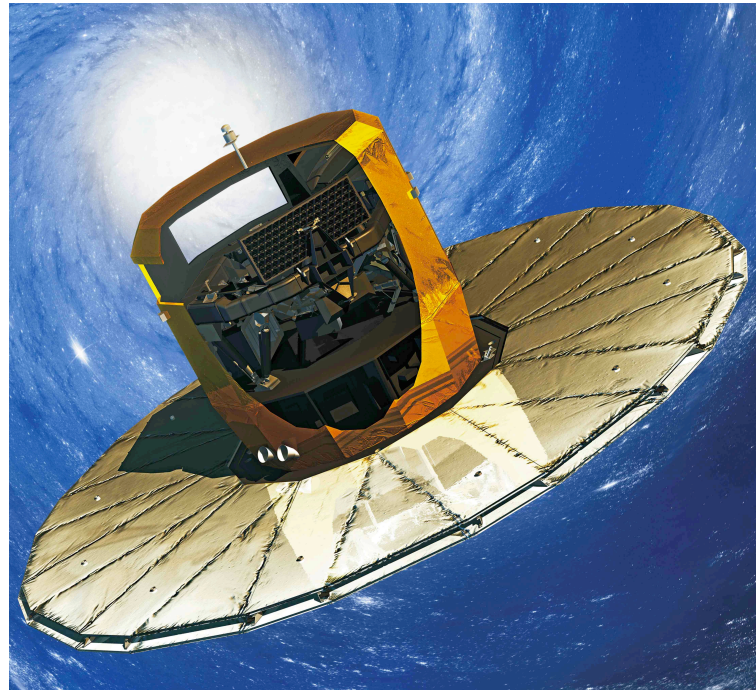


Dark Matter at galactic scales



Olivier Bienaymé, Benoit Famaey & Rodrigo Ibata

Observatoire astronomique de Strasbourg

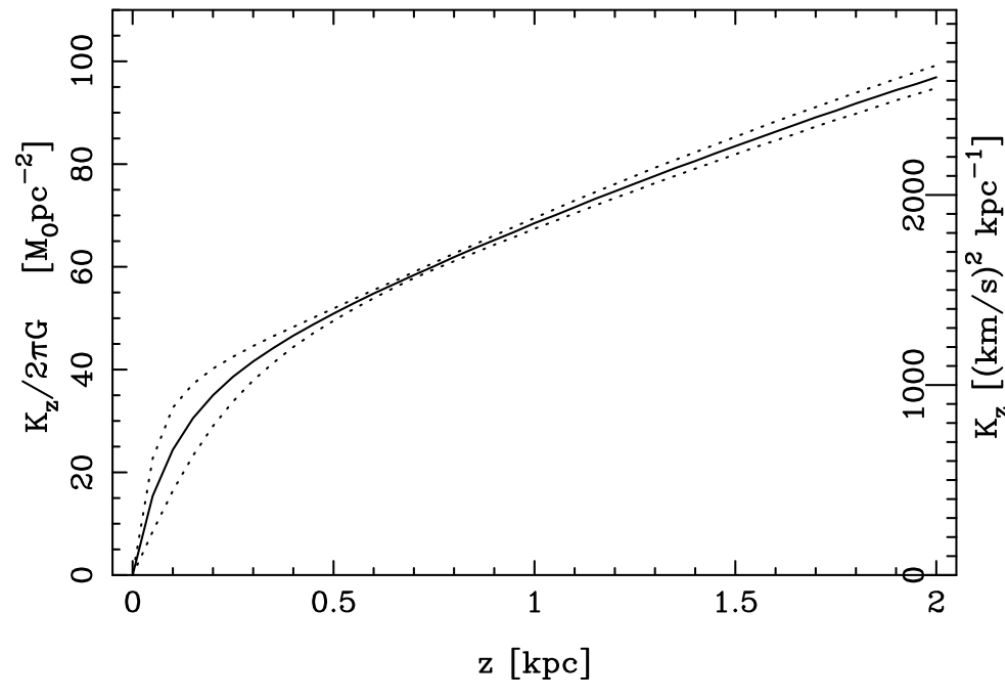
Galactic scales: a challenge for cosmology and a benchmark for DM direct and indirect detection

- Local dark matter density? (important for DM direct detection limits)
- Core-cusp problem? (important for DM indirect detection)
- Radial Acceleration Relation (RAR)?
- Planes of satellites?
- Missing dwarfs (especially in the field)?
- Shape of the DM halo in the MW and external galaxies?
- ...

Local DM density

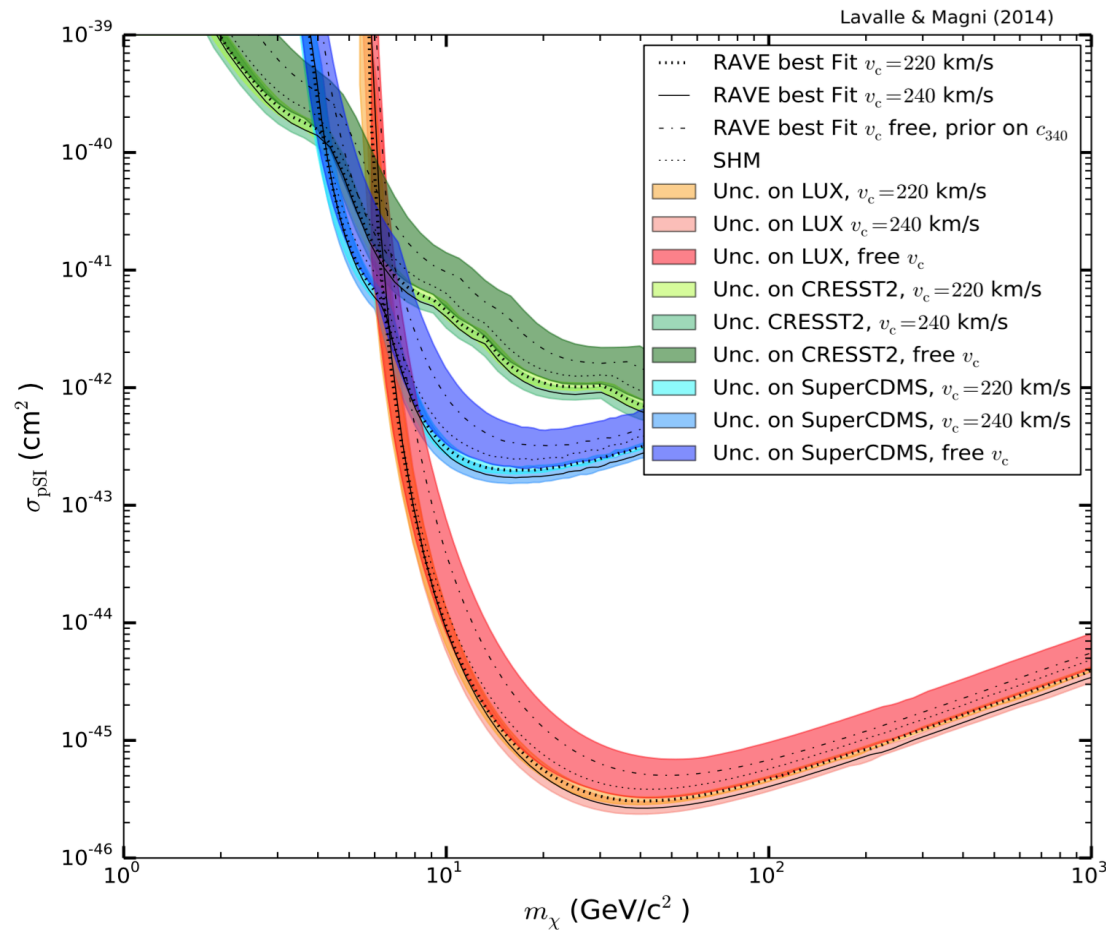
Bienaymé, Famaey, et al. (2014): *Weighing the local dark matter with **RAVE** red clump stars*

=> $\rho_{\text{DM}} = 0.014 M_{\text{sun}}/\text{pc}^3$ ($>0.008 M_{\text{sun}}/\text{pc}^3$ used for DM detection lim)



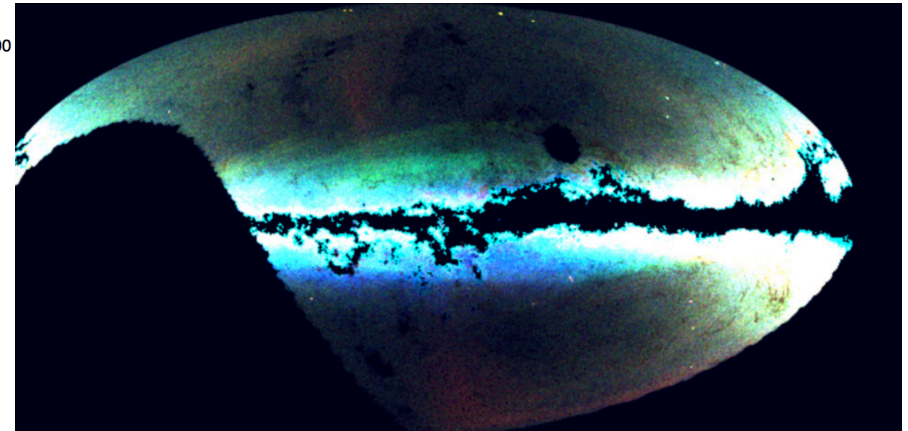
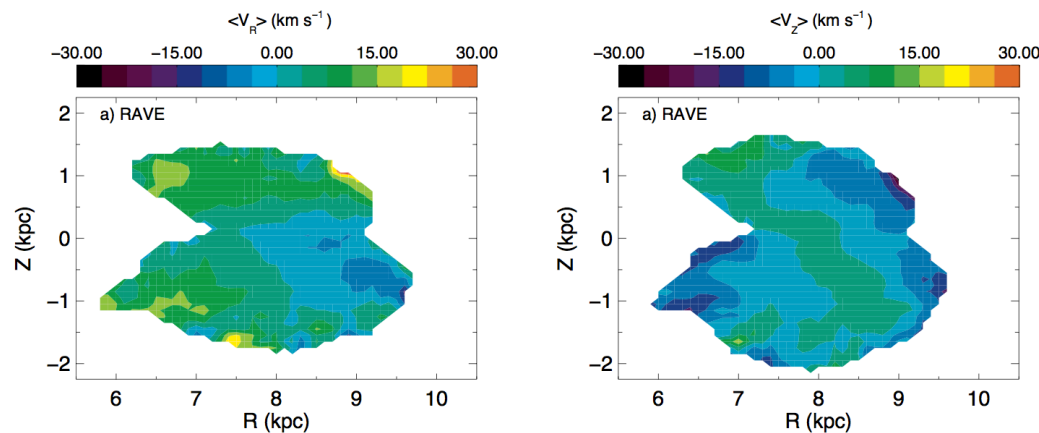
Local DM density

Lavalle & Magni (2014): effect of local DM density and DM velocity distribution (including local escape speed) on DM detection limits



Local DM density

Effects of non-axisymmetry and non-equilibrium??



[Williams et al. \(2013\)](#): *The wobbly Galaxy: kinematics north and south with **RAVE** red clump giants*

⇒ Breathing mode locally

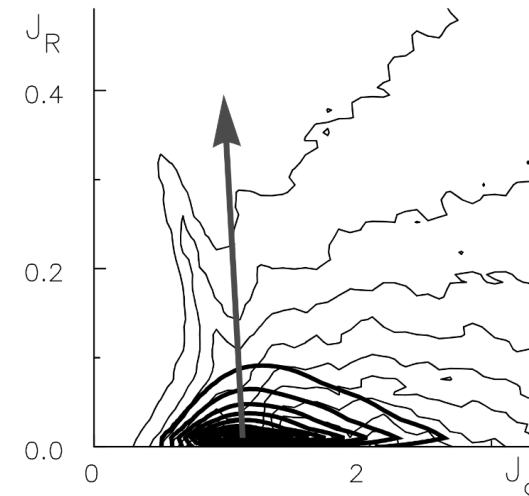
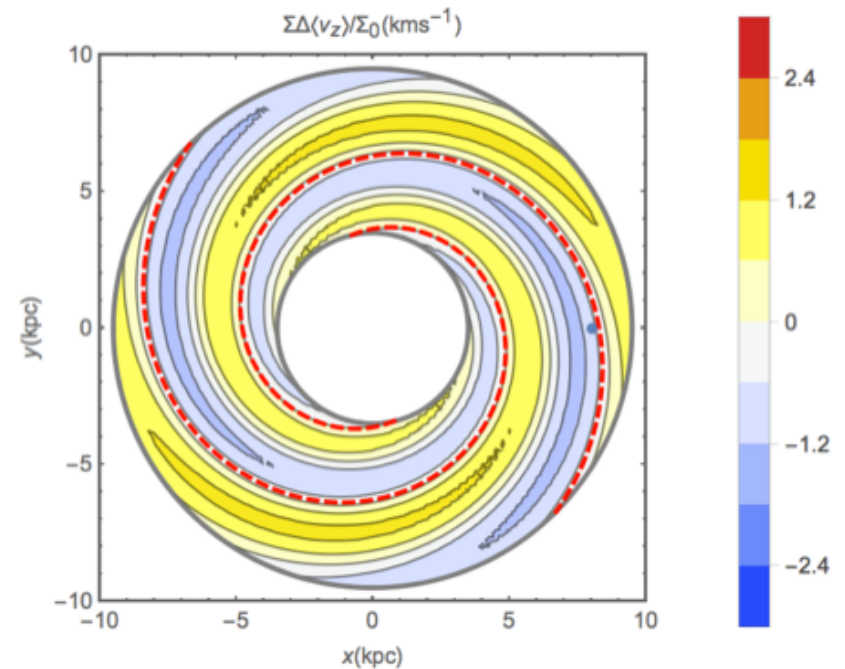
[Slater et al. \(2014\)](#): *The Complex Structure of Stars in the Outer Galactic Disk as revealed by **Pan-STARRS1***

⇒ North-South asymmetries (bending modes) in the outer MW disk

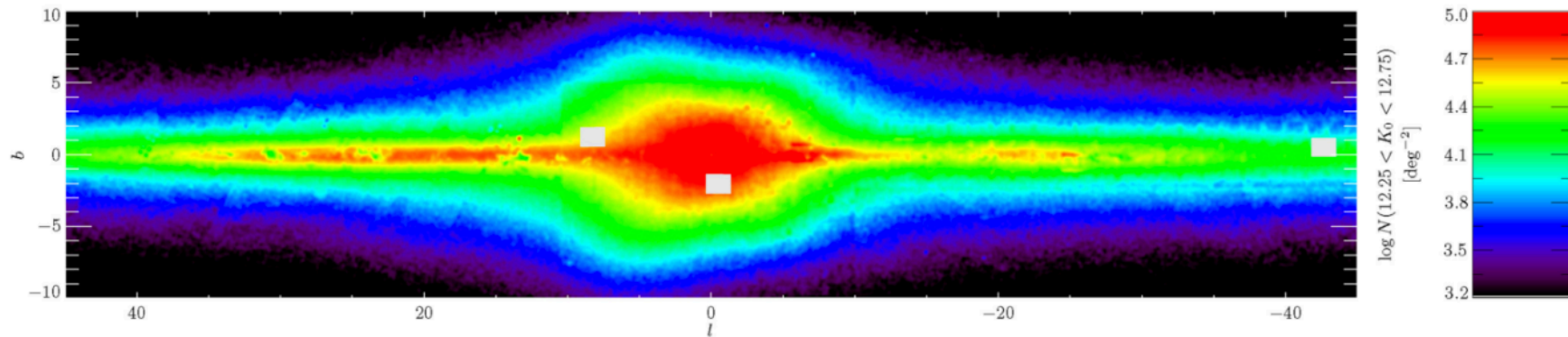
Local DM density

Effects of non-axisymmetry and non-equilibrium??

- [Monari, Famaey & Siebert \(2016\)](#): *Modelling the Galactic disc: perturbed distribution functions in the presence of spiral arms*
 - ⇒ Breathing modes generated by **spirals** and the **bar**
 - ⇒ **Include this in future determinations of DM density**
- [Fouvry, Binney & Pichon \(2015\)](#): *Self-gravity, resonances, and orbital diffusion in stellar disks*
 - ⇒ Effects of **transient spirals** on the evolution of the distribution function (development of **ridges in the space of actions**)



MW bar parameters?



Wegg C., Gerhard O., Portail M., 2015, MNRAS, 450, 4050

Millions of RC stars from VVV survey + 2MASS+ UKIDDS + GLIMPSE
=> long flat ($h_z < 50$ pc) extension of the bar out to 5 kpc from the center ($|l| > 30^\circ$)

+Fit to los velocities of BRAVA (central 10° in long.) & ARGOS ($-30^\circ < l < 30^\circ$)

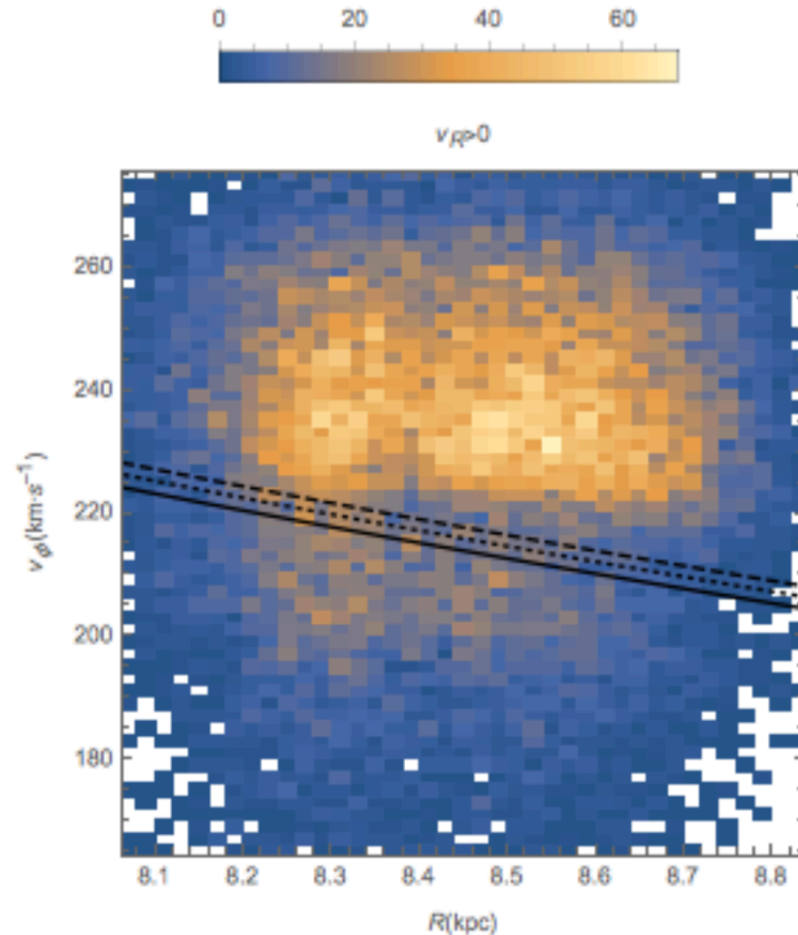
$\Rightarrow \Omega_b = 40 \text{ km/s/kpc} \sim 1.35 \Omega_0$ (Portail et al. 2016)

\Rightarrow Corotation at 6 kpc! (and OLR beyond 10 kpc)

Local signature of the OLR of the bar?

Monari, Kawata, Hunt & Famaey (2016): Tracing the Hercules stream with **Gaia** and LAMOST: new evidence for a fast bar in the Milky Way

One of the first Galactic dynamics results of Gaia!!



⇒ $\Omega_b > 1.8 \Omega_0$ (~55 km/s/kpc)

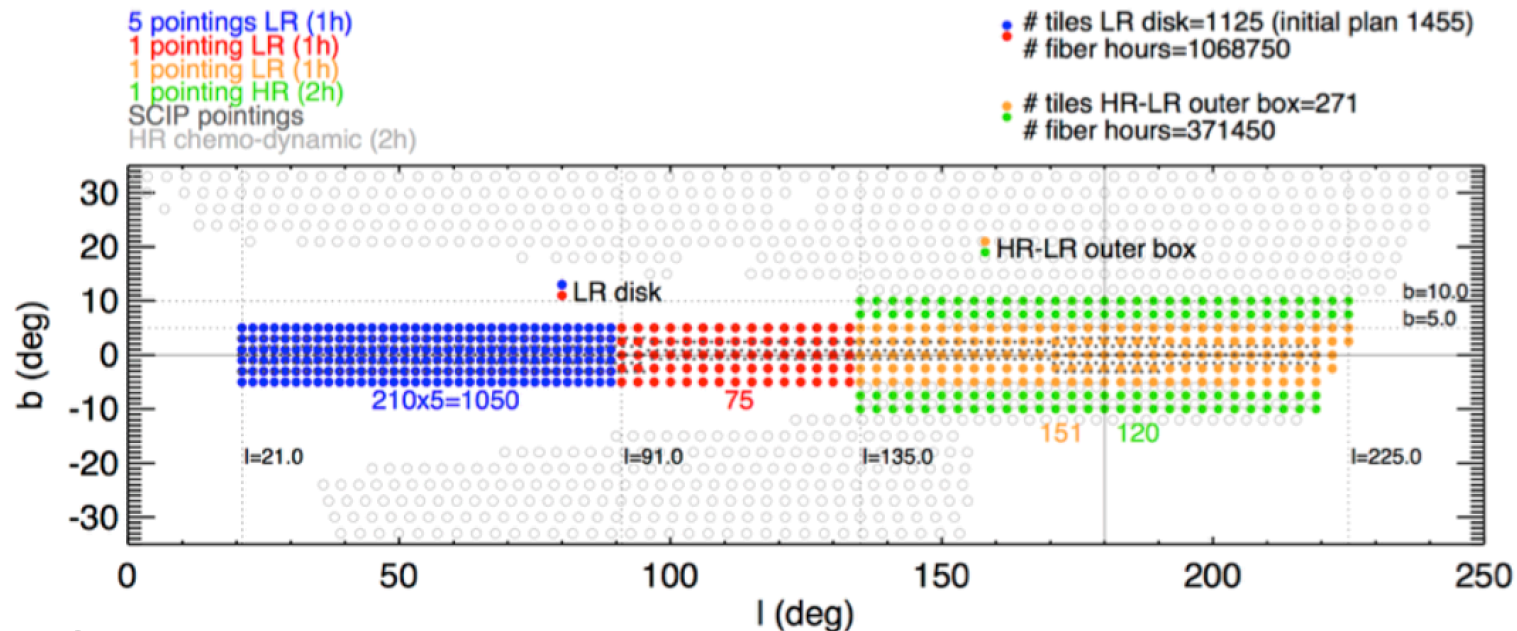
⇒ Long flat extension of the bar = loosely wound spiral?

WEAVE as a complement to Gaia

Survey characteristics

| IMWD survey | Essential |
|---|------------------------|
| $20^\circ < l < 90^\circ$ $ b < 5^\circ$ | 210 los 5 pointings |
| $90^\circ < l < 135^\circ$ $ b < 5^\circ$ | 75 los 1 pointing |
| Estimated number of stars | 1.1×10^6 |

| OMWD survey | Essential |
|---|----------------------------------|
| $135^\circ < l < 225^\circ$ $ b < 5^\circ$ | 151 los in LR mode 1 pointing |
| $135^\circ < l < 225^\circ$ $5^\circ < b < 10^\circ$ | 120 los in HR mode 1 pointing |
| Estimated number of stars | 3×10^5 |

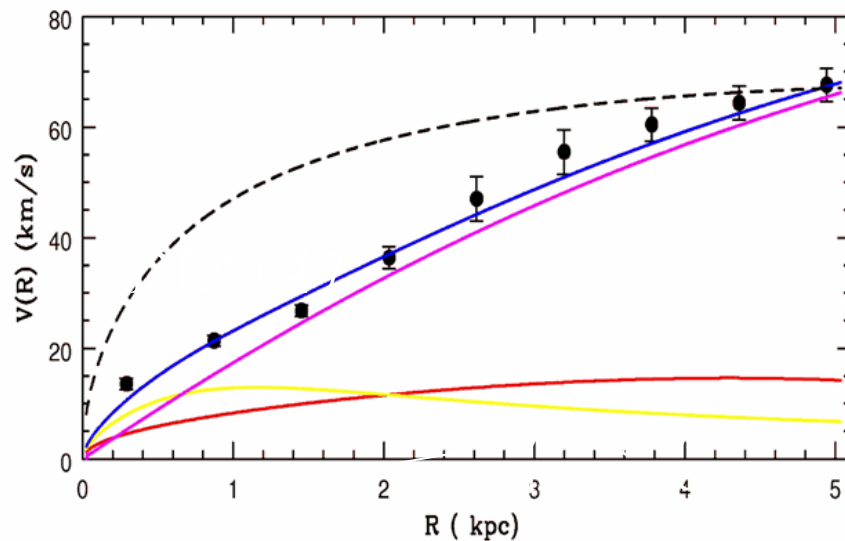


Core-Cusp problem from galaxy rotation curves

CDM halo without baryon feedback :

$$\ln \rho(r) / \rho_{-2} = -2 / \alpha [(r / r_{-2})^\alpha - 1]$$

Slope $d \ln \rho / d \ln r \propto -1.4$ at 1 kpc to -0.8 at 100 pc



Chemin et al. (2011) find best fits with innermost slope of ~ -0.1 ($\Rightarrow -0.5$ for cuspiest)

\Rightarrow DM CORES!
 \Rightarrow FEEDBACK??

Core-Cusp problem in the Milky Way

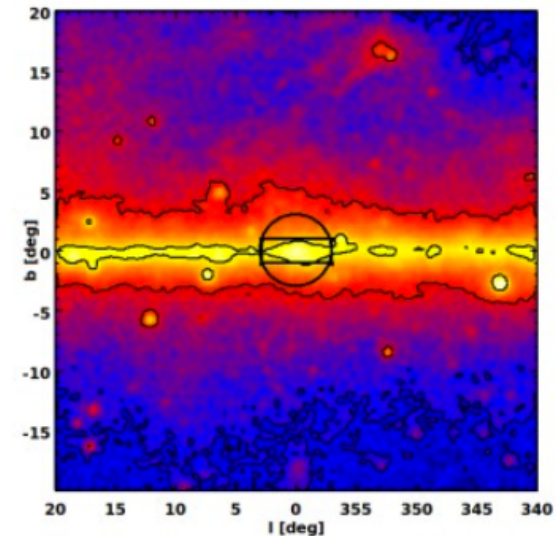
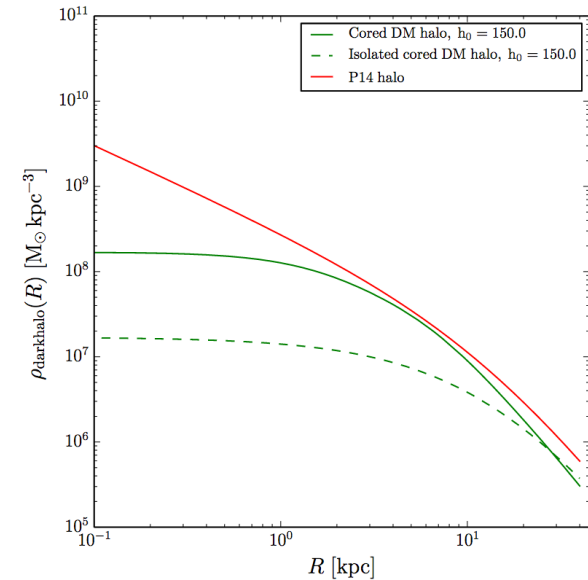
Binney & Piffi (2015): rule out an adiabtically compressed NFW!

Cole & Binney (2016): if adopting a **cored halo with a 2 kpc core**, everything can be fitted

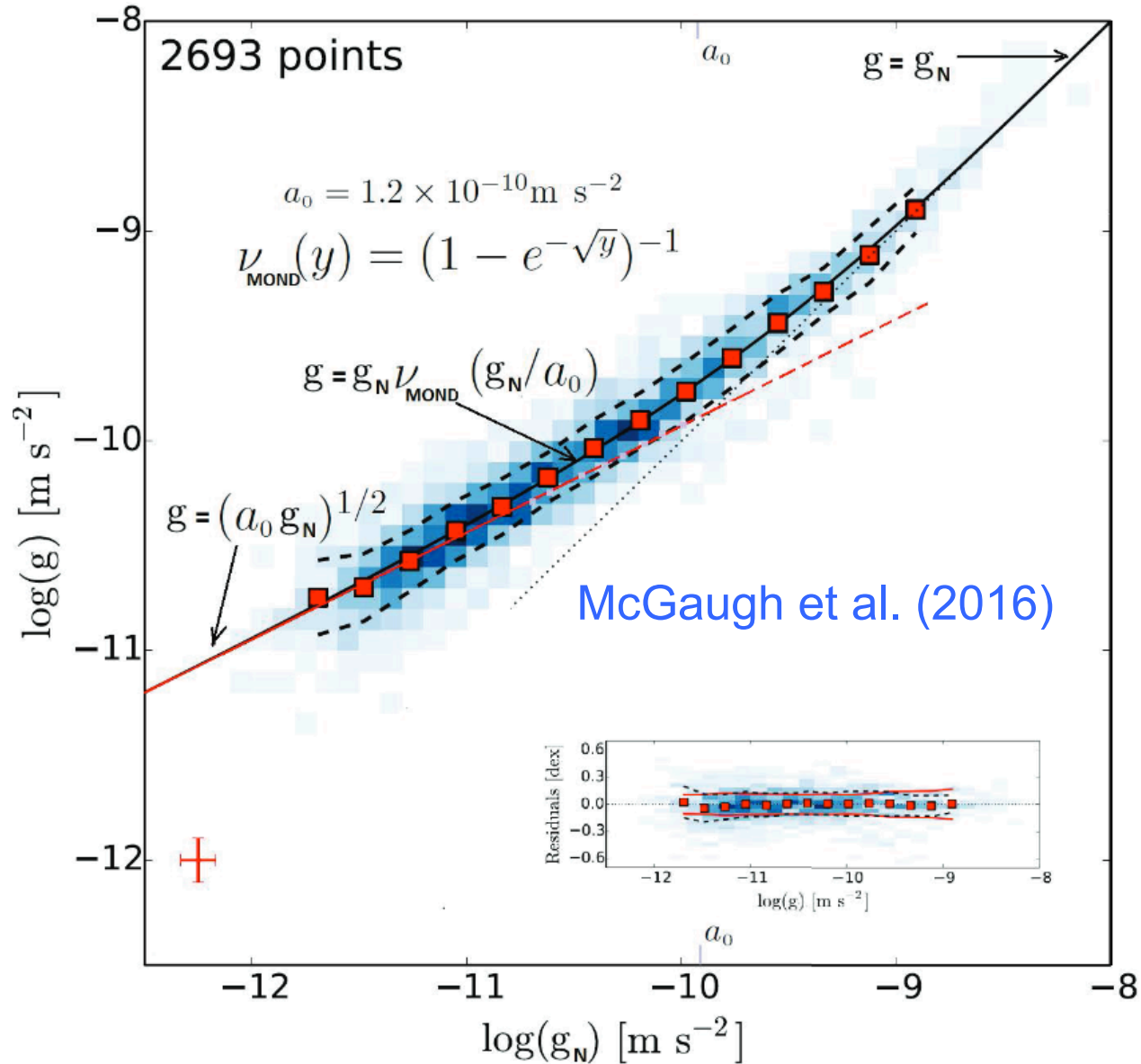
Important for DM indirect detection: claims of an excess emission around 2 Gev from the Galactic center seen by **Fermi**.

The excess was argued to be a possible DM signature because compatible with a **NFW cusp, even a bit steeper...**

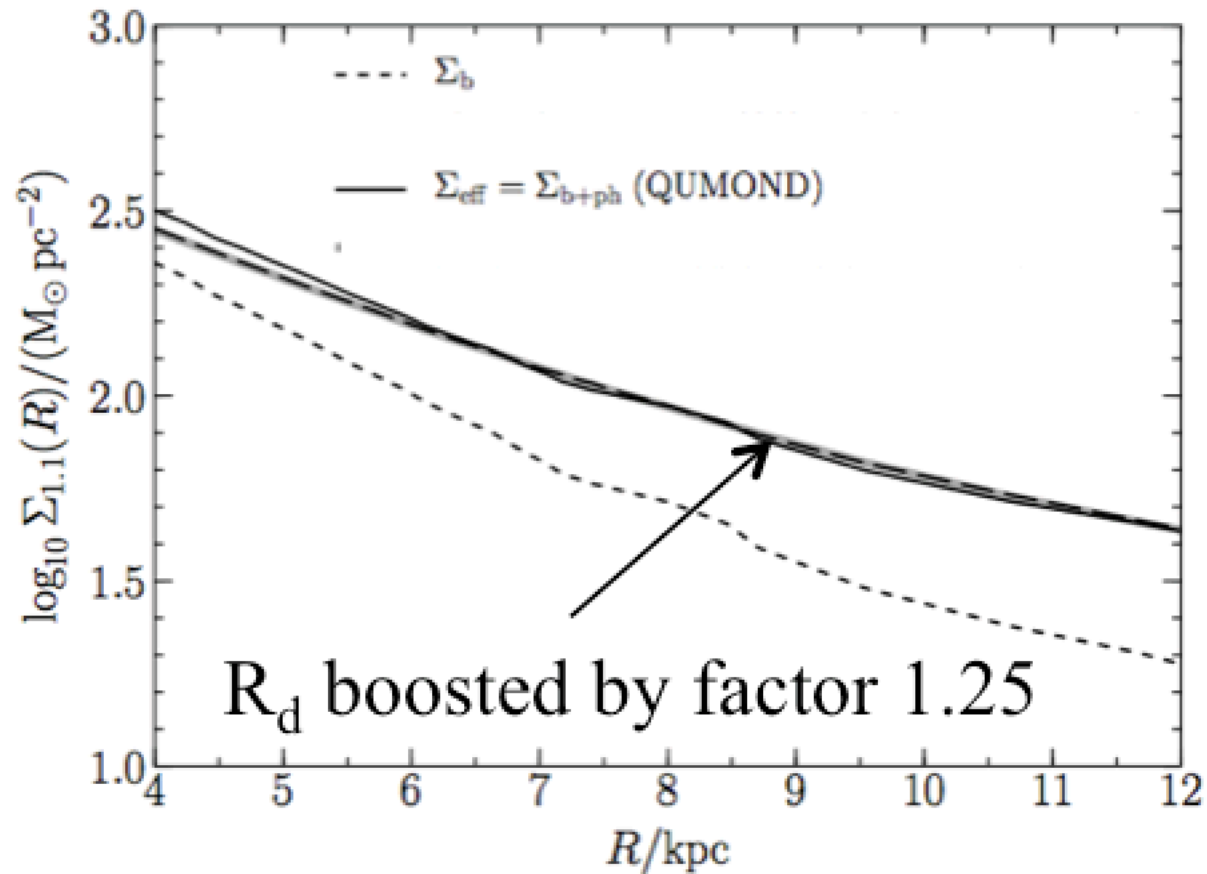
This is actually an **argument against this being a indirect DM detection!**



More generally: Radial acceleration relation (RAR)



Modified Gravity?

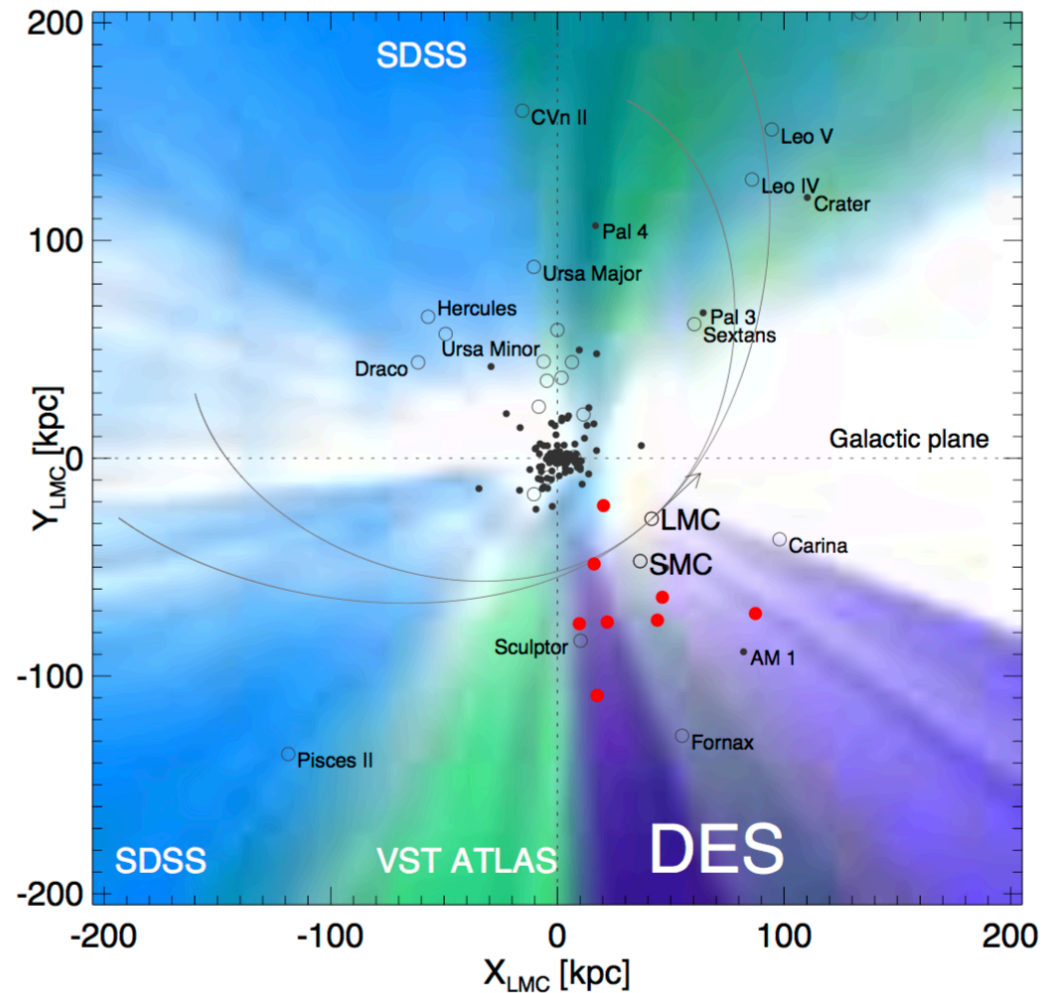


Important test with Gaia: see [Bienaymé, Famaey, et al. 2009](#)

Dwarf galaxies: new discoveries

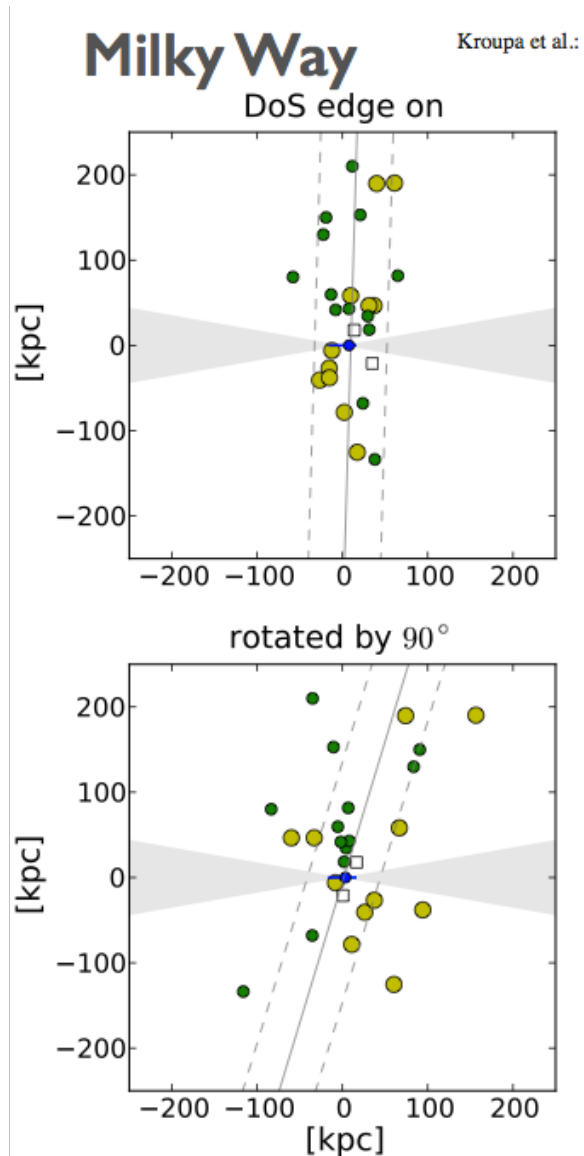
Happy hunting
grounds around the
LMC:

Koposov et al. (2015)
Martin et al. (2015,
2016)

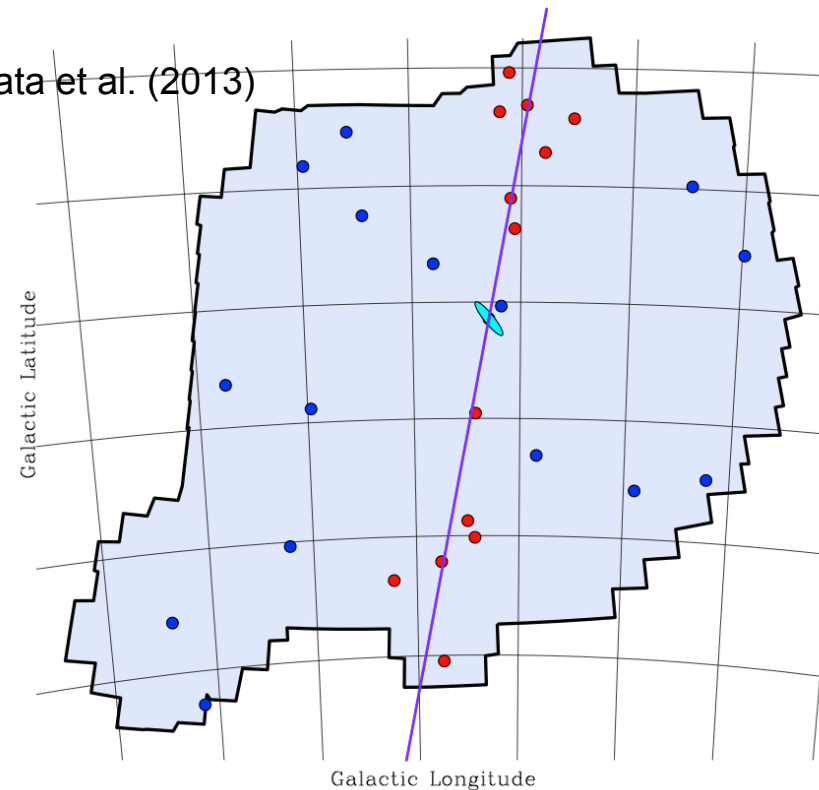


Koposov et al. (2015)

Dwarf galaxies: planes of satellites

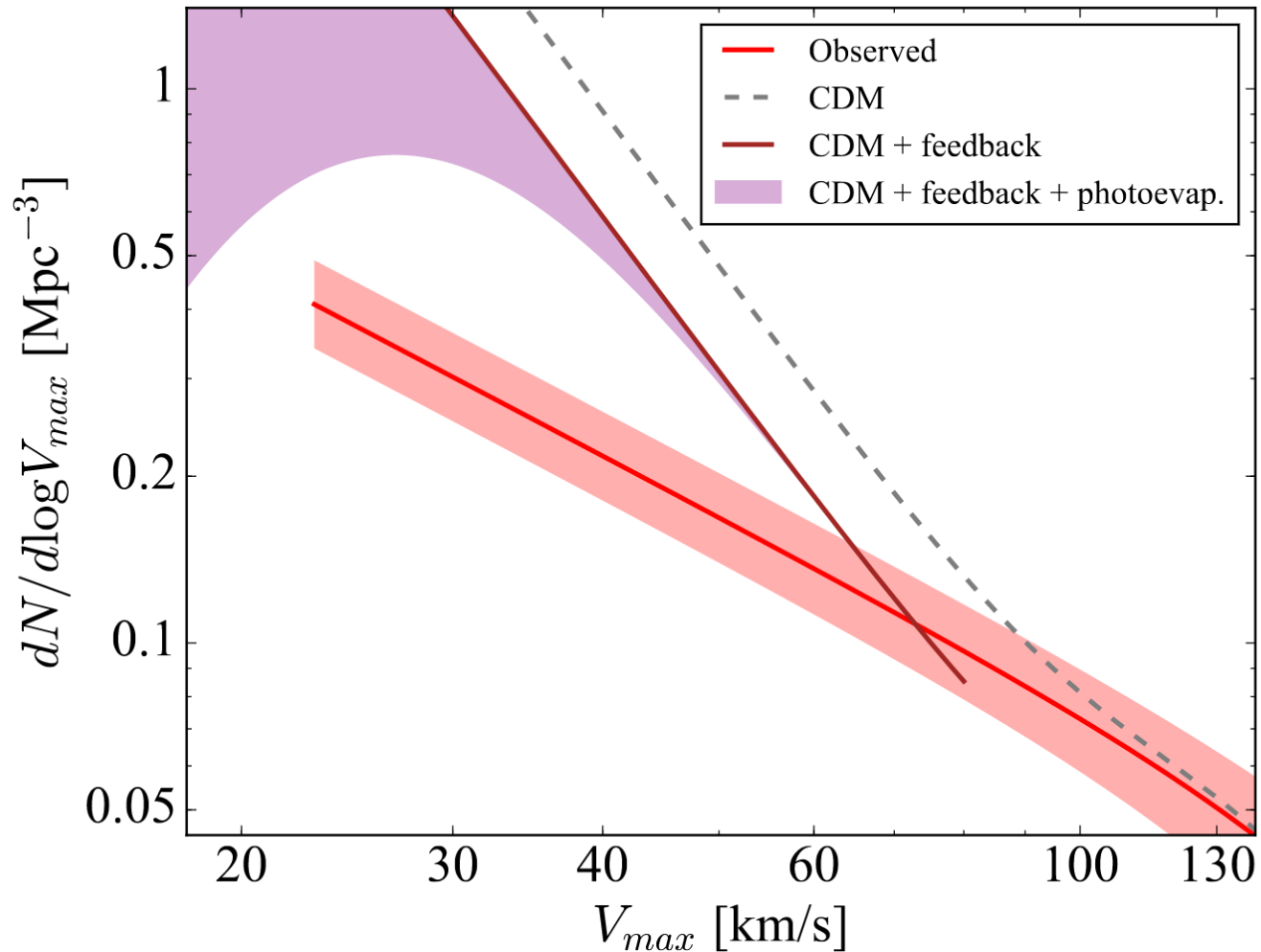


Ibata et al. (2013)



Most probable solution: infalling group. Cosmological implications unclear, but such spatial-kinematic are only found as chance alignments. **Gaia** will tell us whether this is so in reality.

Missing dwarf galaxies in the field

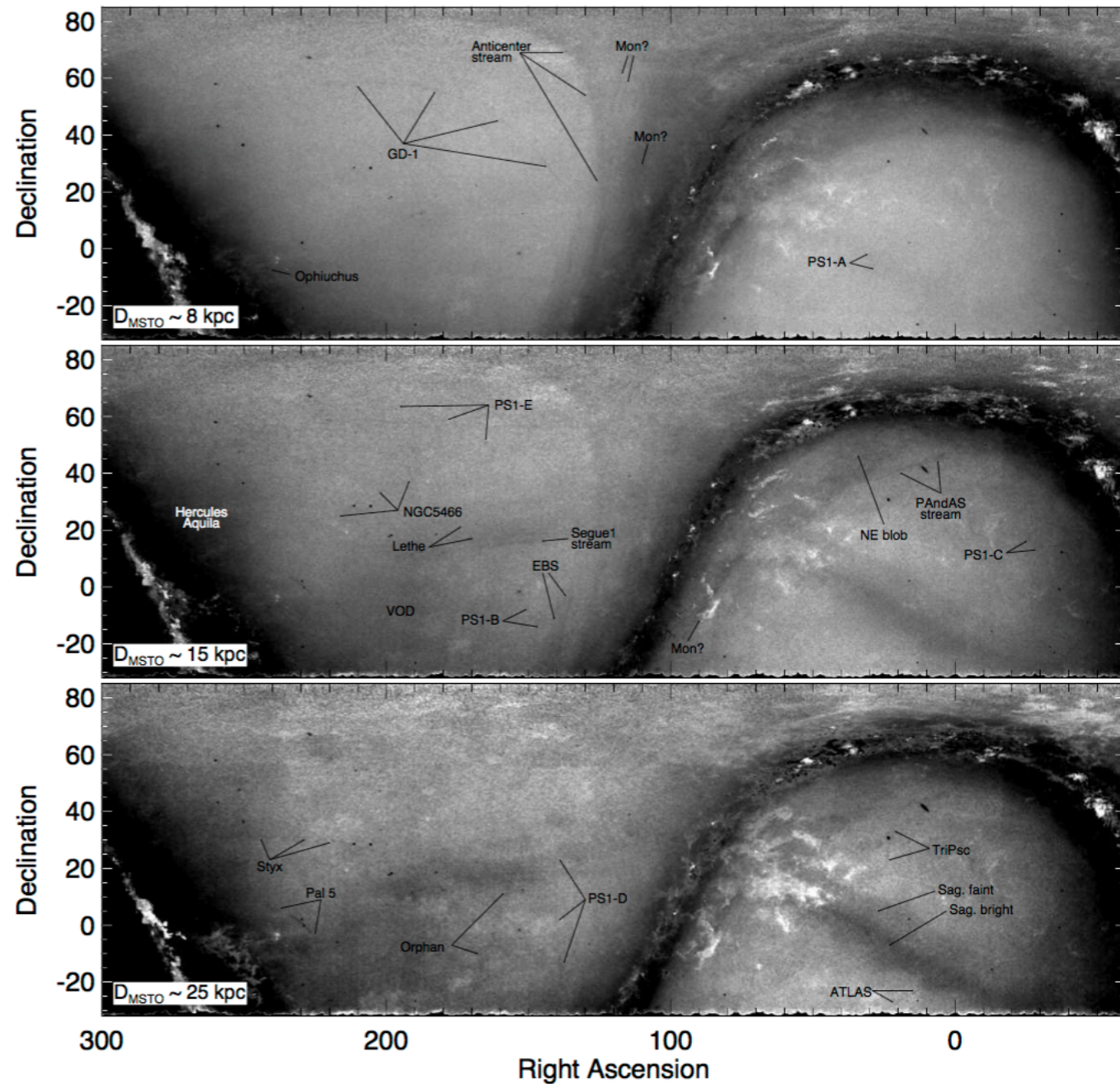


[Trujillo-Gomez et al. \(2016\)](#): feedback does not substantially affect the V_{max} distribution. Dwarfs still missing!

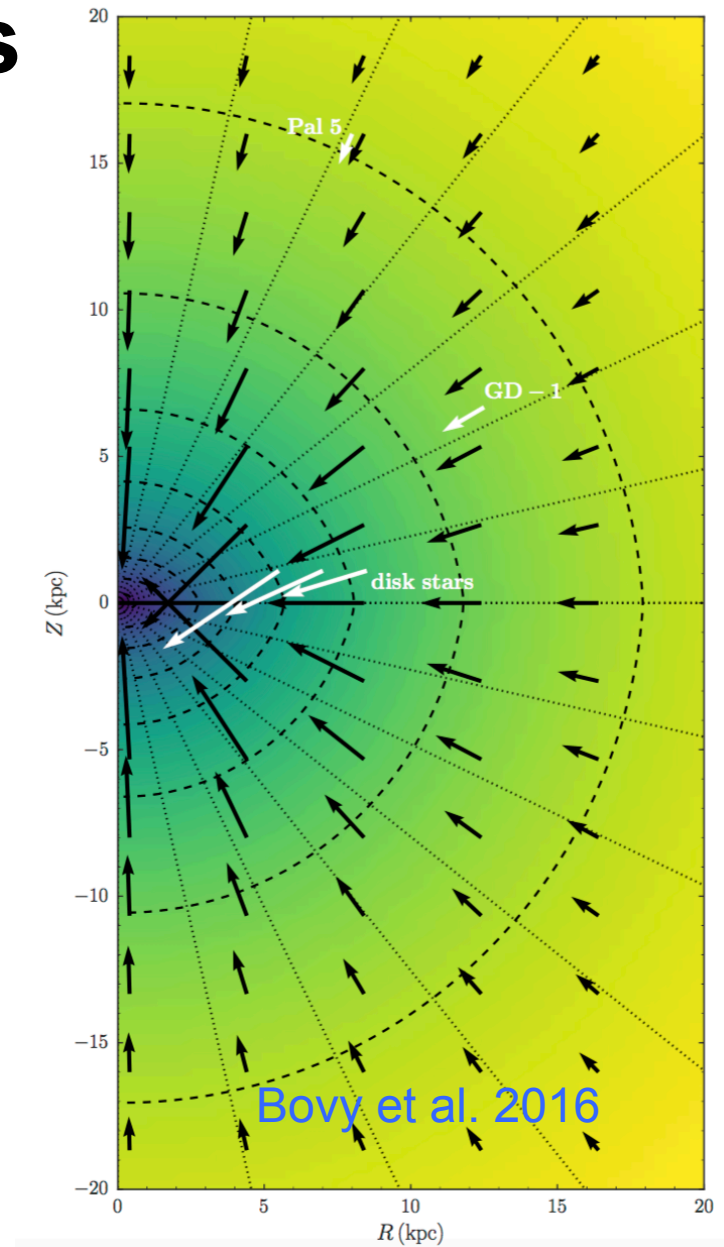
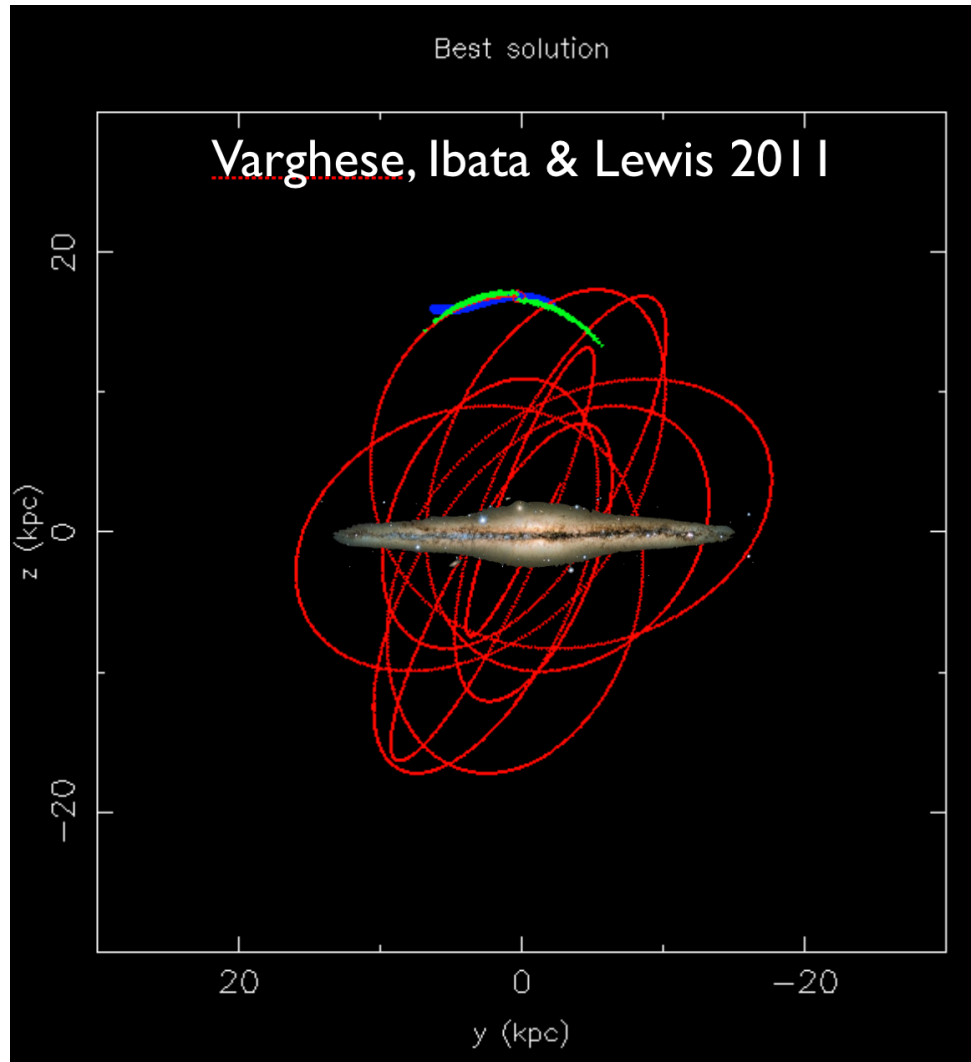
Stellar streams – new detections

PanSTARRS

Bernard et al. 2016



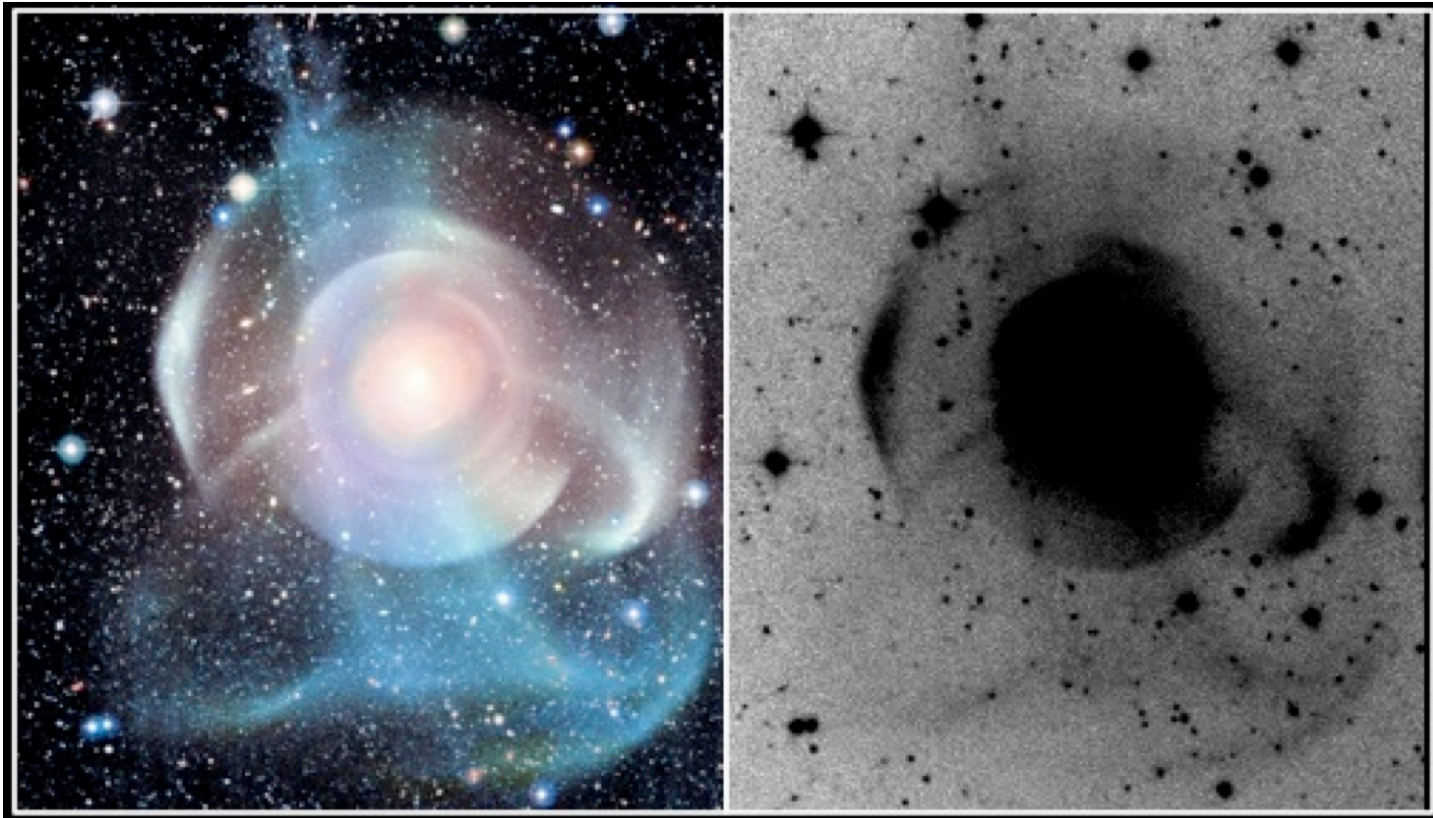
Stellar streams and the shape of DM haloes



The low surface brightness universe: shells as DM probes

MATLAS [Duc et al. 2015](#)

[Sanderson & Helmi 2013](#)



Perspectives

Gaia

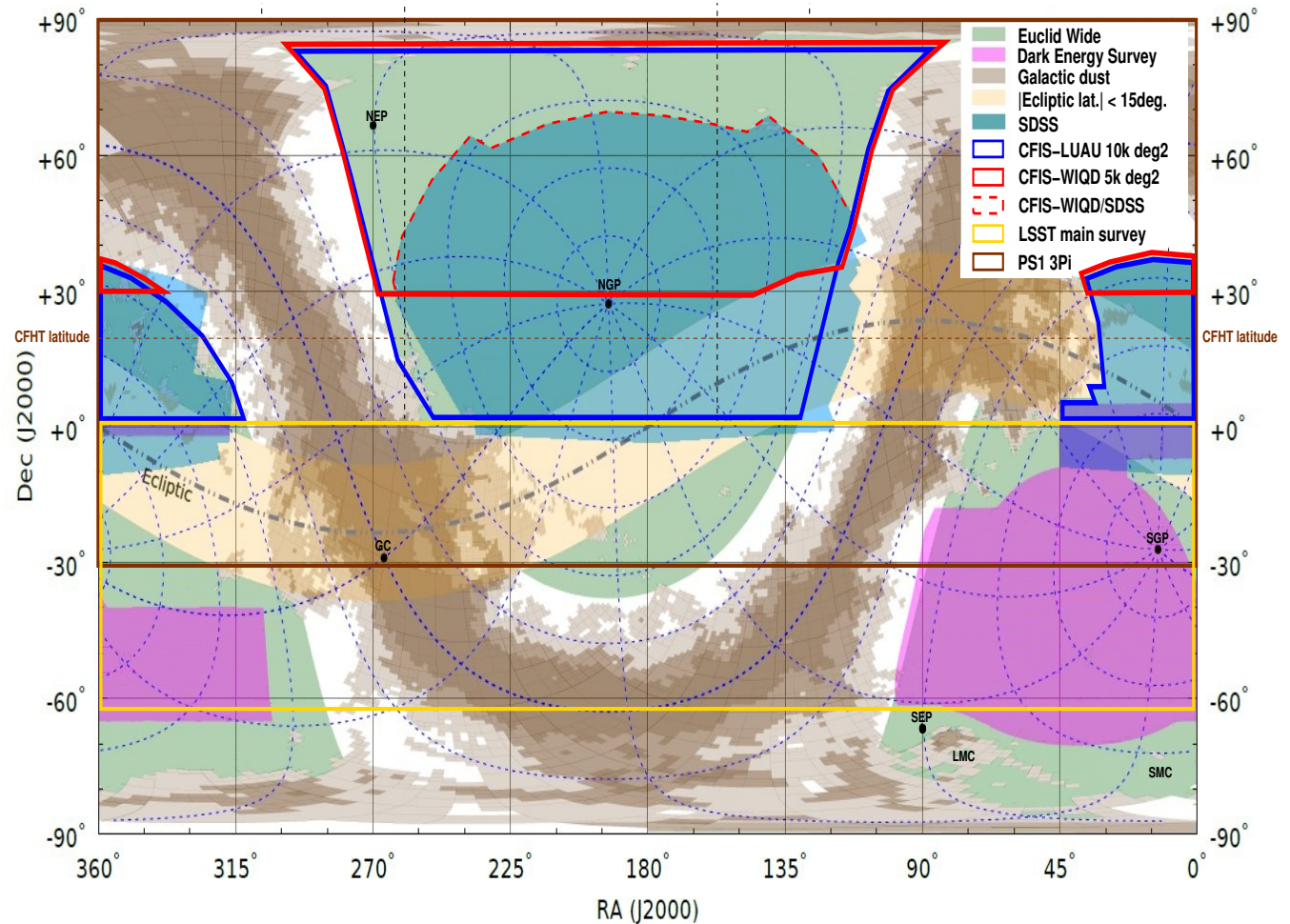
WEAVE

Moons

Luau

LSST

MSE



The next few years will be very exciting!