The implications of the Orion Nebula abundances for other galactic and extragalactic H II regions

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The implications of the Orion Nebula abundances for other galactic and extragalactic H ii regions

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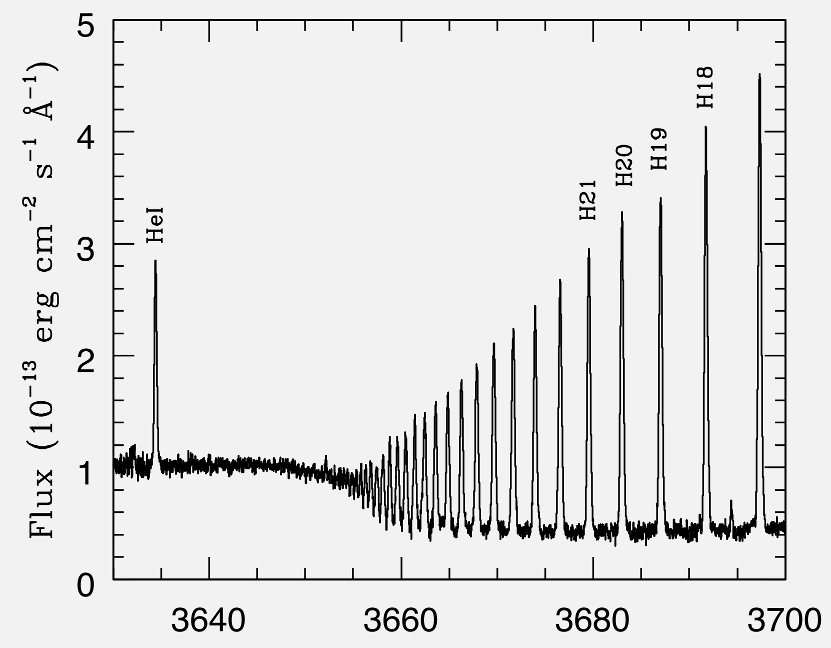
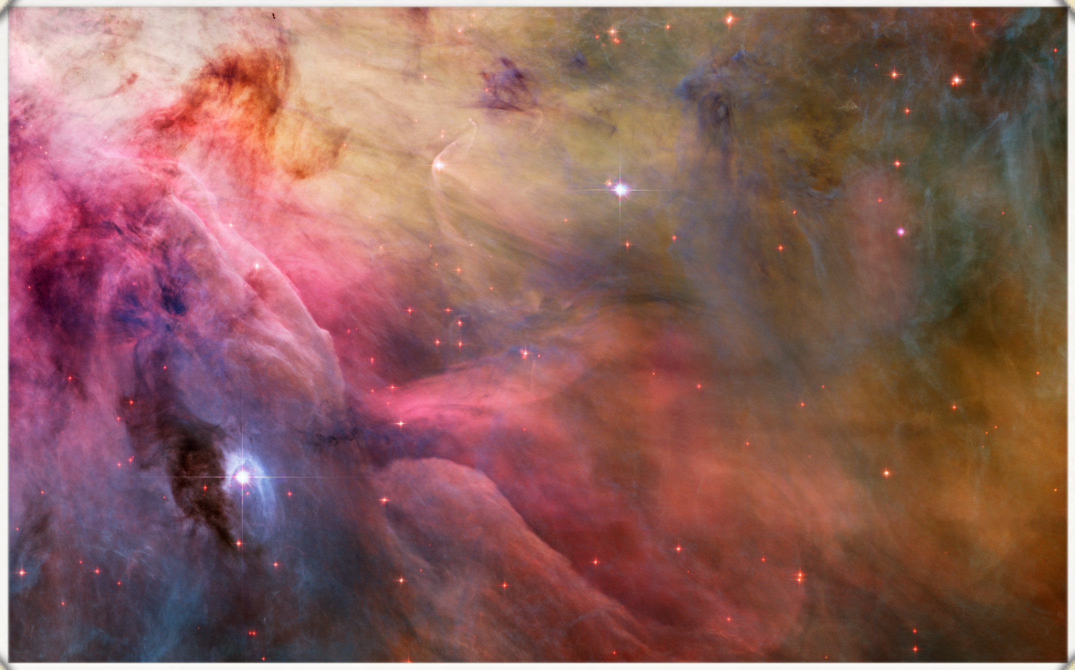
Overview

- The quality of the observations [1 $\Rightarrow$ 5].
- Using objects of intermediate quality [3 & 4] to determine abundances of objects of poor quality [5].
- The insights provided by observations of Orion [1].
- The science derived from observations of Orion [1] (and other good quality objects [2 & 3]).
- Using objects of good quality [1 & 2] to determine abundances of objects of intermediate quality [3 & 4].
- Using objects of good & intermediate quality [1 - 4] to determine abundances of objects of poor quality [5].
- Conclusions.

1st Rate Object

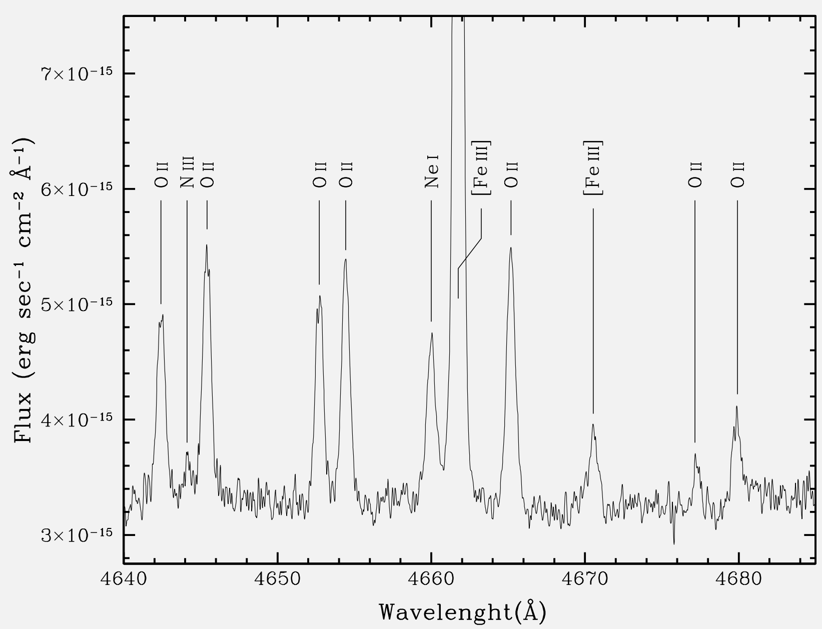
- Echelle spectroscopy shows hundreds of recombination lines with s/n>10
- Imaging allow us to see detailed structure
- The Orion Nebula +UVES/VLT

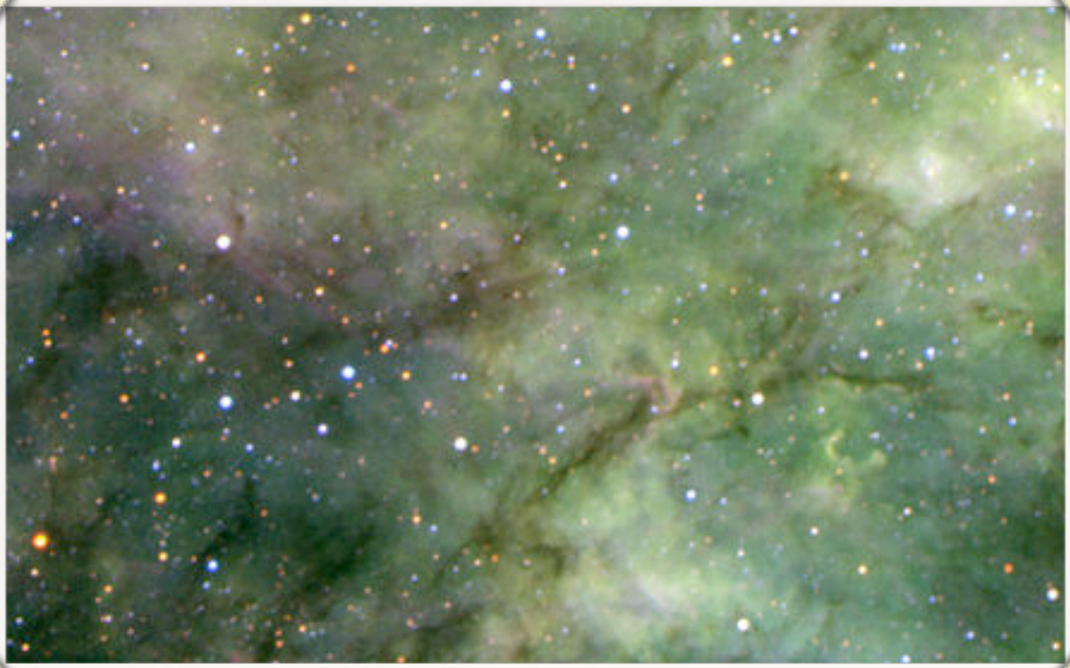




2ND Rate Objects/Observations

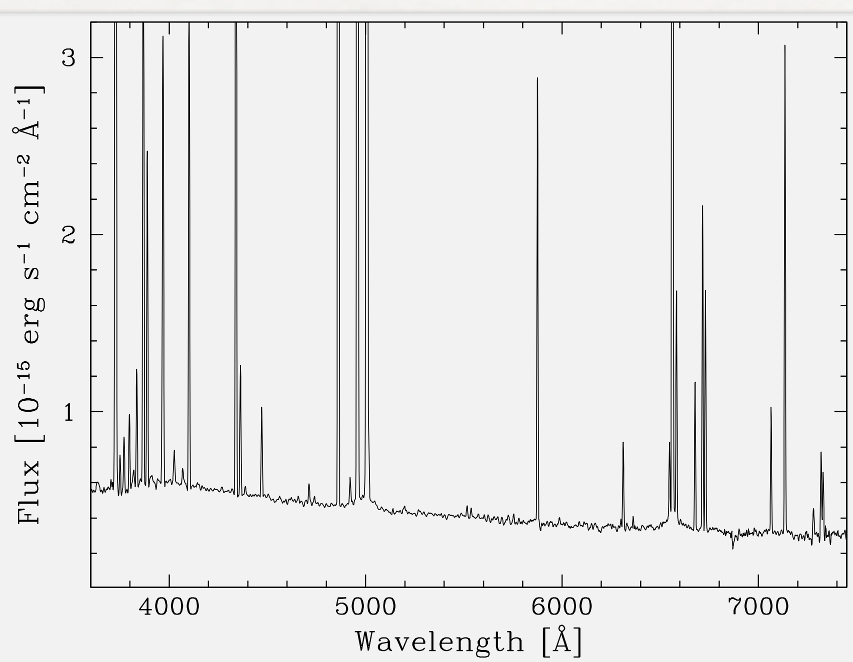
- Deep Echelle observations permit us to observe hundreds of optical emission lines.
- Abundances derived using recombination lines have uncertainties smaller than 0.05dex
- e.g. 30 Doradus





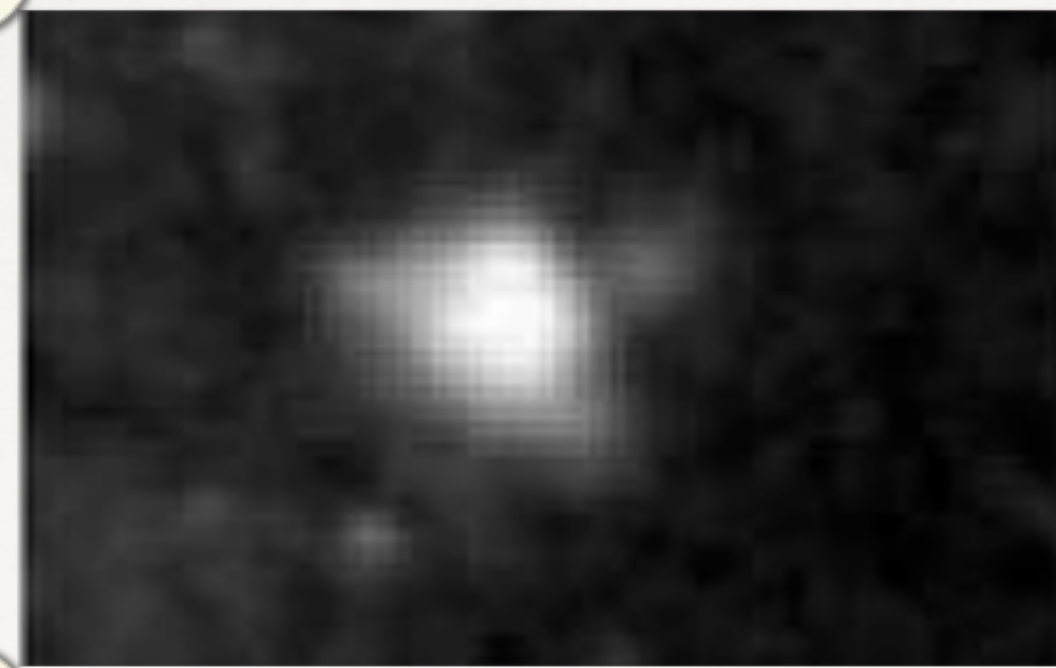
3rd Rate Objects

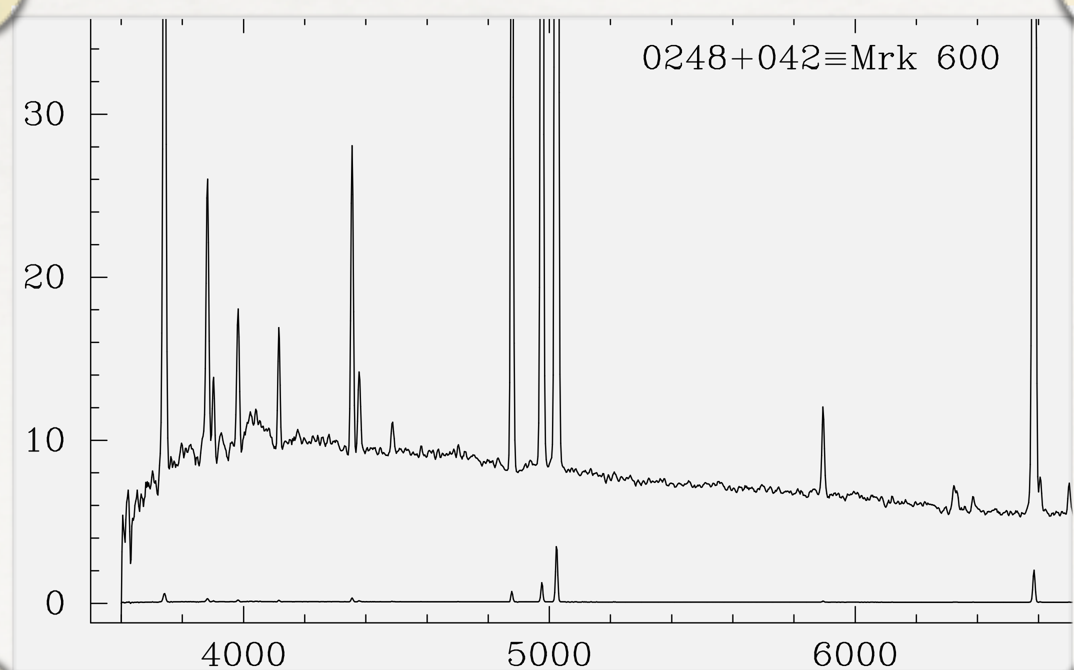
- Nebular and auroral lines are easily measured with good s/n
- Heavy element recombination lines are barely resolved; the abundances derived form them are measured with s/n~3
- e.g. NGC 6822-V

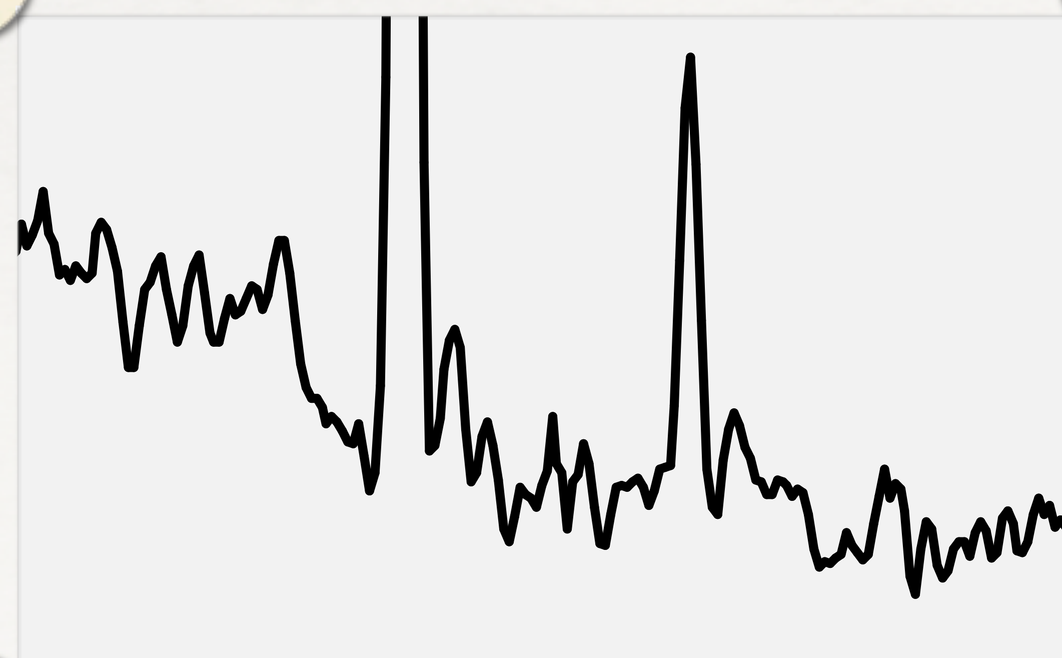


4^{TH} Rate Objects

- Nebular and auroral lines measured.
- T_e(4363/5007) determined.
    - Direct method abundances.
- No heavy element recombination lines measured.
- No (or only minimal) structure observed.

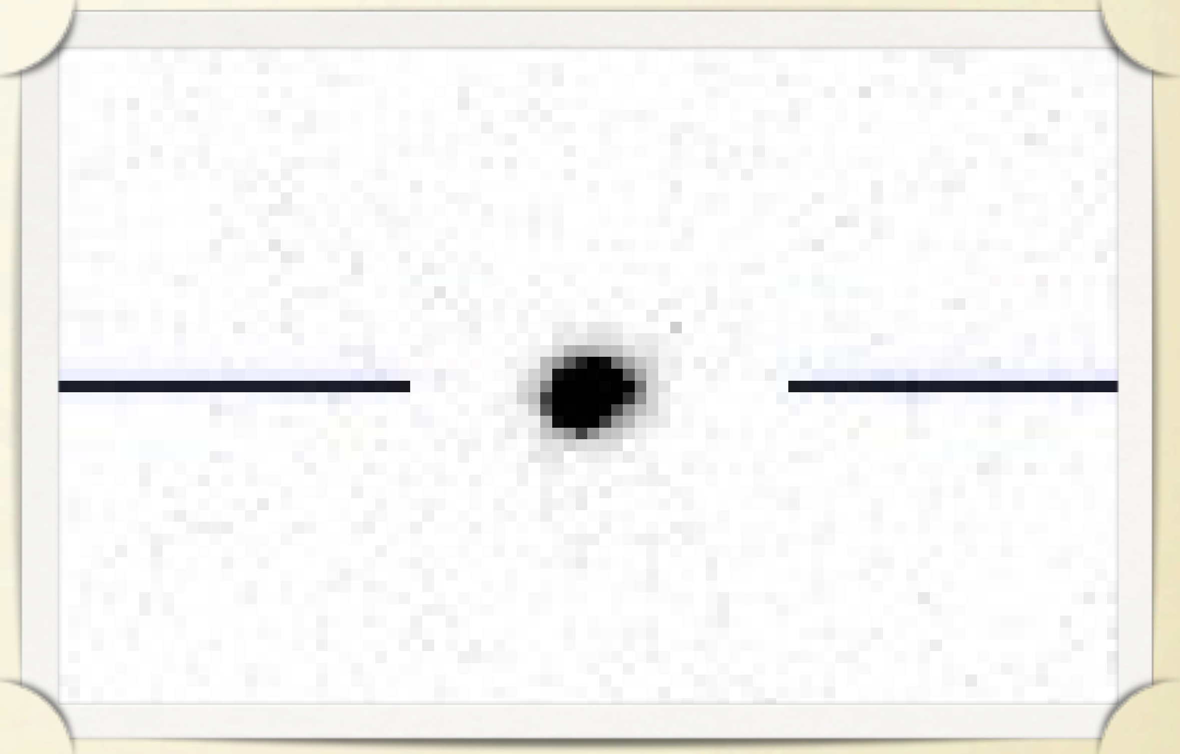


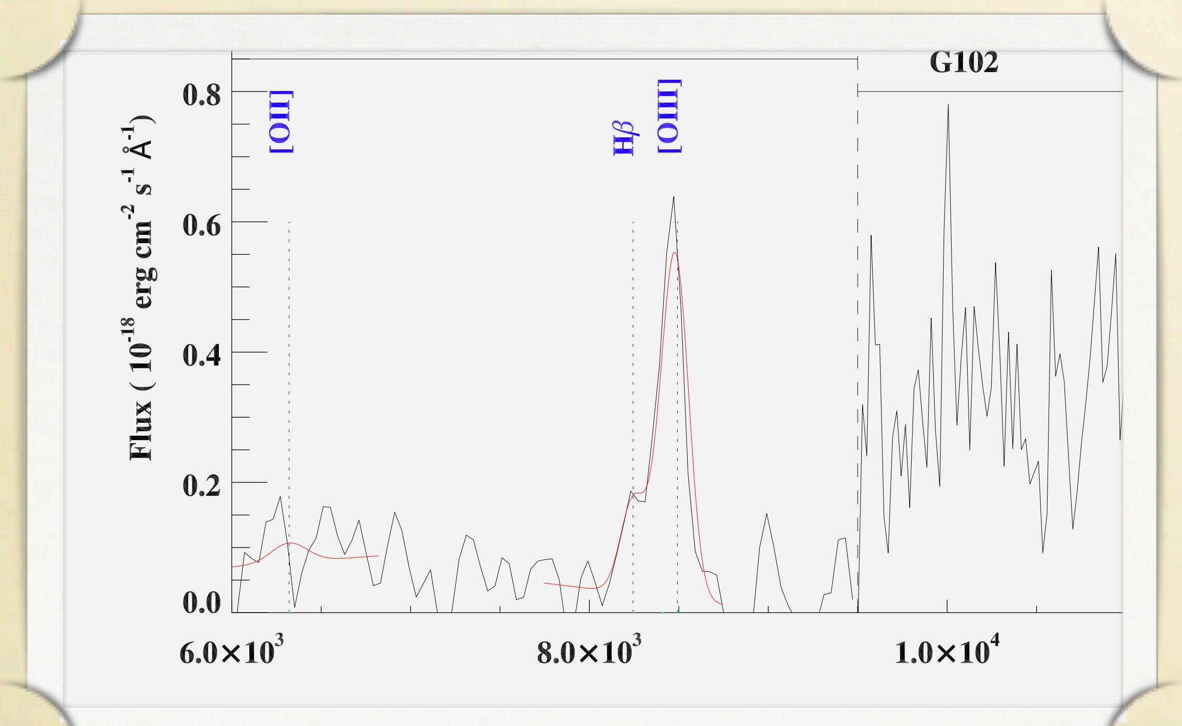


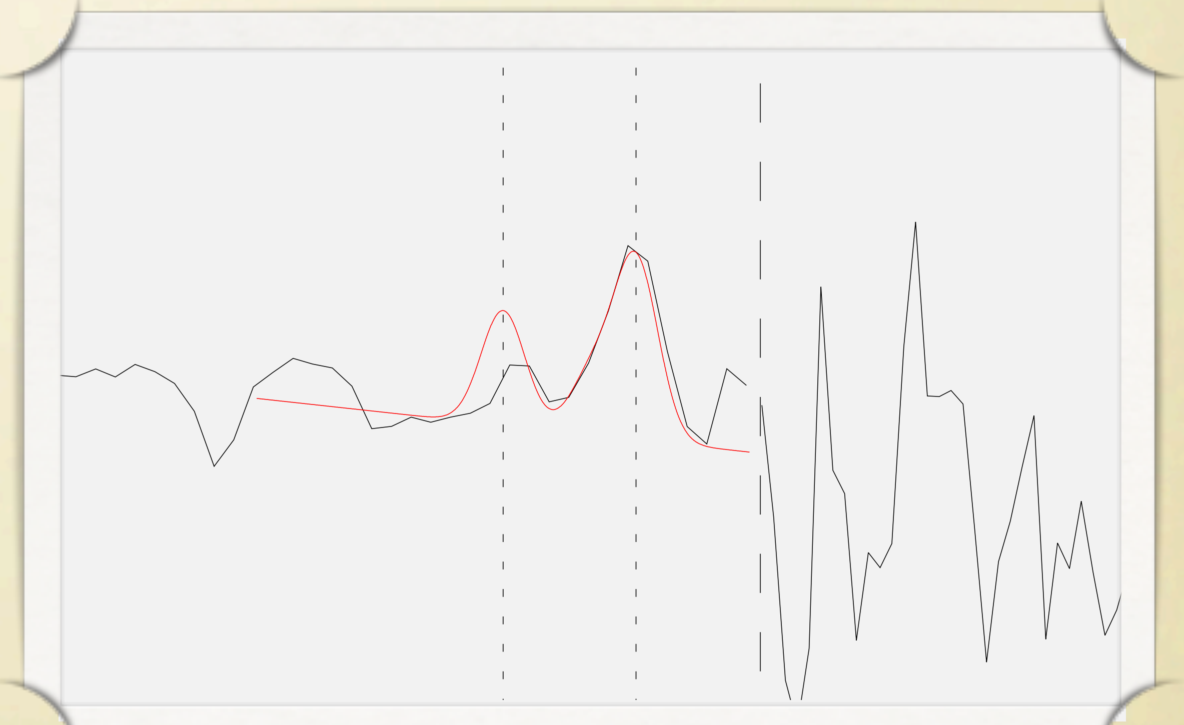


5TH RATE OBJECTS

- Only nebular lines measured.
- No structure observed.
- But..... many, many objects.
    - (many at intermediate redshifts).



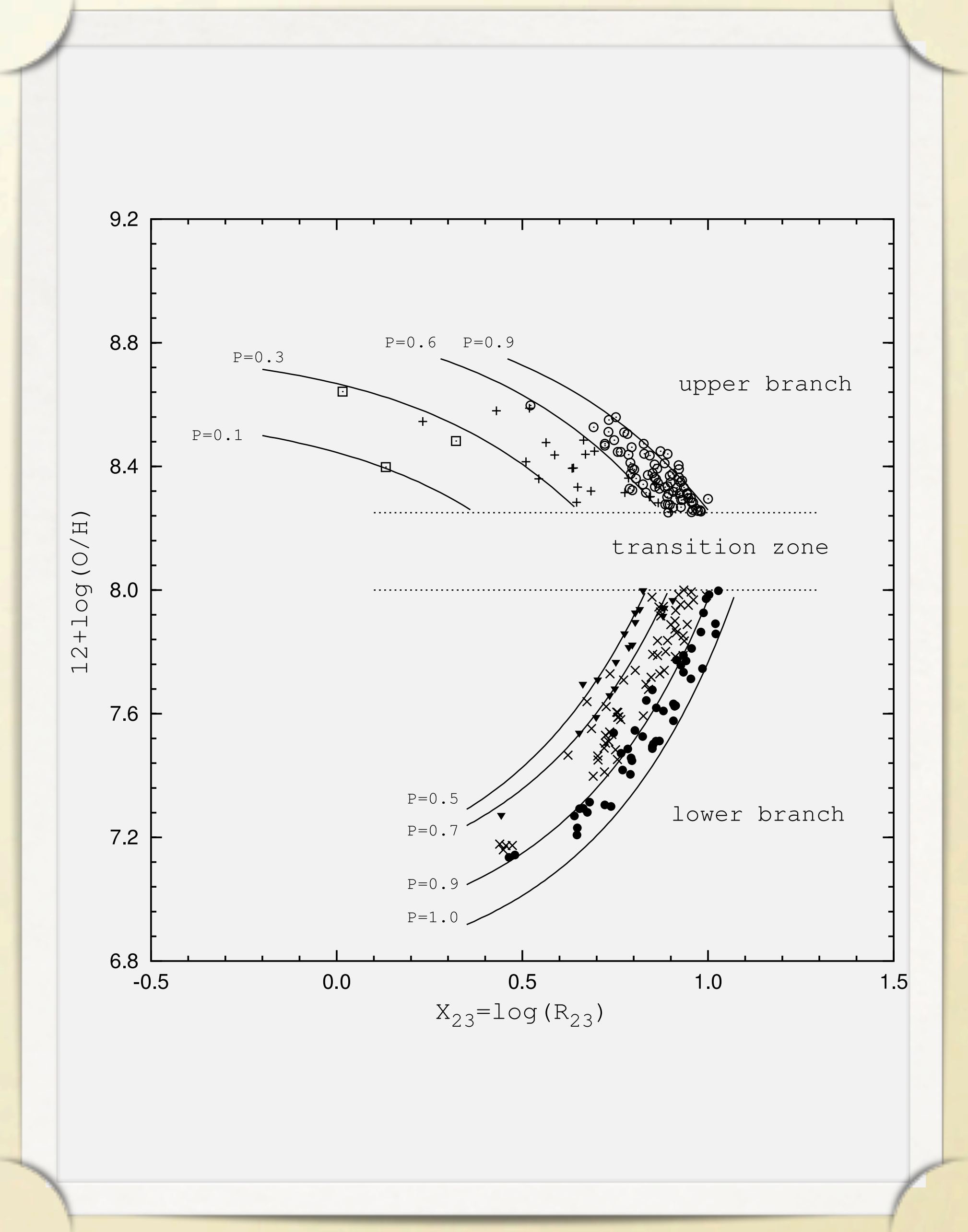


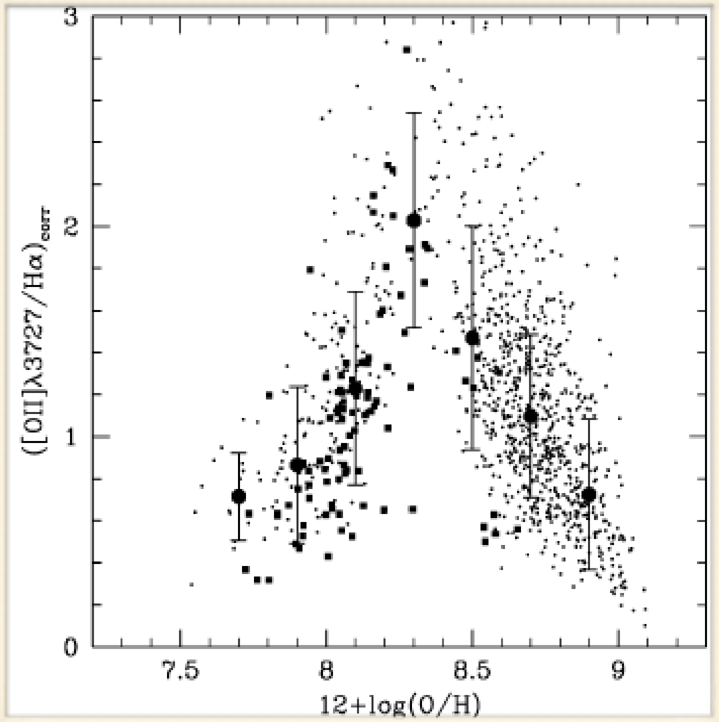


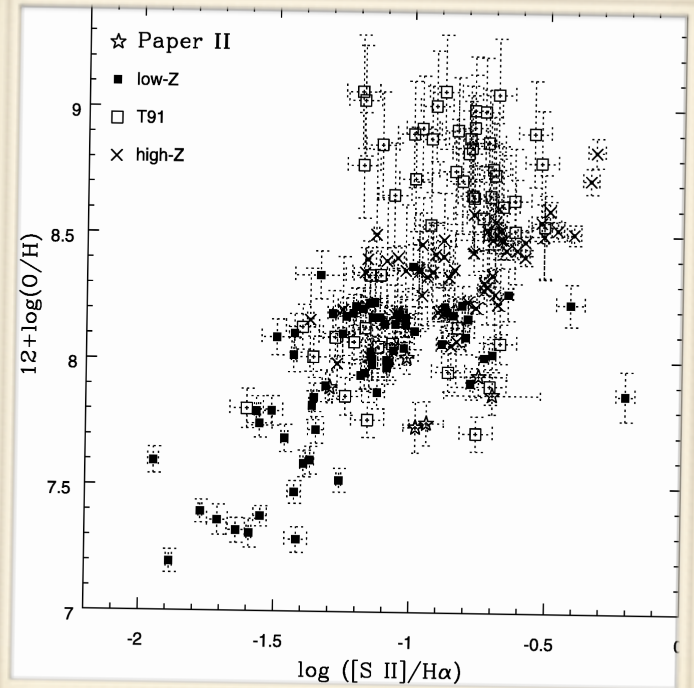
Chemical Abundances using only Nebular Lines

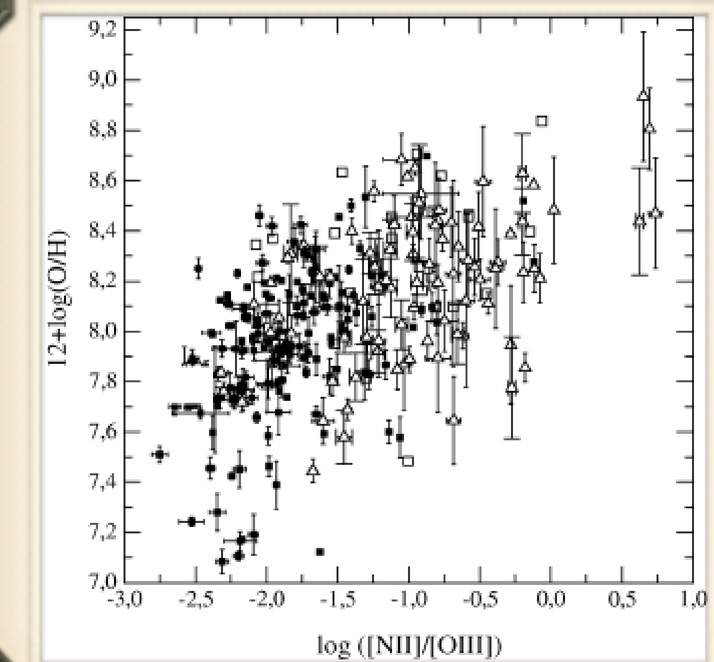
If we ignore the best objects and only work with the intermediate and poor quality objects:

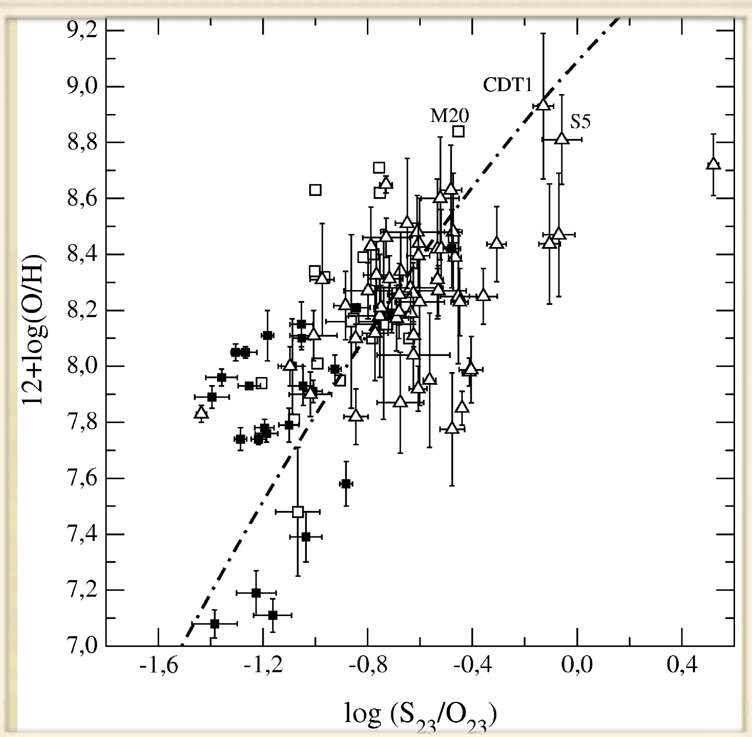
- Everybody knows nebular lines do not posses all the information necessary to determine the physical conditions (and hence the chemical abundances).
- Much work has been done to be able to determine chemical abundances using only nebular lines.
- There are about a dozen ways to do abundance determinations using different nebular lines.

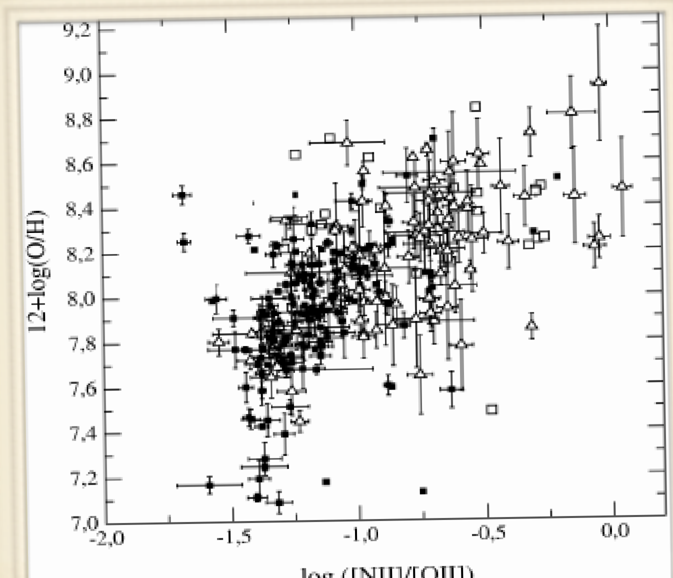


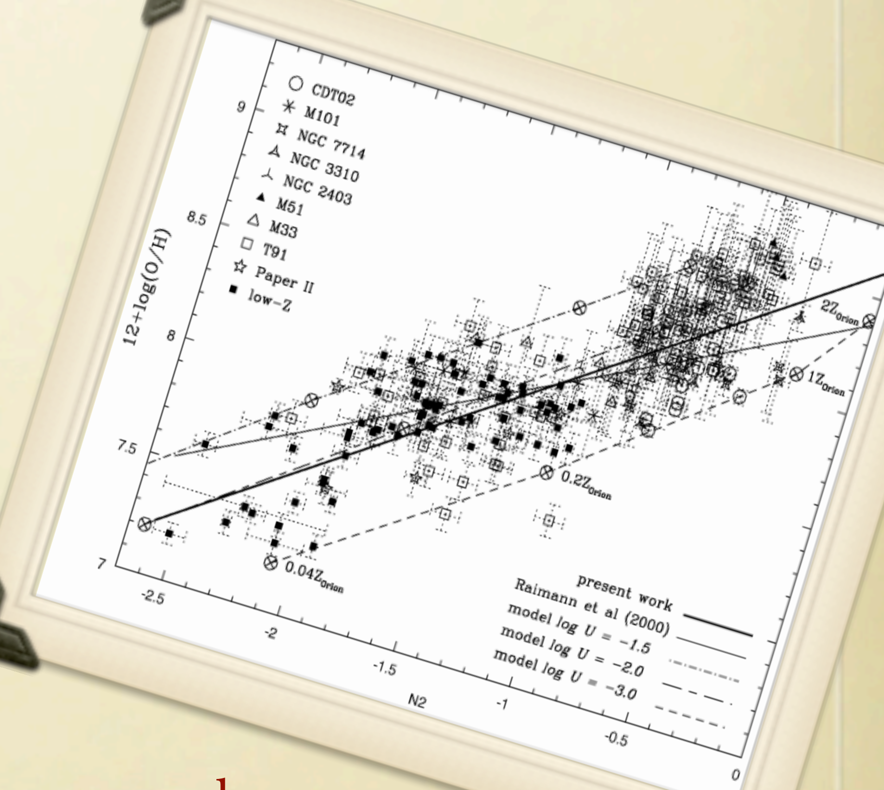












But they all assume that abundances can be derived using only auroral and nebular lines

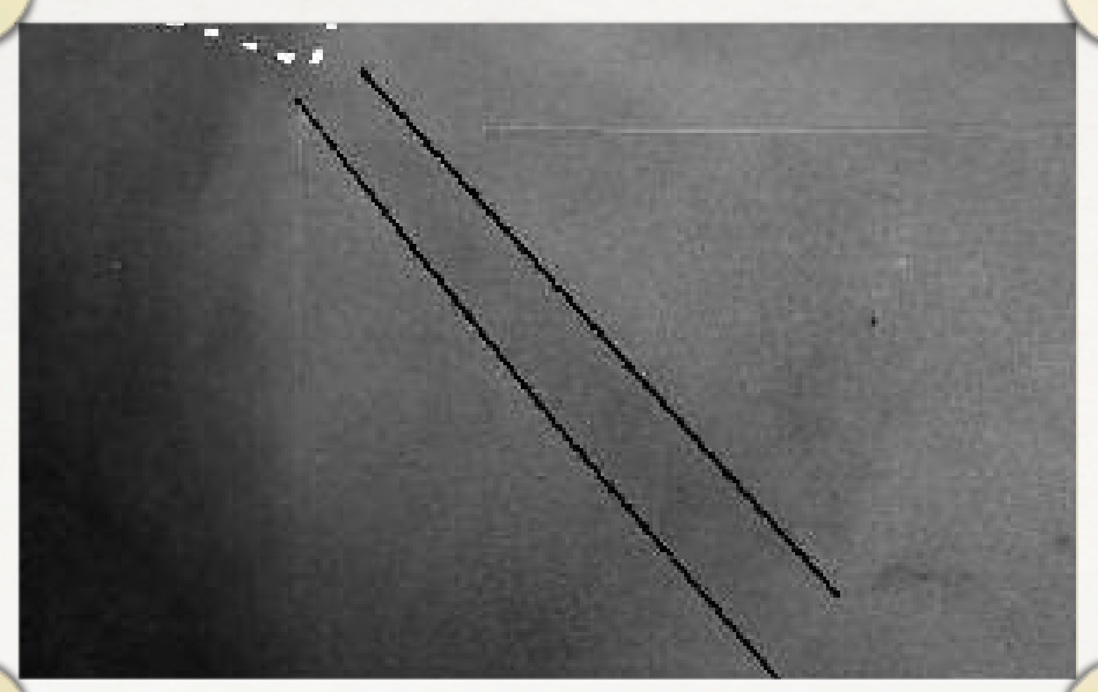
Insights Obtained from the Orion Nebula

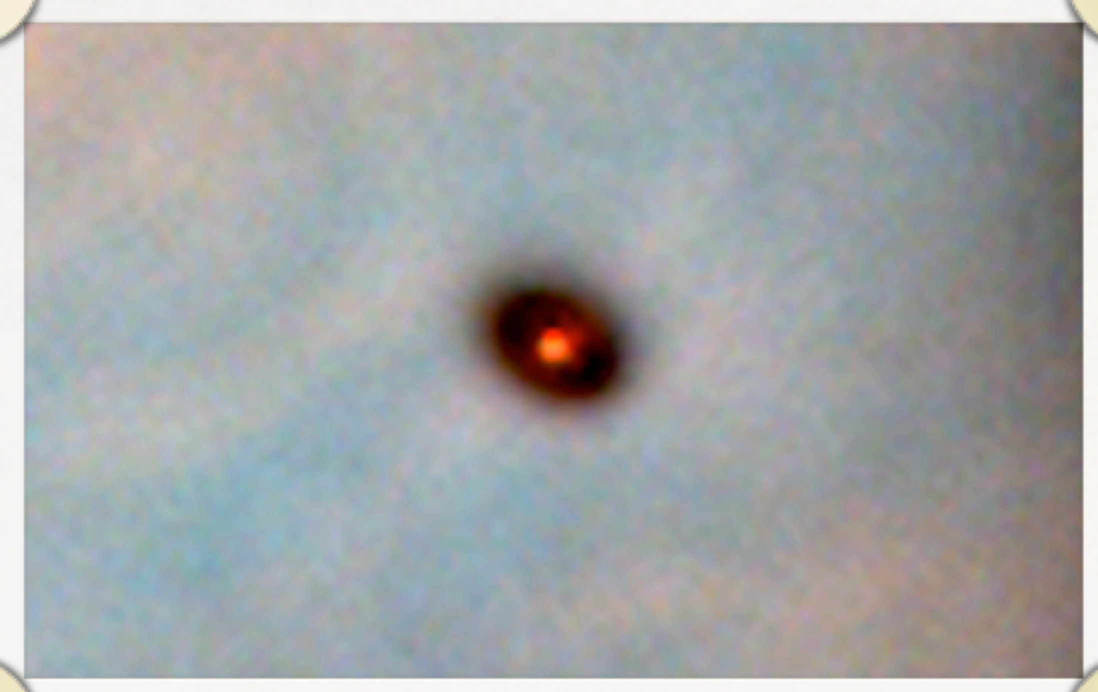
If we consider the information from the best object (Orion) what can we learn:

- The Orion Nebula is a complex object.
- There are lots of physical processes stochastically occurring in them.
- There don't seem to be important chemical inhomogeneities occurring in the Orion Nebula.
    - (Presumably most H II regions are complex, but chemically homogeneous, objects)

Stochastic Processes

- The energy inyection is inhomogeneous
    - Shockwaves
    - Proplyds
    - Shodows
    - Photoionization fronts
    - Magnetic Fields
    - etc.
- The temperature is inhomogeneous





Quantification

- It is not possible to quantify the relevance of each one of these precesses by looking at these images.
- With HST is is possible to measure temperatures across the face of the nebula ($t^2>0.008$) but this is a strict lower limit since inhomogeneities along the line of sight are averaged out (O'Dell et al. 2003).
- Spectroscopically it has been possible to perform several determinations for a small portion of Orion which give $t^2=0.022^{0}\pm0.001^{5}$ [s/n~15] (Esteban et al. 2004)
- Also, by looking at chemical composition behind shock fronts, it is possible to measure an oxygen depletion of ~0.12 dex (Mesa-Delgado et al. 2009).

Implications

- The study of The Orion Nebula shows that:
    - Physical processes are stochastic across H II regions; this implies that:
        - There are thermal inhomogeneities across H II regions.
        - There is no magic formula that permits us to reproduce the detailed temperature structure of these objects (in general; the physical conditions can not be modeled in detail).
            - It is not enough to do photoionization + (1-process) models.
    - Heavy element RLs are needed to determine abundances.
        - Or.... when no RLs are available we are forced to do statistical models to represent the thermal structure.
    - These abundances need to be corrected by depletion if one is interested in total abundances (e.g. for galactic chemical evolution studies, or to compare them with stellar abundances).

Deviation from homogeneous temperature

Once we acknowledge that objects are not homogeneous we would like to characterize t^2 for objects where only partial information is available

Area Ia $\langle t^2 \rangle = 0.087$

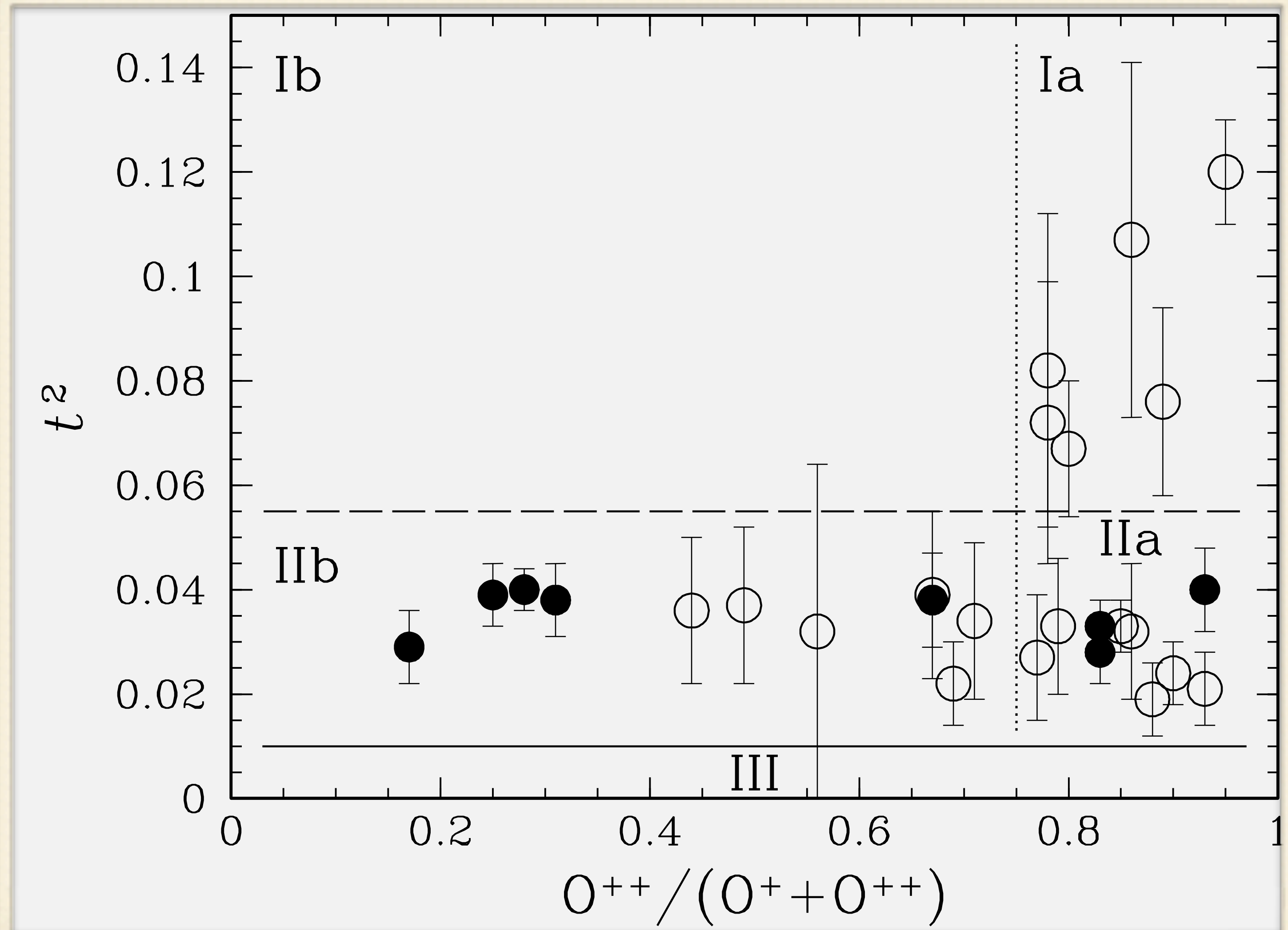
Area Ib - no objects

Area IIa $\langle t^2 \rangle = 0.029$

Area IIb $\langle t^2 \rangle = 0.035$

Area III - no objects

$\langle Ia+IIa \rangle$ $\langle t^2 \rangle = 0.051$



Peimbert, Peña-Guerrero, Peimbert 2012, ApJ, 753, 39

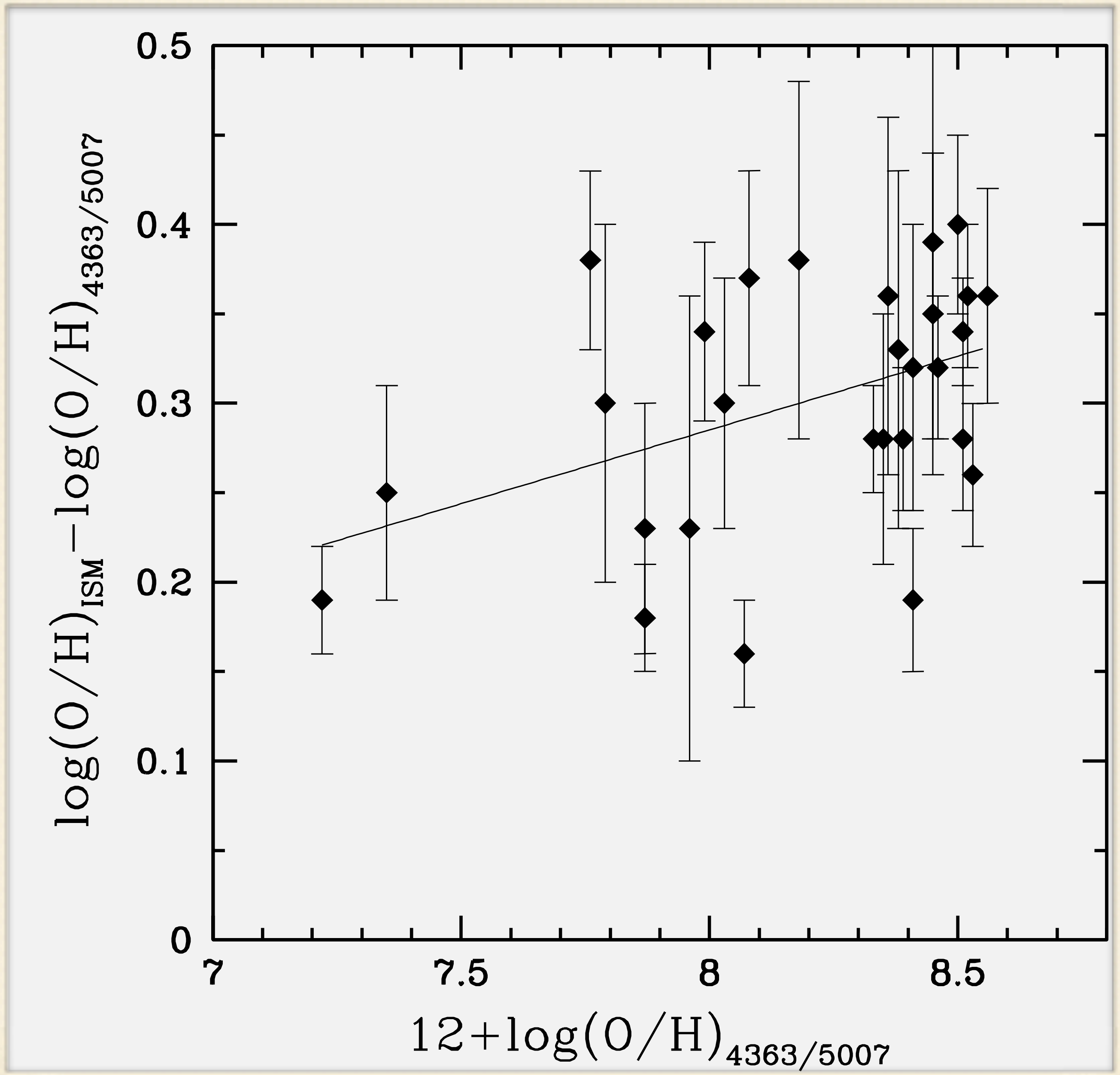
Abundance Correction I

When trying to determine the abundances for objects with only CEL information

- Accounting for the presence of inhomogeneities in the physical conditions as well as for depletion into dust grains.
  - Oxygen abundances are approximately 0.30 dex higher.
  - There is a small dependence with total abundance.

$$(\mathrm{O/H})_{\mathrm{CALM}} = 1.0825(\mathrm{O/H})_{4363/5007} - 0.375.$$

- This correction is statistical.
  - There is a dispersion of about ± 0.10 dex.
  - It depends on the global characteristics of each object as well as the specific characteristics of the observed fraction of such object.



Peña-Guerrero, Peimbert, Peimbert 2012, arXiv 1204.4446

Abundance Correction II

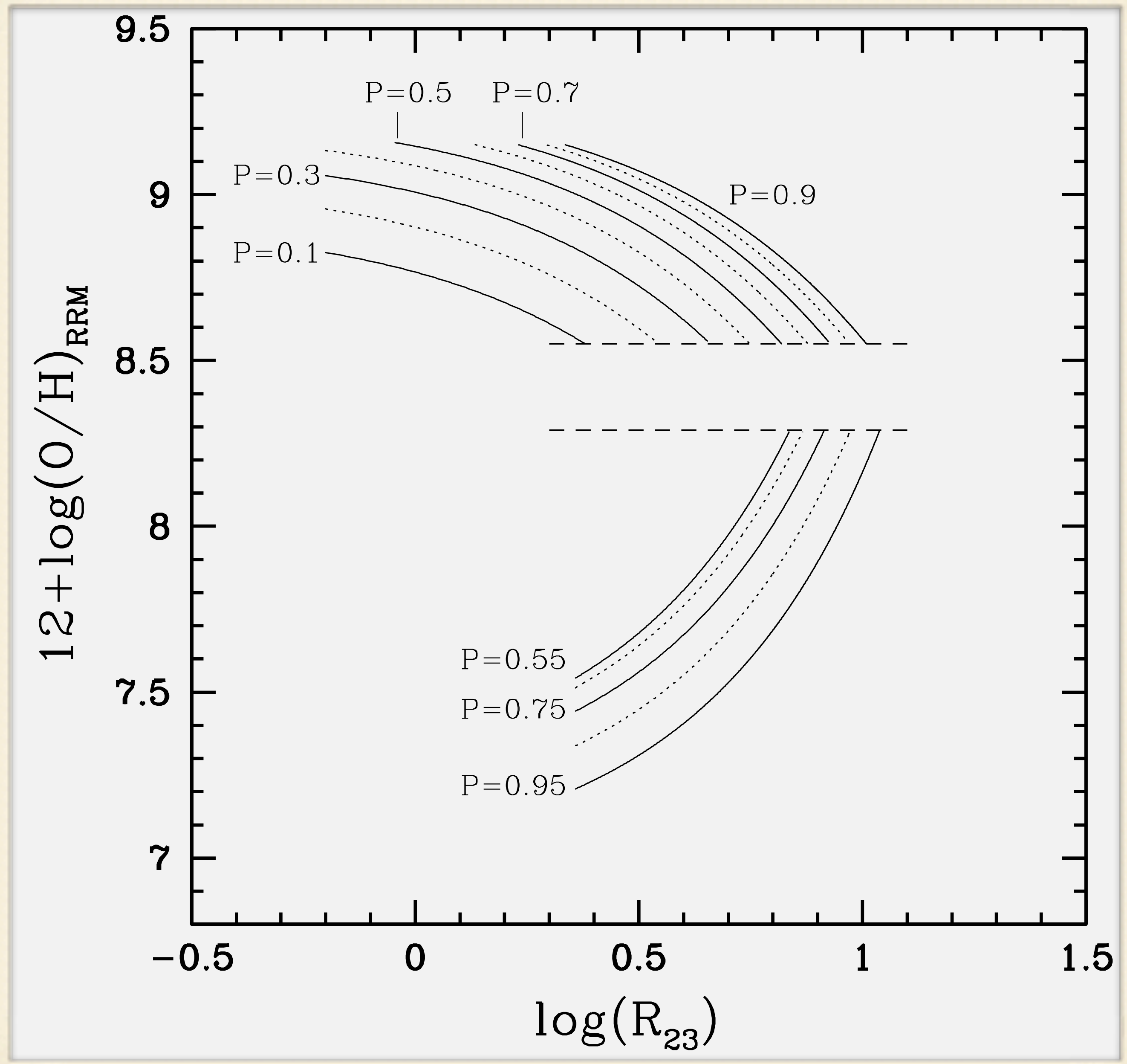
When considering objects with only nebular line information:

- We should take advantage of all the effort that has been invested in determining abundances using only nebular lines.
- The recalibration of the R_{23} method statistically including:
  - Temperature structure
  - Dust depletion
  - Ionization degree

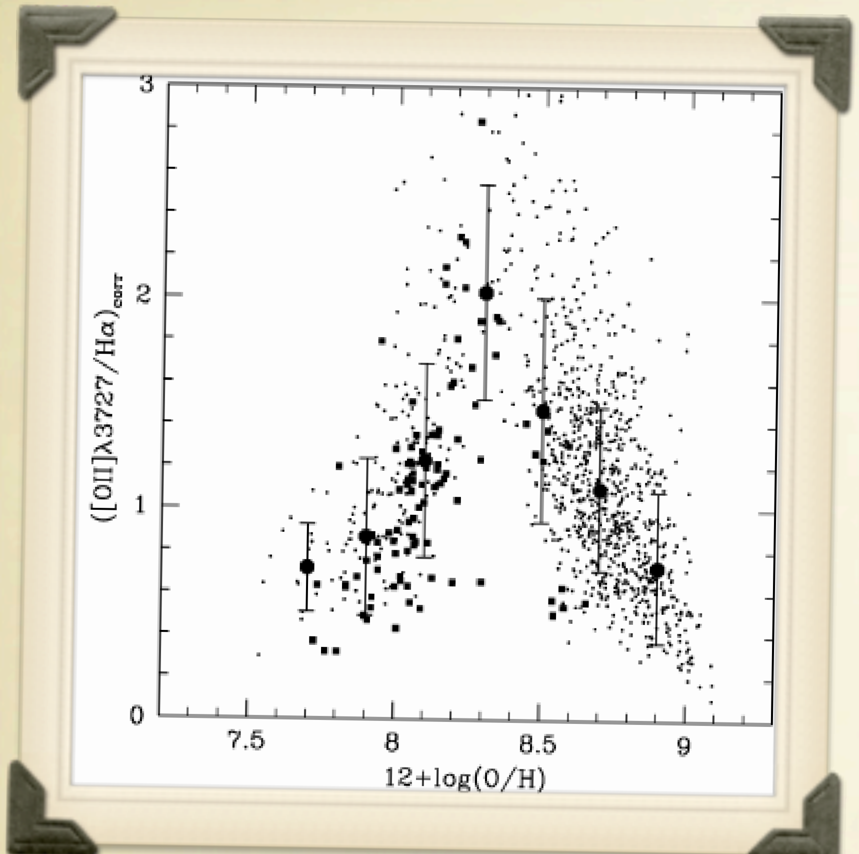
$$(O/H)_{RRM} = \frac{R_{23} + 1837 + 2146P + 850P^2}{209.5 + 201.7P + 107.2P^2 + 4.37R_{23}}$$

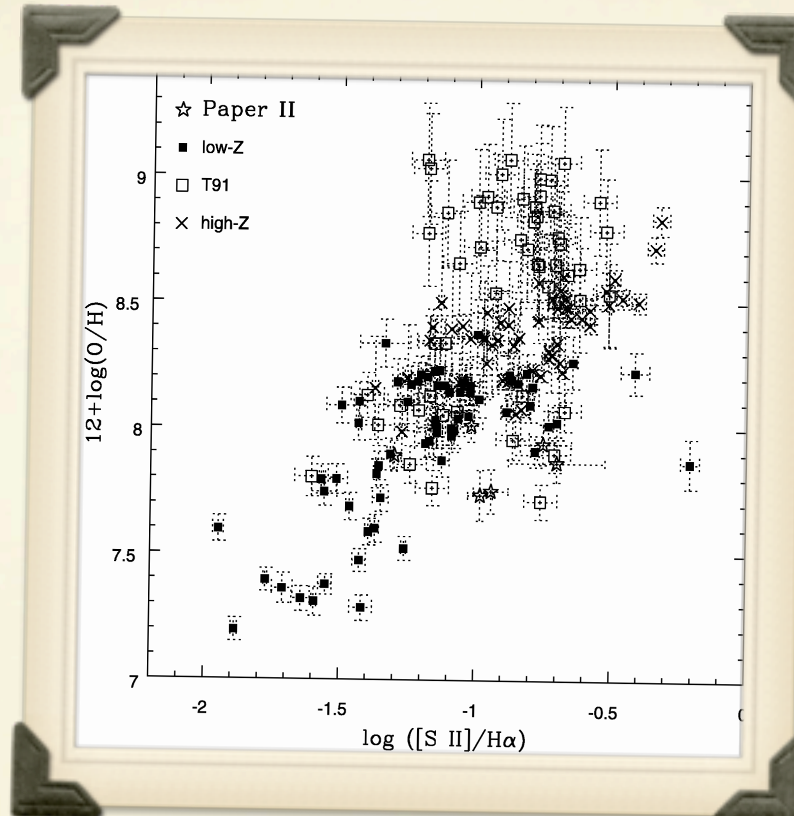
$$(O/H)_{RRM} = \frac{R_{23} + 90.73 + 94.58P - 5.26P^2}{14.81 + 5.52P + 5.81P^2 - 0.252R_{23}}$$

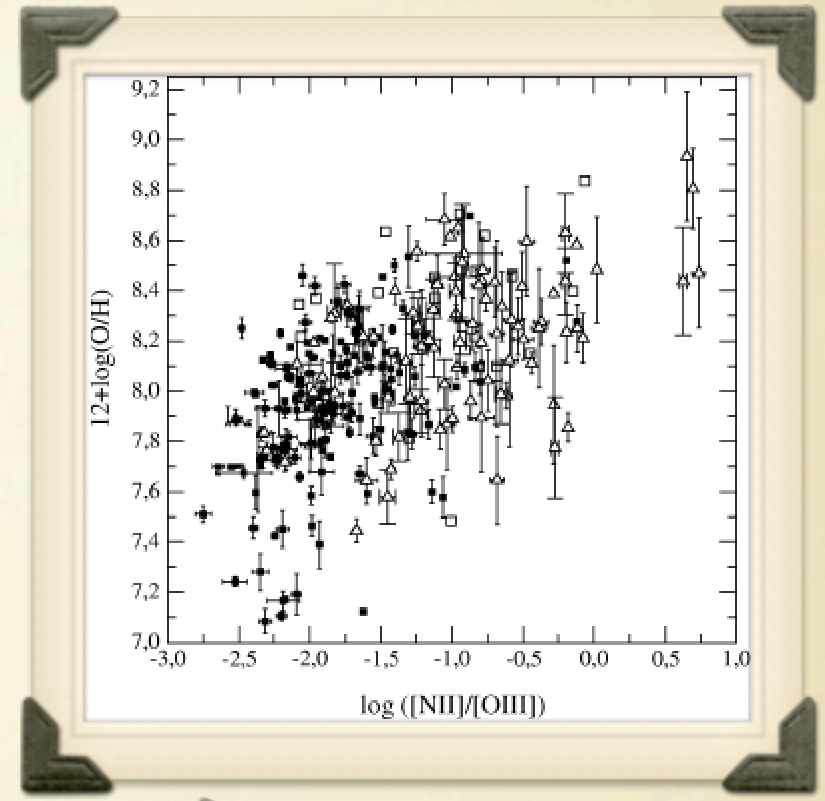
- All the other methods should also be recalibrated.

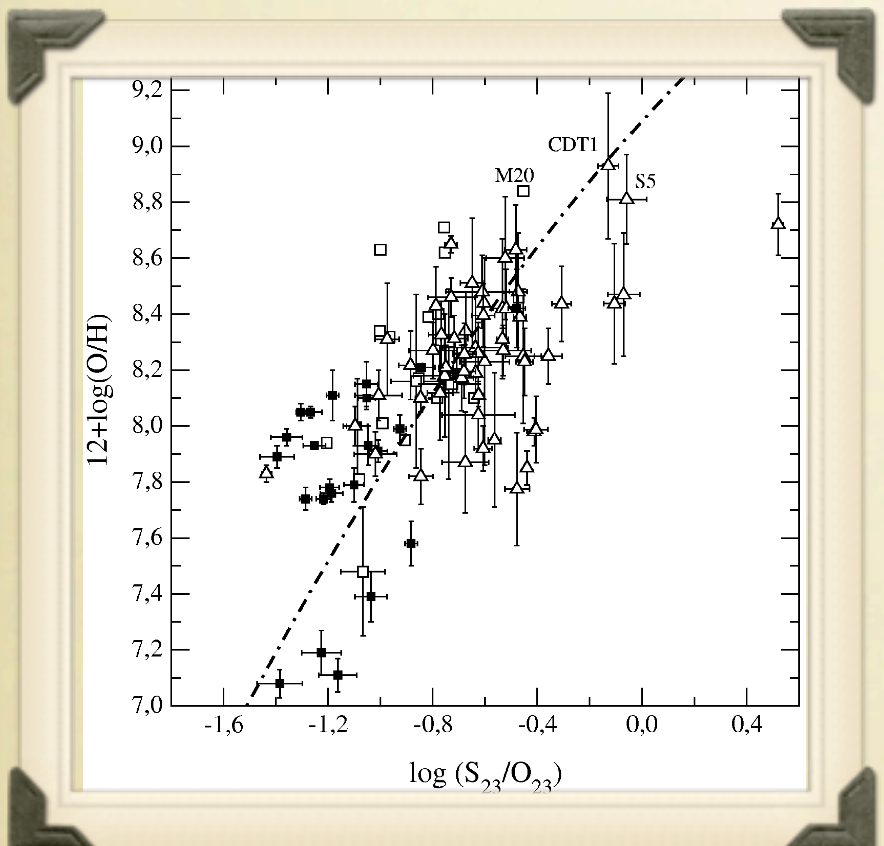


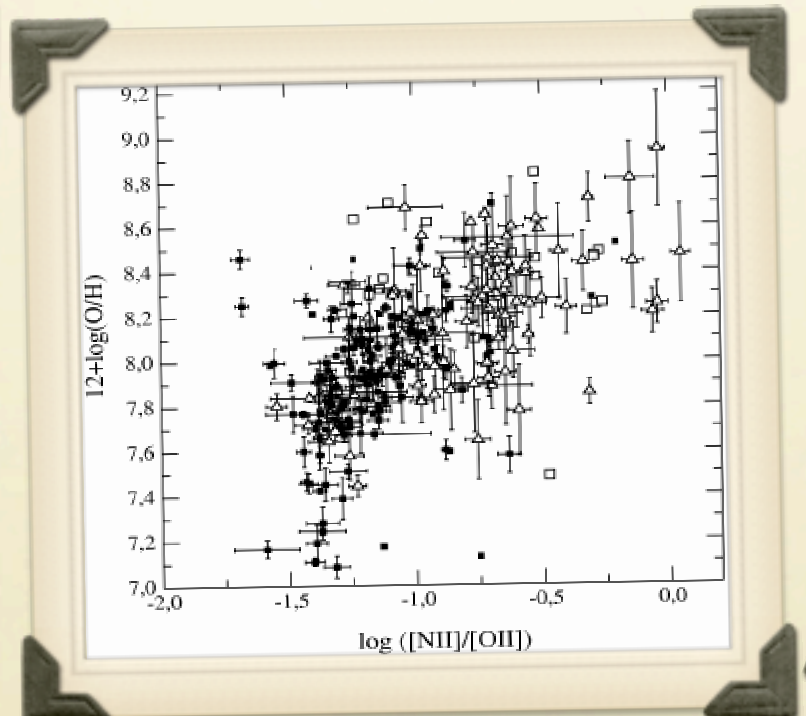
Peña-Guerrero, Peimbert, Peimbert 2012, arXiv 1204.4446

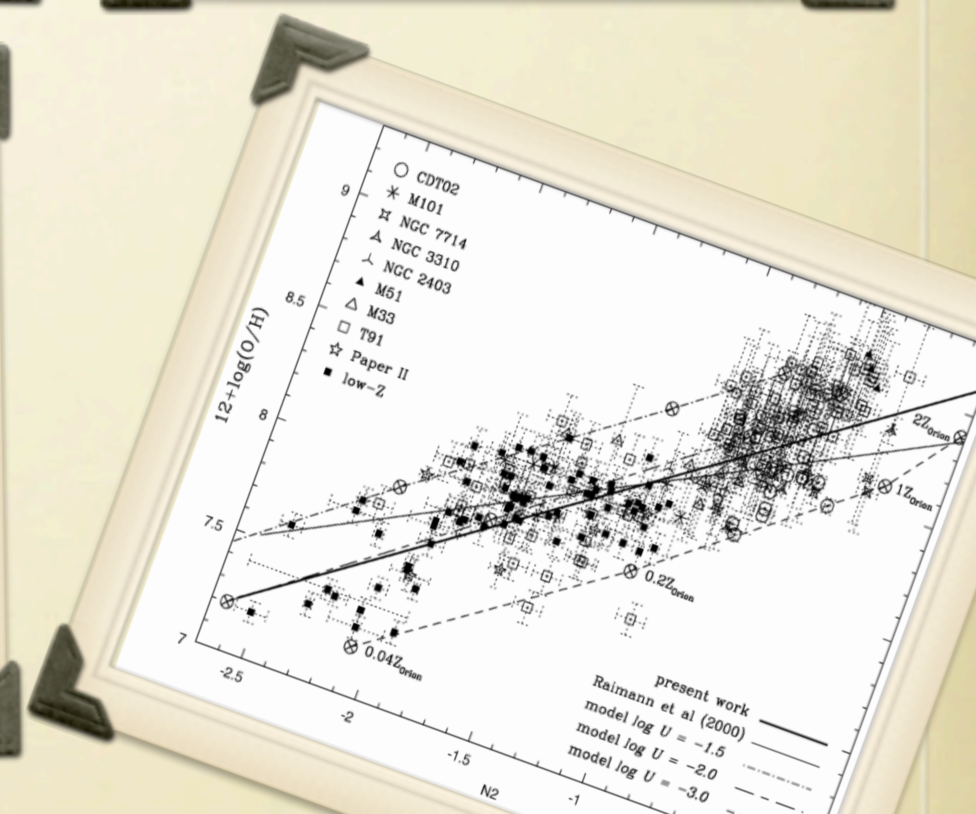












There is no point in trying to measure the horizontal position for an object when there is an important bias in the vertical calibration.

Conclusions 1/2

- We all know that nebular lines do not posses all the information required to derive chemical abundances.
- The Orion Nebula shows (beyond any doubt) that to include the information provided by auroral lines is still not enough.
    - It shows that the temperature is not homogeneous.
    - It shows there is depletion of Oxygen into dust grains.
        - Depletions of other elements are also present.
- The Orion Nebula shows many physical processes that occur in H II regions that will produce biases in determining the average thermal abundance.
    - Shockwaves, shadowed regions, moving ionization front, stellar winds, strong density variations, etc.

Conclusions 2/2

- Detailed tailor made models are better than simple models with statistical corrections.
- We are very far from producing a detailed model capable of reproducing all the physical processes as observed in the Orion Nebula.
    - We are even farther away of reproducing all the physical processes (not observed) in other H II regions.
- Abundances should be determined from RLs only (and corrected for depletion).
    - Or... when only CELs are available, it is necessary to use a correction that has been calibrated using RLs.
        - At this moment only corrections for oxygen abundances have been published, but it is straightforward to do calibrations for other elements.
- Abundances are a factor of ~2 higher than those determined using the direct method (the specific factor is different for each element).

Thank You