Imprints of evolution in the internal kinematics of globular clusters

Laura Watkins · ESO Garching

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

Survival of Dense Star Clusters in the Milky Way System · Heidelberg · 20 November 2018

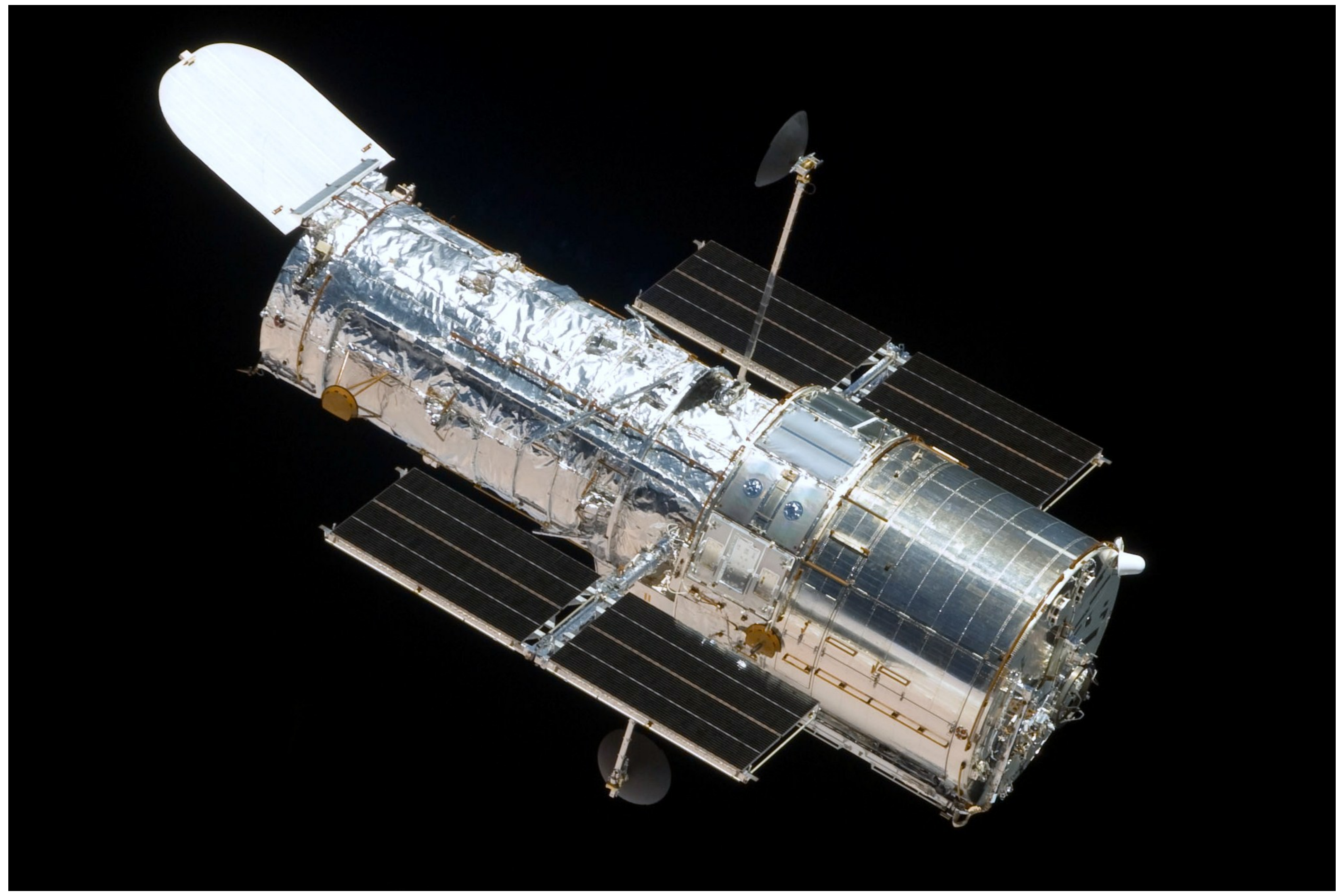
Alison's Conclusions

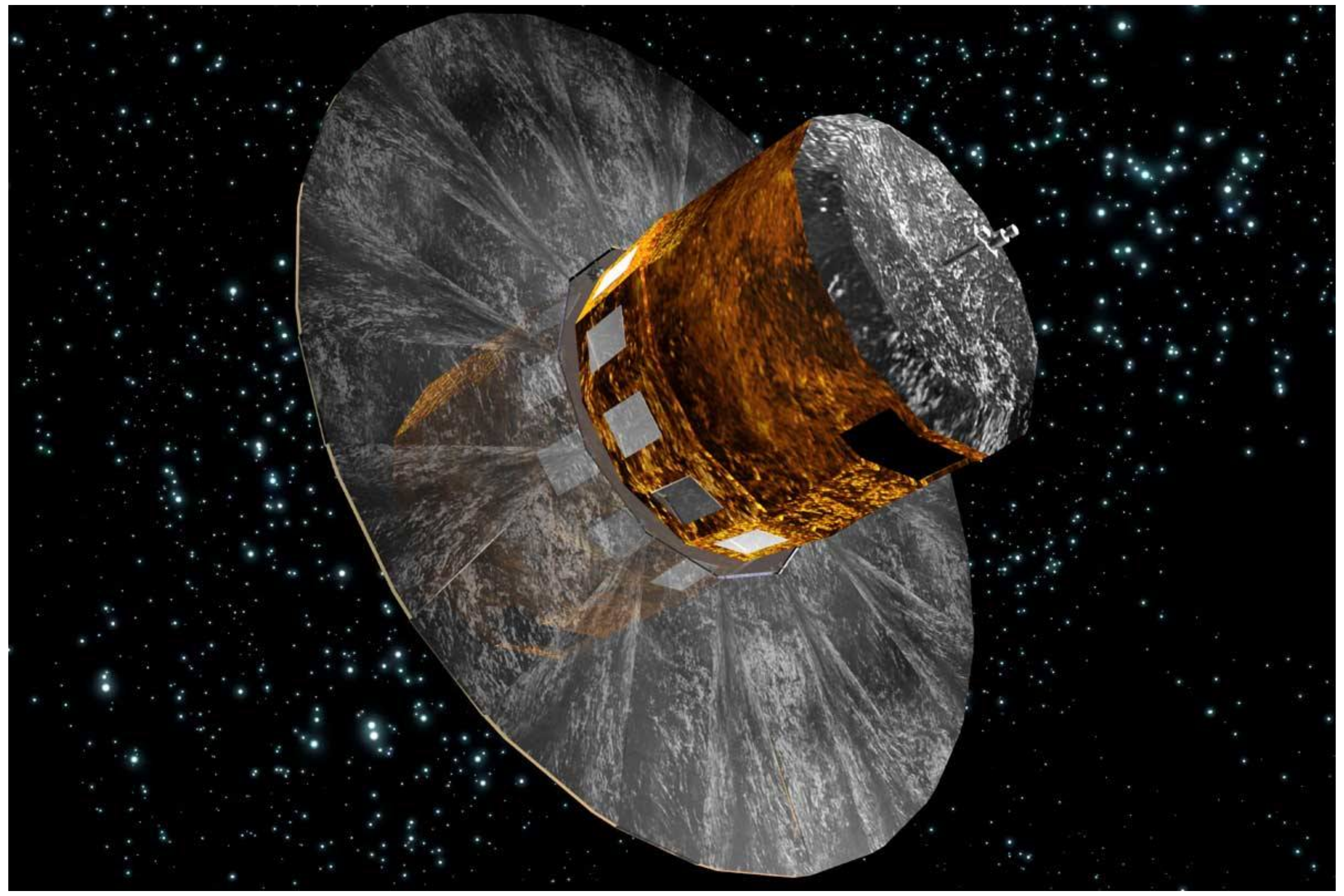
Conclusions

- Structural and kinematic cluster properties are strongly affected by cumulative tidal environment experienced by cluster
- Cluster responds quickly to new tidal environment
  - Within a half-mass relaxation time or two
- Accreted clusters are very hard to identify based on structural & kinematics properties alone
- If you see a cluster that is too big for its current orbit, it was likely accreted recently.
  - Too small doesn't tell you the same thing – may just have always been underfilling

Kinematics for Milky Way Globular Clusters

- Global Motions:
  - Orbits / histories / environments
  - Progenitors of tidal streams
  - Properties of the Milky Way
- Internal Motions:
  - Mass (dark matter, IMBH)
  - Rotation, anisotropy
  - Mass segregation, energy equipartition
  - Dynamical differences with chemistry
- Membership selection for other studies





small fields
few stars / IFU bins
single epoch
-
bright stars

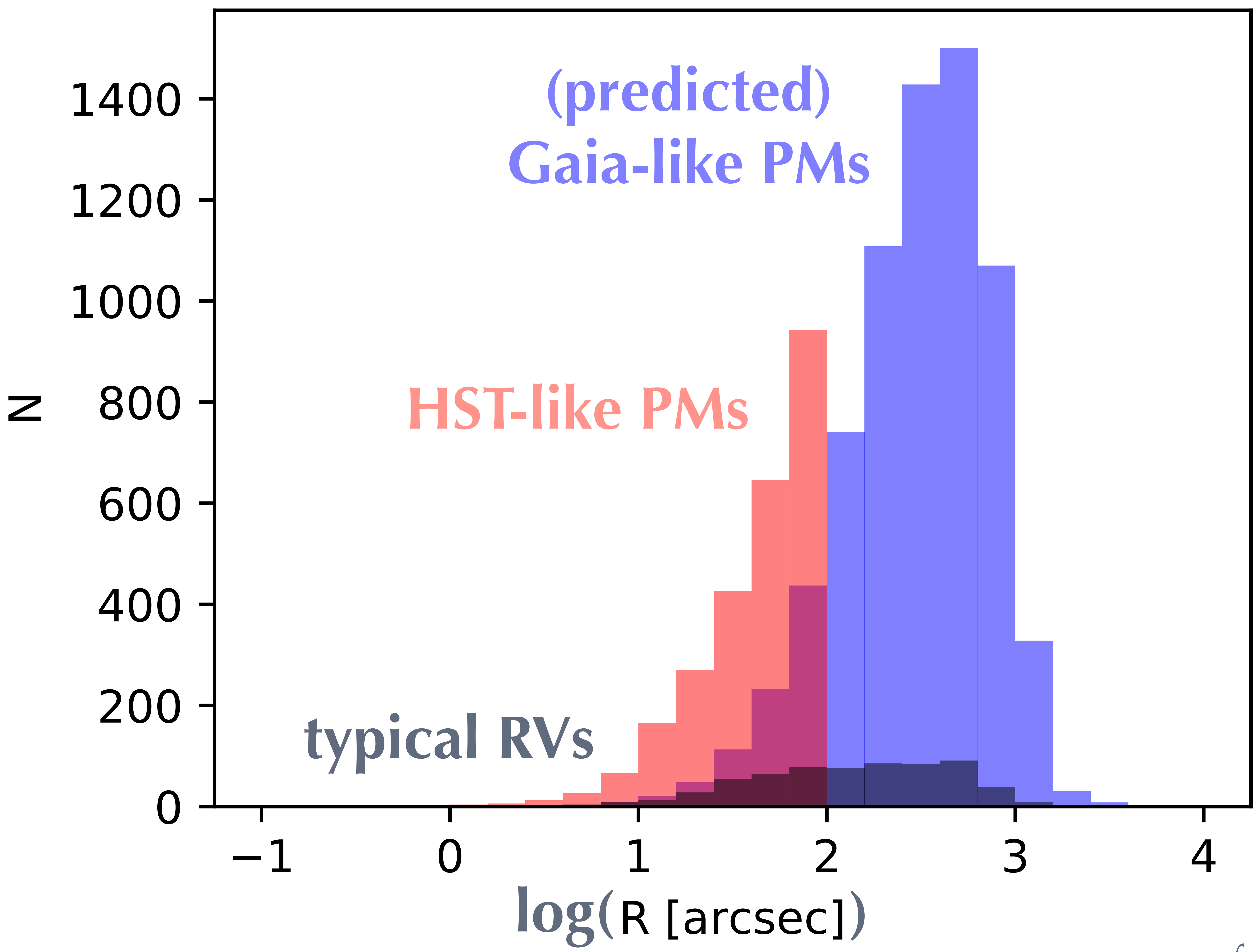
small fields (central)
all* stars in field
needs multiple epochs
up to ~15 year baseline
goes deep

all sky
all* stars in field
many, many visits
2-year baseline (eventually ~~5~~ 7)
G<~21 mag

Gaia DR2 gets HST precision to G~18 mag

line-of-sight velocities HST proper motions Gaia

Highly complementary. Great individually, amazing together.



from Heggie M4 Mock

from Vincent Hénault-Brunet & Elena Pancino

Globular Clusters in the Milky Way

Distances		no → yes	← no	parallaxes eventually
Bulk motions	++	yes	some	yes
Rotation	++	yes	very few	yes (DR2 < 15kpc)
Dispersions		yes, but sparse	yes < ~15 kpc	yes?, limited
Anisotropy	++	no	projected	eventually (projected)
Equipartition		limited	yes	in theory (limited)
Centres (IMBHs)	++	yes, but controversies	~some	no

line-of-sight velocities

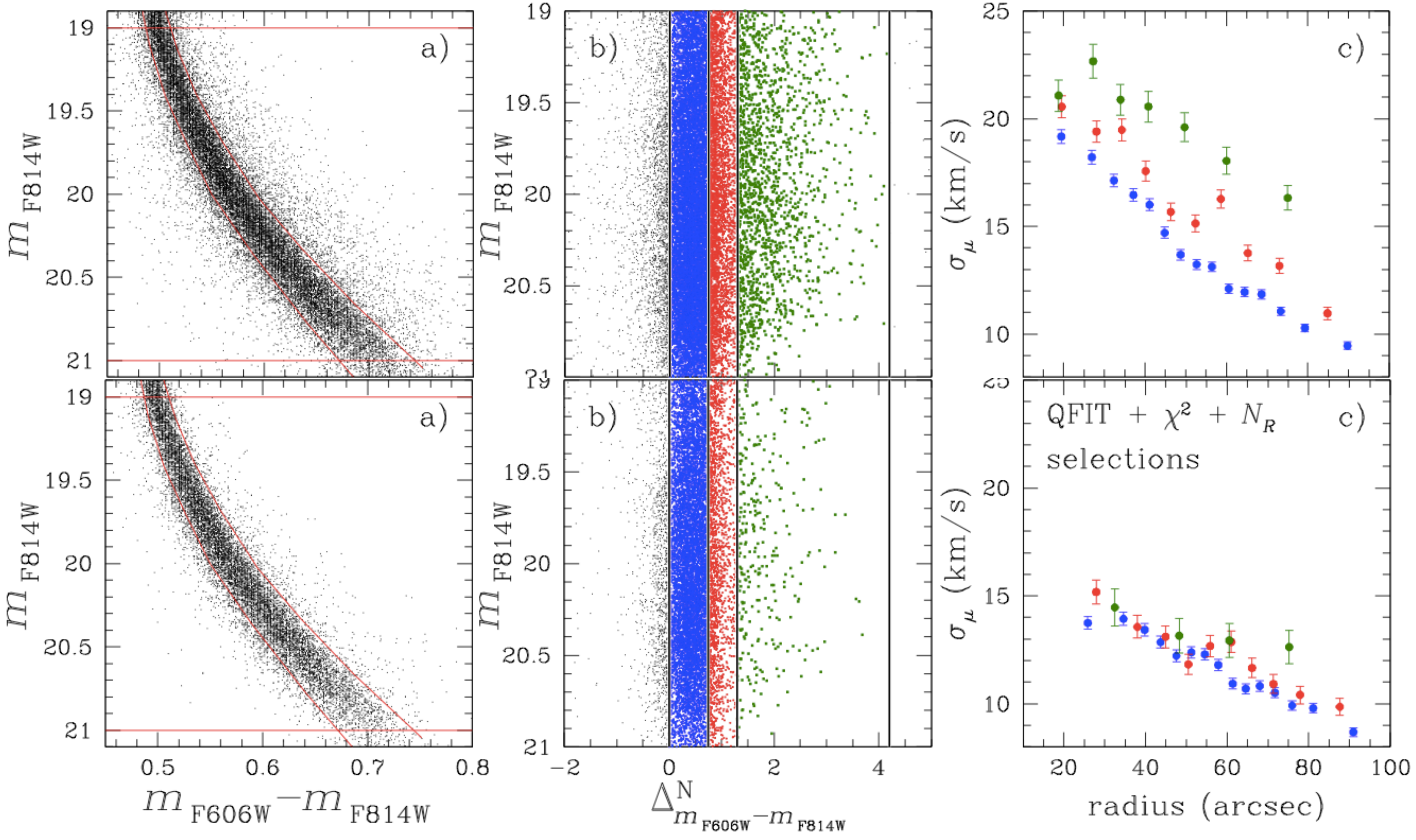
HST

proper motions

Gaia

Poor quality data inflates velocity dispersions

Data quality selections are VERY important



M15 from Bellini et al (2014)

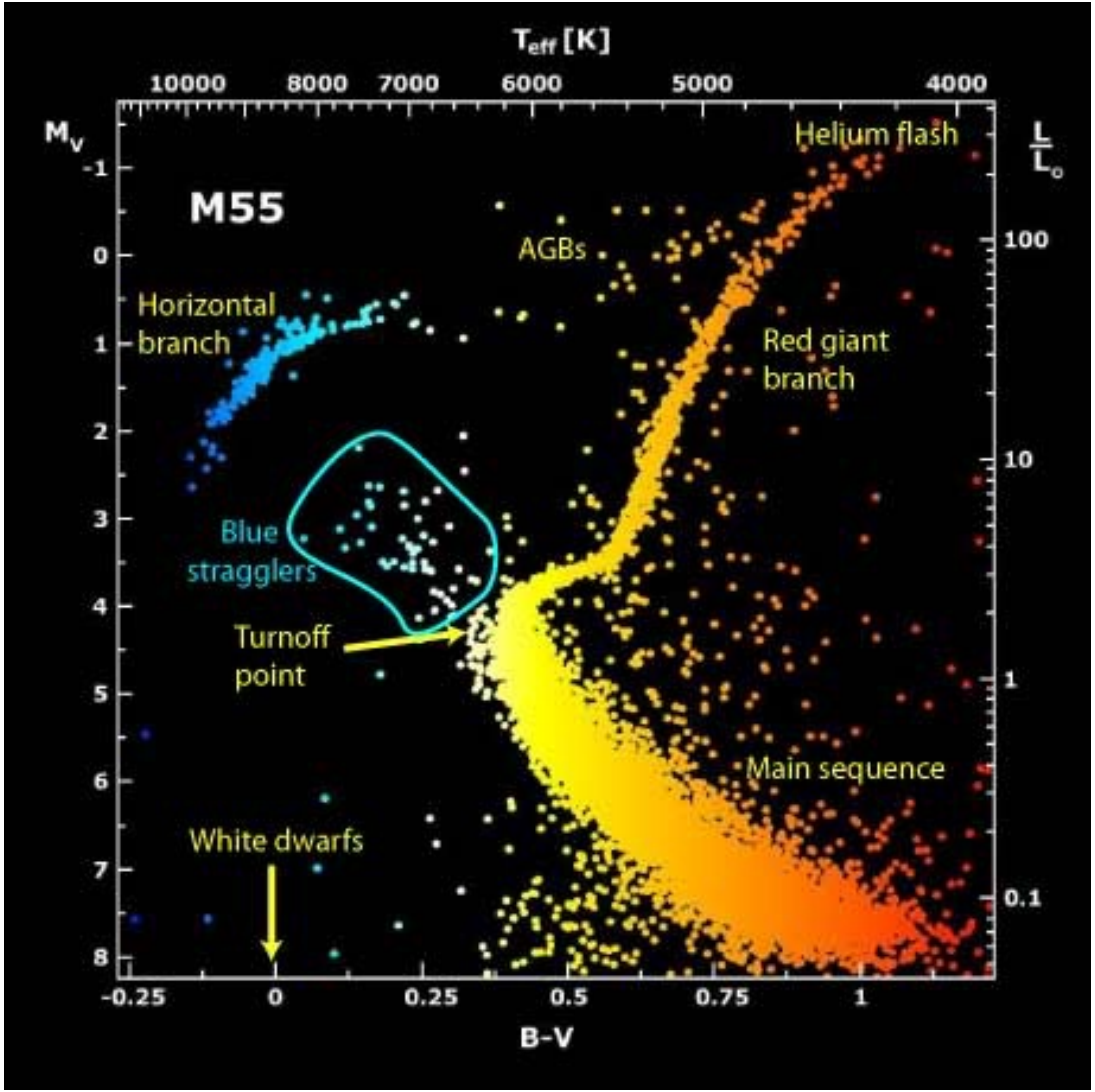
Mass Segregation
&
Energy Equipartition

velocity dispersion

stellar mass

$$\sigma \propto m^{-\eta}$$

amount of equipartition



very small mass range

targets for kinematics

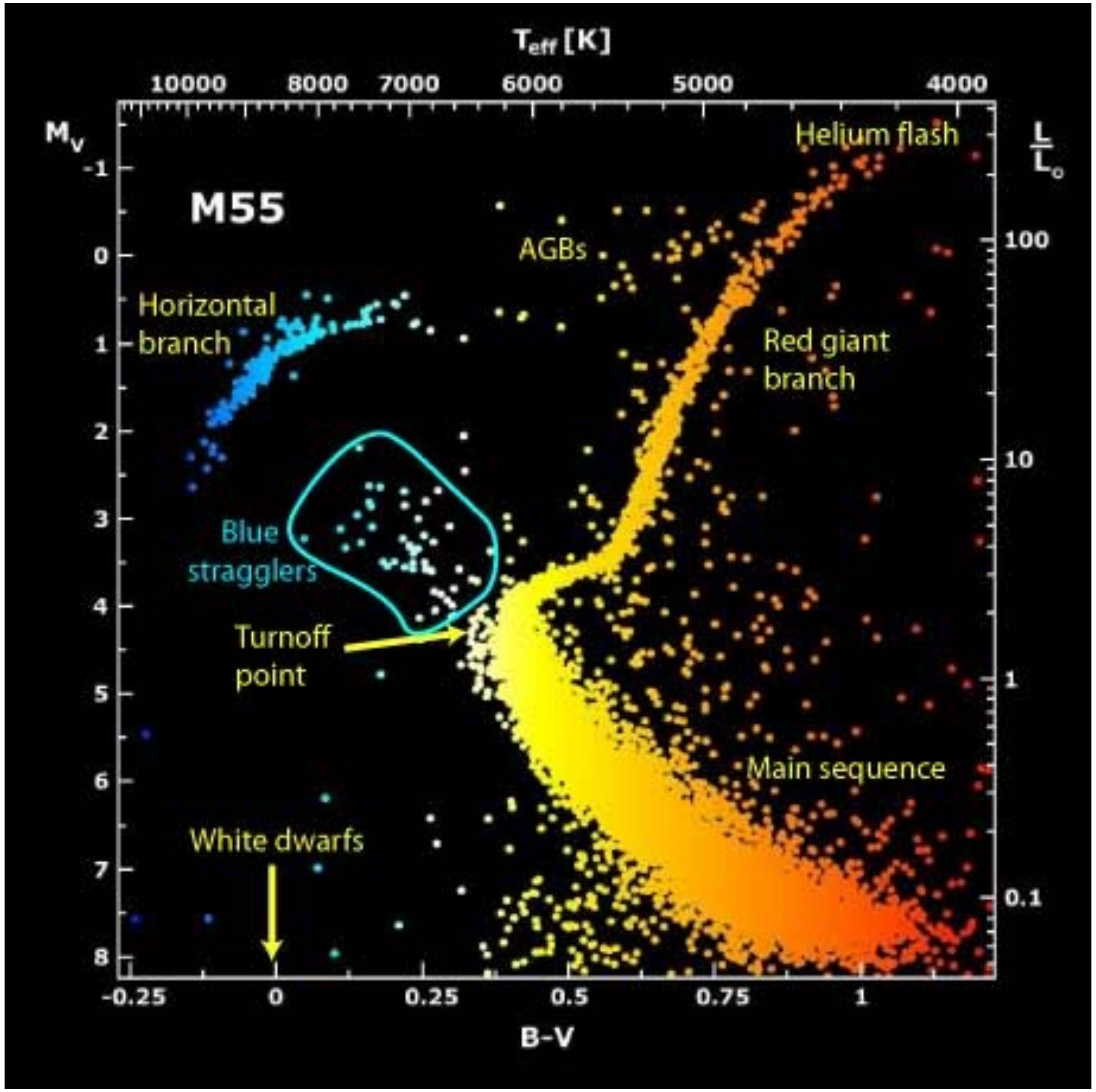
wide mass range

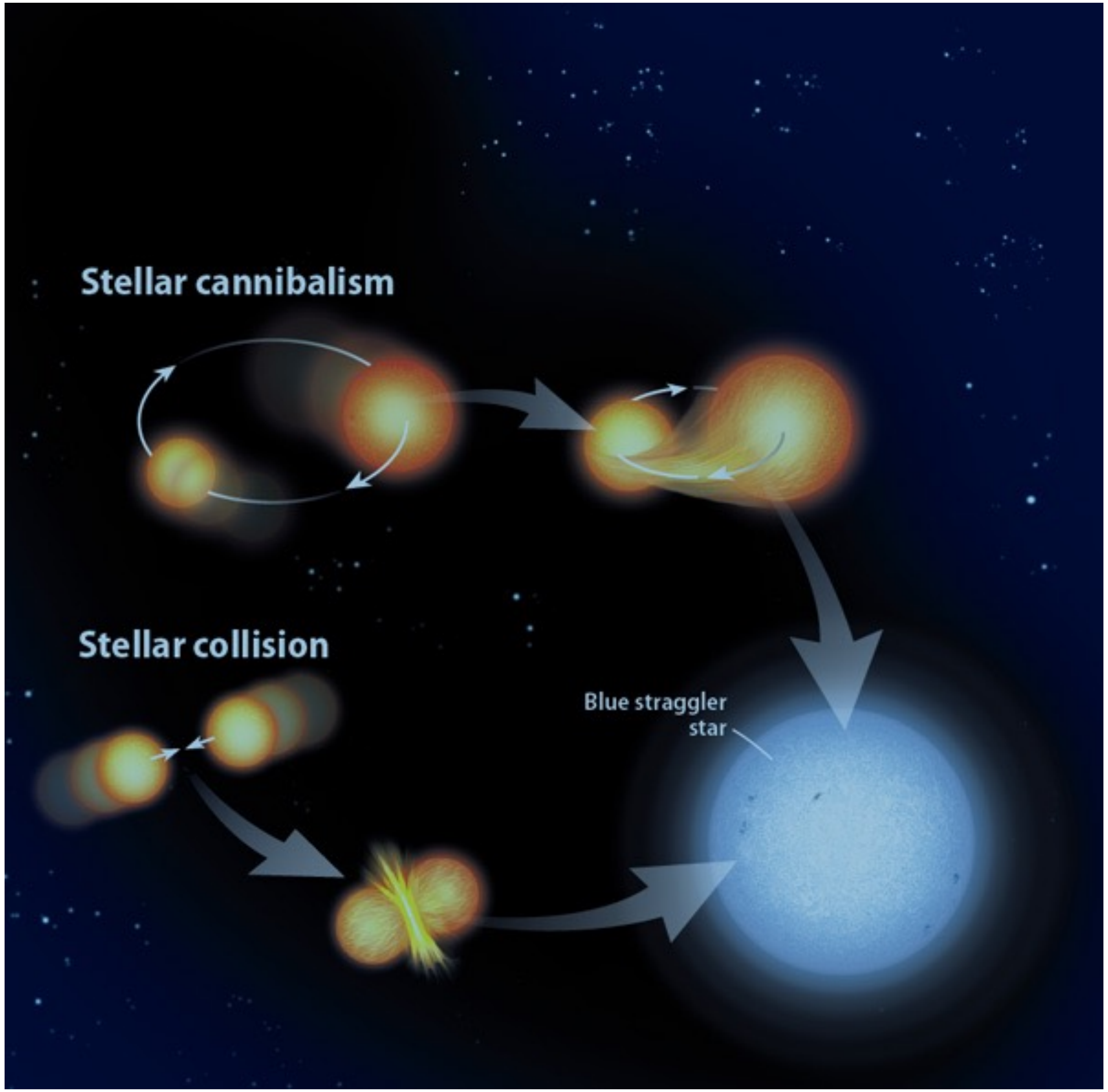
hard to get kinematics

Blue Stragglers

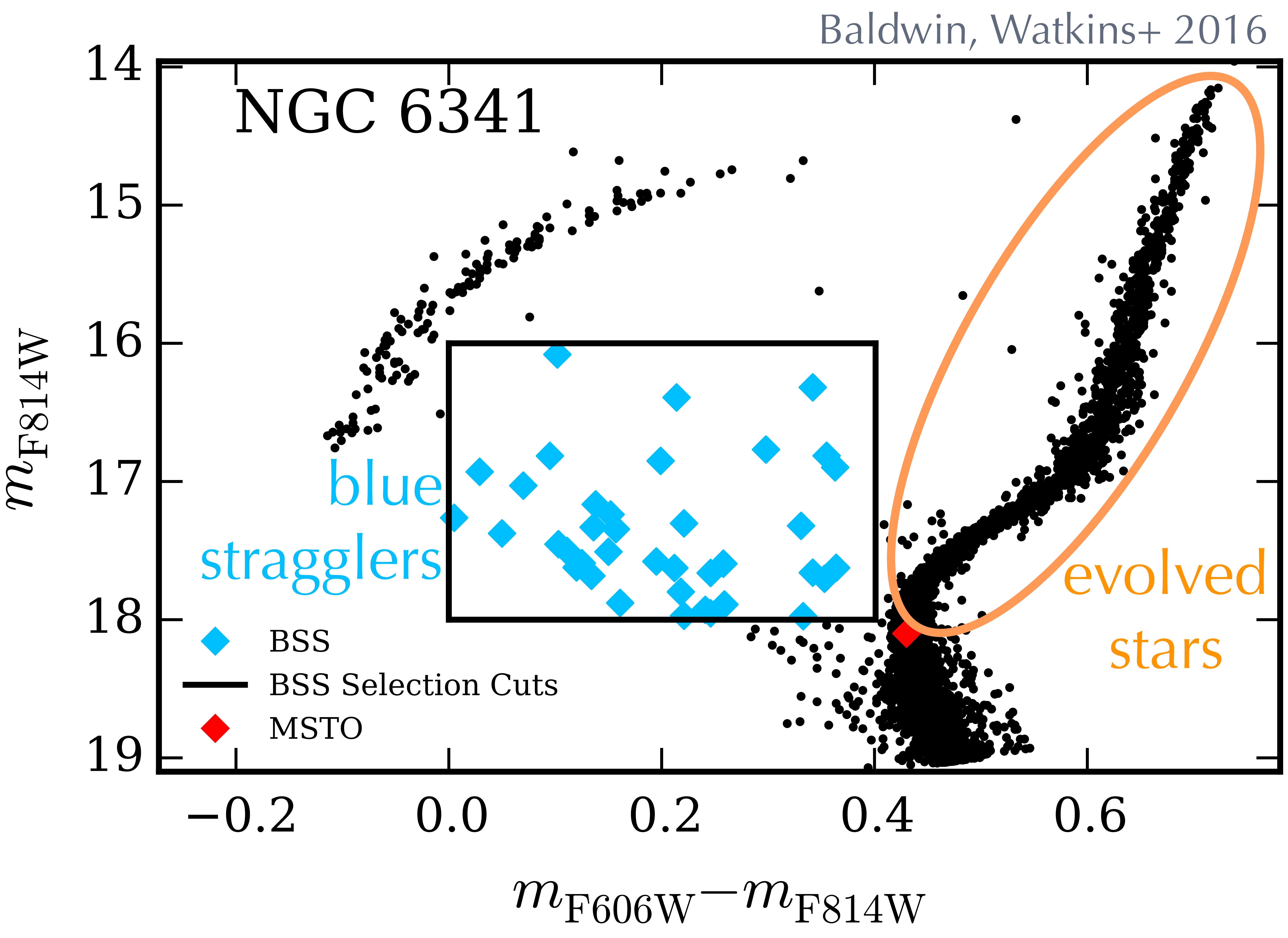
Taylor Baldwin

What are Blue Stragglers?





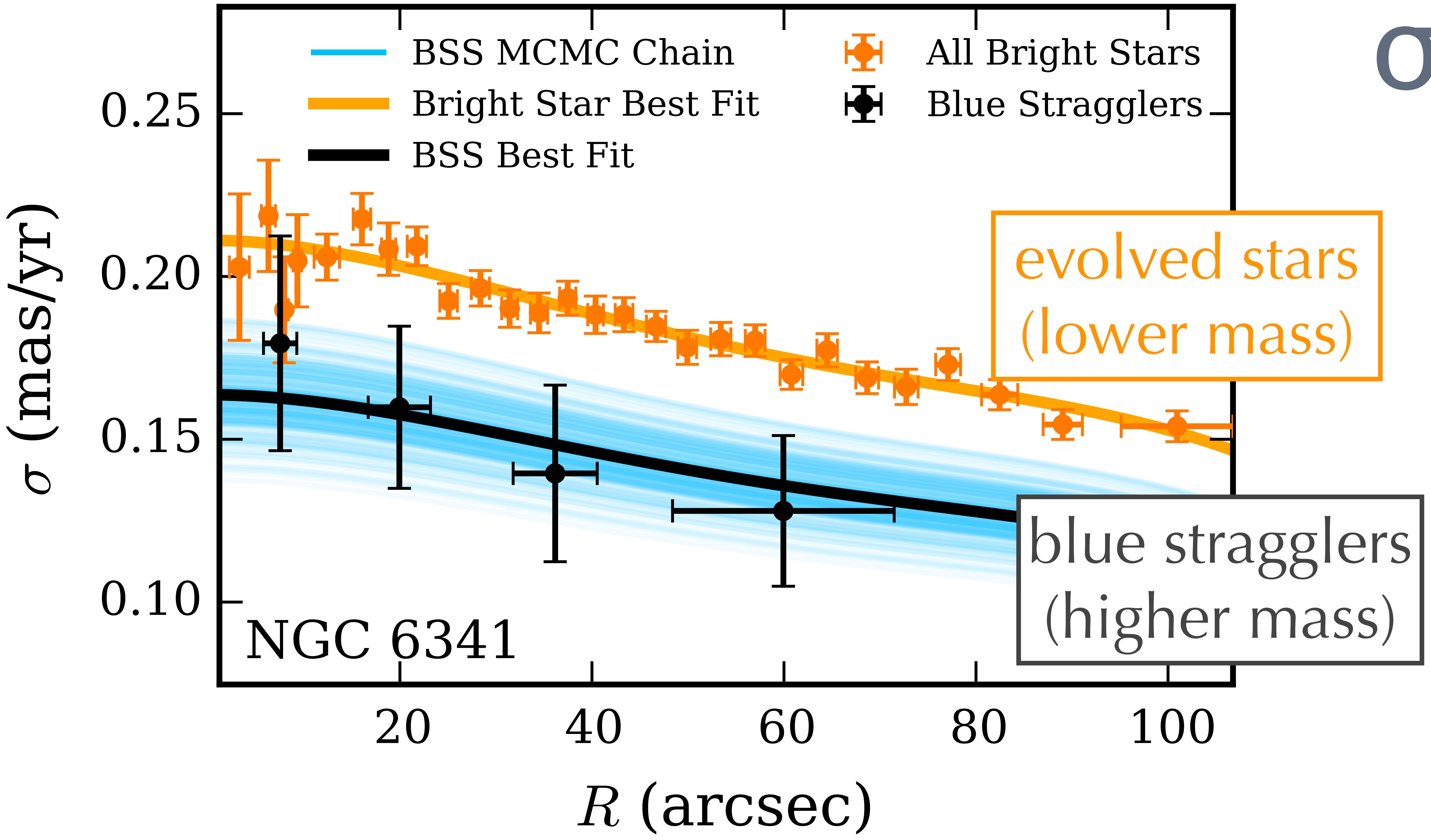
HST Proper Motion Catalogues: Blue Stragglers Selection



HST: Blue Straggler Velocity Dispersions

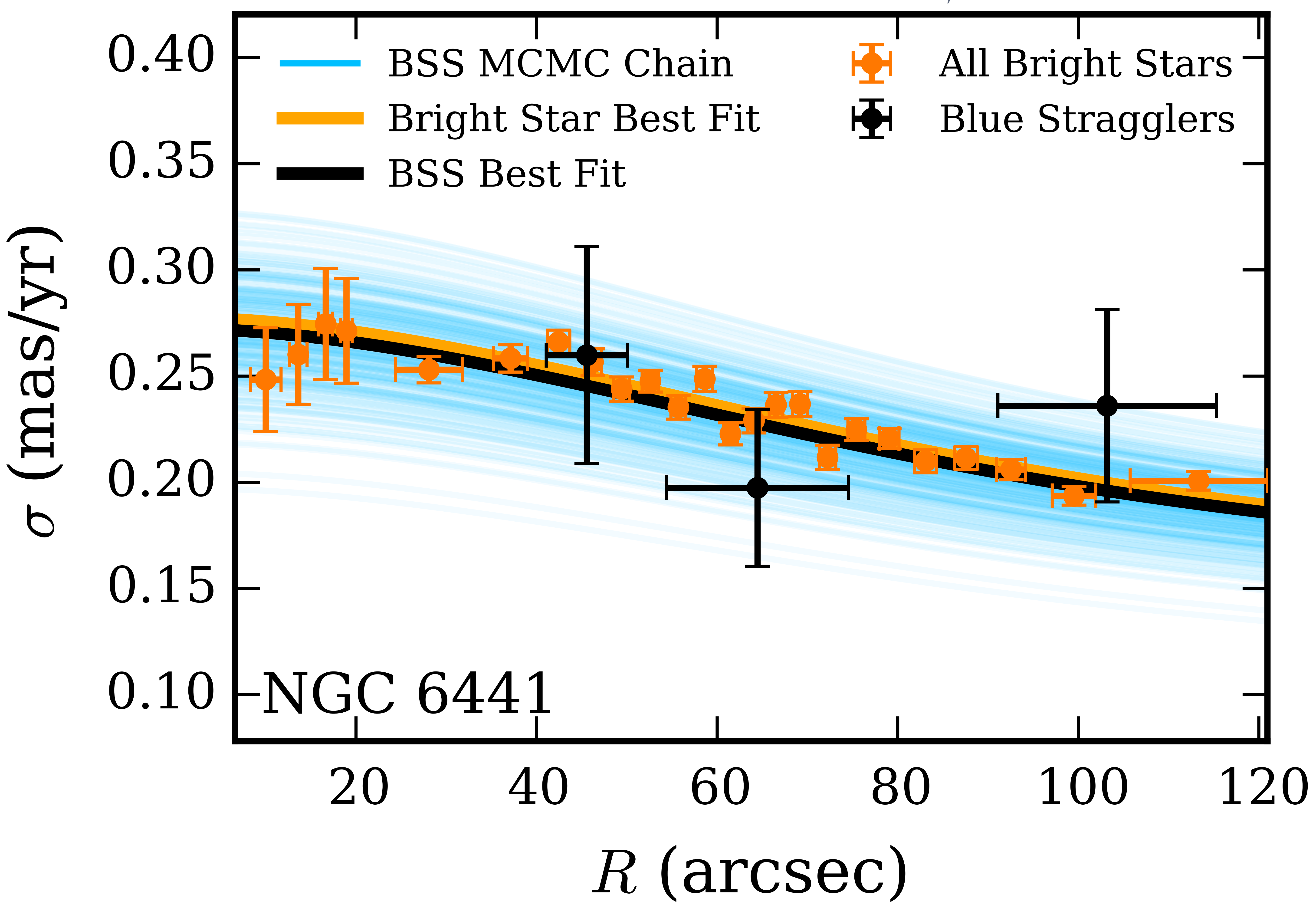
Baldwin, Watkins+ 2016

$\sigma \propto m^{-\eta}$

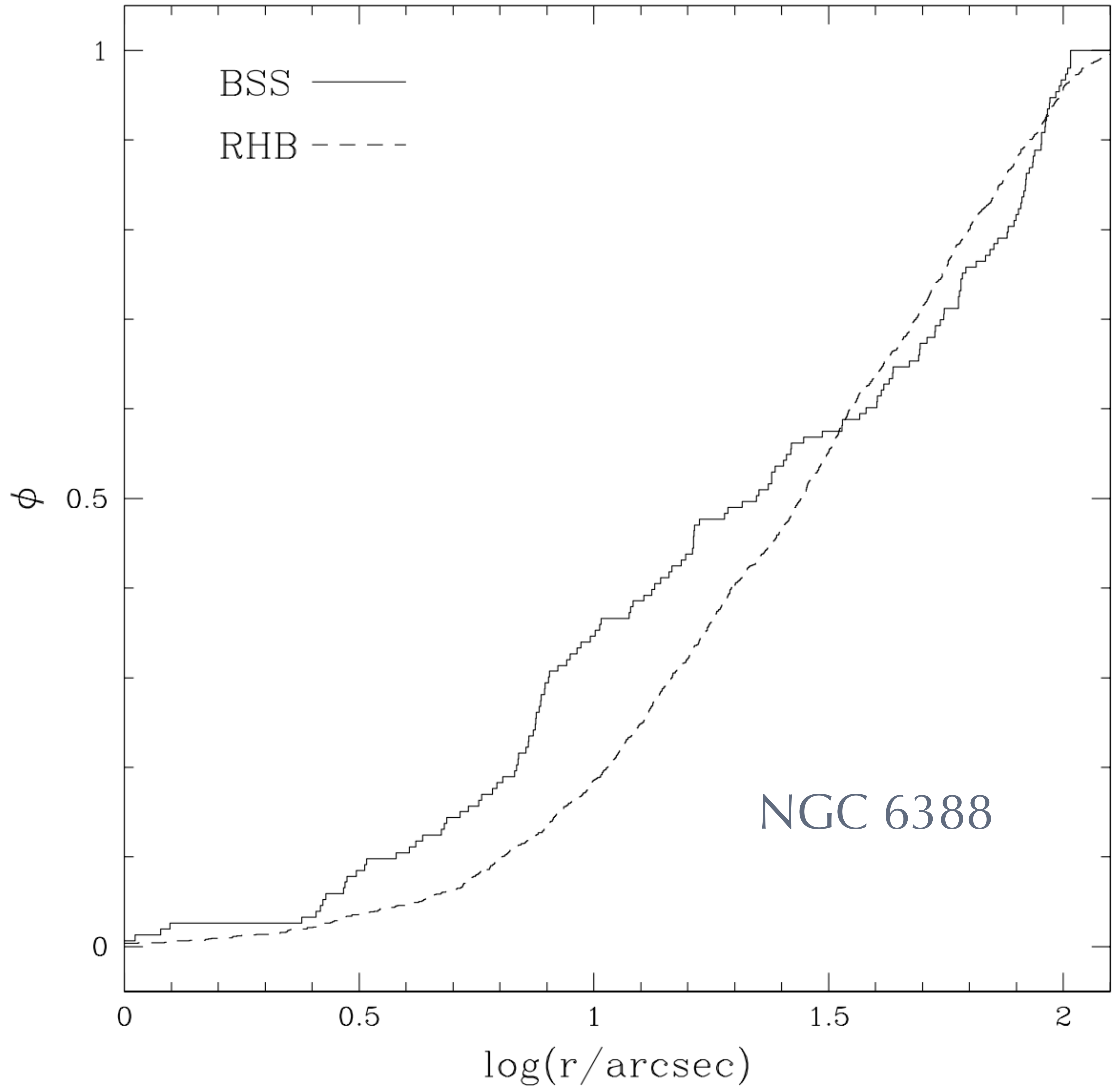


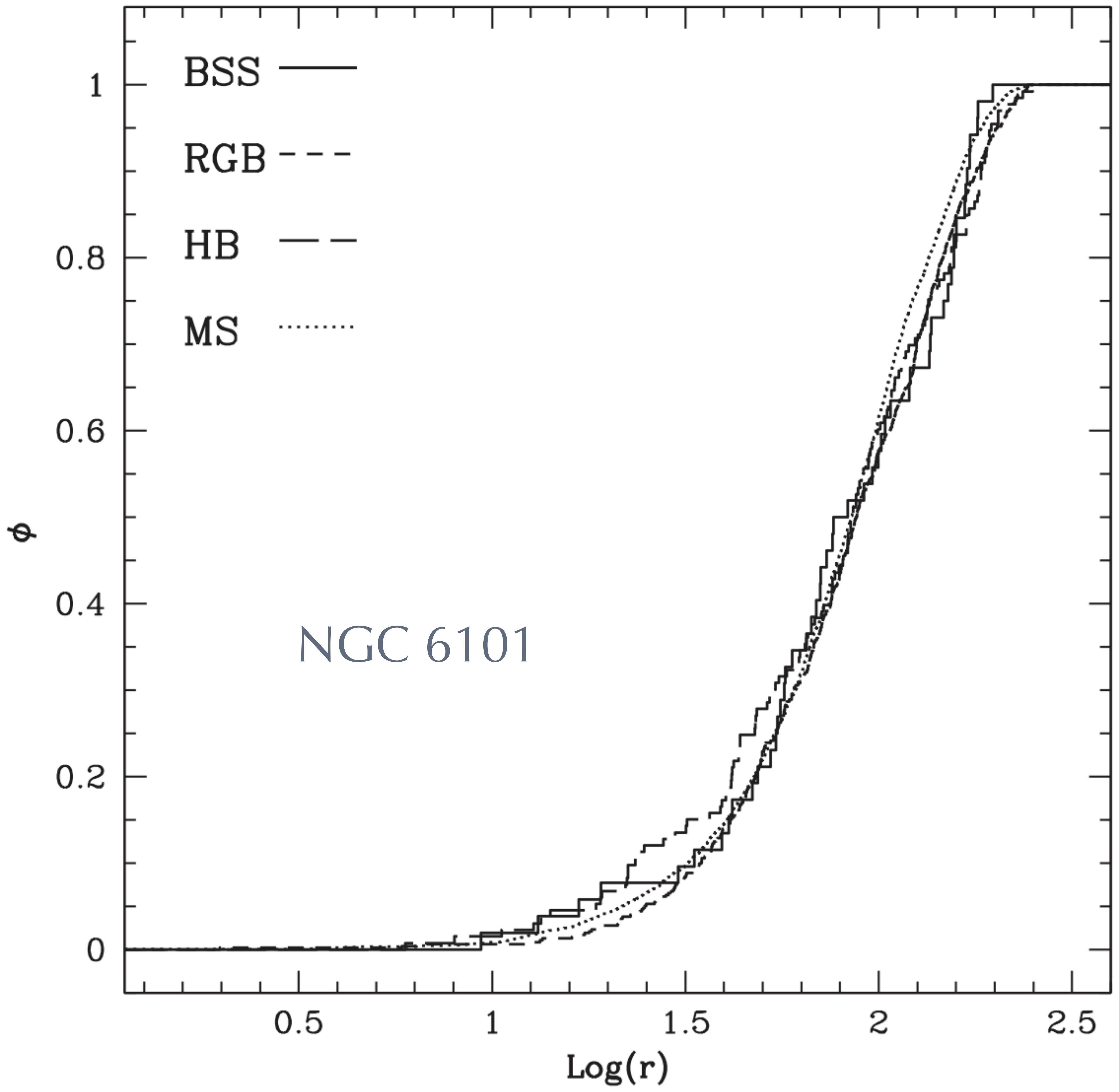
HST: Blue Straggler Velocity Dispersions

Baldwin, Watkins+ 2016



Blue Straggler Mass Segregation





Dalessandro+ 2008

Dalessandro+ 2015

Energy Equipartition on the Main Sequence

(work in progress)

HST: kinematics with stellar mass

work in progress

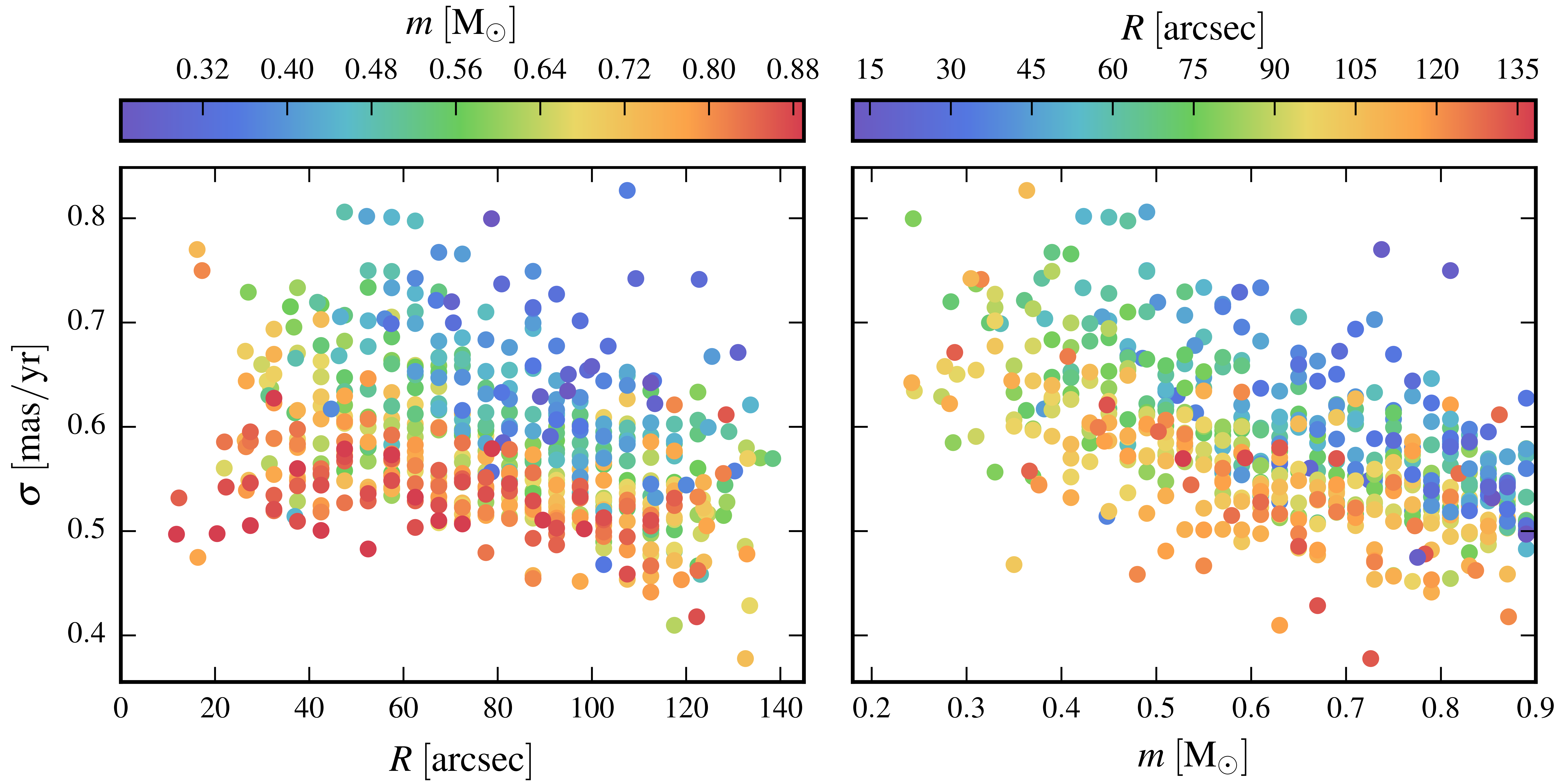
Mass bins have different radial ranges.

Watkins+ in prep

HST: kinematics with position and stellar mass

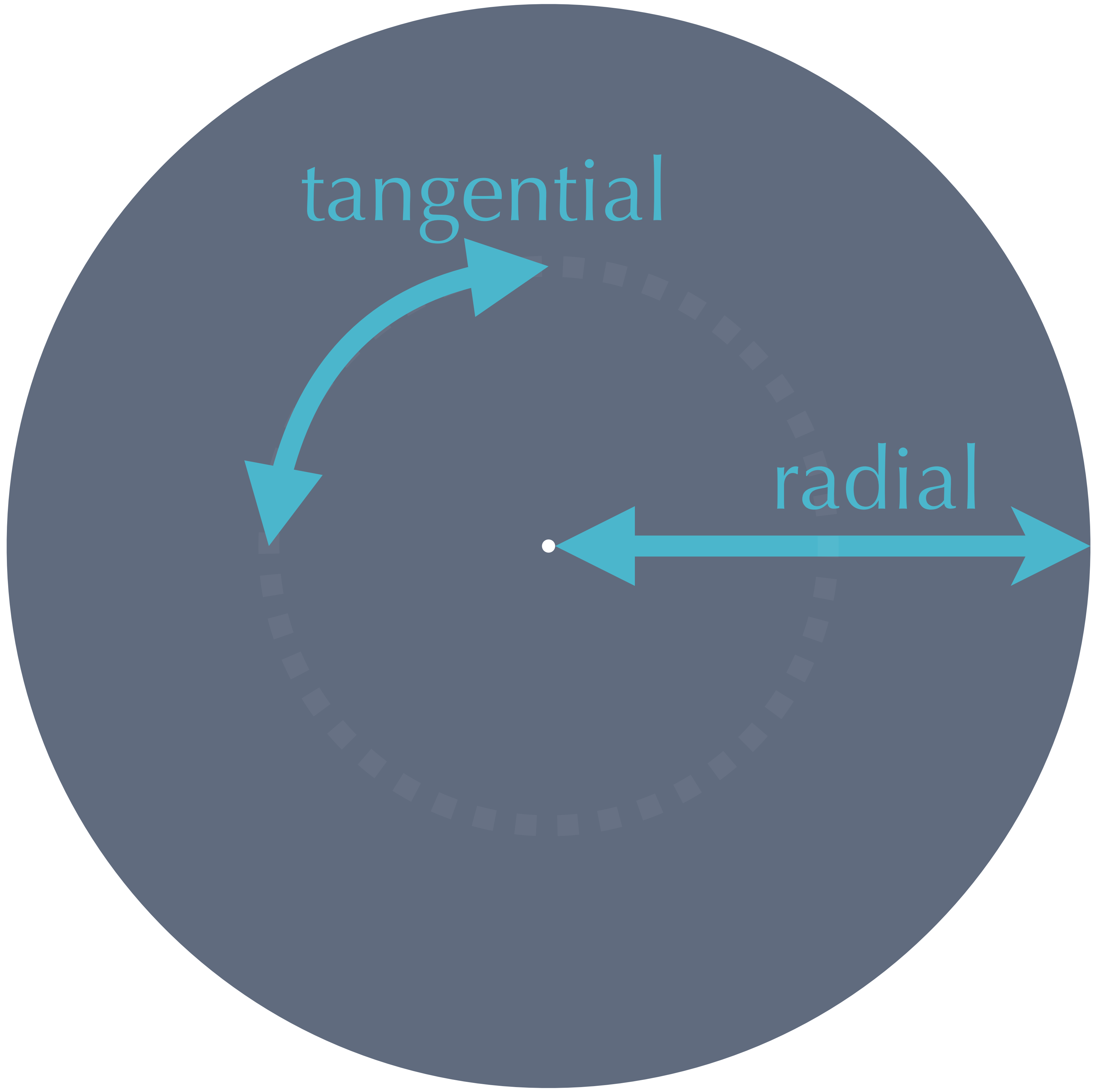
work in progress

NGC 104 / 47 Tuc



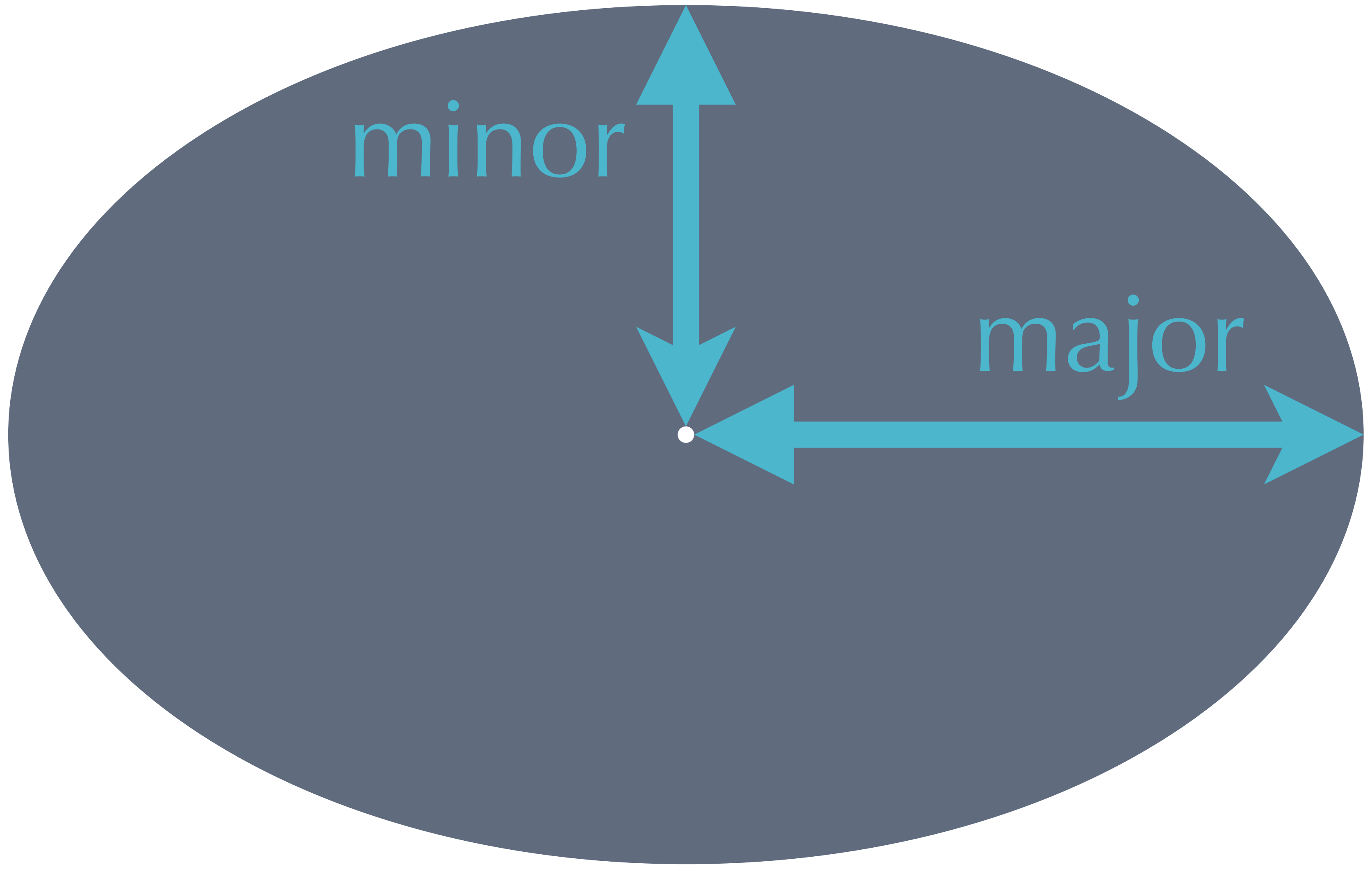
Watkins+ in prep

Anisotropy

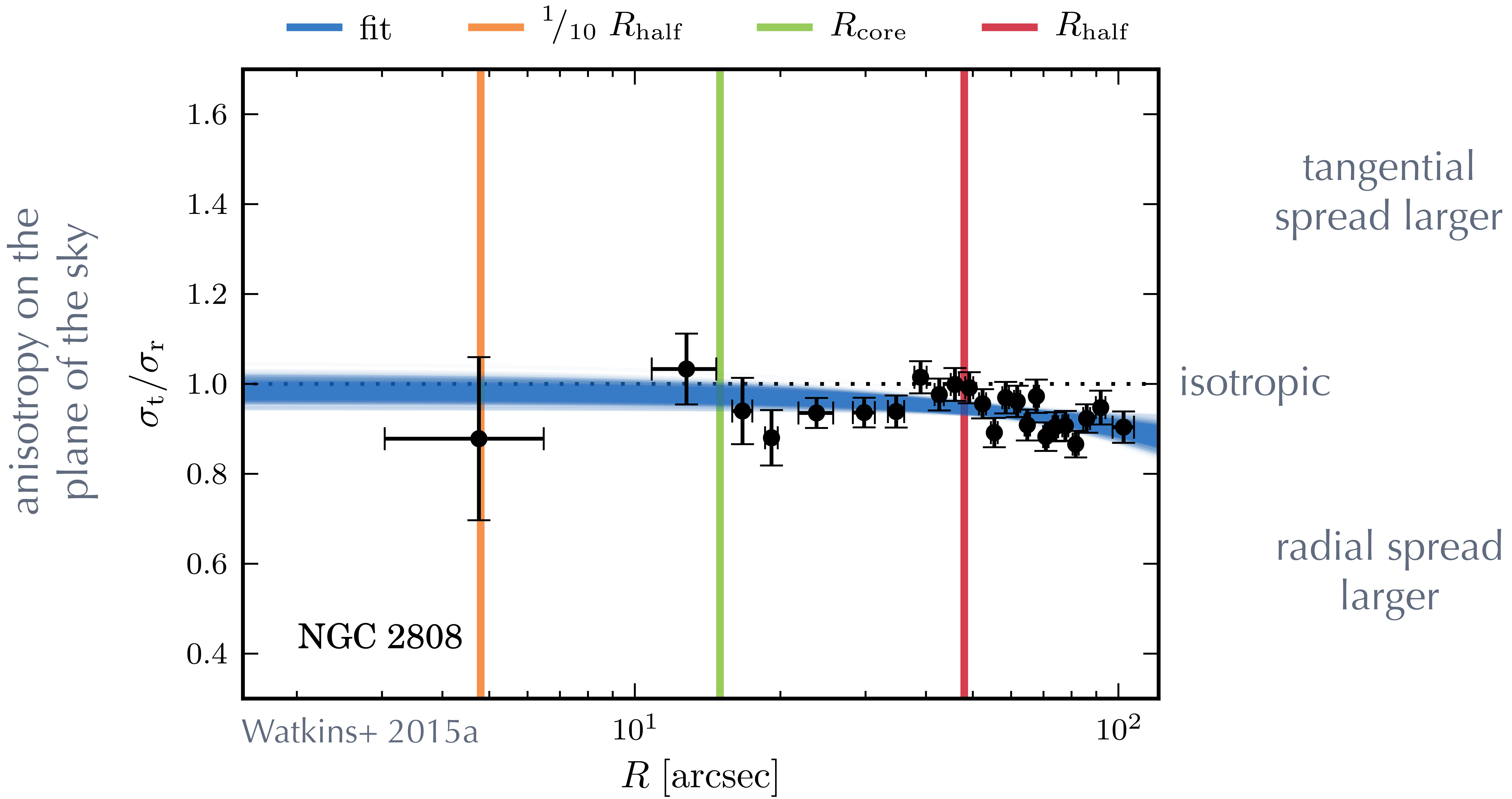


$$\frac{\text{dispersion in direction A}}{\text{dispersion in direction B}}$$

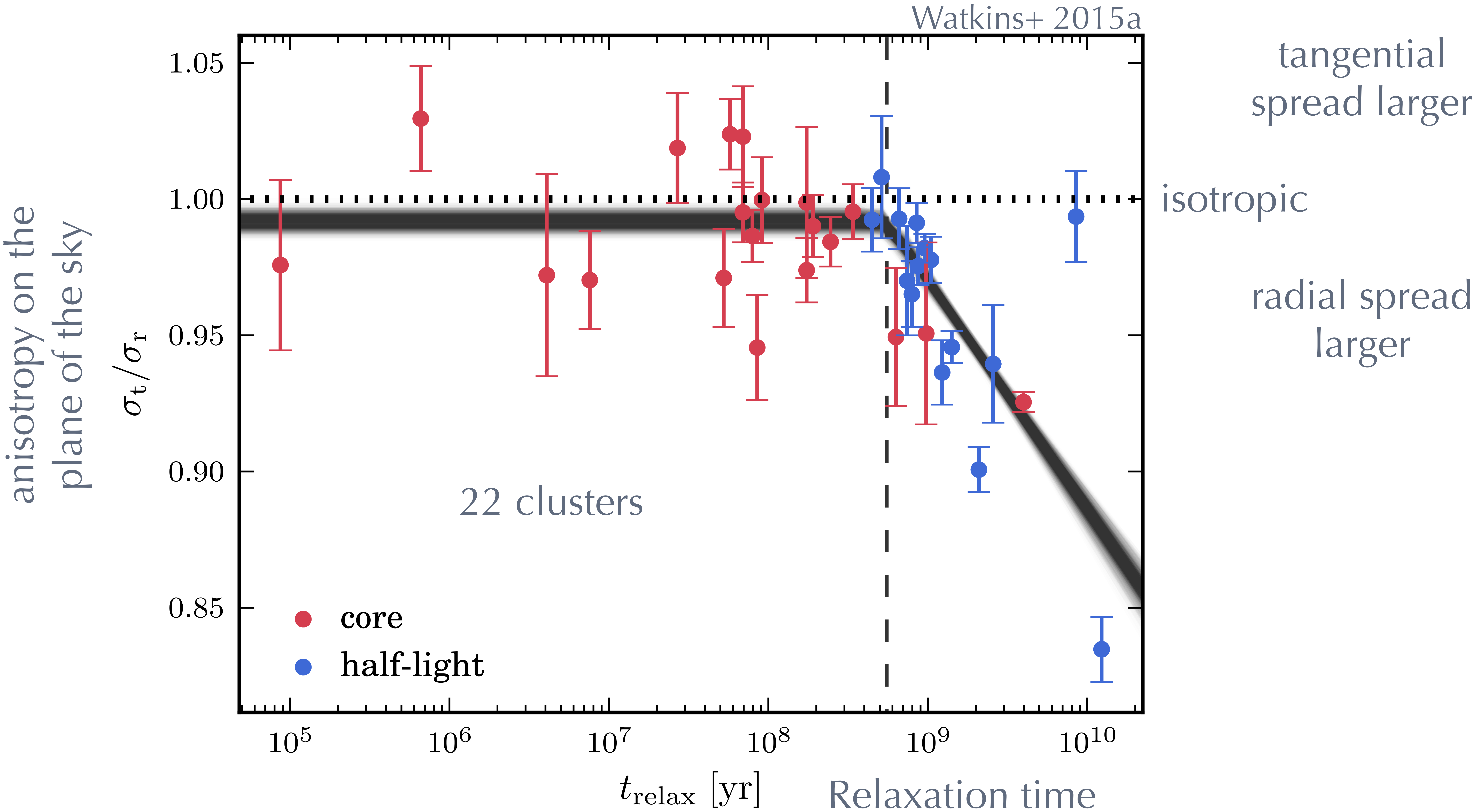
(orthogonal directions)

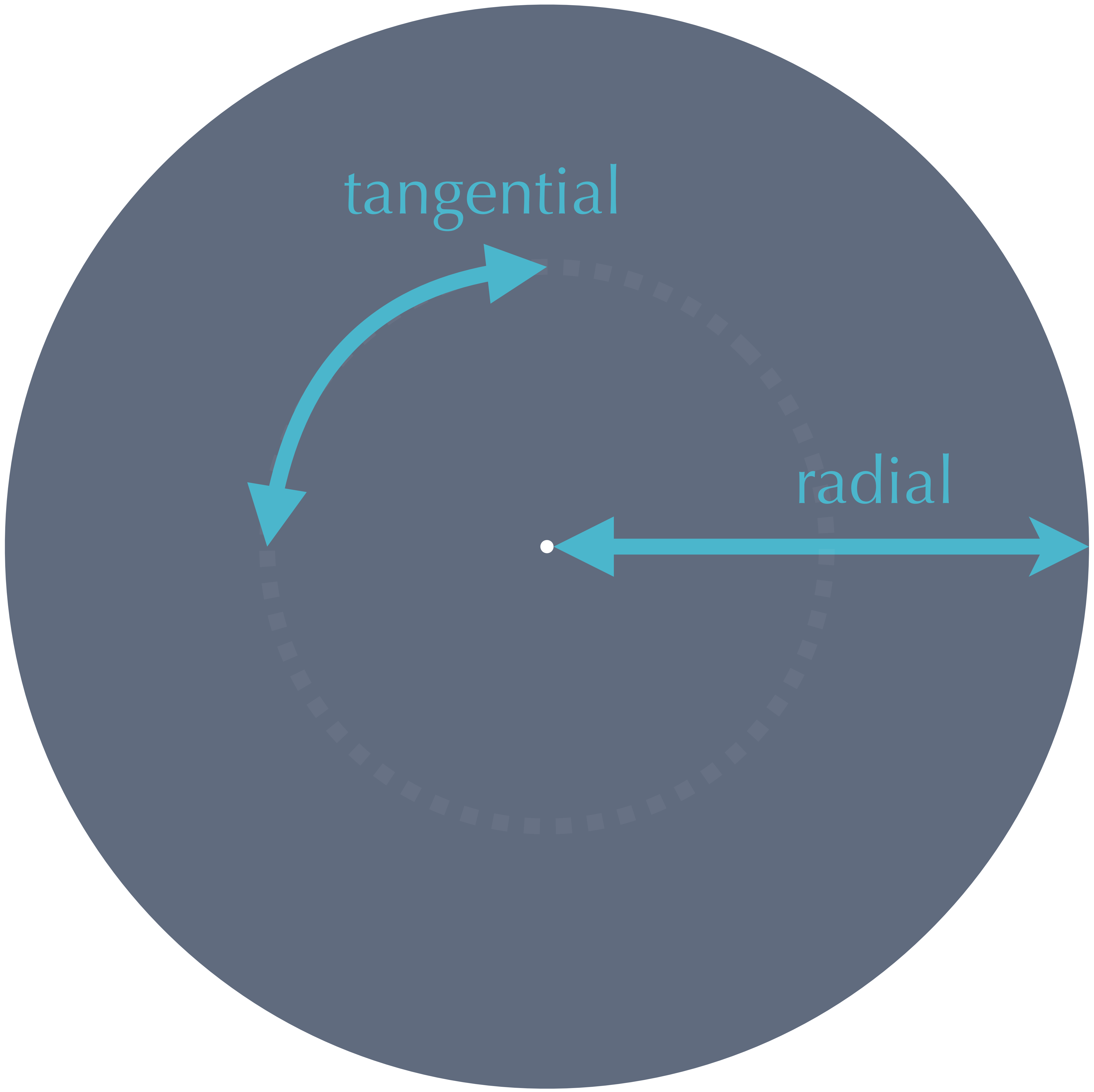


HST Proper Motions: Projected Anisotropy Profiles



HST: Anisotropy vs Relaxation Time

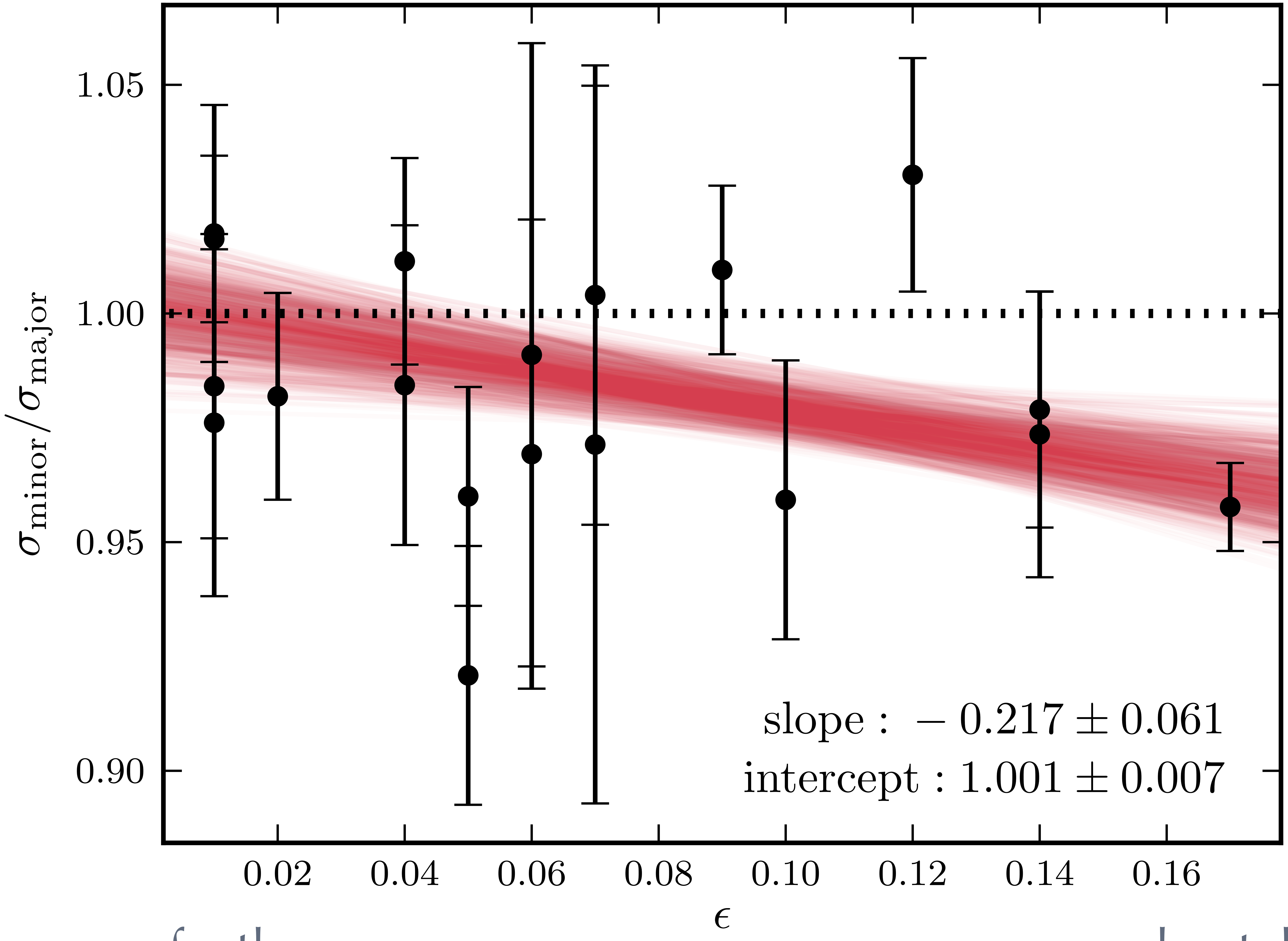




stars on radial orbits
preferentially stripped

HST: Anisotropy vs Ellipticity

Watkins+ 2015a



minor-axis spread larger

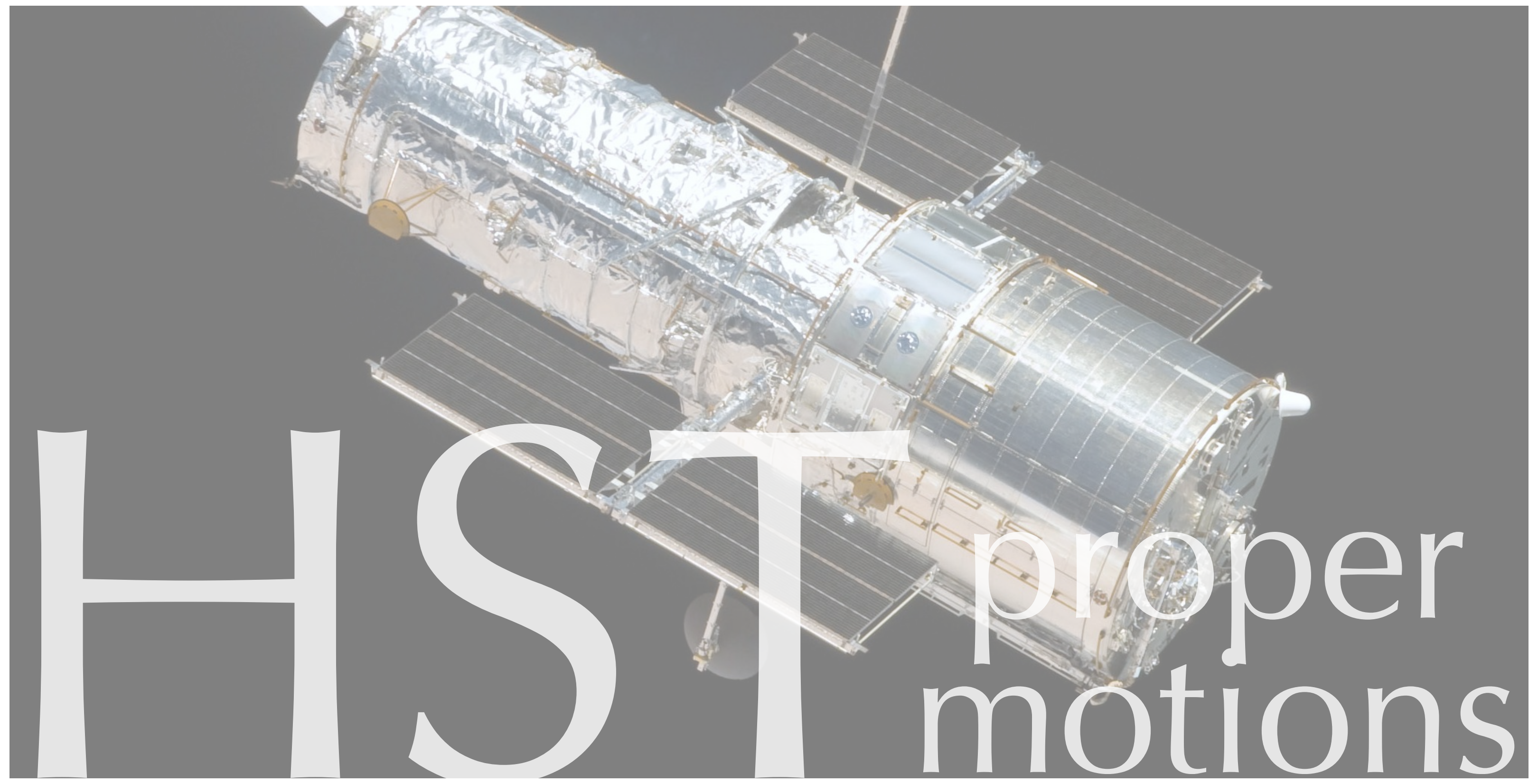
isotropic

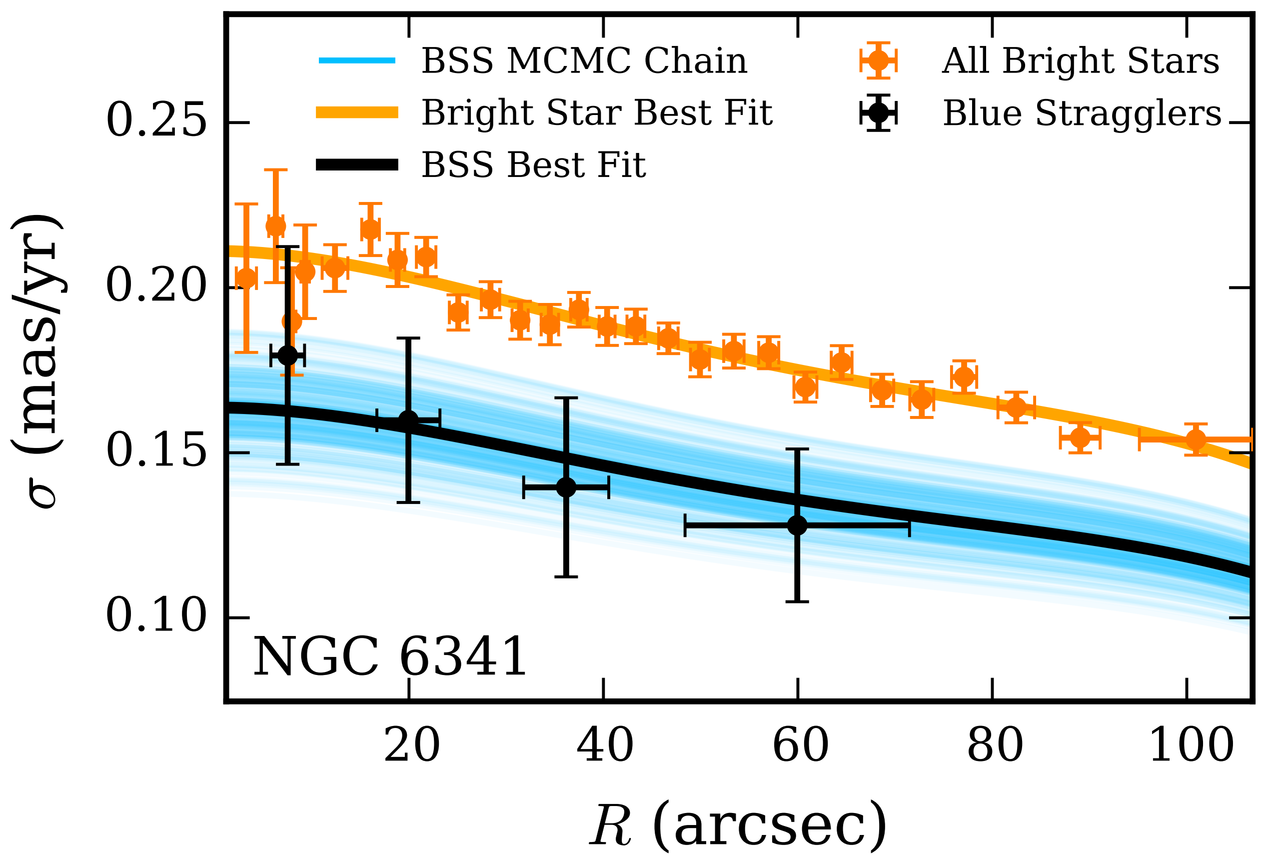
major-axis spread larger

perfectly round

moderately flattened major axis > minor axis

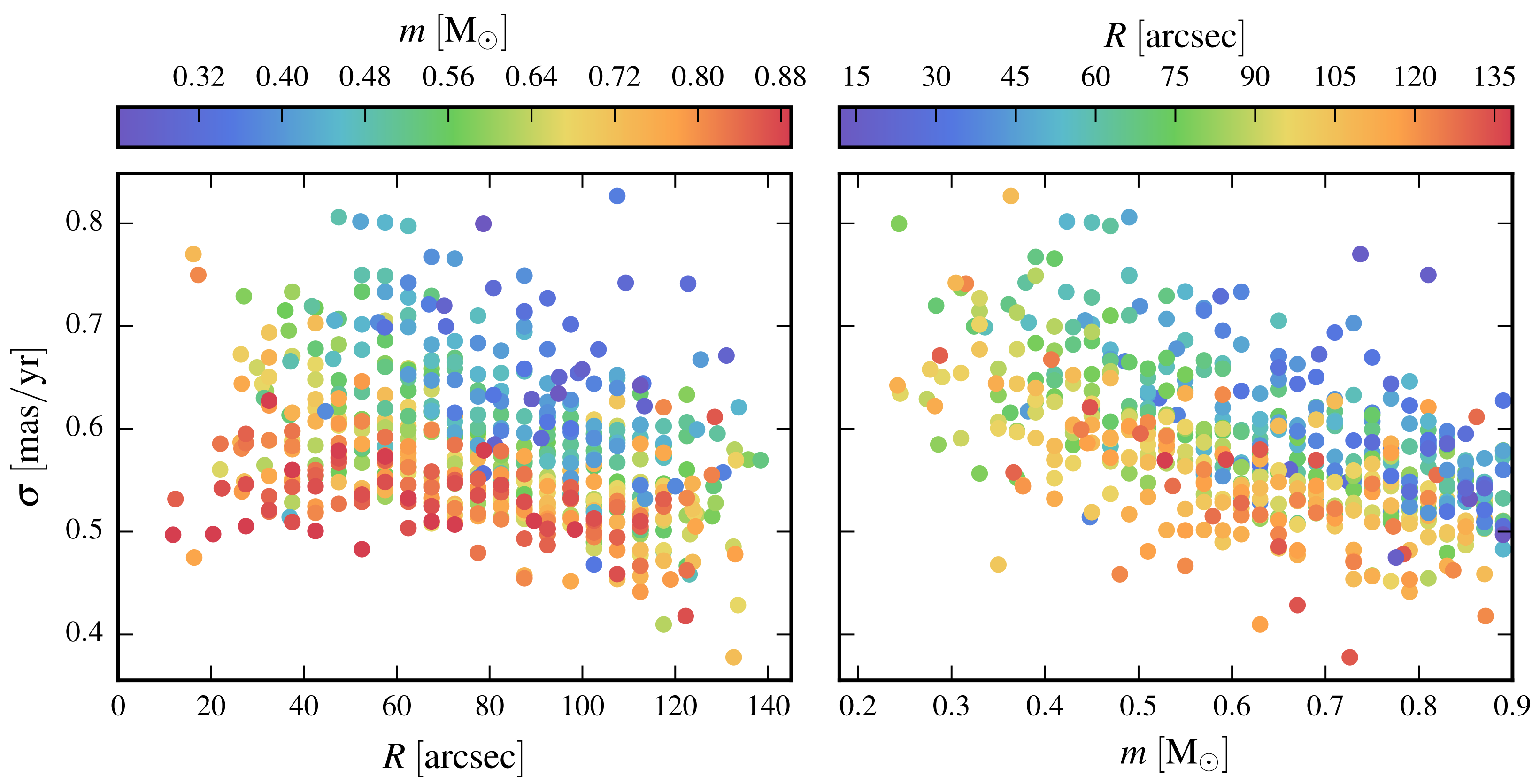
Highly complementary. Great individually, amazing together.

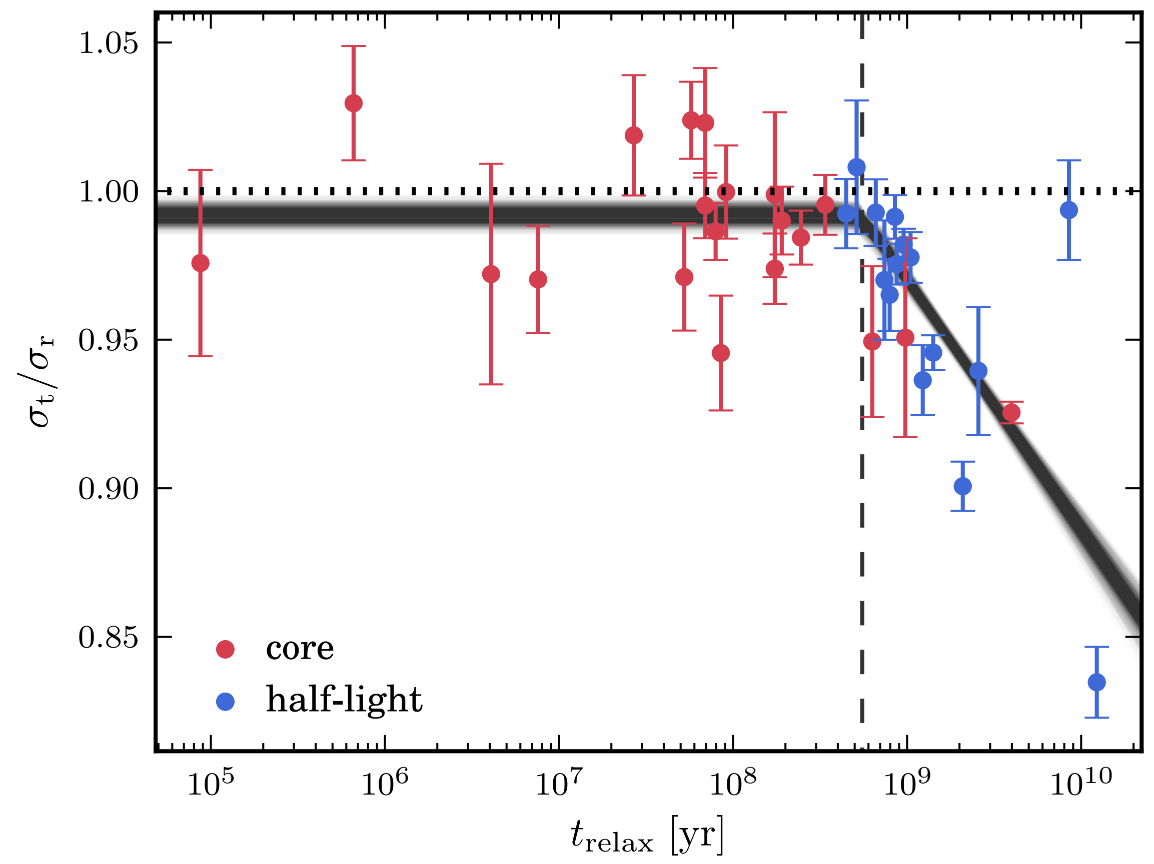




measure mass of blue stragglers via equipartition

measure equipartition on the main sequence





measure anisotropy & correlate with relaxation time

Laura Watkins · ESO Garching