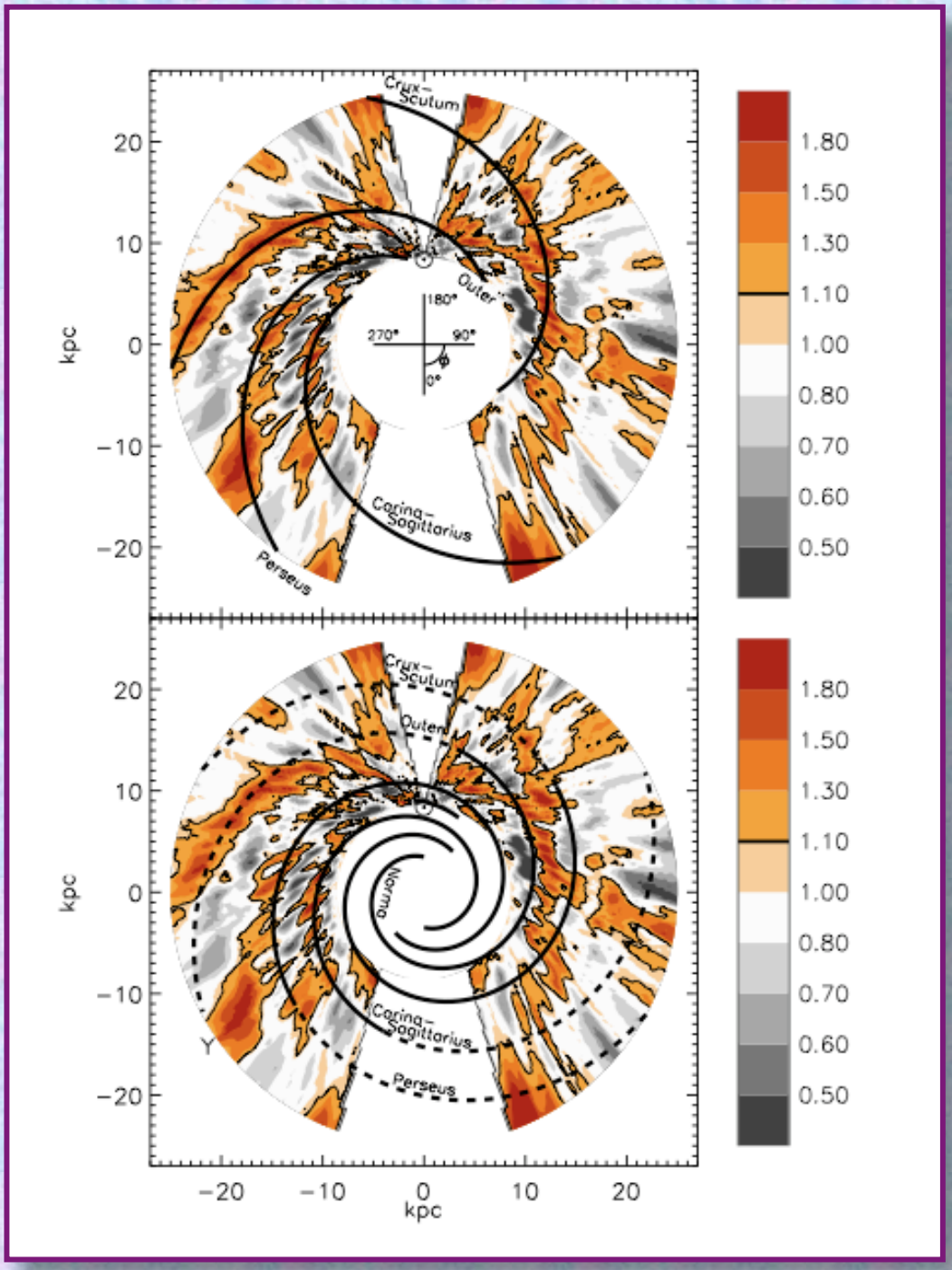
Map of surface density perturbations to HI

Note that arms go beyond edge of stellar disk (> 2 R_O)

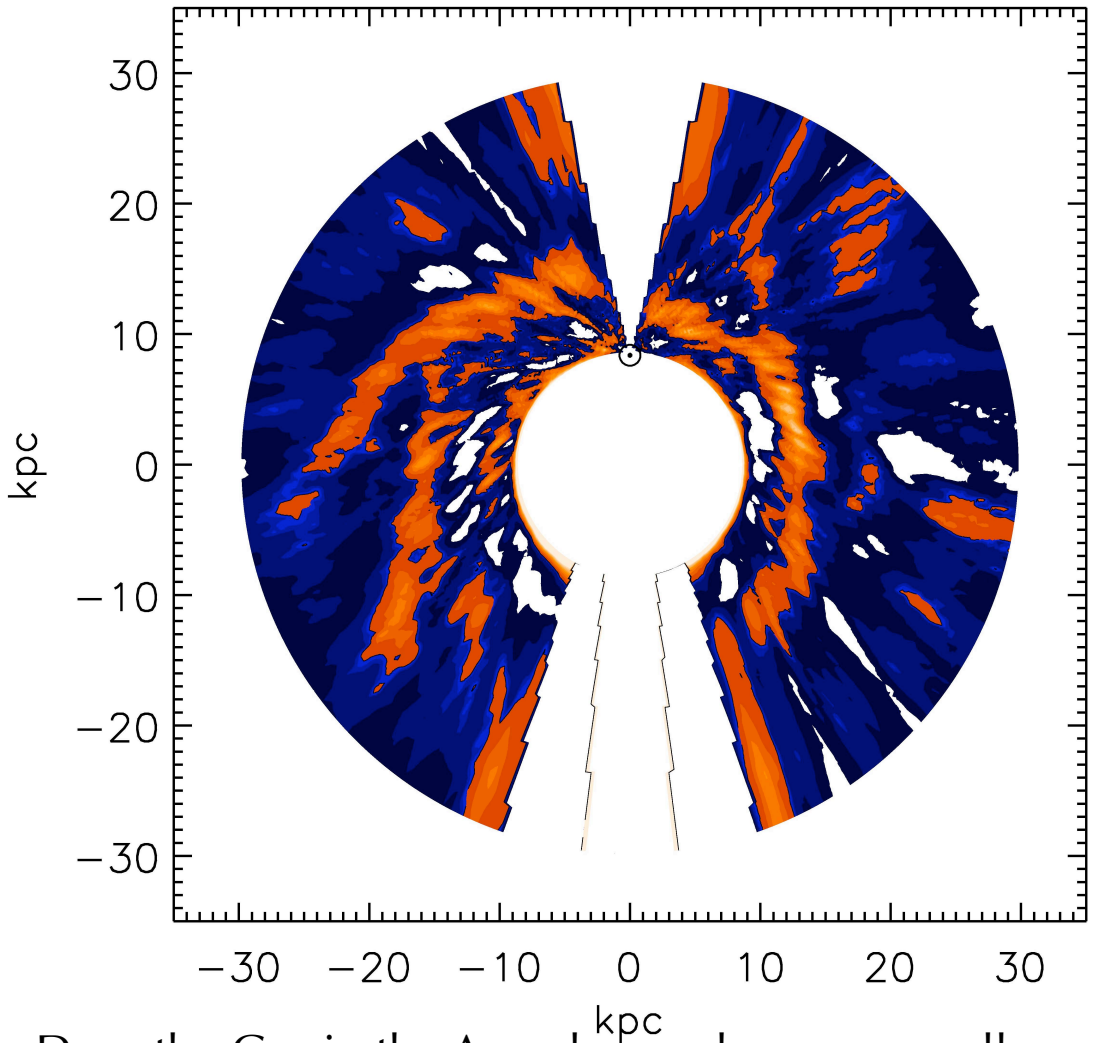


One way of connecting spiral arms.

Classical spiral arm patterns.

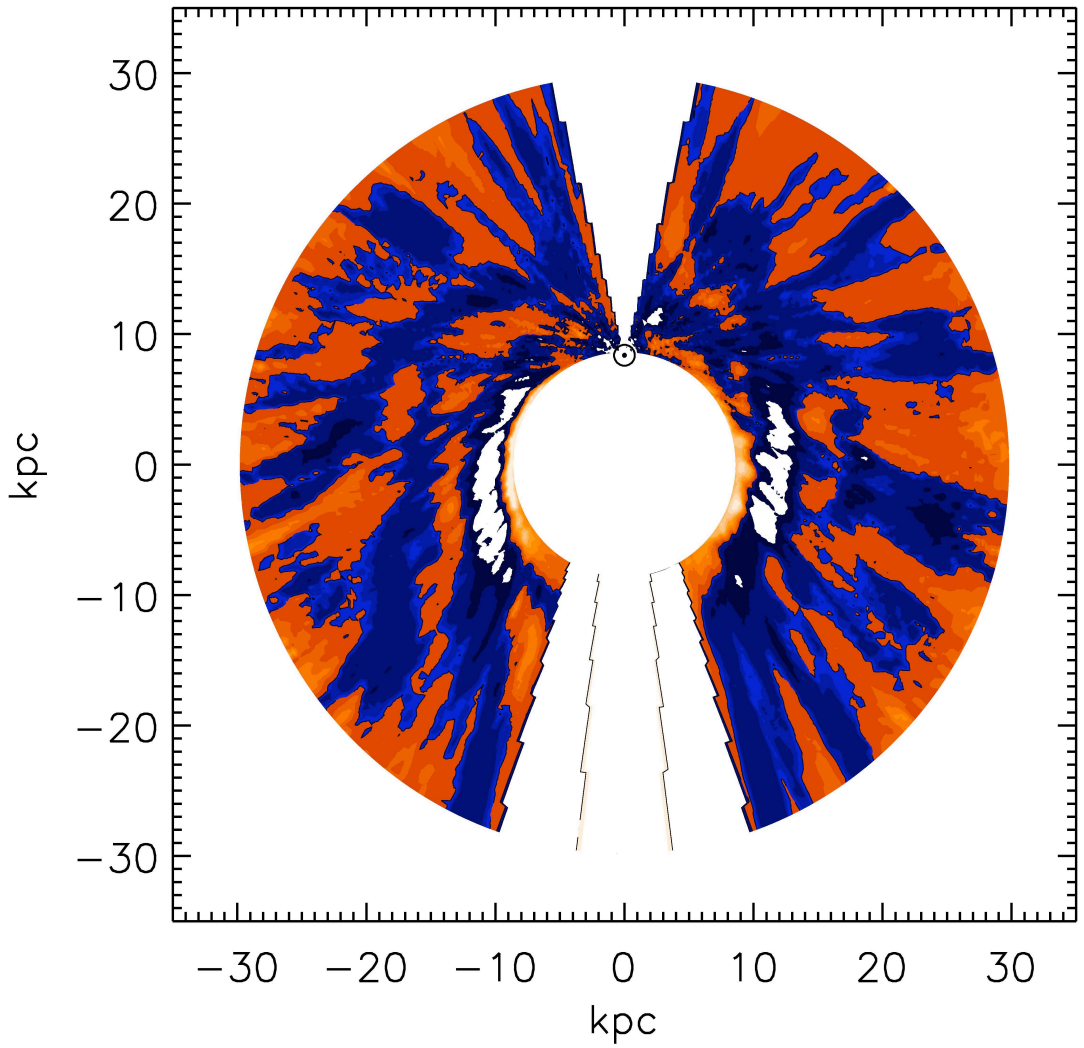


Spiral Arms of the Milky Way

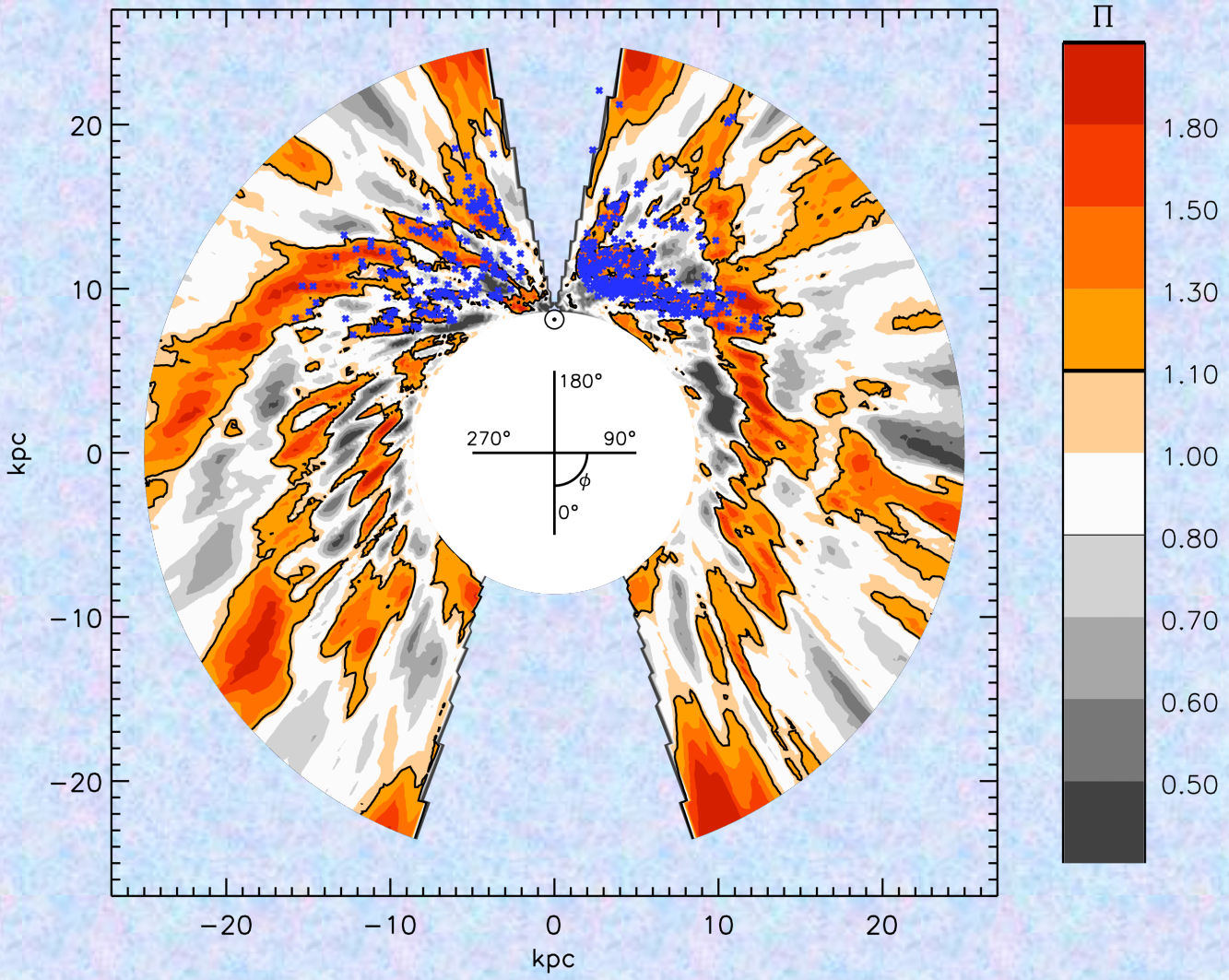


Does the Gas in the Arms have a larger or smaller scale height?

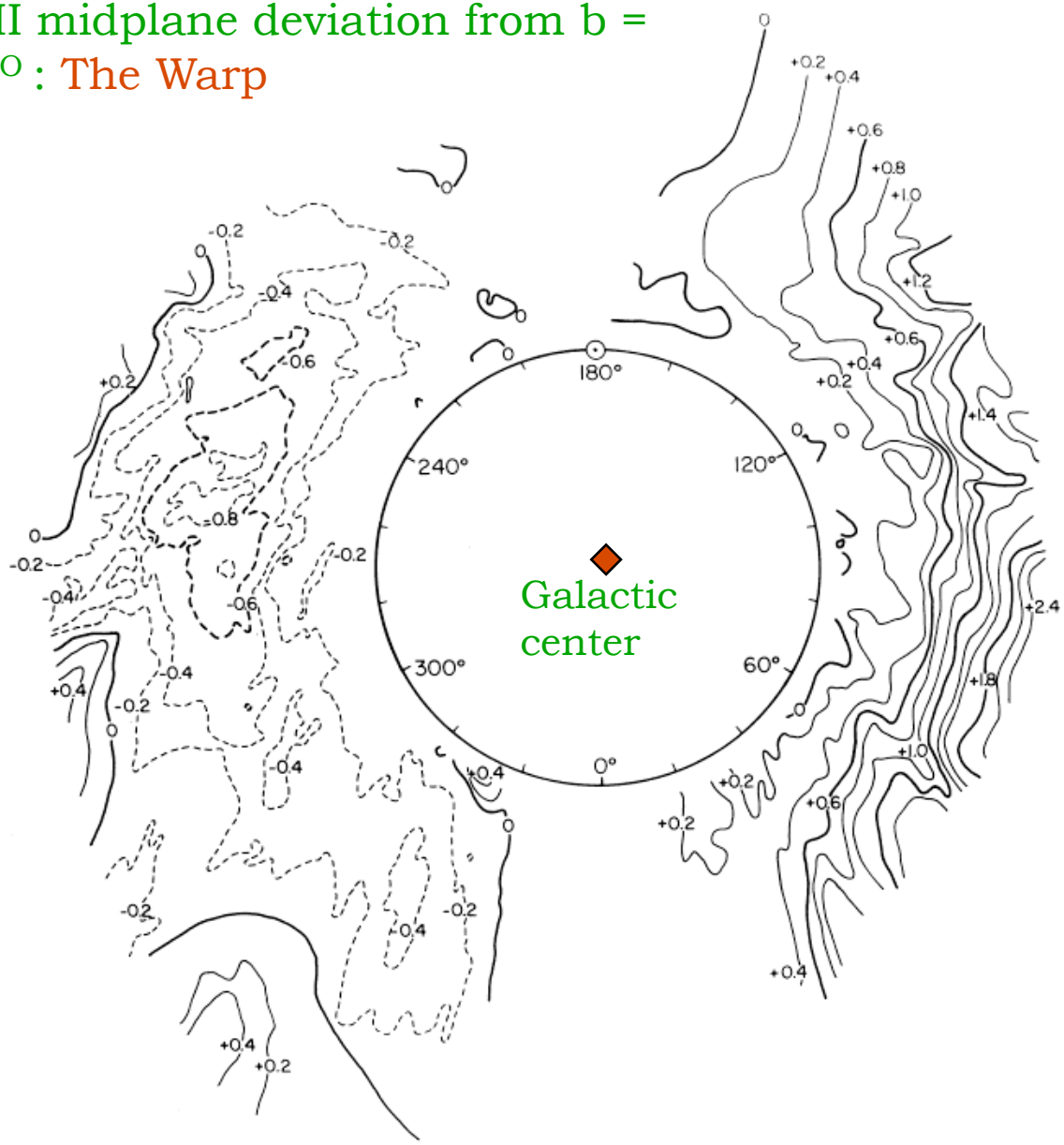
HI Scale Height (Thickness)



Comparison with Distant CO Clouds



HI midplane deviation from b = 0^{O} : The Warp



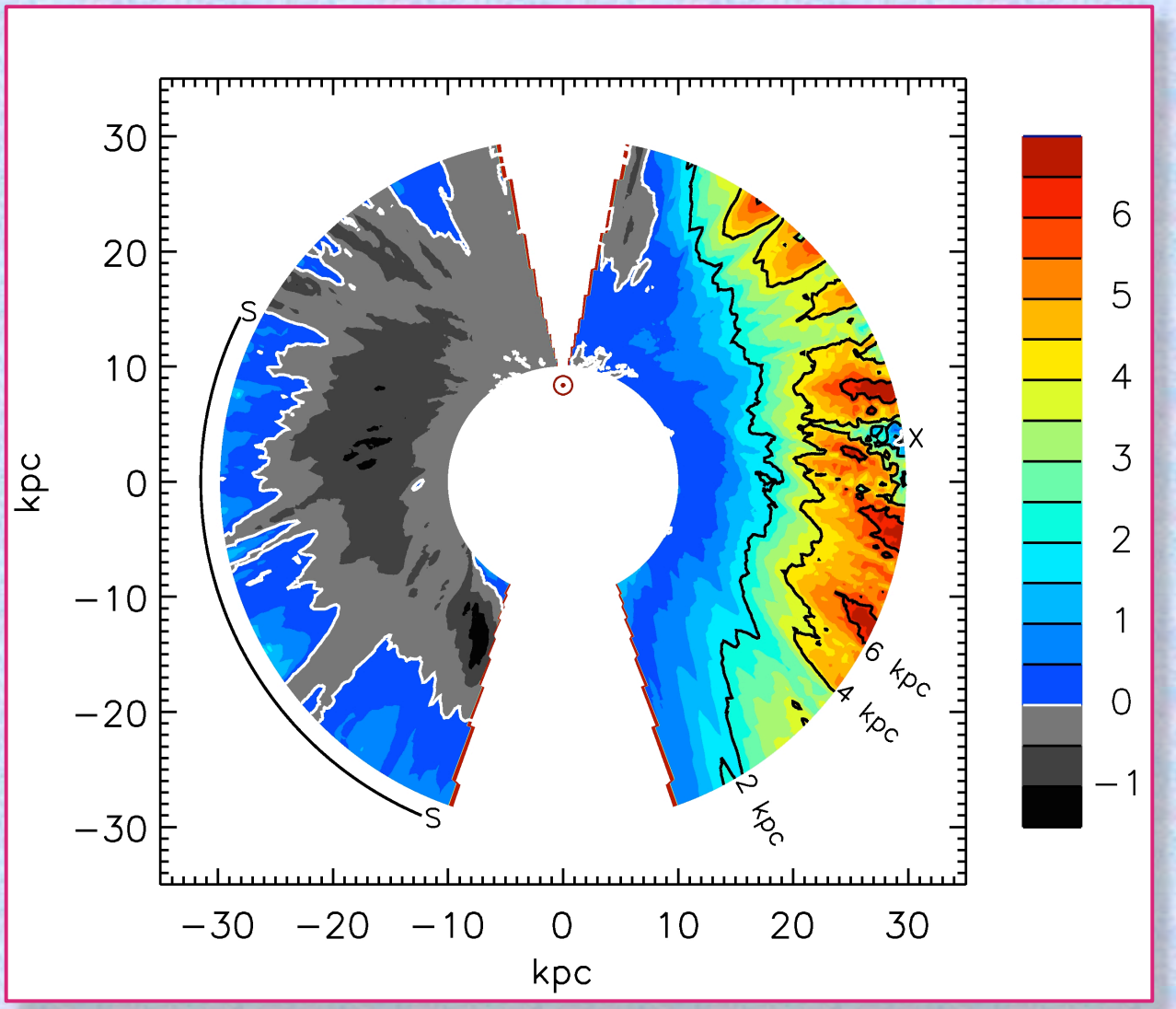
Henderson, Jackson & Kerr 1982

Displacement of mean plane from b = 0°

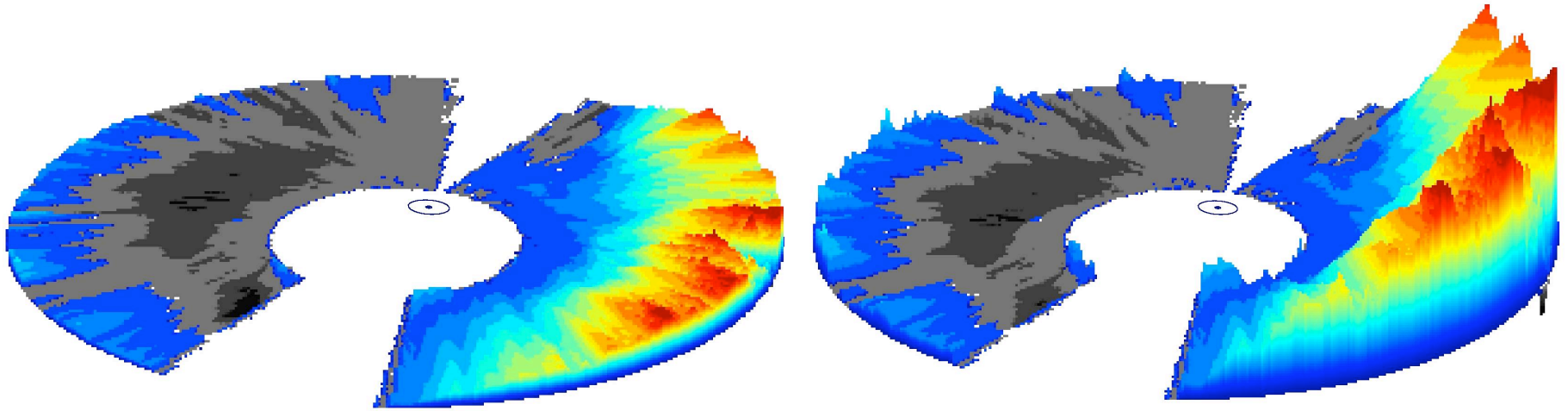
Blue, Red = pos

Grey = neg

Darker hues mean higher amplitude



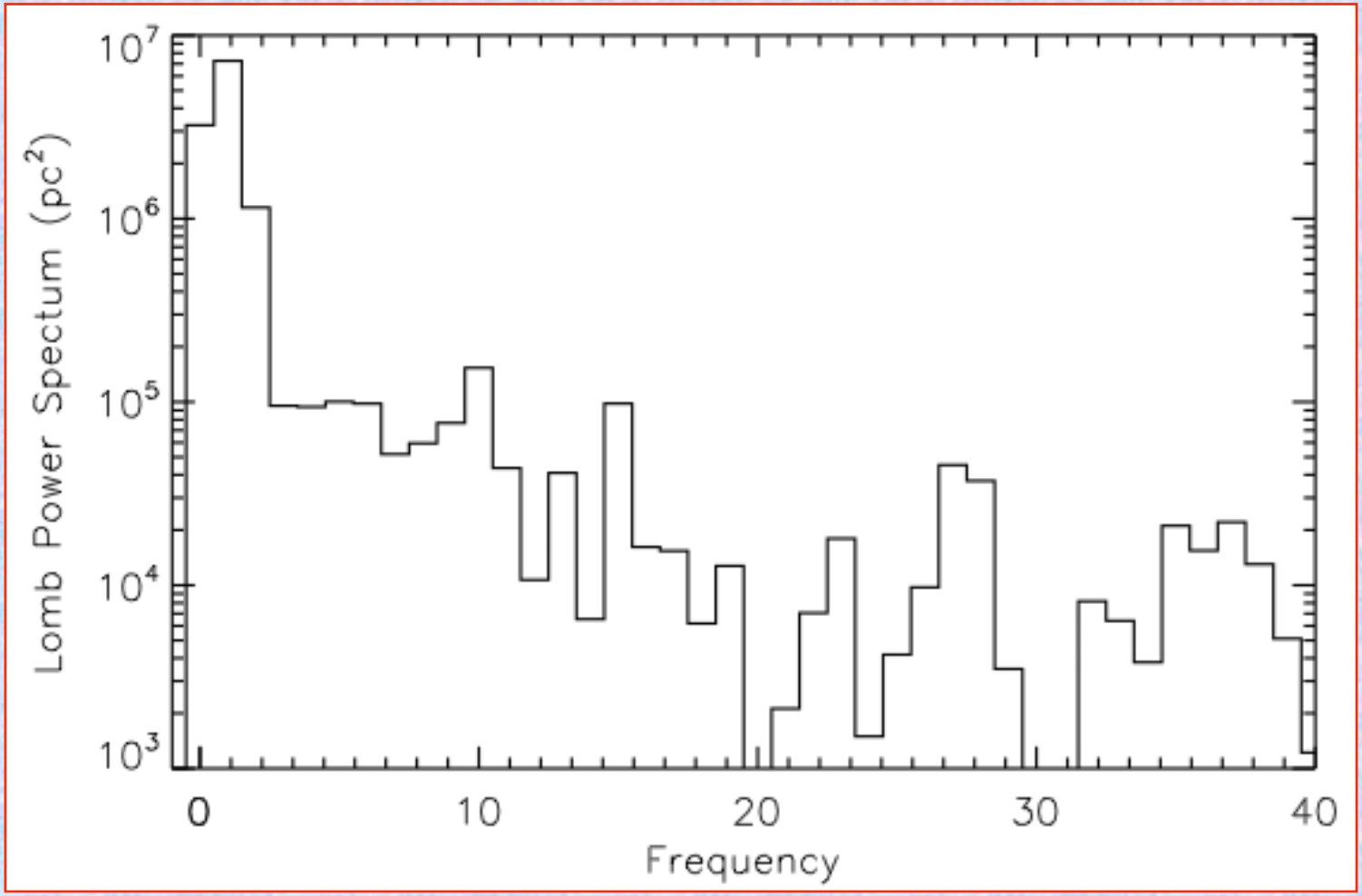
View of warp from l = 30°



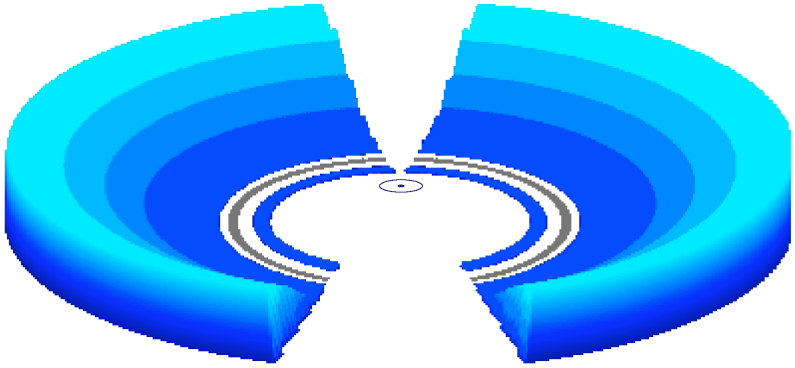
To Scale

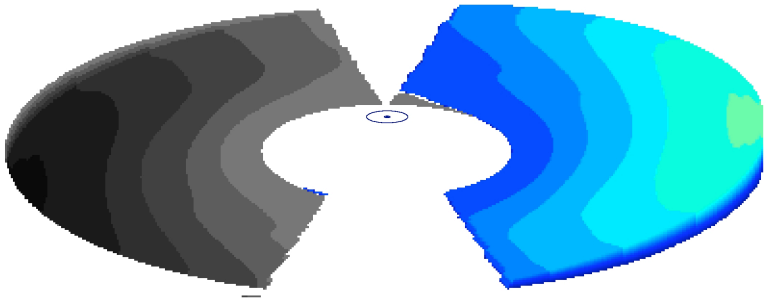
5x exaggeration

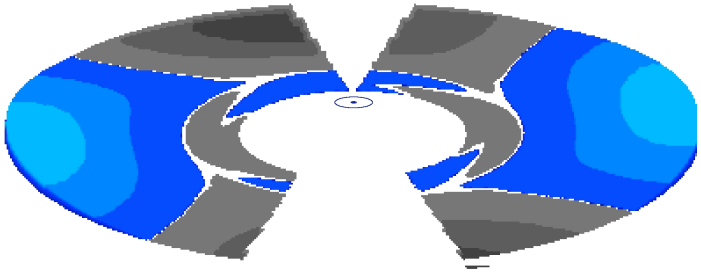
Amplitudes of Global Fourier Modes

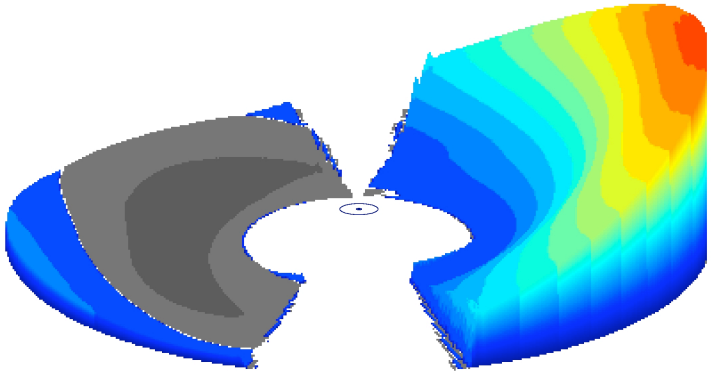


The three main modes to scale (5x exaggeration)





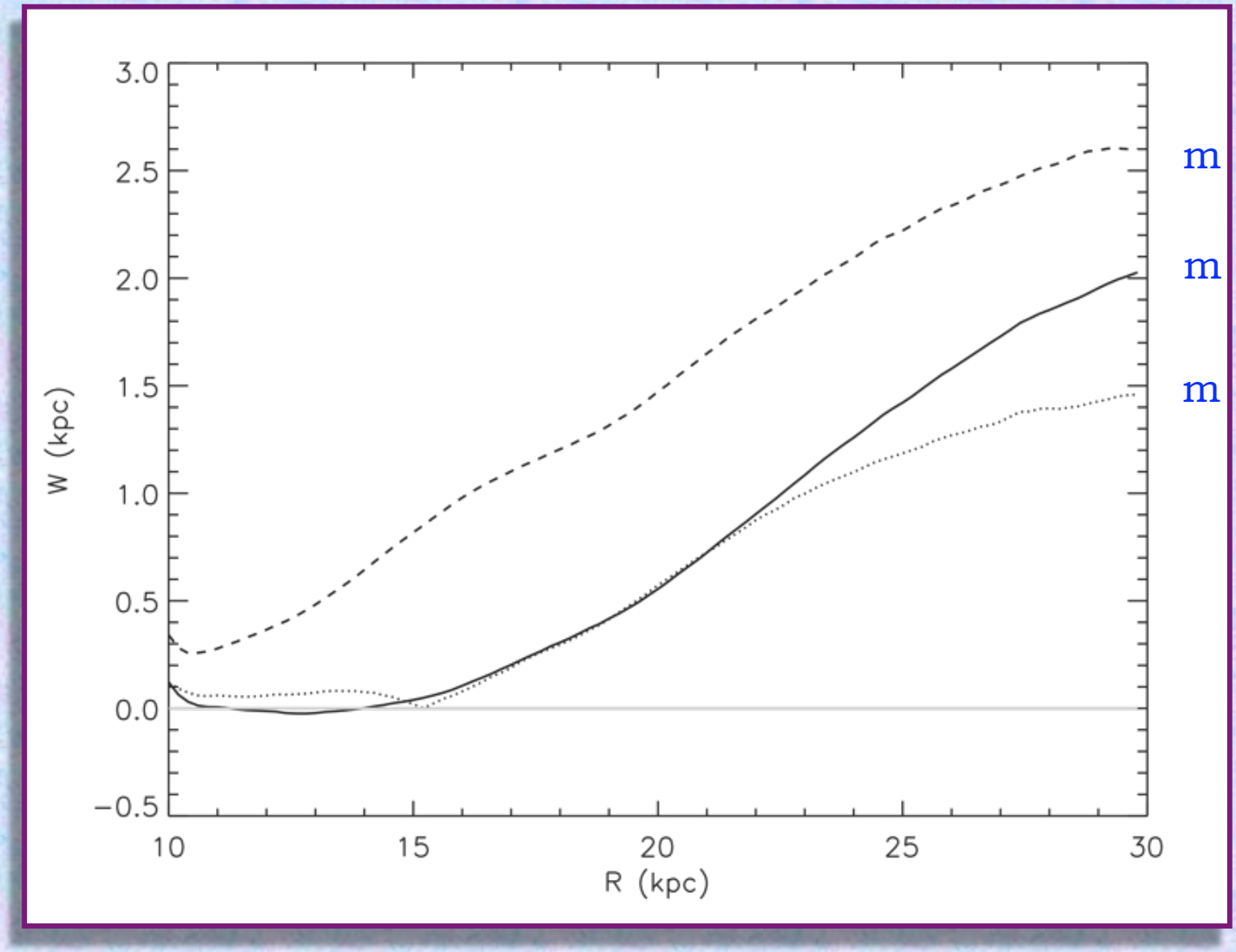




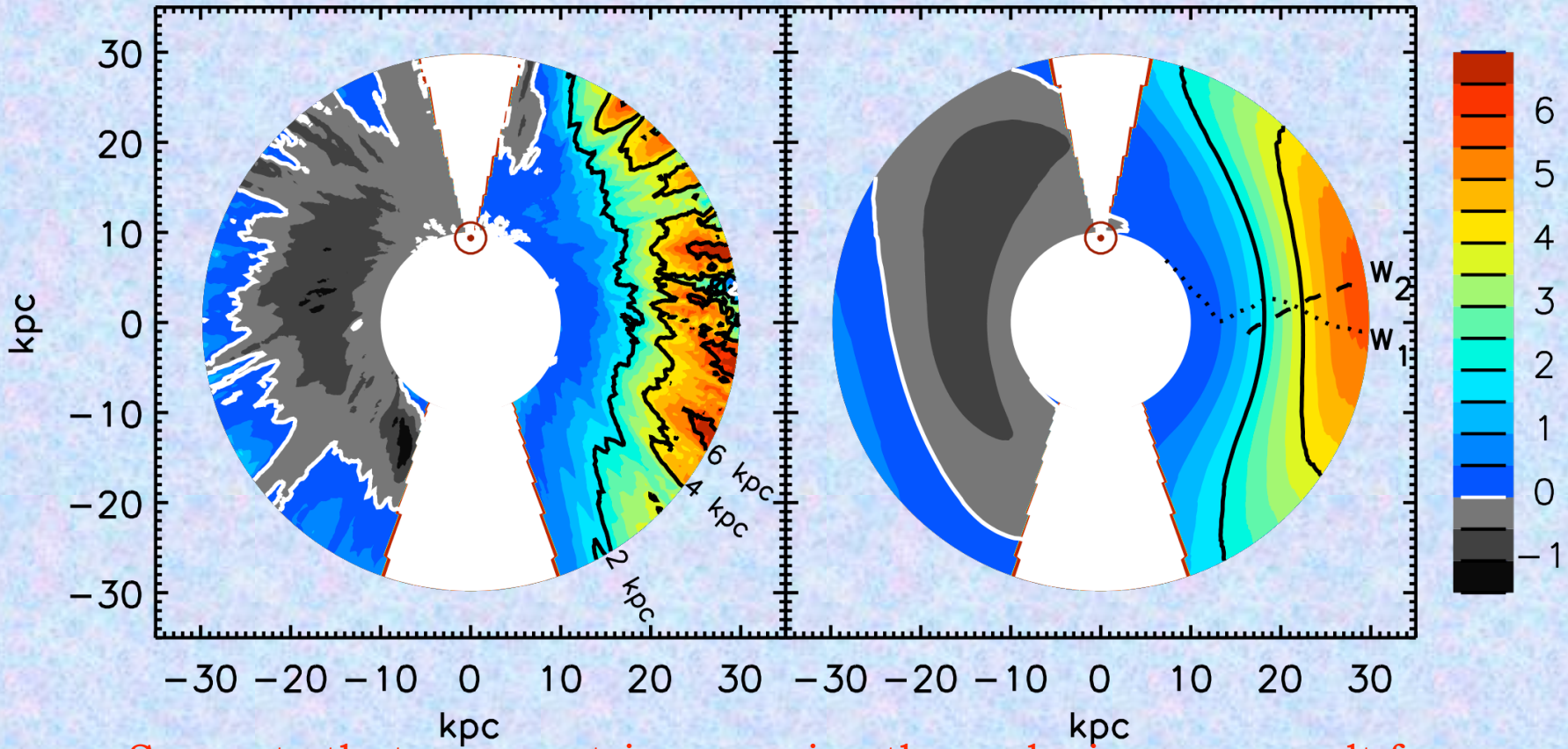
These “notes” are 64 octaves below middle C

Are these modes common in other galaxies?

Amplitude of the first 3 modes as a function of distance

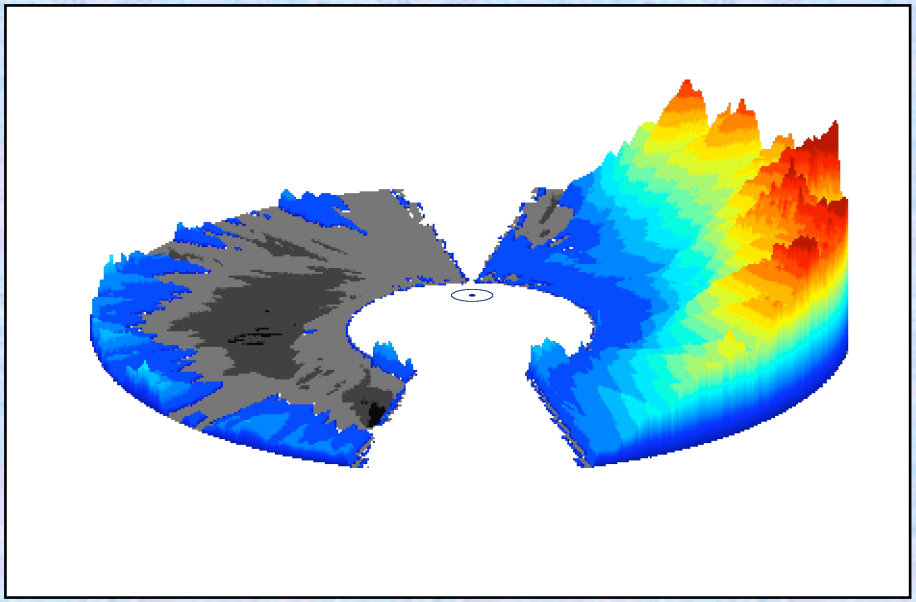


Comparison of Data with Model

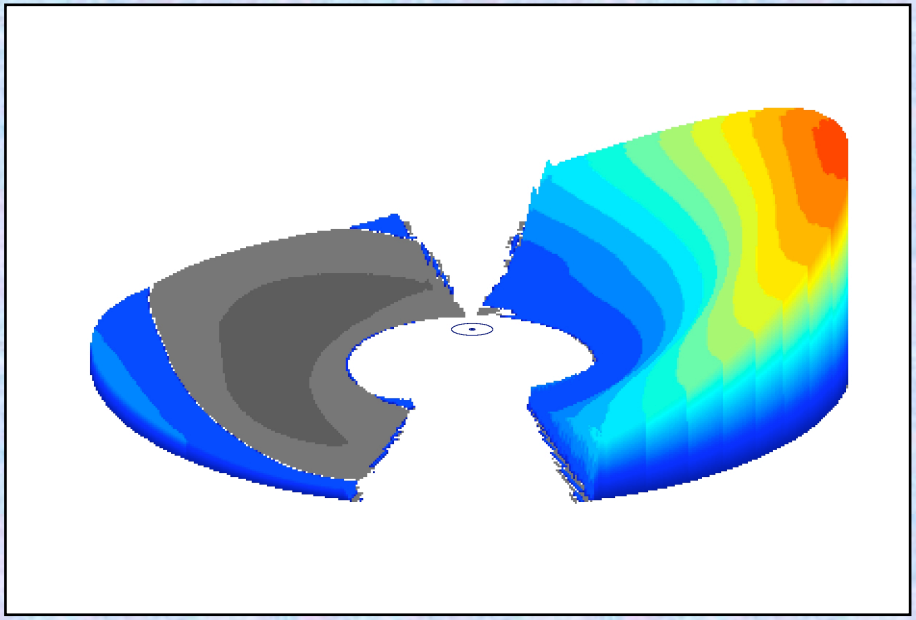


Suggests that asymmetric warps in other galaxies may result from superposition of low order global modes

Comparison of Data with Model

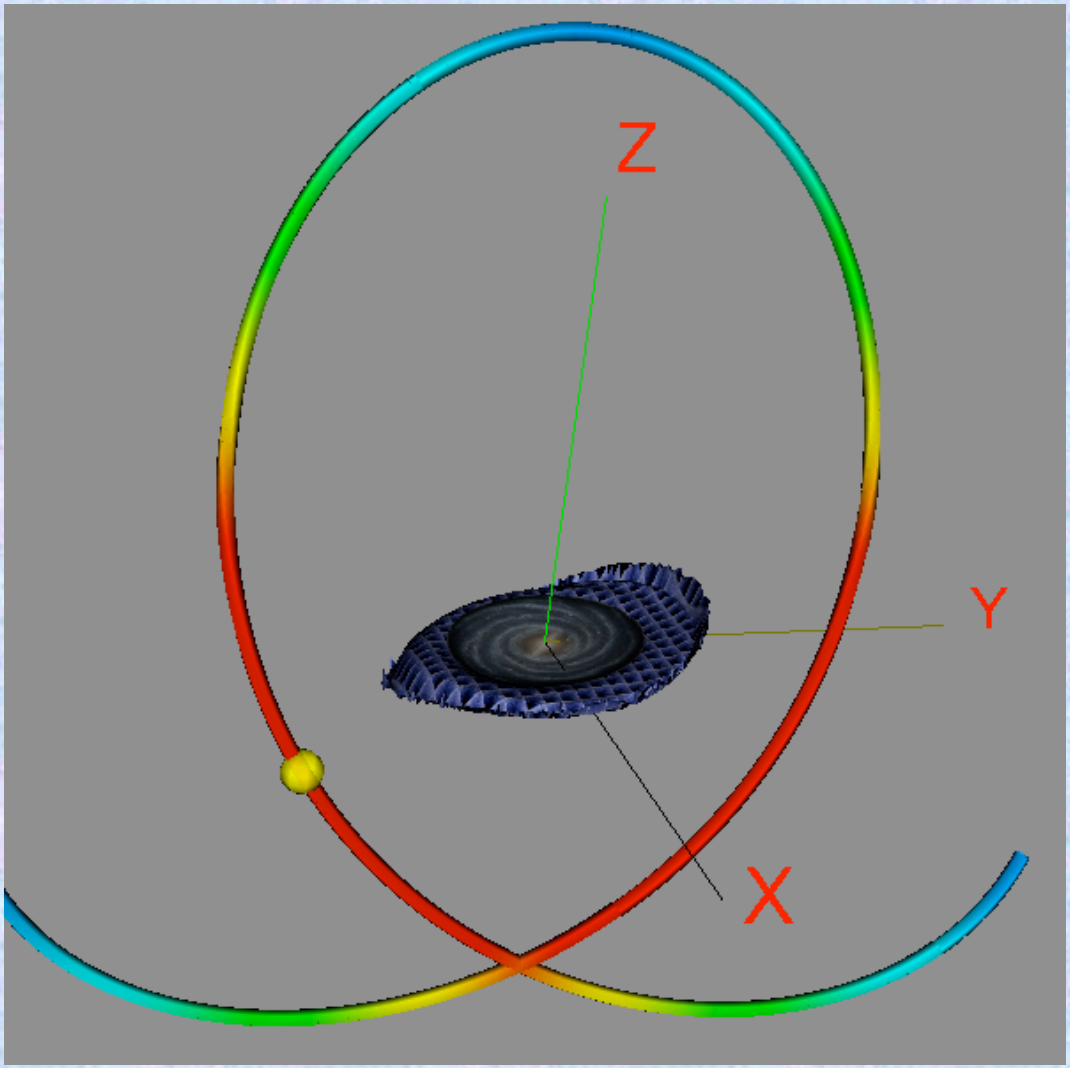


Data

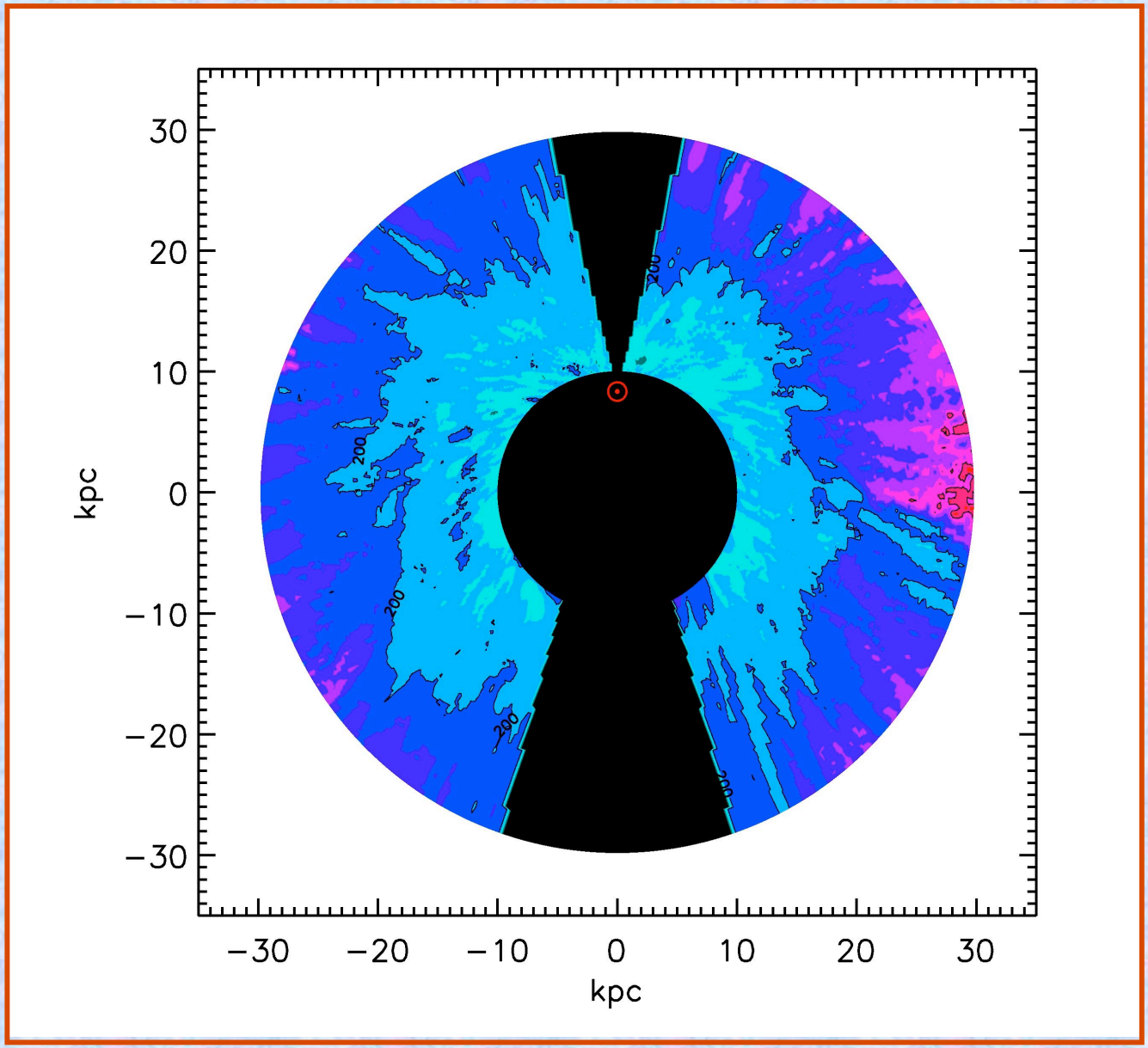


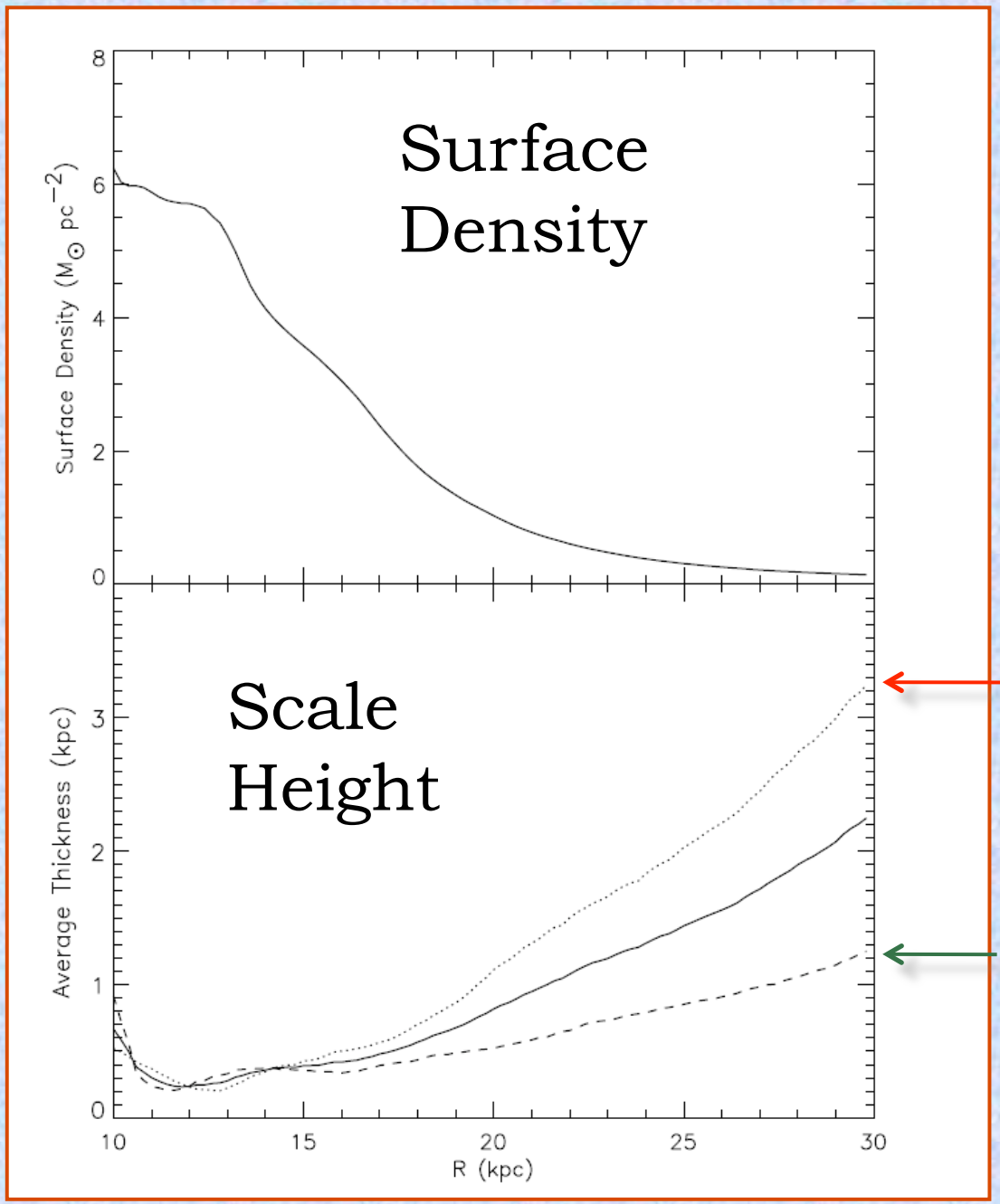
3 mode model

Magellanic Clouds Forcing the Disk Warp



Thickness of the HI layer

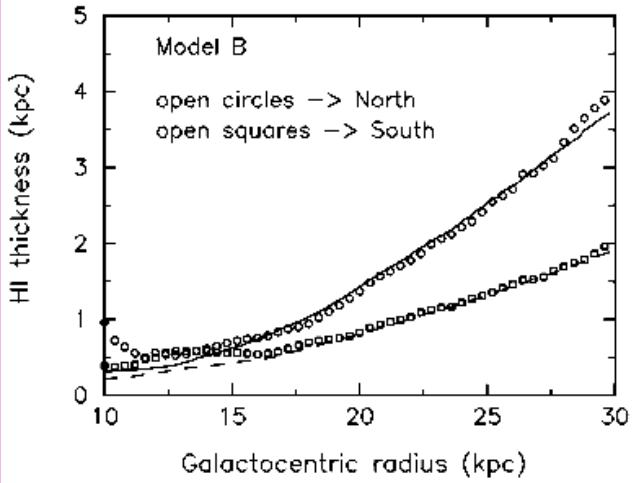


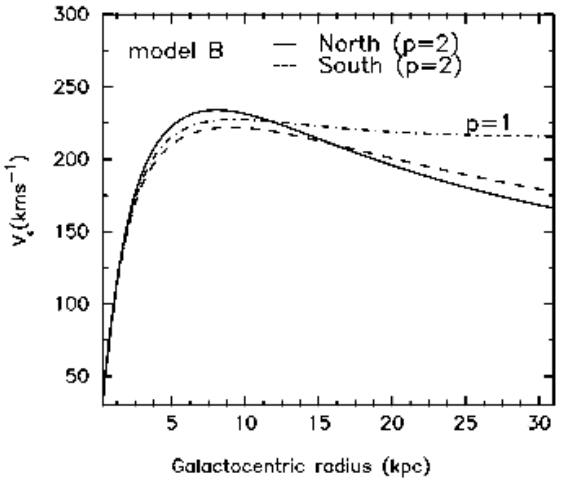


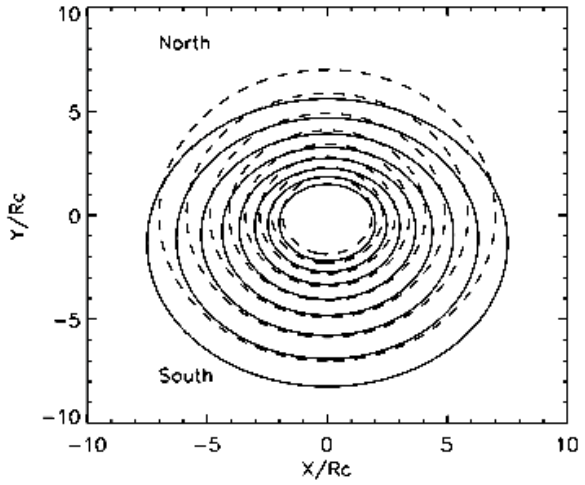
ℓ = 0 - 180^0

ℓ =180^0 - 360^0

Observations vs. Model for Asymmetric Halo





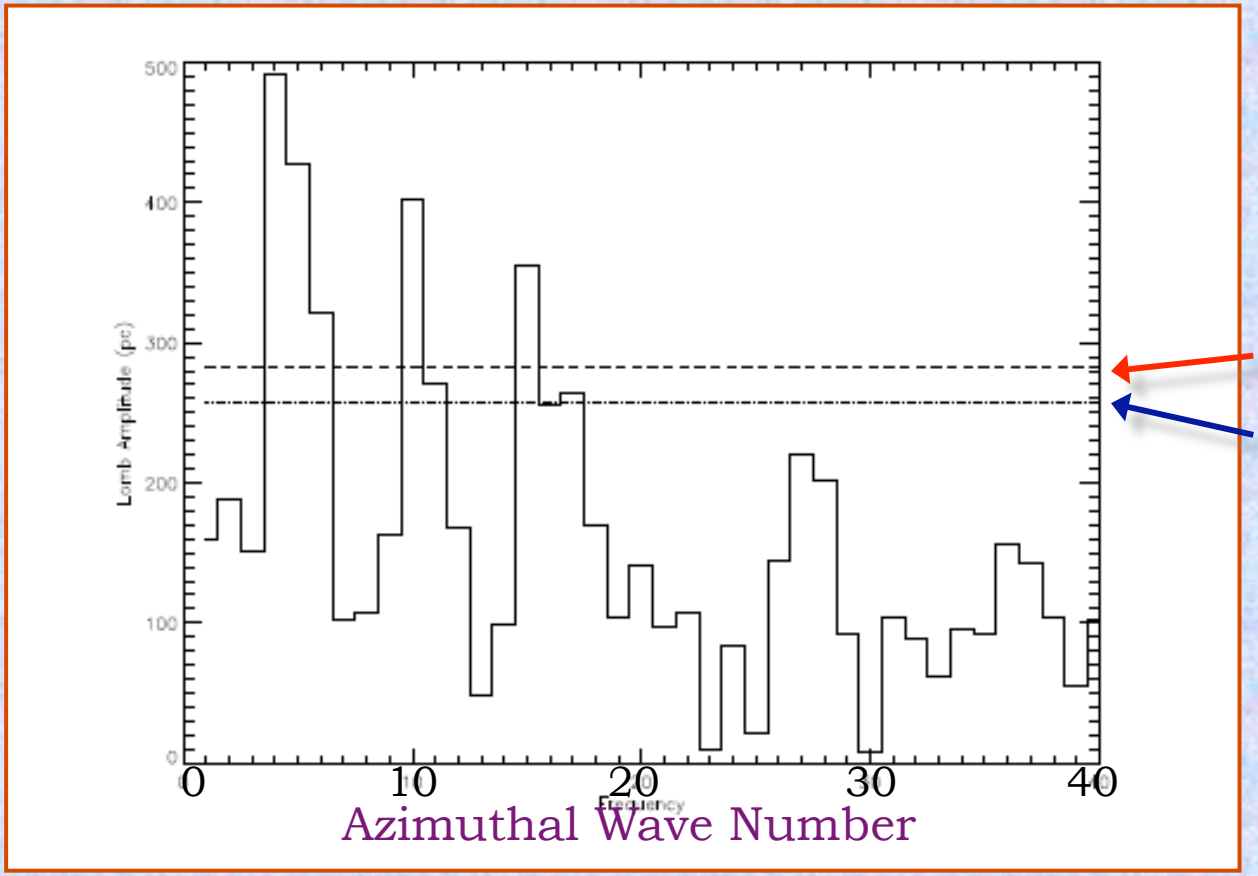


MW DM halo has an m = 1 bending distortion.

Due to halo itself or off-centeredness of disk?

Saha et al. (submitted)

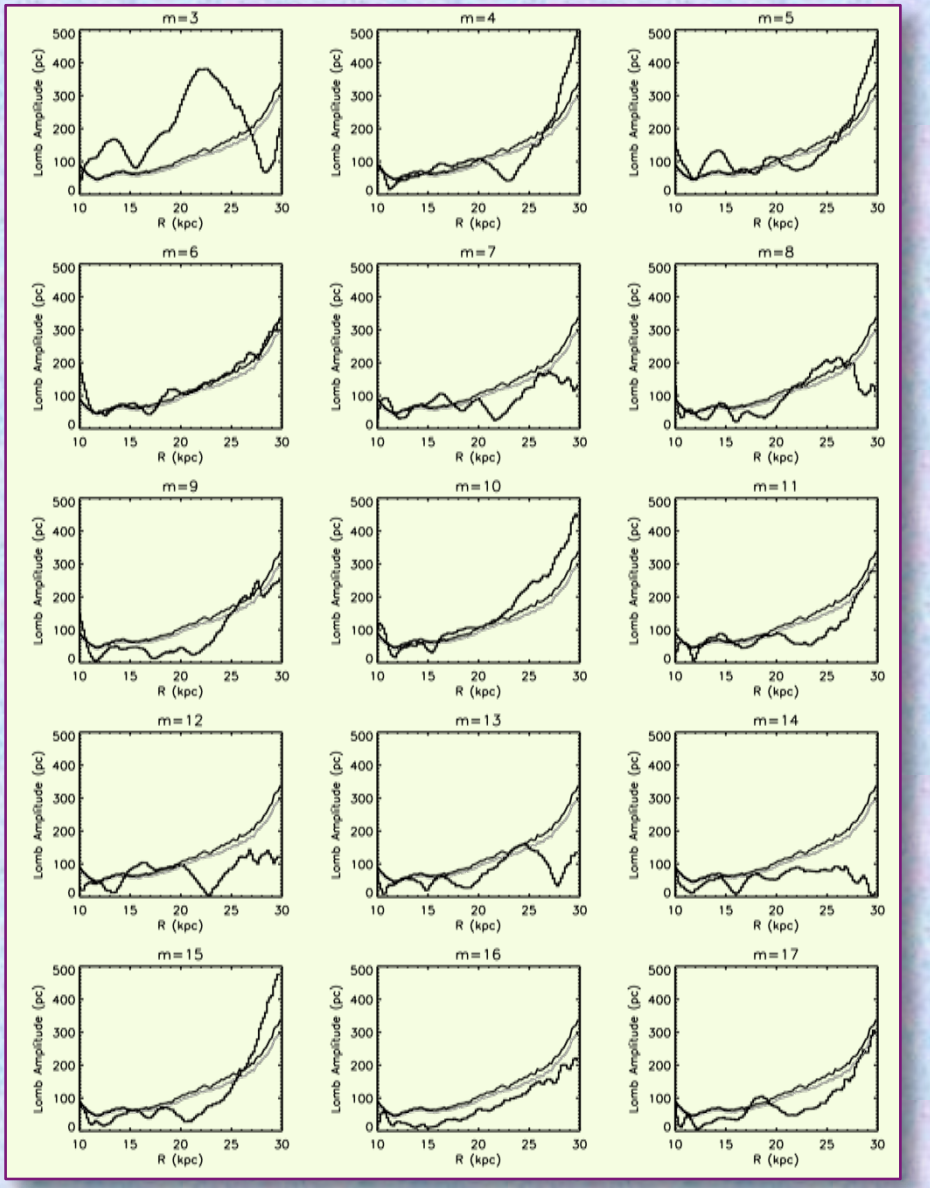
Power in higher order modes at R =28 kpc



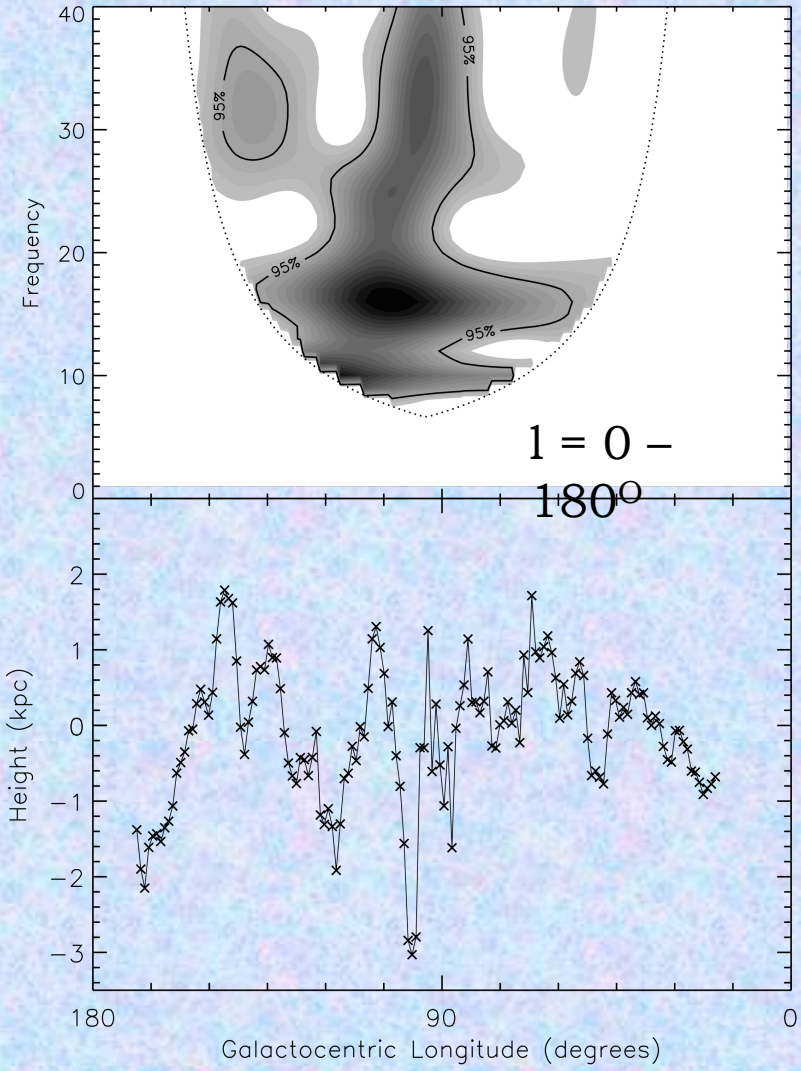
Subtract three lowest order global modes

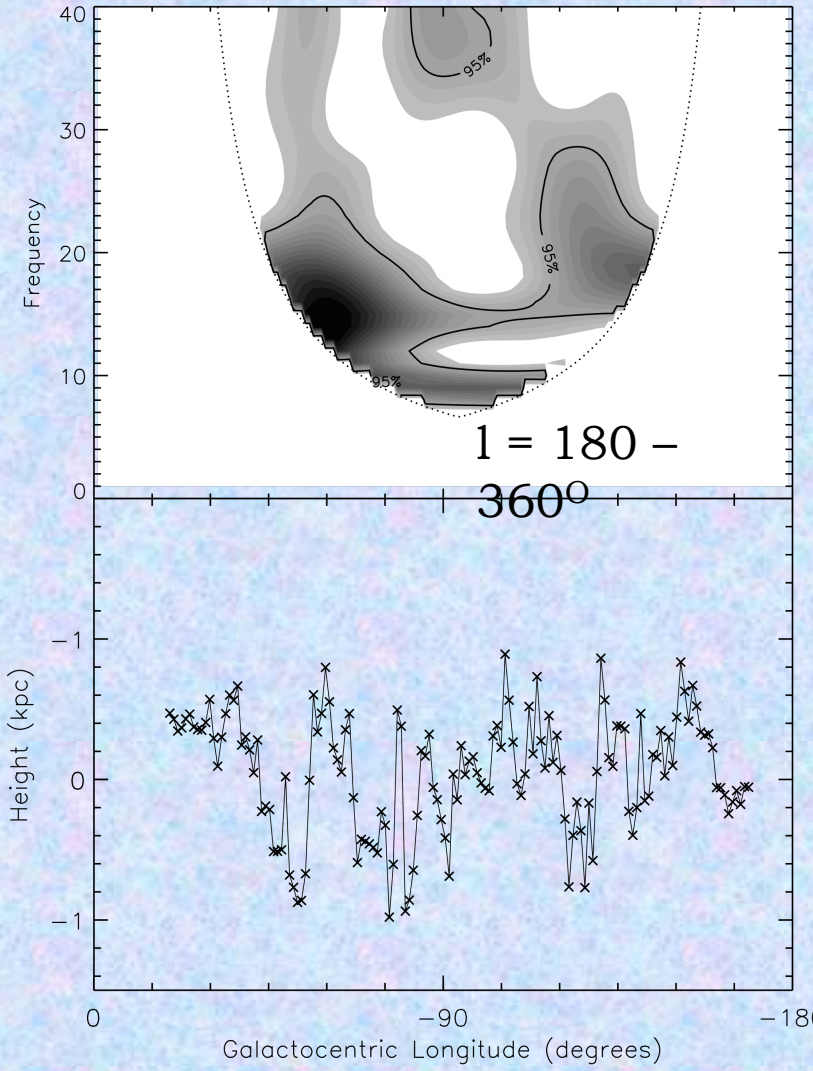
This represents local modes relative to global modes

Development of Modes with R



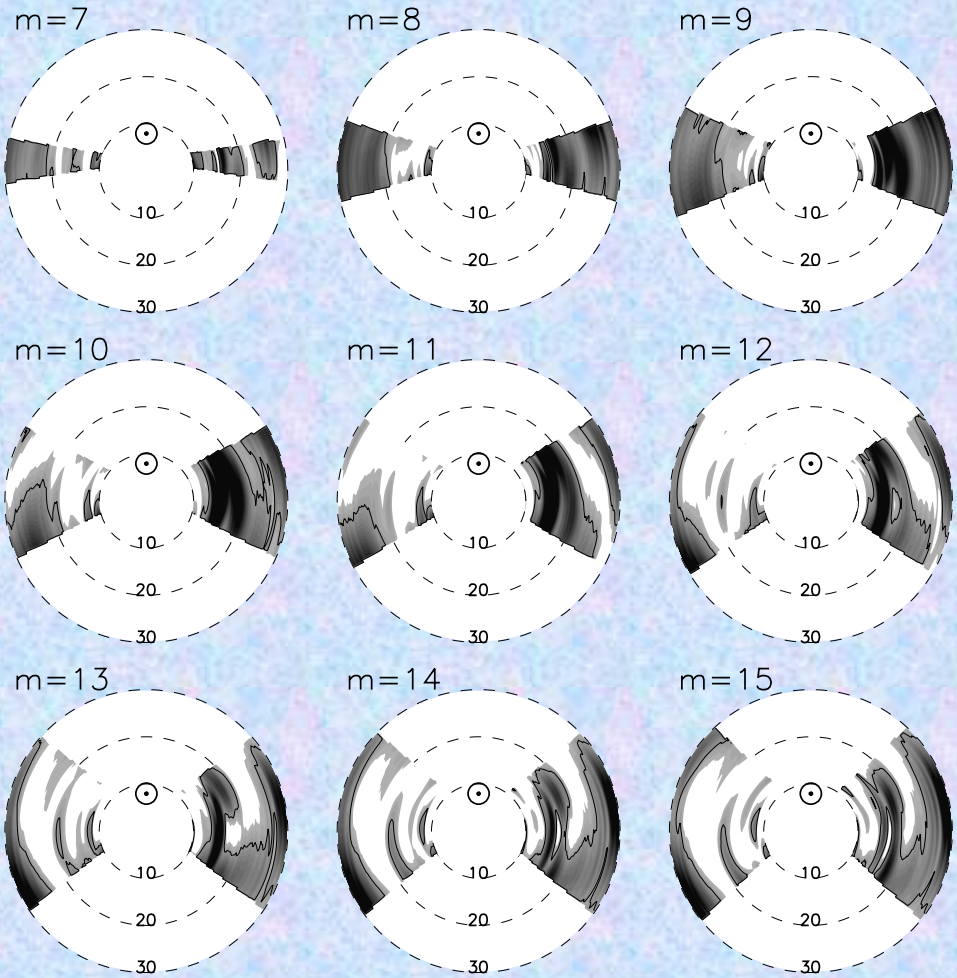
Wavelet Power Spectrum





R = 28 kpc

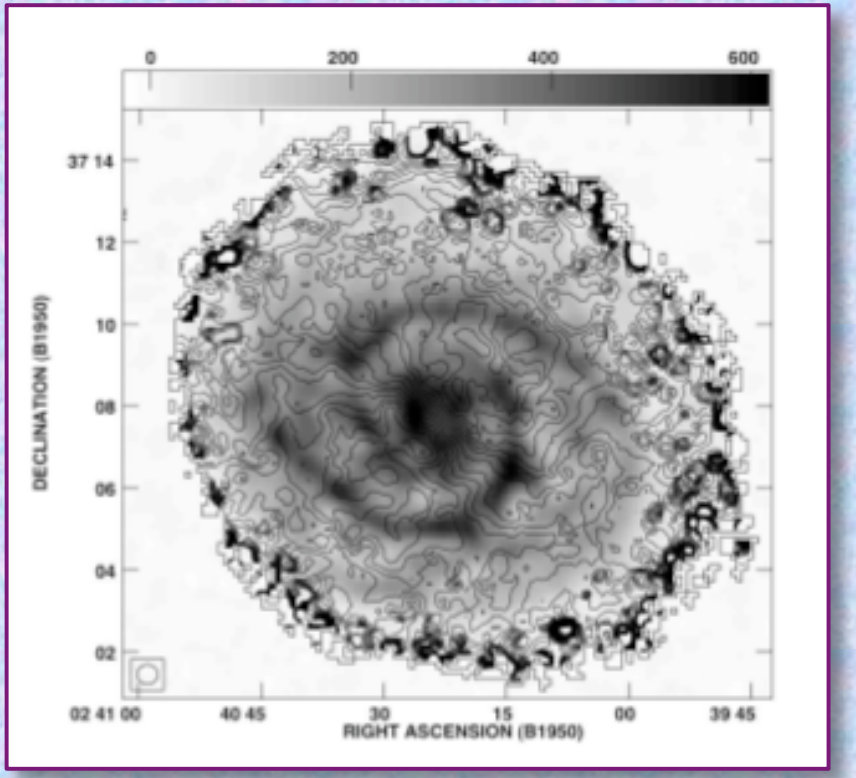
Wavelet power spectrum as a function of azimuth, radius, m

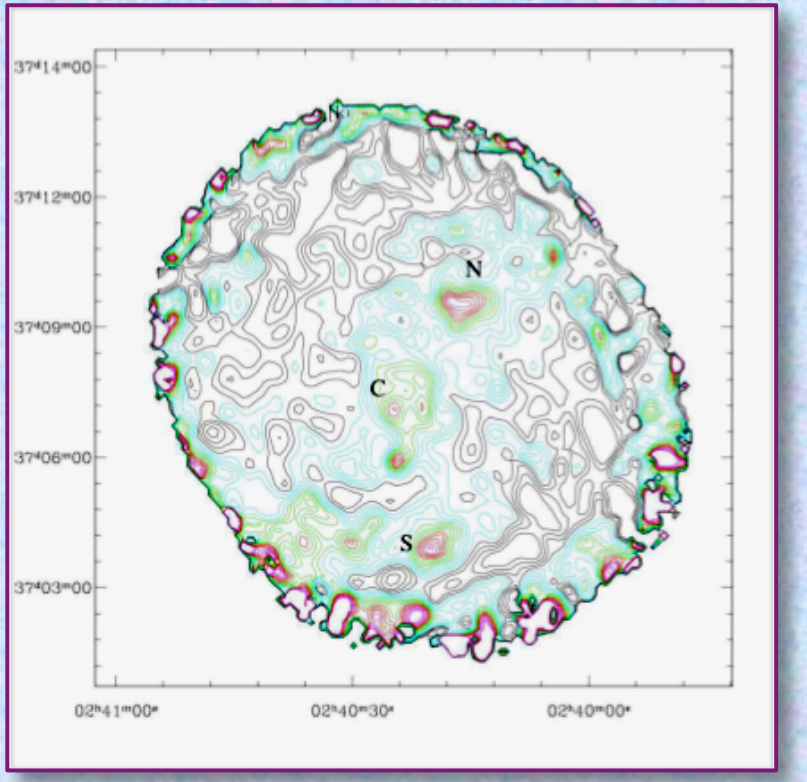


Interpretation

- We are seeing localized perturbations of high azimuthal wavenumber
- These are too large to be due to SN and too far out in the MW to be due to OB associations
- Other possible origins
  - Ringing from dwarfs passing through disk?
  - Ghost tidal streams?
  - Evidence for minihalos?

Evidence from Other Galaxies
HI in NGC 1058





Petric & Rupen (2007)

Some things we've learned

- The Milky Way has an m = 1 asymmetry in the plane of the disk.
- The Milky Way has three prominent modes in the warp; m = 0, m = 1, m = 2; all others much weaker.
- There are a few localized disturbances in the gas disk.
- The HI scale heights are grossly different on either side of the Sun-Center line.
- Spiral arms are thinner than interarm gas.

Some things we'd still like to know

- How does the gas maintain an nearly constant velocity dispersion beyond the edge of the stellar disk?
- What keeps the gas flat beyond the stellar disk?
- How do spiral arms propagate beyond the edge of the stellar disk?
- Are local disk HI disturbances due to DM substructure?
- Gas inflow vs. asymmetric halo?