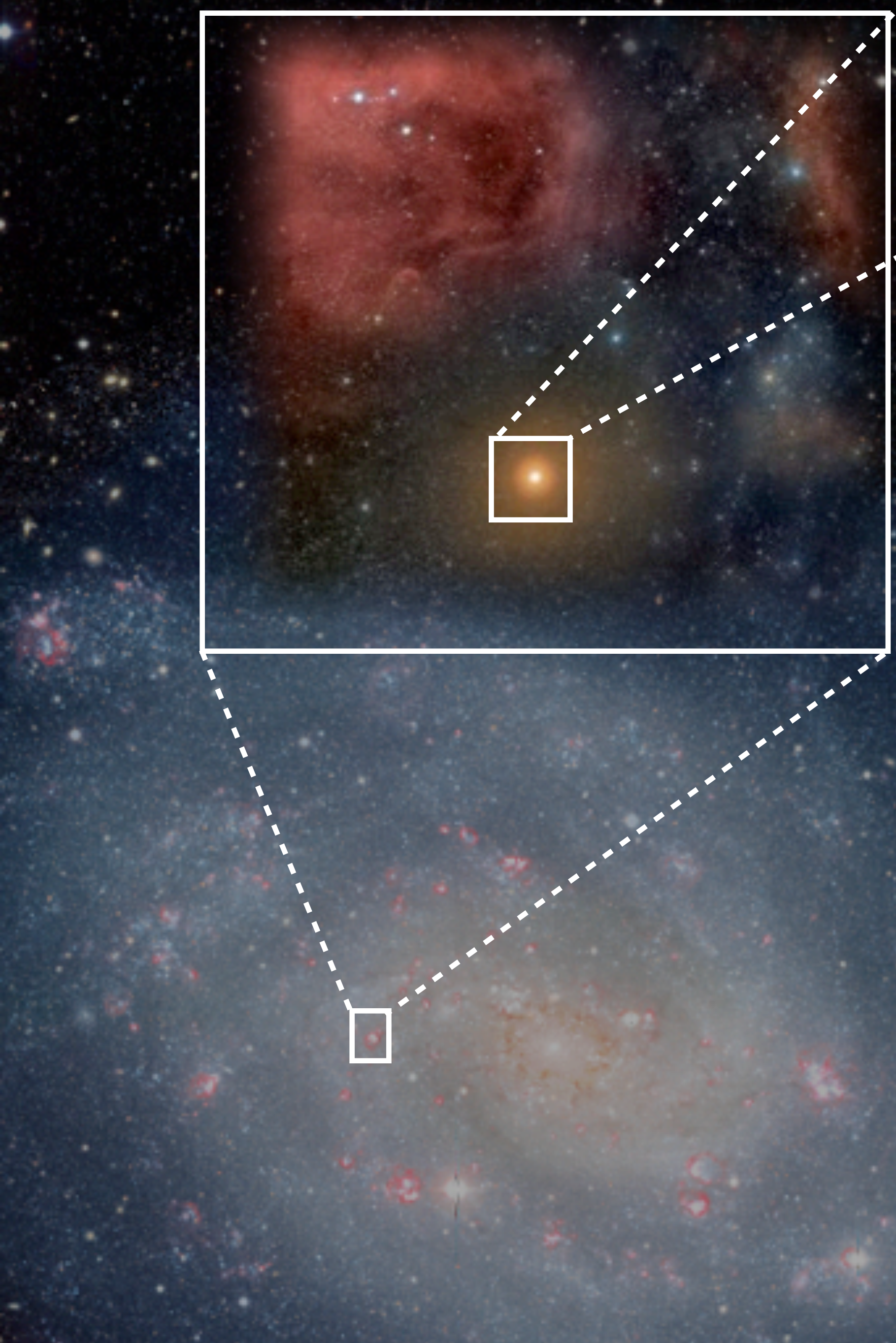
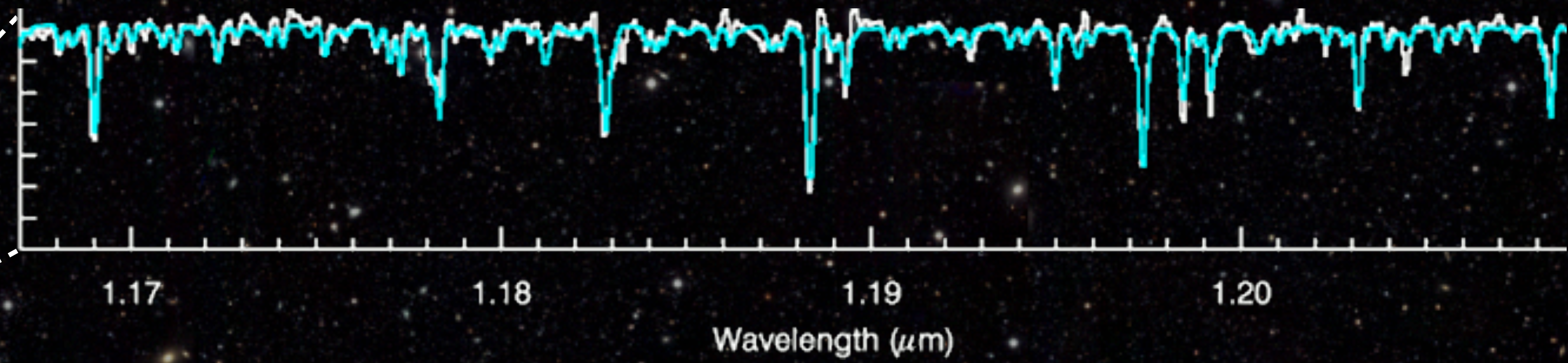
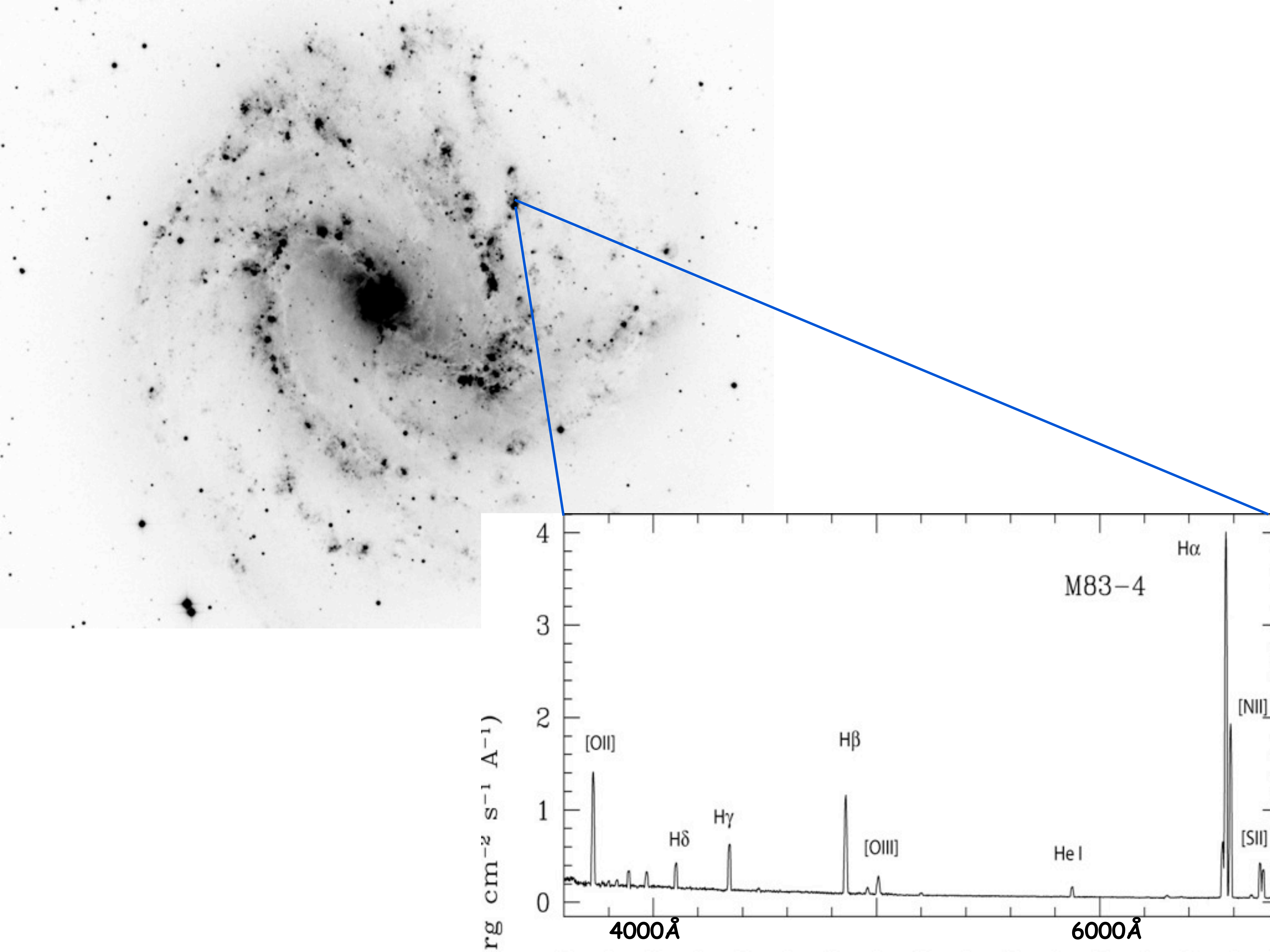




Stellar Spectroscopy Beyond the Local Group with the E-ELT

Ben Davies
Liverpool John Moores University

Shaping E-ELT Science and instrumentation
Feb 29th, 2013


M83−4
Hα
[NII]
[SII]
[OII]
Hβ
Hγ
Hδ
[OIII]
He I
4
3
2
1
0
4000Å
6000Å

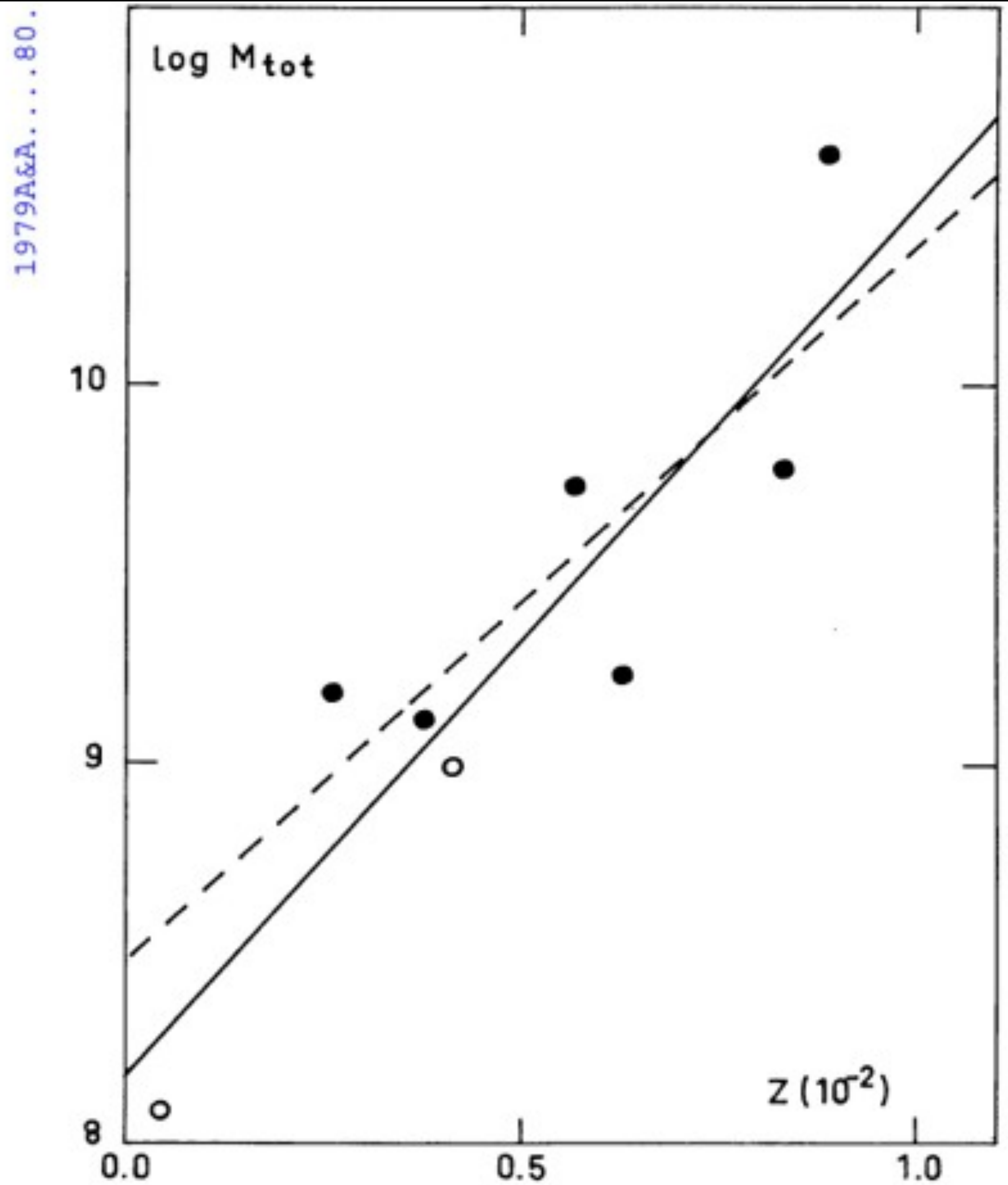
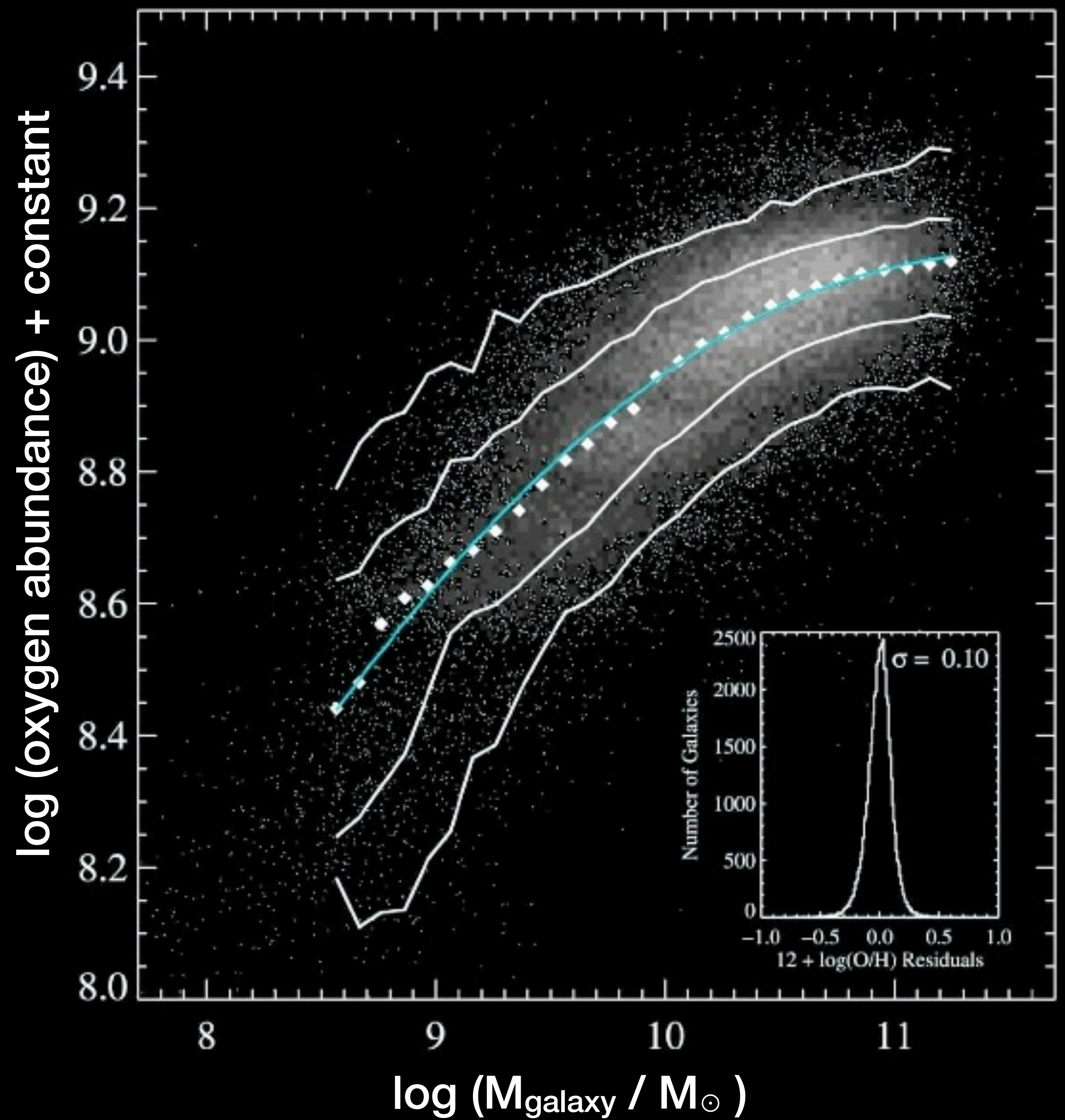


Fig. 4. Observed heavy element abundance, Z, versus total mass for the compact and irregular galaxies under consideration. Filled circles are objects with known mass; open circles are lower limits to the total mass for I Zw 18 and II Zw 40 (for which we adopted 9.9 10^8 $M_{\odot}$). *Solid line*, least-squares fit for all galaxies ($\log M_{tot} = 8.18 + 229\,Z$). *Dashed line*, least-squares fit for galaxies of known mass ($\log M_{tot} = 8.48 + 187\,Z$)

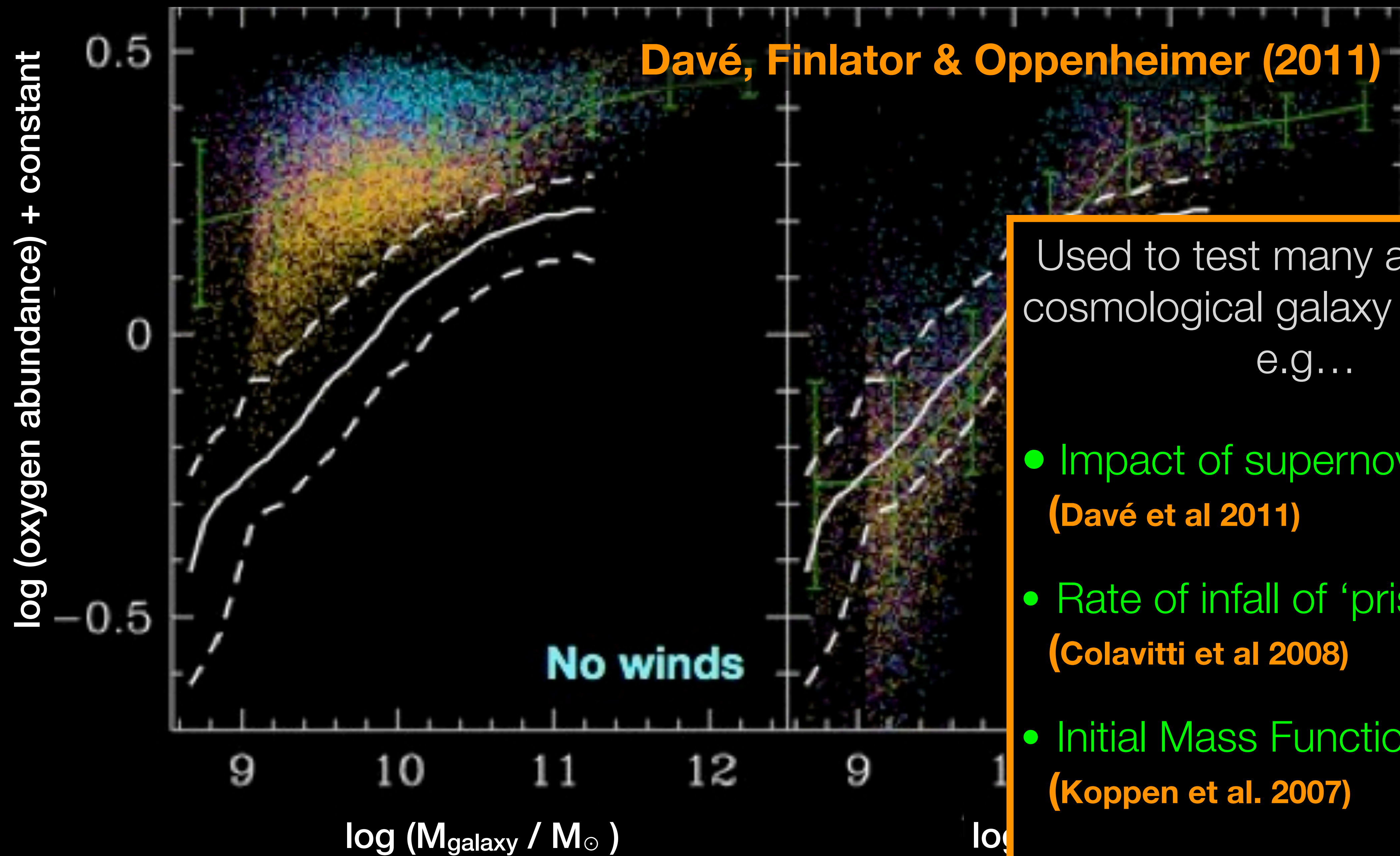
Mass-metallicity relationship of galaxies

Lequeux et al., 1979



Mass-metallicity relationship of galaxies

Tremonti+ 2004



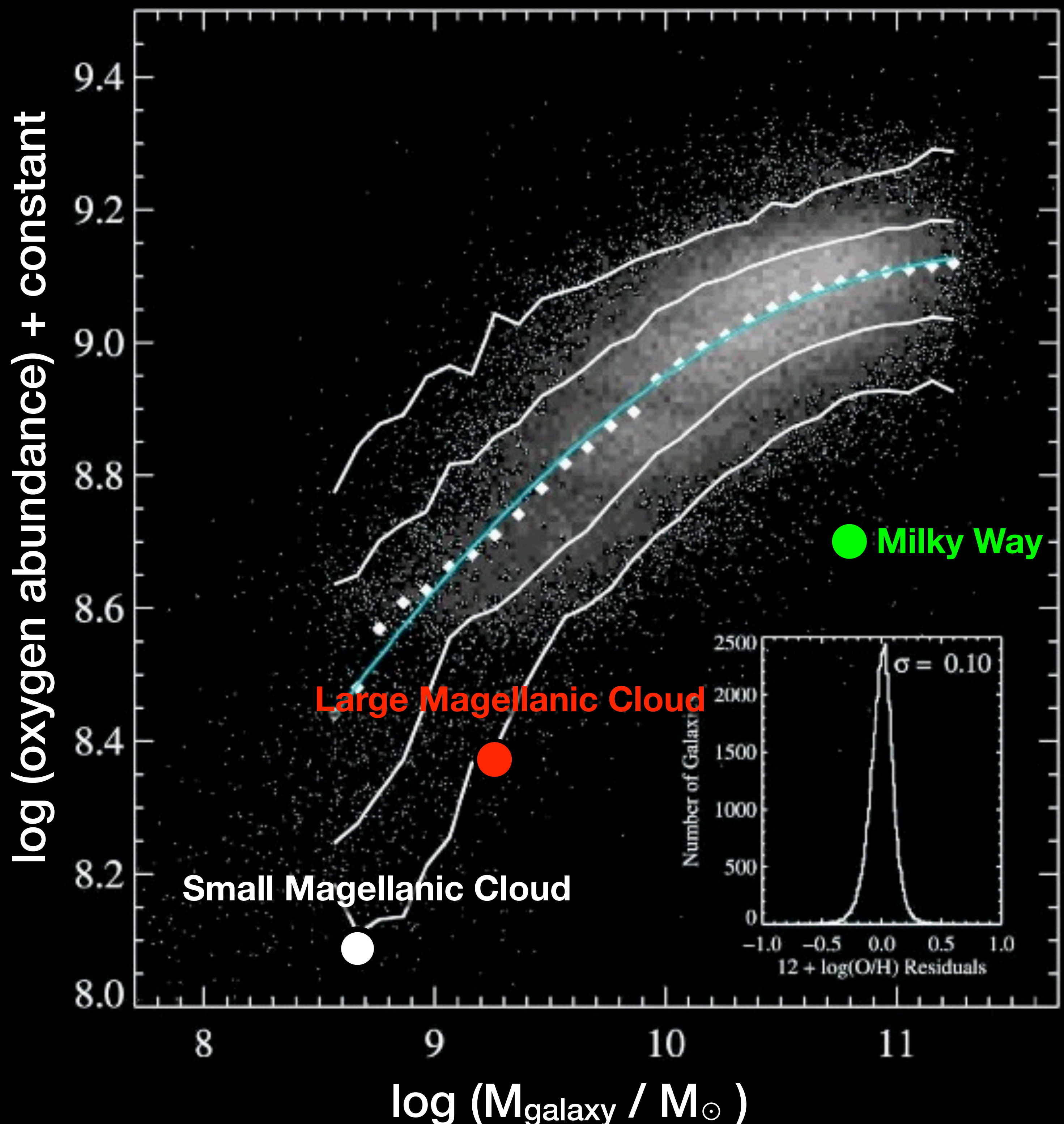
Used to test many aspects of cosmological galaxy formation, e.g…

- Impact of supernova winds **(Davé et al 2011)**
- Rate of infall of 'pristine' gas **(Colavitti et al 2008)**
- Initial Mass Function **(Koppen et al. 2007)**

+ many more...

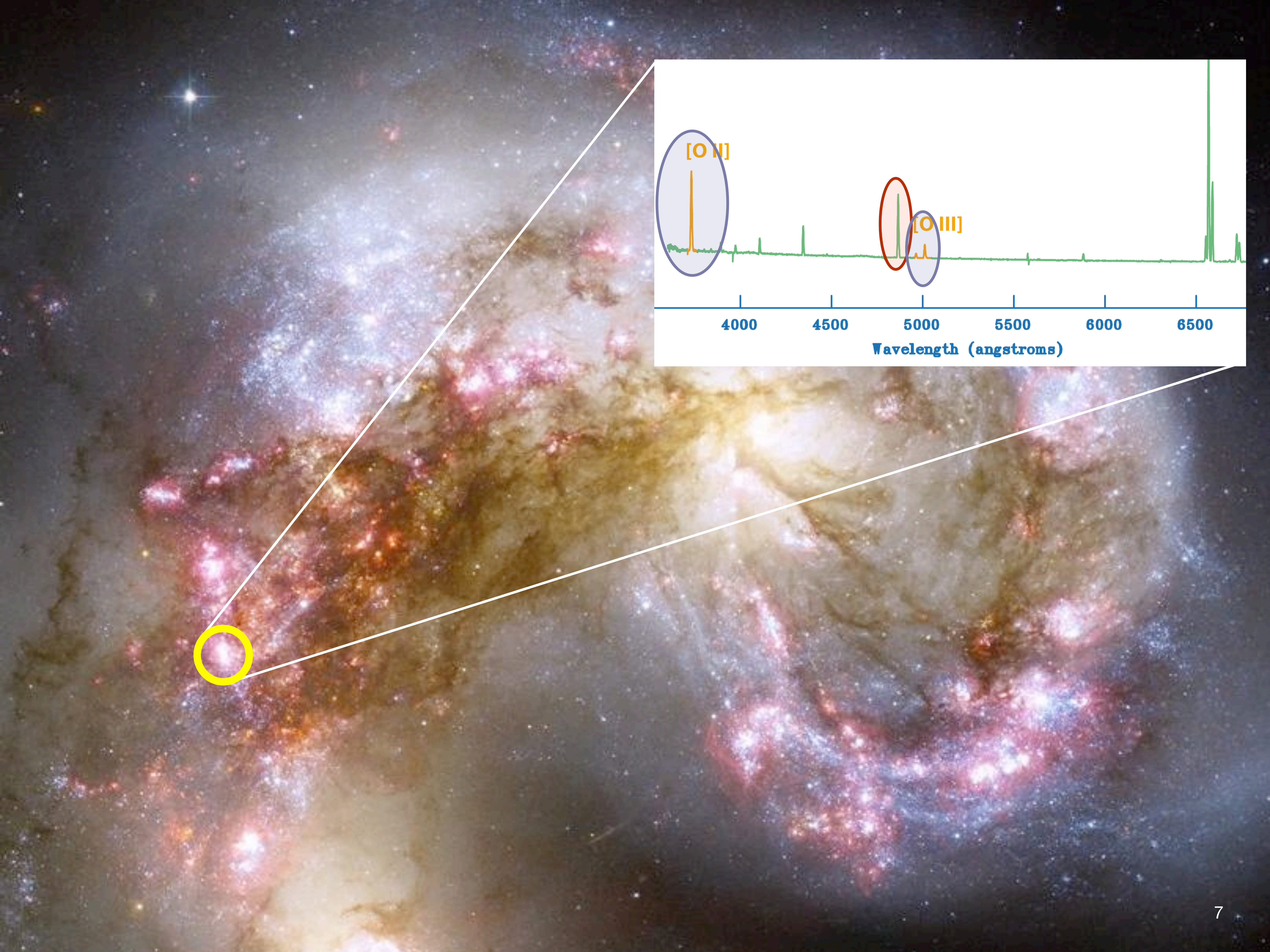
Mass-metallicity relationship of galaxies

Tremonti+ 2004



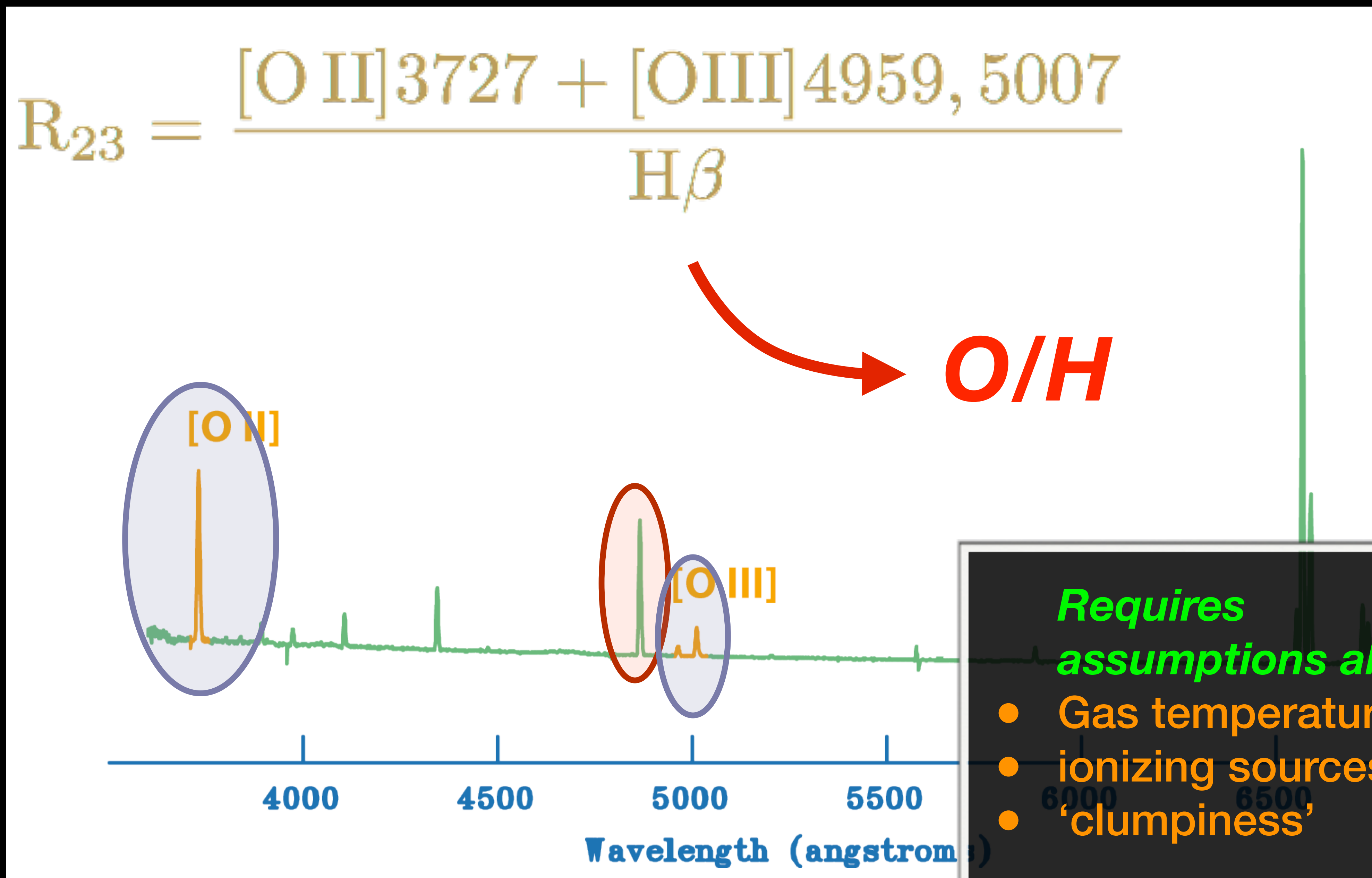
Mass-metallicity relationship of galaxies

Tremonti+ 2004


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

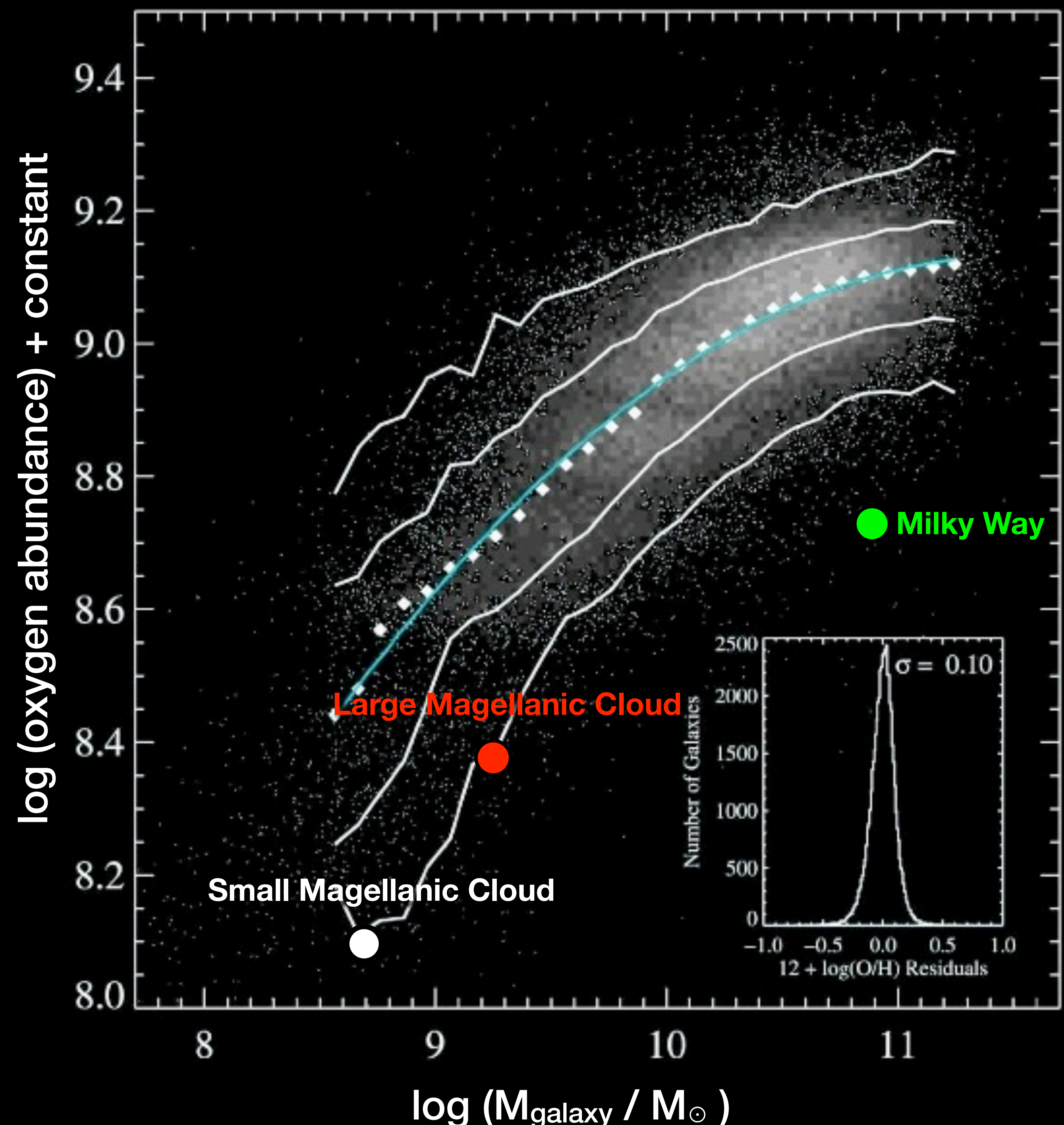
Strong-line method (a.k.a. R_{23})

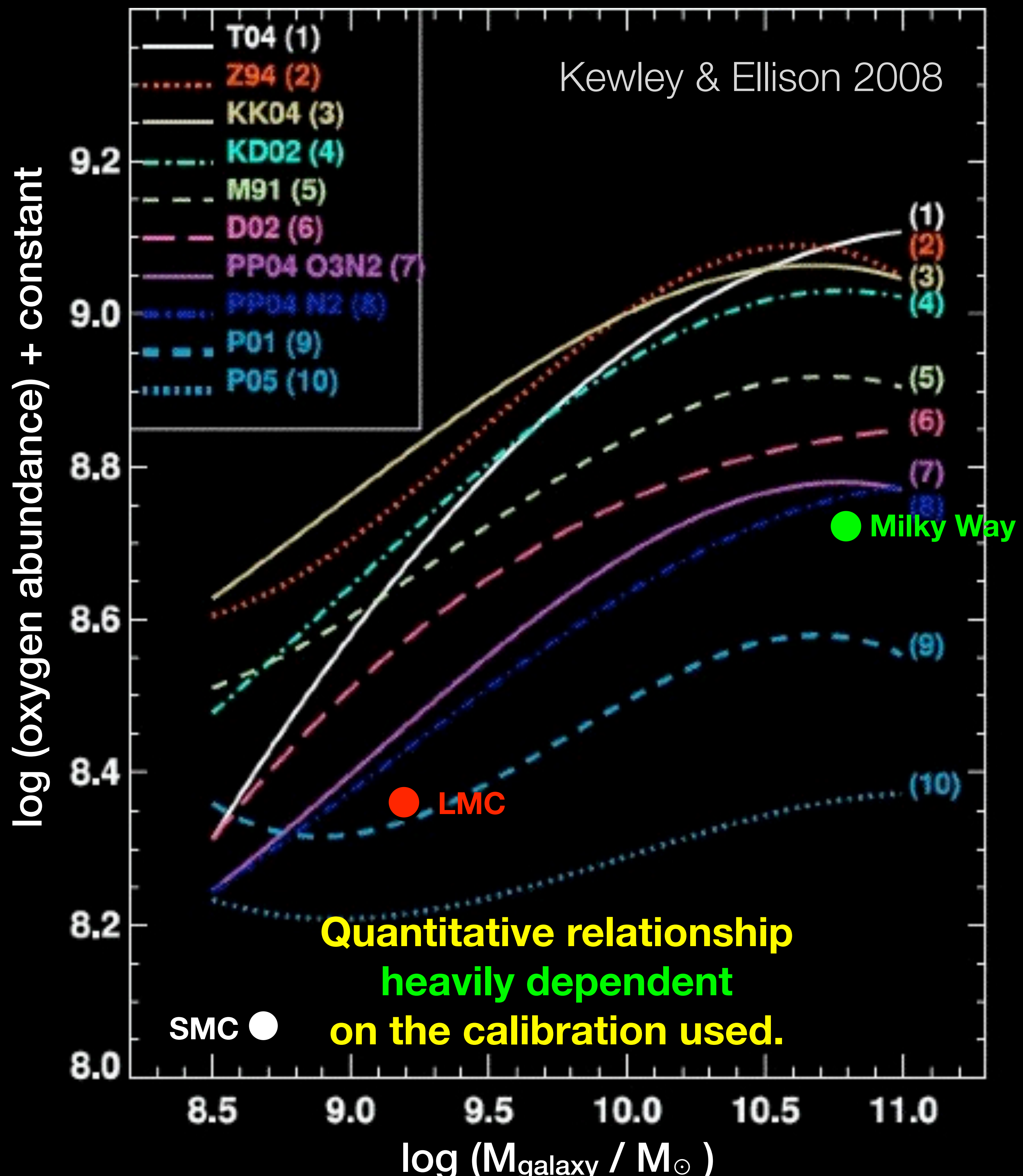
observe strong oxygen emission lines,
& use O as tracer of metallicity

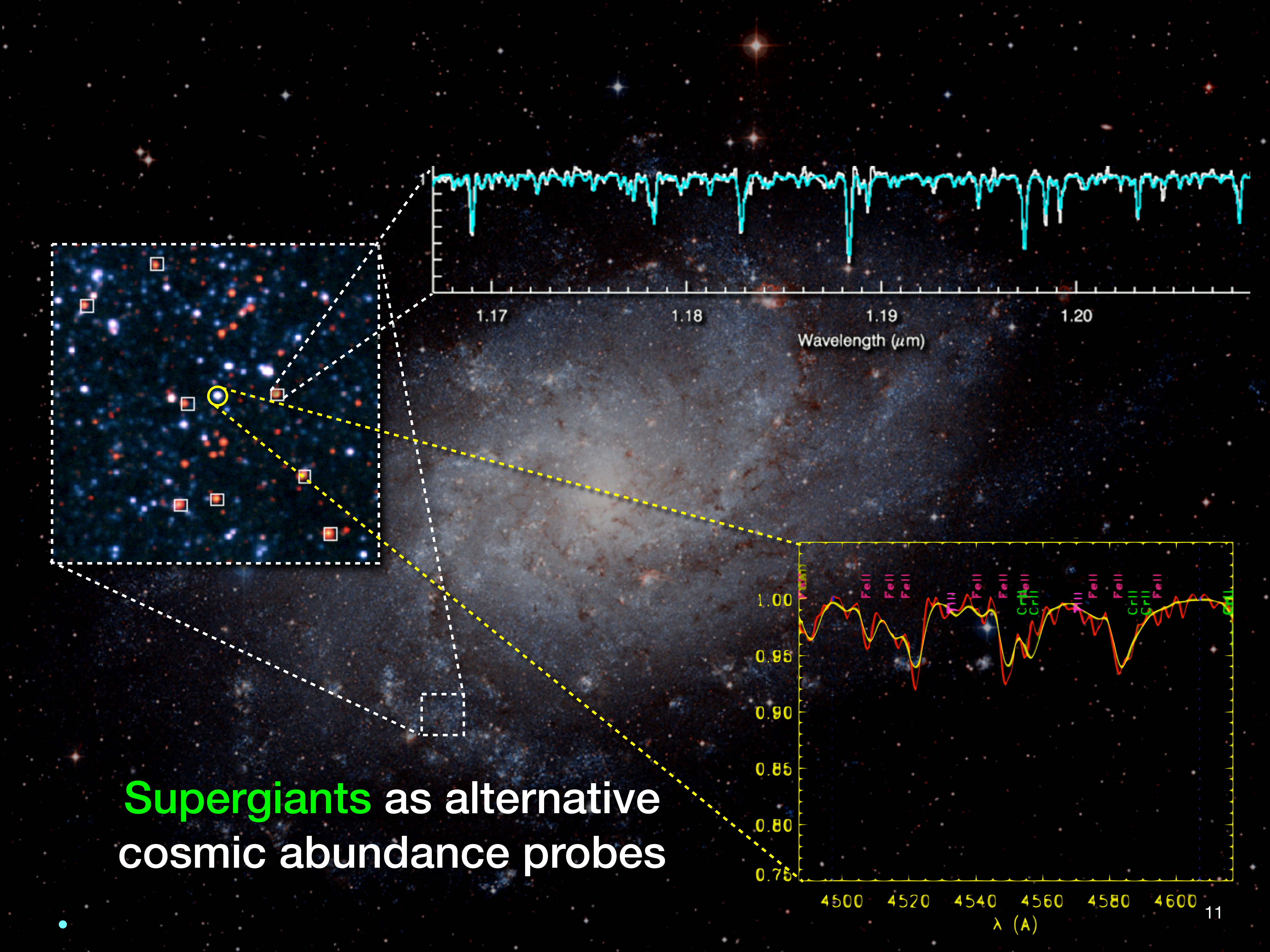


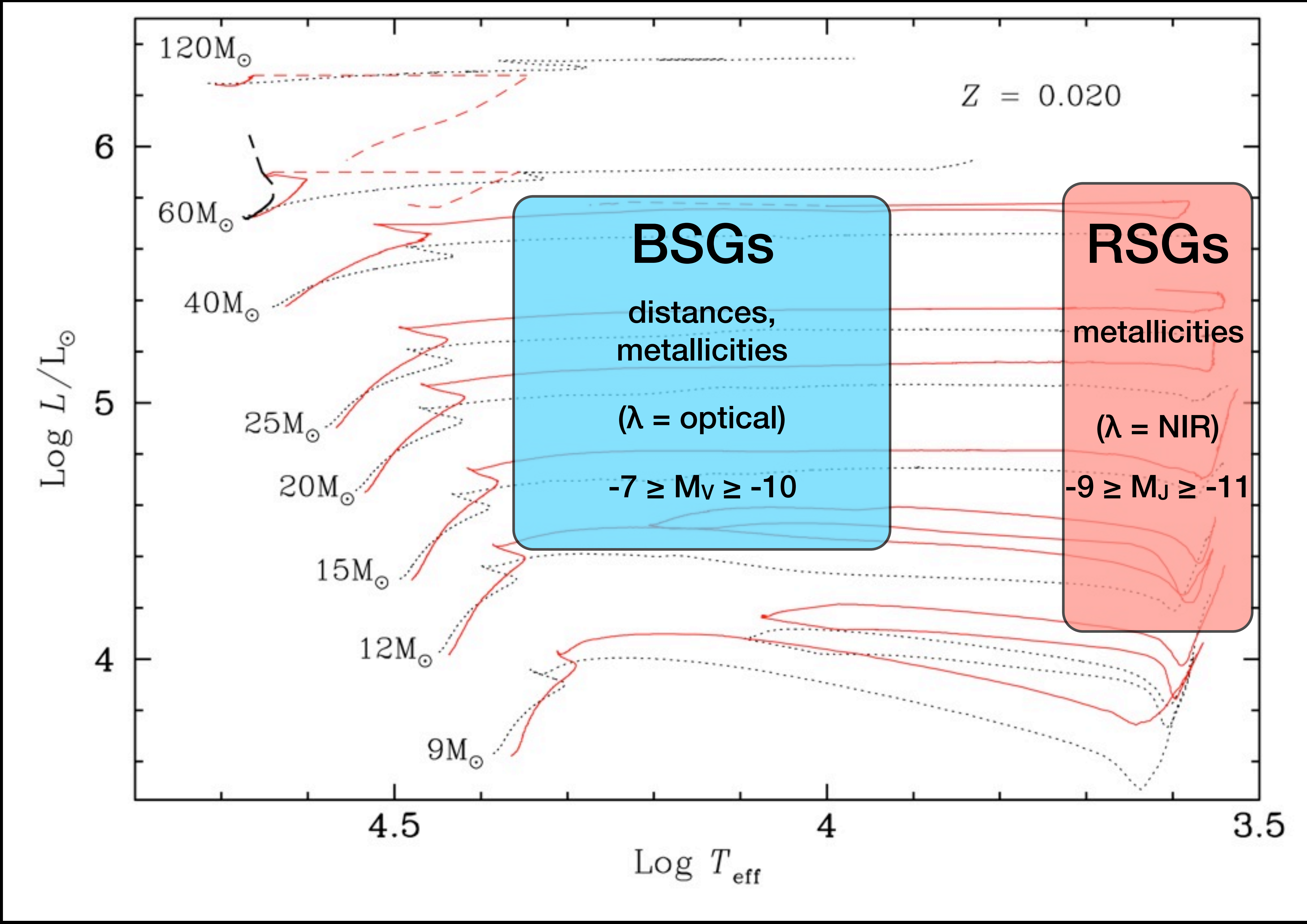
Requires assumptions about:

- 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 (M_{galaxy} / $M_{\odot}$)
Milky Way
Large Magellanic Cloud
Small Magellanic Cloud
σ = 0.10
Number of Galaxies
2500
2000
1500
1000
500
0
−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
log (Mgalaxy / M☉)
9.2
9.0
8.8
8.6
8.4
8.2
8.0
8.5
9.0
9.5
10.0
10.5
11.0
(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
(9)
(10)
Milky Way
LMC
SMC
Quantitative relationship
heavily dependent
on the calibration used.


1.17
1.18
1.19
1.20
Wavelength (μm)
1.00
0.95
0.90
0.85
0.80
0.75
4500
4520
4540
4560
4580
4600
λ (Å)
Supergiants as alternative cosmic abundance probes

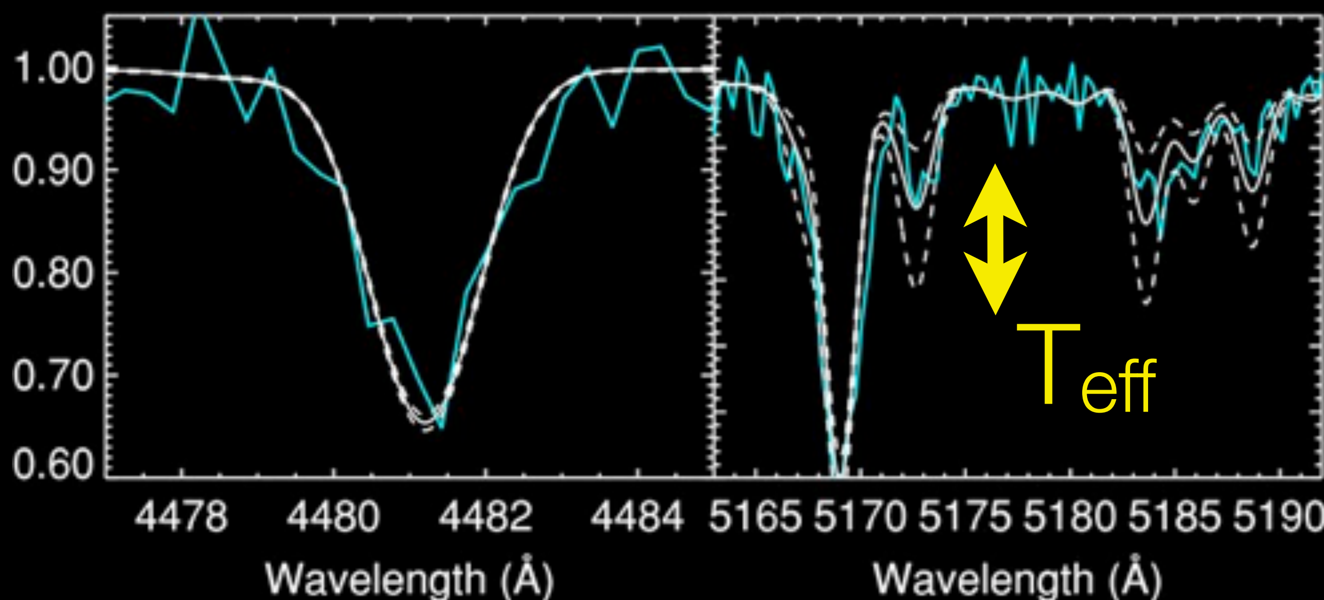


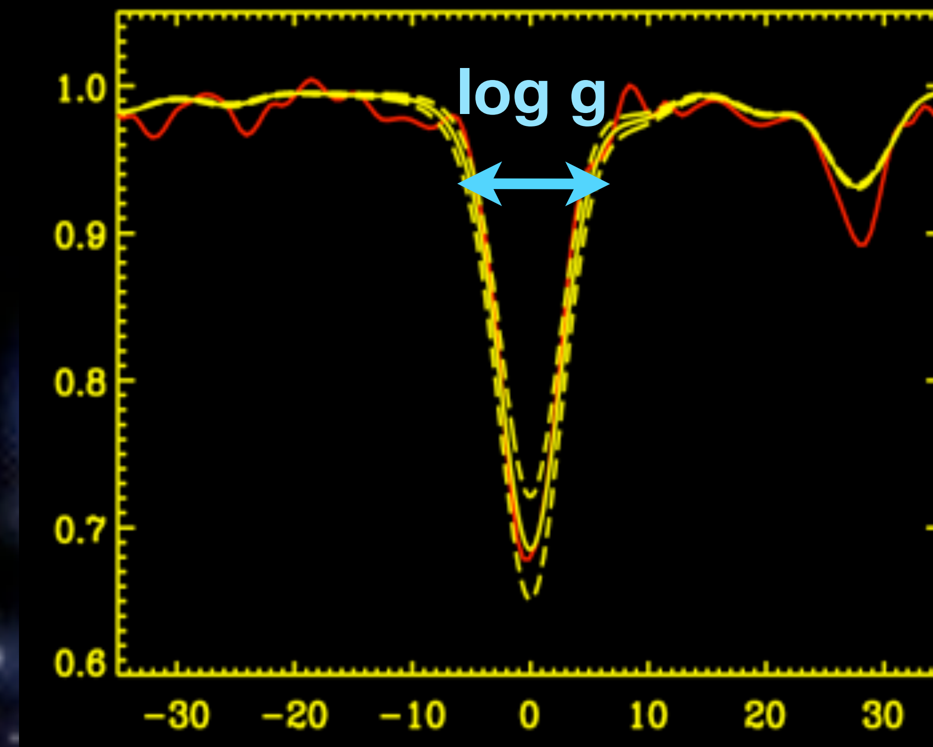
120M⊙
60M⊙
40M⊙
25M⊙
20M⊙
15M⊙
12M⊙
9M⊙
Z = 0.020
BSGs
distances,
metallicities
(λ = optical)
$-7 \geq M_V \geq -10$
RSGs
metallicities
(λ = NIR)
$-9 \geq M_J \geq -11$
6
5
4
$\log L/L_\odot$
4.5
4
3.5
$\log T_{eff}$

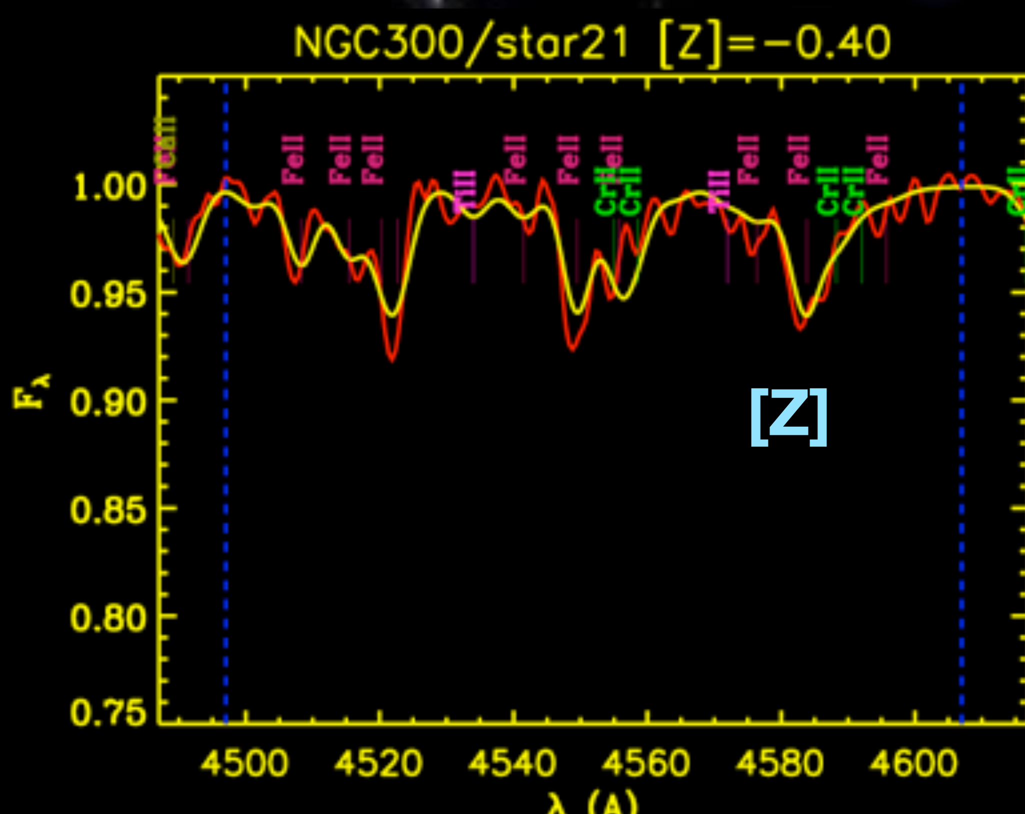
1. Blue Supergiants (BSGs)

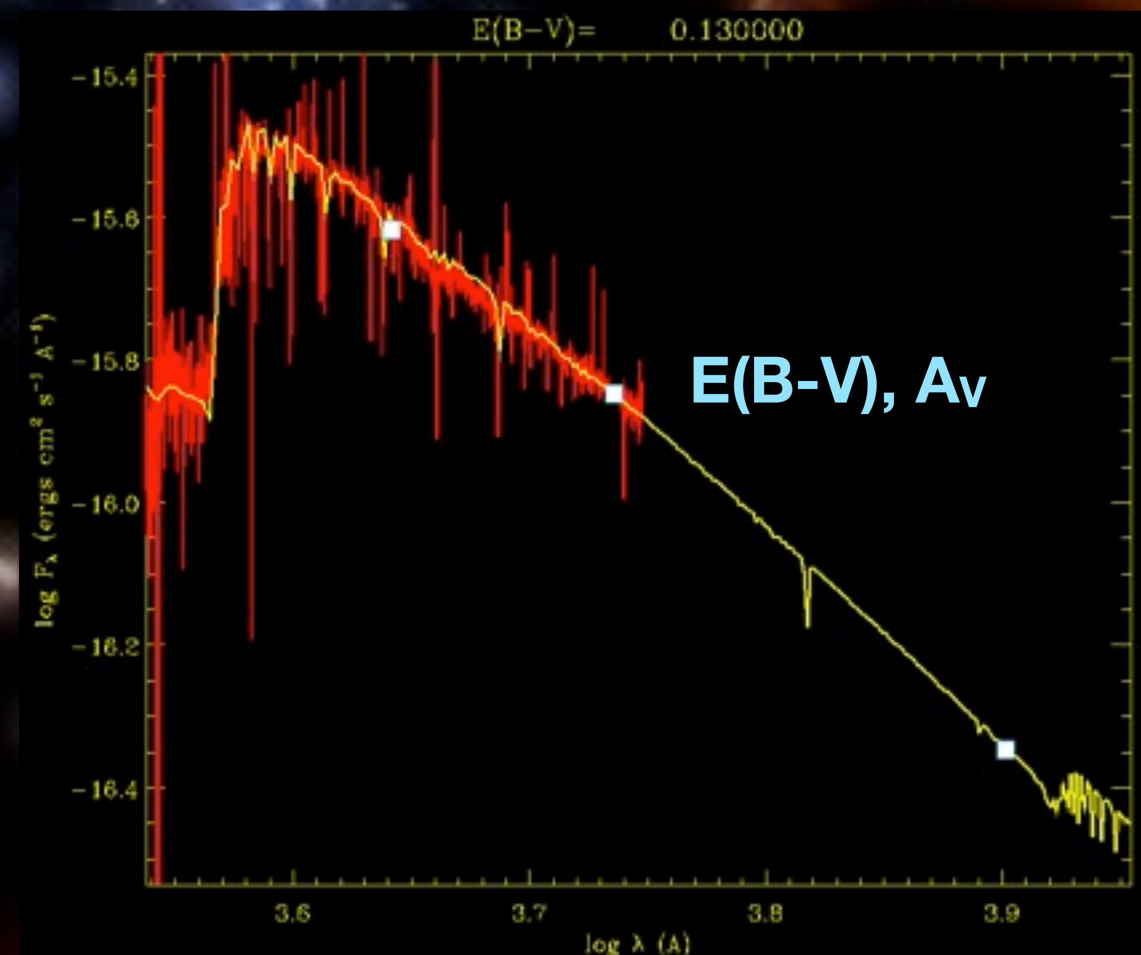
- Hot (T_{eff} ~ 9,000 - 30,000 K).
- Can solve for Teff, gravity...
- … then get abundances.

1. Blue Supergiants (BSGs)

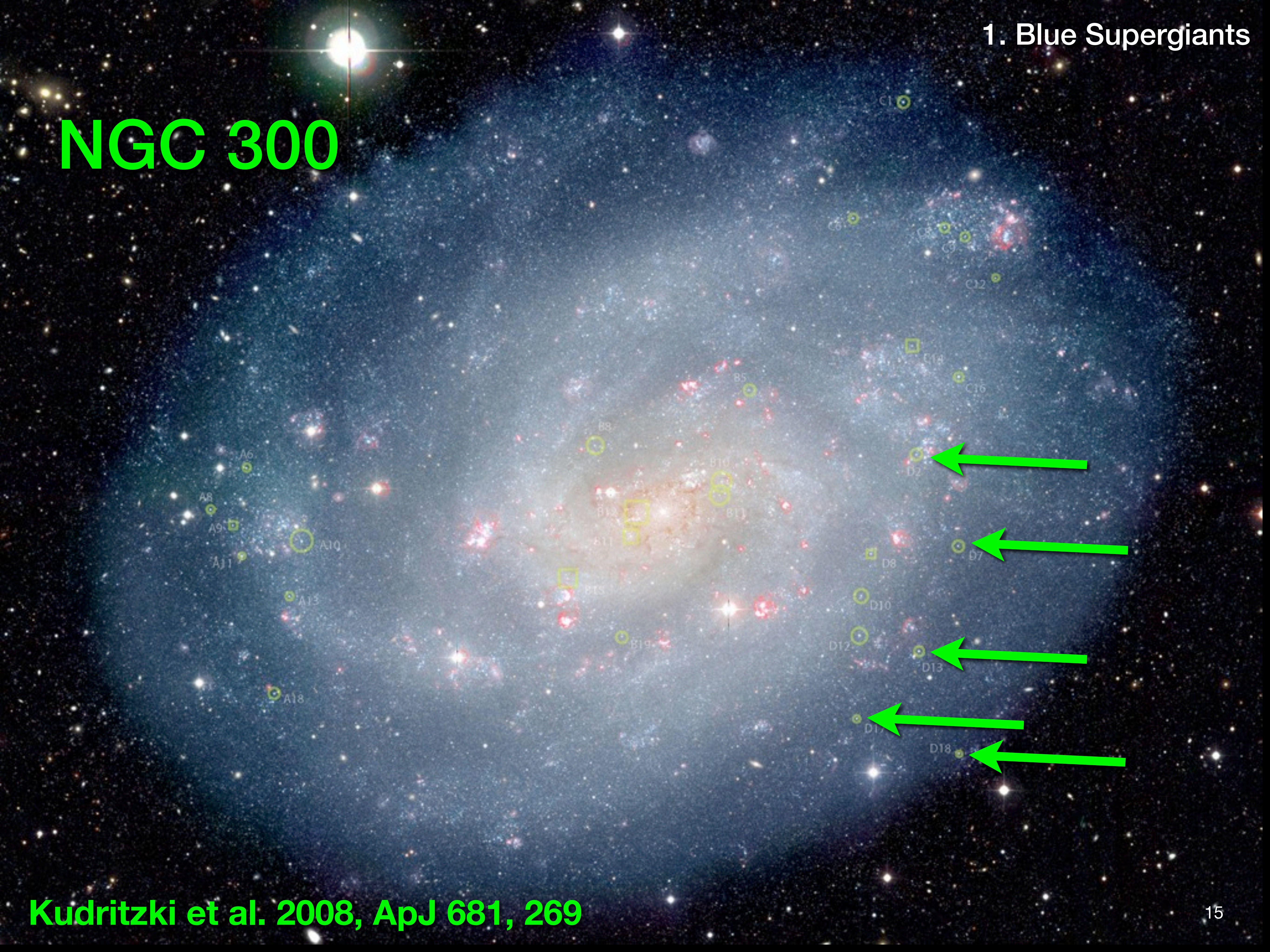






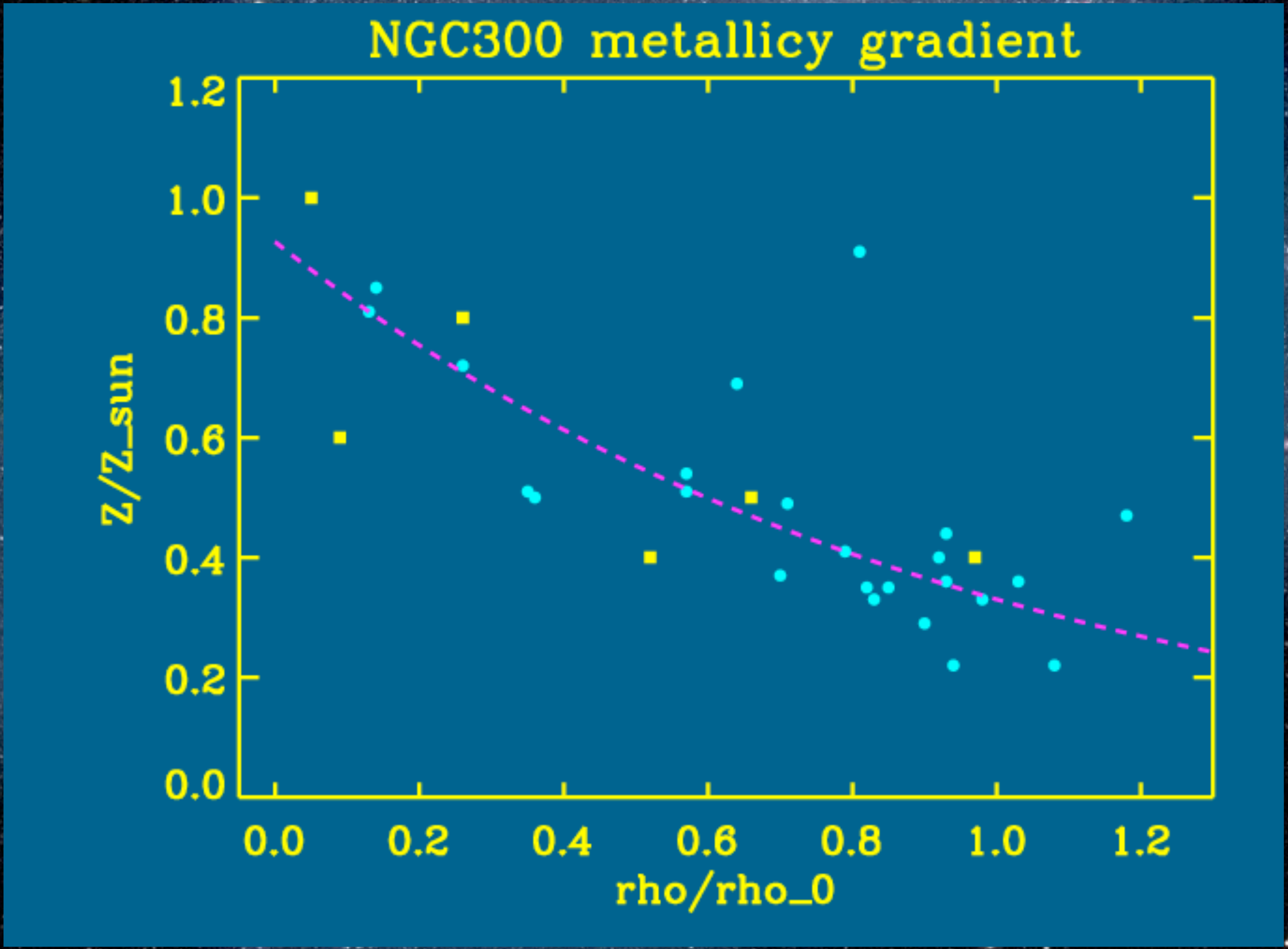


NGC 300



Kudritzki et al. 2008, ApJ 681, 269

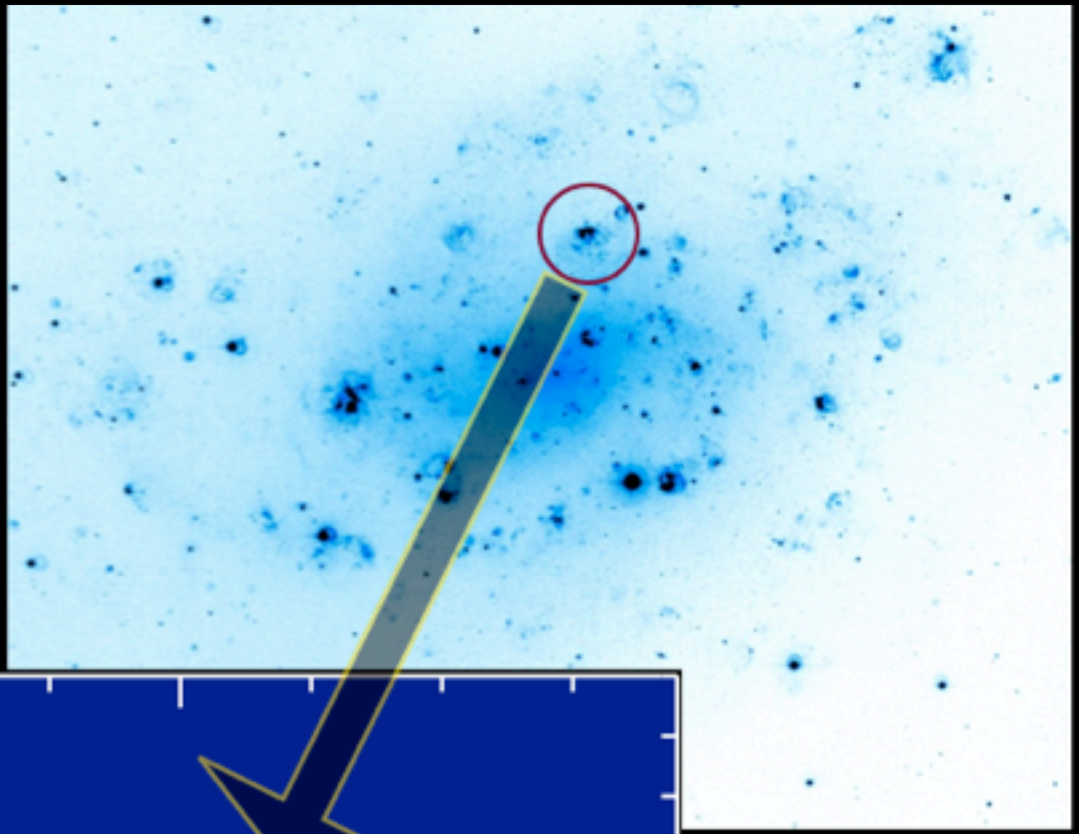
NGC 300

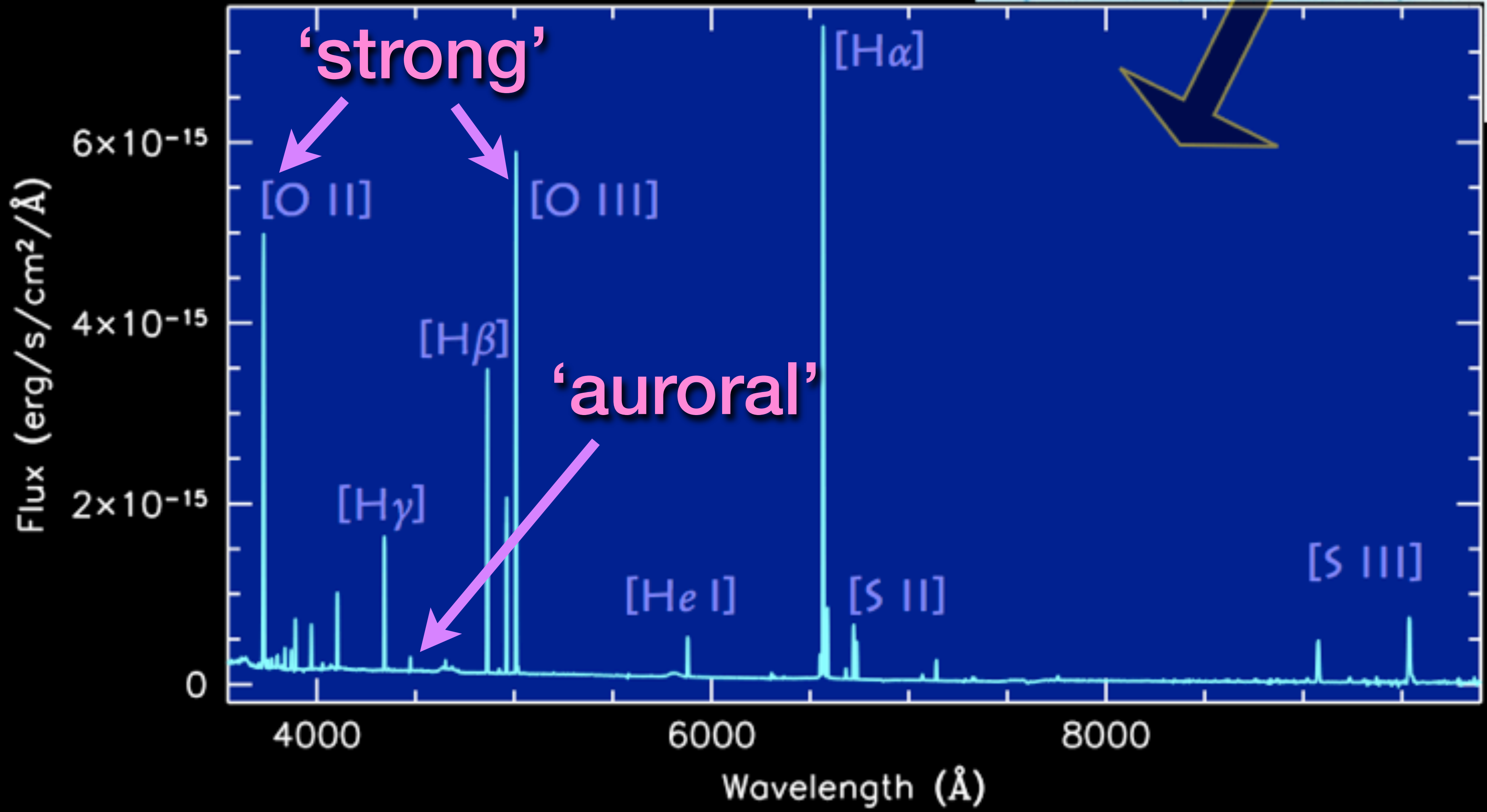


Kudritzki et al. 2008, ApJ 681, 269

NGC 300

Check results using T_e-sensitive 'auroral' lines of HII regions

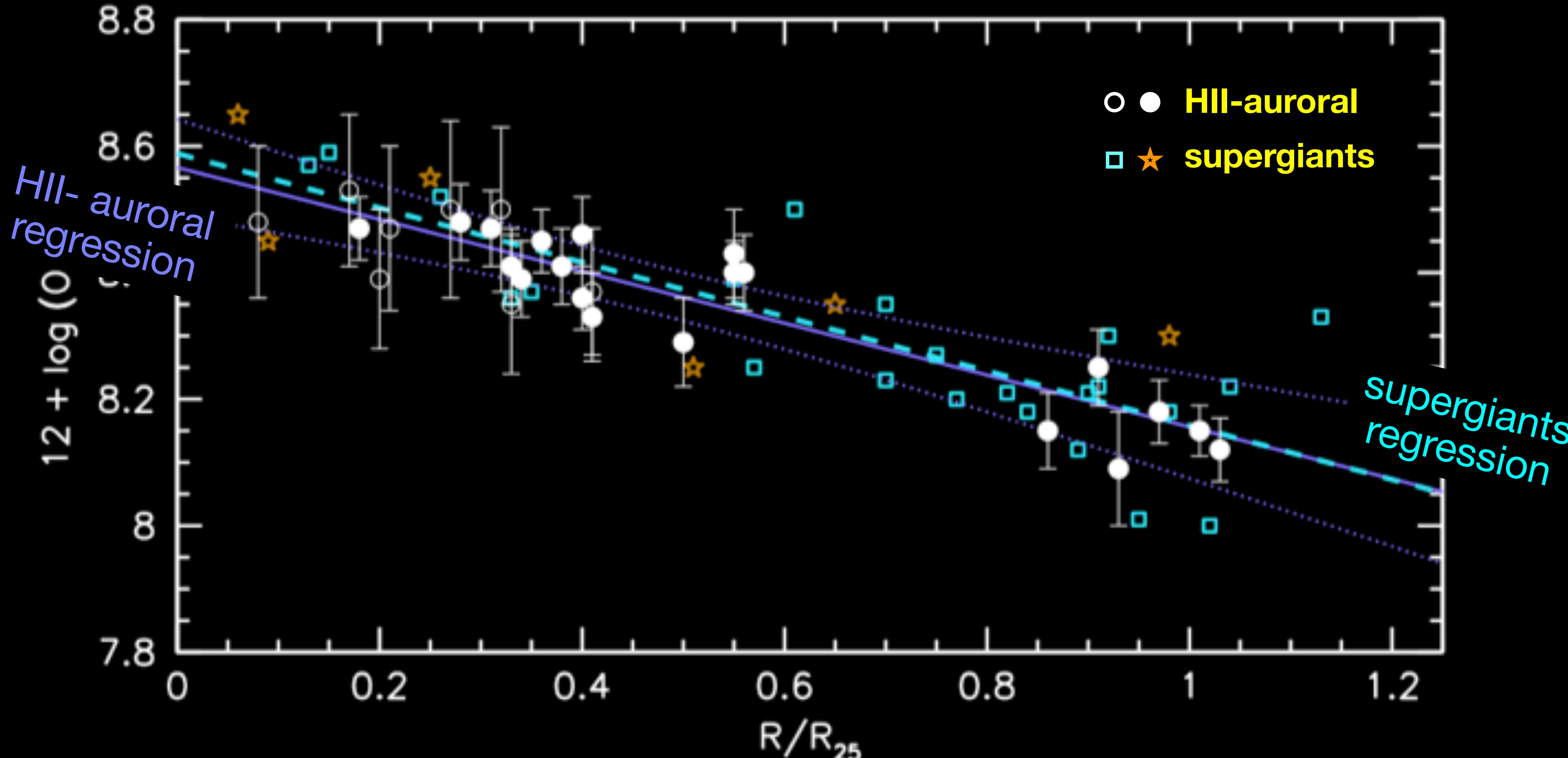




Bresolin et al 2009, ApJ, 700, 309

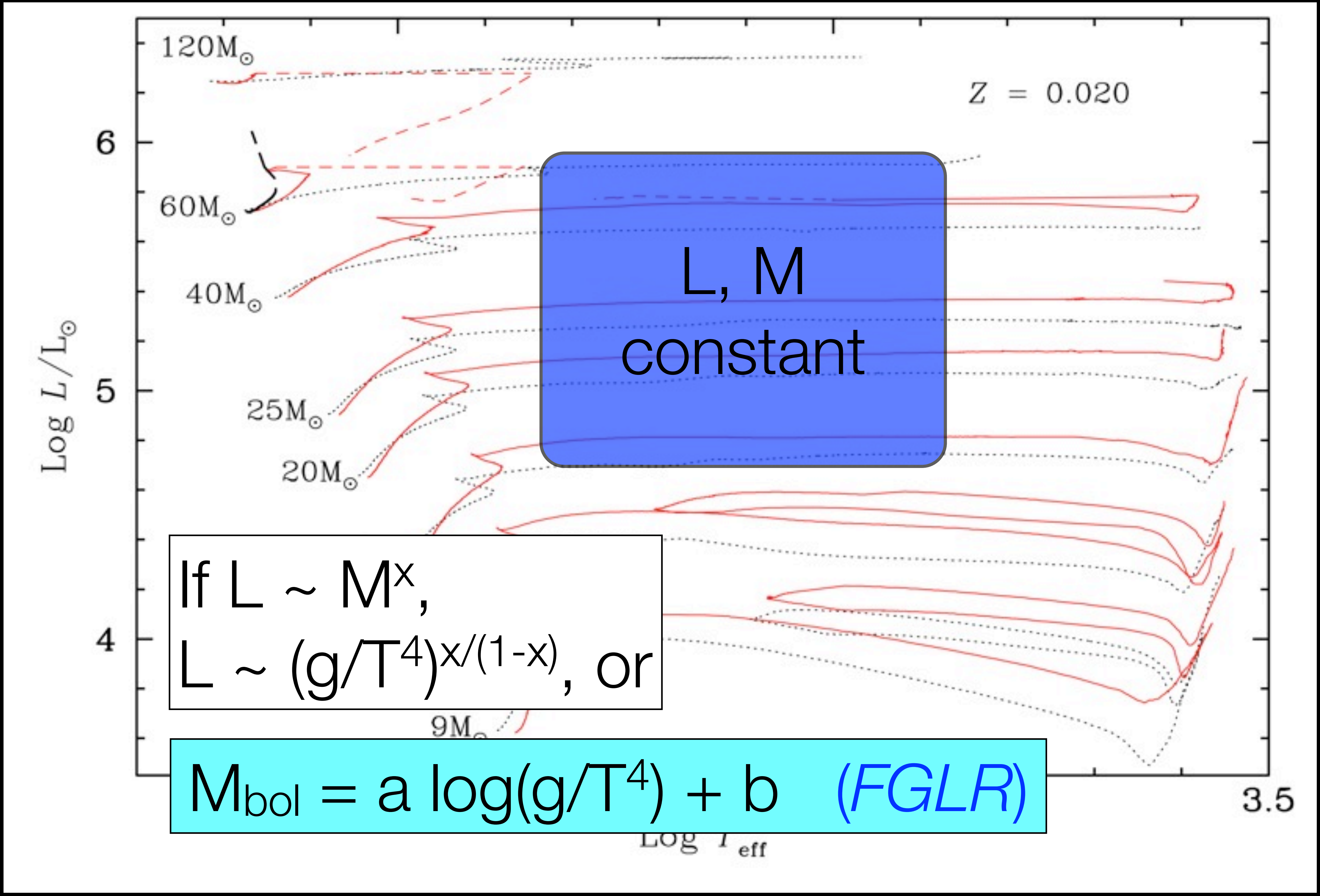
NGC 300

Check results using T_e-sensitive 'auroral' lines of HII regions → Excellent agreement with BSGs!



Bresolin et al 2009, ApJ, 700, 309

Bonus: can be used as distance indicators...

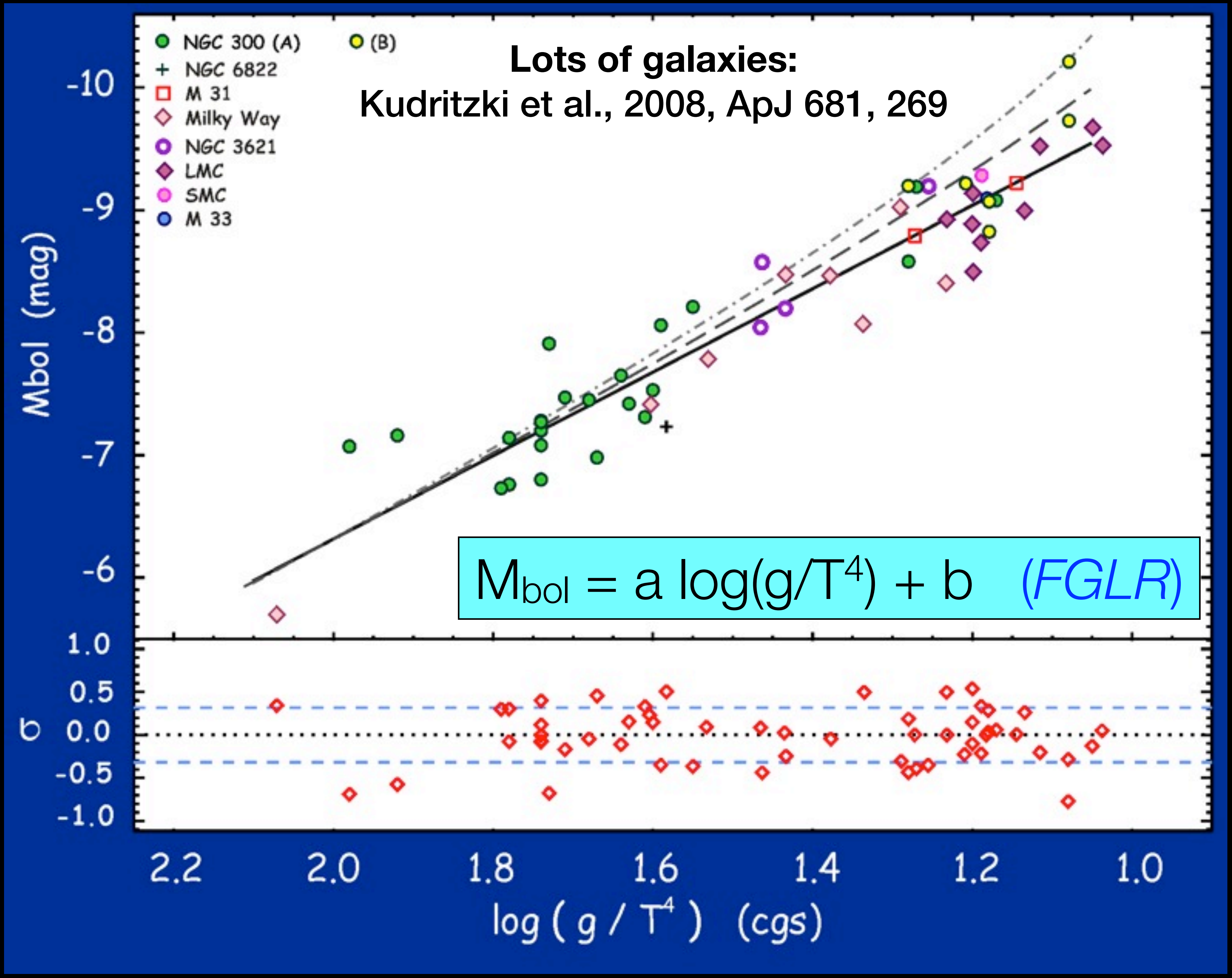


L, M constant

If $L \sim M^x$,
$L \sim (g/T^4)^{x/(1-x)}$, or

$M_{bol} = a \log(g/T^4) + b$ *(FGLR)*

Bonus: can be used as distance indicators...

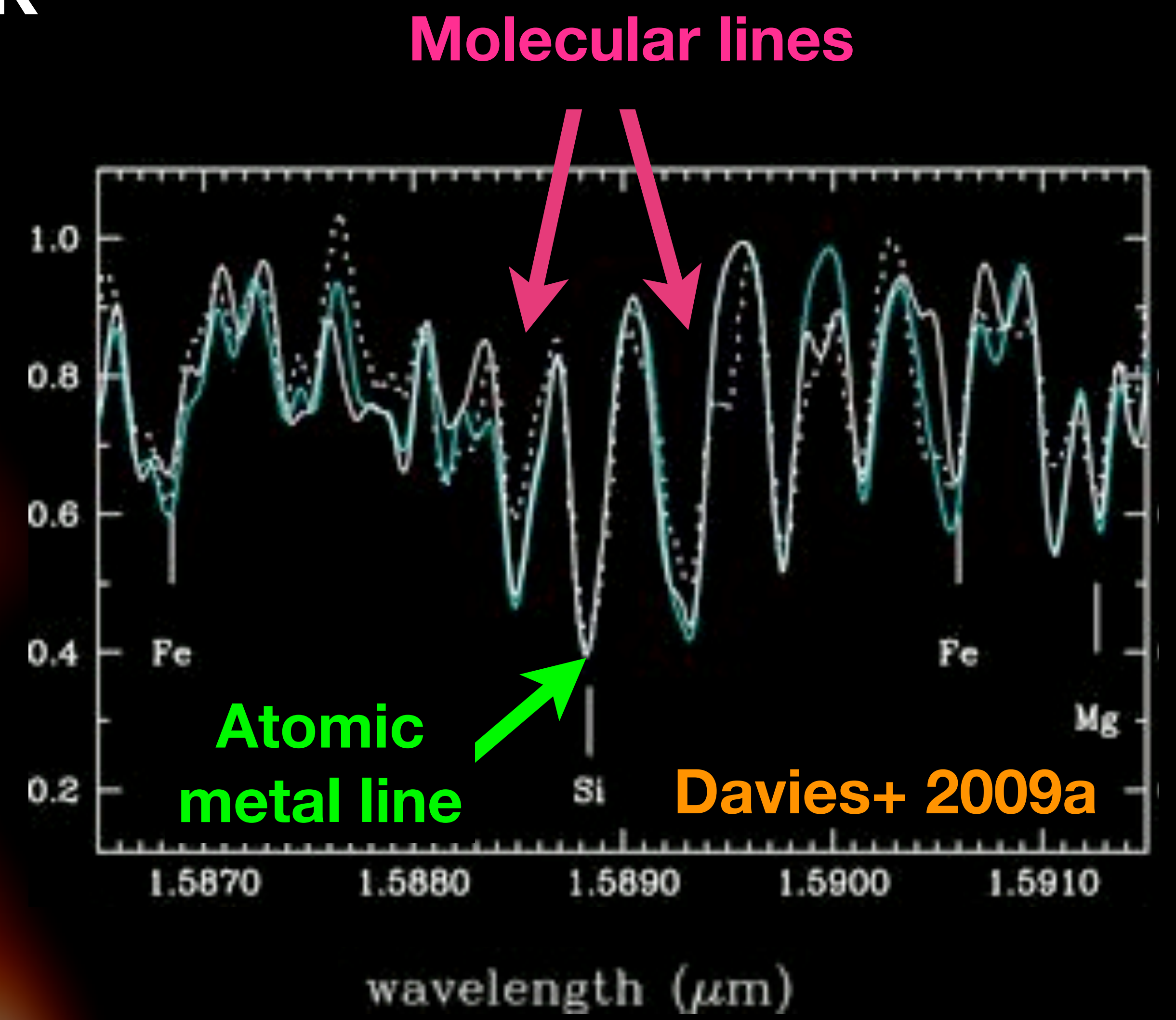


2. Red Supergiants (RSGs)

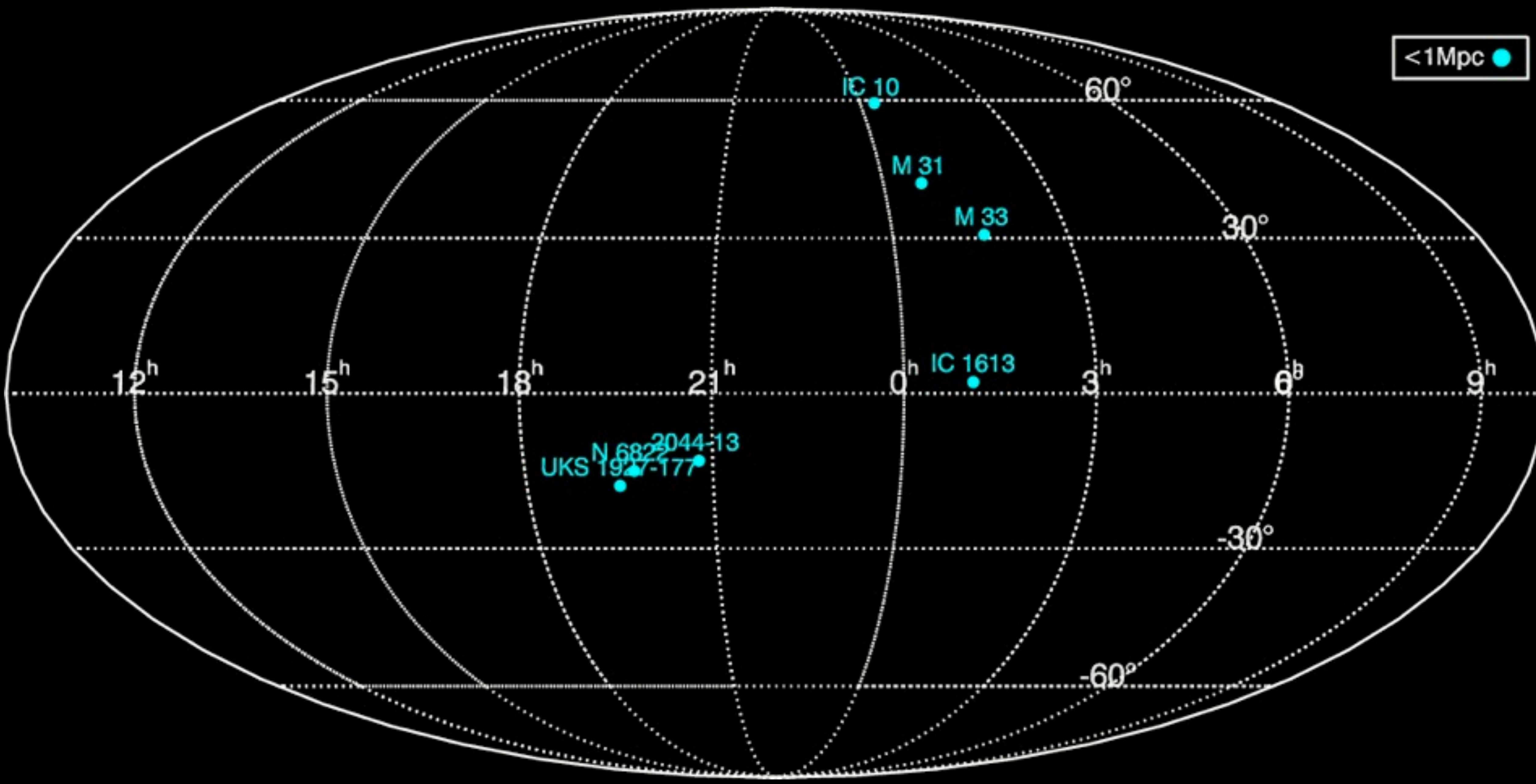
- Complementary to BSGs
- Greater potential for E-ELT:
  - ★ Stars have flux-peaks in NIR
  - ★ Method is NIR-based

Previous RSG abundance work

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



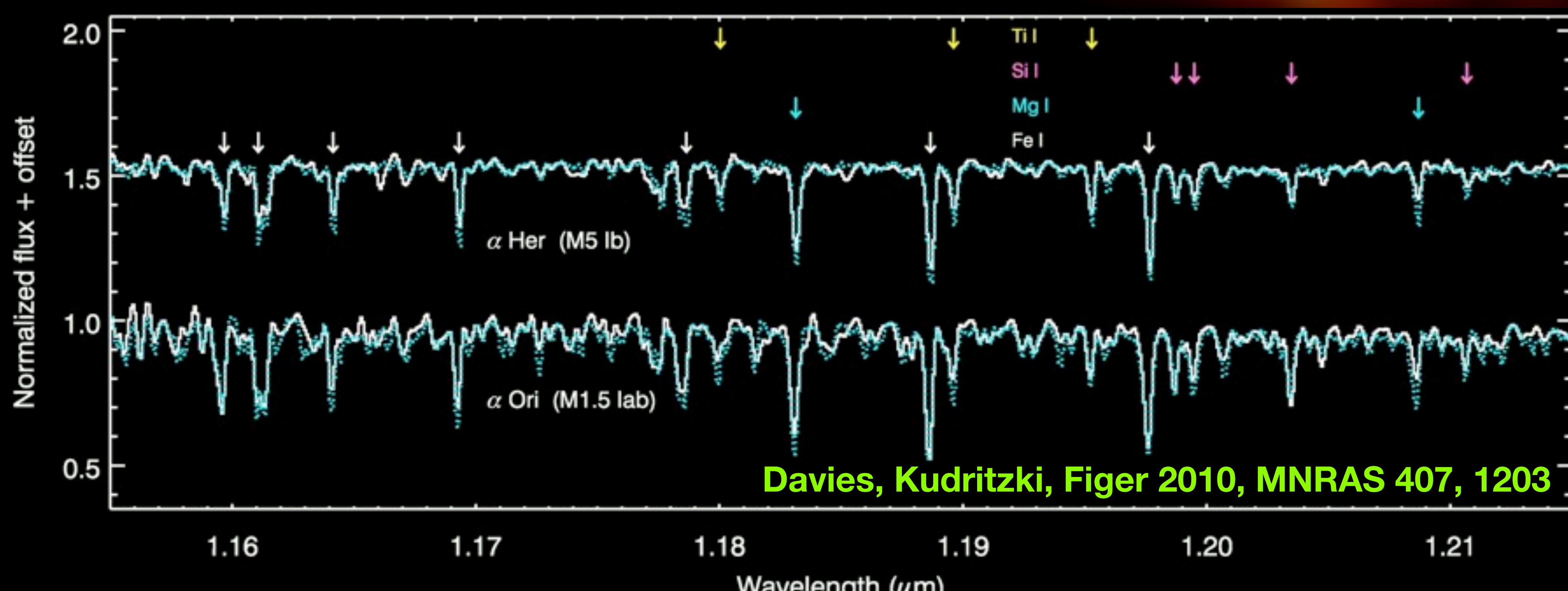
Not currently feasible for extra-galactic work (no targets!)



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

However, if we switch to J-band:

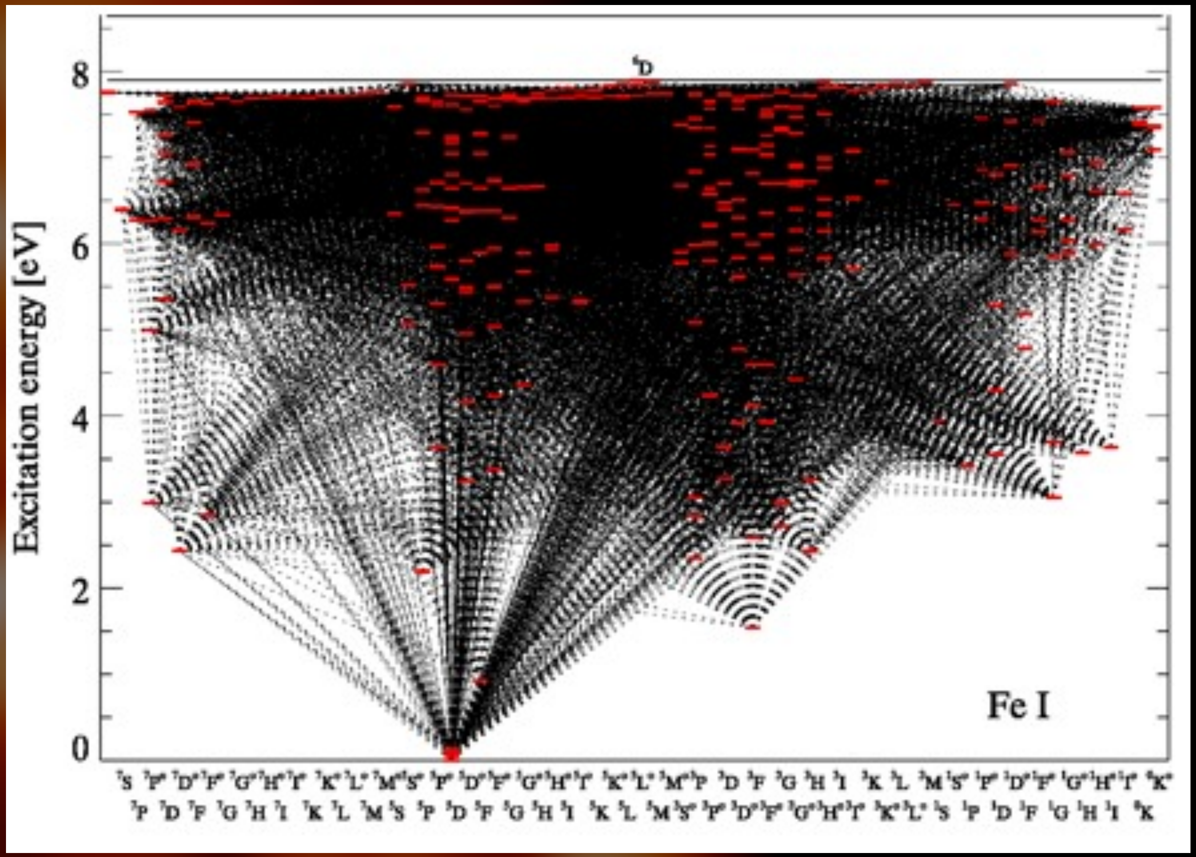
- Only atomic lines (molecular lines v. weak)
- Can get all stellar parameters
- Can drop resolution to R~3000
- Can use a MOS

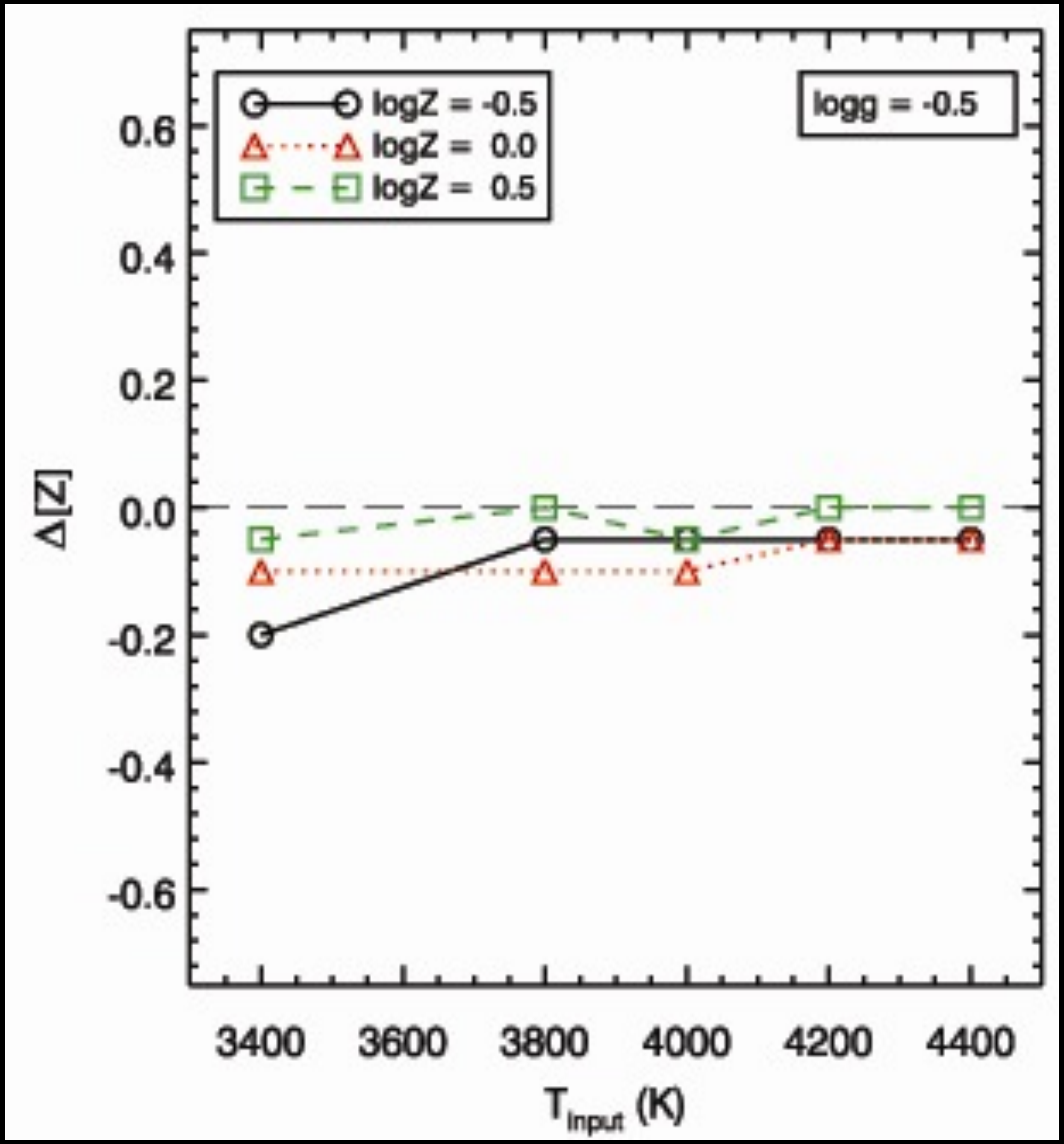


Davies, Kudritzki, Figer 2010, MNRAS 407, 1203

Modelling & Analysis

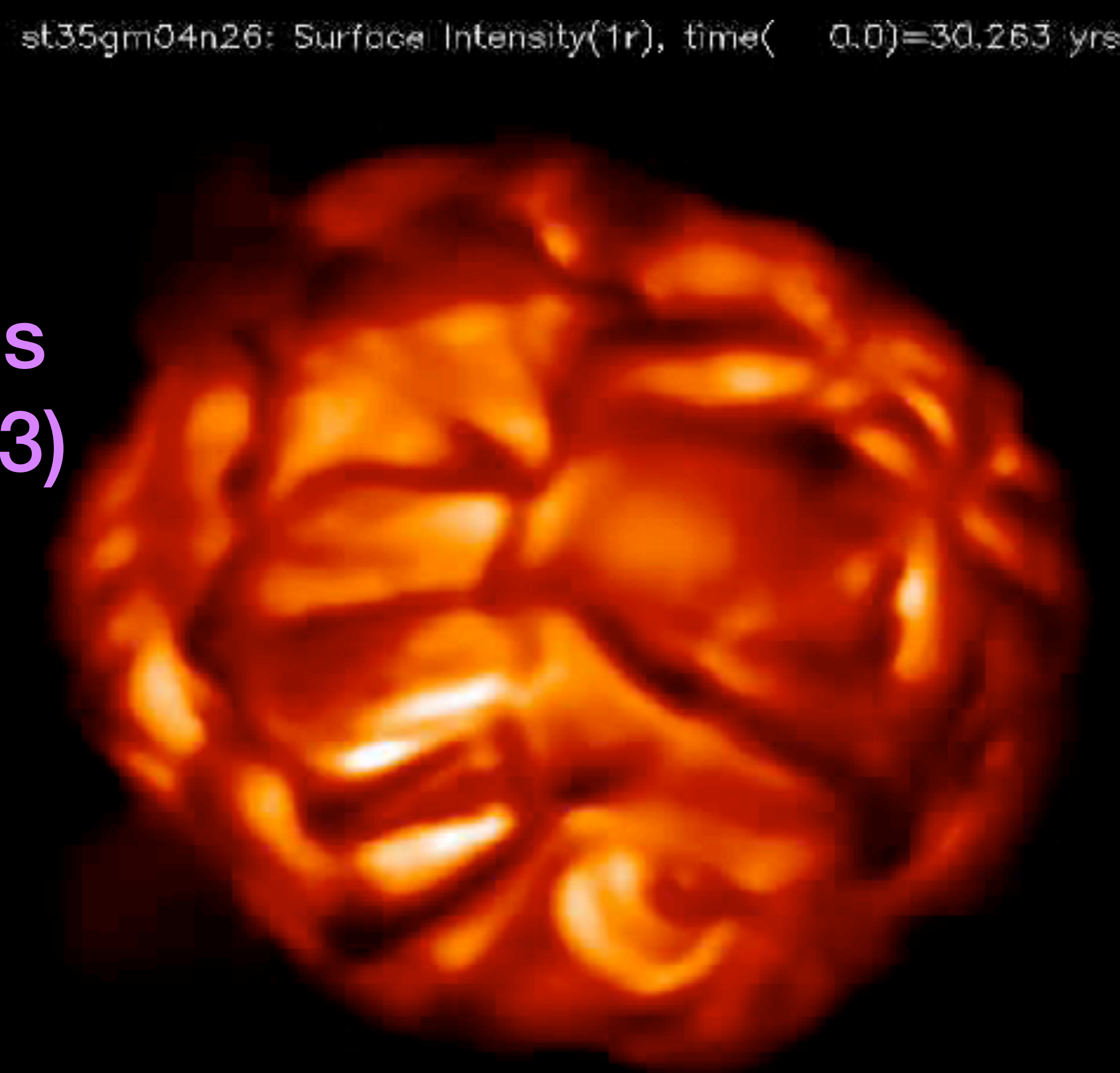
- MARCS models...
  (Gustavsson+ 2008)
- ... with nLTE corrections
  (Bergemann+ 2012,2013)



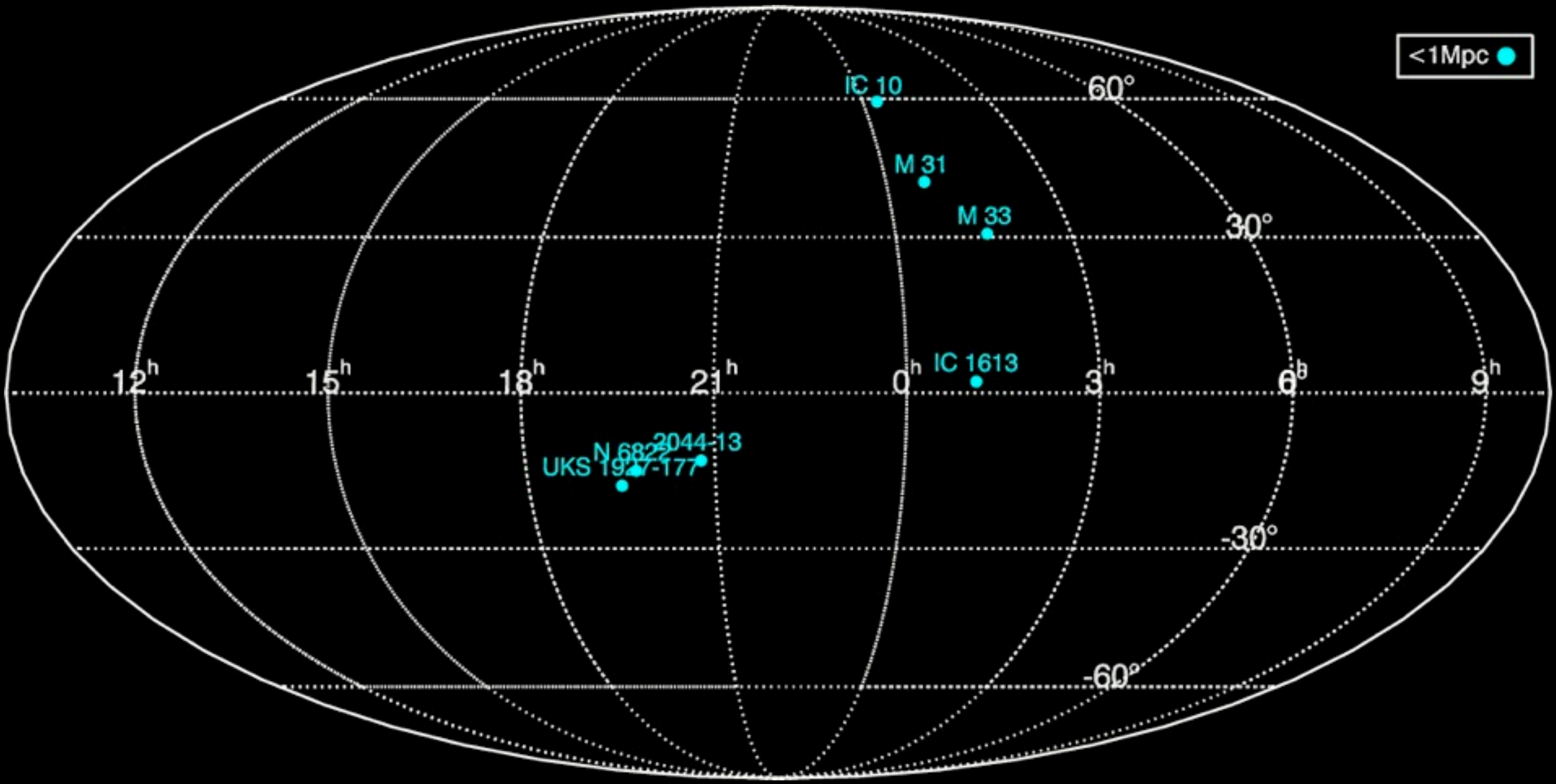


Modelling & Analysis

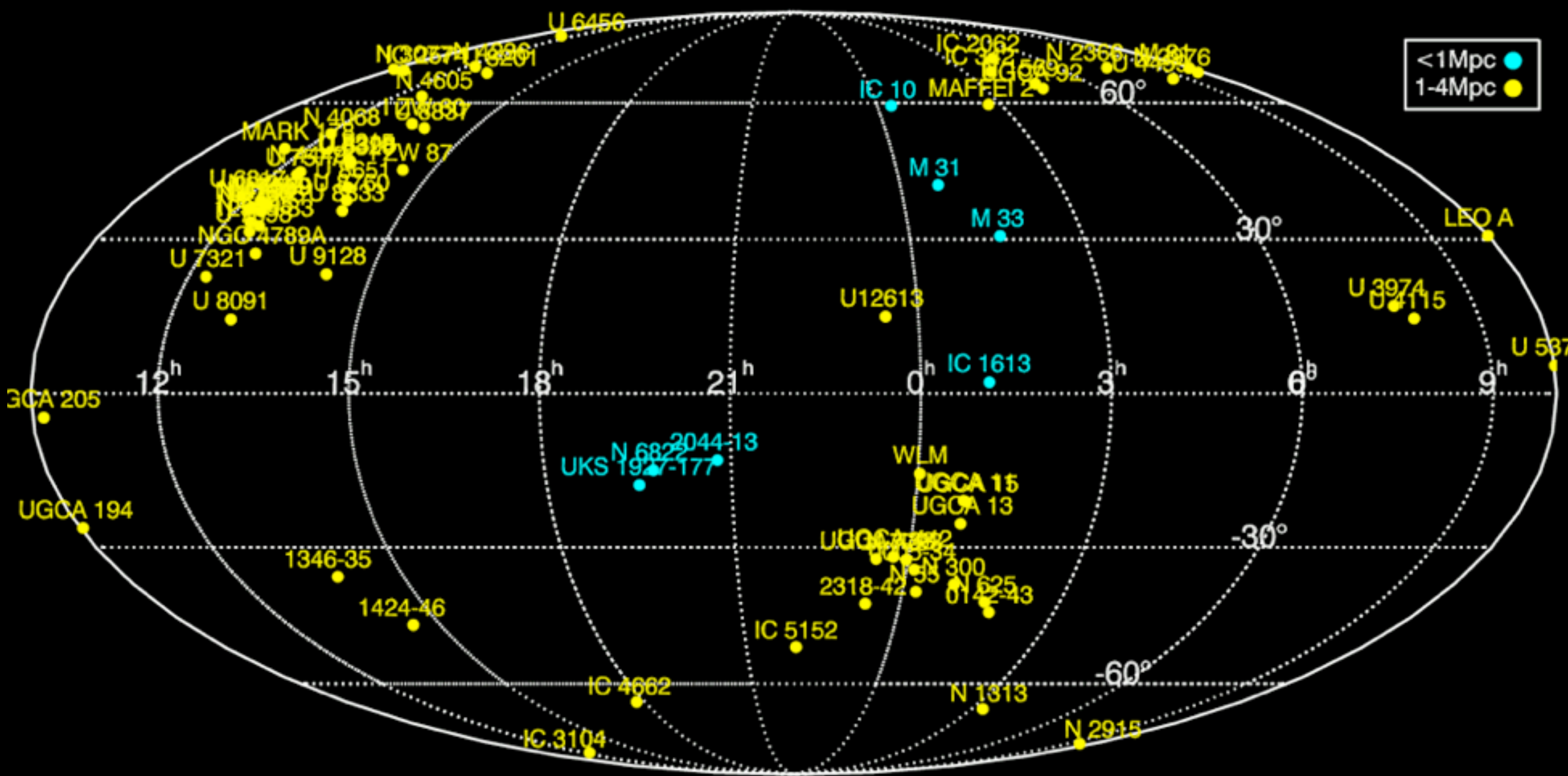
- MARCS models... (Gustavsson+ 2008)
- … with nLTE corrections (Bergemann+ 2012,2013)
- … and 3-D effects (Bergemann+ in prep)



Movie by Bernd Freytag

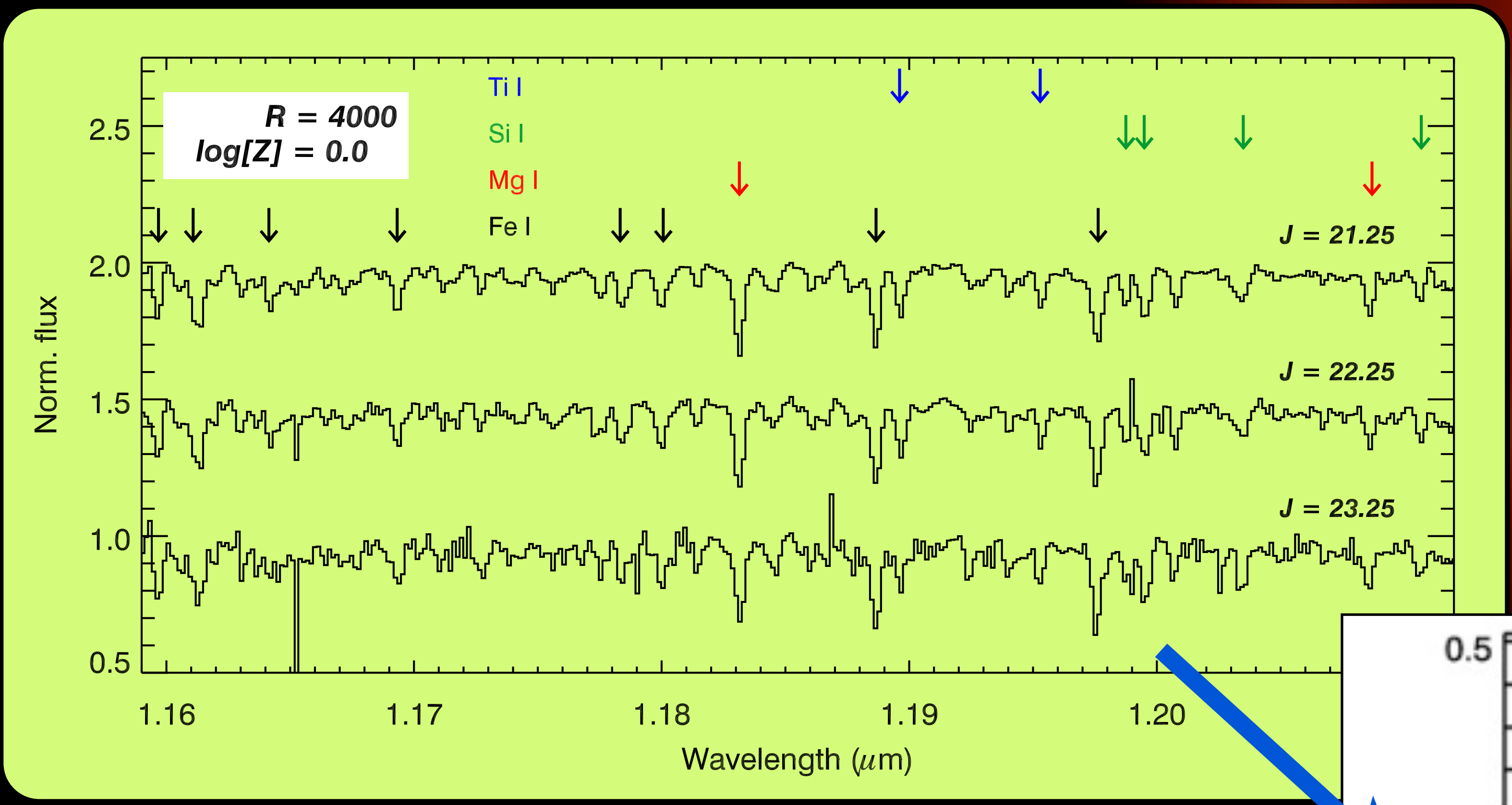


One star per galaxy, per night, at ~1Mpc **(VLT + CRIRES)**

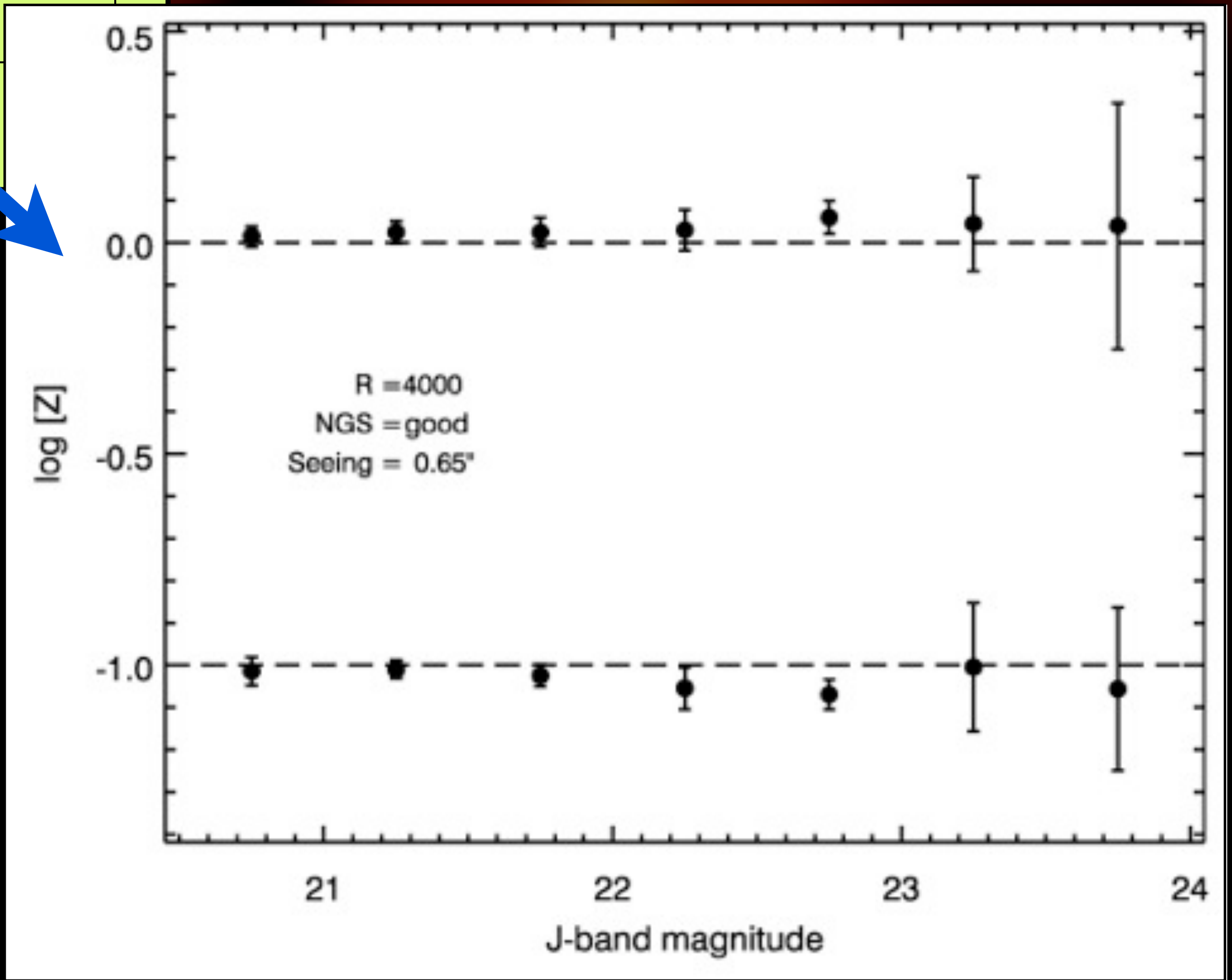


➡ 24 stars at once: 1 galaxy per night at 4Mpc **(VLT + KMOS)**

➡ number of observable targets increased to ~100

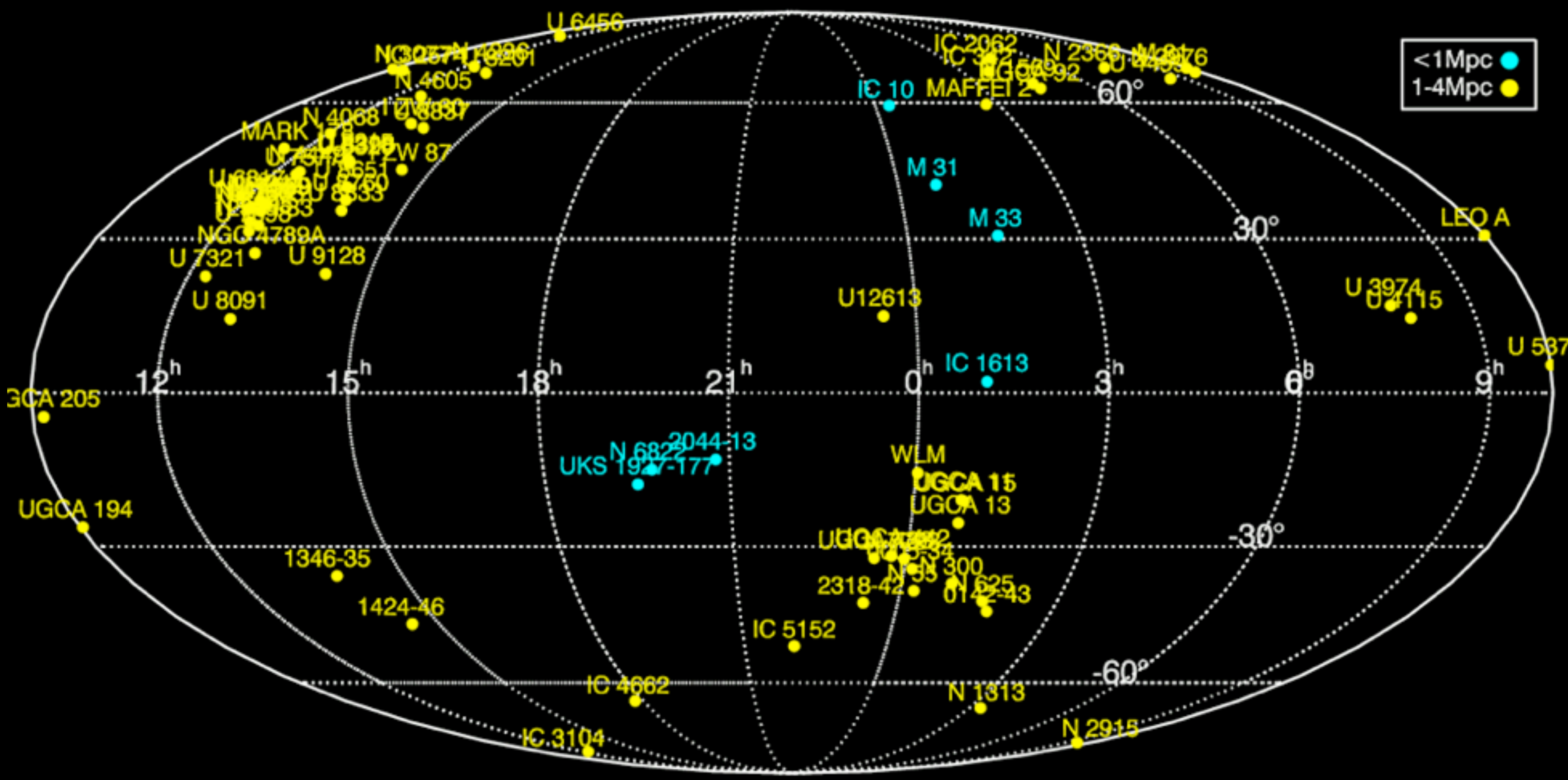


Evans, Davies, Kudritzki et al. 2011 A&A 527, 50



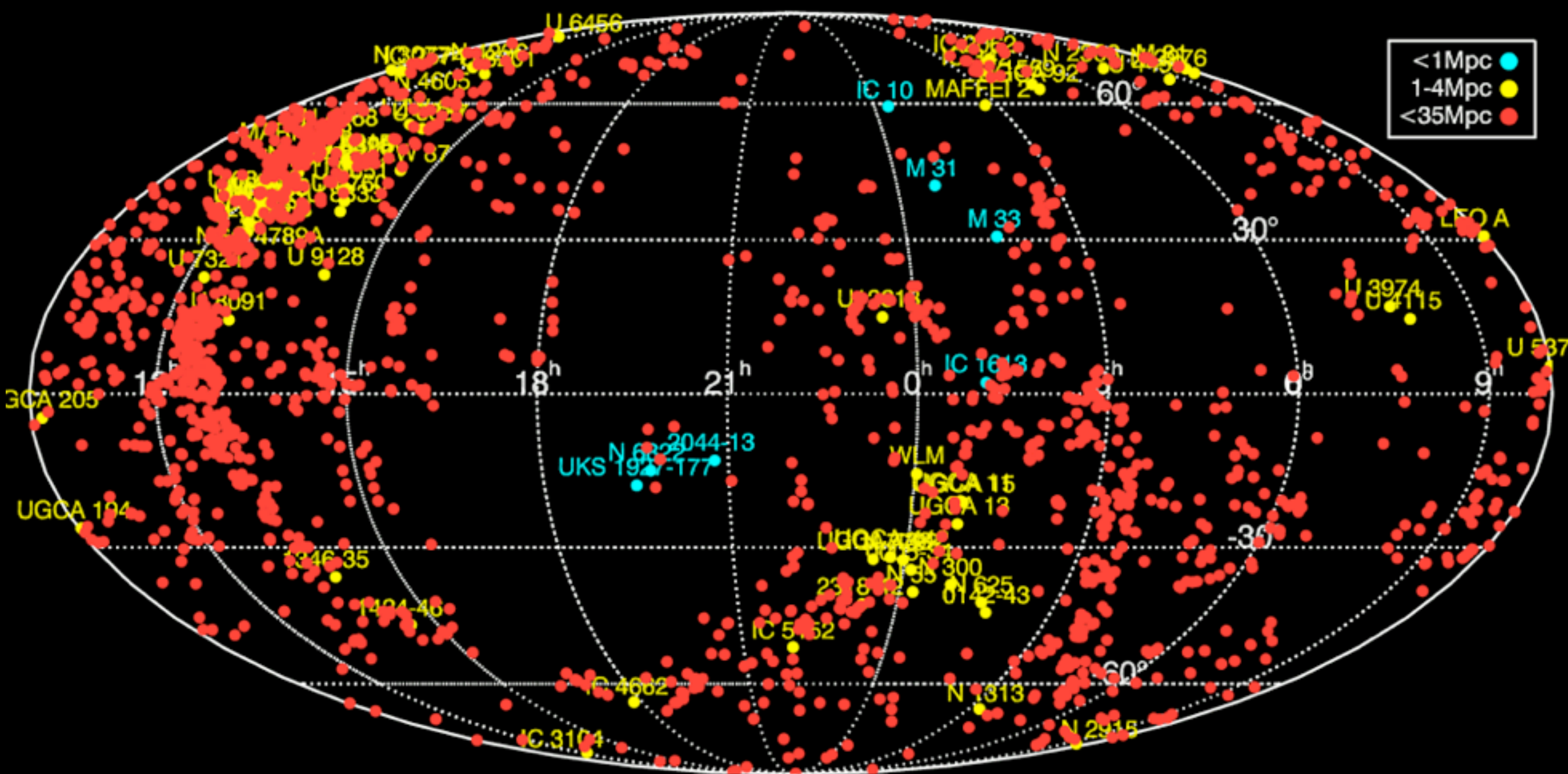
E-ELT potential

- Accurate abundances at J=23
- Limiting distance: 70Mpc
- (35Mpc if we're modest...)



➡ VLT: 1 galaxy per night at 4Mpc

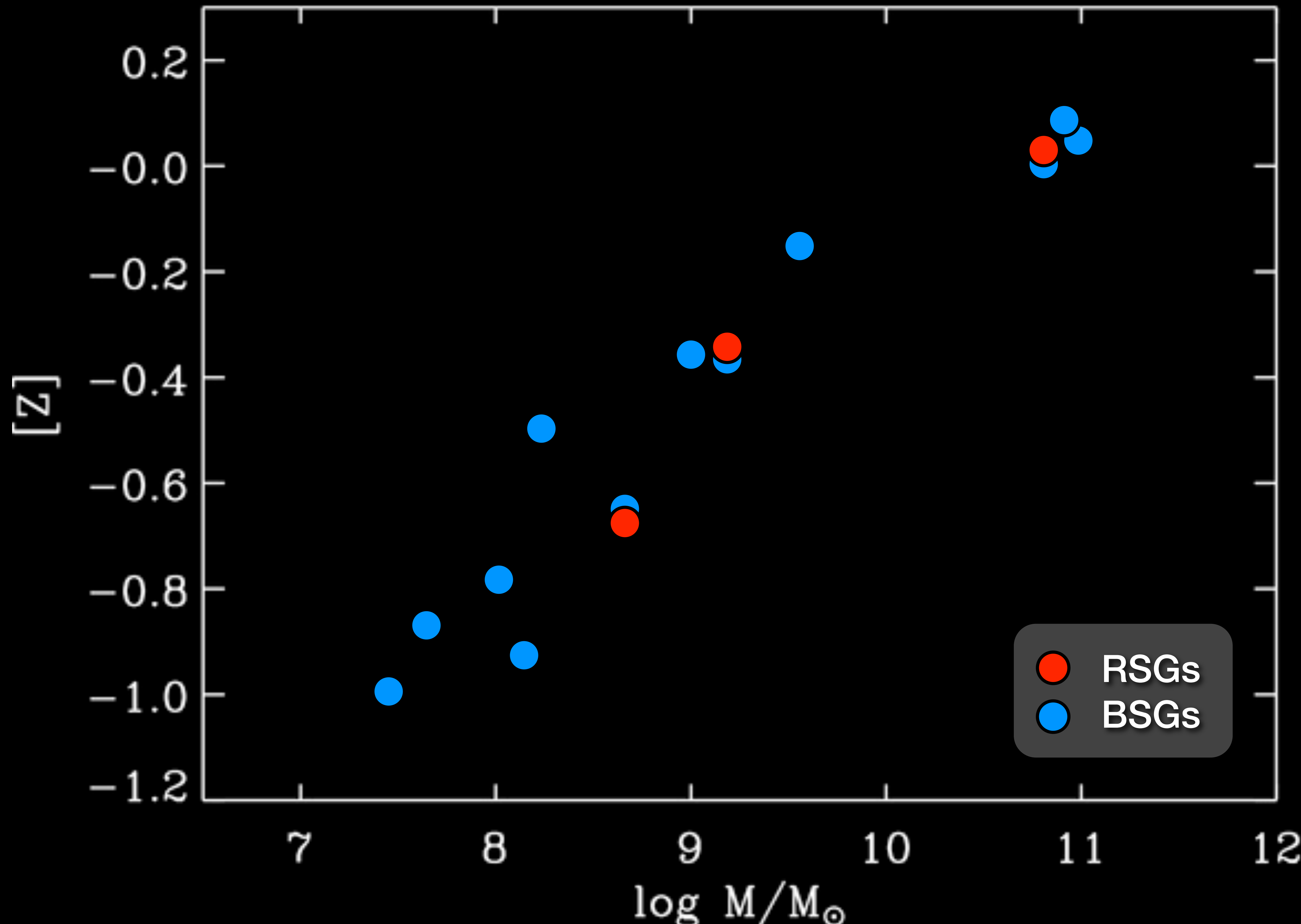
➡ number of observable targets increased to ~100



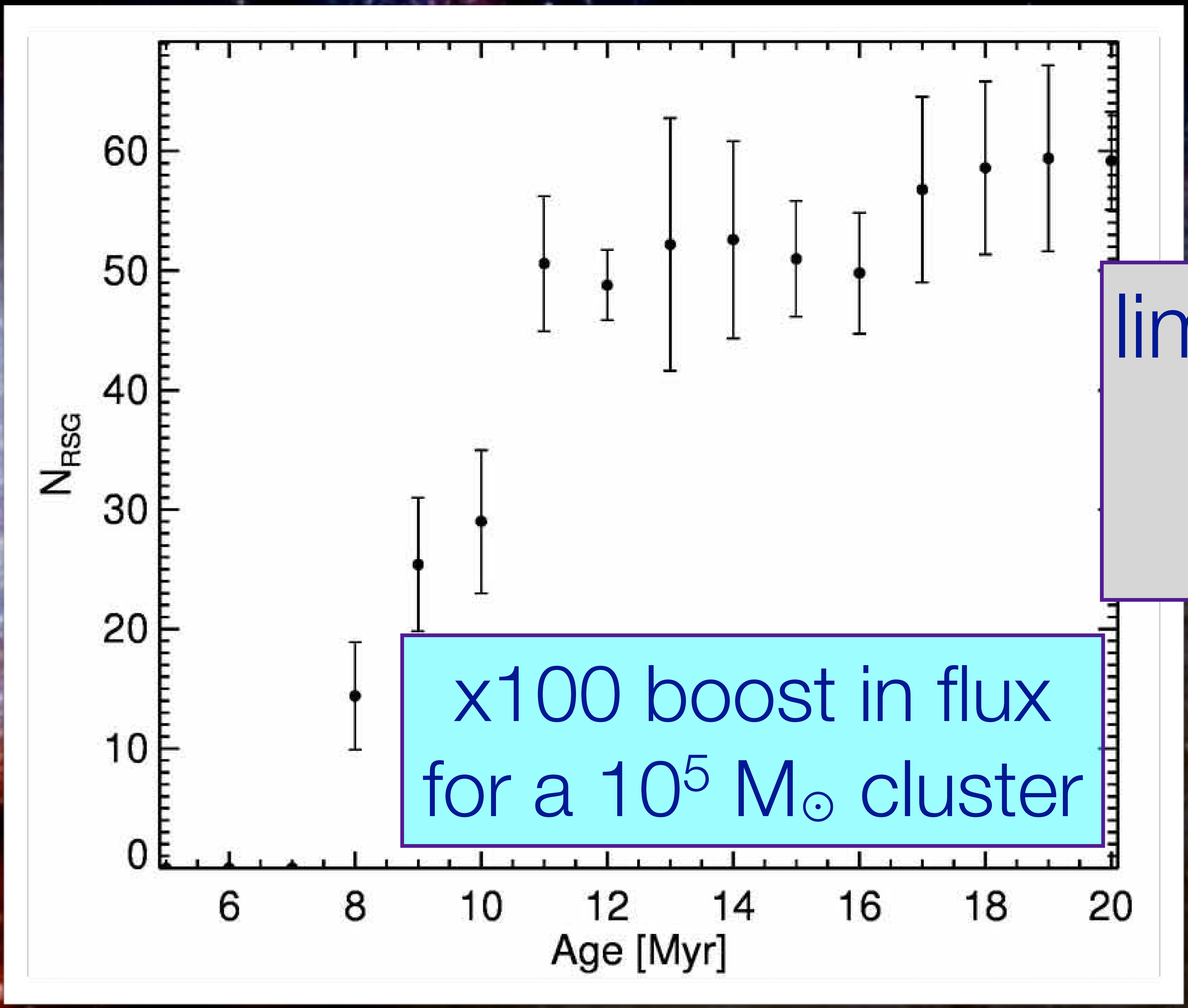
➡ E-ELT: 1 galaxy per night at 35Mpc (modest...)

➡ number of observable targets increased to ~1500!!

Mass-Metallicity Relation (supergiants)



Bonus #1: RSG-dominated star-clusters...



limiting distance with E-ELT: **300Mpc**

Bonus #2: In principle, technique can work on any cool star…

(not just supergiants)

- Red Giants, AGB stars...
- in dSph, Globular Clusters…
- at distances of 3.5Mpc (Andromeda, Sculptor & M91 groups)

Stellar Spectroscopy Beyond the Local Group with the E-ELT

Requirements:

BSGs:

λ = 4000 - 5000Å

R = 1000

Multiplexing: >25

Bonus:

distances accurate to ~10%.

RSGs:

λ = 1.1 - 1.3μm

R = 3000

Multiplexing: >25

Bonus:

- Clusters @ x10 distance.
- RGs in dSph, GCs

Stellar Spectroscopy Beyond the Local Group with the E-ELT

Summary & Outlook :

Quantitative spectroscopy of **individual supergiants,** at distances **>30Mpc**

- Accurate mass-metallicity relation at z=0.
- Can be used to recalibrate strong-line methods for higher z work.
- Greater accuracy for lower end of distance ladder.