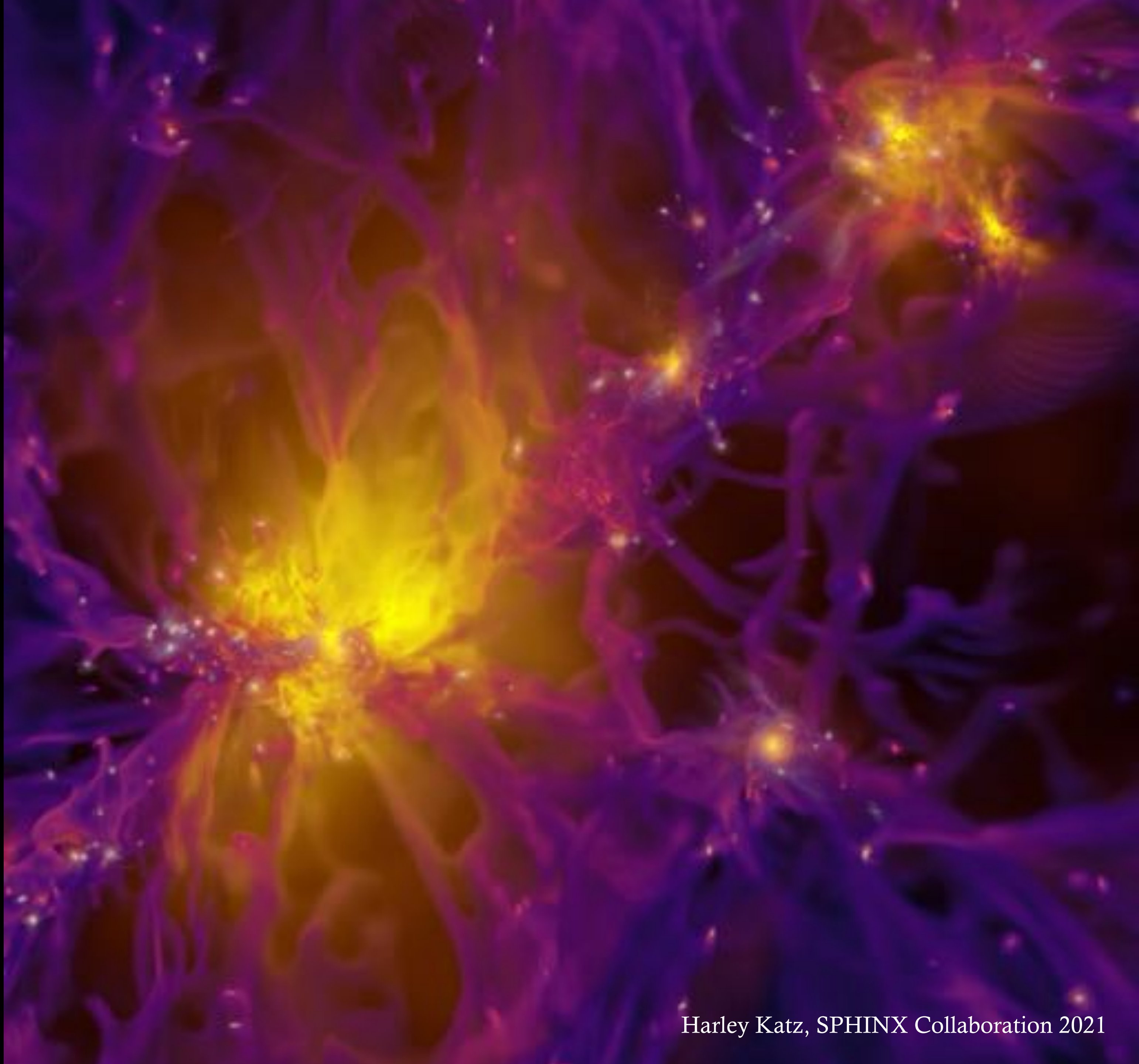
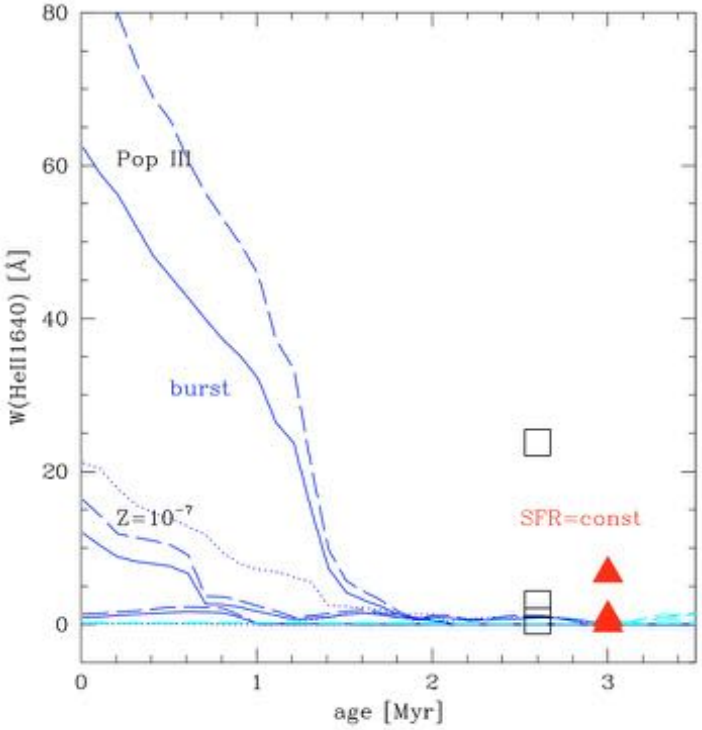
OBSERVATIONAL SIGNATURES OF THE FIRST STARS

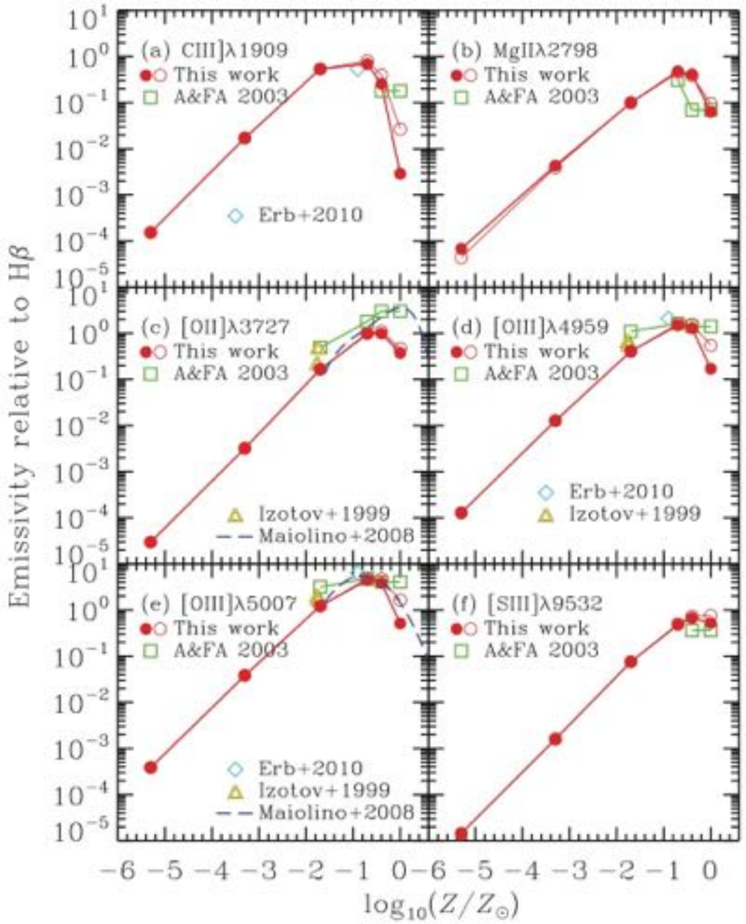
Harley Katz | University of Oxford |
May 16, 2023



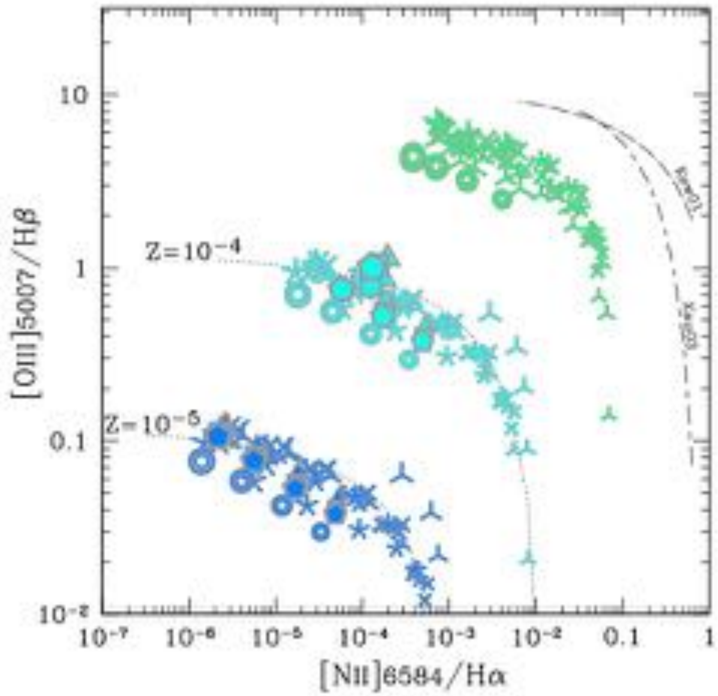
EMISSION LINE SIGNATURES OF POP III AND LOW-Z STARS



Schaerer 2002



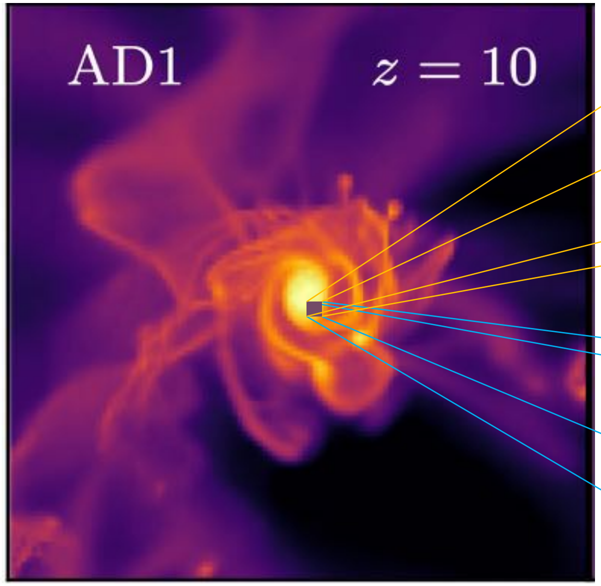
Inoue 2011



Nakajima & Maiolino 2022

HOW THINGS ARE CURRENTLY DONE...

Katz+ 2019a



Operate on stars

age, mass, Z

Unresolved ISM

Resolved ISM

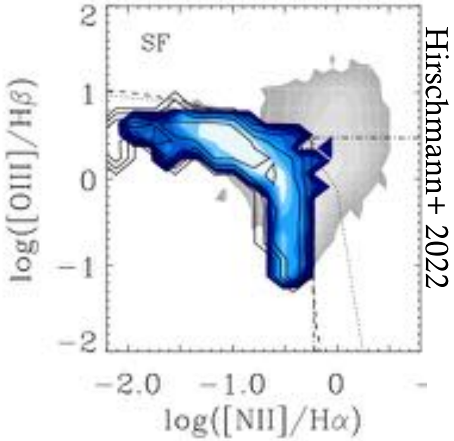
ρ, T, Z, rad. field

Operate on gas cells

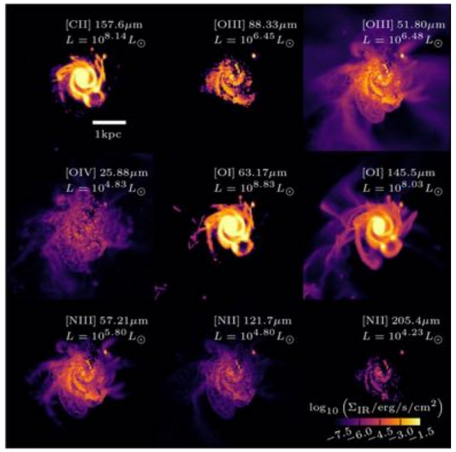
Lots of assumptions

Cloudy grids

1 Cloudy model/cell



Hirschmann+ 2022



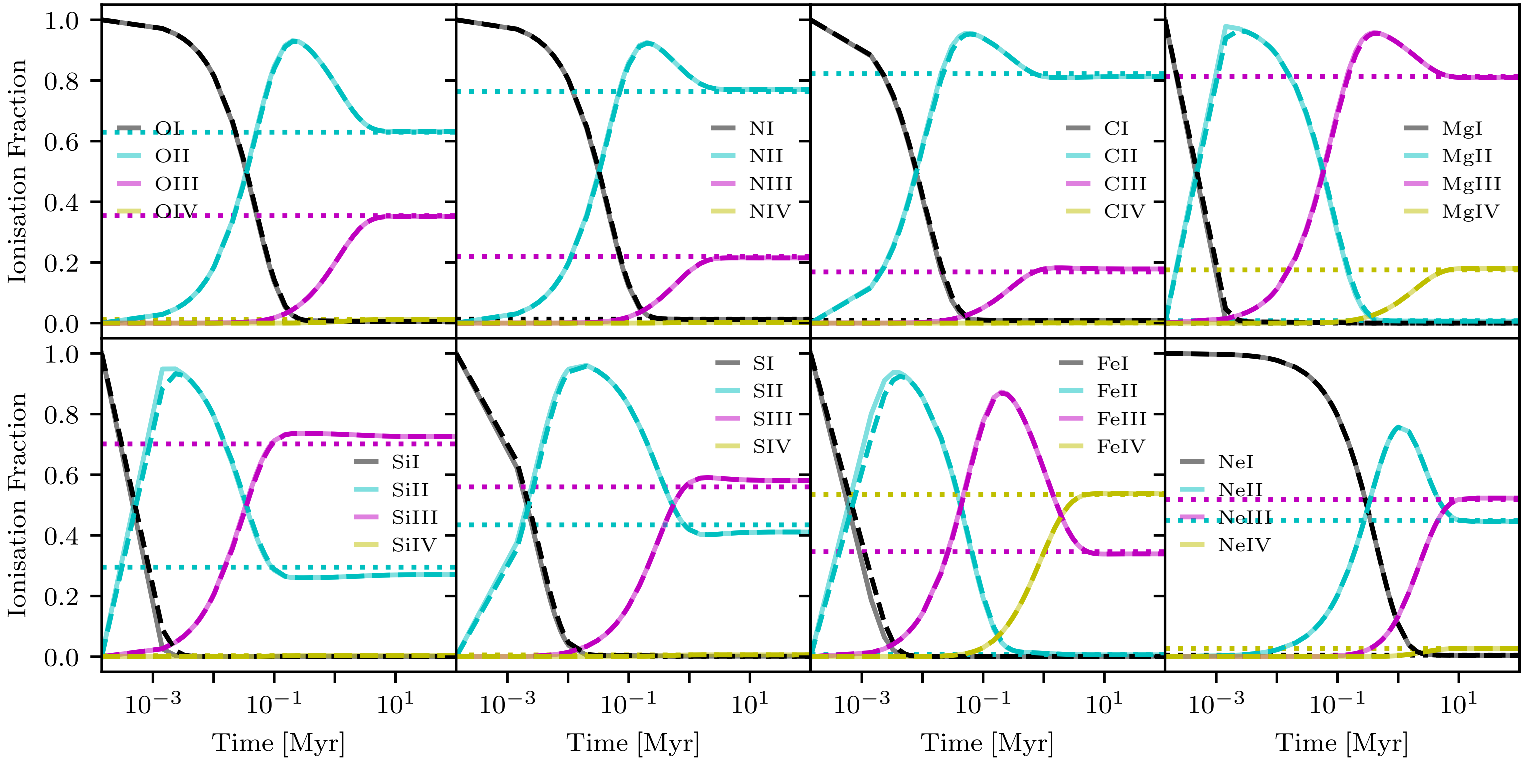
Katz+ 2019a

e.g., system is in equilibrium, ISM properties near the star particles, role of diffuse gas, geometry, constant or free temperature…

RAMSES-RTZ: NON-EQUILIBRIUM CHEMISTRY COUPLED TO ON-THE-FLY RADIATIVE TRANSFER

Processes that control ion and molecular properties:

- Collisional, photo, cosmic-ray ionization
- Radiative, dielectronic, dust recombination
- Charge exchange



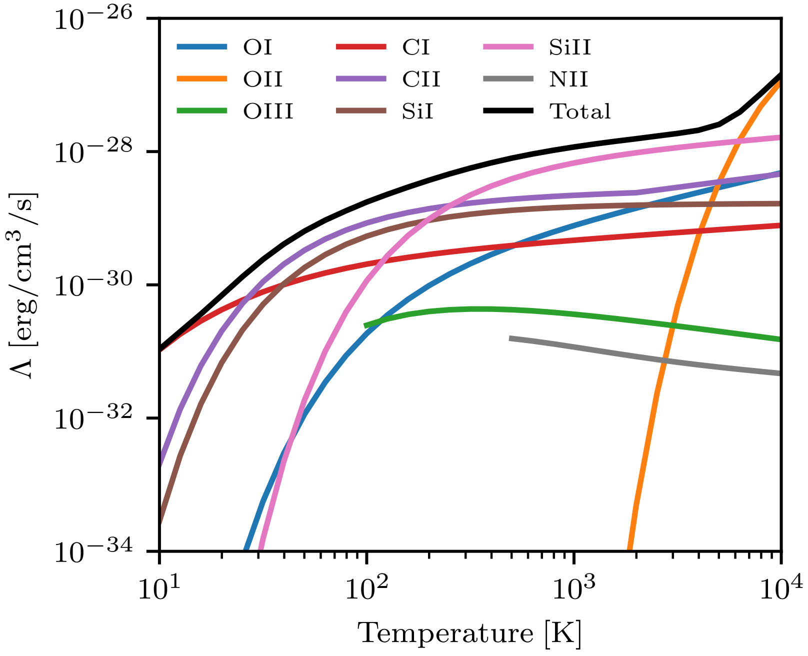
Katz+ 2022a

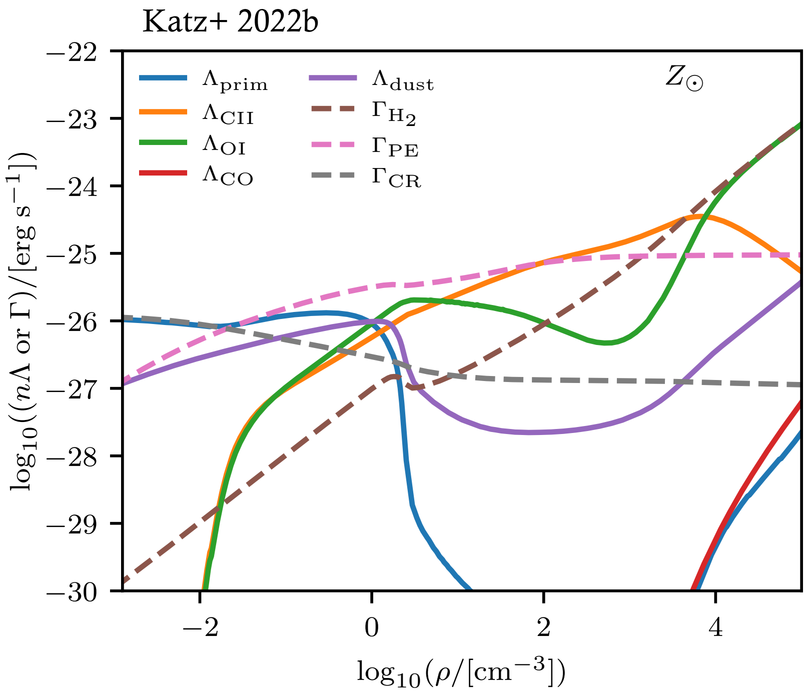
Our new semi-implicit ODE solver is 15× faster than typically used solvers (e.g. Sundials, DVODE, etc.)

PRISM: A STATE-OF-THE-ART THERMO-CHEMISTRY MODEL FOR A MULTIPHASE INTERSTELLAR MEDIUM

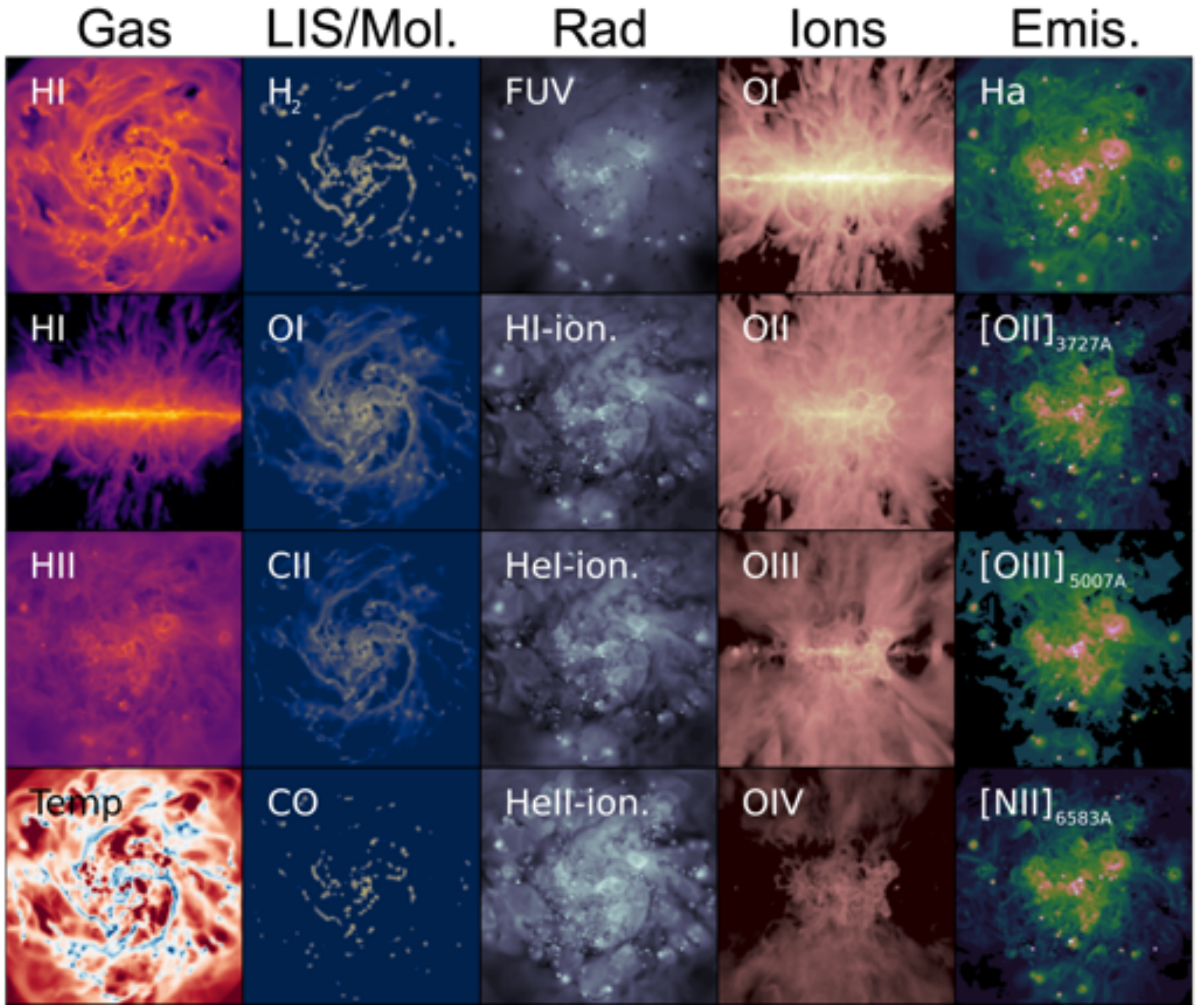
Processes that control gas temperature:

- Cosmic-ray, photo, photo-electric, H_2, dust heating
- Primordial, H_2, CO, metal, dust recombination, dust-gas collisional cooling
- Adiabatic (expansion), shocks (e.g. SN, turbulence), gravitational, etc.

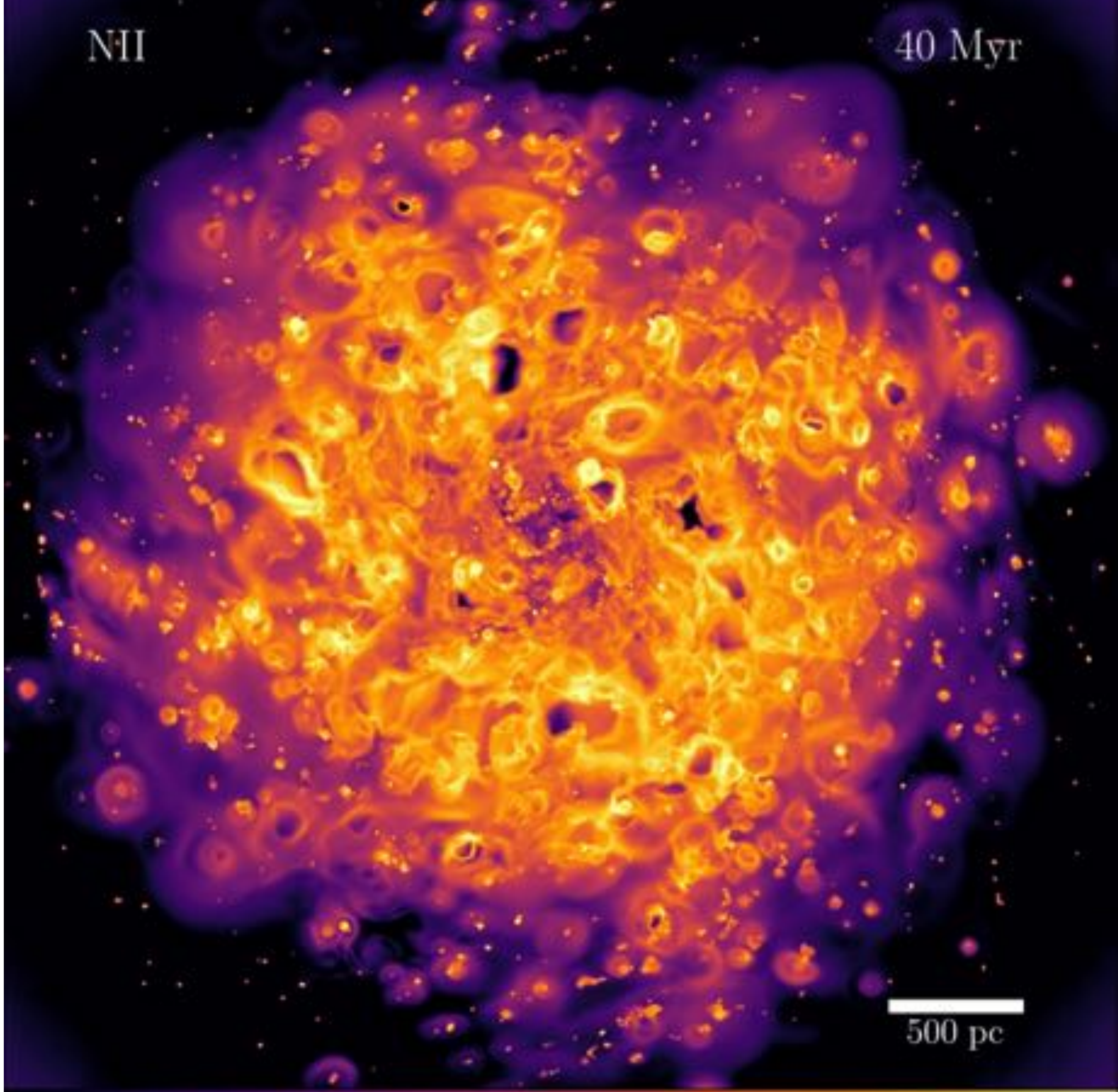




RAMSES-RTZ + PRISM SIMULATIONS ARE DESIGNED TO COMPARE WITH OBSERVATIONS



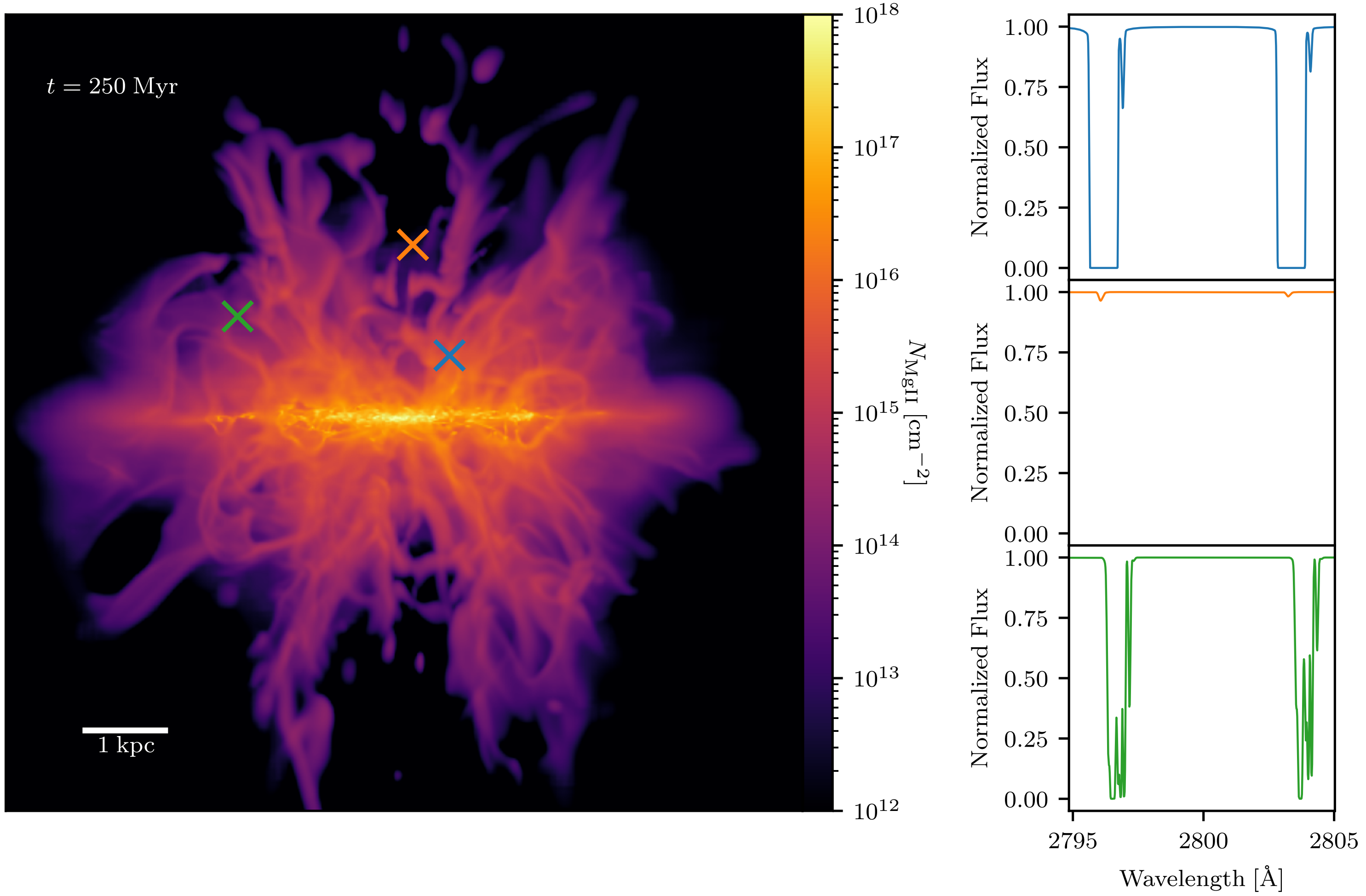
WE CAN PREDICT EMISSION LINE SIGNATURES BY RESOLVING HII REGIONS

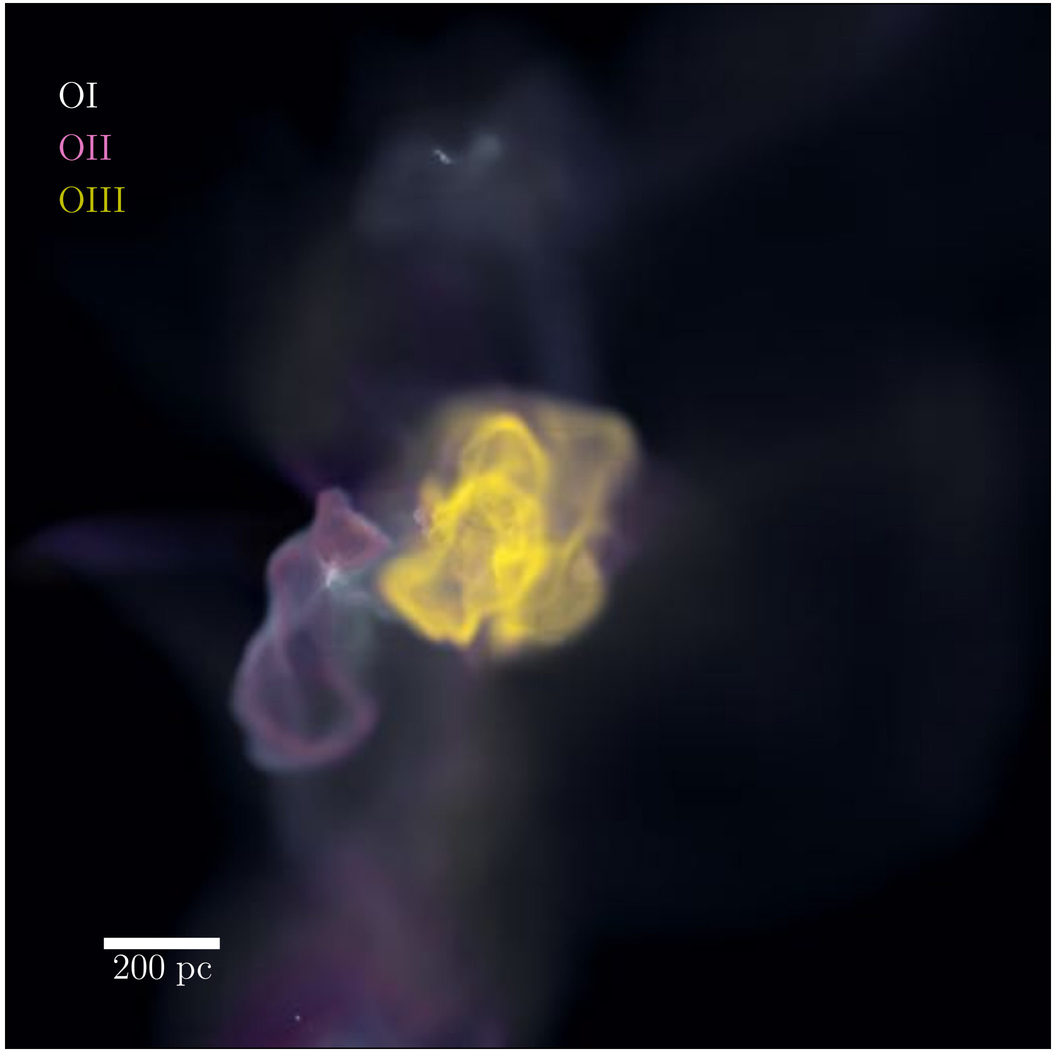


Katz+ 2022b

ULTRA HIGH TIME-CADENCE VIEW OF GALAXY EMISSION

WE CAN STUDY BOTH EMISSION AND ABSORPTION



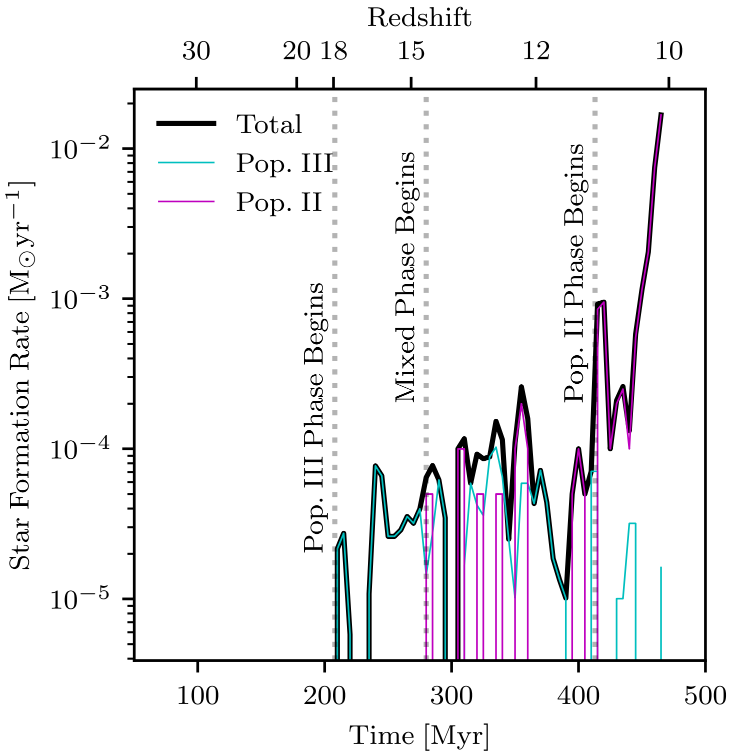


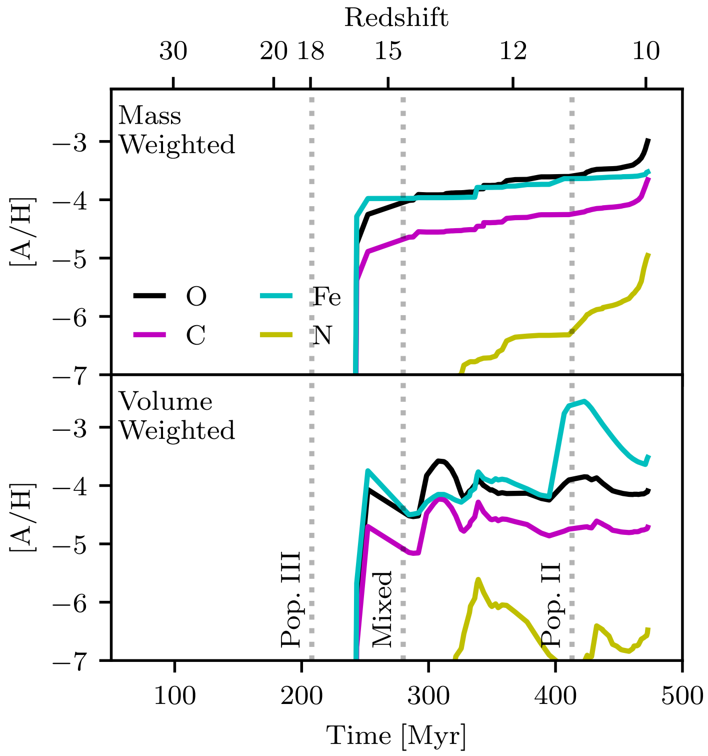
Katz+ 2022c

AN EXTREMELY HIGH RESOLUTION SIMULATION OF GALAXY FORMATION IN THE EOR

- $M_{dm} = 492\ M_{\odot}$, $\Delta x = 0.8$ pc (at $z = 10$)
- 8 group RT (IR – He II ionizing)
- Non-equilibrium chemistry for H, He, H_2, C, N, O, Mg, Fe, Si, S, Ne, (CO in pp)
- Pop III IMF with a characteristic mass of 100 $M_{\odot}$
- Chemical enrichment from Pop III stars (SN+HN+PISN), Pop II stars (CCSN, SNIa, winds)

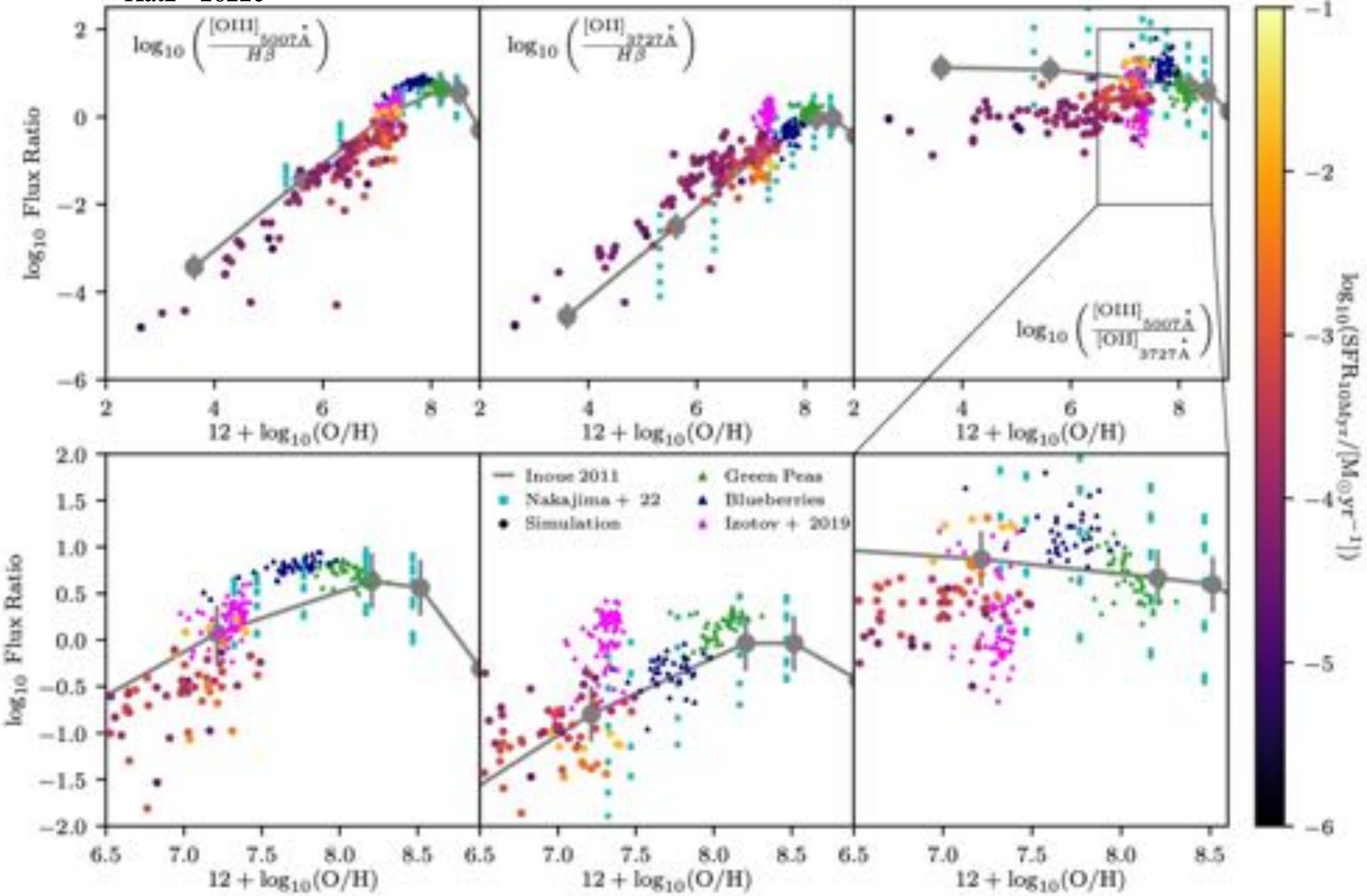
THE POP III – POP II TRANSITION OCCURS VERY QUICKLY



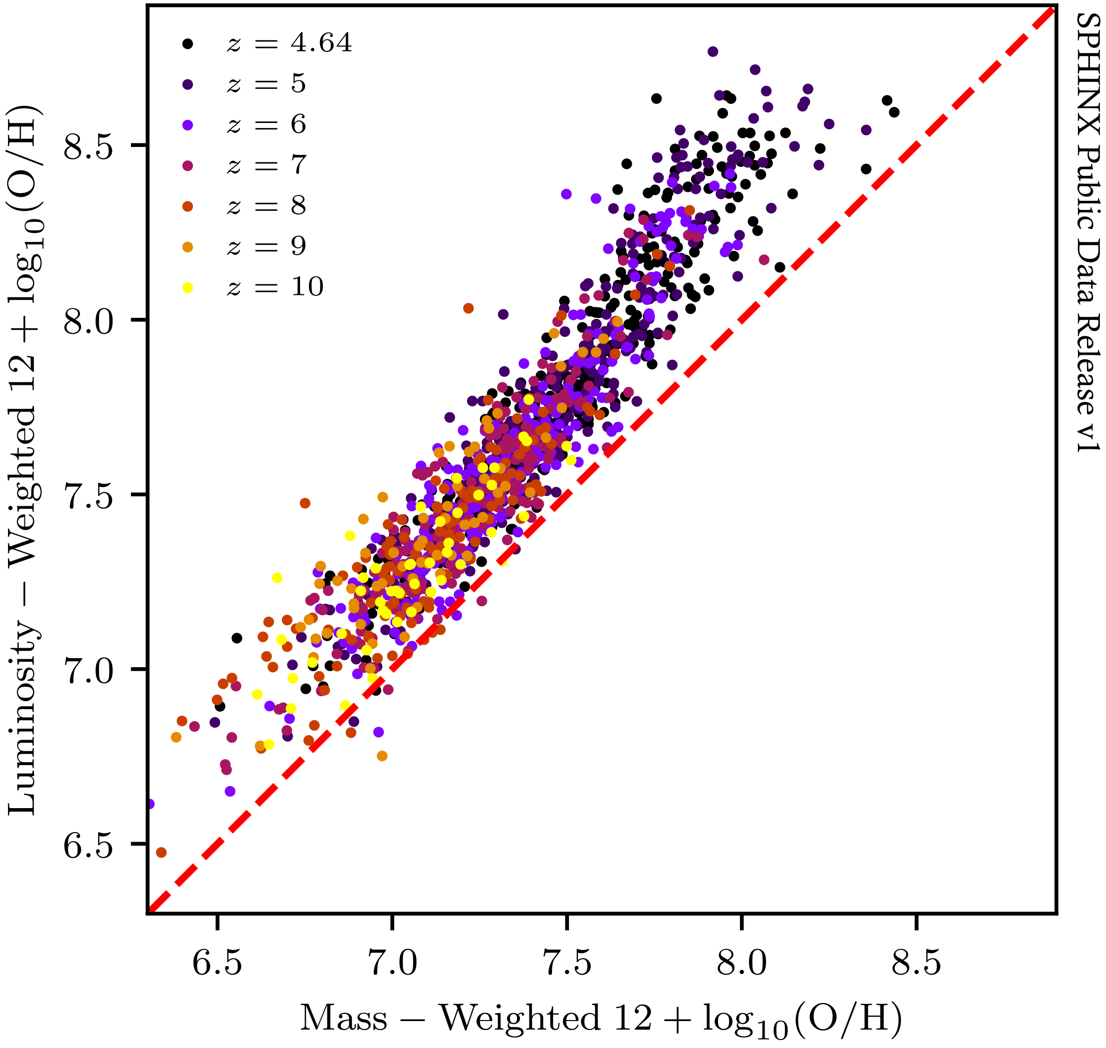


EMISSION LINE SIGNATURES OF POP III STARS

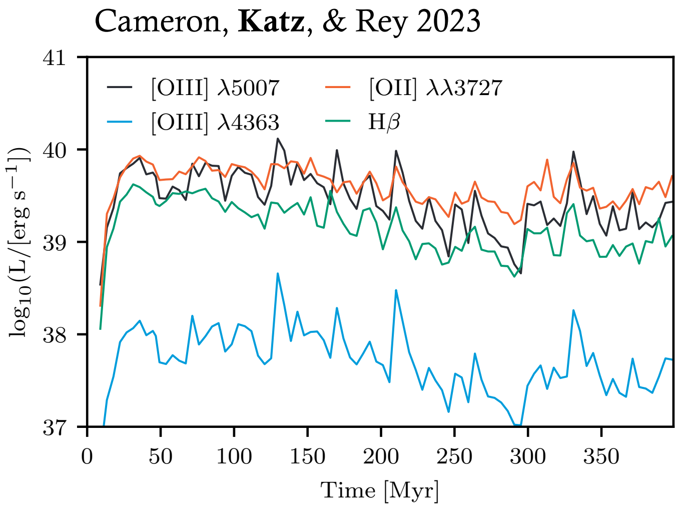
Katz+ 2022c

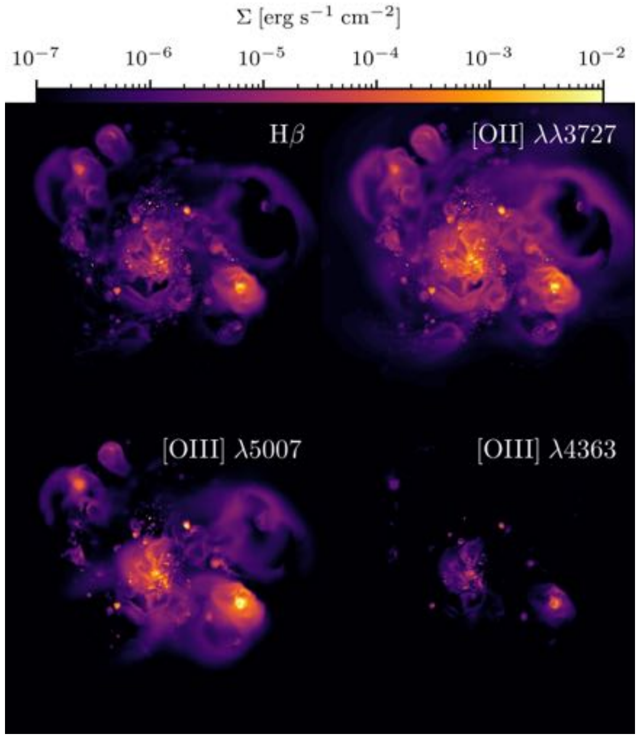


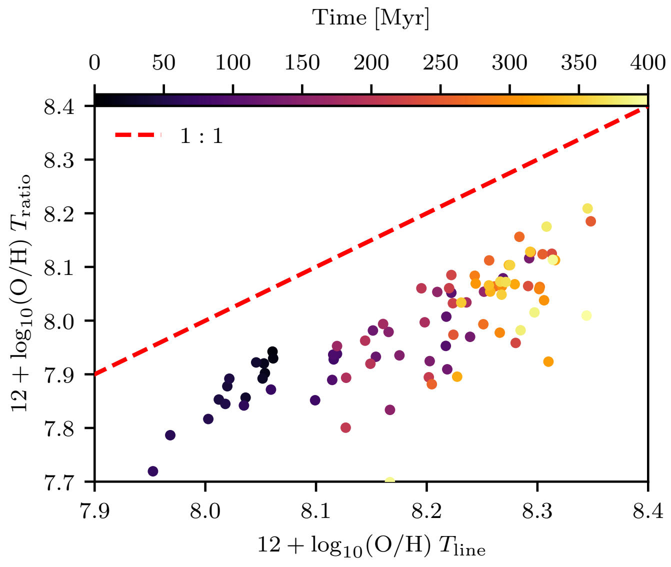
METALLICITES OF HII REGIONS ARE OFTEN DIFFERENT FROM THE MASS WEIGHTED AVERAGE → COULD LEAD TO A MIXED MODE OF SF

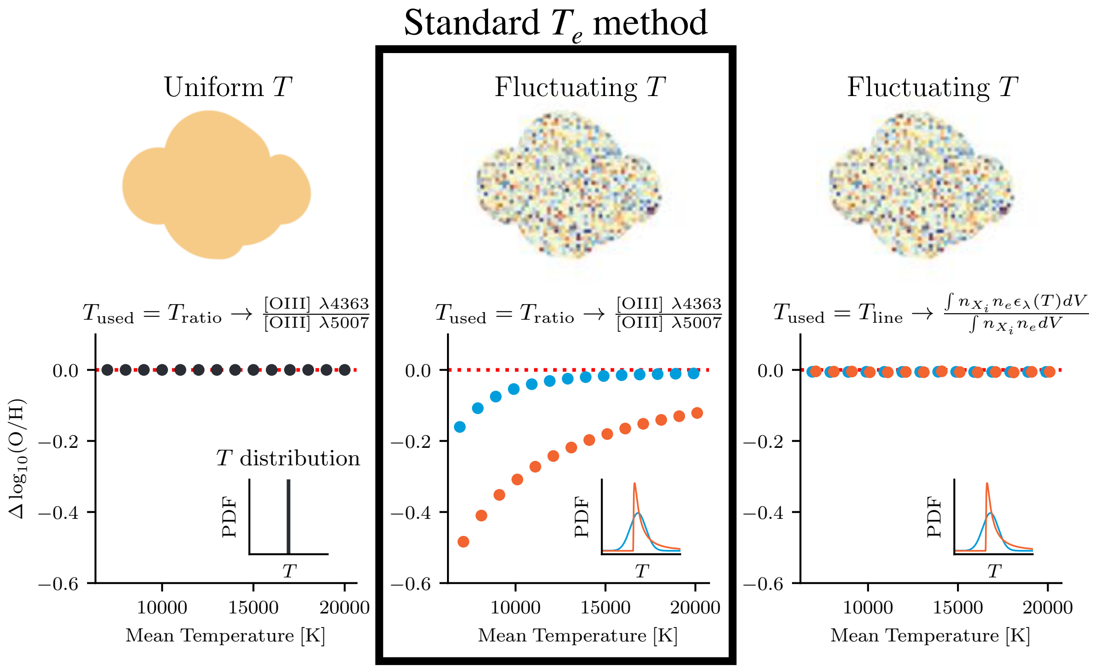


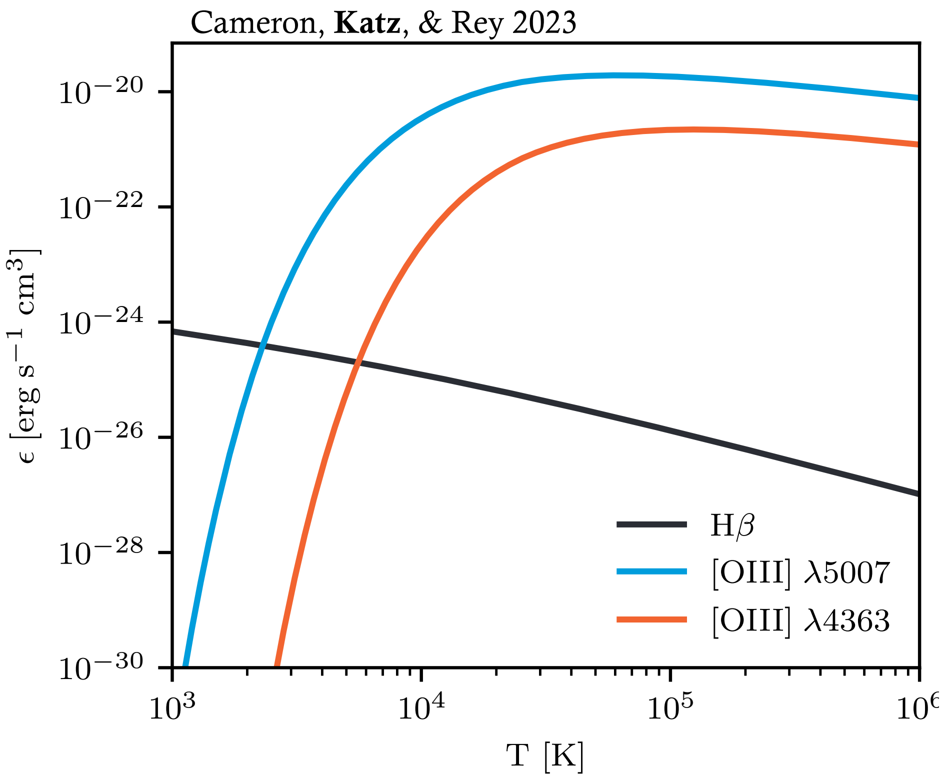
DIRECT METHOD METALLICITIES GENERALLY UNDERPREDICT THE TRUE METALLICITY OF THE SYSTEM





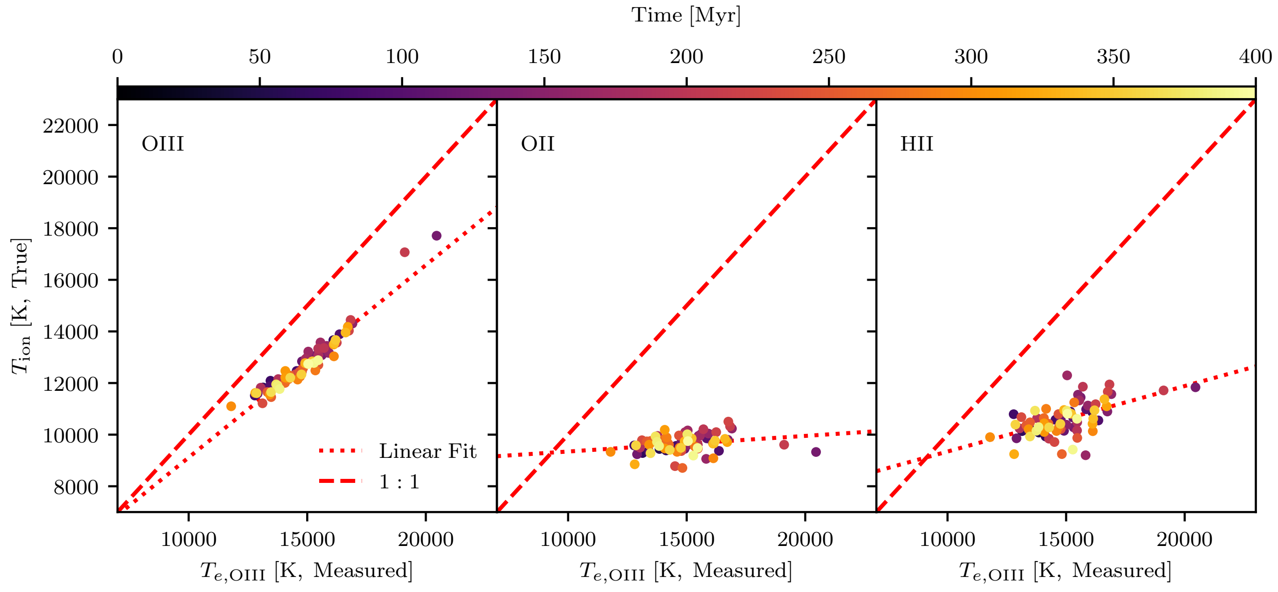




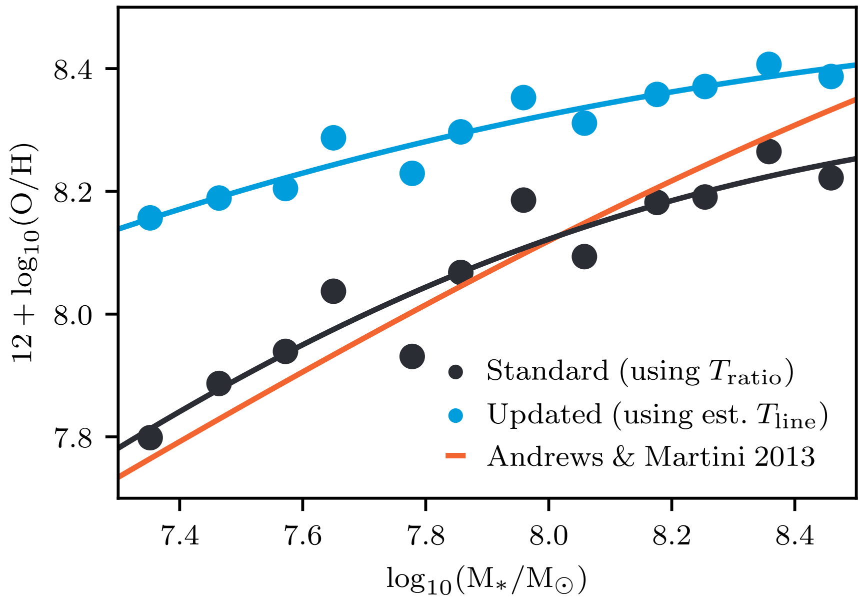


BIAS IS DUE TO EMISSIVITY CURVES

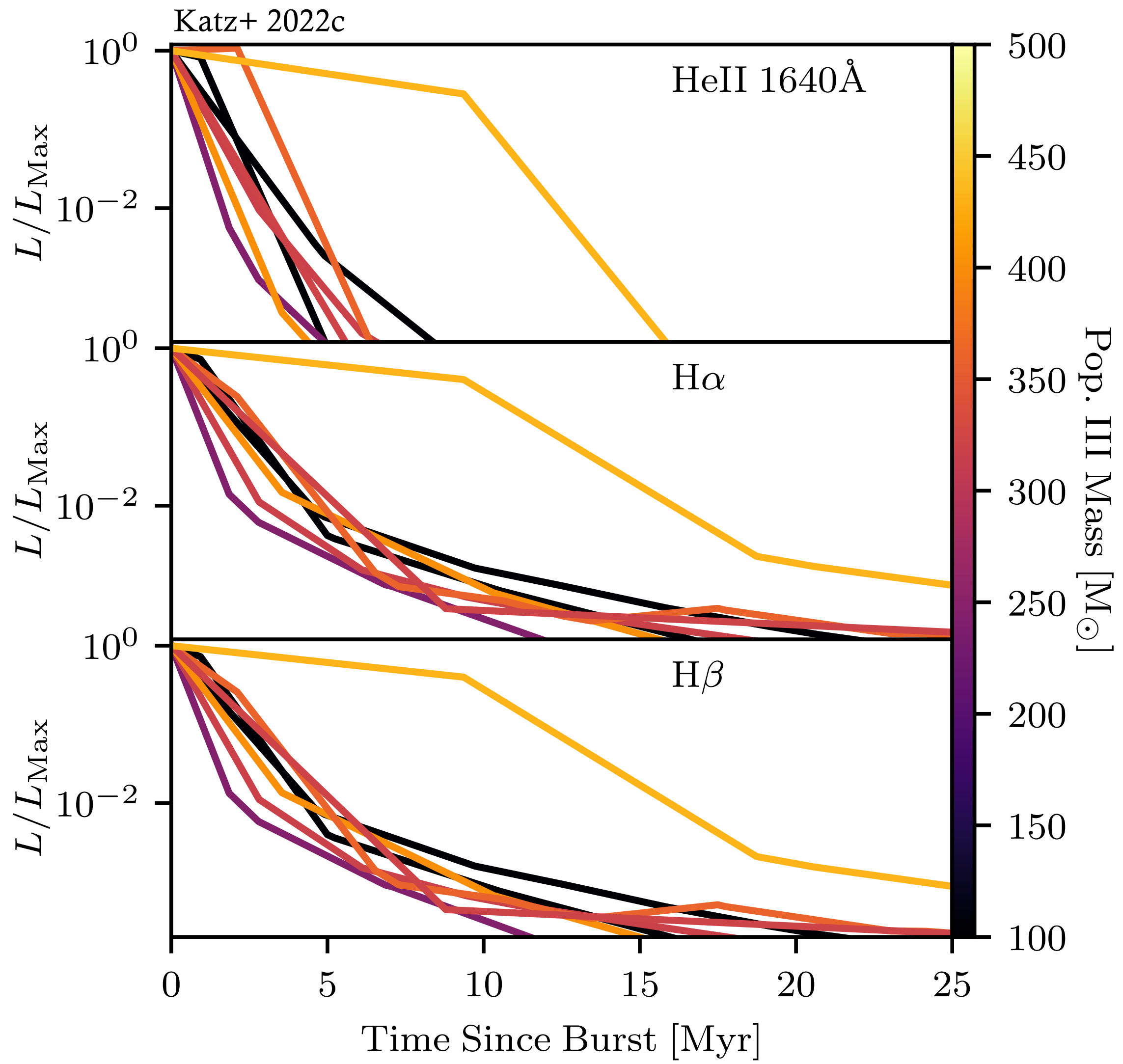
OUR RESULTS CHANGE THE EVOLUTION OF THE MASS-METALLICITY RELATION



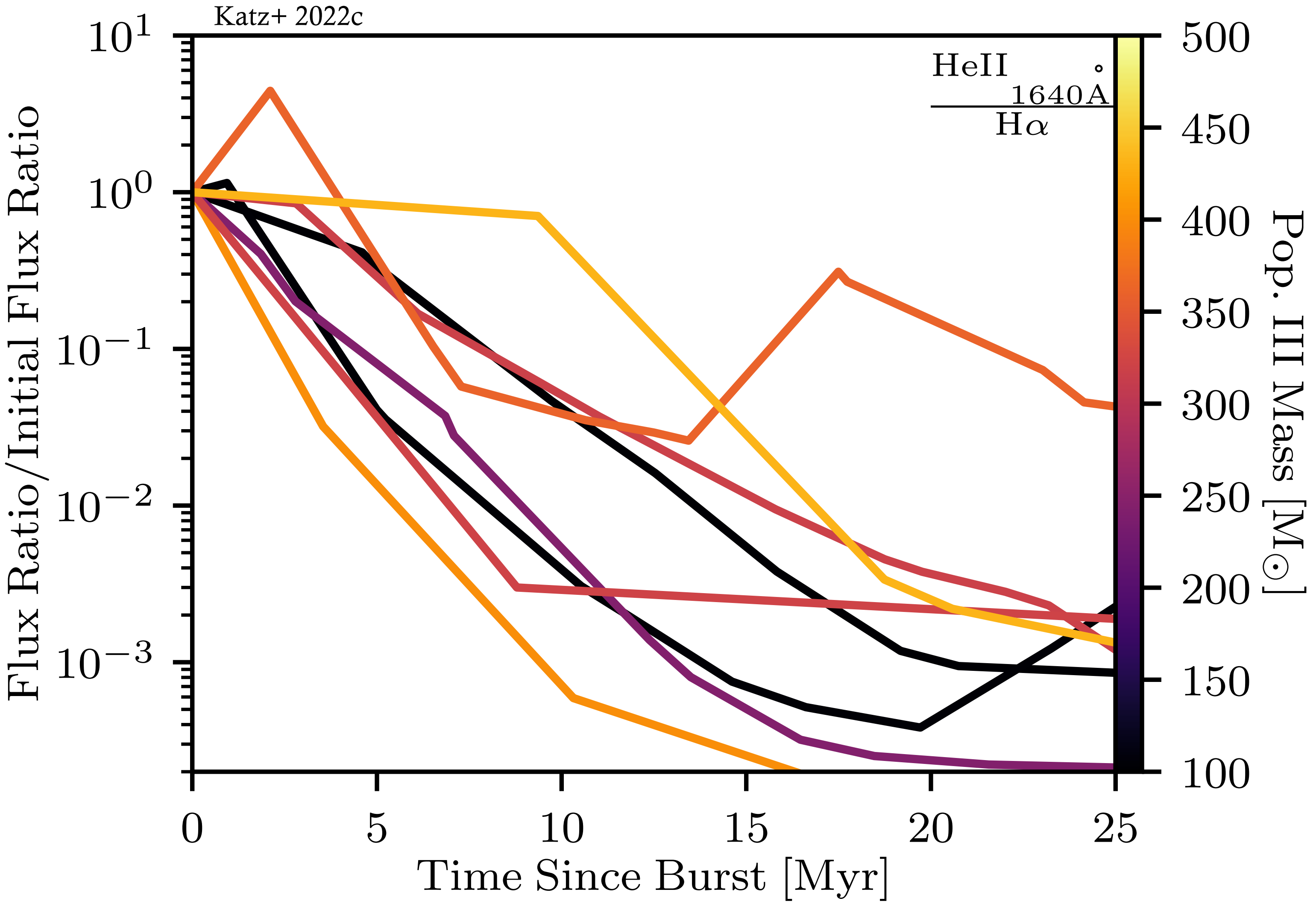
Cameron, **Katz**, & Rey 2023



SHORT POP III LIFETIMES ARE A MAJOR LIMITING FACTOR FOR THEIR DETECTION

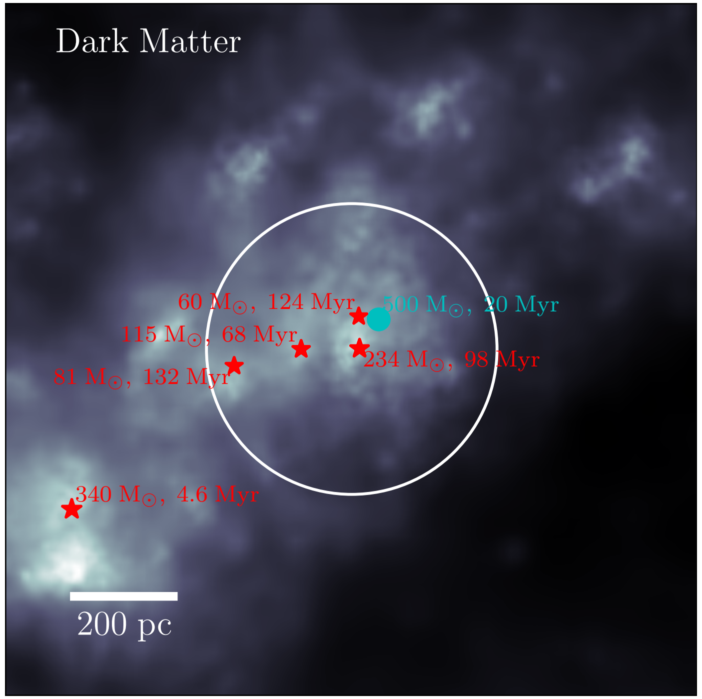


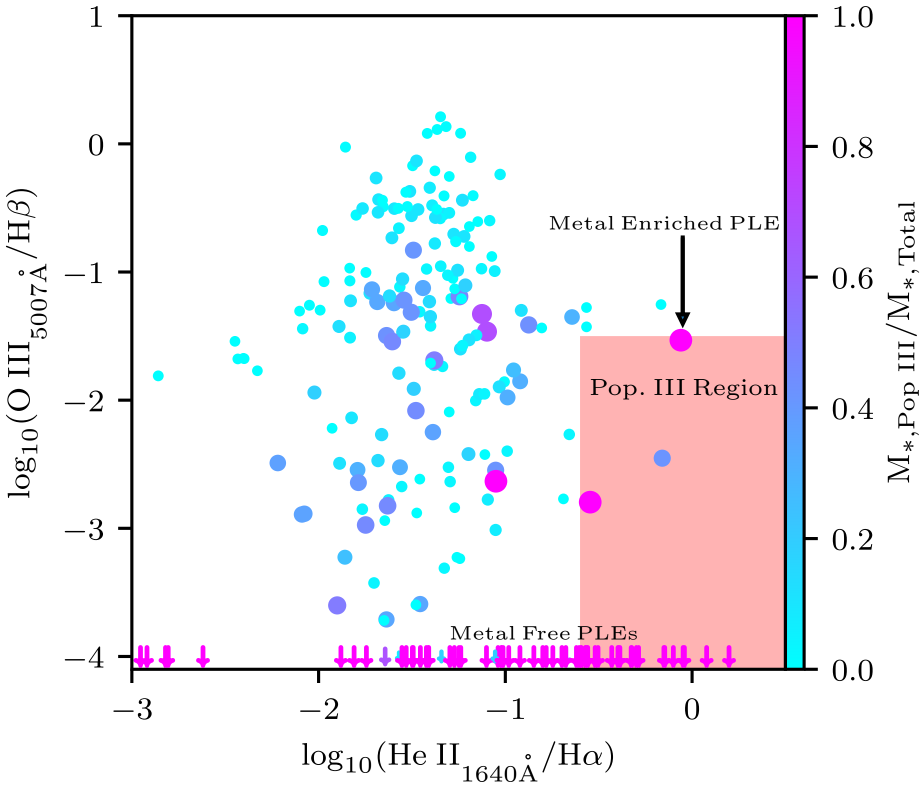
HE II SIGNATURE FADES MUCH FASTER THAN BALMER LINES



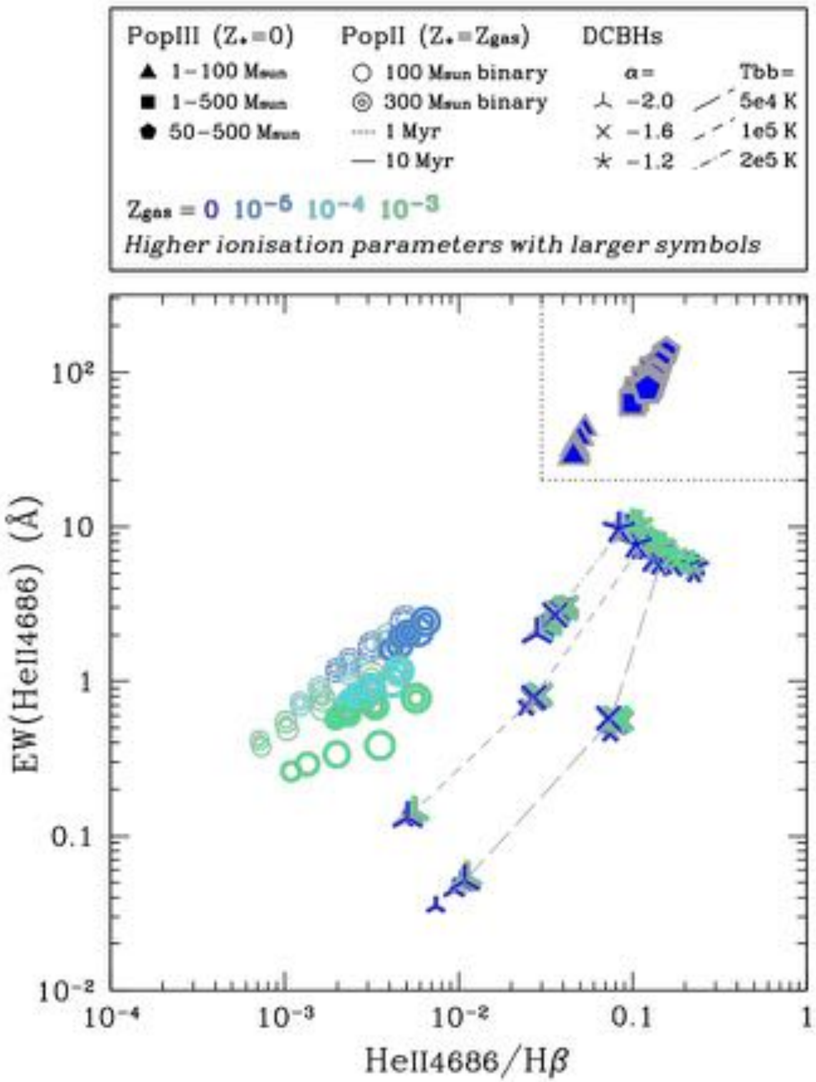
SWITCHING TO A 2D DIFFERENTIATION CAN HELP

Katz+ 2022c





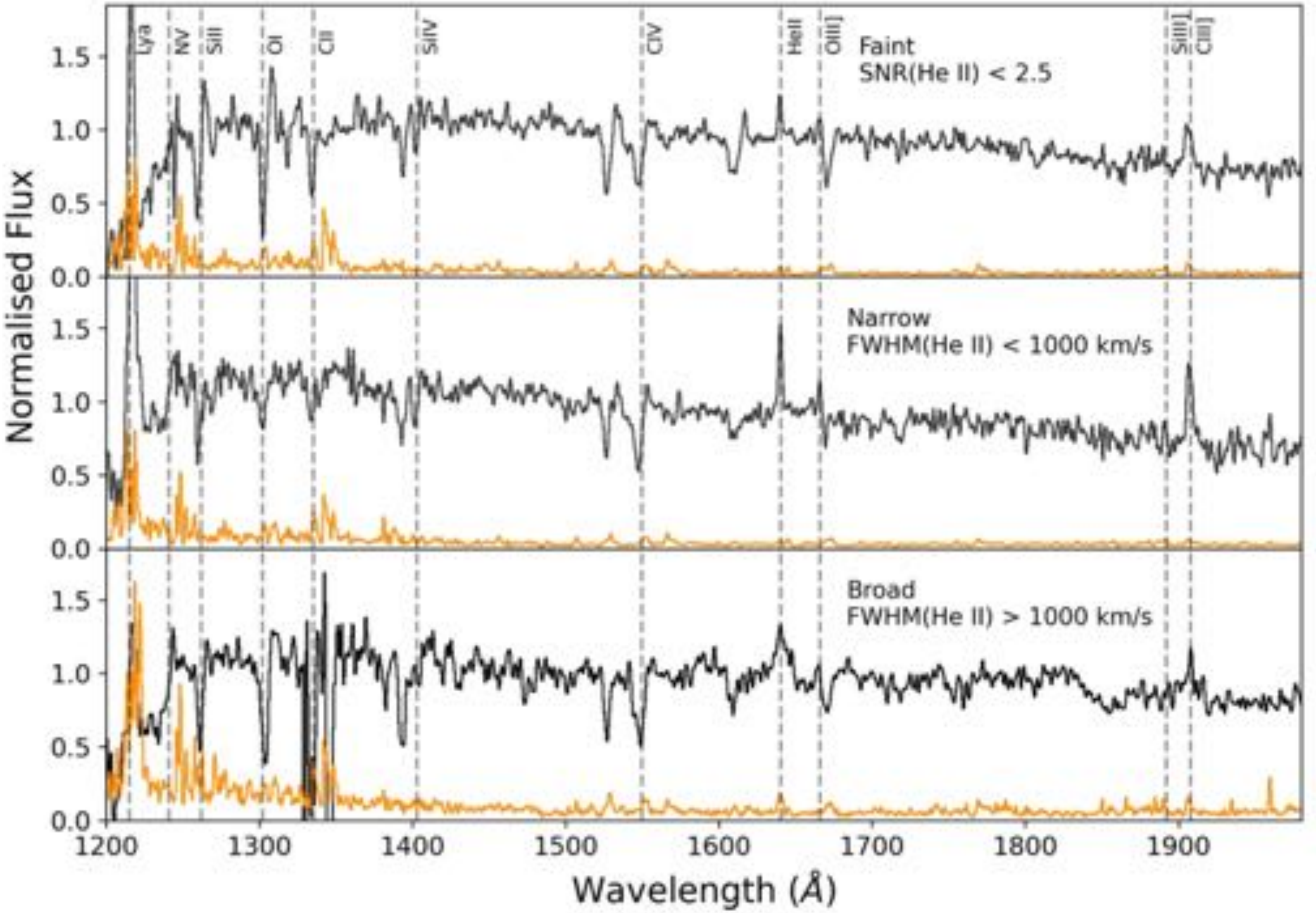
WHAT CAN CONTAMINATE THIS REGION → BLACK HOLES



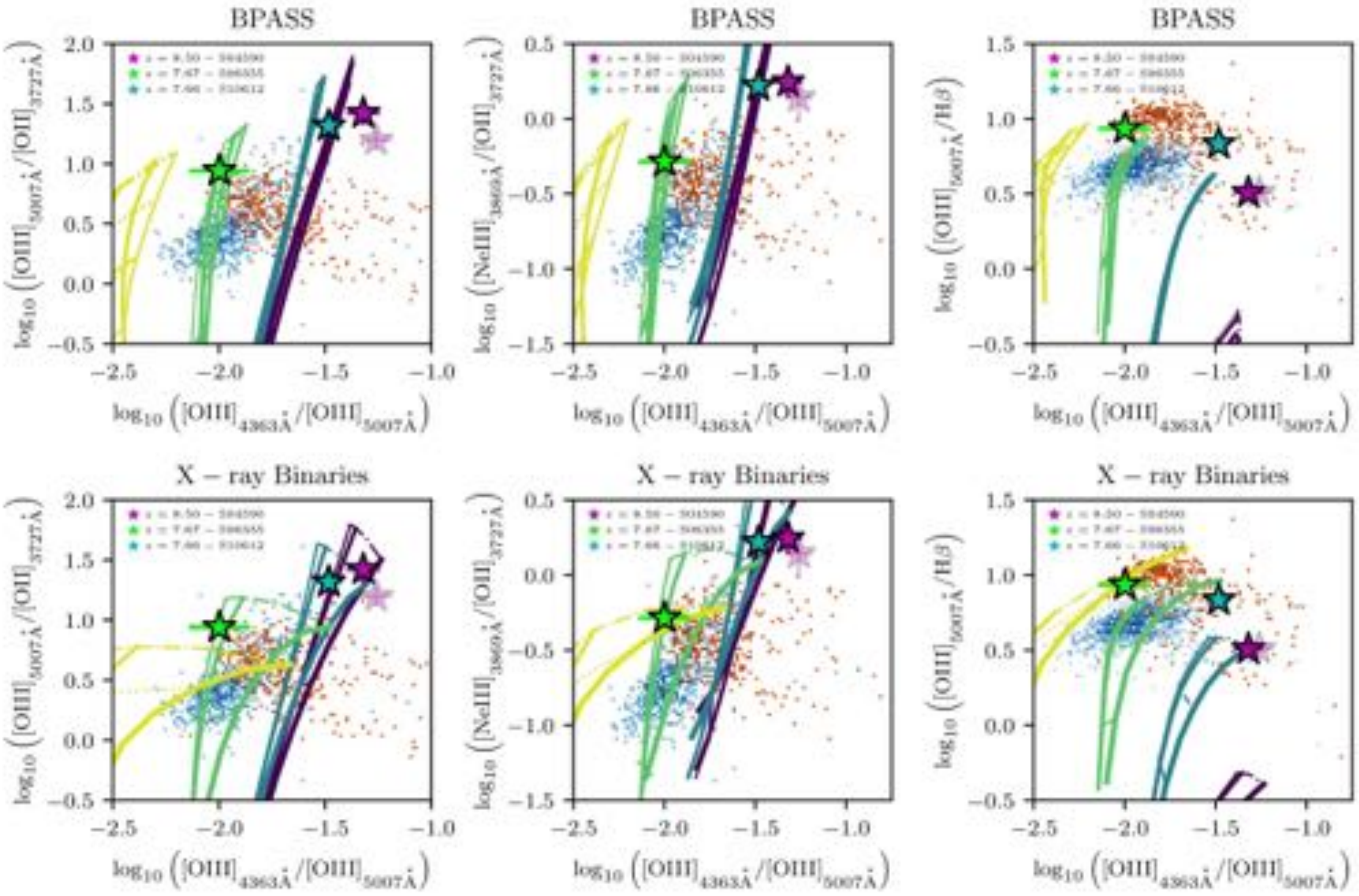
Nakajima & Maiolino 2022

WHAT CAN CONTAMINATE THIS REGION → X-RAY BINARIES

Saxena+ 2020 -- VANDELS

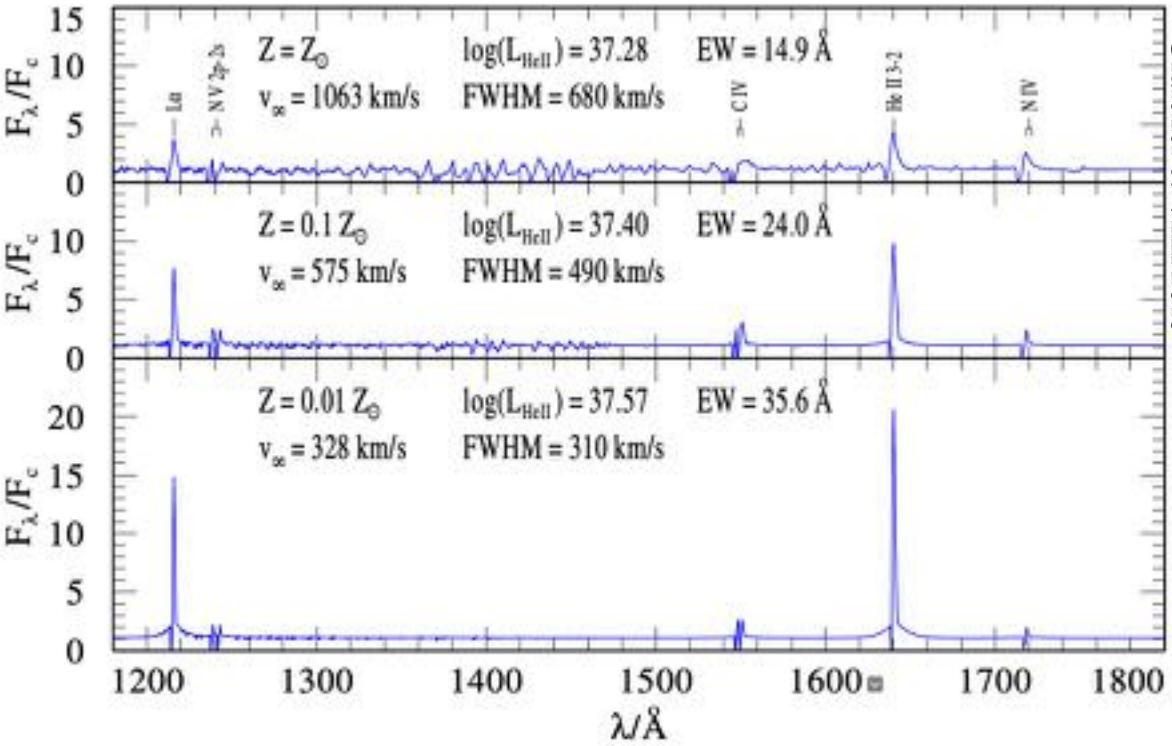


WHAT CAN CONTAMINATE THIS REGION → X-RAY BINARIES

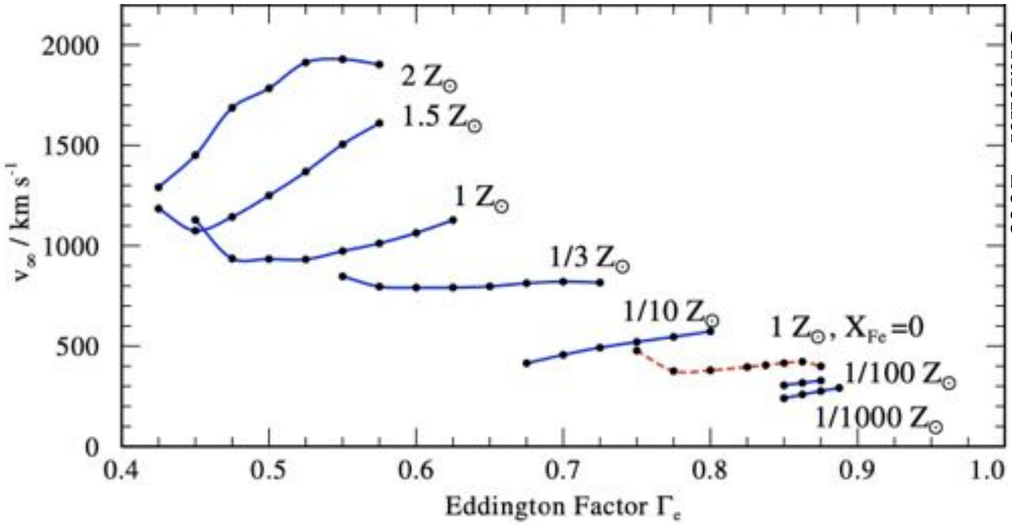


Katz+ 2023a

WHAT CAN CONTAMINATE THIS REGION → LOW-METALLICITY WOLF-RAYET STARS



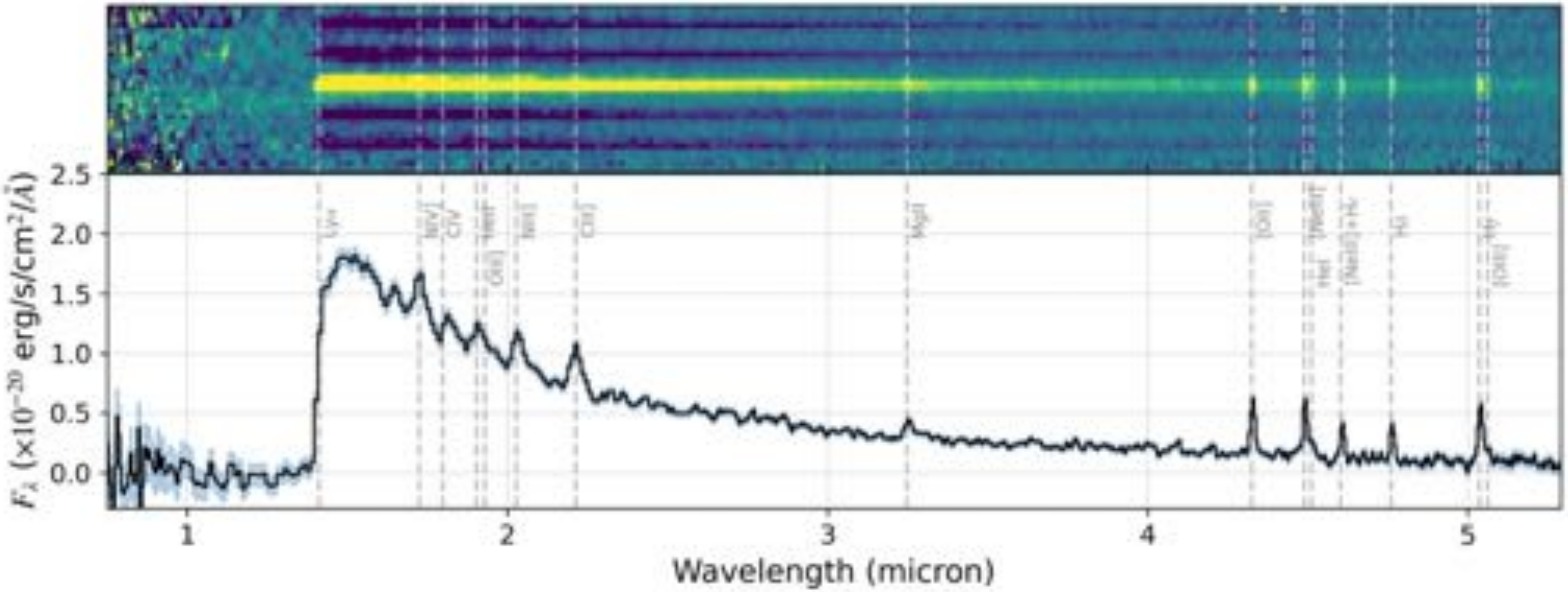
Grafener & Vink 2015



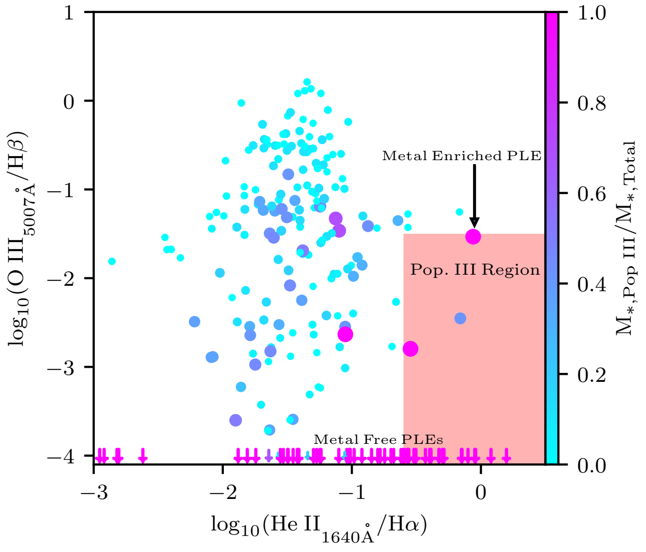
Grafener+ 2005

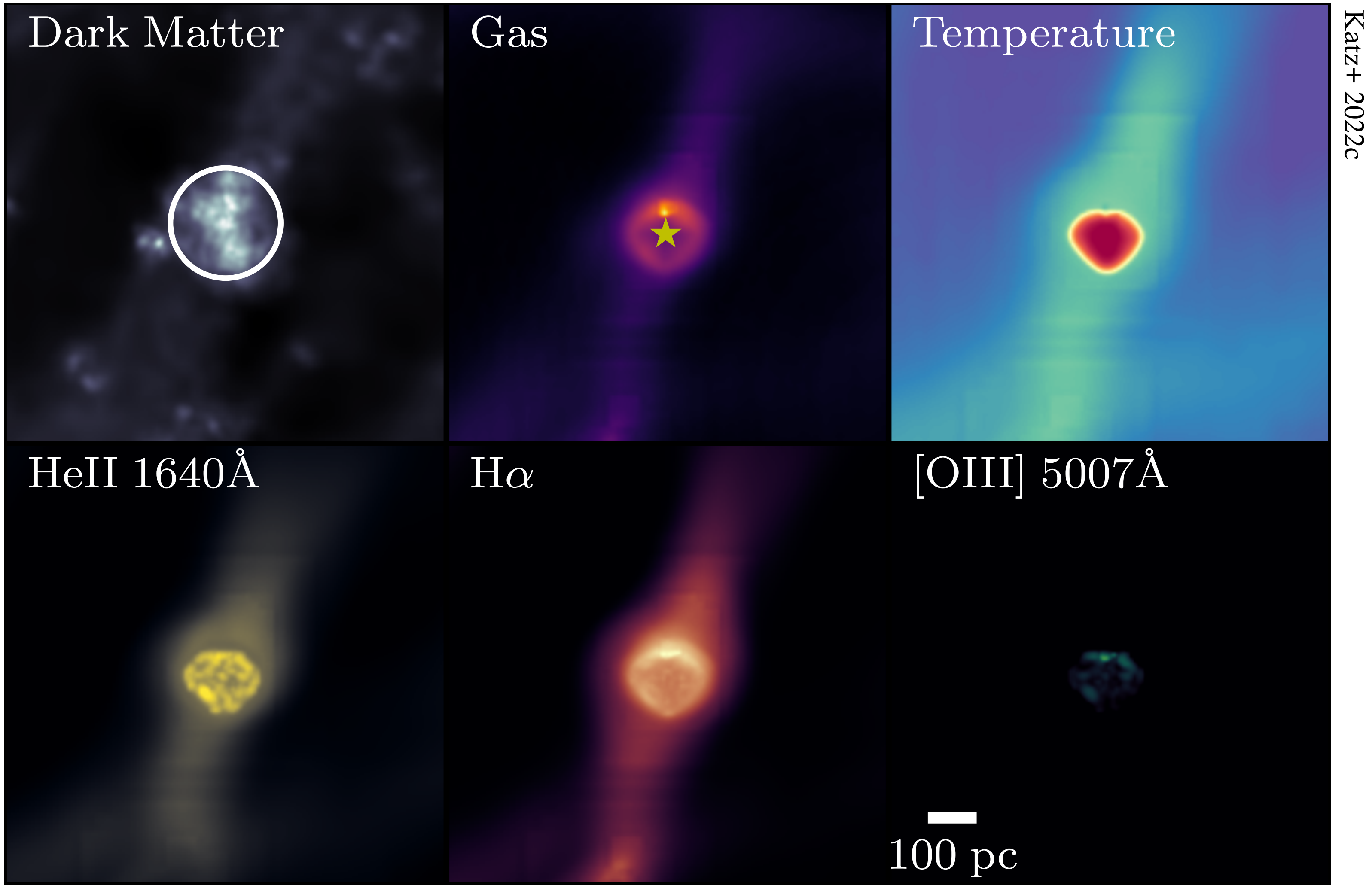
WHAT CAN CONTAMINATE THIS REGION → LOW-METALLICITY WOLF-RAYET STARS

Bunker+ 2023



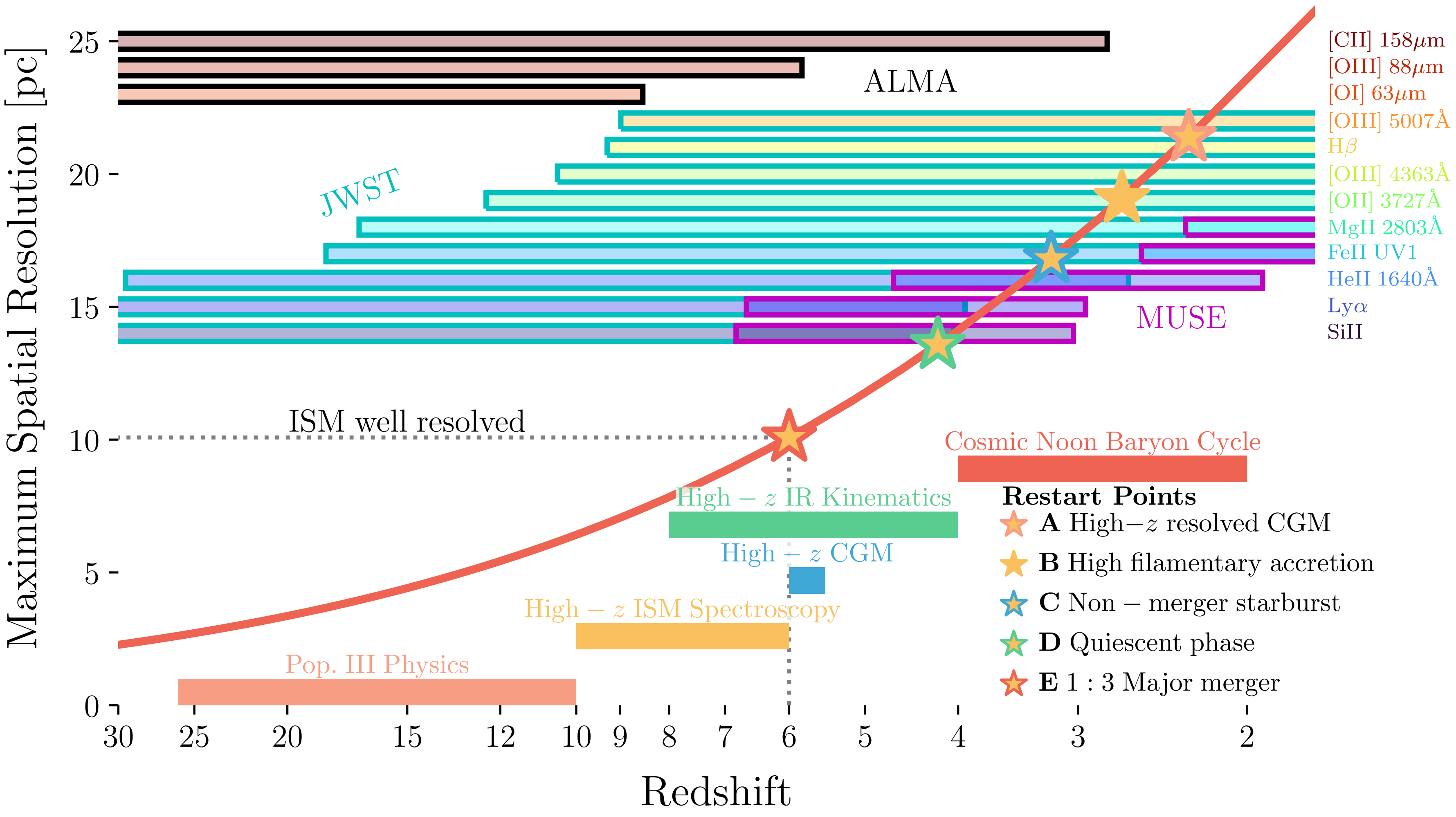
PURE LINE EMITTERS → IF POP III STARS FORM IN ISOLATION





WHAT'S COMING?

TRACE POP III SIGNATURES IN THE LOW-REDSHIFT CGM



WE DO THIS BY EXPLICITLY RESOLVING THE COOLING LENGTH