The science of Gaia and future challenges Lund Aug. 30 – Sept. 1, 2017

Testing the local model of the Milky Way disk with TGAS-RAVE sample

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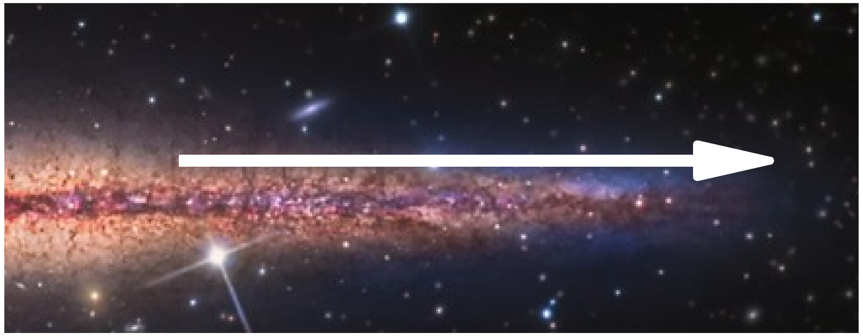
Supervisor: **Dr. A.Just**

Astronomisches Rechen-Institut, Heidelberg

Galactic disks - how to model

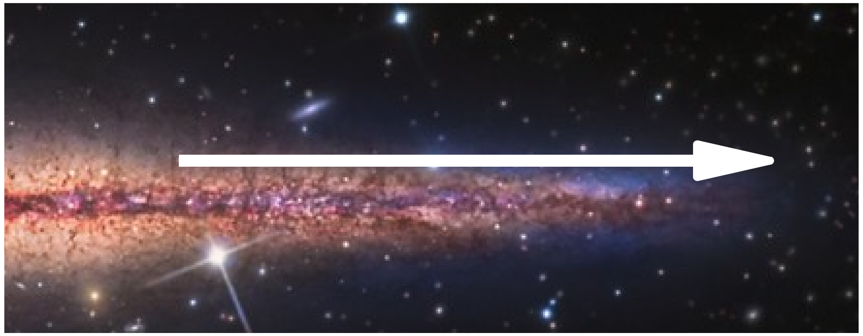


Galactic disks:
inside-out growth?

⇓

Radial gradients
in chemistry, ages, kinematics

Galactic disks – how to model



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Axisymmetric disks	:	equilibrium models
Realistic disks	:	perturbation theory

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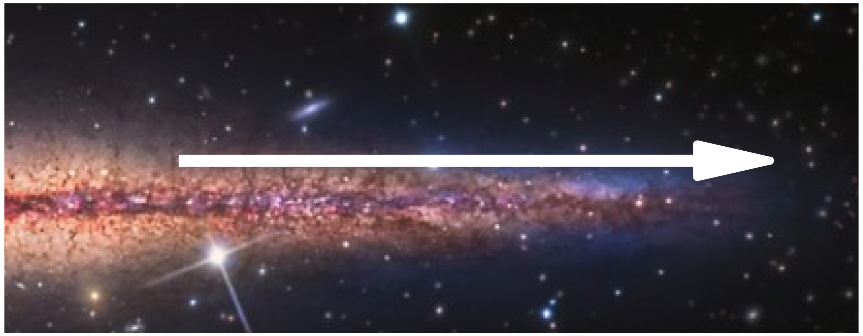

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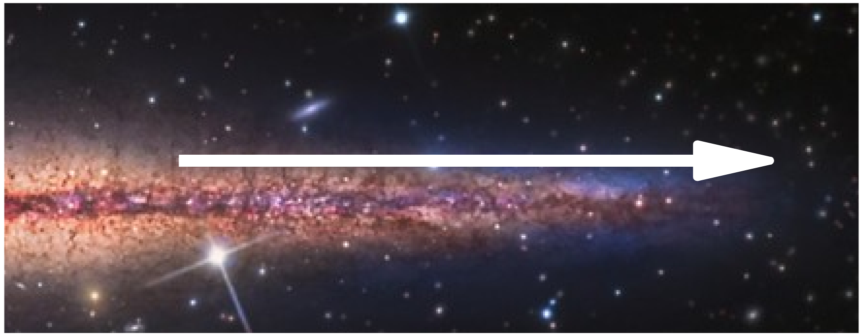


Galactic disks:
inside-out growth?

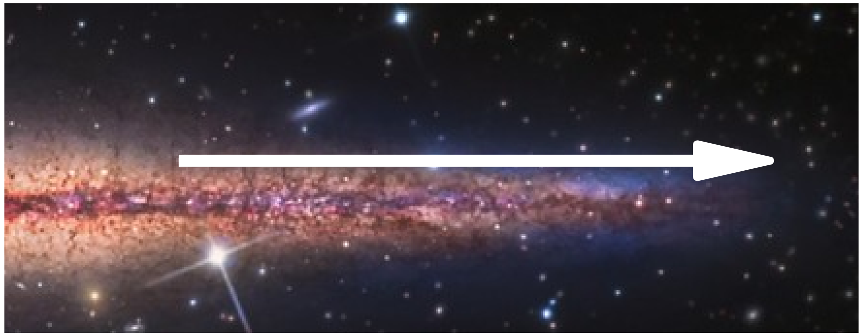
Radial gradients
in chemistry, ages, kinematics

Axisymmetric disks	:	equilibrium models
Realistic disks	:	perturbation theory

To probe the vertical structure of the disk
for each (R, t) we address the following questions:

- How much mass is turned to stars? → SFR
- What is the mass spectrum of newborn populations? → IMF
- What is the metallicity of newly born stars? → AMR
- What fraction of stars does still exist? → Stellar evolution
- What is the dynamical heating? → AVR

Galactic disks – how to model



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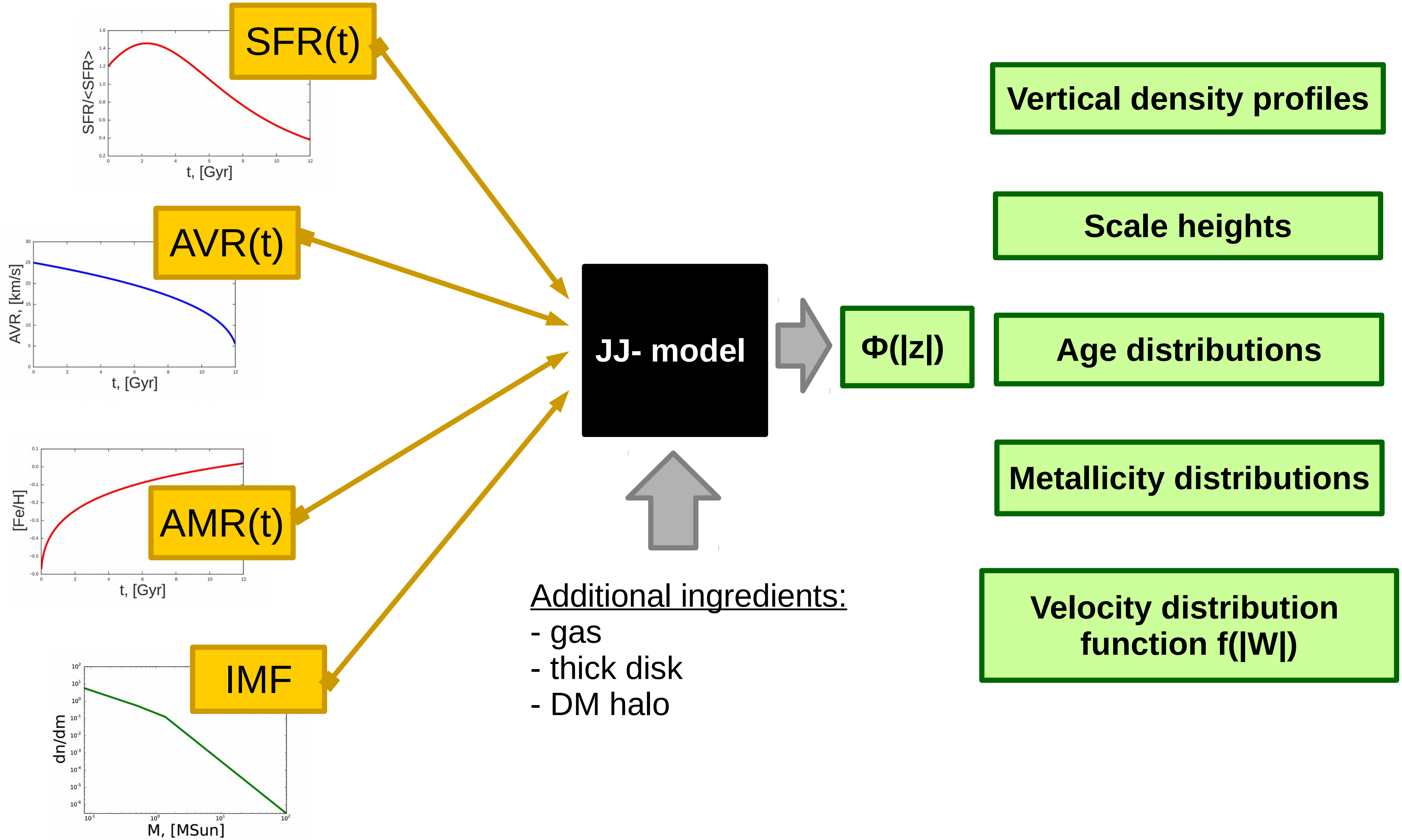
Semi-analytic Just&Jahreiß disk model



JJ-model of the solar neighbourhood

→ Hipparcos: 4 plausible models selected (Just&Jahreiß 2010)

→ SDSS star counts: SFR constrained (Just&Gao 2011)

→ Hipparcos+CNS: IMF constrained (Rybizki&Just 2015)

Fiducial Model A

JJ-model of the solar neighbourhood

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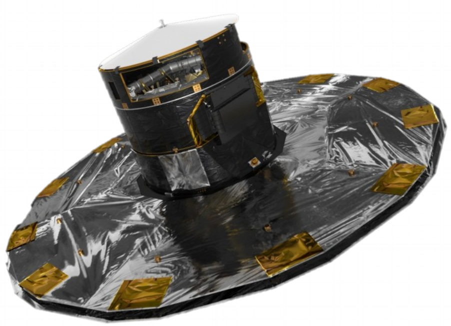
Fiducial Model A

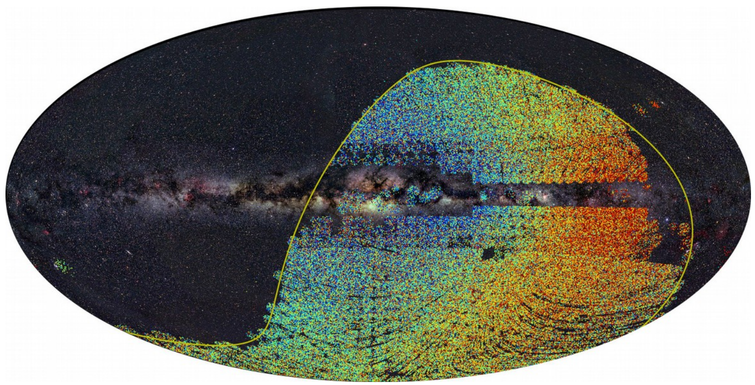


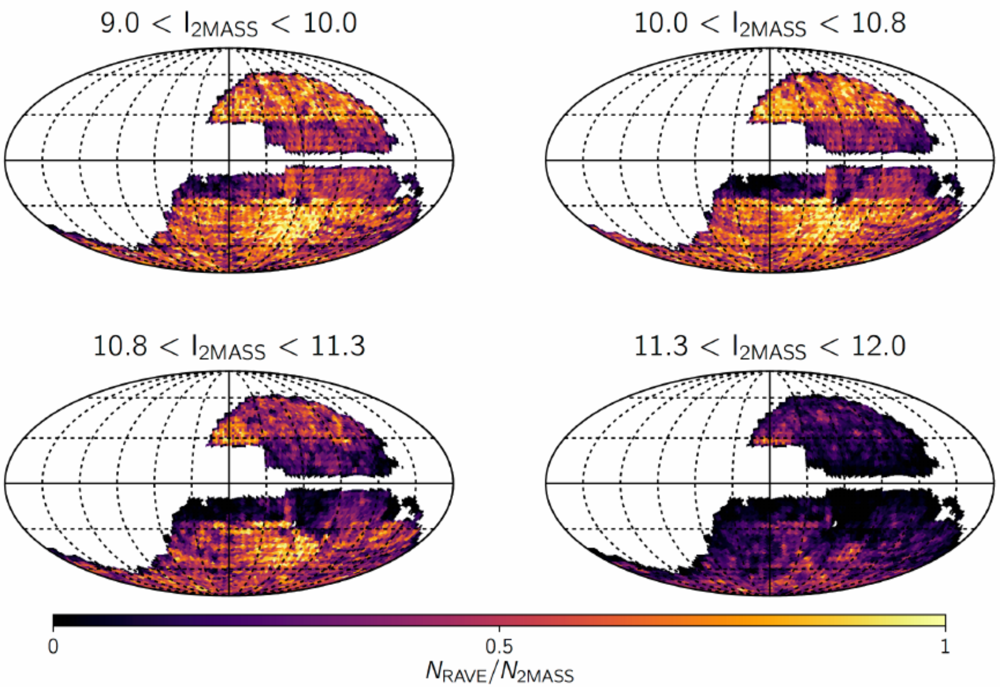
\+ RAVE

Does the model need an improvement?

Data characteristics: RAVE

RAVE DR5 sky coverage:





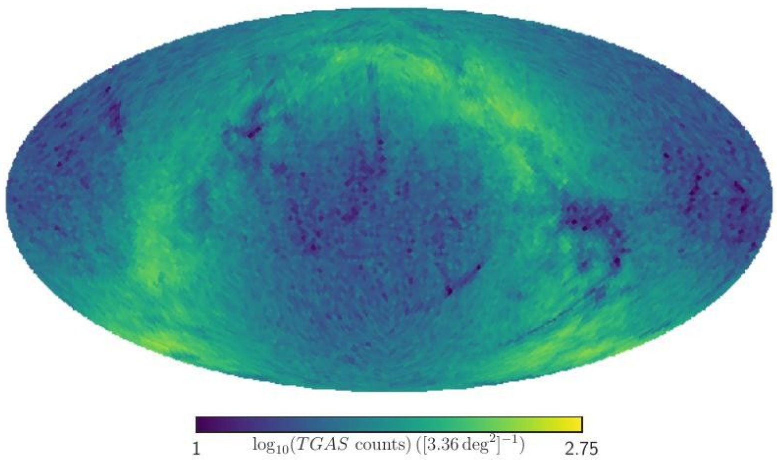
[Wonjo 2016]

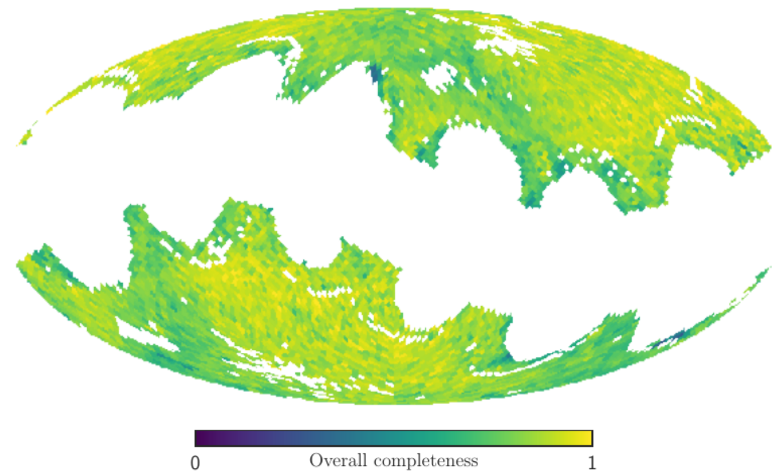
Catalog includes:

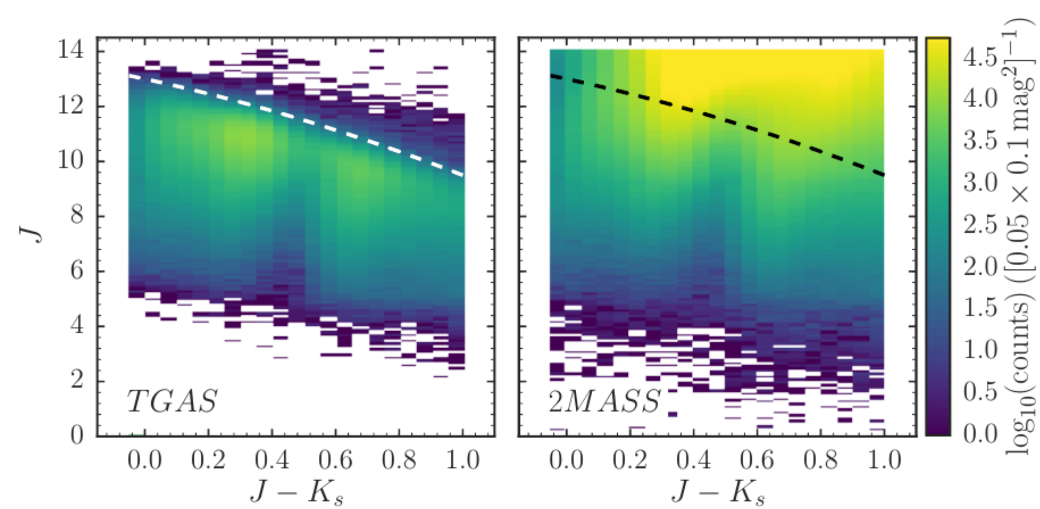
- radial velocites v_r
- photometry Tycho B&V, 2Mass J,H,Ks, etc...
- stellar parameters logT, logg
- abundances Fe,Mg, Al, Ti, Ni, Si

Data characteristics: TGAS

TGAS sky coverage:





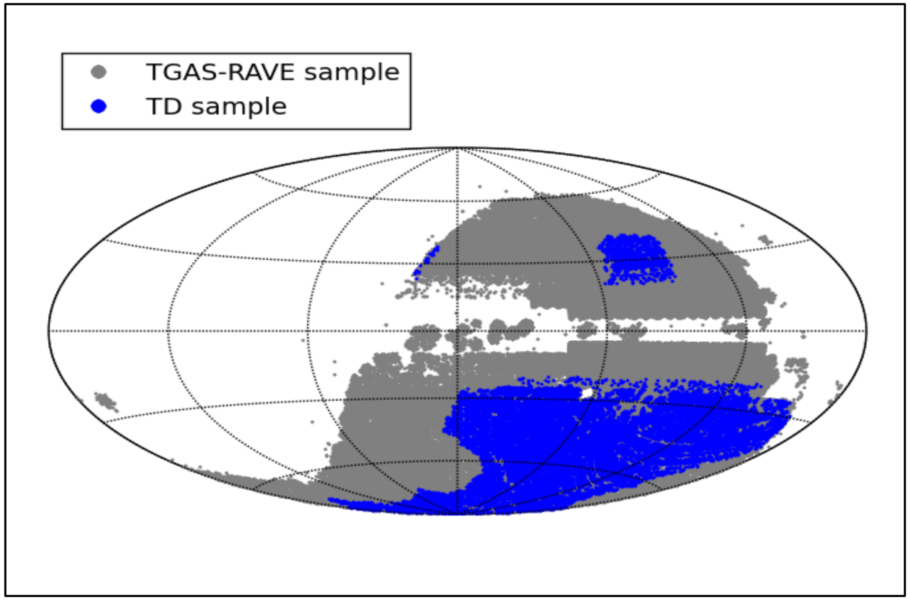


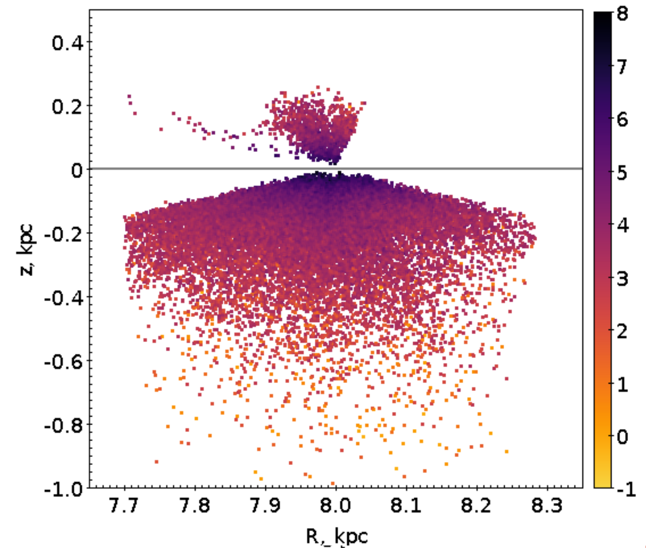
Catalog includes:

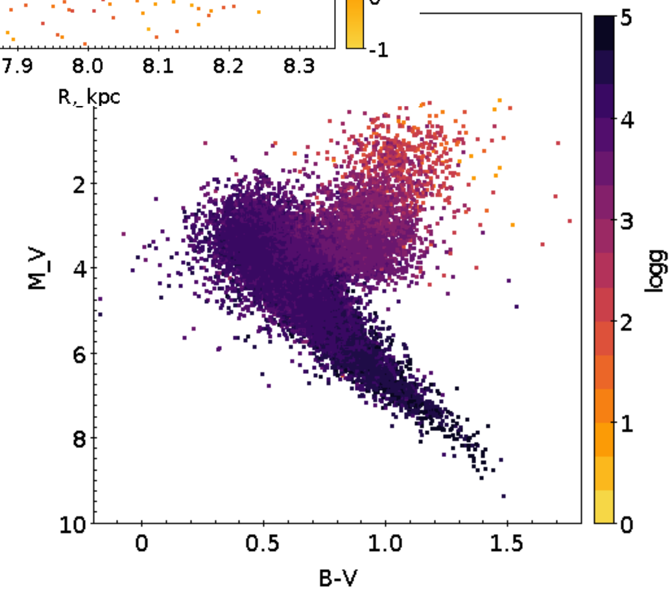
- positions α, δ
- proper motions μ_α, μ_δ
- parallaxes ϖ
- Gaia G-band photometry

[Bovy 2017]

Properties of the selected sample







Parallax cut: $\sigma_{\varpi}/\varpi<0.3$ and $\varpi>0$

Abundance cut: [Fe/H]>-0.6 and [Mg/Fe]<0.2

Geometry cut: x**2+y**2 < 300**2 & |b| < 20°

TGASxRAVE: 255 922 stars, selected 20 091

Geometrically inhomogeneous, incomplete sample, probably contaminated by non-thin-disk stars.

Our approach

- TGAS-RAVE selection criteria
- Sample geometry
- Parallax quality cut $\sigma_{\varpi}/\varpi<0.3$ and $\varpi>0$

must be modeled!

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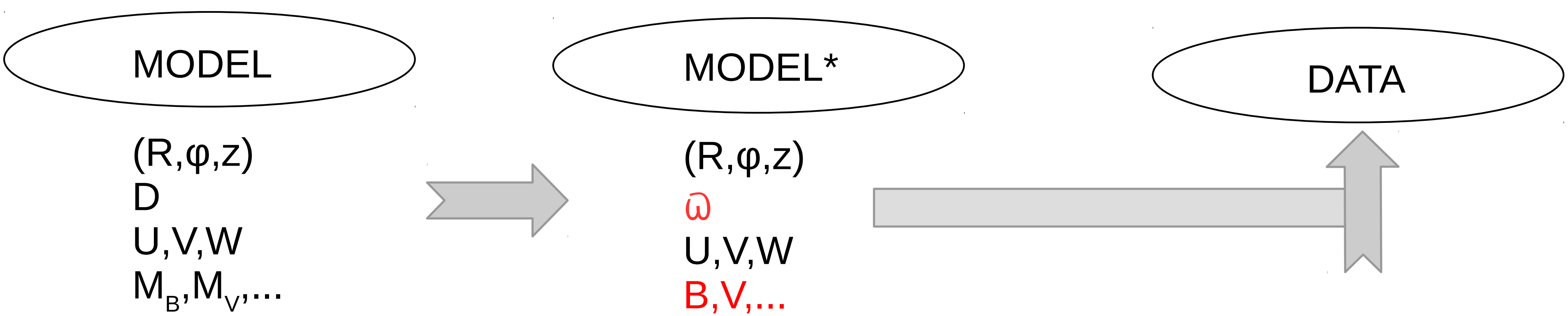
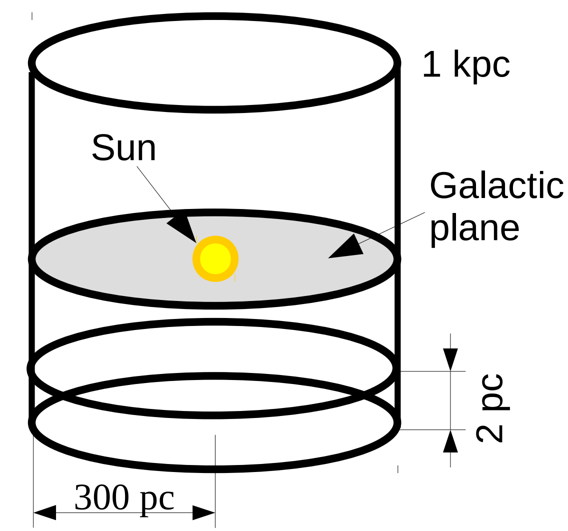
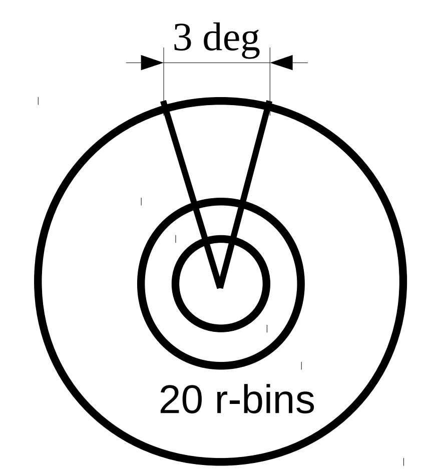


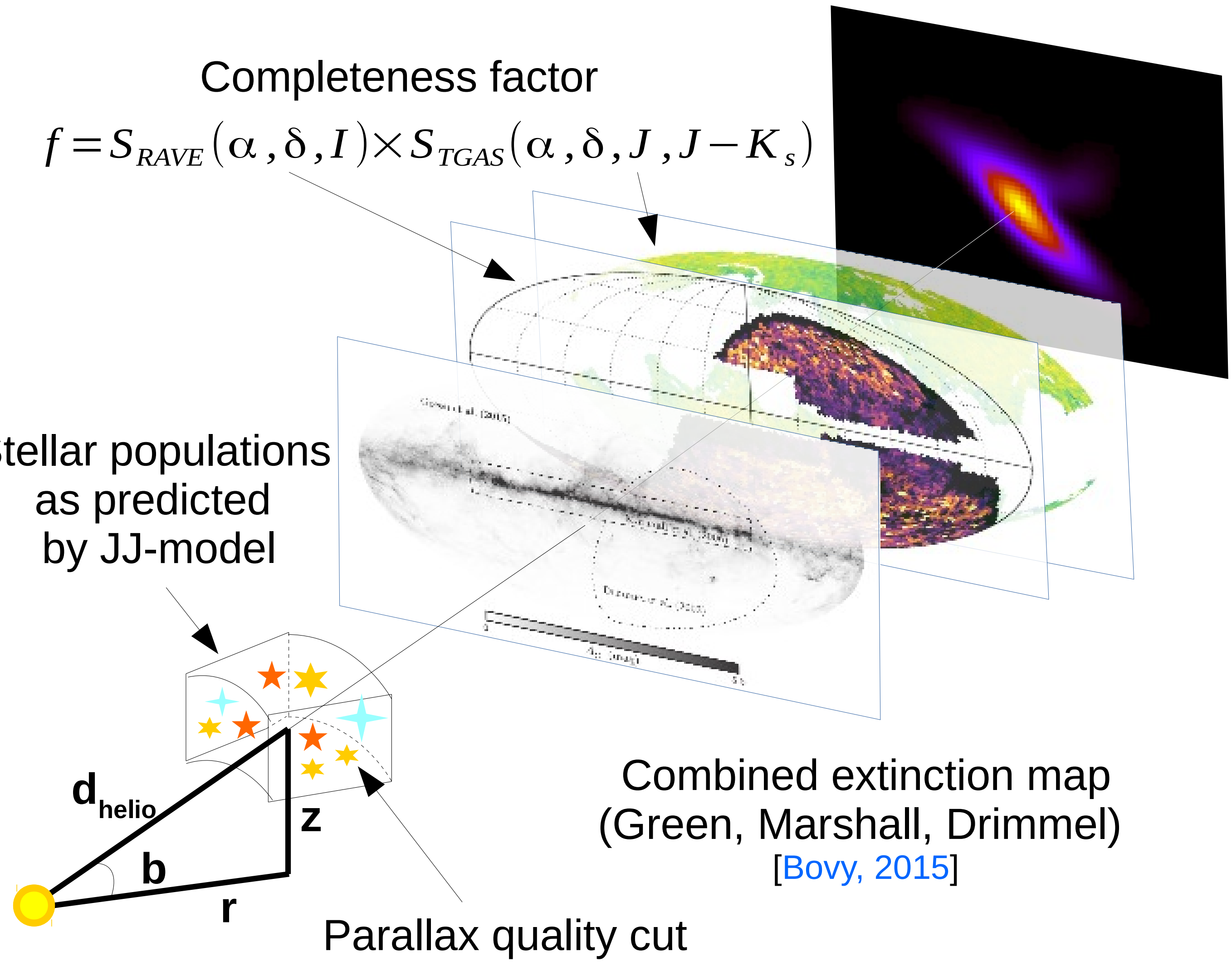
Modelling the thin disk sample

Model grid:

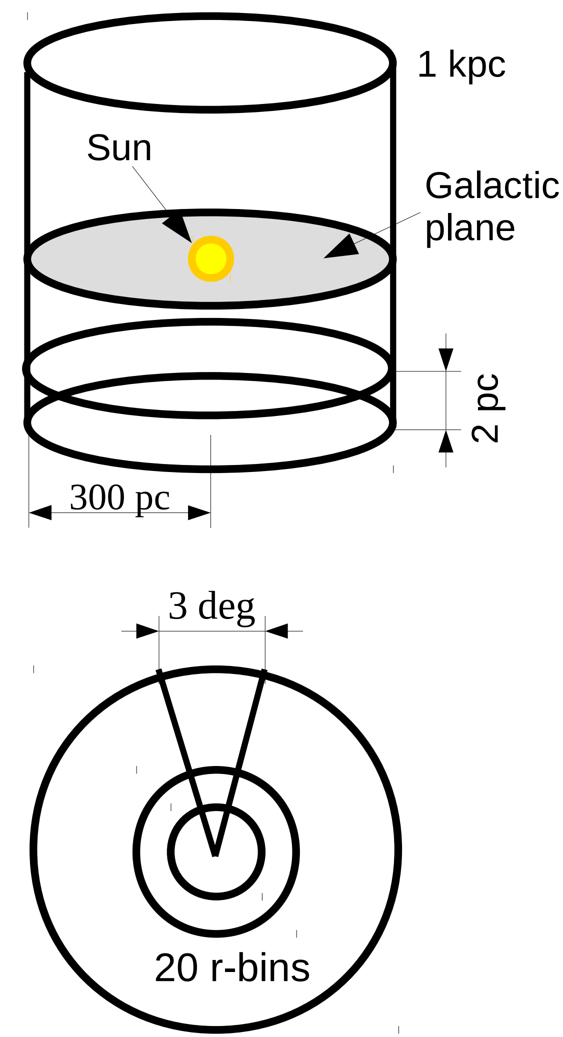




Modelling the thin disk sample

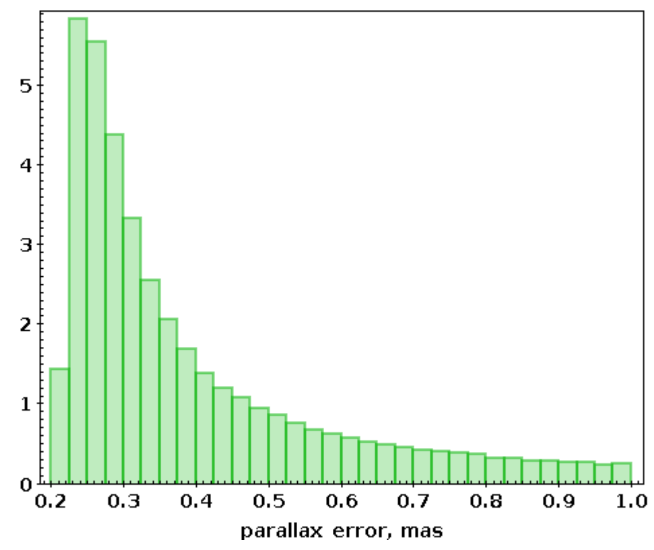


Model grid:



Including the parallax cut

- $1/\varpi$ is a measure of the distance, not the distance itself
- 1% of TGAS-RAVE sources have $\varpi<0$



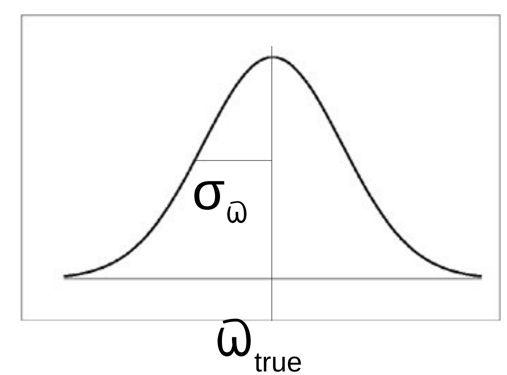
<u>Approach used in the model:</u>

(1) take PDF[σ_ϖ] from the data

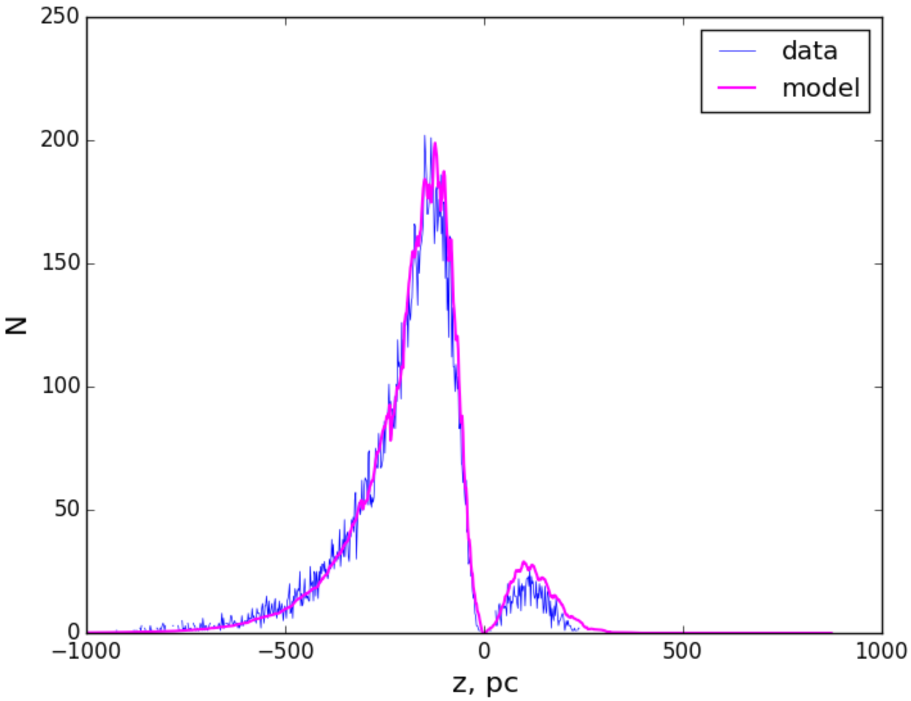
(2) For each modeled subpopulation:

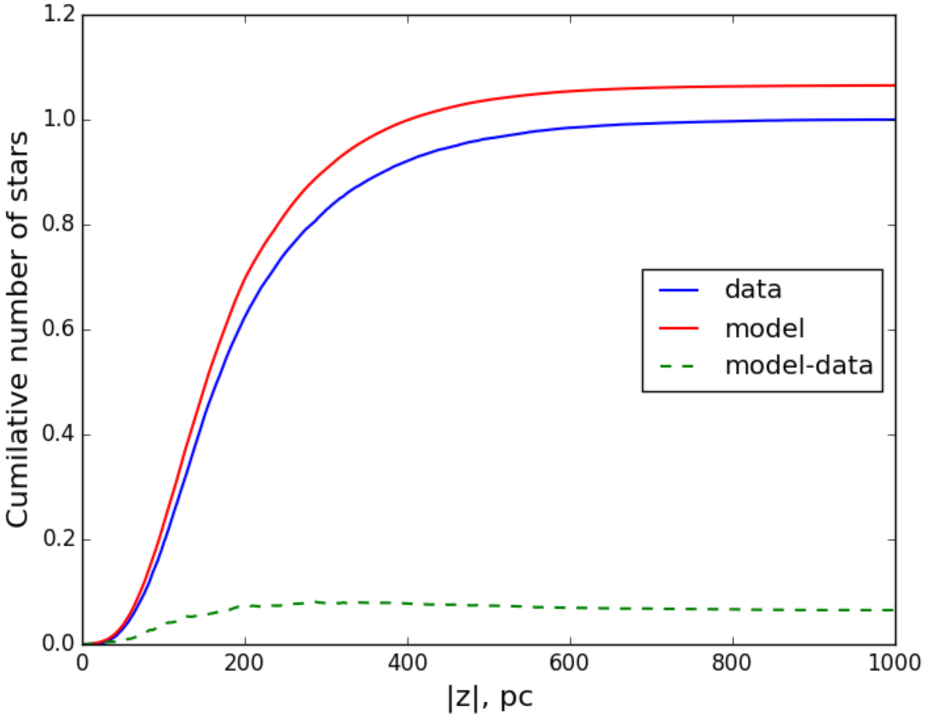
- assign σ_ϖ according to the given PDF
- assign 'observed_parallax' as a random value from Gaussian distribution with $\mu,\sigma=(\varpi_{true},\sigma_\varpi)$
- check if the criteria are fulfilled:
  - -- $\varpi_{obs} > 0$
  - -- $\sigma_\varpi/\varpi_{obs} < 0.3$

If no – remove the subpopulation from further modelling.

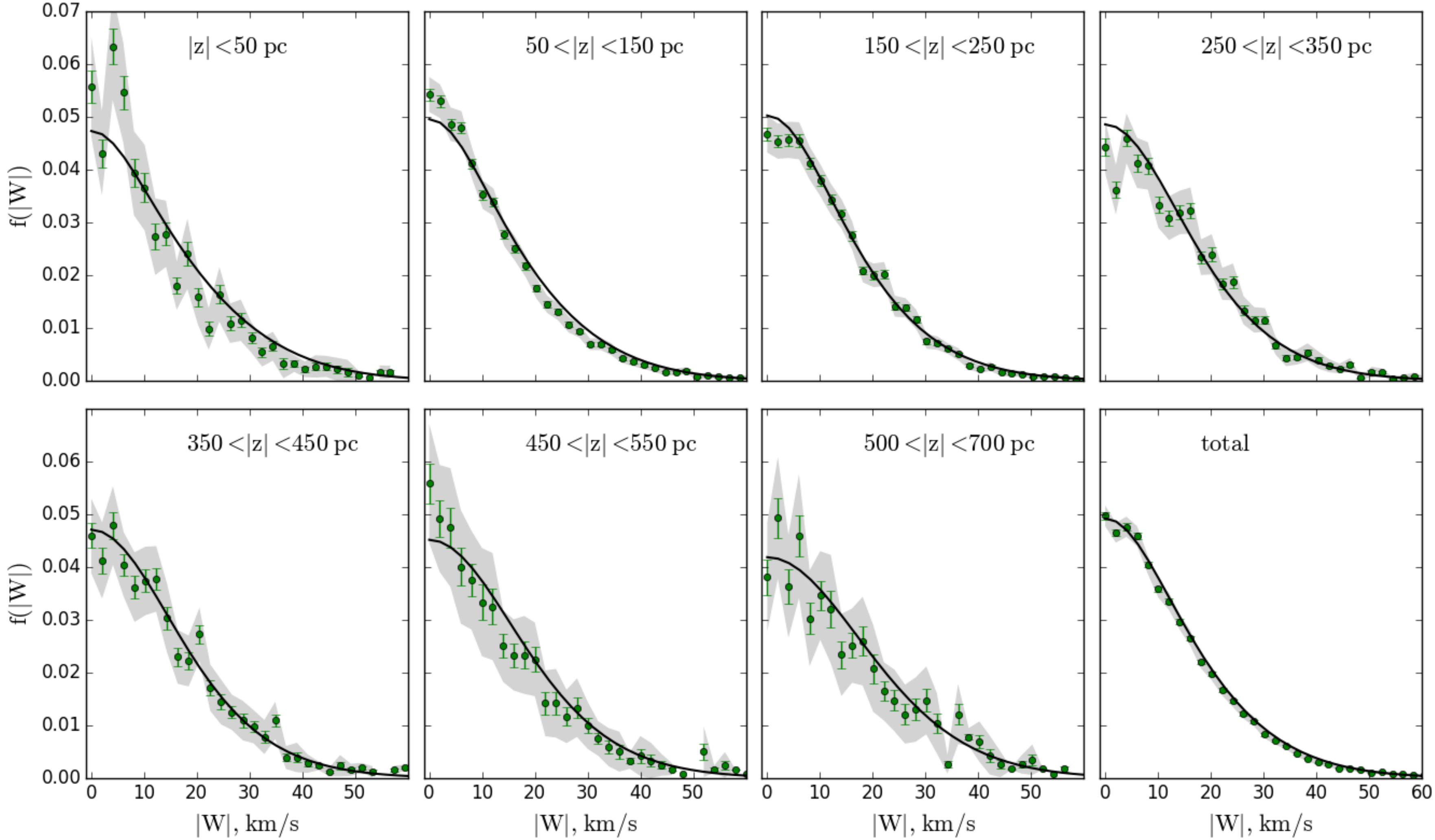


Vertical distribution of stars





Vertical kinematics of the sample



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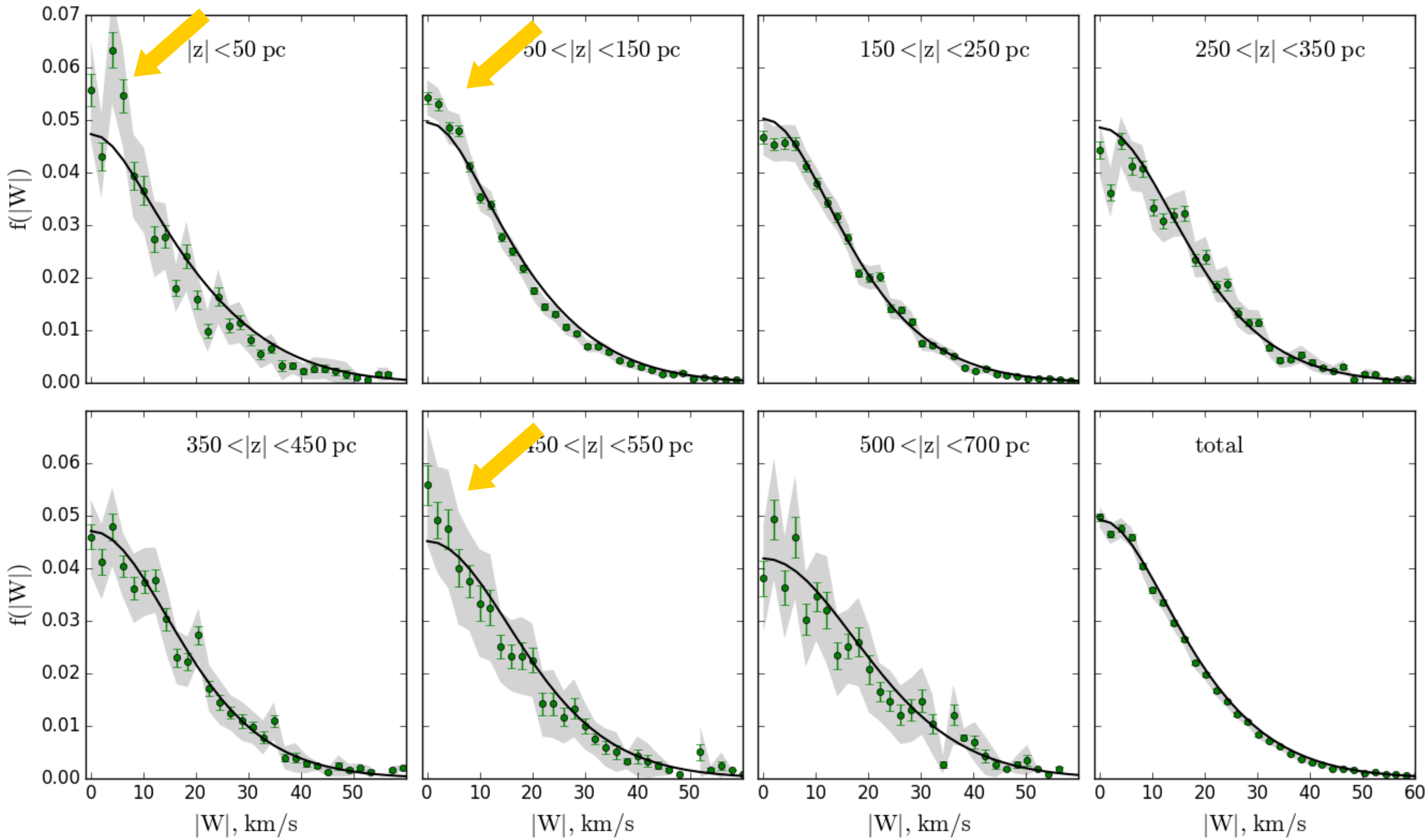

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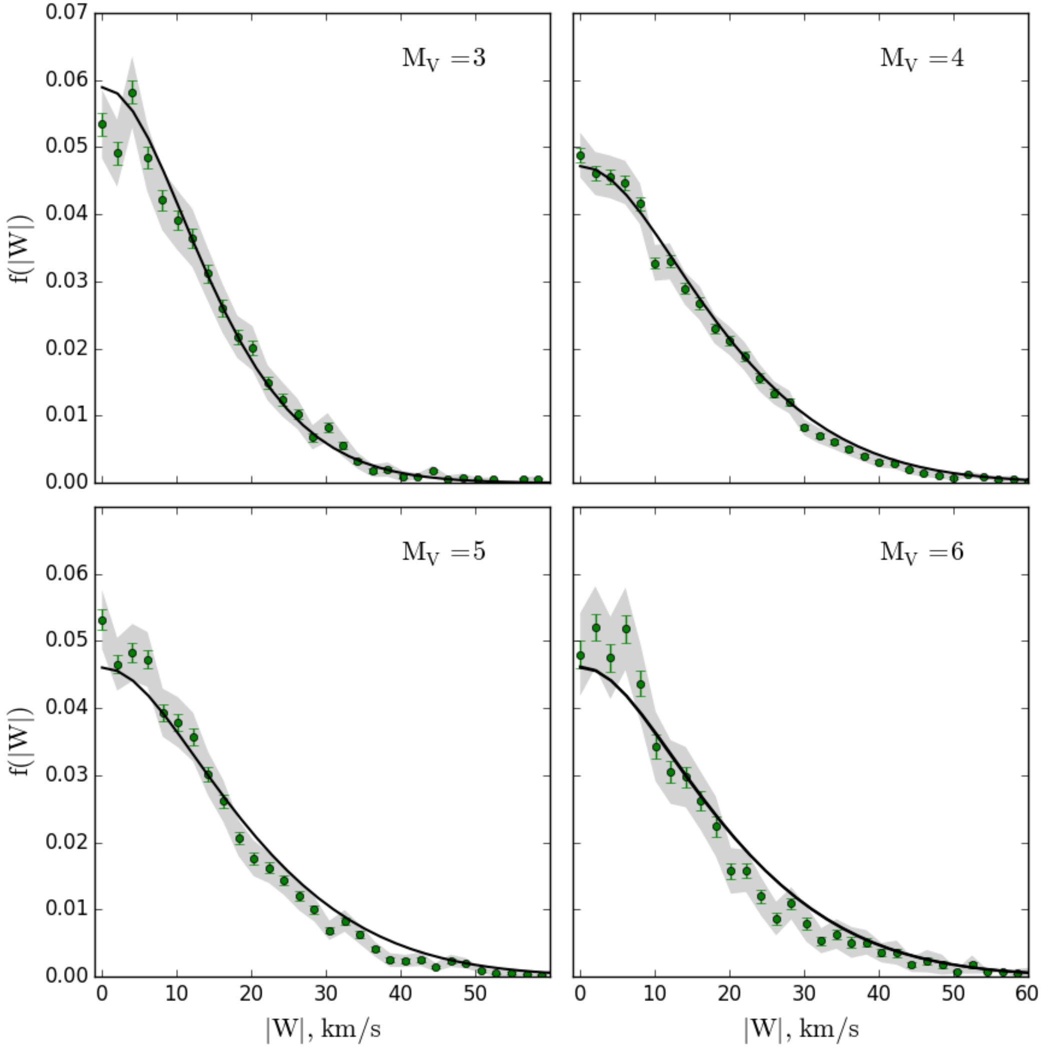
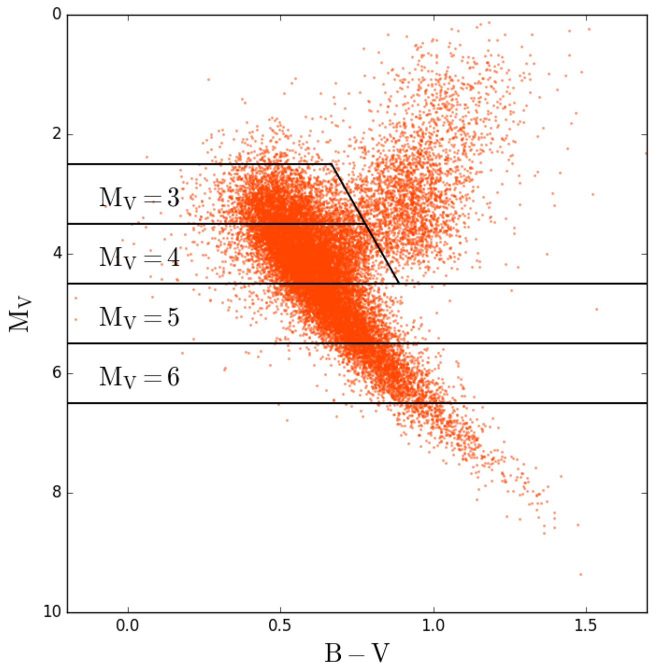
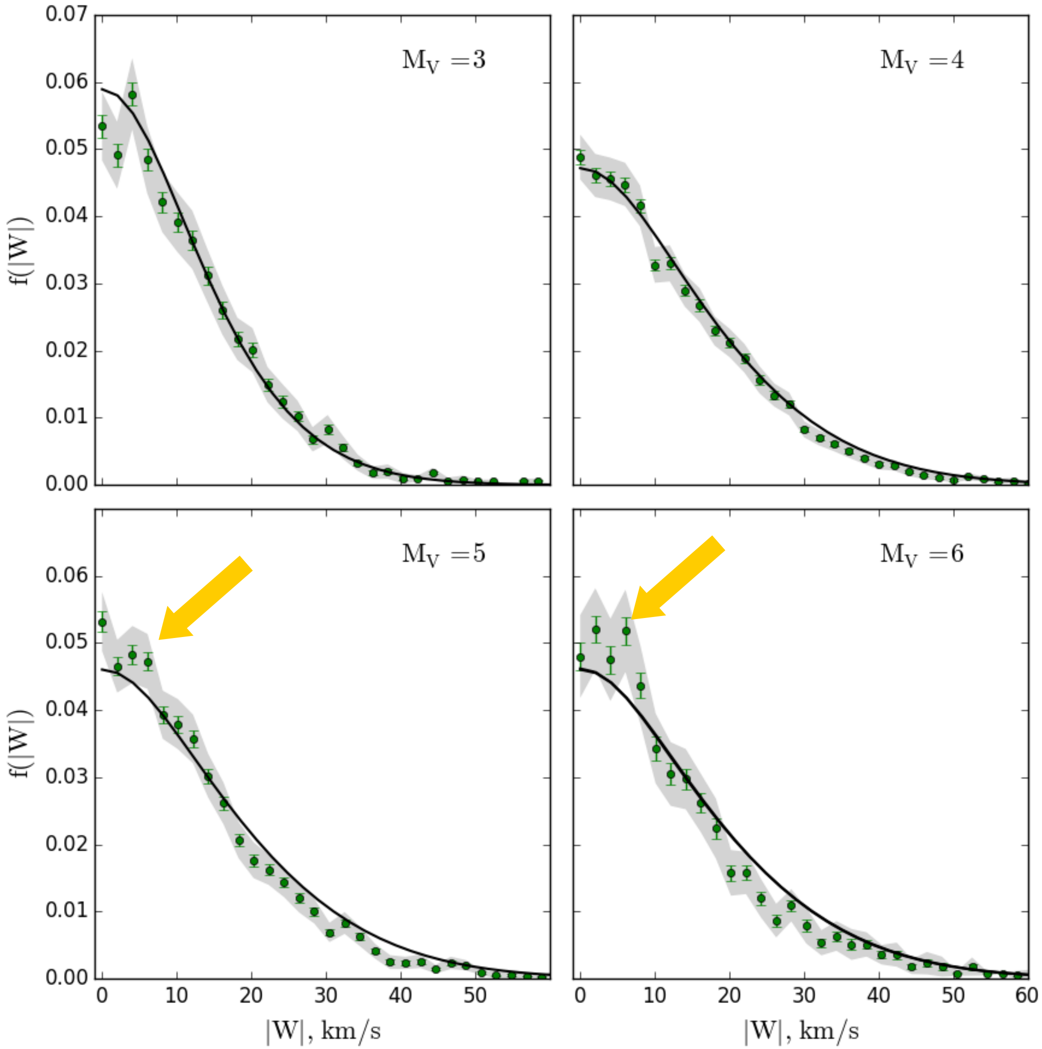
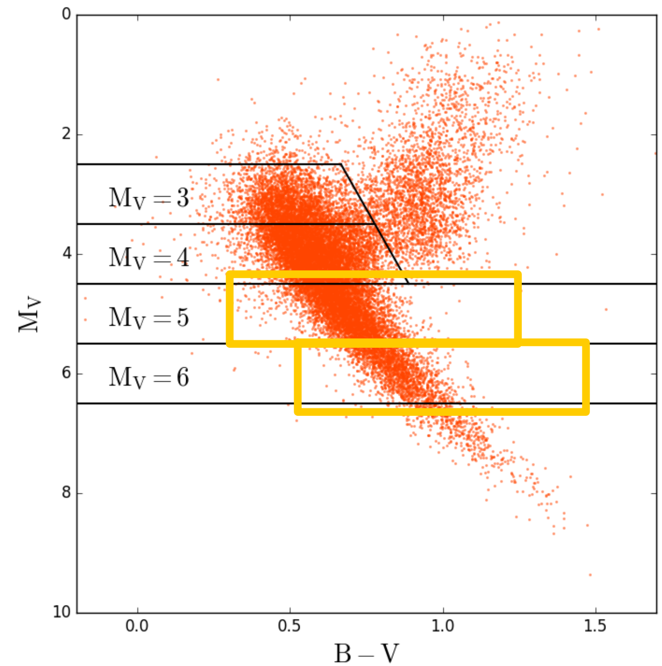




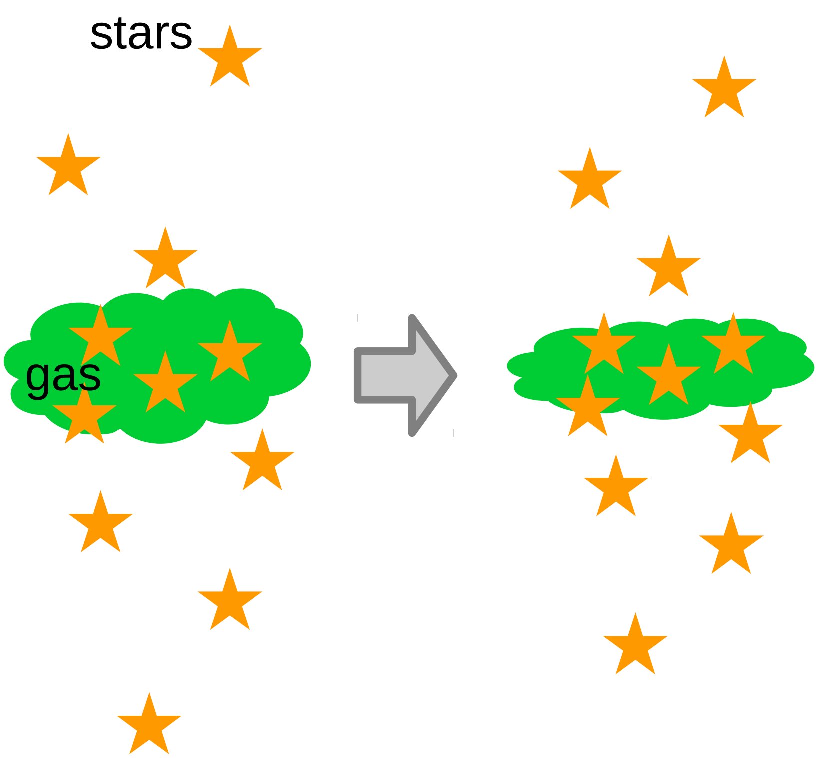
Vertical kinematics of the sample





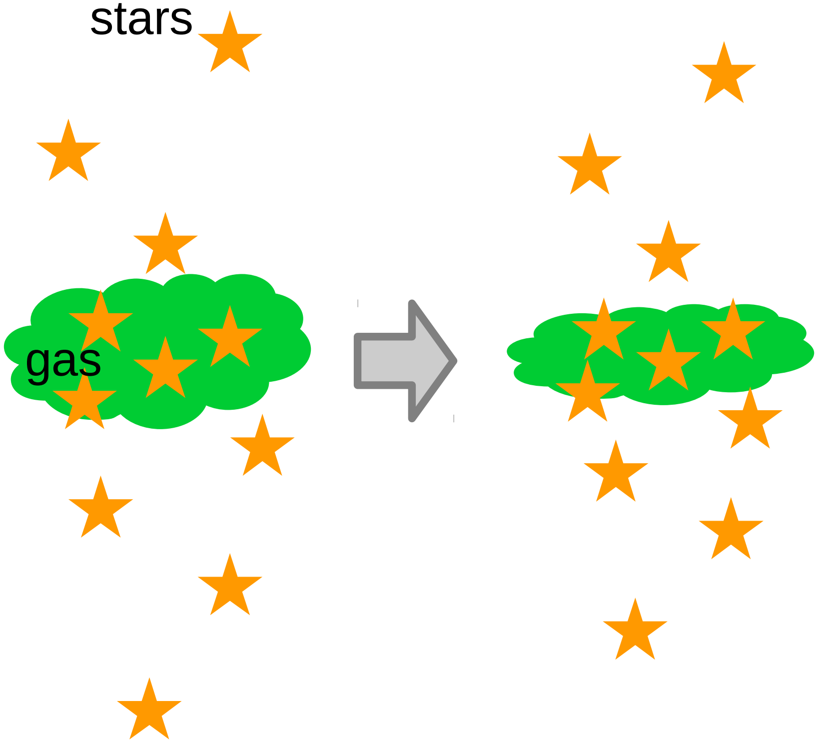
Stars in the sample are colder!

Probing the parameter space



Model A

Probing the parameter space



Model A

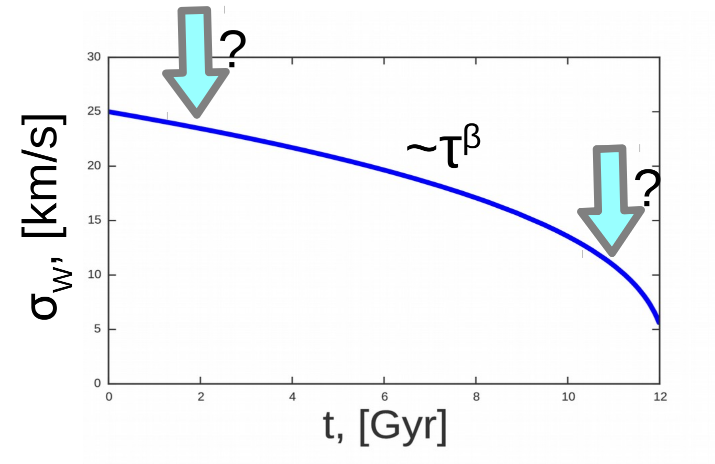
Model A1a
Model A2a
Model A2b

We can:

1. make gas colder

Model A1a:
hg = 150 pc → 100 pc

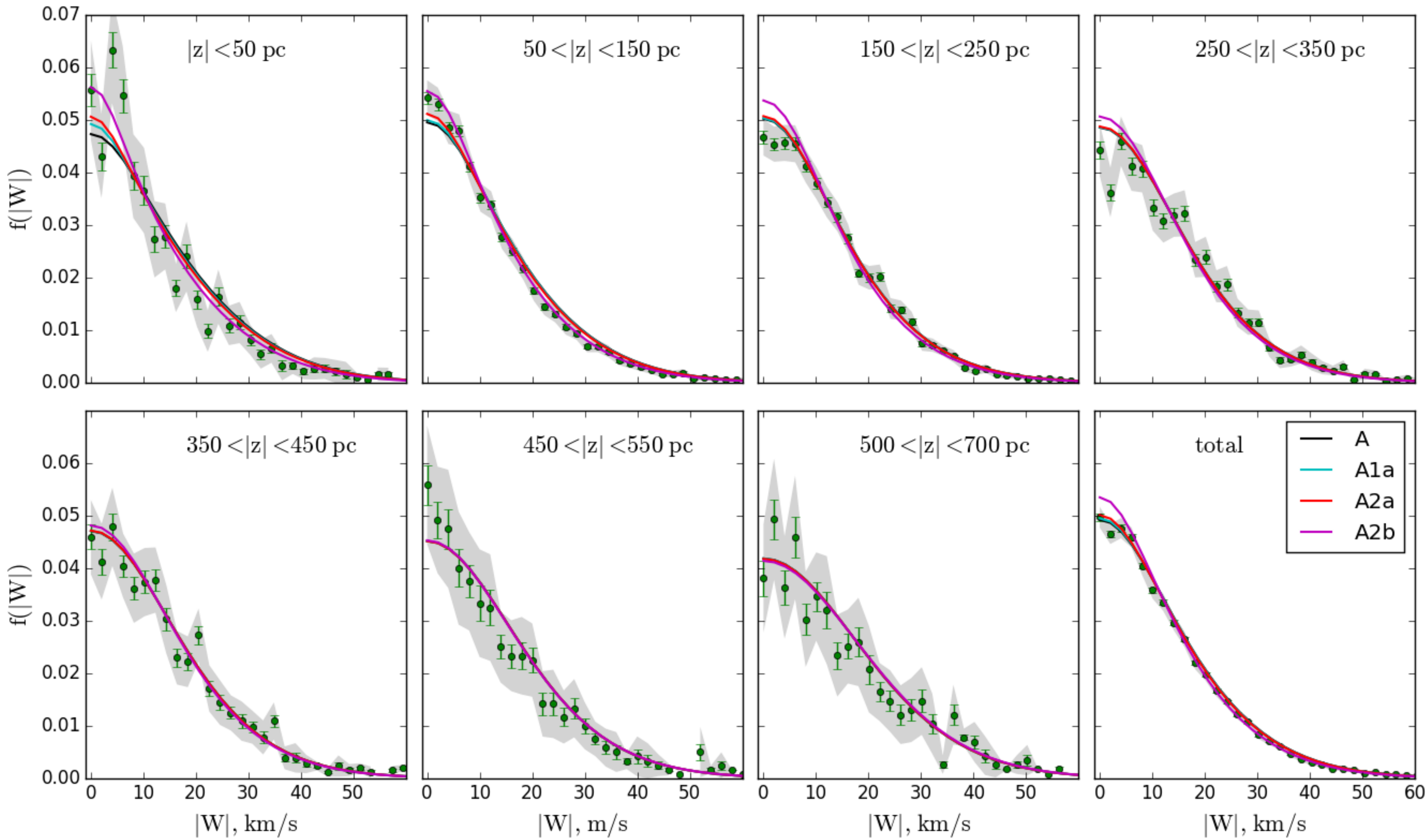
2. make stars colder



Model A2a:
$\sigma_W(\tau=0\ \text{Gyr}) = 5$ km/s → 3.5 km/s

Model A2b:
$\beta = 0.374$ → $\beta = 0.45$

Probing the parameter space



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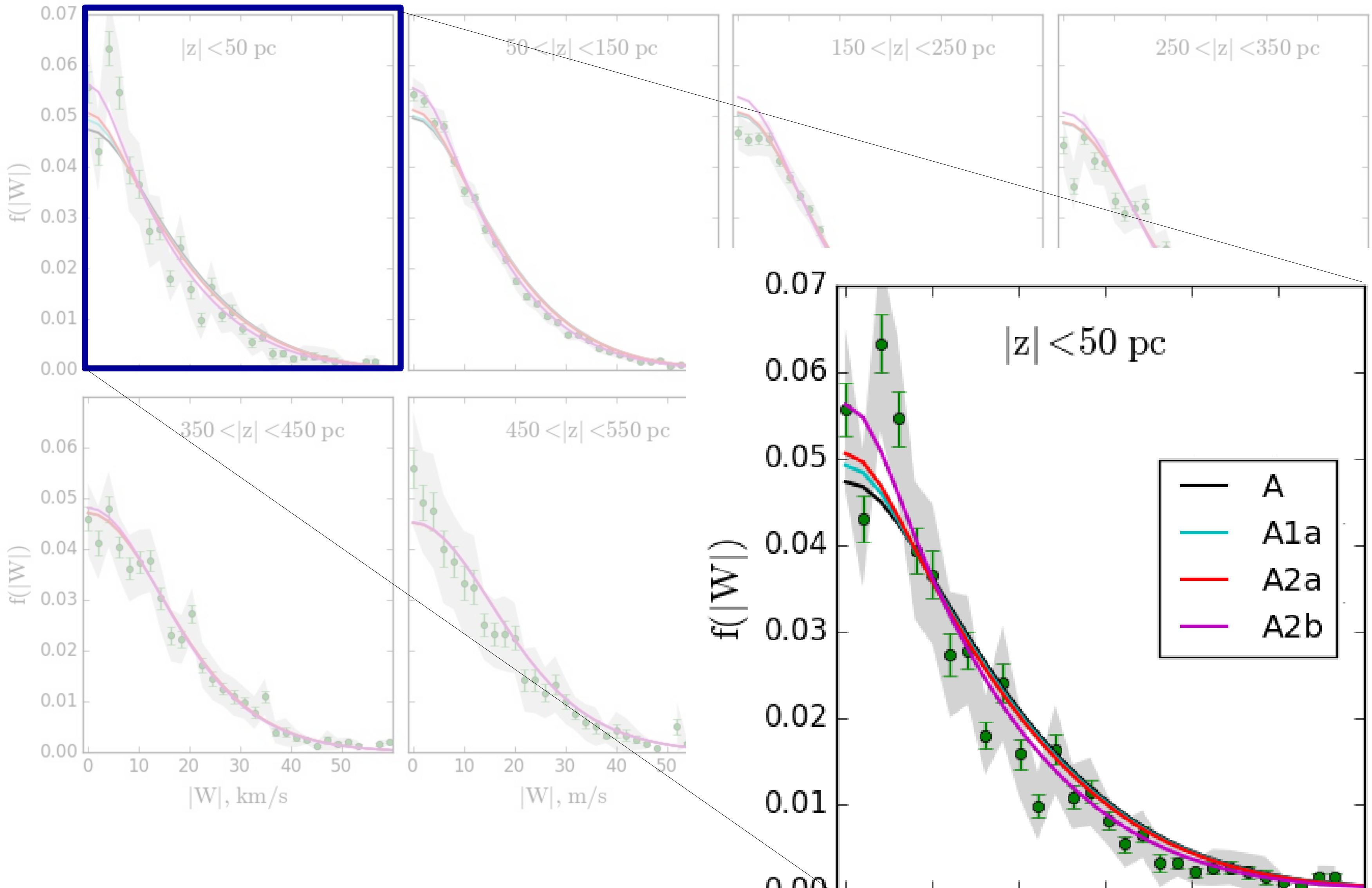

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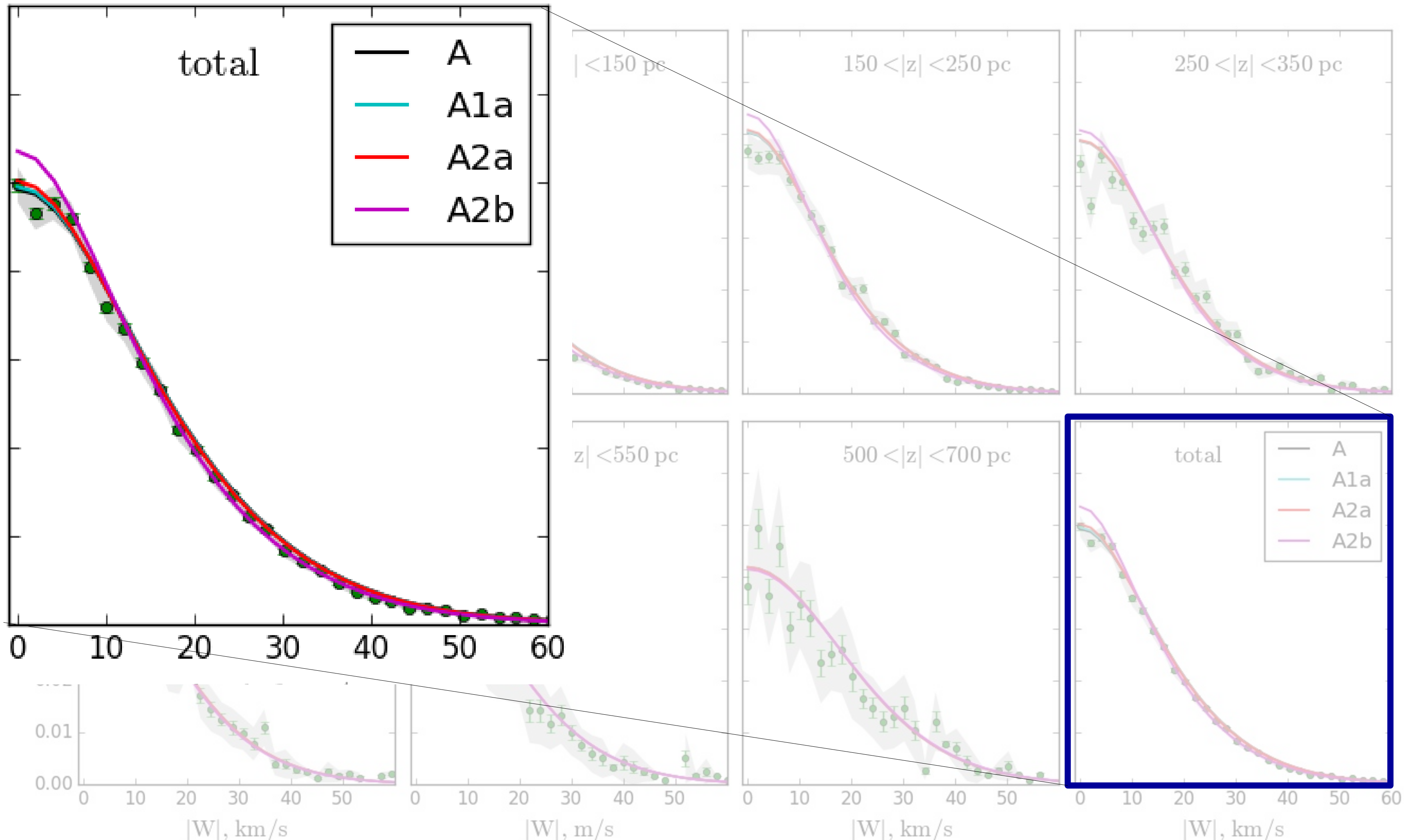

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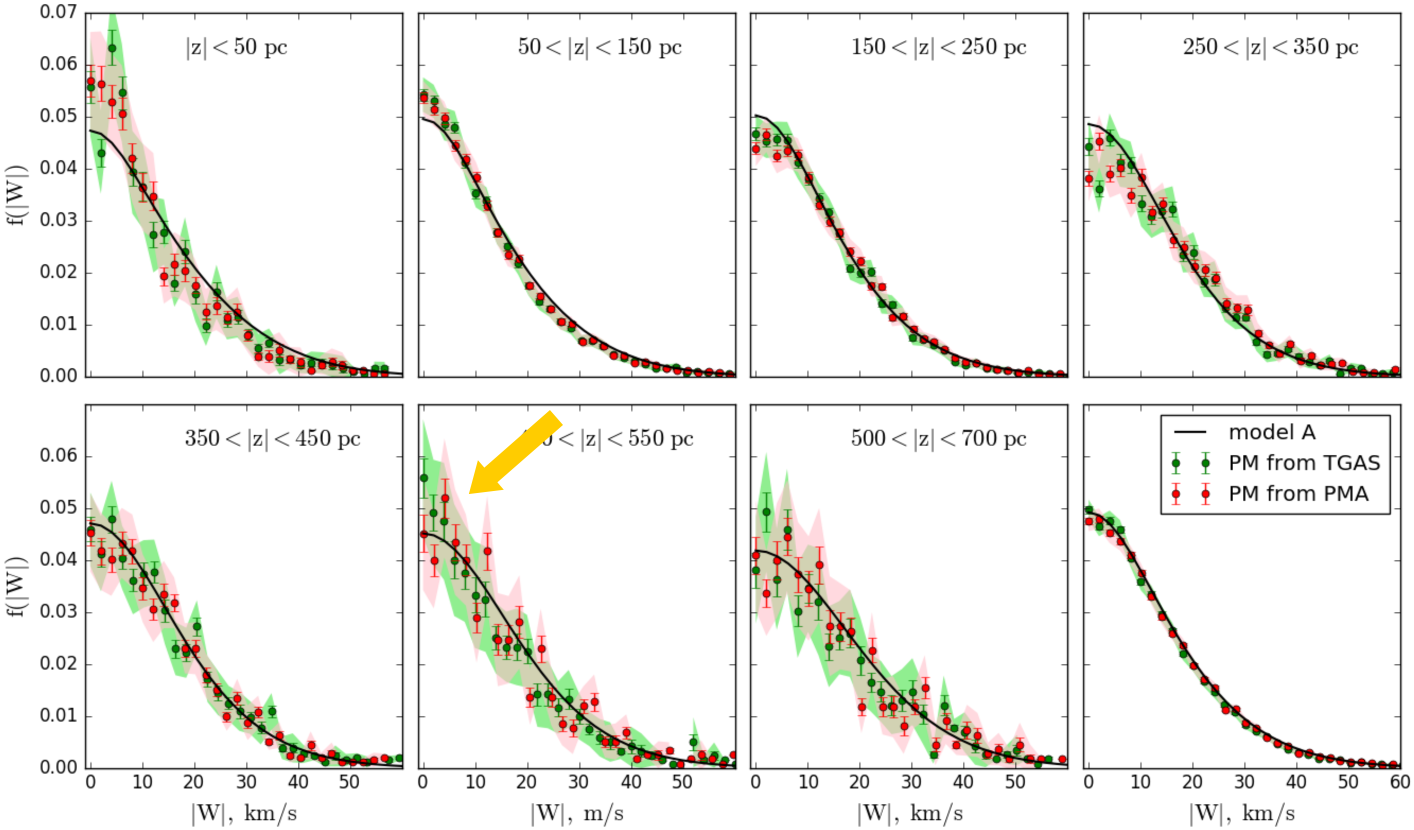
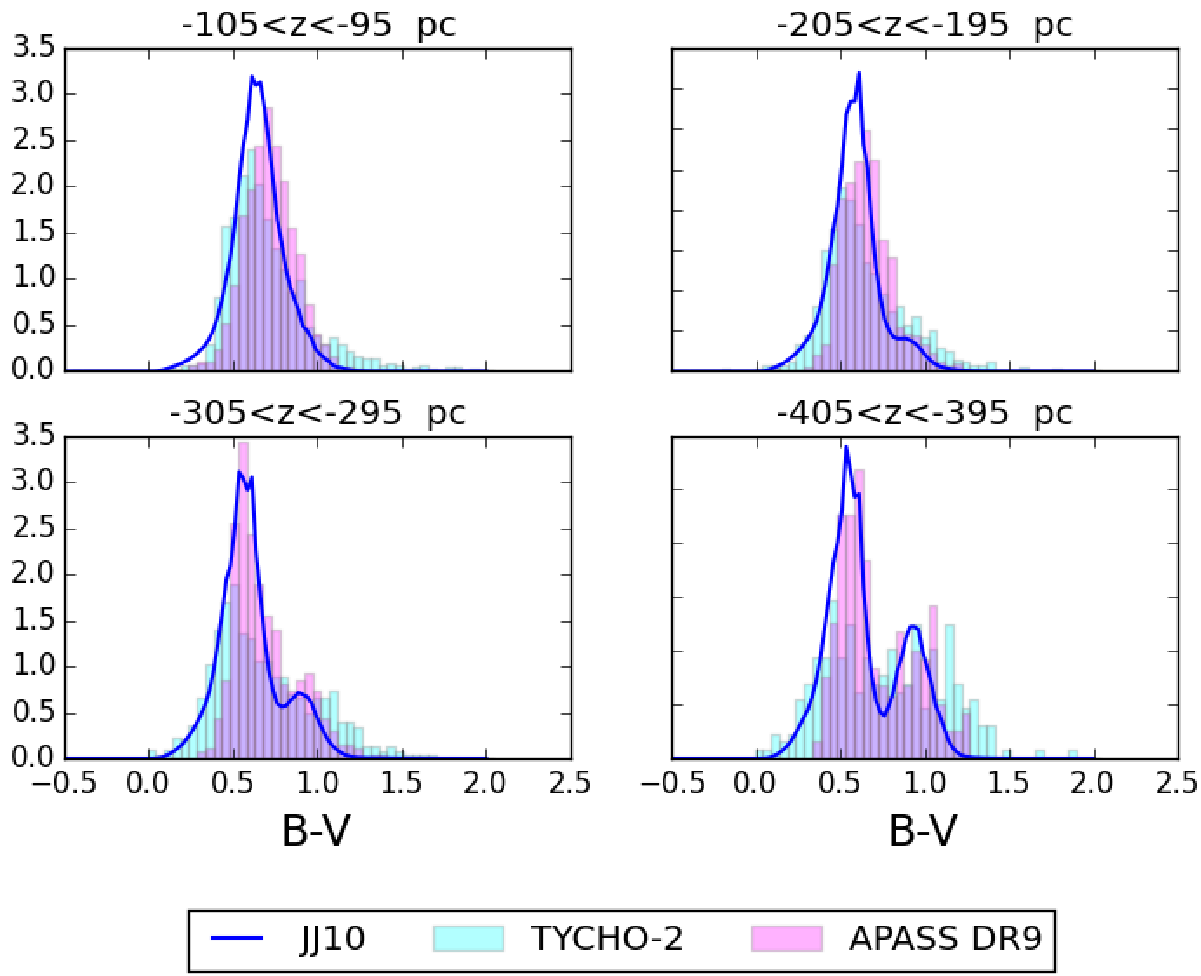


PMA = catalog of Absolute Proper Motions, derived from Gaia DR1 and 2MASS (see poster of V.Akhmetov)

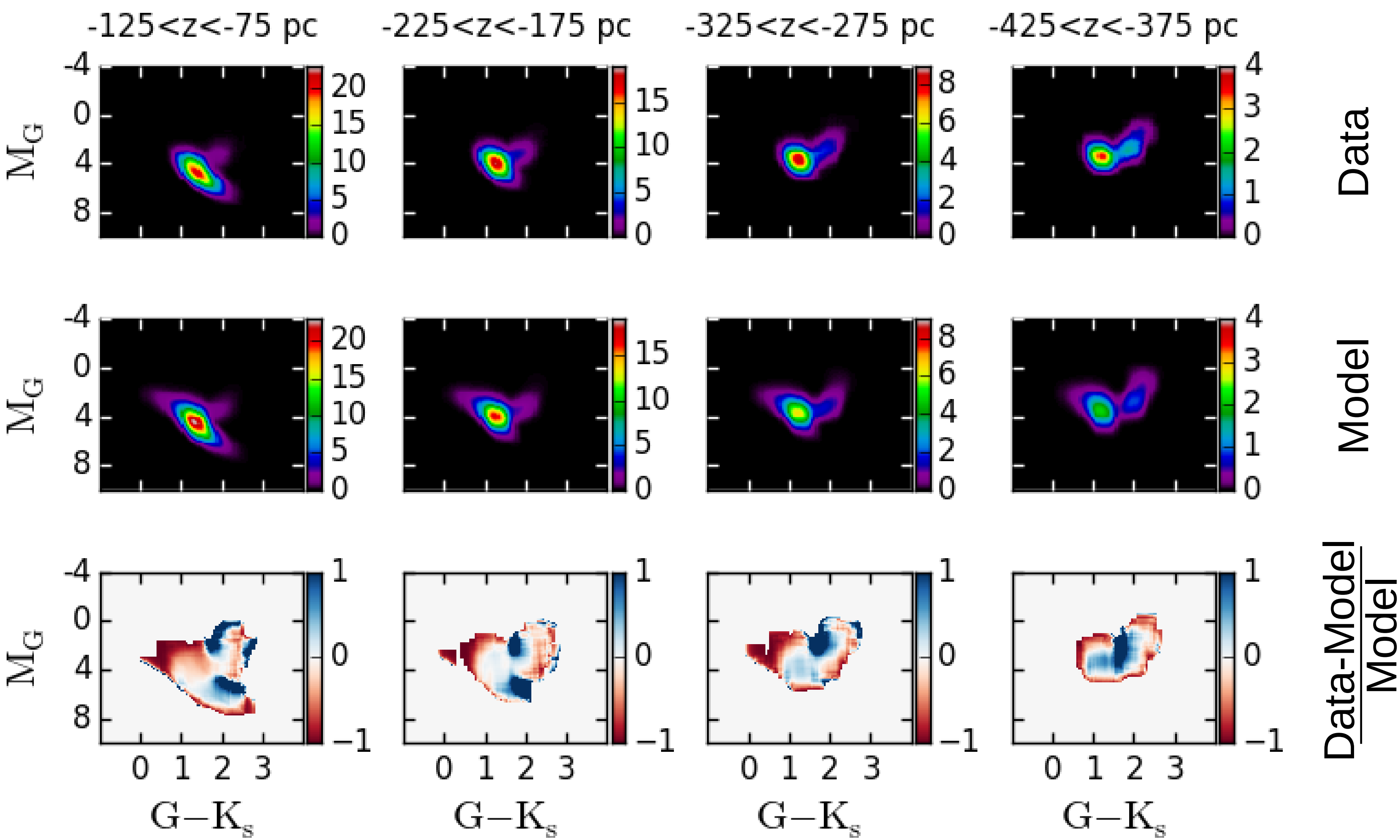
→ both datasets are in a good agreement
→ some of problematic regions vanish

B–V color distributions

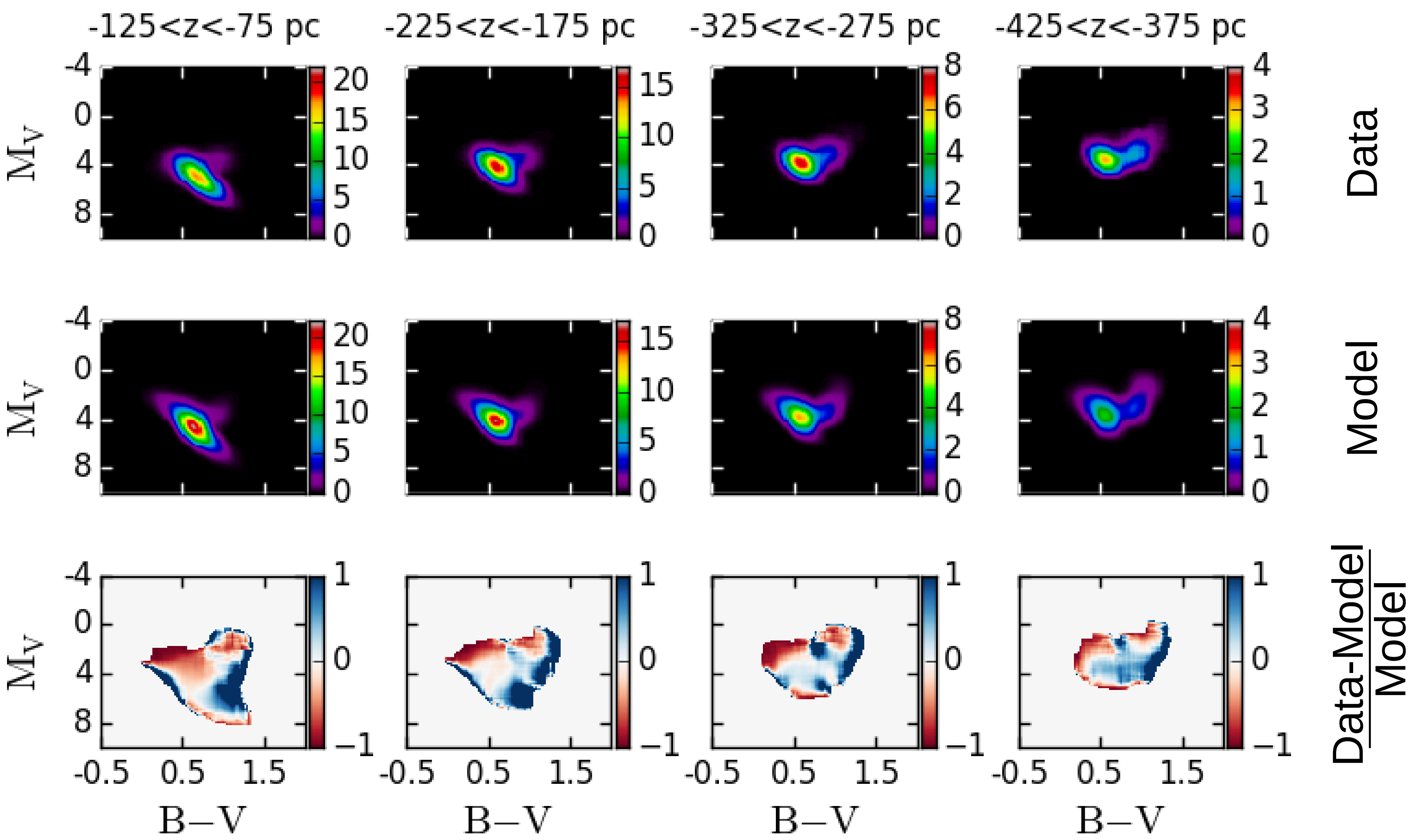
Even with no photometric errors included Model A shows good fit:



Hess diagrams in $(G-K_s, M_G)$



Hess diagrams in (B−V, M_V)



Summary

- Overall consistency of Model A with the data in terms of stellar numbers/ kinematics/ Hess diagrams is good.

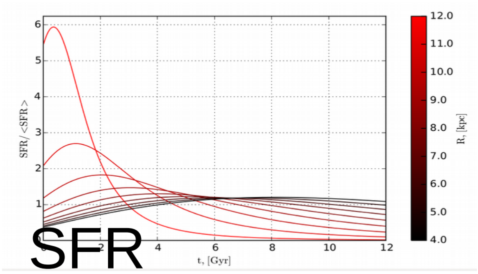
- Discrepancies in kinematics between model and data are observed, but their significance is questionable.

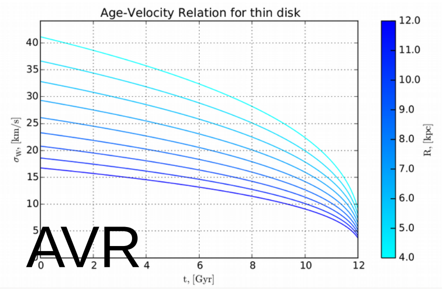
Model performance can be influenced by:

- selection function
  - reddening map
    - projection bias (close to the plane)
      - isochrones
        - clearness of the thin disk sample…

→ no strong argument for the model recalibration is derived from comparison to TGAS-RAVE.

- Next: look at other R.





Thank you!

photo:The Milky Way glimmers over Indonesia. Photograph by Justin Ng, Your Shot.

Semi-analytic Just&Jahreiß disk model

Assumptions:
- disk is axisymmetric
- disk is in a steady state

Definitions:

SFR	star formation rate
z	height above the plane
Φ	gravitational potential
ρ	mass density
σ_w	W-velocity dispersion
h	scale height
g	mass loss function
t_r	time-resolution
k	index of subpopulations

Poisson's eq.:

$$z(\Phi)=\int_0^{\Phi} d\Phi_1 \left[8\pi G \int_0^{\Phi_1} d\Phi_2 \rho(\Phi_2)\right]^{-1/2}$$

+

Vertical density profile of a set of isothermal subpopulations:

$$\rho(\Phi)=\sum_k \rho_{0,k} \exp\left(-\Phi/\sigma_{W,k}^2\right)$$

with $\rho_{0,k}=\frac{SFR_k g_k t_r}{2 h_k}$

=>

Self-consistent pair $\{\Phi(|z|),h_k\}$
- potential and scale heights

Cuts applied to the TGAS-RAVE

Qulity cut:

- $\sigma_\pi/\pi<0.3$ and $\pi>0$
- SNR > 10, algo_conv!=1
- astrometric_excess noise <1 and
- astrometric_excess_noise_sig>2

Abundance cut:

- [Fe/H]>-0.6 and [Mg/Fe]<0.2

Geometry cut:

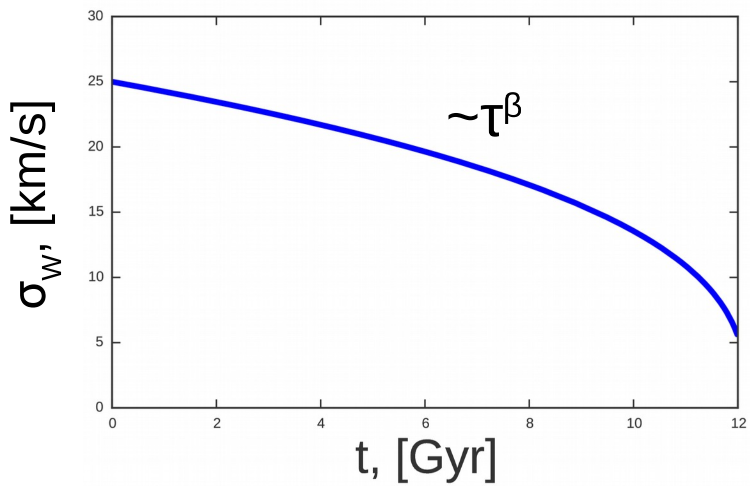
- x**2+y**2 < 300**2 – Solar cylinder with r=300 pc
- |b| < 20 deg – avoiding the plane
- RAVE x TSF geometry
- for some purposes – only z<0 pc

Photometry cut:

- Mv > -2.65*(B-V) + 2
- 7 < I < 13
- 0 < J < 14 and 0 < J-Ks < 1

Needs to be included in simulations

Probing the parameter space

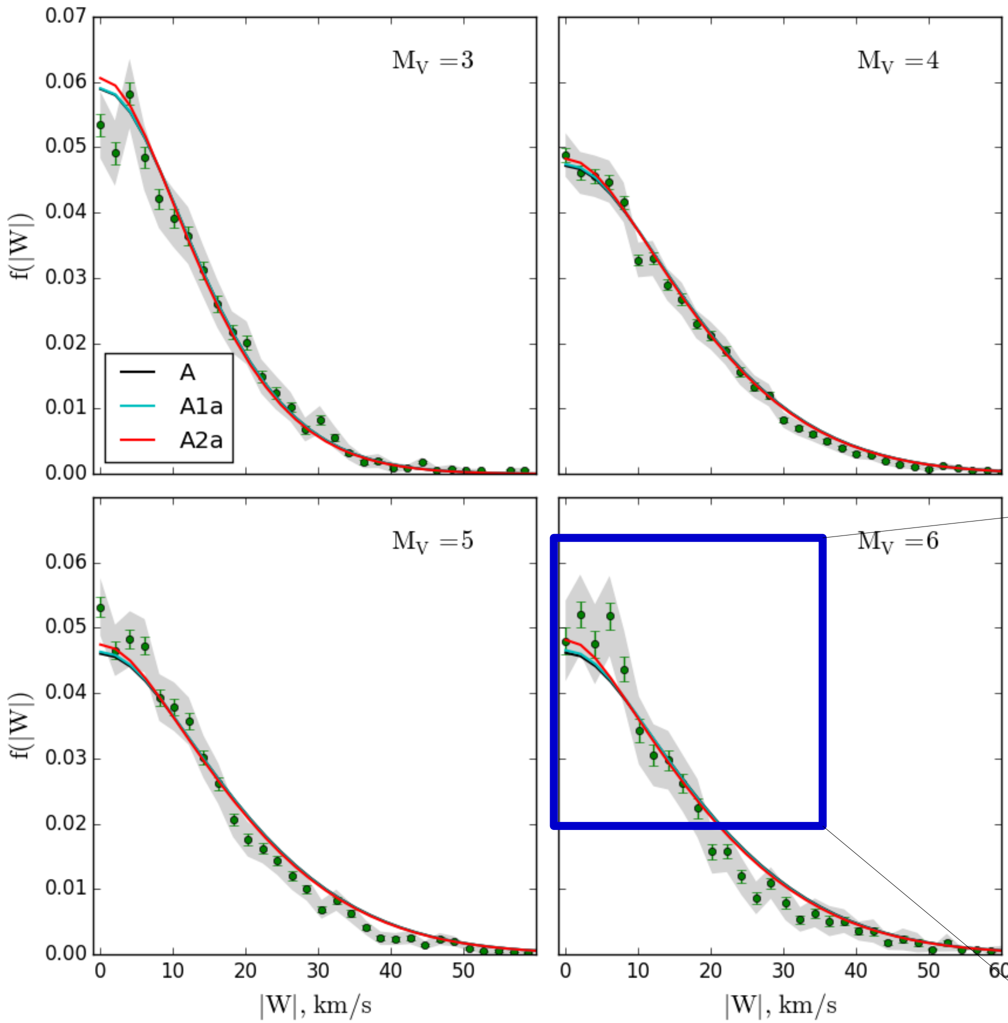


$$\sigma(R,\phi,z) = \sigma_0(R,\phi,z)\left(\frac{\tau + \tau_{\min}}{\tau_{\max} + \tau_{\min}}\right)^{\beta_{R,\phi,z}}$$

Reference	Survey	β_R	β_ϕ	β_z
Nordstrom et al. (2004)	GCS	0.31 ± 0.05	0.34 ± 0.05	0.47 ± 0.05
Seabroke & Gilmore (2007)	GCS	-	-	0.48 ± 0.26
Holmberg et al. (2007)	GCS	0.38	0.38	0.54
Holmberg et al. (2009)	Hipparcos, GCS	0.39	0.40	0.53
Aumer & Binney (2009)	Hipparcos, GCS	0.31	0.43	0.45
Just & Jahreiβ (2010)	Hipparcos	-	-	0.38
Sharma et al. (2014)	GCS	0.20±0.02	0.27±0.02	0.36±0.02
Sharma et al. (2014)	RAVE	0.19±0.02	-	0.3-0.4
Sanders & Binney (2015)	SEGUE	0.33	-	0.4

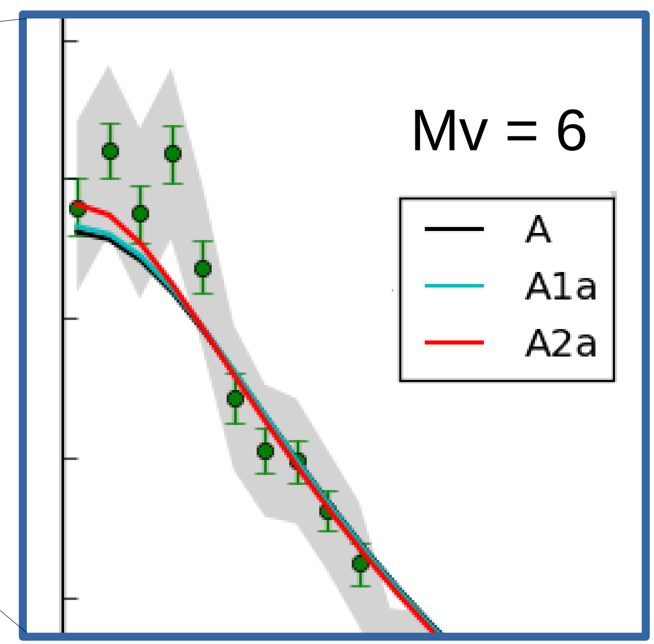
[Bland-Hawthorn 2016]

Probing the parameter space

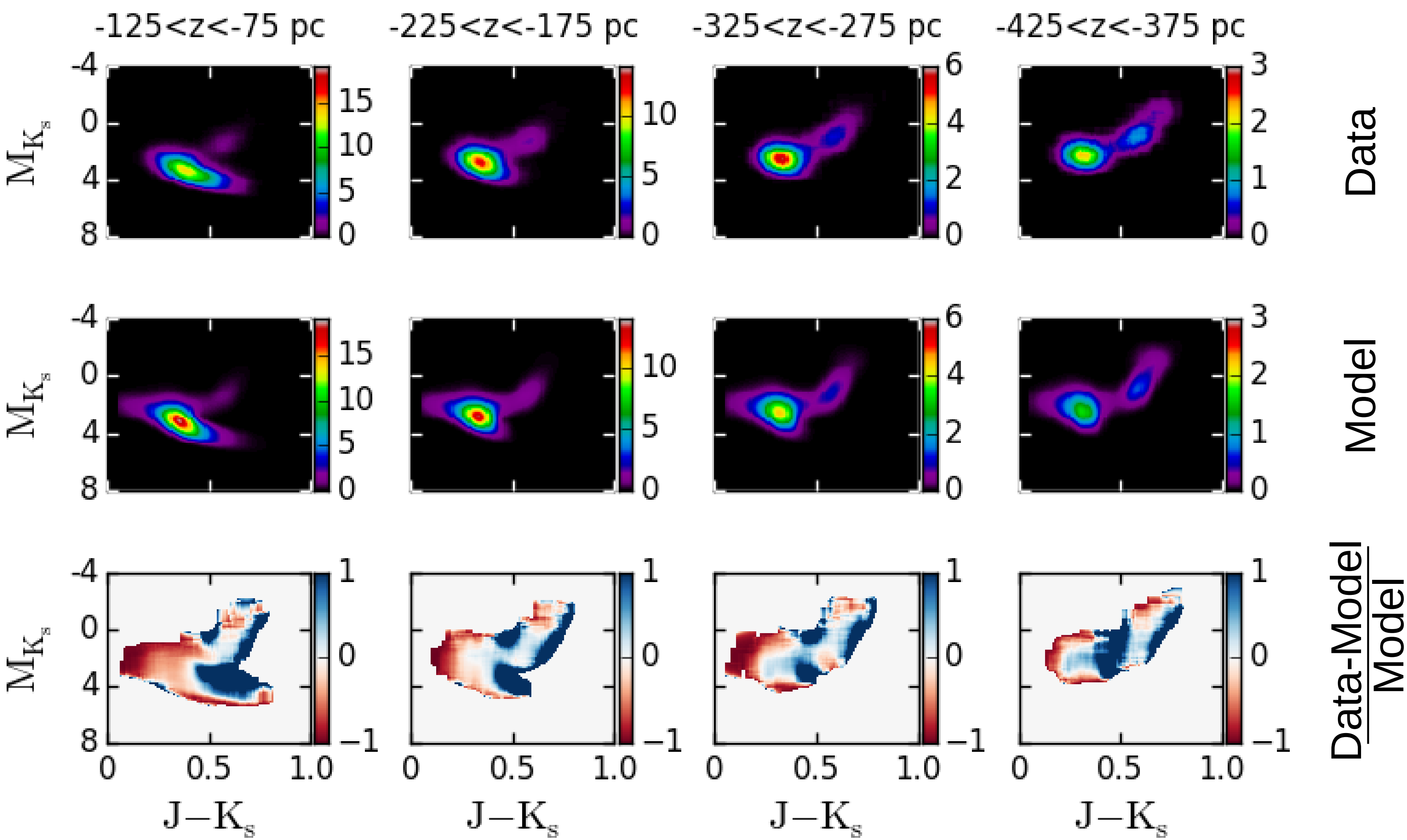


→ model A2a with colder young stellar populations perform a somewhat better

→ the model predictions change only slightly



Model A: Hess diagrams in $(J-K_s, M_{K_s})$



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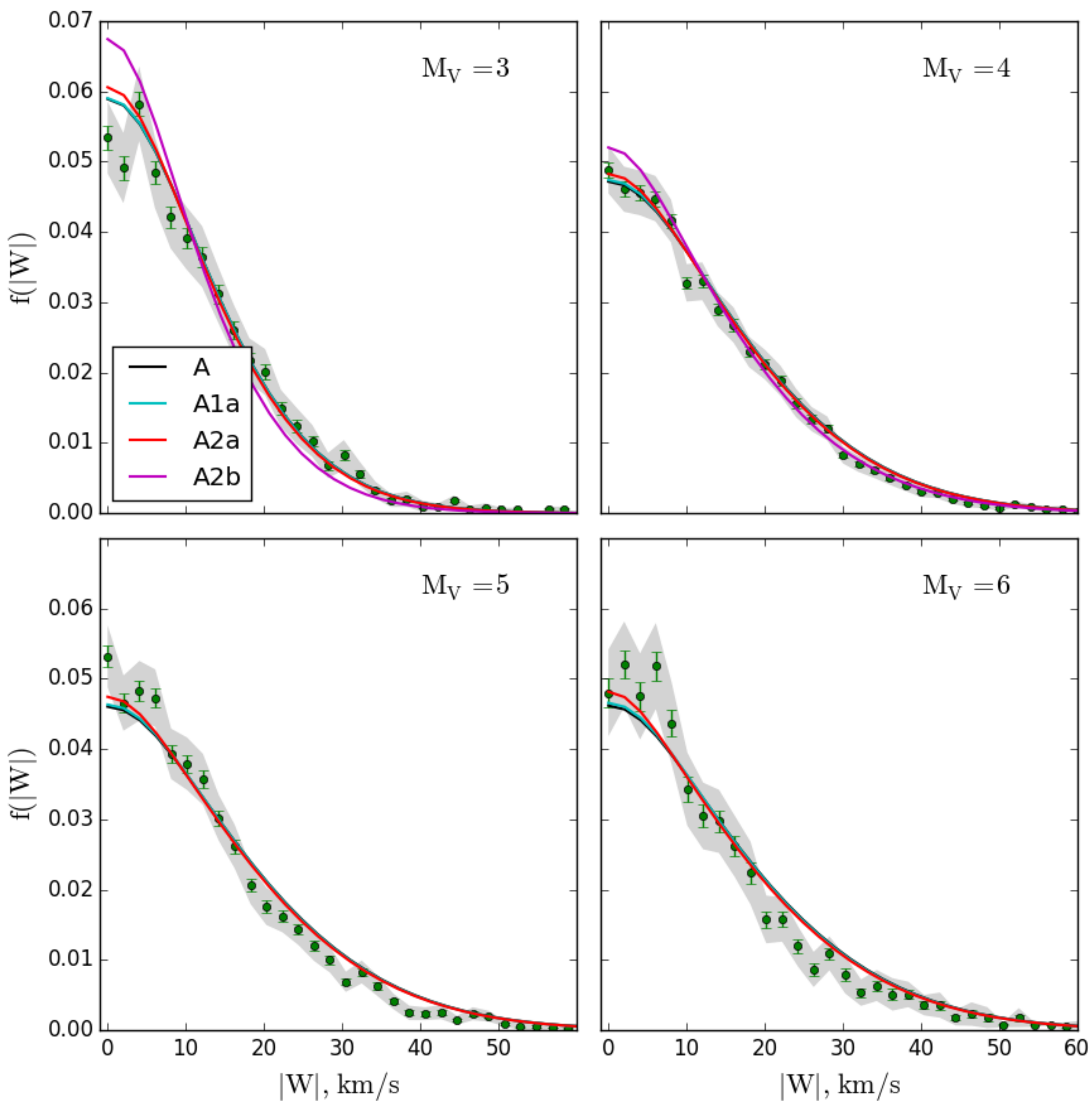

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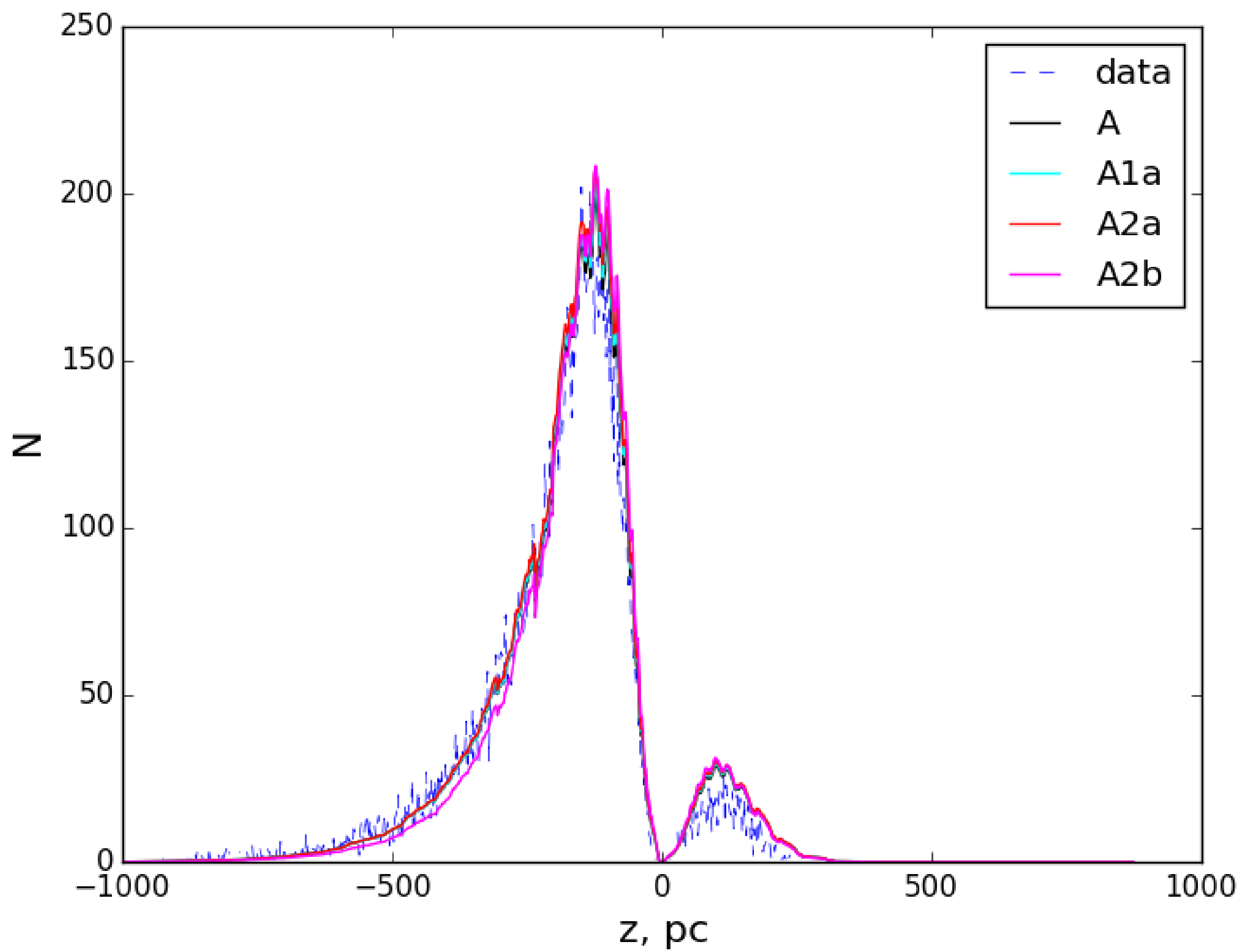
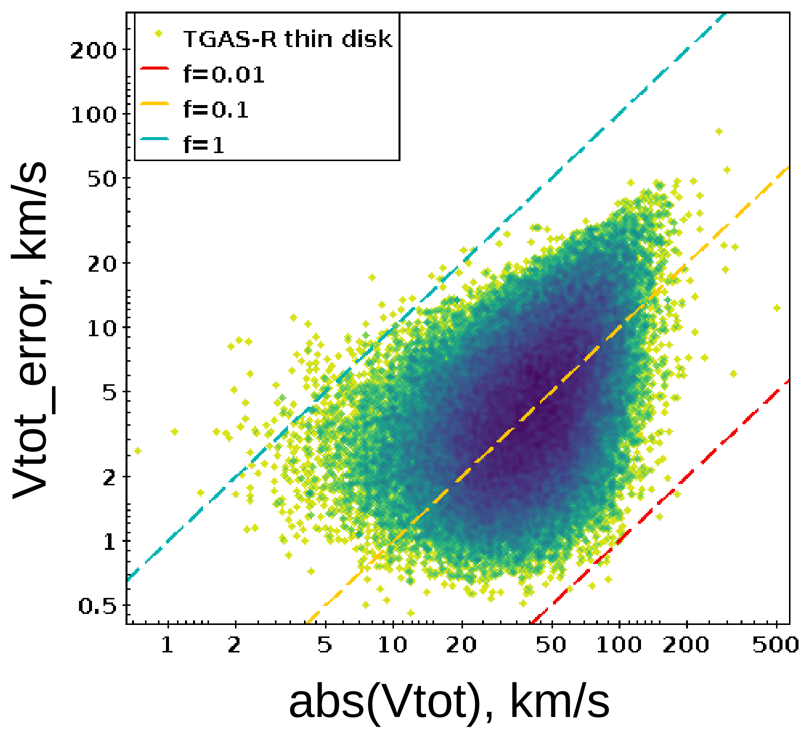
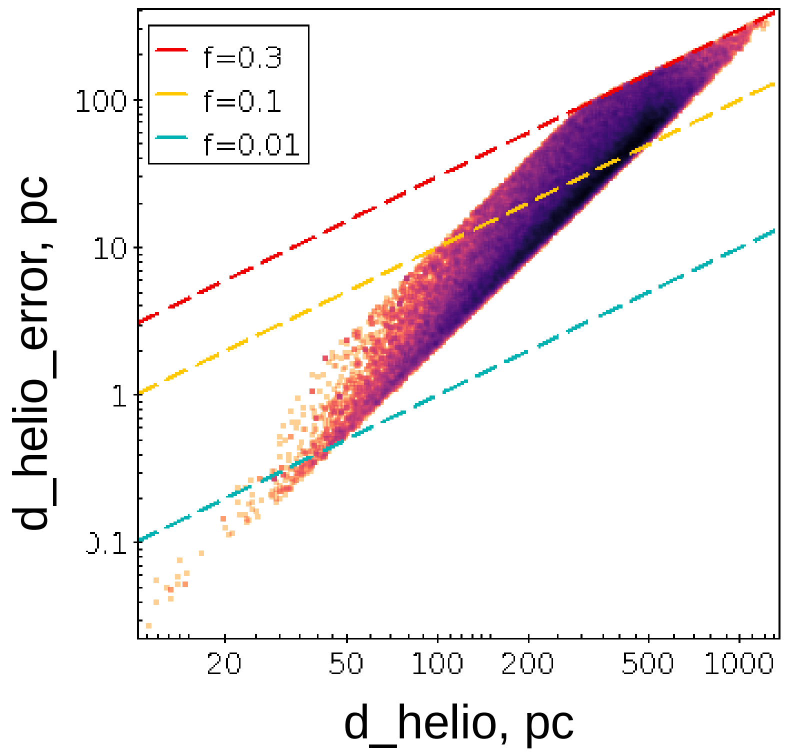


Distances and velocities of the sample

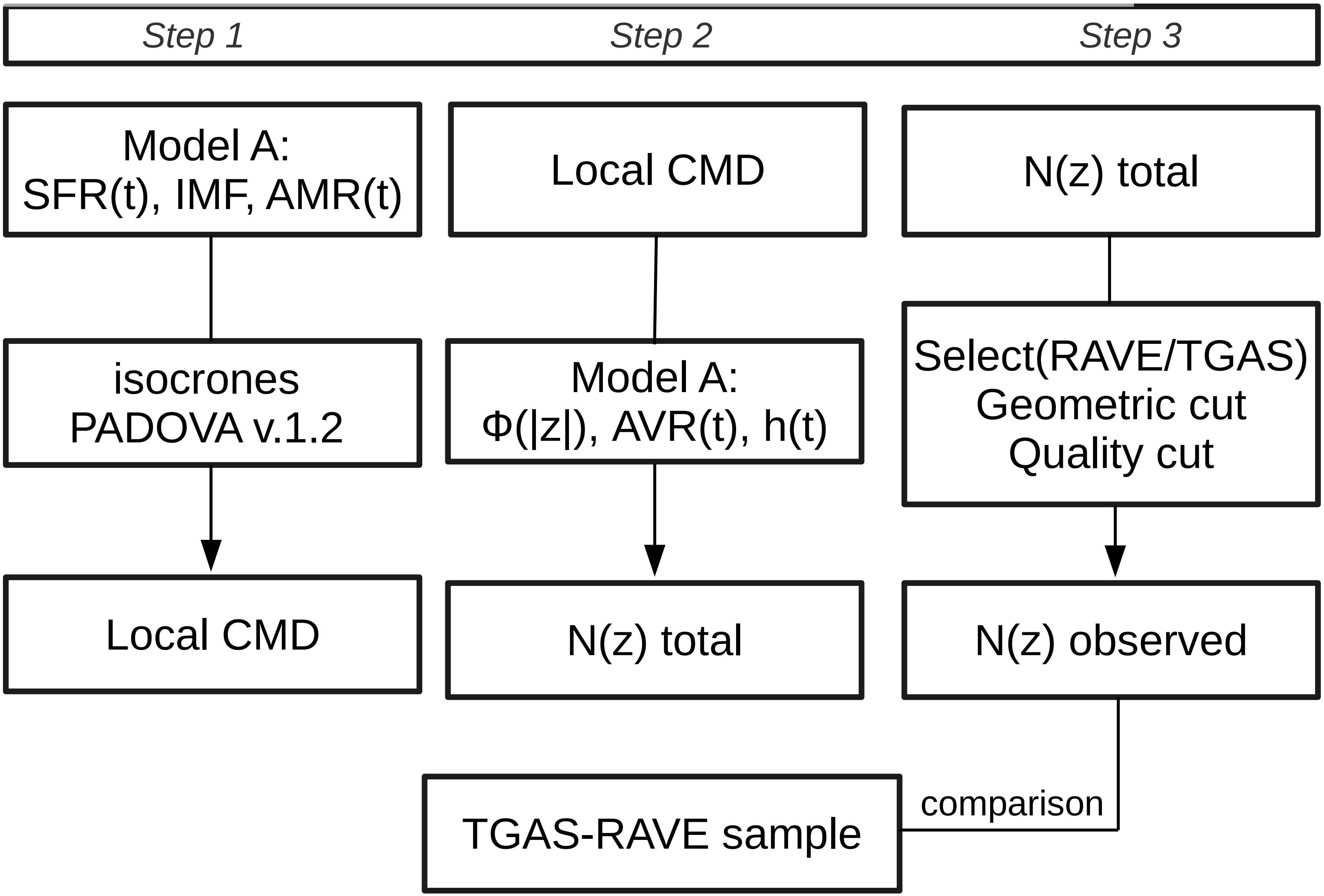
Calculated quantities
(following [Johnson&Soderblom,1986]):

- 3D-velocities in (U,V,W) and (Vφ,Vr,Vz)
- d_helio and R
+ their errors (cross-correlations included)

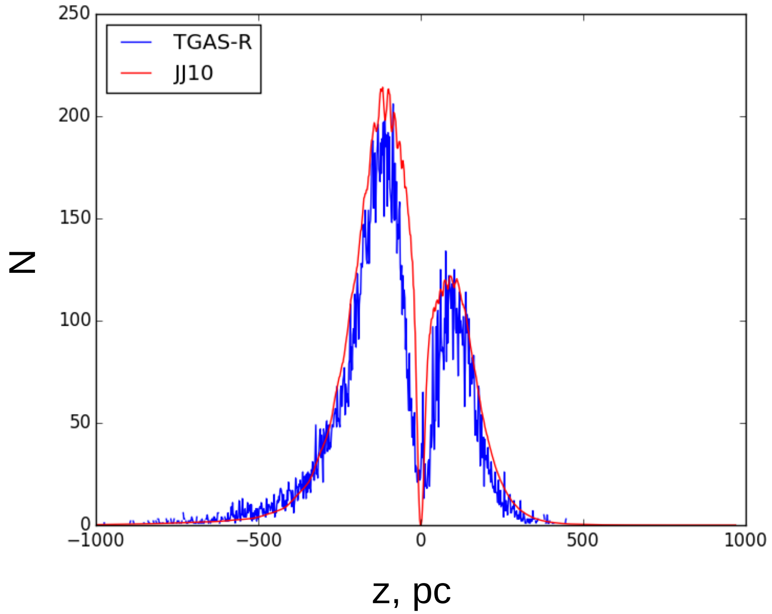




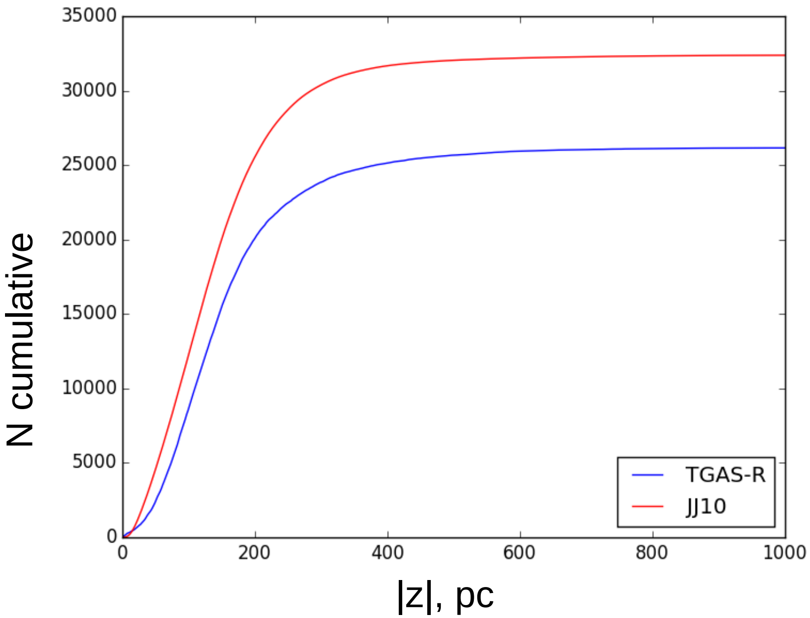
Model to data comparison scheme



V<11 cut

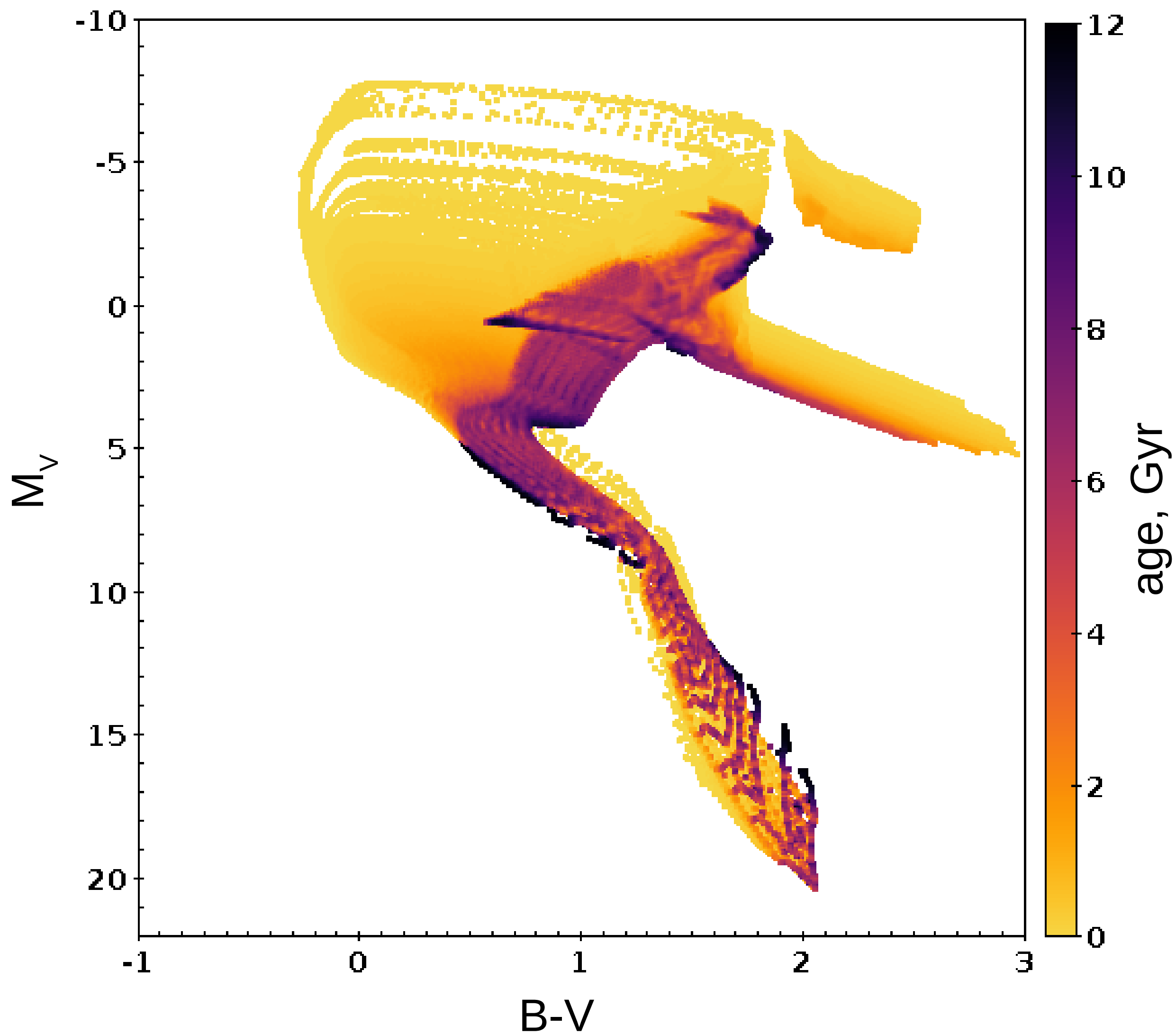


TGAS-R
JJ10
N
z, pc
0
50
100
150
200
250
−1000
−500
0
500
1000

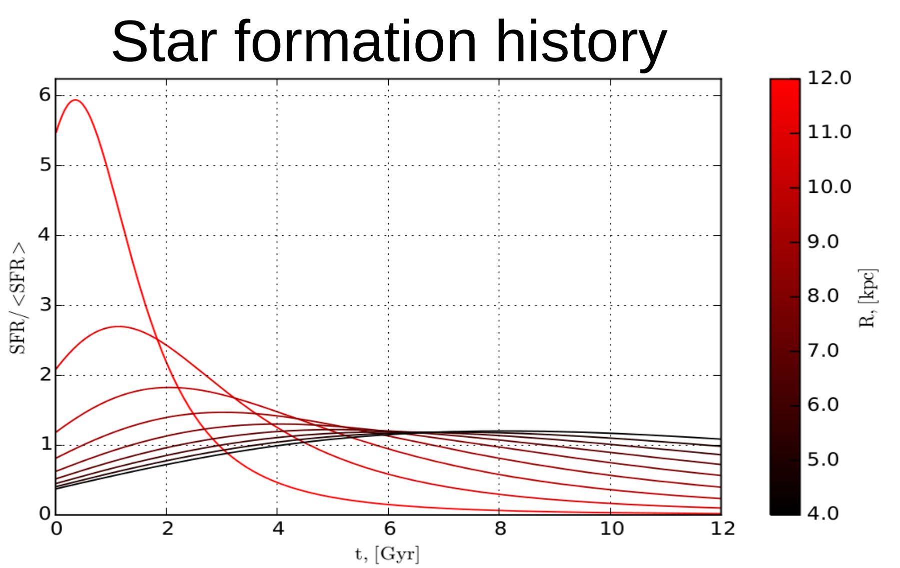


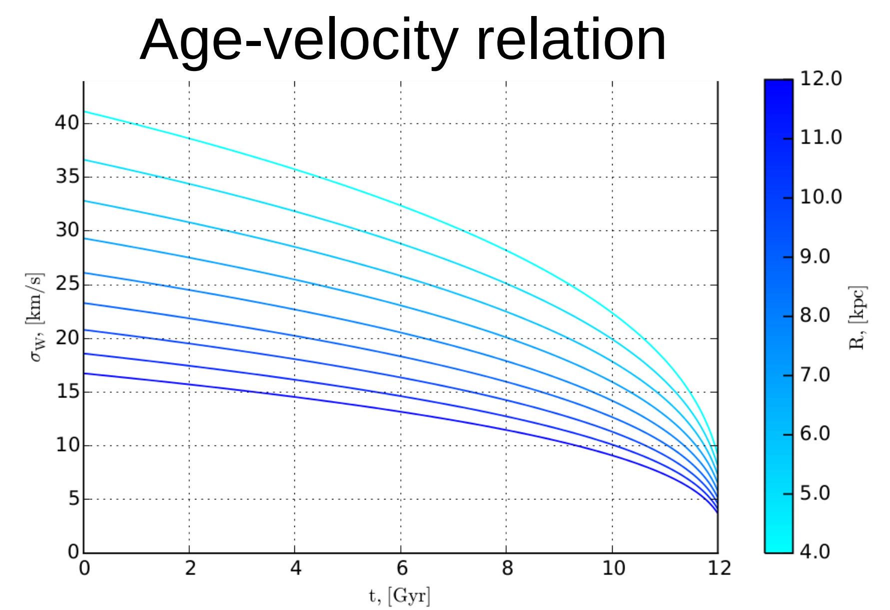
TGAS-R
JJ10
N cumulative
|z|, pc
0
5000
10000
15000
20000
25000
30000
35000
0
200
400
600
800
1000

Local CMD (PADOVA isochrones + JJ10)



Radial extension of the model





$$SFR(R)=\langle SFR\rangle \frac{(t+t_0(R))\,t_n^3}{(t^2+t_1(R)^2)^2}$$

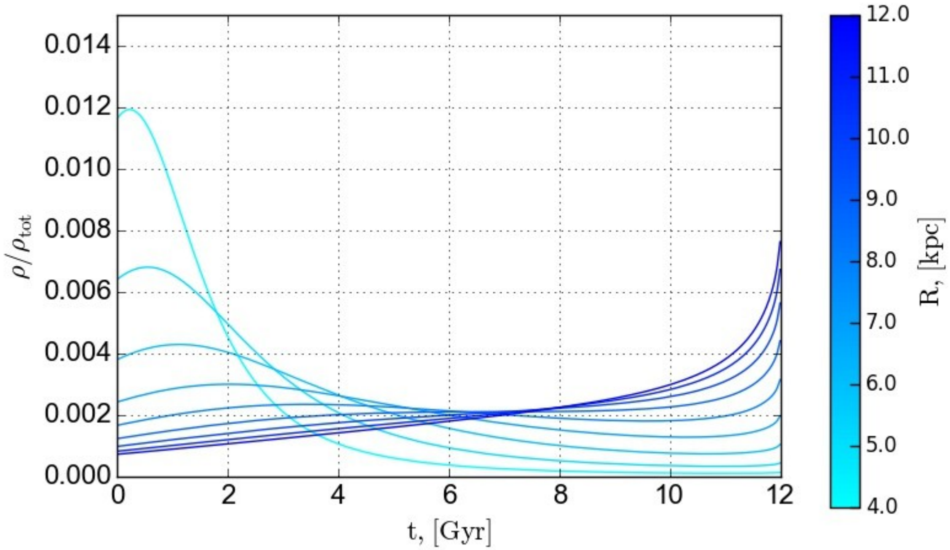
$$AVR(\tau,R)=\sigma_e(R)\left(\frac{\tau+\tau_0}{t_p+\tau_0}\right)^{\alpha}$$

$$t_0(R_{Sun})=5.6$$
$$t_1(R_{Sun})=8.2$$

$$t_p=12\,Gyr$$
$$\tau_0(R_{Sun})=0.17\,Gyr$$
$$\alpha(R_{Sun})=0.375$$
$$\sigma_e(R_{Sun})=25\,km/s$$

Radial extension of the model

Age distributions



There is a positive age gradient towards the center of the disk

Scale heights

Flaring of monoage subpopulations comes out naturally
[see also Bovy 2016, Minchev 2015]