M33 planetary nebulae revisited: checking spectroscopic and chemical results

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abundance gradients in M33: the use of planetary nebulae

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present status
of abundance gradients in M33

HII regions from optical data
Vilchez et al 1988, Kwitter & Aller 1981, Smith 1975
not reliable at high metallicity

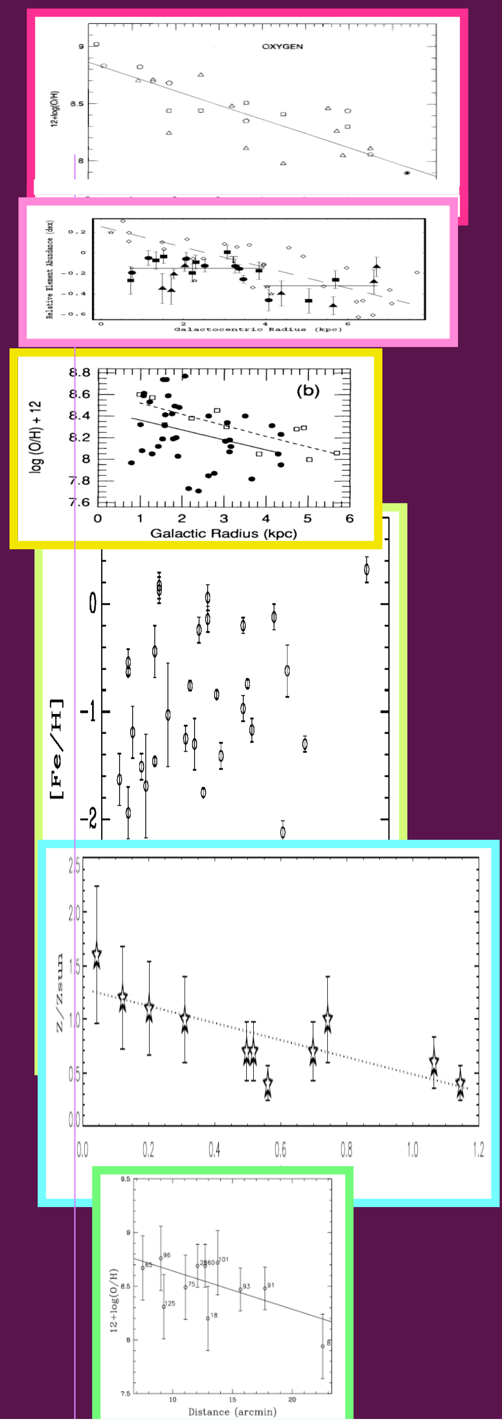
HII regions from FIR data (ISO) (filled symbols)
Willner & Nelson-Patel 2002
in principle, give correct Ne/H at high metallicities
but some revision needed

supernovae Smith et al 1993
not robust abundance determinations

stellar clusters Ma, Zhou, Chen 2004
not robust abundances determinations
probe wide range of ages

B supergiants Urbaneja et al 2005
....

planetary nebulae Magrini et al 2004
probably more uncertain than quoted,
some values could be incorrect



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HII 영역 분광자료를 통한 M31과 M33의 화학원소 결정
CHEMICAL ABUNDANCE ANALYSIS OF M31 AND M33 BASED ON THE SPECTRUM OF HII REGIONS

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ABSTRACT

Chemical evolution of galaxies can be understood by studying the spatial distribution of heavy elements. We selected two nearby galaxies, M31 and M33 and investigated spectrum of their HII regions: a) the electron densities have been derived from the [S II] 6717/6731 ratio along with the most recent atomic constants (Hyung & Aller 1996); b) the electron temperatures were determinated from the Pagel's empirical method. Nebula Model (Hyung 1994) has been employed to predict the spectral line intensities which gives the proper chemical abundances. The model would predict the line intensities correctly only when various input parameters such as the effective central star temperatures, gravity log g, model atmosphere as well as the geometry and the nebula physical condition are appropriate. Thus, the determination of chemical abundances of O, S, N of the two nearby galaxies M31 and M33 has been done, which shows a radial dependance of O/H and N/H: decrease with the distance, or increasing electron temperature due to the elemental deficiency. Abundances of M31 appear to be enhanced than those of M33.

Key words: M31, M33: HII regions: abundances: photoionization models

I. 서 론

여러 화학원소들의 핵융합은 질량이 다른 별들에서 진행되므로, 나선은하의 원반에서 원소 함량에 관한 연구는 이들 은하들에서 별형성과 진화를 이해하는 중요한 방법이다. 성간매질의 원소함량은 행성상 성운 (planetary nebulae, PNe) 또는 전리수소영역 (HII region)들과 같은 이온화된 성운들의 스펙트럼을 이용해 추정될 수 있다.

한 함량분석법이 더욱 선호된다.

지난 수 십 년동안 진보된 디지털 검출기와 개선된 성운 이온화 구조의 결과로 외부은하 HII 영역들의 화학성분에 대한 연구가 진척되었다. 이들 연구의 주목적은 나선은하의 원반을 가로지르는 화학원소함량 기울기 (radial abundance gradient)를 확립하는데 있다. 많은 가까운 밝은 은하들이 자세히 조사되었는데, M101 (Searle 1971; Smith 1975; Shields & Searle 1978; Rayo et al. 1982), M33

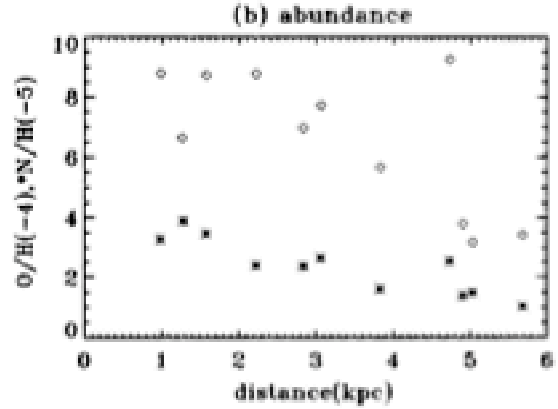

그림 2. M33의 HII regions. (a)은하중심으로부터 거리에 따른 M33의 HII 영역들의 전자온도 변화 (ΔT|≤700 K, error bars를 표시하지 않음); (b) M33에서 은하중심으로부터 거리에 따른 O/H와 N/H의 함량변화 (관측오차에서 비롯된 화학 원소값의 오차는 약 0.2 dex임).

Element	Wave	I_{obs}(MA9)	I_{cal}	I_{obs}(IC133)
	R_{out}		2.209	
Prediction	T_e		7300	
	N_e		100	

表 2-5. Model predictions for HII regions i

Element	Wave	I_{obs}(IC132)	I_{cal}
He I	5876	13.18	13.18
N II	6584	7.08	7.06
	6548	2.34	2.44
O I	6300	–	–
O II	3726/29	107.16	107.51
O III	4363	7.24	2.61
	4959	194.98	195.24
	5007	562.34	562.35
Ne III	3868	46.77	46.75
	3969	22.39	13.94
S II	6717	6.46	6.45
	6731	5.13	4.91
S III	6312	–	–
Ar III	7136	6.92	6.89
OUR	<t>	10600	
	T_e	12600	
	N_e	100	
Central Star	$R_\star$ ($R_\odot$)		7
	$T_\star$(K)		39500
	log g		3.8
Shell(pc)	R_{in}		1.6
	R_{out}		2.78
Prediction	T_e		8800
	N_e		100

this discrepancy between observed and modelled T_e implies an error of over a factor of 3 in the derived O abundance !!!

the problem with abundance determinations in metal rich HII regions

the basics of abundance determination in HII regions

- T_e determined from [OIII]4363/5007
- ionic abundances from line intensity ratios:
  $O^{++}/H^{+} = ([OIII]5007/Hb) \;/\; (e_{[OIII]}(T_e)/e_{Hb}(T_e))$
- elemental abundances
  by adding observed ions or using icfs
  $(O/H = O^{+}/H^{+} + O^{++}/H^{+} + ...)$ $(e.g.\ Ne/O = Ne^{++}/O^{++})$

the problem at high metallicities

- metal cooling depresses the electron temperature
- and the weak [OIII]4363 line is not observed
- one has to derive abundances with "strong line" methods
- which are only of statistical value and not well calibrated

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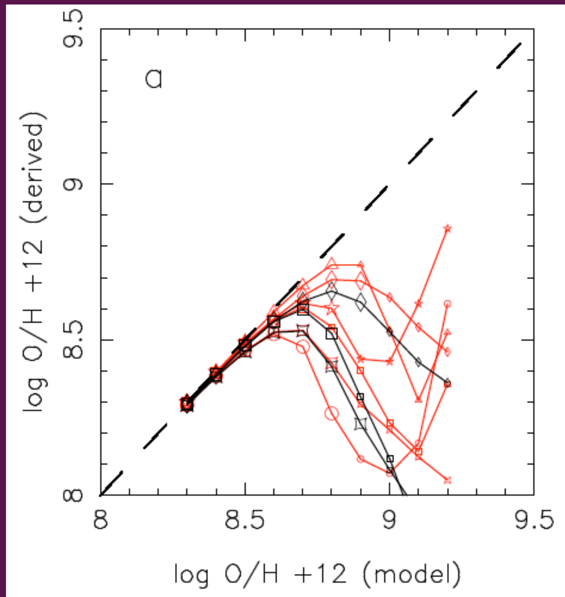
observations with Very Large Telescopes cannot help

- even if [OIII]4363 is measured
- the derived O/H will be underestimated
- since strong T_e gradients due to cooling by [OIII] 52, 88m
- induce a strong overestimation of T_e in the emitting zones



O/H derived using [OIII]4363 as a function of true O/H for model HII regions

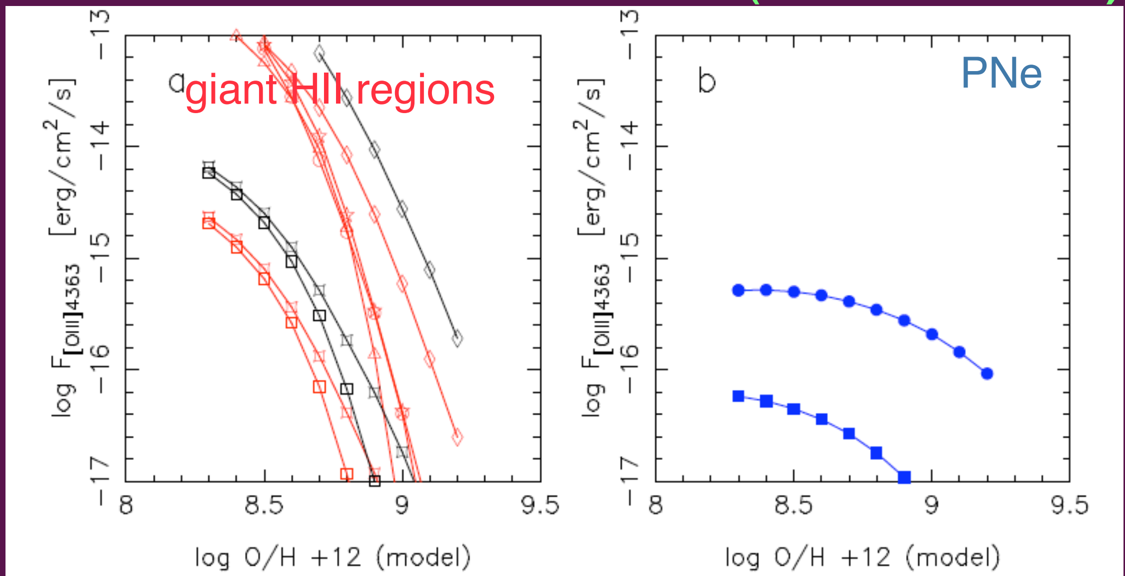
(Stasinska 2005)

the advantage of using extragalactic PNe

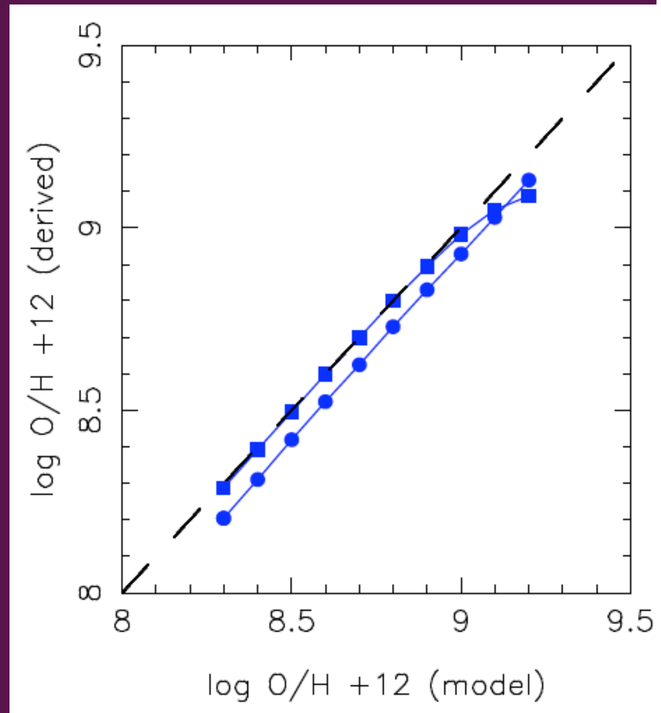
useful spectroscopy can be done only on luminous PNe

- **luminous PNe have n_H > 1000 and T_{eff} >100 000K during a large fraction their lifetime**

- **a high n_H and a high T_{eff} increase T_e with respect to that in giant HII regions of same metallicity =>**
  - **[OIII]4363 can be observed even at high metallicity**
  - **the derived O/H is not biased (Stasińska 2005)**



$F_{[OIII]4363}$ as a function of O/H for photoionization models



O/H derived using [OIII]4363 as a function of true O/H for models of luminous PNe

a note on abundance determinations in PNe

if T_e can be measured directly from the spectra

- empirical abundances from optical lines are ~ correct
- are abundances from tailored photoionization models better?
  - if the photoionization model fits all the constrains, perfectly, the abundance should be roughly the same as from the empirical methods
  - if the photoionization model fit is not perfect, it does not give correct abundances

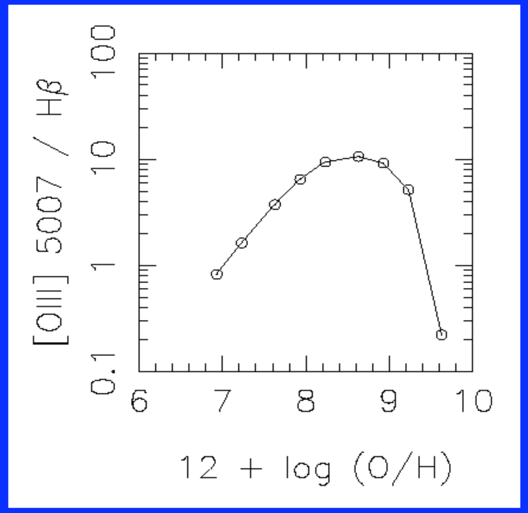
if T_e cannot measured directly from the spectra

- empirical abundance determinations cannot be used
  - no strong line method is possible for PNe because the temperatures of the central stars vary strongly from object to object)
- abundances from photoionization models are not uniquely determined

example: is the PN M 2-5 O-poor or O-rich ?

obs		Ratag	B1	B2	B3
T*		37500K	39000K	37000K	39000K
r* (cm)			5.00+10	5.75+10	4.90+10
Rin			0.062 pc	0.050 pc	0.065 pc
Rout	0.10 pc		0.087 pc	0.081 pc	0.085 pc
F(Hbeta)	3.9-12		3.92-12	3.90-12	3.88-12
ne (cm-3)		2050	1800	1700	1800
He		0.117	0.117	0.180	0.100
C			1.50-3	1.00-3	1.20-3
N		4.80-4	2.50-4	5.50-4	6.00-4
O		2.20-4	2.40-4	1.00-3	1.20-3
Ne			5.00-5	2.00-4	2.40-4
S		2.30-5	3.00-6	6.00-6	7.00-6
[OII] 3727	0.596		0.587	0.613	0.604
[NeIII] 3869			0.014	0.0084	0.0096
[OIII] 4363	<0.0013		0.0006	0.0002	0.0001
HeII 4686			0.0004	0.0003	0.0003
HI 4861	1.00		1.00	1.00	1.00
[OIII] 5007	0.283		0.304	0.281	0.275
[NI] 5200	0.0149		0.0043	0.0093	0.0087
[NII] 5755	0.0071:		0.0151	0.0069	0.0060
HeI 5876	0.128		0.126	0.124	0.128
[OI] 6300			0.0054	0.0106	0.0116
[NII] 6584	2.85		2.79	2.87	2.81
[SII] 6717	0.0565		0.053	0.0602	0.0558
[SII] 6731	0.084		0.077	0.0868	0.0826
[OII] 7325	0.0091:		0.0126	0.0070	0.0063
T(NII)			6734	5422	5426
T(OIII)			7319	5876	5394

- Ratag 1992 claimed it to be O-poor
- Stasinska, Malkov, Golovatyj 1995 found that both O-poor (B1) and O-rich (B2 abd B3) models can fit all the available data within the error bars



- this is due to the behaviour of [OIII]5007/Hb, [OII]/Hb etc ... as a function of O/H

our observations of PNe in M33

planned observations: 10 bright PNe in the inner disk of M33

due to weather conditions only 4 PNe were observed

Observations were performed using the ISIS spectrograph attached to the WHT4.2m of the ORM in La Palma in October 2003.

The exposures were of 3 hours per spectrum

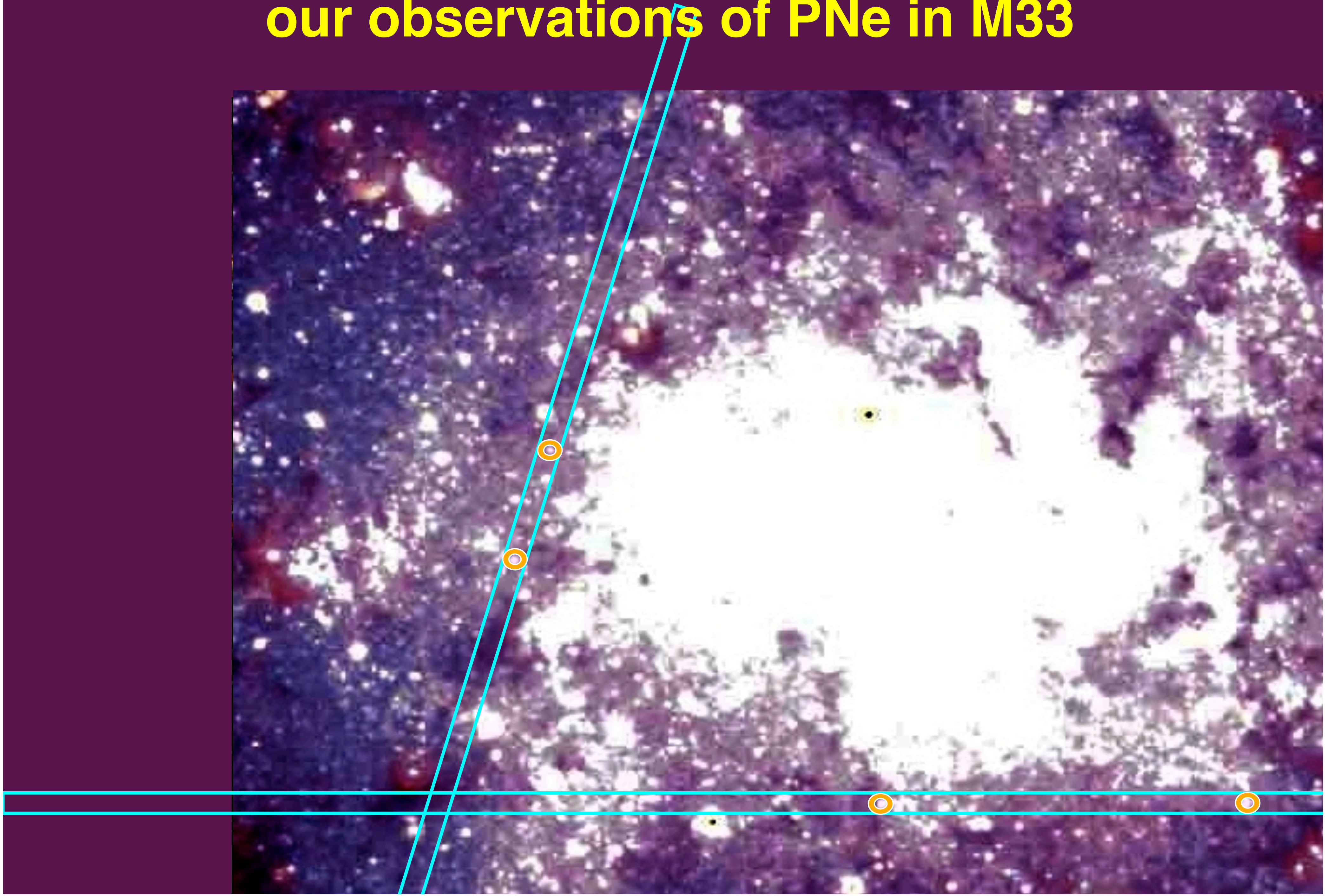
Both, blue and red arms were used with a dichroic set to an effective wavelength of 5400 A. The slit width was set to 1.5 arcsec.

Seeing 1.2 - 1.6 arcsec

The grating R600B was used in the blue arm, centered at 4400 A, yielding a reciprocal dispersion of 0.45 A/pix ; the grating R300R was used in the red arm centered at 6130 A yielding a dispersion of 0.84 A/pix.

more observation to come in summer 2005 at Calar Alto with PMAS (ifu)

our observations of PNe in M33



our spectra

detected lines

H Balmer lines, HeI, HeII, [OII]3727, [OIII]4959, 5007, [OIII]4363, [NeIII]3869, [NII]6585, [SII]6716, 6731, [Ar III] 7135

in 3 of our PNe, we could measure Te[OIII]

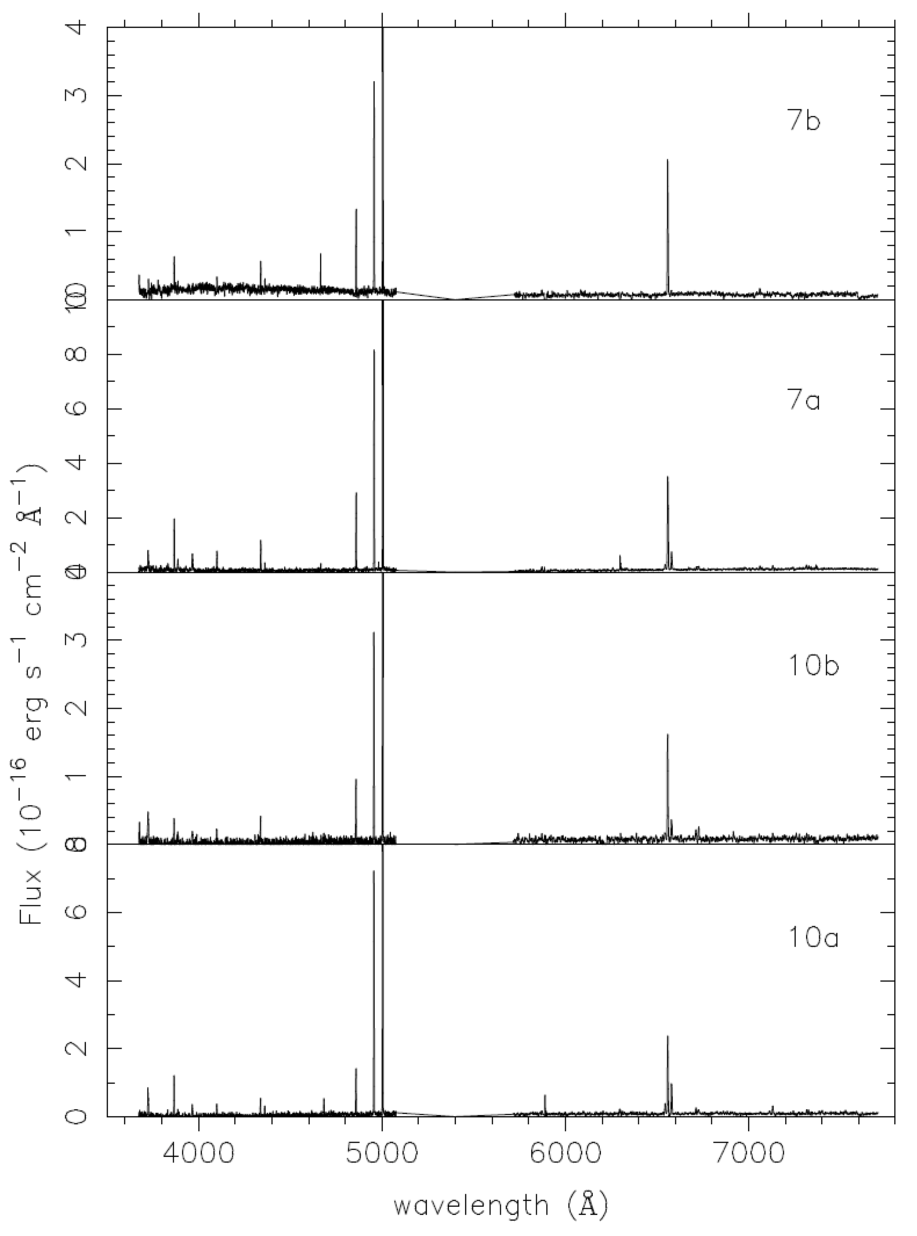
for them we derived the abundances with the classical empirical method

problems

- subtraction of the diffuse emission in the galaxy
- stellar absorption lines affecting the observed intensities of Hb, Hg etc...

results

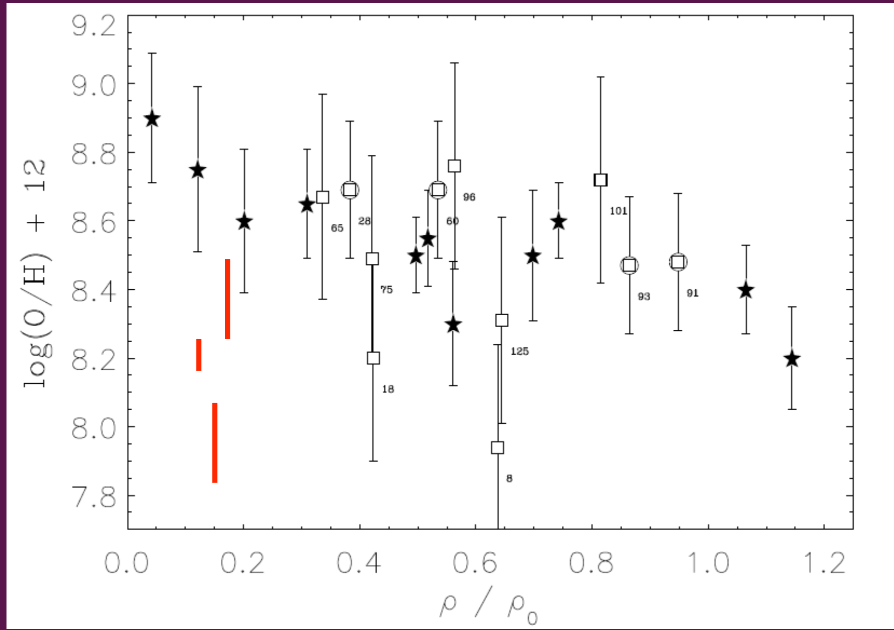
- the abundances derived for O and Ne are well below solar



how do our (preliminary) oxygen abundances fit in the global picture of the chemical abundances in M33 ?

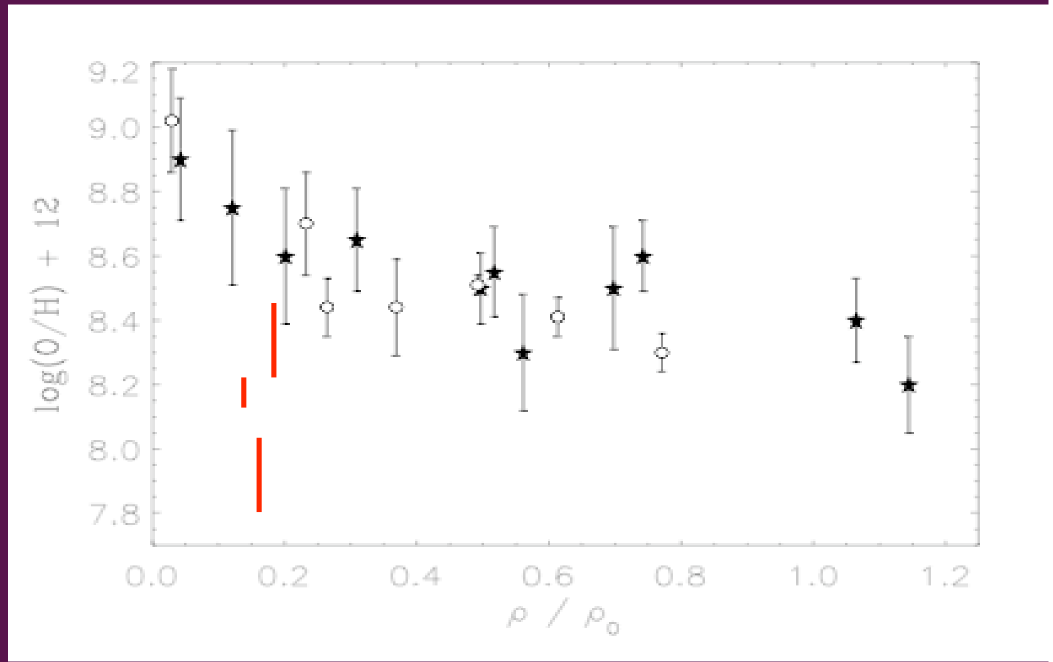
they strongly differ from those indicated by the B supergiants analyzed by Urbaneja et al 2005 (black stars)

They are lower than for the innermost PNe analyzed by Magrini et al 2004 (open circles)

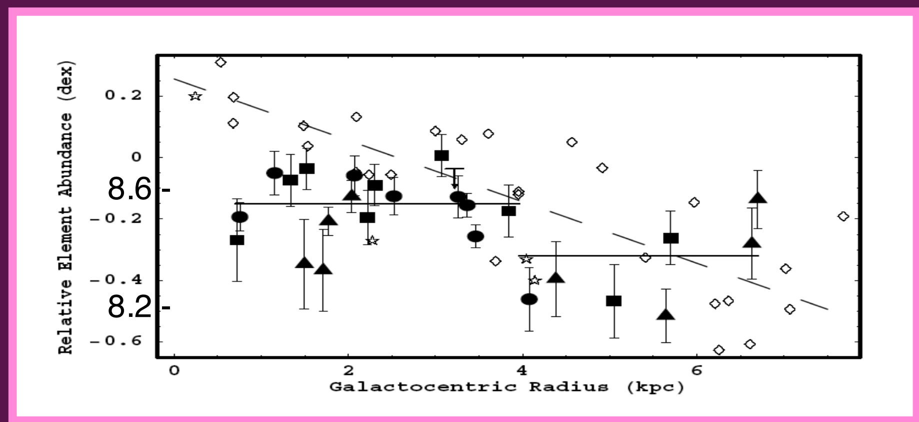


how do our (preliminary) oxygen abundances fit in the global picture of the chemical abundances in M33 ?

they are lower than than in the innermost giant HII regions analyzed by Vilchez et al 1988 (open circles)



They are rather compatible with the abundances derived by Willner & Nelson-Patel 2002 from ISO data on HII regions



Questions: are PNe good tools to investigate gradients of chemical composition in galaxies?

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- is it a worry that, in Galactic PNe, ORL give higher abundances than CEL?

- is it a worry that PN span a certain age range?

- is the oxygen abundance in PNe strongly affected by dredge-up and HBB?

- now that abundances in external galaxies can be derived from B supergiants, are PNe useless?

There are arguments to answer no to all those questions