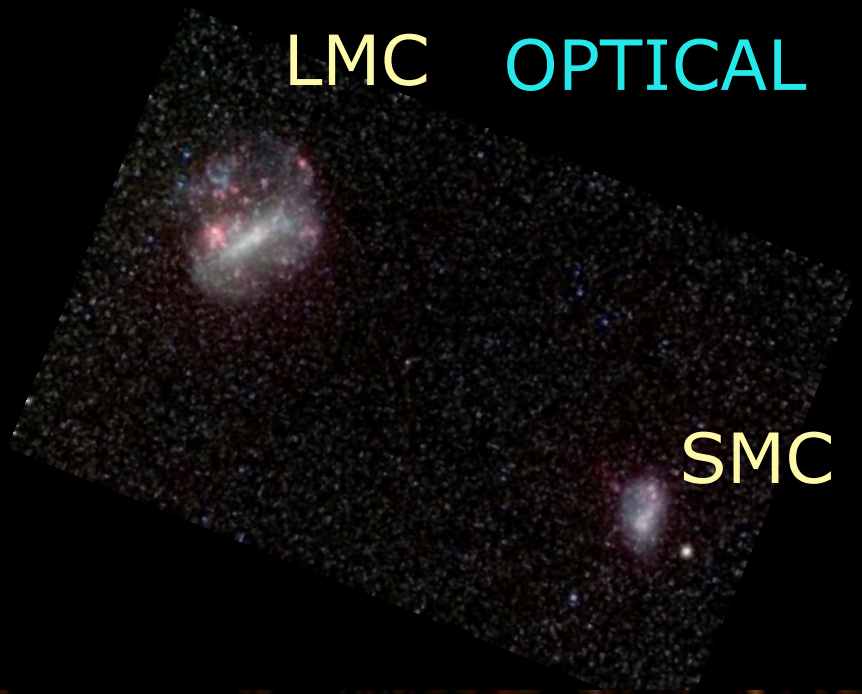
The Magellanic Clouds and Stream: Galactic Accretion in Action

Nitya Kallivayalil

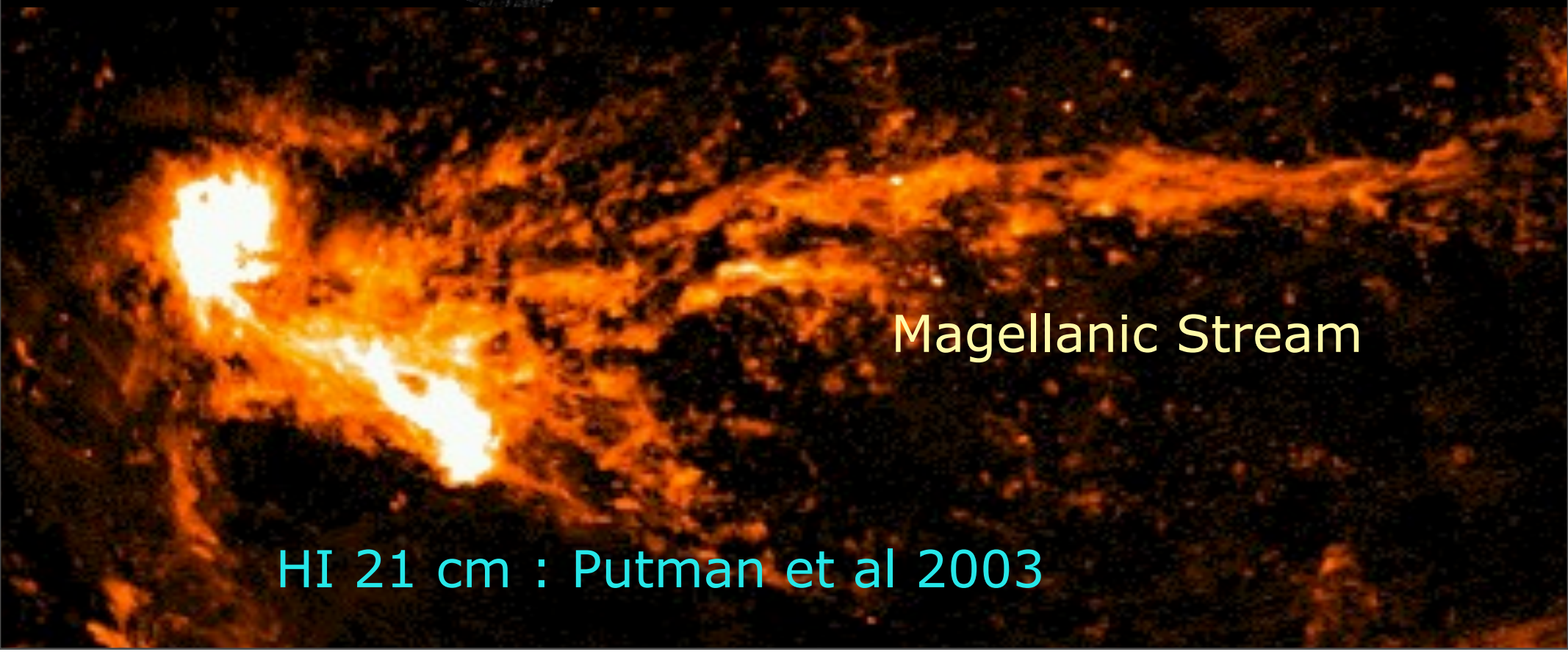
Collaborators:
Roeland van der Marel
Jay Anderson
Charles Alcock
Gurtina Besla
Lars Hernquist

KITP, March 2012

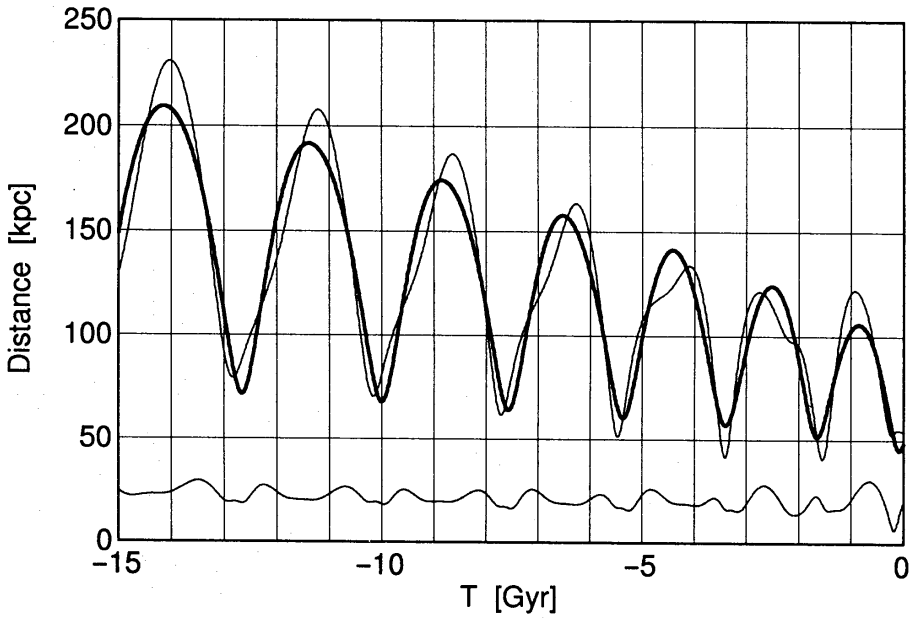
Magellanic Clouds



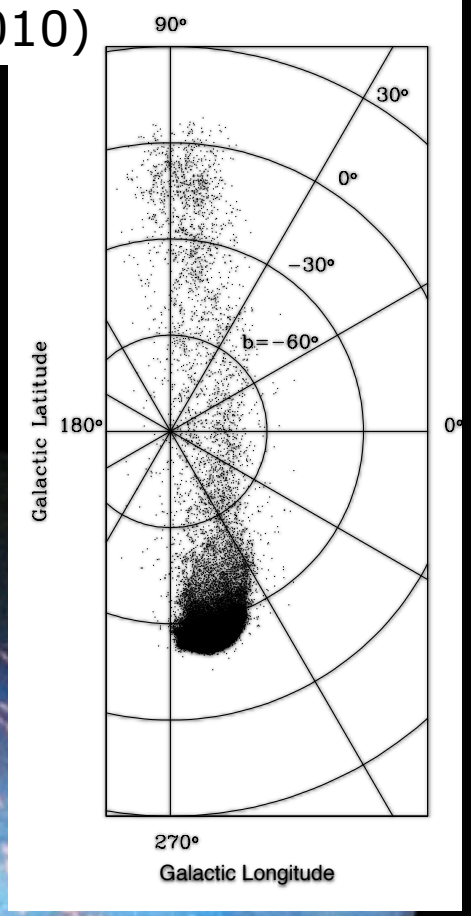
- Irregular dwarf galaxies
- Gas rich, likely similar to galaxies in the early universe i.e. building blocks of larger galaxies

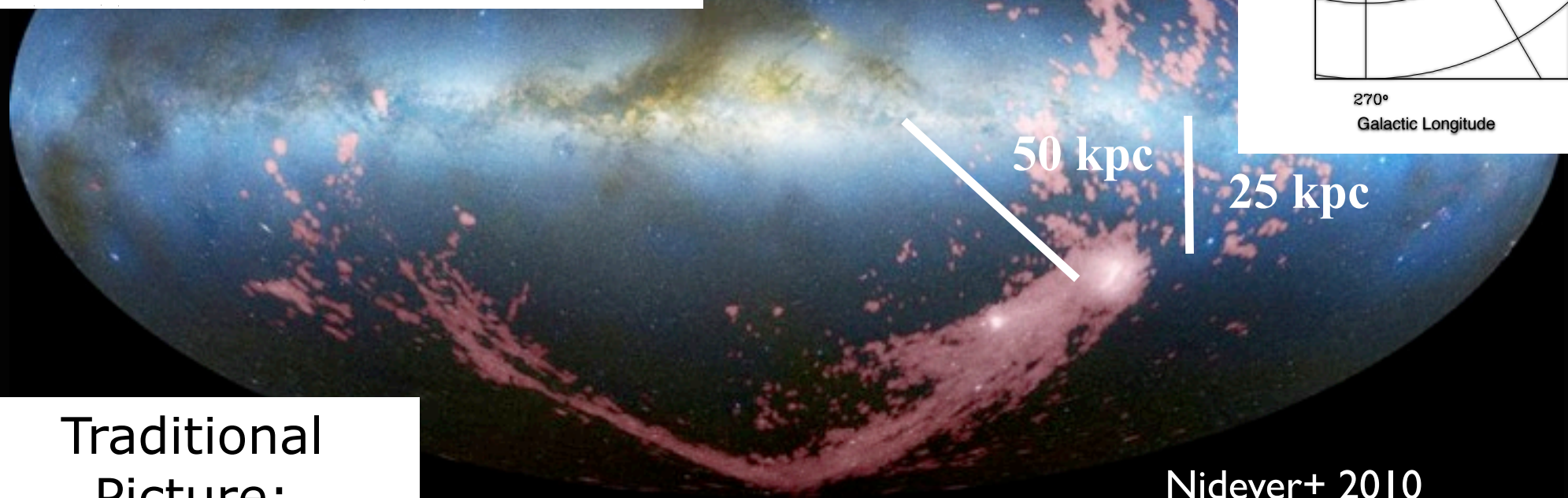


Tidal Stripping: Gardiner & Noguchi (1996)



Ram Pressure Stripping: Mastropietro + (2010)





Traditional Picture:

Nidever+ 2010

Required Proper Motion Uncertainty

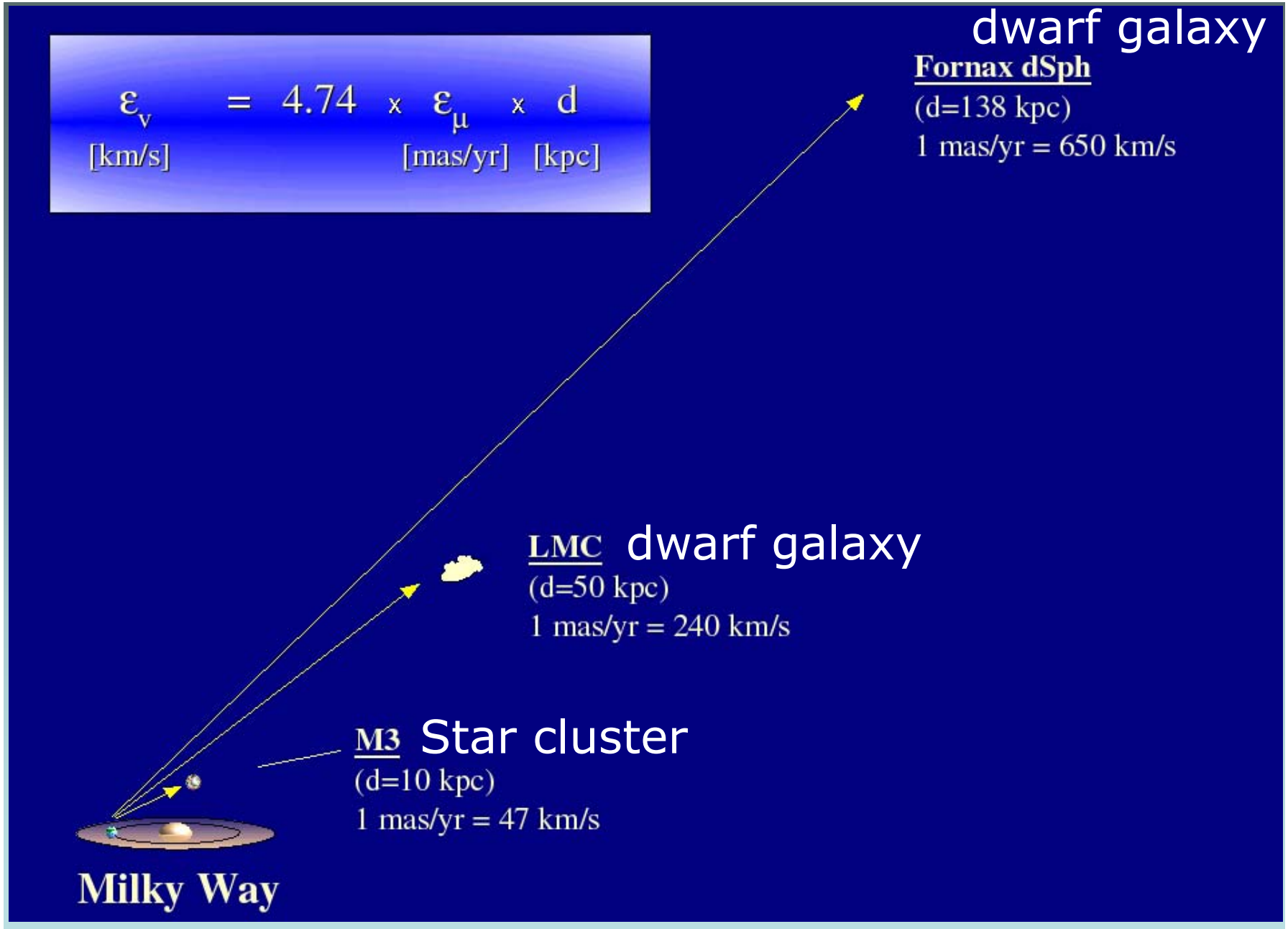
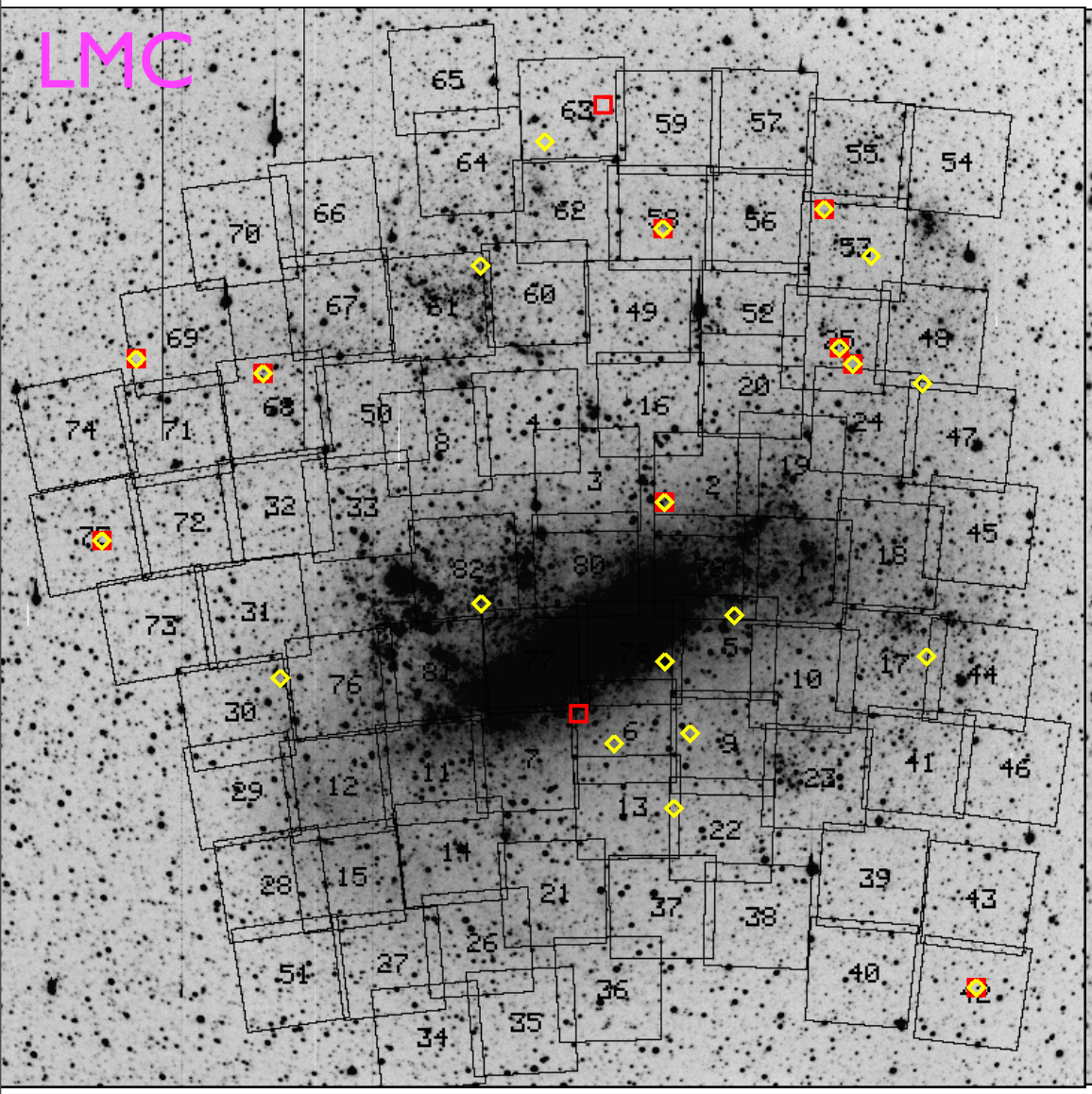
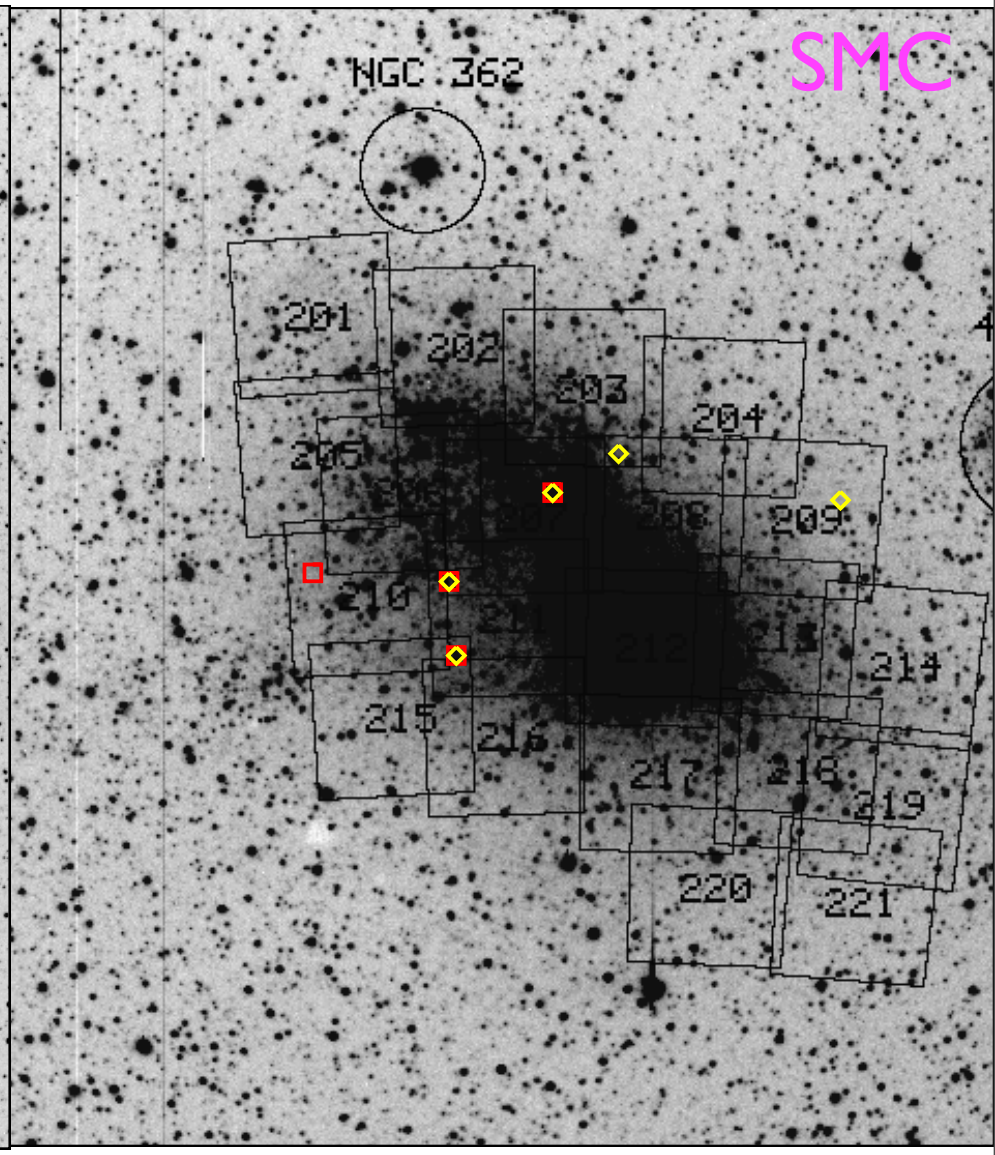


image credit: Dana Dinescu

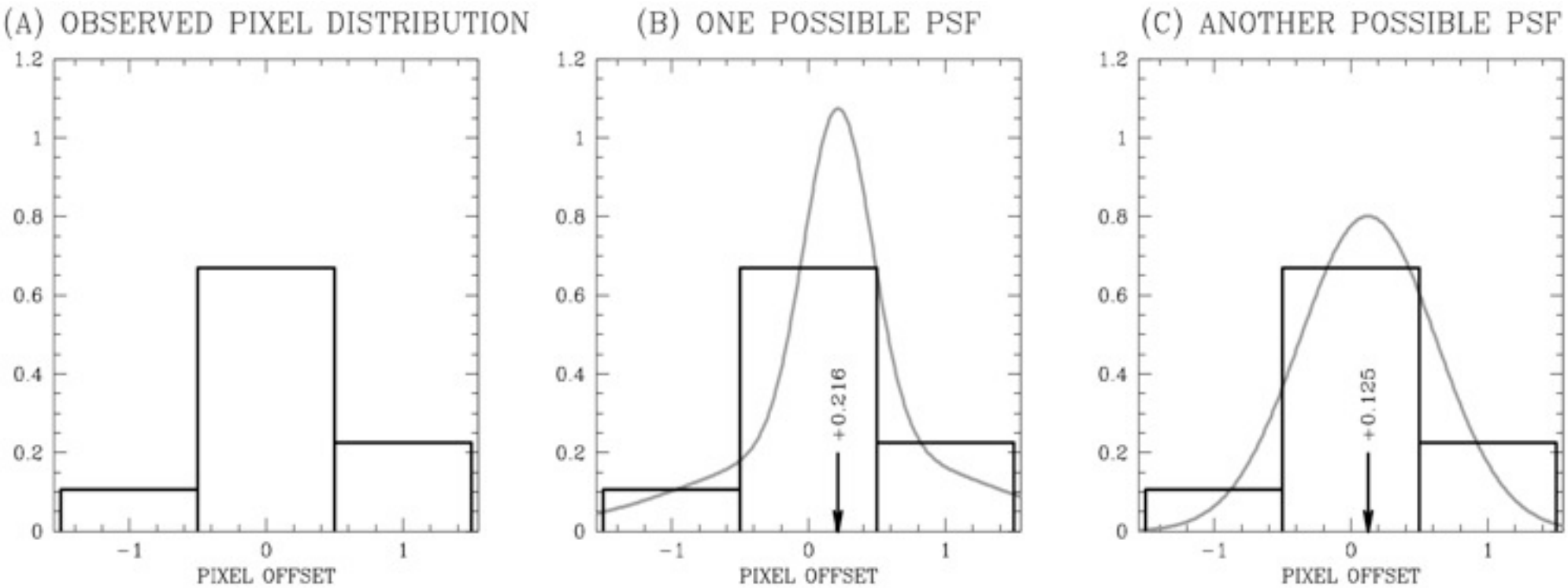
Distribution of QSOs behind the Clouds





Geha et al. 2003

a note on PSF-fitting



(a) hypothetical 1-D star profile

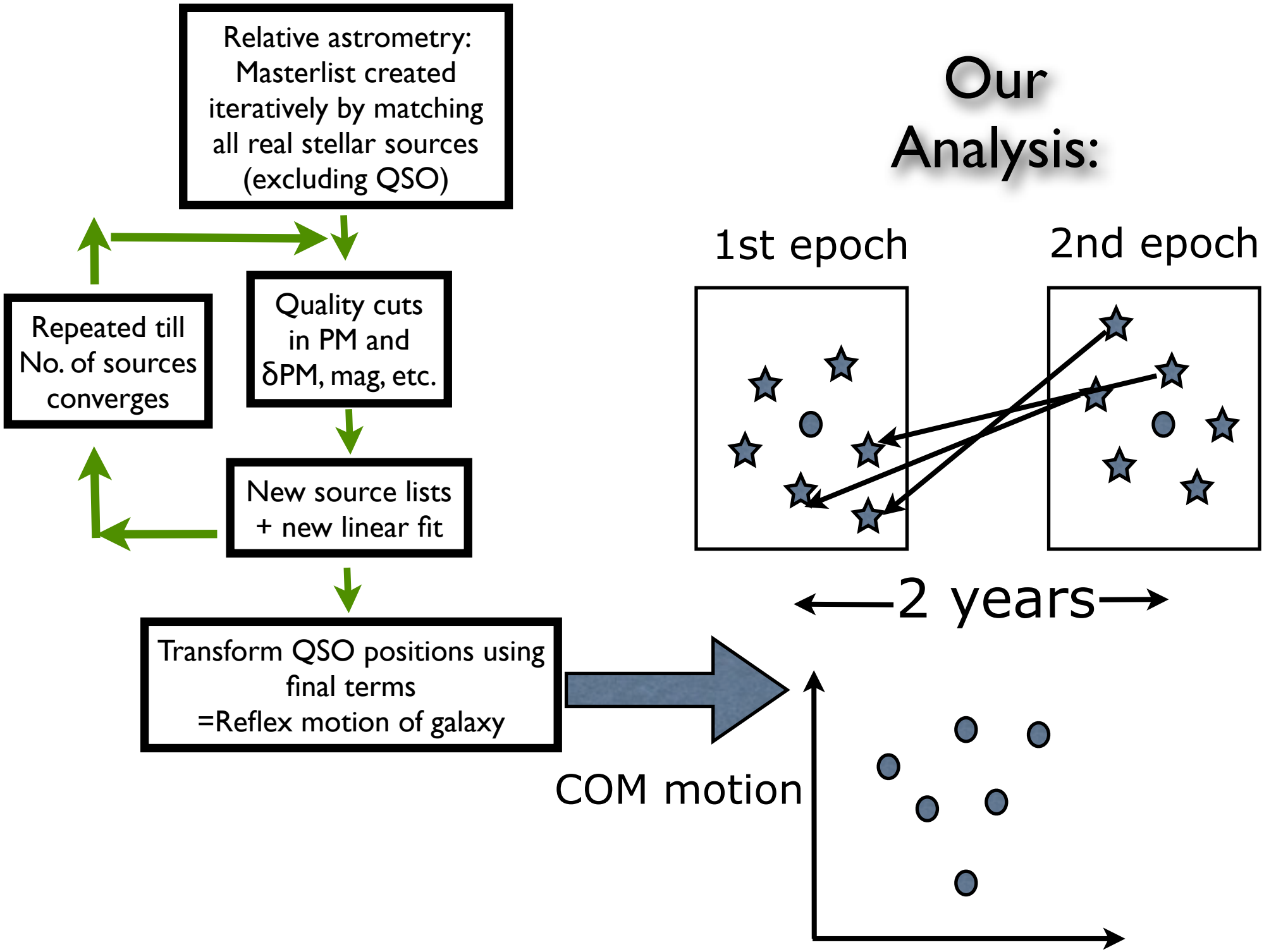
(b) the profile can be fit by the sum of a sharp Gaussian PSF with a broad Gaussian halo

(c) the profile can also be fit by a single medium-width Gaussian.

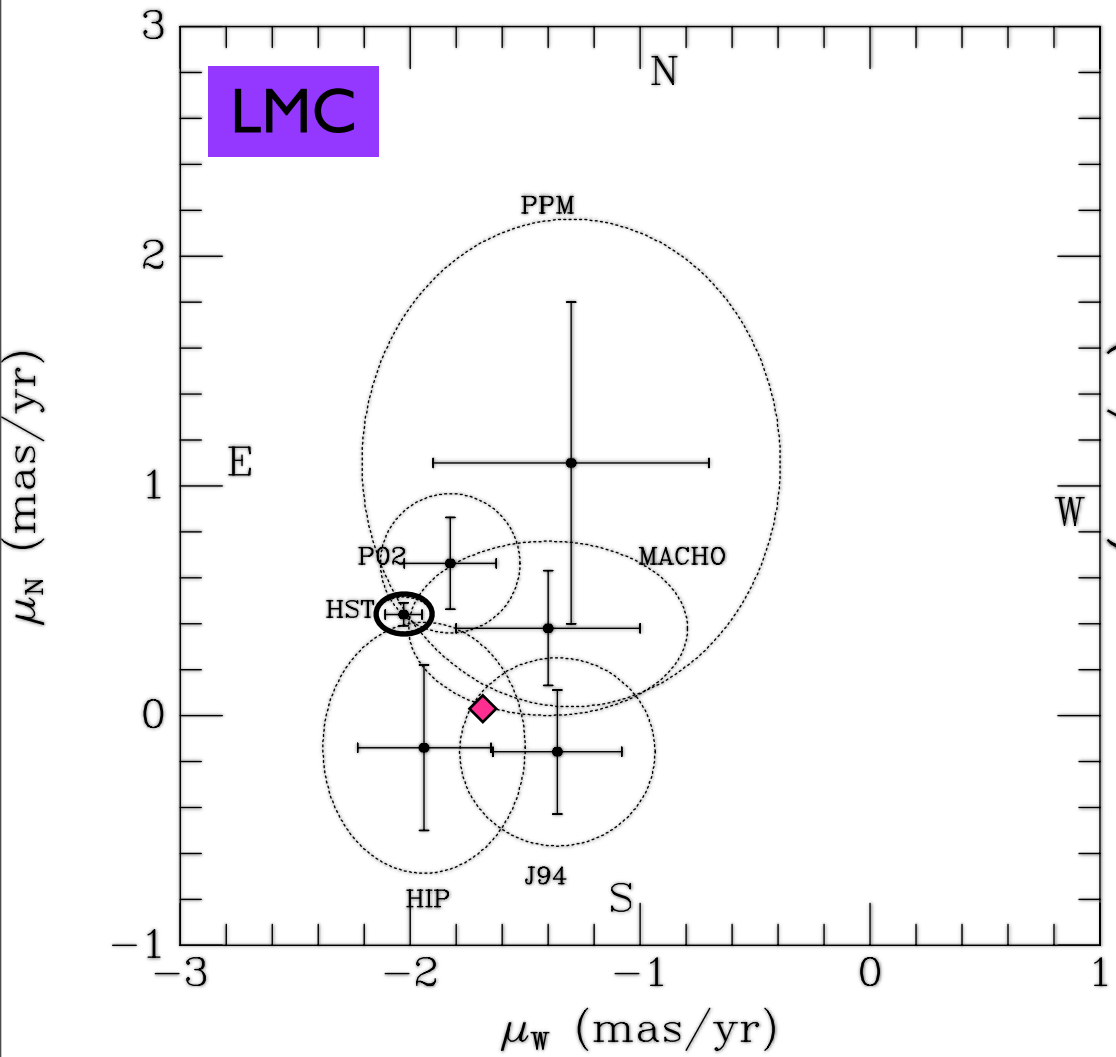
==> Pixel-phase Bias

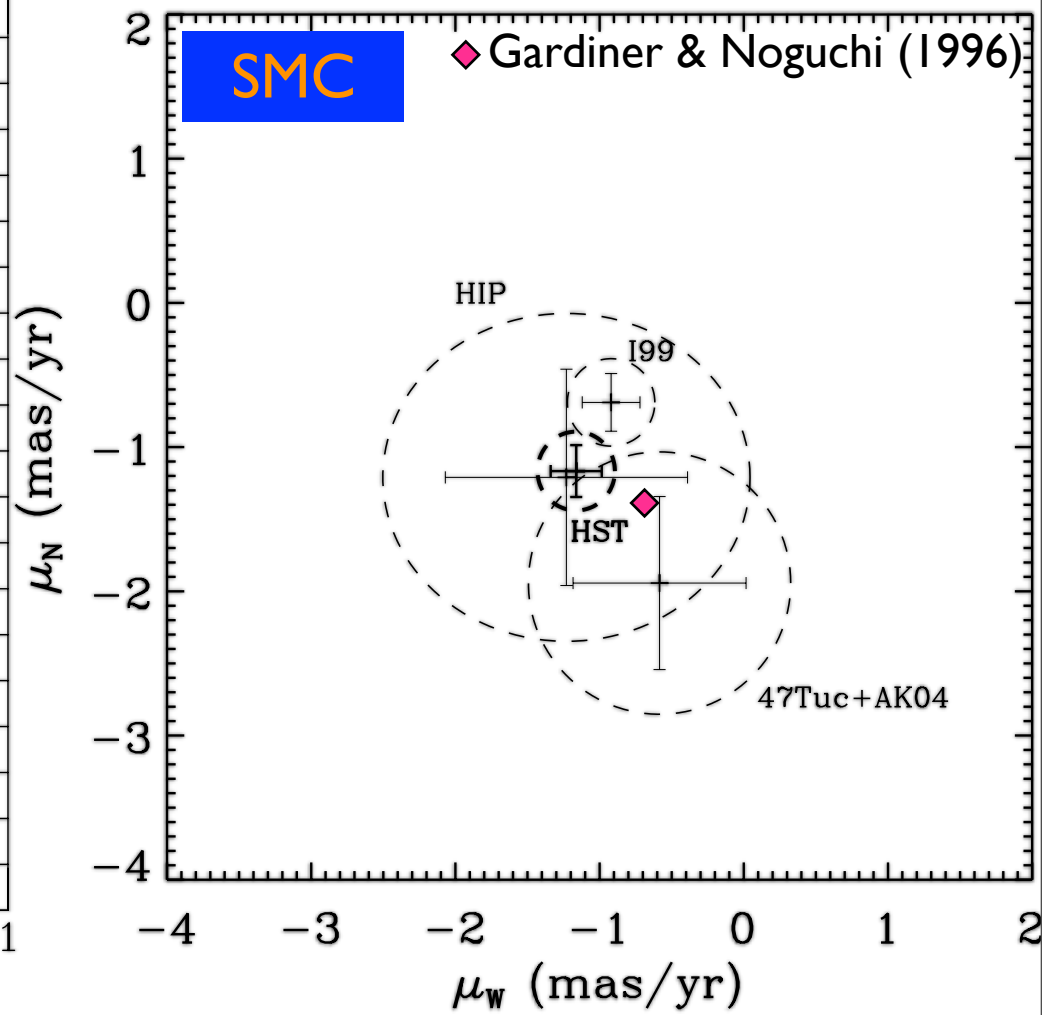
cf. Jay Anderson

Our Analysis:



LMC result : μ_W = -2.03 +/- 0.08; μ_N = 0.44 +/- 0.05 mas/yr ~ 370 km/s
errors ~ 18 km/s





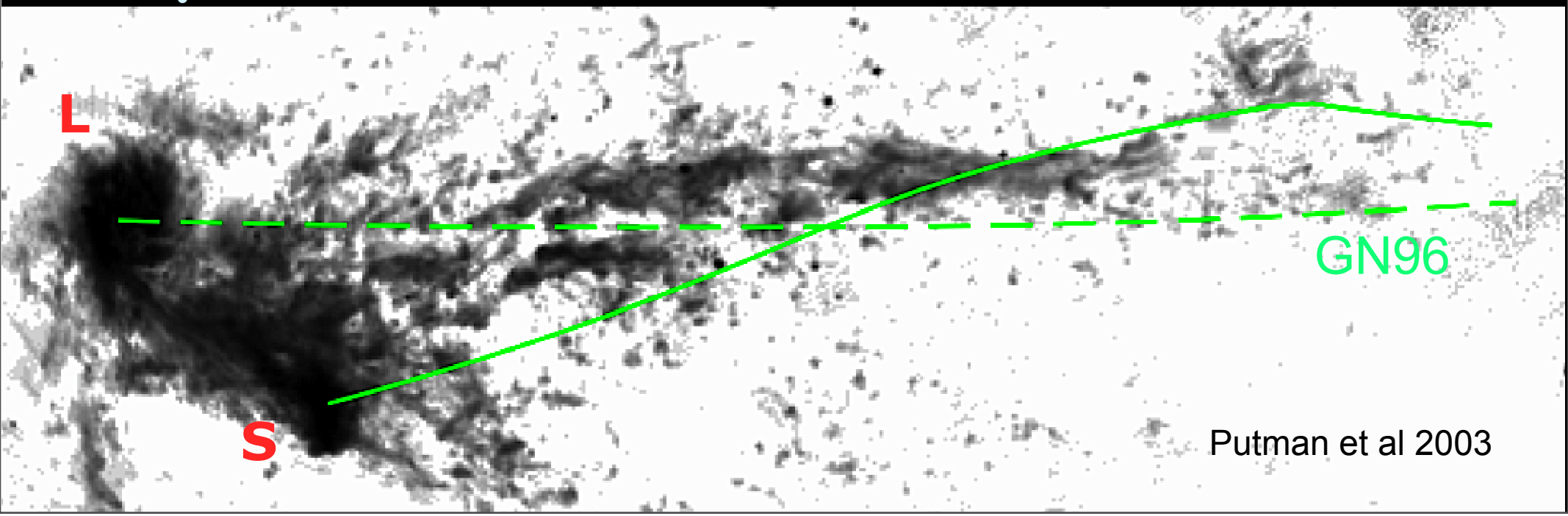
SMC result : μ_W = -1.16 +/- 0.18 mas/yr
μ_N = -1.17 +/- 0.18 mas/yr
~ 300 km/s (errors ~ 50 km/s)

NK+ (2006a,b)

Magellanic Clouds
Orbit Properties

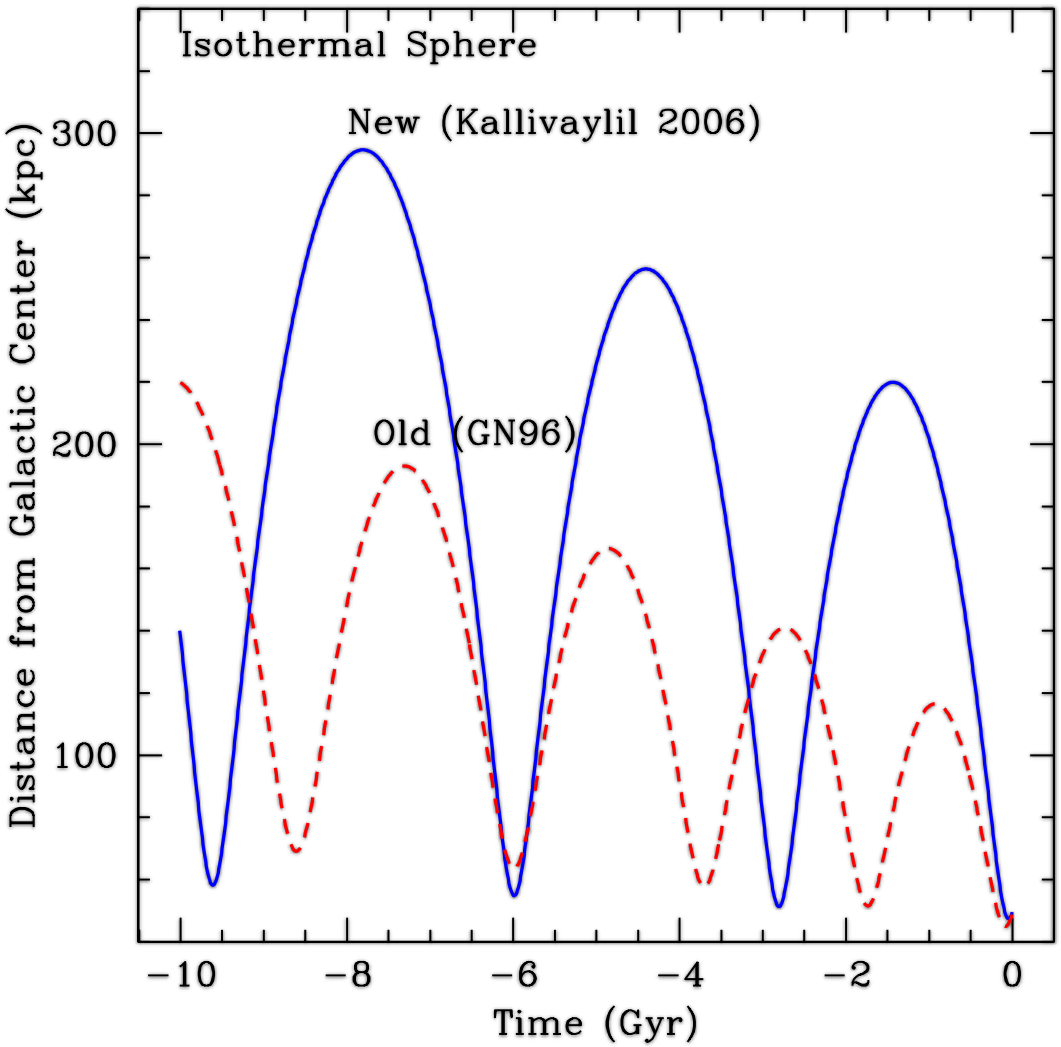
- **Previous work**
- Assume logarithmic potential
- Estimate proper motion from Magellanic Stream models
  - Gardiner & Noguchi (1996): v_{tan} = 287 km/s
  - [redacted]

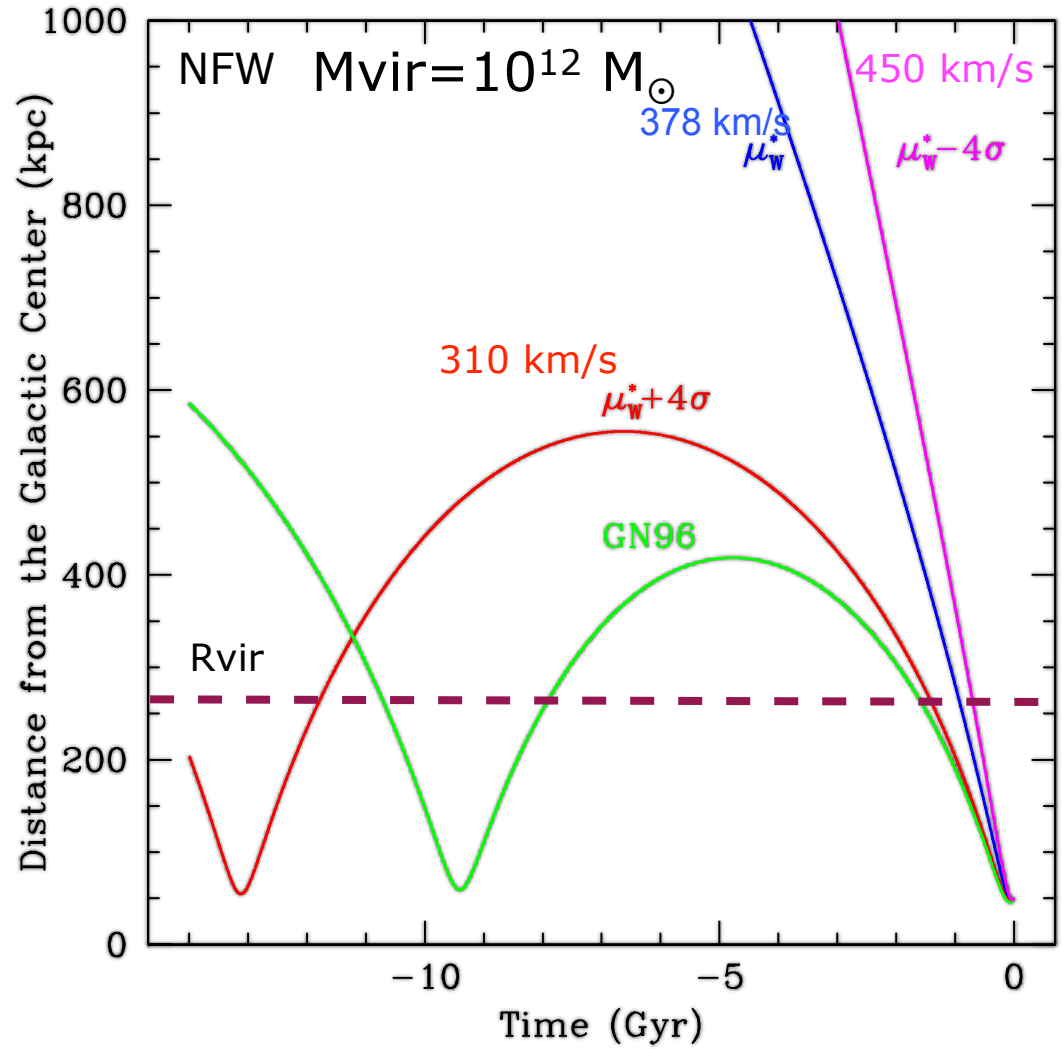
Period ~2 Gyr ⇒ **multiple passages**



Putman et al 2003

Orbital properties in a cosmological context



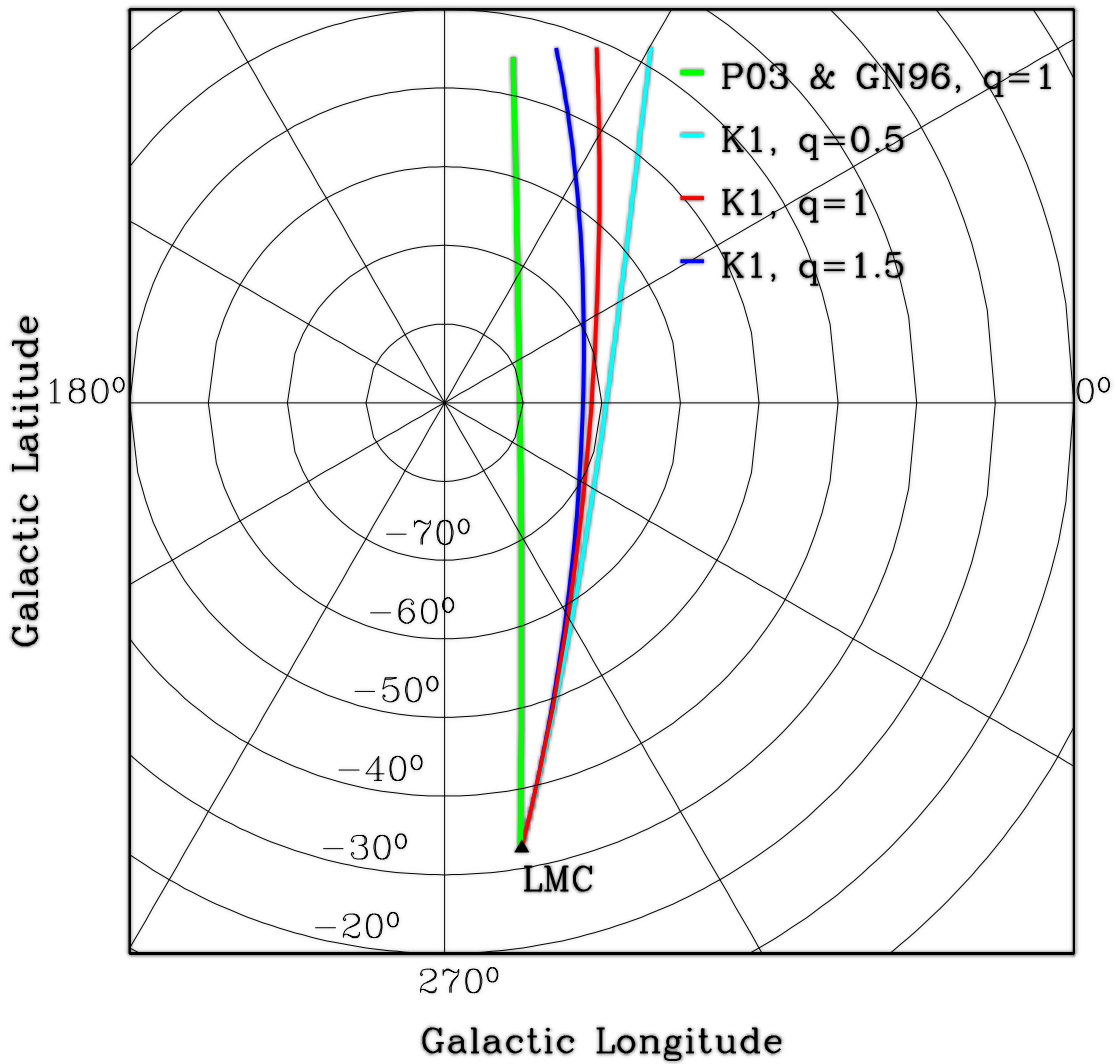


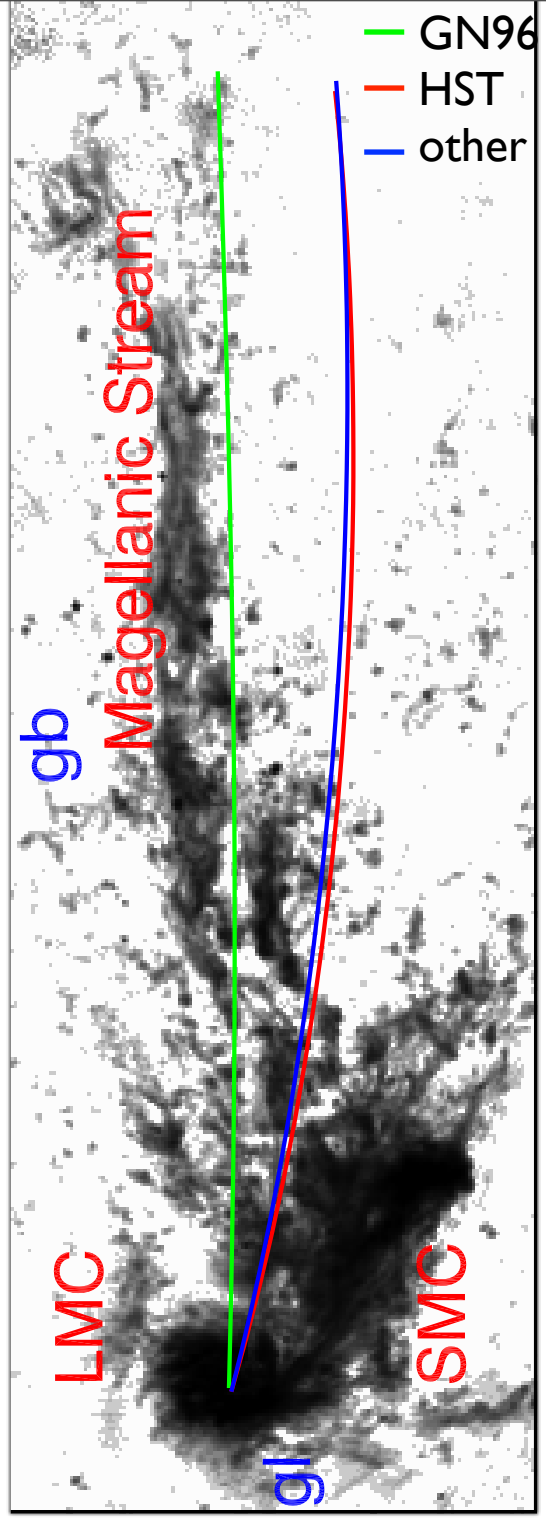
Note that models are static in time

Besla, NK+ (2007); NK+ (2009)

$$\psi = \frac{\psi_a R_c^{\beta}}{(R_c^2 + R^2 + z^2 q^{-2})^{\beta/2}}$$ (Evans 1994)

q = axial ratio
q<1 : oblate q>1: prolate
β = slope of the rotation curve
β < 0 : rising β > 0 : falling

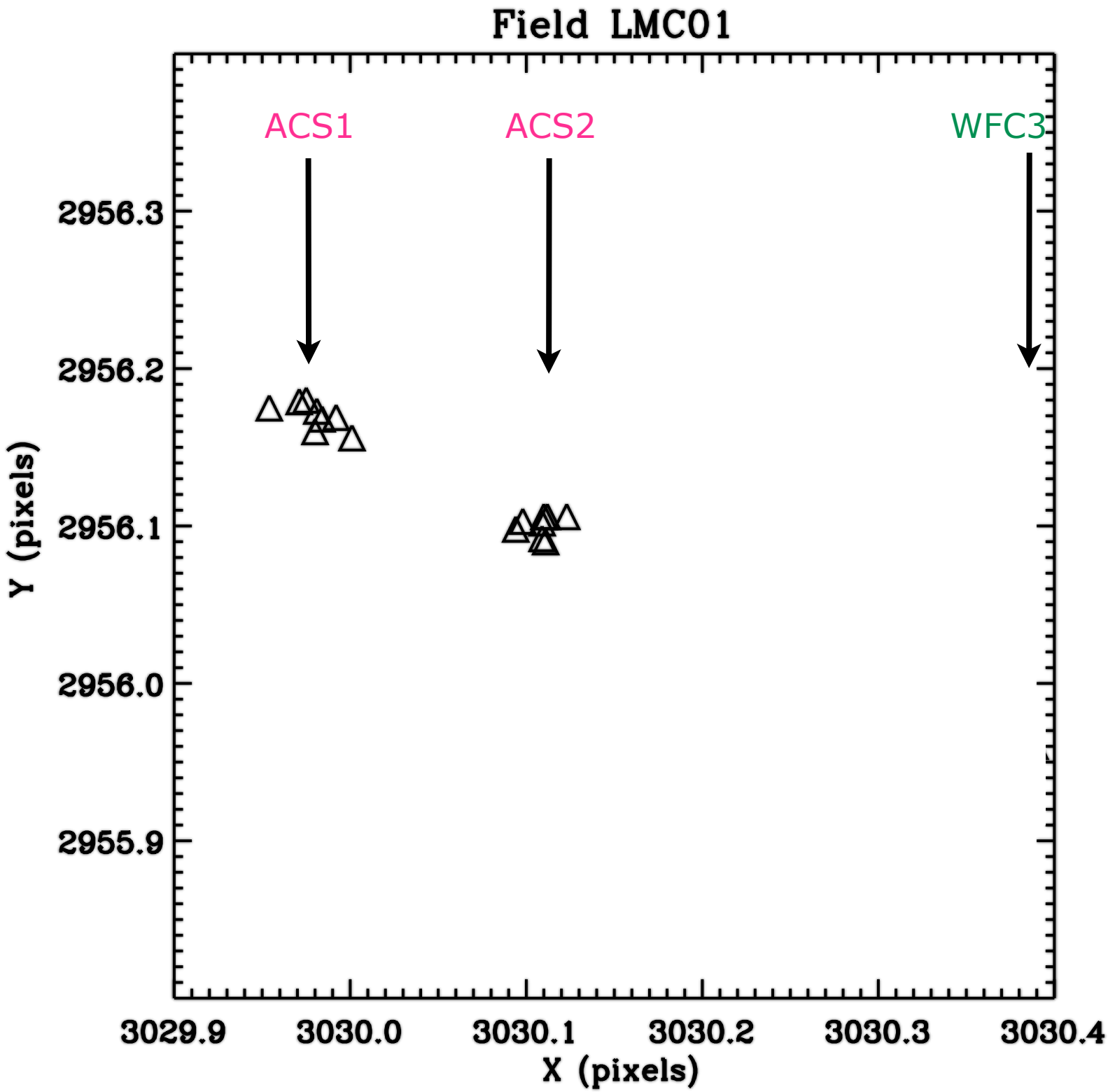




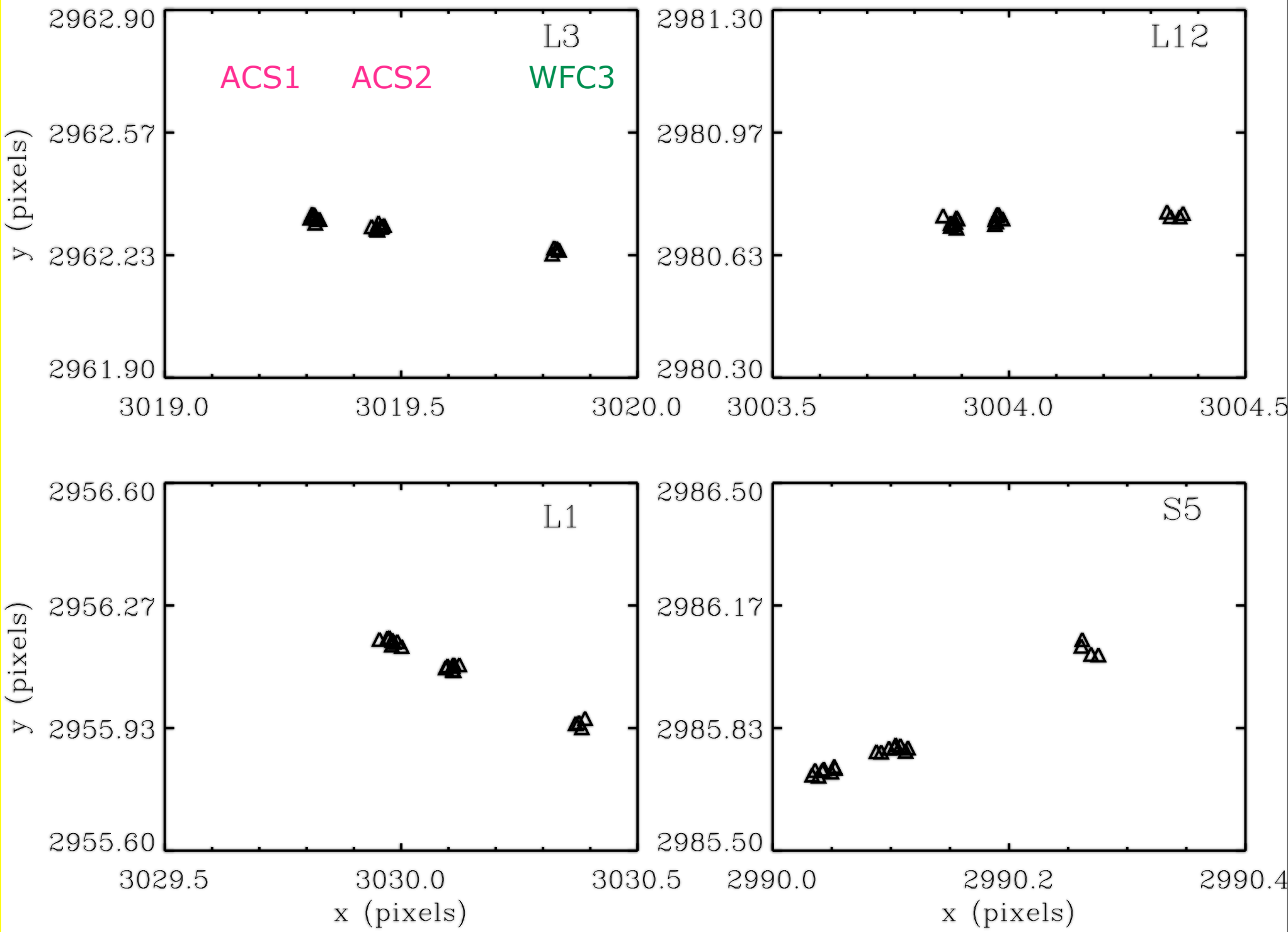
A New Epoch of Data: WFC3/UVIS

- A third epoch could (1) reduce random errors, and (2) provide a check on systematic errors.
- **15** fields obtained (12 LMC & 3 SMC). ~ Same observing strategy as ACS: S/N~200 for QSO.

3 Epcoh Analysis (ACS+WFC3) Random Errors:

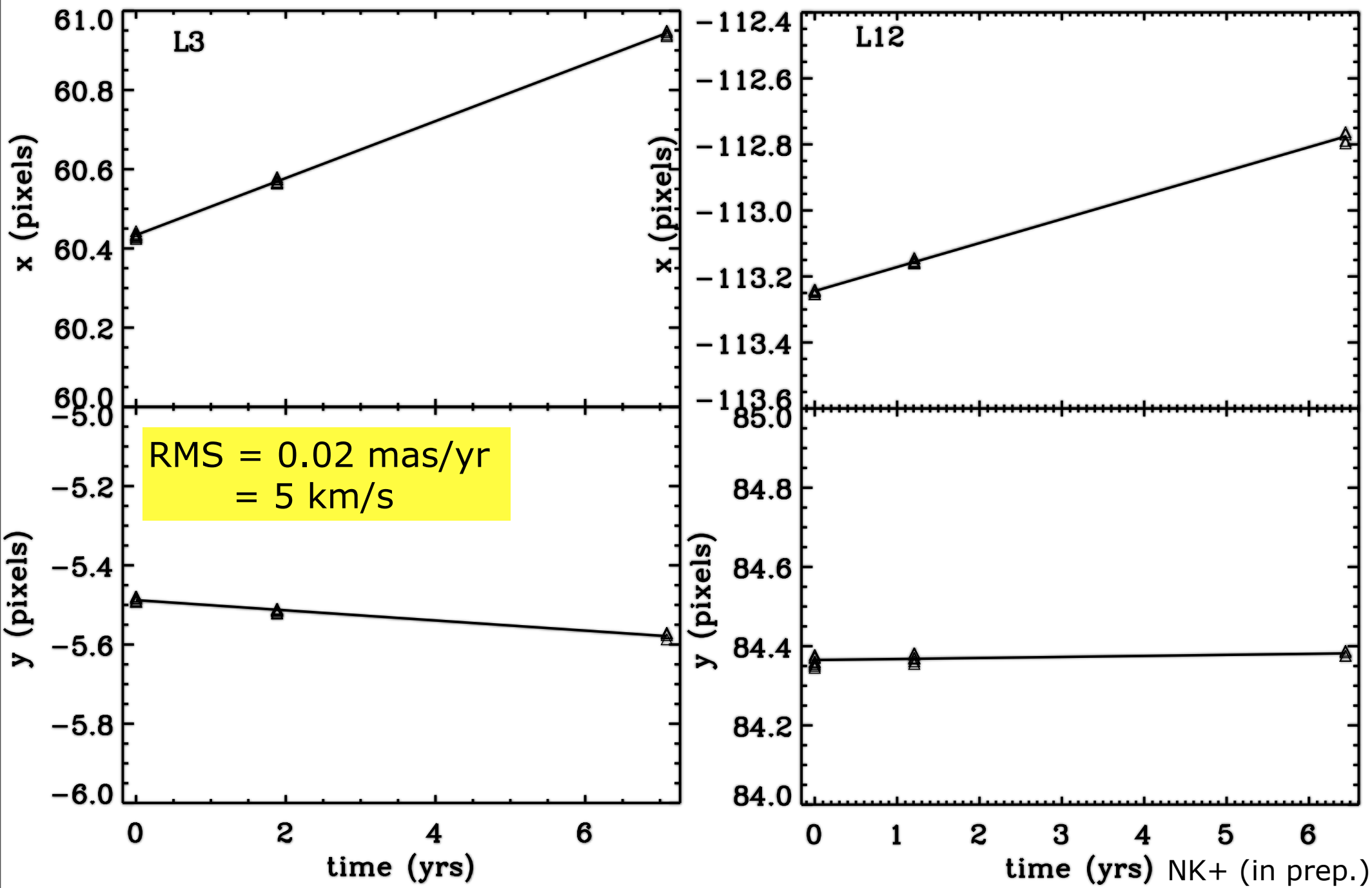


3 Epoch Analysis (ACS+WFC3) Random Errors:



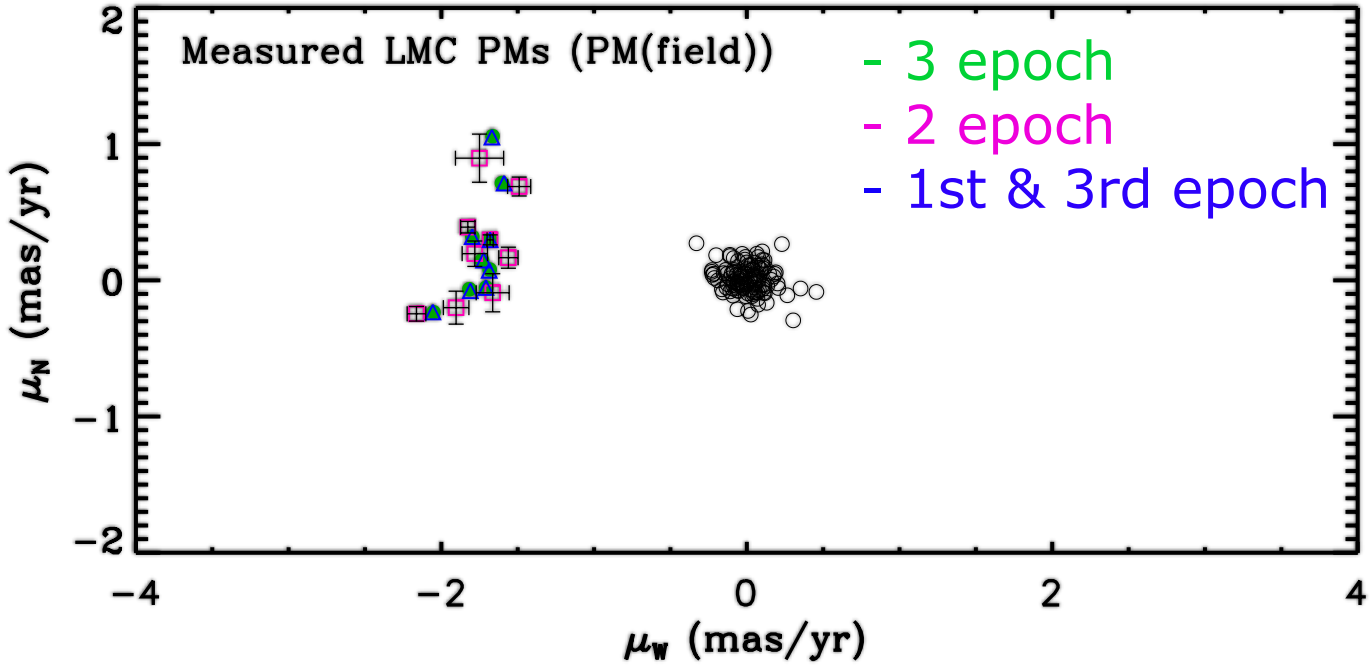
NK+ (in prep.)

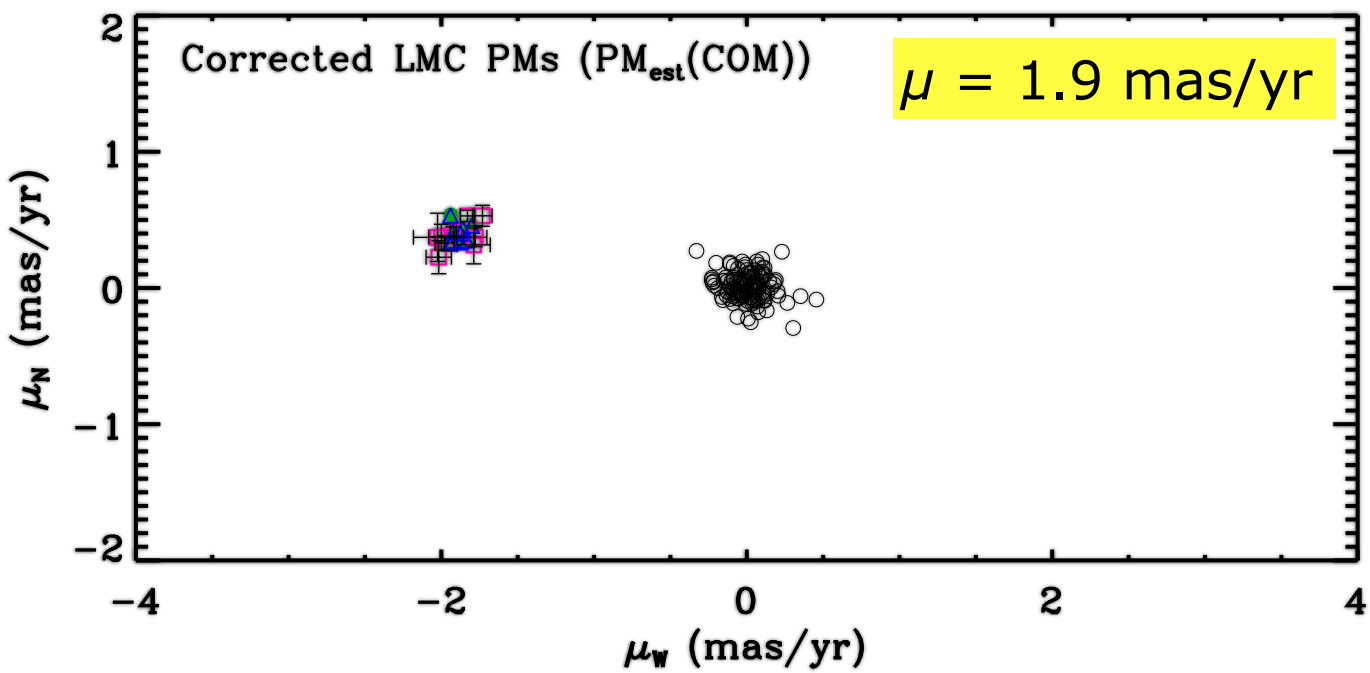
Three-Epoch Analysis Systematic Errors:



NK+ (in prep.)

Three-Epoch Proper Motion of the LMC



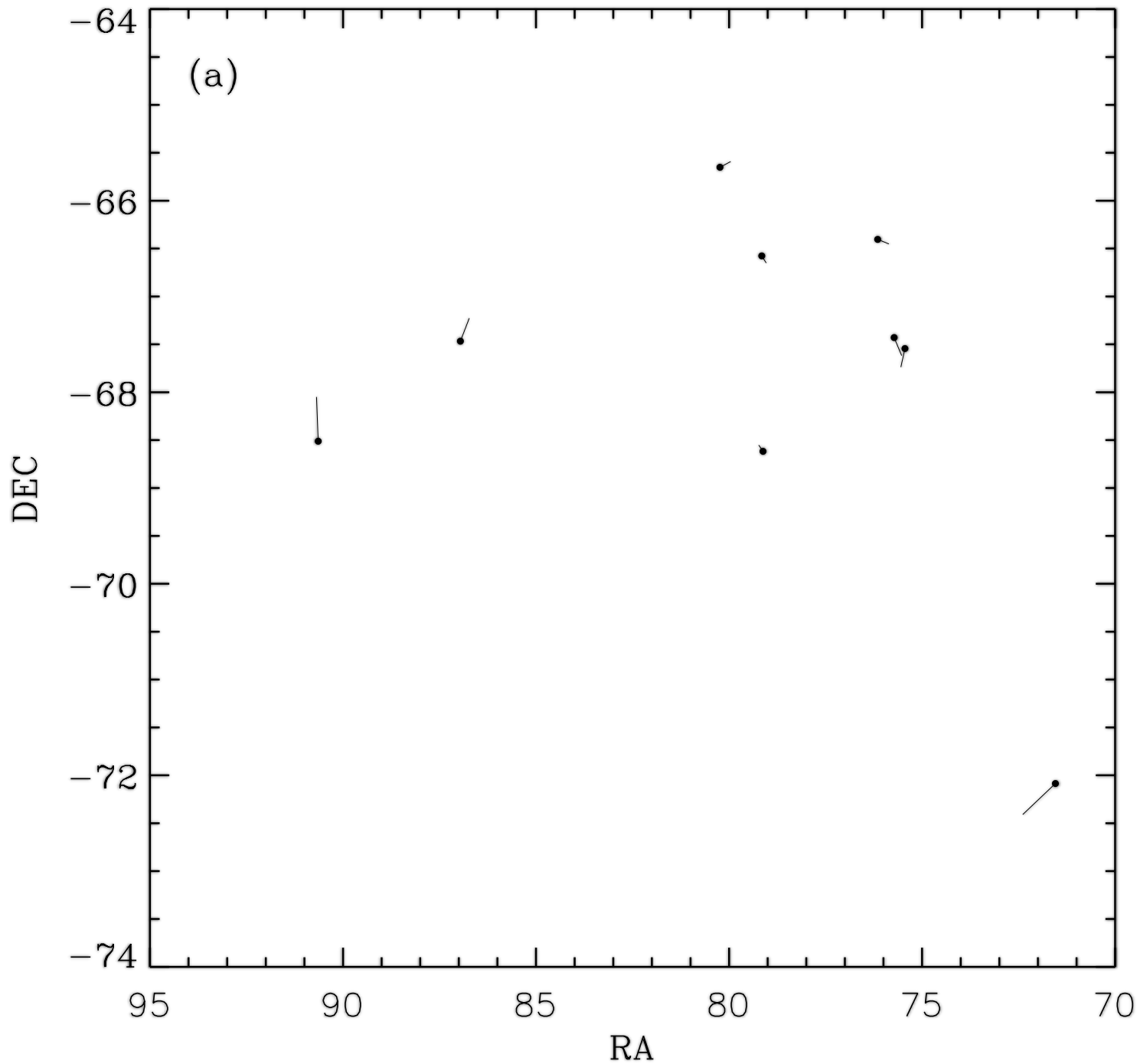


NK+ (in prep.)

LMC proper-motion rotation: $\hat{\mu} = \mathrm{PM(field)} - \mathrm{PM(CM)} - \mathrm{PM_{res}(field)}$

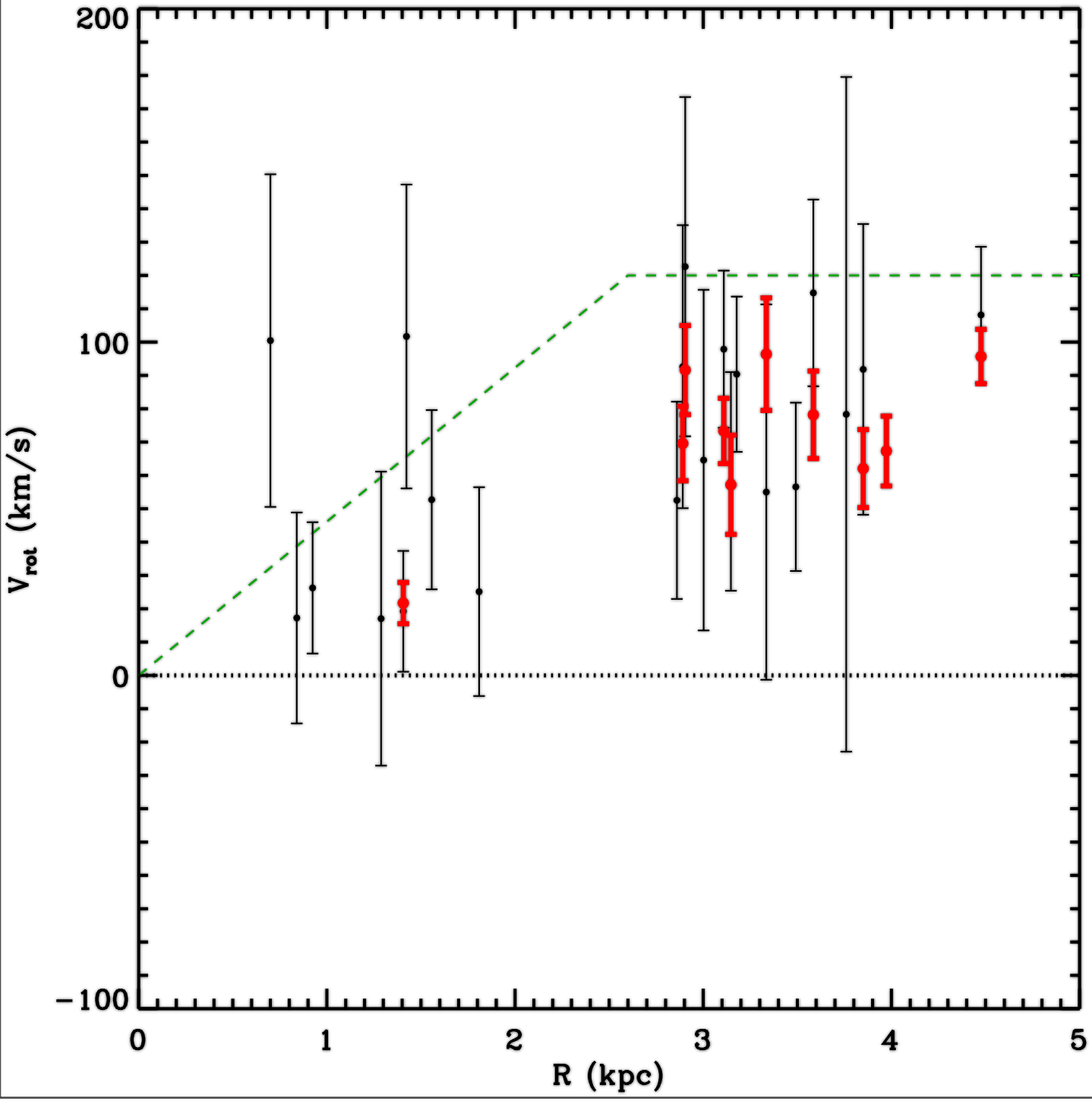
$$\hat{\mu}_{\parallel} = \hat{\boldsymbol{\mu}} \cdot \boldsymbol{u}_{\parallel}$$

$$\hat{\mu}_{\perp} = \hat{\boldsymbol{\mu}} \cdot \boldsymbol{u}_{\perp}$$



NK+ (in prep.)

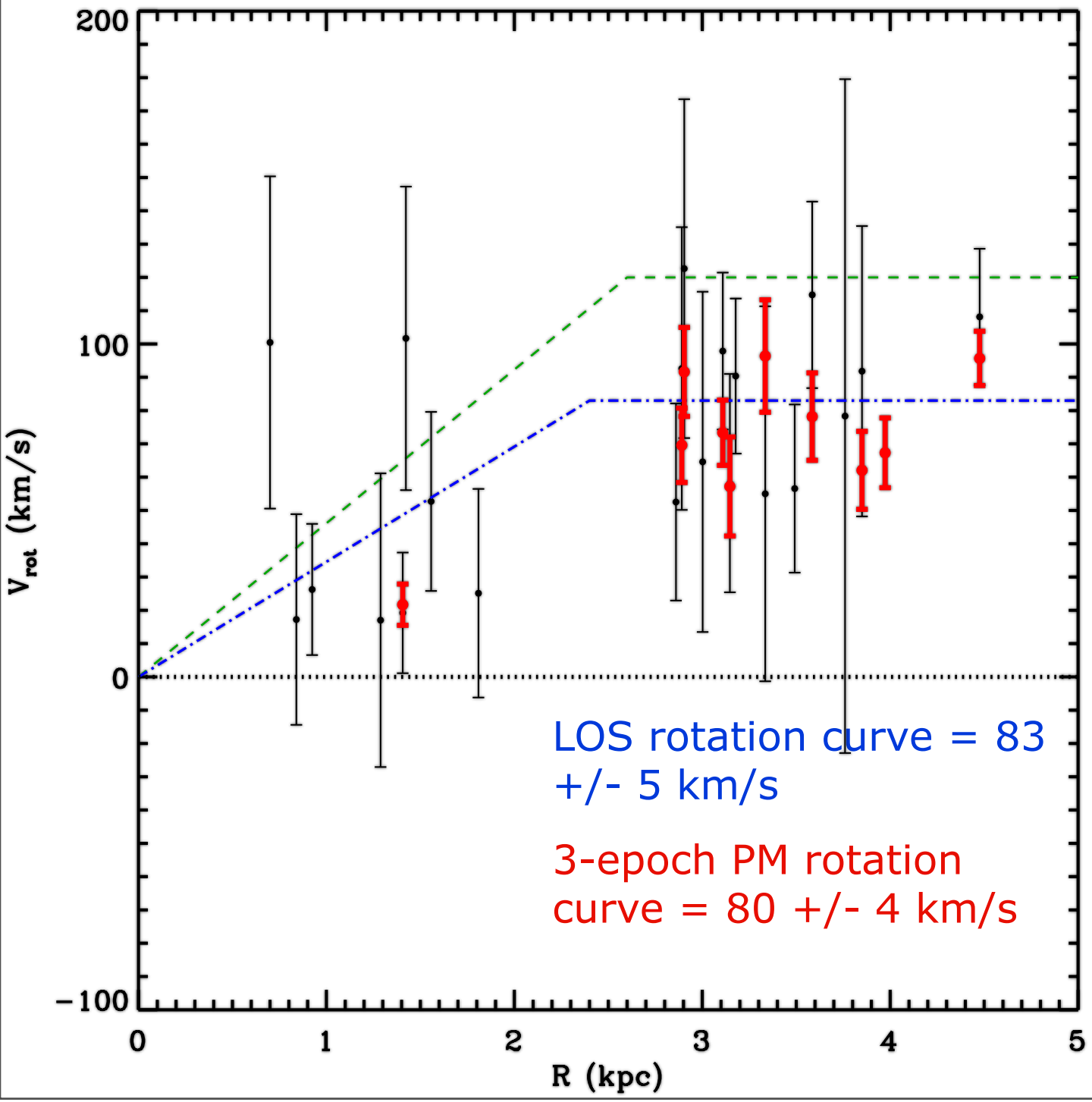
Proper Motion Rotation Curve



Stars:
- ACS reanalysis PMs
- 3 epoch PMs
- Piatek 2008 PMs

HI ~ 80 km/s (Kim+ 03)
Piatek = 120 km/s

Proper Motion Rotation Curve

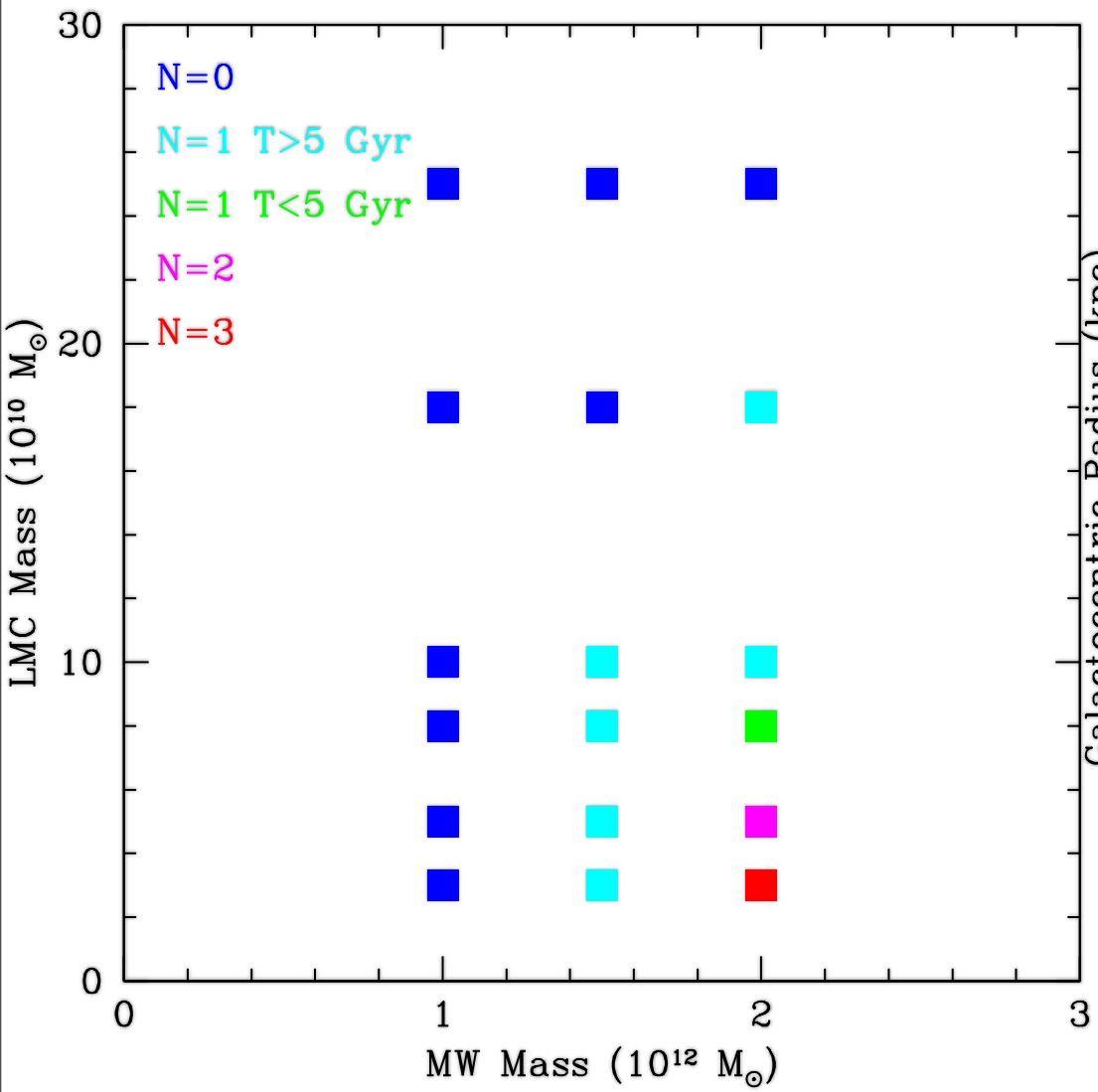


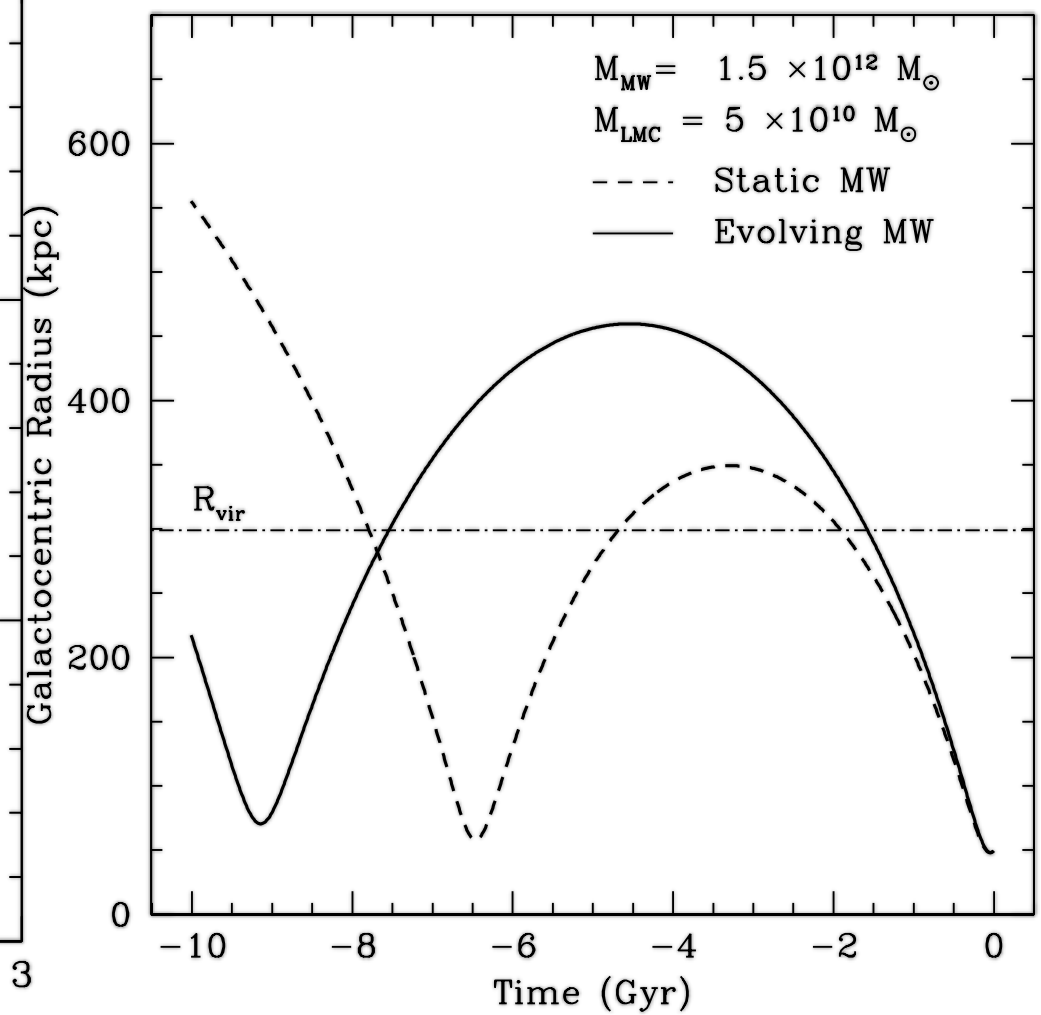
Stars:
- ACS reanalysis PMs
- 3 epoch PMs
- Piatek 2008 PMs
- RSGs, AGBs LOS (Olsen+ 2011)

HI ~ 80 km/s (Kim+ 03)
Piatek = 120 km/s

Cleared up long-standing issue with LMC's dynamical center

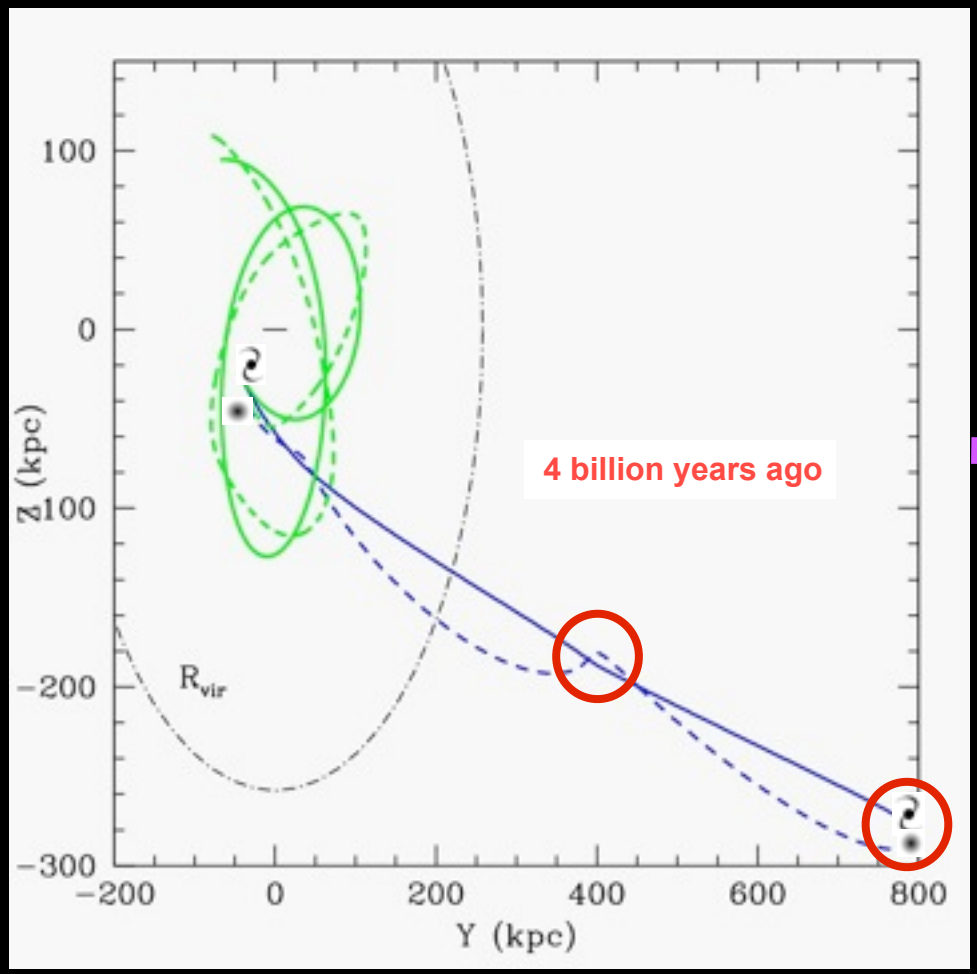
New Orbits (NK+ 2012, in prep.)

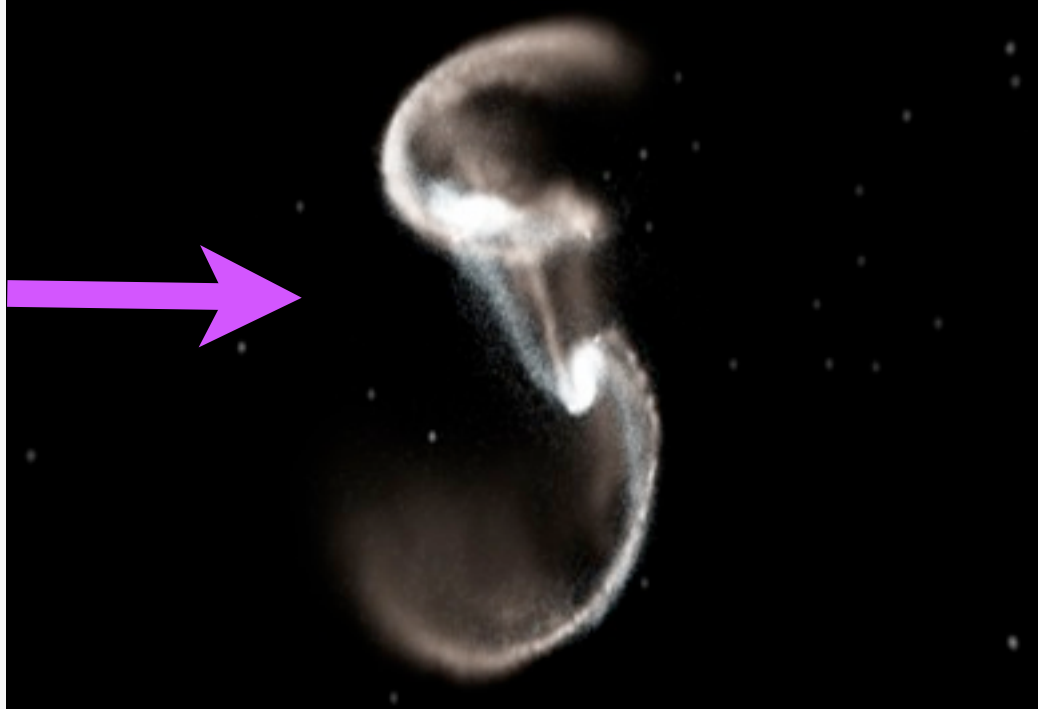




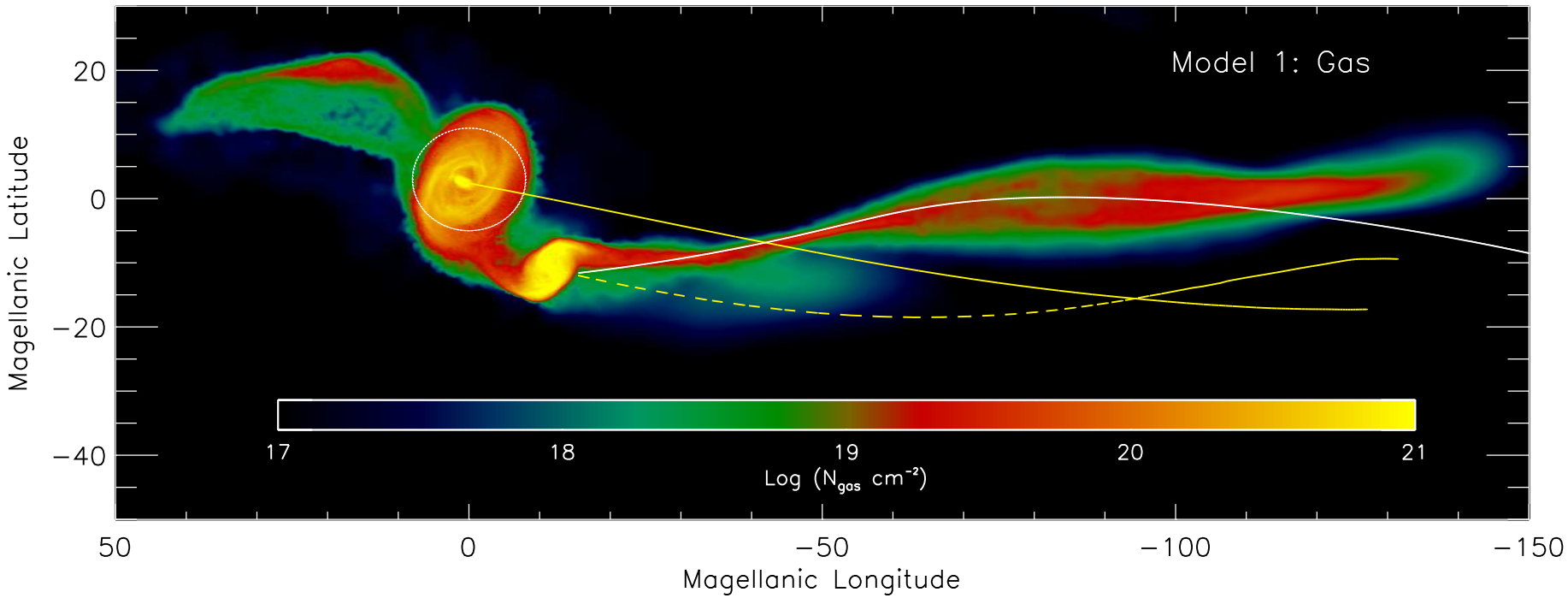
New Magellanic Stream Model (Besla, NK+ 2010; 2012)

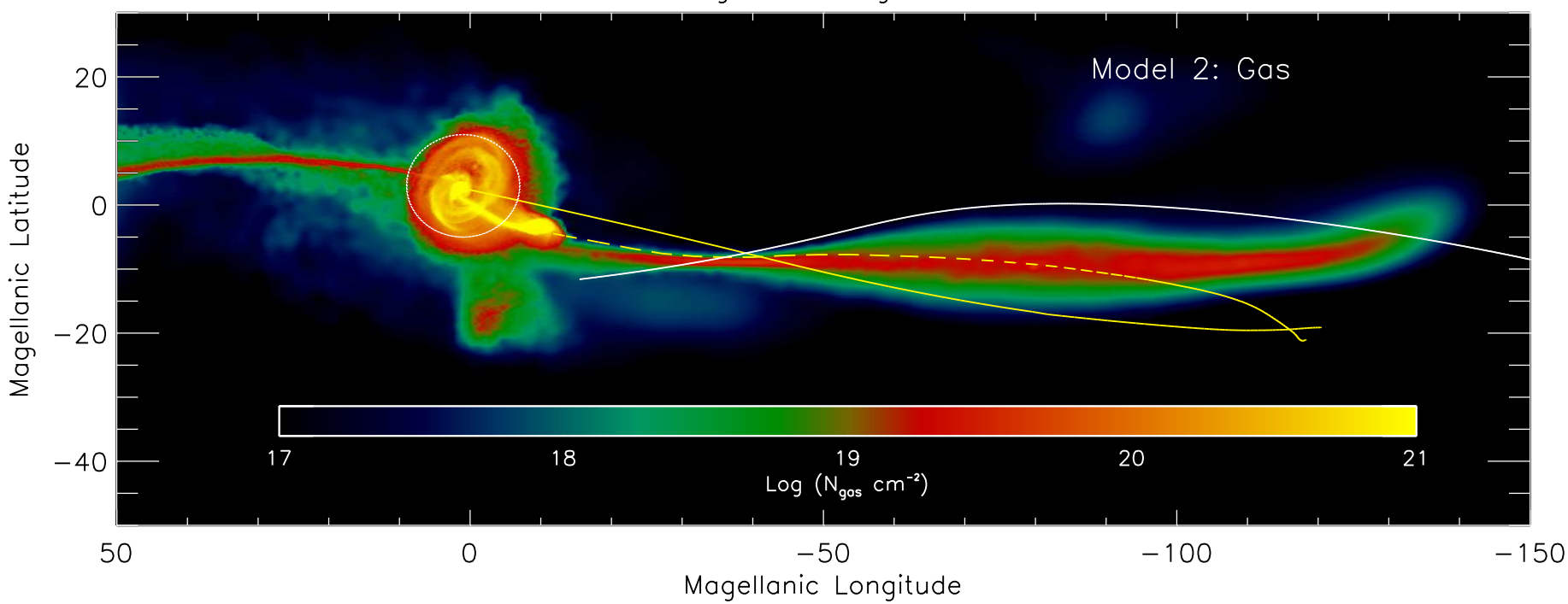
Our new model relies on the interactions of the Clouds with each other rather than the Milky Way





Apart from viability in a first passage, also explains other orbital specifics





Conclusions

- HST is stable enough to provide good proper motions with relatively short baselines (~2 years).
- The longer baseline of 7 years is providing PMs with unprecedented precision at 50 kpc, and we have measured LMC rotation and all geometric parameters from PMs. Comparison to LOS study also gives distance.
- The consistency with the first two-epochs confirms that the Clouds are on their first passage: see also Rocha et al. 2011; Boylan-Kolchin et al. 2011; Busha et al. 2010
- We infer that dwarf-dwarf galaxy interactions may be important drivers for the morphological evolution of dwarf galaxies and can affect the efficiency of baryon removal via the formation of extended tidal bridges and tails.
- **And now, back to stellar streams....**