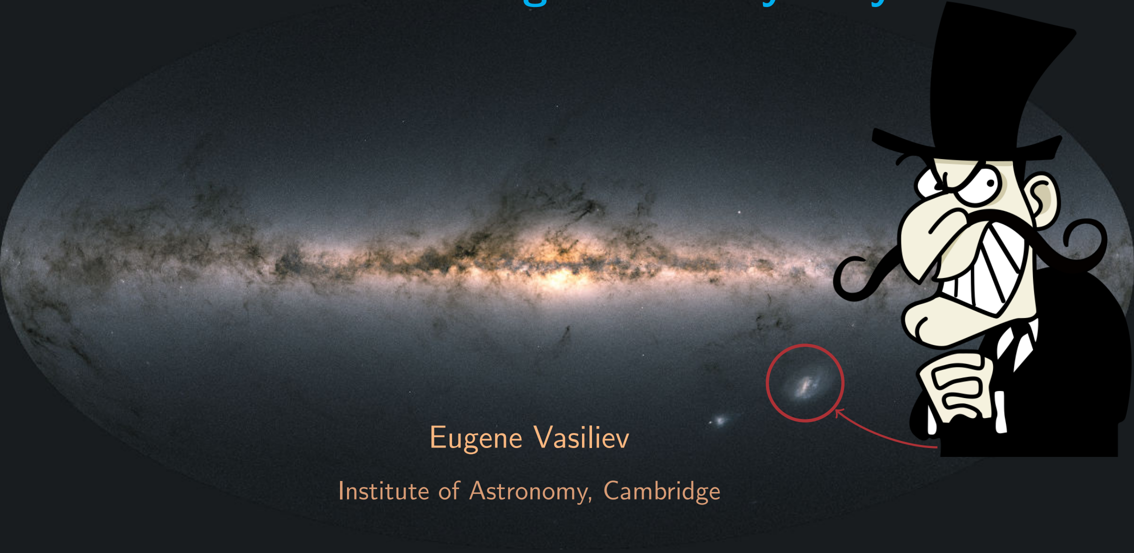
The unquiet neighbour: how the LMC bugs the Milky Way

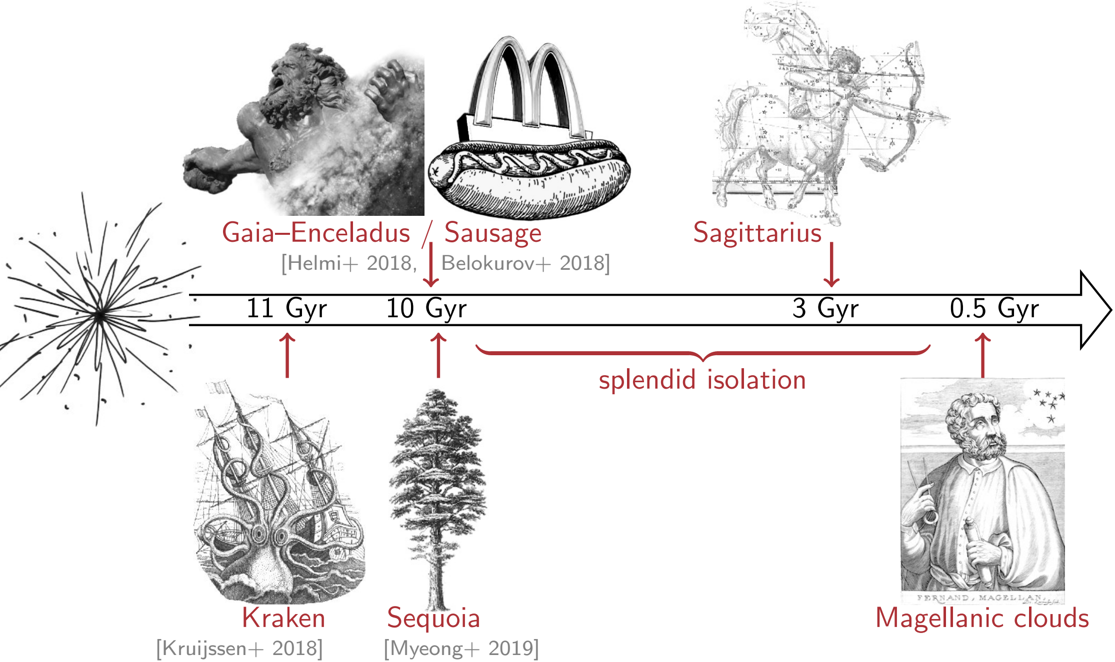


Eugene Vasiliev

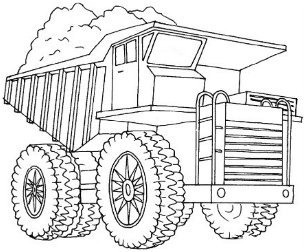
Institute of Astronomy, Cambridge

IoA wednesday seminar, 20 october 2021

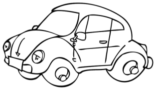
A brief history of the Milky Way



Rendez-vous with the LMC



MW mass: $\sim 10^{12}\,M_\odot$;



LMC mass: $(1-2)\times 10^{11}\,M_\odot$

Dire consequences of the MW–LMC encounter:

0. LMC brings its own satellites, stars and clusters

1. LMC deflects stars and streams passing close to its trajectory

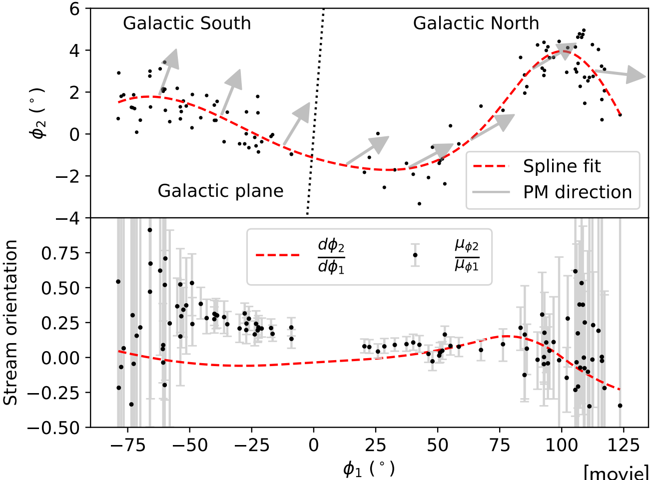
2. LMC creates a density wake in the MW halo

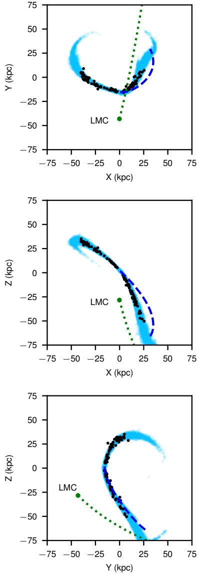
3. LMC displaces the Milky Way

4. LMC creates a dipole asymmetry in the outer MW halo

Local effects: deflection of stellar streams

Orphan–Chenab stream: no remnant, spans $> 200^\circ$ on the sky.
Sky-plane velocity (reflex-corrected PM) is misaligned with the stream track; stream can be fitted only when taking LMC into account.



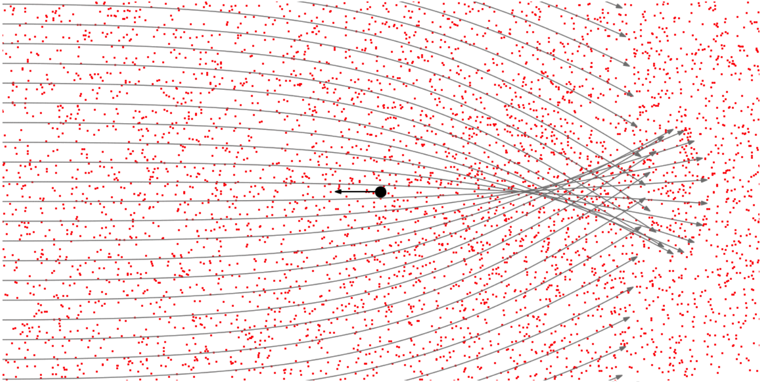


[movie] [silly movie]

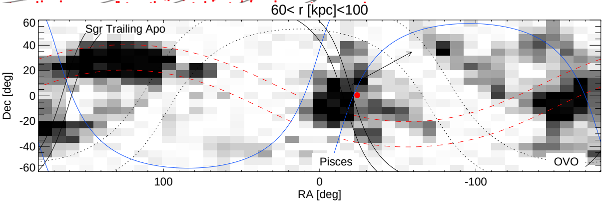
[Erkal+ 2019; see also Shipp+ 2021 for updated analysis with a few other streams]

Local effects: density wake and dynamical friction

deflection of incoming stars by the moving massive object creates an overdensity behind it, which in turn causes its deceleration [Chandrasekhar 1943]

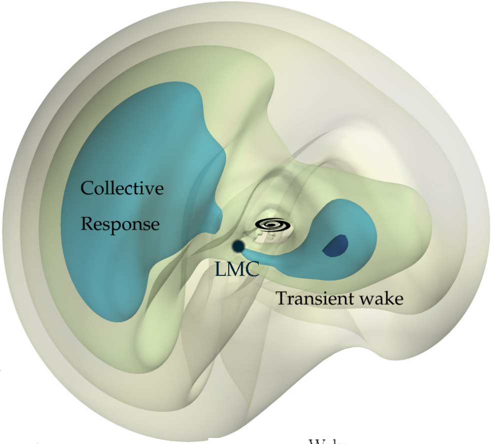


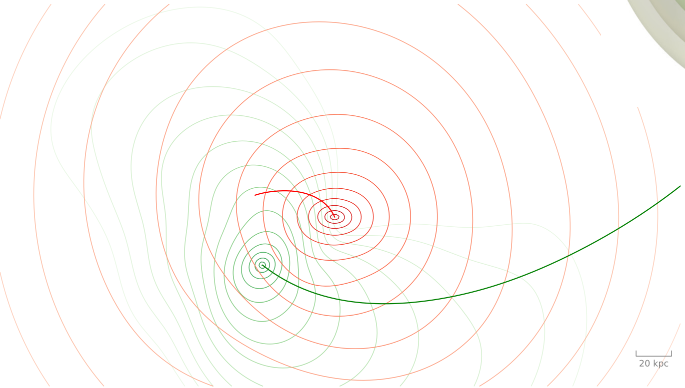
possibly detected as the Pisces overdensity [Belokurov+ 2019]

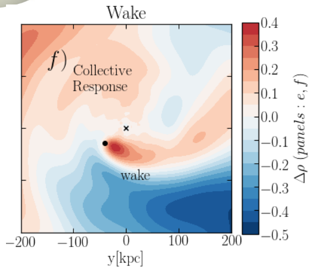


Global perturbation

- central part of the MW is pulled towards the LMC
- outer halo is too slow to catch up
- this creates a dipole "polarization cloud"



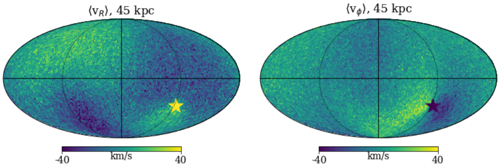




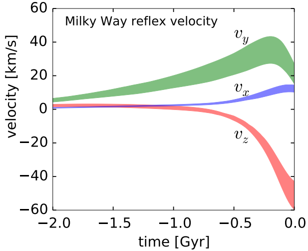
[Garavito-Camargo+ 2021]

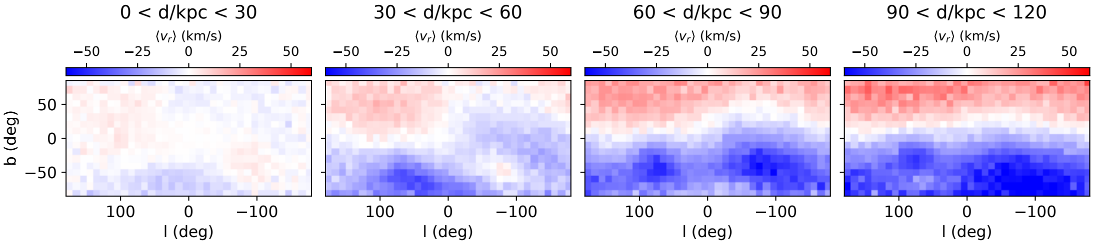
Global perturbation – predicted signatures

Since the MW is pulled "down" (in z) recently, most of the kinematic signal is in the north–south asymmetry of line-of-sight velocities



[Cunningham+ 2020]





[Erkal+ 2020]

Global perturbation – observed signatures

Density polarization

[Conroy+ 2021]

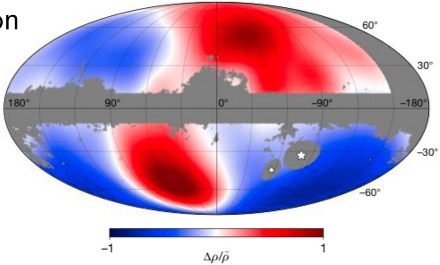
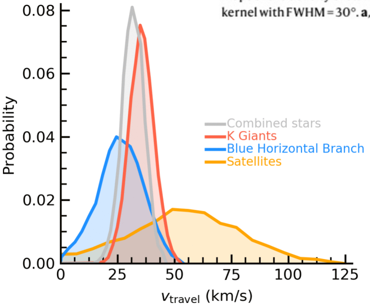
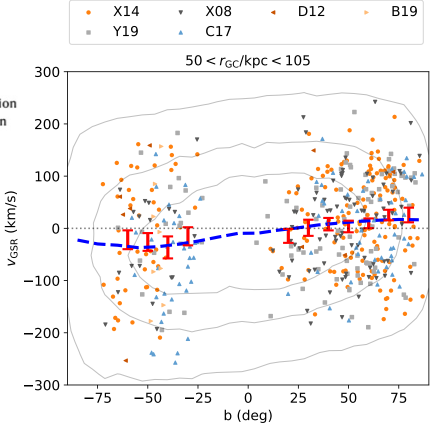


Fig. 1 | Distribution of stars in the Galactic halo. All-sky Mollweide projection maps of the density of stars at 60 kpc < R_{gal} < 100 kpc, smoothed by a Gaussian kernel with FWHM = 30°. **a**, Data based on K giant stars.



[Petersen & Peñarrubia 2021]

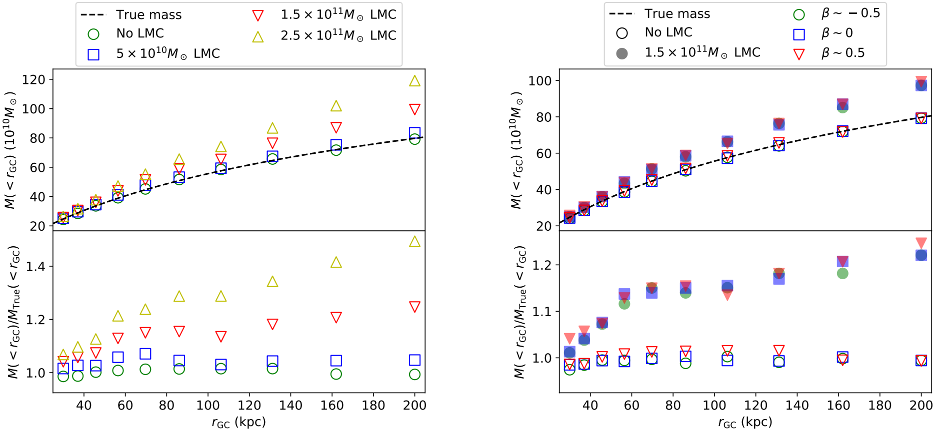
Velocity offset



[Erkal+ 2021]

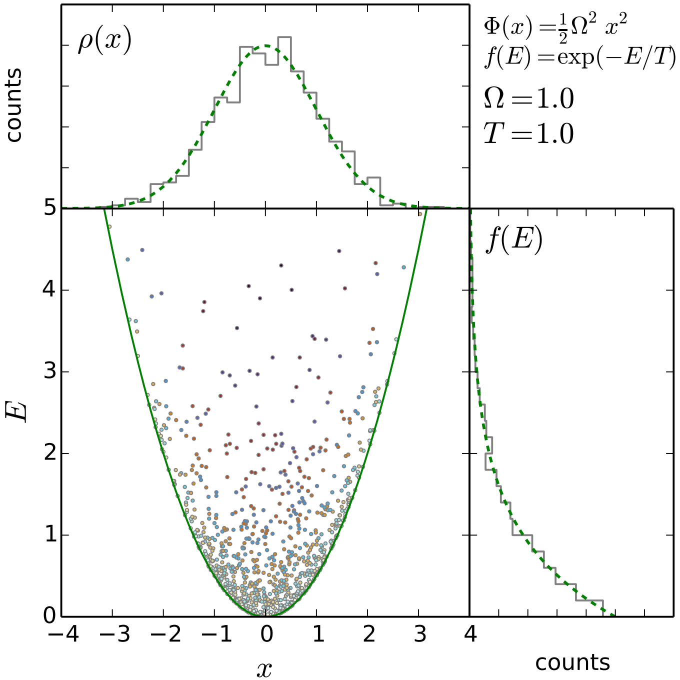
Bias in Milky Way potential measurement

Perturbations in the kinematics of outer halo stars and other tracers (globular clusters, satellites) cause an upward bias in Milky Way mass estimates



[Erkal+ 2020]

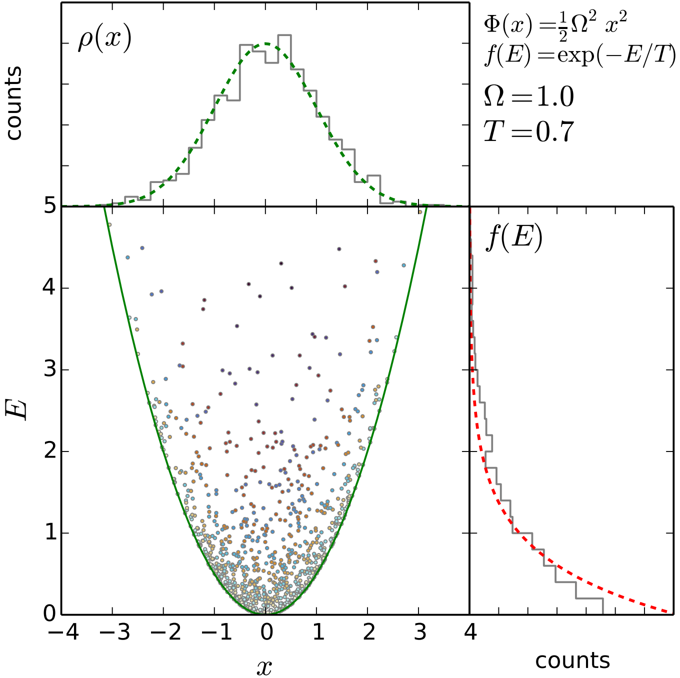
Dynamical modelling with discrete tracers



Example: particles moving in a 1d simple harmonic oscillator potential with a Maxwell–Boltzmann distribution function.

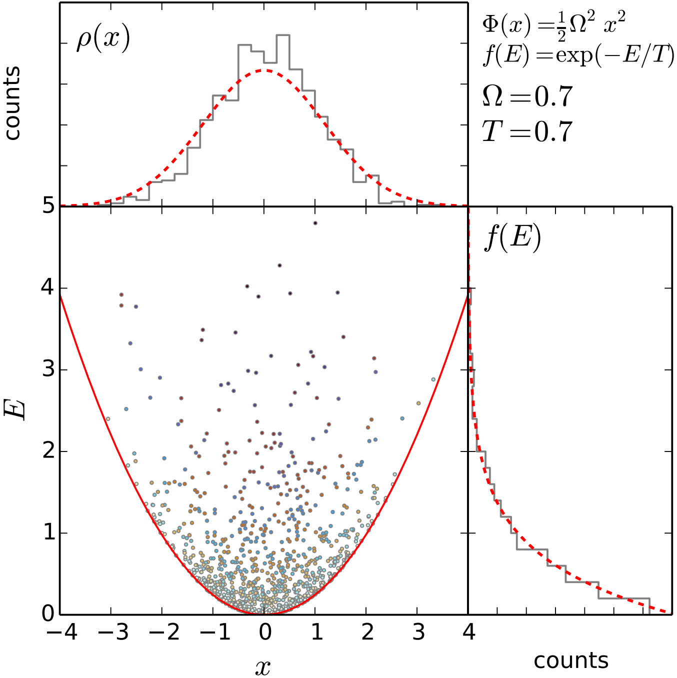
We have measured positions and velocities for $N \gg 1$ particles and want to infer the parameters of the potential (Ω) and the DF (T) that best describe the observed sample.

Dynamical modelling with discrete tracers



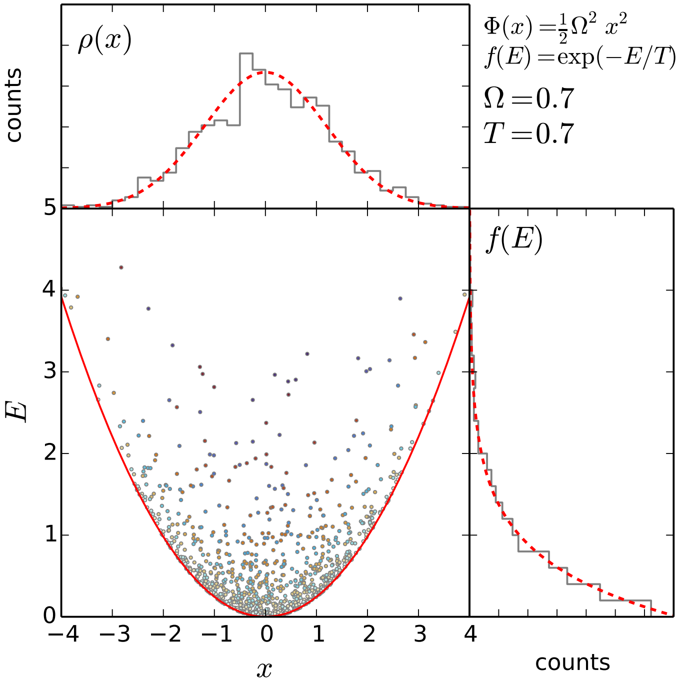
If we assume a wrong temperature T in the true potential, obviously the predicted $f(E)$ will differ from the actual distribution.

Dynamical modelling with discrete tracers



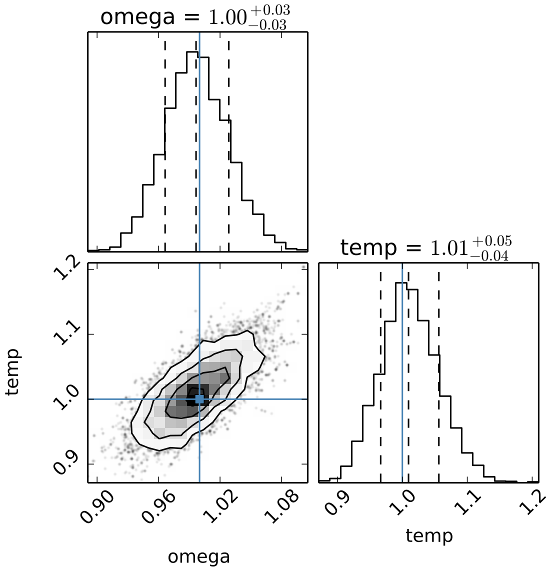
But what if we assume wrong values for both Ω and T? $f(E)$ now agrees with the observed (but incorrectly computed) energy distribution of particles, but their predicted spatial distribution should be wider: there are too many particles near $x = 0$ and too few near turnaround points ($v = 0$).

Dynamical modelling with discrete tracers



The phase-mixed population of particles predicted by the model with wrong parameters will differ from the observed distribution.

Dynamical modelling with discrete tracers



Thus we should be able to infer *both* the potential and the DF from the observed distribution of points in phase space *under the assumption of equilibrium (phase-mixedness)*.

Compensating the LMC perturbation

Summer internship project of Lily Correa Magnus [arXiv:2110.00018]

Assumption: the MW was in a tranquil equilibrium
before the unceremonious arrival of the LMC.

To reconstruct the original unperturbed state for *any* choice
of Galactic potential and LMC mass:

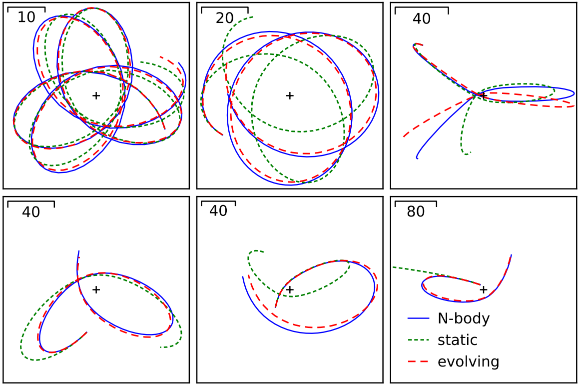
1. Reconstruct the past trajectories of both the MW and the LMC;
2. Rewind the orbits of tracers (halo stars, globular clusters, MW satellites . . .)
in the evolving MW+LMC potential back in time
until the LMC is far enough not to cause trouble ($\sim 2-3$ Gyr).

Vary the LMC mass, the parameters of the potential and the tracer DF
to maximize the likelihood of the *unperturbed* (rewound) dataset.

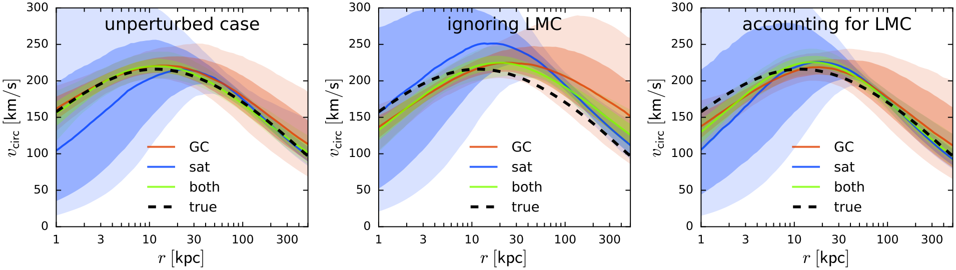
Use two tracer populations: $\sim$150 globular clusters and 36 satellite galaxies
with 6d phase-space coordinates (*Gaia* EDR3 and other recent measurements)
[Baumgardt & Vasiliev 2021; Vasiliev & Baumgardt 2021; Battaglia+ 2021].

Tests of the method

orbit rewinding

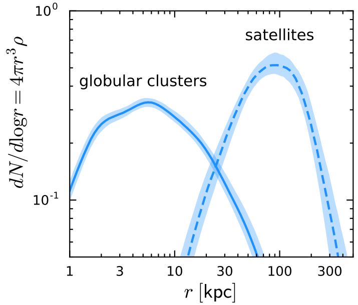


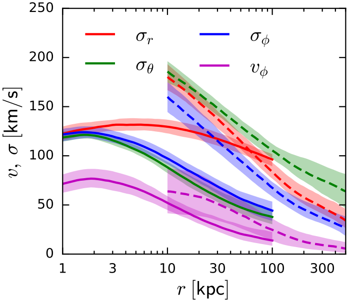
potential reconstruction

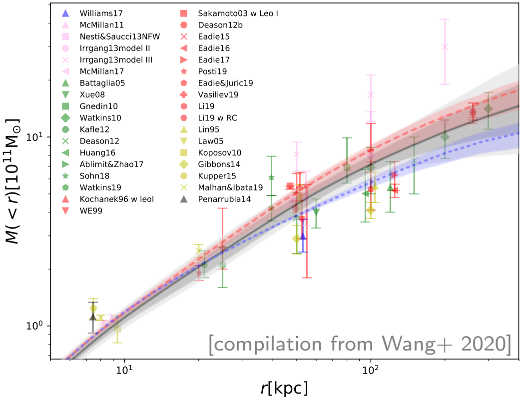


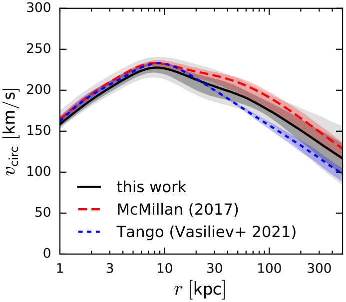
Results

tracer
populations





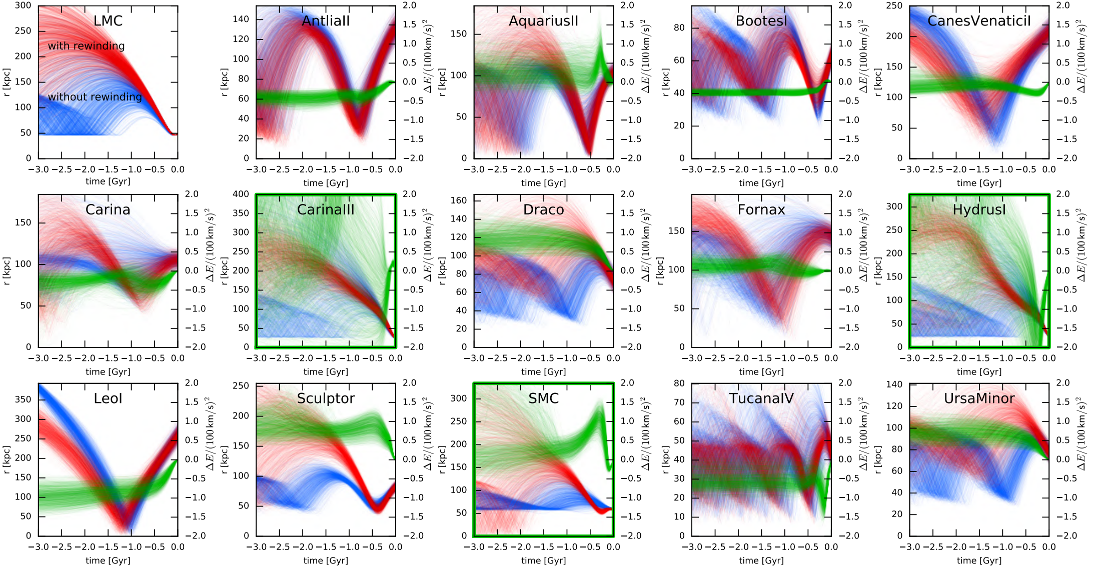




MW potential

Changes in satellite orbits caused by the LMC

could be quite substantial!



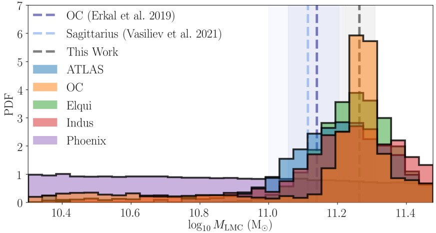
blue: without LMC; red: with LMC; green: energy evolution with LMC; green frame: LMC satellites

Further applications

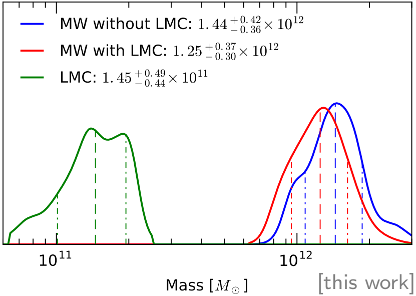
Measurement of the LMC mass:

- from the MW reflex motion (this work and other recent studies of spatial and kinematic asymmetries in the MW halo)
- from local perturbations on stellar streams [Erkal+ 2019; Shipp+ 2021]
- future prospects: measure the dependence of perturbation on distance of closest approach $\Rightarrow$ LMC mass distribution

Details of MW recoil depend on the velocity anisotropy of the *dark* halo – a unique probe!



[Shipp+ 2021]



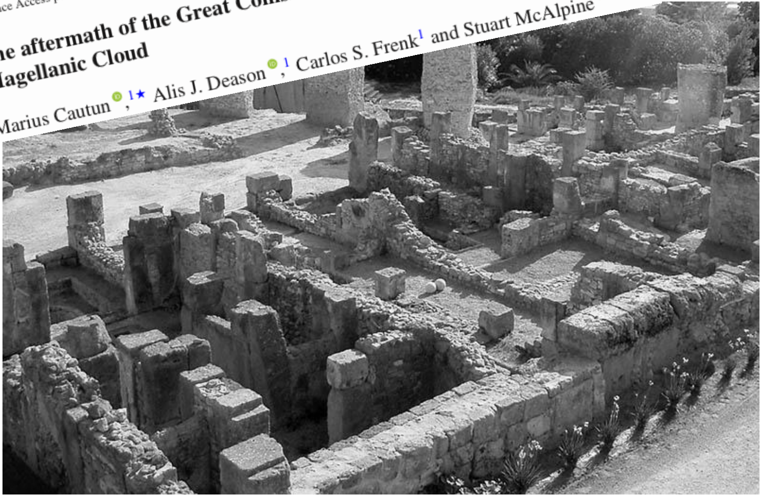
[this work]

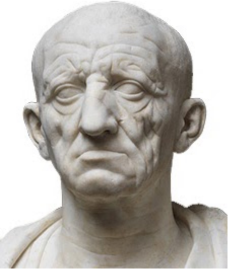
Future fate

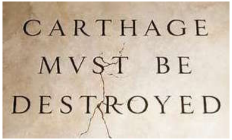

doi:10.1093/mnras/sty3
MNRAS 483, 2185–2196 (2019)
Advance Access publication 2018 November 13

The aftermath of the Great Collision between our Galaxy and the Large Magellanic Cloud

Marius Cautun[1★], Alis J. Deason[1], Carlos S. Frenk[1] and Stuart McAlpine[1,2]







[Cato −149]

"This catastrophic and long-overdue event will restore the MW to normality"

[Cautun+ 2019]