Internal 3D kinematics of dwarf spheroidal galaxies with Gaia + HST

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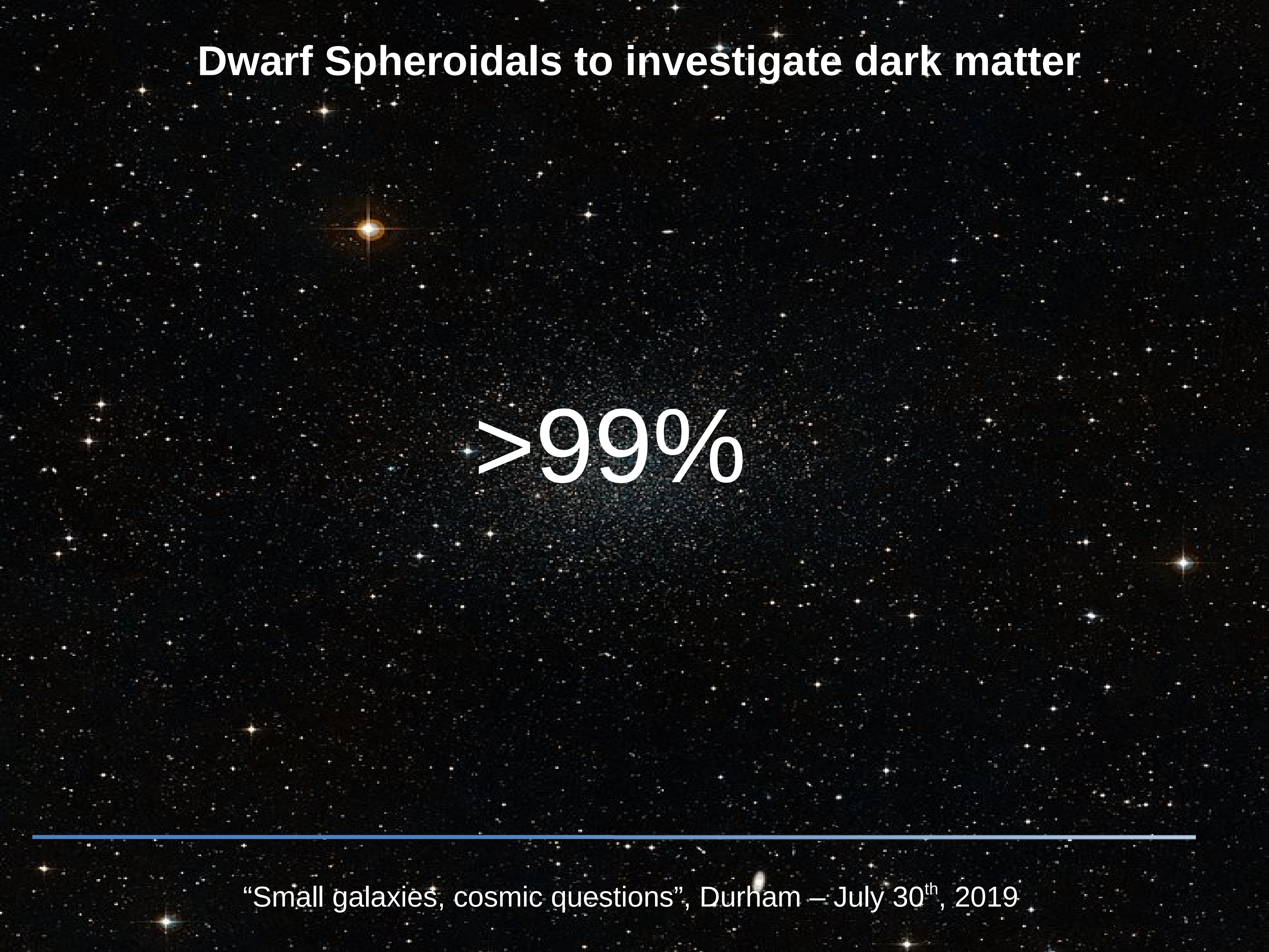
Main collaborators: A. Helmi, E. Tolstoy, A. Mucciarelli, L. Sales

Gaia DR2, Gaia Collaboration+2018

"Small galaxies, cosmic questions", Durham – July 30th, 2019

Dwarf Spheroidals to investigate dark matter



PMs in dSph to investigate dark matter

Dynamics

⟷

Mass distribution

⟷

Test DM models

PMs in dSph to investigate dark matter

Dynamics

⇕

Mass distribution

⇕

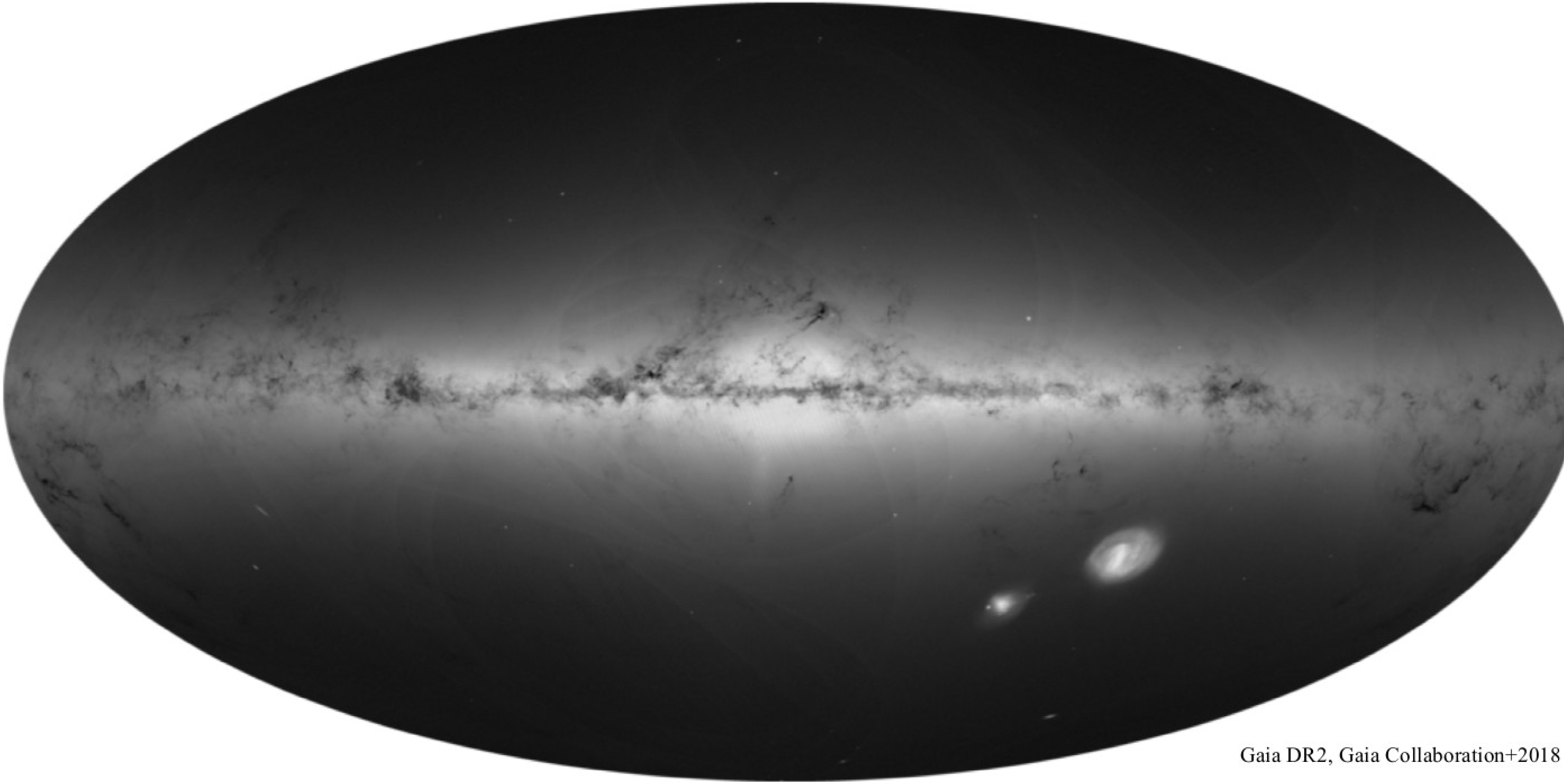
Test DM models

BUT

No PMs = mass-β degeneracy

Golden era of Astrometry: *Gaia* DR2

Positions + Proper motions for 1.3 billion stars



Gaia DR2, Gaia Collaboration+2018

Absolute PMs vs Internal PMs

Absolute proper motions:

- systemic
- easier to measure
  (large number of members helps)
- σ(absolute) = σ(single)/sqrt(N)
- ingredient to determine orbits

Internal proper motions:

- how stars move within a stellar system
- Most difficult to measure
- **σ(PM) [km/s] < velocity dispersion**
- ingredient to investigate the internal
  dynamics of a stellar system

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$\sigma(PM) < 0.03$ mas/yr at $G>18$ ✗

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$$\sigma(PM) = sqrt(\sigma^2(posI)+\sigma^2(posII)) \,/\, \Delta t$$

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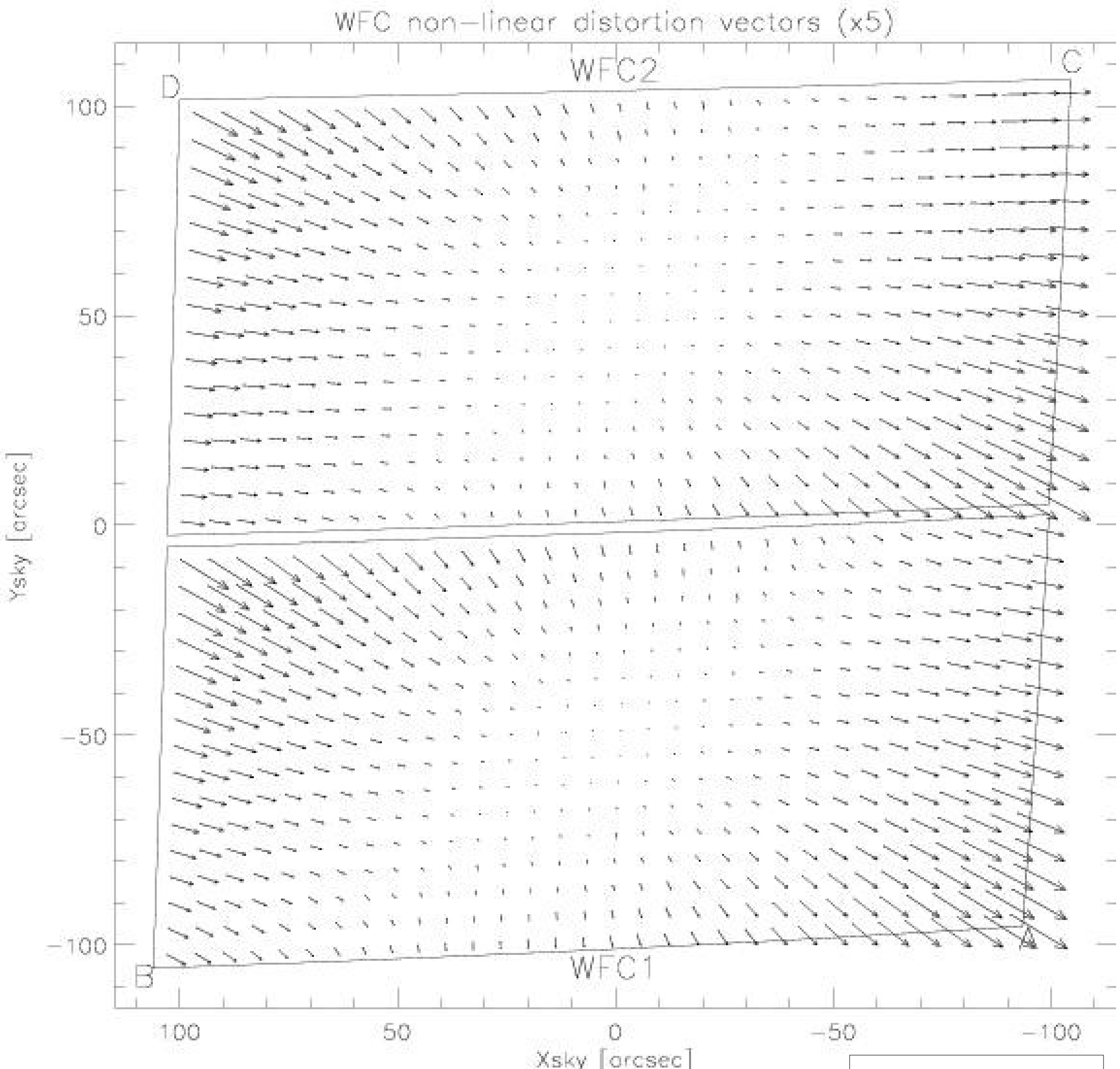
↓ <<< ↓ ??? ↓ Gaia ↓ >>>

Proper Motions: HST

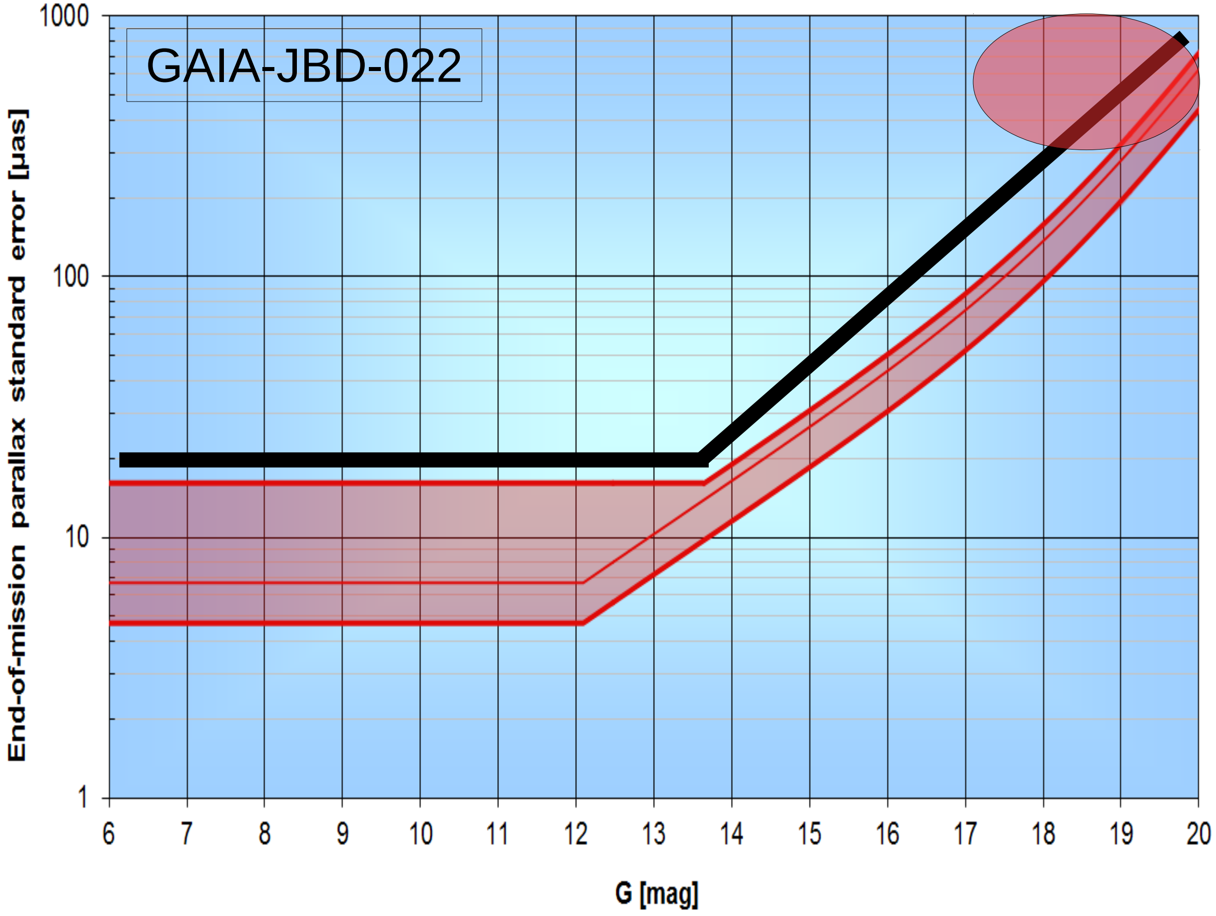


Anderson+06

PSF knowledge	0.01 pixels
+	+
Geometric distortion corrections	0.01 pixels

Positional precision
=
0.7 mas

Proper Motions: *Gaia*

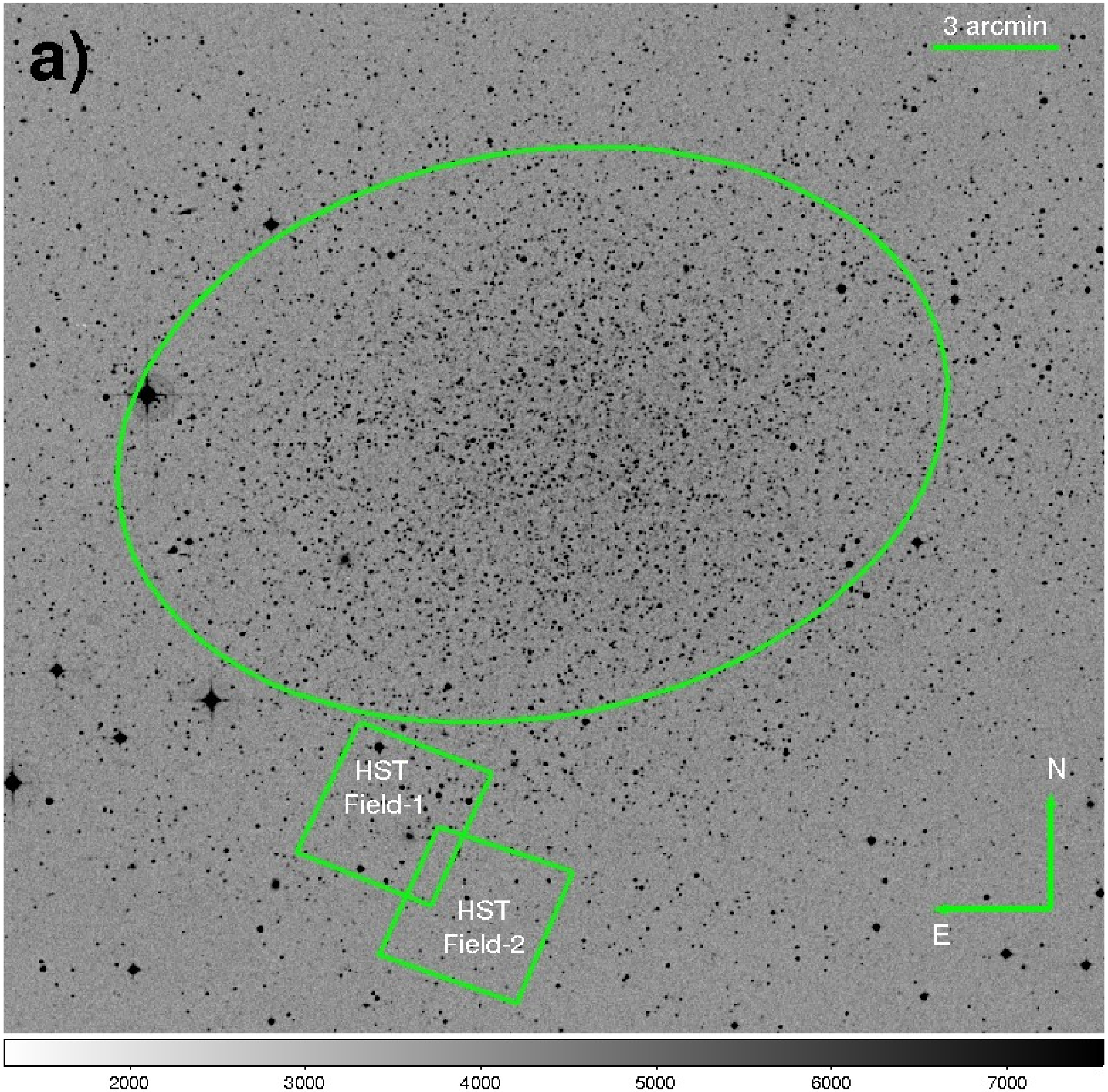


At the typical magnitude of HB for 100 kpc distant stellar population

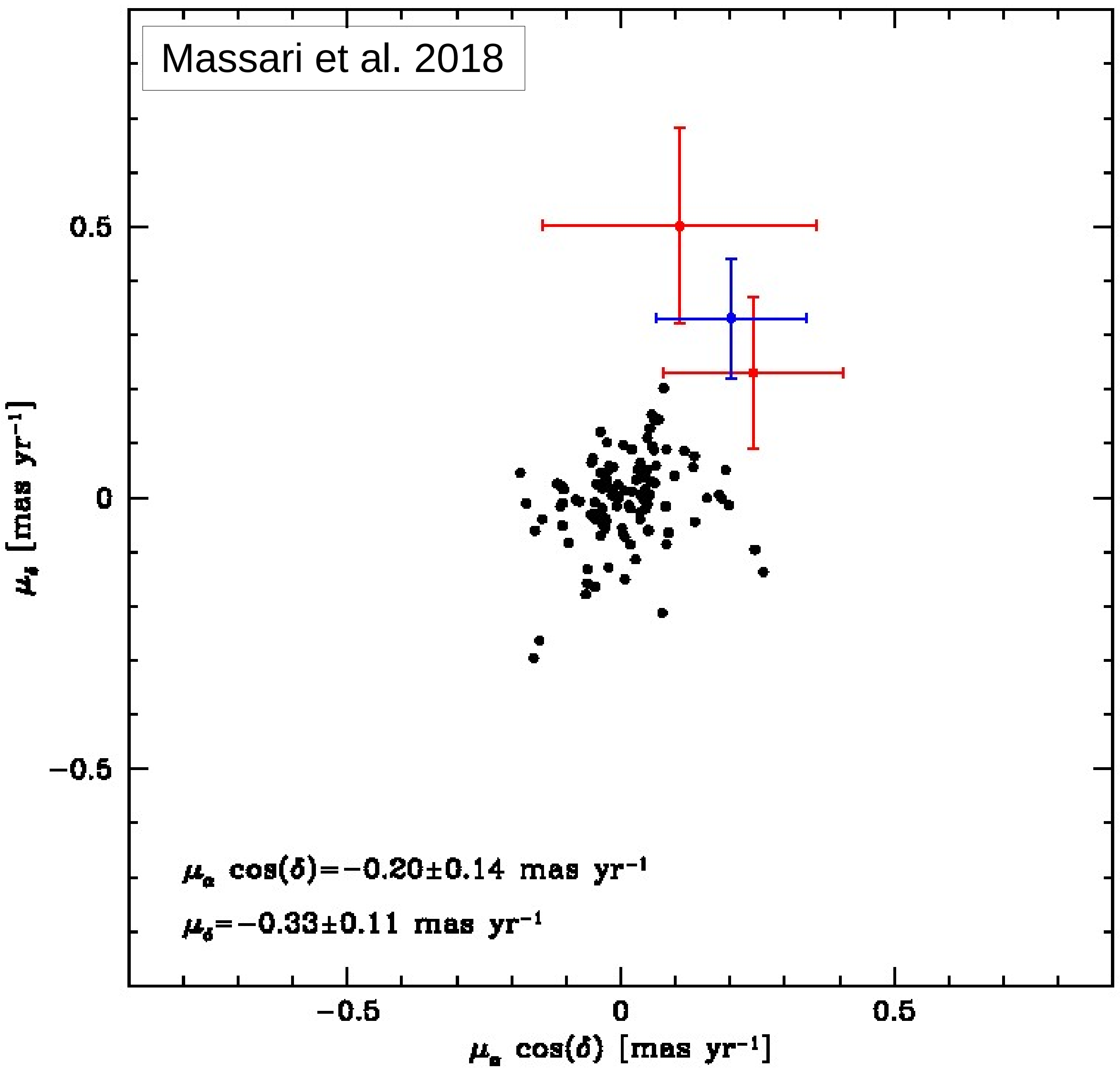
=

Precision similar to HST!

Sculptor dSph PM



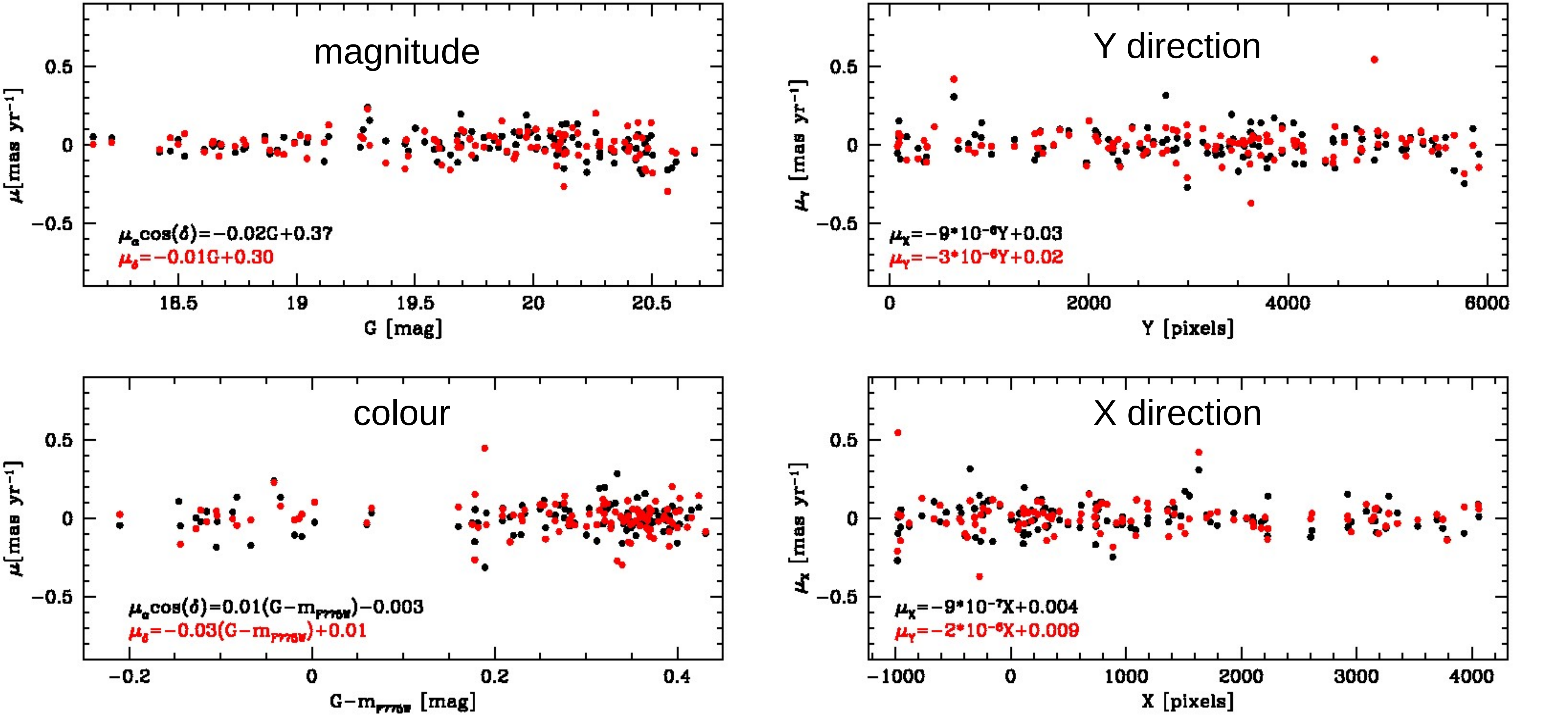
Sculptor dSph PM



Sculptor tangential velocity dispersion

Massari et al. 2018

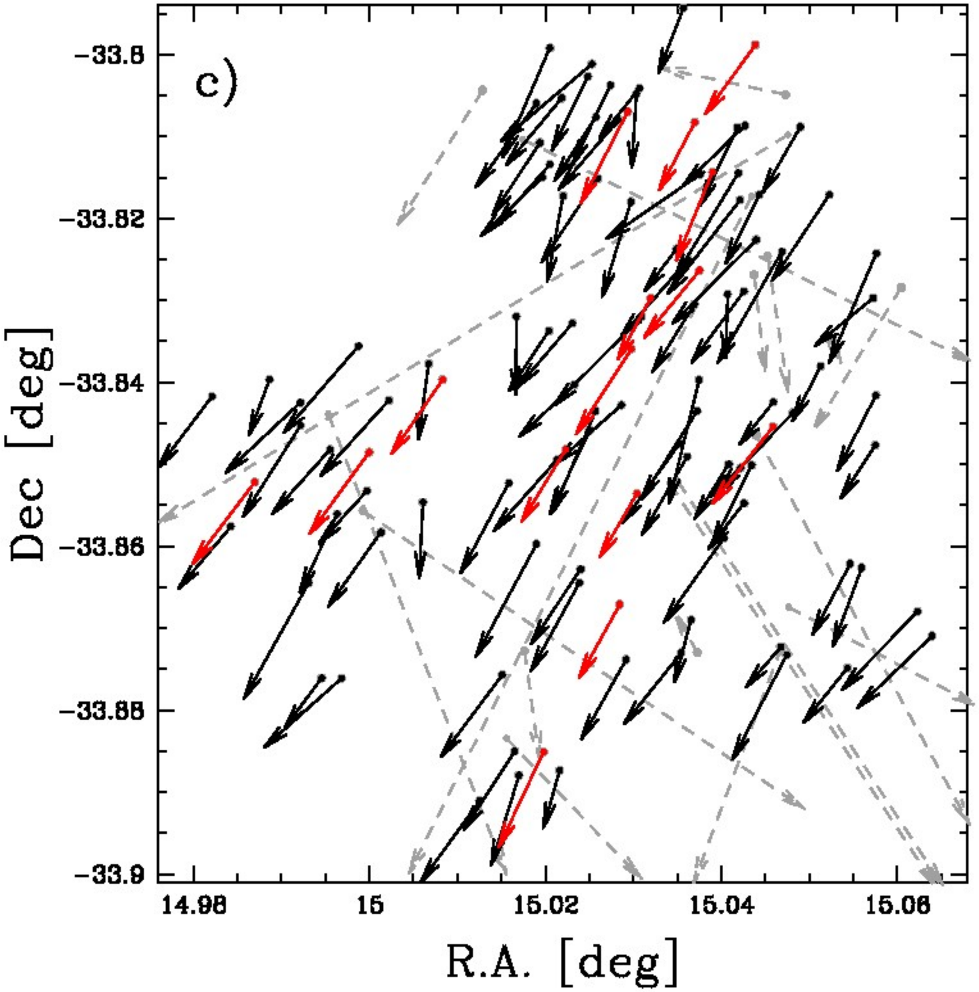
Check for systematics



No systematic trends wrt colour, magnitude, position

Sculptor tangential velocity dispersion

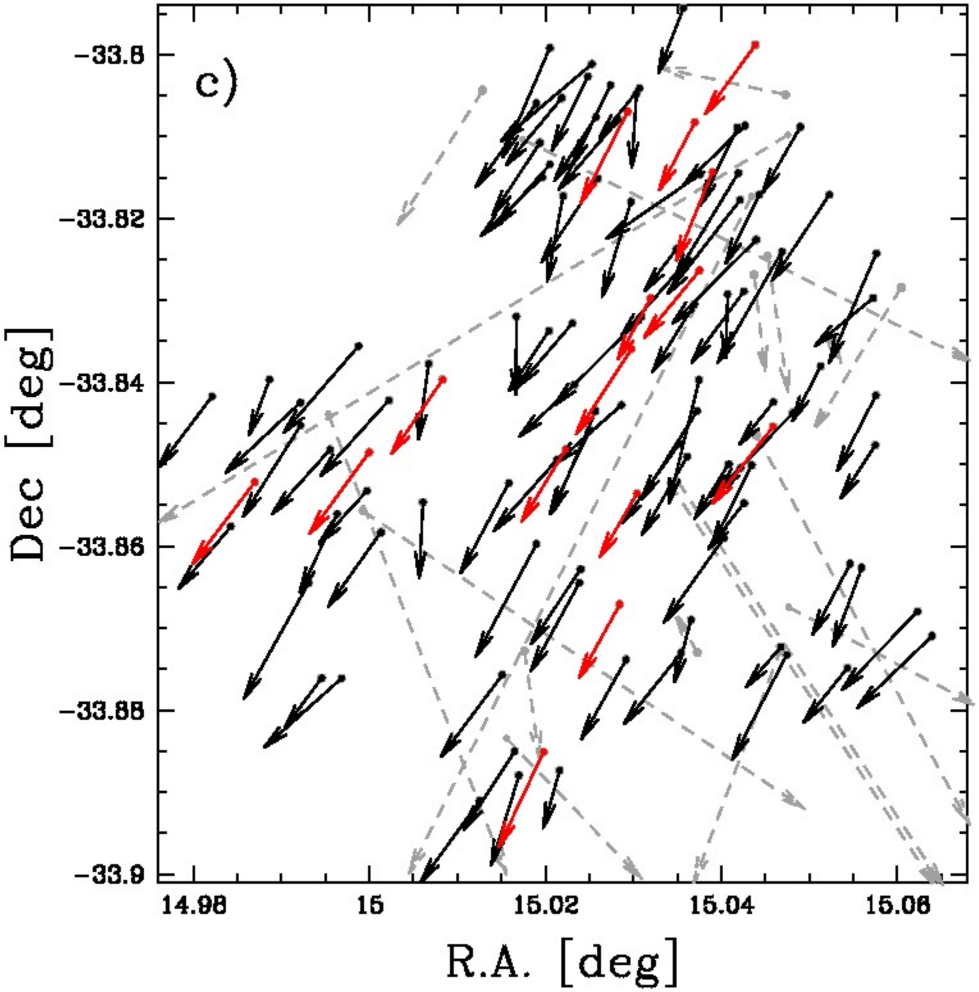
Massari et al. 2018



Sub-sample of 15 best stars

Sculptor tangential velocity dispersion

Massari et al. 2018



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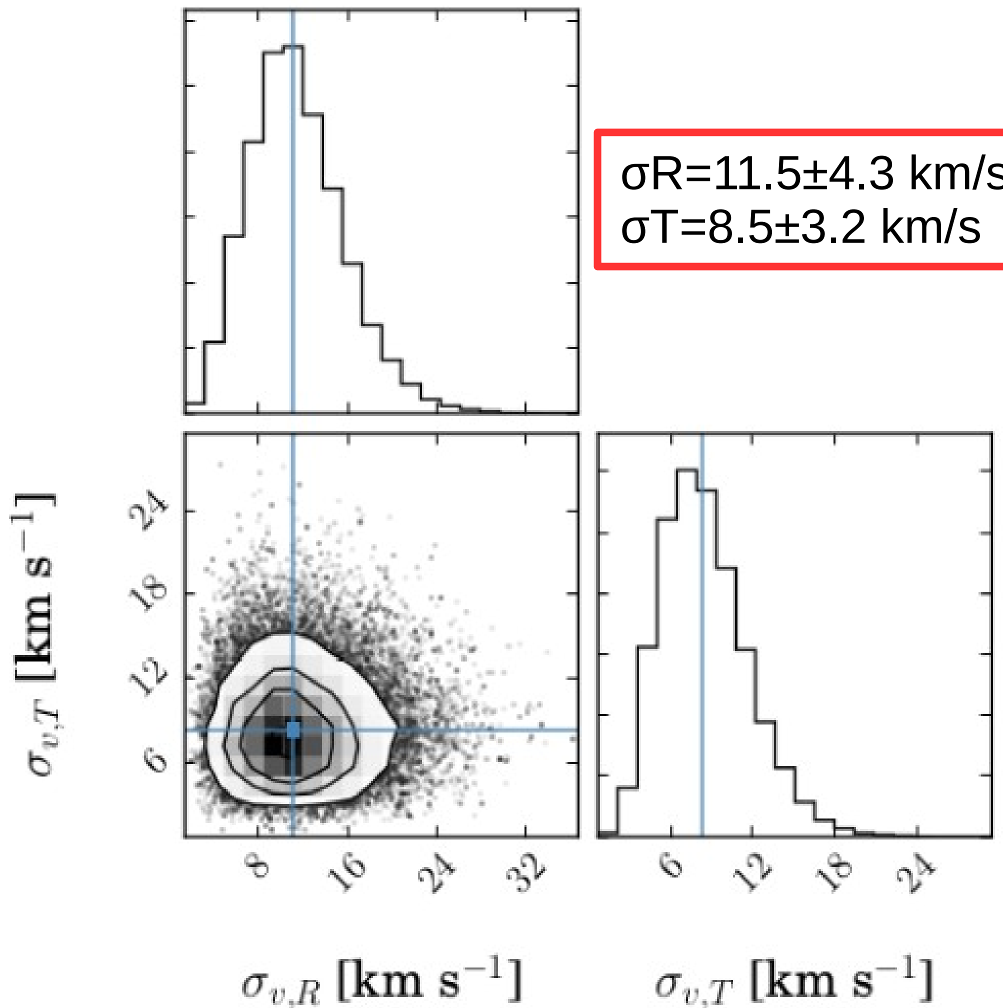
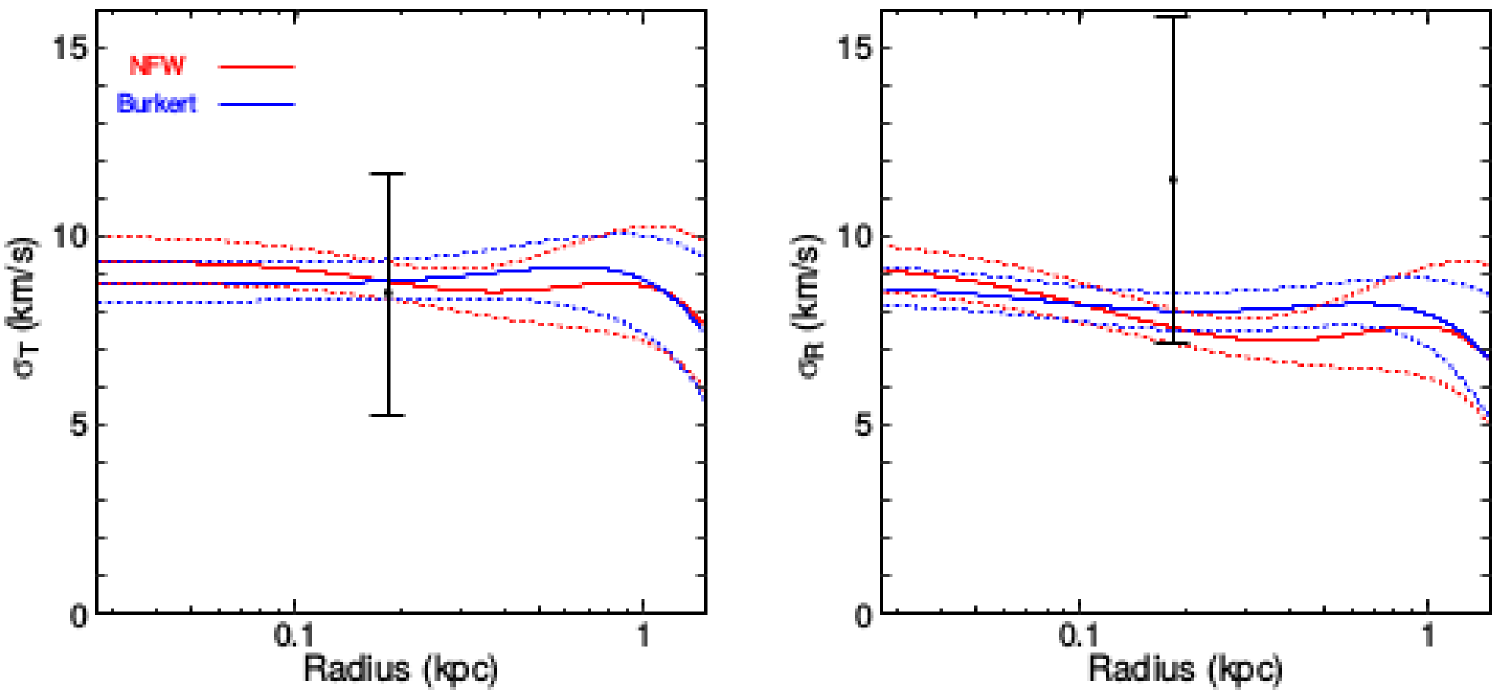


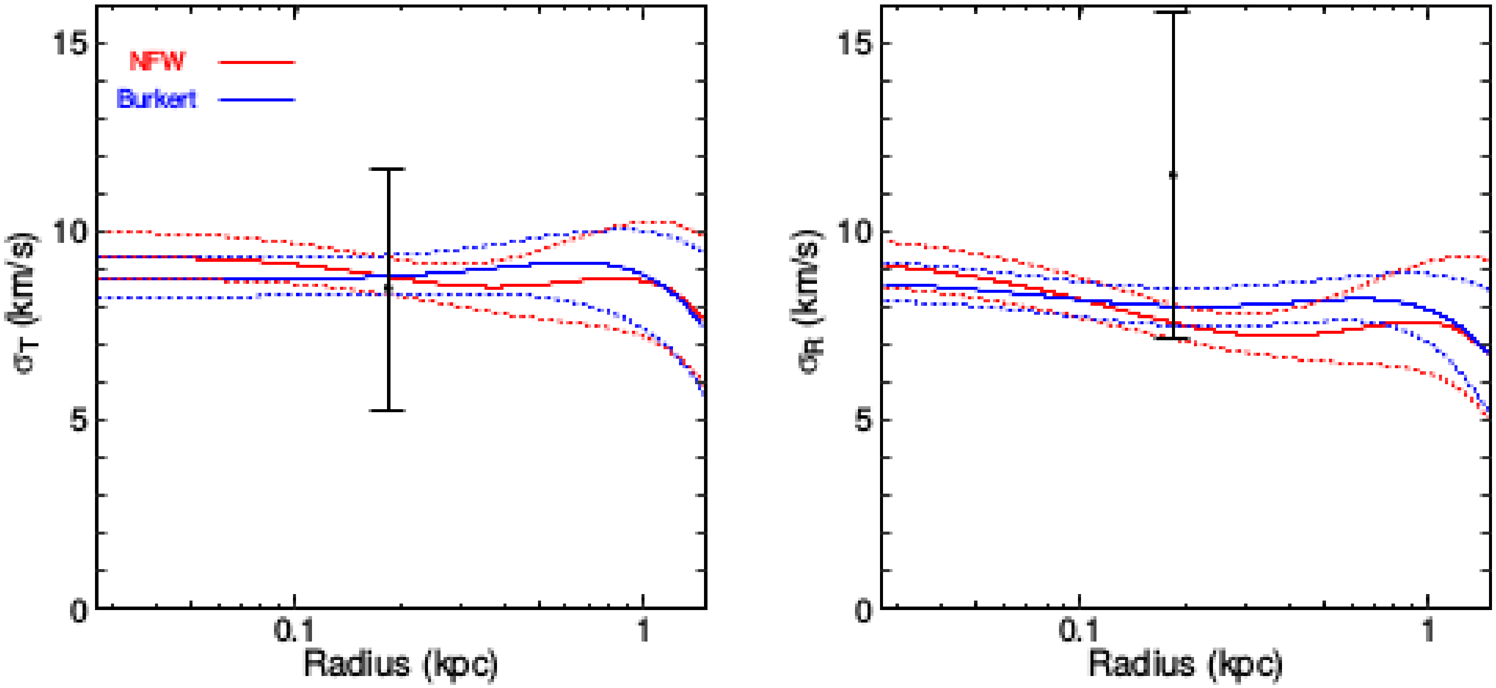
σR=11.5±4.3 km/s
σT=8.5±3.2 km/s

Sculptor tangential velocity dispersion



Strigari, Frank & White 2018
(see also Lazar & Bullock 2019)

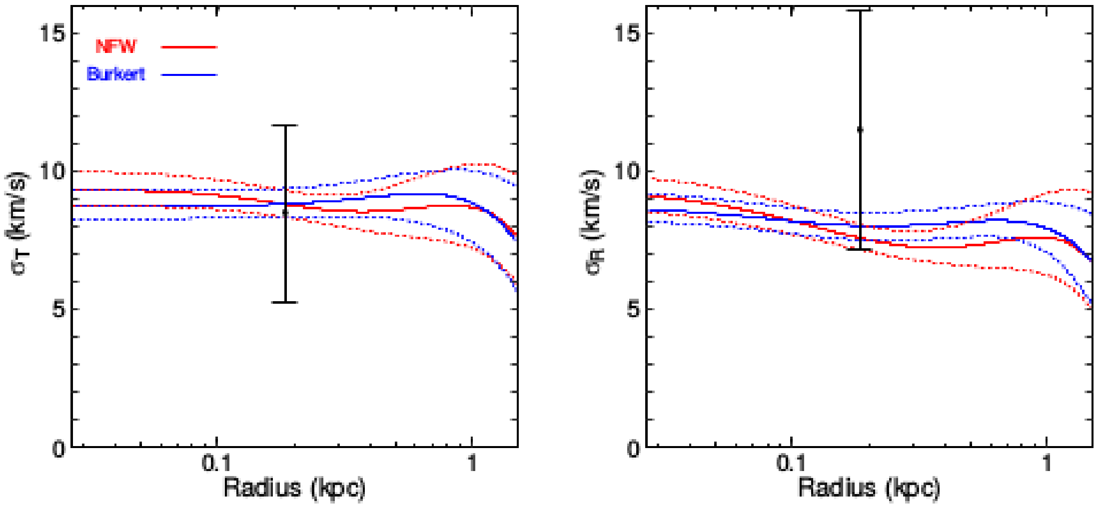
Sculptor tangential velocity dispersion



Strigari, Frank & White 2018
(see also Lazar & Bullock 2019)

First glimpse of what Gaia will enable in few years

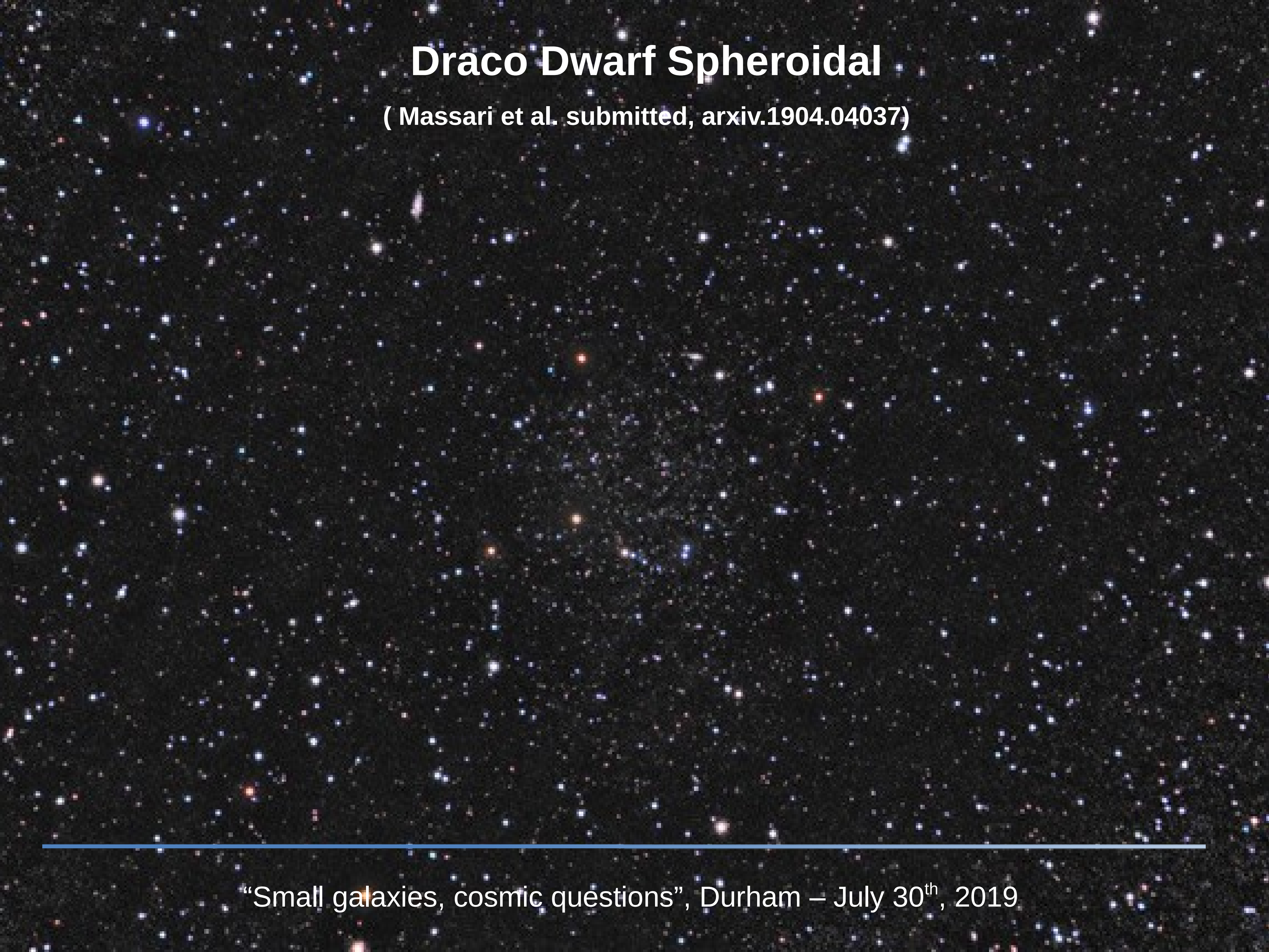
Sculptor tangential velocity dispersion



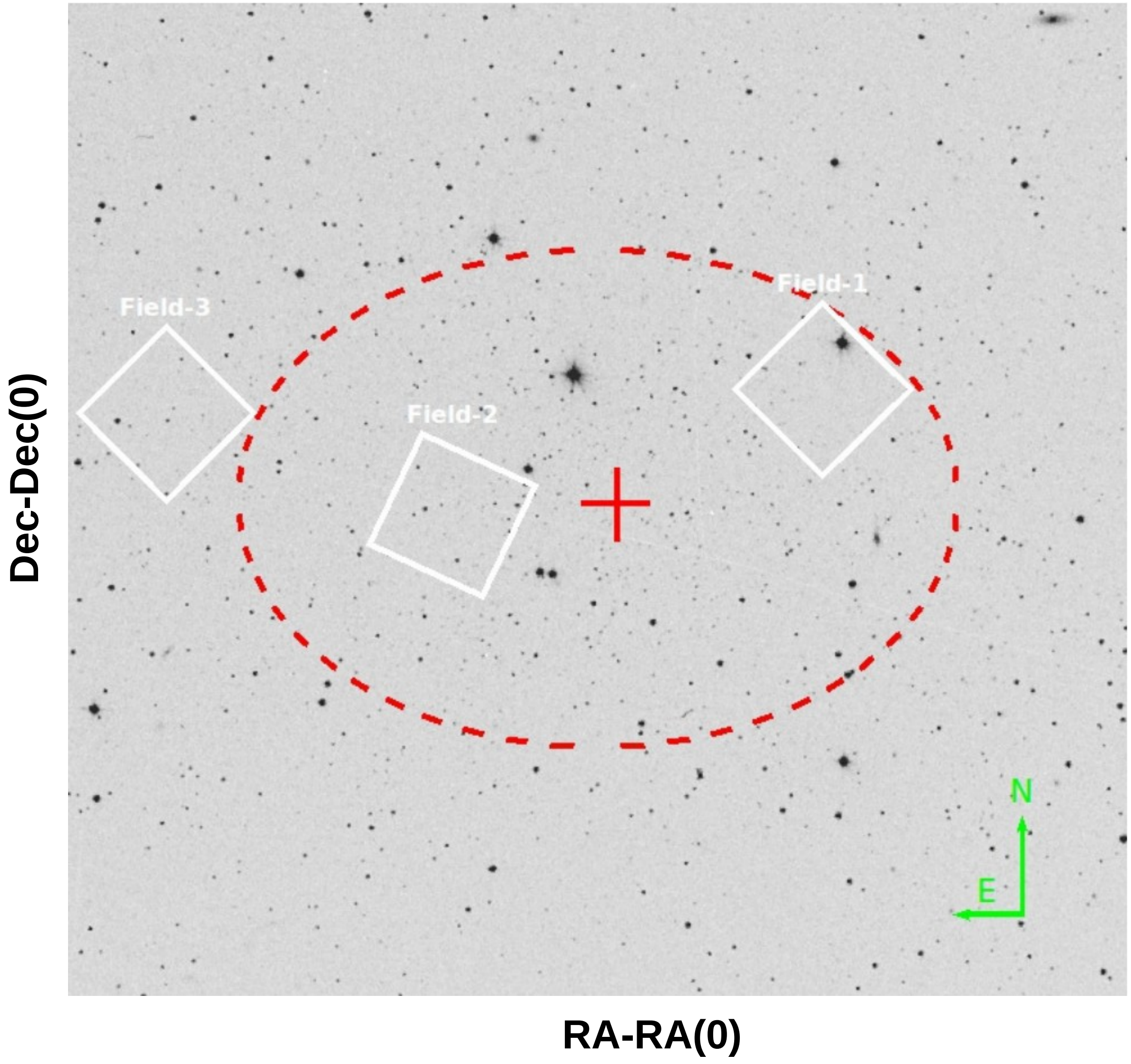
- DR1 positions
- Few stars with precise PMs
- Location at R>R_h

Draco Dwarf Spheroidal

(Massari et al. submitted, arxiv.1904.04037)



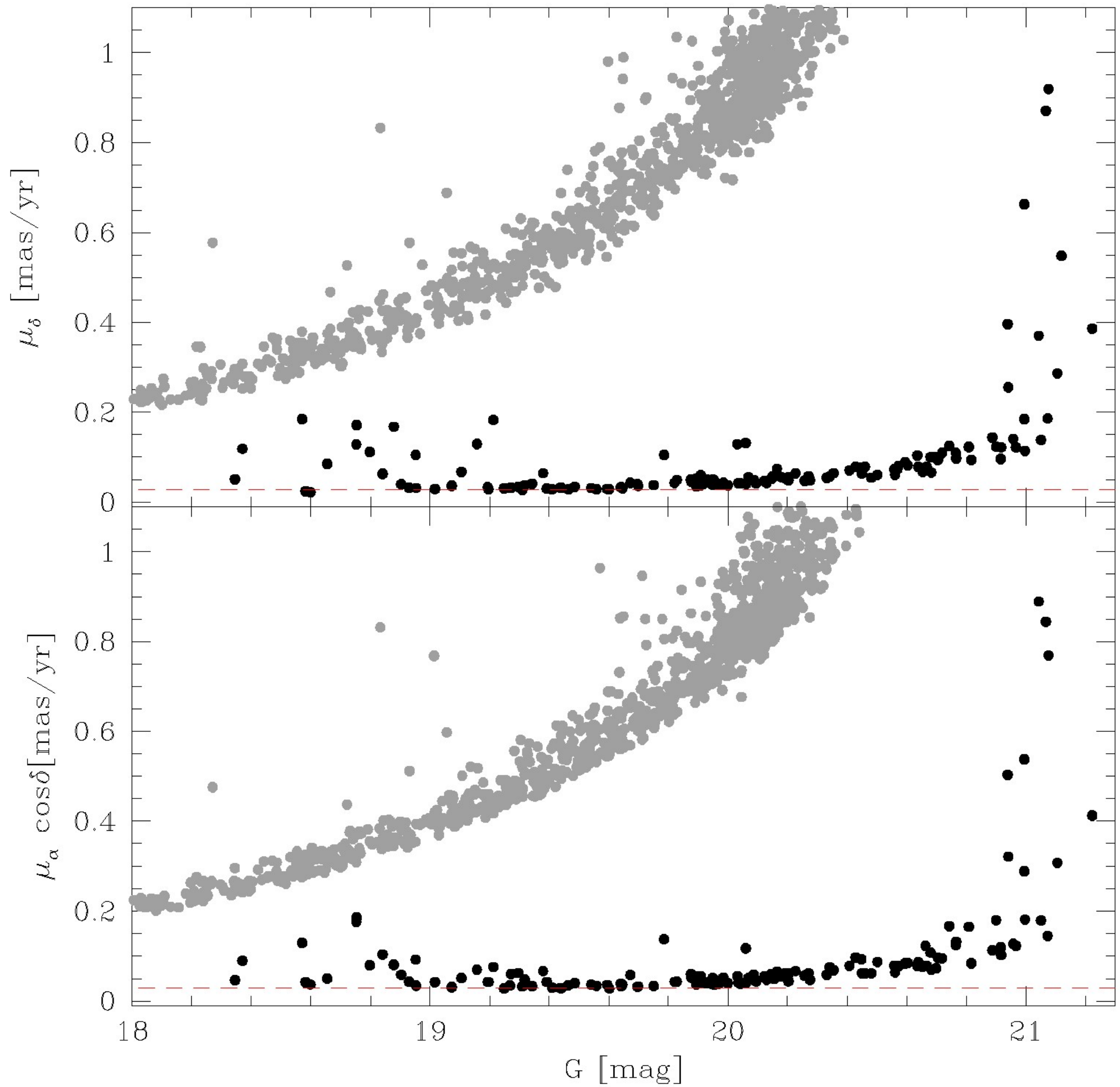
Draco Dwarf Spheroidal



- Gaia DR2 positions
- 3 HST pointings taken in 2004
- 2 pointings within half light radius
- Distance = 76 kpc (McConnachie 2012)

PM for 149 stars!

Draco dSph: proper motions



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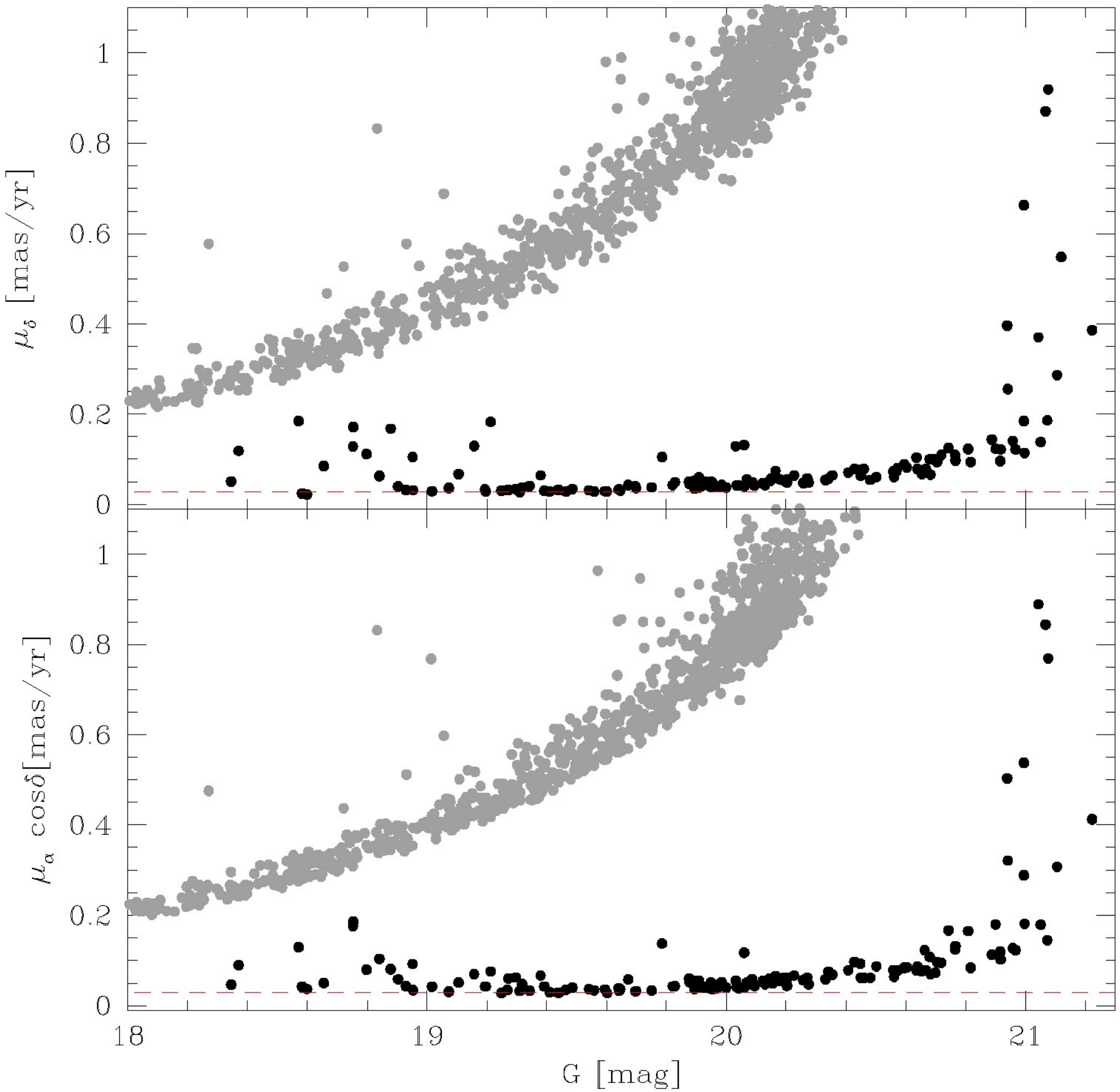
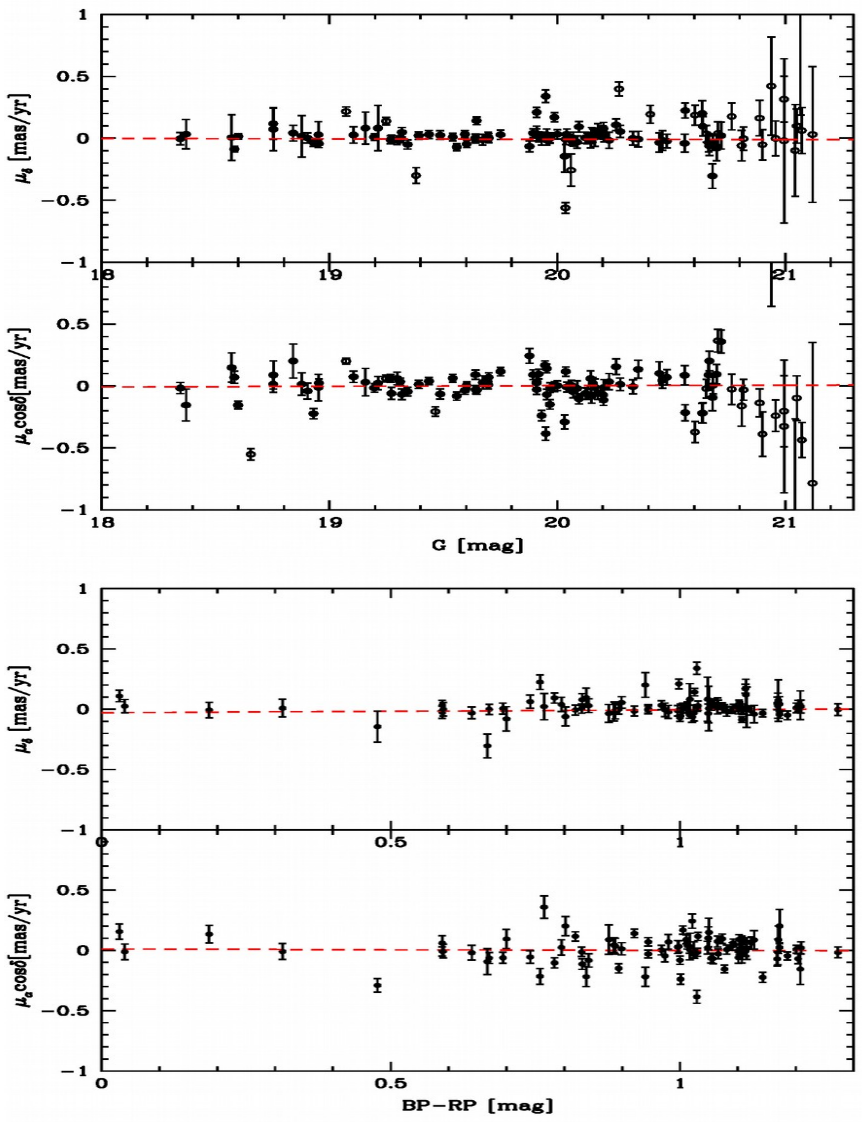
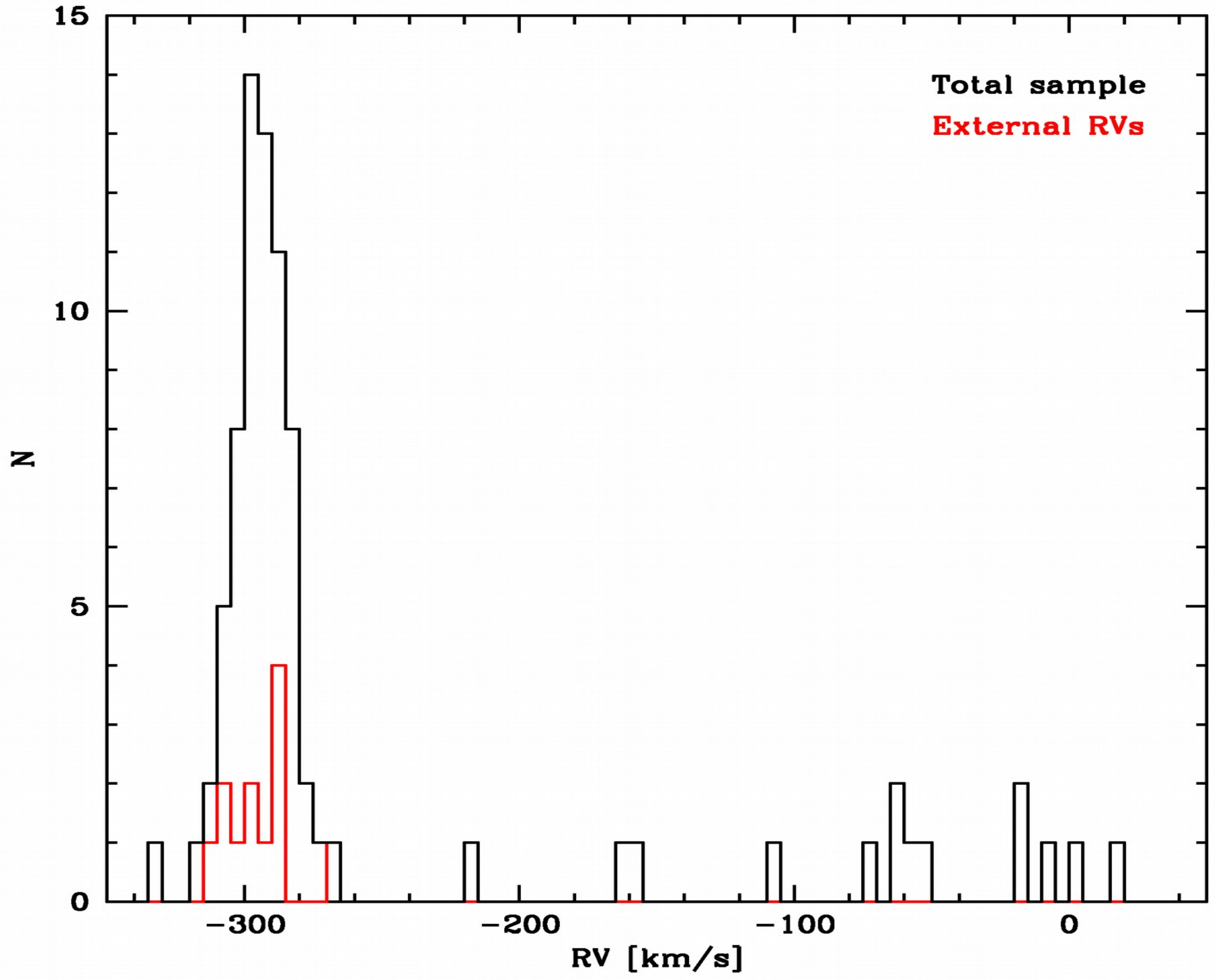




Draco dSph: LOS velocities

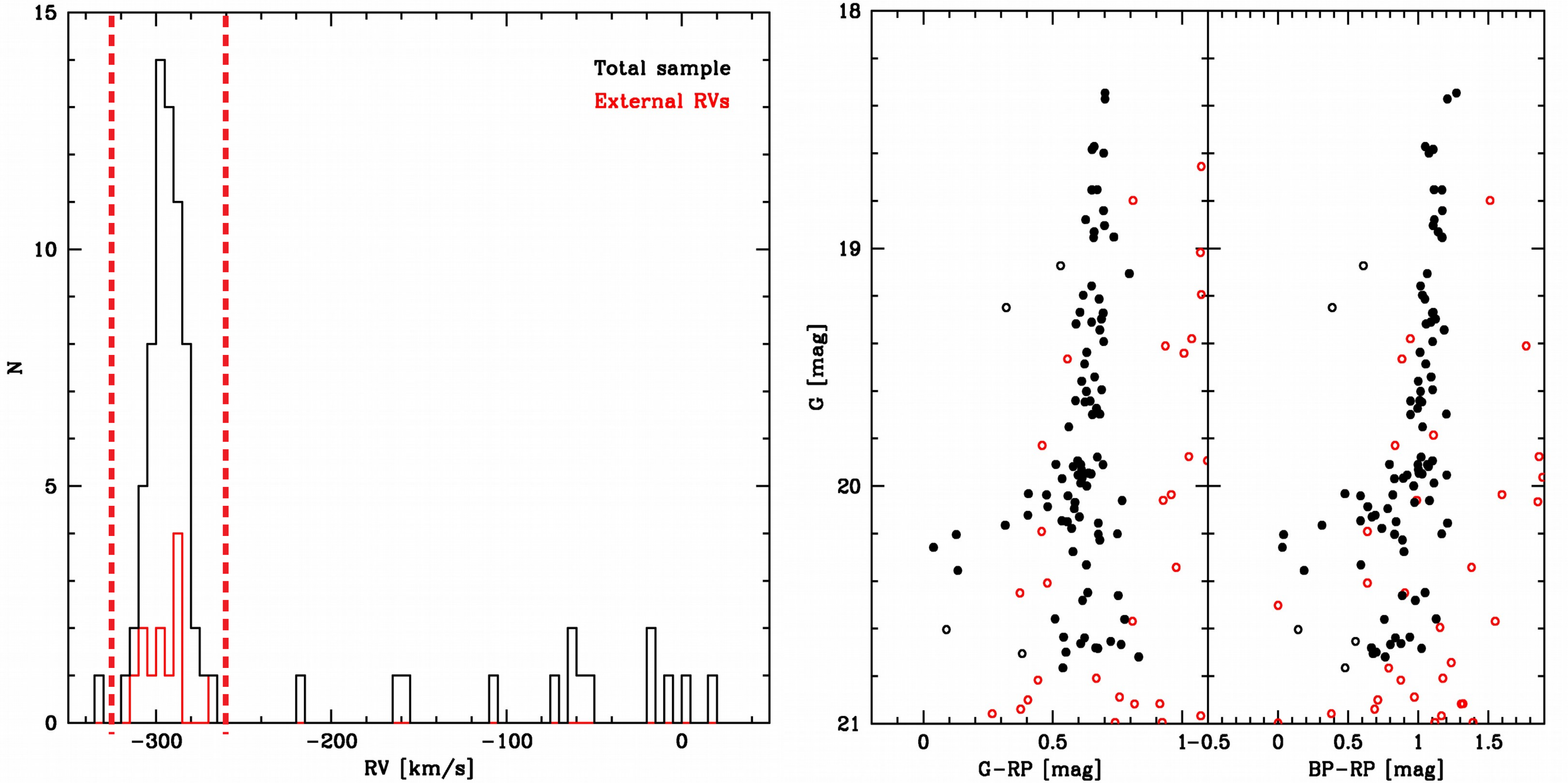
6 hours of observing time with DEIMOS@ Keck telescope



External samples:
Armandroff et al.1995
Kleyna et al.2002
Kirby et al.2010
Walker et al.2015

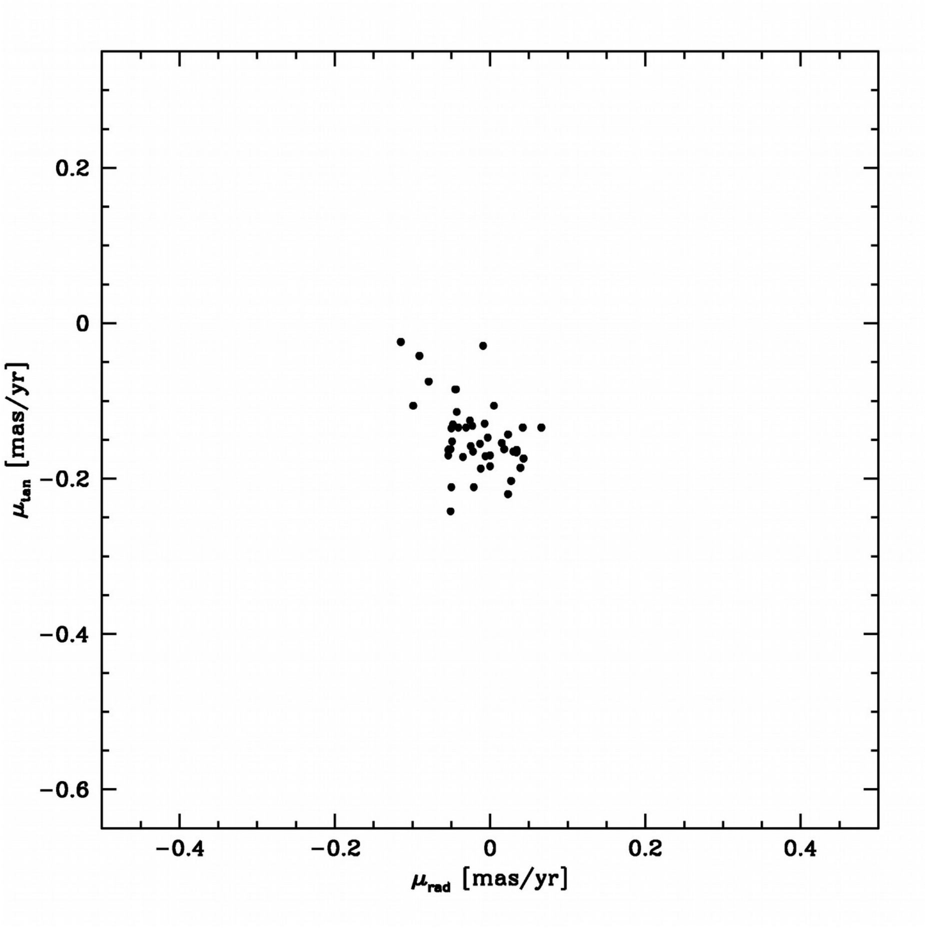
RVs for 81 stars!

Draco dSph: membership

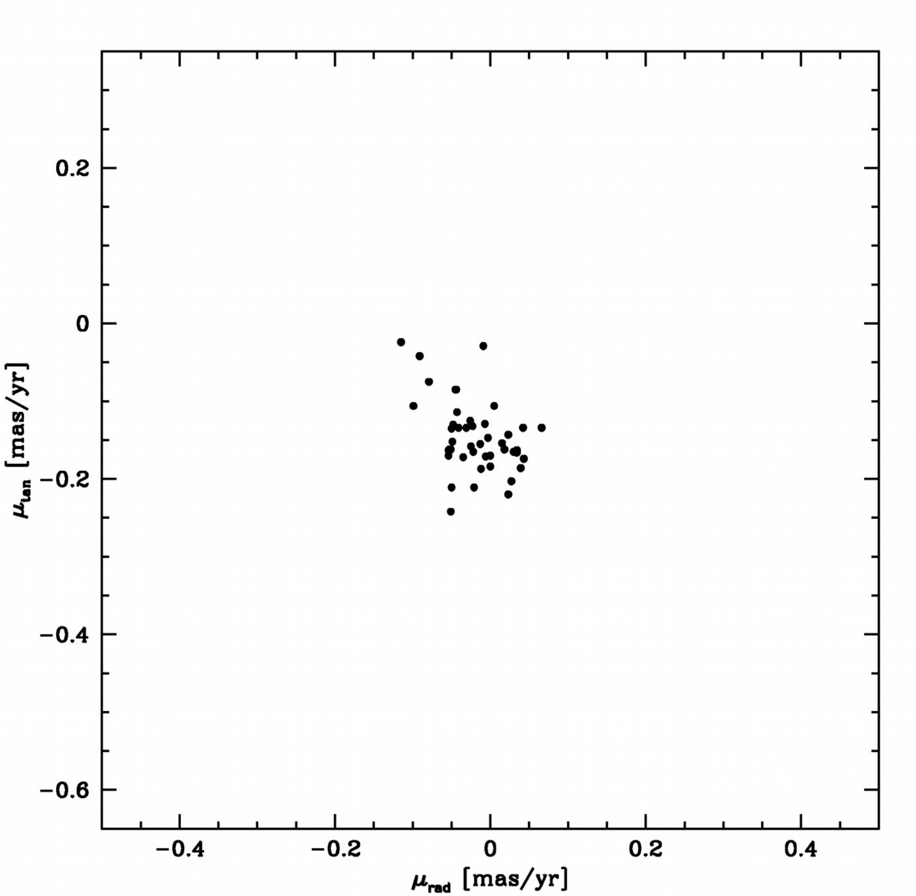


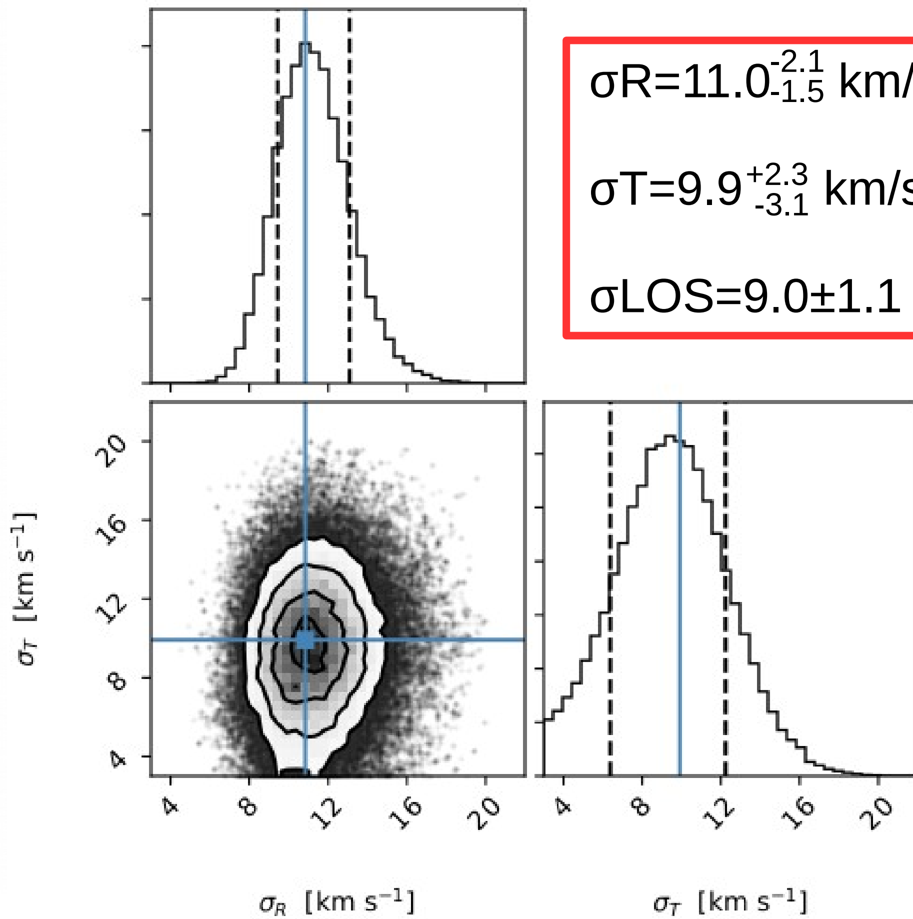
PMs and RVs for 45 members

DRACO Dwarf Spheroidal



Draco dSph: velocity dispersions





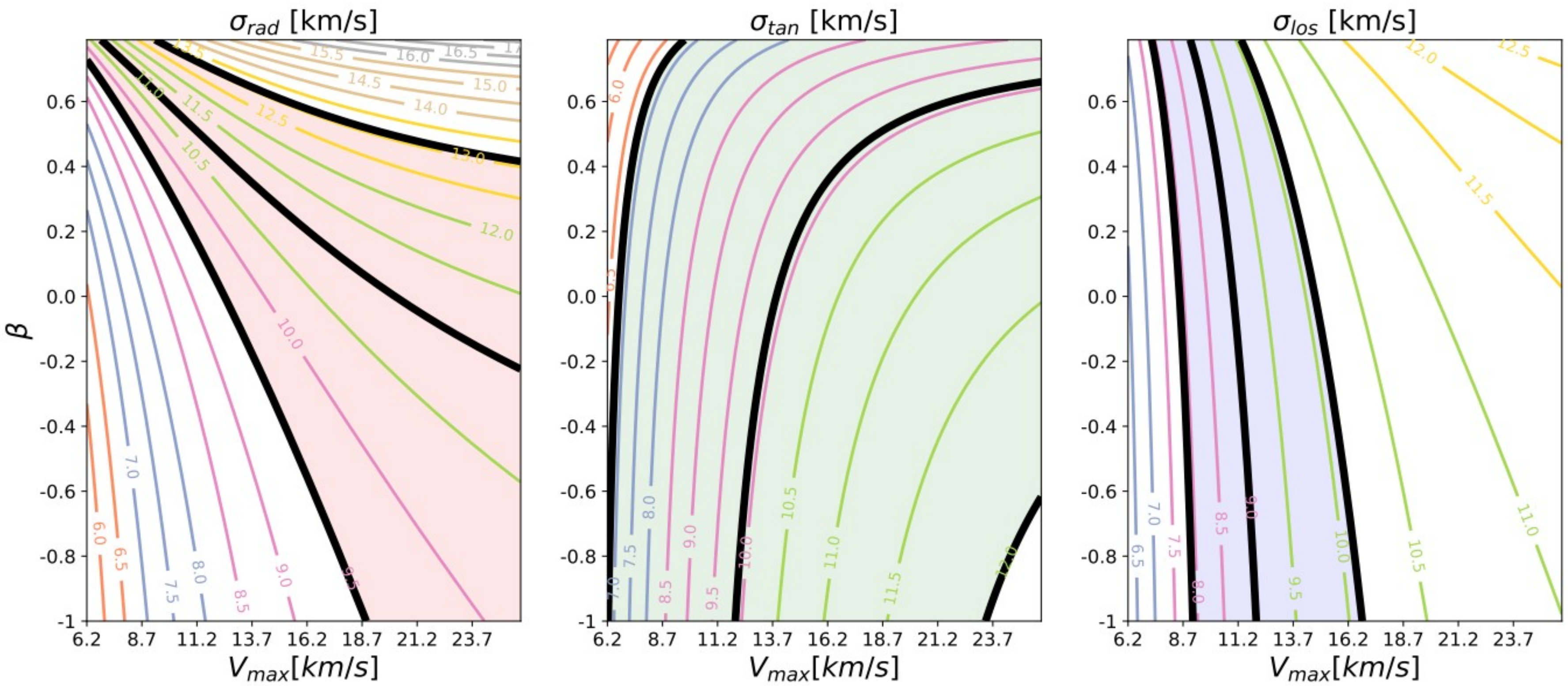
$\sigma R=11.0^{-2.1}_{-1.5}$ km/s

$\sigma T=9.9^{+2.3}_{-3.1}$ km/s

σLOS=9.0±1.1 km/s

Draco dSph: dynamical modelling

σR=11.0$^{+2.1}_{-1.5}$km/s σT=9.9 $^{+2.3}_{-3.1}$km/s σlos=9.0±1.1 km/s



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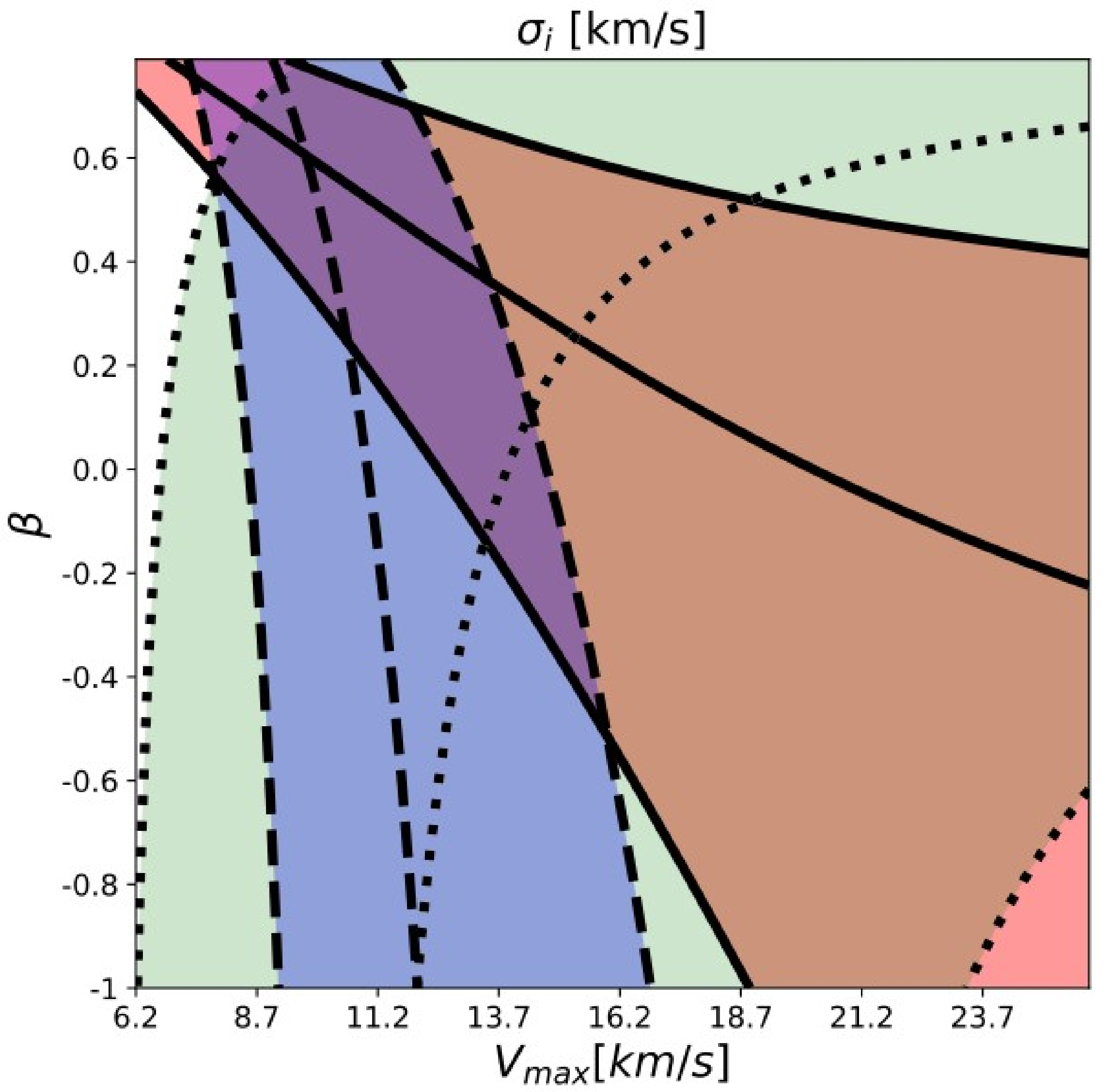

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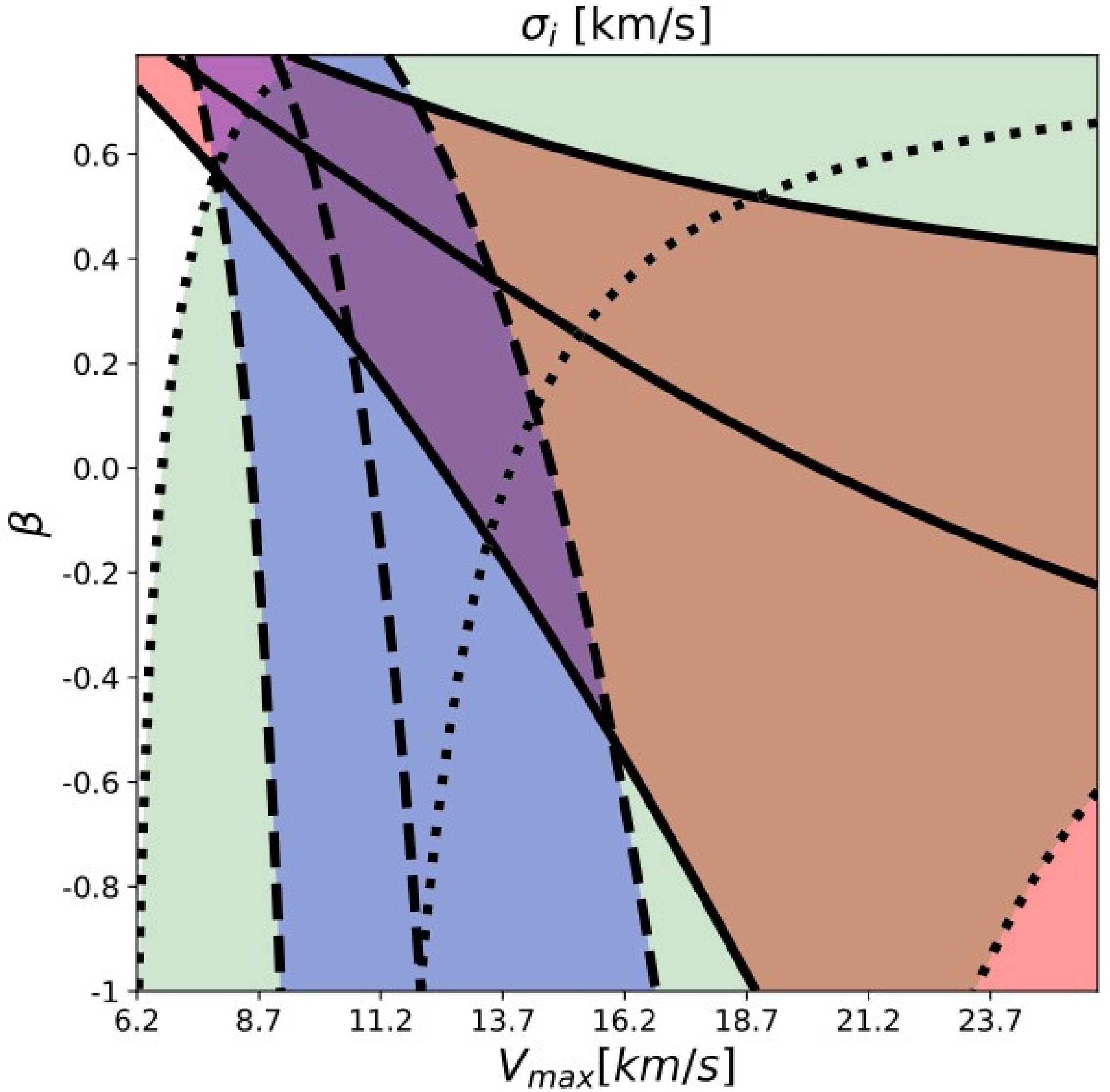
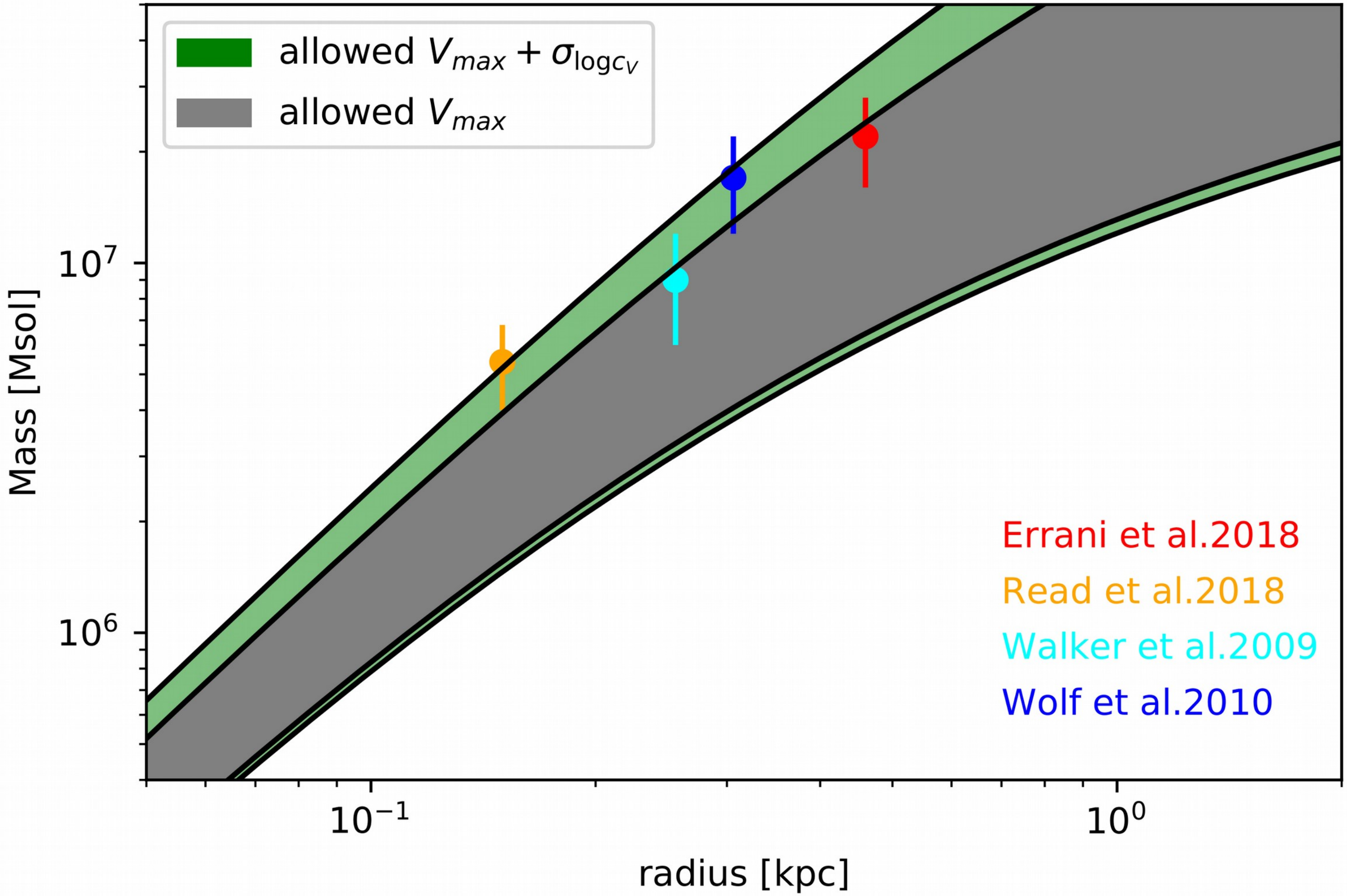


Vmax
+
NFW
Plummer
Vmax-c
(Moline+2017)

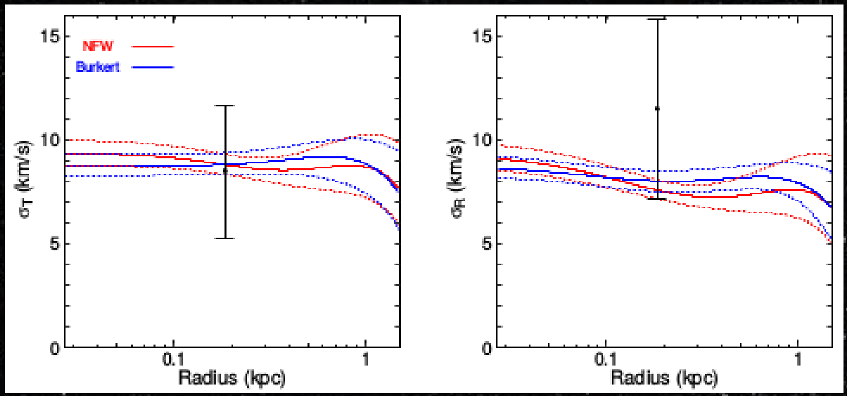
Mass

Draco dSph: dynamical modelling



Consistent with DM cusp

Conclusions



Internal PMs of Sculptor

- radial anisotropy
- need to sample the core and improve PMs

Internal PMs of Draco

- Better PMs than Scl
- 45 stars with 3D kinematics
- Support for DM cusp