

4MOST and the Magellanic Clouds

The megaMaC Survey

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The Magellanic Clouds: why they matter

- Large (LMC) and Small Magellanic Cloud (SMC) are dwarf irregulars
- LMC is largest satellite of our Milky Way, and third closest
- connected to SMC via Magellanic Stream (post-near miss HVC)
- Very well known **distance** and low and fairly uniform **extinction**:
 - LMC: 50 kpc, DM = 18.5 mag, A_V = 0.5 mag typically
 - SMC: 60 kpc, DM = 18.9 mag, A_V = 0.2 mag typically
- Can be **resolved** into individual stars: **complete** populations!
- Lower-than-solar **metallicity**: LMC: $\sim 0.5 Z_{\odot}$, SMC: $\sim 0.2 Z_{\odot}$
- Easily observable in the optical

The Clouds are ideal laboratories for stellar astrophysics!

The Magellanic Clouds post-*Gaia*

- *Gaia* will finally render the Milky Way a good place for stellar astrophysics (known distances, sample size, completeness, etc.)
- **The MCs will retain their special status for stellar astrophysics even (or rather: especially) after *Gaia***
- Differential analyses of metallicity effects on stellar populations in MW, LMC, and SMC with statistically viable samples
- Any stellar science case is for these three galaxies, thus MCs should be seen in context with Galactic science (and v.v.)
- Ideally, every study of stellar populations in the Galaxy is complemented by a similar study in the Clouds

4MOST makes such studies possible at very large scale; hence requests for survey(s) in MCs will come up, and have to be accommodated!

A 4MOST survey in the Clouds: motivation (1)

- Current 4MOST key science (DRS) are **large-area, single-visit surveys**
- Any additional science can be accommodated as long as it is large-area, single-visit, too (demonstrator: BAO)
- **Small-area, repeated-visits surveys** are not yet implemented in 4MOST science operations (no such DRS), but could emerge as key science surveys during later project phases
- As example of such a small-area, repeated-visits survey, we have created a “**container survey**” for the MCs: **megaMaCS**
- Primary goal: to study impact on 4MOST key science surveys
 - Robustness of DRS strategies (and optimization thereof) in presence of “adverse” requirements (e.g., use up dark time, massive repeats)
 - More realistic operations scenario (expectation management)
- Secondary goal: to provide a scientific envelope for such a survey

A 4MOST survey in the Clouds: motivation (2)

- Main driver: **variable stars** in the Clouds (following up of OGLE, etc.)
 - Cepheids and RR Lyr:
 - calibrators for cosmic distance scale
 - (eclipsing) Binaries:
 - **calibrators** for stellar structure models and atmospheres (radii, temperatures, luminosities, masses), binary fraction... fundamental for 4MOST key science
 - independent calibrators for distances
 - **Follow-up of eROSITA**: high/low-mass X-ray binaries, etc.
 - Any other variables: SPB stars, transients (LBV, novae, etc.)
- Additional, **single-visit science**
 - Open clusters (1000 clusters identified in MCs so far):
 - calibrators for age-Z relation, internal Z spread, tracer of LMC (bar) rotation, internal kinematics, dynamical evolution, etc.
 - Field stars:
 - **All things 4MOST**, but in MCs: chemo-dynamical evolution, etc...
 - Characterization of complete populations (follow-up VMC, etc.), SFH, rotation, etc.
 - 3D structure of MCs; **fully characterized populations down to $M_V = 2$**

A 4MOST survey in the Clouds: data products

- The current system should be able to deliver (full co-add)
 - LR:
 - in 80 hrs, S/N~10 for R~22.5 mag kinematic studies
 - S/N~40 for R~21.5mag chemical abundances
 - HR:
 - in 80 hrs, S/N~40 for R~18 mag chemical abundances
 - In 2 hrs, S/N~40 for R~16 mag RVs (Cepheids, RR Lyr, clusters)

A 4MOST survey in the Clouds: by-products

- High-precision extinction maps towards Clouds
- In combination with Gaia: fairly complete and well-characterized foreground population
- High-velocity stars from MCs

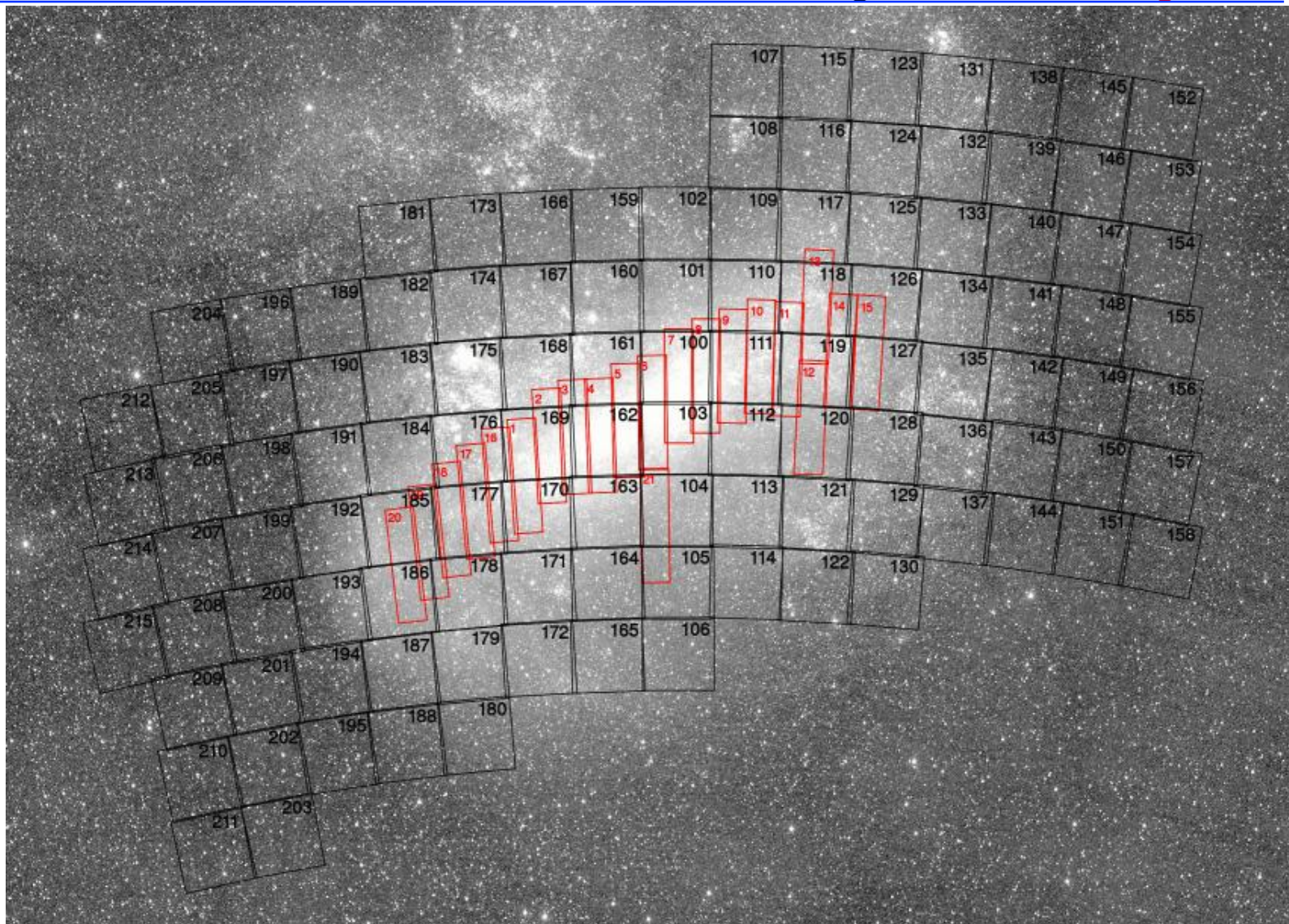
Approx. numbers from OGLE-II and –III campaigns
(out of ~40 millions sources in LMC/SMC)

	40 sqdeg	20 sqdeg	100 sqdeg
Type of variables	LMC	SMC	Galactic Bulge
Classical Cepheids	3,400	4,600	30
Type II Cepheids	200	40	390
RR Lyrae	24,000	2,500	16,800
Long-period variables	92,000	19,000	n/a
Ellipsoidal variables	1,700	n/a	n/a
Eclipsing binaries	29,000	1,400?	10,000
Miras and SRVs	3,000	n/a	n/a
Other variable stars			200,000

from OGLE website

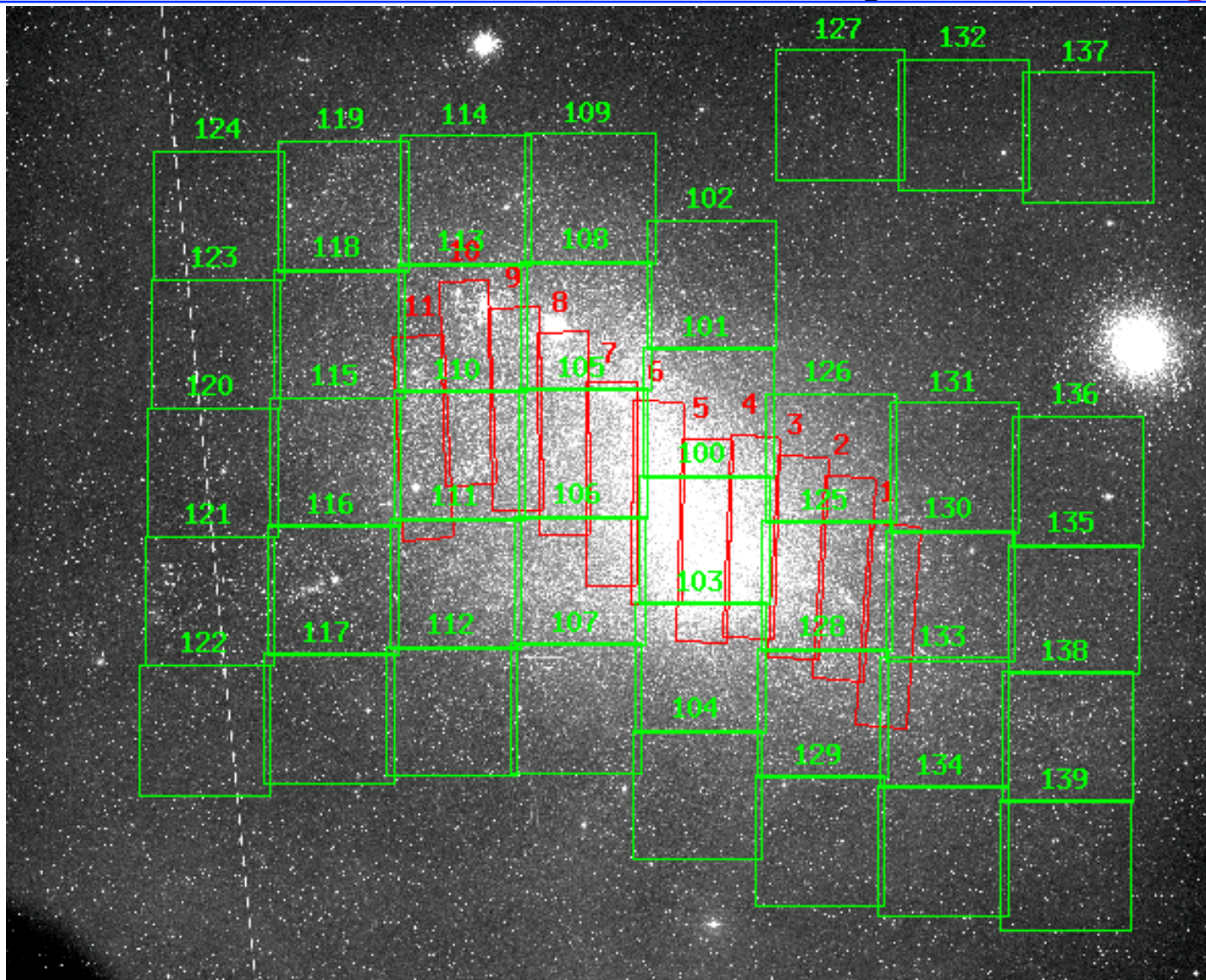
Limited numbers, but demanding S/N and time-coverage requirements!

LMC

**OGLE-II fields** **OGLE-III fields**

(from OGLE website)

SMC



OGLE-II fields OGLE-III fields

(from OGLE website)

A 4MOST survey in the Clouds: design

LMC survey

- Covered area: $4.7^\circ \times 6.4^\circ = 30 \text{ sqdeg}$, organized in 16 fields à 4 sqdeg FOV each
- 40 repeats per field
- $16 \times 40 \times 1600 = 1,024,000 \text{ LR spectra}$ (half of that unique)
- $16 \times 40 \times 800 = 512,000 \text{ HR spectra}$ (mostly for co-adds)
- Total number of spectra LMC: 1,536,000; unique $\sim 10^6$
- $6 \times 20 \text{ min} = 120 \text{ min}$ exposure time; total loitering time 2.4 hrs per field
- Total time spent on LMC: 1,540 hrs

SMC survey

- Covered area: $3.5^\circ \times 4.7^\circ = 14 \text{ sqdeg}$, organized in 6 fields à 4 sqdeg FOV each
- 40 repeats per field
- $6 \times 40 \times 1600 = 384,000 \text{ LR spectra}$ (half of that unique)
- $6 \times 40 \times 800 = 192,000 \text{ HR spectra}$ (mostly for co-adds)
- Total number of spectra SMC: 576,000; unique $\sim 300\text{k}$
- $6 \times 20 \text{ min} = 120 \text{ min}$ exposure time; total loitering time 2.4 hrs per field
- Total time spent on SMC: 580 hrs

Total time spent on Clouds: 2100 hrs of dark and grey time (as substantial as a DRS!)

one million stars in the Magellanic Clouds Survey: megaMaCS

A 4MOST survey in the Clouds: options

- Go wider:
 - probe outer LMC disk (kinematics, dark matter, etc.)
 - cover Magellanic Bridge
 - complement OGLE-IV plus any future OGLE, and VST/LSST surveys (however, existing, 1m-class imaging already pushes limit of 4m spectroscopy)
- Go deeper
 - Probably not an option...

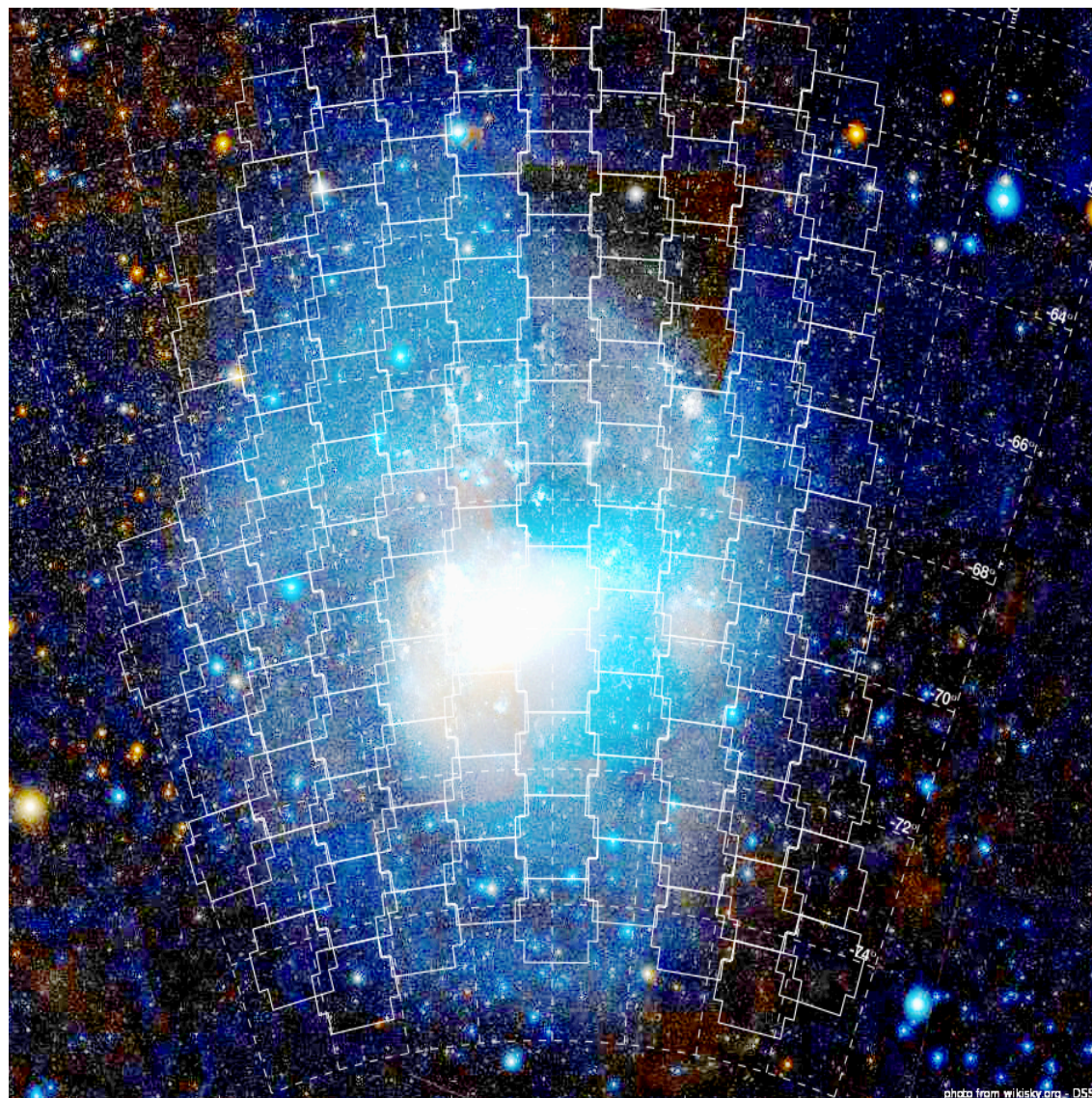


Credit: Yuri Beletsky (ESO)

OGLE-IV fields overlaid
on high-contrast image of
of LMC

Covers essentially the
entire LMC disk +
control fields

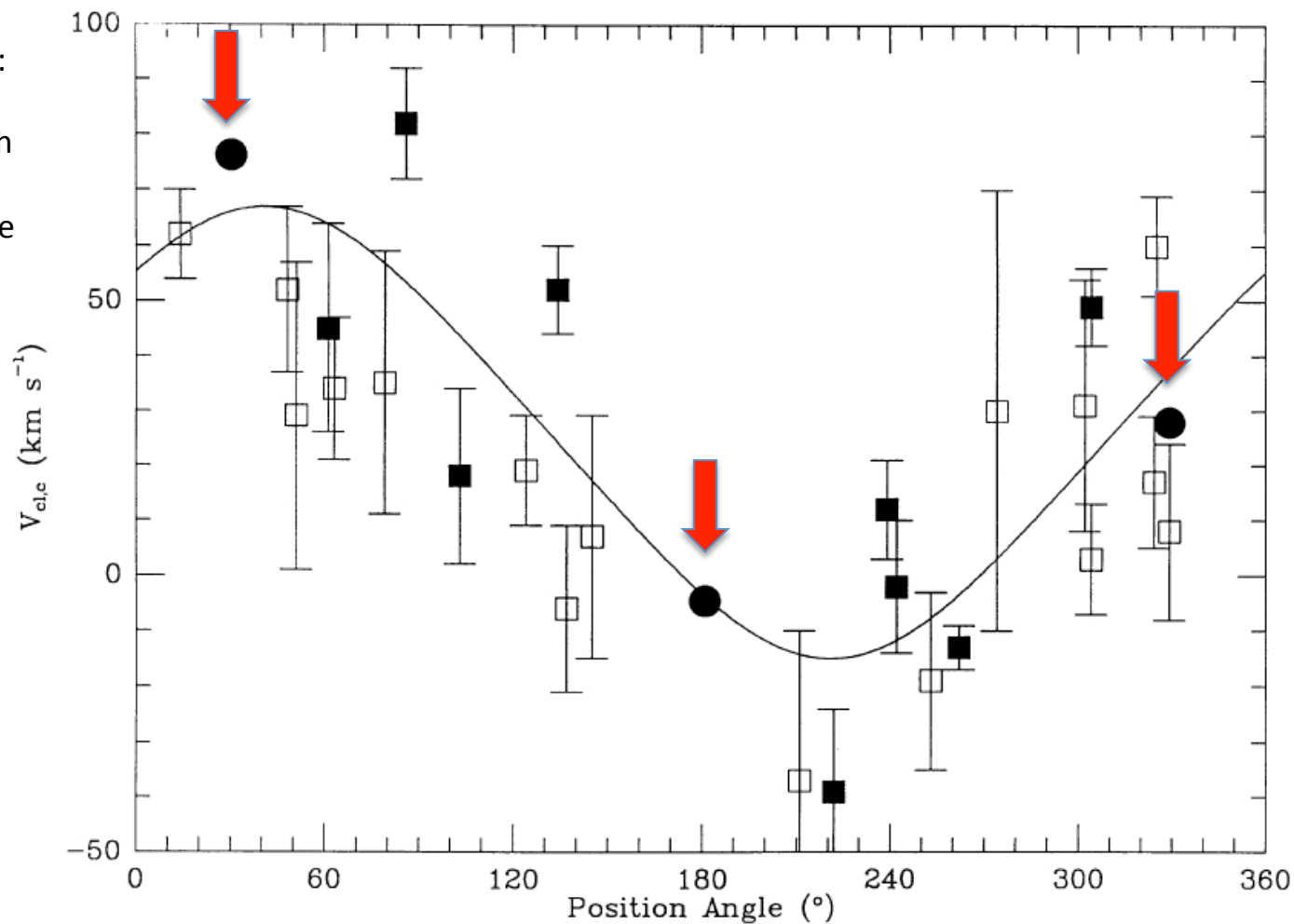
from OGLE website



LMC CLUSTER VELOCITIES

From Storm et al. (1991):

RVs of three clusters with LMC-centric distances of 8 to 12 kpc, i.e. far off the LMC bar



A 4MOST survey in the Clouds: options

- Go wider:
 - probe outer LMC disk (kinematics, dark matter, etc.)
 - add Magellanic Bridge
 - complement OGLE-IV plus any future OGLE, and VST/LSST surveys
 - however, existing, 1m-class imaging already pushes limit of 4m spectroscopy
- Go deeper
 - Probably not an option...
- Go narrower
 - Regions of interest in the Clouds?
- Reduce repeats
 - Limit covered period space of variable stars

megaMaCS and 4MOST key science: conclusion

- By design, megaMaCS is merely a “container survey”
- No science that is proper to the MCs
- Due to *Gaia*, Galactic Disk plus Bulge offer very similar science opportunities (cf. [ESO-Gaia survey](#)):
 - **Eclipsing binaries** to calibrate Galactic stellar models (self-consistent within the framework of 4MOST data!); follow-up of OGLE, VVV, etc.
 - Cepheids, RR Lyr, et al. (Z effects)
 - Clusters (age-Z, etc.), rotation + mixing
 - Respective science cases will apply for **significant** amount of 4MOST time in the MCs (up to ~few 1000s hours)
 - **Variable Stars** towards the Galactic **Bulge** Survey: **VariBuS** (with OGLE-IV)
- The 4MOST consortium anticipates this community request
- **Accommodation of megaMaCS/VariBuS-like surveys is currently under study (no mock input catalogs will be harmed during Phase A)**