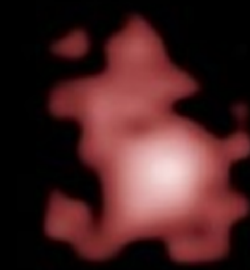
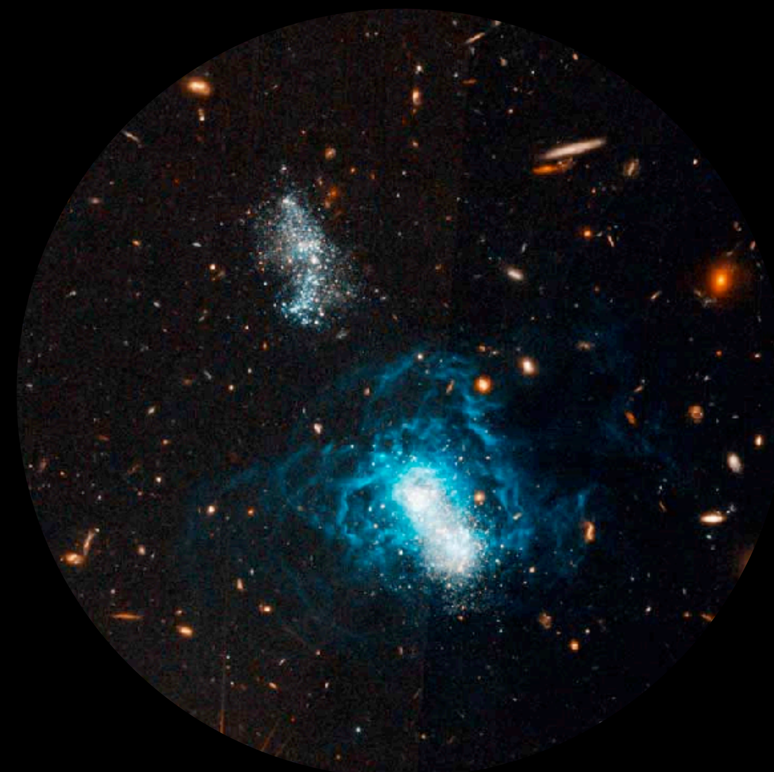
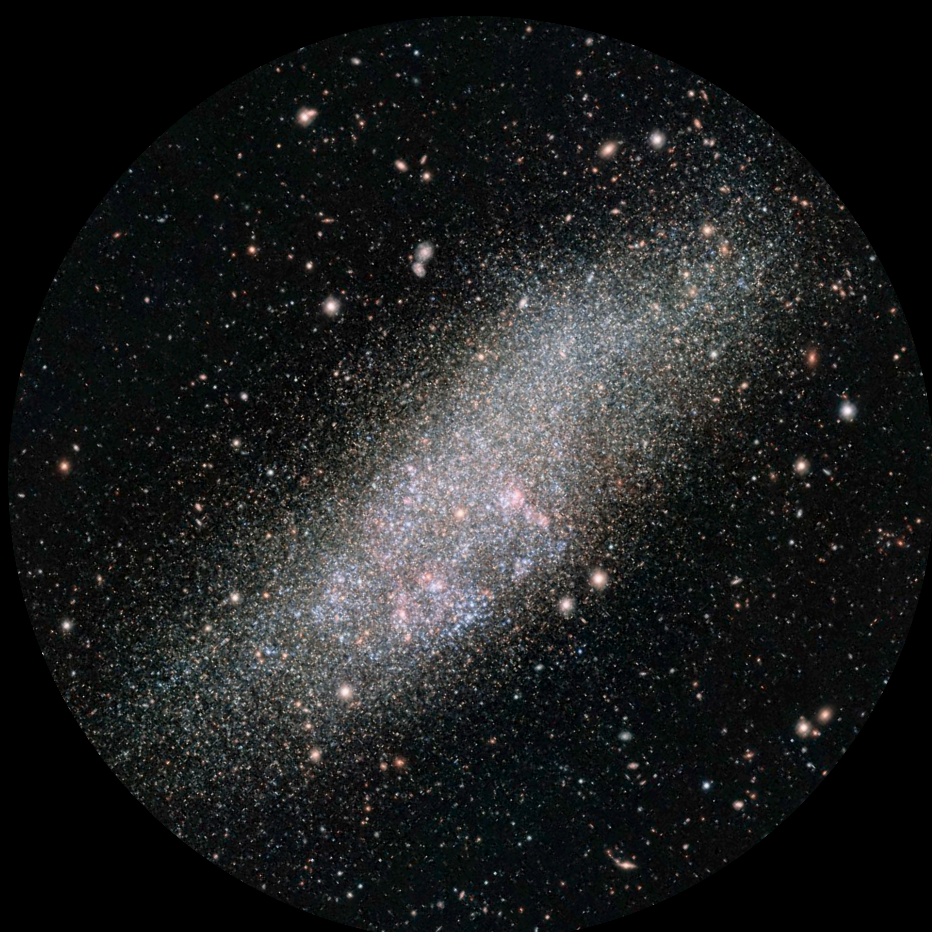
Intertwined uncertainties in metal-poor massive star populations from z~10 to 0



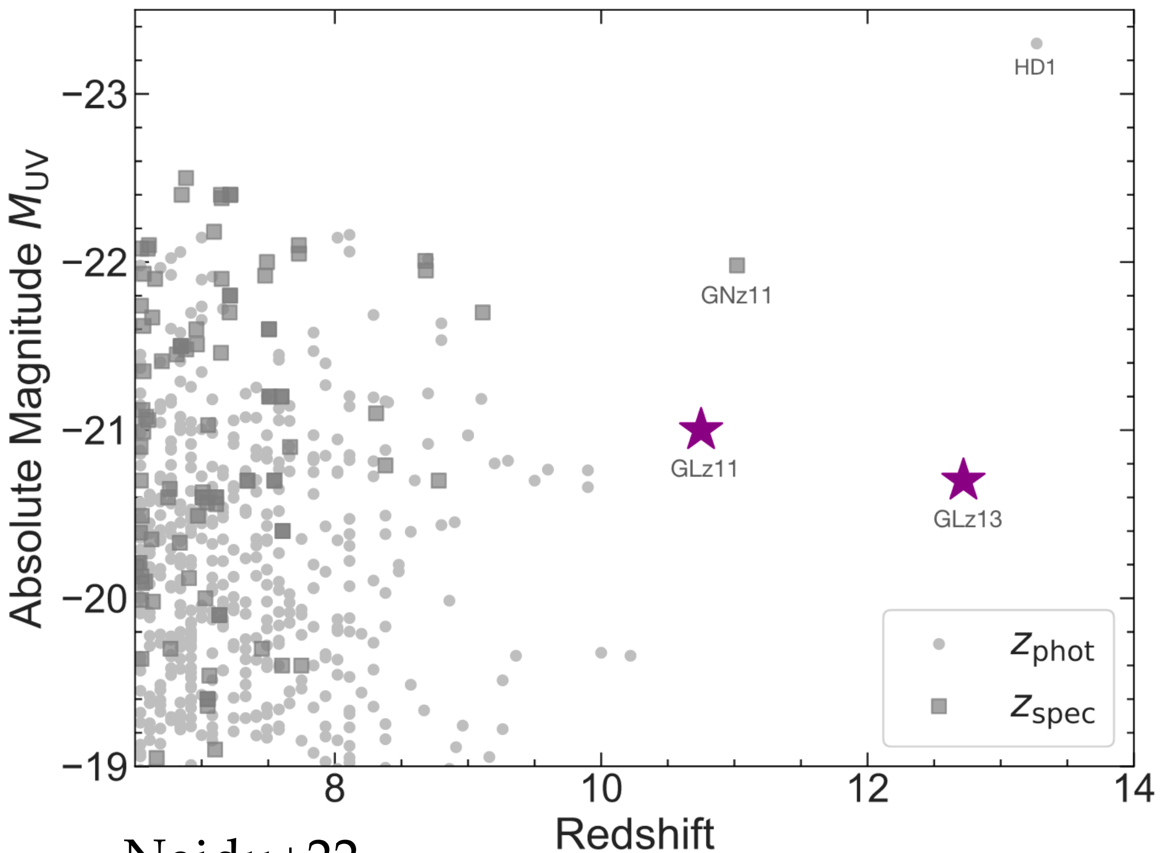




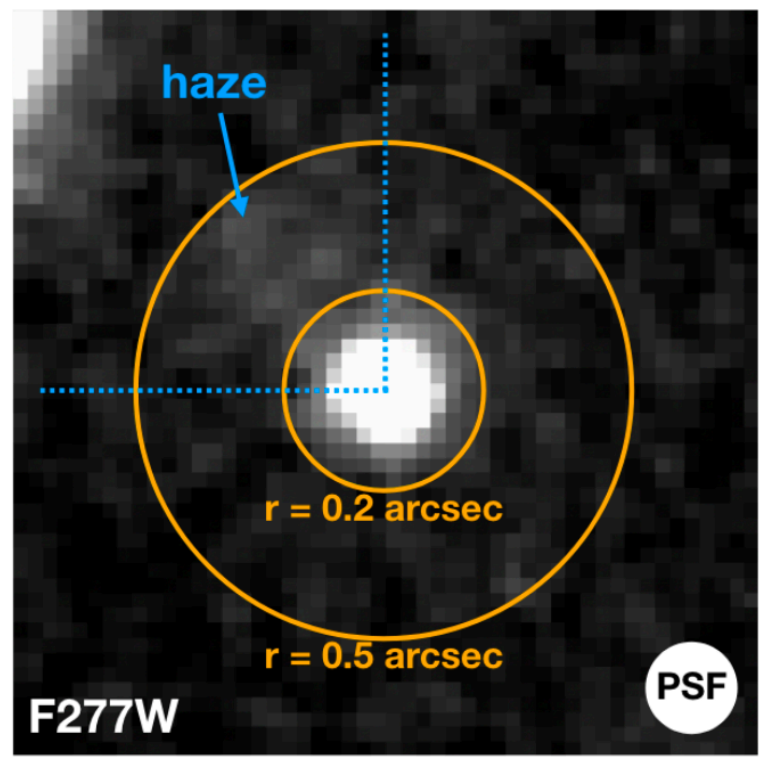
Peter Senchyna (Carnegie Fellow)

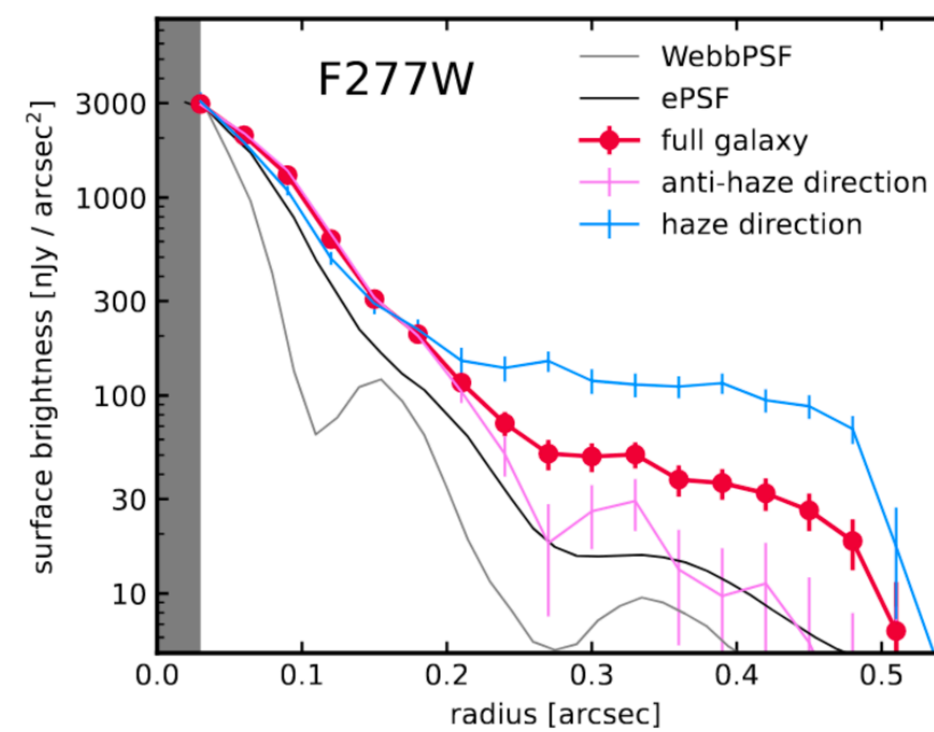
ELTs — 14 Dec 2023

GN-z11: a pre-JWST redshift record holder, and extremely luminous `Universe breaker'



Naidu+22

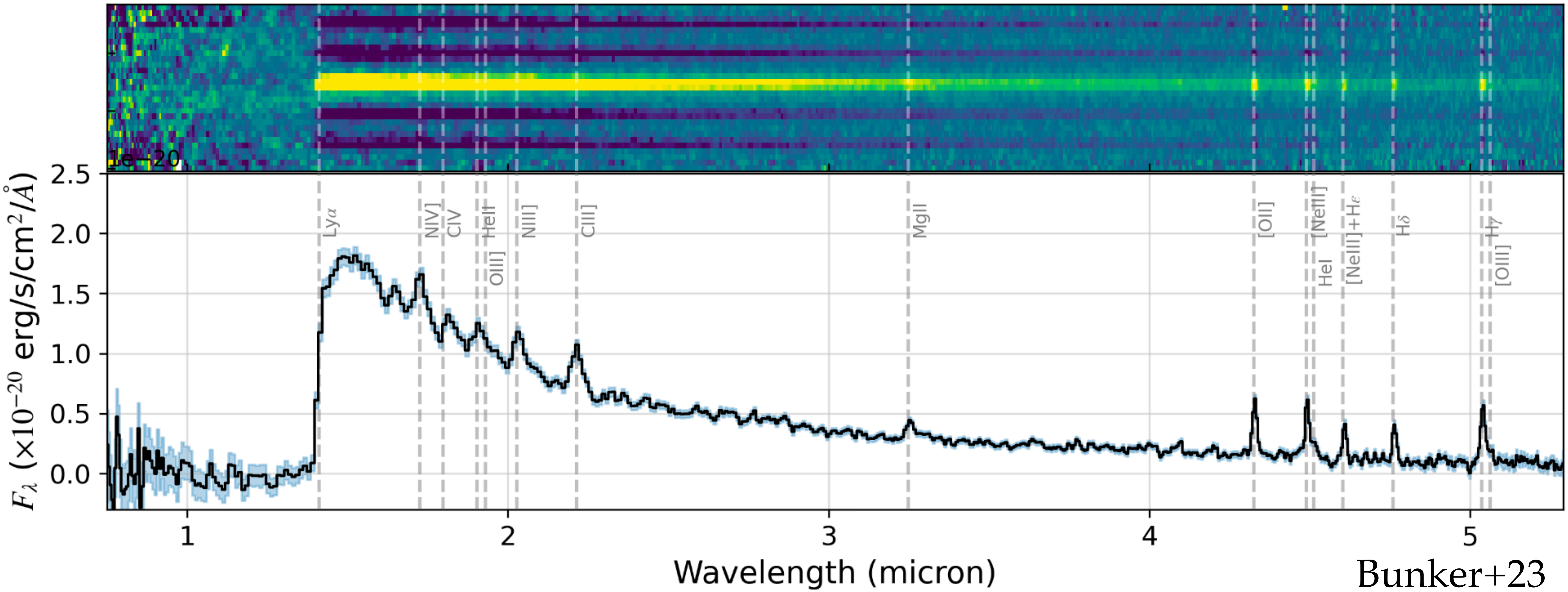




Tacchella+23

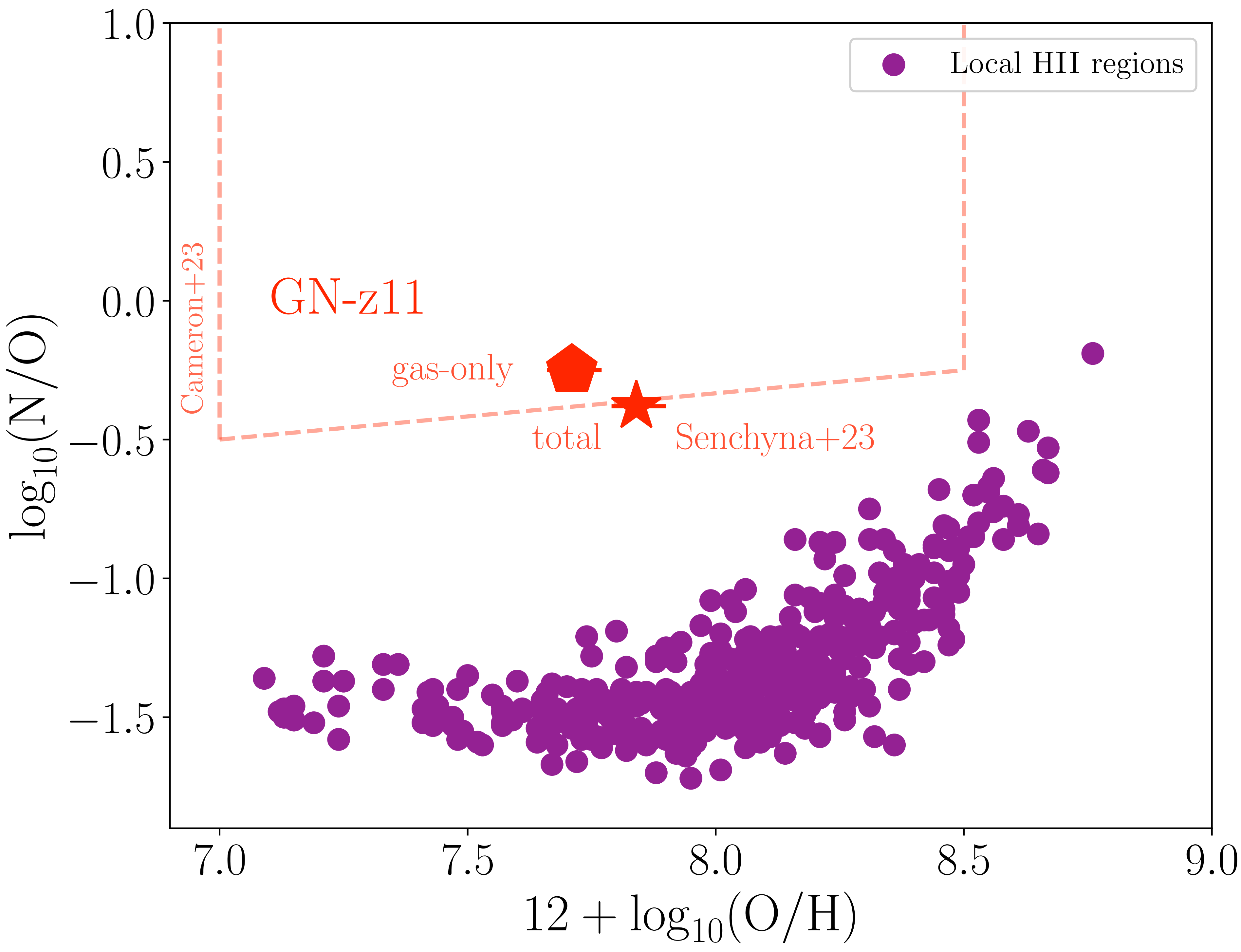
JWST/JADES confirms: nearly unresolved clump at $z = 10.6$; $r \sim 0.016''$: 20 $M_\odot$/yr in a **64 pc** radius (!)

To UV-aficionados: one of the first truly *shocking* JWST spectra:



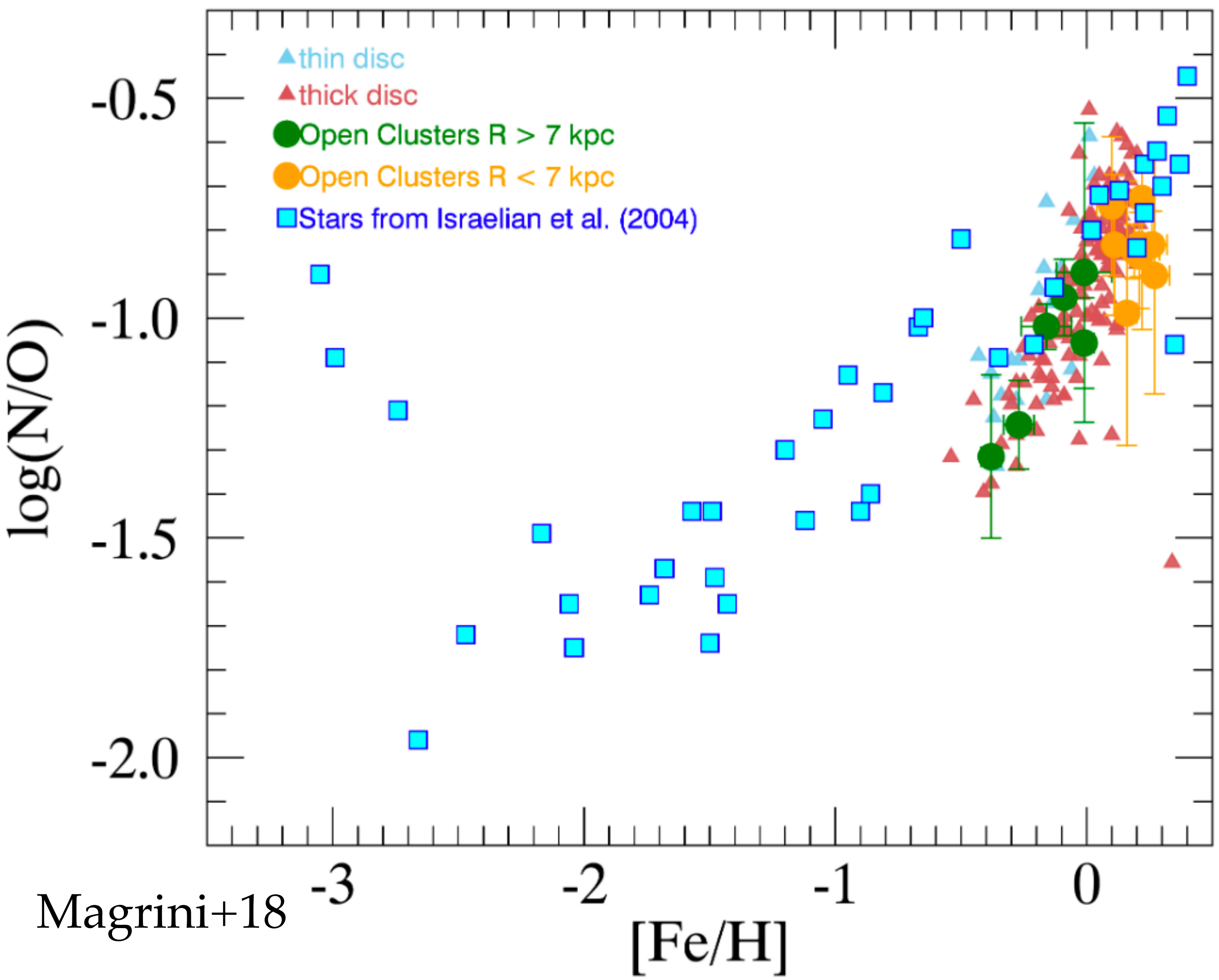
Bunker+23

Most prominent lines are **N IV]**, **N III]**, and C III];
these nitrogen lines are rarely seen let alone this prominent in spectra of star-forming galaxies or AGN



Photoionization models can reproduce this emission; but only with a very elevated nitrogen abundance

Why is this so surprising?



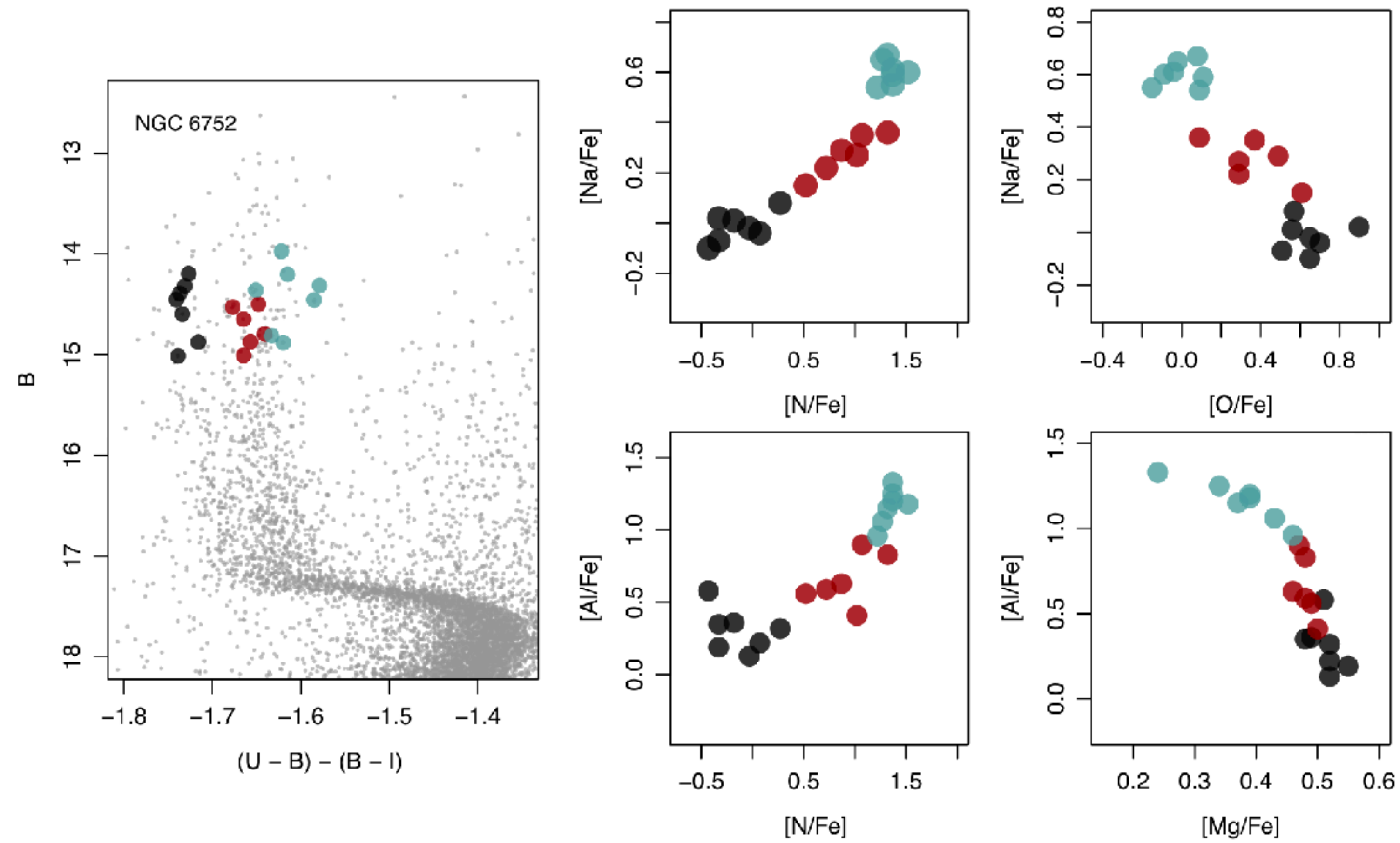
Magrini+18

Nitrogen *generally* follows a tight correlation in the local Universe:

- low N/O at low-Z,
- increase in N/O only as O/H approaches solar
  - slow, secondary injection of CNO-processed material by AGB star winds

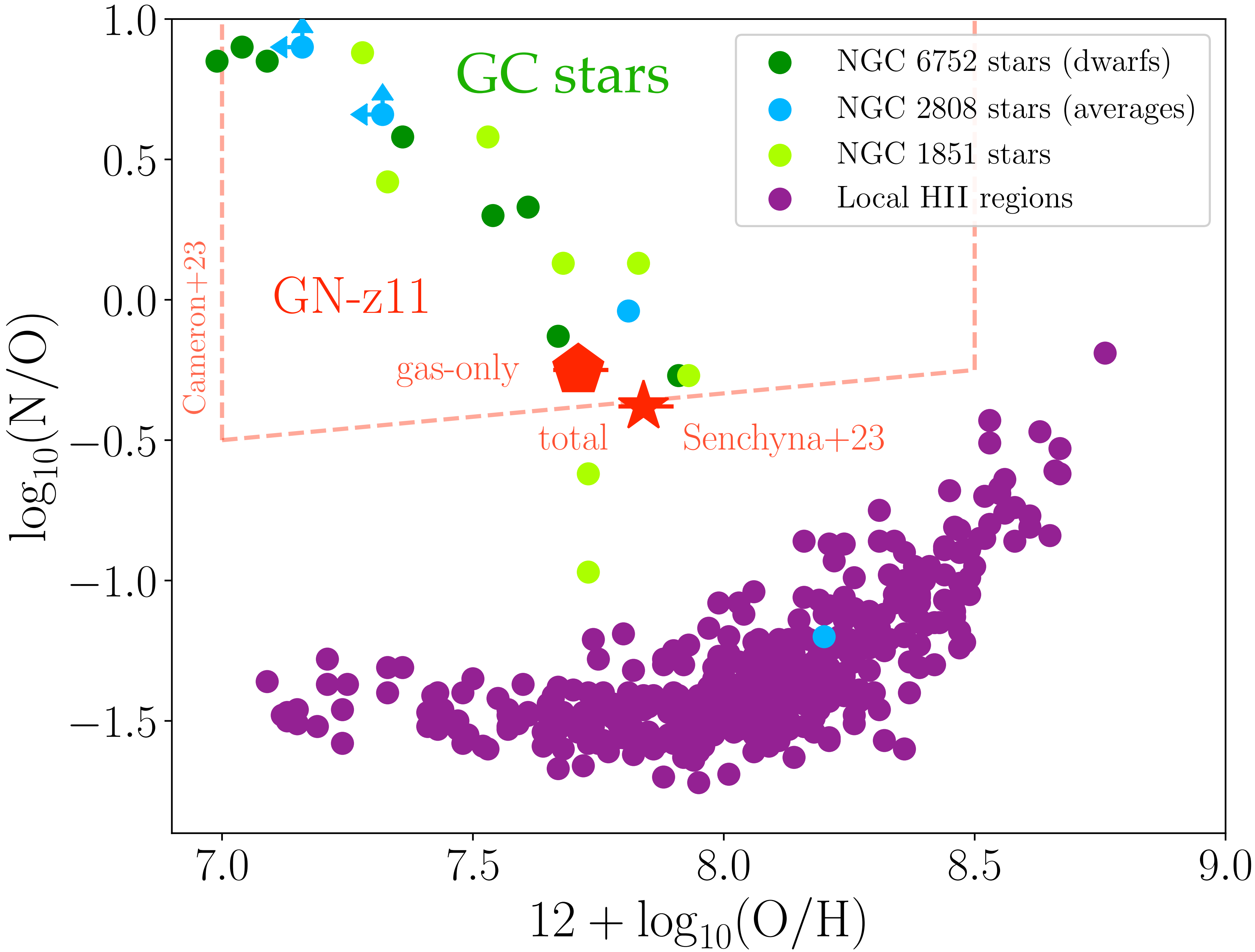
Massive stars are the primary site of N-production, via the CNO process - this bottlenecks at N, so produces N at the cost of C+O

Perhaps not *entirely* unexpected..



Gratton+12, Bastian&Lardo 18, …

Globular cluster populations encode enrichment signatures from **high-temperature nuclear burning**, including the CNO-process (large dex+ N,O anti-correlations)

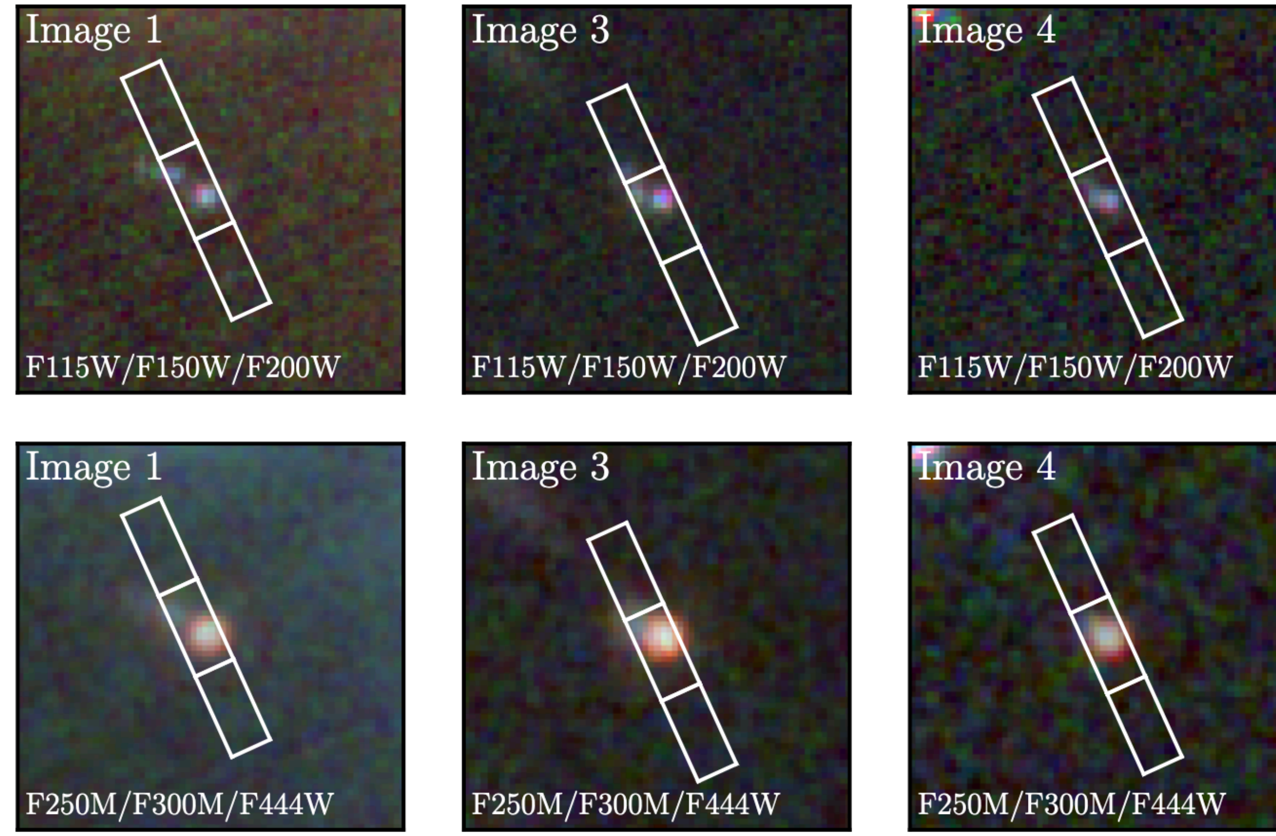


Intriguingly: looks strikingly similar to abundance trends long discussed in **globular clusters** and other ancient remnants

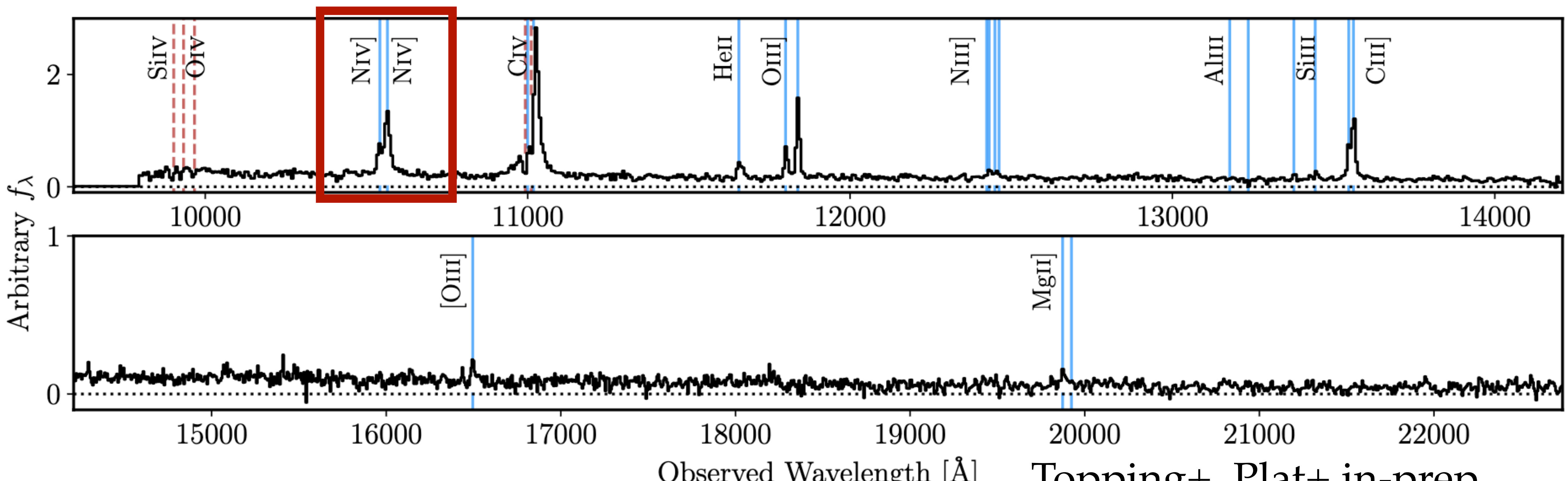
See also Charbonnel+23, Belokurov&Kravtsov 23, Bekki&Tsujimoto 23, Vink 23, D'Antona+23

Is GN-z11 unique?

Need larger samples of high-SNR, high-resolution JWST spectroscopy in the rest-UV…



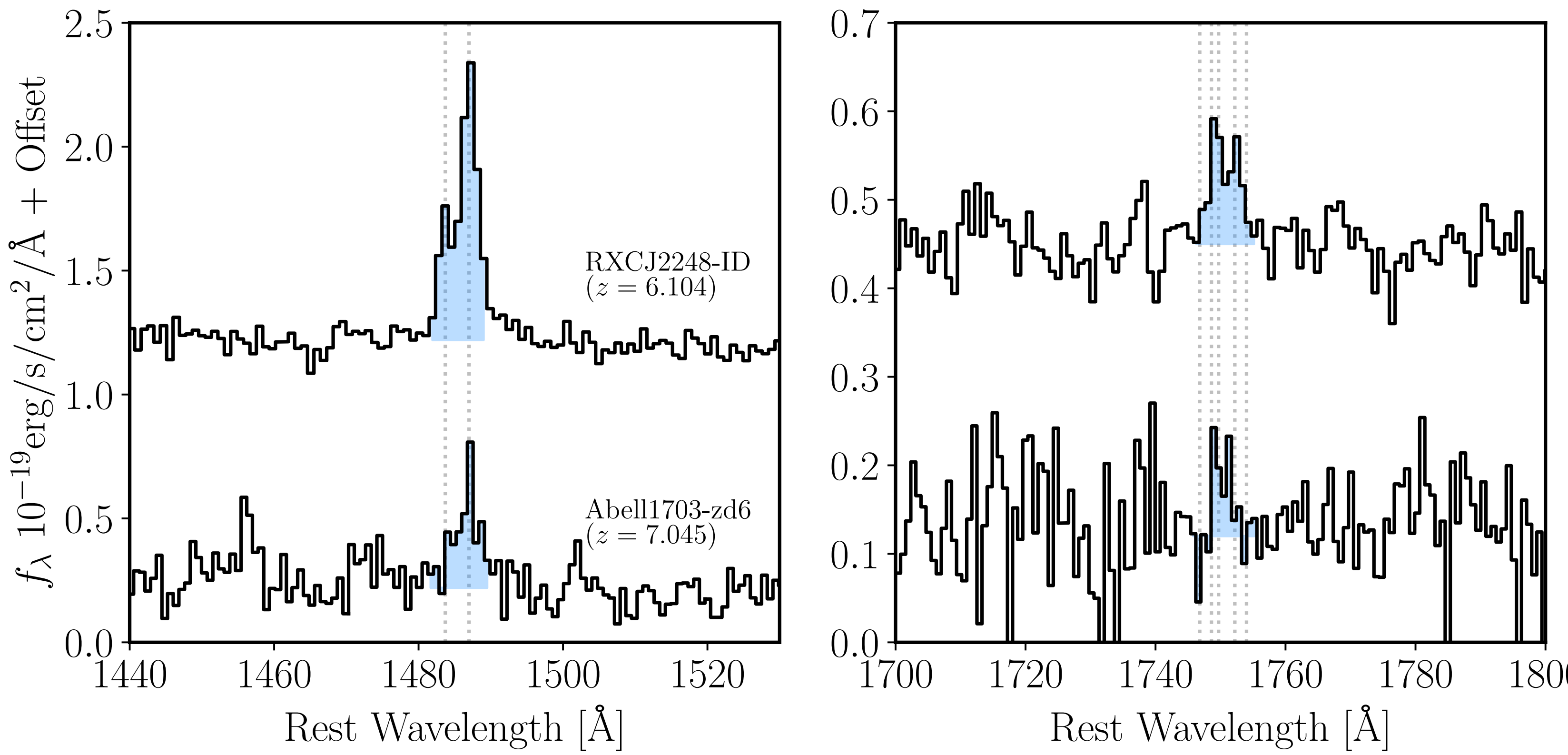
RXCJ2248-ID: $z = 6.11$ multiply-imaged lensed system (Mainali+17, Schmidt+17)



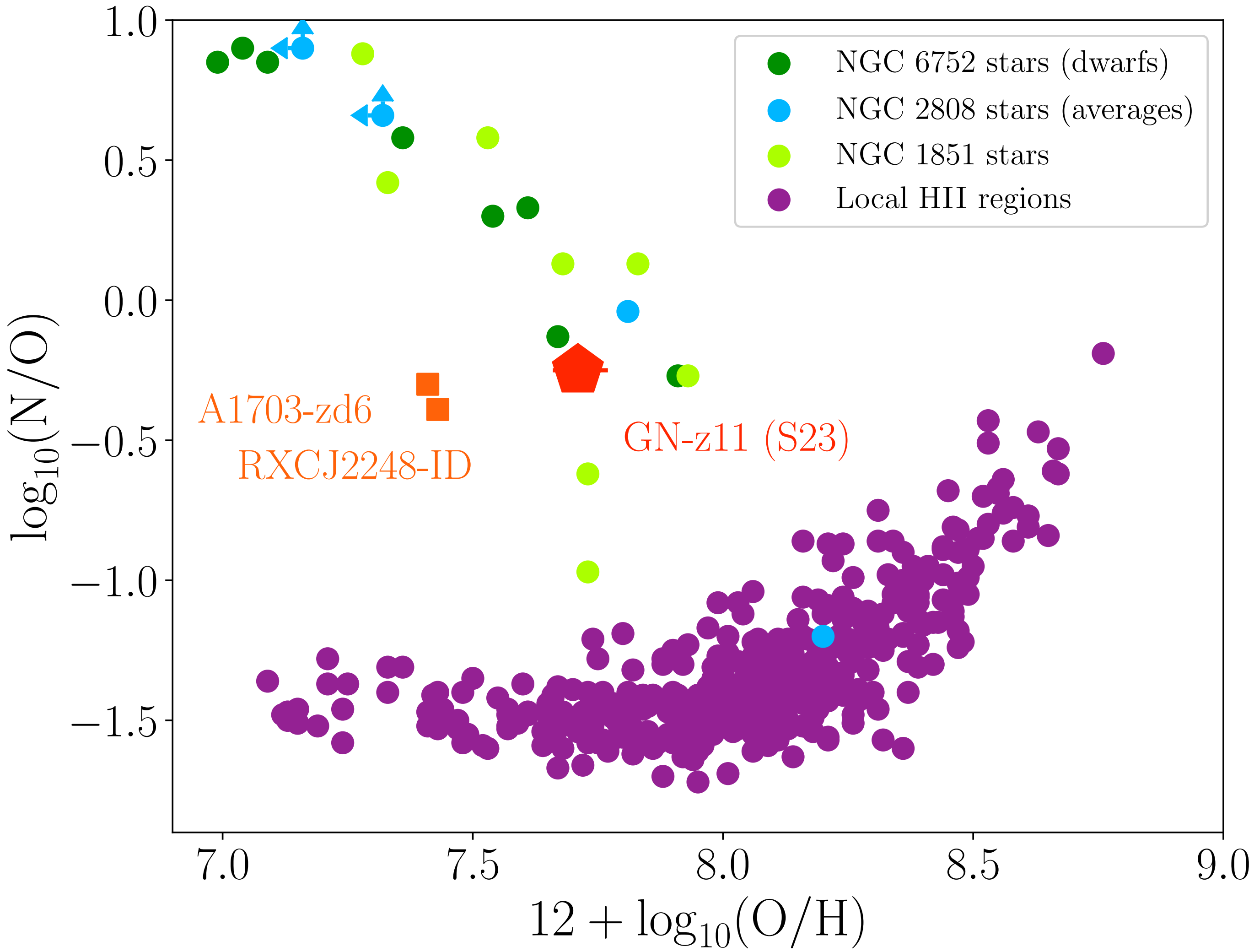
Topping+, Plat+ in-prep

Confirmed 34 Å CIV emission; and prominent **NIV]**

Two lensed systems selected on other UV nebular emission (CIV) show strong NIV] (+NIII])



Topping+, Plat+ in-prep

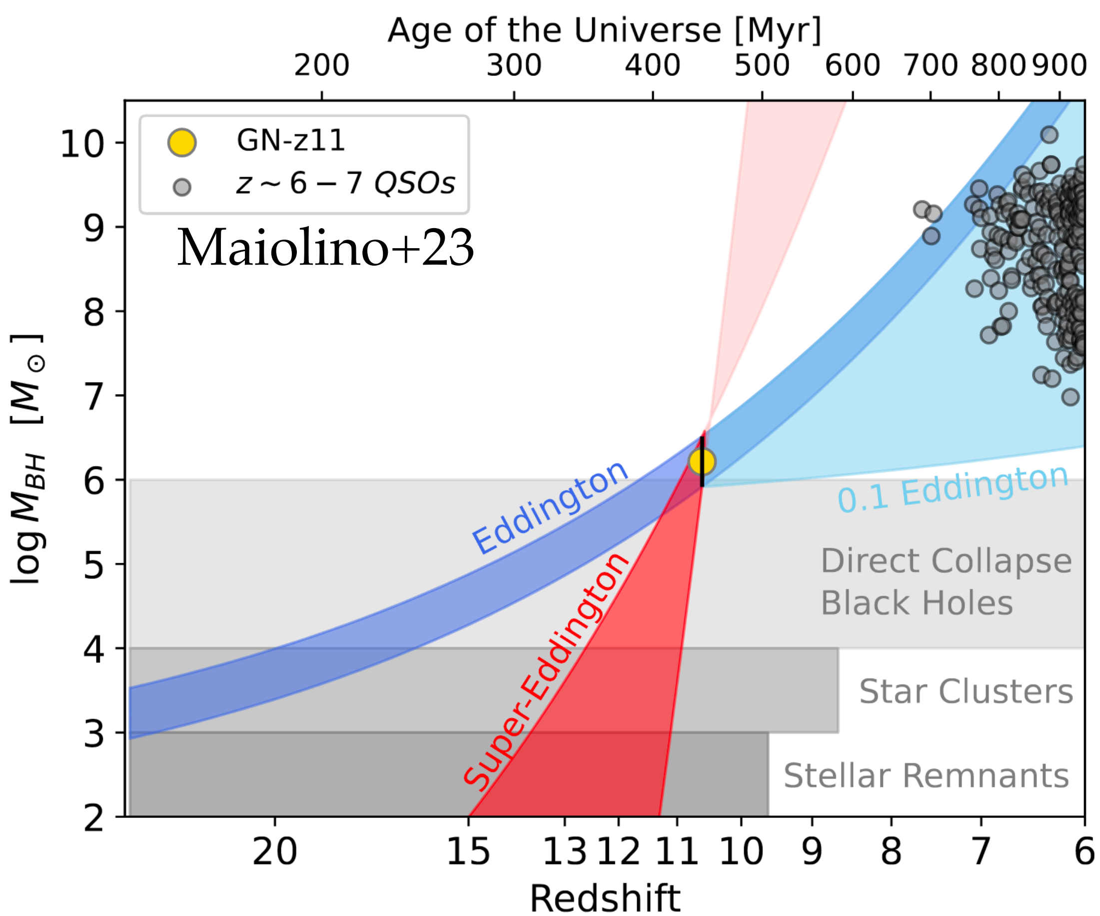


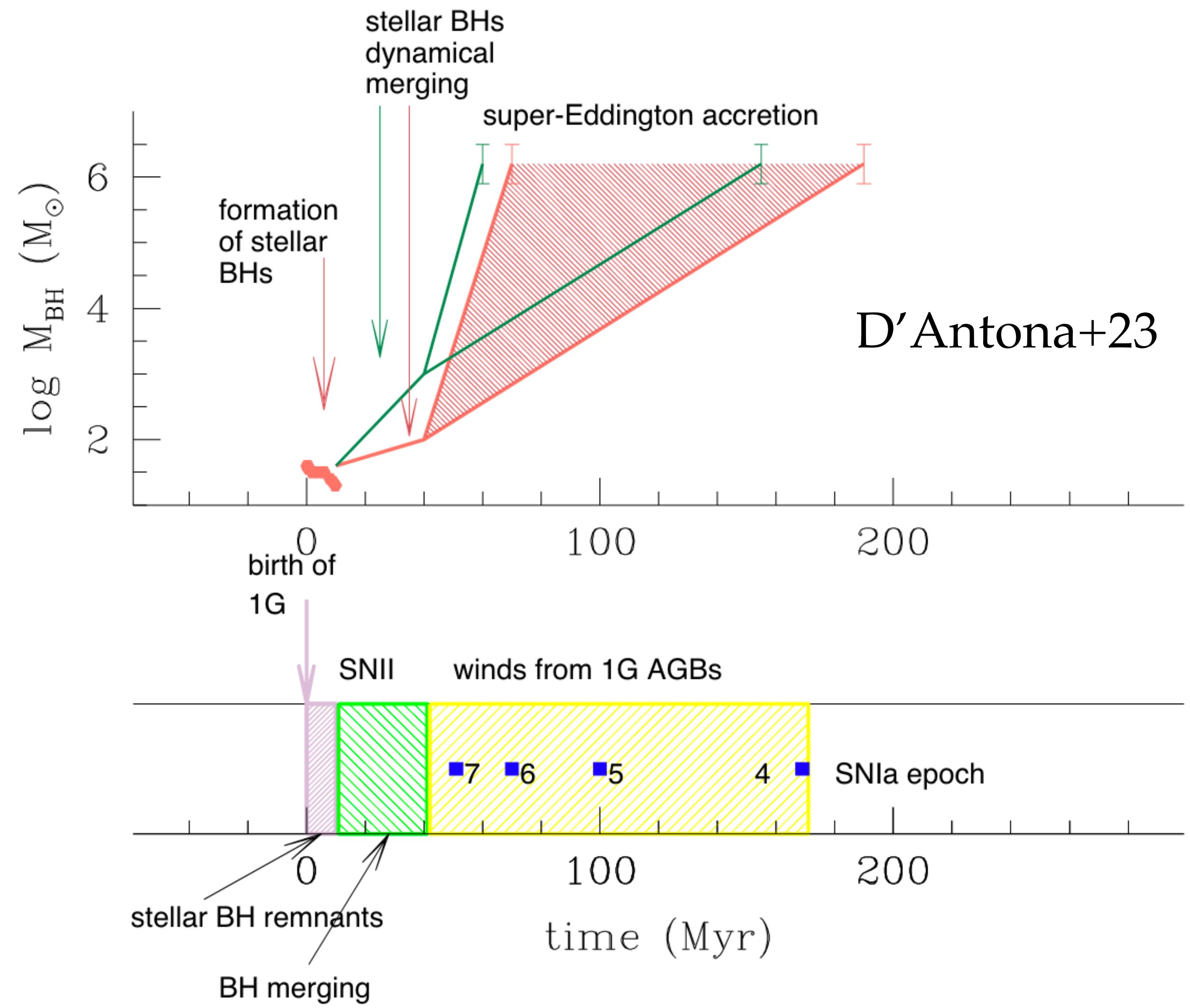
Implies similarly-elevated N/O — emergence of a new pattern in z>7 galaxies?

see also Pascale+23 (*Sunburst Arc*), Marques-Chaves+23, Isobe+23

Potentially directly constraining GC-like SF & enrichment by massive stars in-situ - a dream! But complicated:

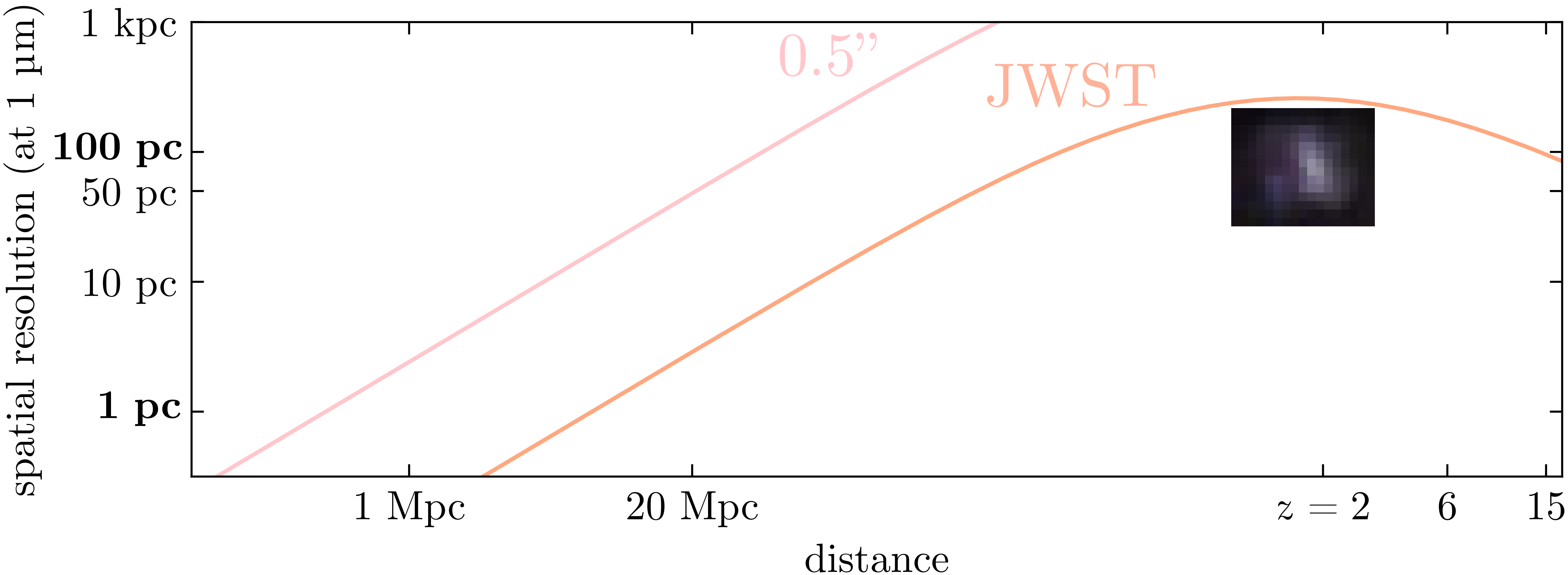
- Unclear AGN contribution - an N-enhanced Broad Line Region?
  - Possible (I/S)MBH seeding in a dense star-forming region





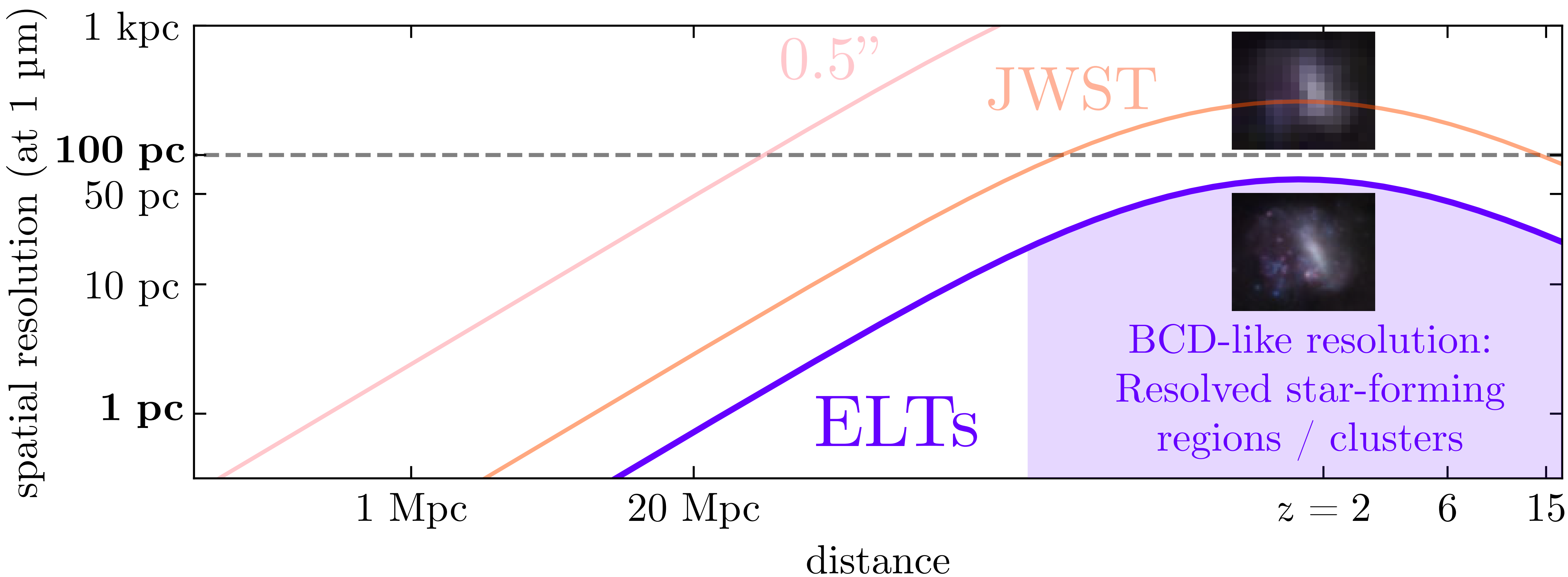
- Where is the N actually coming from?
  - Supermassive stars? AGBs? Binaries?

Densely clustered star formation - need spatial resolution!



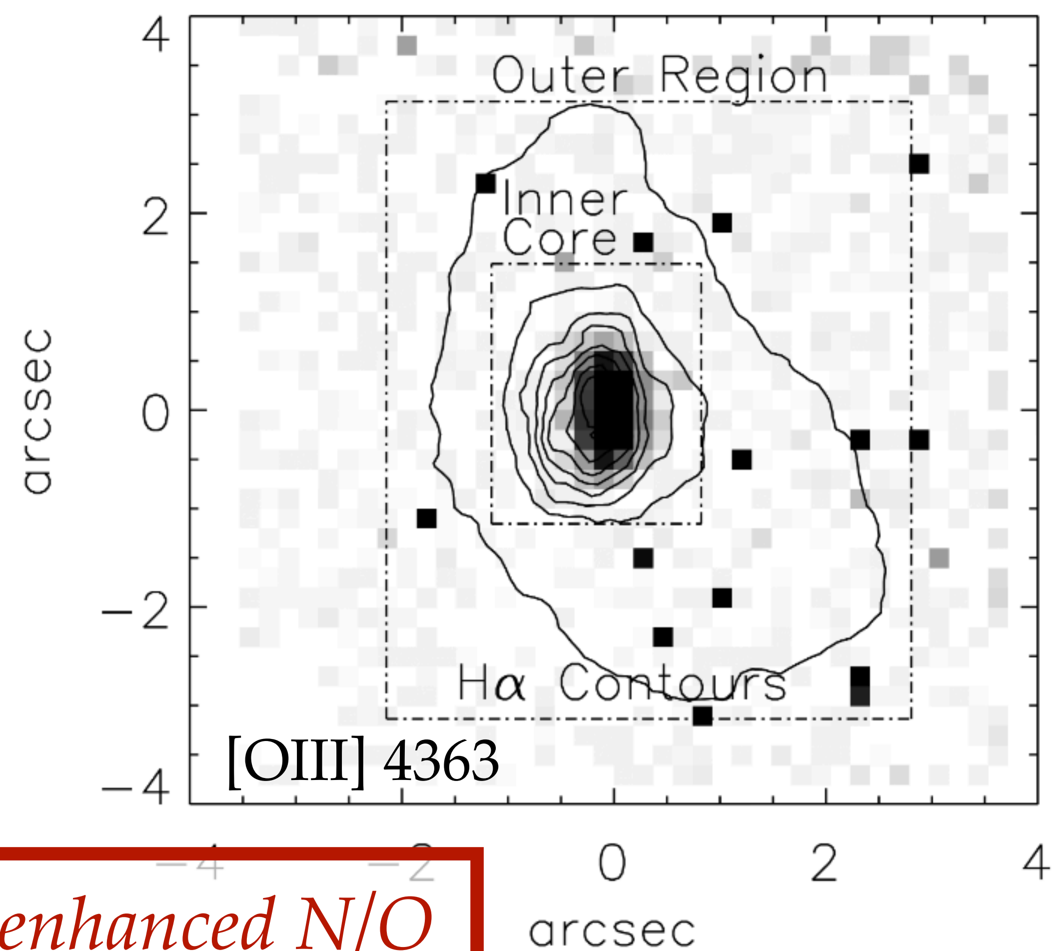
JWST only gets us to of-order 100pc resolution - can do better with lensing, but have to be lucky

Densely clustered star formation - need spatial resolution!



ELTs will resolve *everything* at <100pc scales:
gets us stellar populations & gas at z>6 at the resolution typical of nearby (<100 Mpc) blue compact dwarf galaxies

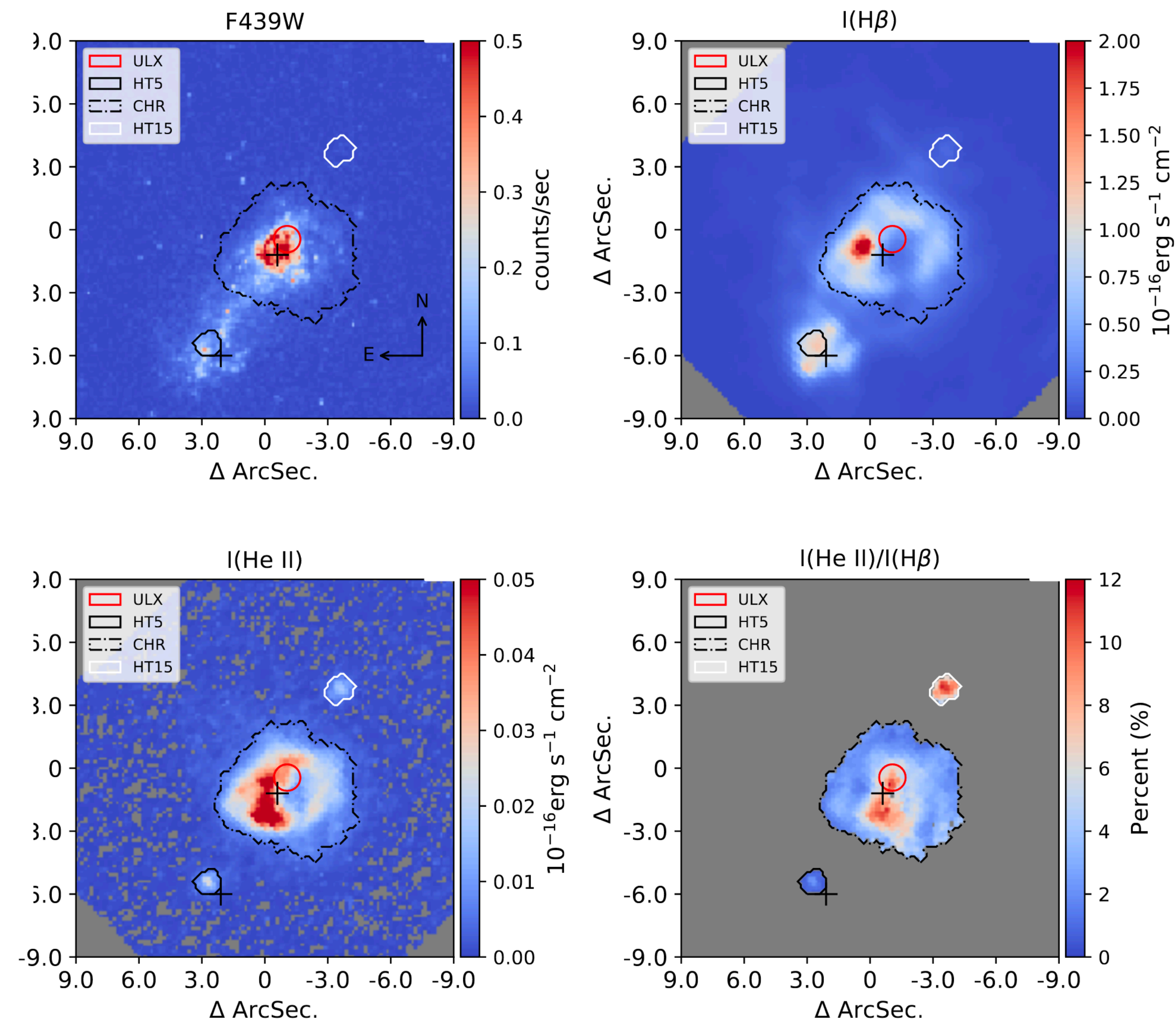
Already revolutionary: resolved optical spectroscopy of nearby blue compact dwarfs has taught us a lot (and rest-UV could tell us even more..)



Similar enhanced N/O in a dense burst?

James+09

VLT/VIMOS, Mrk996



KCWI, IZw18

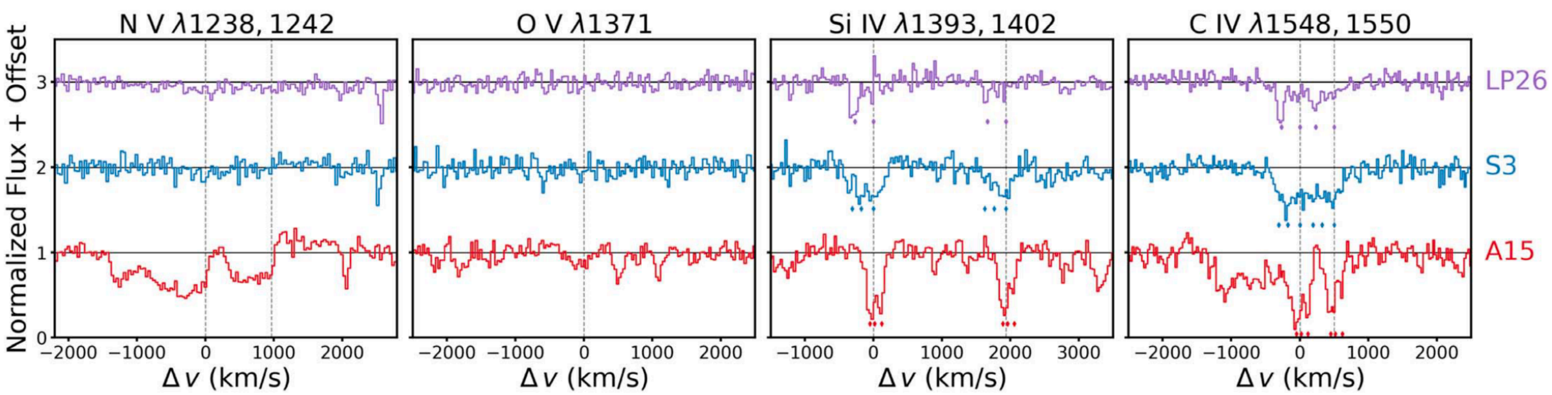
Rickards Vaught+21

But: at 20 Mpc, 0.2″ ~ **20 pc**

A lot of physics is still hidden in the cores of these star-forming regions

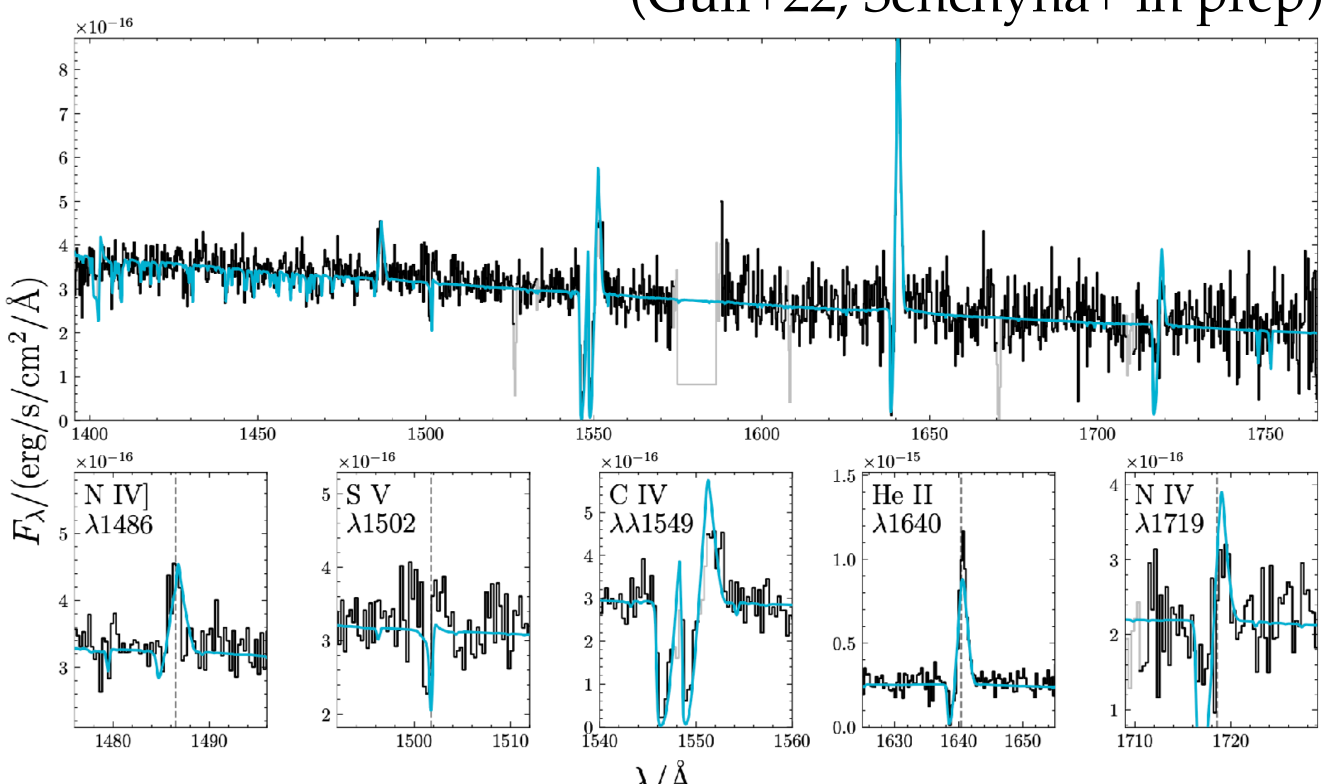
Much of the detailed physics awaits observations pushing to pc-scales

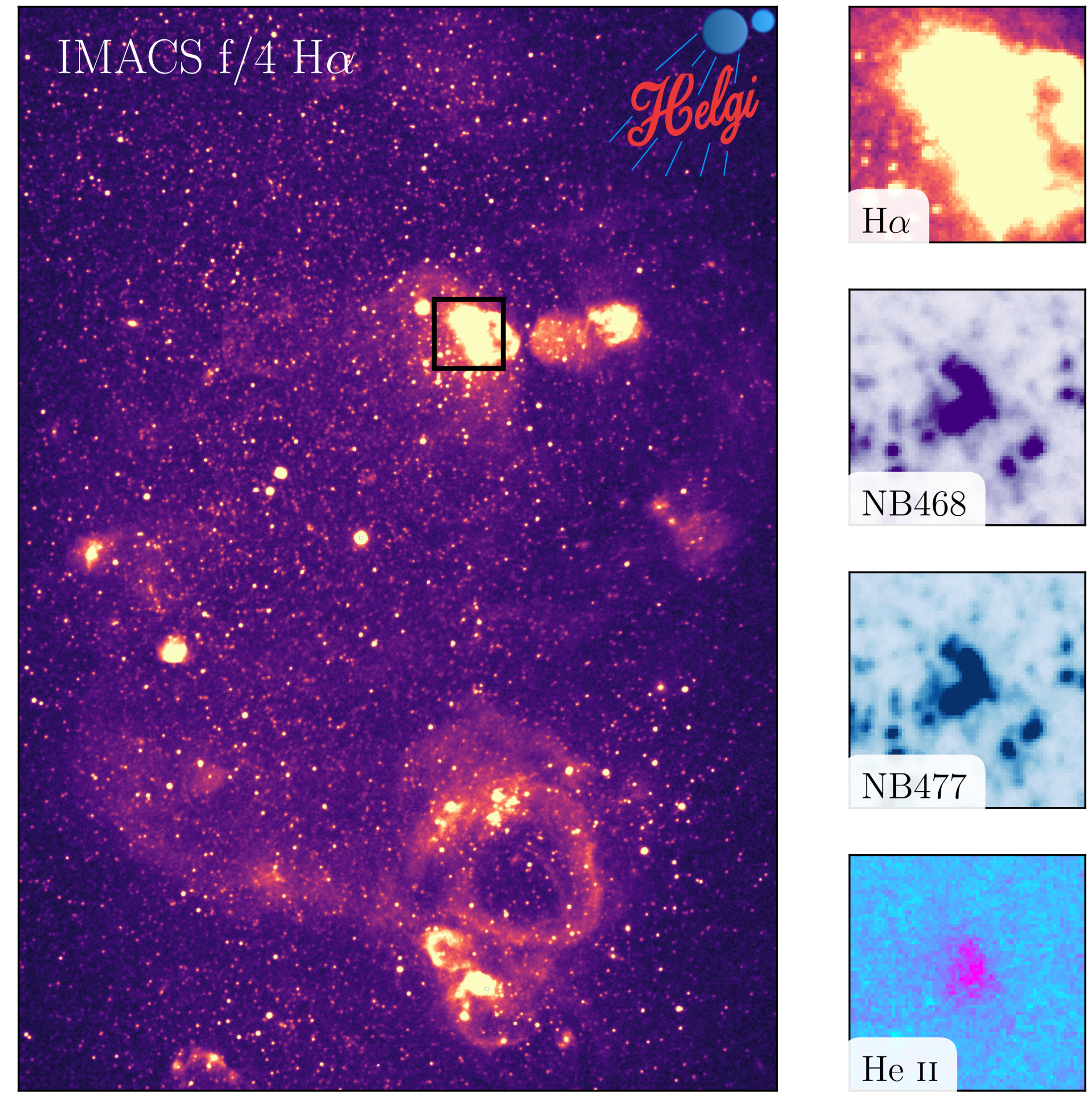
Frontier now: resolved metal-poor massive stars at the edge of the Local Group



Winds, H-ionizing radiation of metal-poor OB stars
(Garcia+14,21; Telford+21,23; Senchyna+ in prep, ULLYSES)

Stripped stars & other products of binary evolution
(Gull+22, Senchyna+ in prep)

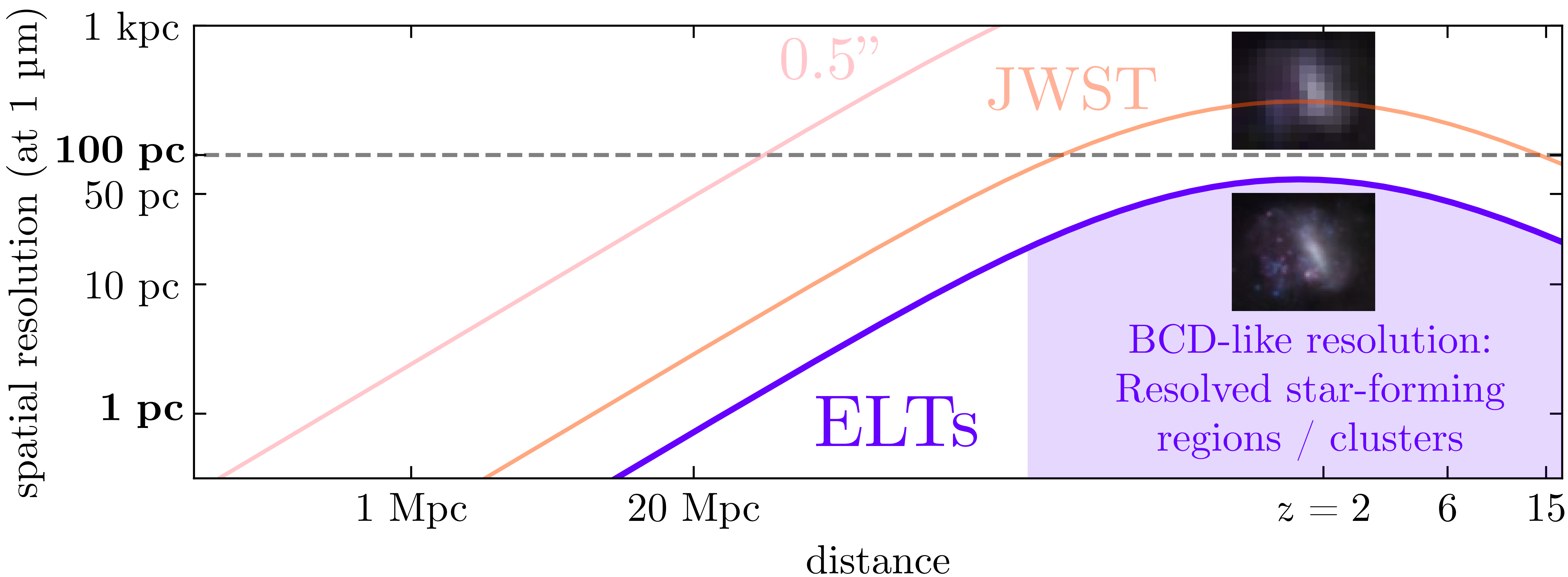




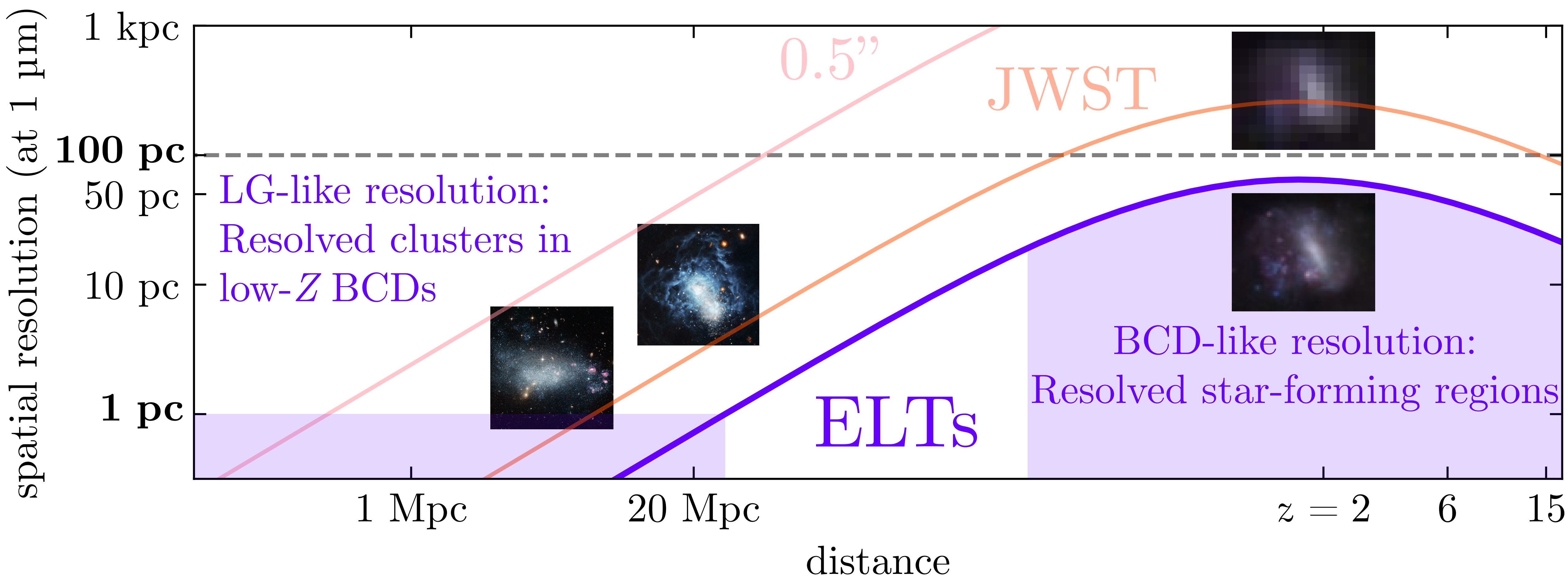
HelgI: deep narrowband He II search
(Senchyna, Götberg+ in prep)

ELTs + HabWorlds will revolutionize this work; and open the next frontier

The *only* place we'll resolve stellar clusters at pc-scale
(sans lensing, for $\lesssim$ 30m apertures) is at $\lesssim$ 20 Mpc

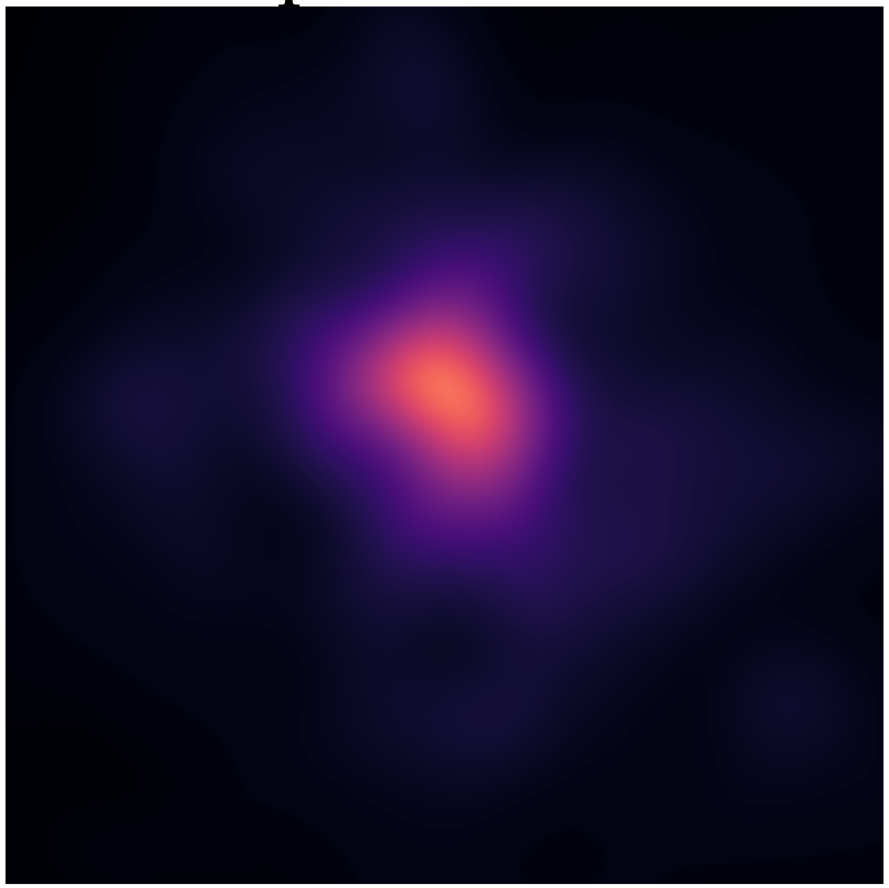


The *only* place we'll resolve stellar clusters at pc-scale
(sans lensing, for $\lesssim$ 30m apertures) is at $\lesssim$ 20 Mpc



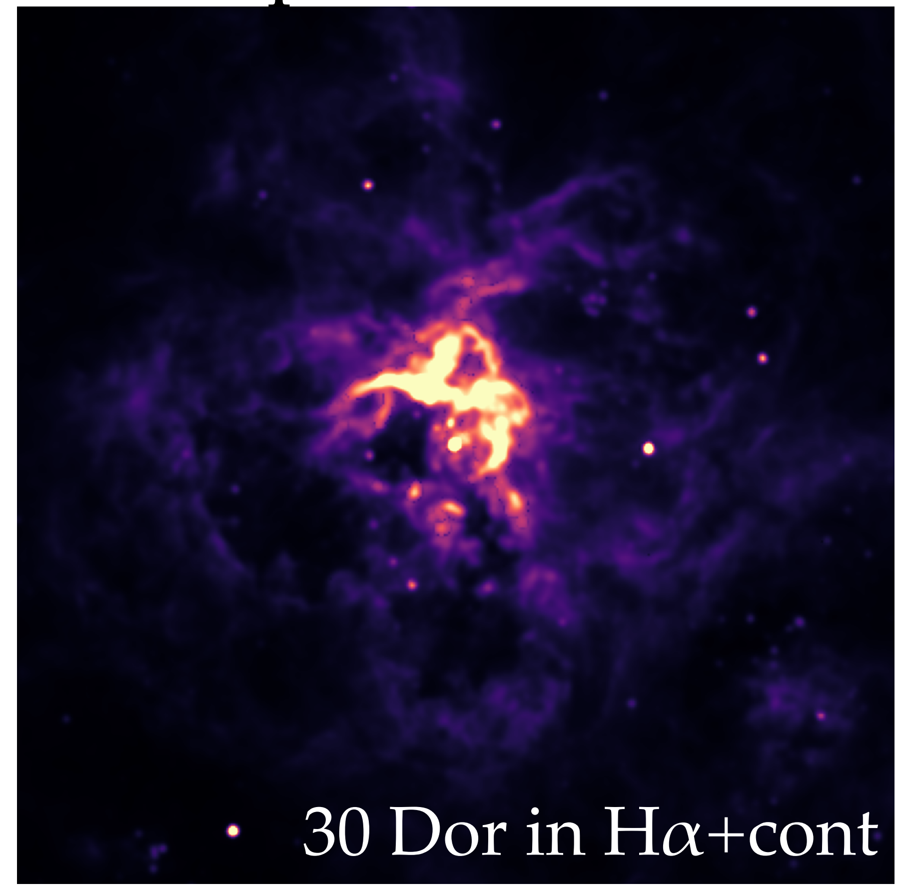
Our best hope for understanding massive stars in detail at the extreme **metallicities, ages, SFR densities** we're glimpsing at high-z

~10 pc resolution



- Unlensed galaxies at z>6 with the ELT
- Current best for blue compact dwarfs at $\gtrsim$ 20 Mpc

~1 pc resolution



Resolved clusters - **only possible in the <20 Mpc Universe** (and for lucky lensing)

A new frontier for ELTs (-> HabWorlds):

- Ideally want max throughput & diffraction-limited resolution at <5000Å (and UV..); but ELTs will be the pathfinders!
- Resolved (luminous) stars/clusters, ionizing radiation, stellar winds & feedback, chemical enrichment & mixing; **approaching early-Universe conditions**

Summary:

- First spectra of GN-z11 (and some other $z>6$ galaxies) reveal evidence of a massive star-driven pollution event on an galaxy-wide scale - a glimpse of a mode of dense clustered star formation evocative of globulars/early MW?

- Our understanding of these objects will be limited by our understanding of massive stars at high SFR densities and extremely low metallicities

- The ELTs will open new windows for detailed physics by both:

  - resolving field $z>6$ galaxies into star-forming regions

  - resolving the <20 Mpc Universe into clusters & stars - crucial synergies with next-generation space flagships