The metallicity gradient of nearby spiral galaxies

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Metallicity gradients in nearby galaxies

1. Their temporal evolution: study of stellar populations of different ages to derive snapshots of the metallicity distribution

2. Their shape: insight on the process of galaxy formation

In this review:

1. The **time-evolution** of the **metallicity radial gradient**:
    1. approaching the problem with emission-line popultaion, such as HII regions and Planetary Nebulae (PNe)
    2. recent results in the spiral galaxies M33 and M81
    3. New proposed observations

2. The **shape** of the gradient in the **outskirts of galaxies**

   1. New observations of HII regions in the extended disk of spiral galaxies

Metallicity radial gradients and PN population in spiral galaxies

<u>Open questions on radial metallicity gradients:</u>

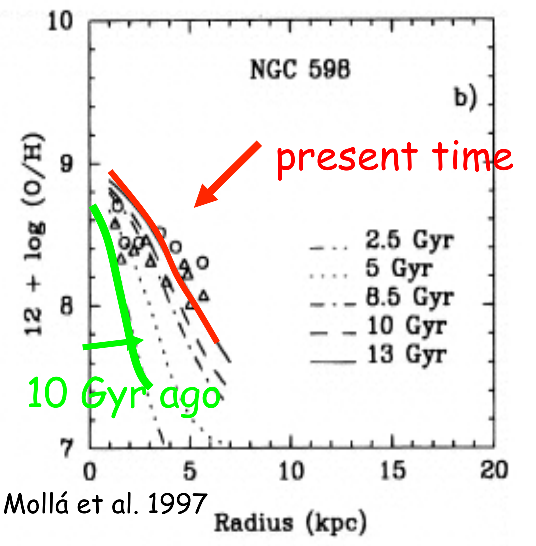
- How do they evolve with time?
- Do they become flatter or steeper with time?

What chemical evolution models tell us:

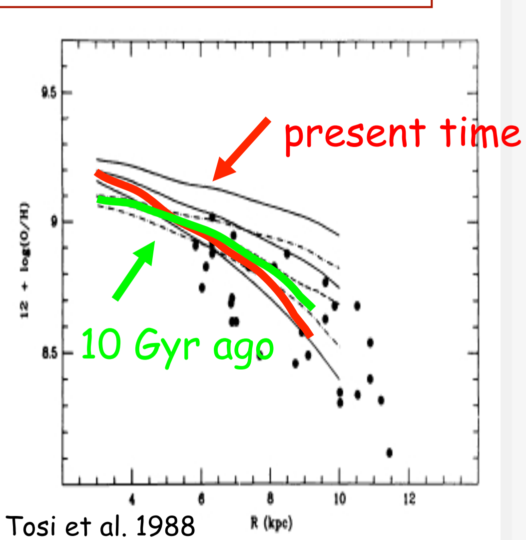
Both behaviours are possible, strong observational constraints are needed!

Flattening with time, e.g. Allen et al. (1998), Molla' et al. (1997), Hou et al. (2000), Magrini et al. (2007,2009)

Inner regions: very fast enrichment 2-3 Gyrs
Outer regions: primordial, slower enrichment



Mollá et al. 1997



Tosi et al. 1988

Steepening with time, e.g, Tosi et al. (1988), Chiappini et al. (1997, 2001)

Outer regions: pre-enriched by the halo and little affected by the following low SFR
Inner regions: vigorous SF

Spectroscopy of Planetary Nebulae and HII regions:
studying the evolution of the metallicity gradient

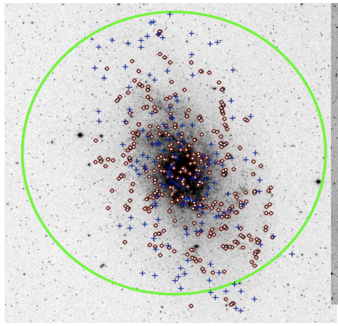
The method:

- Simultaneous observations of PNe and HII regions having similar spectra (both ionized by hot stars-white dwarfs and O-B stars), despite their different evolutionary stage
- Same method to derive chemical abundances (ionic abundances and Ionization Correction Factors (ICF)) and same measured elements (helium,oxygen, neon, nitrogen, argon, sulphur)
- Avoiding the distance scale problem of PNe in our Galaxy **(see Letizia's talk)**
- In the hypothesis that PNe do not modify the initial composition of O/H in ISM from which they were formed, we are able to analyse the time-evolution of the metallicity gradient (as traced by oxygen)

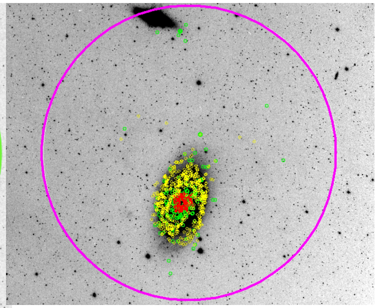
Metallicity radial gradients and PN population in spiral galaxies

The observations: Planetary Nebulae and HII regions in M33 and M81

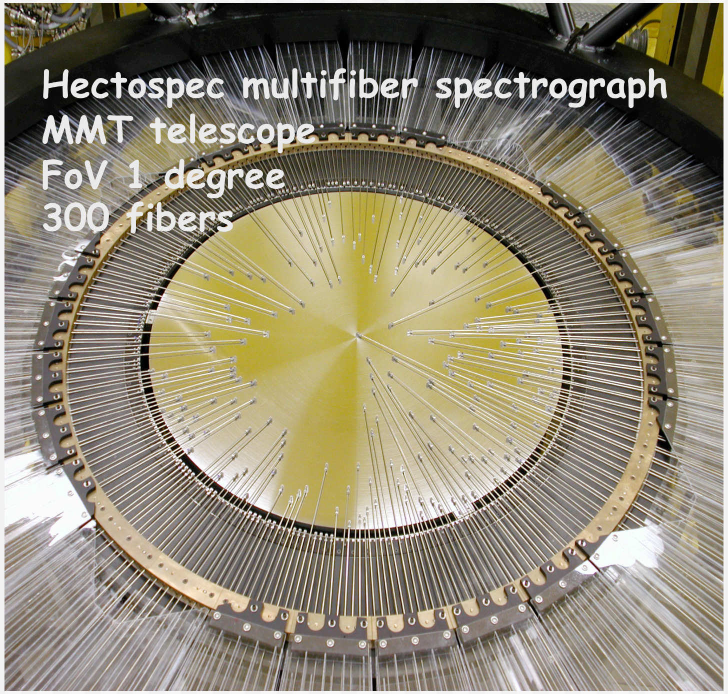
- Target galaxies:
  - M33: late-type spiral with a conspicuous population of PNe and HII regions (840 kpc)
  - M81: morphological type similar to our Galaxy, but strongly interacting with its companions (M82 and NGC3077) (3.5 Mpc)
- Telescope and Instrument:
  - MMT 6.5m
  - Hectospec



Observed 100 PNe ✚ and 50 HII regions o



39 PNe o-o 20 HII regions o

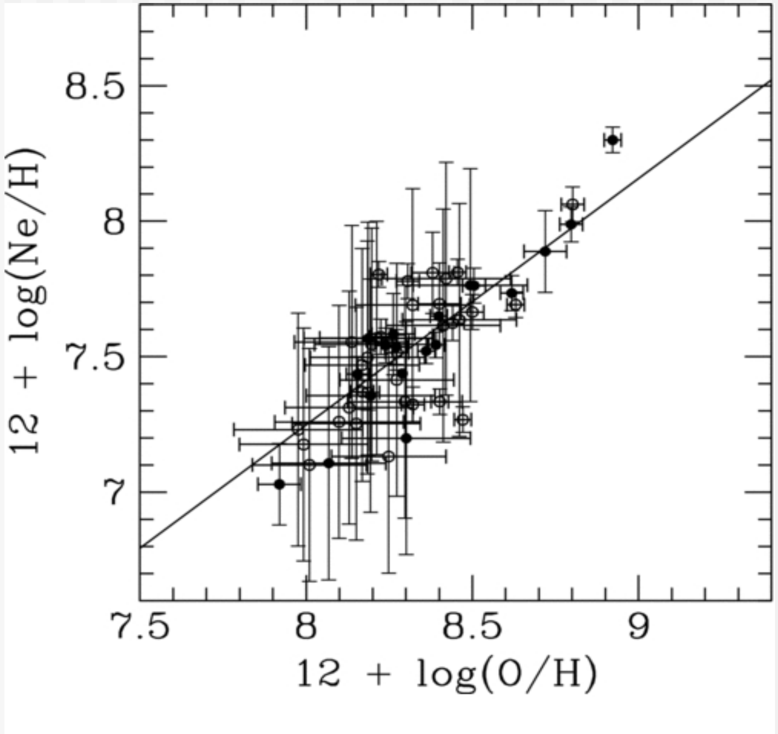


Metallicity radial gradients and PN population in spiral galaxies

Confirming oxygen as tracer of the ISM past composition

- Is oxygen a good tracer of the past metallicity? Is it really unchanged, nor produced neither destroyed?
- Ne is not modified by PN progenitor nucleosynthesis--> Ne/O constant means-->
- no important oxygen modification in the low metallicity range where the 3rd dredge-up might be in place

PNe in M33



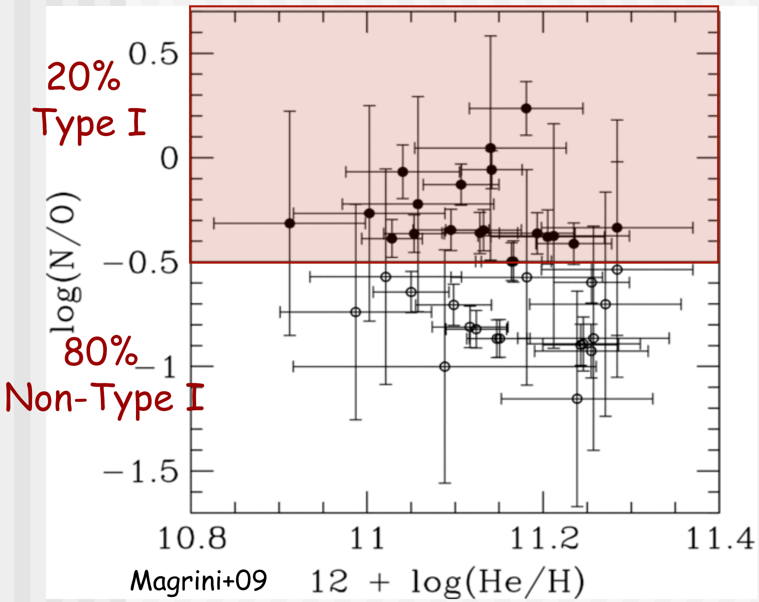
For M81 the information on Ne/H is not available--> However 3rd dredge-up is not expected at high metallicity

Metallicity radial gradients and PN population in spiral galaxies

Dating the progenitors: Type I vs non-Type I PNe

- **Type I**: young progenitors, M>3 $M_\odot$ --> **abundances similar to HII regions**
- **Non-Type I**: *Age ≥ 1 Gyr* --> **signature of galactic chemical evolution**

M33

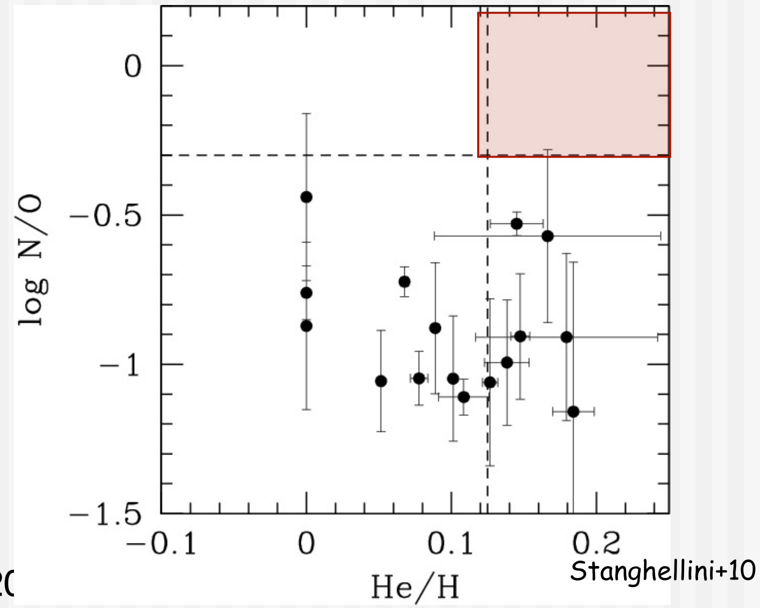


The Type I definition depends on metallicity:

•at relatively low metallicity (as in M33) it depends only on the N/O ratio (e.g., Dopita+91)

•while at higher metallicity (as in M81) it depends also on He/H

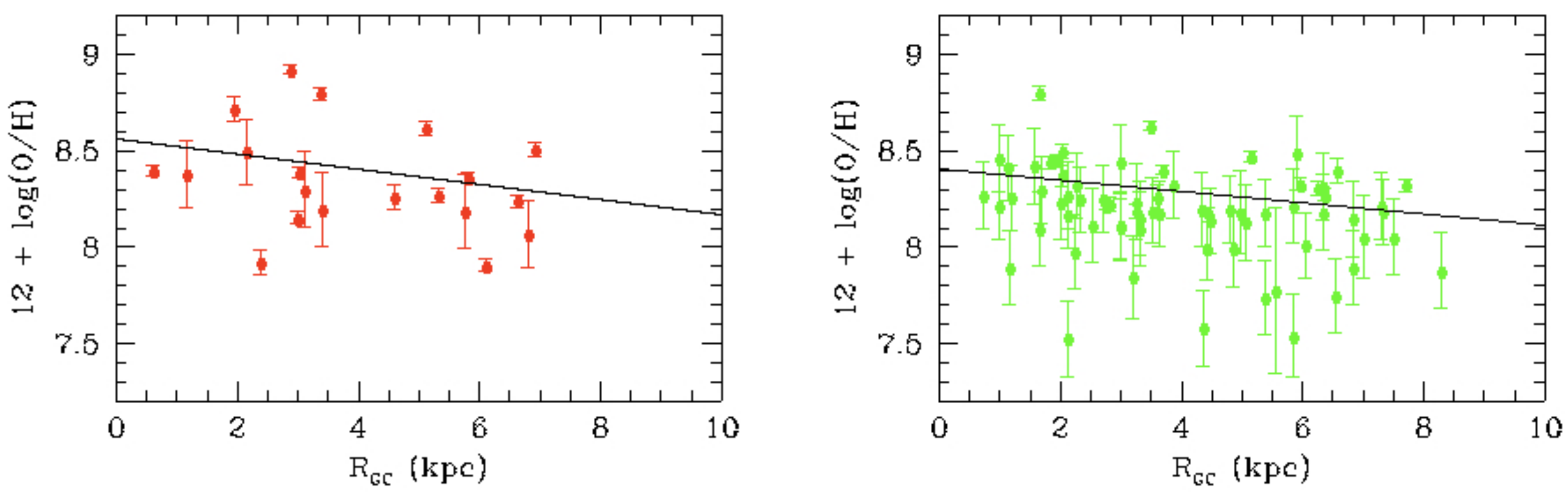
M81



Metallicity radial gradients and PN population in spiral galaxies

The time evolution of the metallicity gradient: M33

- **Non-type I (72):** $12+\log(O/H)=(8.41 \pm 0.06) - (0.030 \pm 0.013) \times R_{gc}$
- **Type I (19):** $12+\log(O/H)=(8.56 \pm 0.15) - (0.039 \pm 0.033) \times R_{gc}$
- HII regions (>100): $12+\log(O/H)=(8.50 \pm 0.02) - (0.045 \pm 0.006) \times R_{gc}$ (including the recent results of Bresolin+11)



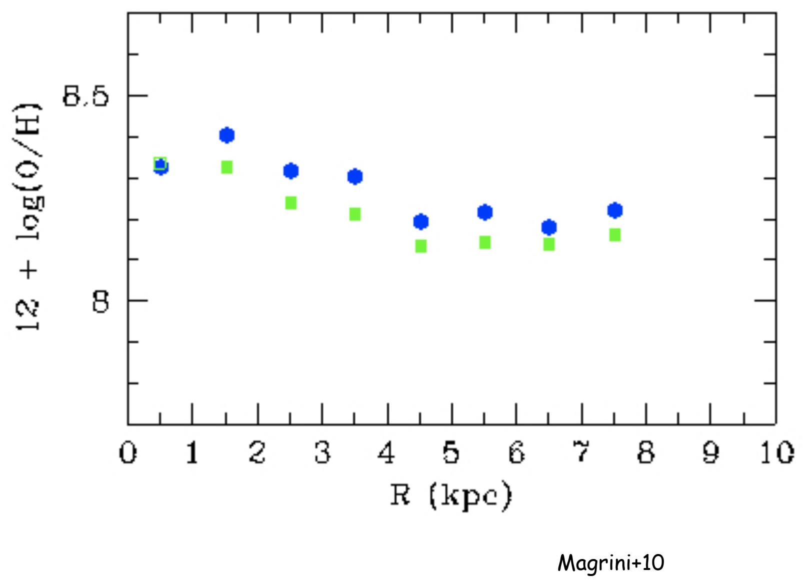
Magrini+09

Metallicity radial gradients and PN population in spiral galaxies

The time evolution of the metallicity gradient: M33

•The result is more appreciable if we compare O/H averaged on bins of 1 kpc and excluding the Type I PNe

● Non Type I PNe
● HII regions



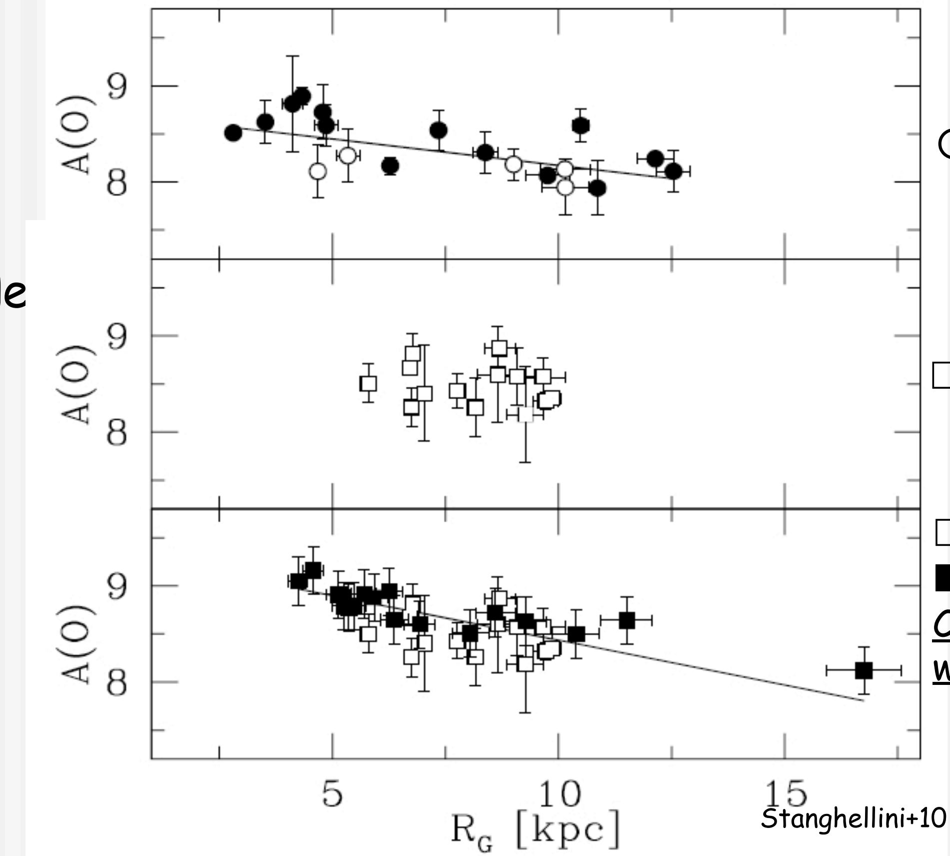
Result:

1. **The two gradients are indistinguishable within the errors** taking into account the new gradient of HII regions (Bresolin+11) there is a slight trend to a steepening with time
2. The **metal content has evolved ~0.1 dex** from the epoch of the formation of the PN progenitors to the present

Metallicity radial gradients and PN population in spiral galaxies

The time evolution of the metallicity gradient: M81

● Non Type I PNe
▲ HII regions



○●PNe (Stanghellini+10)

□HII regions (Stanghellini+10)

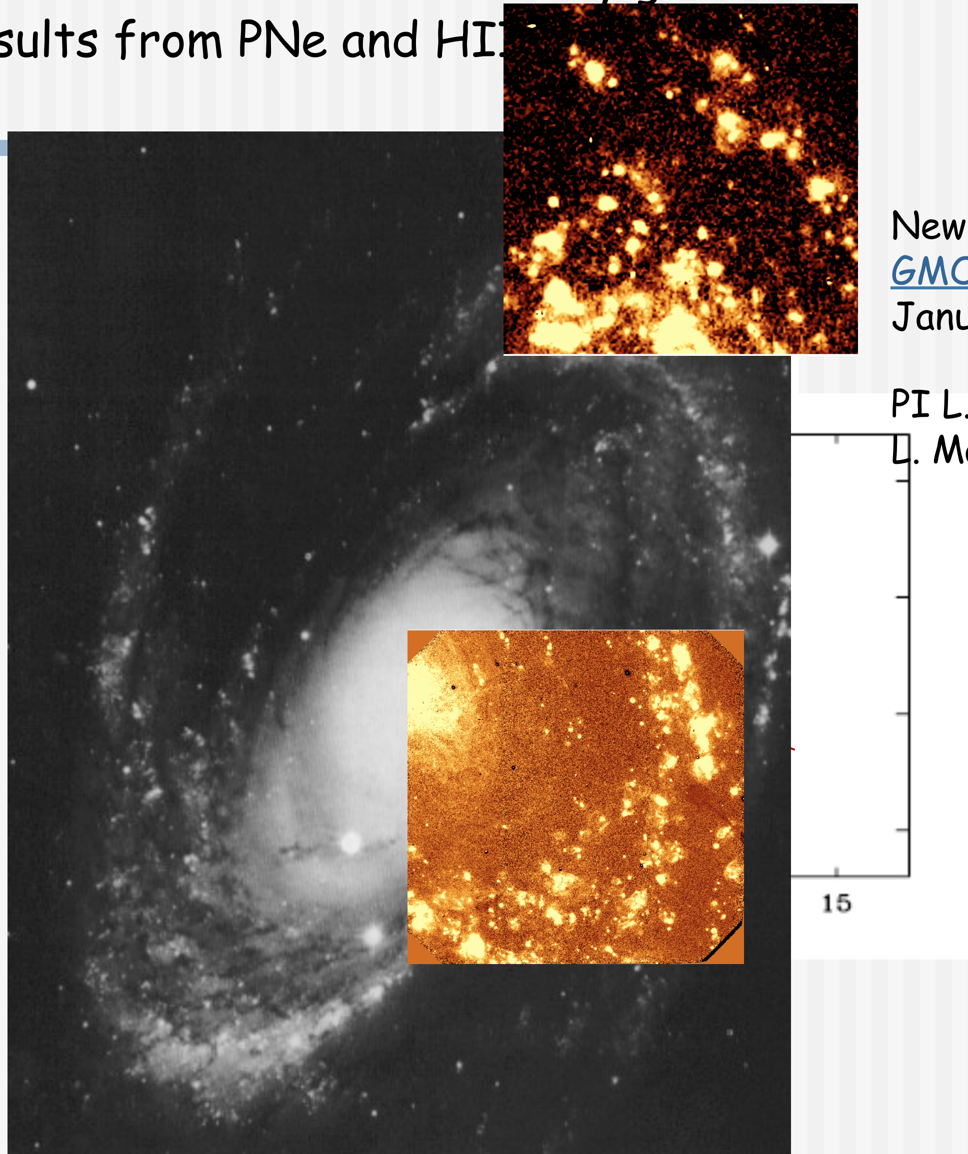
□HII regions (Stanghellini+10)
■HII regions (Garnett+87)--> Calibrated with bright lines without Te

Stanghellini+10

- **Non-type I (19):** 12+log (O/H)=(8.72 ±0.18) - (0.055 ±0.02) x R_{gc}
- HII regions (31): 12+log (O/H)=(9.37 ±0.24) - (0.093 ±0.02) x R_{gc}

Metallicity radial gradients and PN population in spiral galaxies

The time evolution of the metallicity gradient:
results from PNe and HII



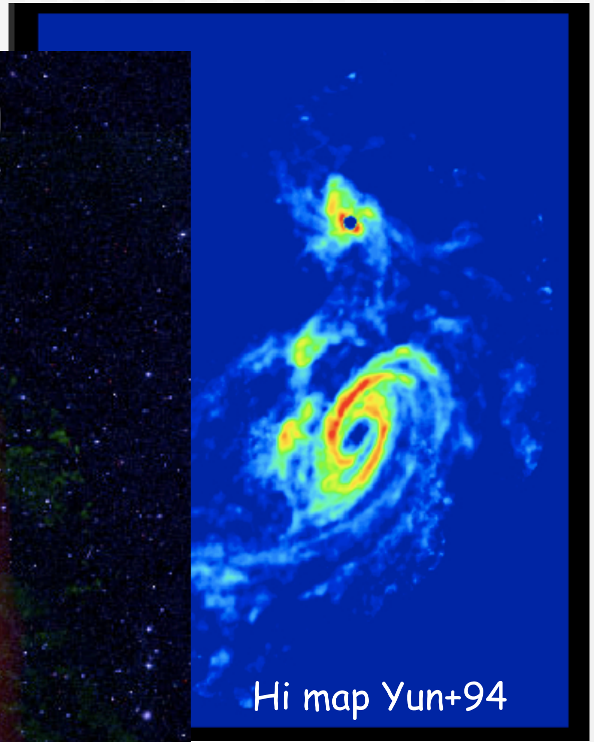
New observations at
GMOS@Gemini
January 2012

PI L. Stanghellini, with
L. Magrini, V. Casasola

To be confirmed with new observations:

- **Extending the radial range**
- **Detecting Te diagnostic lines**

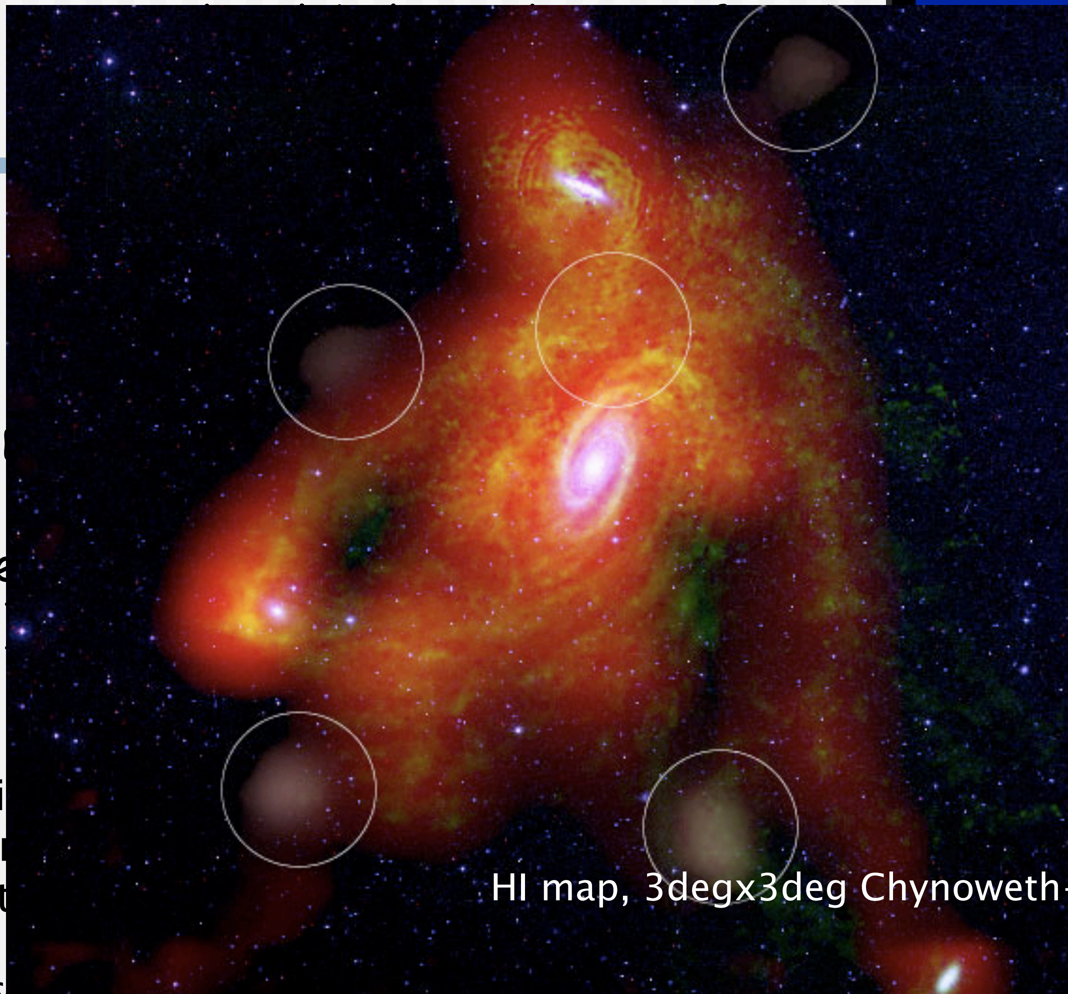
Metallicity radial gradients and PN population in spiral galaxies



- **Non-type I:**
- HII regions:

Large enrich

Also from Blue
(Kudridsky+12)



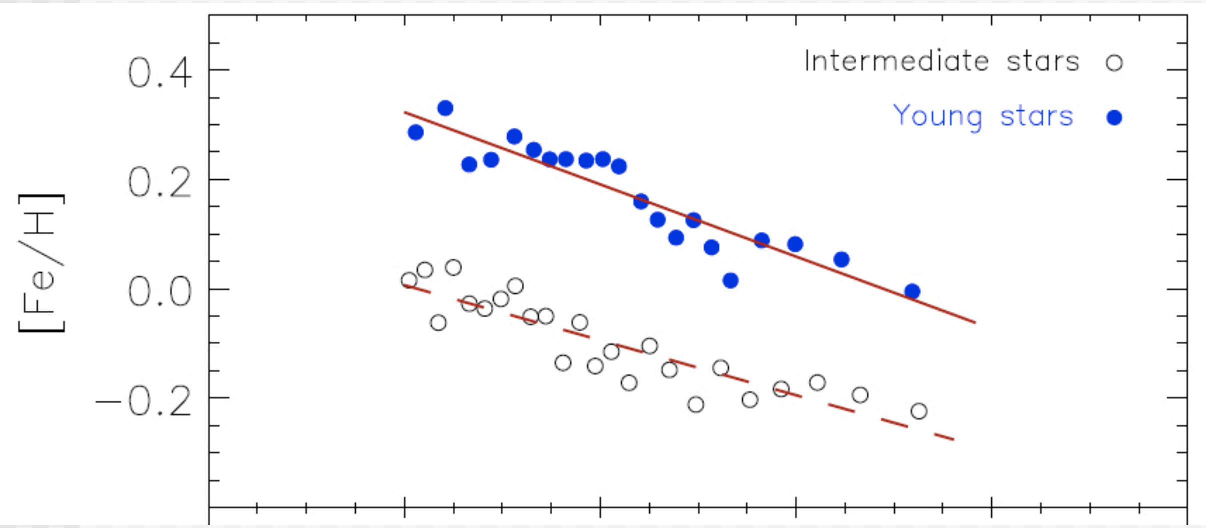
• M81 has satelli gas and
metal rich (Marti
with M81 (Applet

• Recent inflow from such satellites or the tidal interaction induced by them and leading to recent bursts of star formation could then have influenced the chemical evolution.

Metallicity radial gradients and PN population in spiral galaxies

The time evolution of the metallicity gradient:
Comparison with chemical evolution model in a cosmological context

From a cosmological point of view: radial abundance gradients of the disc stars of a galaxy simulated with a three dimensional, fully cosmological chemical and dynamical galaxy evolution code (Rahimi+11)



R_{GC} (kpc)

- "young" disc stars formed during the final 2 Gyr
- "intermediate" disc stars with ages **2 Gyr<Age <6 Gyr** --> **similar to non-type I PNe**

Metallicity radial gradients and PN population in spiral galaxies

More coming soon:

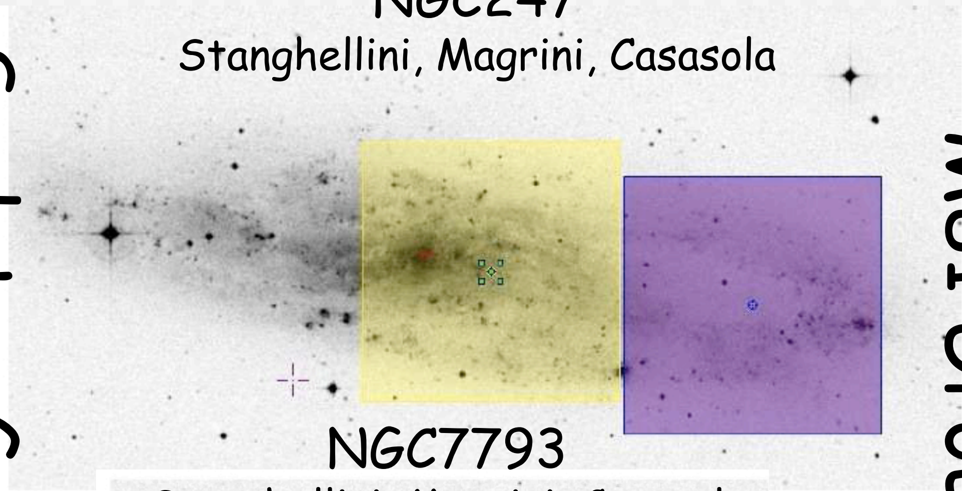
Observational time requested at Gemini South and North (Semester 2012B)

Aim: to extend the study to other spiral galaxies to set a firm benchmark for model comparison with a **variety of metallicities and galaxy types**

Sculptor Group

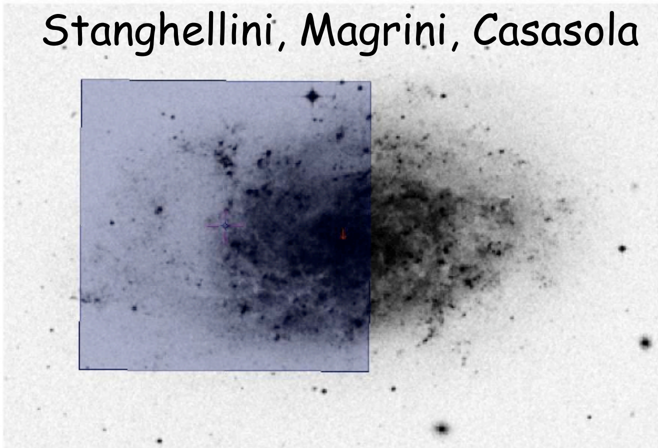
NGC247

Stanghellini, Magrini, Casasola



NGC7793

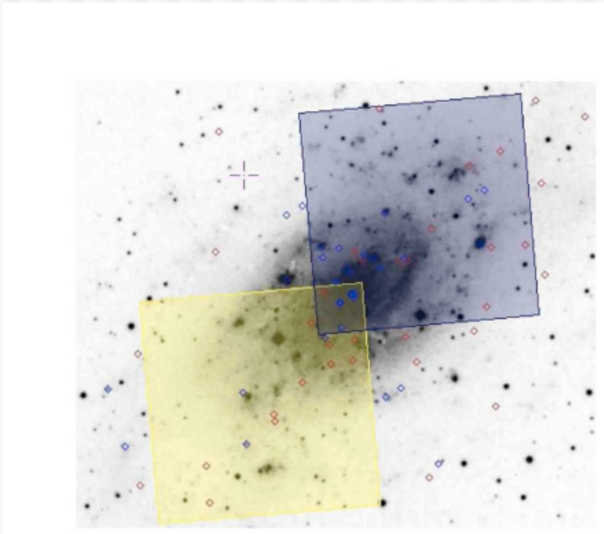
Stanghellini, Magrini, Casasola



M81 Group

NGC2403

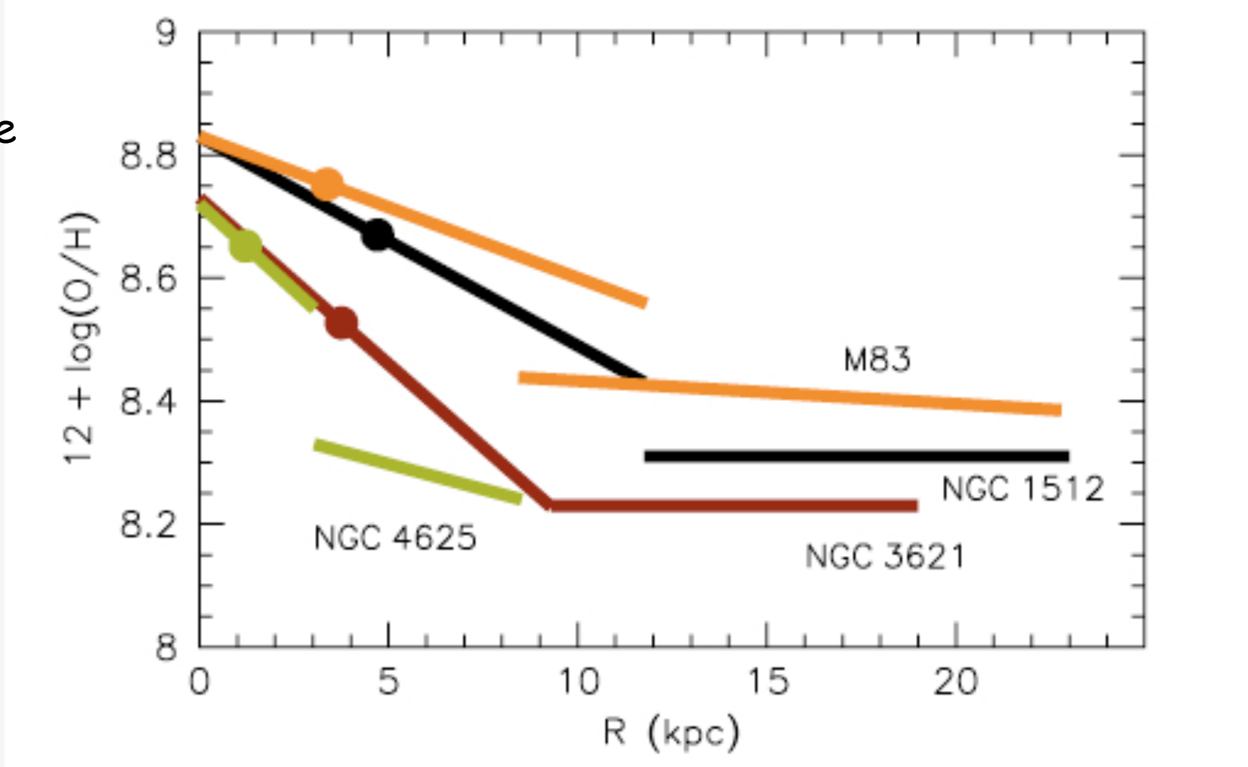
Stanghellini, Magrini, Casasola



Metallicity radial gradients in extended disks

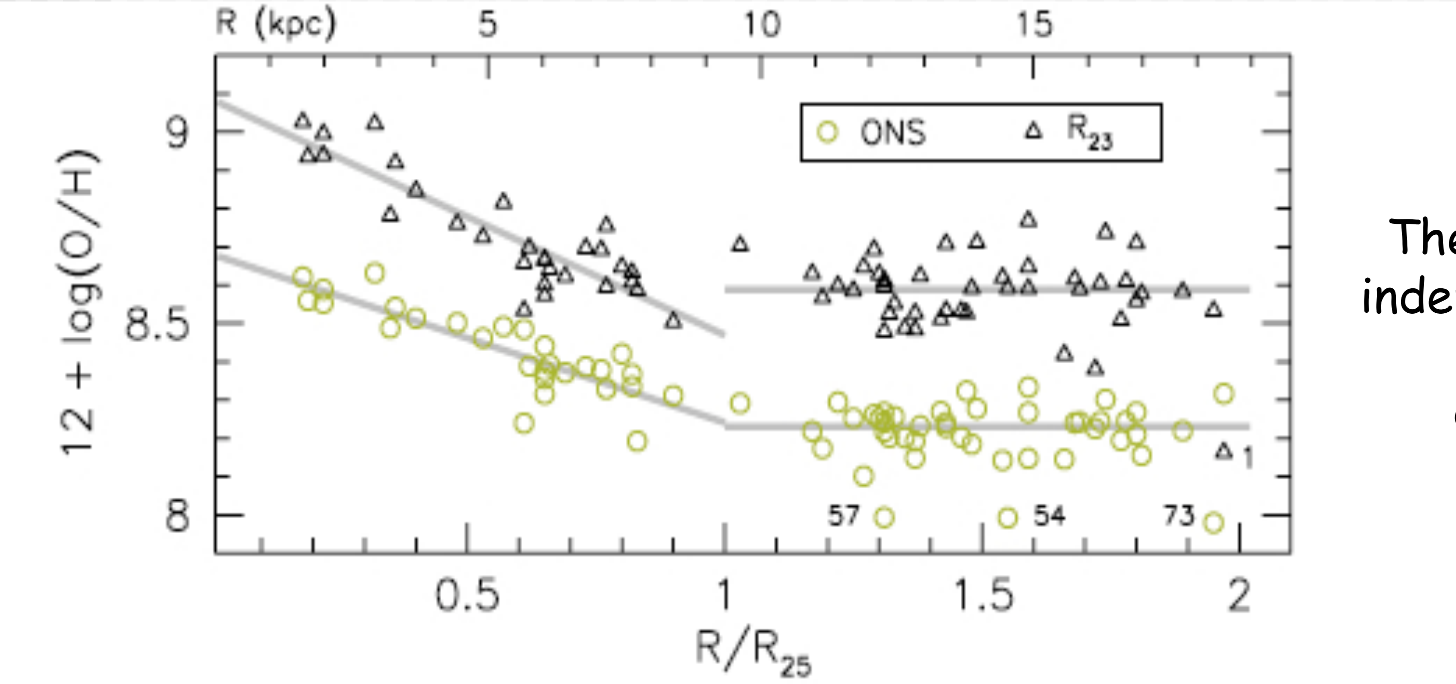
Bresolin et al. (2009b) (M83), Goddard et al. (2011) (NGC 4625), Werk et al. (2011) (13 interacting galaxies), Bresolin et al. (2012) (NGC1512, NGC3621)

- a flattening of the radial abundances ~at the isophotal radius
- the metallicity flattening mimics the behavior of the star formation efficiency



Metallicity radial gradients in extended disks

One of the best example: NGC3621
Bresolin et al. (2012)



The flattening is independent on the metallicity calibrators!

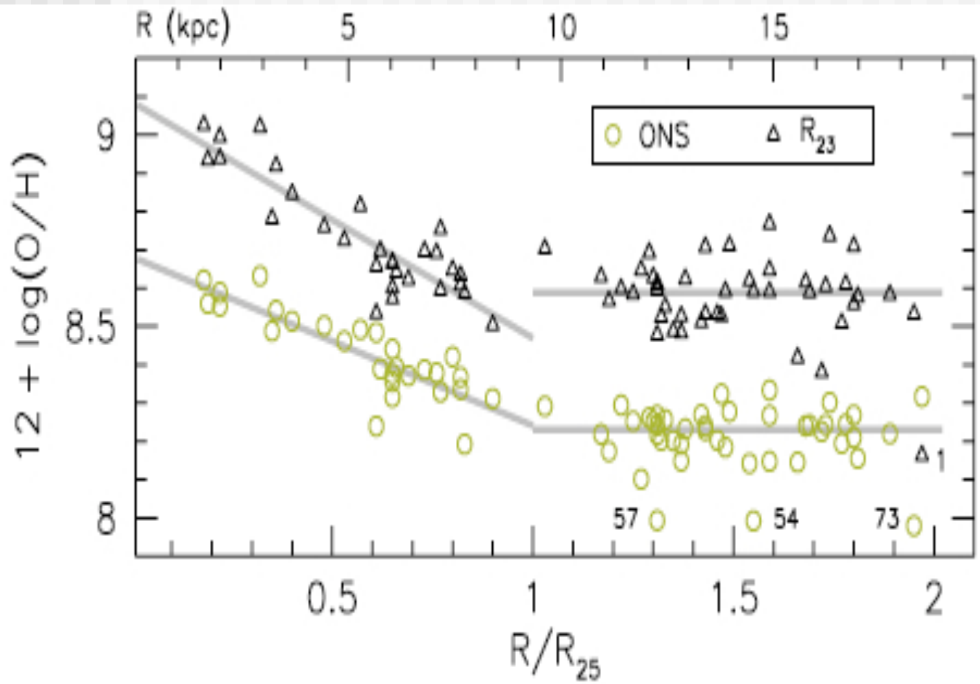
(1) mixing and turbulence processes (e.g. effects of radial gas flows induced by bars)

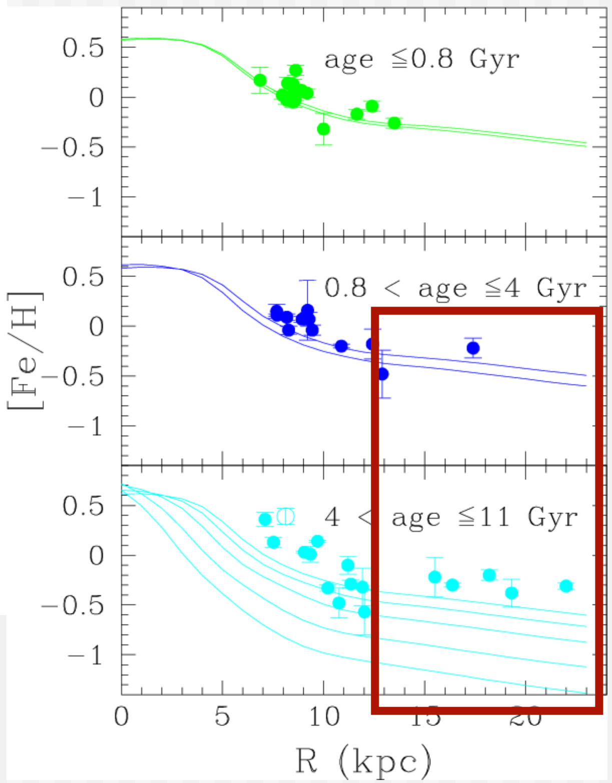
(2) galactic scale outflows (to explain the enrichment of the circumgalactic and intergalactic medium via galactic winds (e.g., Tumlinson et al. 2011), the origin of the mass-metallicity relation (Finlator & Dav´e 2008))

(3) enriched accretion (Dave' et al. (2011) highlight the importance of re-accretion of metal enriched gas in defining the observed galaxy mass-metallicity and mass-gas fraction relations at redshift z < 1)

Metallicity radial gradients in extended disks

One of the best example: NGC3621
Bresolin et al. (2012)





Very similar to our Galaxy (data from open clusters, and Cepheids)

Summary and conclusions

•Abundance ratios of PNe and HII regions in nearby galaxies are important tools to analyze:

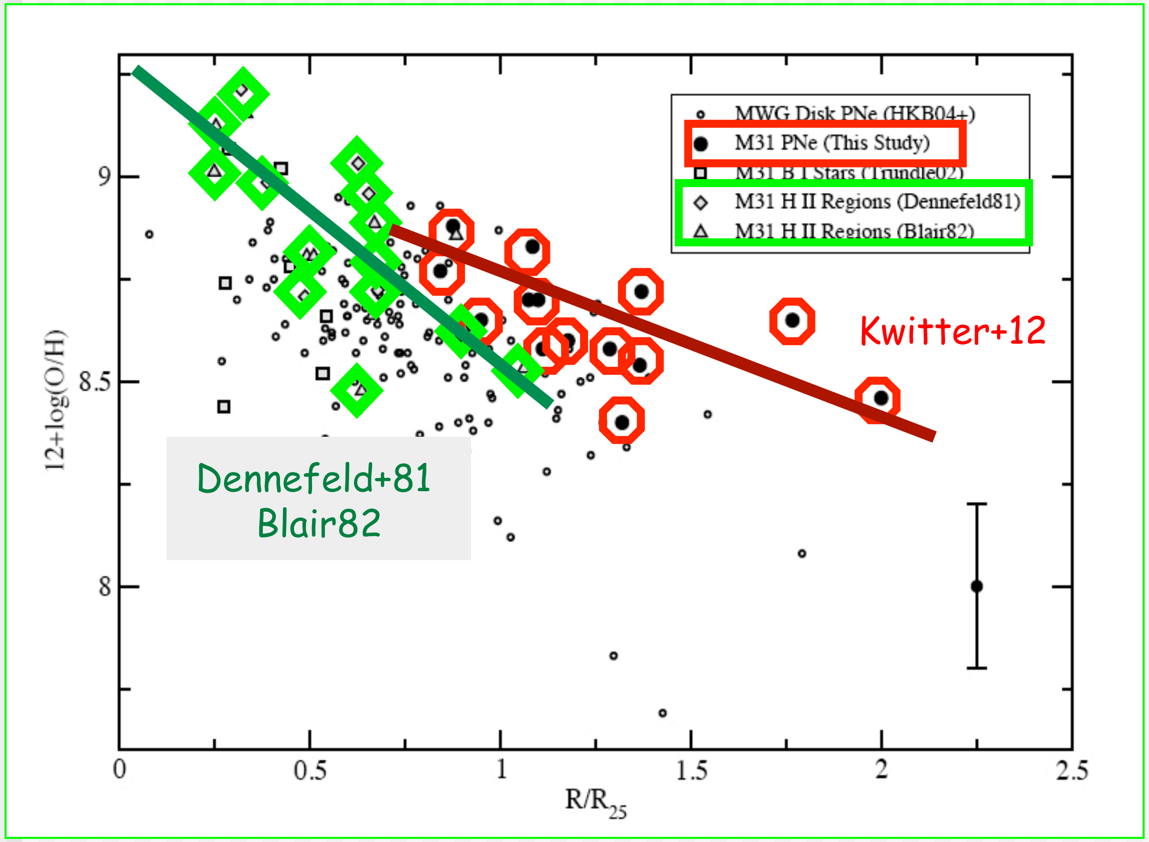
- •The **time-evolution of the radial metallicity gradient** in disk of spiral galaxies, and have revealed in M33 and M81 a **very limited evolution** of the slope of the gradient consistent with the most recent fully cosmological chemical and dynamical galaxy evolution code (Rahimi+11).

- •**The shape of the gradients**: confirmed the **negative slope within one optical radius**, and new observations of **flat gradients in the outskirts** of several galaxies, consistently with the results obtained in our Galaxy

Metallicity radial gradients and PN population in spiral galaxies

New results in M31 (Kwitter et al. 2012)

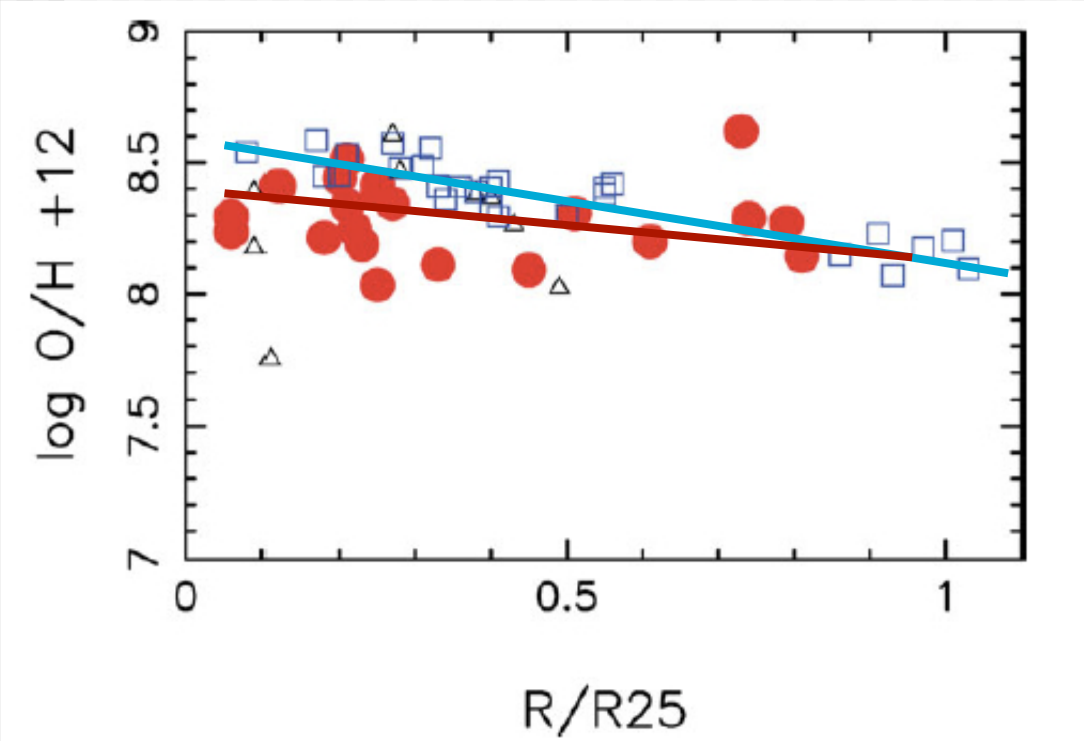
16 PNe in the disk of M31 whose projected galactocentric distances range between 18 kpc to 43 kpc.



PN progenitors observed in M31 have masses below the HBB threshold (~3 Msun) and non-Type I PNe

Metallicity radial gradients and PN population in spiral galaxies

New results in NGC300 (Peña et al. 2012)



PNe (red dots) and HII regions (open squares, data from Bresolin et al. 2009)
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Similar gradient of PNe and HII regions (preliminary analysis)

Metallicity radial gradients and PN population in spiral galaxies

M33 and M81: two different populations of bright PNe

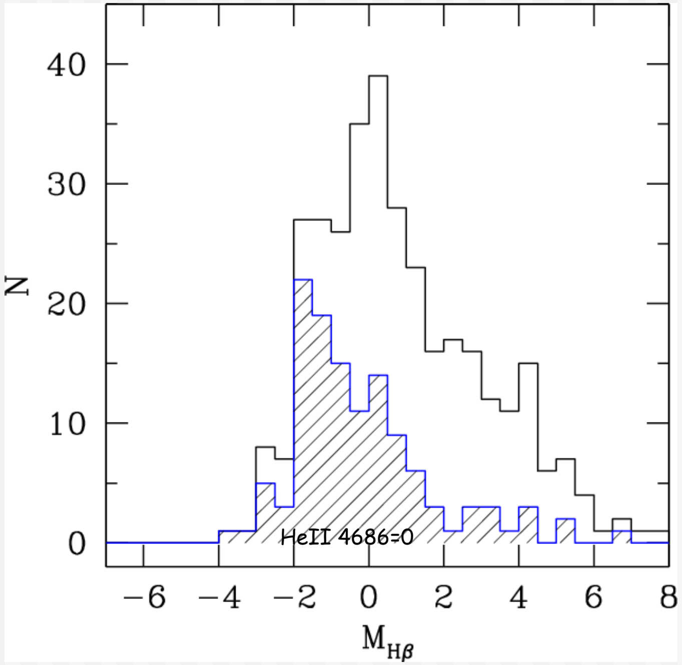
- In M81: we did not observe type I PNe and we did not detect the HeII 4686 emission line
- In M33: 20% of the observed PNe are Type I and we detected HeII 4686 in many PNe

At high metallicities (as M81 or MWG) the brightest PNe are not those with the hottest Central Stars (CSs).

WHY?

The post-AGB shells with very hot CSs are enshrouded **in dust at early phases** of their evolution, thus still **thick to the Hα radiation**. The **thinning time depends on metallicity**, being shorter at low metallicity, and **too long at M81 metallicity to allow us to observe PNe with massive progenitors among the brightest ones**.

Galactic PNLF: data from Stanghellini & Haywood (2010).



Stanghellini+10