Magellanic clouds – dynamics and evolutionary phases

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COST MW-Gaia WG1/WG4 Workshop
Gaia - Beyond the Milky Way
September 28th, 2022

Motivation

- Full structure and dynamical studies in barred galaxies in theoretical models and N-body simulations
- Partial information for the Milky Way and external galaxies until Gaia DR3
- Structure requires 3D: positions and accurate distances
- Dynamics requires 6D: positions, distance, proper motions and line-of-sight velocities
- For a statistically large sample, with homogeneous sky coverage

Goals

- Use of Gaia astrometry and photometry to classify LMC stars
- Use of 3D kinematic maps to characterise the LMC disc:
  - Structure: angular orientation, length of the galactic bar
  - Dynamics: resonances, pattern speed of the bar and/or spiral arm
- Study the dependence on different stellar populations

Outline

- Updates on the data selection: LMC/MW separation
- Very basic galactic kinematics and dynamics concepts
- Gaia (E)DR3 and the Large Magellanic Cloud:
  - General kinematic maps
  - Kinematic profiles of the different evolutionary phases

Gaia Collaboration, Luri, Chemin+2020
Jiménez-Arranz, Romero-Gómez, Luri+2022 (under review)

LMC/MW classification

LMC/MW classifier

Training sample: Gaia Object Generator (GOG) [LMC + MW]

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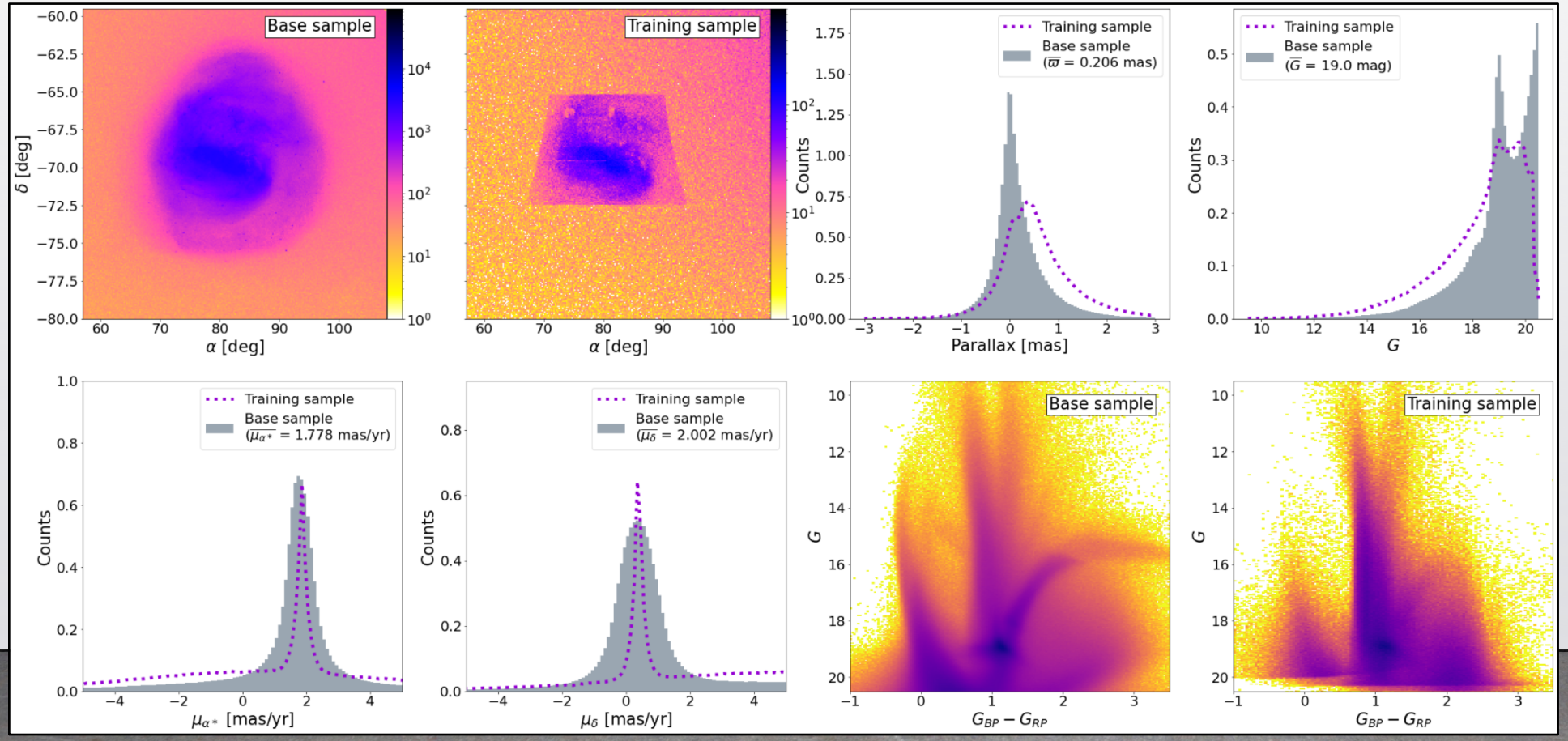

Comparing data and simulation

LMC/MW classifier

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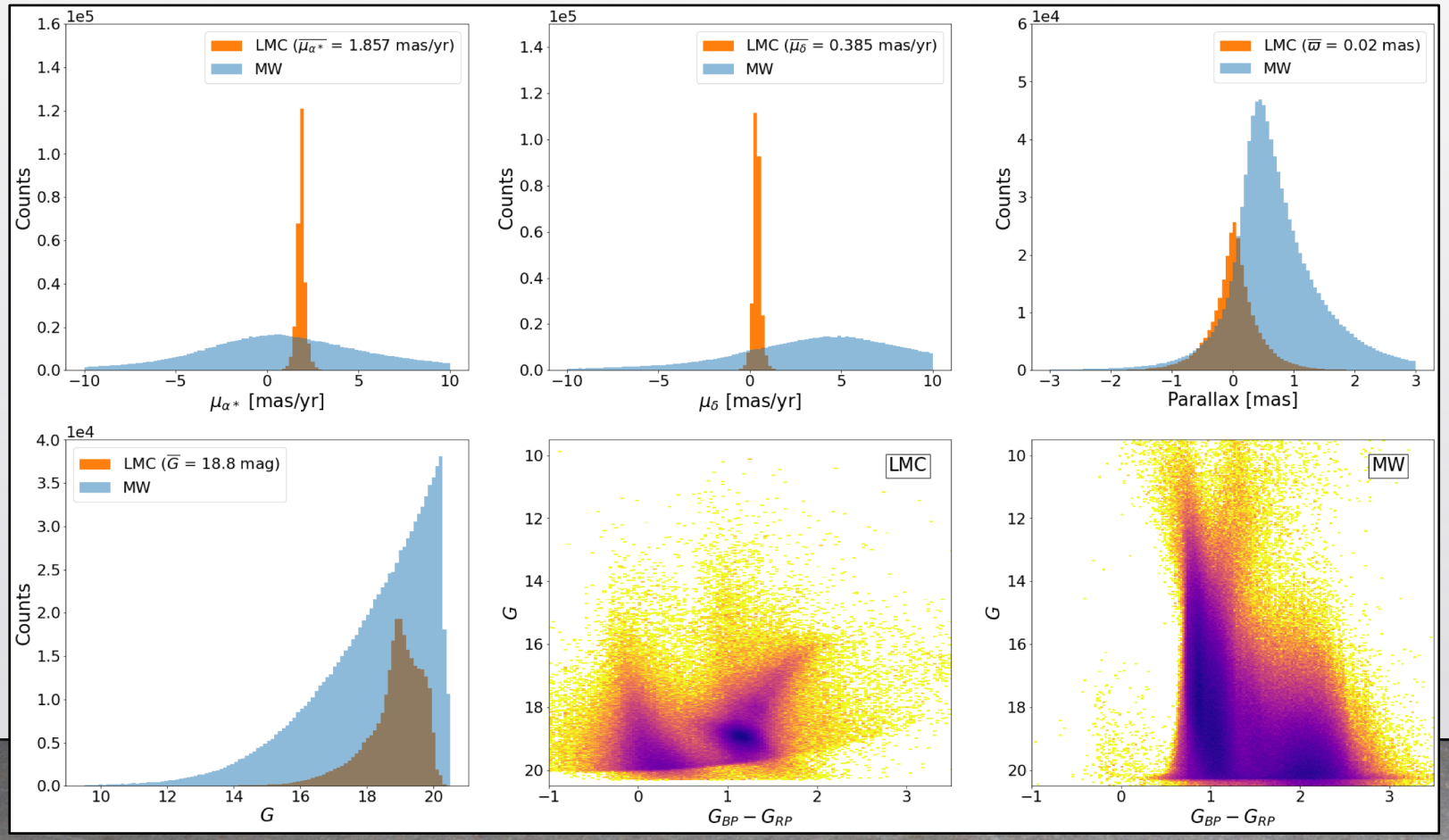


LMC GOG
MW GOG

LMC/MW classifier

Classifier: Neural Network

LMC/MW classifier

Classifier: Neural Network

Also tested:

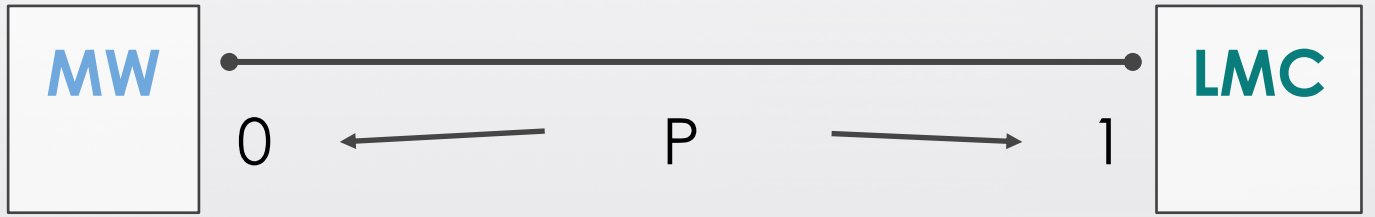
1) Logistic Regression
2) K-Nearest Neighbours
3) Random Forest

LMC/MW classifier

Classifier: Neural Network

Inputs:
- Position (a, δ)
- Parallax and its uncertainty (π, σ_π)
- Proper motion and their uncertainties (μ_{a*}, μ_δ, $\sigma_{\mu\, a*}$, $\sigma_{\mu\, \delta}$)
- Gaia photometry (G, G_{BP} , G_{RP})

Output:
- Probability P of being a LMC star. P close to 1 (0), highly likely to be of the LMC (MW).



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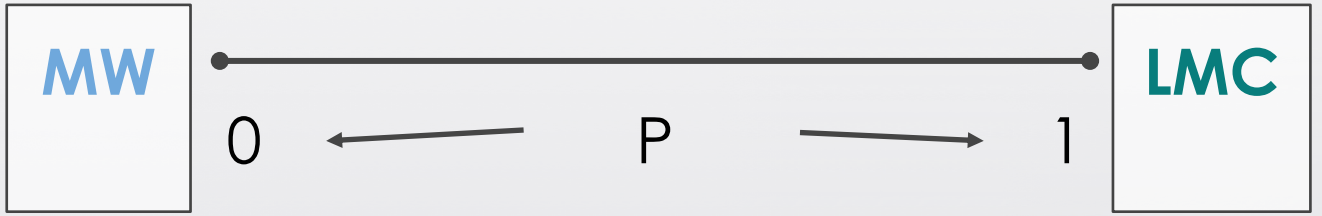

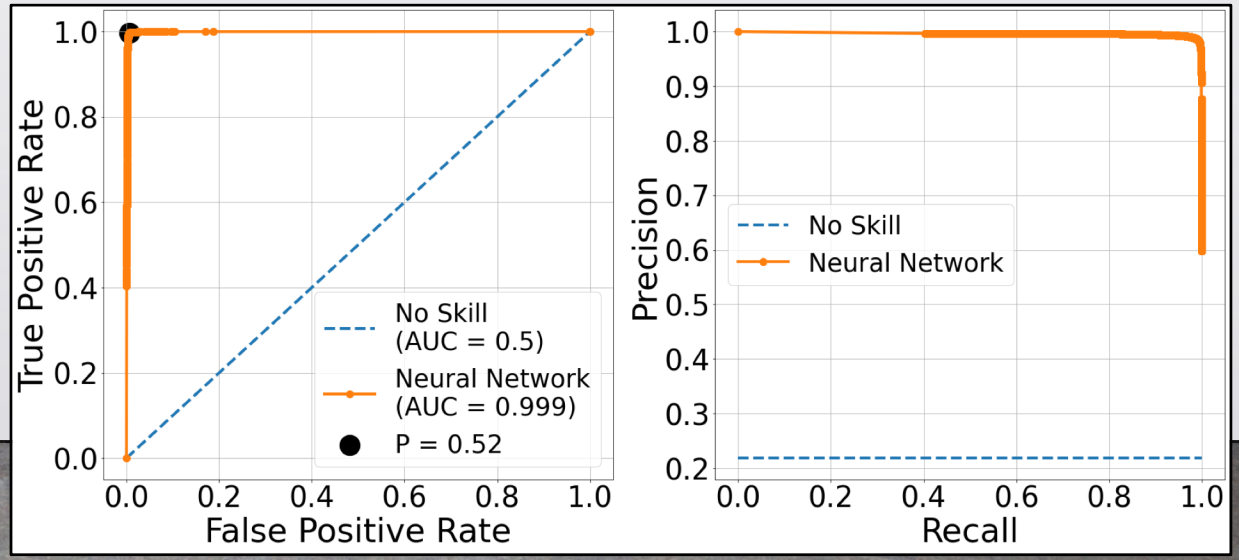

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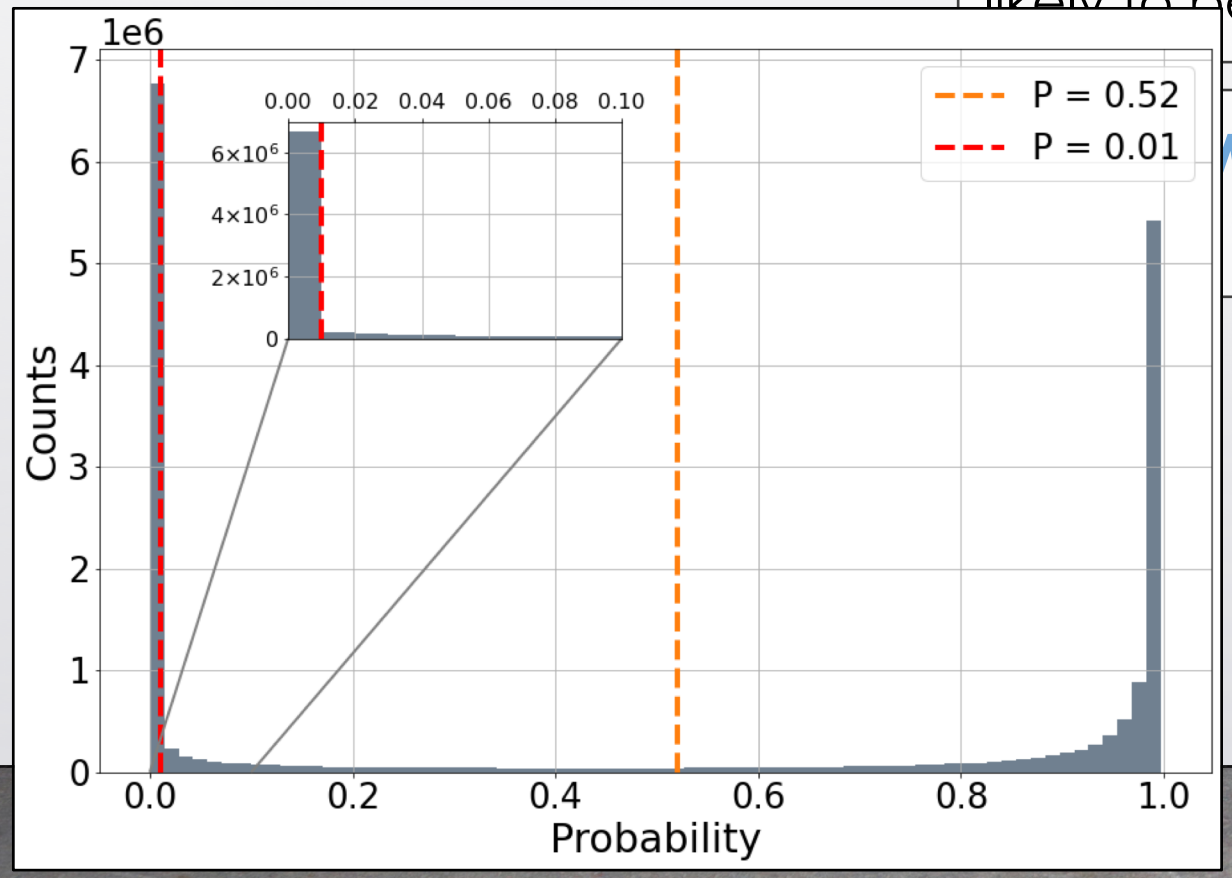
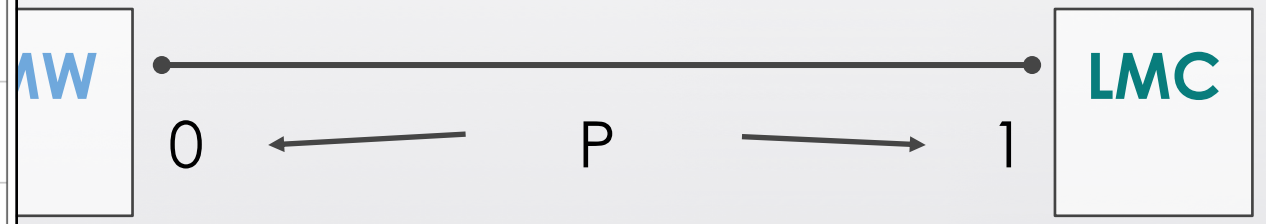
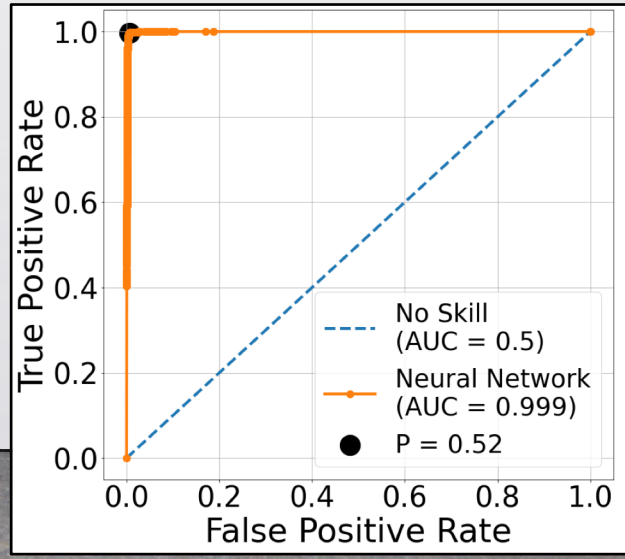
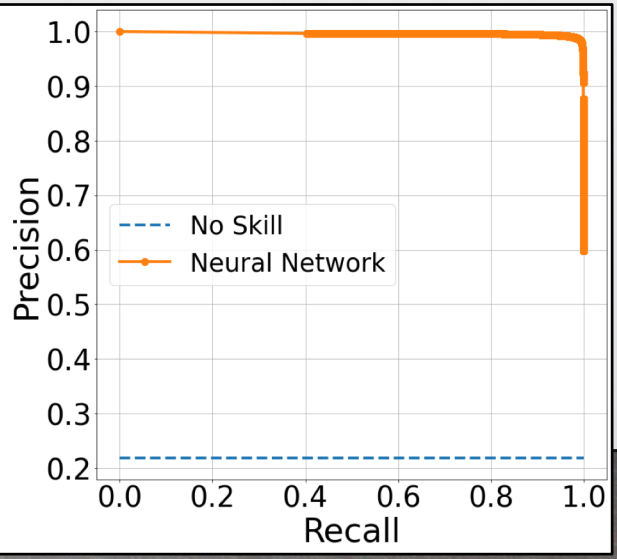








LMC/MW classifier

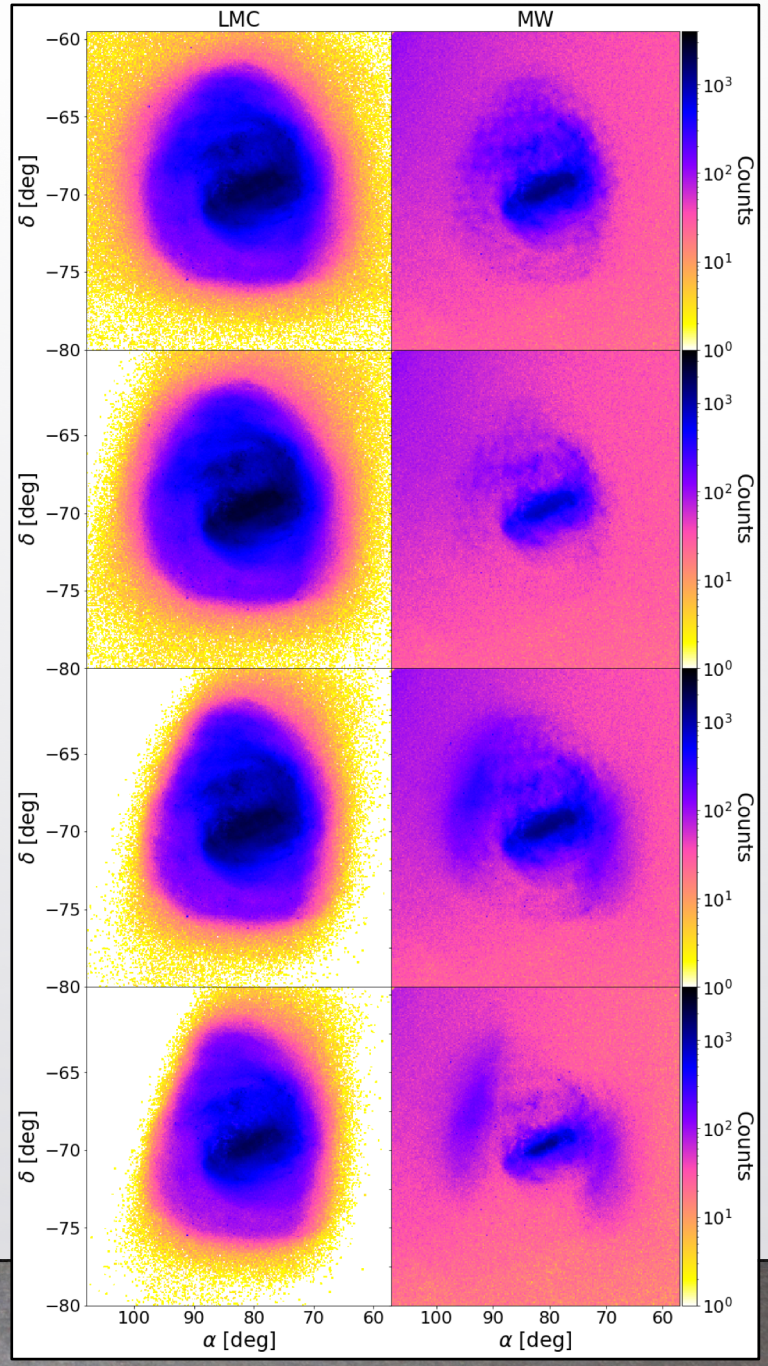
LMC clean samples:

Proper motion selection classification (Gaia Collaboration, Luri+20)

Complete sample:
P = 0.01

Optimal sample:
P = 0.52

Truncated Optimal sample:
P = 0.52
G < 19.5 mag



LMC/MW classifier

LMC clean samples:

Validating the samples:

1) LMC Cepheids (Ripepi et al. 2022) [4 467]
2) LMC RR-Lyrae (Cusano et al. 2021) [21 271]
3) StarHorse (Anders et al. 2022)
   LMC: [985 173]
   MW: [2 940 282]

Proper motion selection classification (Gaia Collaboration, Luri+20)

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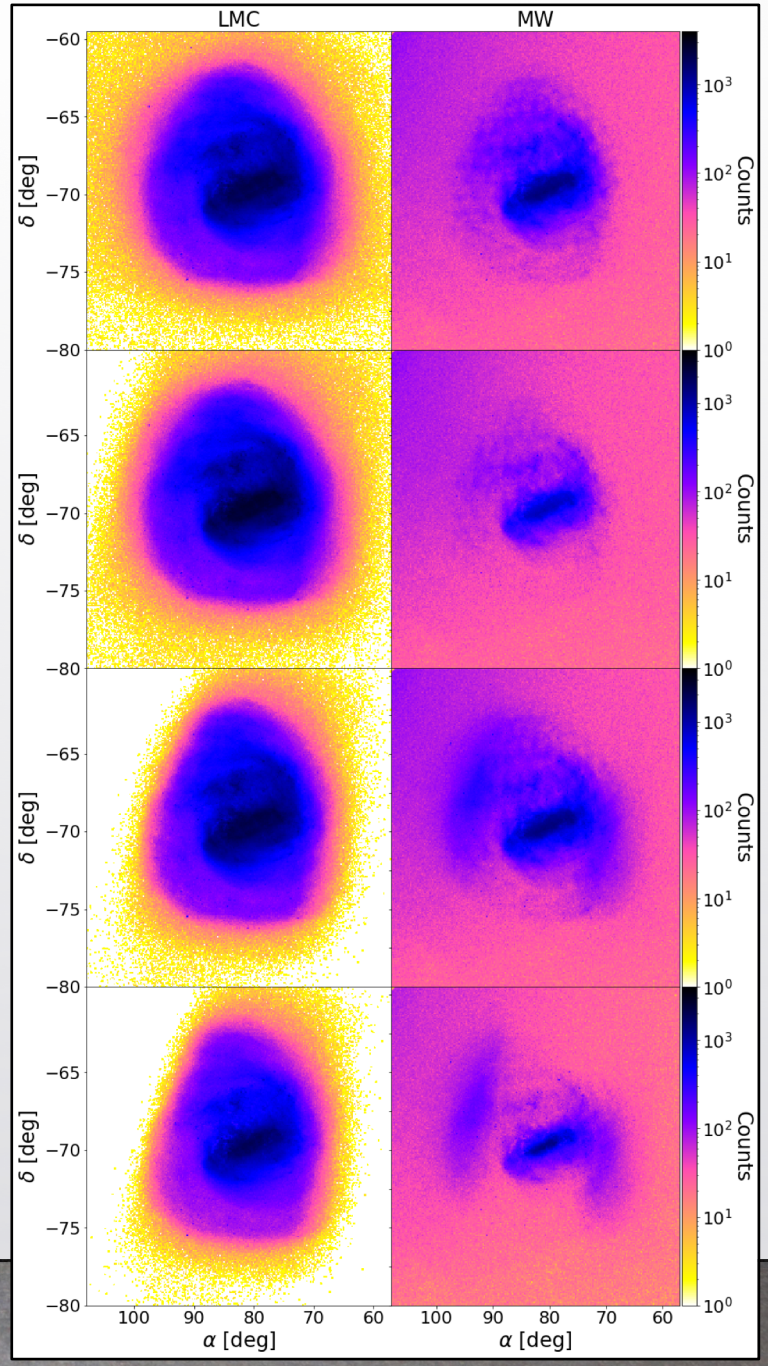

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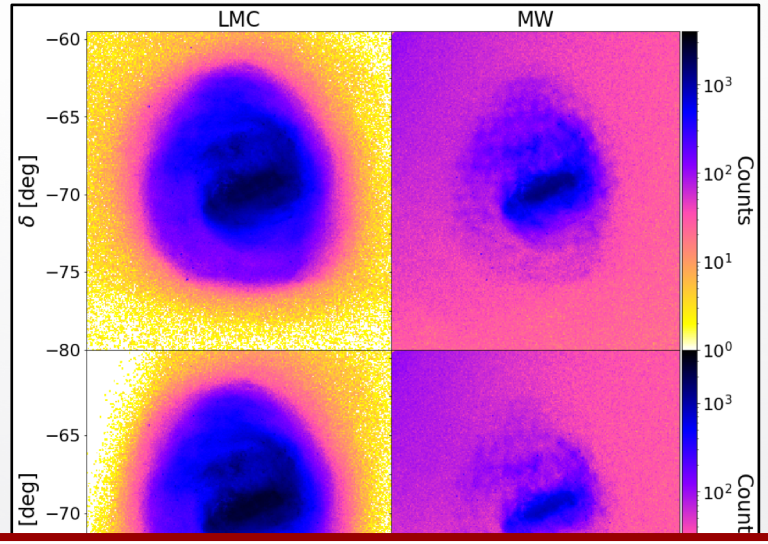
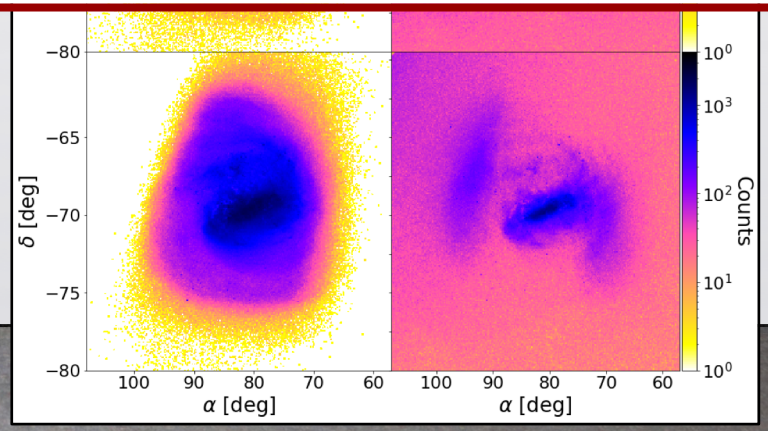


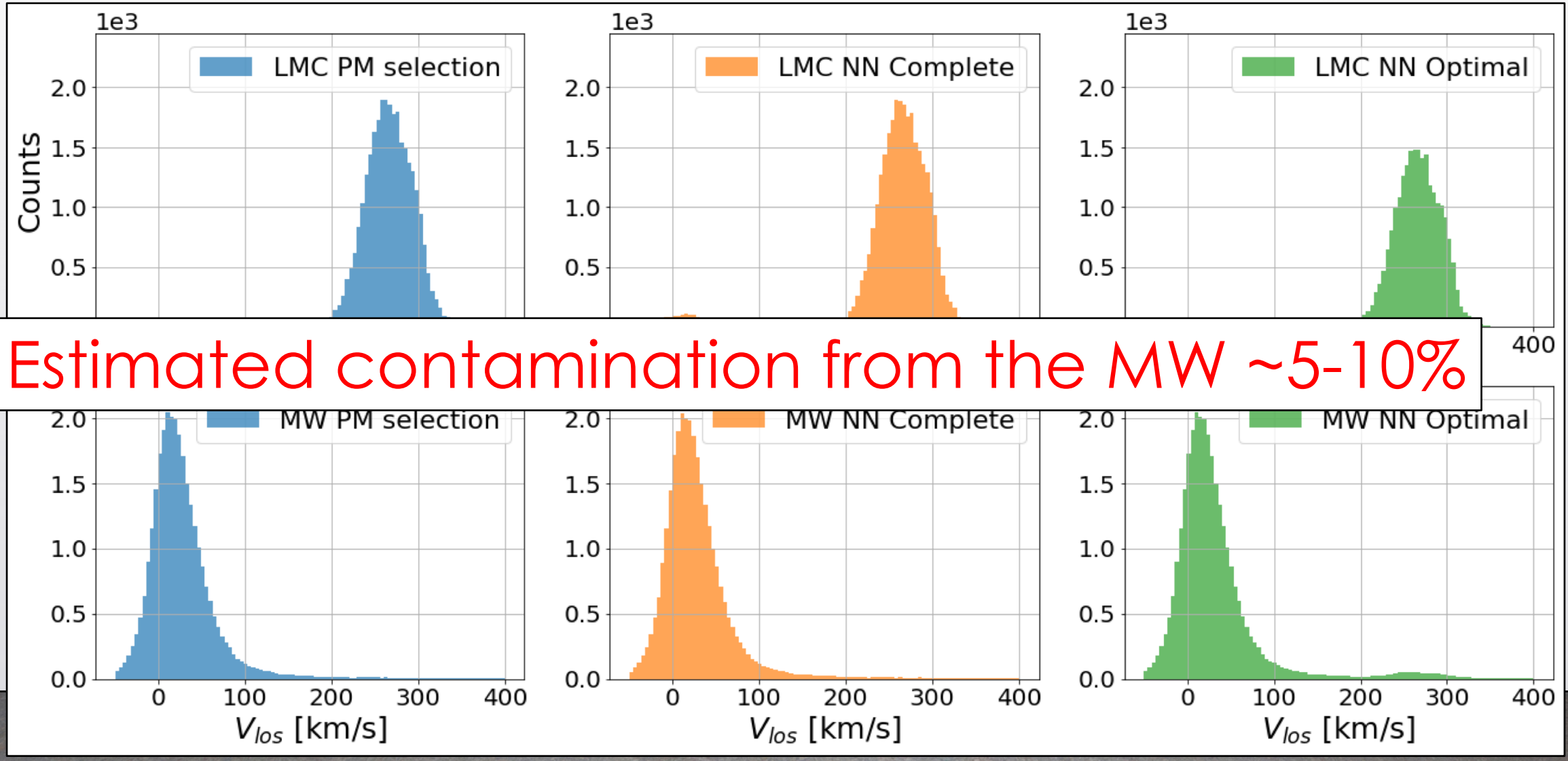
Stars classified as LMC	LMC Cepheids (4 467)	LMC RR-Lyrae (21 271)	LMC StarHorse (985 173)	MW StarHorse (2 940 282)
Proper motion selection	4 366 (97.7%)	18 673 (87.8%)	970 173 (98.5%)	704 932 (24.0%)
Neural Network (Complete)	4 407 (98.7%)	20 223 (95.1%)	970 719 (98.5%)	722 750 (24.6%)
Neural Network (Optimal)	4 160 (93.1%)	17 860 (84.0%)	832 733 (84.5%)	627 619 (21.3%)
Neural Network (Truncated Optimal)	4 160 (93.1%)	14 750 (69.3%)	832 733 (84.5%)	627 619 (21.3%)

MW: [2 940 282]

Truncated Optimal sample:
P = 0.52
G < 19.5 mag



LMC/MW classifier



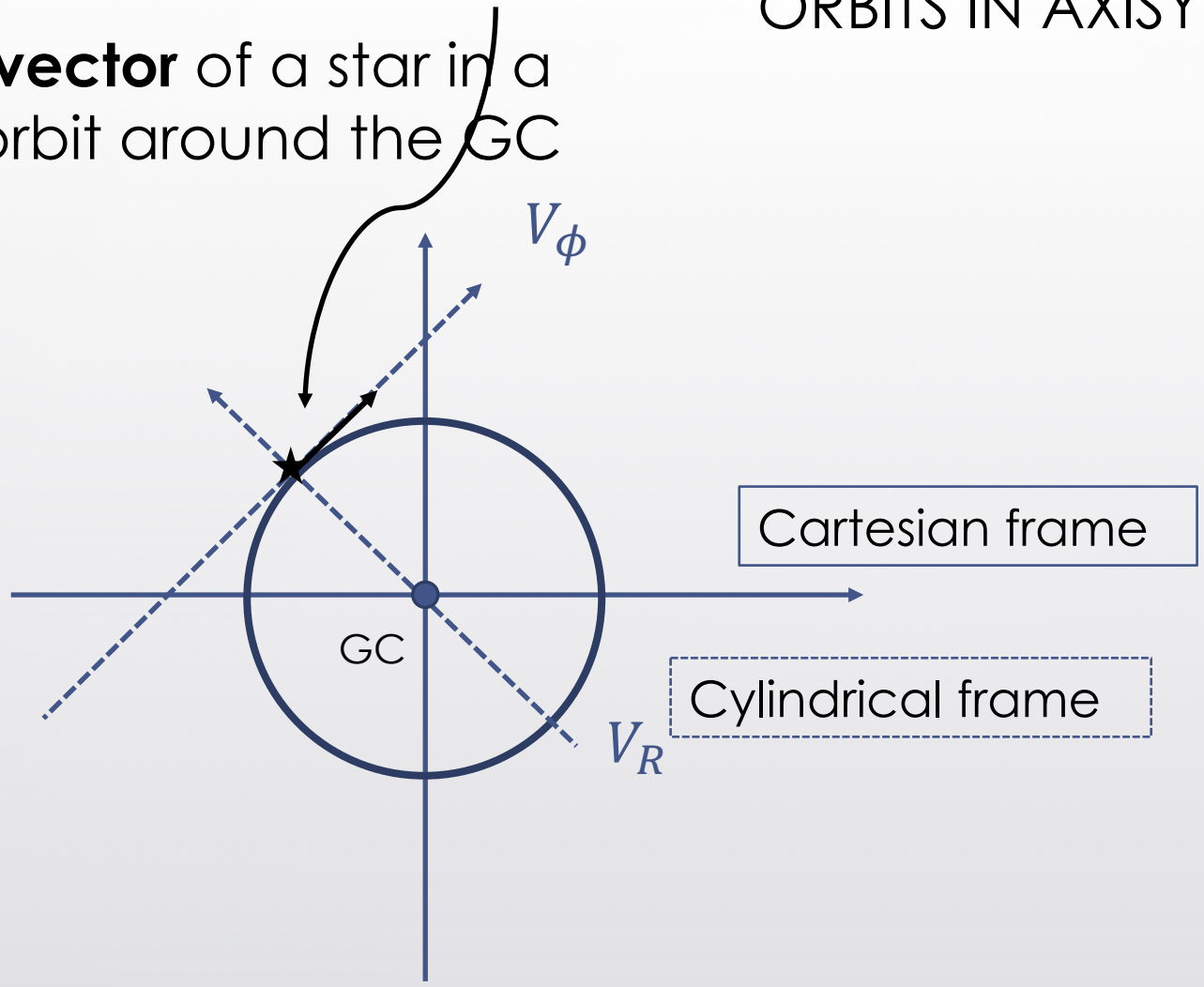
Estimated contamination from the MW ~5-10%

Galactic kinematics and dynamics

SIMPLE MODELLING

ORBITS IN AXISYMMETRIC DISC GALAXIES

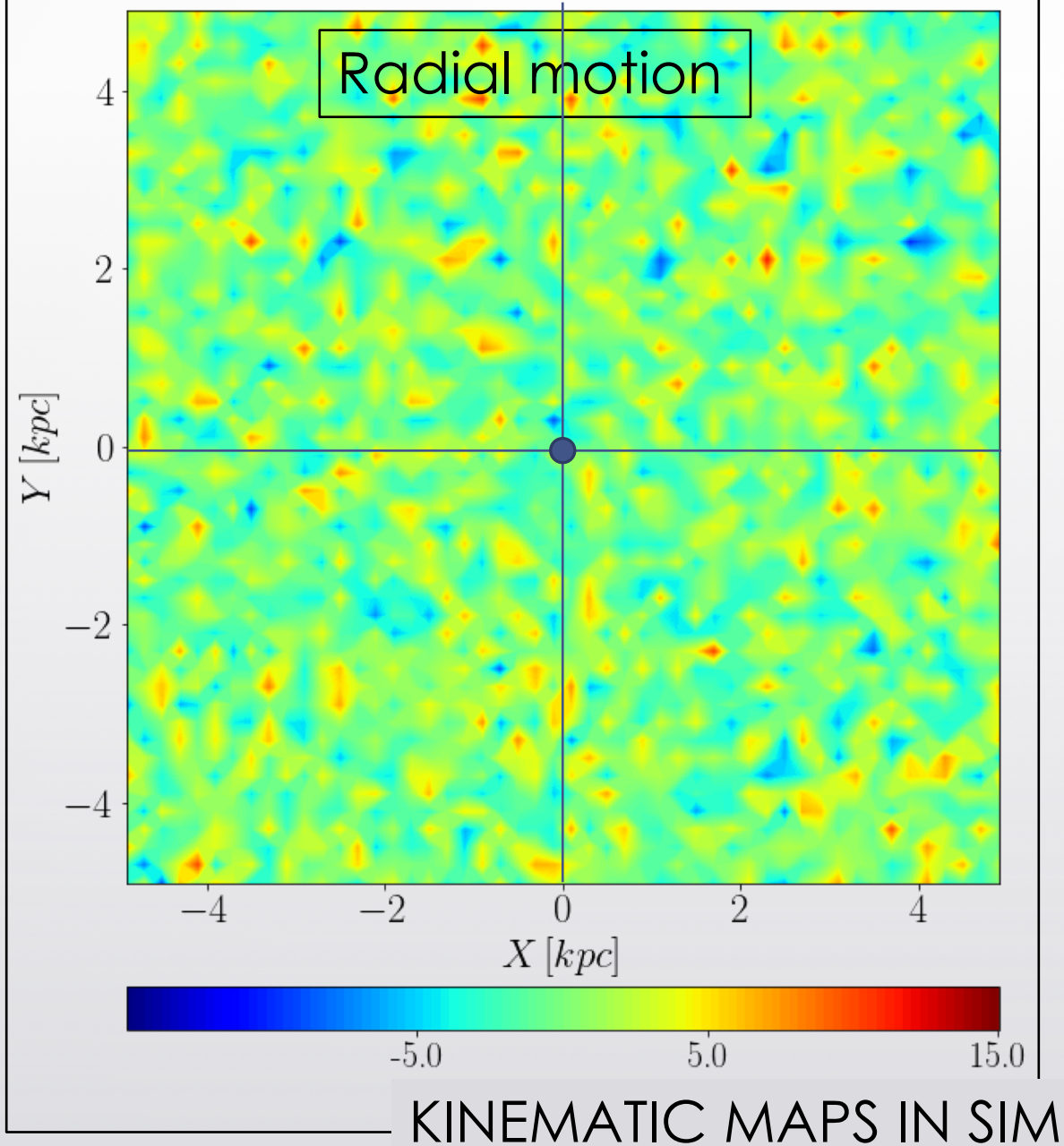
Velocity vector of a star in a **circular** orbit around the GC

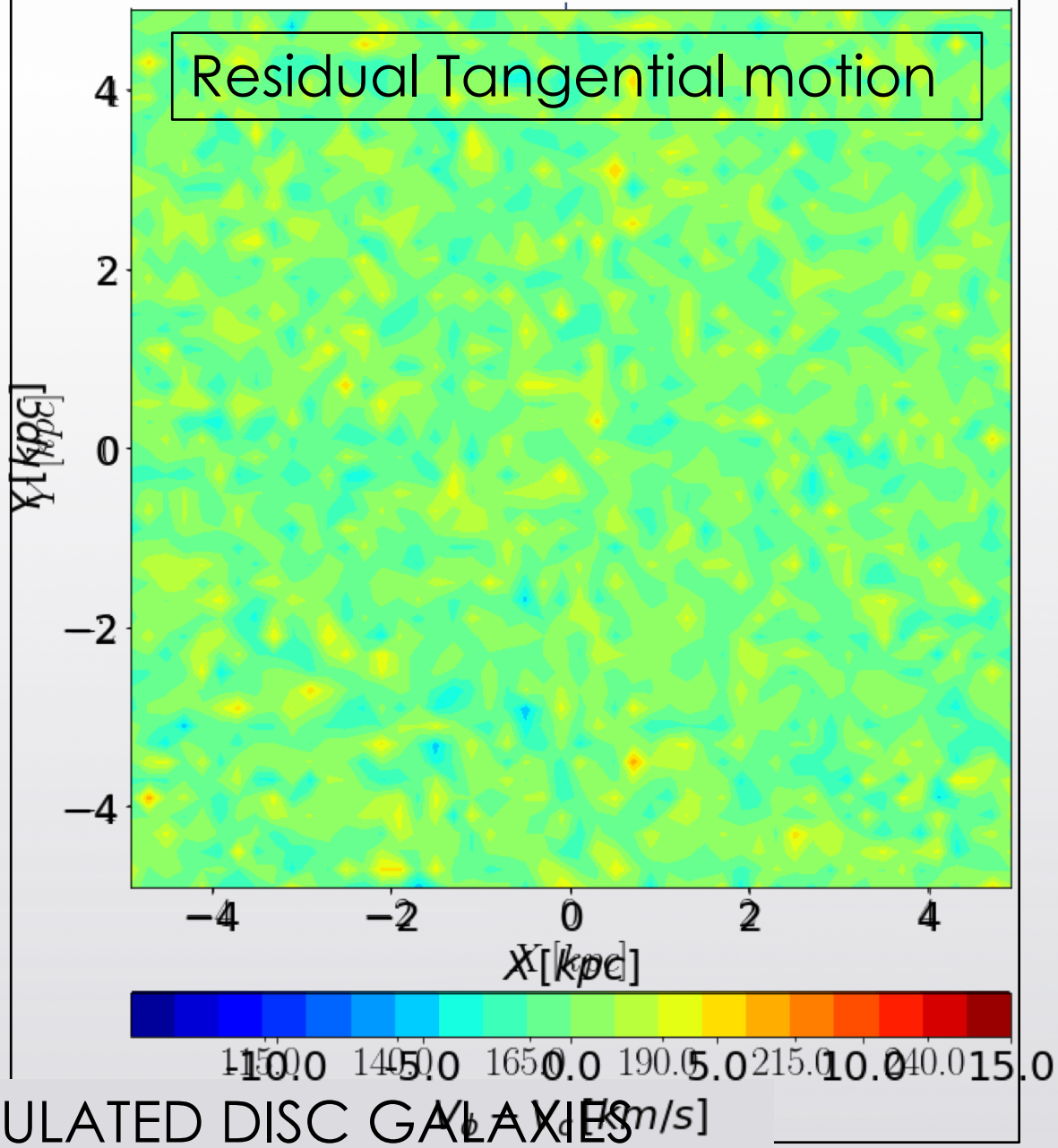


All the motion is along the tangential direction:

$V_\phi = V_{circ}$ ← From the rotation curve

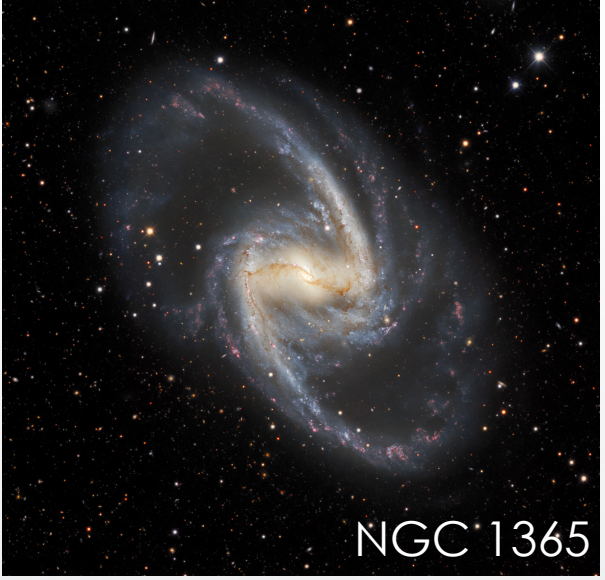
$V_R = 0$

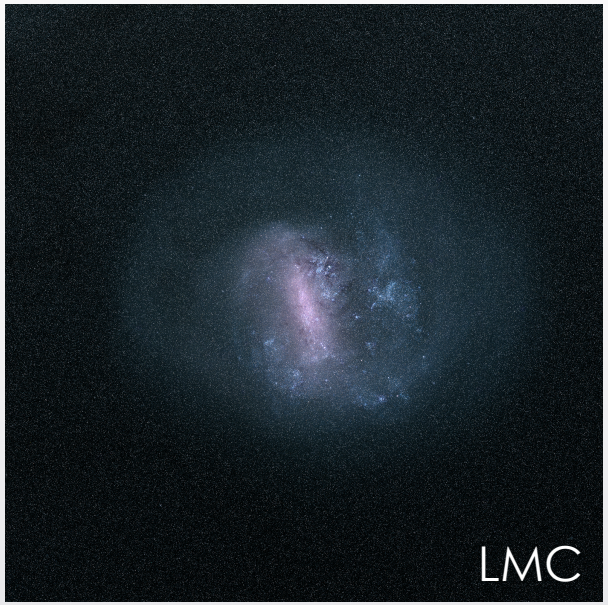


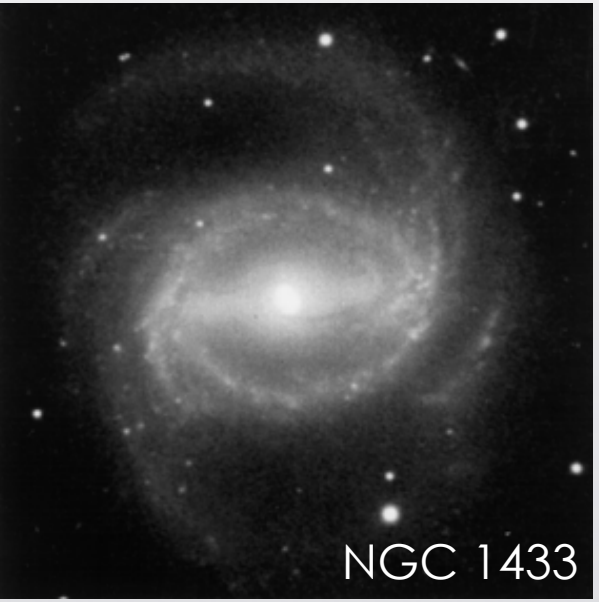


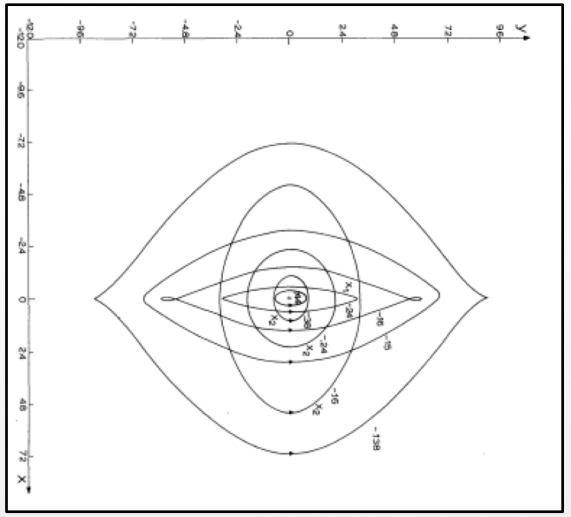
KINEMATIC MAPS IN SIMULATED DISC GALAXIES

ORBITS IN BARRED GALAXIES

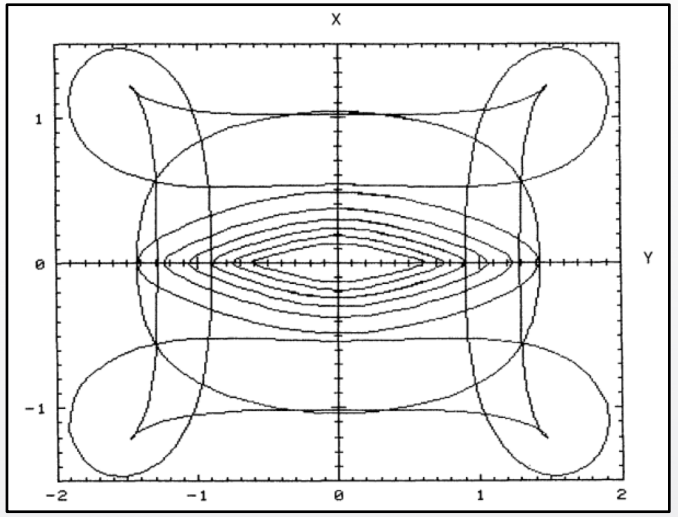




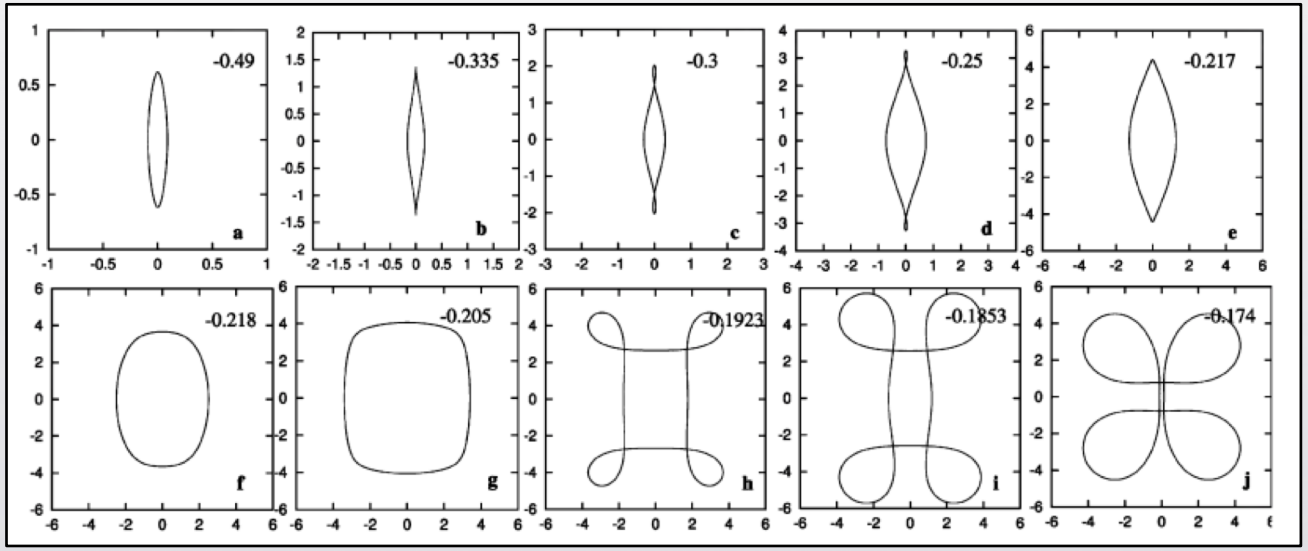




Contopoulos & Papayannopoulos 1980

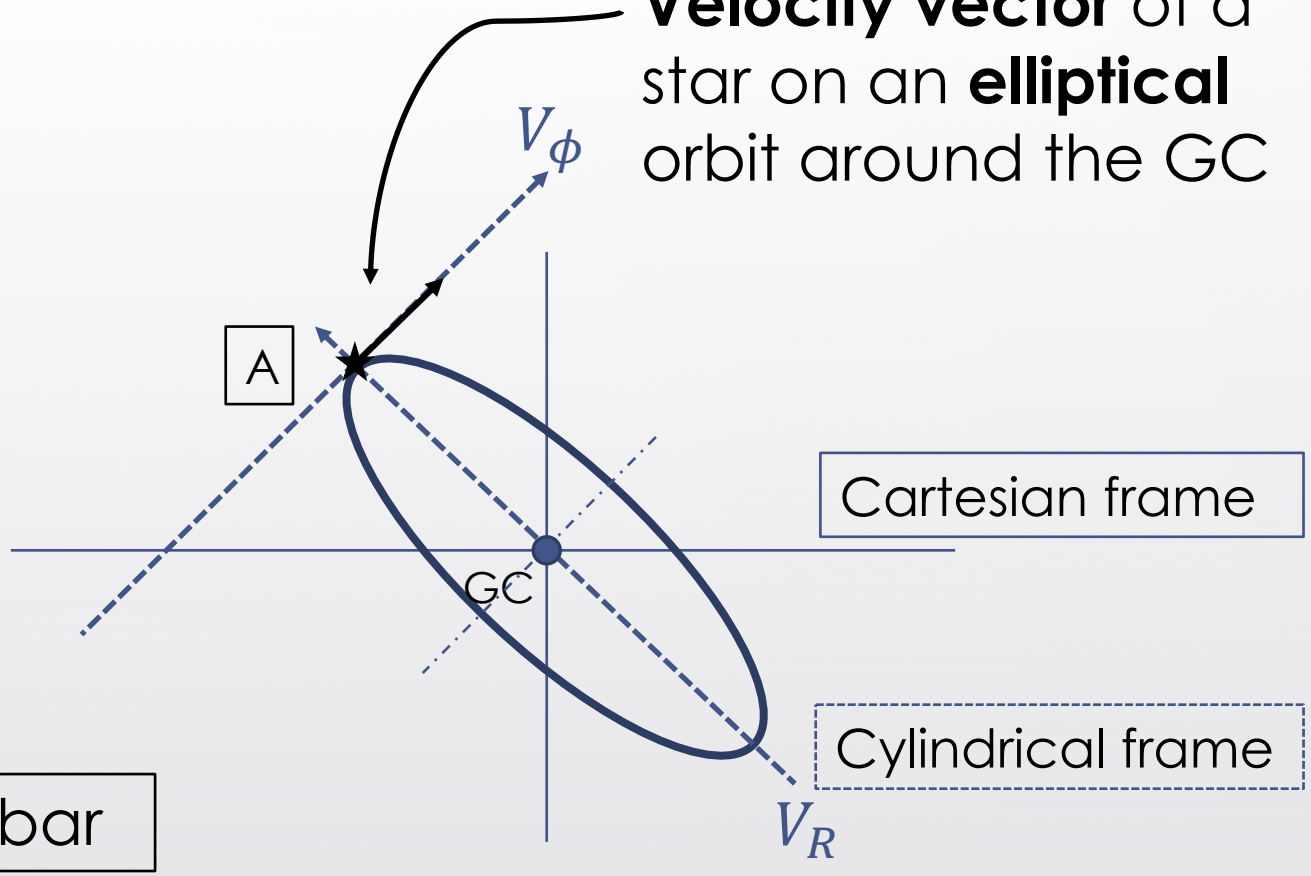


Athanassoula+1983



Skokos, Patsis & Athanassoula 2002

ORBITS IN BARRED GALAXIES



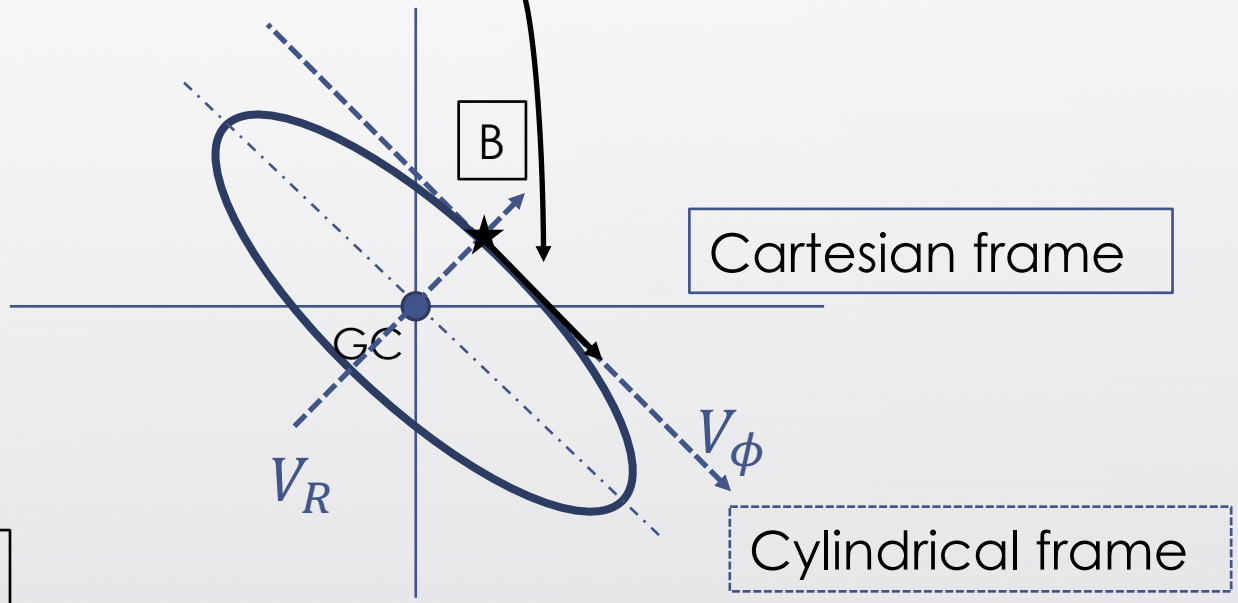
A | Along the major axis of the bar

$V_\phi = V_{circ}$

$V_R = 0$

ORBITS IN BARRED GALAXIES

Velocity vector of a star on an **elliptical** orbit around the GC



B	Along the minor axis of the bar

$V_\phi = V_{circ}$

$V_R = 0$

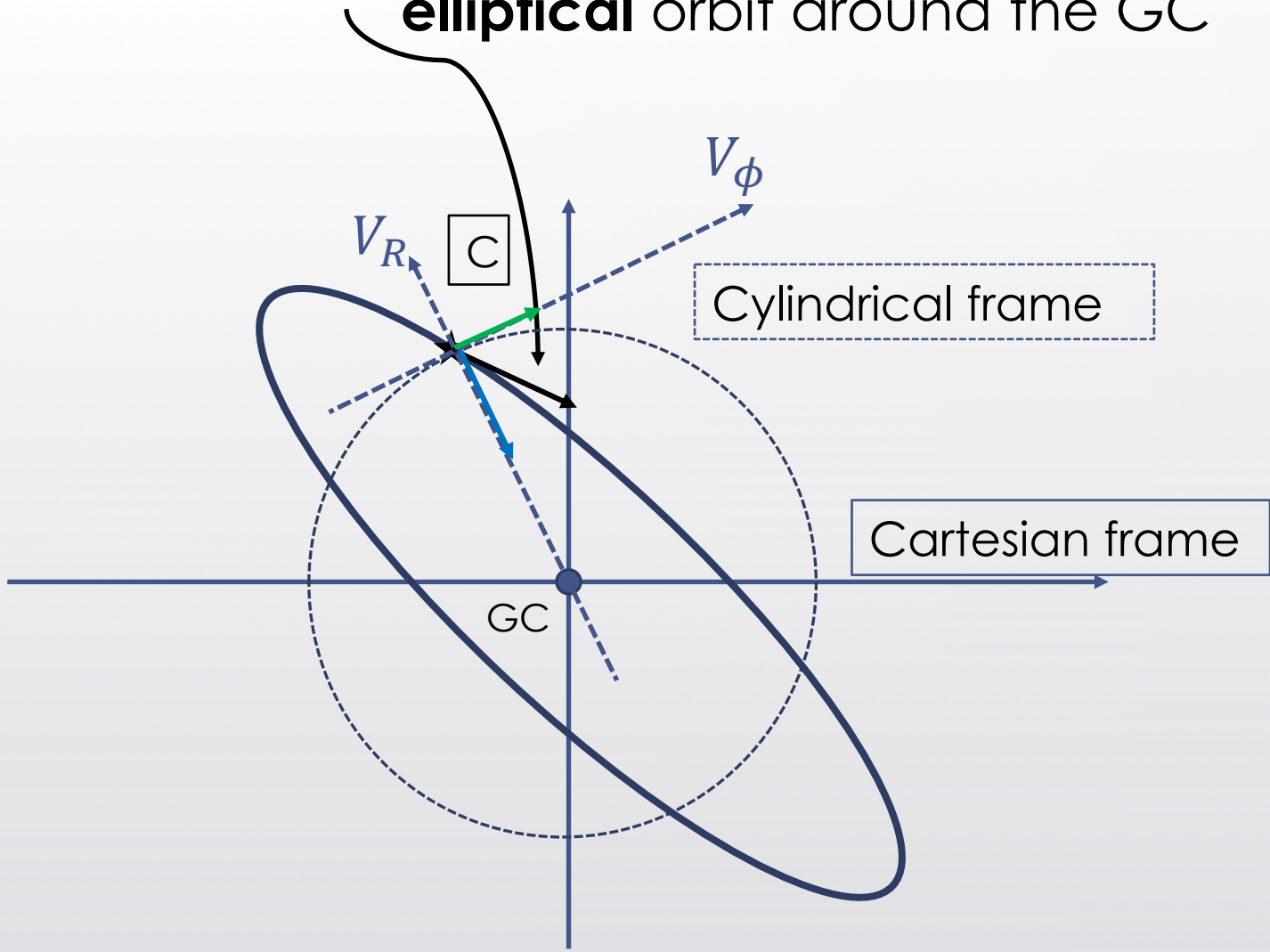
ORBITS IN BARRED GALAXIES

C

$V_\phi > 0$

$V_R < 0$

Velocity vector of a star on an **elliptical** orbit around the GC



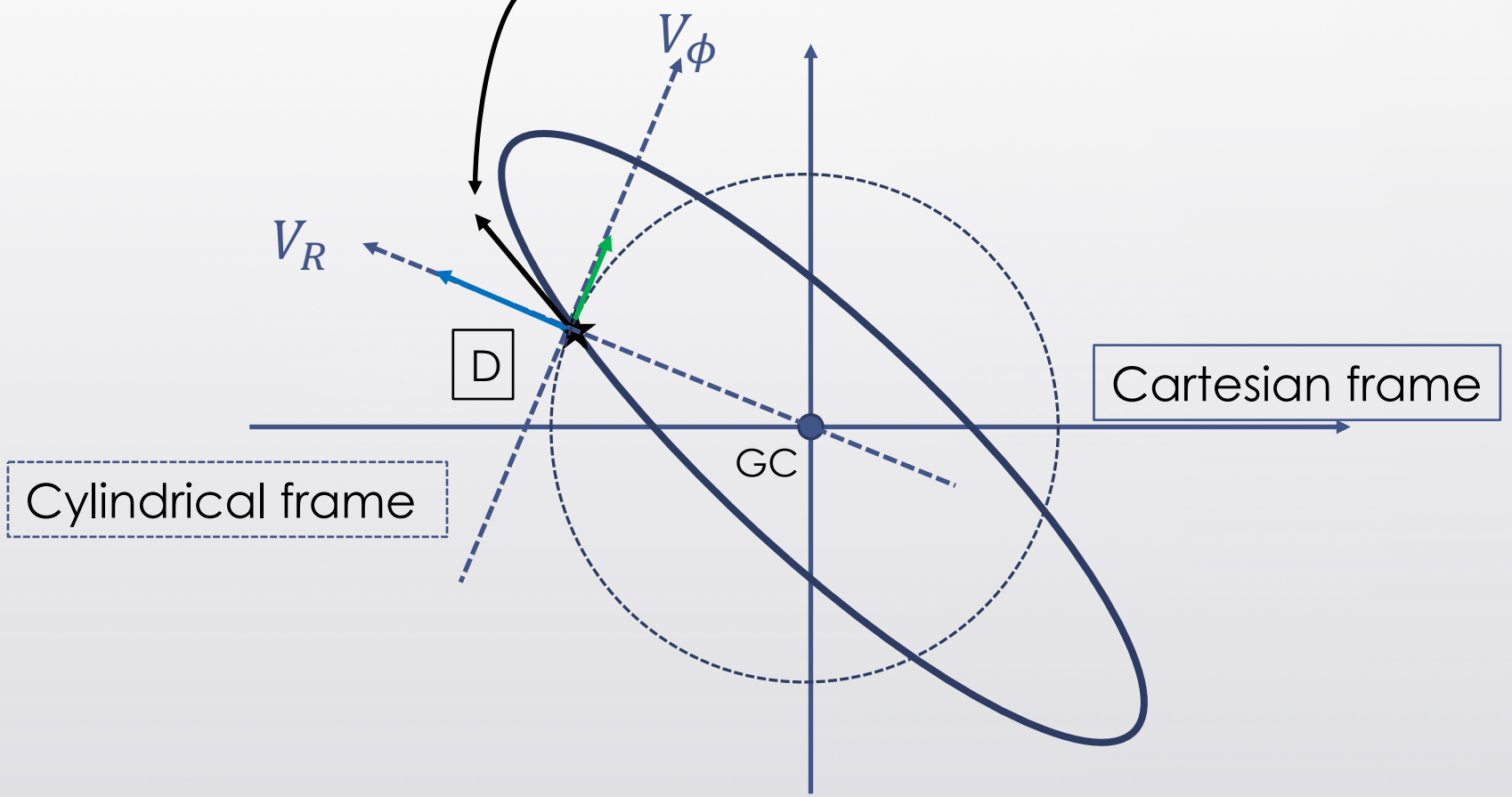
ORBITS IN BARRED GALAXIES

Velocity vector of a star on an **elliptical** orbit around the GC

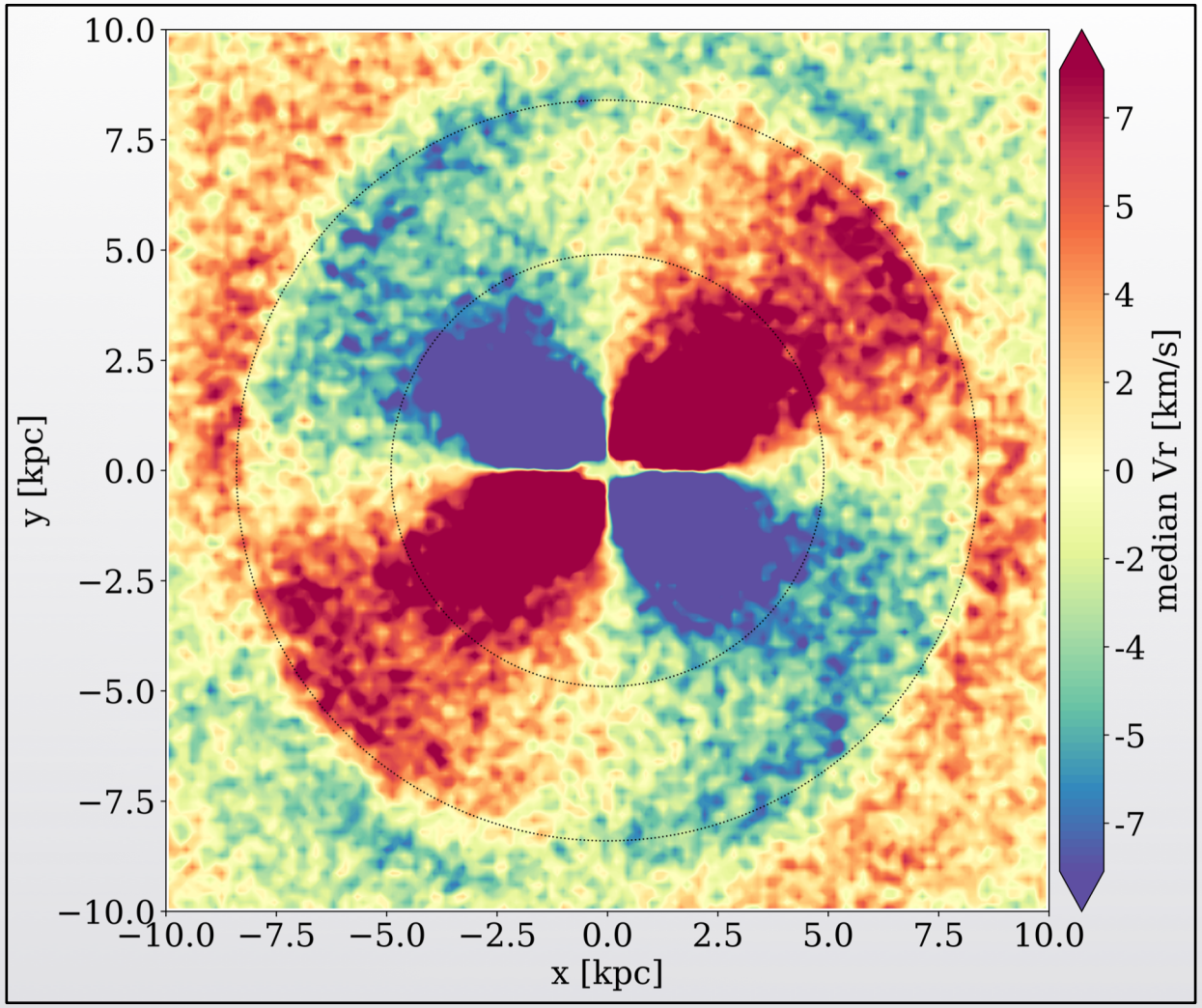
D

$V_\phi > 0$

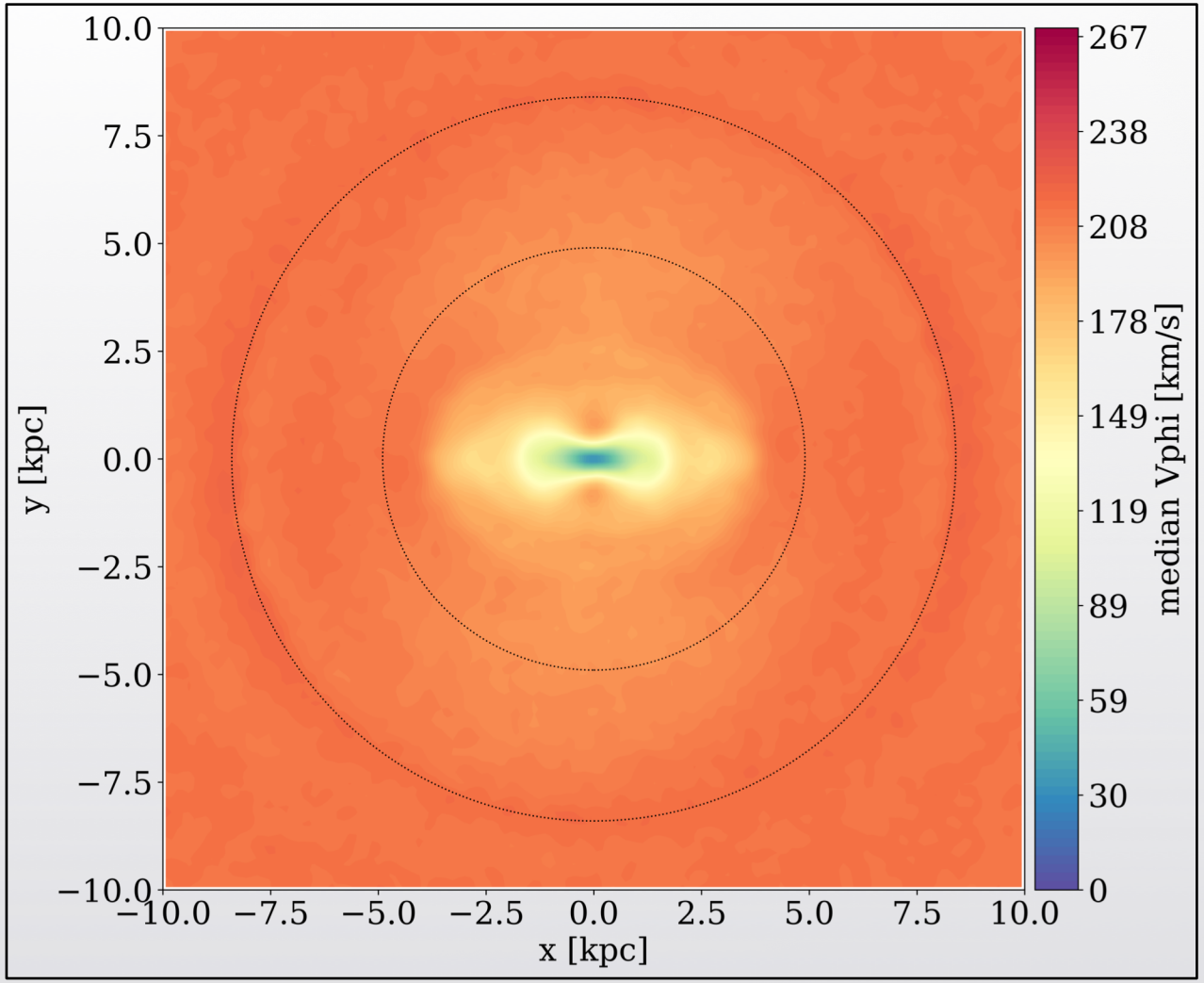
$V_R > 0$



Radial motion



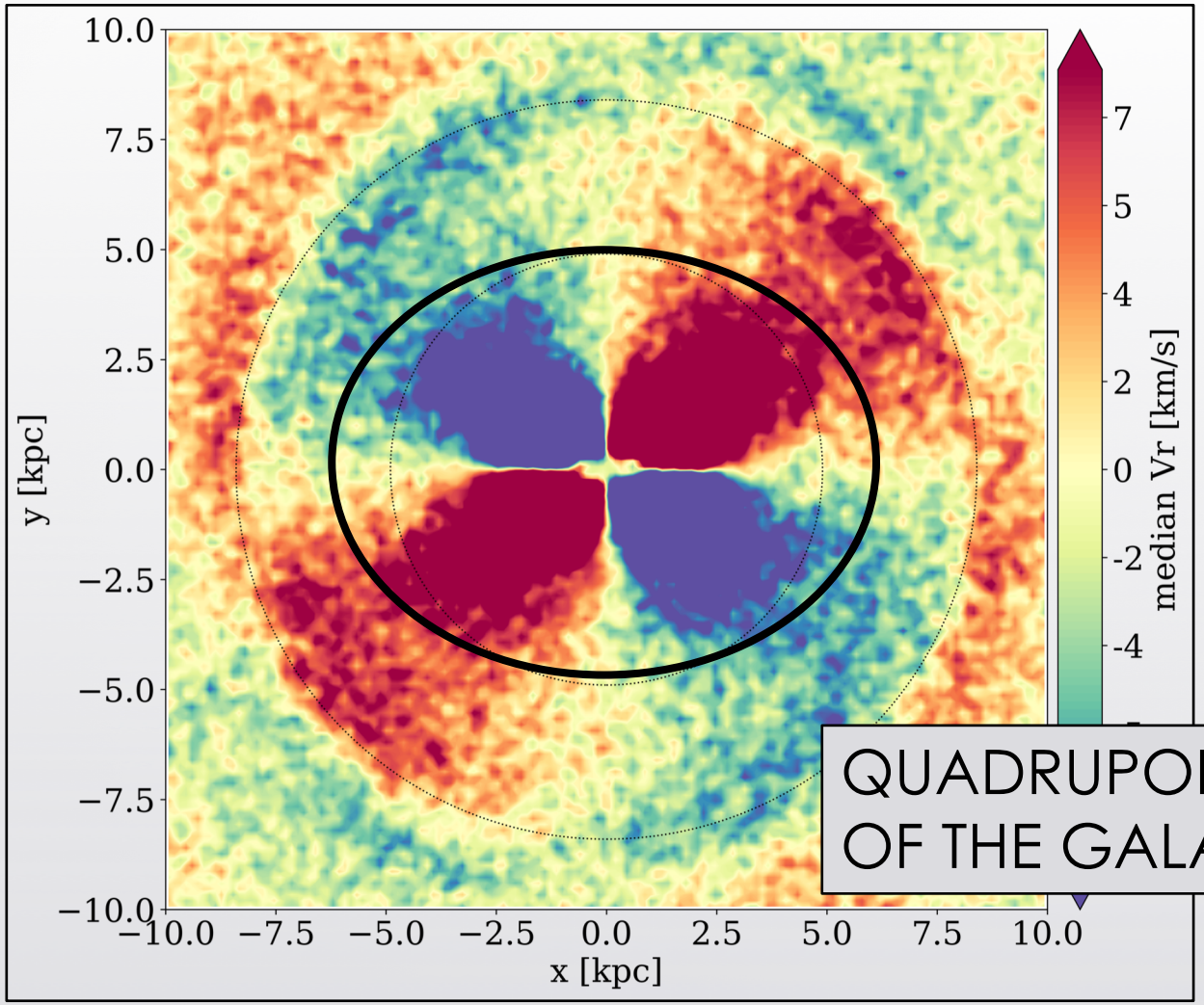
Tangential motion

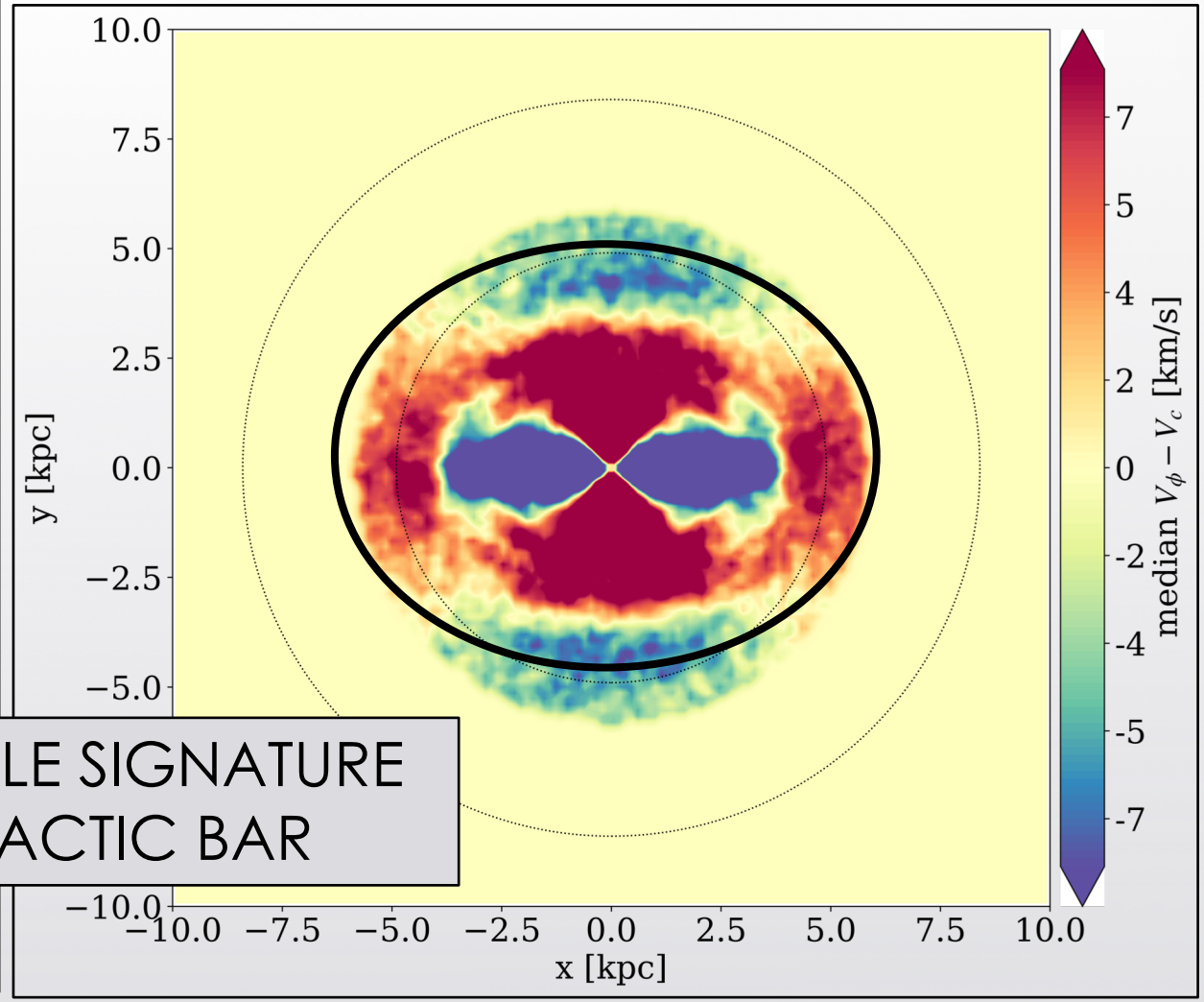


KINEMATIC MAPS IN SIMULATED BARRED GALAXIES

Radial motion

Residual Tangential motion





QUADRUPOLE SIGNATURE OF THE GALACTIC BAR

KINEMATIC MAPS IN SIMULATED BARRED GALAXIES

GAIA (E)DR3 and the Large Magellanic Cloud

Gaia Collaboration, Luri, Chemin+2020

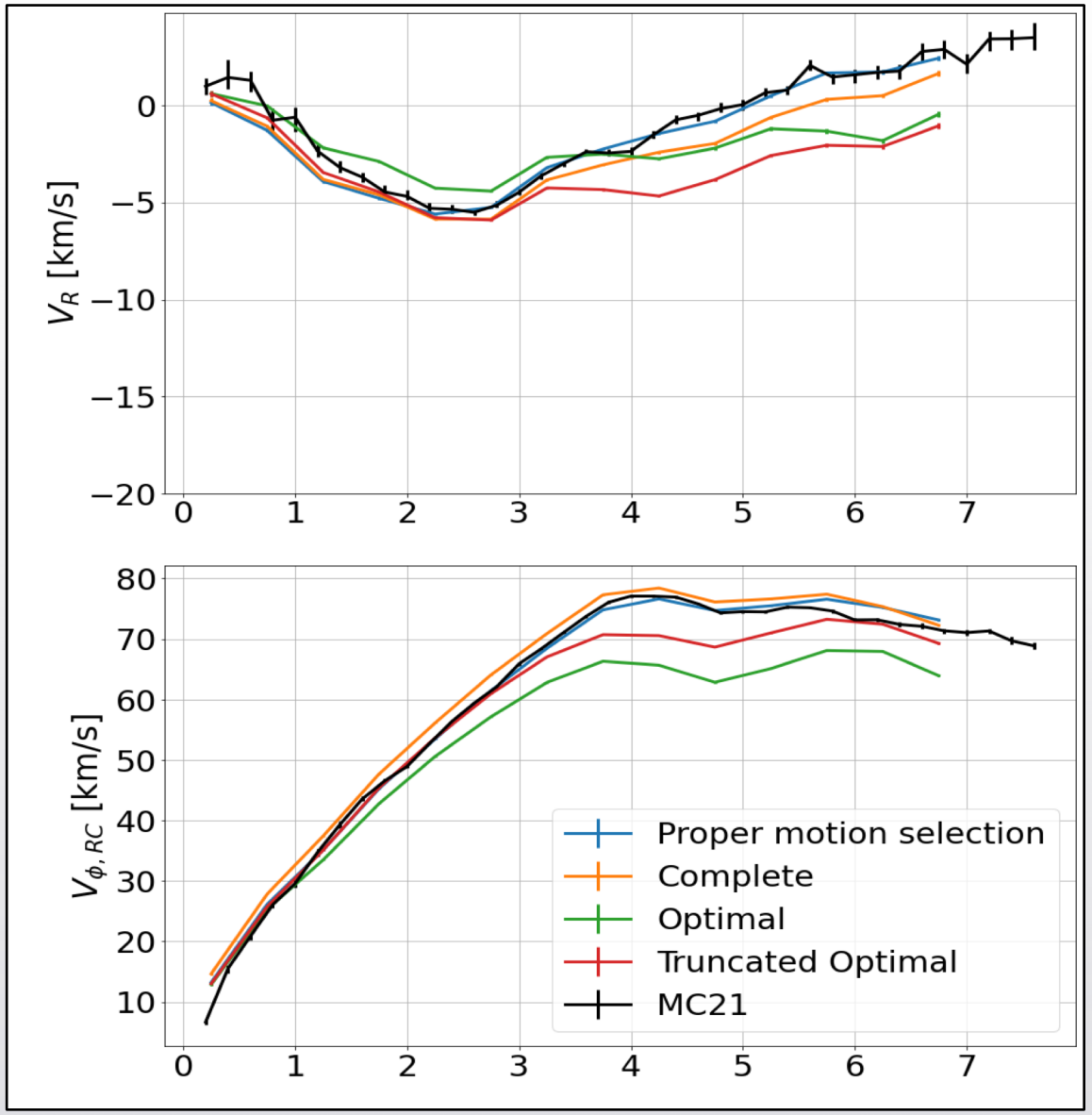
Jiménez-Arranz, Romero-Gómez, Luri+2022 (under review)

Kinematic maps in the LMC

- New sample selection based on Neural Networks: complete and optimal samples
- Positions, proper motions and line-of-sight velocities from Gaia DR3
- New coordinate transformation allowing to infer:
  - 3D velocity maps based on proper motion only or proper motion + line-of-sight velocities
- Velocity profiles in the LMC frame (removing bulk motion and perspective effect): radial, residual tangential and vertical velocity maps

LMC kinematic profiles

Gaia EDR3 data: no line-of-sight velocity.



Kinematic maps in the LMC

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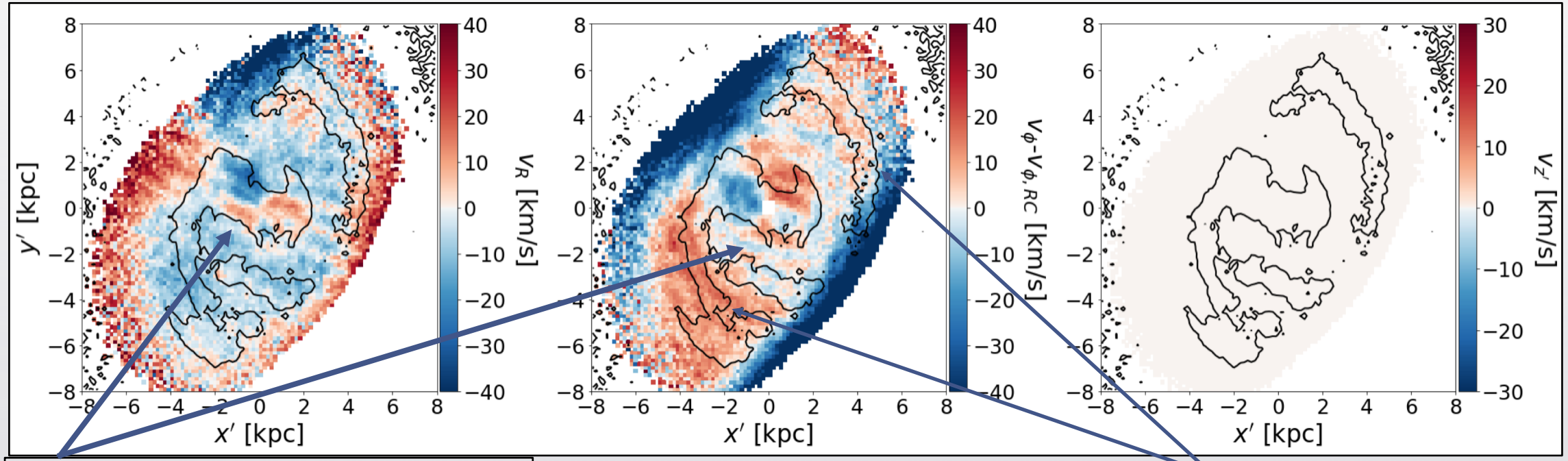
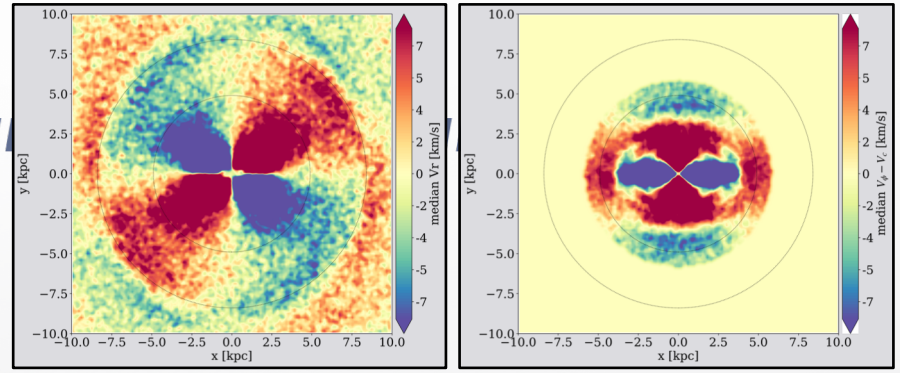


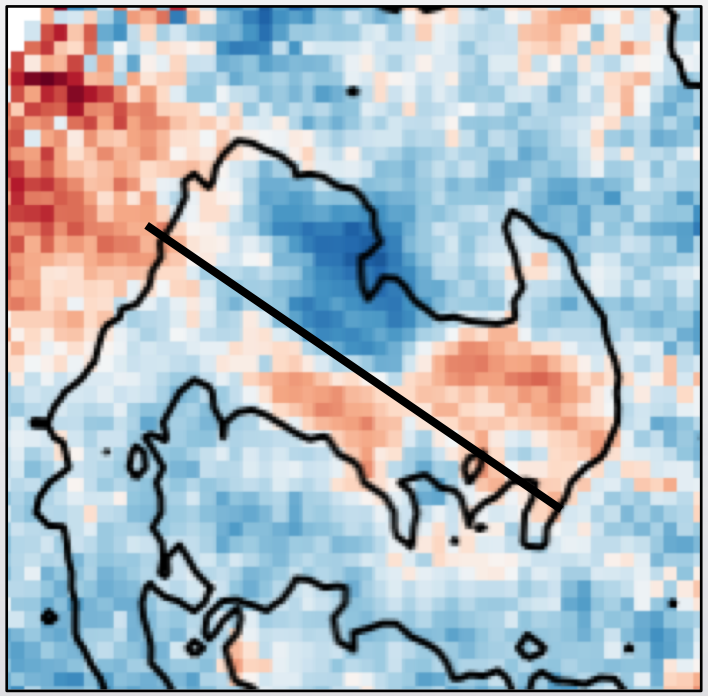
Confirmation of the quadrupole trend in the bar. Definitely asymmetric.

Motion of stars along the spiral arm: disentangle its nature?

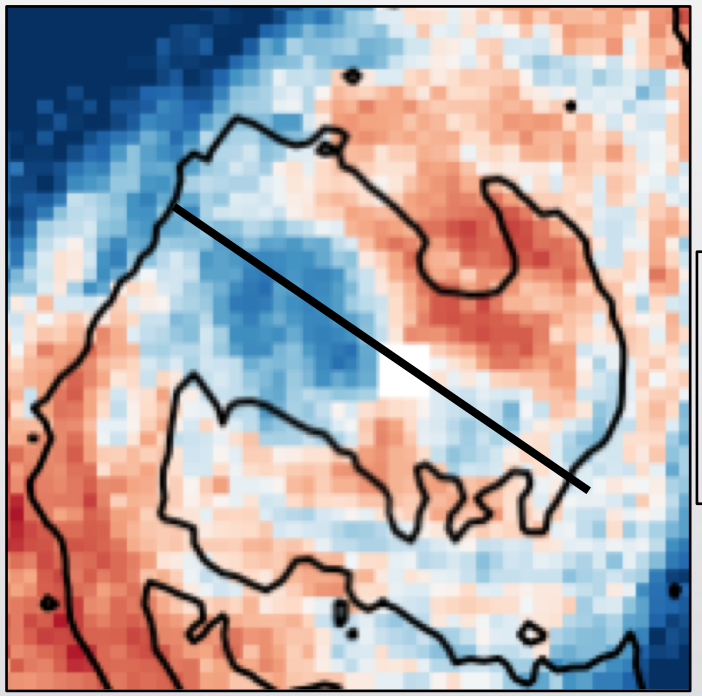
Kinematic maps in the LMC



Radial velocity



Residual tangential velocity



Confirmation of the quadrupole trend in the bar.
Definitely asymmetric.

LMC 3D kinematic maps

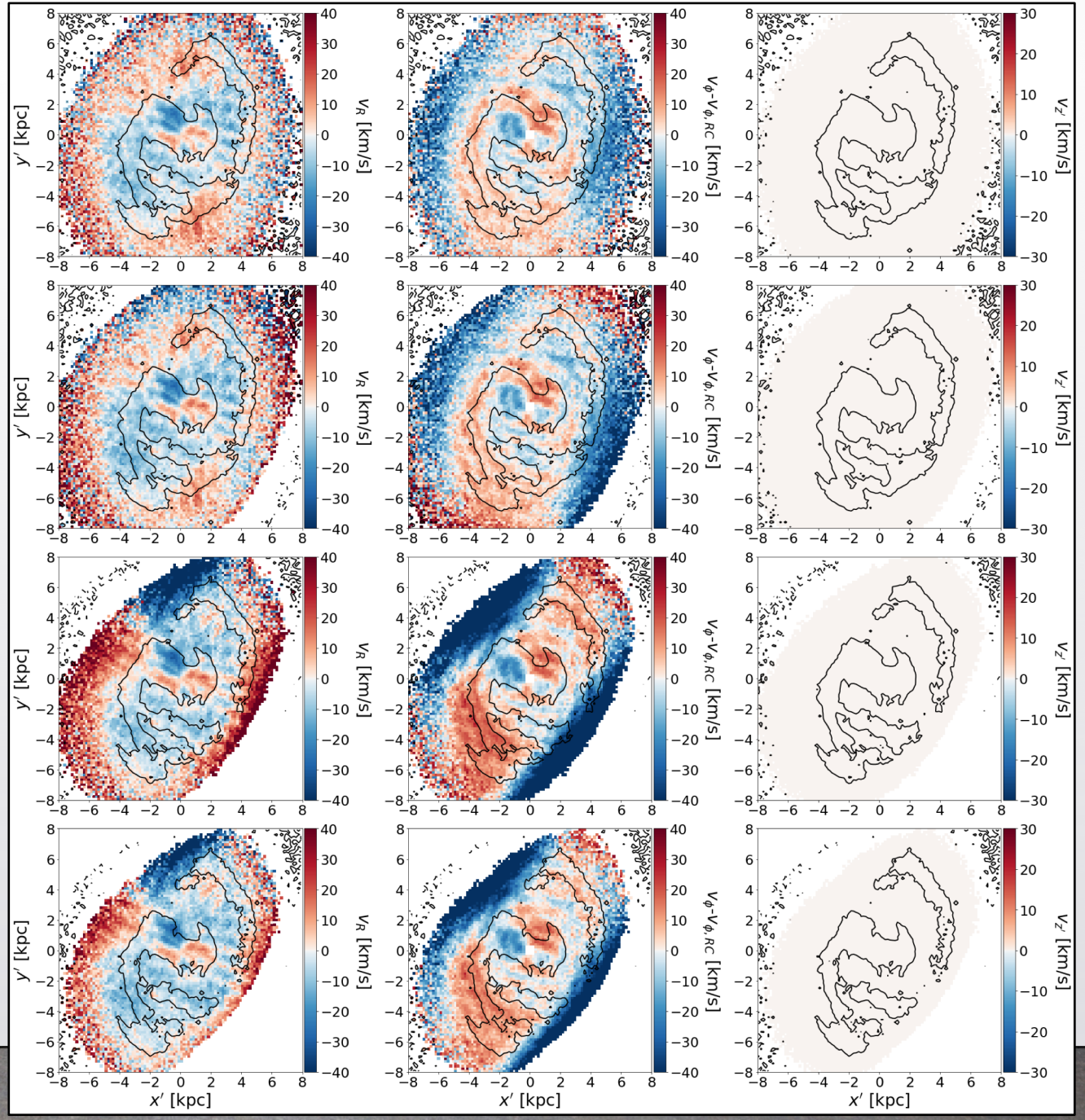
Gaia EDR3 data: no line-of-sight velocity.

Proper motion selection classification (Luri+20)

Complete sample

Optimal sample

Truncated Optimal sample: G < 19.5 mag



LMC 3D kinematic maps

Gaia DR3 data:
w/ line-of-sight velocity [30k].

Proper motion selection classification (Luri+20)

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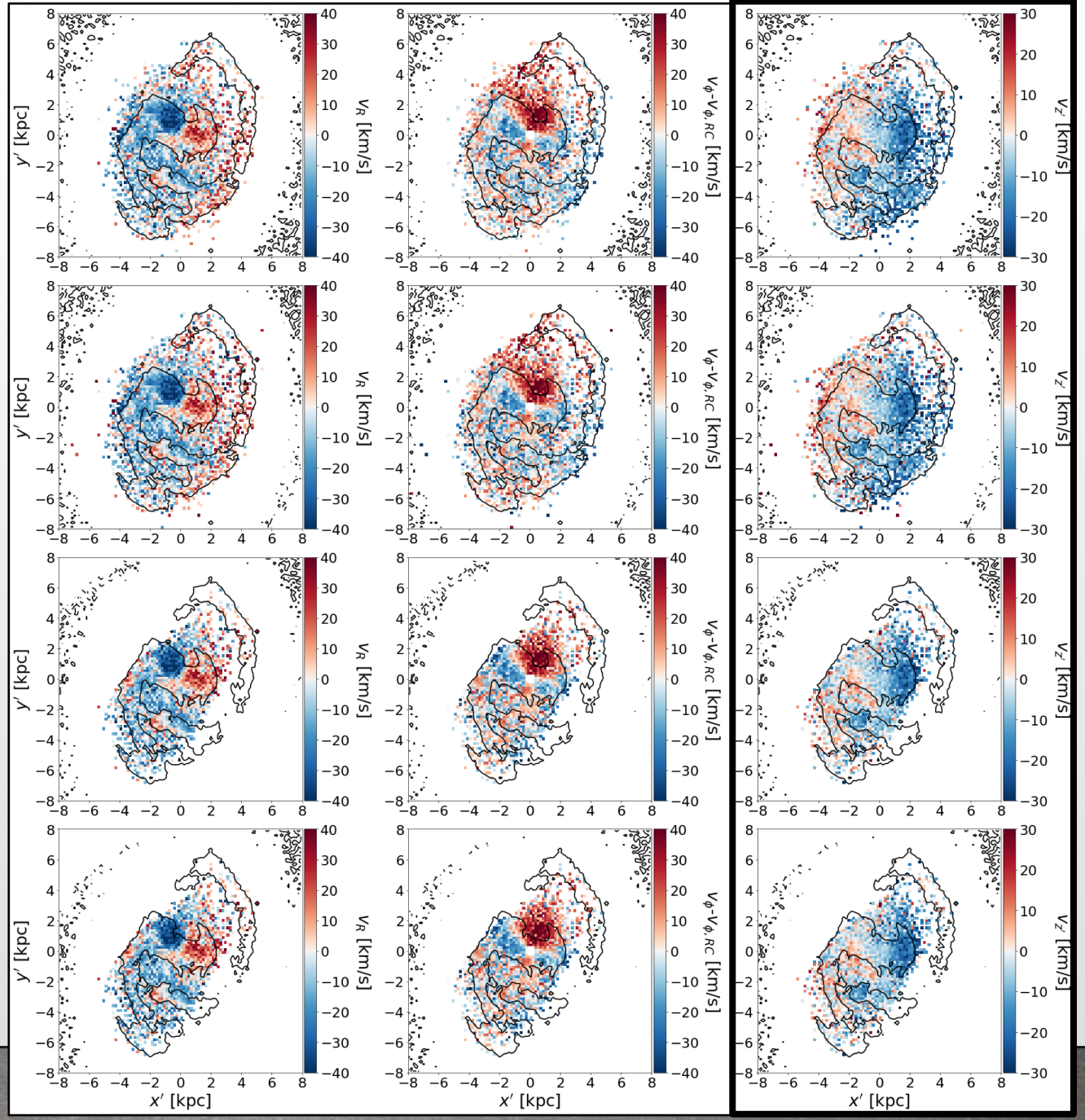
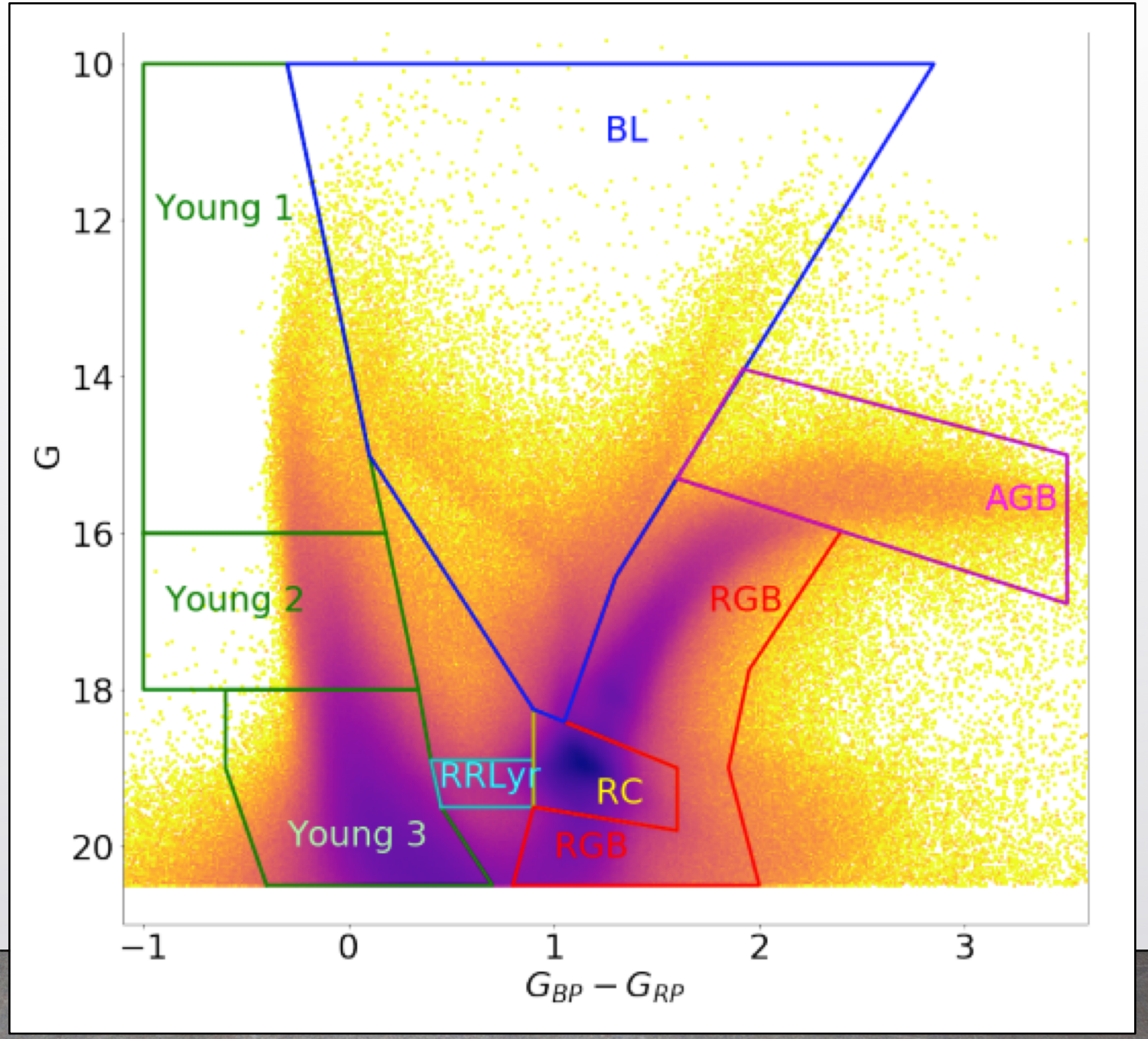


LMC KINEMATIC PROFILES BY EVOLUTIONARY PHASES



Gaia Collaboration,Luri, Chemin+2020

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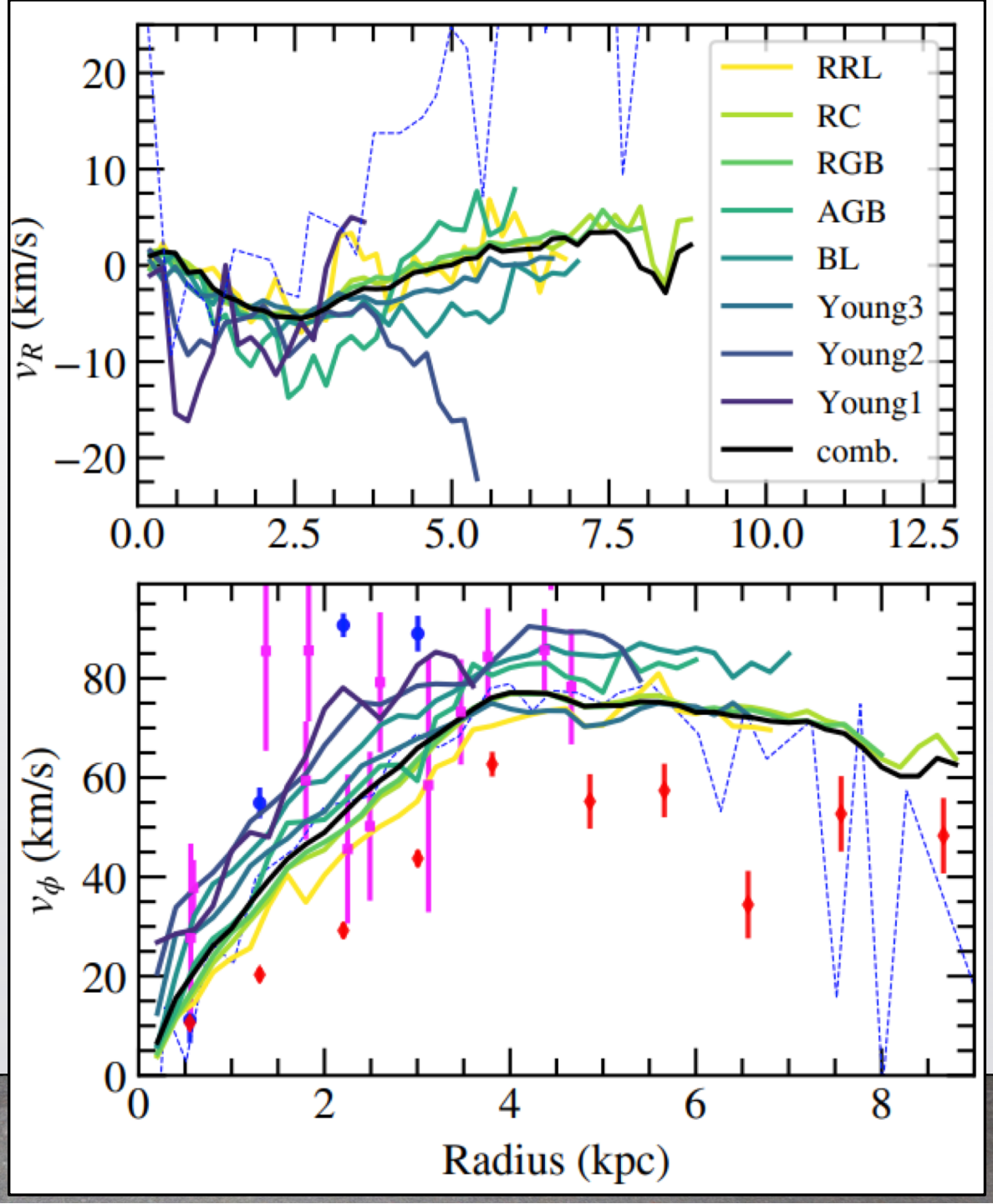

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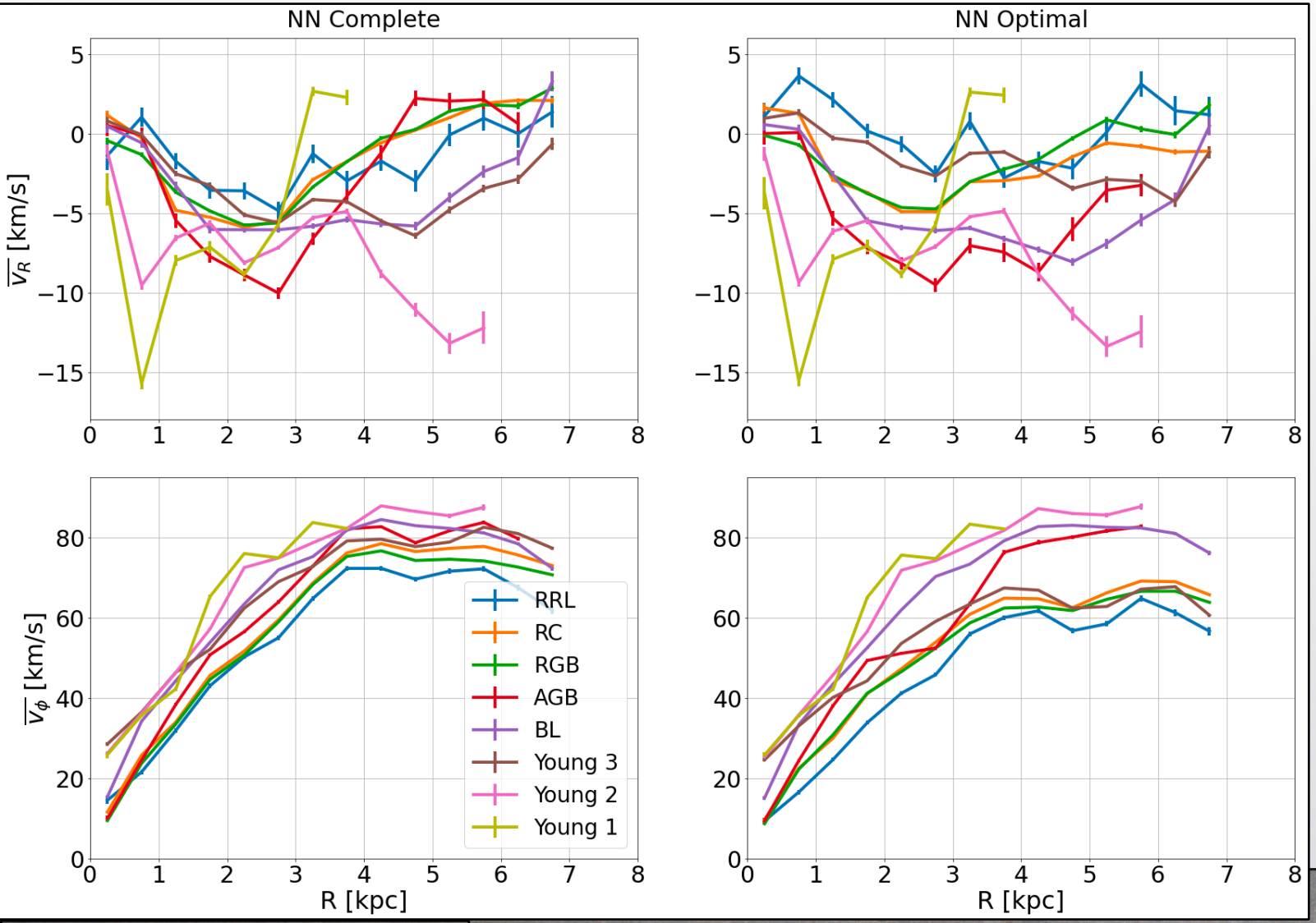
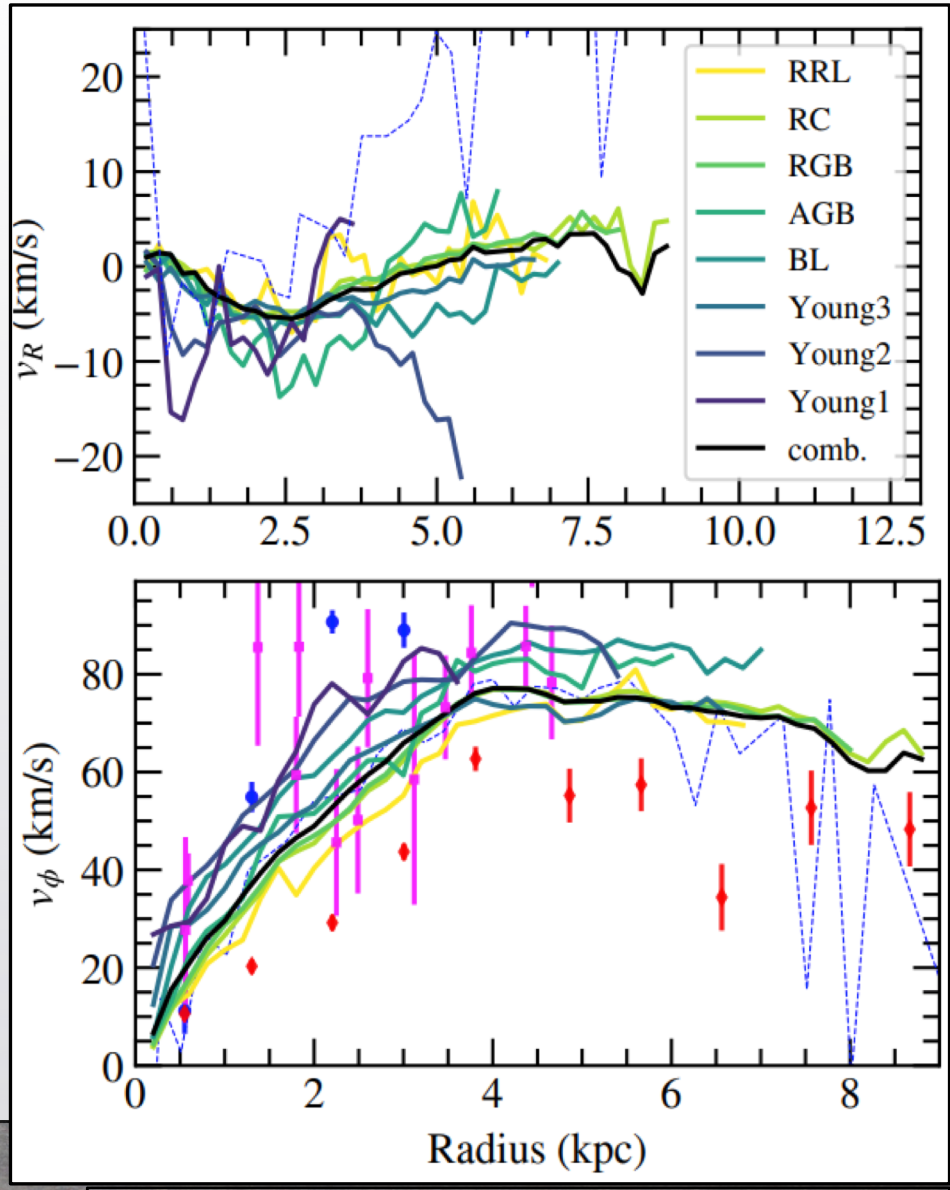


Jiménez-Arranz+2022



Gaia Collaboration,Luri, Chemin+2020

Structure and dynamics with Gaia DR3

- Now it is the time to check dynamical models with the Large Magellanic Cloud, to study pattern speed of non-axisymmetric components, nature of the spiral arms.
- Different evolutionary phases thanks to photometry.
- Line-of-sight velocities allow 3D kinematic maps, interesting vertical velocity component.