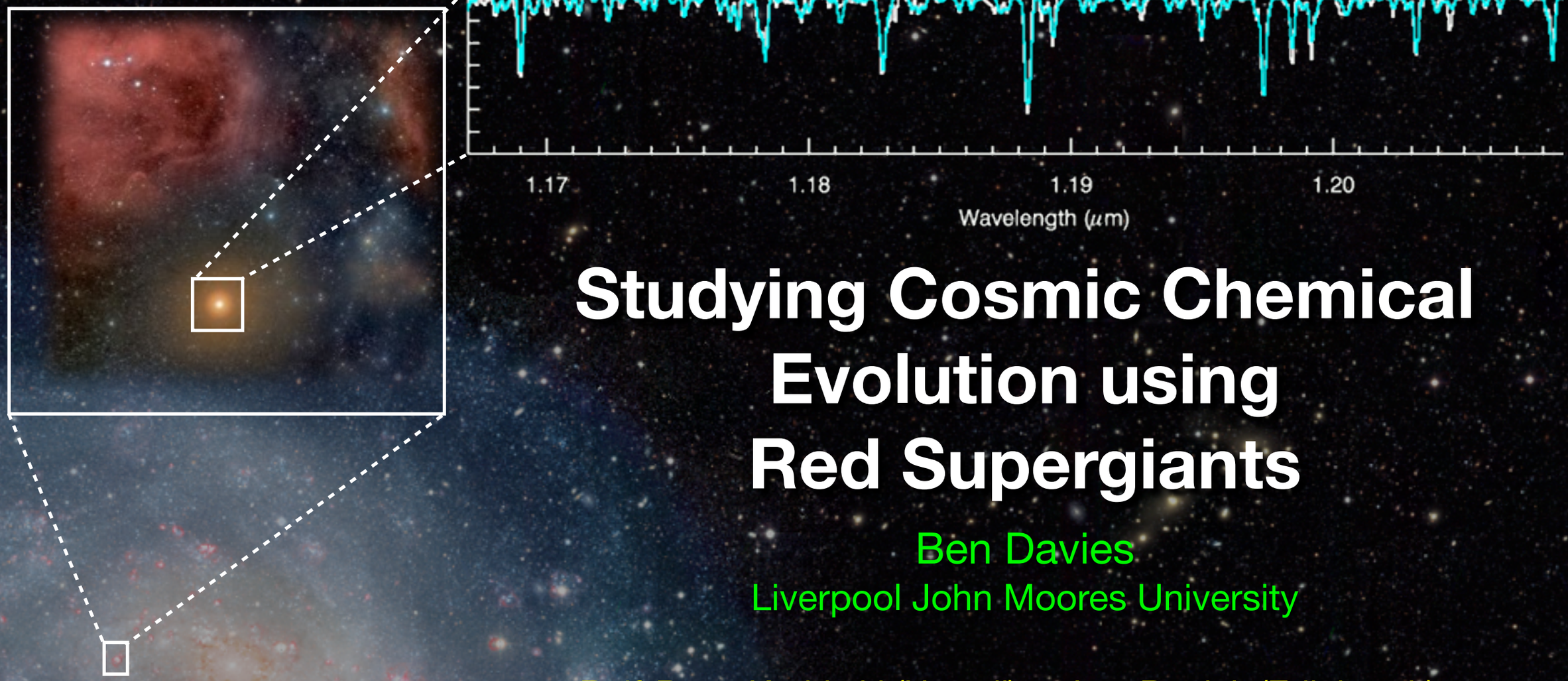
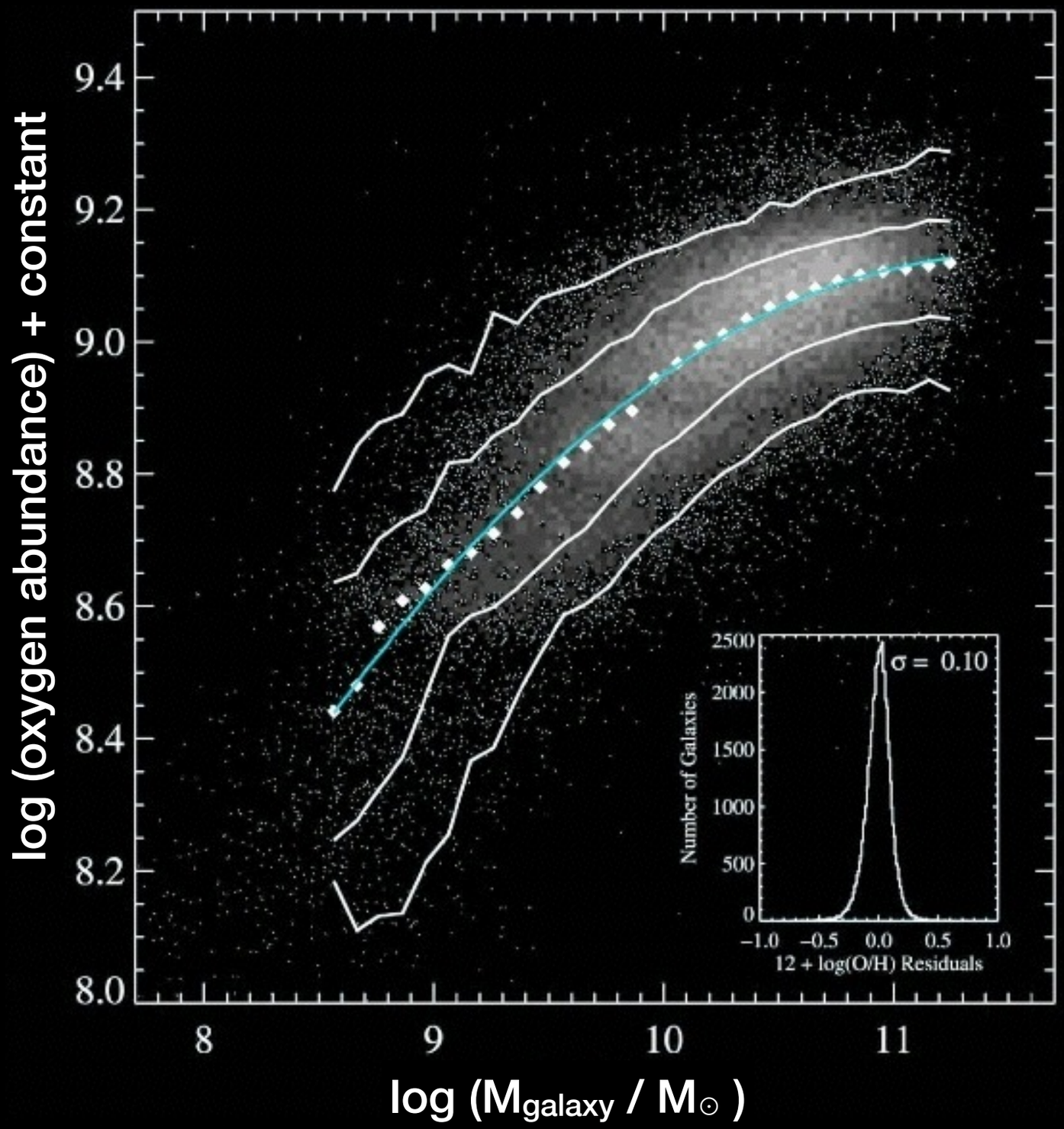


Studying Cosmic Chemical Evolution using Red Supergiants

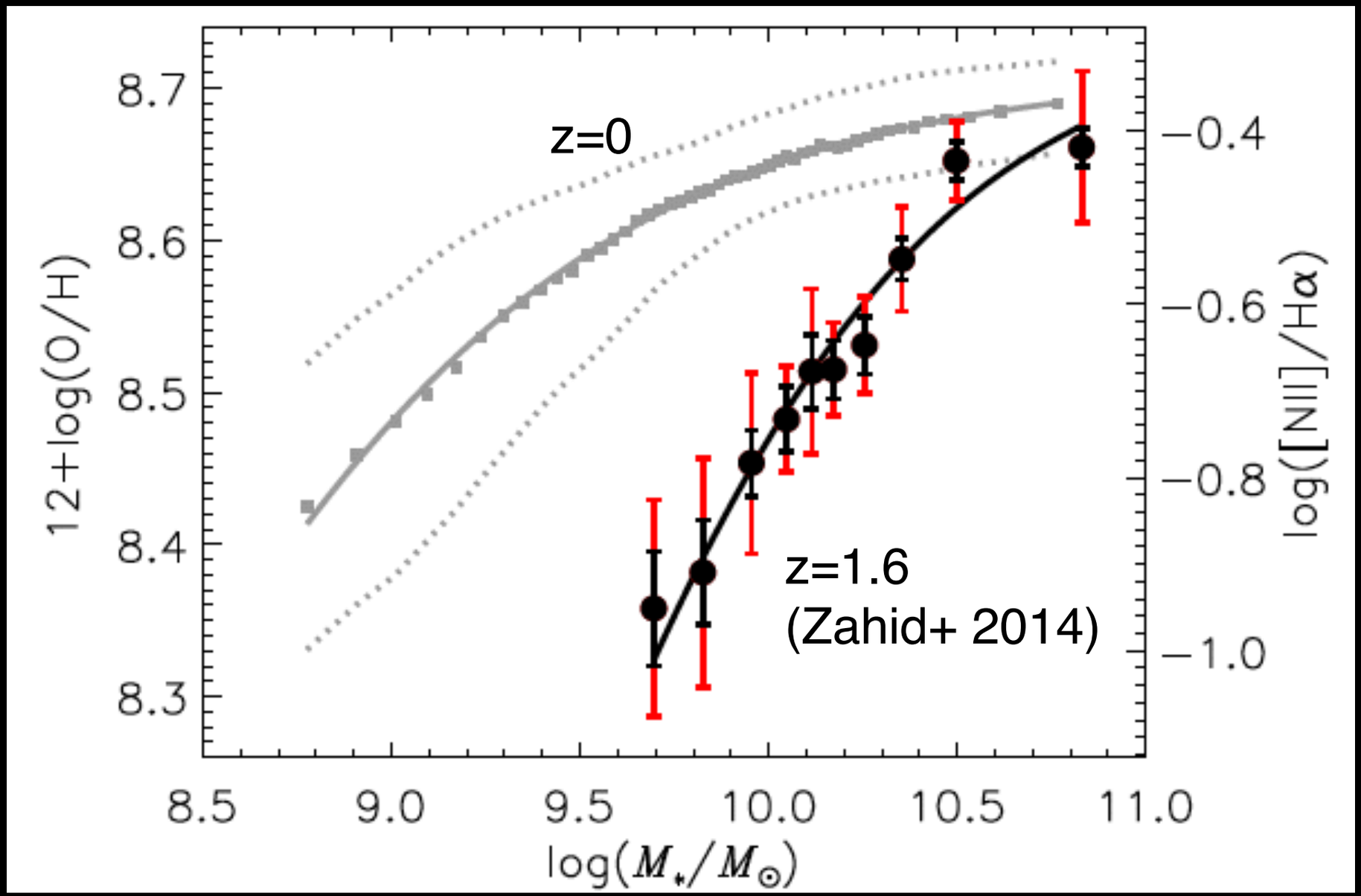
Ben Davies
Liverpool John Moores University

Rolf-Peter Kudritzki (Hawaii)
Zach Gazak (Hawaii)
Maria Bergemann (MPIA)
Chris Evans (Edinburgh)
Lee Patrick (Edinburgh)
Bertrand Plez (Montpellier)
Carmela Lardo (Liverpool)
Nate Bastian (Liverpool)

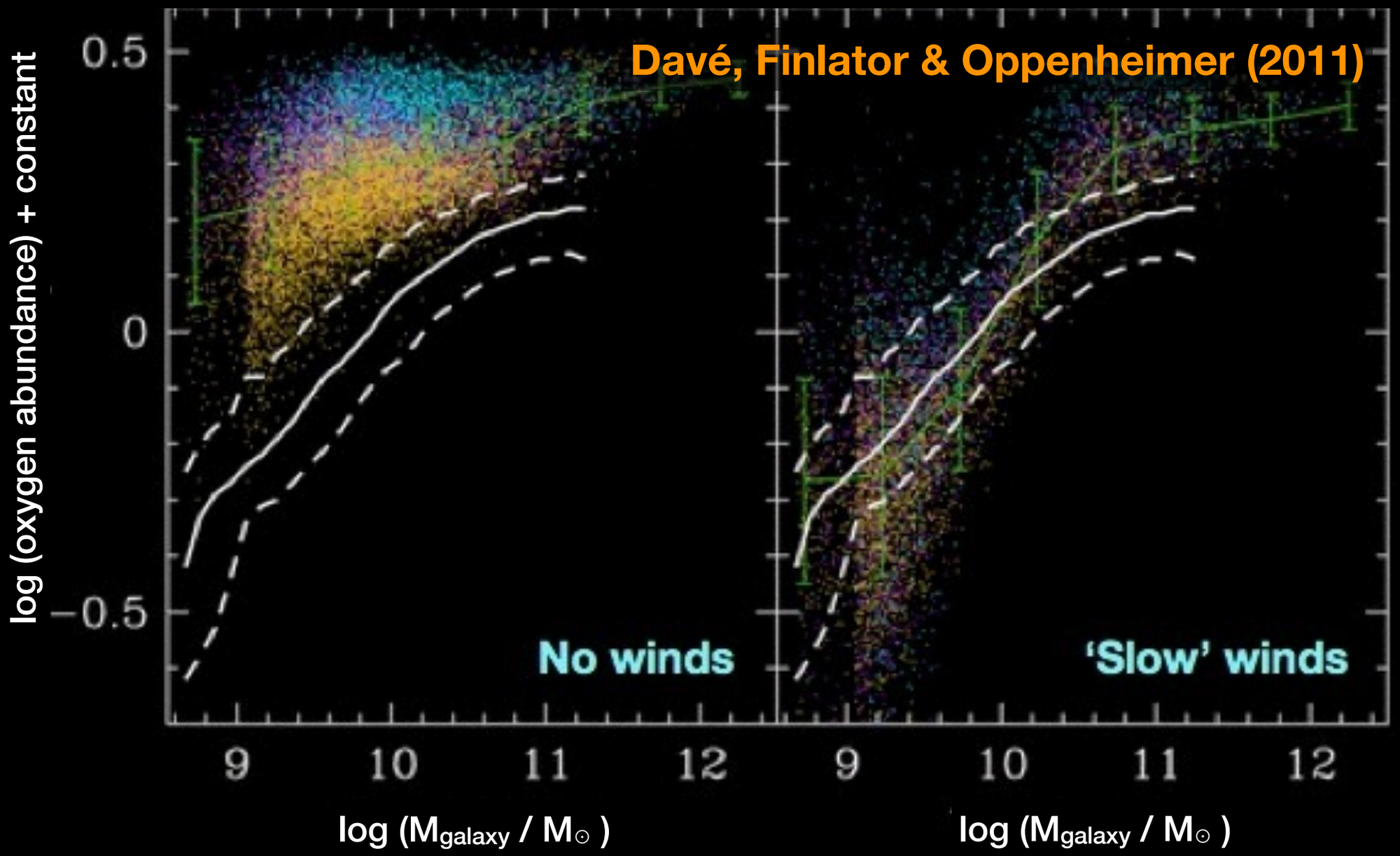


Mass-metallicity relationship of galaxies

Tremonti+ 2004

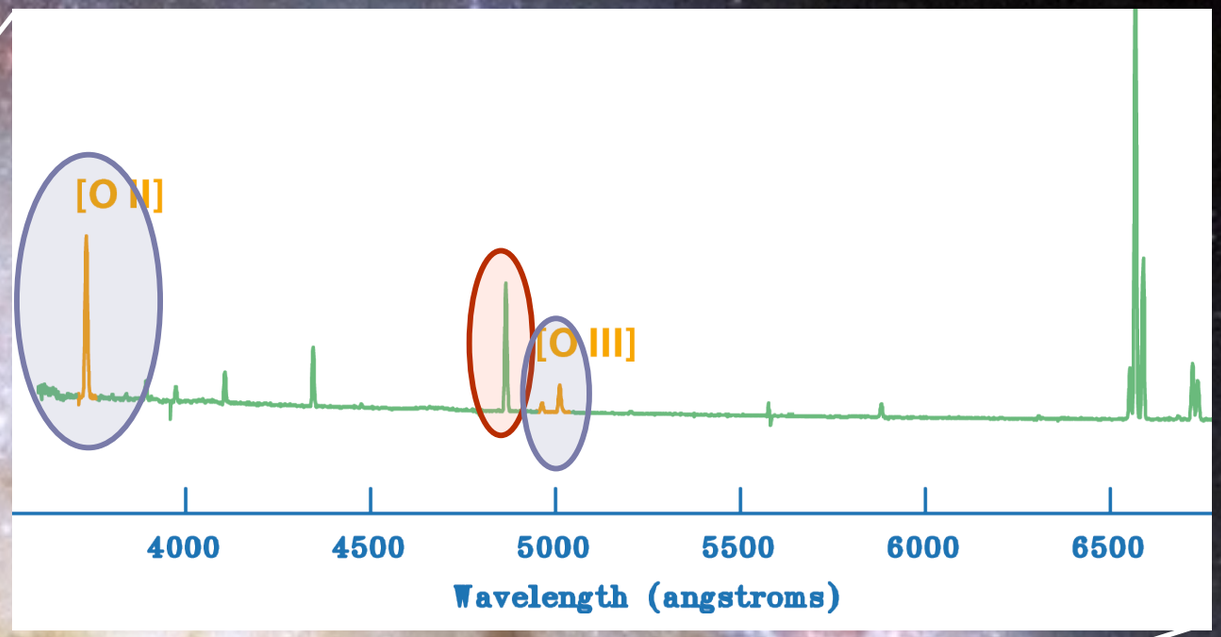


Zahid+ 2014: steepening of MZR at increased *z*
(strong line methods)



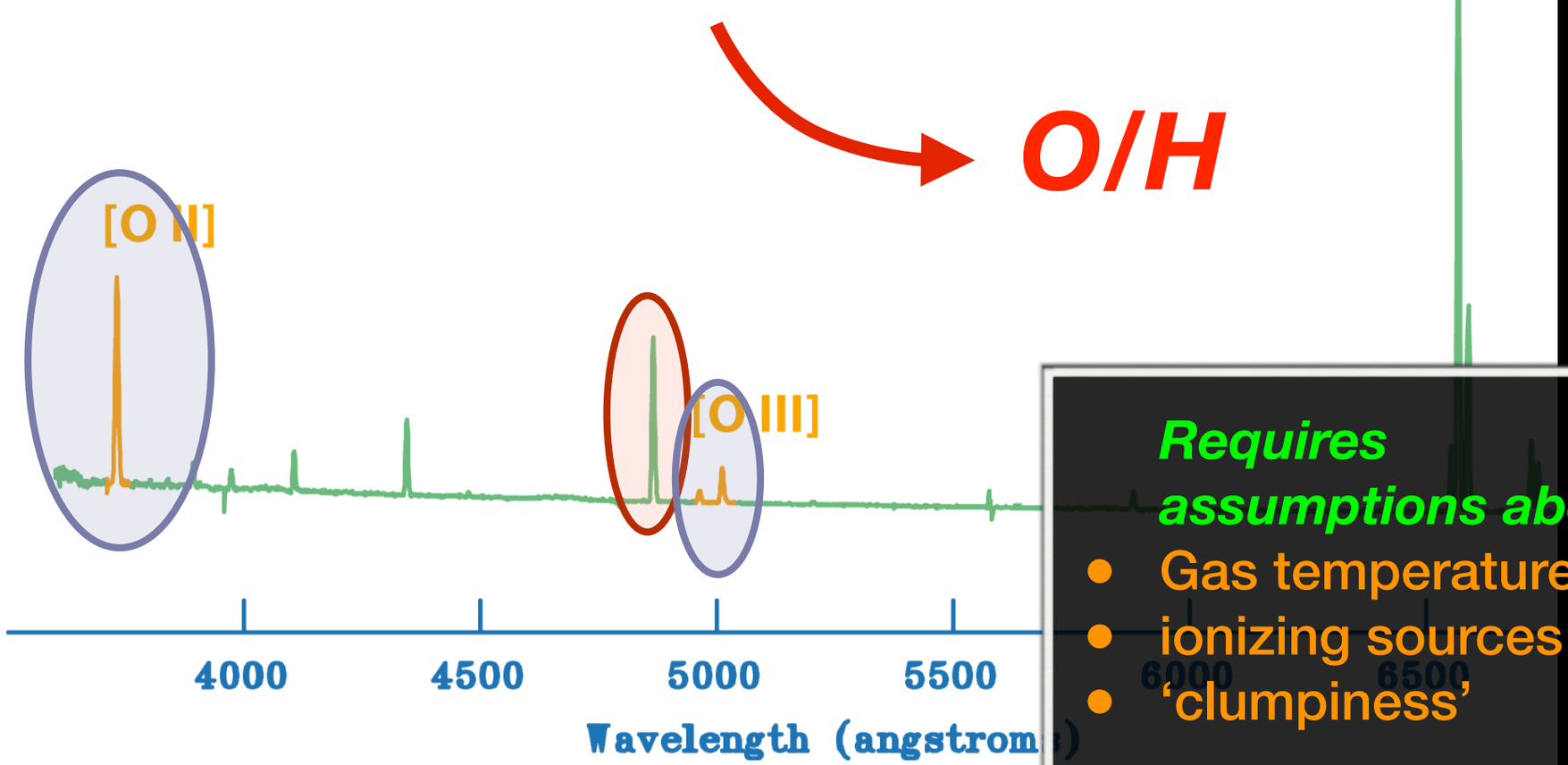
Mass-metallicity relationship of galaxies

Tremonti+ 2004


[O II]
[O III]
4000
4500
5000
5500
6000
6500
Wavelength (angstroms)

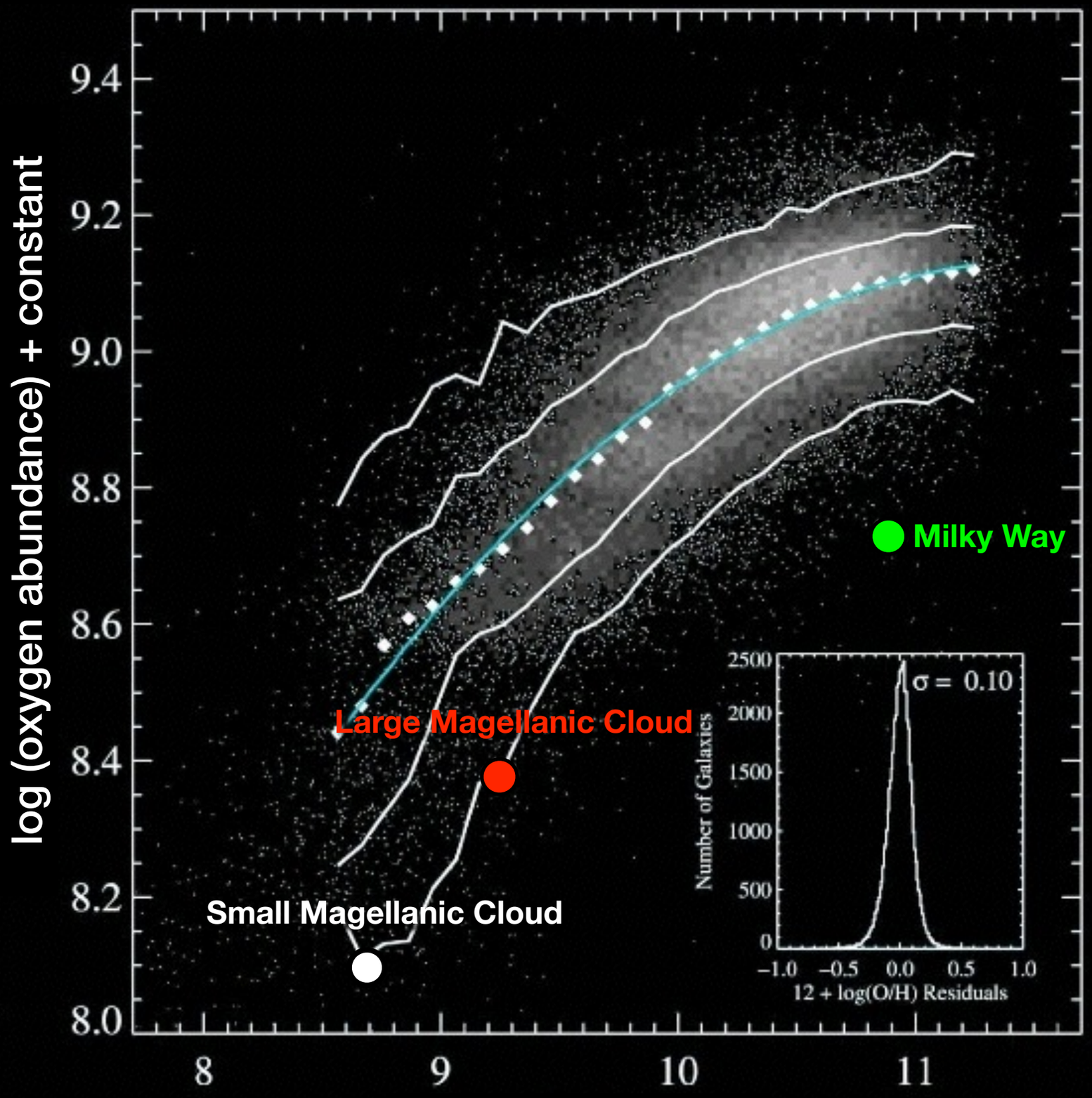
Strong-line method (a.k.a. R_{23})
observe strong oxygen emission lines,
& use O as tracer of metallicity

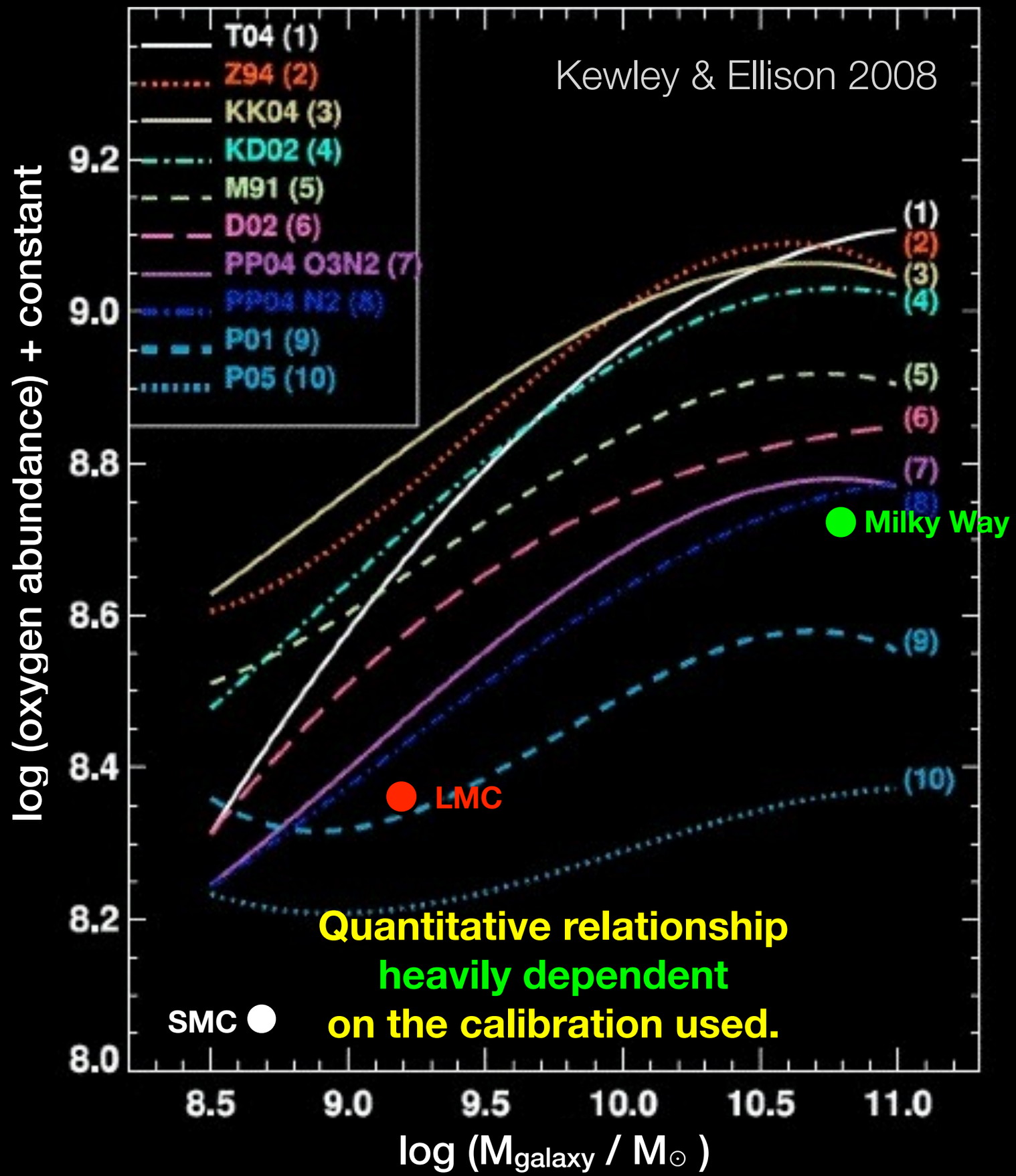
$$R_{23} = \frac{[\mathrm{O\,II}]3727 + [\mathrm{OIII}]4959, 5007}{\mathrm{H}\beta}$$

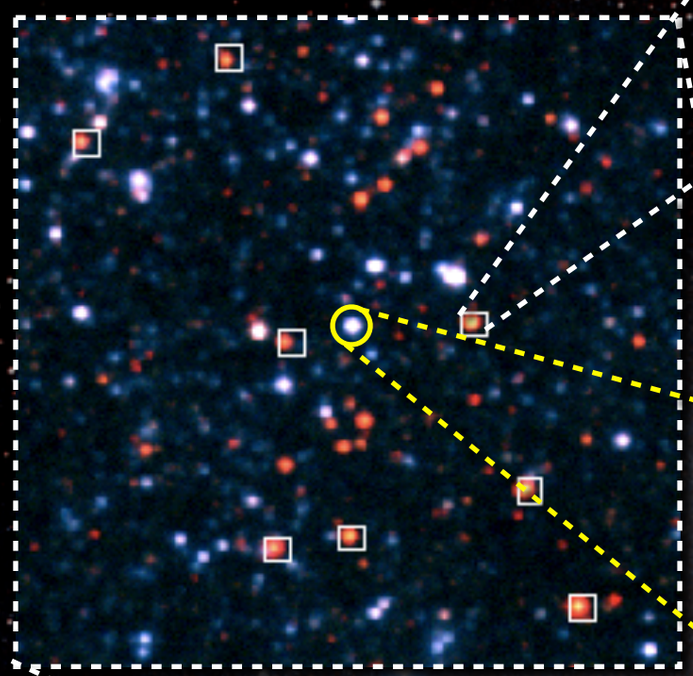


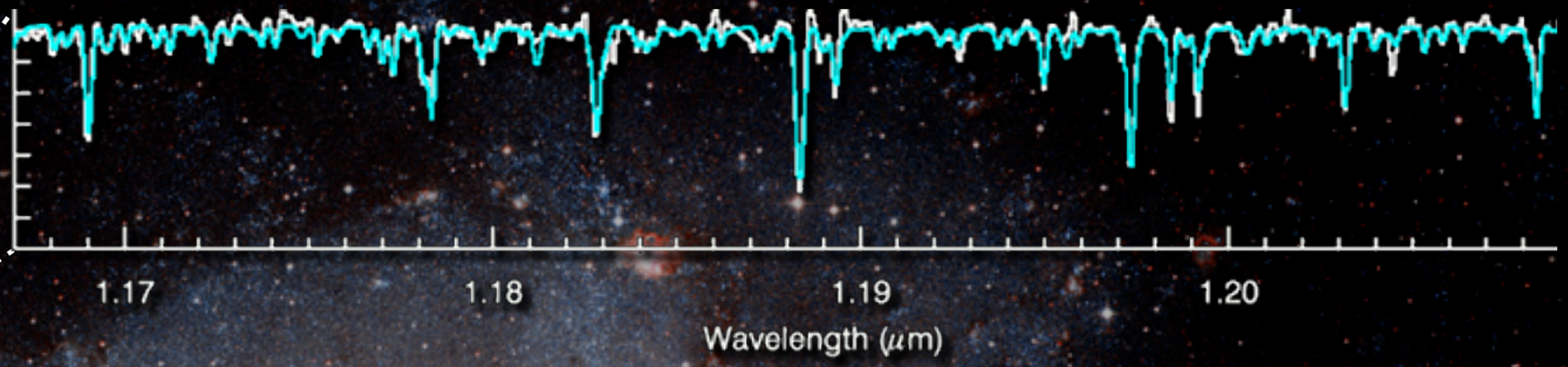
Requires assumptions about:

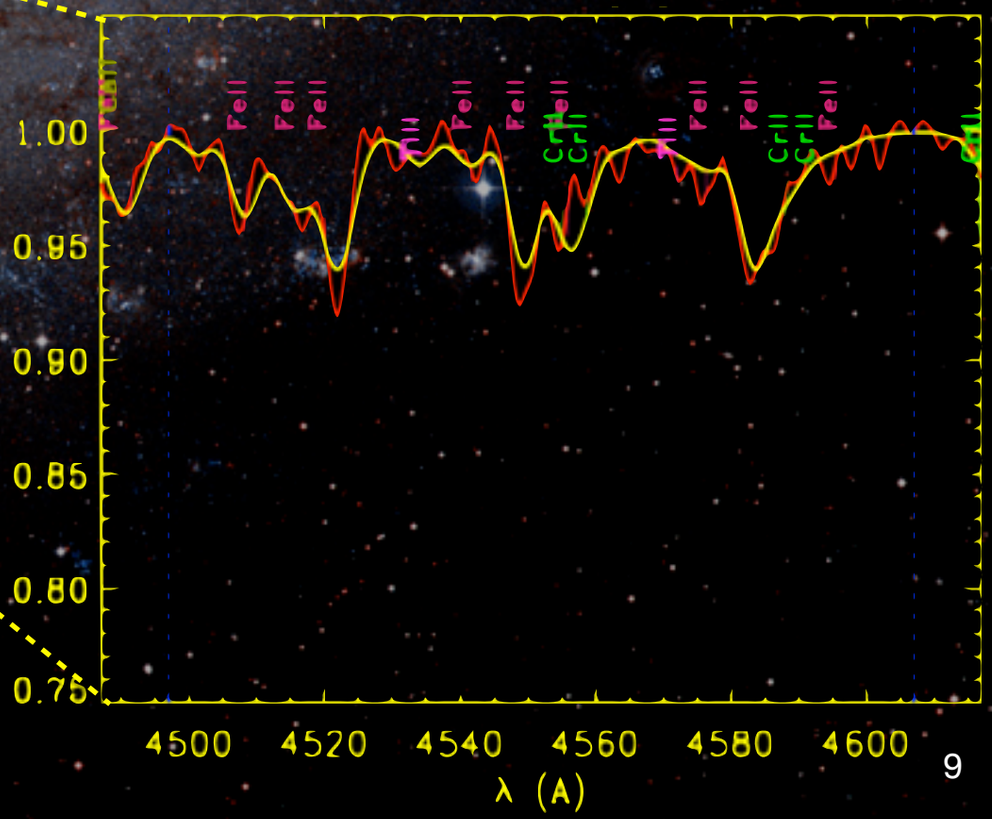
- Gas temperature
- ionizing sources
- 'clumpiness'


log (oxygen abundance) + constant
9.4
9.2
9.0
8.8
8.6
8.4
8.2
8.0
8
9
10
11
log (Mgalaxy / M⊙)
Milky Way
Large Magellanic Cloud
Small Magellanic Cloud
Number of Galaxies
2500
2000
1500
1000
500
0
σ = 0.10
−1.0
−0.5
0.0
0.5
1.0
12 + log(O/H) Residuals


Kewley & Ellison 2008
T04 (1)
Z94 (2)
KK04 (3)
KD02 (4)
M91 (5)
D02 (6)
PP04 O3N2 (7)
PP04 N2 (8)
P01 (9)
P05 (10)
log (oxygen abundance) + constant
9.2
9.0
8.8
8.6
8.4
8.2
8.0
(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
(9)
(10)
Milky Way
LMC
SMC
Quantitative relationship
heavily dependent
on the calibration used.
8.5
9.0
9.5
10.0
10.5
11.0
log (Mgalaxy / M⊙)







Supergiants as alternative cosmic abundance probes

Red Supergiants (RSGs) as cosmic abundance probes…

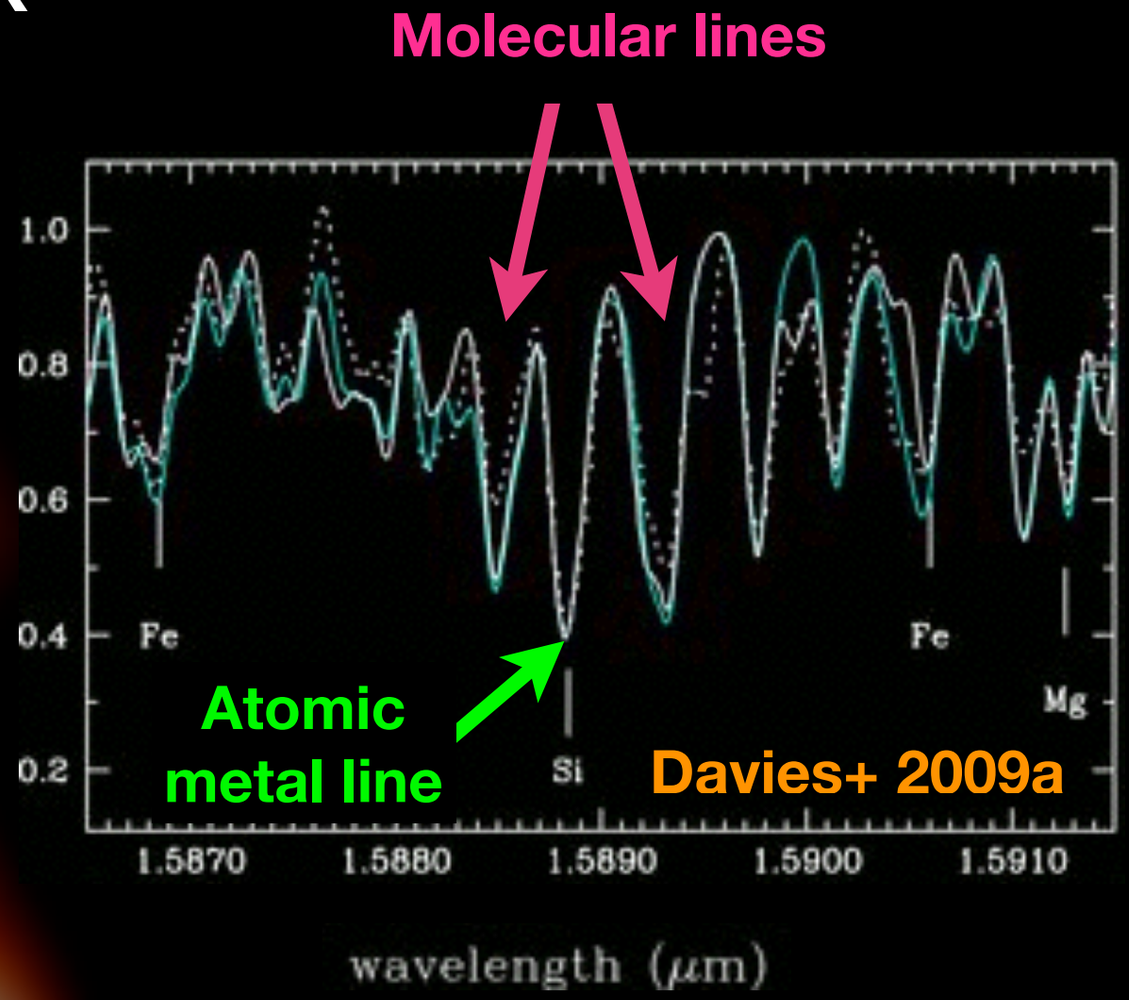
- Complementary to BSGs
- Greater potential for E-ELT:

★ Stars have flux-peaks in NIR

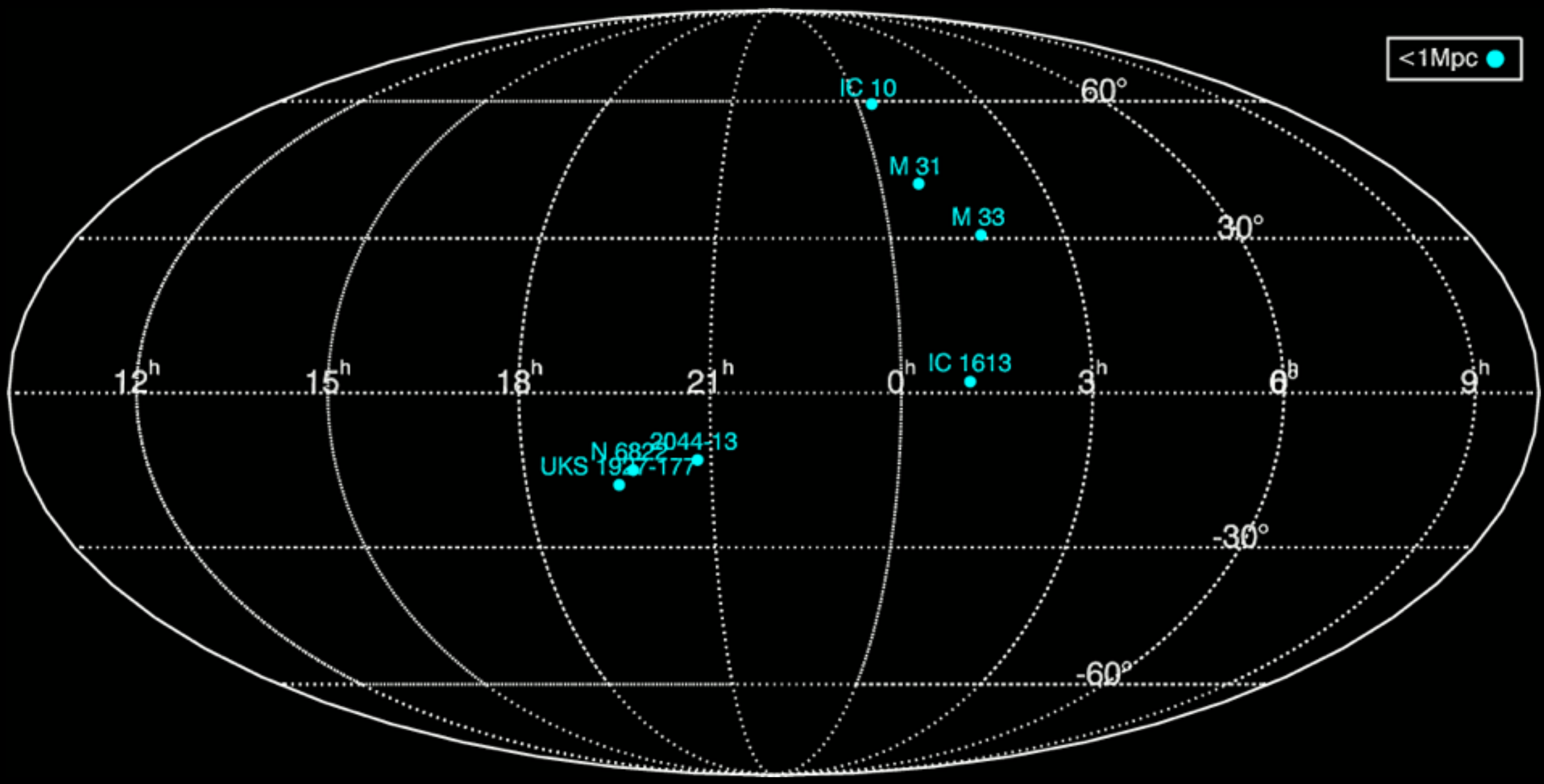
★ Method is NIR-based

Previous RSG abundance work

- Cool (T_{eff} ~ 4000K).
- Lots of molecular lines.
- High-res required (R>20,000)



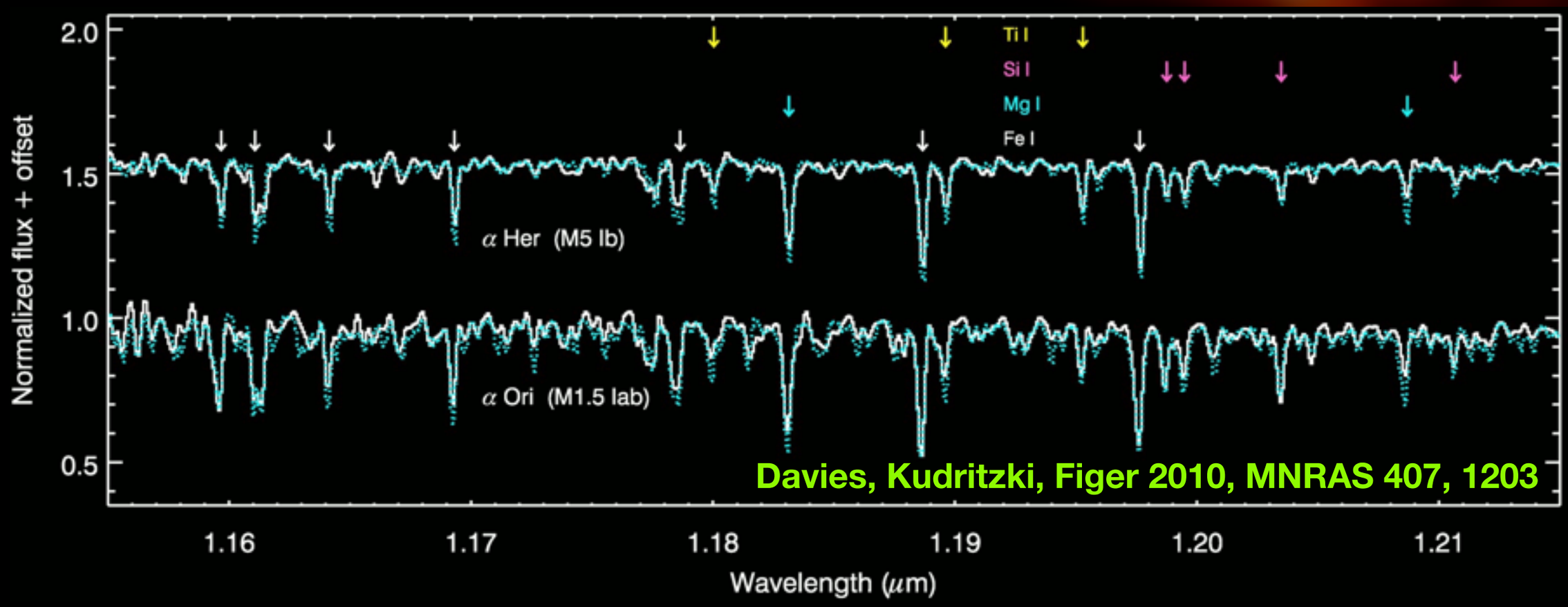
Not currently feasible for extra-galactic work (no targets!)



One star per galaxy, per night, at ~1Mpc **(VLT + CRIRES)**

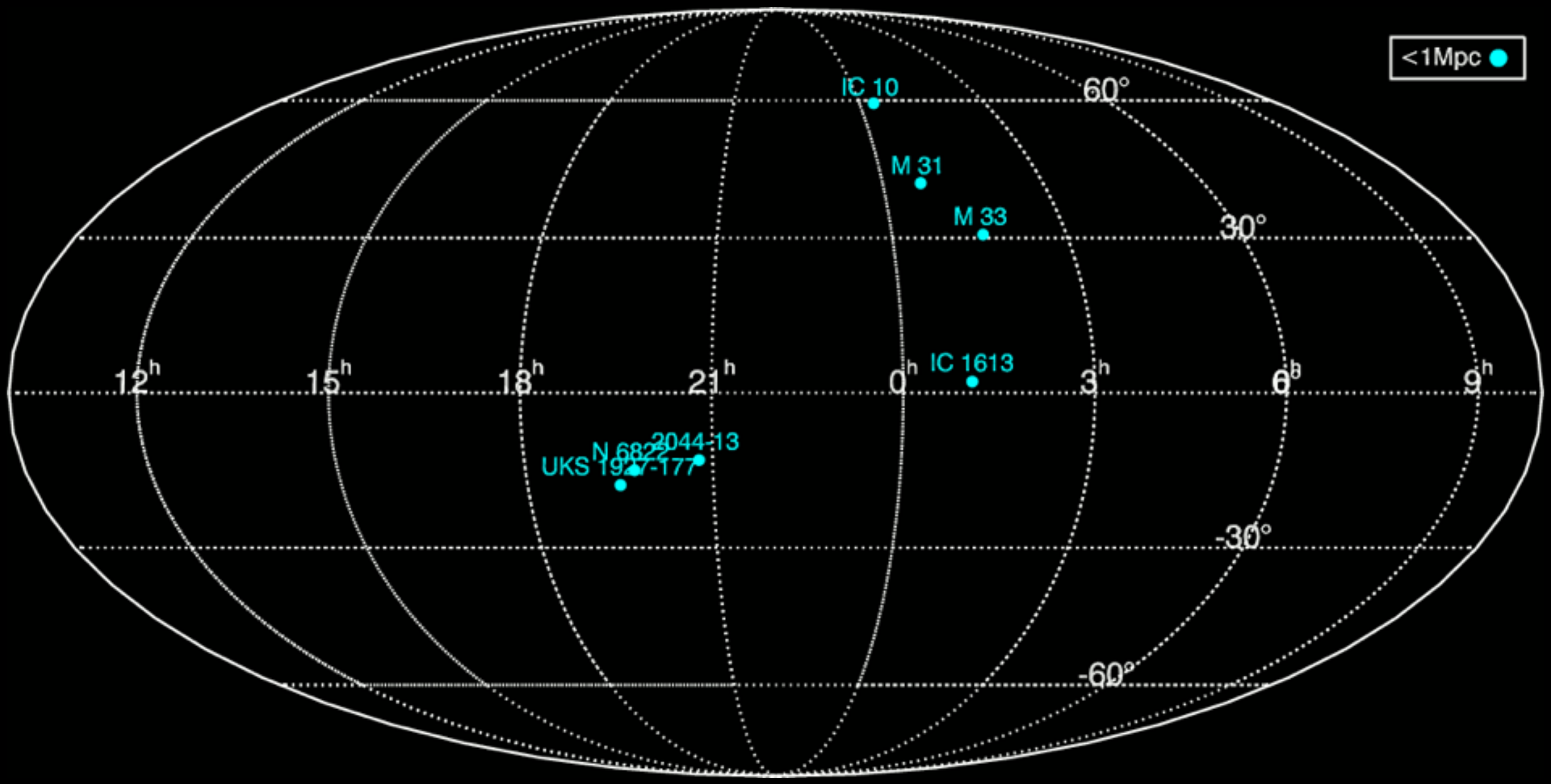
However, if we switch to J-band:

- Only atomic lines (molecular lines v. weak)
- Can get all stellar parameters
- Can drop resolution to R~3000
- Can use a MOS



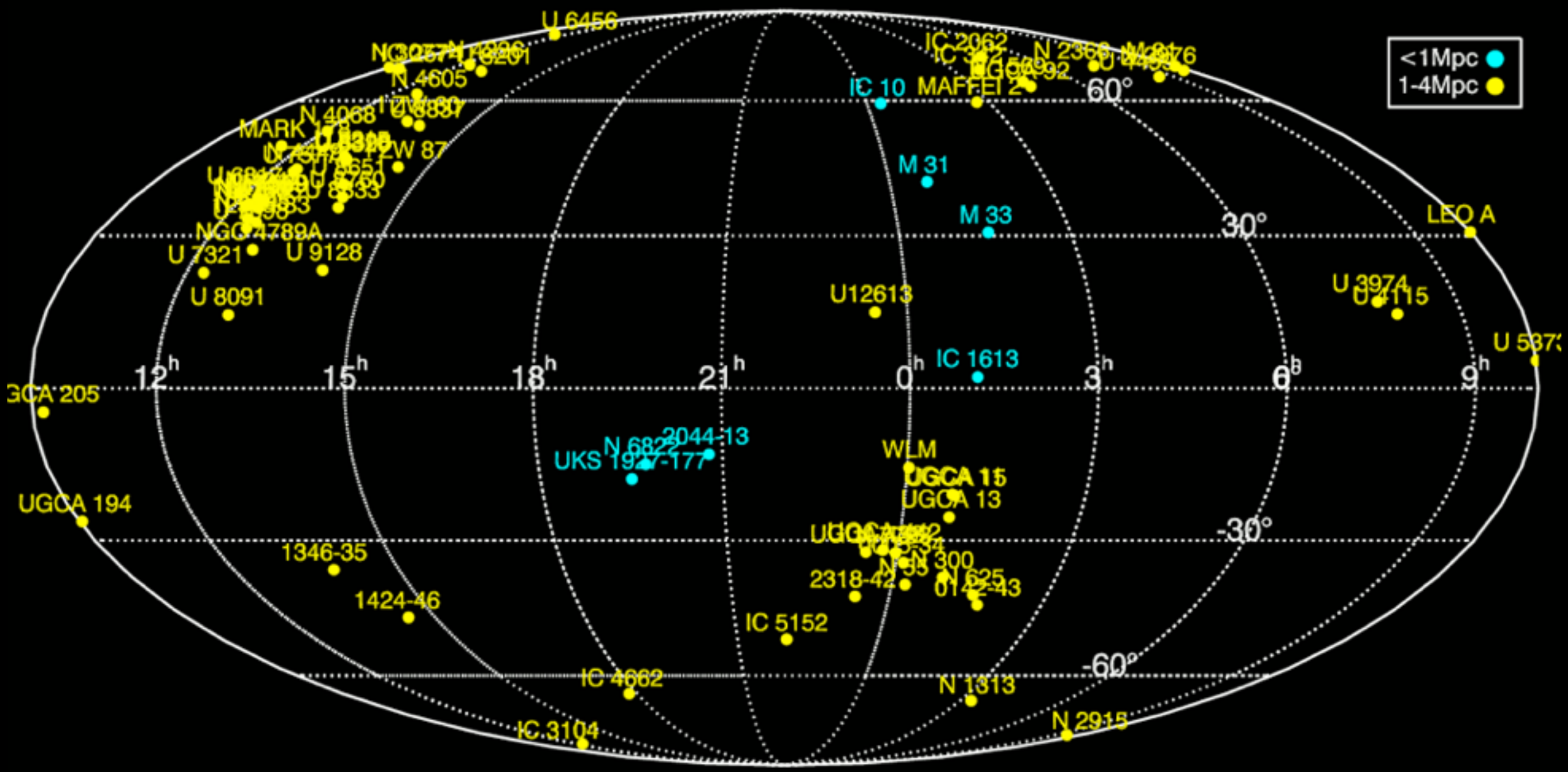
Davies, Kudritzki, Figer 2010, MNRAS 407, 1203

2. Red Supergiants



One star per galaxy, per night, at ~1Mpc **(VLT + CRIRES)**

2. Red Supergiants

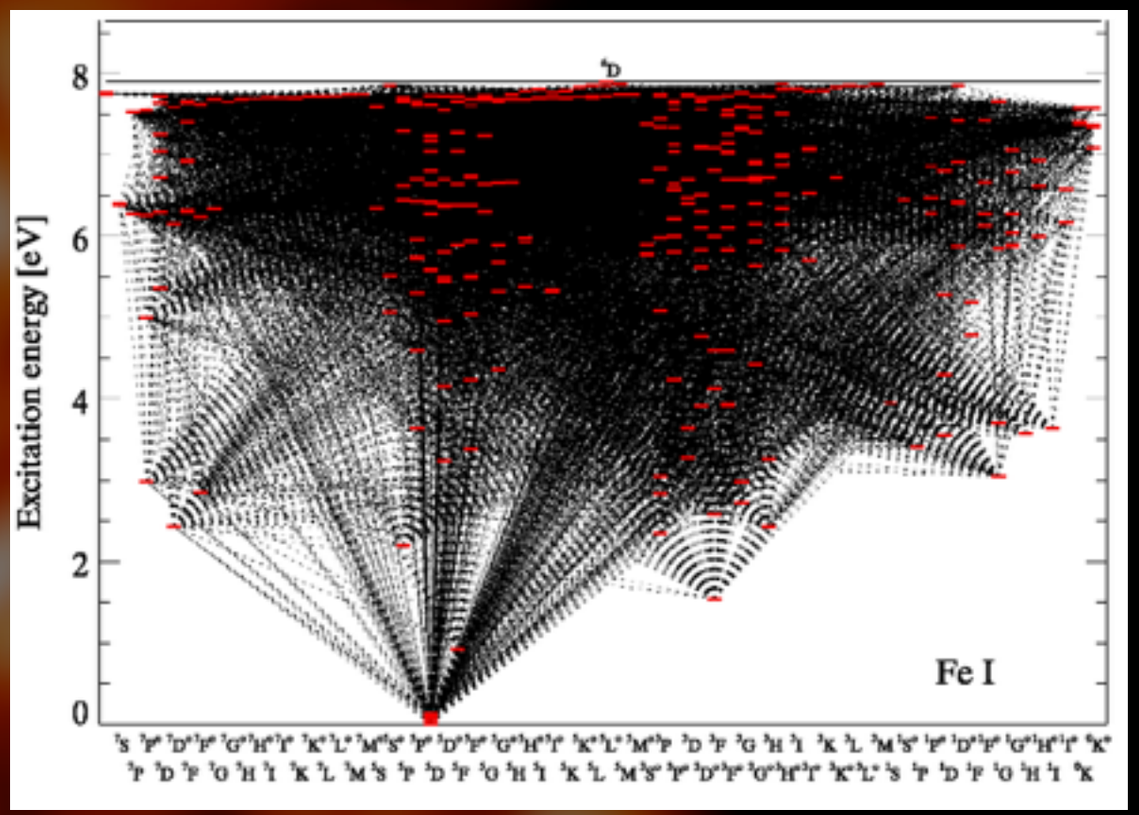


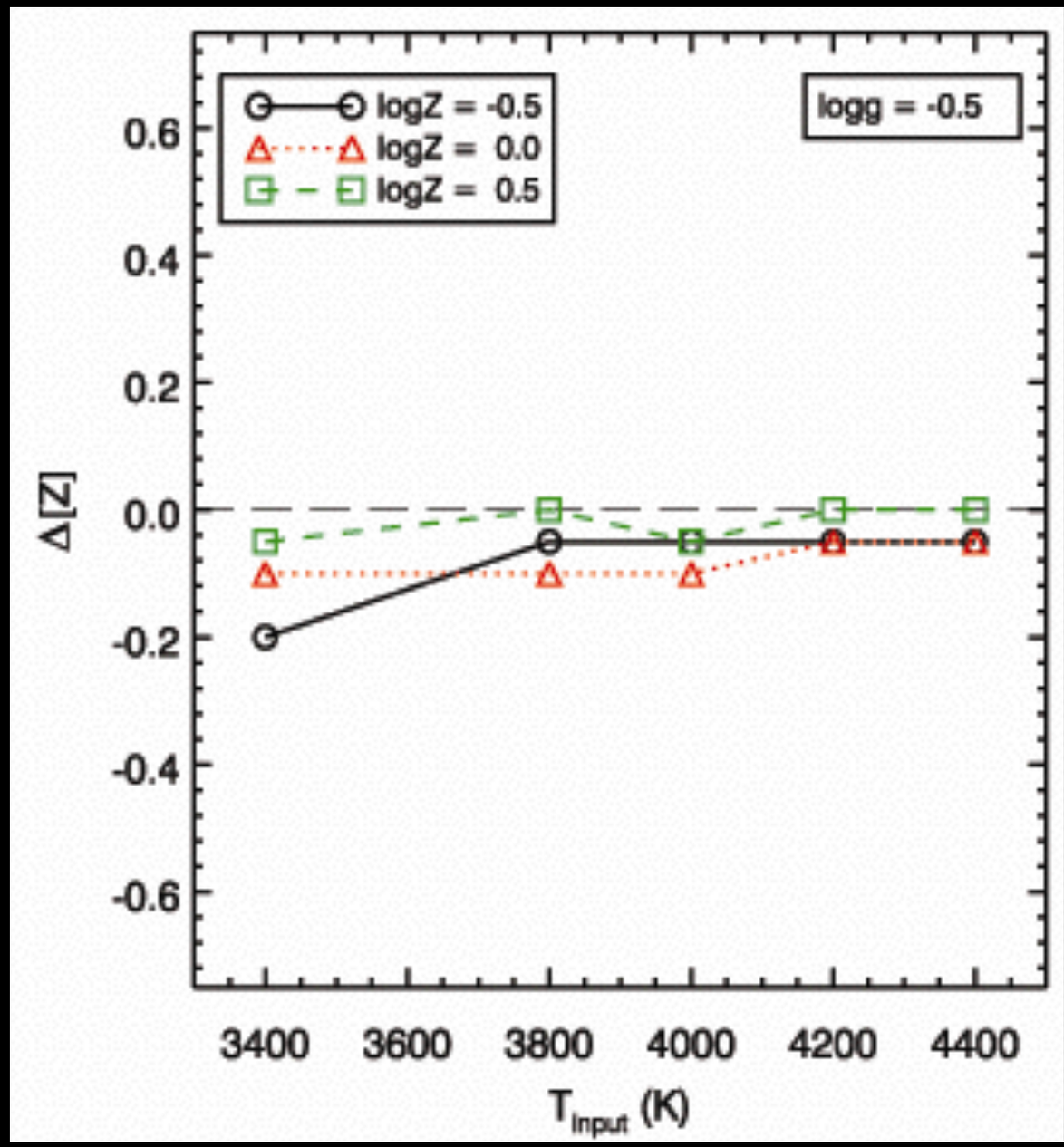
➡ 24 stars at once: 1 galaxy per night at 4Mpc **(VLT + KMOS)**

➡ number of observable targets increased to ~100

Modelling & Analysis

- MARCS models... (Gustavsson+ 2008)
- … with nLTE corrections (Bergemann+ 2012, 2013, in prep)





‘Nearby Universe’ phase...

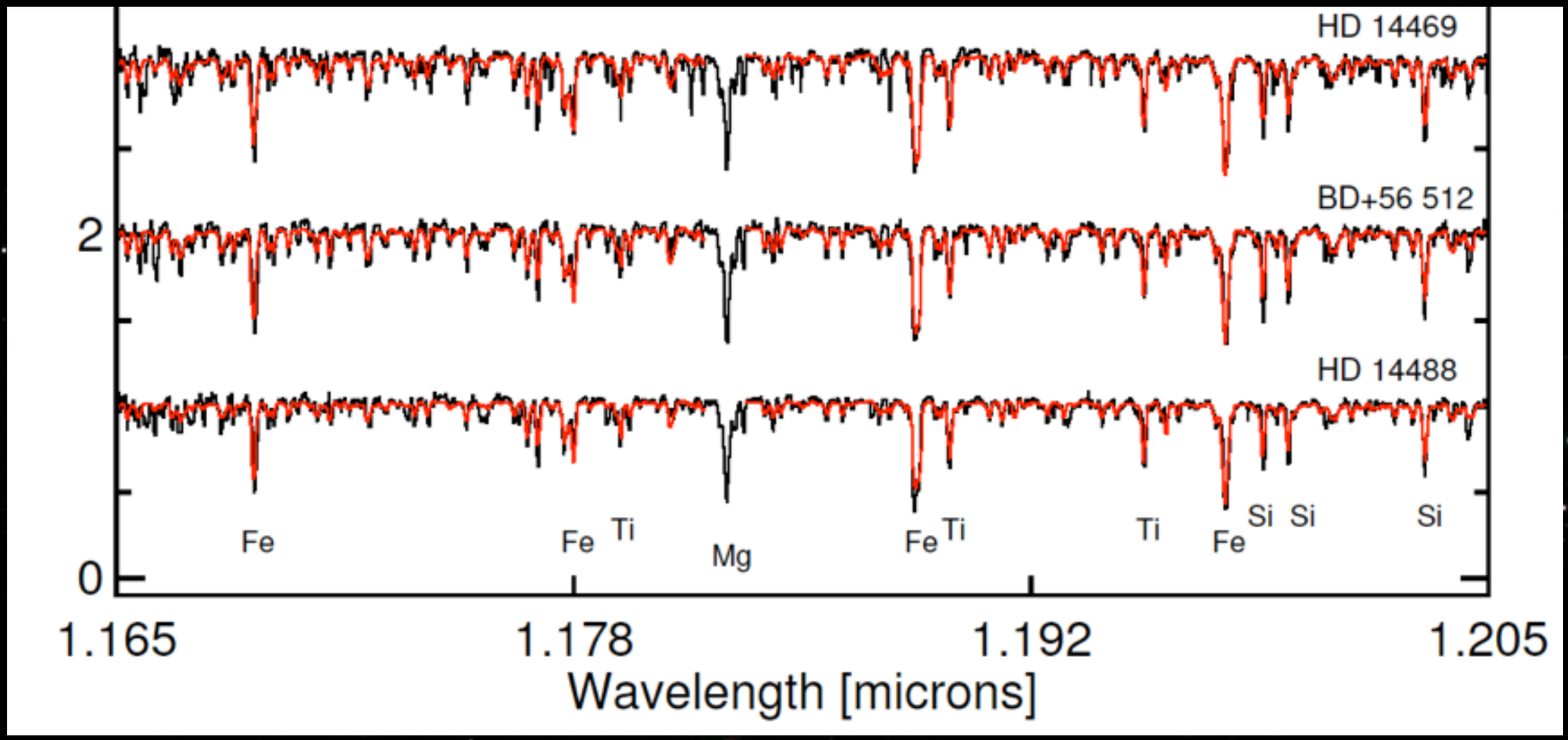
- Study RSGs in three closest galaxies
  (with different masses & metallicities)...

Per OB1 (Subaru+IRCS, R=20,000)
[Z] = -0.04±0.10

Gazak, Davies, Kudritzki+ (2014, ApJ 788, 58)

‘Nearby Universe’ phase...

- Study RSGs in three closest galaxies
  (with different masses & metallicities)...



Gazak, Davies, Kudritzki+ (2014, ApJ 788, 58)

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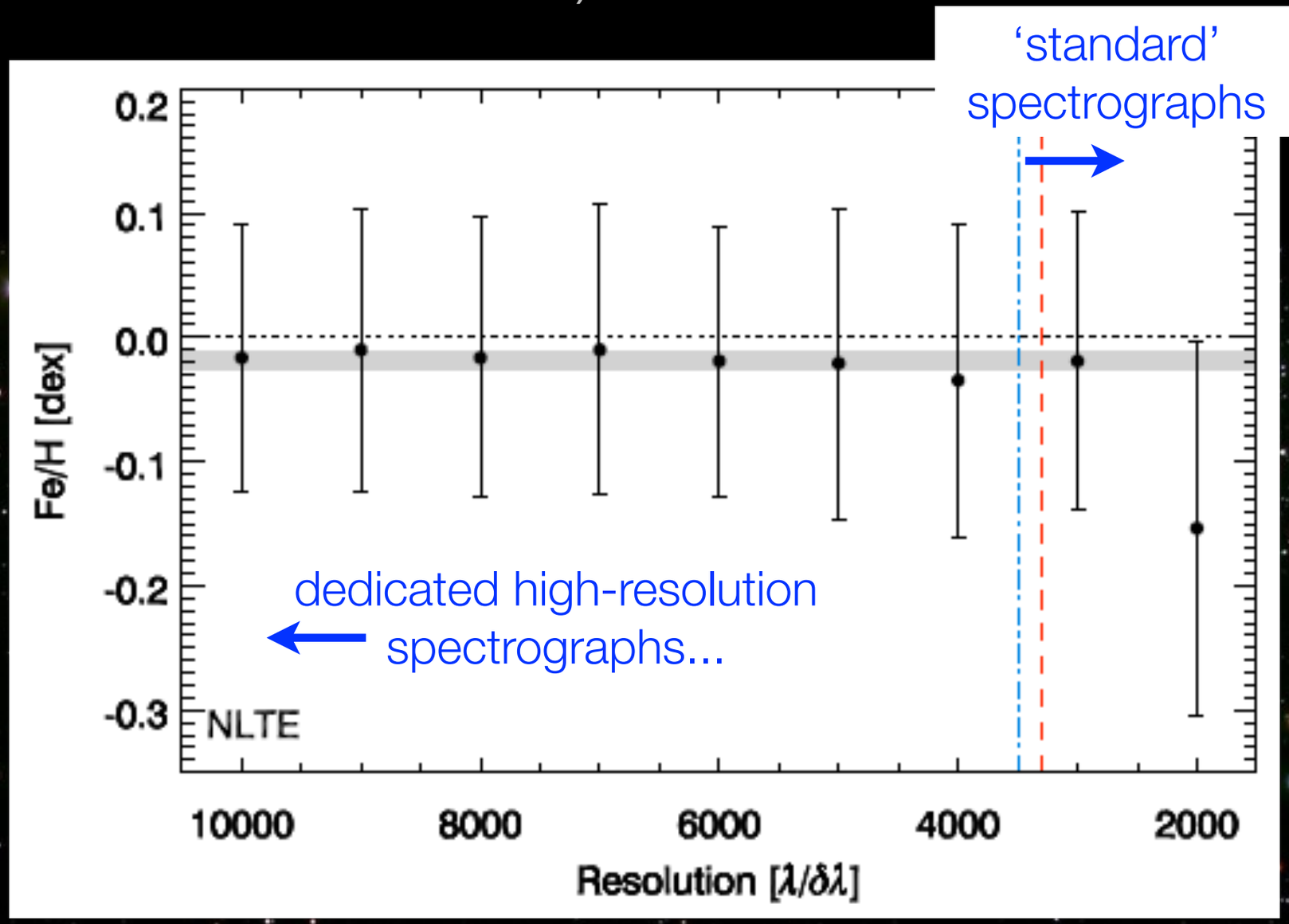

Gazak, Davies, Kudritzki+ (2014, ApJ 788, 58)

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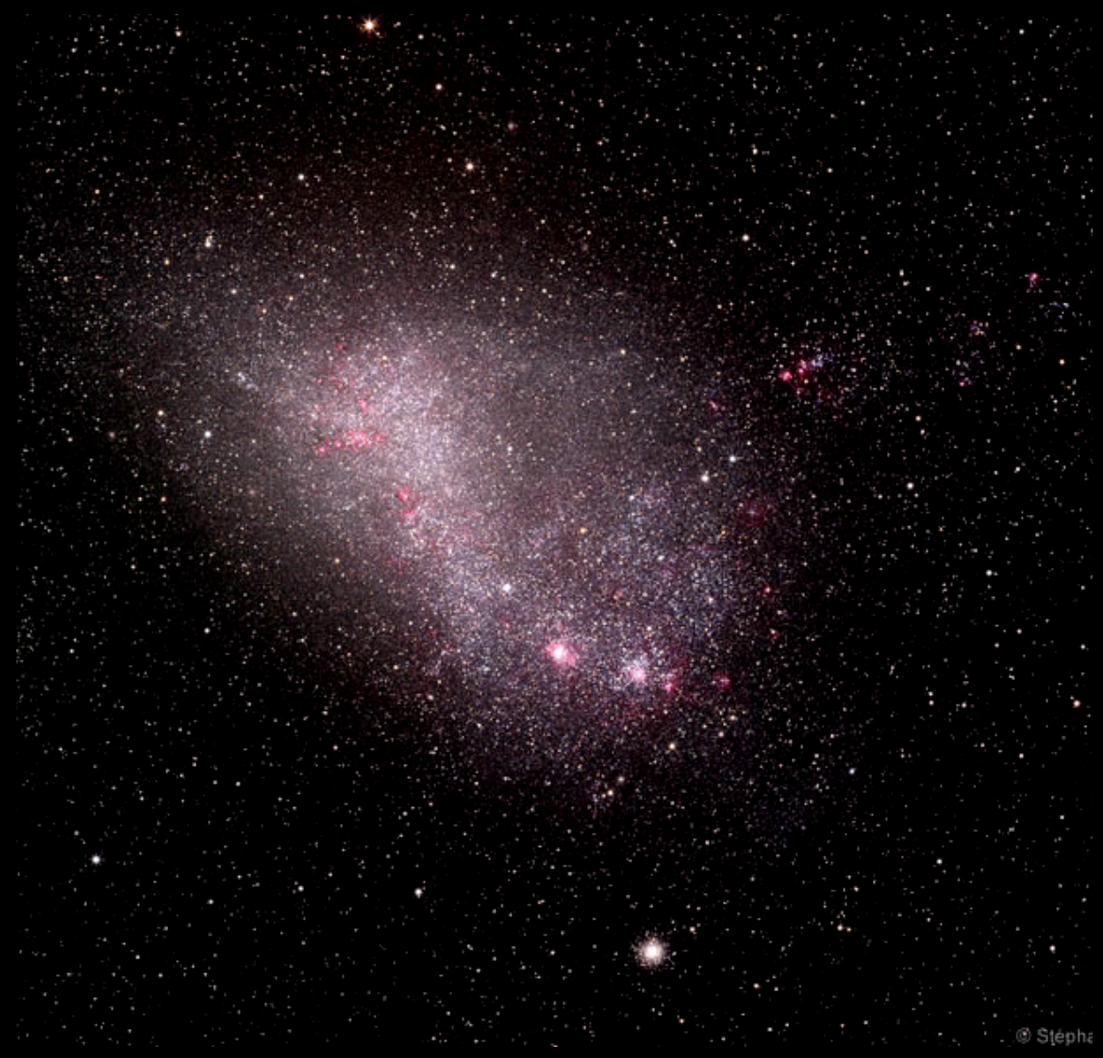
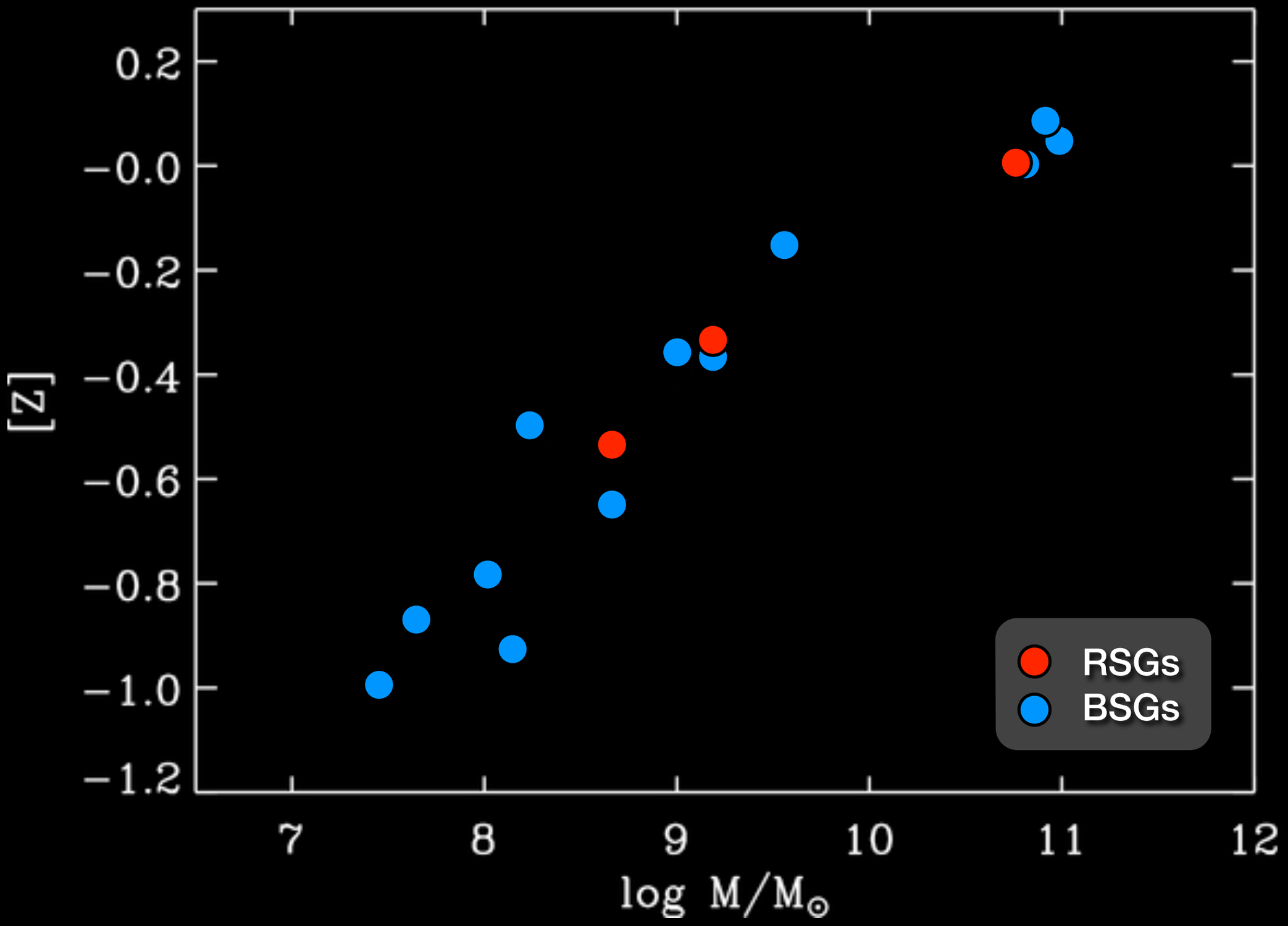


Davies et al (submitted)

Mass-Metallicity Relation (supergiants)



Survey of galaxies within 4Mpc:

NGC 3109

NGC 300

Gazak et al. (in prep)

NGC 6822

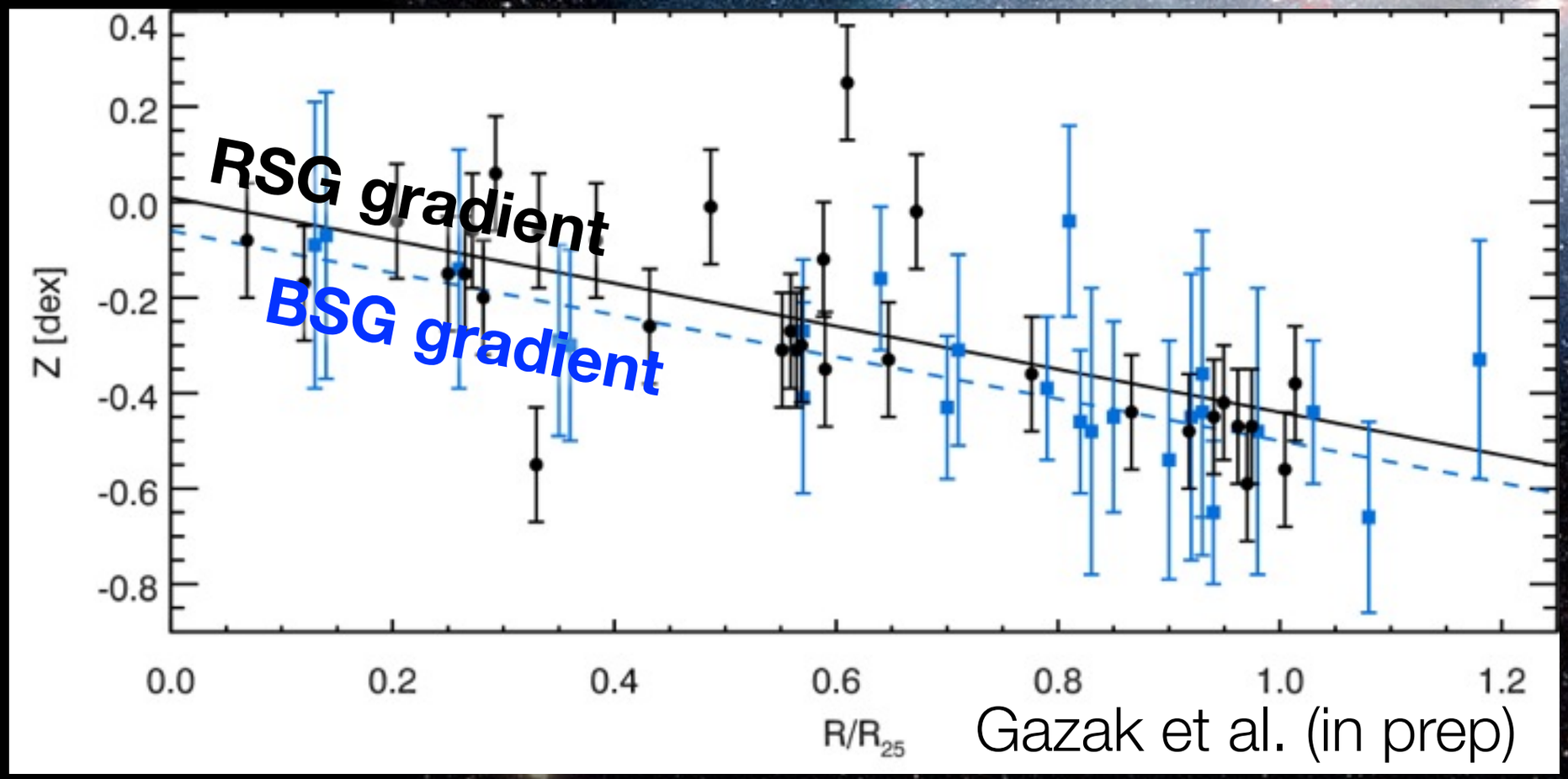
Patrick et al (in prep)

NGC 55

WLM

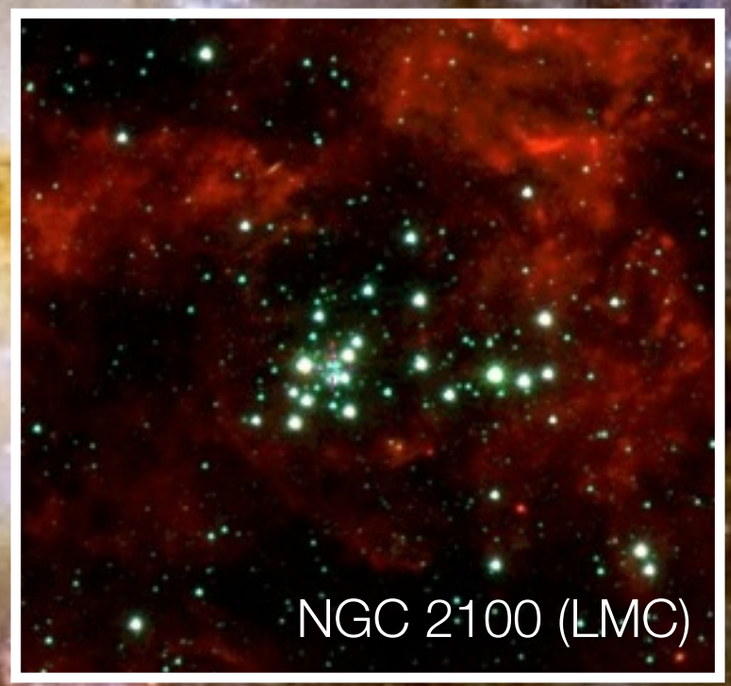
Davies et al (in prep)

NGC 300 metallicity gradient

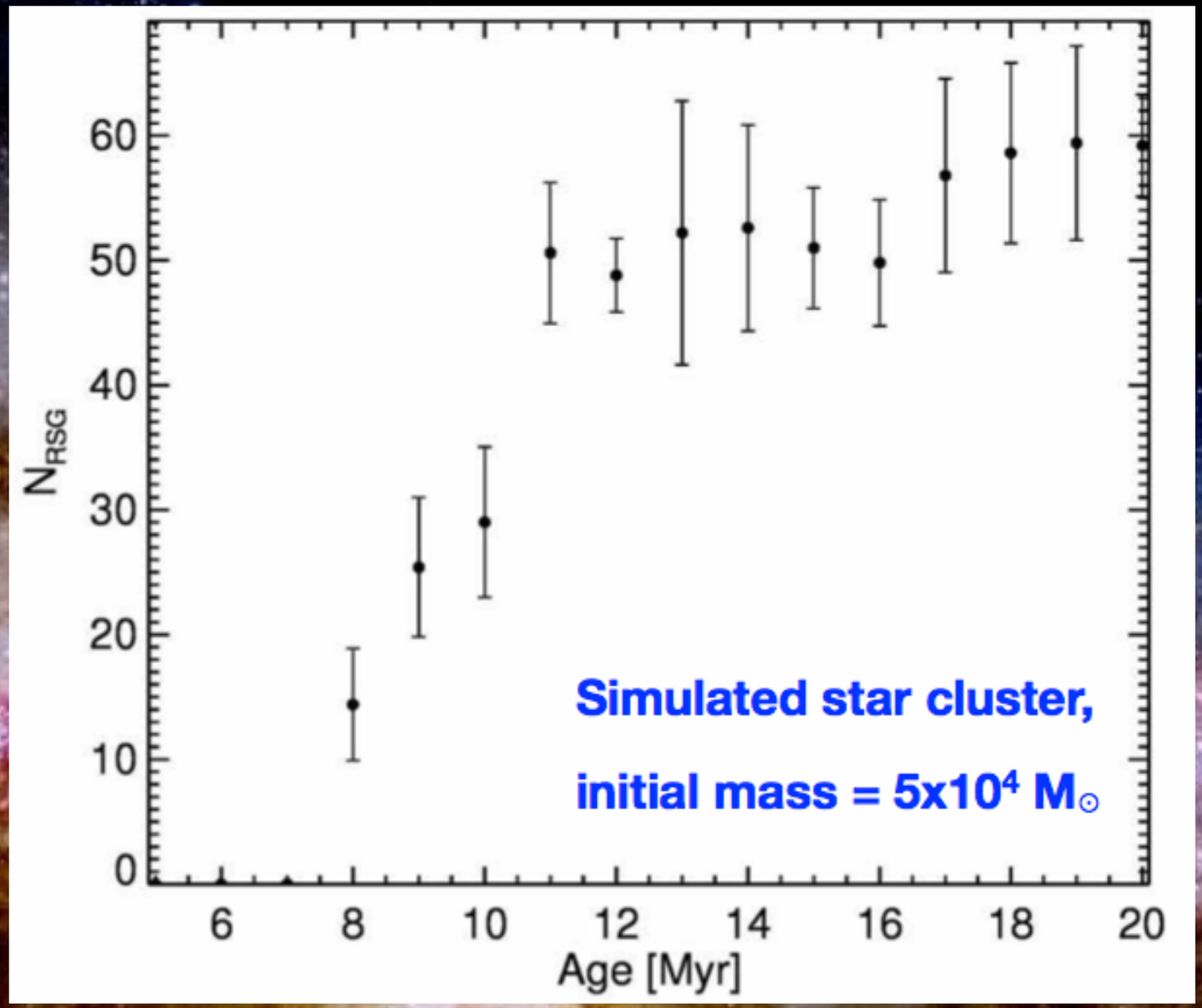


Gazak et al. (in prep)

RSG-dominated star-clusters...

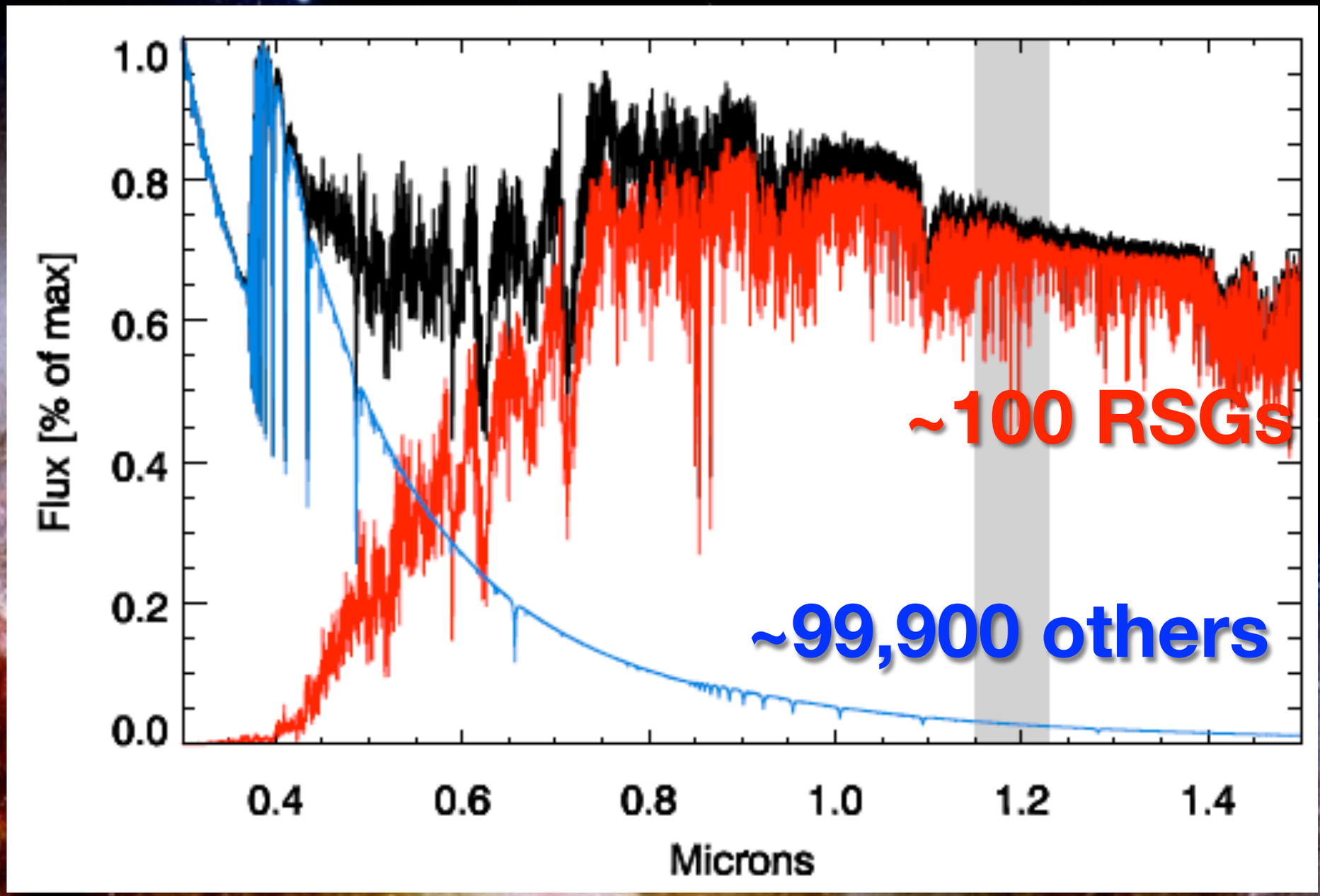


RSG-dominated star-clusters...



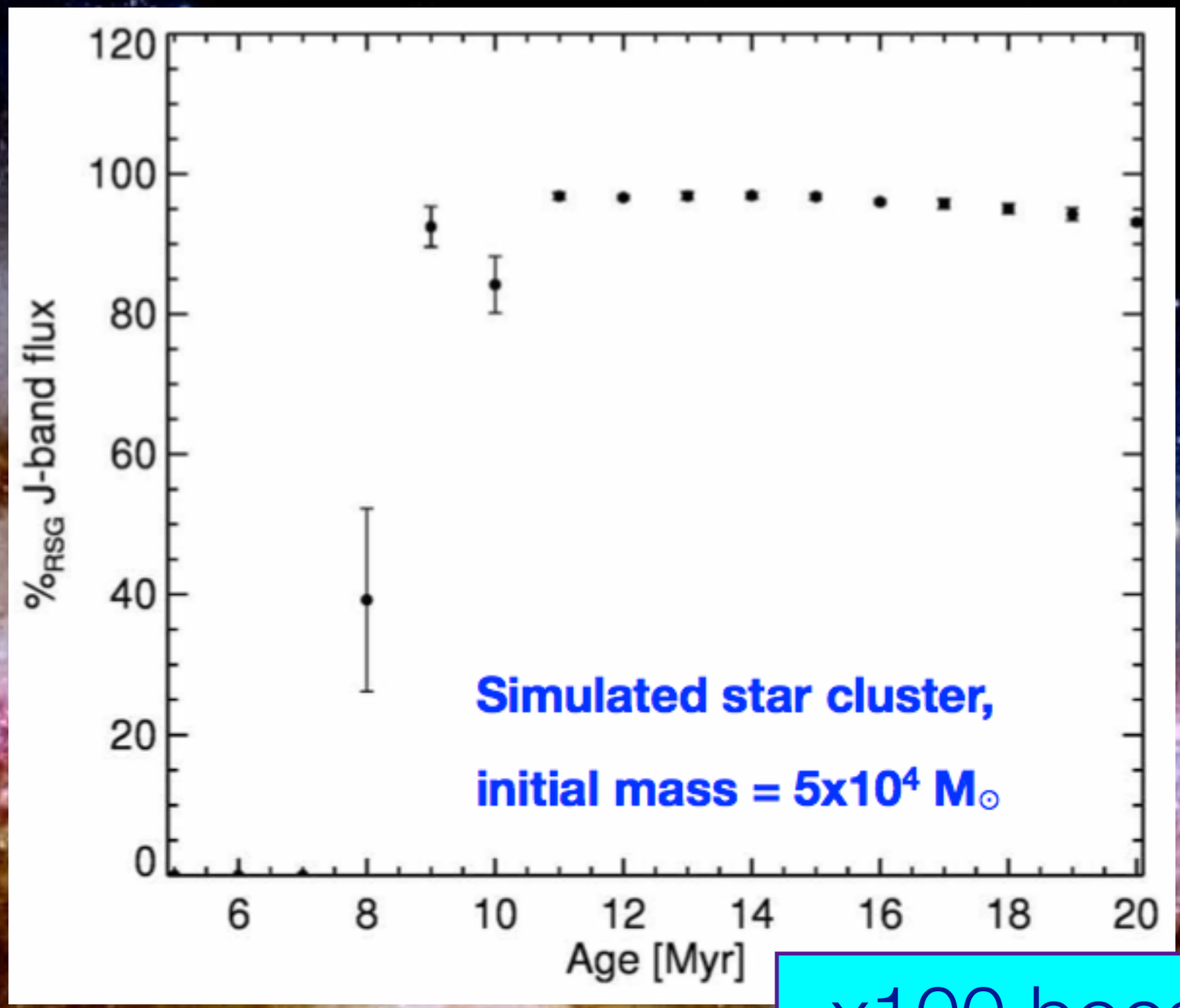
Gazak et al (2013, MNRAS 430, 35)

RSG-dominated star-clusters...



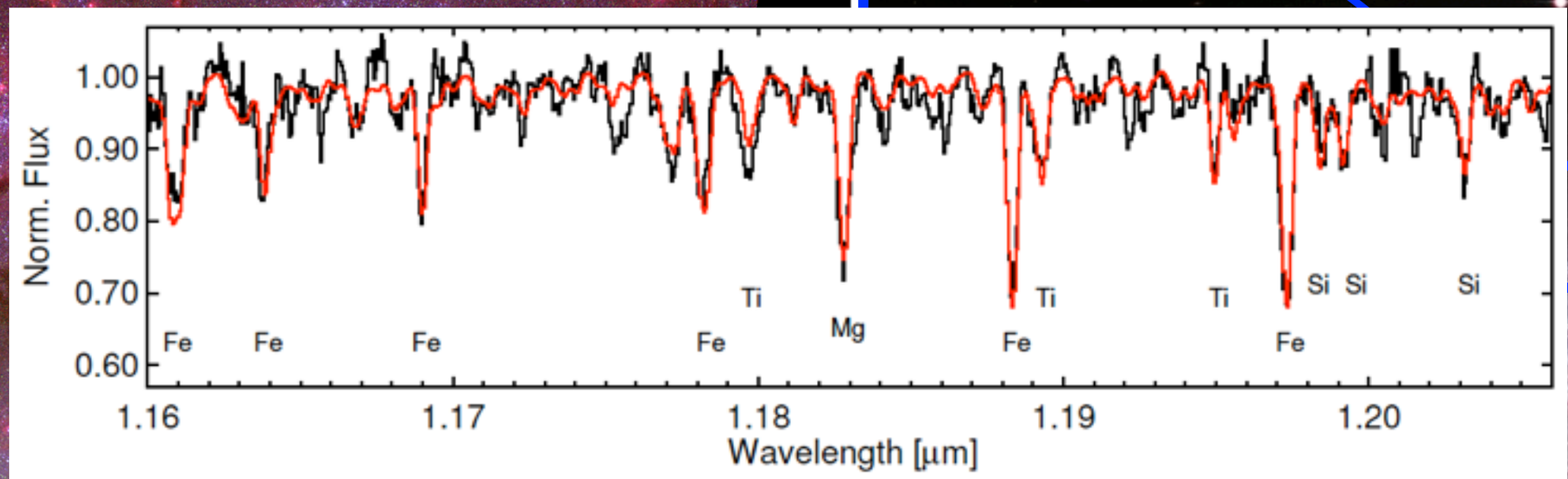
Gazak, Davies, Bastian et al. (2014, ApJ 787, 142)

RSG-dominated star-clusters...



Gazak et al (2013, MNRAS 430, 35)

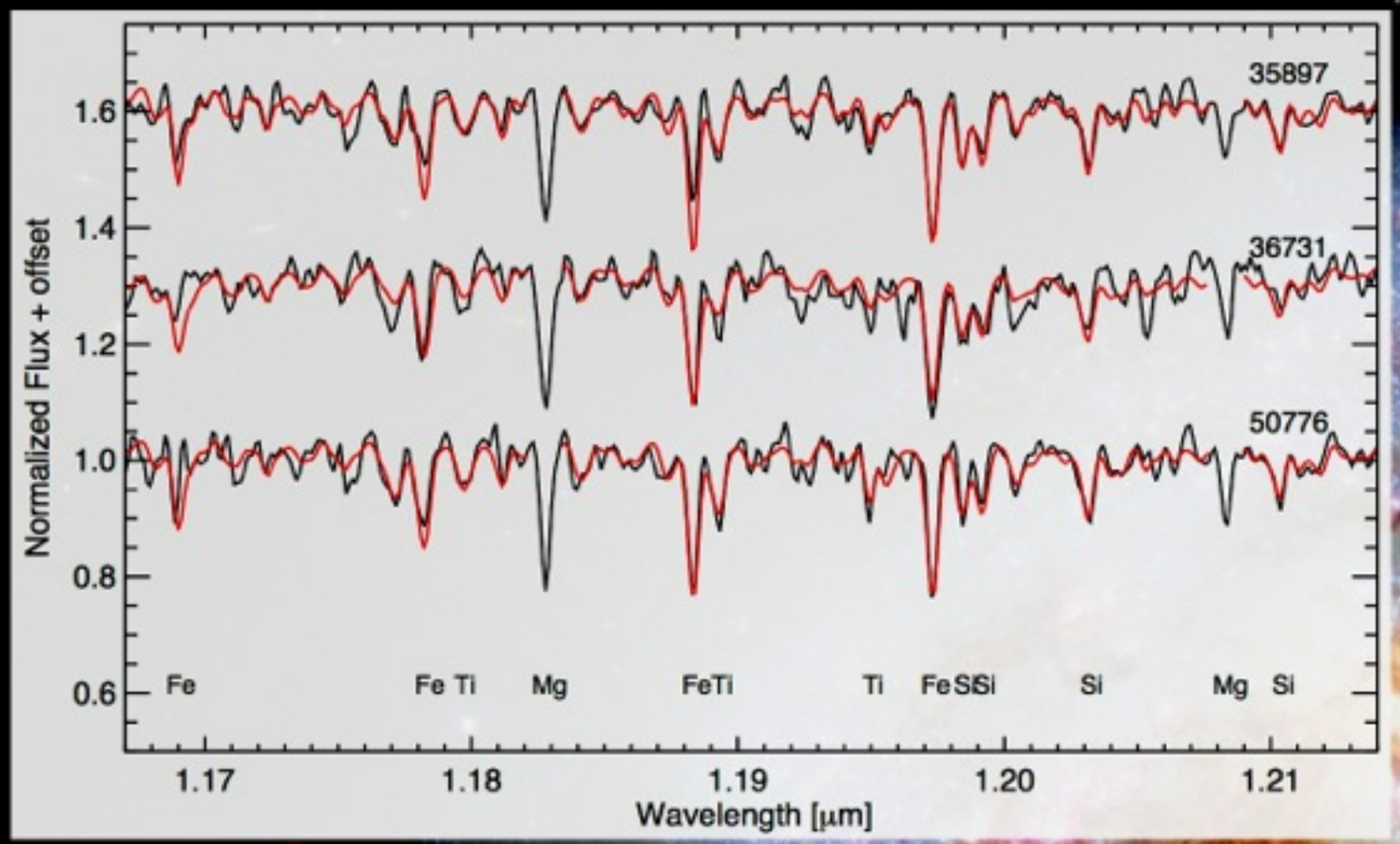
x100 boost in flux for a 10^5 $M_\odot$ cluster



[Z] = +0.28±0.14

Gazak, Davies, Bastian et al. (2014, ApJ 787, 142)

Survey of RSG clusters in high SFR galaxies



$Z = +0.02 \pm 0.13$

SSC 50776

SSC 36731

$Z = +0.03 \pm 0.14$

SSC 35897

$Z = -0.11 \pm 0.16$

Antennae

Gazak et al. (in prep)

Survey of RSG clusters in high SFR galaxies

M83

Lardo et al (in prep)

Cosmic Chemical Evolution using Red Supergiants

Summary & Outlook :

Quantitative spectroscopy of **individual Red Supergiants,** at distances out to **4Mpc**

- Accurate mass-metallicity relation at z=0.
- Can be used to recalibrate strong-line methods for higher z work.

Quantitative spectroscopy of RSG-dominated star clusters out to 40Mpc

E-ELT potential - see talk tomorrow by Chris Evans...