Radial metallicity gradients from MOS observations of emission-line probes: Constraining galactic chemical evolution

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Outline

background

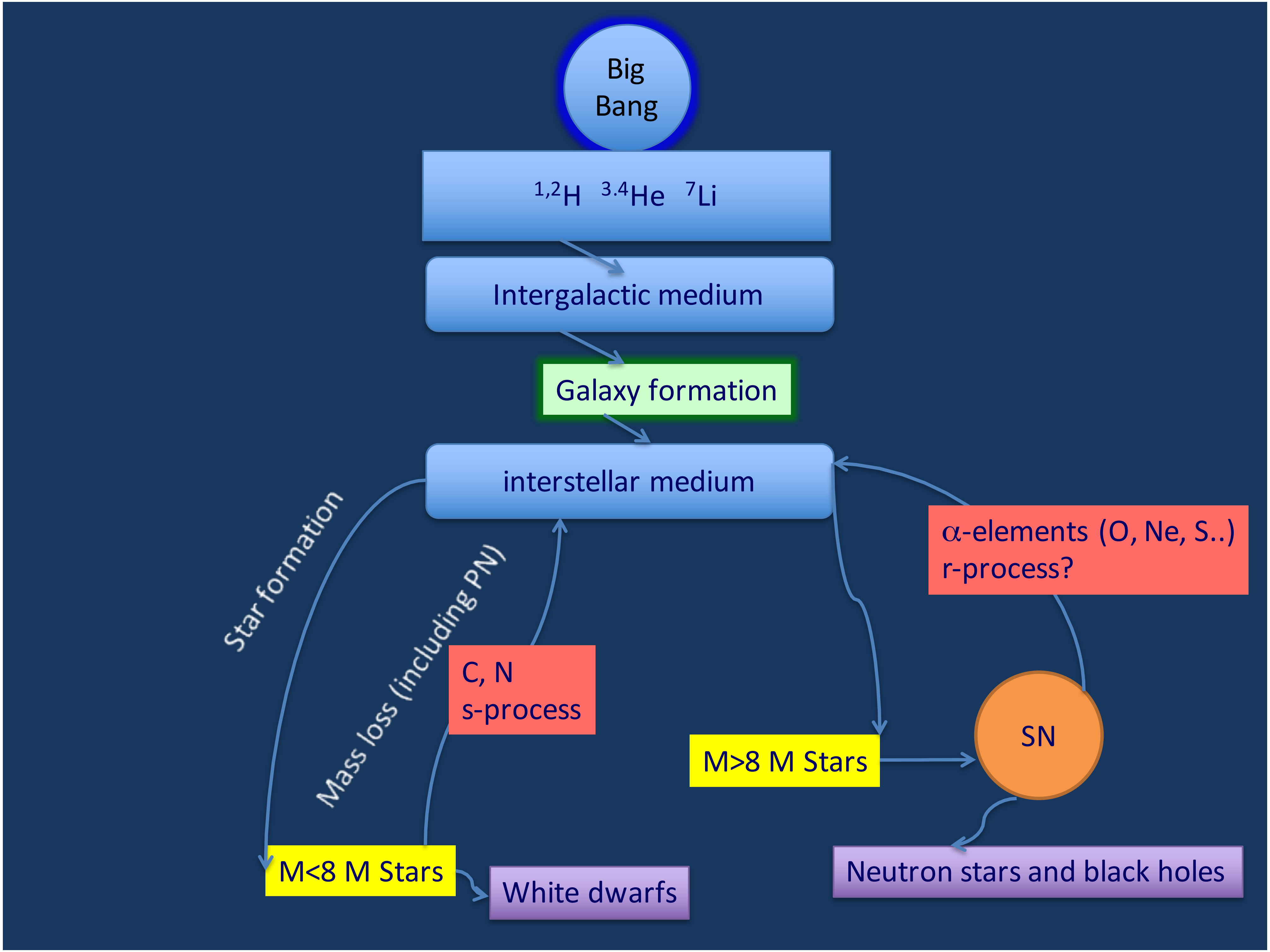
- Radial metallicity gradients and their evolution
- Emission-line probes

Latest results

- Direct abundances
- Strong-line abundances

The future

- Advances with TMT/ELTs


Big Bang
1,2H 3.4He 7Li
Intergalactic medium
Galaxy formation
interstellar medium
Star formation
Mass loss (including PN)
C, N
s-process
α-elements (O, Ne, S..)
r-process?
M<8 M Stars
White dwarfs
M>8 M Stars
SN
Neutron stars and black holes

The chemical evolution of galaxies

- The Universe starts off *chemically simple* and evolves into chemical complexity, thanks to the evolution of galaxies and stars
- Chemical evolution depends on IMF and SFH. To reconstruct them one needs to constrain galactic evolutionary model predictions
- *Radial metallicity gradients* in star-forming galaxies are key predictions from models
- <u>Gradients can not be determined ab initio</u> from cosmological models, <u>they need to be well constrained by data</u>
- *Gradient evolution (i.e., radial metallicity gradients of different age populations)* offers a even better constraint to models

Gradient evolution with emission-line probes in nearby galaxies

O/H is used as metal tracer in HII regions and PNe

- HII regions probe chemical evolution though galaxy lifetime. Age of stellar population $t_\star \approx 0$; time since galaxy formation t_{gal}~ 13.5 Gyr (redshift z=0)
- Since oxygen evolution in AGB stars is minimal, PNe probe chemical environment at the time of progenitor formation

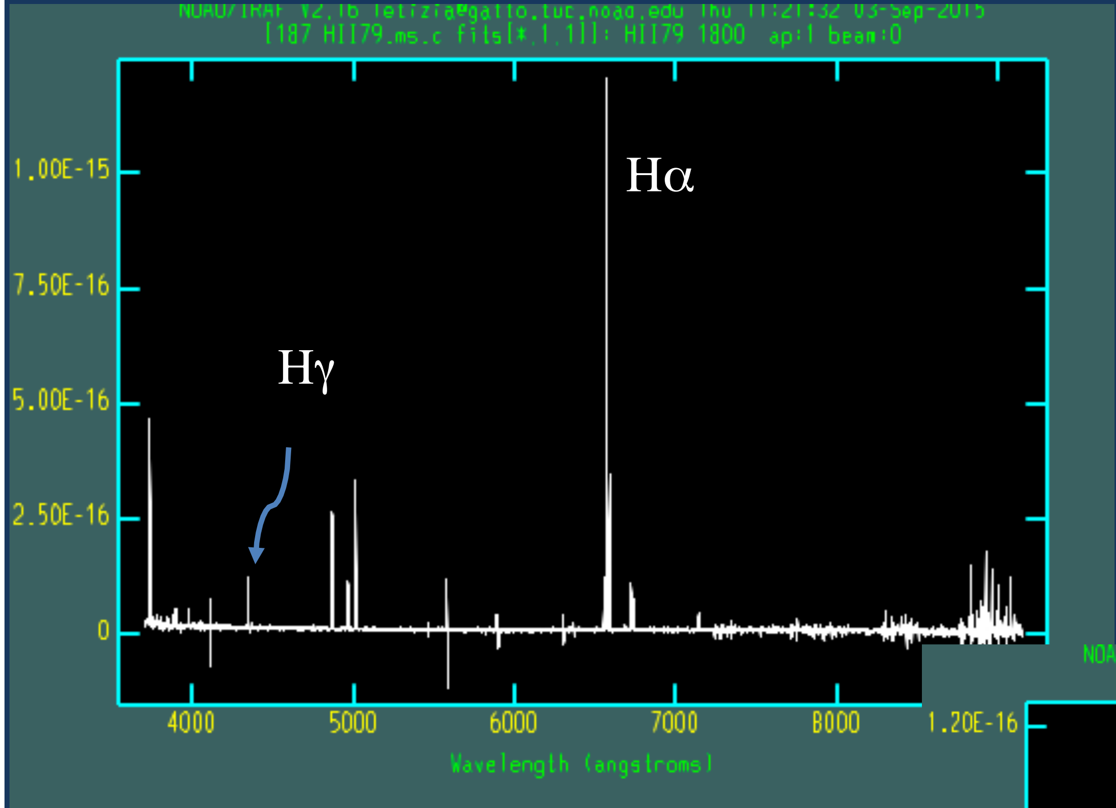
- Different PN types time tag chemical evolution through progenitor dating.

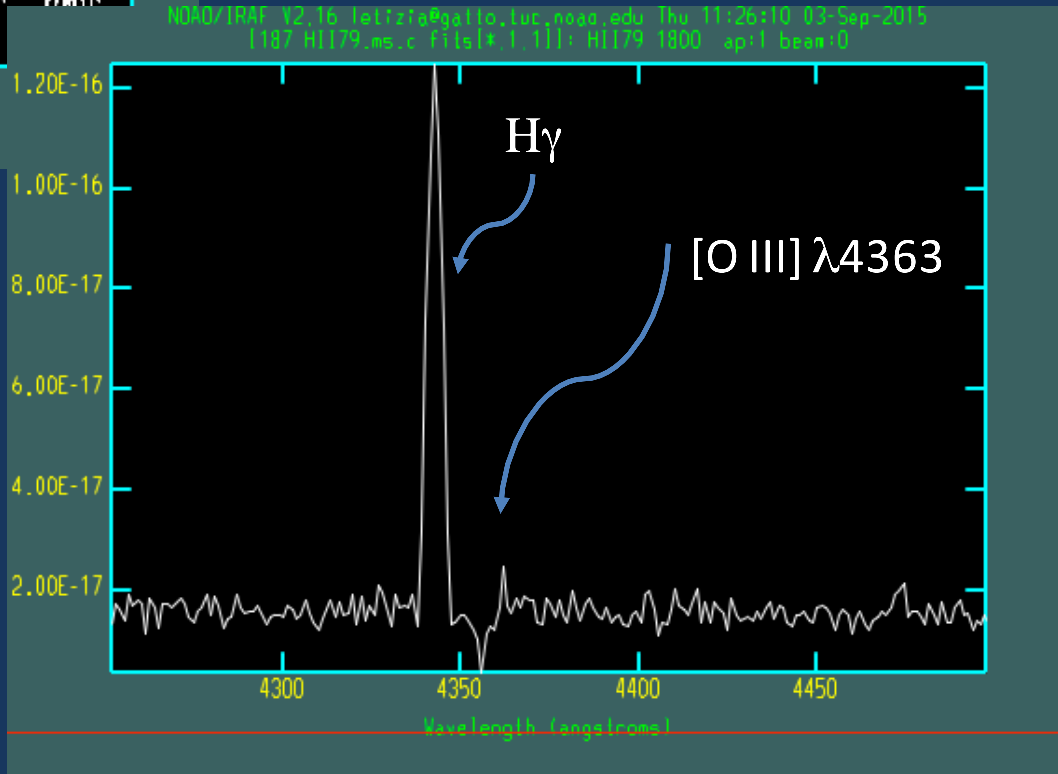
Type	M_{to} [$M_\odot$]	$t_\star$ [Gyr]	t_{gal} [Gyr]	z
I	>2	≤ 1	> 12.4	≤0.08
II	1.2 -2	1-5	8.5-12.4	0.08-0.5
III	< 1.2	> 5	<8.5	>0.5

- Direct emission-line abundances, calculated from T_e, N_e, and ionic emission lines, need weak auroral line detection for T_e (e.g., [OIII] λ4363)

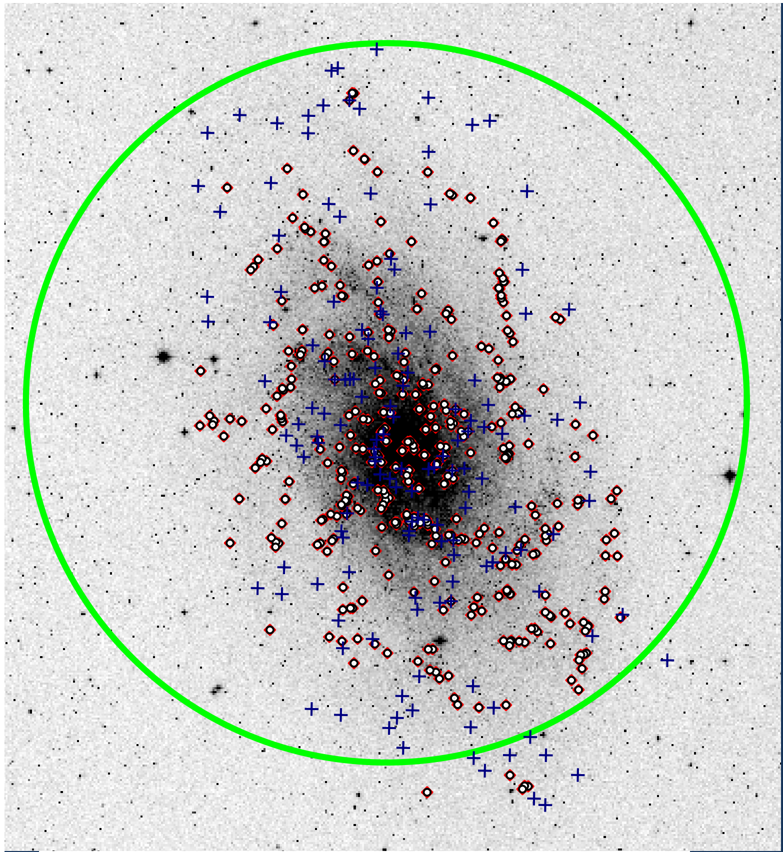
HII region in M81

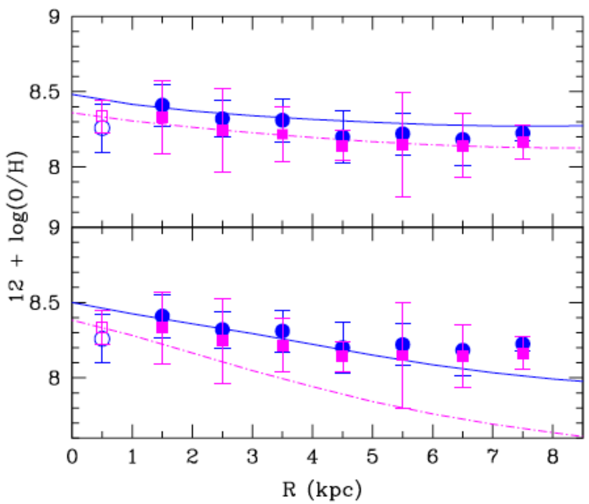
Example of weak diagnostic line for T_e





Direct O/H gradients and their evolution - M33





Magrini et al. 2010

Hectospec@MMT

muti-fiber mid-resolution spectrograph with 3600-9100 Å coverage; 1.2 Å/pix dispersion; 1 deg FoV; 300 1.5” fibers; on 6.5m MMT (Mt. Hopkins, AZ)

Exquisite correspondence of science and technical experiment for M33

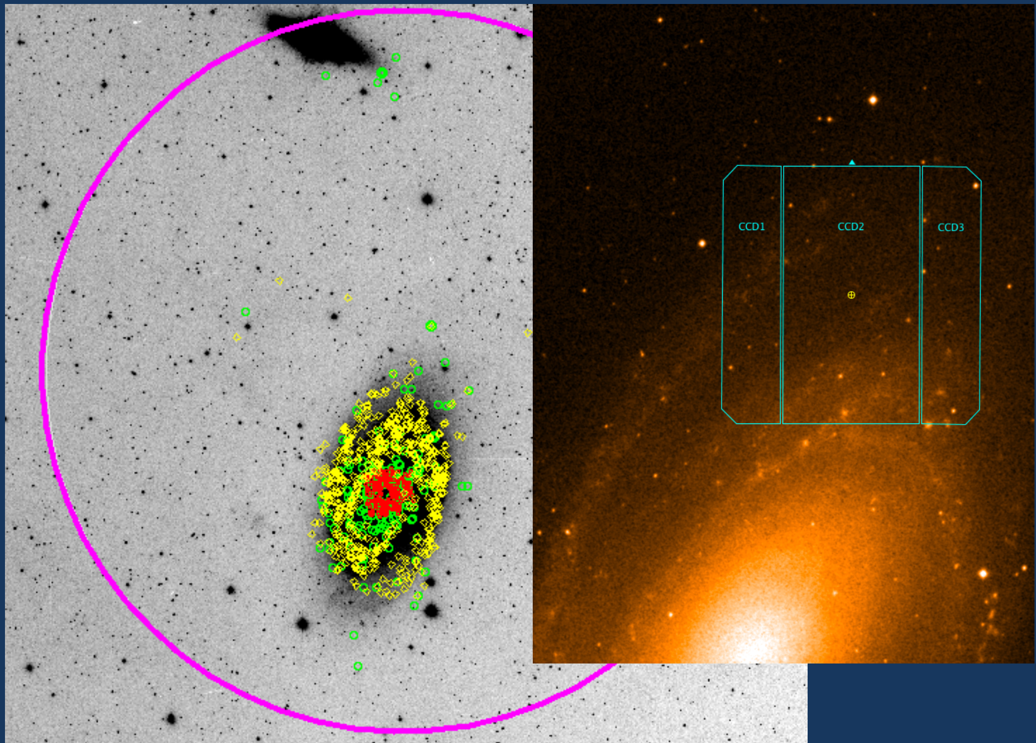
PN and HII gradients from exactly same observations, frames, data analysis (Magrini et al. 2009)

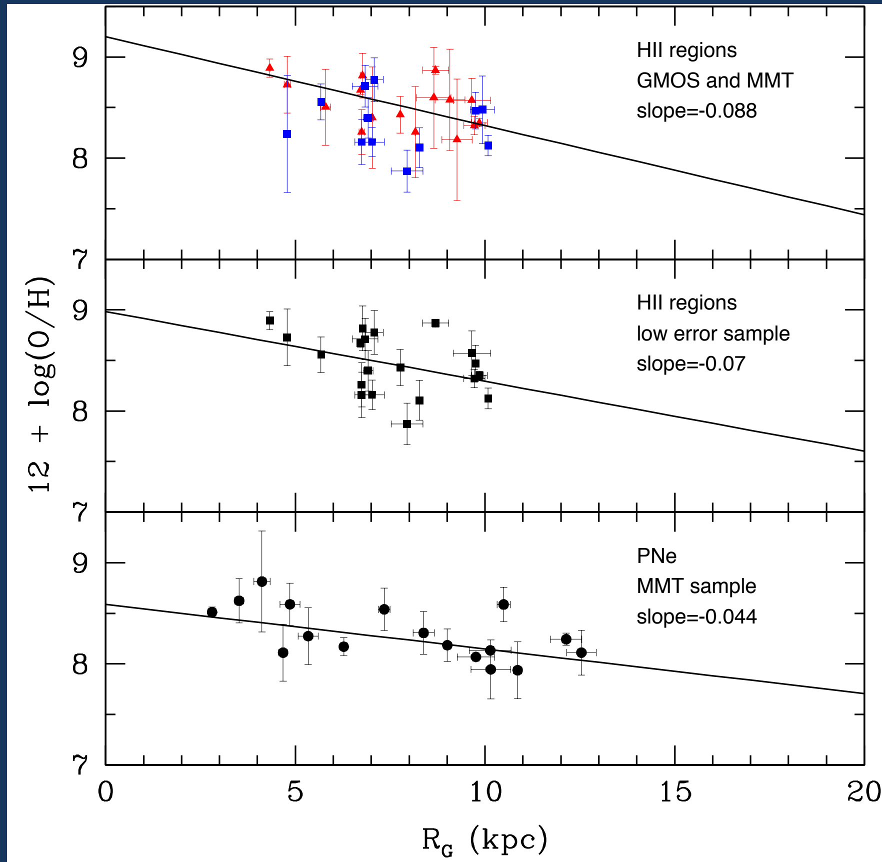
Two PN populations (i.e, ages) are clearly detected

Non-Type I PNe (magenta) and HII regions (blue) show very similar gradients, the former shallower than the latter.

Direct O/H gradients and their evolution - M81

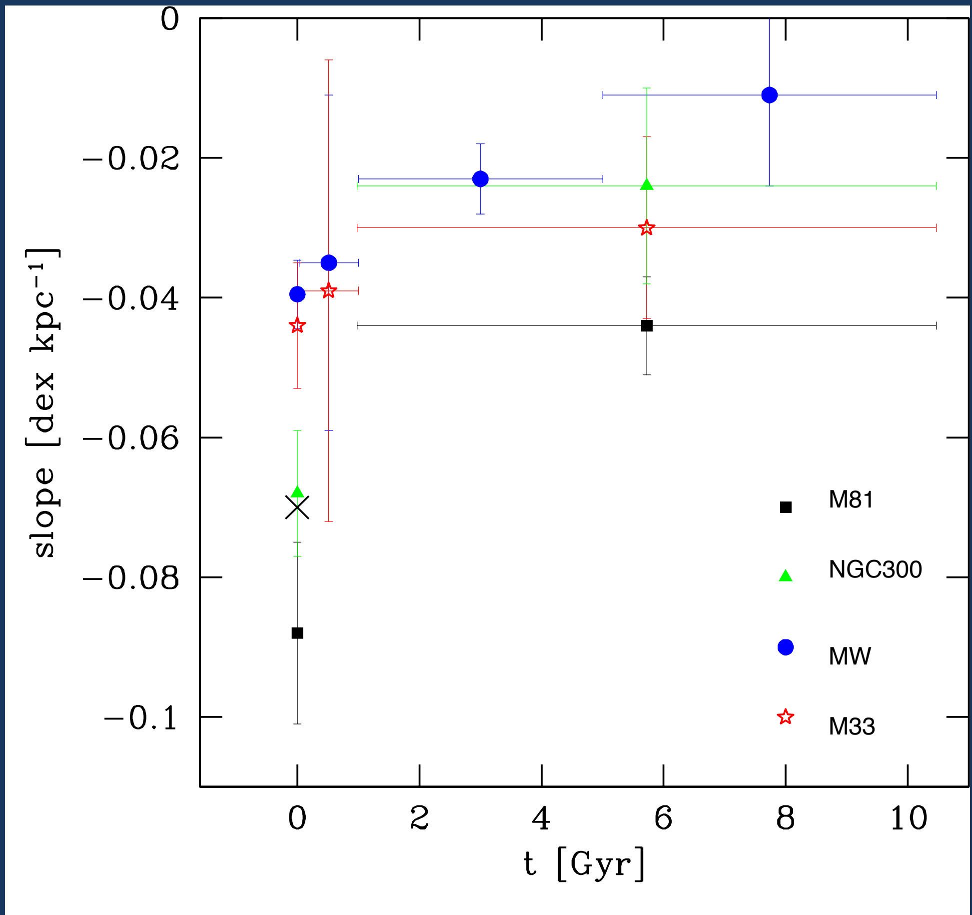
PNe from Hectospec@MMT; HII regions from MMT and GMOS-N frames (Stanghellini et al. 2010, 2014)





GMOS (on Gemini N and S) slit spectrograph, 3200-9000 Å coverage; 1” slitlets; $(5.5')^2$ FoV 0.45 (B600) and 0.67 (R400) Å/pixel

Direct O/H gradient evolution in nearby spiral galaxies – current status



<u>spiral galaxies where direct O/H of PNe and HII regions are simultaneously available</u>.

Slope of radial oxygen gradients are always steeper for younger populations

radial O/H gradients steepen with time (flatten with age of stellar pop.)

Squares: M81 (Stanghellini et al. 2010)
Cross: M8 (Stanghellini et al. 2014)
Triangles: NGC300)Stasinska & Pena 2013)
Circles: MW
PNe (Stanghellini& Haywood 2010)
HII regions (Balser et al. 2011)
Stars: M33 (Magrini et al. 2009, 2010)

Reaching the experimental limit

- Radial metallicity gradient evolution in star-forming galaxies, based on direct abundances of emission-line probes, are currently available for 3 nearby spirals and the MW.
- They could be determined for few additional galaxies with current technology (planned GMOS observations in both hemispheres), but need excellent observing conditions and long exposures!

- Evolution of metallicity gradients is also feasible by comparing gradients from HII regions of nearby galaxies, and those of redshifted galaxies (but defining which $z>1$ galaxies are comparable to nearby spirals may be a challenge!)

Gradient evolution: PNe vs. high-z galaxies

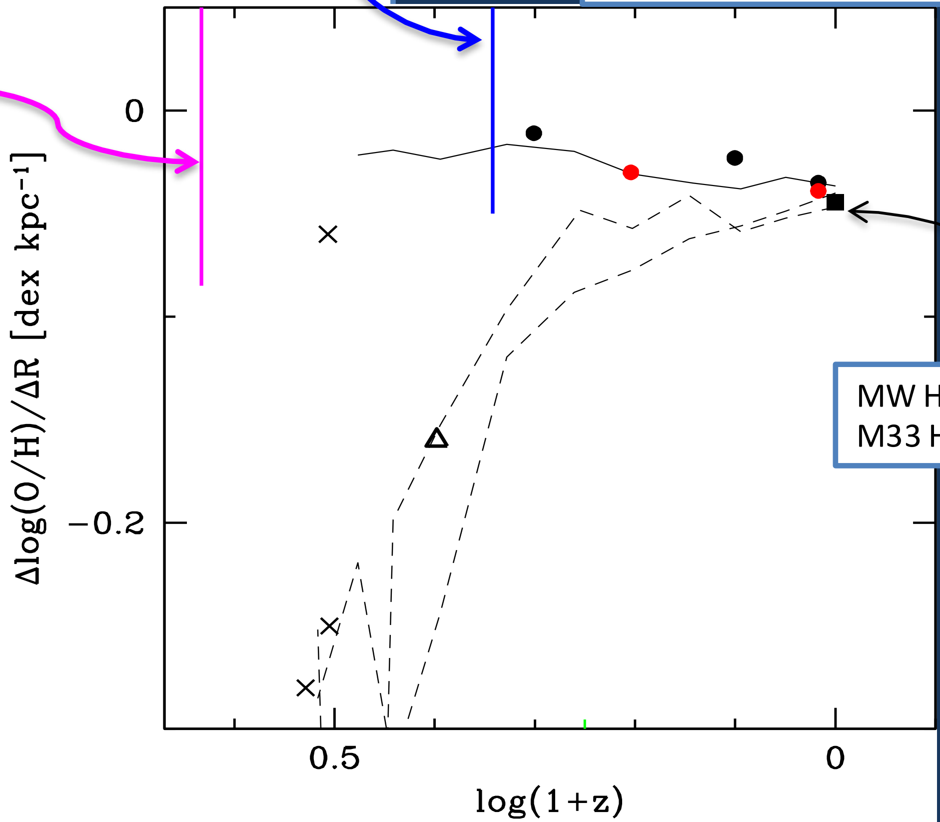
PNe in nearby galaxies trace look-back metallicity gradients (~7.7 Gyr, or 0<z<1, when the Universe was only 5.7 Gyr old)

Dots: MW PNe and M33 PNe

Queyrel et al. 2012 (MASSIV), z~1.2

Troncoso et al. 2014's, 40 star-forming galaxies at z~3.4 have Flat or positive grad. (errorbar plotted)

Lensed galaxies:
x Jones et al 2013
Δ Yuan et al. 2011



MW HII regions (Balser et al. 2011)
M33 HII regions (Magrini et al. 2009)

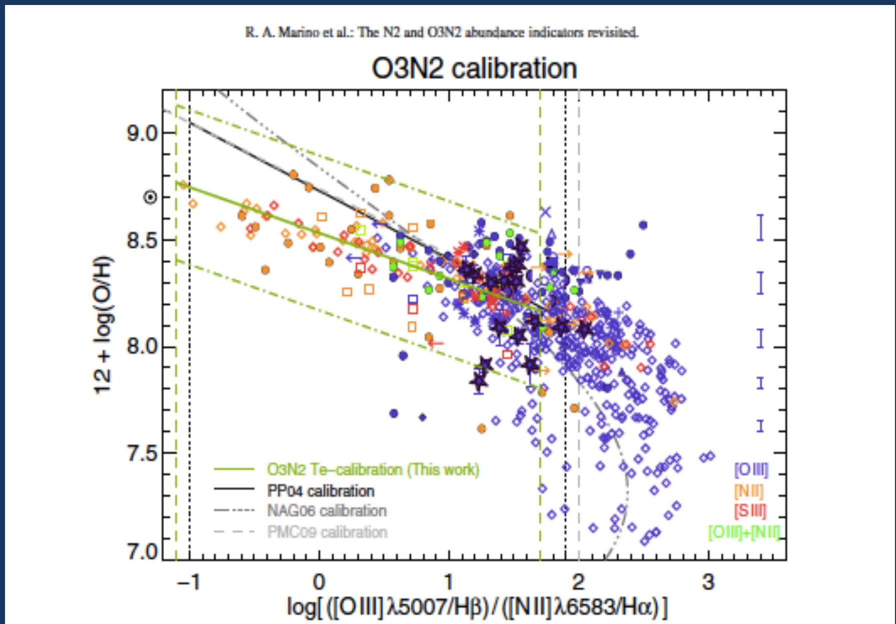
Thin lines: inside-out chemical galaxy evolution models in a cosmological context. Solid line: with enhanced feedback (Gibson et al. 2013).

Models are poorly constrained. How to improve the situation?

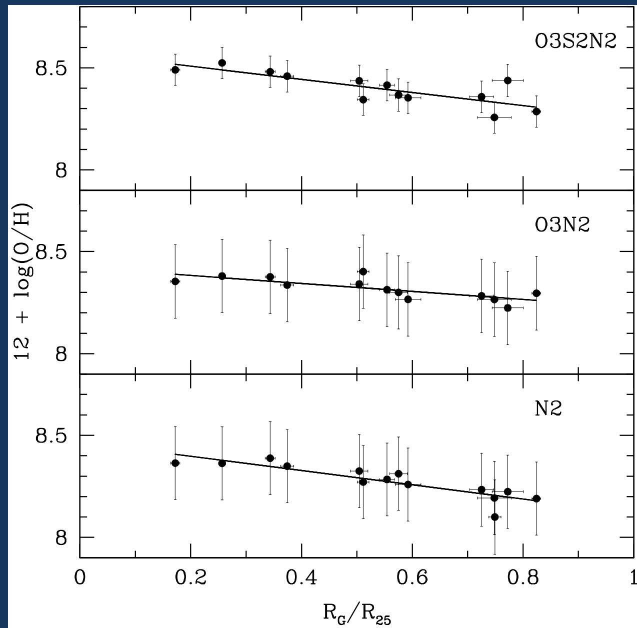
Strong-line abundances

We can go a little farther away with strong-line abundance calibrations

Latest calibrations
O3S2N2 (Pilyugin & Mattsson 2011)
O3N2 and N2 (Marino et al. 2013)



Observational example:
NGC 7793 with GMOS-S
$\Delta\log(O/H)/\Delta R_G = -0.05$ [dex kpc^{-1}]
(Stanghellini et al. 2015)



Progress with the ELTs

<u>MOS and direct abundances</u>

- WFOS@TMT: good FoV (~8x3 arcmin), good sampling of galactic probes across spiral disks
- Bright PN in M81 $F_{\lambda 4363} \sim 5 \times 10^{-17}$ [erg cm^{-2} s^{-1}], S/N~3 in 8 hr with Hectospec@MMT; few minutes with TMT; much fainter PNe and HII regions within reach with reasonable exposures
- Direct abundances in Virgo galaxies (much larger, diverse galaxy sample)

<u>MOS and strong-line abundances</u>

- can be done very quickly for any resolved spiral galaxy

<u>Near-IR IFU and z>1 galaxies</u>

- O/H variation of z>1 galaxies feasible via IFU
- IRIS@TMT: FoV is a good match for ~1" galaxies
- 0.8-2.5 μm range allows detection of major redshifted diagnostic lines
- Examples:

  z~1.6 weak -line abundances may be possible ([OII] λ3727; [OIII] 4363, λ4959, λ5007; Hβ, Hα, [NII] λ6548, λ6584 in YJH bands)

  2<z<2.6 strong-line diagnostics in JHK