Stellar black hole mergers as probes of cosmic chemical evolution

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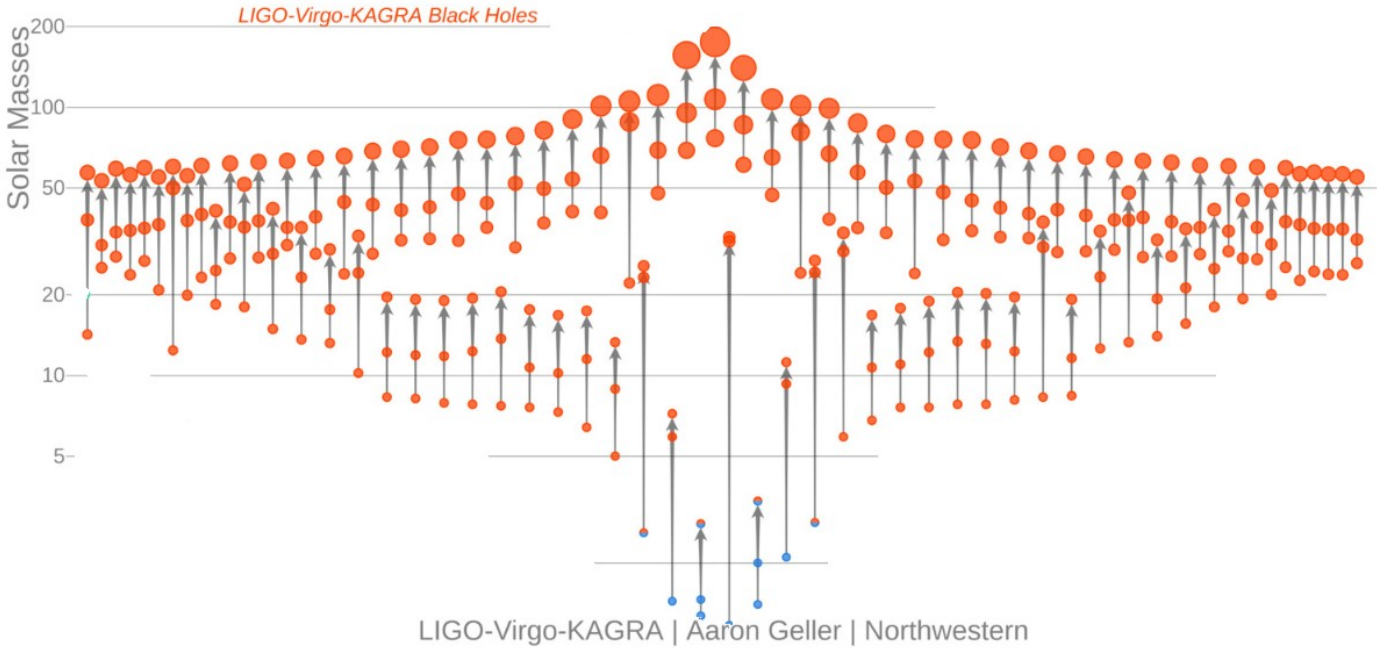
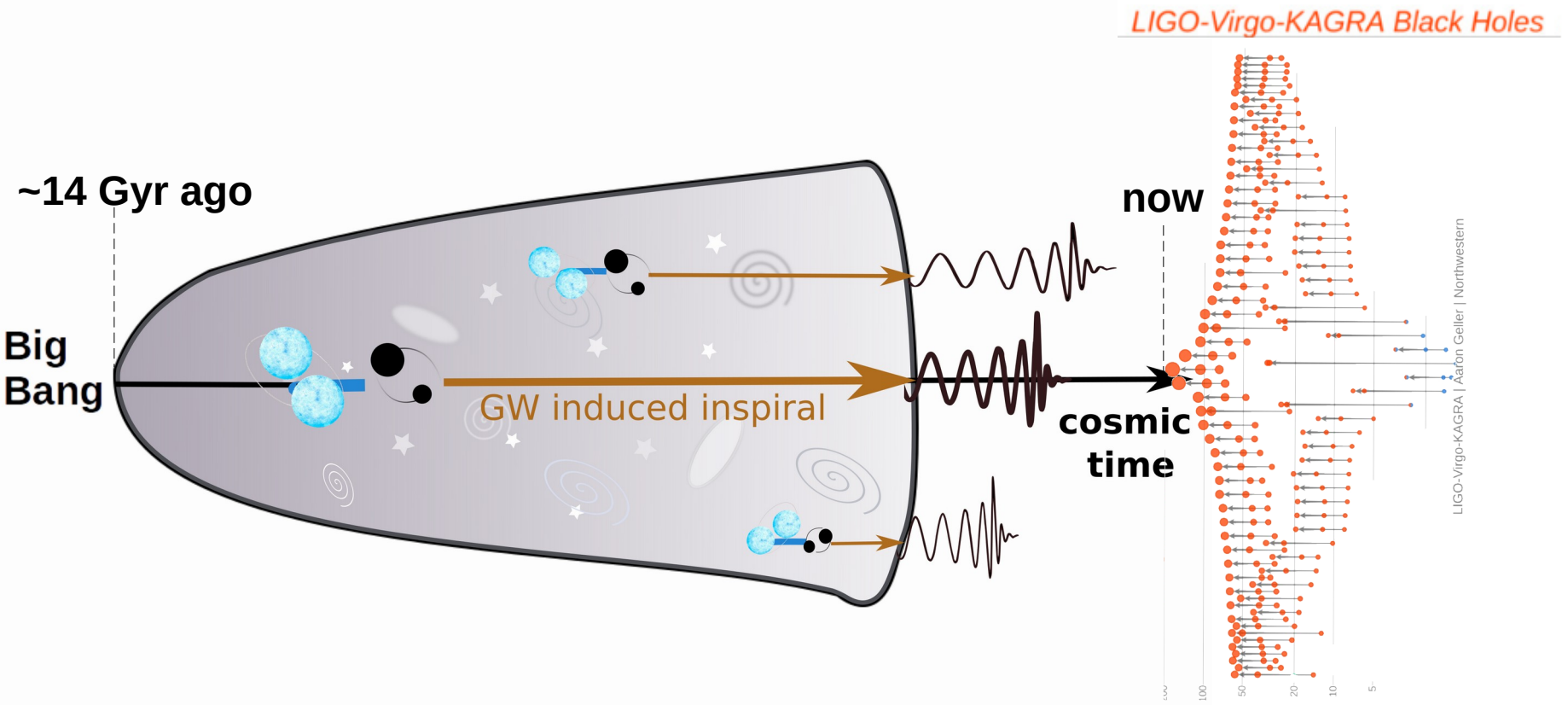
*borehole cores from ET drilling site
for geological analysis



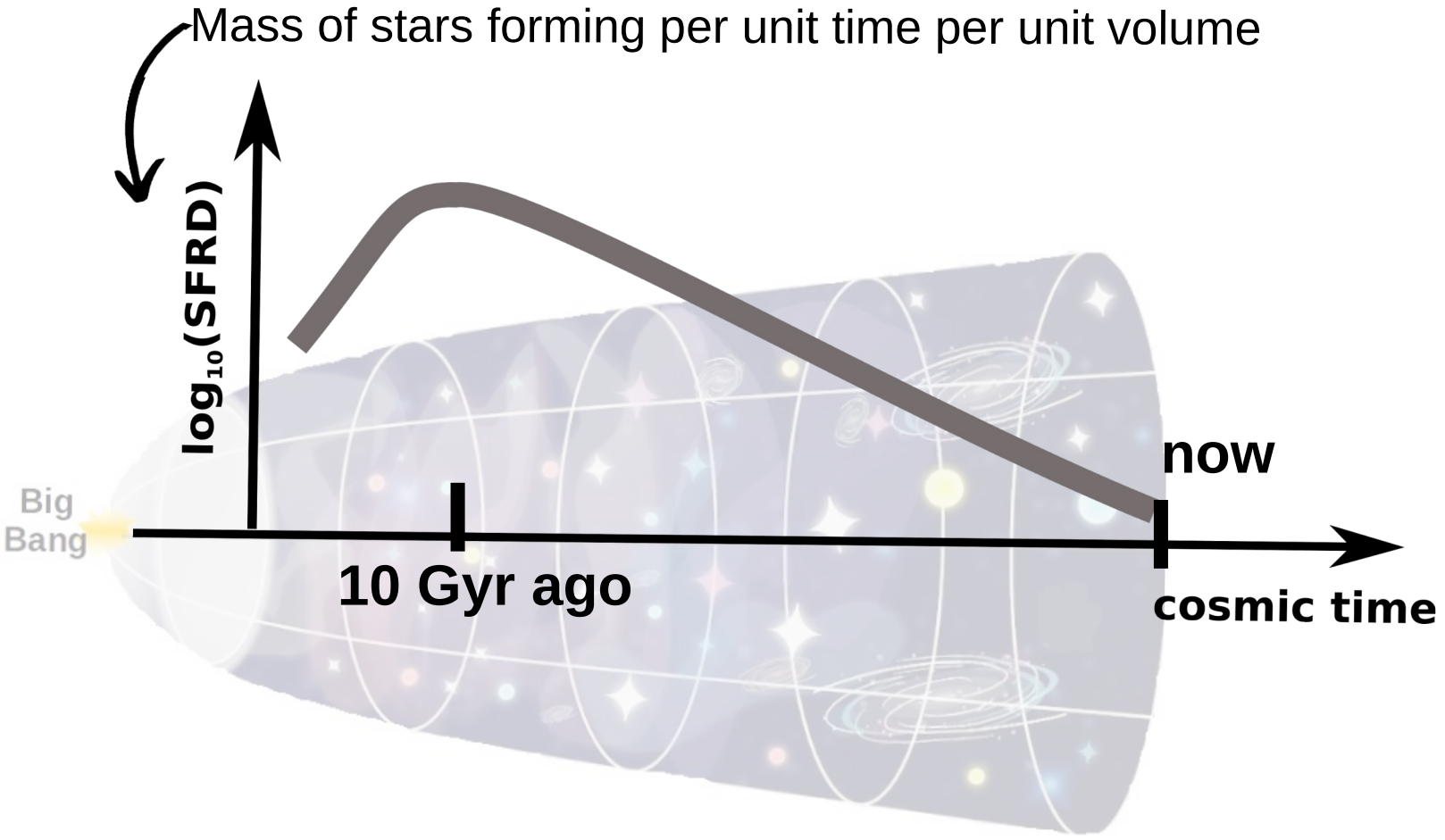
*black hole masses from GW observations
for astrophysical analysis

where, when and how
did they form?

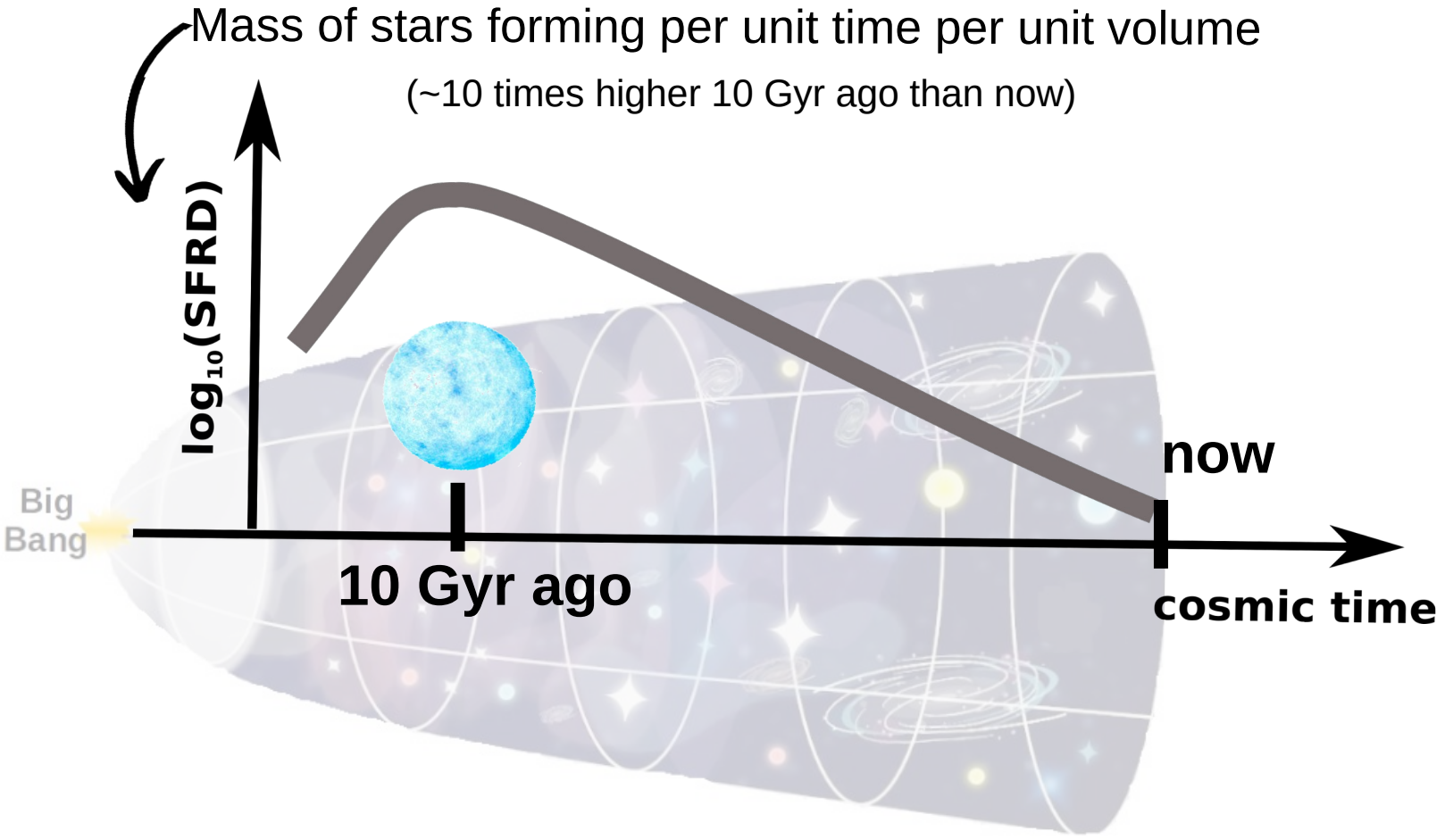


progenitor stars formed *somewhere* in the Universe

Long history of cosmic star formation

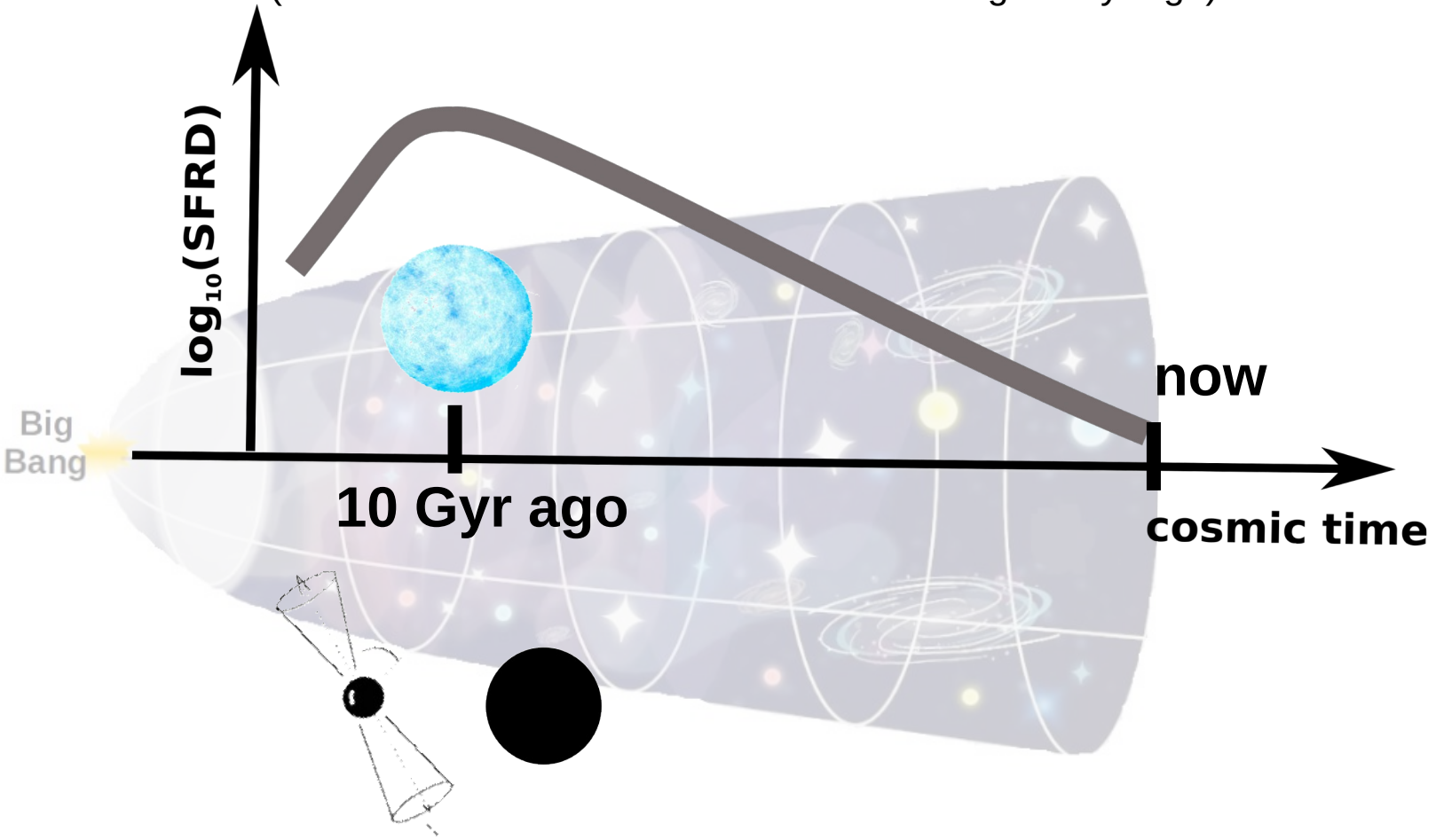


Long history of cosmic star formation

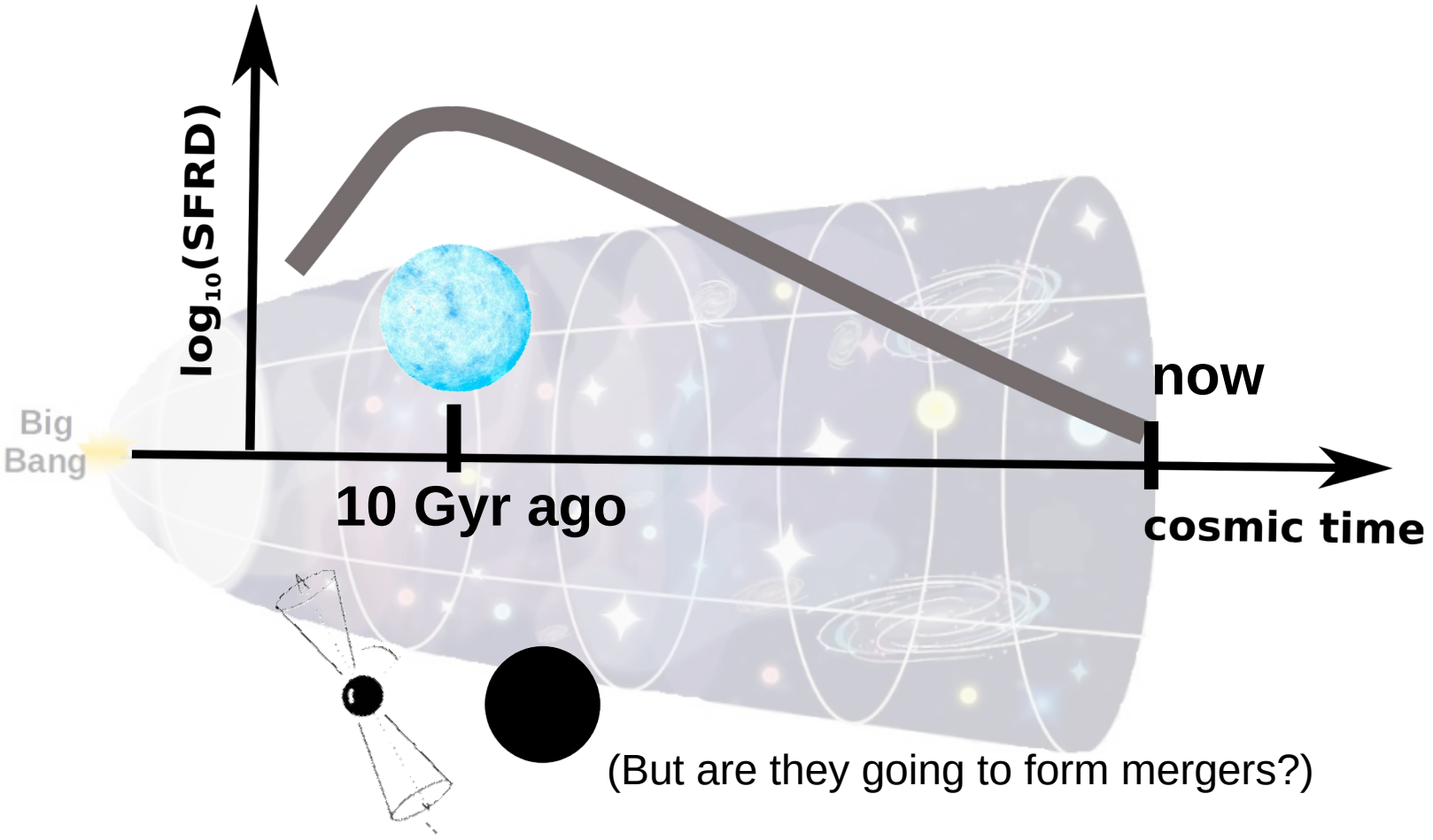


Long history of cosmic star formation

(more black holes and neutron stars forming 10 Gyr ago)



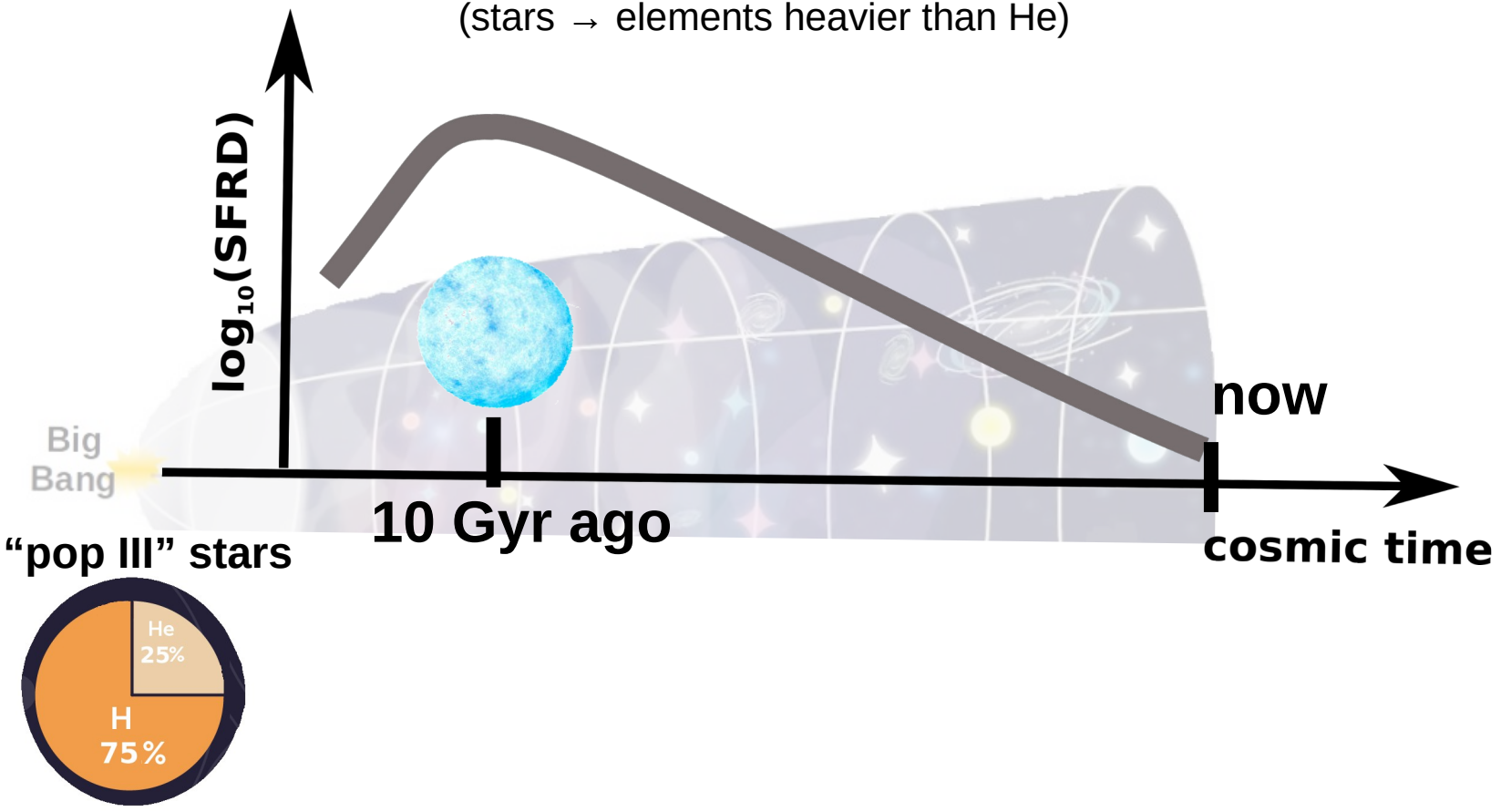
Long history of cosmic star formation



(But are they going to form mergers?)

Long history of cosmic star formation
and chemical evolution

(stars → elements heavier than He)



Long history of cosmic star formation
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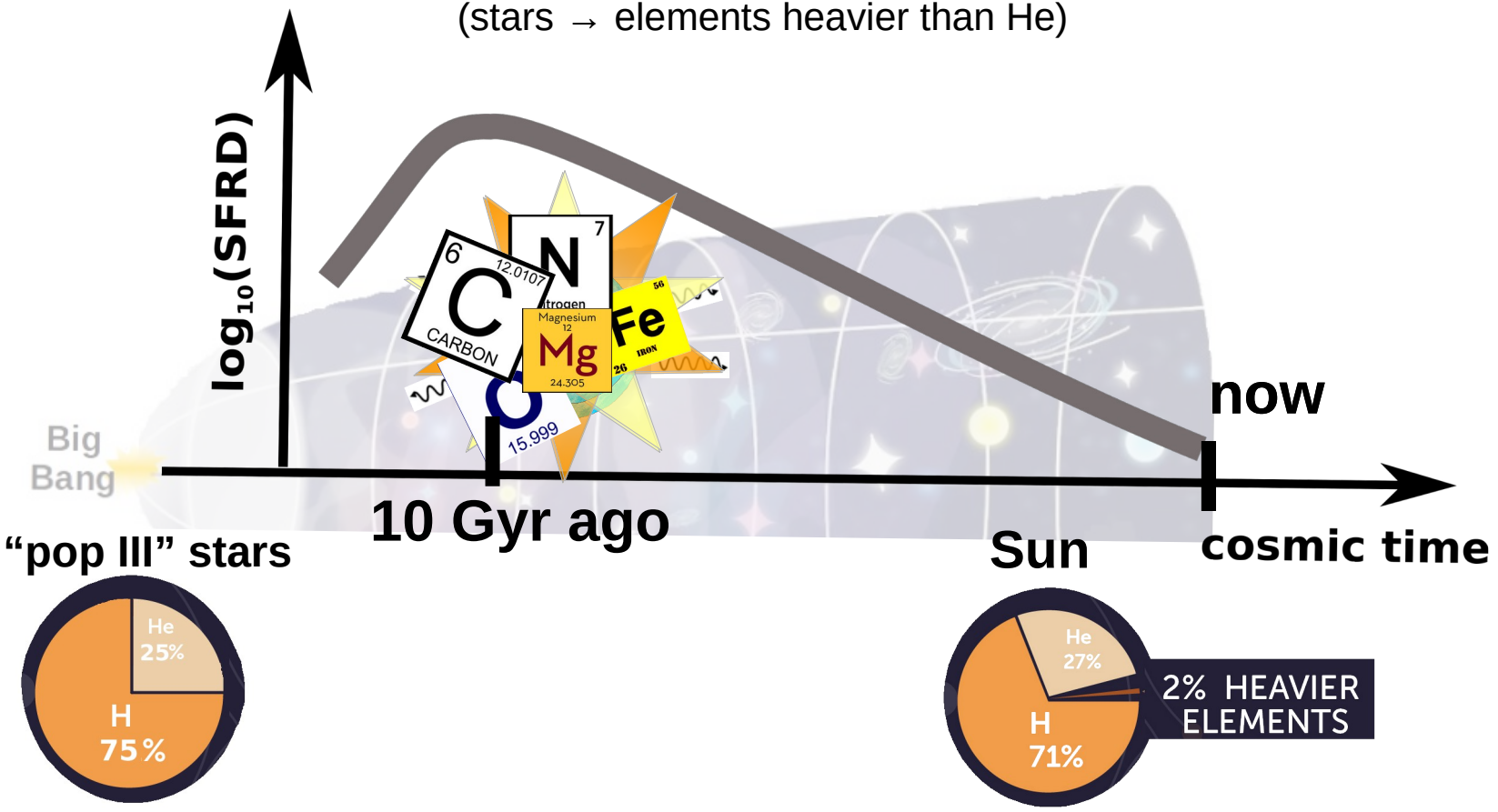

Long history of cosmic star formation
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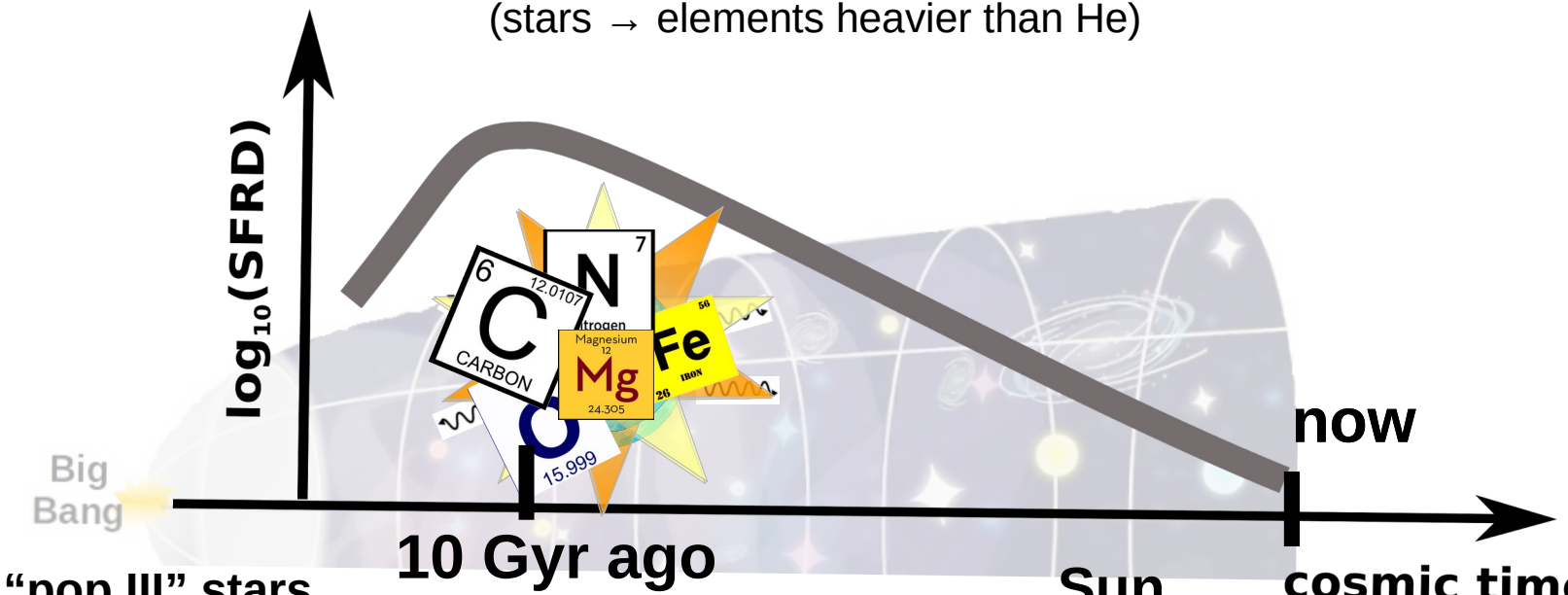
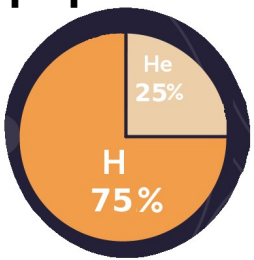
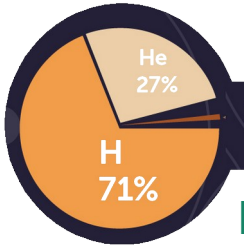


“pop III” stars



Sun

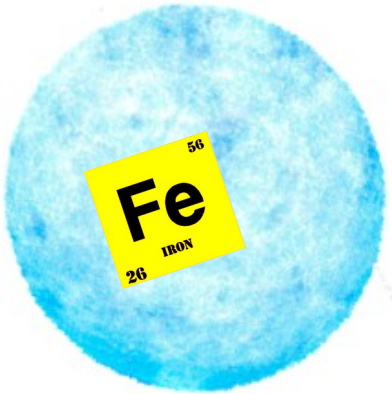


2% HEAVIER ELEMENTS

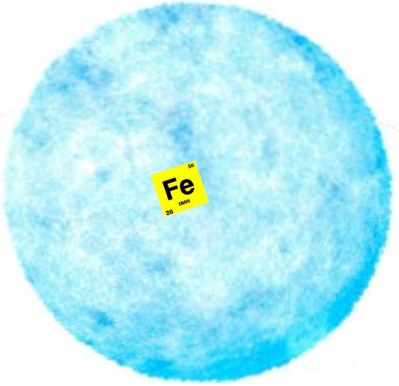
“metallicity”

Influence astrophysical processes

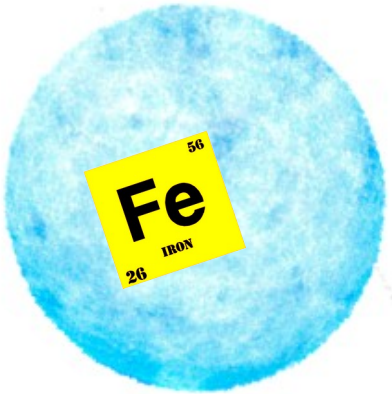
lives of massive stars are sensitive to metallicity (*iron*)

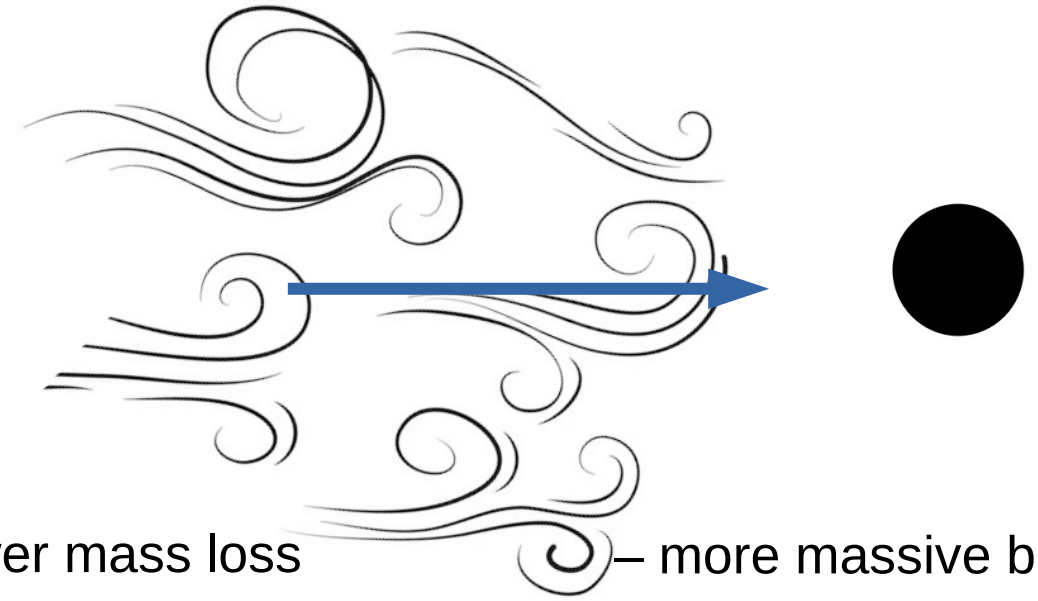


lower metallicity – lower mass loss

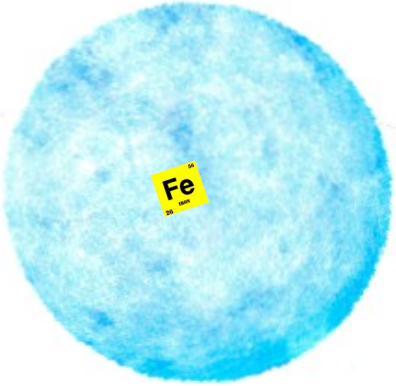


*(**after**)lives* of massive stars are sensitive to metallicity (*iron*)



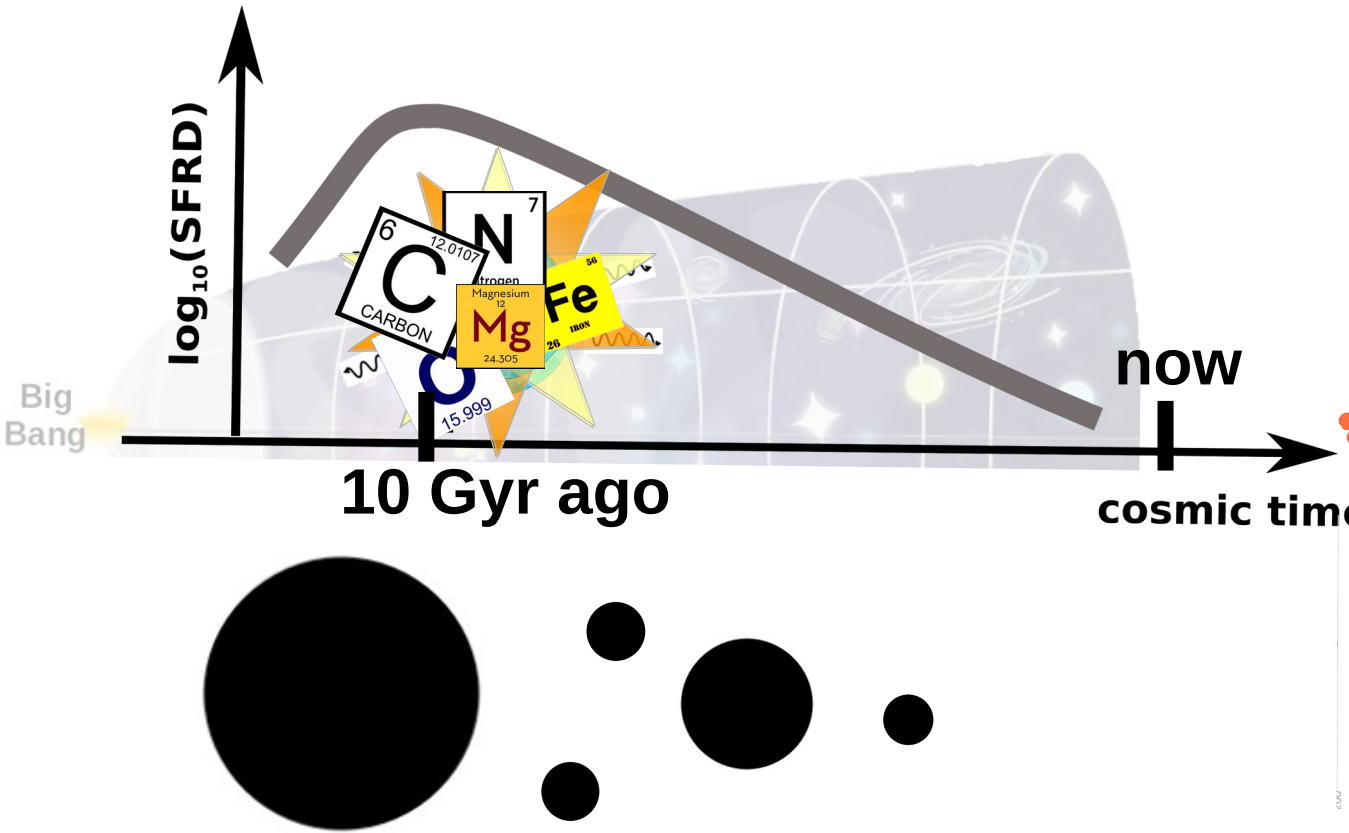


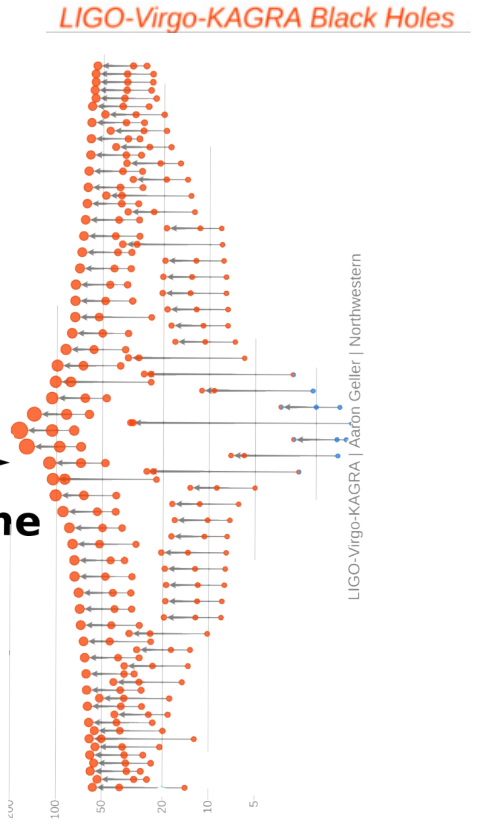
lower metallicity – lower mass loss – more massive black holes



Metallicity-dependent cosmic star formation history

is part of the interpretation !





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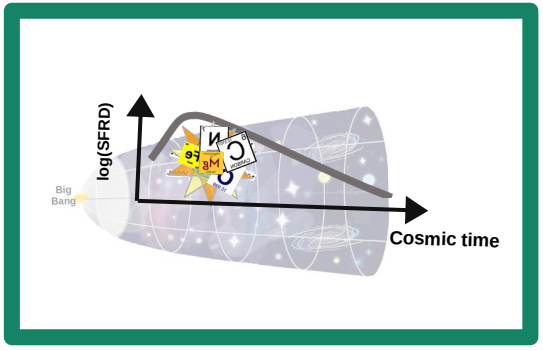
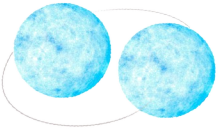
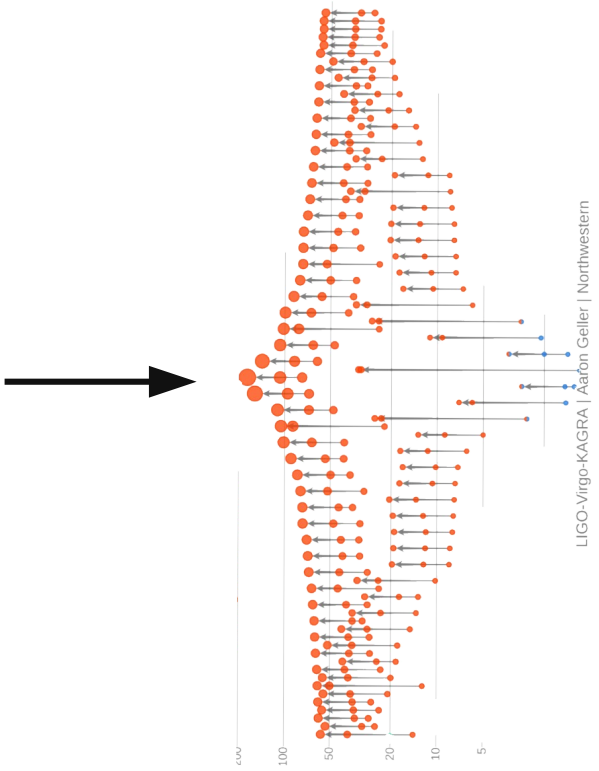


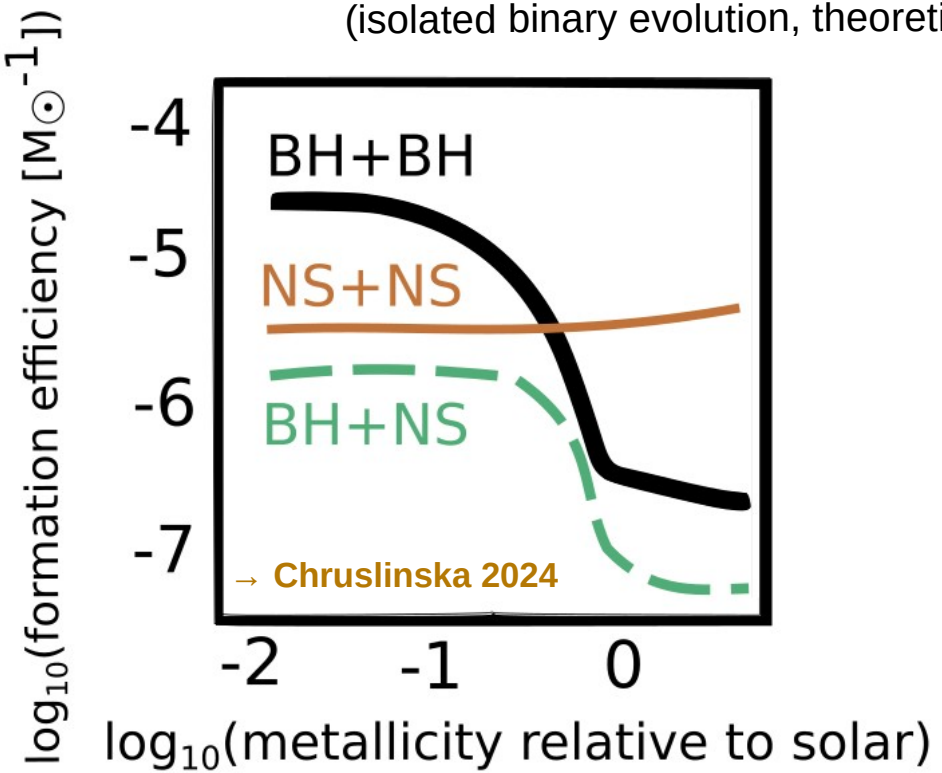
+





...may be key for the interpretation

(isolated binary evolution, theoretical) ← see talk by Lieke



e.g. Belczynski et al. 2010, Dominik et al. 2012, Eldridge & Stanway 2016, Stevenson et al. 2017, Klencki et al. 2018, Giacobbo et al. 2018, **Neijssel+19, Chruslinska et al. 2019, Santoliquido+21 Broekgaarden et al. 2022** ...

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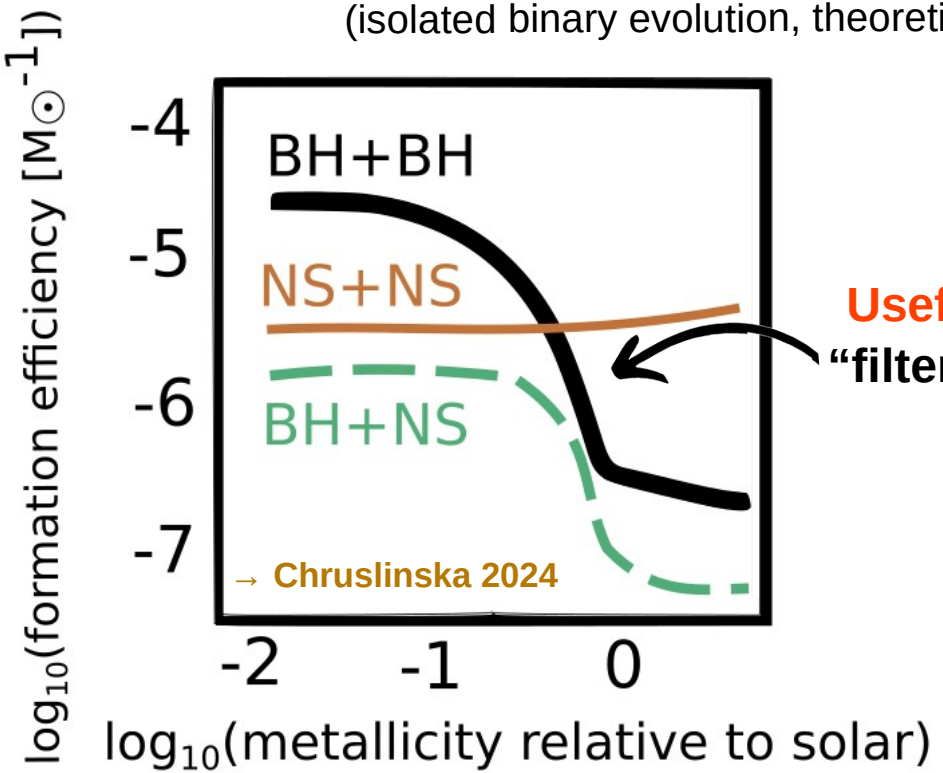
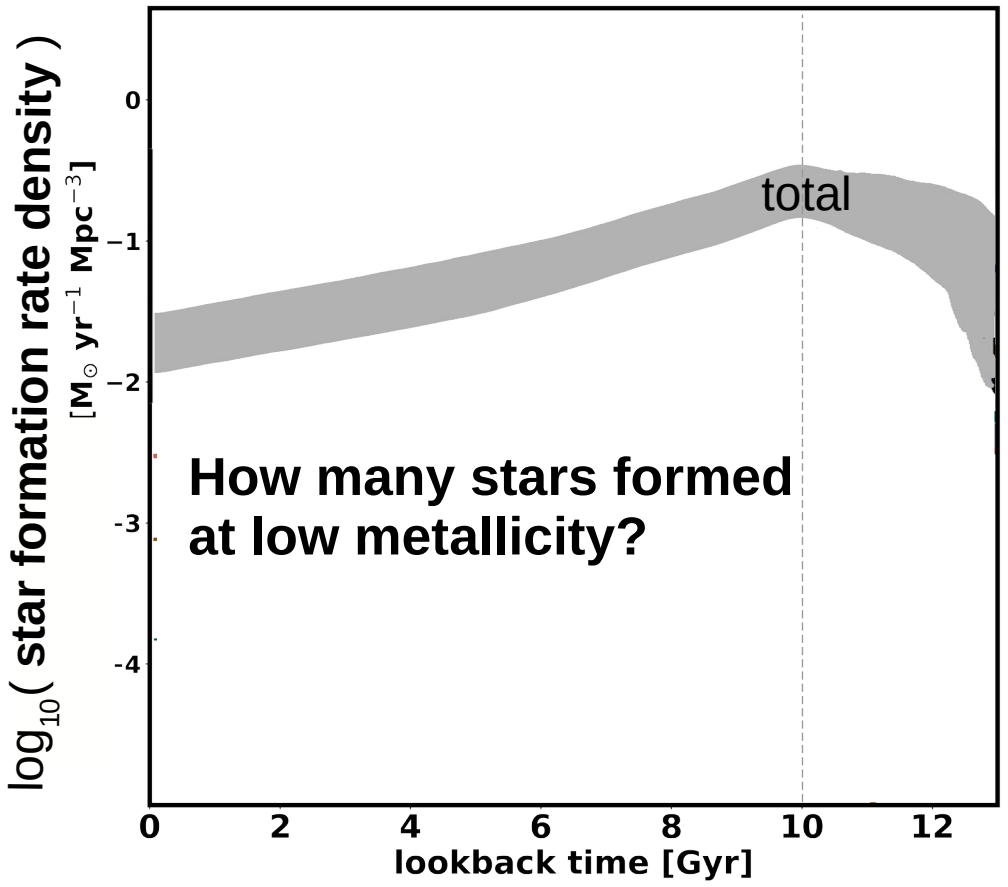


Useful!

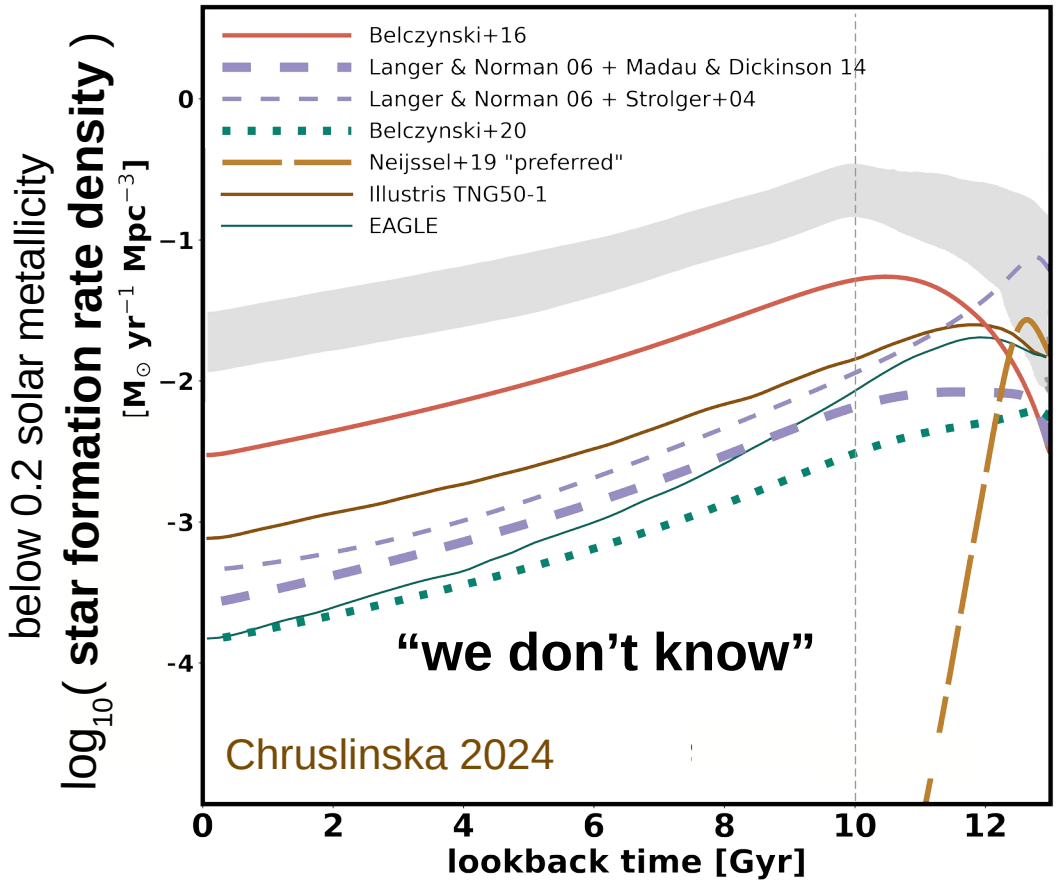
"filter" low metallicity star formation

e.g. Belczynski et al. 2010, Dominik et al. 2012, Eldridge & Stanway 2016, Stevenson et al. 2017, Klencki et al. 2018, Giacobbo et al. 2018, **Neijssel+19, Chruslinska et al. 2019, Santoliquido+21 Broekgaarden et al. 2022** ...


log10(star formation rate density)
[M⊙ yr−1 Mpc−3]
0
−1
−2
-3
-4
total
How many stars formed
at low metallicity?
0
2
4
6
8
10
12
lookback time [Gyr]

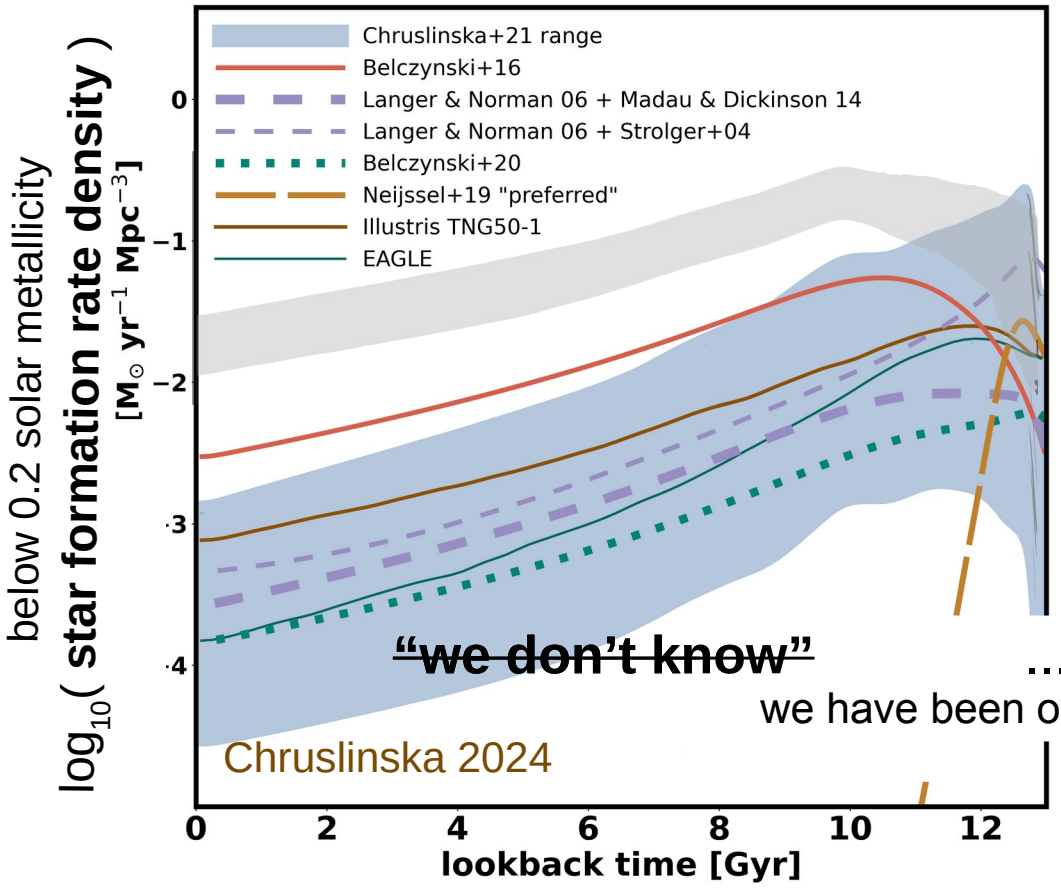
Literature assumptions

“low metallicity” cosmic star formation history



Constraints

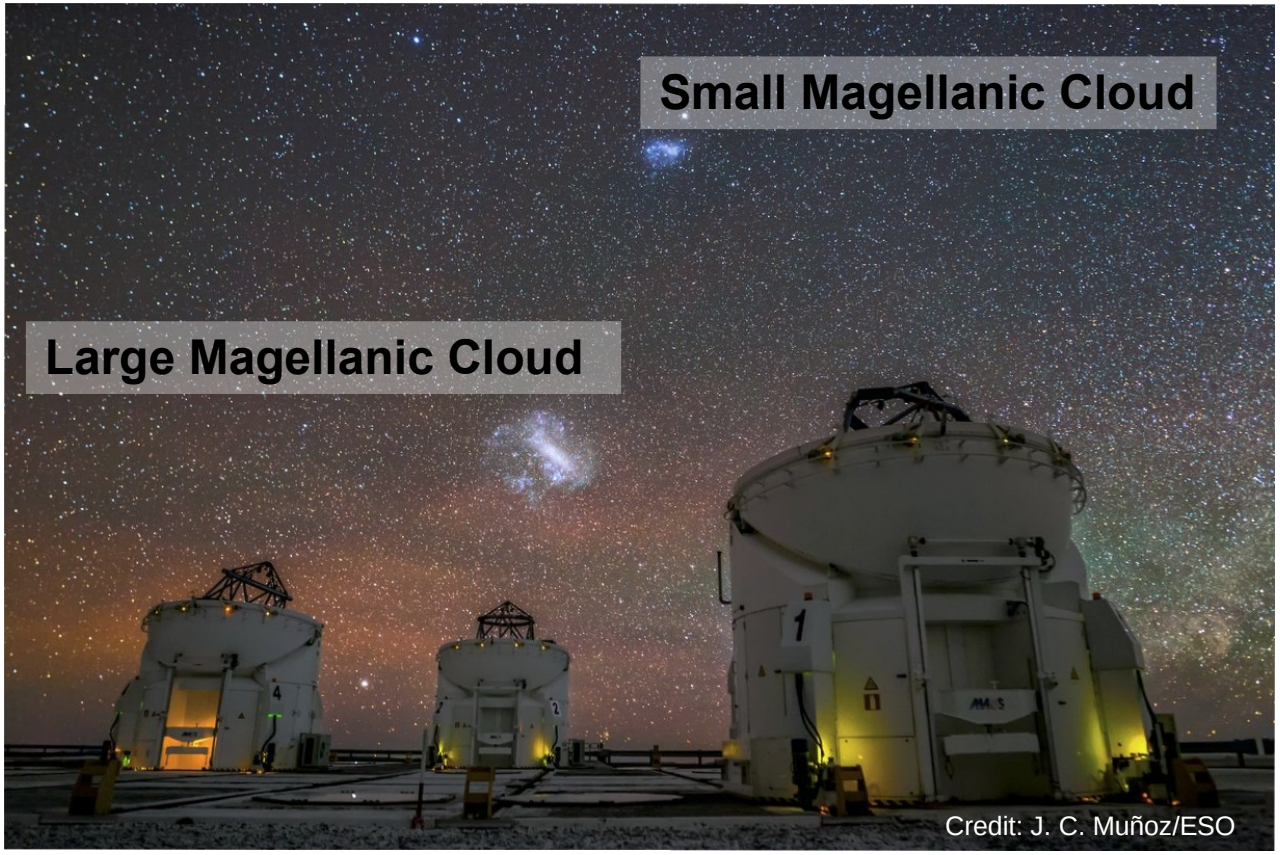
“low metallicity” cosmic star formation history

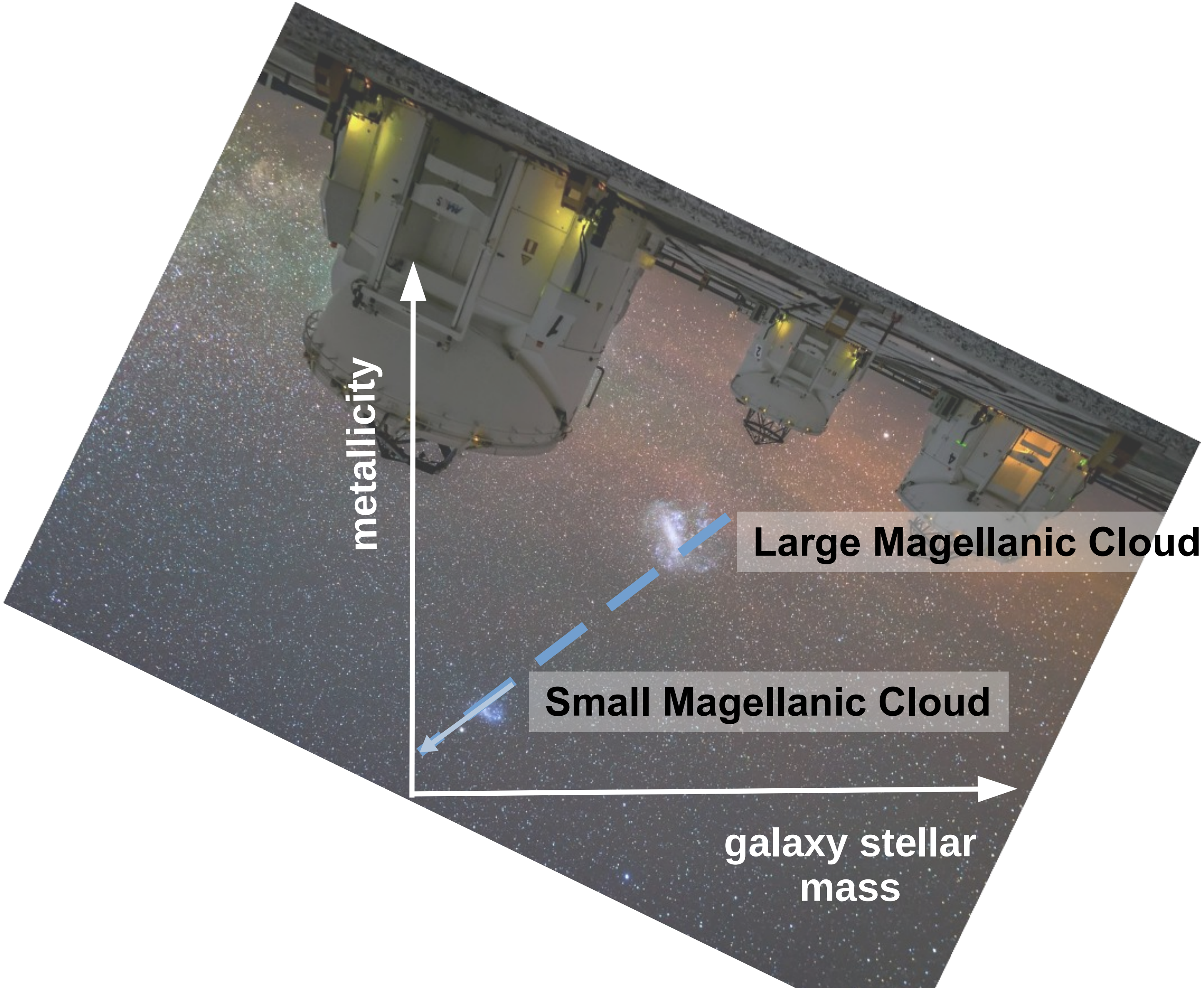


~~**“we don’t know”**~~

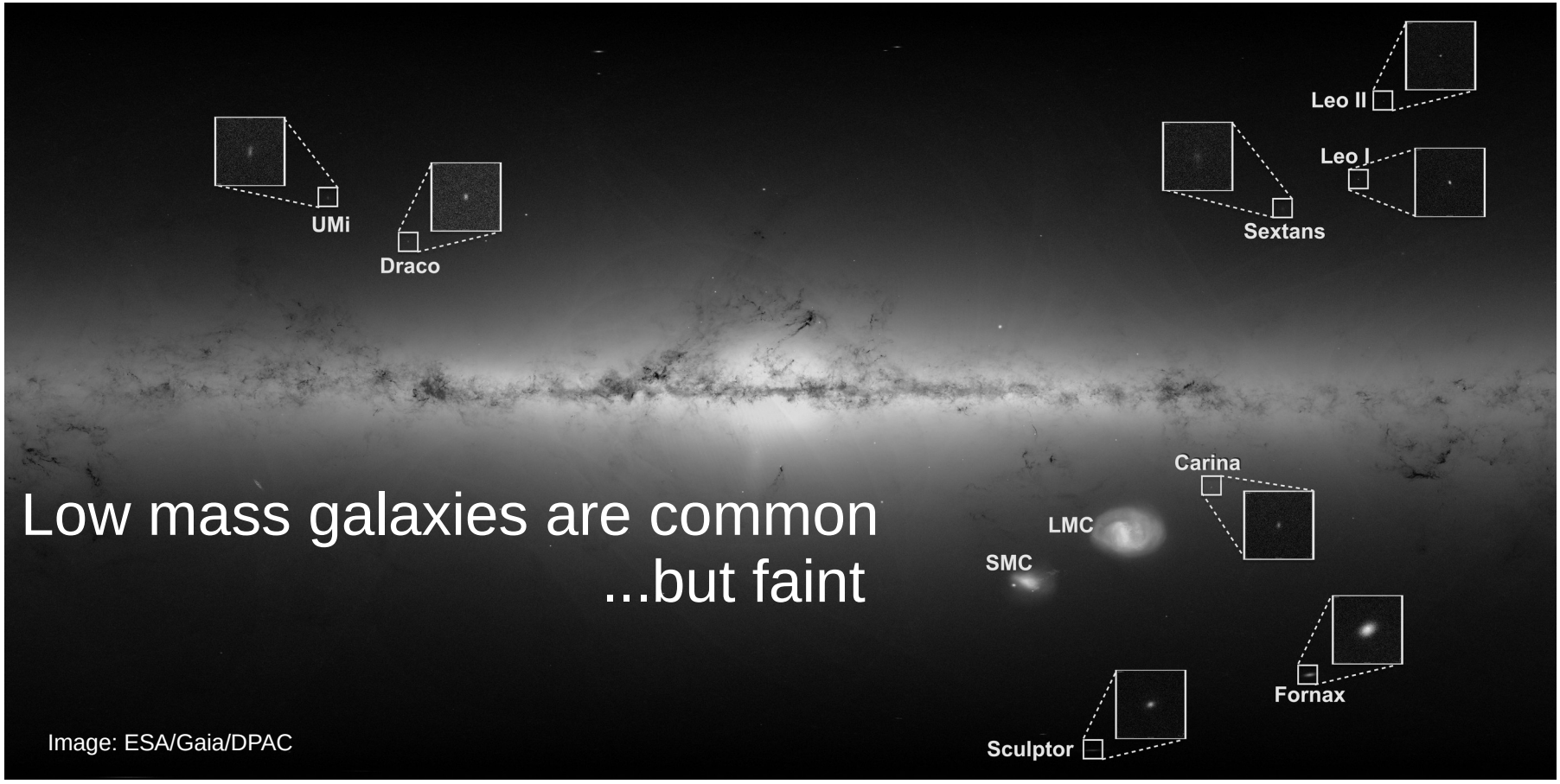
...we **know *something***

we have been observing galaxies for years!

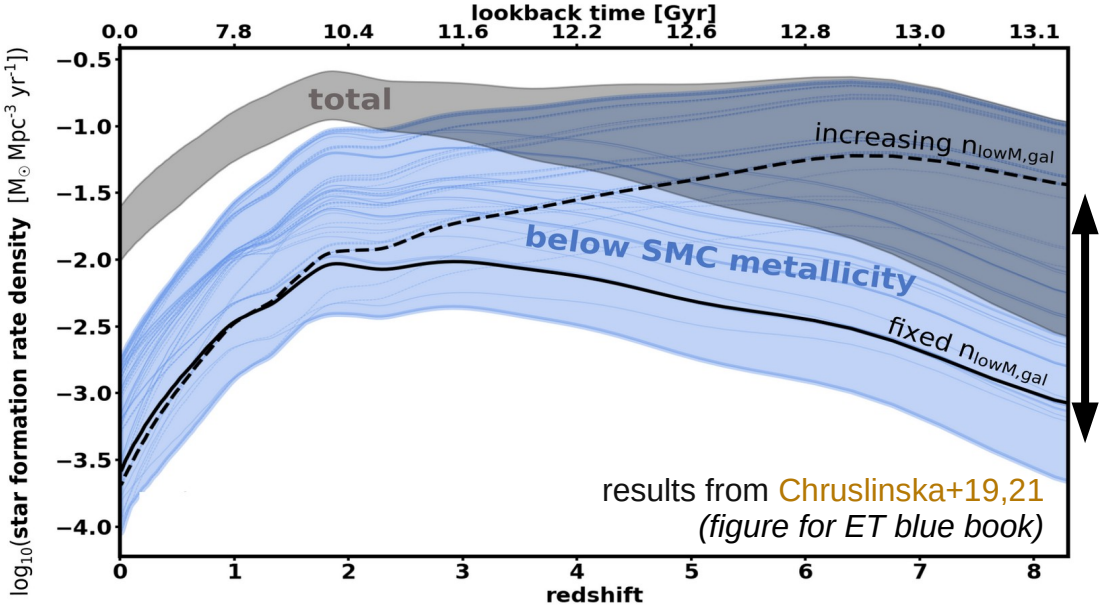

Small Magellanic Cloud
Large Magellanic Cloud
Credit: J. C. Muñoz/ESO


metallicity
Large Magellanic Cloud
Small Magellanic Cloud
galaxy stellar mass

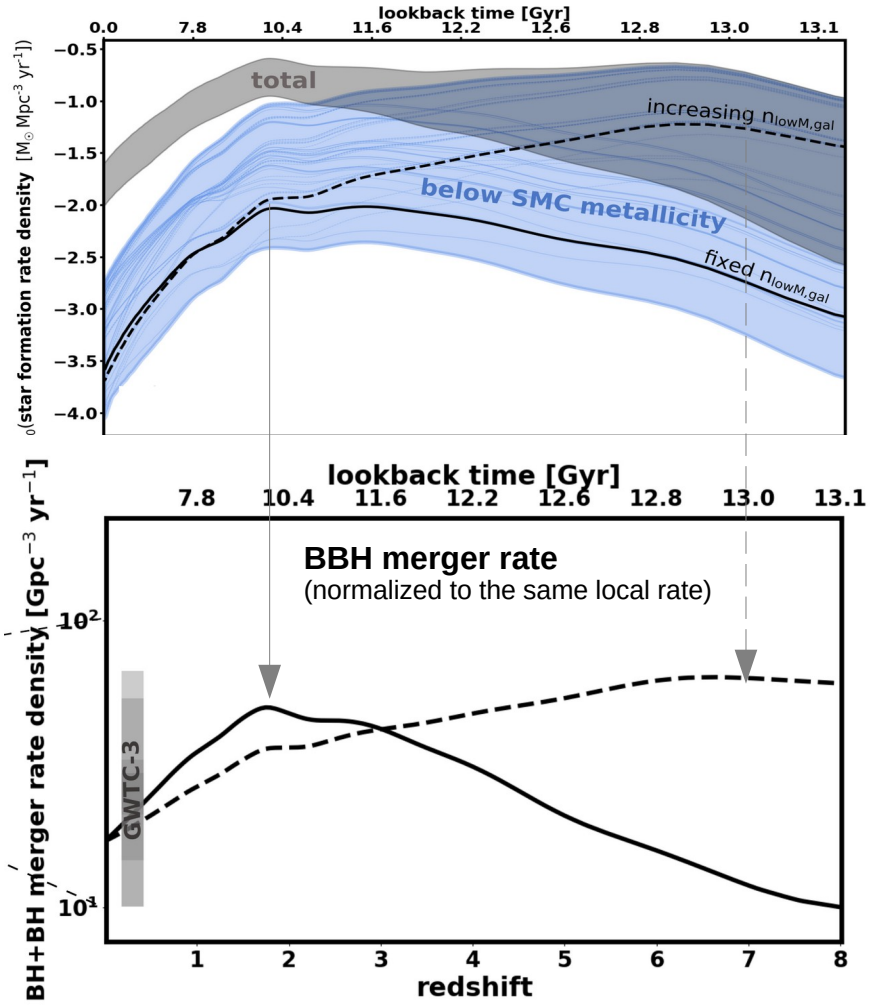
Star formation history at low metallicity:



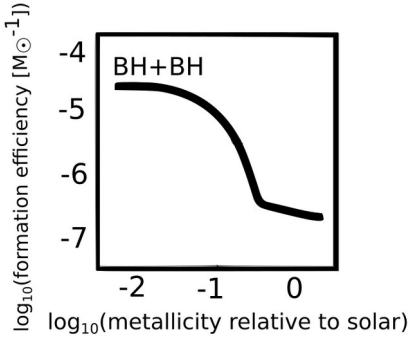
Star formation history at low metallicity & high redshift

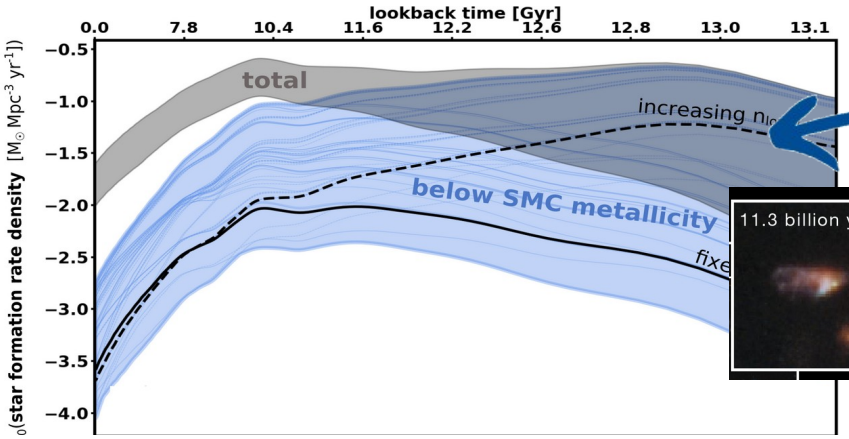


“low mass galaxies
are common but faint”

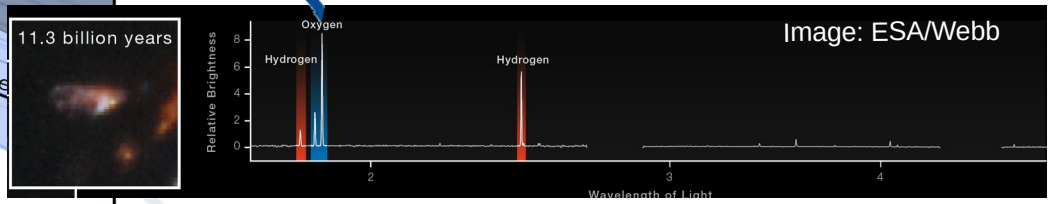


“low mass galaxies
are common but **faint**”
(for electromagnetic studies, not for GW)

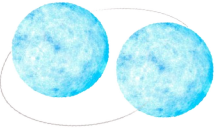




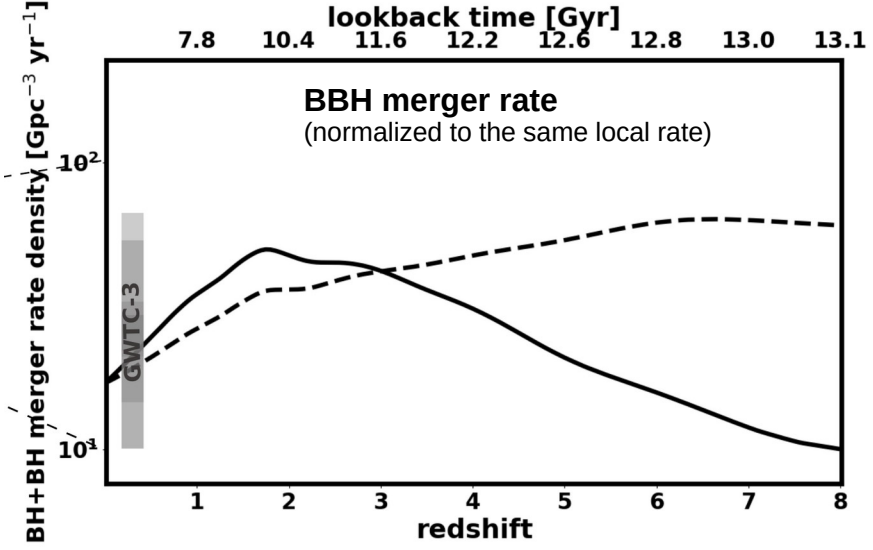
oxygen

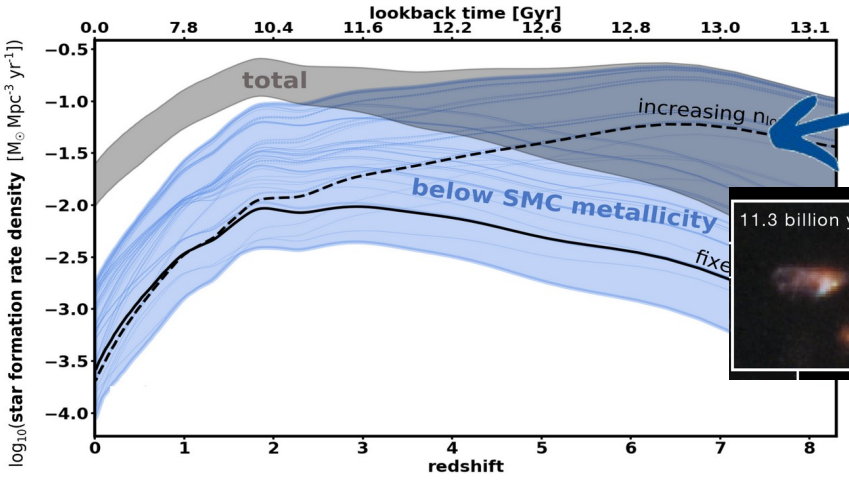


what we **measure is not** always what we **need**

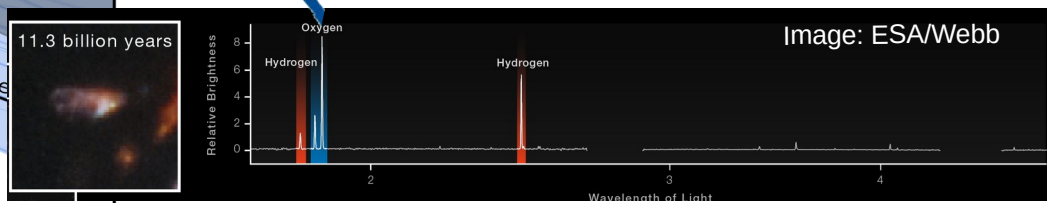


IRON - sensitive

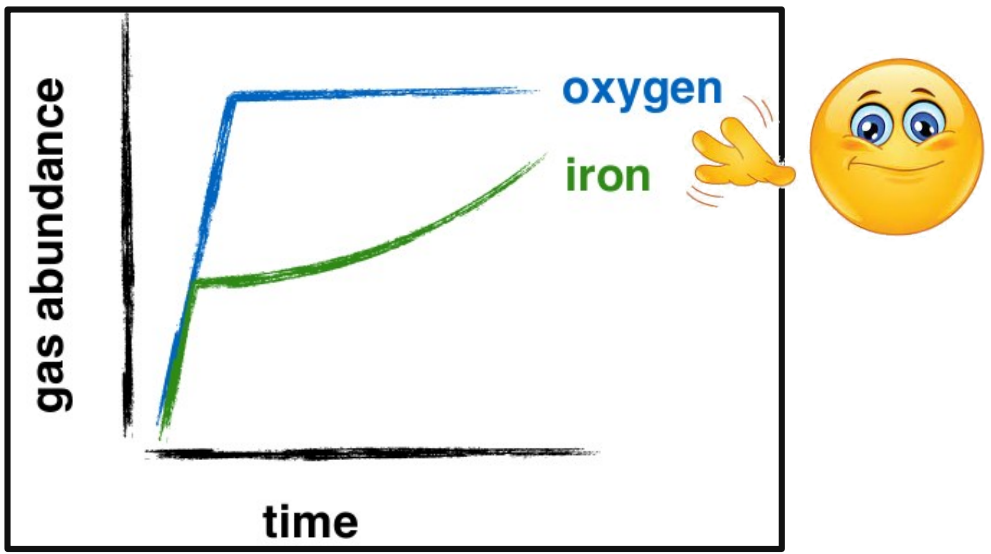




oxygen



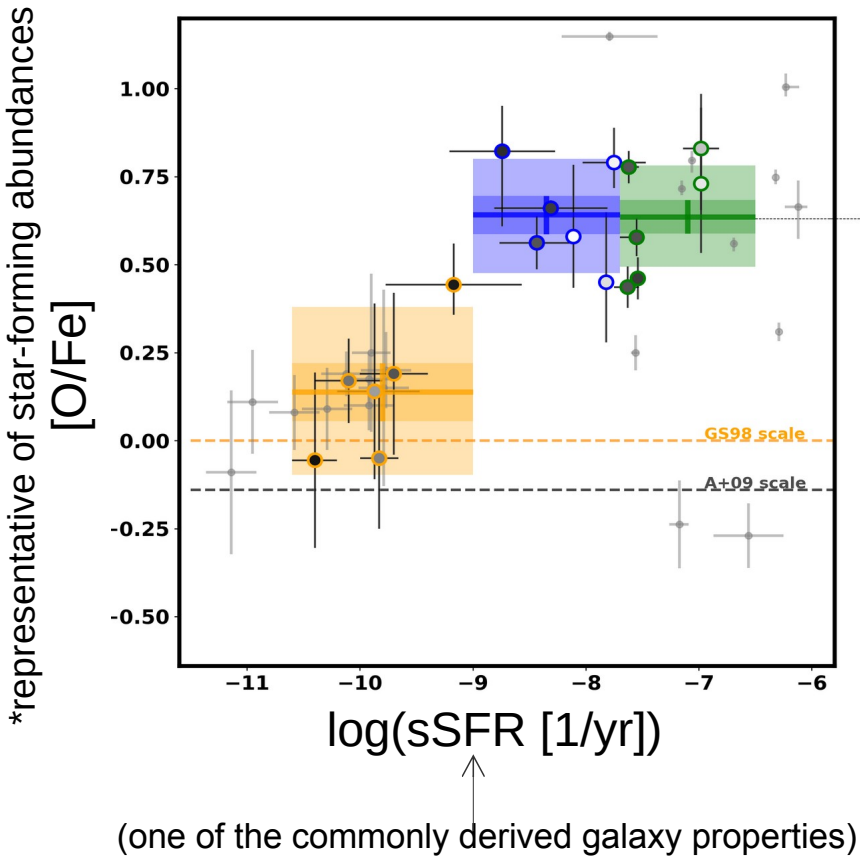
Oxygen can be a very poor proxy for iron abundance!



Workaround!

[O/Fe] – specific SFR relation for galaxies: method to “trade oxygen for iron”

Chruslinska+23,
+work in prep.



Metallicity-dependent cosmic star formation history

- necessary part of the GW population interpretation & modelling
- may dominate uncertainty of BBH mergers vs redshift
- constraints can be derived *(statistical galaxy properties)* but *(will remain)* challenging at “low metallicity” for EM studies *(even at low redshift!)*
- GW observations can provide **complementary constraints**
  [early (iron) enrichment history, properties of low-mass galaxies in the reionisation epoch]
- different biases and systematics

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