5th May 2020
Seminaire Lagrange

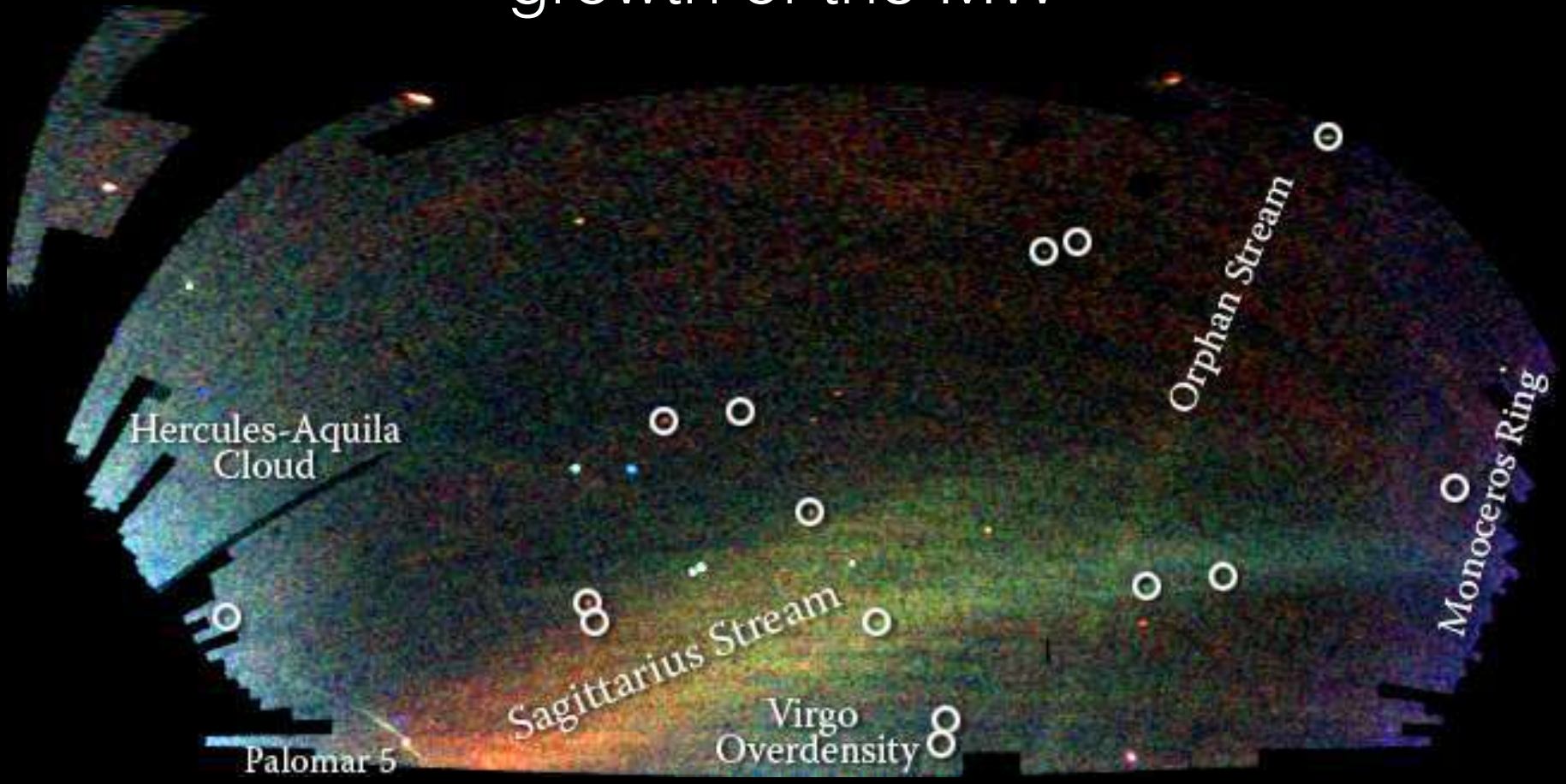
The Milky Way as a laboratory for galaxy formation and dark matter

Chervin F. P. Laporte

IPMU Fellow

The Milky Way Galaxy as a laboratory for galaxy formation and dark matter

The Field of Streams - a testament of the hierarchical growth of the MW



Belokurov+06

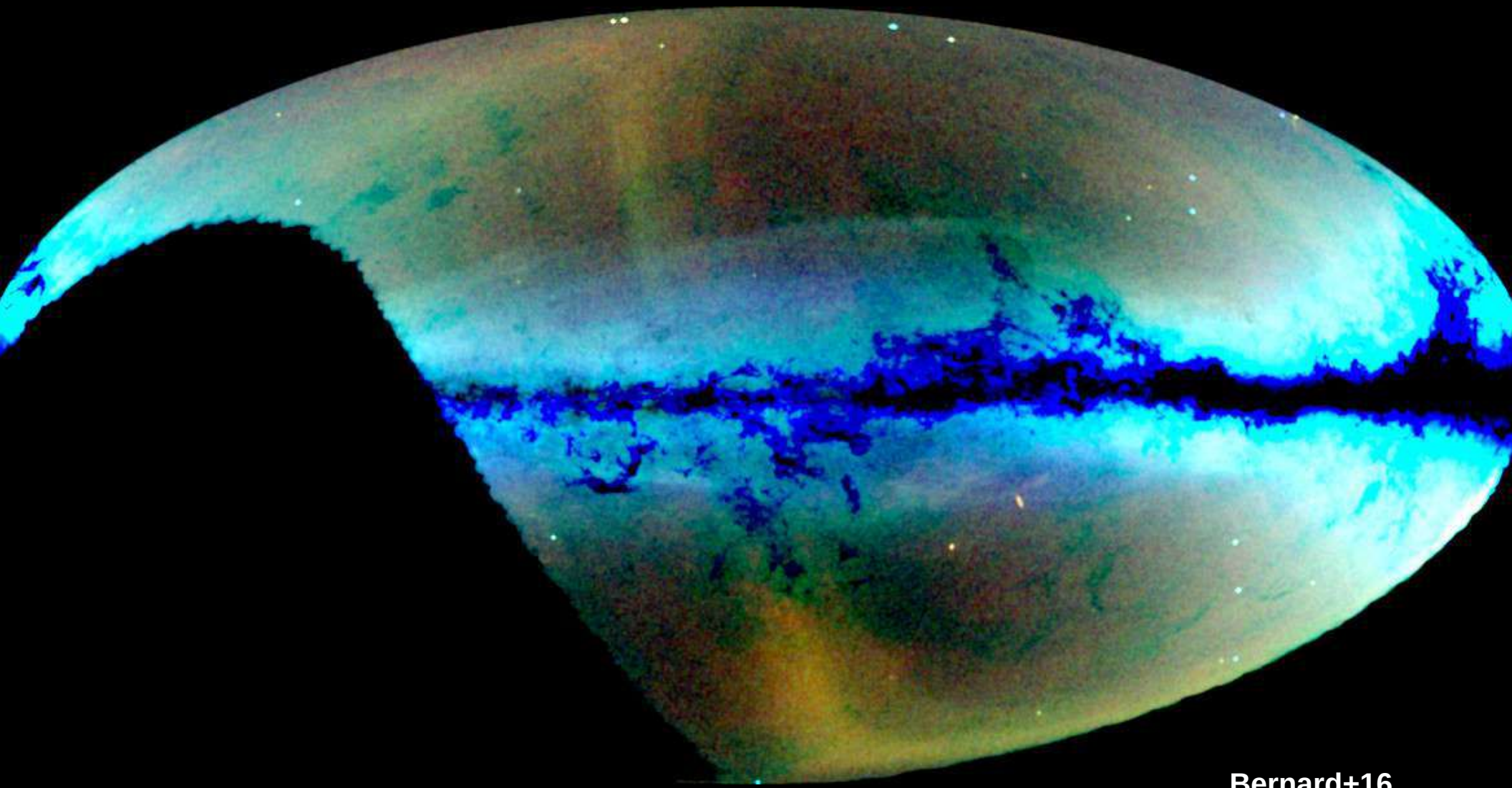
But are all streams on the sky necessarily accreted?

The Field of Streams - a testament of the hierarchical growth of the MW

Belokurov+06

But are all streams on the sky necessarily accreted?

The Anticenter viewed by Pan-STARRS



Bernard+16

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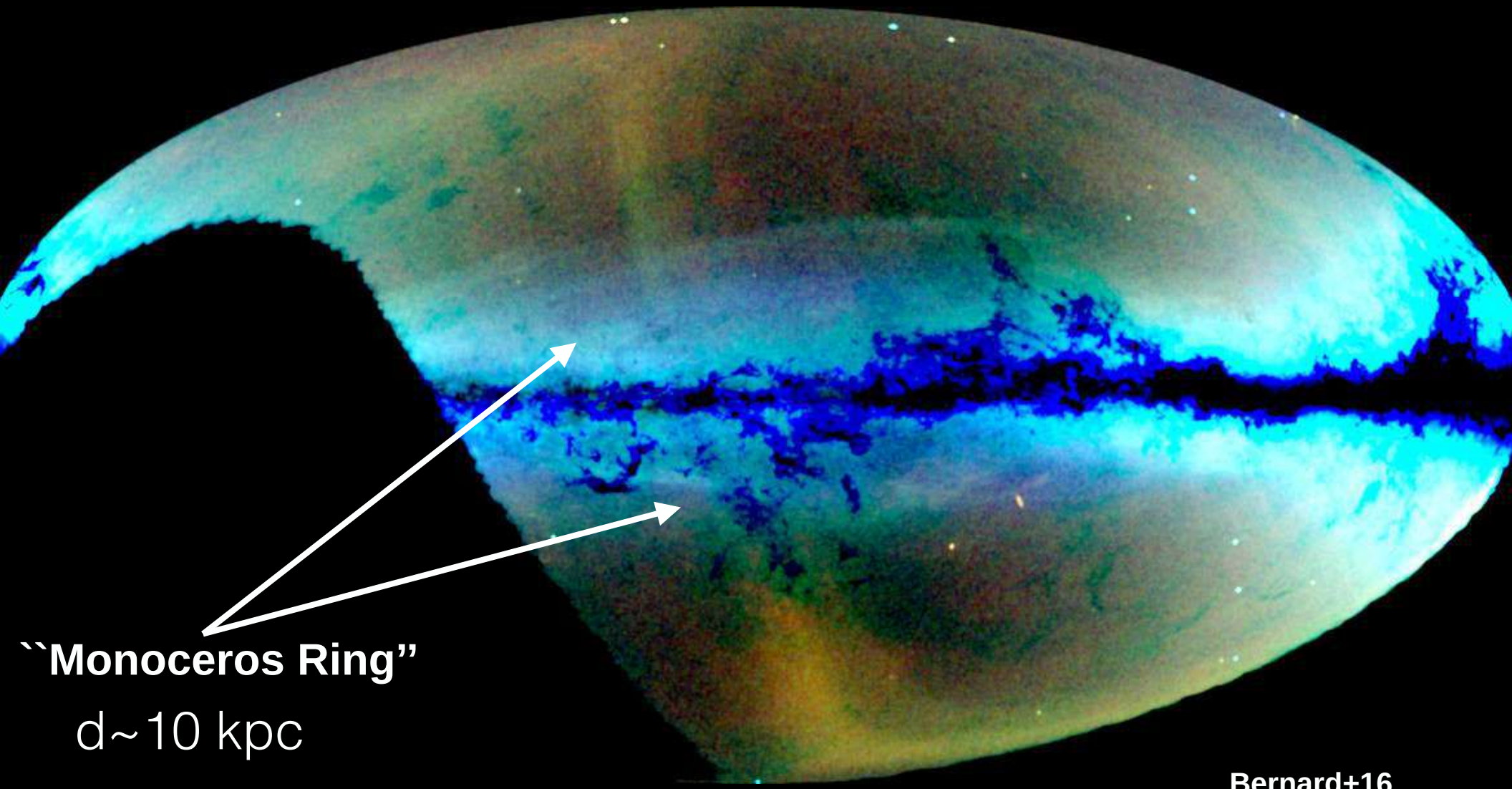

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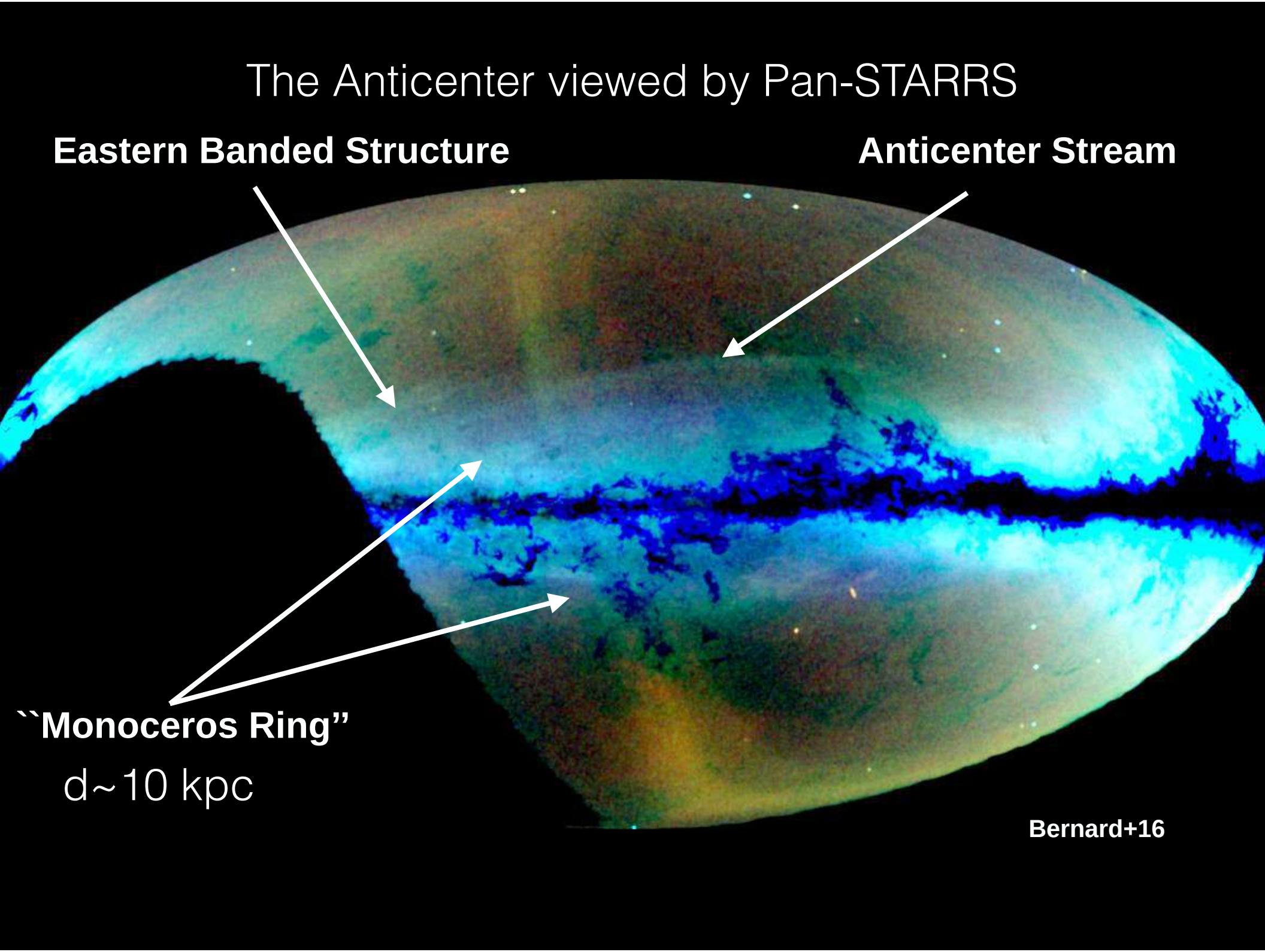

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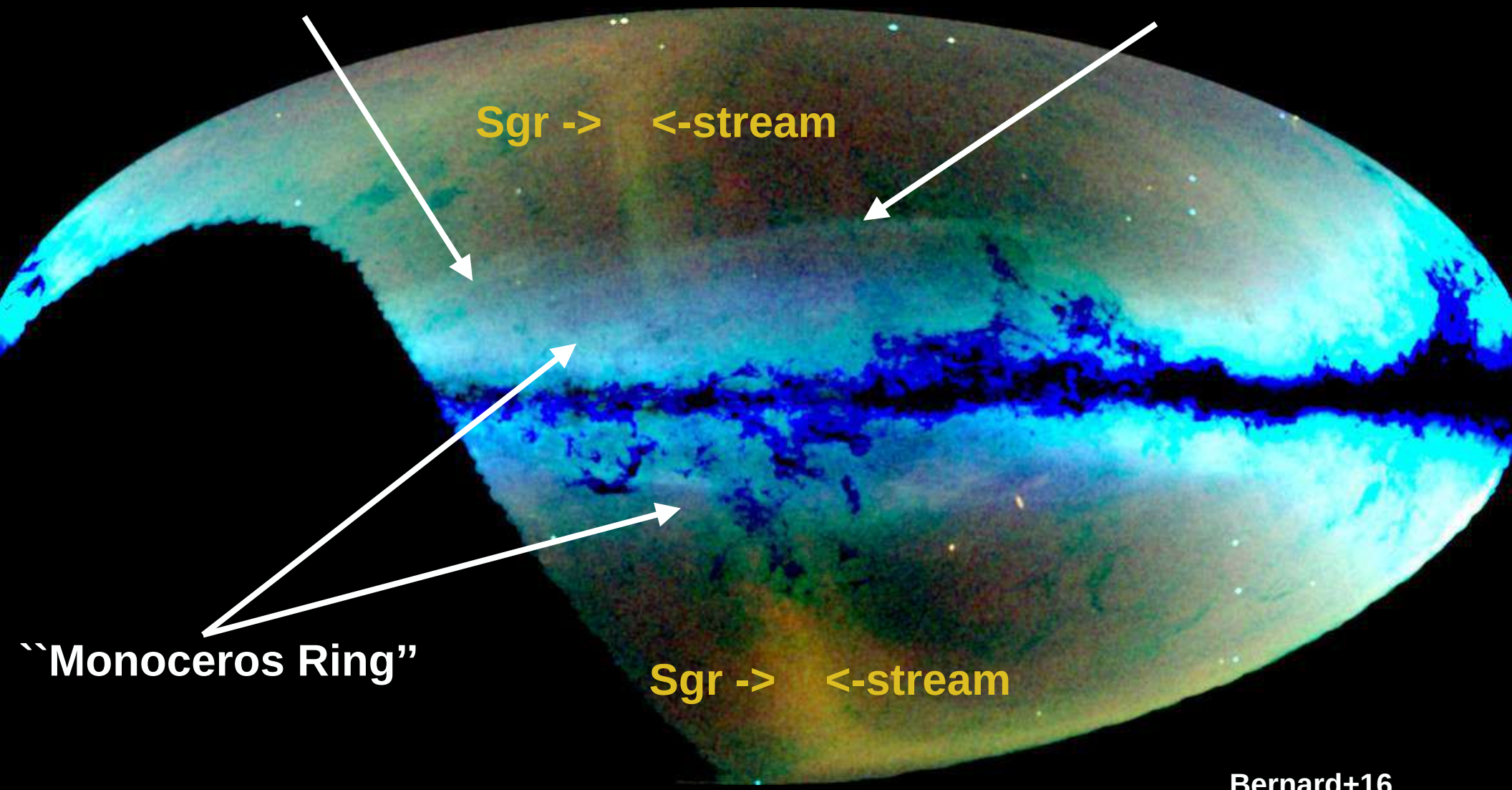
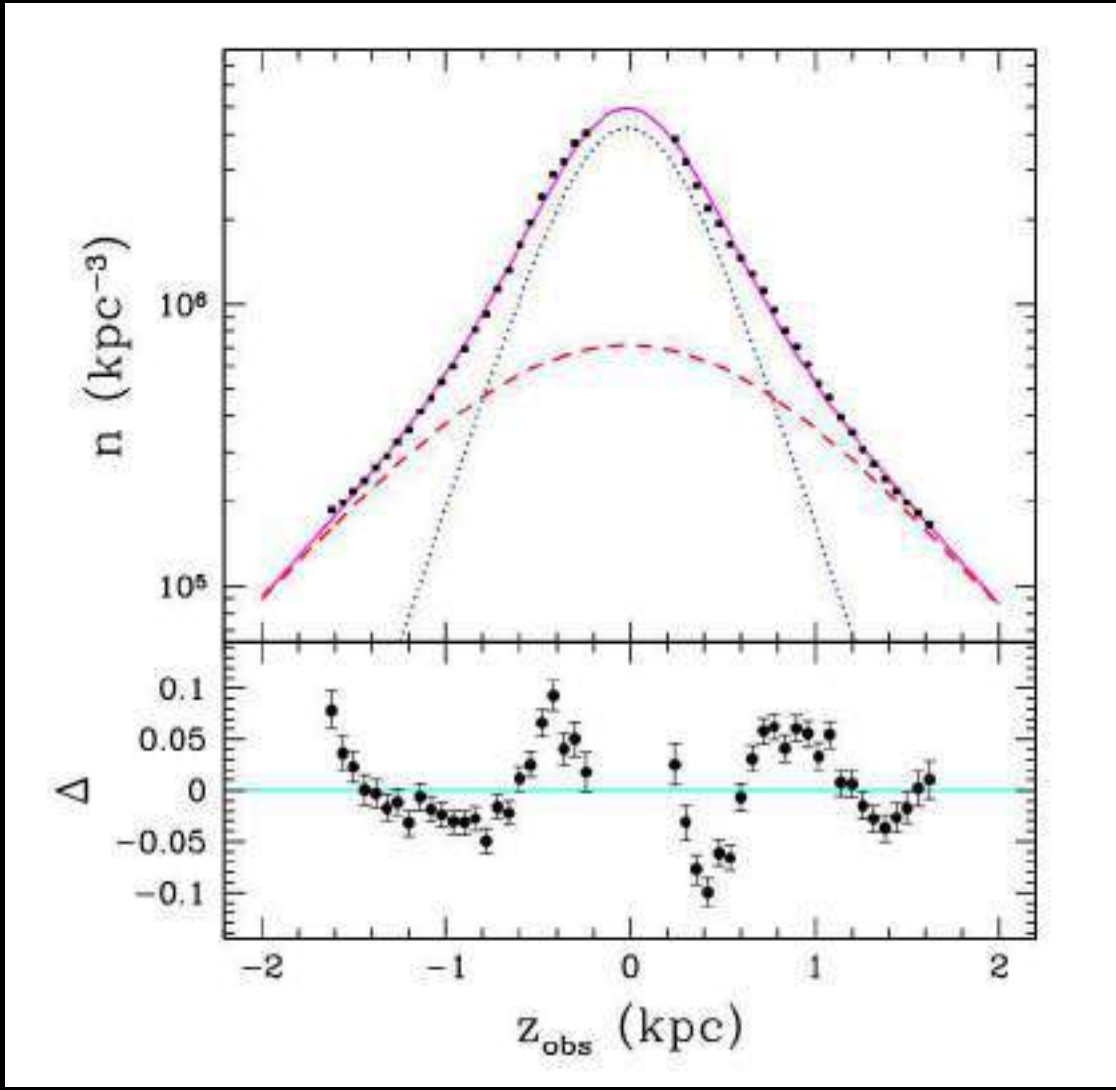


Local oscillations of the disc

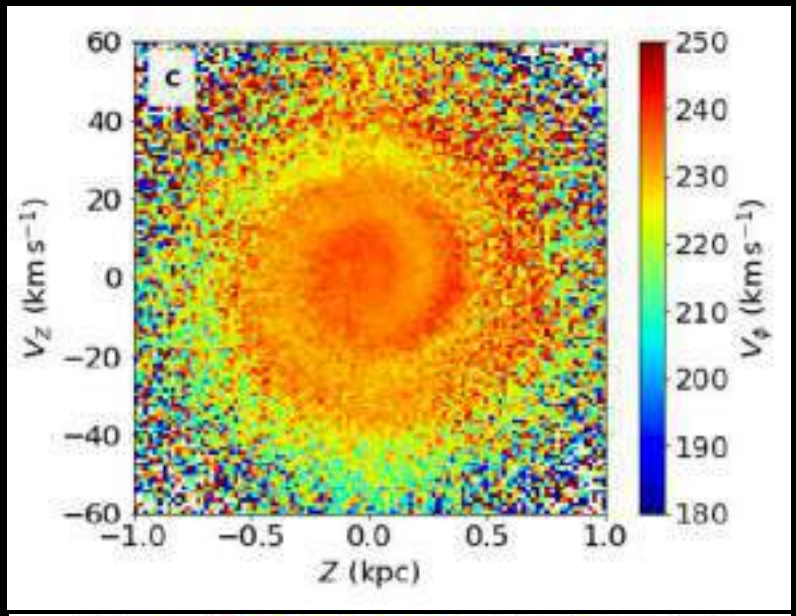
pre-Gaia

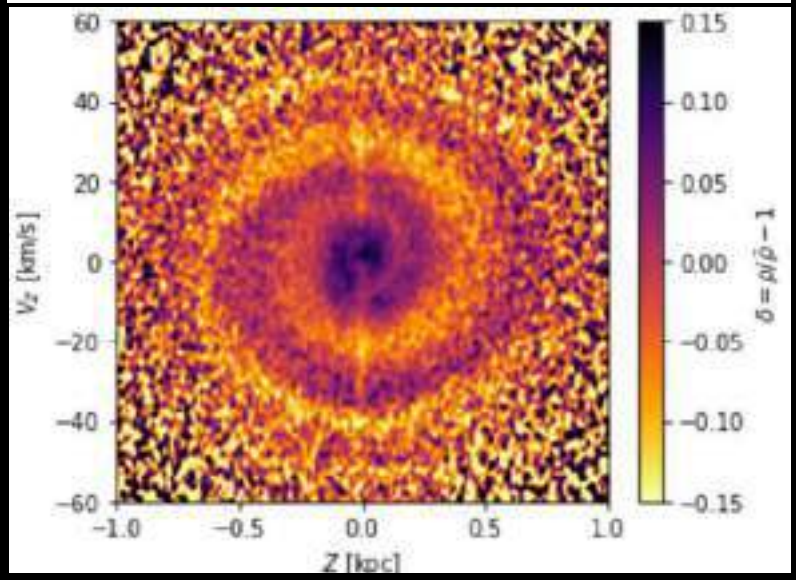


Widrow+12

Gaia DR2

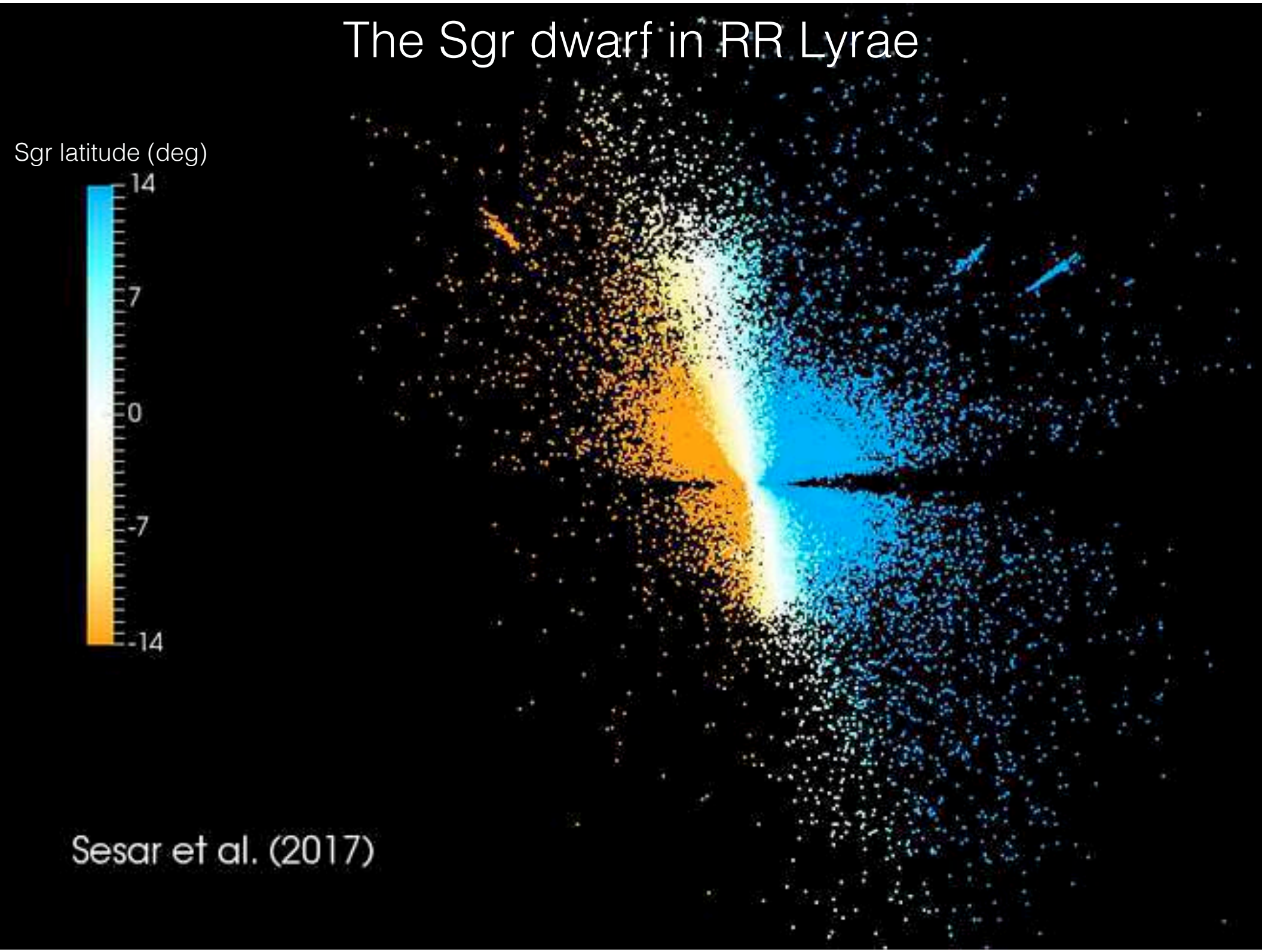
Antoja+18





Laporte+19c

The Sgr dwarf in RR Lyrae

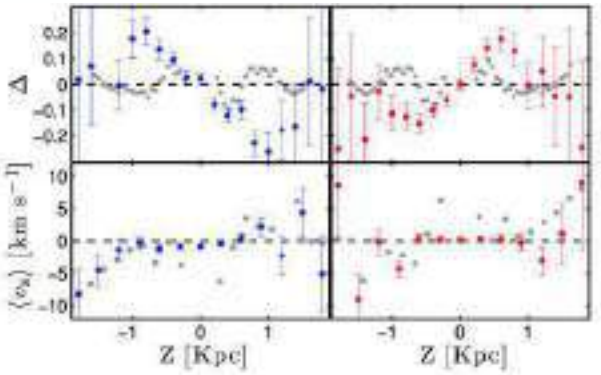


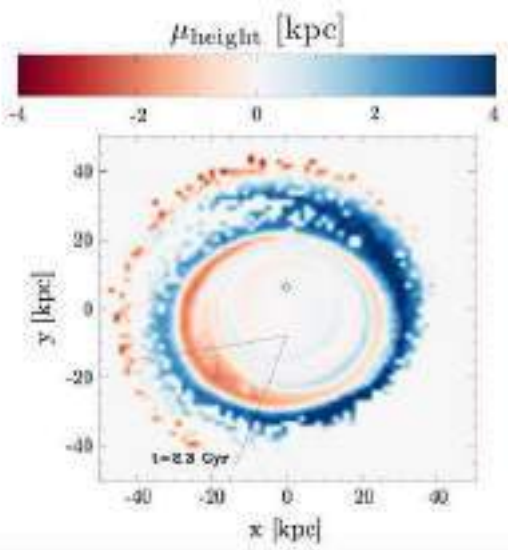
Prelude
pre-Gaia DR2 models

Previous works on impact of Sgr on the disc

- Test-particle simulations: Quillen+09 - Warp, Ring-like structures **(qualitative only, quickly phase mixes**)
- N-body: Purcell+11, similar conclusions, **but qualitative only,** Monoceros ring not reproduced, also ad-hoc ICs.
- Gomez+13: disc bending in SN, but **amplitudes are too high, phases not matched**. same ICs P11.
- Laporte+18a (used in Price-Whelan+15): TriAnd-like structure **qualitatively reproduced too but amplitude too low.** same ICs P11.

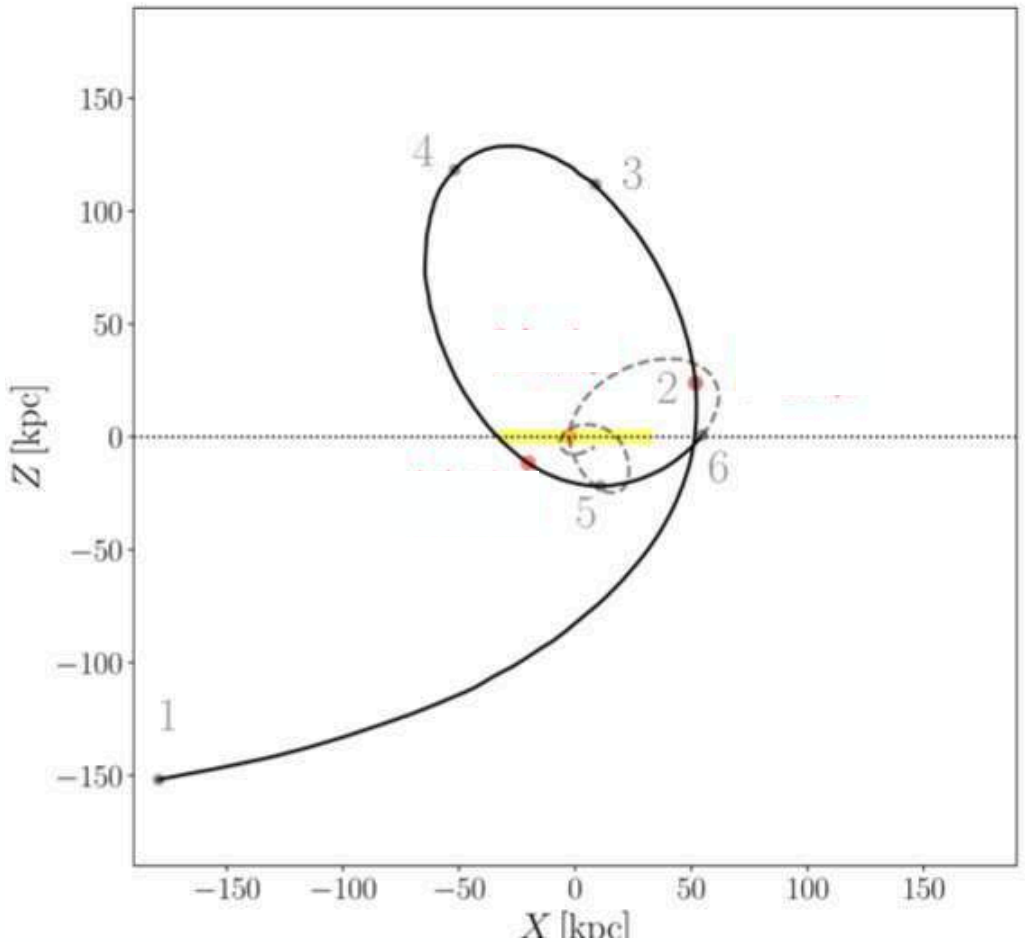
Gomez et al. 2013



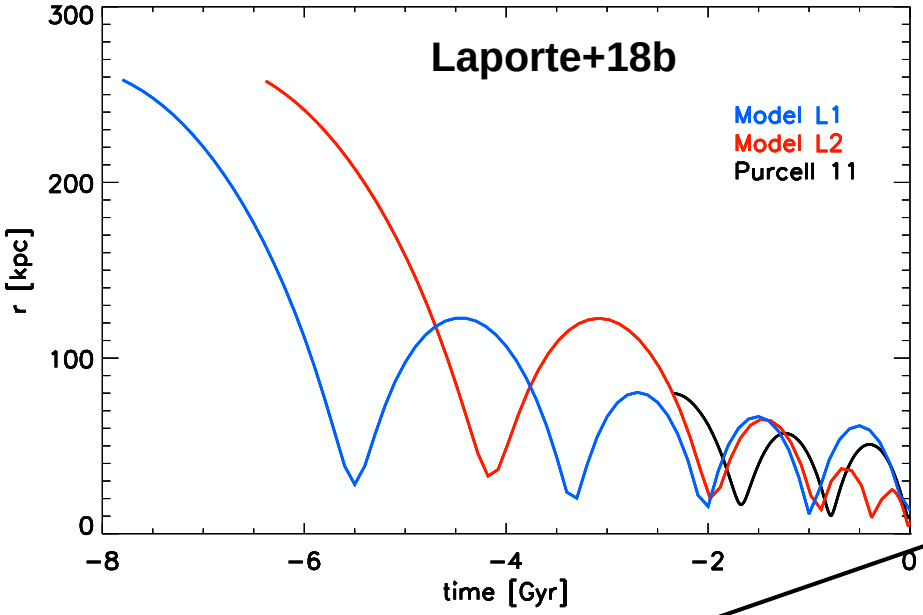


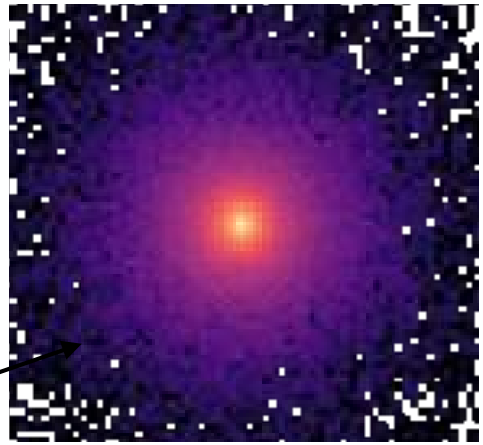
Price-Whelan…CFPL+ 15

Prelude
pre-Gaia DR2 models

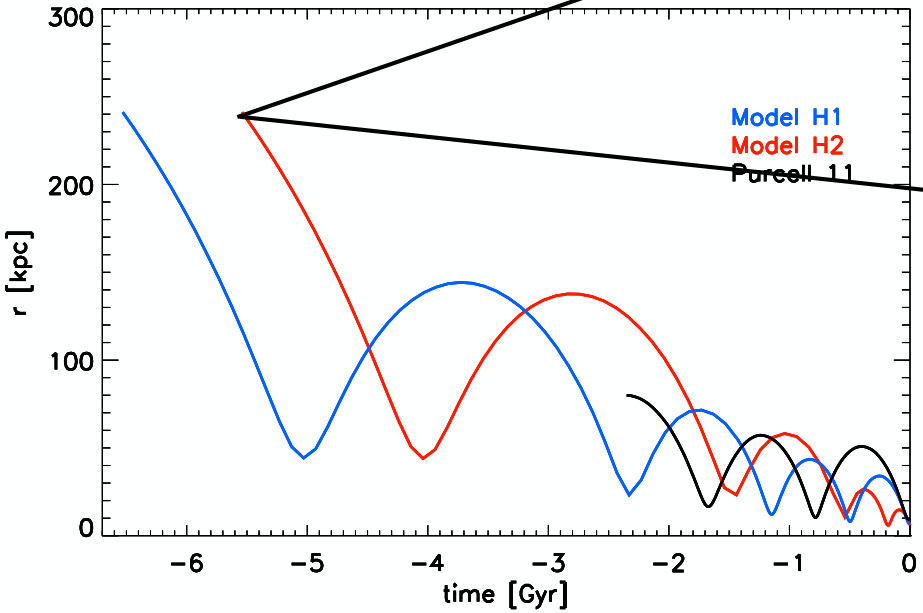


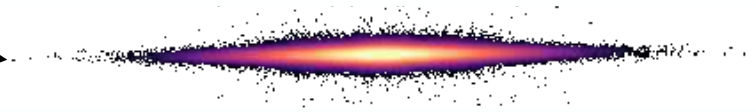
Live N-body simulations of massive Sgr dwarf interaction with MW disc





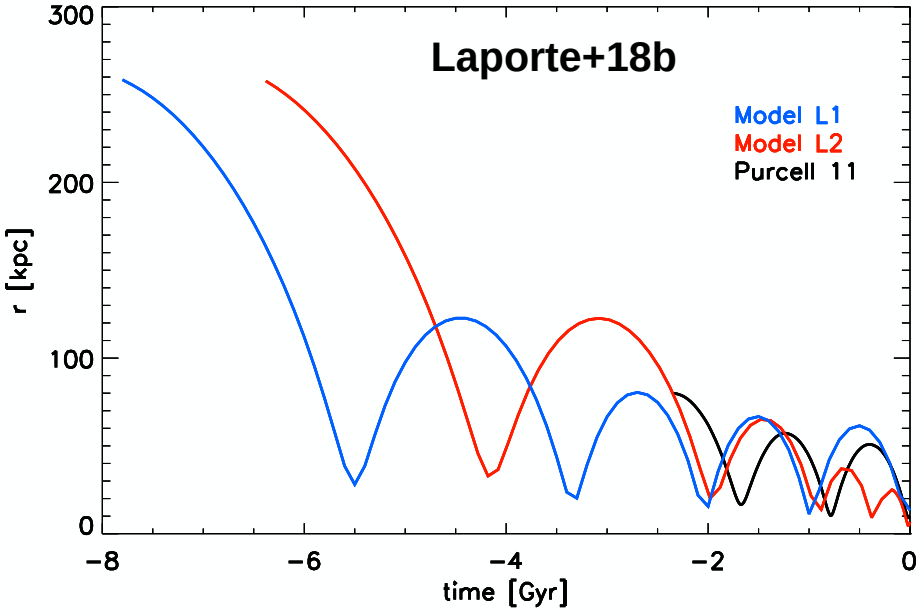
Sgr

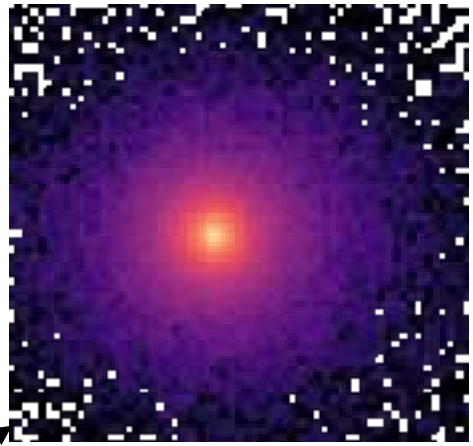




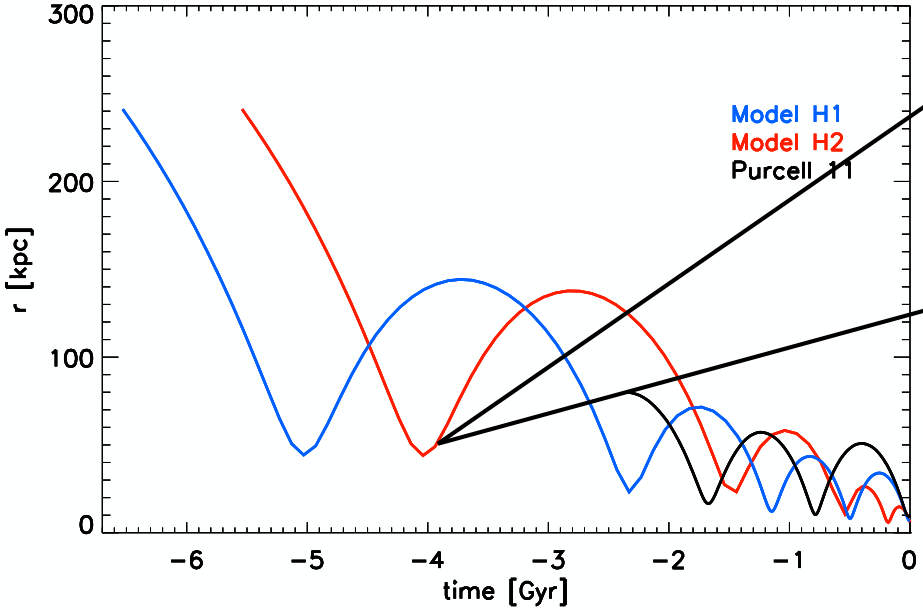
Disc

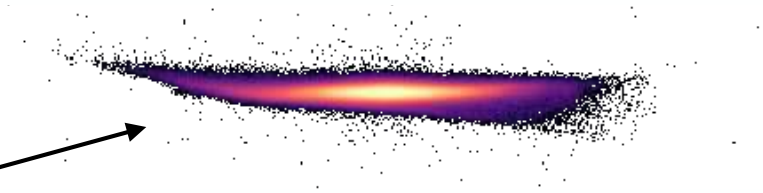
Live N-body simulations of massive Sgr dwarf interaction with MW disc





Sgr





Disc

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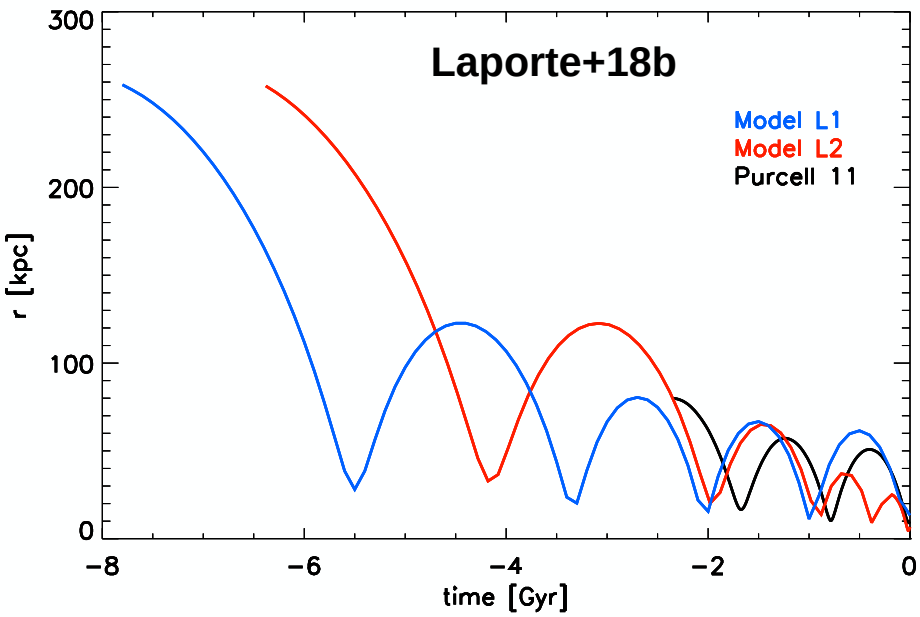

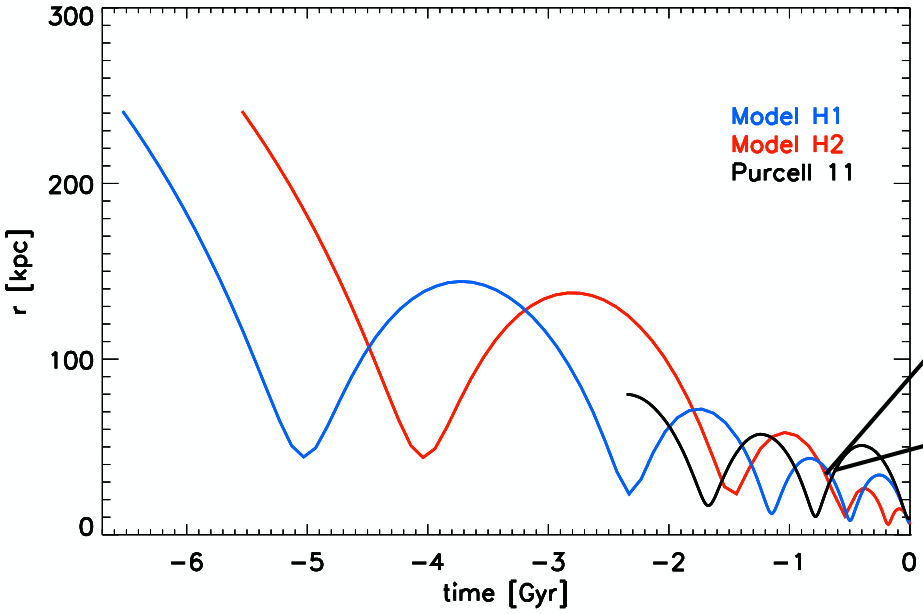

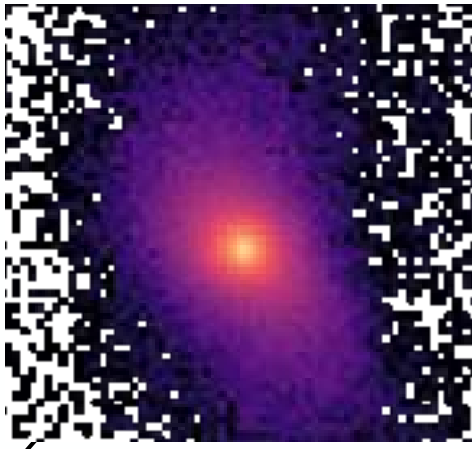

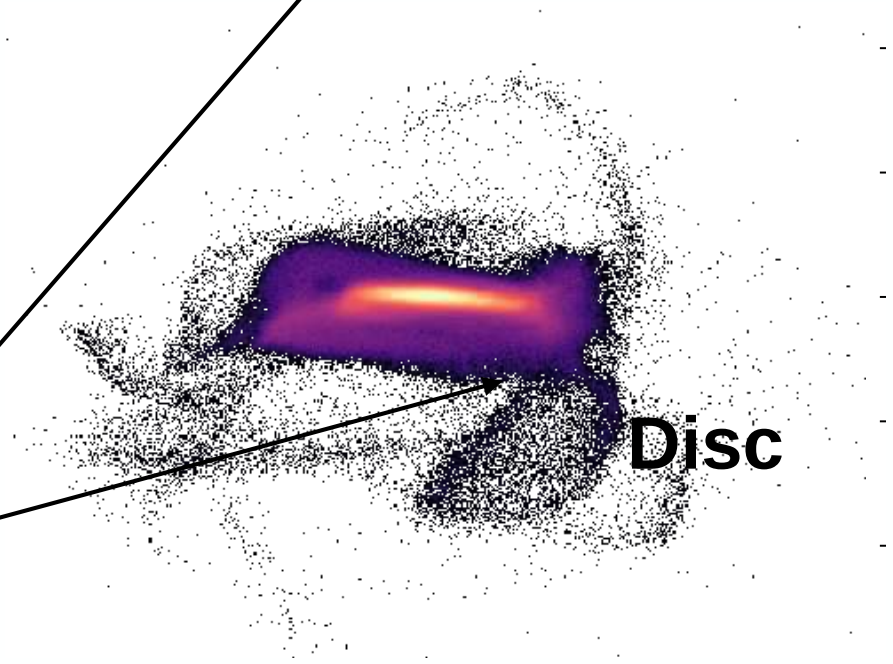

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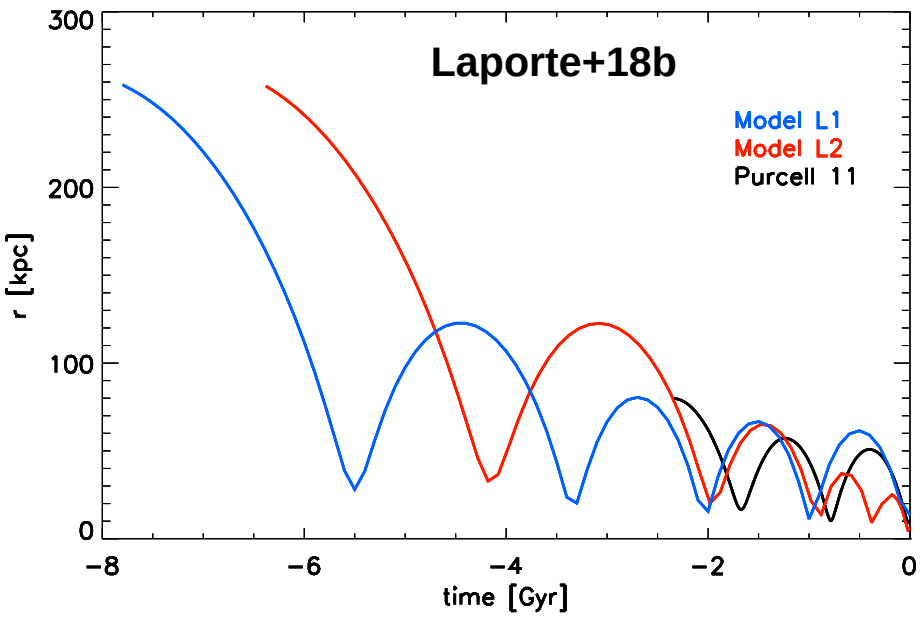
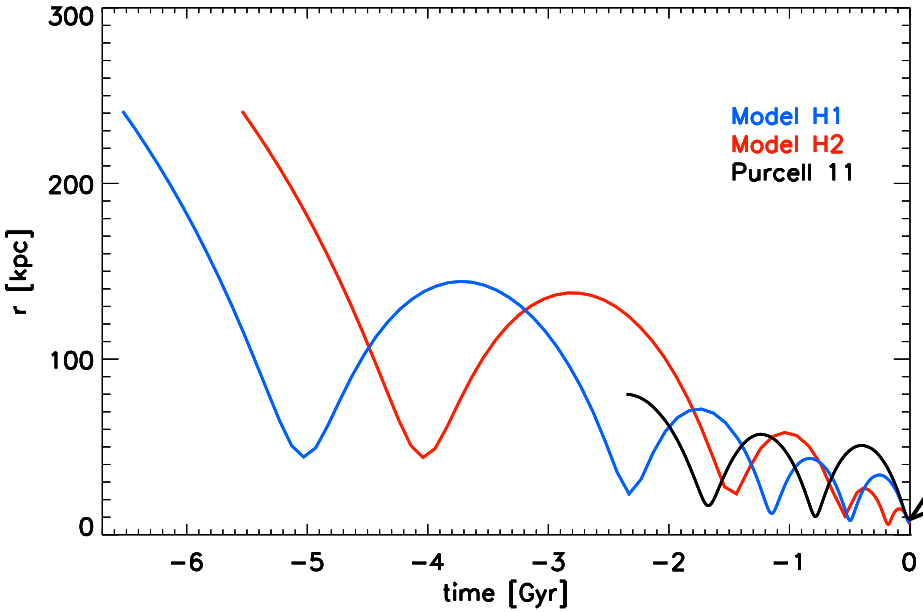
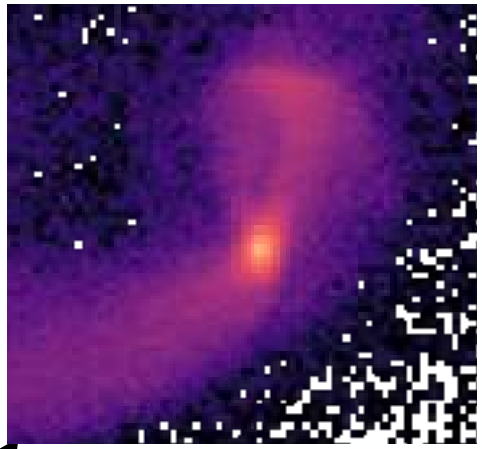
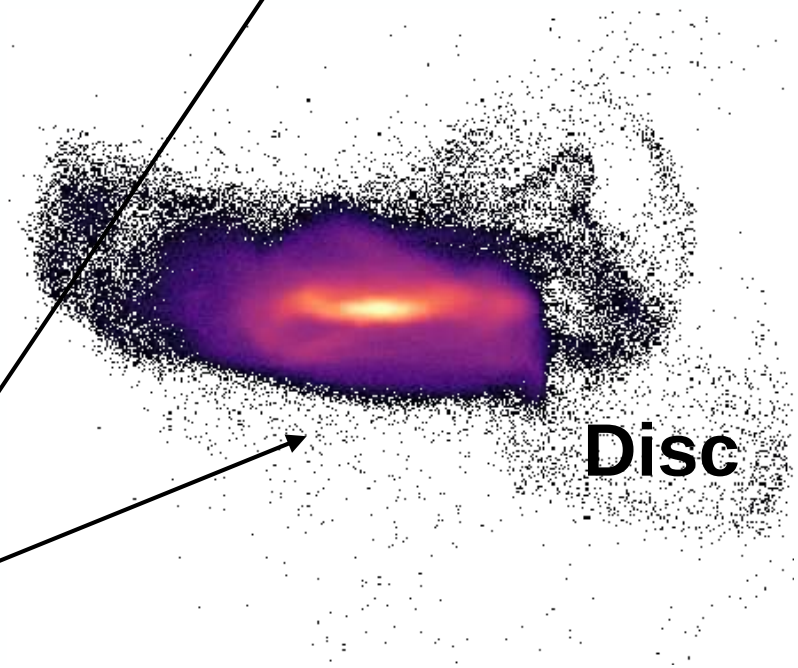




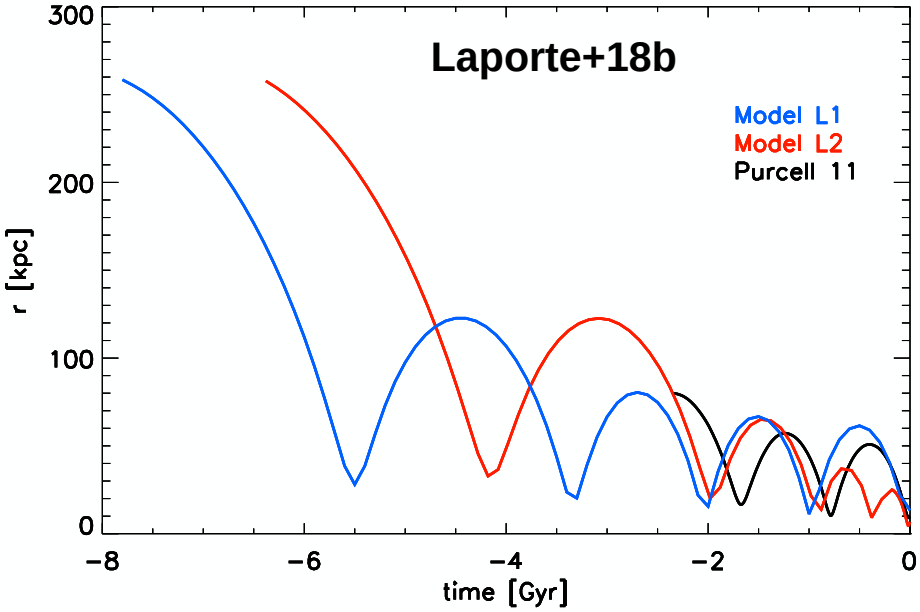


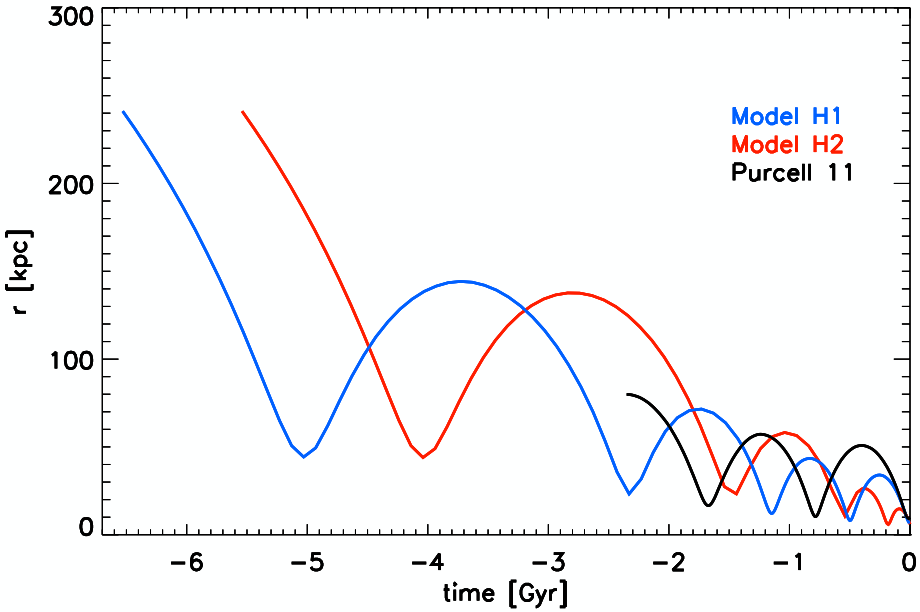
Sgr

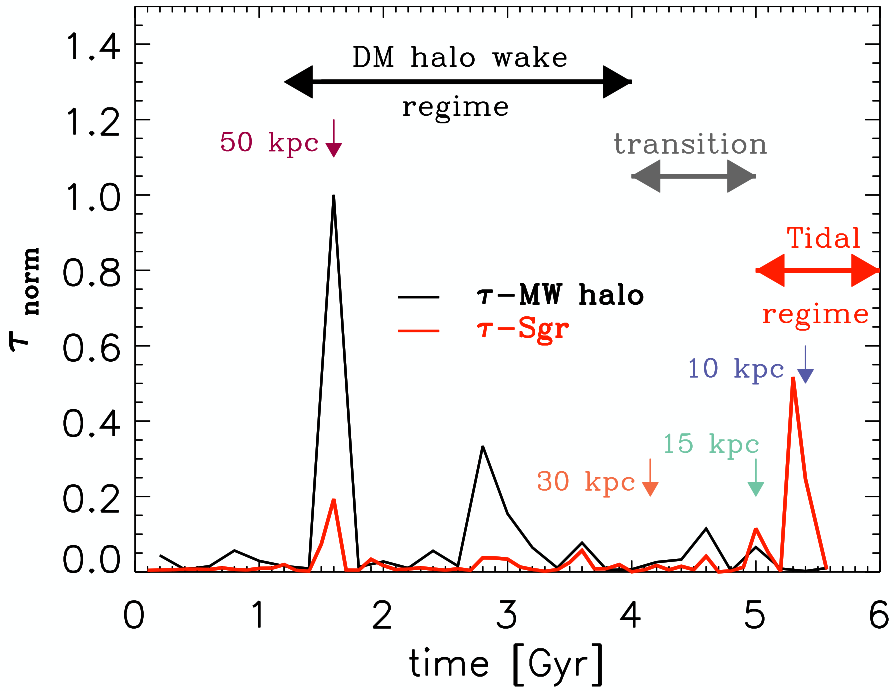


Disc

Live N-body simulations of massive* Sgr dwarf interaction with MW disc

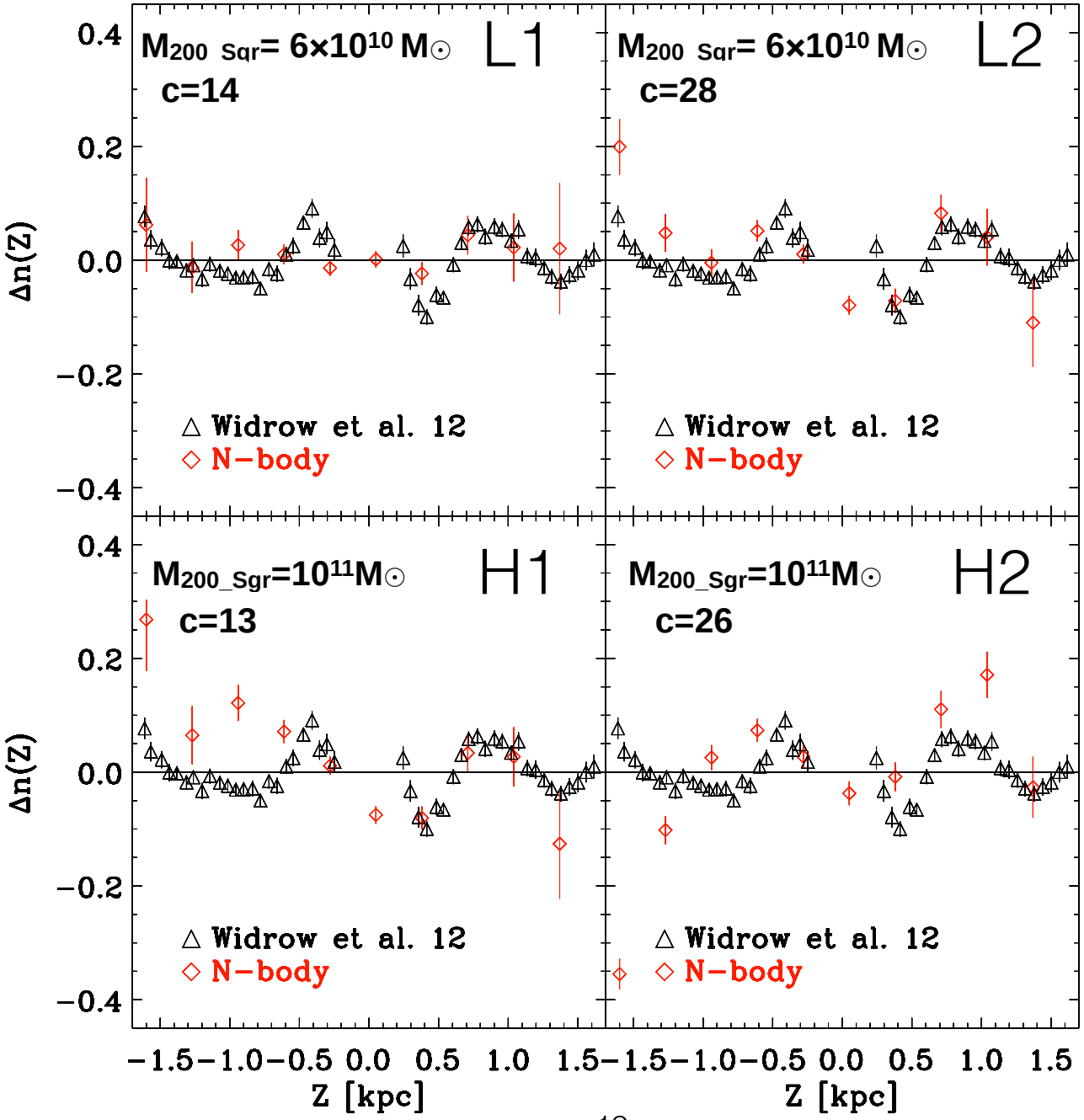






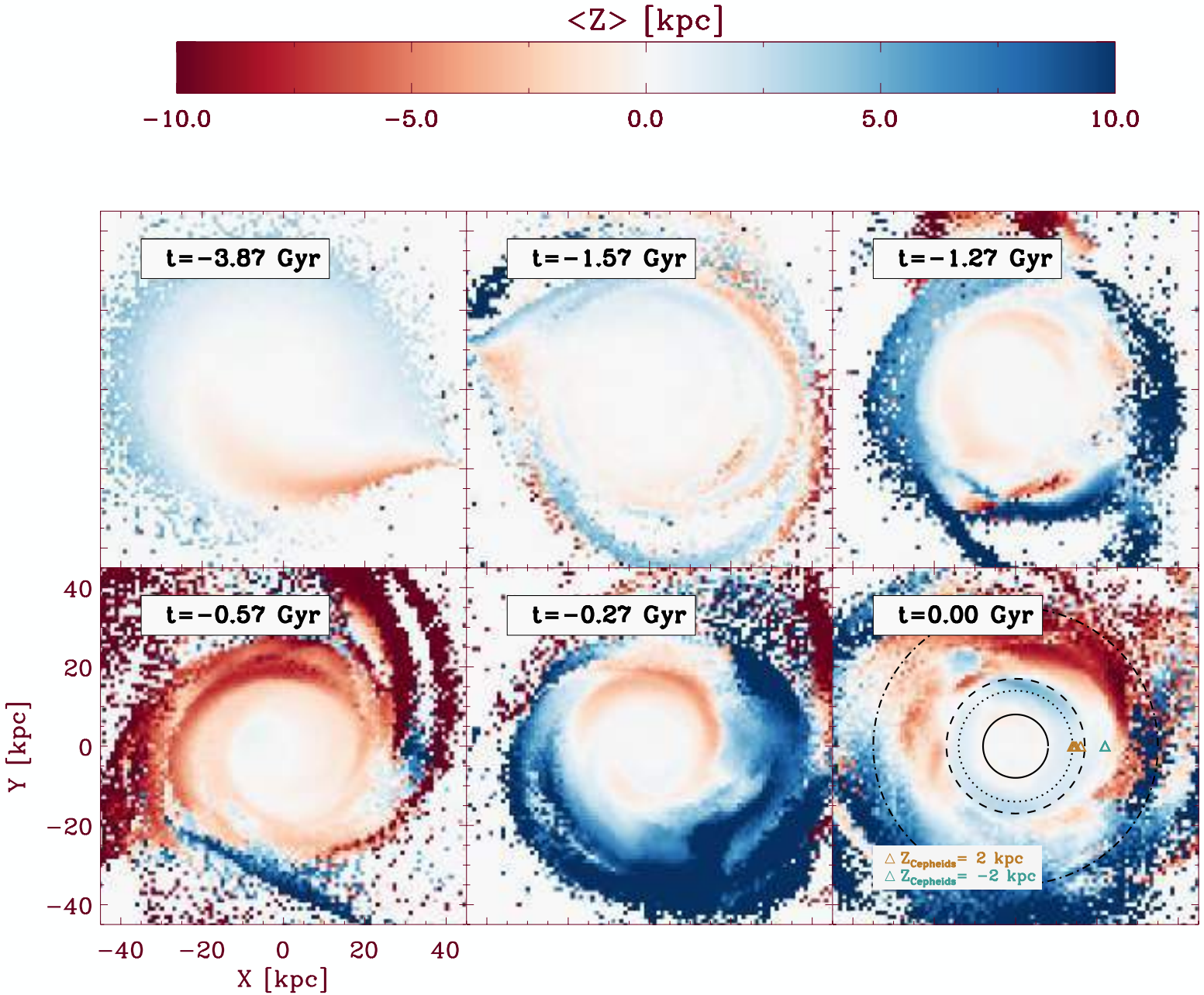
*see Jiang&Binney00, de Boer+14, Gibbons+16

Sgr induces vertical oscillations in the Solar neighbourhood



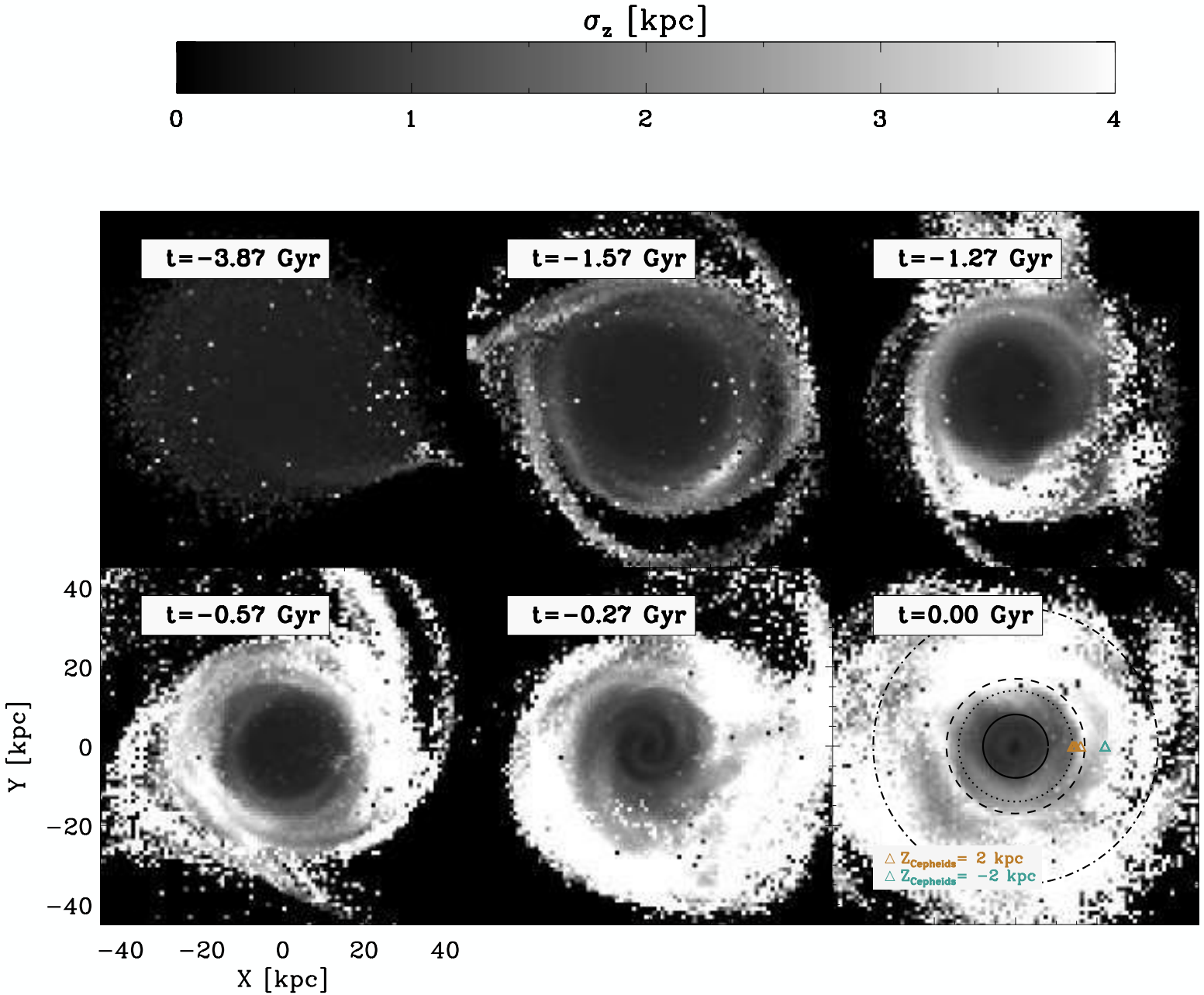
Laporte+18b

vertical displacements about the midplane of the disc



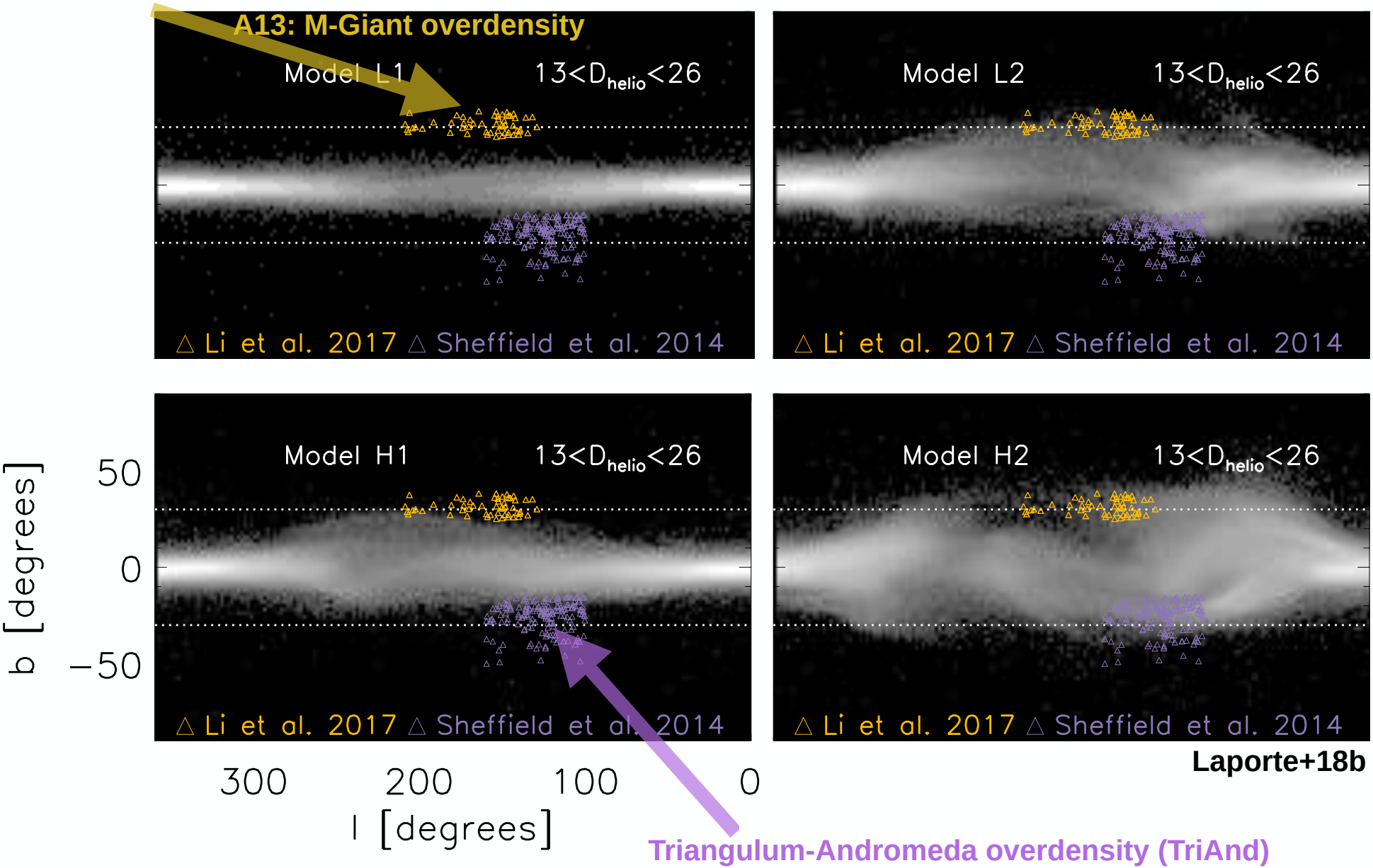
Laporte+18b

vertical heating (flaring) about the midplane of the disc



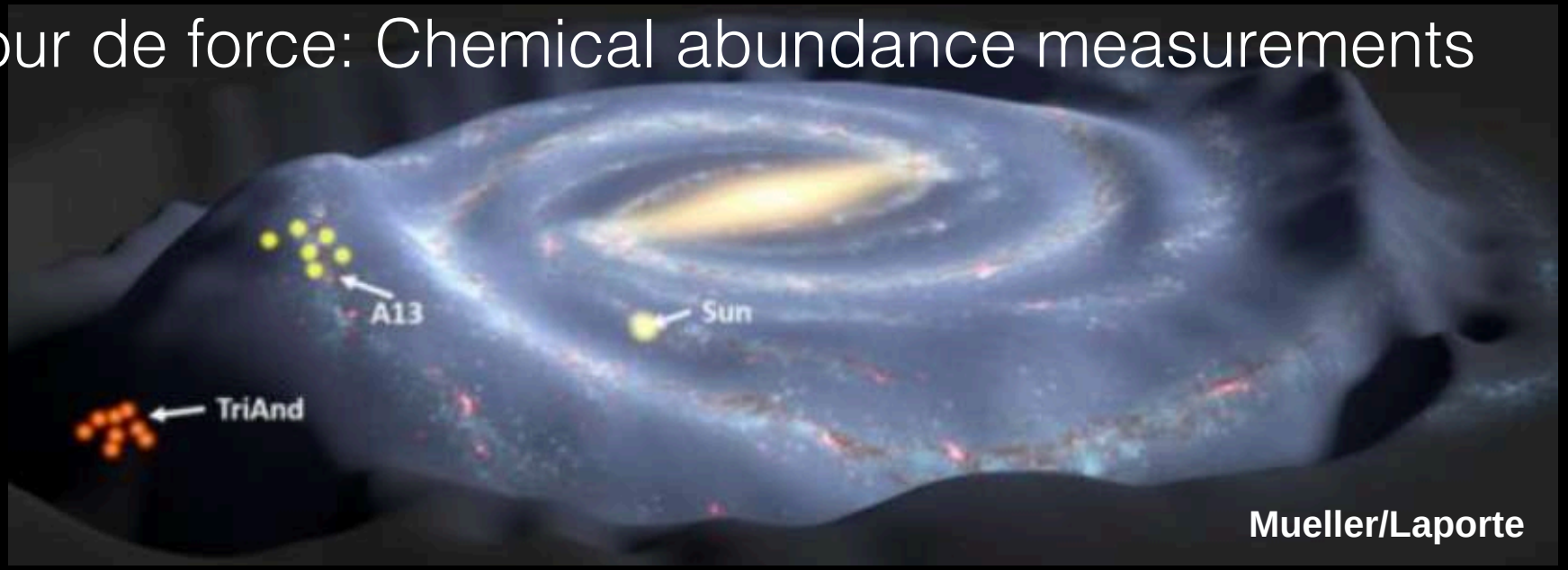
Laporte+18b

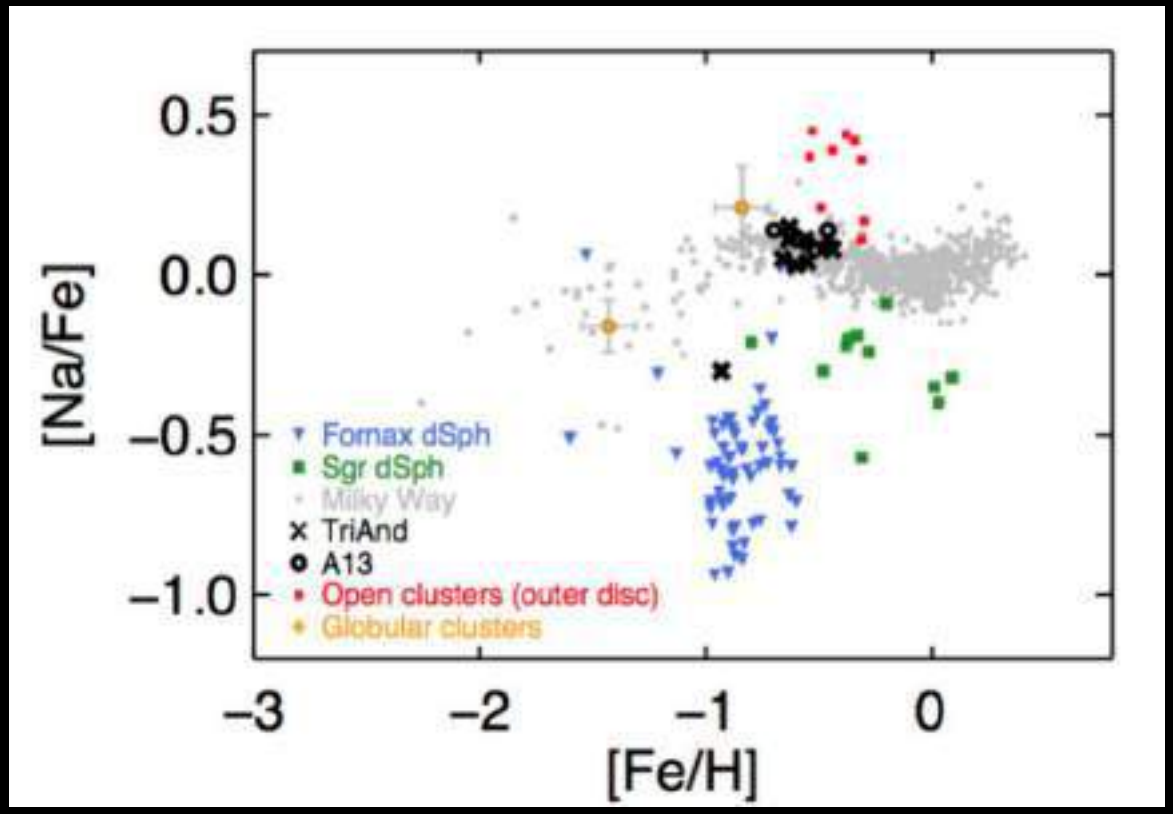
…and outer disc structures



Laporte+18b

A tour de force: Chemical abundance measurements



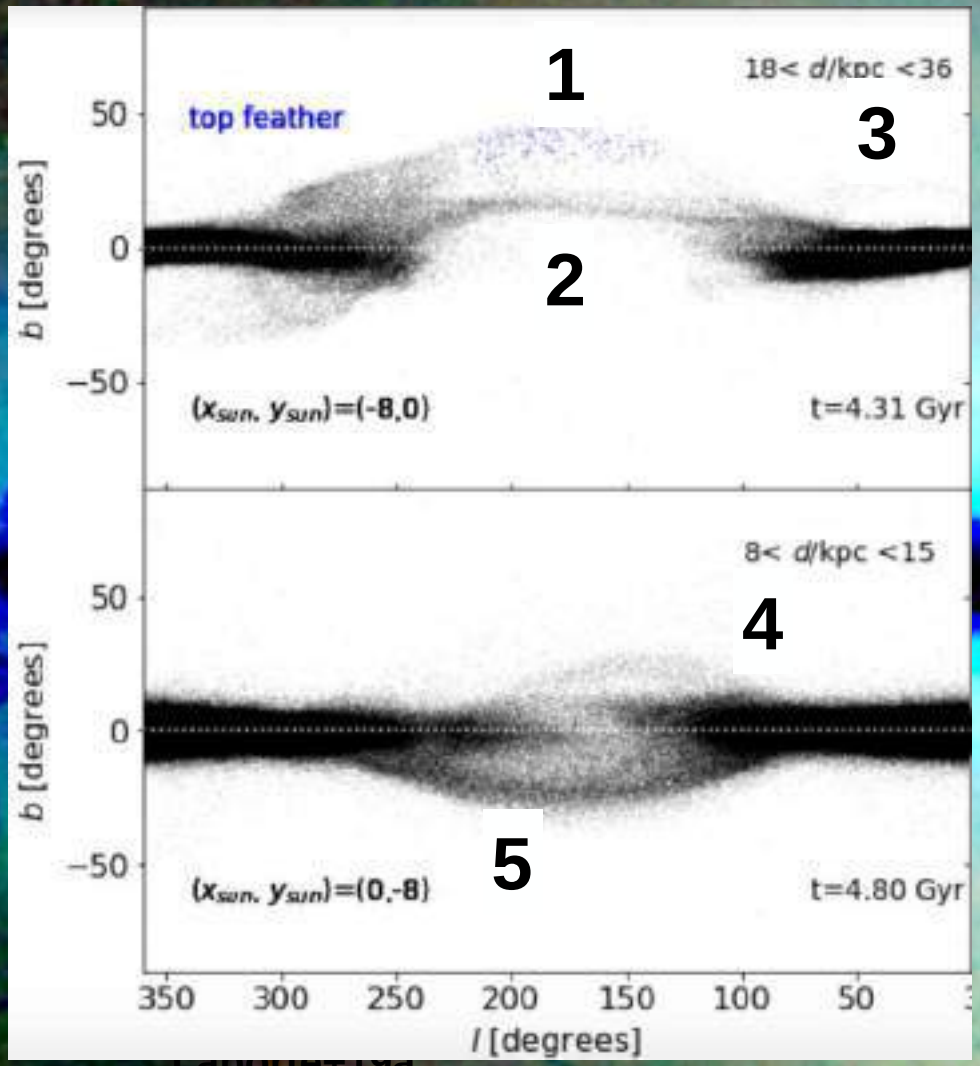


Bergemann+18 (incl CFPL)

ACS-like structures in numerical N-body simulations

feathers

Laporte, Johnston, Tzanidakis+19a



Laporte+19a

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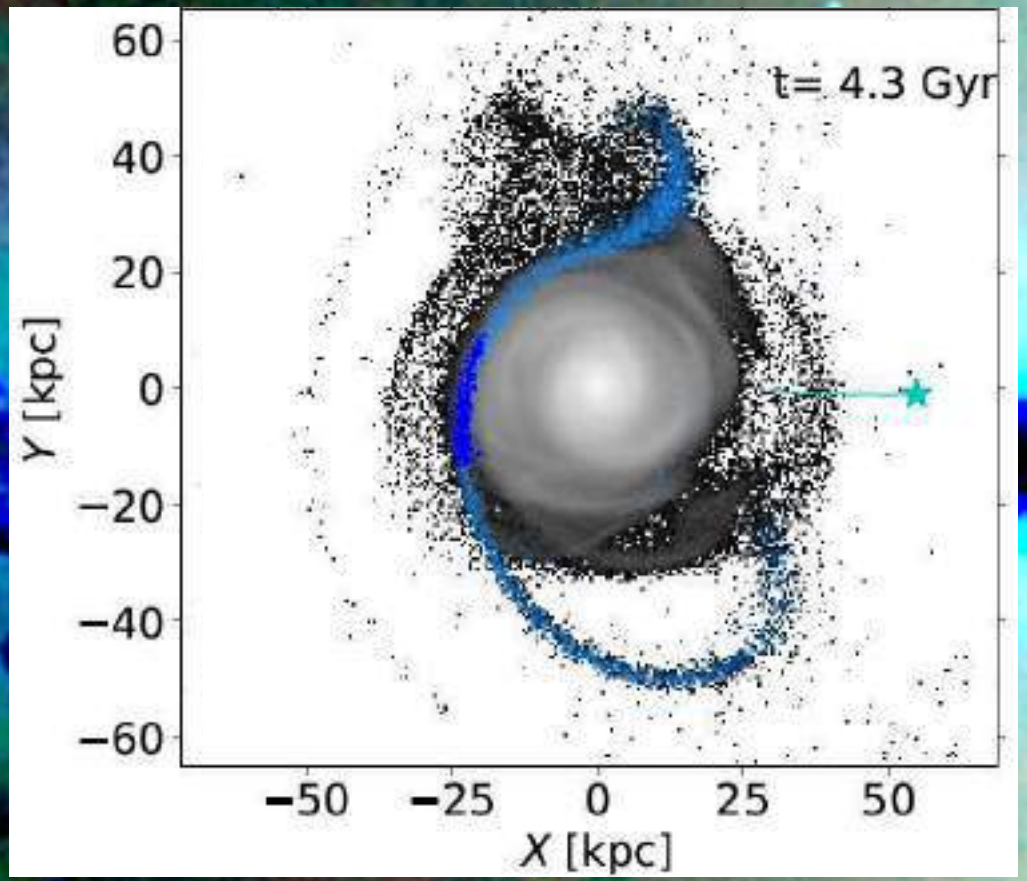
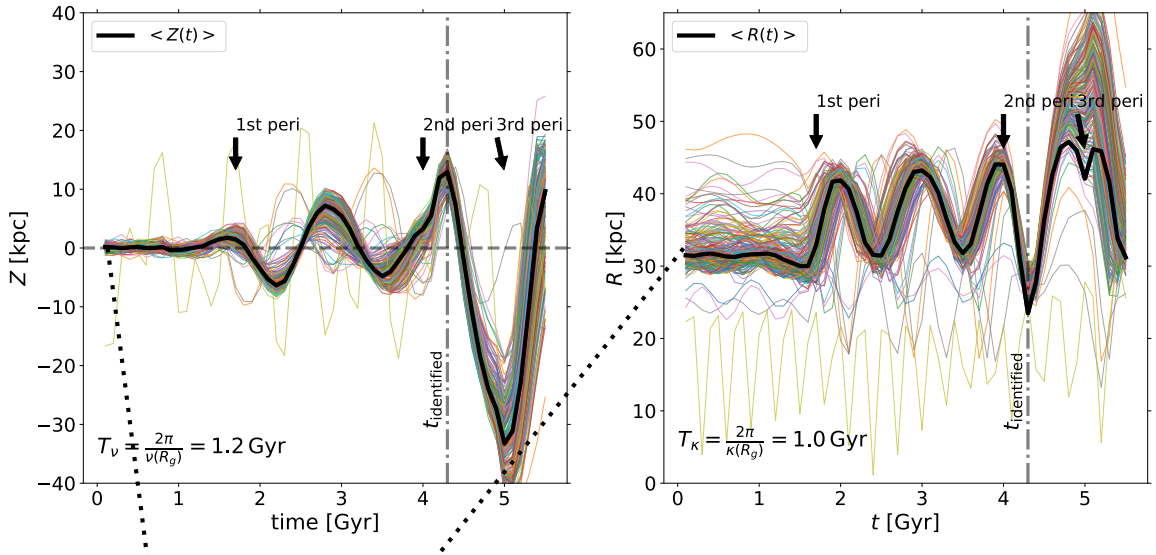


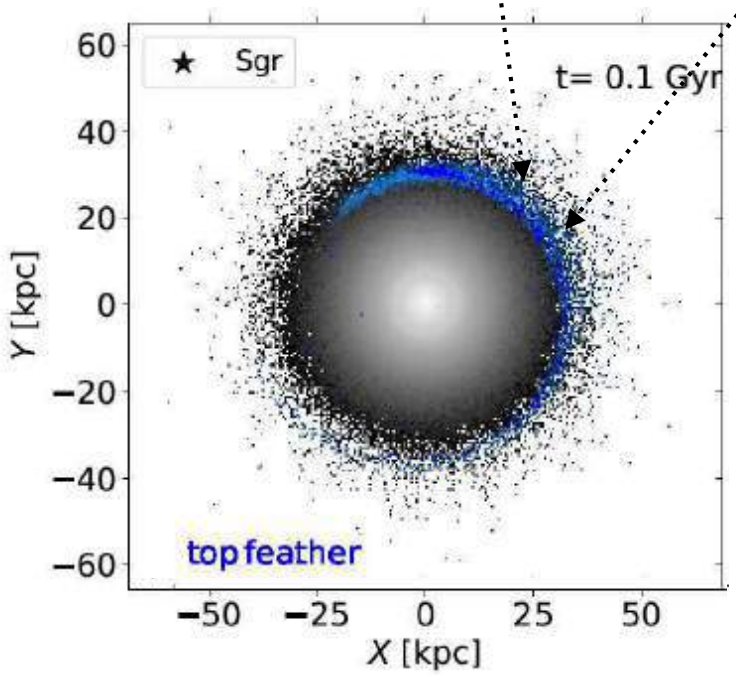
Bernard+16

Laporte+19a

A closer look at an **individual ``feather”** mean motion about epicyclic/vertical frequencies.



Laporte+19a



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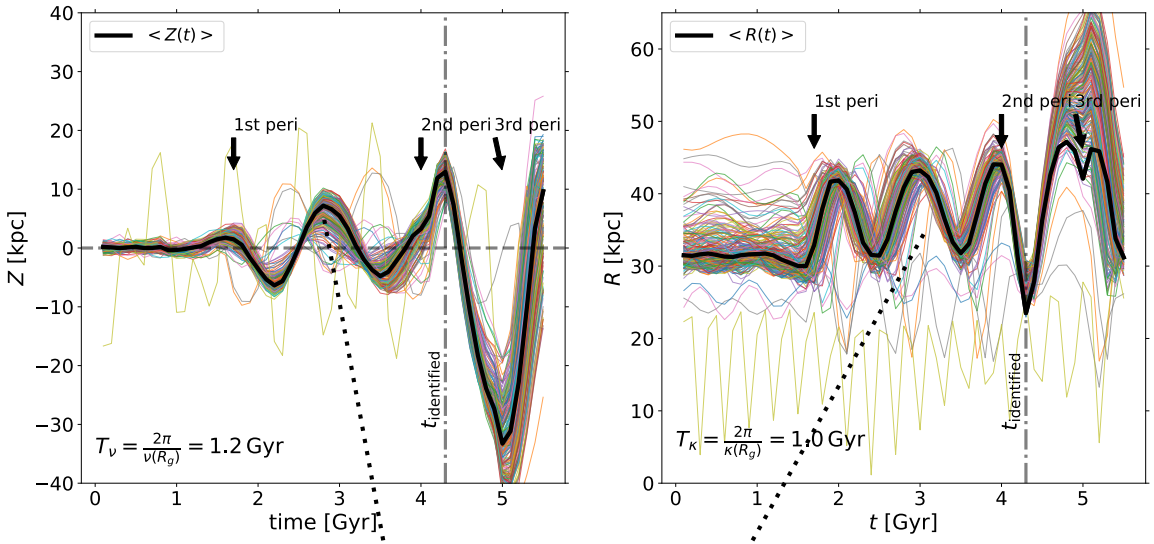
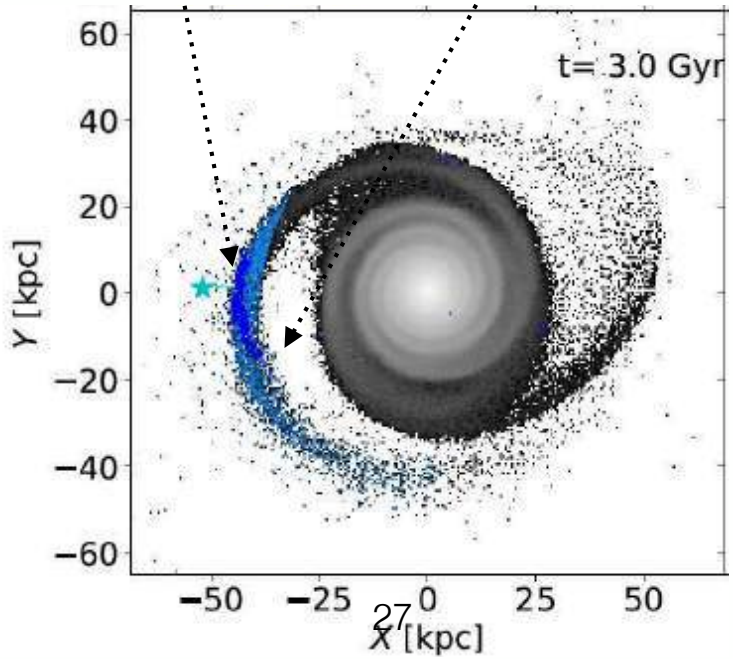


Laporte+19a



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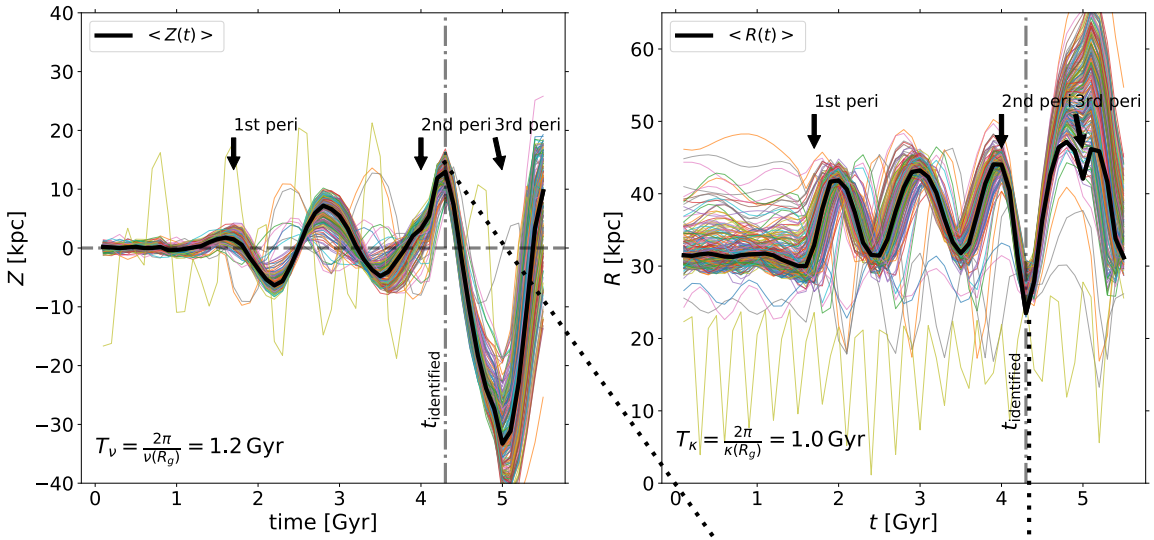
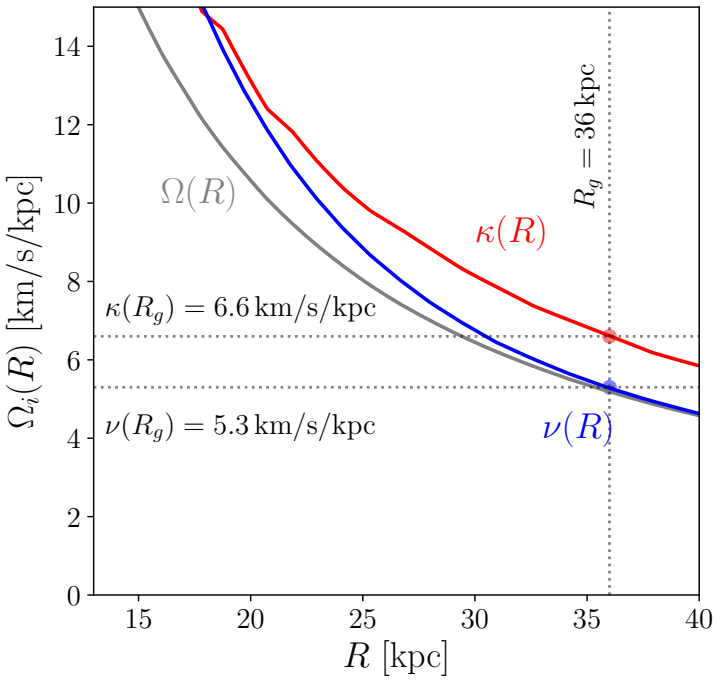
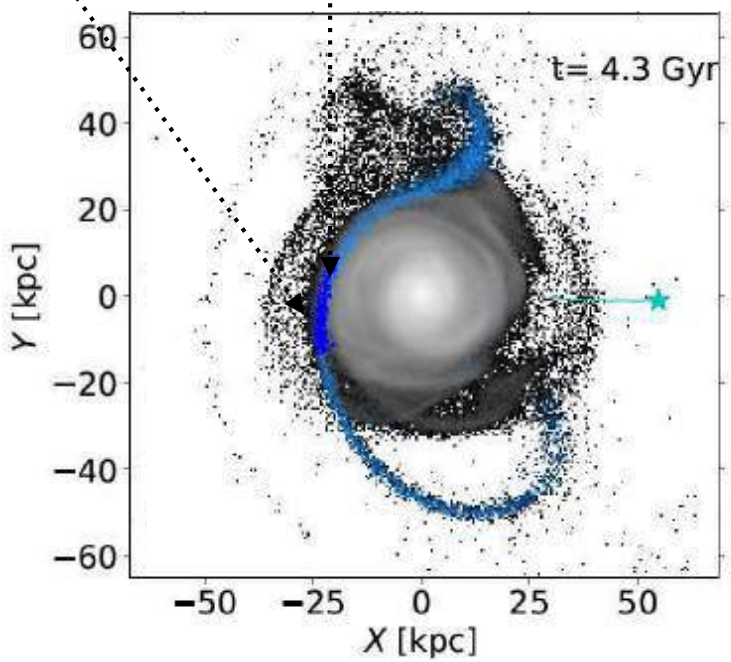
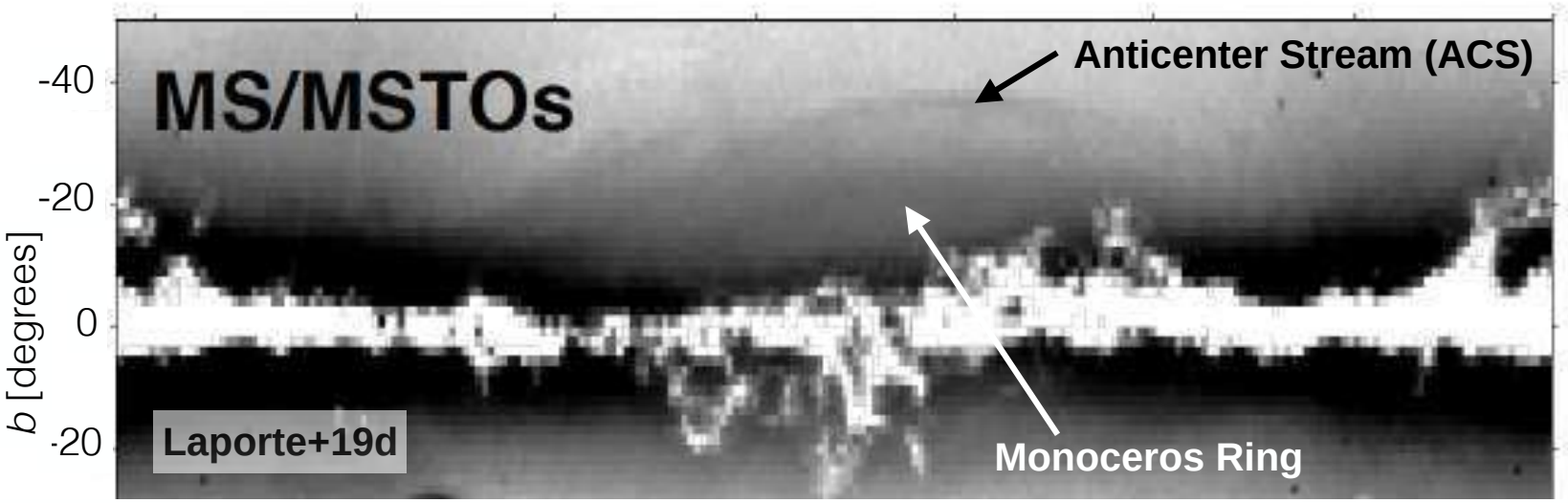


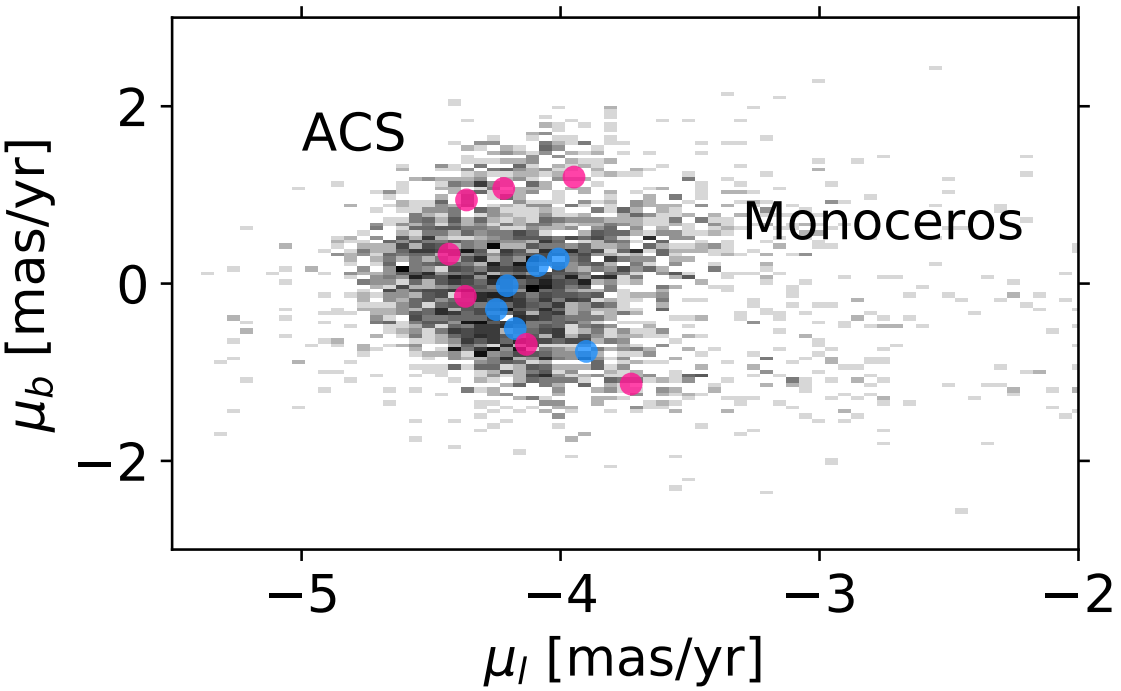




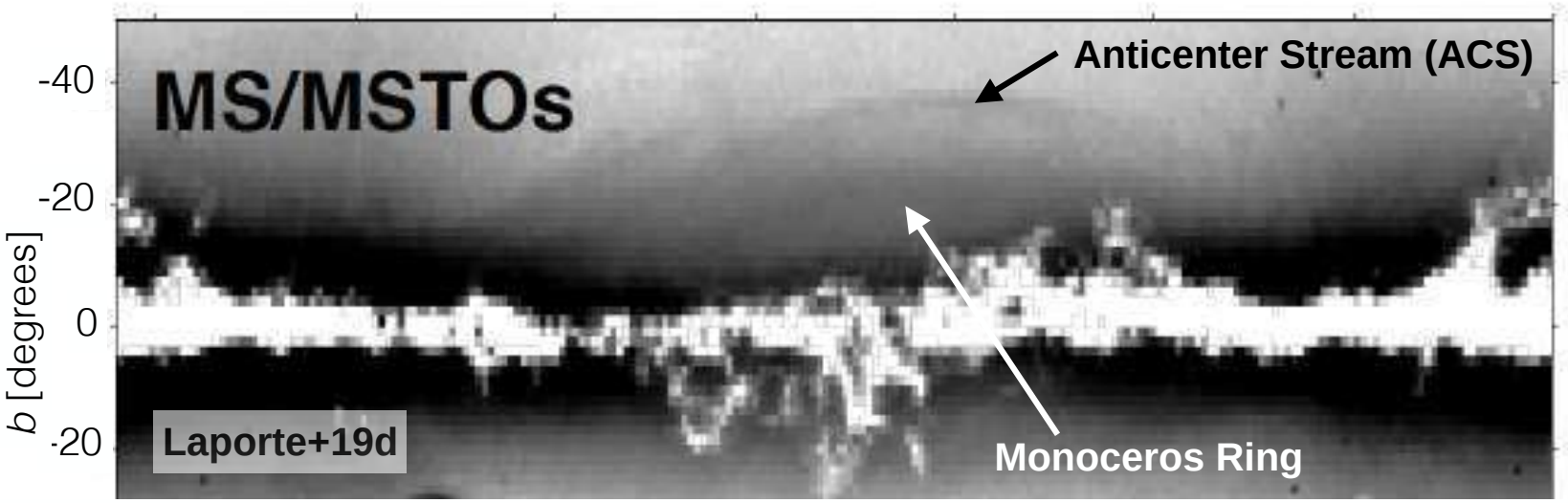
Does this interpretation hold in the MW?

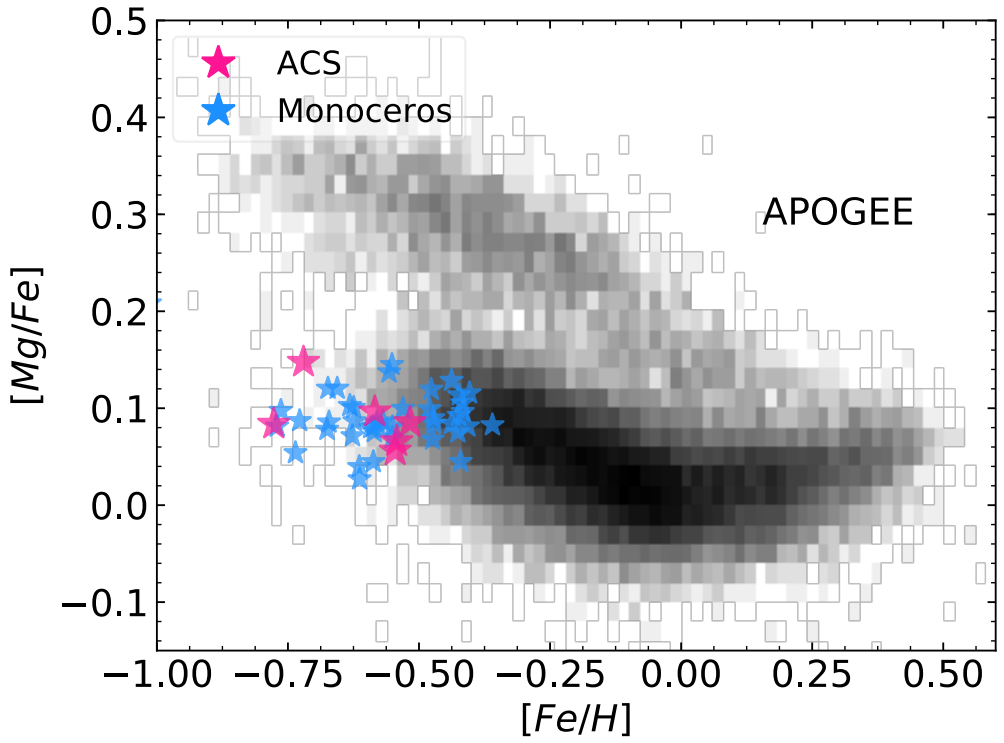
Confirmation of the disc nature of feathers kinematics



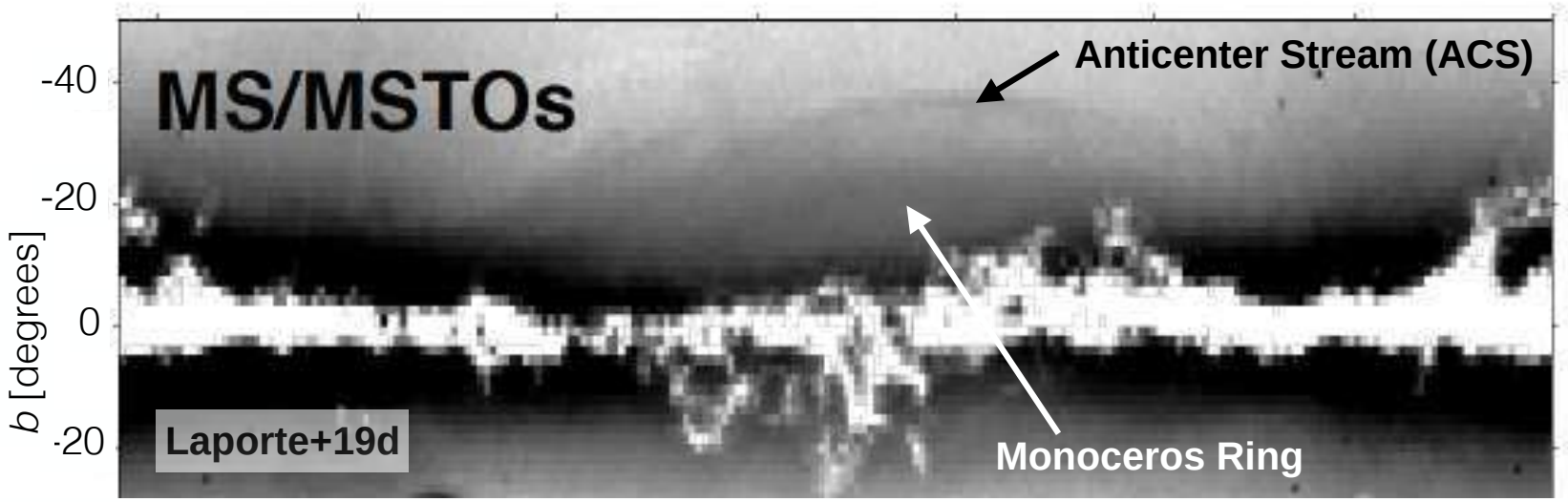


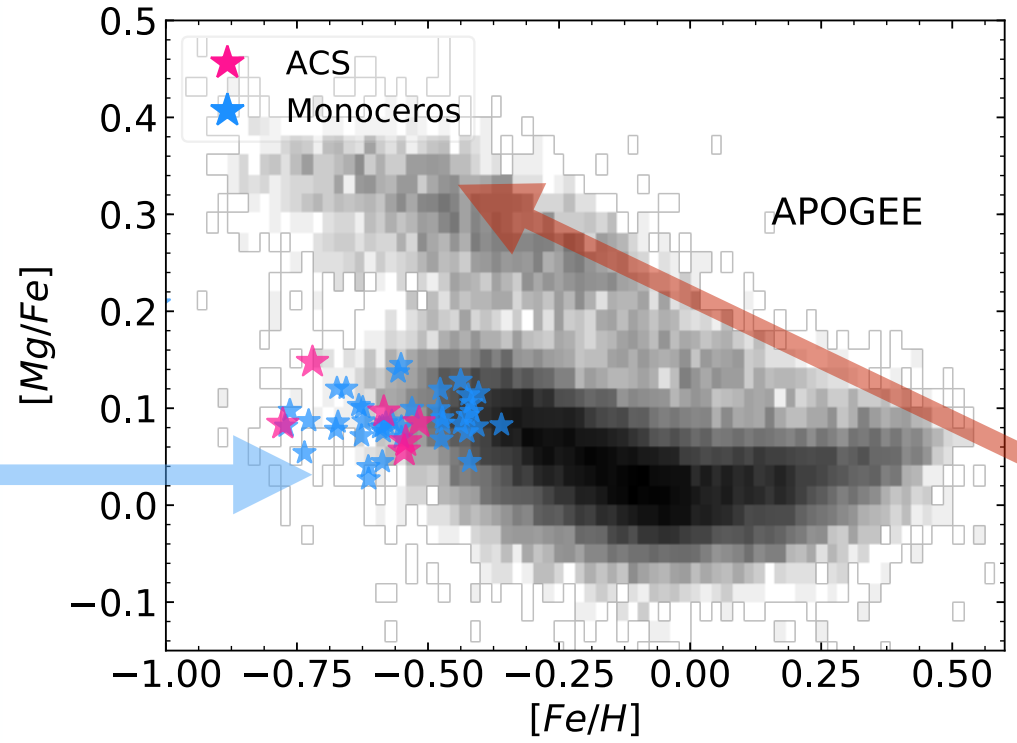
Confirmation of the disc nature of feathers chemistry





Confirmation of the disc nature of feathers chemistry

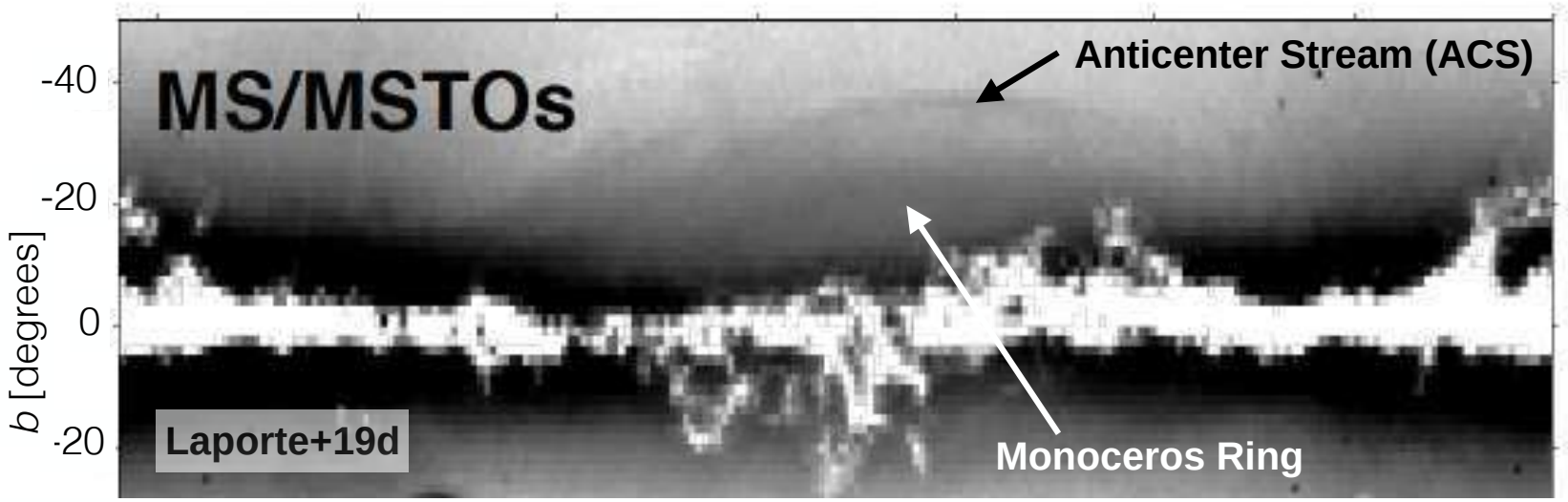


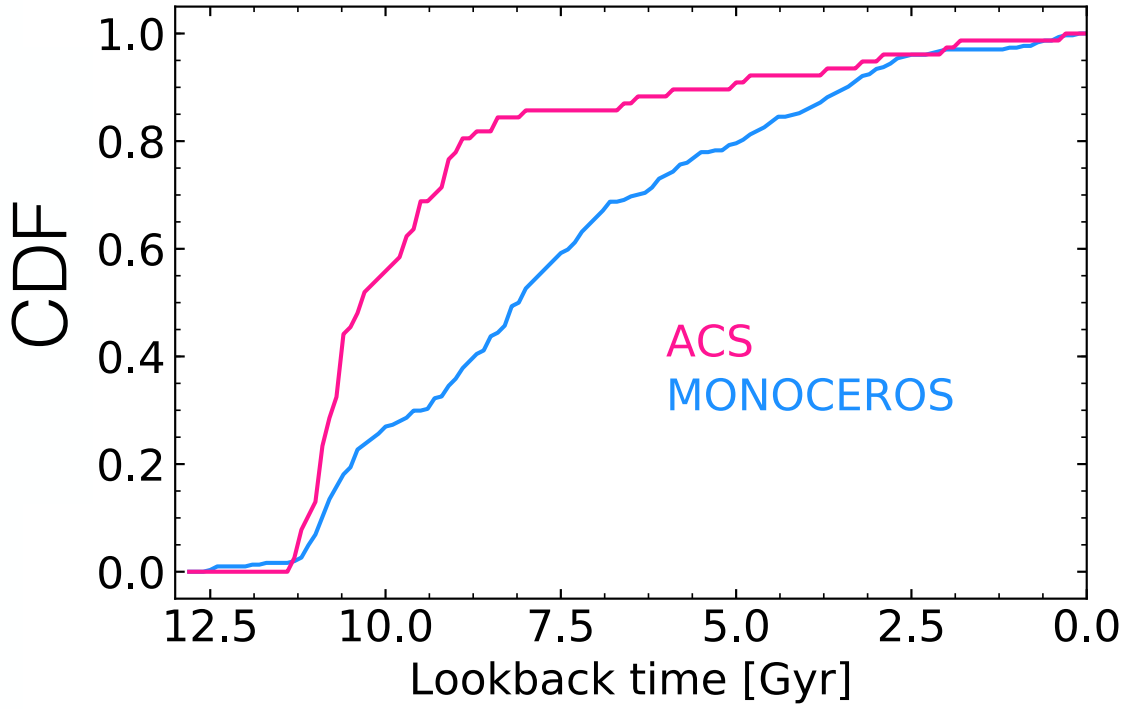


alpha-poor 'thin disc'

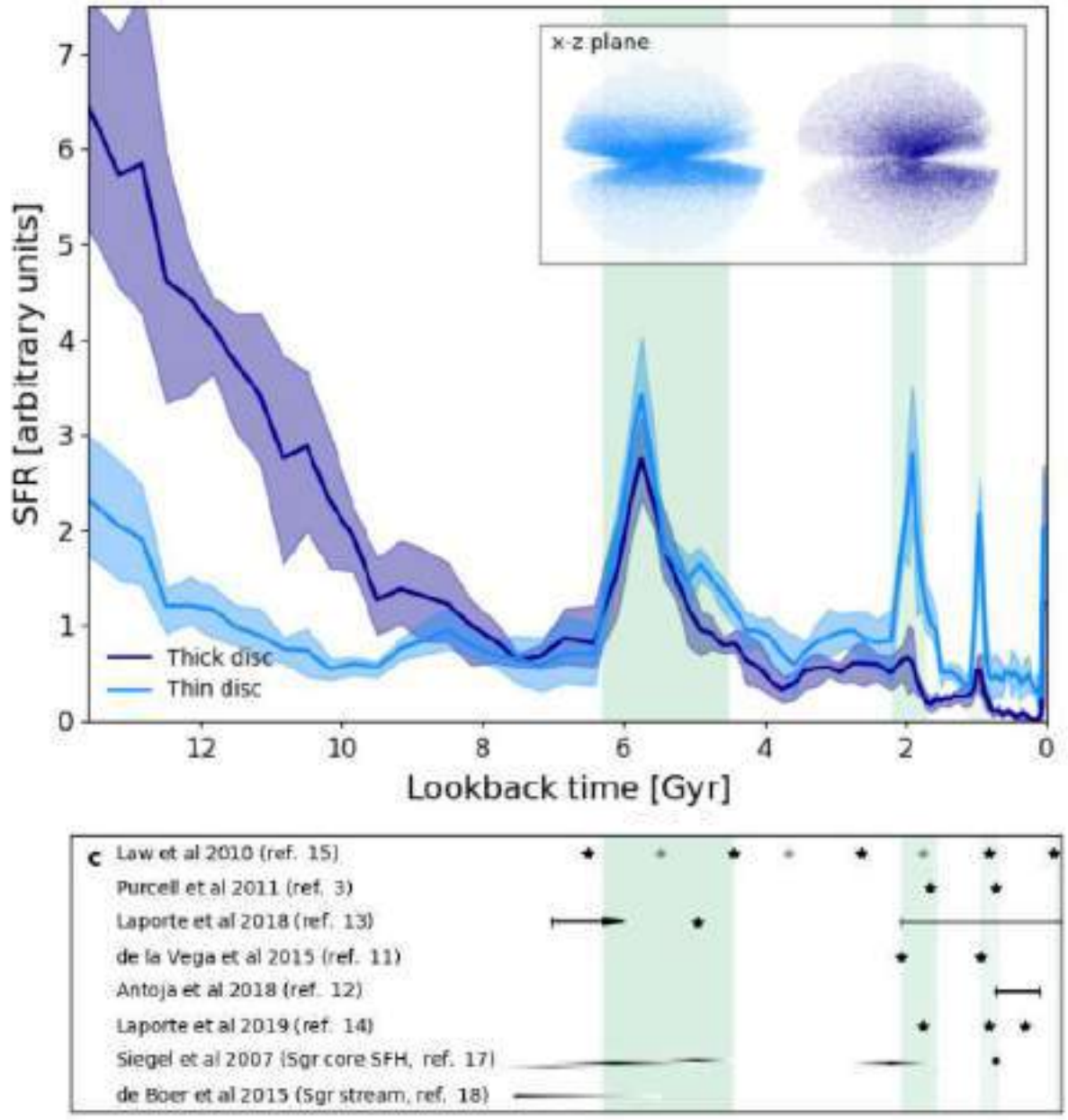
alpha-rich 'thick disc'

Confirmation of the disc nature of feathers ages distributions





Using the disc to constrain the orbital mass loss history of Sgr

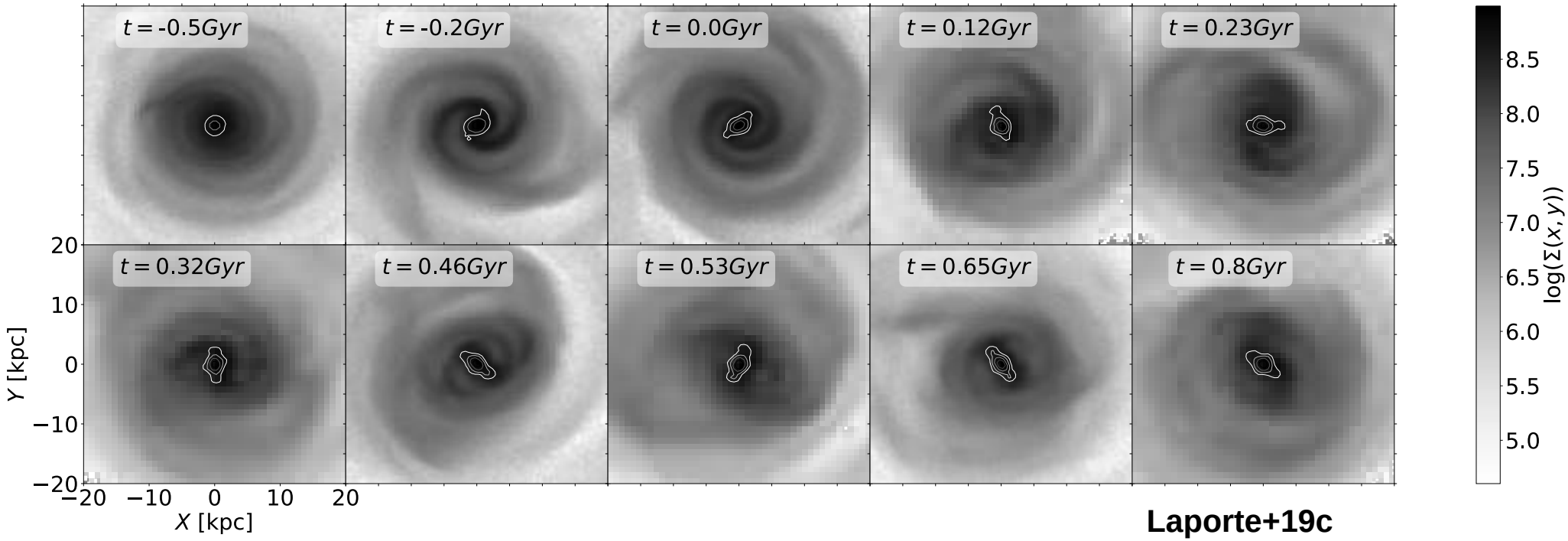


Lara-Ruiz et al. 2020

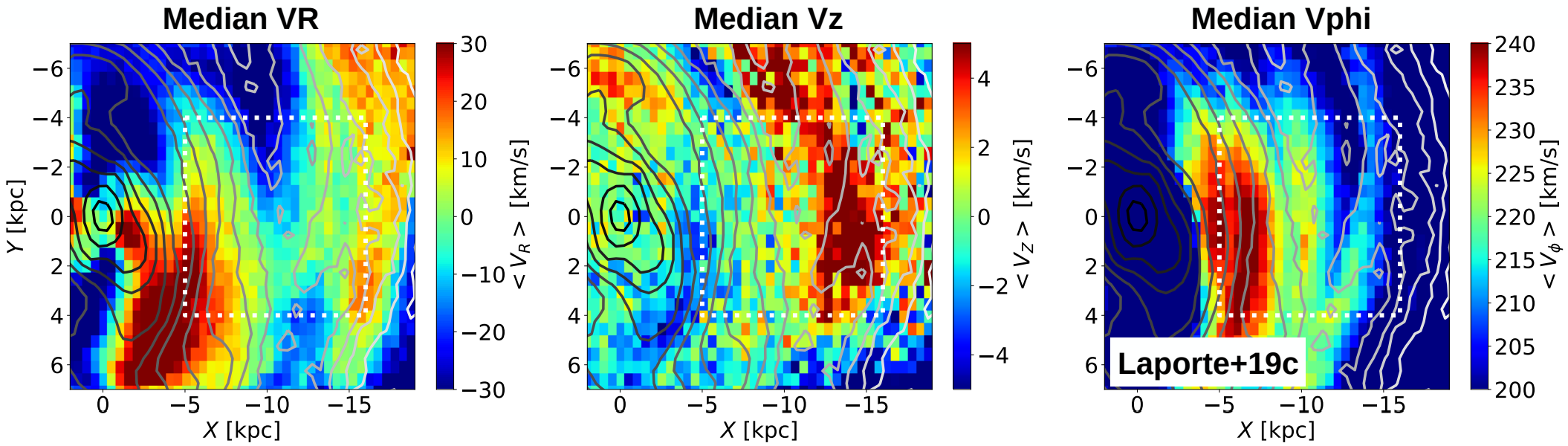
Pre-Gaia DR2 models in light of the Gaia DR2 era

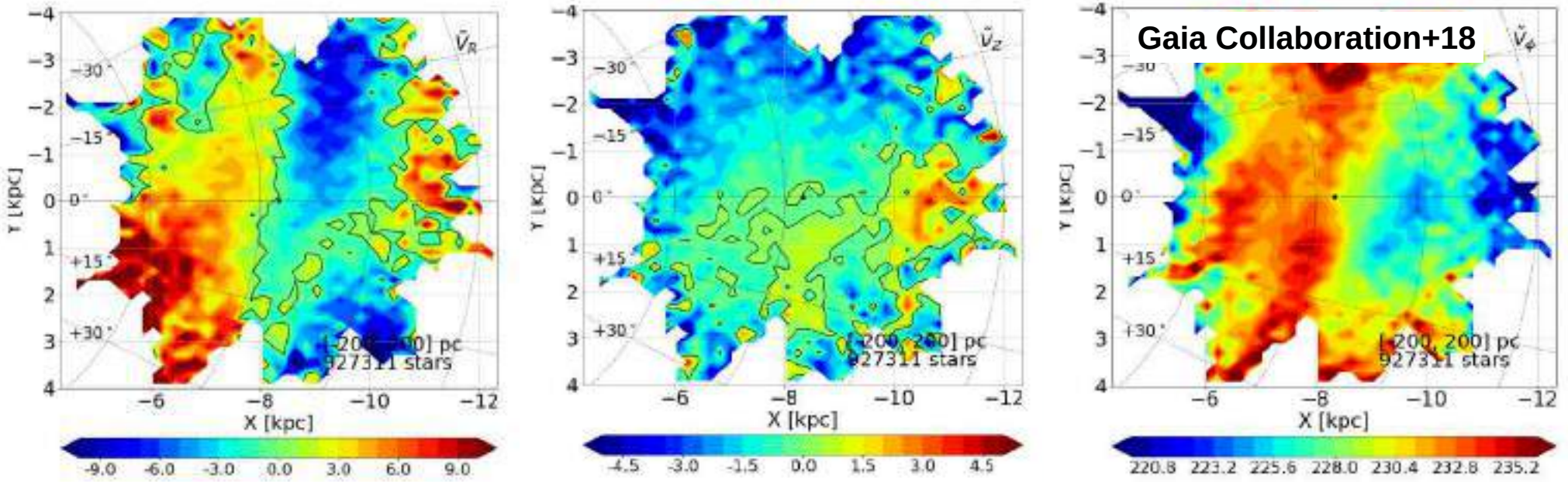
The non-axisymmetric & non-steady state Galaxy

Evolution of Galactic disc during very last stages of Sgr's orbit

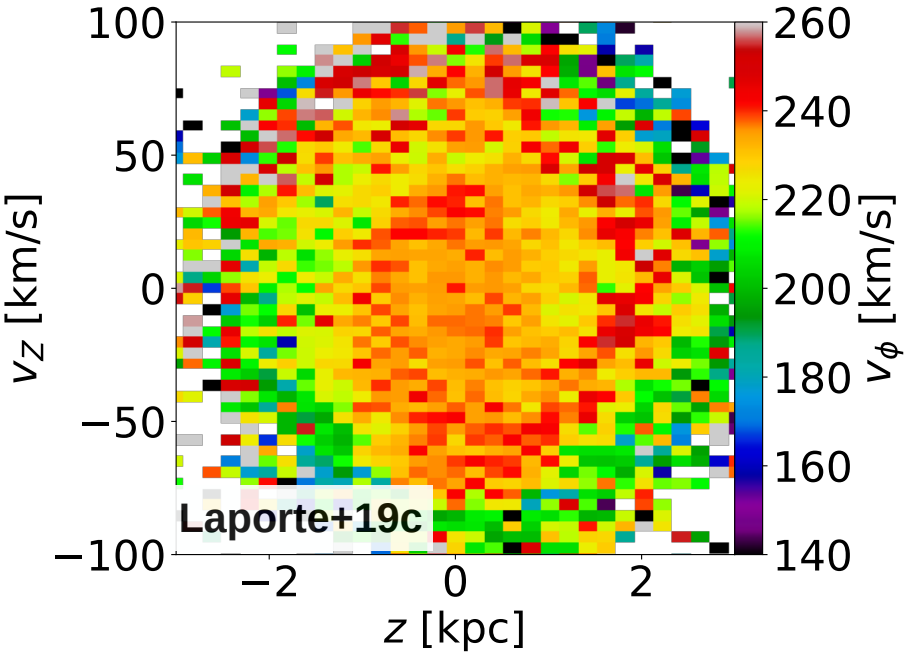


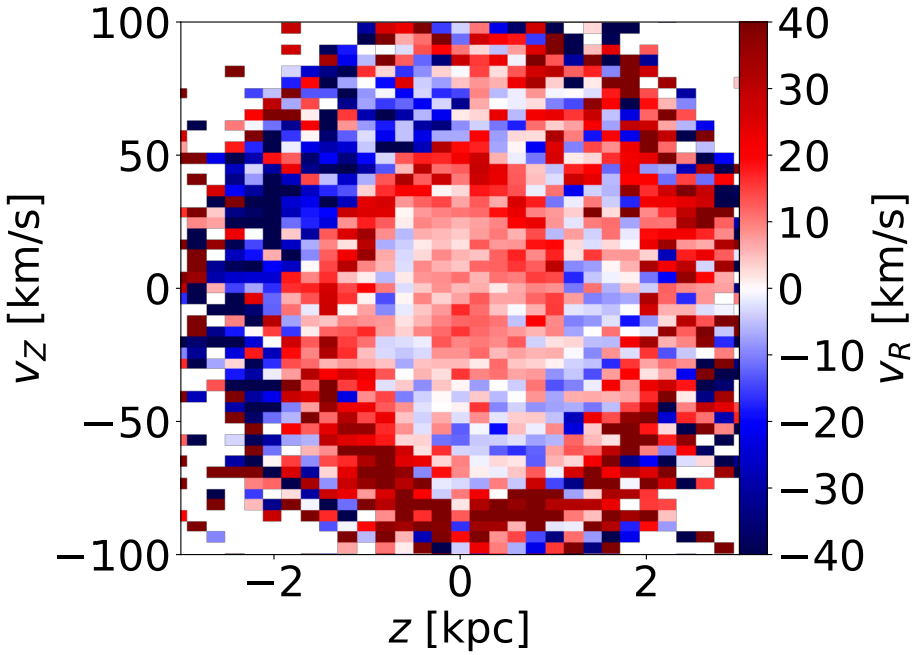
Simulated velocity fields

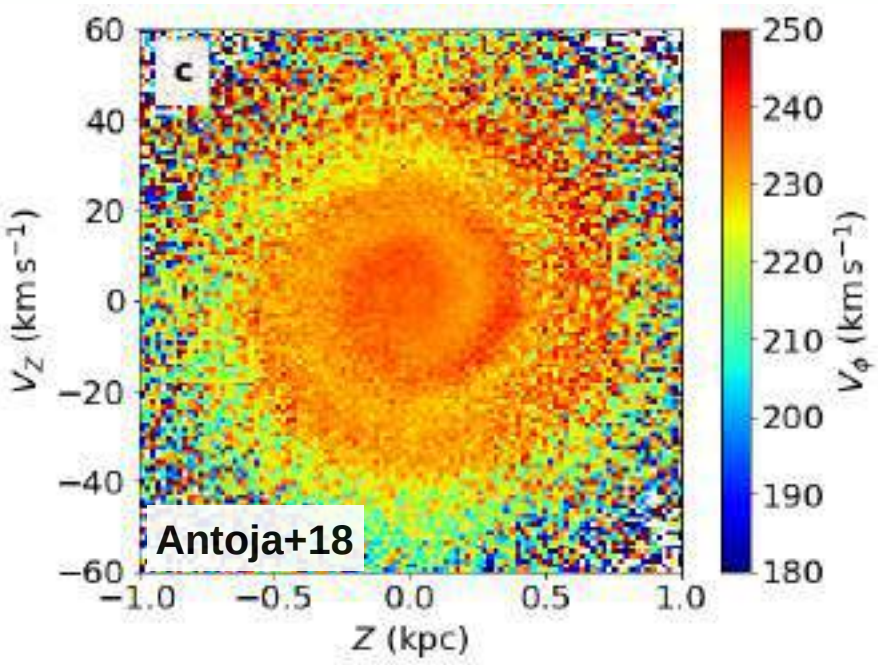


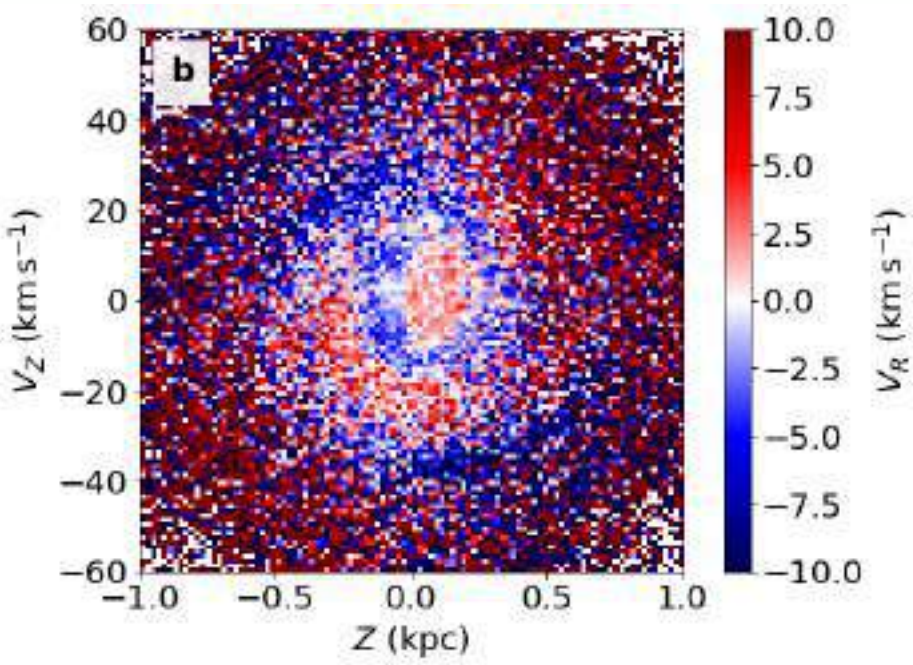


Local effect of Sgr in the Solar Neighbourhood



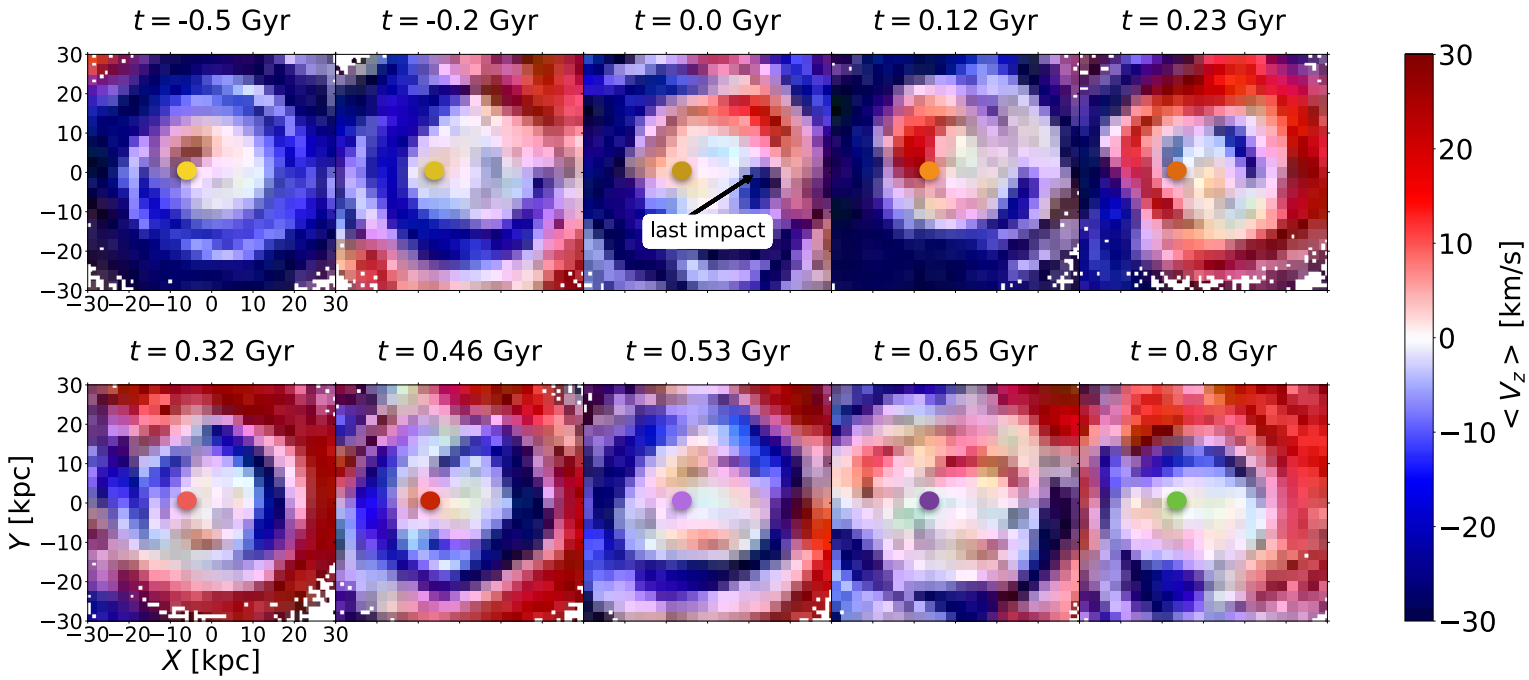




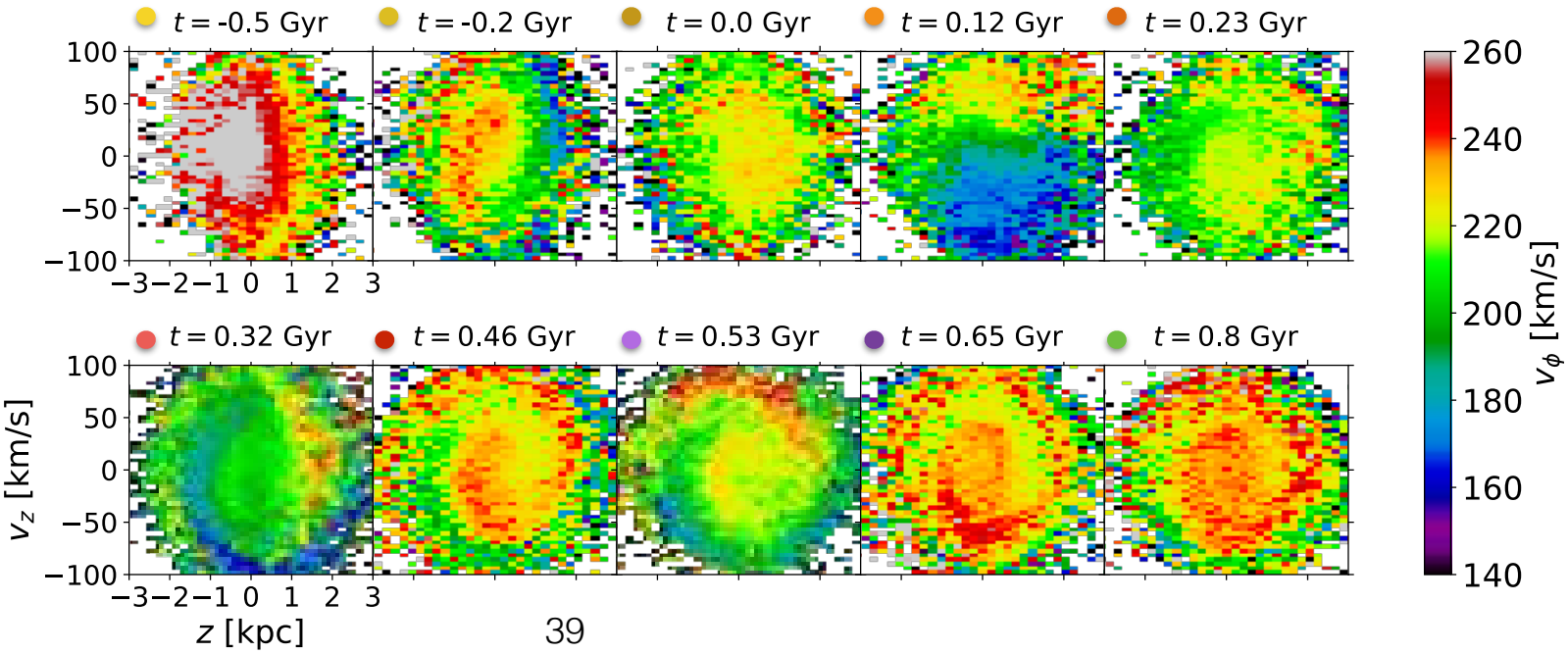


Disc response during last stages of Sgr's orbit

Global

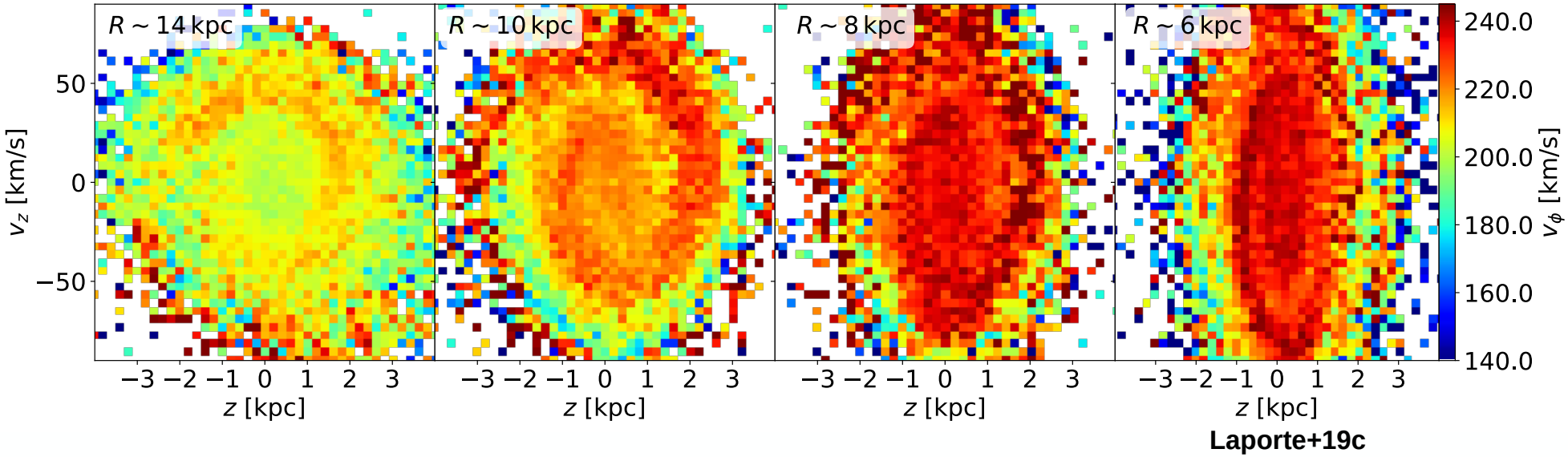


Solar Neighbourhood



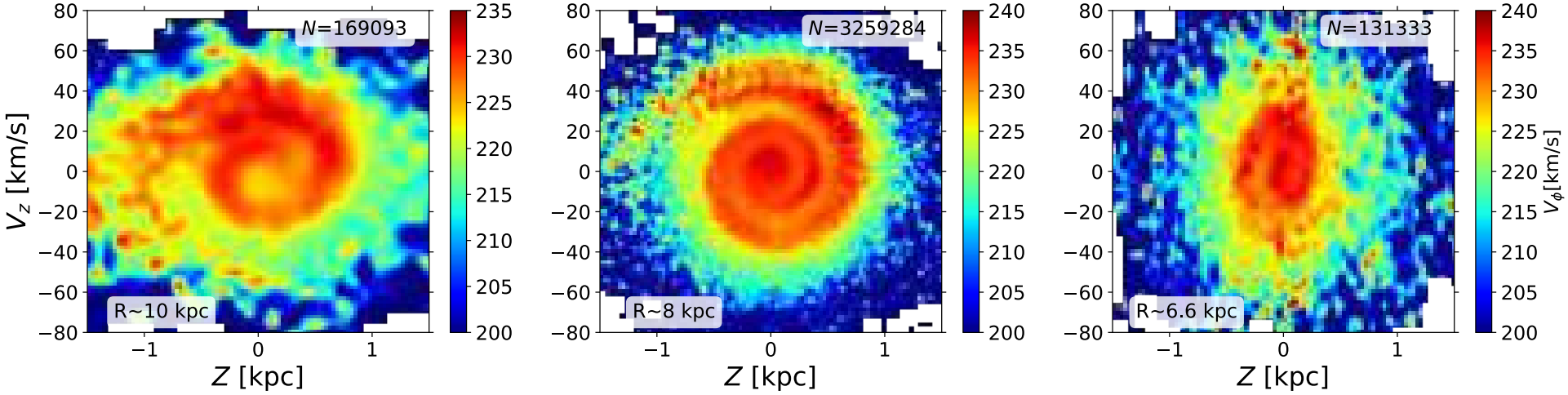
phase-space spiral behaviour in a **Galactic** potential perturbed by a recent satellite encounter

pre-Gaia DR2 N-body simulations



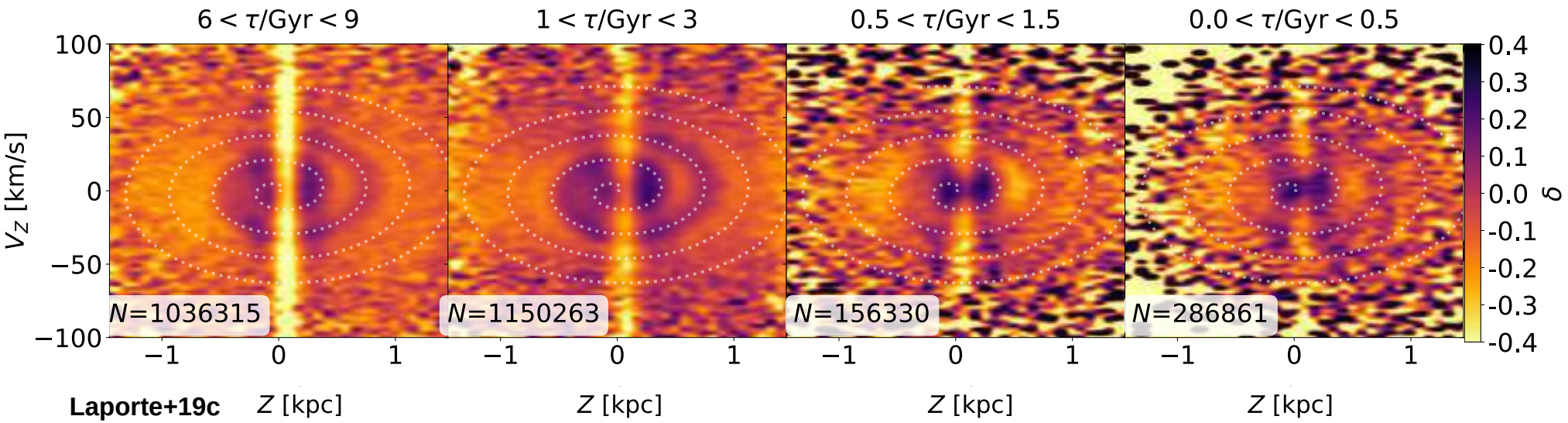
Laporte+19c

Gaia DR2 observations



Laporte+19c

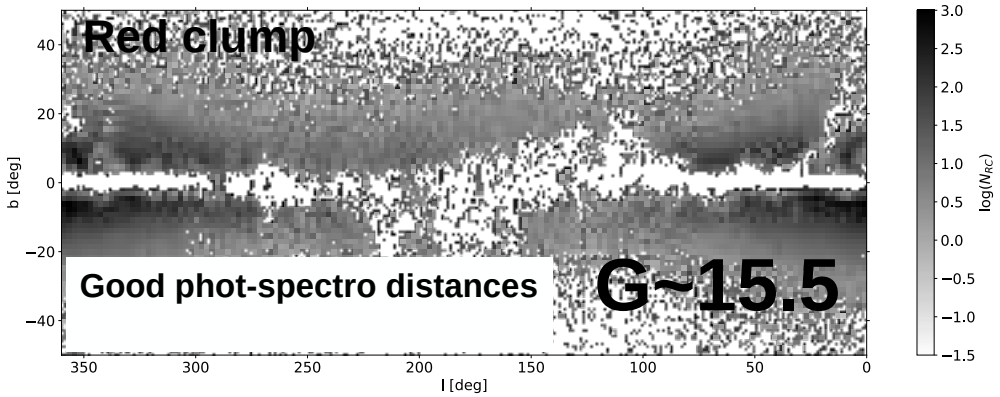
Timing the event with (isochrone*) ages

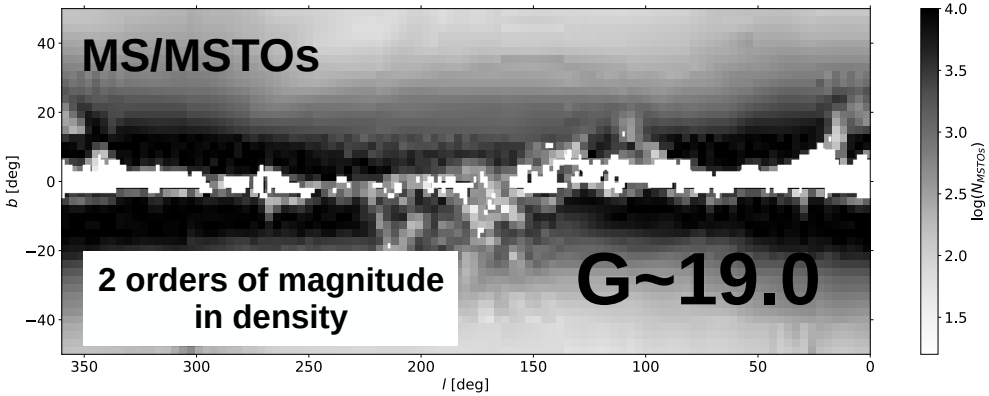


Decomposed by age young or old, all spirals have the same shape -> consistent with t_onset~1.0-0.5 Gyr and t_orb~0.7-1Gyr

Rules out bar excitation model (e.g. Khoperskov+19)

Probing ***prior and most recent perturbation events*** **constraining the orbital mass loss of Sgr**

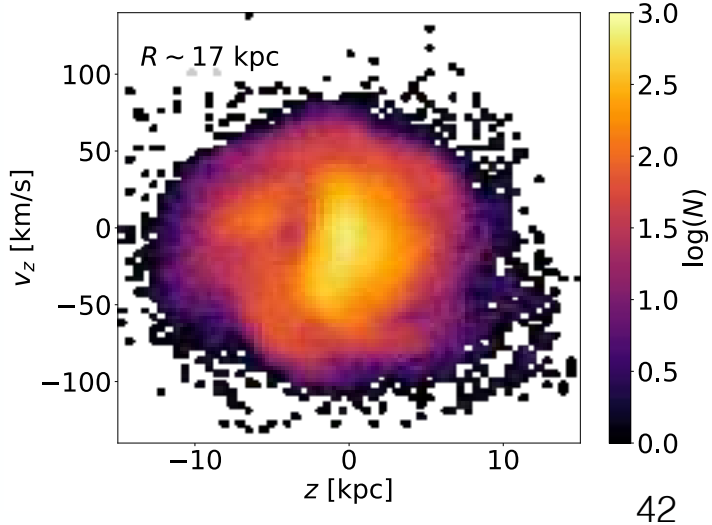


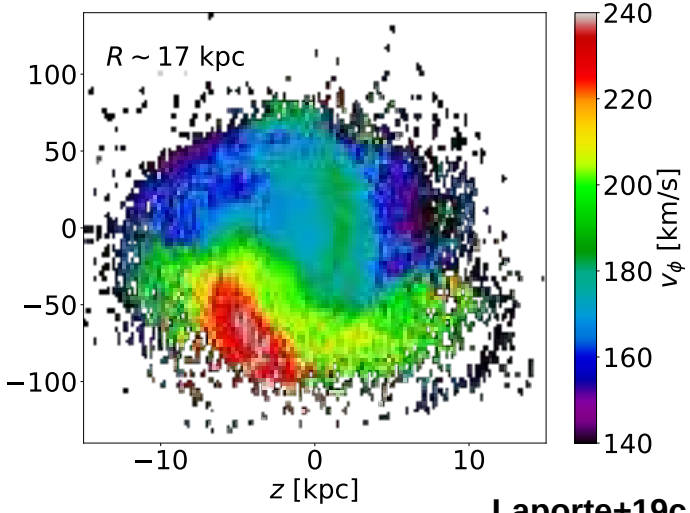


Gaia DR2

Laporte+19d

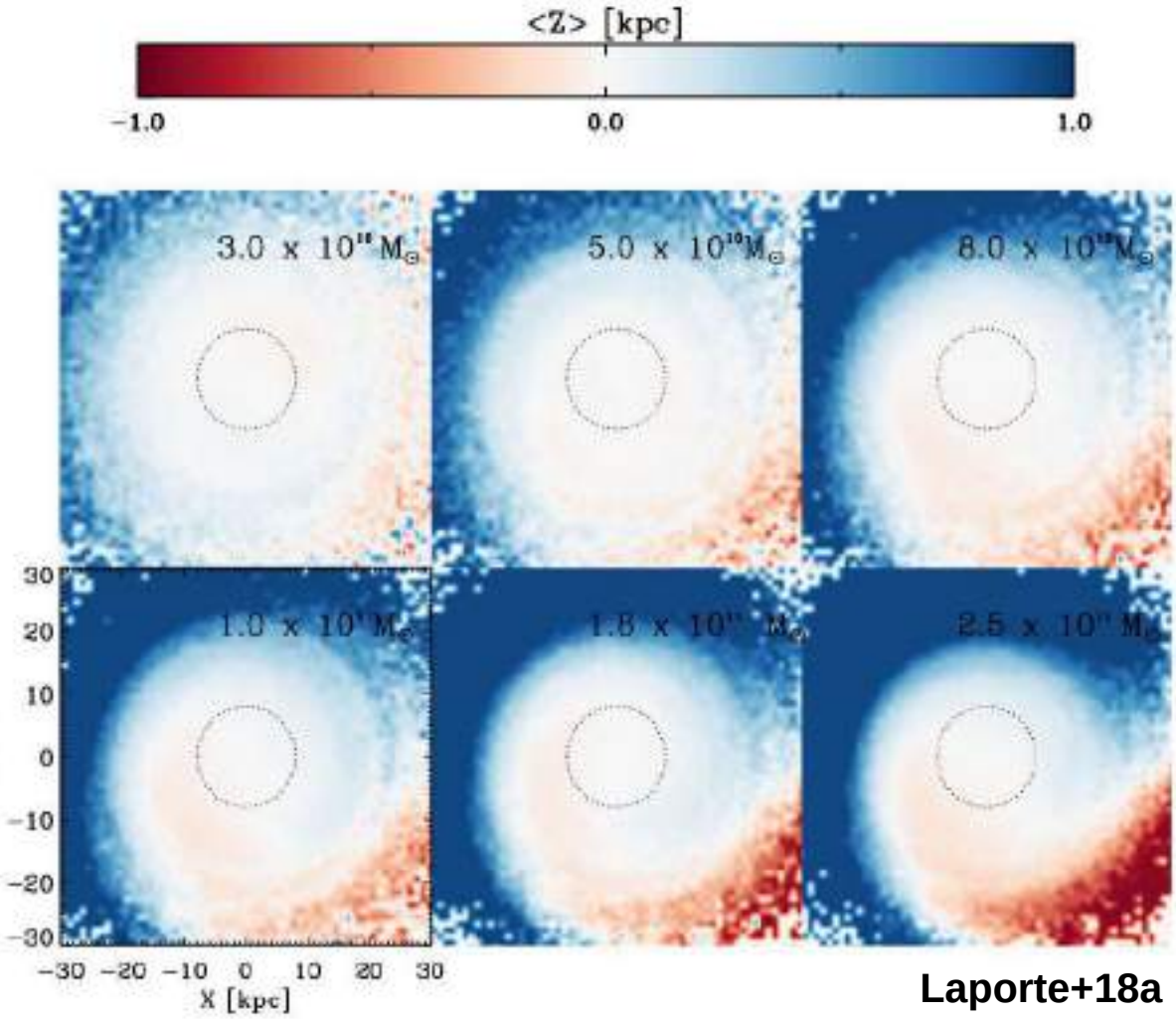
N-body simulations





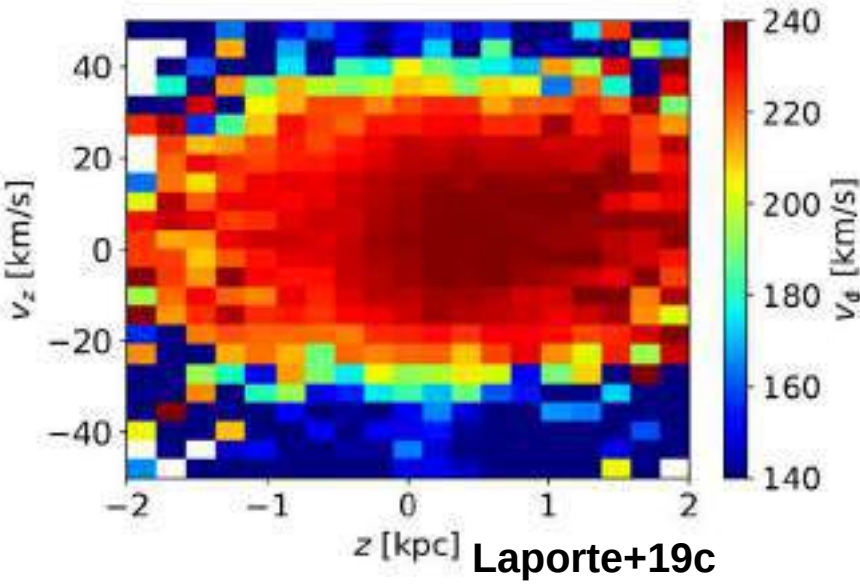
Laporte+19c

But what about the LMC?



Laporte+18a

LMC warps the disc

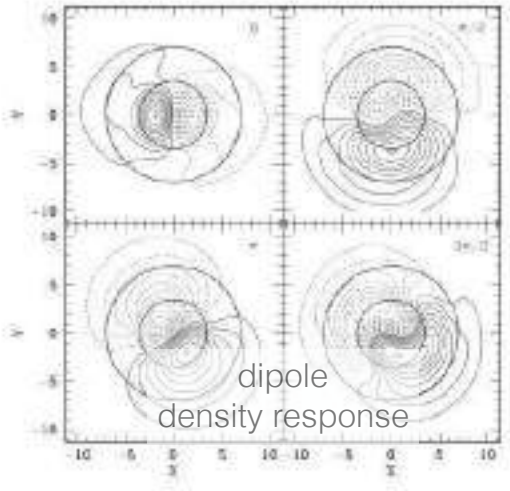


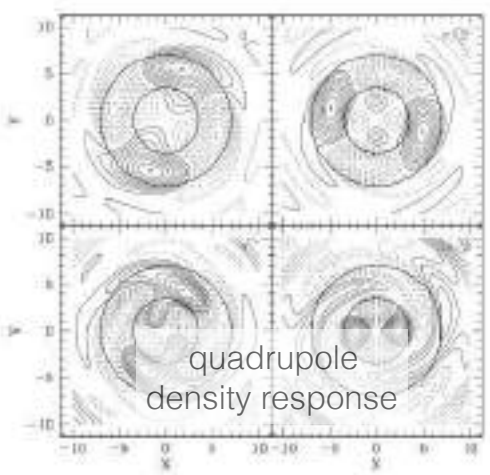
Laporte+19c

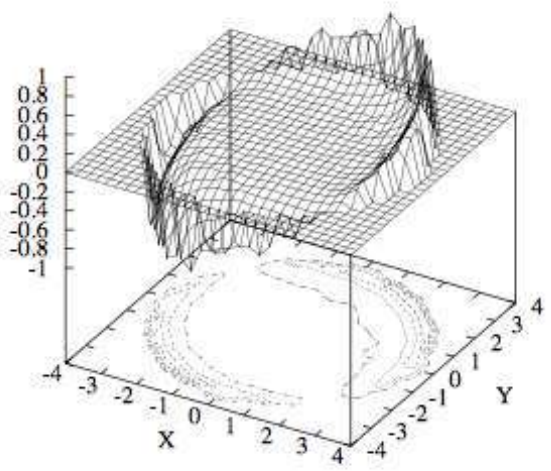
Not enough time to form (vz,z) spiral

Dynamical friction and its effect on dark (and luminous) matter

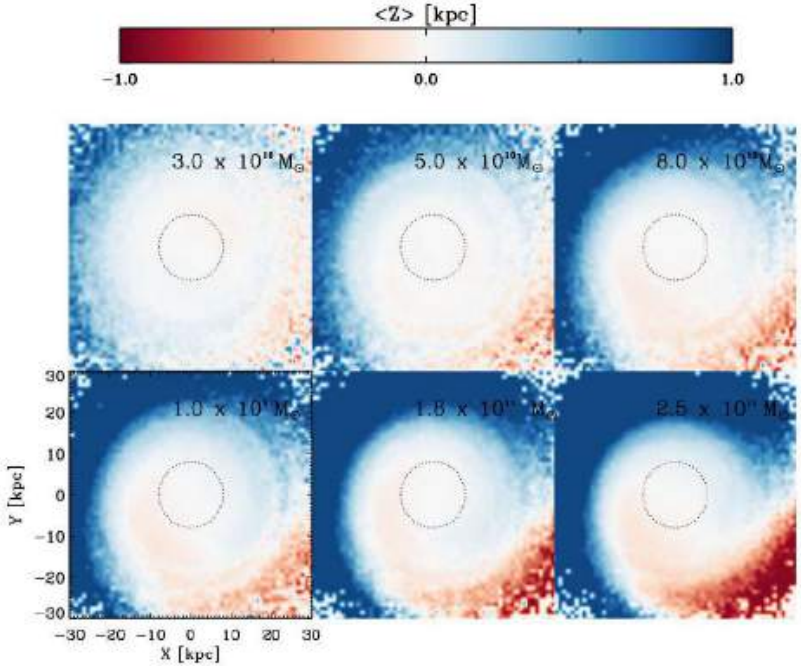
linear perturbation theory: Weinberg 1998 (see also Weinberg 1989)







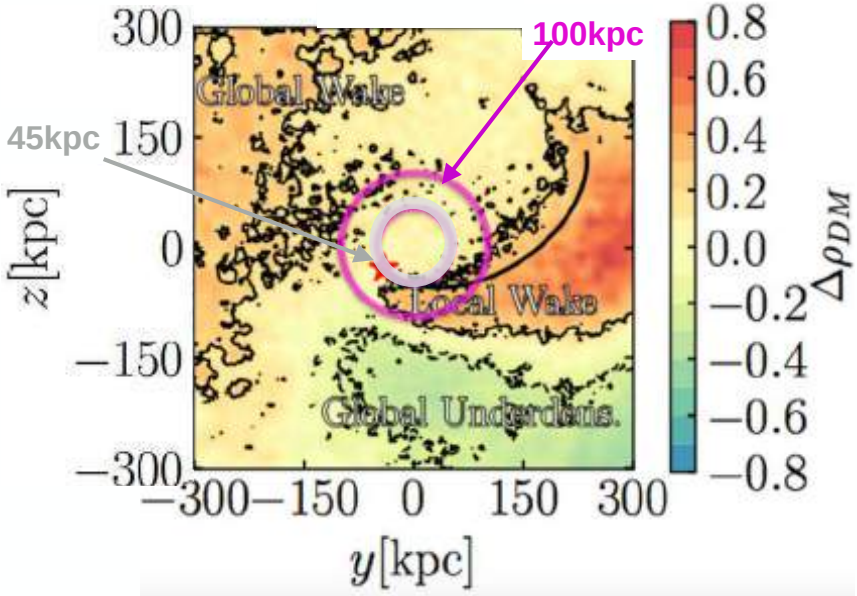
live N-body simulations of LMC on first infall orbit



Laporte et al. (2018a)

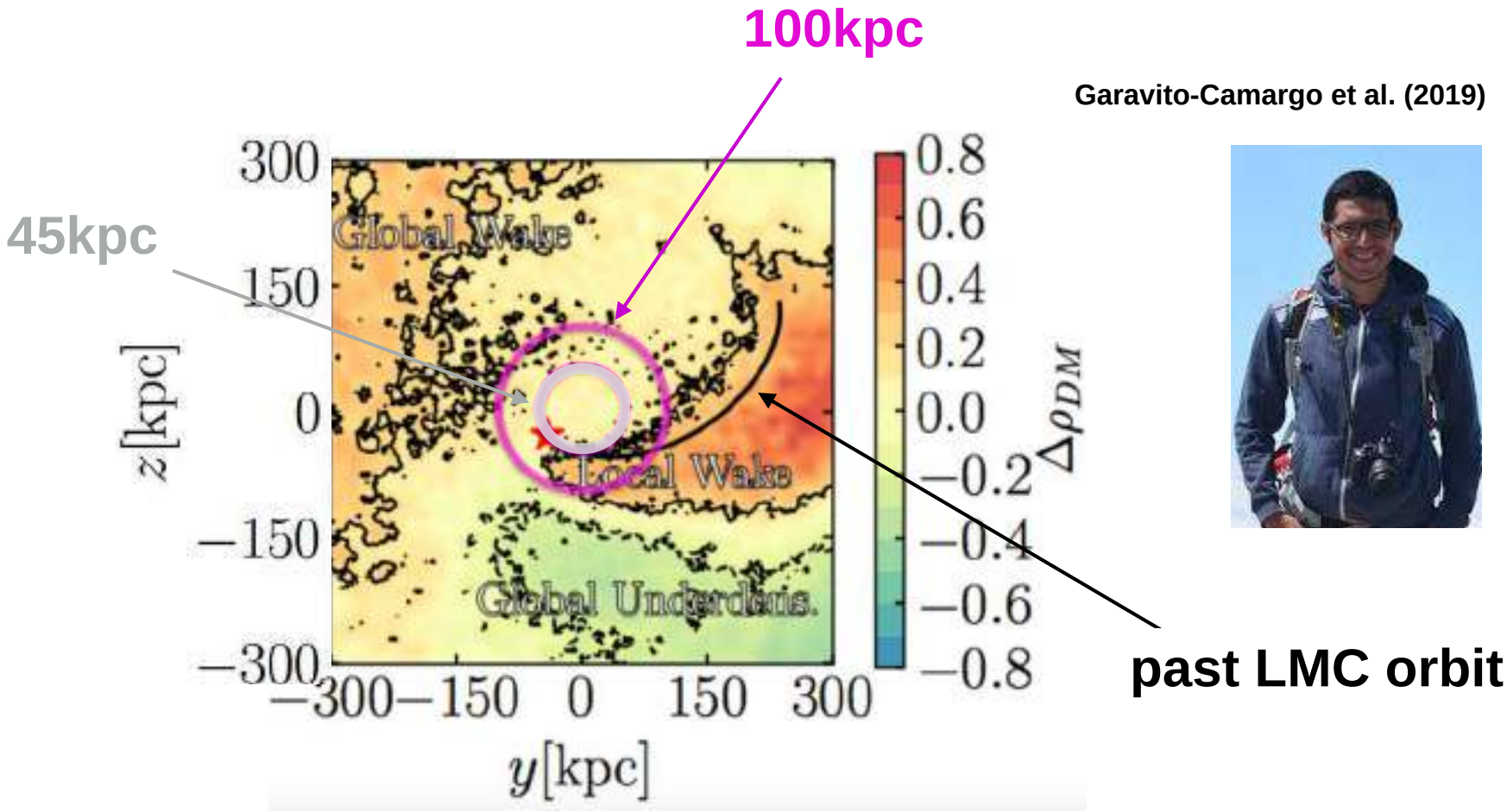
effect on disc

effect on DM halo -> **falsifiable prediction of collisionless/collisional DM** (and galaxy formation



Garavito-Camargo, Besla, CFPL, et al. (2019)

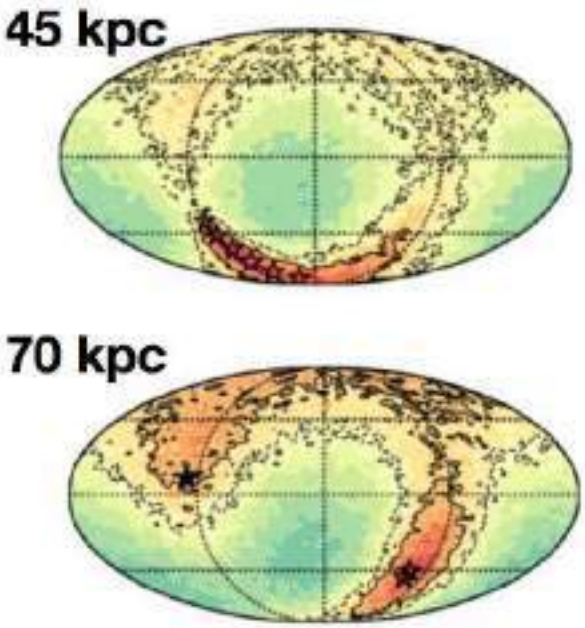
Dynamical friction and its effect on dark (and luminous) matter



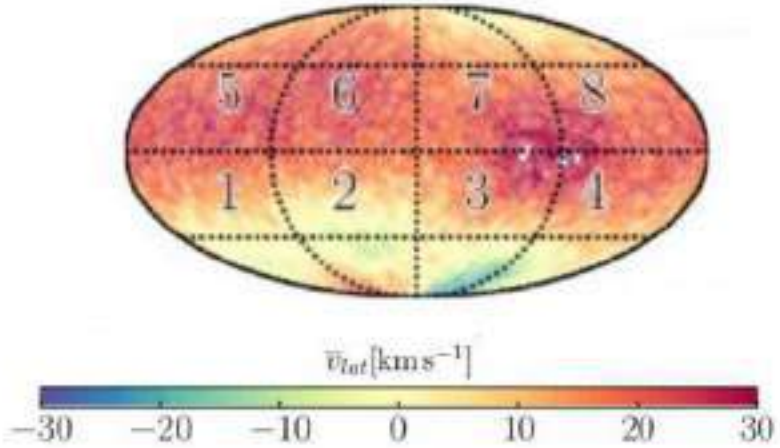
- The LMC creates a wake in the MW: **Local** (Chandrasekhar43) and a global one (Weinberg89,98) -> overdensity in stellar halo
- The LMC pulls the MW down -> upward motion relative to us

DM halo response translated onto the **stellar halo density** & **kinematics**

Wake behind LMC



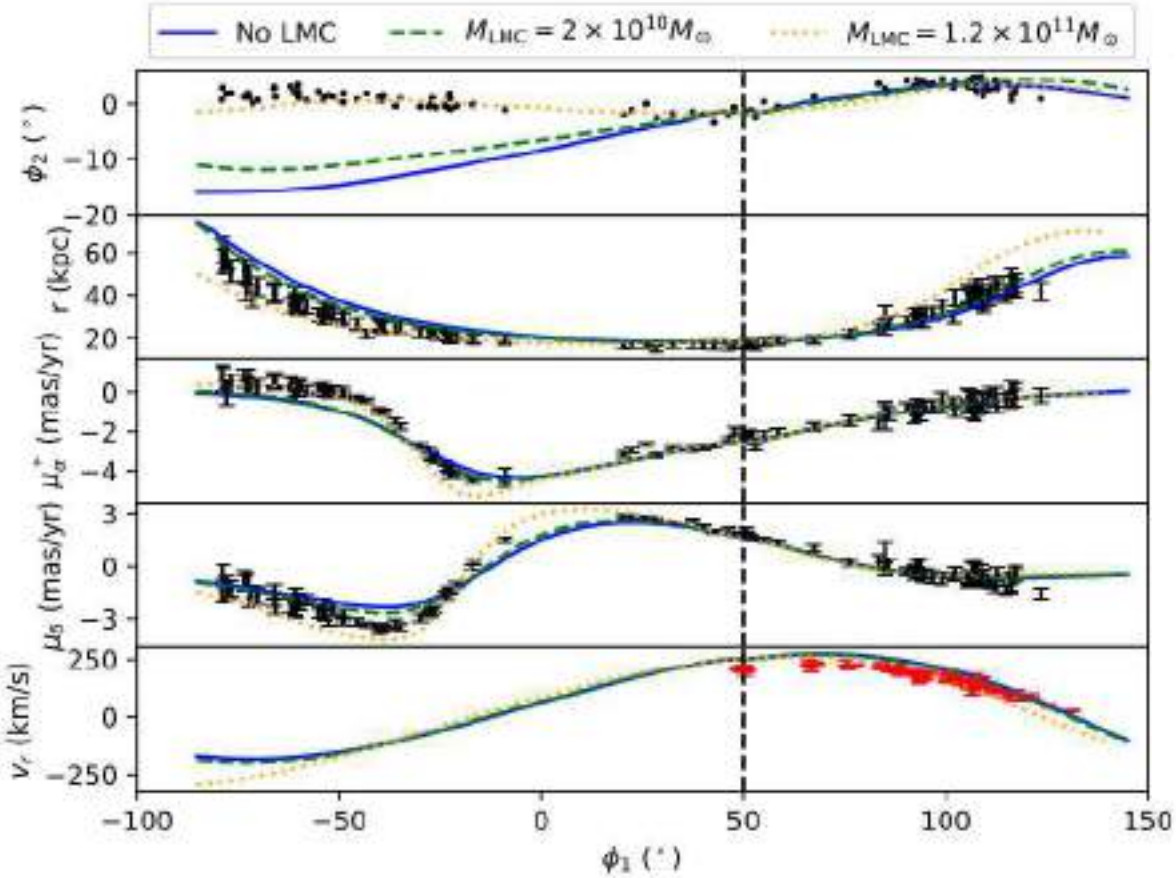
Predicted upward motion of stellar halo

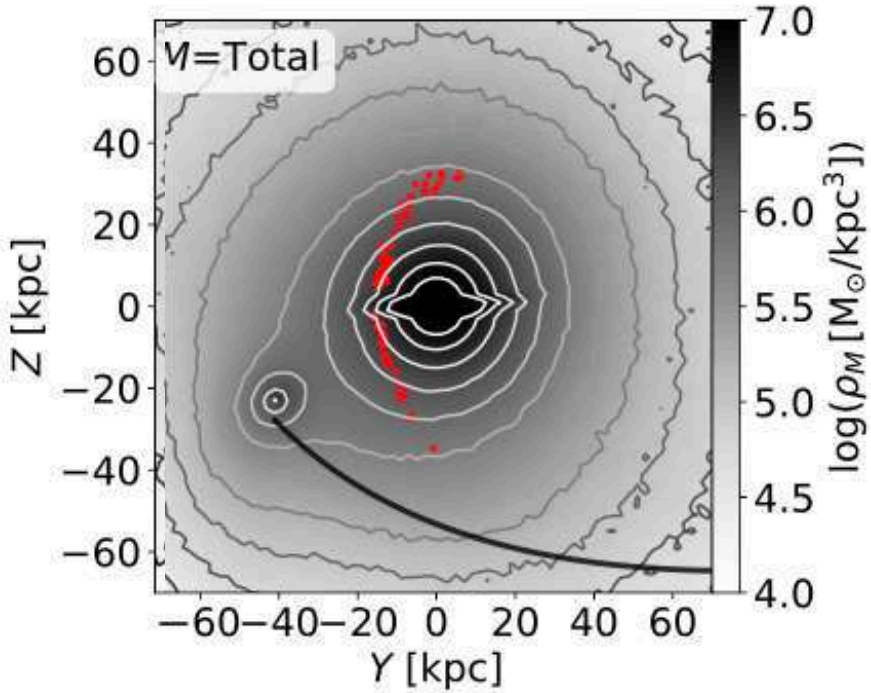


Garavito-Camargo, Besla, CFPL, et al. (2019)

see also Gomez+15, Peterson+20, Erkal+20 for barycenter motion induced by LMC infall

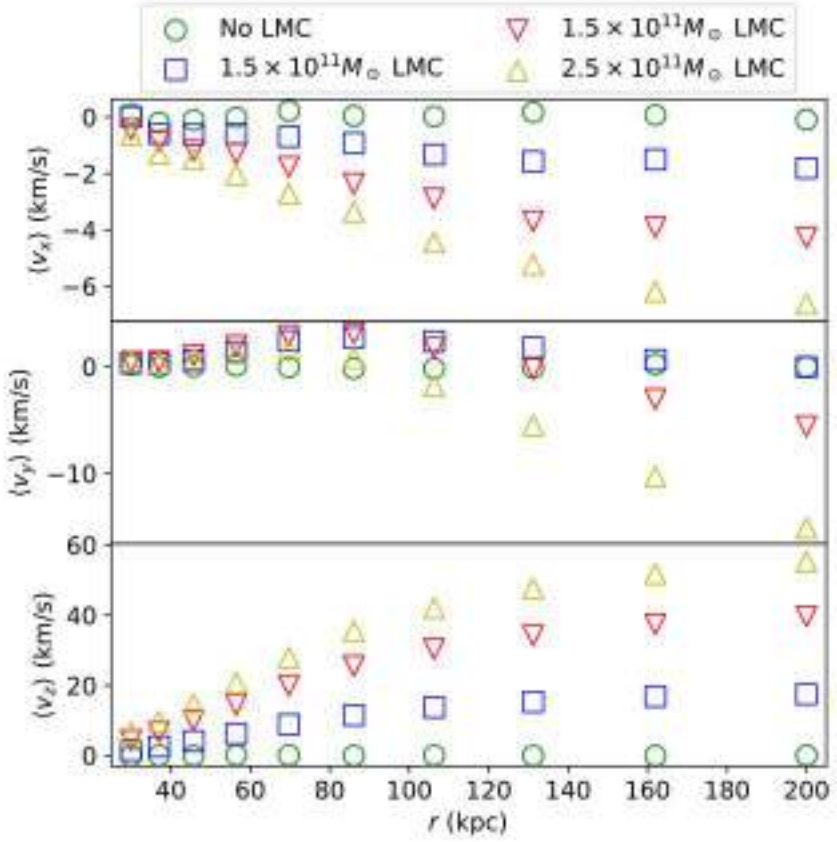
LMC tides also affects streams like Orphan



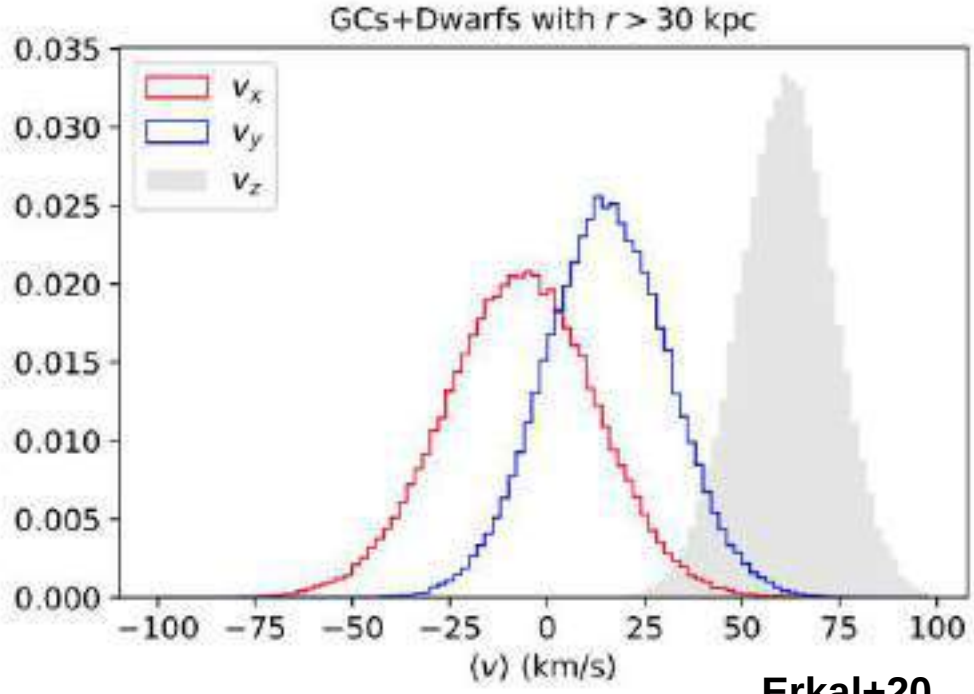


Erkal, Belokurov, Laporte+19

Implication for kinematics of satellites >30 kpc



Erkal+20

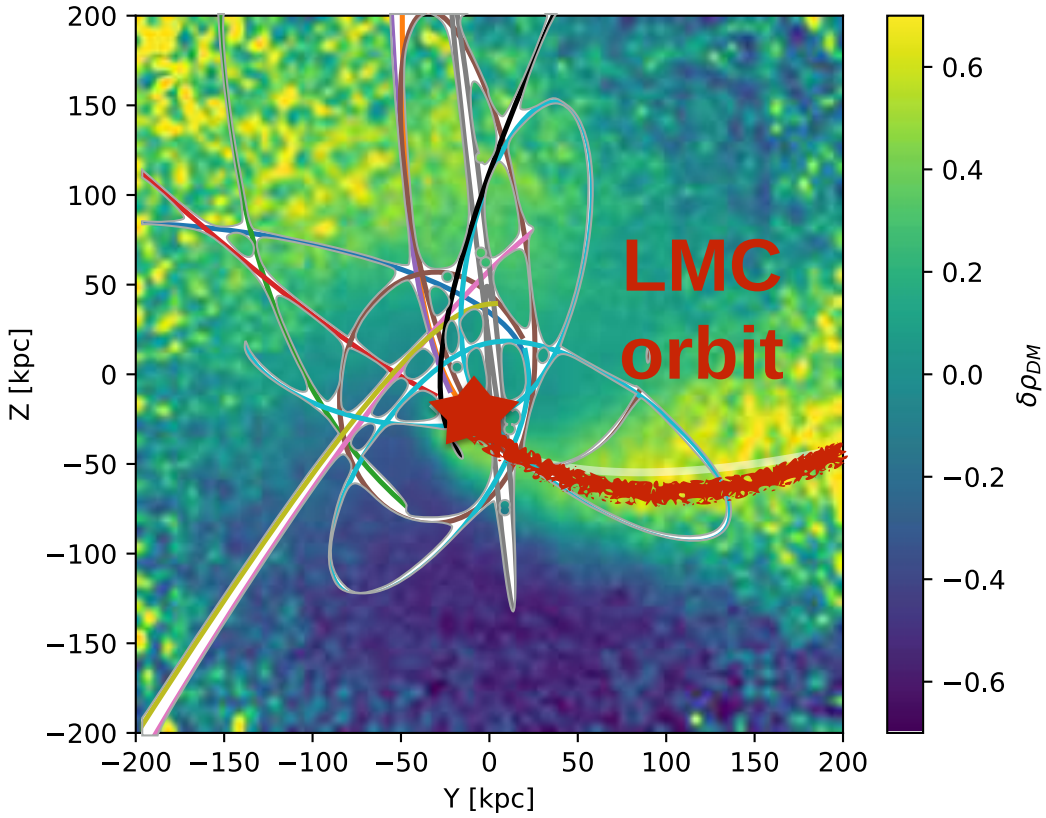


Erkal+20

-> biases mass measurements high (~50%) and shape measurements

Implications for ignoring the effect of the LMC affects

- Inferred orbits of satellites
- Mass (>30 kpc)
- Shape measurements



adapted from Laporte+18a & Simon18

Conclusions

- Sagittarius as a prime architect of the MW: **local perturbations** and **global perturbations** of the disc
- Many accreted structures turn out to be just kicked stars from past interactions with Sgr (Laporte+18b)
- Sgr affects the dynamics but also star formation history of the Galaxy (Laporte+20, Lara-Ruiz+20)
- LMC major recent perturber of the **DM halo**, **stellar halo** and **outer disc** (warp): affects streams, satellites, GCs, tracers - cannot be ignored anymore (Laporte+18a, Garavito-Camargo+19).
- Distortions produced in MW DM halo are a central falsifiable prediction of all DM models, can be mapped with future facilities. Some signs of detection already exist (Belokurov+19).
- Understanding the data from Gaia needs development of **detailed models of the MW in its local environment** (past & present) to interpret and piece together its formation.
- For disc: Sgr is a strong driver of non-axisymmetries across the disc.
- For halo: Basis function expansion methods should prove useful to describe the contributions of the debris of the LMC, the LMC, the wake and the underlying MW halo (and its shape).