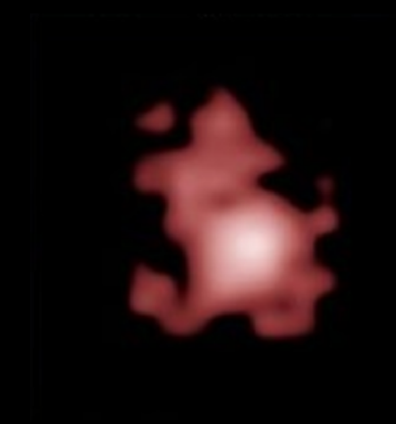
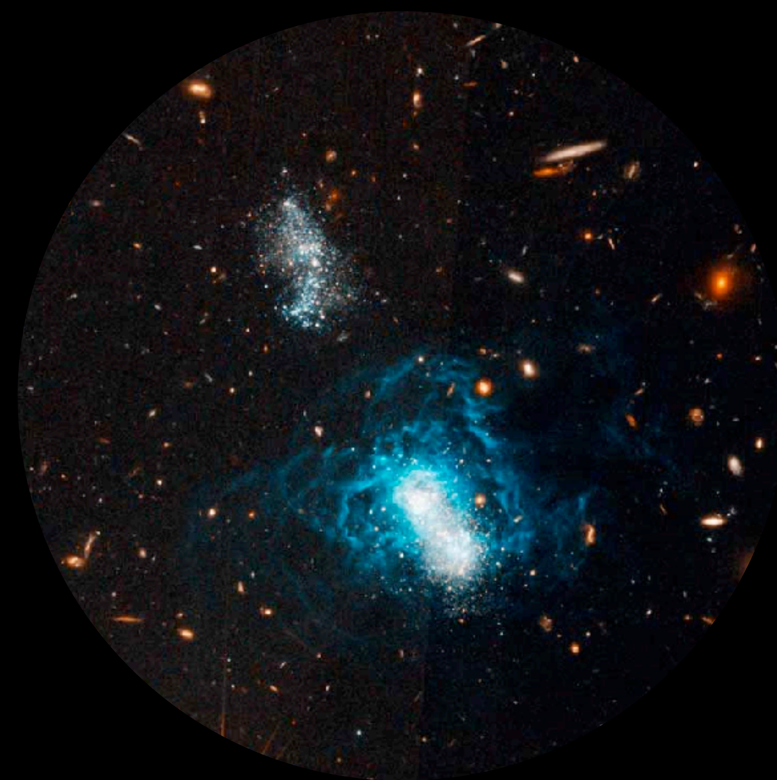
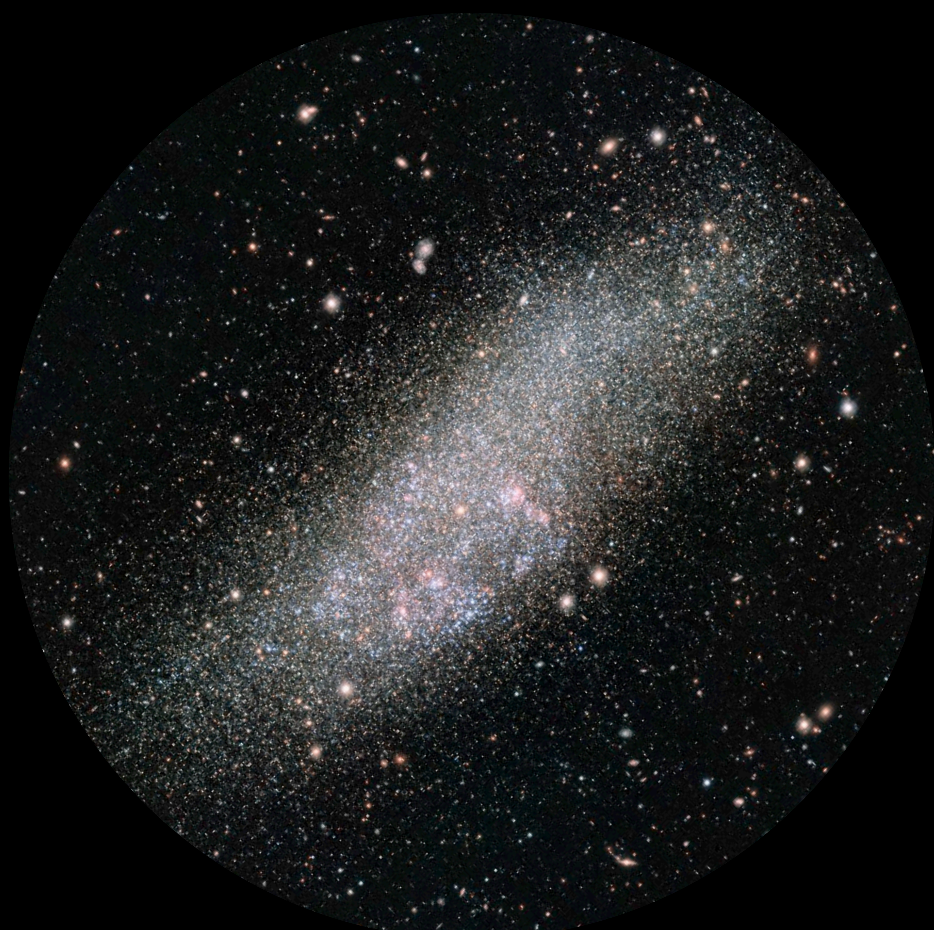
Massive stars at low metallicity in the lead-up to HabWorlds



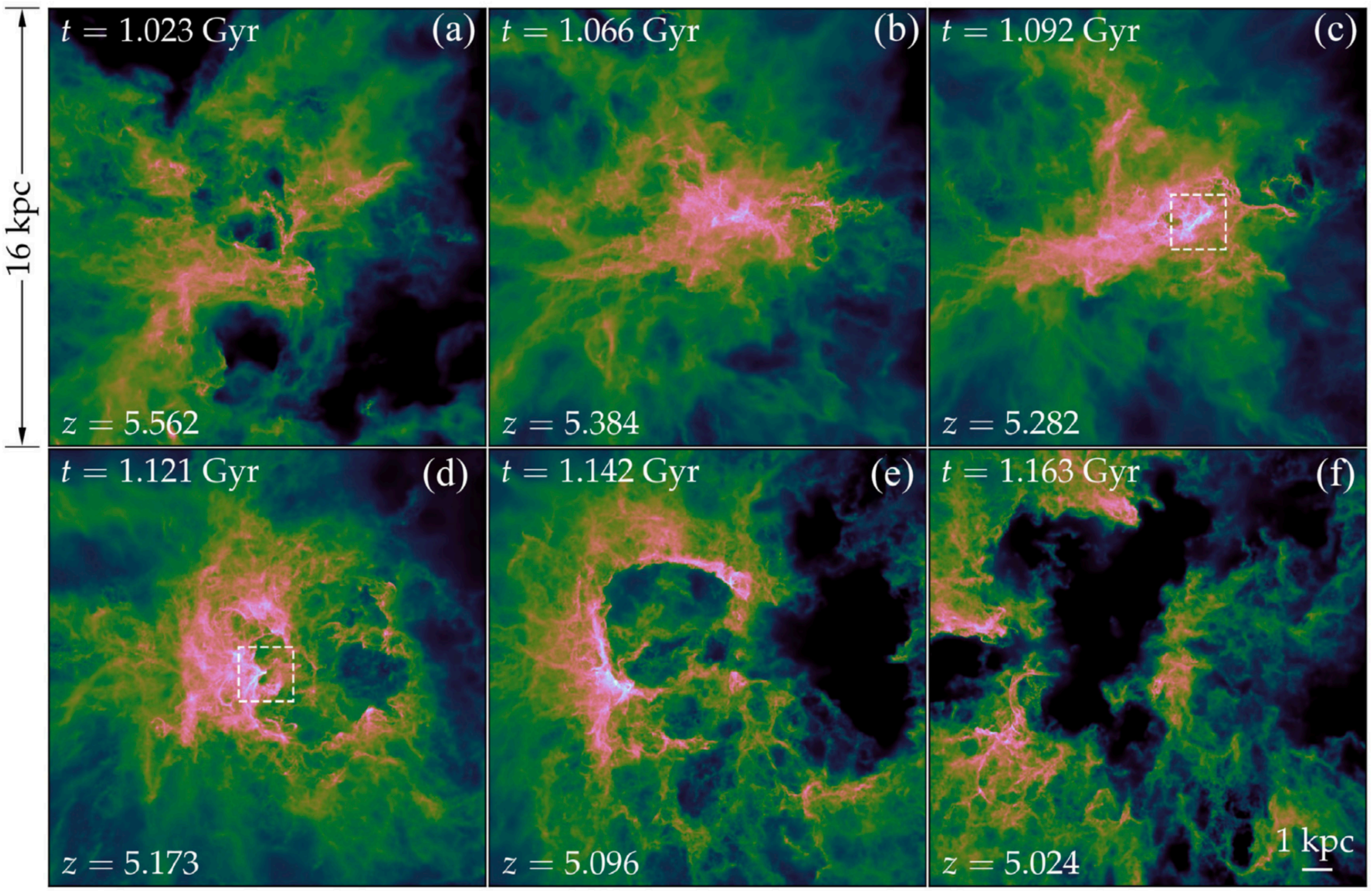




Peter Senchyna (Carnegie Fellow)

AAS 243, New Orleans — COPAG Splinter Session, January 7 2024

The first generations of massive stars reshaped the Universe:



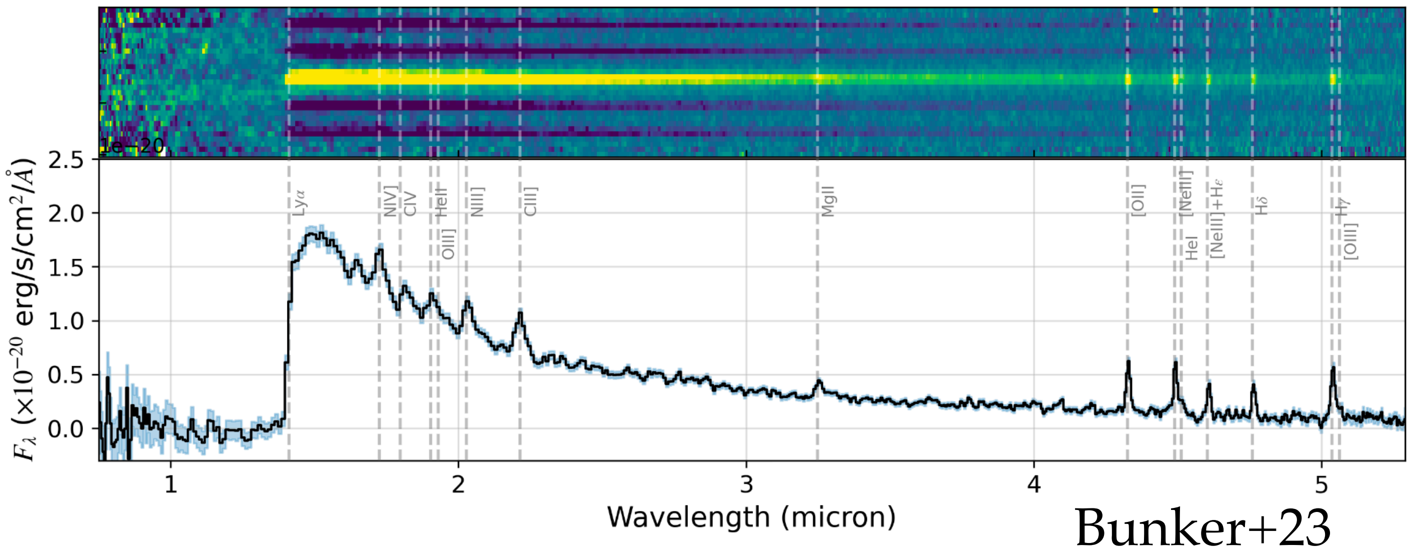
Ma+2020

- first phases of chemical enrichment
- buildup of ancient GCs, oldest MW substructure
- seeding / feeding first SMBHs
- local & global feedback; reionization

Yet we know remarkably little for sure about these near-primordial massive stars (MSs)

JWST is providing our best view yet of these first systems in-formation

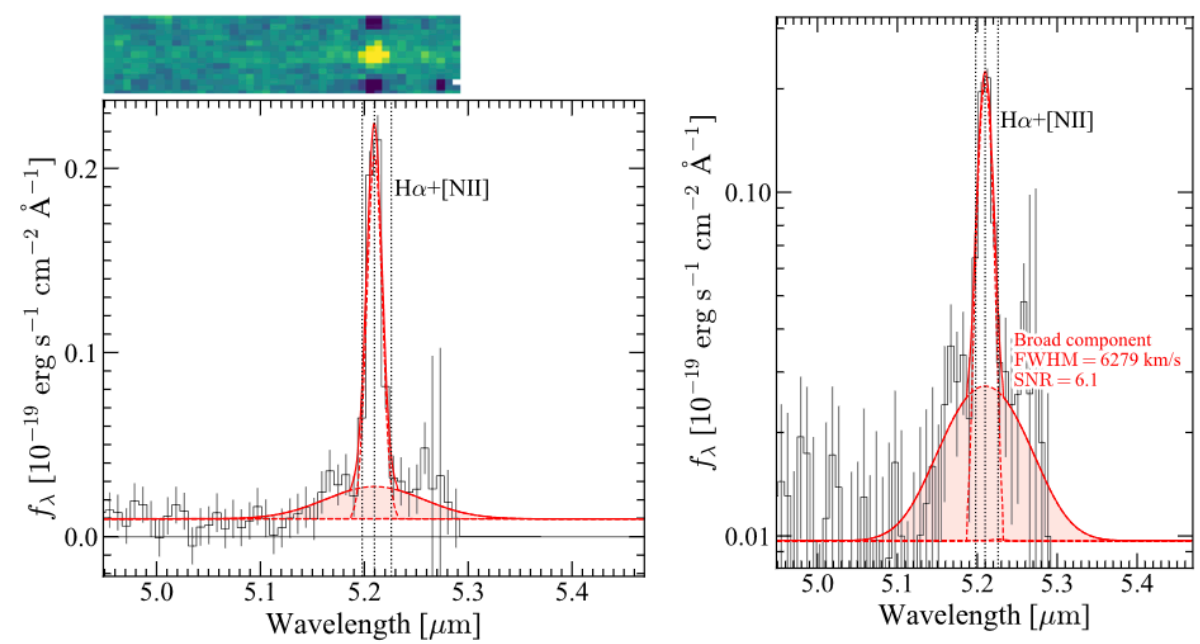
But: many surprises and significant ambiguity in results of this **nebular spectroscopy**



Bunker+23

peculiar UV lines almost never seen at lower-z (NIII]+NIV])
Bunker+23, Cameron+23, Senchyna+23, Maiolino+23, Marques-Chaves+23, Isobe+23, …

and detections of broad $\gtrsim 1000$ km/s components in optical lines Kocevski+23, Harikane+23, Oesch+23, Larson+23, Maiolino+23, …

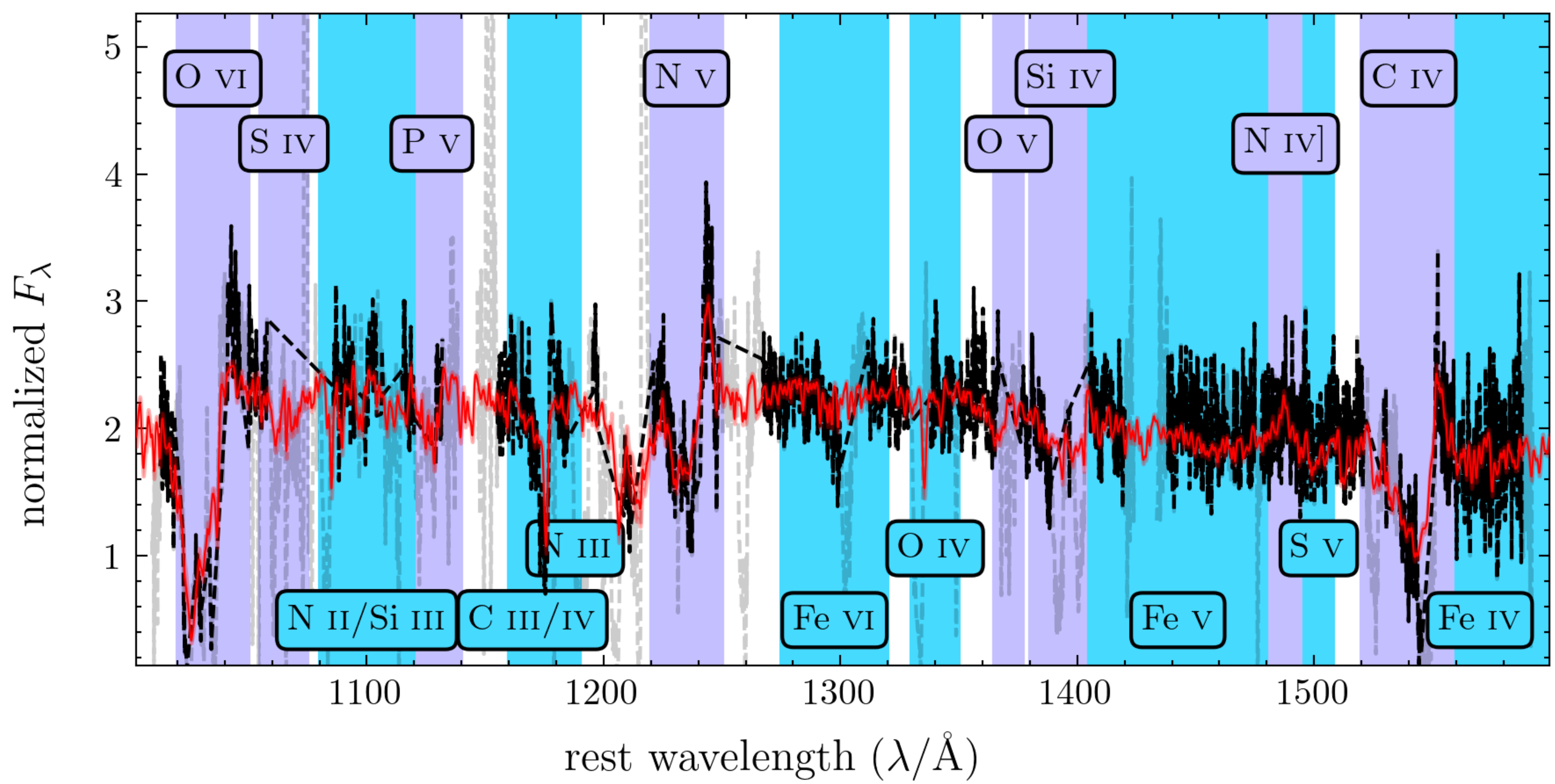


Harikane+23

Metal-poor massive stars in the EoR are intermixed with AGN, winds/outflows, signs of rapid enrichment — a messy picture!

The **rest-frame UV** is key for understanding these earliest massive stars:

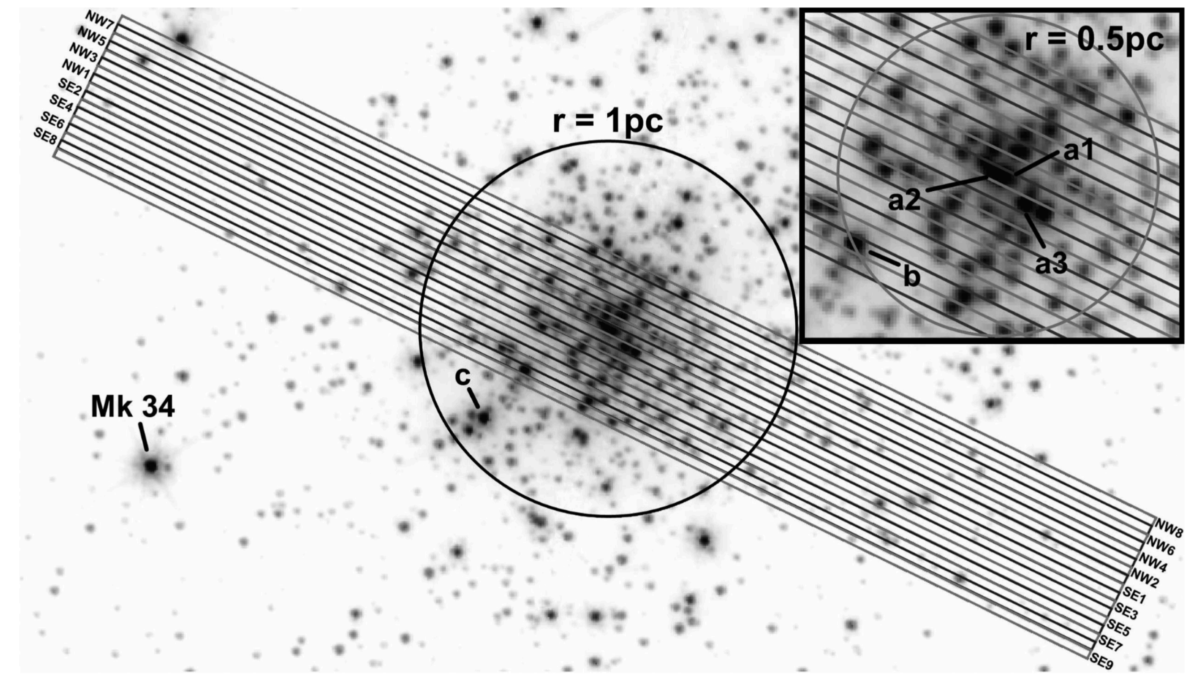
- High-ionization nebular emission - key signposts for hot metal-poor stellar pops
  - *& direct link to JWST observations*
- Access to the brightest & most feature-rich region of massive star atmospheres
  - real access to massive star physics (winds/mass loss, CNO/Fe abundances, highest-T_e diagnostics, dissecting binaries, …)



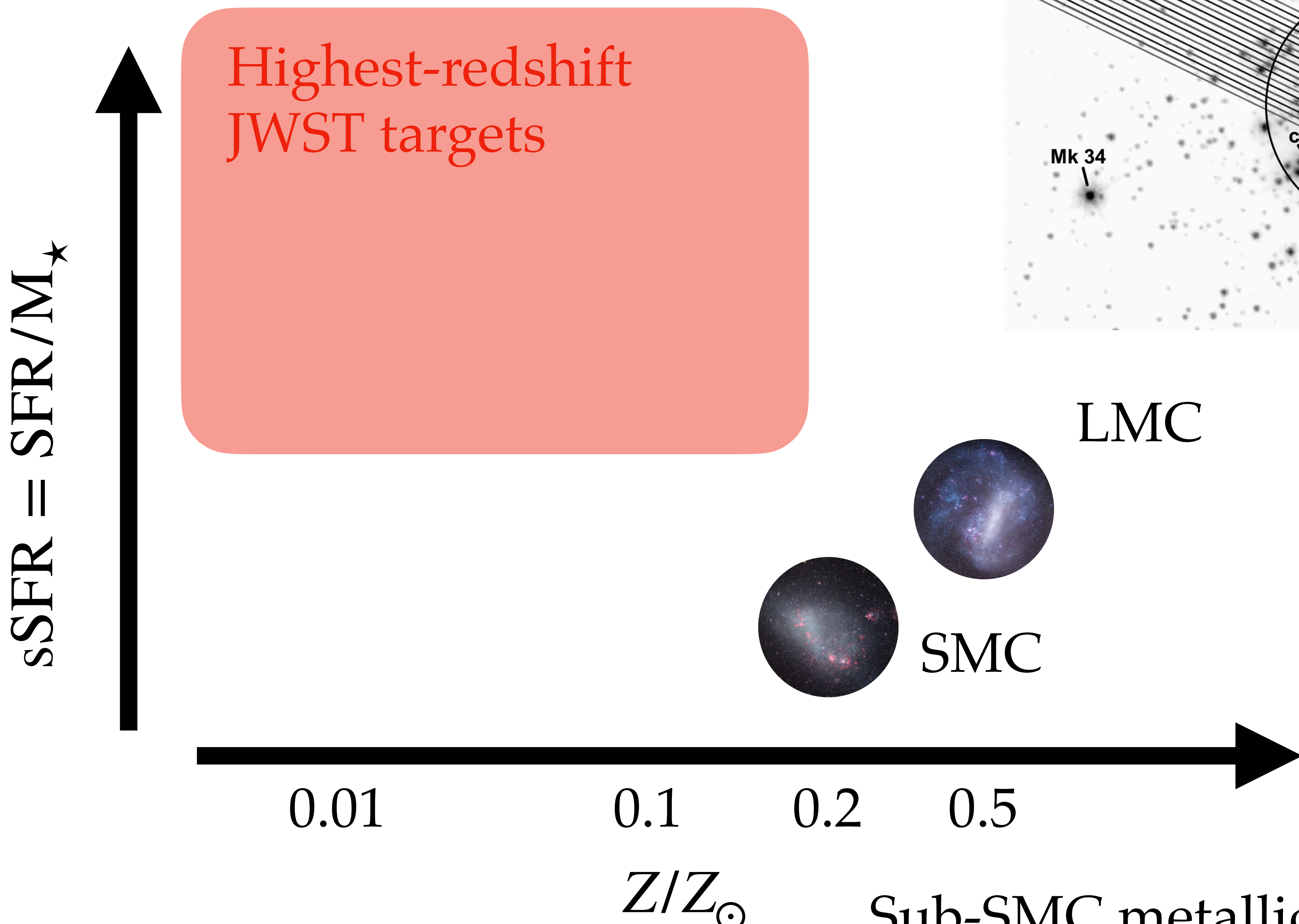
resonant/wind lines

photospheric lines

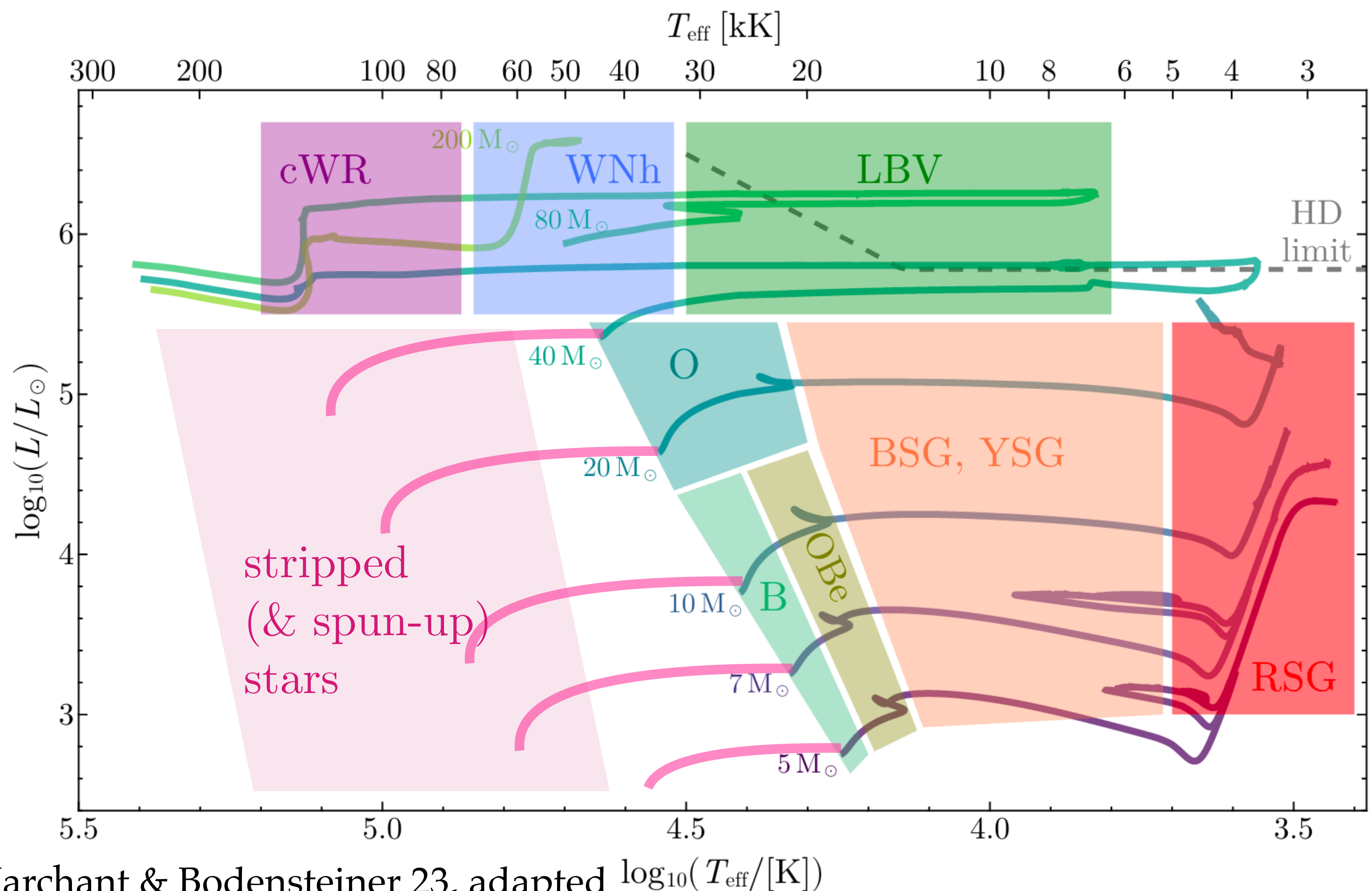
Most of what we can know confidently about massive stars comes from resolved spectroscopy — i.e., the Milky Way and now LMC / SMC



Crowther+16



Sub-SMC metallicities ($<$ 20 % Z$_\odot$):
almost entirely unconstrained



Marchant & Bodensteiner 23, adapted

Models for massive star populations at low metallicity are still essentially *theoretical*

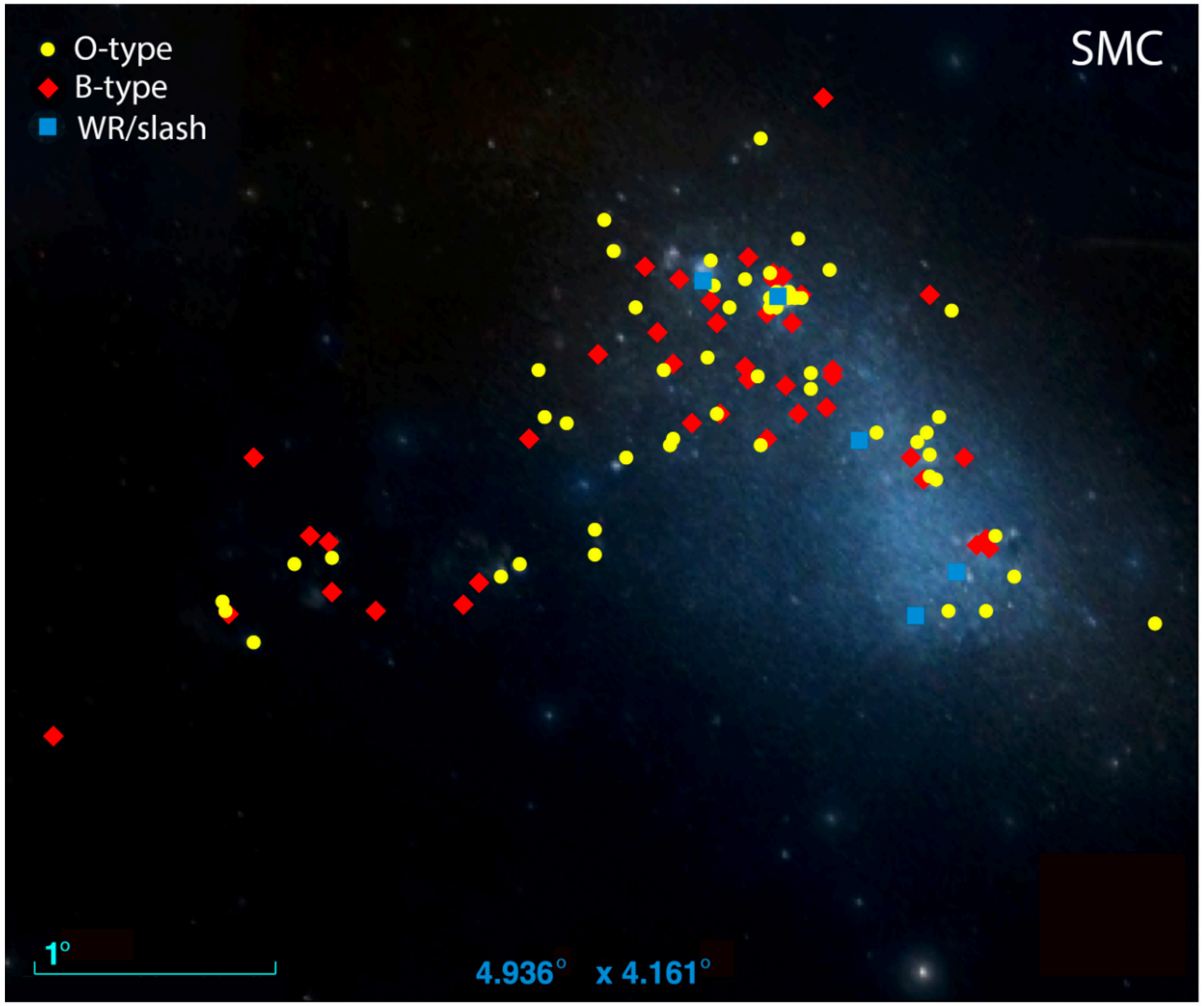
Why does this matter?

- First massive star pops are ≪ SMC metallicity in Fe (JWST confirms)
- The ionizing radiation (nebular emission), ejecta&yields, remnants depend sensitively on Z and esp. Fe (opacities / post-MS behavior, winds, IMF, binary statistics&interactions) + many other factors
- If you want to understand the first galaxies, this physics must be constrained via other observations

A multi-pronged path forwards:

In the Clouds (20 – 50 % $Z_\odot$):

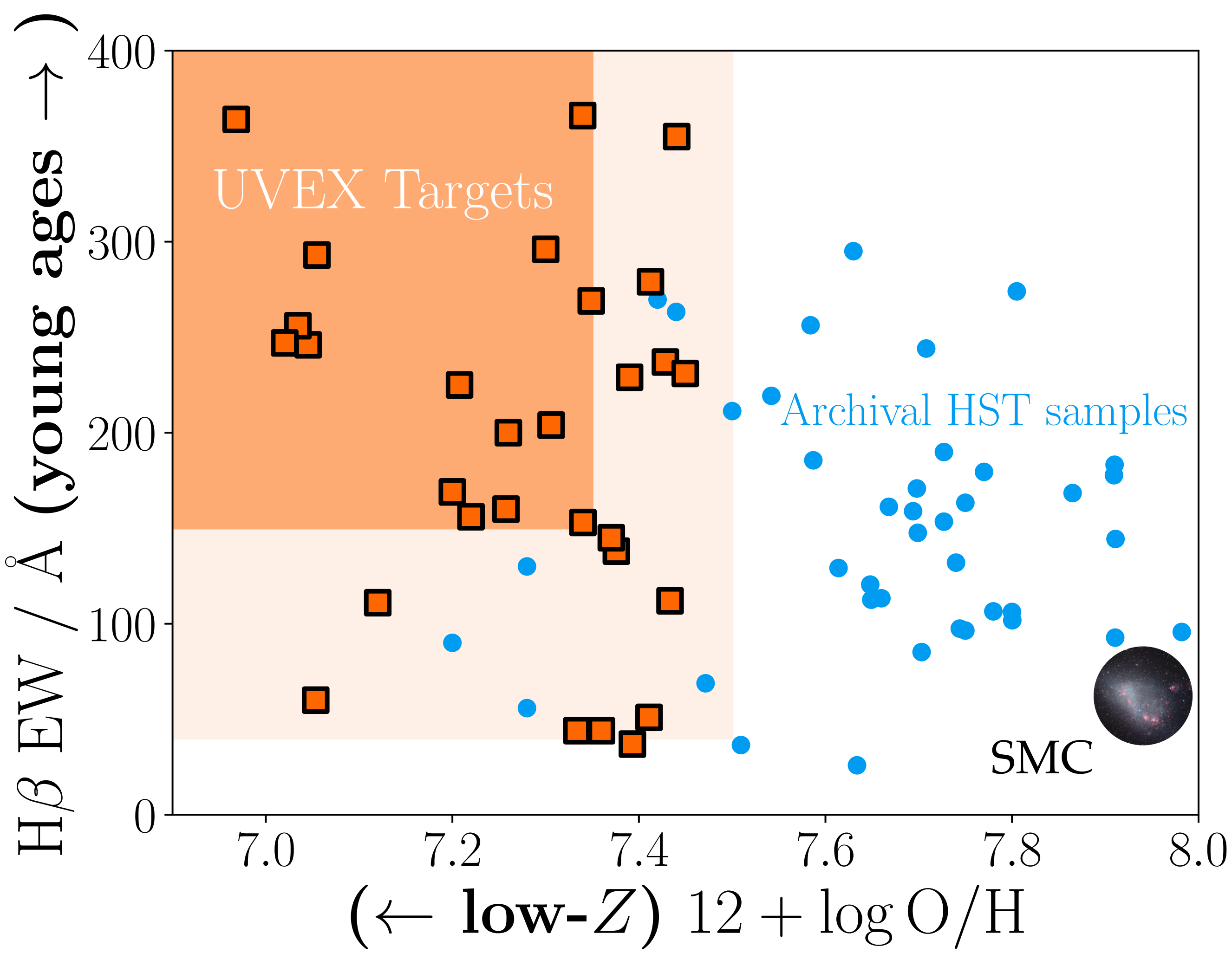
- (now) **HST / ULLYSES**: ~250 O/B/WR stars in the UV
  - detailed modeling of fundamental evolution, wind physics for 'typical' luminous MSs
- (now/soon) + **SDSS-V/Local Volume Mapper** IFU coverage:
  - nebular emission & ionizing radiation, feedback, …
- (2025+) + **Rubin**:
  - time-resolved obs: variability, binarity/interaction
- (2028+) + **UVEX**
  - UV phot+spectra: spectroscopy across the HR diagram of all ionizing MSs (including crucial **faint but *hot* stripped stars** just now being identified: Götberg/Drout+23)

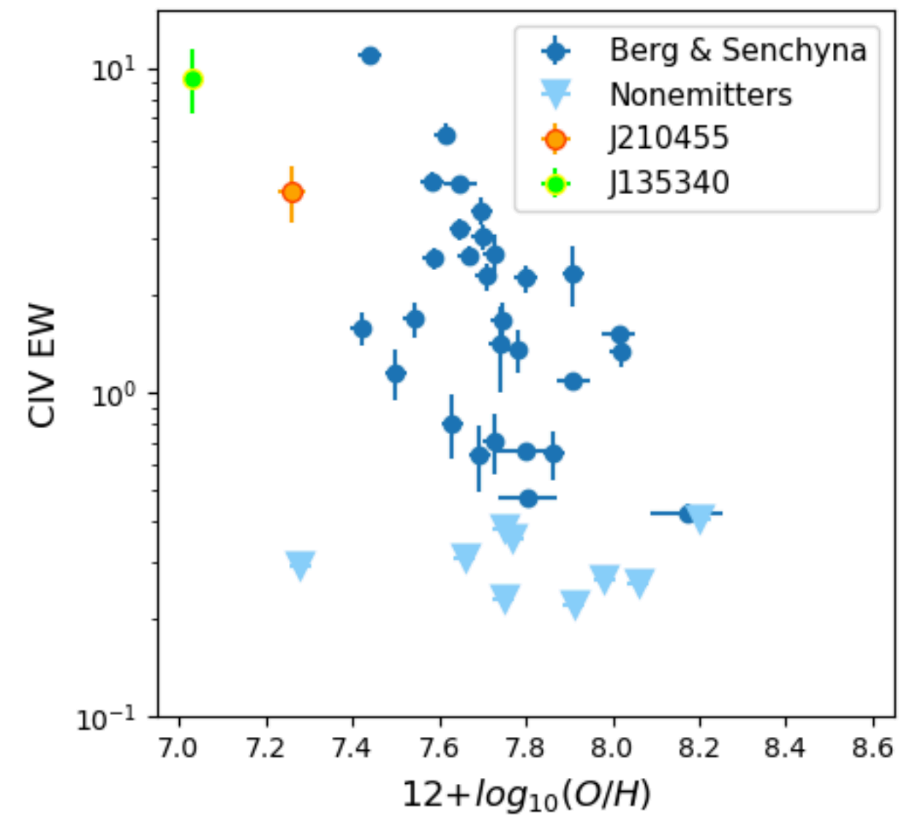


Vink+23

In unresolved dwarfs further-afield ($\sim 1\,(?) - 20\,\%\ Z_\odot$):

- (now) **HST**: pushing COS to the limits
  - e.g. deep UV continuum spectroscopy of $< 10\,\%\ Z_\odot$ bursts
- (2028+): **Rubin+UVEX**: discovery & UV nebular spectroscopy of nearby galaxies closest to early-Universe bursts in age & metallicity
  - timely reference points for high-*z* observations; and target-finding for deep HabWorlds investigations (challenging without a UVEX all-sky survey)



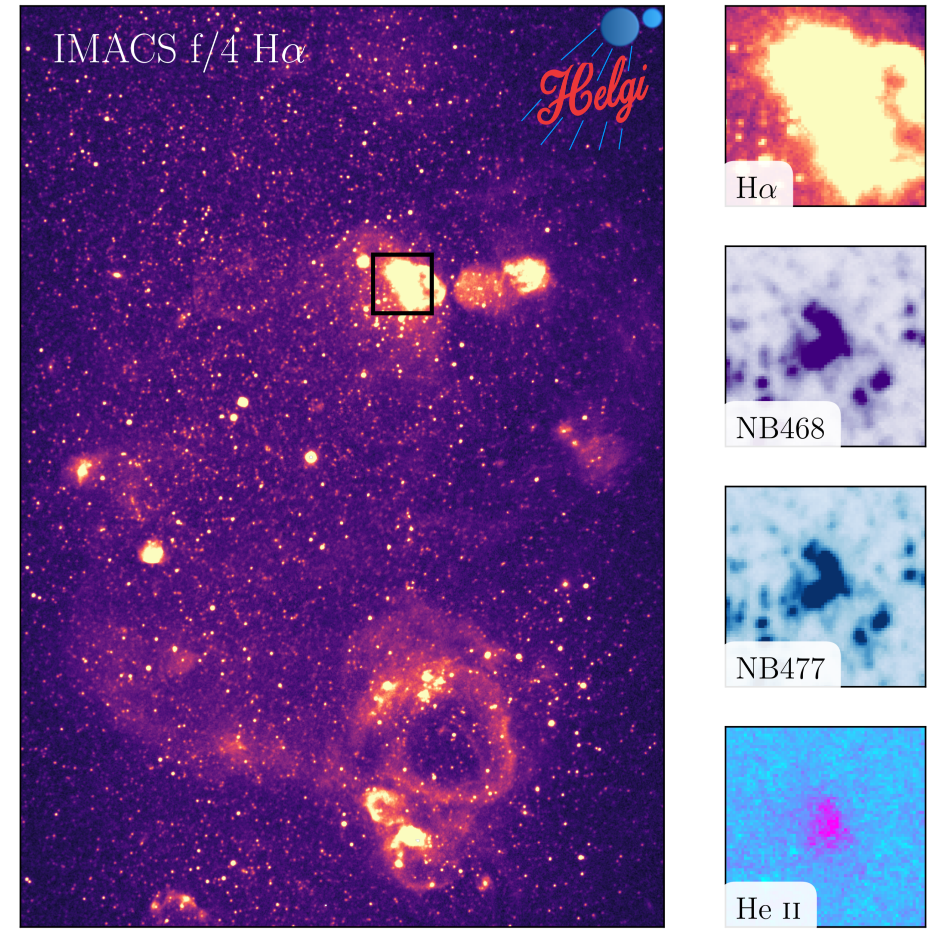


Preview of this discovery space: high-ionization line emitters appear common

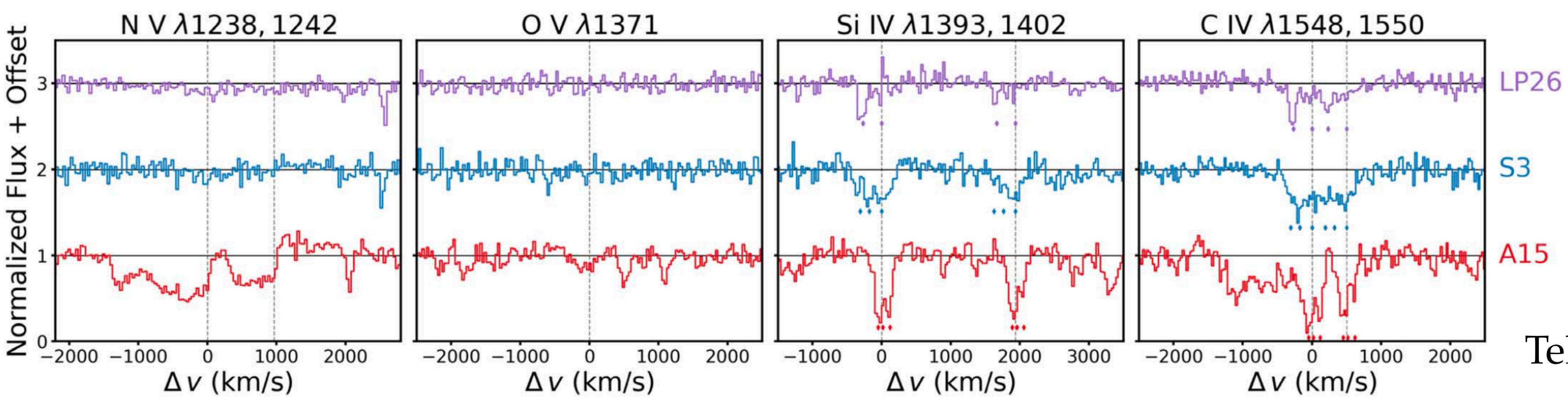
L. Henson, PS + in-prep

- (now) **HST**: UV spectroscopy of 'normal' individual stars below SMC Z
  - brightest main sequence and evolved OB stars; e.g. Garcia+14,21 Telford+21,23, Gull, .. PS+22
  - *key guidance for HabWorlds*: what do we need (in resolution, and wavelength coverage) to confidently measure e.g. $\dot{M}$ for extremely metal-poor MSs? Role for JWST?
- (now+) other facilities: finding & characterizing the hottest ionizing sources in these galaxies
  - path towards finding exemplars we can study now; e.g. UV-luminous products of metal-poor binary evolution
- (2027+) **Roman**: deeper and wider-field photometric characterization of low-Z pops

In Local Group dIrrs ($\sim 5\,(?) - 30\,\%\ Z_\odot$):



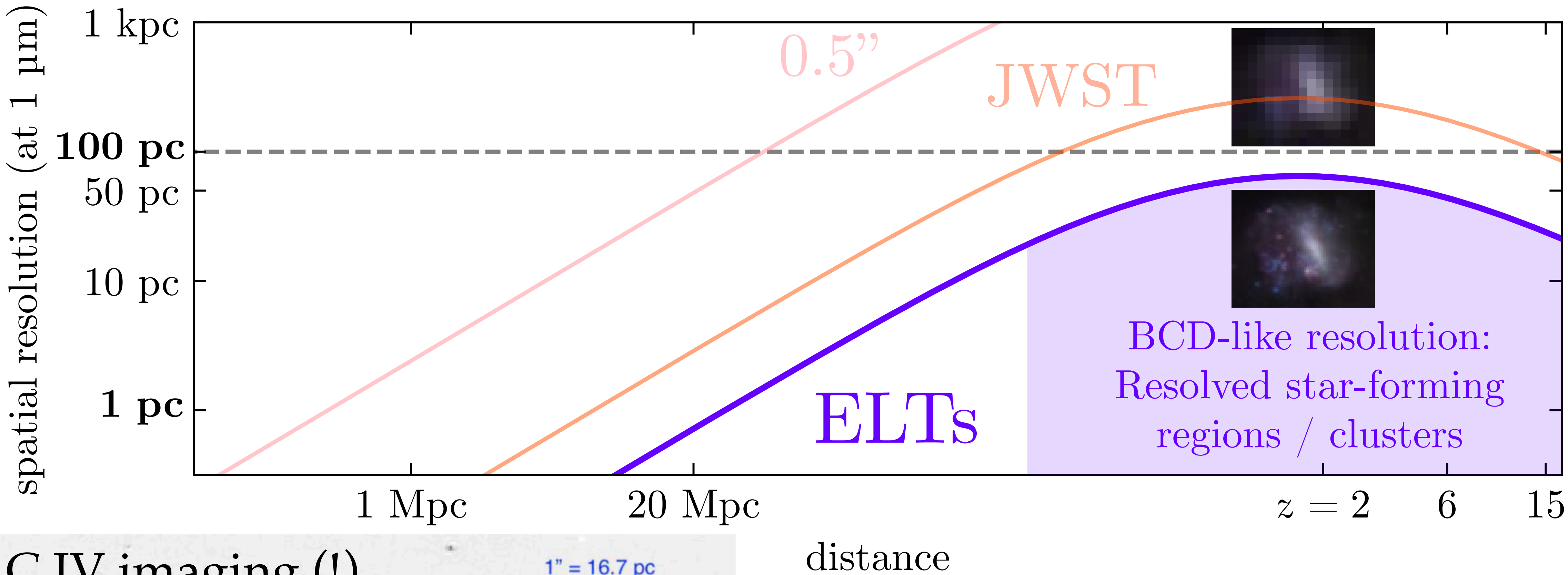
HelgI: deep narrowband He II search (Senchyna, Götberg+ in prep)

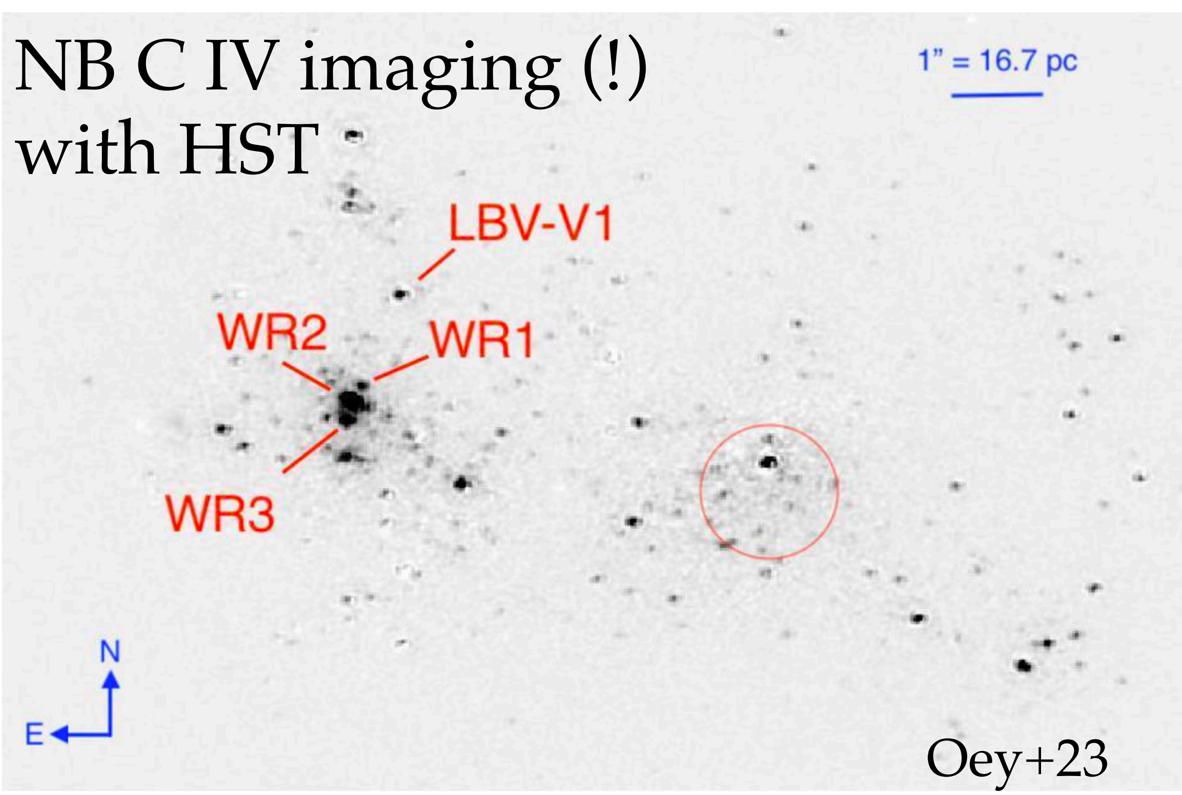


Telford+21

Bridging to HabWorlds with the ELTs

The **NIR IFUs** on the ELTs (e.g. ELT/HARMONI, ~2028..) are **rest-UV IFUs** at $z \gtrsim 6$





An interesting situation: may have more spatial info in the UV for highest-z galaxies than those nearby

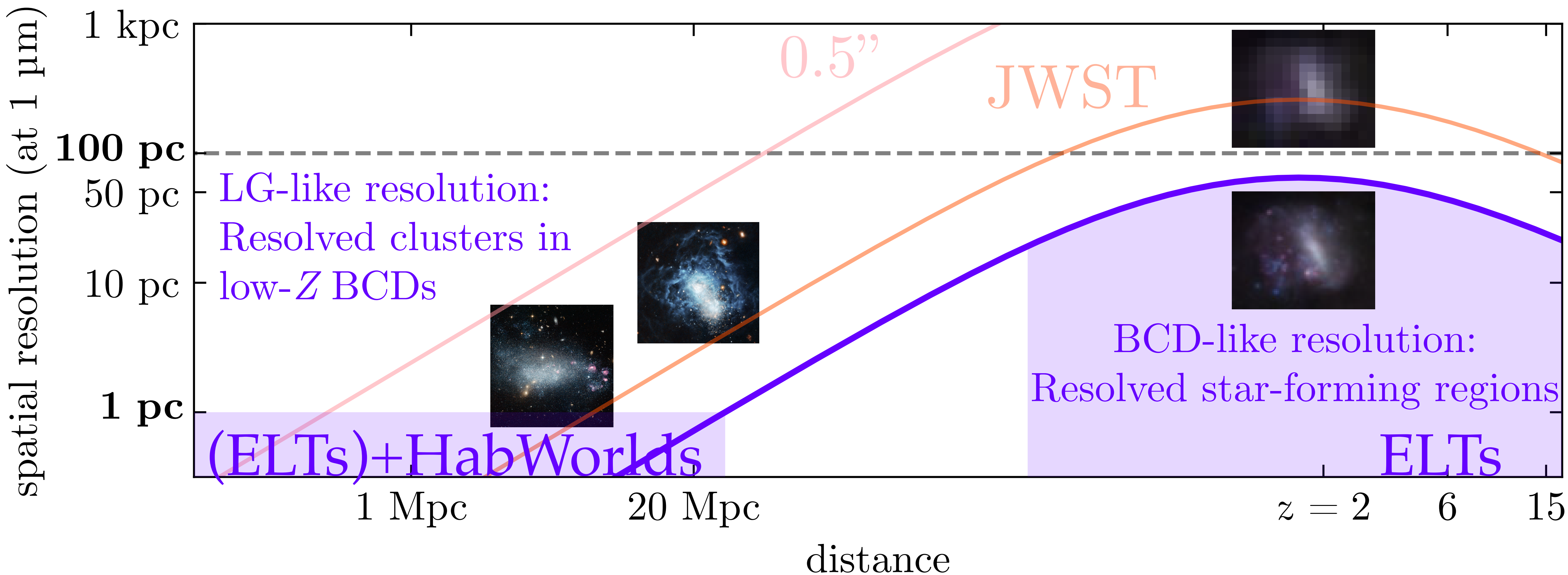
Resolved stellar pops in IZw18 (+friends)

Best possible view onto near-primordial MSs;
10x lower-Z *and* higher-intensity SF than SMC

What does this require?

- **Full** UV (100-200nm+) at R>5000 - useful stellar+neb features throughout
  - + optical: still need both!
- Ideally: an IFU
  - dense clusters and extended&complex nebular morphology

Bridging to HabWorlds with the ELTs



ELTs -> HabWorlds: pushing the resolved frontier for massive stars out to $\sim$ 20 Mpc

- Fundamental stellar properties & resolved ionizing feedback in ~few-percent solar young stellar pops
  - *(key qustion:)* what can we do to prep best for HabWorlds with (optical/)NIR spectroscopy&imaging in these galaxies?

Summary

- Understanding lowest-metallicity massive stars: a conversation between $z > 6$ galaxies and dissection of galaxies in our backyard
- UVEX would be a key driver for MS science in the HST -> HabWorlds gap
  - Key synergies with Rubin, Roman in SMC/LMC and unresolved dwarf galaxies, in-conversation with JWST
- ELTs as a bridge to HabWorlds
  - UV IFU at $z > 6$; can we get one at home?