Dynamical model of the Milky Way

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With: BRAVA collaboration

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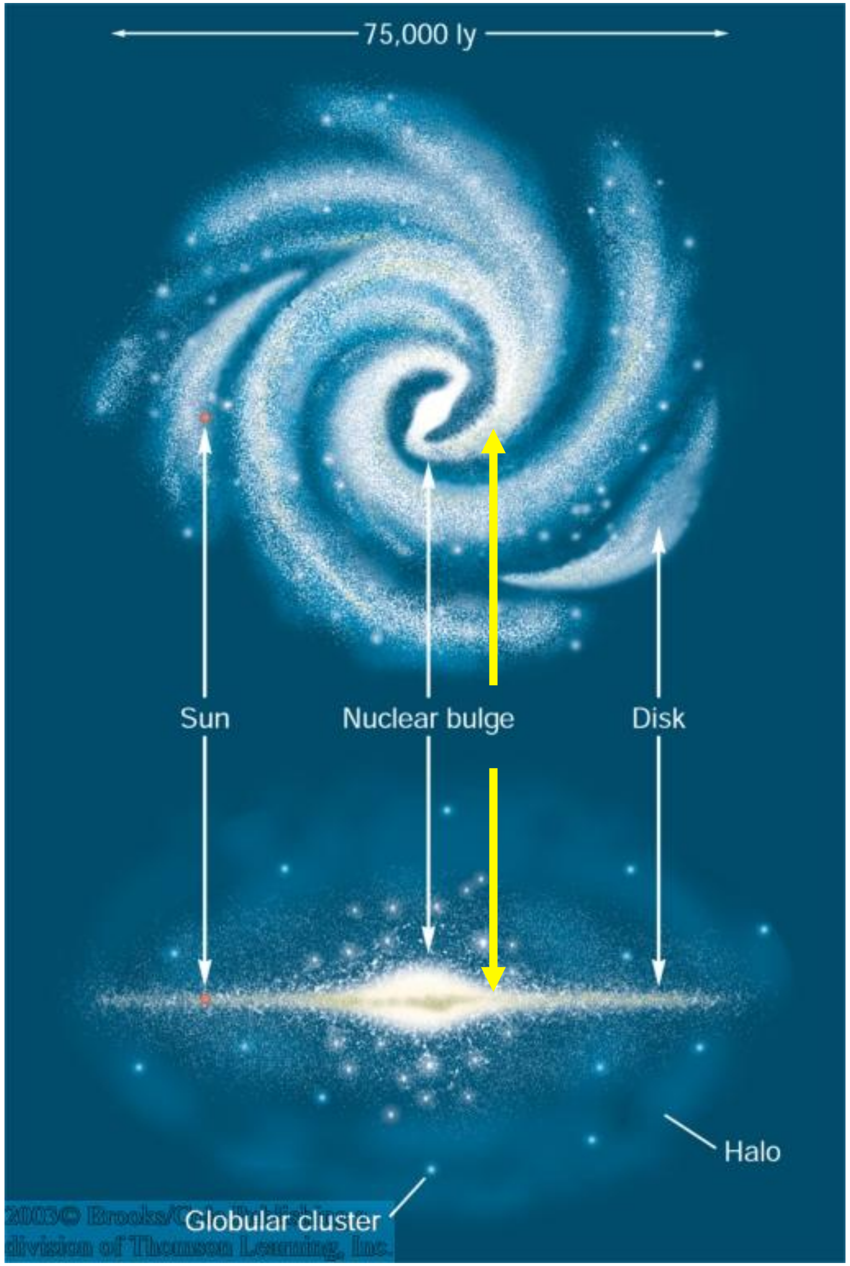
Outline

- Background
- Dynamical models
- Summary & Discussion
- LAMOST survey

Milk Way Galaxy-A typical barred spiral galaxy



横看成岭侧成峰，
远近高低各不同。
不识庐山真面目，
只缘身在此山中。

苏轼（1037～1101）

It's like a range
when you look at the mountain from the front.
But it's like a peak
When you look at it sideways.
The mountain shows its different features
In different levels near and far.
You don't know the real Lushan Mountain,
Because you are in the mountain yourself.

- Precision cosmological model:
- $\Omega_b h^2 = 0.02273 \pm 0.00062$
- $\Omega_c h^2 = 0.1099 \pm 0.0062$
- $\Omega_\Lambda h^2 = 0.742 \pm 0.030$
- $n_s = 0.963^{+0.014}_{-0.015}$
- $\tau = 0.087 \pm 0.017$
- $\sigma_8 = 0.796 \pm 0.0036$

- Loose Galaxy model:
- Total mass:
- $0.8\text{-}2.4 \times 10^{12} = M_{solar}$
- Bar:

  bar mass, pattern speed, bar angel
- Disk:

  thin, thick, gas,
- Dark matter halo:

  triaxial or axis-symmetrical

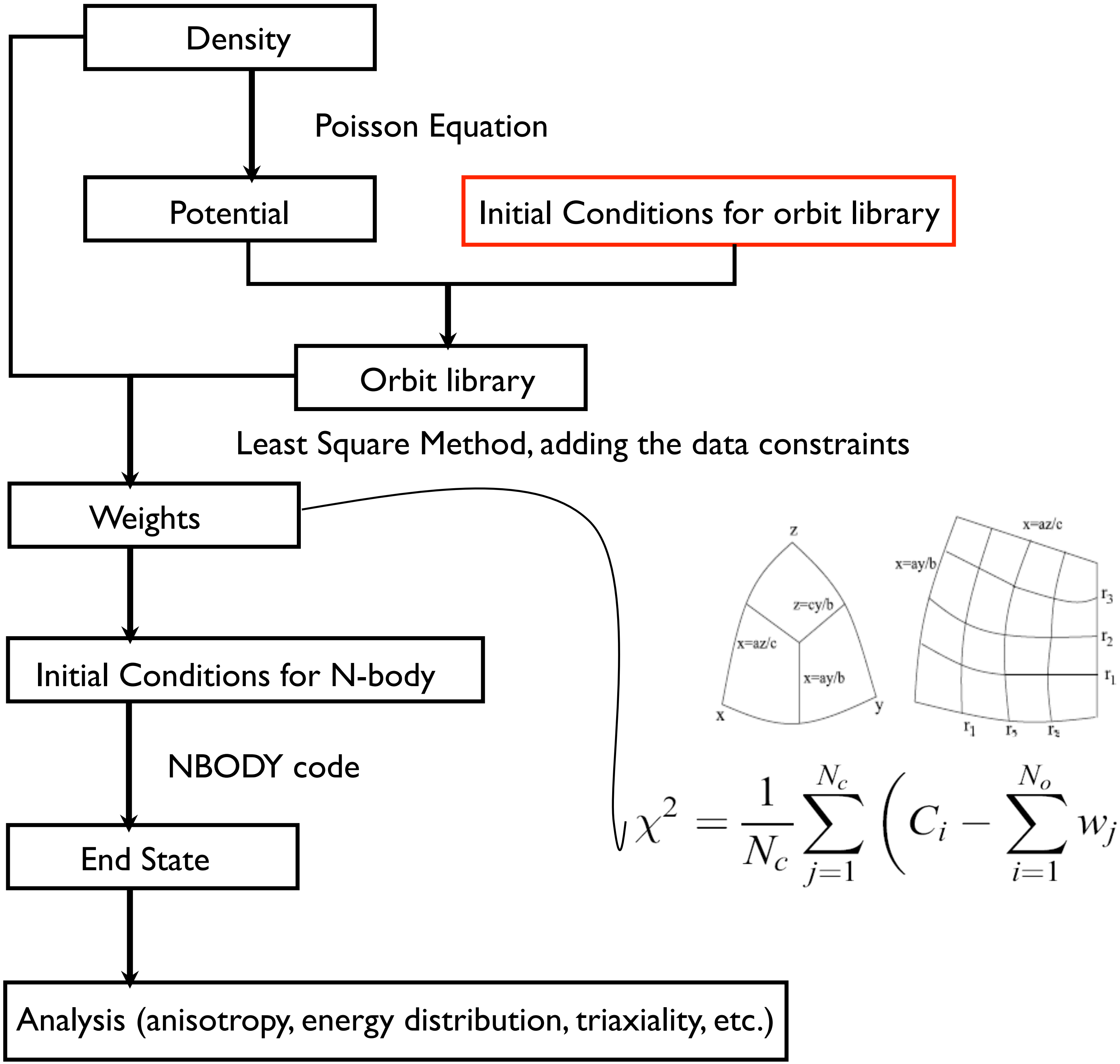
？ ？ ？

Data

Observations	Star type	Number	Photometric/ spectrum	region	date
Hipparcos	common	118218	Photometric	Solar neighborhood	1997
OGLE	common	30 million	Photometric	bulge	2002
BRAVA	M-type giants	10000	spectrum	bulge	2012
ARGOS	Clump giants	28000	spectrum	bulge	2012
RAVE	common	483330	spectrum	disk+halo	2013
APOGEE	Red giants	100000	spectrum	full	2014
LAMOST	common	>3 million	spectrum	disk+halo	2014

Five modeling methods

- Jeans equation
- Schwarzschild method: Orbit based method
- Made-to-Measure (M2M): Particle based method
- Torus Method
- N-body



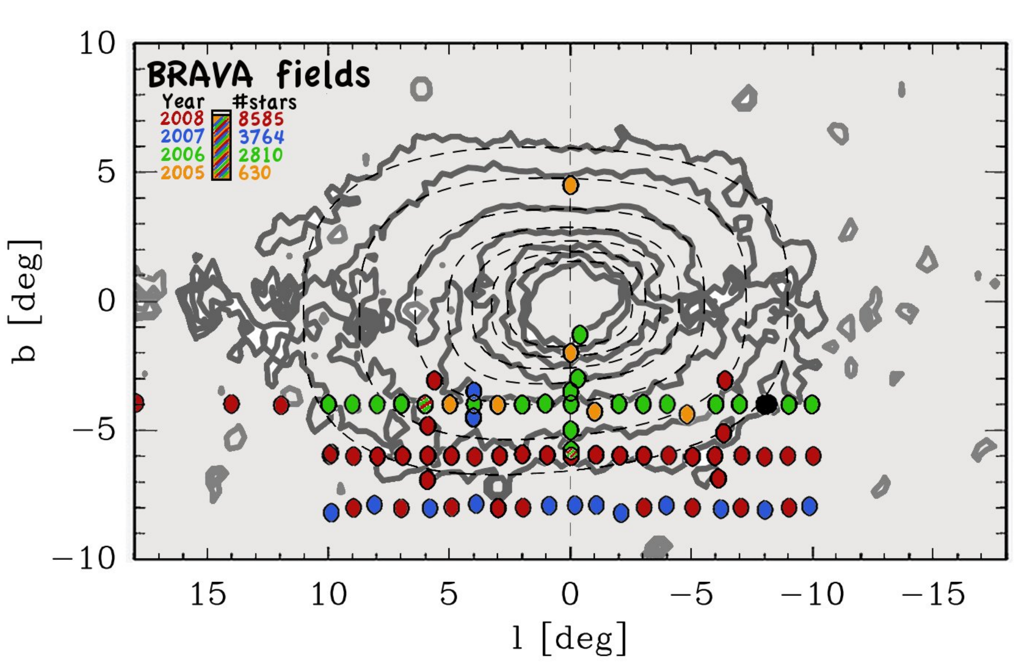
$$\chi^2 = \frac{1}{N_c}\sum_{j=1}^{N_c}\left(C_i - \sum_{i=1}^{N_o} w_j O_{ij}\right)^2 .$$

Why do we want to study the bar region

- Bar is main driver for the secular evolution of disc galaxies
- Pushes mass from the bar region to the center where it creates a a central mass concentration
- Drives the angular momentum exchange within a disc galaxy.
- bar is triaxial
- bar has the fixed pattern speed
- pathfinder to the full Milky Way model

BRAVA data
(Bulge Radial Velocity Assay)

- ~10,000 M stars
- The velocity error is ~5km/s
- The data has been released by http://brava.astro.ucla.edu/data.htm



Cerro Tololo Inter-American Observatory 4 m Hydra multiobject spectrograph.

Model of the Milky Way

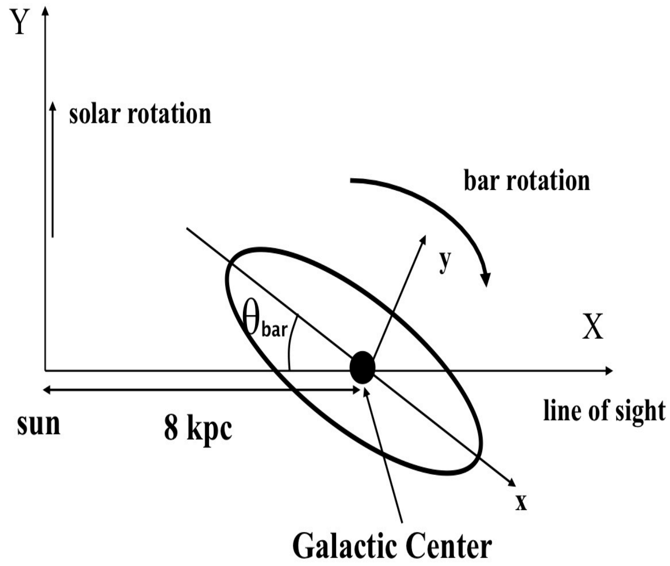
Schwarzschild model(1)

- Bar + bulge

$$\rho(x,y,z) = \rho_0 \left[\exp\left(-\frac{r_1^2}{2} \right) + r_2^{-1.85} \exp(-r_2) \right]$$

$$r_1 = \left\{ \left[\left(\frac{x}{x_0}\right)^2 + \left(\frac{y}{y_0}\right)^2 \right]^2 + \left(\frac{z}{z_0}\right)^4 \right\}^{1/4}$$

$$r_2 = \left[\frac{q^2(x^2+y^2)+z^2}{z_0^2} \right]^{1/2}$$

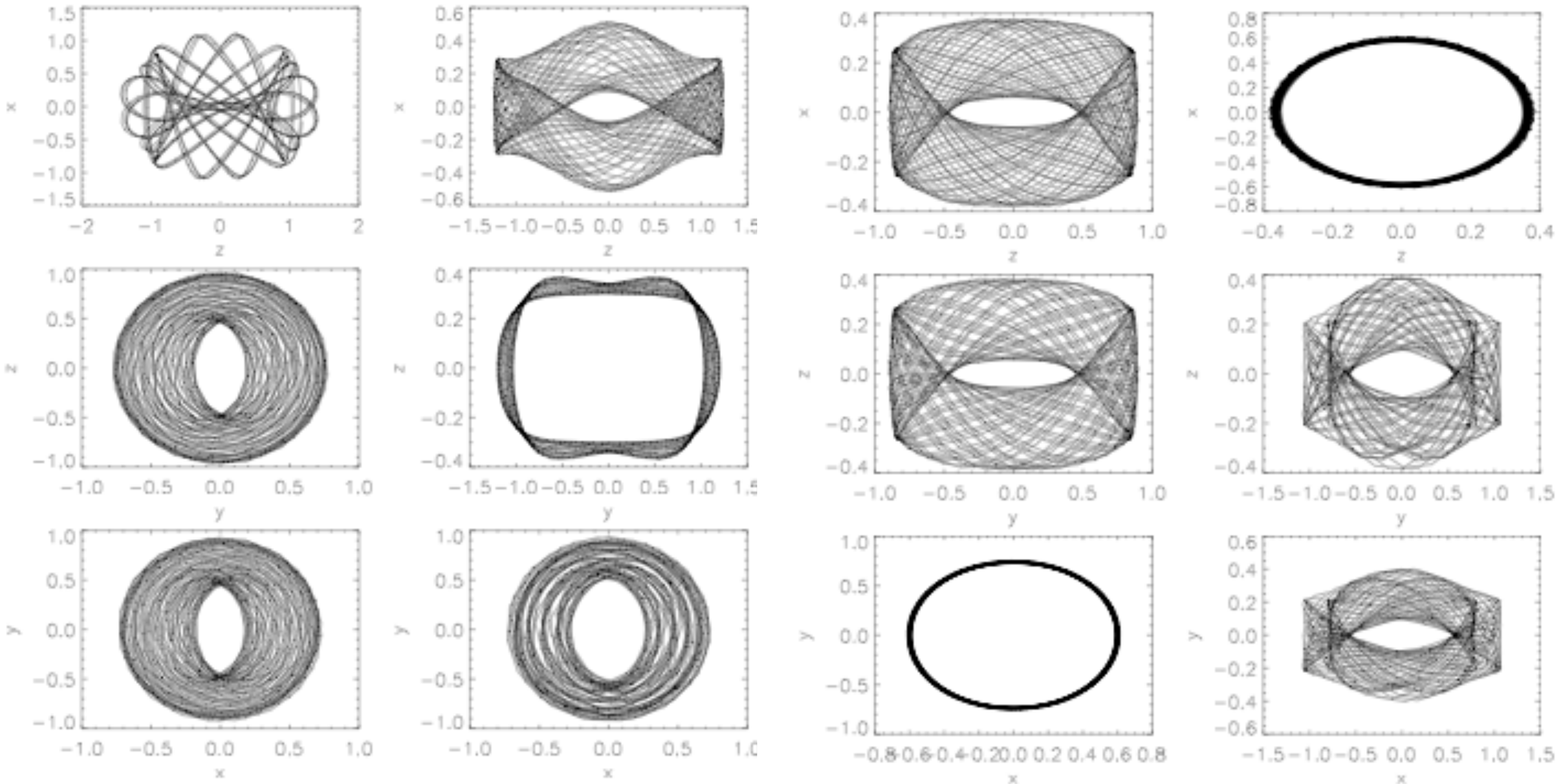


- Miyamoto-Nagai disk

$$\Phi_d(x,y,z) = -\frac{GM_d}{r_3},$$

$$r_3 = \left\{ x^2 + y^2 + \left[a_{\rm MN} + (z^2 + b_{\rm MN}^2)^{1/2} \right]^2 \right\}^{1/2},$$

Some typical regular orbits

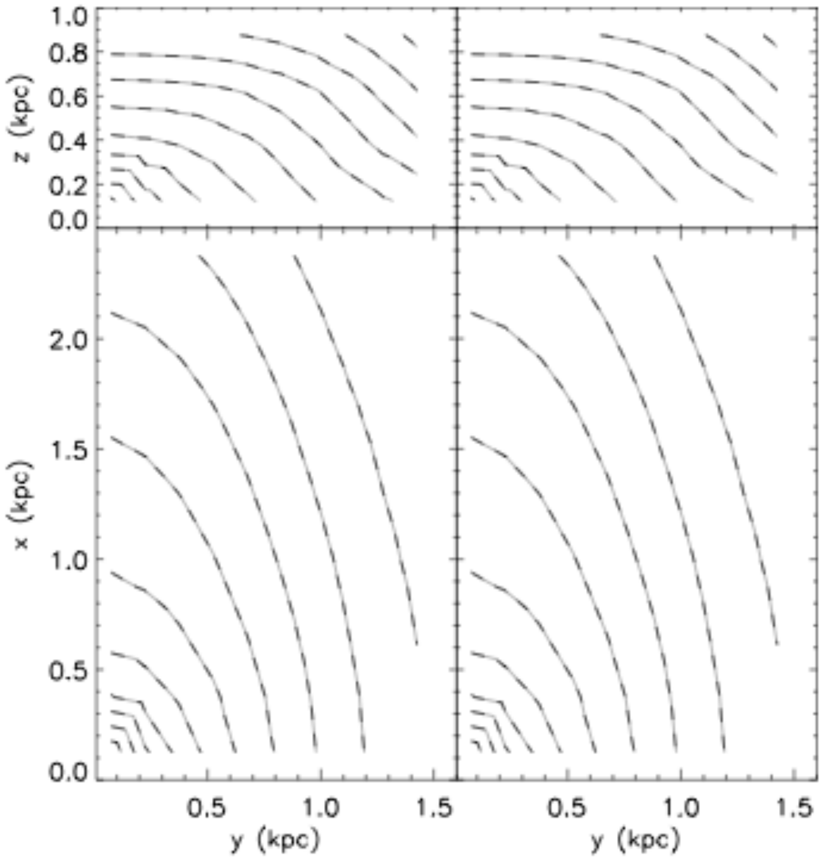


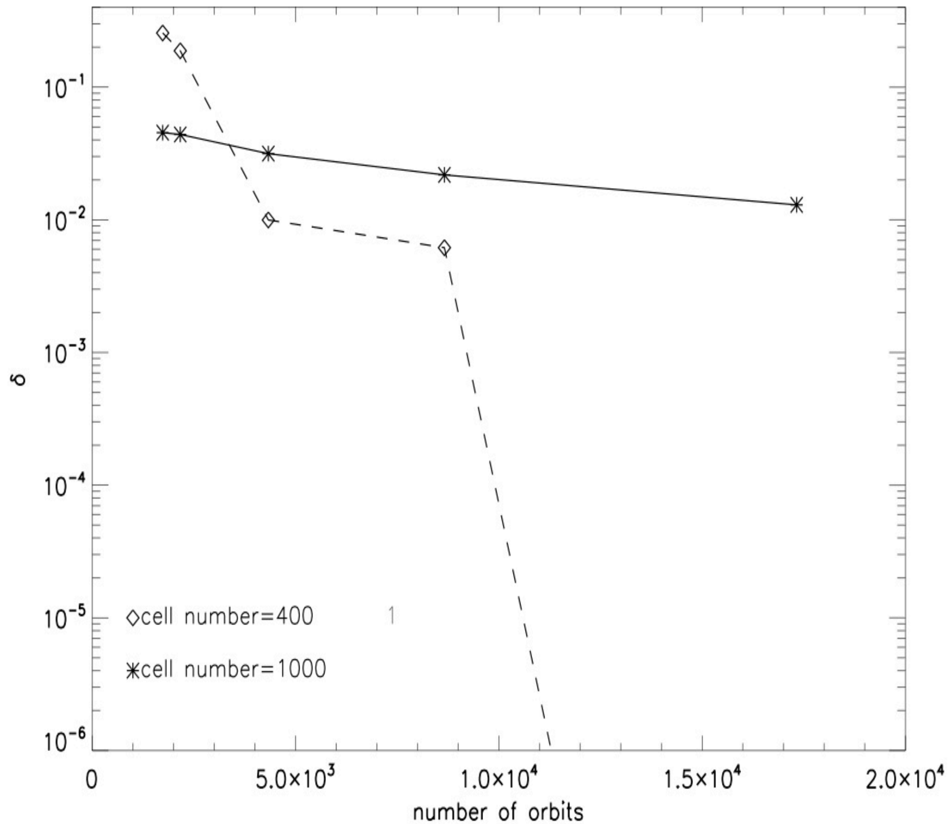
Self-consistency of the model

$$\Omega_p = -60 km/s/kpc$$

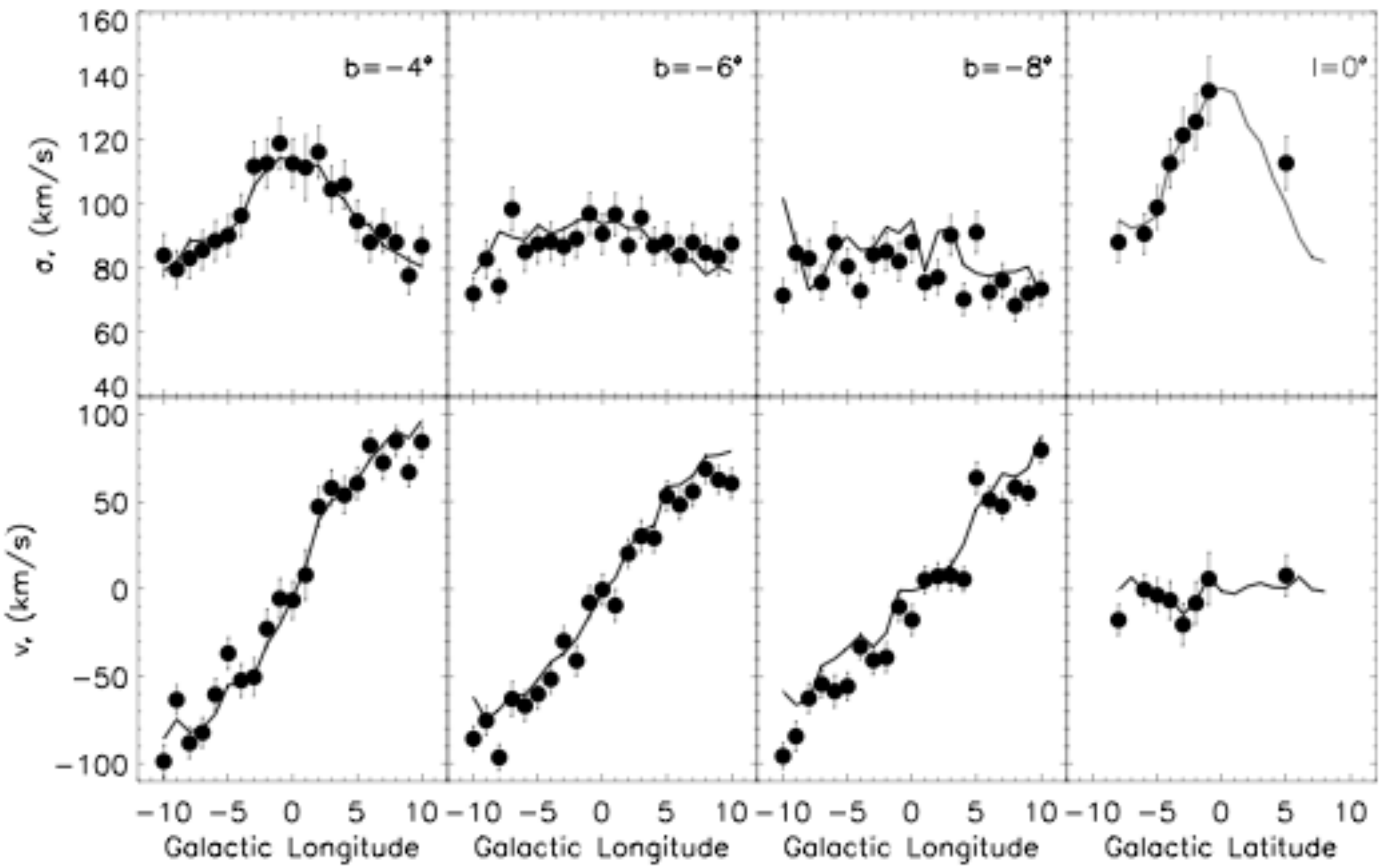
$$M_{disk} = 10^{11} M_{sun}$$

$$\theta_{bar} = 20^{\circ}$$





Best-fitting model



$$\Omega_p = -60 km/s/kpc$$

$$M_{disk} = 10^{11} M_{sun}$$

$$\theta_{bar} = 20^{\circ}$$

2012,MNRAS, Wang et al., 427,1429

Proper motion & Stability

Field	(l,b)	σ_l	σ_b	Ref.
	(°)	(mas yr^{-1})	(mas yr^{-1})	
Baade's Window	(1,-4)	3.2 ± 0.1	2.8 ± 0.1	Spaenhauer et al. (1992)
Baade's Window	(1,-4)	3.14 ± 0.11	2.74 ± 0.08	Zhao et al. (1996)
Baade's Window	(1.13,-3.77)	2.9	2.5	Kuijken & Rich (2002)
Baade's Window	(1,-4)	2.87 ± 0.08	2.59 ± 0.08	Kozłowski et al. (2006)
Baade's Window	(0.9,-4)	3.06 ± 0.11	2.79 ± 0.13	Soto et al. (2007)
Baade's Window	(1,-4)	3.13 ± 0.16	2.50 ± 0.10	Babusiaux et al. (2010)
Baade's Window	(1.13,-3.76)	3.11 ± 0.08	2.74 ± 0.13	Soto (2012) in preparation
Plaut's Window	(0,-8)	3.39 ± 0.11	2.91 ± 0.09	Vieira et al. (2007, 2009)
Sagittarius I	(1.25,-2.65)	3.3	2.7	Kuijken & Rich (2002)
Sagittarius I	(1.27,-2.66)	3.07 ± 0.08	2.73 ± 0.07	Kozłowski et al. (2006)
Sagittarius I	(1.25,-2.65)	3.067	2.760	Clarkson et al. (2008)
Sagittarius I	(1.26,-2.65)	3.56 ± 0.08	2.87 ± 0.08	Soto (2012) in preparation
NGC 6558	(0.28,-6.17)	2.90 ± 0.11	2.87 ± 0.13	Soto (2012) in preparation
Baade's Window	(1,-4)	4.44	2.52	Model 23
Plaut's Window	(0,-8)	5.28	2.32	Model 23
Sagittarius I	(1,-3)	4.43	2.67	Model 23
NGC 6558	(0,-6)	4.46	2.36	Model 23

The bar is only stable within 0.5 Gyr !!!

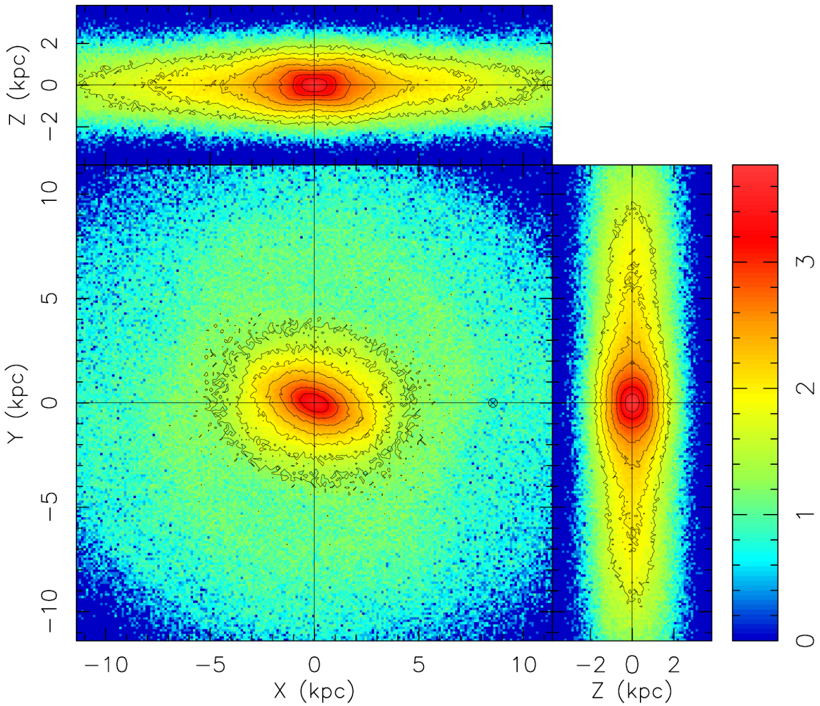
Regular orbit fraction

Orbit integrated time	1/4Hubble time	1/3Hubble time	1/2Hubble time	Hubble time
Regular orbit fraction	19.4%	18.7%	8.8%	7.1%
Irregular orbit fraction	80.6%	81.3%	91.2%	92.9%

New density input model

Schwarzschild model(2)

Shen et al. 2010's model



- Bar is evolved from an unbarred, thin disk with

  $$M_{disk} = 4.25 \times 10^{10} M_{sun}$$

- 10^6 particles

- A log halo potential

  $$\Phi = \frac{1}{2} v_c^2 \ln(1 + r^2 / R_c^2)$$

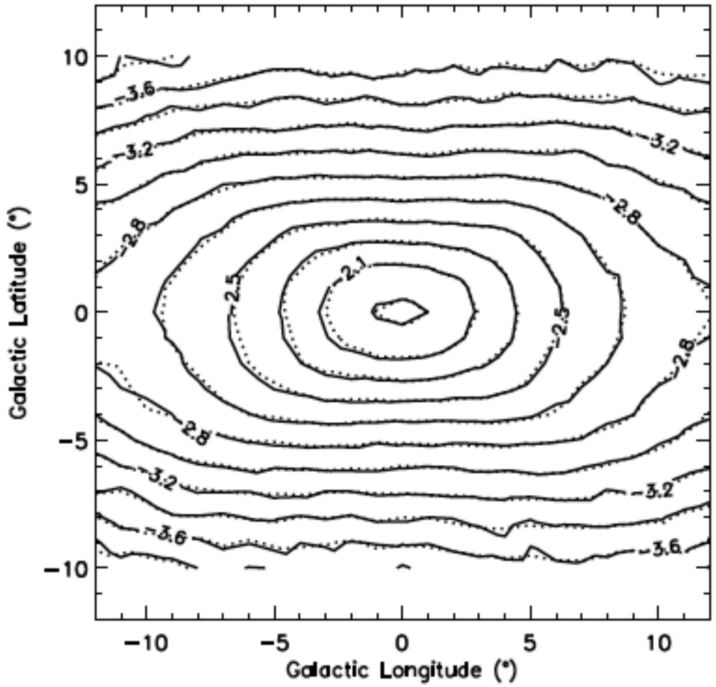
Parameters

Model ID	Ω_p (km s^{-1} kpc^{-1})	θ_{bar} (°)	χ^2
1	30	13.4	556
2	30	20	422
3	30	30	441
4	30	45	465
5	30	60	408
6	40	13.4	313
7	40	20	339
8	40	30	310
9	40	45	262
10	40	60	337
11	50	13.4	360
12	50	20	401
13	50	30	391
14	50	45	359
15	50	60	343
16	60	13.4	417
17	60	20	365
18	60	30	410
19	60	45	407
20	60	60	442
21	70	13.4	445
22	70	20	503
23	70	30	488
24	70	45	568
25	70	60	534
26	80	13.4	505
27	80	20	510
28	80	30	525
29	80	45	604
30	80	60	618

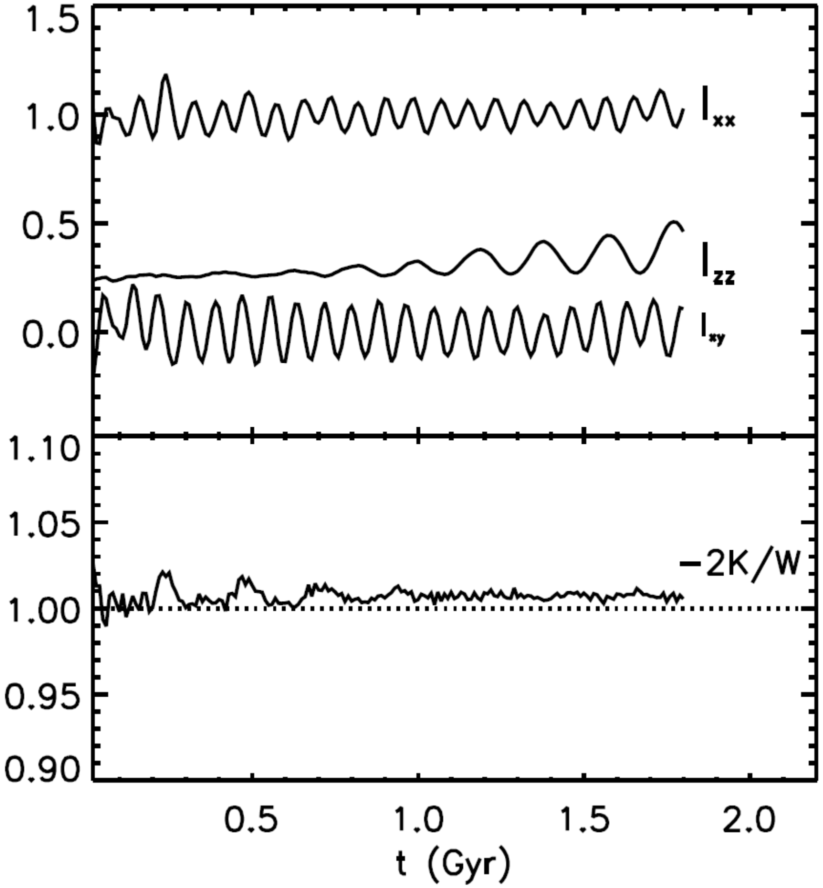
- The best-fit model

$$\Omega_p = -40 km/s/kpc$$

$$\theta_{bar} = 45^\circ$$



Stability & proper motion



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Baade's Window	(1,-4)	3.74	2.49	Model 9
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Sagittarius I	(1,-3)	3.61	2.58	Model 9
NGC 6558	(0,-6)	3.67	2.48	Model 9
Baade's Window	(1,-4)	4.44	2.52	Wang et al. (2012)
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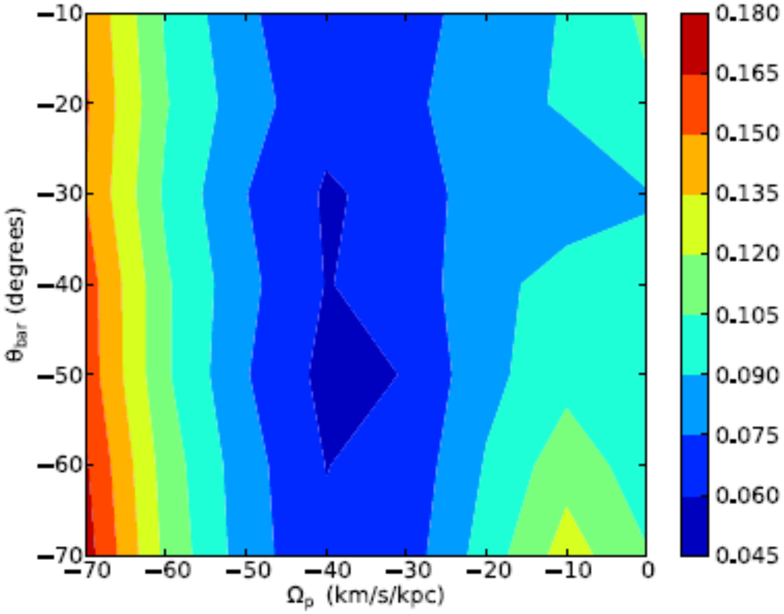
2013,MNRAS, Wang et al., 435,3437

Made-to-Measure model



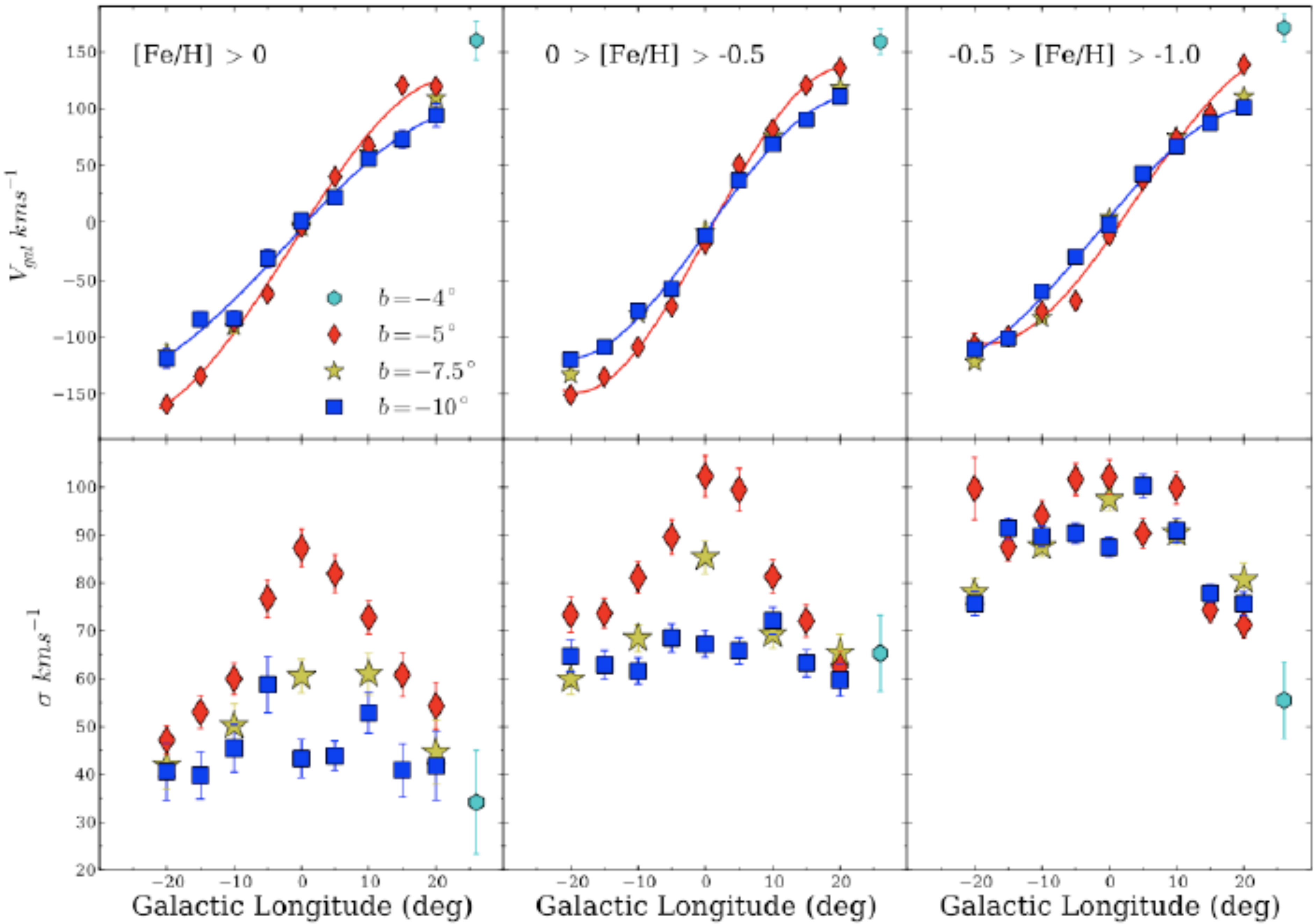
$$\Omega_p = -40 km/s/kpc$$

$$\theta_{bar} = 30^{\circ}$$

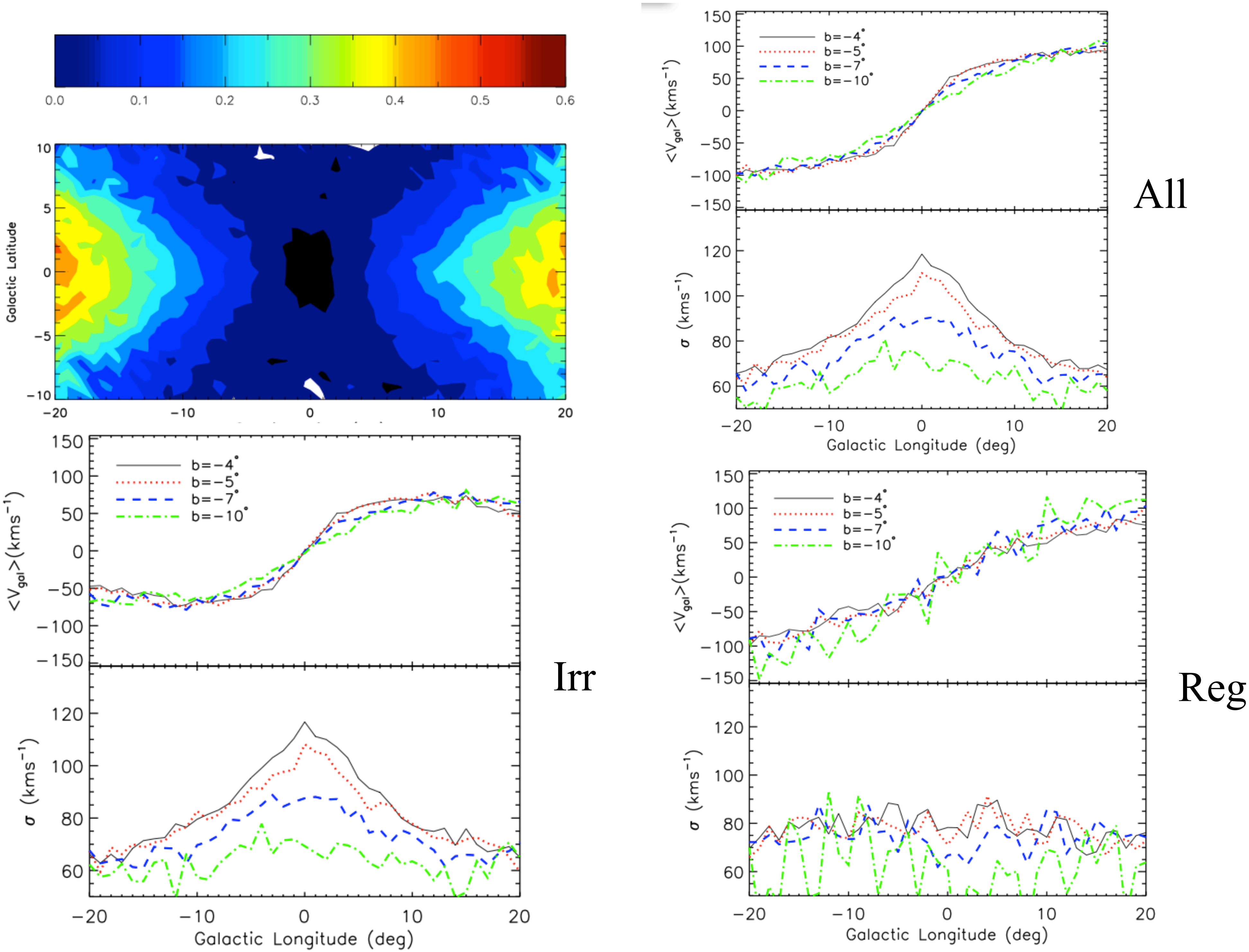
2013,MNRAS, Long, Mao, Shen. Wang, 428,3478

Summary & Discussion

- The BRAVA data can be fitted by models within large pattern speed, patter speed from 40 to 60km/s/kpc, bar angle 20-45 degrees
- Results from M2M are consistent with from Schwarzschild
- Proper motion problems
- New density model

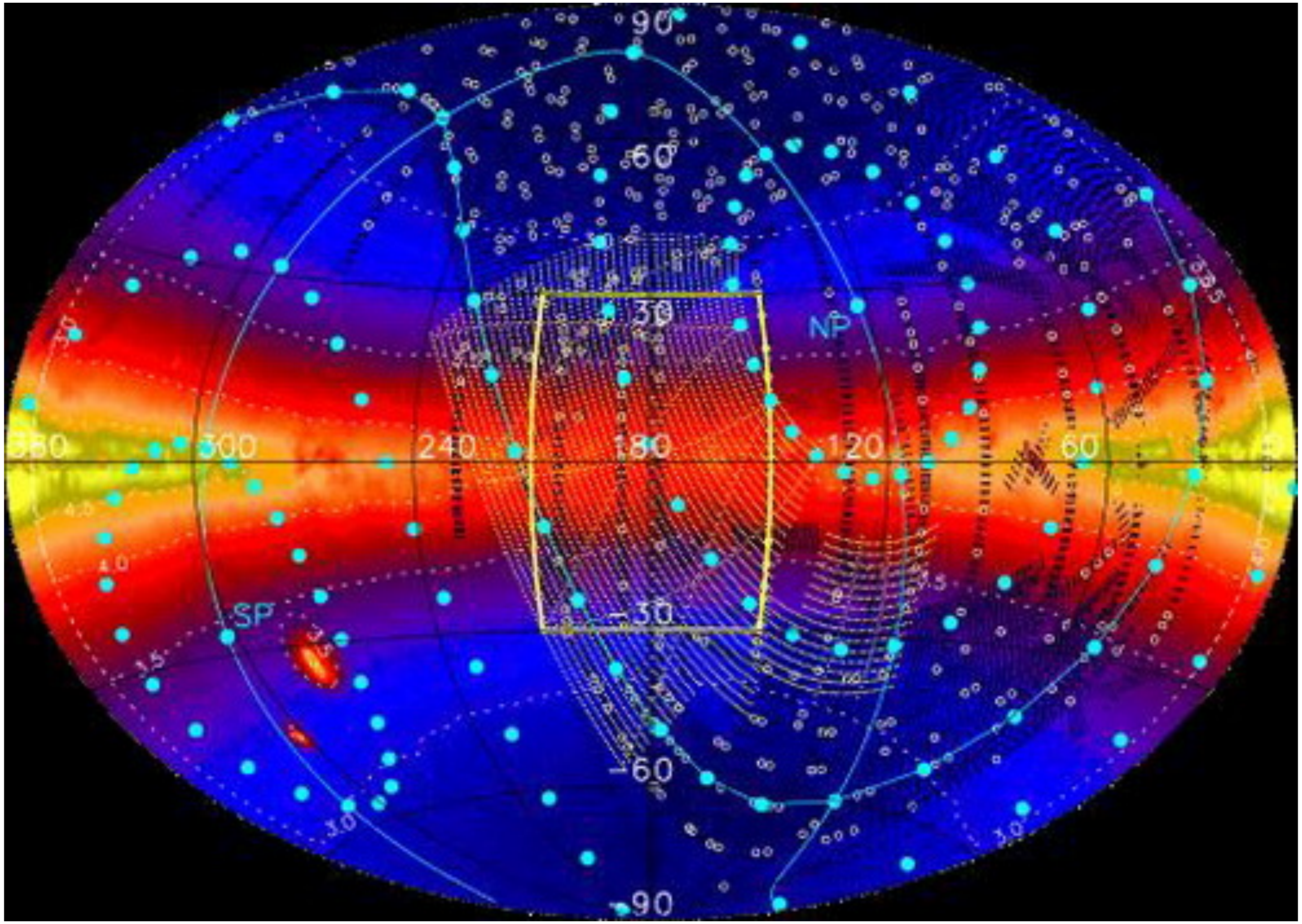


Ness et al. 2013, ARGOS

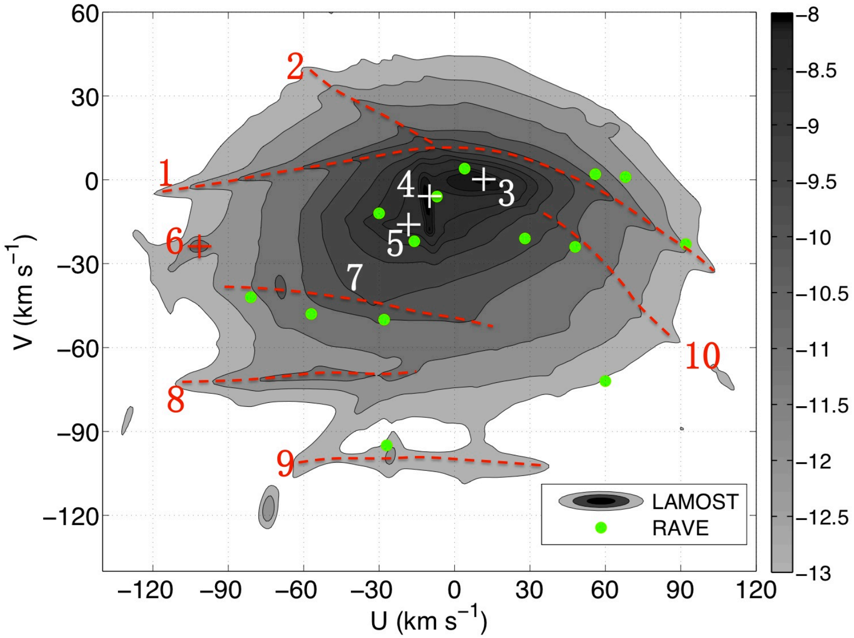


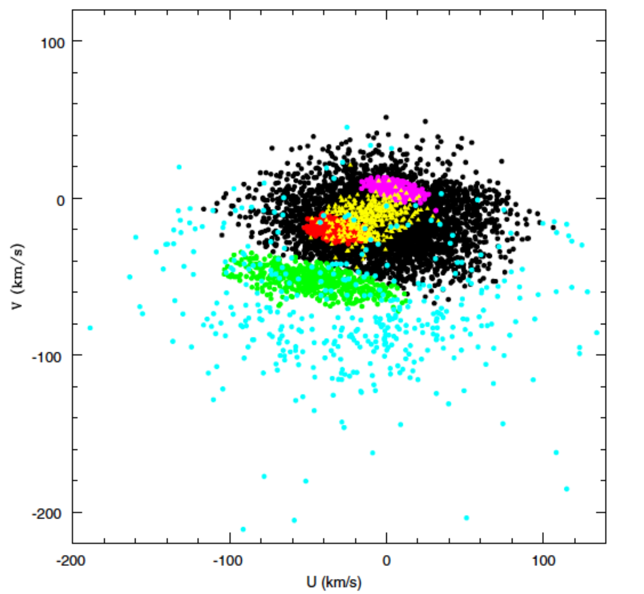
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Galactic Latitude
10
5
0
−5
−10
−20
−10
0
10
20
All
<Vgal>(kms−1)
σ (kms^−1)
b=−4°
b=−5°
b=−7°
b=−10°
150
100
50
0
−50
−100
−150
120
100
80
60
Galactic Longitude (deg)
Irr
Reg

LAMOST Galactic Anti-Center Survey



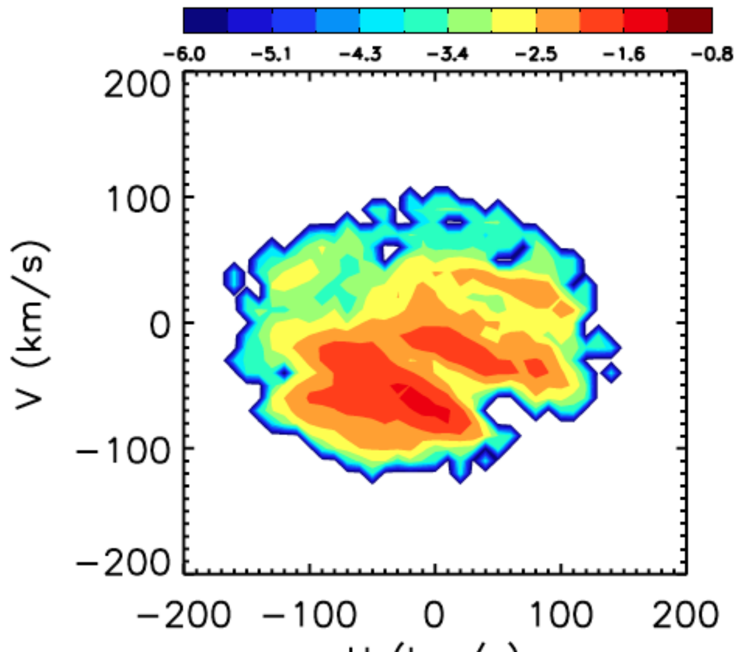
2.5 million stars brighter than r<19, 5 million stars brighter r<17

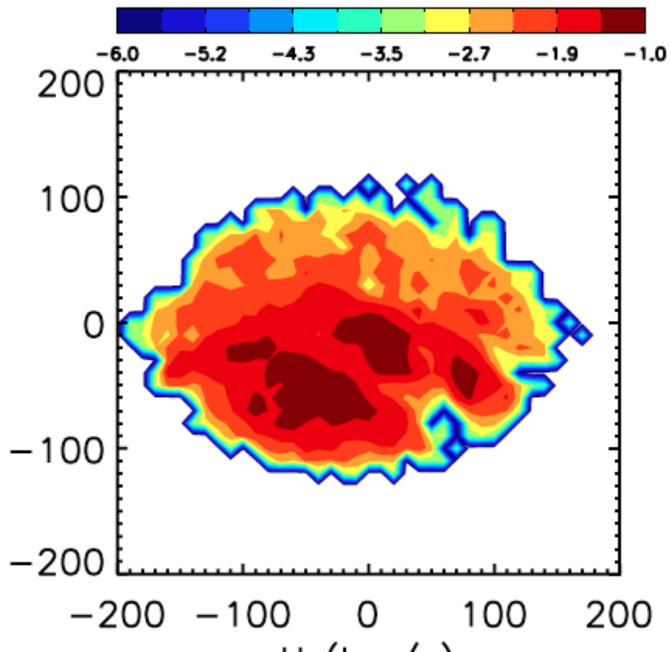


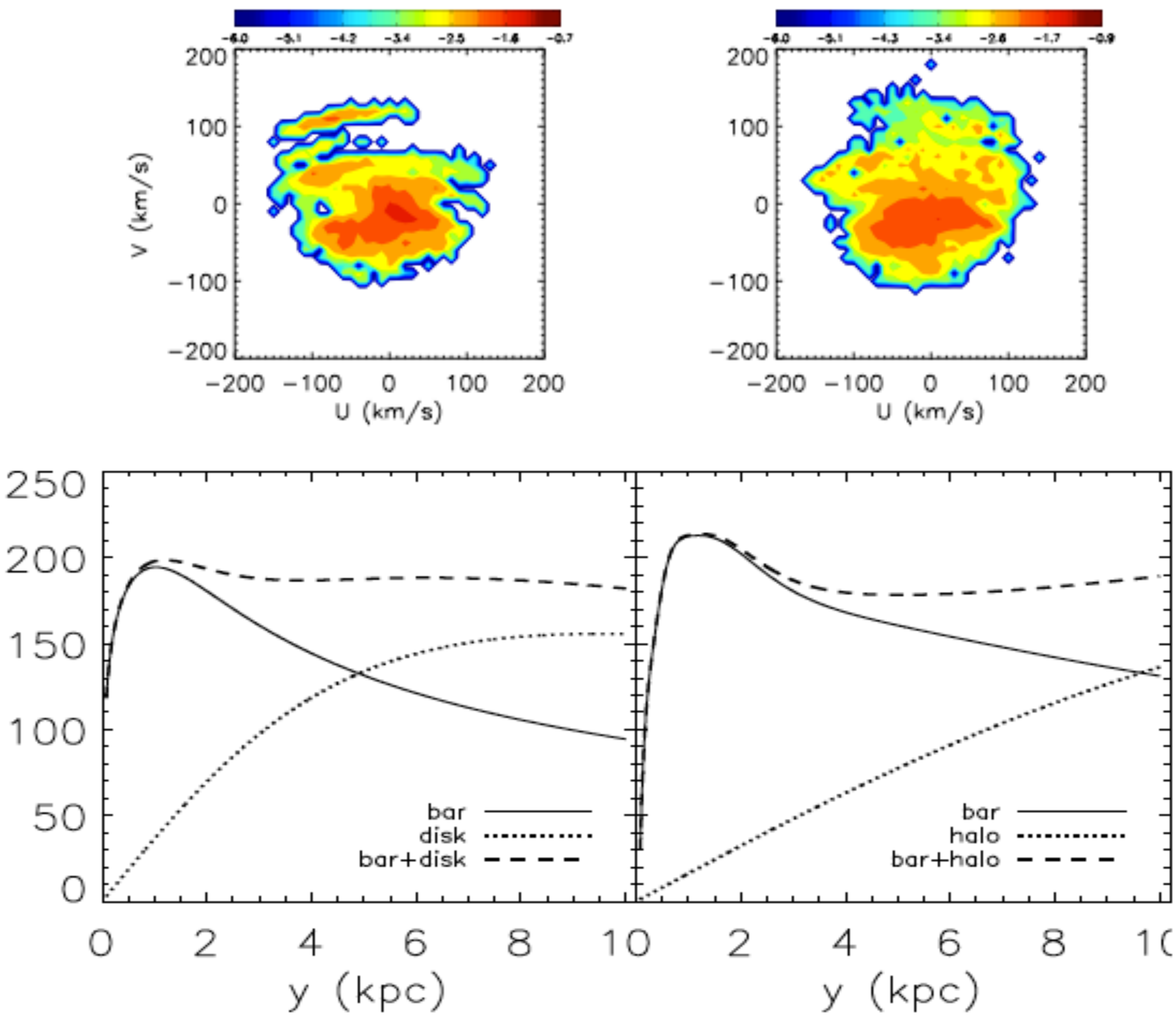


Xia Q., Liu C., Mao S et al. 2014
15000 F/G dwarf from LAMOST

Famaey et al. 2005/
Hipparcos/ K Gaints

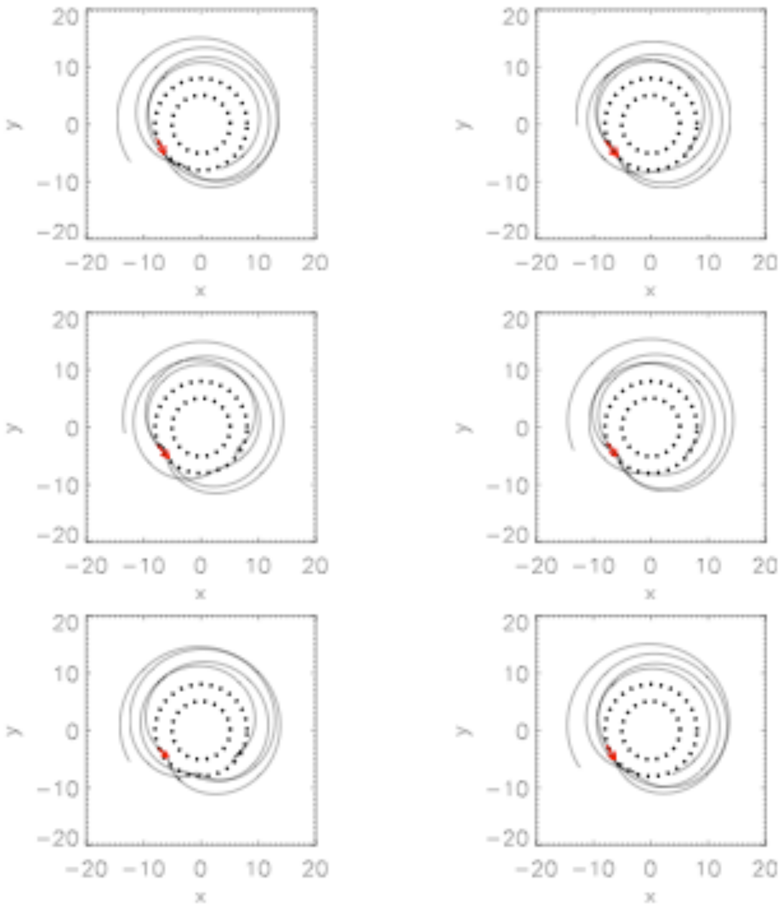




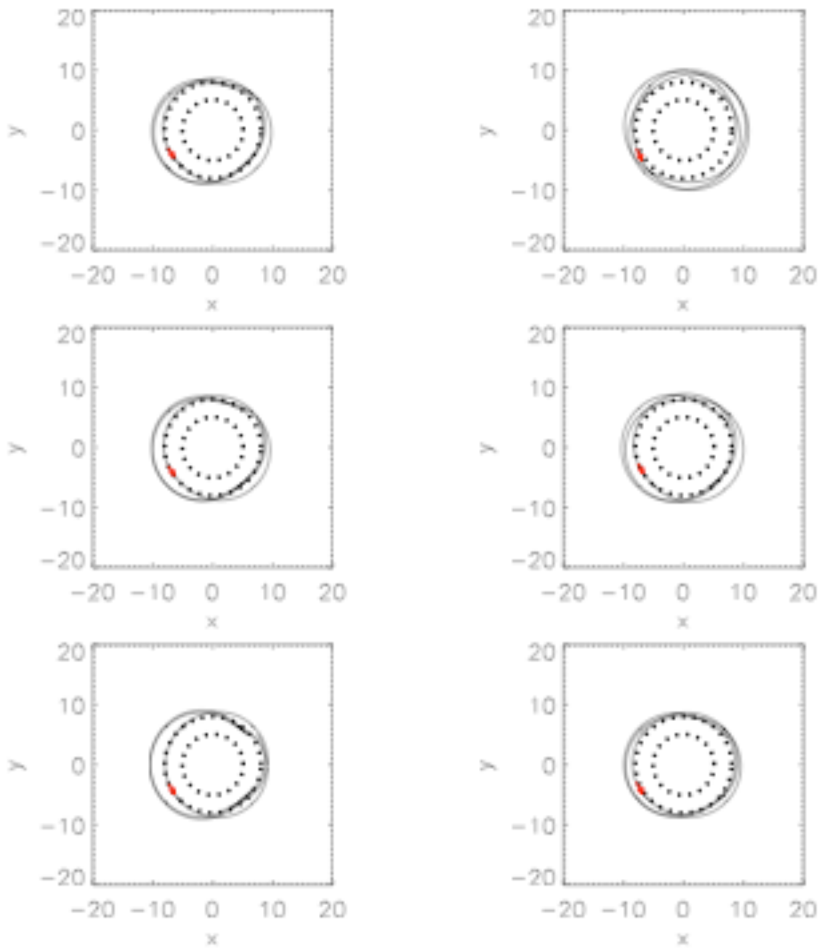


V (km/s)
U (km/s)
U (km/s)
bar
disk
bar+disk
bar
halo
bar+halo
y (kpc)
y (kpc)

Orbits from different region



bottom region



up region

The K giant stars from the LAMOST survey data I: identification, metallicity, and distance

Chao Liu[1], Li-Cai Deng[1], Jeffrey L. Carlin[2], Martin C. Smith[3], Jing Li[1,3], Heidi Jo Newberg[2], Shuang Gao[1], Fan Yang[1], Xiang-Xiang Xue[4], Yan Xu[1], Yue-Yang Zhang[1], Y Xin[1], Ge Jin[5]

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ABSTRACT

We present a support vector machine classifier to identify the K giant stars from the LAMOST survey directly using their spectral line features. The completeness of the identification is about 75% for tests based on LAMOST stellar parameters. The contamination in the identified K giant sample is lower than 2.5%. Applying the classification method to about 2 million LAMOST spectra observed during the pilot survey and the first year survey, we successfully select 298,036 K giant stars. The metallicities of the sample are also estimated with uncertainty of $0.13 \sim 0.29$ dex based on the equivalent widths of Mg_b and iron lines. A Bayesian method is then developed to estimate the posterior probability of the distance for the K giant stars, based on the estimated metallicity and 2MASS photometry. The synthetic isochrone-based distance estimates have been calibrated using 7 globular clusters with a wide range of metallicities. The uncertainty of the estimated distance modulus at K=11 mag, which is the median brightness of the K giant sample, is about 0.6 mag, corresponding to $\sim 30\%$ in distance. As a scientific verification case, the trailing

Opportunities and challenges

- We have many data
- Improved the methods and models
- A long way to construct a full Galactic model which can fit most of observations

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Thank You