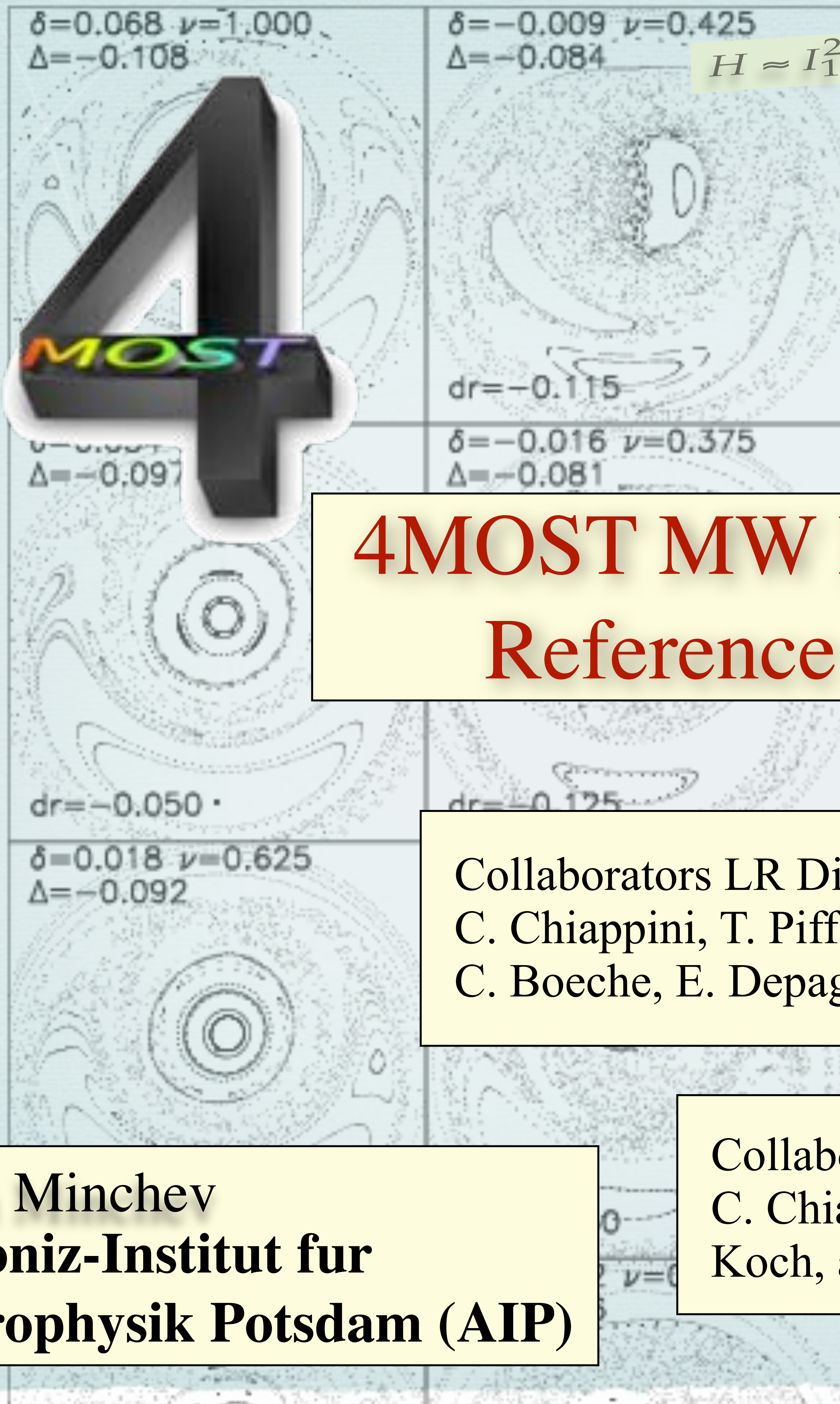
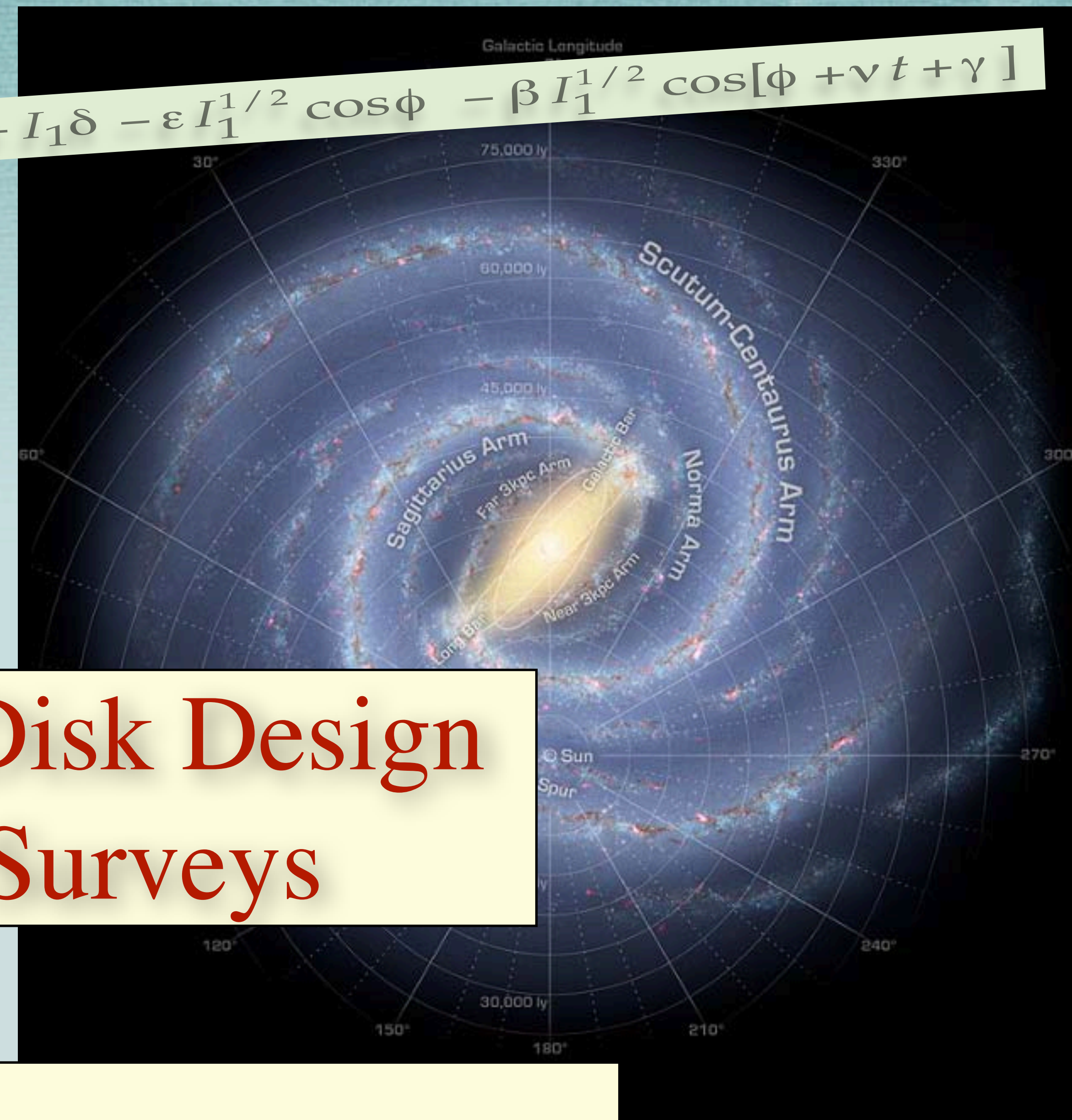




$$H \approx I_1^2 + I_1\delta - \varepsilon I_1^{1/2} \cos\phi \;\; - \beta I_1^{1/2} \cos[\phi + \nu t + \gamma]$$

4MOST MW Disk Design Reference Surveys

Collaborators LR Disk:
C. Chiappini, T. Piffl, A. Koch, E. Caffau,
C. Boeche, E. Depagne, M. Williams

Collaborators HR Disk:
C. Chiappini, T. Piffl, E. Caffau, A. Koch, and SWPIb HR

Ivan Minchev
Leibniz-Institut fur Astrophysik Potsdam (AIP)

AIP
Leibni
Astrop

Galactic archeology done for the first time

- The first step toward understanding the MW disk past history is understanding its current morphology and dynamics. We can use two approaches:

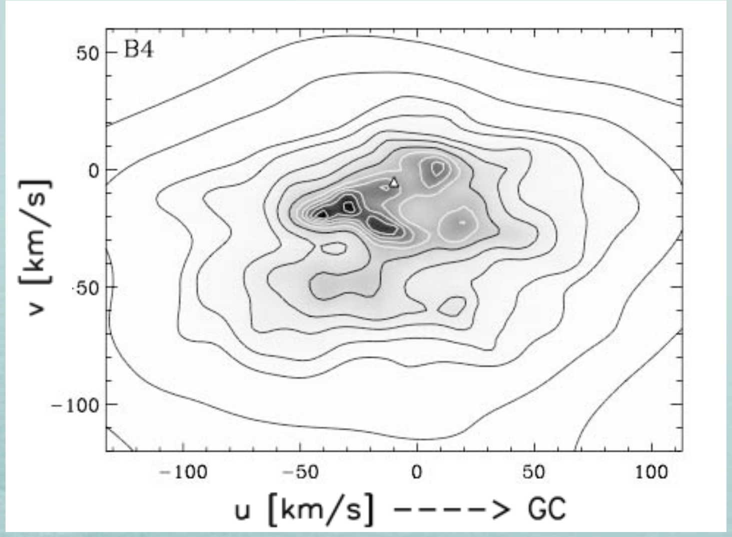
  (1) study a volume of d<2 kpc around the Sun (Extended Solar Neighborhood), where a high level of precision in velocities and distances is achievable.

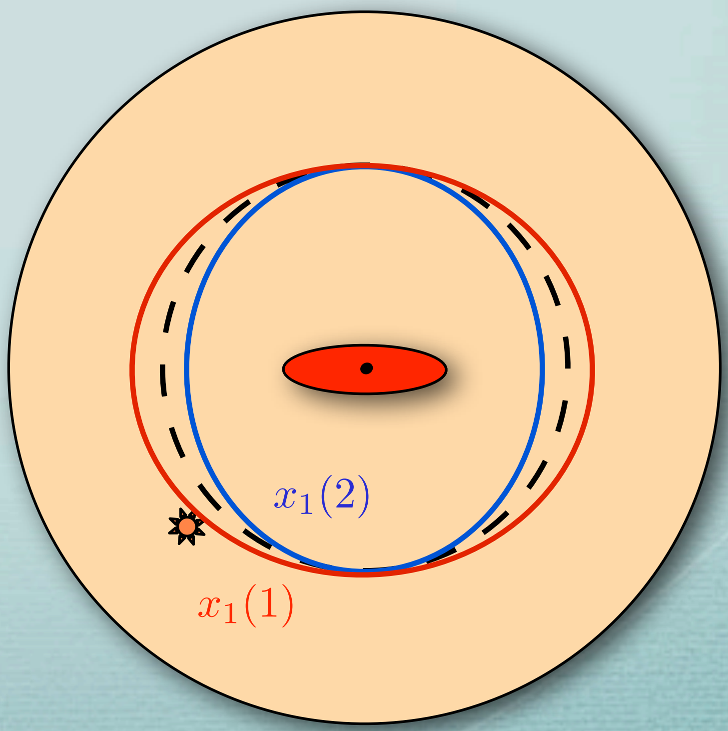
  (2) study the disk morphology and dynamics globally.

- Using constraints from (1) and (2), we can get, for the first time, an unambiguous picture of the MW disk dynamics.

- Combining with good chemistry (Disk LR and HR), we can then go back in time and recover the disk past evolution.

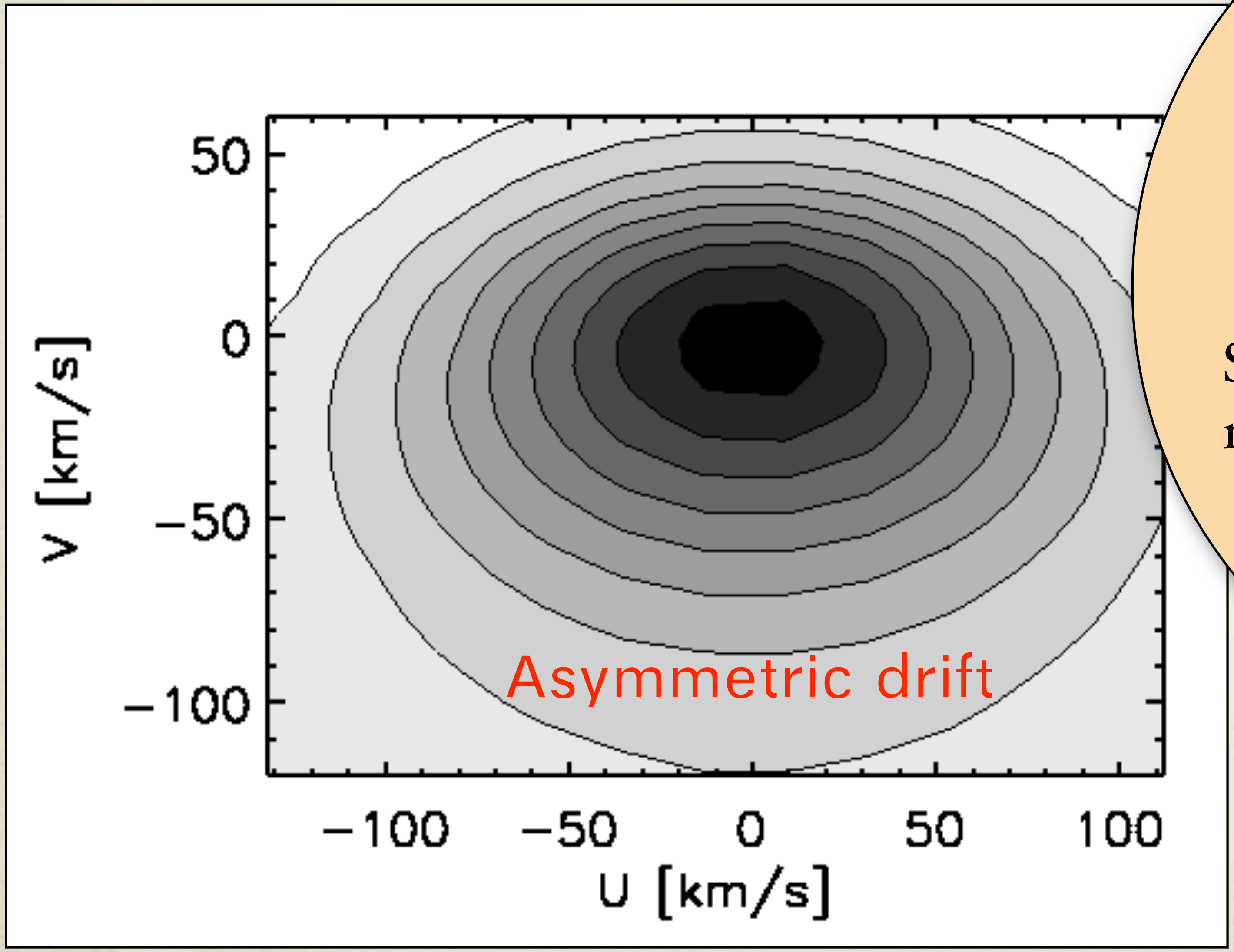
Resonant moving groups in the EXTENDED Solar neighborhood

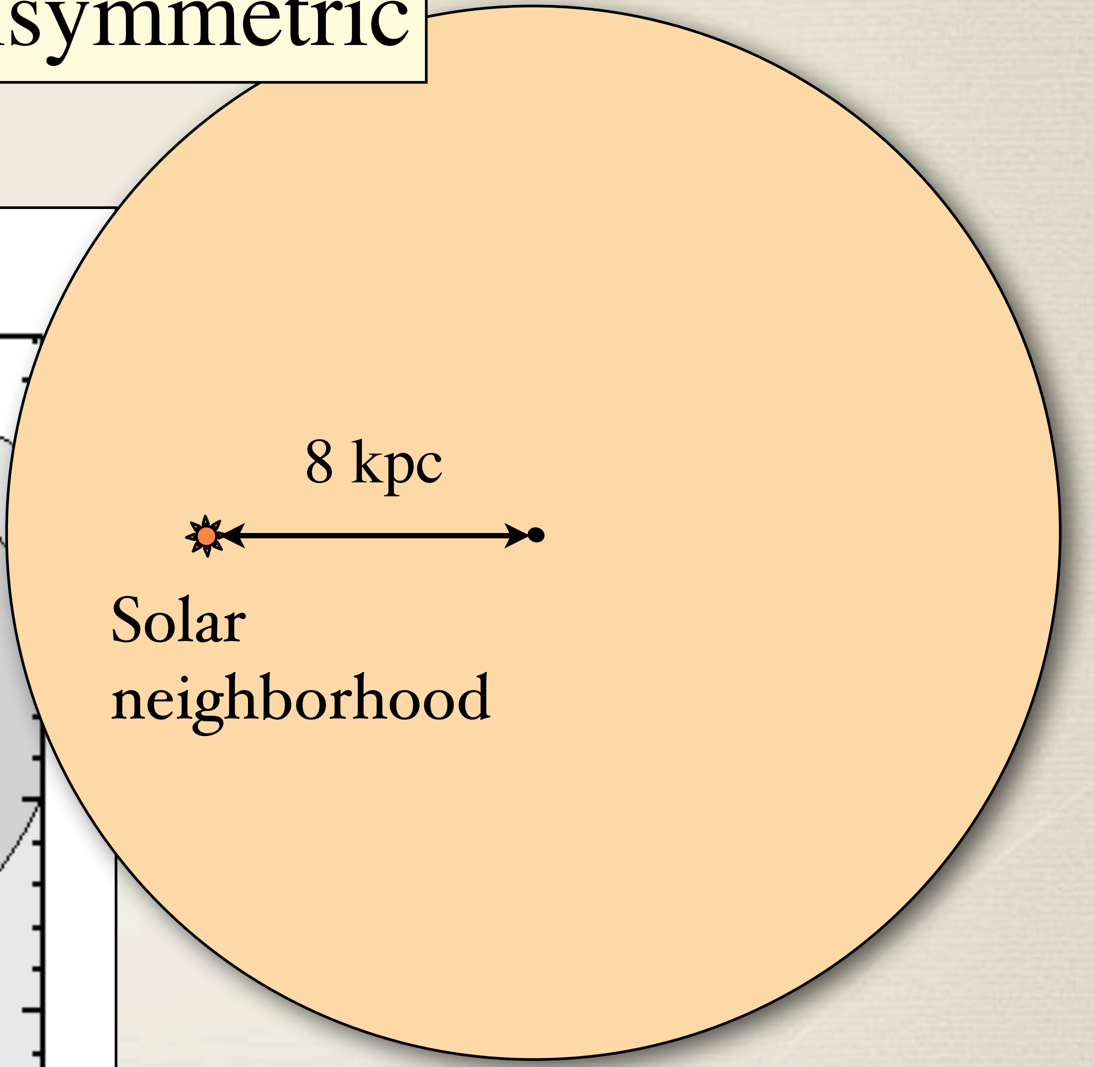




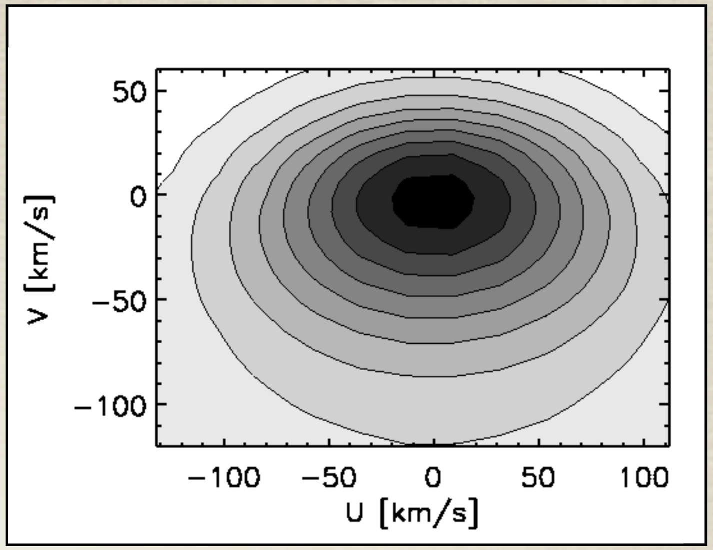
The u-v plane

If the Milky Way disk were axisymmetric





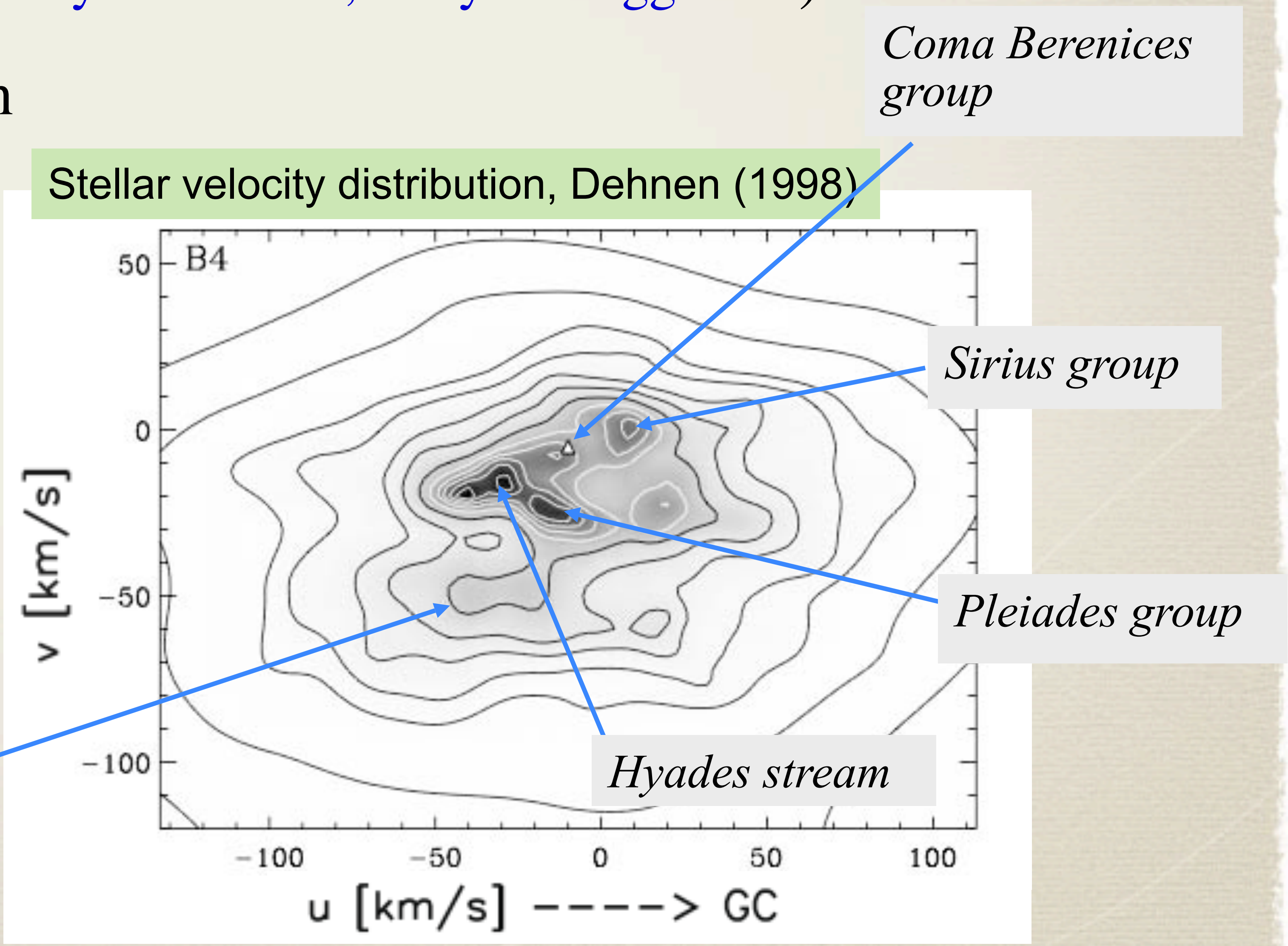
Hipparcos stellar velocity distribution



- Lots of structure in the u-v plane.
- The most prominent low-velocity moving groups in the solar neighborhood favor a dynamical origin (Famaey et al. 2008, Bovy & Hogg 2009).
- Created near resonances with bar or spiral structure

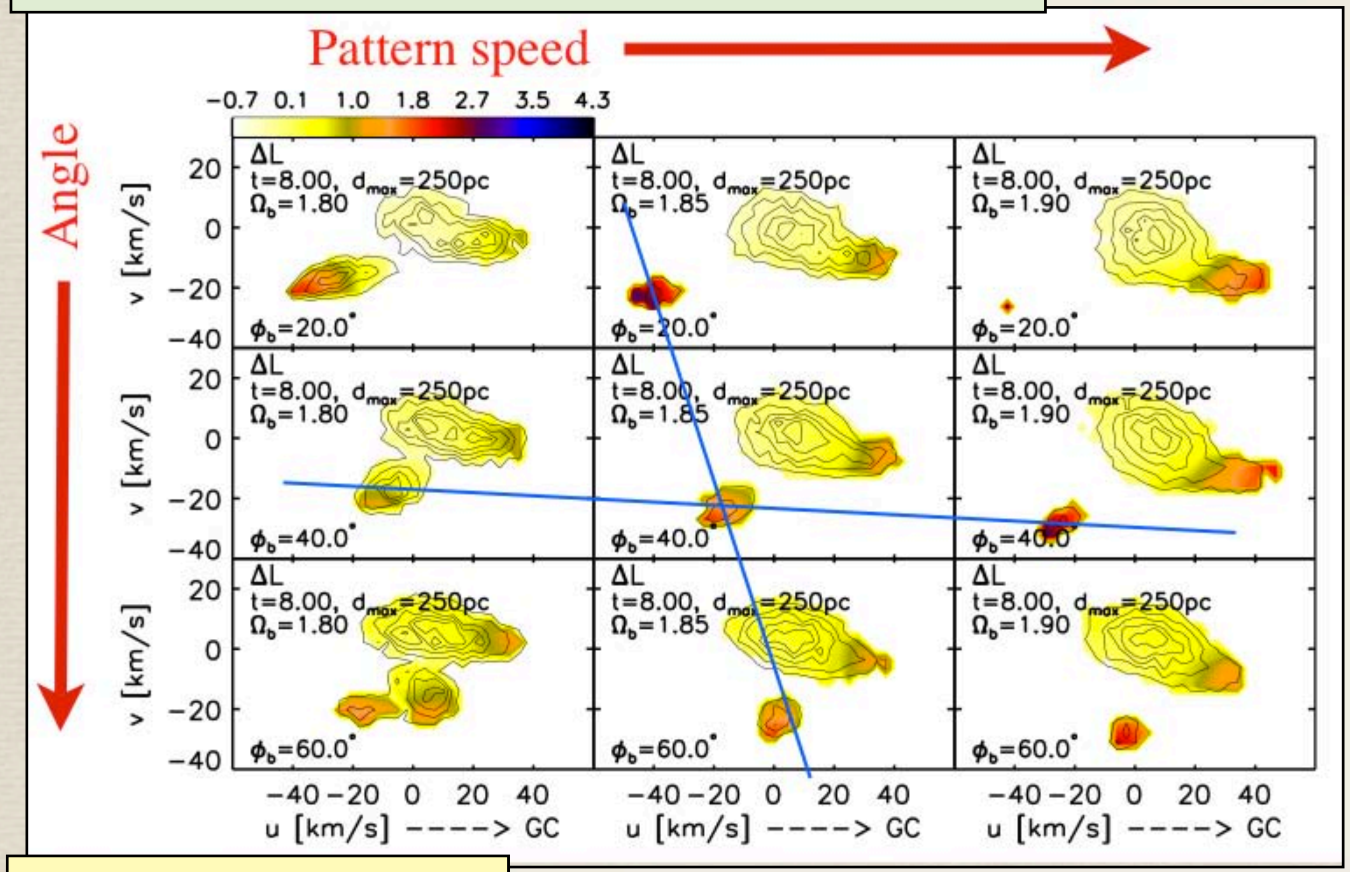
Can constrain both angular velocity and orientation

Dehnen (2000)
Quillen & Minchev (2005)
Minchev et al. (2010)
Antoja (2009, 2011)

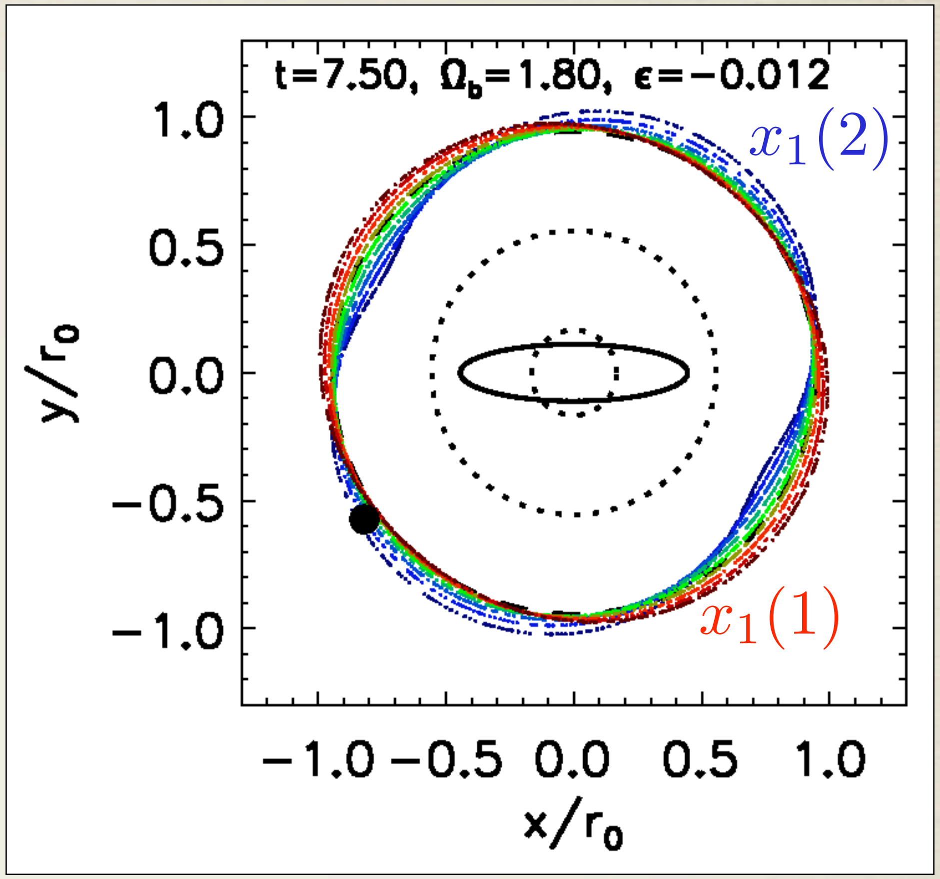


Modeling the u-v plane

The effect of the Galactic bar



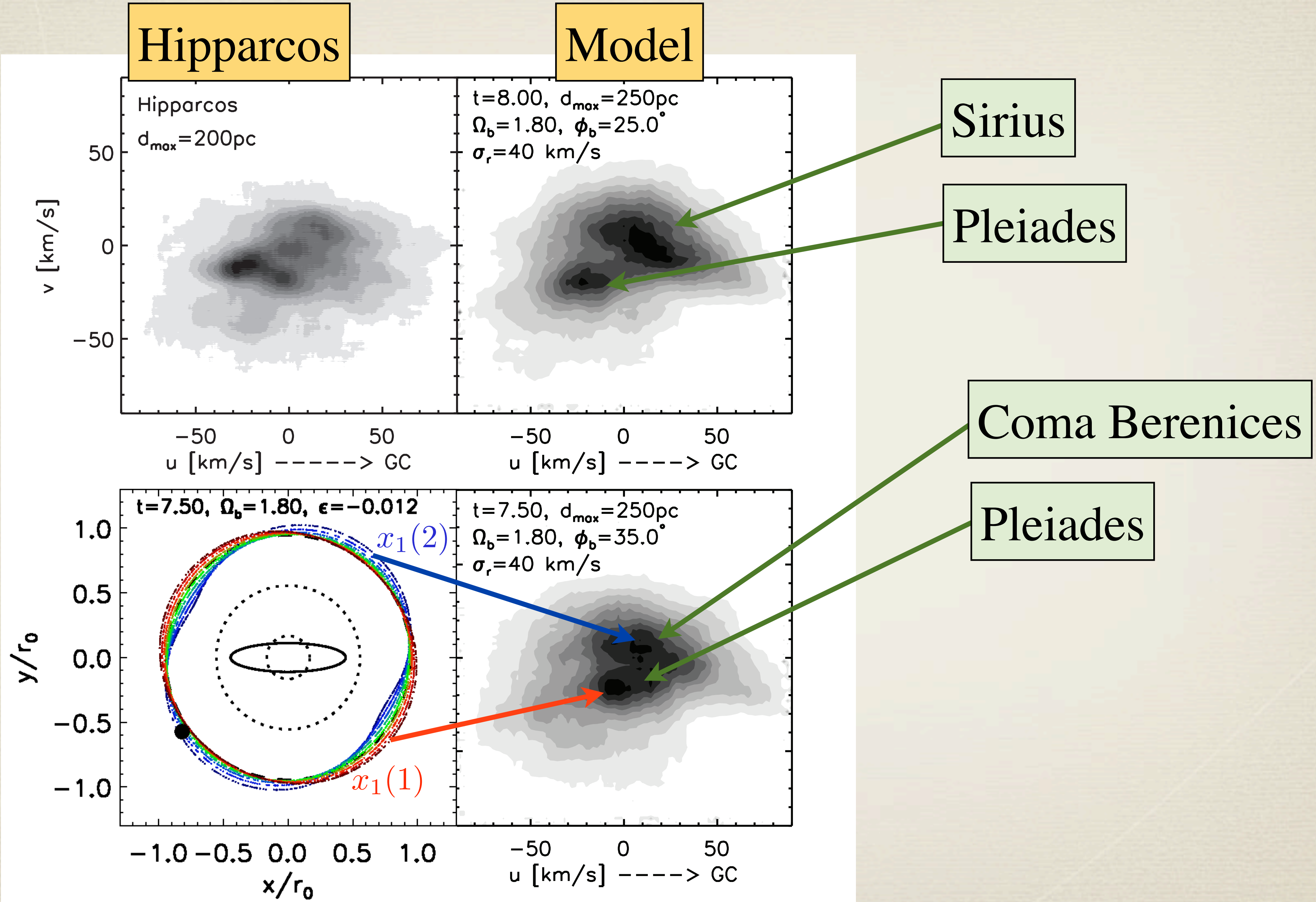
Minchev et al. (2010)



- Clumps shift with galactic radius and azimuth

- Each region on the u-v plane corresponds to a different family of closed/periodic orbits

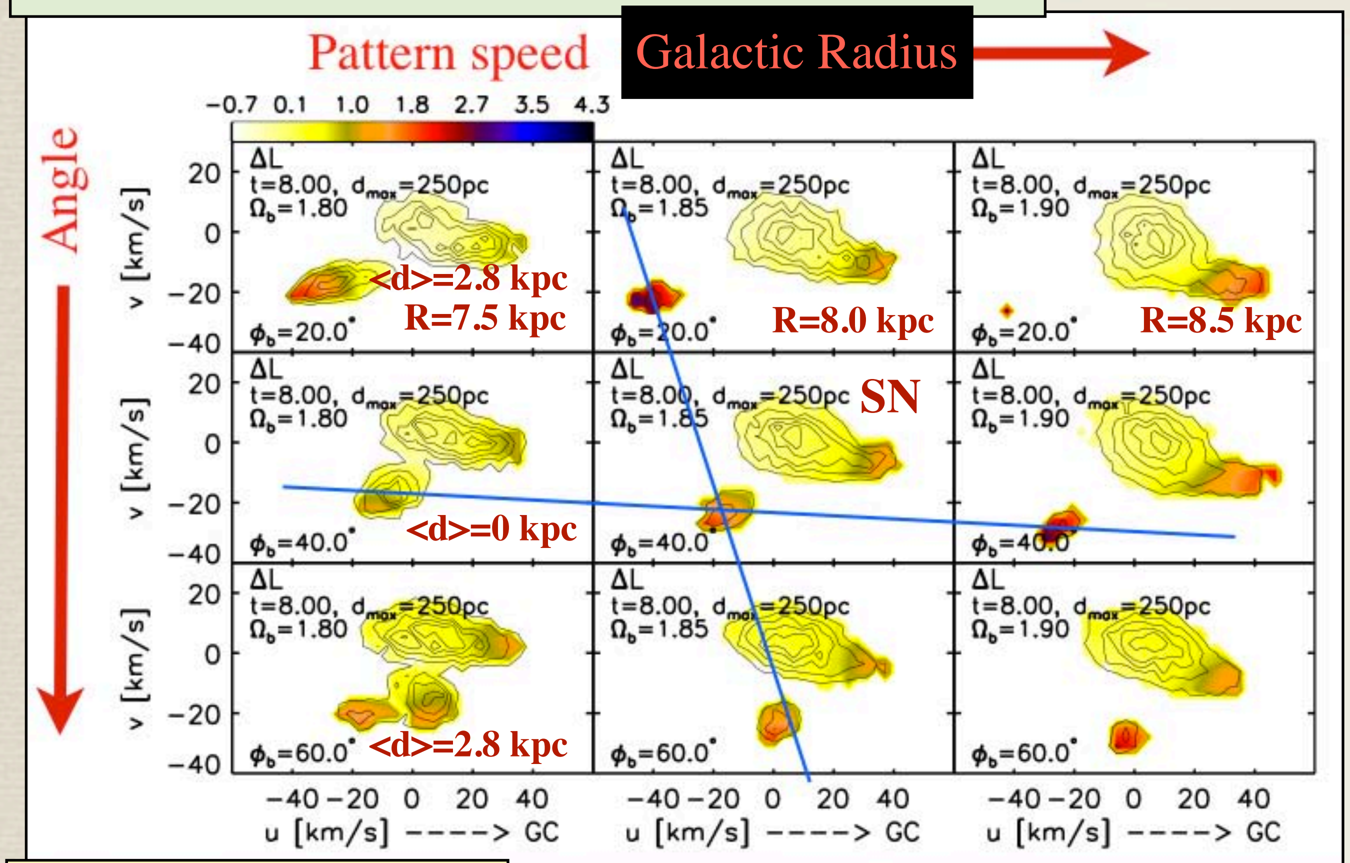
Matching to Hipparcos data



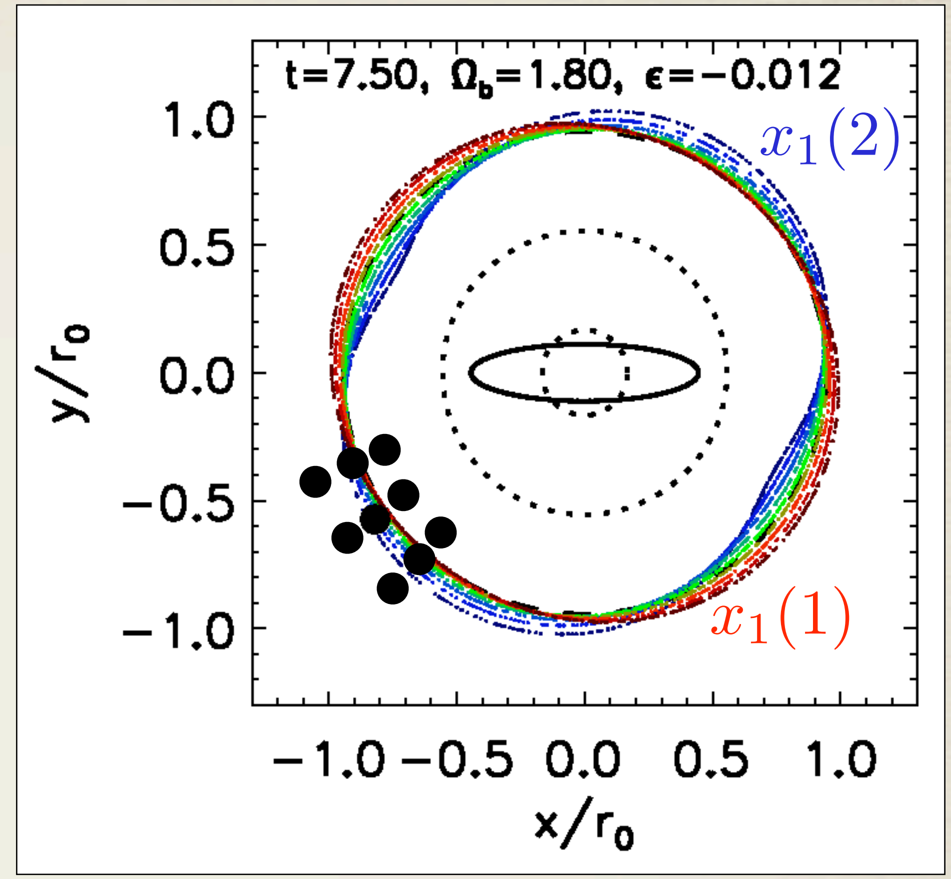
Minchev et al. (2010)

Modeling the u-v plane at different positions in the disk

The effect of the Galactic bar



Minchev et al. (2010)



- Clumps shift with galactic radius and azimuth (~5 km/s).

We need ~2 to 5 km/s error in U, V, W (depending on streams) to detect this shifting.

- Neighborhoods are spheres of radius 250 pc.

—> Needed distance precision to 200 pc

Gaia distances

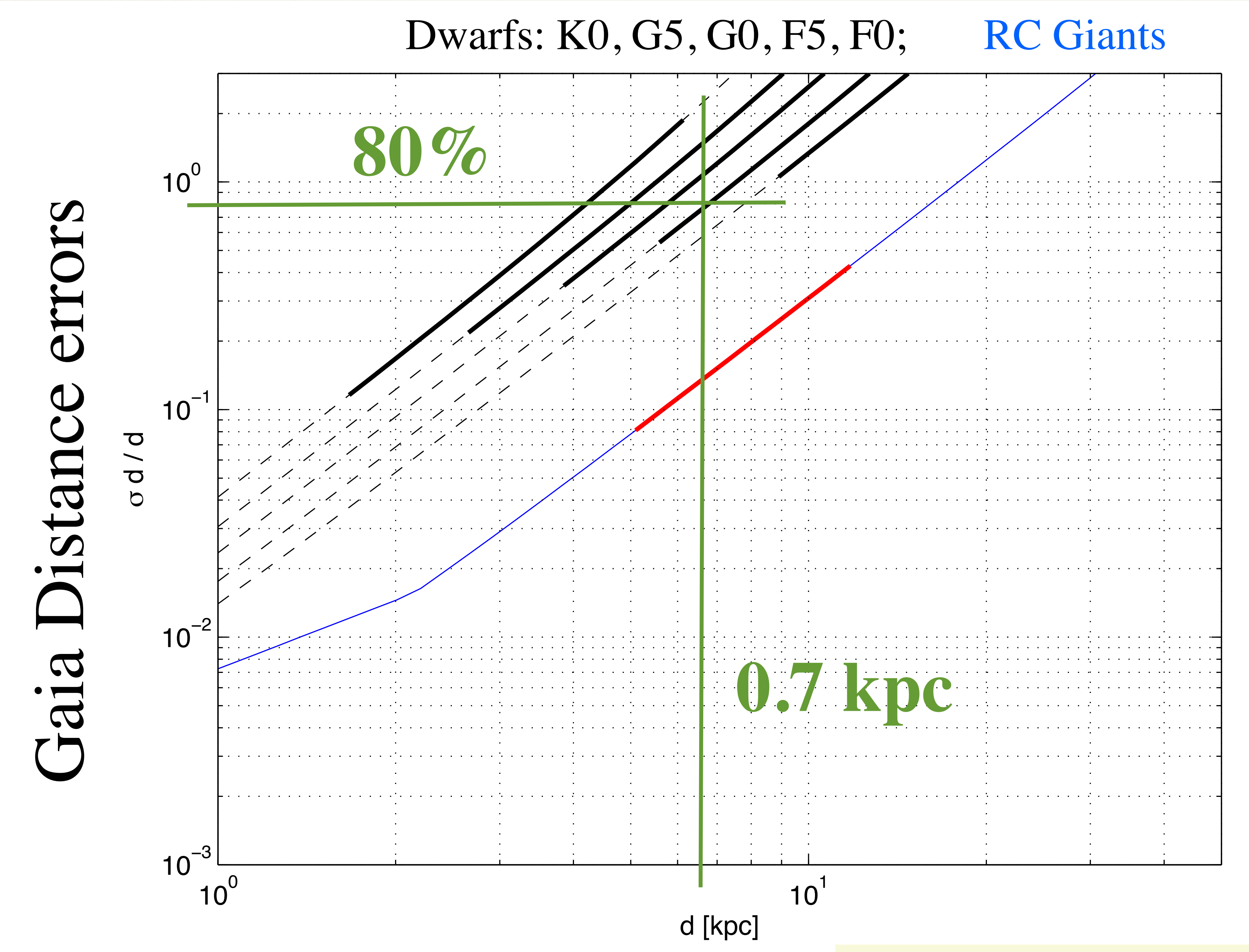


Fig. provided by A. Koch

solid lines: 17<V<20

- We need distance precision to 200 pc.

Gaia distances

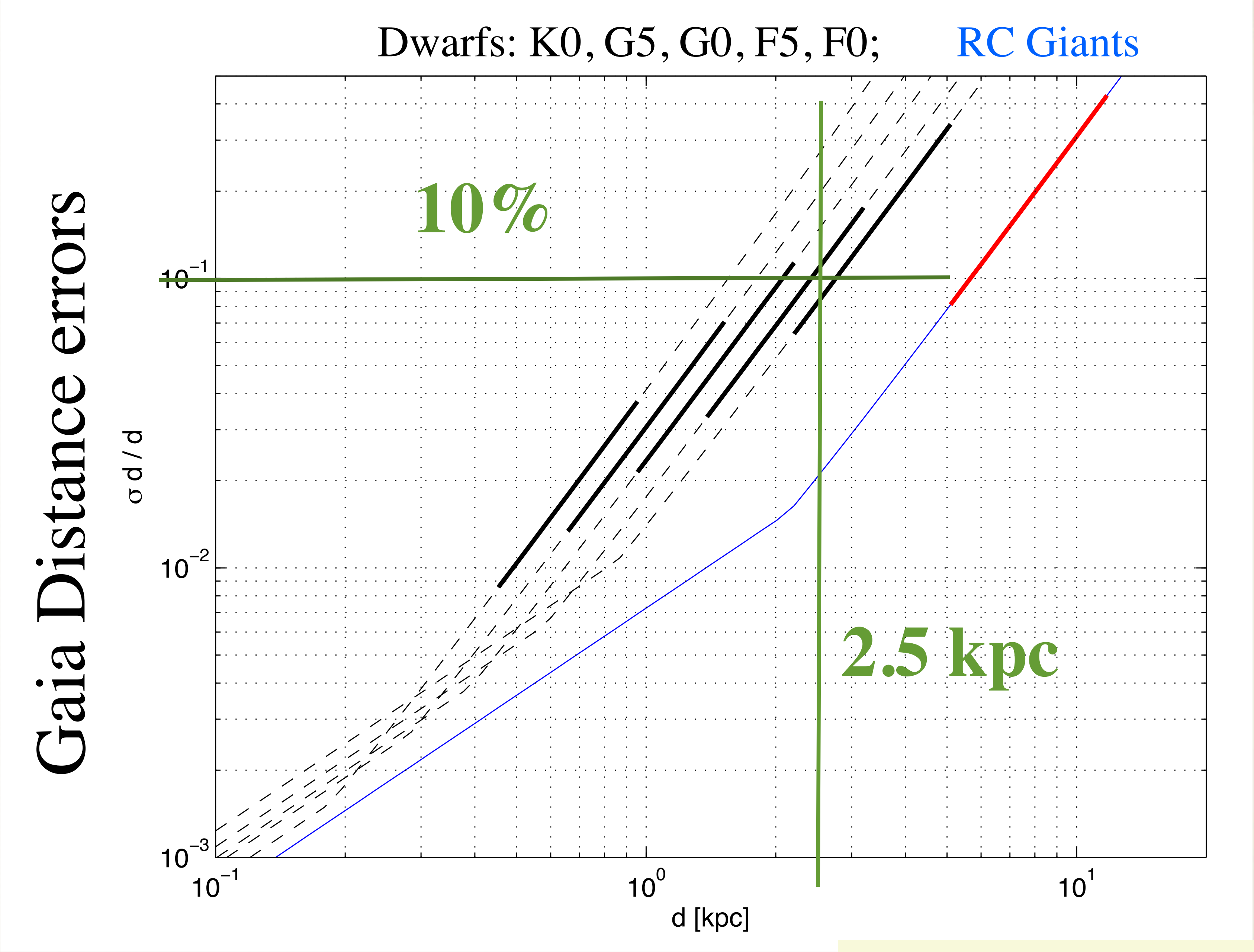


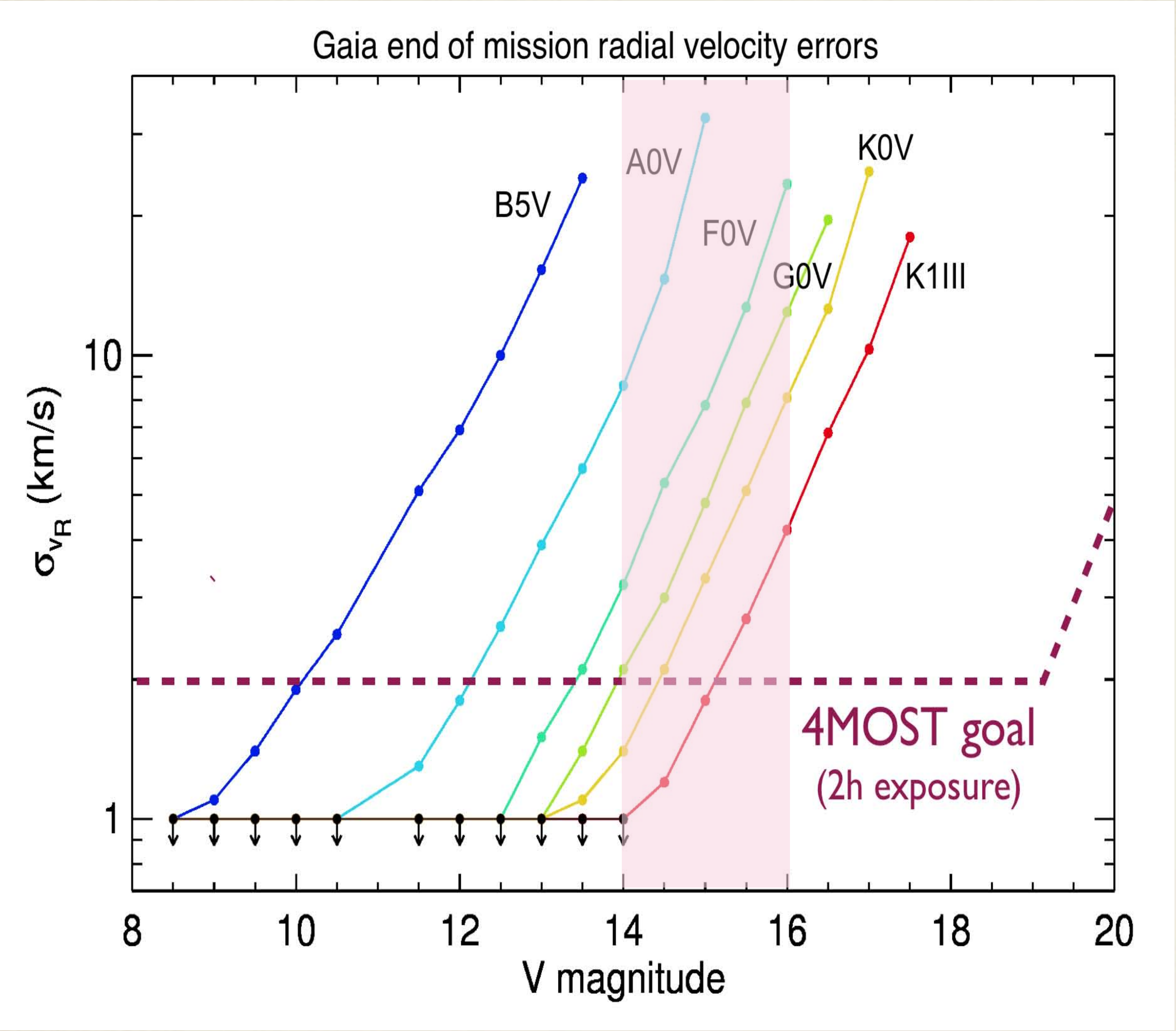
Fig provided by A. Koch

solid lines: 14<V<16

Using RCG, we can get out to ~7 kpc

- We need distance precision to 200 pc.
- Possible from Gaia for d<~2.5 kpc

Gaia RVs



Gaia will provide RVs in the range 14<V<16

This precision may not be sufficient for studying the U-V plane at the detail we want.

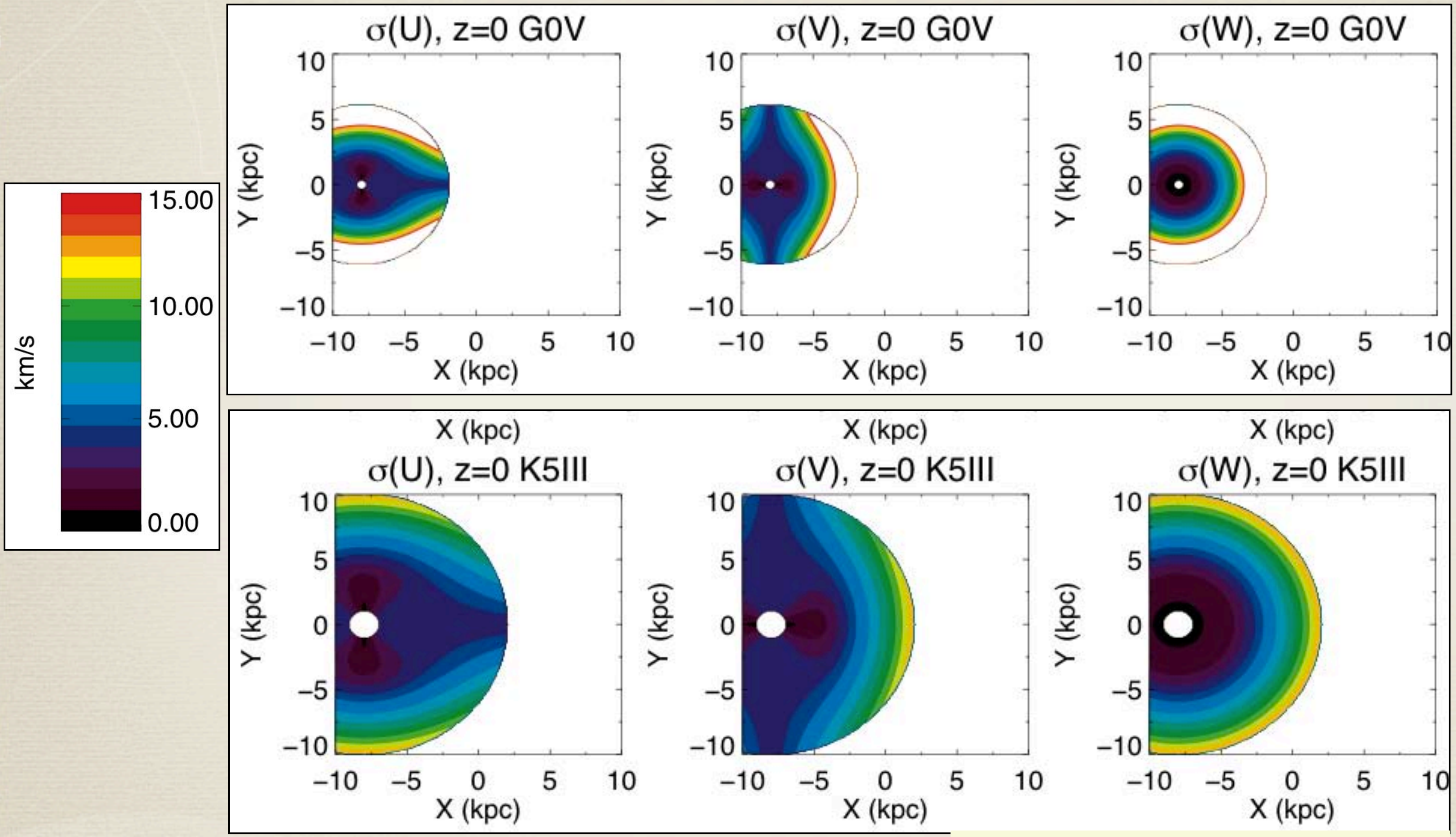
However, 4MOST will provide RV errors < 2 km/s.

We need ~2 km/s error.

(Gaia + 4MOST) UVWs

For Gaia distances in 14<V<16

For RVs error of 2 km/s from 4MOST



Dwarfs

Giants

Figure provided by M. Williams

- We need ~2 km/s error in UVW.
- Possible for d < 2-3 kpc (Dwarfs) and d < 5 km/s (Giants)!

Disk LR mock catalogue using Galaxia

Extended Solar Neighborhood

Data provided by S. Sharma

$14 < V < 16.5$, V=apparent magnitude with reddening

log_g > 2.7 to select dwarfs

$5200 < T_{eff} < 7500$, to select **F and G dwarfs**

$-70 < dec < 20$ deg

$d<2$ kpc from Sun

$|z| < 500$ pc

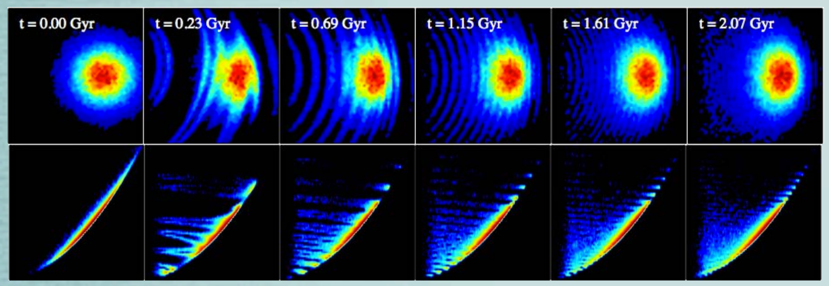
We aim for as uniform spatial distribution as possible.

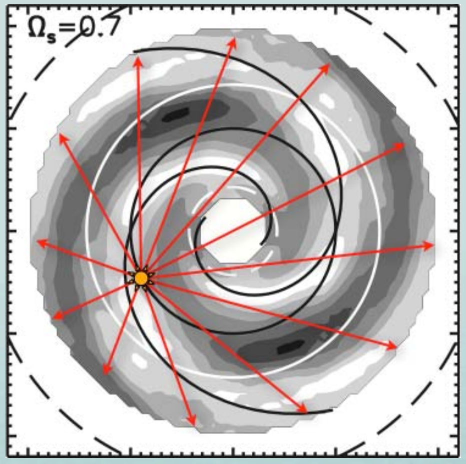
Minimum density required: 10^4 stars in a sphere of radius 200 pc, reasoned from tests with the GCS.

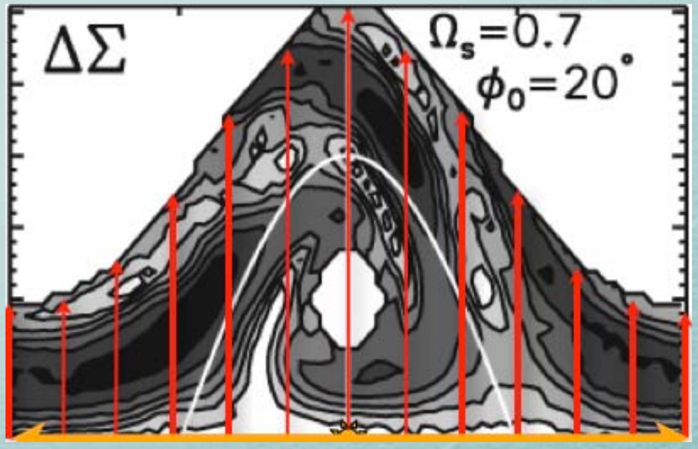
Number of targets for Extended Solar Neighborhood study: ~2.5×10^6 stars.

Studying the extended solar neighborhood is NOT sufficient to constrain large–scale morphology, and thus the disk evolution

Studying the entire available disk



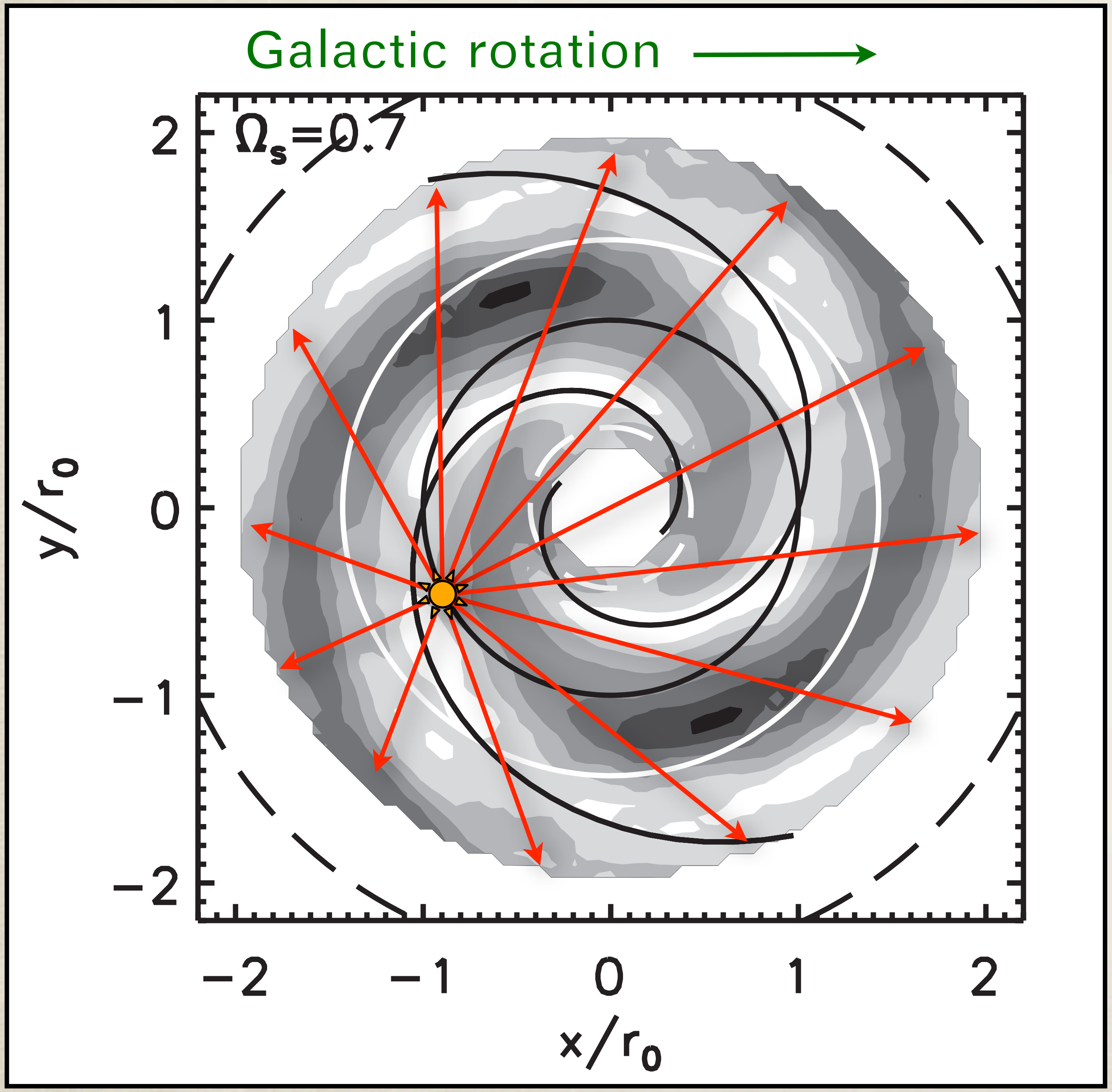




Why study the whole disk?

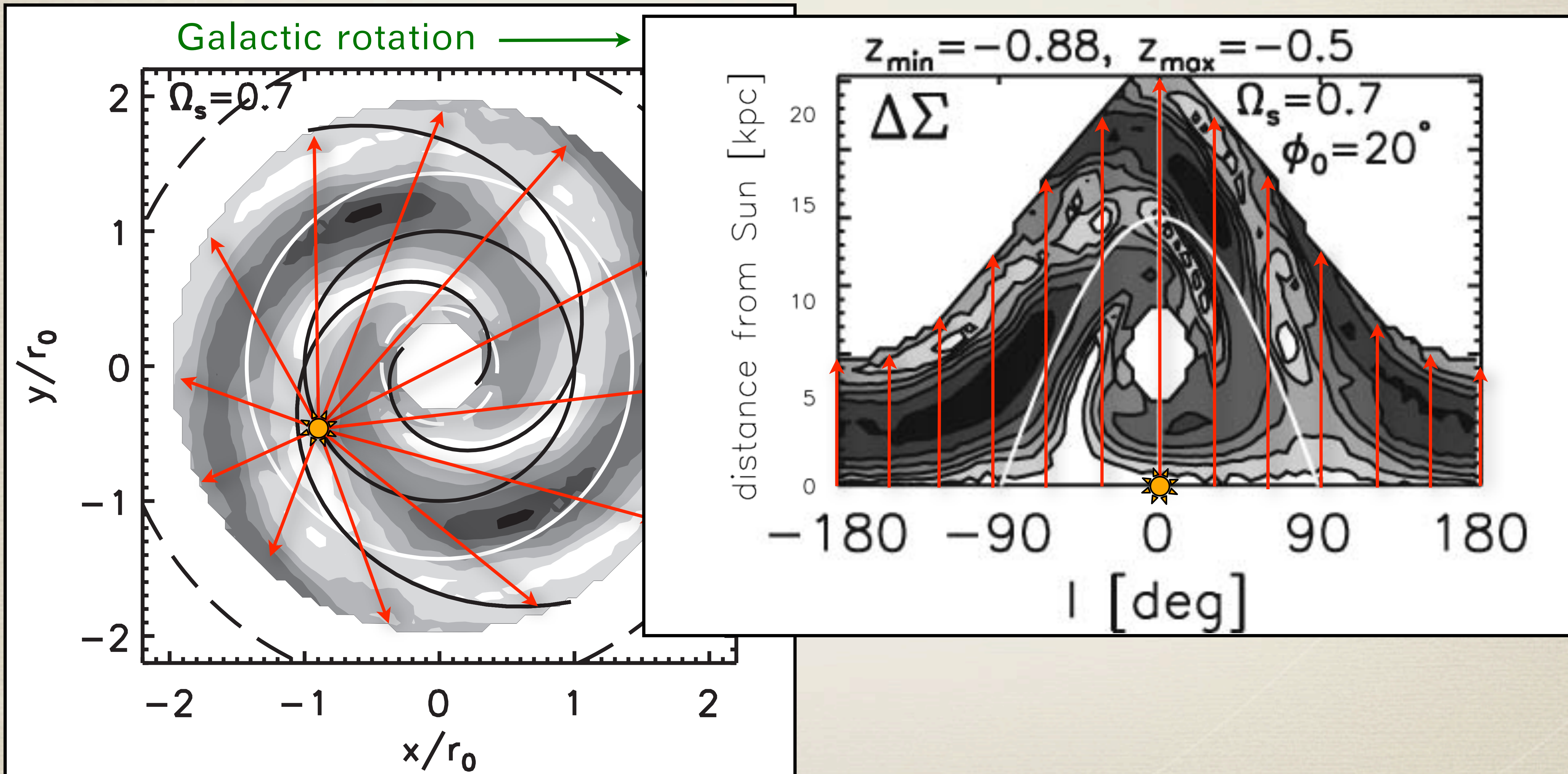
- To break degeneracies in various dynamical models consistent with phase-space structure in the Solar Vicinity we require information over the entire visible disk.
- Complexity of disk asymmetries expected, e.g., number of spiral arms, different pattern speeds, amplitude variation with radius...
- Strong variation in the migration efficiency expected with galactic radius and time.
- Given the number of asymmetric pattens and their characteristics, in combination with good metallicity distributions and gradients, we can put constraints on the amount of mixing which has taken place in the past.

Large-scale surveys: Gaia and 4MOST



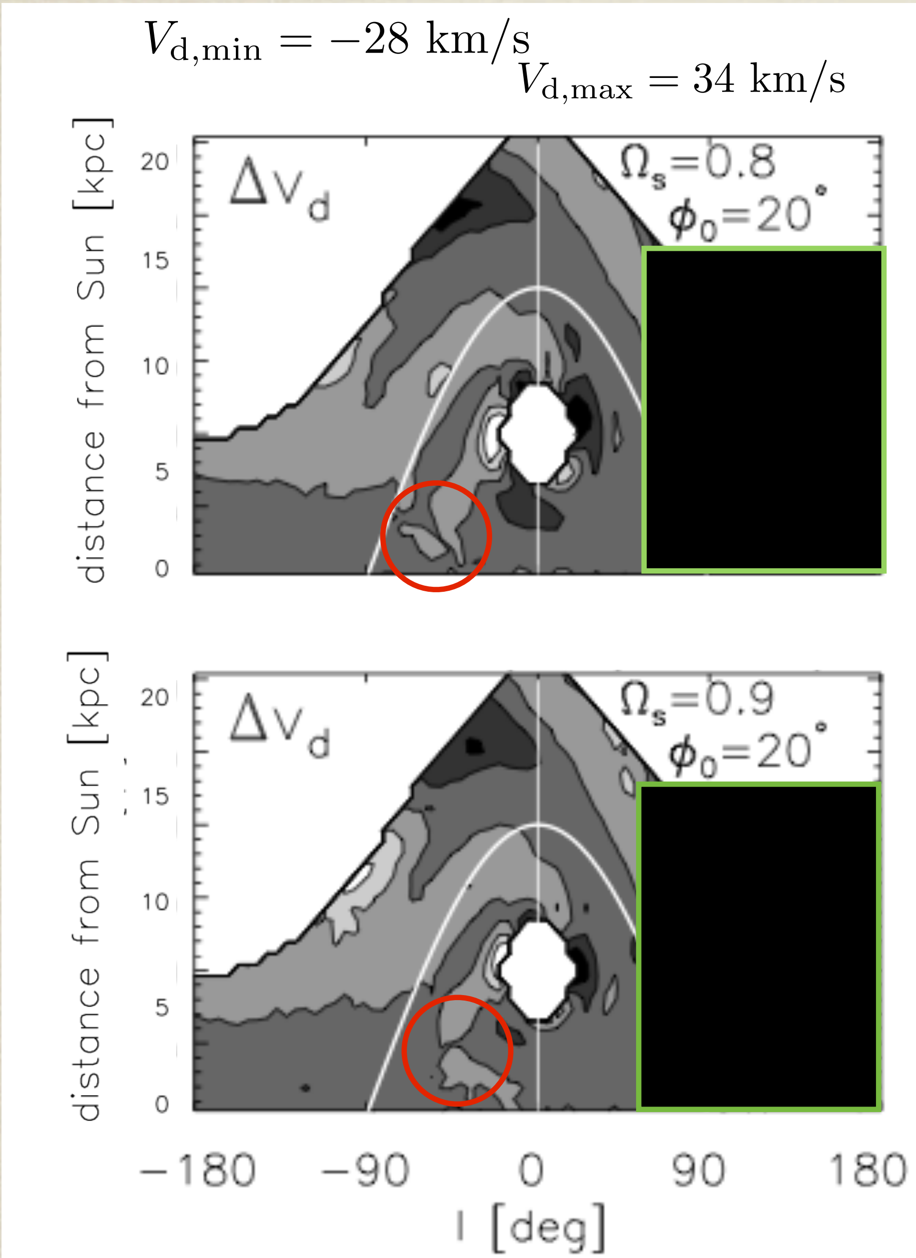
- Take spectroscopic and photometric measurements.
- Bin in Galactic longitude and Heliocentric distance.
- Create line of sight velocity and number density maps.

x-y to l-d plane

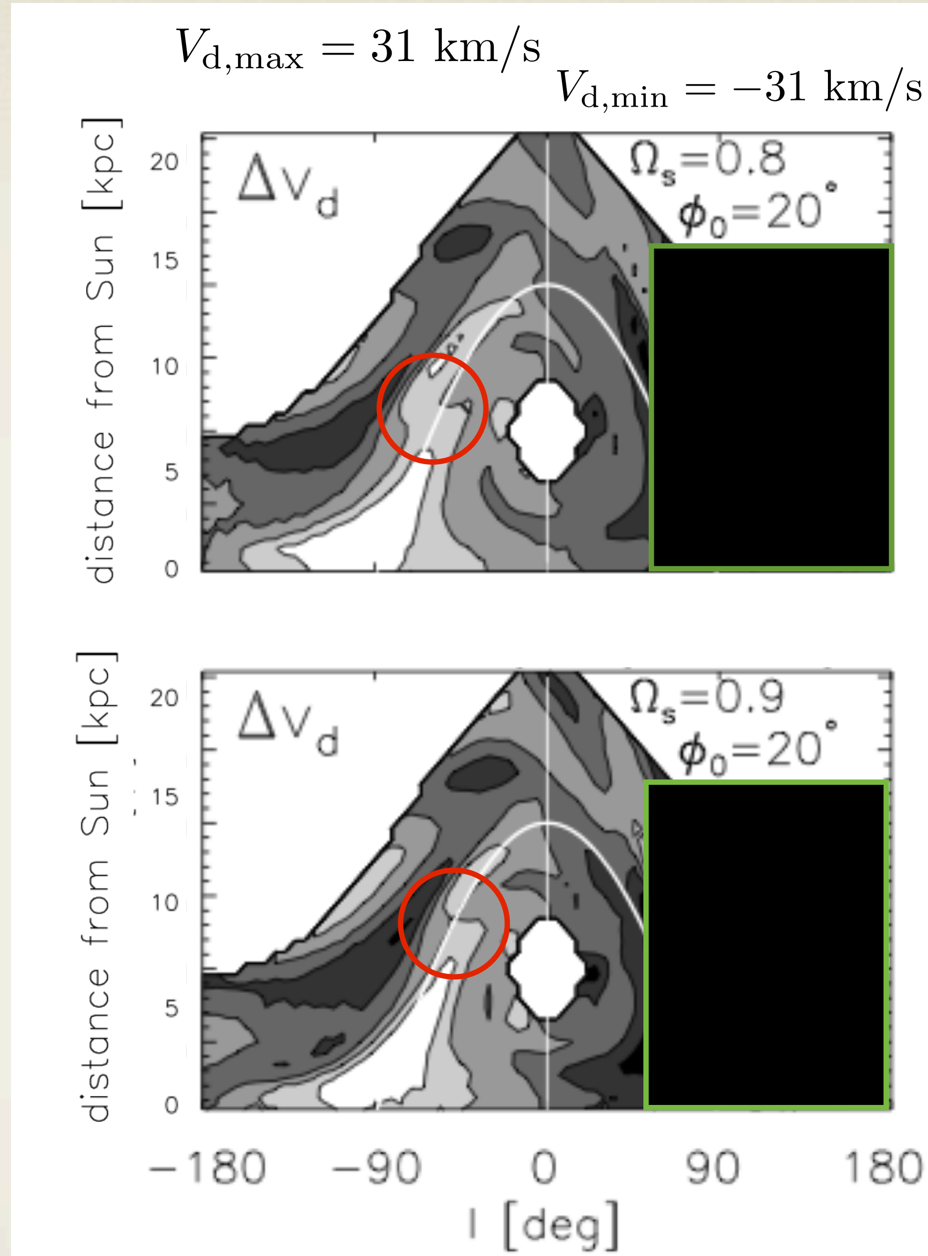


Learn about the disk morphology and dynamics

2-armed



4-armed



Same spiral orientation but different angular velocity, Ω

Ω=24 km/s/kpc

Resonant features

Ω=27 km/s/kpc

- We need to know:

distances better than ~15% (1.5 kpc error at 10 kpc)

line of sight velocities to ~2-5 km/s

We can do good with 5, but much better with 2 kpc!

Disk LR mock catalogue using Galaxia
Full disk coverage

Data provided by S. Sharma

(1) Dynamical Disk (Giants): **Used for line-of-sight velocity maps**

14<V<20 Apparent magnitude with reddening

log_g < 2.7 for Giants

-70 < dec < 20 deg

|z| < 1 kpc, where z = distance from the Galactic plane

r > 1.5 kpc, where r = Galactocentric radius

Uniform distribution of 2.5×10^6 particles in a 2D disk of radius 20 kpc sufficient for this study (Minchev and Quillen 2008).

Generalization to 3D requires minimum density of 8000 Stars/kpc^3. In r<15 kpc 4MOST covers 431 kpc^2, resulting in a minimum of ~3.45×10^6 targets.

Disk LR mock catalogue using Galaxia
Full disk coverage

Data provided by S. Sharma

(2) Sparse disk sample (Giants): Used to study extensively the chemo-dynamics of the disk, accounting for metallicity gradients and [α/Fe] vs. [Fe/H] relations, while covering a large range in both in R and Z.

Same as in (1), except $1 < |z| < 2.5$ kpc.

Combine with the higher S/N stars with V<18 from (1) above.

Minimum Density required is 5000 Stars/kpc^3 based on a minimum number of targets required to sample radius and vertical distance from disk plane.

Minimum targets required: ~2.4×10^6 targets.

Due to the constraint V > 14, this sample misses the nearby stars (giants) within 3 kpc. This is complemented by the dwarf sample defined in (3) below.

Disk LR mock catalogue using Galaxia
Full disk coverage

Data provided by S. Sharma

(3) Sparse disk sample (F, G dwarfs): **Complement our sparse disk sample (giants)**

F and G dwarfs

d < 3 kpc from the Sun

High enough S/N in order to obtain both kinematics and chemical information. For |z| < 500 pc the ESN dwarfs will also deliver chemical information.

Minimum Density required is 5000 Stars/kpc^3 as (1) in above.

Selection criteria: Same as for the ESN sample, except |z| > 500 pc.

No restriction on galactic latitude is imposed. This results in ~8.1×10^5 targets.

Disk LR mock catalogues

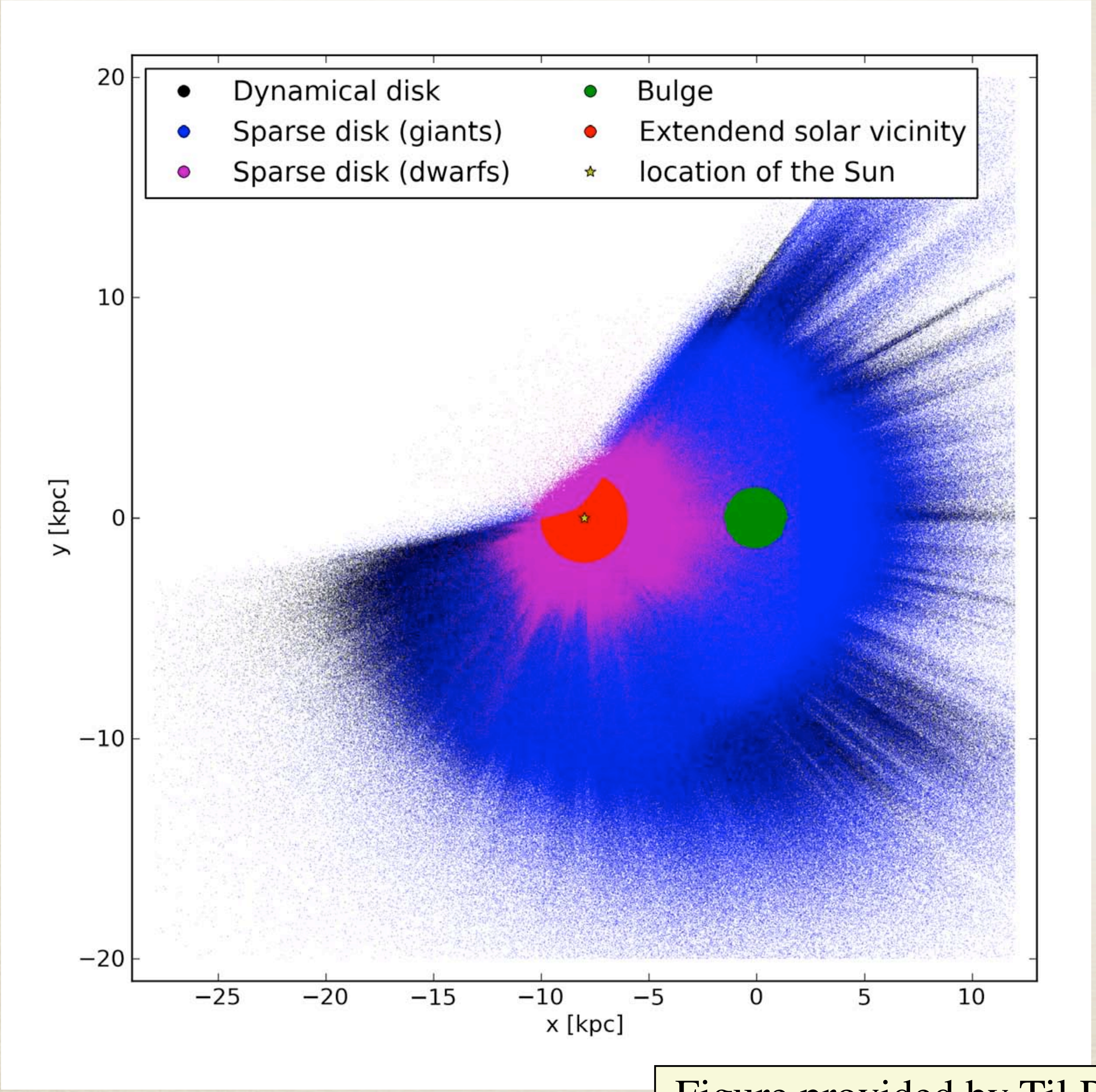


Figure provided by Til Piffl

The HR Disk sample will provide chemical information over the entire Milky Way disk

- Current observational chemo-dynamical studies of the stellar disk are confined to the immediate solar neighborhood.
- Away from the Solar Vicinity predictions are model dependent.
- We need to map the density of stars in a multi-dimensional space: age, metallicity + 6D phase-space.
- In the Gaia era we need to go beyond RAVE and SEGUE disk coverage.

Accurate abundance measurements required over the entire disk!

Disk HR mock catalogue using Galaxia

Data provided by S. Sharma

Disk sample (Dwarfs and Giants):

- 14 < V < 16; V = apparent magnitude, including reddening
- log_g < 2.7 or 5200 K < T_{eff} < 7500 K to select giants and F&G dwarfs

Targets selected in the R-z plane with a maximum of 20×10^3 objects per 2 kpc x 0.33 kpc bin. No limits imposed on R or z.

Targets required: ~2.2×10^6 objects

High latitude, metal-poor sample ("Thick disk", Dwarfs and Giants):

- all stars of the halo_HR and the disk_HR catalog were discarded before the selection process.
- this provides an entirely completely new, independent sample.
- log_g < 2.7 or 5200 K < T_{eff} < 7500 K; as in disk case: giants and F&G dwarfs
- Galactic latitude |b| > 30 degree
- Metallicity [M/H] < -0.5 dex

Targets required: ~1.2×10^6 objects

Disk HR mock catalogue using Galaxia

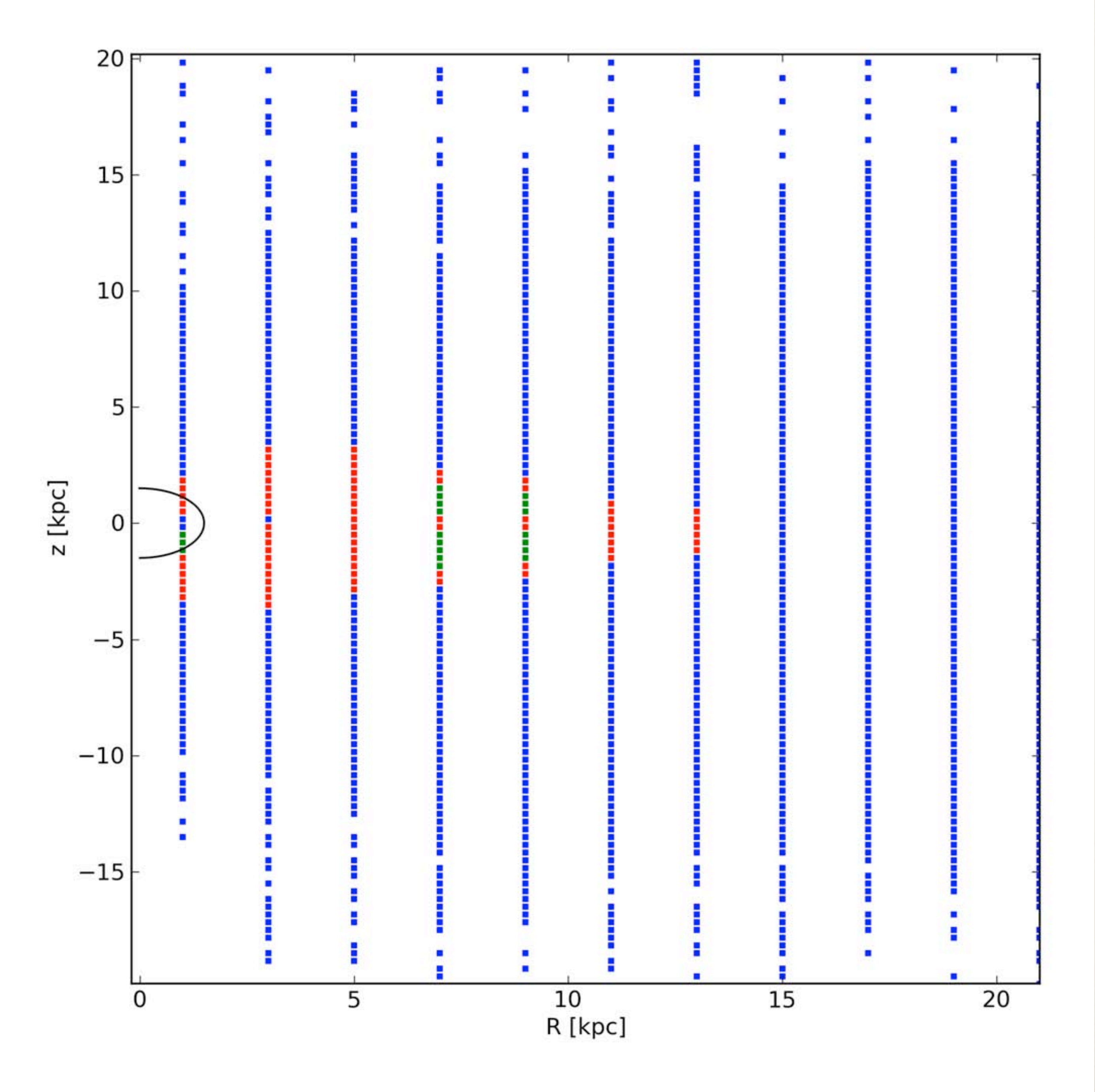


Figure produced by Til Piffl

Summary

- With Gaia complemented by 4MOST RVs and chemical abundances we can study the Milky Way disk chemo-dynamical evolution for the first time.
- We will cover the entire disk visible from the southern hemisphere, ~12000 deg^2.
- Science requirements: **RV precision of ~2 km/s and Distance errors better than 15%**.
- We need to observe ~8.6-13.8x10^6 disk targets at LR at 14<V<20 mag.
- The Disk HR sample requires ~1.1-1.5x10^6 targets at 14<V<16 mag.