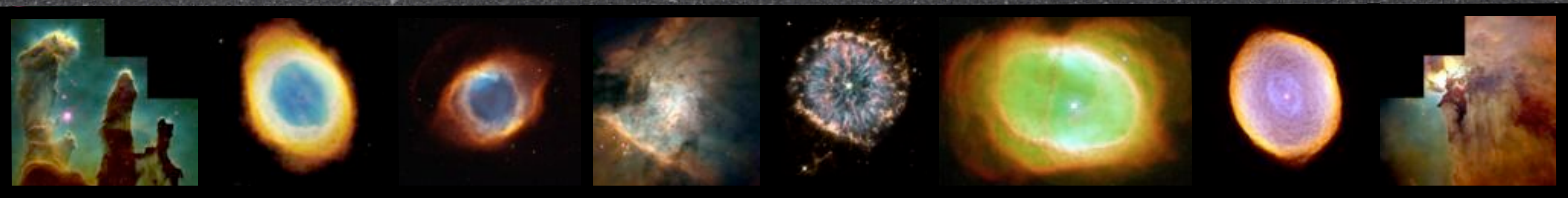
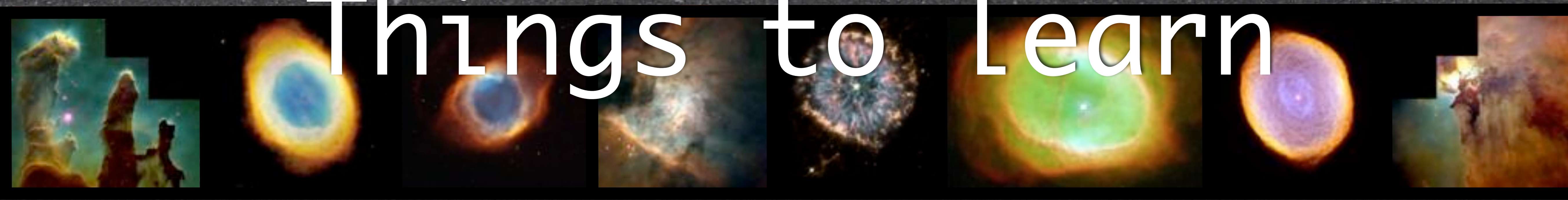


Temperature-based oxygen abundances in H II regions and PNe: methods and uncertainties

Mónica Rodríguez
INAOE

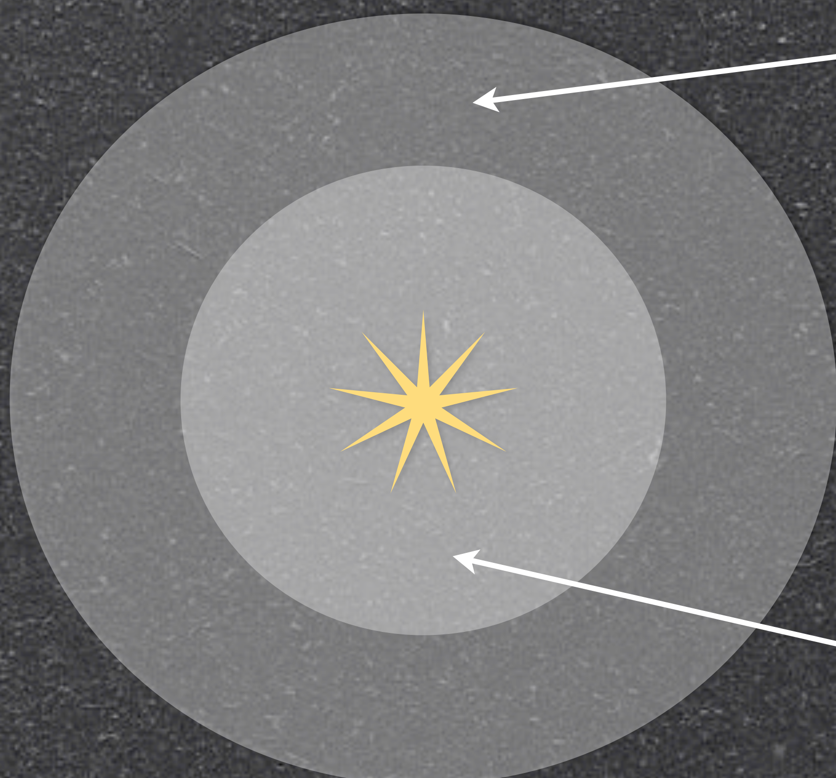
Things to learn



- We want to use ionized nebulae to study the chemical composition of the present-day ISM and the ISM of several Gyr ago, when the progenitors of PNe formed.
- A comparison with stellar results.

Oxygen is the element for which we can derive the most reliable abundances in ionized gas.

In H II regions and low-ionization PNe:



N_e from:
N_e[O II]
N_e[S II]
N_e[Cl III]
N_e[Ar IV]

<u>O^+ region</u>

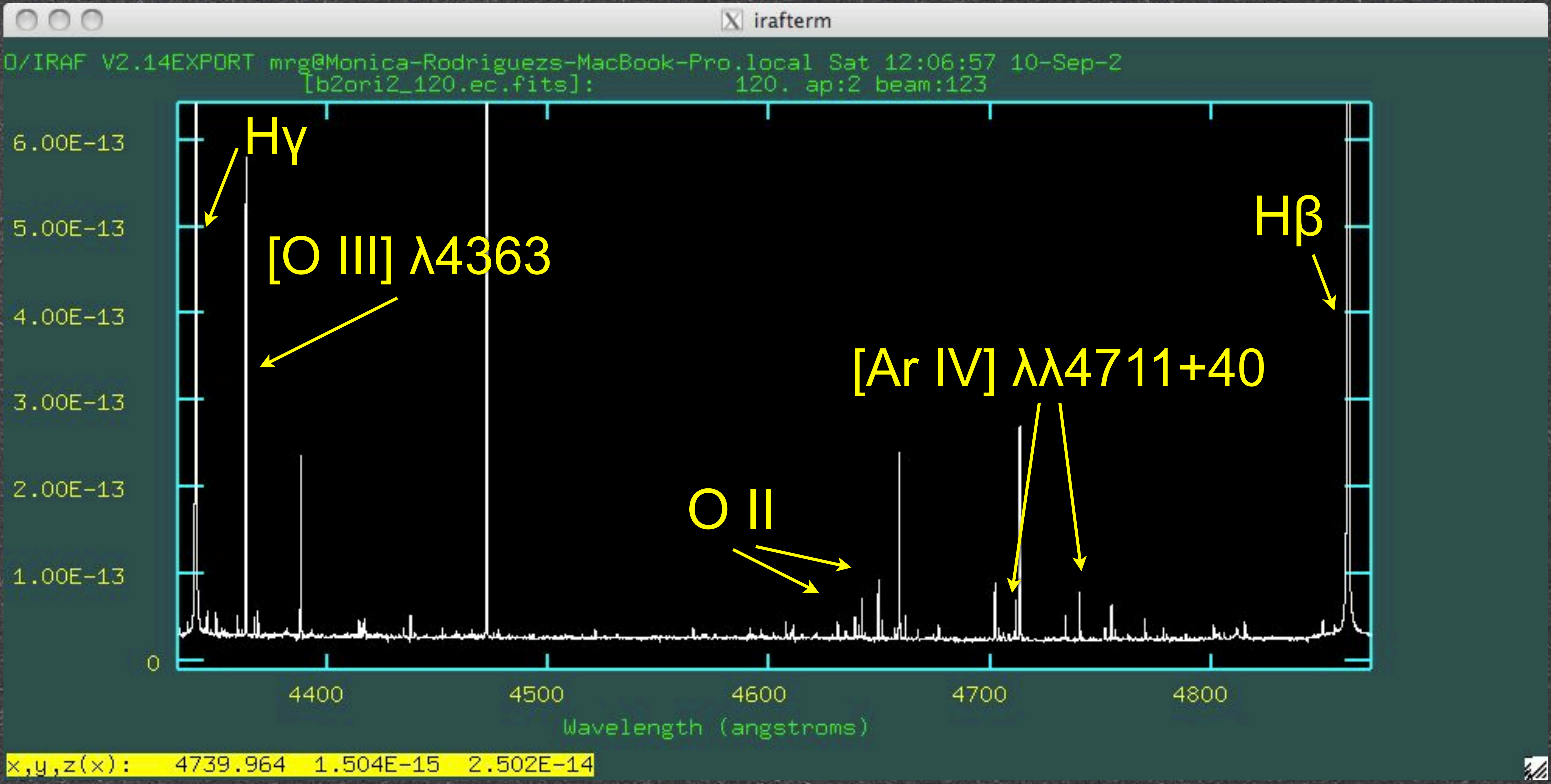
O^+/H^+ = function of I([O II] λ3727)/I(Hβ), T_e[N II], and N_e

<u>O^{++} region</u>

O^{++}/H^+ = function of I([O III] λ5007)/I(Hβ), T_e[O III], and N_e

$$O/H = O^+/H^+ + O^{++}/H^+$$

Orion Nebula (UVES/VLT)



(Esteban et al. 2004)

The abundance discrepancy problem

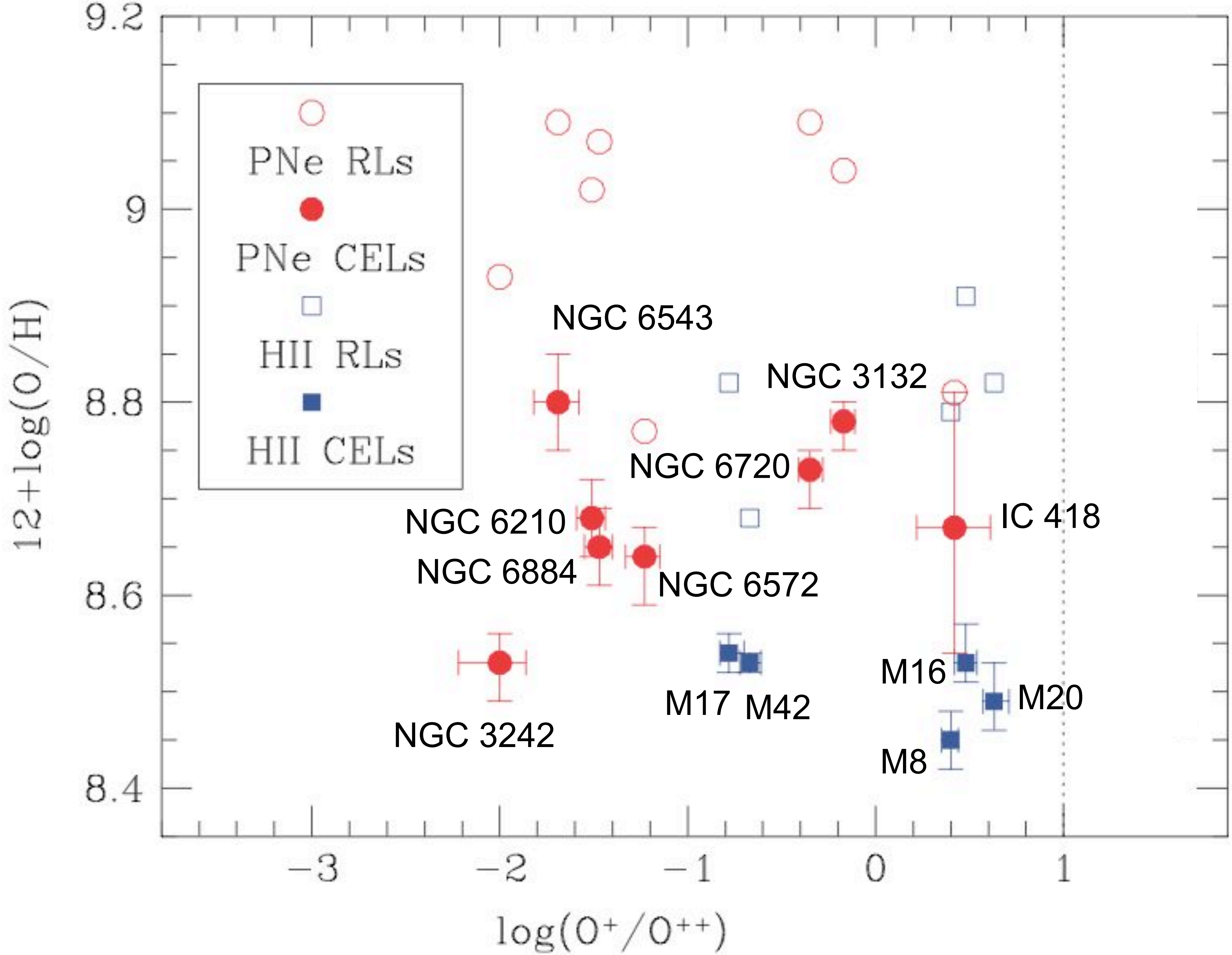
- Deep spectra of H II regions (Esteban+04; García-Rojas+04,05,06,07) and PNe (e.g., Liu +00,04; Tsamis+03) confirm the discrepancy between the oxygen abundances implied by recombination lines (RLs) and collisionally excited lines (CELs, Peimbert+93; Liu+95): O^{++}(RLs)/O^{++}(CELs) ~ 2 (and up to 70 for some PNe).

Explanations for the abundance discrepancy

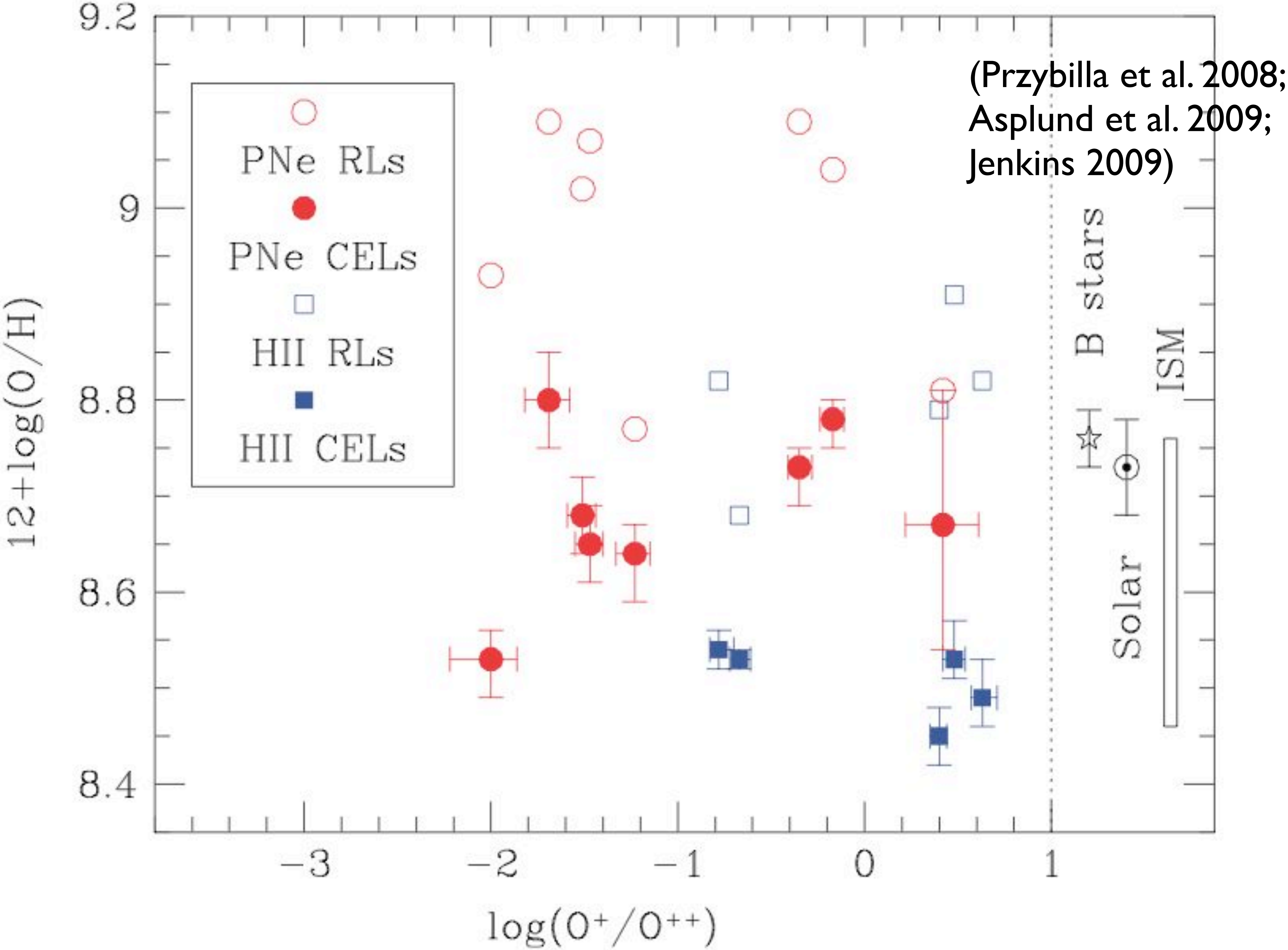
- Temperature fluctuations (t^2, Peimbert 1967). Problem: finding a mechanism that produces enough fluctuations.
- Metal-rich inclusions (Liu+00; Tsamis+05; Stasińska+07; Henney+10). Problem: their origin and survival.
- Errors in the recombination coefficients (Rodríguez +10). Problem: other ions show the discrepancy.

Let’s see some numbers

- An study of H II regions and PNe of the solar neighborhood (distances d < 2 kpc) and with the best available spectra ([O II] λ3727, [O III] λ4959, M1 of O II, several line ratios sensitive to N_e, T_e[N II], and T_e[O III]).



Rodríguez & Delgado-Inglada (2011a)



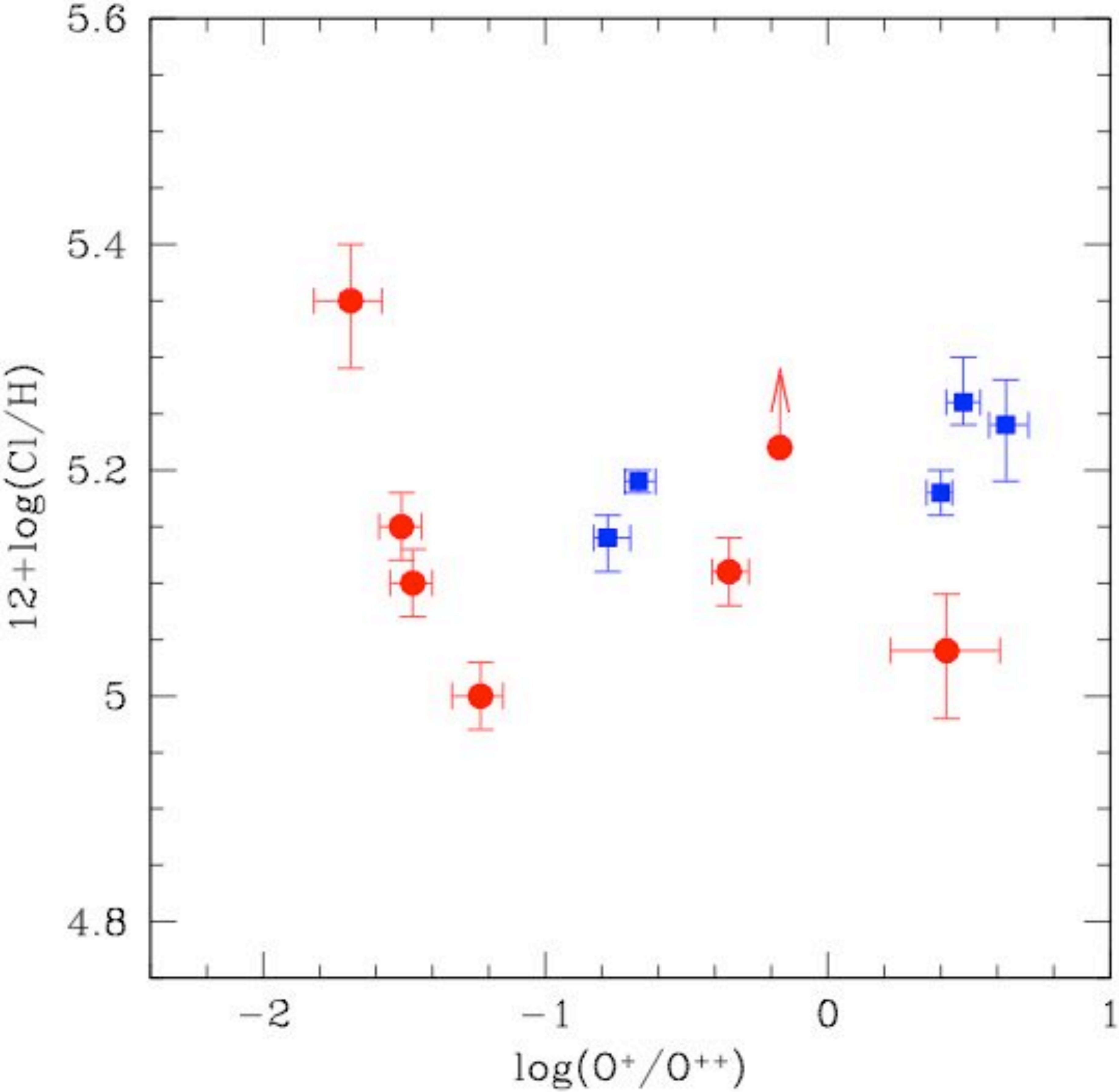
Rodríguez & Delgado-Inglada (2011a)

The missing oxygen

- Jenkins (2009) finds that the depletion of oxygen in the diffuse ISM cannot be explained with silicates and oxides. Ices?
- Whittet (2010) discusses a similar shortfall of oxygen in molecular clouds and argues for depletion into organic refractory dust components produced by the irradiation of ices by UV photons in molecular clouds.
- Do H II regions have cometary-like dust grains?

The other elements

- Ionization correction factors are likely to introduce a bias that depends on the degree of excitation (e.g., the sulfur anomaly: Henry+12, Rodríguez +11b).
- Another possible source of bias: the assumed temperature structure.



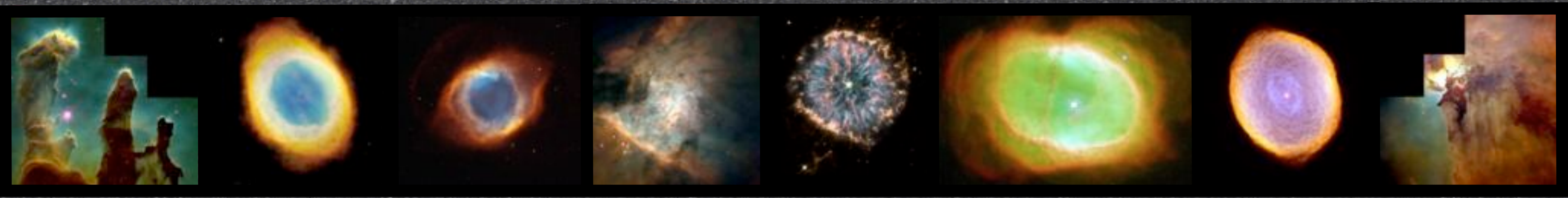
[Cl II] λ9124

[Cl III] λλ5517+37

[Cl IV] λλ7530, 8046

I(line)/I(Hβ) $\leq 10^{-4}$
in some cases

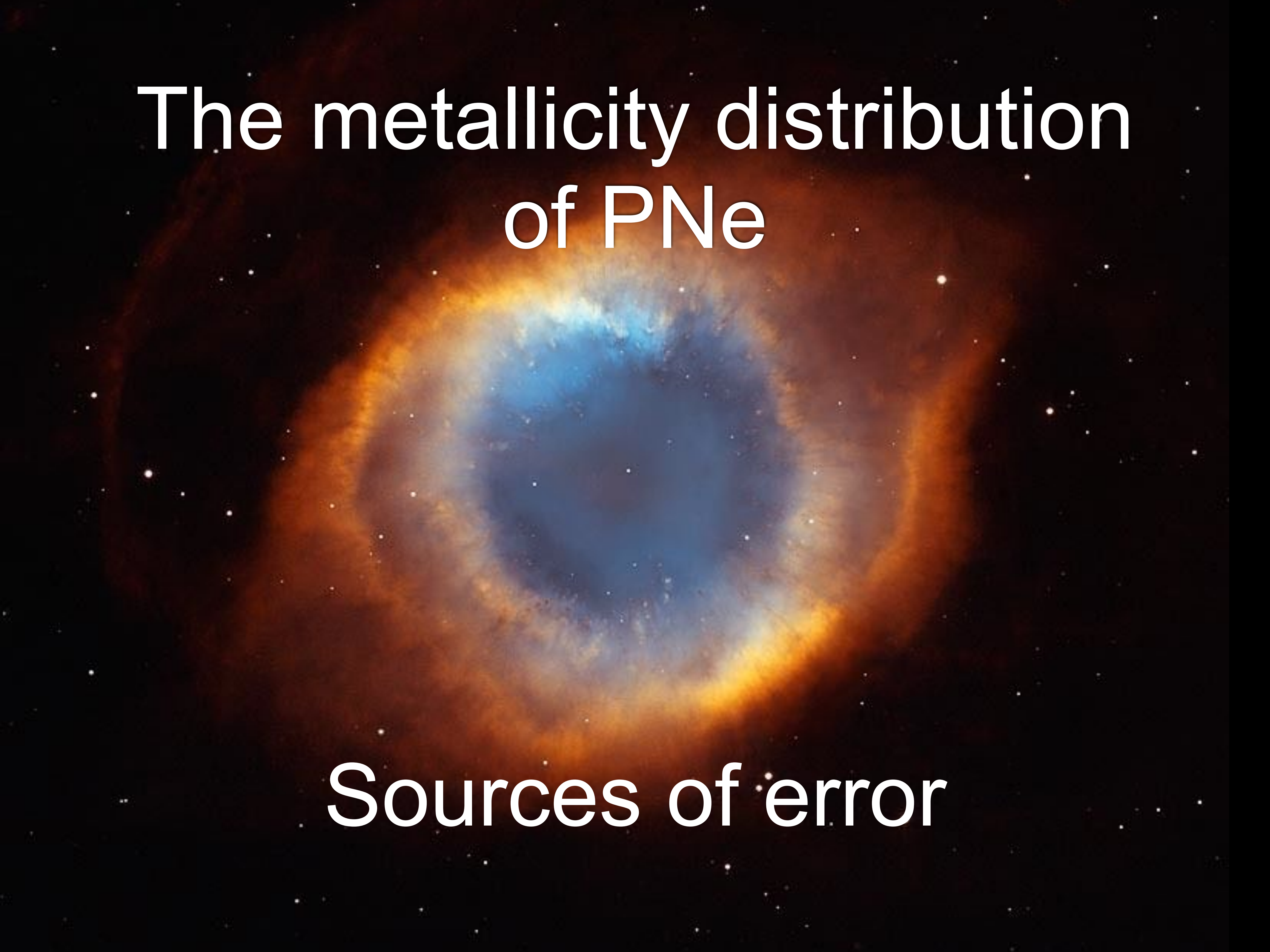
Rodríguez & Delgado-Inglada (2011b)



- Have we reached an agreement between our most reliable stellar and ISM abundances?
- Or do we still have important systematic errors in our abundance determinations?
- Do the progenitors of PNe produce significant amounts of oxygen?

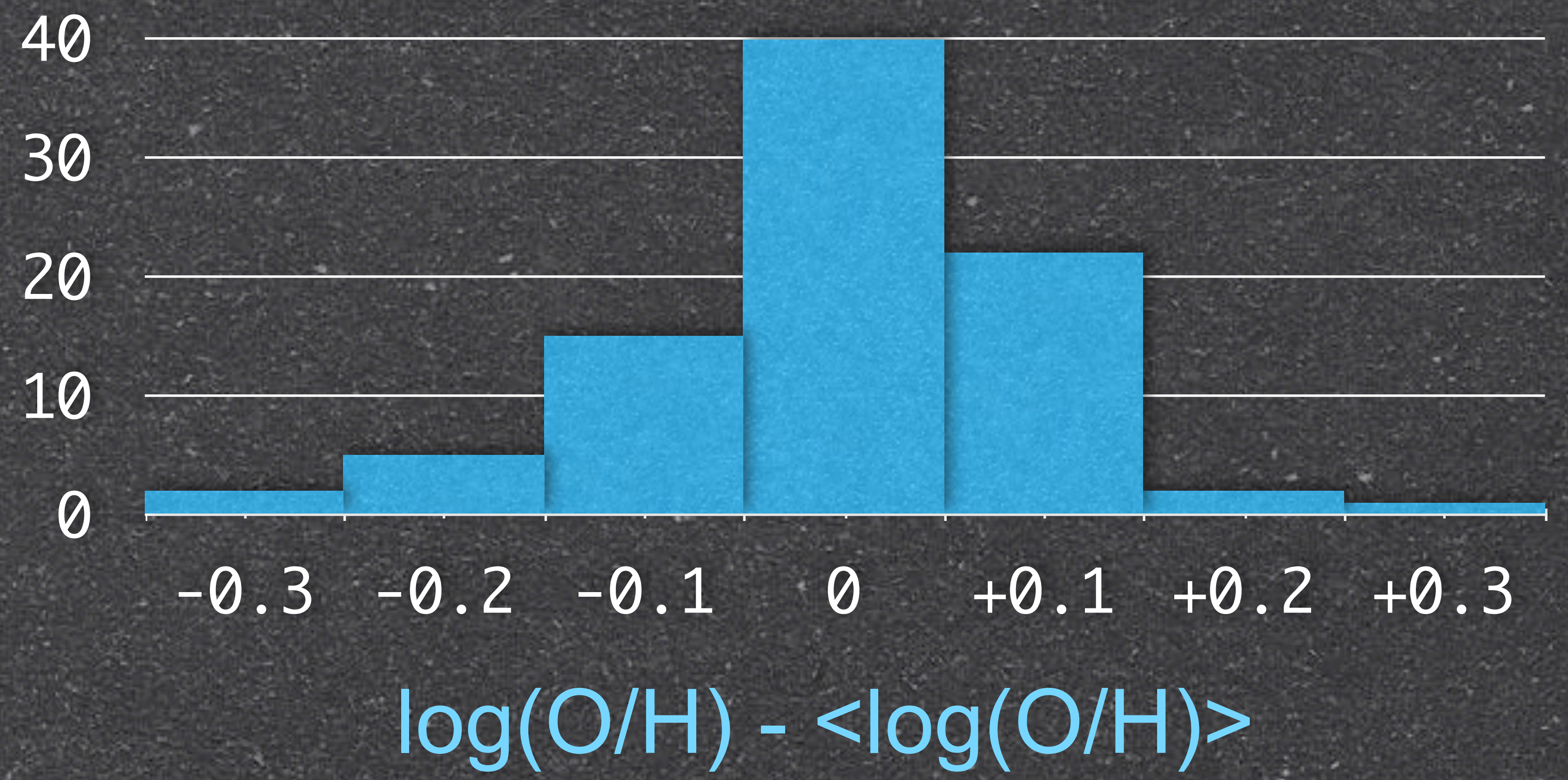
Can we increase the sample?

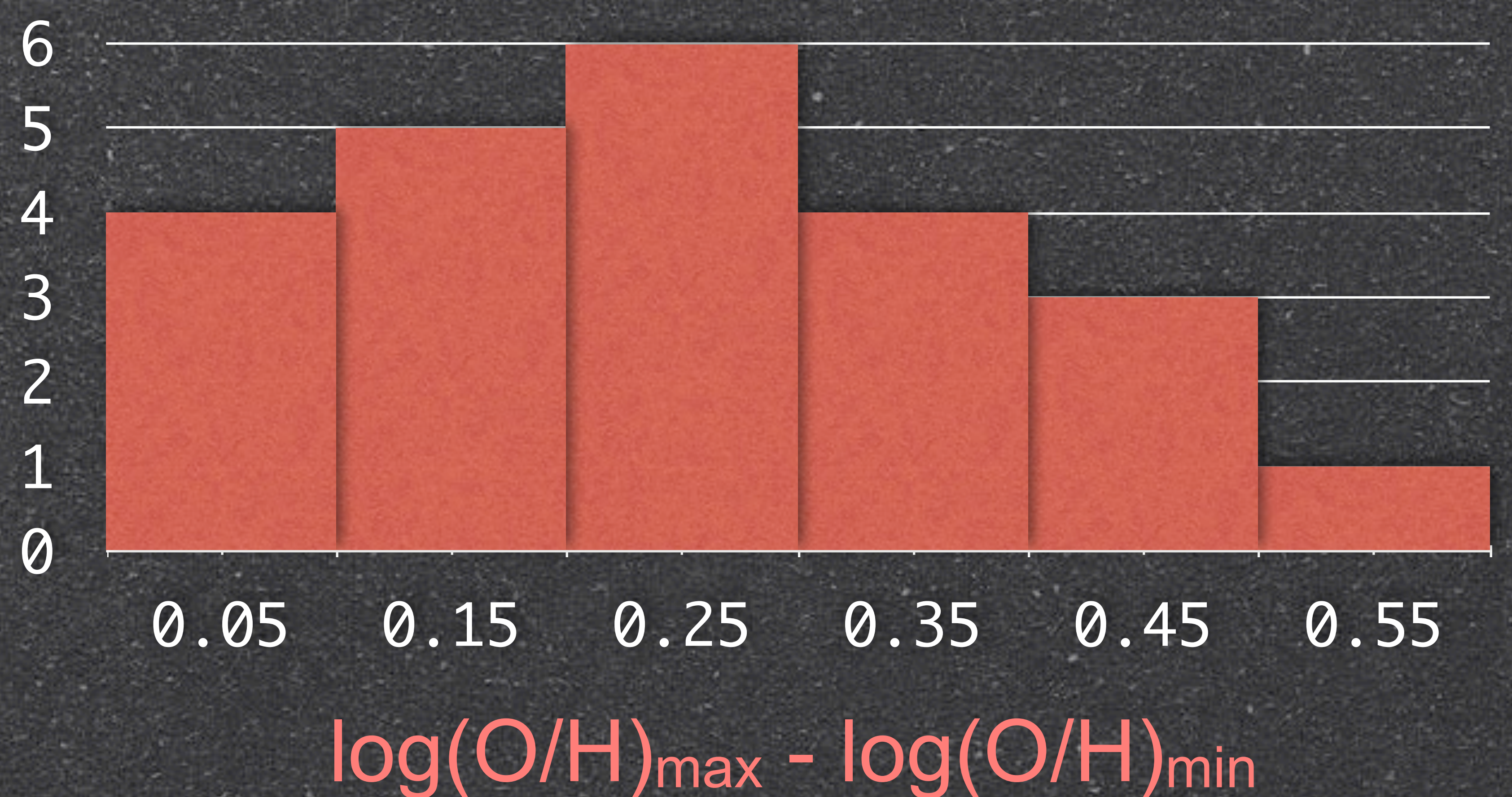
- There are more than 200 PNe in the solar neighborhood (Frew+06, Frew08).
- About 500 of the known Galactic PNe have some observed spectrum, 131 (up to 2004) whose spectra have reasonable quality (Perinotto+04).
- The oxygen abundance determination is more robust for PNe (when O^{++} is dominant).

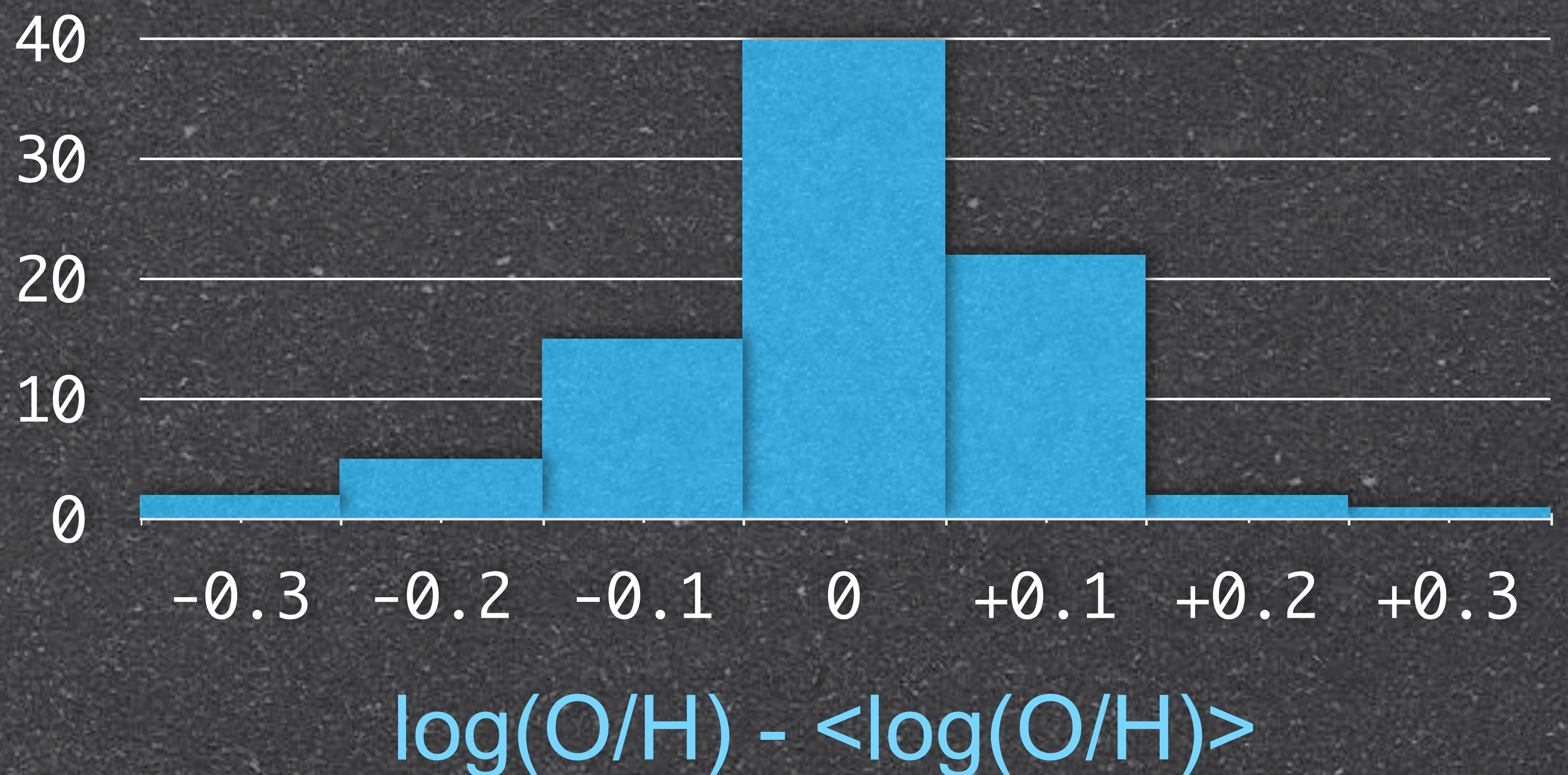

The metallicity distribution of PNe
Sources of error

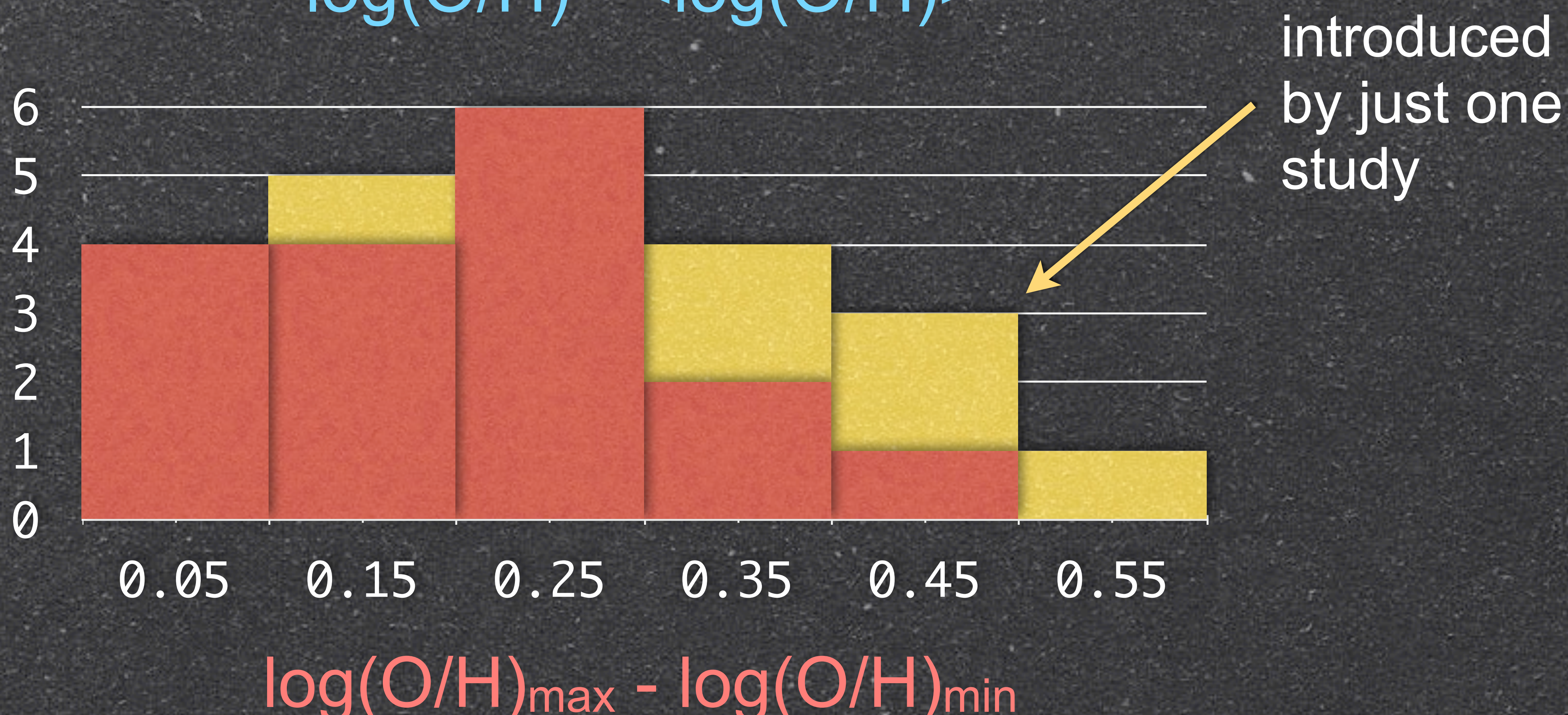
The metallicity distribution of PNe

- Spectra compiled by Perinotto+04 plus more recent results: 23 Galactic PNe with at least three observed spectra ([O II] λ3727, [O III] λ4959, N_e[X], T_e[N II], and T_e[O III]).
- Ionization correction factor:
  $O/H = [(He^{+}+He^{++})/He^{+}]\,(O^{+}/H^{+}+O^{++}/H^{+})$ from Peimbert+87.

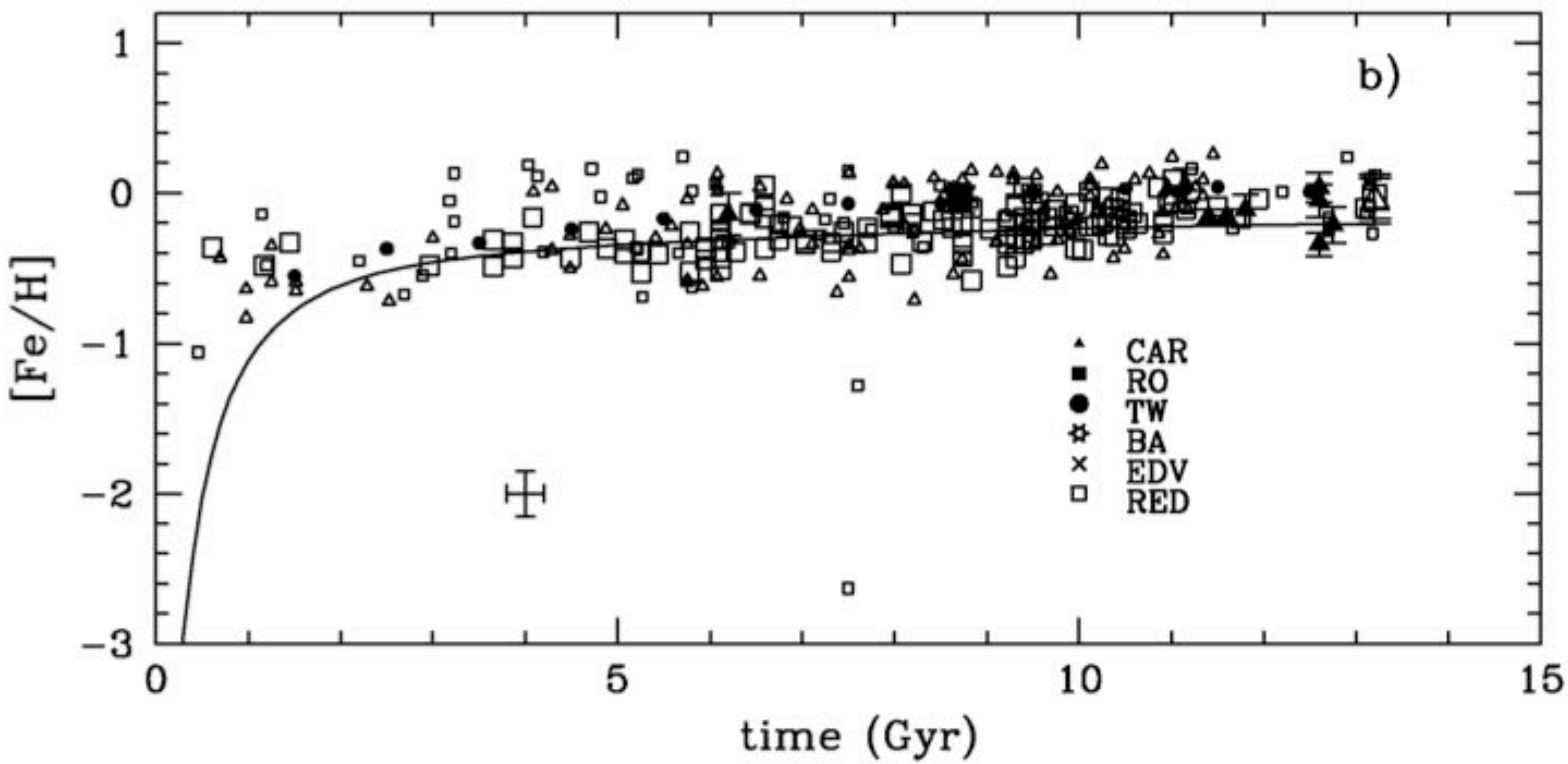

40
30
20
10
0
-0.3
-0.2
-0.1
0
+0.1
+0.2
+0.3
log(O/H) - <log(O/H)>


6
5
4
3
2
1
0
0.05
0.15
0.25
0.35
0.45
0.55
$\log(O/H)_{max} - \log(O/H)_{min}$


40
30
20
10
0
-0.3
-0.2
-0.1
0
+0.1
+0.2
+0.3
log(O/H) - <log(O/H)>


6
5
4
3
2
1
0
0.05
0.15
0.25
0.35
0.45
0.55
log(O/H)max - log(O/H)min
introduced by just one study

The age-metallicity relation



Mollá & Díaz (2005)

3.5.1. *The Age-Metallicity Relation*

We have assumed that there is an AMR in all four components of the Galaxy, represented by a geometric equation. The average metallicity of a star formed at time t is

$$\langle\zeta\rangle(t) = \log(Z/Z_{\odot}) = a(t-b)^{c} + d, \qquad (12)$$

with fitting parameters a, b, c, and d. Several authors (Carraro et al. 1998; Ibukiyama & Arimoto 2002; Bensby et al. 2004; Ibukiyama 2004; Haywood 2005), however, have found scattering in the AMR, with ~90% of stars formed at a given time scattered over about 1 dex interval in metallicity. We therefore assume that the metallicity distribution of stars formed at any given time t follows a Gaussian function:

$$\zeta(t, \log(Z/Z_{\odot})) = \frac{1}{\sqrt{2\sigma}} \exp\left\{\frac{-[\langle\zeta\rangle(t) - \log(Z/Z_{\odot})]^2}{2\sigma^2}\right\}, \qquad (13)$$

where σ, the width of the AMR at any given time t, is chosen to be 0.25 dex for the bulge and spheroid and 0.15 dex for the thin

Moe & De Marco (2006)

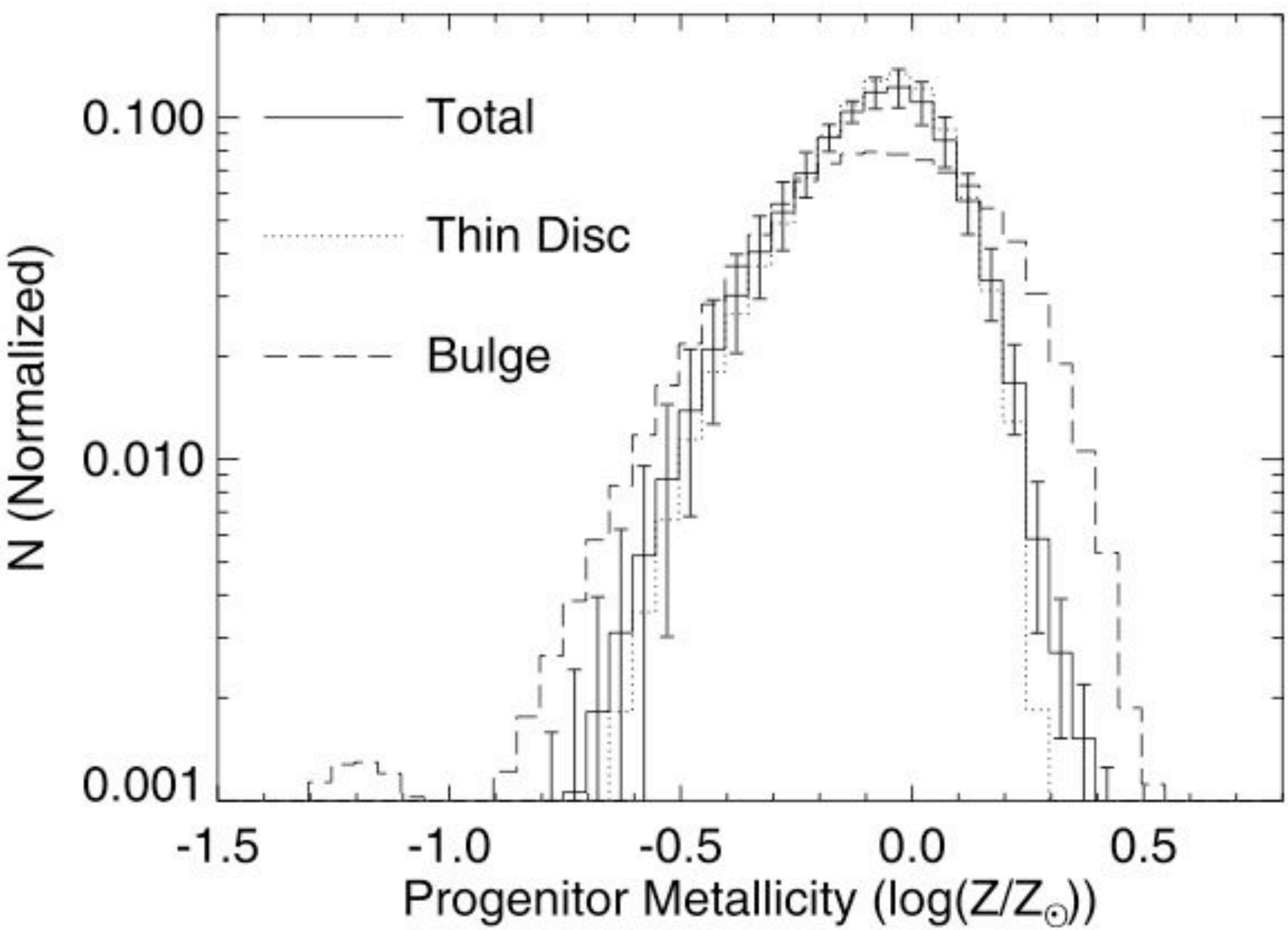
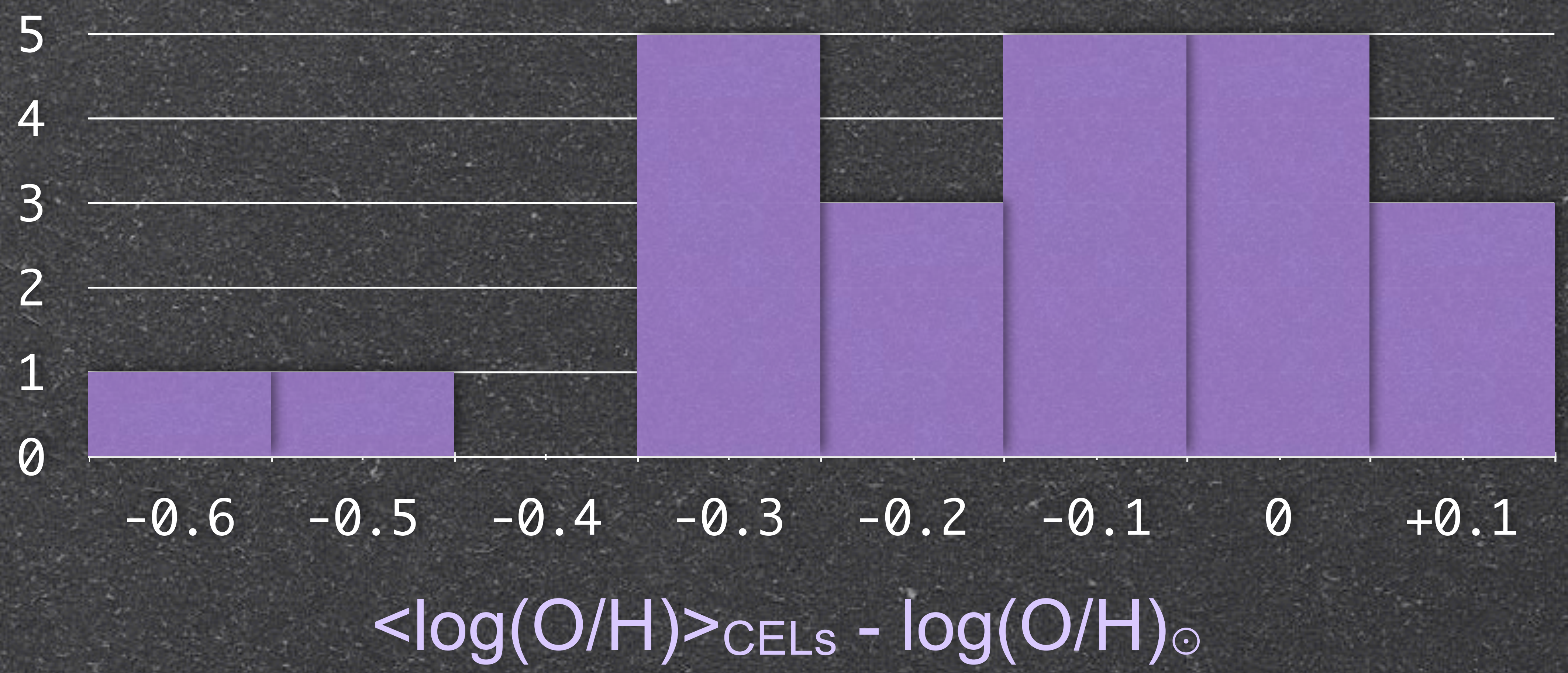


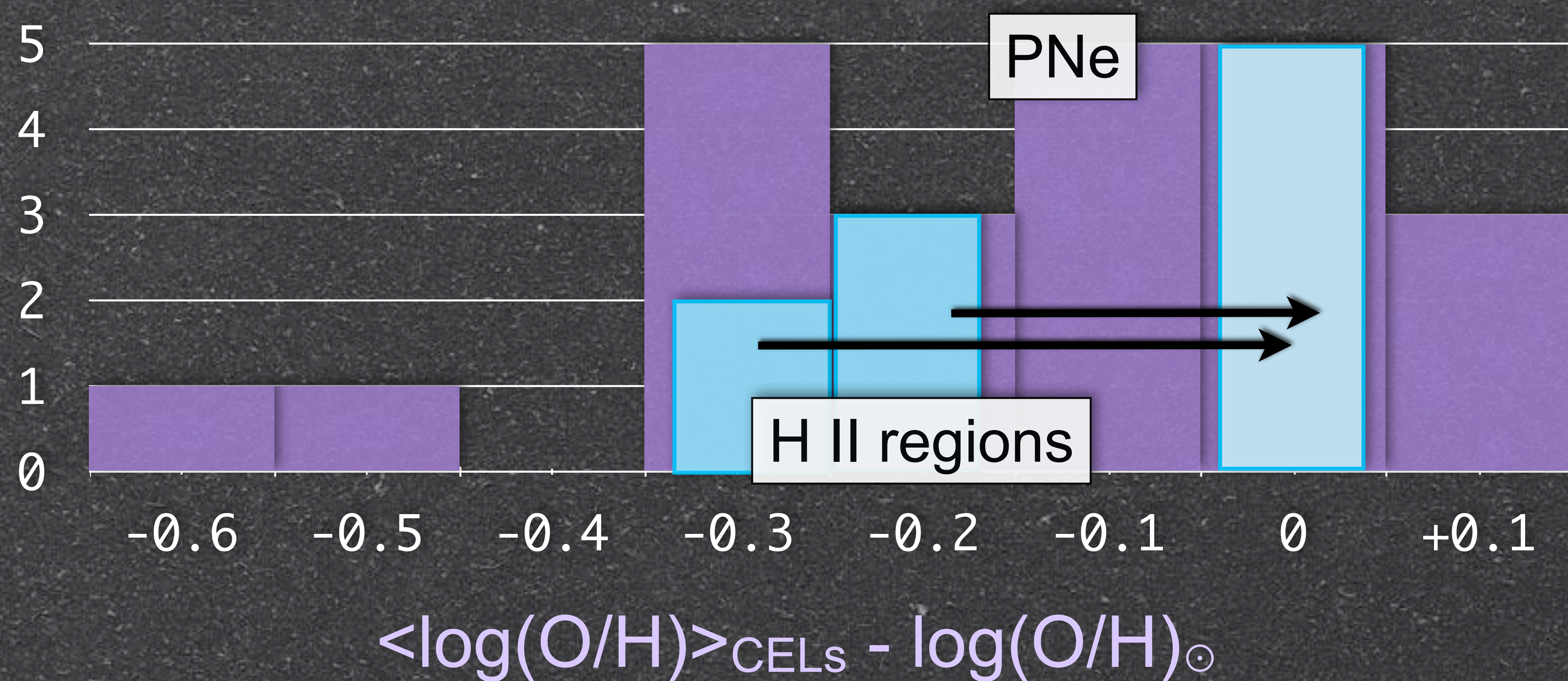
FIG. 12.—PN central star progenitor metallicity distribution. Error bars are for the total population.

Moe & De Marco (2006)

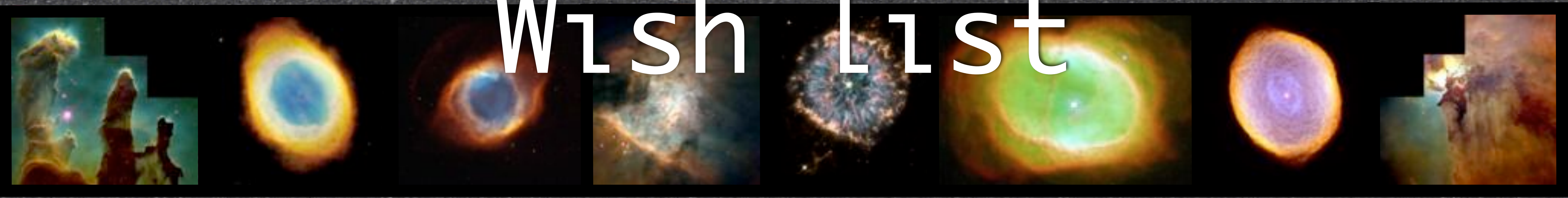
The metallicity distribution of PNe



The metallicity distribution of PNe



Wish list



- Deep spectra of relatively high spectral resolution with reliable flux calibrations.
- We need to understand better (via good spectra and photoionization models) the temperature structure of nebulae and the biases and uncertainties introduced by ionization correction factors.
- Solve the abundance discrepancy problem.

Future work

- The final objectives: to derive reliable metallicities and constrain or confirm the results obtained for stars.