Infrared tracers to study the chemical evolution of galaxies

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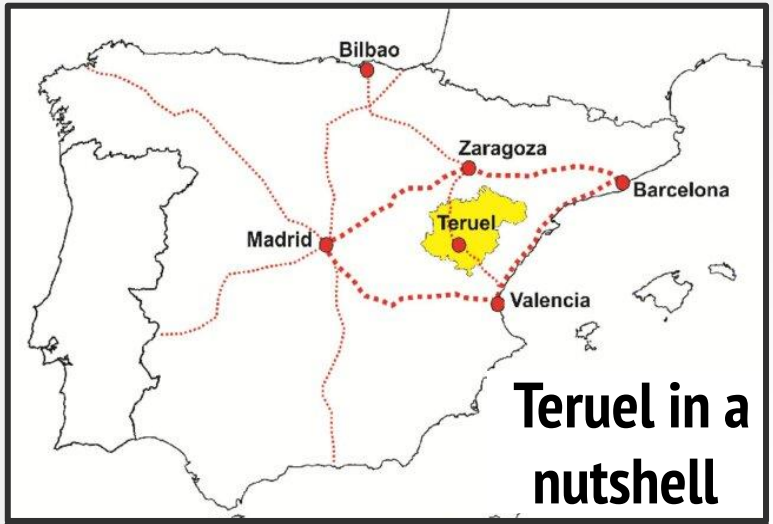
R. Amorín (U. La Serena)
L. Spinoglio (INAF-IAPS)

Shedding new light on the first billion years of the Universe
Marseille, 7th July 2023


Bilbao
Zaragoza
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Teruel
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Valencia
Teruel in a nutshell

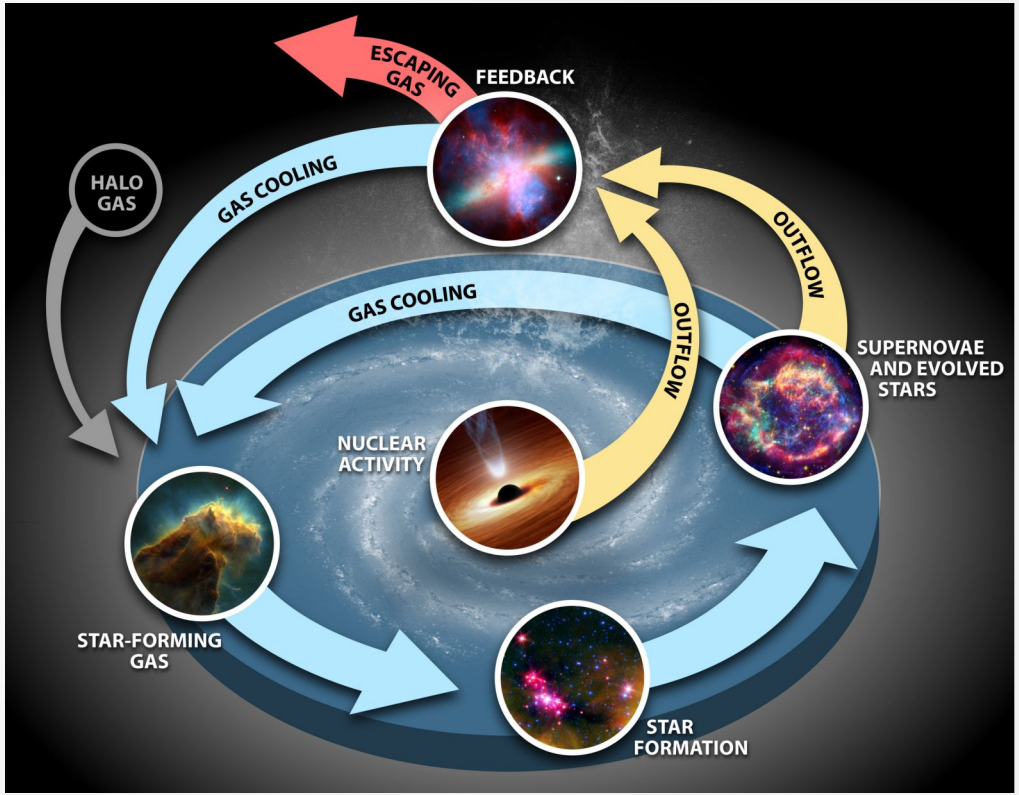

¡TERUEL EXIST


Observatorio Astrofísico de Javalambre
Centro de
Estudios de
Física del Cosmos
de Aragón
CEFCA

Introduction

Heavy elements (0.02% baryons), main role from galaxies to planets

ISM witness of **chemical enrichment** gas and dust content + composition



Origins white book

Mass-metallicity relation

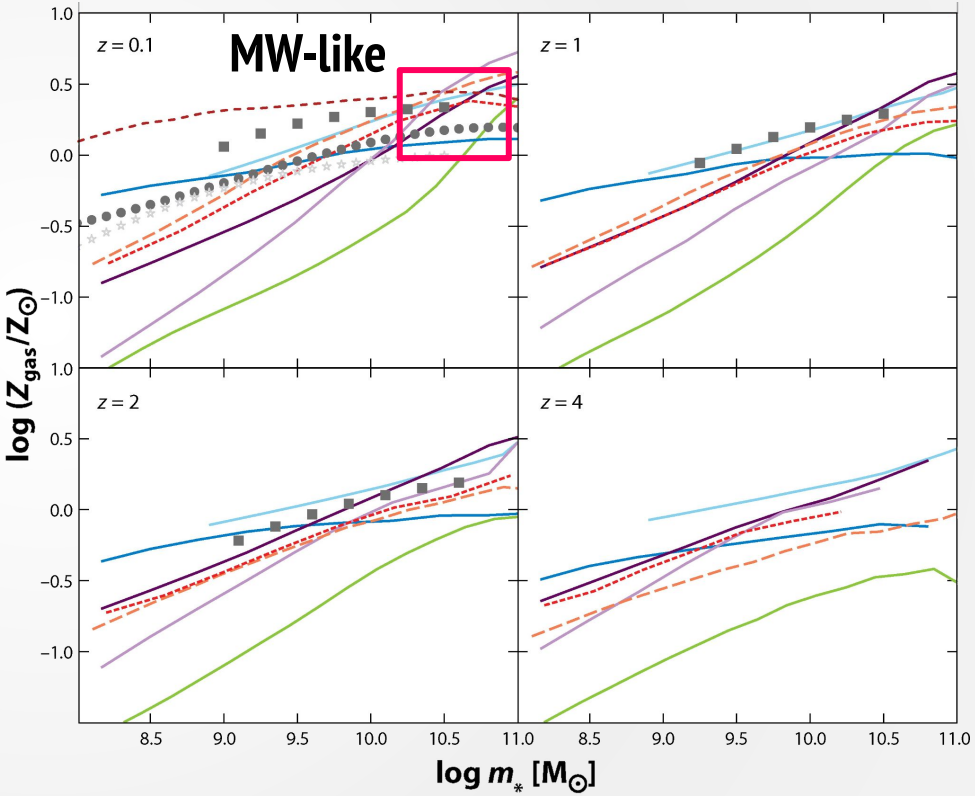
Metals & dust production **linked** to M_*

$Z(M_*, SFR, ...)$ → **Models**

Z depends on gas **accretion** and **feedback**

Tension with numerical simulations

Somerville & Davé 2015



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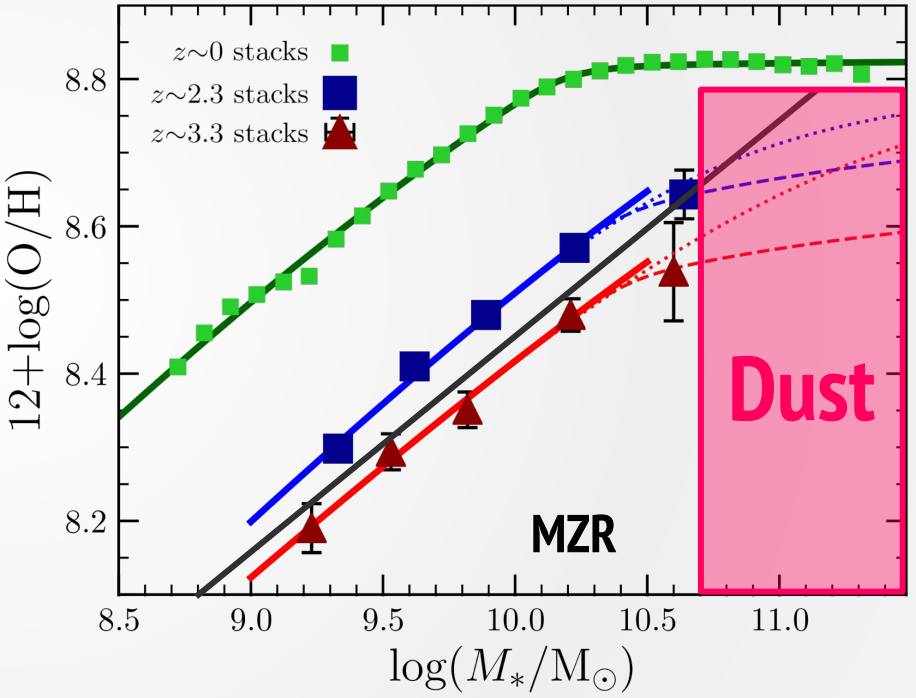
Tension with numerical simulations

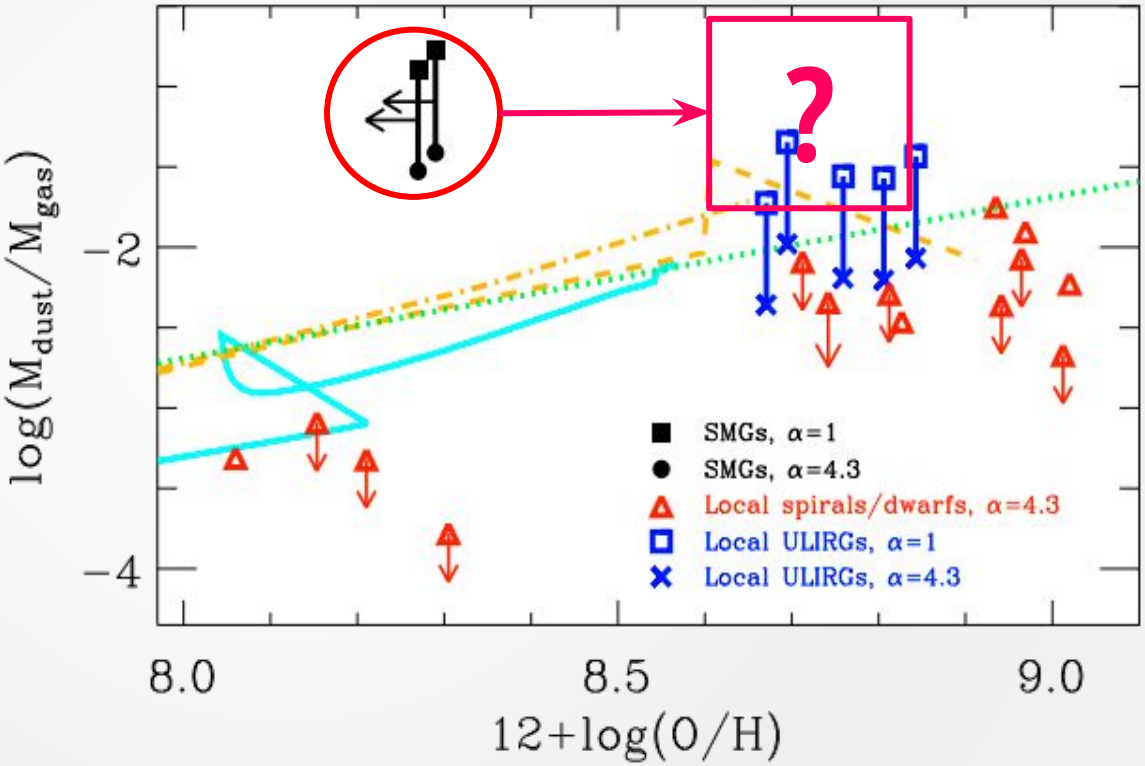
Sanders+21



Dust at high redshift

Low optical metallicities
in dusty **submm. galaxies**

Santini+10, Rowlands+14

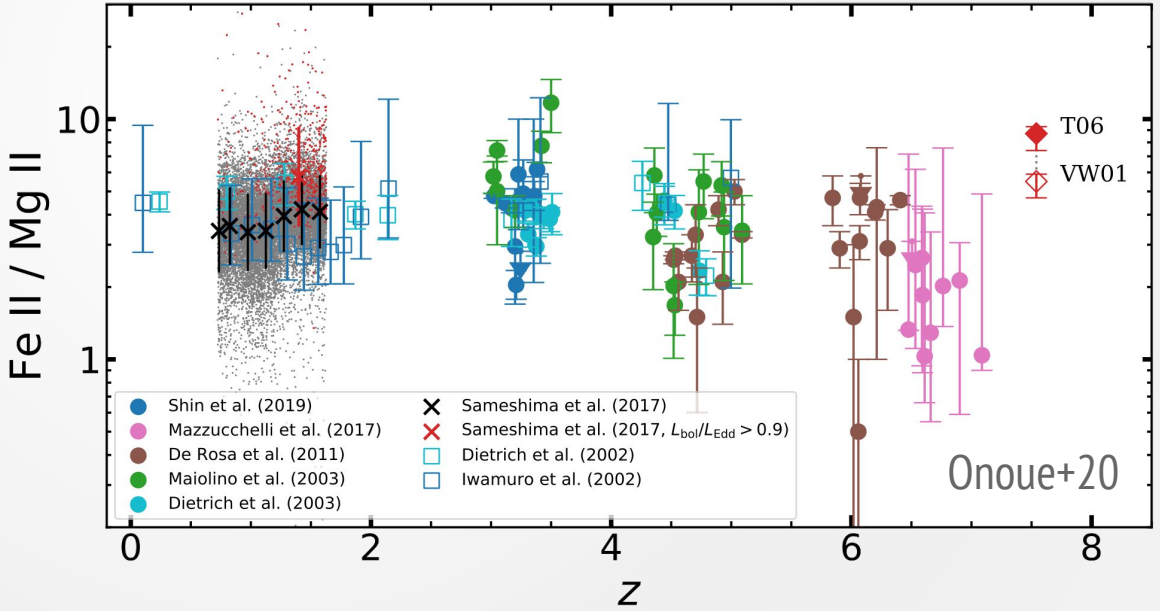


The Astrophysical Journal, 898:105 (16pp), 2020 August 1 https://doi.org/10.3847/1538-4357/aba193

No Redshift Evolution in the Broad-line-region Metallicity up to $z = 7.54$: Deep Near-infrared Spectroscopy of ULAS J1342+0928

Masafusa Onoue[1], Eduardo Bañados[1], Chiara Mazzucchelli[2], Bram P. Venemans[1], Jan-Torge Schindler[1], Fabian Walter[1], Joseph F. Hennawi[3], Irham Taufik Andika[1], Frederick B. Davies[4], Roberto Decarli[5], Emanuele P. Farina[1,6], Knud Jahnke[1], Tohru Nagao[7], Nozomu Tominaga[8,9], and Feige Wang[10,11,12]

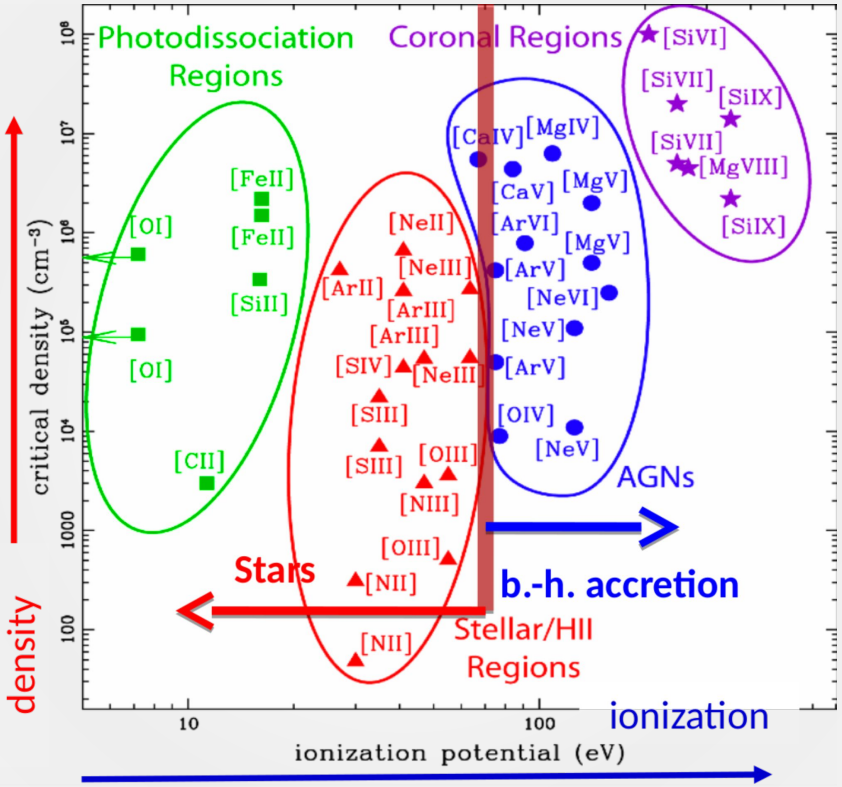
No chemical evolution in **quasars?**



Why IR lines?

Temperature dependence of optical lines

Dust obscuration with increasing SFR

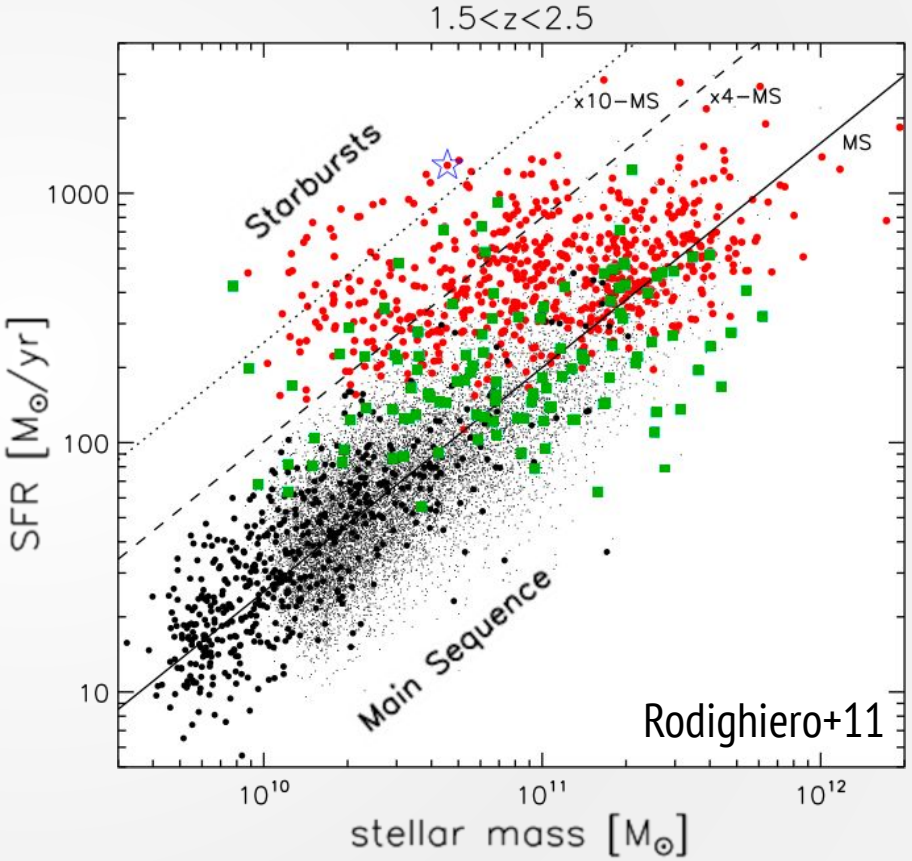


Spinoglio & Malkan 1992

Dust obscuration

Obscured phases during evolution

Dominate cosmic noon, **dawn?**



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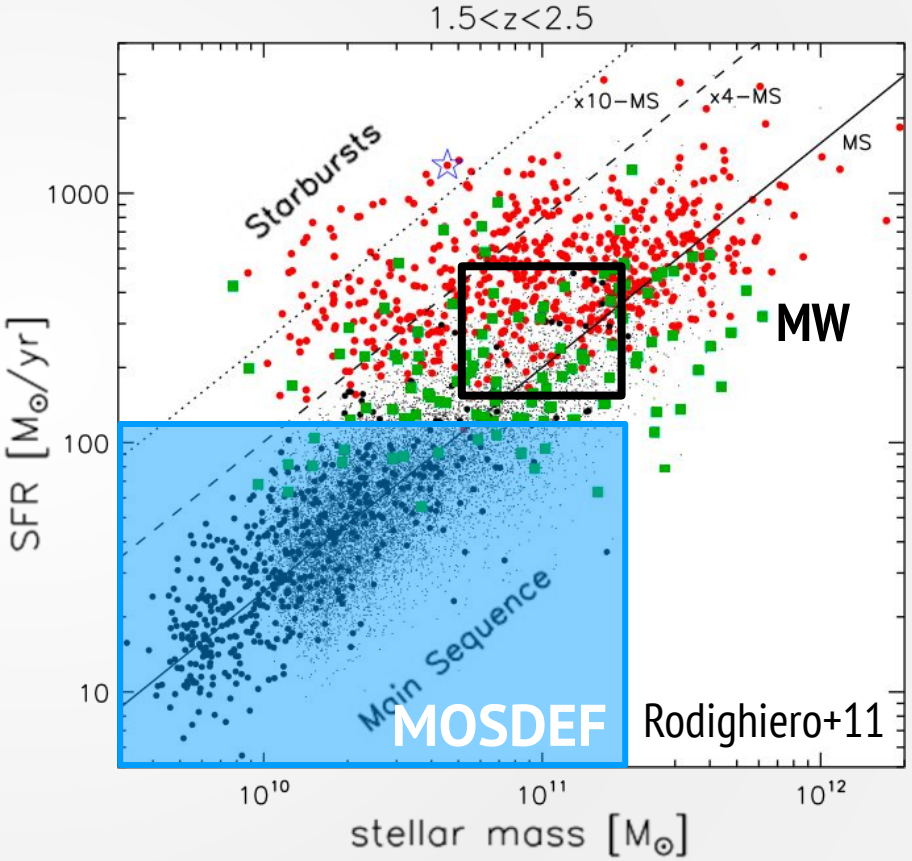
Dominate cosmic noon, **dawn?**



Dust obscuration (even at low metallicities)

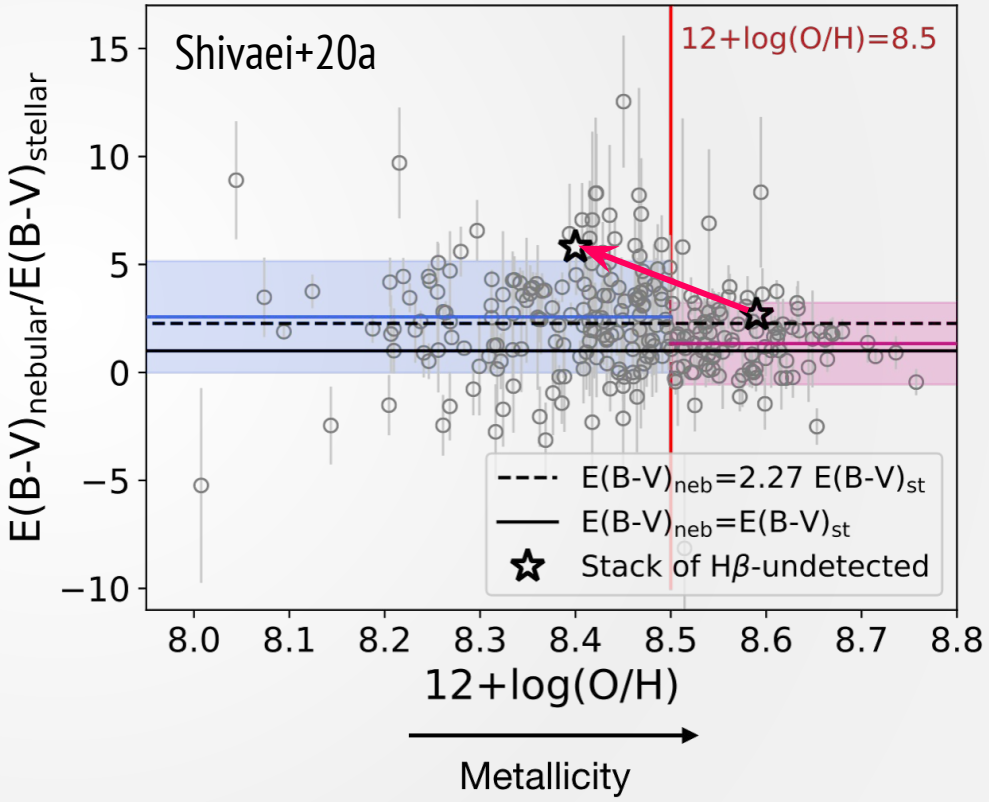
Obscured phases during evolution

Dominate cosmic noon, **dawn?**

MOSDEF survey (1.5 < z < 3.5)

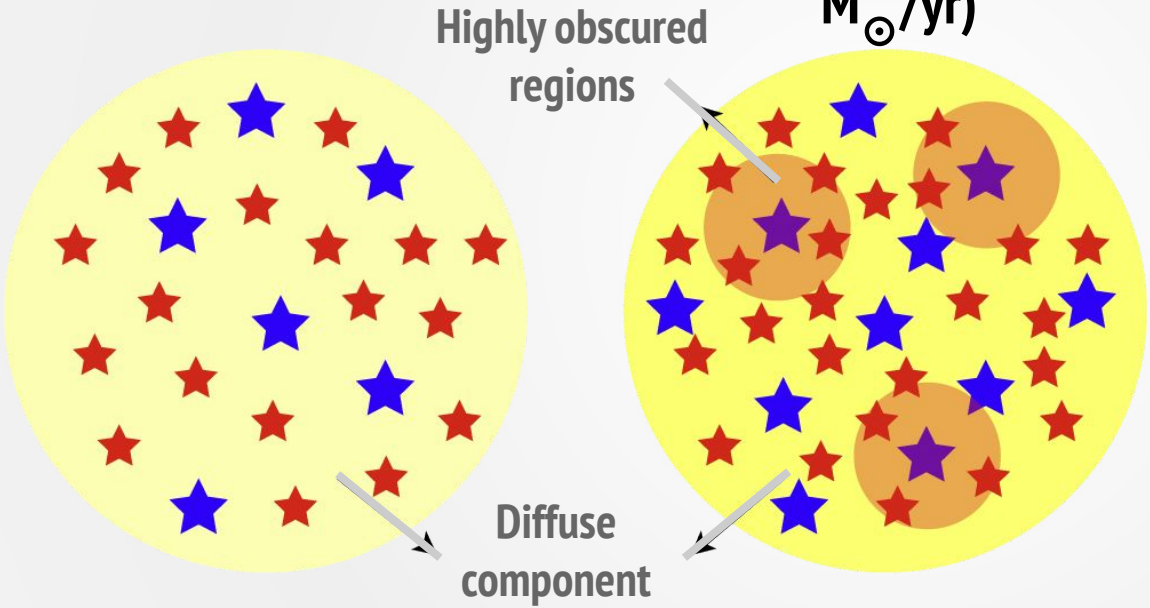
$E(B\text{-}V)_{neb} \propto$ **SFR**

$\propto$ decreasing **O/H**



Solar metallicity
(SFR < 10 $M_\odot$/yr)

Low metallicity
(SFR ~20 – 100 $M_\odot$/yr)



Reddy+15, Shivaei+20a

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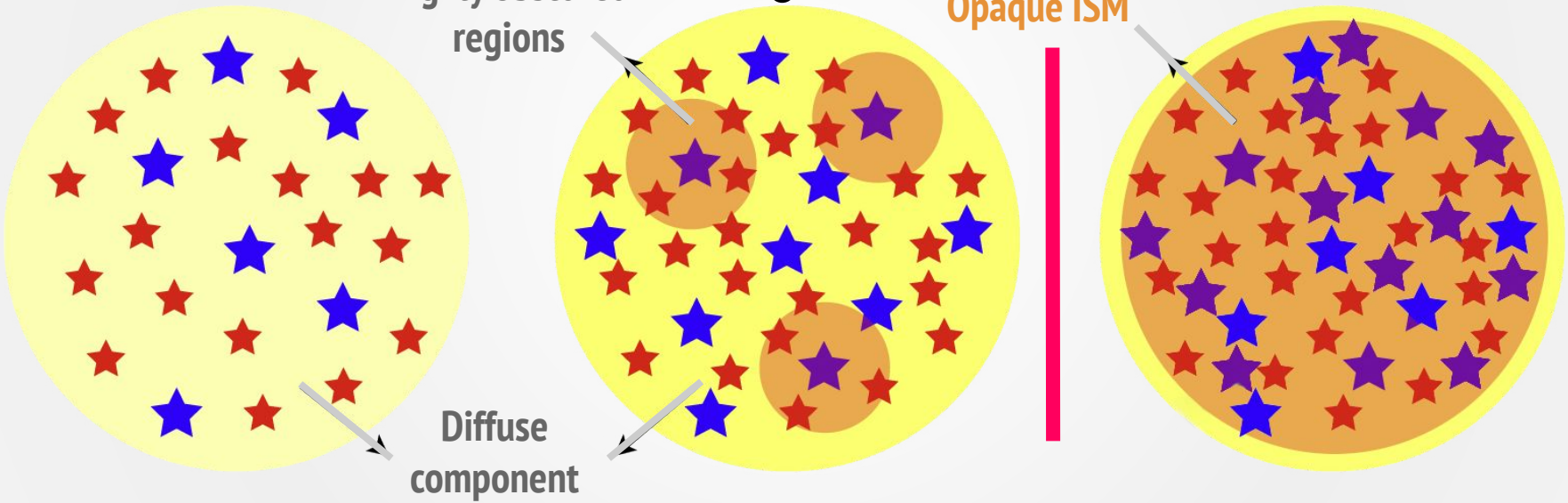
> 100 $M_\odot$/yr?



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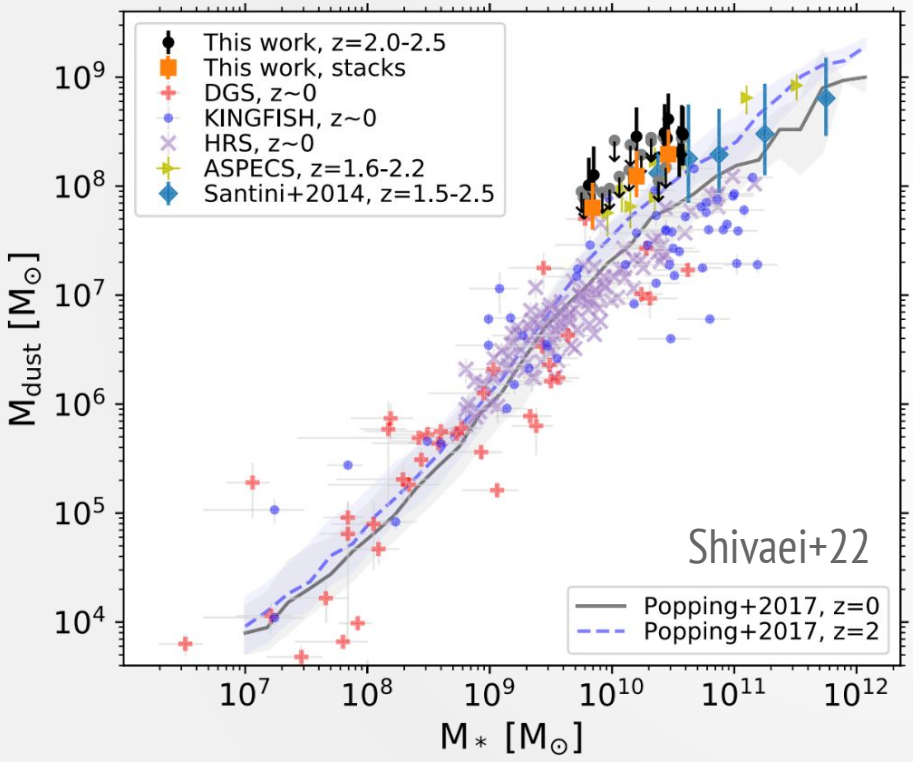
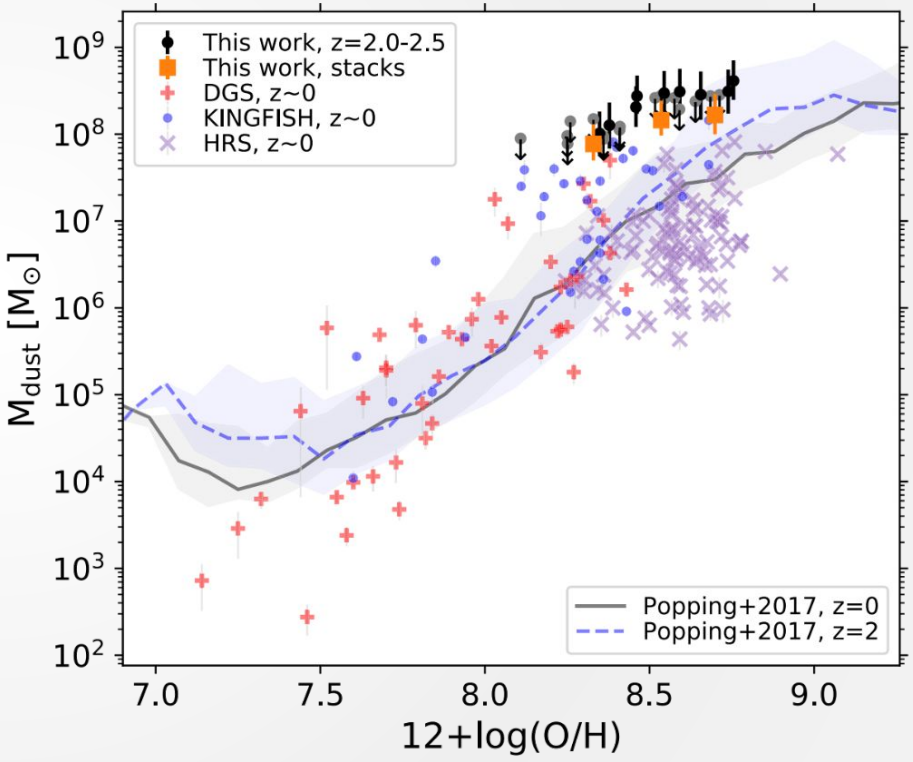
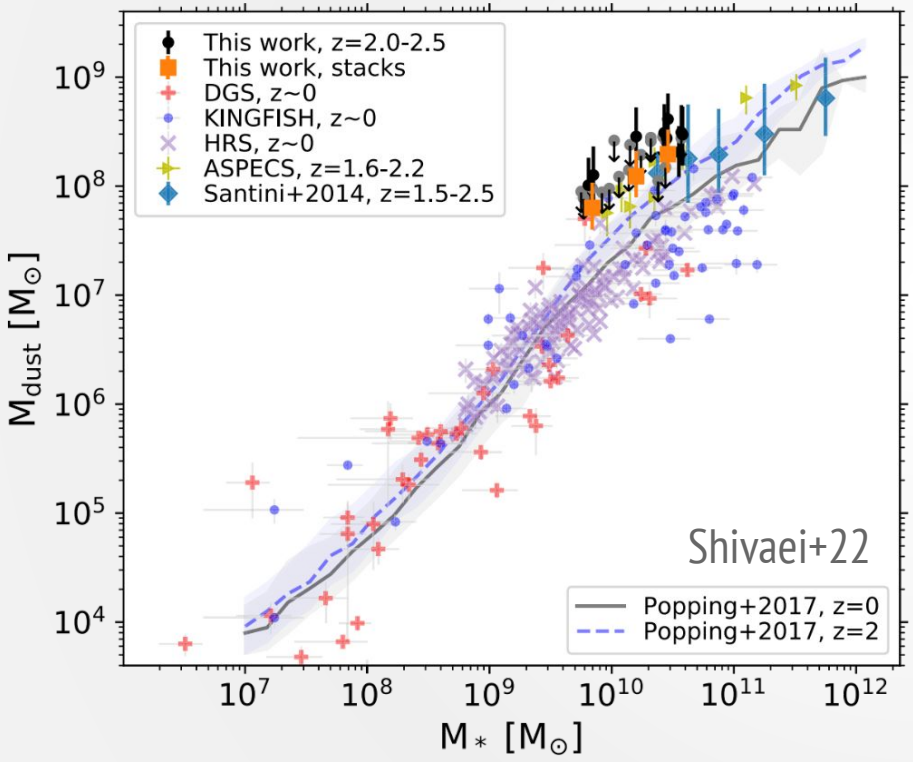
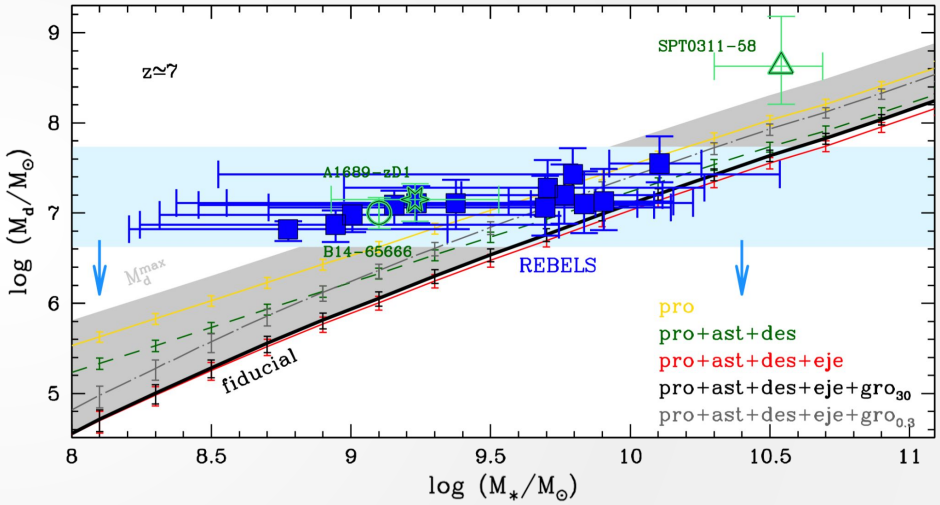
Dust obscuration (even at low metallicities)





Dust at low metallicities





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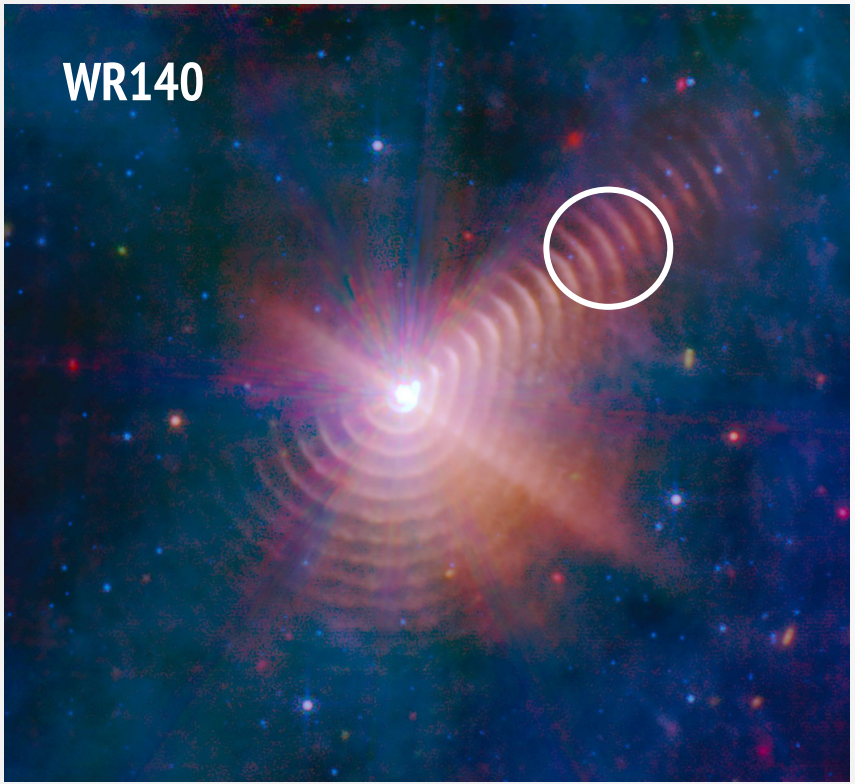
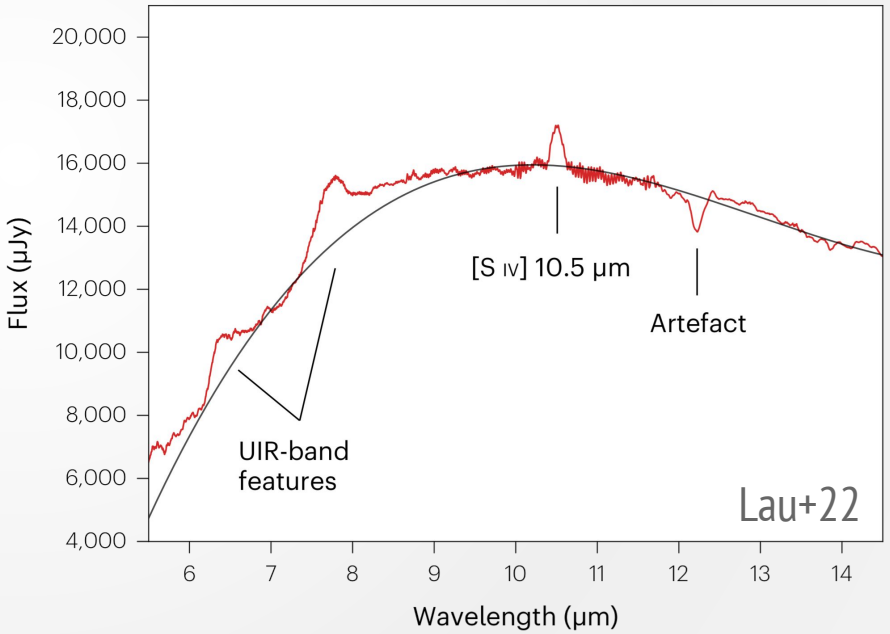


Dust produced in massive star **winds?**



Temperature

Direct method (DM)

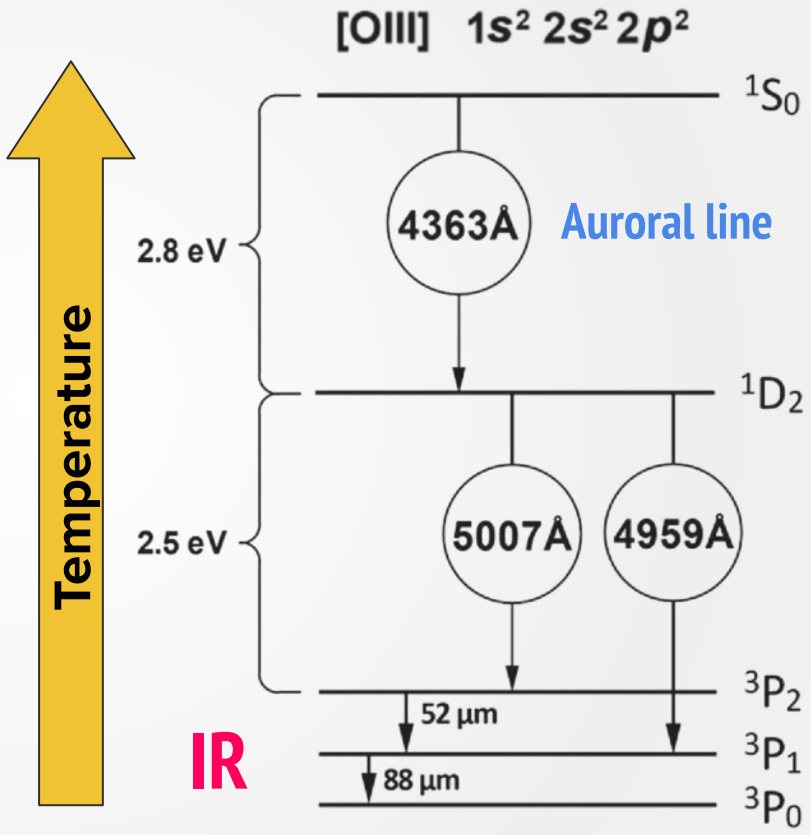
optical nebular lines + auroral lines **(Te)**

Strong-line methods

few bright lines, fainter galaxies

Calibrations (**~0.7 dex**, Kewley & Ellison 08)

Secondary **nitrogen** production channel



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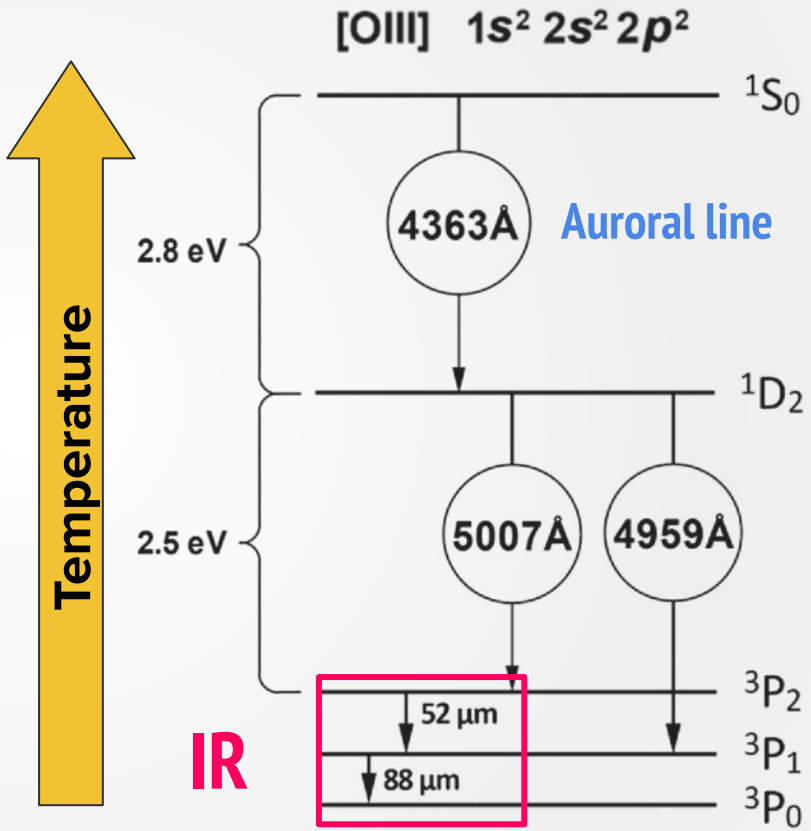
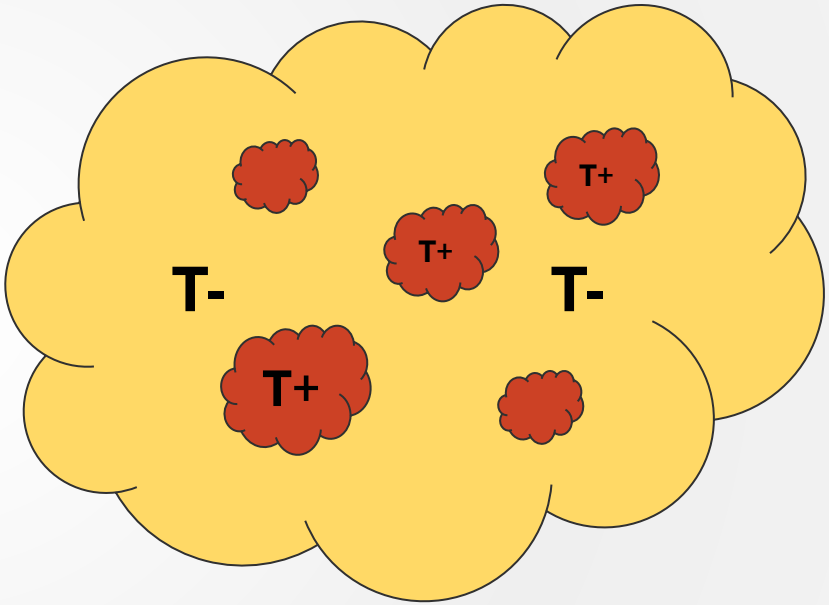


Temperature

IR lines are insensitive to **Te effects**

- Inhomogeneities
- **t^2-problem** (Peimbert 67)
- Low-Te components (PNe; Liu+06)



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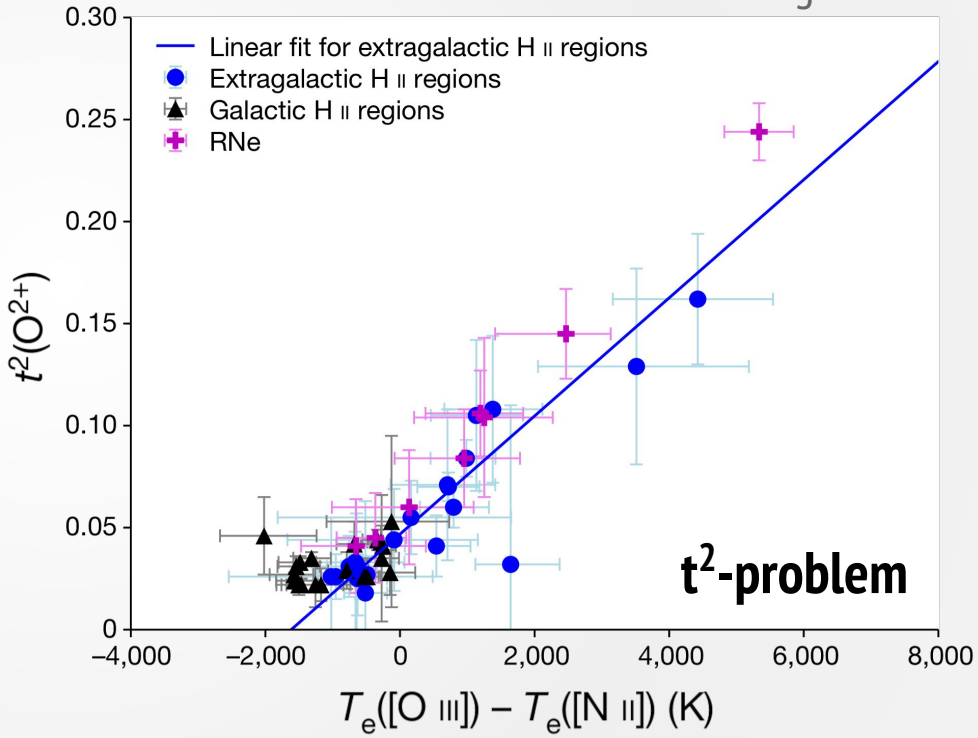
Méndez-Delgado+23



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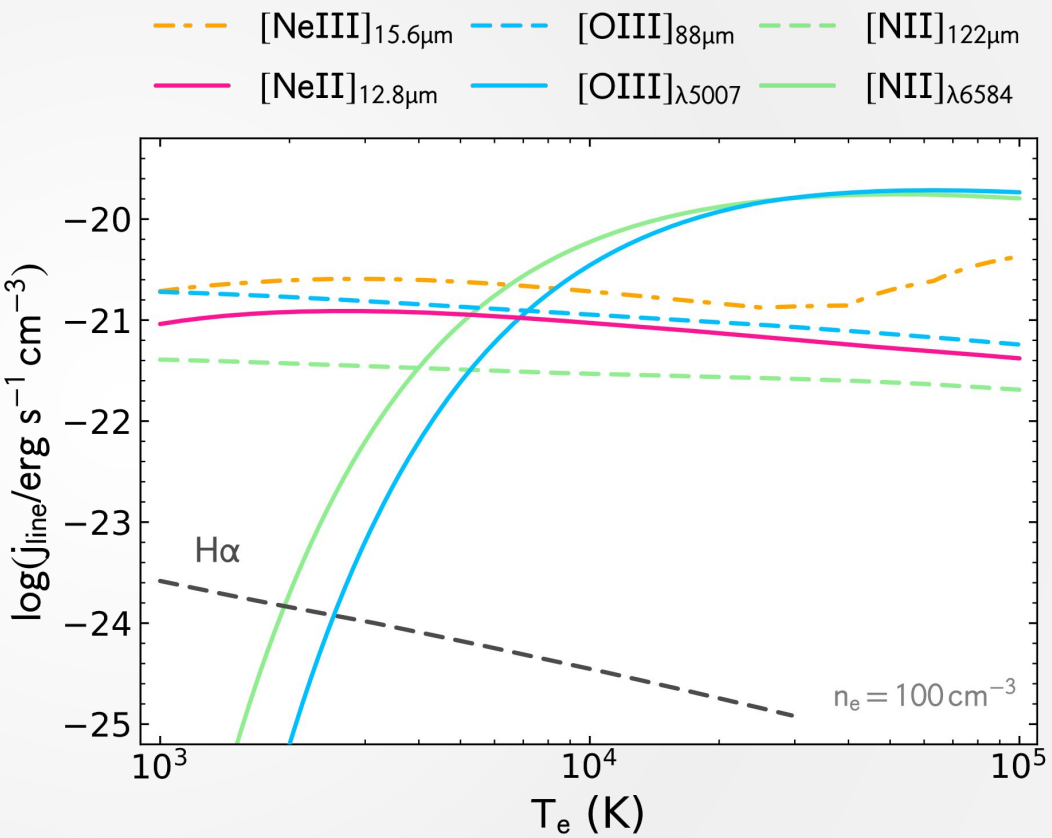
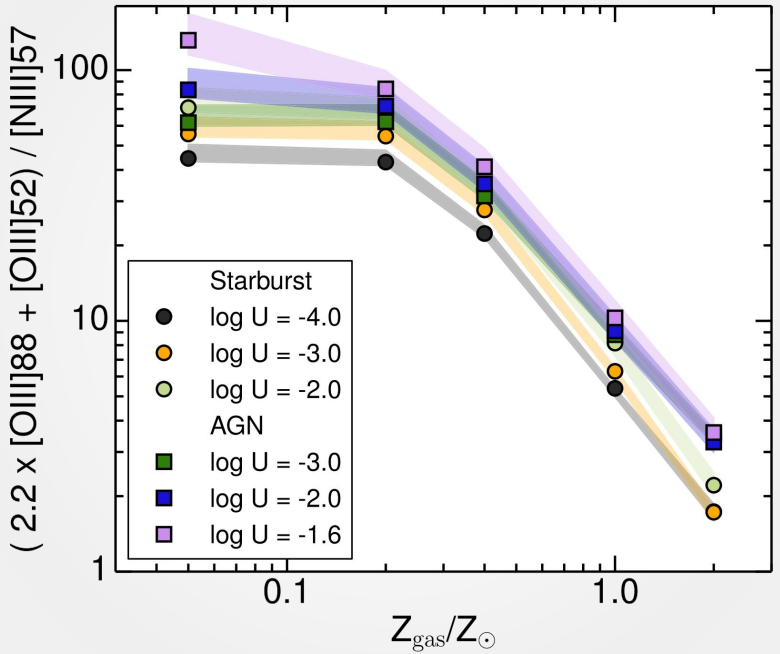
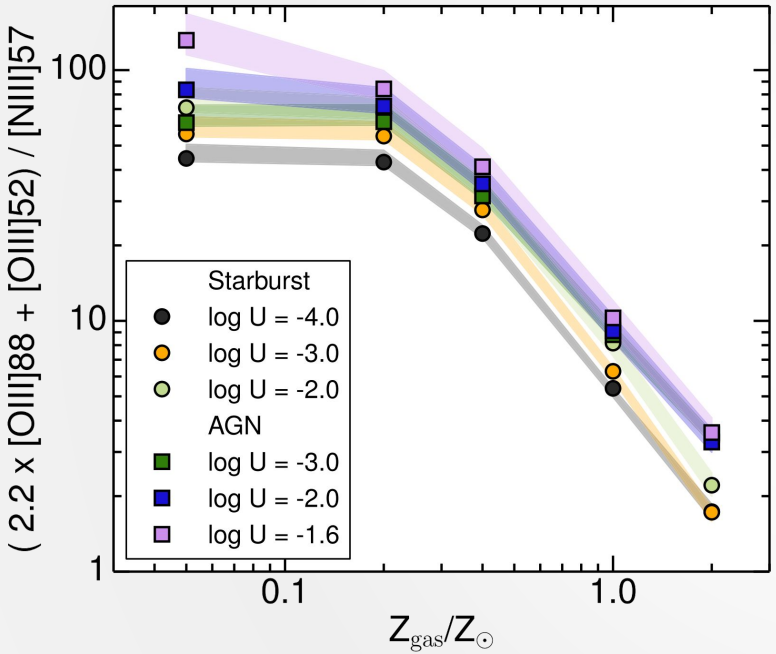


Fernández-Ontiveros+21

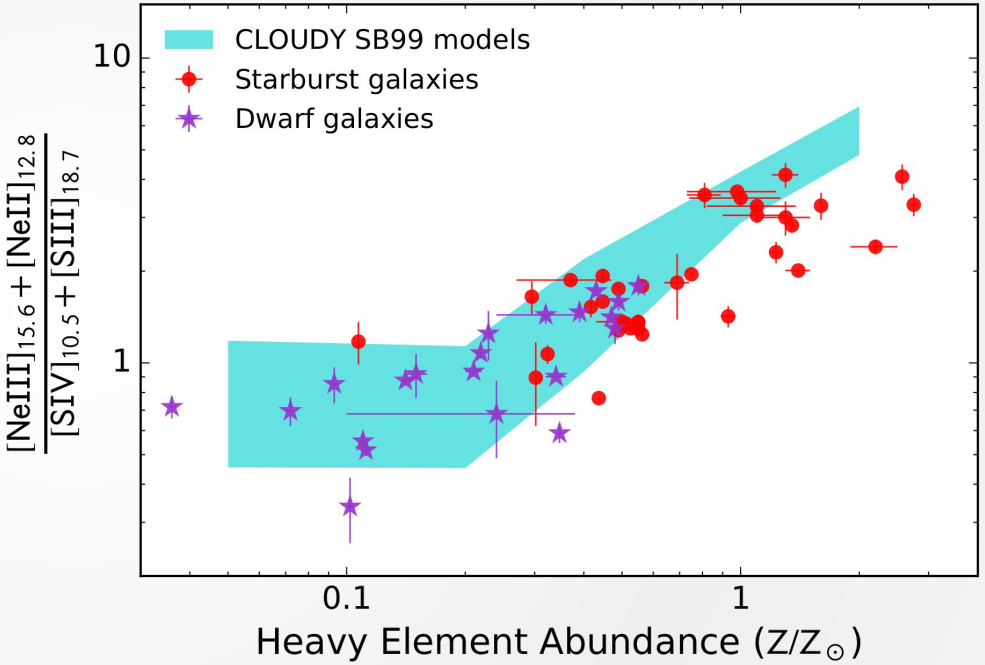
IR abundance tracers



Few IR-based diagnostics in the market



Photoionisation, relies on **N/O-OH** prescription (Nagao+11, Pereira-Santaella+17, Herrera-Camus+18)



Empirical calibration (Fernández-Ontiveros+16,17)

HII-CHI-MISTRY-IR (HCm-IR)

Nebular **IR** lines (**Spitzer + Herschel + SOFIA**):

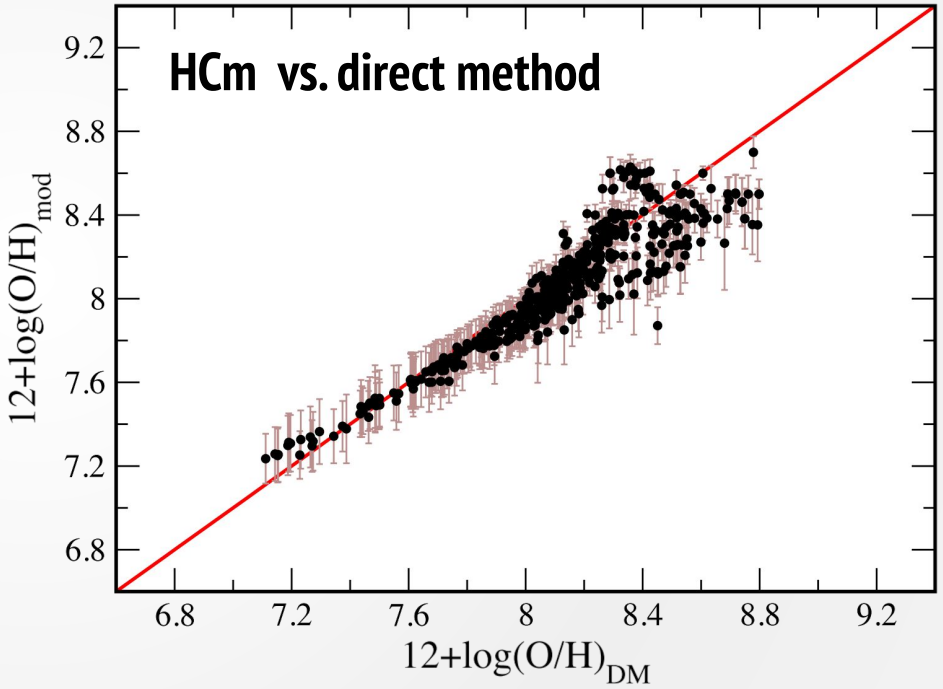
[NeII]$_{12.8}$ [NeIII]$_{15.6}$ [SIII]$_{18.7,33.5}$ [SIV]$_{10.5}$
[OIII]$_{52,88}$ [NIII]$_{57}$ [NII]$_{122,205}$ + Brα Pfα Huα

Photoionisation models (**O/H, N/O, logU**)

Star formation and **AGN** models

(Fernández-Ontiveros+21, Pérez-Díaz+22)

28 dwarfs, 19 solar-like **starbursts, 9**
(U)LIRGs, 8 High-z galaxies + 58 AGN



Based on **HCm**, Pérez-Montero 14, 21

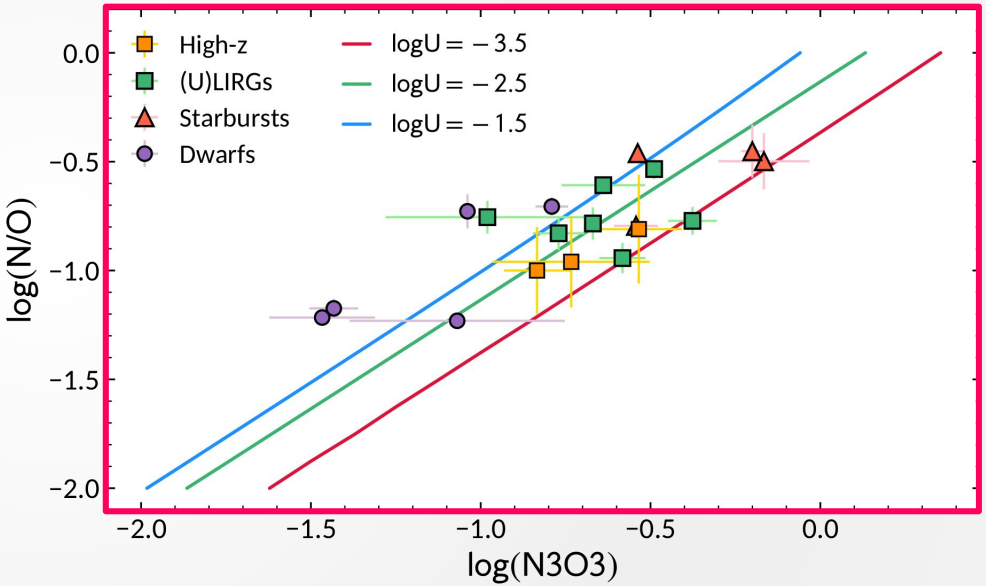
HII-CHI-MISTRY-IR (HCm-IR)

Independent N/O determination

$$\log(\mathrm{N3O3}) = \log\left(\frac{\mathrm{I}\left([\mathrm{N\,III}]_{57\,\mu\mathrm{m}}\right)}{\mathrm{I}\left([\mathrm{O\,III}]_{52\,\mu\mathrm{m}}\right)}\right)$$

IRAS15543+3013, HLSW-01, SDP.11

(0.1 < z < 3)



Fernández-Ontiveros+21, Pérez-Díaz+22

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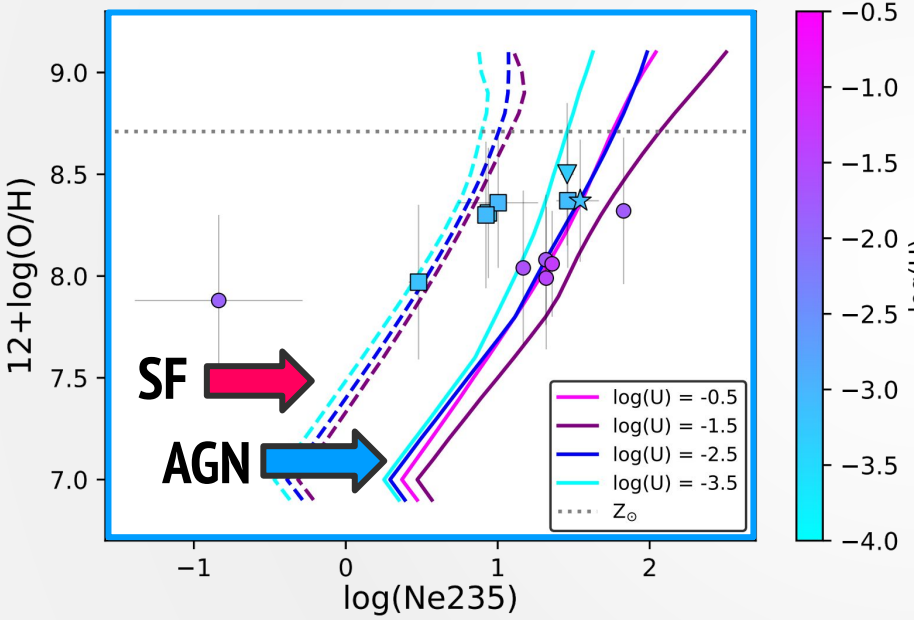
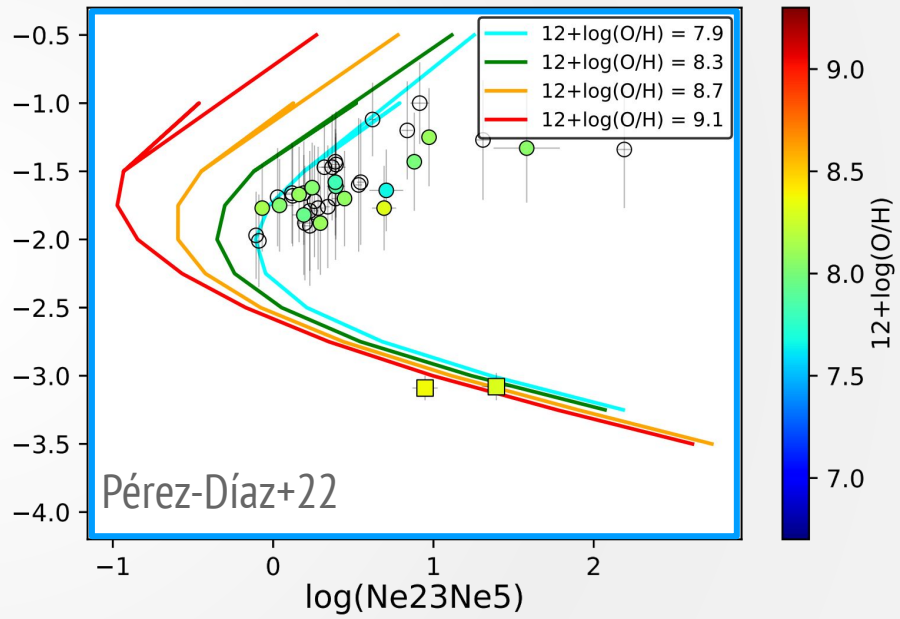
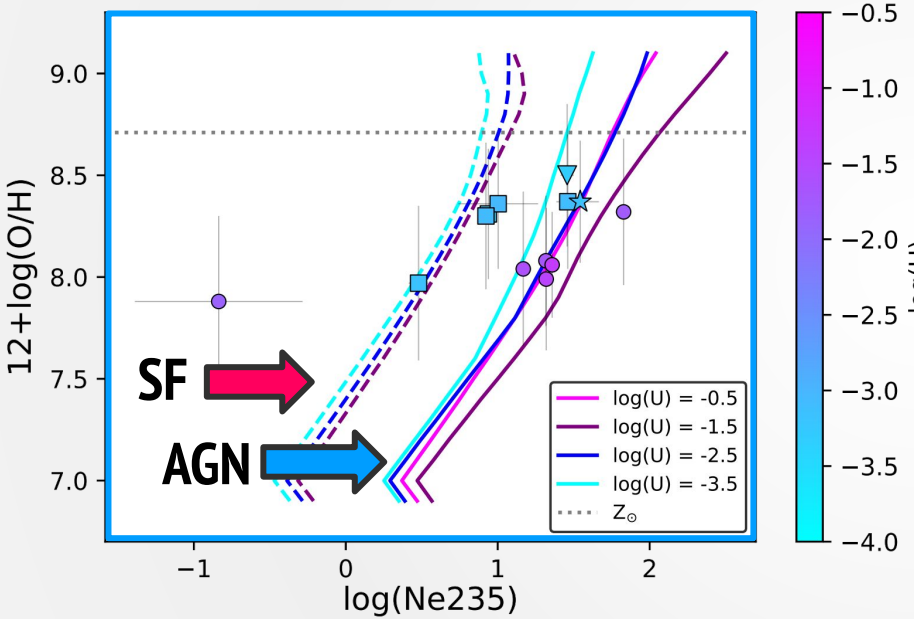




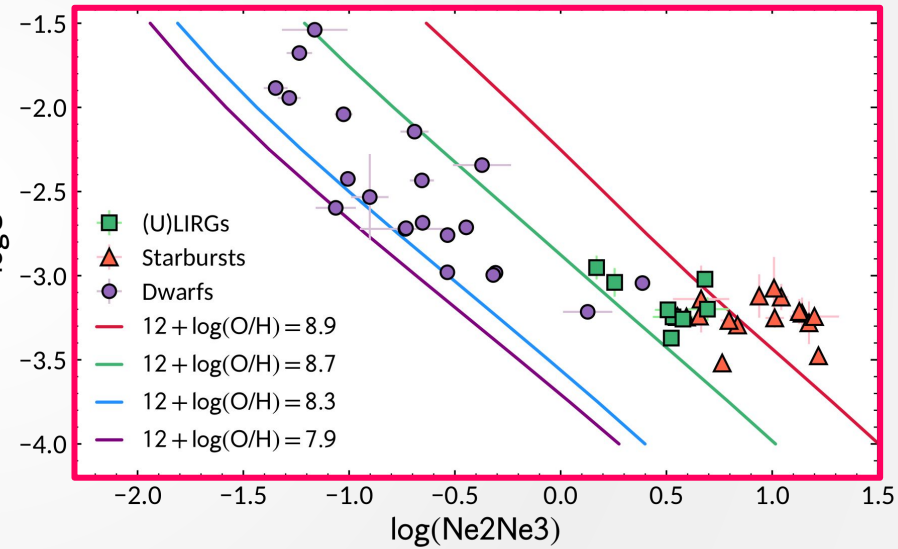
$Ne235 = ([NeII]_{12.8} + [NeIII]_{15.6} + [NeV]_{14+24}) / H$

$Ne23Ne5 = ([NeII]_{12.8} + [NeIII]_{15.6}) / [NeV]_{14+24}$

HII-CHI-MISTRY-IR (HCm-IR)



Fernández-Ontiveros+21



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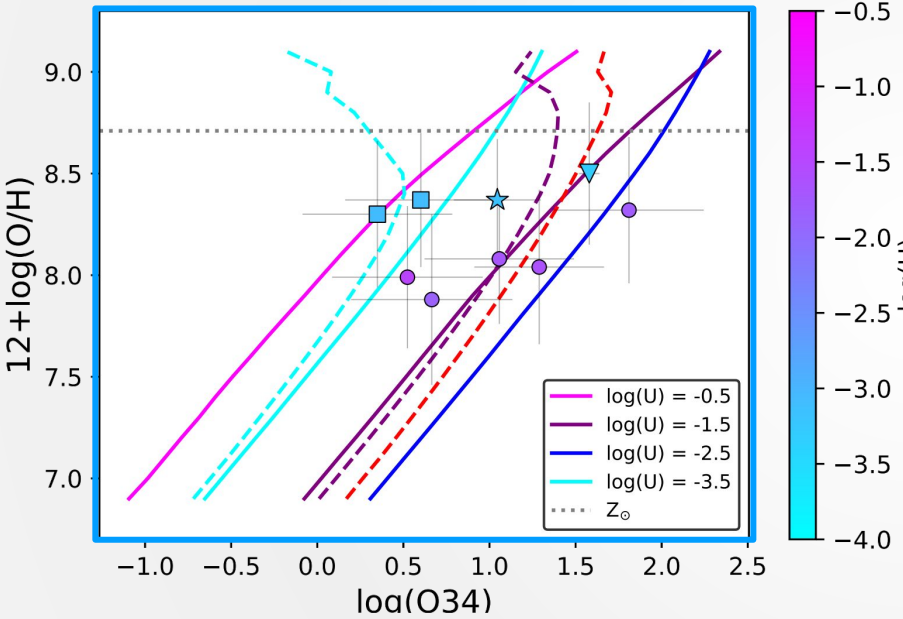
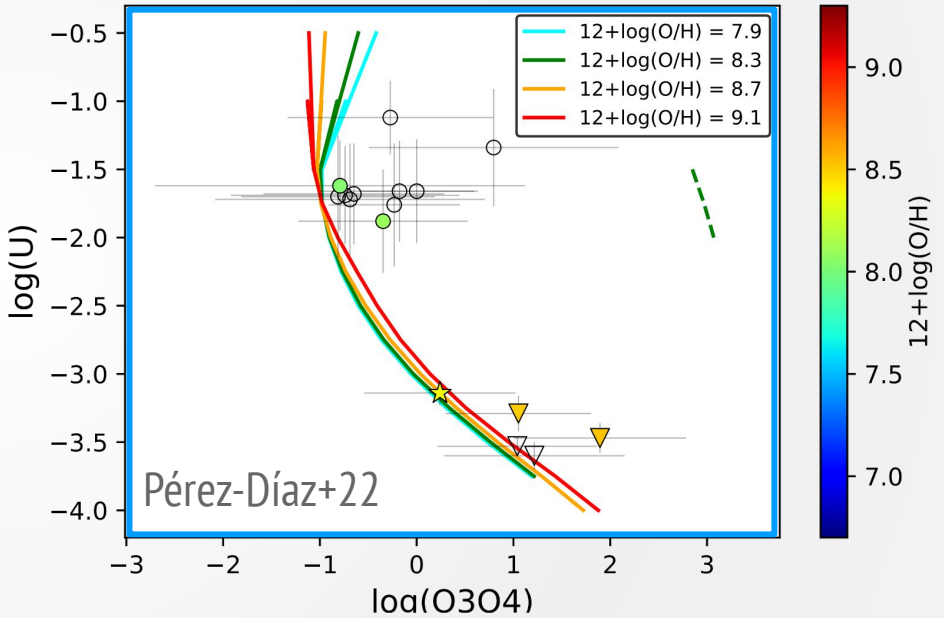
$Ne2Ne3 = [NeII]_{12.8} / [NeIII]_{15.6}$

HII-CHI-MISTRY-IR (HCm-IR)



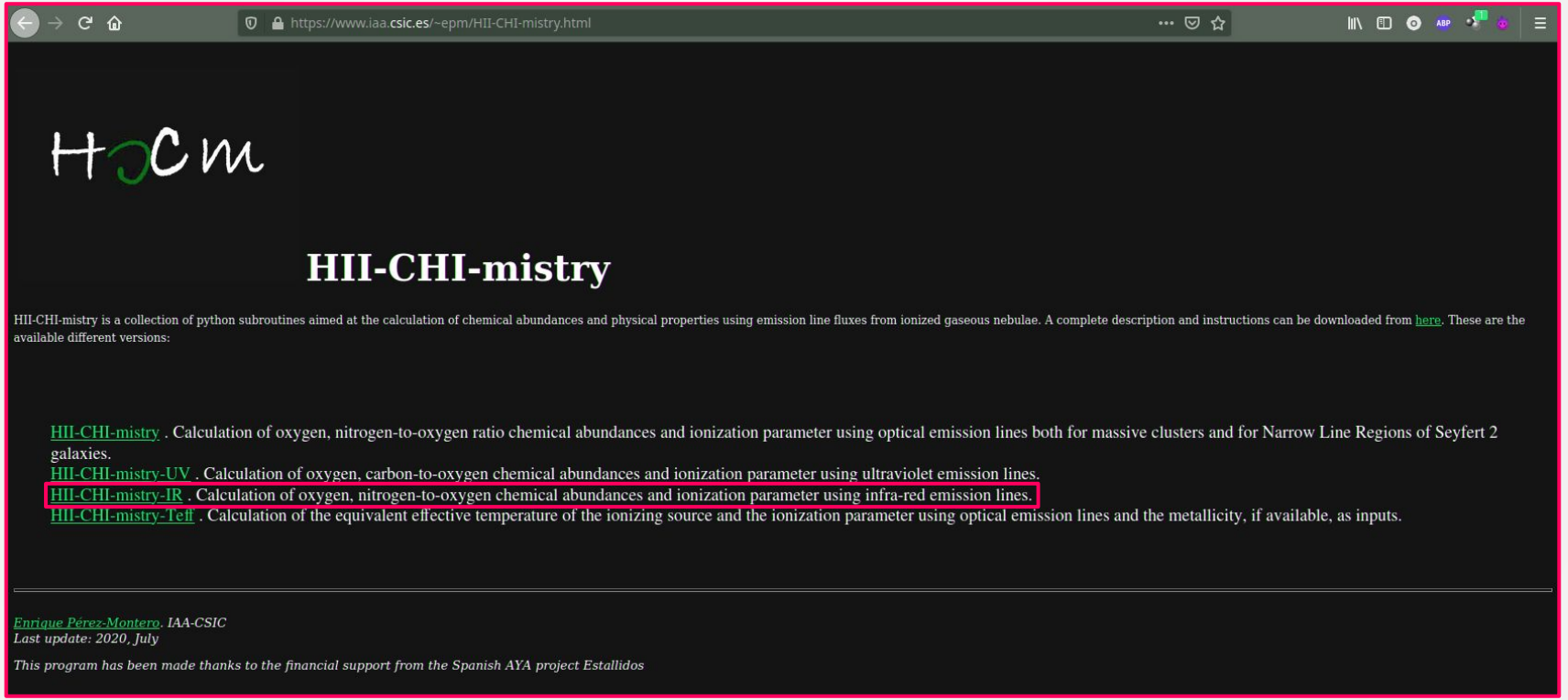
$O34 = ([OIII]_{52} + [OIV]_{26}) / H$



$O3O4 = [OIII]_{52} / [OIV]_{26}$

HCm-IR is publicly available

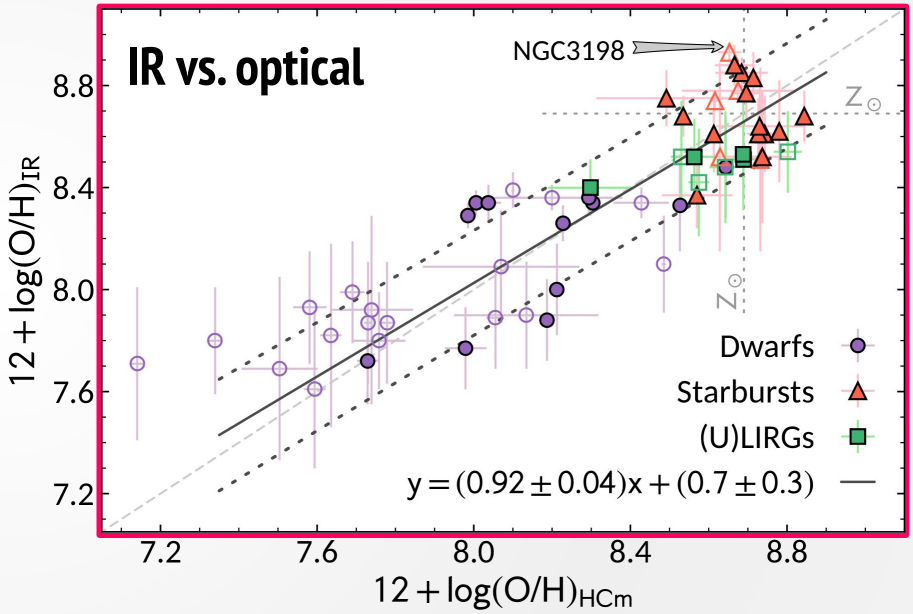
https://www.iaa.csic.es/~epm/HII-CHI-mistry.html



IR vs optical abundances

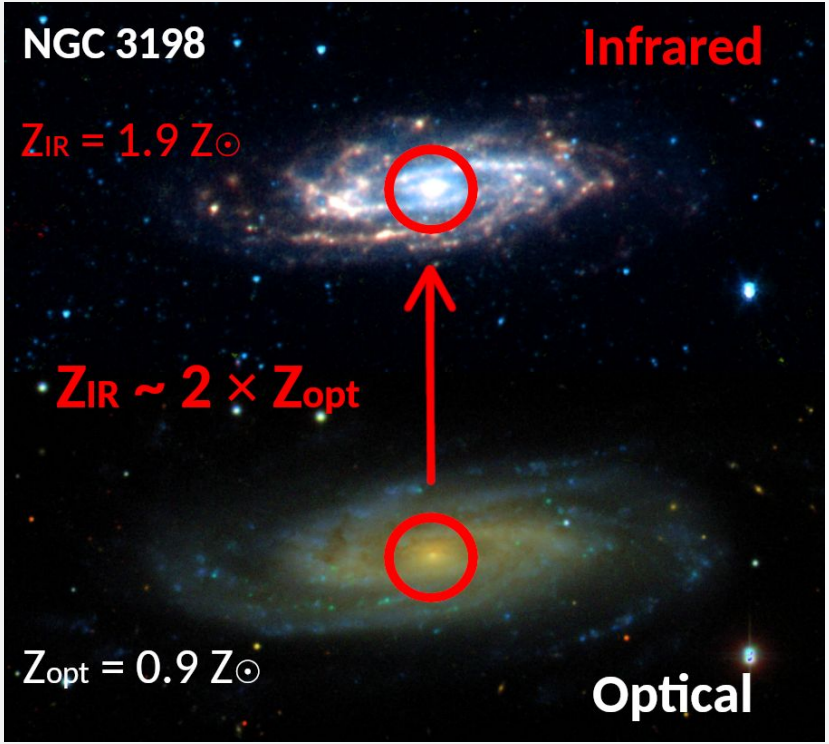
IR vs optical

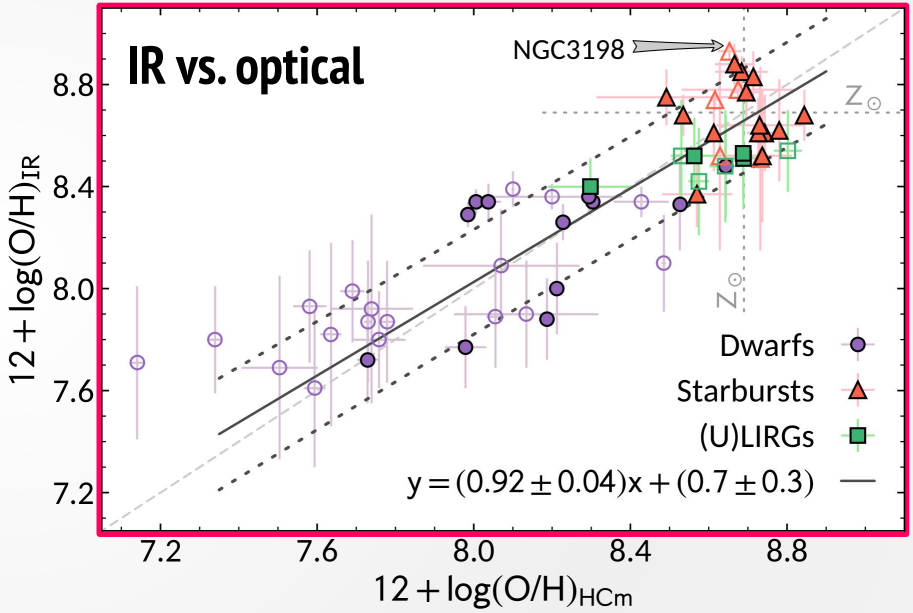
~0.2 dex scatter from aperture, Te, Av



Fernández-Ontiveros, Pérez-Montero+21

IR vs optical





Fernández-Ontiveros, Pérez-Montero+21

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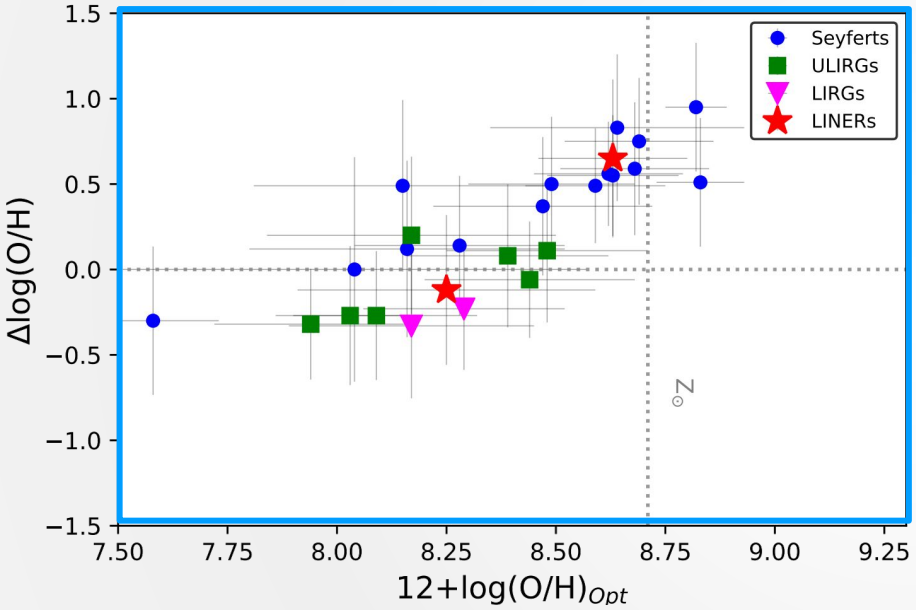
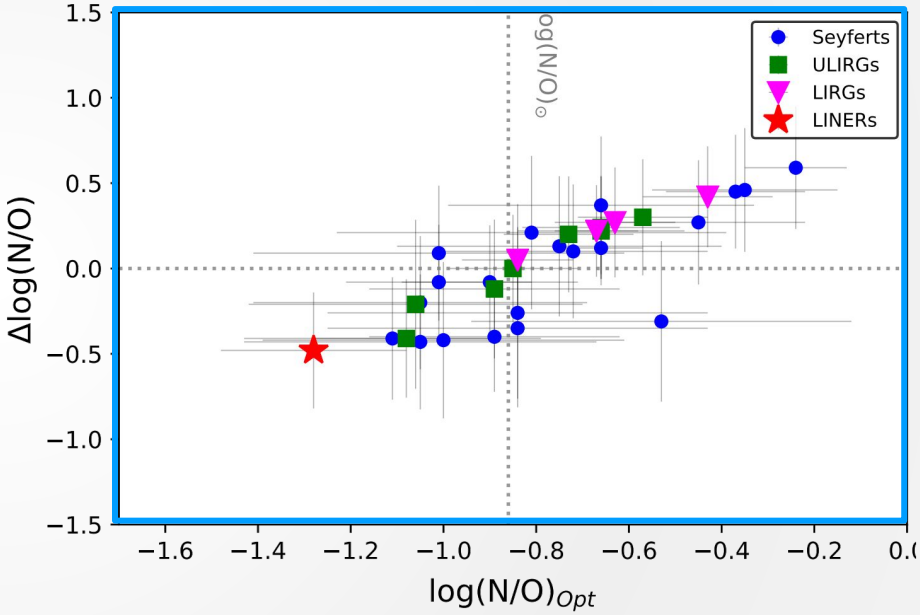
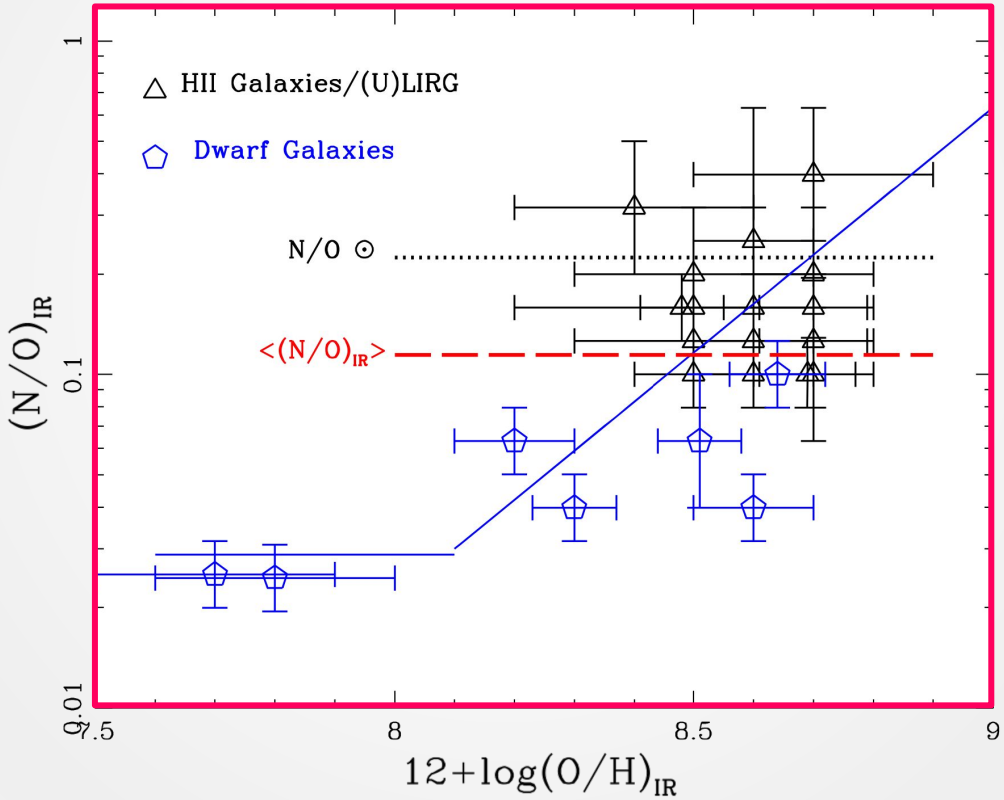




To be explored with JWST in nearby resolved HII and AGNs

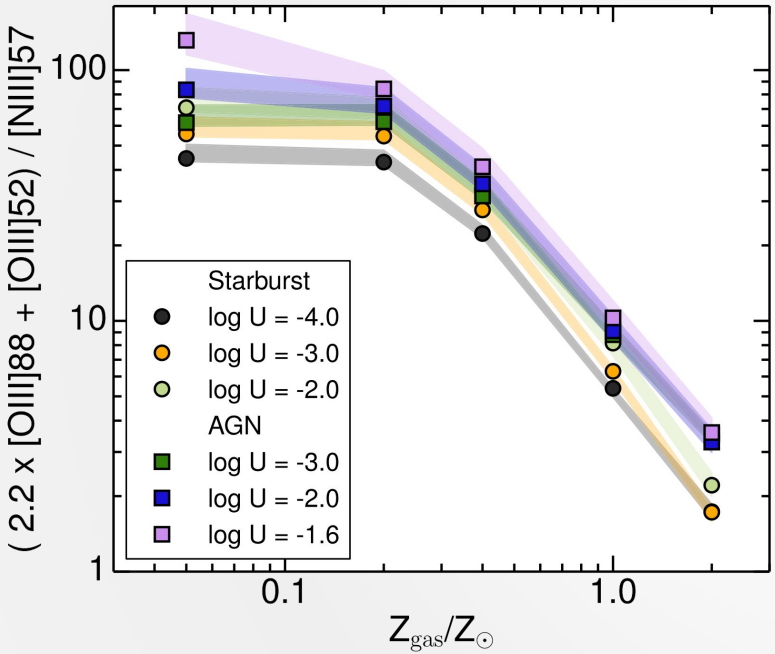
Pérez-Díaz+22

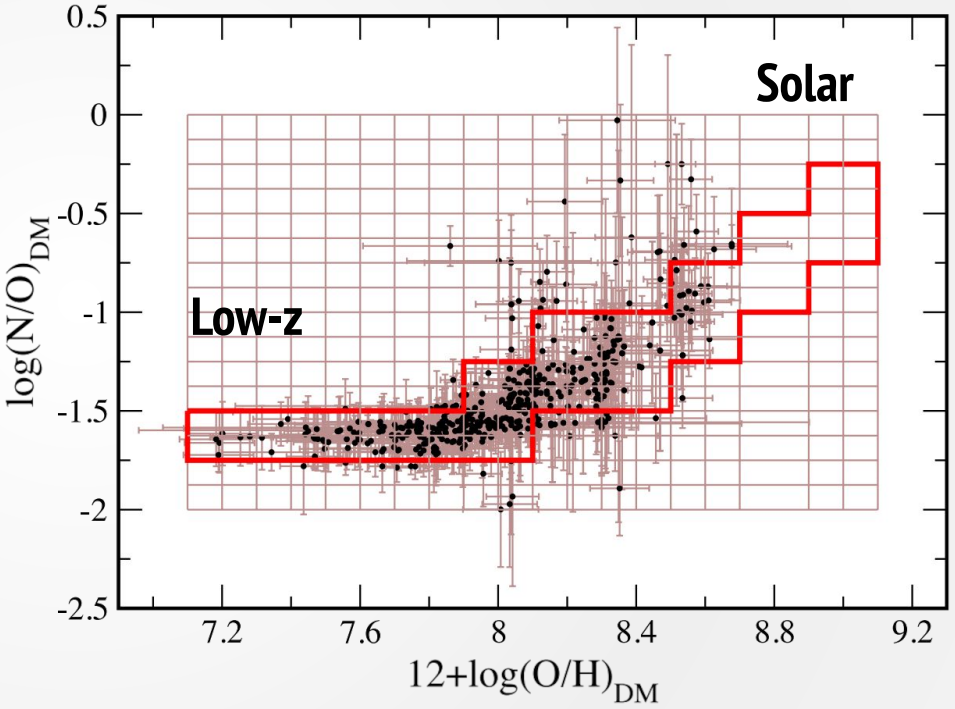
IR vs optical



Spinoglio+22

Beware of N/O-based metallicities

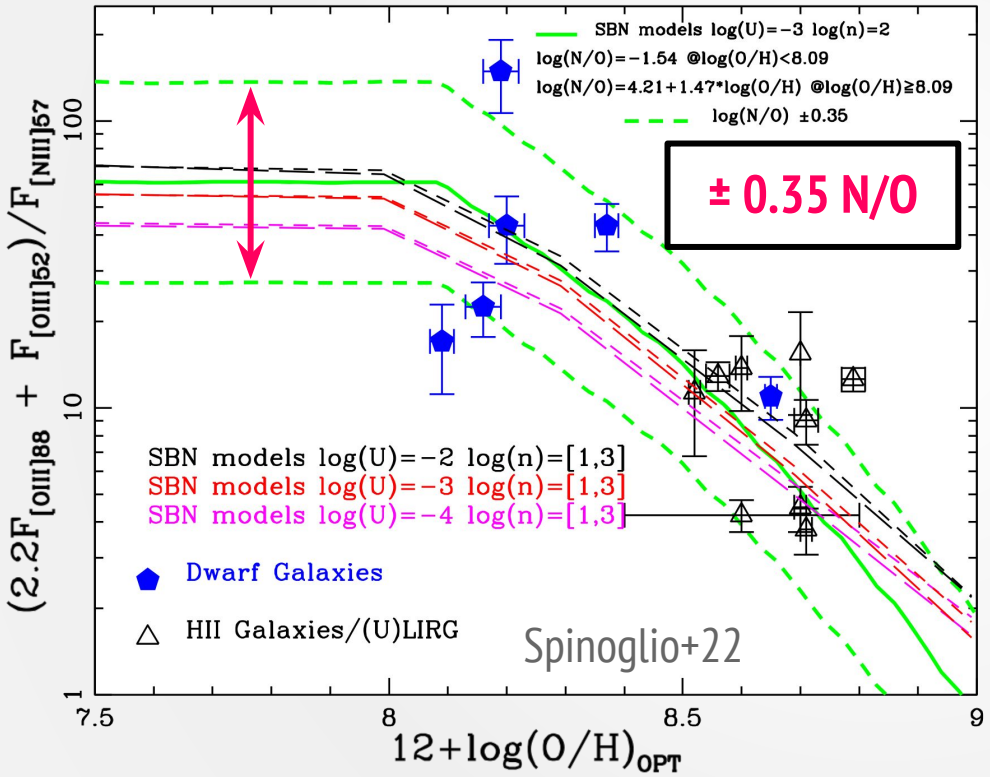


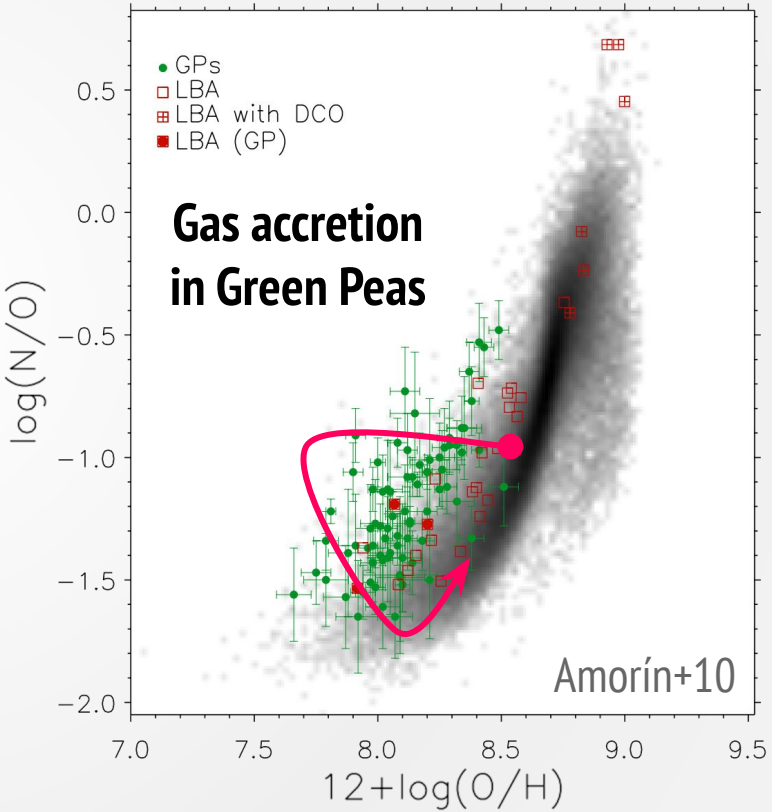


Relies on **N/O-OH** (Nagao+11, Pereira-Santaella+17)

Pérez-Montero 14

Beware of N/O-based metallicities



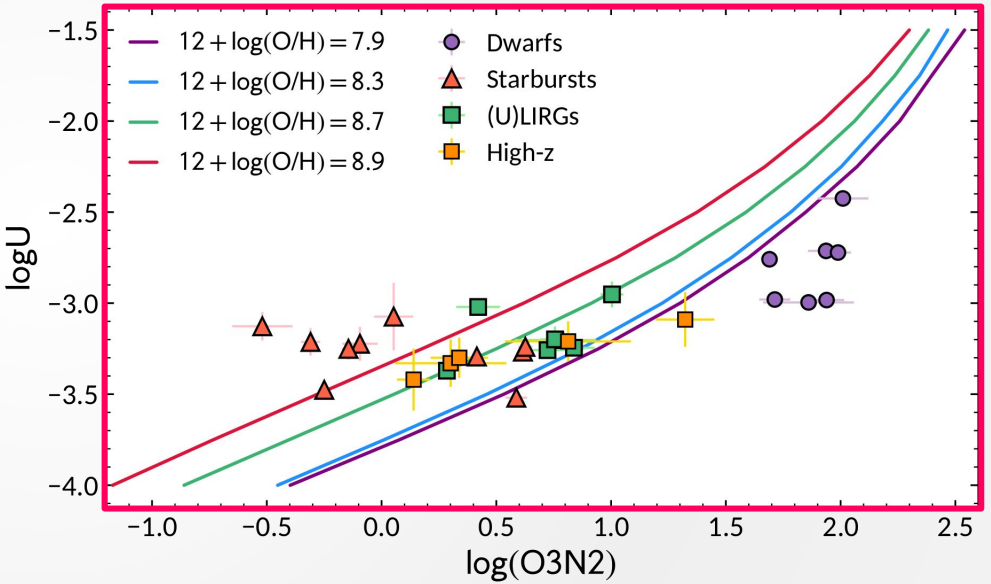


HII-CHI-MISTRY-IR (HCm-IR)

Solar-like metallicities at **high-z**

Independent **N/O** ⟶ **ALMA**

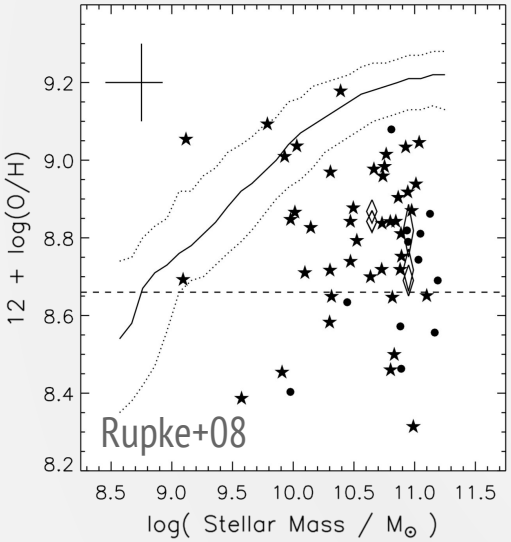
$$\mathrm{O3N2} = \log\left(\frac{\mathrm{I}([\mathrm{O\,III}]_{88\mu m})}{\mathrm{I}([\mathrm{N\,II}]_{122\mu m})}\right)$$



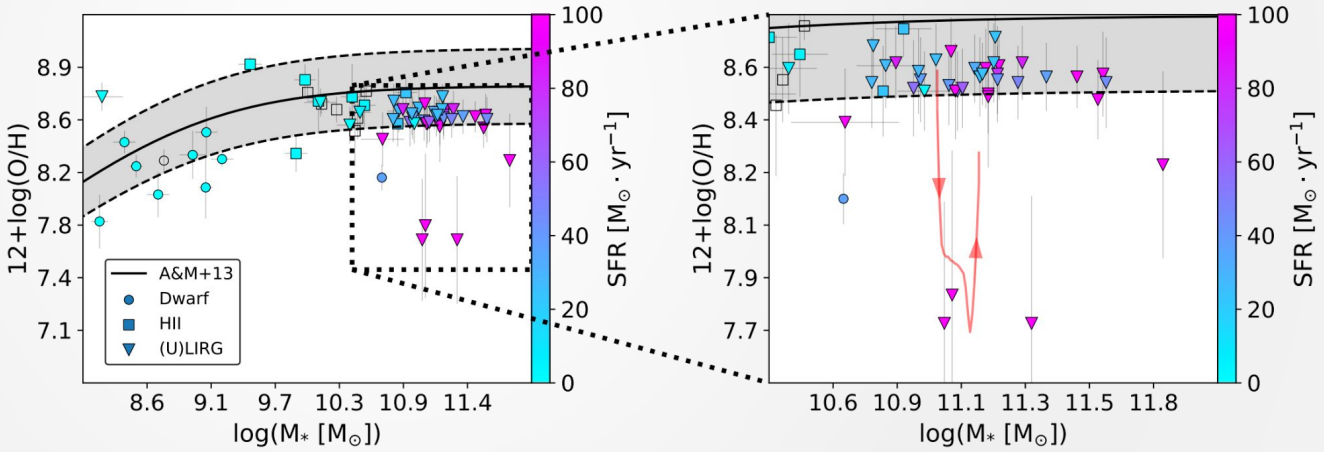
Fernández-Ontiveros+21

Gas mixing in ‘deep-diving’ ULIRGs

Optical



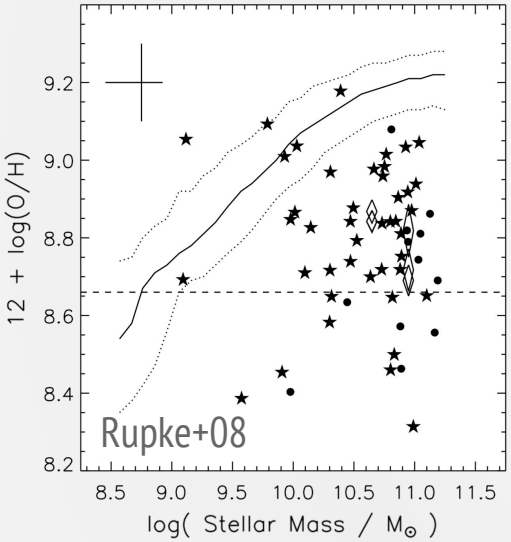
IR



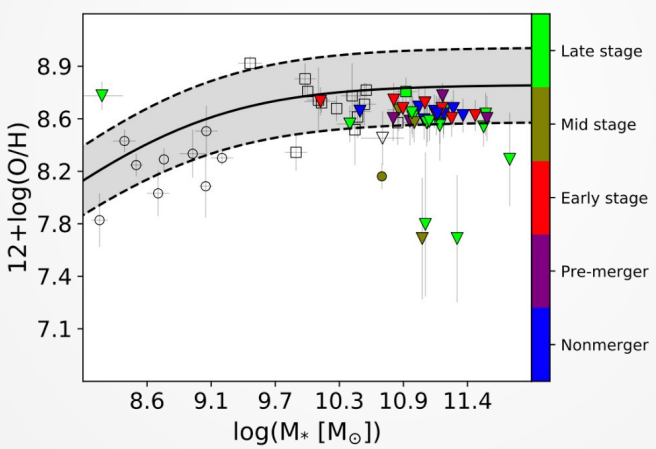
Pérez-Díaz+23 arXiv:2306.14843
(also Chartab+22)

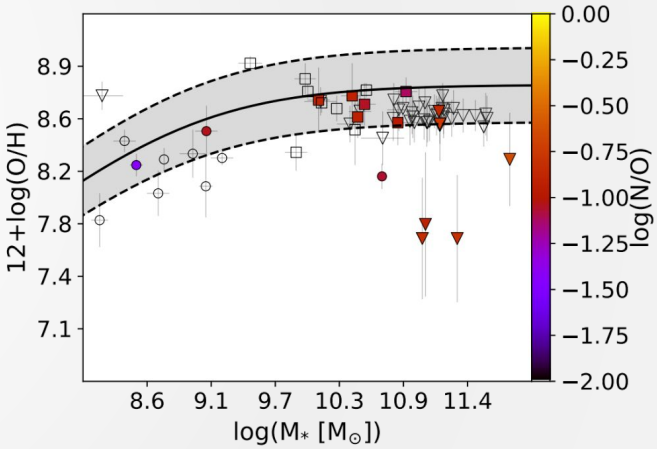
Gas mixing in ‘deep-diving’ ULIRGs

Optical



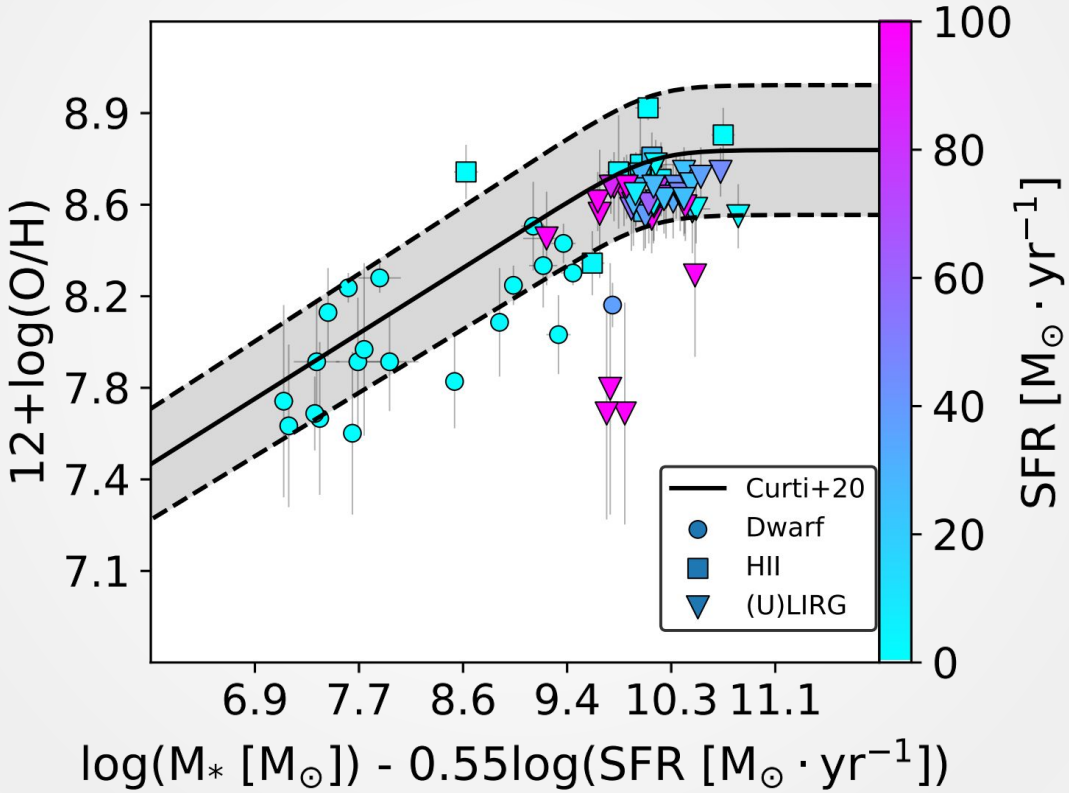
IR





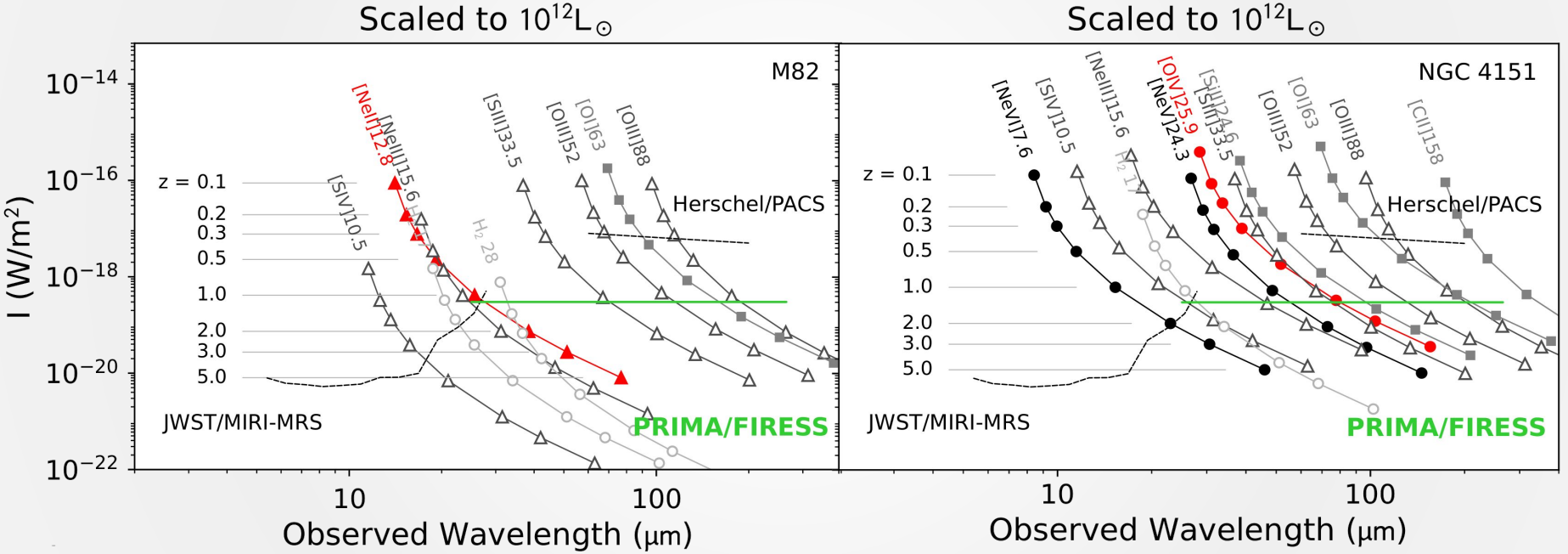
Pérez-Díaz+23
arXiv:2306.14843

Gas mixing in ‘deep-diving’ ULIRGs



Pérez-Díaz+23
arXiv:2306.14843

Future IR spectroscopic observatories?



HCm-IR robust chemical **abundances** from nebular **IR lines**

Te effects, **obscuration**, **N/O**

JWST	+	**PRIMA?**	+	**ALMA**
local		cosmic noon		high-z

thanks!