HST proper motion kinematics of Milky Way globular clusters

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Roeland van der Marel, Andrea Bellini, Austin Baldwin, Paolo Bianchini, Jay Anderson + HSTPROMO collaboration

AMNH, MODEST NYC, 6 September 2016
anisotropy

distances and M/Ls

blue stragglers
HSTPROMO
Hubble Space Telescope PROper MOfion Collaboration
van der Marel, Anderson, Bellini, Besla, Bianchini, Boylan-Kolchin, Chanamé, Deason, Do, Fardal, Guhathakurta, Kallivayalil, Lennon, Massari, Meyer, Platais, Sabbi, Sohn, Soto, Trenti, Watkins

- globular clusters
- young star clusters
- Local Group galaxies (M31, dSphs, LMC/SMC)
- stars and stellar streams in the MW halo
- AGN black hole jets

http://www.stsci.edu/~marel/hstpromo.html
proper motion catalogues

HST proper motions for 22 Milky Way globular clusters
Bellini+ 2014

- 1.4 million stars (datasets ~3k to ~300k each)
- few km/s accuracy (~35 \( \mu \)as/yr = ~ 1.4km/s)
- different environments
- different dynamical states
- mass segregation / energy equipartition
anisotropy
mass-anisotropy degeneracy

mass estimates require **total** velocity
anisotropy profiles

Watkins+ 2015a
anisotropy and relaxation time

Watkins+ 2015a
anisotropy and ellipticity

\[
\frac{\sigma_{\text{minor}}}{\sigma_{\text{major}}} \quad \epsilon
\]

slope : \(-0.217 \pm 0.061\)
intercept : \(1.001 \pm 0.007\)

Watkins+ 2015a
dynamical distances and mass-to-light ratios
dynamical distances

- line-of-sight velocities
- physical distance / time
- proper motions
- angular distance / time

+ mass-to-light ratios

- compare to photometric estimates
distances

\[ \left( \frac{\Upsilon}{d} \right)^{1/2} \]

(\( \Upsilon \) is a parameter, \( d \) is distance, \( \Upsilon/d \) is the ratio of \( \Upsilon \) to the distance, and \( (\Upsilon/d)^{1/2} \) is the square root of the ratio.)

- Model fit
- Proper motions
- Line-of-sight velocities
- NGC 2808

\[ 9.45^{+0.13}_{-0.15} \text{ kpc} \]

Watkins+ 2015b
dynamical distances

NGC 5904

proper motions

line-of-sight velocities

7.79$^{+0.47}_{-0.61}$ kpc

model fit
photometric vs dynamical distances

\begin{align*}
\frac{(d_{\text{our}} - d_{\text{Harris}})}{d_{\text{Harris}}} & \leq 1.7 \pm 1.9\% \\
\end{align*}

Watkins+ 2015b
population synthesis vs dynamical M/Ls

\[ \left( \Gamma_{\text{our}} - \Gamma_{\text{McLaughlin}} \right) / \Gamma_{\text{McLaughlin}} \]

\[ -8.8 \pm 6.4\% \]

\[ (d_{\text{our}} - d_{\text{Harris}}) / d_{\text{Harris}} \]

Watkins+ 2015b
mass-to-light ratios vs metallicity

Strader+ (2011) •
McLaughlin+ (2005)
HSTPROMO

mass segregation? (Shanahan & Gieles 2015)
Watkins+ 2015b
blue stragglers
(with REU student Austin Baldwin)
what are blue stragglers?
blue straggler selection

NGC 6341

$m_{F814W}$ vs. $m_{F606W} - m_{F814W}$

- BSS
- BSS Selection Cuts
- MSTO

Baldwin, Watkins+ 2016
energy equipartition

\[ \sigma \propto m^{-\eta} \]

velocity dispersion

stellar mass

amount of equipartition

\[ \frac{\sigma_{\text{BSS}}}{\sigma_{\text{evolved}}} \propto \left( \frac{m_{\text{BSS}}}{m_{\text{evolved}}} \right)^{-\eta} \]

estimate from Bianchini simulations
Blue straggler velocity dispersions

\[ \frac{\sigma_{BSS}}{\sigma_{\text{evolved}}} \propto \left( \frac{m_{BSS}}{m_{\text{evolved}}} \right)^{-\eta} \]

\[ \sigma (\text{mas/yr}) \]

\[ R \text{ (arcsec)} \]

NGC 6341

Baldwin, Watkins+ 2016
blue straggler velocity dispersions

$\sigma$ (mas/yr) vs. $R$ (arcsec)

- BSS MCMC Chain
- Bright Star Best Fit
- All Bright Stars
- Blue Stragglers

NGC 6441

Baldwin, Watkins+ 2016
mass ratio: $1.50 \pm 0.14$
mass: $1.22 \pm 0.12 \, M_{\text{sun}}$
energy equipartition
(work in progress)
dispersion vs mass
work in progress

\eta = 0.26 \pm 0.01

\sigma \propto m^{-\eta}

NGC 6656

\[M \ [M_\odot]\]

\[\sigma \ [\text{mas/yr}]\]
dispersion vs mass and radius

work in progress

\[ \sigma \propto \text{mass} \]

\[ m_{F606W} \text{ [mag]} \]

\[ R \text{ [arcsec]} \]

NGC 6341

0.136 [mas/yr]

0.314 [mas/yr]
**proper motions** are really awesome
HST PMs for **22 Milky Way globular clusters**

**anisotropy** profiles
→ break mass-anisotropy degeneracy

+LOS→ distances
(and **mass-to-light ratios**)

estimate masses for **blue stragglers**

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