Oxygen abundances from optical O I and O II recombination lines in planetary nebulae with [WC] central stars

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Motivation: Are there H-deficient inclusions in PNe?

Presence of H-deficient inclusions in PNe not predicted by current theories of stellar evolution, but proposed to explain ADFs in PNe.

Iben et al. (1983) proposed that an evolved star undergoing a very late helium flash may harbor H-deficient material. Also, other possible origins have been proposed (see Henney & Stasinska 2010)

Have WRPNe something to say in the origin of H-deficient inclusions in PNe?

PNe with Wolf-Rayet [WC] central stars

Only about 15% of PNe ionized by stars with WR features (WRPNe).

Prominent wide emission lines of C, O and He due to intense wind characterized by a high mass-loss rate.

Stellar atmospheres almost pure helium, carbon and some oxygen → **H-deficient stars**.

Requirements for the data

To obtain precise abundances in photoionized nebulae we need:

✓ High resolution spectra to avoid as much as possible line blendings

✓ Enough S/N ratios
  - CELs are strong lines in Galactic PNe
  - Very deep spectra needed to detect heavy element RLs

✓ Precise physical conditions determinations (T_e and n_e)

✓ A complete updated atomic data set

Talk by M. Rodríguez

Some difficulties with echelle data

✓ Flux calibration is not trivial (specially for the bluest wavelengths)

✓ Continuum measurements quite difficult in several cases.

✓ Red spectra contaminated with strong telluric emission lines

The WRPNe sample

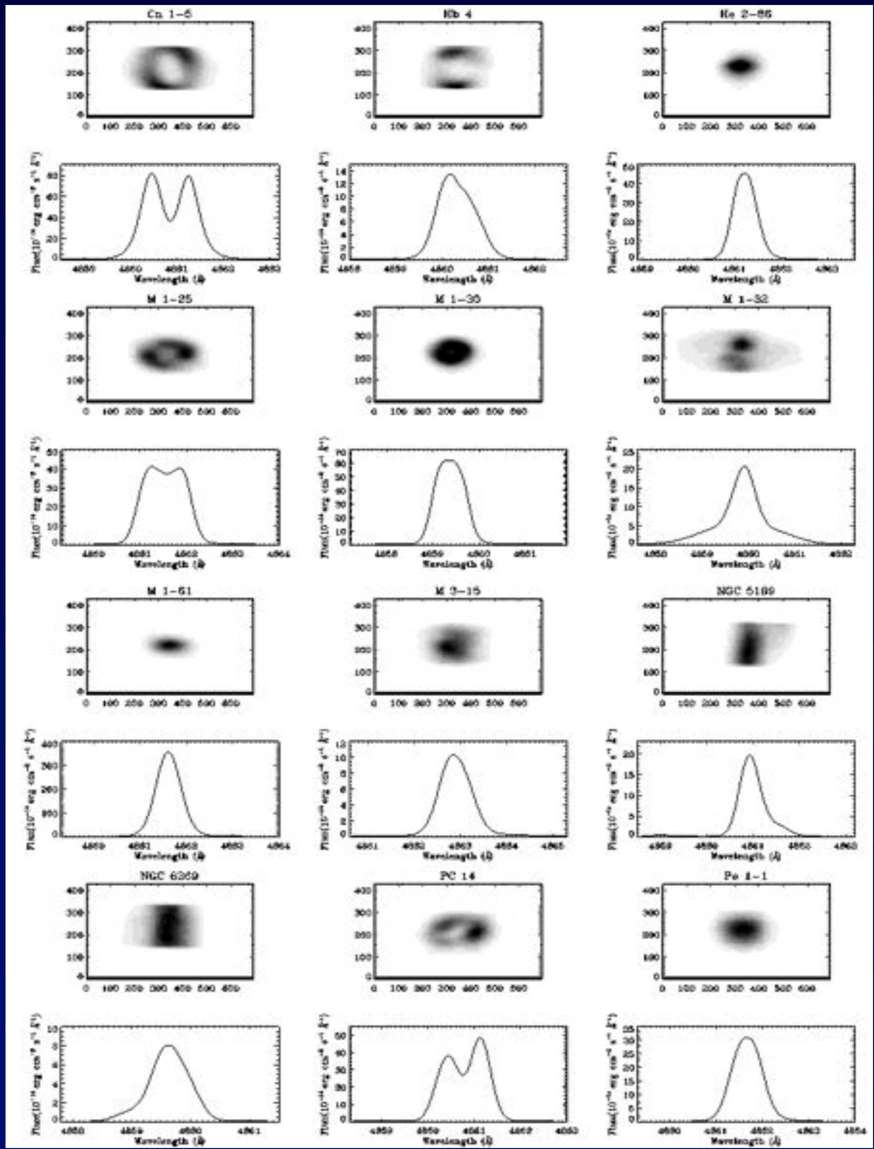
14 WRPNe and wels with detected ORLs of OI, OII, CII and CIII, covering from low-medium to high ionization degree. **Observed in September 2009 and June 2010**

MIKE@6.5m Clay Magellan Telescope

- ✓ Wide spectral range (3300-9400 Å)
- ✓ High spectral resolution ($\Delta\lambda$=0.14-0.27 Å)
  To avoid line blending
- ✓ Slit size 1” x 5”
- ✓ Good seeing (< 1”)
- ✓ O II and C II (and sometimes O I and C III) ORLs with good S/N ratio

(X^{+i}/H^{+}) (ORLs) → cuasi-independent of T_e and n_e

✓All 1-D spectra were flux calibrated with an average uncertainty of about 5 %



García-Rojas et al. 2012)

The WRPNe sample

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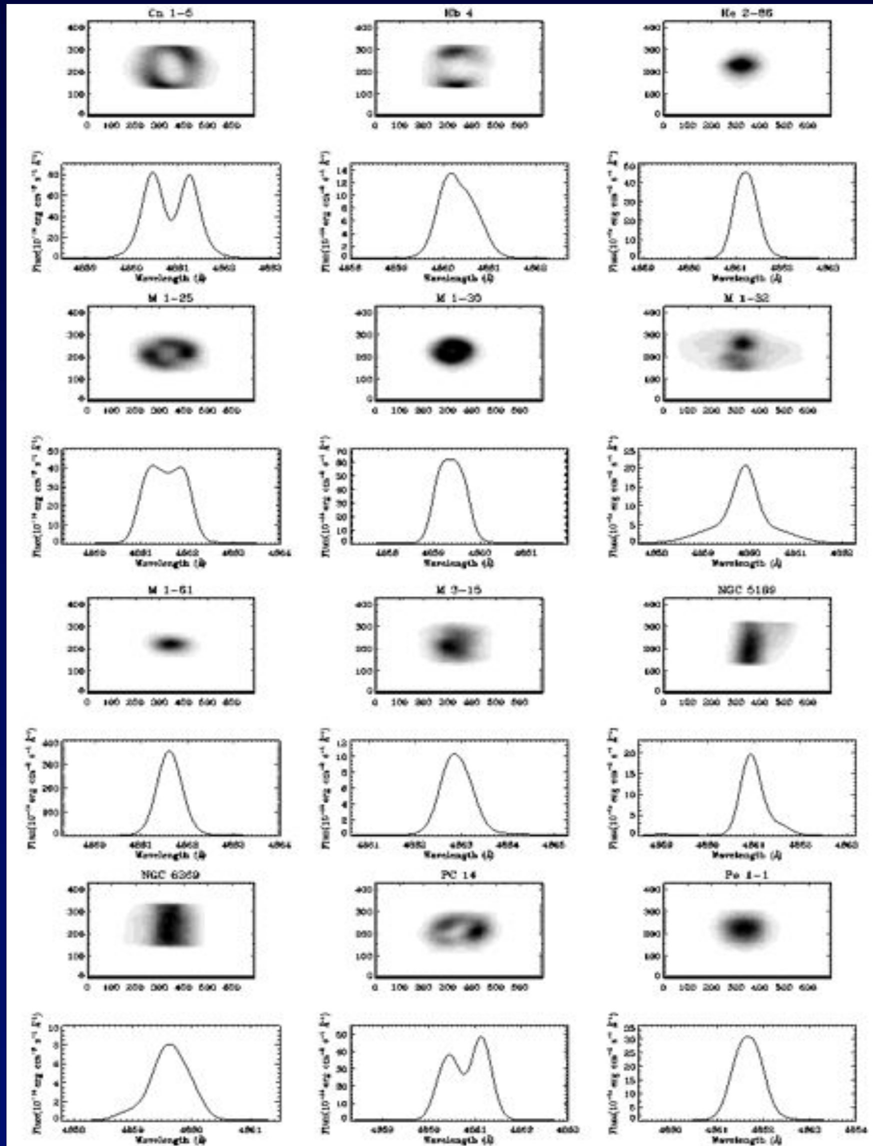
Object	Type	Diameter (´)
Cn1-5	WO4pe	7
Hb4	WO3	7.2
He2-86	WC4	---
M1-25	WC4	3.2
M1-30	wel	3.5
M1-32	WO4pe	9
M1-61	wel	1.8
M3-15	WC4	4.5
NGC2867	WO2	14
NGC5189	WO1	147
NGC6369	WO3	38
PB8	WC5.5	10
PC14	WO4	7
Pe1-1	WO4	3



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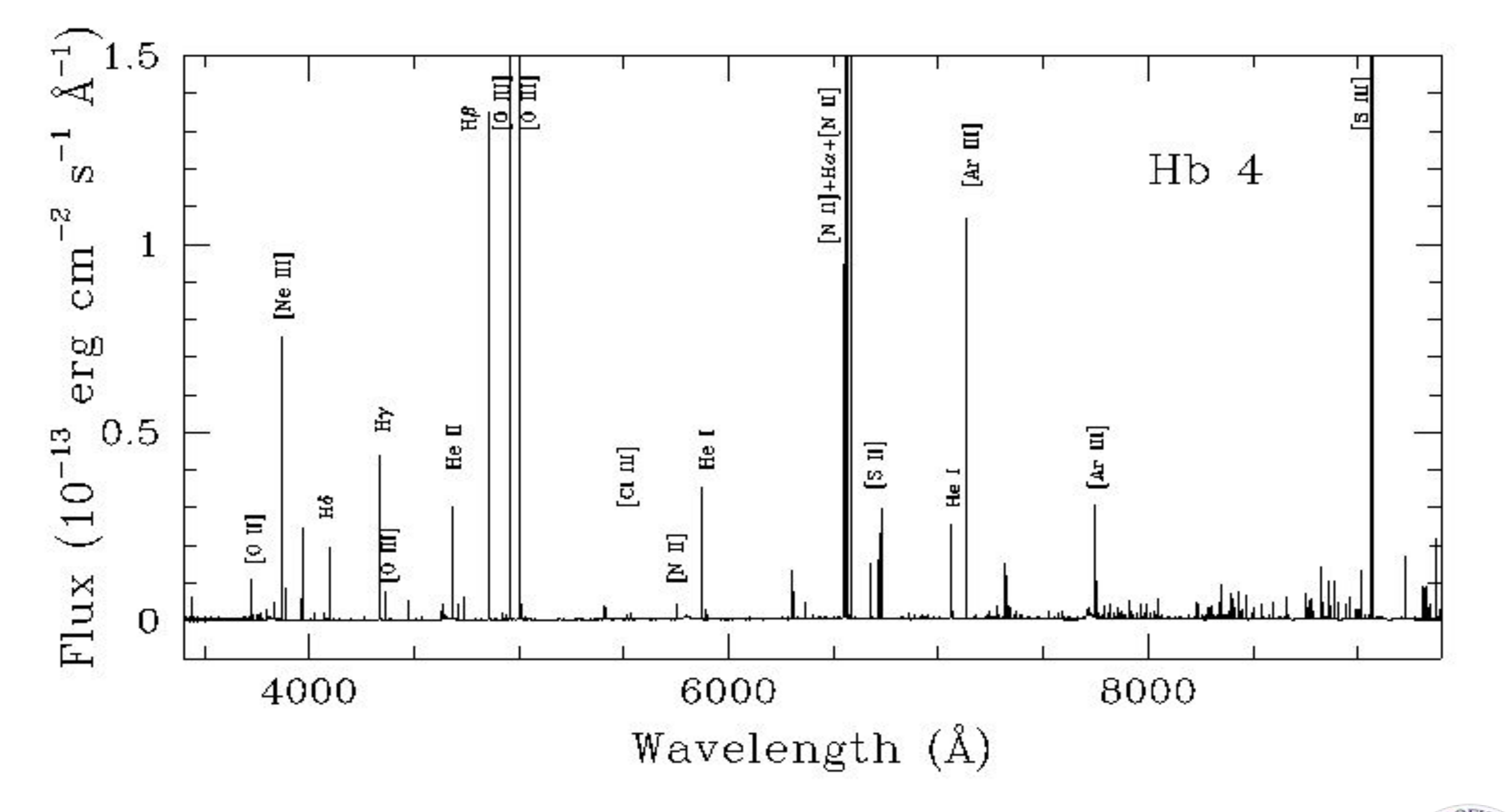
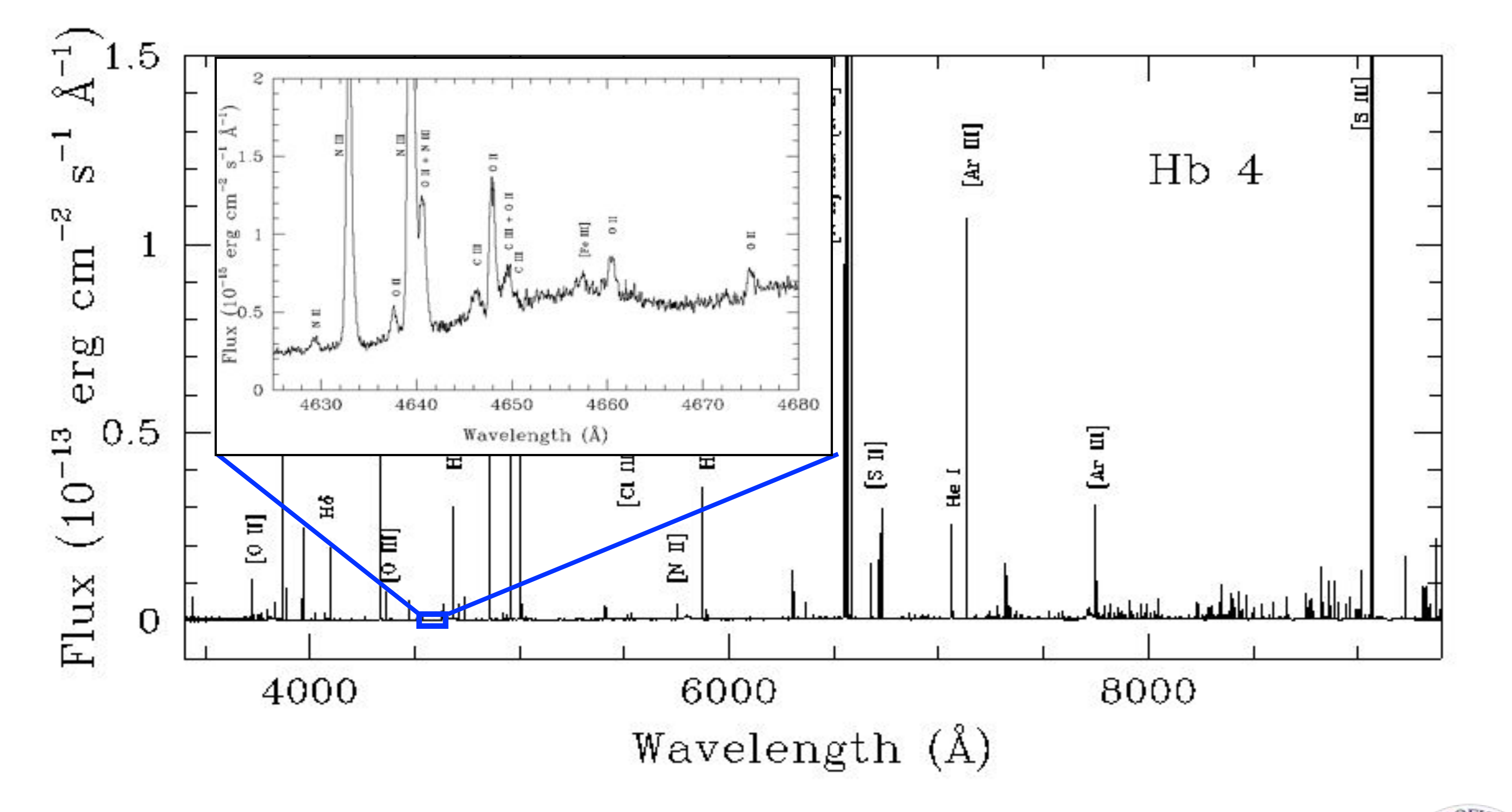
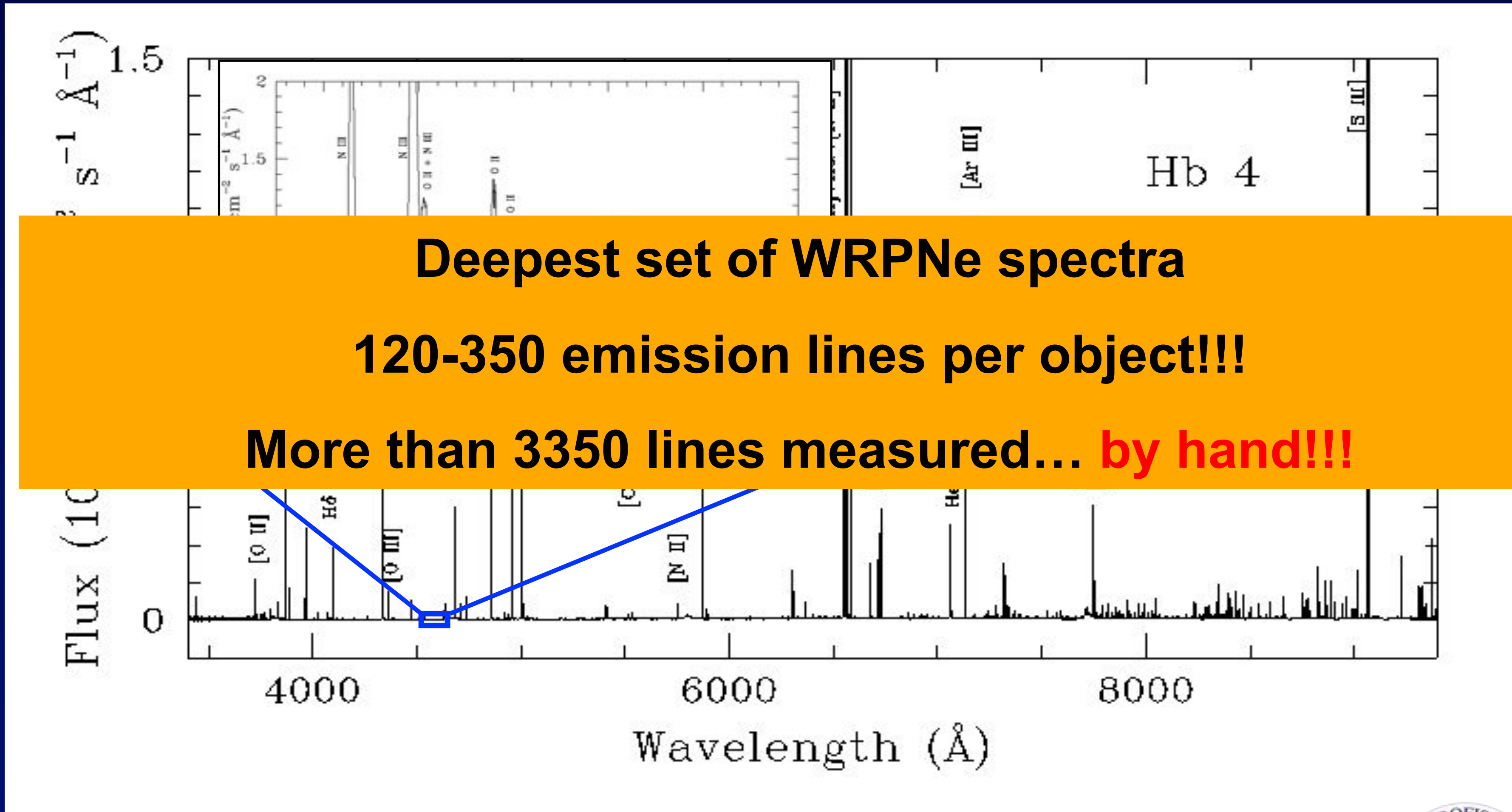
An example of 1-D spectra



An example of 1-D spectra



An example of 1-D spectra

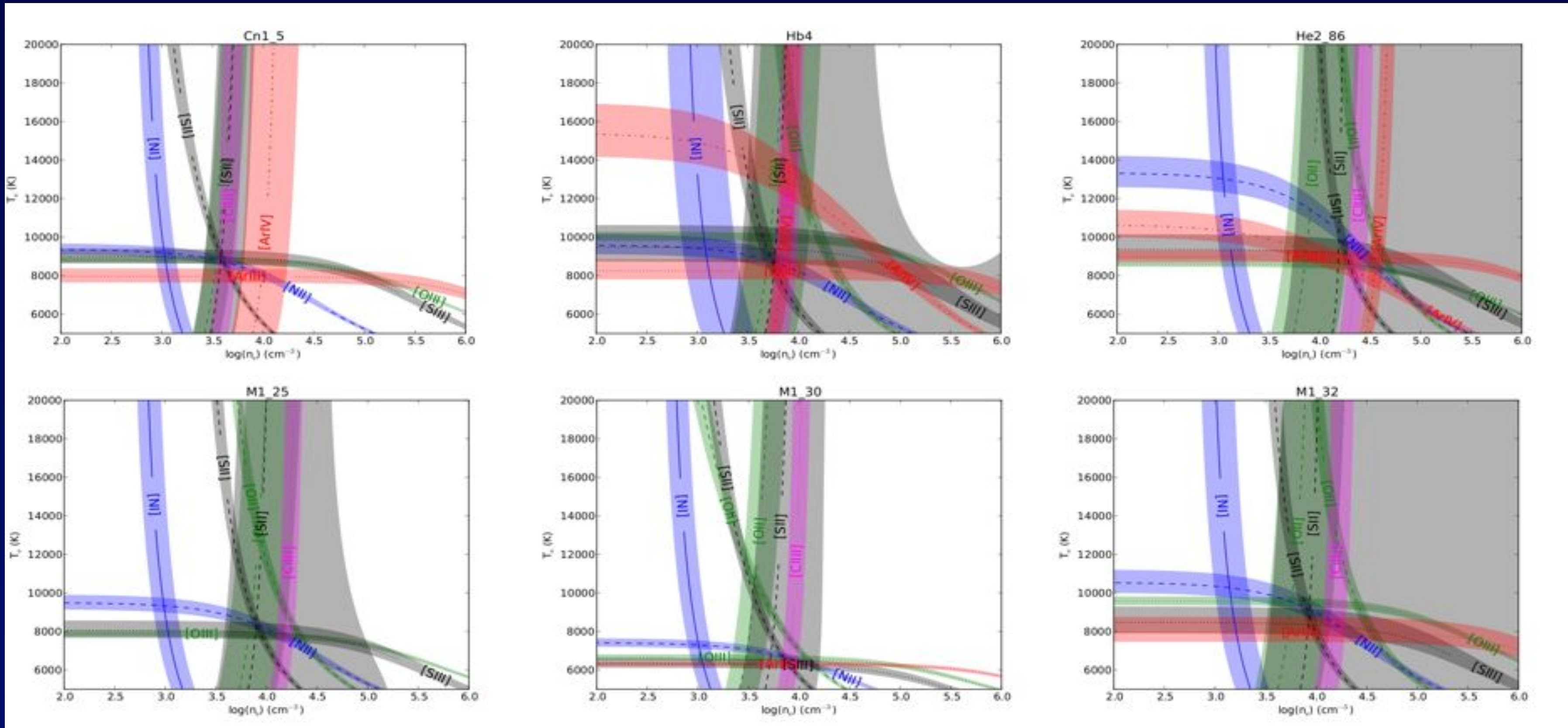


Deepest set of WRPNe spectra

120-350 emission lines per object!!!

More than 3350 lines measured… by hand!!!

Physical conditions



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Electron temperature and density derived from several diagnostics

Abundance determinations

Oxygen Abundances from CELs

Classical [O II] and [O III] CELs → O^{+}/H^{+} and O^{++}/H^{+} ratios

Oxygen Abundances from ORLs

O^{++} abundances derived from ORLs in all the objects (O^{+} in 7 objects)

Atomic data for O^{+} abundances (Pequignot 1991, Escalante & Victor 1992)

Atomic data for O^{++} (Storey 1994, Liu et al. 1995)

New atomic data calculations needed

Talk by X. Fang

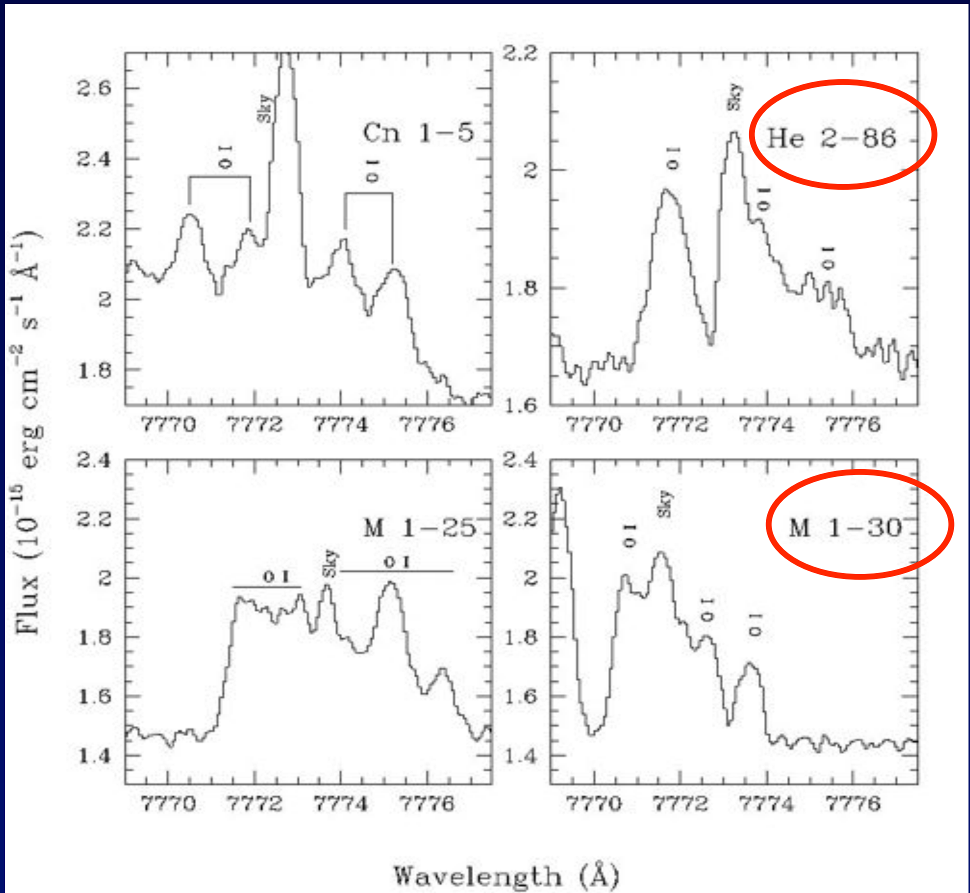
NLTE effects corrected for O II multiplet 1 → Affect individual line intensities, but not multiplet intensity.

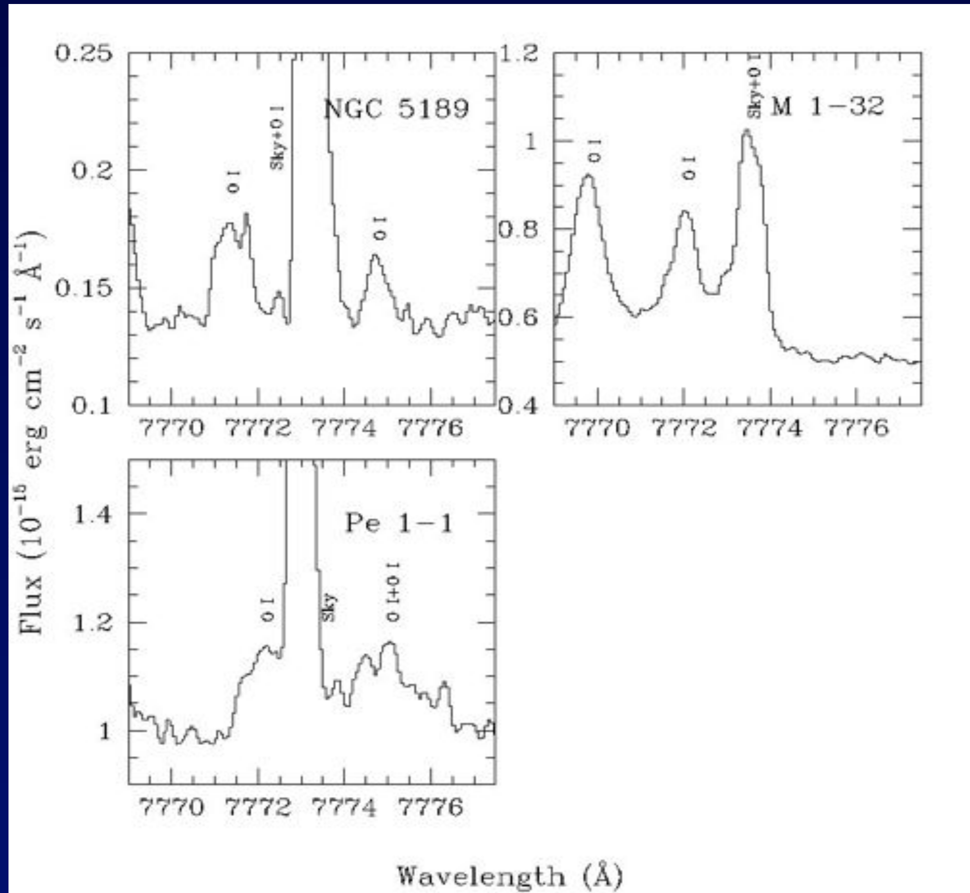
(Tsamis et al. 2003; Ruiz et al. 2003; Peimbert et al. 2005)

Abundance Discrepancy Factor for a given ion defined by Liu (2000)

$$\mathrm{ADF}\,(X^{+i}) = (X^{+i}/H^{+})_{\mathrm{ORLs}} \,/\, (X^{+i}/H^{+})_{\mathrm{CELs}}$$

Abundance determinations from ORLs. O I M1 lines





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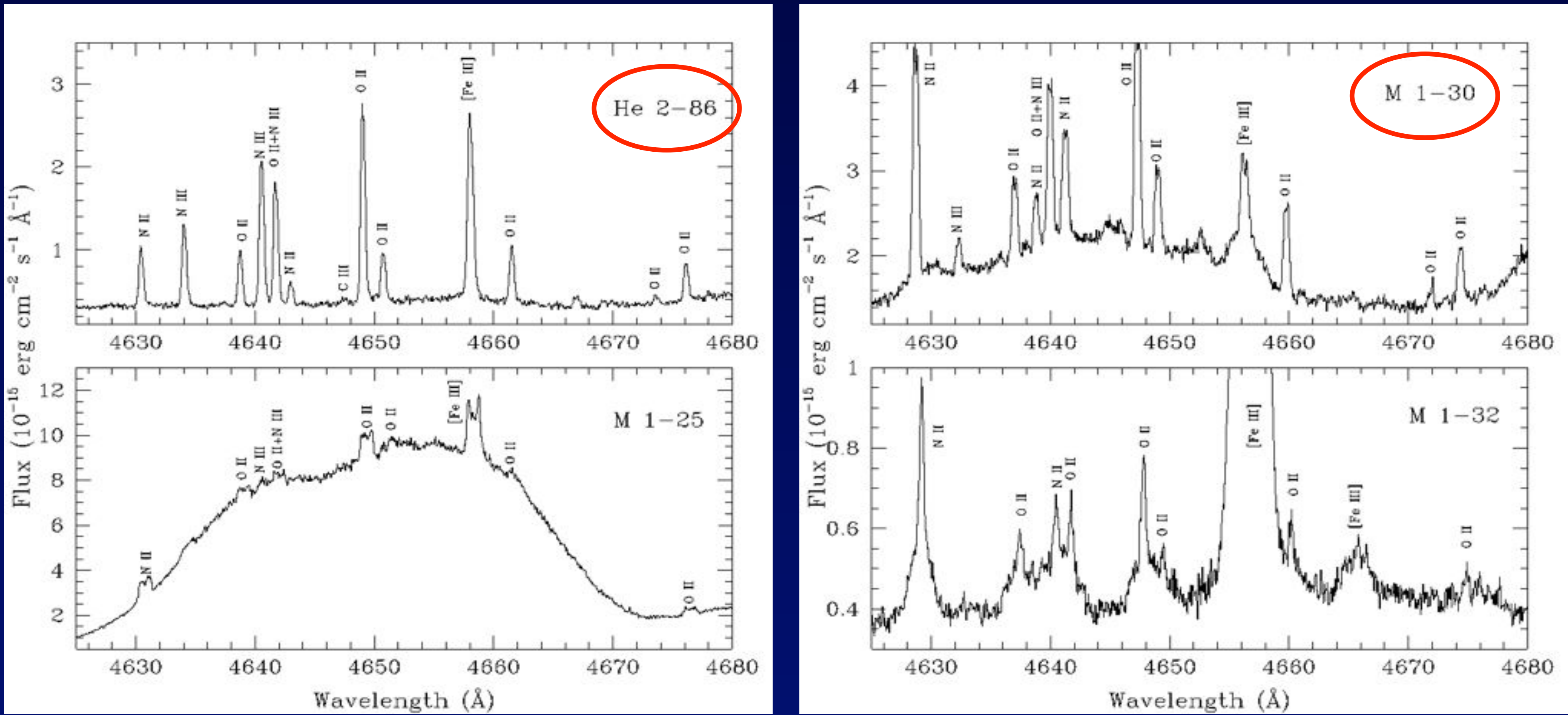
Abundance determinations from ORLs. O II M1 lines



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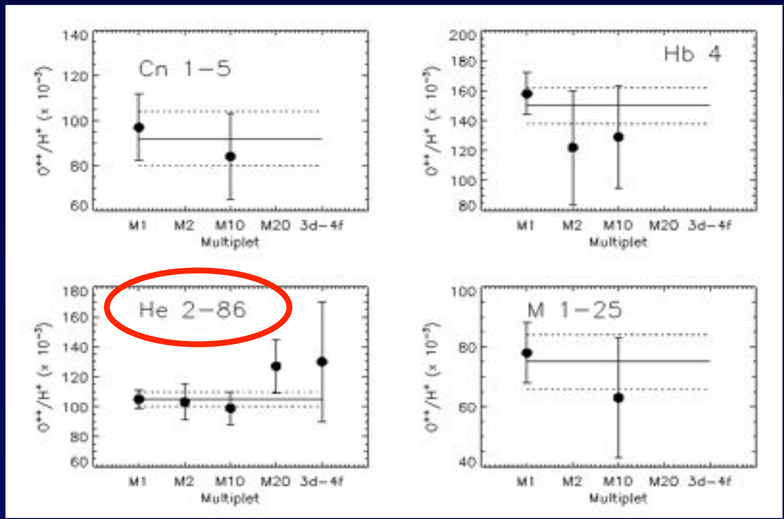
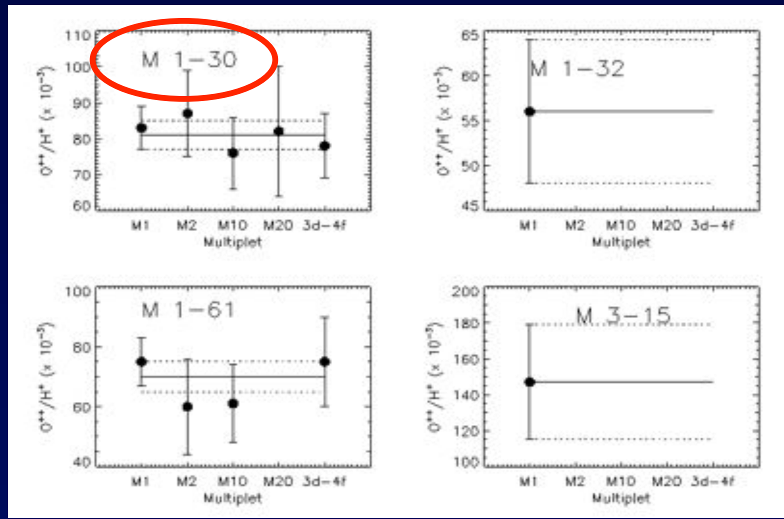
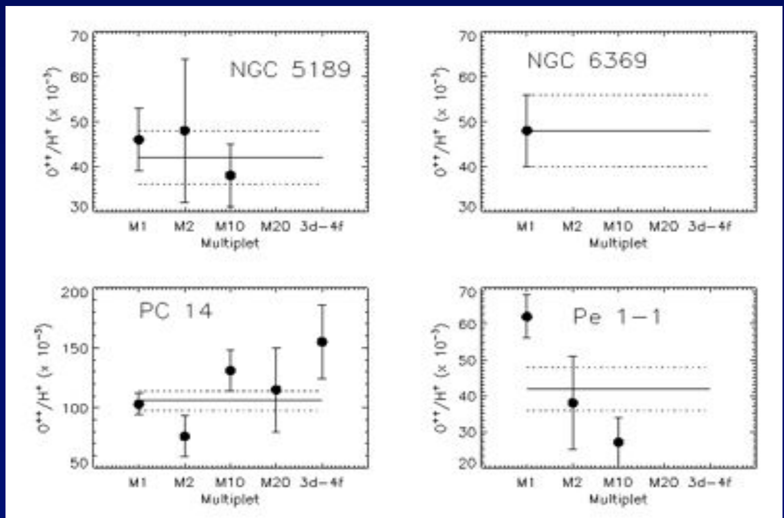
Abundance determinations from ORLs







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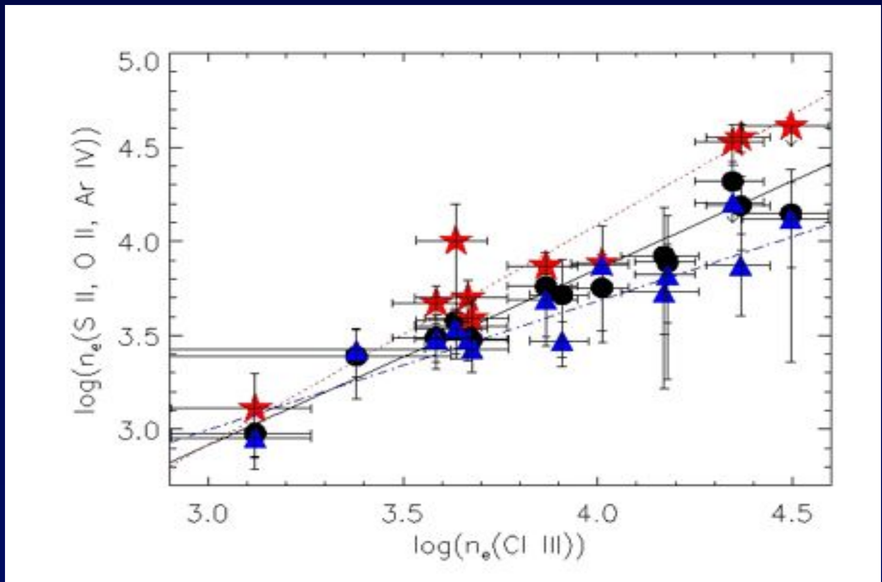
He 2-86 and M 1-30 have the largest S/N ratio of our data.
In most cases M1 abundance determination is representative of the averaged abundance

Abundance determinations from ORLs



García-Rojas et al. (2012)

There are trends in the computed densities. In general we find that:

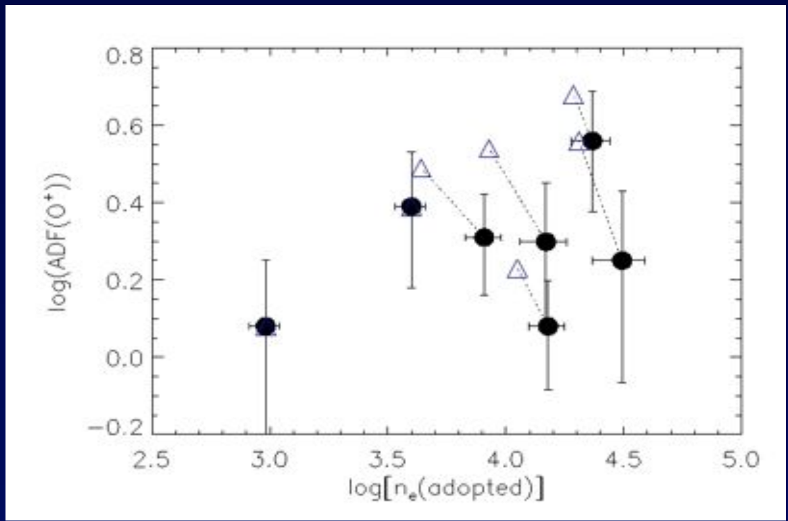
n_e([Ar IV]) ≥ n_e([Cl III]) > n_e([S II]) > n_e([O II])

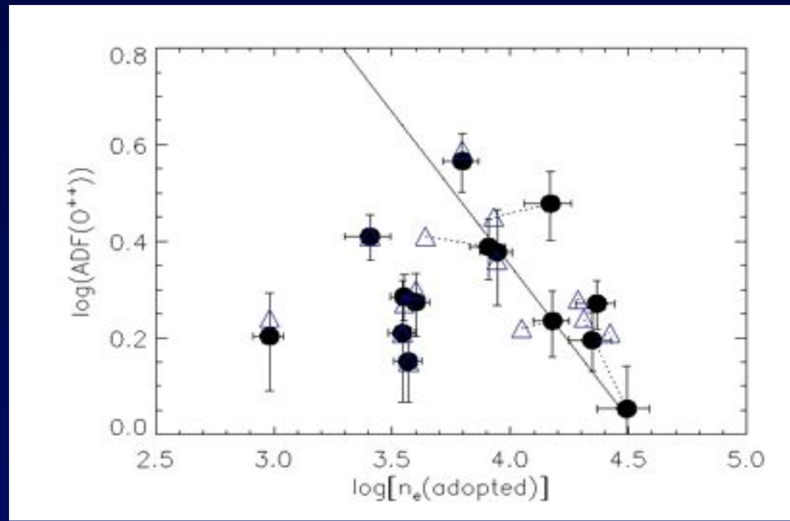
O^+/H^+ ratio from CELs very dependent on the assumed density. But…

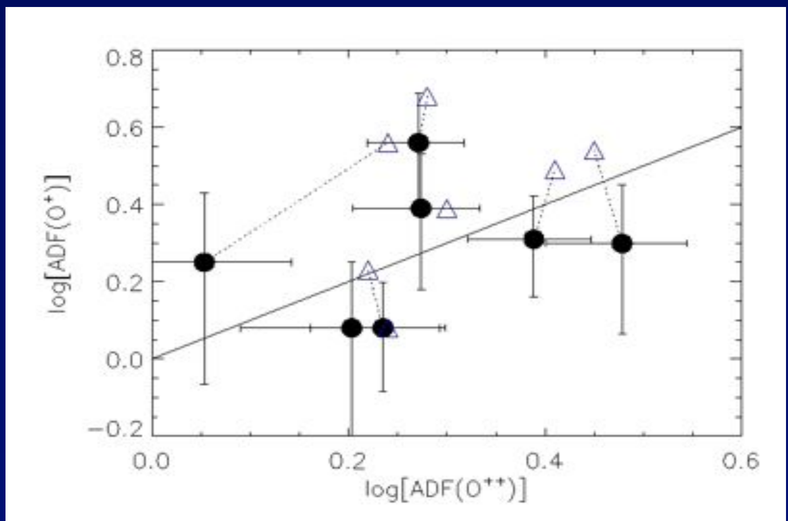
What is the “real” density in the O^+ zone?

Parameter	Line ratio	Cn1-5	Hb4	He2-86	M1-25	M1-30	M1-32	M1-61
n_e (cm^{-3})	[O II]	3450 ± 930	4900 ± 1770	7430 ± 3420	6650 ± 2940	2950 ± 800	5370 ± 2180	16040:
	[S II]	3780 ± 1400	5760:	15450:	7740:	5180 ± 2770	8350:	20810:
	[O II]$_{na}^{c}$	–	12300:^{d}	25100 ± 2600	13150 ± 1320	7150 ± 700	19780 ± 2600	28050 ± 3750
	[S II]$_{na}^{e}$	3775 ± 350	7700 ± 1100	18000 ± 1750	8900 ± 850	7250 ± 275	9180 ± 1120	20400 ± 2000
	[Cl III]	4320 ± 900	7360 ± 1480	23280 ± 4360	15100 ± 2600	8100 ± 1400	14800 ± 3300	22200 ± 4500
	[Fe III]	13100 ± 6150	–	30950 ± 6500	16500 ± 11900	–	16700 ± 3350	94100 ± 8000
	[Ar IV]	10050 ± 5700	7400 ± 1300	35810 ± 5990	–	–	–	33590 ± 8070

Abundance Discrepancy Factor (ADF)







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We have to be sure what is the real density of the gas to properly compute ADF(O^+)

(see talk by Mesa-Delgado)

This value could be very useful as an additional constraint to bi-abundance photoionization models, both in PNe and H II regions (Stasinska et al 2007)

CONCLUSIONS

✓ High resolution and high S/N spectra are needed to obtain good determinations of ORLs abundances and ADFs to constraint bi-abundance model, temperature fluctuations (talk by A. Peimbert), effect of shocks (see talk by R. Matadamas) or the presence of κ-distributed electrons (see talk by D. Nicholls)

✓ O^{++}/H^{+} derived from high S/N O II spectra gives consistent values from multiplets 1, 2, 10, 20 and 3d-4f transitions.

✓ *ADF*(O^{+}) is strongly dependent on assumed density. Need to carefully address this problem. What is the real density on the O^{+} zone?

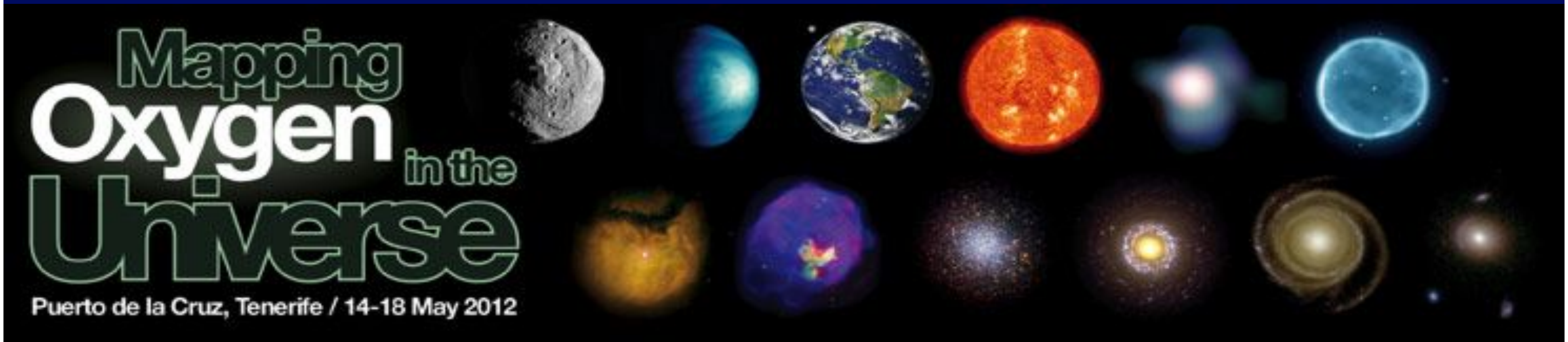
To be done

✓ Comparison of the behavior of the ADF in WRPNe with other detailed studies in non-WR PNe. Are WRPNe different from “normal” PNe?

✓ Comparison of the C/O ratio obtained from UV/Optical CELs (when available)and from ORLs. Comparison with C/O obtained in stellar wind when available.

✓ Photoionization modelling of individual objects.

Thank you


Mapping
Oxygen
in the
Universe
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