Gas-phase Fe/O and Fe/N abundances in Star-Forming Regions
Relations between nucleosynthesis, metallicity and dust

Méndez-Delgado et al., arXiv :2408.06215v1

ABSTRACT

Context. In stars, metallicity is usually traced using Fe, while in nebulae, O serves as the preferred proxy. Both elements have different nucleosynthetic origins and are not directly comparable. Additionally, in ionized nebulae, Fe is heavily depleted onto dust grains.
Aims. We investigate the distribution of Fe gas abundances in a sample of 452 star-forming nebulae with [Fe III] λ4658 detections and their relationship with O and N abundances. Additionally, we analyze the depletion of Fe onto dust grains in photoionized environments.
Methods. We homogeneously determine the chemical abundances with direct determinations of electron temperature (T_e), considering the effect of possible internal variations of this parameter. We adopt a sample of 300 Galactic stars to interpret the nebular findings.
Results. We find a moderate linear correlation ($r = -0.59$) between Fe/O and O/H. In turn, we report a stronger correlation ($r = -0.80$) between Fe/N and N/H. We interpret the tighter correlation as evidence of Fe and N being produced on similar timescales while Fe-dust depletion scales with the Fe availability. The apparently flat distribution between Fe/N and N/H in Milky Way stars supports this interpretation. We find that when 12+log(O/H)<7.6, the nebulae seem to reach a plateau value around log(Fe/O) ≈ −1.7. If this trend is confirmed, it would be consistent with a very small amount of Fe-dust in these systems, similar to what is observed in high-z galaxies discovered by the *James Webb Space Telescope* (JWST). We derive a relationship that allows us to approximate the fraction of Fe trapped into dust in ionized nebulae. If the O-dust scales in the same way, its possible contribution in low metallicity nebulae would be negligible. After analyzing the Fe/O abundances in J0811+4730 and J1631+4426, we do not see evidence of the presence of very massive stars with $M_{ini} > 300 M_\odot$ in these systems.
Conclusions. The close relation observed between the N and Fe abundances has the potential to serve as a link between stellar and nebular chemical studies. This requires an expansion of the number of abundance determinations for these elements in both stars and star-forming nebulae, especially at low metallicities.

1 Introduction

Metallicity = Abundance of heavy element(Z>3): key to understanding formation/evolution of galaxies

Oxygen(O):
- Tracer of metallicity in ionized nebulae
- Produced by type II supernovae (SNe)

Nitrogen(N):
- Produced by ①Massive stars ②CNO cycle in intermediate-mass stars
- ① is analogues to O, and the timescale of ② (~40Myr) is also necessary for type Ia SNe(production of Fe)
- Could serve as a bridge between stellar metallicities and nebular ones?

Iron(Fe):
- Tracer of stellar metallicity
- Produced by type Ia SNe
- **Comparison with metallicity in ionized nebulae is not straightforward**
- **Most of Fe in ionized nebular are depleted onto dust grains**

↳ **Dependence of depletion on abundance of other elements**
  - Active research area
  - Key to understanding the properties of interstellar dust

Contents of this research:
- **Discuss the relation between the abundance of N, O and Fe**
- **Compare the nebular abundance with stellar ones**

2 Samples

Selected from observation data in JWST/DESIRED project

Sample selection criteria(star forming region):
- S/N([FeIII]4658Å)>2.5
- At least one of the auroral lines ([OIII]4363Å, [NII]5755Å, [SIII]6312Å) are detected
- To ensure the quality of the data, the measured value of [OIII](5007Å/4959Å), [SIII](9531Å/9069Å) and [NII](6584Å/6548Å) are consistent with theoretical values within 20%(Quality check)

They adopt galactic stellar abundances for Fe, O and N from B-type stars and dwarf stars(low-mass stars)

3 Abundance determination

3.1 Electron temperature/Electron density

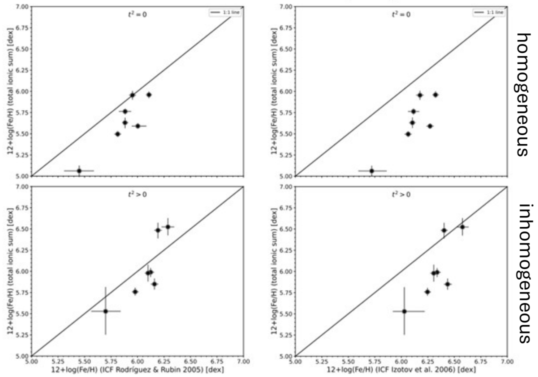
Electron density:
1. **Derive electron density with [SII], [OII], [Cl III], [FeIII], [ArIV], respectively**
2. **Decide the representative value of nebulae:**
   ① n_e**([SII])<100 cm^{-3} : 100 ± 100 cm^{-3}**
   ② n_e**([SII])=100~1000cm^{-3} : Average between n_e([SII]) and n_e([OII])**
   ③ n_e**([SII])>1000 cm^{-3} : Average of n_e([SII]), n_e([OII]), n_e([Cl III]), n_e([FeIII]) and n_e([ArIV])**

Electron temperature:
1. **Derive with [SIII], [OIII] and [NII]**
2. **If the "Quality check" is not passed, their use for determining electron temperature is discarded**

3.2 Ionic/Total abundance

Ionic abundance
1. Calculate the emissivity of [FeIII], [NII], [OII] and [OIII] with electron density and temperature
   a. [FeIII], [NII], [OII]: utilize [NII] electron temperature
   b. [OIII]: utilize [OIII] electron temperature, considering homogeneous and inhomogeneous conditions
2. Transform flux ratio of each lines to Hβ, to ionic abundance with emissivity

Total abundance
- Sum the contribution of ionic abundance to estimate the total abundance
- Oxygen: ignore the contribution of O^{3+}, and the difference of (in)homogeneous situation
- Nitrogen: Consider the contribution of N^{2+} with the ICF introduced by Amayo et al.(2021)
- **Iron: Discuss the contribution of Fe^{3+} with two ICFs and (in)homogeneous models with Fe^{3+} abundance measured with [FeIV] lines**

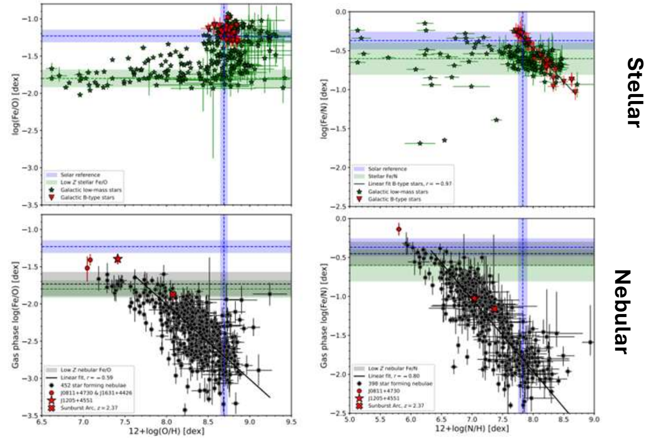


ICF(Rodriguez+05)　　ICF(Izotov+06)

⇒Rodriguez's ICF and inhomogeneous model is the most consistent with measured value with "direct method"

4 Result

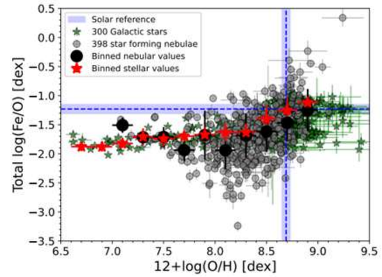
4.1 Gas abundance



Fe/N abundance ratio of low mass stars are constant

⇒Utilize this relation for correction of depletion:

$$\frac{Fe_{Dust}}{Fe_{Total}} = 1 - 1 \times 10^{-5} \times \left(\frac{N}{H}\right)^{-0.91}$$



5 Conclusion

- **We adopted ICF produced by Rodriguez & Rubin(2005) and inhomogeneous electron temperature model for correction of Fe^{3+}**(more samples is necessary to resolve)
- **Fe/O and Fe/N of nebulae have linear relation (due to the depletion onto dust) and large dispersion (because of the dust destruction by shocks). In metal-poor objects, these ratio can be constant**
- **We corrected the depletion of Fe with Fe/N relation. N abundance is one of the good tools to bridge between the stellar metallicities and nebular ones**