Using photoionization models in the softness diagram to Estimate the escape fraction of ionizing photons

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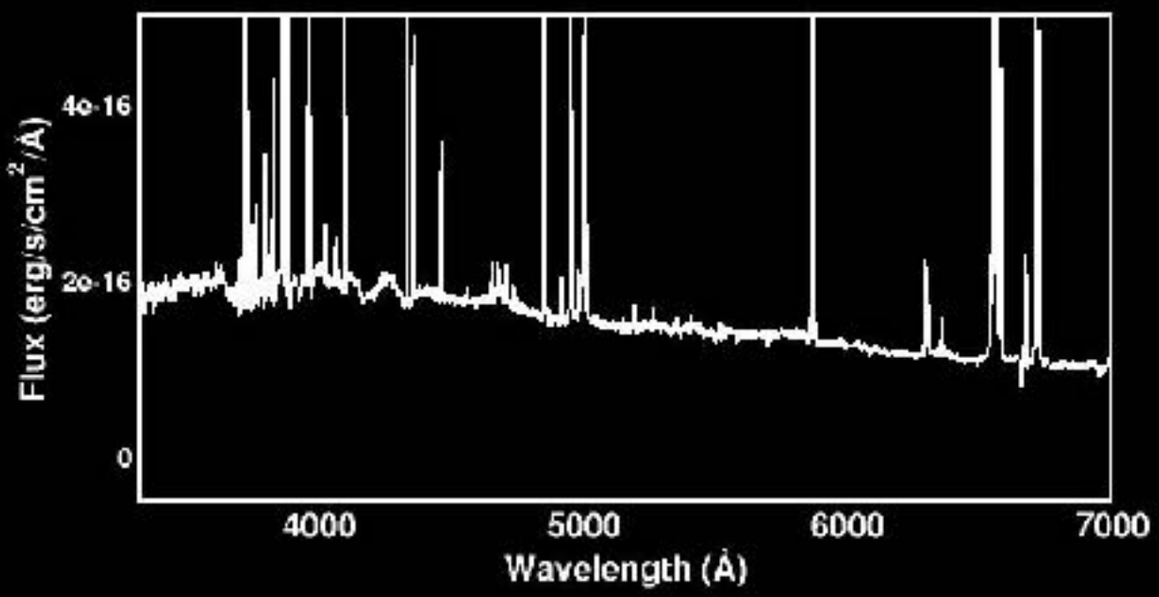
FUNCTIONAL PARAMETERS



Metallicity
(Z)

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

Ionization parameter
(U)

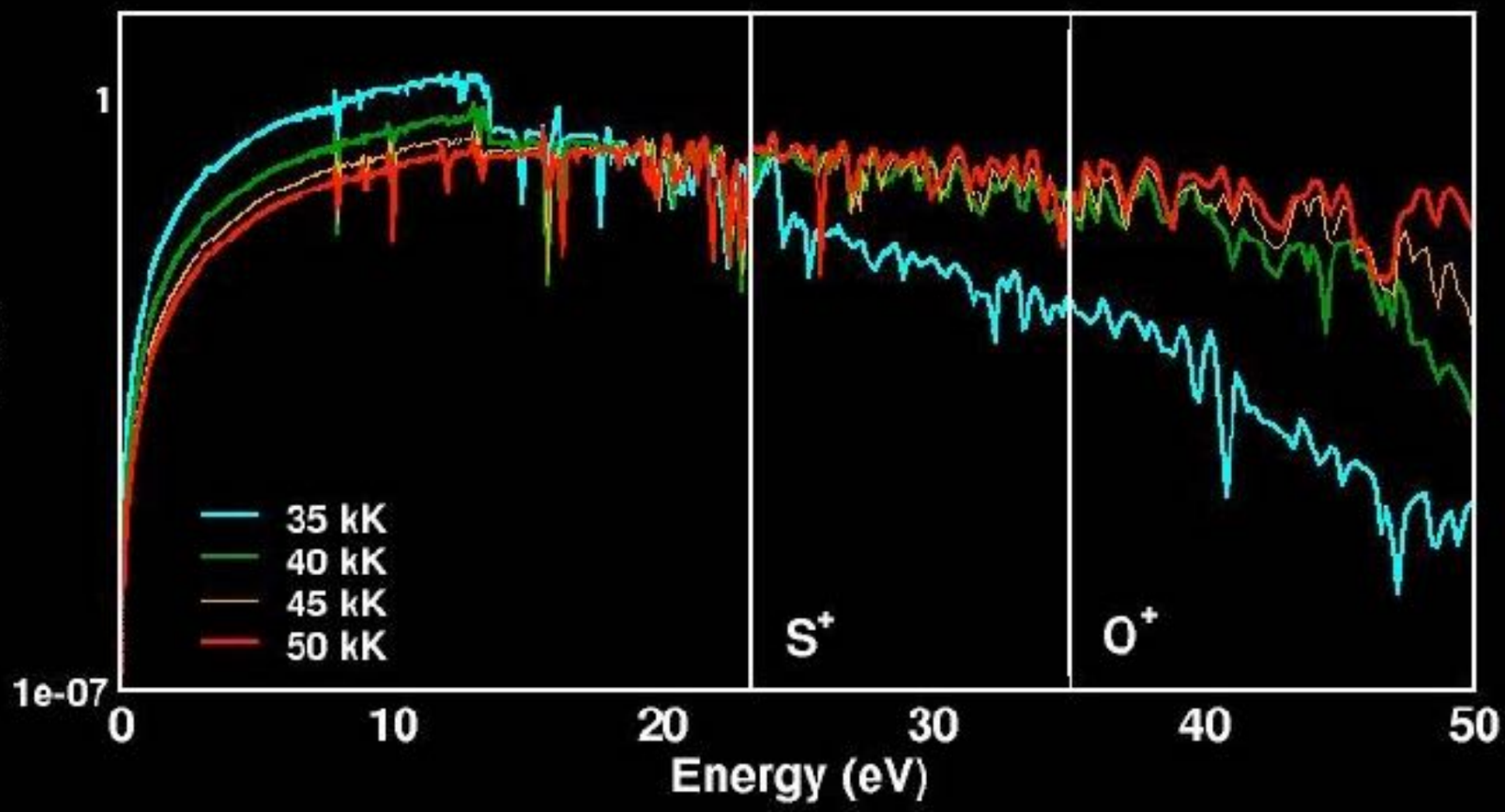
(i.e. ratio between ionizing photons and particles)

Effective equivalent temperature
(T_*)

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

THE "SOFTNESS" PARAMETER

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



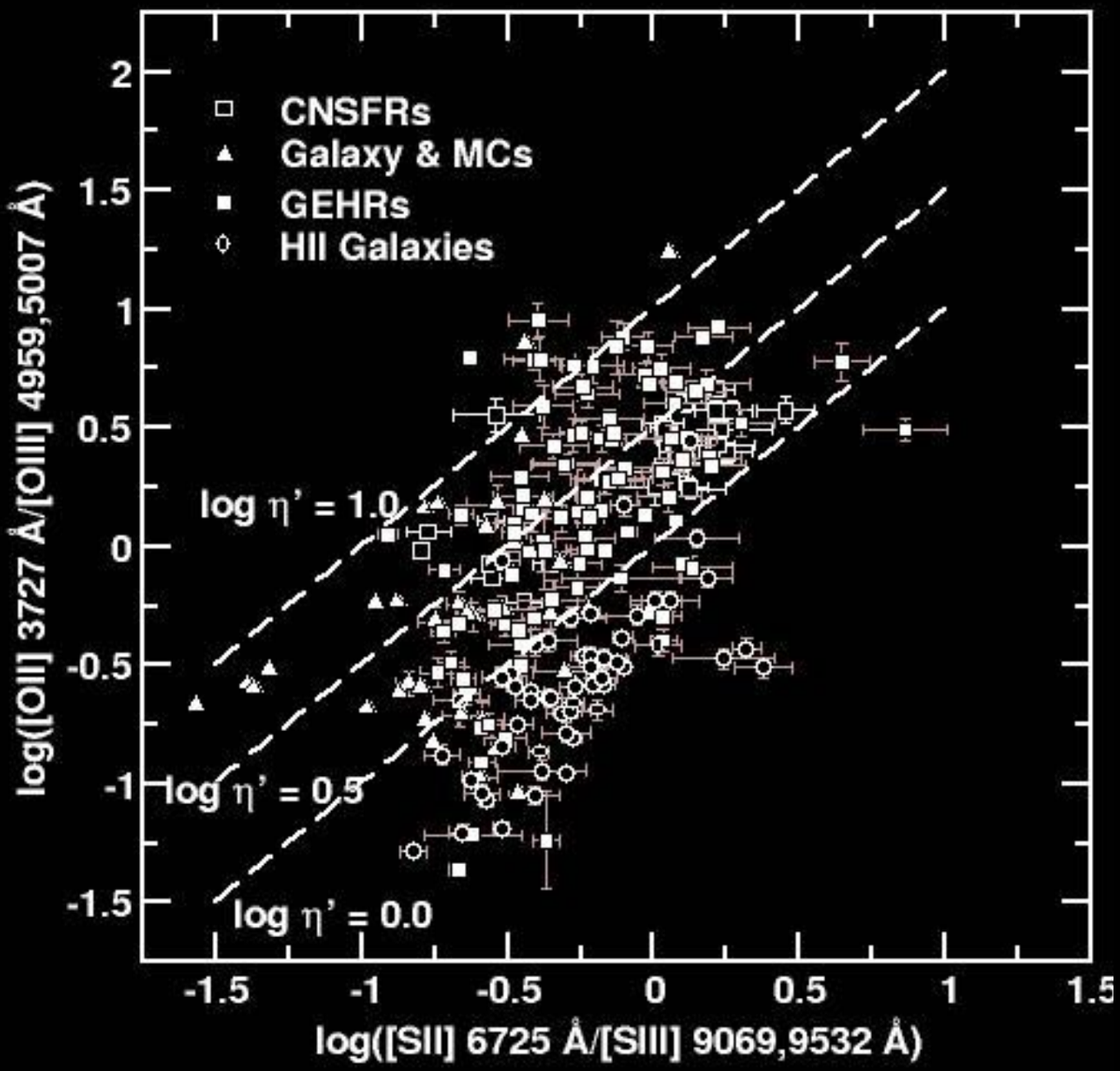
$$\eta = \frac{O^+/O^{2+}}{S^+/S^{2+}} = \frac{[OII]/[OIII]}{[SII]/[SIII]} + o(Z) \propto \frac{Q(O^+)}{Q(S^+)}$$

Vílchez & Pagel (1988)

THE "SOFTNESS" DIAGRAM

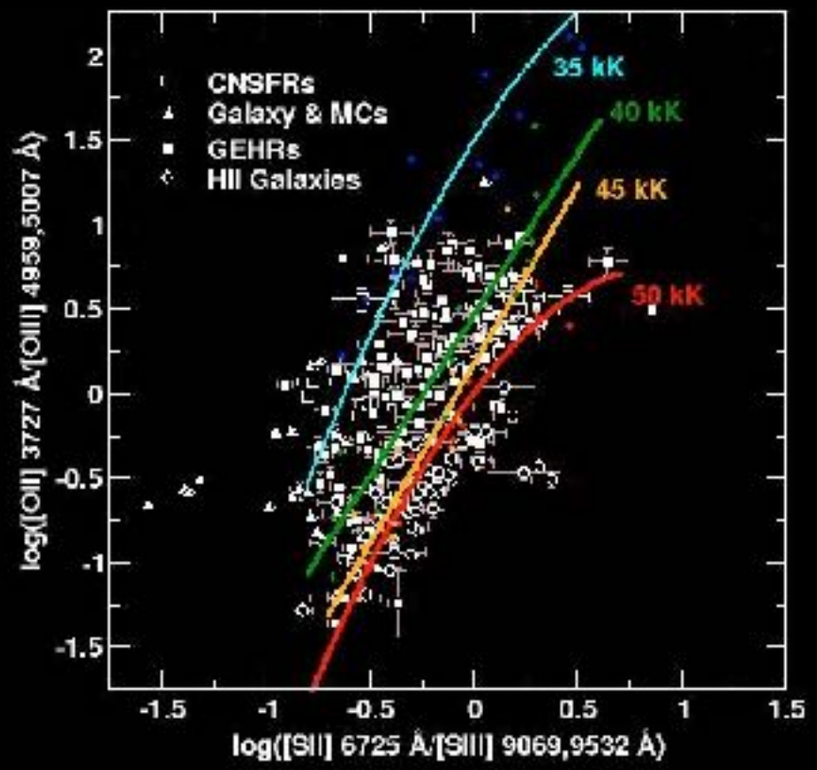
Higher values of η' lead to lower values of T*

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

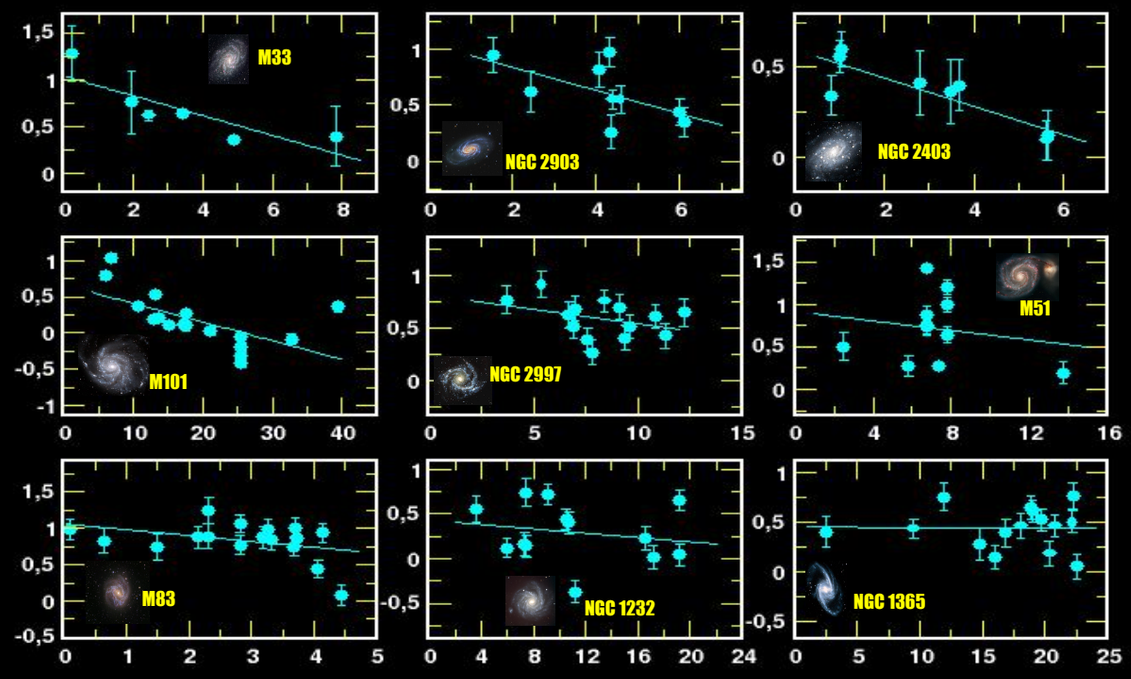


Pérez-Montero & Vílchez (2009)

THE "SOFTNESS" DIAGRAM



WMBasic model stellar atmospheres

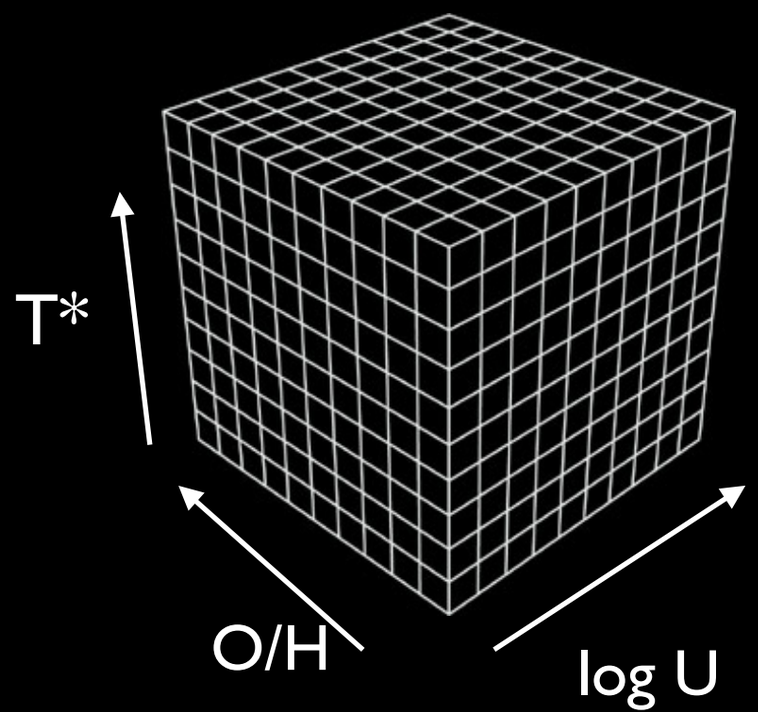


Pérez-Montero & Vílchez (2009)

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, metallicity, and log U.

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. 17.00 (Ferland et al. 2017)
- **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

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.

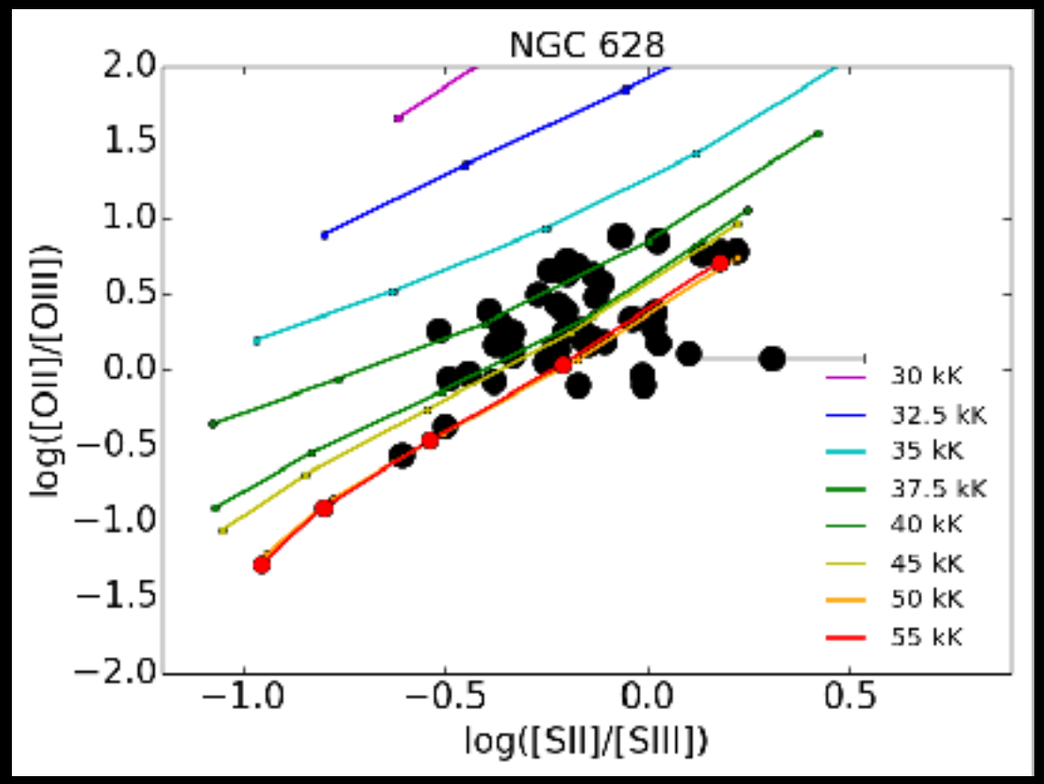
$$T_{*f} = \frac{\sum_i T_{*i} / \chi_i^2}{\sum_i 1 / \chi_i^2}$$

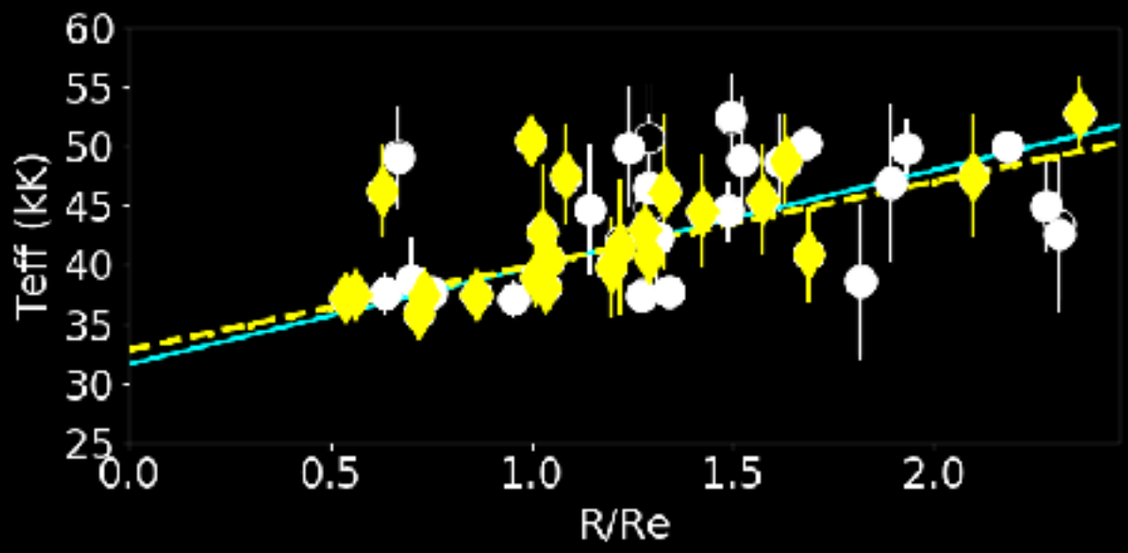
$$\log(U)_f = \frac{\sum_i \log(U)_i / \chi_i^2}{\sum_i 1 / \chi_i^2}$$

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.

All versions of HCm can be retrieved from the HII-CHI-mistry webpage !!!

STUDY OF GRADIENTS IN M74

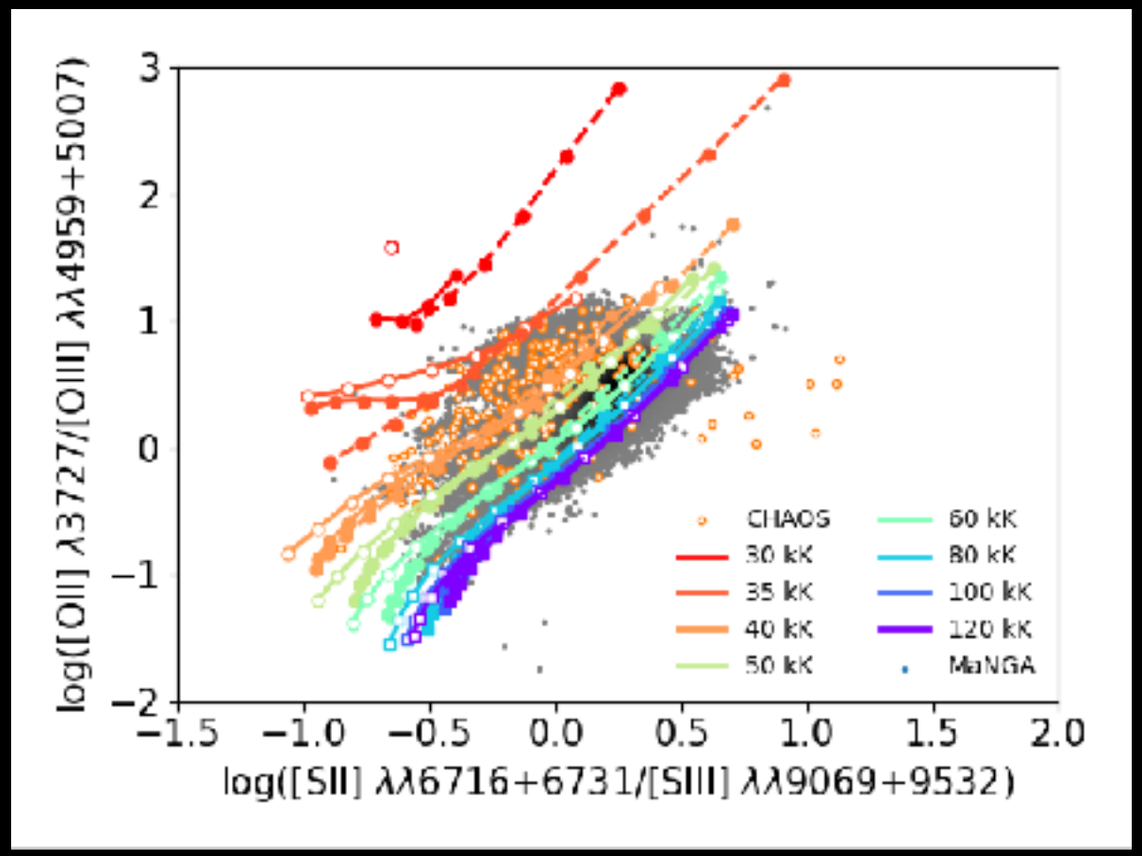


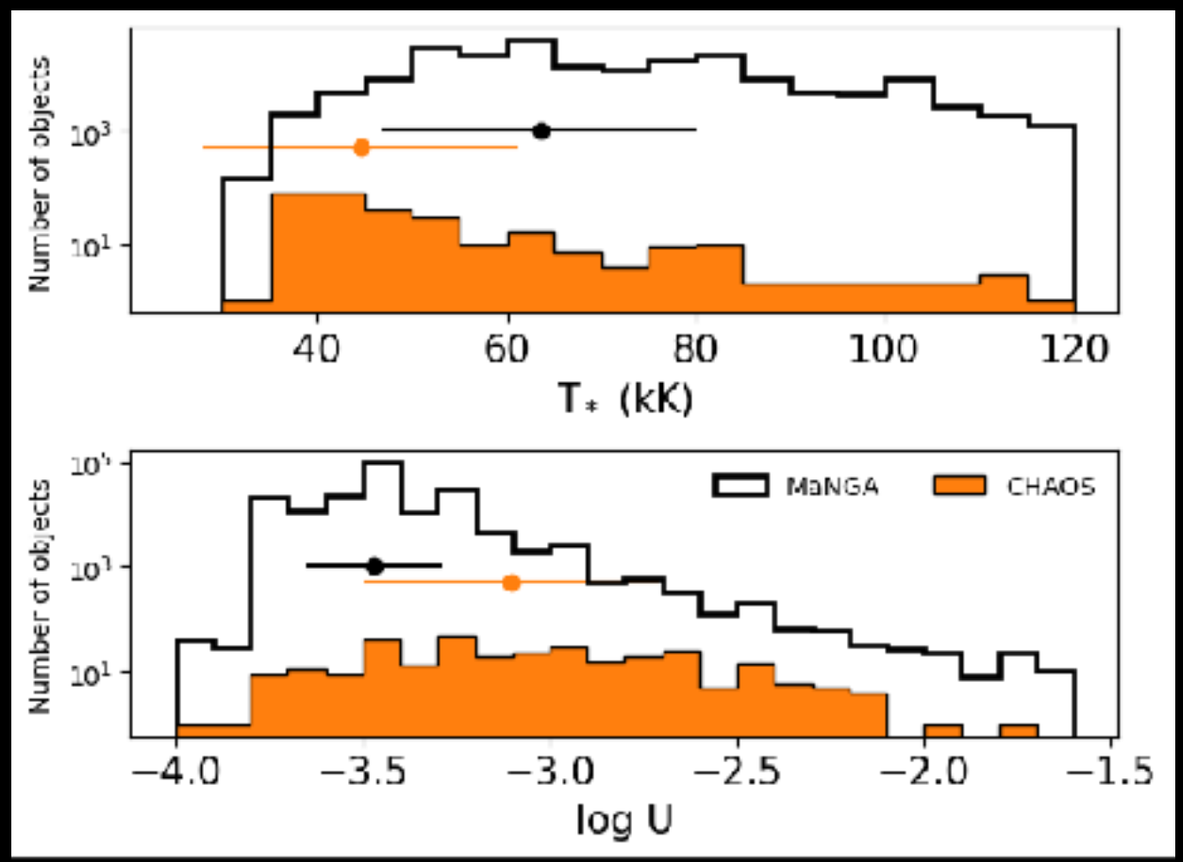


Pérez-Montero et al (2019)

THE IMPORTANCE OF GEOMETRY

More than 60% of HII regions in MaNGA would have T* > 60 kK, contrary to CHAOS.
This fraction is hugely reduced when replacing [SII] with other low-excitation line less affected by DIG.

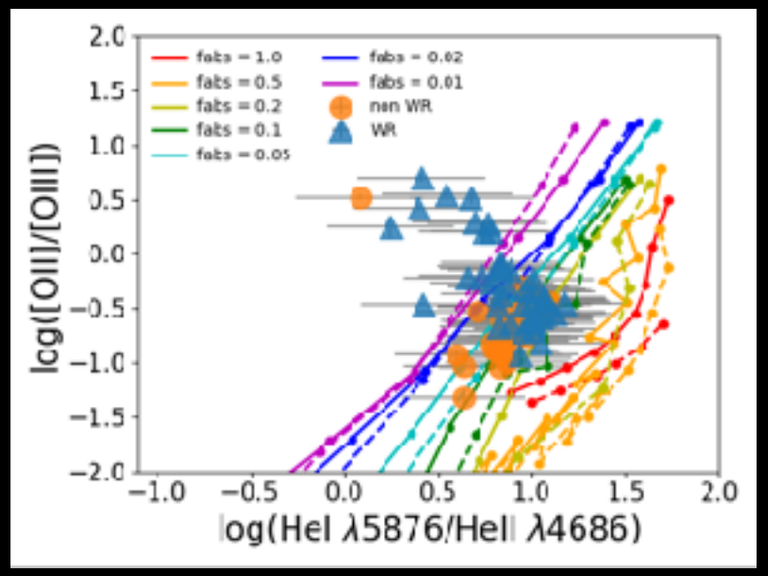


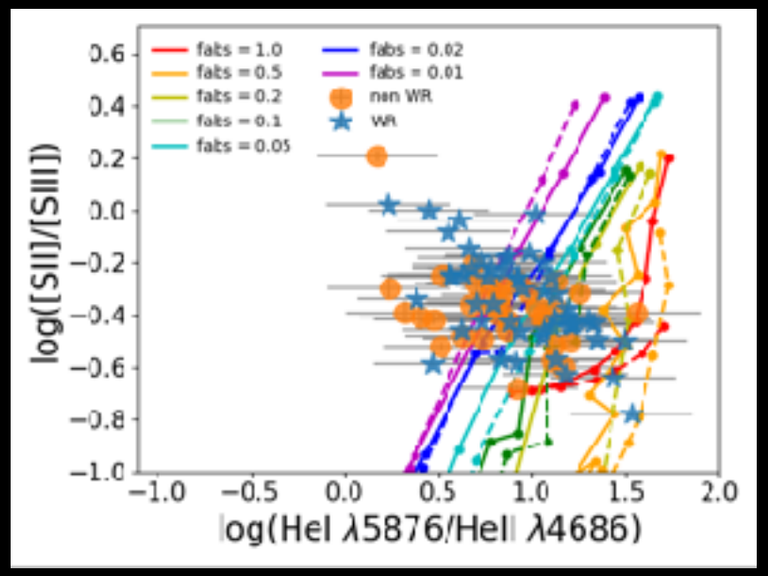


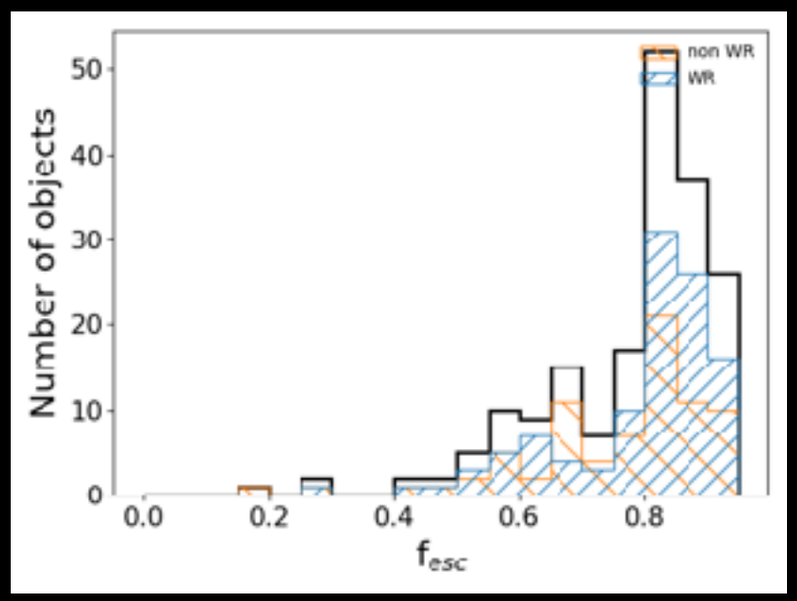
Pérez-Montero et al (2023a)

USING THE DIAGRAM FOR PHOTON ESCAPE FRACTION

Pérez-Montero et al (2020)



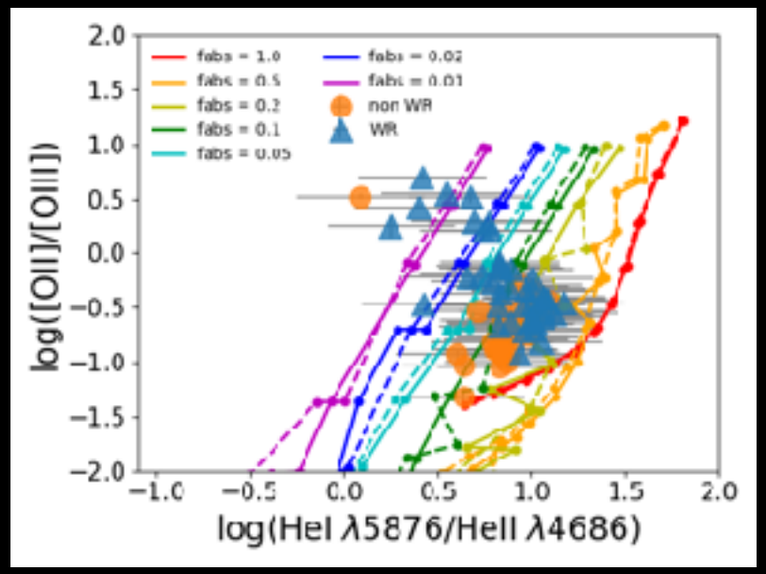


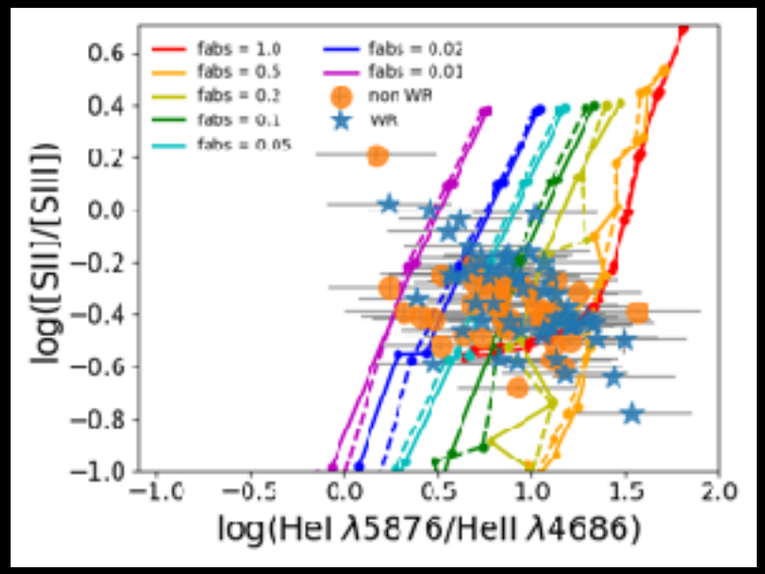


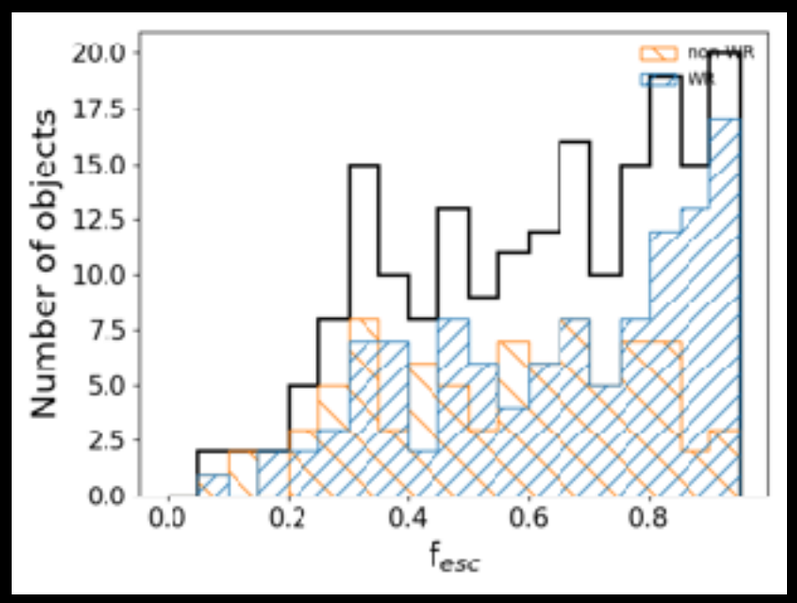
We can calculate f_esc from models using other line ratios.
The analysis of 129 HeII emitters in SDSS using BPASS v.2.1 models assuming Z* = Zg yields a mean value of 79% for both Wr and non WR objects.

USING THE DIAGRAM FOR PHOTON ESCAPE FRACTION

Pérez-Montero et al (2020)



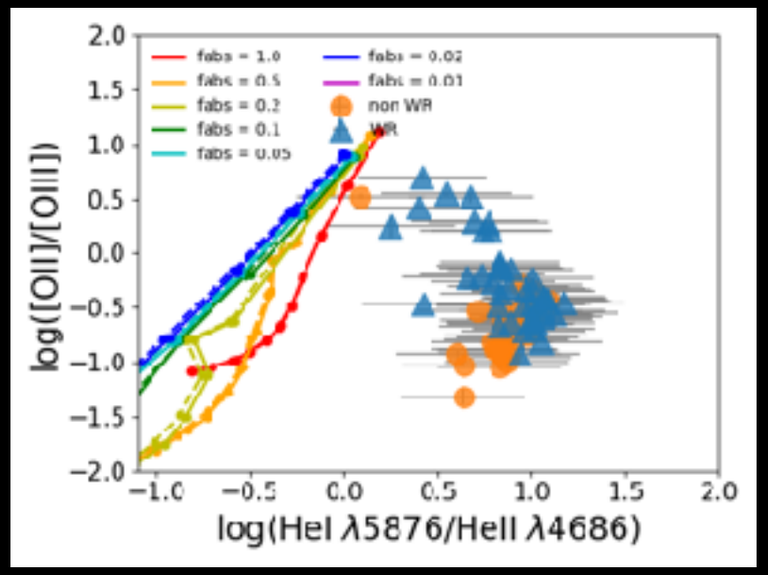


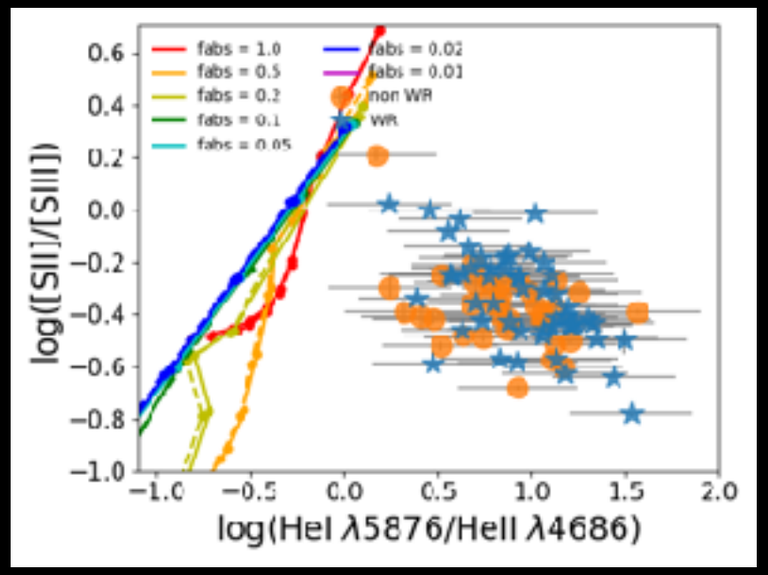


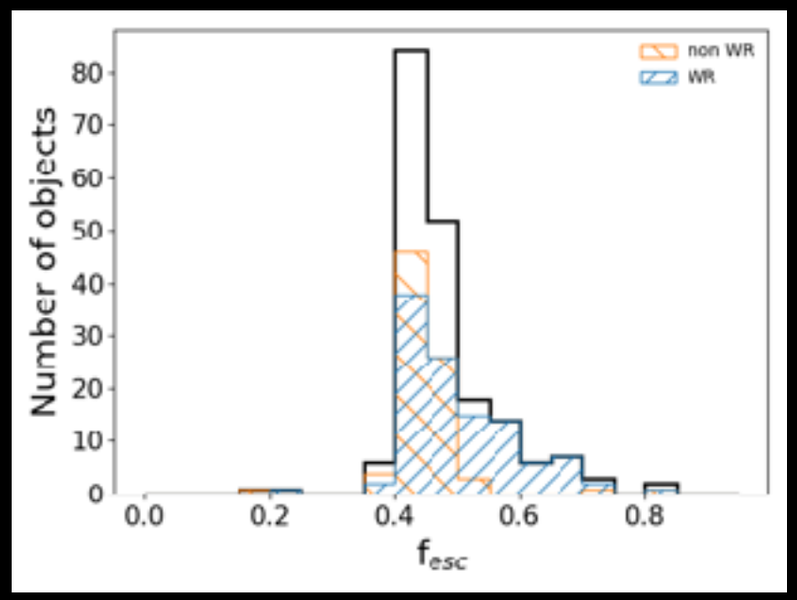
But this is sensitive to the assumed SED. For very-low Z stars (Z = 1e-5), the mean escape fraction for this sample is reduced to 62%.

USING THE DIAGRAM FOR PHOTON ESCAPE FRACTION

Pérez-Montero et al (2020)

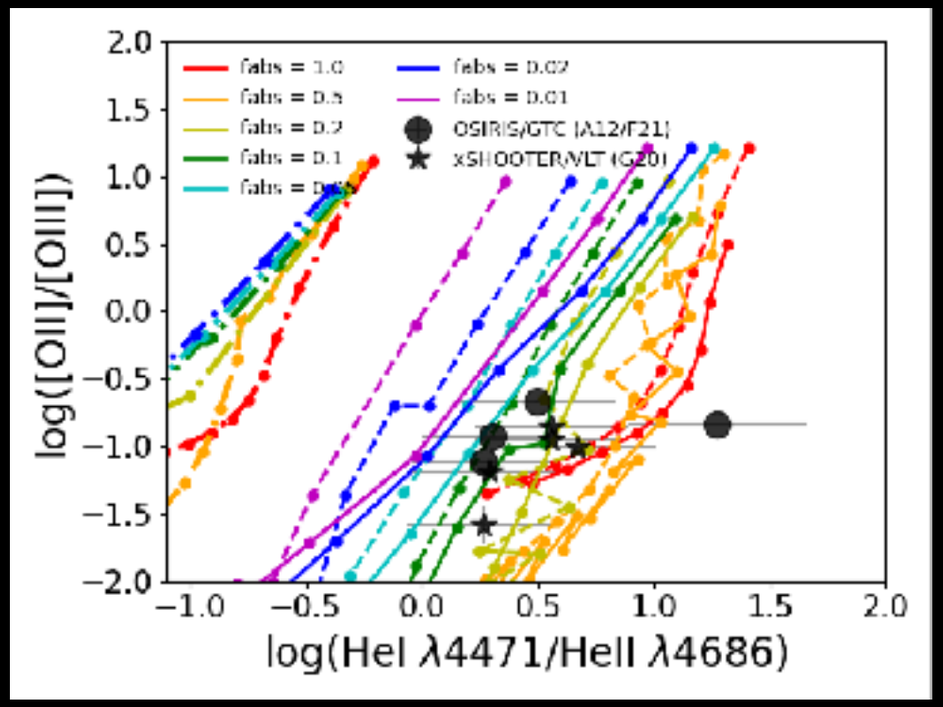


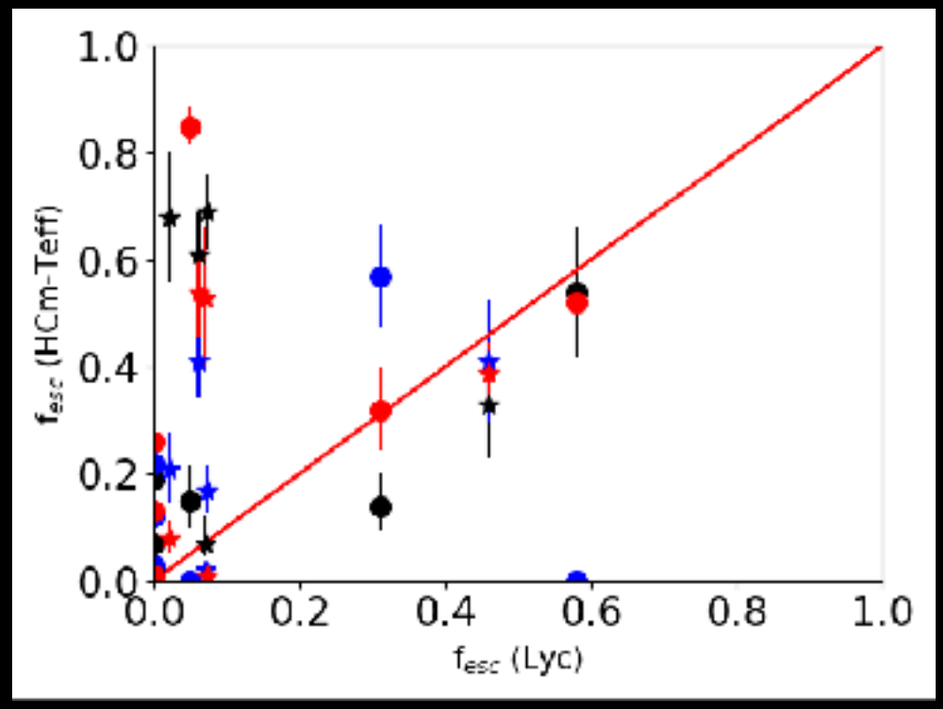




… and assuming SEDs for blackbody at T* = 1e5K)thought to be equivalent to PopIII stars= the mean fraction is reduced to 48%.

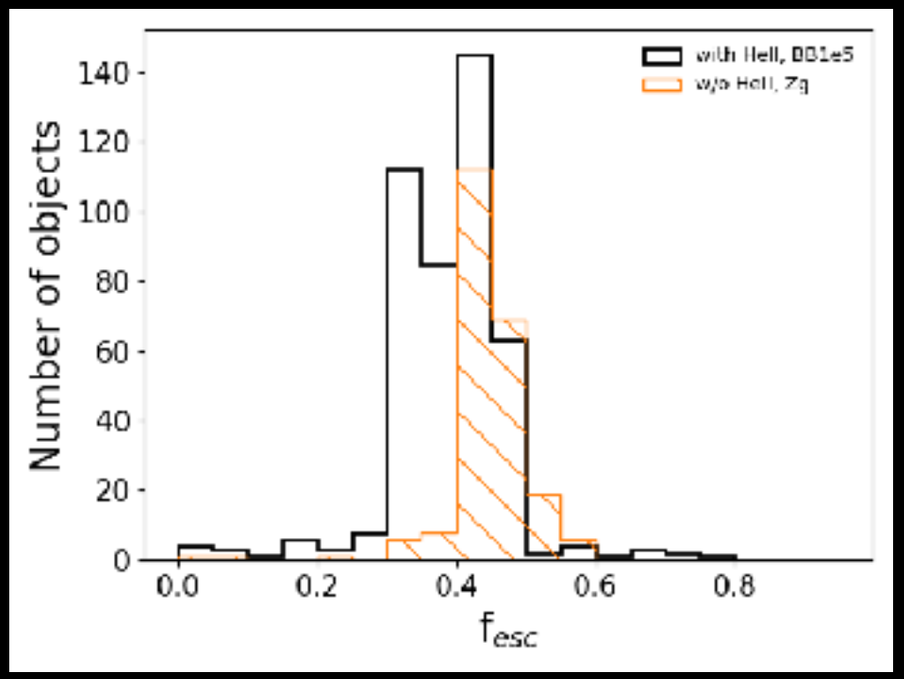
ANALYZING DEEP OPTICAL OBSERVATIONS OF GP

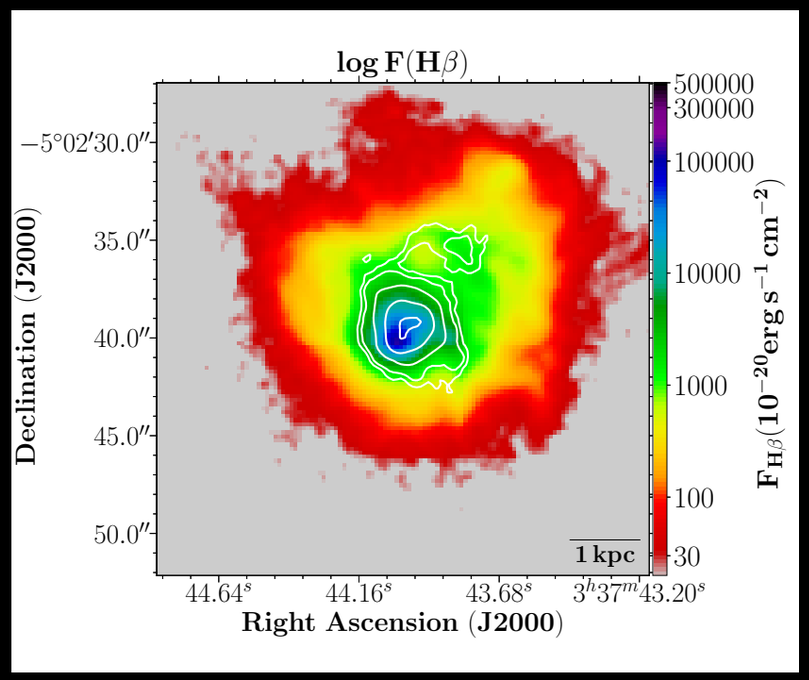




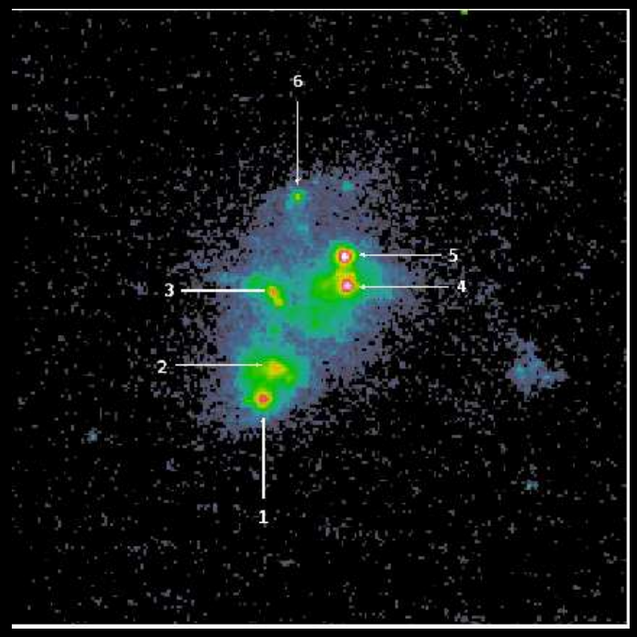
HeII emission has been retrieved from very deep spectroscopy in some GPs (OSIRIS/GTC: Amorín+12, Fernández+21 and xSHOOTER/VLT: Guseva+20). The derived escape fractions can be compared with data from Ravindranath+20, but the agreement is very dependent on the assumed Z in the stars.

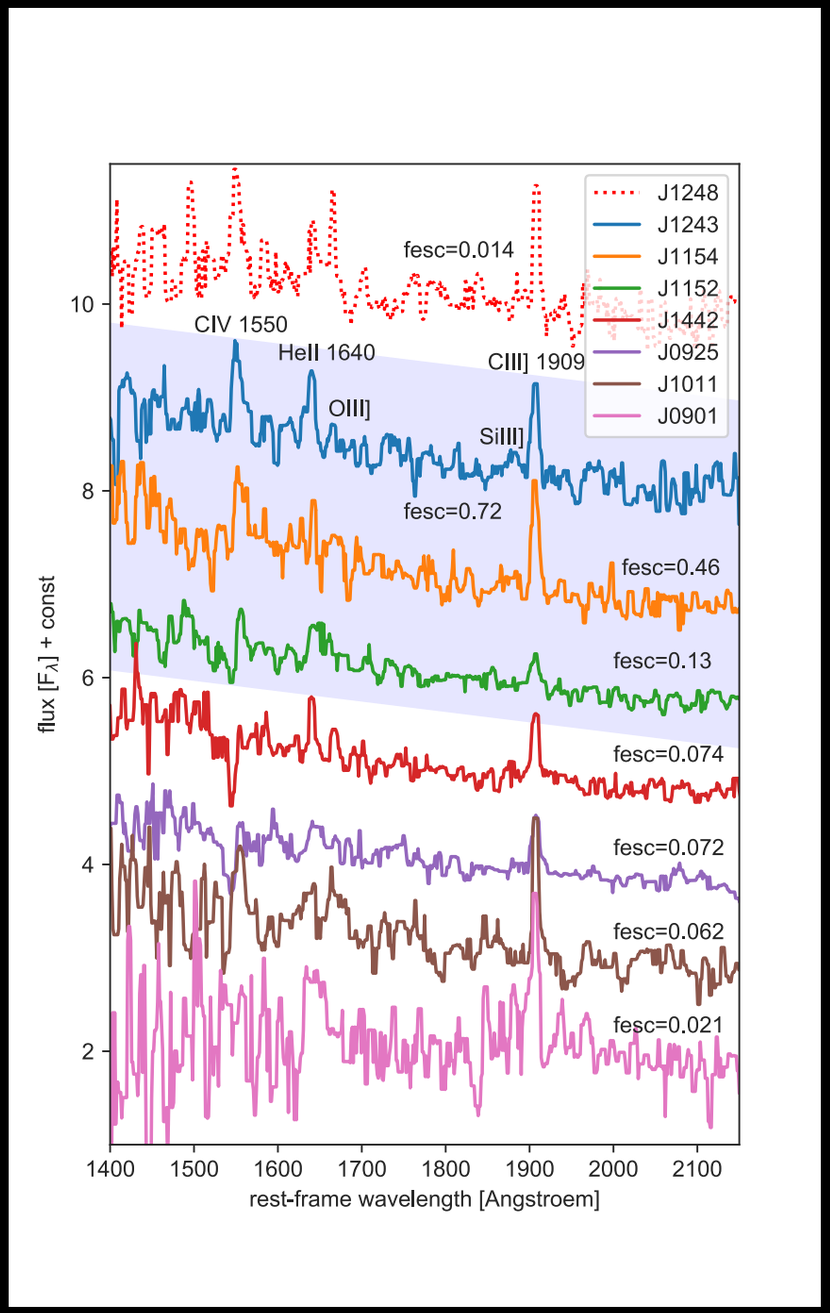
SPATIALLY-RESOLVED HeII EMITTERS

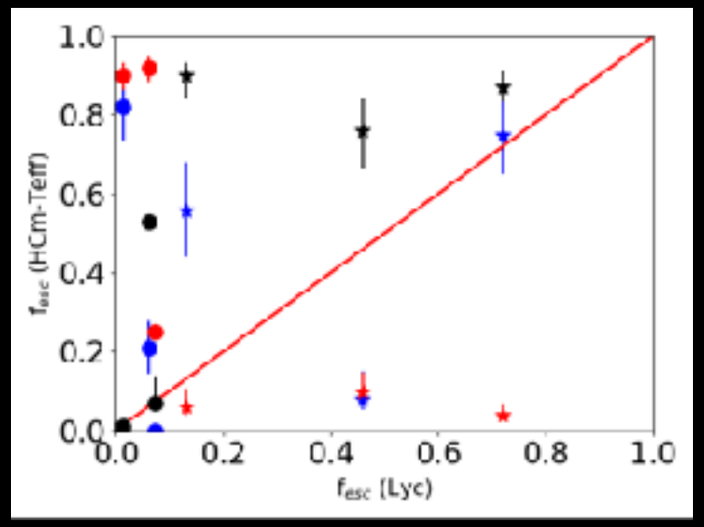


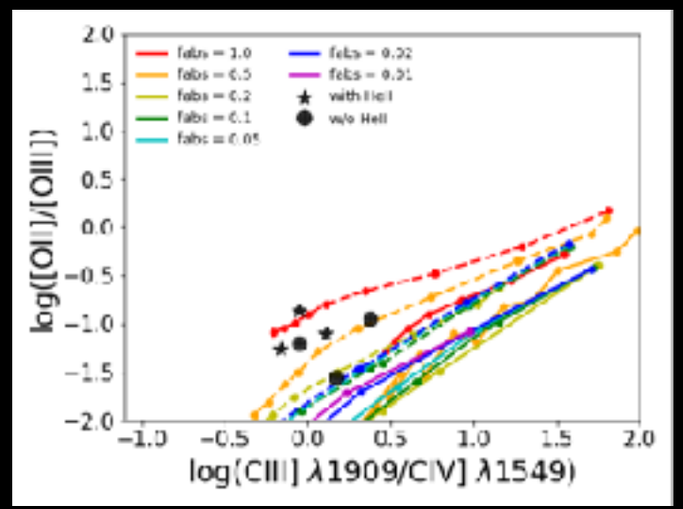


Analyzing MUSE data from SBS0335-052, escape fraction in spaxels with nebular HeII emission is consistent (~40%) with the rest of the galaxy only assuming PopIII stars (Kehrig et al in prep.)





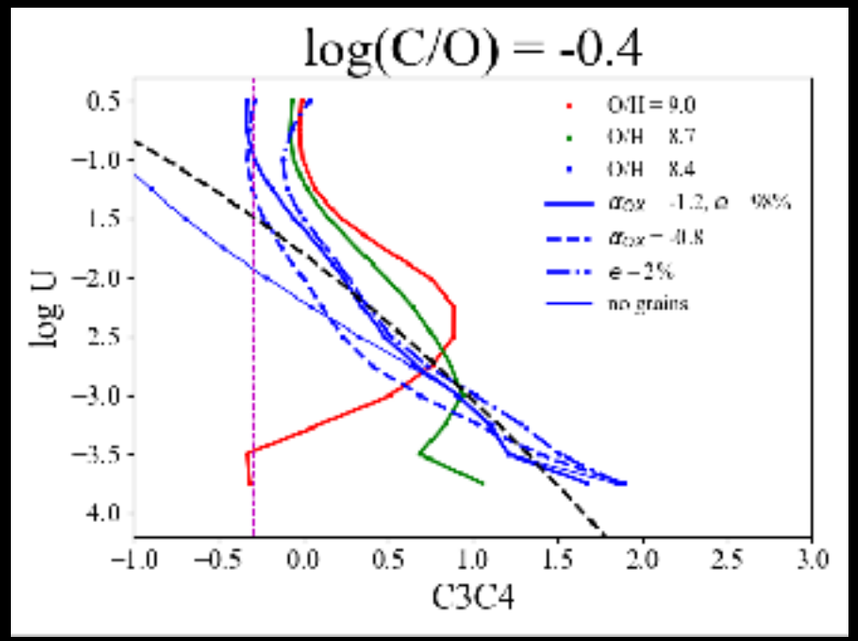


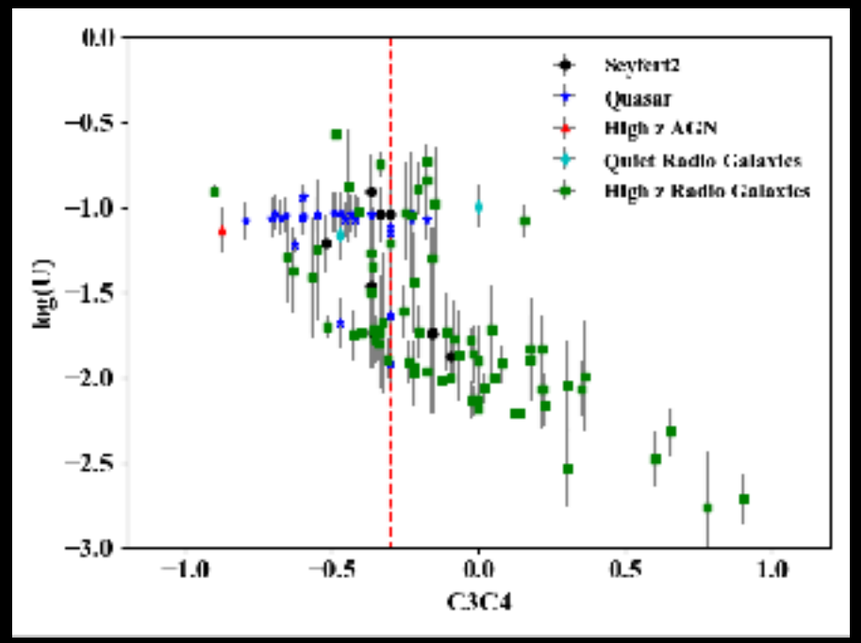


A version of the diagram using CIII]/CIV] can also be applied for leakers whose escape fraction can be measured directly from Lyman continuum (Schaerer+22).

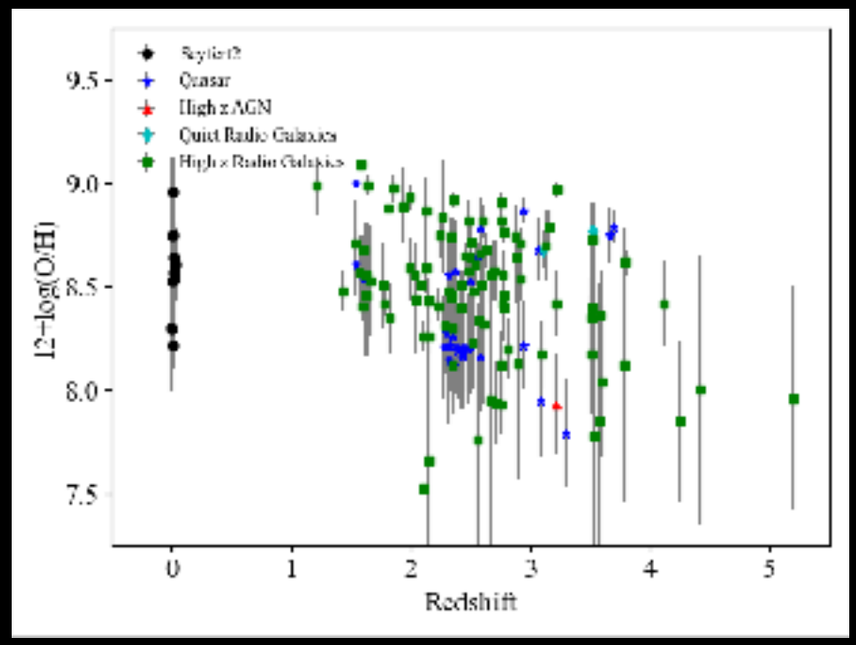
The agreement for HeII emitters is better when assuming very-low Z stellar populations.

¿PHOTON ESCAPE IN AGN





Half of the narrow-line AGN compiled sample with UV lines shows very low values of C3C4.
Thiscan only be reproduced by dust-free models, although matter-bounded geometry looks to be also possible at the derived Z.



Pérez-Montero et al (2023b)

SUMMARY AND CONCLUSIONS

The softness diagram 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 diagram also depends on geometry so it can be used to derive the fraction of escaping ionizing photons. The code is adapted to be used as a function of observed different ratios such as HeI/HeII or CIII]/CIV].

*Alternatively, it can be used to analyze the properties of the ionizing cluster or to explore the possible photon leaking in AGN.