Lecture 3.
Extra-galactic archaeology

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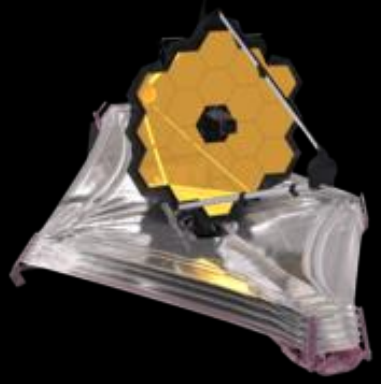
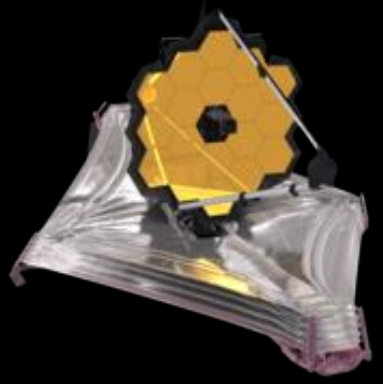
25 Dec 2021 launch



Where’s the the most distant galaxy?

25 Dec 2021 launch



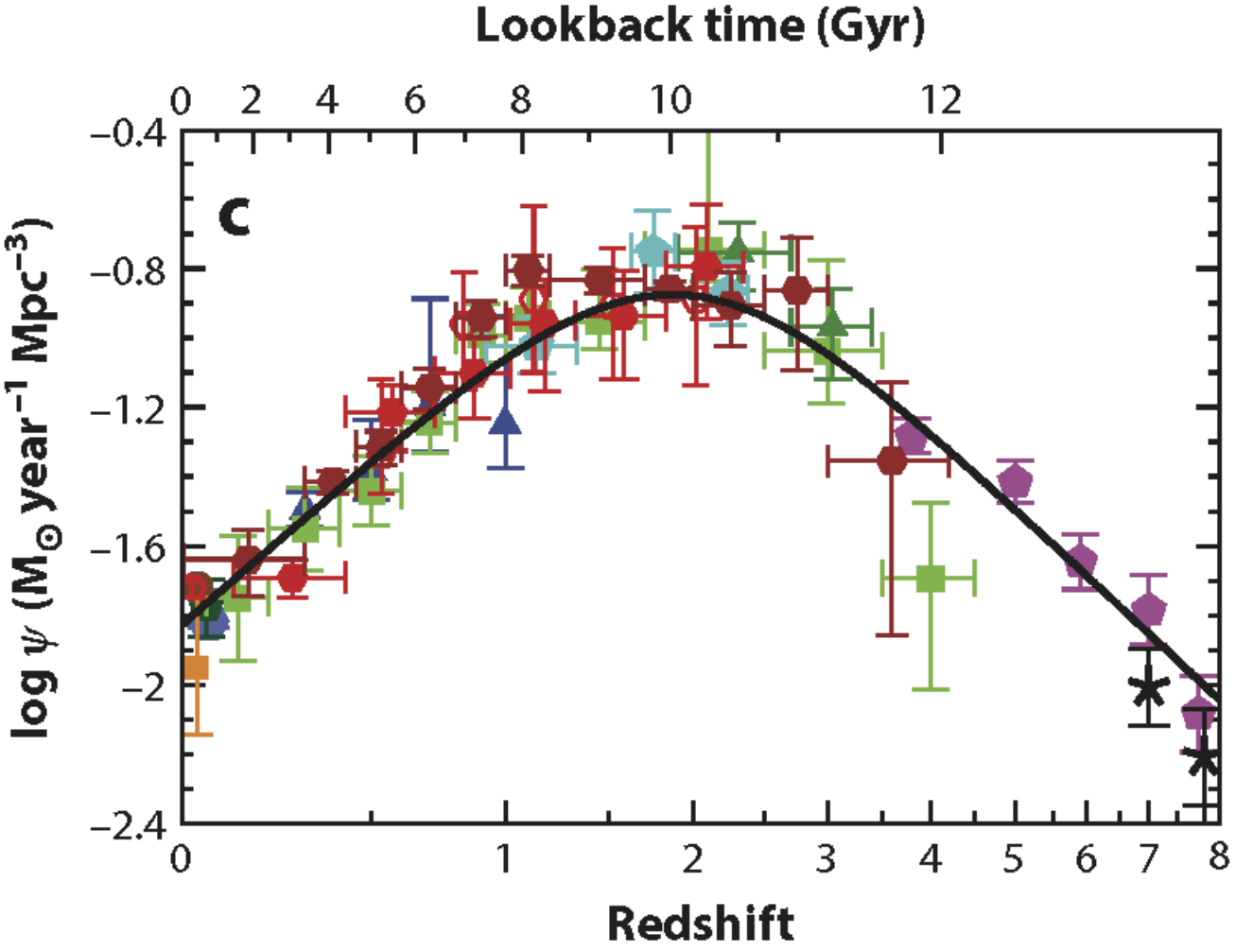
300 Myrs after the Big Bang

JADES-GS-z14-0

Carniani+24

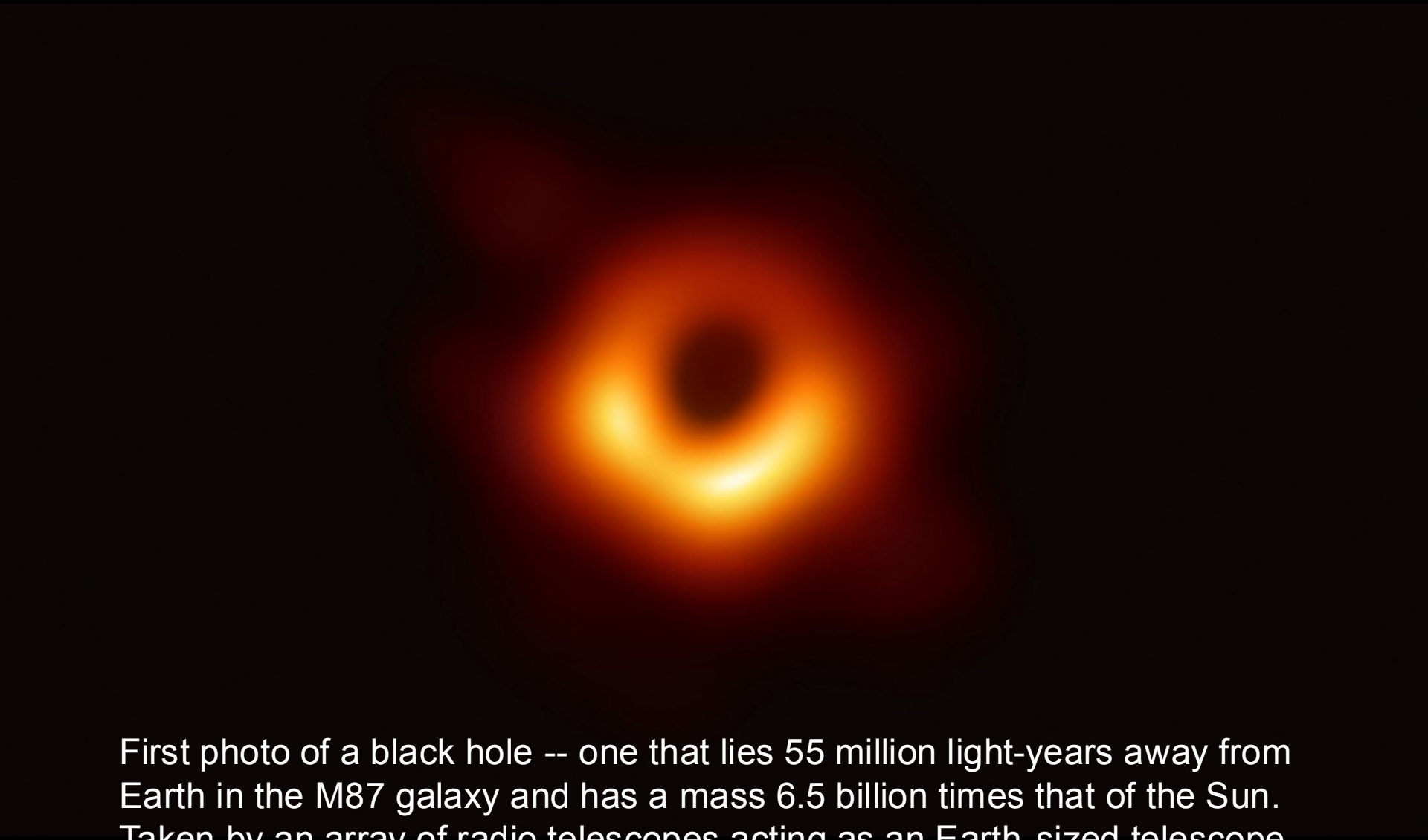
Cosmic Star Formation Rate

Present Cosmic Noon Cosmic Dawn



Madau+ 1996, Lilly et al. 1996, figure from Madau & Dickinson 2014

10 April 2019, Event Horizon Telescope (EHT)

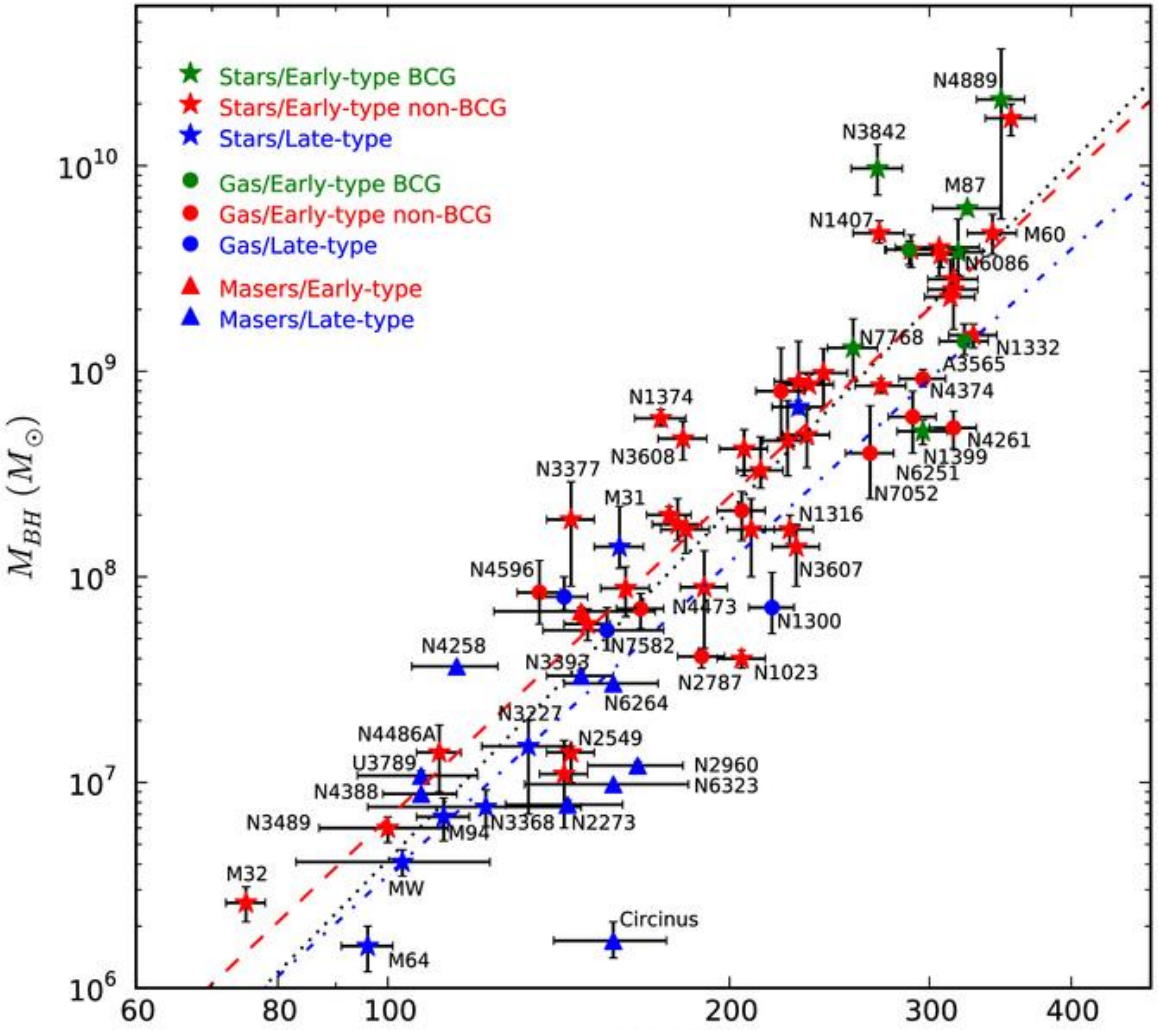


First photo of a black hole -- one that lies 55 million light-years away from Earth in the M87 galaxy and has a mass 6.5 billion times that of the Sun. Taken by an array of radio telescopes acting as an Earth-sized telescope.

https://eventhorizontelescope.org

BH-mass – bulge mass (M–σ) relation

at z=0

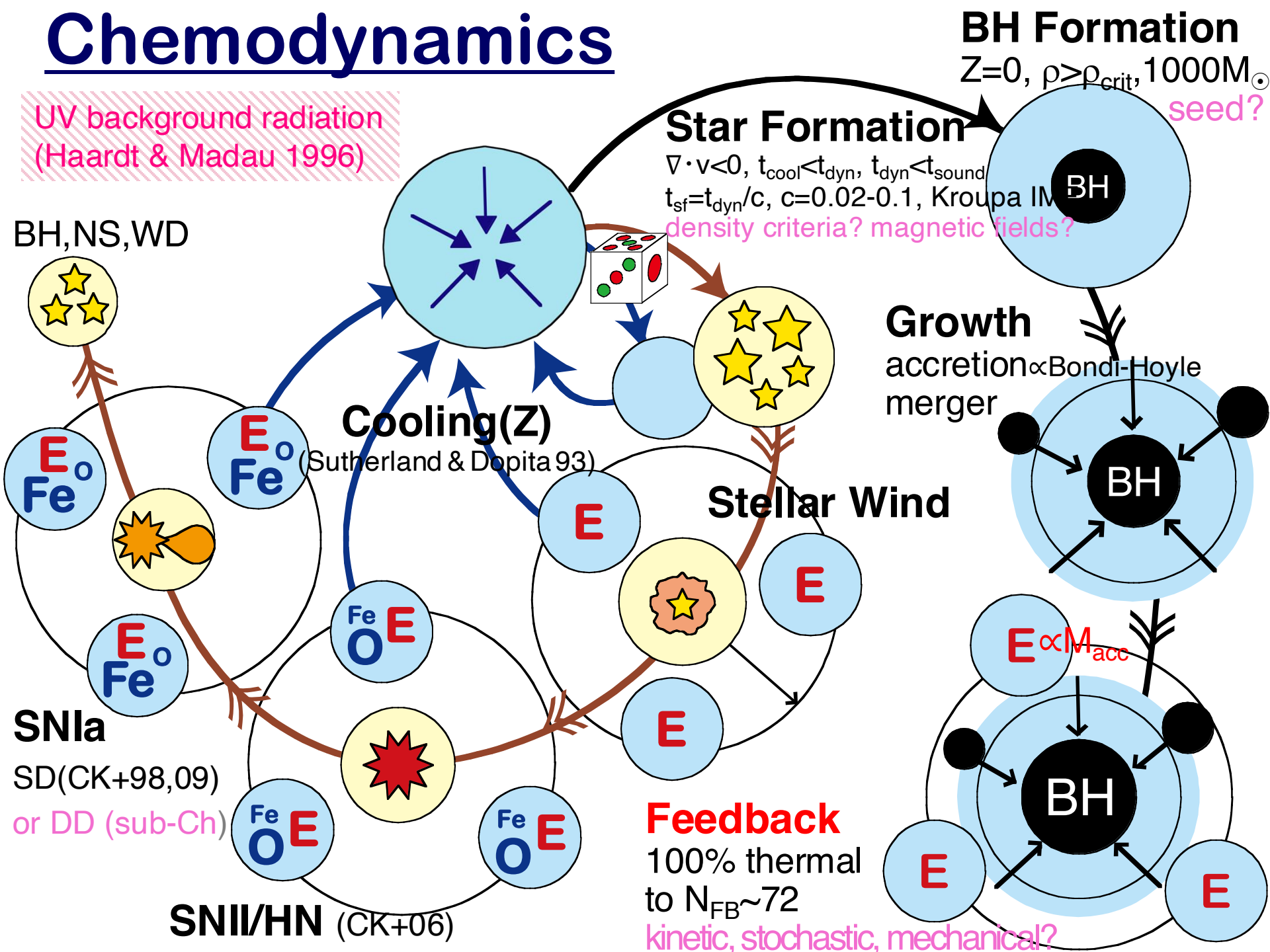


velosity disepersion of stars σ (km/s) ~ galaxy mass

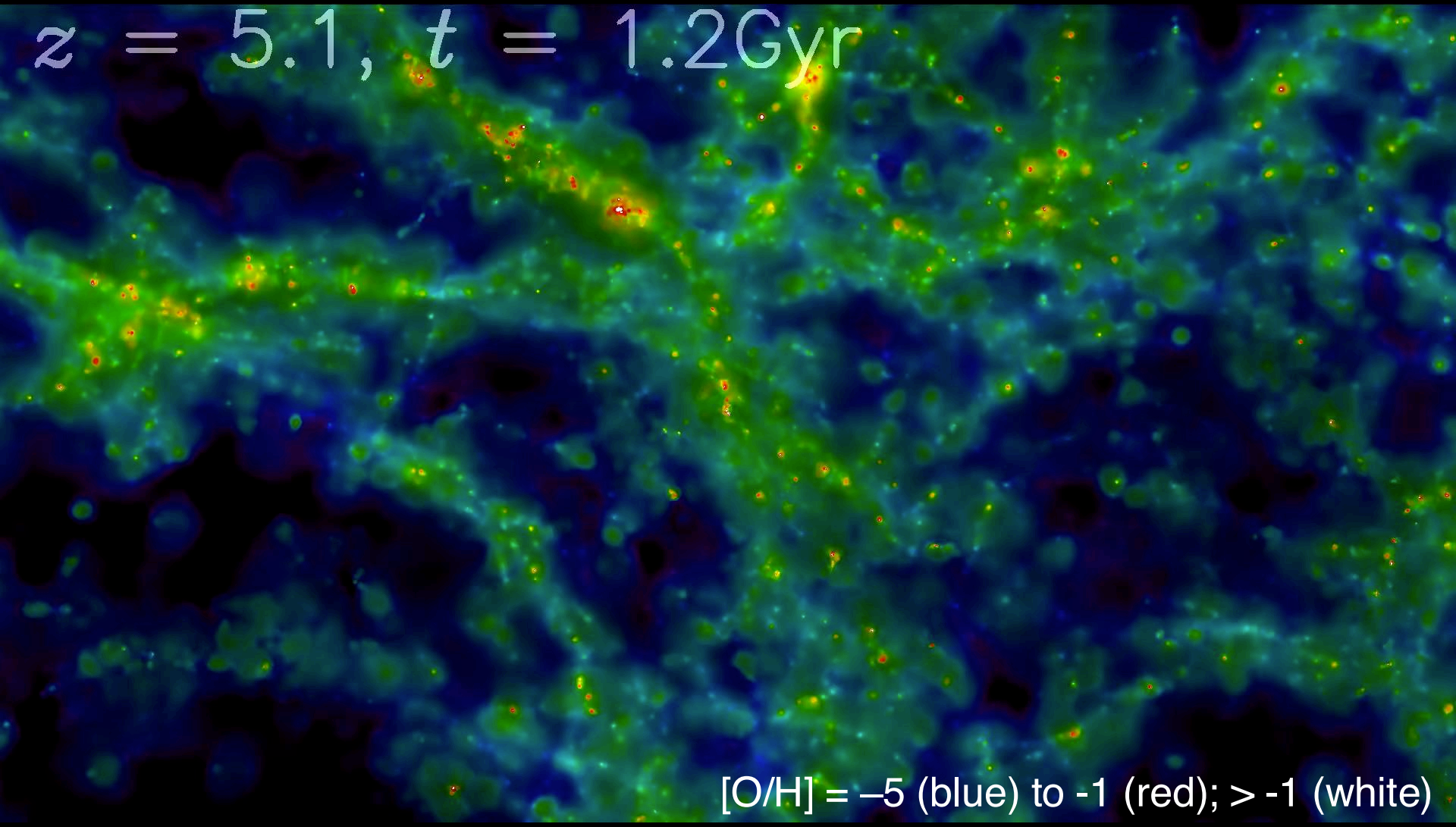
Supermassive black holes (SMBHs) are observed as **Active Galactic Nuclei** (AGN) up to z~12.

Magorrian+ 1998; Kormendy & Ho 2013; figure from AAS

Chemodynamics



Cosmological box simulation

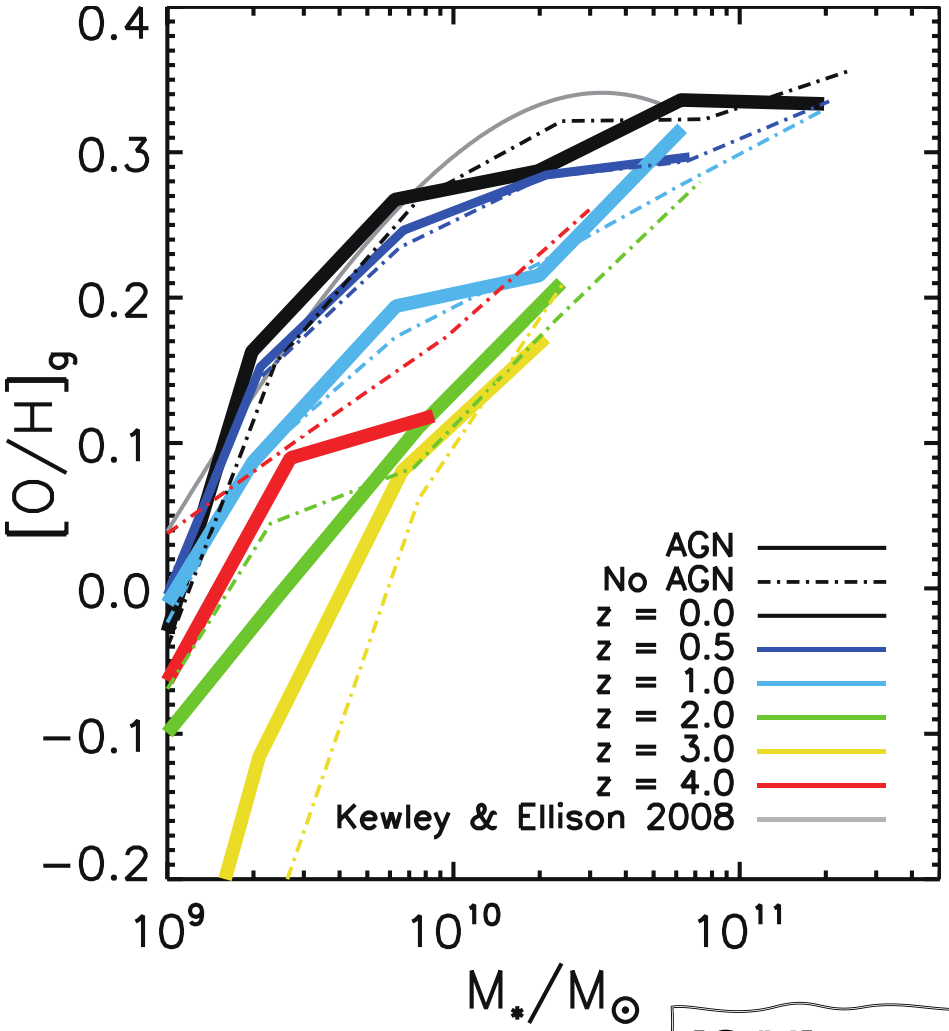


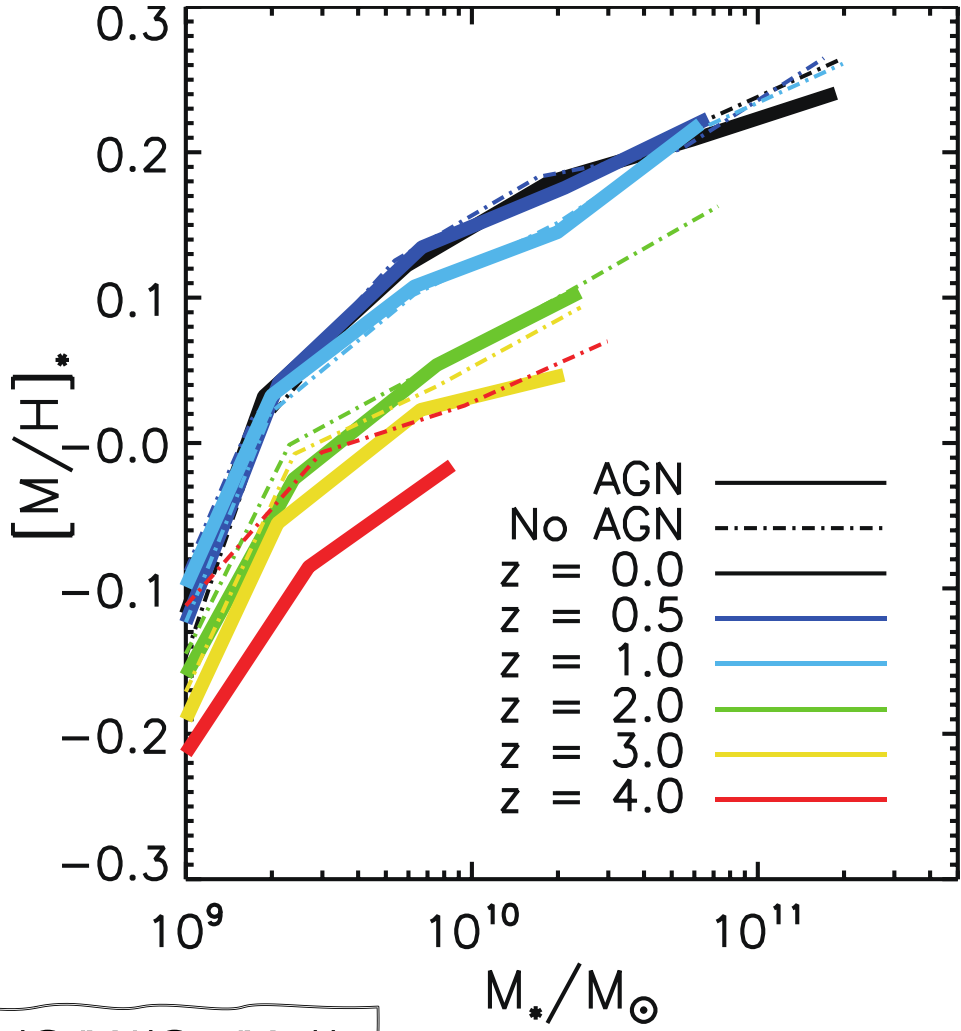
25Mpc, 1.4x$10^7 M_\odot$, 1.6kpc resolution, SMBHs grow along M-σ from “light” seeds
Philip Taylor (ANU), https://www.youtube.com/watch?v=jk5bLrVI8Tw

Mass-metallicity relations

Taylor & CK 2016a

- Gas: Steeper slope is at higher-z.
- Stars: Normalization shifts.



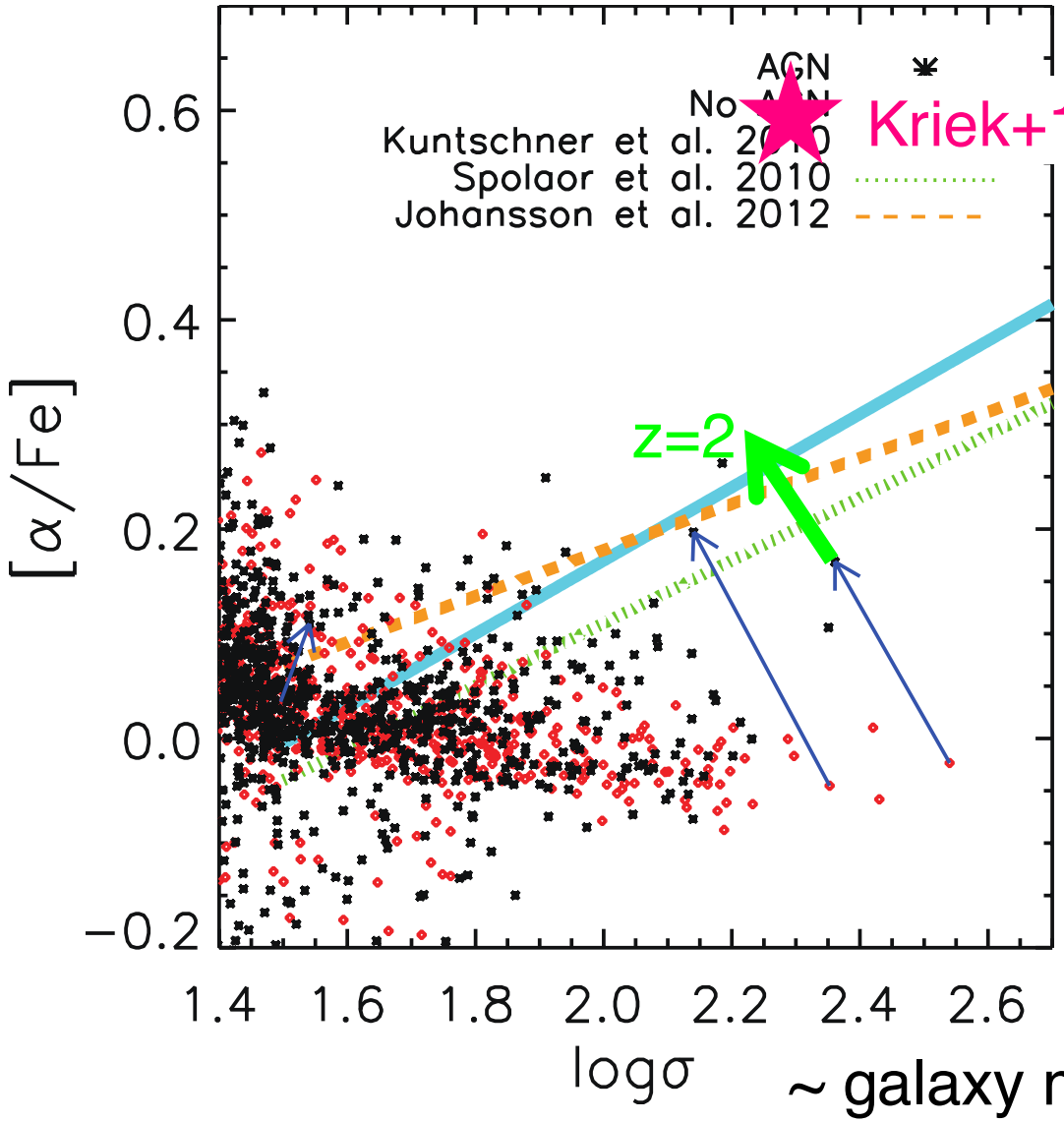


$[O/H]=\log_{10}(O/H/(O_\odot/H_\odot))$

[α/Fe]* ratios of ETGs

Philip Taylor & CK 2015, MNRAS, 448, 1835

Cosmological simulations w/wo AGN feedback

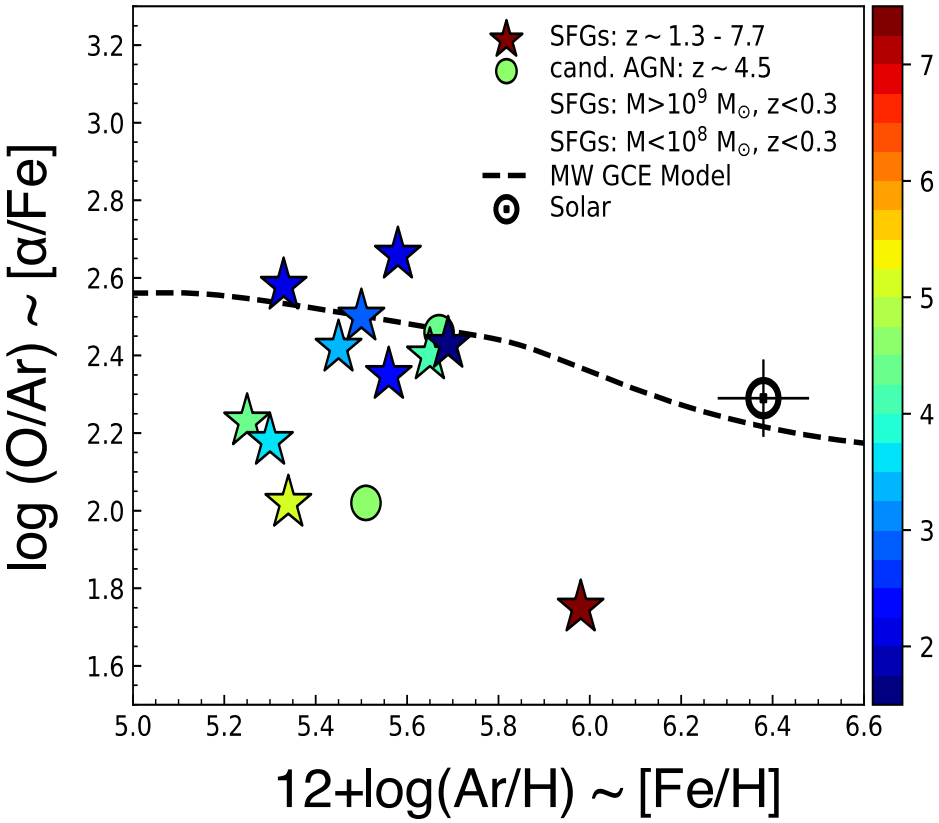


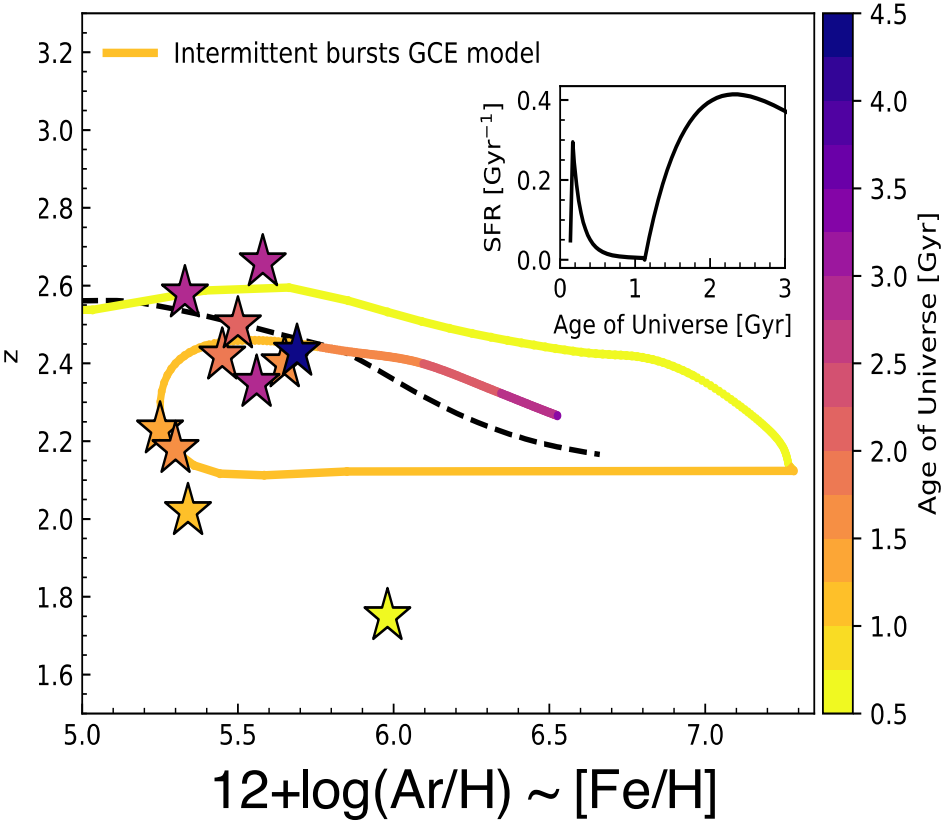
longer SF
more SNe Ia

The O/Argon-Ar/H relation

Analogous to [α/Fe]-[Fe/H] of stars in Galactic archaeology
as 34% Ar comes from SNe Ia (*CK+23, ApJL, 956, 14)*

Adapted from *Souradeep Bhattacharya+24, arXiv: 2408.1339*

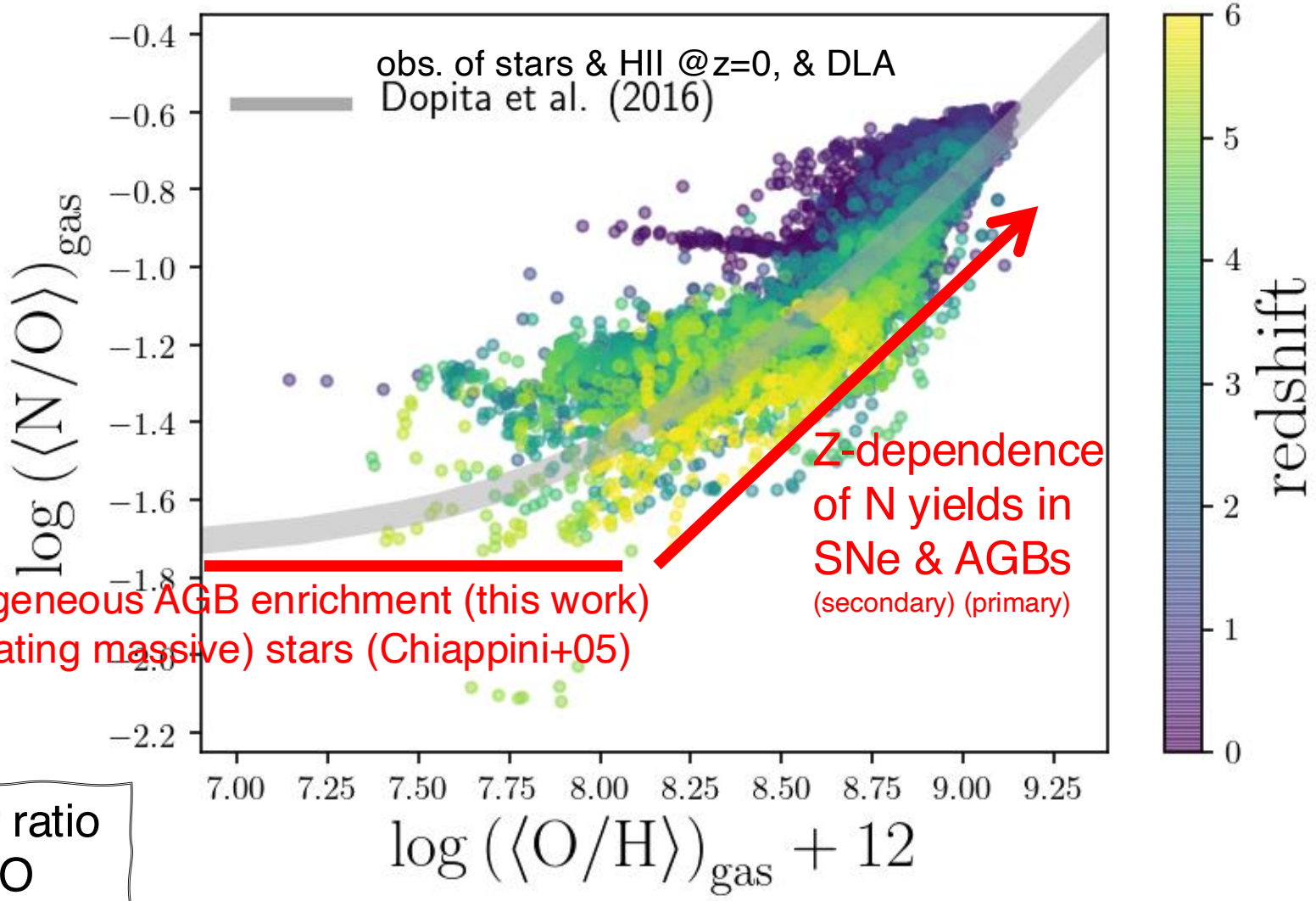




- z<3.5 galaxies are self-regulated, consistent with the MW model
- higher-z galaxies tend to have lower O/Ar due to inflow & outflow?

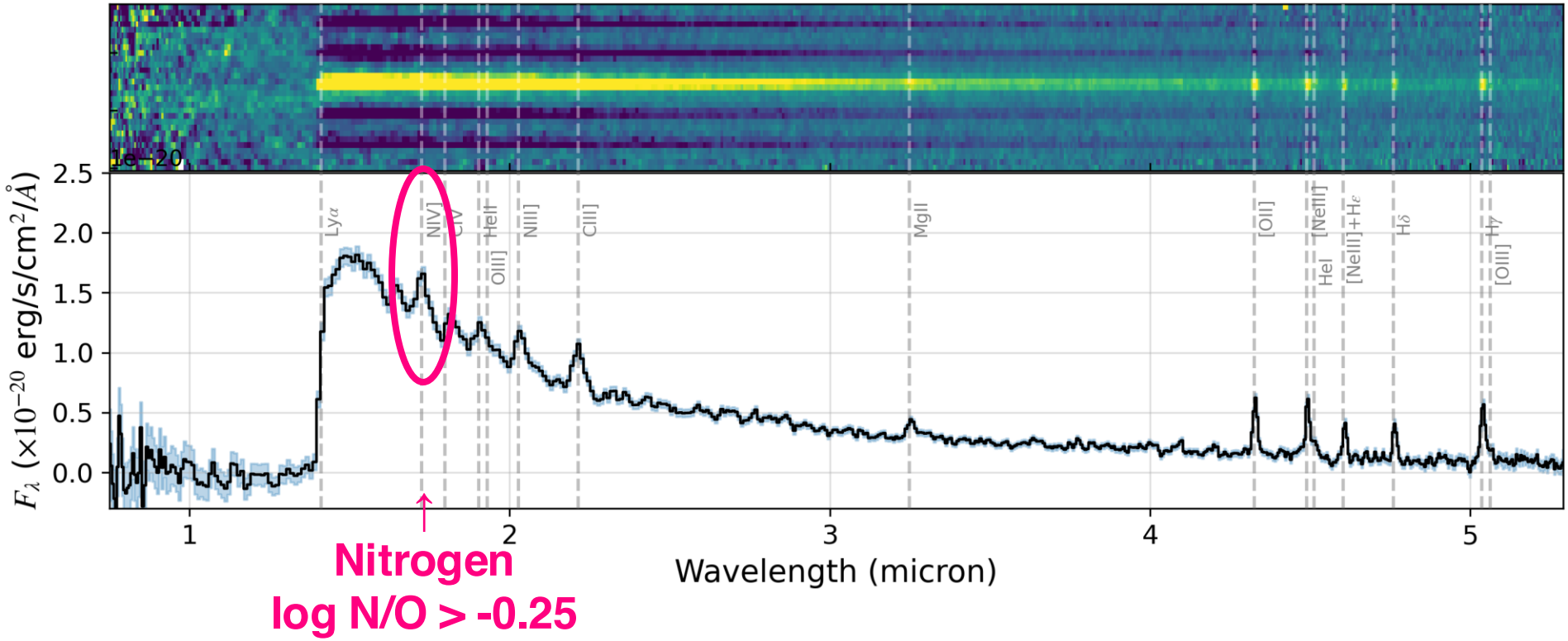
The N/O-O/H relation

Vincenzo & CK 2018b, MNRAS, 478, 155
33 star-forming galaxies in cosmological simulation



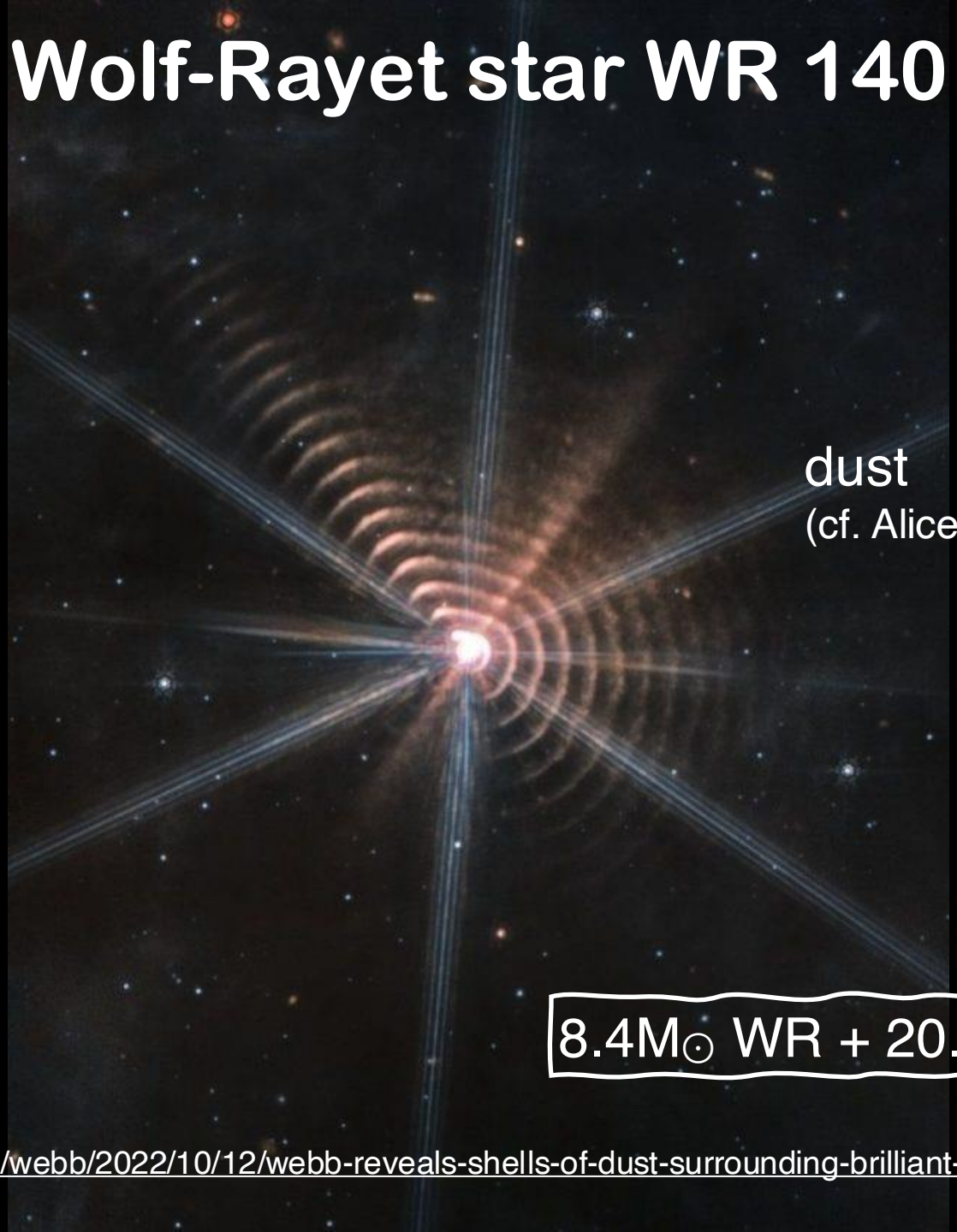
GN-z11 @ z=10.6, 430 Myr after Big Bang

Bunker+2023, NIRSpec PRISM/CLEAR (R~100)



- M_*~$10^9 M_\odot$, SFR~10/yr, age~20Myr, R_e~200pc, n~0.9
- Similar N-rich (Isobe+23; Marques-Chaves+24; Castellano+24, z=12.3), high C (D'Eugenio+23, z=12.5), or low C (Curti+24, z=9.4) galaxies

Wolf-Rayet star WR 140



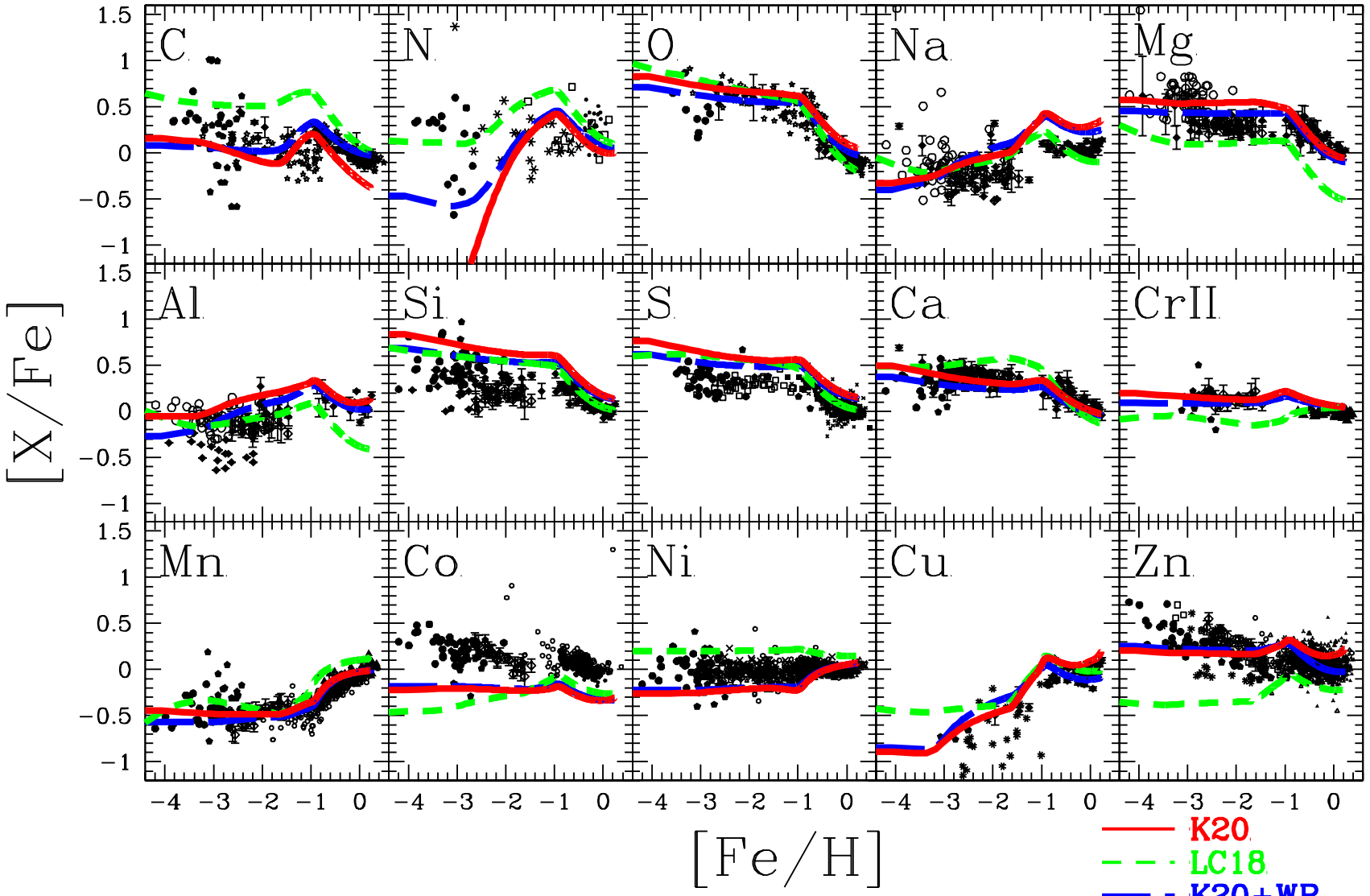
dust
(cf. Alice Ferreira poster)

8.4$M_\odot$ WR + 20.5$M_\odot$ Ostar

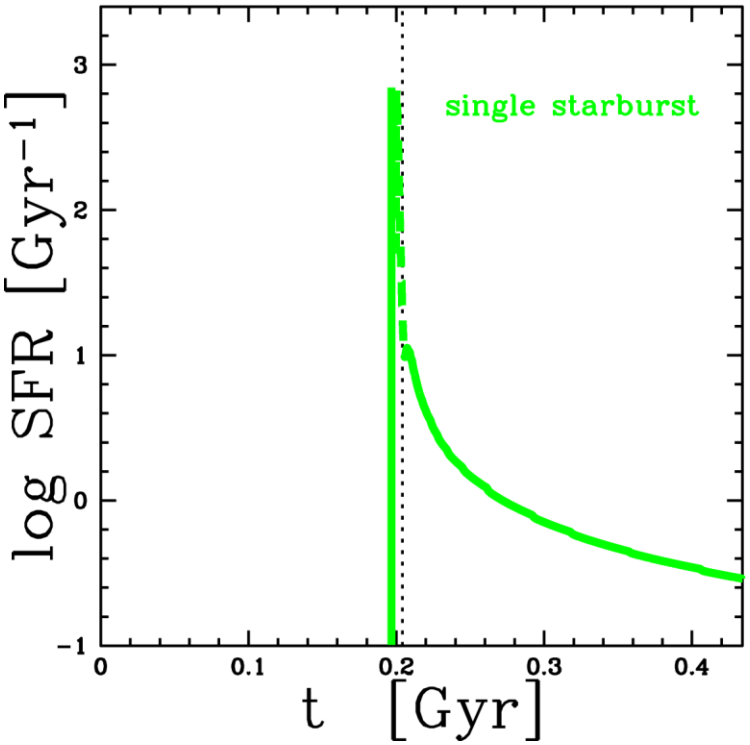
https://blogs.nasa.gov/webb/2022/10/12/webb-reveals-shells-of-dust-surrounding-brilliant-binary-star-system/

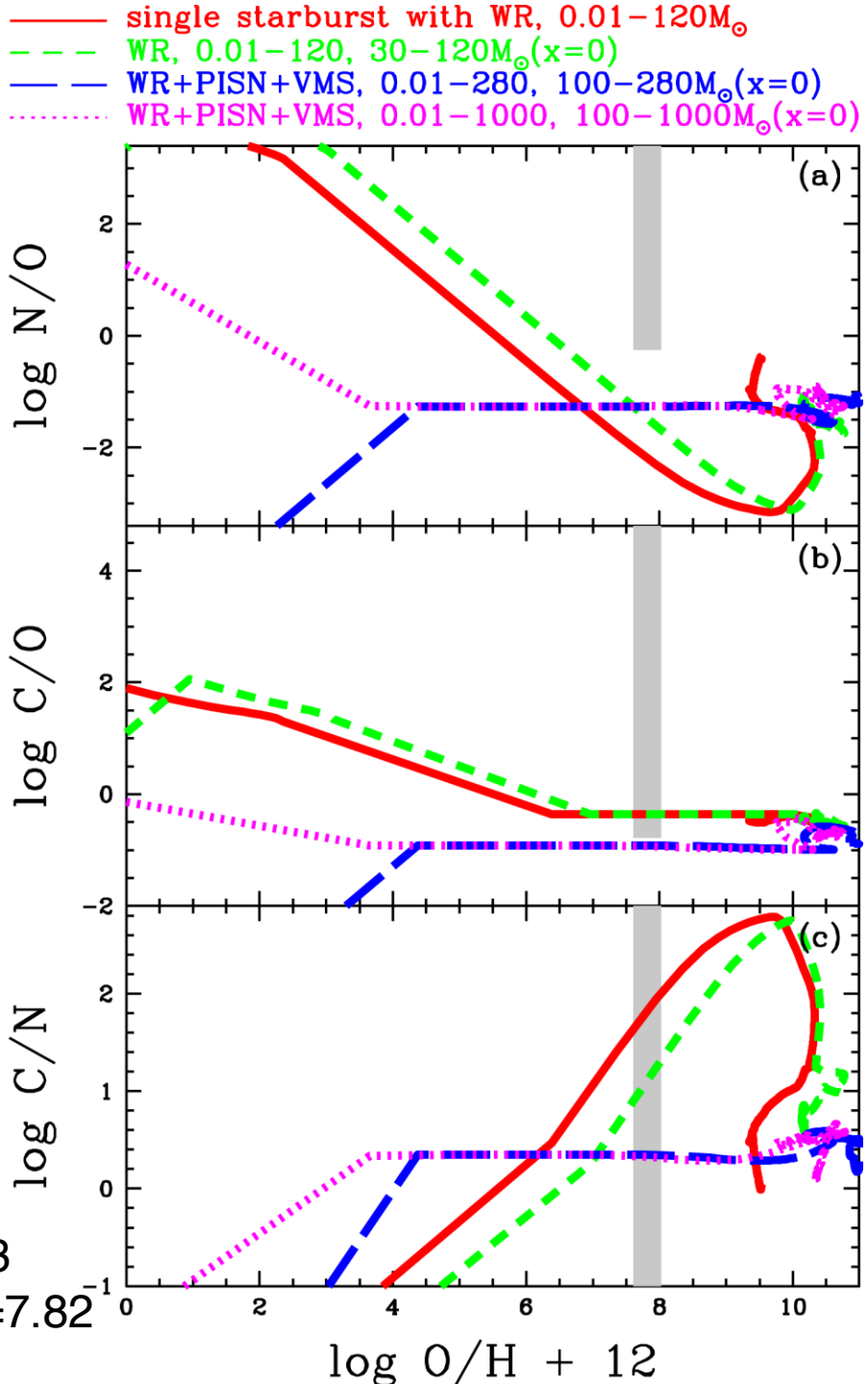
Yields with WR stars

- Model with the rotational velocity by Prantzos+18 (green) – C-overproduction
- Combined with Limongi & Chieffi 18 yields assuming rotation for HN/MRSN (blue)



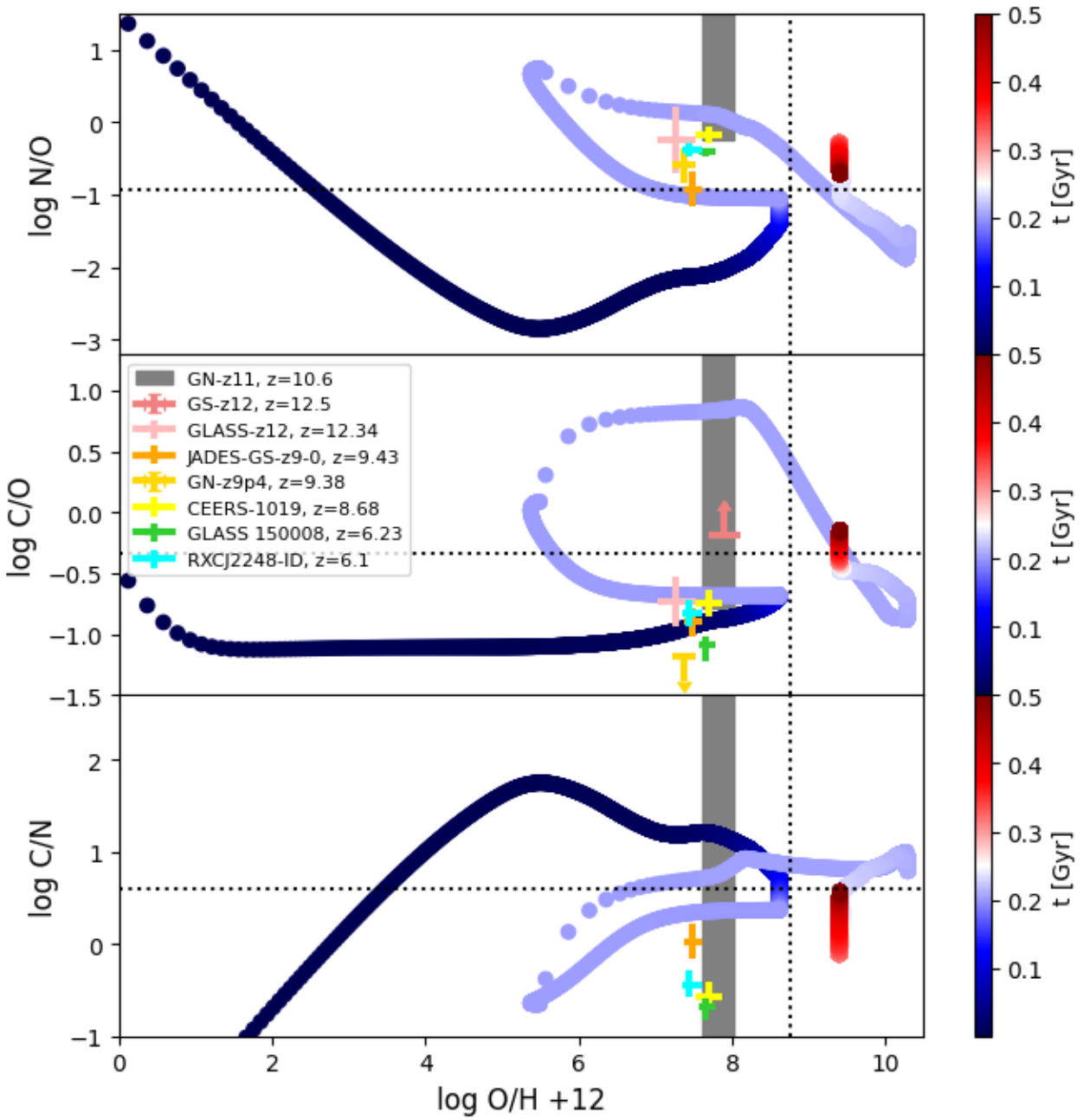
K20+LC18 yields combined assuming HNe are rotating.





CK & Ferrara 24
ApJL, 962, L6

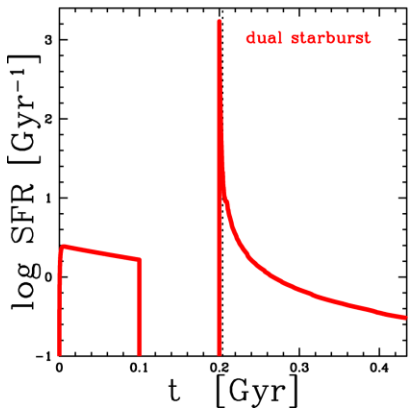
gray bar:
Cameron+23
log O/H+12=7.82



gray bar at log O/H+12=7.82 (Cameron+23)

GCE model for GNz-11
Adapted from
CK & Ferrara 24
ApJL, 962, L6

dual starburst model
standard IMF <120$M_\odot$
with **Wolf-Rayet stars**

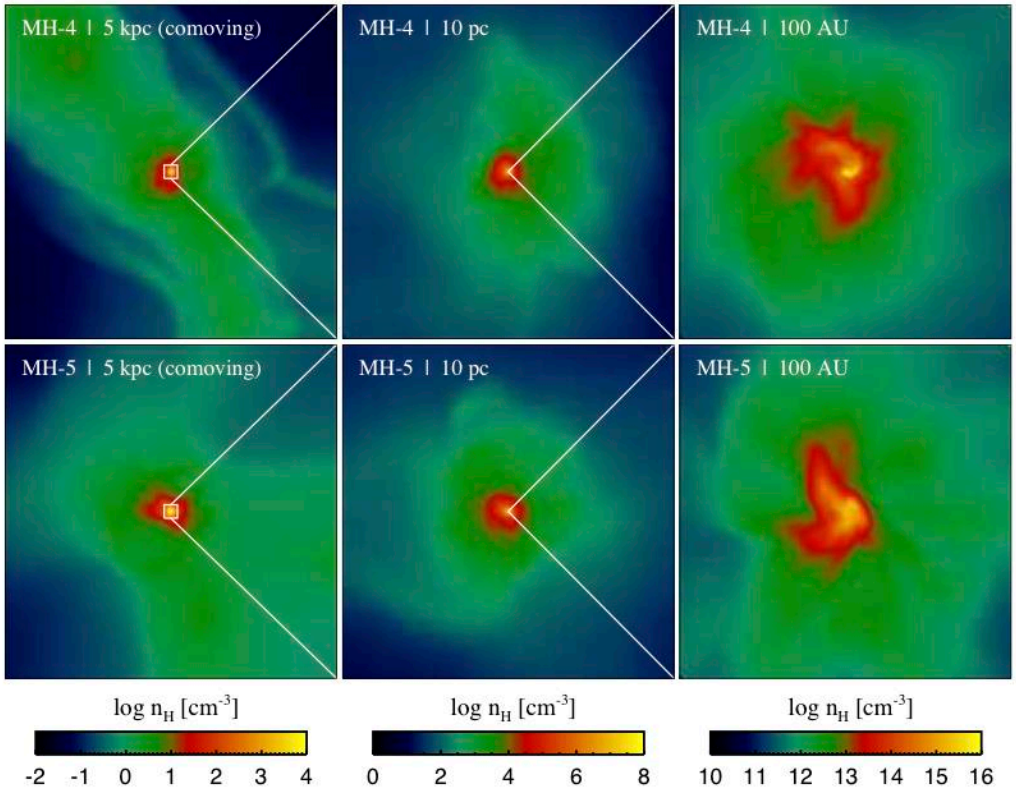


time spent in the observed range < 1Myr
i.e. rare but luminous

Subaru PFS will get 30-1000 N-emitters out of 30,000 LBG/LAE!

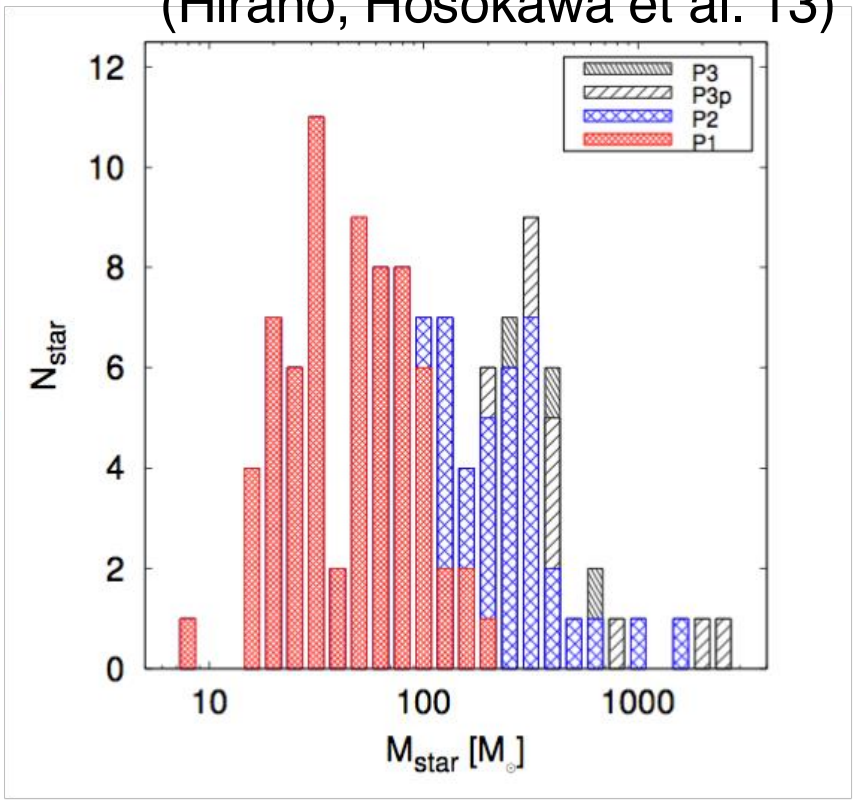
Primordial Star Formation

- Z=0, M_{star}>>100$M_{\odot}$(Abel, Bromm, Yoshida…)
- However, fragmentation? accretion?

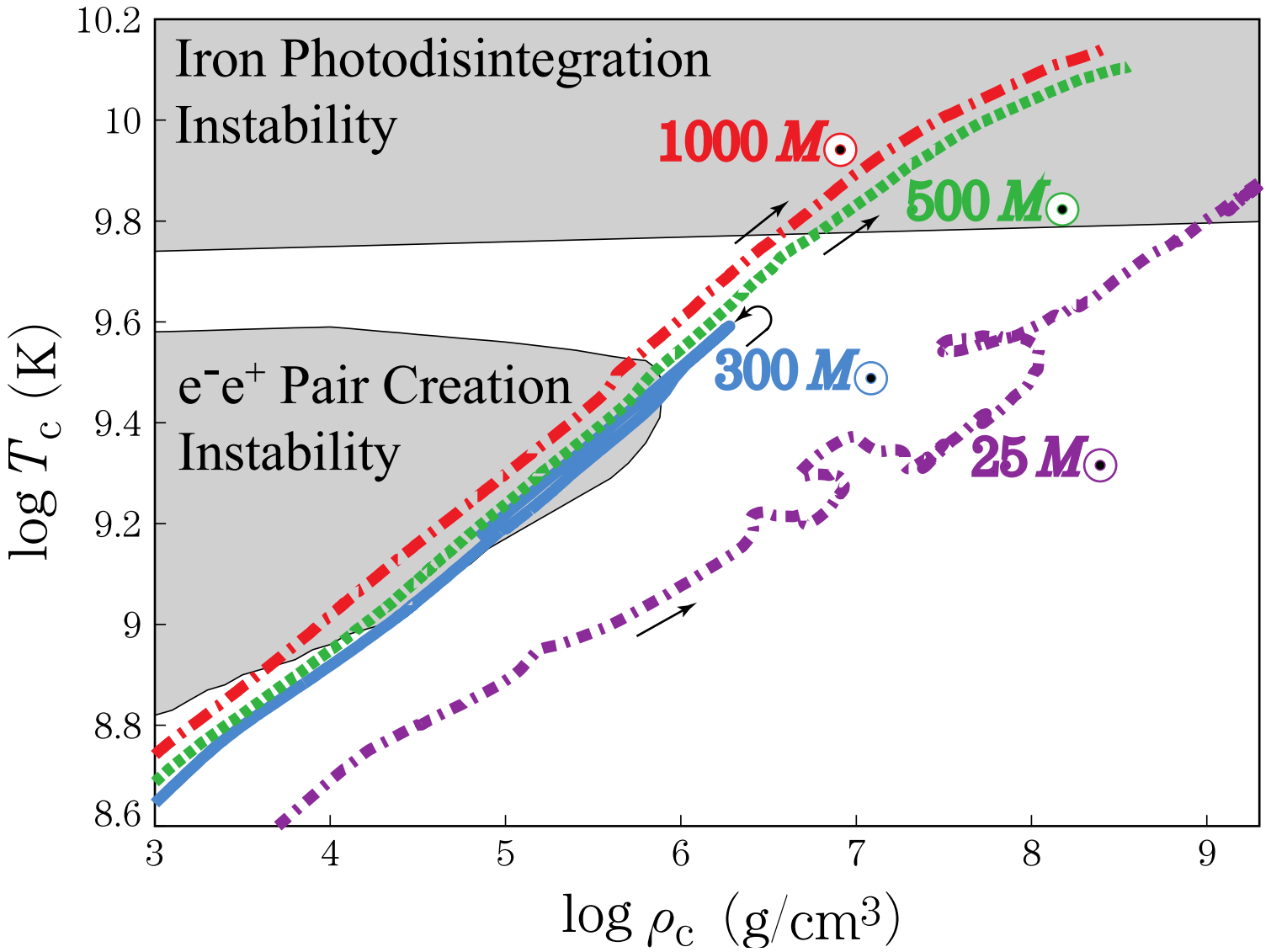


moving mesh method AREPO
(Greif et al. 11)

With feedback from the central star
(Hirano, Hosokawa et al. 13)



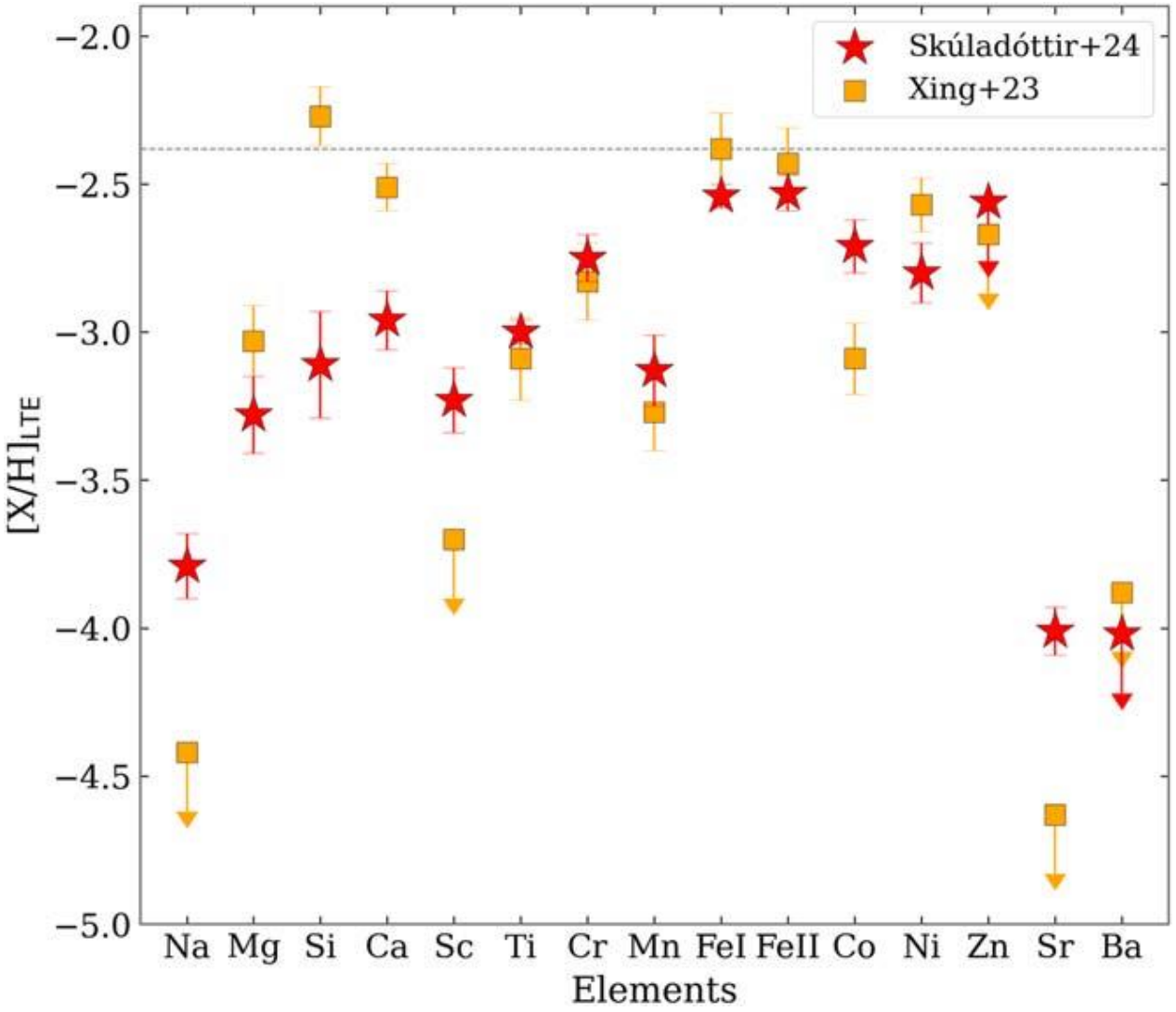
Pair Instability Supernova



- **SN 2006gy** (SNIIn)**, 2007bi** (Gal-Yam et al. 2009), but could be normal SNII with circumstellar interaction (Moriya et al. 2010)

No star enriched by PISN in MW!

J1010+2358 (the LAMOST star)



Skúladóttir +2024

More by Federico Sestito

Very massive stars (VMS, >100$M_\odot$)

Pair-instability SN

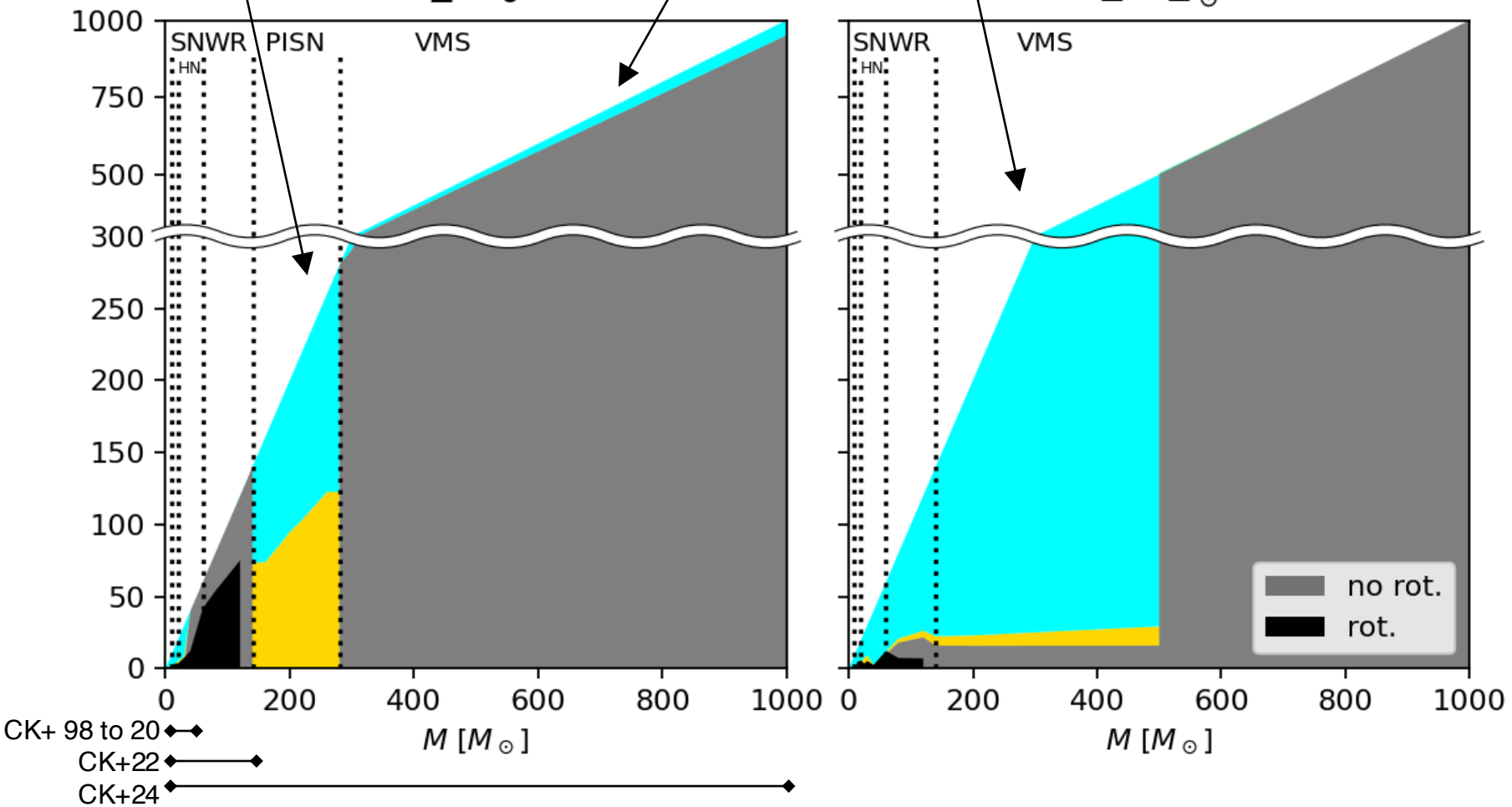
Heger+02
Umeda+02
Takahashi+18

Intermediate-mass BH

Volpato+23 (PARSEC)

Mass Loss

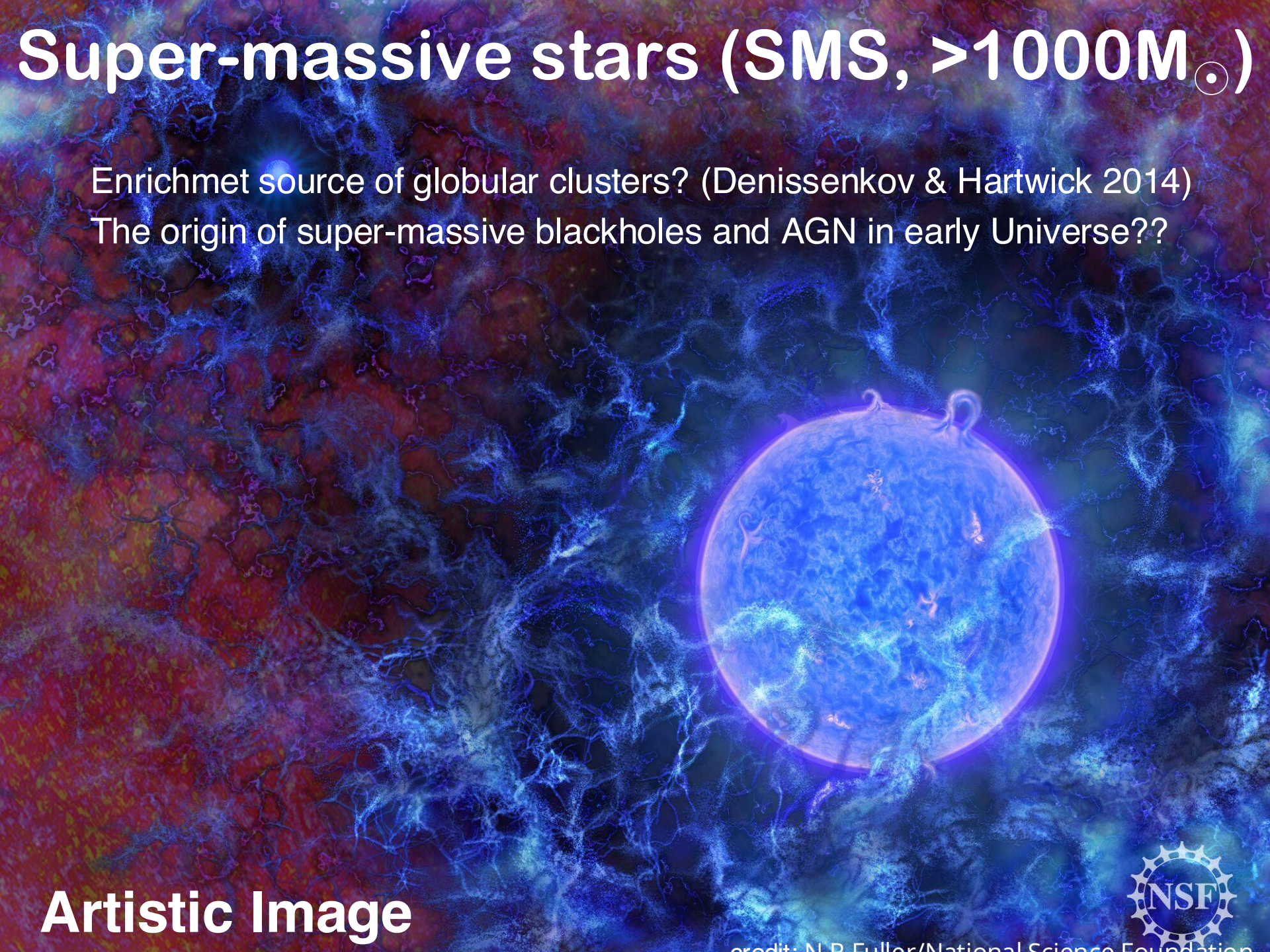
Higgins+23 (MESA)



Super-massive stars (SMS, >1000$M_\odot$)

Enrichmet source of globular clusters? (Denissenkov & Hartwick 2014)

The origin of super-massive blackholes and AGN in early Universe??



Artistic Image

credit: N.R.Fuller/National Science Foundation