Milky Way and nearby galaxies: a summary

Annapurni Subramaniam

Indian Institute of Astrophysics, India

Members

Aoki, Wako	aoki.wako@nao.ac.jp	NAOJ	Japan
Chiba, Masashi	chiba@astr.tohoku.ac.jp	Tohoku	Japan
Das, Mousumi	mousumi@iiap.res.in	IIA, Bangalore	India
Davidge, Tim	Timothy.Davidge@nrc-cnrc.gc.ca	NRC	Canada
de Grijs, Richard	grijs@pku.edu.cn	KIAA	China
Debattista, Victor	vpdebattista@gmail.com	University of Central Lancashire	other
Fang, Xuan	fangx@iaa.es	Instituto de Astrofisica de Andalucia	other
Geha, Marla	marla.geha@yale.edu	Yale	US
Gogoi, Rupjyoti	rupjyotigogoi@gmail.com	Tezpur University	India
Goswami, Aruna	aruna@iiap.res.in	IIA, Bangalore	India
Guhathakurta, Puragra	raja@ucolick.org	UCSC	UC
Hao, Lei	haol@shao.ac.cn	Shanghai Astronomical Observatory	China
Inami, Hanae	inami@noao.edu	NOAO	US
Knierman, Karen	karen.knierman@asu.edu	ASU	US
Lepine, Sebastien	slepine@amnh.org	Georgia State University / AMNH	US
Li, Cheng	leech@shao.ac.cn	SHAO	China
Liu, Fengshan	fsliu@synu.edu.cn	Shenyang Normal University	China
Macri, Lucas	lmacri@tamu.edu	Texas A&M	US
Mao, Shude	shude.mao@gmail.com	NAOC	China
McConnachie, Alan	alan.mcconnachie@nrc-cnrc.gc.ca	HIA	Canada
McGaugh, Stacy	stacy.mcgaugh@case.edu	Case Western Reserve University	US
Peng, Eric	peng@pku.edu.cn	Peking University	China
Pilachowski, Catherine	catyp@astro.indiana.edu	Indiana	US
Puthiyaveettil, Shalima	shalima.p@gmail.com	IIA, Bangalore	India
Reddy, Eswar	ereddy@iiap.res.in	IIAP	India
Rich, Michael	rmr@astro.ucla.edu	UCLA	UC
Sand, David	david.sand@ttu.edu	Texas Tech University	US
Schombert, James	jschombe@gmail.com	University of Oregon	US

ISDT - Summary

One of the largest group – 32 members

Divided into 3 sub-groups: Milky Way, Local Group, other galaxies

Most of the members responded to the initial call of identifying their area of interest – encouraged to form teams.

Detailed proposal were sought from the members - about 60% contributed with write up and figures

We had one telecon with these members to finalise the content.

Conveners: Shude Mao and Annapurni
Editor: Aruna Goswami

Breakout session presentations

- 1. Aruna Goswami – Summary of contributions – Milky Way & Probing the contribution of AGB stars to the Galactic chemical inventory with TMT

- 2. Raja Guhathakurta (UCSC): Summary of contributions - Nearby galaxies & The Milky Way, Andromeda, and Distant Galaxies: Insights from Deep Keck Spectroscopic Surveys

- 3. Alan McConnachie – Summary of contributions - Local Volume of galaxies & Star formation histories of the Local Volume: developing a key program for the TMT

Contributed talks (20min: 15+5)

- 1. Judith Cohen (Caltech): - Outward Bound with RR Lyrae Stars: Studies of the Outer Halo of the Milky Way

- 2. Jason Kalirai (STScI): – The initial-final mass relation: 2.0

- 3. Xuan Fang (CSIC): TMT survey of planetary nebulae in the Local Universe

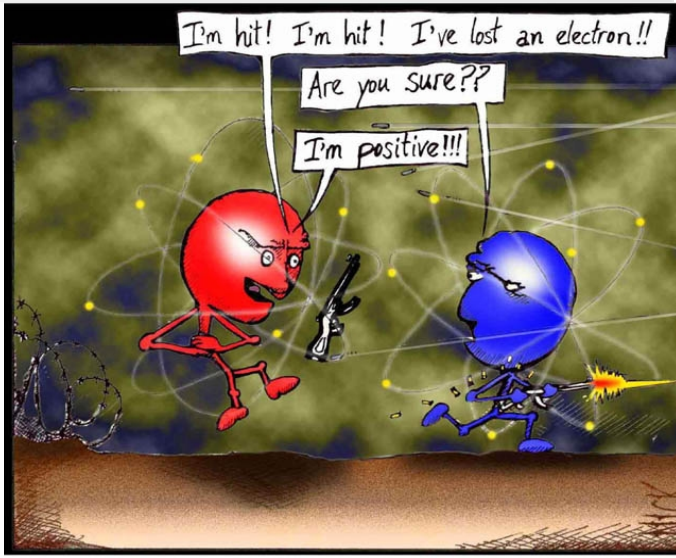
- 4. Caty Pilachowski: Identifying Multiple Populations in Globular Clusters in External Galaxies

- Two poster presentations

The Cosmic Chemistry

1. Nucleosynthesis in stars
   - C, N, O elements
   - Be puzzle: primary or secondary.
2. Probing the oldest stars in the Milky Way
3. Mass distribution of first generation of stars
4. Looking deeper: isotope ratios
   - Isotopes of Li and Big Bang Nucleosynthesis
   - The isotopic ratios of neutron-capture elements
   - Origins of heavy elements
   - Carbon isotopic ratios and cosmic homogeneity
   - Cosmo-chronometry

(High Resolution Spectroscopy)

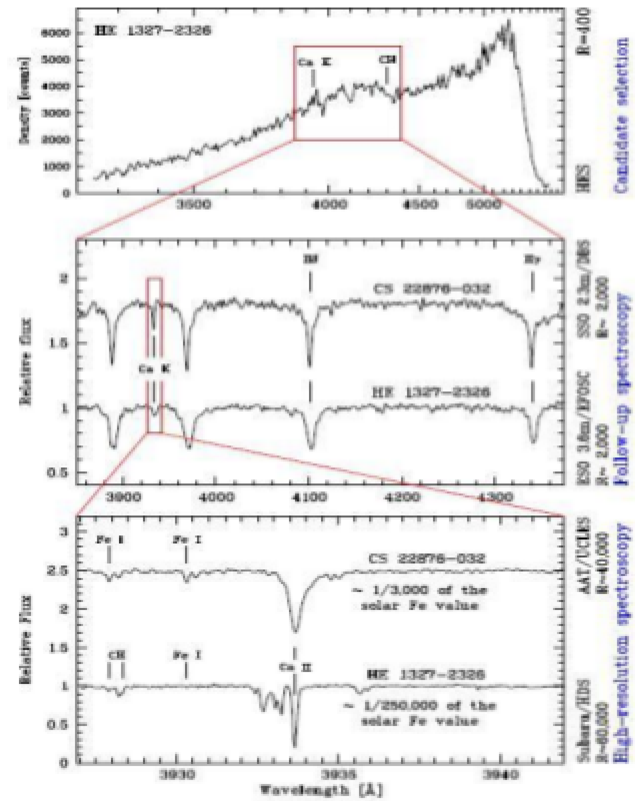


Another casualty in the War of the Atoms.

Probing the oldest stars with TMT

The detailed element abundances of the oldest stars can provide insight into many aspect :

- The origin & evolution of the chemical els.
- The relevant nucleosynthesis processes and sites of chemical element production
- Nature of the first stars and their IMF
- Early star & galaxy formation processes
- Nucleosynthesis and chemical yields of the first/early supernovae
- Chemical and dynamical history of MW.
- A lower limit to the age of the universe.



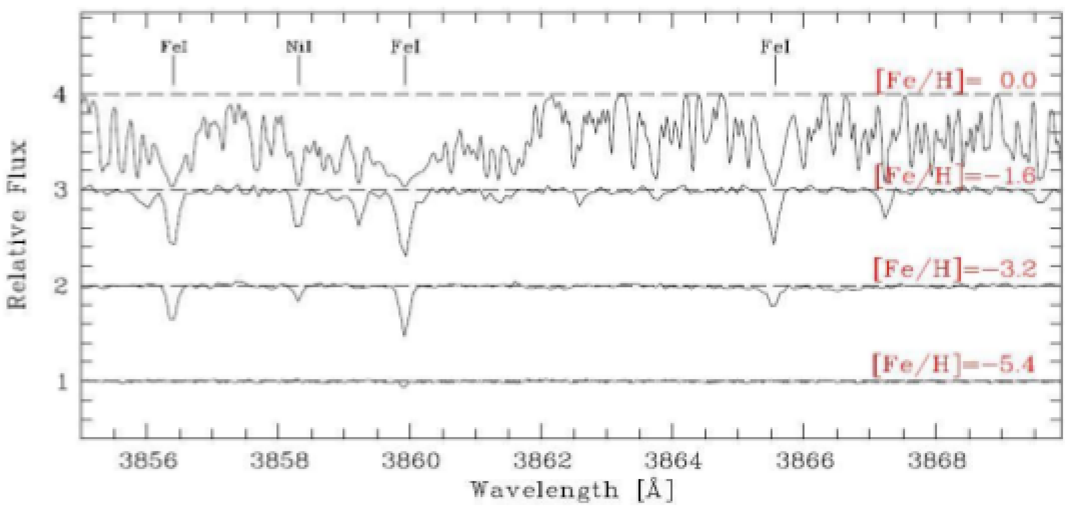
Beers & Christlieb 2005

Finding MP stars……..

Candidate objects will come from surveys: SDSS/SEGUE, LAMOST , ASTROSAT
Newly discovered objects would require spectroscopy for detailed studies i

➢ MP stars: Observational challenges

- Many potentially interesting stars are too faint (V > 13) for current 8 -10m tel
- Relevant absorption lines are weak,
- High precision, high spectral resolution data (R ~ 50000, SNR ~ 100)
- Long exposure time, (HE 1327-2326: with VLT/UVES, exp time ~ 18 hrs)



The variations in line strength reflect the different metallicities.

From top to bottom: Sun ([Fe/H] =0); G66-30 ([Fe/H] = -1.6; G64-12 ([Fe/H] = -3.2, HE 1327-2326 ([Fe/H] = -5.4). (Frebel 2010)

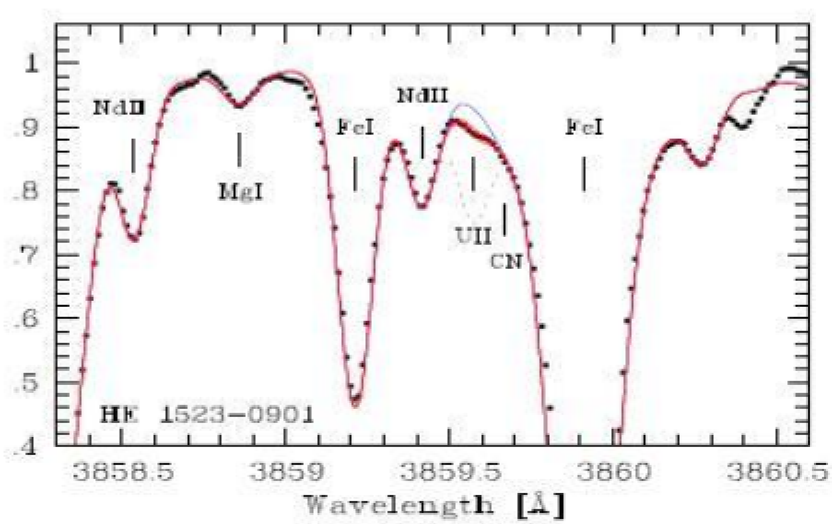
- ➢ Objects accessible to TMT will be much larger,
- ➢ With TMT/HROS, to acquire a spectrum of an object of Vmag ~ 21, at R ~ 40000 and SNR ~ 200 , the required exp time ~ 4 hrs

➢Cosmo-chronometry: TMT/HROS studies of r-process rich stars

Radioactive, long-lived isotopes 232Th (14 Gyr) , and 238U (4.5 Gyr) , are suitable for measurements of cosmic timescales. (have transitions in the optical range)

Stellar age estimates (in r-process MP stars, CS 31082-01, 14Gyr, Cayrel et al.)
Typically range from 11 – 14 billion years (Th/U),
- provide a lower limit to the age of the Galaxy.

With TMT, lines due to these elements could be measured relatively easily in faint old stars. Uncertainties in the age estimates can be reduced.



C abundance soulld be low. CH features blend with many important n-capture lines (U – 3859, Pb- 4057A)

Th/U, U/Os, U/Eu, U/Th make useful chronometers.

R > 60,000, S/N ~ 500 at 4000 A

Exploration of the Milky Way and nearby galaxies

"What do you mean, you can't look at the Milky Way because you're lactose-intolerant?"

5. Dissecting the Galactic halo: ages and metallicities of old, Nearby low-mass stars and white dwarfs.

6 The Milky Way Galaxy Structure

7. Globular Clusters: the origin and evolution

8. High Resolution Spectroscopy of Stellar Systems in the Local Group

9. Probing chemical evolution in Local Group dwarf galaxies

10. Chemical evolution histories in the Local Group and beyond

11. Stellar Astrophysics – models and line ratios

12 Kinematics of the local group with TMT

13. Astrometry, proper motion and internal dynamics of dwarf spheroidal galaxies

An experiment: Stacking globular cluster satellites of Virgo Cluster dwarf ellipticals

– We are targeting dEs that are low enough luminosity such that they each contain only a handful of GC satellites

– Photometric selection of GC satellites candidates using the Next Generation Virgo Survey (NGVS)

– Keck/DEIMOS spectroscopy of GC satellite candidates; TMT will go fainter than the peak of the GC luminosity function

Characterizing dwarf satellites in the Local Group

– Chemical abundance measurements of old stars are very challenging with Keck

– Metallicity distribution functions of dwarf satellites from spectra of *individual* stars versus mean metallicities of dwarf satellites from *co-added* spectra

Substructure in and mass of the Milky Way

– Leveraging the remarkable *astrometric* potential of deep, multi-epoch HST images

– Need TMT to measure radial velocties of faint blue main sequence turnoff stars in the MW outer halo

Nearby galaxies

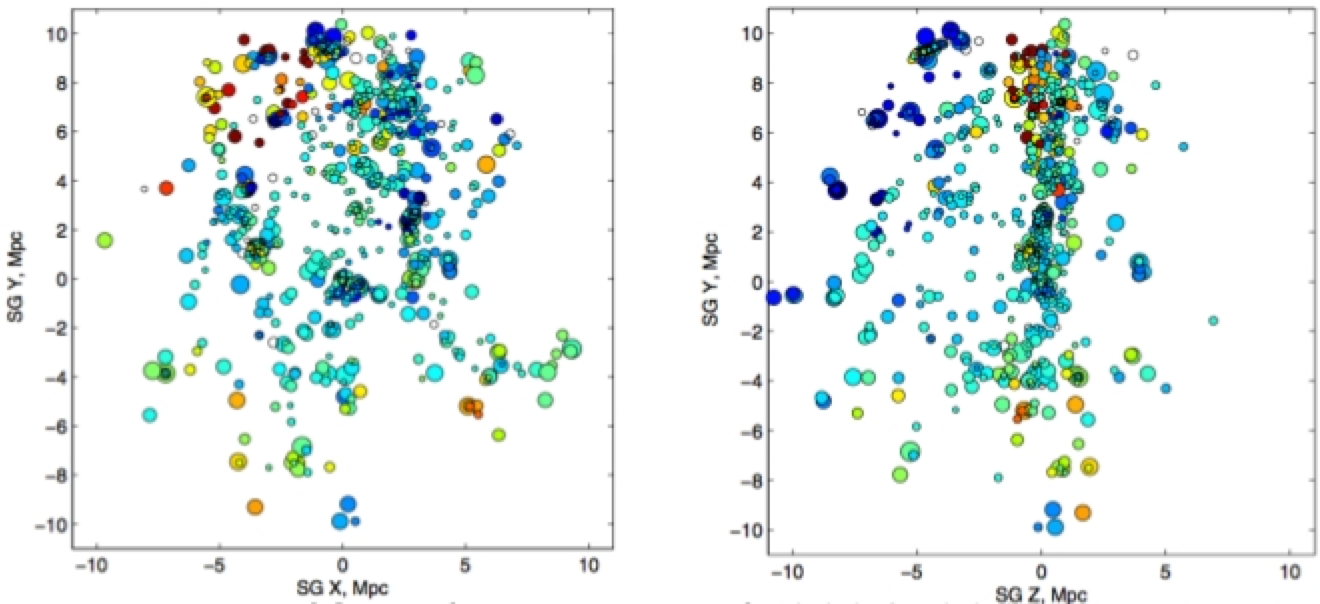
- 14. Planetary nebulae as tracers of substructures in nearby galaxies
- 15. Infrared counterparts of X-ray sources in globular clusters
- 16. Star cluster formation and evolution and their environmental dependence
- 17. Resolved stellar populations as tracers of galaxy evolution
- 18. Reconstructing the star formation histories of nearby galaxies
- 19. The time-resolved history of the galaxies in the Local Volume: the TMT era

20. LSB and BCD galaxies

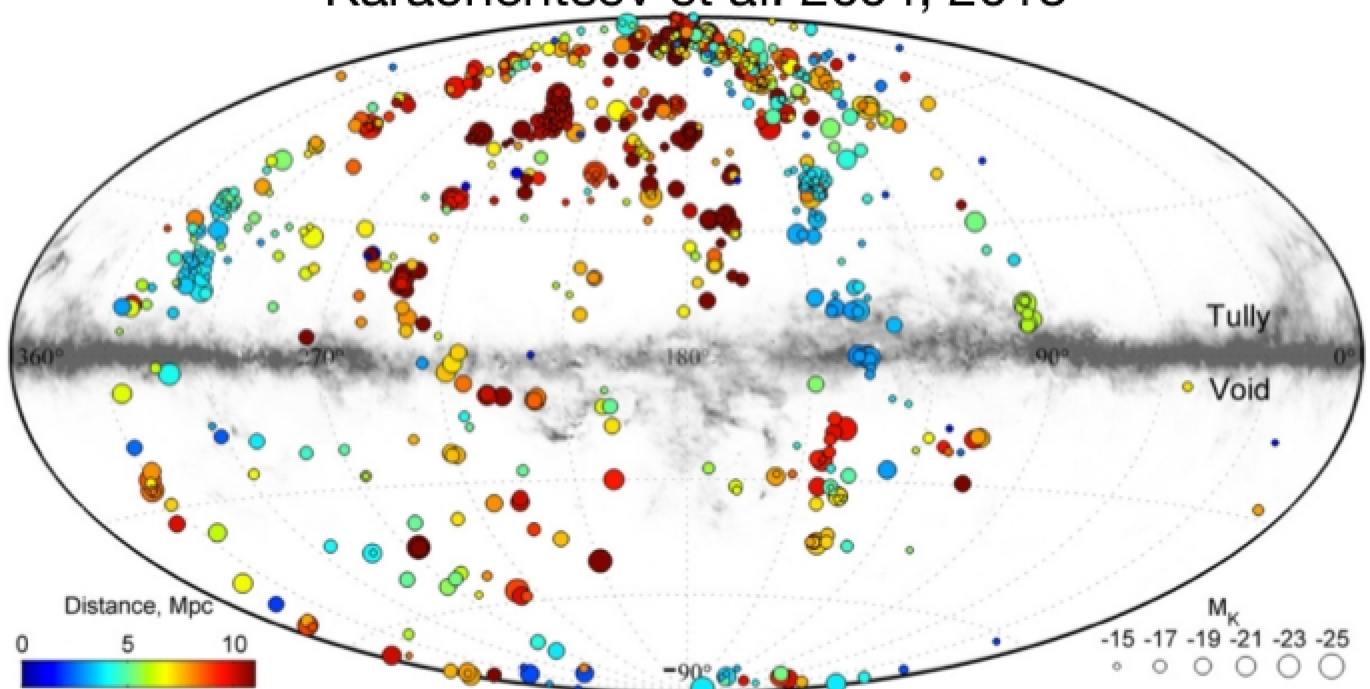
21. Resolving Extreme Star Formation Environments in Luminous Infrared Galaxies at Low Redshift

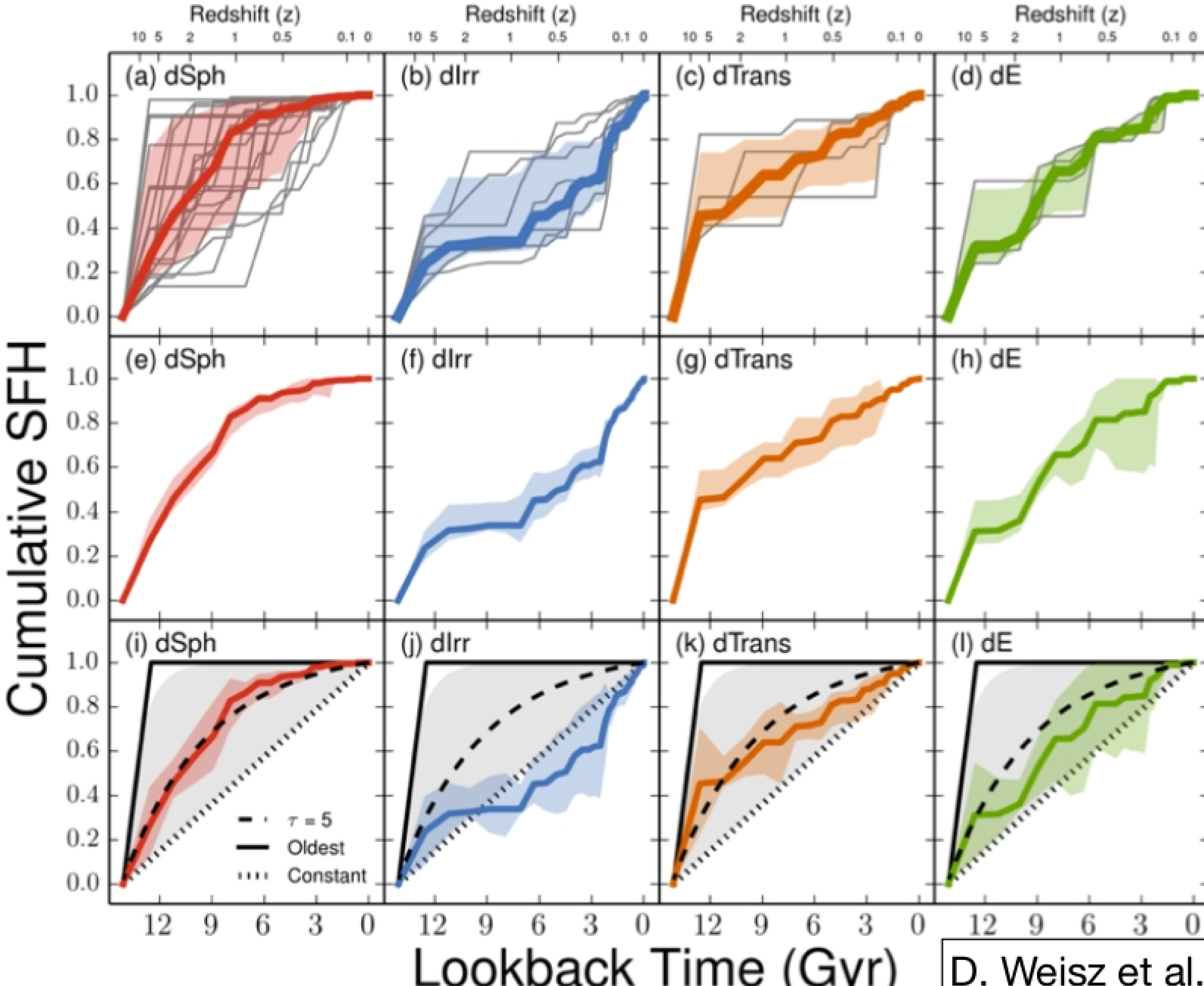
22. Kinematics of star forming galaxies at z = 2 – 3

The Local Volume of 879 galaxies (D<11Mpc)



Karachentsev et al. 2004, 2013



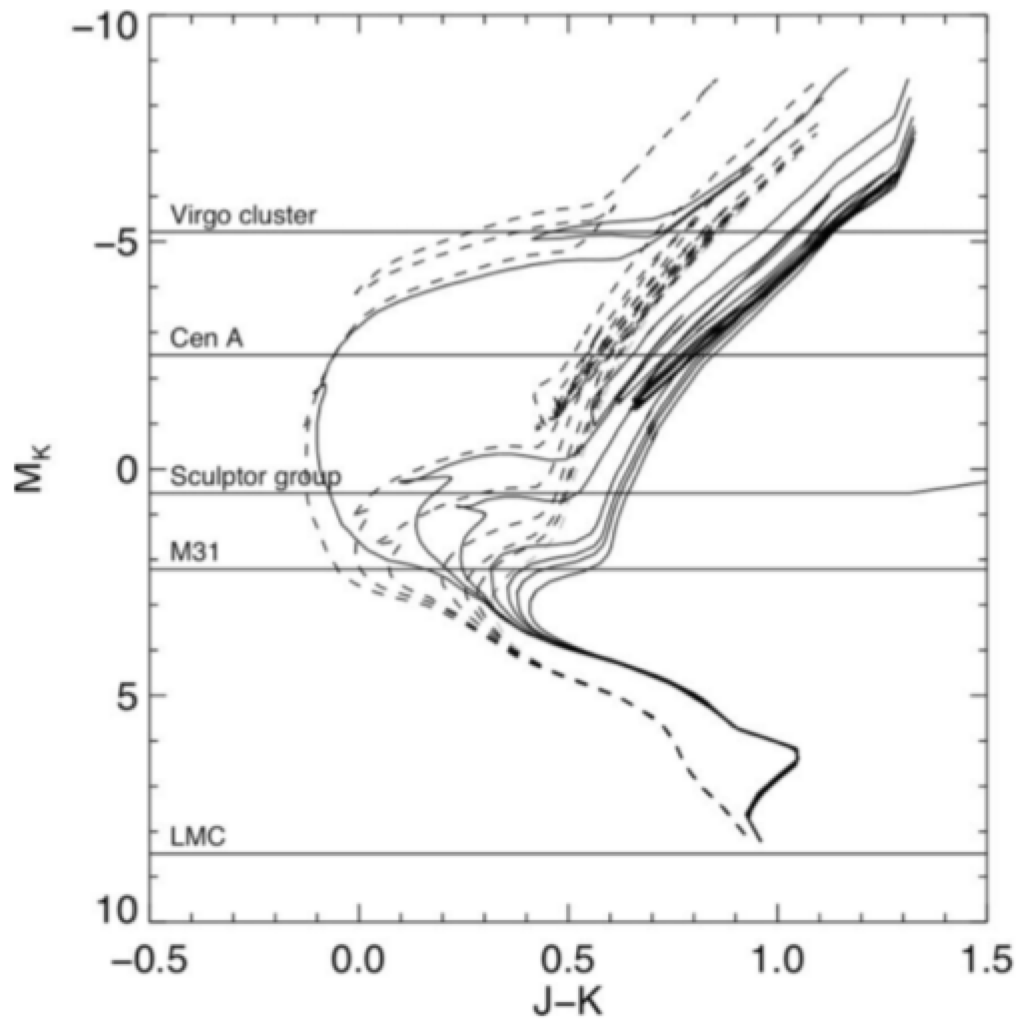


D. Weisz et al. 2014

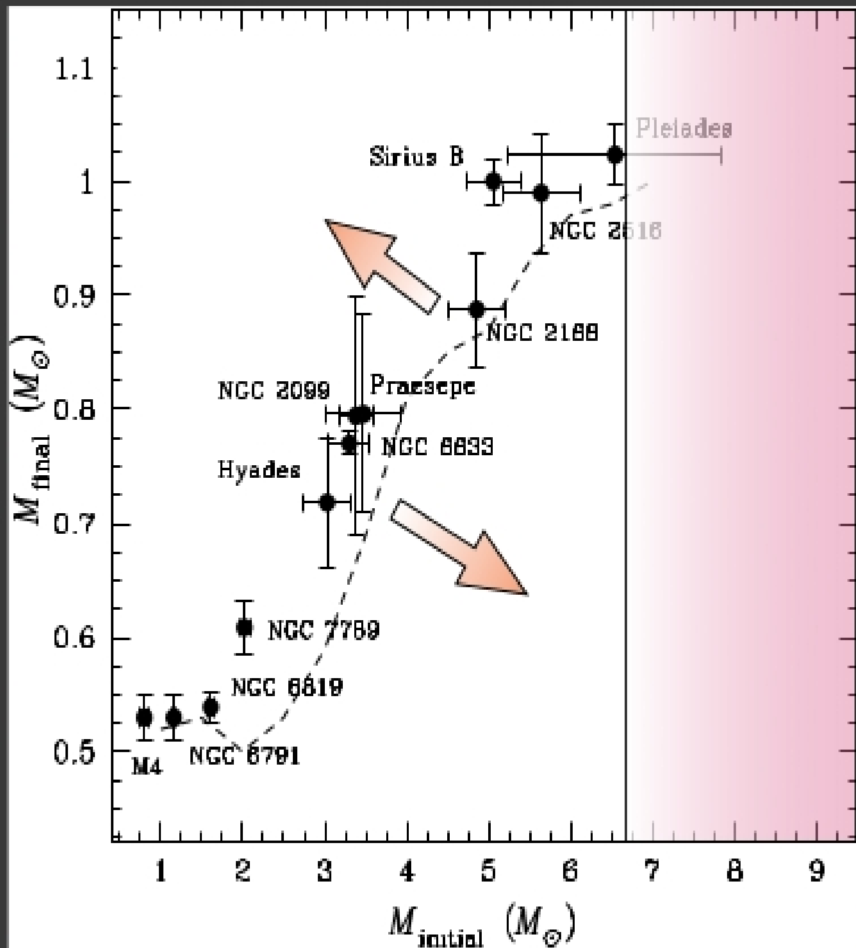
Near IR considerations

- Optical is information rich for stars (peak of SED, large number of transitions at blue wavelengths)
- Optical + NIR bands give excellent temperature sensitivity

- RGB and AGB stars prominent, especially for more distant systems
    - **Theoretical: AGB stars are hard (mass loss)**
    - **Empirical: can we calibrate AGB stars? (difficult since few single stellar pops with AGB stars e.g. Galactic globular clusters)**



TMT - The Initial-Final Mass Relation: 2.0

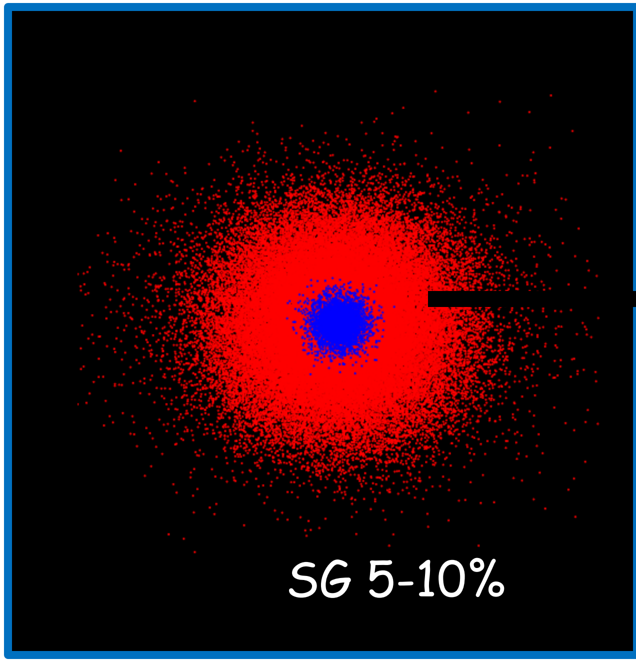


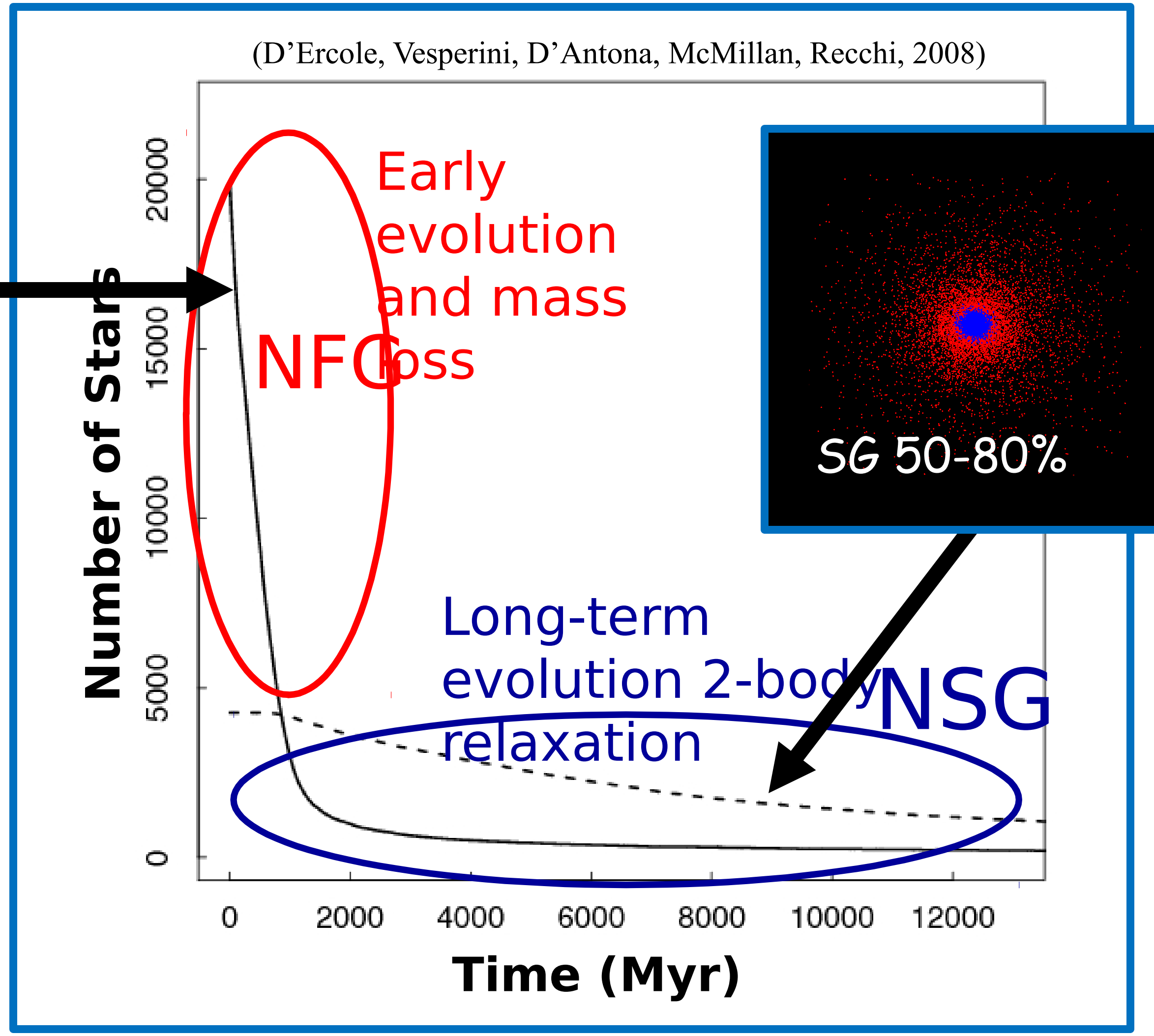
Weidemann (1977, 1987, 2000)
Reimers & Koester (1980's)
Claver et al. (2001)
Dobbie et al. (2004, 2006)
Williams et al. (2004, 2007)
Liebert et al. (2005)
Kalirai et al. (2005a, 2005b)
Kalirai et al. (2005a, 2005b)
Kalirai et al. (2007, 2008, 2009)

Future Direction - Adding Two New Dimensions to the Initial-Final Mass Relation

1.) Constraining the upper mass limit to WD formation

2.) Exploring the metallicity dependence of stellar mass loss



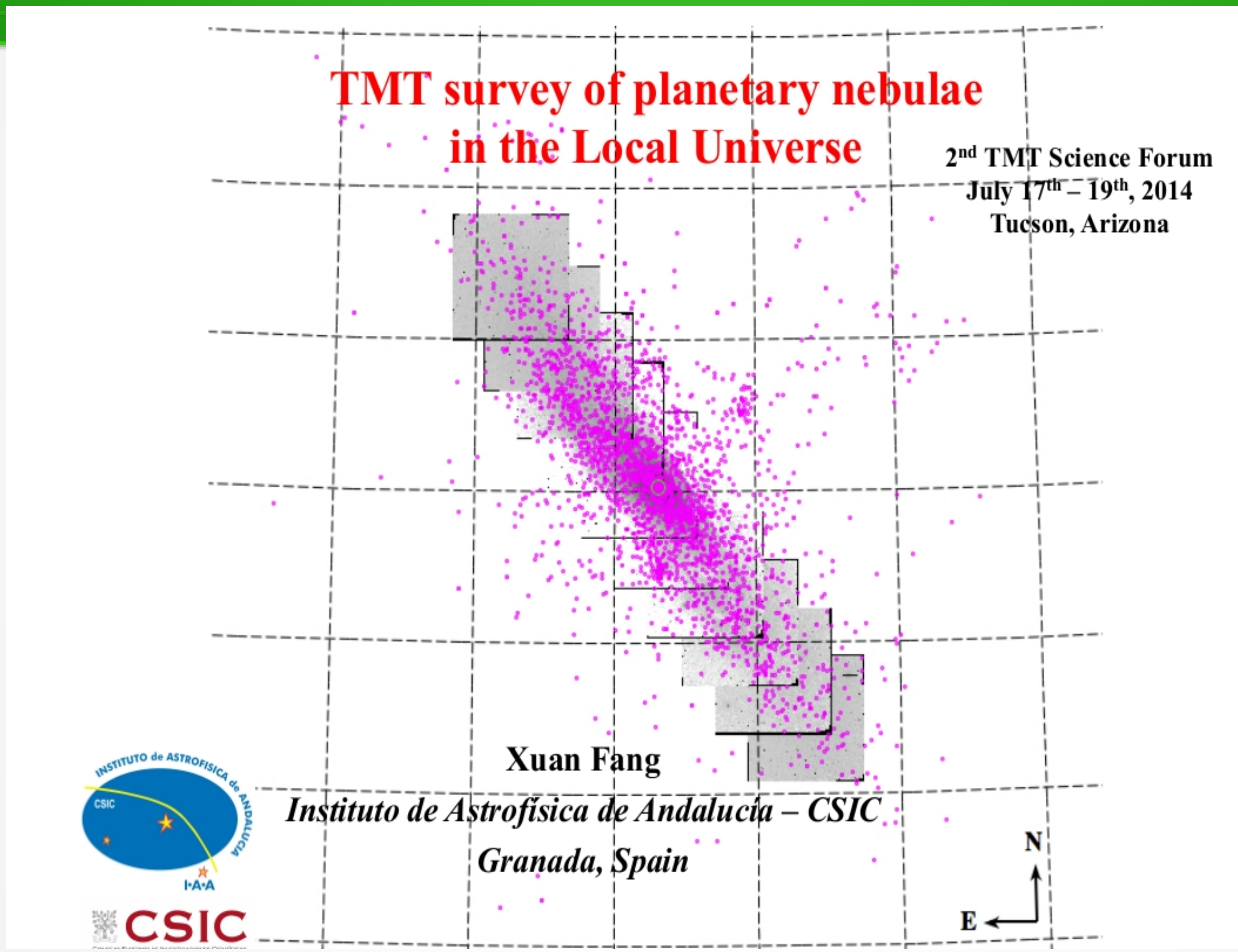


90% of Original FG Mass is Lost

- Outer, 1st generation stars stripped off
- 2nd generation stars become dominant

Reaching beyond 110 kpc

- <R> = 20.6 is D 100 kpc
- Only ~180 beyond 90 kpc in ~9,000 sq deg
- Need deep survey, many epochs, very high sky coverage = LSST !!
- Can’t integrate spectra too long due to vr phase blurring, need bigger telescope than Keck to get vr of very distant RR Lyr
- NEED TMT AND LSST to construct the best possible map of the extreme outer halo of our galaxy


TMT survey of planetary nebulae
in the Local Universe
2nd TMT Science Forum
July 17th – 19th, 2014
Tucson, Arizona
Xuan Fang
Instituto de Astrofísica de Andalucía – CSIC
Granada, Spain
INSTITUTO de ASTROFISICA de ANDALUCIA
CSIC
I·A·A
CSIC
N
E

Summary

High Resolution Spectroscopy – need to think about best approach

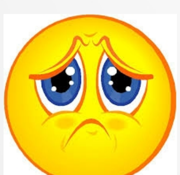
High precision astrometry over a field – TMT can make an impact

Wide field optical medium resolution spectroscopy – fainter and far away objects

Key programs:

1. Galaxies in the local Volume: Kinematics, Chemical Evolution and Star formation history

2. Cosmic Chemistry: First stars, Nucleosynthesis, and isotopic ratios



Magellanic Clouds – the galaxies TMT will not see

1. Poor chemical enrichment:

2. Rich in Gas, vigorous star formation – nearest star burst region (30 Dor - LMC)

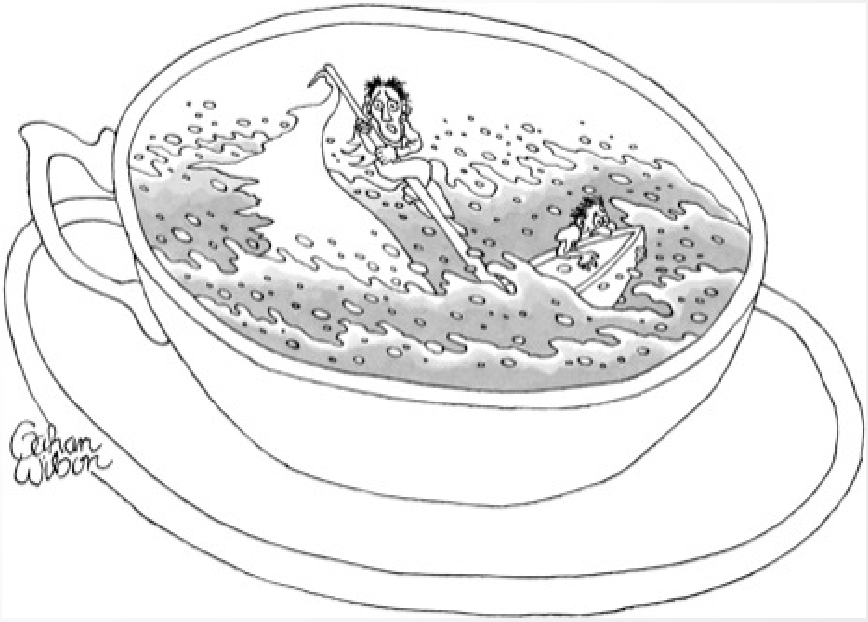
3. Rich star clusters in L&SMC

4. Gas kinematics do not show a bar

5. No direct evidence of a halo

   Structure of the SMC is not clear

6. Nearest interacting pair
7. Individual stars can be resolved



Using public data (OGLE II&III, MCPS, IRSF-MCPSC)

- ► **To understand the structure and evolution of the Magellanic Clouds**
- ► **Using different stellar populations in these galaxies.**

► **The stellar populations we have studied are:**

- **Cepheids** – **young stars (~ a few100 Myr Population I)**
- **Red clump stars** – **intermediate age stars (~ 2-8 Gyr Population I)**
- **RR Lyrae stars** – **old age stars (~ 10 -12Gyr Population II)**

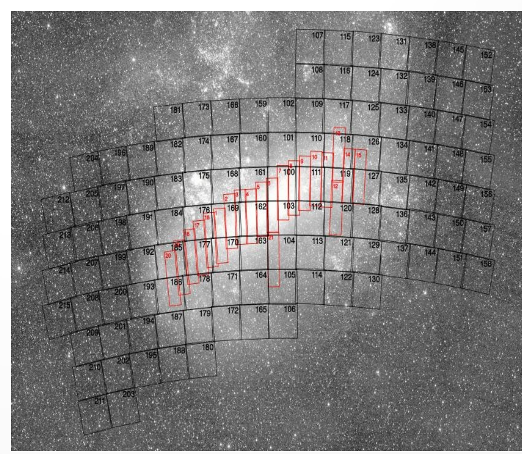
➢ **We use them to estimate:**

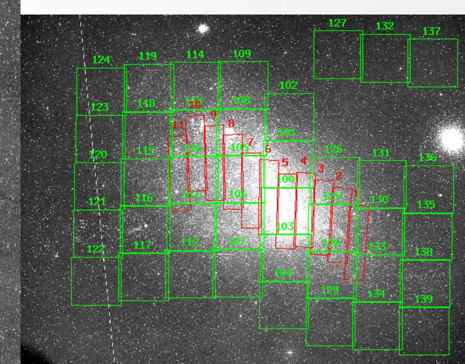
➢

Reddening (as a function of population)

Line of sight depth

Structural evolution of the MCs

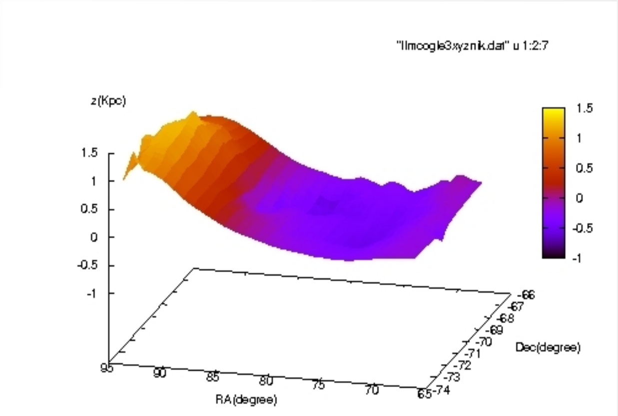




LMC Disk and Halo

LMC Disk found to be fairly thick - 3.4 (1.2) kpc

Subramanian.S & Subramaniam.A, 2009, A&A, 496, 399



LMC bar – very much part of the disk

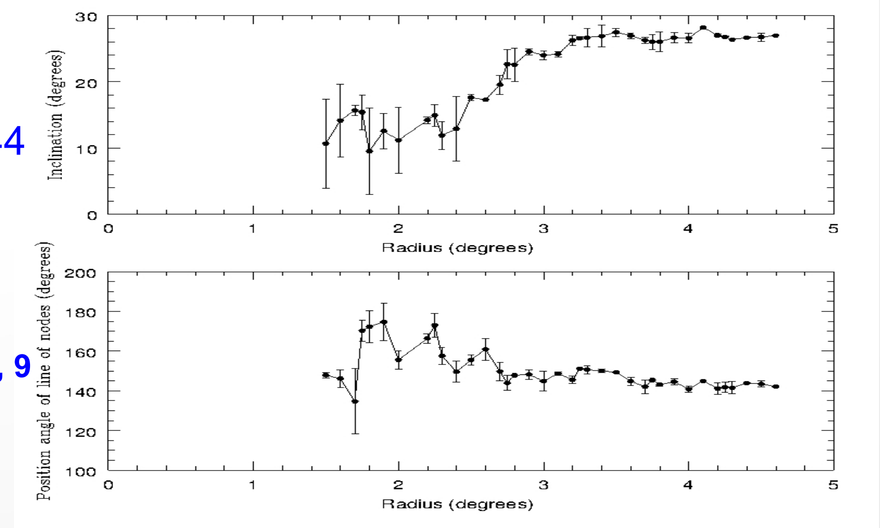
Subramaniam.A & Subramanian.S., 2009, ApJ Letters, 703, L37

3D picture of the LMC disk

Subramanian, S & Subramaniam, A., 2010, A&A, 520, 24

LMC structure in IR (less reddening)

Subramanian & Subramaniam, 2013, A&A, 552, 144



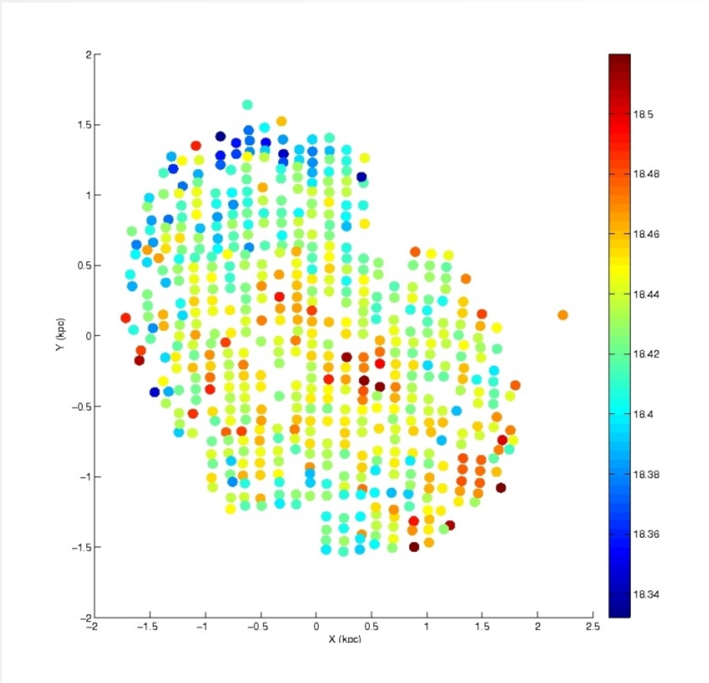
RR Lyrea stars – mostly in the disk!

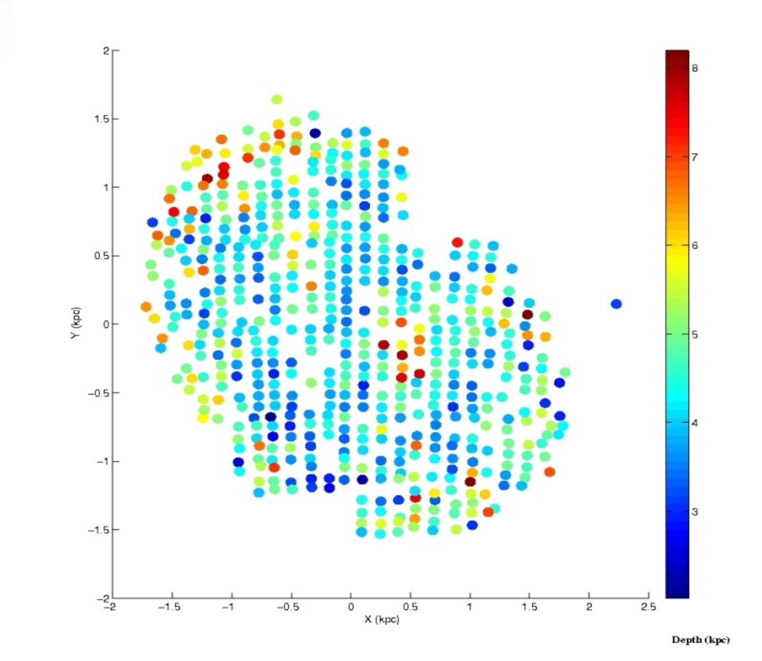
Subramaniam, A., 2005, A&A, 449, 101

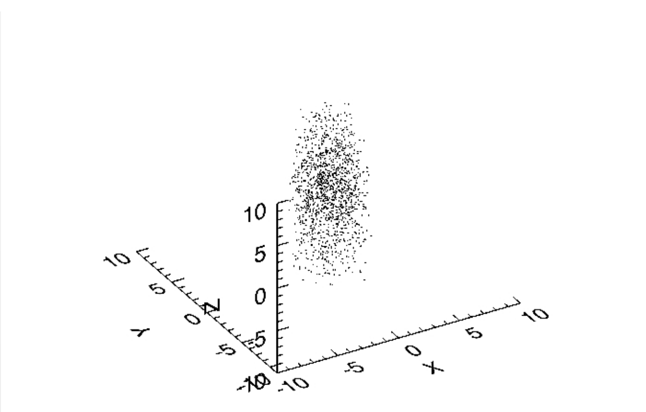
Subramaniam, A & Subramanian, S., 2009, A&A Letters, 503, 9

SMC structure – spheroidal/ellipsoidal

Subramanian, S & Subramaniam, A., 2012, ApJ, 744, 128

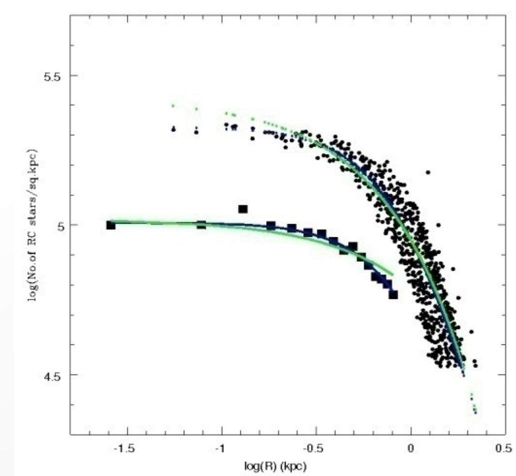




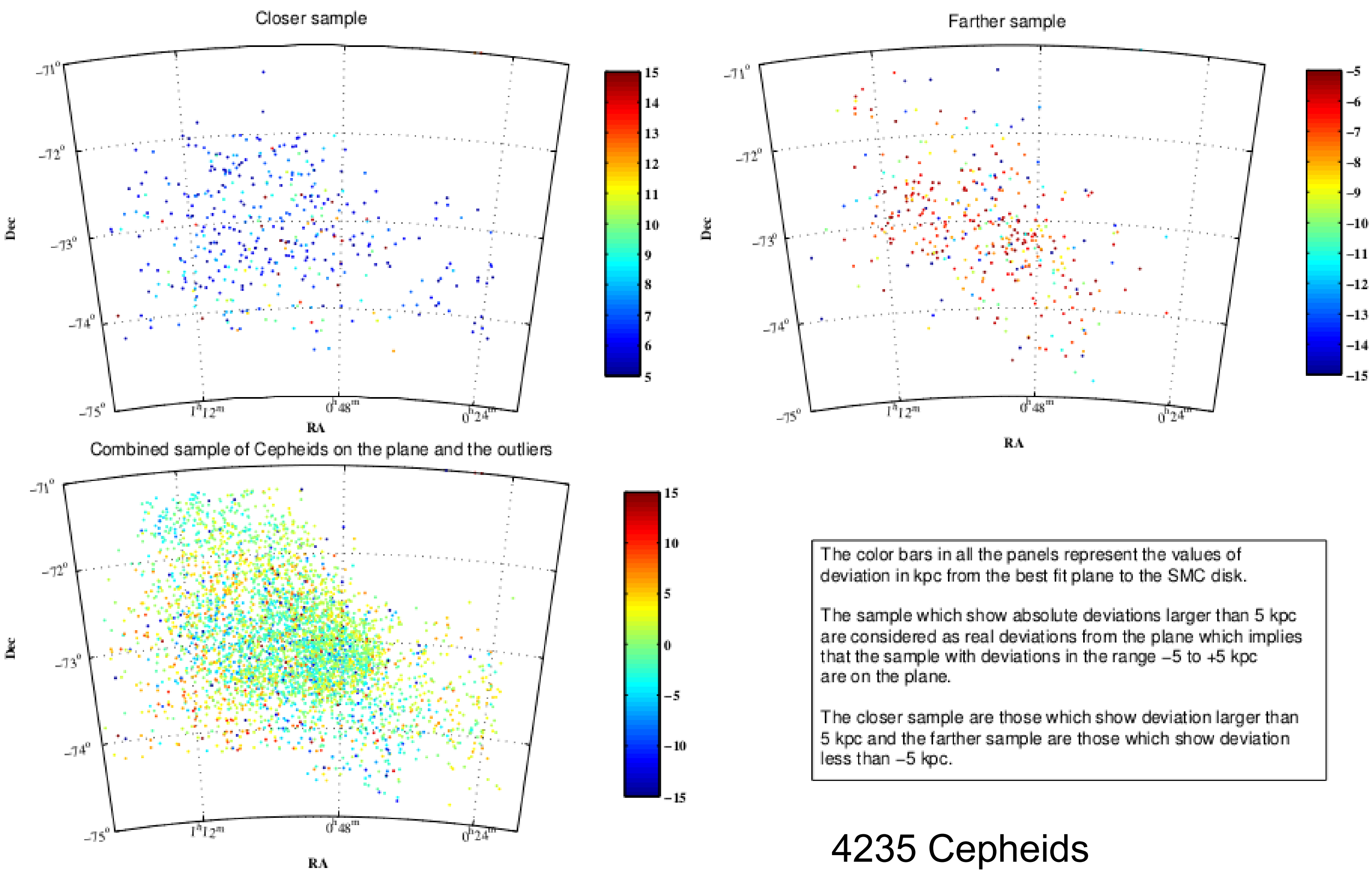


X:Y:Z

1:1.3:1.6



SMC – Cepheids



The color bars in all the panels represent the values of deviation in kpc from the best fit plane to the SMC disk.

The sample which show absolute deviations larger than 5 kpc are considered as real deviations from the plane which implies that the sample with deviations in the range –5 to +5 kpc are on the plane.

The closer sample are those which show deviation larger than 5 kpc and the farther sample are those which show deviation less than –5 kpc.

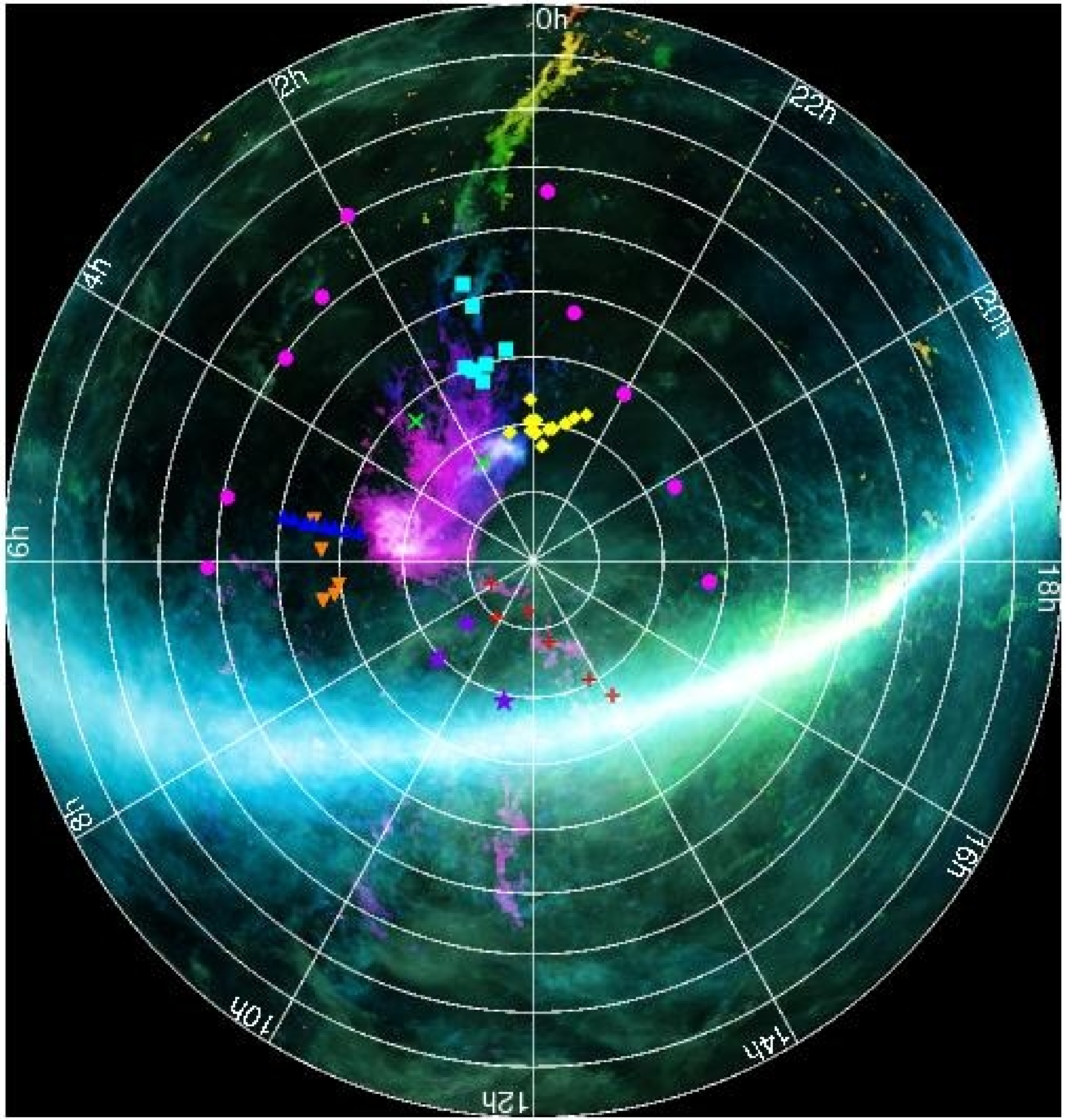
4235 Cepheids

SMC Cepheids

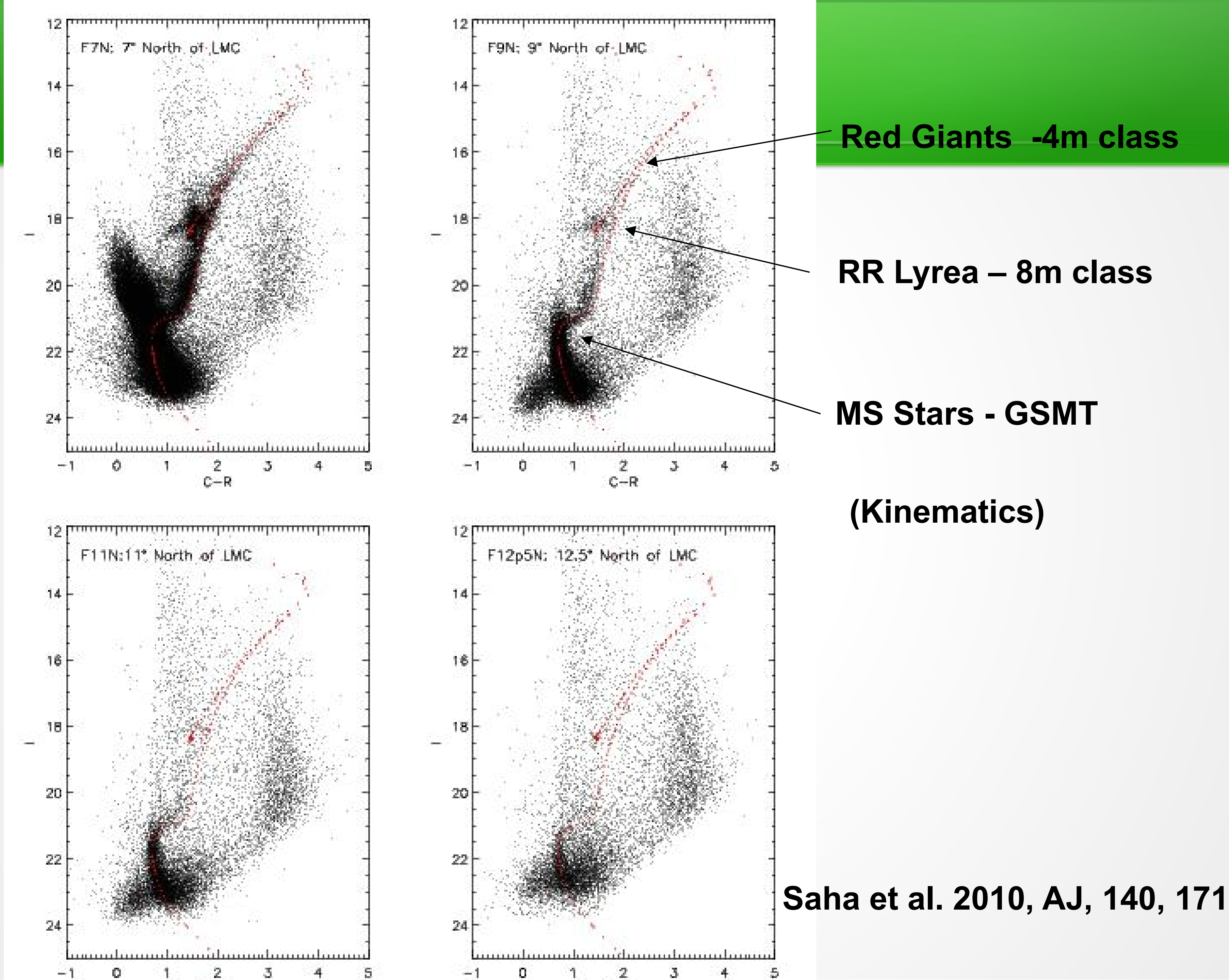
The orientation corrected depth/thickness of the SMC disk - 2.32 ± 0.5 kpc

Subramanian & Subramaniam, 2014, A&A, submitted

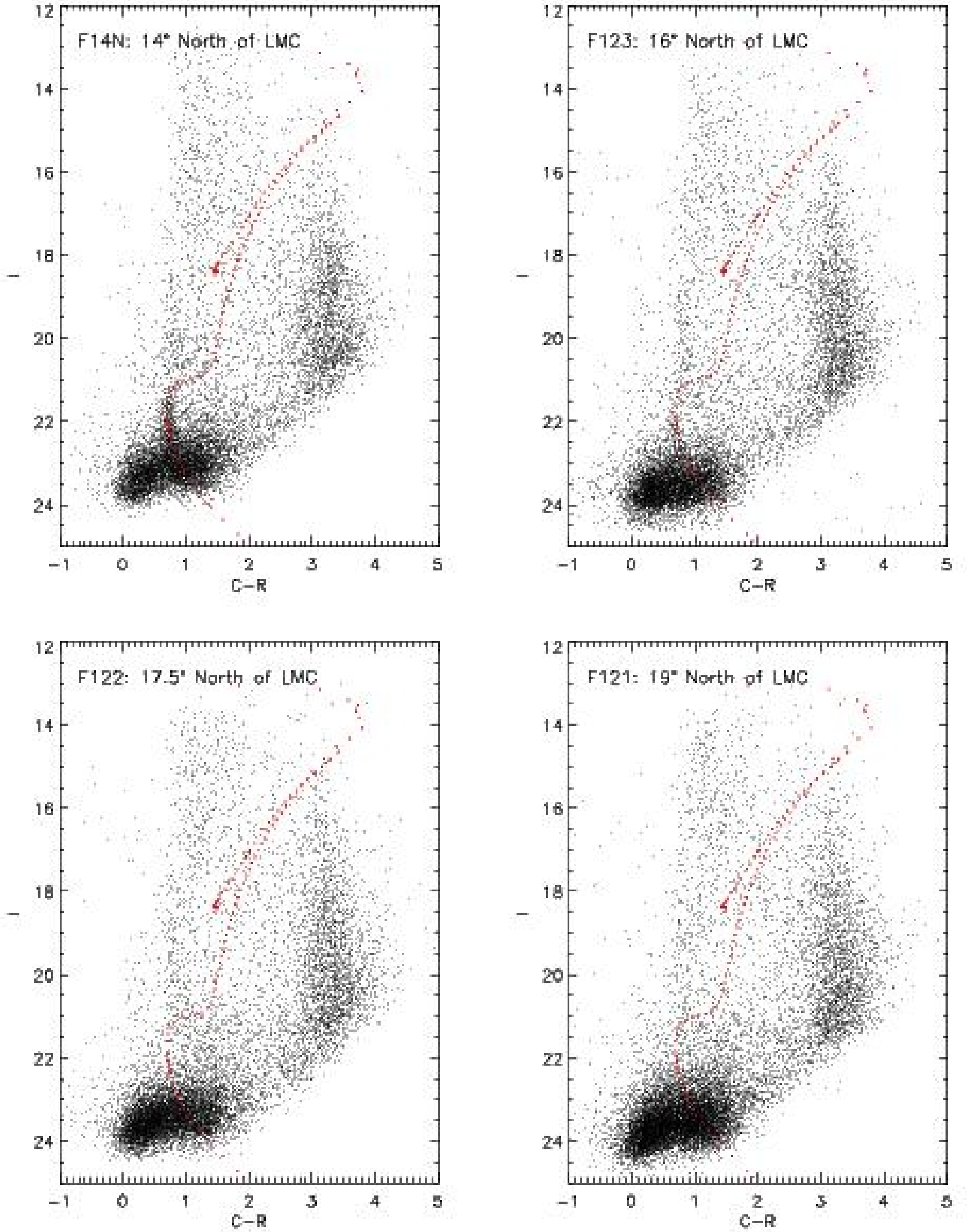
SMC - Cephieds



Outer Limits Survey – Outer stellar population of MCs Survey using 4m Blanco (Saha et al. 2010)



Saha et al. 2010, AJ, 140, 1719

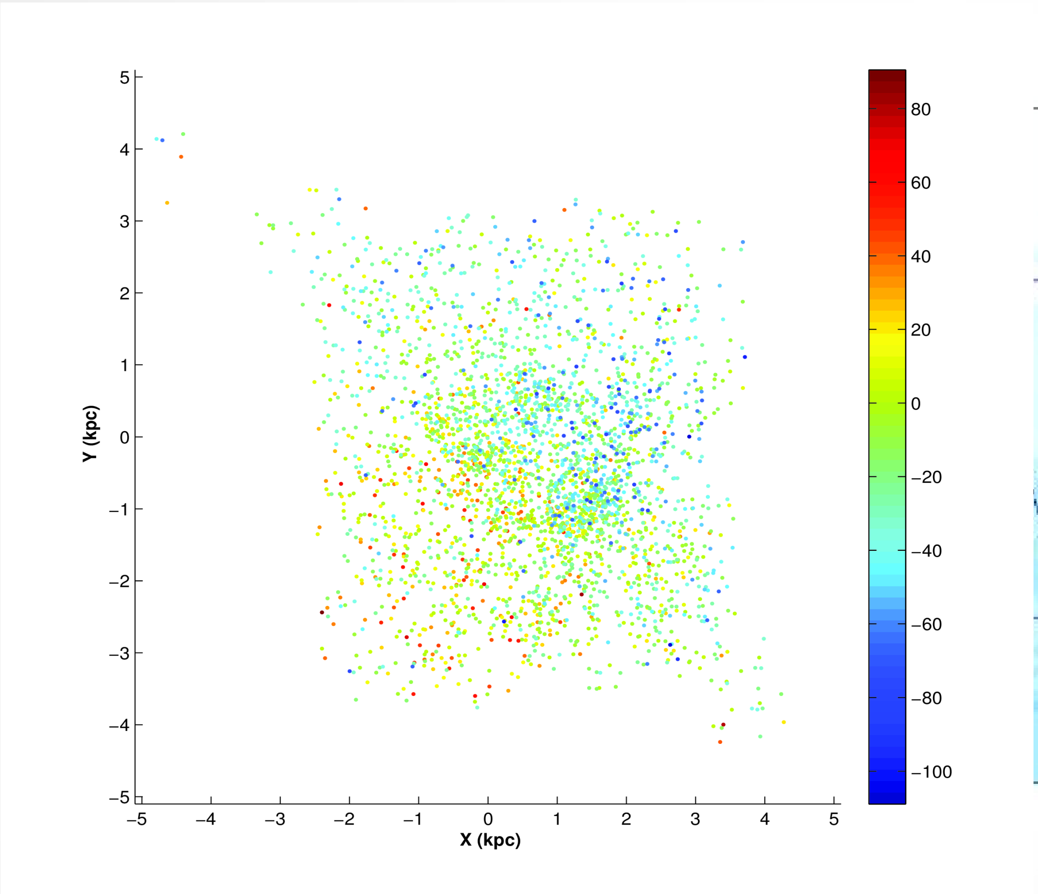


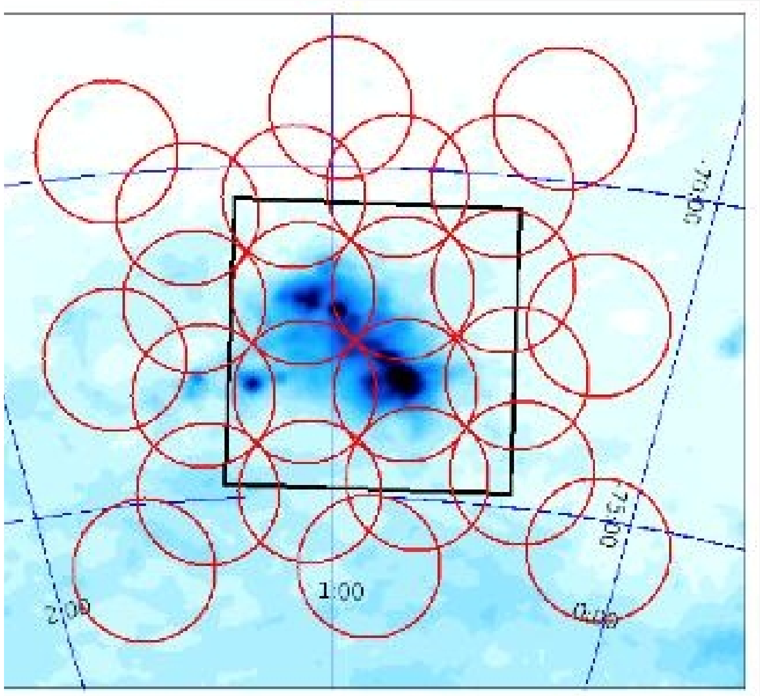
Disk till 16 degree North

No detectable Halo

Stellar density drops after 9 deg

Inner kinematics of the SMC –AAOmega – spectra of 8000 stars





SMC – Kinematics and Metallicity

- 3037 stars identified as members (excluding carbon stars and foreground stars)
  vlos ≈147.8±0.5km s−1 ; σ vlos ≈26.4±0.4km s−1

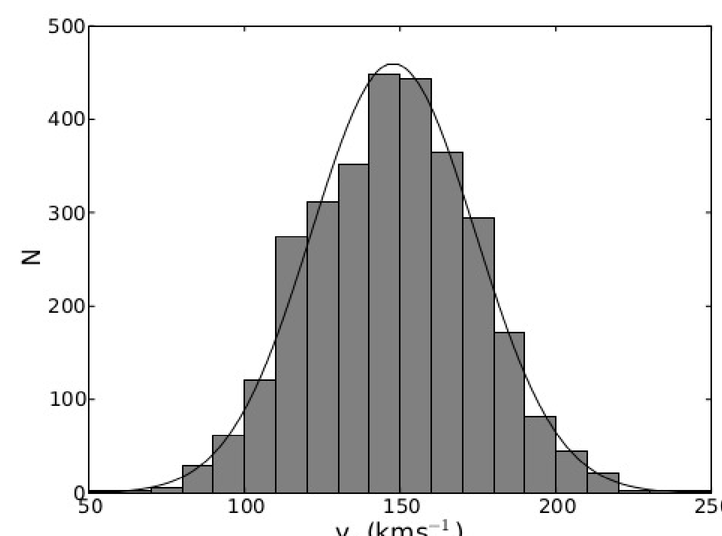
The metal-poor stars exhibit a lower velocity gradient and higher velocity dispersion than the metal-rich stars.

Kinematic substructure in the north-west part – Counter Bridge

Lower line-of-sight velocities towards the Wing - Magellanic Bridge

Our results reinforce the notion that the intermediate-age stellar population of the SMC is subject to substantial stripping by external forces.

- Red Giants in the Small Magellanic Cloud. I.
- Disk and Tidal Stream Kinematics -
- P. D. Dobbie, A. A. Cole, A. Subramaniam, S. Keller
- MNRAS – 2014, 442, 1663



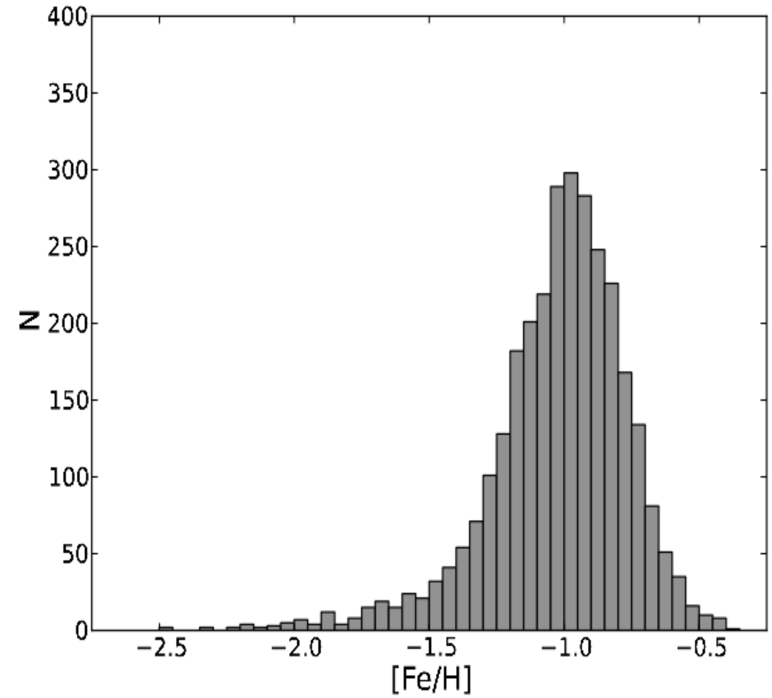
SMC – Kinematics and Metallicity

find a median metallicity of [Fe/H]=-0.99±0.01

ar evidence for an abundance gradient of -0.075±0.011 dex deg−1 over the inner 5

e metal poor and metal rich quartiles of our RGB star sample are predominantly ol
younger than approximately 6Gyr

d Giants in the Small Magellanic Cloud. II.
tallicity Gradient and Age-Metallicity Relation -
). Dobbie, A. A. Cole, A. Subramaniam, S. Kelle
RAS – 2014, 442, 1680
ugust 2014 issue)



Summary

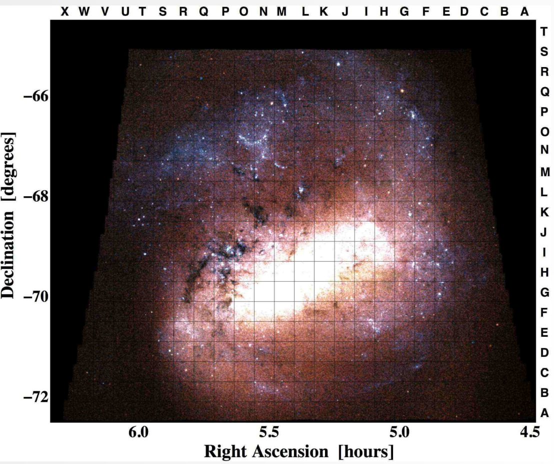
he three (RR Lyrae, Red Clump and Cephied) tracers. There is no major structura

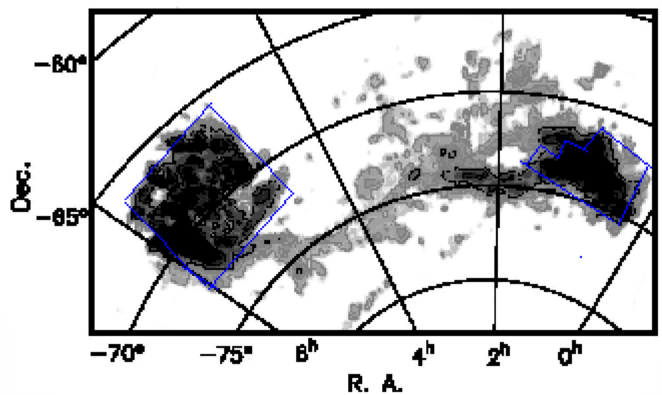
s changed drastically in the last 10 Gyr

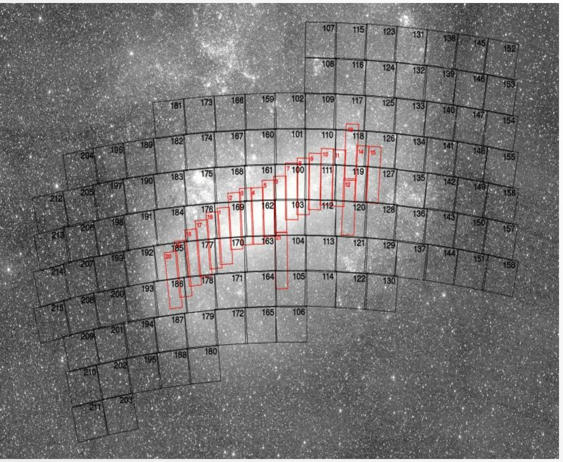
ellipsoidal
e support and less rotation
rotation (orthogonal to gas rotation!)
l disk

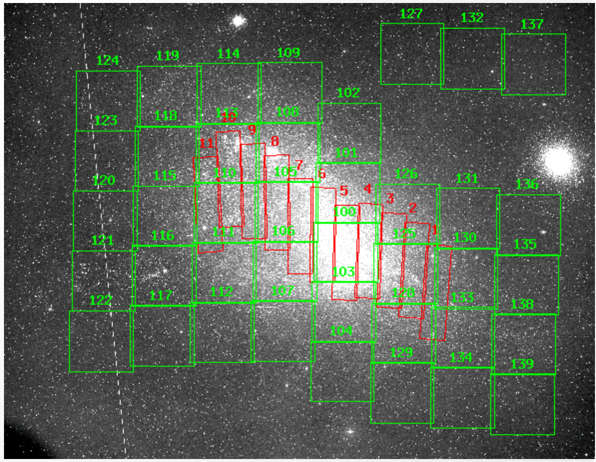
galaxies: LSST, PANSTARRS...
MT
d space motion – TMT specific

Sky coverage of data sets (OGLEII, OGLE III, MCPS, IRSF-MCPSC)



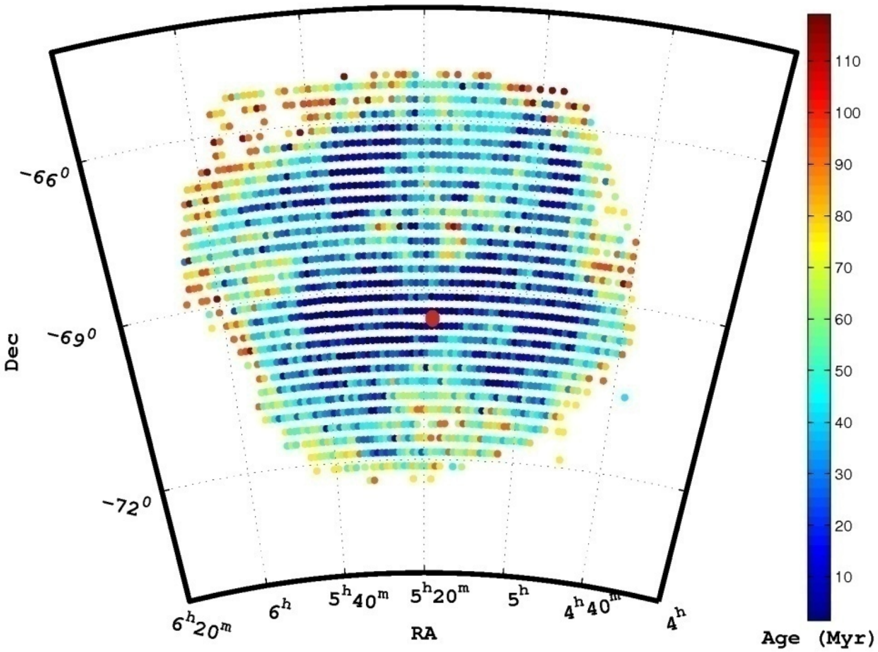


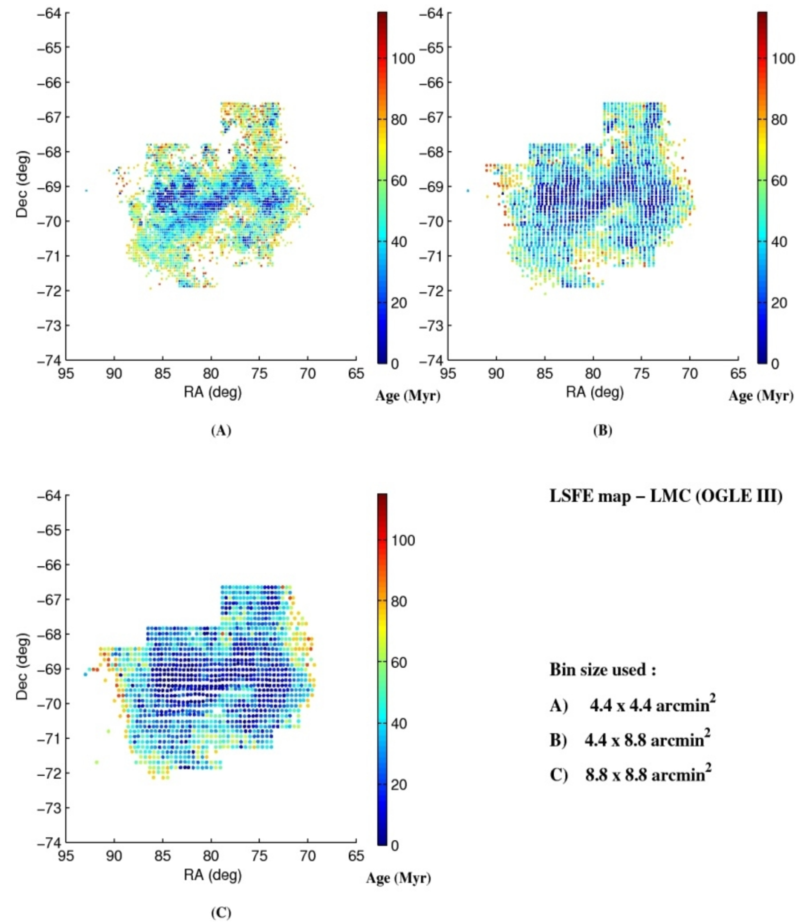




Age distribution of the last star formation event - LMC

Indu, G. & Subramaniam, A., 2011, A&A (highlighted paper)



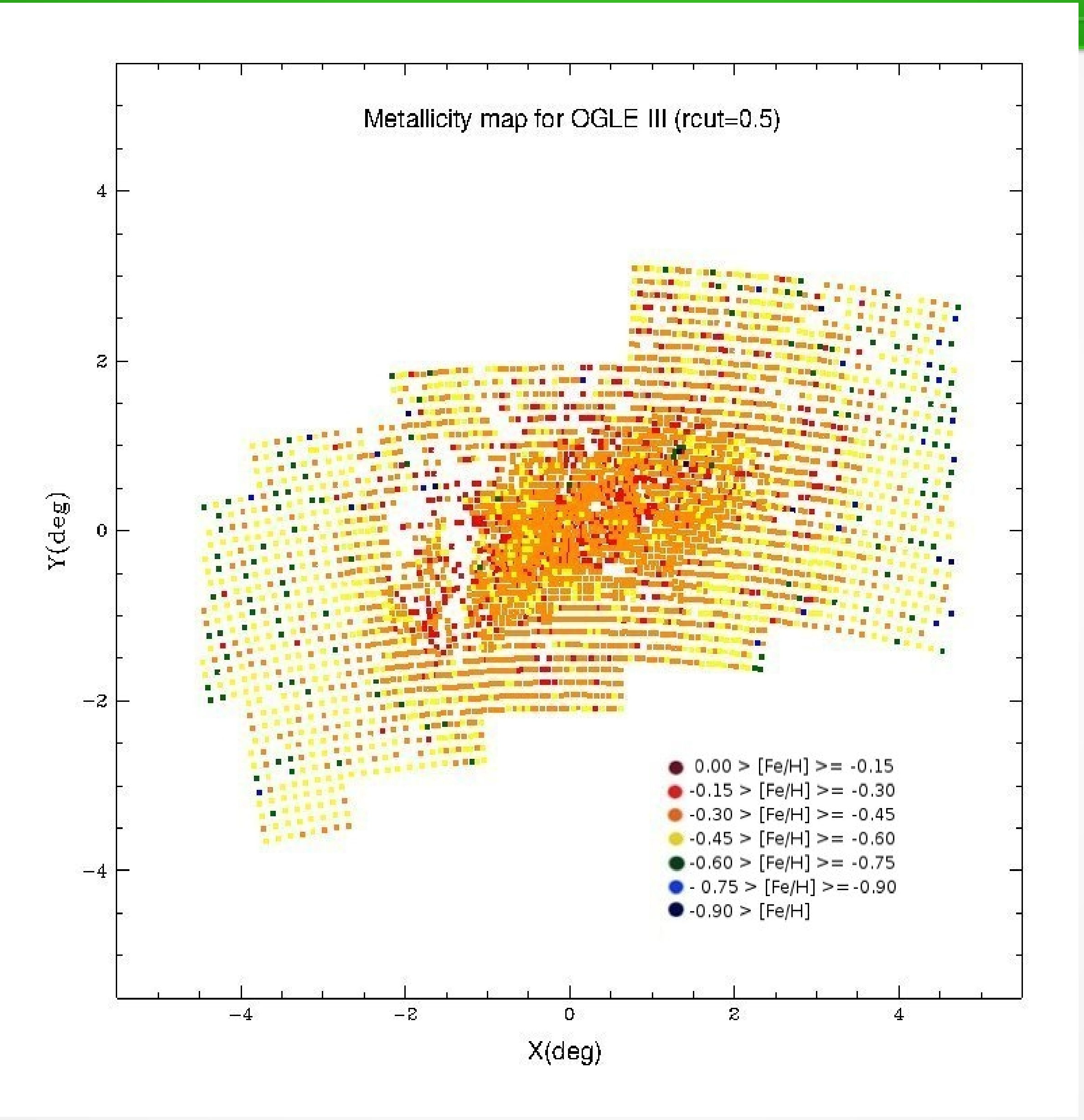


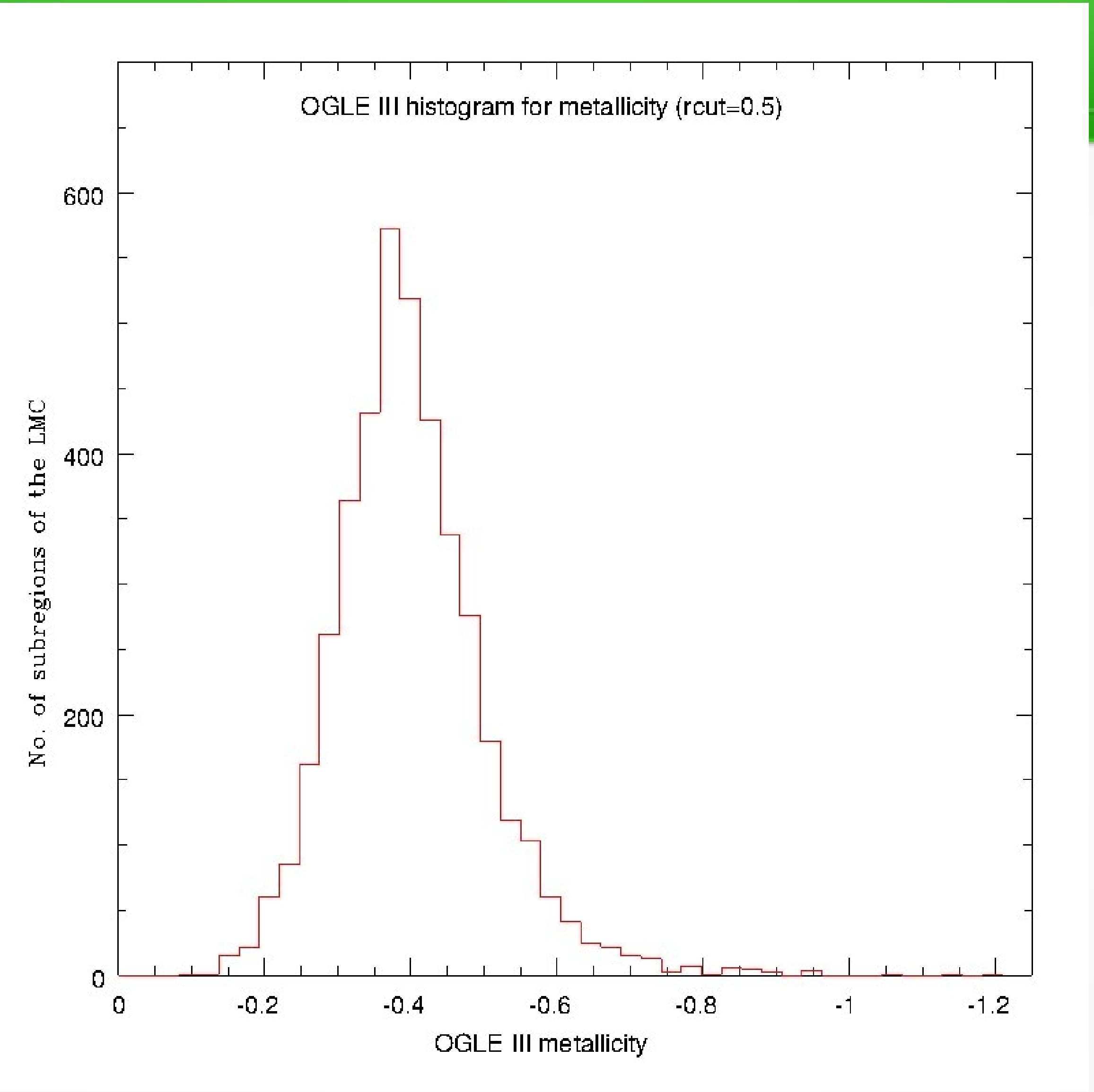
- **Out side to inside quenching of star formation which propagates radially inward**
- **A lopsidedness of young star forming regions with respect to optical center**

Ongoing studies

- Chemo-dynamics of the Clouds (+ Paul Dobby, A. Cole)
- Structure of the Clouds using IR data (Smitha)
- Kinematics of stars and gas – (Indu)
- Kinematics of the central/bar region – Warren Hankey, A. Cole
- Metallicity gradient in the LMC using photometry (Samy, A. Cole
- Study of 50 faint star clusters in the LMC(Samy, Andres Piatti)
- Effect of metallicity on stellar evolution:
- 1. Properties of stars with fast rotation (Be stars – Ronald Mennickent, Paul, Mathew

Metallicity map of the LMC




OGLE III histogram for metallicity (rcut=0.5)
600
400
200
0
No. of subregions of the LMC
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
OGLE III metallicity

Collaborators:

Abhijit Saha (NOAO), Andrew Cole (UTAS, Australia), Ronald E. Mennickent (Chile), Andres Piatti (Argentina)

Students:

Smitha Subramanian (Thesis study)
Indu G. (Ongoing Thesis Study)
Paul K.T. (Ongoing Thesis Study)
Samyaday Choudhury (Ongoing Thesis study)
Project students