# Some first stars were RED: detecting signatures of massive population III formation through long term stochastic color variations

Woods et al. 2021

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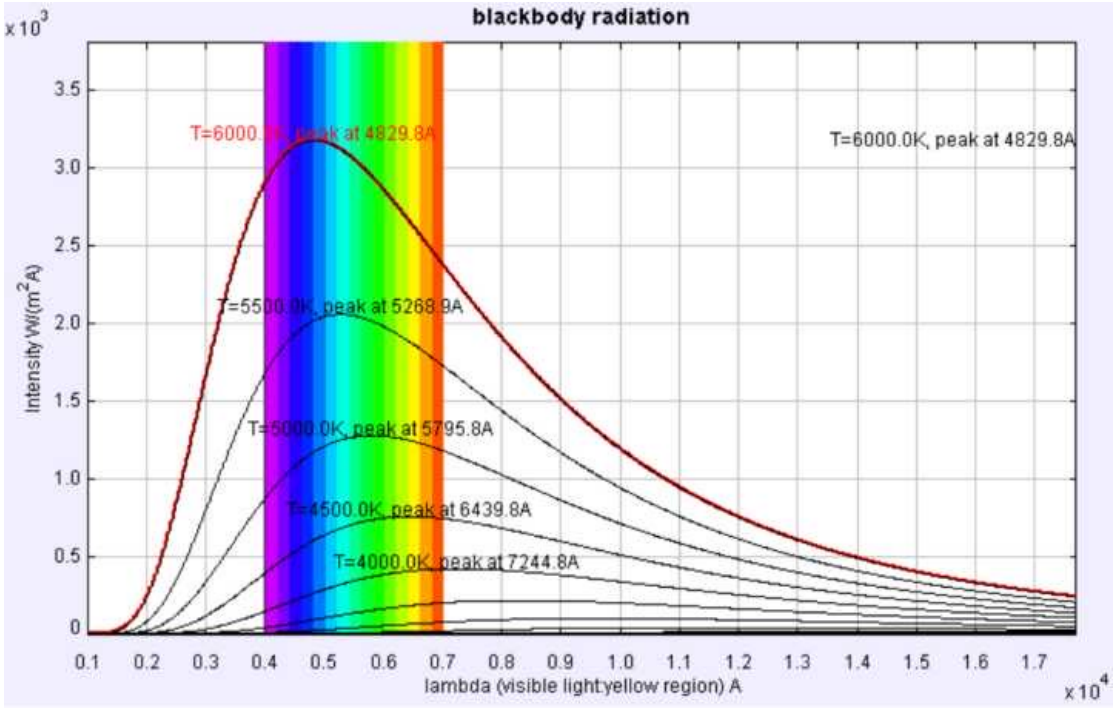
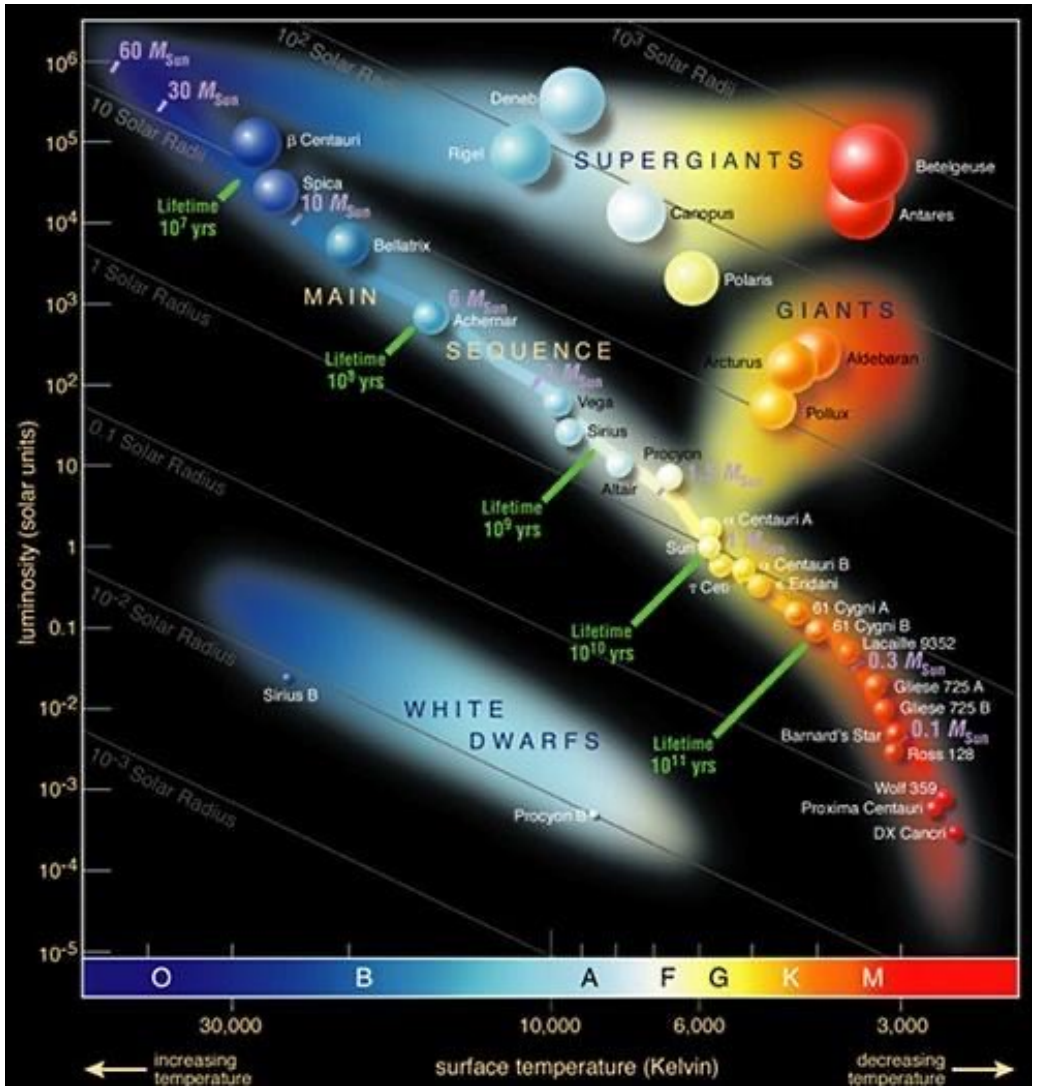
# Red vs Blue


blackbody radiation
x 10^3
Intensity W/(m^2 A)
T=6000.0K, peak at 4829.8A
T=5500.0K, peak at 5268.9A
T=5000.0K, peak at 5795.8A
T=4500.0K, peak at 6439.8A
T=4000.0K, peak at 7244.8A
T=6000.0K, peak at 4829.8A
lambda (visible light:yellow region) A
x 10^4

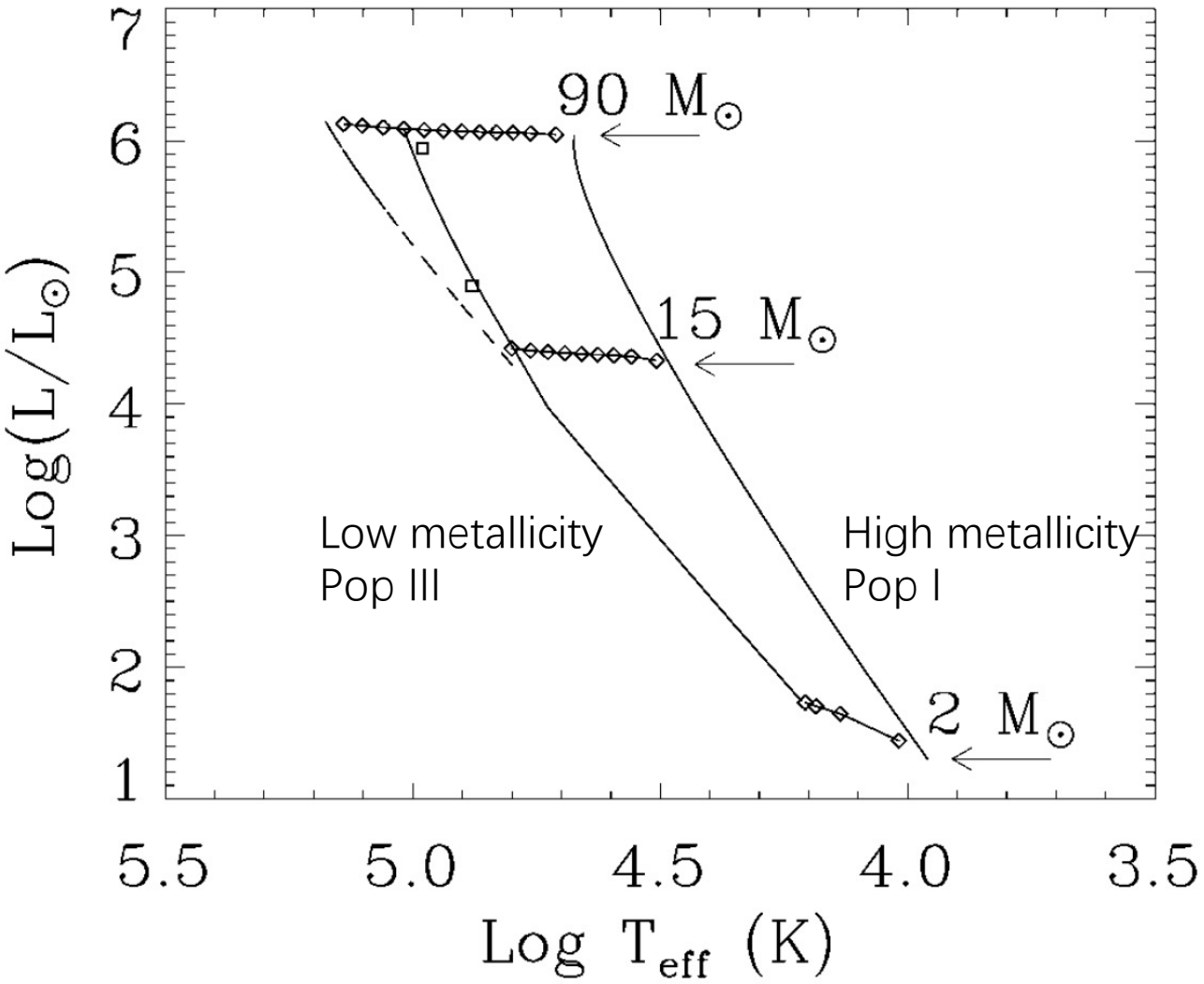

luminosity (solar units)
60 M_Sun
30 M_Sun
10 Solar Radii
10^2 Solar Radii
10^3 Solar Radii
1 Solar Radius
0.1 Solar Radius
10^-2 Solar Radius
10^-3 Solar Radius
Deneb
Rigel
β Centauri
Spica
10 M_Sun
Bellatrix
Lifetime 10^7 yrs
SUPERGIANTS
Betelgeuse
Antares
Canopus
Polaris
MAIN
SEQUENCE
6 M_Sun
Achernar
Lifetime 10^8 yrs
GIANTS
Arcturus
Aldebaran
Pollux
Vega
Sirius
Procyon
Altair
Lifetime 10^9 yrs
α Centauri A
Sun
α Centauri B
ε Eridani
τ Ceti
61 Cygni A
61 Cygni B
Lacaille 9352
0.3 M_Sun
Gliese 725 A
Gliese 725 B
0.1 M_Sun
Ross 128
Barnard's Star
Lifetime 10^10 yrs
Lifetime 10^11 yrs
Sirius B
WHITE
DWARFS
Procyon B
Wolf 359
Proxima Centauri
DX Cancri
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
increasing temperature
surface temperature (Kelvin)
decreasing temperature

# Metal-poor stars tend to be hotter.

$$\frac{dT}{dr} \propto -\kappa(r)L(r)$$

$$\frac{dL}{dr} \propto \varepsilon(r)$$

$$Z \downarrow \quad \kappa \downarrow \quad \varepsilon \downarrow$$

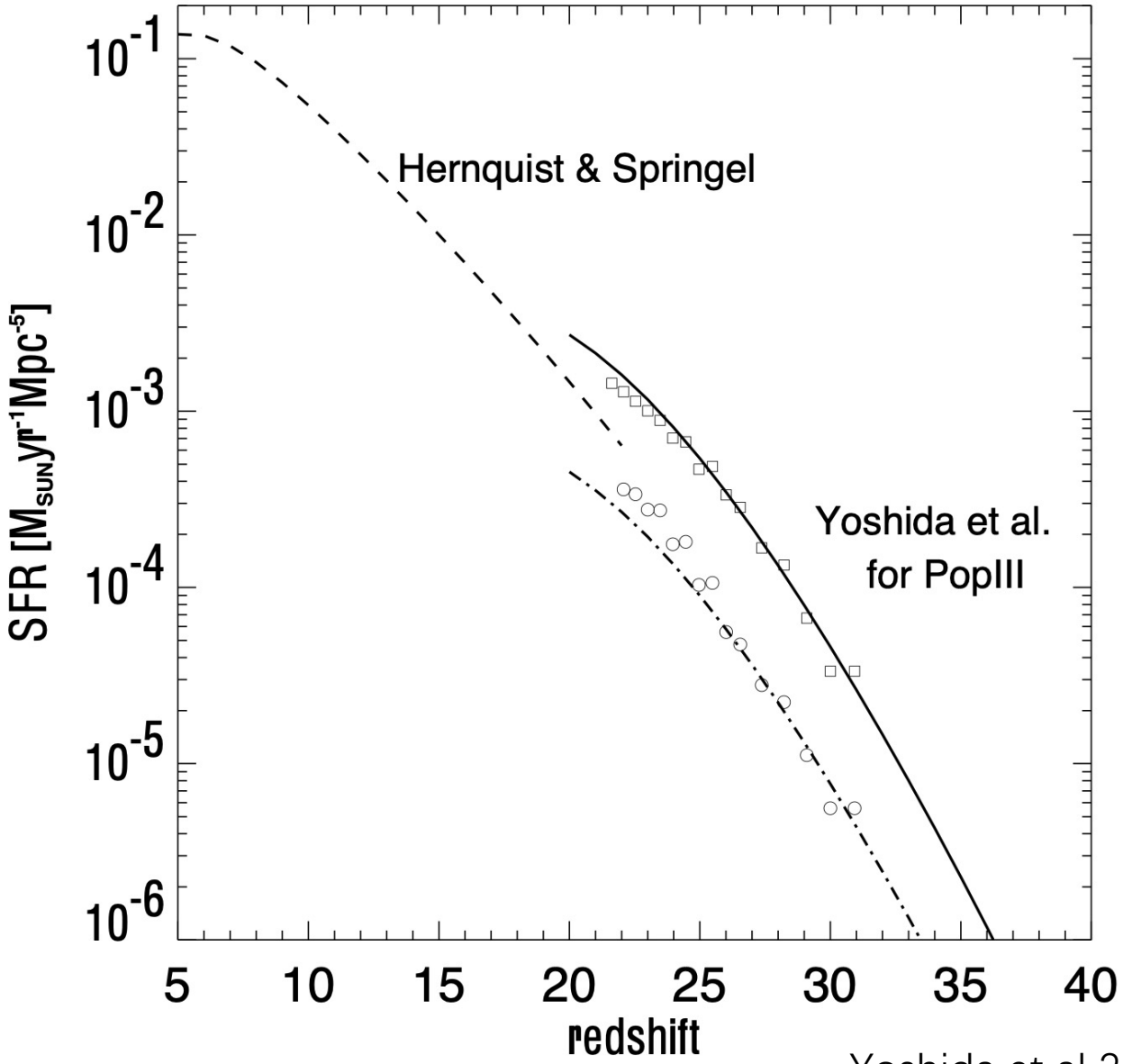



Tumlinson et al 2000

# First stars are massive, faint, metal-poor and rare.

- M≈10-1000 $M_\odot$
- z≈10-50
- Z≈0
- T≈ $10^5$ K

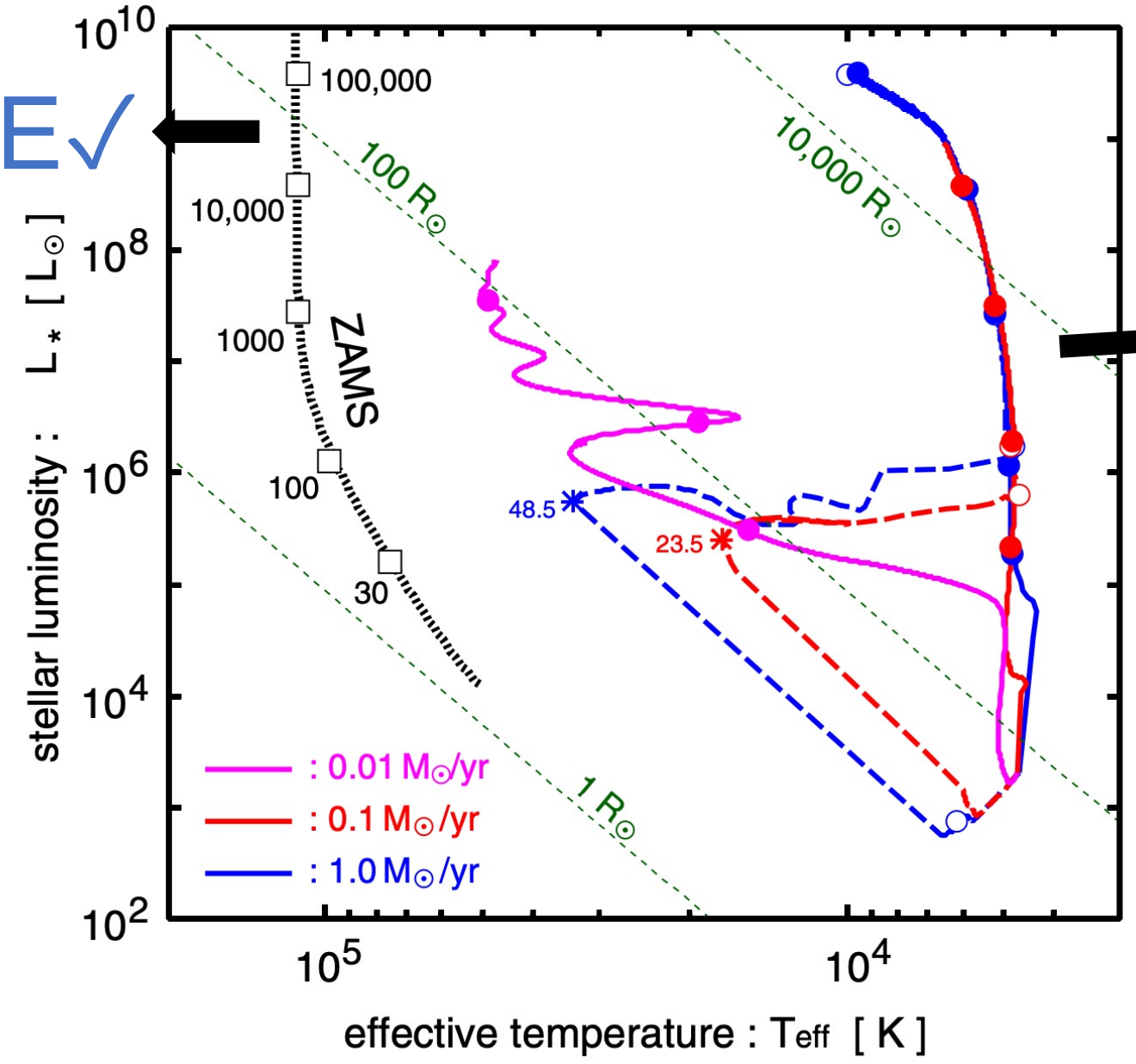
BLUE!




Yoshida et al 2003

However

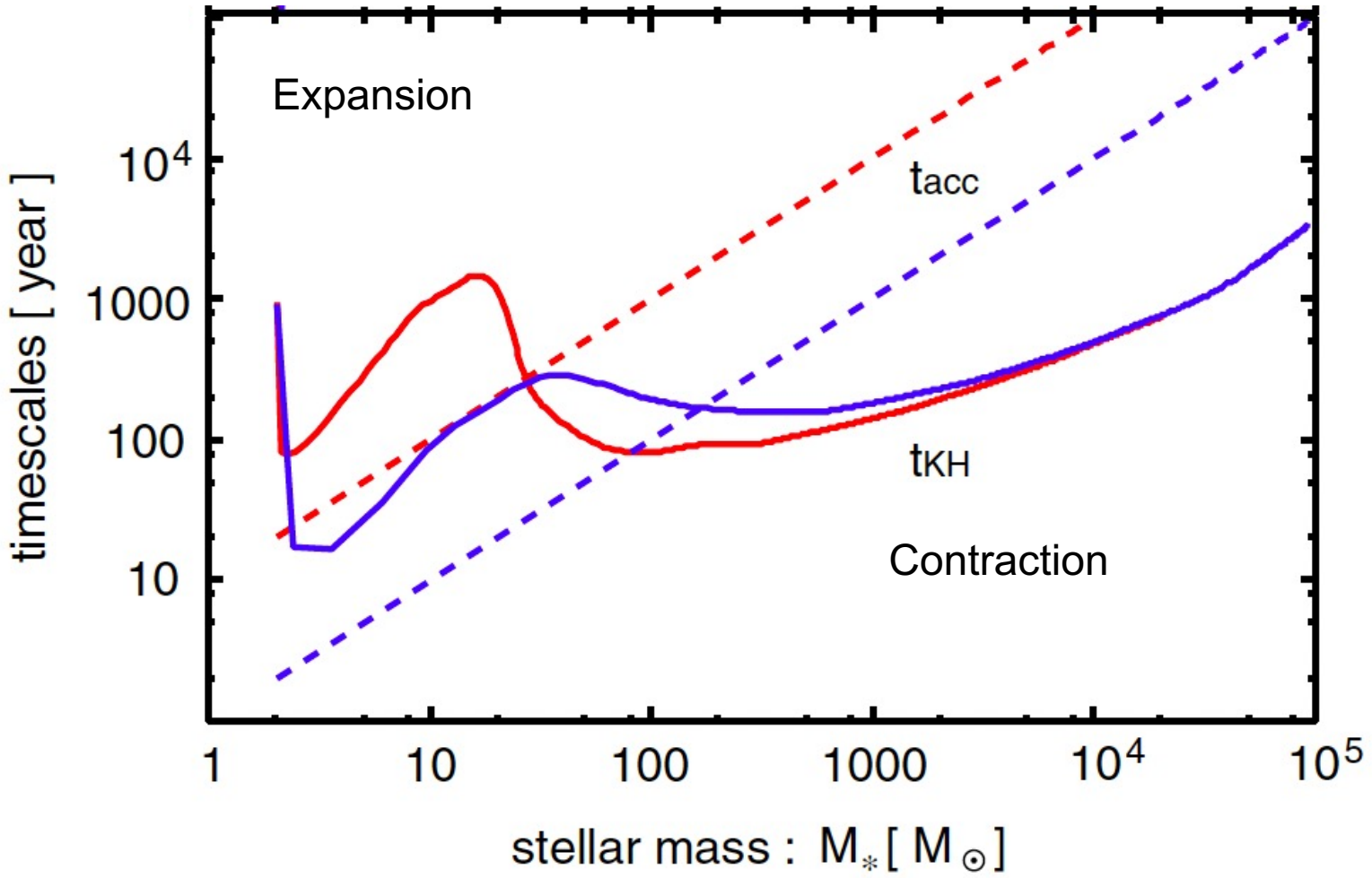
BLUE✓




RED?

Hosokawa et al 2013

# Rapid accretions push down the temperature.



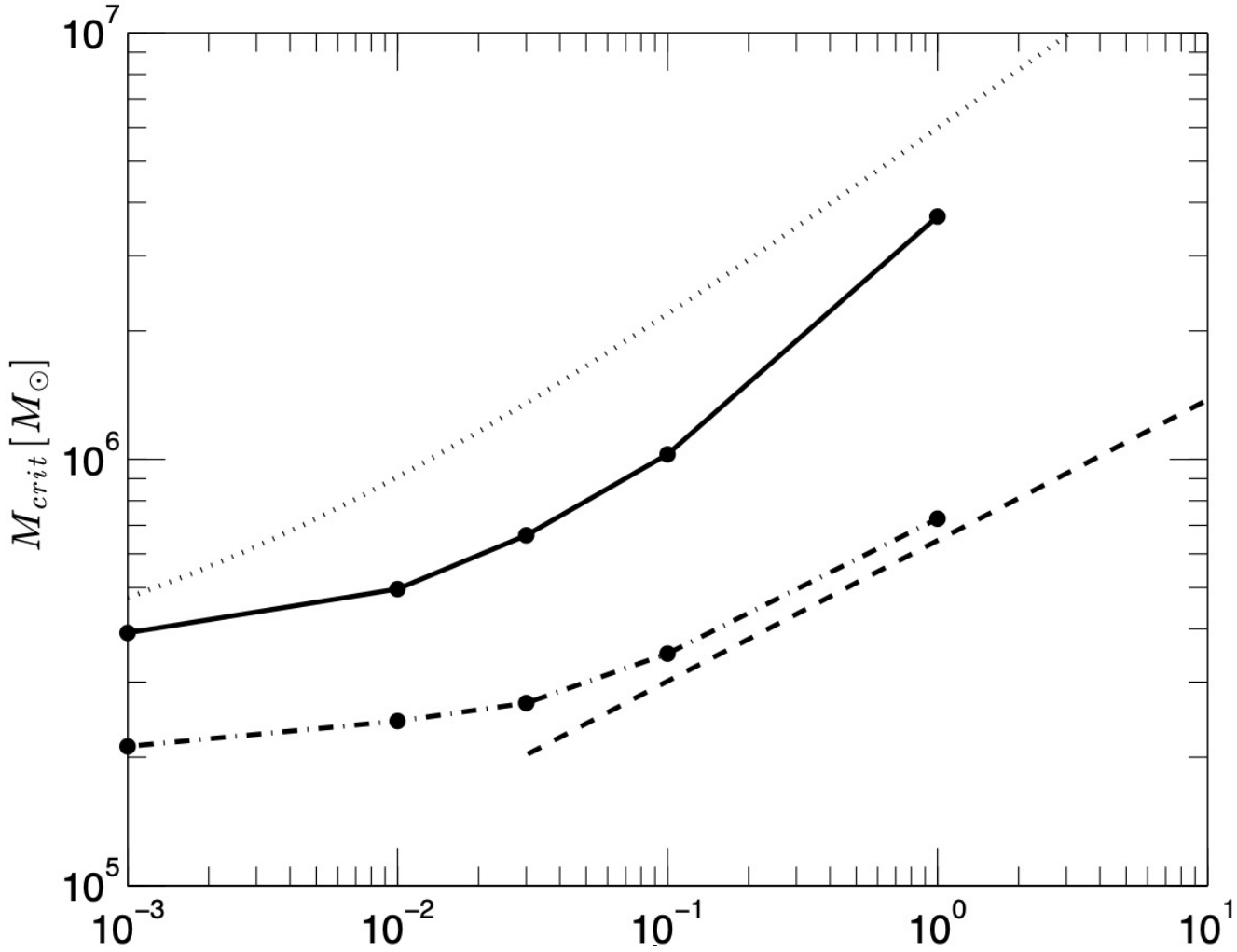

$$t_{acc} = \frac{M_*}{\dot{M}_*}$$

$$t_{KH} = \frac{GM_*^2}{R_* L_*}$$

Hosokawa et al 2013

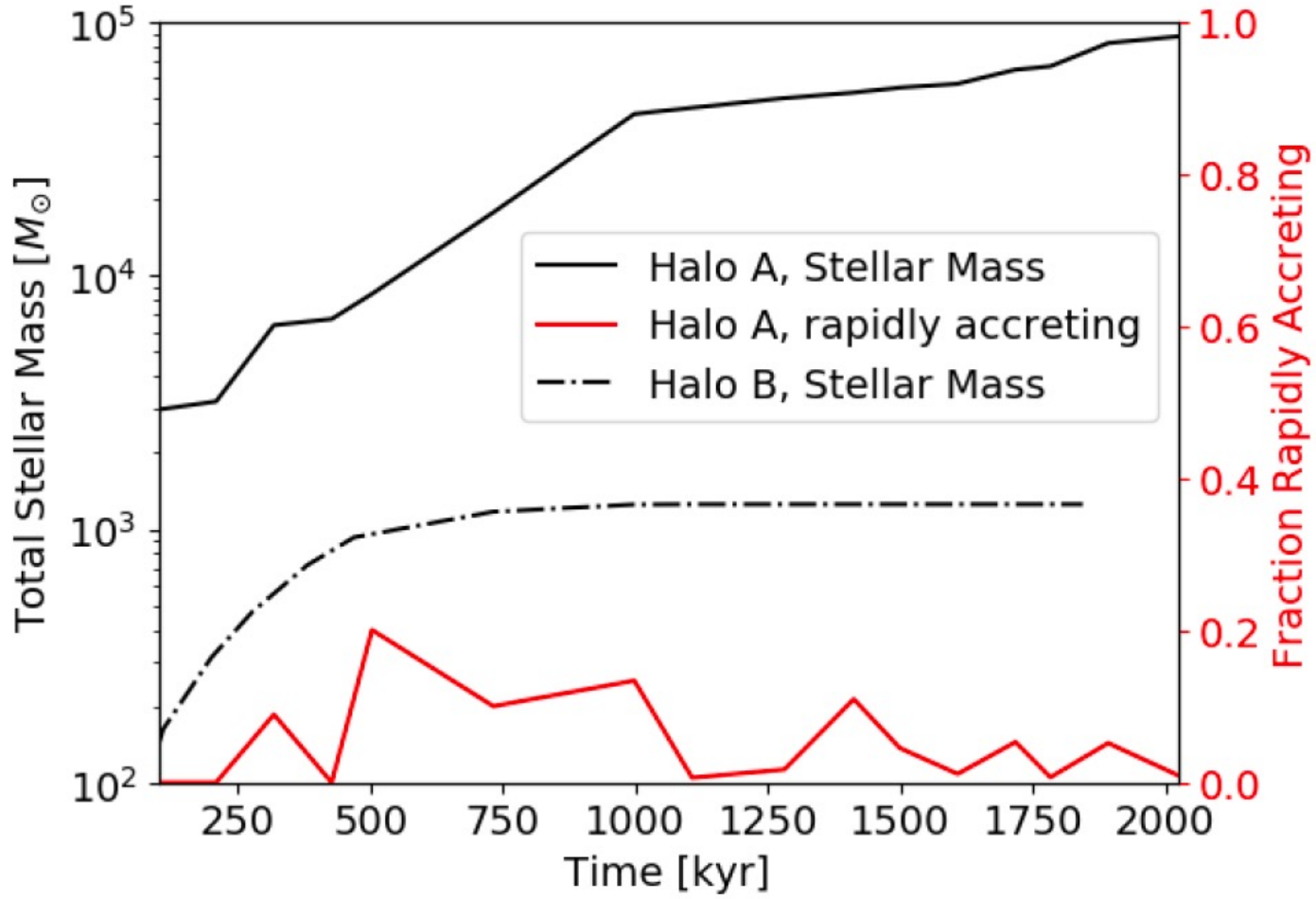
# More massive halo can result in rapid accretion.

Lyman-Werner background
Dynamical heating
…




Visbal et al 2014

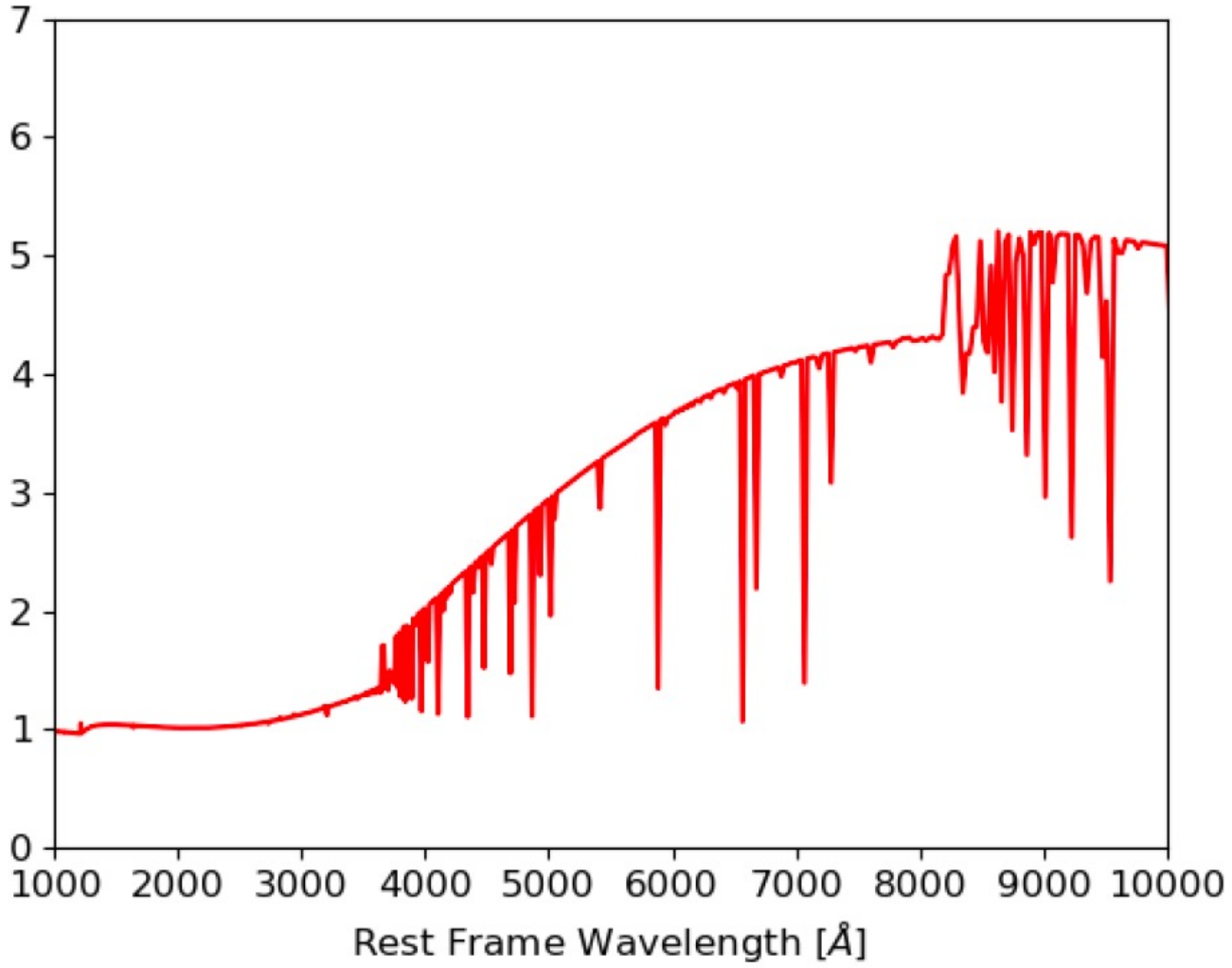
# Rapid accretion phase cannot be sustained.




Wood et al 2021

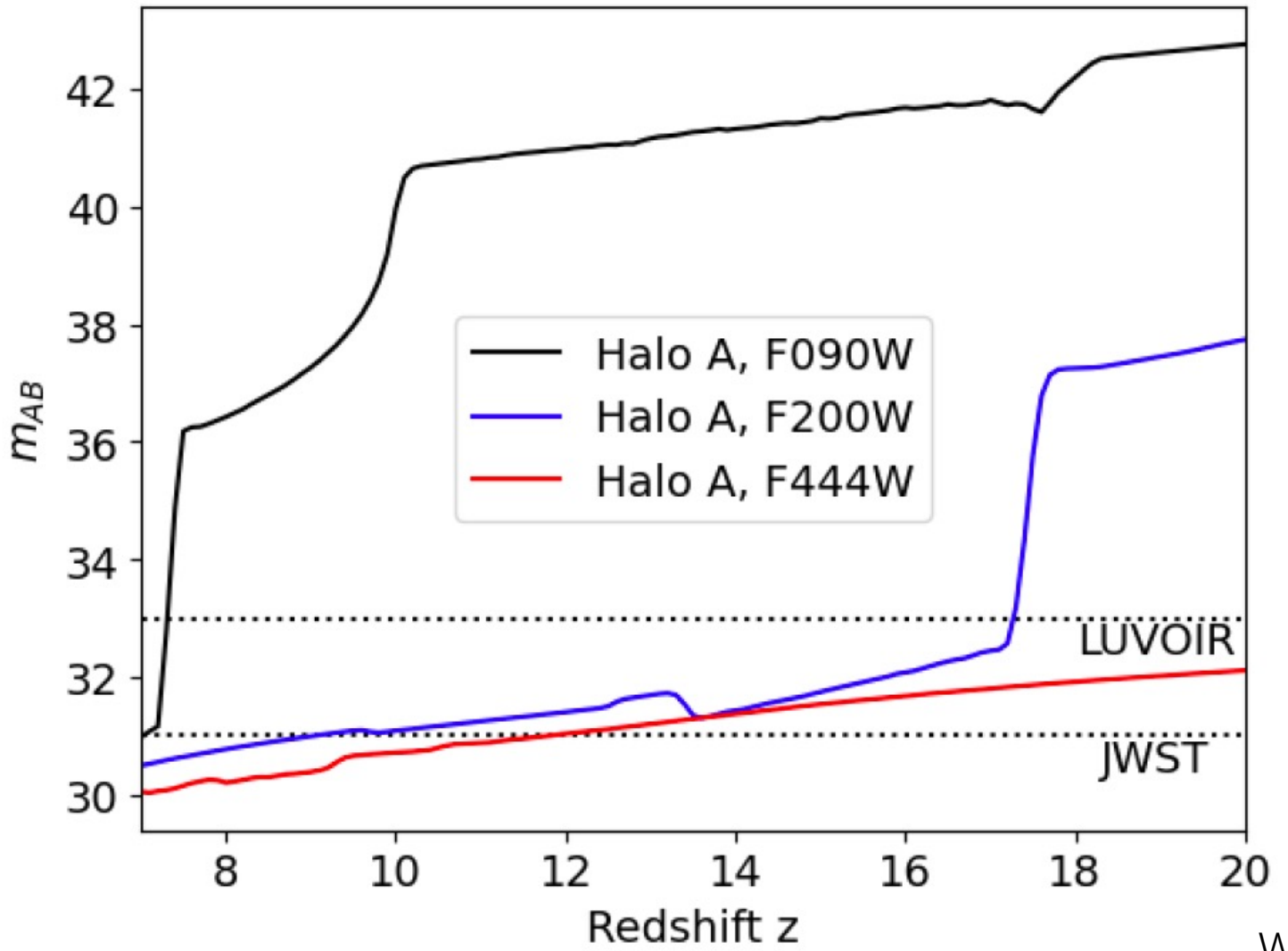
# We might see a broad continuum enhancement.

$$\frac{F_{\text{rapid accreting}}}{F_{\text{quiescent}}}$$




Wood et al 2021

# Observation possibility




Wood et al 2021

# Summary

- Pop III stars could be red during rapid accretion phase.
- JWST/LUVOIR can detect these color variations in the future.

# Comment and Question

- Such rapid accreting Pop III stars will change the understanding of the mechanism for first star formation.
- The reddening spectra might be strongly attenuated.
- We need extra strong evidence to distinguish such PopIII stars from Pop II or Pop I stars.