Proper Motion of LMC

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1 Introduction
- Objectives and motivations

2 Observation Method and Analysis
- Scheduling and Execution
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LMC, SMC and MS

The **Magellanic Clouds** (LMC and SMC)

- Closest galaxies to MW, fundamental for various astrophysical studies
- Members of the local group, orbit our galaxy
- Located at about 55 kpc from the Sun, about 25 kpc from galactic plane

The **Magellanic Stream** (MS)

- High-velocity cloud of HI gas connecting the small and large MCs
- Material stripped from SMC some 1.5 Gyr ago
- Spans more than 100^{o} across the sky

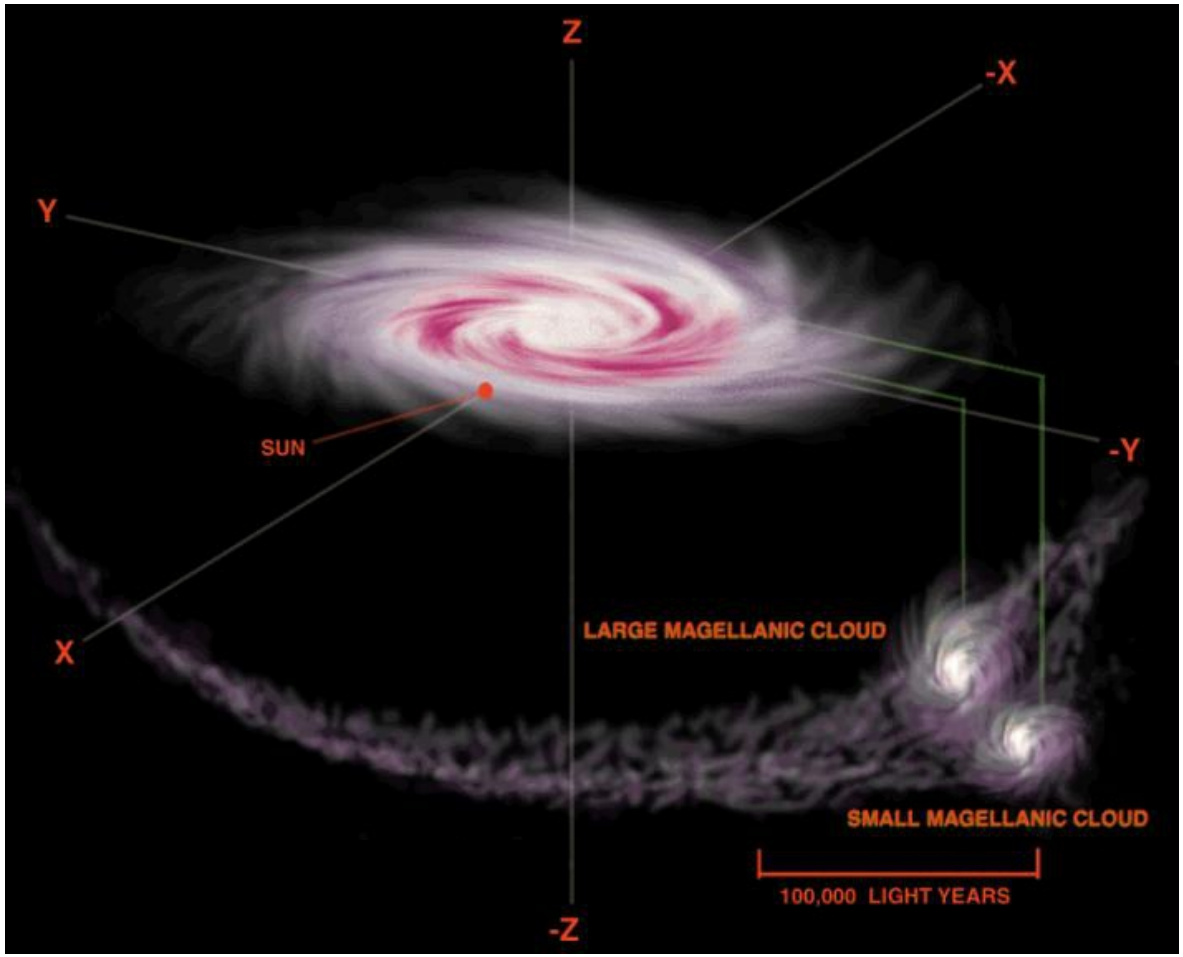

Figure: The Magellanic Stream and its relative position to SMC, LMC and MW

Objectives

Precise measurements for proper motions of MCs in order to:

- Determination of orbit of MCs. Requirements:
  1. Position of MCs in sky
  2. Distance MCs-Sun
  3. MCs radial velocities
  4. Proper motions of MCs
  5. Grav potential of dark halo
- Improve models of shape and density distribution of the Galactic dark halo
- Help constrain theoretical models of the formation of the Magellainc Stream

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Sample selection and procedure I

Idea: Image QSO behind clouds in 2 different epochs

- Initially identified 54 QSO (44 behind LMC, 10 behind SMC)
- Use HST's HRC on the ACS $\longrightarrow$ **Snapshot mode!**
- 34 observed in first epoch, 27 in second, **21 common** to both epochs for LMC
- Final sample of 21 QSO to serve as reference (21 fields)

Sample selection and procedure II

- Mean baseline: 1.9 years
- *Dither* pattern of 8+1 exposures per epoch and field
  - 16 samples in V band
  - 2 in I band

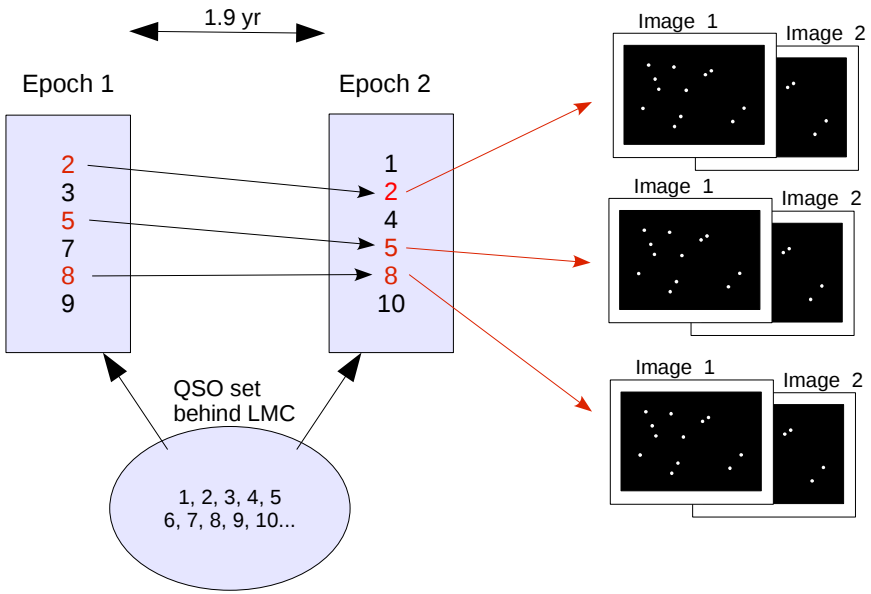

Figure: Simplified imaging system used in observations

Image of QSOs

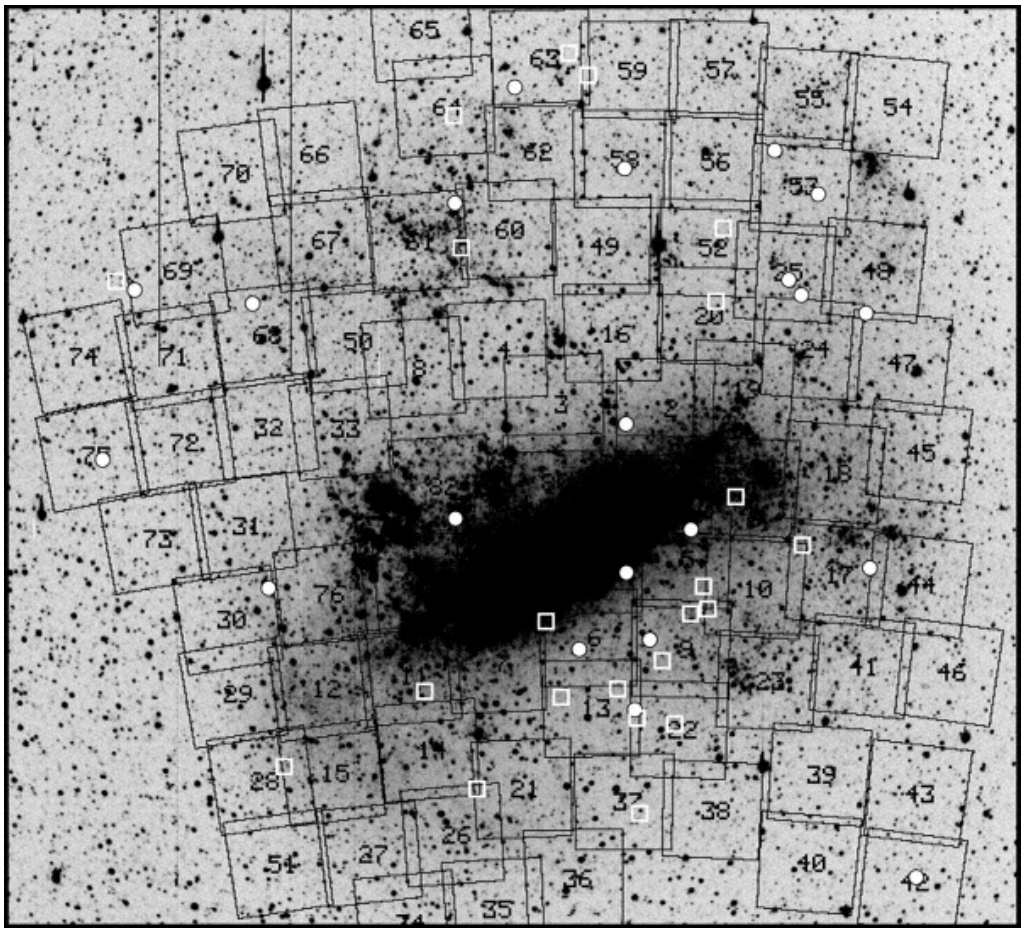

Figure: QSOs behind LMC. White circles are those for which two epochs of data were obtained, white squares are QSOs that did not make it to either the first or the second epoch.

PSF and distortion methodology

Hubble's HRC PSF and distortion treated with code by Anderson & King (2004)

- Fit PSF to determine stellar position and flux

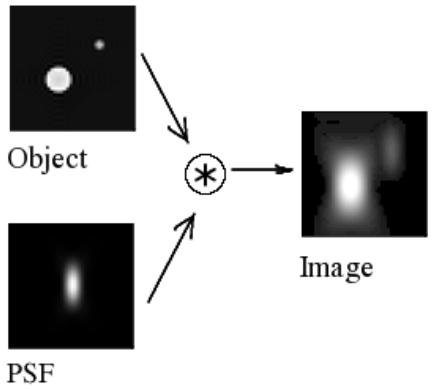

Figure: Point Spread Function [source: Wikipedia]

- Geometric distortion (aberration, heat effects, etc) $\longrightarrow$ 6-parameter linear transformation to bring observations to common frame

Data Analysis I

Single field images

Apply conservative cut in images to select sources

- Cross-identify sources in all 18 images of each field $\longrightarrow$ *Master list* of sources for each QSO field with 18 appearences per source
- Reject **cosmic rays**, **bad pixels**, **stars off image** due to dither or CCD rotation between epochs

This process cuts down $N_{sources}$ by a factor of ~ 2

Data Analysis II

Single field images

- Identify QSO for each field using MACHO discovery images
- Remove identified QSO from master list

Obtain list of LMC objects each appearing in every exposure $\longrightarrow$ Ready to start deriving *PMs*

Proper motion derivation I

Method based on aligning star field between epochs and then calculate QSO movement

- Iteratively apply linear fit and take stars with PM and δPM relative to others are < 0.1 pixels
- This rejects foreground stars $\sim 8\ mas \cdot yr^{-1}$
- Align fields and work out relative motion of QSO from epoch 1 to 2

Do not measure proper motion of a star with respect to each other
Measure average motion of stars with respect to QSO

Proper motion derivation II

We have PM of QSO! Actually, it reflexes the motion of LMC stars, QSO is fixed in sky

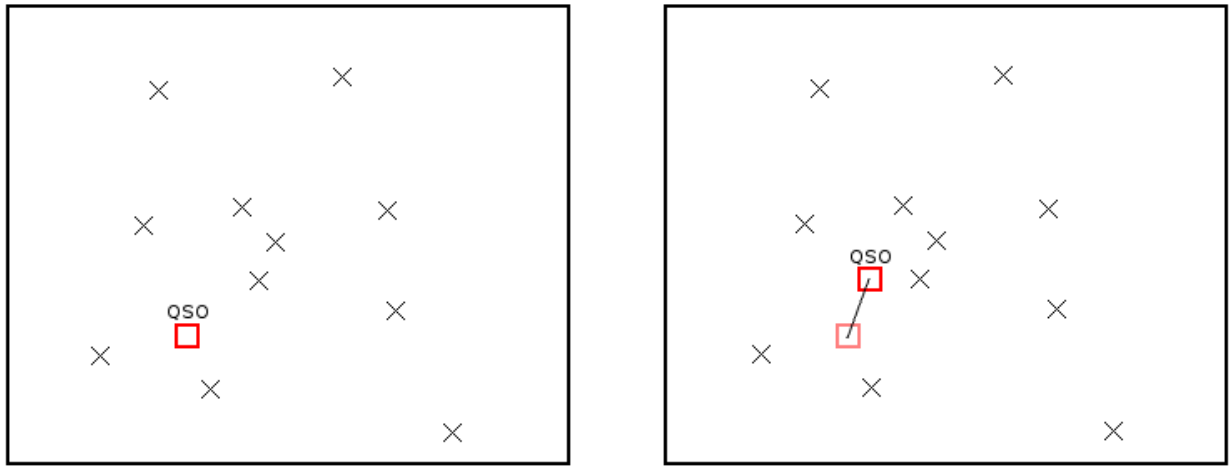

Figure: Proper Motion of QSO in a field image

There's even more: Error treatment!

Proper motion derivation III

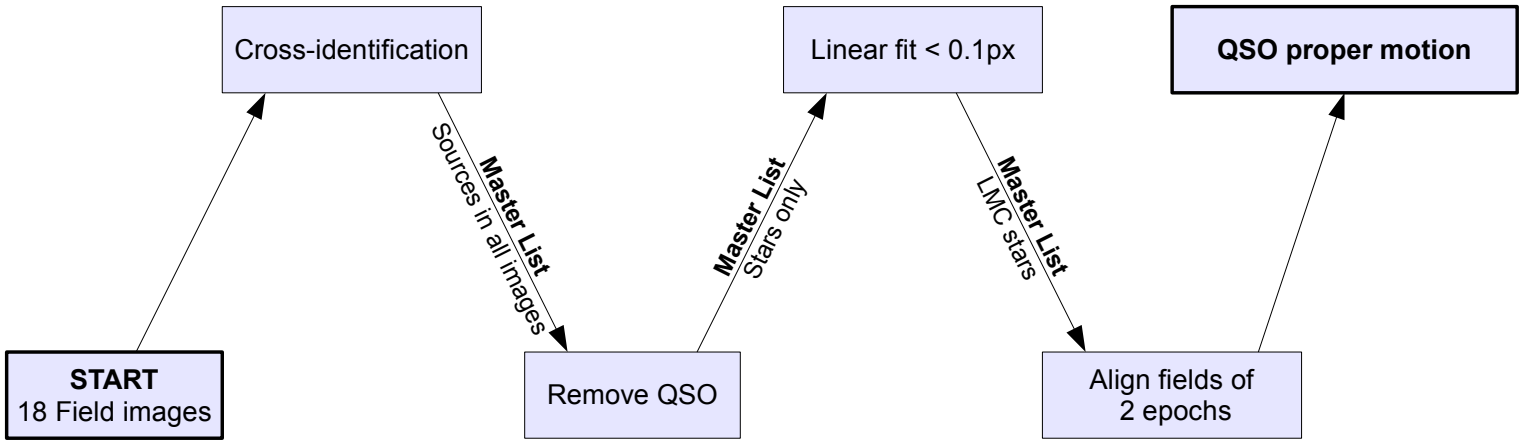

Figure: Schematic process to derive QSO proper motion

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PM estimation

How to estimate the PM of LMC center of mass

- Average results of 21 fields $\longrightarrow$ not very accurate
- Cool approach: take into account field-dependant movement

$$PM(f_i) = PM(CM_{LMC}) + PM_{res}(f_i)$$

- Using models for PM_{res}

$$PM_i^{est}(CM_{LMC}) = PM(f_i) - PM_{res}(f_i)$$

Wheight average $PM_i^{est}(CM_{LMC})$ to $PM(CM_{LMC})$

PM results

The study yielded the following proper motions

$$\mu_\alpha = 203 \pm 8 mas \cdot cen^{-1}$$
$$\mu_\delta = 44 \pm 5 mas \cdot cen^{-1}$$

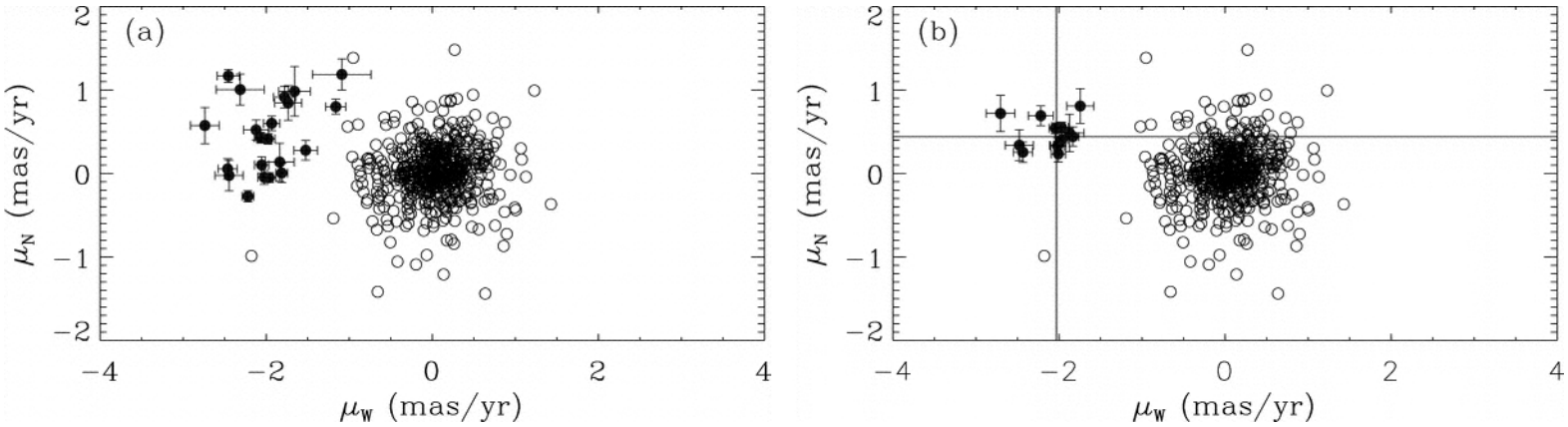

Figure: (a) Observed $PM(\mu_W, \mu_N)$ (filled circles) and (b) estimates $PM_{est}(CM)$.

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Conclusions and Scientific applications

- We've seen a method to determine the PM of the LMC
- One can use HST to determine PM of LMC with high accuracy
- Longer baselines could improve the results, tho
- These results, in combination with PM of SMC can serve us to better understand the physics and origin of the MS
- Also, use data to improve models of internal motion of LMC
- Galactic dark halo shape and density profile

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