Exploration of the Milky Way and Nearby galaxies : Summary of the ISDT proposals

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ISDT: The Milky Way and nearby galaxies
TMT DSC -2014: Chapter 4

Members: 32

Members contributed so far: 18

Number of write-ups received: 13

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Three main sections are identified-

- The Milky Way: Chemical abundances, formation, evolution
- Local volumn: Kinematics, stellar population
- Low red-shift galaxies

➢ The Milky Way: Chemical abundances, formation, evolution

- Extremely metal-poor stars in the Milky Way and the Local group
- Isotopic ratios and cosmo-chronometry
- Globular clusters: origin and evolution
- Dissecting the Galactic halo: ages and metallicities of old, nearby low-mass stars and white dwarfs.
- High resolution spectroscopy of stellar systems in the local group
- Stellar astrophysics

Background

The stellar contents of nearby galaxies (including MW) make up the fossil records of the galaxy formation and evolution process that can be observed at high redshift.

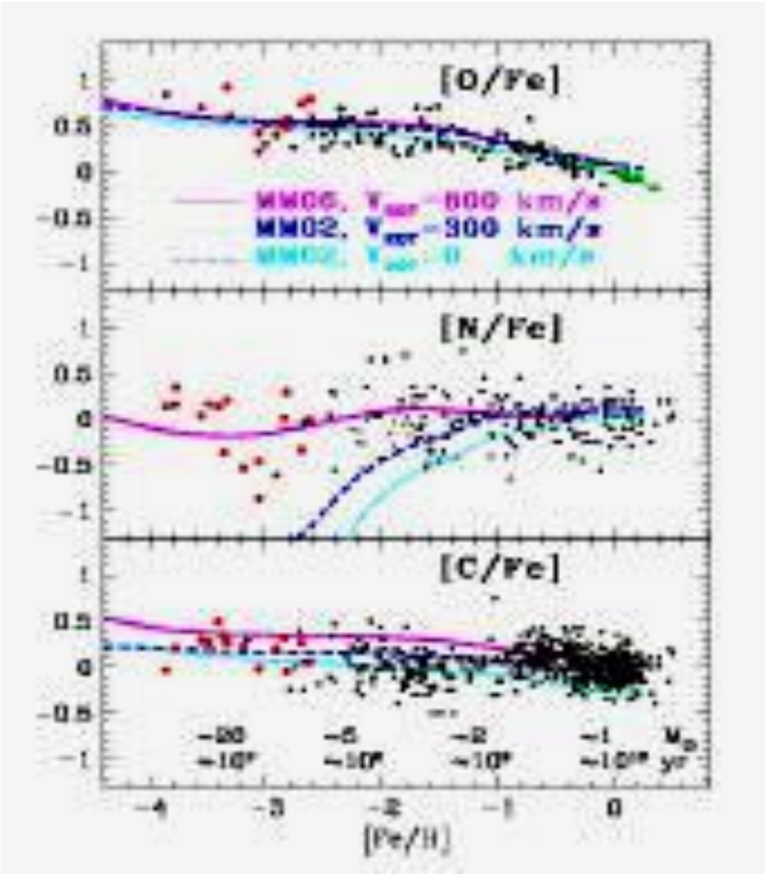
The spatial, temporal and abundance distributions of these stars provide important details.

Due to limitations in observations these details are unobtainable from observations of galaxies at high redshift.

The study of nearby stellar populations complements the study of galaxy formation and evolution at high redshift and provides important clues to the underlying astrophysical processes involved.

➢ Nucleosynthesis in stars

- C, N, O elements
- Be puzzle: primary or secondary
- Radial abundance profiles of LiBeB
- Heavy elements: origin
- Stellar nucleosynthesis of F & Sr



Prantzos et al.

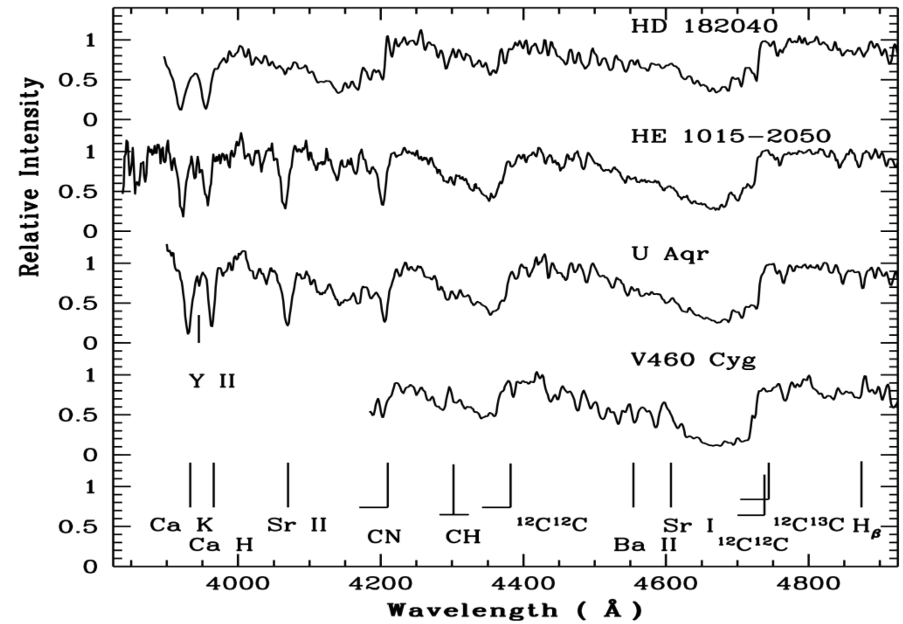
TMT will have great impact on nucleosynthesis studies ....
It will aid detection of faint spectral features and open up hitherto unreachable classes of stars for studies.

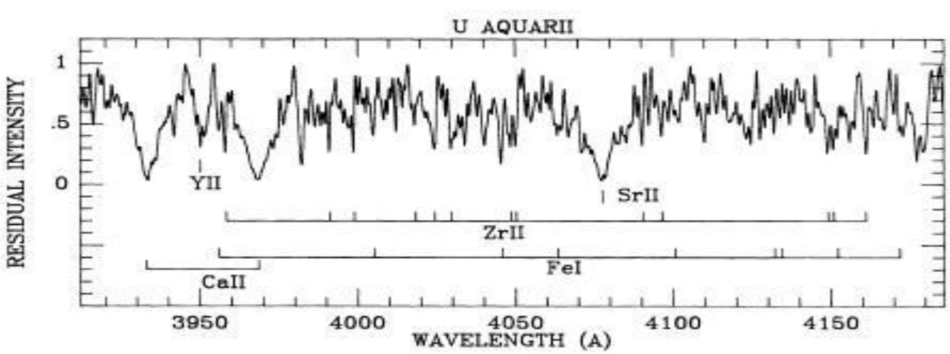
➢ Discovery of HdC star HE 1015-2050 with an extraordinarily strong Sr feature brought the issue of Sr synthesis in stellar interiors to forefront (Goswami et al. 2010, ApJ Letter, 723, L238)

V mag ~ 16.3, Teff comparable to RCBs (S Aps, WX CrA, U Aqr) ~ 5263 K

Strong Sr II at 4077 A, 4215 A
Distinct Y II at 3950 A, Zr II is detected.
No significant enhancement of Ba II at 4554 A and 6496 A.

Subaru HR spectrum taken in January 2013 shows evidence of RCB light decline. (Goswami & Aoki, 2013, ApJ Letter, 763, L37)





Malaney 1985, MNRAS

Many surprises are expected to be revealed with TMT/HROS.

➢ Origin of Sr in HE 1015-2050

The main s-process occurs within the ^{13}C pocket : PMP into the radiative ^{12}C layer –
$^{12}C\ (p,\gamma)^{13}N\ (\beta)^{13}C(\alpha,n)^{16}O$: source of neutrons : $^{13}C(\alpha,n)^{16}O$

The weak s-process occurs in massive stars --- source of neutrons : $^{22}Ne(\alpha,n)^{25}Mg$ (limited efficiency)
Most of the neutrons produced are captured by the light elements (Self-poissoning)
A small fraction are captured by the ^{56}Fe seed nucleus.

Weak s-process allows production of light s-process nuclei with mass numbers $65 < A < 90$
Sr, (A = 87), falls into this range.
Ba (A = 137), does not, (a very little amount is produced by this process (Prantzos 1990)).

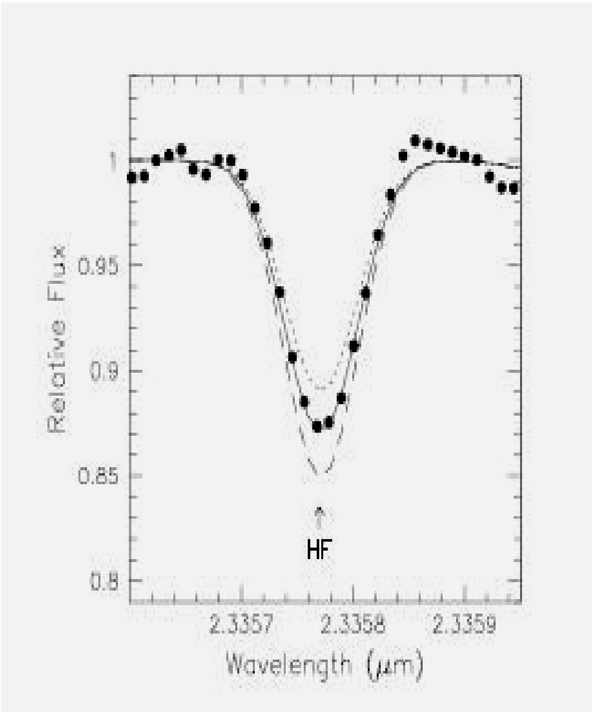
Formation scenarios: a He-C core of an evolved star– He-core flash → ejected its H-rich envelope → a single n-exposure occurred at the flash → resulting in a brief n-irradiation producing light s-process elements till Zr

A primary challenge is to demonstrate a mechanism which must explain
a) H-deficiency; b) Overabundance of C; c) Enhancement of light s-process elements

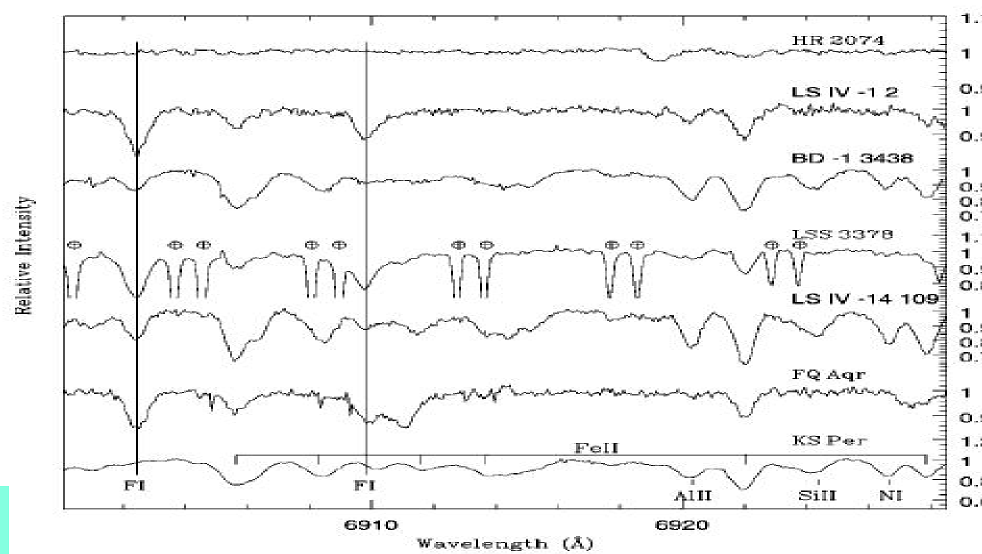
Higher resolution spectra with high S/N ratio needed for detailed chemical composition study to understand the origin and evolution is possible with TMT/HROS.

An important source of observational constraints for studying s-process nucleosynthesis.

➢ Fluorine in CEMP and EHe stars: investigation with TMT



HF (1-0)R9 line at 2.3357 µm. The observed HR Near-IR Phoenix spectrum of HE 1305+0132 (filled circles). The best-fit synthetic spectrum, (solid line) gives A(^{19}F) = 4.96 +/- 0.21. . The broken lines are with ^{19}F abundances +/- 0.10 dex of the best-fit abundances.



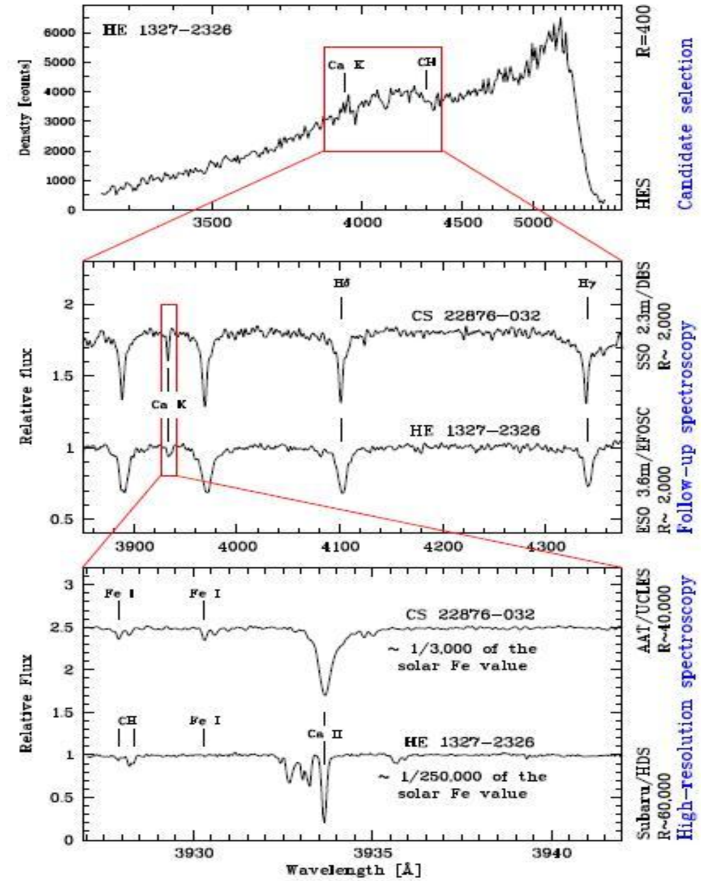
TMT will enable measurement of F in a large sample of K and M giants with a range of metallicities and ages and unravel its origin and evolution.

First detection of F1 lines in cool EHe stars (Pandey 2006)

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: HK, Hamburg/ESO, SDSS, SkyMapper

CD -38245 (UMP, [Fe/H] < -4 , Bessel and Norris 1984)

HE 0557-4840 (UMP, [Fe/H] < -4, Norris et al. 2007)

HE 1327-2326 (HMP, [Fe/H] < -5, Frebel et al. 2005, Aoki et al. 2006)

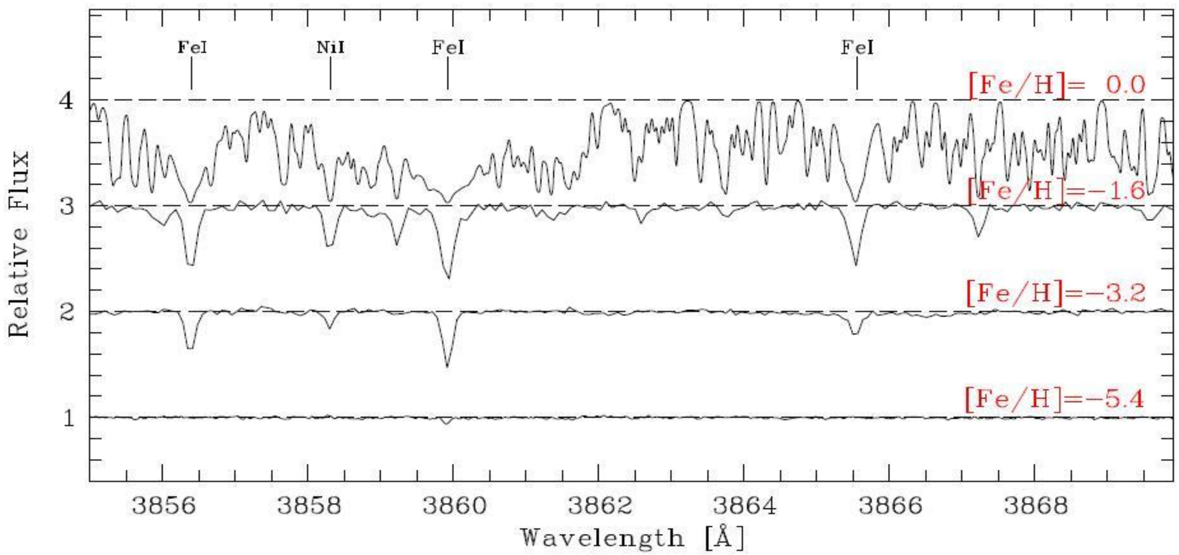
HE 0107-5240 (HMP, [Fe/H] < -5, christlieb et al. 2002)

SMSS 0313-6708 ([Fe/H] < -7, upper limit, Keller et al. 2014)

If low-mass (< 0.8 $M_{\odot}$) stars were able to from in primordial, metal-free gas clouds, stars with zero-metallicity are expected to be found in the present Galaxy

➢ 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,

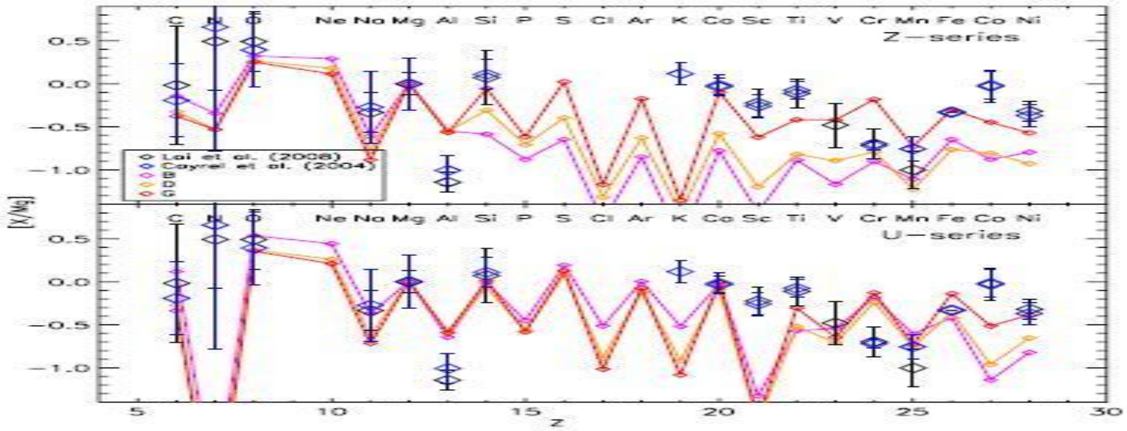
  at R ~ 40000 and SNR ~ 200 , the required exp time ~ 4 hrs

Mass distribution of first generation of stars

- There have been attempts to indirectly constrain the masses of Pop III stars by comparing the cumulative elemental yield of their supernovae to the chemical abundances found in ancient metal-poor stars in the Galactic halo, some of which may be 2^{nd} -generation stars.

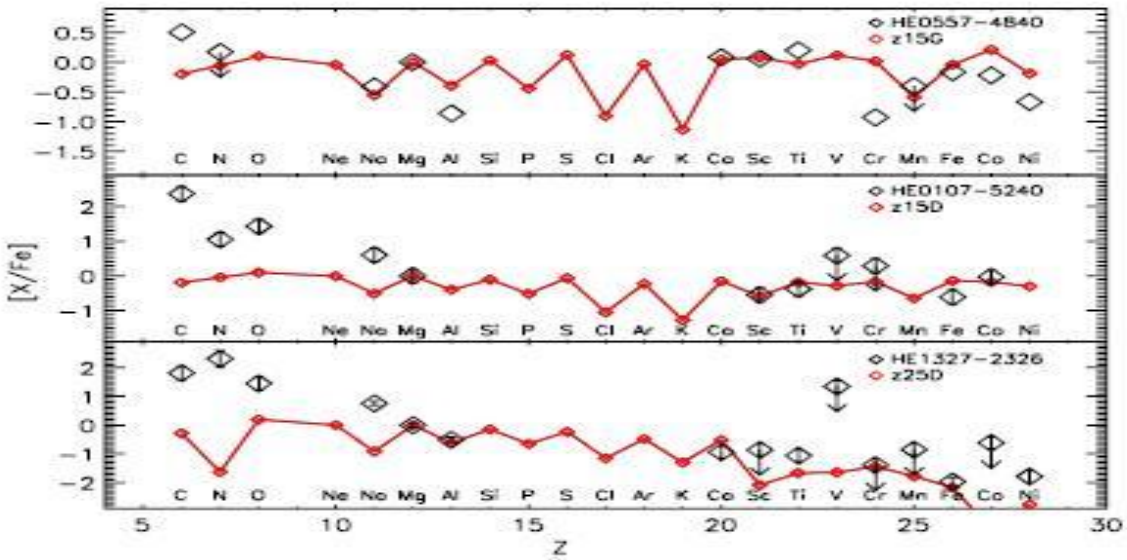
➢ Constraining the Pop III IMF with stellar archaeology

Chemical imprint of low-mass Pop III SNe on later generations of stars obtained by modelling mixing and fallback onto the central blackhole in 15 – 40 $M_{\odot}$ Pop III CC explosions (Joggerst et al. 2010)



Salpeter power-law IMF average of the elemental yields of explosions from a zero metalilcity 15 $M_{\odot}$ is in good agreement with the abundances in a sample of 130 extremely metal-poor stars with $Z < 10^{-4} Z_{\odot}$

➢ Comparison of best-fit yields with observations: HMP stars



Joggerst et al. (2010)

HE 0557-4840

Abundances well reproduced by the yields from model z15G. Above Na -- modelled well

HE 1327-2326 and HE 0107-5240

High C, N, O abundances are not well reproduced by z15D and z25D models

Origin of HMP stars?

Inheriting the ejecta from a single SN II, multiple generations of SN, result of mass transfer binary ?

- Reconciling Pop III SN yields to the elemental abundance patterns in MP stars in still in its infancy

- Abundance from a small no of MP stars,
- Abundance uncertainties,
- Poor understanding of the intervening hydrodynamical processes between the expulsion of the first metals and their uptake into new stars

Detailed measurements of chemical compositions of metal-poor stars with peculiar abundance ratios, will provide useful constraints on the existence or fraction of very massive stars in the early universe (Karlsson et al. 2008). High resolution spectra for such studies can be obtained witth TMT/HROS.

ISOTOPE RATIOS

A new window into

Nucleosynthesis,

GCE

Mixing within stars and stellar evolution.

Such data when available significantly improves our understanding of nuclear processes in various astrophysical sites.

A spectral resolution of at least 90,000 combined with very high S/N ratios is required to measure isotopic ratio s in stellar spectra.

➢ Exploring contribution of AGB stars to the Galactic chemical inventory using isotopic ratios of Mg

In young Galaxy there was not enough time for AGB stars to contribute

CC SNe started exploding quickly after massive stars first formed

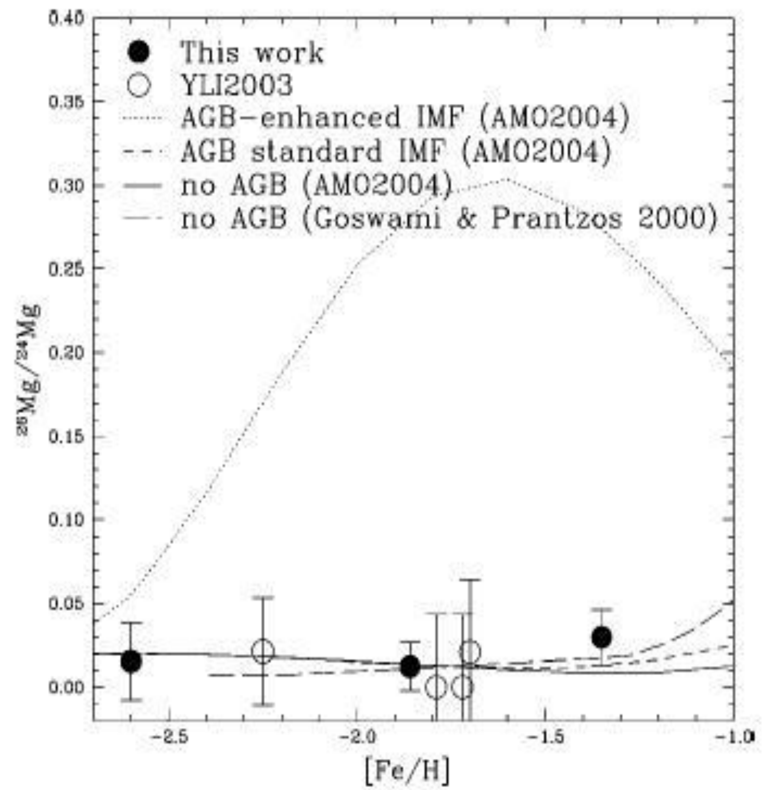
^{24}Mg : produced in massive stars

^{25,26}Mg: produced in AGB stars

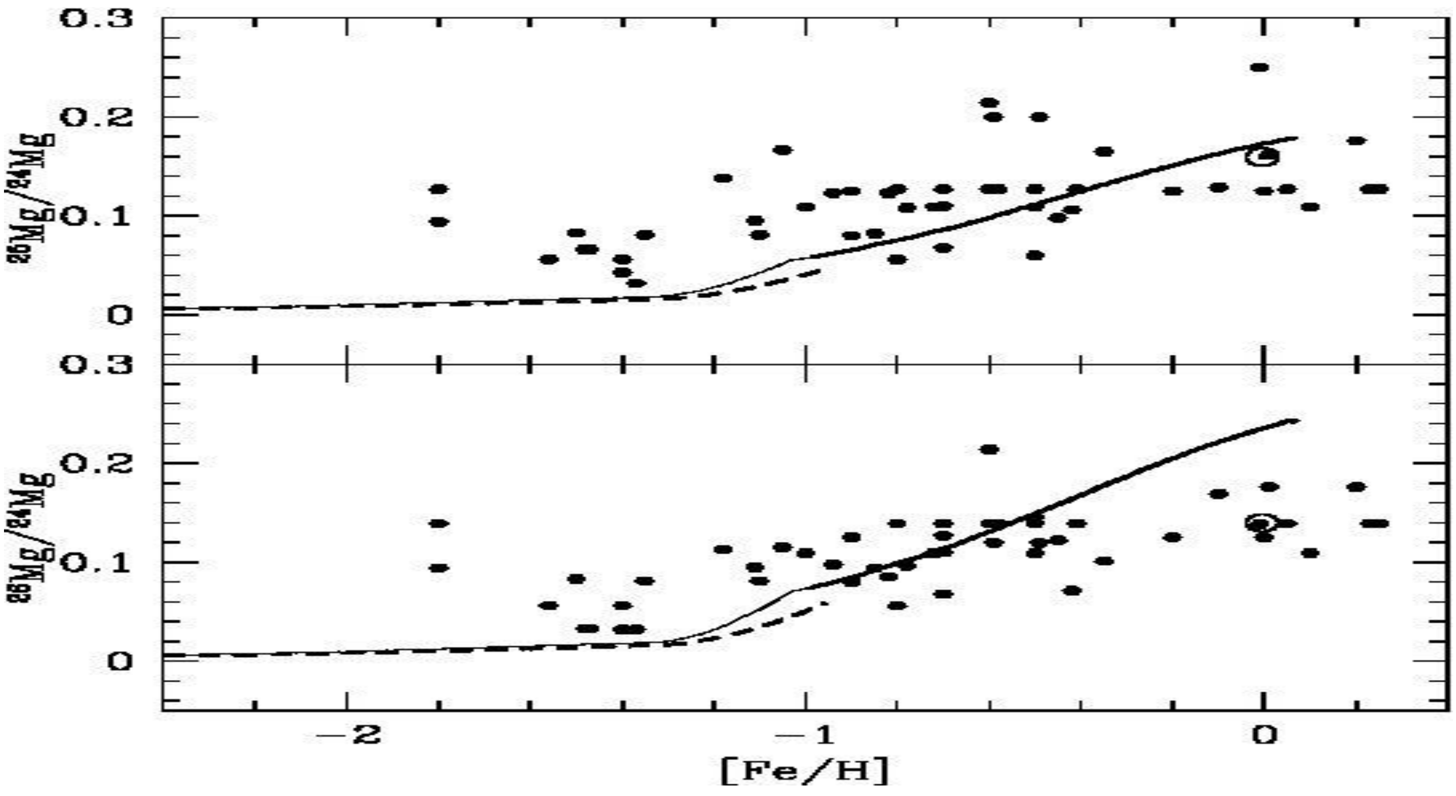
Ratios among the Mg isotopes can be used to explore when the AGB stars began to contribute to the GC inventory

(^{24,25,26}Mg): MgH band near 5140Å

R > 90000, S/N = 200 per spectral resolution element



^{26}Mg/^{24}Mg as a function of [Fe/H] in halo stars. Galactic nucleosynthesis models including yields of massive stars and in some cases intermediate-mass AGB stars are shown (Melendez & Cohen 2007). (Source: TMT.PSC.TEC.07.003.REL01)



Evolution of the isotopic abundance ratios of Mg as a function of metallicity [Fe/H]. The observed isotopic ratios from literature are shown with black dots . In both the panels the solid line corresponds to the disk model , the dashed line corresponds to halo model.

➢ Testing cosmic chemical homogeneity with isotopic ratios

$^{12}C/^{13}C$: to infer the degree of mixing of internally processed material with the outer layers of stellar atmosphere

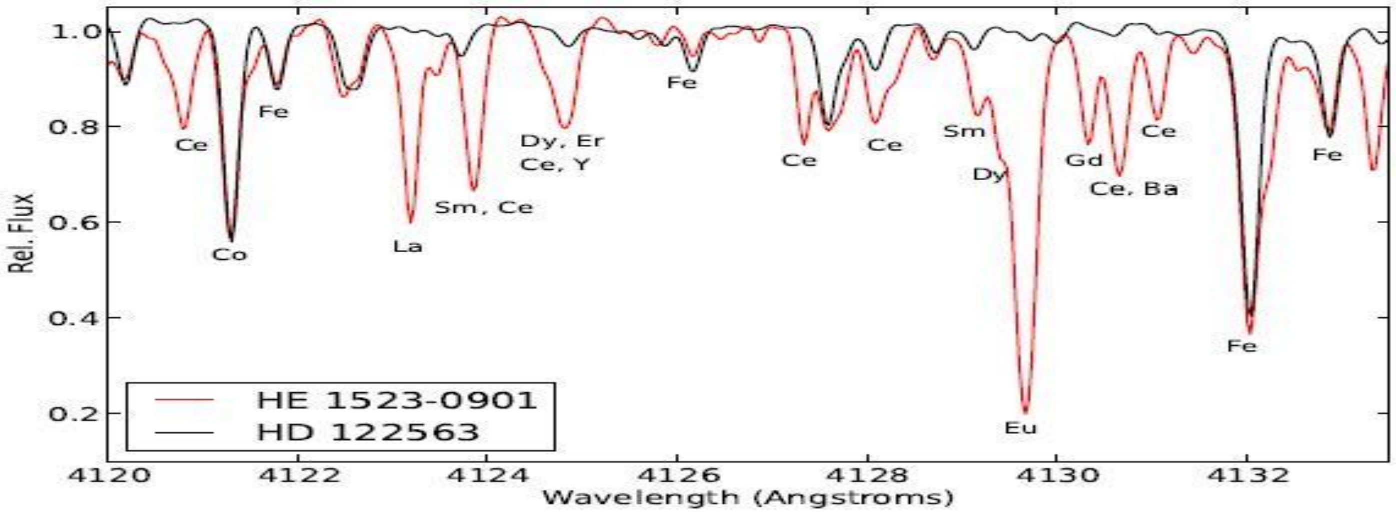
- ➢ stellar classification
- CH stars: extrinsic / intrinsic
- Origin of RCBs : merger of white dwarfs/ Helium shell flash

➢Finding the Origin of heavy elements using isotopic ratios

^{151}Eu/^{151}Eu+^{153}Eu

< 0.5 if there is substantial contribution from r-process

> 0.6 if s-process dominated



HR spectra (R ~ 30000) of r-process element rich star HE 1523-0901. HD 122563 is r-process element deficient (black); these two stars have similar [Fe/H] values and atmospheric parameters.

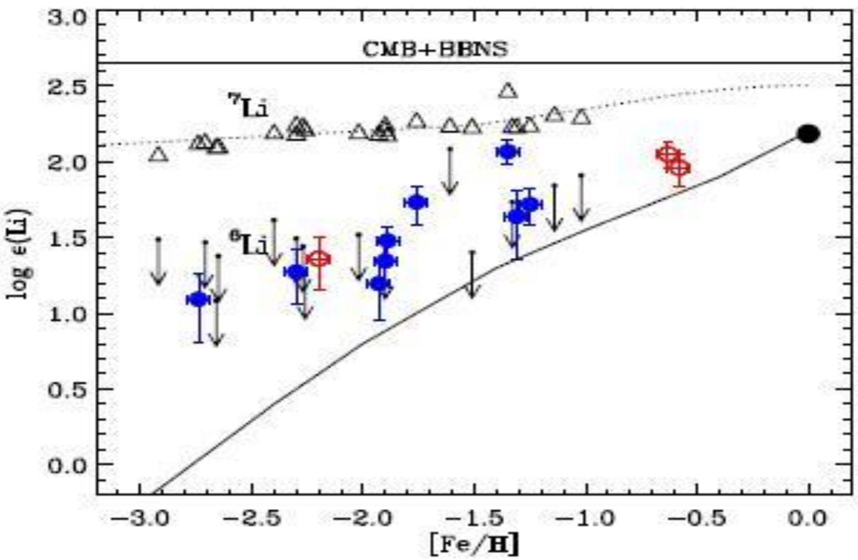
With TMT/HROS it will be possible to obtain spectra with, R > 90000 and measure the isotopic ratios .

Useful to determine the origin of n-capture elements in CEMP-r/s stars.

➢ Isotopic abundances of Li and Big Bang nucleosynthesis

➢ $^{6}Li/^{7}Li$: is Li in MPs primordial?

Insight from MS stars of GCs, Local dwarfs



Small but statistically significant

increase of ^{7}Li abundance with [Fe/H]

Existence of a plateau of ^{6}Li ?

(Asplund et al. 2005)

log Є(Li) = 2.62 +/- 0.05, based on WMAP baryon density

(larger by a factor of 3) (Coc et al. 2004) $^{7}Be(d,p)2^{4}He$, $^{7}Be(n,p)^{7}Li$

Currently, no experimental data at SBBN energies are available for these reactions

Another disagreement : $^{6}Li/^{7}Li = 10^{-5}$ (theory); $^{6}Li/^{7}Li = 10^{-2}$ (observation)

No detectable ^{6}Li is produced in SBBN-

Possibilities: non-standard BBN, or pre-galactic fusion of ^{4}He (Prantzos 2005)

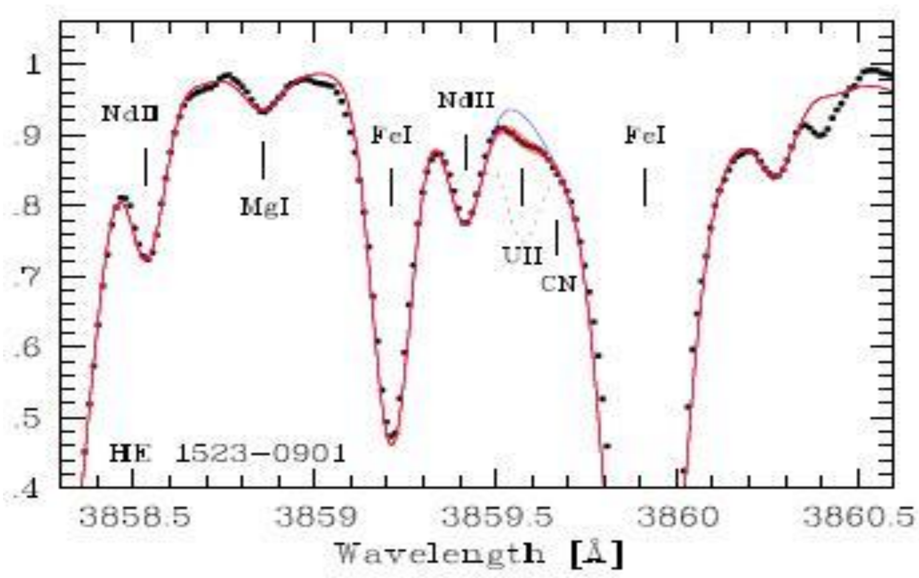
HE 1327-2326: Li abun is 0.6 dex lower than the primordial value of 2.09; appears to have been depleted by a presently unknown mechanism (Ryan et al. 2000, Asplund et al. 2007).

➢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

➢ TMT studies of Globular clusters: the origin and evolution

Photometric and spectroscopic evidence confirms the presence of multiple stellar populations in nearly all Galactic globular clusters.

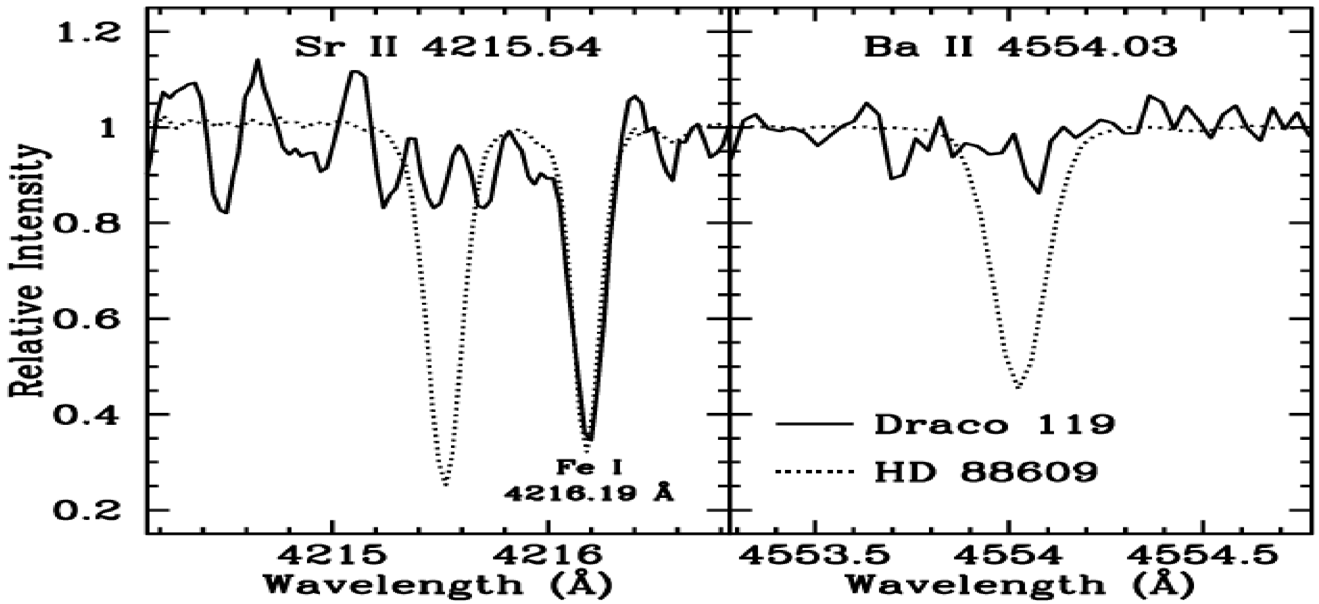
To understand the star forming regions in the early universe that will be detected and studied with TMT,, we need to study first the origin and evolution of such clusters in the local universe.

Galctic clusters study:
possible with 8 – 10 m telescope

Understanding the implications of multiple stellar populations in globular clusters beyond the local group will require TMT (spatial resolution and light gathering power of TMT).

➢HR spectroscopy of Stellar Systems in the Local Group

Ultrafaint dwarfs in the Milky Way subjected to high dispersion abundance analysis show striking anomalous enhancements in individual elements.



Neutron-capture elements are deficient in a red giant (D119) in the Draco Dwarf Spheroidal galaxy (Fe/H = -2.95); comparison with HD 88609, which has similar metallicity (Fulbright, Rich & Castro 2004). The Hercules dwarf spheroidal galaxy is showing similar striking deficiencies (Koch et al. 2013). The proposed MOBIE instrument on TMT would be capable of making measurements on giants similar to these even as distant as the Andromeda galaxy. Recently, a metal-poor giant has been found in a binary system in Hercules (Koch et al. 2014).

➢ Probing Galactic halo assembly history

- Model simulation of structure growth: Halos of the Galaxies like the Milky Way have accreted and subsequently destroyed 10s - 100s of small dwarf galaxies in the past 10 Gyr

- Abundance of RGB stars belonging to Local Group dwarf Galaxies are found to be very different from stars of Milky Way halo, disk, bulge and moving groups (Venn et al. 2004, Navarro et al. 2004)

- To investigate environmental differences between the various dwarf Galaxies detailed examination of the kinematics, metallicities, and abundance ratios of stars in dwarf galaxies beyond the Milky Way halo are necessary.

With 8 – 10m, Exposure time 14 hrs,

Stars, Local group spheroidal galaxies, V ~ 17-18, distance 250 kpc

With TMT/HROS,

Stars, V ~20, 400-500 kpc, in more isolated systems

To be complemented by TMT/NIRES obs of stars below the tip of the RGB

throughout the Local group – useful for CNO abundances.

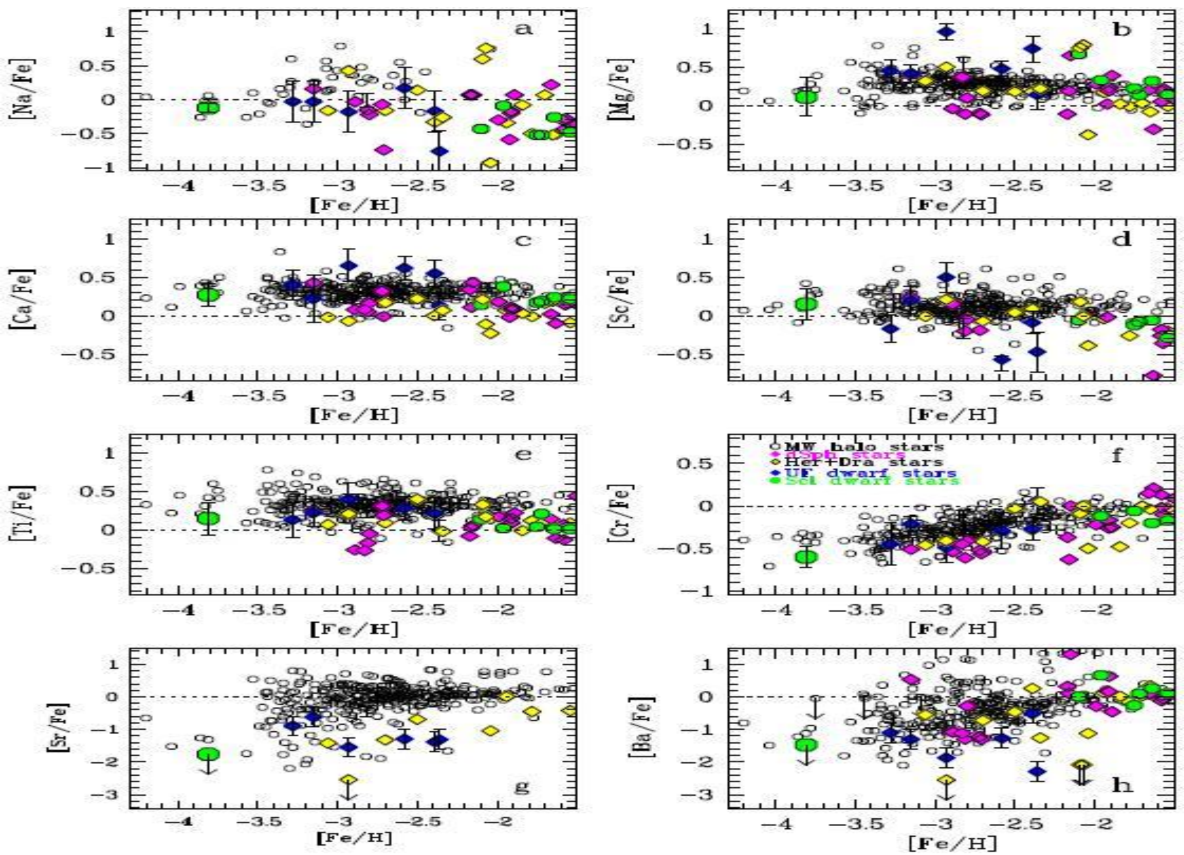
Based on the apparent absence of the most metal-poor stars in present-day dwarf galaxies, recent studies (Helmi et al. 2006) claimed that the true Galactic building blocks must have been vastly different from the surviving dwarfs.

The discovery of an extremely iron-poor star (S102054, [Fe/H] -3.8) in the Sculptor dwarf galaxy based on a medium-resolution spectrum (Kirby et al. 2009) cast some doubt on this conclusion.

However, verification of the iron-deficiency and measurements of additional elements, such as the alpha-element Mg, are mandatory for demonstrating that the same type of stars produced the metals found in dwarf galaxies and the Galactic halo.

Frebel et al. showed that the overall abundance pattern mirrors that seen in low-metallicity halo stars, including alpha-elements. Such chemical similarity indicates that the systems destroyed to form the halo billions of years ago were not fundamentally different from the progenitors of present-day dwarfs, and suggests that the early chemical enrichment of all galaxies may be nearly identical.

➢ Galactic building blocks different from surviving dwarfs?



Abundance ratios as a function of iron abundance in S1020549 and other metal-poor stars. In eight elements, **S1020549 (big green filled circle** at [Fe/H] -3.8) is compared with **halo stars (black circles), ultra-faint dwarf galaxy stars (blue diamonds)** and the **brighter dwarf galaxy stars (pink and yellow diamonds)**. Small green circles indicate higher metallicity Sculptor targets (Frebel et al.)

➢ Stellar astrophysics

TMT could make major contributions in several area of stellar astrophysics study.

- ➢ Diffusion of heavy elements in the outer parts of stars
- Acts slowly with time scales of 10^9 yrs
- Most important for MS stars, particularly MP stars
- To observe diffusion in action is to compare the elemental abundances for heavy elements near the Fe-peak of MS versus red giant and sub-giant stars in metal-poor globular clusters

➢ Evolution of massive stars with low-metallicity

Rapid-rotators significantly enrich the ISM in H- and He-burning products

Study of young massive stars in a very metal-poor star-forming dwarf galaxy

Star-forming dwarf galaxies are not close enough to obtain spectroscopy with existing 8 -10m telescope

With MOBIE, it will be possible to observe brightest supergiants in the nearest very metal-poor dwarf galaxies to determine the mass-loss rate as a function of metallicity.

➢ Studies for which TMT is critical

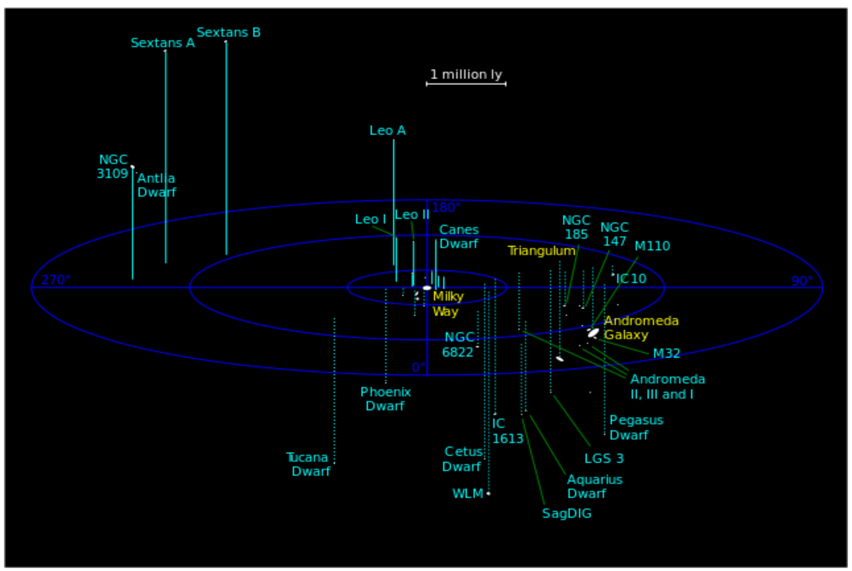
- ❖ Probing Galactic halo assembly history
- ❖ Probing chemical evolution of nearby galaxies
- ❖ Diffusion of heavy elements in the outer parts of stars
- ❖ Evolution of massive stars with low-metallicity
- ❖ Globular cluster abundance variations

➢ Limiting distances for spectroscopic observations of point sources

	M_v (mag)	WFOS (Mpc)	HROS (Mpc)	NIRES (Mpc)
Blue supergiant	−6.7	10.0	7.0	2.5
Red supergiant	−5.9	7.0	3.5	8.0
RGB Tip	−2.7	1.5	0.5	3.8

Assumes 4 hr integrations at $\lambda/\delta\lambda$ = 5000, 50000, and 25000 for WFOS, HROS, NIRES. The corresponding central WLs are 0.5 µm, 0.5µm, and 1.2µm,. SNR, 100, 100, 60

(J Cohen, CIT)



HROS

WL: 0.31 – 1.1 µm

Slit length: 5” ; R > 50000

NIRES

WL: 1 – 5 µm

Slit length : 2”, R ~ 20000 – 100000

Local Group –

Observable with TMT

Thank you