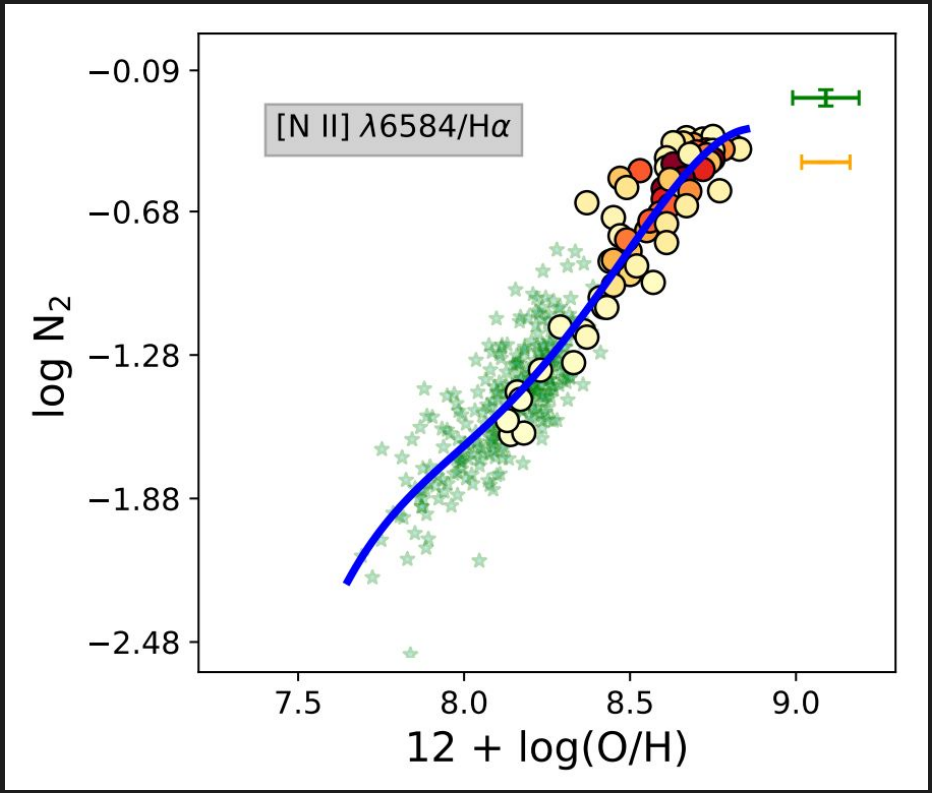
Charting the redshift evolution of metallicity indicators using SIMBA

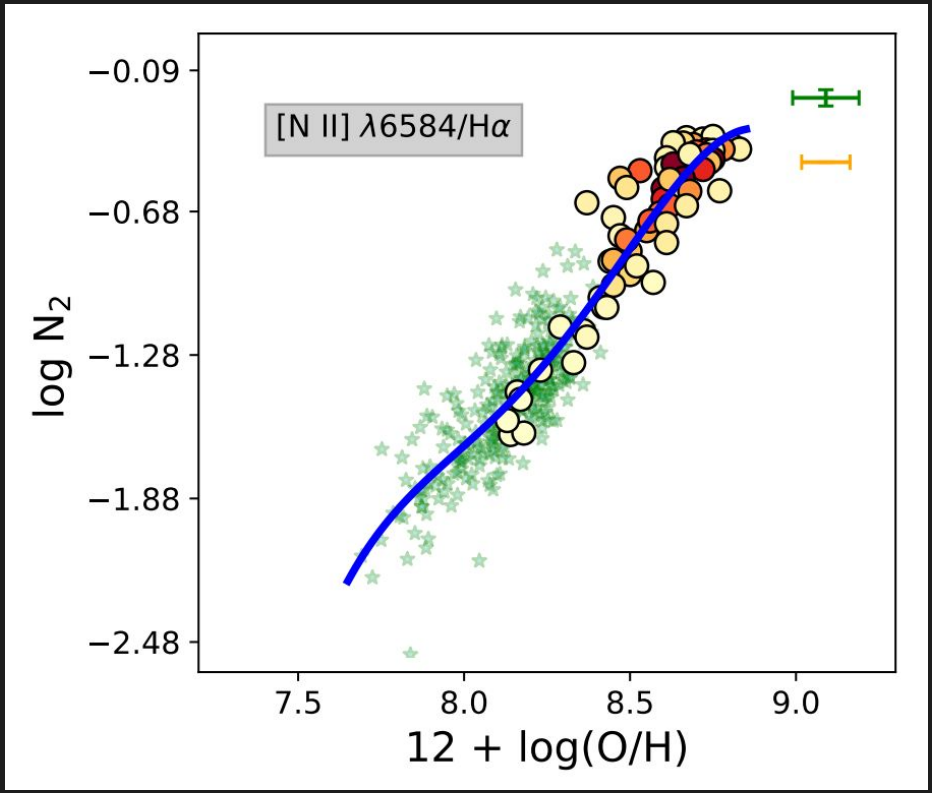
Prerak Garg
(University of Florida)

Advisor: Desika Narayanan

In collaboration with Nell Byler, Ryan L. Sanders, Alice E. Shapley, Allison L. Strom, Chris Lovell and others



(Curti et al. 2017)

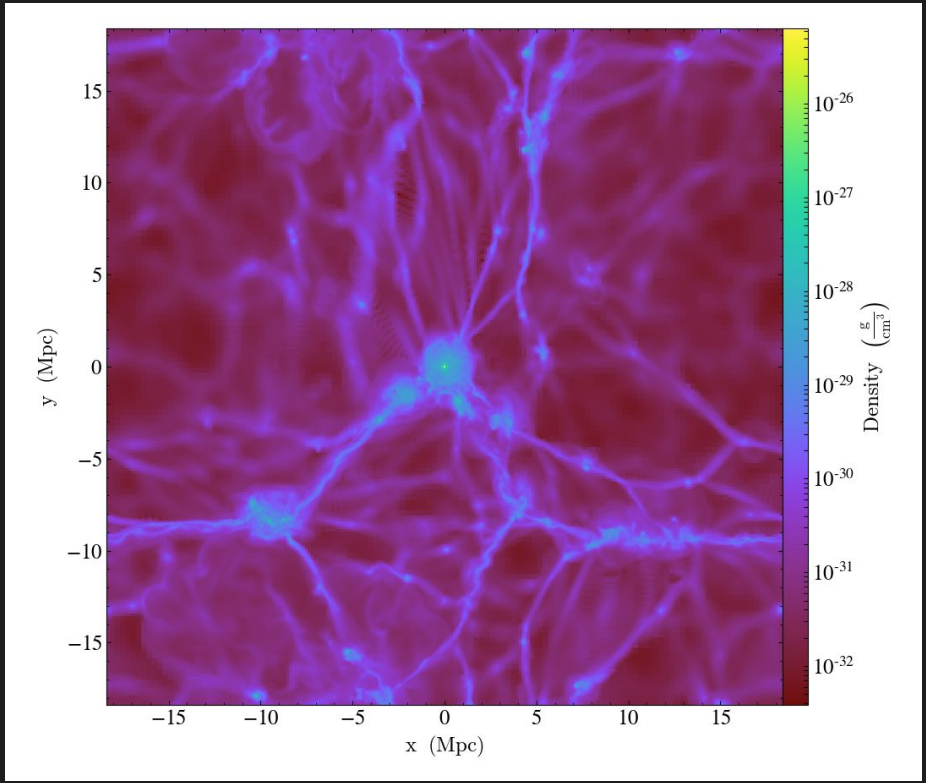


(Curti et al. 2017)

Auroral lines: [OIII] λ4363, [OII]λ7320,7330, [SII]λ4069 and many more.

Do the strong line metallicity indicators evolve with redshifts ?

SIMBA Box



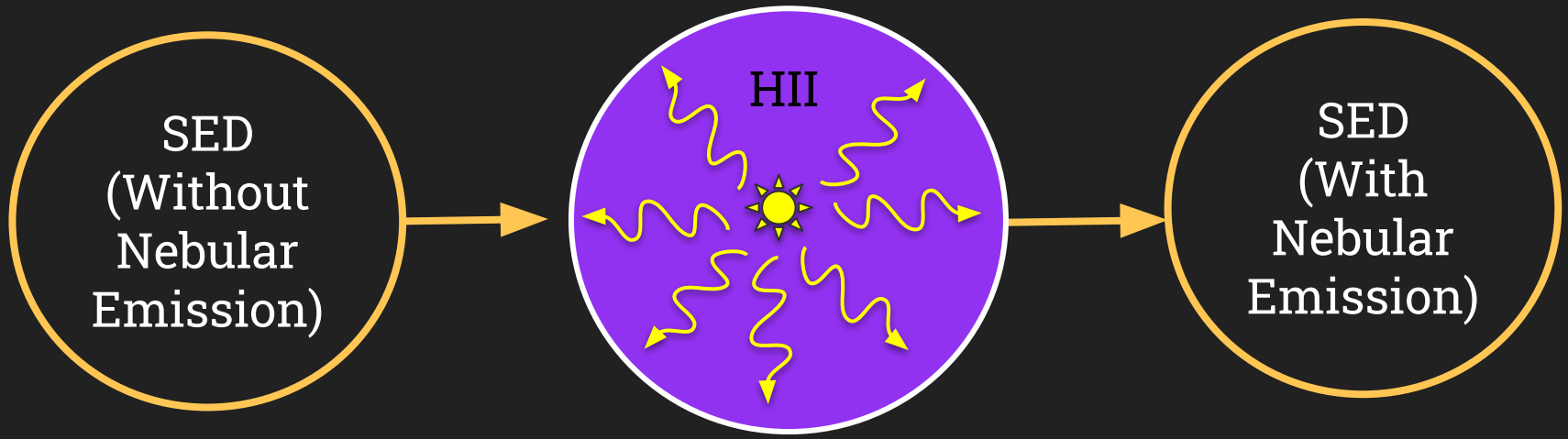
(Davé et al 2019)

We use 4 simulation boxes: $25h^{-1}$ Mpc with 512^3 particles.

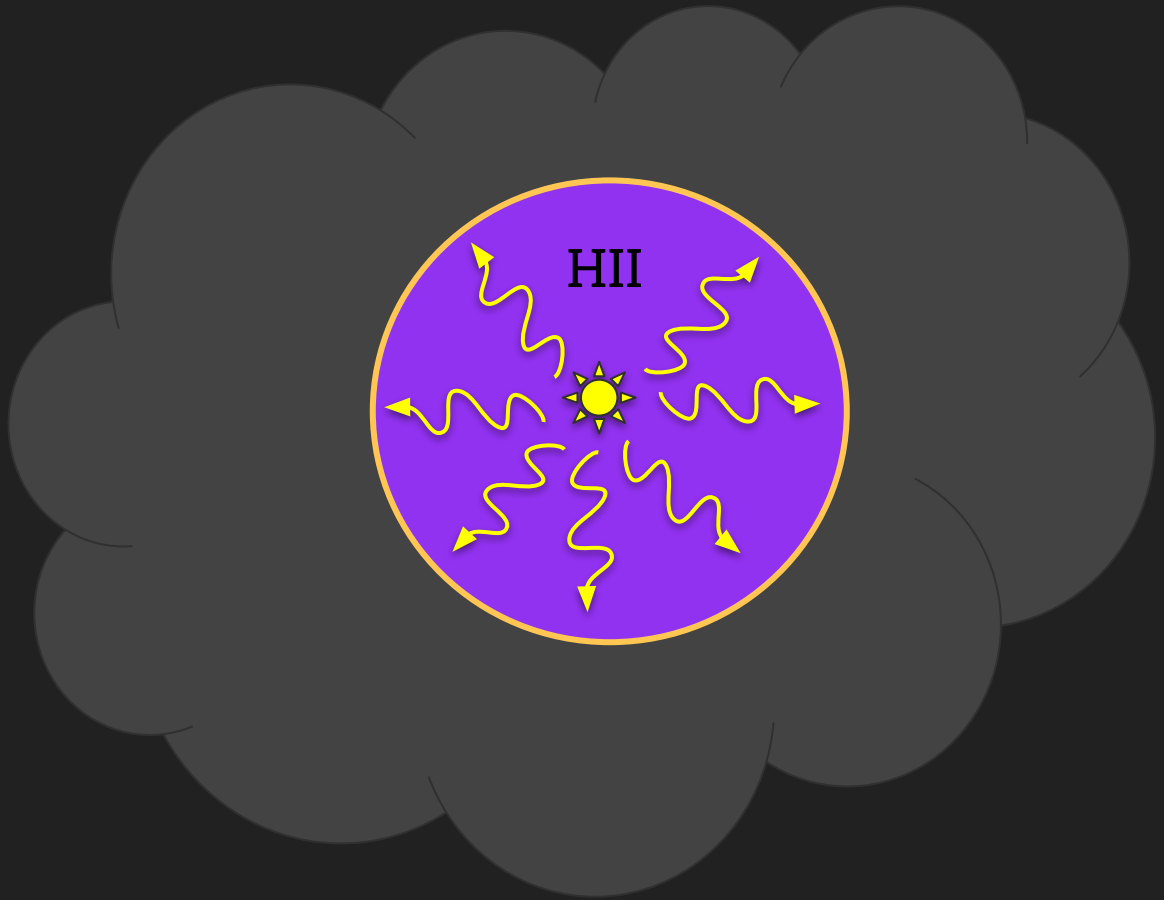
z = 0 - 5 : 2000 galaxies per redshift

CLOUDY

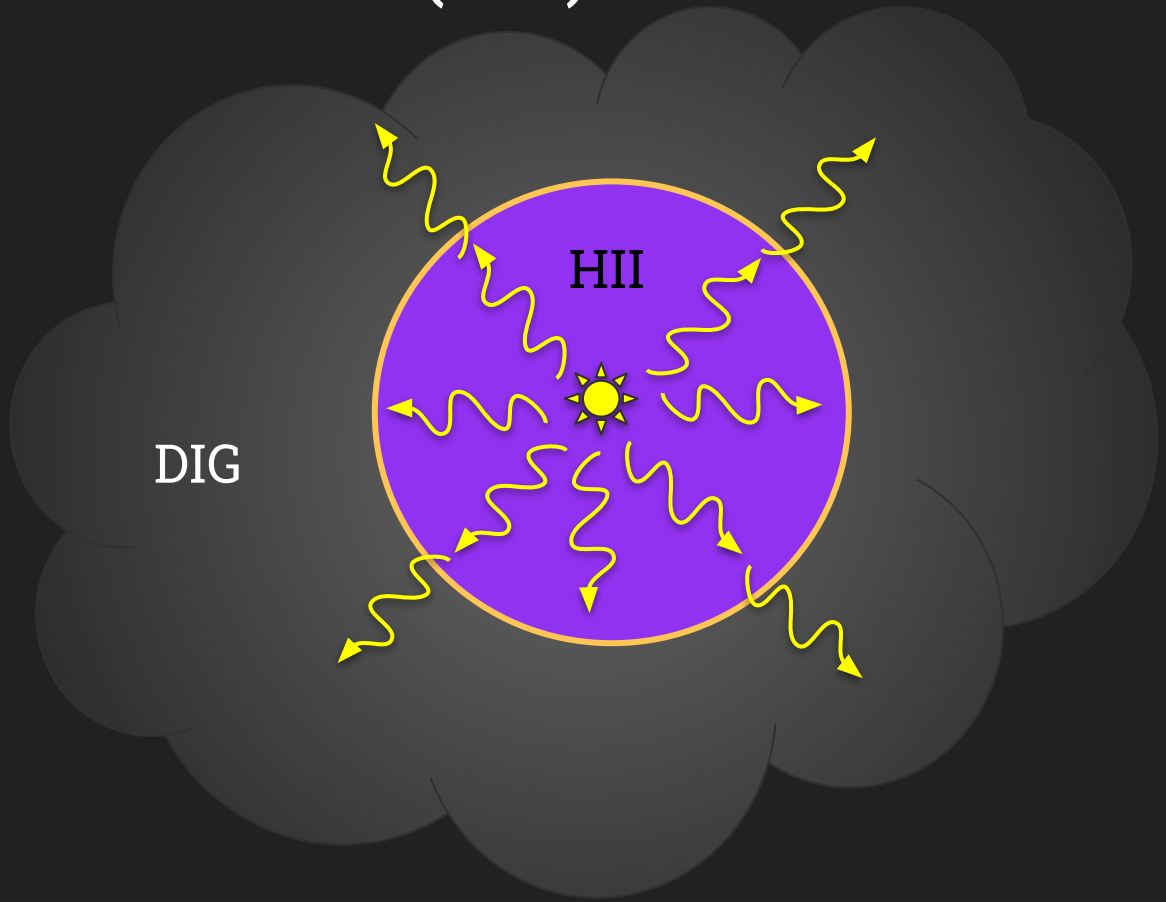
It is a photoionization code. It simulates physical conditions within gas clouds over a wide range of density , temperature and physical state.

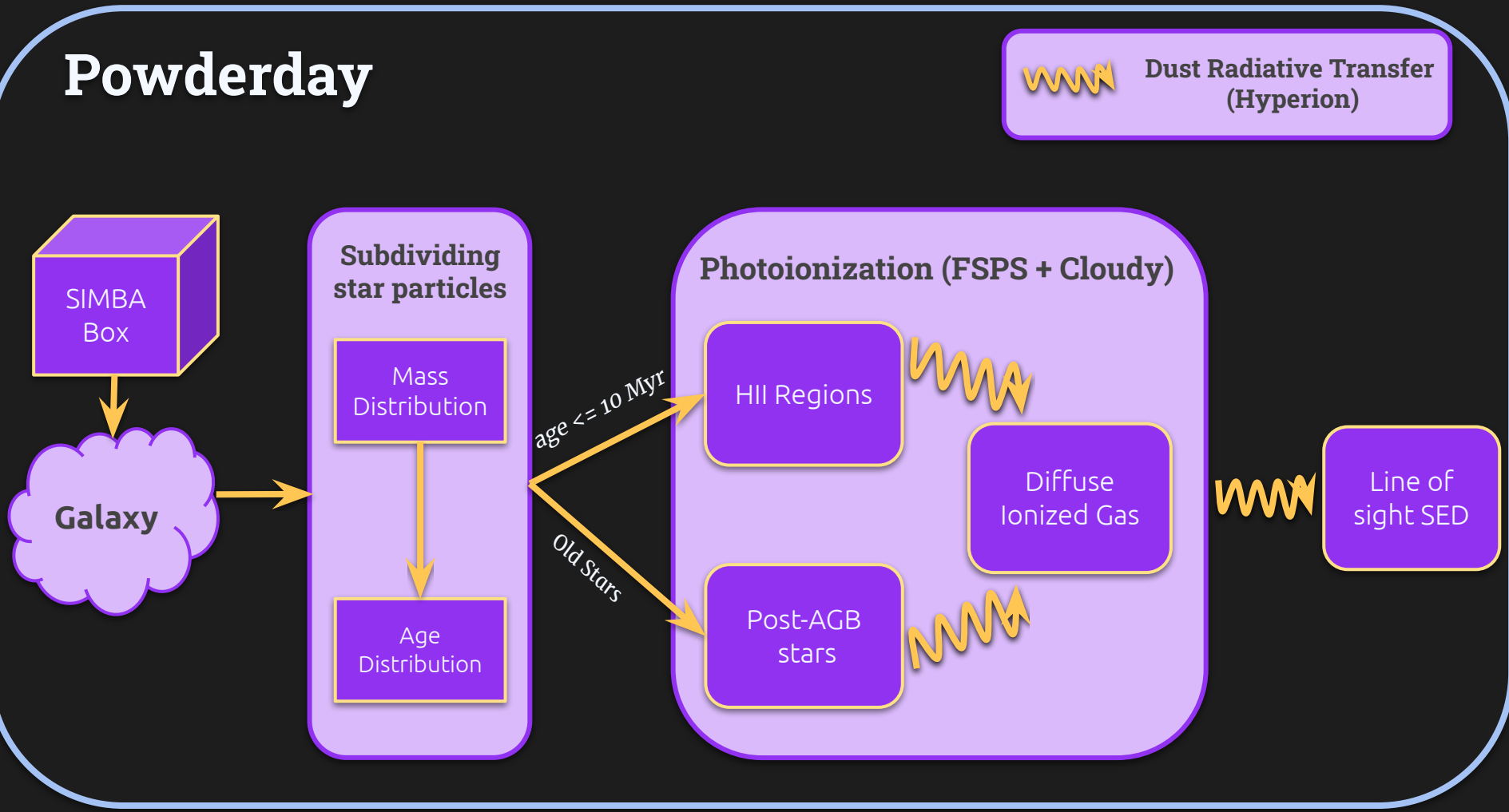


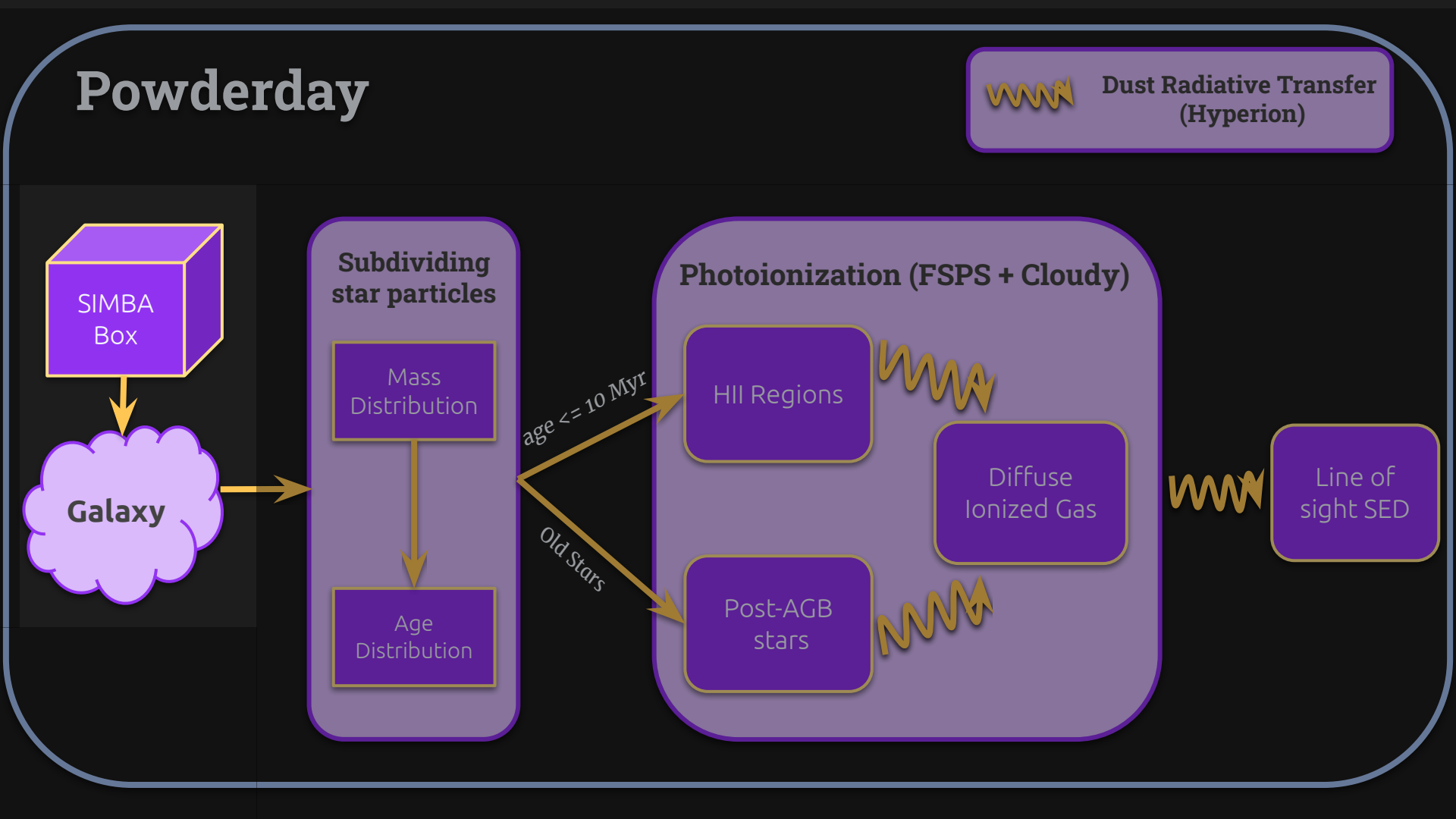
Young stars and Post-AGB stars



Diffused Ionized Gas (DIG)




Powderday
Dust Radiative Transfer (Hyperion)
SIMBA Box
Galaxy
Subdividing star particles
Mass Distribution
Age Distribution
age <= 10 Myr
Old Stars
Photoionization (FSPS + Cloudy)
HII Regions
Diffuse Ionized Gas
Post-AGB stars
Line of sight SED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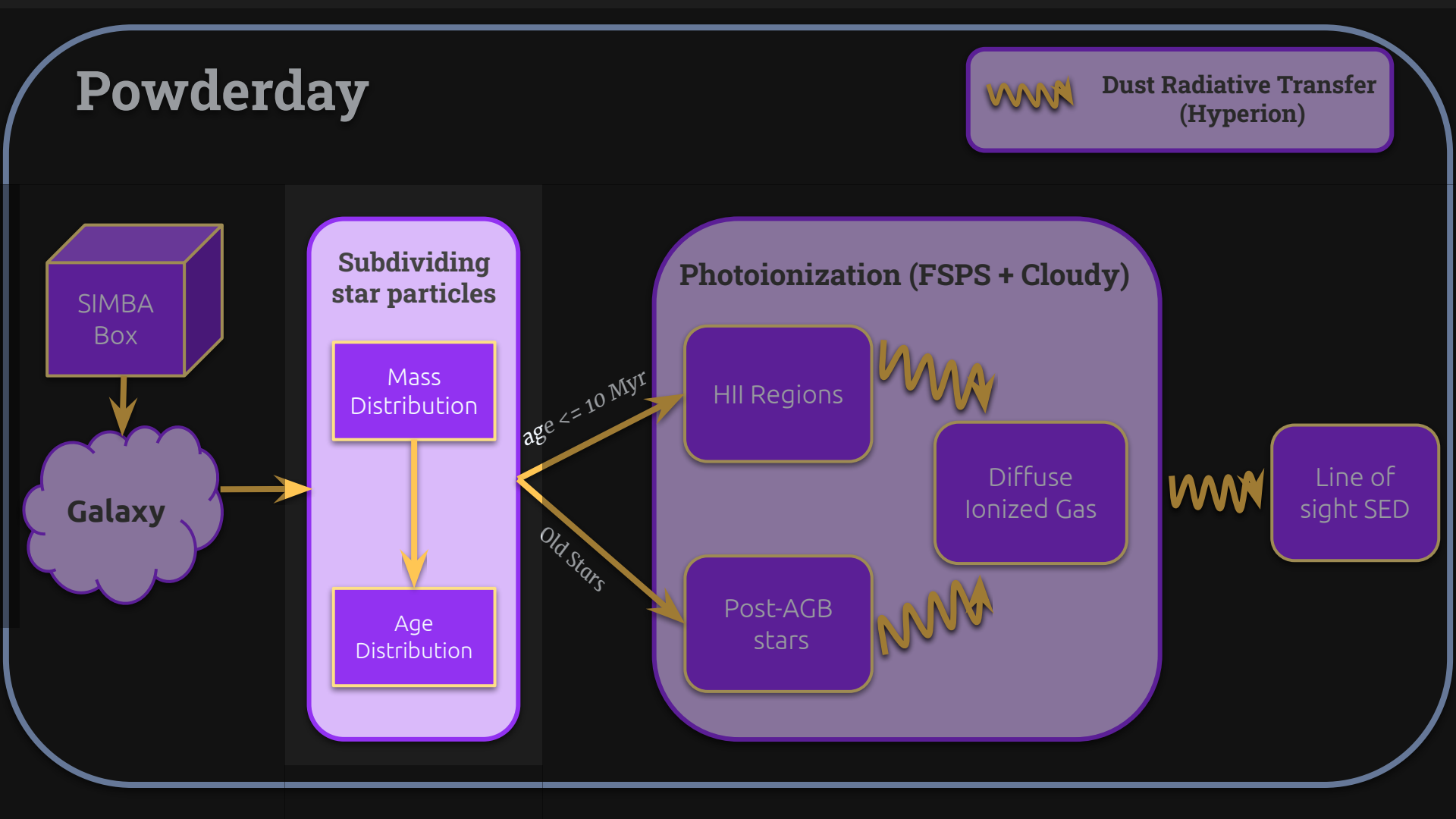
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Dust Radiative Transfer (Hyperion)

SIMBA Box

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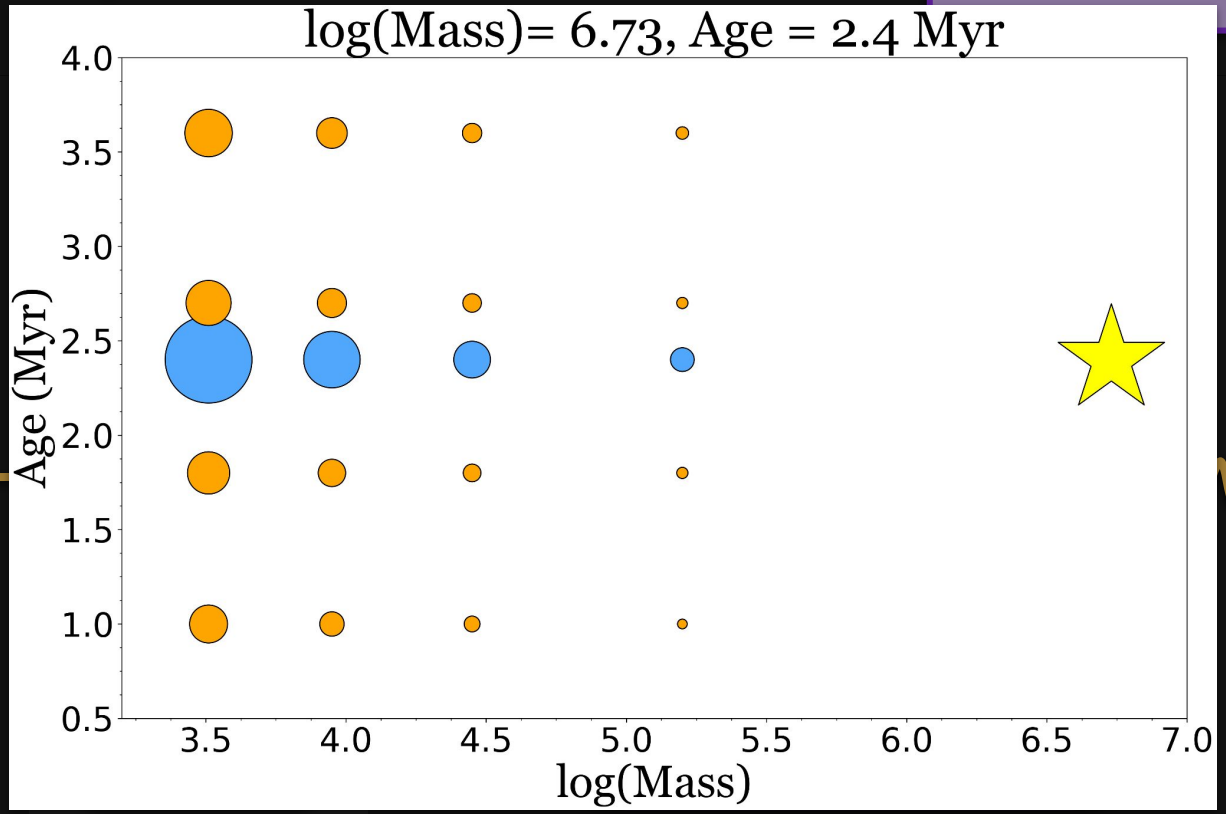

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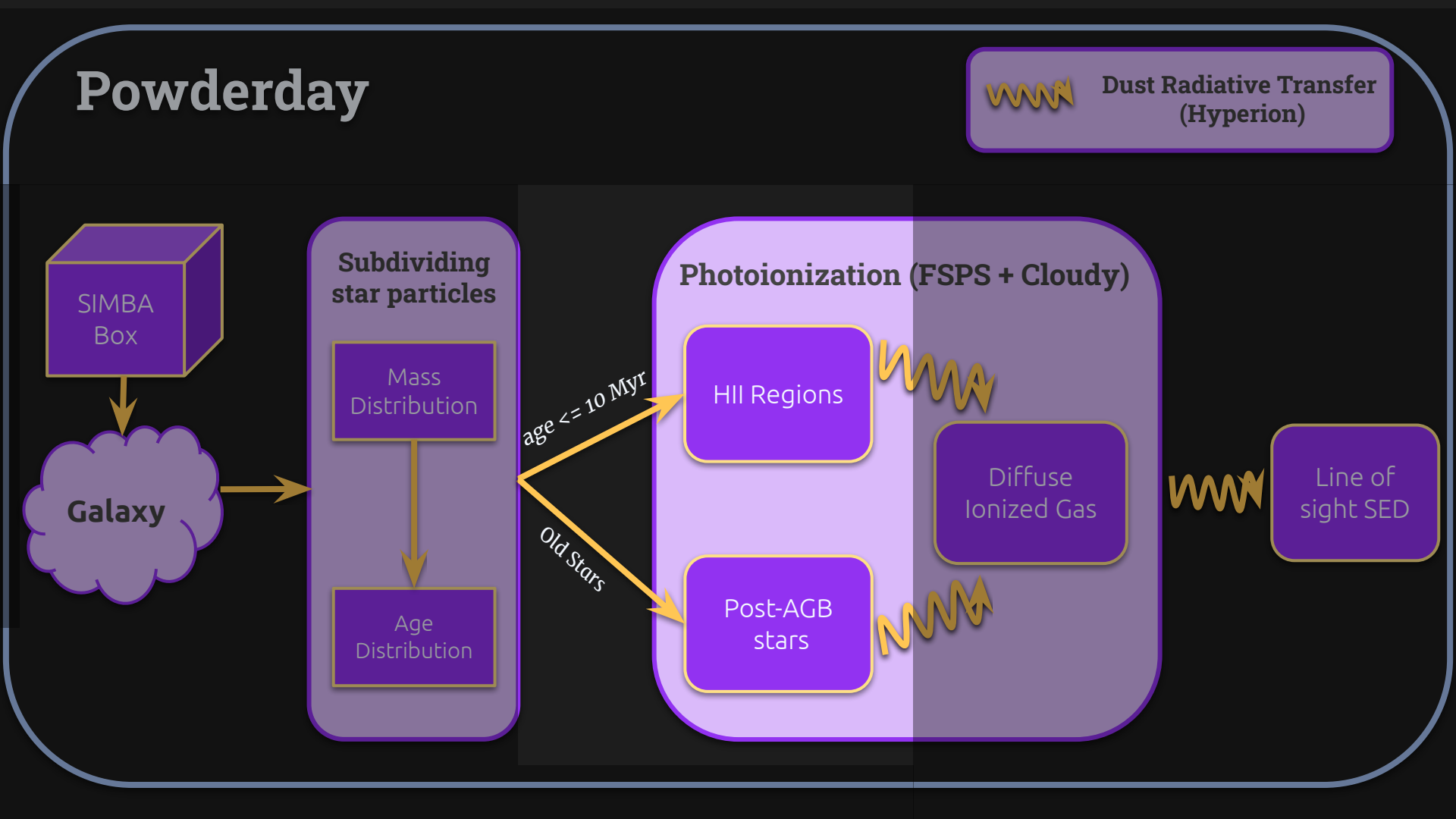
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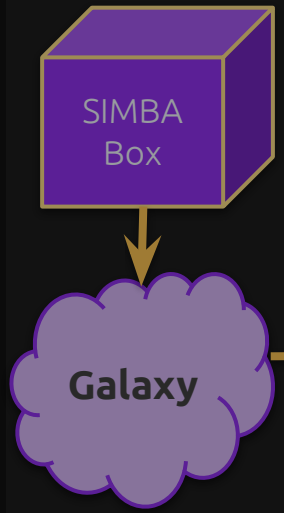
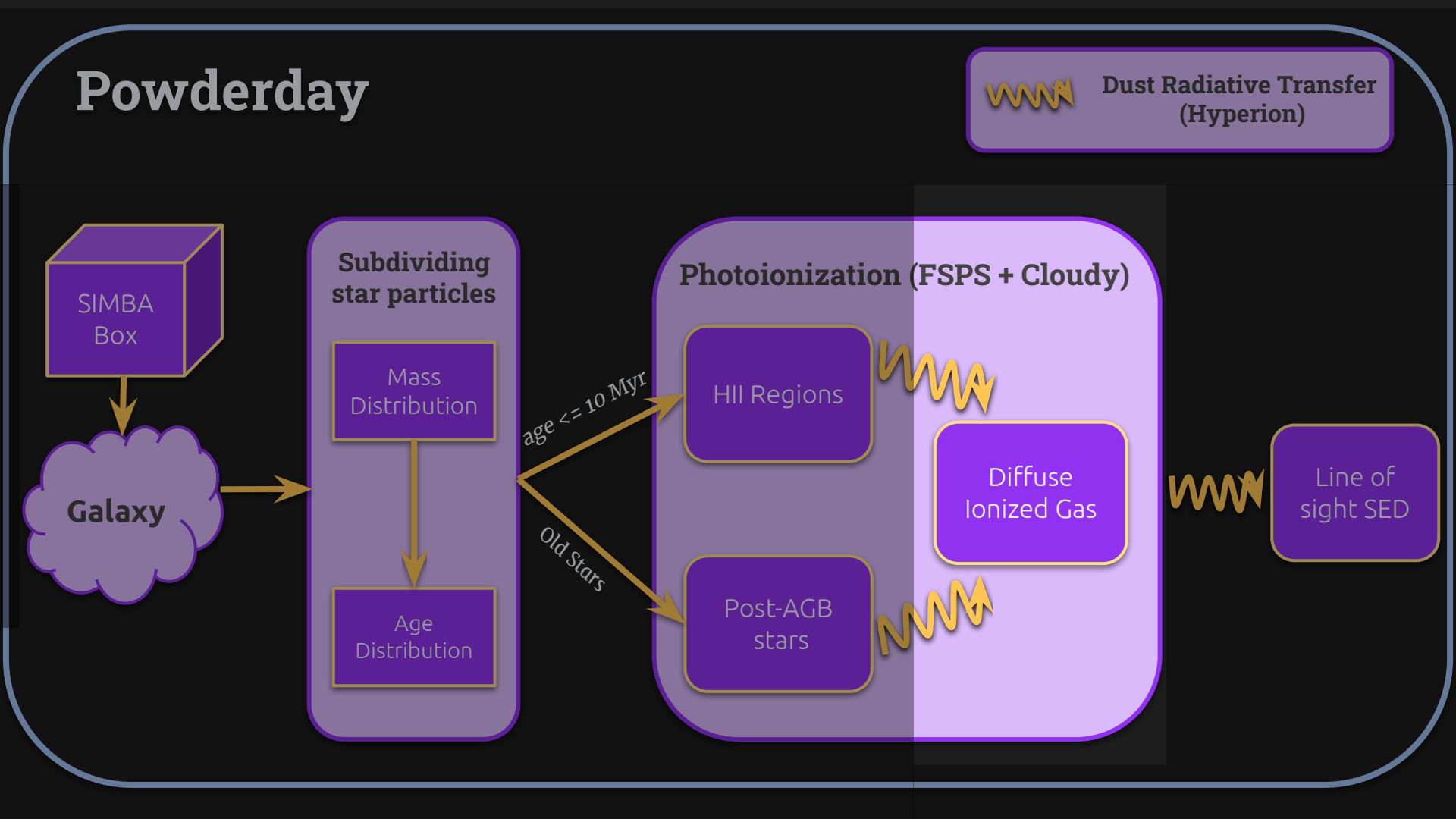
Dust Radiative Transfer (Hyperion)



- Constant density (n_H)
  - HII regions & pAGB - 30 cm^3
  - DIG - 1 cm^3
- BPASS model grids (Binary Stars)
- Geometry
  - HII regions & pAGB - Spherical shell
  - DIG - Plane parallel
- Escape Fraction: 40% & 60% for HII regions and post-AGB stars

Line of sight SED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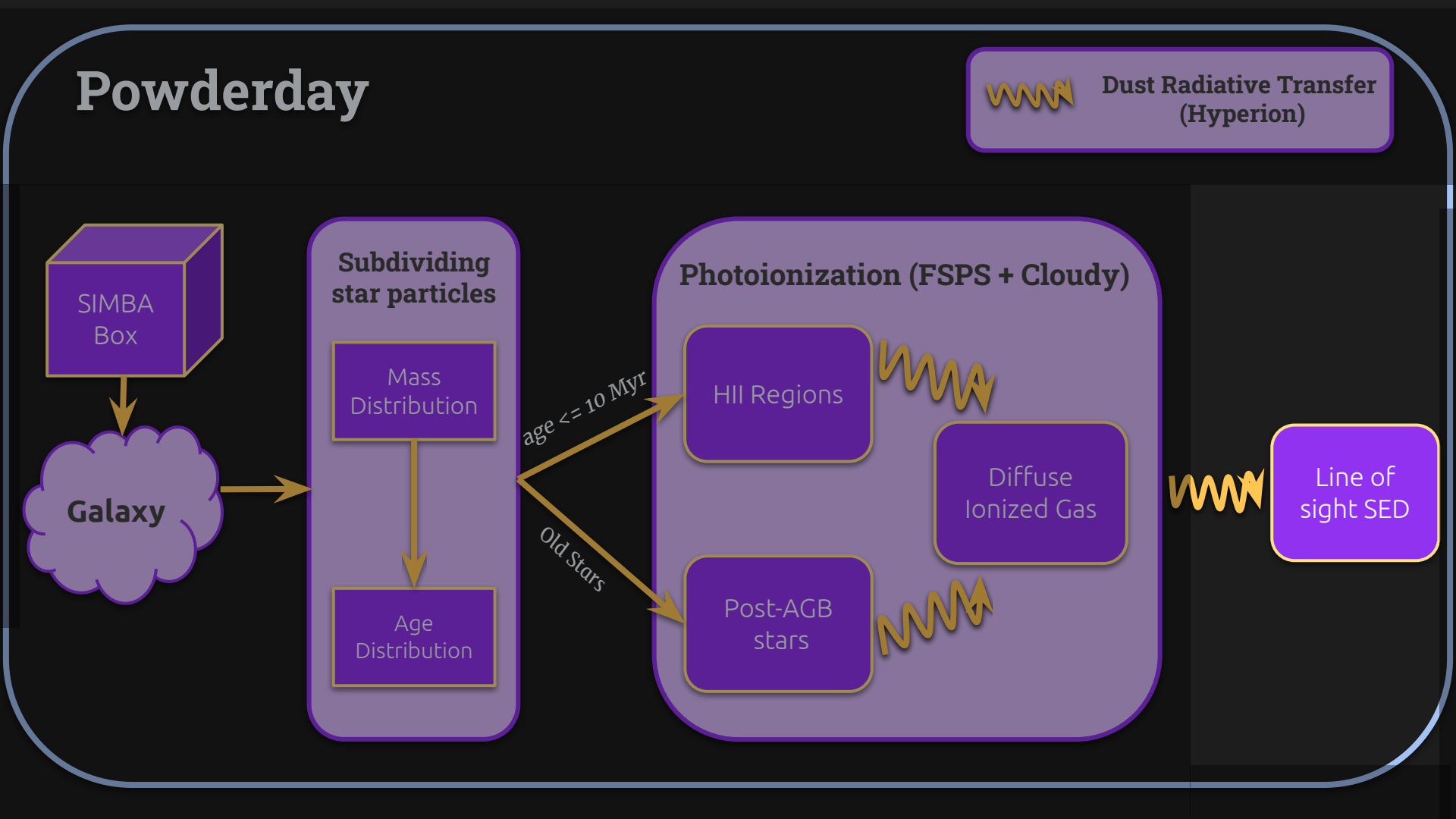
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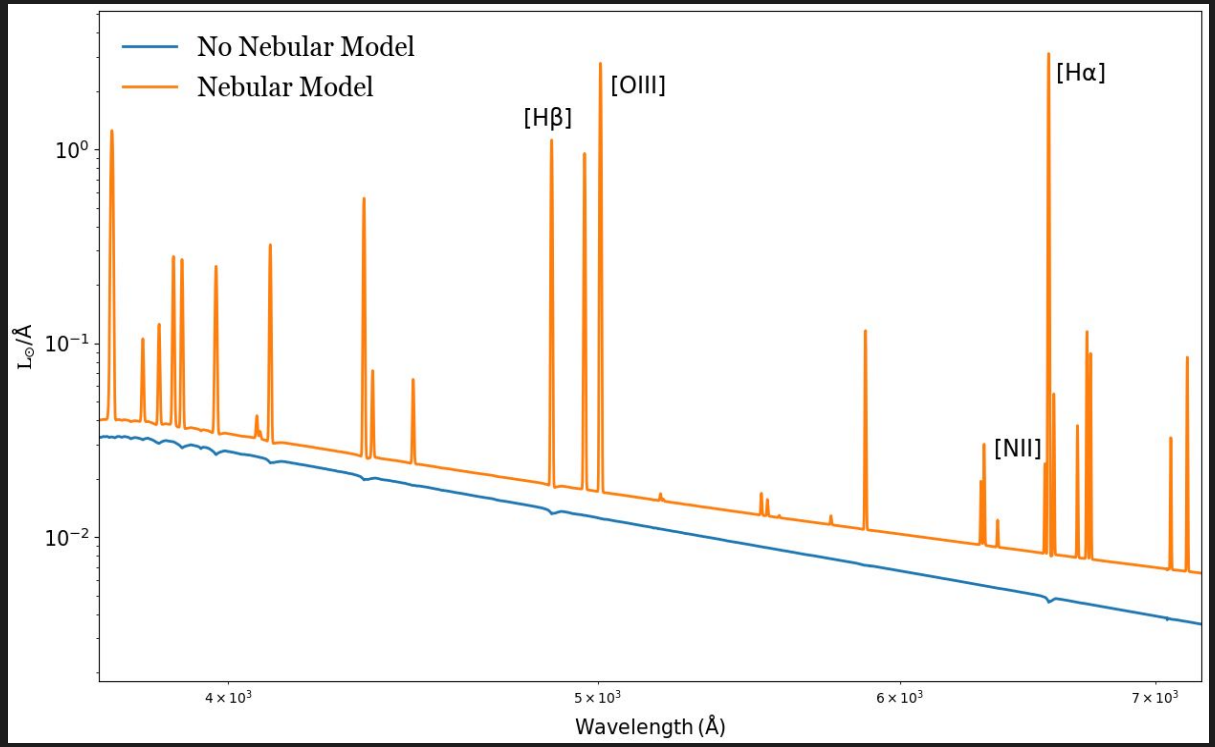
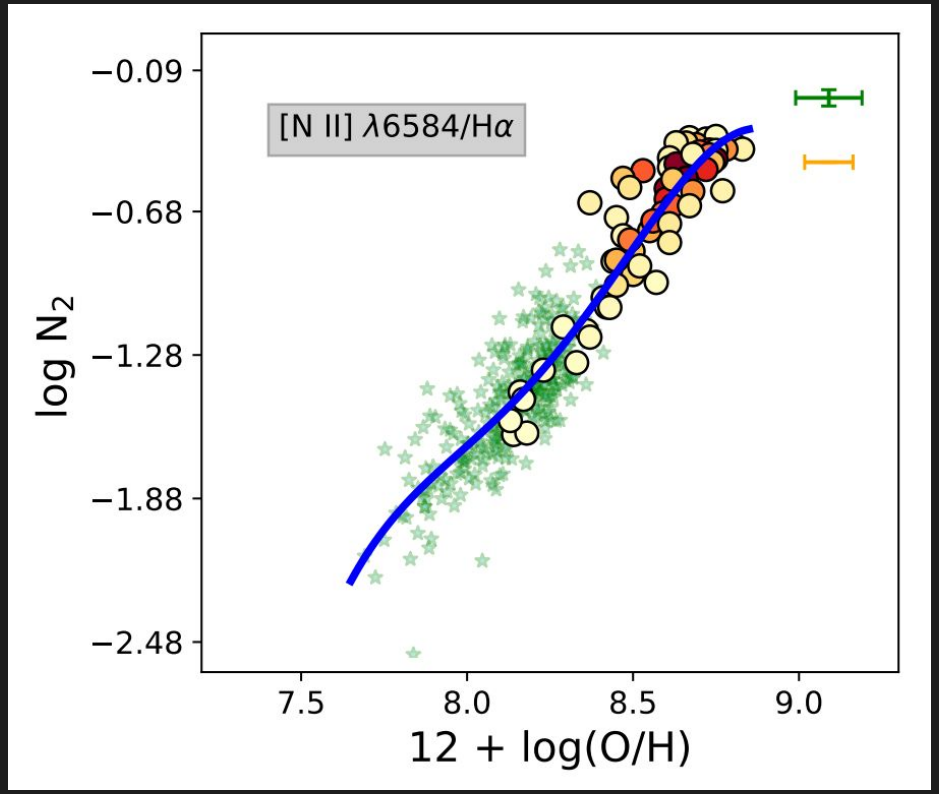
Nebular Line Emission

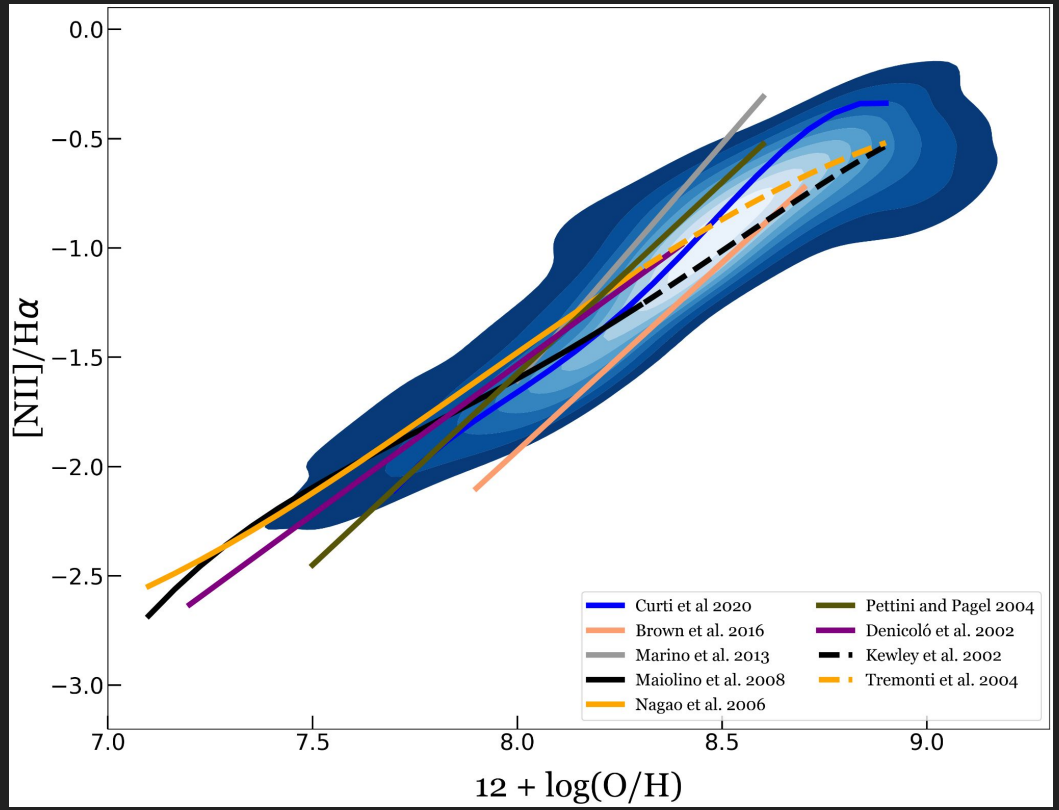


- **Bright**
- **Ionized elements**



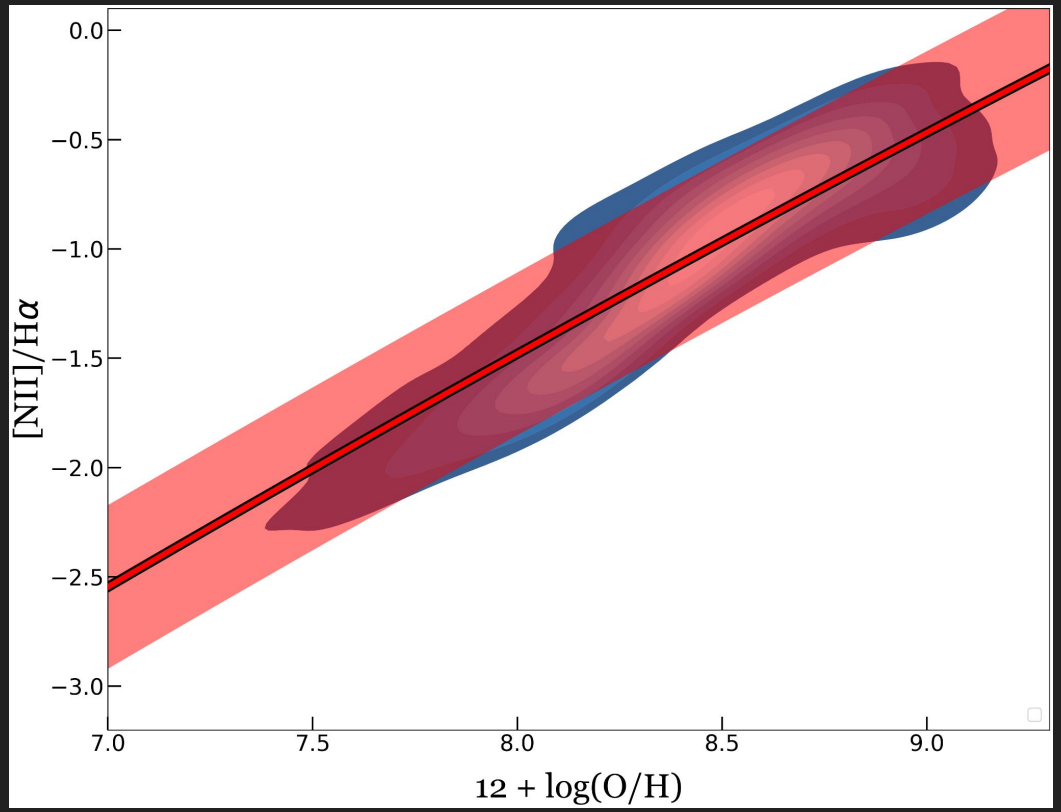
(Curti et al. 2017)

[NII]/Hα (z = 0)



Garg et al. (in prep)

[NII]/Hα (z = 0)



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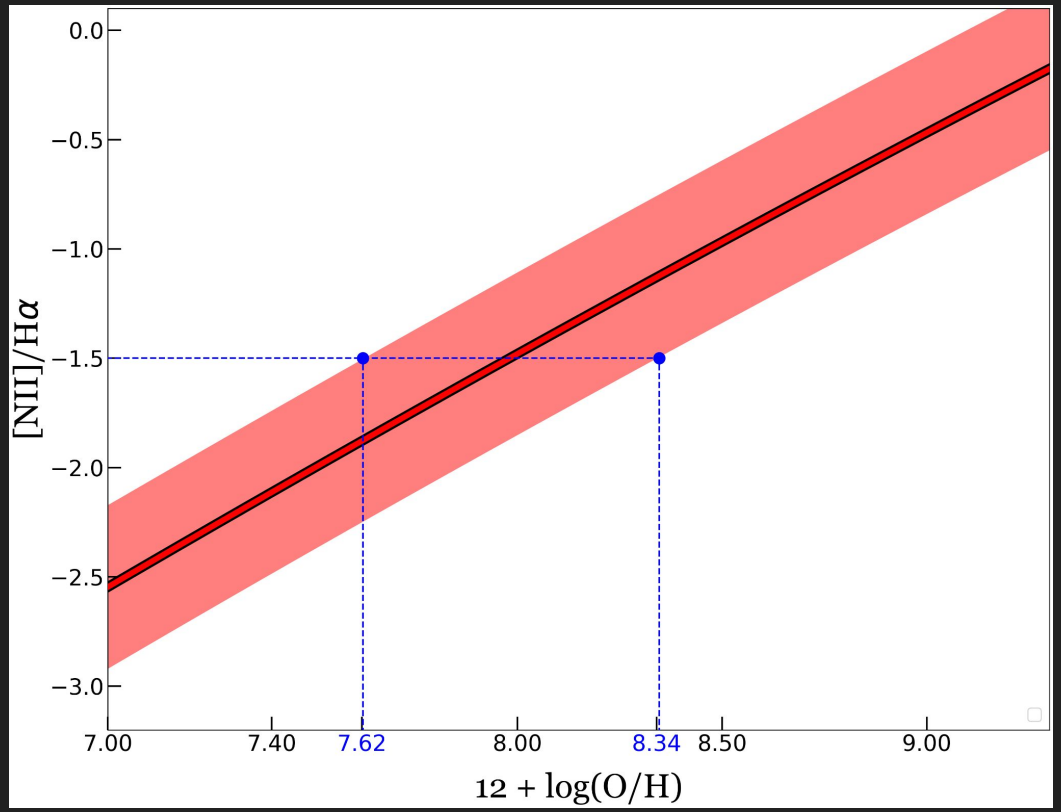
[NII]/Hα (z = 0)



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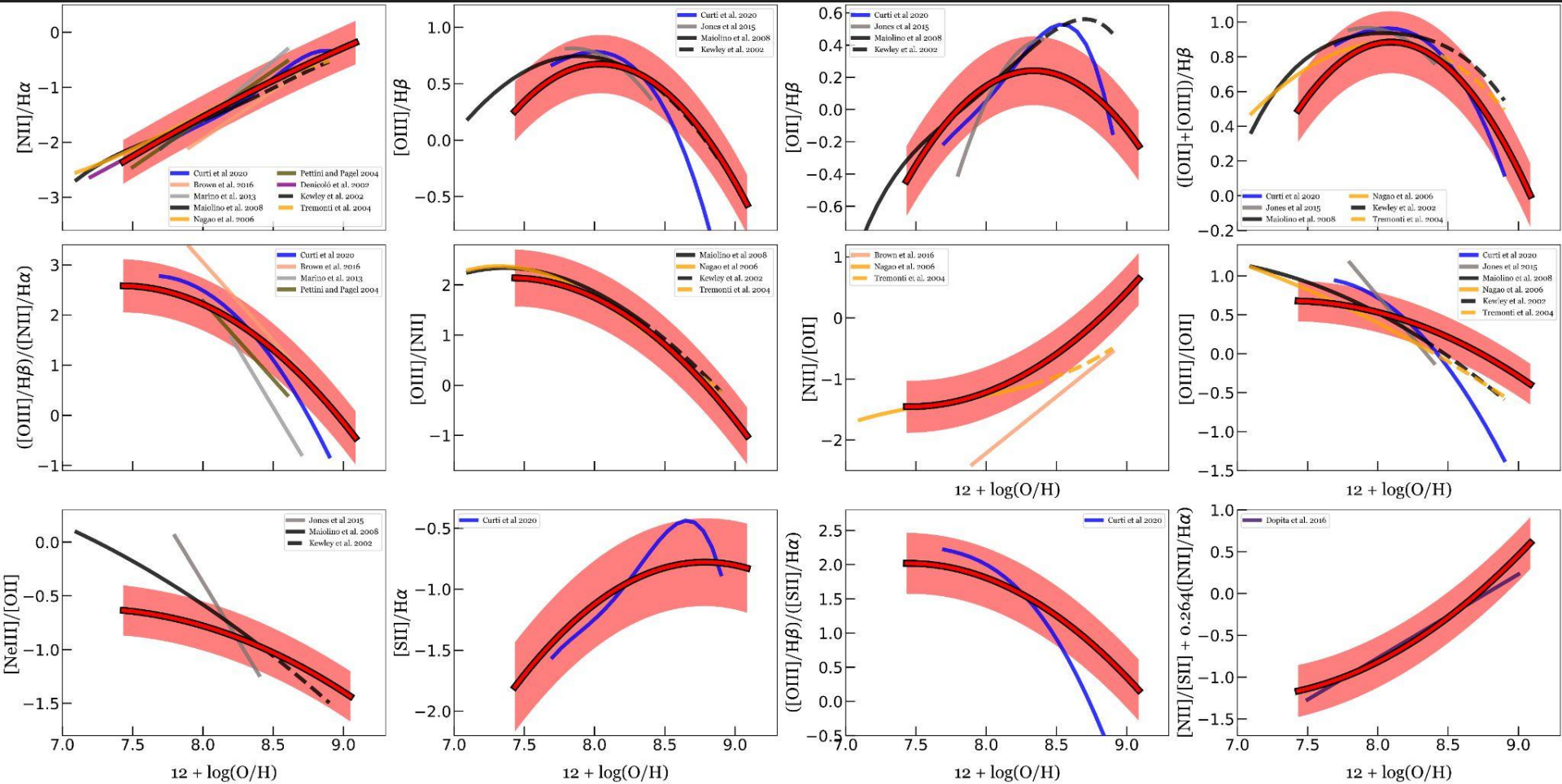
[NII]/Hα
Curti et al 2020
Brown et al. 2016
Marino et al. 2013
Maiolino et al. 2008
Nagao et al. 2006
Pettini and Pagel 2004
Denicoló et al. 2002
Kewley et al. 2002
Tremonti et al. 2004
[OIII]/Hβ
Curti et al 2020
Jones et al 2015
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Kewley et al. 2002
[OII]/Hβ
Curti et al 2020
Jones et al 2015
Maiolino et al 2008
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([OII]+[OIII])/Hβ
Curti et al 2020
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Tremonti et al. 2004
([OIII]/Hβ)/([NII]/Hα)
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[OIII]/[NII]
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Kewley et al. 2002
Tremonti et al. 2004
[NeIII]/[OII]
Jones et al 2015
Maiolino et al. 2008
Kewley et al. 2002
[SII]/Hα
Curti et al 2020
([OIII]/Hβ)/([SII]/Hα)
Curti et al 2020
[NII]/[SII] + 0.264[NII]/Hα)
Dopita et al. 2016
12 + log(O/H)
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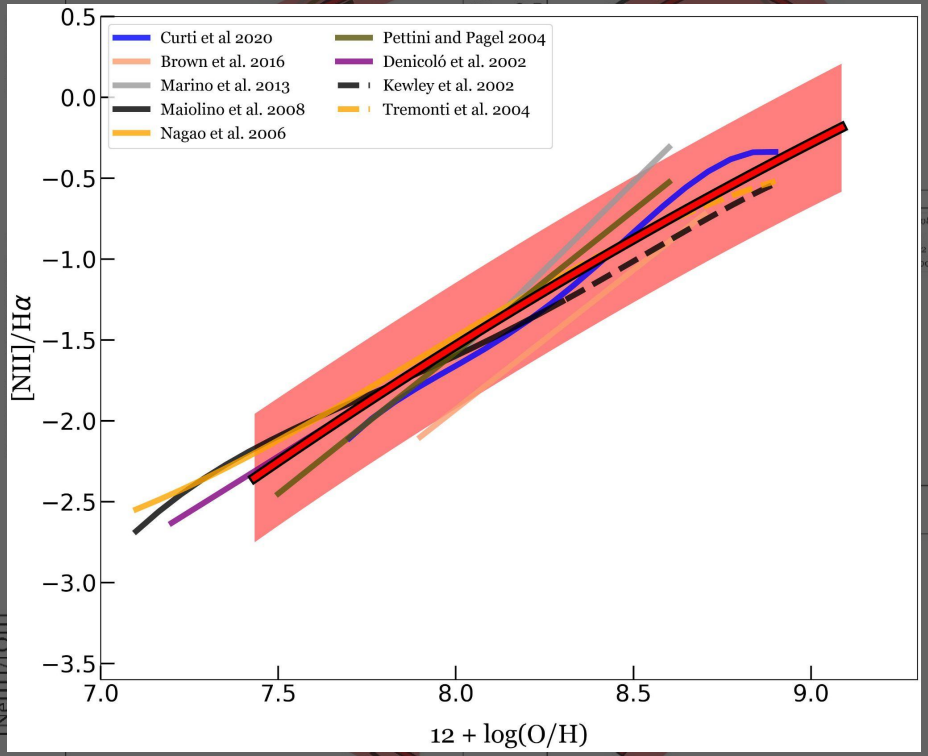
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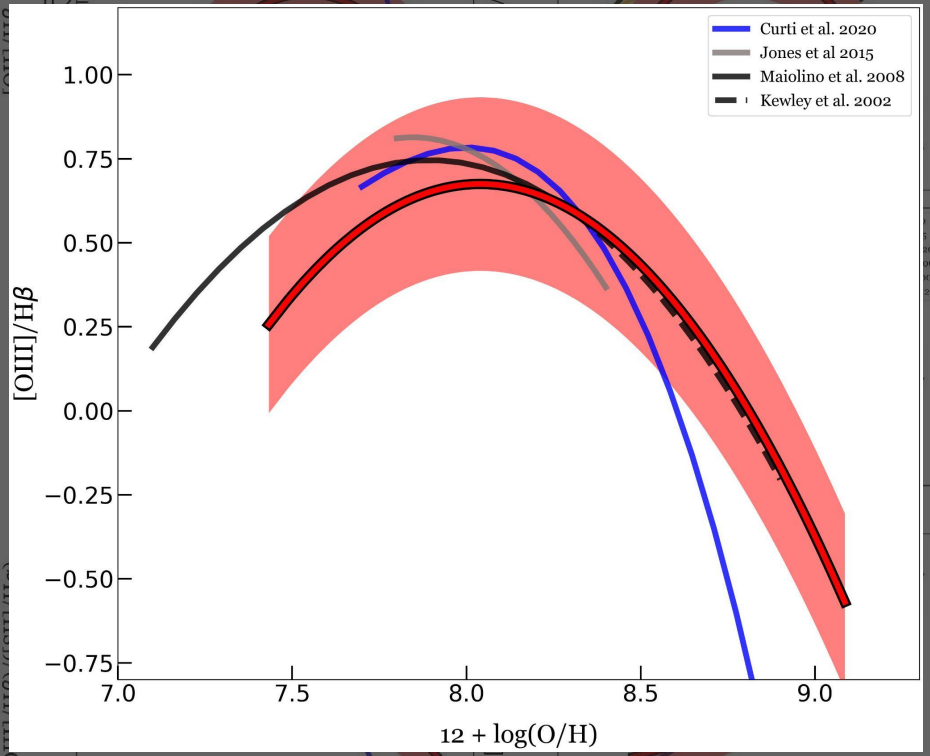
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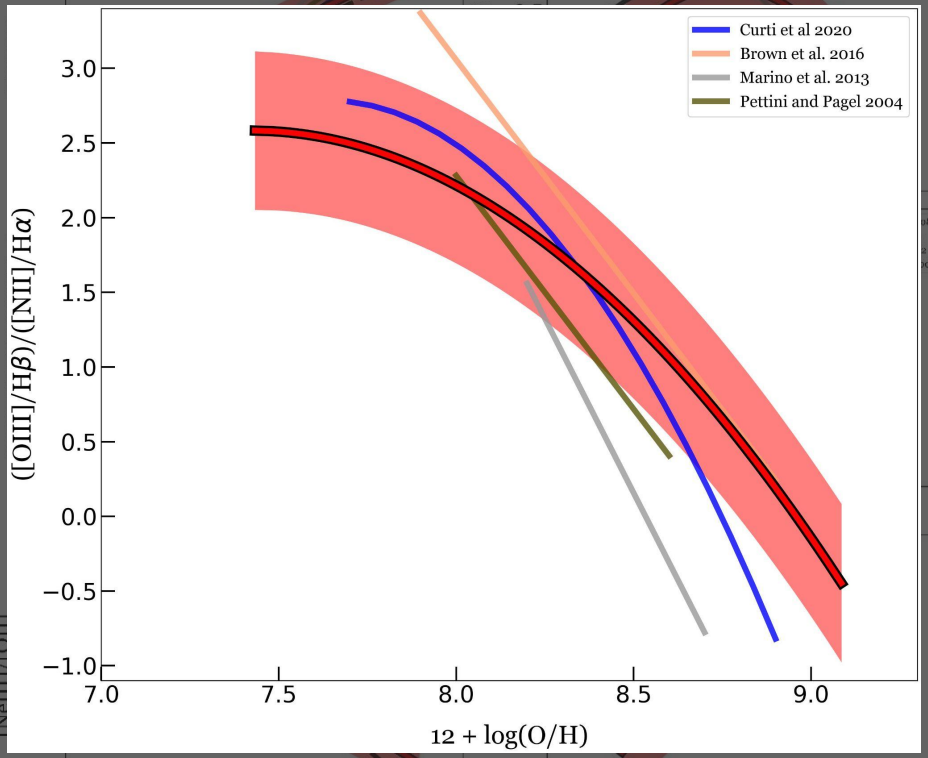
Kewley et al. 2002
[OIII]/Hβ
12 + log(O/H)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([OIII]/Hβ)/([NII]/Hα)
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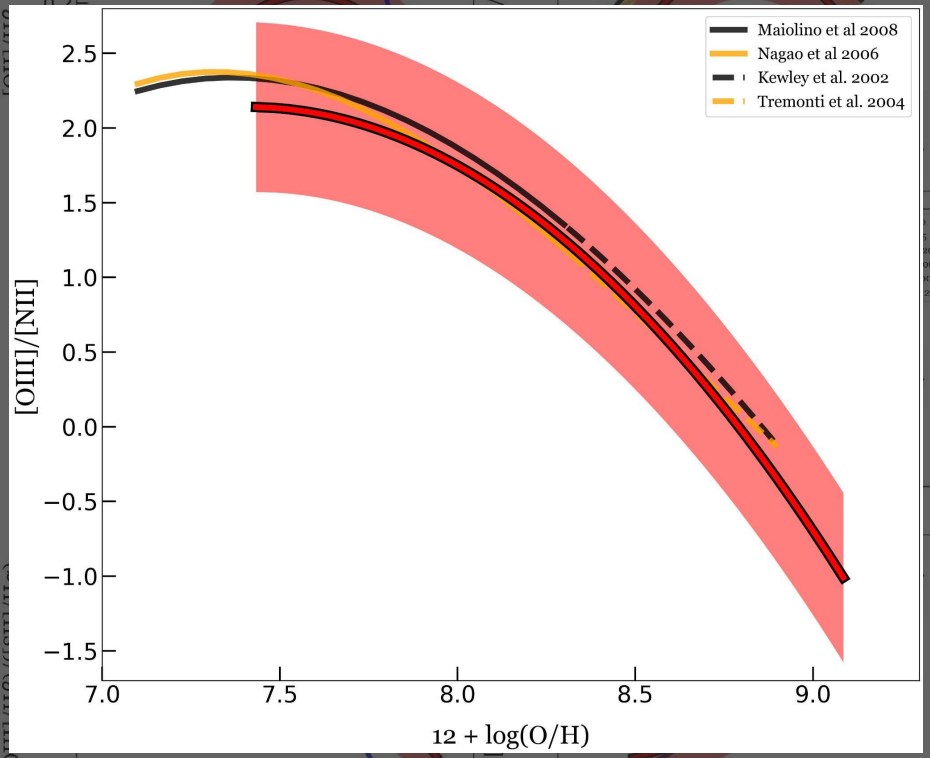
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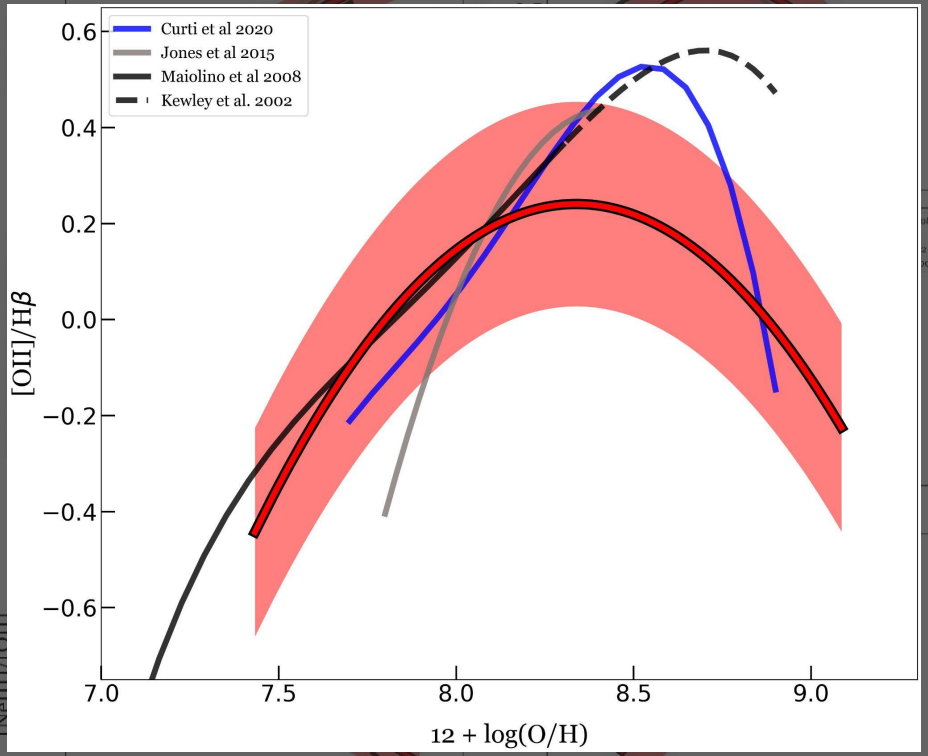
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[OII]/Hβ
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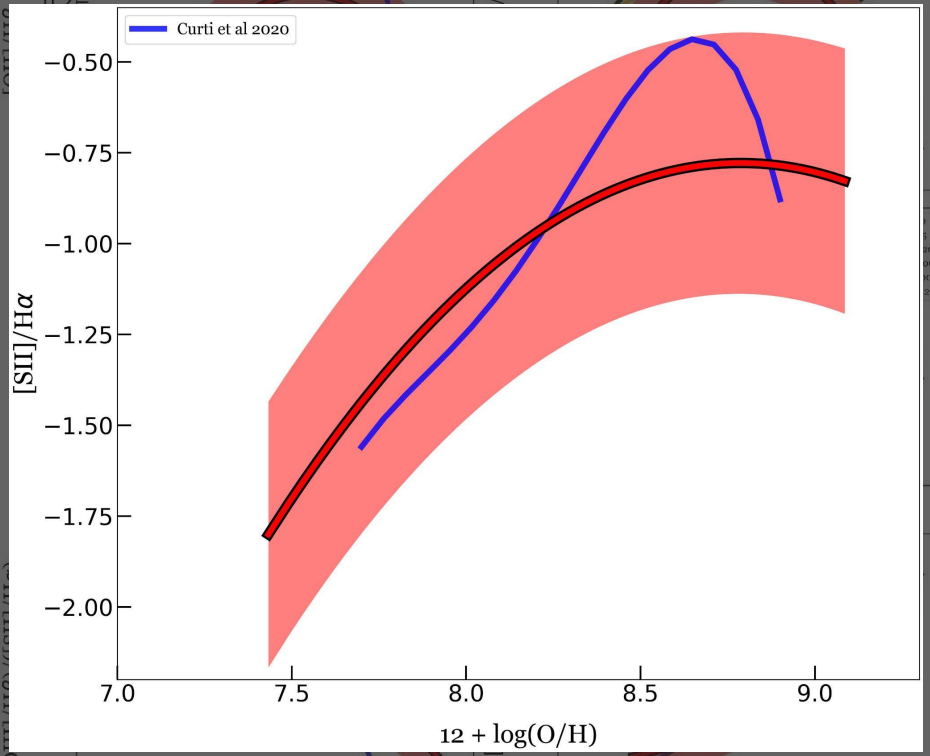
Curti et al 2020
[SII]/Hα
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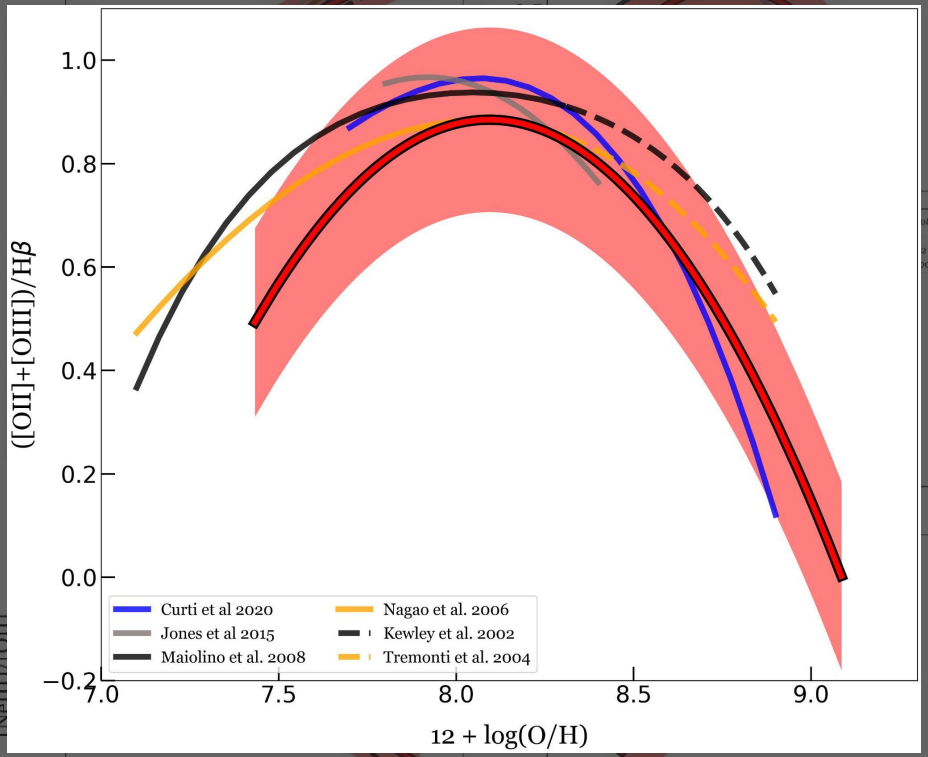
([OII]+[OIII])/Hβ
12 + log(O/H)
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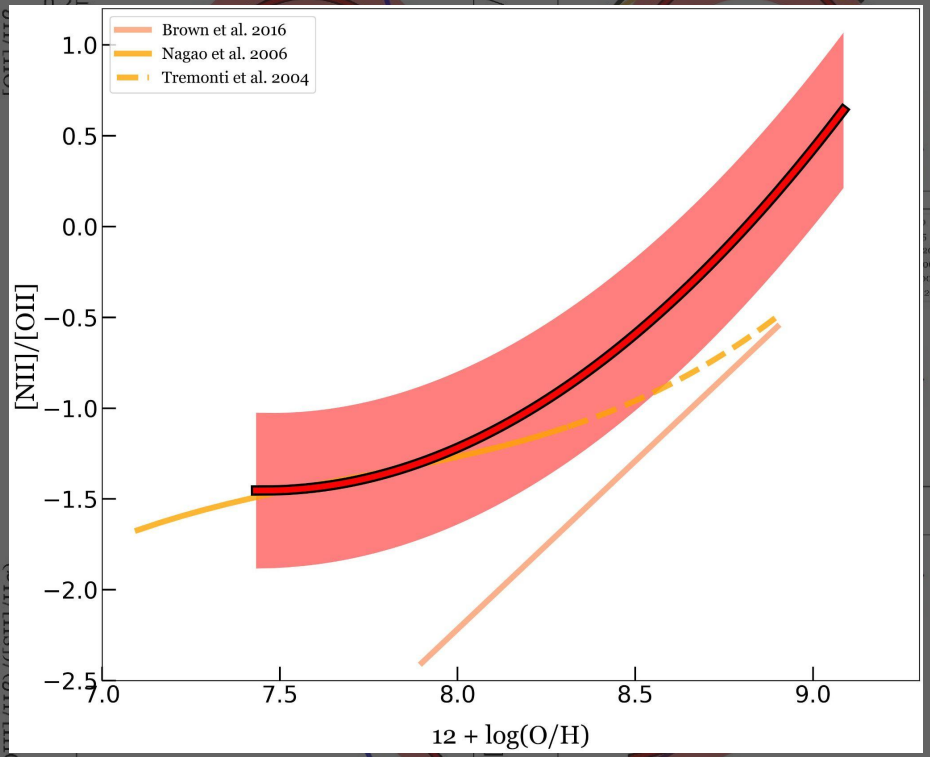
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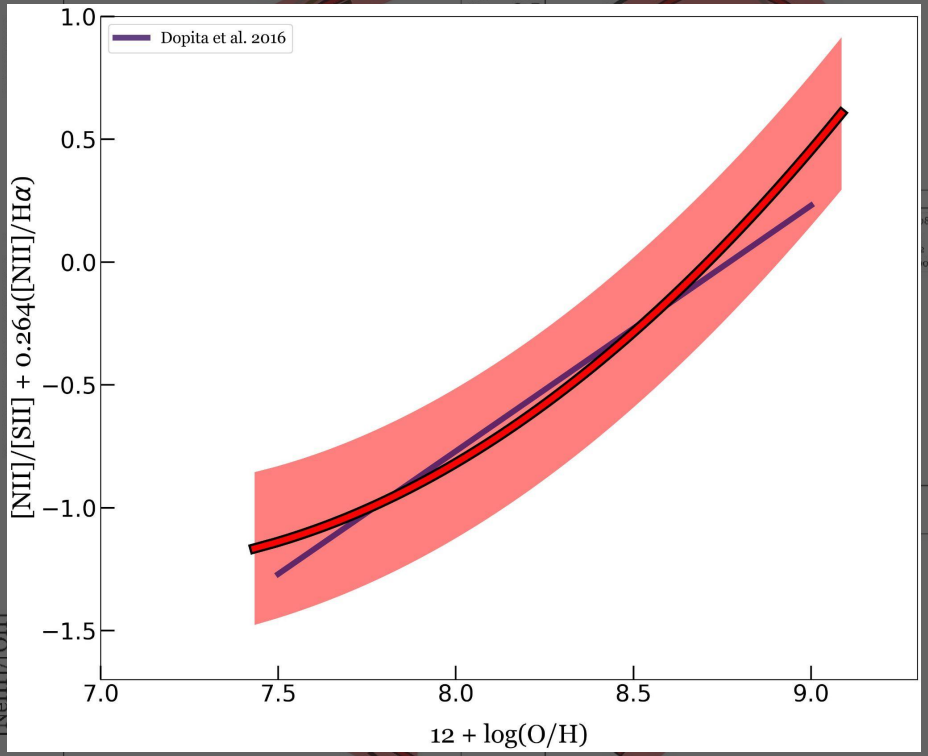
Dopita et al. 2016
[NII]/[SII] + 0.264([NII]/Hα)
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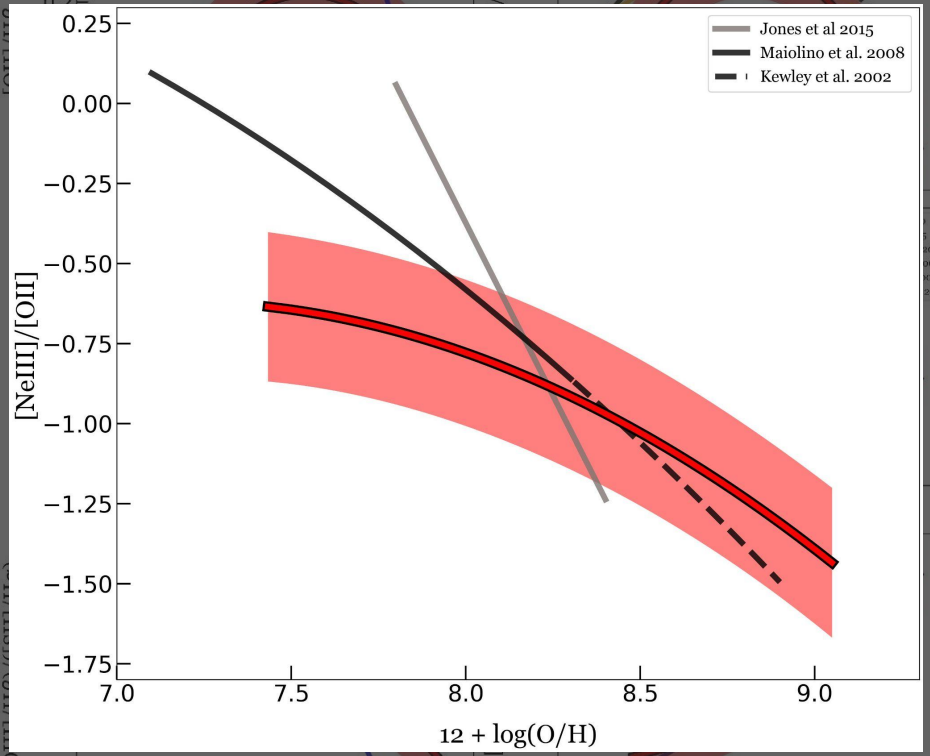
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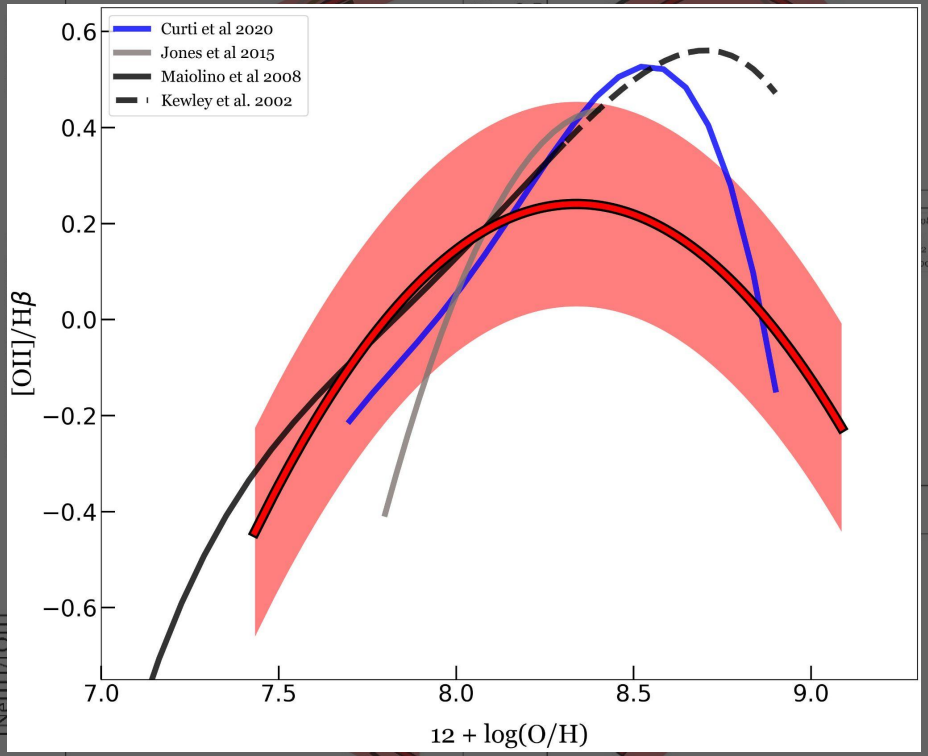
[NeIII]/[OII]
12 + log(O/H)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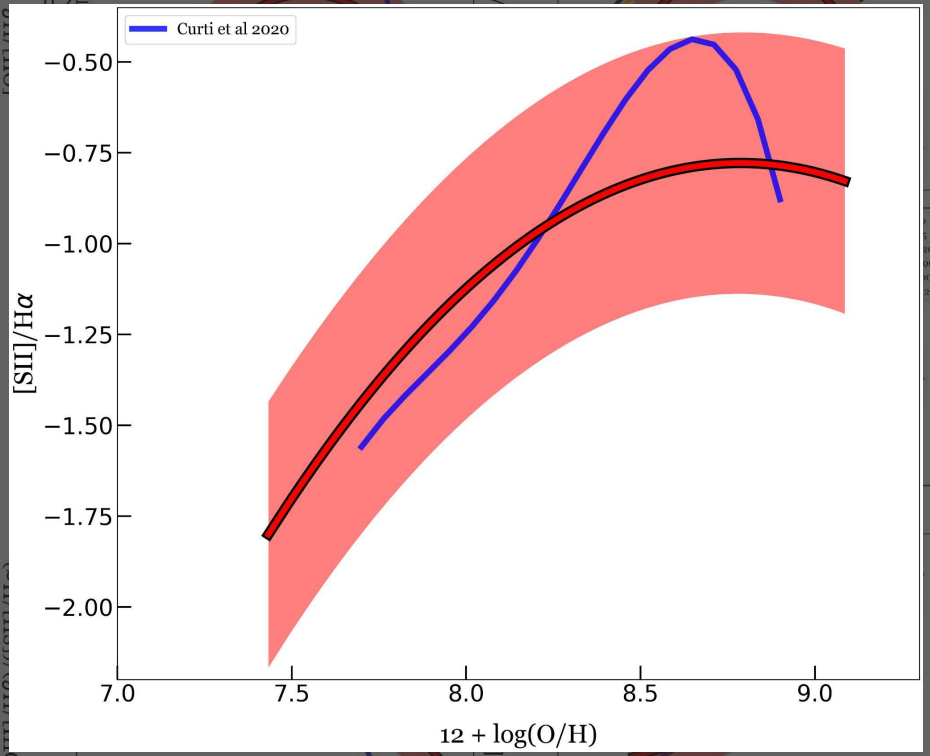
Curti et al 2020
[SII]/Hα
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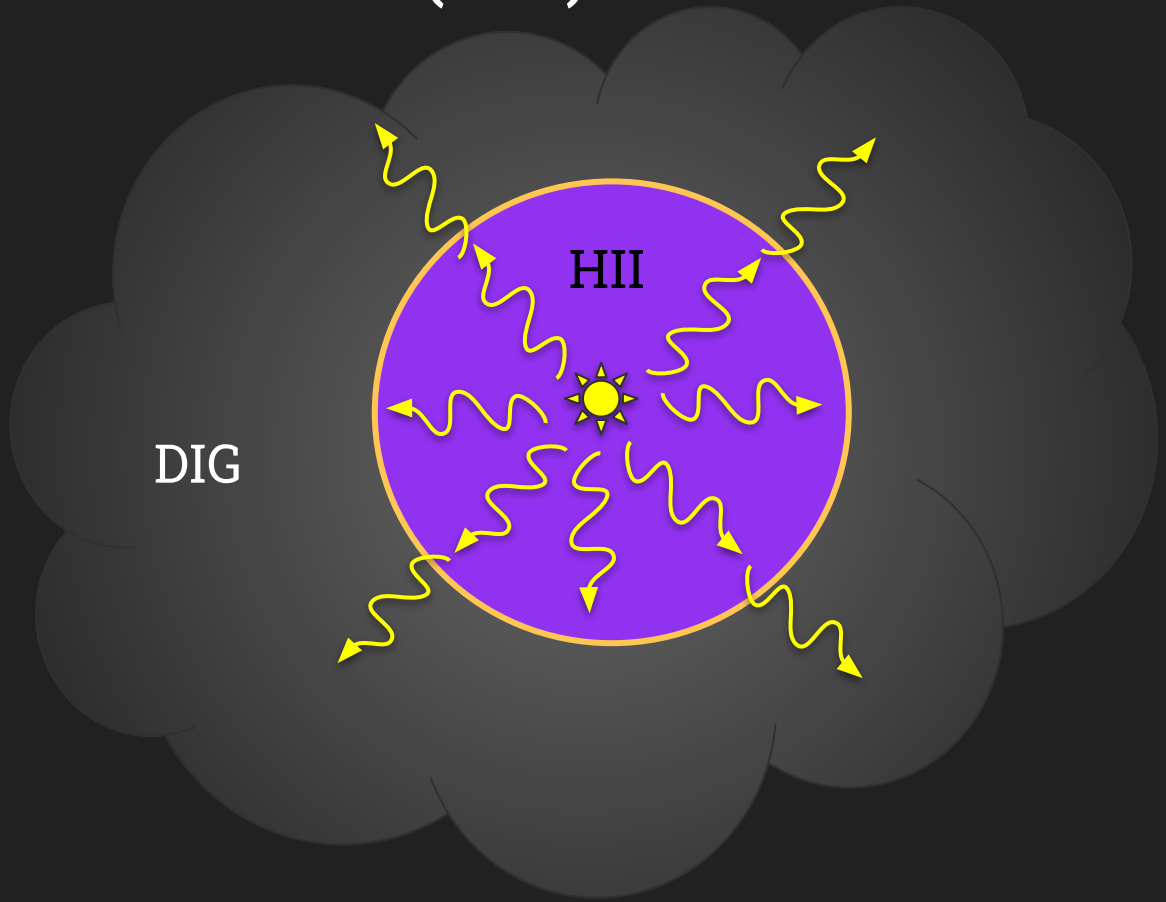
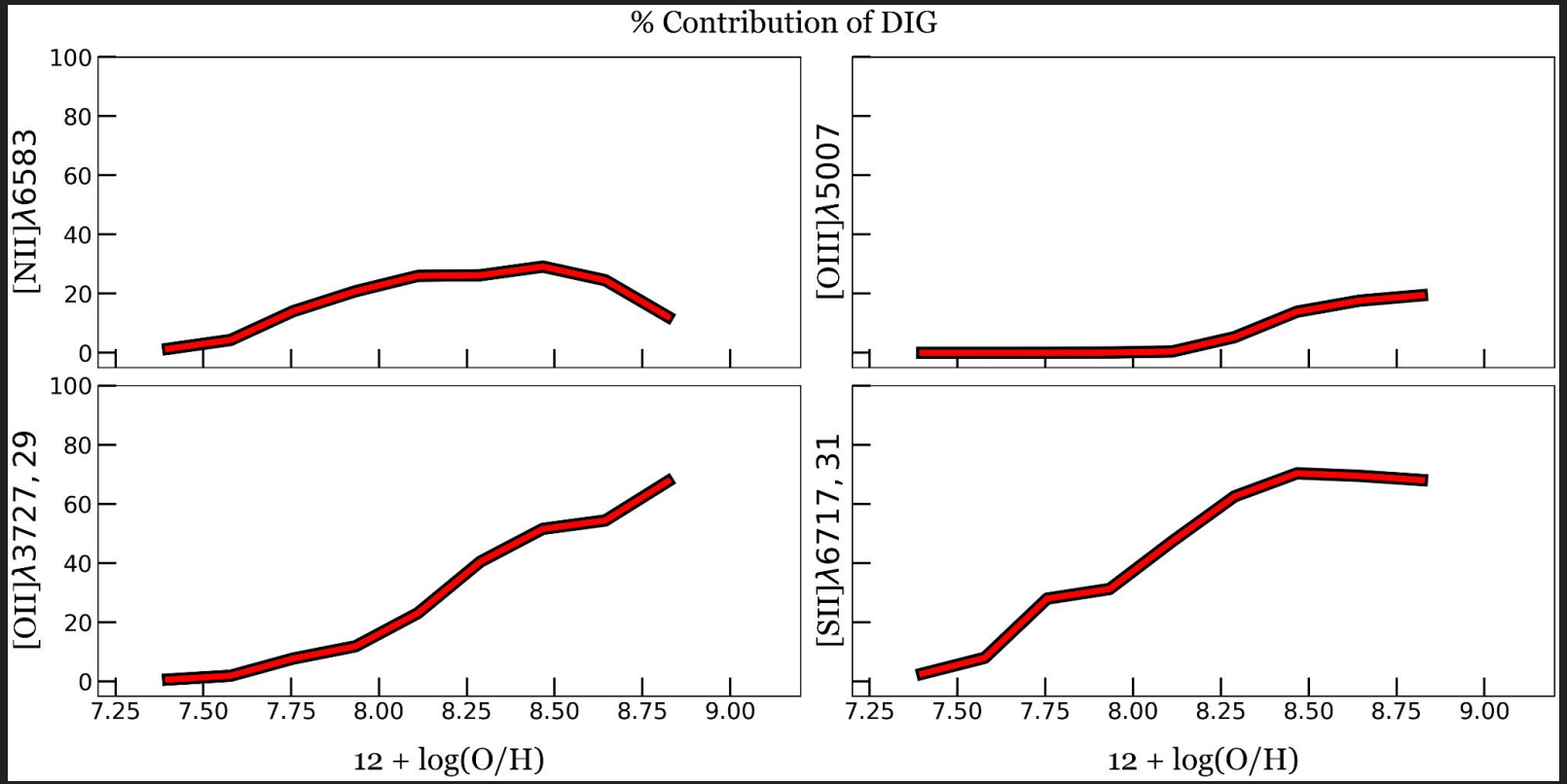
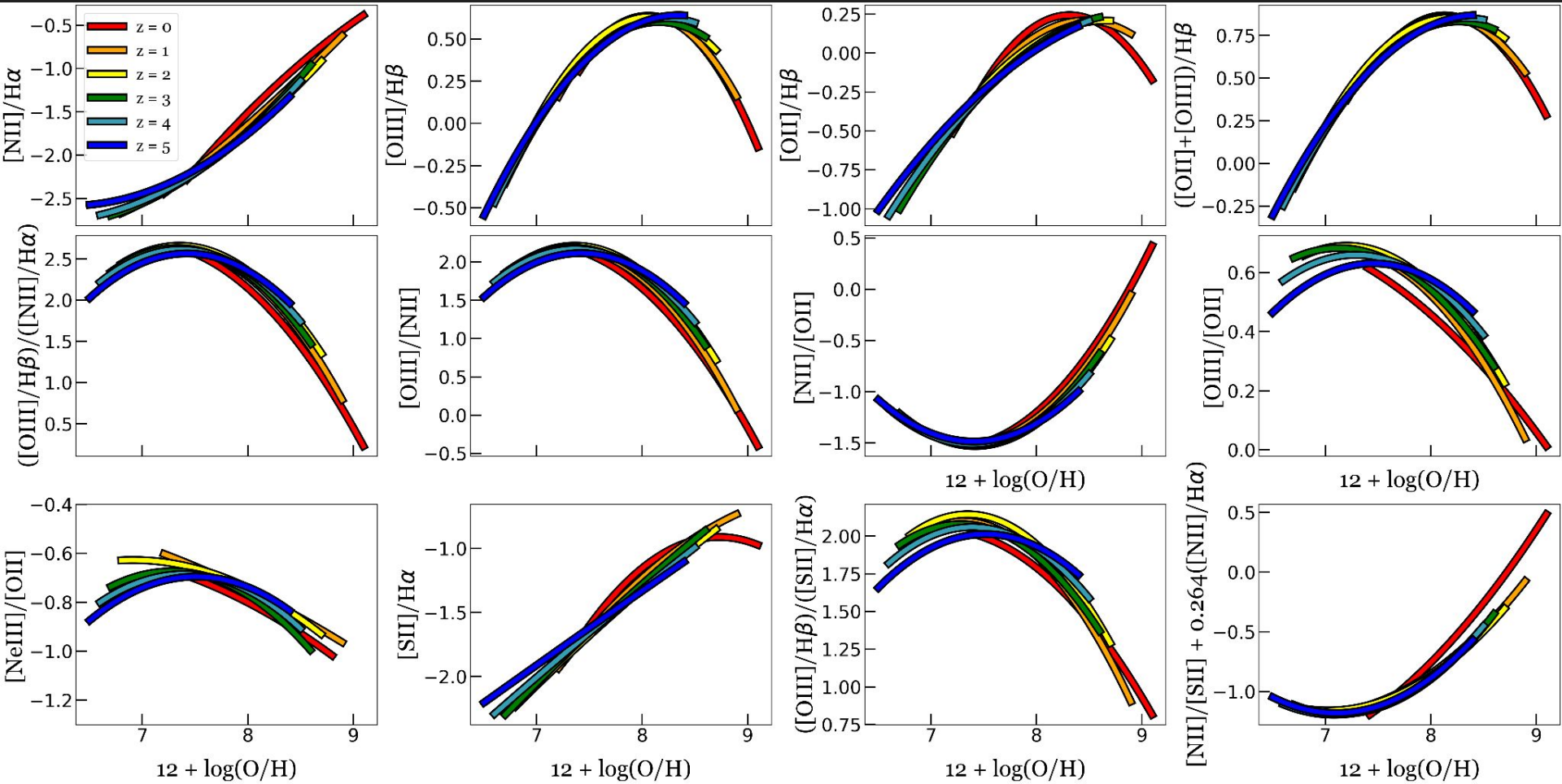
Diffused Ionized Gas (DIG)



Relative Contribution of DIG




z = 0
z = 1
z = 2
z = 3
z = 4
z = 5
[NII]/Hα
[OIII]/Hβ
[OII]/Hβ
([OII]+[OIII])/Hβ
([OIII]/Hβ)/([NII]/Hα)
[OIII]/[NII]
[NII]/[OII]
[OIII]/[OII]
[NeIII]/[OII]
[SII]/Hα
([OIII]/Hβ)/([SII]/Hα)
[NII]/[SII] + 0.264([NII]/Hα)
12 + log(O/H)

Do the strong line metallicity indicators evolve with redshifts ?

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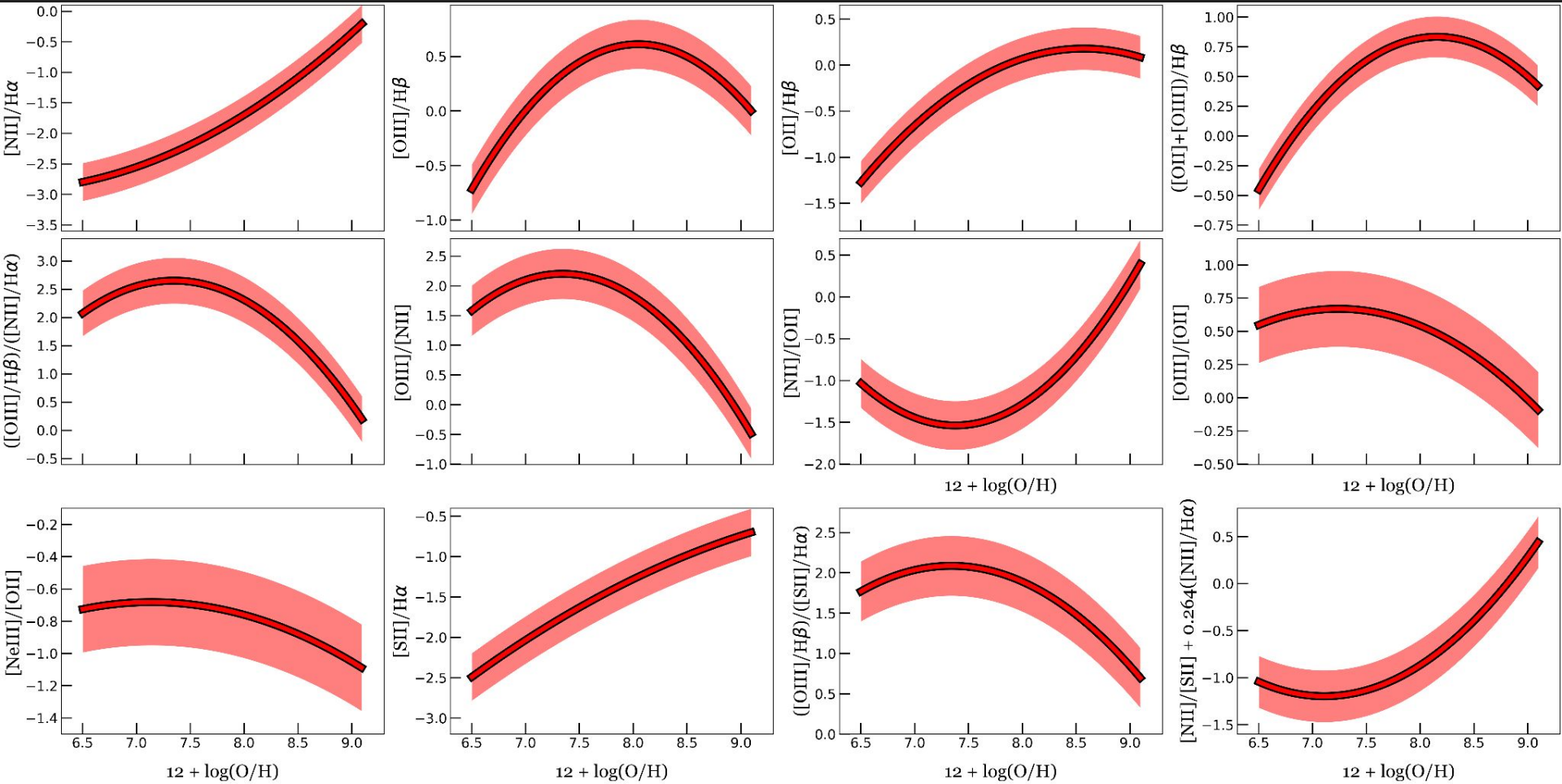
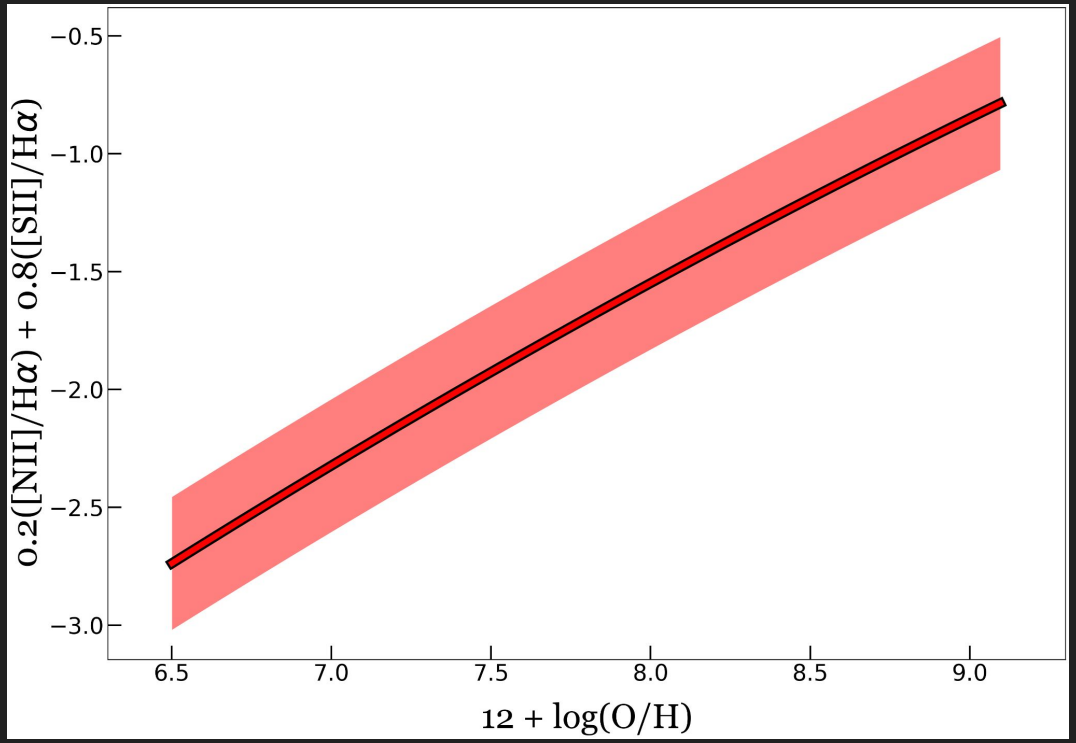
Maybe Not.....

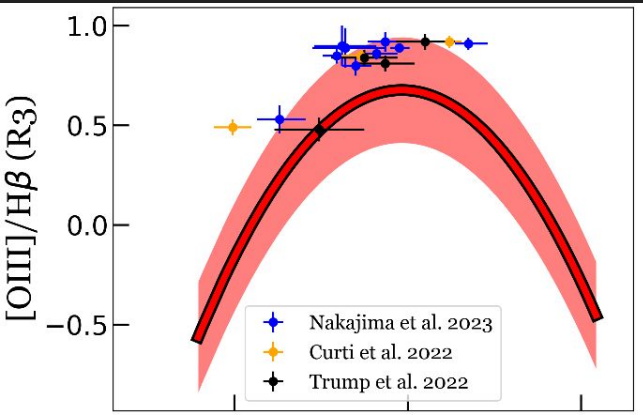
Model properties that vary across redshifts

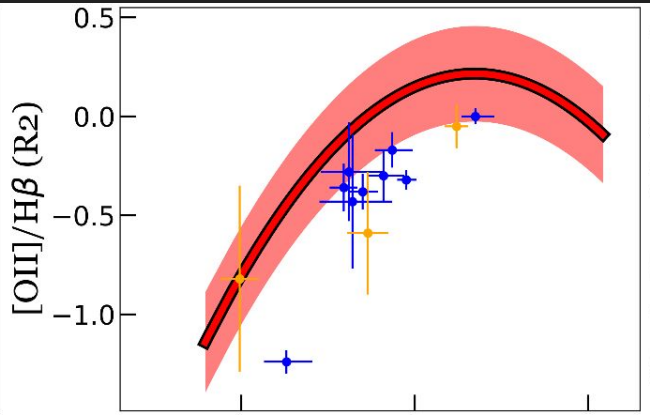
- Stellar and gas metallicities
- Spectrum of ionizing photons in HII regions and post-AGB stars
- Incident radiation field for DIG emission
- Frequency of young and post-AGB stars
- Amount of gas available for ionization

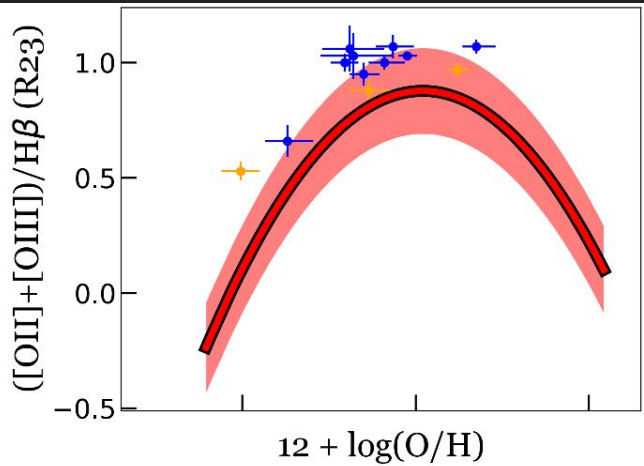

[NII]/Hα
[OIII]/Hβ
[OII]/Hβ
([OII]+[OIII])/Hβ
([OIII]/Hβ)/([NII]/Hα)
[OIII]/[NII]
[NII]/[OII]
[OIII]/[OII]
[NeIII]/[OII]
[SII]/Hα
([OIII]/Hβ)/([SII]/Hα)
[NII]/[SII] + 0.264([NII]/Hα)
12 + log(O/H)

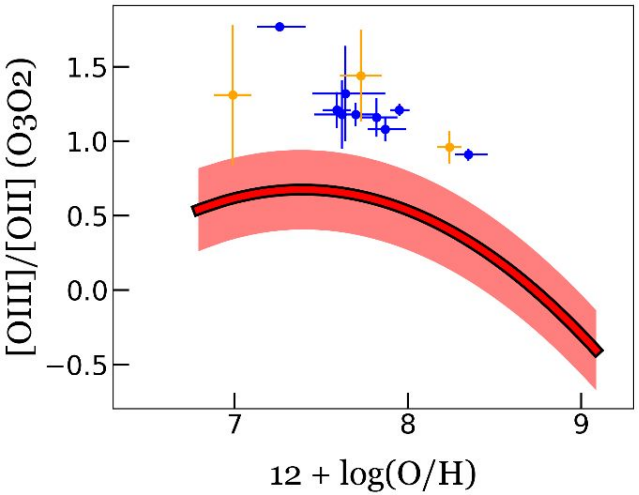
N2S2: 0.2[N II]/Hα + 0.8[S II]/Hα

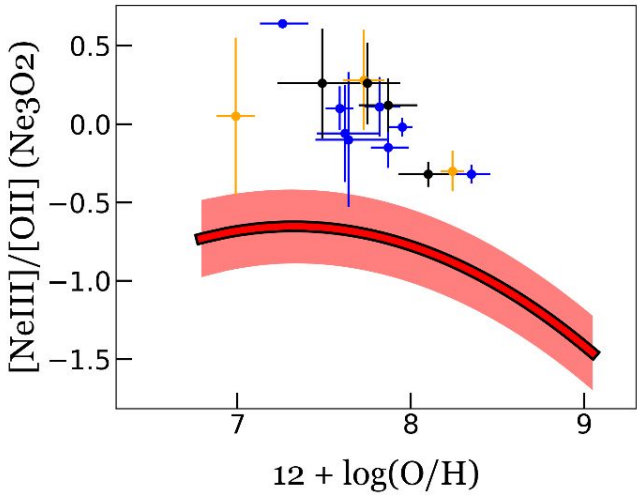



[OIII]/Hβ (R3)
Nakajima et al. 2023
Curti et al. 2022
Trump et al. 2022


[OII]/Hβ (R2)


([OII]+[OIII])/Hβ (R23)
12 + log(O/H)


[OIII]/[OII] (O3O2)
12 + log(O/H)

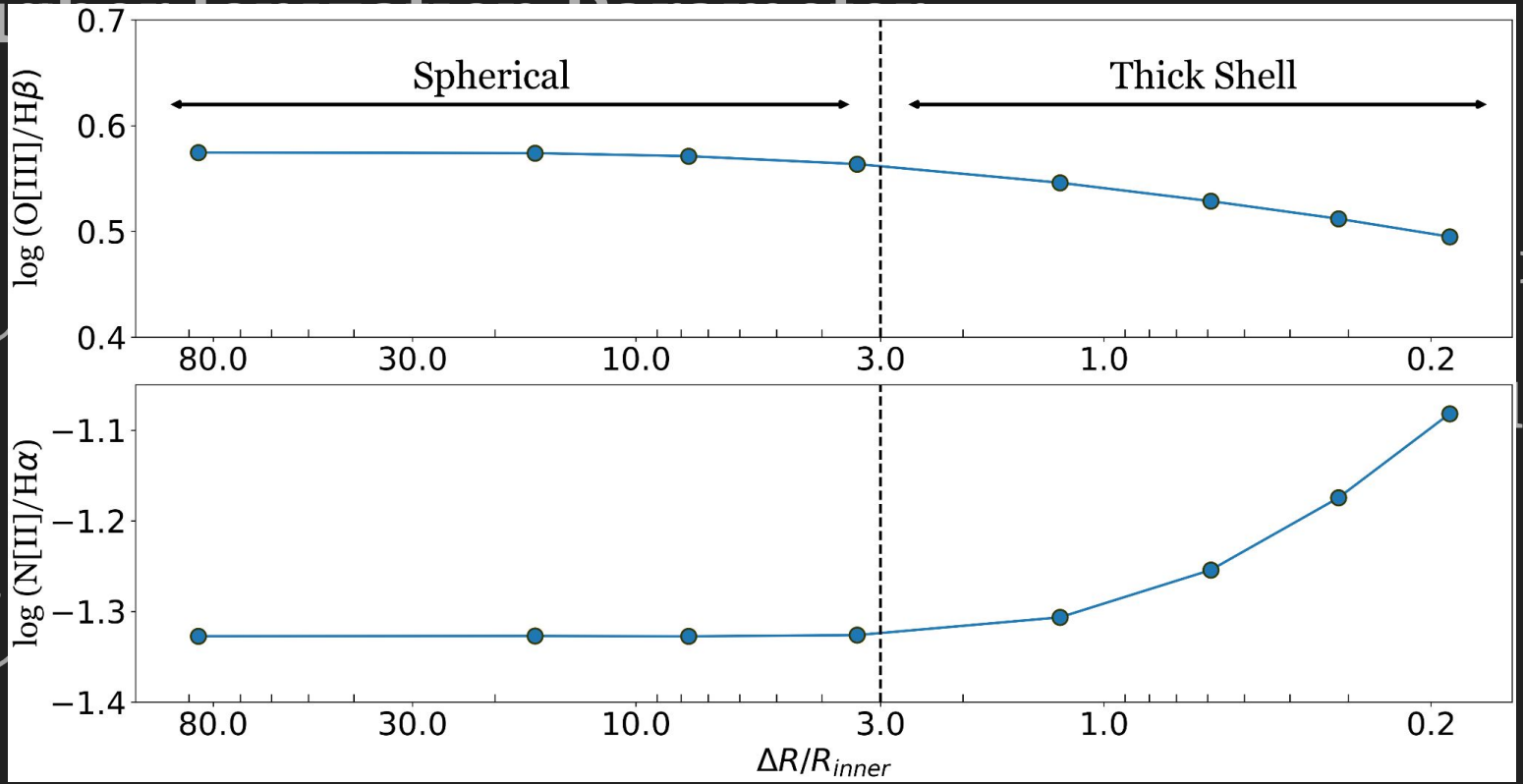

[NeIII]/[OII] (Ne3O2)
12 + log(O/H)

Higher Ionization Parameter

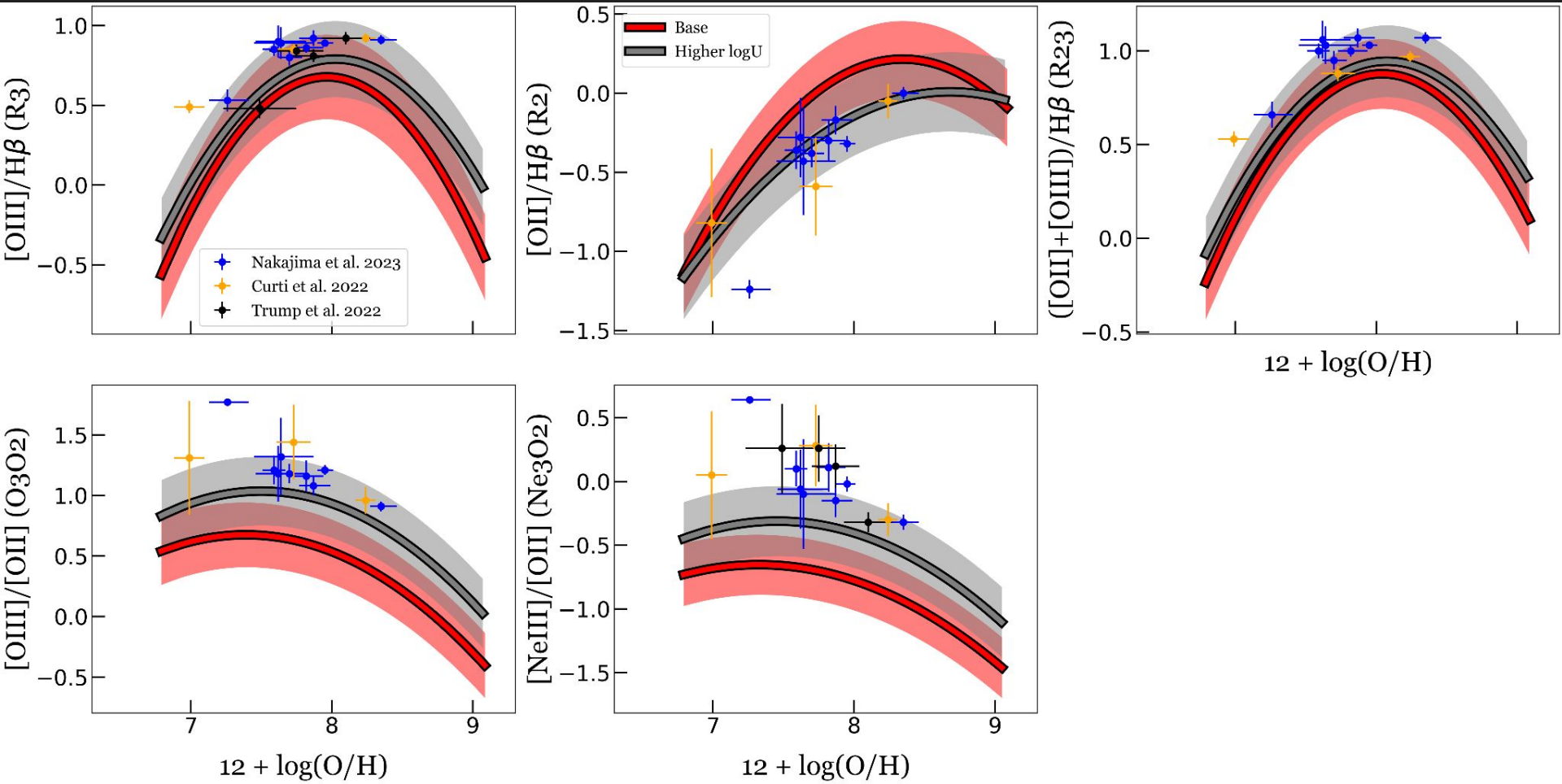
$$U = \left(\frac{Q}{4\pi \, R_S^2 \, n_H \, c} \right)$$

$$U \propto n_H^{1/3} Q^{1/3}$$

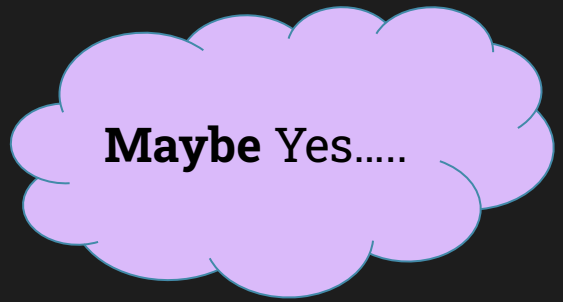
- Increase n_H to 100 cm^3
- Move to a Spherical Shell Geometry



Garg et al. 2022


[OIII]/Hβ (R3)
[OII]/Hβ (R2)
([OII]+[OIII])/Hβ (R23)
[OIII]/[OII] (O3O2)
[NeIII]/[OII] (Ne3O2)
12 + log(O/H)
Base
Higher logU
Nakajima et al. 2023
Curti et al. 2022
Trump et al. 2022

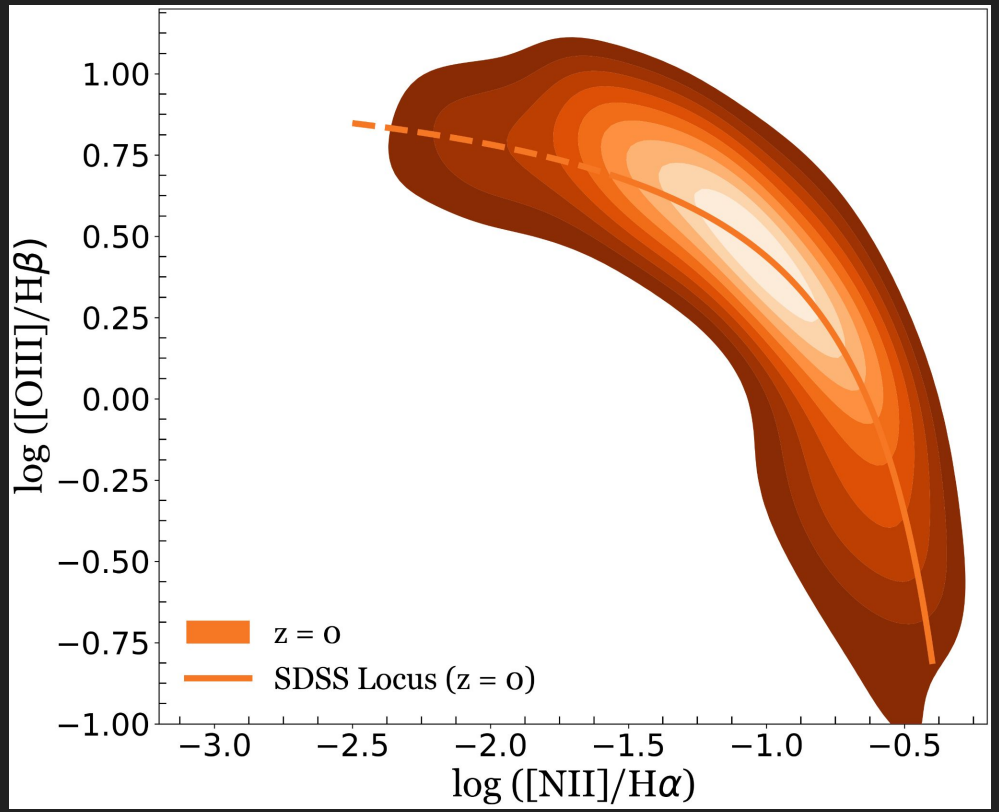
Do the strong line metallicity indicators evolve with redshifts ?



Summary

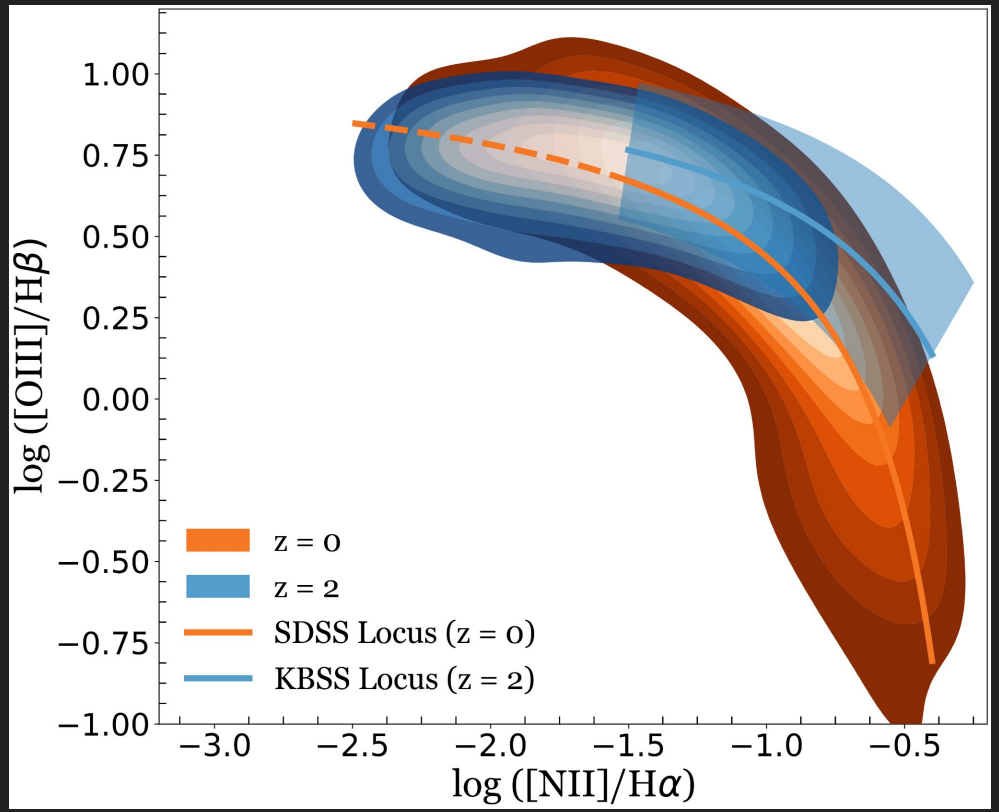
- Our updated nebular emission model now includes nebular emission contribution from HII regions, Post-AGB stars and Diffused Ionized Gas.
- We can reproduce the general trends for different strong line metallicity calibrations at z = 0.
- We show that DIG is important source of nebular emission and can contribute as much as 70% of the line flux in some cases.
- Preliminary JWST observations indicate that metallicity indicators might evolve at high-z towards having a higher ionization parameter.

z = 0 SIMBA galaxies on the BPT diagram



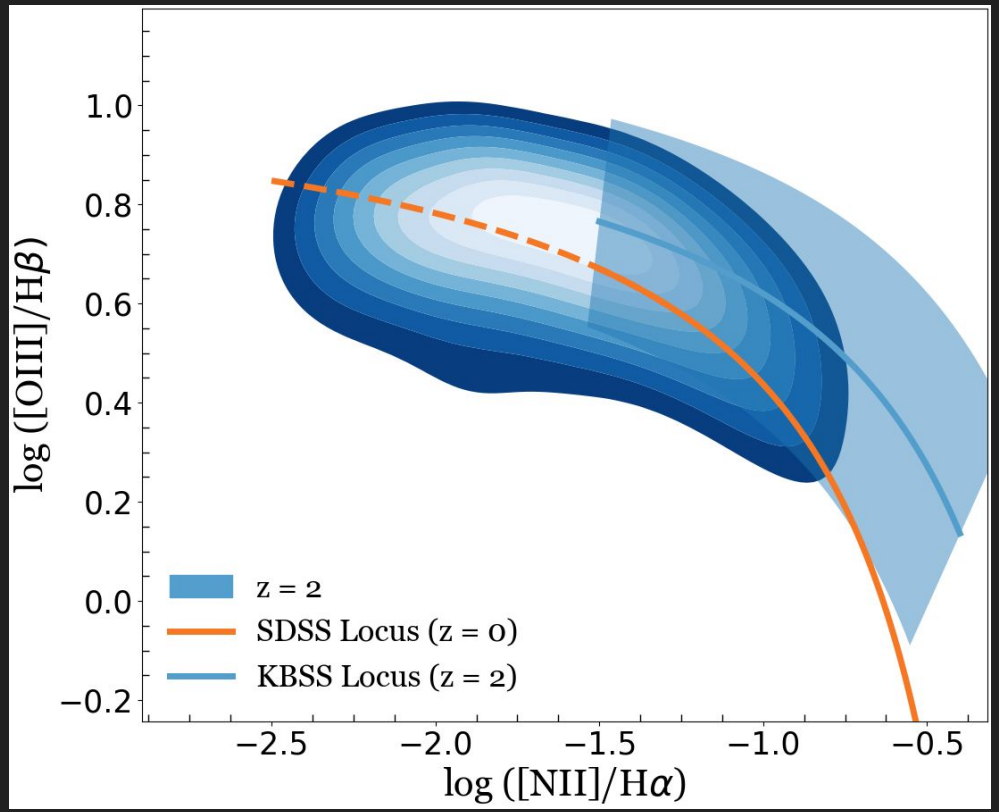
Garg et al. 2022

z = 2 SIMBA galaxies on the BPT diagram



Garg et al. 2022

z = 2 SIMBA galaxies on the BPT diagram



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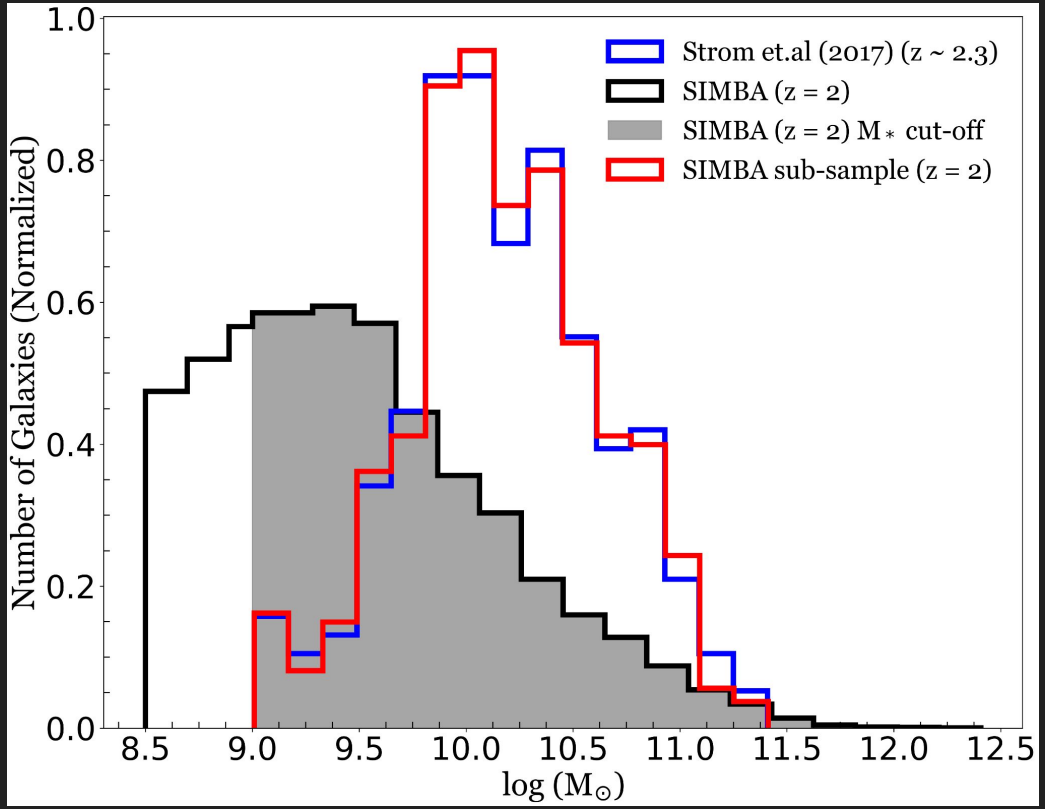
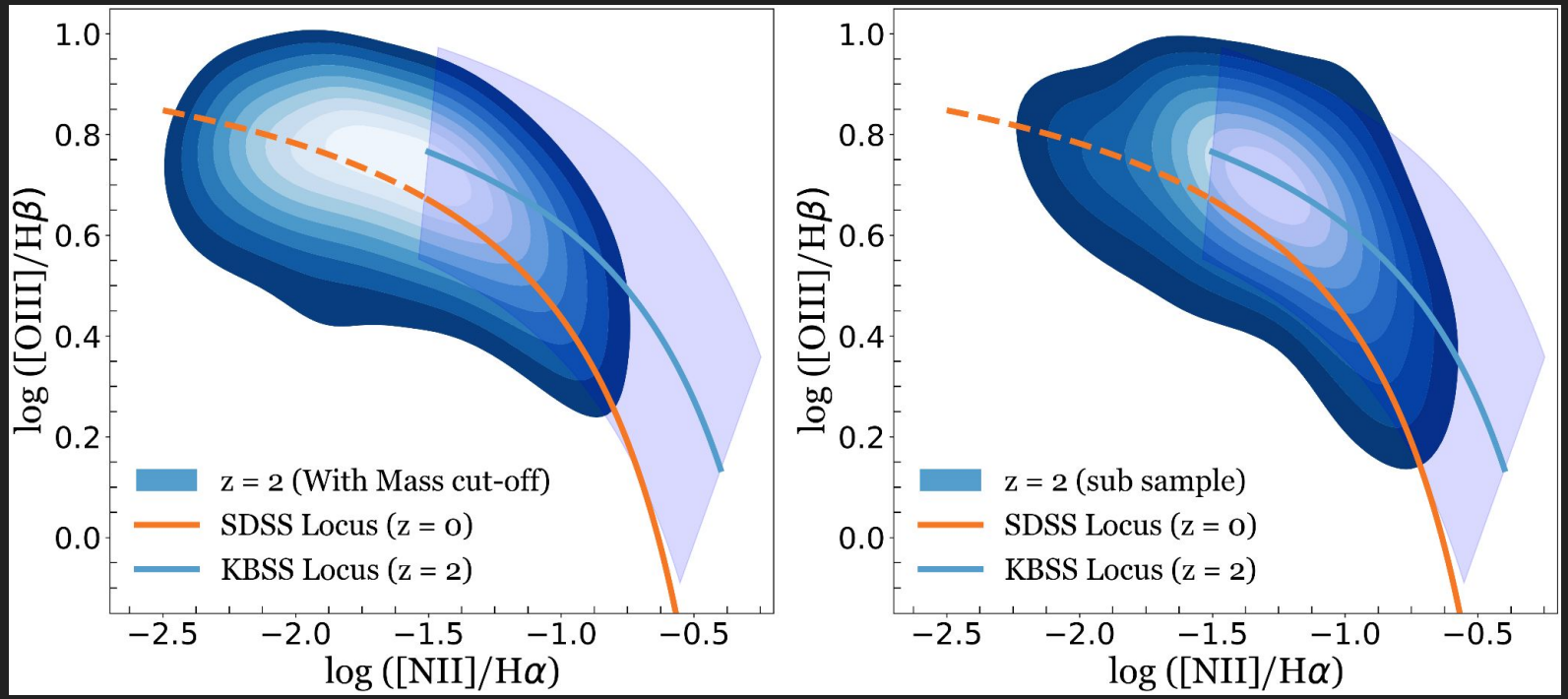
SIMBA and KBSS Mass Distribution

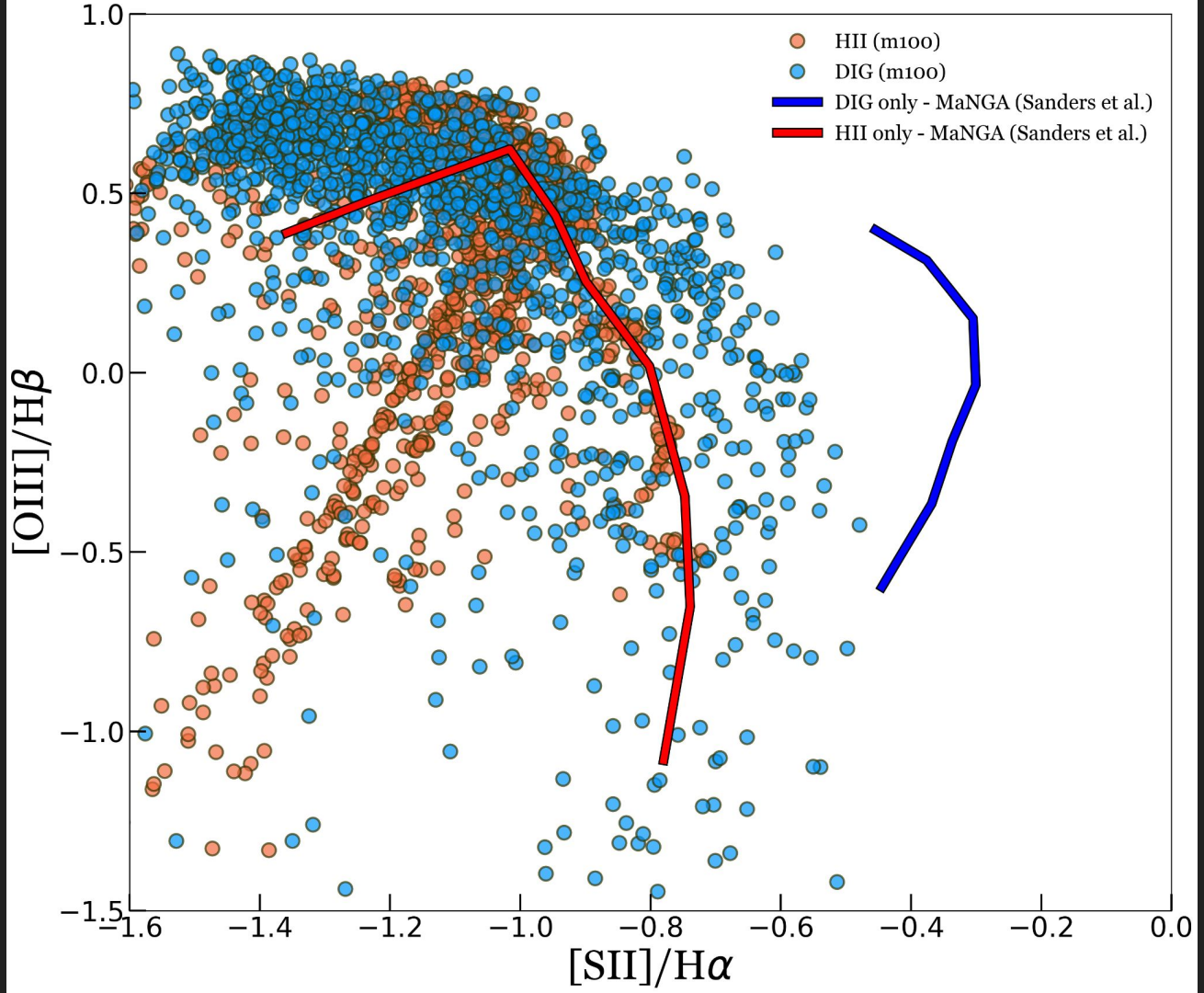


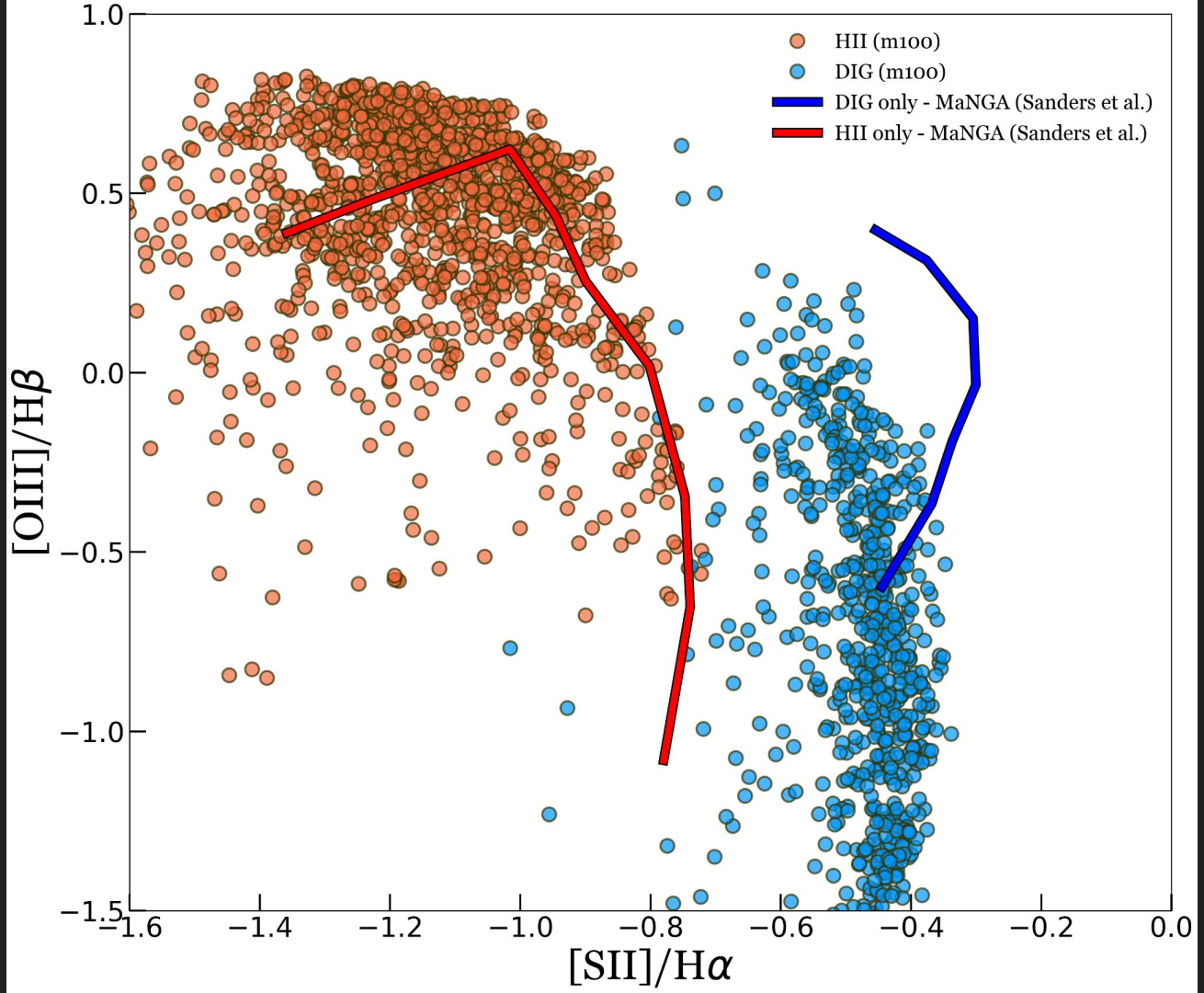
Garg et al. 2022

z = 2 SIMBA galaxies on the BPT diagram



Garg et al. 2022


HII (m100)
DIG (m100)
DIG only - MaNGA (Sanders et al.)
HII only - MaNGA (Sanders et al.)
[OIII]/Hβ
[SII]/Hα
1.0
0.5
0.0
−0.5
−1.0
−1.5
−1.6
−1.4
−1.2
−1.0
−0.8
−0.6
−0.4
−0.2
0.0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−1.0
−0.8
−0.6
−0.4
−0.2
0.0