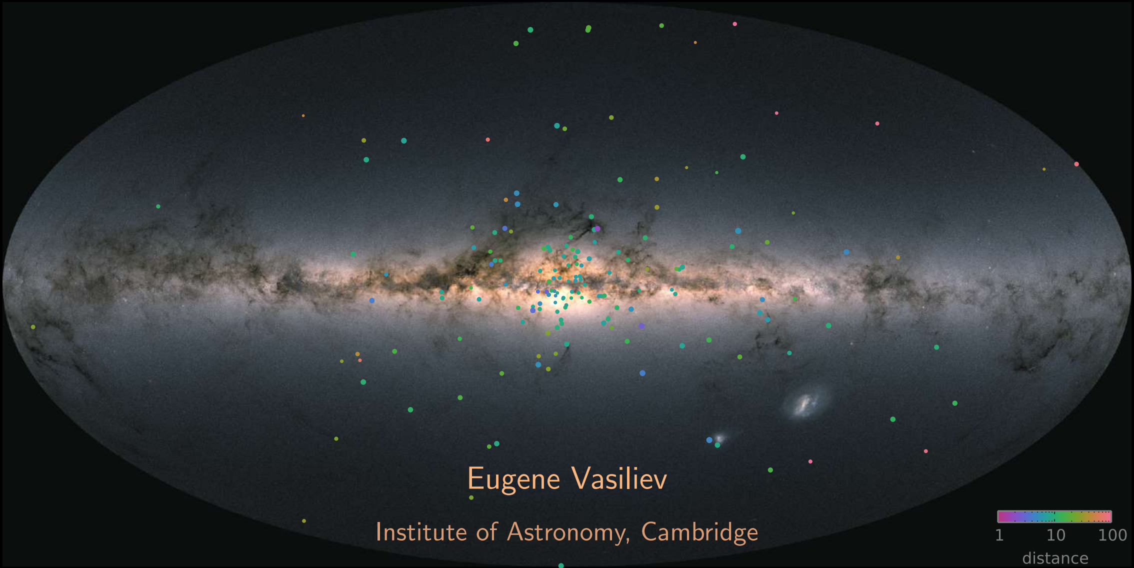
Gaia EDR3 view on Galactic globular clusters



Eugene Vasiliev

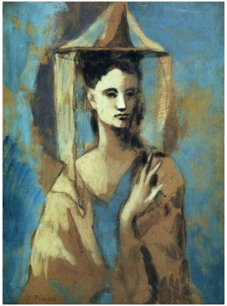
Institute of Astronomy, Cambridge

MW-Gaia workshop, 10 February 2021

The Gaia [r]evolution

DR1 $\Longrightarrow$ DR2

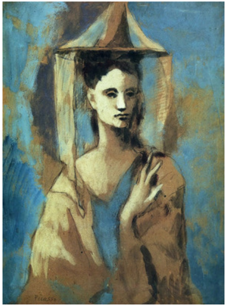
The Gaia [r]evolution



DR1 $\Longrightarrow$

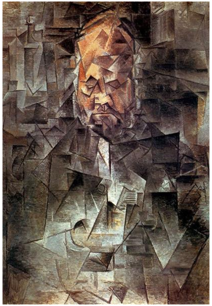
DR2

The Gaia [r]evolution



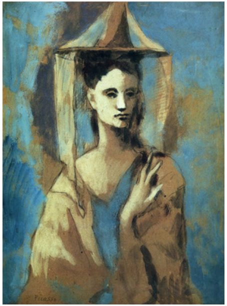
DR1 $\Longrightarrow$

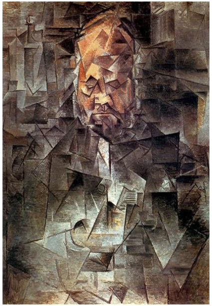
DR2 $\Longrightarrow$



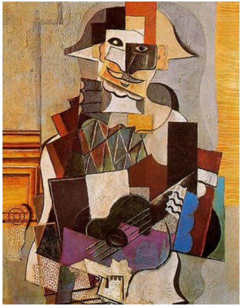
EDR3

The Gaia [r]evolution



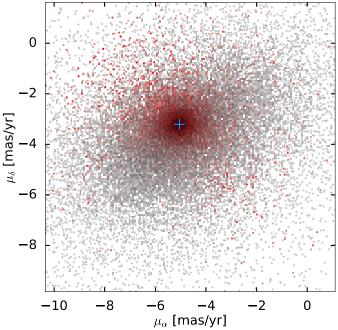
pre-Gaia $\Longrightarrow$ DR1 $\Longrightarrow$ DR2 $\Longrightarrow$ EDR3 $\Longrightarrow$



Determination of cluster properties and membership

Criteria for selecting a "clean" subset of stars:

$G \geq 13$;
RUWE < 1.15;
`astrometric_excess_noise_sig` < 2;
`ipd_gof_harmonic_amplitude` $< \exp\left[0.18\,(G-33)\right]$;
`ipd_frac_multi_peak` ≤ 2;
`visibility_periods_used` ≥ 10;
`phot_bp_rp_excess_factor` $< C^{\star}(\mathrm{bp\_rp}) + 3\,\epsilon_{C^{\star}}(G)$;
usually only 5p sources (when have enough of them).



Mixture modelling approach:

measurements: $\varpi, \boldsymbol{\mu}, R$

$$\text{maximize}\ \ \ln \mathscr{L} \equiv \sum_{i=1}^{N_\mathrm{stars}} \ln \left[\eta\, f_\mathrm{memb}(\mathbf{x}_i \mid \boldsymbol{\theta}_\mathrm{memb}) + (1-\eta)\, f_\mathrm{field}(\mathbf{x}_i \mid \boldsymbol{\theta}_\mathrm{field})\right],$$

parameters of distributions

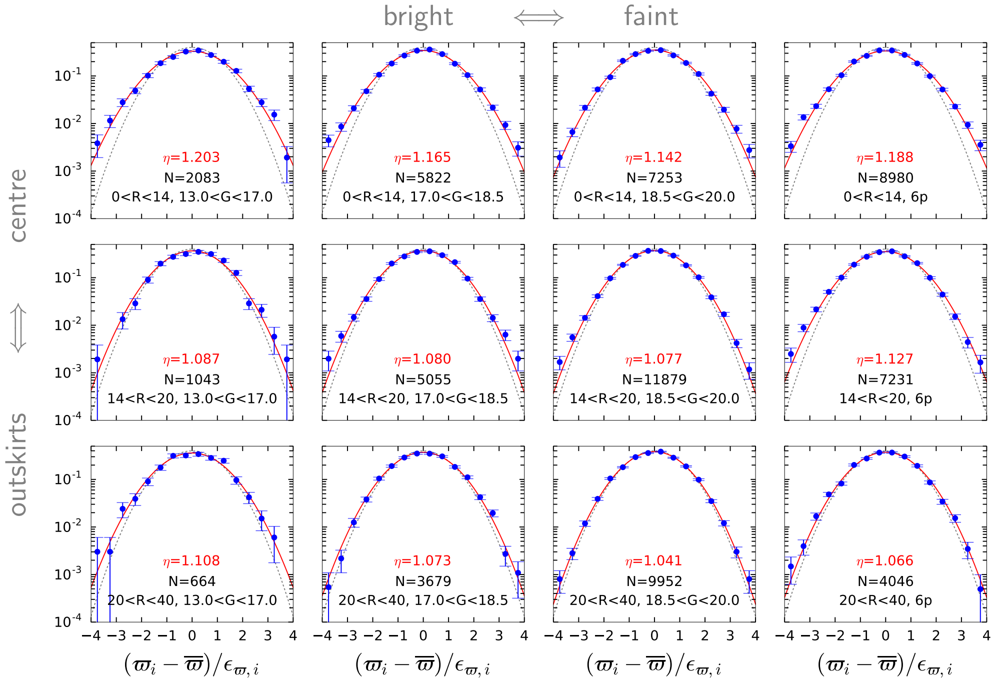
membership probability of i-th star:

$$p_i = \frac{\eta\, f_\mathrm{memb}(\mathbf{x}_i)}{\eta\, f_\mathrm{memb}(\mathbf{x}_i) + (1-\eta)\, f_\mathrm{field}(\mathbf{x}_i)}$$

fraction of members

Results: $\overline{\varpi},\ \overline{\boldsymbol{\mu}},\ \sigma_\mu(R),\ \mu_\mathrm{rot}(R),\ \eta,\ p_i,\ \ldots$

1.1 Statistical uncertainties are slightly underestimated



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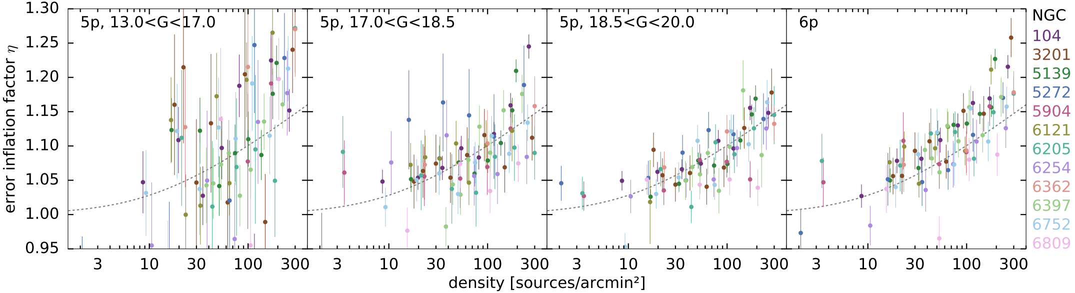

Actual vs. formal uncertainty:

$$\epsilon^2_{\text{actual}} = \eta^2\,\epsilon^2_{\text{formal}} + \epsilon^2_{\text{add}},$$

error inflation factor

$$\begin{aligned} \eta &= (1+\Sigma/\Sigma_0)^{\zeta}, \\ \Sigma_0 &= 10 \text{ stars/arcmin}^2, \\ \zeta &= 0.04, \\ \epsilon_{\text{add}} &= 0.01 \text{ mas.} \end{aligned}$$

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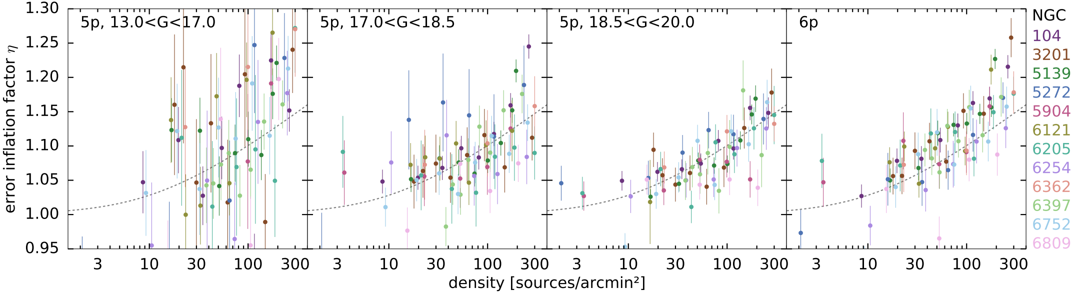

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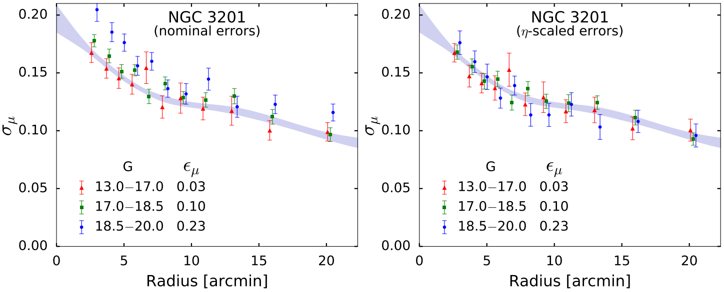
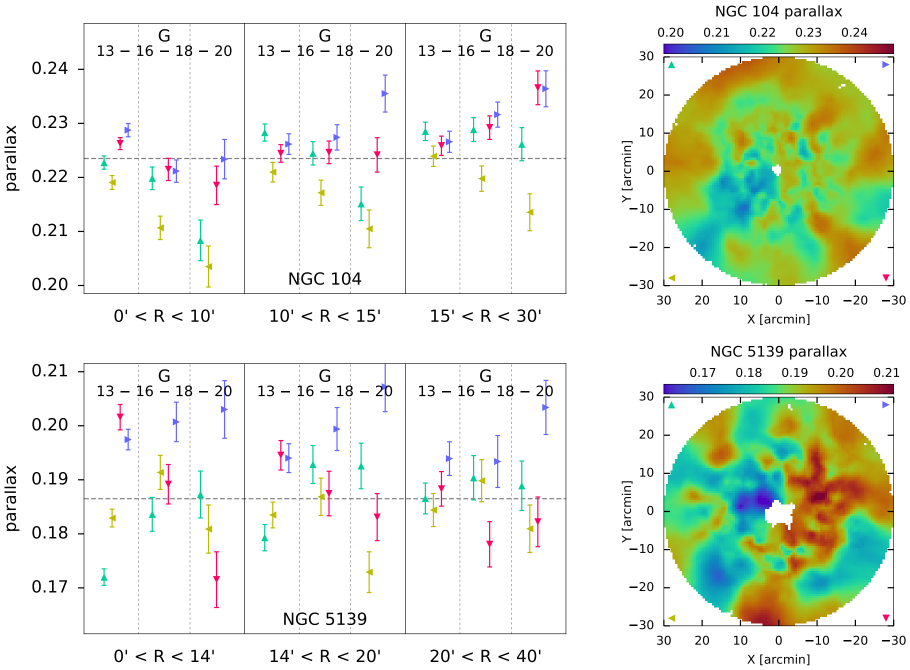
Deconvolved PM dispersion profiles



1.2 Systematic errors are spatially correlated



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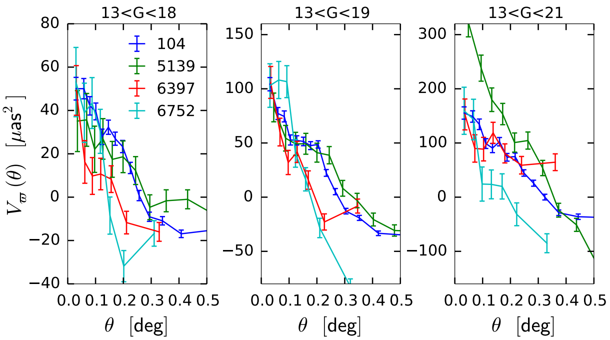


Spatial covariance function: $V_\varpi(\theta) = \langle (\varpi_i - \overline{\varpi})(\varpi_j - \overline{\varpi}) \rangle$,
where θ is the angular distance between stars i and j.

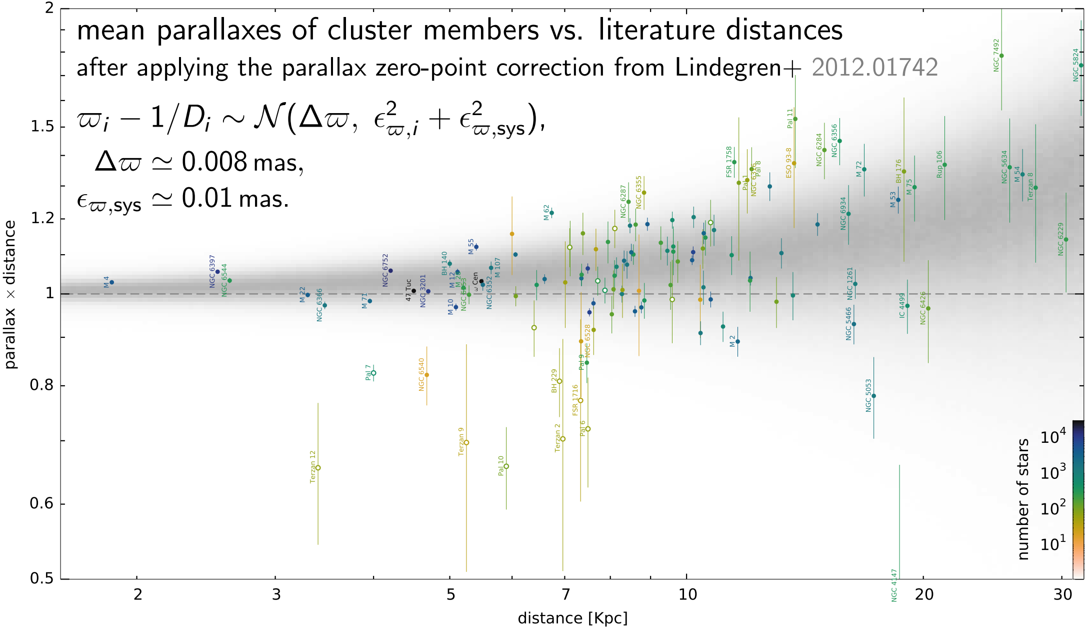
see Lindegren+ 2012.03380, Maíz Apellániz+ 2101.10206
for $V_\varpi(\theta)$ determined on scales $\theta \gtrsim 1^\circ$ from LMC stars and quasars.

For bright stars ($13 < G < 18$): $\epsilon_{\varpi,\mathrm{sys}} \equiv \sqrt{V_\varpi(\theta = 0)} \simeq 0.01$ mas;
for fainter stars it may be $\sim 1.5 - 2\times$ higher.

Same for PM: $\epsilon_{\mu,\mathrm{sys}} \simeq 0.025$ mas/yr.

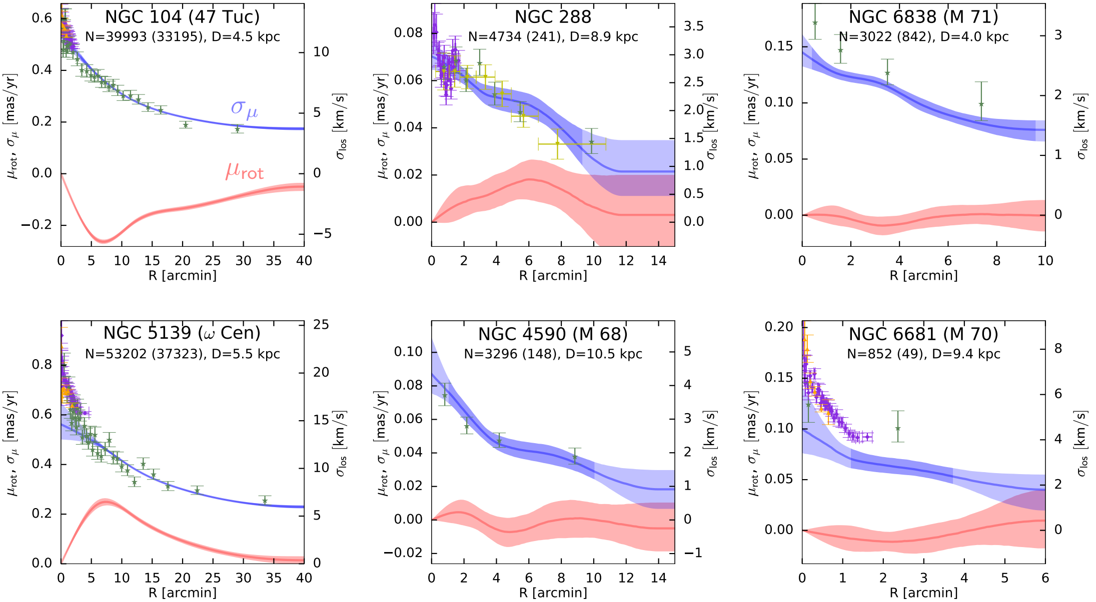
DR2:
$\epsilon_{\varpi,\mathrm{sys}} \sim 0.043$
$\epsilon_{\mu,\mathrm{sys}} \sim 0.066$

1.3 [Corrected] parallaxes might be slightly overestimated



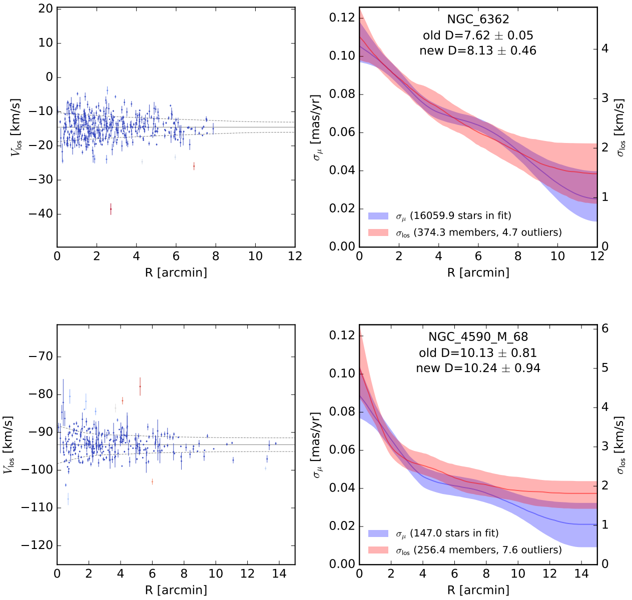
(compilation of literature data by H.Baumgardt)

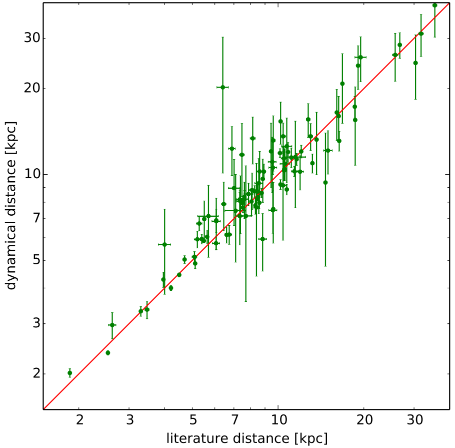
2.1 Internal kinematics: rotation, dispersion



Good agreement with HST σ_μ [Watkins+ 2015, Cohen+ 2021] and σ_{LOS} from literature

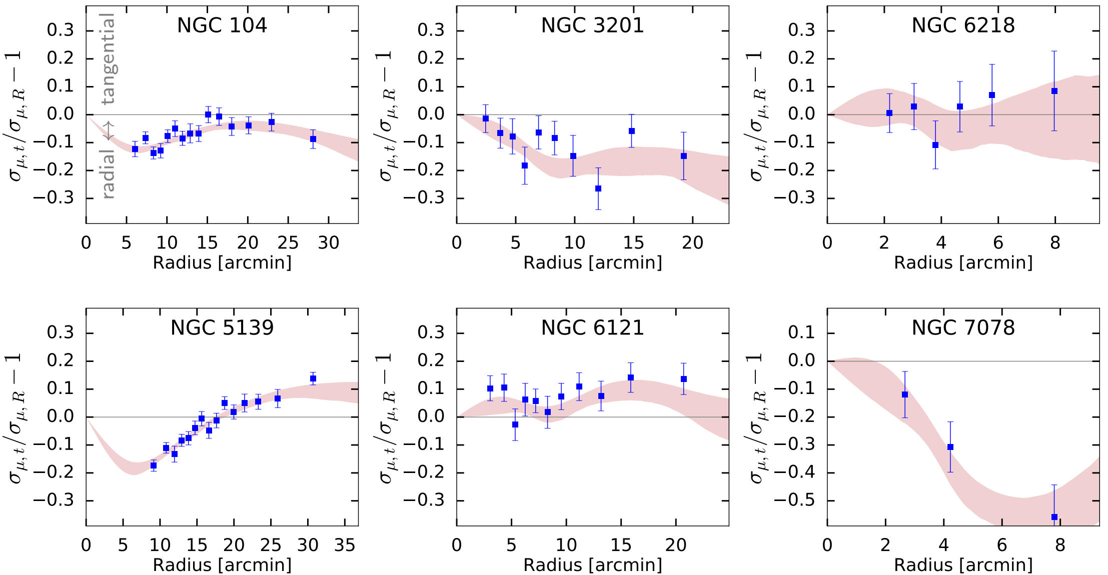
2.2 Dynamical distance determination





large uncertainties but
general agreement with literature

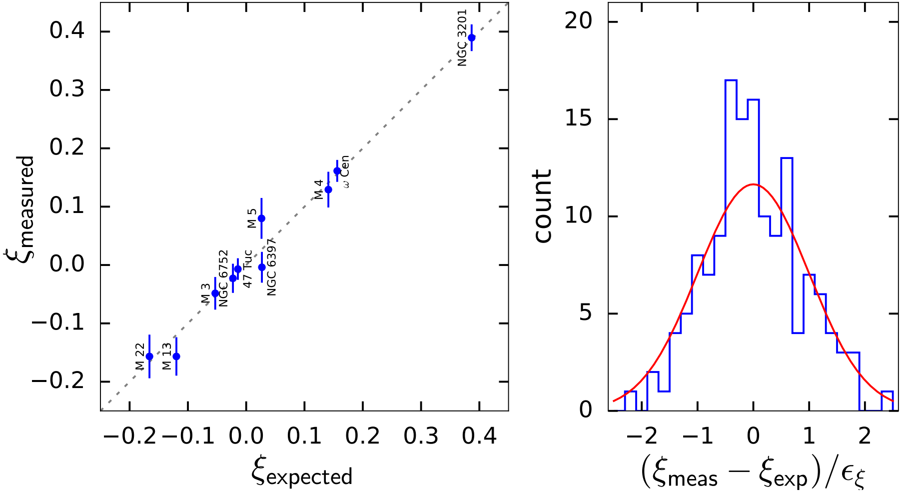
2.3 PM anisotropy profiles



variety of profiles, mostly weakly radial or isotropic

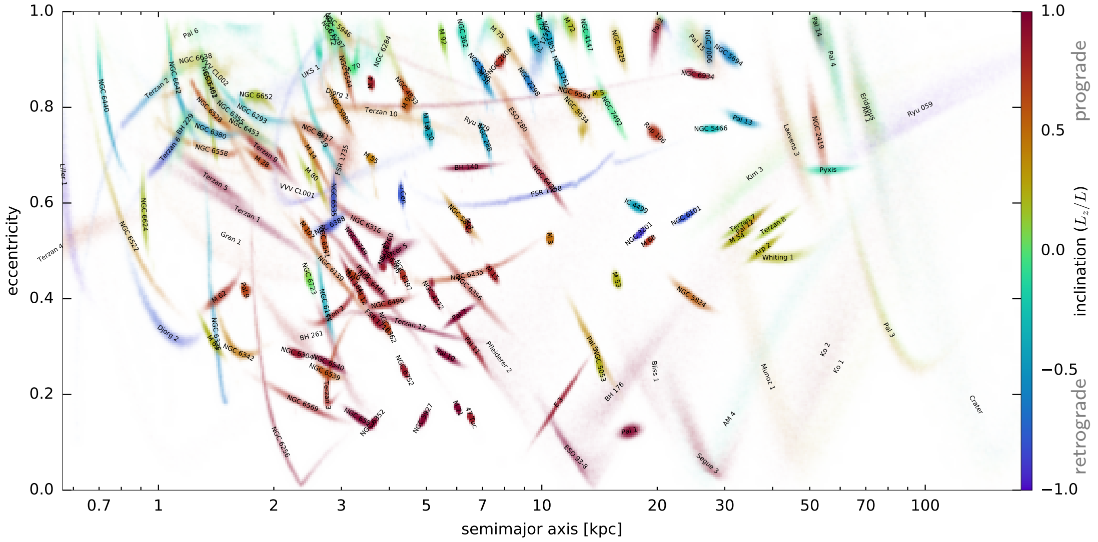
2.4 Perspective effects in the radial PM component

Perspective contraction/expansion due to line-of-sight motion:
$\mu_R(R) = \xi\, R, \;\; \xi_{\text{expected}} = -v_{\text{LOS}}/D \times (\pi/180^\circ/4.74)$ mas/yr/degree.



(error bars take into account spatially correlated systematics)

2.5 Orbits of clusters in the Milky Way



distance errors are the major source of uncertainty in orbit parameters

Summary: Gaia EDR3 $\Longleftrightarrow$ globular clusters

- Statistical uncertainties are underestimated by $10-20\%$ in dense regions (even for the clean subset);
- Spatially correlated systematic errors on sub-degree scales: $\epsilon_\varpi \simeq 0.01-0.02$ mas, $\epsilon_\mu \simeq 0.025$ mas/yr;
- Parallax zero-point correction overshoots by ~ 0.008 mas.

- Mean parallaxes, PM and orbits determined for 170 globular clusters;
- PM dispersions and dynamical distances – for ~ 100 clusters;
- Rotation detected in ~ 20 clusters;
- PM anisotropy measured in ~ 20 clusters.