

# Density biases and temperature relations for DESIRED H II regions

Mendez-Delgado et al.(2023), MNRAS 523, 2952–2973

## 1 Introduction

### Chemical abundances of ionized nebulae:

- Essential tool for studying chemical composition/evolution of the Universe
- **Determined from emission line spectra**(Collisionally excited lines)  
 ⇒ **Electron temperature and electron density are required, and their inhomogeneities should introduce a systematic bias**

Big surveys or deep spectra allow us to explore and minimize statistical errors  
 ⇒ **They constructed DESIRED (DEep Spectra of Ionized Regions Data base) to explore faint lines from ionized regions, such as recombination lines and auroral lines for electron temperature**

## 2 Samples

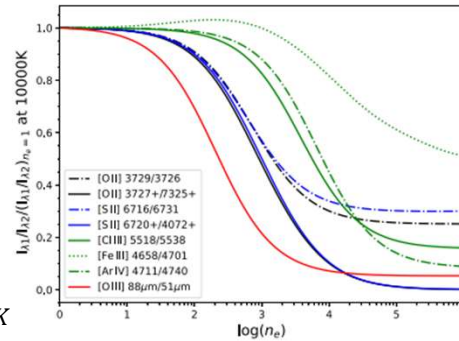
DESIRED comprises a set of 190 spectra(galactic/extragalactic HII region, PNe, etc.)

- **High resolution(R~20000) and medium resolution(R~3000)**
- **Metallicity(12+log(O/H)): 7.7~8.8**
- **They tried to have a strict control on telluric absorption/emission, but it is not perfect on [SIII](9069, 9532 Å)**  
 (they test [SIII] line with I(9532 Å)/I(9069 Å), because their theoretical ratio is 2.47)

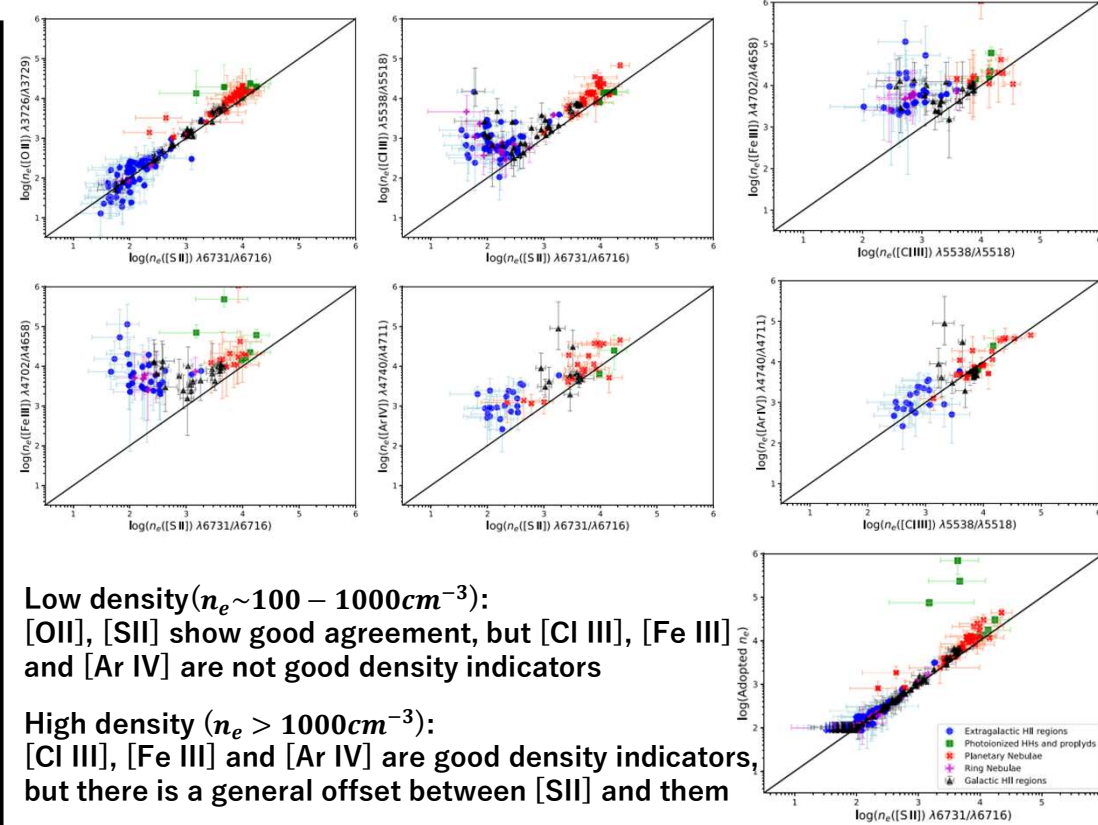
## 3 Density Structure

### Diagnosis of electron density:

- [S II]6716, 31 Å
- [O II]3726, 29 Å
- [Cl III]5518, 38 Å
- [Fe III]4658, 4701 Å
- [Ar IV]4711, 40 Å



Line ratio of density diagnosis, when  $T_e = 10000K$



**Low density ( $n_e \sim 100 - 1000cm^{-3}$ ):**  
 [OII], [SII] show good agreement, but [Cl III], [Fe III] and [Ar IV] are not good density indicators

**High density ( $n_e > 1000cm^{-3}$ ):**  
 [Cl III], [Fe III] and [Ar IV] are good density indicators, but there is a general offset between [SII] and them

The nebulae may contain inhomogeneities (like high-density clumps), then **they adopted a representative density for chemical abundance determinations**

- I. If  $n_e([S II]) < 100cm^{-3}$ , they adopted  $n_e = 100 \pm 100cm^{-3}$
- II. If  $100 < n_e([S II]) < 1000cm^{-3}$ , they adopted the average of  $n_e([OII])$  and  $n_e([S II])$
- III. If  $n_e([S II]) > 1000cm^{-3}$ , they adopted the average of  $n_e([OII])$ ,  $n_e([S II])$ ,  $n_e([Cl III])$ ,  $n_e([FeIII])$  and  $n_e([ArIV])$
- IV. For Herbig–Harro objects, they adopted  $n_e([FeIII])$  or  $n_e([S II] 4069, 76\text{Å})$  (proplyd 170-337)

# 4 Temperature Structure

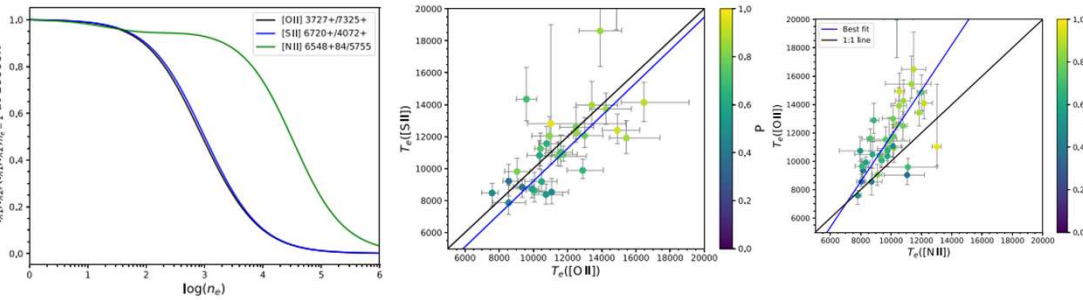
## 4.1 [SII], [OII] [NII] electron temperature

Diagnosis of electron temperature:

- [S II] 4069, 76, 6716, 31 Å
- [O II] 3726, 29, 7319, 20, 30, 31 Å
- [N II] 5755, 6548, 84 Å
- [O III] 4363, 4959, 5007 Å
- [S III] 6312, 9069, 9532 Å
- [Ar III] 5192, 7135 Å

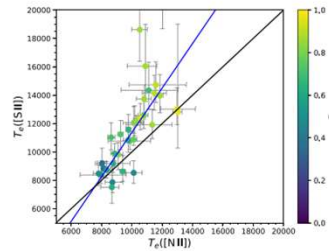
According to photoionization model,  $T_e([SII]) \sim T_e([OII]) \sim T_e([NII])$

However, **this is not satisfied observationally due to density variations**

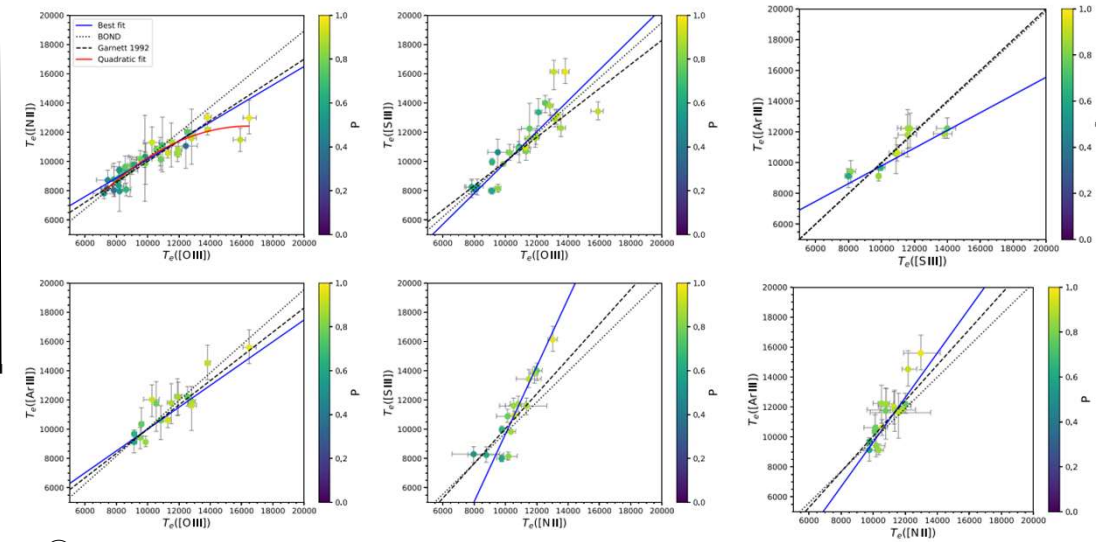


$n_e([SII])$  underestimates the density by  $\sim 300 cm^{-3}$  on average

↓  
If  $T_e([NII])$  is adopted, it has small impact on temperature and abundance



## 4.2 Temperature relationship for extragalactic HII regions



①  $T_e([OIII]) - T_e([NII])$ :

Confirm a departure from a linear relationship, predicted with models, due to temperature inhomogeneities

(Correction of this effect is proposed by Mendez-Delgado et al. (2023))

②  $T_e([Ar III])$ :

It shows the similar behavior as  $T_e([OIII])$

③  $T_e([OIII]) - T_e([SIII])$

It shows a linear trend, but the dispersion is large because of the telluric absorptions

④  $T_e([NII]) - T_e([SIII])$

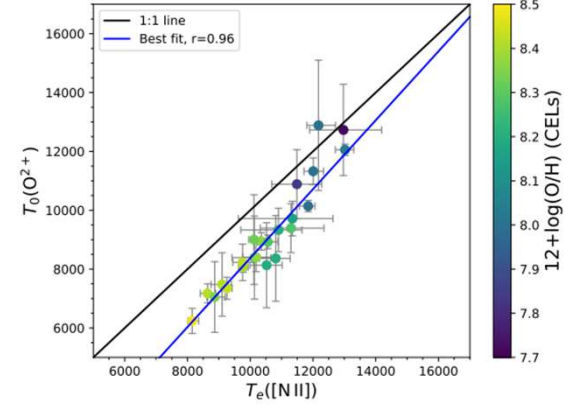
Slope of linear trend is steeper than prediction, but the cause is not be filtered (temperature inhomogeneities, telluric absorptions, etc.)

## 5 Conclusion

- With DESIREd, they explored the density/temperature structure of ionized regions
- They determined representative electron densities for chemical abundance
- [OII] and [SII] should not be used as diagnosis of electron temperature
- Confirm a departure from a linear fit in  $T_e([OIII]) - T_e([NII])$ , due to temperature inhomogeneities

**Table A8** Ionic abundances of the H II regions and other nebulae.

Region	$12+\log(\text{O}^+/\text{H}^+)$ CELS	$12+\log(\text{O}^{2+}/\text{H}^+)$ CELS $t^2(\text{O}^{2+})=0$	$12+\log(\text{O}^{2+}/\text{H}^+)$ RLs	Ref.
<b>Extragalactic H II regions</b>				
NGC 5461	$7.78^{+0.08}_{-0.06}$	$8.29 \pm 0.05$	$8.46^{+0.14}_{-0.13}$	[62]
NGC 588	$7.40^{+0.27}_{-0.11}$	$8.11^{+0.09}_{-0.06}$	$8.33 \pm 0.08$	[63]
NGC 595	$8.29^{+0.05}_{-0.04}$	$8.02^{+0.14}_{-0.05}$	$8.34^{+0.08}_{-0.09}$	[62]
K 932	$7.87^{+0.05}_{-0.03}$	$8.30 \pm 0.03$	$8.50 \pm 0.07$	[62]
IC 132	$7.17^{+0.21}_{-0.14}$	$8.24^{+0.09}_{-0.06}$	$8.38 \pm 0.10$	[63]
N 11B	$7.99^{+0.03}_{-0.04}$	$8.17^{+0.03}_{-0.01}$	$8.37 \pm 0.03$	[38]
NGC 5471	$7.17^{+0.07}_{-0.06}$	$7.93^{+0.02}_{-0.01}$	$8.05 \pm 0.15$	[64]
N 66A	$7.49^{+0.06}_{-0.04}$	$7.84 \pm 0.02$	$7.99 \pm 0.05$	[38]
NGC 604	$7.92 \pm 0.06$	$8.23 \pm 0.04$	$8.43 \pm 0.07$	[62]
NGC 6822	$7.37^{+0.36}_{-0.16}$	$8.08^{+0.03}_{-0.02}$	$8.31^{+0.08}_{-0.07}$	[65]
UV-1	$7.80^{+0.14}_{-0.09}$	$8.09 \pm 0.02$	$8.50^{+0.13}_{-0.14}$	[66]
NGC 5408	$7.29^{+0.14}_{-0.12}$	$7.70 \pm 0.03$	$8.18 \pm 0.10$	[65]
NGC 1714	$7.65^{+0.13}_{-0.08}$	$8.27^{+0.03}_{-0.05}$	$8.45 \pm 0.07$	[38]
N 81	$7.30^{+0.04}_{-0.03}$	$7.90^{+0.03}_{-0.02}$	$8.22 \pm 0.03$	[38]
IC 2111	$8.05^{+0.08}_{-0.06}$	$8.18 \pm 0.04$	$8.34^{+0.09}_{-0.10}$	[38]
NGC 2363	$6.57^{+0.12}_{-0.13}$	$7.69^{+0.02}_{-0.03}$	$8.02^{+0.11}_{-0.10}$	[62]
30Dor	$7.62 \pm 0.05$	$8.27 \pm 0.01$	$8.42 \pm 0.05$	[67]
N 44C	$7.30 \pm 0.05$	$8.23 \pm 0.02$	$8.56^{+0.04}_{-0.03}$	[38]
HII-2	$7.66^{+0.11}_{-0.10}$	$8.06 \pm 0.02$	$8.57^{+0.15}_{-0.14}$	[66]
NGC 5455	$7.74 \pm 0.03$	$8.18 \pm 0.03$	$8.28^{+0.15}_{-0.14}$	[64]
VS44	$7.91^{+0.08}_{-0.06}$	$8.15^{+0.04}_{-0.06}$	$8.41 \pm 0.15$	[62]
N 88A	$6.88 \pm 0.07$	$8.00^{+0.02}_{-0.01}$	$8.18 \pm 0.02$	[38]
HII-1	$7.59^{+0.09}_{-0.06}$	$8.07 \pm 0.02$	$8.57 \pm 0.16$	[66]



**Fig. 2** Relation between  $T_e([\text{N II}] \lambda 5755/\lambda 6584)$  and  $T_e(\text{O}^{2+})$  for extragalactic H II regions.

$$T_0(\text{O}^{2+}) = (1.17 \pm 0.05) \times T_e([\text{N II}]) - (3340 \pm 470) \text{ (K)}. \quad (4)$$