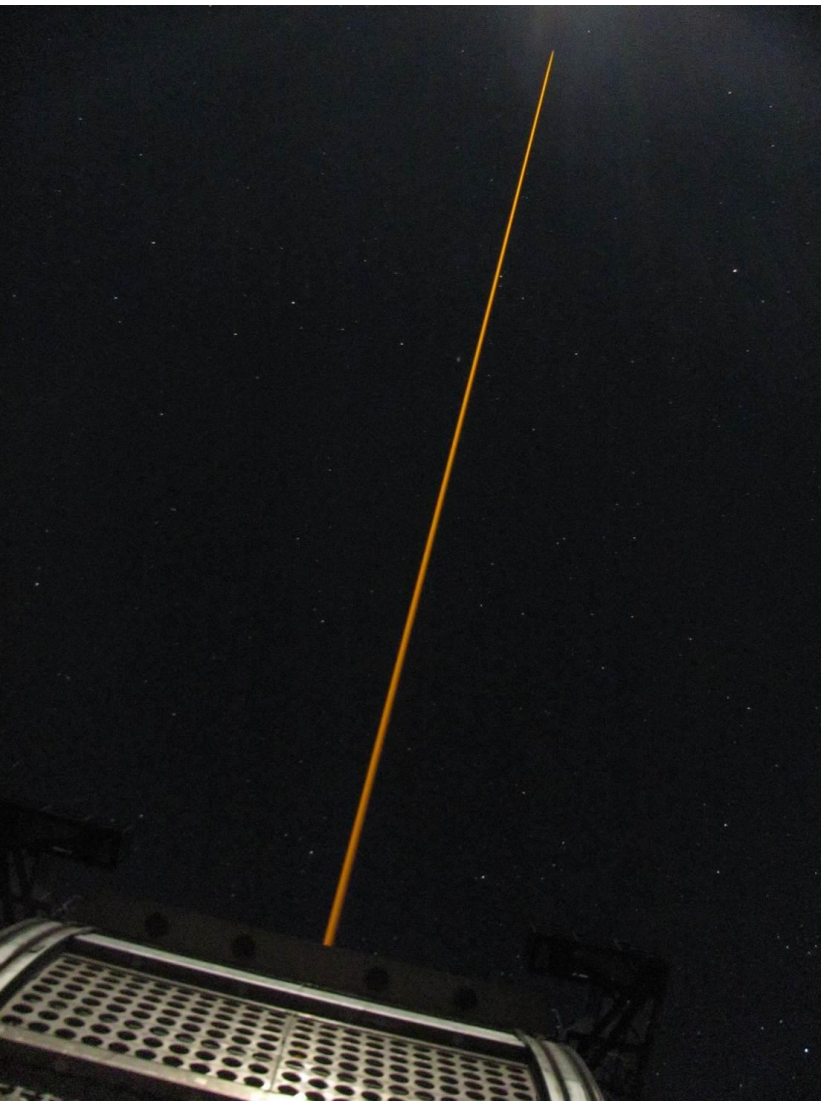
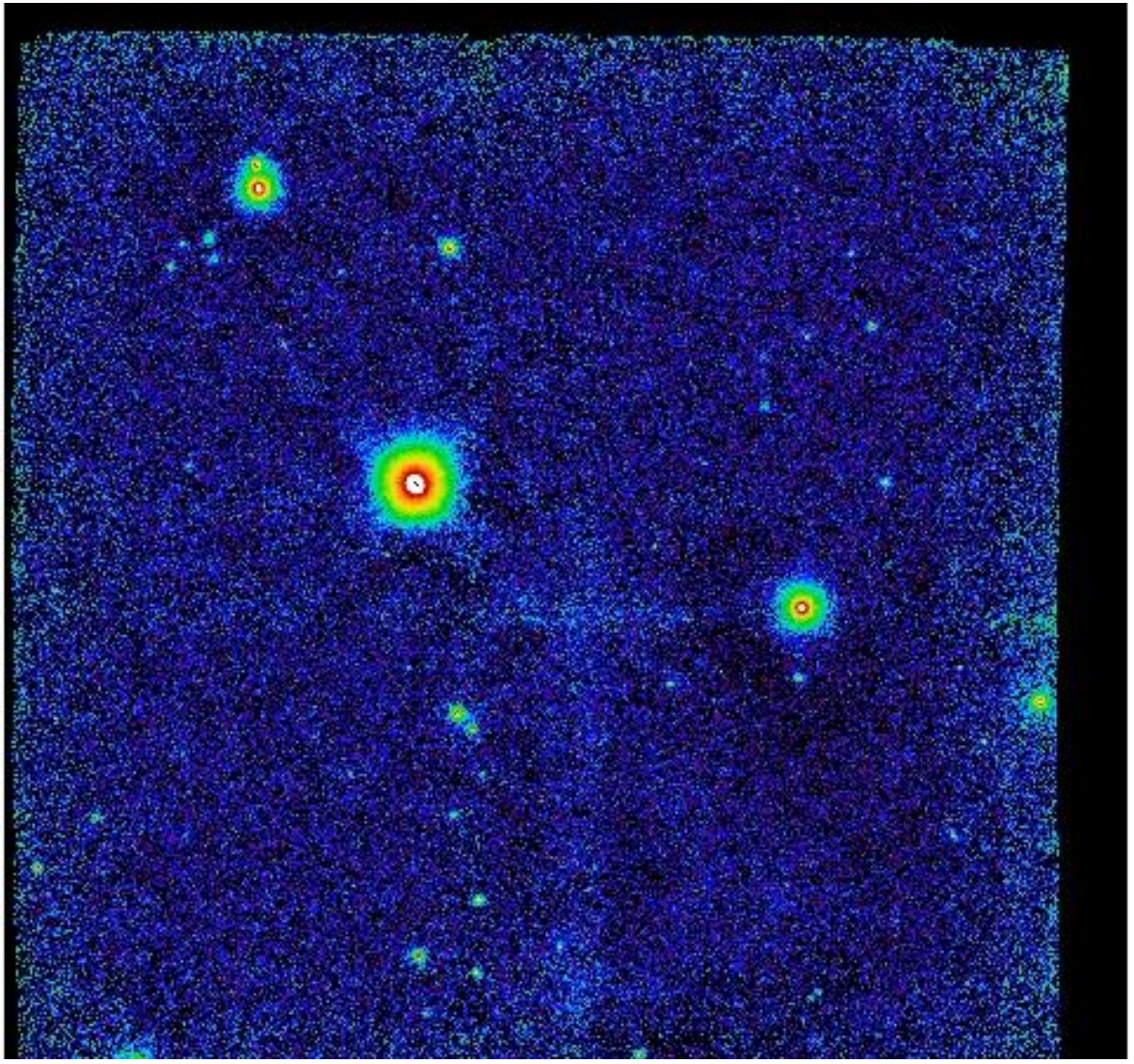
Probing the dark halo of the Milky Way with GeMS/GSAOI





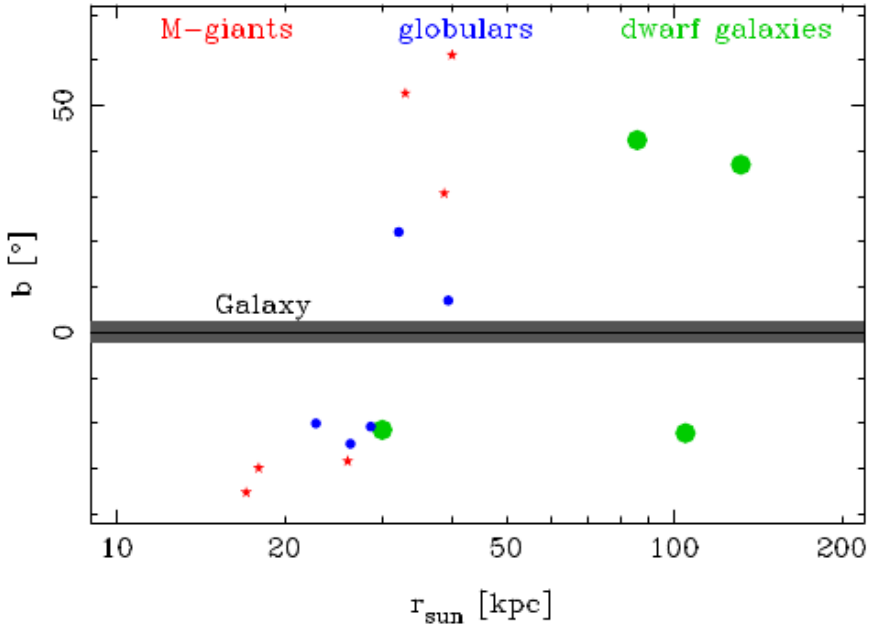
T. K. Fritz, **N. Kallivayalil**, S. Majewski, G. Damke, R. Beaton, J. Bovy, M. Boylan-Kolchin, R. Carrasco, R. van der Marel, T. Sohn, R. Davies, D. Angell, P. Zivick, B. Neichel

Open questions in near field cosmology

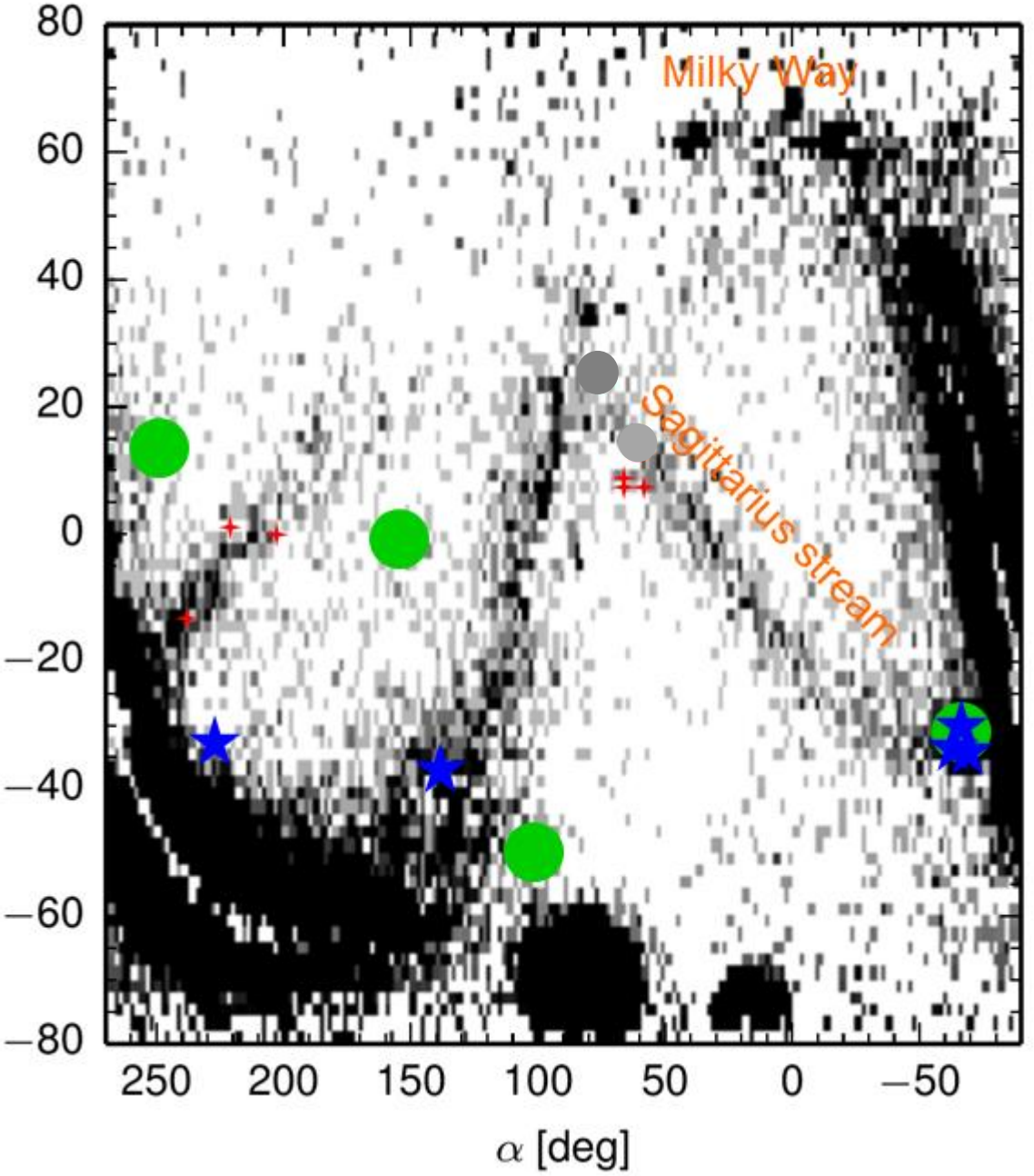
- **Mass** of the **Milky Way** uncertain, e.g. compare
  - $1.6 \pm 0.4 * 10^{12}$ M_{sol} (Boylan-Kolchin et al. 2013)
  - $0.56 \pm 0.12 * 10^{12}$ M_{sol} (Gibbons et al. 2014)
- **Too big to fail**:
  - There are too few dwarf galaxies with central dispersion of 30~<v~<60 km/s. (Zavala et al 2009, Boylan-Kolchin et al. 2012)
    - Are such dwarf galaxies missing?
    - Or have the dwarf less dense cores?
    - Less massive Milky Way could be (part of) the solution (Wang et al 2012)
- **Shape of the halo uncertain**:
  - Oblate but edge on the disk? (Law & Majewski 2010)

- We address these points with **proper motions** in the halo of the Milky Way.

The Targets



- **15 targets**
- **6 M-giants** in the Sagittarius stream
- **5 globulars**
  - 3 possible members of Sagittarius system: Arp 2, Terzan 7, Terzan 8
  - 2 others in outer halo: NGC5824, Pyxis
- **4 dwarf galaxies**:
  - Sagittarius, Hercules, Sextant, Carina

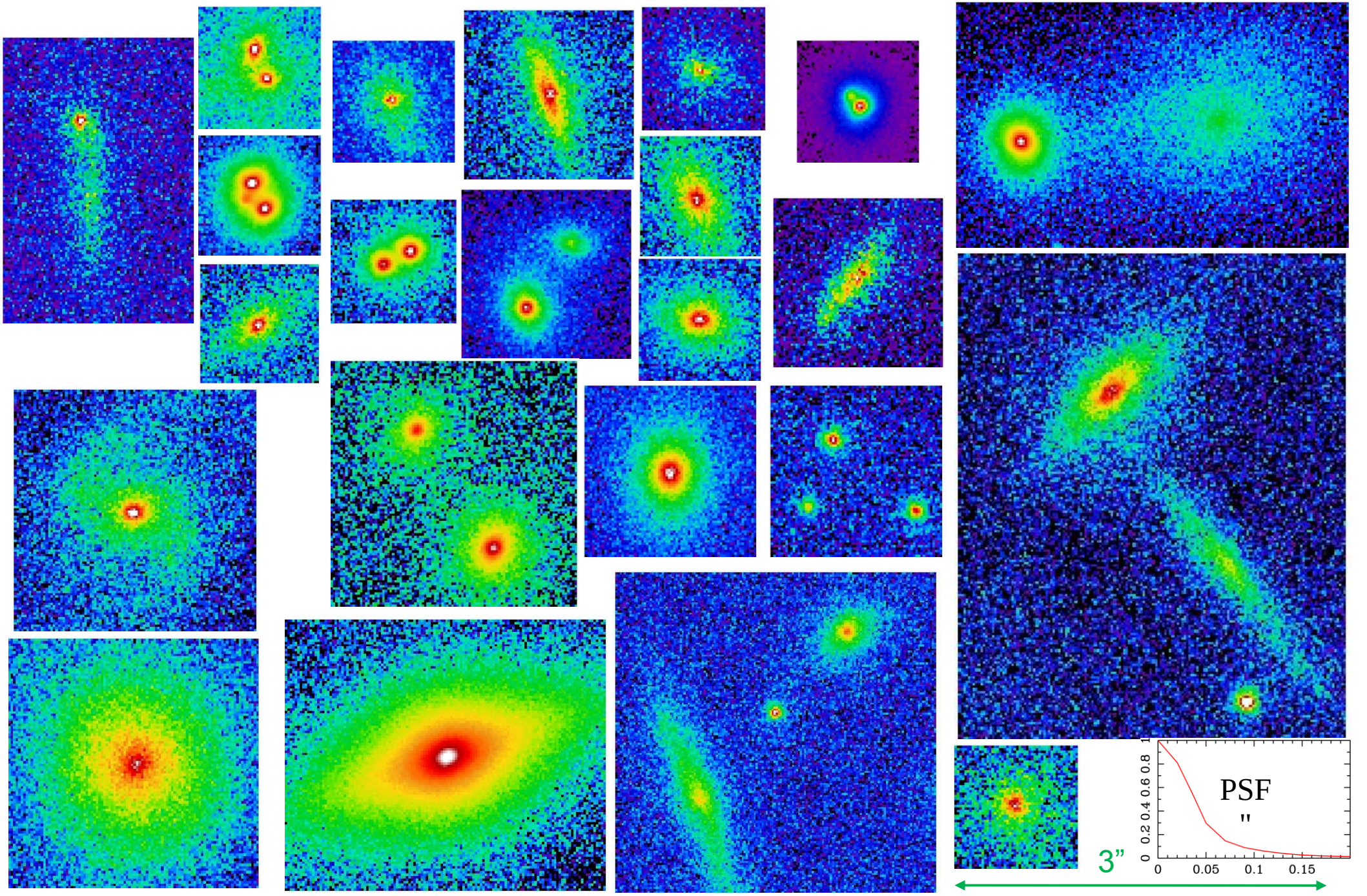


M-giant density map from Koposov et al. 2015

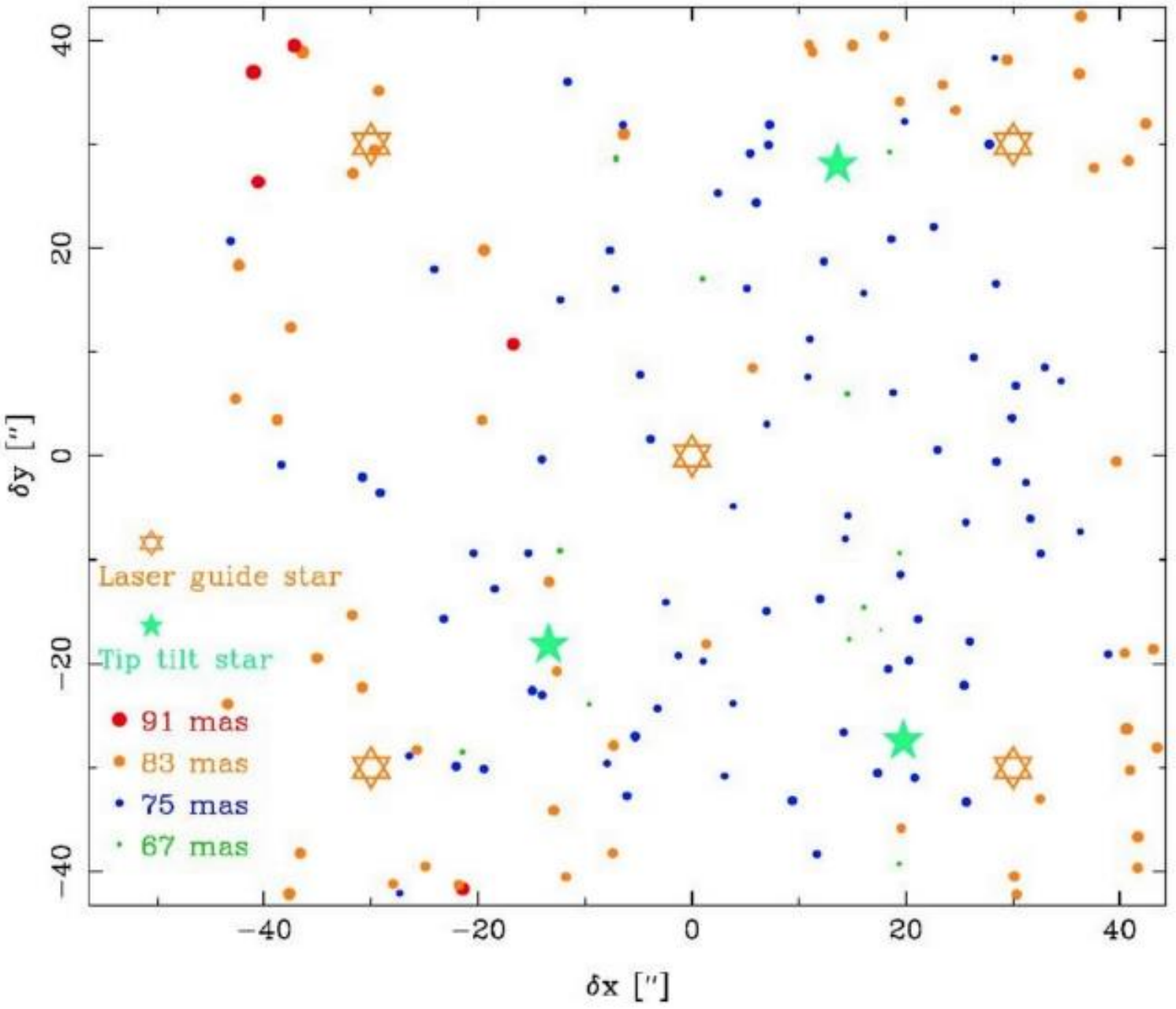
Strategy

- Two epochs of **astrometric data** with a **two year base line** for proper motions
  -with wide field adaptive optics **(GeMS/GSAOI)** usually 1h in K'/H
- Reference frame: **Background galaxies**
  -using many galaxies reduces the impact of systematic errors
- **Colors** with H/K'-band GSAOI, GMOS i-band for
  -object separation (object stars, foreground stars, galaxies)
  -differential chromatic refraction correction
- Usually **2 fields per target** for
  -systematic error control
  -error reduction

Some Galaxies and Stars in the images

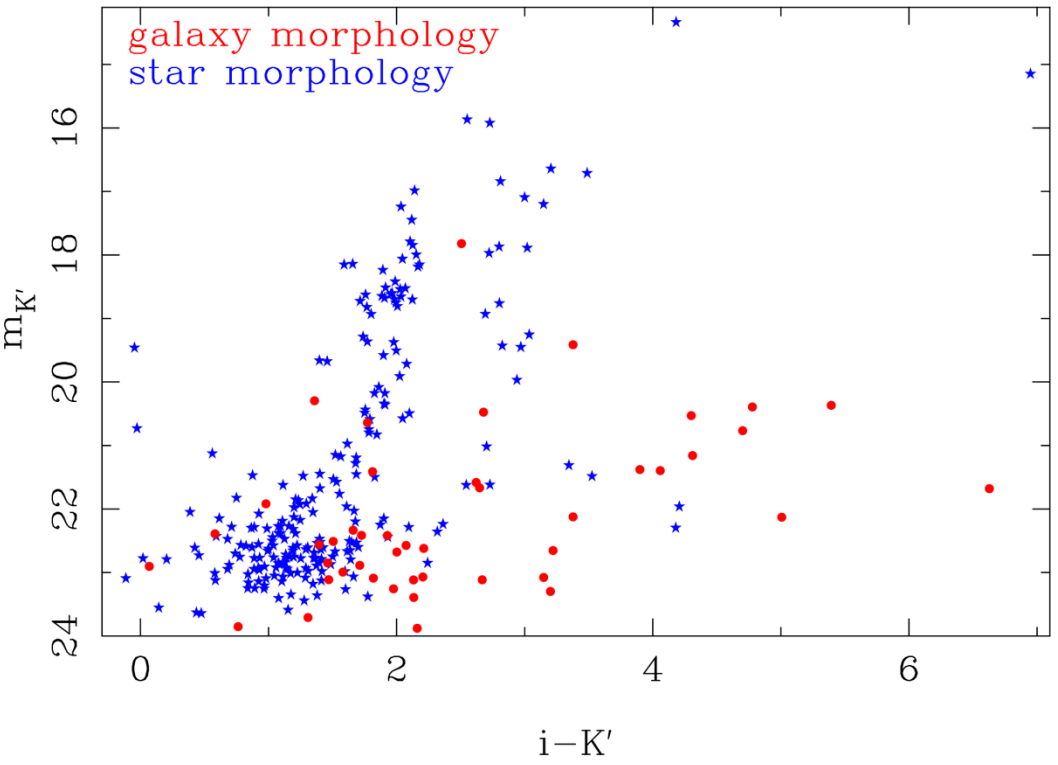


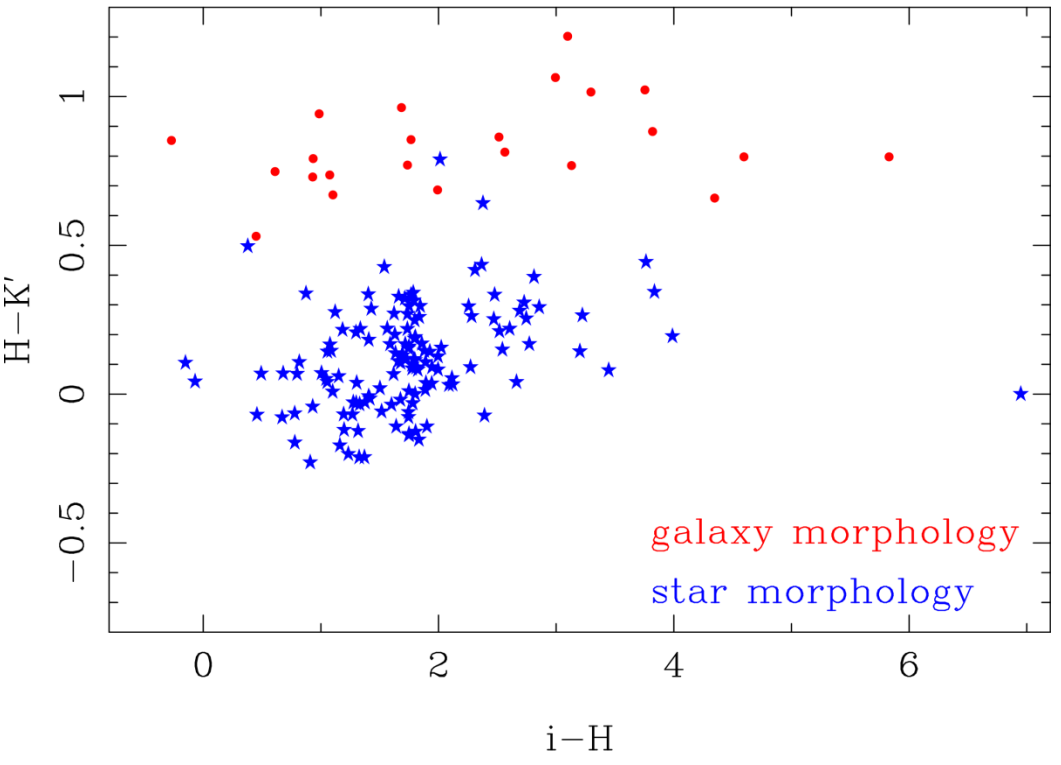
High image quality: FWHM of 79 mas



Pyxis field 1 K'-band

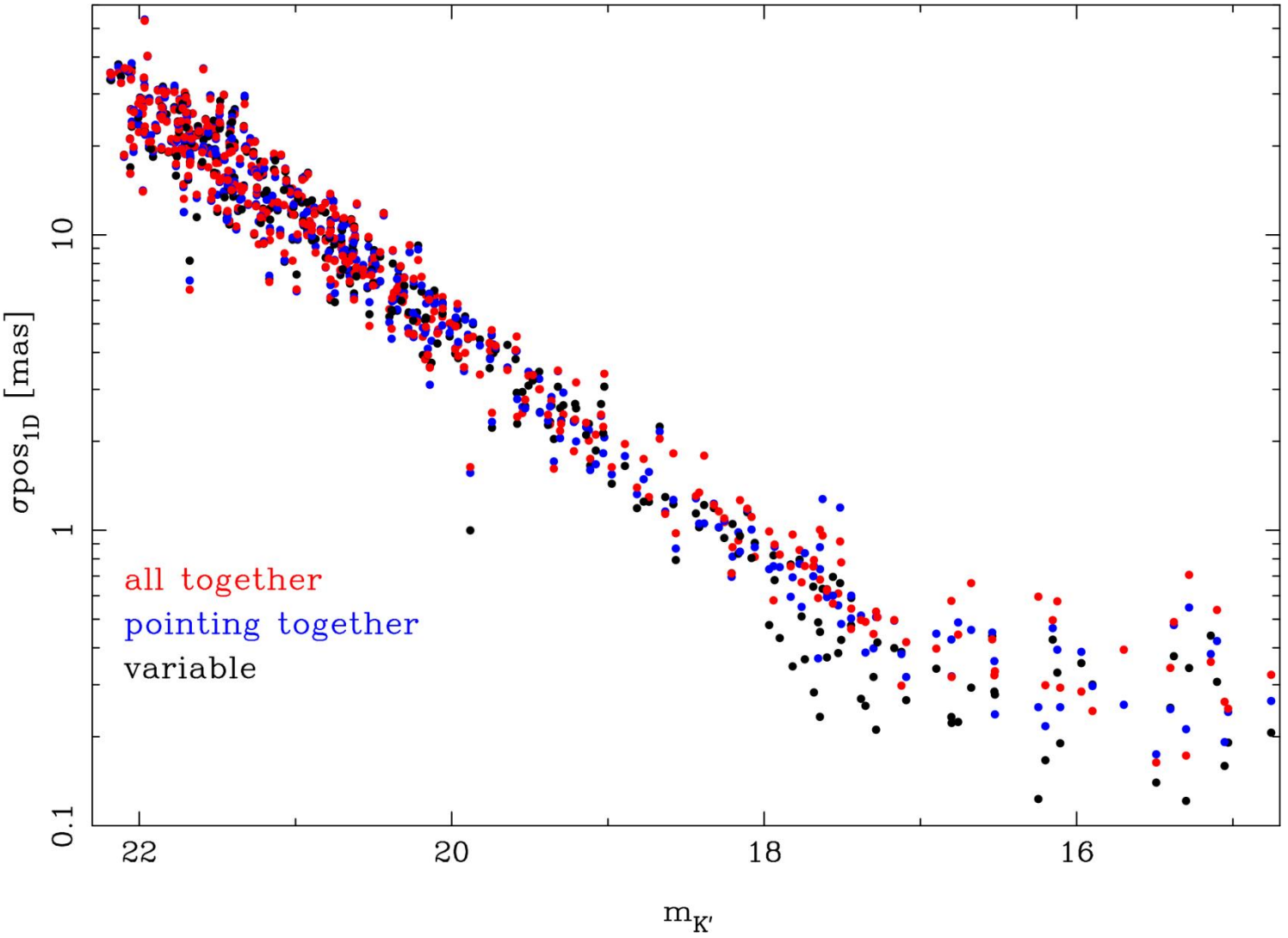
Object classes can be well separated with colors





Carina field 1
(Preliminary)

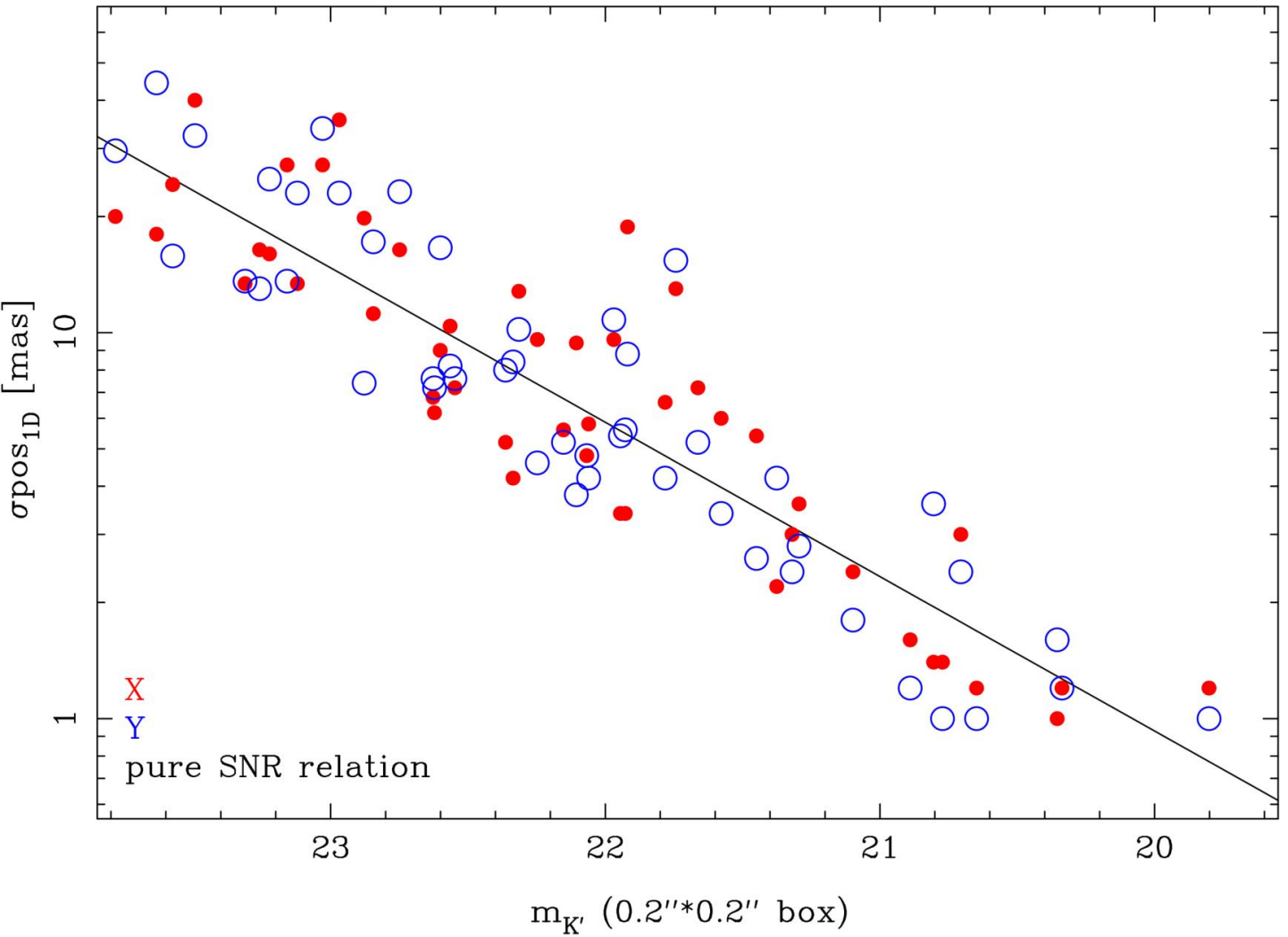
Position uncertainties of stars

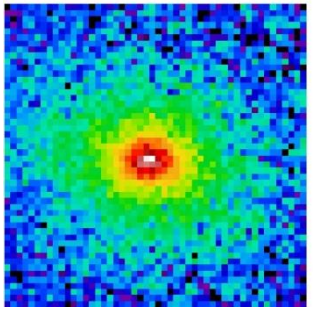


- For single 120 sec images of Pyxis field 1
  - Dithered images to cover chip gap (up to 5”), with pointings of slight dithers (0.8”)
- For distortion correction: Quadratic transformation, **shown different variability trials.**
- Position uncertainty of **0.2 to 0.4 mas** on single image
- Error always <0.4 mas on 3600 sec -> Precise transformation scheme not very important

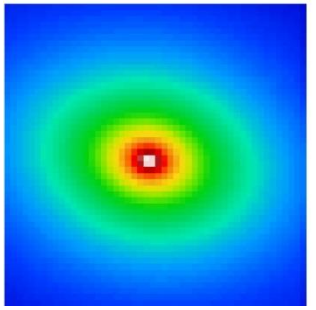
(Preliminary)

Position uncertainty of galaxies

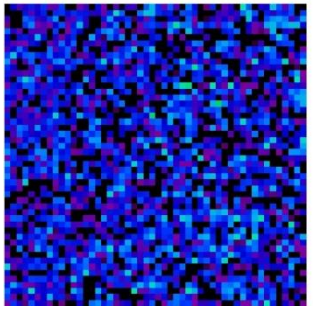




Image



Model

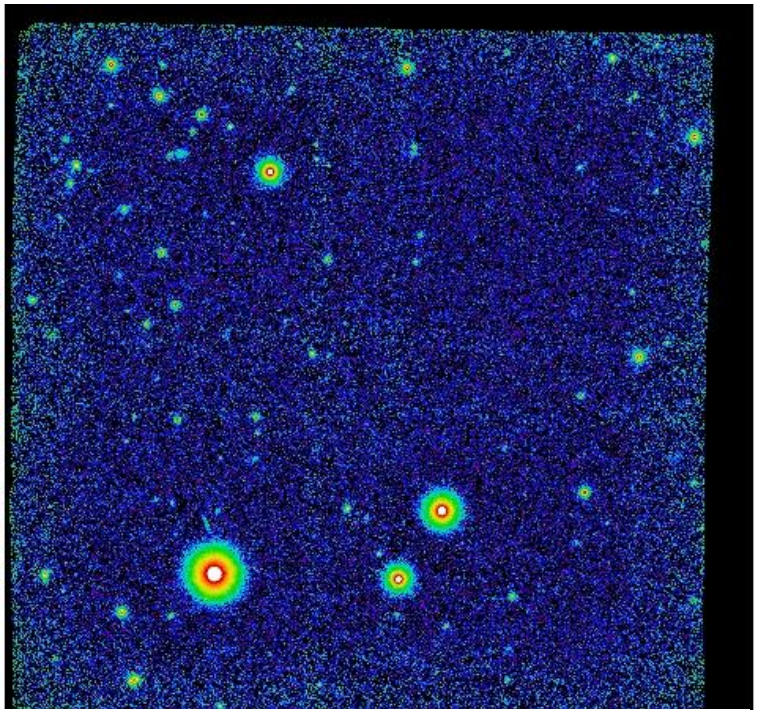


Residuals

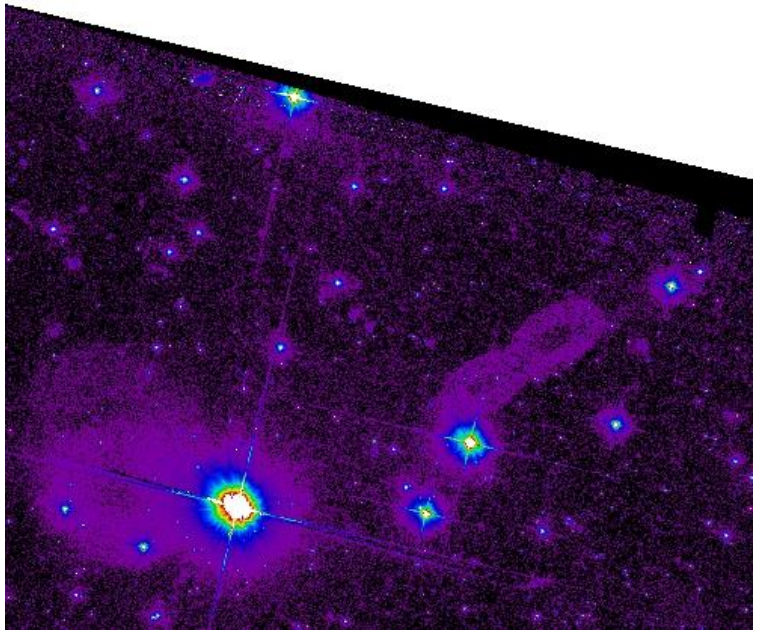
- For full (3600 sec) image of Pyxis field 1
- Position fit: single Sersic with Galfit
- Results in total registration error of ~0.3 mas. That includes a distortion systematics of 0.5 mas per object. (Neichel et al 2014)
- → total proper motion error of **~0.15 mas/yr per target**

(Preliminary)

Pyxis Field 1: HST + Gemini

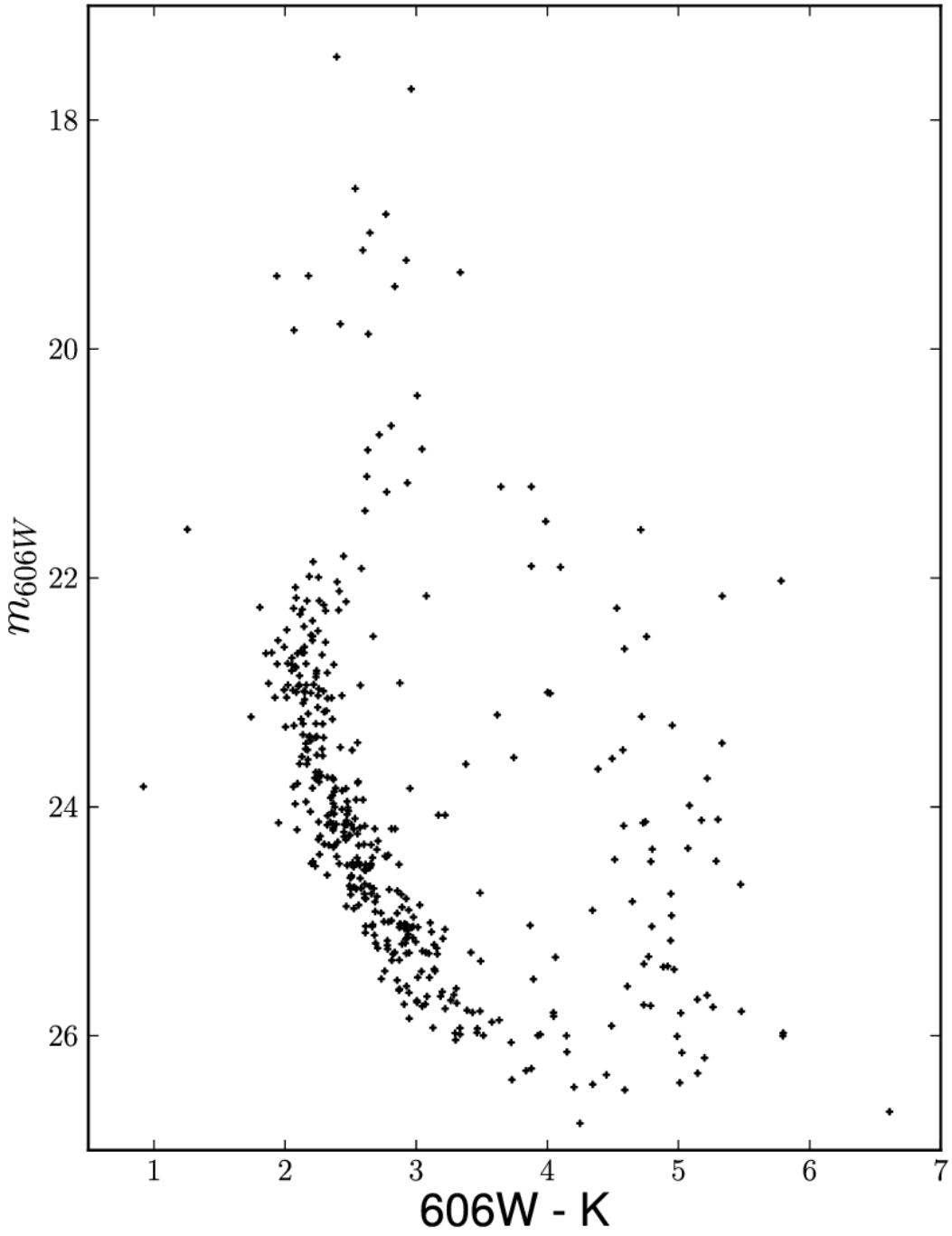


K' GSAOI
2015

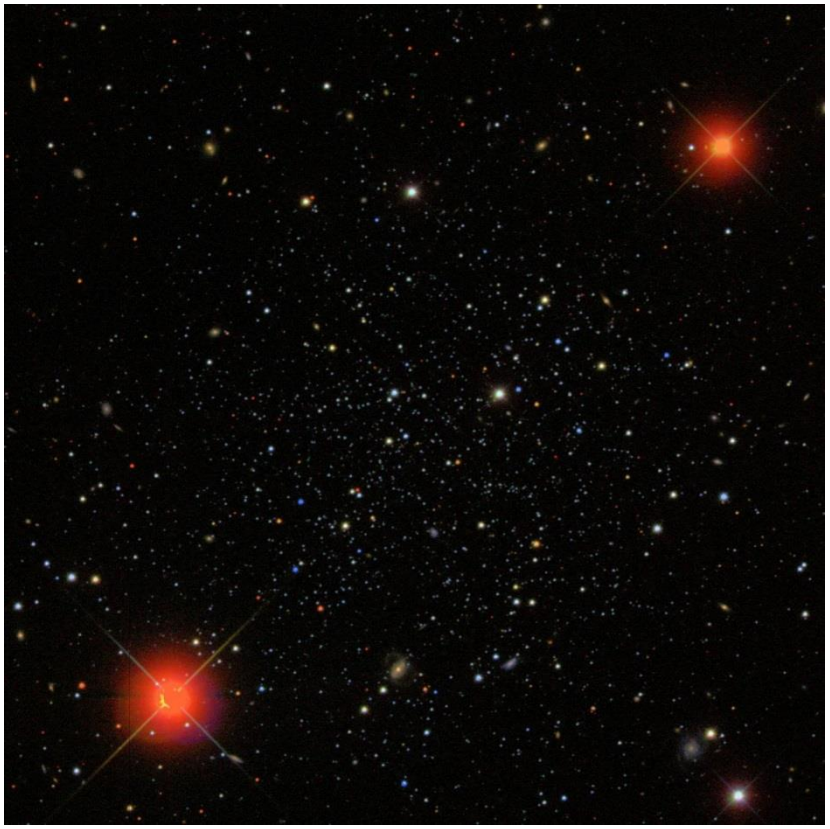


606W ACS
2009

(Preliminary)

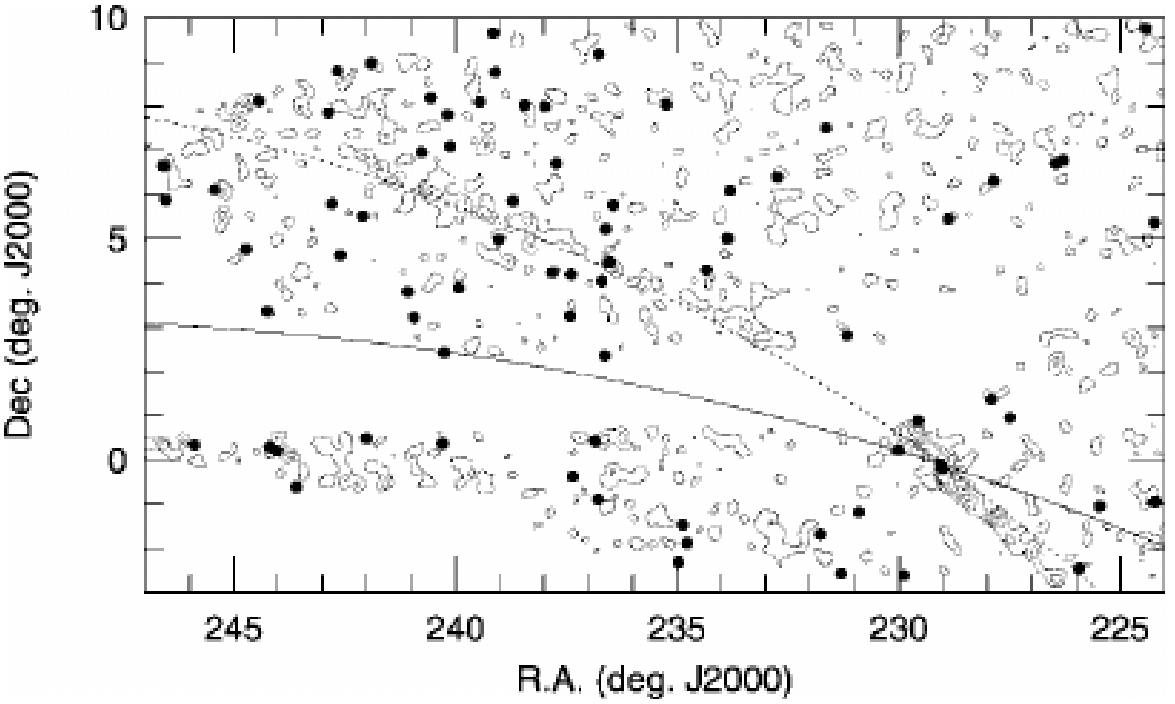


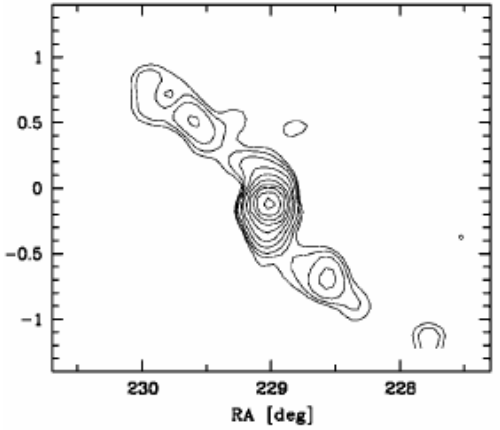
Palomar 5: globular cluster + stream



10'

Faint (M_V=-5.2), low mass
(σ<1 km/s, Odenkirchen et al. 2002)

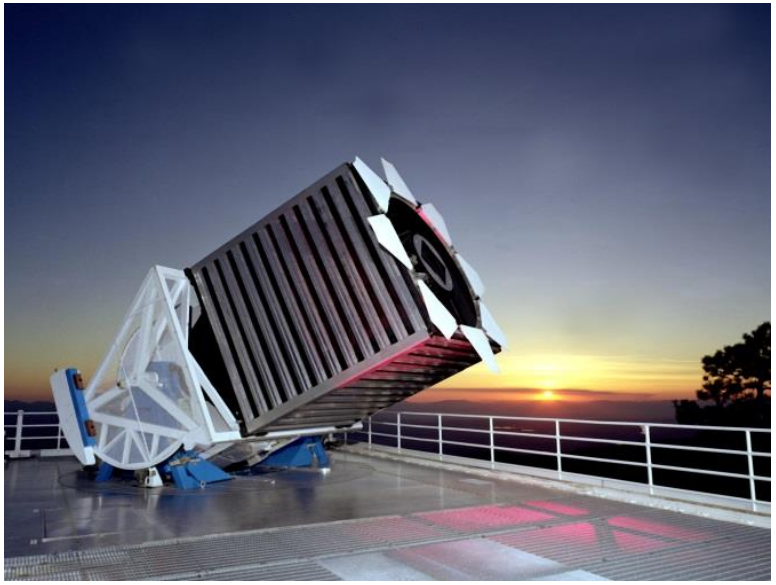




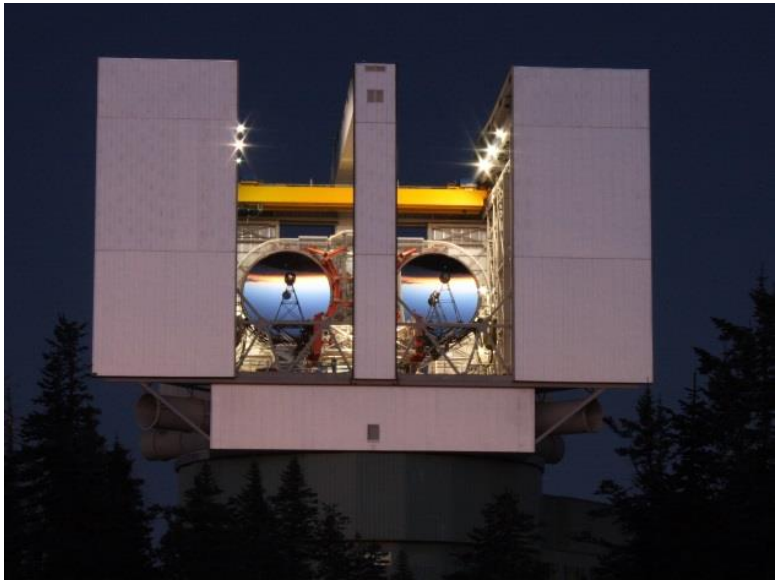
22 degree long tails
Grillmaier & Dionatos 2006

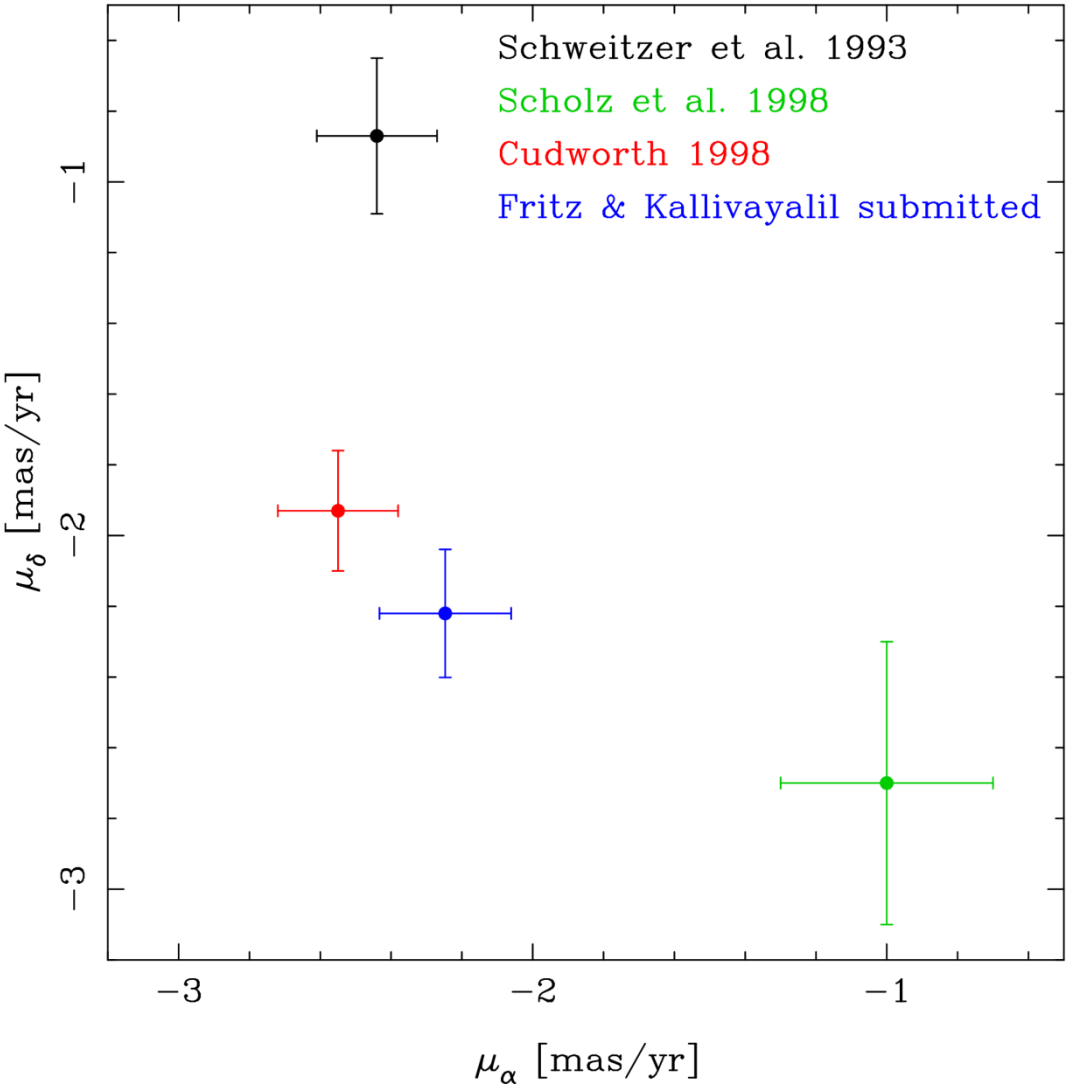
Odenkirchen et al. 2001

Proper motion of Palomar 5 cluster



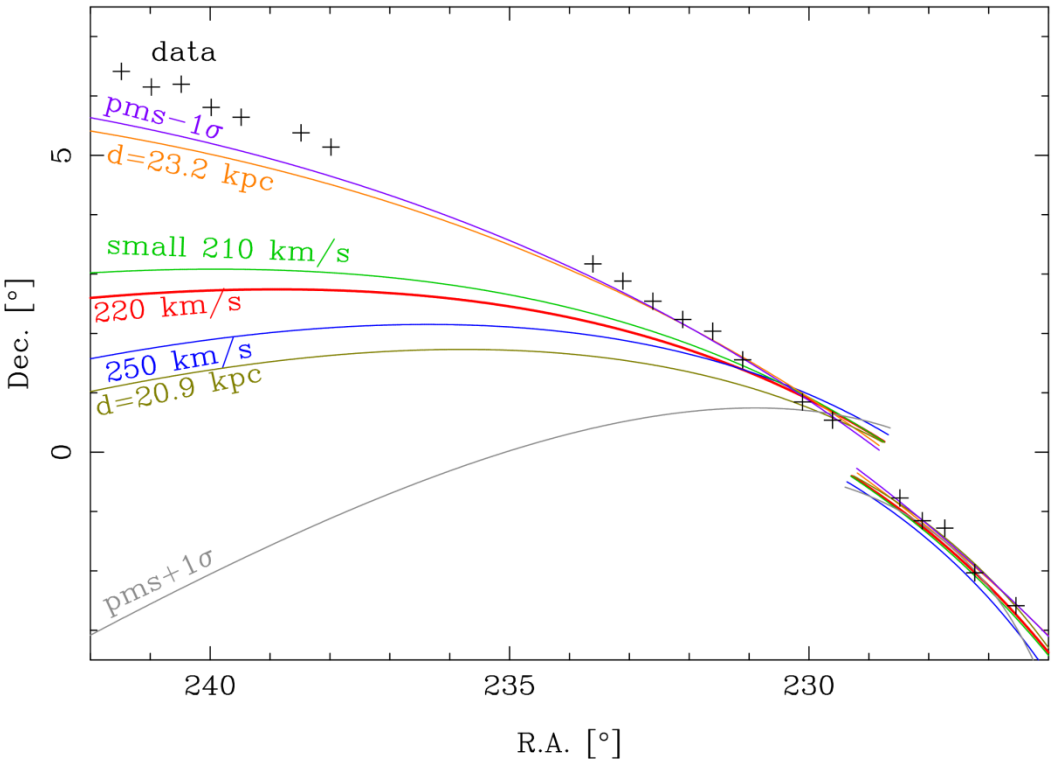
15 years baseline with SDSS and LBT/LBC
First CCD measurement

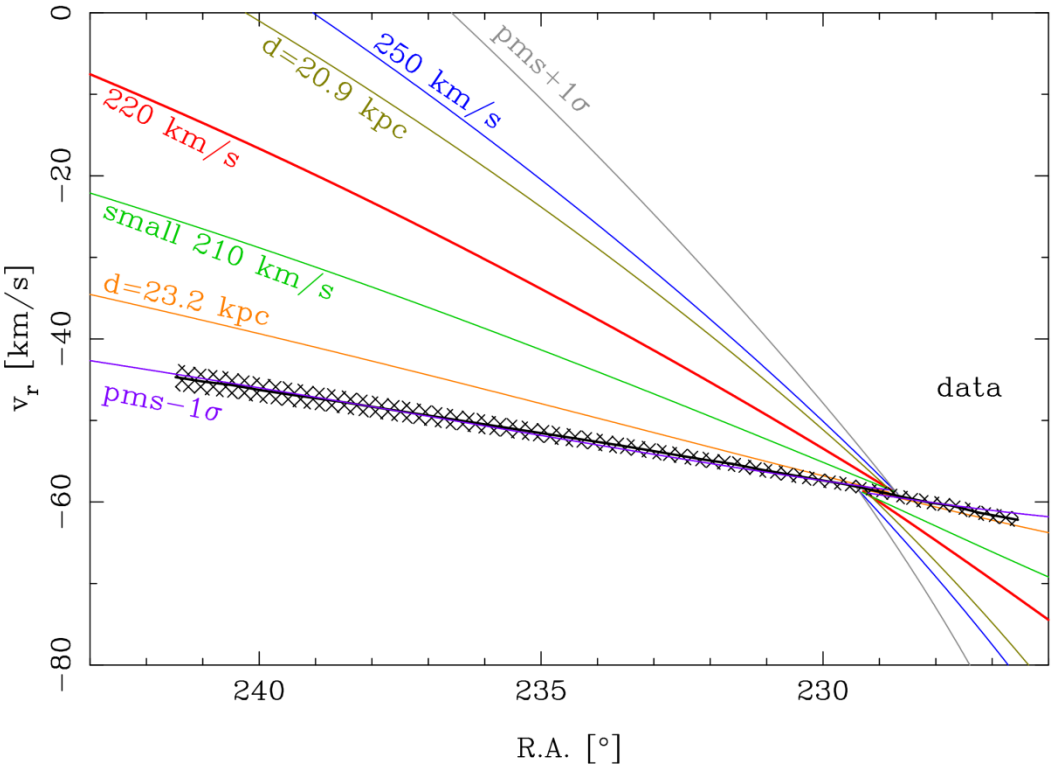




μ_α=-2.25+/-0.19 mas/yr
μ_δ=-2.21+/-0.18 mas/yr
Fritz & Kallivayalil submitted

Constraining the Milky Way





- We investigate V_0, distance of Palomar 5 and its proper motion using Galpy (Bovy 15).
  - **Standard model: V_0=220 km/s, d=22.05 kpc, -2.25/-2.21 mas/yr**
- We change one parameter in each other model.
- **Standard model** does not match the data.

  ->But V_0=220 km/s + some other parameter changed (probably distance to ~24kpc) matches roughly
- Our proper motion matches with the proper motion predictions of Pearson et al 2015 for a **spherical halo**, that strengthens their case for such an inner halo.

Conclusions

- The large and long Program (143 h, 3 years; 2014 to 2017) **“Probing the dark halo of the Milky Way with GeMS/GSAOI”** has already observed 16 fields with usually good image quality. But 9 fields not yet, due to too few Laser blocks, bad weather has impact.
- Morphology & colors work well to separate between the different object classes.
- There are enough background galaxies to obtain an accuracy of ~0.15 mas/yr over two years.
- The proper motion of Palomar 5 matches roughly a spherical Milky Way halo with V_0~220 km/s with d_{Pal5}~24 kpc

Reduced images are available at
http://www.astro.virginia.edu/~tkf4w/Gemini_Data/