The Besançon Galaxy model: comparisons to photometric surveys and modelling of the Galactic bulge and disc

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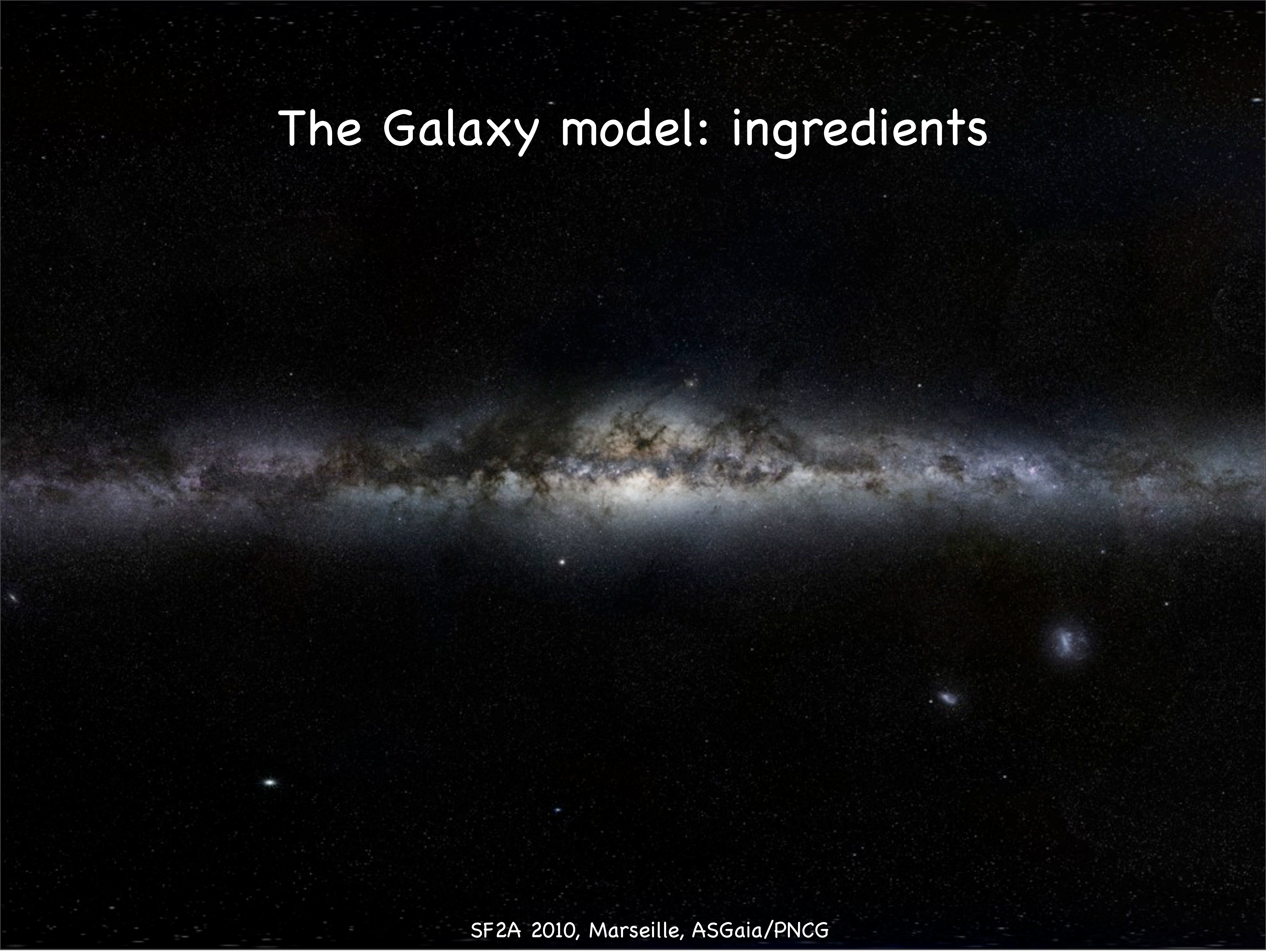
Coll: Annie Robin, Mathias Schultheis, Doug Marshall

The Galaxy model: ingredients



SF2A 2010, Marseille, ASGaia/PNCG

The Galaxy model: ingredients

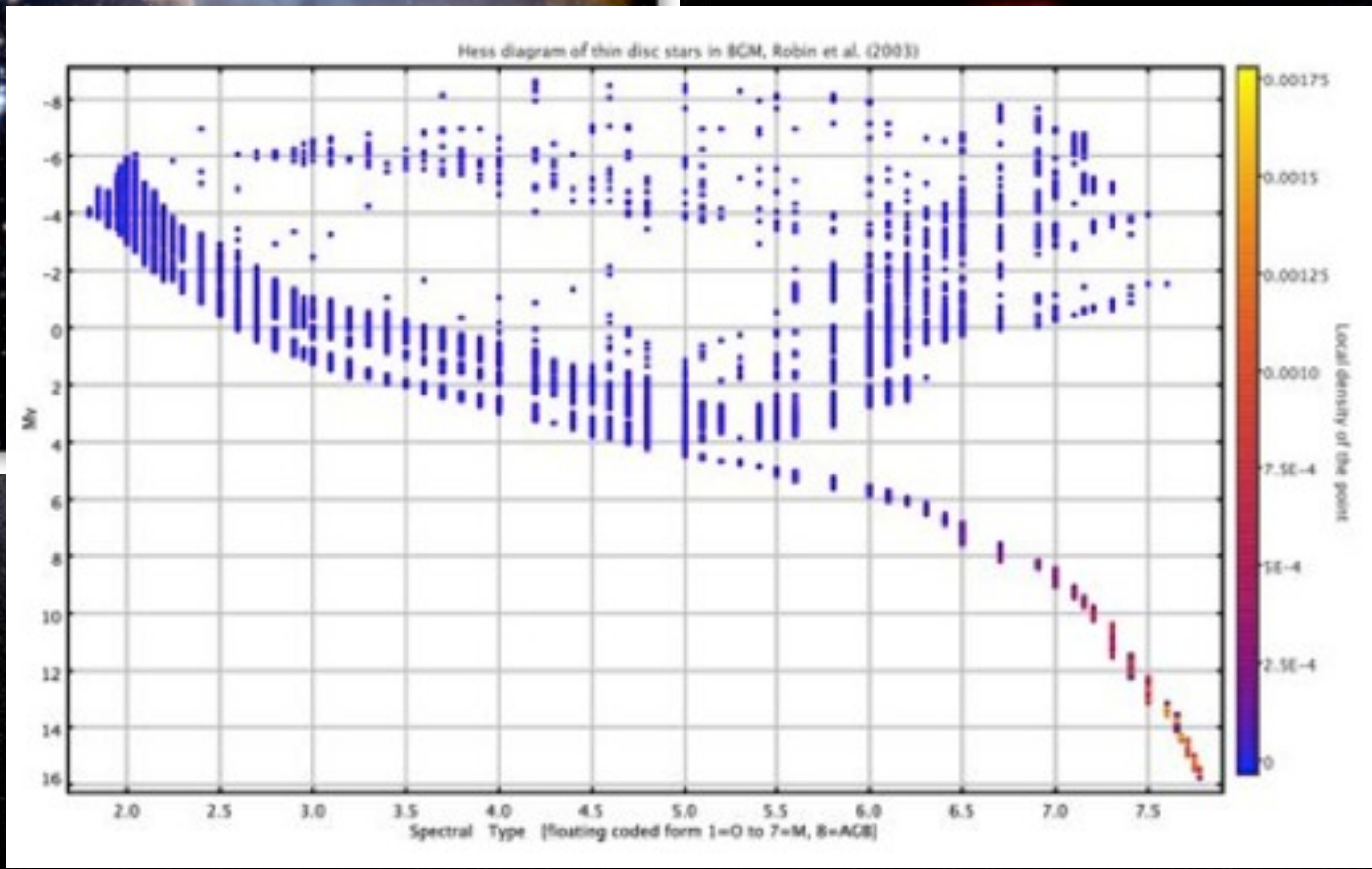
Mass distribution (IMF)
Age distribution (SFR)

The Galaxy model: ingredients

Mass distribution (IMF)
Age distribution (SFR)

Evolutionary tracks

The Galaxy model: ingredients



Hess diagram

$\Phi(M_V, T_{eff}, \log g, mass, age)$

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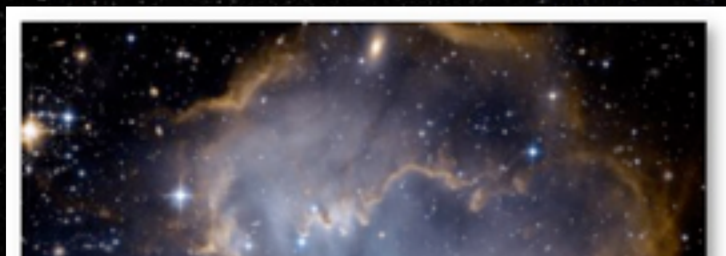
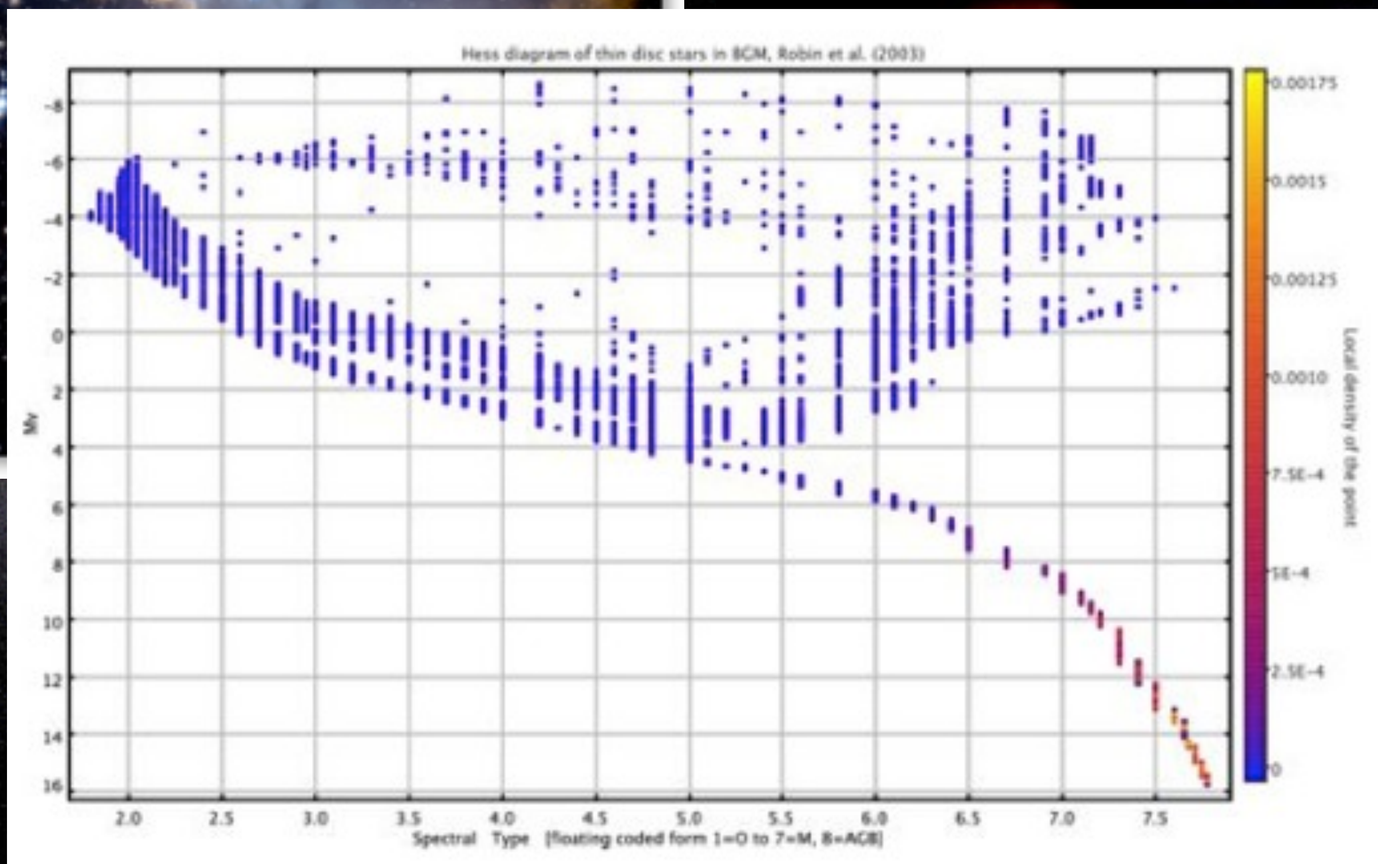
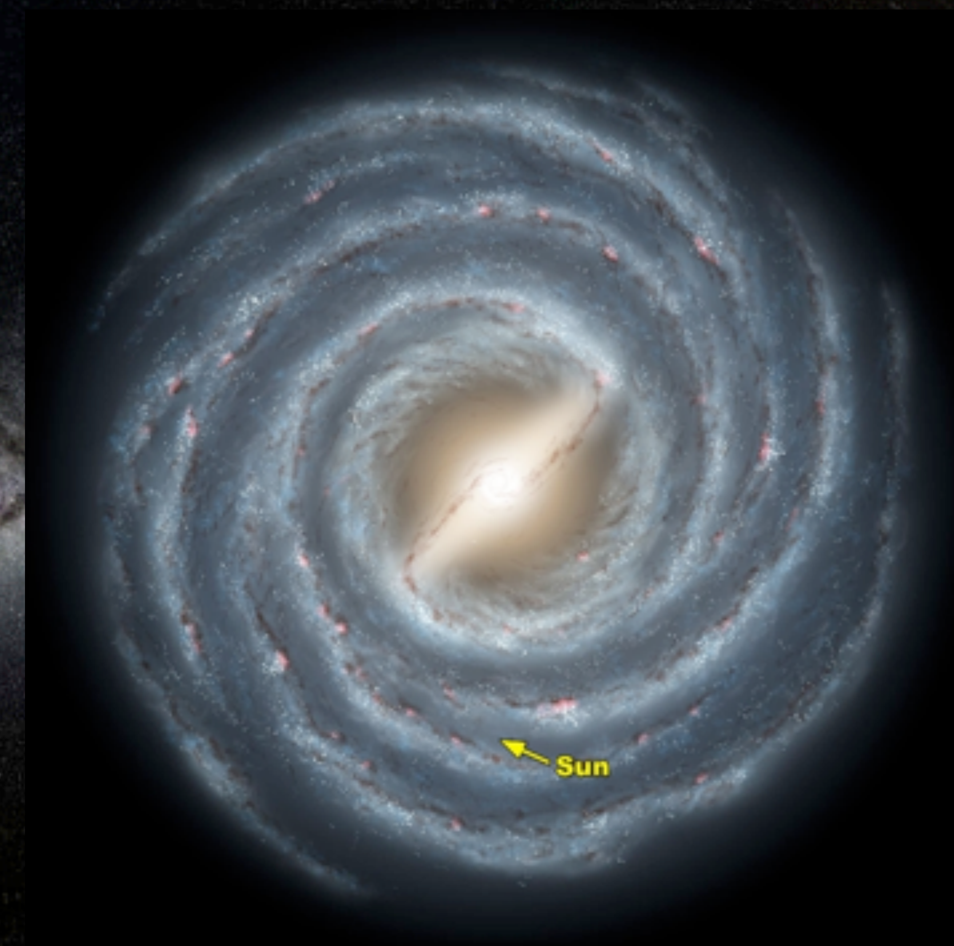


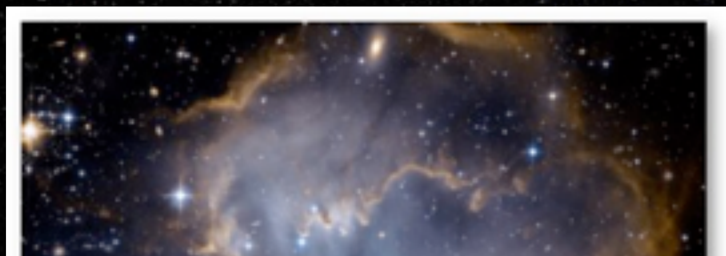


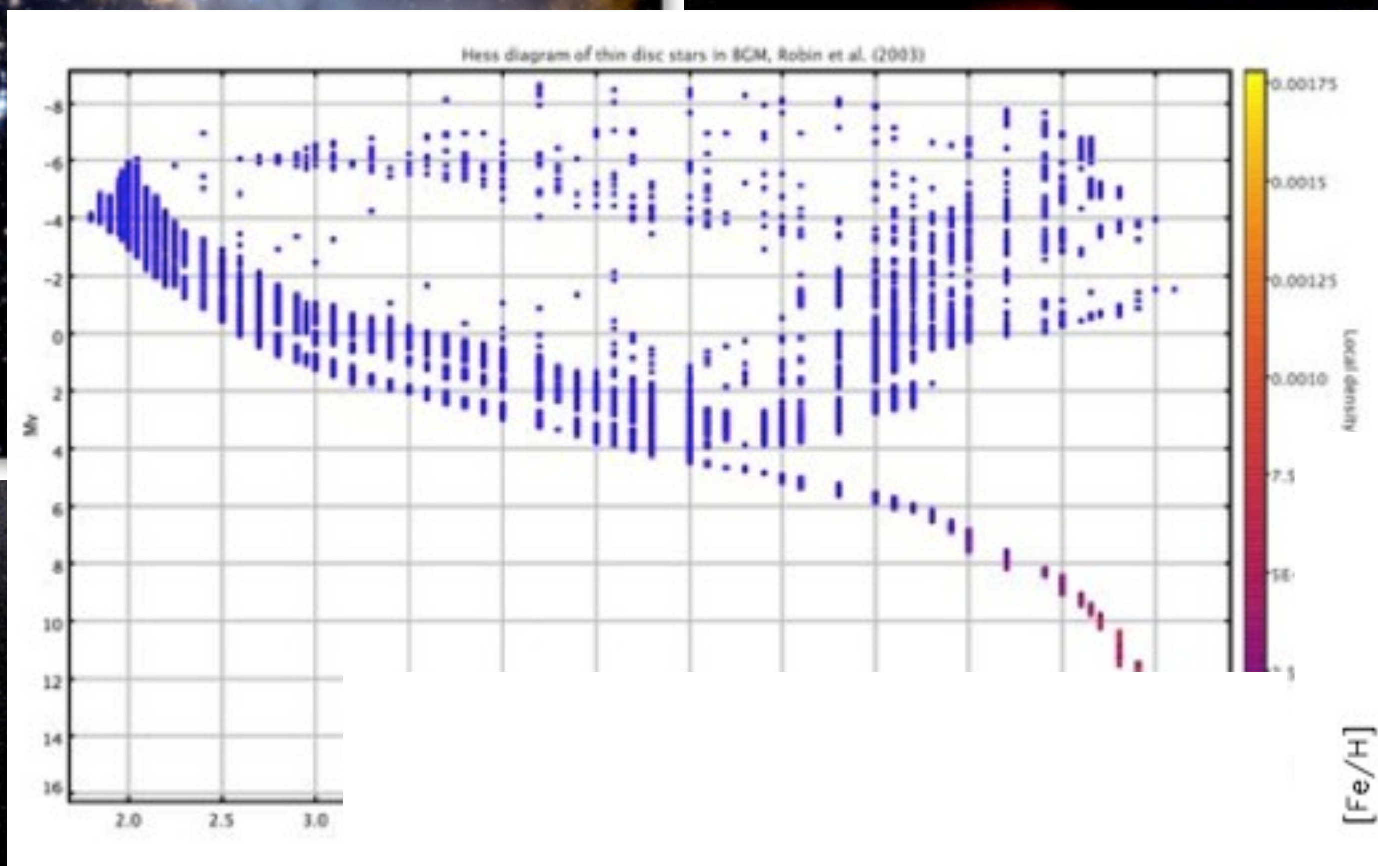
Hess diagram
$\Phi(Mv, T_{eff}, \log g, mass, age)$

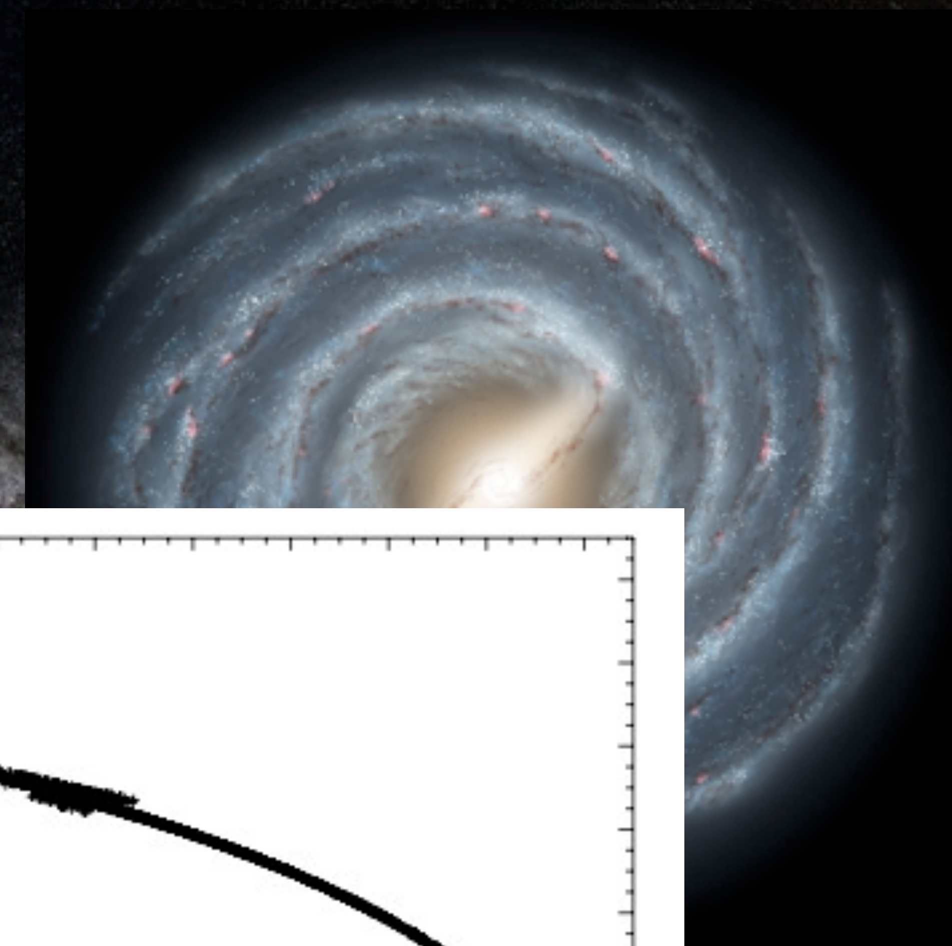


Structure $\rho(r,z,age)$

The Galaxy model: ingredients

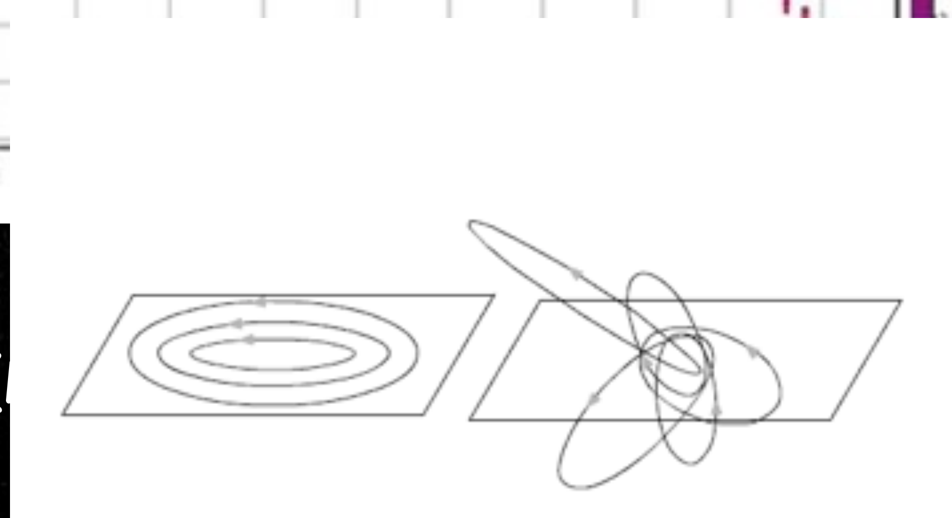


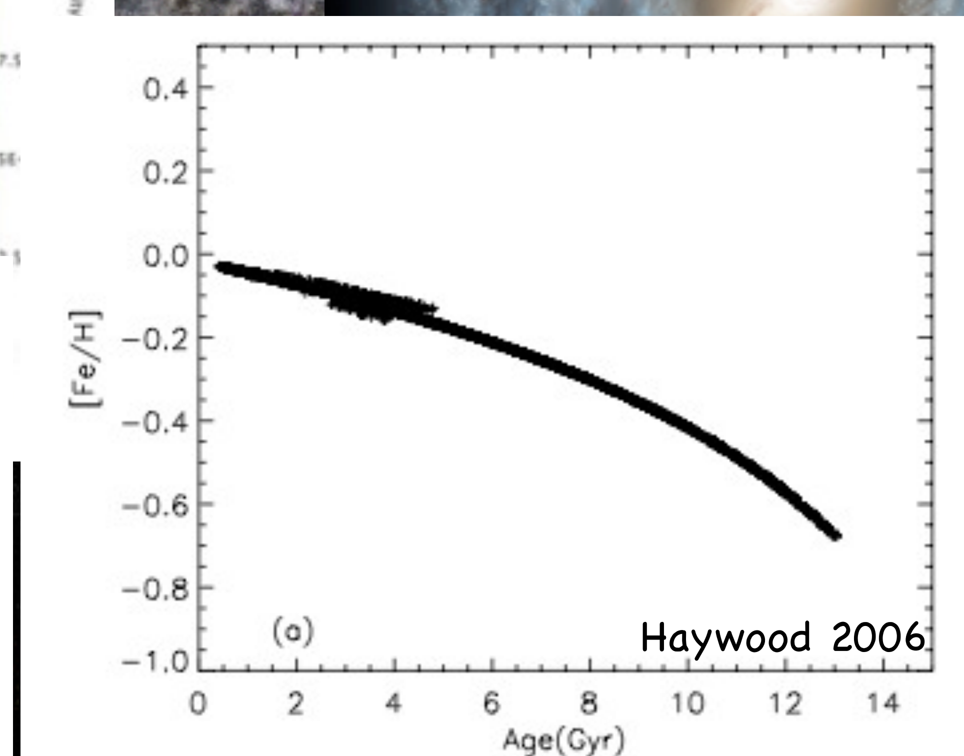




age)

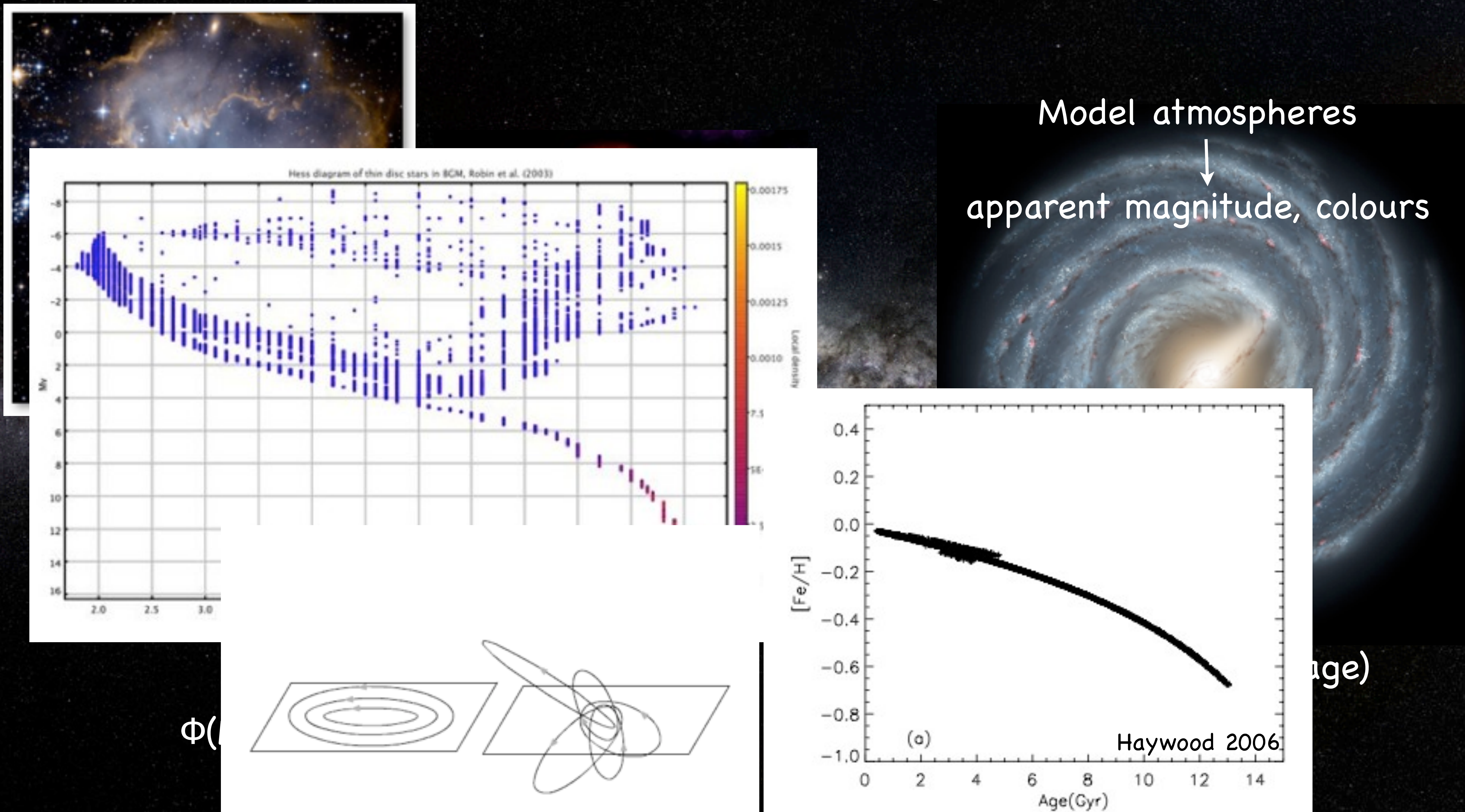
Φ(





Kinematics and metallicity(age)

The Galaxy model: ingredients



Kinematics and metallicity(age)

The Galaxy model: ingredients

The Galaxy model: recipe

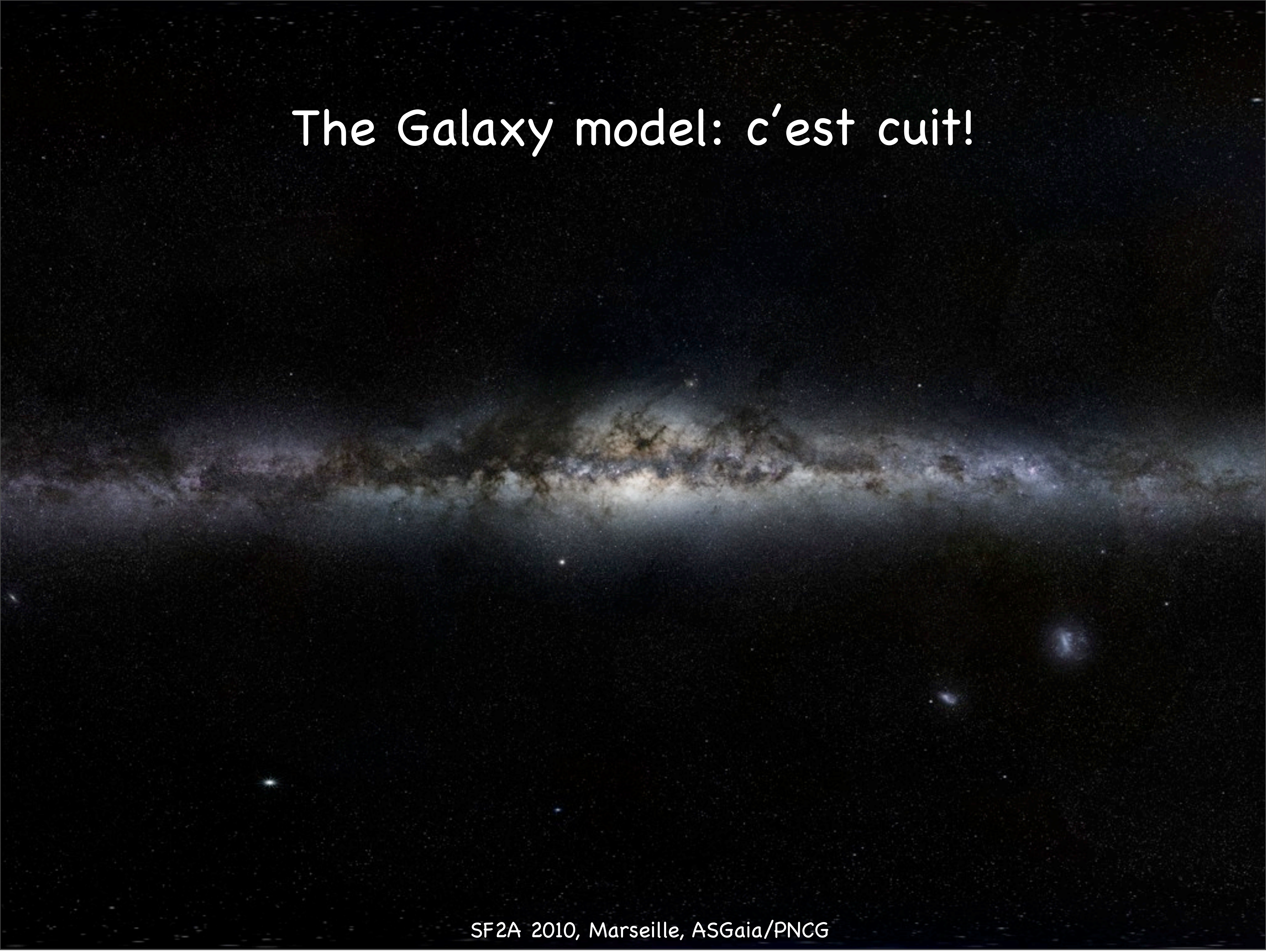
The Galaxy model: recipe

Simulated catalogues
& star counts via the
equation of stellar statistics

$$A(m)= \int \Phi(M_V)\rho(r)\Omega r^2 dr$$

Observationnal errors
Extinction distribution (3D)

The Galaxy model: c’est cuit!



The Galaxy model: c'est cuit!

V	B-V	I-J	J-K	V-I	mux	muy	Vr	UU	VV	WW	Mv	CL	Typ	Teff	logg	Age	Mass	Mbol	Radius	[Fe/H]	l(deg)	b(deg)	RA2000.0	DEC2000.0	Dist	x(kpc)	y(kpc)	z(kpc)	Av
11.739	1.395	0.948	0.830	1.752	0.701	-2.592	-48.05	53.50	-32.17	-26.92	8.84	5	7.02	3890.	4.72	7	0.600	7.466	0.630	-0.45	199.248886	30.541803	126.100349	24.395578	0.038	-8.031	-0.011	0.034	0.014
12.114	1.478	1.069	0.770	1.848	0.060	1.920	77.18	-66.39	-3.09	44.48	10.29	5	7.12	3733.	4.93	8	0.384	8.902	0.353	-0.73	199.761826	29.433413	125.105759	23.620707	0.023	-8.019	-0.007	0.026	0.014
15.341	1.560	1.395	0.837	2.355	-0.156	-1.483	-8.17	11.03	-33.44	-18.50	11.61	5	7.29	3396.	4.95	2	0.330	10.007	0.256	-0.18	200.026398	29.531054	125.288101	23.434656	0.055	-8.045	-0.016	0.042	0.027
12.141	1.408	0.960	0.816	1.768	-1.805	-0.878	76.60	-79.72	-33.89	3.81	8.96	5	7.03	3867.	4.75	5	0.590	7.566	0.609	-0.56	199.725723	30.286879	125.977783	23.924854	0.043	-8.035	-0.012	0.037	0.027
19.723	1.725	1.801	0.898	3.152	0.304	-1.156	-2.67	14.25	-36.51	-4.13	15.48	5	7.52	3028.	5.14	1	0.110	13.553	0.063	0.16	200.237915	29.344276	125.161499	23.199511	0.069	-8.057	-0.021	0.049	0.040
18.268	1.648	1.698	0.886	2.981	-0.442	0.283	-4.94	-4.68	11.33	-10.77	14.25	5	7.46	3117.	5.06	2	0.160	12.316	0.105	0.07	200.286026	29.703793	125.546120	23.277554	0.063	-8.051	-0.019	0.046	0.040
17.720	1.682	1.645	0.877	2.876	-0.339	-0.355	26.09	-25.27	-16.74	1.44	13.56	5	7.43	3161.	5.05	4	0.180	11.780	0.131	-0.12	199.846725	30.572777	126.310608	23.916851	0.067	-8.054	-0.019	0.049	0.040
17.357	1.747	1.522	0.858	2.796	0.338	-2.961	-18.85	35.30	-78.34	-25.71	13.35	5	7.42	3177.	4.99	7	0.190	11.580	0.142	-0.48	199.706985	30.296787	125.982430	23.943346	0.062	-8.050	-0.018	0.046	0.040
14.752	1.527	1.260	0.814	2.116	-0.076	-1.248	21.51	-11.48	-46.63	-4.03	10.40	5	7.19	3568.	4.86	5	0.450	8.939	0.380	-0.26	200.356461	29.487194	125.345200	23.148848	0.073	-8.059	-0.022	0.051	0.040
17.465	0.225	0.239	0.177	0.469	-0.321	-0.901	0.66	-1.34	-24.68	-15.49	13.38	6	9.00	7484.	8.00	6	0.593	13.094	0.013	-0.09	199.874466	29.849171	125.569778	23.662613	0.064	-8.052	-0.019	0.047	0.040
19.345	0.861	0.699	0.397	1.169	-1.515	-0.512	118.33	-122.28	-44.16	11.01	15.00	6	9.00	4575.	7.50	7	0.322	14.647	0.017	-0.52	200.084991	29.754480	125.536499	23.459114	0.073	-8.059	-0.022	0.051	0.040
12.712	1.260	0.831	0.760	1.471	0.326	-0.268	68.13	-48.12	-29.67	40.40	8.50	5	6.79	4150.	4.75	8	0.566	7.583	0.525	-0.70	199.773331	30.150156	125.850471	23.842226	0.068	-8.056	-0.020	0.049	0.040
19.904	1.803	1.830	0.892	3.182	-0.082	-0.320	40.86	-32.72	-23.55	14.52	15.27	5	7.51	3035.	5.11	3	0.120	13.453	0.066	-0.13	200.205032	30.351841	126.189575	23.553623	0.082	-8.067	-0.025	0.057	0.052
15.242	1.513	1.303	0.820	2.099	-0.166	-0.321	-7.30	4.50	-9.15	-12.98	10.50	5	7.19	3568.	4.86	3	0.450	8.939	0.380	-0.11	200.301270	29.510471	125.352028	23.201857	0.087	-8.071	-0.026	0.058	0.052

The Galaxy model: c'est cuit!

V B-V I-J J-K V-I mux muy Vr UU VV WW Mv CL Typ Teff logg Age Mass Mbol Radius [Fe/H]

l(deg) b(deg) RA2000.0 DEC2000.0 Dist x(kpc) y(kpc) z(kpc) Av

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Simple dynamical principles

Stellar populations
Interstellar matter } Mass model ⊃ Potential Φ
Dark matter

Boltzmann constraint (isothermal and relaxed thin disc population)

$$\rho(z)/\rho(0) = \exp(-\Delta\Phi/\sigma^2)$$

Thin disc secular evolution: $\sigma = f(age)$ ⊃ Scale height $= f(age)$

Stellar population synthesis model

4 populations

Thin disc: 10 Gyr, with cst SFR, IMF renormalised to the solar neighbourhood (Hipparcos + CNS3), kinematics and [Fe/H] function of age and Galactocentric radius

Thick disc: single burst, 11 Gyr, power law IMF, density, IMF and kinematics constrainted by obs.

Spheroid: single burst, 14 Gyr, power law IMF, density, IMF and kinematics constrainted by obs.

Bulge/bar: single burst, 10 Gyr, 2 slope power law IMF, density constrained by NIR star counts

http://model.obs-besancon.fr, Robin et al 2003

Stellar population synthesis approach

Are the a priori hypothesis realistic enough ?
Are the parameters sufficiently constrained a posteriori ?
Is the solution unique ?

Use of multi-wavelength data (Visible, IR, UV, X)
Use of multi-parameter data (photometry / spectroscopy / astrometry)

Step by step approach (less parameters to start with, adding parameters when required)

Observational tests

In optical, many directions (beam surveys) to mag 22, Hipparcos catalogue, mostly at high latitudes (b>40°)

A few directions to mag 24-25 (NGP, Cosmos field, CFHT-LS)

All sky : GSC2

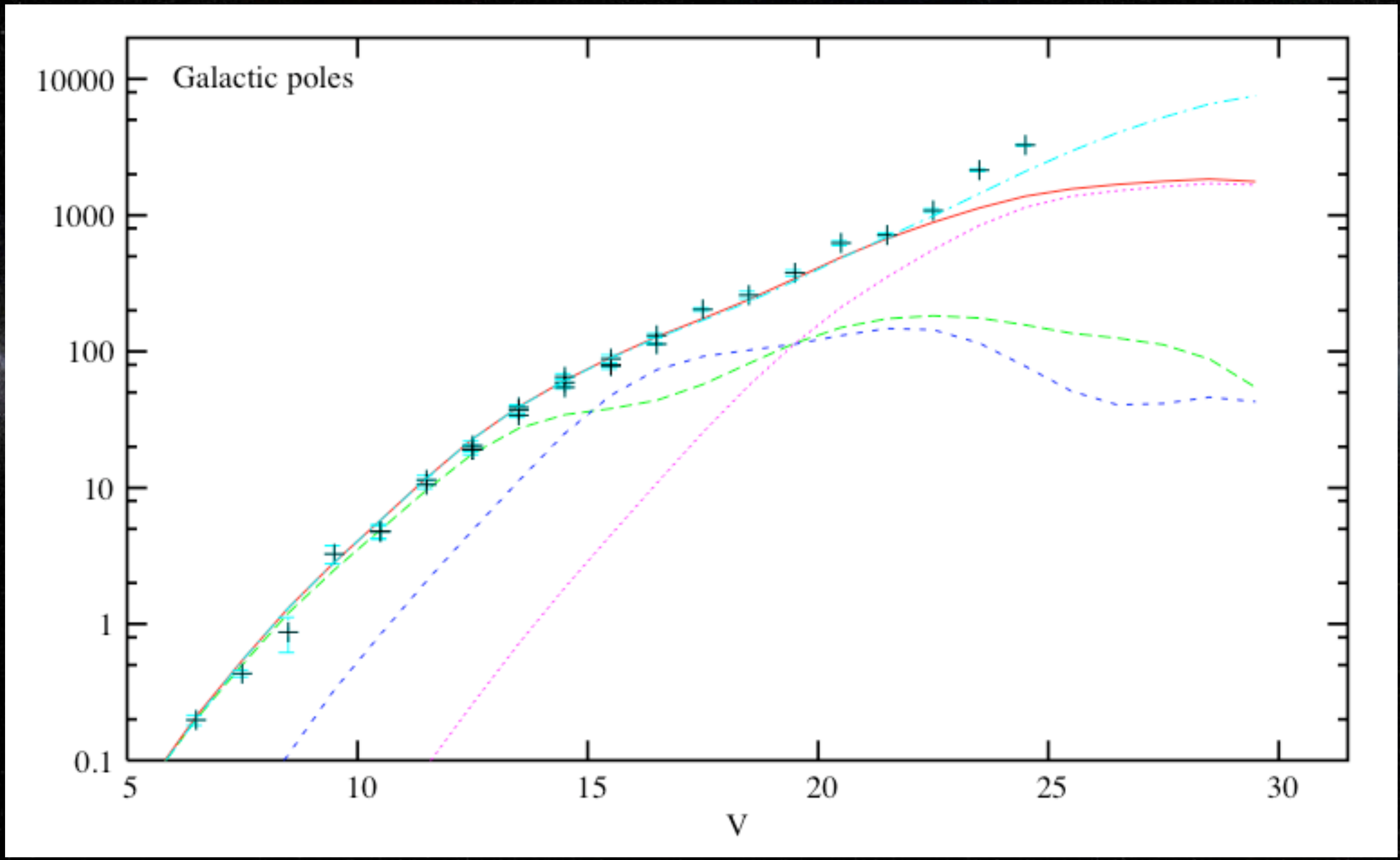
Near-infrared : DENIS, 2MASS : Galactic plane, central regions

X : Guillout et al (1996)

UV : Galex : Ojha et al., in prep

Kinematical tests: pencil beams (proper motions, radial velocities)

Star counts towards the Galactic pole



Kinematics

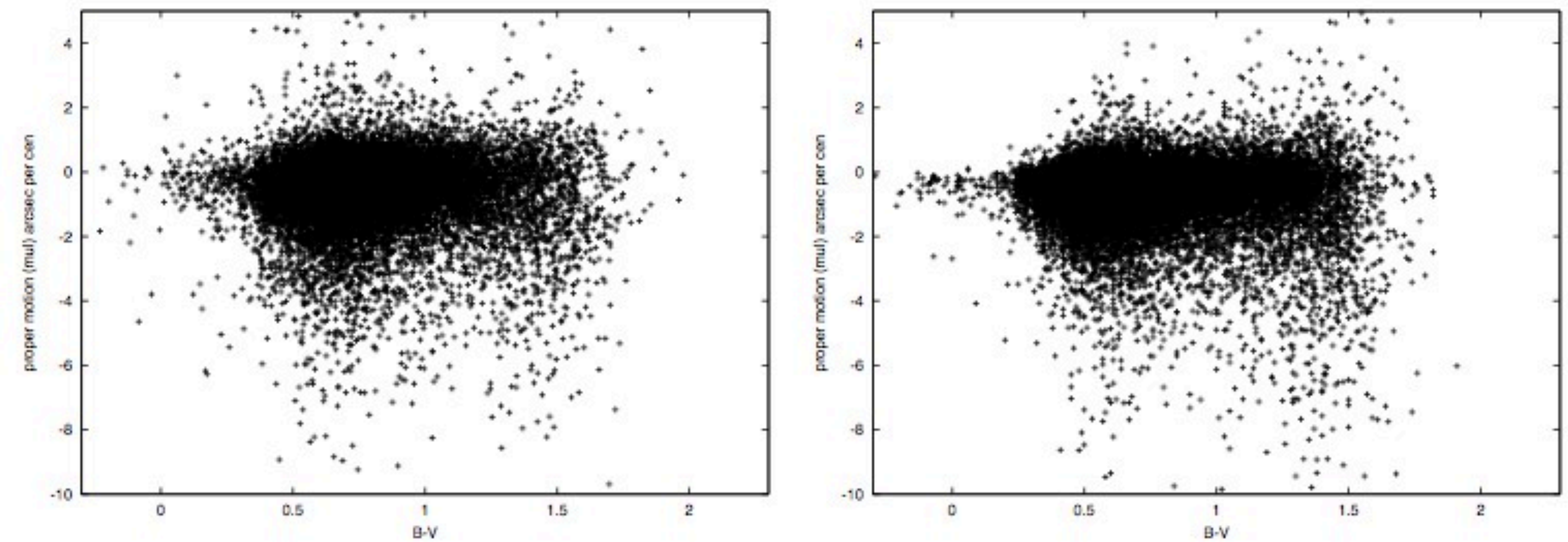


Fig. 11. B-V versus proper motion μ_l diagrams towards l=4°, b=47°, for stars with $12 < V < 18$.
a) Observations from Ojha et al. (1996). b) Simulation.

Kinematics

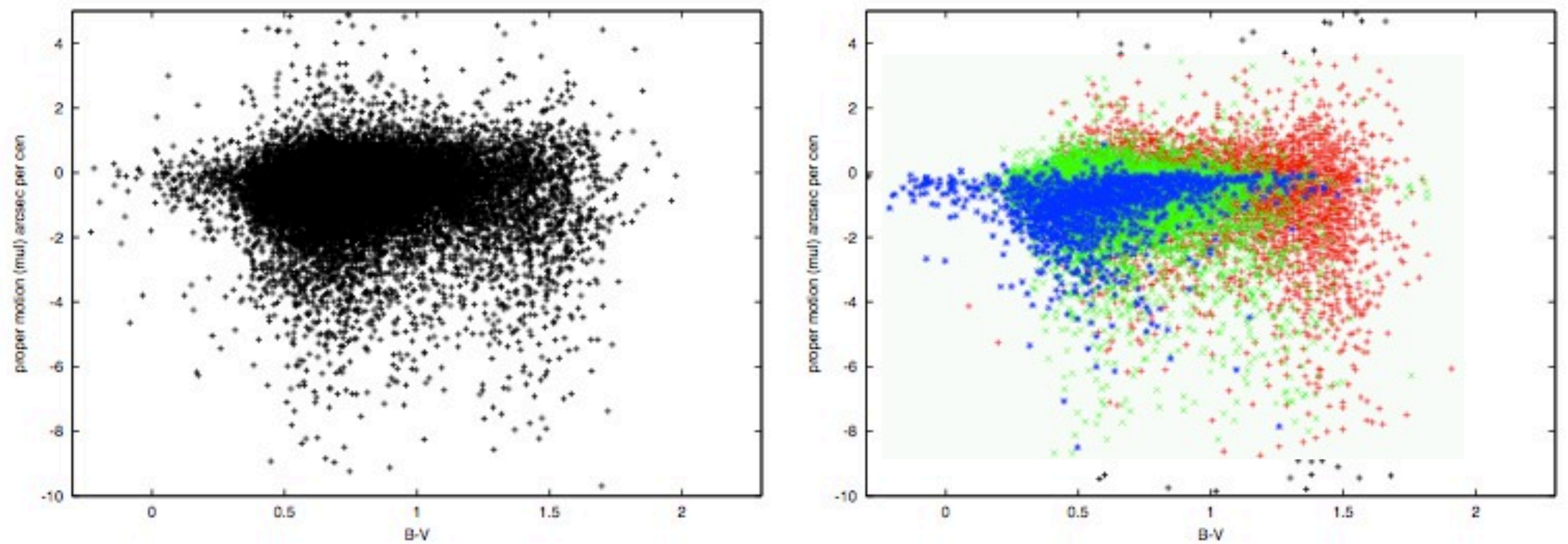
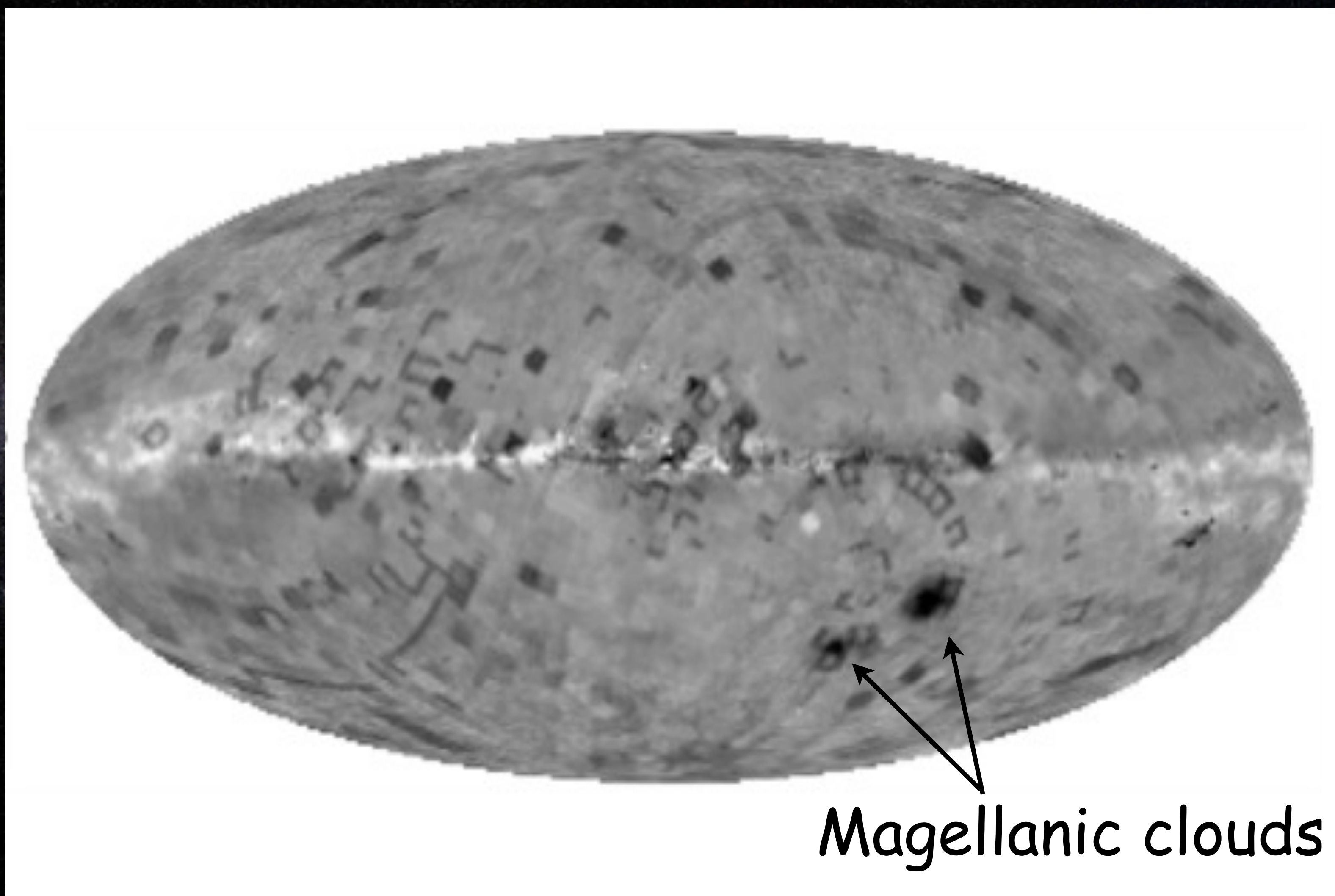


Fig. 11. B-V versus proper motion μ_l diagrams towards l=4°, b=47°, for stars with $12 < V < 18$.
a) Observations from Ojha et al. (1996). b) Simulation.

disc
thick disc
spheroid

GSC2 versus BGM



GSC2 – Model at G=17 agrees at 10% outside plane with Drimmel et al 2003 extinction model

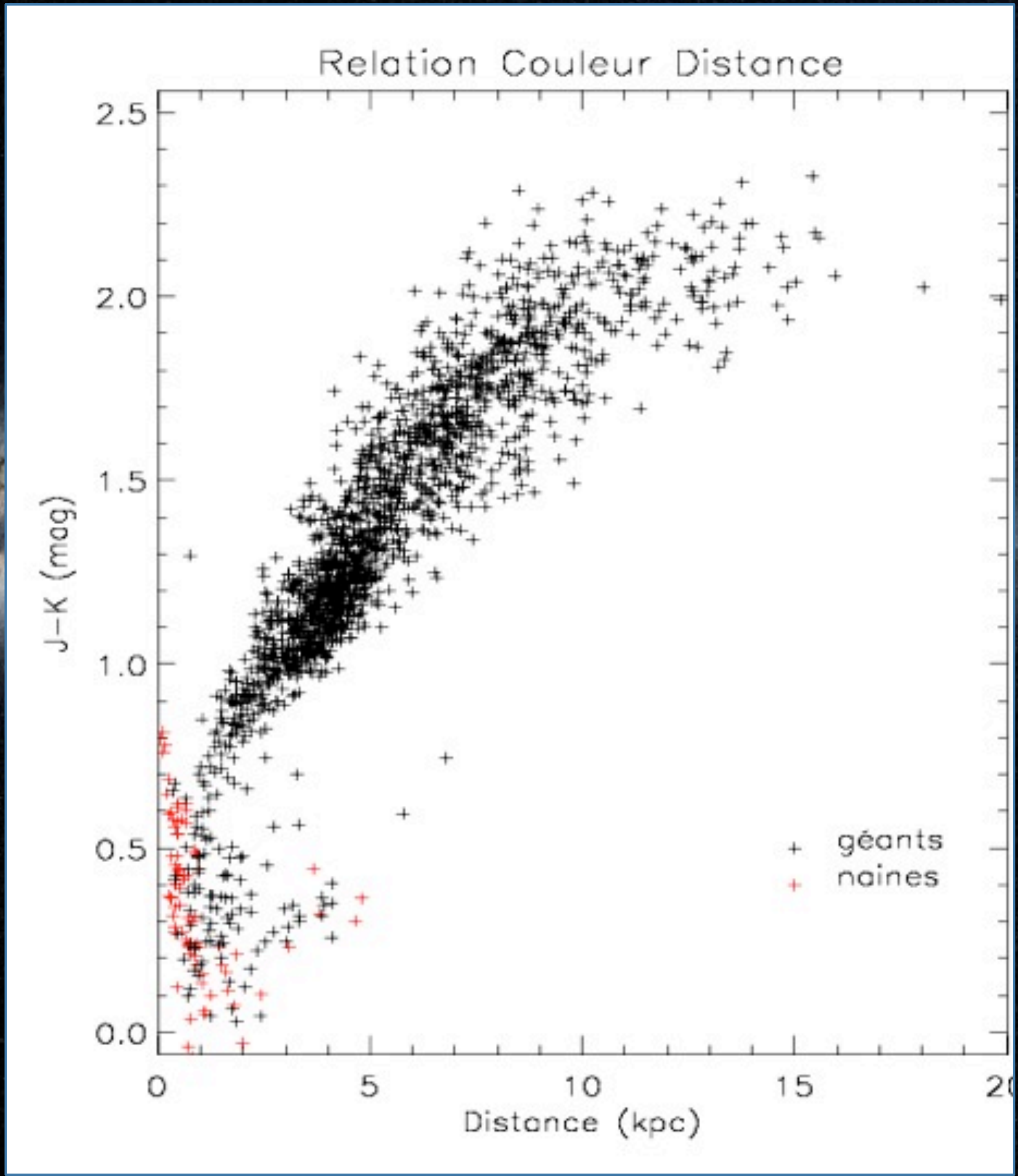
Galactic plane

NIR data requires a good extinction map

3D Extinction map

Correlation between J-K and distance for red clump giants

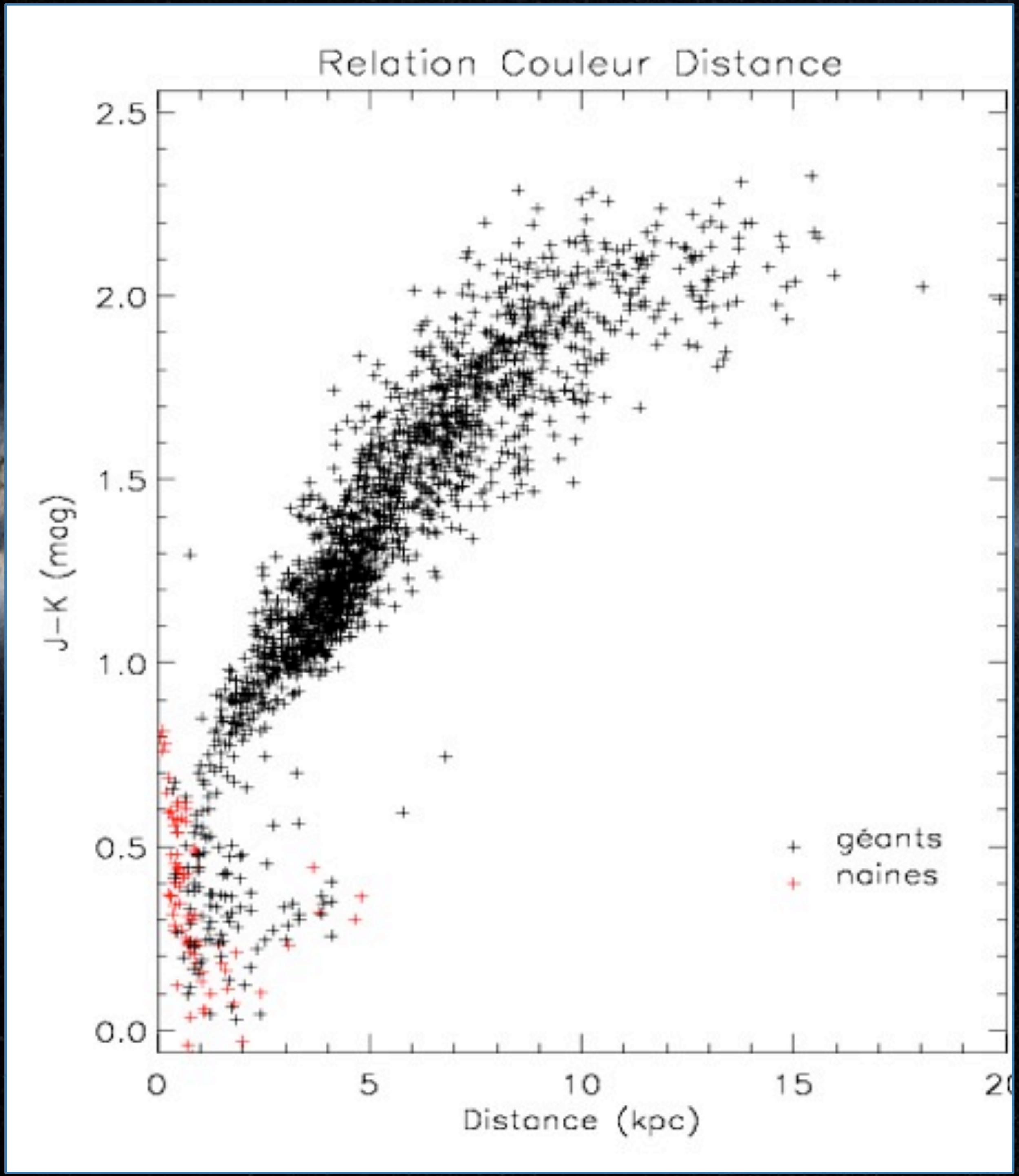
➲ determination of Av vs distance



3D Extinction map

❶ 2MASS and simulated data sorted by increasing J-K and binned

❷ J-K colour of the simulated stars adjusted to the observed ones by adding extinction



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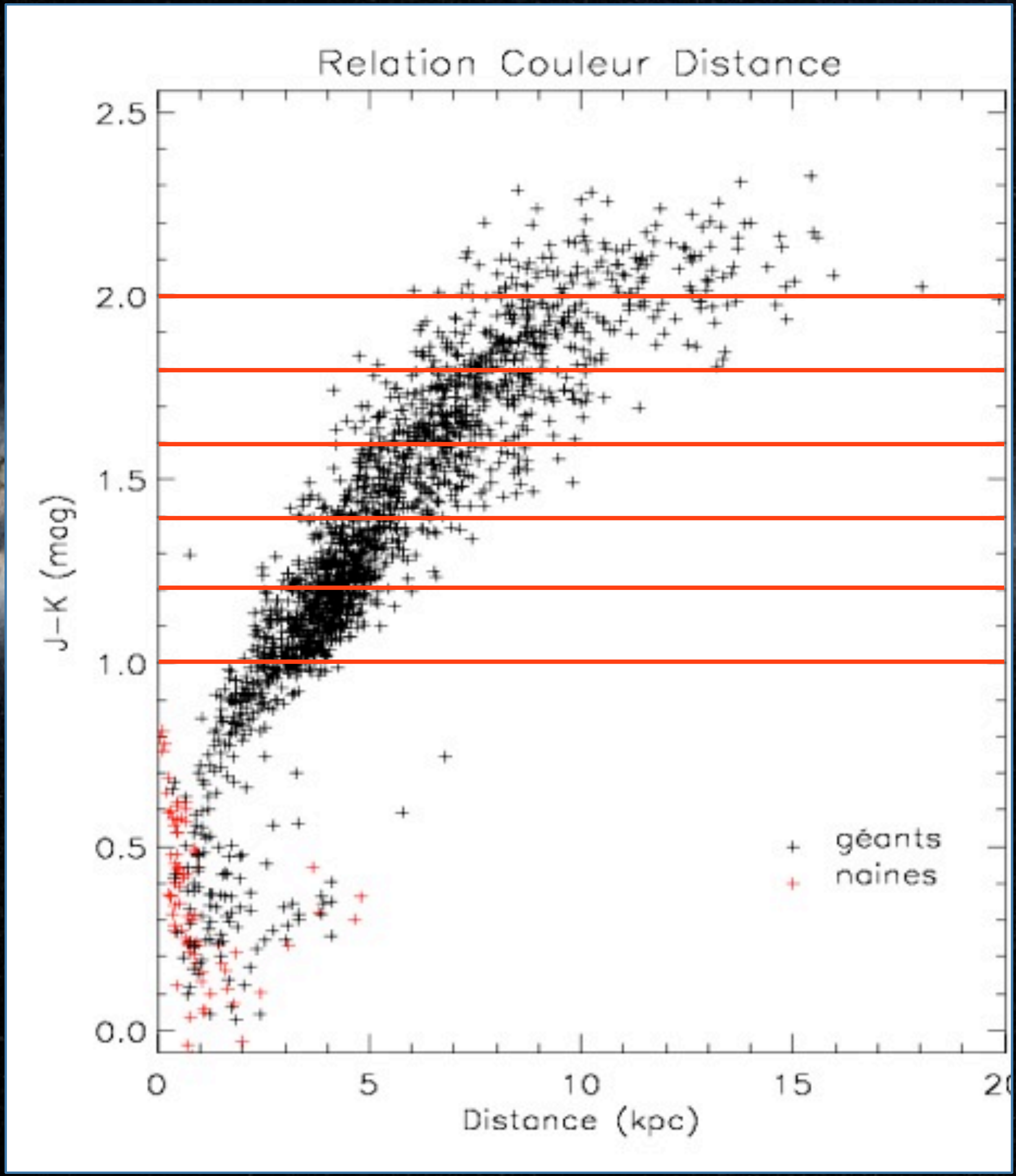

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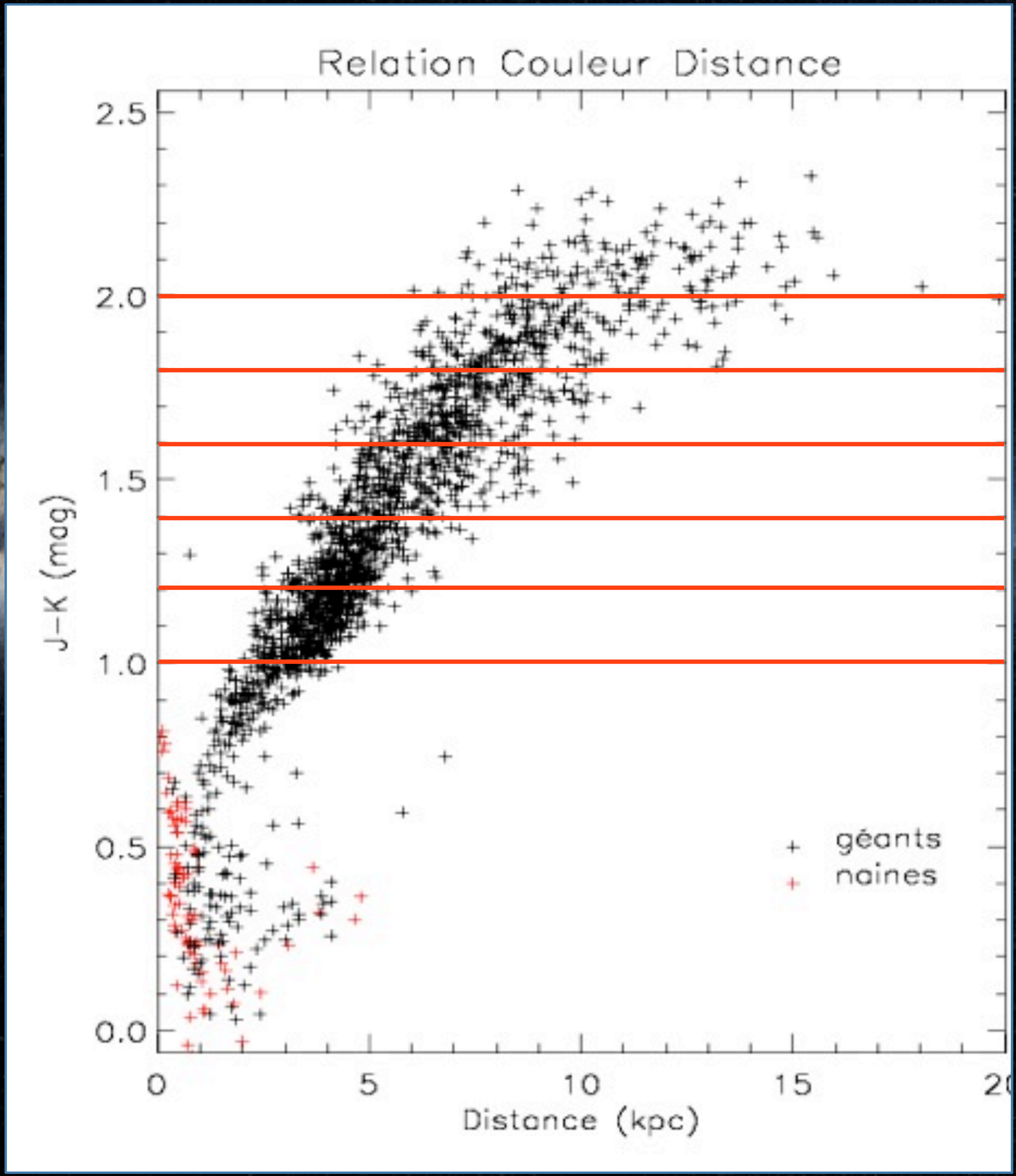

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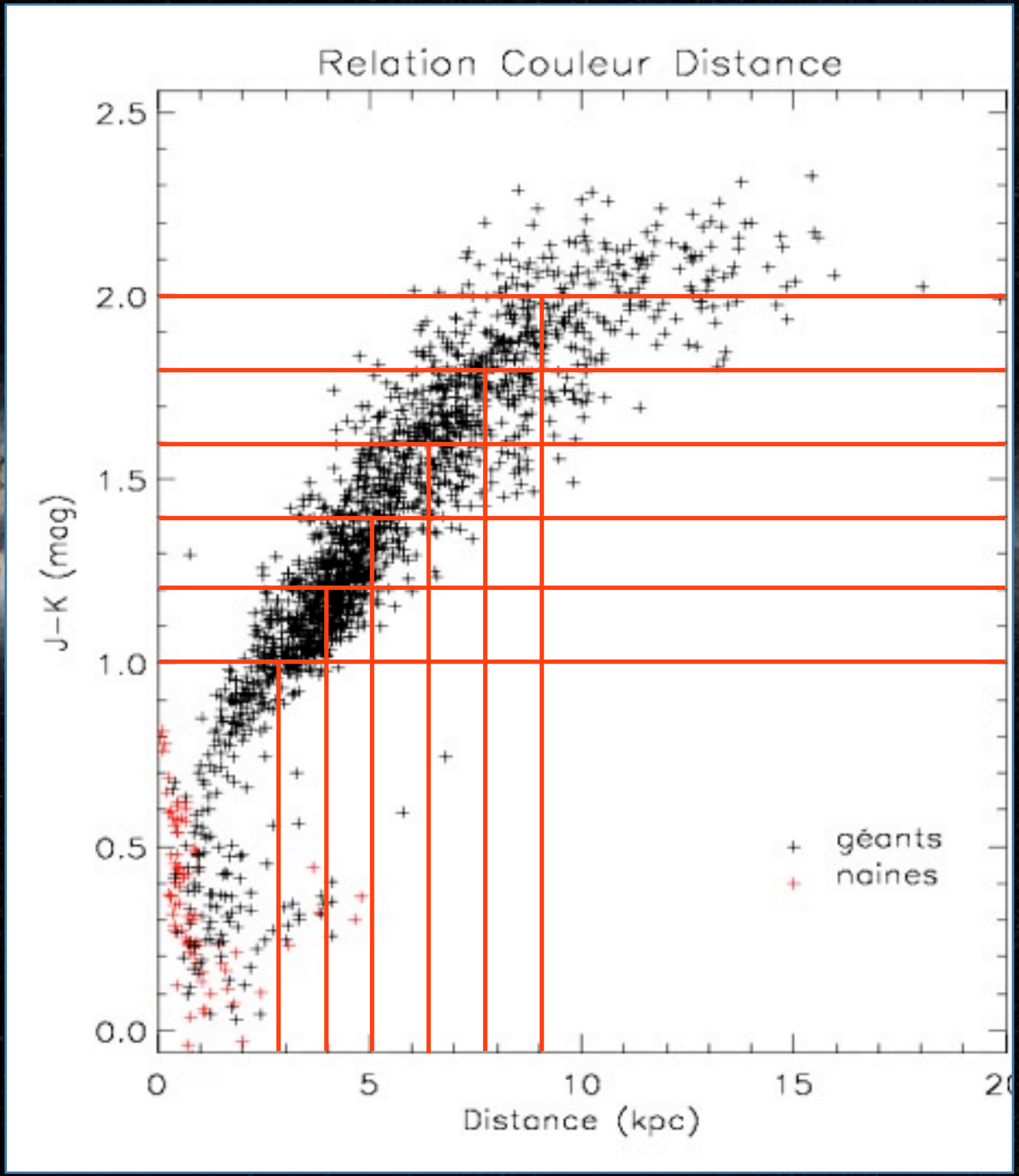

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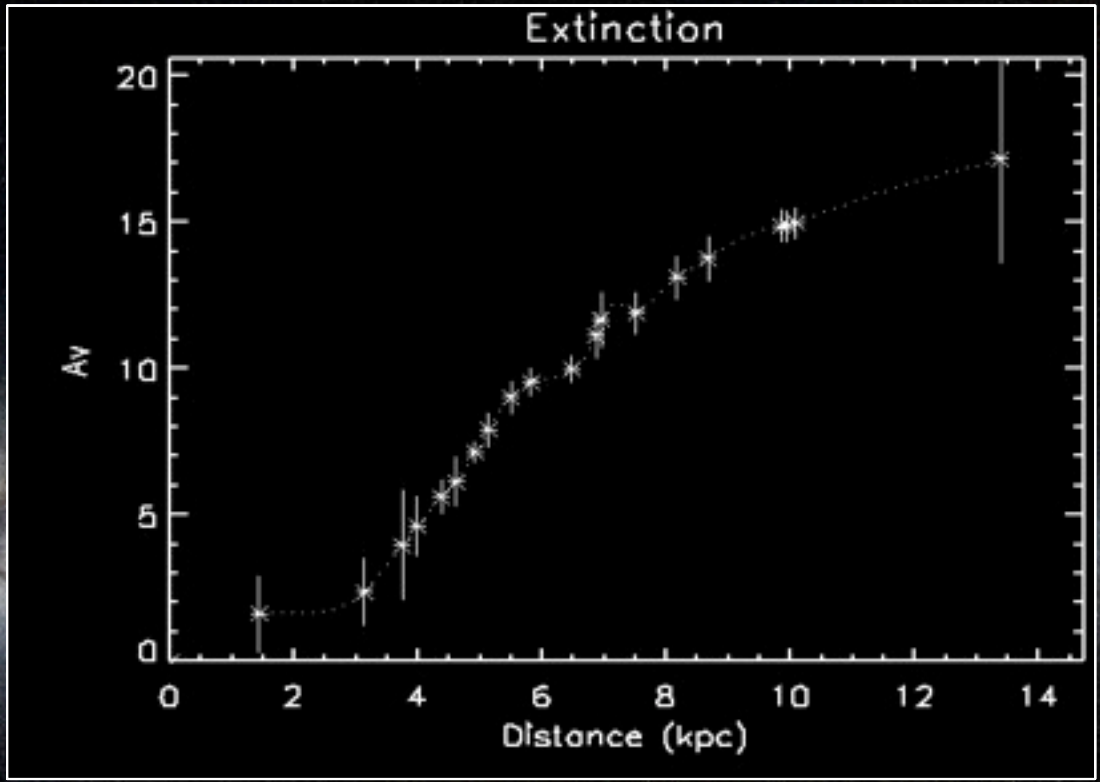

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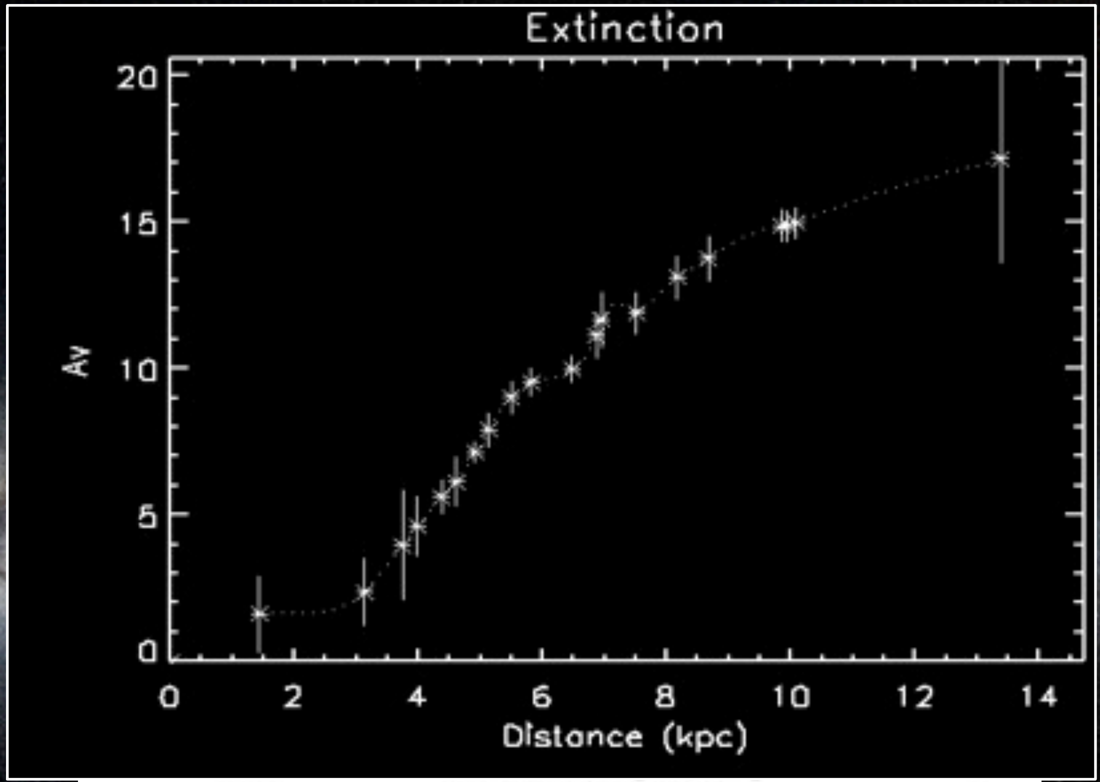

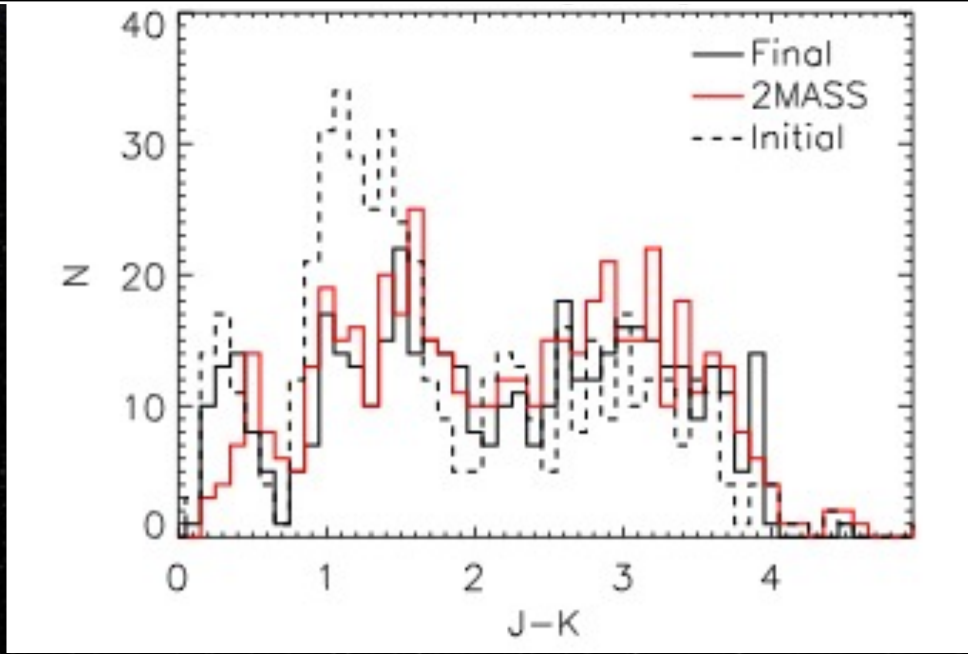

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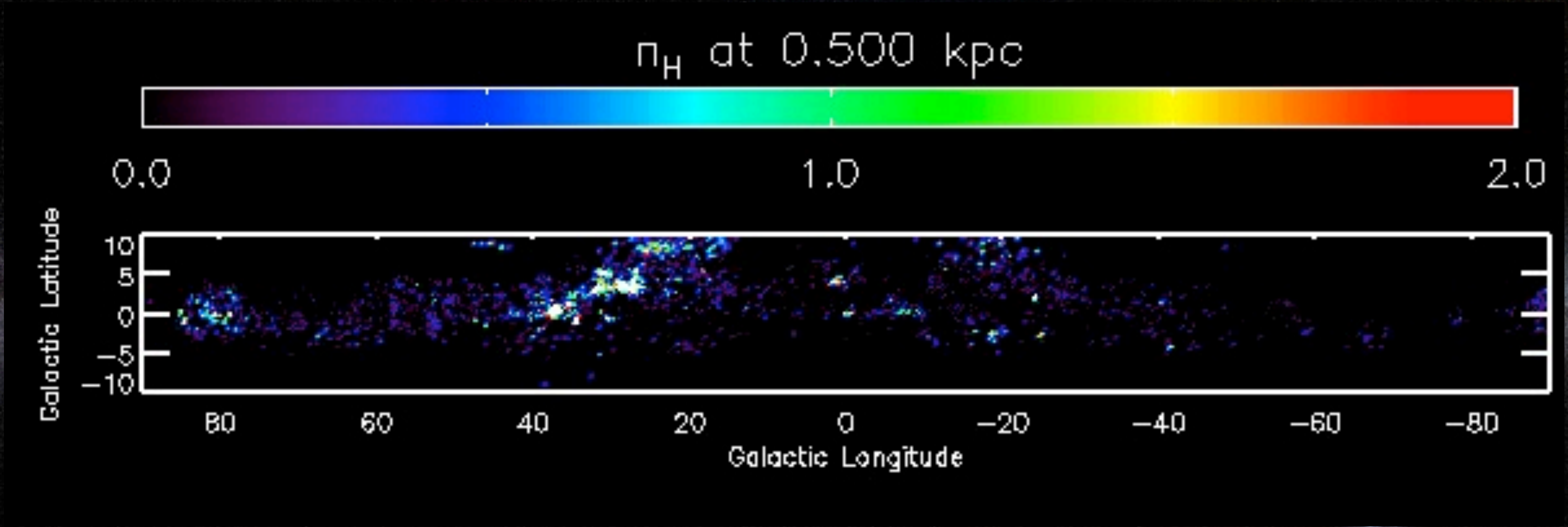

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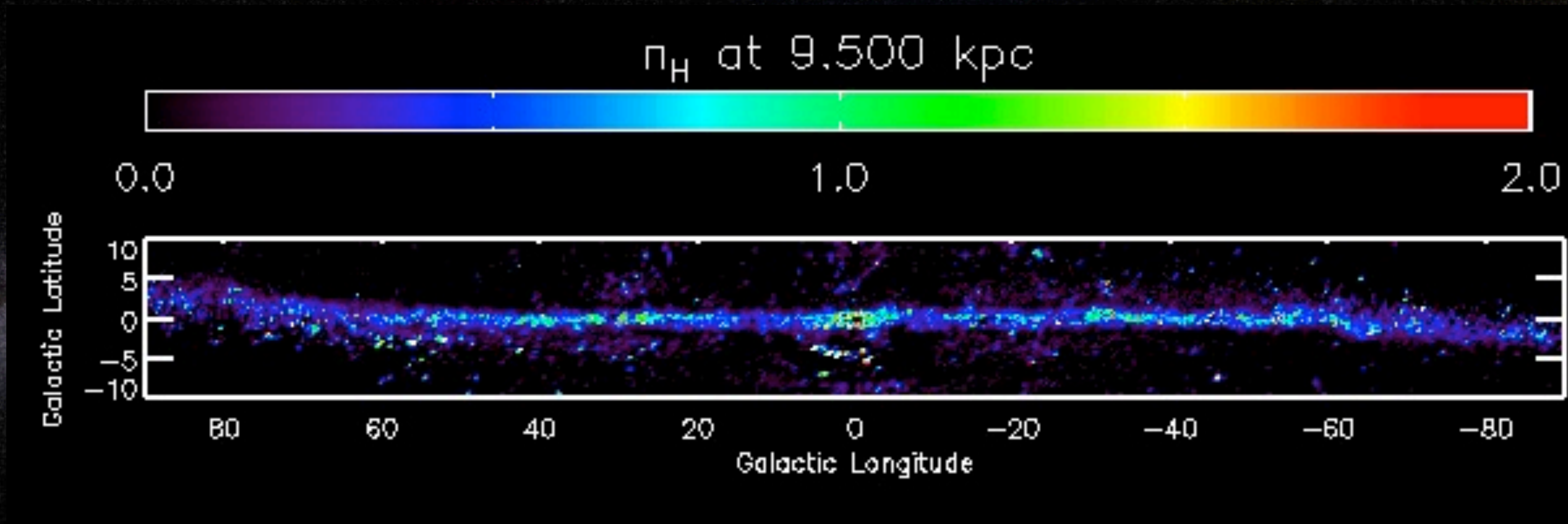

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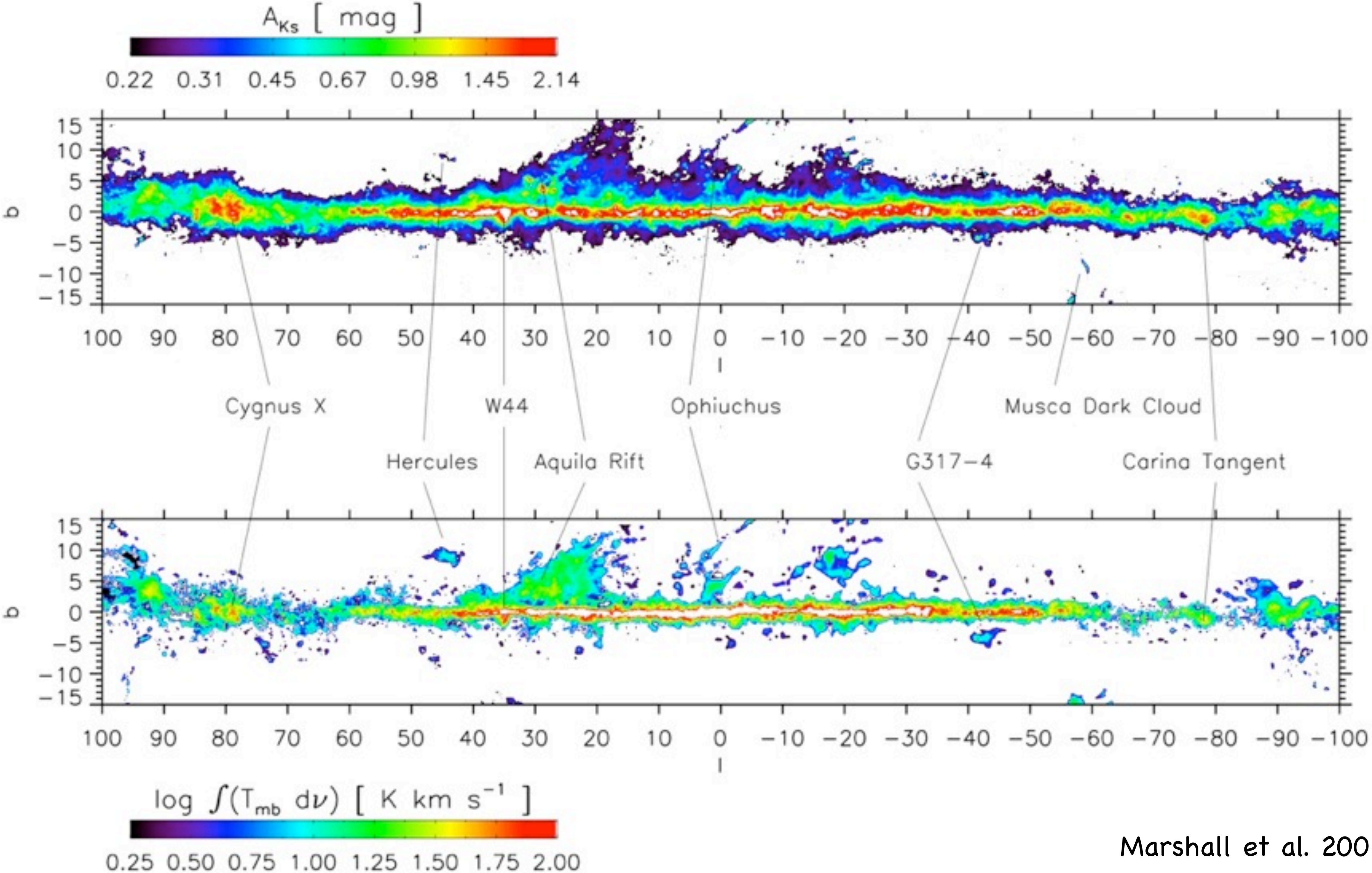
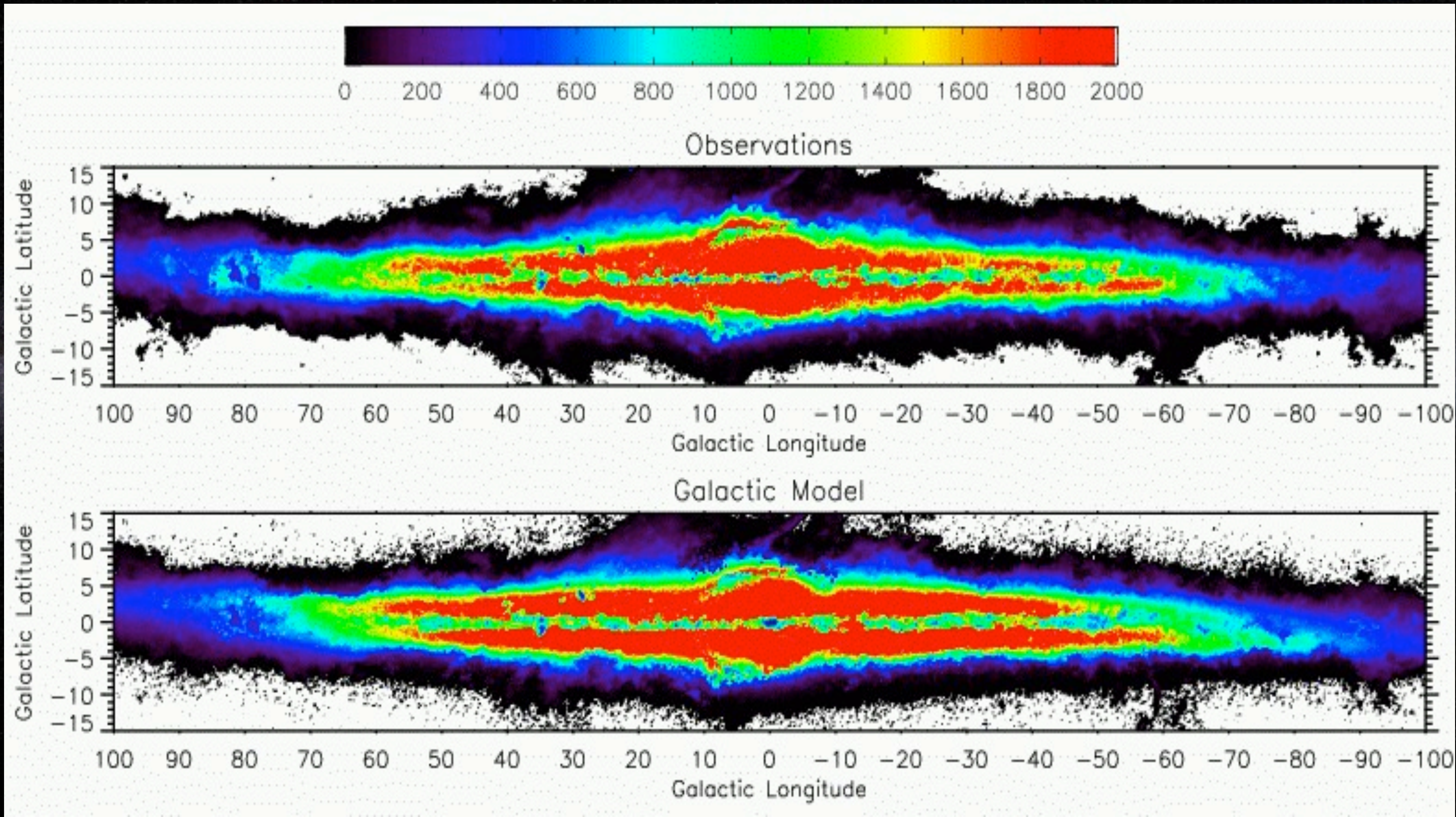


Marshall et al. 2006

2MASS versus BGM



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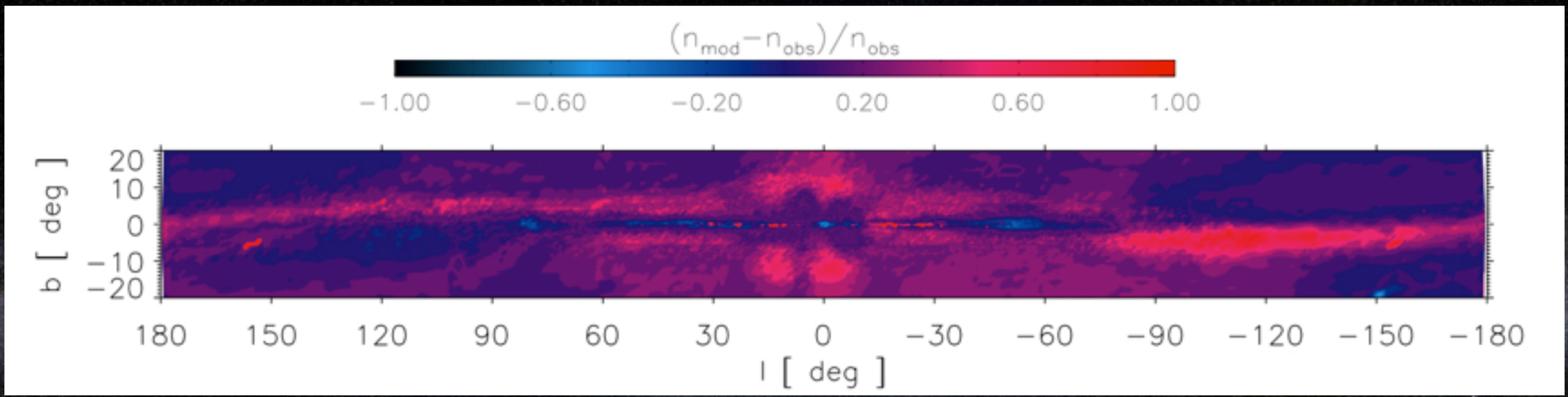


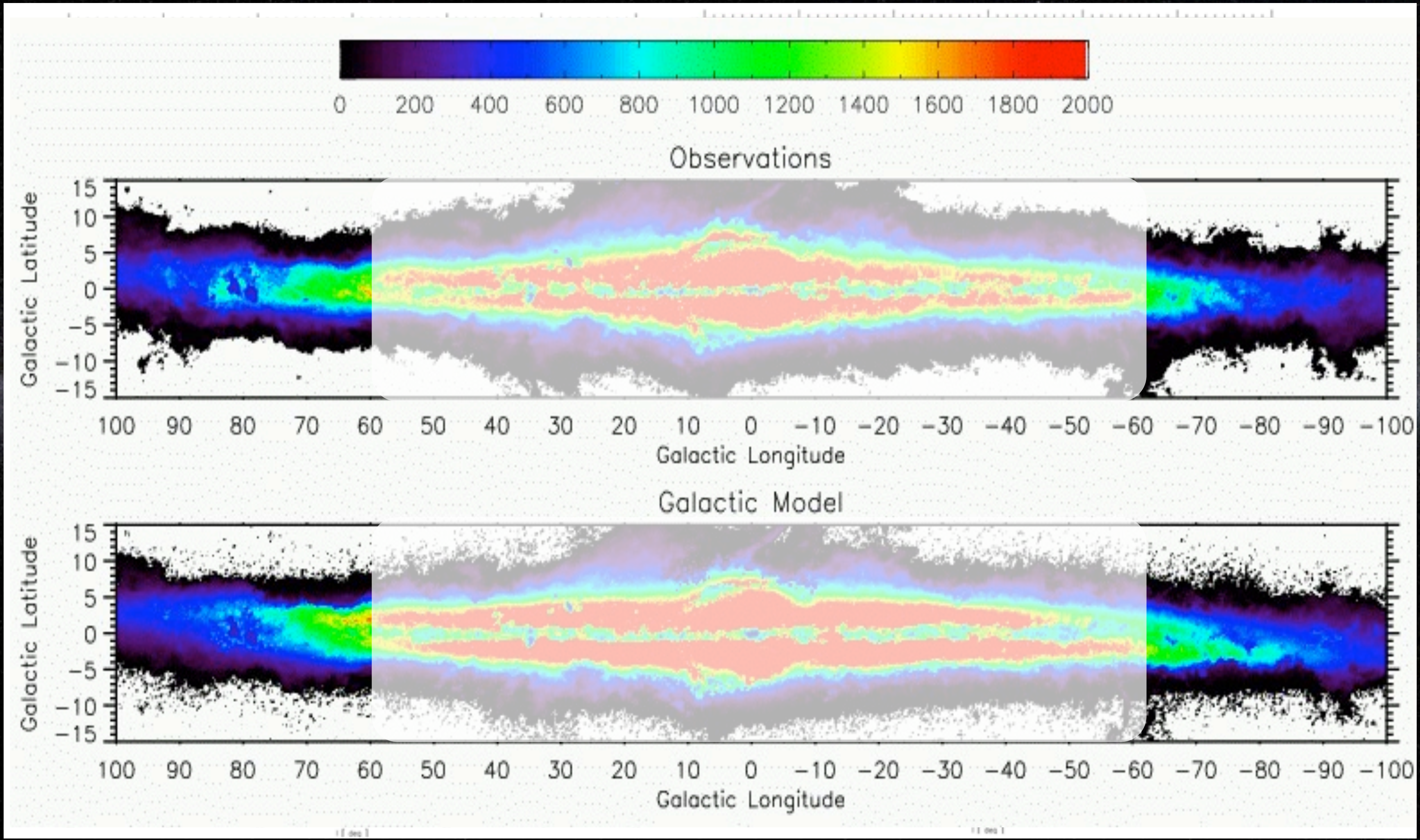
Systematic differences in two regions:

outer bulge

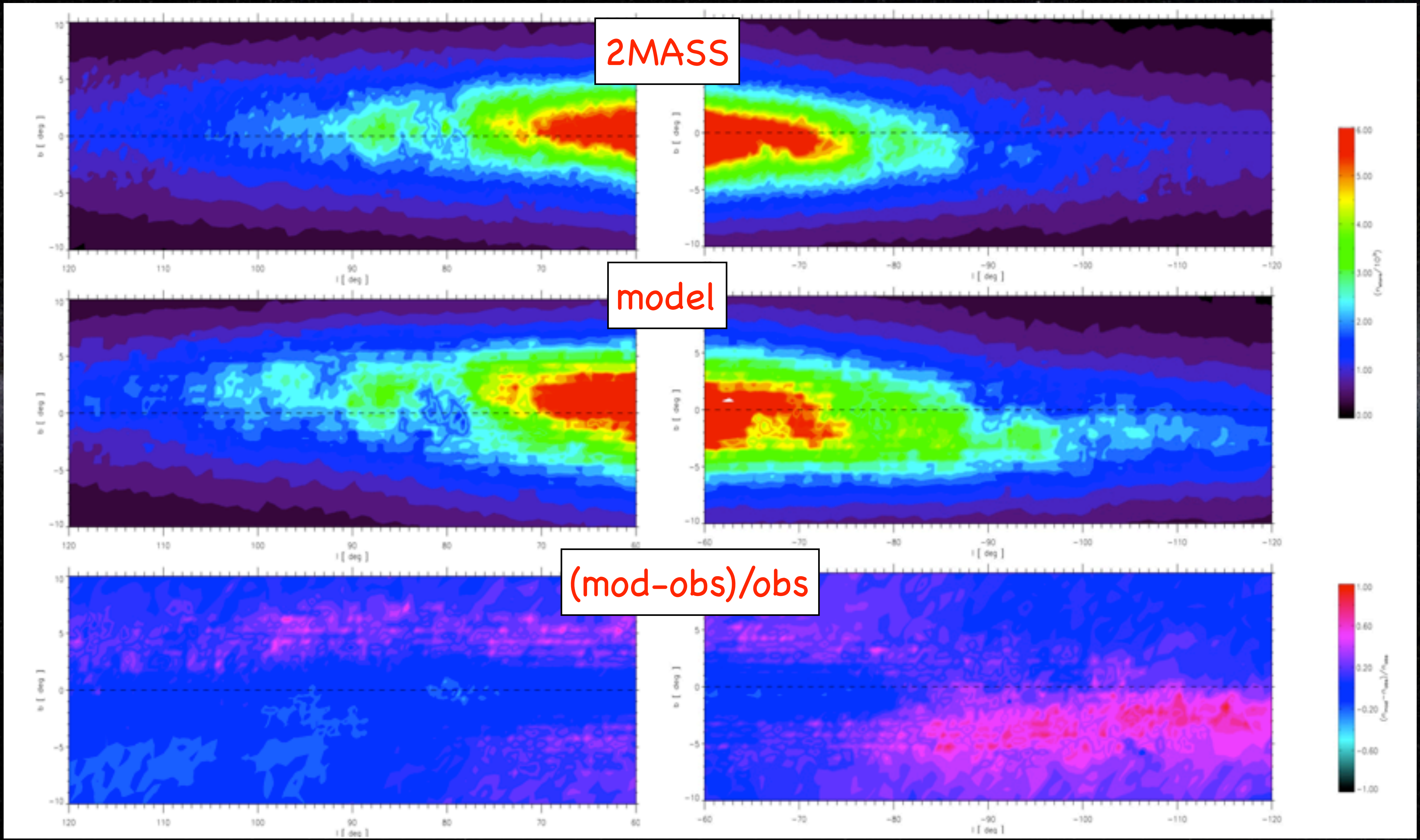
external disc

The external disc and warp

The external disc and warp



The external disc and warp



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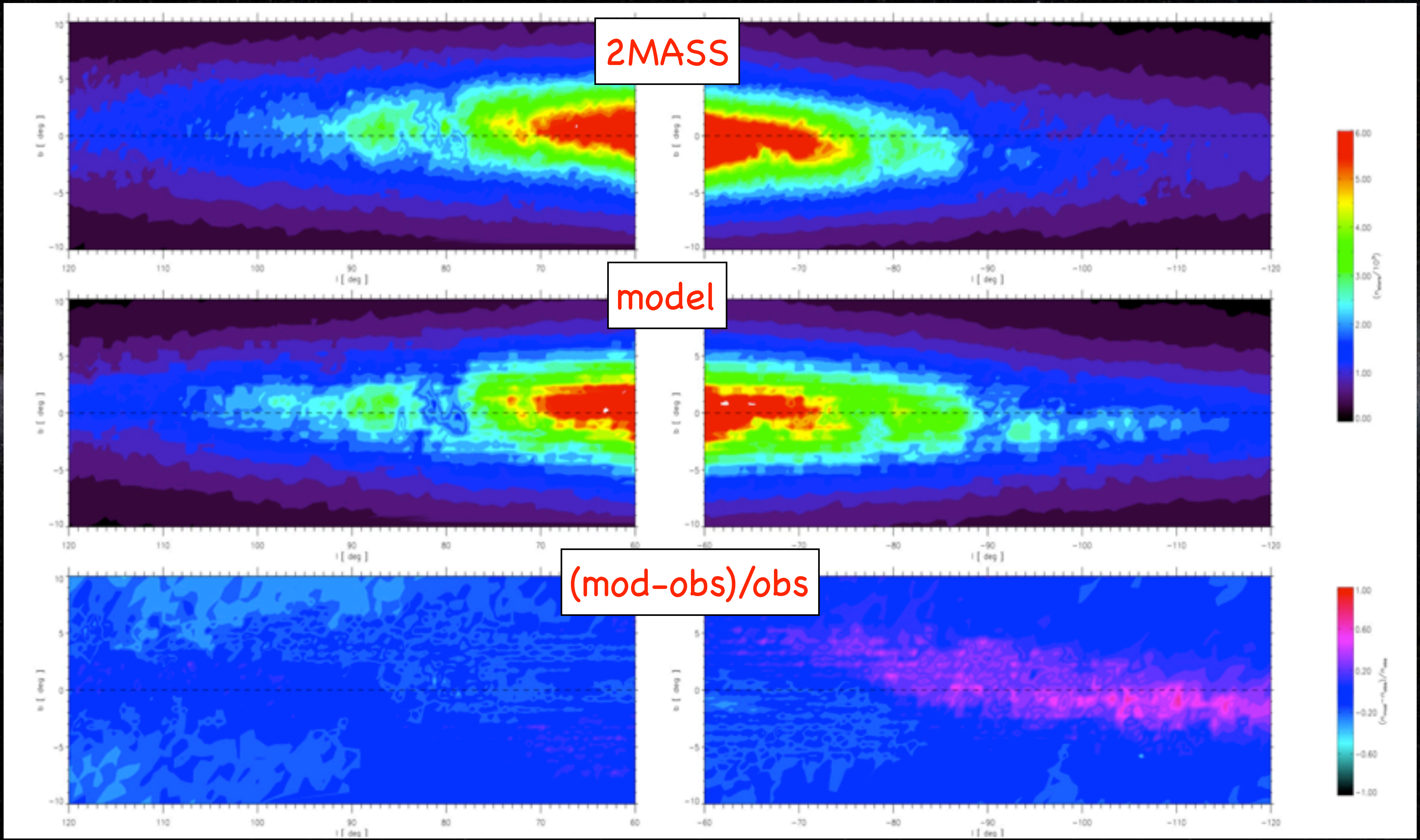
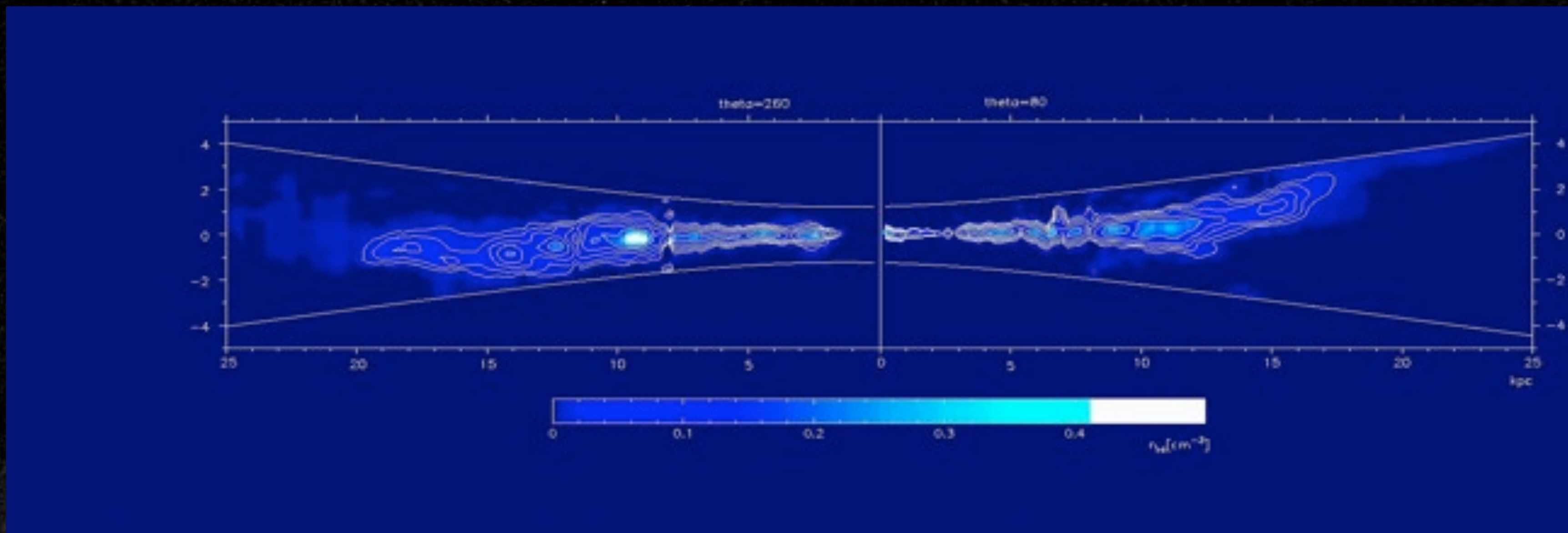
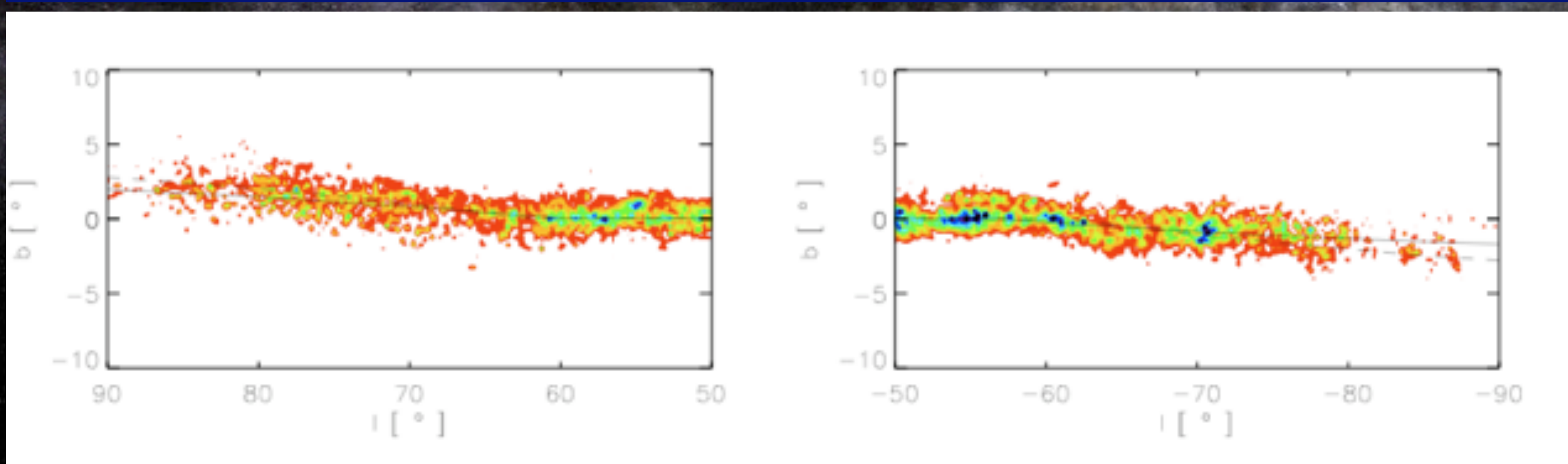


The external disc and warp



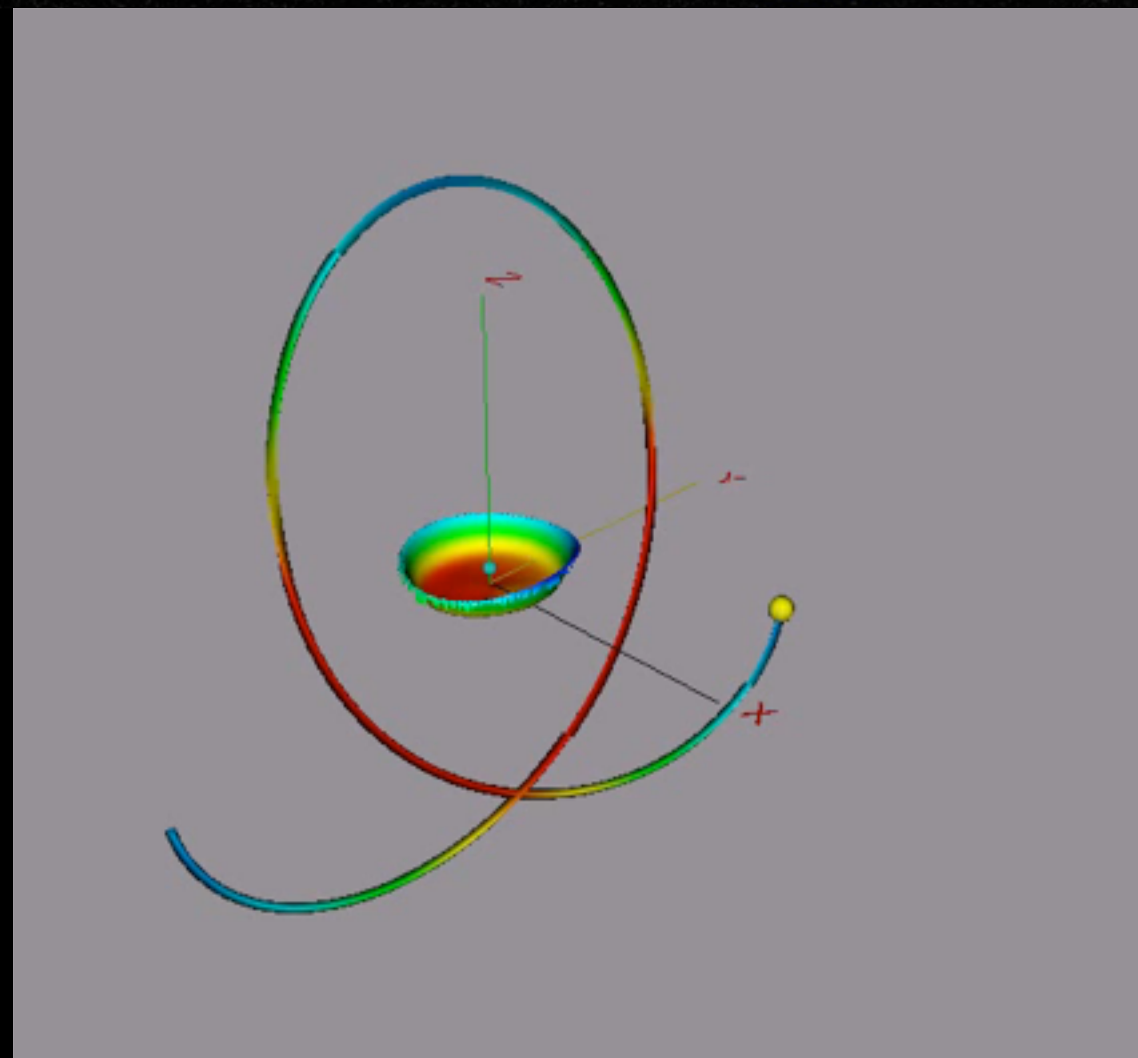
HI warp
(Nakanishi & Sofue)



Dust warp
(Marshall et al.)

The Milky Way has a complexe, asymmetric warp. Different components follow slightly different warp shape (and/or amplitude). Different components react differently to the forces at the origin of the warp. Warp origin ?

The external disc and warp



Weinberg, 1995

The Milky Way has a complexe, asymmetric warp. Different components follow slightly different warp shape (and/or amplitude). Different components react differently to the forces at the origin of the warp. Warp origin ?

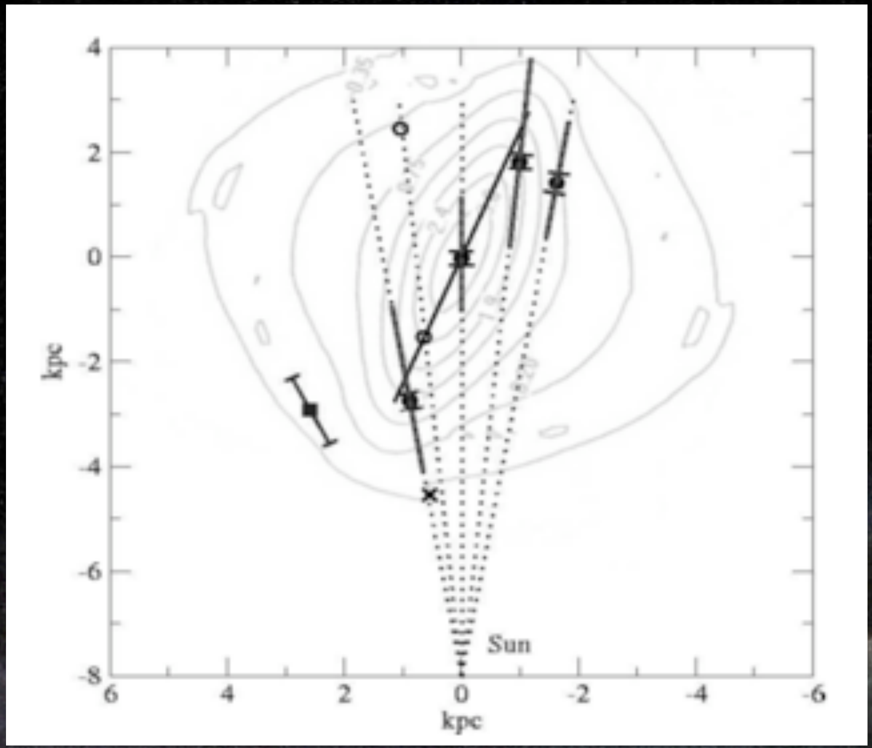
The central region: bulge and bar

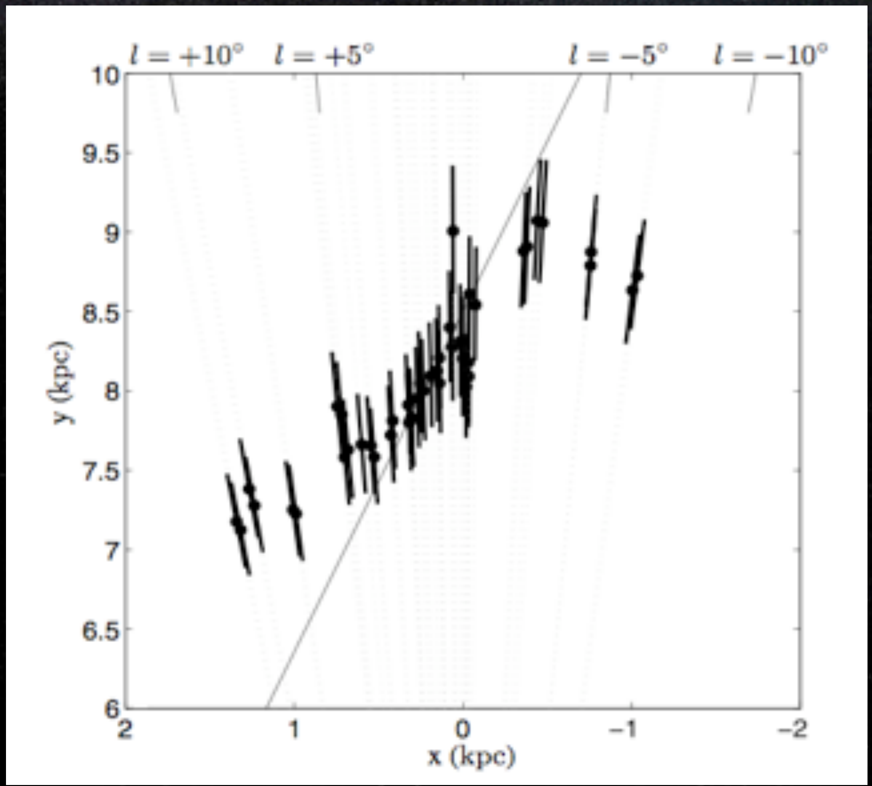
Bulge: fast and early star formation, and/or accretions of spheroidal structure in the center of disc galaxies

Bar: secular evolution in the disc by instability

What do we see in the center of the Milky Way ?

Previous investigations: bar angle

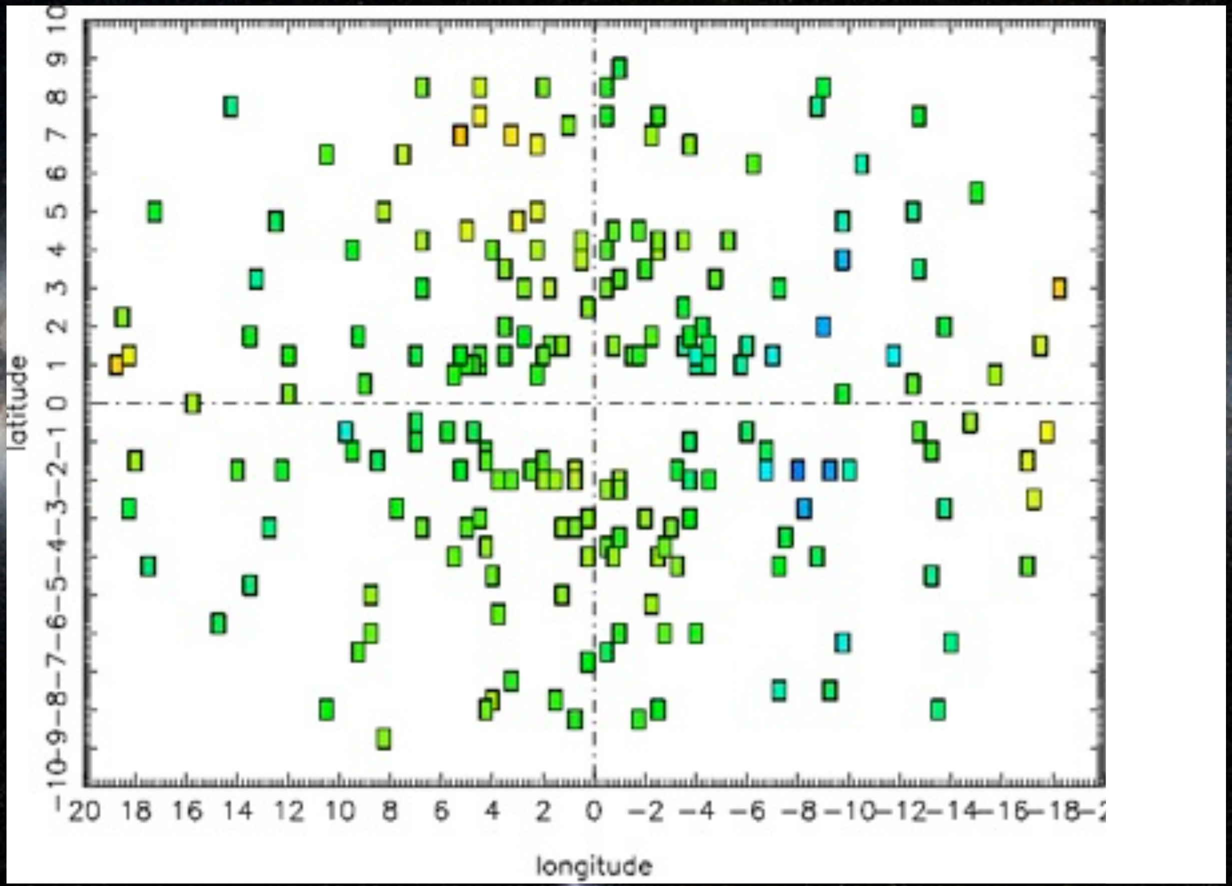




Lopez-Corredoira et al.	long bar 43°
Picaud et al.	10°
Babusiaux et al.	22±6°
Benjamin et al.	45°
Cabrera-Lavers et al.	2 bars 45° and 13°
Rattenbury et al.	25°

Bulge/bar: new investigation

- 200 windows selected in 2MASS
- Wide region covered: -20°<l<20° and -10°<b<10°
- BGM+3D Marshall extinction model
- Monte Carlo exploration of parameter space + maximum likelihood fit, 10-19 parameters



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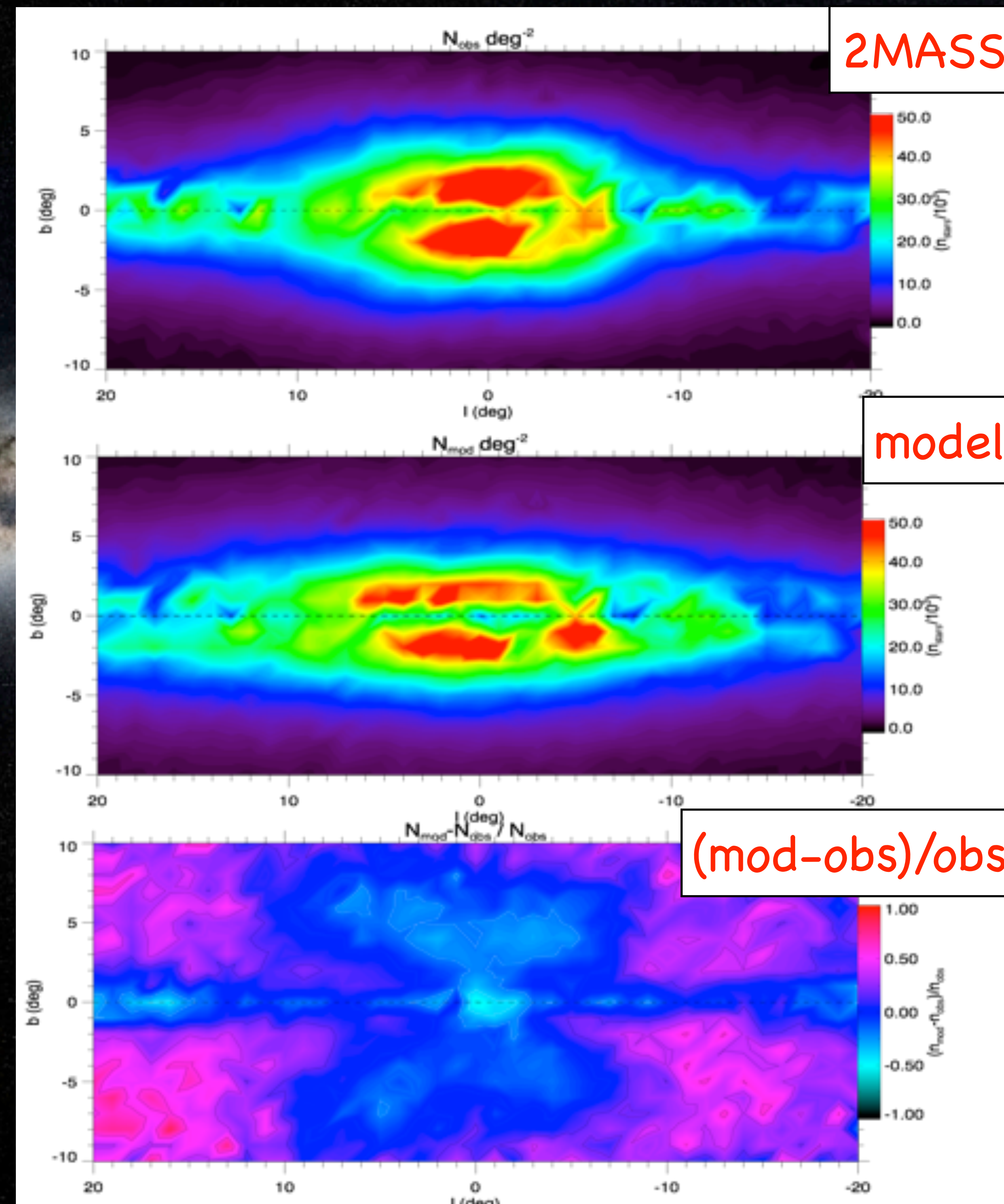


Best fit model: angle of 9°

$y_0/x_0=0.3$, $z_0/x_0=0.1$

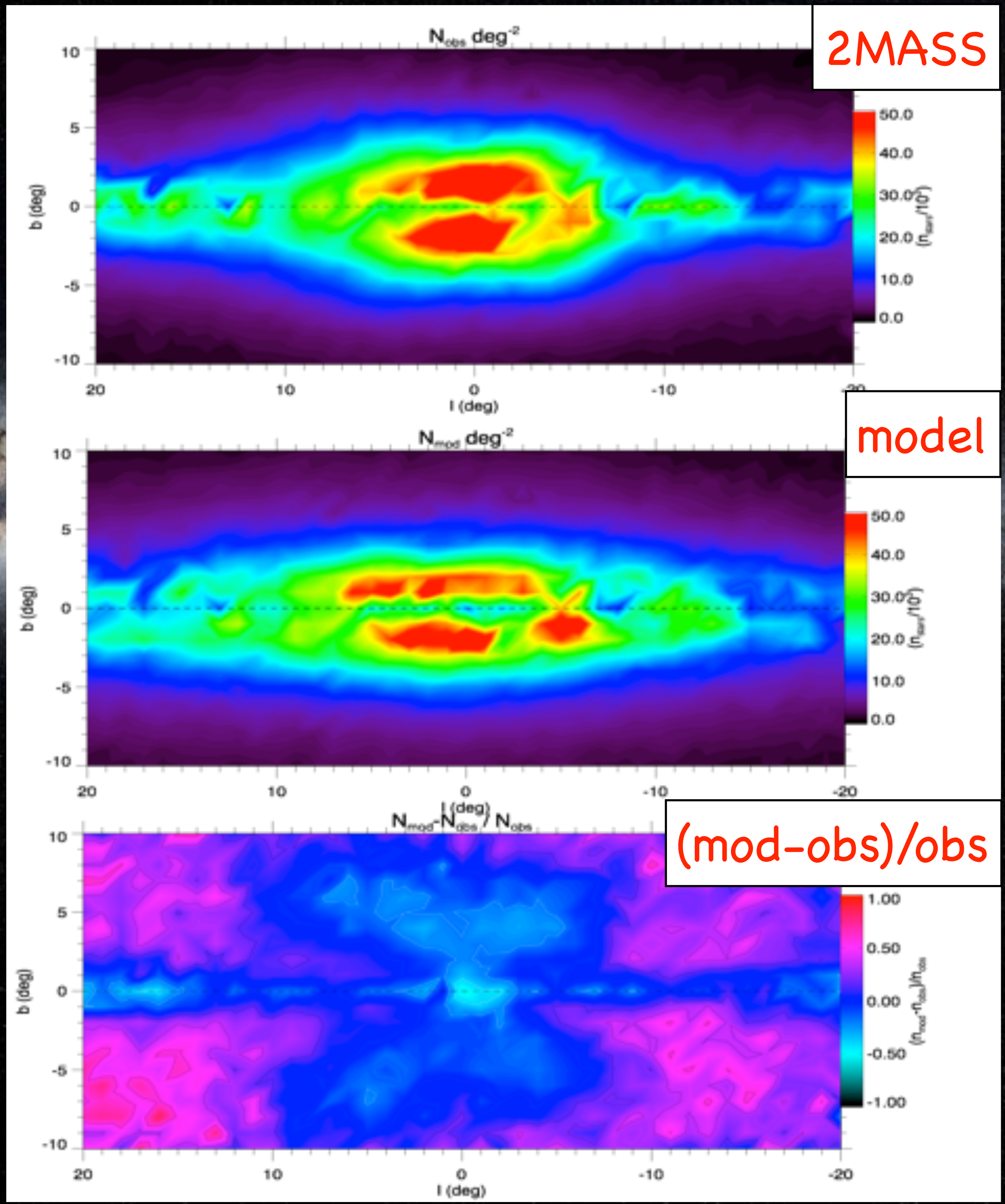
Bulge/bar: new investigation

Selected regions :

Low b or high l: angle 13-14°

High b or small l: angle 6-7°

➲ need to fit two structures



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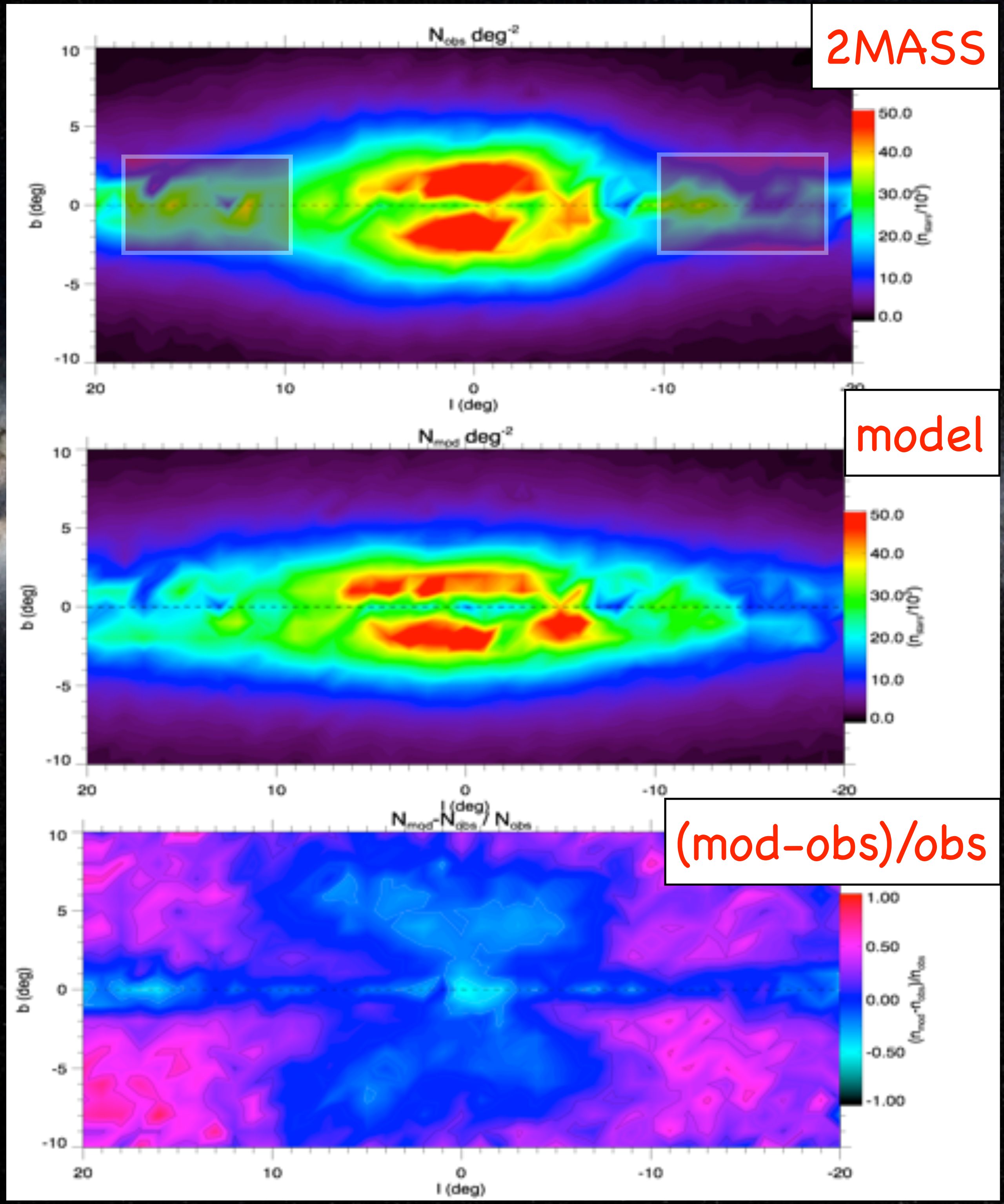

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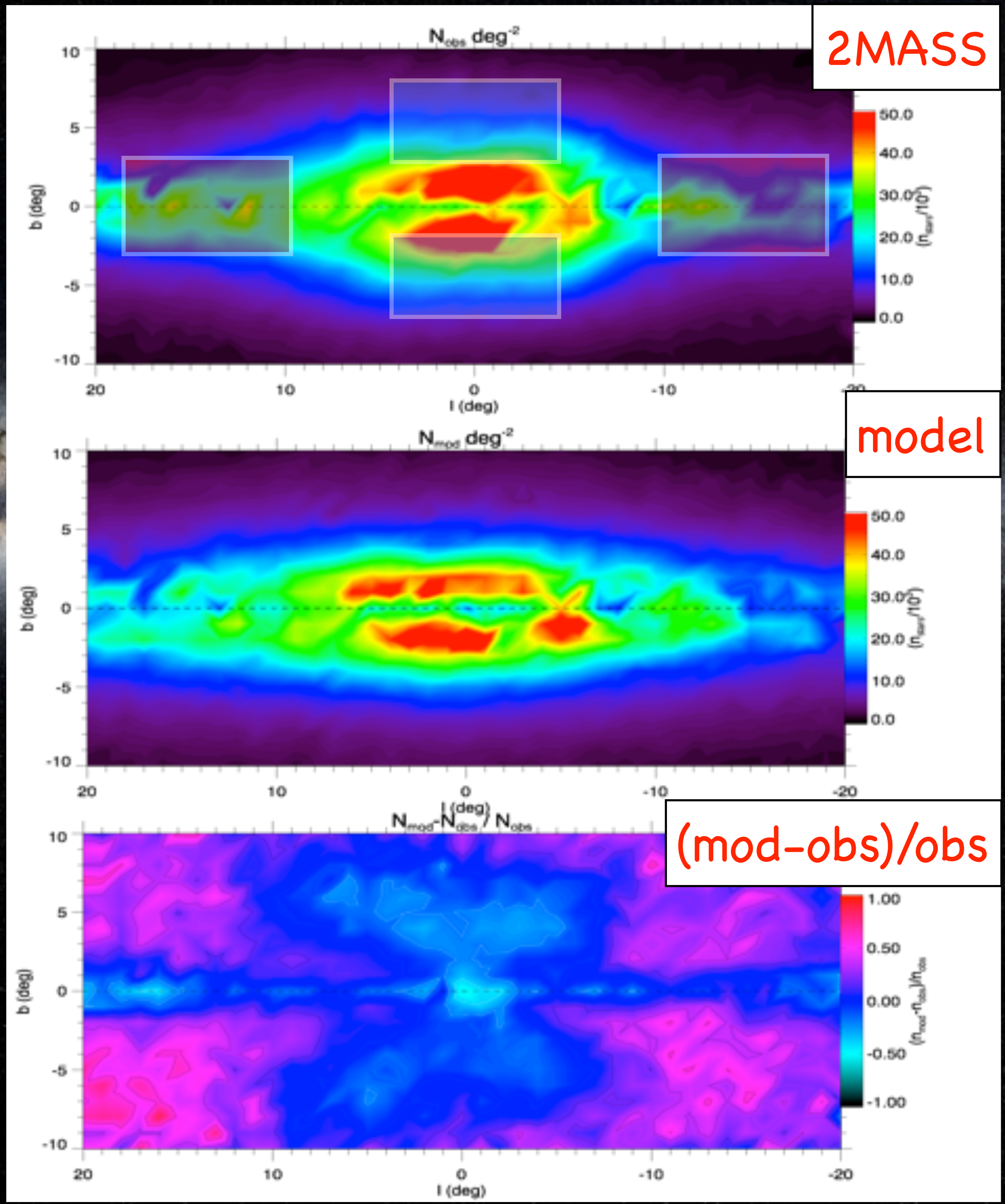

Bulge/bar: new investigation

Selected regions :

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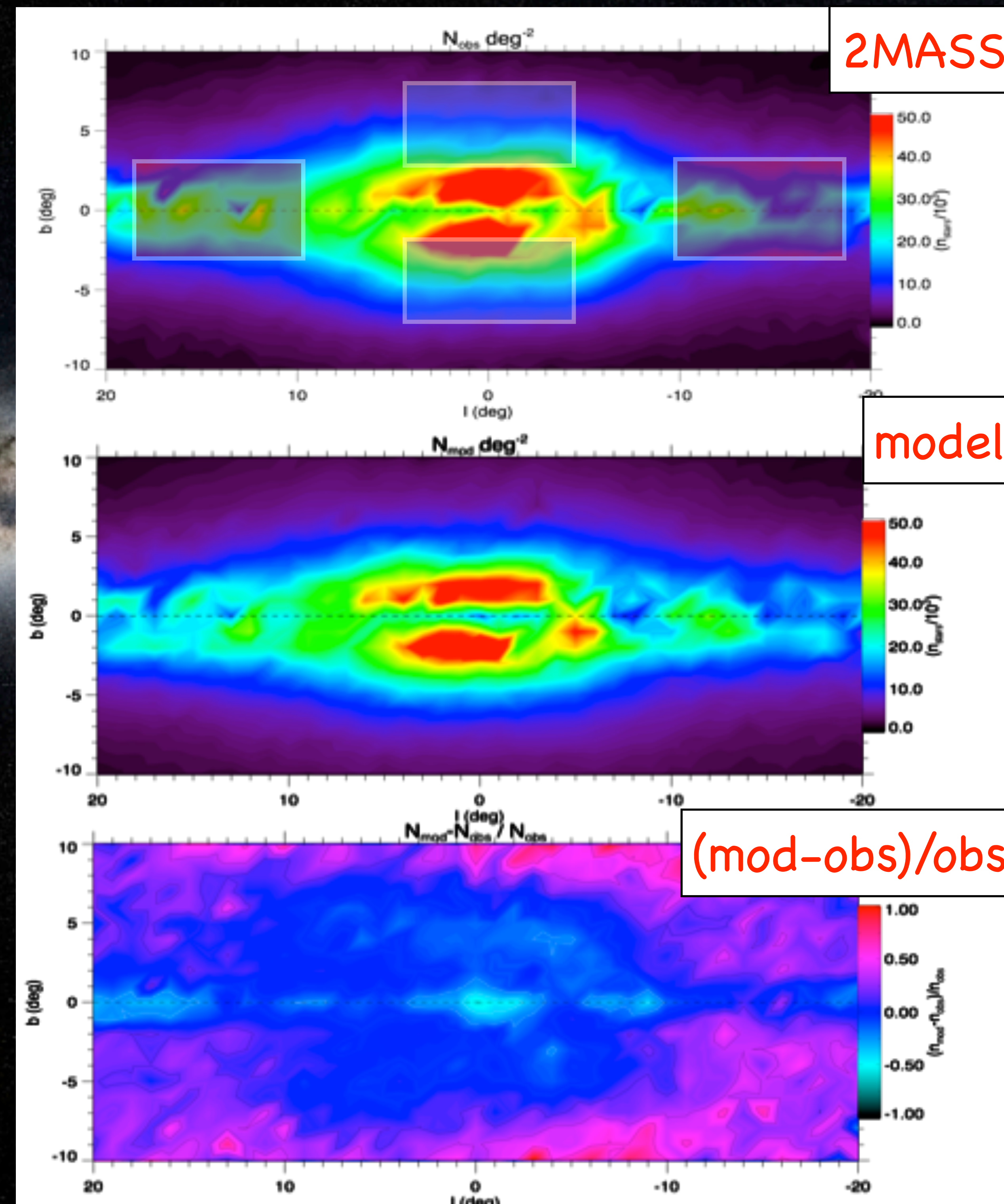
High b or small l: angle 6-7°

➲ need to fit two structures

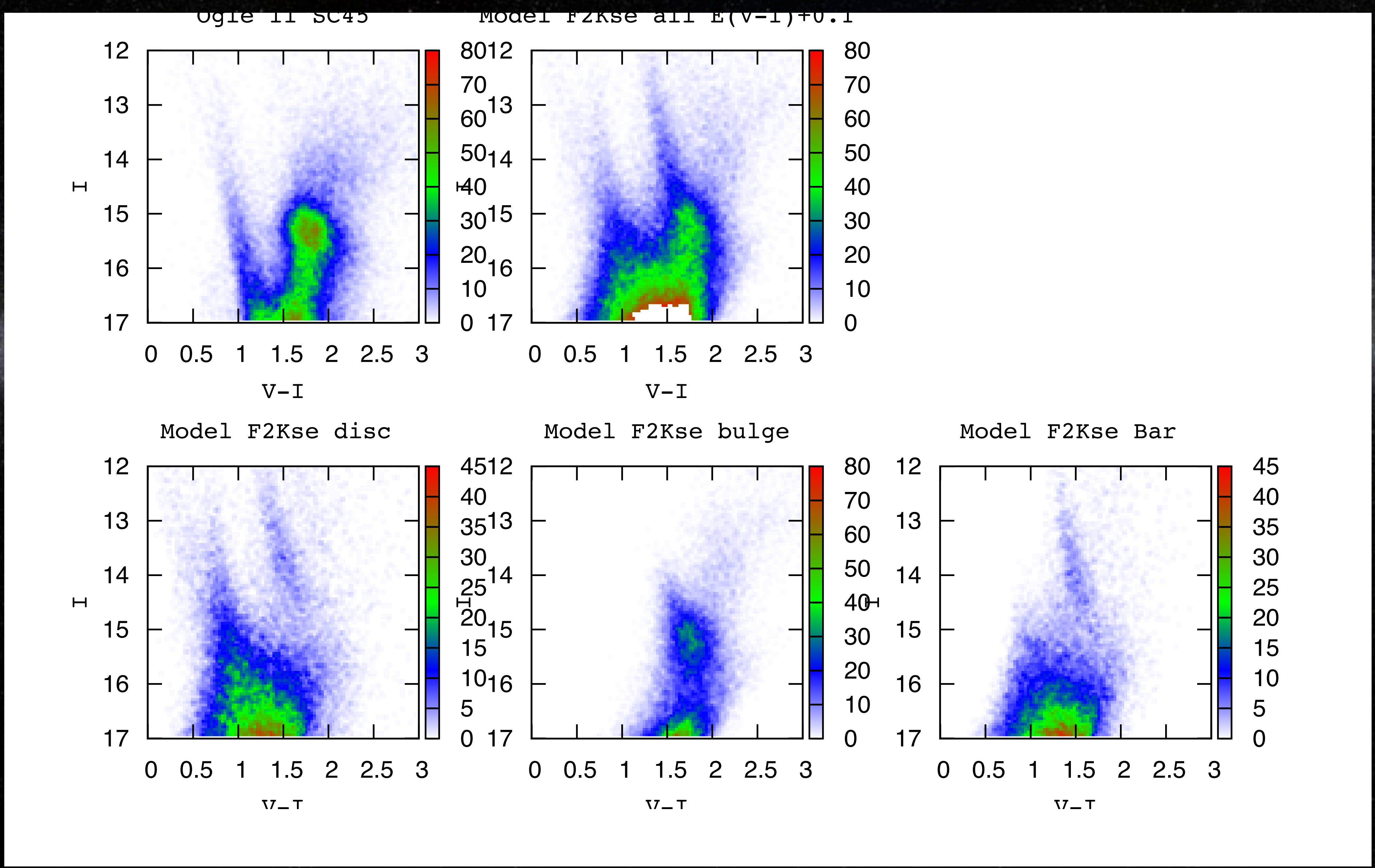
triaxial boxy bulge with angle of 20° + structure oriented along the Sun-center direction seen only in the in-plane region (|l|<4°)

In agreement with Nishiyama et al. 2005 (distance of the red clump), Babusiaux et al. 2009 and Hill et al. 2010 (abundances)

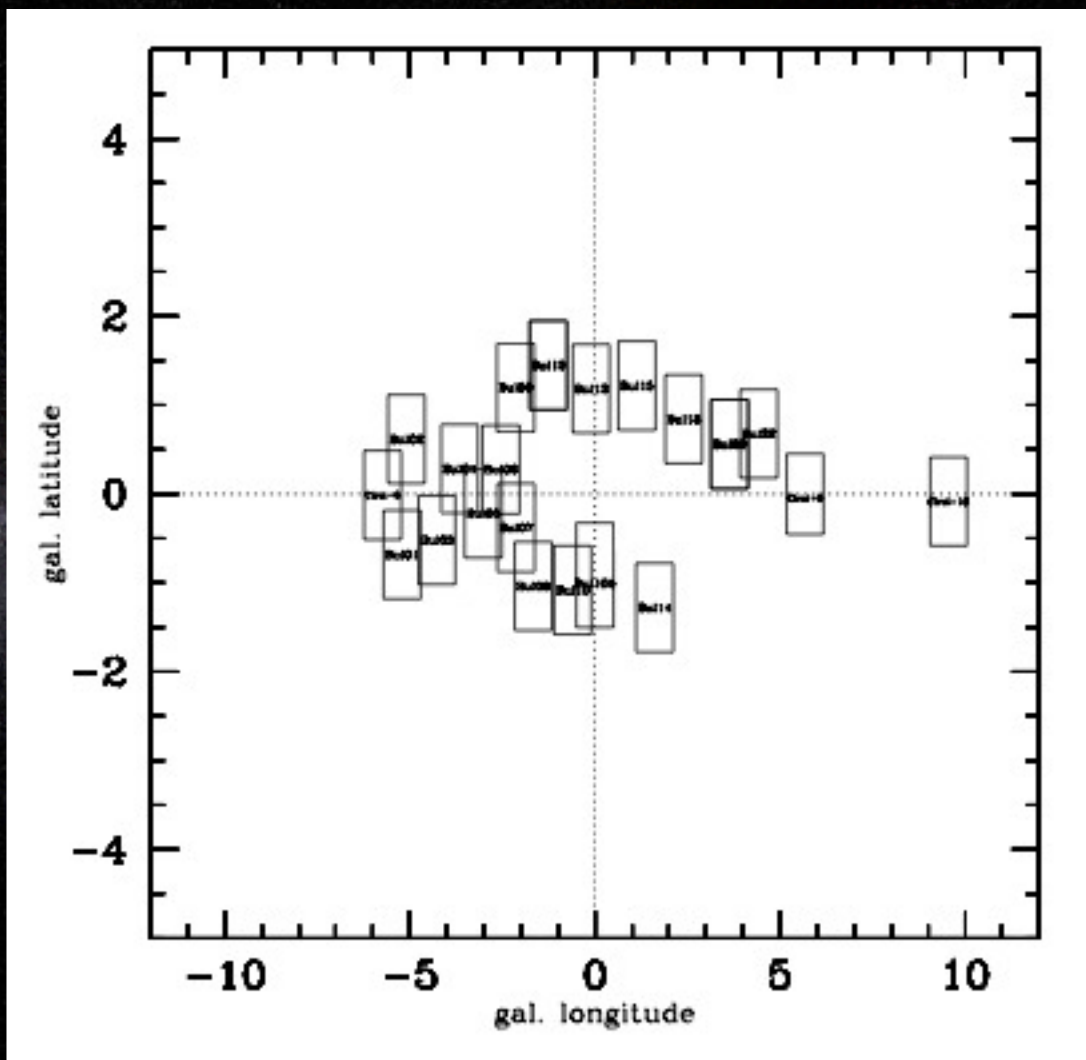


Bulge/bar: new investigation

OGLE II data, Baade's window

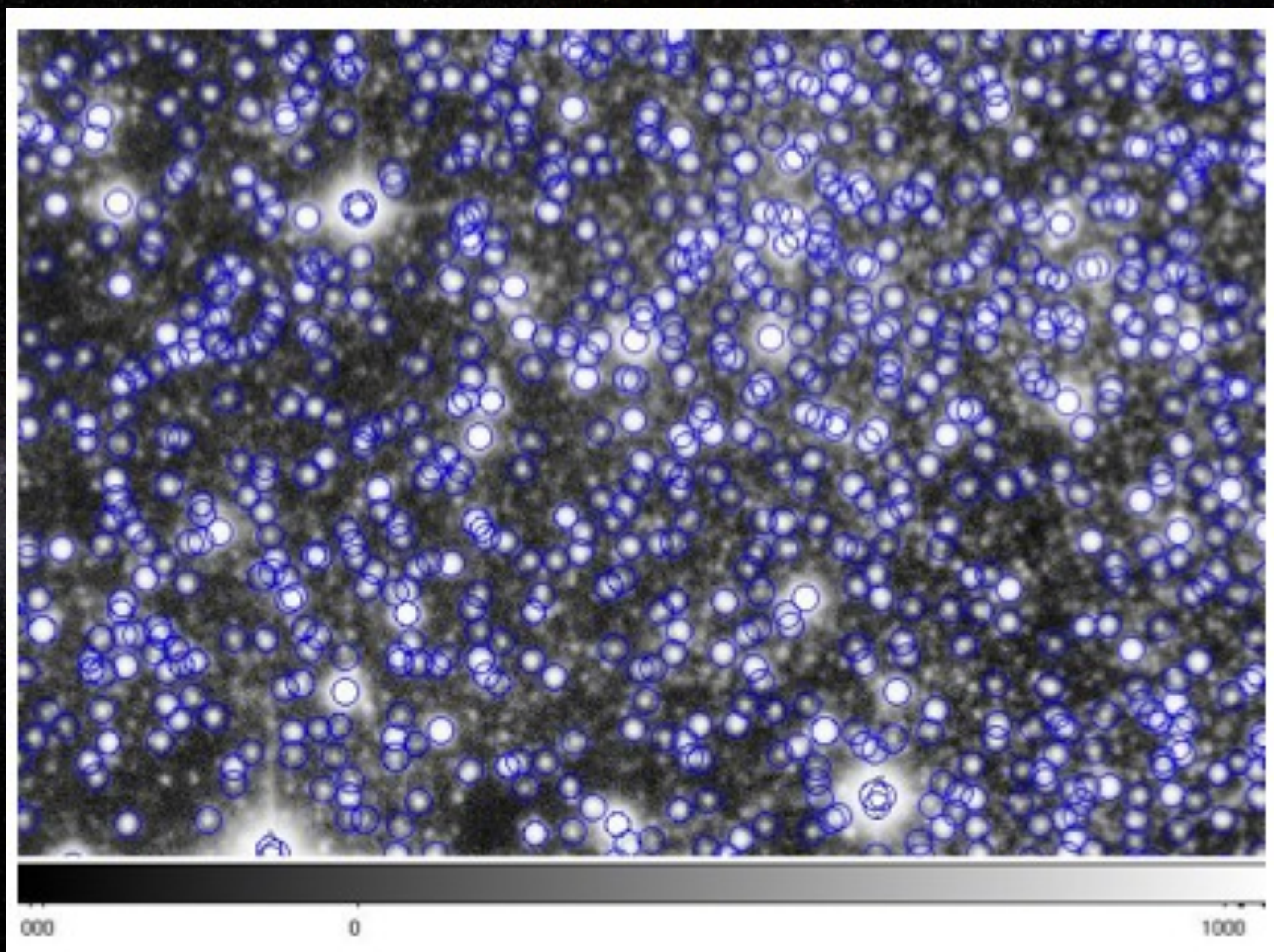


Megabulge



2 epochs: proper motion 1mas/yr (18km/s on the velocity at the distance of the bulge)

Megabulge



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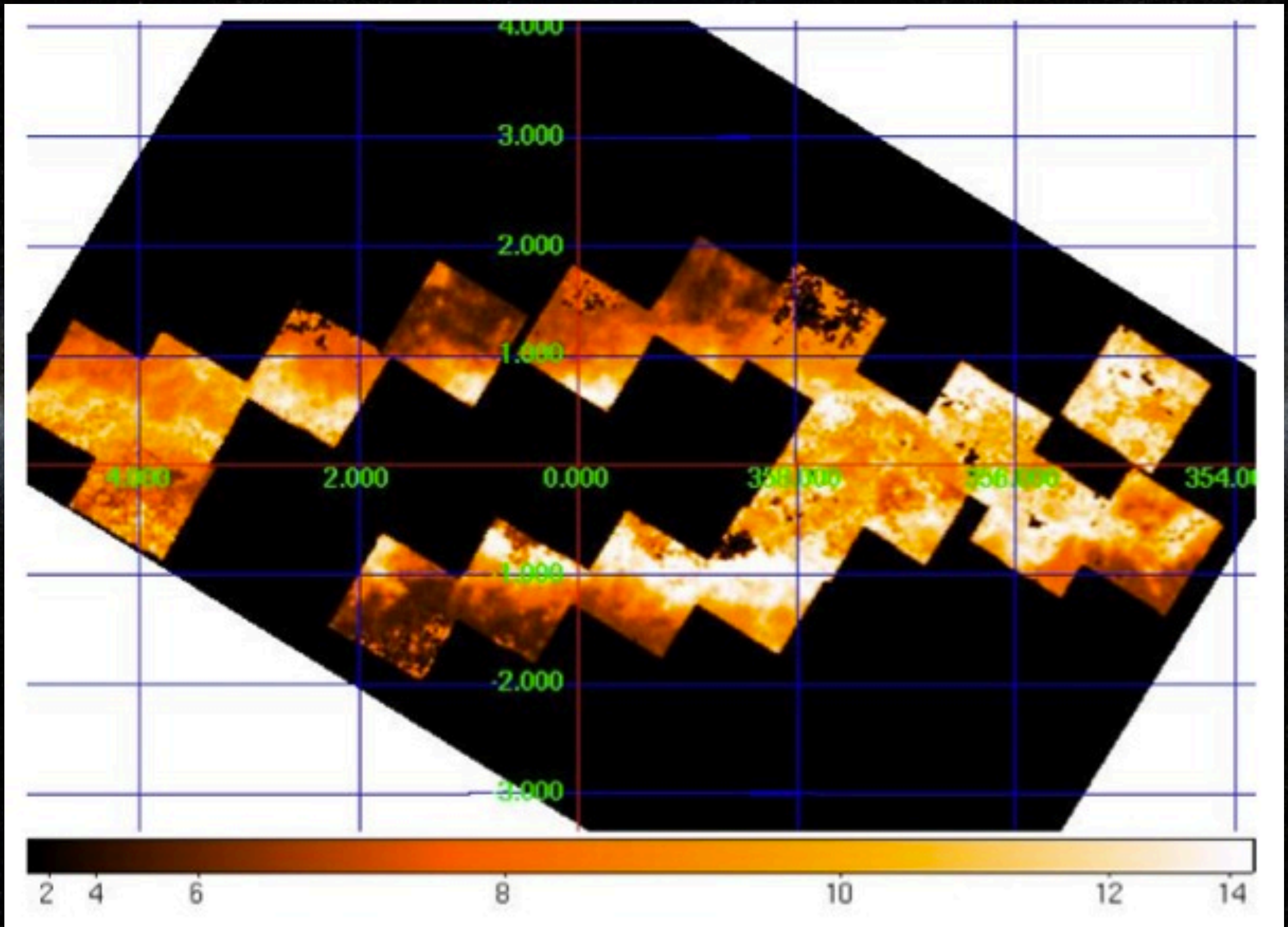
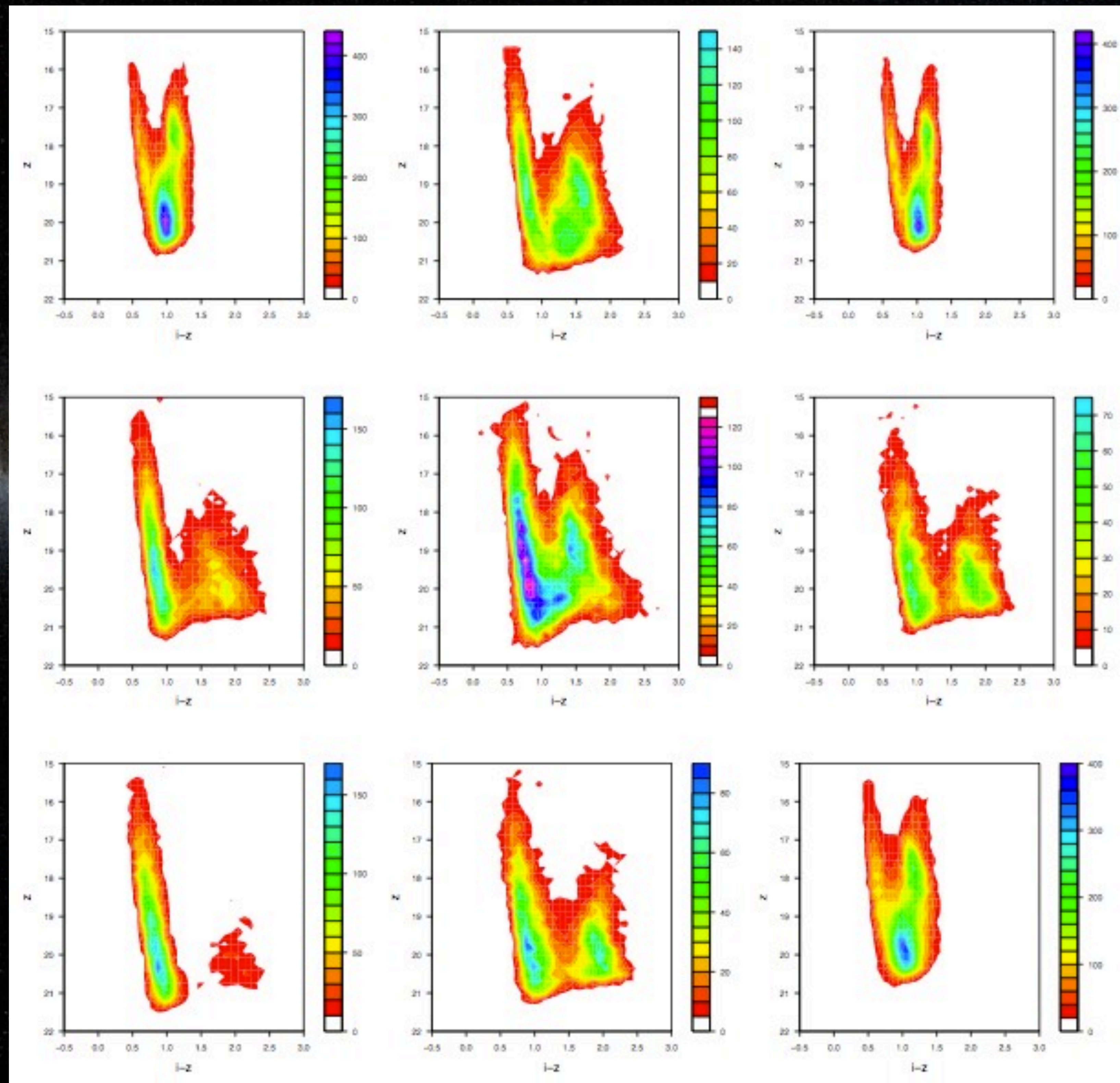


4.000
3.000
2.000
1.000
4.000
2.000
0.000
358.000
356.000
354.0
-1.000
-2.000
-3.000
2
4
6
8
10
12
14

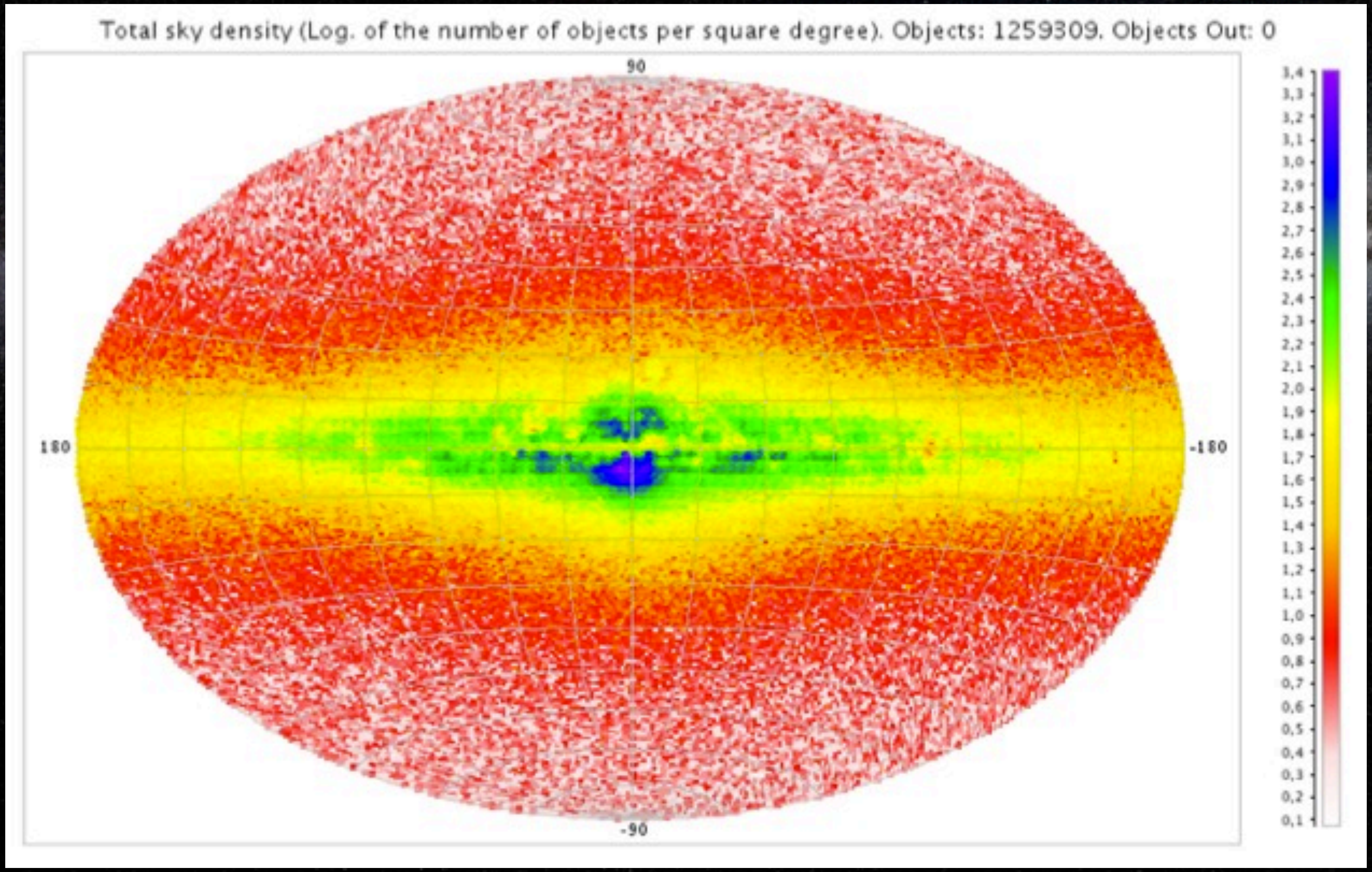
Megabulge

z vs i-z diagrams



Simulating the sky for Gaia

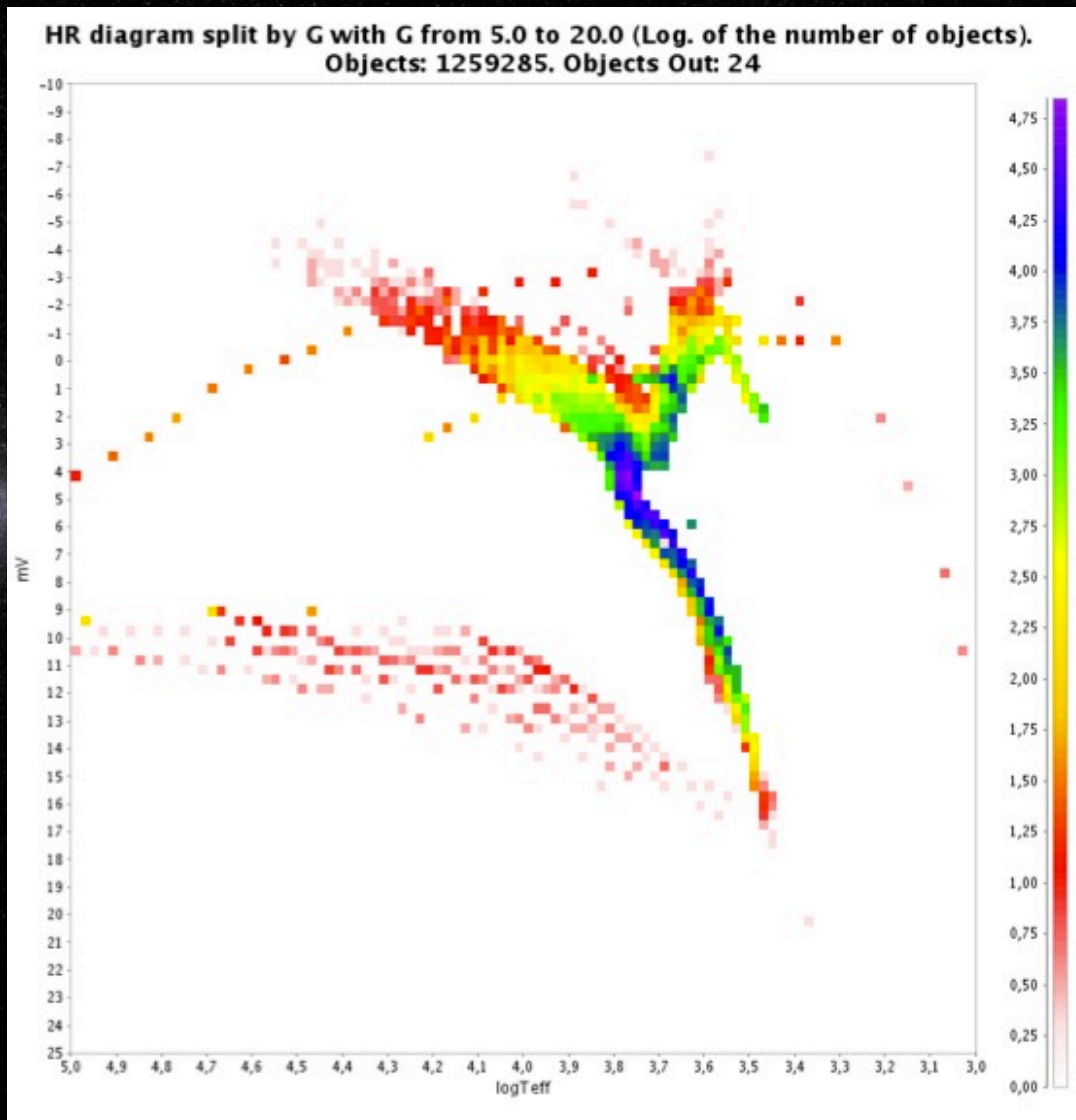
BGM used in the Gaia simulator: results from GUMS (coll. with X. Luri, O. Martinez, Y. Isasi)



Disc: 873×10^6
Thick disc: 262×10^6
Spheroid: 15×10^6
Bulge: 108×10^6

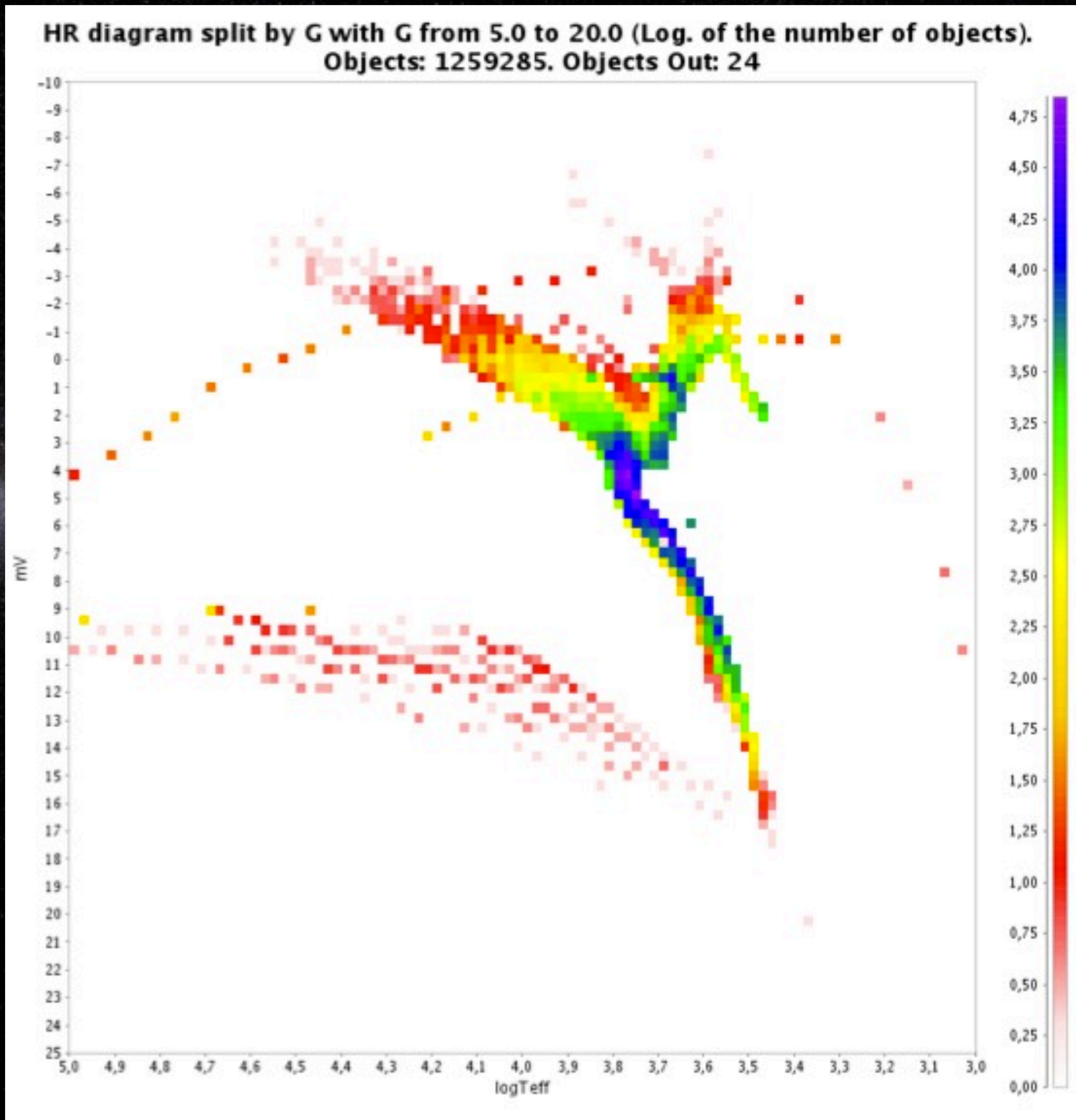
Total 1.2×10^9

Simulating the sky for Gaia



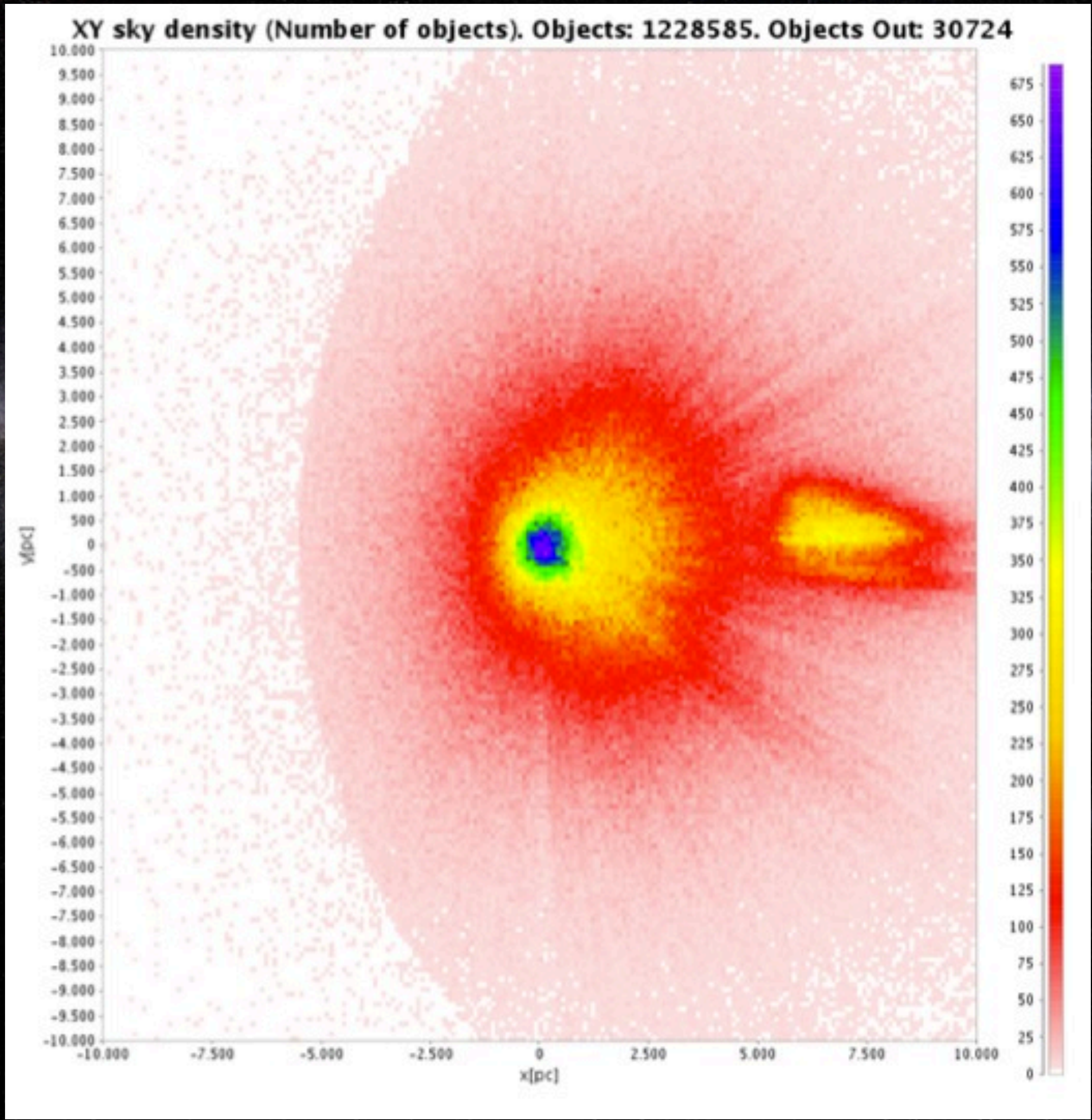
lumClass	Total
BrightGiant	8812
Giant	173305
MainSequence	885651
Other	401
PreMainSequence	4584
SubGiant	185774
SuperGiant	18
WhiteDwarf	764
Total	1259309

Simulating the sky for Gaia



spectralType	Total
O	3
B	3589
A	24916
F	296763
G	473337
K	349763
M	99937
L	1
Be	0
WR	0
AGB	9817
Other	1183
Total	1259309

Simulating the sky for Gaia



Conclusion

Population synthesis models are useful tools for data interpretation

Although imperfect they allow a better understanding
of galactic structure and evolution, eases the interpretation,
make useful preparation for future surveys

Gaia:
distance, proper motions of 1 billion stars (0.75-1% of the Galaxy)
astrophysical parameters, radial velocities for ~250 million stars
abundances for a few million stars

A challenge to fit Gaia data with (simplistic) models!
Efforts have to been made to get self-consistent dynamical + stellar population models