GPS1(GAIA-PANSTARRS1-SDSS) PROPER MOTIONS

Haijun Tian (CTGU-CASS&MPIA)

Branimir Sesar, Hans-Walter Rix, etc.

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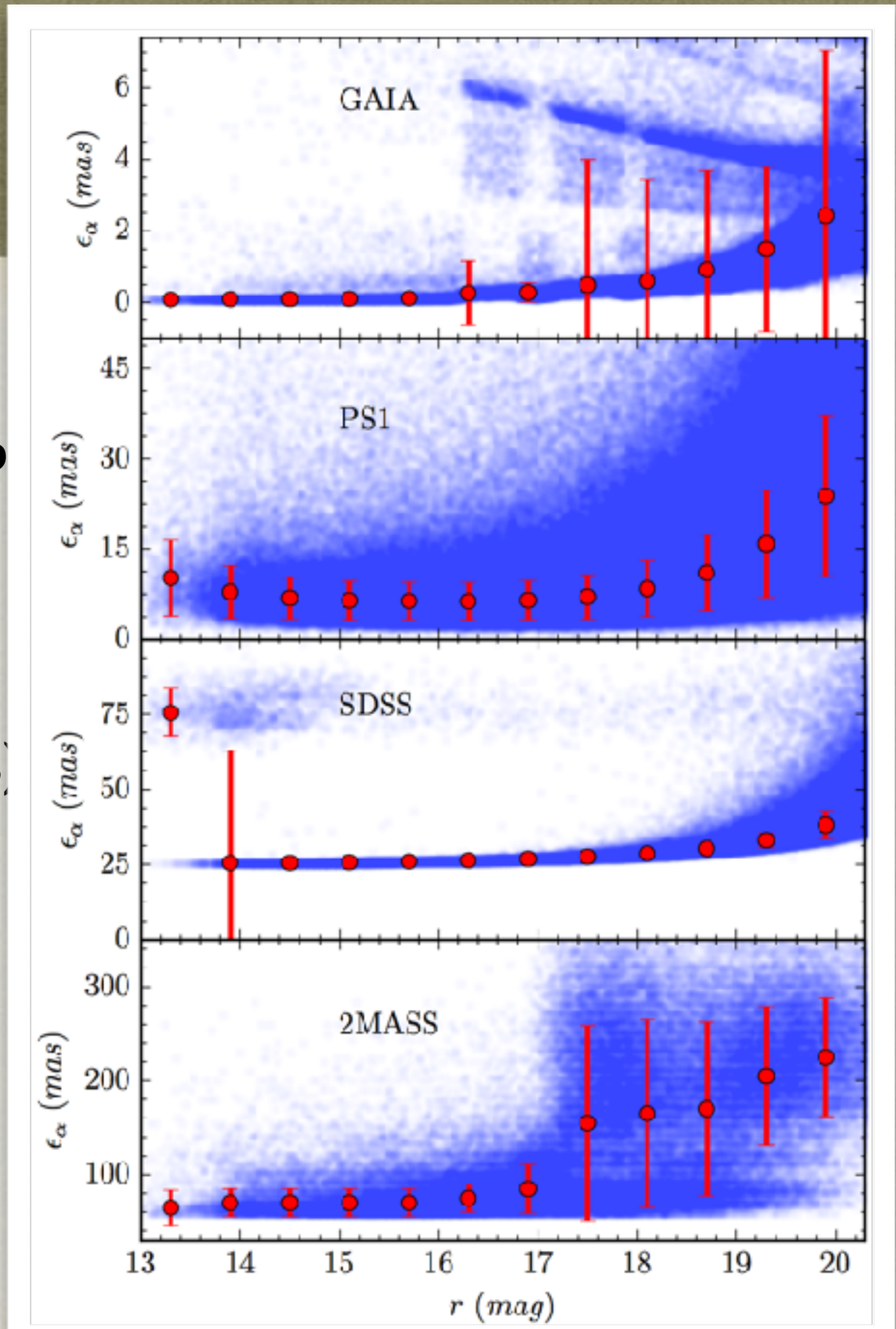
OUTLINE

- **Data and X-calibration**
- **Proper motion Fitting and Validation (simulations)**
- **Results**
- **Validation (Galaxies, Open cluster, etc.)**
- **Conclusion for GPS1(Tian+ 20017)**
- **GPS1+ is coming (Tian+ in preparing)**
- **Scientific Applications (Qiu+ in preparing)**
- **Conclusion for GPS1+**

DATA

- **Can we get proper motions now?**
  - **Gaia (1-year, <2mas)**
  - **PS1 (>4-years, ~10mas)**
  - **SDSS (~10 years ago, ~25 mas)**
  - **2MASS (~10 years ago, ~100 mas)**

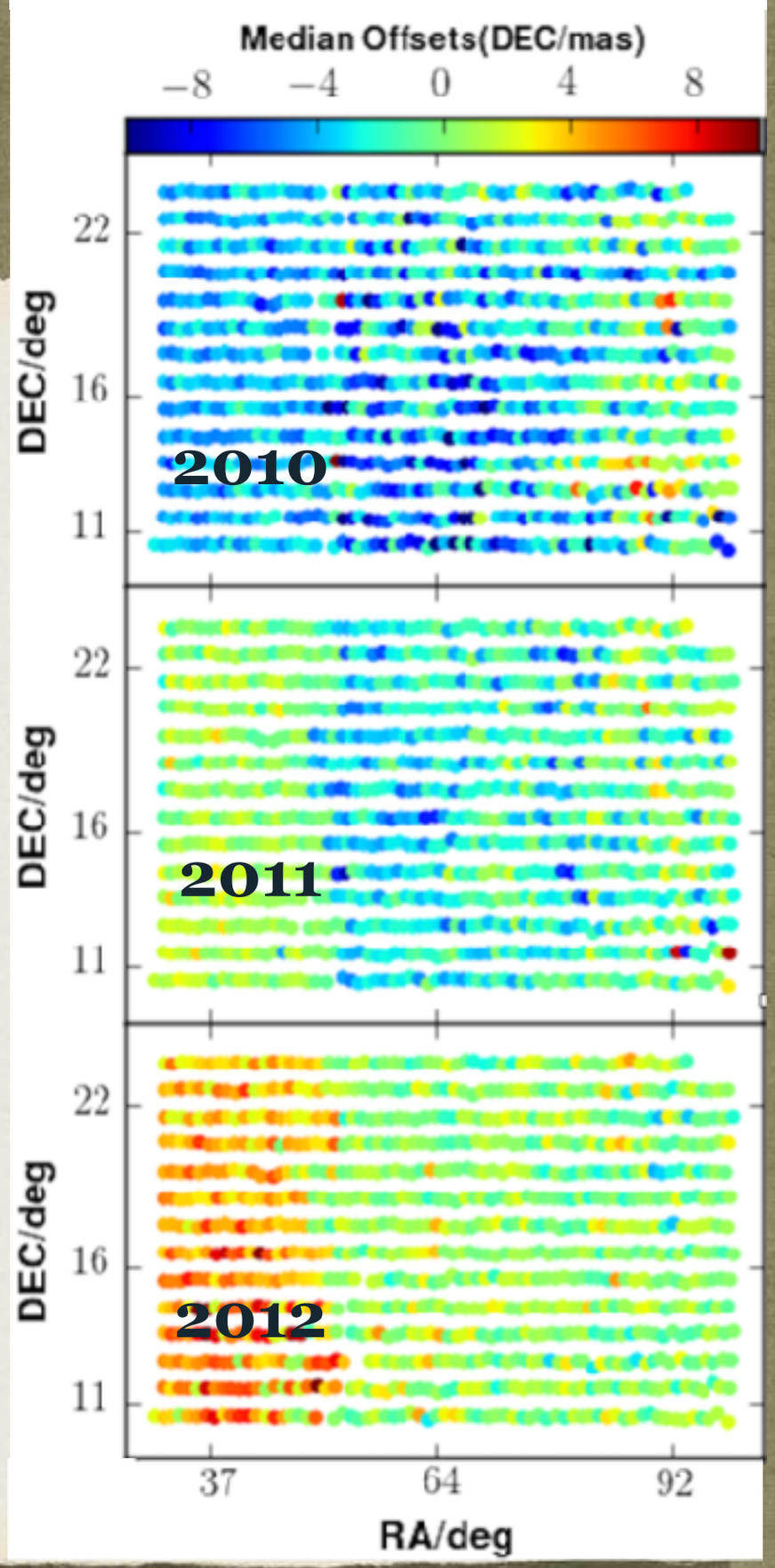
- **How to cross-calibrate stars in the different surveys?**



X-CALIBRATION
(DIRECTION DEPENDENT OFFSET PATTERN)

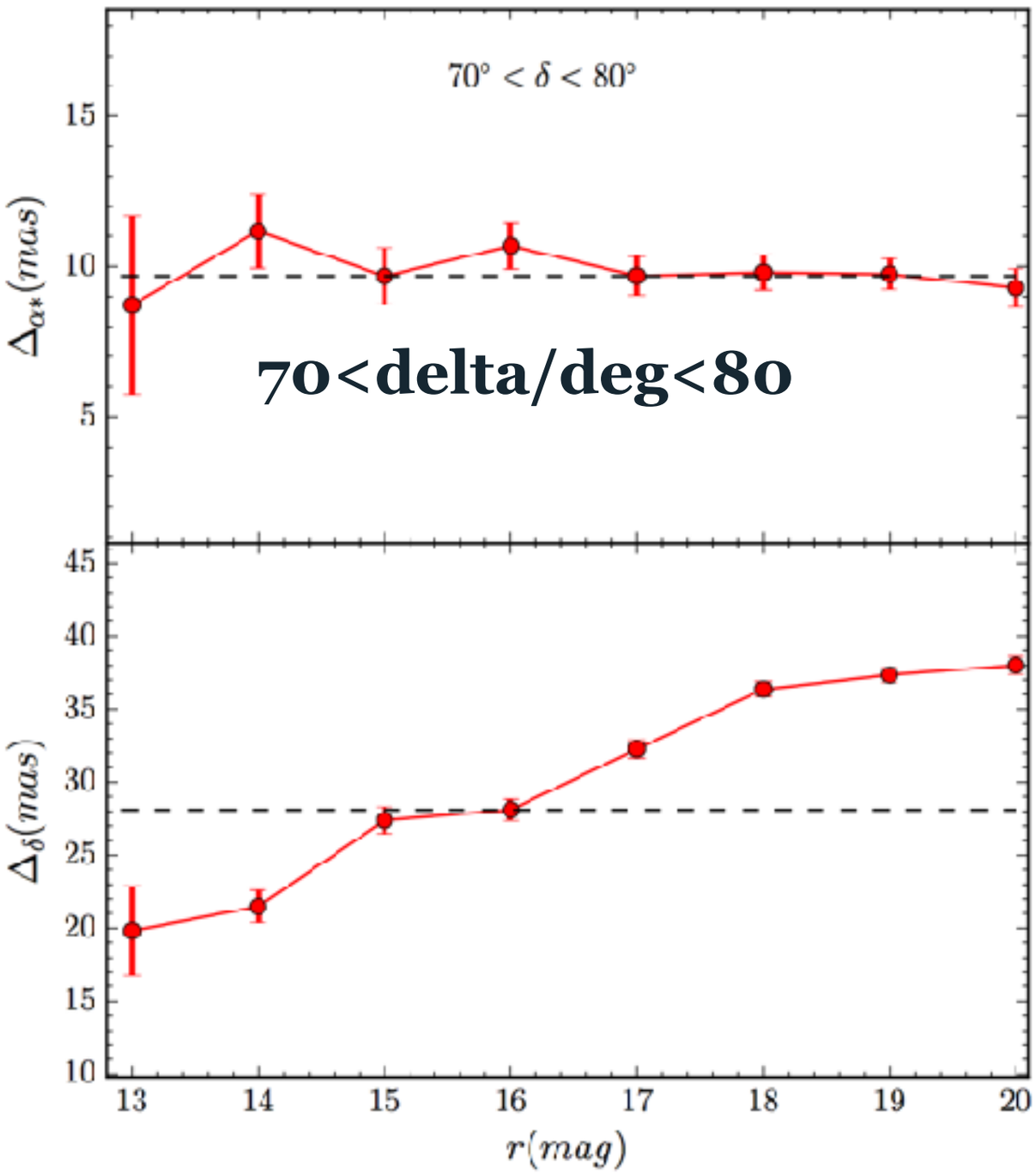
- **The direction-dependent offsets**

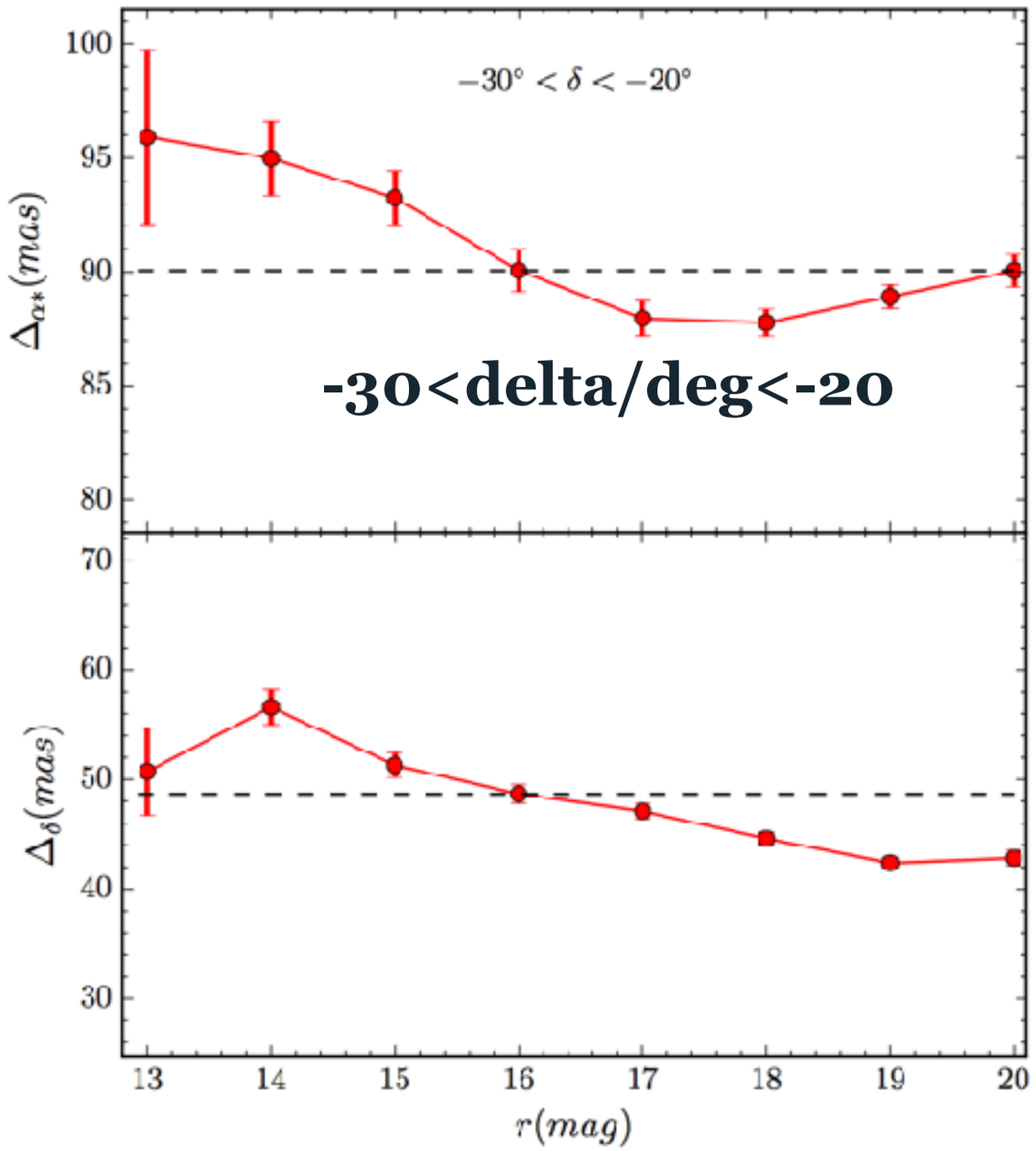
Mean offsets of galaxy position between different years



X-CALIBRATION

(MAGNITUDE AND DECLINATION DEPENDENT OFFSET PATTERN)

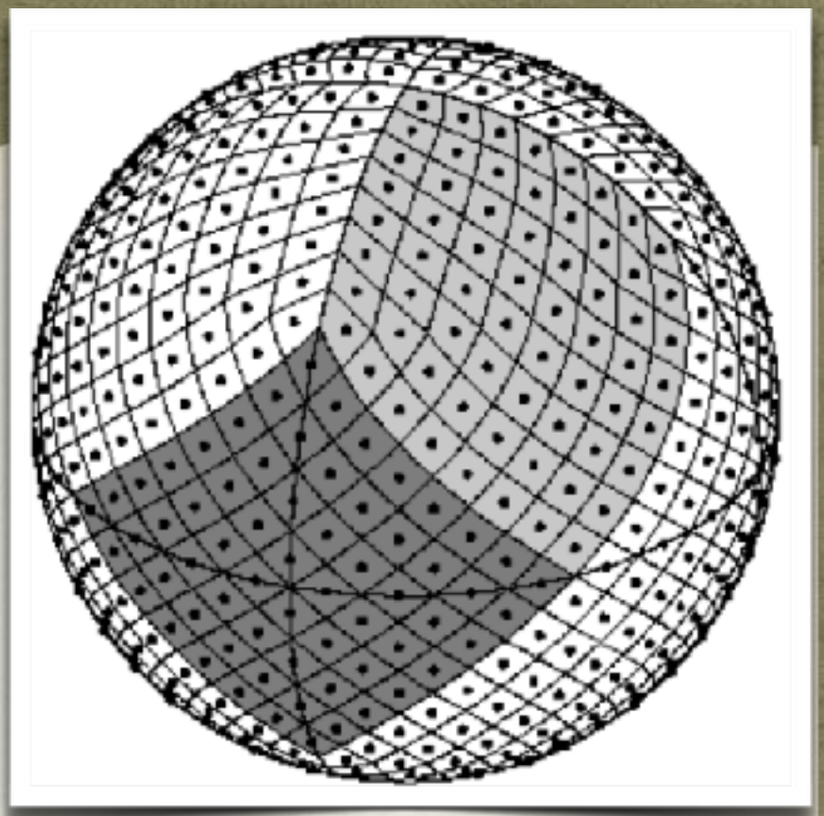




- The magnitude and declination dependent offsets (Gaia)

X-CALIBRATION
(PROCEDURE)

Assuming:
1. Stars have the same offset with galaxies in the same regions and MJDs
2. Galaxies should not move (Too distant)



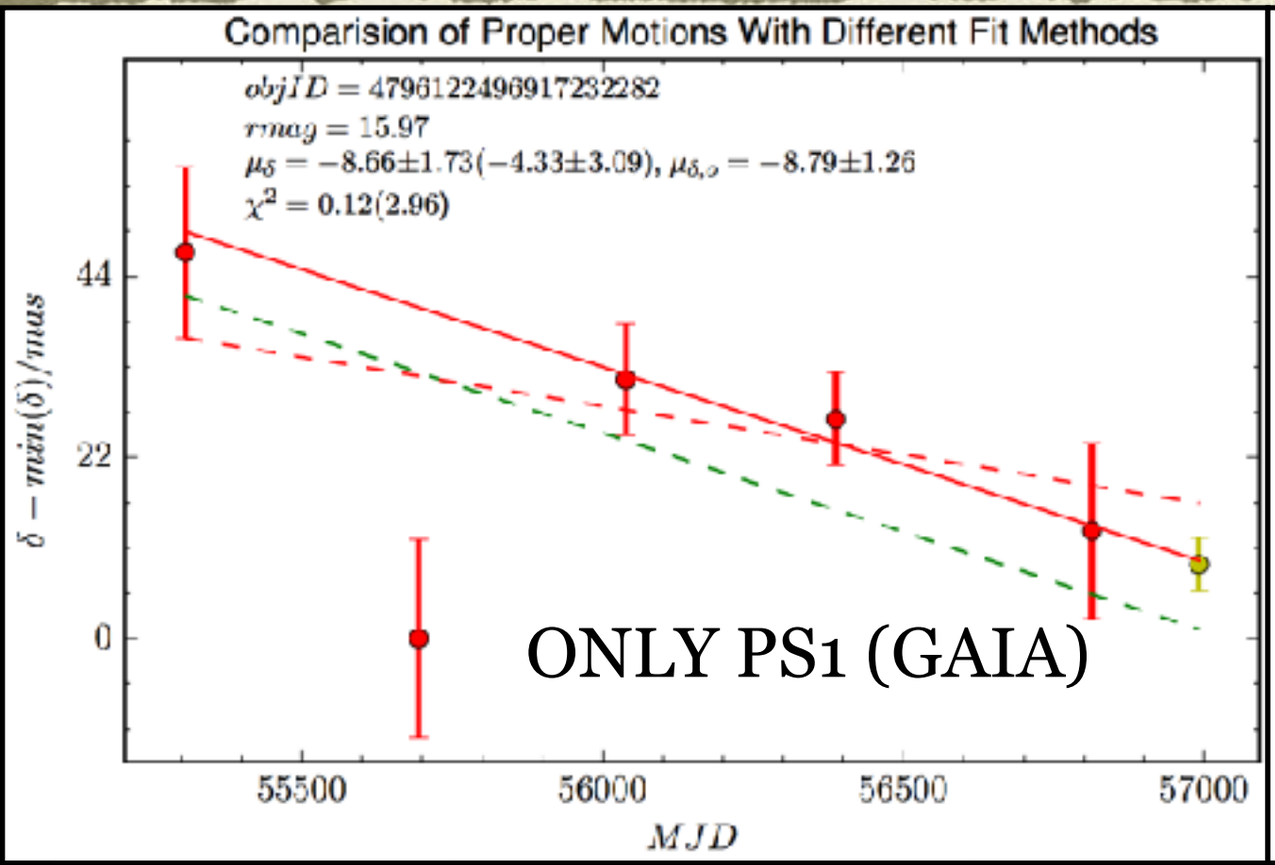
1. **Pick up a chunk (10deg X 10deg) in the sky;**
2. **Classify the objects as stars and galaxies;**
3. **Divide the sky into equal-area pixels (Anchor Point, AP);**
4. **Construct a reference position catalog (galaxies);**

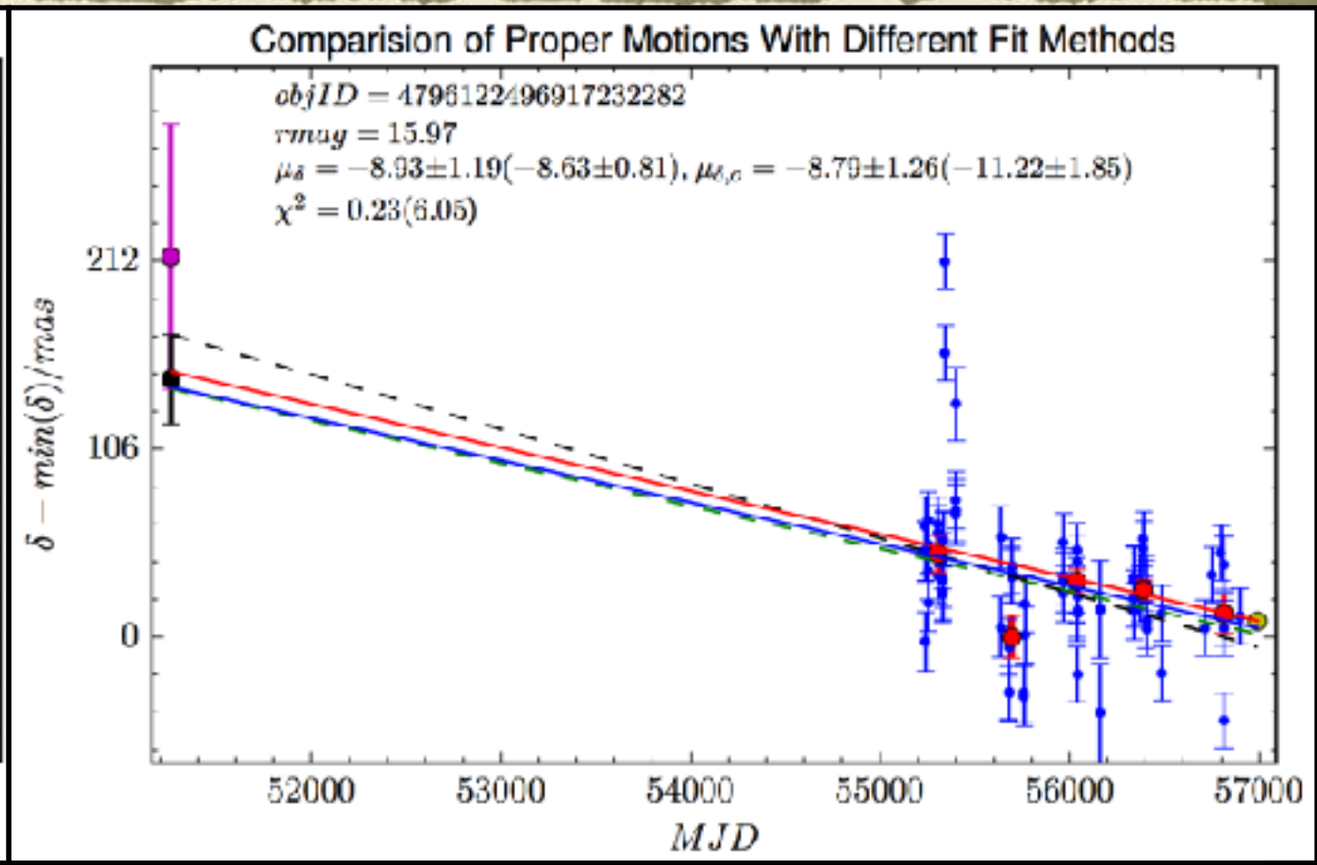
4.1 The median value of observed positions in different MJD as the "TRUE" position for each galaxies.

4.2 For each AP, find the closest 600 galaxies to calibrate the positions of galaxies within this pixel.

5. **Calibrate the positions of stars with the reference catalog.**
6. **Using nearby 100 bright stars(14.5<r<17 mag) to do the calibration for Gaia**

PROPER MOTION FITTING
(A TYPICAL EXAMPLE)



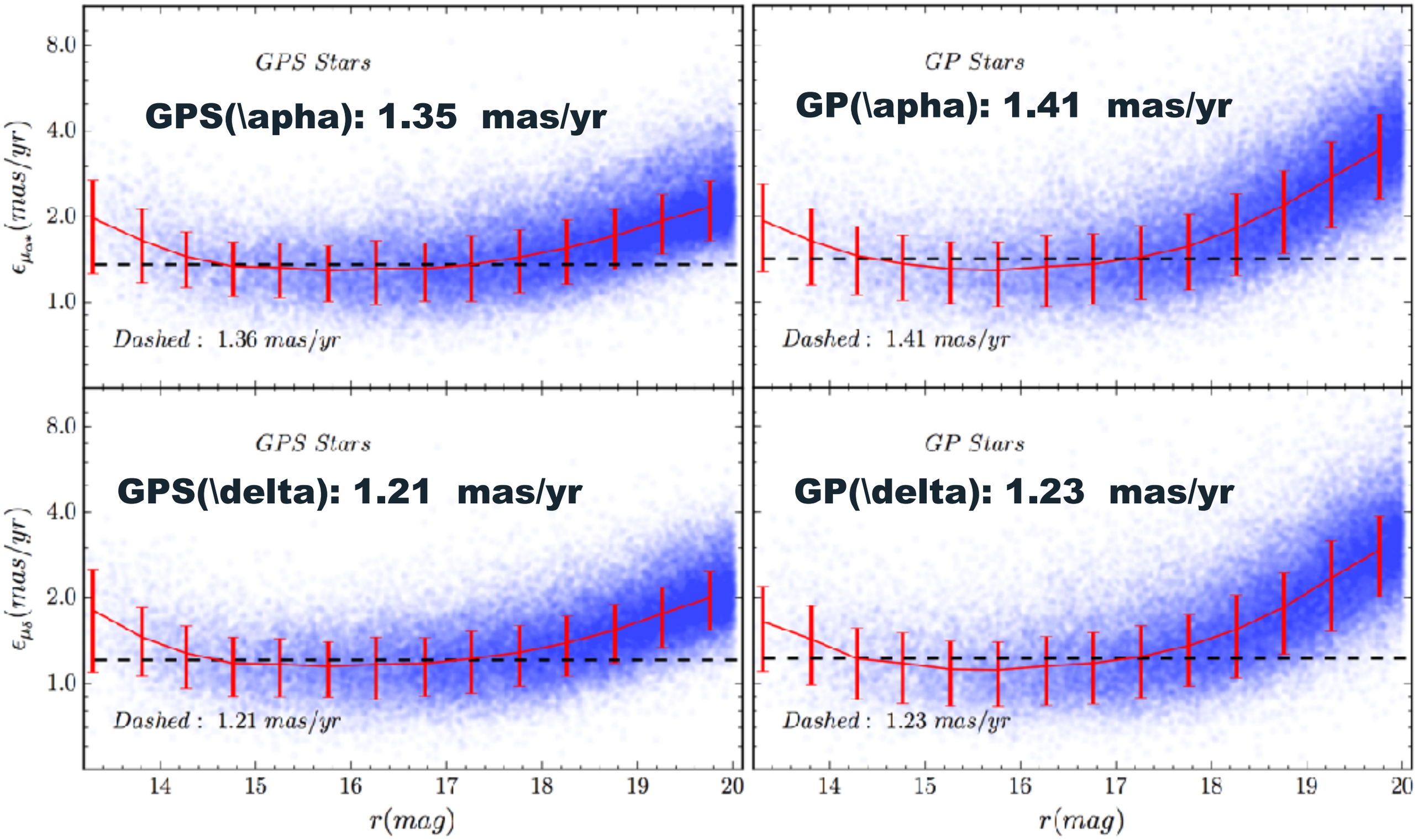


- red points (Season-AVG PS1)
- yellow point (Gaia)
- blue points (individual PS1)
- pink point (2MASS)
- black point (SDSS)

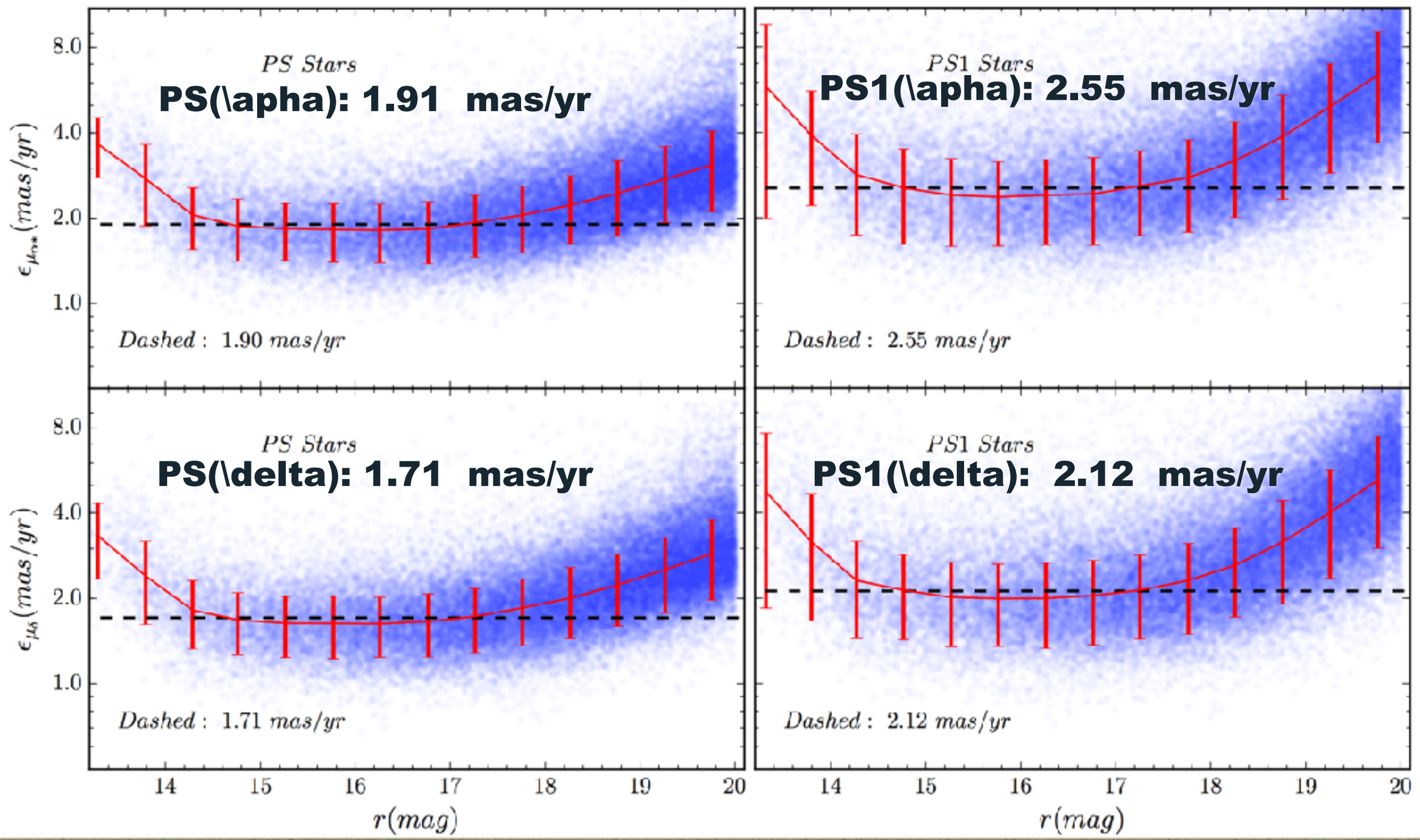
- red line(red points, excluding 1 outlier)
- red dash line(red points, including 1 outlier)
- blue line(blue points fitting)
- black dash line(from PV3)
- green dash line(from Fritz + 2015)

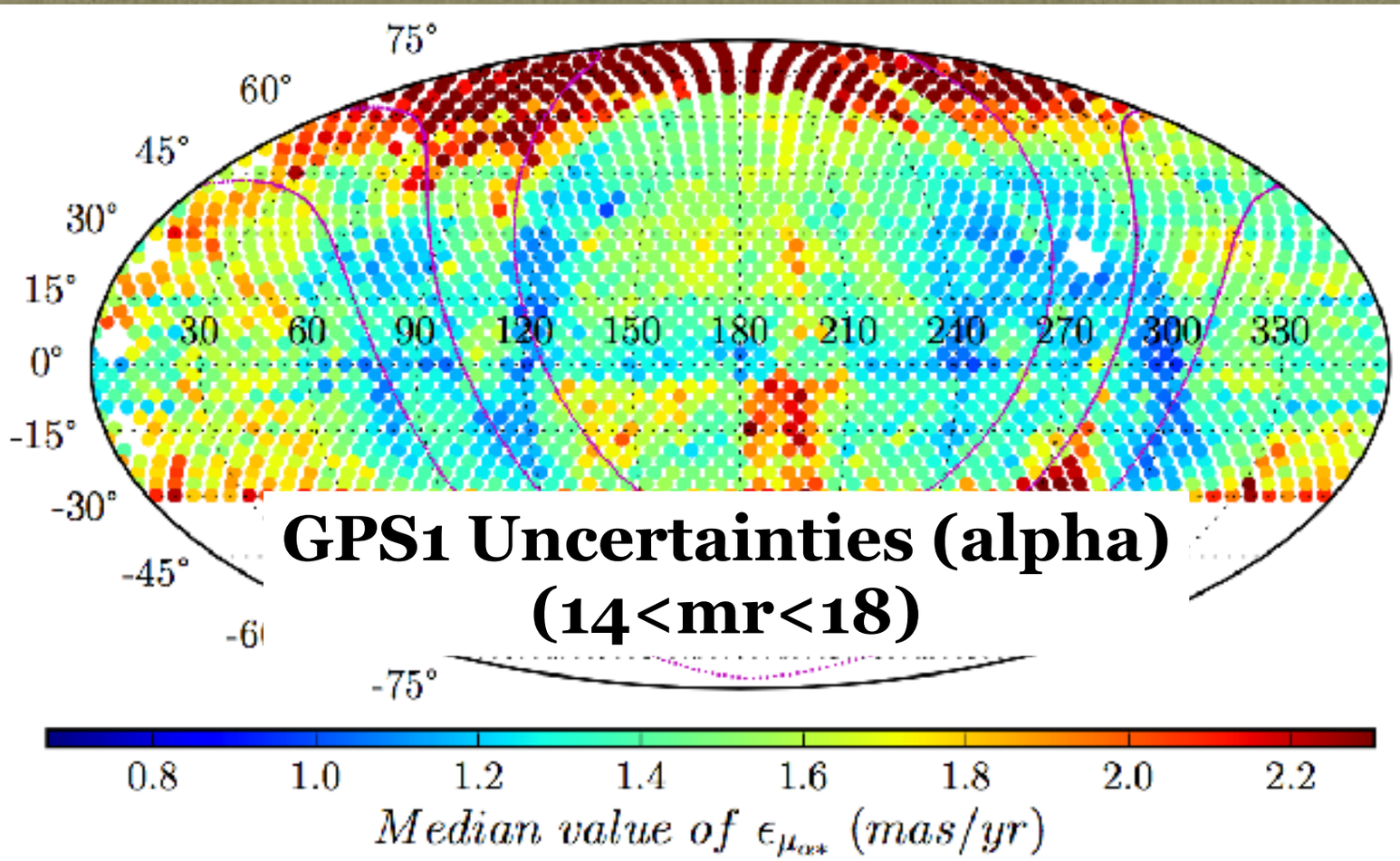
Finally, We choose the red solid fitting (MODEL INDEPENDENT).

RESULTS
(PRECISION, WITH GAIA)

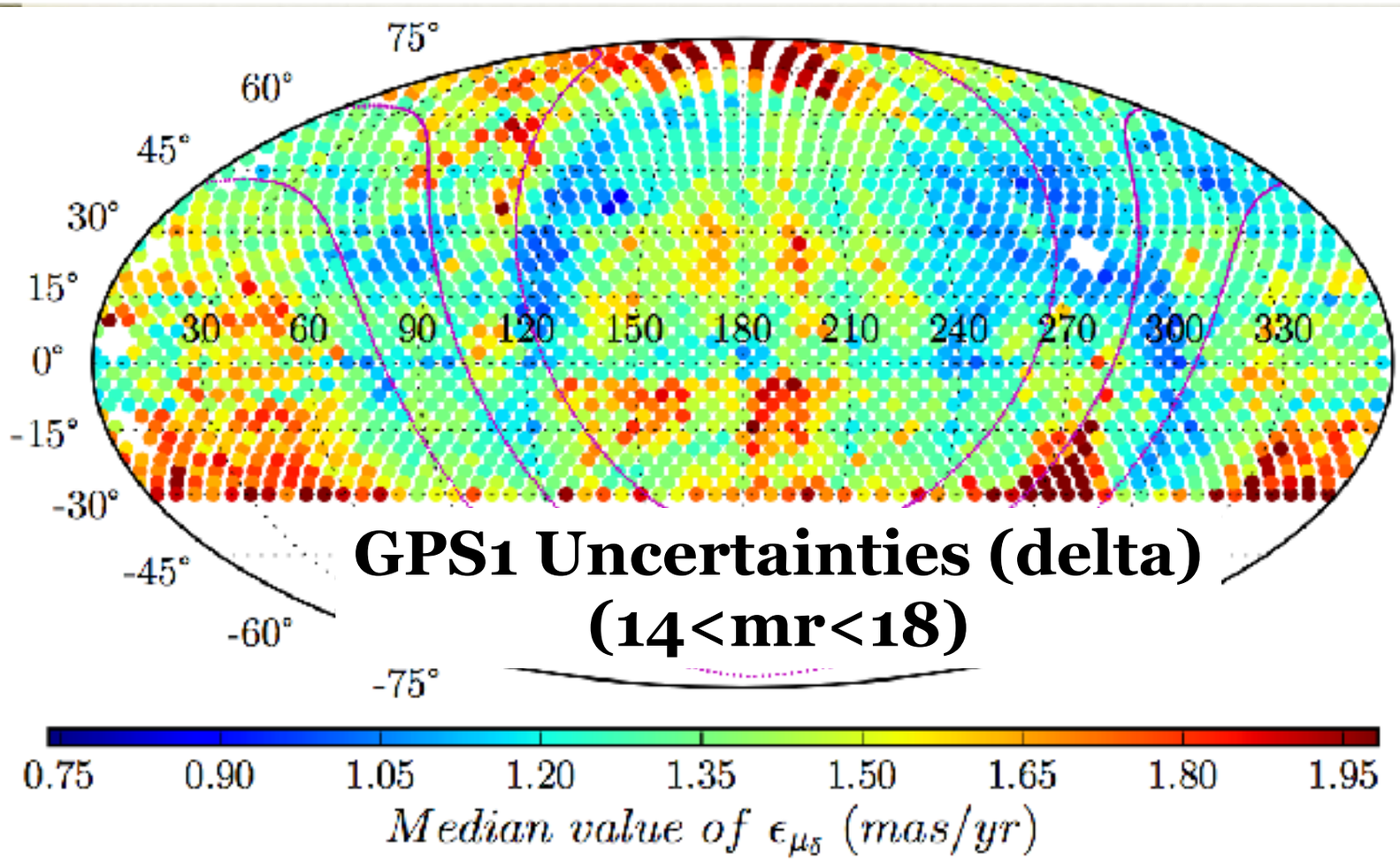


RESULTS
(PRECISION, W/O GAIA)

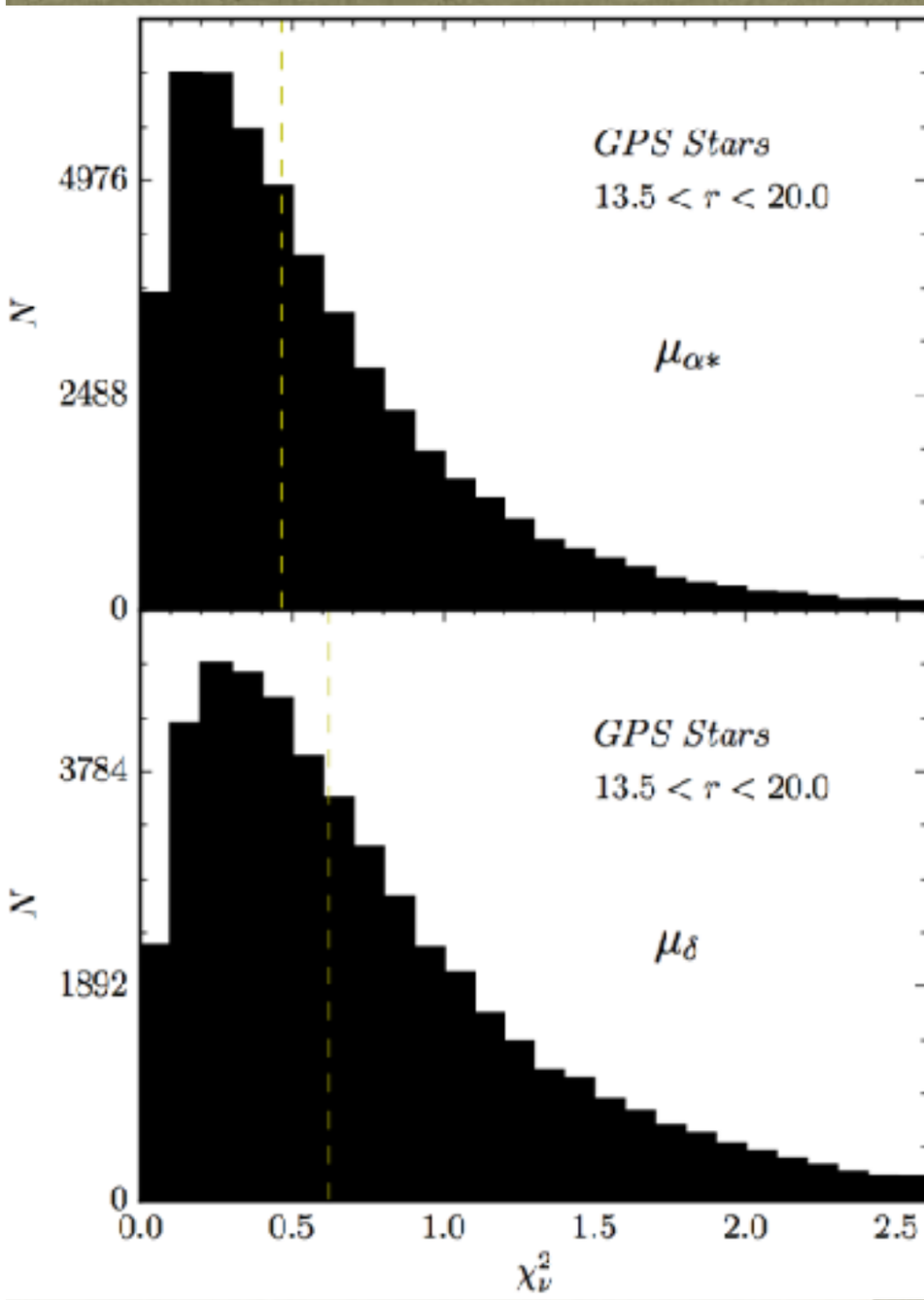




GPS1 Uncertainties (alpha) (14<mr<18)

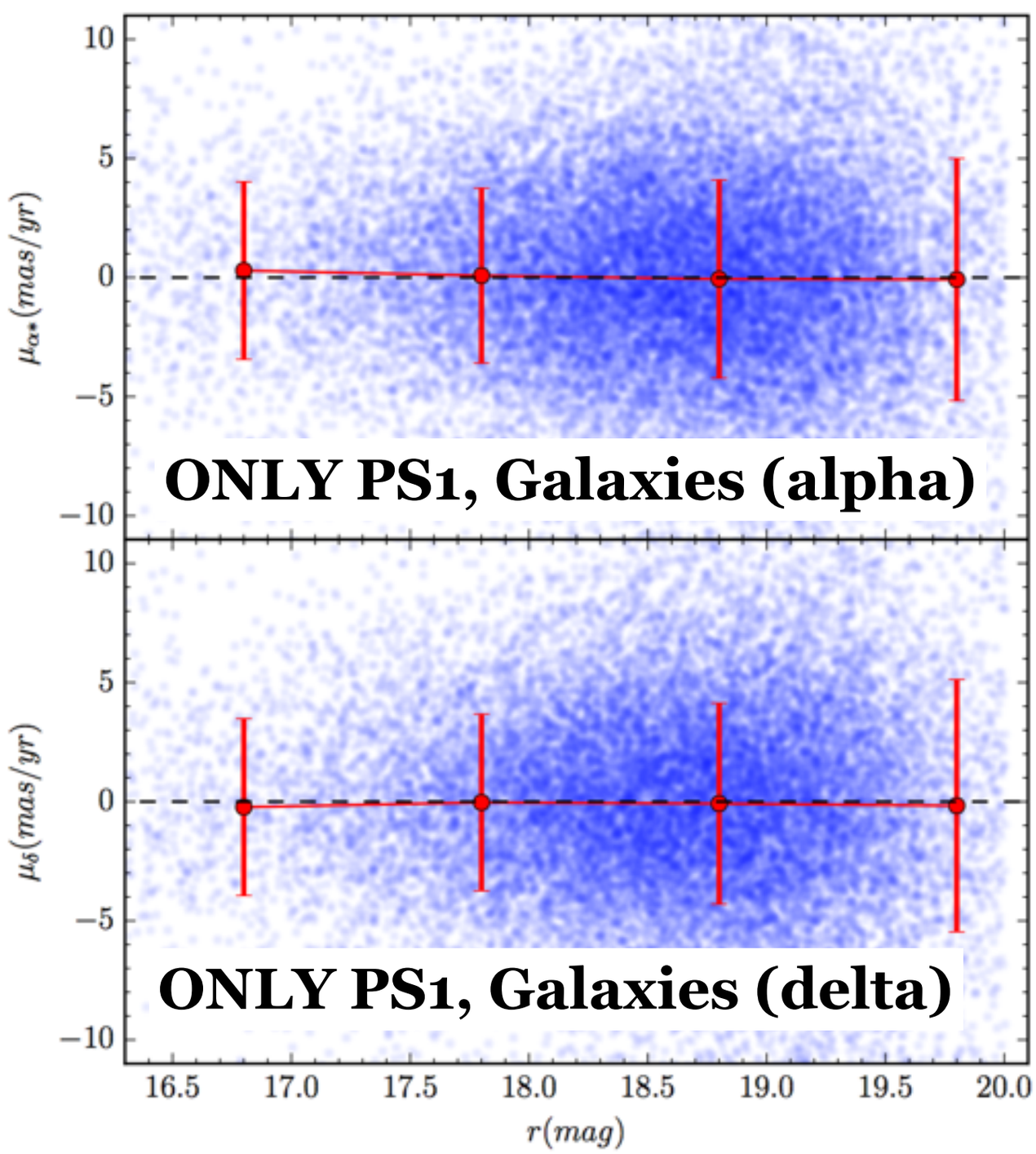


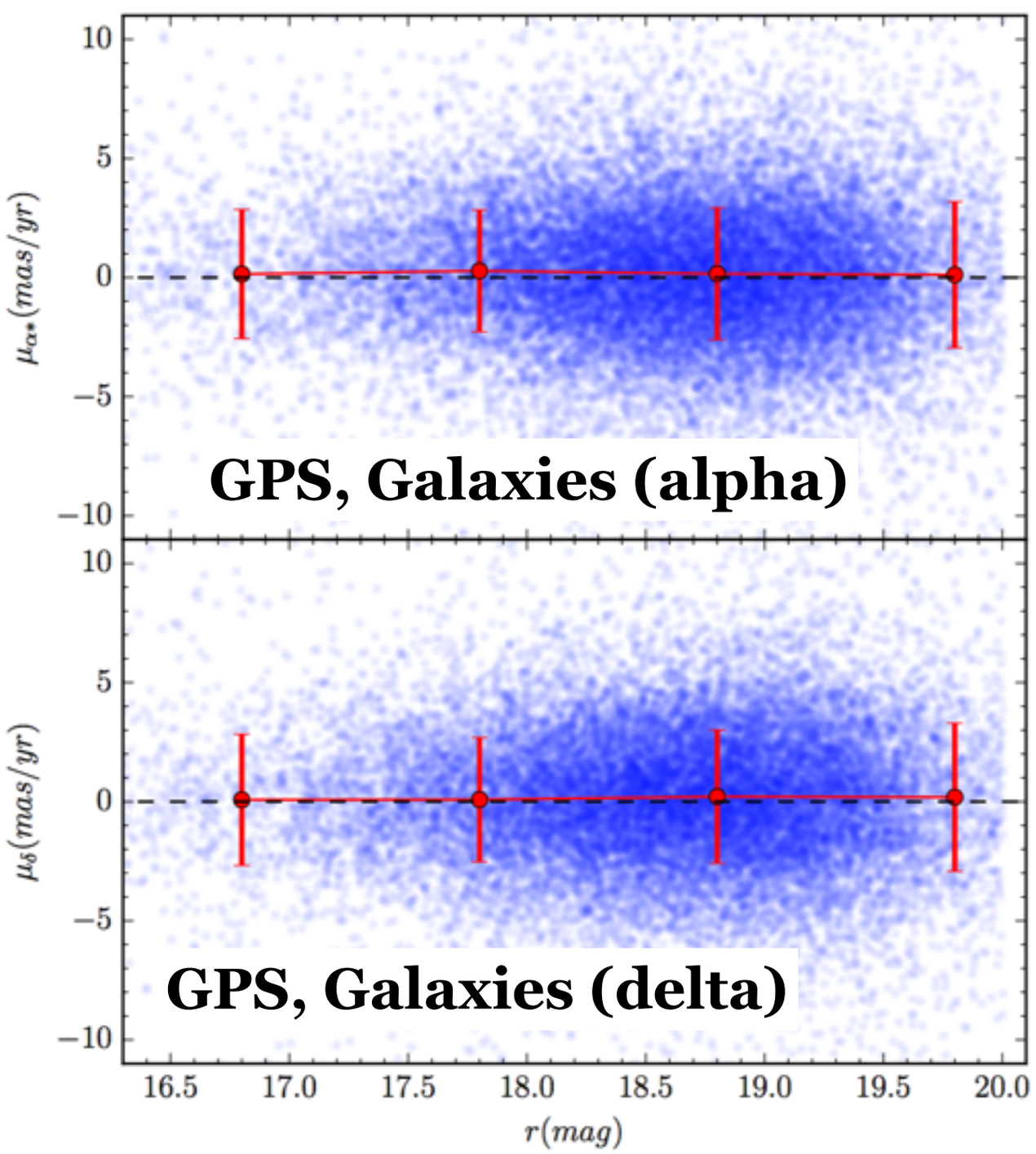
GPS1 Uncertainties (delta) (14<mr<18)



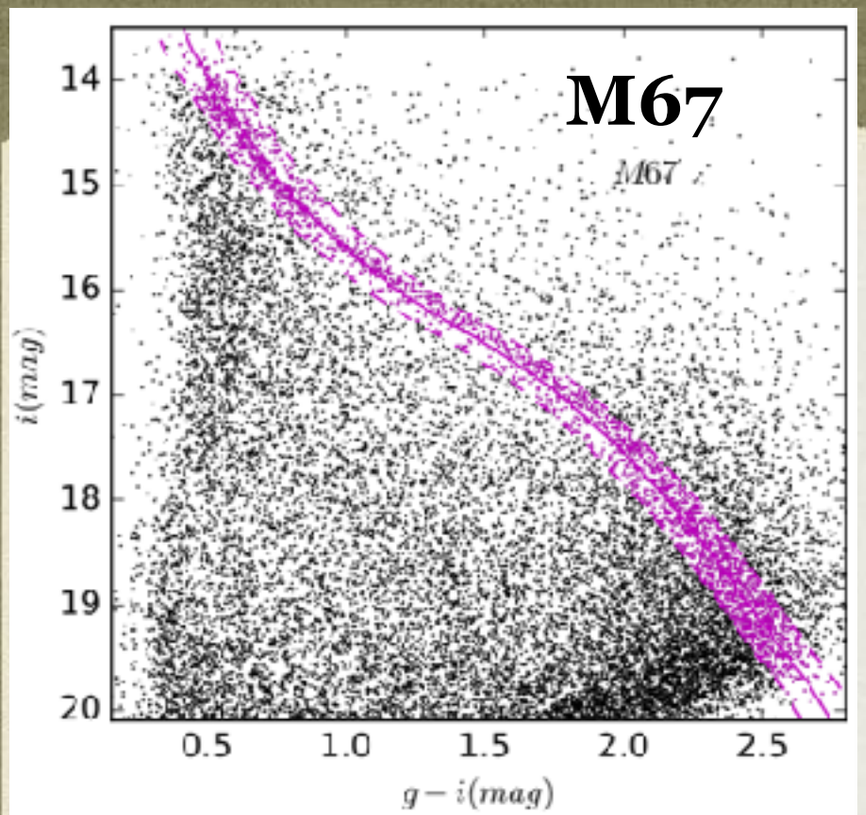
Reduced chi2

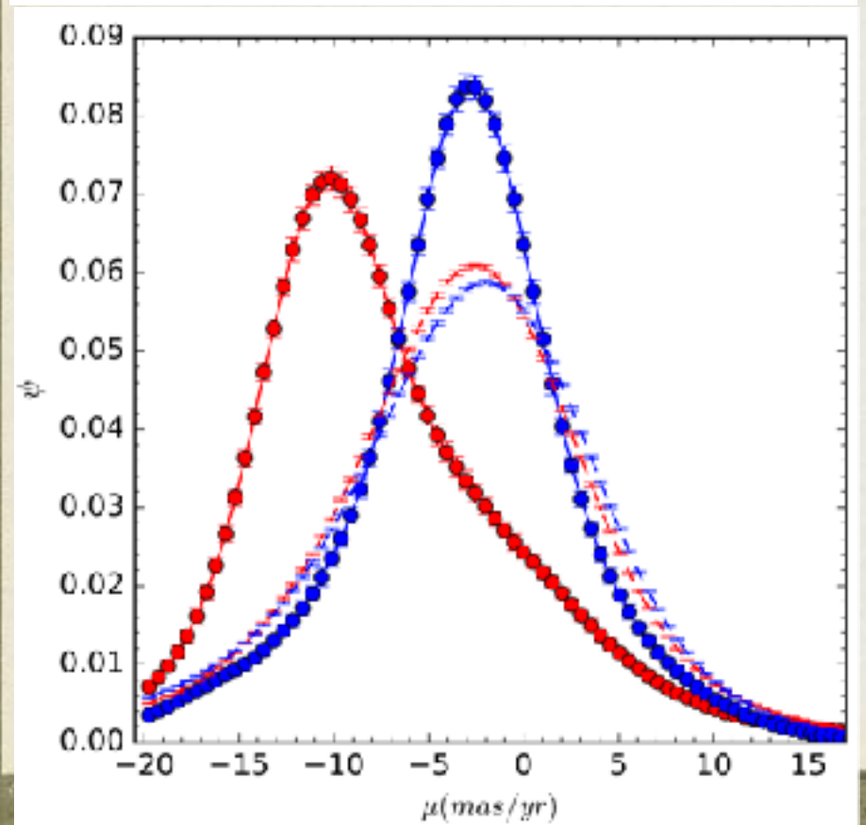
VALIDATION
(ACCURACY, GALAXIES)

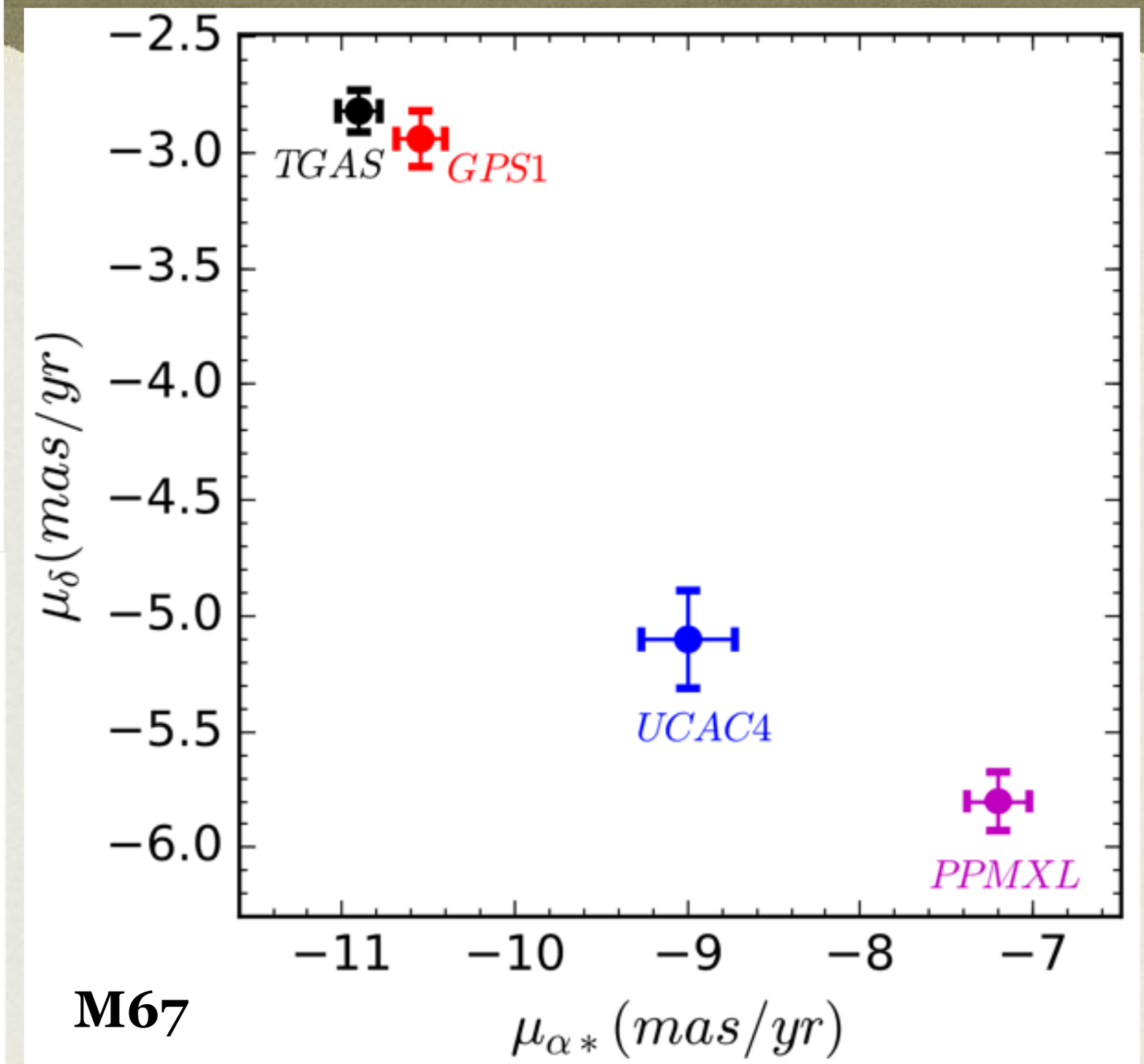




VALIDATION
(ACCURACY, OPEN CLUSTER)







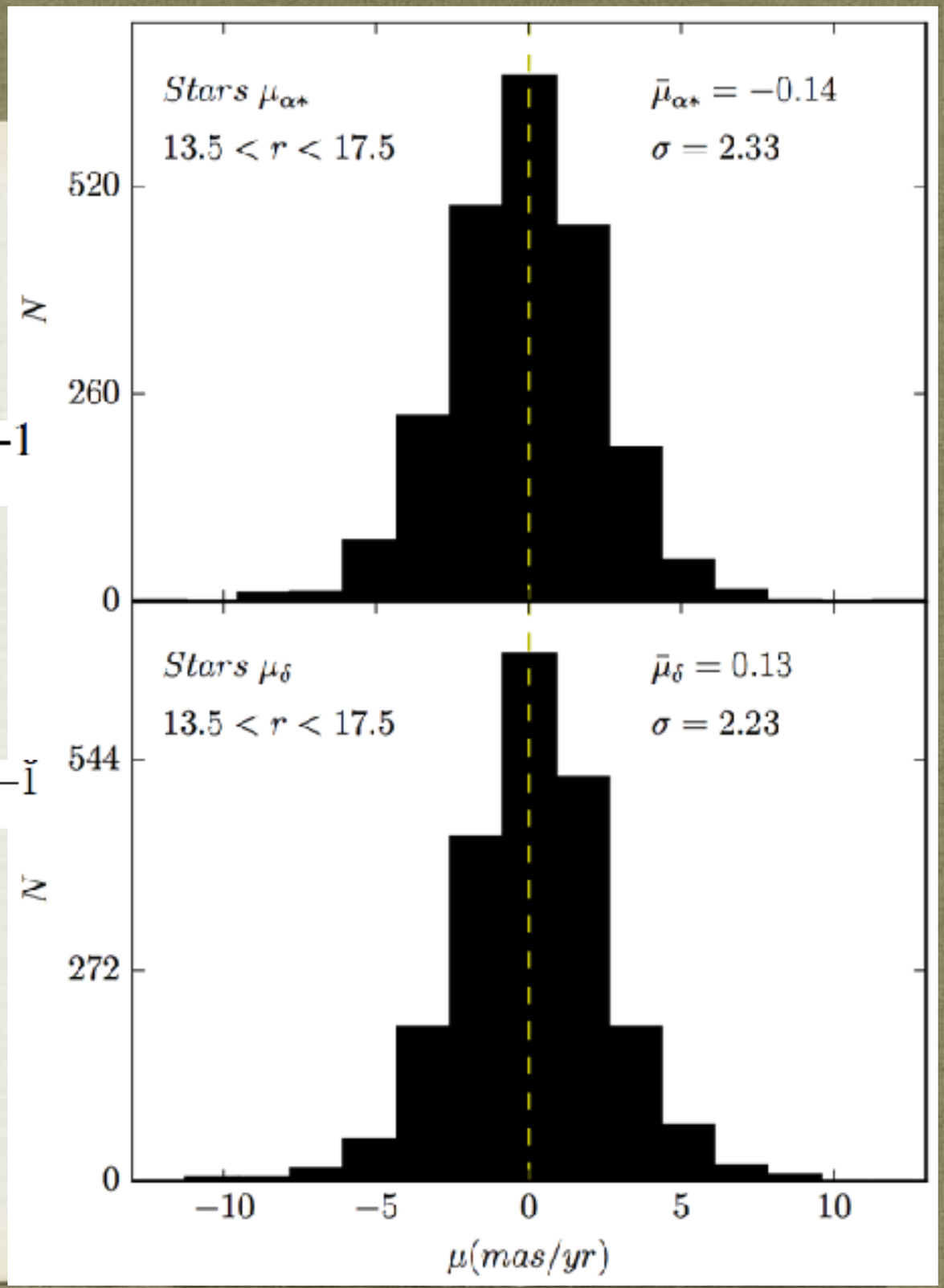
VALIDATION
(ACCURACY, DISTANT STARS)

~2200 BHB (Xue +, 2010)
and Giant stars (Xue + 2014)
(d>20kpc, 13.5<r<17.5)

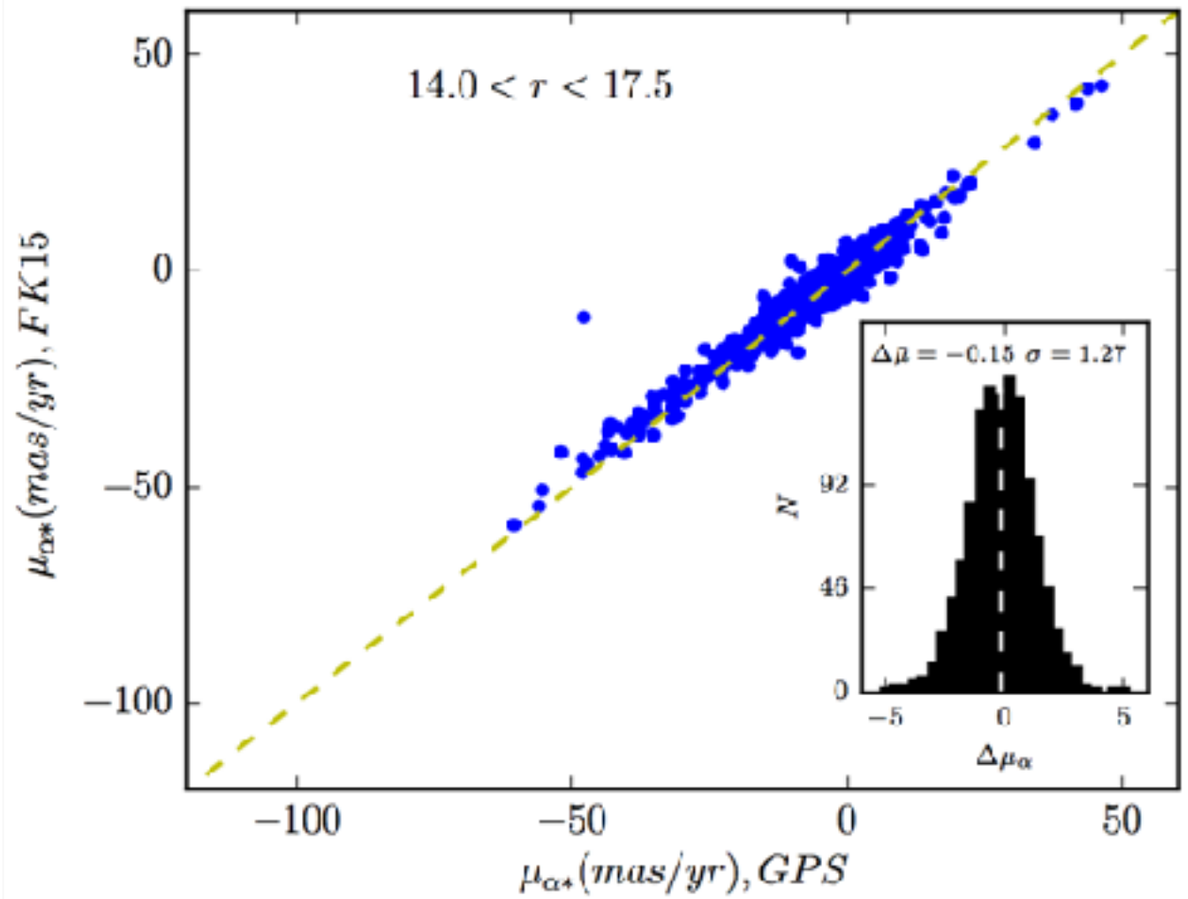
$$(U_\odot, V_\odot, W_\odot) = (9.58, 10.52, 7.01)\,\mathrm{kms}^{-1}$$

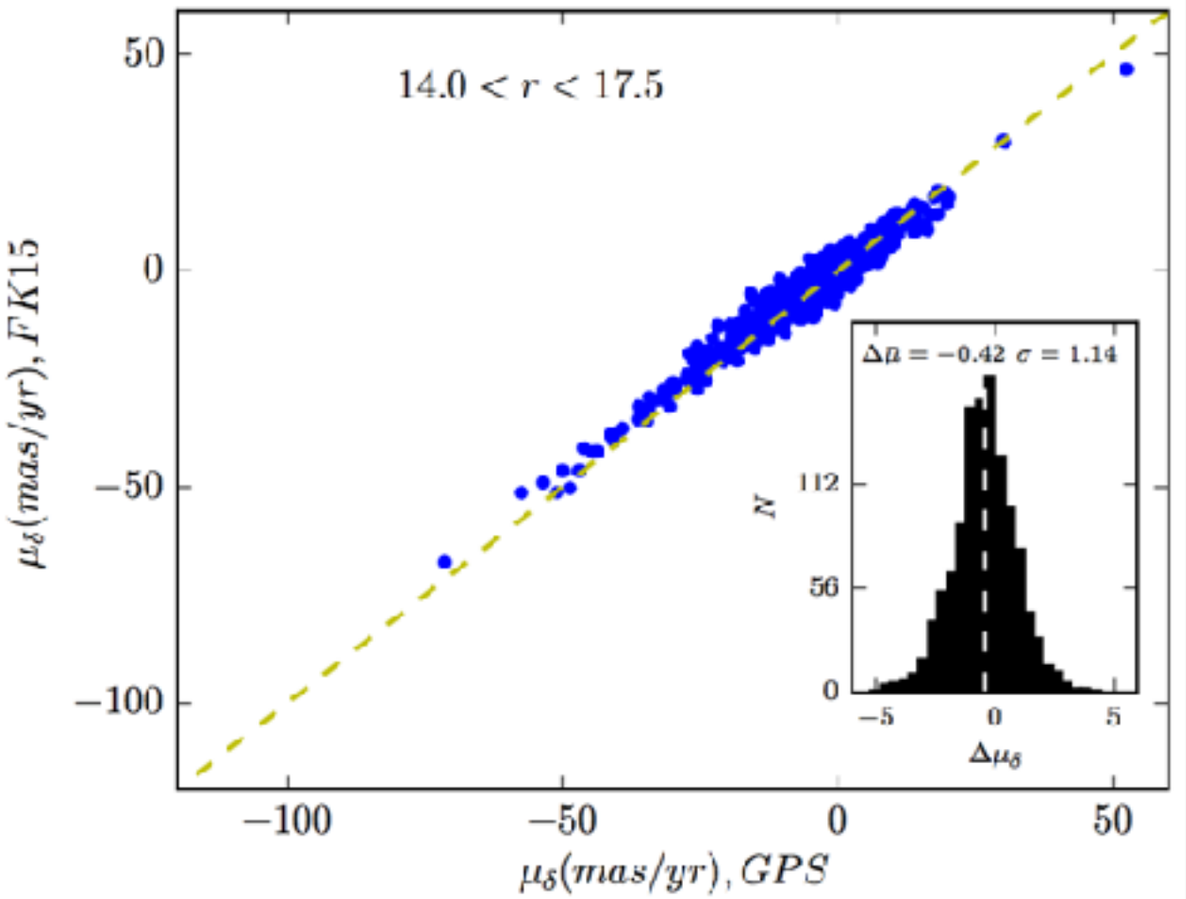
(Tian et al. 2015)

the IAU circular speed of LSR as $v_0 = 220\,\mathrm{kms}^{-1}$



VALIDATION
(COMPARISON, PALOMAR 5)





Fritz & Kallivayalil (2015)

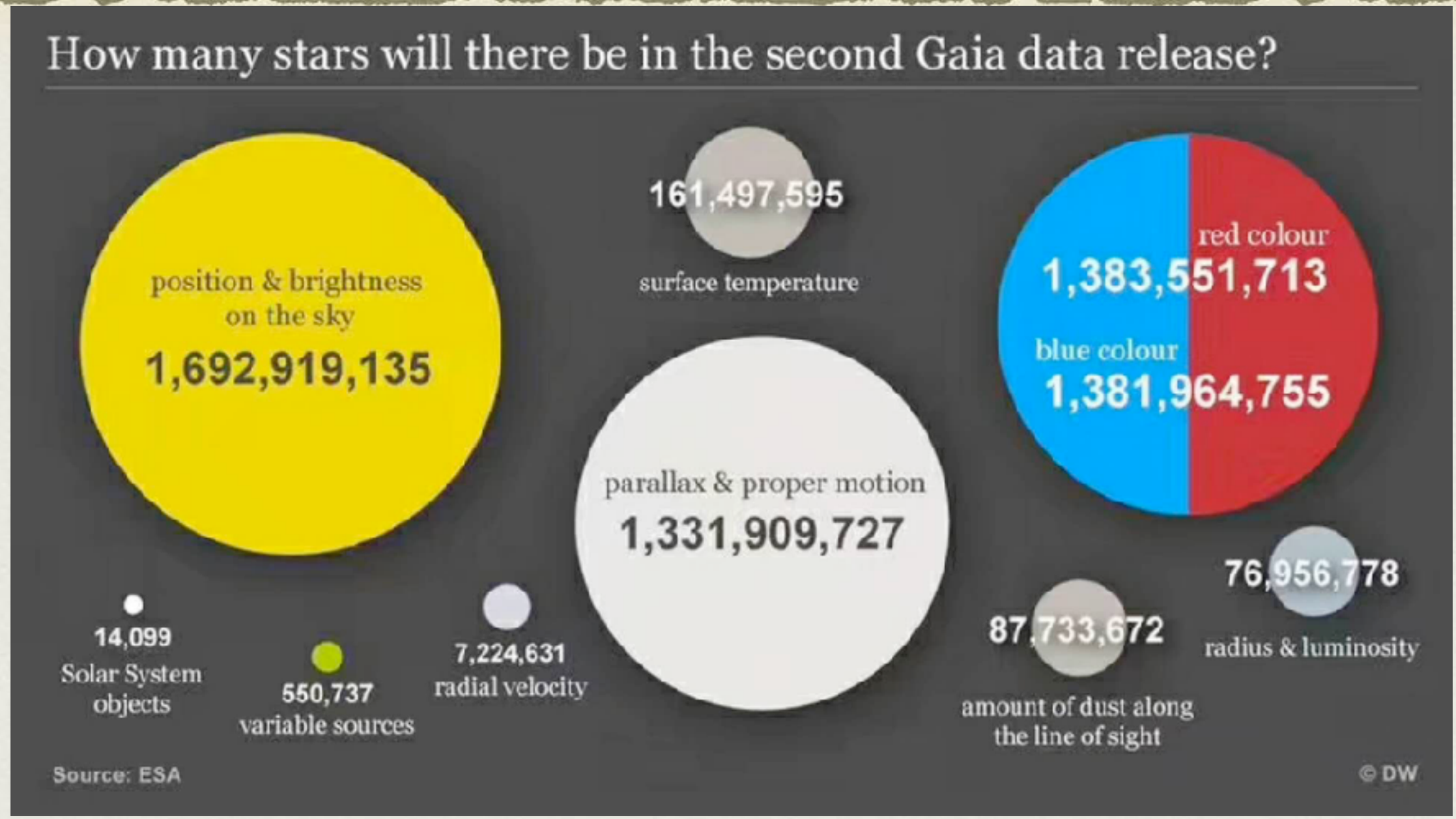
CONCLUSION FOR GPS1
(TAKE-TO-HOME POINTS)

- **With Gaia+PS1+SDSS, we construct a proper motion catalog (GPS1) for ~350 million stars across 3/4 sky region, down to mr<20.**

- **The characteristic systematic error <0.3 mas/yr (~10x better than PPMXL, UCAC4), the precision ~1.5 mas/yr. (~4x better than PPMXL, UCAC4)**

- **GPS1 almost has been superseded by Gaia DR2**

GAIA DR2
(RELEASED IN APR. 25TH 2018)



- The uncertainties in the proper motion are up to 0.06 mas/yr (for G < 15 mag), 0.2 mas/yr (for G = 17 mag) and 1.2 mas/yr (for G = 20 mag).

GAIA DR2
(RELEASED IN APR. 25TH 2018)

LIMITATIONS:

- **>361 million sources only have positions (precision~2 mas) in J2015.5 and the mean G magnitude, MISSING proper motions and parallax etc;**
- **The proper motions are hard to reach to the precision of sub-mas/yr for faint sources;**
- **Gaia DR2 is complete in 12<G<17, but incomplete at an ill-defined faint magnitude limit;**
- **no sources with G>20.7 mag**

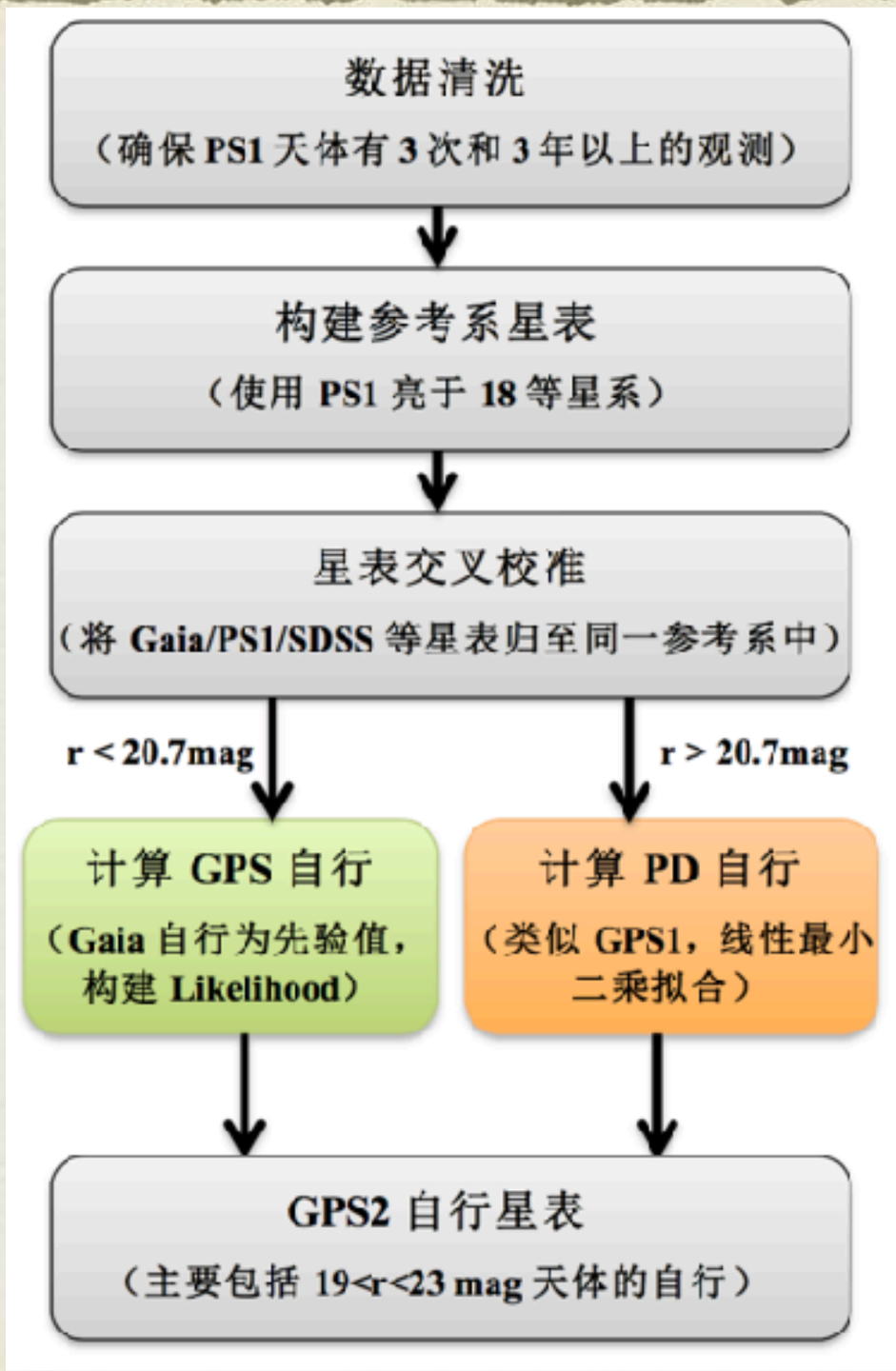
GPS1+
(NECESSITY)

GPS1+ will mainly focus on:

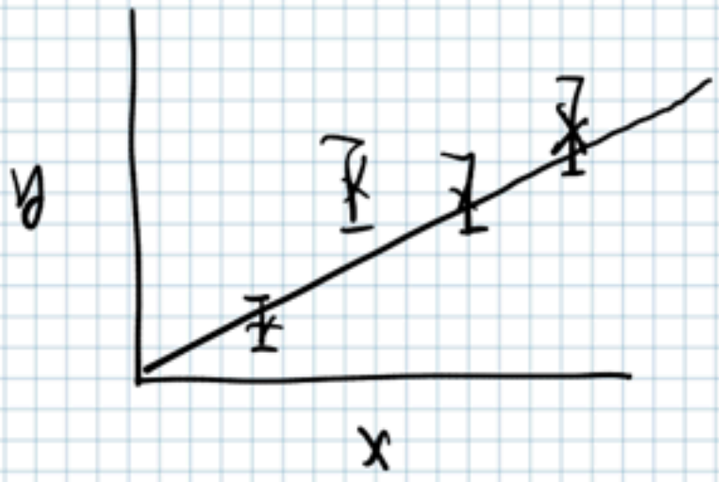
(1) The sources (19<G<20.7), using the Gaia DR2 proper motions as priors to improve the proper motions combining PS1 and SDSS;
(2) To fill up the missing sources (>361 million) in Gaia DR2;
(3) The sources (20.7<G<23), using the similar procedure as GPS1;
(4) Visualization for individual sources.

GPS1+
(BASIC PROCEDURE)

Basic procedure for GPS1+



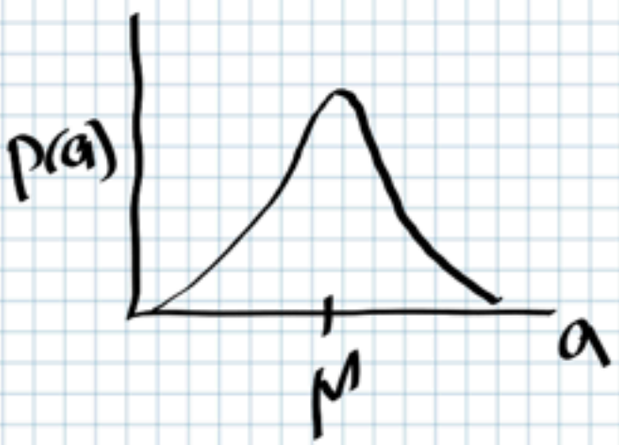
GPS 1+
(BASIC PROCEDURE)



$$f(x) = ax + b$$

likelihood: $$p(x,y \mid a,b) = \exp\left[-\sum_i \frac{[y_i - (ax_i+b)]^2}{2\sigma_y^2}\right]$$

prior of a: $$p(a) = \exp\left[-\frac{(a-\mu)^2}{2\tau^2}\right]$$



posterior:

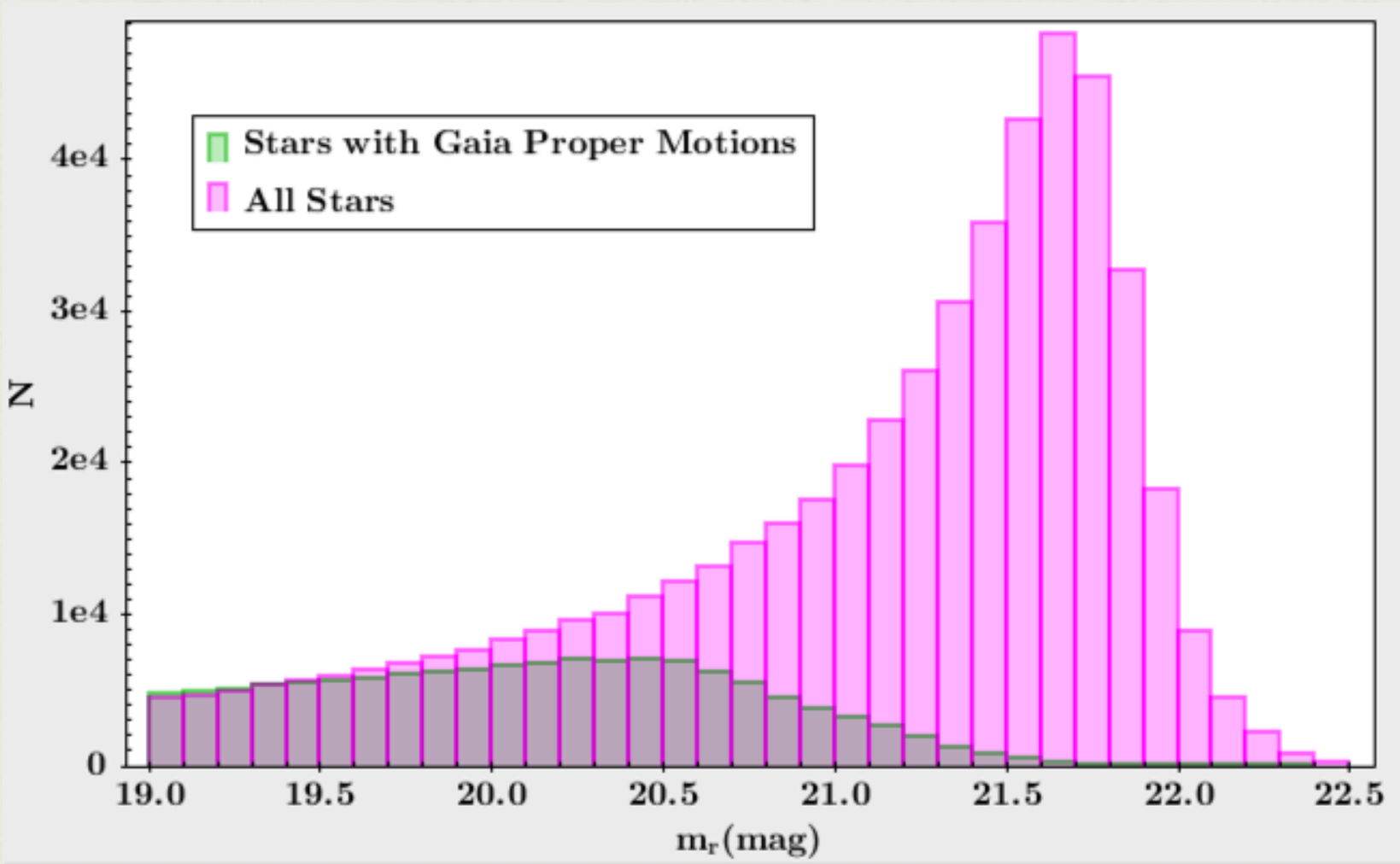
$$p(a,b \mid x,y) = p(x,y \mid a,b)\, p(a,b)$$

$$= p(x,y \mid a,b)\, p(a)\, p(b)$$

set $p(b) = 1$

GPS1+

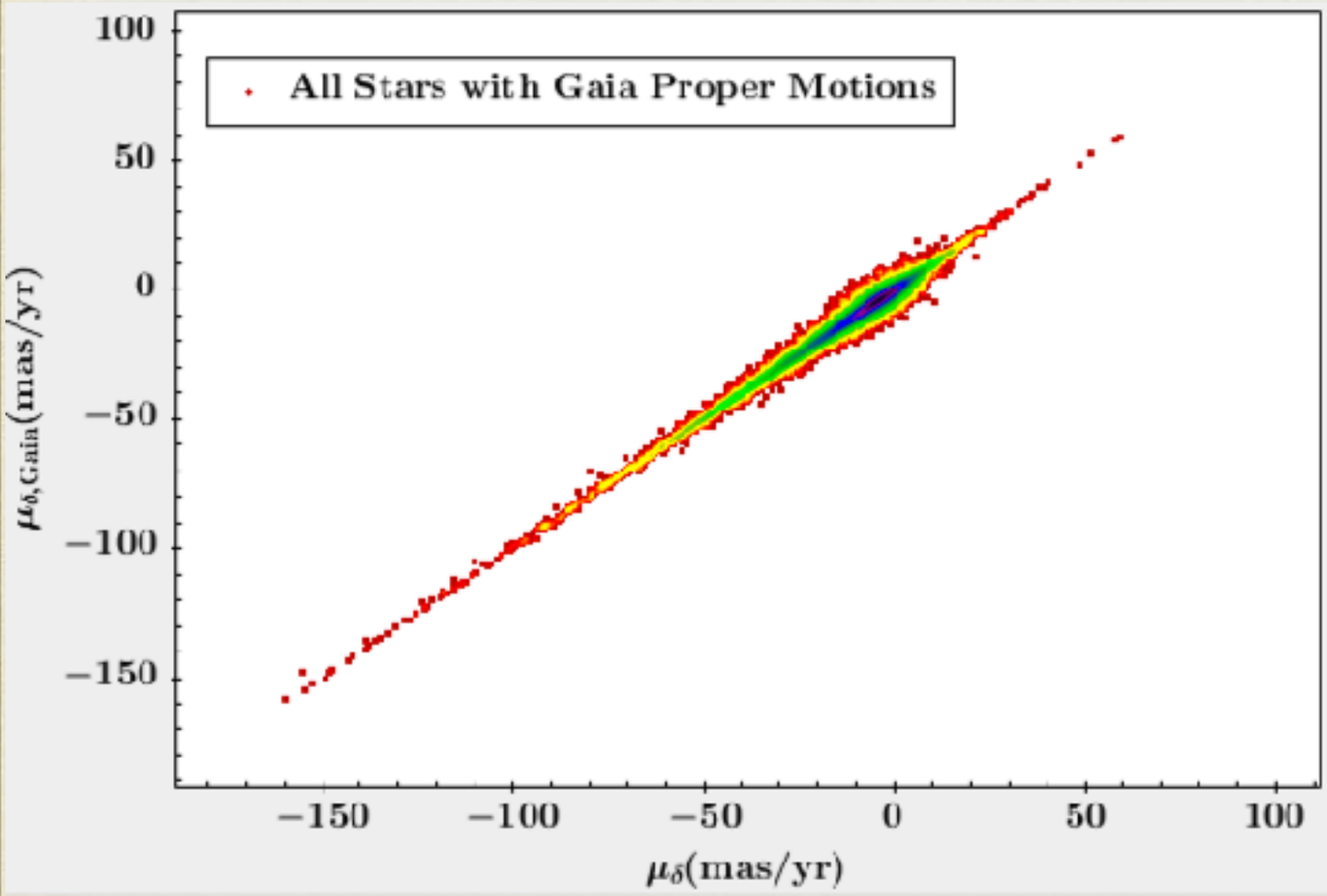
(TESTING ON ~100 DEG^2)

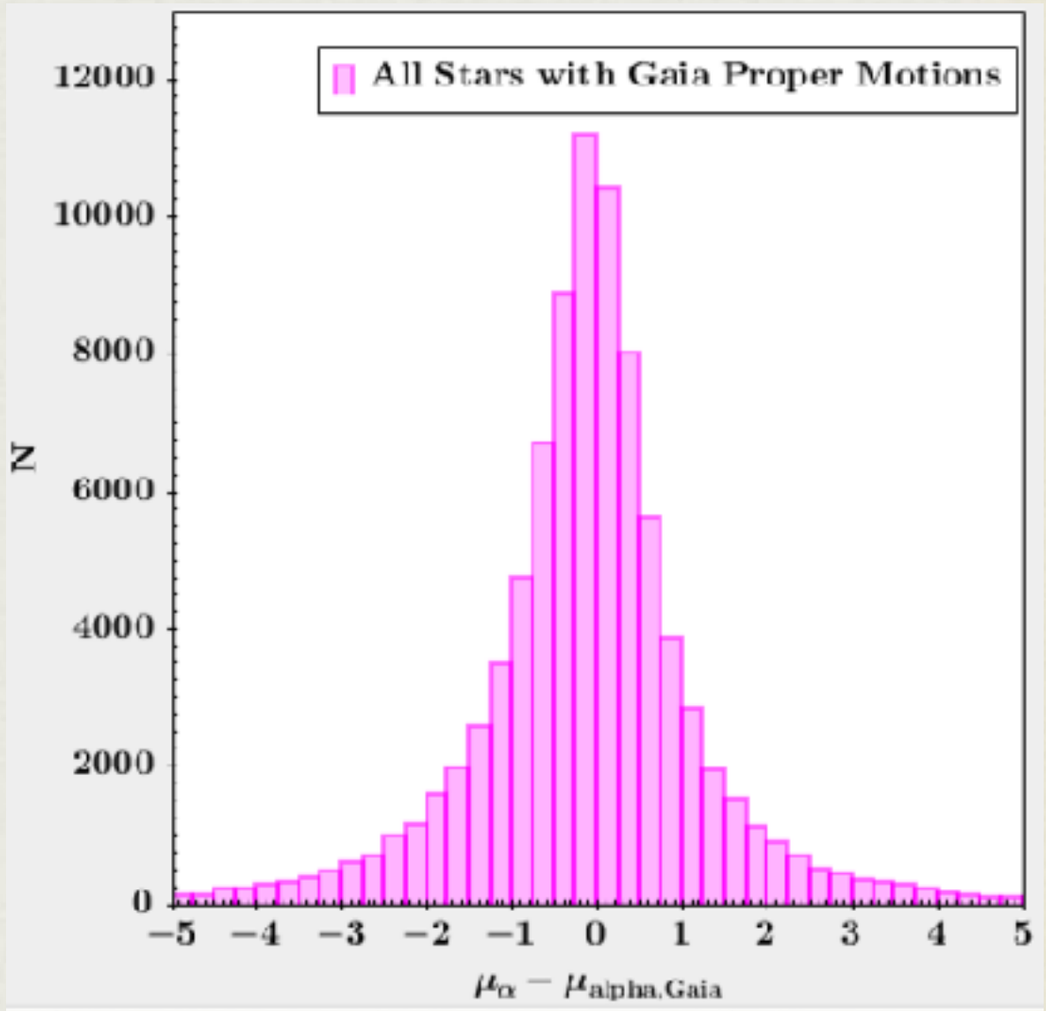


The stars with Gaia proper motions take fraction of ~24% in the sample.

GPS1+

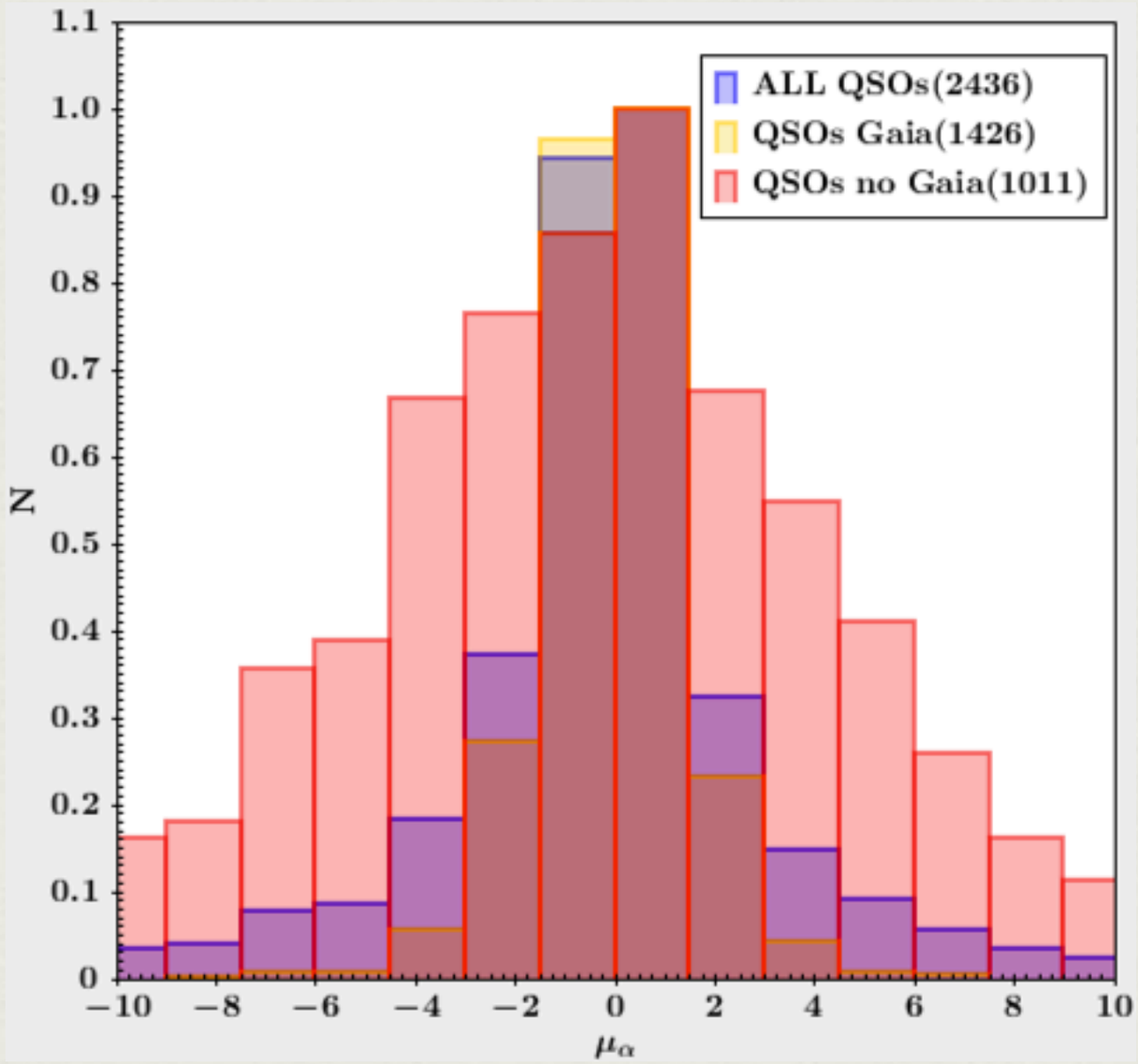
(TESTING ON ~100 DEG^2)



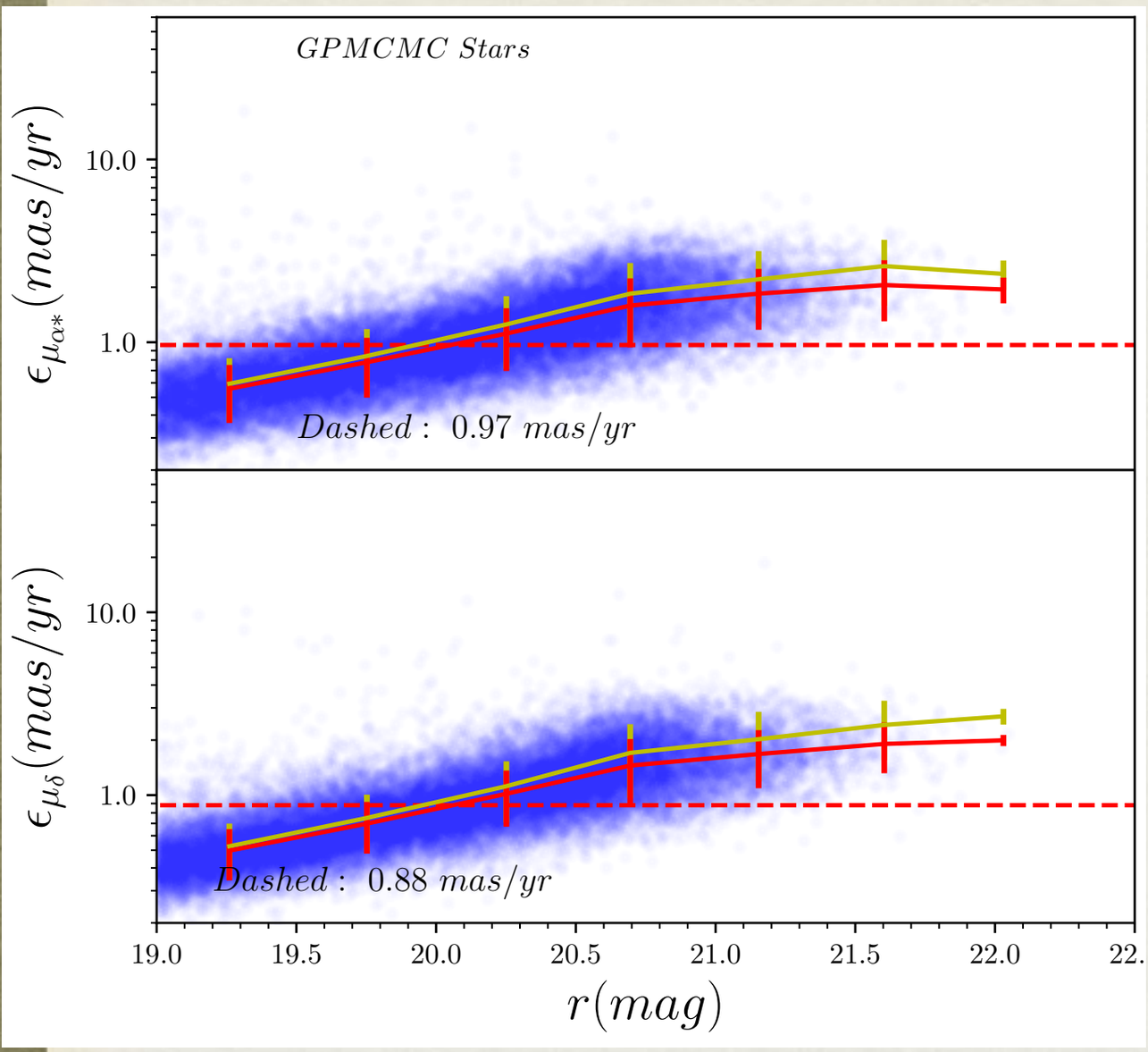


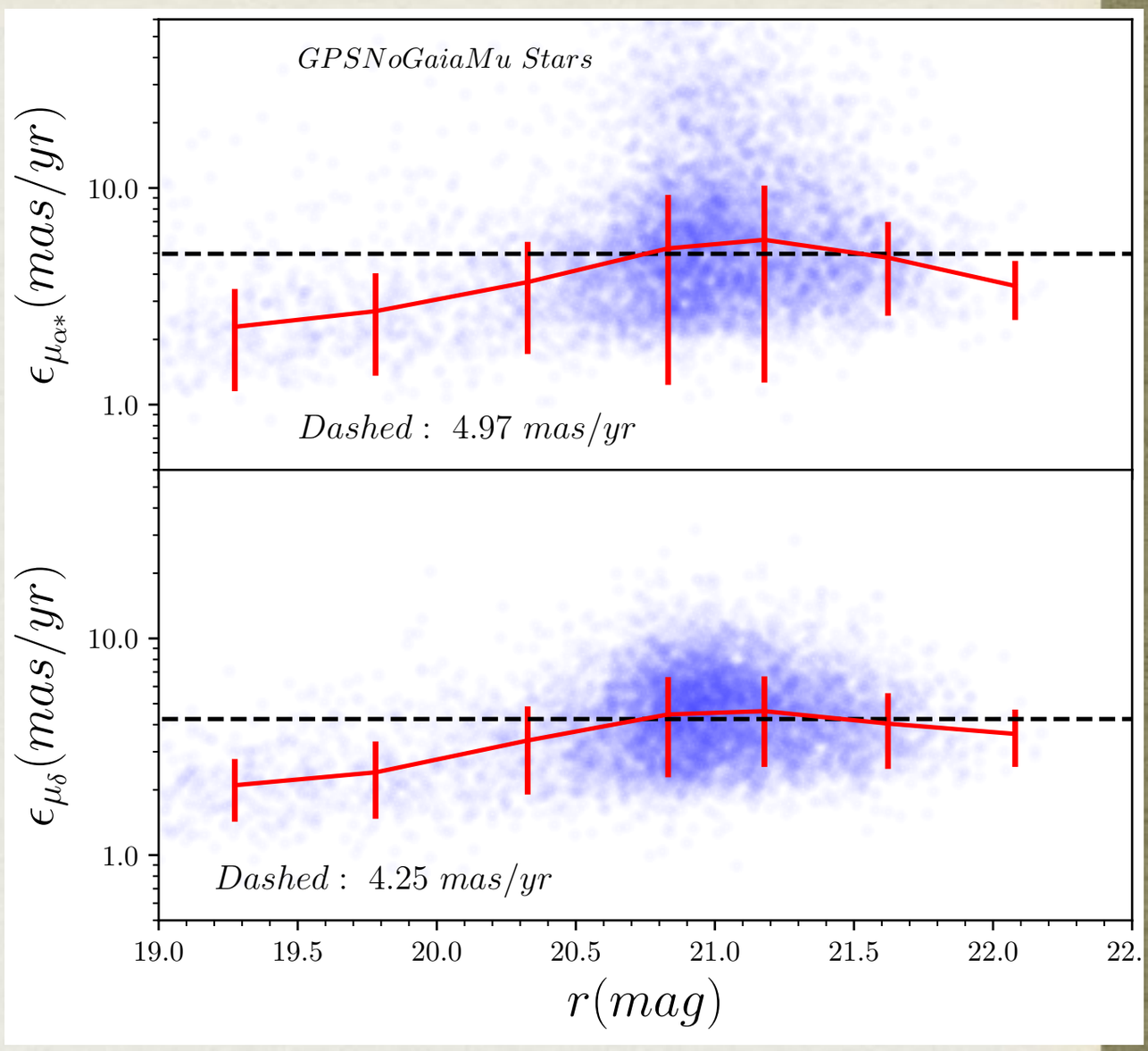
GPS1+

(TESTING ON ~100 DEG^2)



GPS1+
(~300 MILLION OBJECTS)





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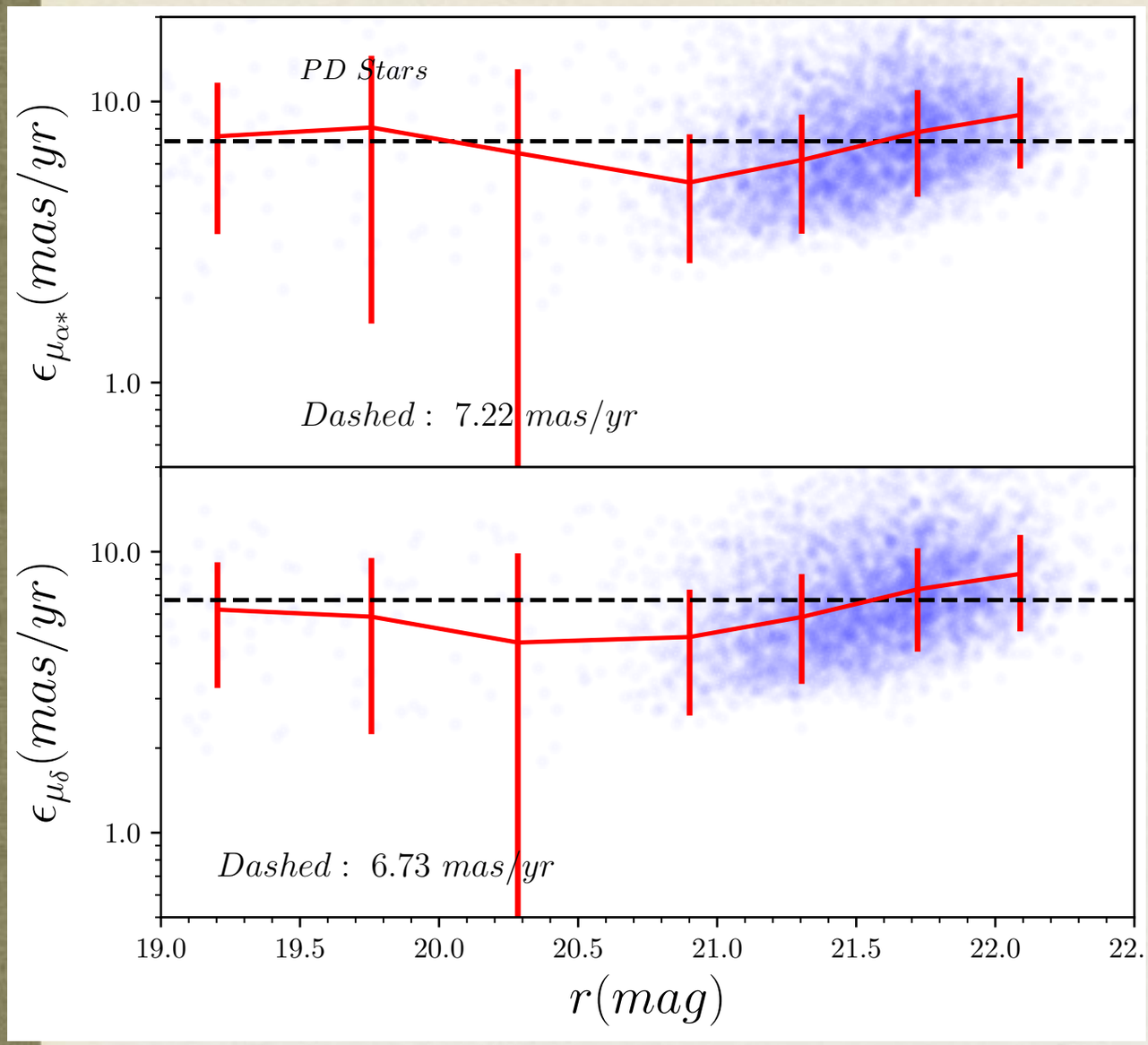
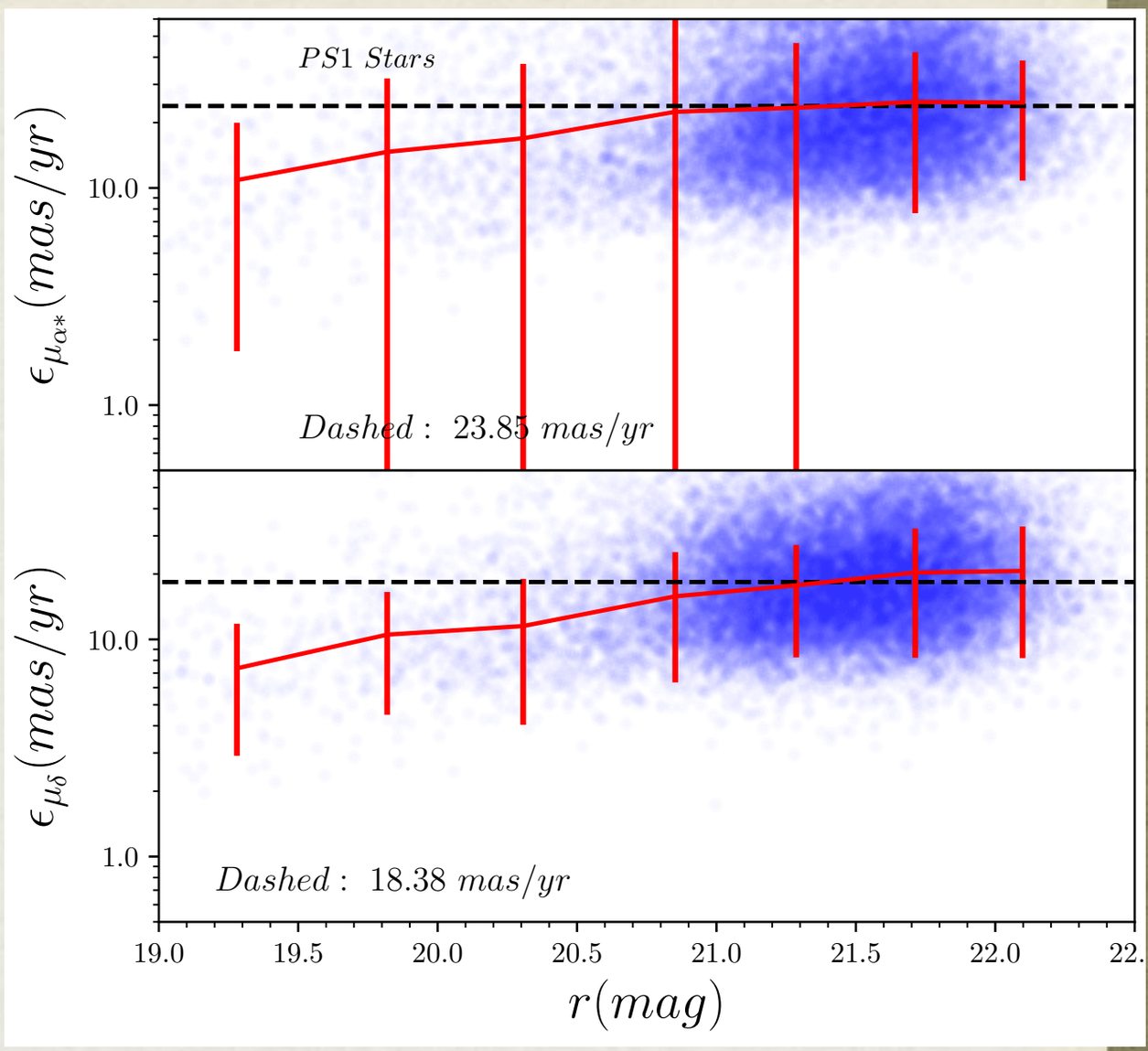
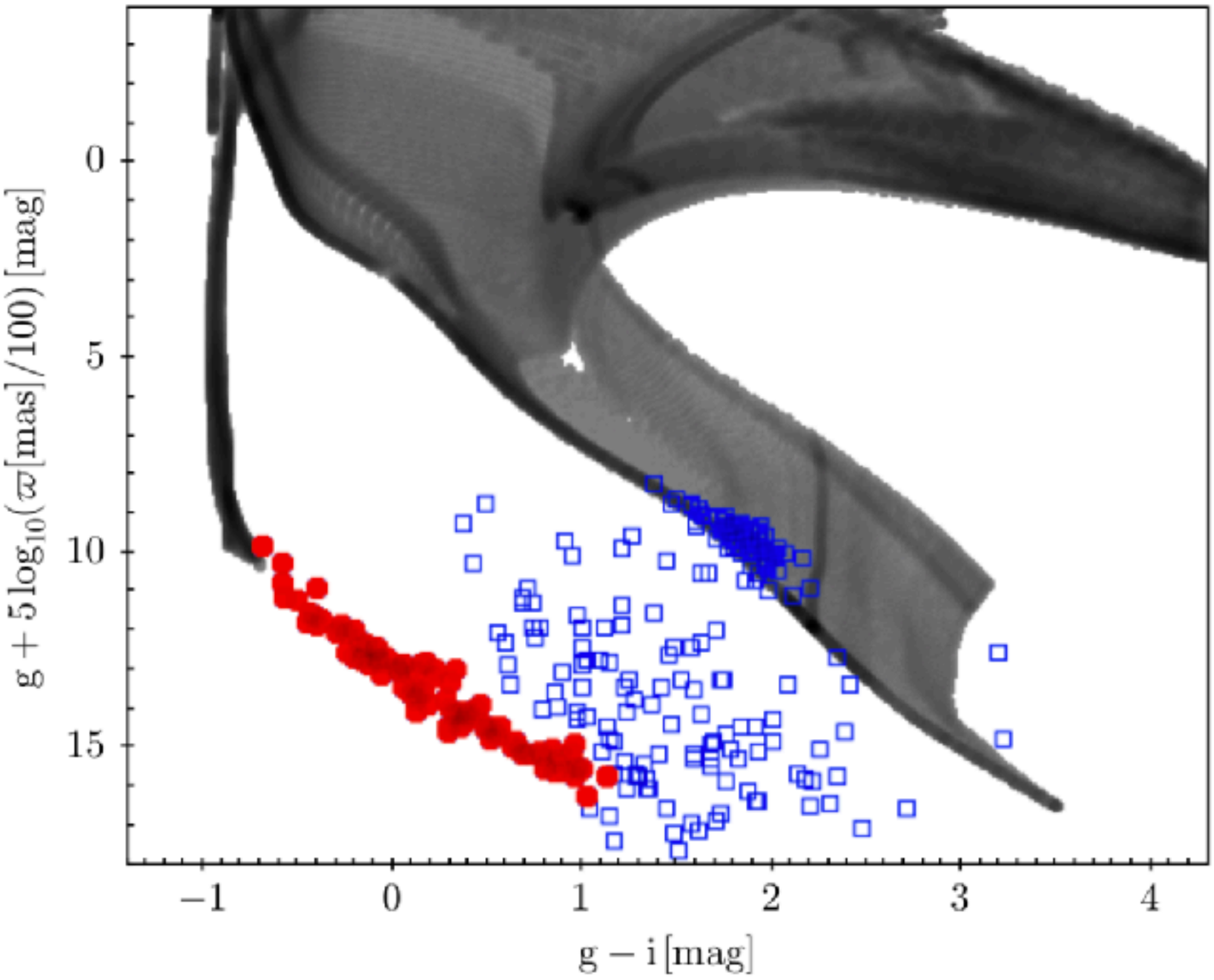




PRECISE AGES OF FIELD STARS FROM WHITE DWARF COMPANIONS

(SCIENTIFIC APPLICATION)



Fouesneau + 2019

PRECISE AGES OF FIELD STARS FROM WHITE DWARF COMPANIONS

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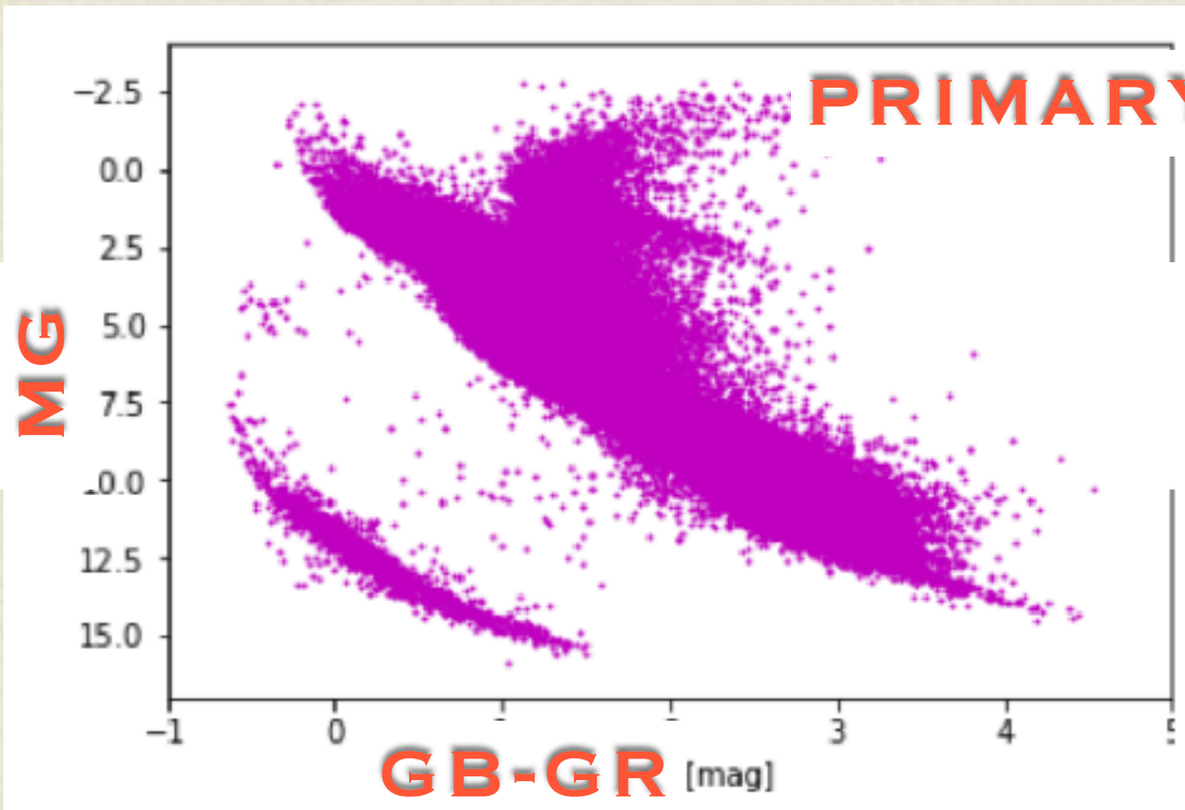

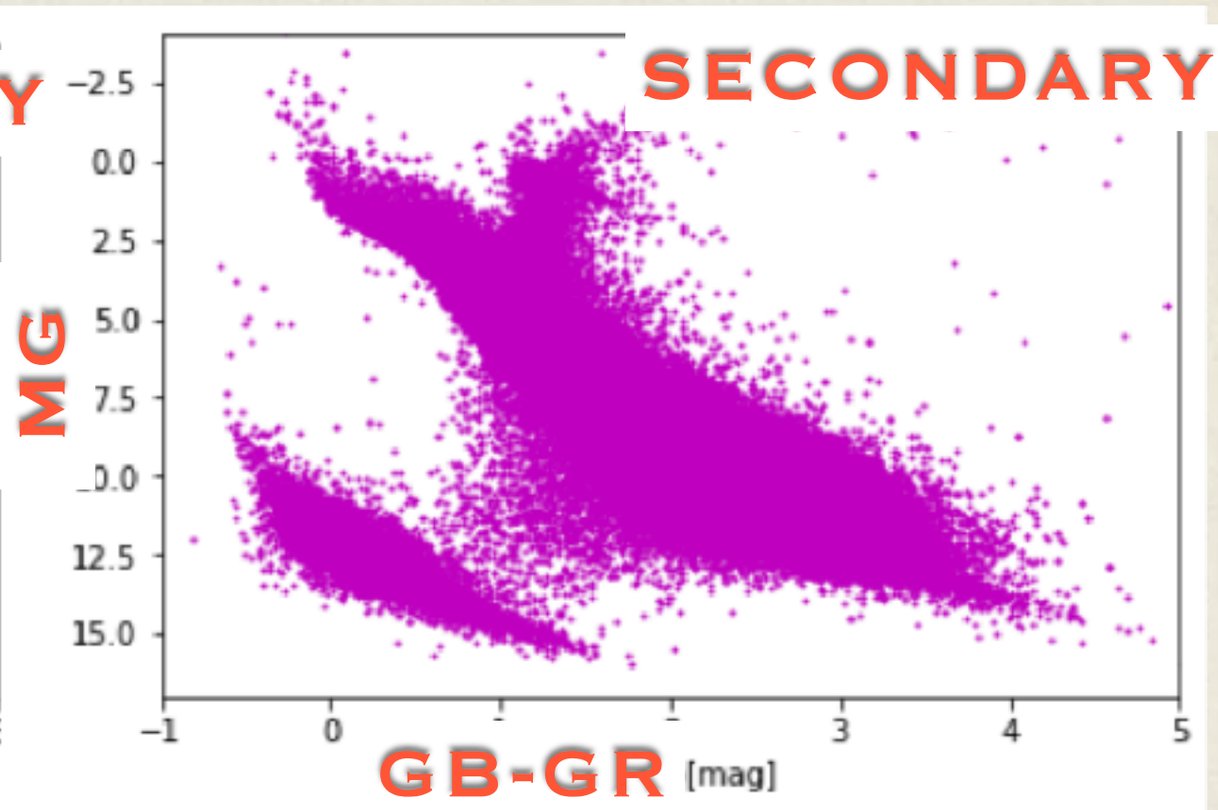

Tian + 2019

PRECISE AGES OF FIELD STARS FROM WHITE DWARF COMPANIONS

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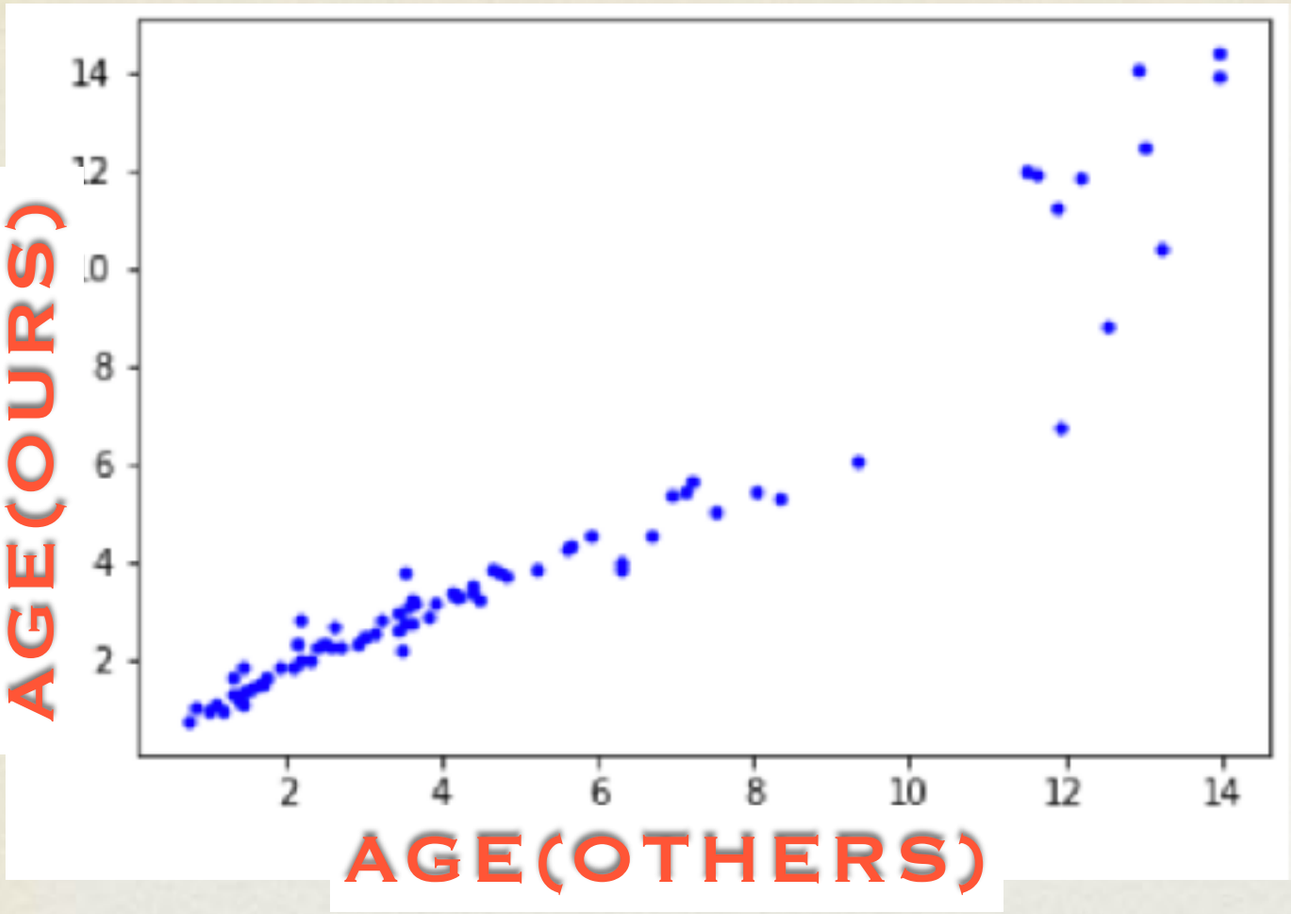
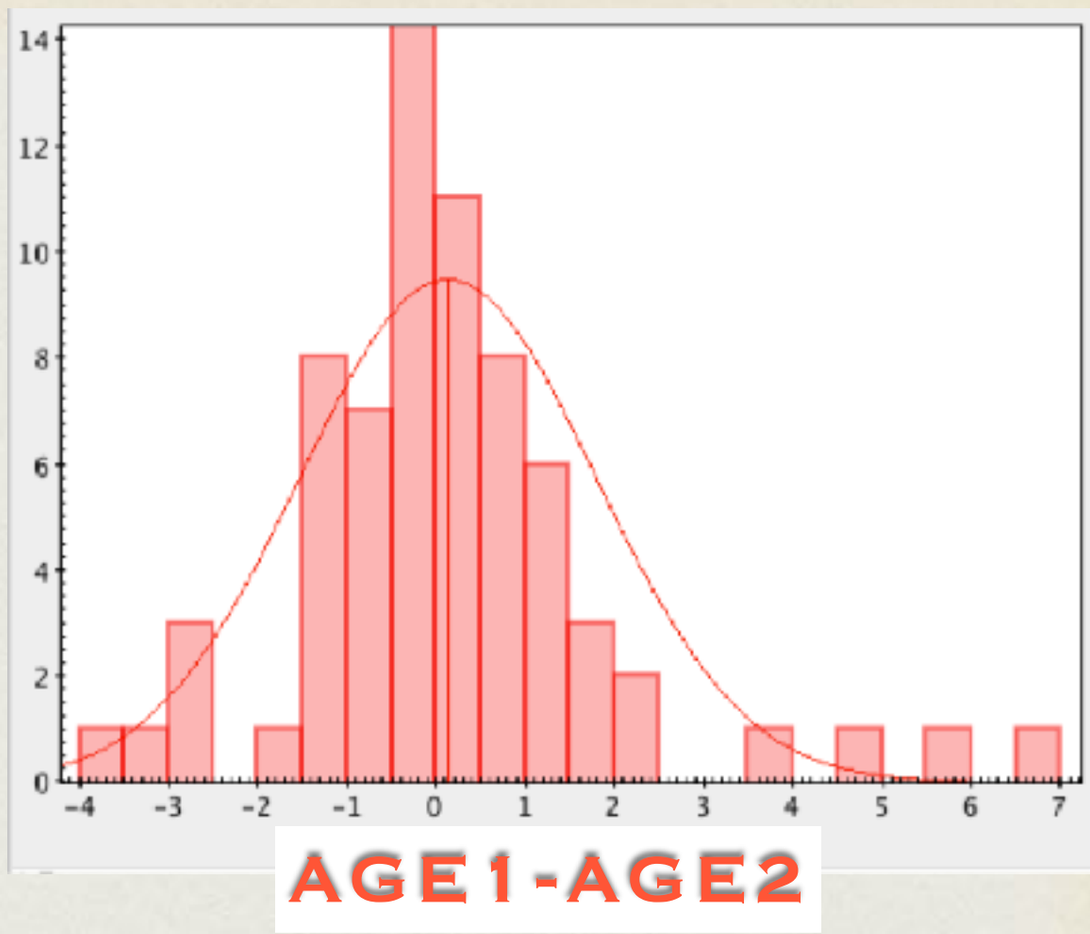




Qiu, Tian, et. al. in preparing

CONCLUSION FOR GPS1+
(TAKE-TO-HOME POINTS)

- **With Gaia+PS1+SDSS, we update GPS1 and release GPS1+ for about 300 million stars across 3/4 sky region, down to mr<22.5.**

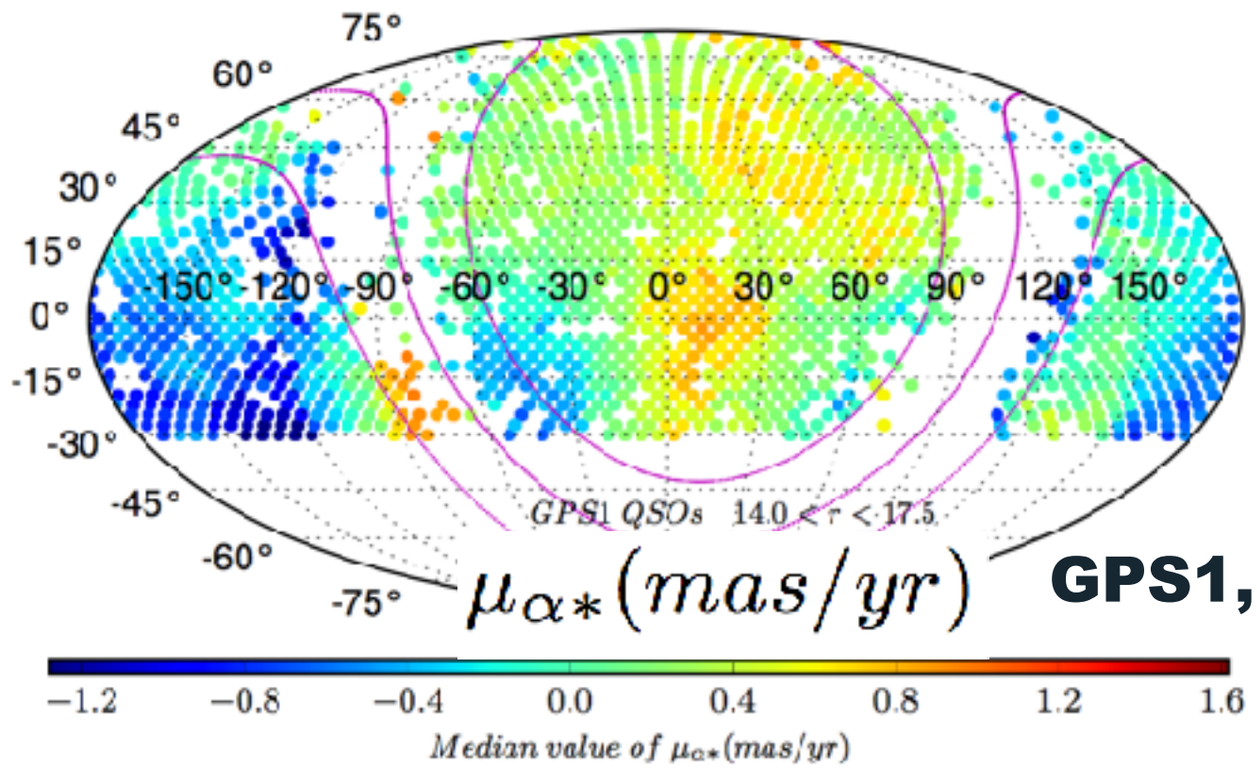
- **The GPS1+ perform well if Gaia or SDSS points are included.**

- **GPS1+ will fill up the gap of Gaia DR2. This catalog will be useful for the scientific researches (Age, CSST, etc).**

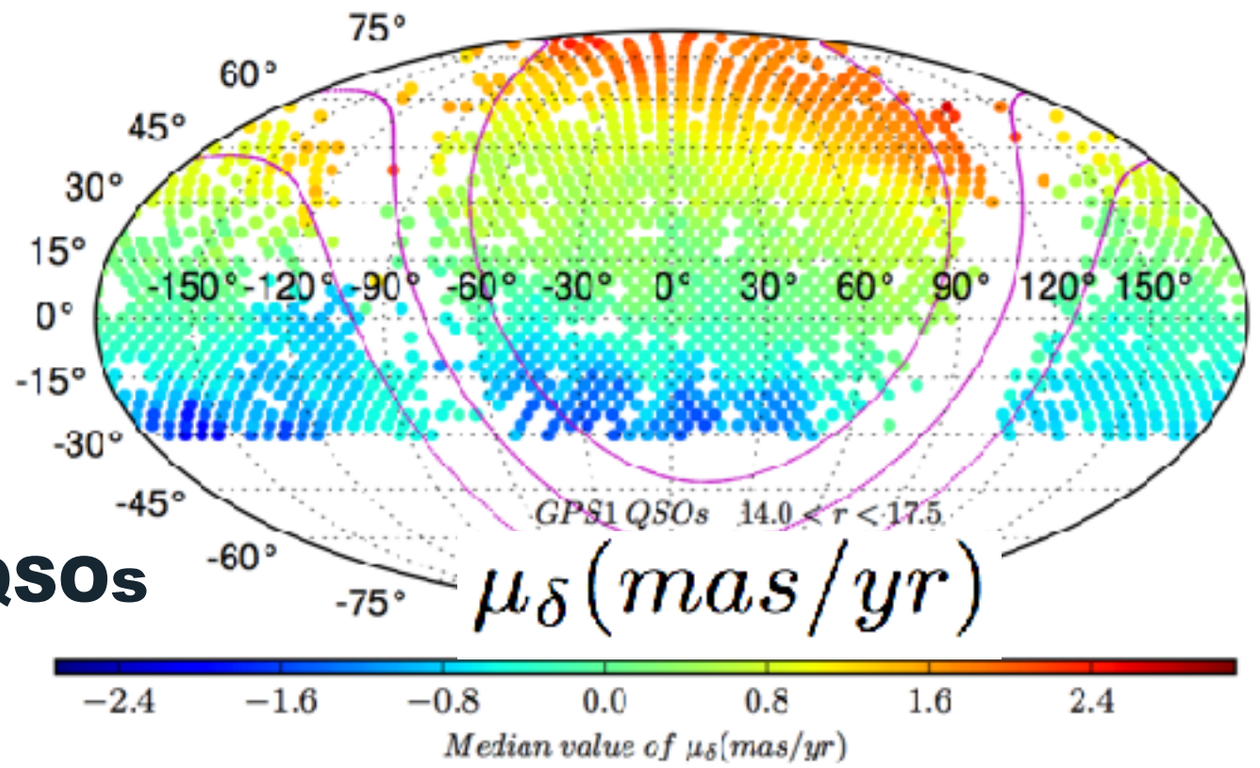
- **We hope GPS1+ could be released via China-VO (TAP service)**

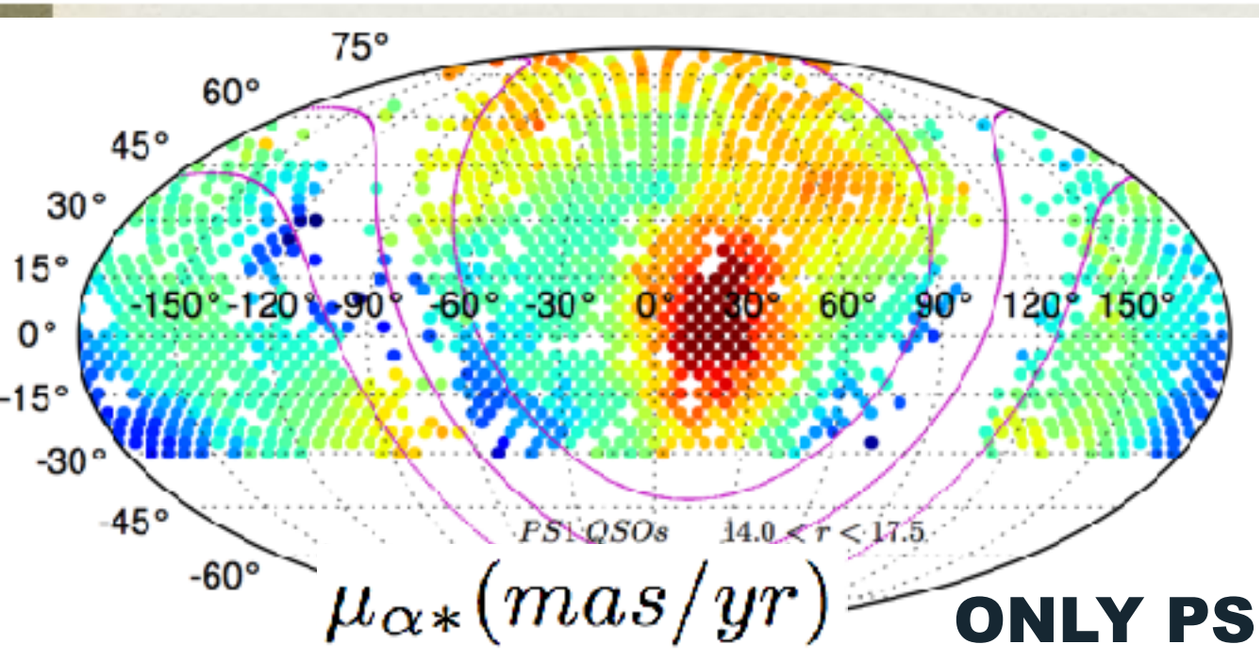
THANKS!

VALIDATION
(PERFORMANCE, QSOS)

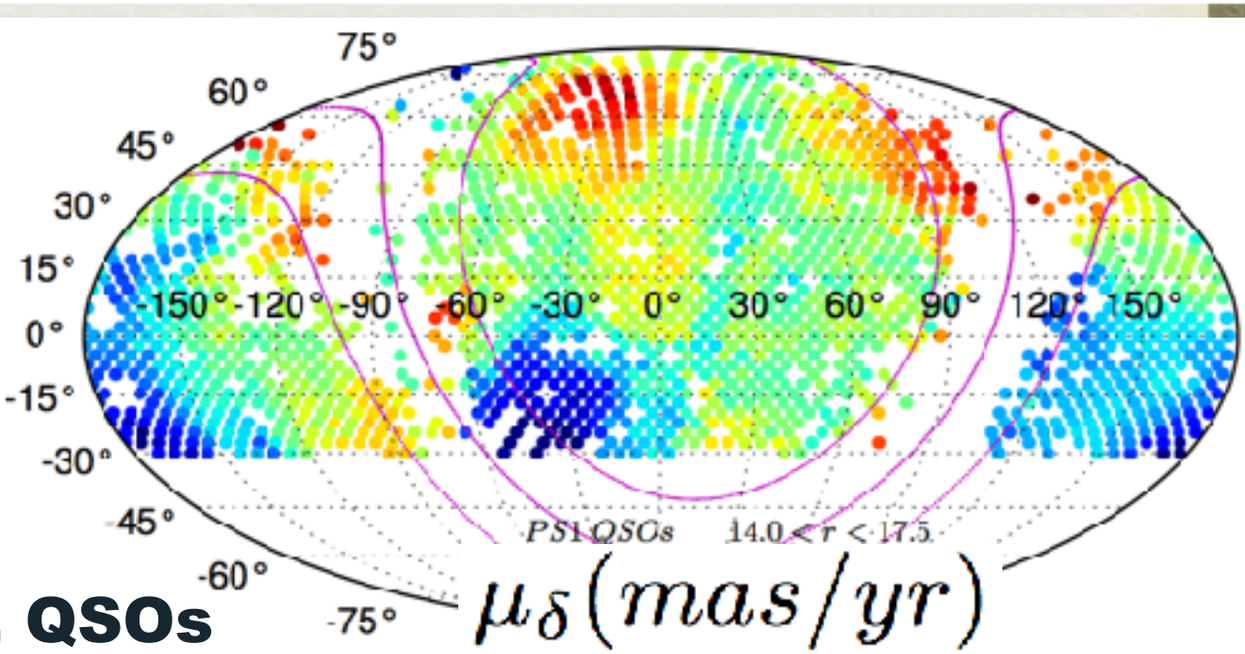


GPS1, QSOs

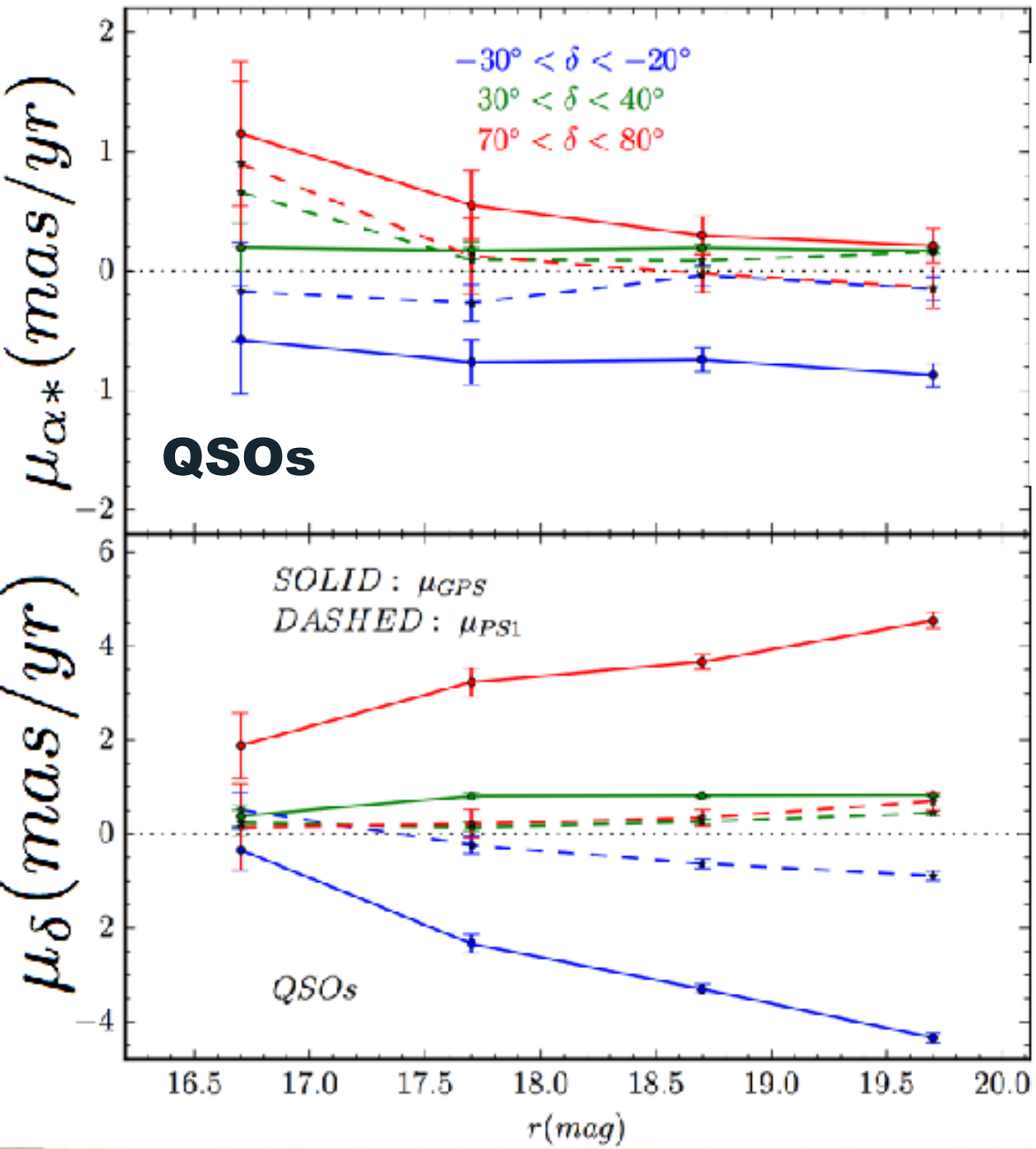


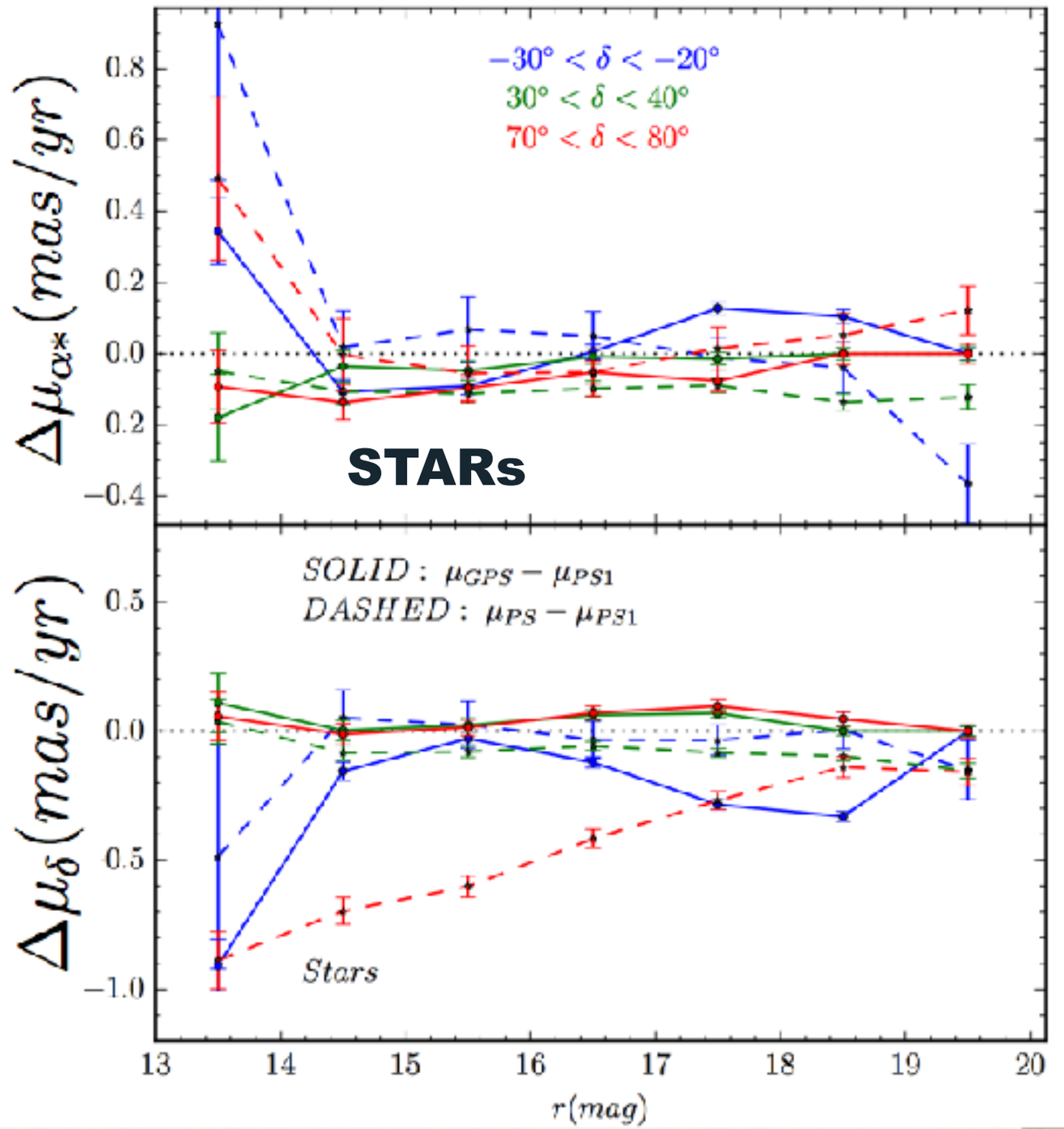


ONLY PS1, QSOs

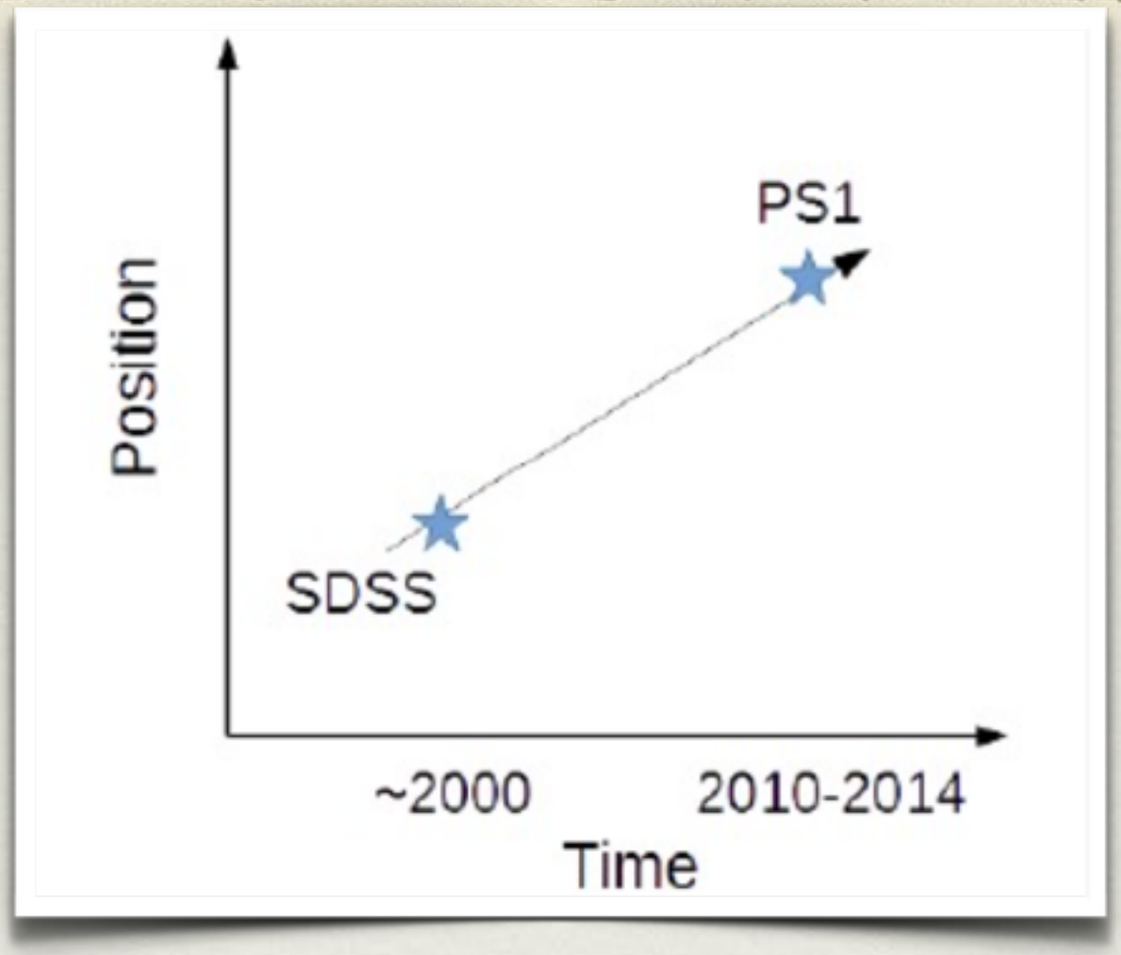


DISCUSSION
(INVESTIGATION, DEC/MAG)





PROPER MOTION FITTING
(ALGORITHM)



$$\chi^2 = \sum_i^N \frac{[\hat{y}_i^o - y_i^{model}(t_i)]^2}{\epsilon_i^2},$$

$$\hat{y}_i^o = y_i^o - \Delta_i(\alpha,\delta) - \Delta_i(\delta,m),$$