GREAT WGA1:
The Gaia – Model Interface

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Objetivos:

- Plantear/mejorar los modelos de la galaxia: estructura, cinemática, dinámica, hidrodinámica, química
- Comparar modelos con nuevos surveys
- Datos Gaia > mejorar modelos > iterar

- Intercambiar información sobre las precisiones y capacidades de Gaia en el campo

WGA1: The Gaia – Model Interface

- 35 miembros
- Participación española:
  - IAC: A. Cabrera-Lavers, F. Garzón
  - UA: C. González
  - UB: T. Antoja, J.M. Carrasco, F. Figueras, C. Jordi, E. Masana, M. Romero-Gómez

Meetings:

29-31 March 2010	Gaia model for Gaia/GREAT Chemo-Dynamics Survey Programme (GCDS)	MSSL/UCL
7-11 June 2010	ELSA conference: Gaia: at the frontiers of astrometry	Sèvres
Summer 2010? X	Workshop: Preparing for modelling the Galaxy based on Gaia data	Leiden
18-22 April 2011	Conference: Assembling the Milky Way puzzle: structure & dynamics	Le Grand Bornand

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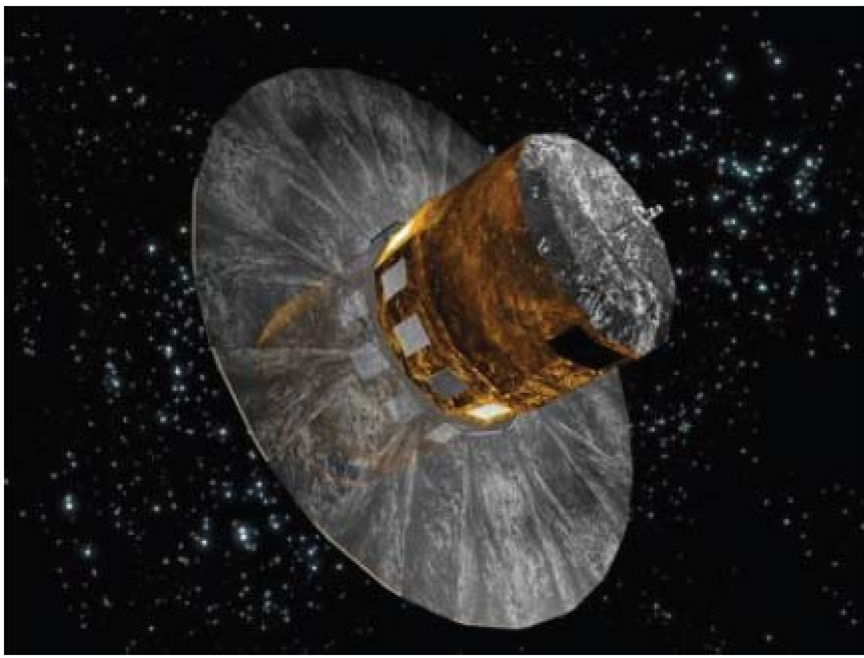
MSSL: 29–30 March 2010: Aims:

- A meeting for chemical evolution and dynamical evolution modelling experts to discuss the key sciences that will be opened up by the complementary spectroscopy survey for Gaia (Chemical Tagging meeting, April 2010).

- **What observational data is required to allow comparison with models in terms of for instance positional, velocity, chemistry information?**

Modeling the Milky Way dynamics around 2015 will differ from past practices



Pfeninger, ELSA meeting, June 2010

Why: our goals

- Determine structure of bar, discs & halo
- Determine the mass density of baryons
- Determine distribution of DM
- Determine structure & dynamics of spiral structure
- Probe origin of MW: organic growth vs mergers, origins of bulge & thick disc

How: carry models into space of observables

- Parallaxes can be <0
- Distance errors endemic & insidious

What we need

- Hierarchy of dynamical models of variable complexity that yield number density of stars in $(m_{app},\mathrm{Colour},Z,g,\varpi,l,b,v_{los},{}^{1}_{®},{}^{1}_{\pm})$
- Apparatus to optimise fit of model to data

Theoretical “Wish List” (1):

- NIR multi-objects spectrograph Radial velocity of disk and bulge/bar
- Radial velocity of stream stars→ identify streams → gravitational potential
- Chemical labeling of streams, chemical abundances (α + several elements) → star formation history of progenitor galaxies

5,000<R<15,000, 100 stars per stream

... chance for EMP stars?

Theoretical "Wish List" (2):

- Radial abundance gradient (α+several elements) → crucial to constrain the degree of radial migration
- Detailed position and velocity map of nearby (a few kpc) stars → reconstruct local spiral structure, but need more model developments
- Kinematics of stars in disk plane and above (inner halo stars, streams?) → disk and DM potential shapes

Theoretical "Wish List" (3):

- chemical tagging of disk stars (α+several elements) → initial molecular clouds mass function.
- accurate ages of stars → strong constraints on formation history

Gaia: Good parallaxes → Recalibration of stellar models → New stellar models → New ages

Further model developments:

- Comparison among N-body/SPH chemodynamics codes: the Aquila project
- How to transfer N-body simulations to observational plane?
- N-body simulation can be used for testing analytic modelling?
- We need a common interface between different types of models.

Future workshop and exchange programmes

(volunteer: Debattista, Font)

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«Assembling the Puzzle of the Milky Way»
Le Grand-Bornand (France) - April 18 to 22, 2011

GREAT Proposal sent 7 June 2011

- **Science Organising Committee (SOC)** :
- C. Reylé, A. Robin, M. Schultheis (Besançon, France)
- Luri, F. Figueras (Barcelona, Spain)
- T. Beers (Michigan State University, USA)
- J. Binney (Oxford, UK)
- H. Dejonghe (Gent, Belgium)
- S. Feltzing (Lund, Sweden)
- K. Freeman (Canberra, Australia)
- M. Haywood (Paris, France)
- A. Helmi (Groningen, Netherlands)
- D. Kawata (Surrey, UK)
- D. Minniti, M. Zoccali (Santiago, Chile)
- D. Pfenninger (Geneva, Switzerland)
- Quillen (Rochester, USA)

- **Local Organising Committee (LOC)** :
- C. Reylé, A. Robin, M. Schultheis, L. Laffont, K. Van Keulen, E. Soudagne, E. Burgey

All these works and others point to the need to consider the Milky-Way as a time-dependent and asymmetric system

Only fully self-consistent N-body models can achieve the level of detail required by future observational data such as those of GAIA

Pfeninger, ELSA meeting, June 2010

How? N-bodies?

- Flexible and easy to relate to cosmology
- But
  - Doesn’t deliver DF
  - Limited resolution
  - Difficult to control
  - Difficult to characterise

How? Torus model?

- Instead of finding orbit as time sequence x(t), v(t) can find as 3d object $x_J(\mu)$, $v_J(\mu)$
- $J=(J_1,J_2,J_3)$ special integrals "actions"
- $\mu=(\mu_1,\mu_2,\mu_3)$ phases that increment linearly in time
- Actions essentially unique – facilitates comparison of models
- Actions adiabatic invariants – facilitates study of secular evolution
- We have code that takes J as input and returns $x_J(\mu)$, $v_J(\mu)$ as analytic functions – this code essentially replaces Runge-Kutta / leapfrog etc integrator

Future simulations

- With N=10^{10} -10^{11} particles each (bright) star can be represented in a Milky Way N-body model where particles can represent at least all the massive stars, and groups of low mass stars/binaries

  => Phase space correlations (streams) can be studied and compared

- The problem of softening almost disappears
- Large sets of smaller N-body models with different initial conditions can be performed
- Precise simulations of observations are possible at a level matching GAIA results

Conclusions

- The bar (= bulge) is an essential feature that introduces chaos and orbit diffusion, including the disk thickening
- At GAIA epoch disk galaxies must be seen as time-dependent structures with multiple patterns rotating at different speeds
- Modeling the optical part of the Milky-Way with fully consistent N-body models containing as much particles as stars will be feasible during the next decade
- Gas and dust modeling, as well as star formation, will remain a difficulty for a longer time

Outline

Particular cases:

Spitzer/GLIMPSE (Benjamin et al. 2005)

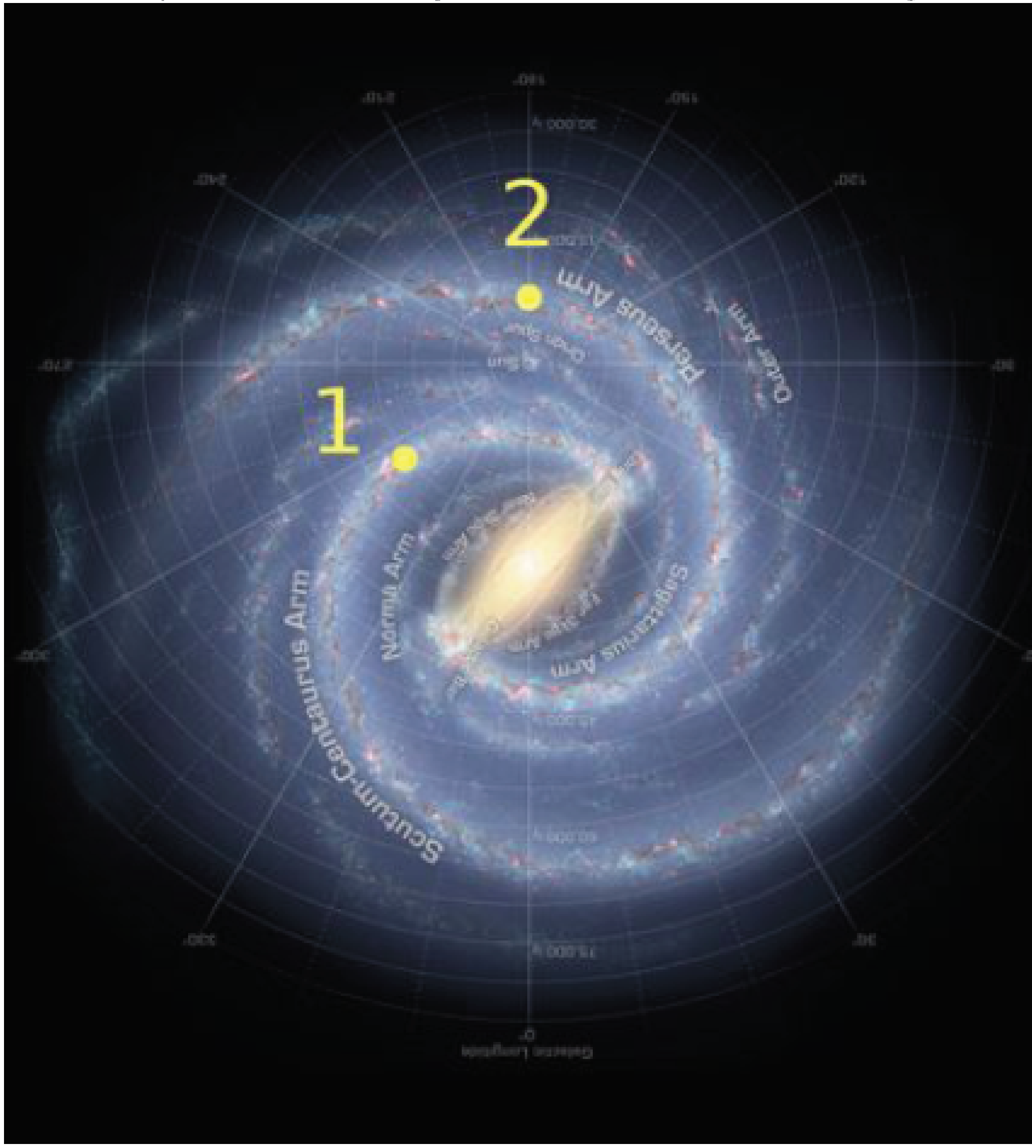
1) Scutum-Centaurus tangency

2) Perseus arm in the anti-center

Why these positions?

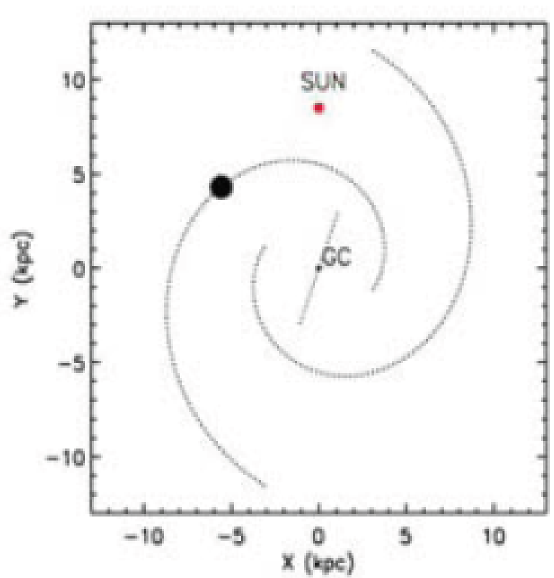
- Particularly rich in resonant substructure
- Regions that experience the spiral arm perturbation

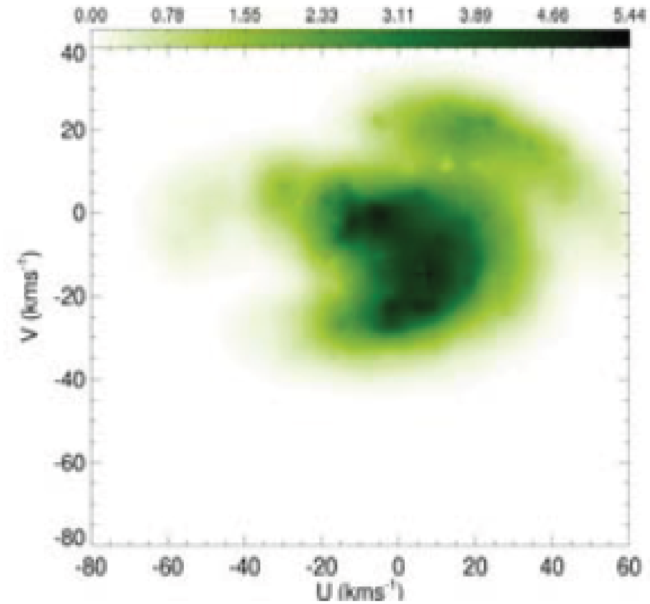
SIMULATIONS
WITH SPIRAL ARMS
+
GAIA EXPECTED ACCURACIES

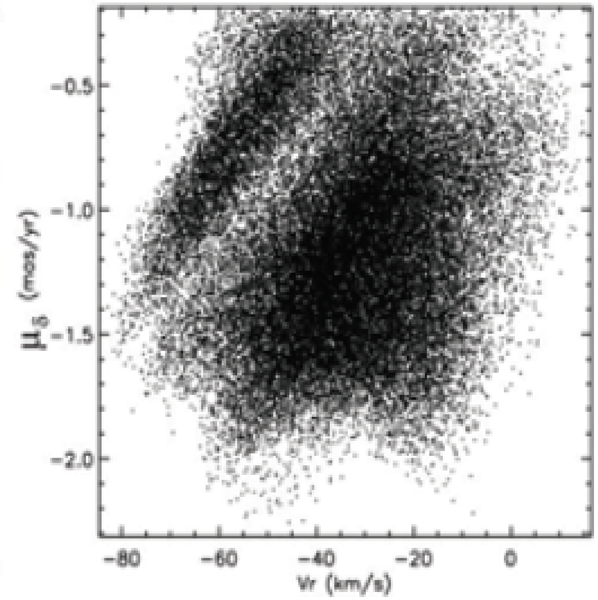


Scutum-Centaurus tangency

$l = 305^{\circ}, \beta = 0^{\circ},$
$dist = 6.9\,\mathrm{kpc}$







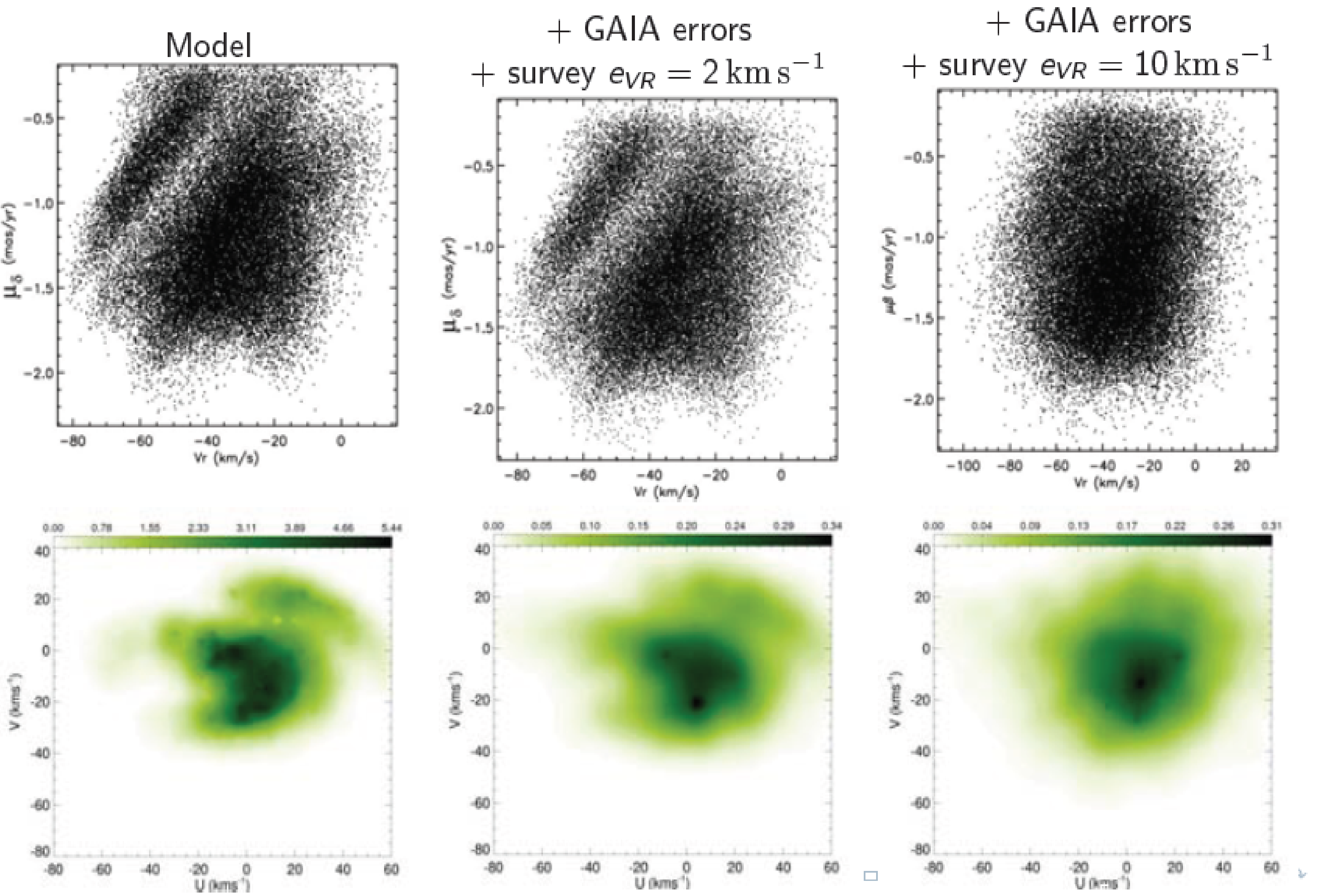
K4-5 III
M_V, $(V\text{-}I)_i$, A_V, A_I

$\Longrightarrow$

$G \sim 18$
$e_\pi \sim 90\ \mu as$ (62% !!)
$e_\mu \sim 50\ \mu as/yr$
No radial velocities!!

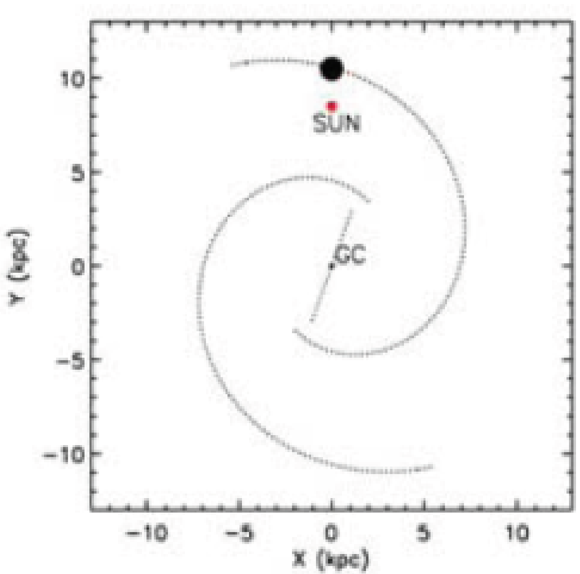
- Radial velocities needed
- Better distances

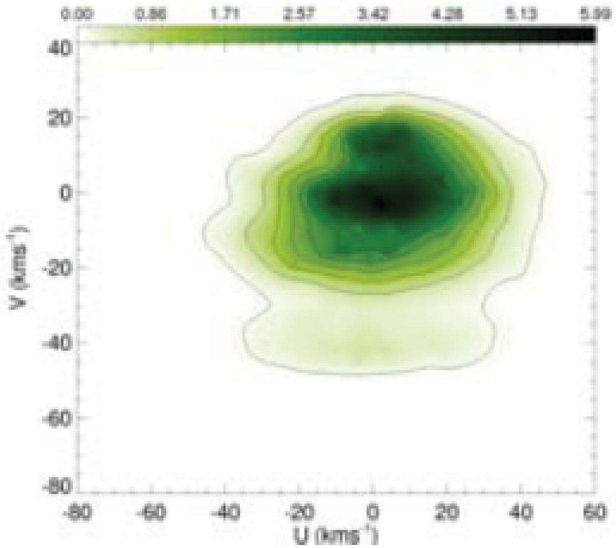
Scutum-Centaurus tangency

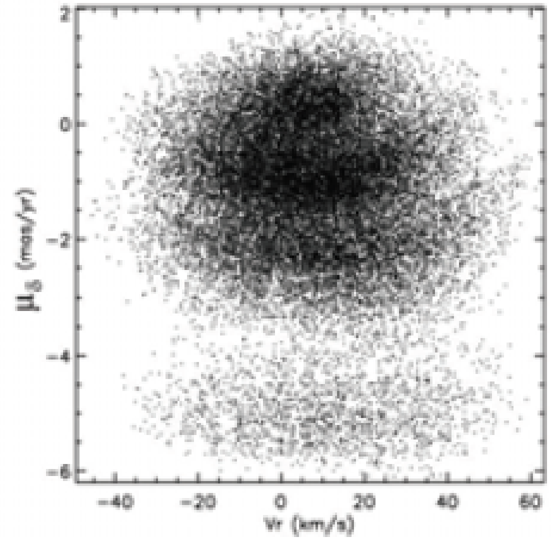


Perseus arm in the anti-centre

$l = 180°, \beta = 0°,$
$dist = 2.0\,\mathrm{kpc}$





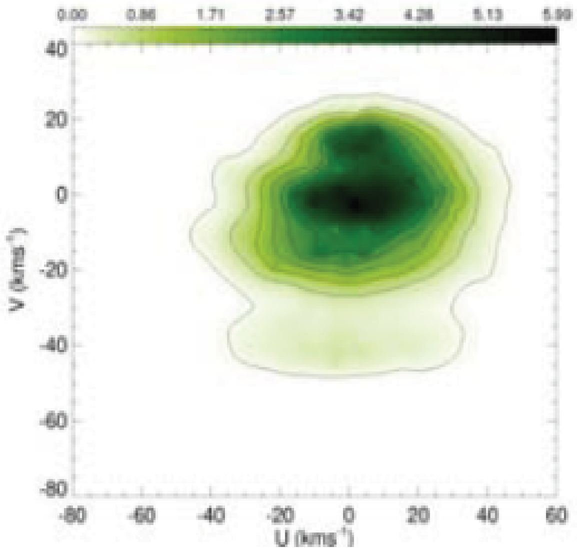


M_V, $(V\text{-}I)_i$,
A_V, A_I $\Longrightarrow$

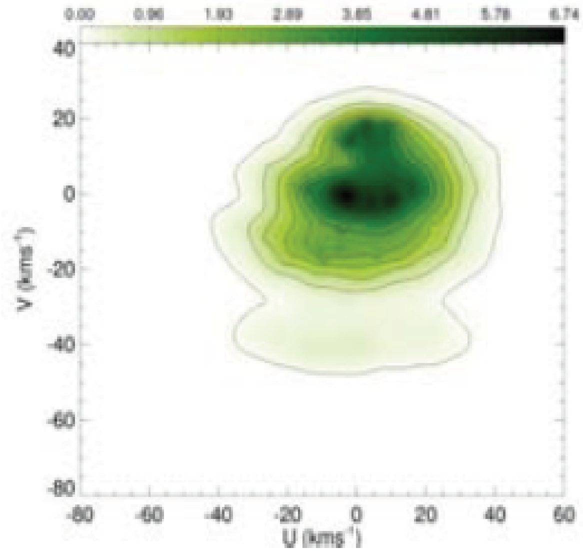
ST	G	$e_\pi(\mu as)$	$e_\mu(\mu as)$	$e_{VR}(\,\mathrm{km\,s^{-1}})$
B5 V	13	8 (2%)	4	10
K5 III	13	8 (2%)	4	1
A5 V	15	23(5%)	12	20

Perseus arm in the anti-centre

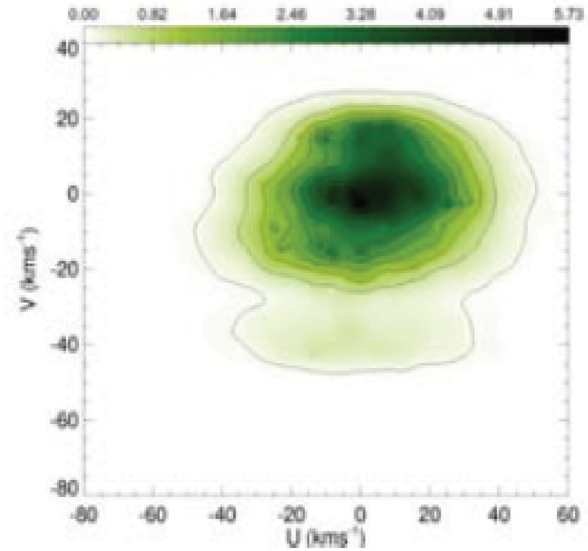
Model

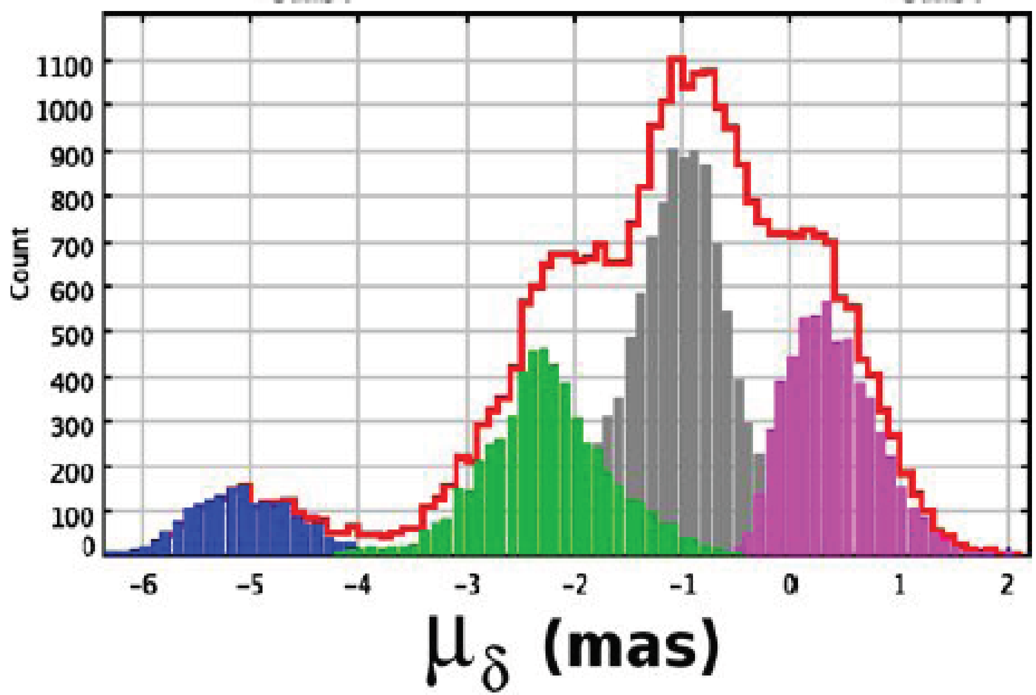


+ GAIA errors (K5 III)

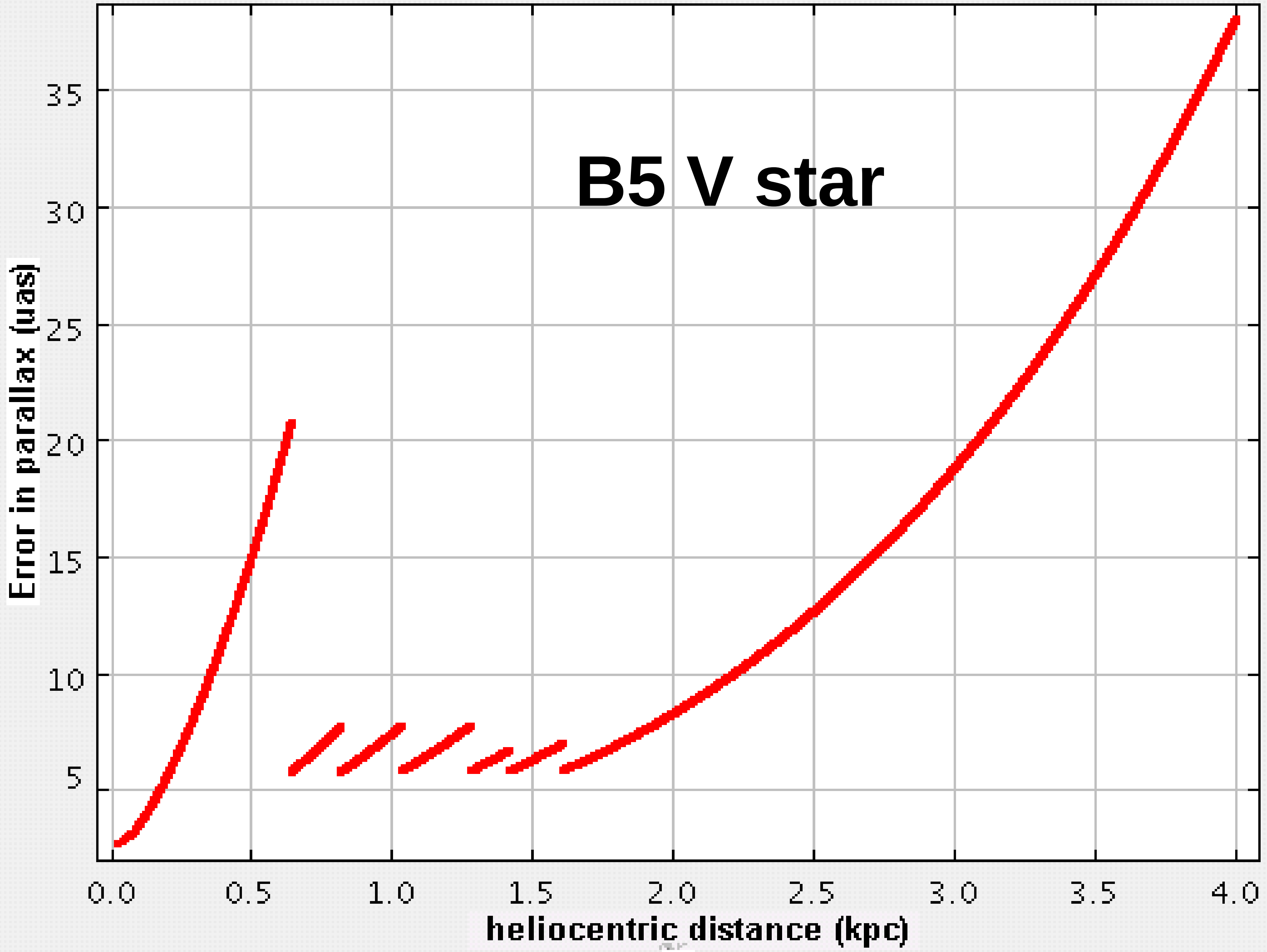


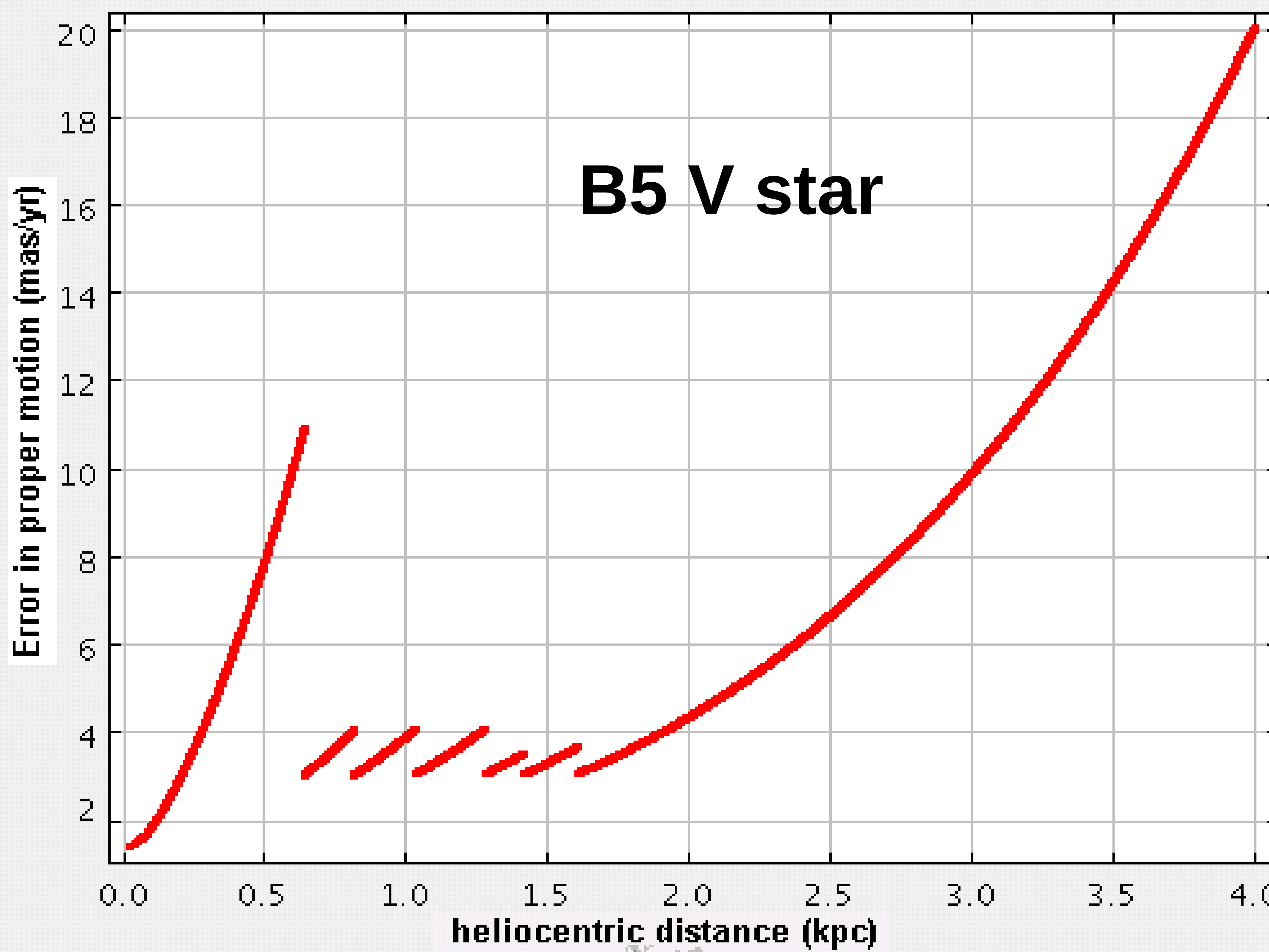
+ GAIA errors (B5 V)



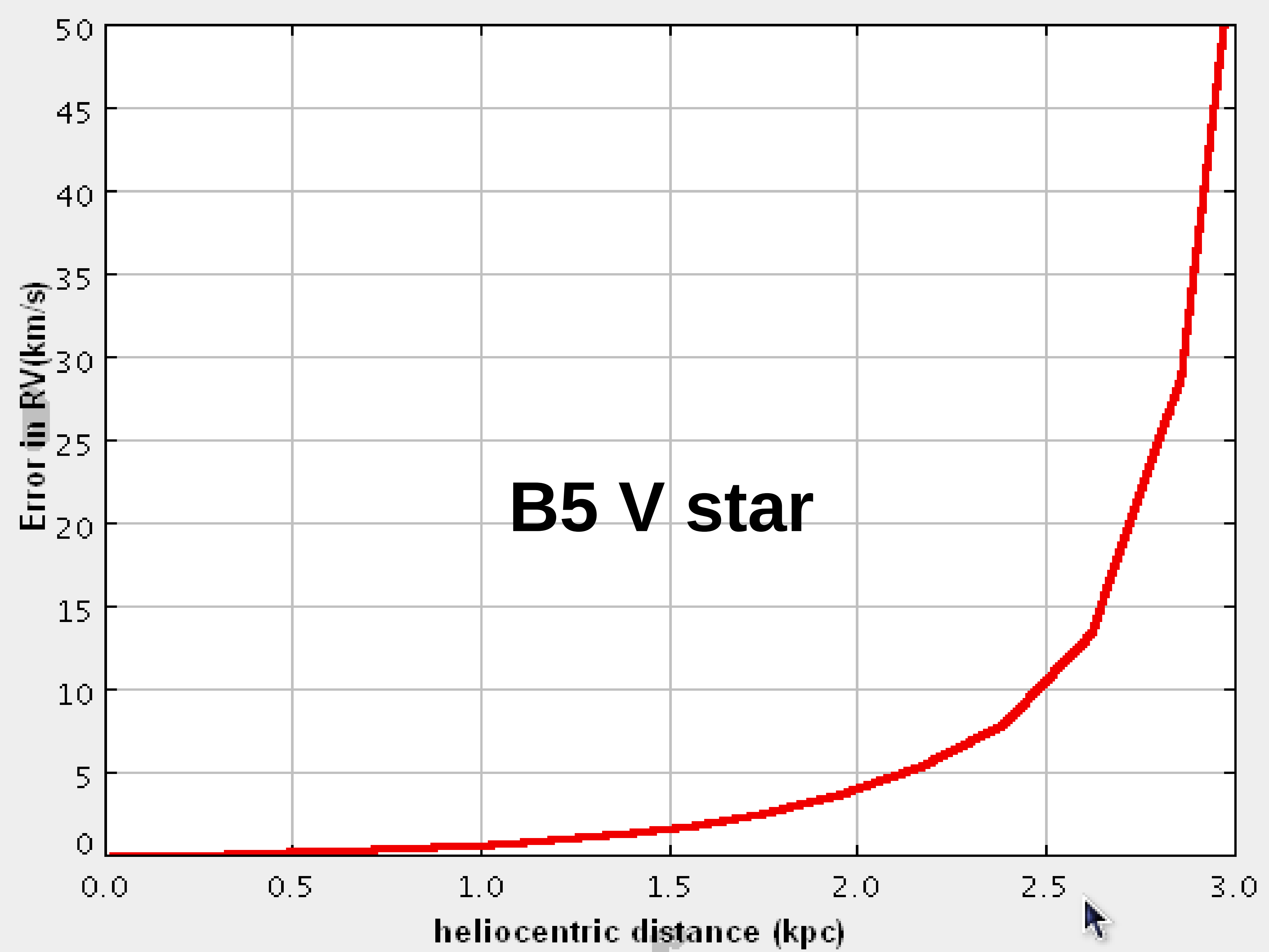


Very good job
in the Perseus arm!

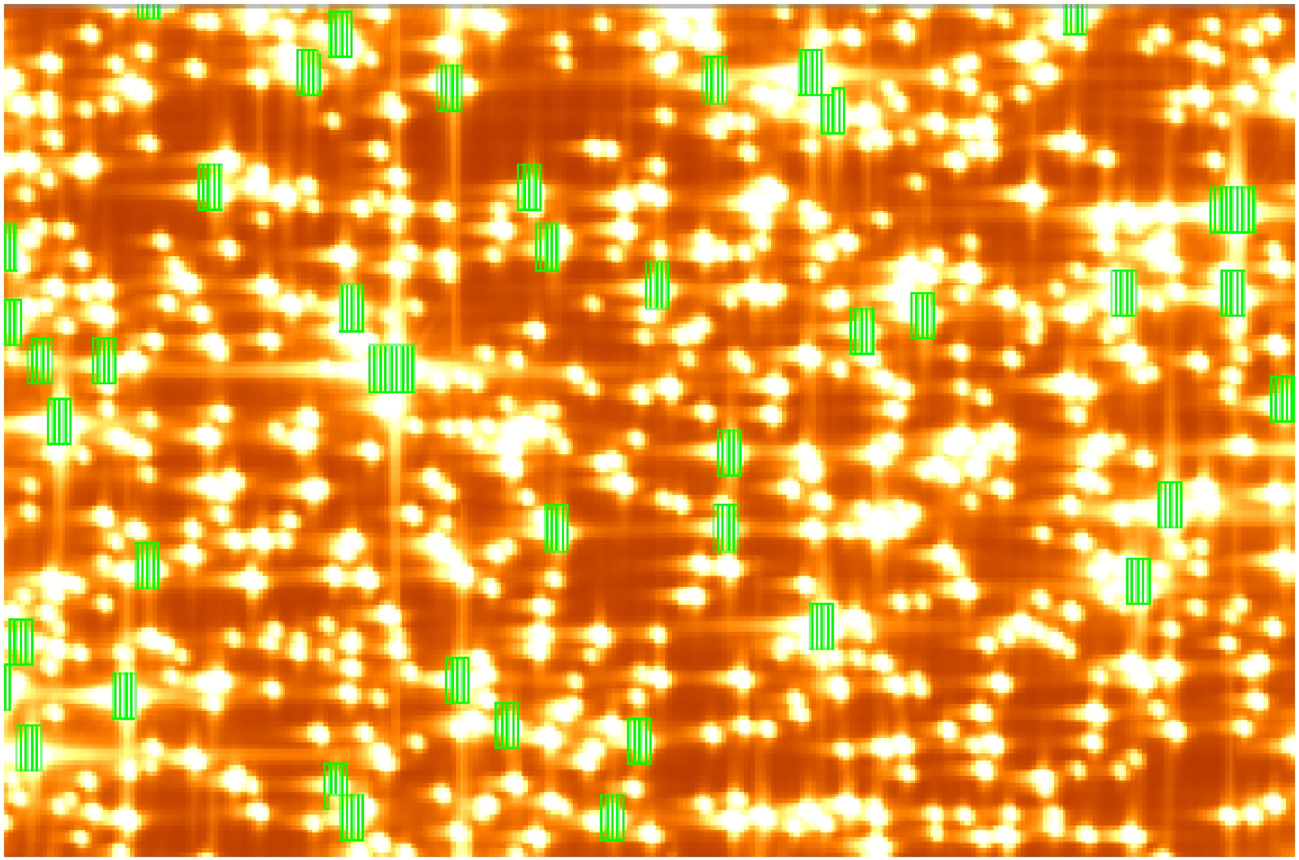

B5 V star
Error in parallax (uas)
5
10
15
20
25
30
35
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
heliocentric distance (kpc)



B5 V star
Error in proper motion (mas/yr)
heliocentric distance (kpc)
2
4
6
8
10
12
14
16
18
20
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0


B5 V star
Error in RV(km/s)
heliocentric distance (kpc)
0
5
10
15
20
25
30
35
40
45
50
0.0
0.5
1.0
1.5
2.0
2.5
3.0

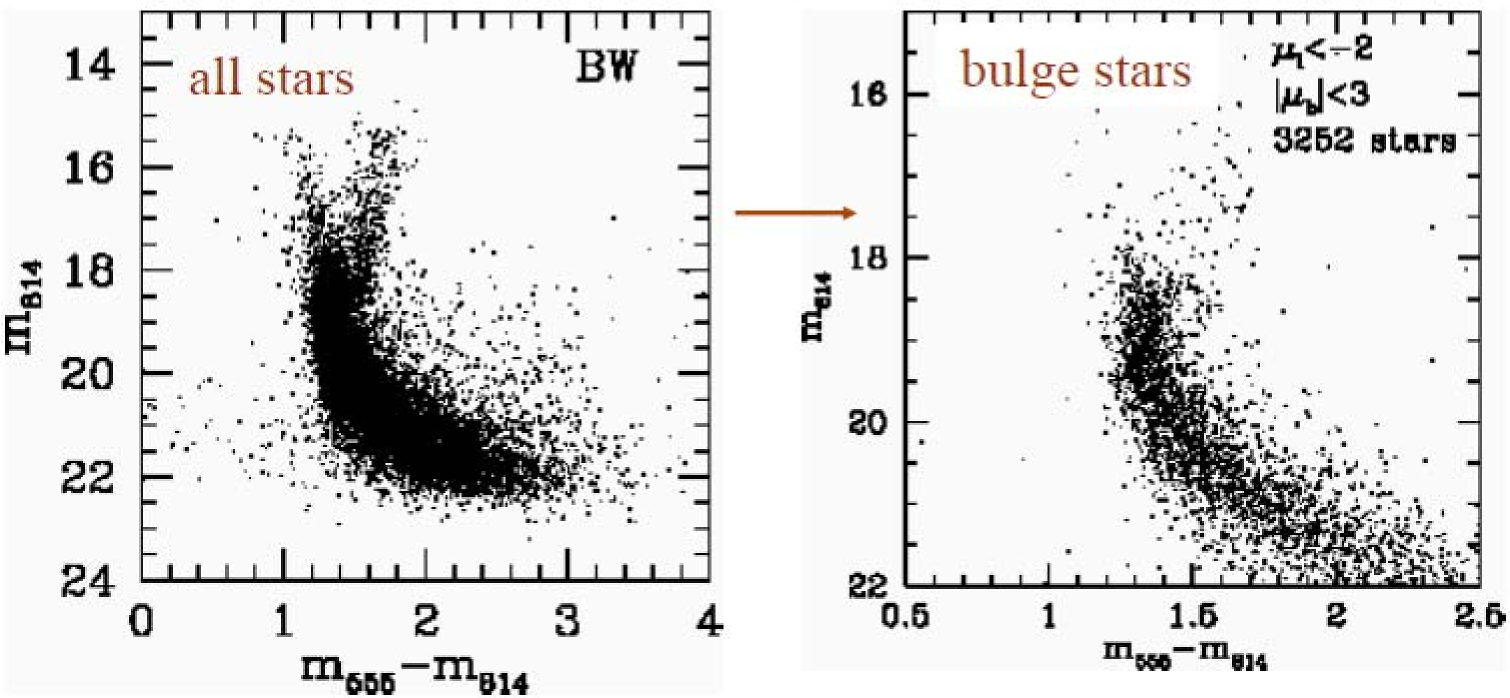
Gaia AF1 observation of Baade's Window



20" x 40"
pix: 59 x 177 mas

Babusiaux (2010, ELSA)

Using proper motion in Baade's Window to select bulge stars :



Kuijken & Rich 2002

Babusiaux (2010, ELSA)

The largest proper motions induced by galactic rotation in the Milky-Way

Brunetti & P 2010

- Proper motion field

Axisymmetric model

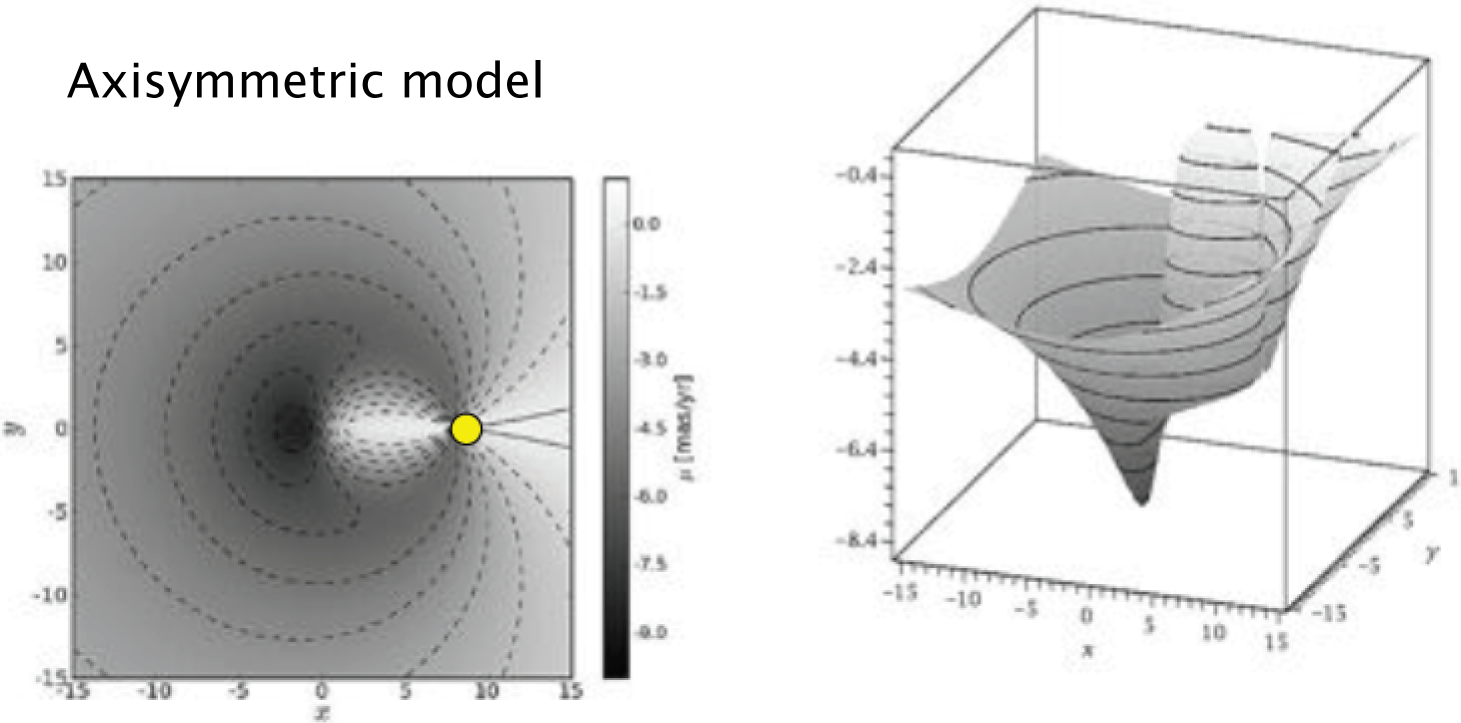


Fig. 3. On the left, contour map of the magnitude of the proper motion μ as observed from the observer's position at $x_0 = 8, y_0 = 0$ as in Fig. 1. The dark/light grays correspond to low/large values. On the right, the side view of the same contour map shows the relative importance of proper motion, with the most negative, largest absolute value slightly beyond the Galactic center as seen from the observer's position.