Astrophysics I: Stars and Stellar Evolution

AST 4001

Alexander Heger[1,2,3]

[1]School of Physics and Astronomy
University of Minnesota

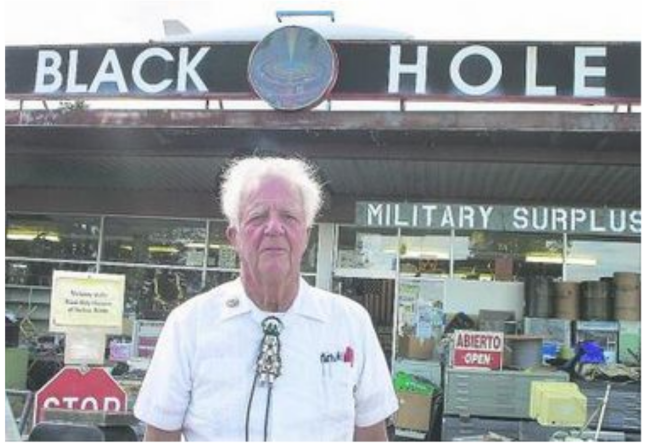
[2]Nuclear & Particle Physics, Astrophysics & Cosmology Group, T-2
Los Alamos National Laboratory

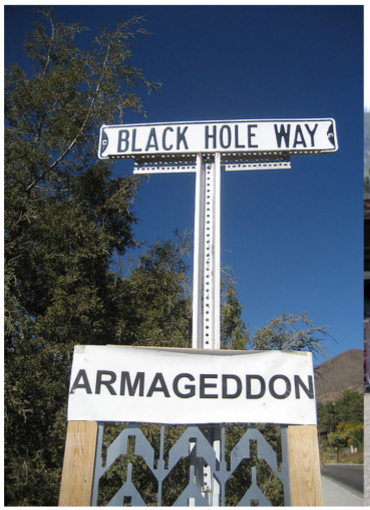
[3]Department of Astronomy and Astrophysics
University of California at Santa Cruz

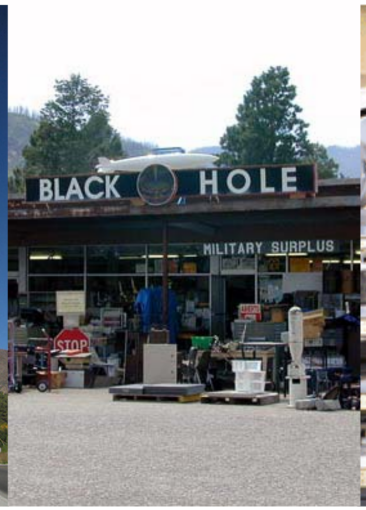
Stars and Stellar Evolution, Fall 2008

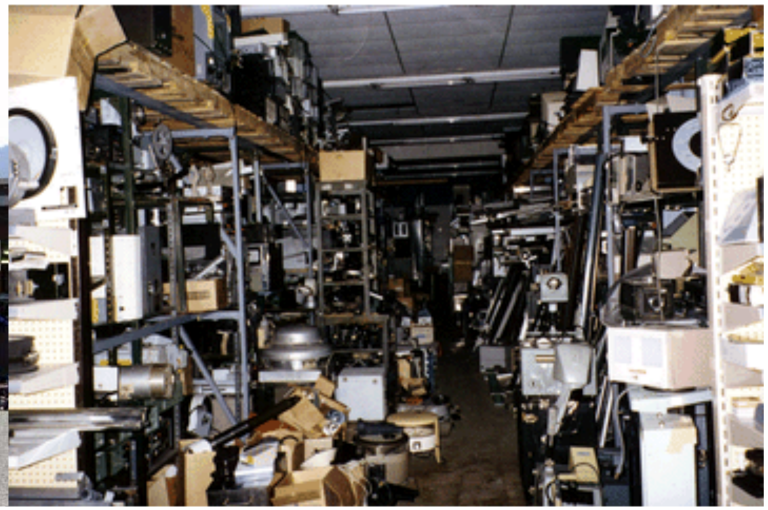
The Black Hole at Los Alamos

"The Black Hole is a gold mine for students with science projects, researchers on a tight budget, tinkerers and would-be wizards."





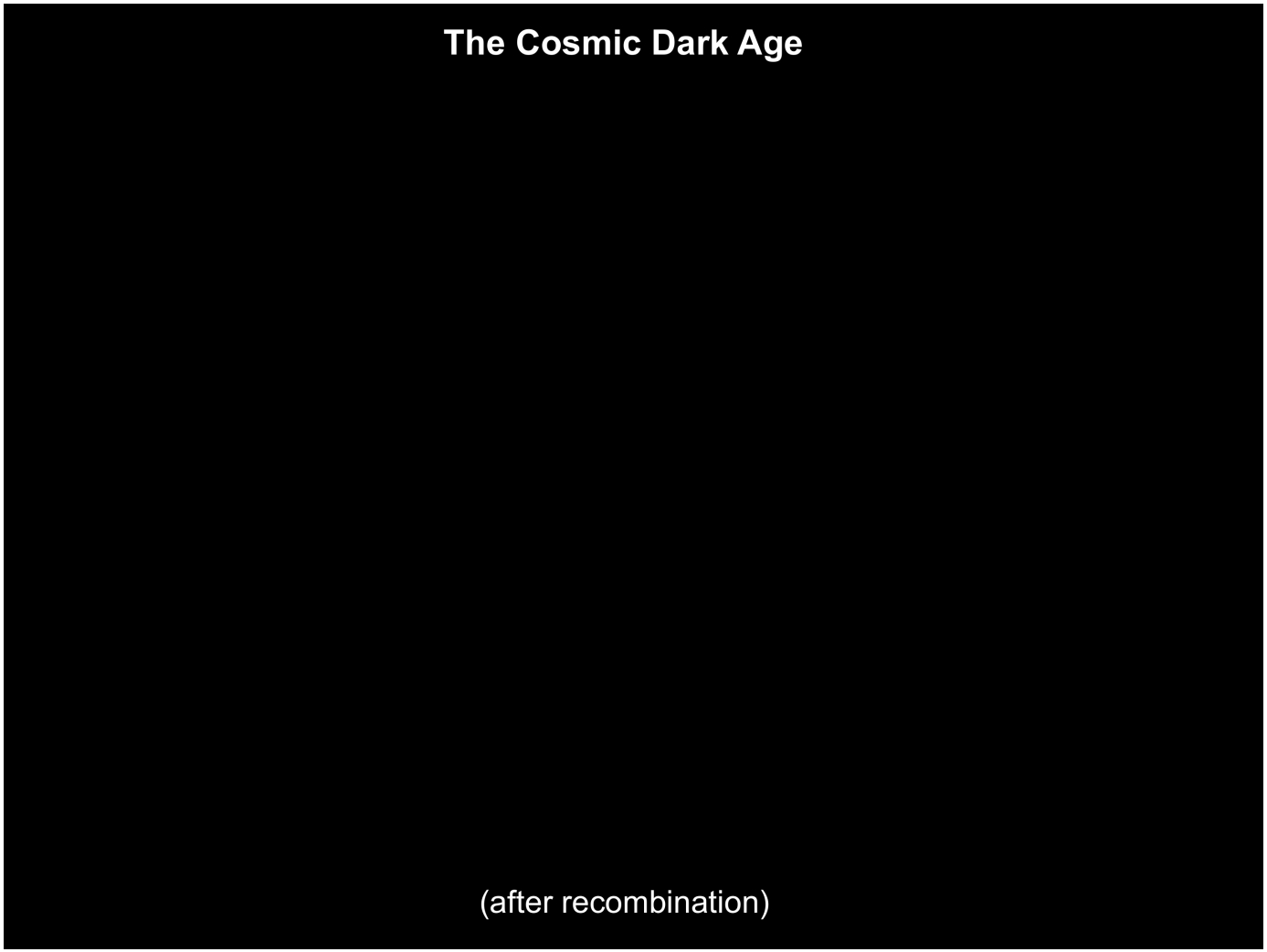




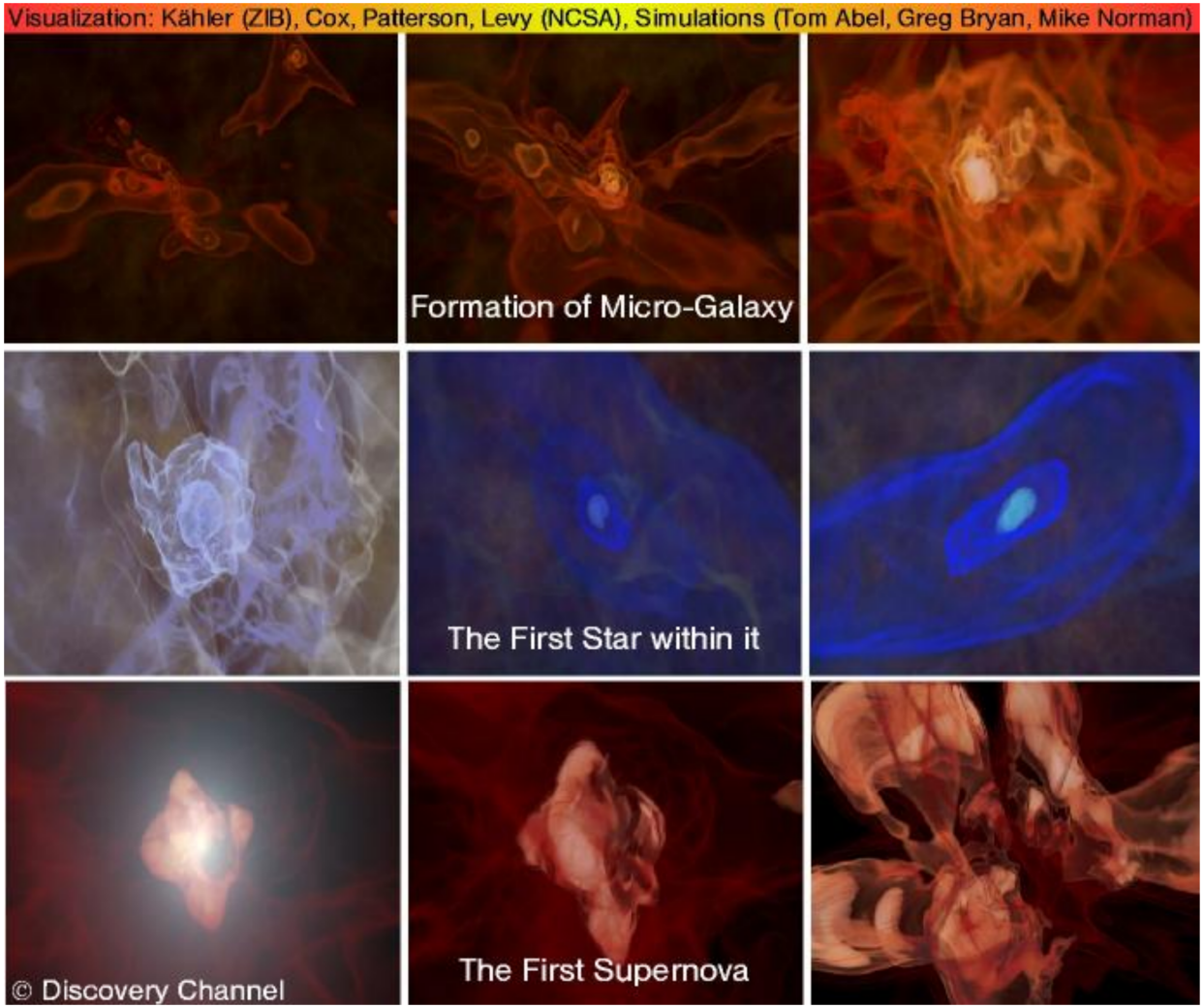
$S=10^{77}$?

Overview

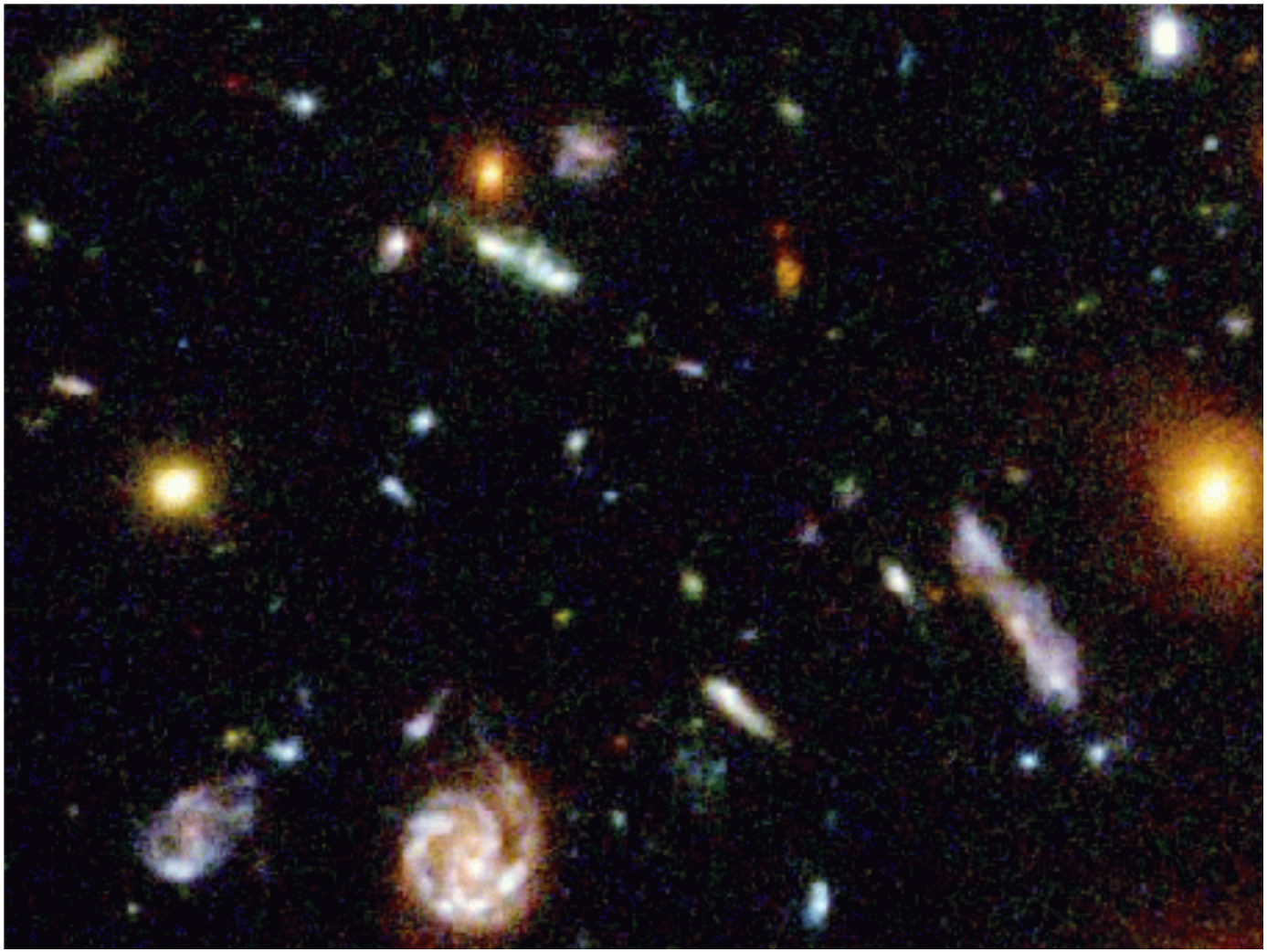
Formation of the First Stars



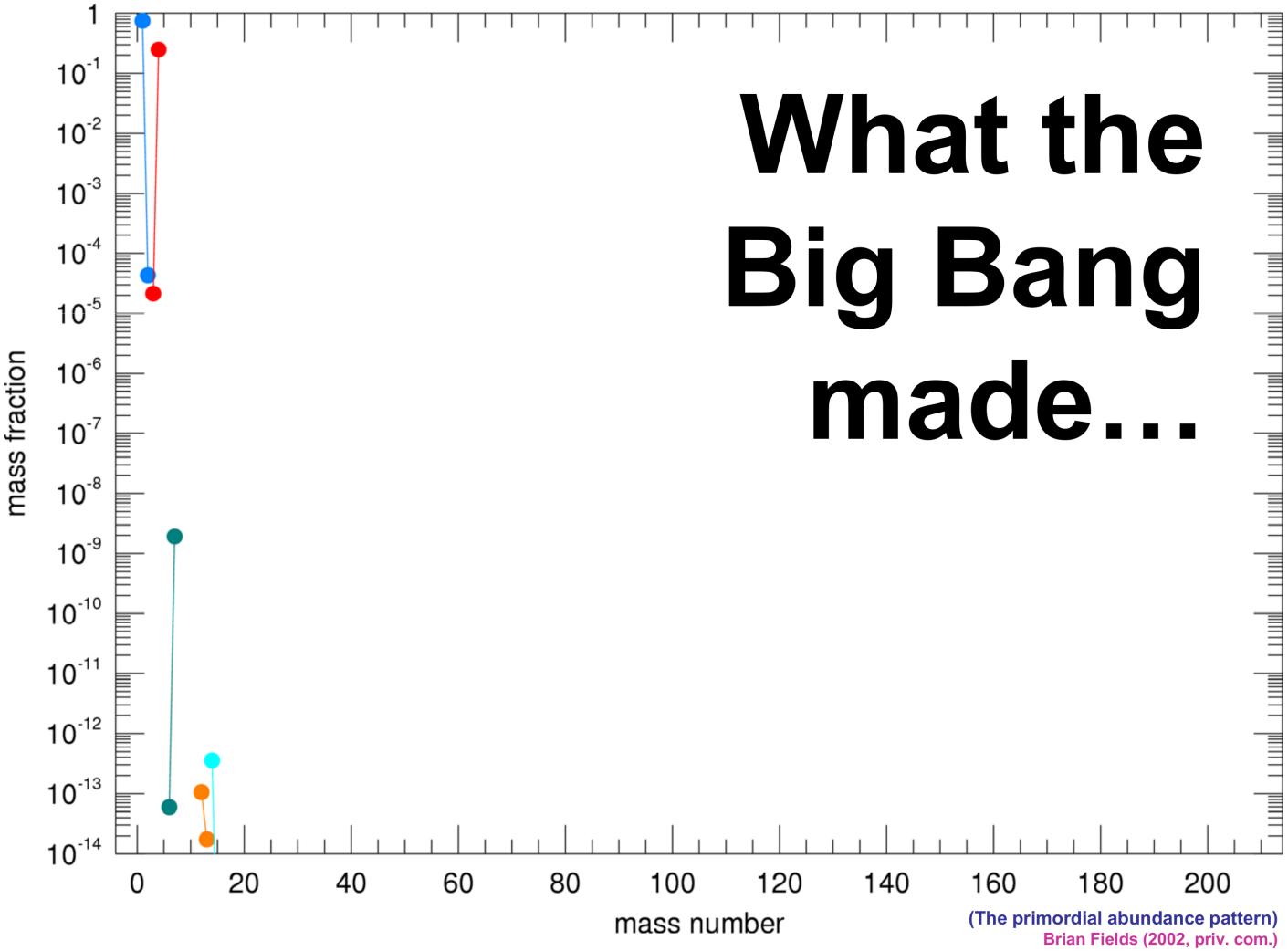
Formation of the First Stars



Formation of the First Stars

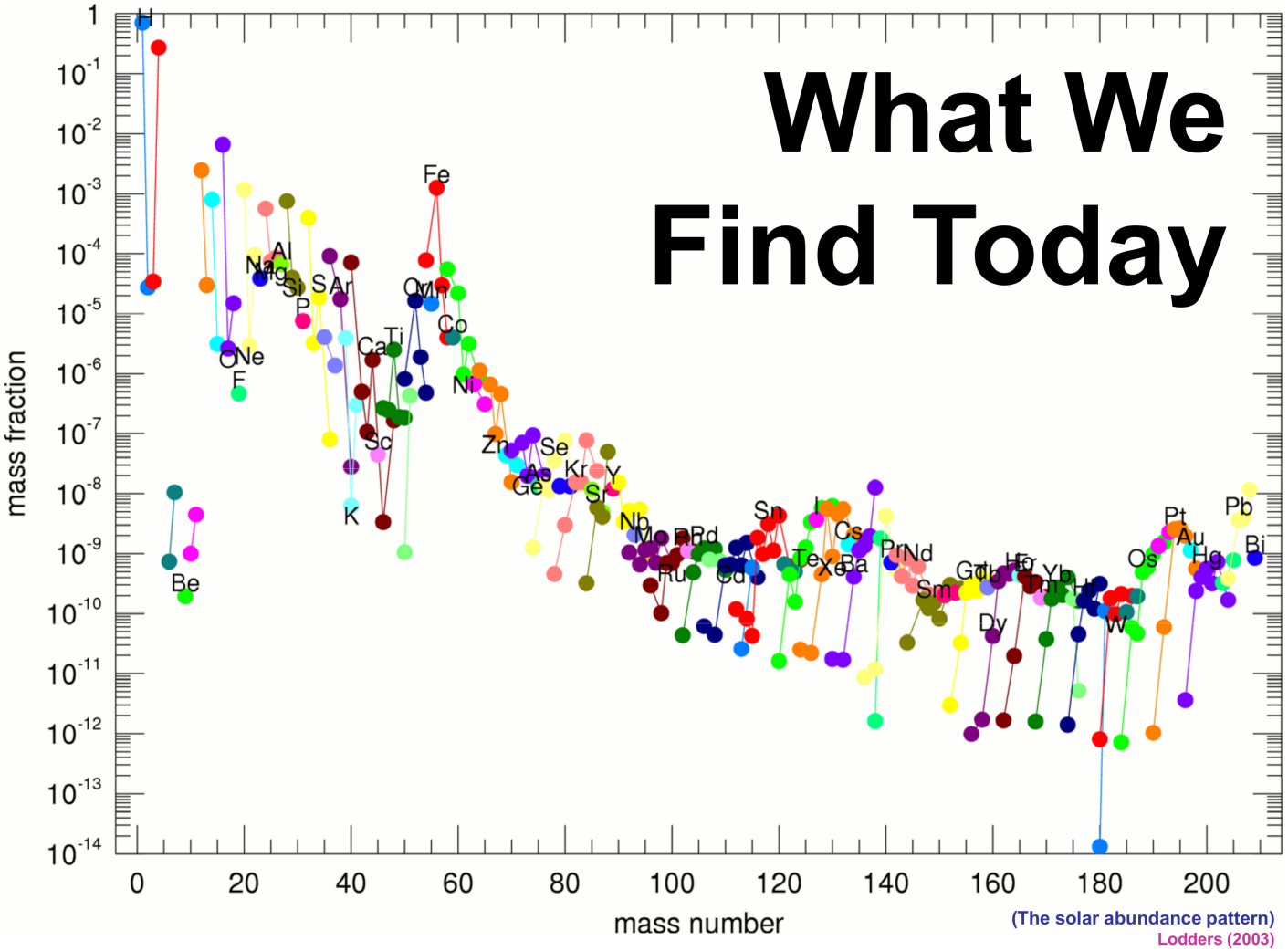


First Stars and Nucleosynthesis

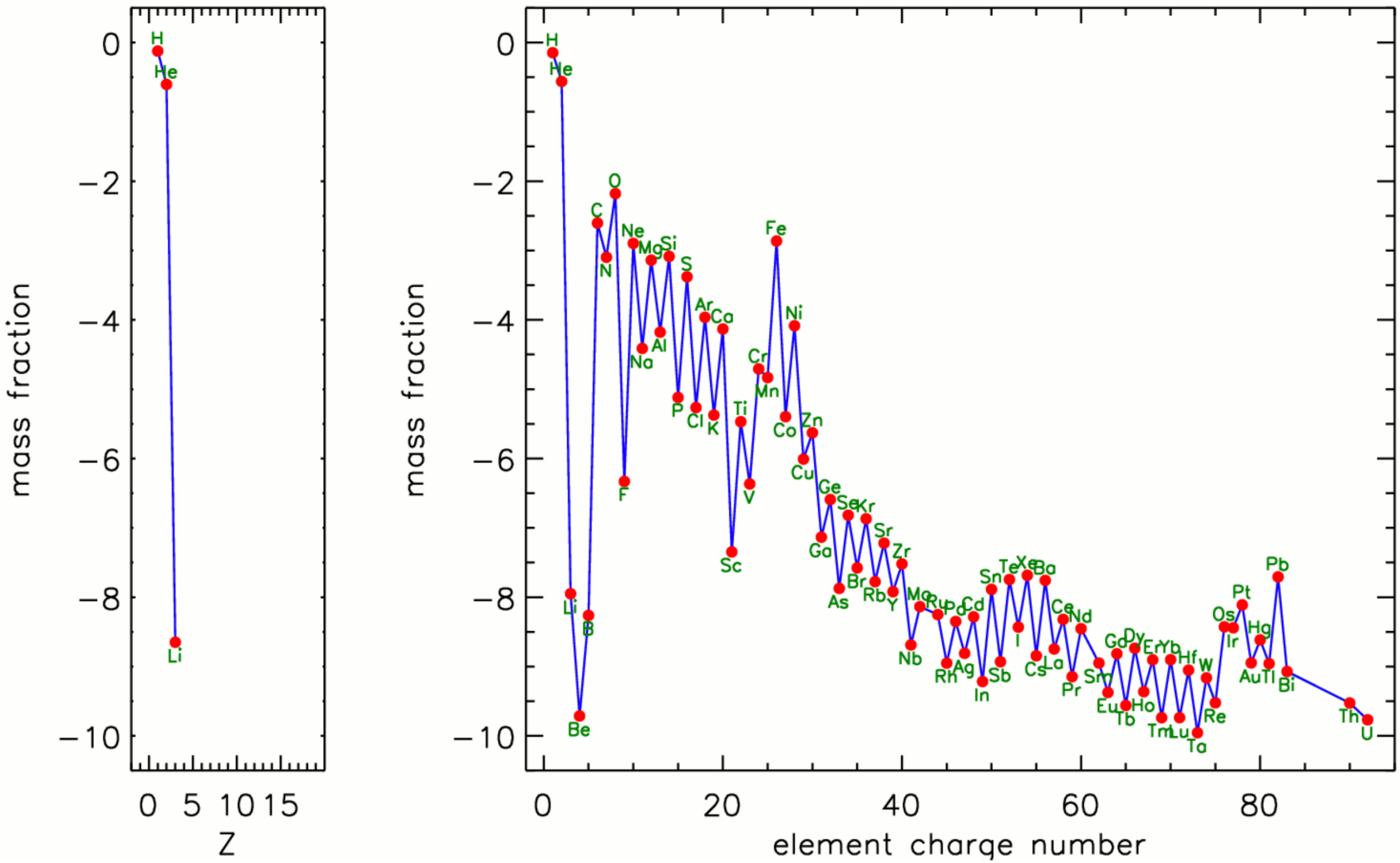


(The primordial abundance pattern)
Brian Fields (2002, priv. com.)

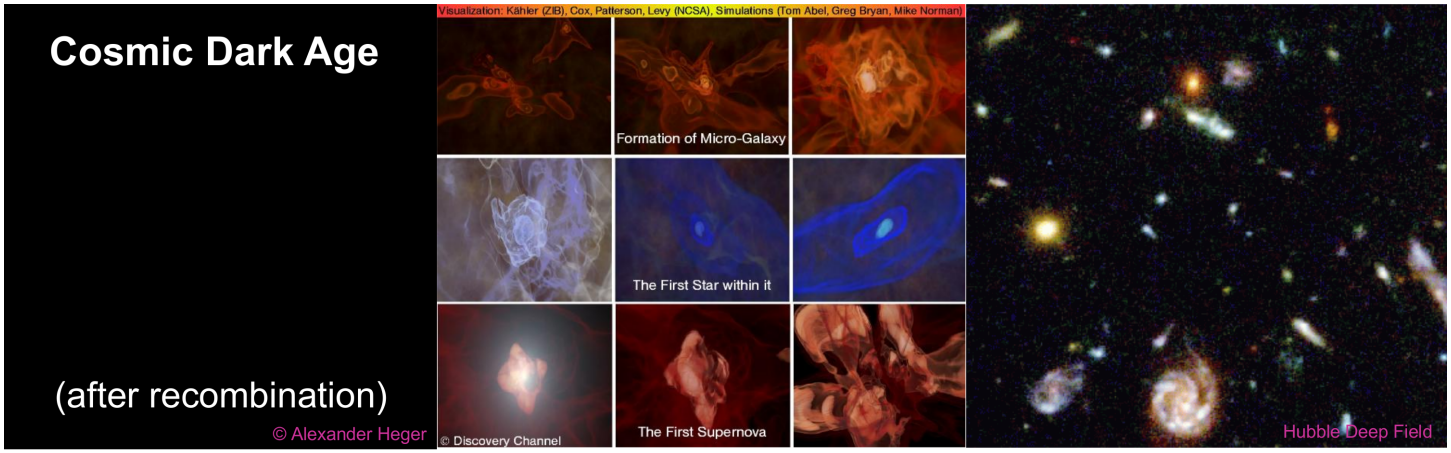
First Stars and Nucleosynthesis



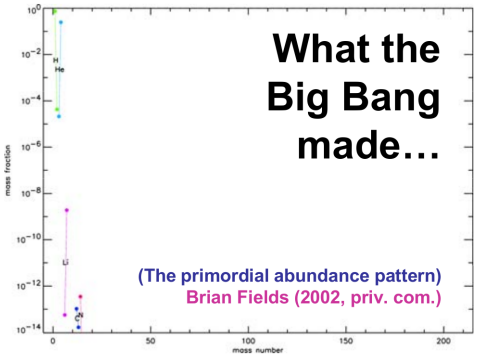
First Stars and Nucleosynthesis

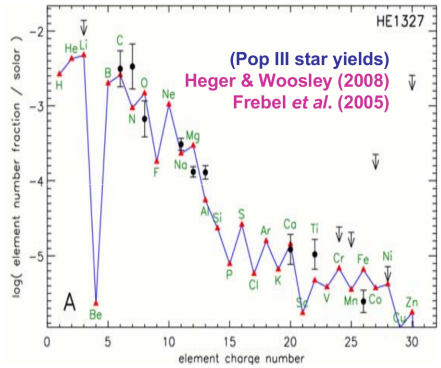


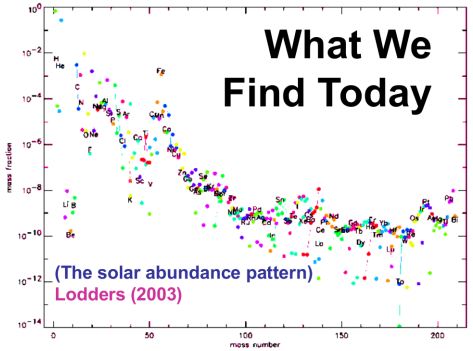
Formation of the First Stars



time







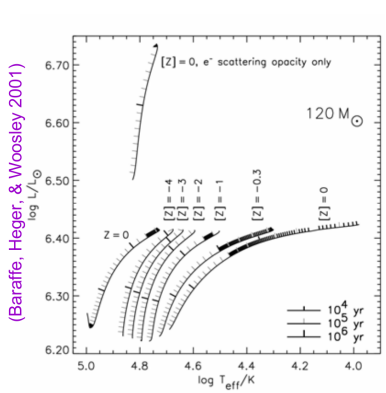
Formation of the First Stars

Formation and Properties of the First Stars

No metals ➔ no metal cooling ➔ more massive stars

(Bromm, Coppi, & Larson 1999, 2002; Abel, Bryan, & Norman 2000, 2002;Nakamura & Umemura 2001; **O'Shea & Norman 2006**)

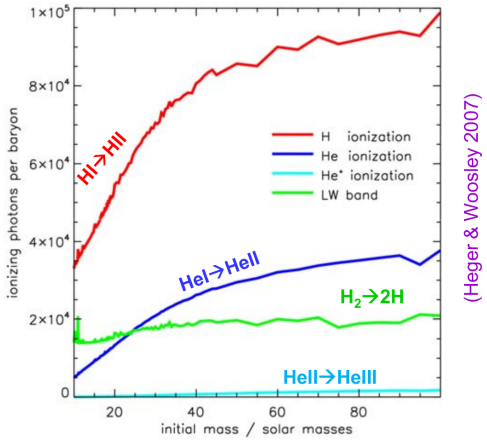
➔ typical mass scale ~100 $M_\odot$



(Baraffe, Heger, & Woosley 2001)

First stars are very hot and very bright

➔ ionizing radiation

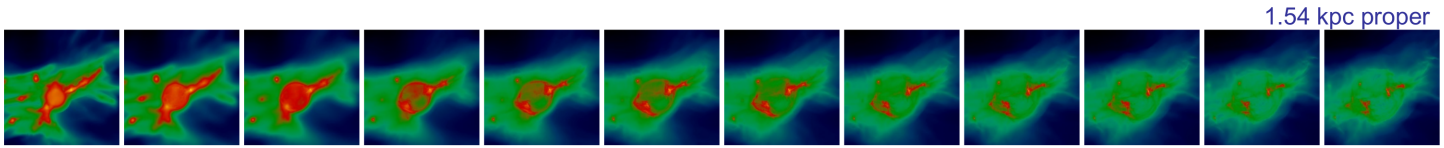


(Heger & Woosley 2007)

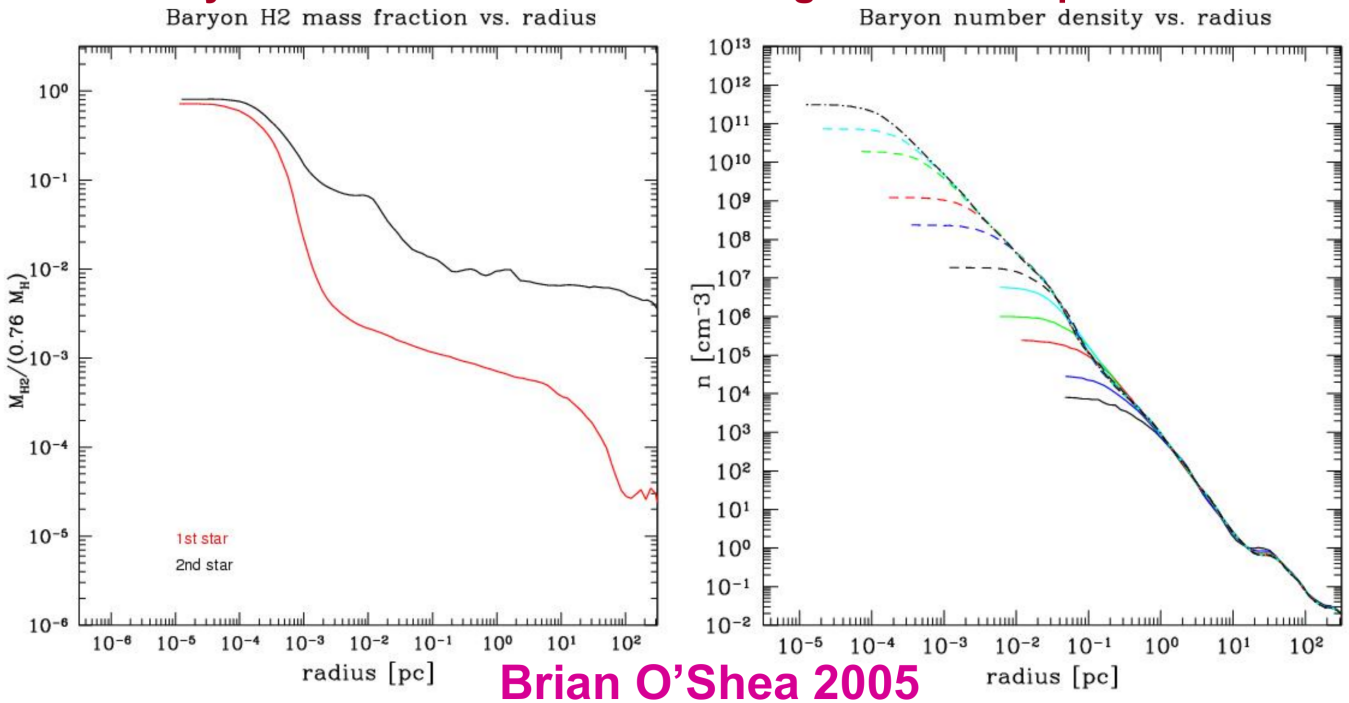
No metals ➔ no mass loss ➔ end life as massive stars

Formation of the Second Stars

Formation of the *Second Stars*



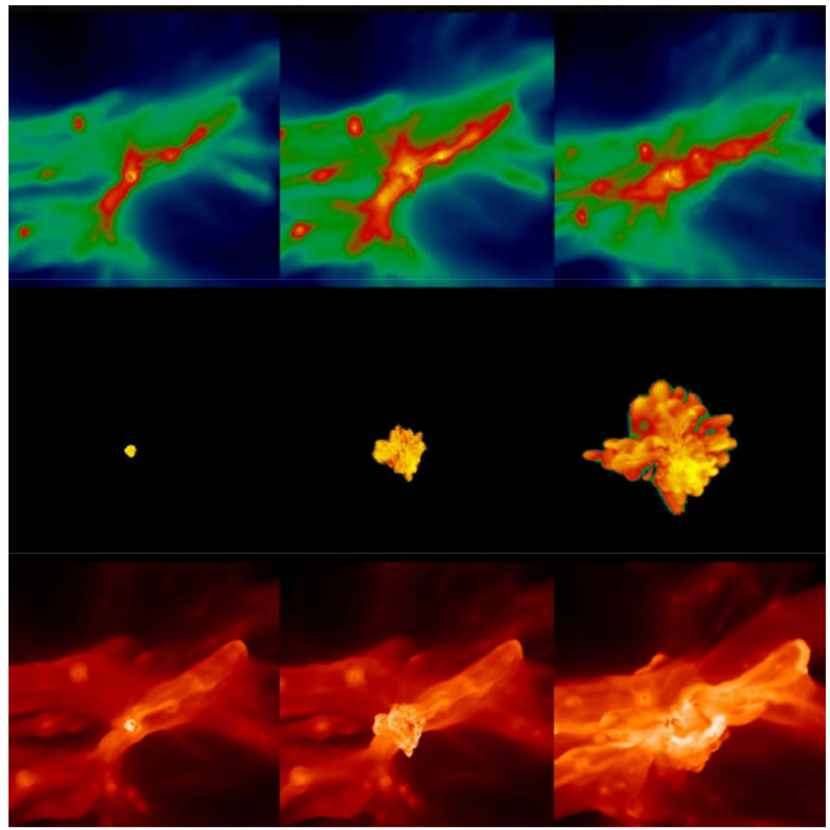
Ionization by the first star initiates second generation of primordial stars



Brian O'Shea 2005

Formation of the First Stars

Explosion of 30 $M_\odot$ Pop III Star



Brian O'Shea 2006

Mass of the First Stars

What is the IMF of the first stars?

Mass of the First Stars

What do we Mean by *First* Stars?

(after McKee, 2008; O'Shea, McKee, Heger, Abel 2008)

- **Population III**
  Stars of primordial composition
  - **Population III.1**
    Form "independently"
    Formation only determined by cosmological parameters
  - **Population III.2**
    Formation changed by input from radiation, kinetic feedback, cosmic rays, etc. from Population III.1 stars
- **Polluted Stars**
  - **Population II.5**
    Enrichment does not affect cooling for stars formation
    Below "critical" limit ([Z] < ~ -3.5)
  - **"True" Population II**
    Enrichment affects formation and evolution

Fate of the First Stars

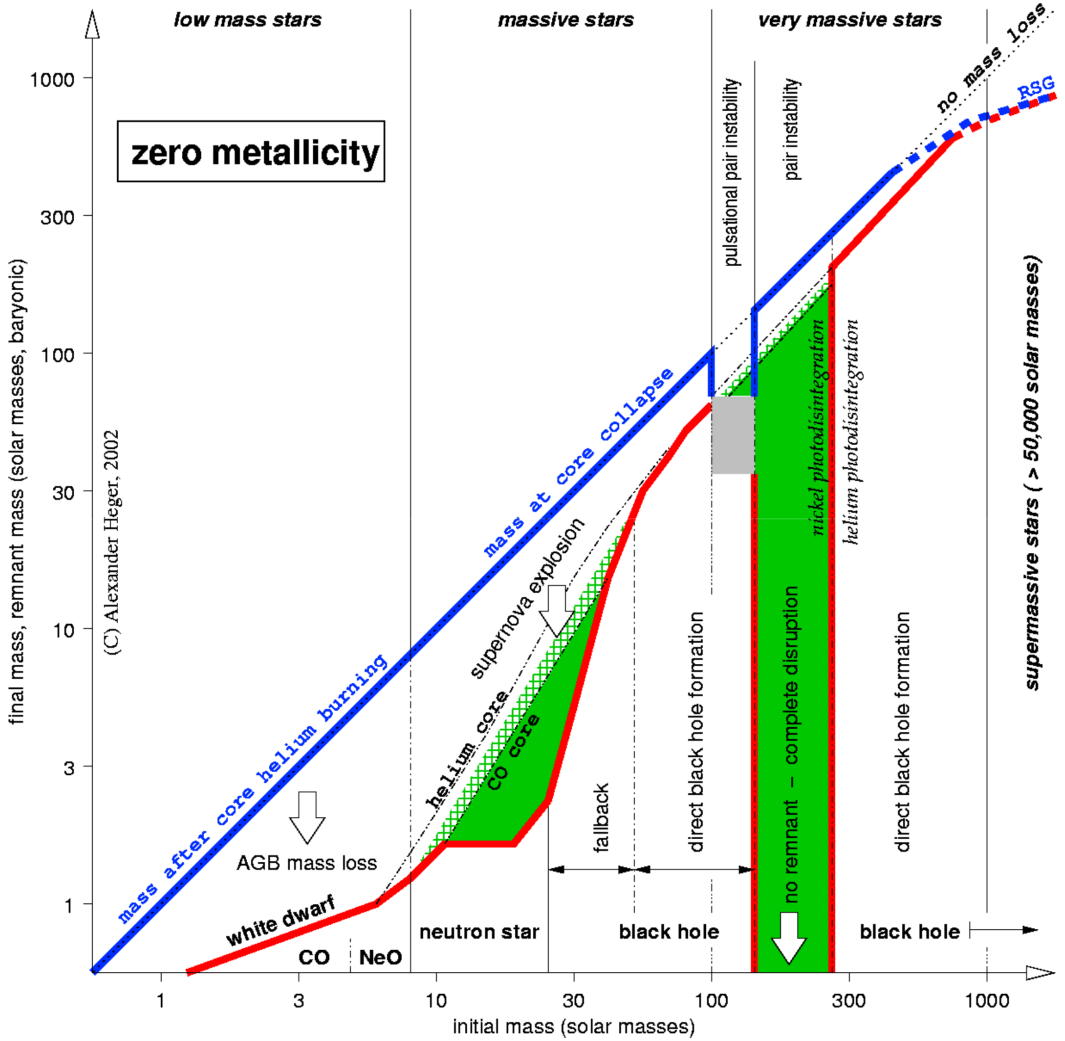
What is the fate of the first stars?

Fate of the First Stars

Nuclear burning stages

Burning stages		20 $M_\odot$ Star		200 $M_\odot$ Star	
Fuel	Main Product	T (10^9 K)	Time (yr)	T (10^9 K)	Time (yr)
H	He	0.02	10^7	0.1	2×10^6
He	O, C	0.2	10^6	0.3	2×10^5
C	Ne, Mg	0.8	10^3	1.2	10
Ne	O, Mg	1.5	3	2.5	3×10^{-6}
O	Si, S	2.0	0.8	3.0	2×10^{-6}
Si	Fe	3.5	0.02	4.5	3×10^{-7}

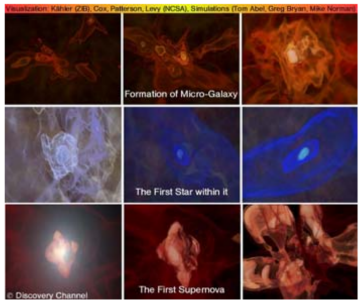
Fate of the First Stars



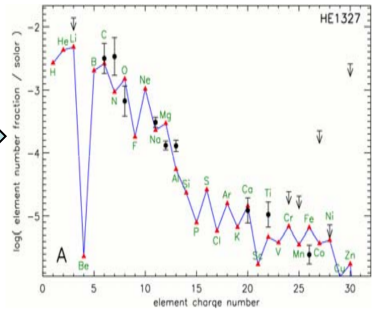
Ejected "metals"

Fate of the First Stars

Reconstruction of the IMF



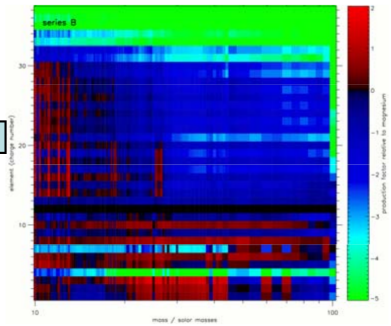
primordial stars form, nucleosynthesis ejected



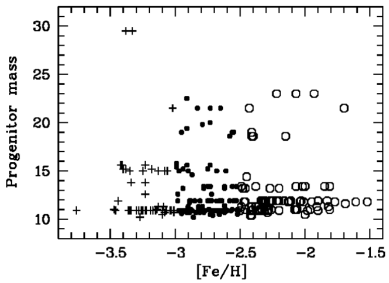
ejecta incorporated in low-Z halo stars

find low-Z halo stars (HERES, SEGUE, …)

measure abundances (VLT, KECK, …)



compare abundances to primordial star nucleosynthesis library



obtain IMF of population of progenitor stars

First Stars - Open Questions

The Legacy of the First Stars

- **Where were the stars that we see today as UMP halo stars really form?**
- **Where to find the ejecta of primordial stars and can we see their supernovae?**
- **Feedback of the first stars on their environment**
- **Metal pollution of the early universe**