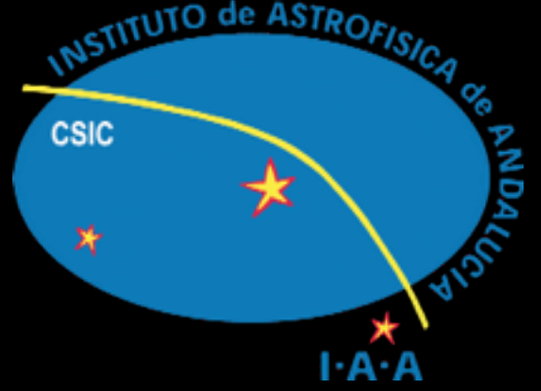
THE GALACTIC RADIAL DISTRIBUTION OF THE IONIZING OF RADIATION IN HII REGIONS

E. Pérez-Montero, J.M. Vílchez, R. García-Benito

Instituto de Astrofísica de Andalucía - CSIC





Reunión científica Estallidos. Madrid. June 2018

EFFECTS OF MASSIVE STARS ON THE ISM

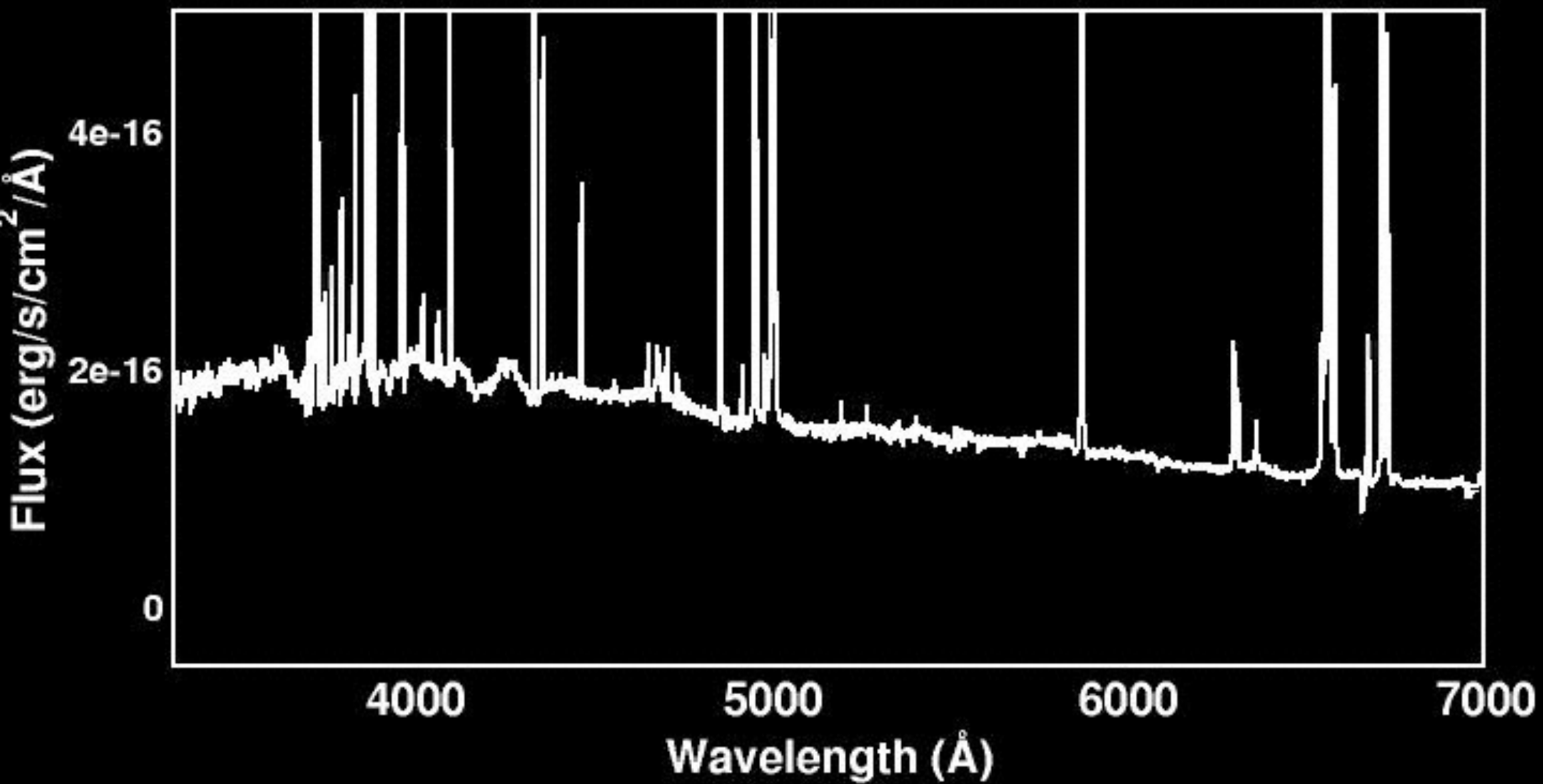
1) Contribute with mechanical energy to the gas
2) Pollute the surroundings with new fresh metals
3) Emit UV energetic radiation which ionizes and excitates the atoms



HST image of R136 cluster @ 30Dorados

EMISSION LINE-LIKE SPECTRUM

Properties of the ionizing clusters can only be derived from the emission-line intensities



Optical spectrum of the Blue Compact Dwarf Galaxy SDSS J003218.59+150014.1 taken in the WHT (Hägele et al., 2006)

FUNCTIONAL PARAMETERS

Metallicity (Z)

(i.e. density of elements heavier than H and He)

Ionization parameter (U)

(i.e. ratio between ionizing photons and particles)

Effective equivalent temperature (T*)

(i.e. the shape of the ionizing SED)

FUNCTIONAL PARAMETERS

$$\frac{n(X^{i+1})}{n(X^{i})} = \frac{uc \cdot \langle \sigma \rangle}{\beta\,(X^{i})} \cdot \frac{Q(X^{i})}{Q(H)}$$

FUNCTIONAL PARAMETERS

ionic abundances

ionization parameter

speed of light

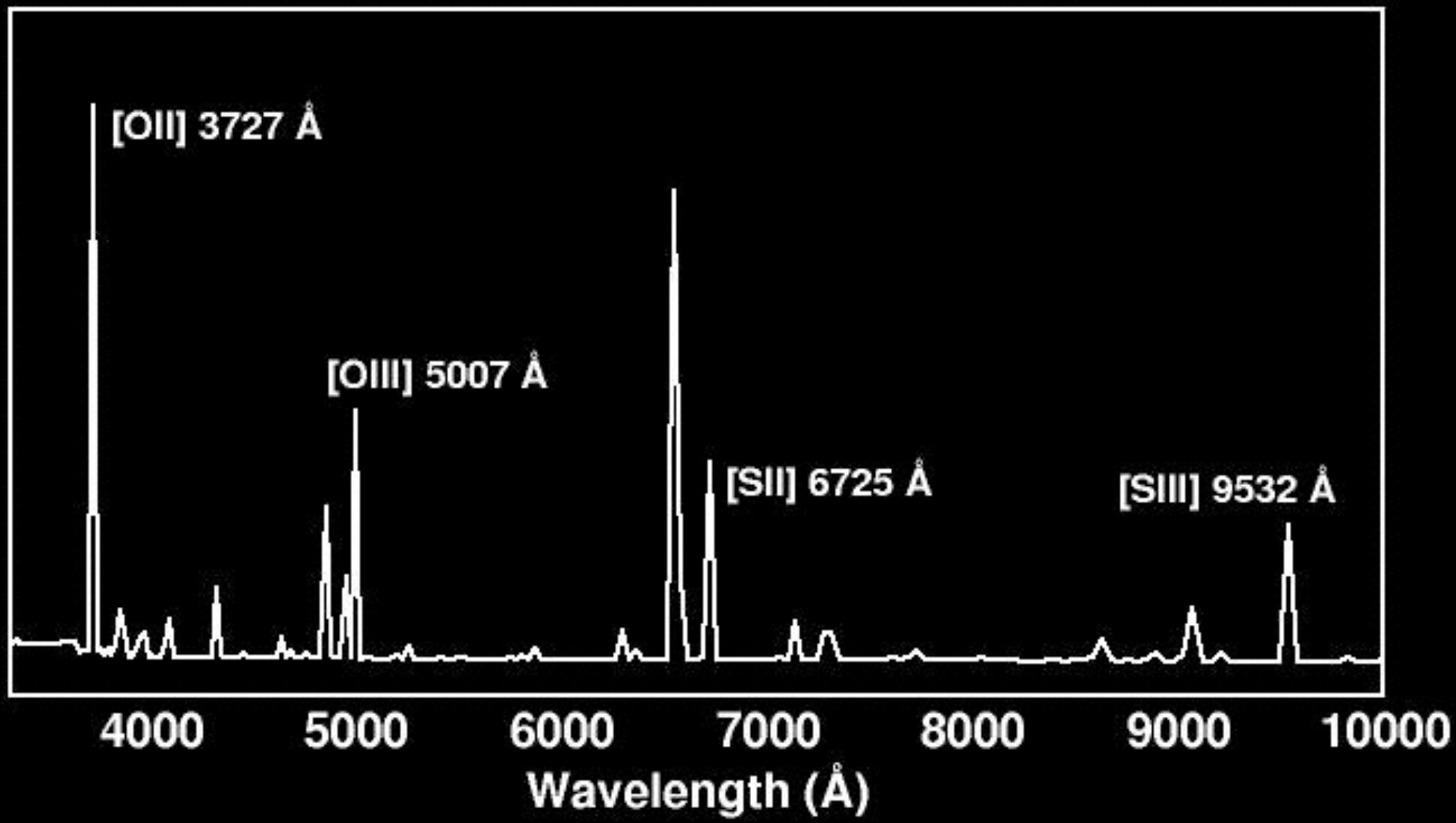
cross section

$$\frac{n(X^{i+1})}{n(X^{i})} = \frac{uc \cdot \langle \sigma \rangle}{\beta\,(X^{i})} \cdot \frac{Q(X^{i})}{Q(H)}$$

recombination coef.

ionizing photons

THE "SOFTNESS" PARAMETER

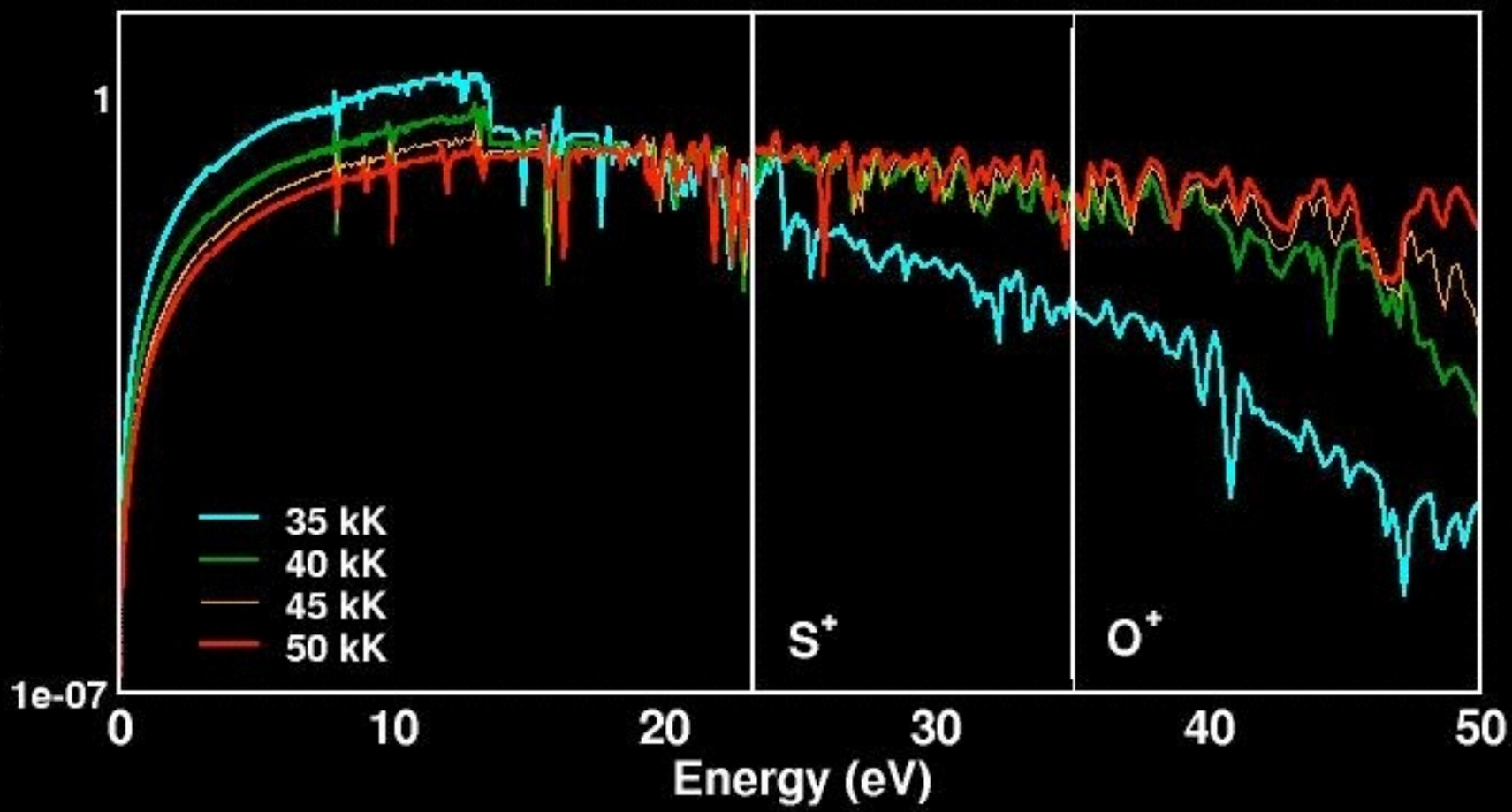


$$\eta = \frac{O^+/O^{2+}}{S^+/S^{2+}} = \frac{[OII]/[OIII]}{[SII]/[SIII]} + o(Z) \propto \frac{Q(O^+)}{Q(S^+)}$$

Vílchez & Pagel (1988)

THE "SOFTNESS" PARAMETER

WM-Basic, log(g)=4.0, [Z] = -0.3



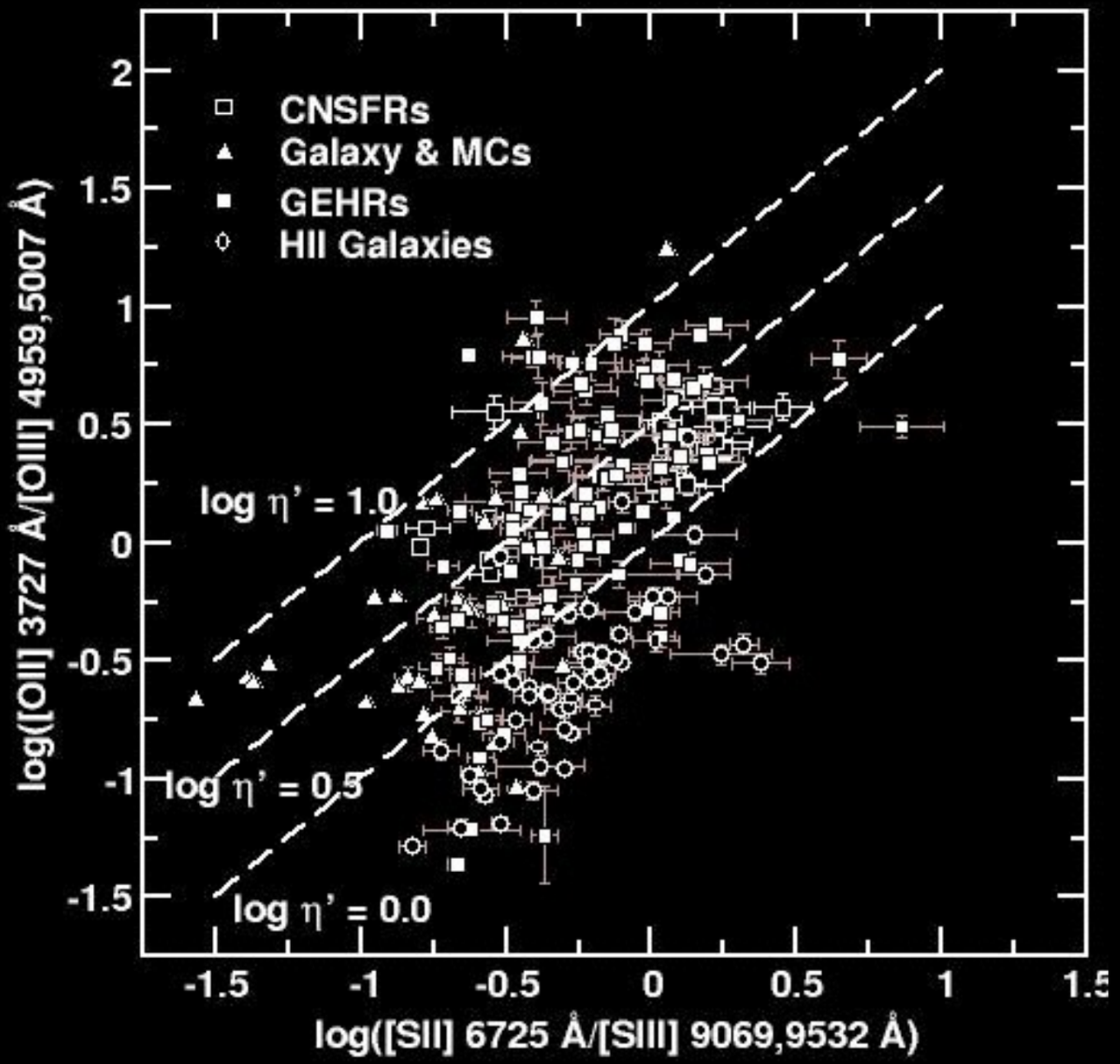
$$\eta = \frac{O^+/O^{2+}}{S^+/S^{2+}} = \frac{[OII]/[OIII]}{[SII]/[SIII]} + o(Z) \propto \frac{Q(O^+)}{Q(S^+)}$$

Vílchez & Pagel (1988)

THE "SOFTNESS" PARAMETER

Higher values of η' lead to lower values of T*

CNSFRs and HII galaxies have the largest relative values of T* in YMSCs



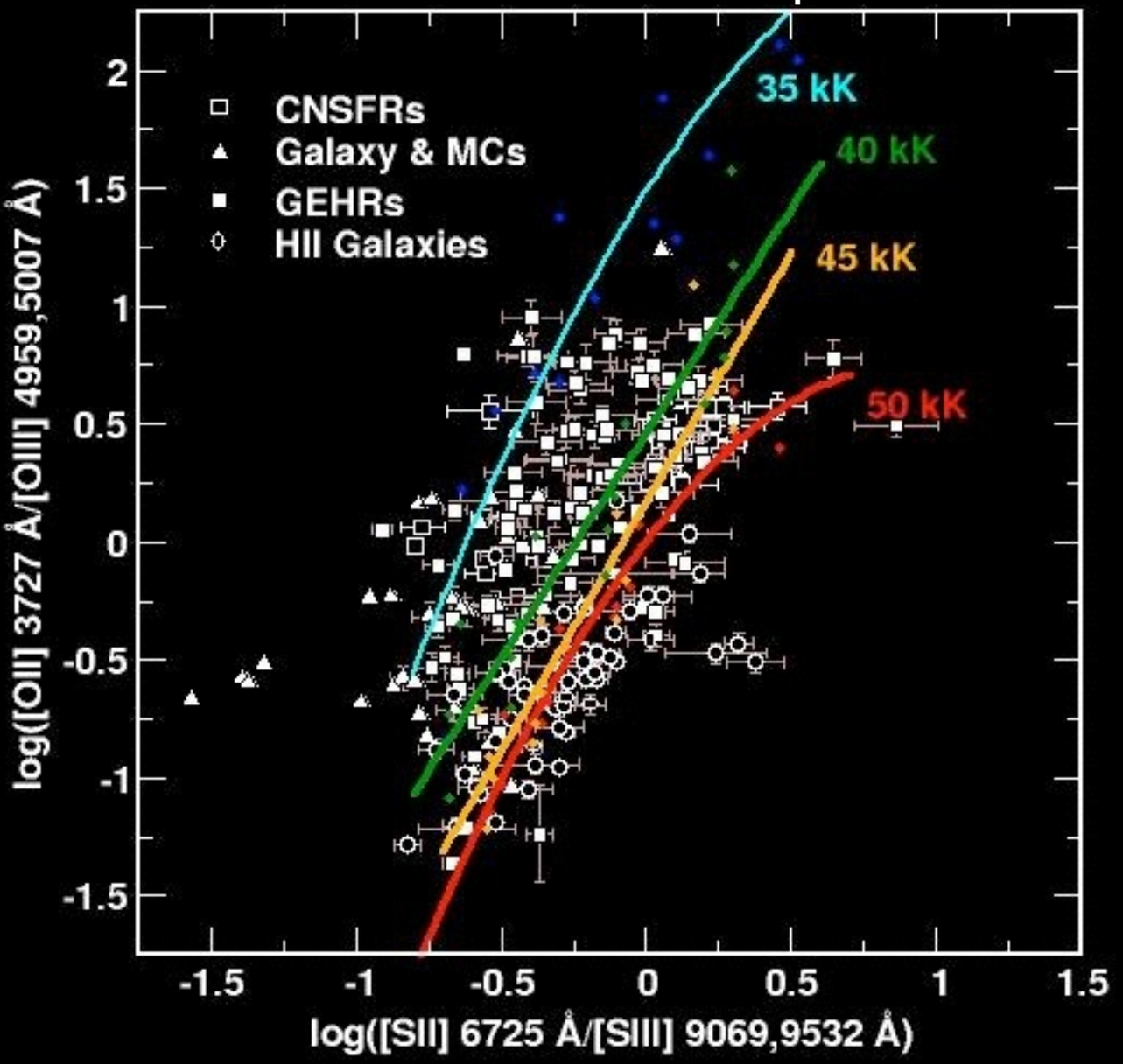
Pérez-Montero & Vílchez (2009)

THE "SOFTNESS" PARAMETER

Photoionization models confirm the relation between η' and the effective temperature of the ionizing source ....

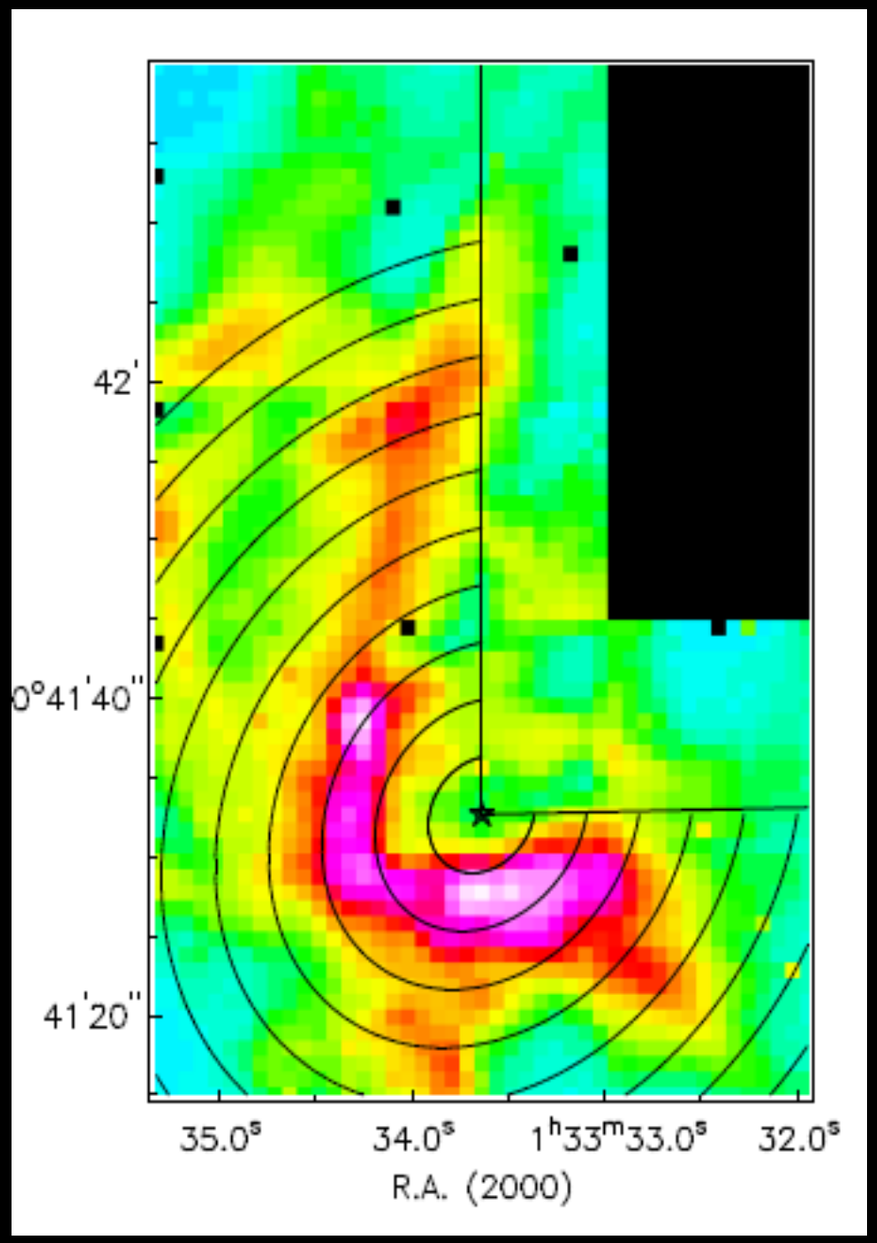
but the absolute calibration scale depends on the model stellar atmosphere (e.g. Simón-Díaz & Stasinska, 2008)

WMBasic model stellar atmosph.



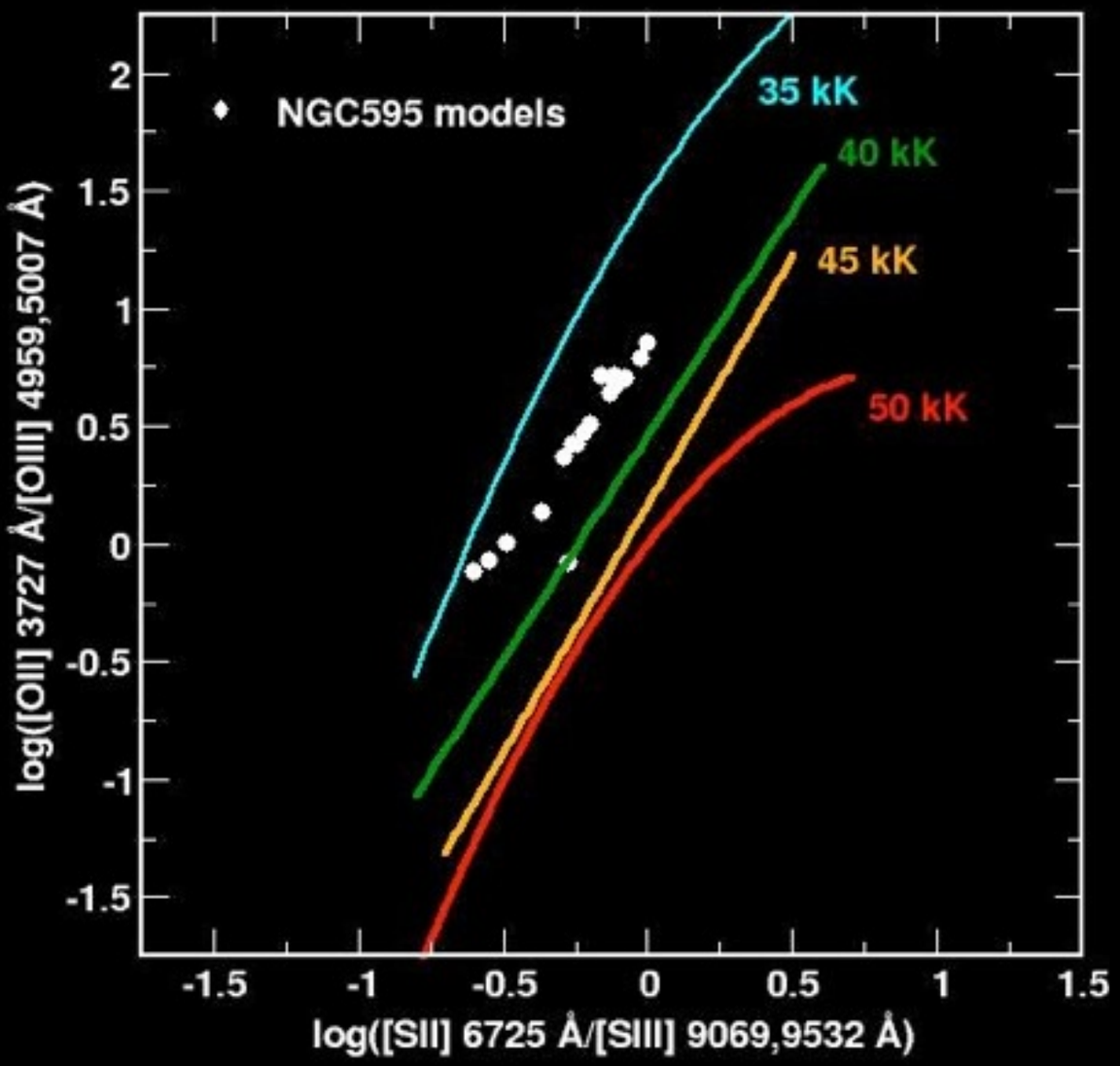
Pérez-Montero & Vílchez (2009)

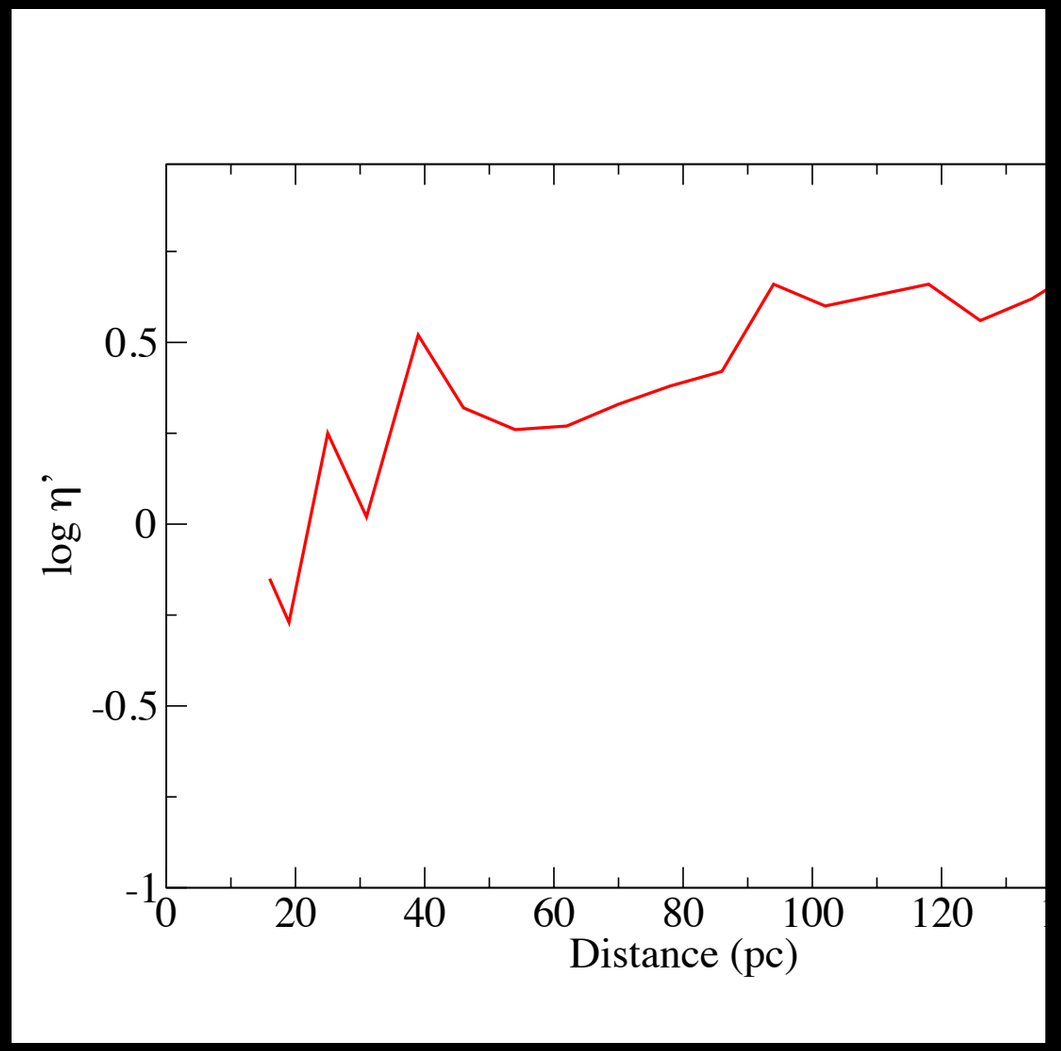
CAUTIONS WITH THE "SOFTNESS" PARAMETER



PMAS IFU optical observations of NGC595 (Relaño et al., 2010) and Spitzer images have been modelized to reproduce its optical and IR structure (Pérez-Montero et al., 2011)

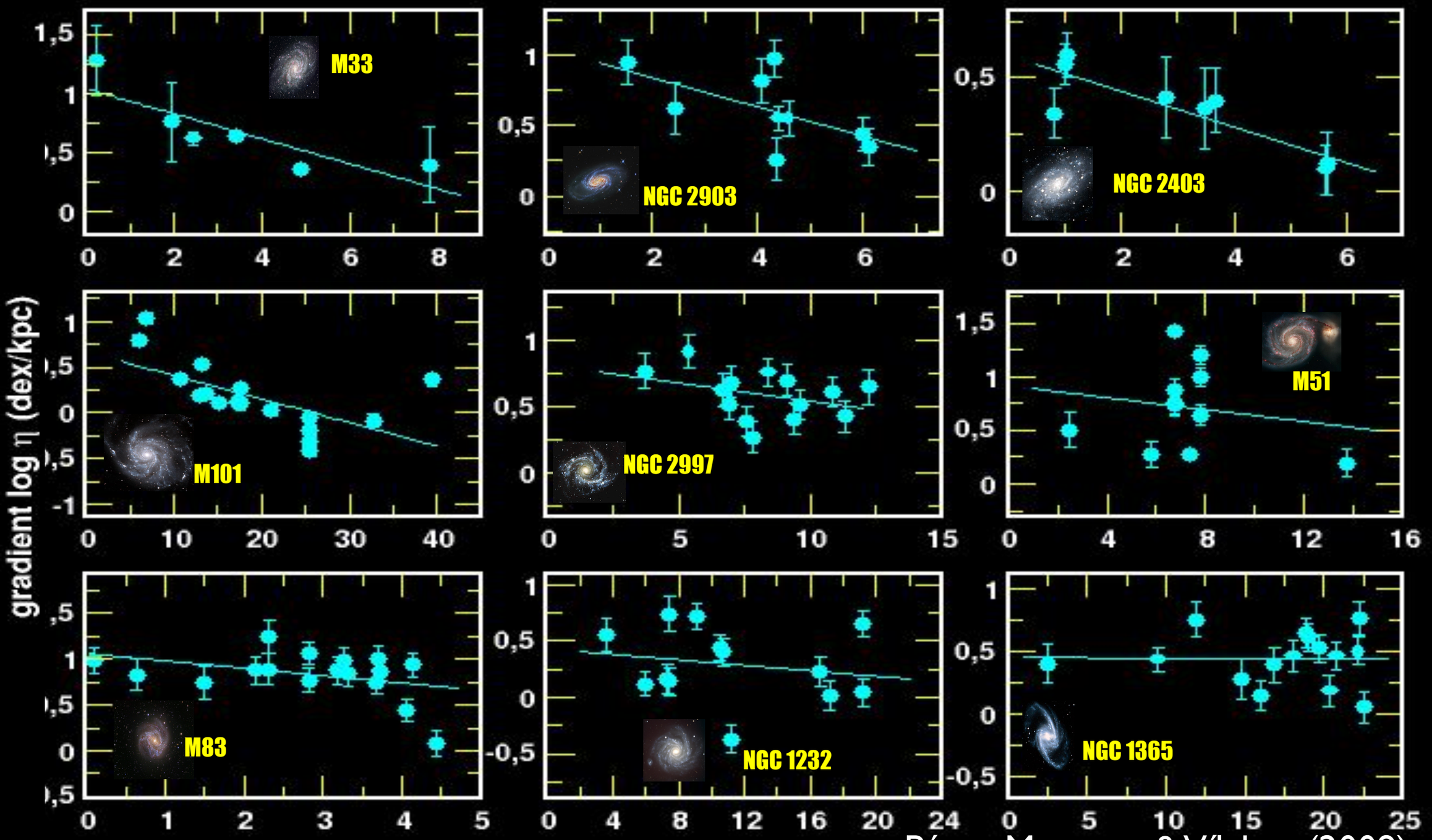
CAUTIONS WITH THE "SOFTNESS" PARAMETER





The models of the gas give T* consistent with the stellar cluster (39200K) although the radial profile of the softness parameter increases according to models

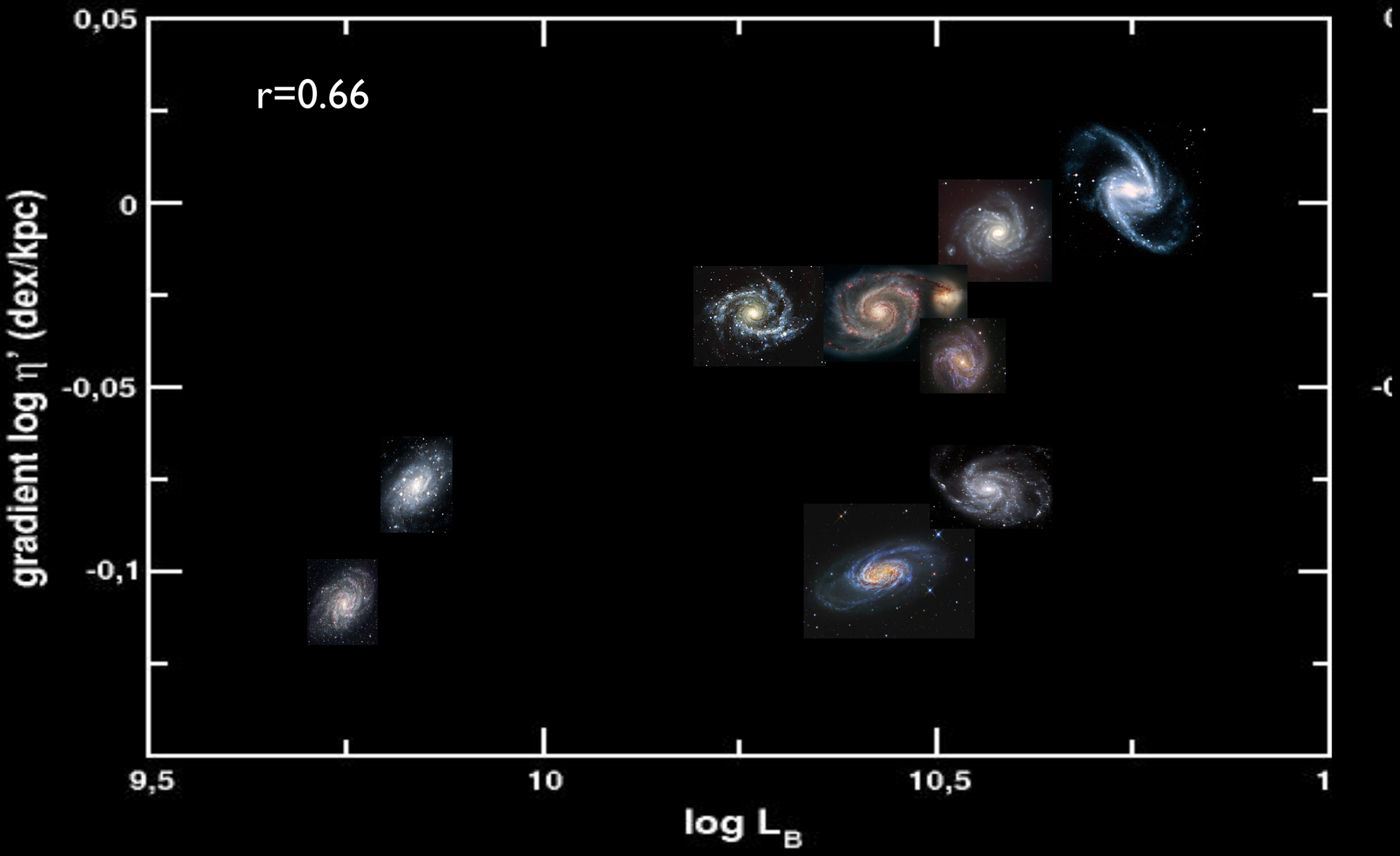
SPIRAL DISKS GRADIENTS OF η



Pérez-Montero & Vílchez (2009)

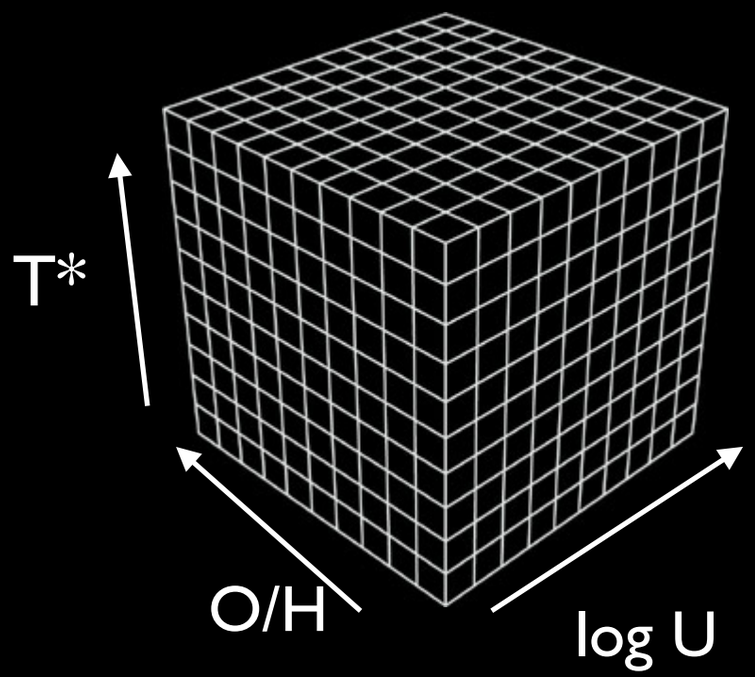
Are the observed radial decreasing of η in galaxies owing to a hardening of the ionizing stellar radiation?

CORRELATIONS BETWEEN SLOPES AND OTHER GALACTIC PROPERTIES



Pérez-Montero & Vílchez (2009)

A GRID OF MODELS TO DERIVE T*



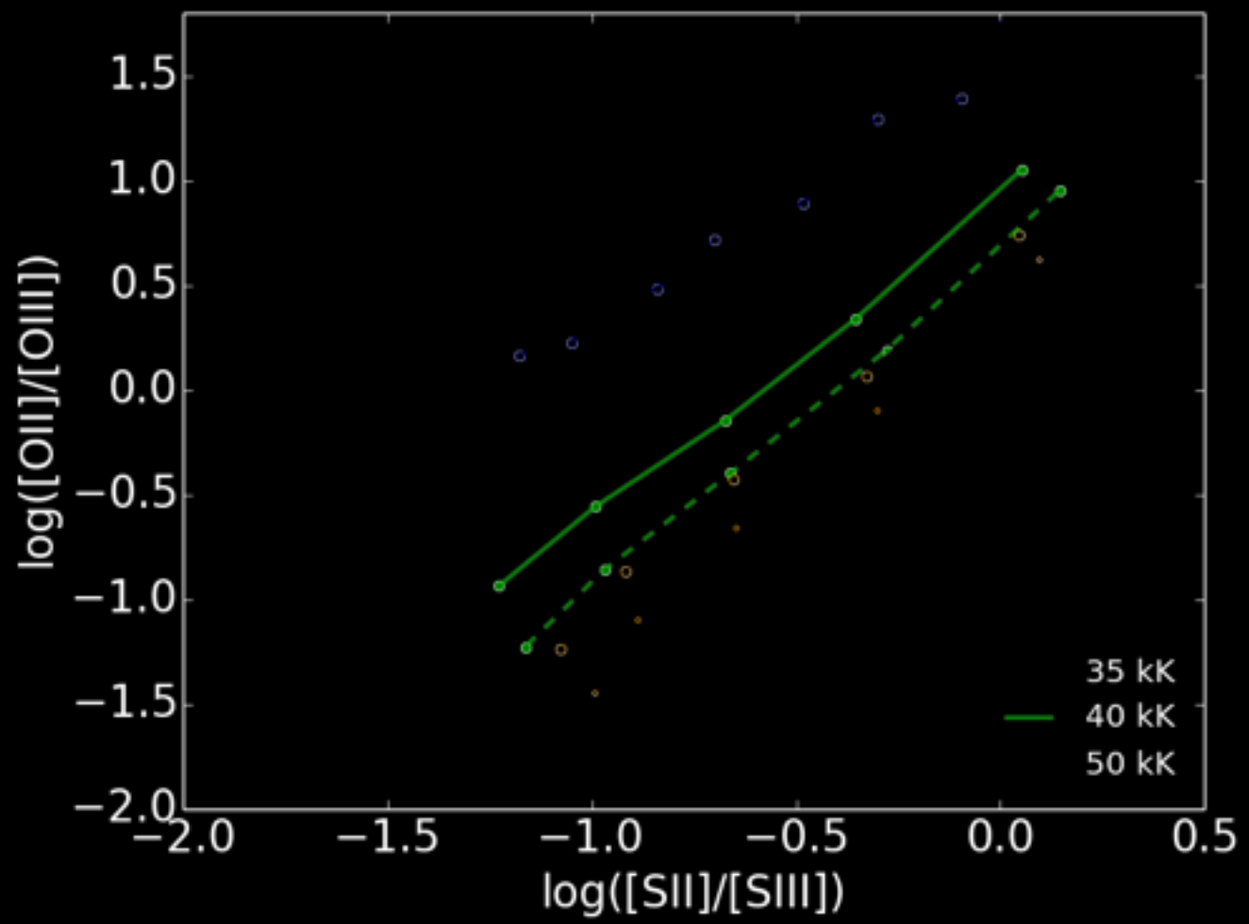
We calculated a grid of models to derive U and T* from the lines of the softness parameter

- **Cloudy v. 13.03 (Ferland et al. 2013)**
  - **WM-Basic single-star atmospheres (Pauldrach2002) (same Z as the gas,**
  - **- Constant density**
- **Radiation-bounded geometry**
- **All elements scaled to O, except N**
- **Standard MW dust-to-gas ratio**
- **Variation of input parameter:**
  - **12+log(O/H): [7.1, 8.9] 0.3bin**
  - **T*): [30,000,55,000]]**
  - **log U: [-3.5,-1.5] 0.5bins**

This gives a total of 280 models

METALLICITY DEPENDENCE

The lines of equal U or T* depend strongly on the metallicity of the model. The first step then is to choose or interpolate the models to be applied to a dataset.



Metallicity is key to provide accurate values. When O/H is known the used grid is interpolated.

THE HII-CHI-mistry Teff CODE

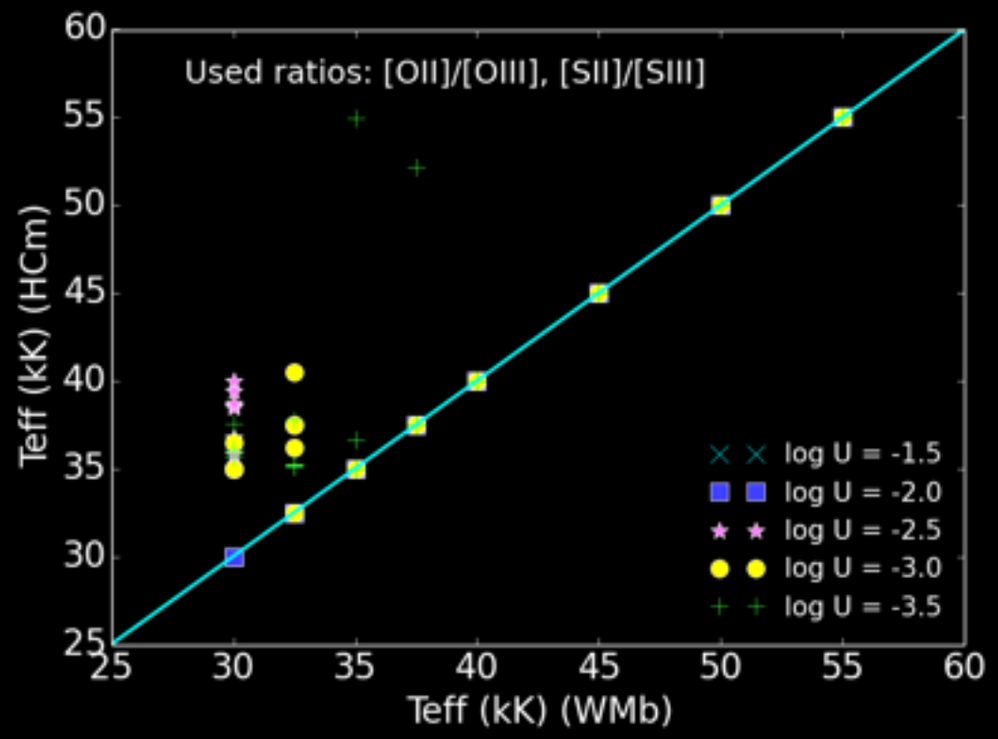
The HCm-Teff code calculates T* and U comparing the input emission-line fluxes of [OII], [OIII], [SII], and [SIII] with the values in the models as the chi2-weighted means of the values of the grid.

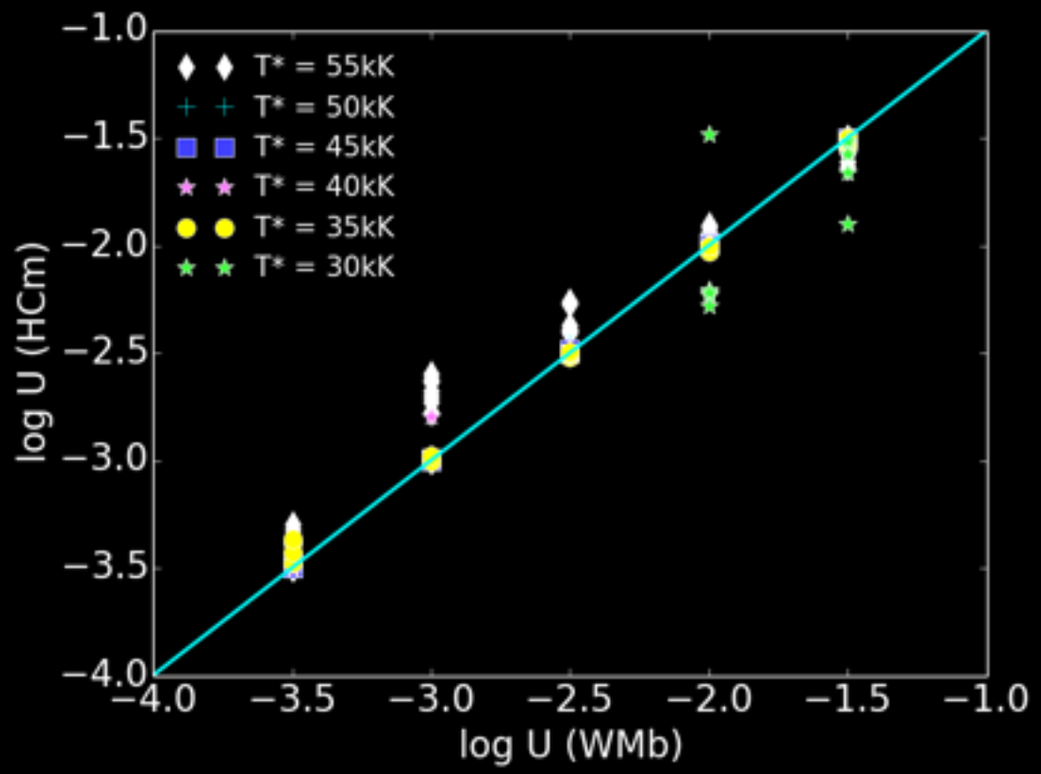
$$T_{*f} = \frac{\sum_i T_{*i}/\chi_i^2}{\sum_i 1/\chi_i^2}$$

$$\log(U)_f = \frac{\sum_i \log(U)_i/\chi_i^2}{\sum_i 1/\chi_i^2}$$

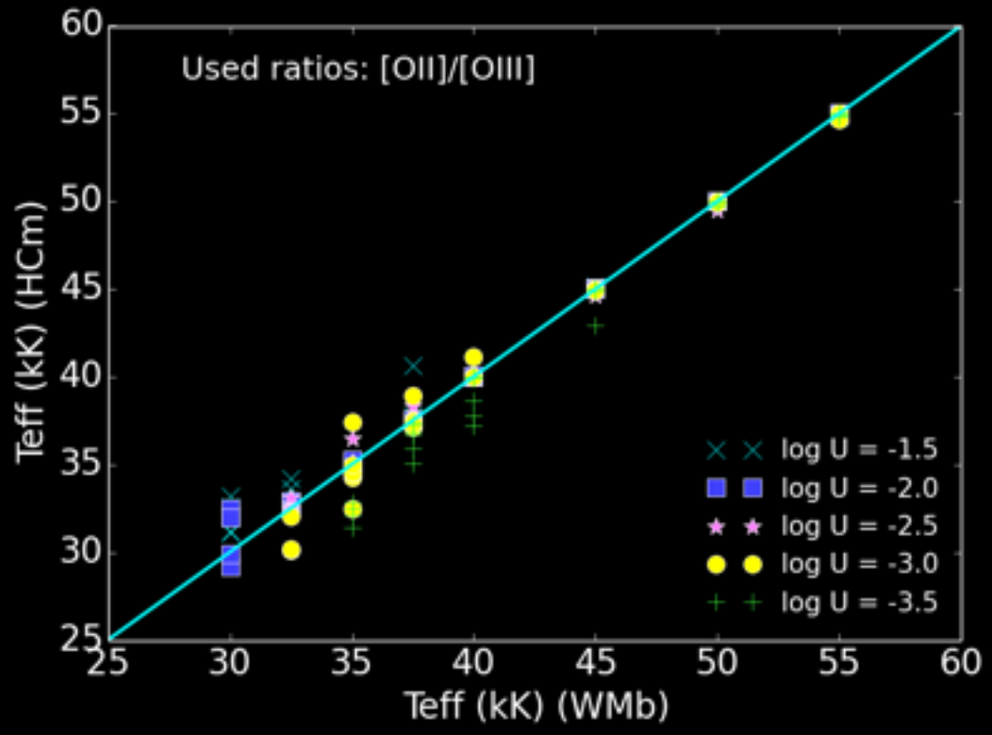
Errors are calculated as the standard deviation of the weighted distributions. In addition the observational errors of the lines are considered in a monte-Carlo iteration that is later added to final error balance.

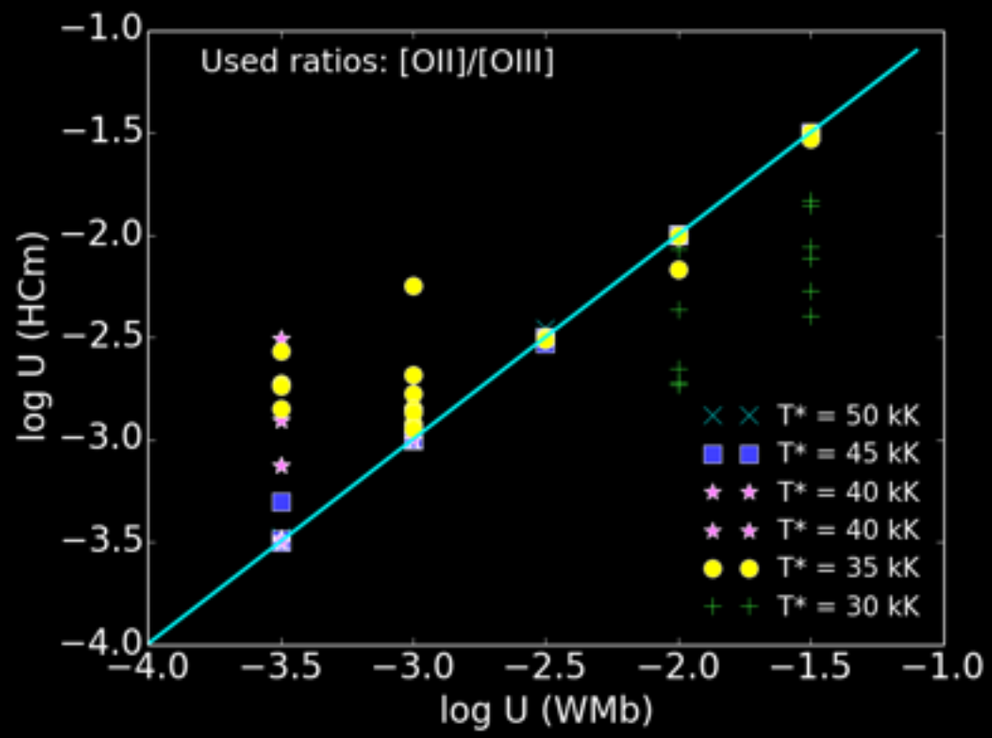
COMPARISON WITH SINGLE-STAR MODELS



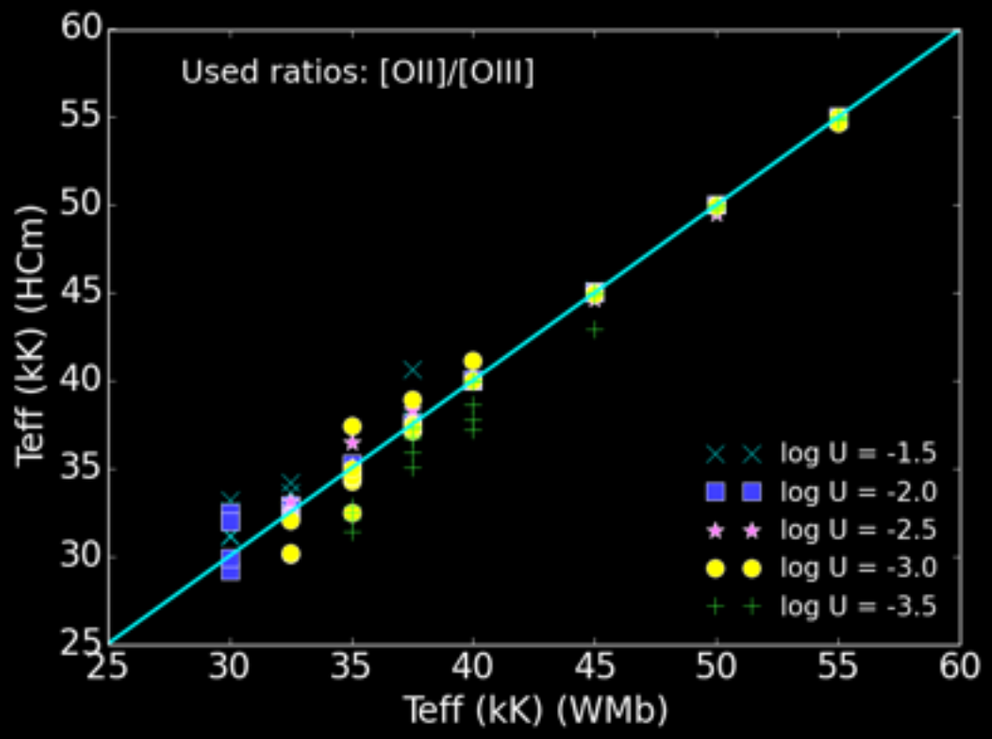


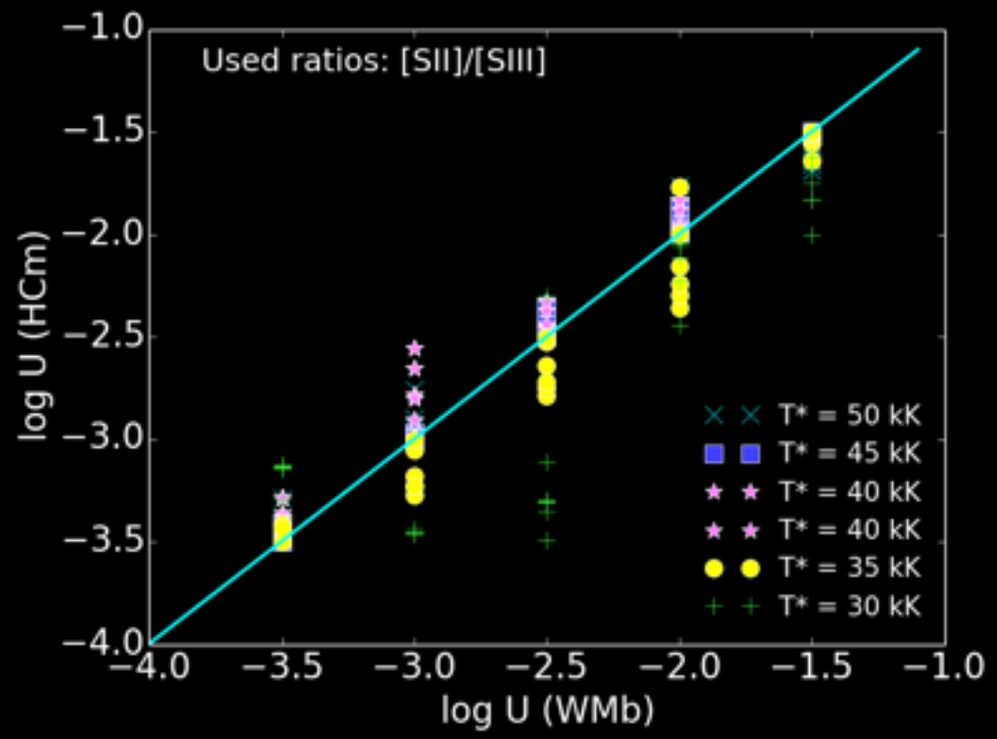
COMPARISON WITH SINGLE-STAR MODELS



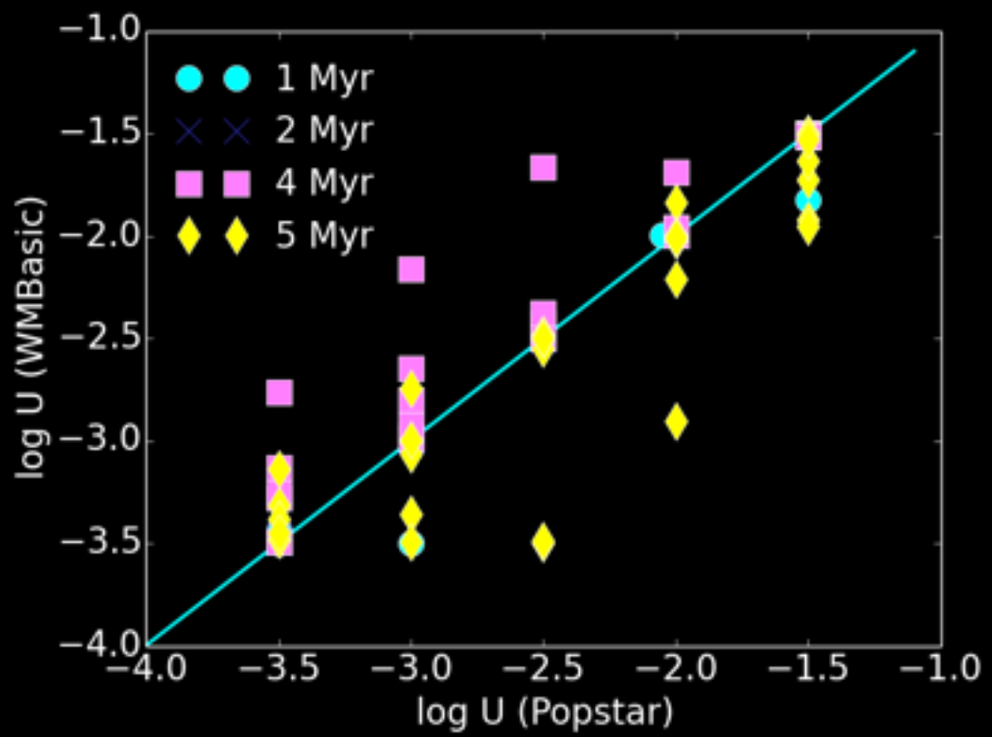


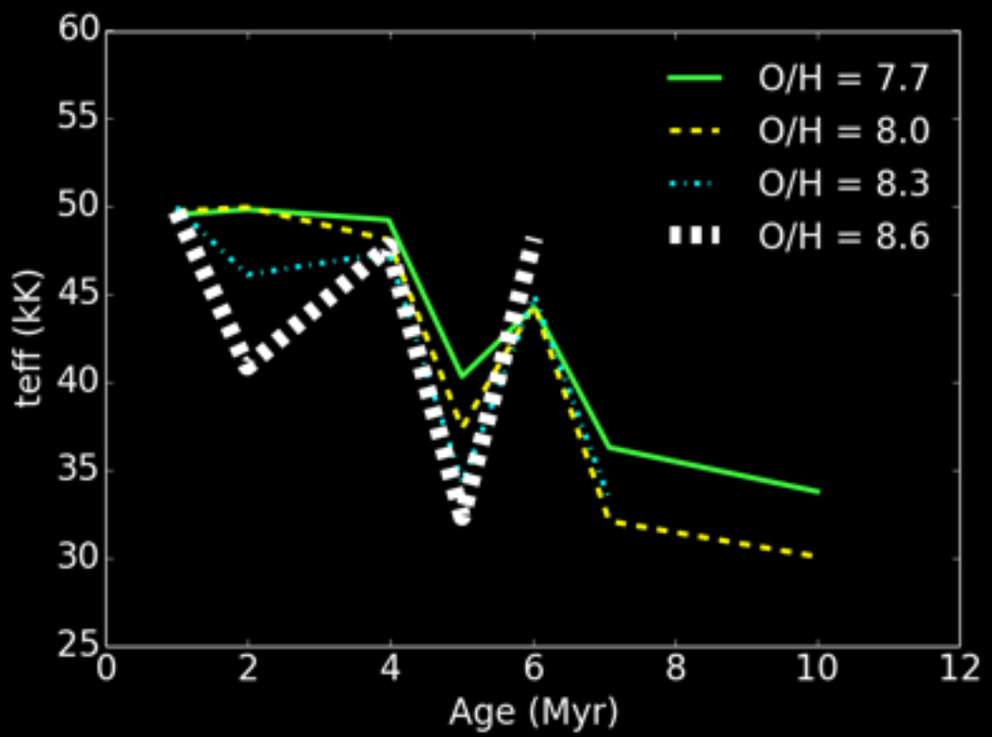
COMPARISON WITH SINGLE-STAR MODELS



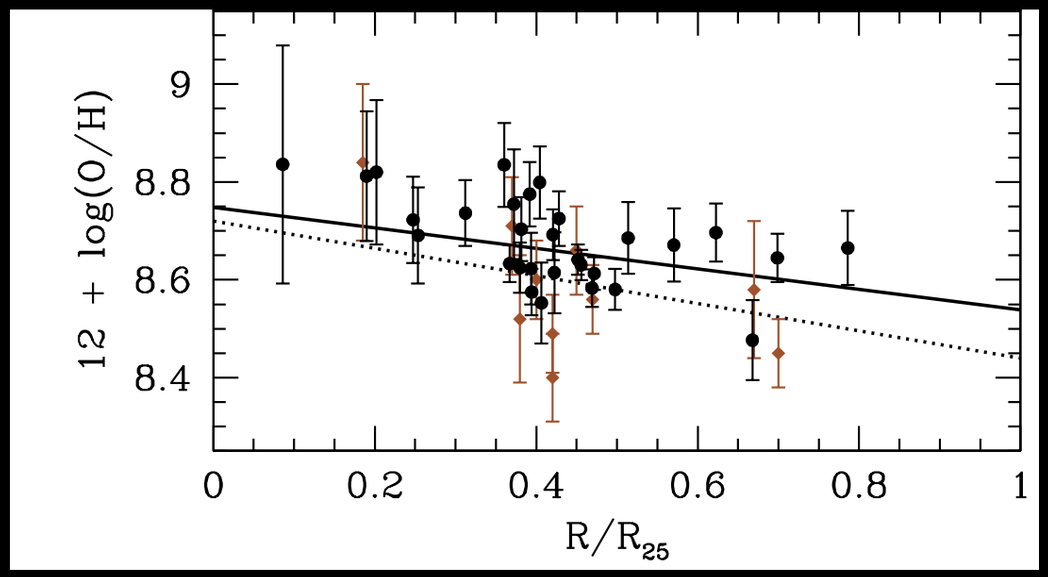


COMPARISON WITH CLUSTER MODELS

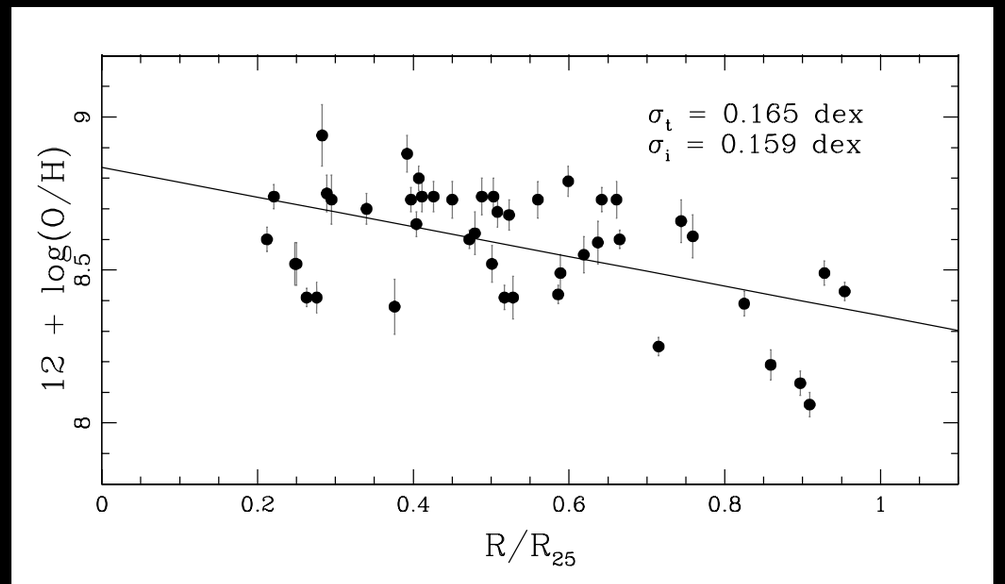




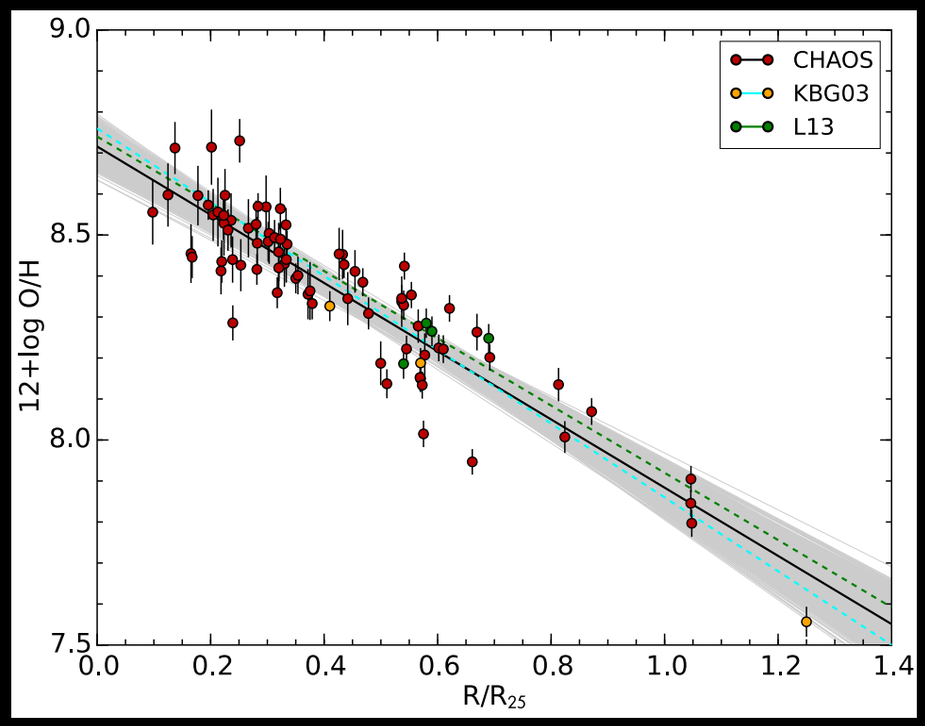
APPLICATION TO CHAOS GALAXIES



M51 Croxall+ (2014)



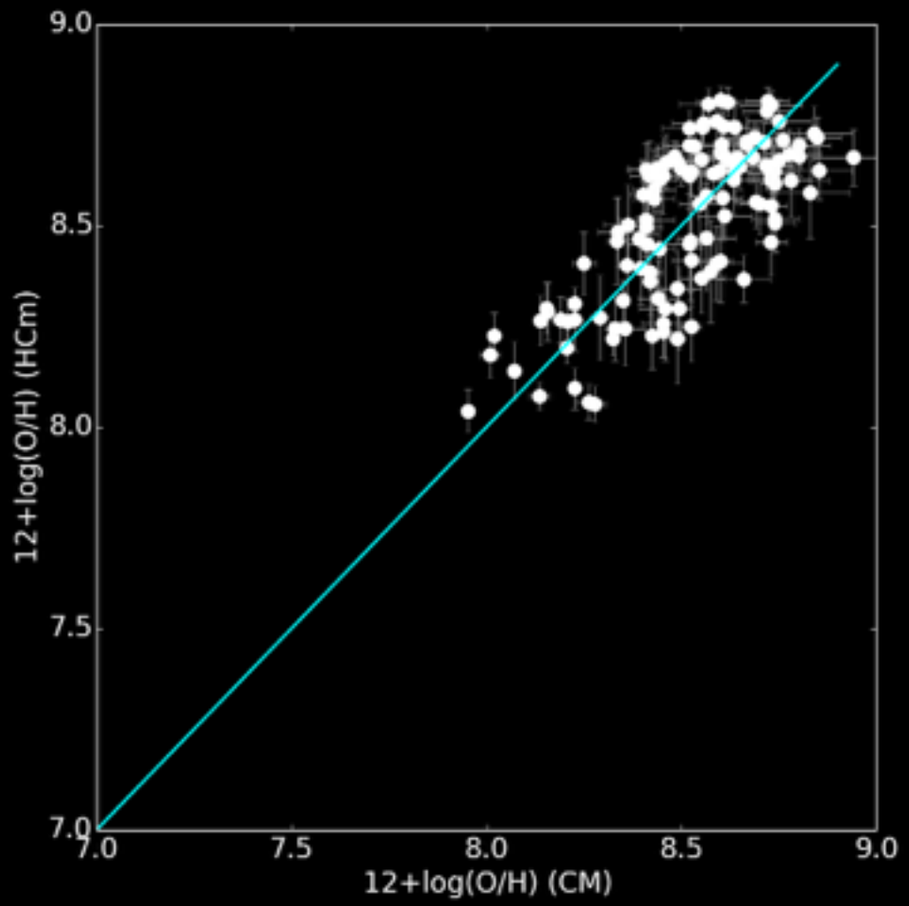
M74 Berg+ (2011)



M101 Croxall+ (2016)

CHAOS (CHemical Abundances Of Spiral galaxies) is carried out from LBT and covers the range of the four involved emission lines in the softness parameter.

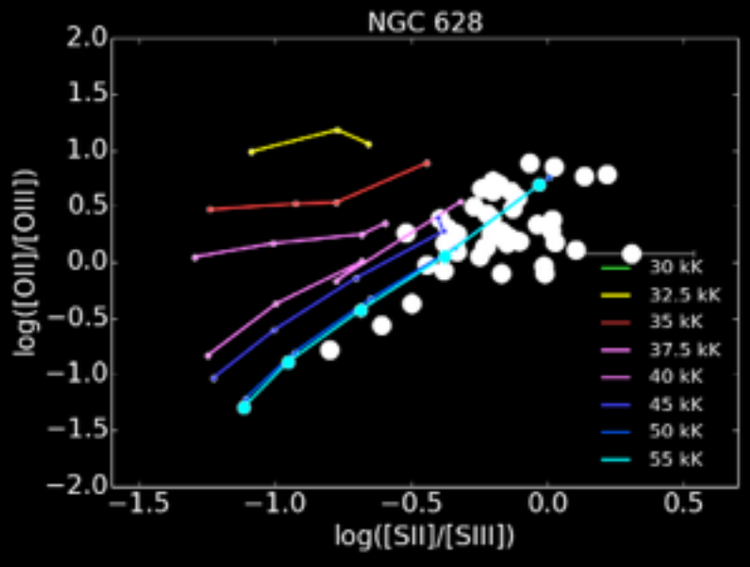
DERIVATION OF METALLICITY

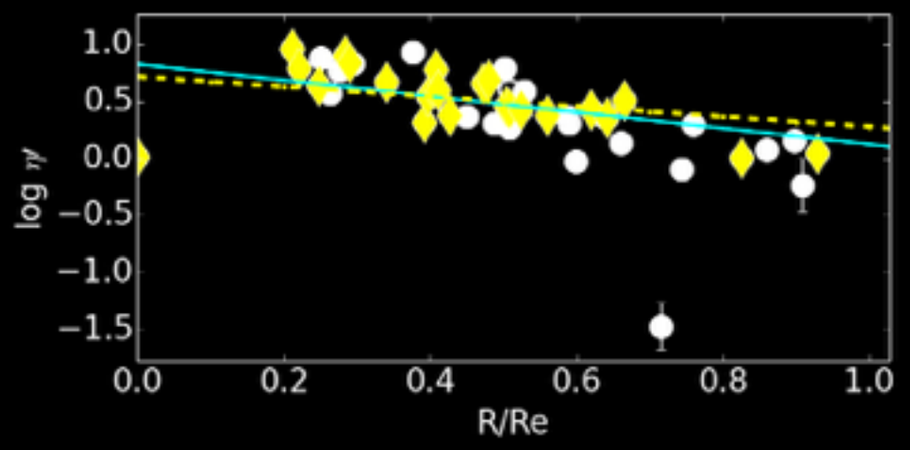


Oxygen abundances are taken from the direct method. For those HII regions without any auroral line, we applied the HIICHI-mistry code (Pérez-Montero 2014).

The agreement for those HII regions with a determination from the DM is pretty good even in the absence of the [OIII] 4363 (mean offset ~0 dex, st.dev. ~0.2 dex)

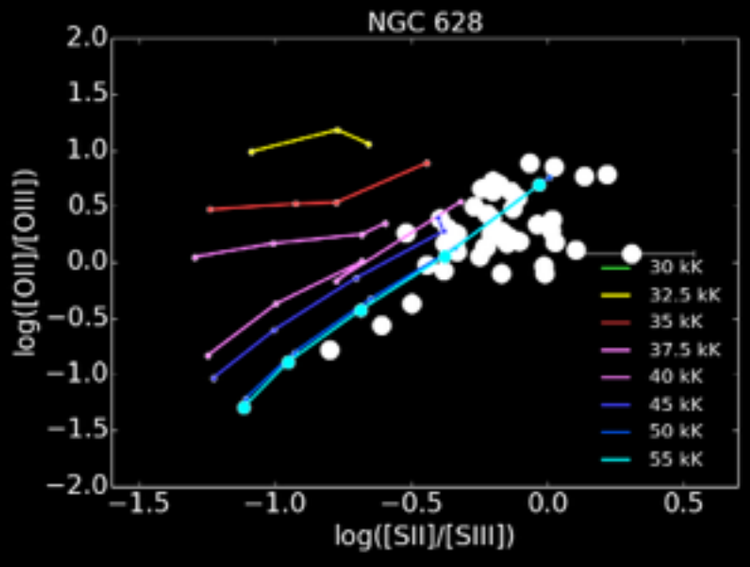
STUDY OF GRADIENTS IN M74



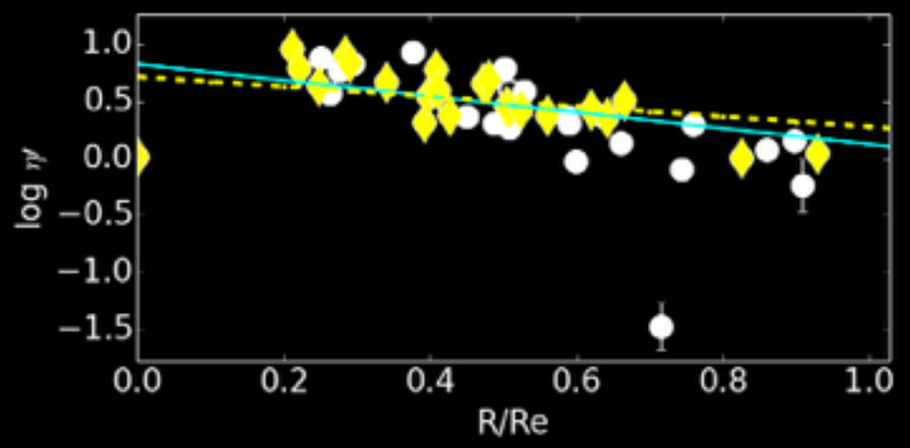


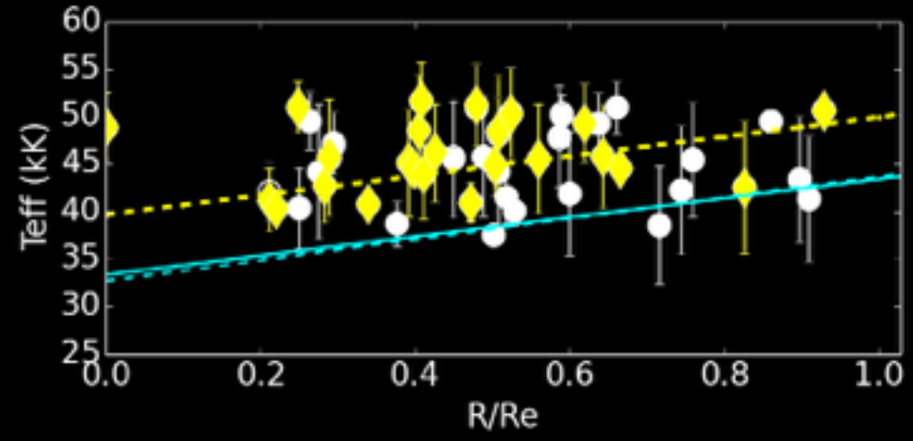


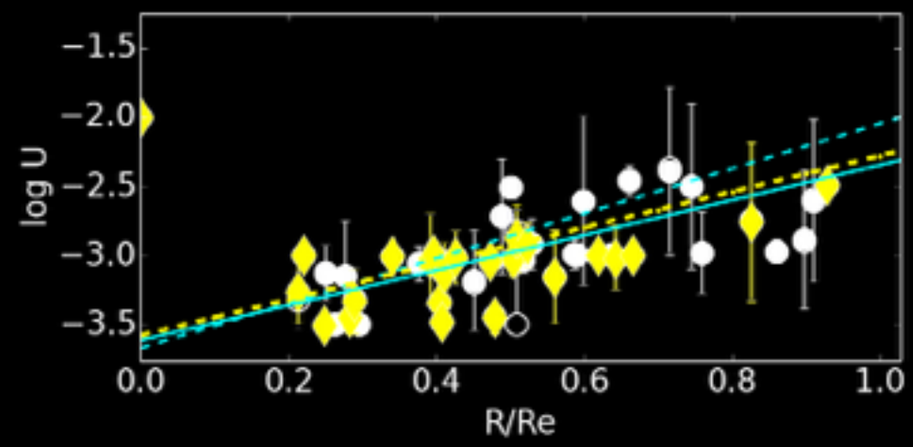
STUDY OF GRADIENTS IN M74



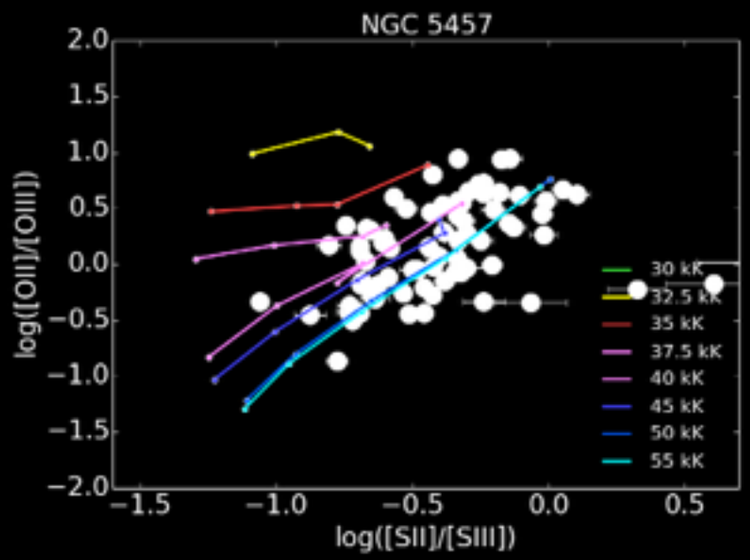


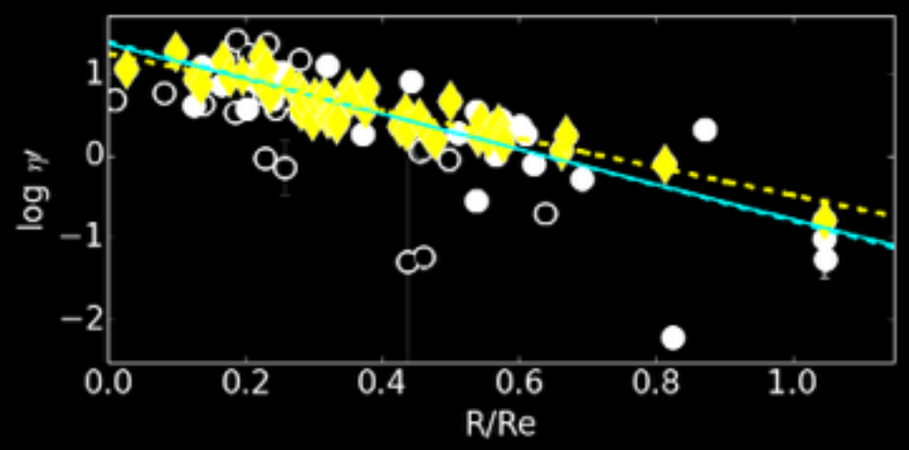






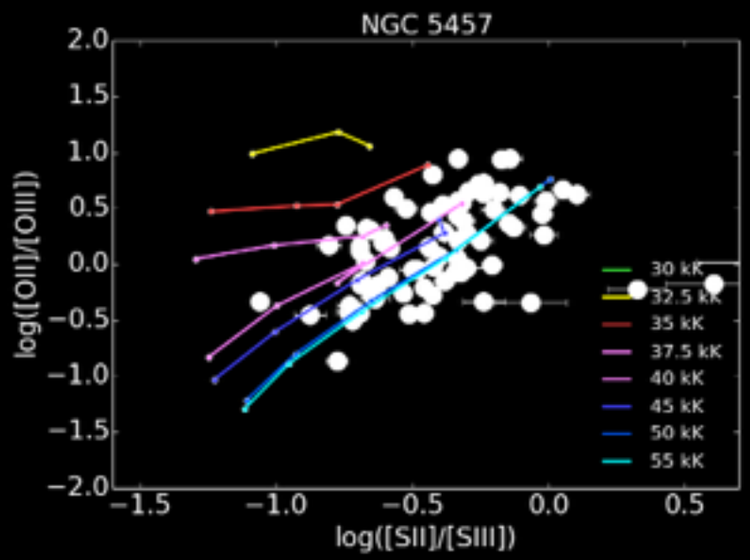
STUDY OF GRADIENTS IN M101



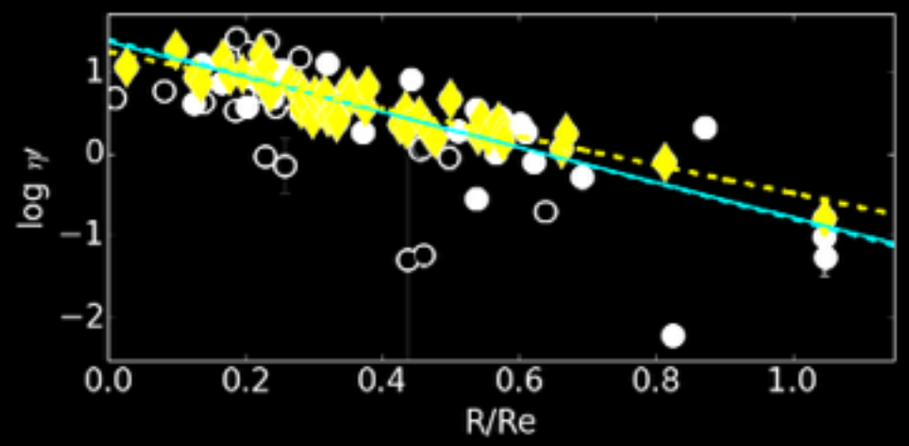


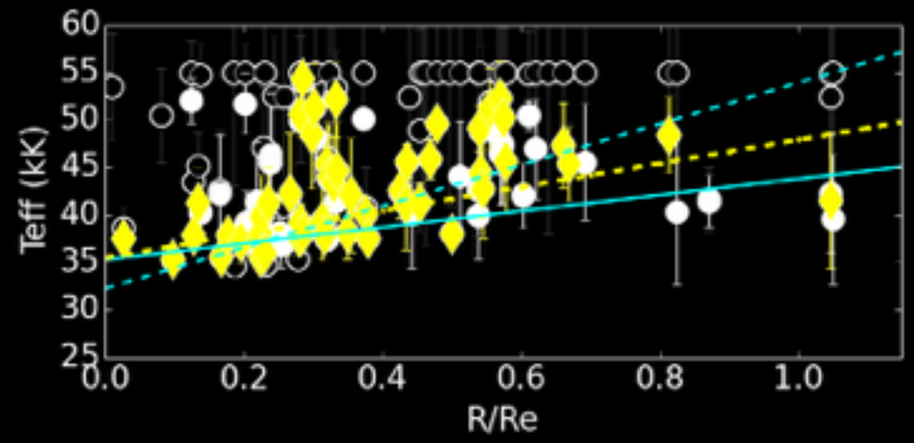


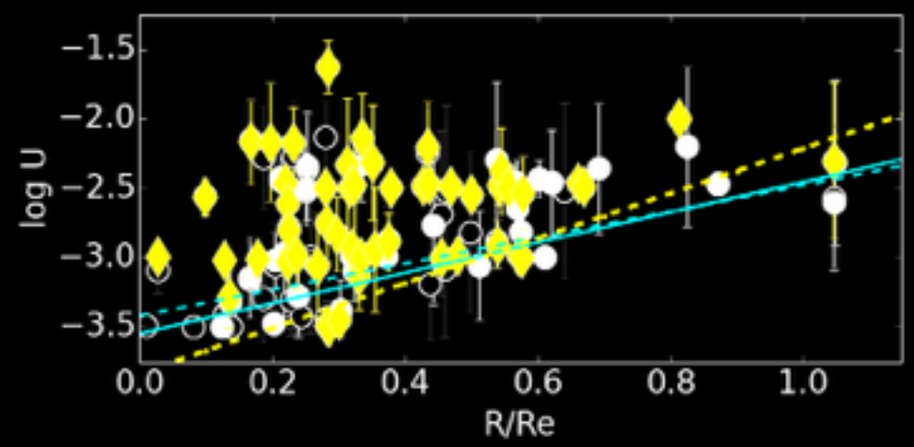
STUDY OF GRADIENTS IN M101



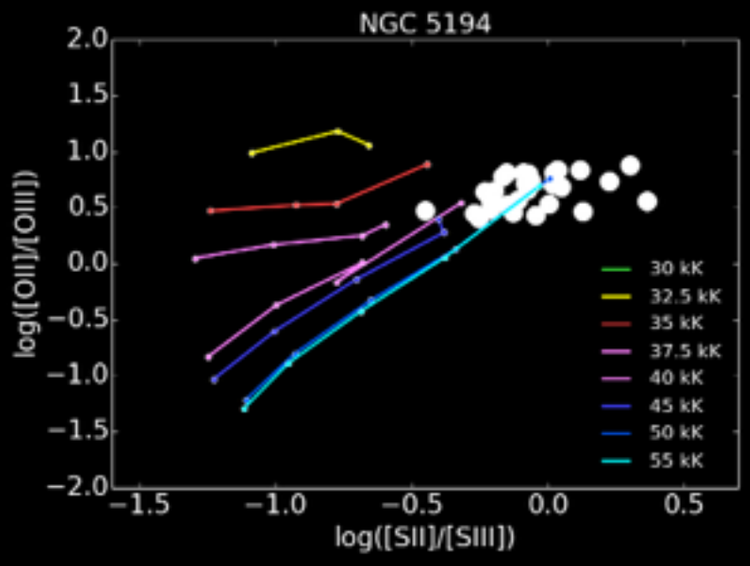


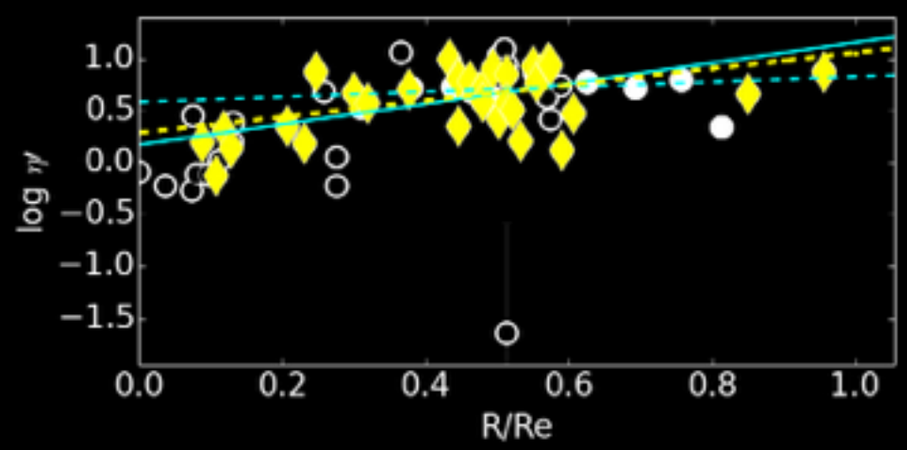






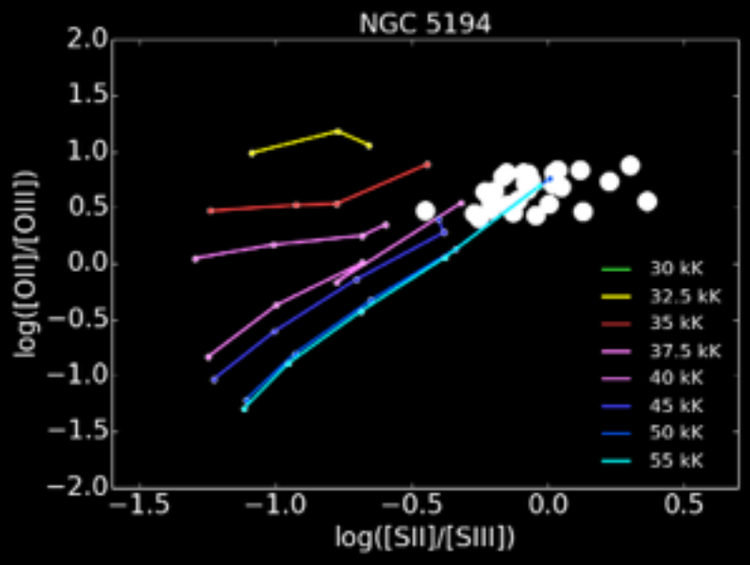
STUDY OF GRADIENTS IN M51



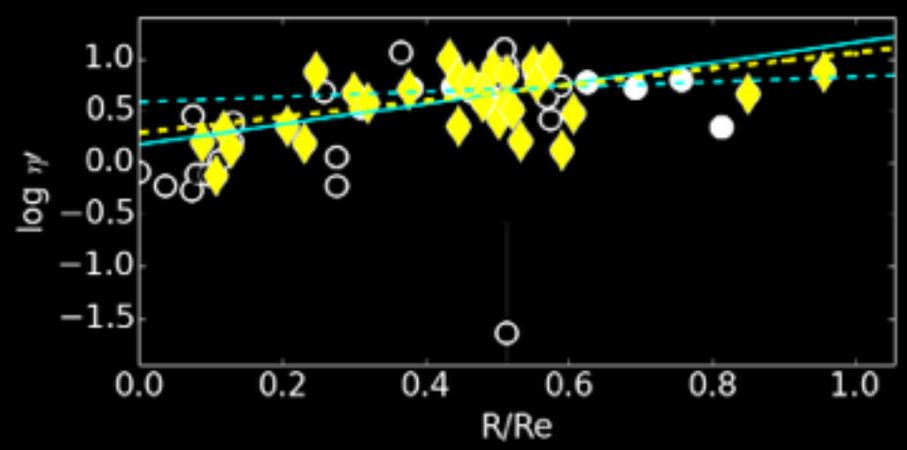


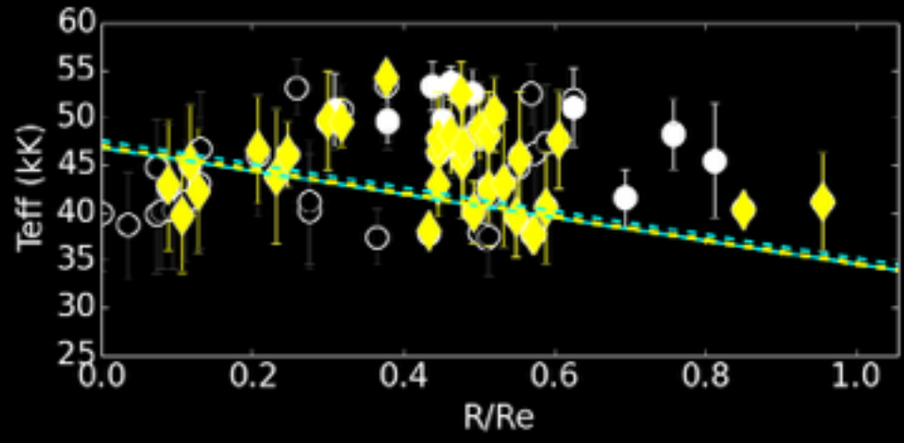


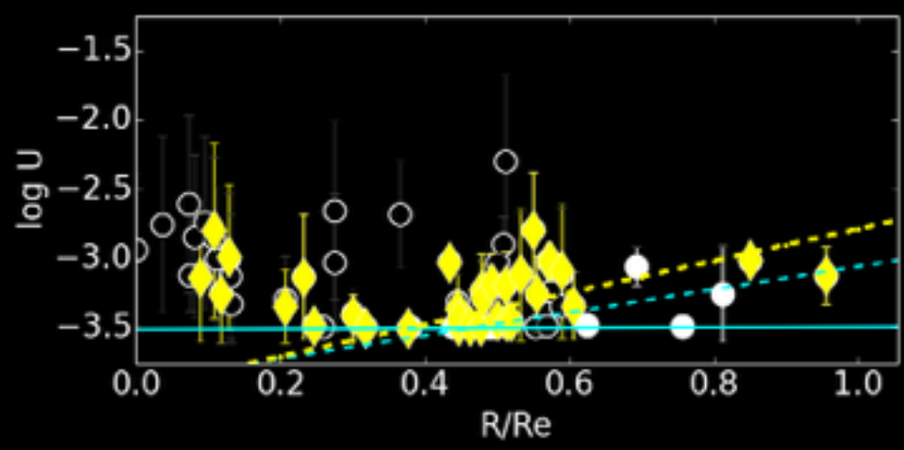
STUDY OF GRADIENTS IN M51



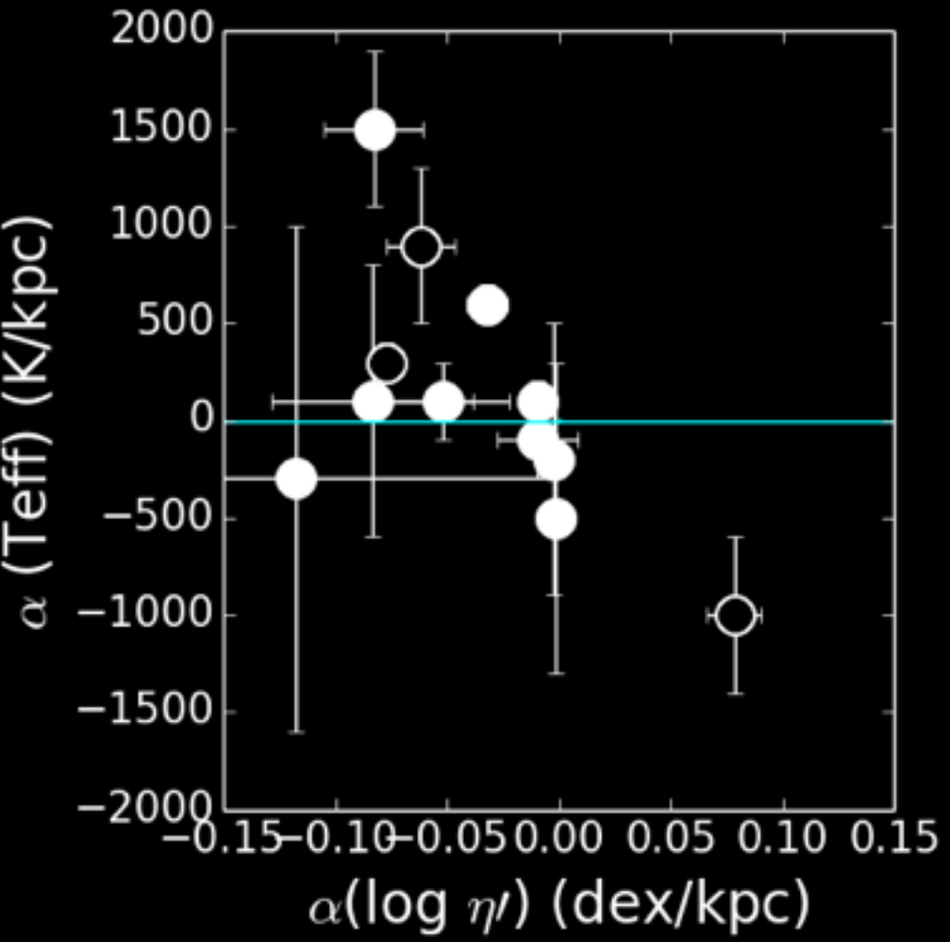


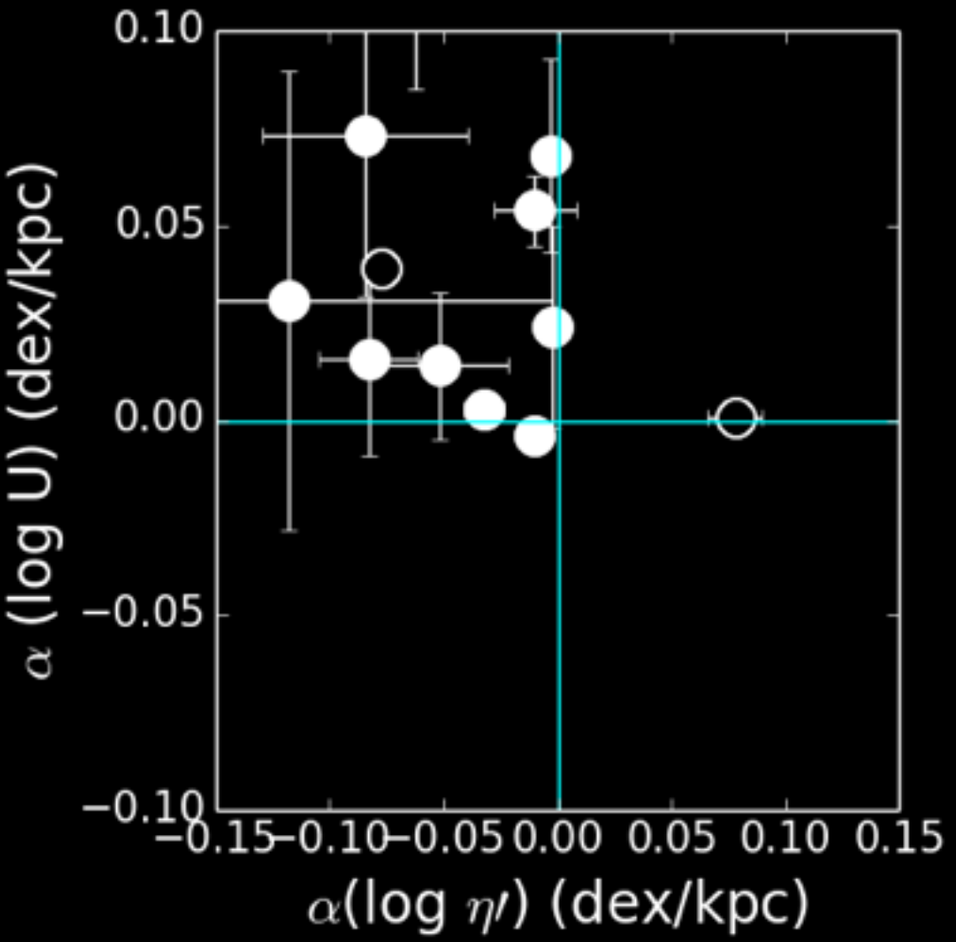




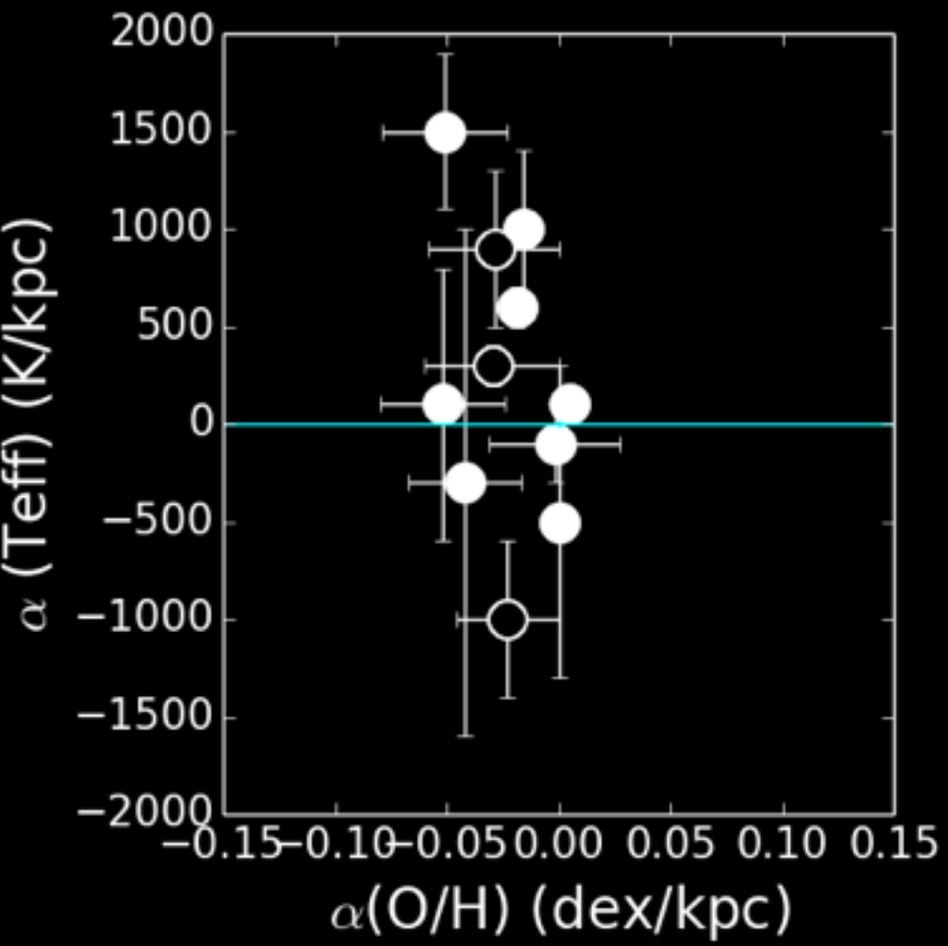


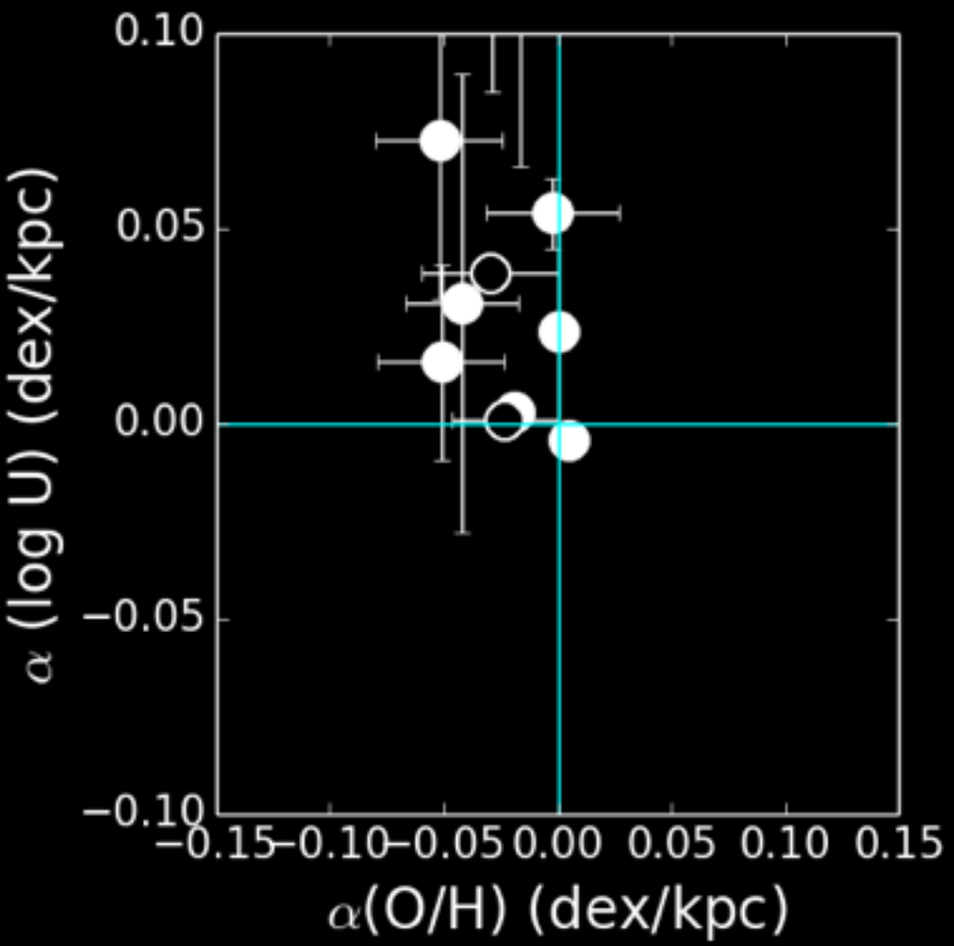
CORRELATION BETWEEN SLOPES



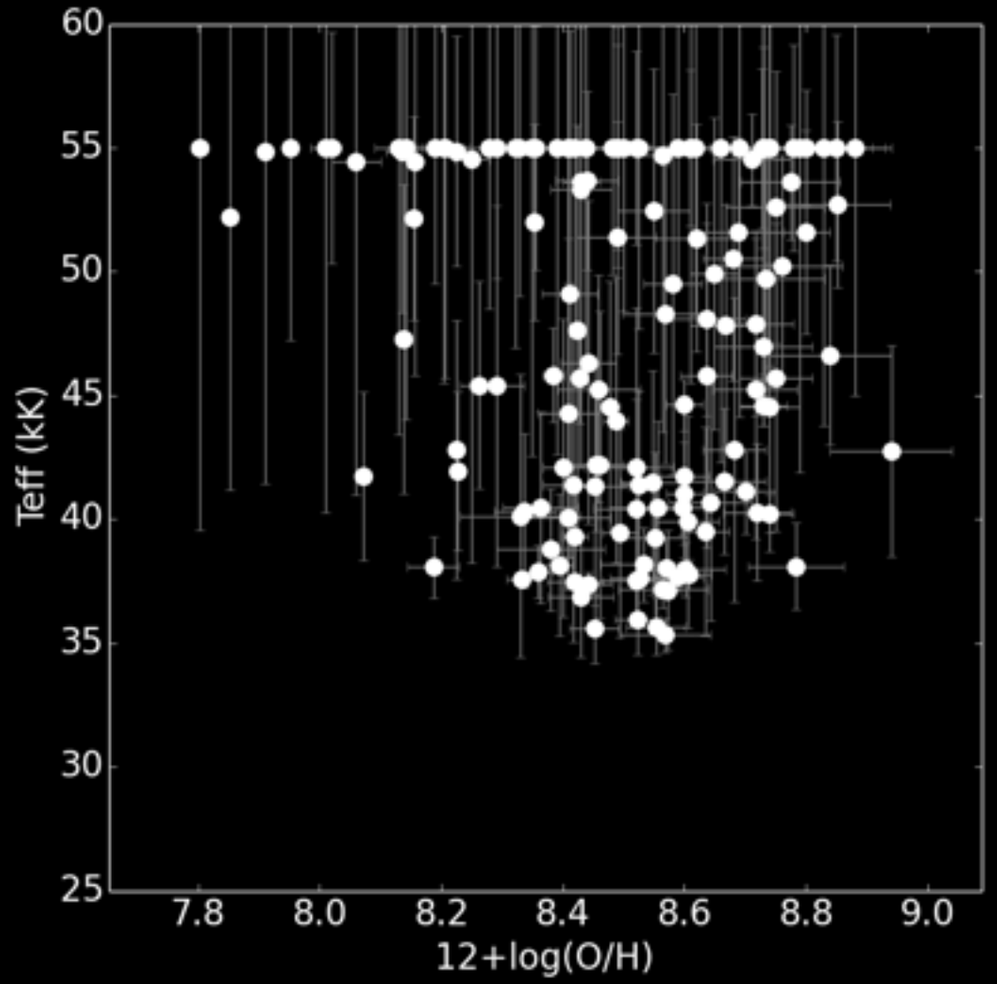


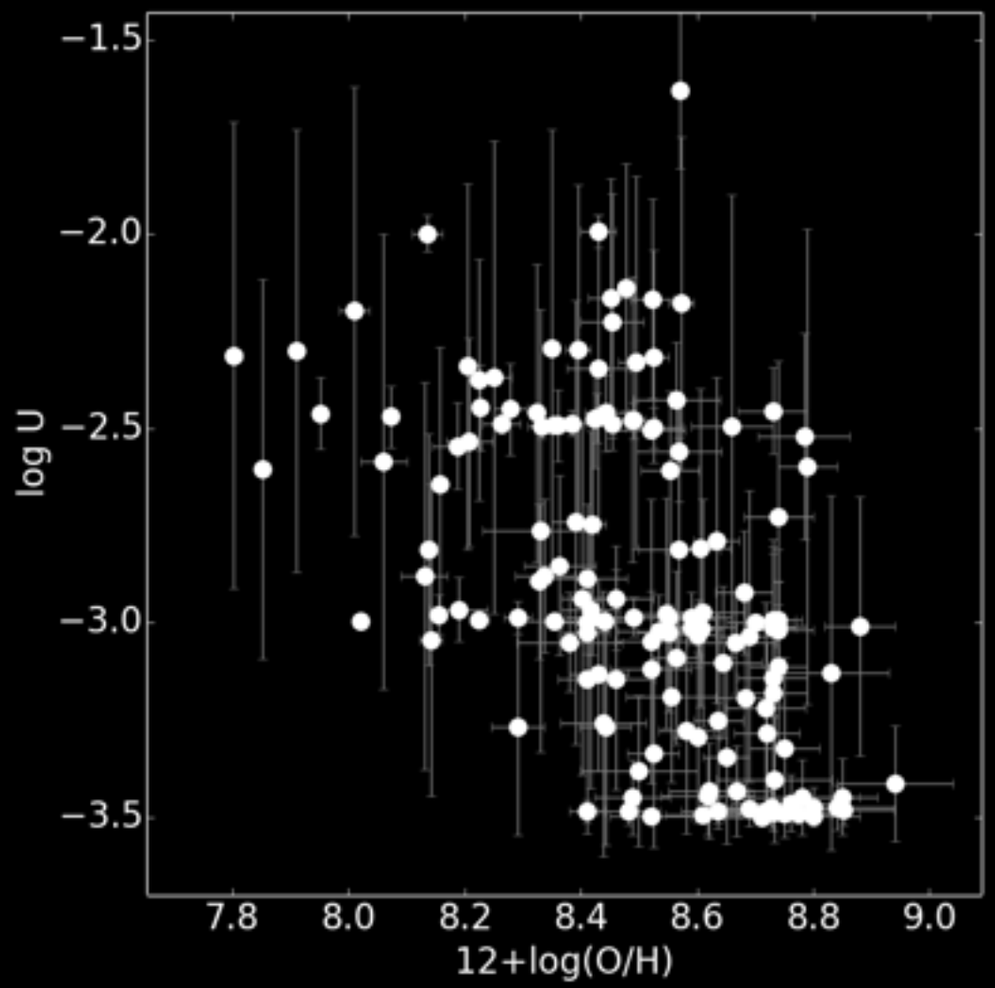
CORRELATION BETWEEN SLOPES





CORRELATIONS WITH METALLICITY





SUMMARY & CONCLUSIONS

The softness parameter can be used to derive T in massive stellar clusters but it presents additional dependence on Z, U and other conditions.

* HCm-Teff allows to extract U and T^from the observational information from the lines, helping to clarify if the radial decreasing of eta can be interpreted as a hardening of the field of radiation.

* The observed eta gradient in disk galaxies is related to T*, but it is mostly related with a radial excitation gradient linked to the gradient of metallicity in the same objects.