

First Stars and Galaxies, the Roadmap Ahead: Theory

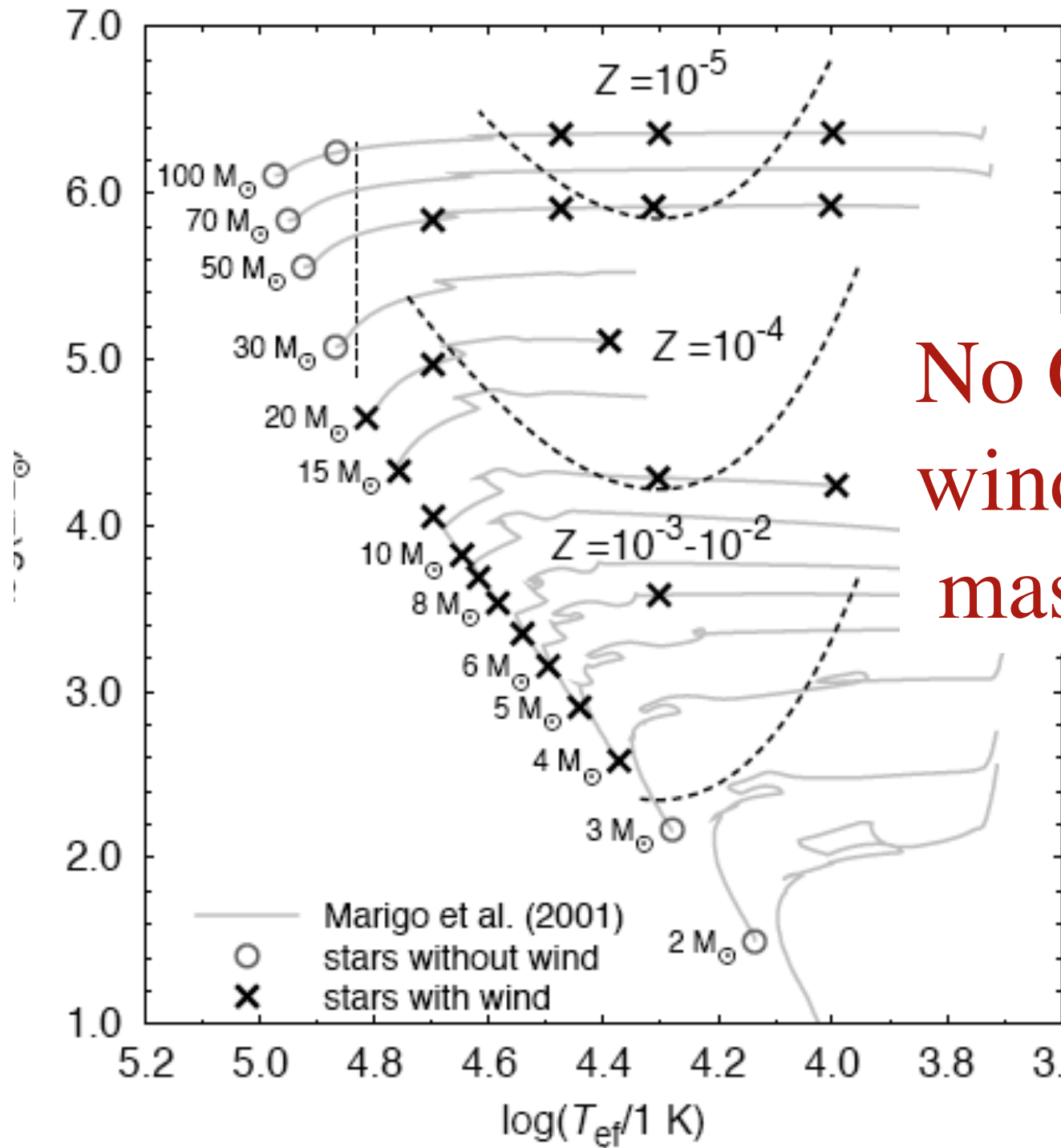


First Stars

pp and triple alpha burning occur

CNO cycle takes over after CNO exceeds $\sim 10^{-10}$

Rotational mixing dredges up CNO



No CNO-driven winds in first massive stars

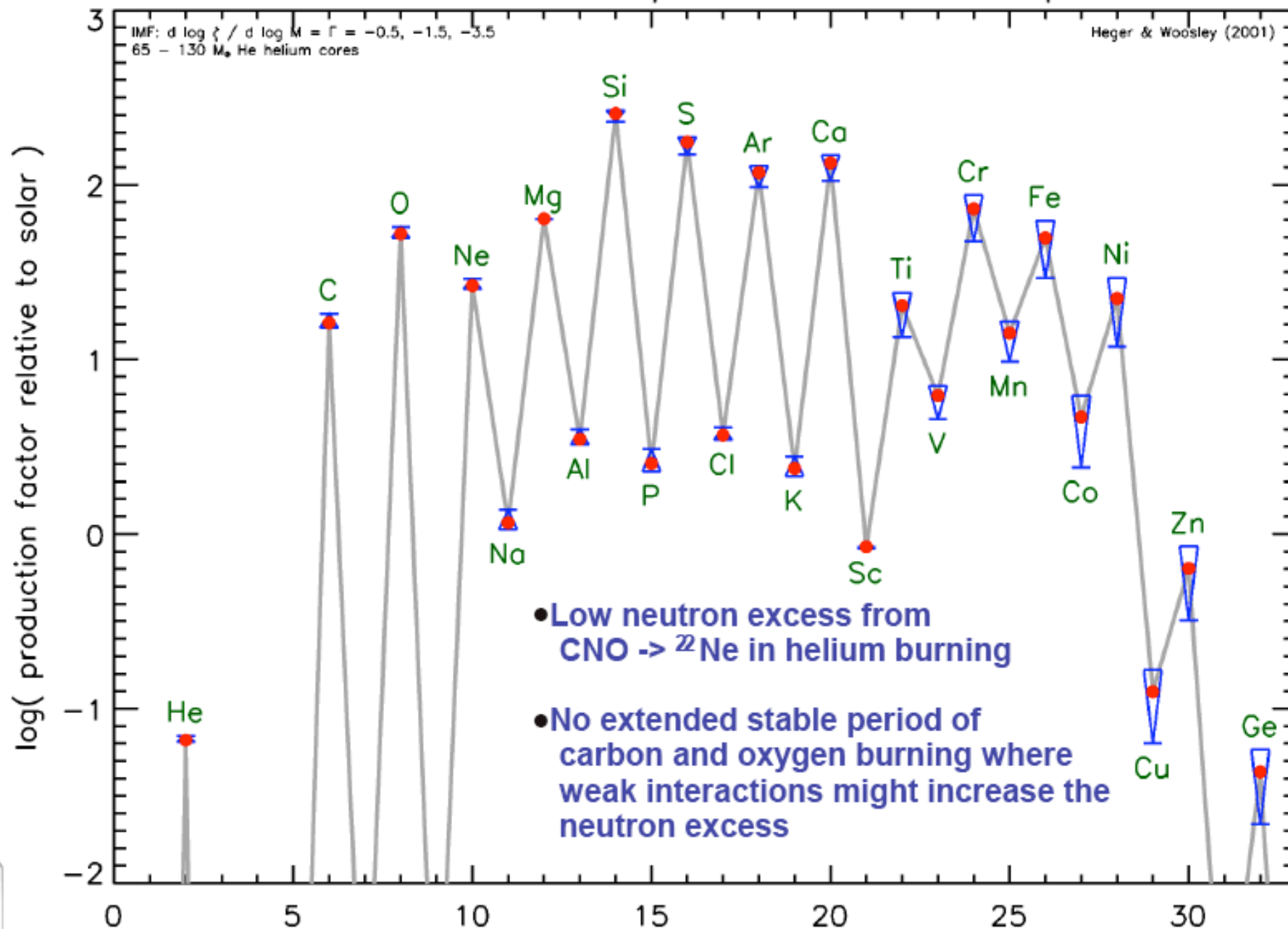
Krticka & Kubat 08

POP III.anything

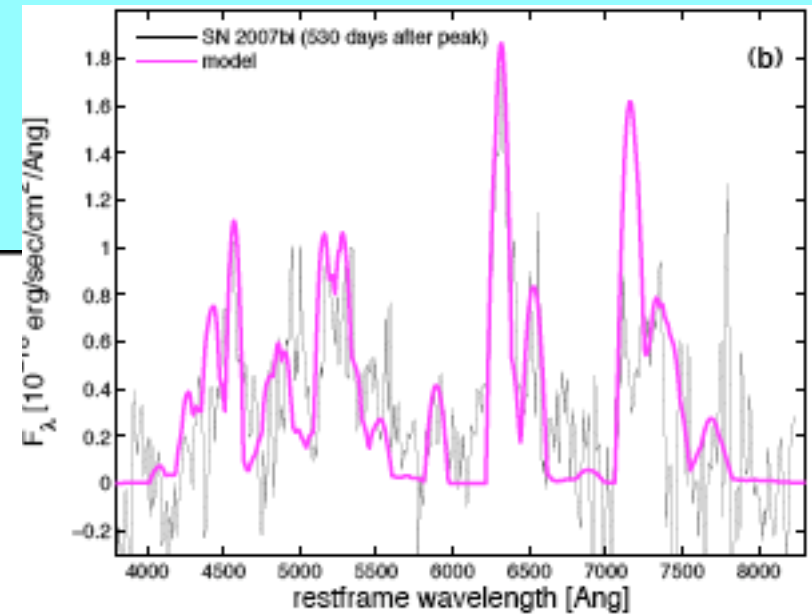
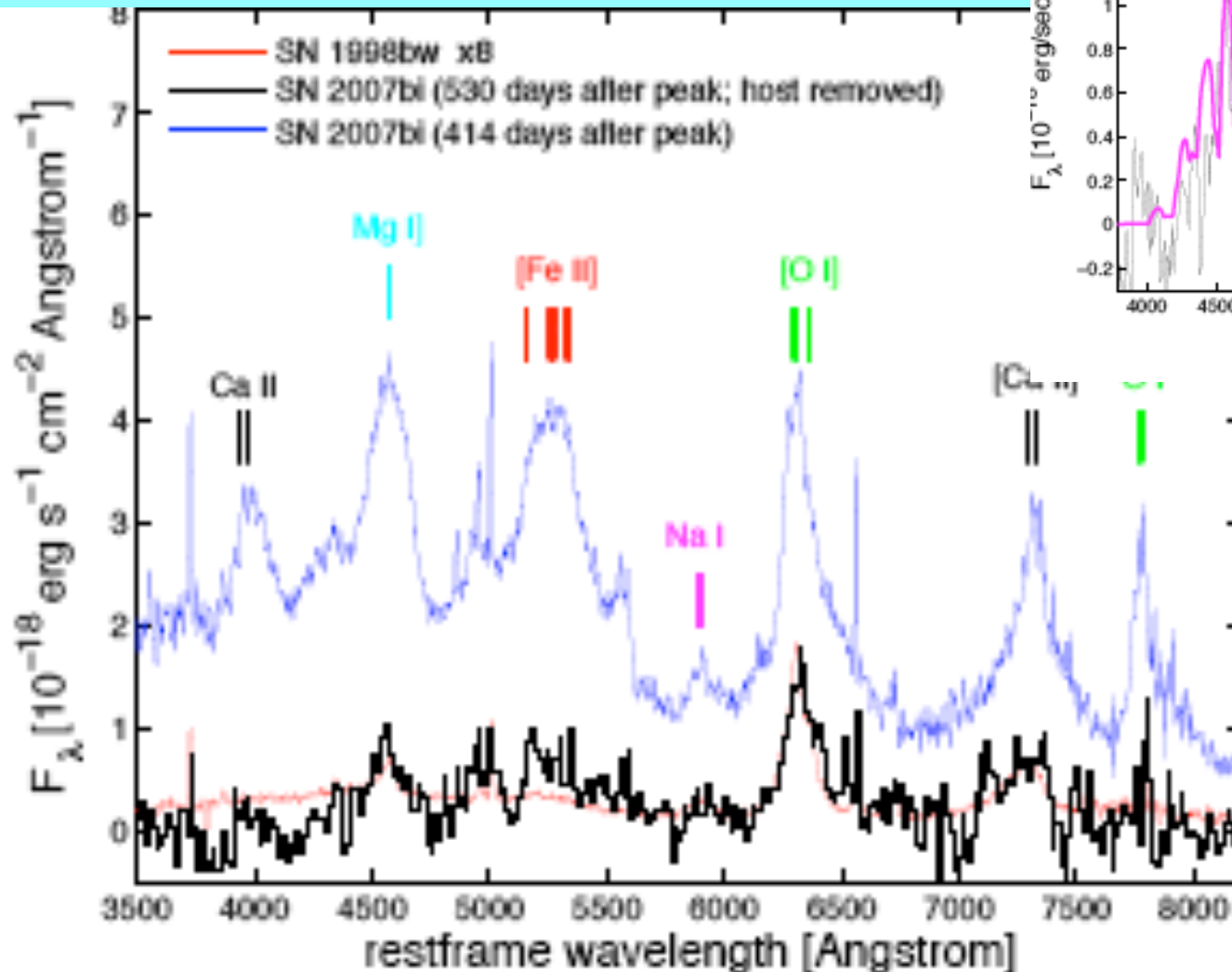
Z=0

Pair Instability supernovae
are probably inevitable

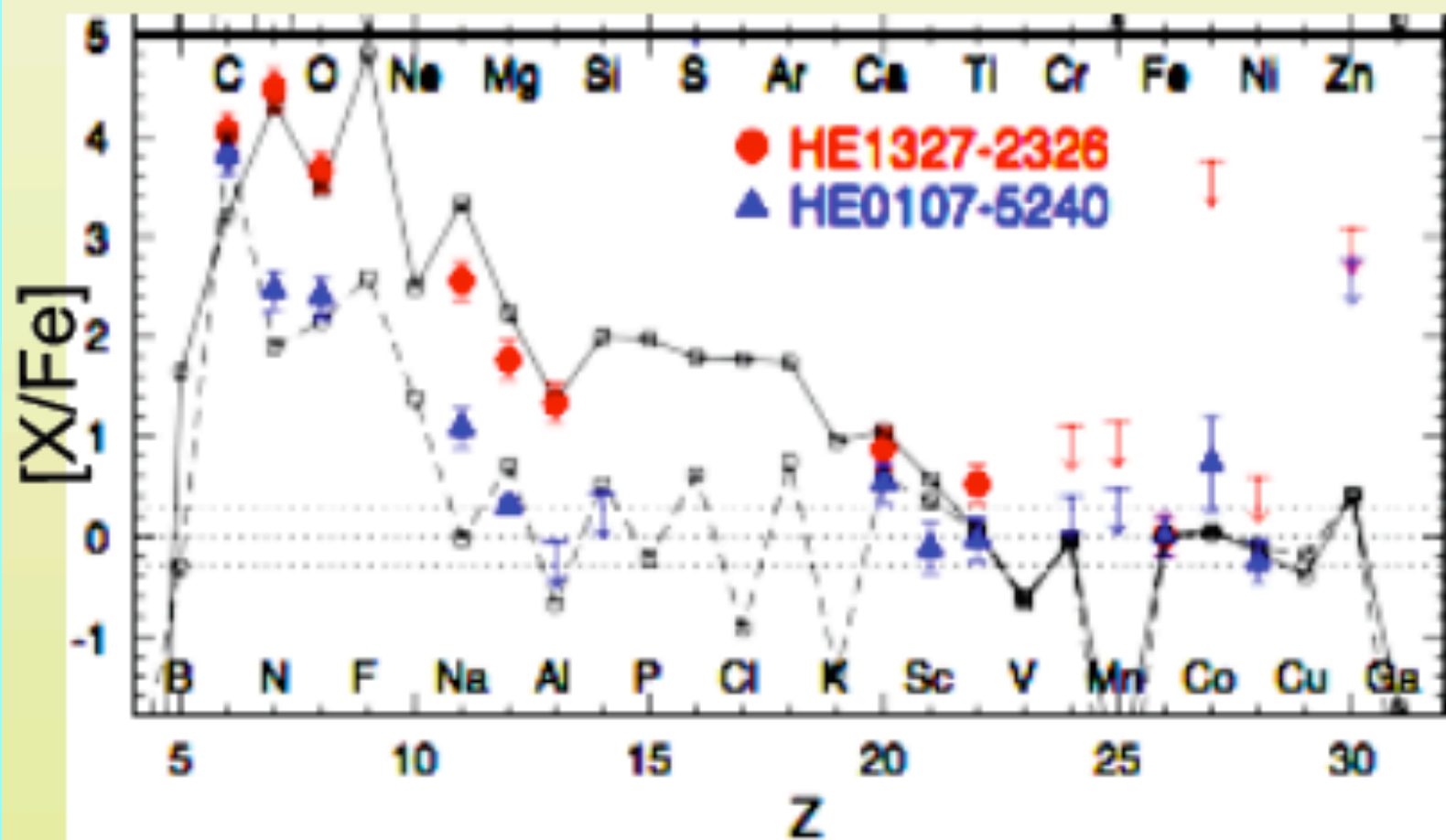
Production Factor of Pop III Pair Creation Supernovae



Has a PISN been discovered?



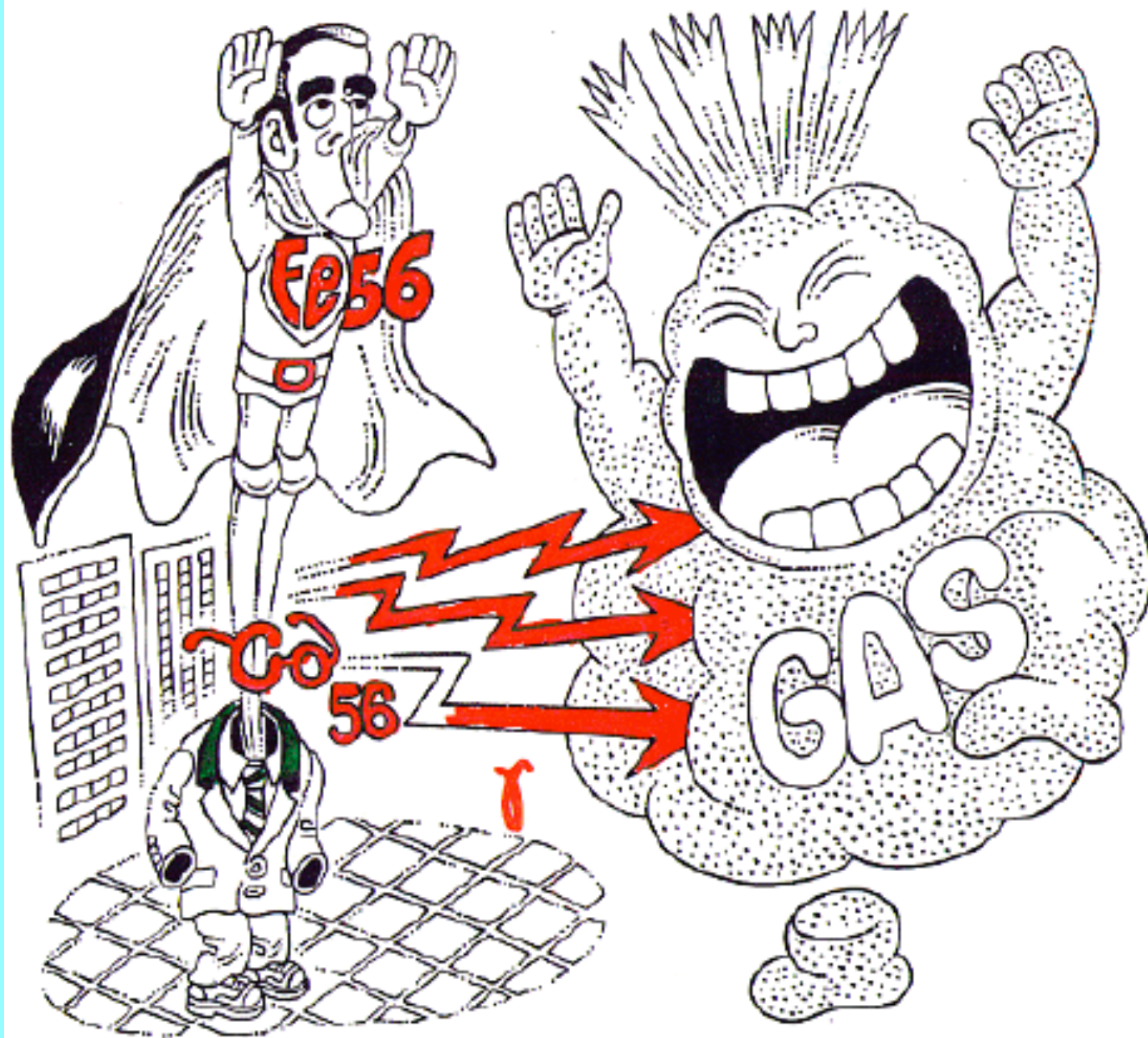
HMP stars $[Z] < -5$



Tominaga et al. 2007

25Msun faint
 mixing and fallback SN
 (mass, expl. energy, mass cut)

UMP stars $-5 < Z < -4$



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Ken Nomoto

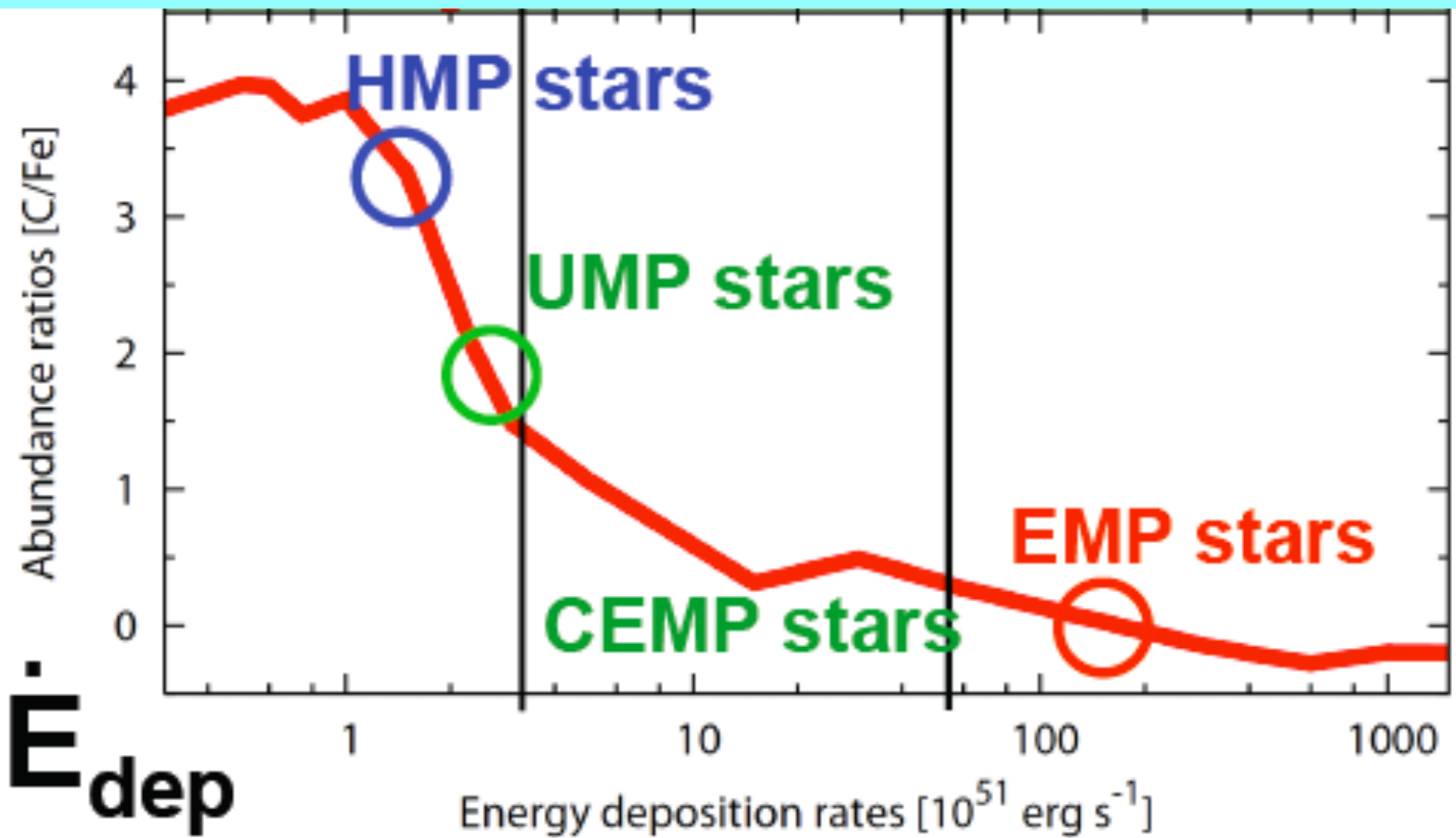
$\sim 100 M_{\text{sun}}$ core collapse SN

+ fall-back: low Fe, faint SNe

+ jet-induced explosion...high (C, Co, Zn)/Fe

Extremely luminous SN 2007bi:

Ni^{56} decay fuelled ... GRB connection



Alex Heger

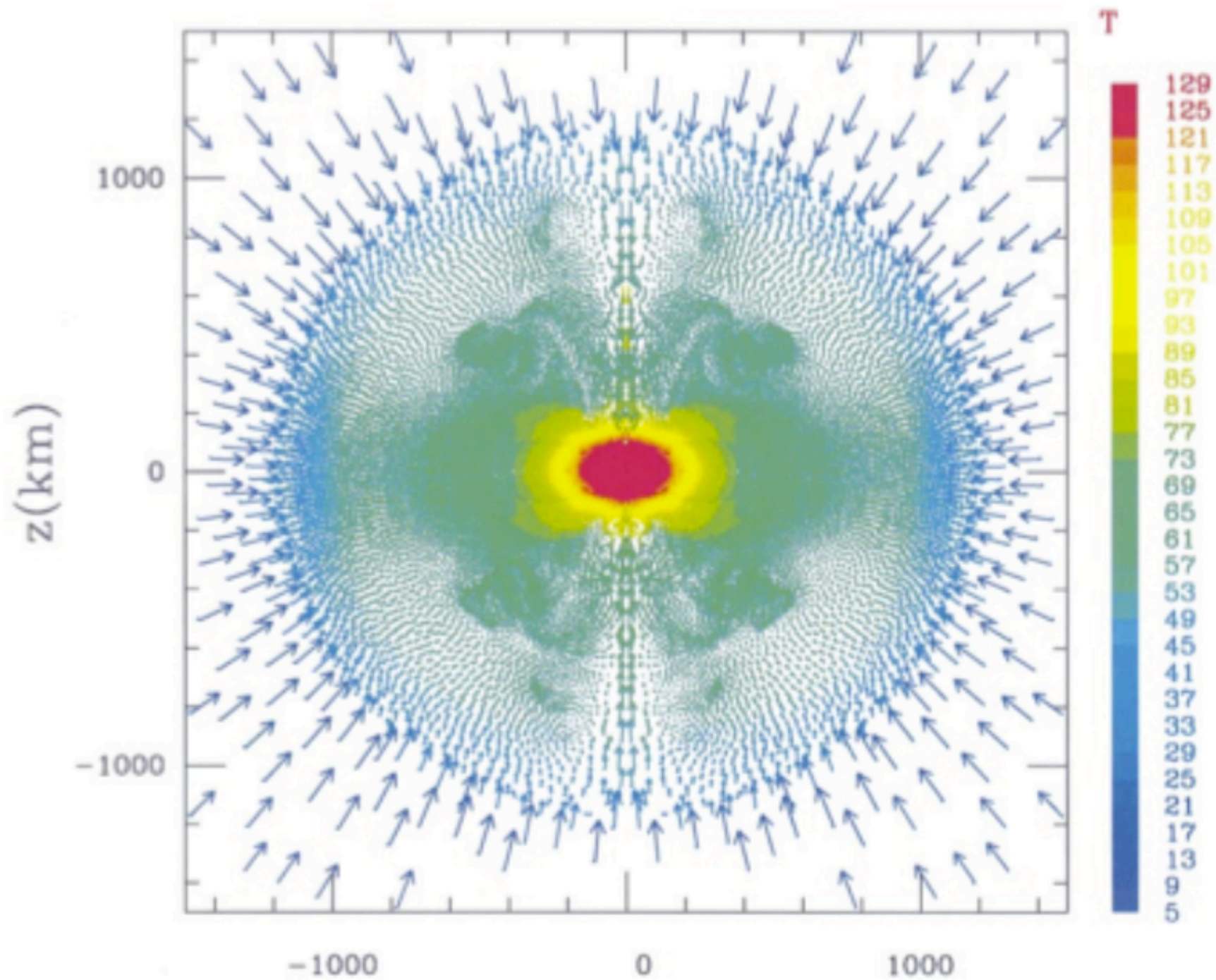
140-300 M_{sun} PISN: good news after all!

Core -envelope mixing,

pulsational CNO ejection to enrich UMPs

He compact core collapse to 100 M_{sun} BH

One more complication



Chris Fryer

Dan Kasen

Environment counts...shocked debris

PISN x-ray burst at breakout

0.1 keV -2000Å rest frame

duration several days in observed frame at hi z

Feedback

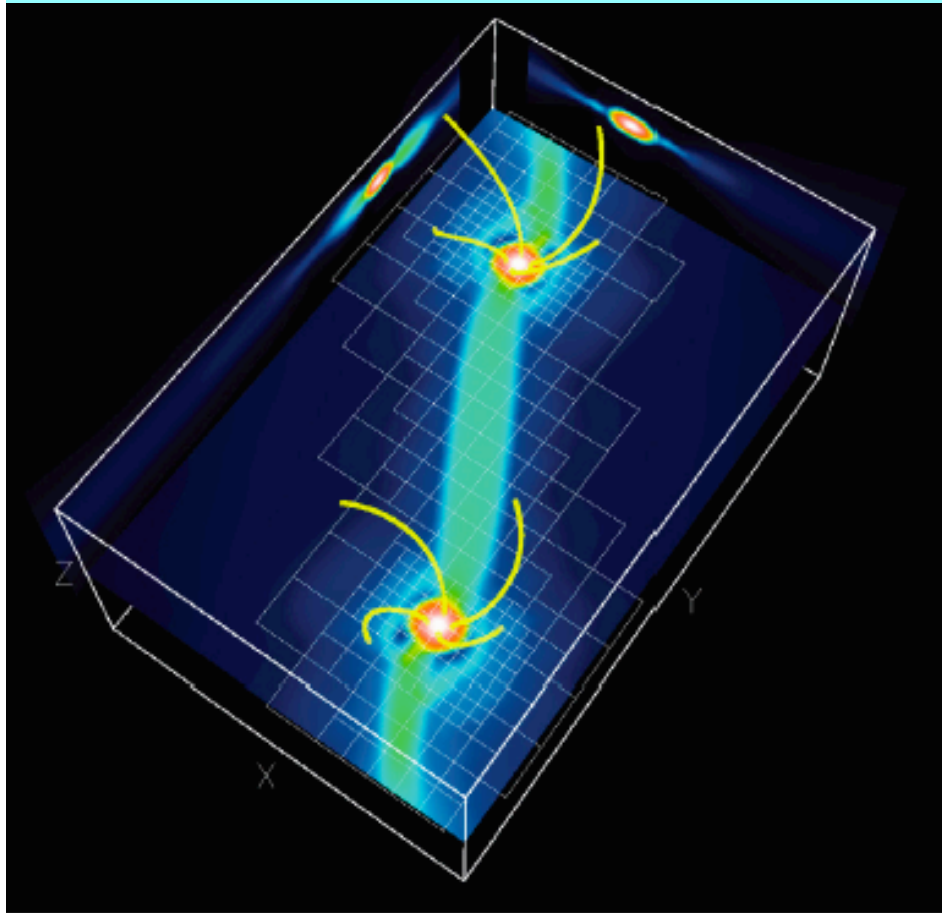
Ralf Klessen

Masahiro Michida

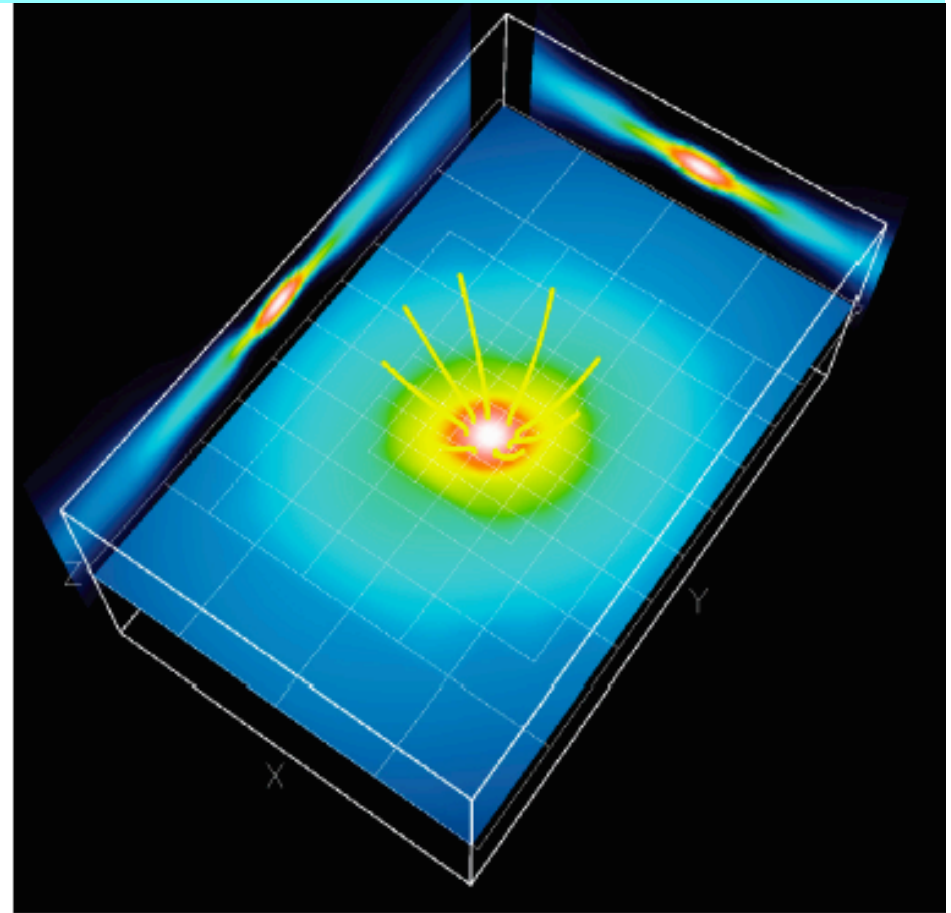
Tom Abel

Feedback is everything

**B suppresses fragmentation, but very
large B needed to modify PopIII IMF**



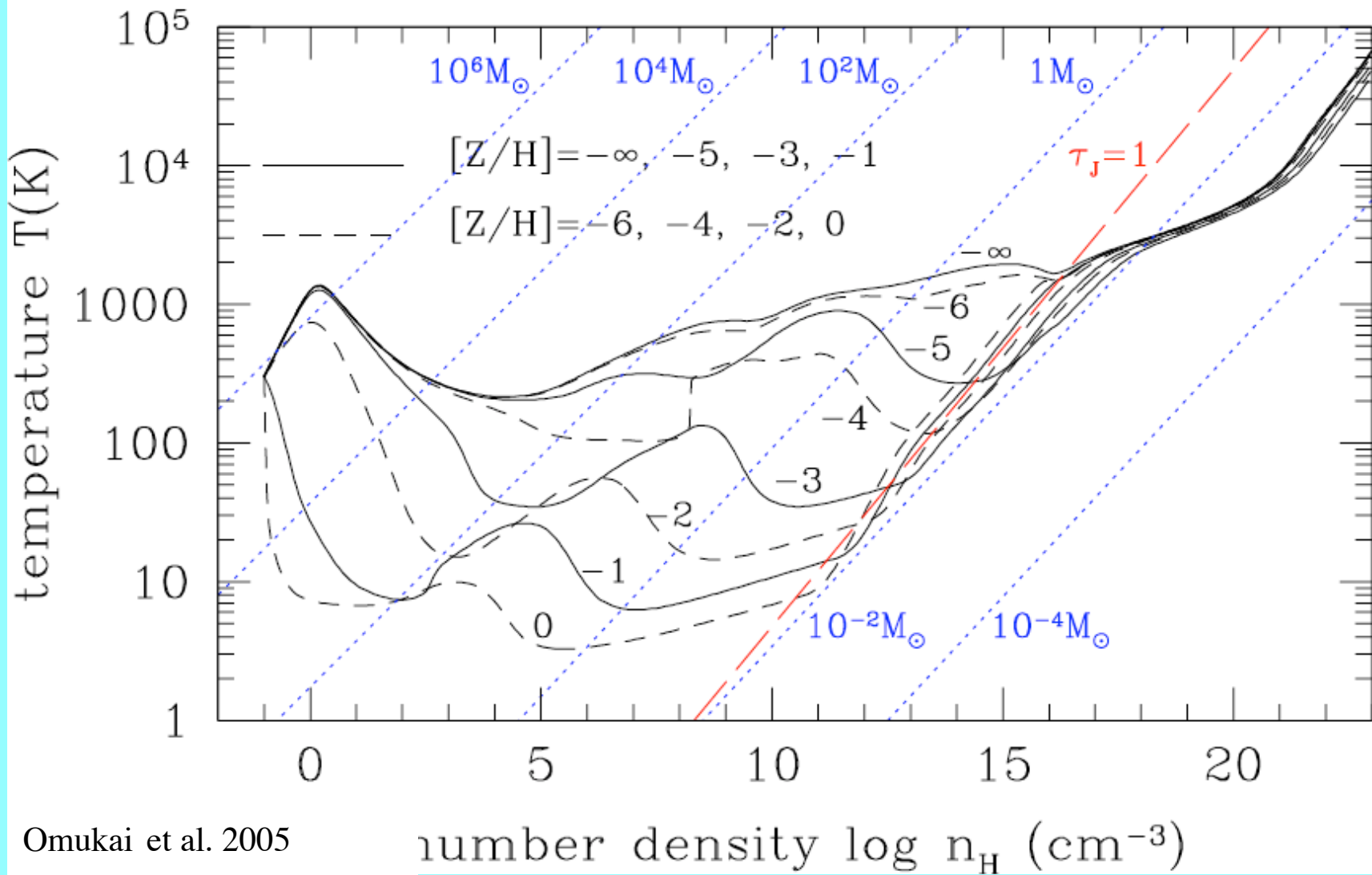
weak field: binary formation



sufficient field strength: single star

Where does B come from?

Fragmentation



the Omukai diagram

Matt Turk

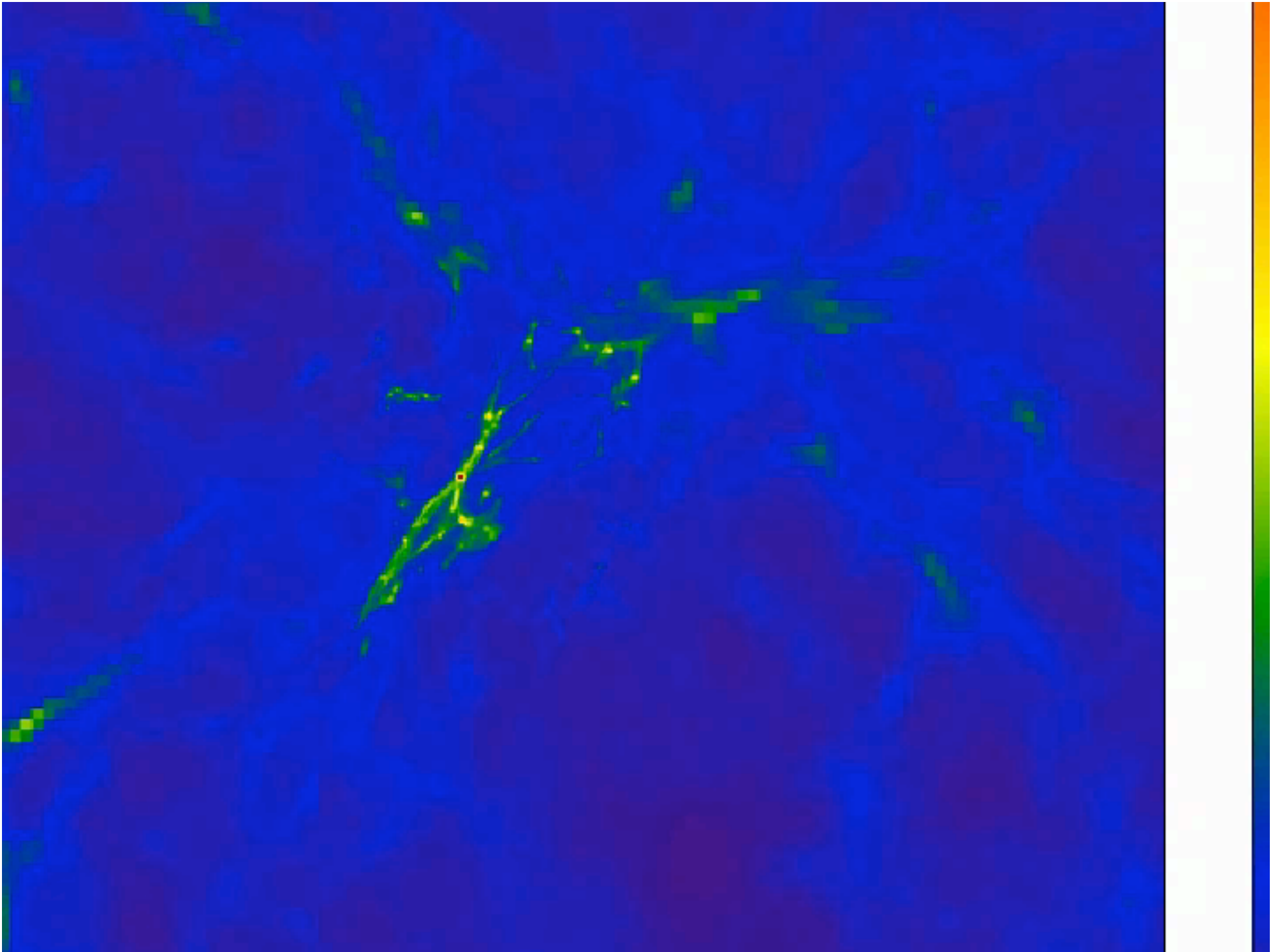
Paul Clark

Angular momentum transfer in
protostellar disk

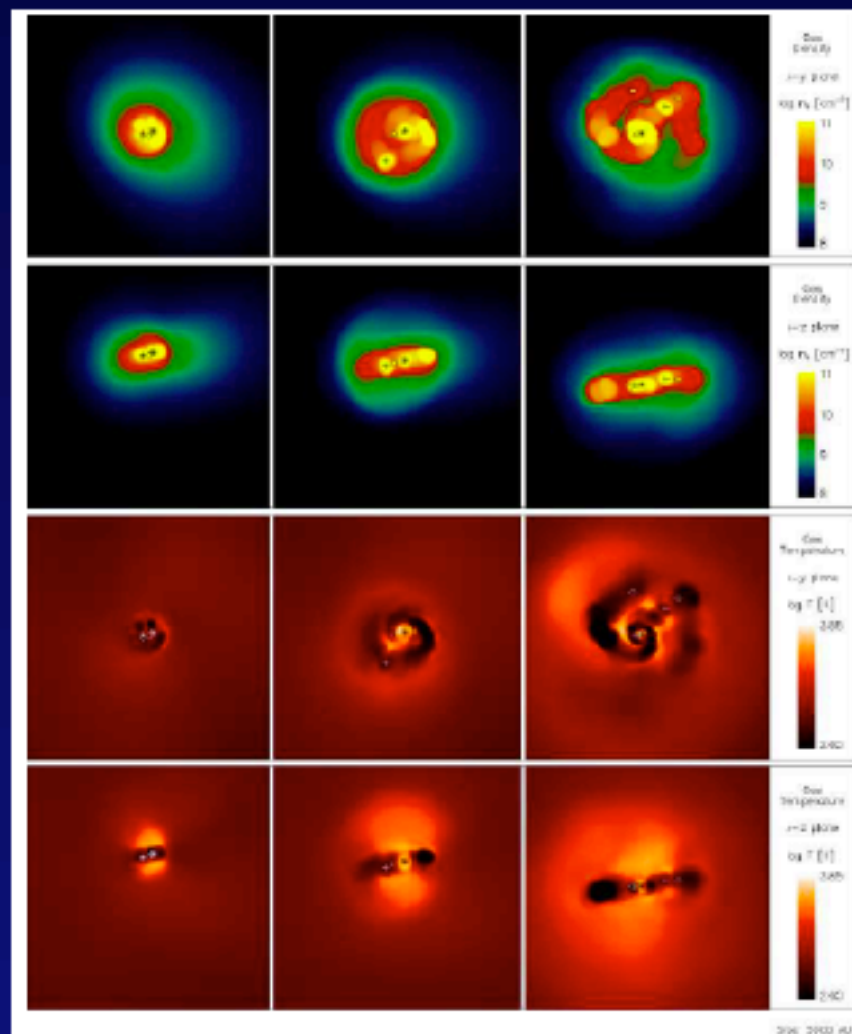
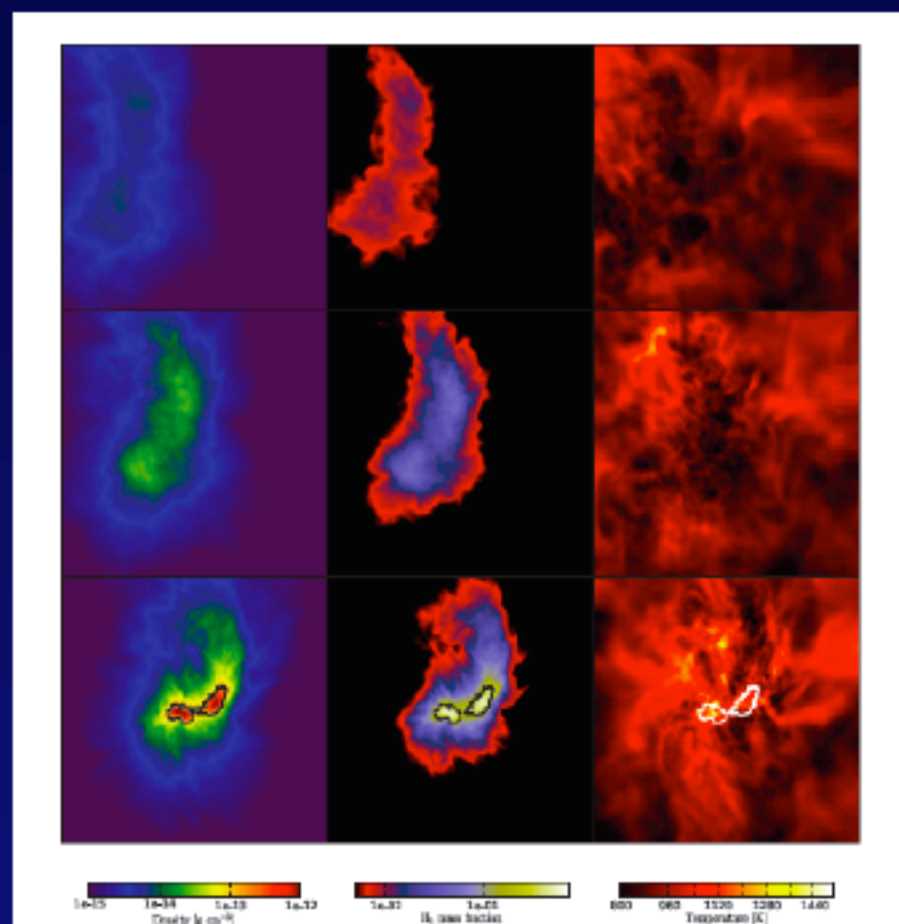
Unstable to fragmentation

Down to solar mass at $Z=0$?

Forms binaries: 1 in 5?



Population III Binaries



Turk, Abel, & O'Shea 2009

Stacy, Greif, & Bromm 2009

Jonathan Tan

It's a long way to stars!!

*And what happens outside the
central parsec??*

WIMPs

Katie Freeze

Fabio Iocco

WIMP-annihilation powered stars

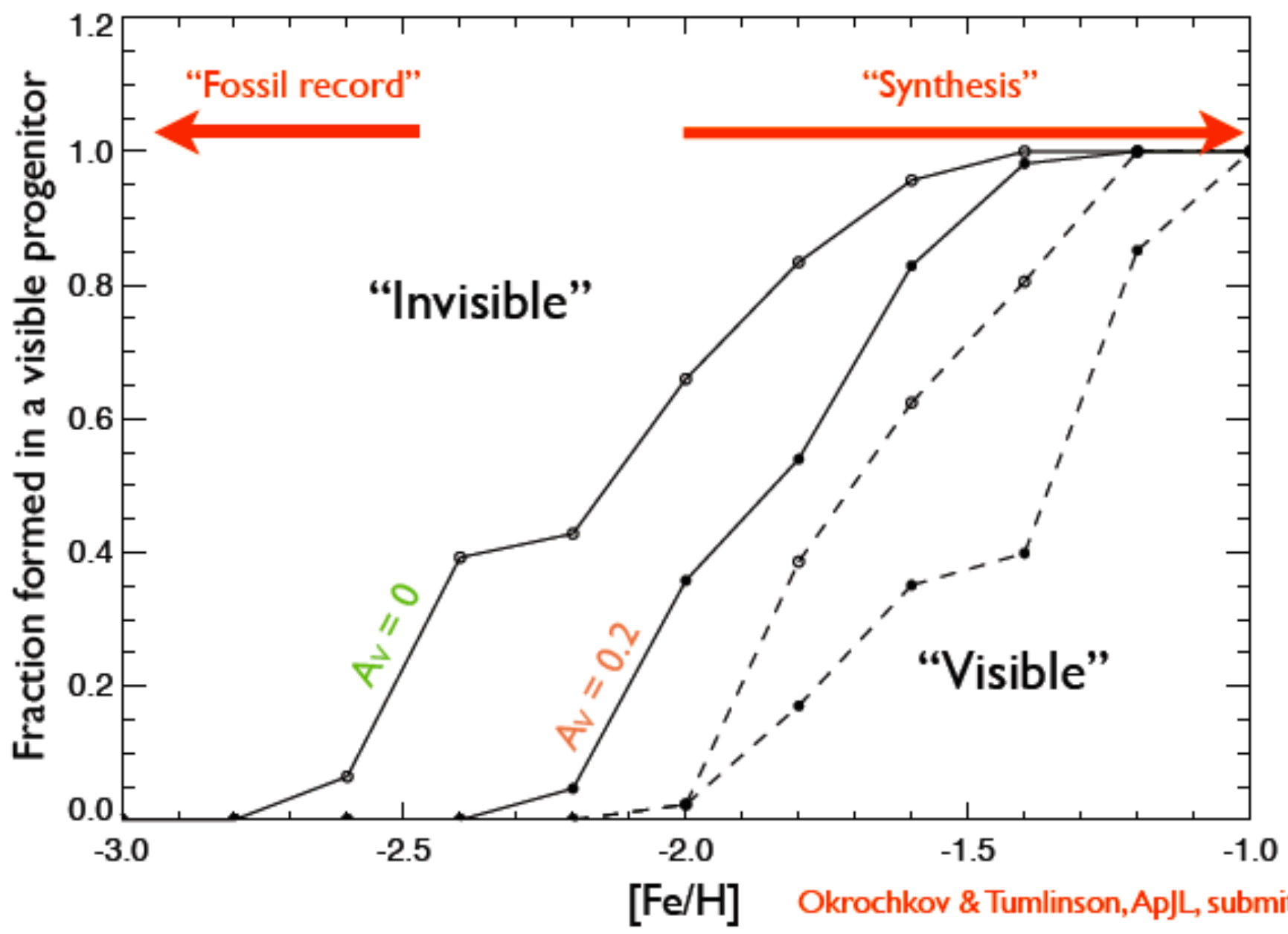
**but if the first stars formed by merging
are dark matter cusps destroyed?**

Where is Pop III?

Jason Tumlinson

galactic archaeology

complements high z universe



Tim Beers

Outer halo is where to trace Pop III signatures

Jason Tumlinson

Look in the bulge for Pop III

Brian O'Shea
Michele Trenti

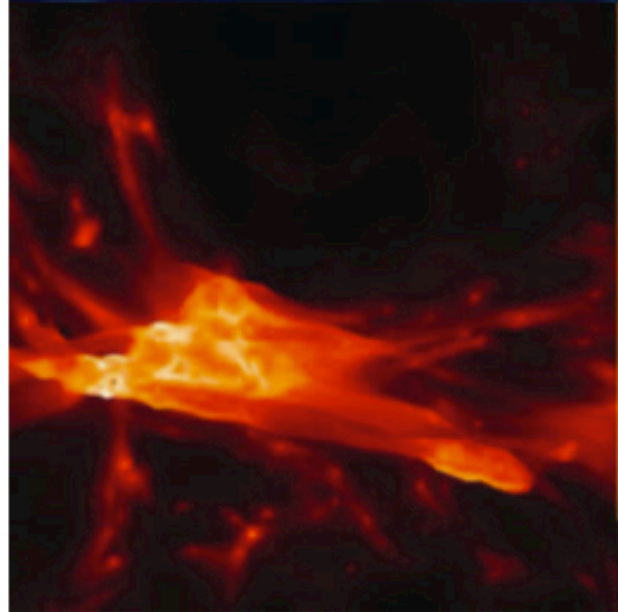
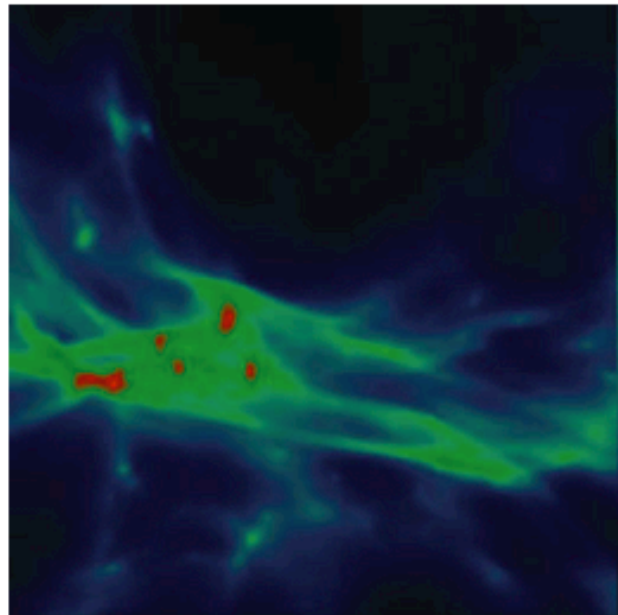
UV/FUV delays PopIII

Results in more massive minihalos

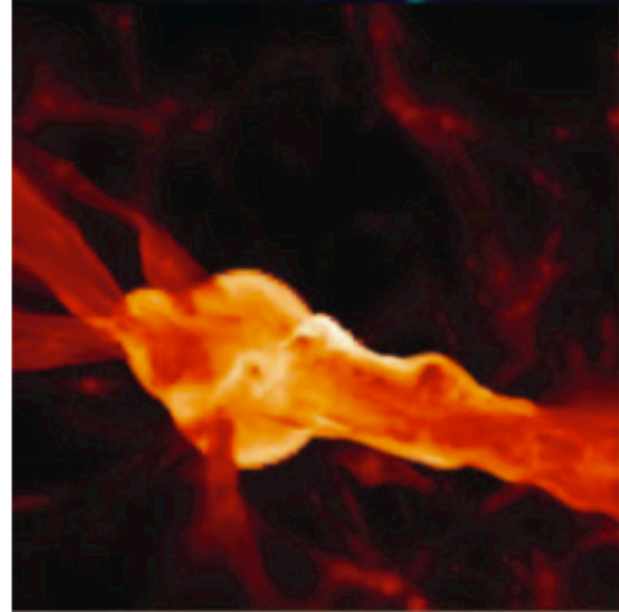
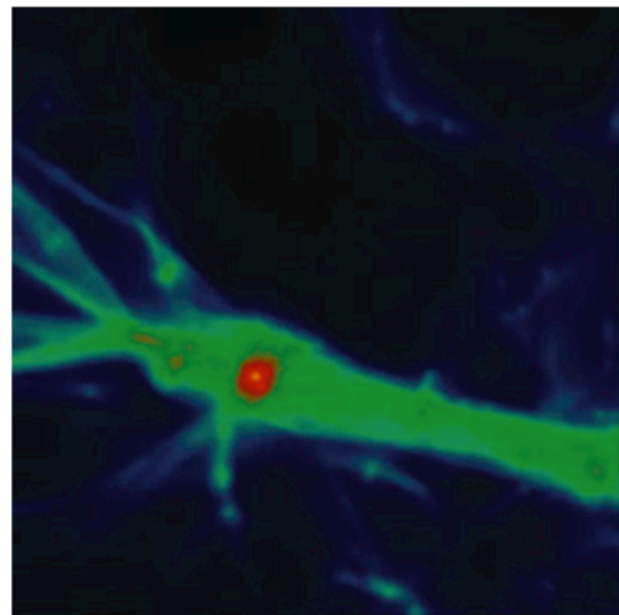
Pop III relics in voids?

Pop III subdominant (10%) in EMP

$z_c = 24.1$
 $M_v = 5.7e5$



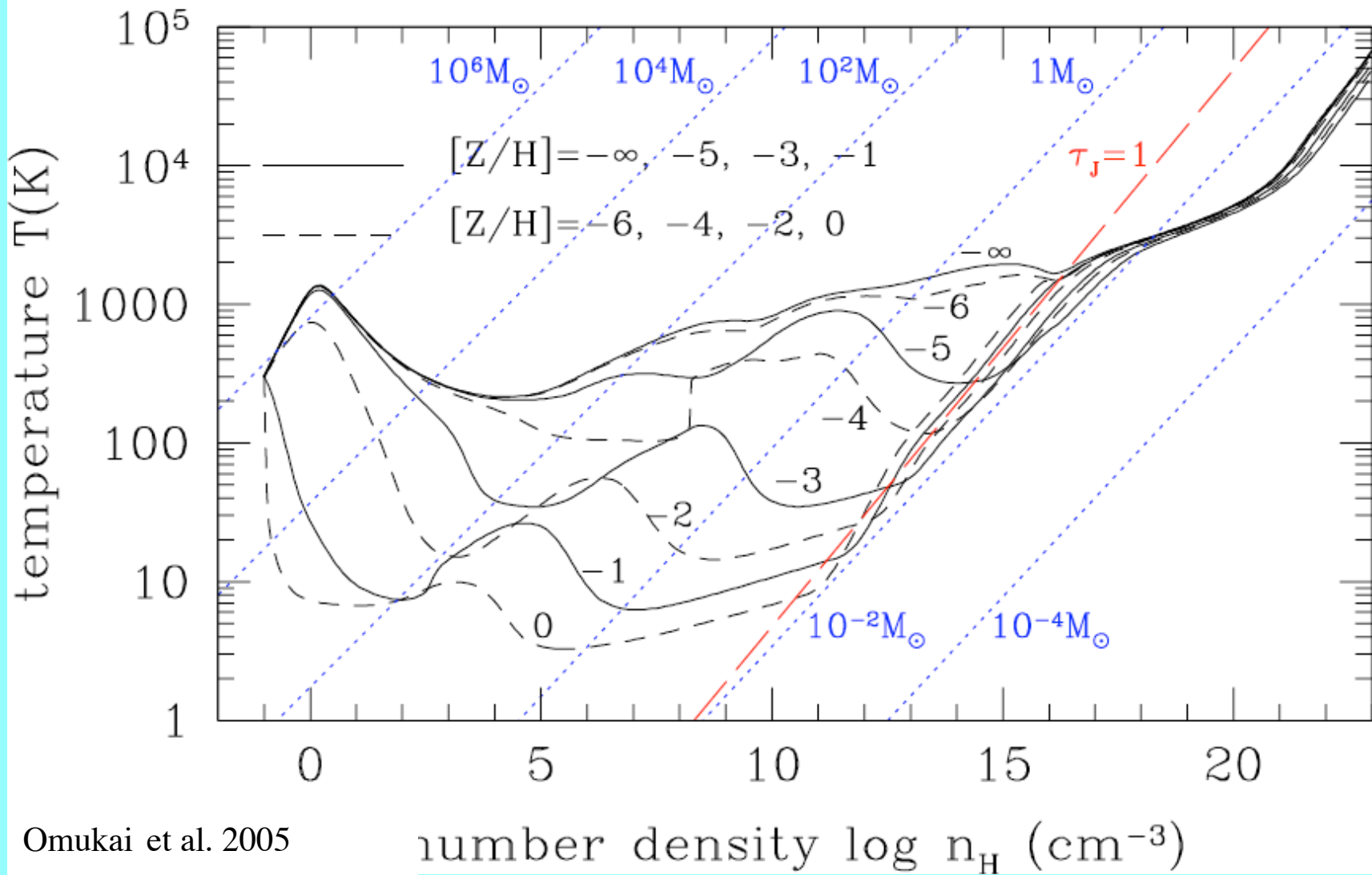
$J_{21} = 0$



$z_c = 17.3$
 $M_v = 1.3e7$

$J_{21} = 1$

Pop III-Pop II transition



the Omukai diagram

Kazu Omukai

Raffella Schneider

Eli Dwek

Britton Smith

Fragmentation to $0.01 M_{\text{sun}}$

+ accretion to $\sim 100 M_{\text{sun}}$... to be confirmed!

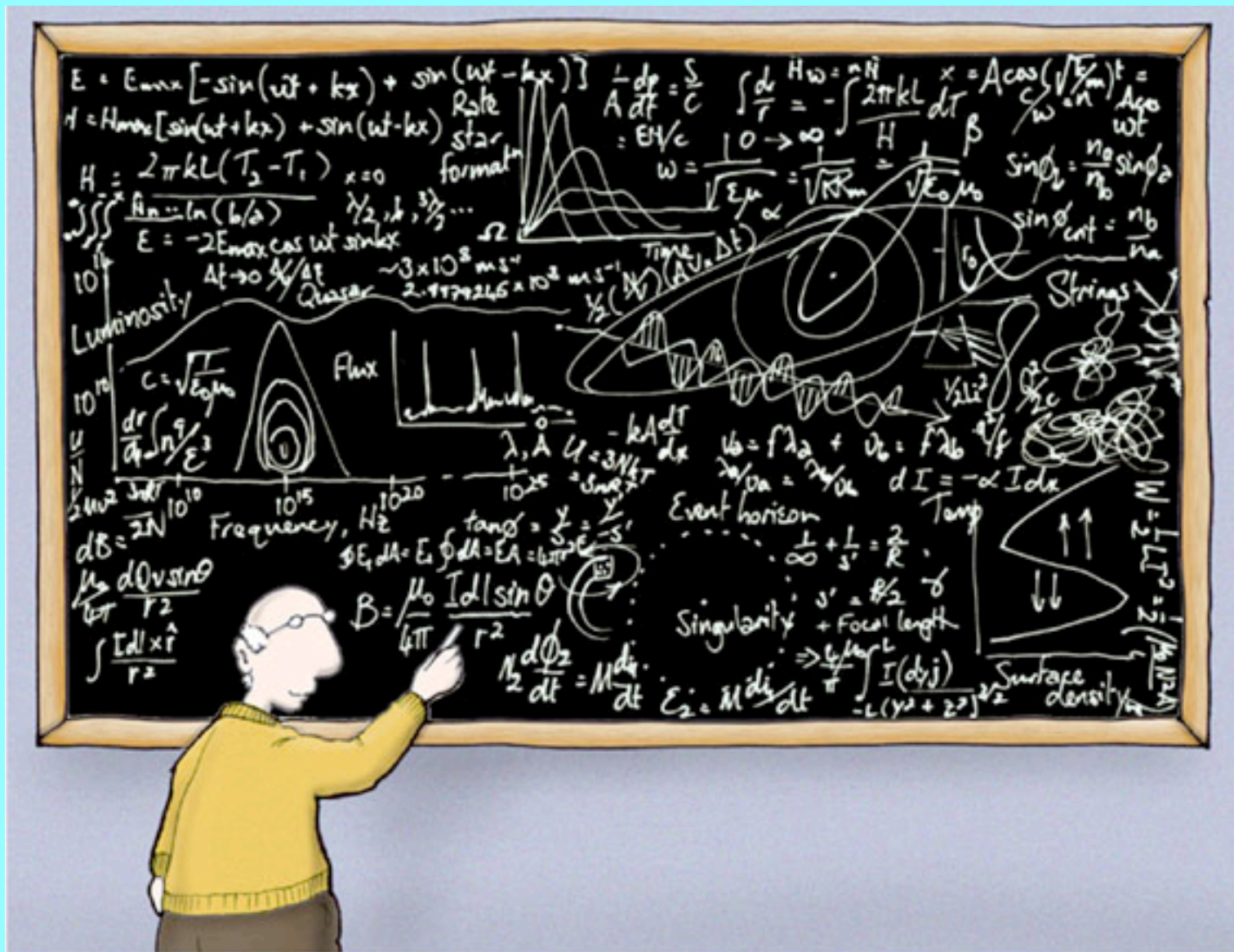
Dust threshold marks PopII transition, enhances fragmentation

Is enough Pop III dust formed...destroyed?

CMB floor to fragmentation at $z=20$...affects PopIII IMF?

Does B or Z dominate the transition?

Reionization

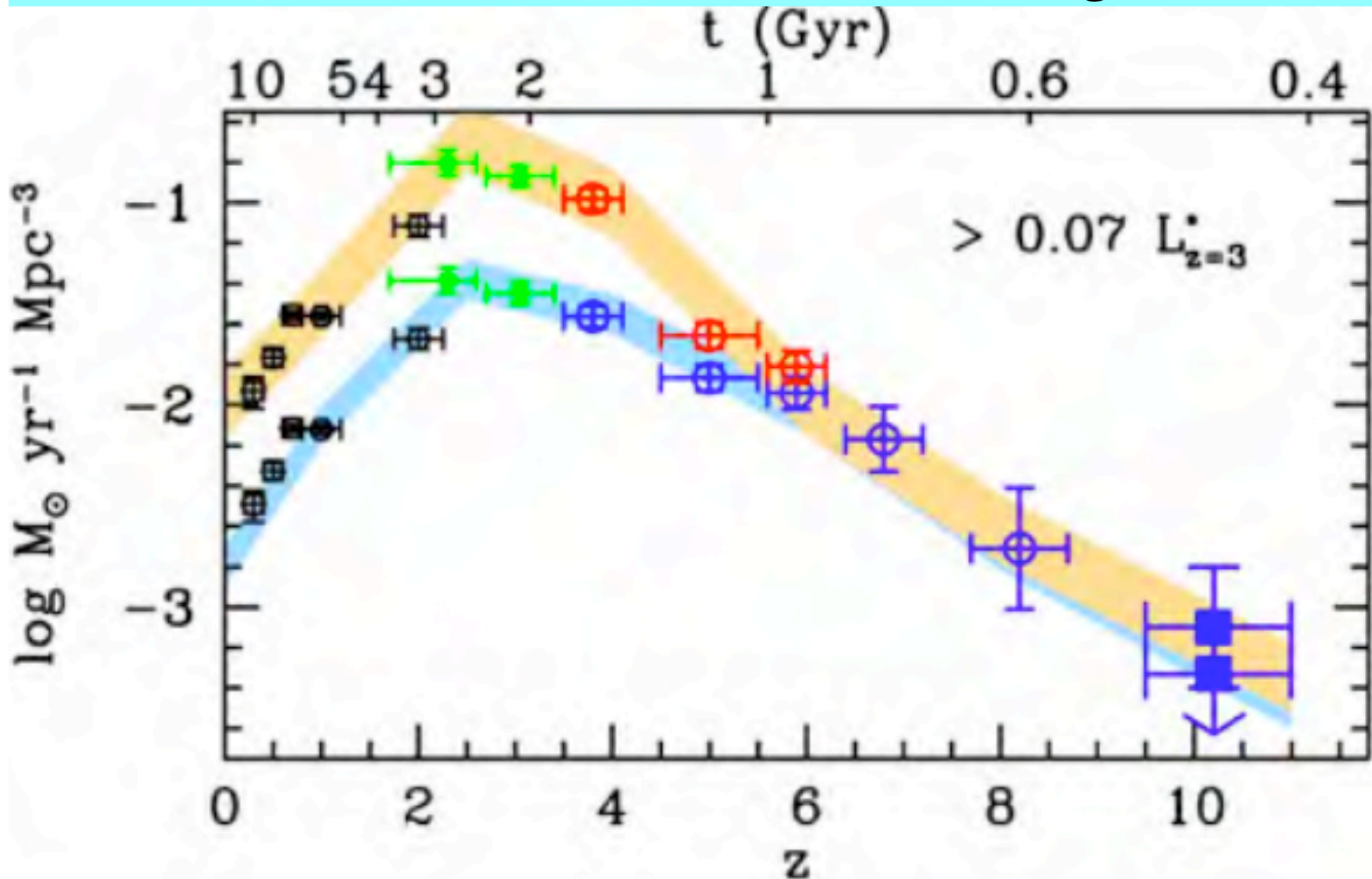


Reionization made simple

Avi Loeb

Reionization epoch $z \sim 10$ (WMAP7)
is the holy grail

reionise the universe with observed galaxies?



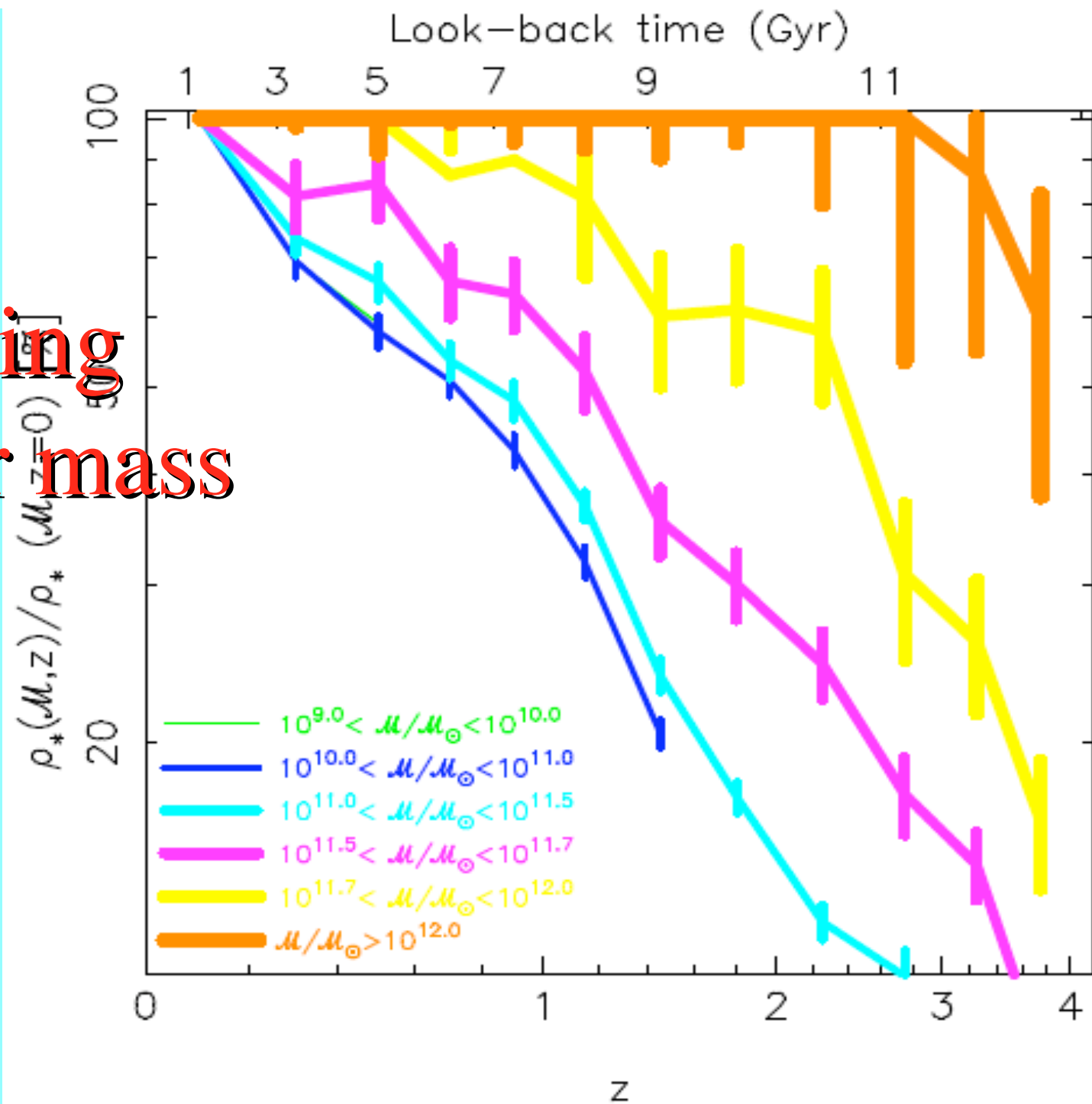
Avi Loeb

star formation at high z

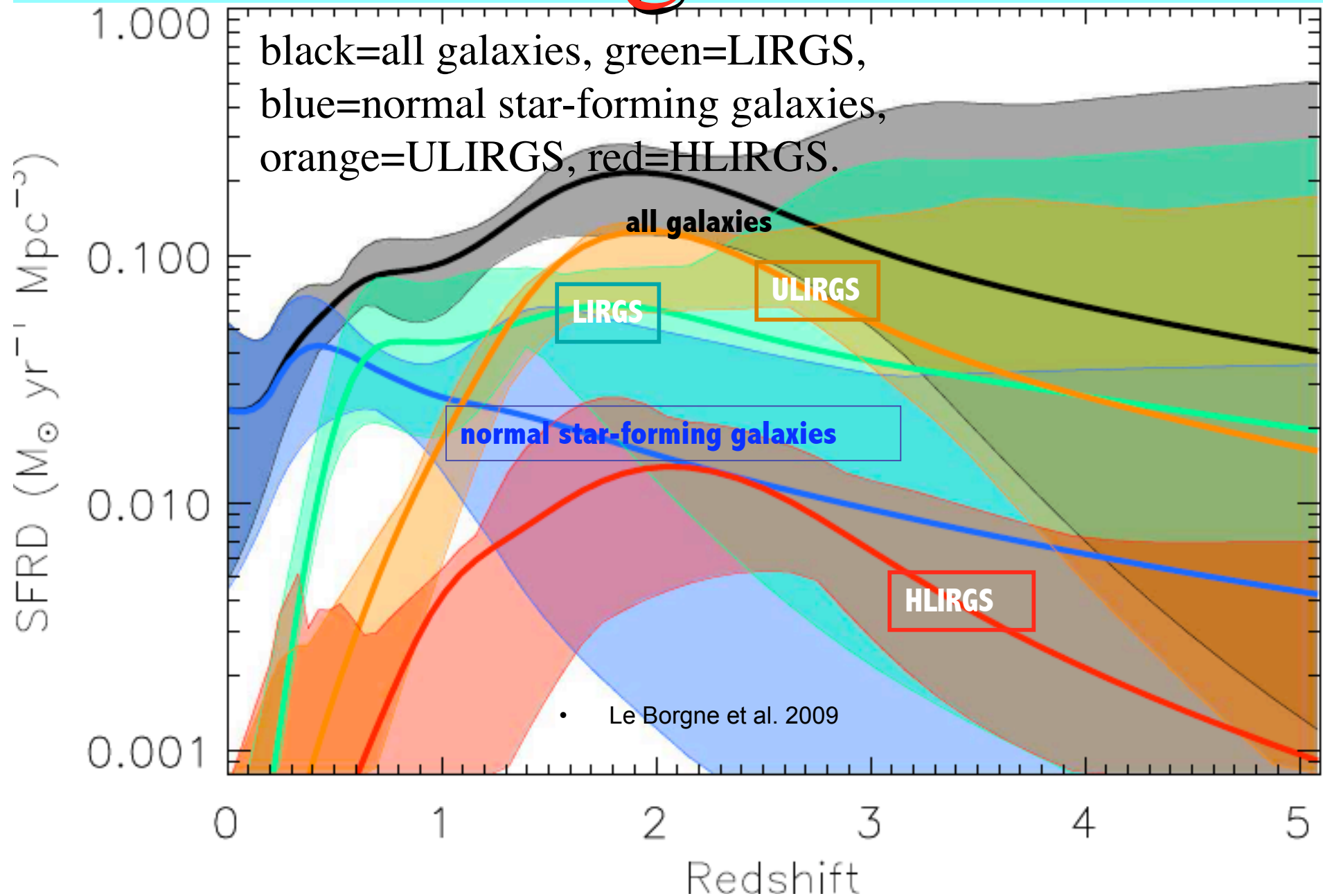
occurs mostly in small objects

But the biases are highly uncertain!

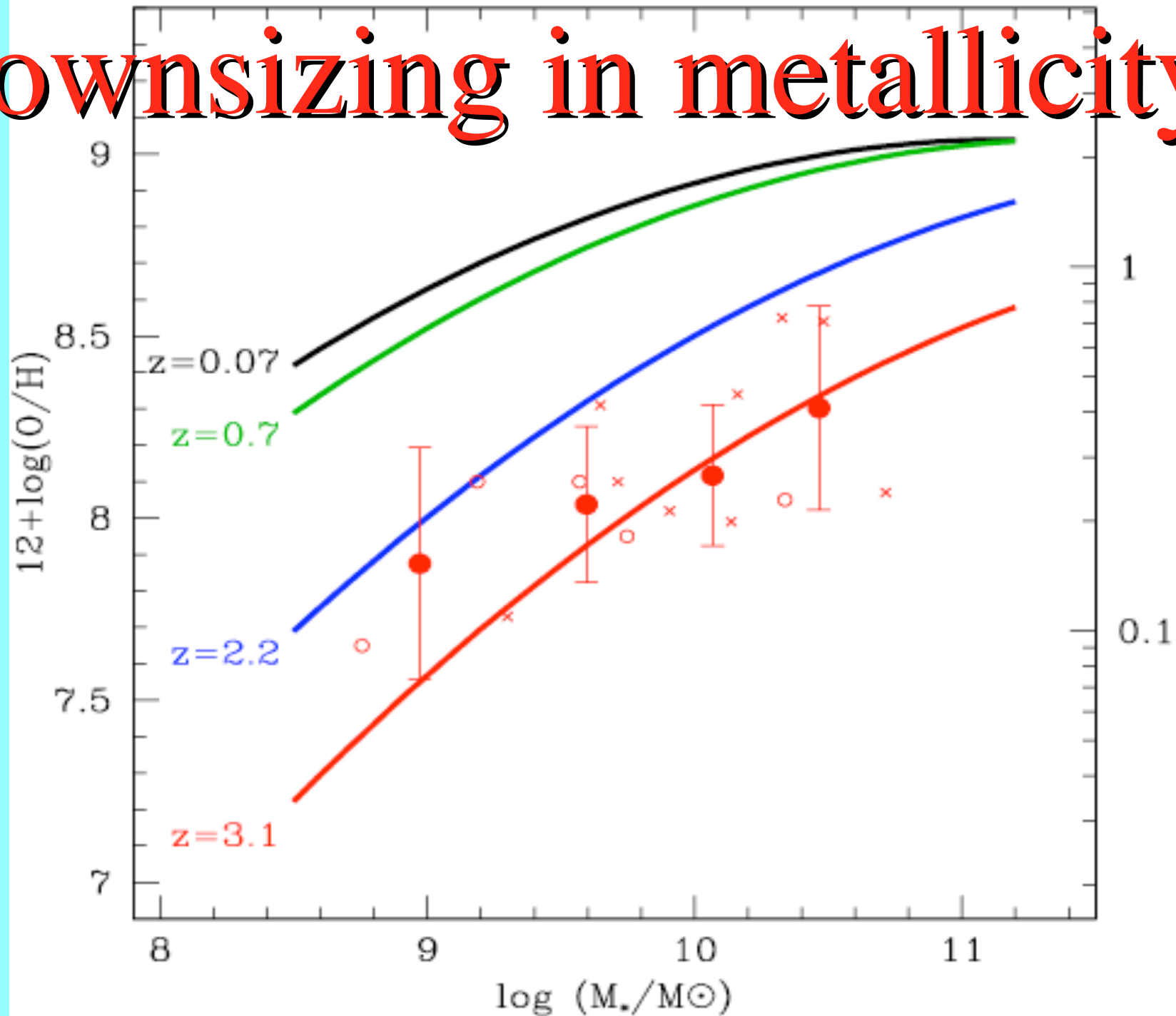
downsizing
in stellar mass



downsizing in violence

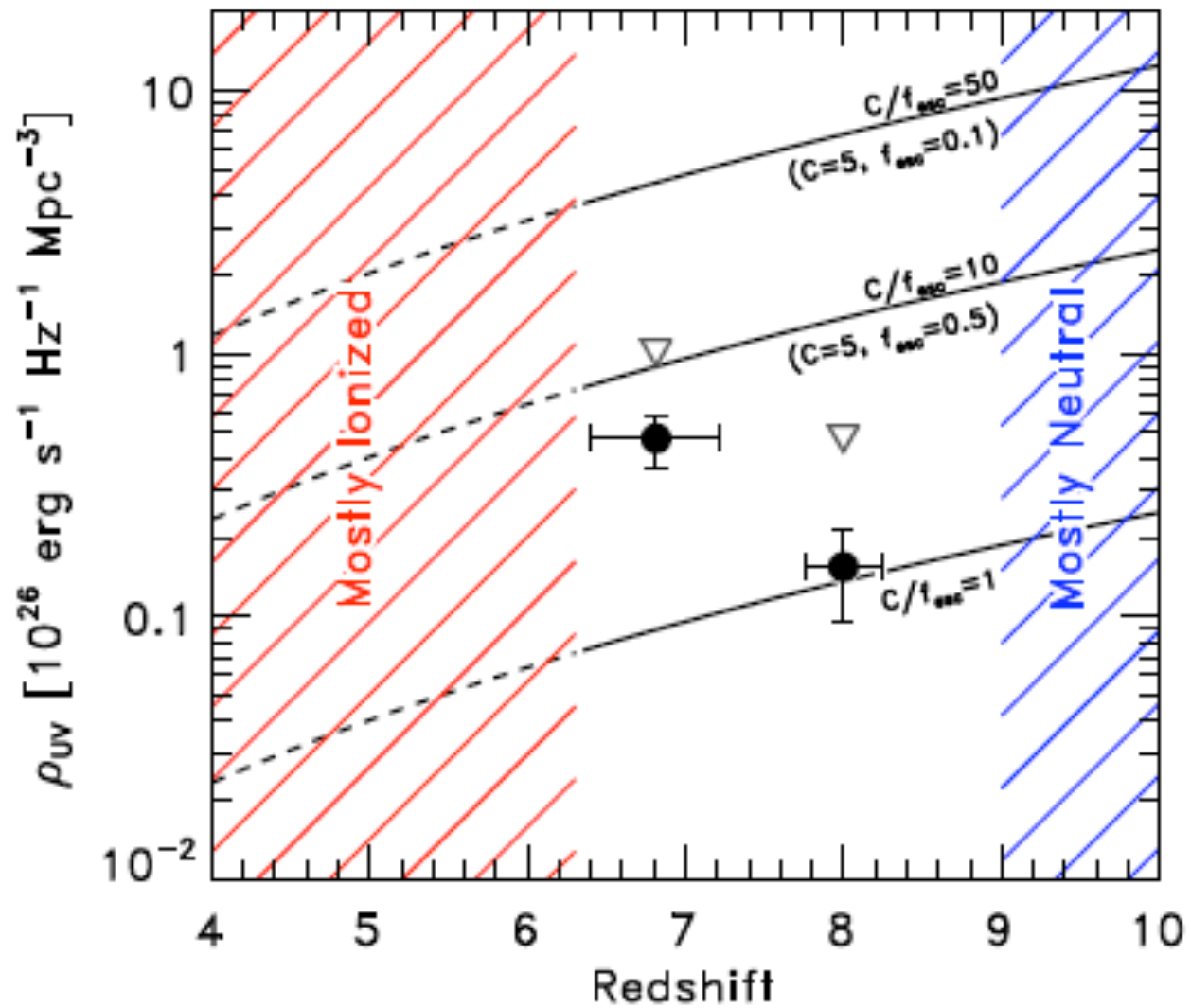


downsizing in metallicity



What reionized
the U?

Steve Finkelstein



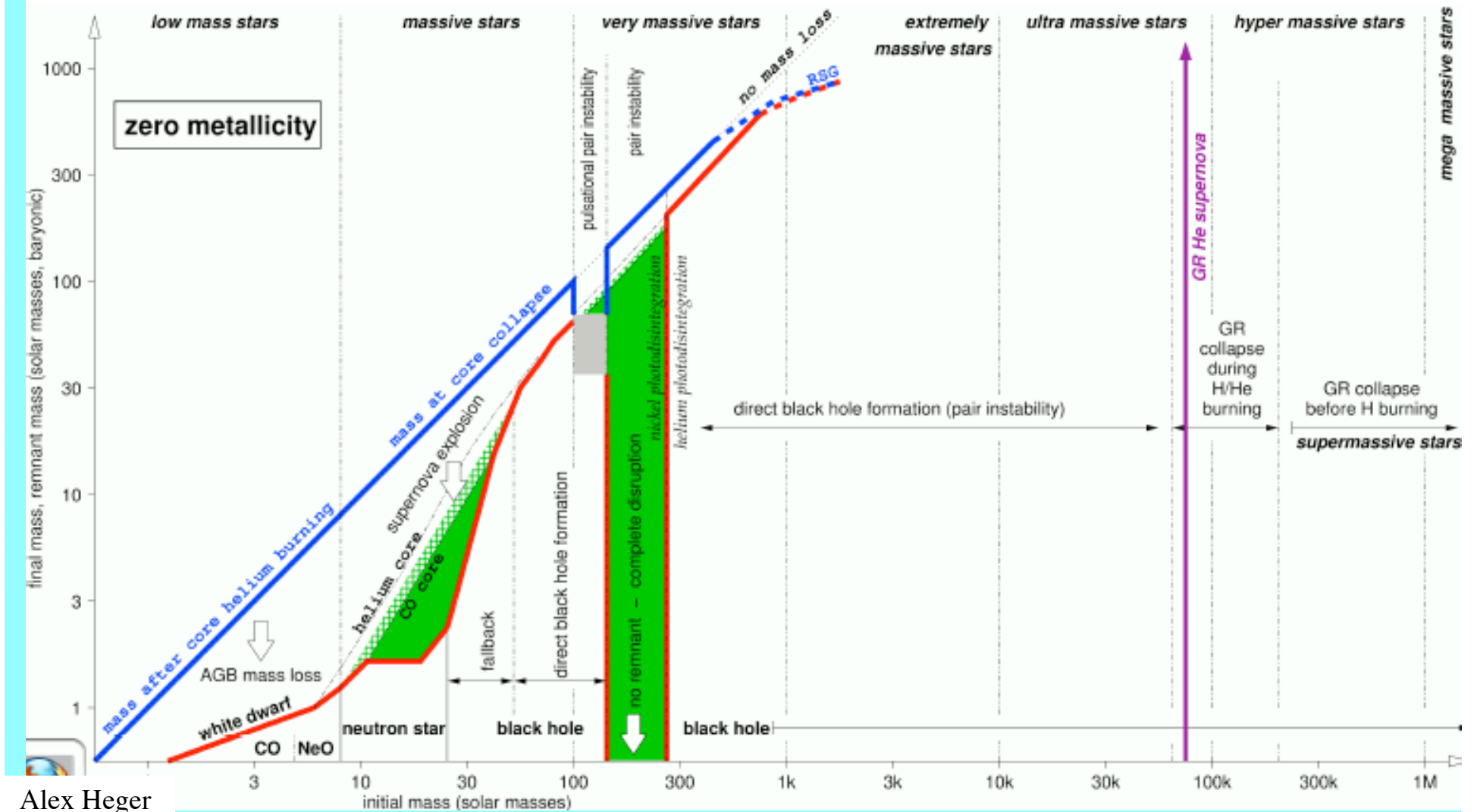
Andrea Ferrara
Ranga Ram Chary
Massimo Stiavelli
Zoltan Haiman

Are UFD precursors the reionization source?

Top-heavy IMF needed?

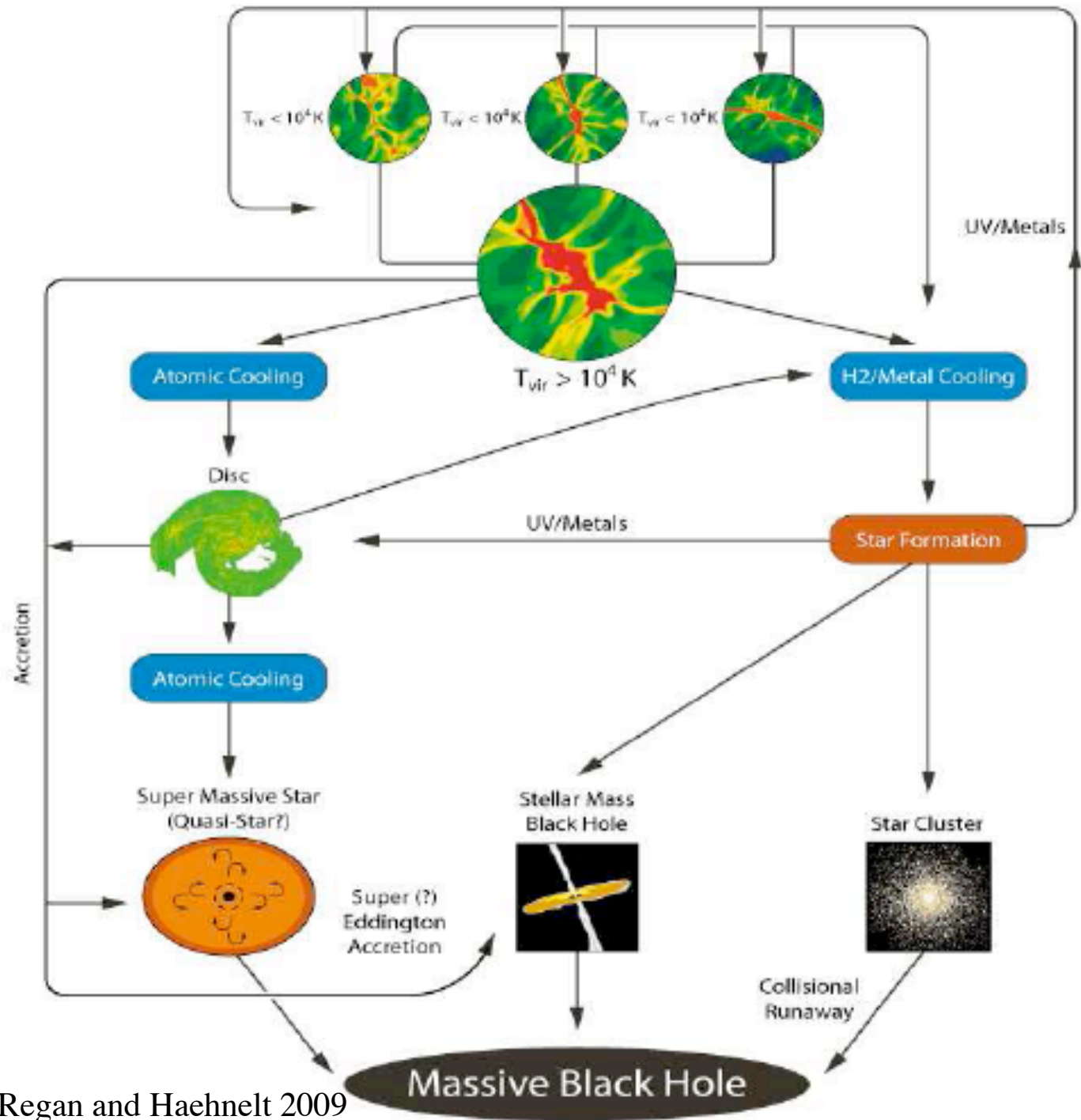
**Mini-AGN/seed SMBH (especially if
reionization source) would be observable
by JWST/LISA**

Supermassive Stars



Alex Heger

Milos Milosavljevic
Dan Whalen



Regan and Haehnelt 2009

First galaxies and star clusters

Thomas Greif

Stefania Salvadori

$10^8 M_{\text{sun}}$ first generation galaxy

enriched to $[Z] \sim -3$, long tail to low Z

Mark Dijkstra

Jarret Johnson

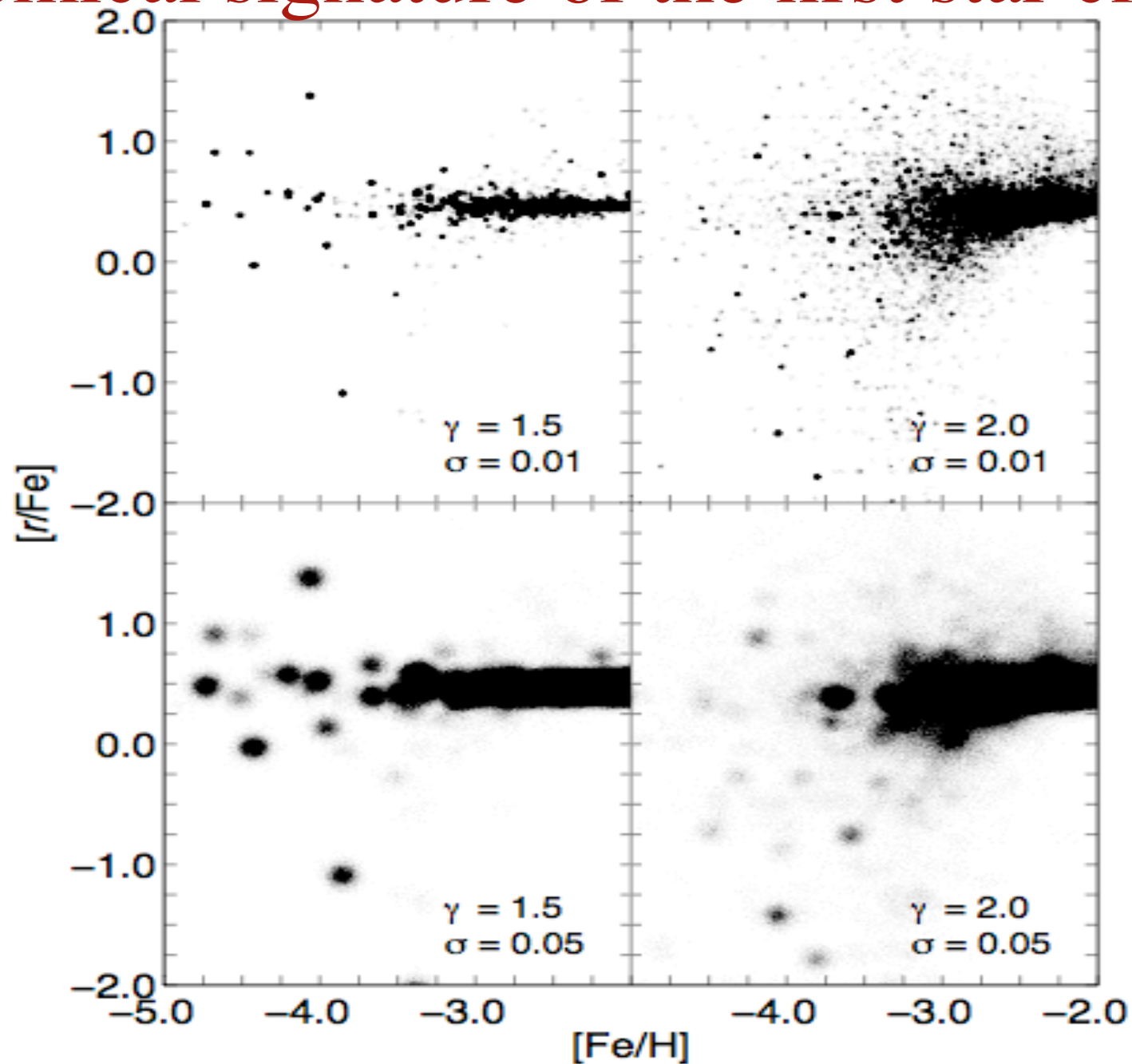
Outflows render LAEs visible at high z

He recombination emission λ 1640 +
 $\text{Ly}\alpha$ traces pop III star clusters

something new: first galaxies via archaeology

Joss Bland-Hawthorne, Torgny Karlsson, Mark Krumolz, JS

Chemical signature of the first star clusters



THANK YOU