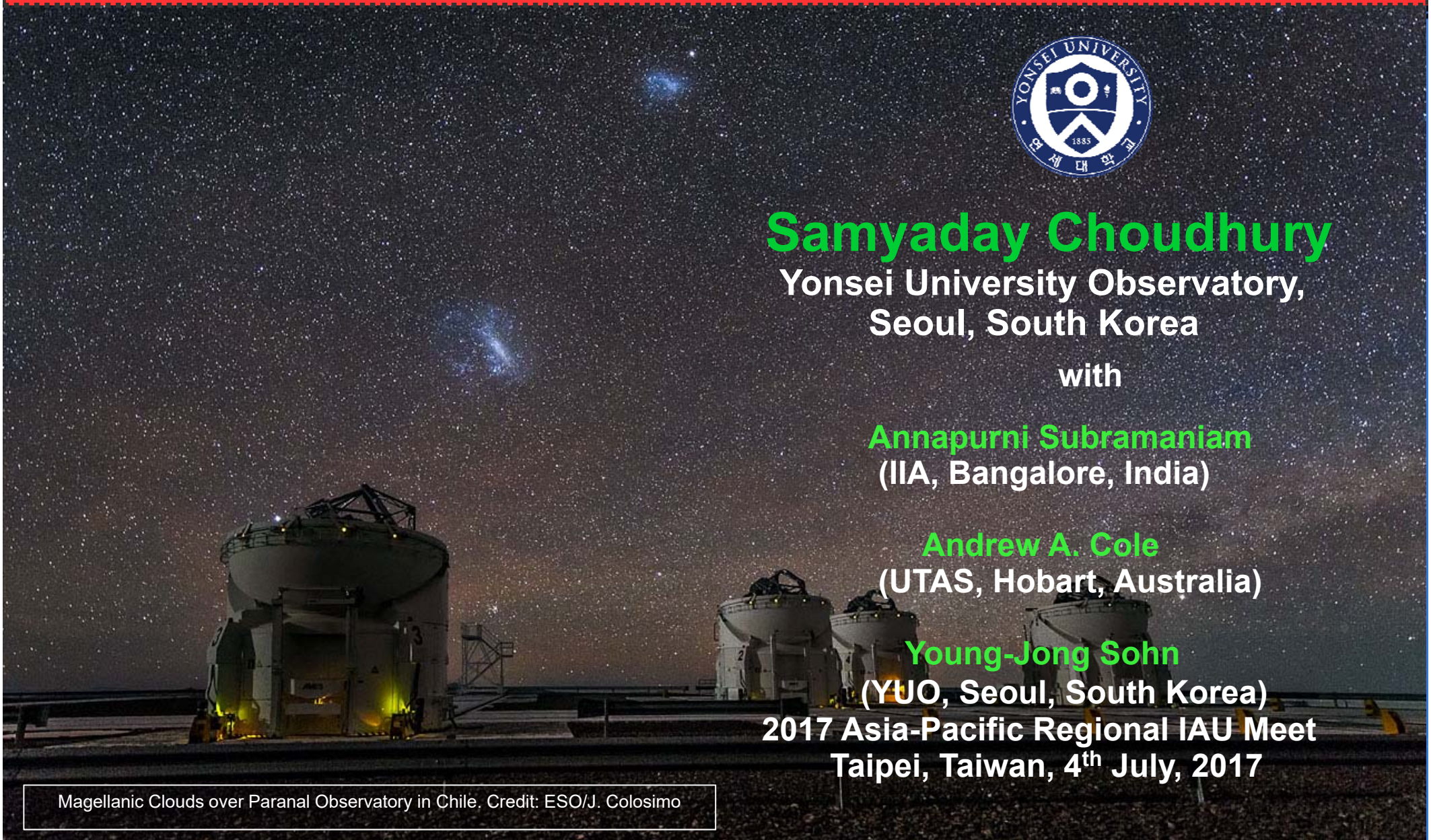
What do the metallicity maps tell us about the Magellanic Clouds?



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2017 Asia-Pacific Regional IAU Meet
Taipei, Taiwan, 4th July, 2017

Magellanic Clouds over Paranal Observatory in Chile. Credit: ESO/J. Colosimo

Introduction

MCs: Irregular galaxies; Gas rich & metal poor.

MCs: Proximity; Location at high galactic latitude; **Can resolve individual populations as well as detect faint stellar populations.**

MCs: Ideal test beds to study star formation, stellar evolution, star clusters in low metallicity enviornment.

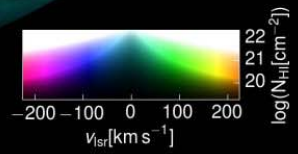
MCs are interacting amongst each other as well as with Milky Way (MW) (Fujimoto and Murai 1984; Gardiner et al. 1994; Westerlund 1997)

Evolution and interation of the MCs is still not well understood.

The evolved stellar populations (RG, RC, HB, AGB etc.) in the MCs help us to understand their evolution/interaction process.

There is a dominant population of evolved stars in the MCs (in field as

Figure: Four Components of Magellanic System (d ~57Kpc) shown by H I map from Putman et al., (2003).



Benjamin Winkel & HI4PI Collaboration

Background figure: HI all sly map showing Mcs w.r.t. the Galactic plane. Benjamin Winkel and HIP4I collaboration.

MOTIVATION: To estimate a high spatial resoultion metallicity map of the MCs using evolved stellar population

(1) LMC:

To understand the metallicity distribution and its trend within the galaxy.

Problem with previous studies to understand chemical enrichment history (CEH)- Small size of sample (Star clusters- Olszewski et al. 1991; Grocholski et al. 2006; Field stars - Cole et al. 2005; Carrera et al. 2008; Olsen et al. 2011). Inconsistency between traces and calibrators (Cioni 2009).

High spatial resolution Metallicity Map for the inner LMC was not available until **Choudhury, Subramaniam, Cole, 2016, MNRAS** – created using Red Giant Branch (RGB) stars from photometric data and calibrated it using spectroscopic data of field and cluster RGB stars!

(2) SMC:

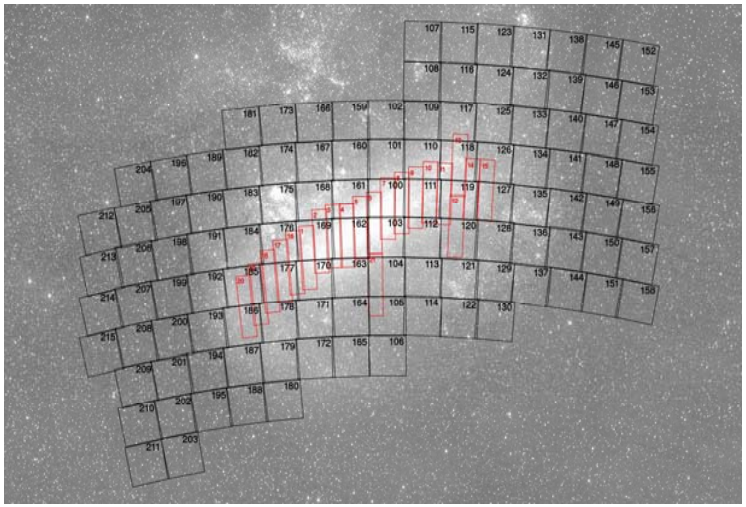
Problem with previous studies to understand CEH - Small size of sample (Star clusters- Piatti et al., 2007a,b Parisi et al, 2009, 2015; Field stars – Carrera et al. 2008, Parisi et al. (2010, 2016), Dobbie et al. 2014. Inconsistency between traces and calibrators (Cioni 2009).

The nature of any metallicity gradient in the SMC, is a matter of great current controversy - Requires a study using global, homogeneous datasets to make significant advances.

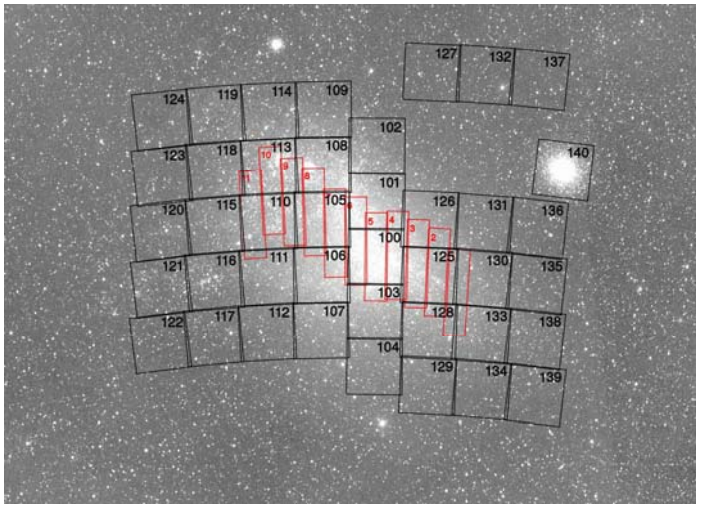
Aim- To create the same for inner SMC using a similar technique employed for the LMC! **(Choudhury, Subramaniam, Cole, Sohn, 2017 - in Preparation)**

DATA: Photometric data for the MCs in V& I band

(I) Optical Gravitational Lensing Experment, *Third phase* (OGLE III)-
LMC:Udalski et al. (2008a);
SMC:Udalski et al. (2008b)
- 2001-2009
- 1.3 m Warsaw Telescope, La Campanas Observatory, Chile
- 0.26 arcsec/pixeal
- 39.7 sq deg for the LMC.
- 14.0 sq deg for the SMC.

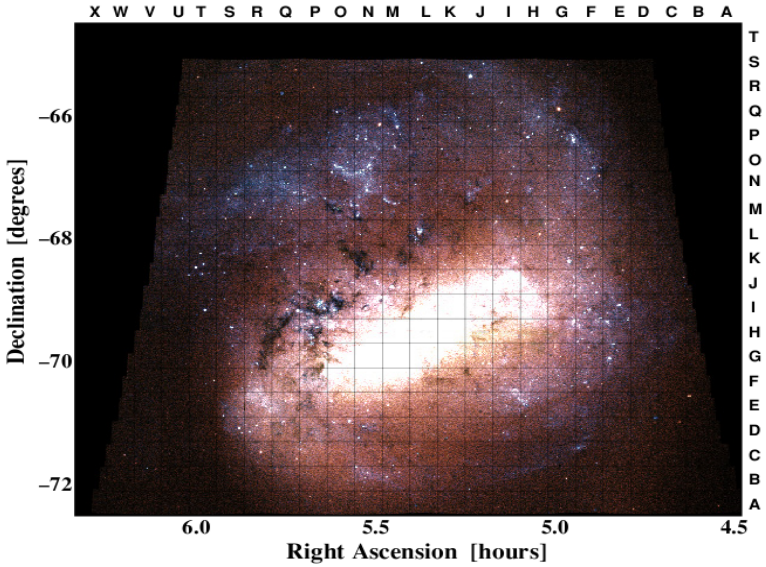


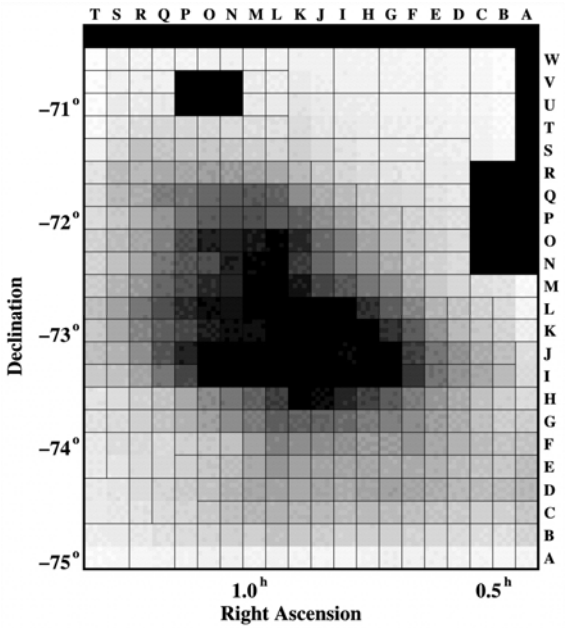
LMC



SMC

(II) Magellanic Cloud Photometric Survey (MCPS) – SMC: Zaritsky et al. (2002); LMC: Zaritsky et al. (2004).
- 1995-2000
- 1.0 m Swope Telescope, La Campanas Observatory, Chile
- 0.70 arcsec/pixel
- 64.0 sq deg for the LMC.
- 16.0 sq deg for the SMC.





METHOD

- **Red Giant BRANCH (RGB) stars- th TOOL!**
  - The slope of the RGB in the CMD of a small region in the galaxy is used as an indicator of the mean metallicity of the region.

- **A region in a galaxy with metal-rich stars is expected to have a shallower RGB slope when compared to a relatively metal-poor region.**

- The dependence of slope of the RGB on metallicity is well known (Da Costa & Armandroff 1990; Kuchinski et al.1995).

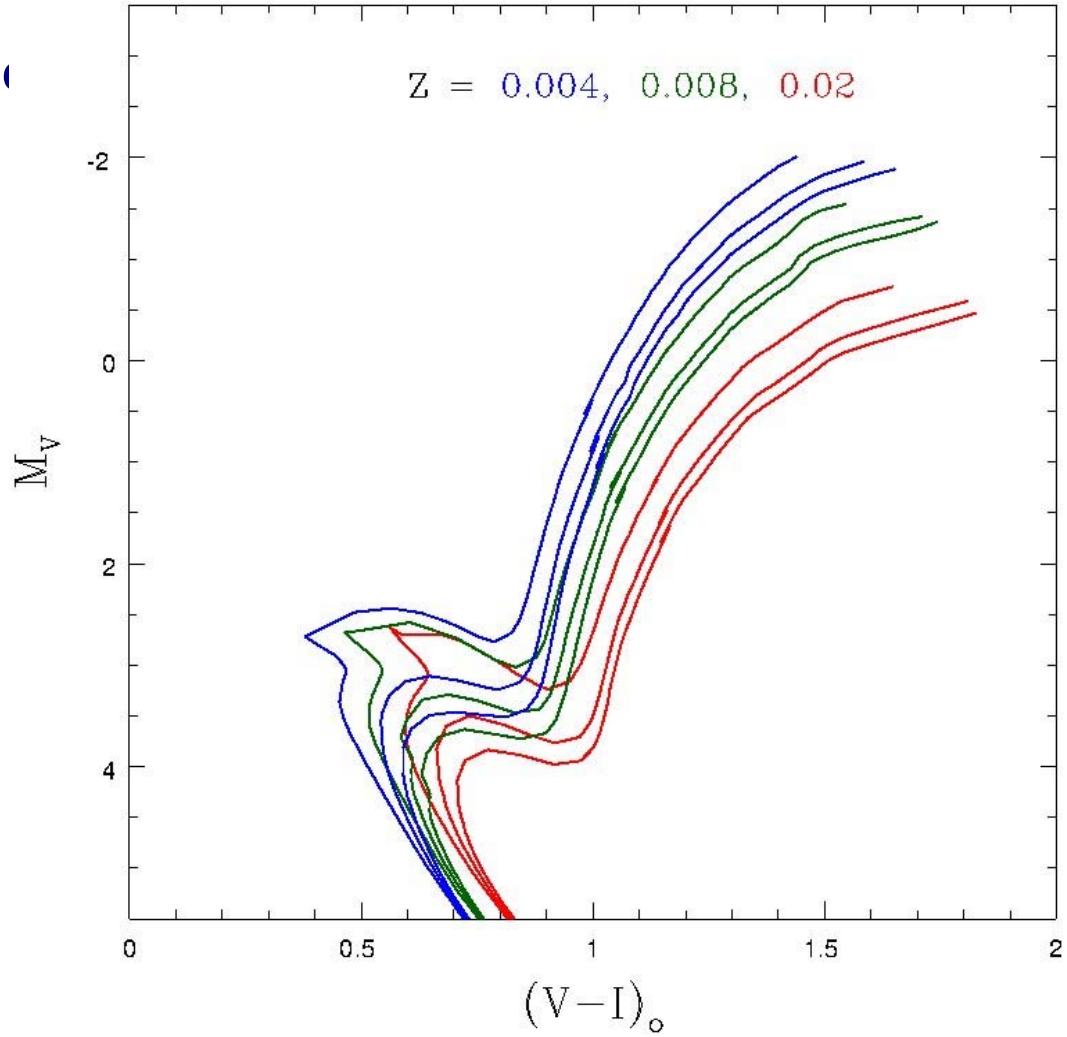


Figure: CMD showing RGBs of three different ages ~ 3,6,9 Gyr (Marigo et al. 2008), plotted for three different metallicities: Z= 0.004 (blue), 0.008 (green) and 0.02 (red).

The Photometric Metallicity Map of the LMC

Choudhury et al., 2016, MNRAS

Analysis

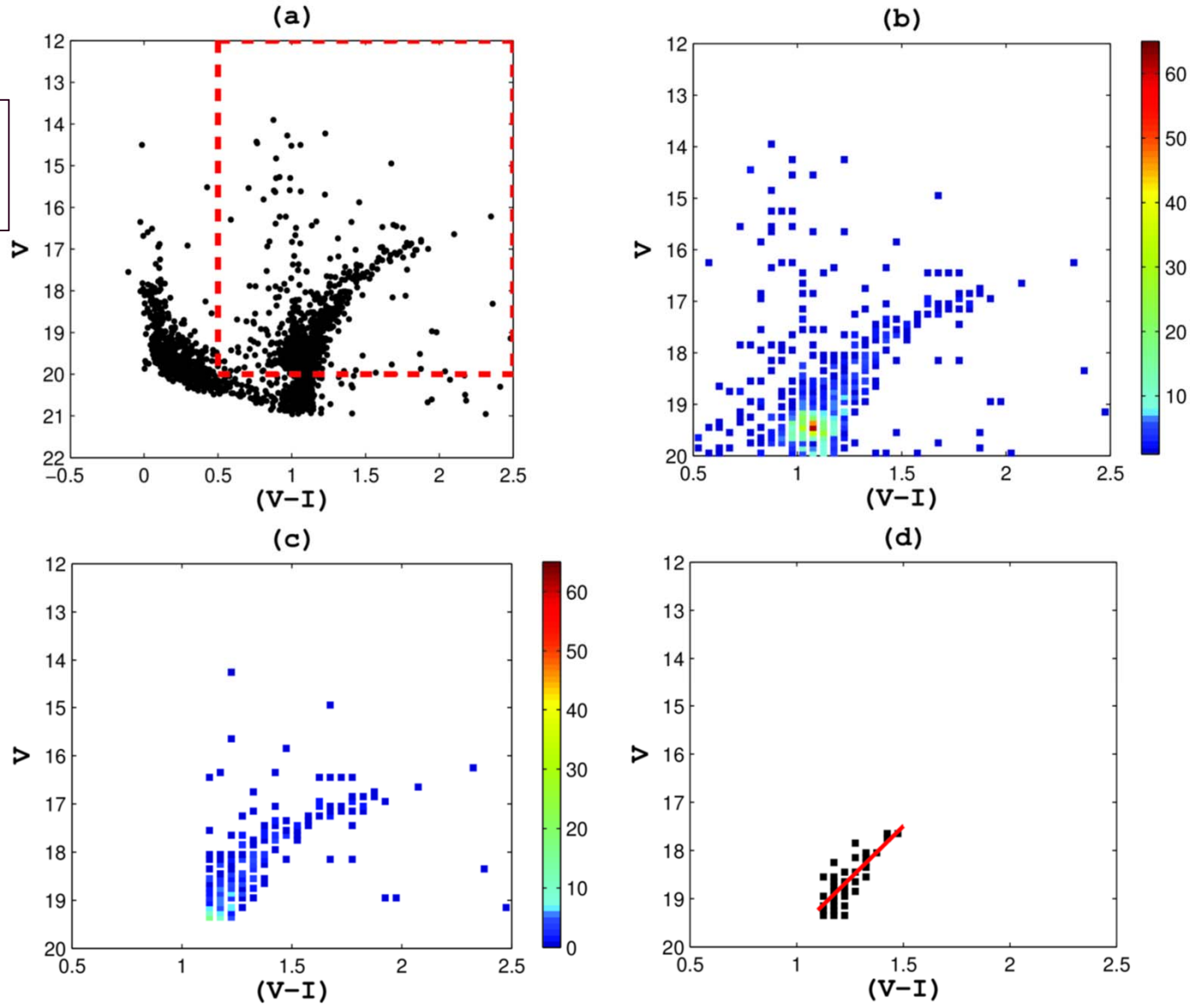


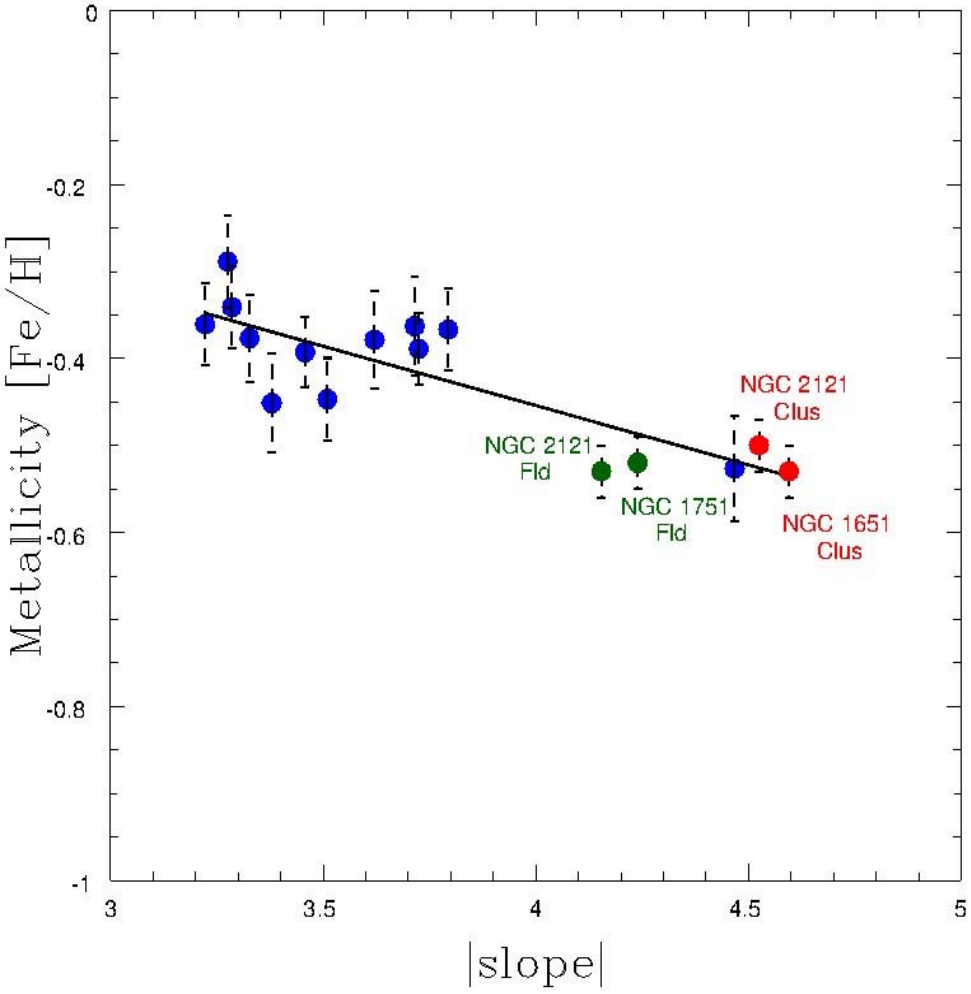
Figure: An OGLE III region at (70.78◦ , −70.07◦) with N=1762 stars. The estimated parameters are: |slope|= 4.34 ± 0.56, r = 0.80, and N_p = 36.

Analysis (contd.)

- **OGLE III & MCPS** observed regions binned spatially into several small regions (~ 4700 each data set) upto a spatial dimension of ~(32 x 43)pc^2 and (51 x 73) pc^2 respectively

- Slope is converted to metallicity using spectroscopically derived metallicities of RGB stars near the central field region (Cole et al., 2005), within star clusters (Grocholski et al., 2006), and field regions around these clusters (Cole et al., in preperation) in the LMC.

- Same slope-metallicity relation used to calibrate OGLE III and MCPS slopes (after correcting for systematic difference between the I filters).



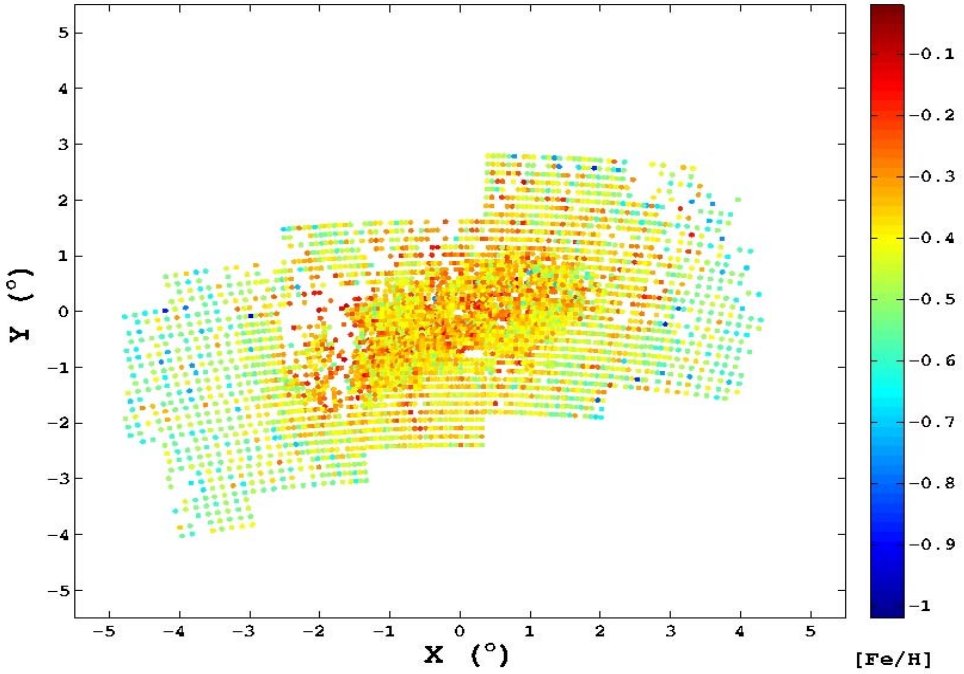
The slope-metallicity relation estimated is given by:

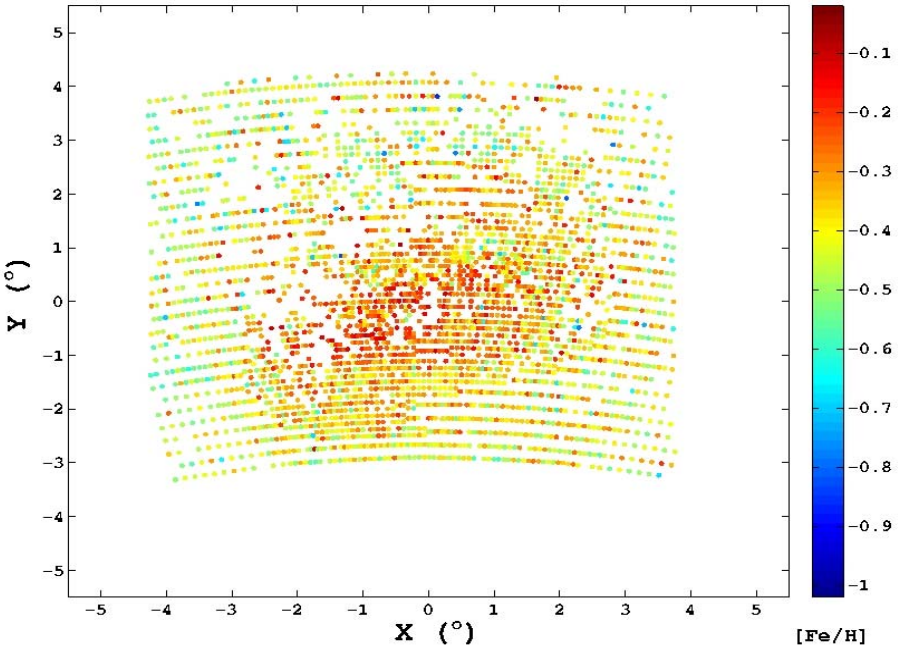
$[Fe/H] = (-0.137 \pm 0.024) \times |slope| + (0.092 \pm 0.091)$; with r=0.83.

LMC Metallicity Map

OGLE III

MCPS

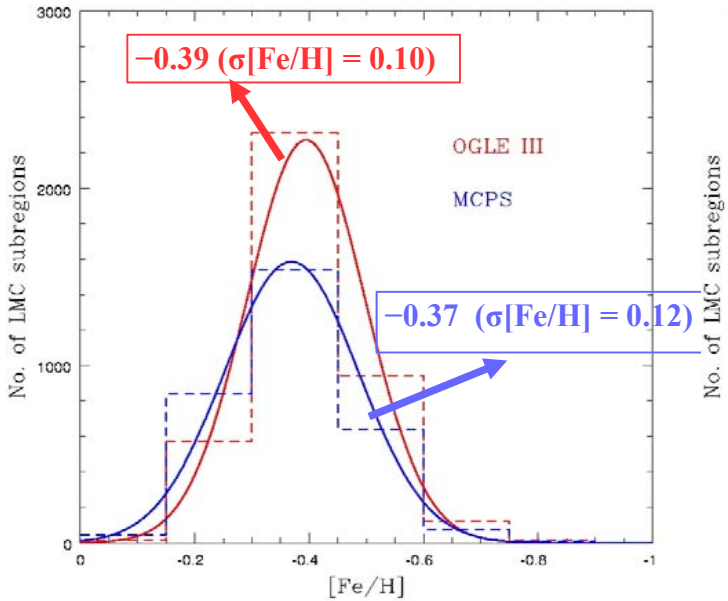


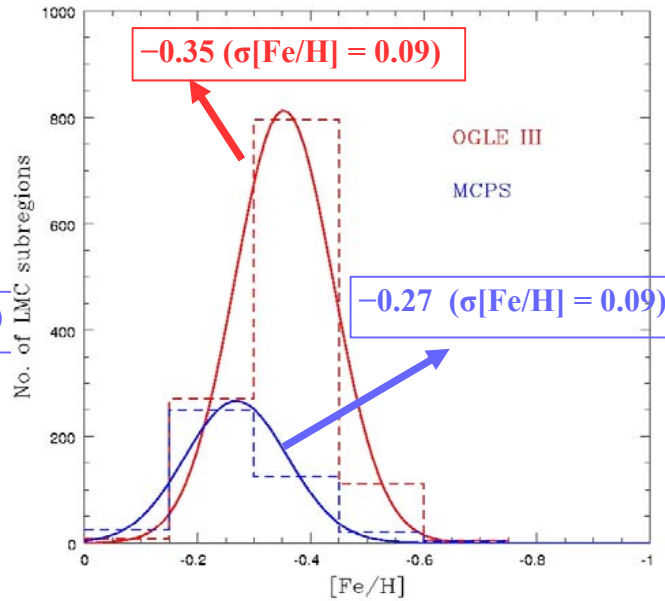


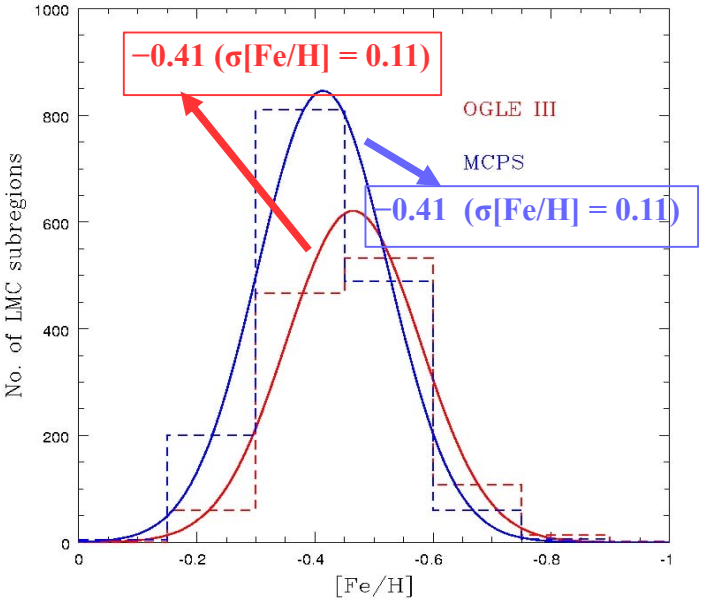
COMPLETE

BAR

OUTER

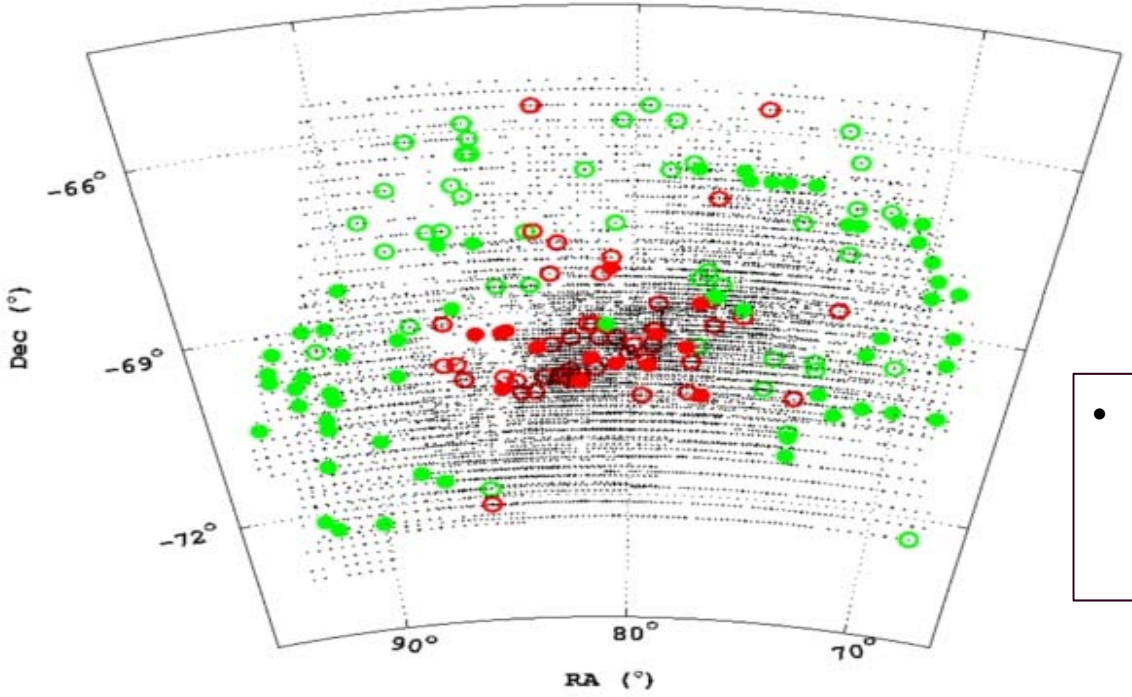


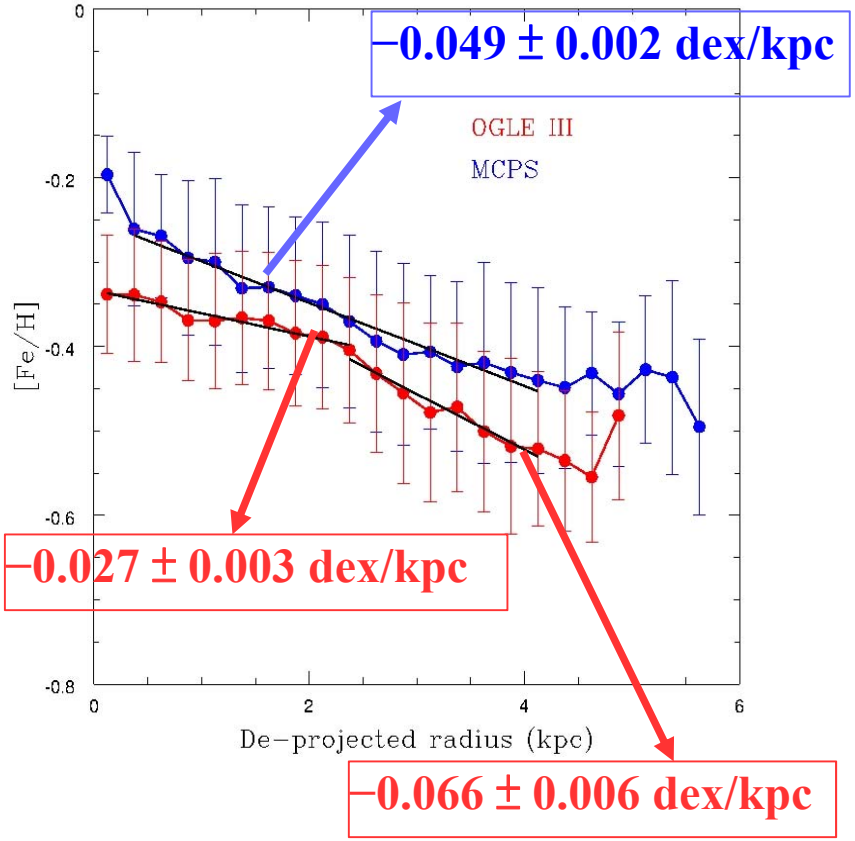




LMC Metallicity Map

- Both the data sets suggest a shallow radial metallicity gradient for the LMC disk, up to a radius of 4 kpc from −0.049±0.002 dex/kpc (for MCPS) to −0.066±0.006 dex/kpc for (OGLE III) which agree with Cioni (2009) (-0.047±0.002 dex/kpc).
- **The LMC metallicity gradient of the disk, though shallow, resembles the gradient seen in spiral galaxies (-0.05 dex/kpc, Pilkington et al., 2012) and in our Galaxy (-0.06 dex/kpc, Luck et al., 2006)**





- We identify a few areas where the metallicity is found to be significantly different from the surrounding regions, which need to be studied in detail using spectroscopic studies.

The Photometric Metallicity Map of the SMC

Choudhury et al.,2017- in Preperation

Analysis

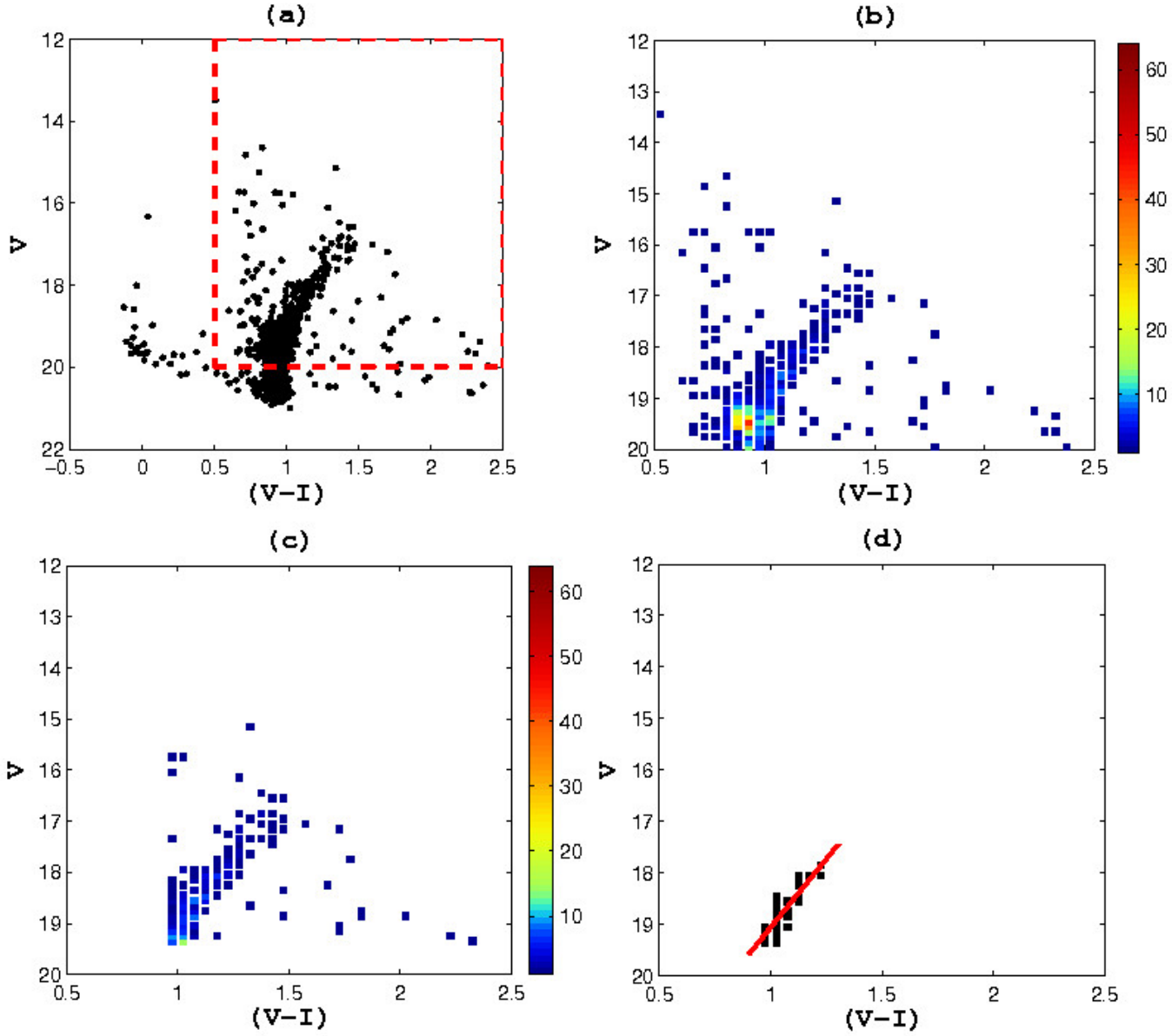
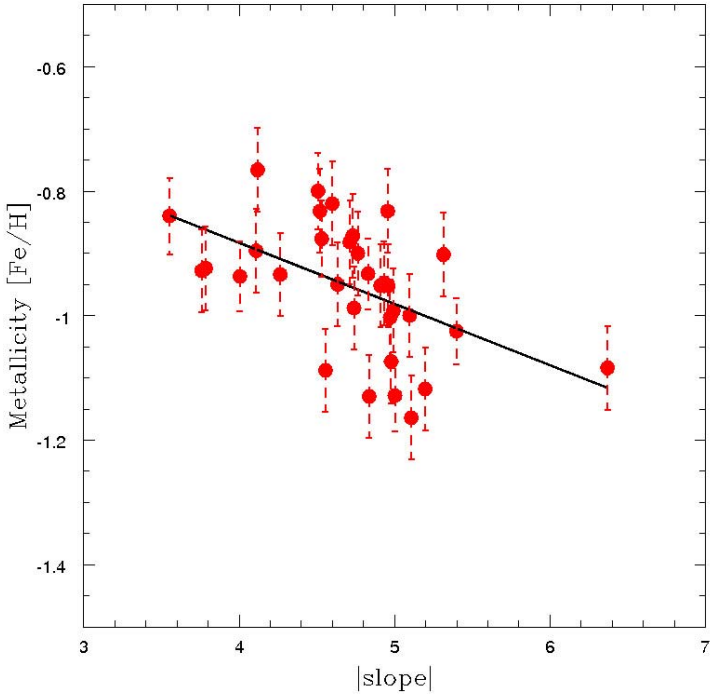
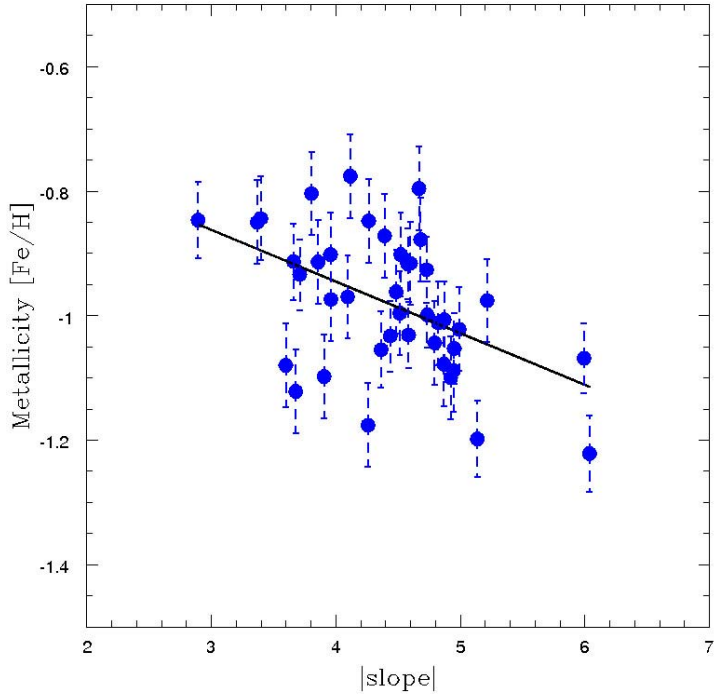


Figure: An OGLE III region at (8.39◦ , −72.51◦) with N=952 stars. The estimated parameters are: |slope|= 5.31 ± 0.66, r = 0.85, and N_p = 26.

Analysis (contd.)



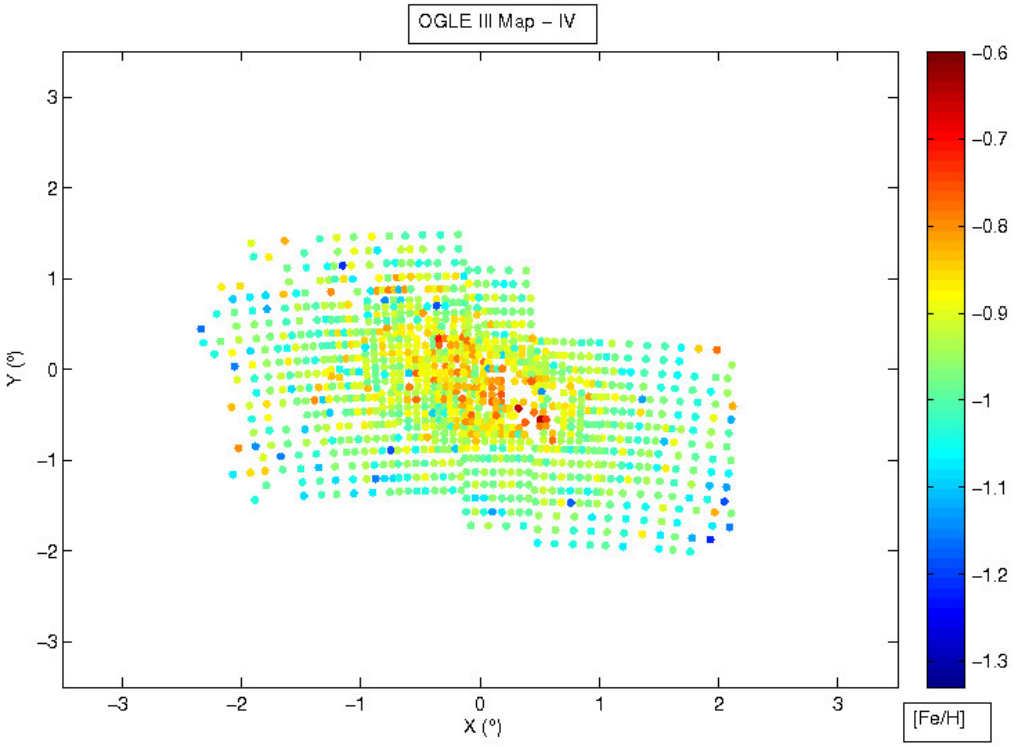


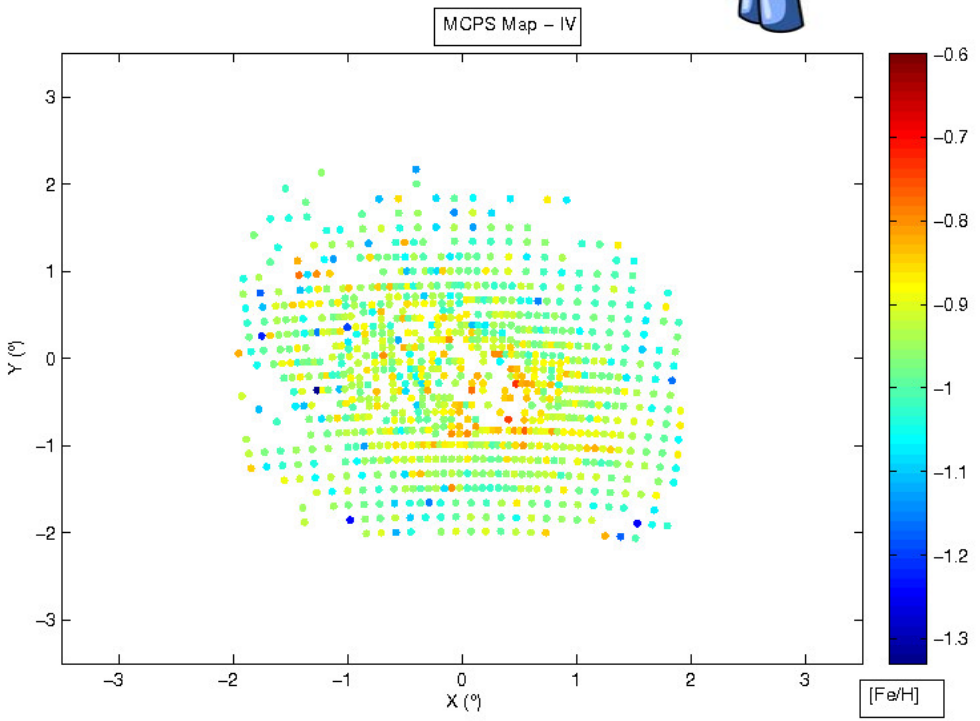
OGLE III slope-metallicity relation:
[Fe/H] = (−0.0983 ± 0.029) × |slope| + (-0.489 ± 0.14); with r = 0.51

MCPS slope-metallicity relation:
[Fe/H] = (−0.0829±0.0237) × |slope| +(−0.613±0.11); with r=0.49

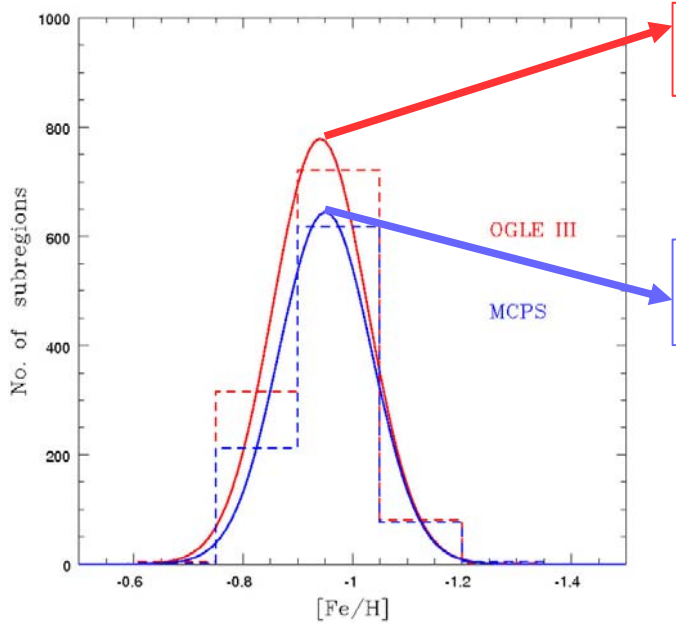
- **OGLE III & MCPS** observed regions binned spatially into several small regions (~ 1300 each data set) upto a spatial dimension of ~(39 x 77)pc^2 and (52 x 87) pc^2 respectively.
- Slope is converted to metallicity using spectroscopically derived metallicities of RG stars (~3037) within 37.5 sq. deg about the central SMC from **Dobbie et al. 2014.**
- Independent slope-metallicity relation estimated for OGLE III and MCPS data sets.

SMC Metallicity Map



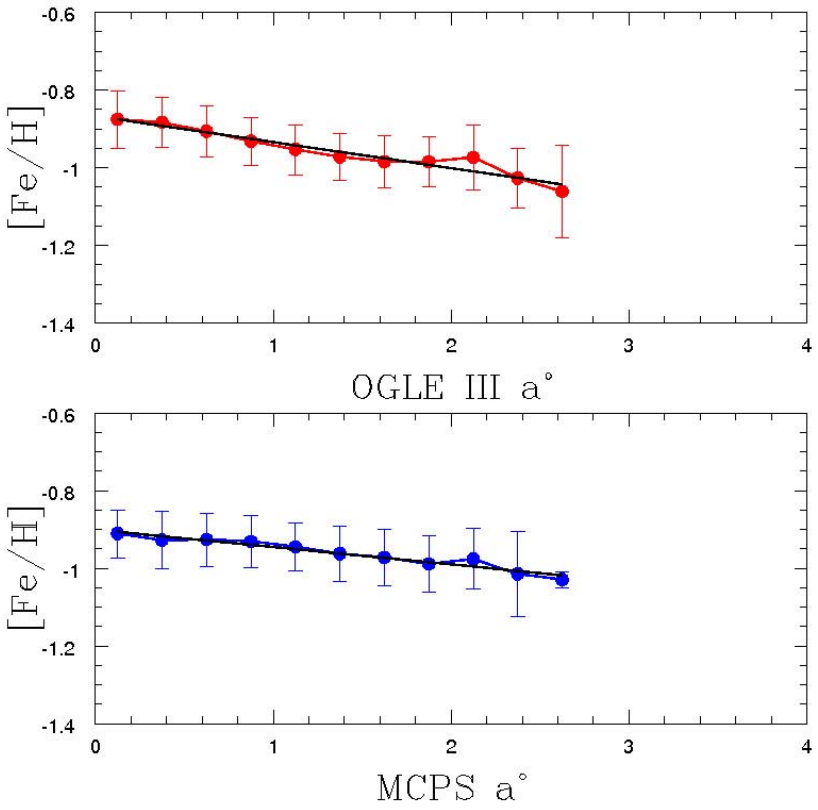


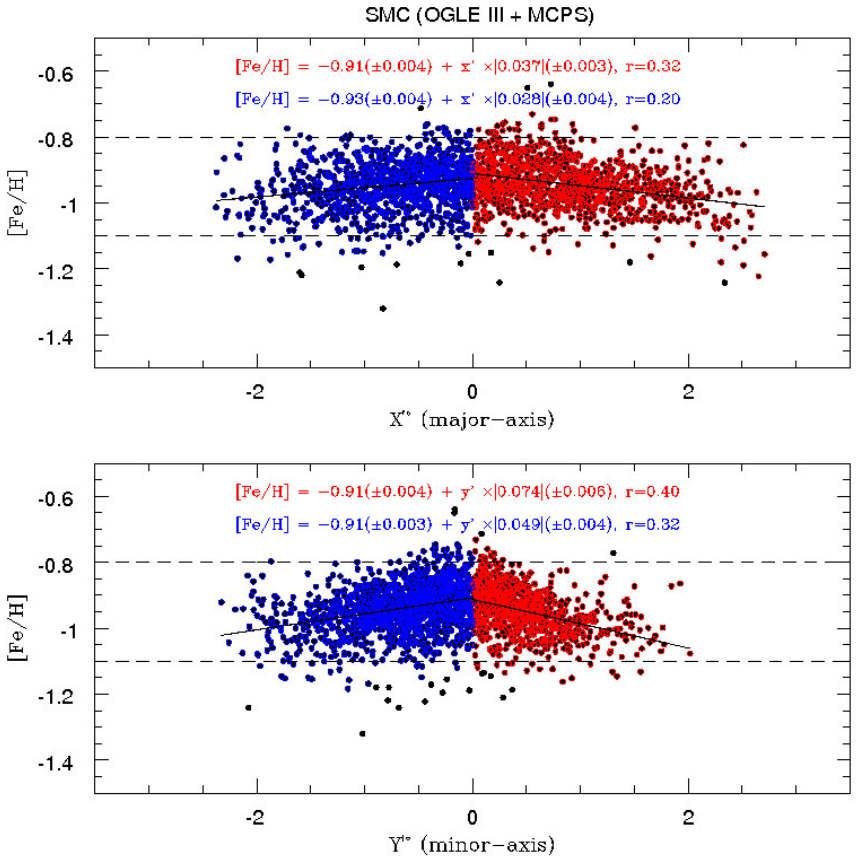
Mean metallicity is in agreement with previous studies of Carrera et al. 2008, (mean [Fe/H] ~ -1.0 within inner SMC); Parisi et al. 2010 (mean [Fe/H] ~ -0.99± 0.08 within 4º); Parisi et al. 2016 (median [Fe/H] ~ -0.97± 0.01 within 8º); (Dobbie et al., 2014b (Median [Fe/H] = -0.99 ± 0.01 within inner 5º).



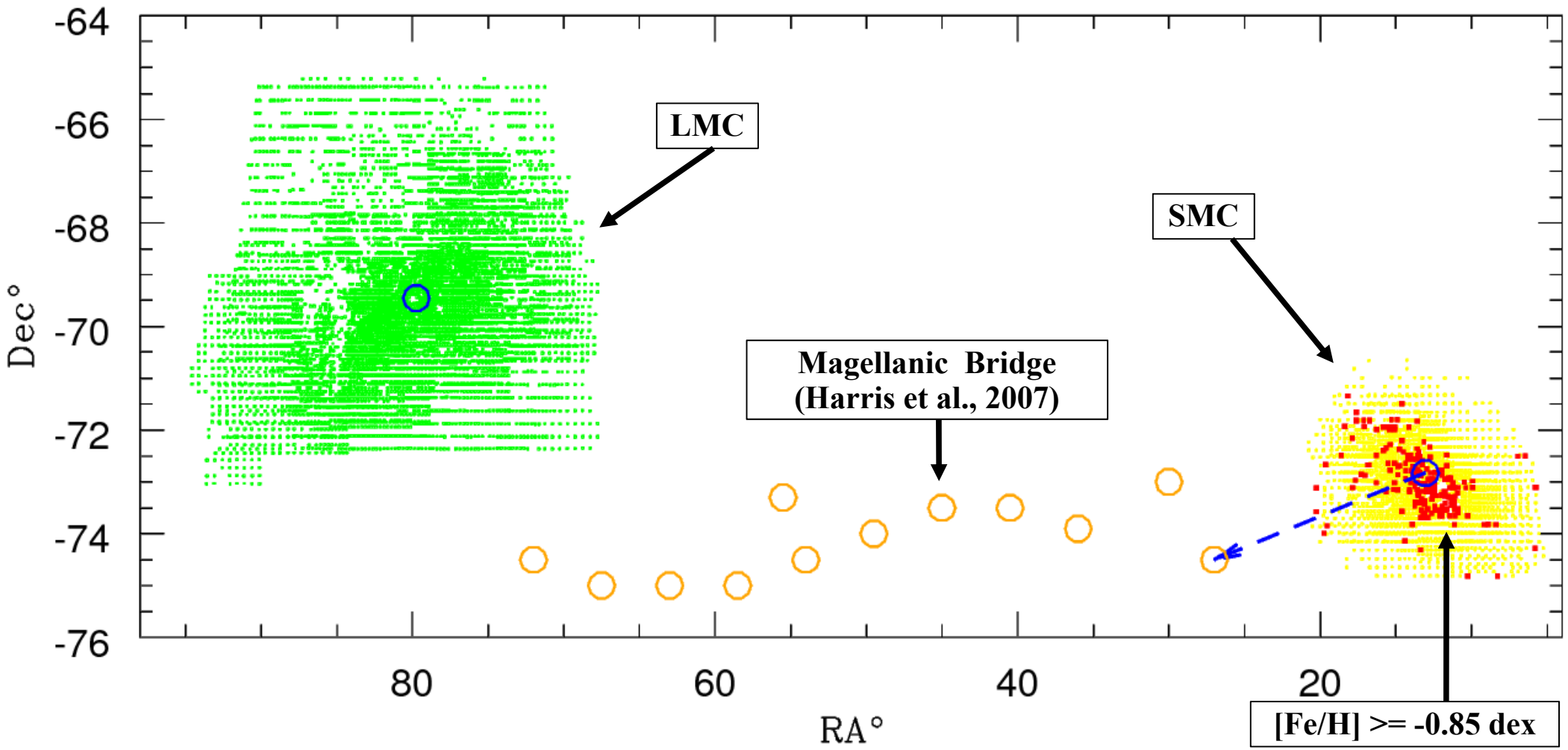
−0.94 (σ[Fe/H] = 0.09)

−0.95 (σ[Fe/H] = 0.08)





- A gradual and shallow metallicity gradient detected: **-0.067±0.006 (OGLE III)** & **-0.045±0.004 (MCPS)** dex/degree within the inner ~ 2.5º.
- Confirmation of the presence of a metallicity gradient (MG) in the SMC (Carrera et al. 2008, Dobbie et al., 2014b). The value of OGLE III metallicity gradient is similar to that detected by Dobbie et al. 2014 (-0.075±0.011 dex/deg), Parisi et al. 2016 (-0.08±0.02 dex/deg) within the error.
- MG along positive and negative Minor-axis: -0.074 and -0.049 dex/deg respectively; Along positive and negative Major-axis: -0.037 and -0.028 dex/deg respectively.


-64
-66
-68
-70
-72
-74
-76
Dec°
80
60
40
20
RA°
LMC
SMC
Magellanic Bridge
(Harris et al., 2007)
[Fe/H] >= -0.85 dex

CONCLUSION

High spatial resolution metallicity maps of the LMC and the SMC: First such attempt in these nearby and well studied galaxies.

LMC

- The bar of the LMC is chemically distinct & the most metal rich component - Chemically fits the general definition of bars.
- The chemical distinction of the bar and lack of recent star formation puts the LMC in the class of low mass galaxies (Ellison et al., 2011).
- **The bar of the LMC must have been active in the past** - Necessary to explain the uniform and high metallicity.
- **Metallicity gradient of the LMC disk resembles that of spiral galaxies and MW.**

SMC

- **Confirmation of the presence of metallicity gradient (shallow but gradual) within the inner SMC.**
- **Metallicity gradient is not radially symmetric –** it' s steeper along minor axis as compared to the major axis.
- Eastern (towards the North East and South East connecting to the Bridge region) SMC has more perturbed spatial metallicity distribution compared to the Western part.

Thanks

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