Impact of the First Stars/Binaries

Ke-Jung (Ken) Chen

Johnston Graduate Fellow, University of Minnesota
The low-metallicity ISM meeting, Göttingen, Oct. 8-12, 2012

Team Members

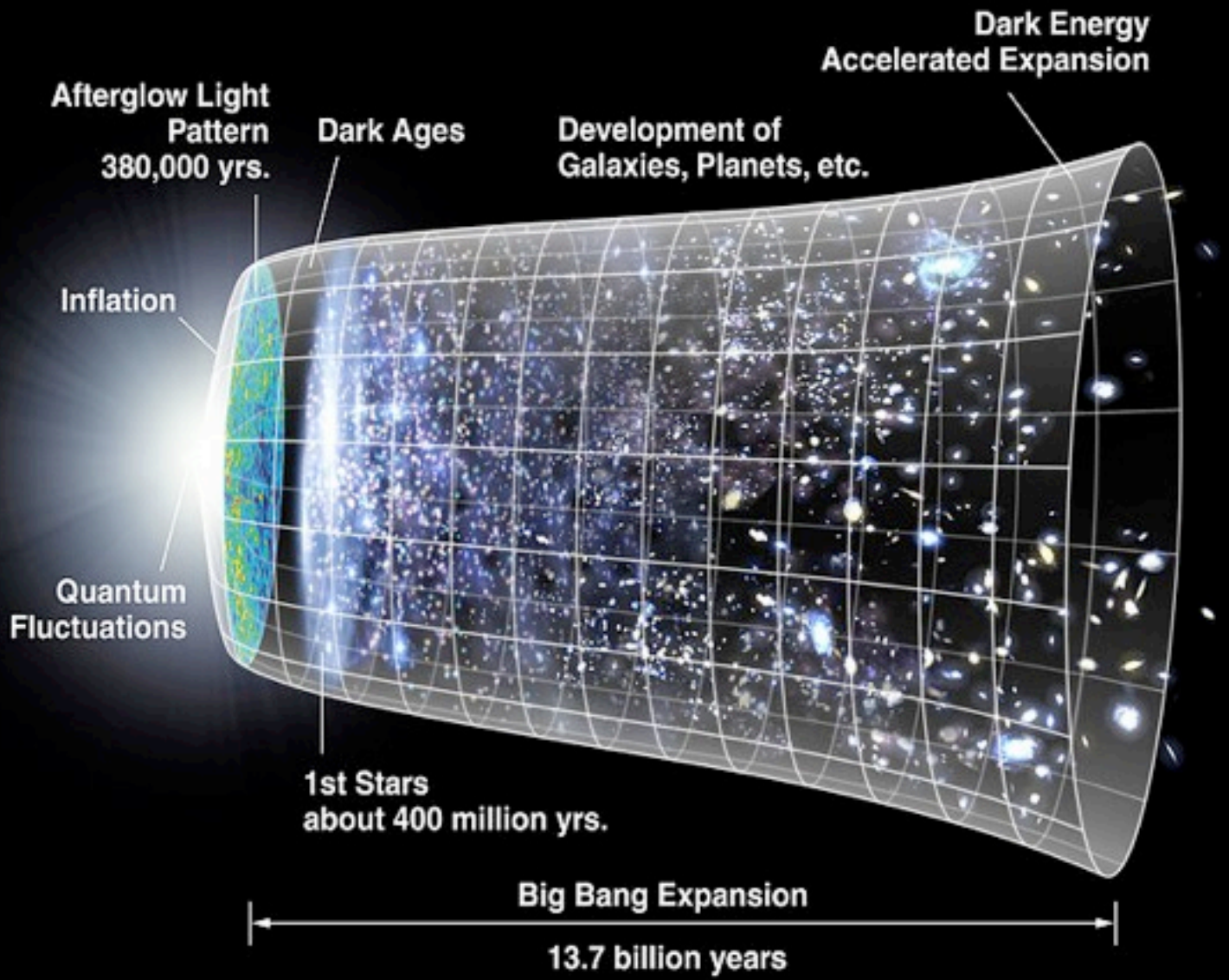
Volker Bromm
UT-Austin

Alexander Heger
MoCA Monash

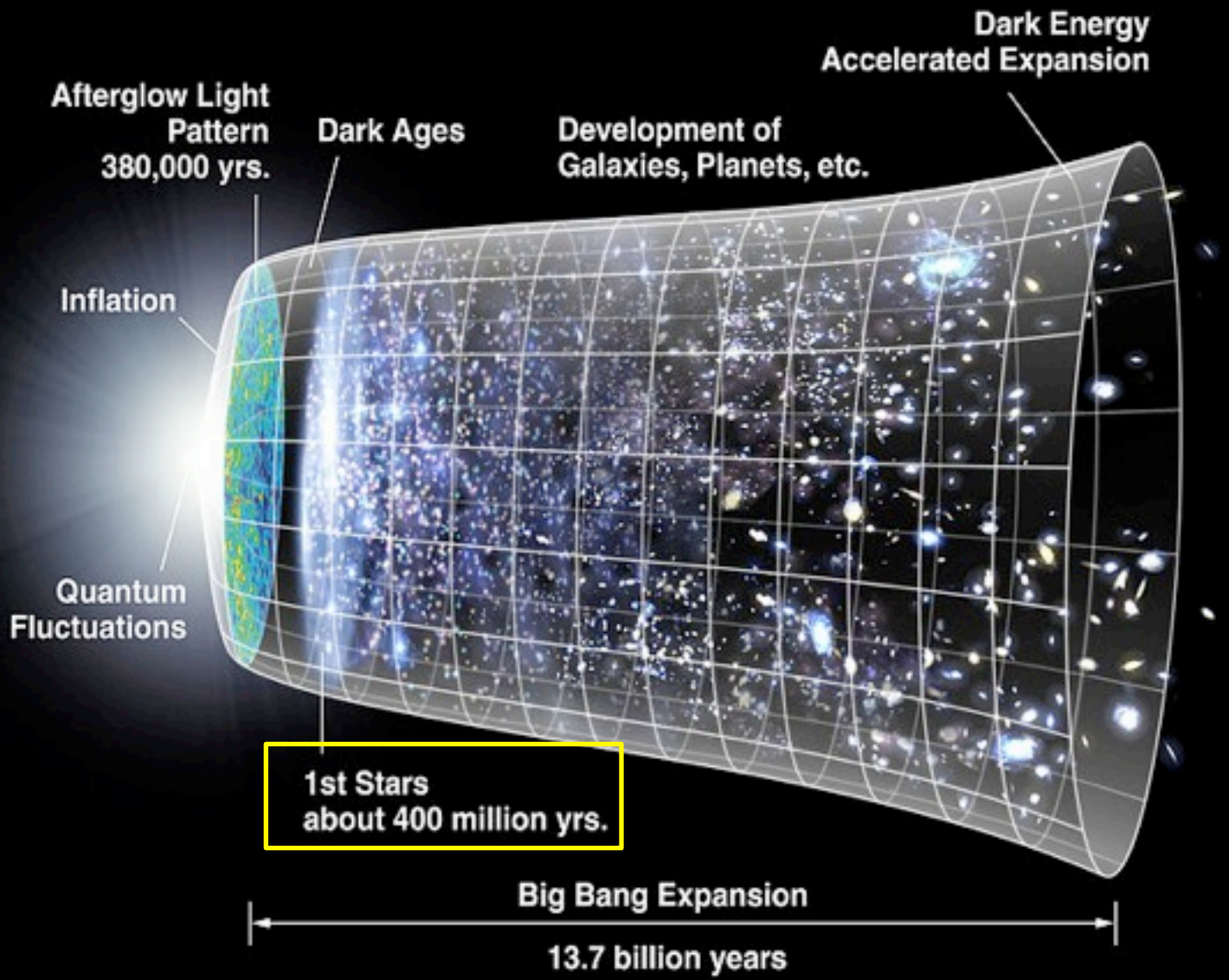
Myoungwon Jeon
UT-Austin

Thomas Greif
ITC Harvard

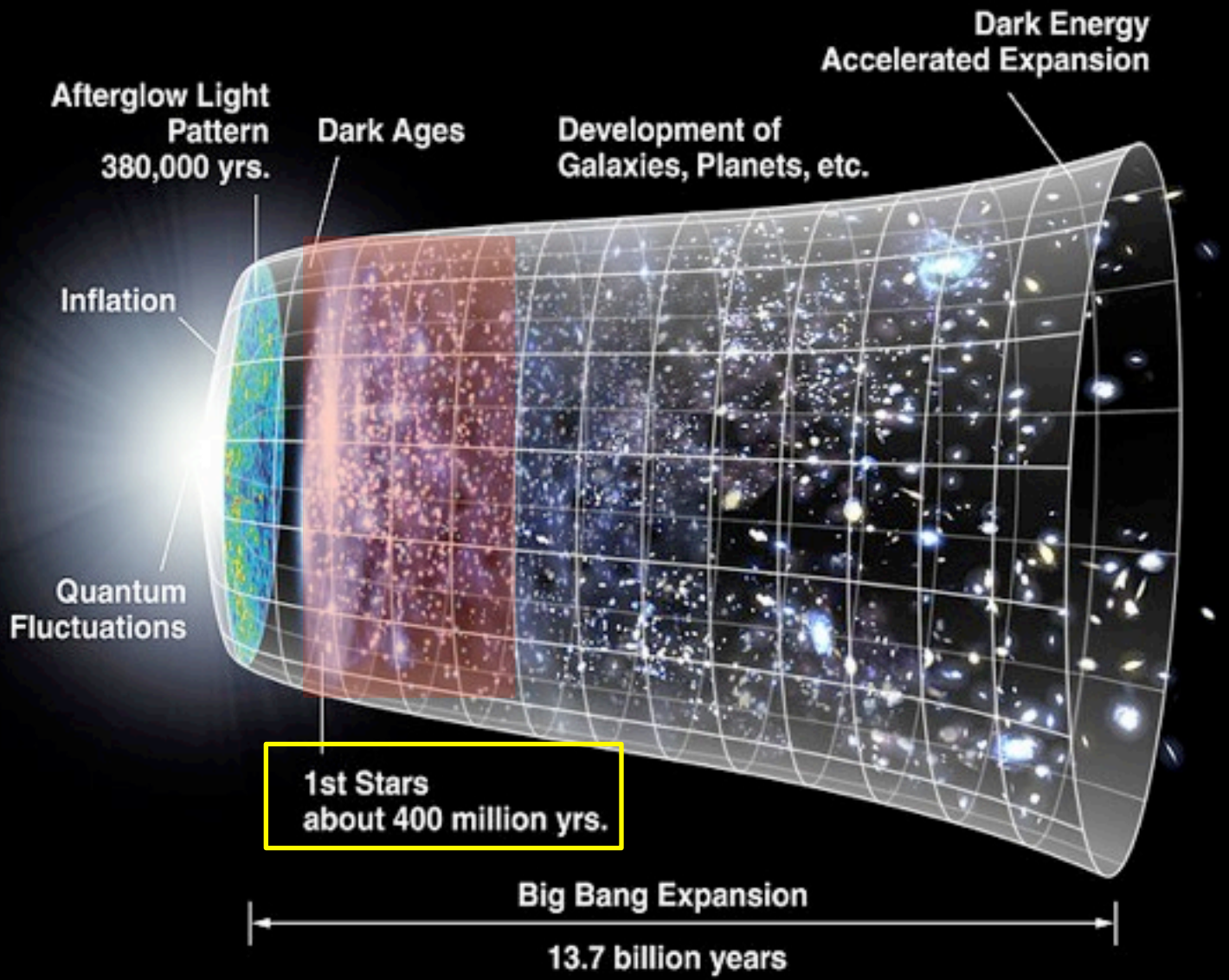
History of Universe



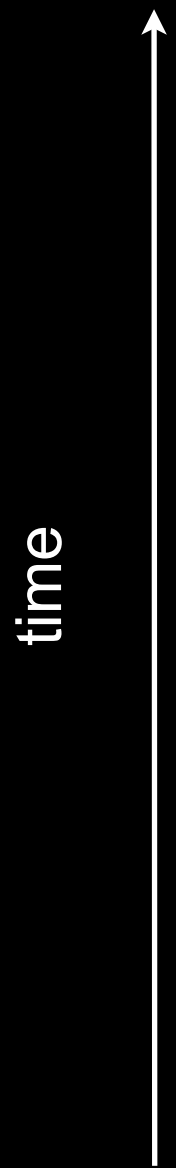
History of Universe



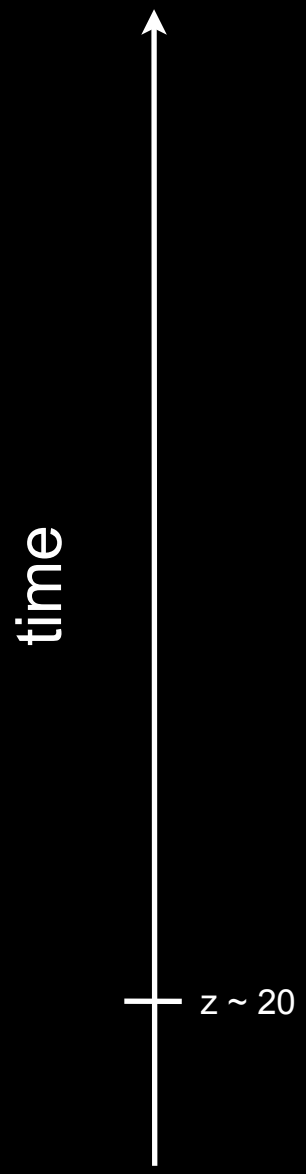
History of Universe



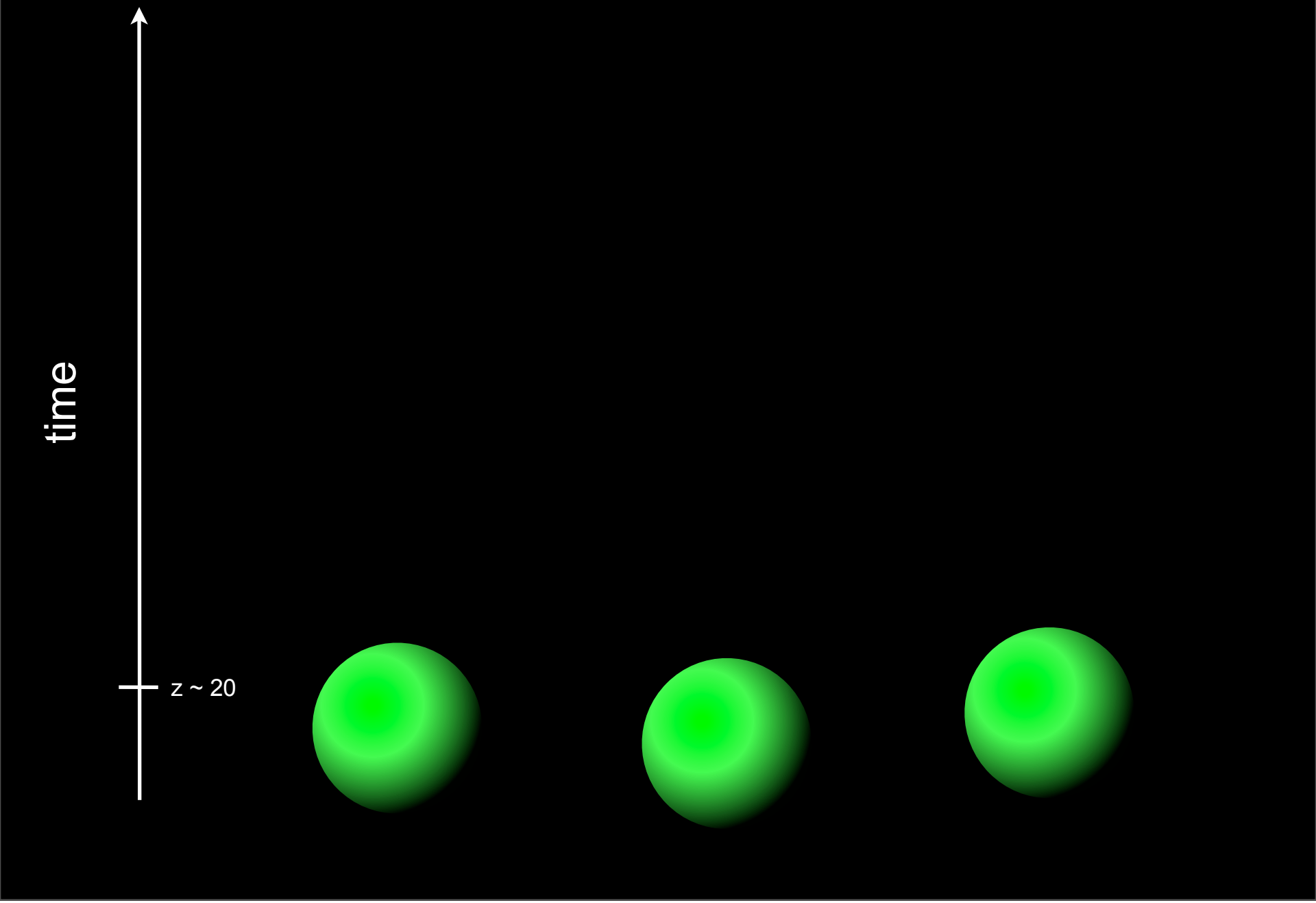
Assembly of the First Galaxies



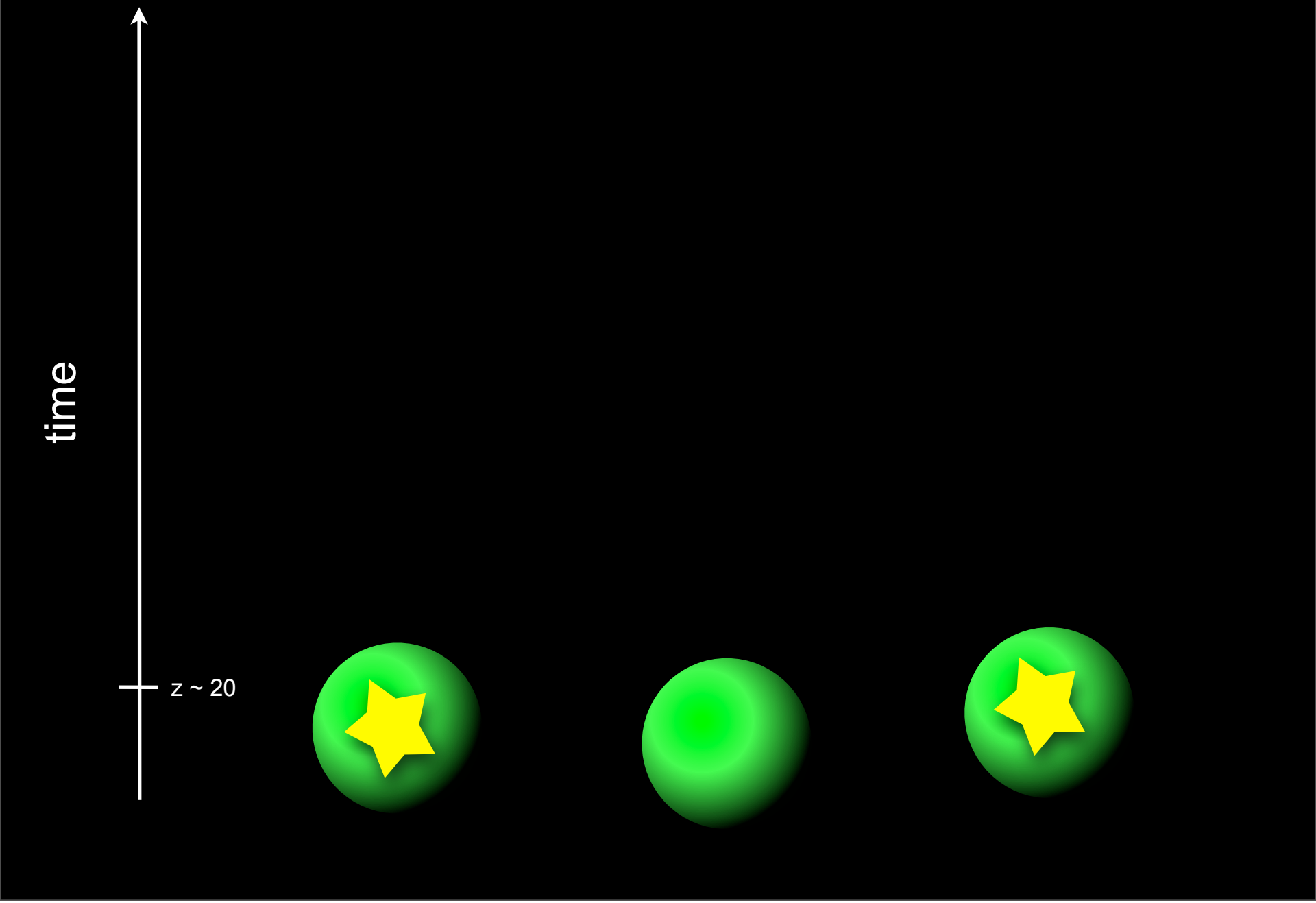
Assembly of the First Galaxies



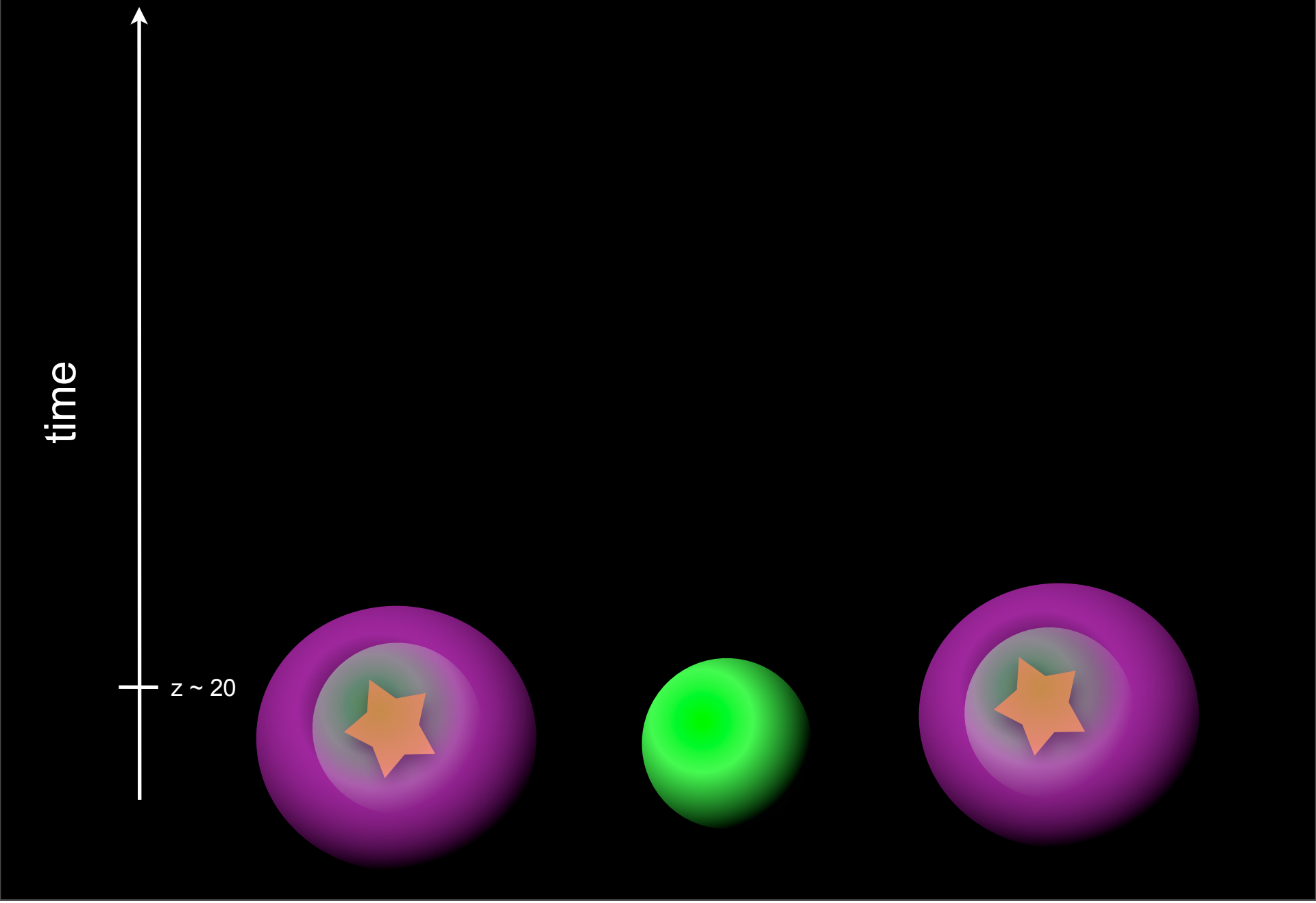
Assembly of the First Galaxies



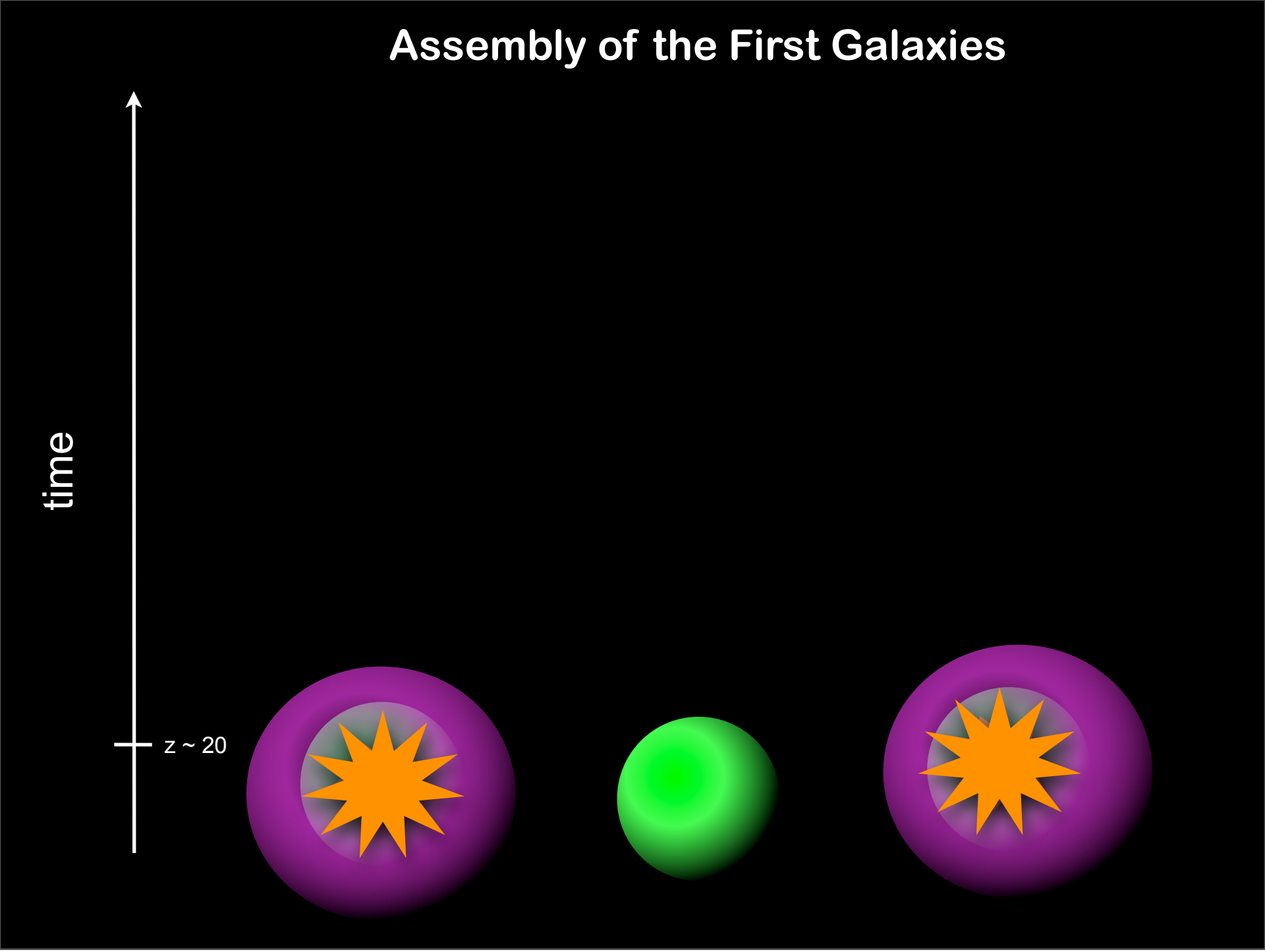
Assembly of the First Galaxies



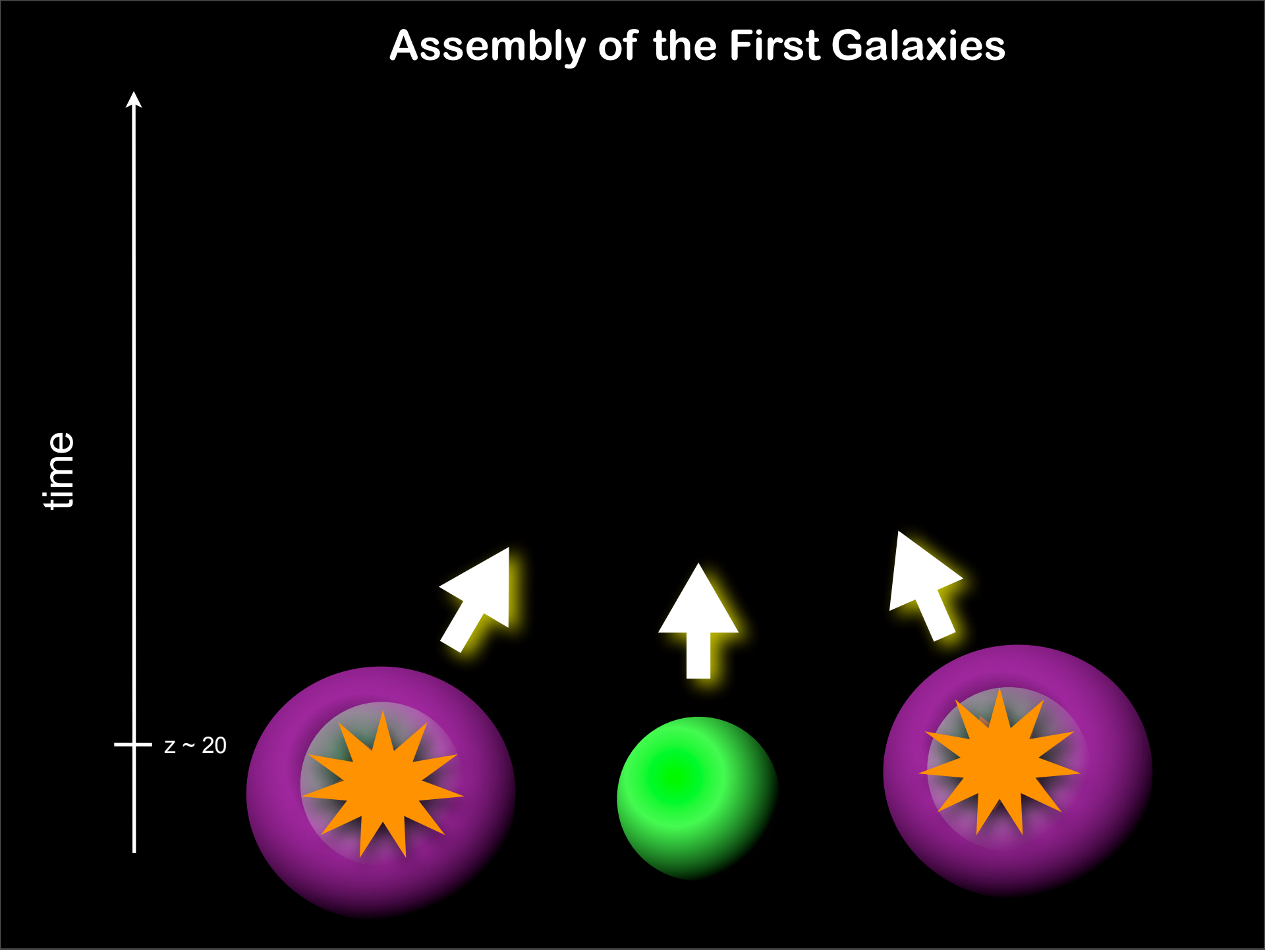
Assembly of the First Galaxies



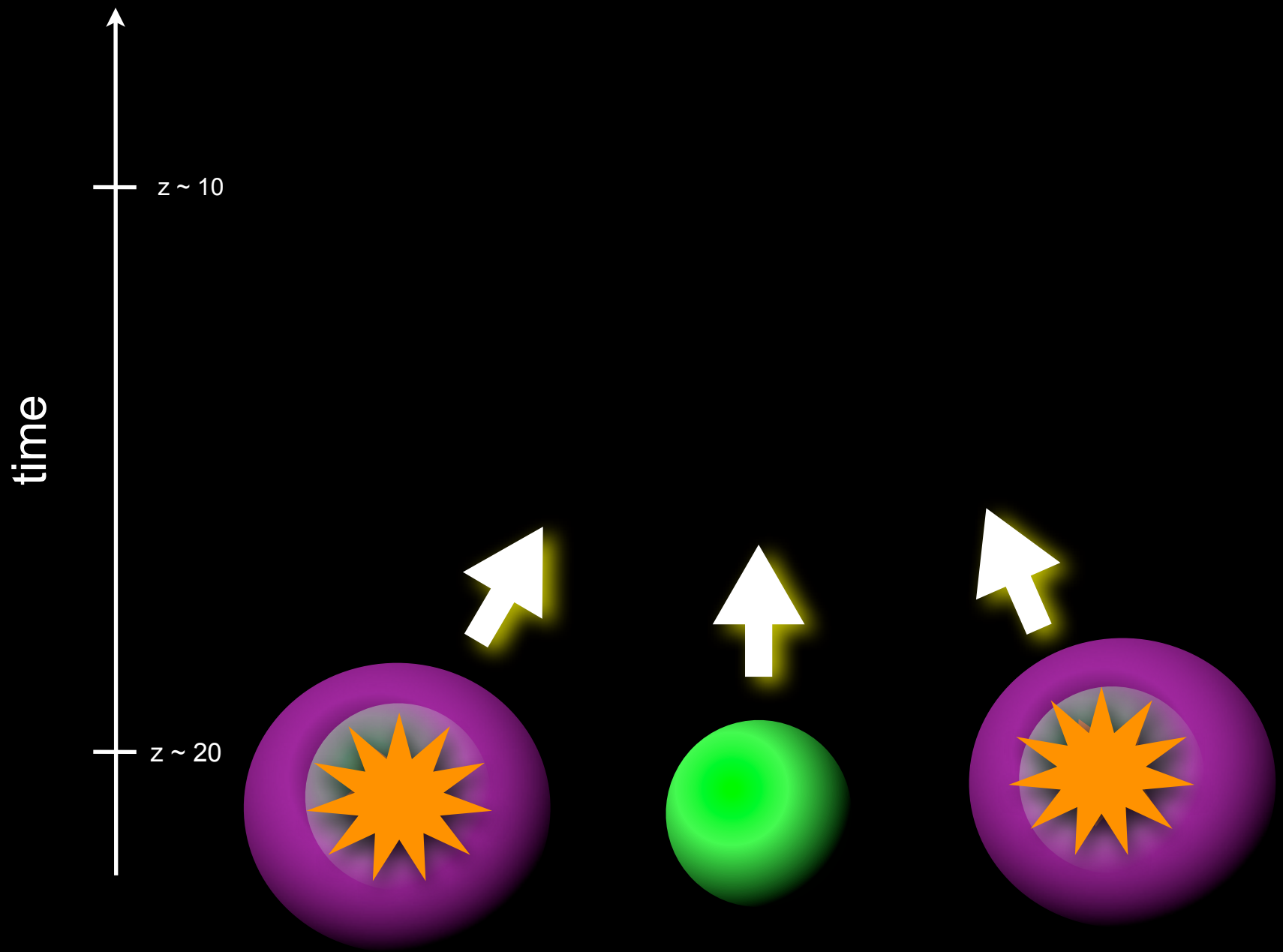
Assembly of the First Galaxies



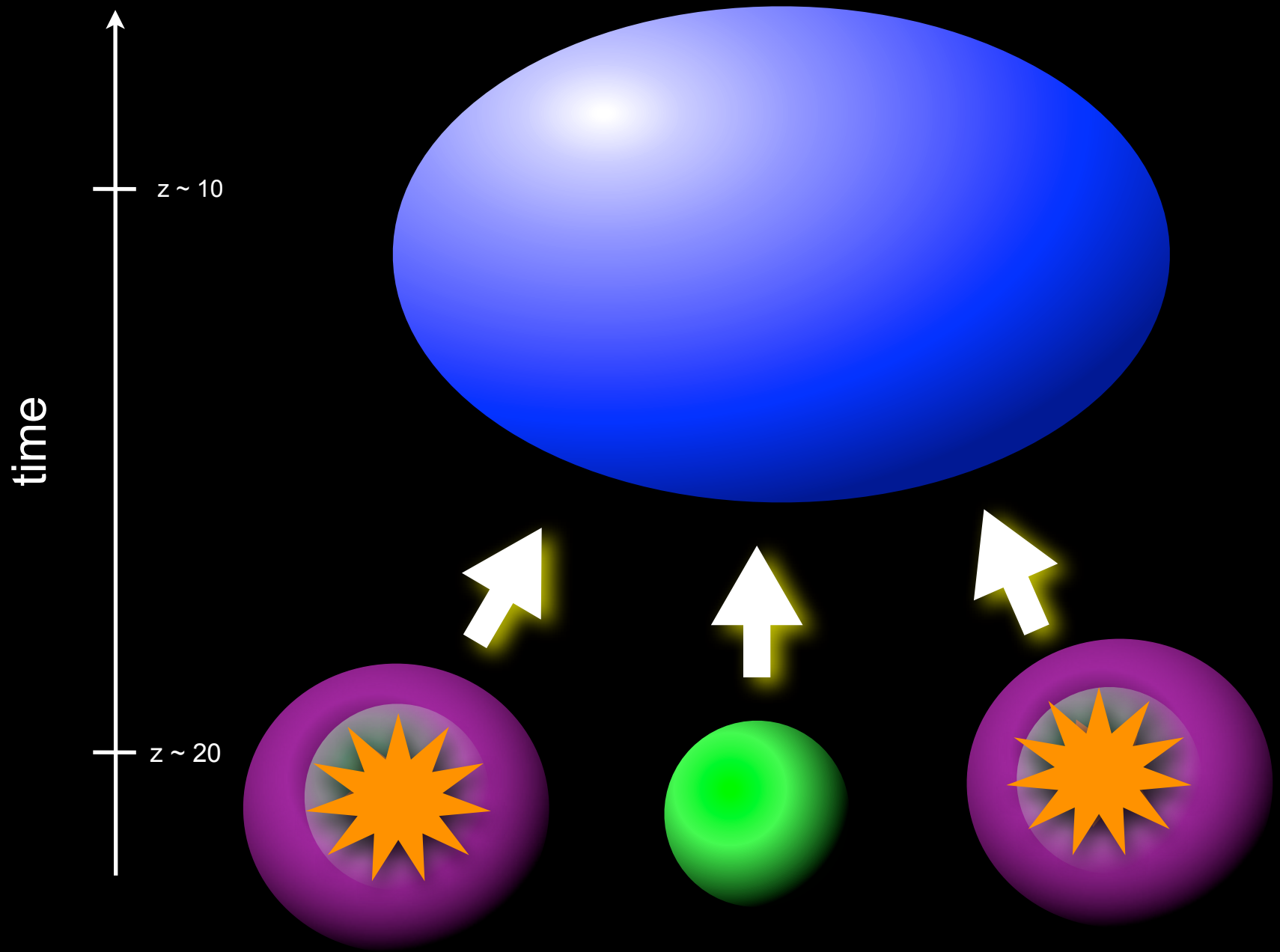
Assembly of the First Galaxies



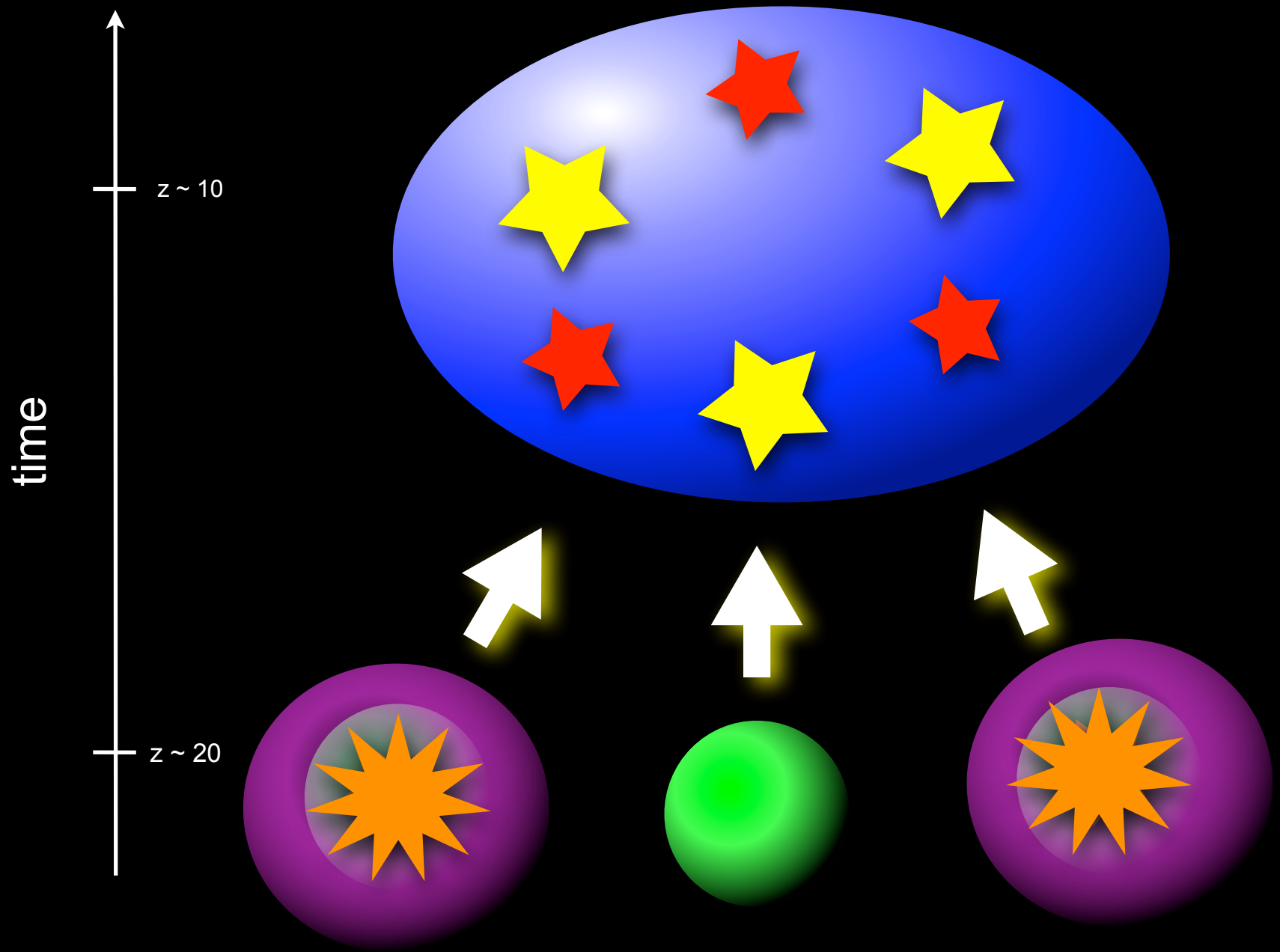
Assembly of the First Galaxies

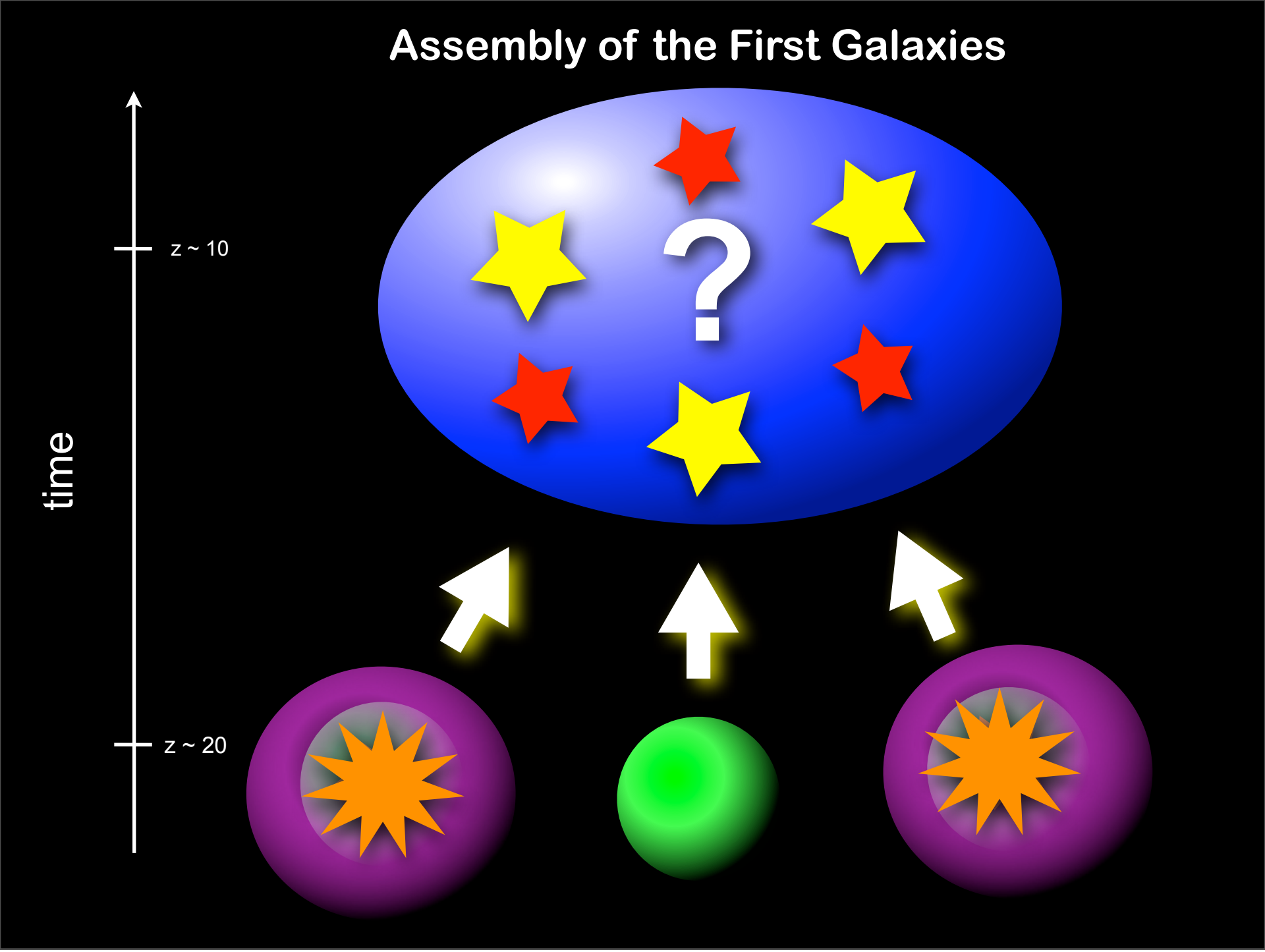


Assembly of the First Galaxies



Assembly of the First Galaxies




Assembly of the First Galaxies
time
z ~ 10
z ~ 20
?

Characters of the First Galaxies

Bromm, & Yoshida (2011)

- Mass scale ~ 10^8 $M_\odot$
- Redshift ~ 10
- Self-bound system.
- Affected from the previous stellar feedback
- Hosted the Pop III and Pop II stars

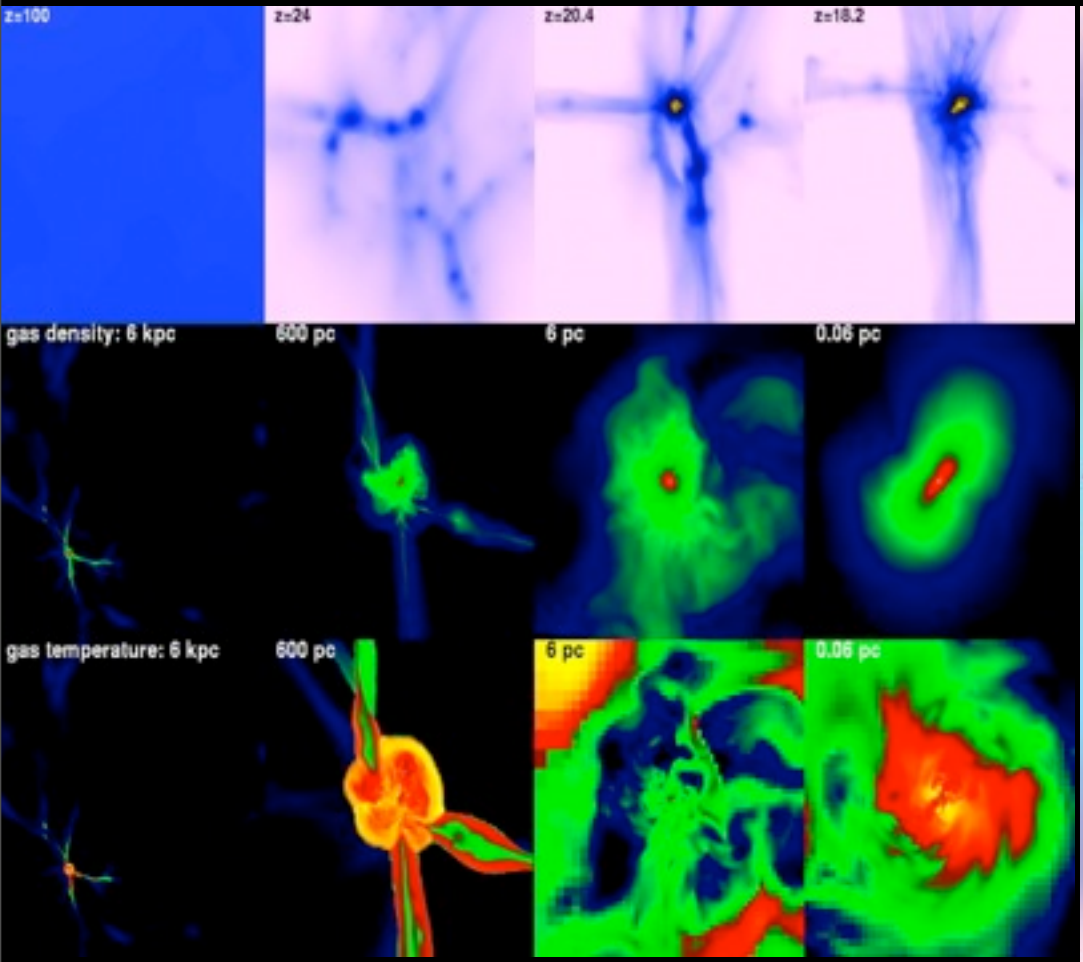
Characters of the First Galaxies

Bromm, & Yoshida (2011)

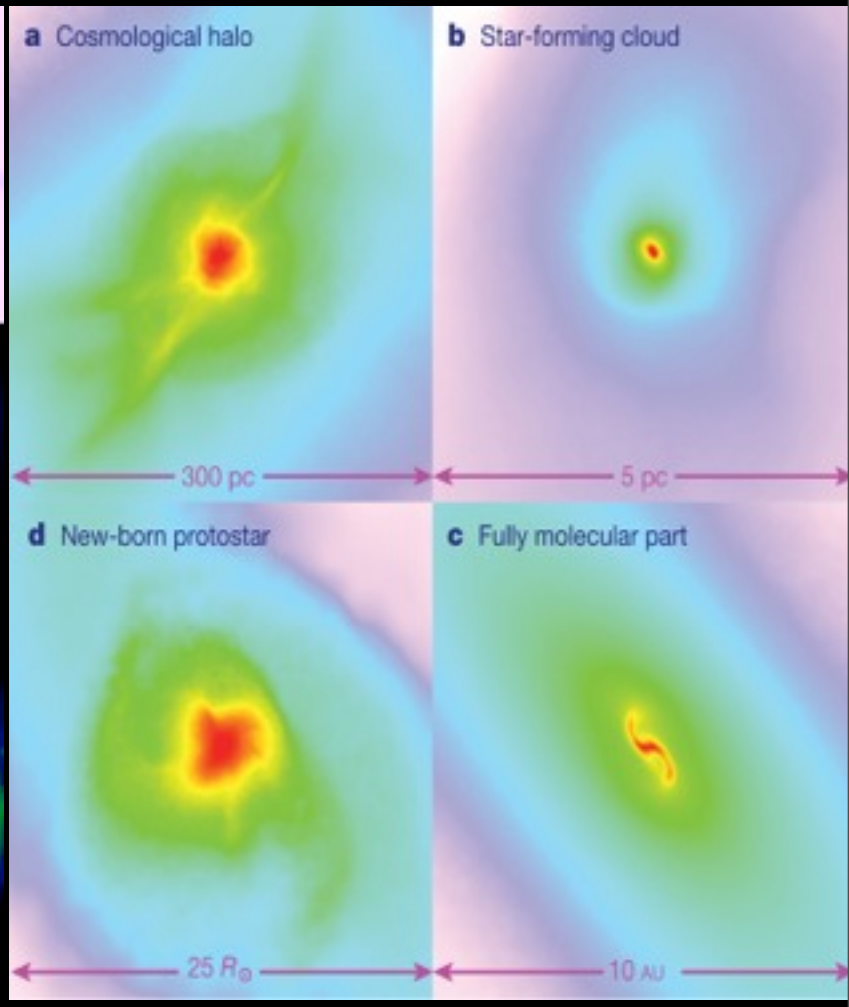
- Mass scale ~ 10^8 $M_\odot$
- Redshift ~ 10
- Self-bound system.
- Affected from the previous stellar feedback
- Hosted the Pop III and Pop II stars

The First Stars

Talks: Ferrara, Omukai, Clark, Yoshida



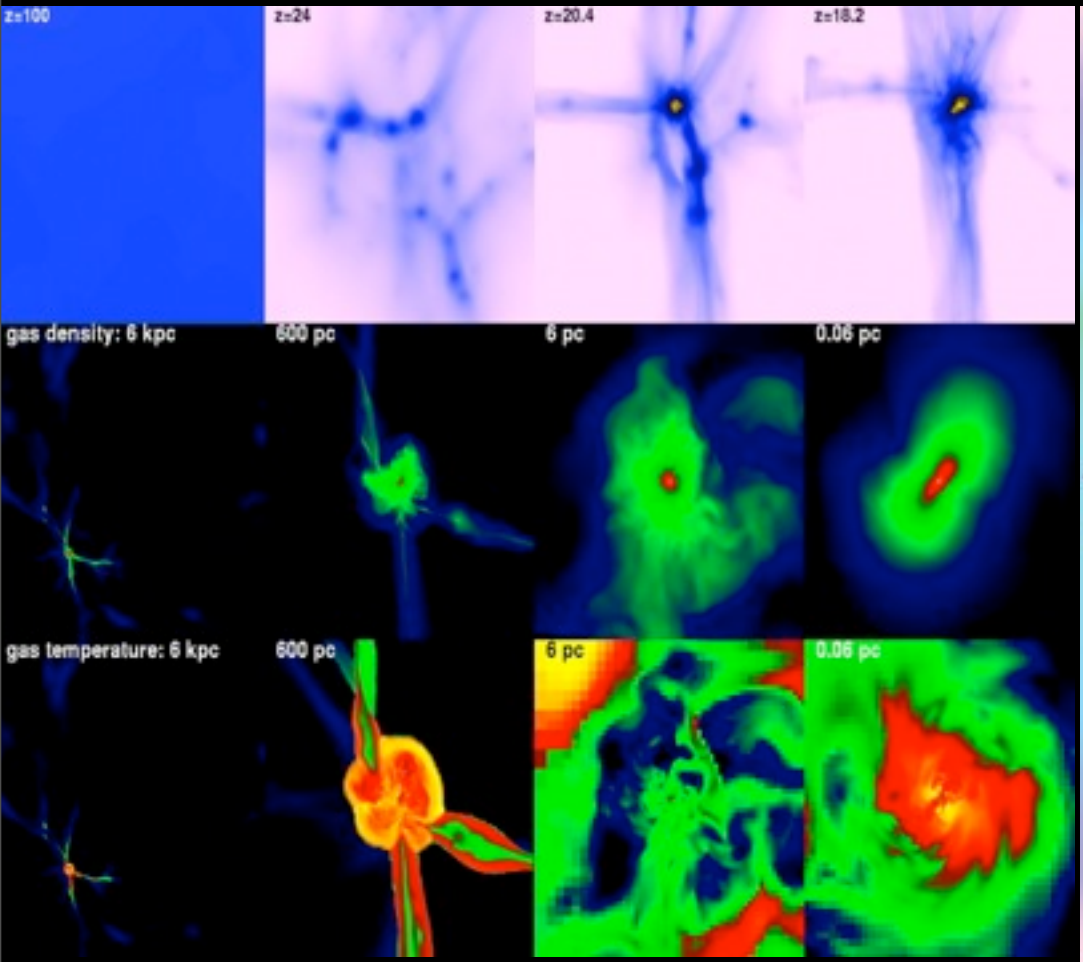
Abel, et al. Science (2002)



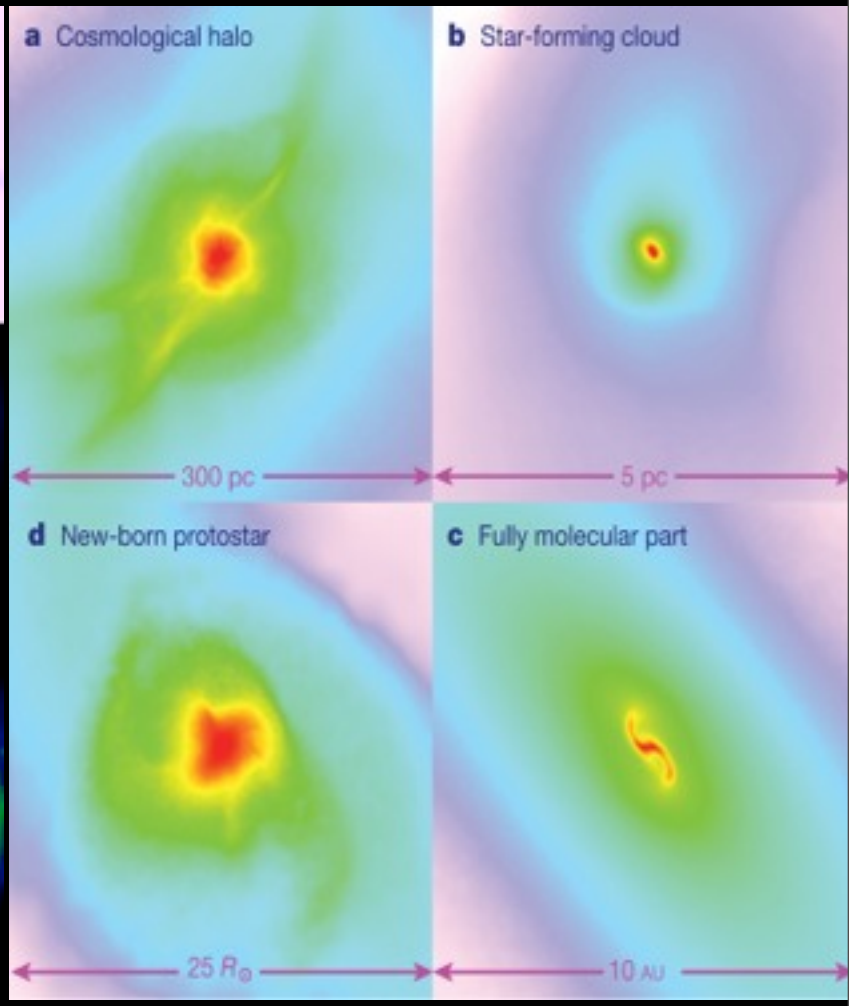
Bromm, et al. Nature (2009)

The First Stars

Talks: Ferrara, Omukai, Clark, Yoshida



Abel, et al. Science (2002)



Bromm, et al. Nature (2009)

Mass Scale ~ 50 - 100 $M_\odot$

The Death of Massive Stars

Woosley, Heger, & Weaver (2002)

MS Mass	He Core	Supernova Mechanism
$10 \leq M \leq 85$	$2 \leq M \leq 32$	Fe core collapse to a neutron star or black hole
$80 \leq M \leq 150$	$35 \leq M \leq 60$	Pulsational pair instability followed by core (PPSN)
$150 \leq M \leq 250$	$60 \leq M \leq 133$	Pair instability supernova (PSN)
$250 \leq M$	$133 \leq M$	Black holes

Mass Unit: solar mass $\odot$

The Death of Massive Stars

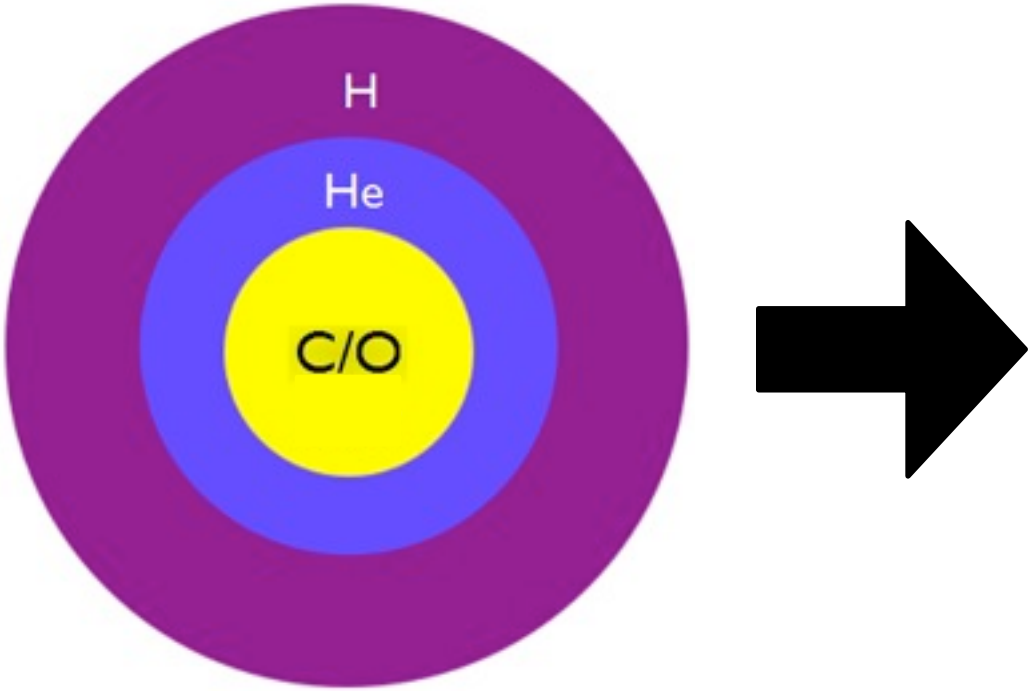
Woosley, Heger, & Weaver (2002)

	MS Mass	He Core	Supernova Mechanism
	$10 \leq M \leq 85$	$2 \leq M \leq 32$	Fe core collapse to a neutron star or black hole
	$80 \leq M \leq 150$	$35 \leq M \leq 60$	Pulsational pair instability followed by core (PPSN)
First Stars	$150 \leq M \leq 250$	$60 \leq M \leq 133$	Pair instability supernova (PSN)
	$250 \leq M$	$133 \leq M$	Black holes

Mass Unit: solar mass $\odot$

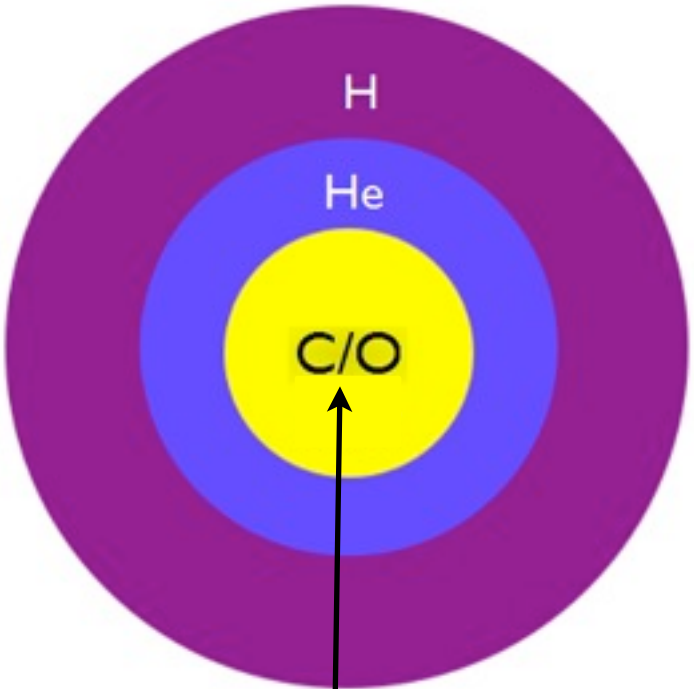
Physics of PSN

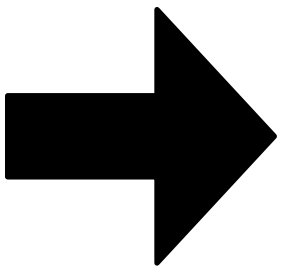
250 M⊙ > M > 150 M⊙

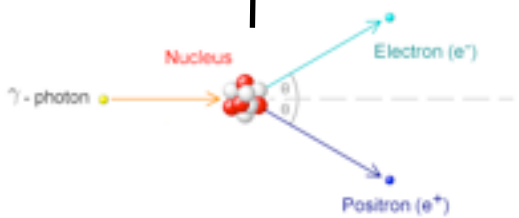


Physics of PSN

250 M⊙ > M > 150 M⊙



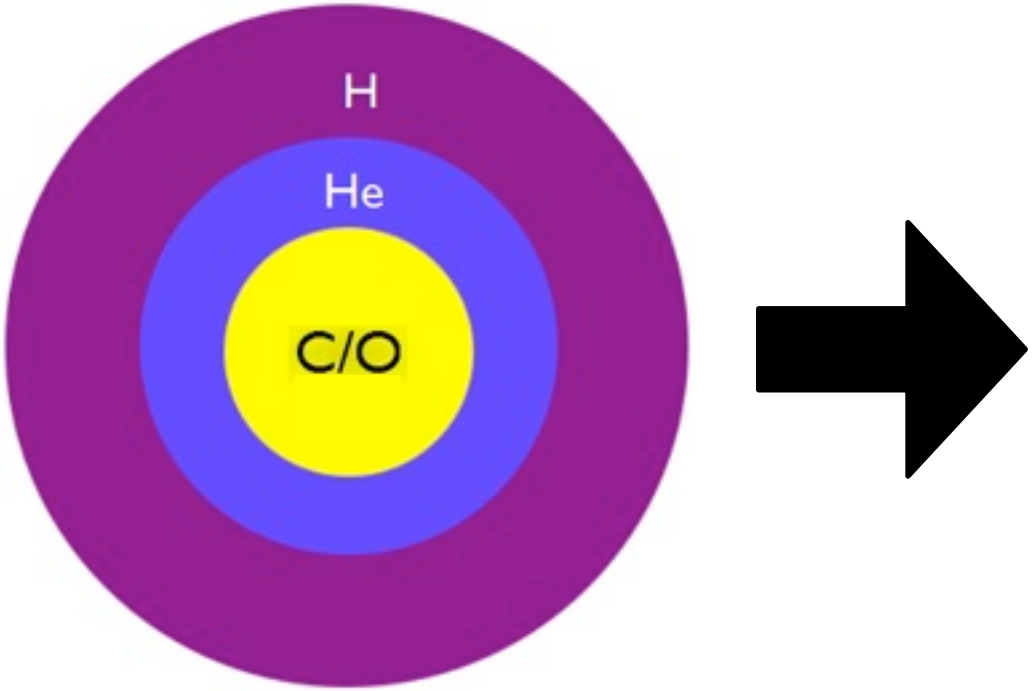




$E_o > 2m_0c^2$, where m_0 is the electron rest mass

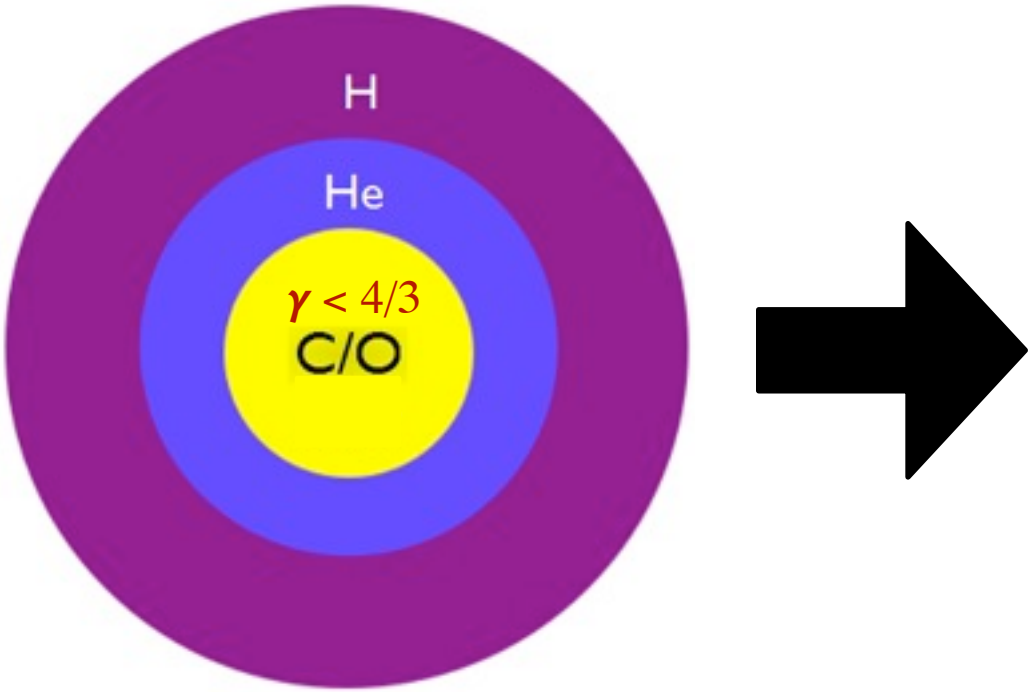
Physics of PSN

250 M⊙ > M > 150 M⊙



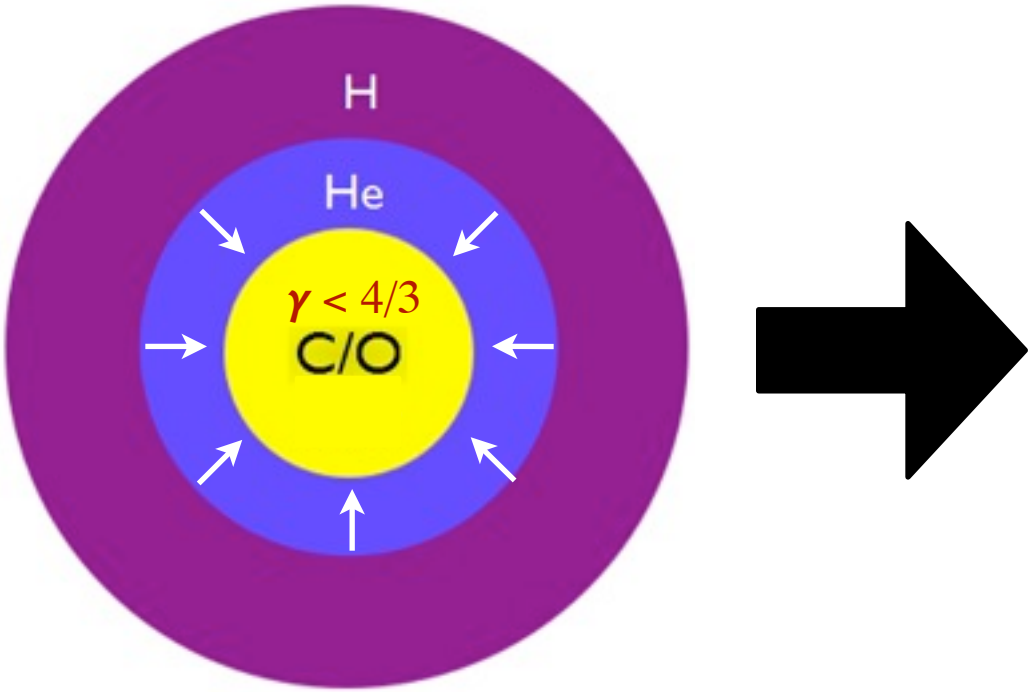
Physics of PSN

250 M⊙ > M > 150 M⊙



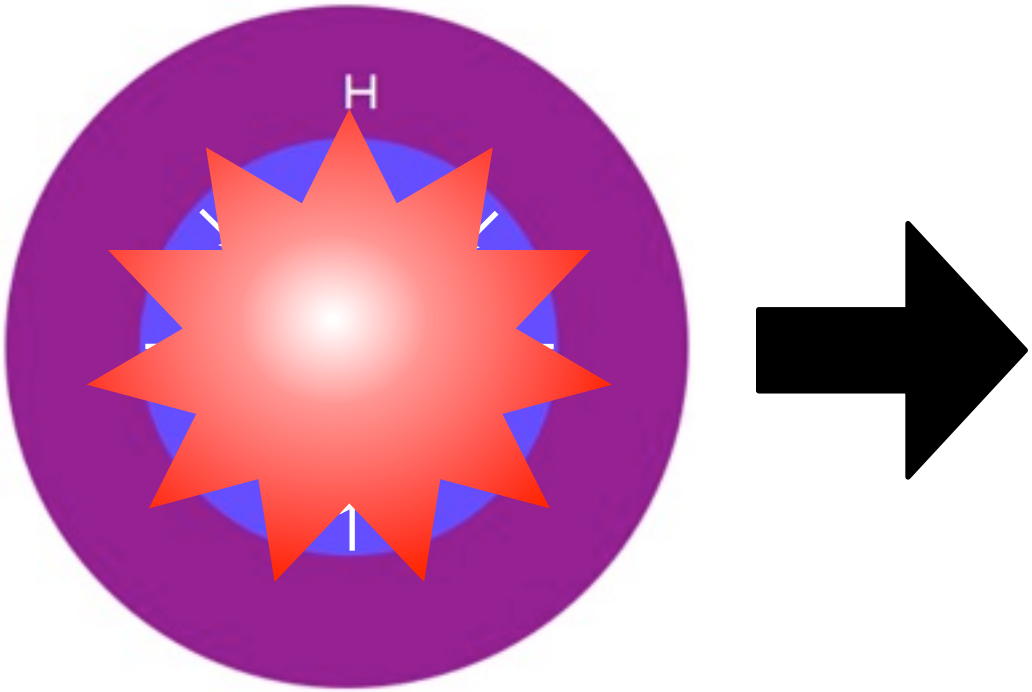
Physics of PSN

250 M⊙ > M > 150 M⊙



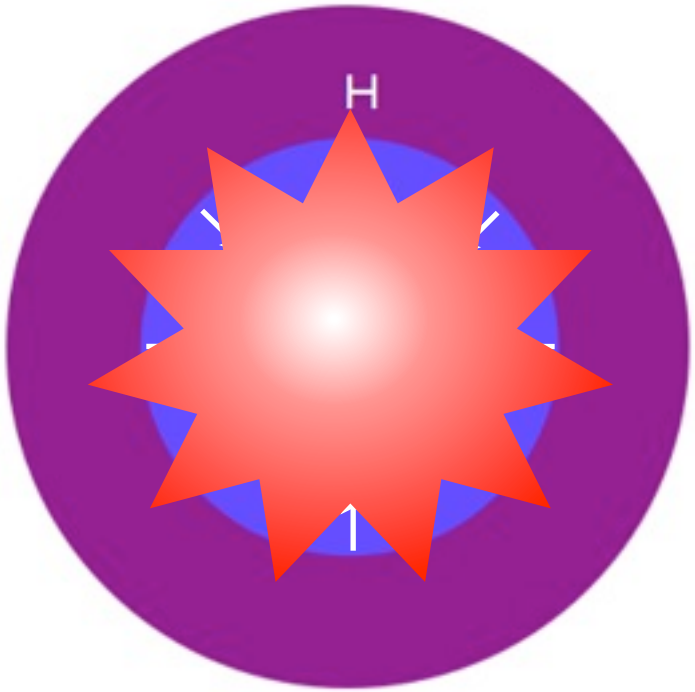
Physics of PSN

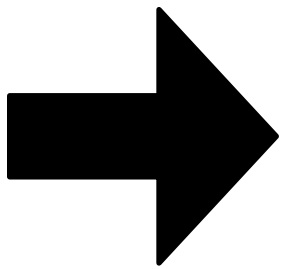
250 M⊙ > M > 150 M⊙

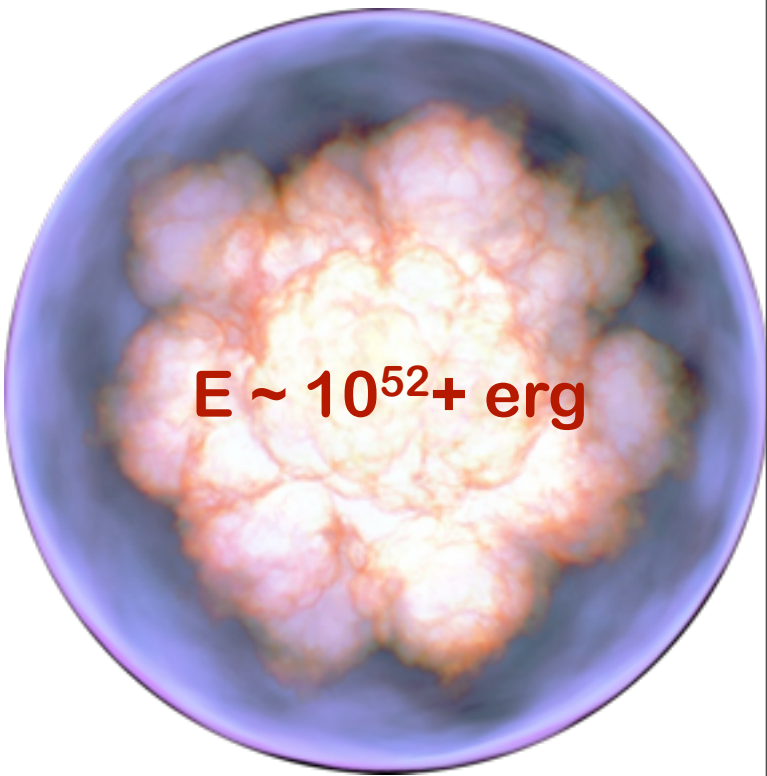


Physics of PSN

250 M⊙ > M > 150 M⊙



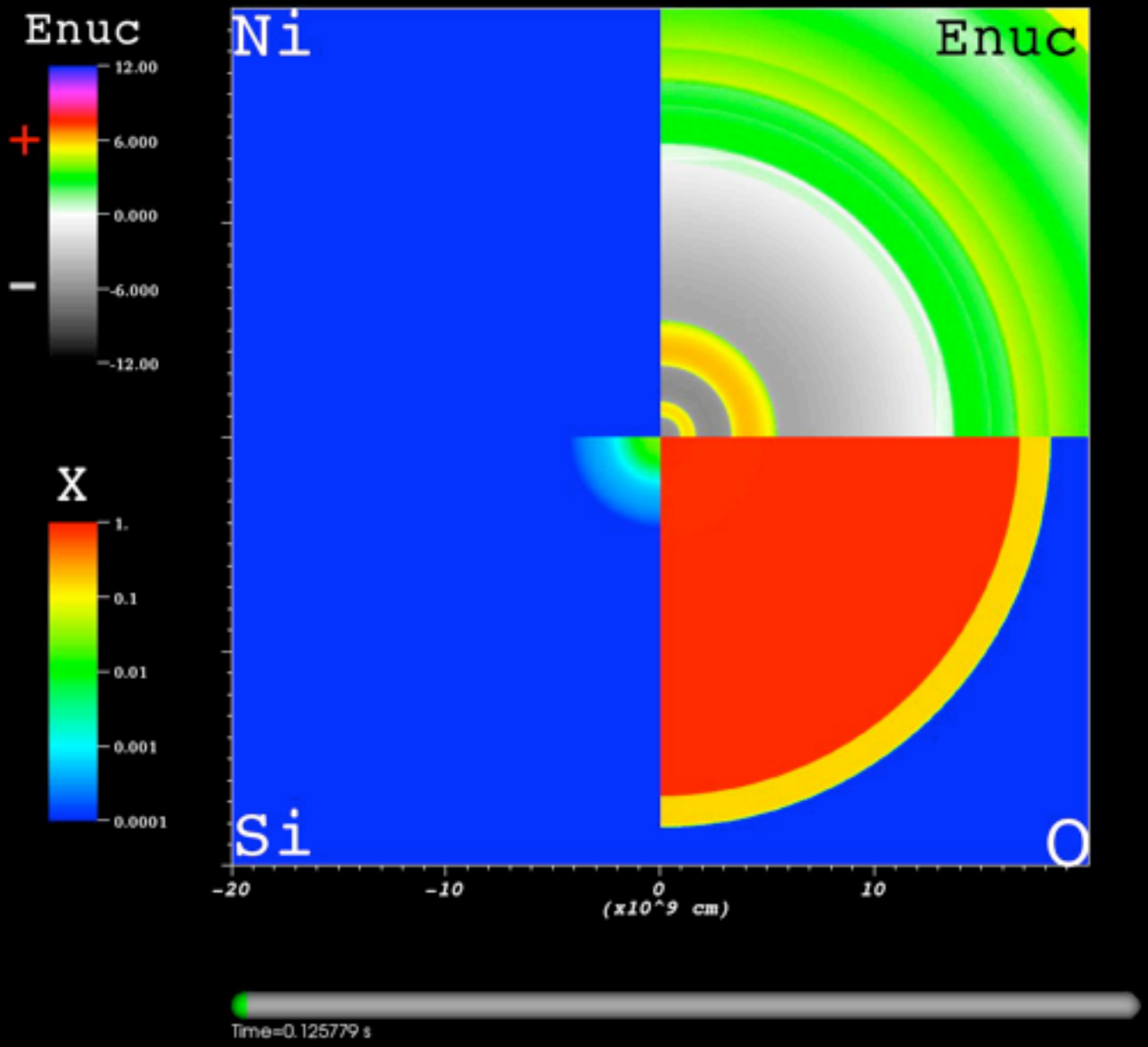




Explosive Burning of 150 M⊙ Star

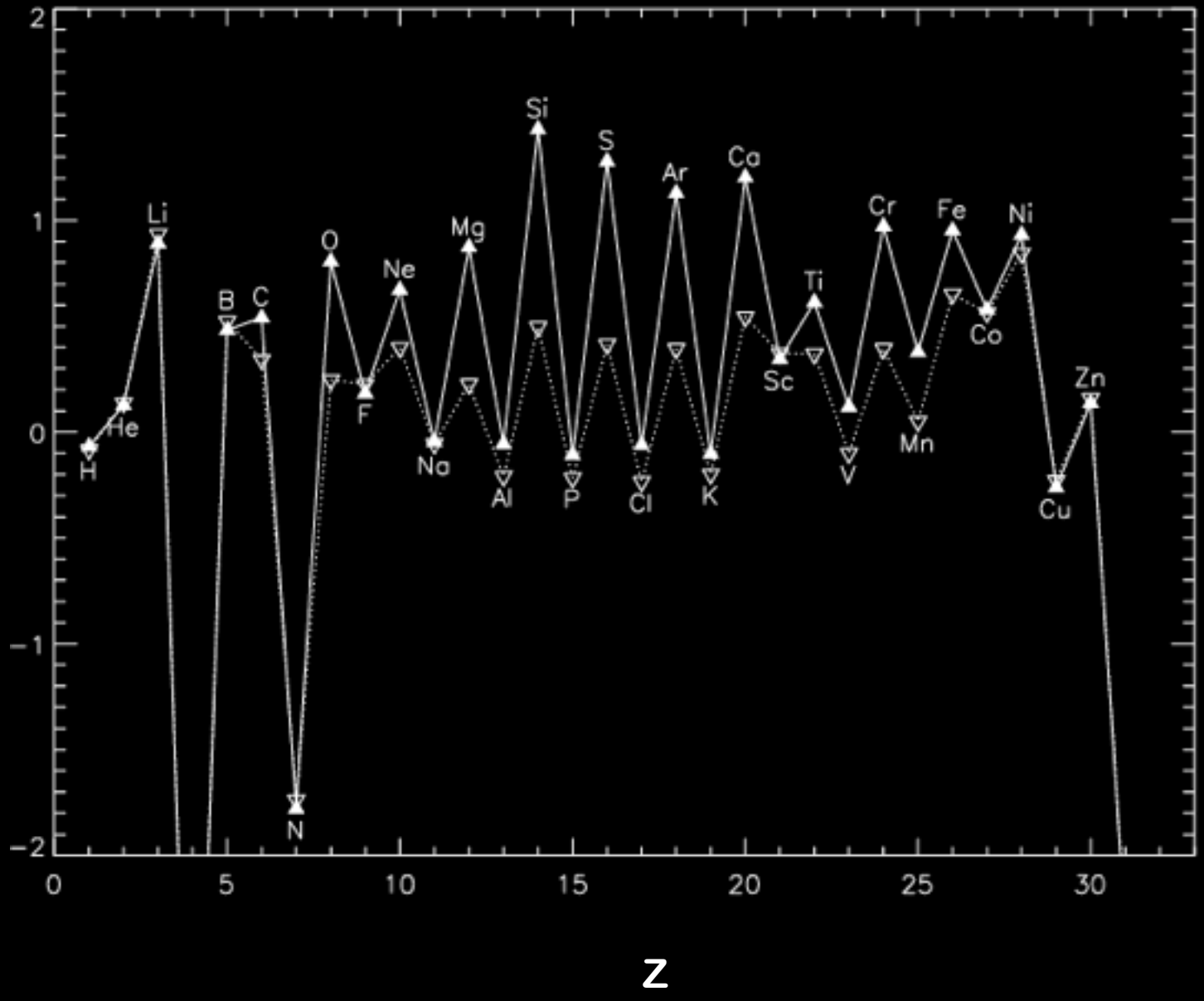
PSN Explosion
Chen+ (2012)
Using CASTRO

Explosive Burning of 150 M⊙ Star

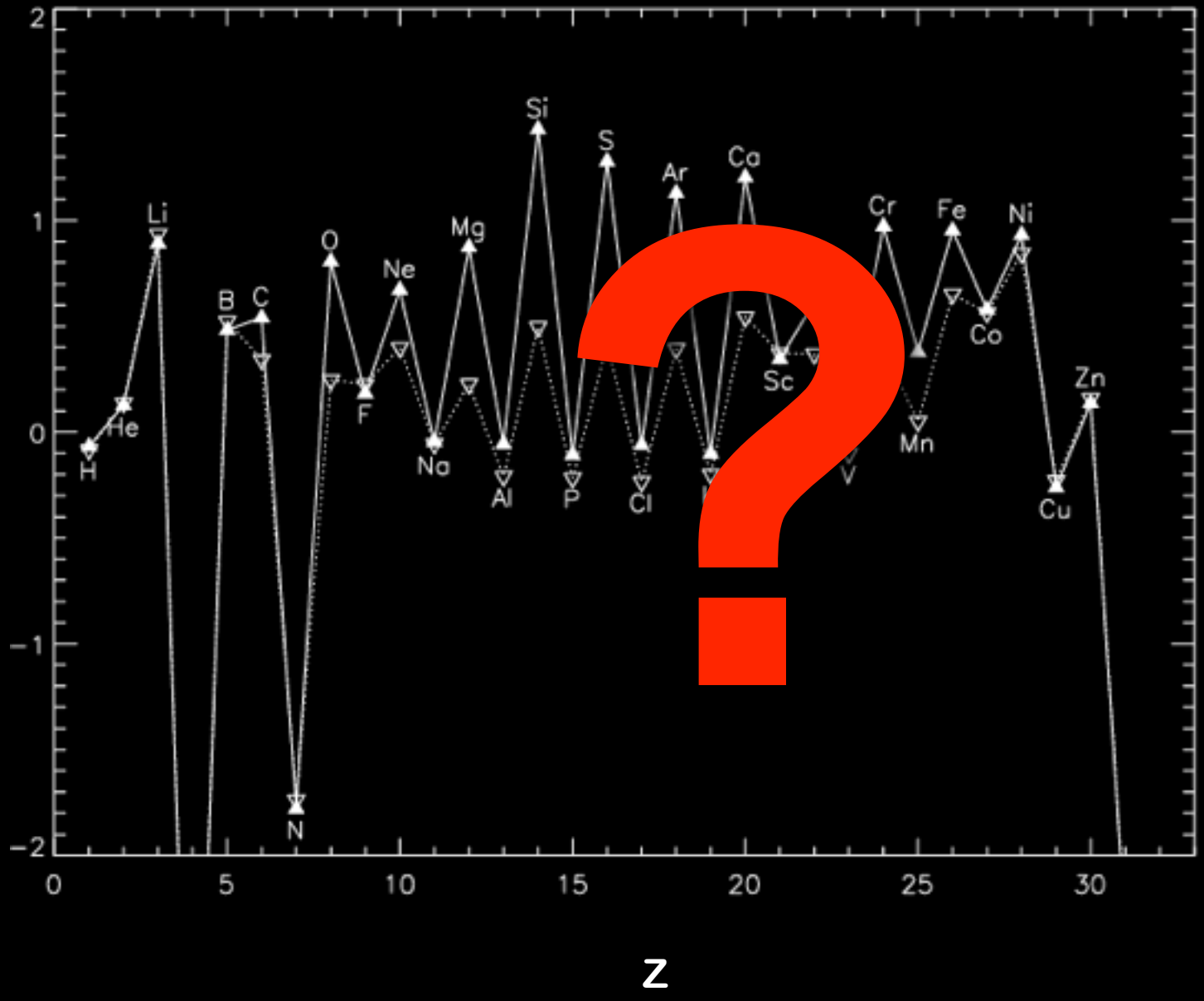


PSN Explosion
Chen+ (2012)
Using CASTRO

Chemical Abundance ?



Chemical Abundance ?

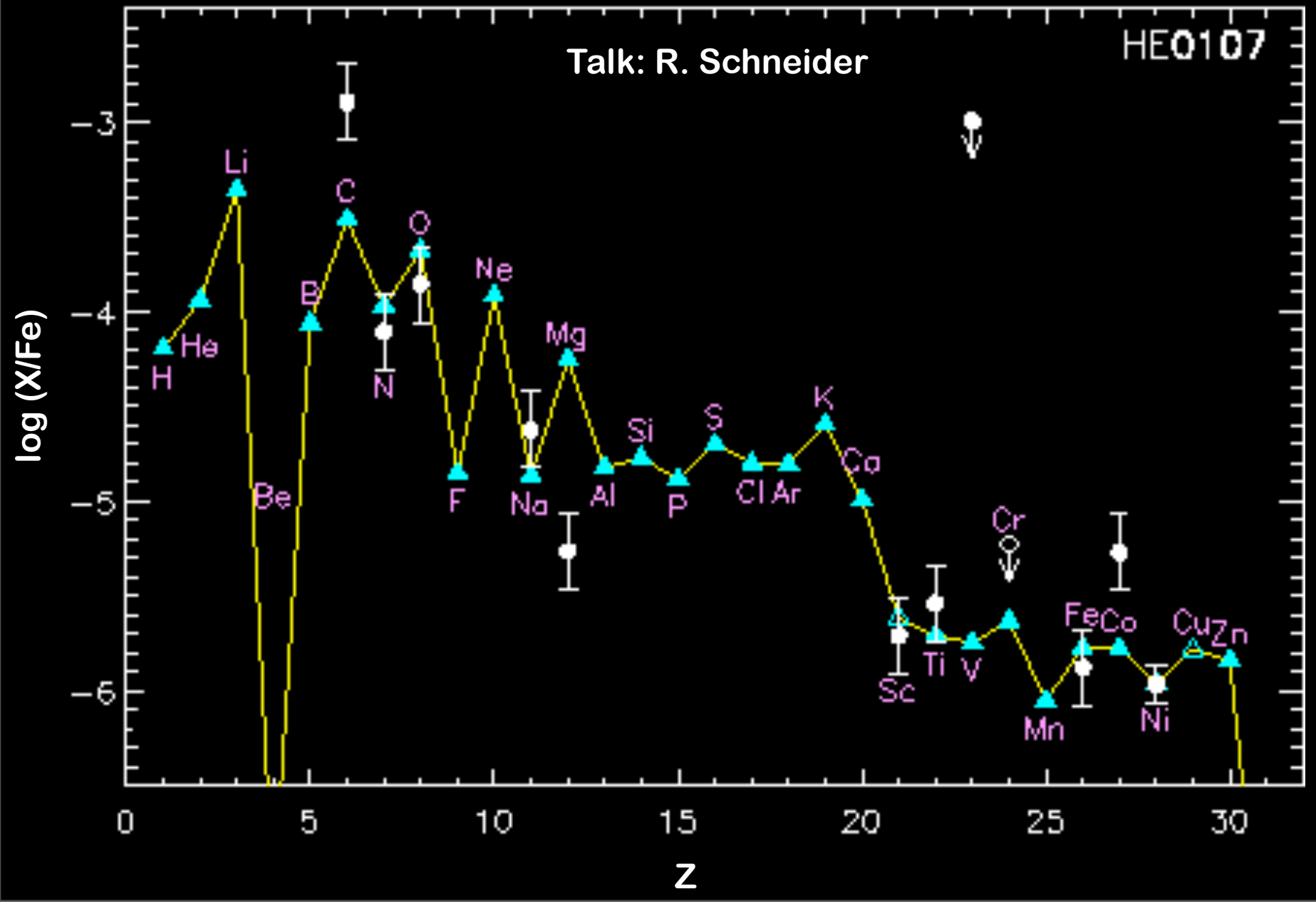


Chemical Abundance ?

Chemical Abundance ?

Fe-core Collapse SNe
Nordhaus+ 2010
Using CASTRO

Chemical Abundance ?



Approaches

Gadget-2 (Springel 2005)

Star formation
Radiative transfer
Diffusion mixing
Chemical cooling

Bromm+ 2002,2003 Johnson+ 2007
Greif+ 2009, 2010 Jeon+ 2012

THE UNIVERSITY OF TEXAS AT AUSTIN

Supercomputers

Itasca

Franklin

Hopper

Jaguar

Approaches

Gadget-2 (Springel 2005)

Star formation
Radiative transfer
Diffusion mixing
Chemical cooling

Bromm+ 2002,2003 Johnson+ 2007
Greif+ 2009, 2010 Jeon+ 2012

THE UNIVERSITY OF TEXAS AT AUSTIN

Detailed Stellar Models

Supercomputers

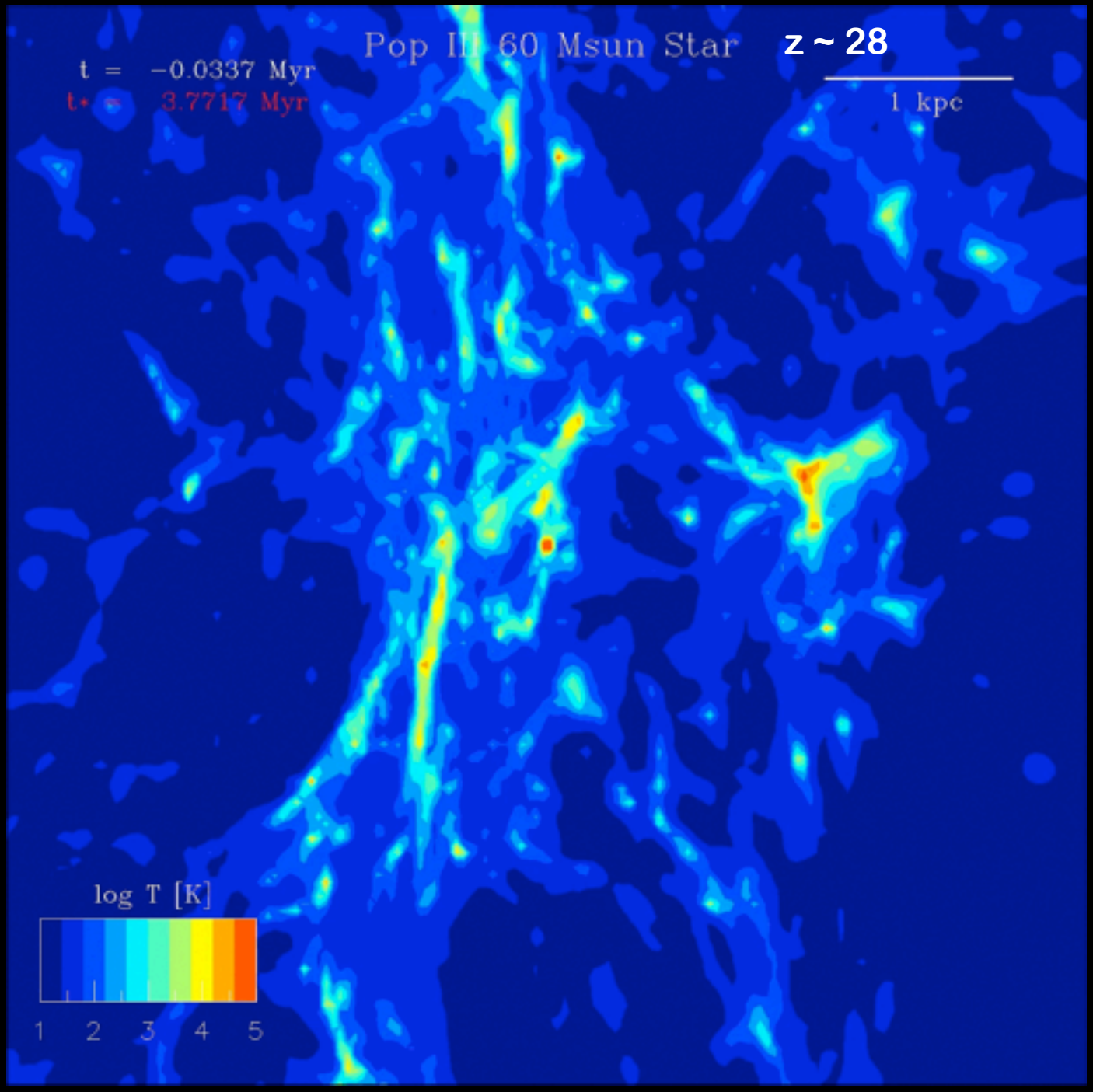
Itasca

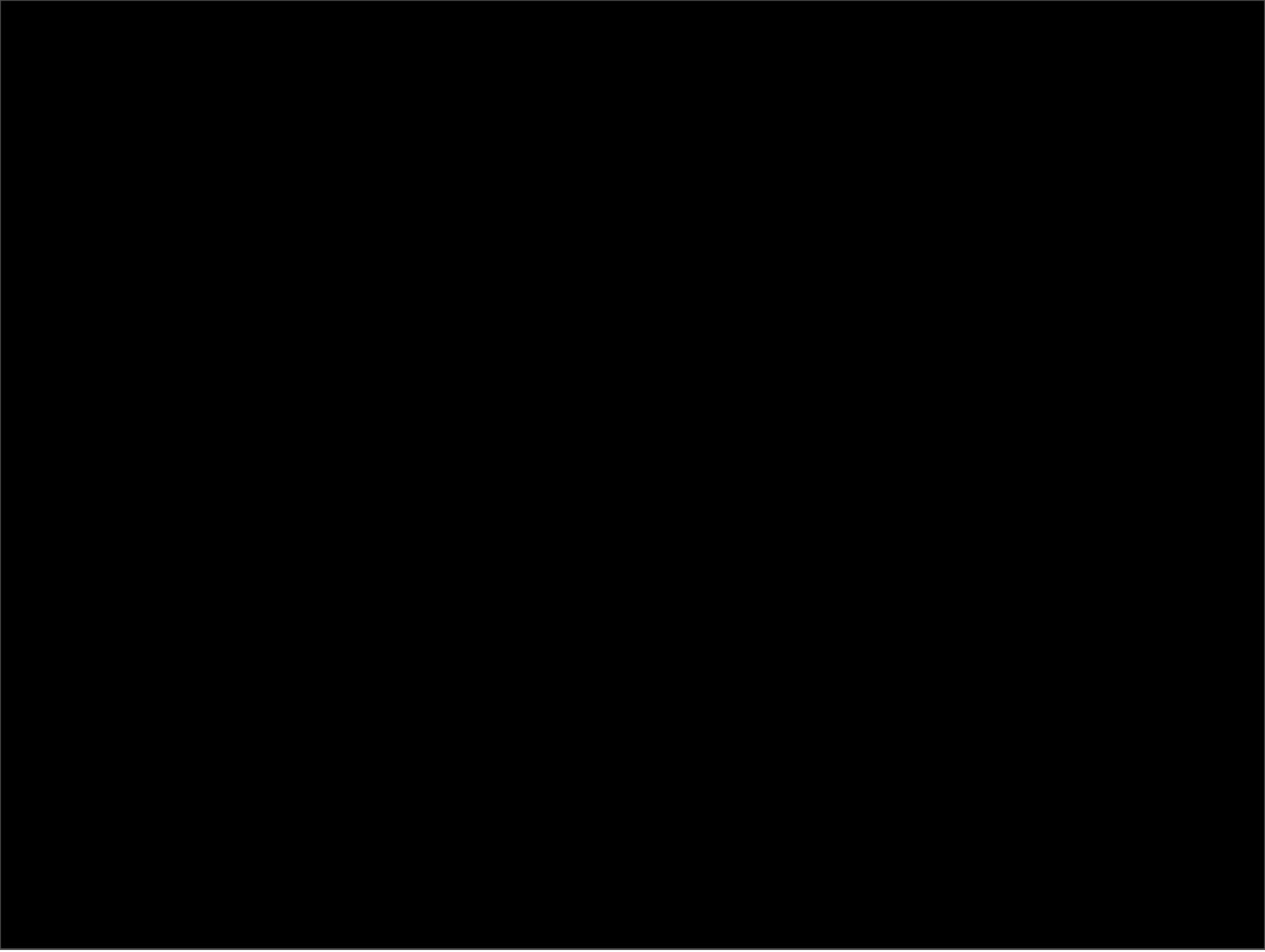
Franklin

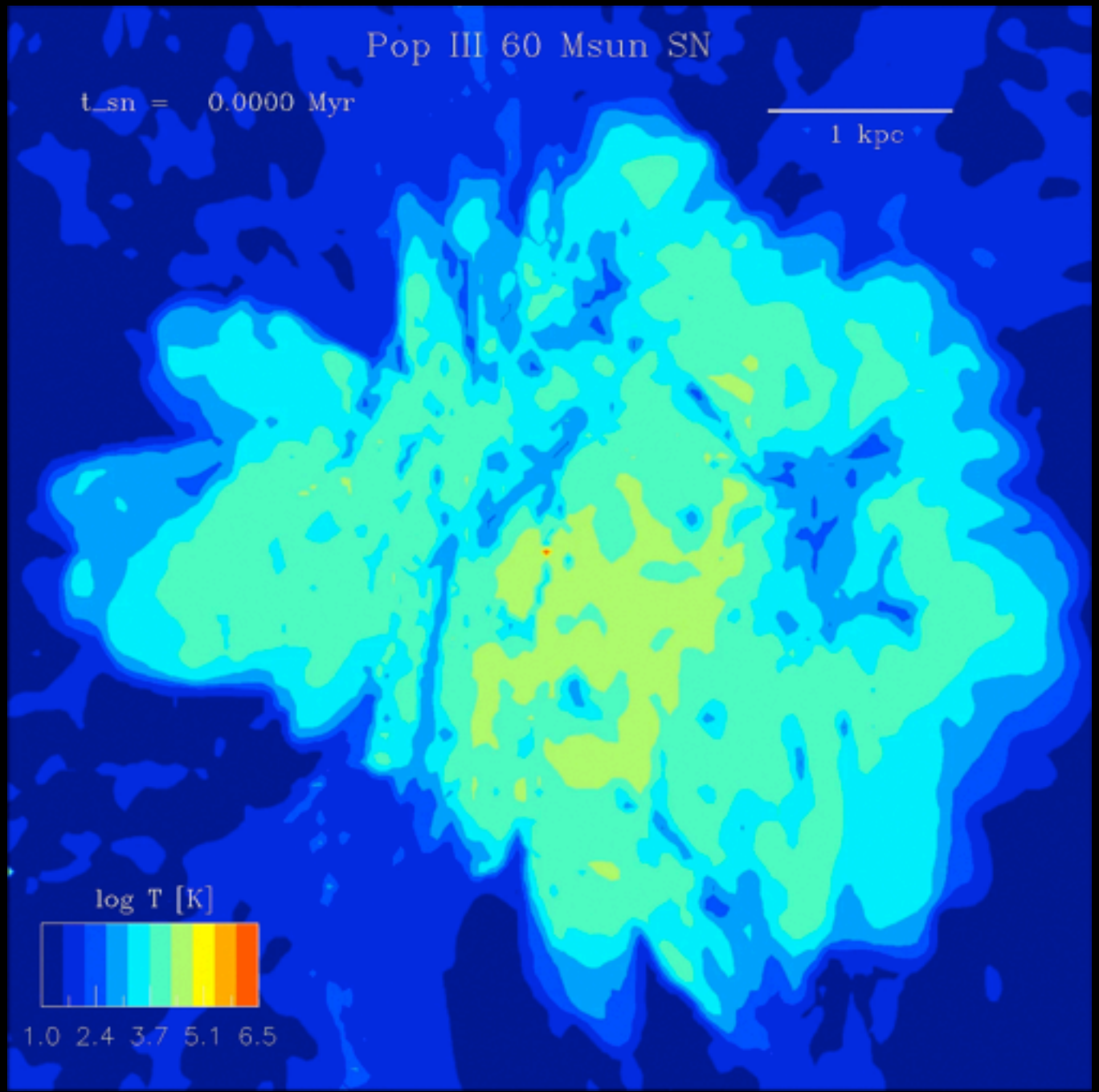
Hopper

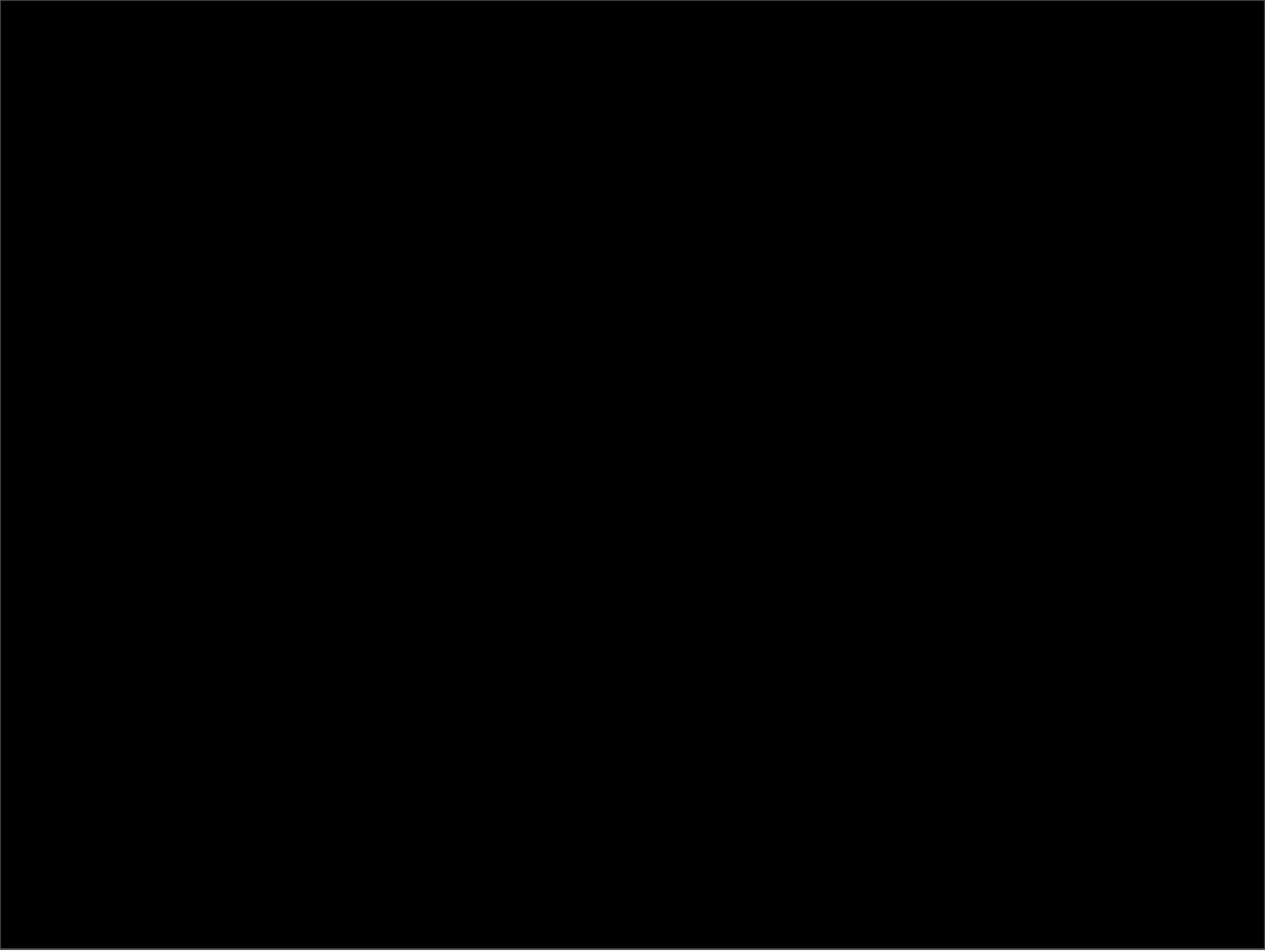
Jaguar

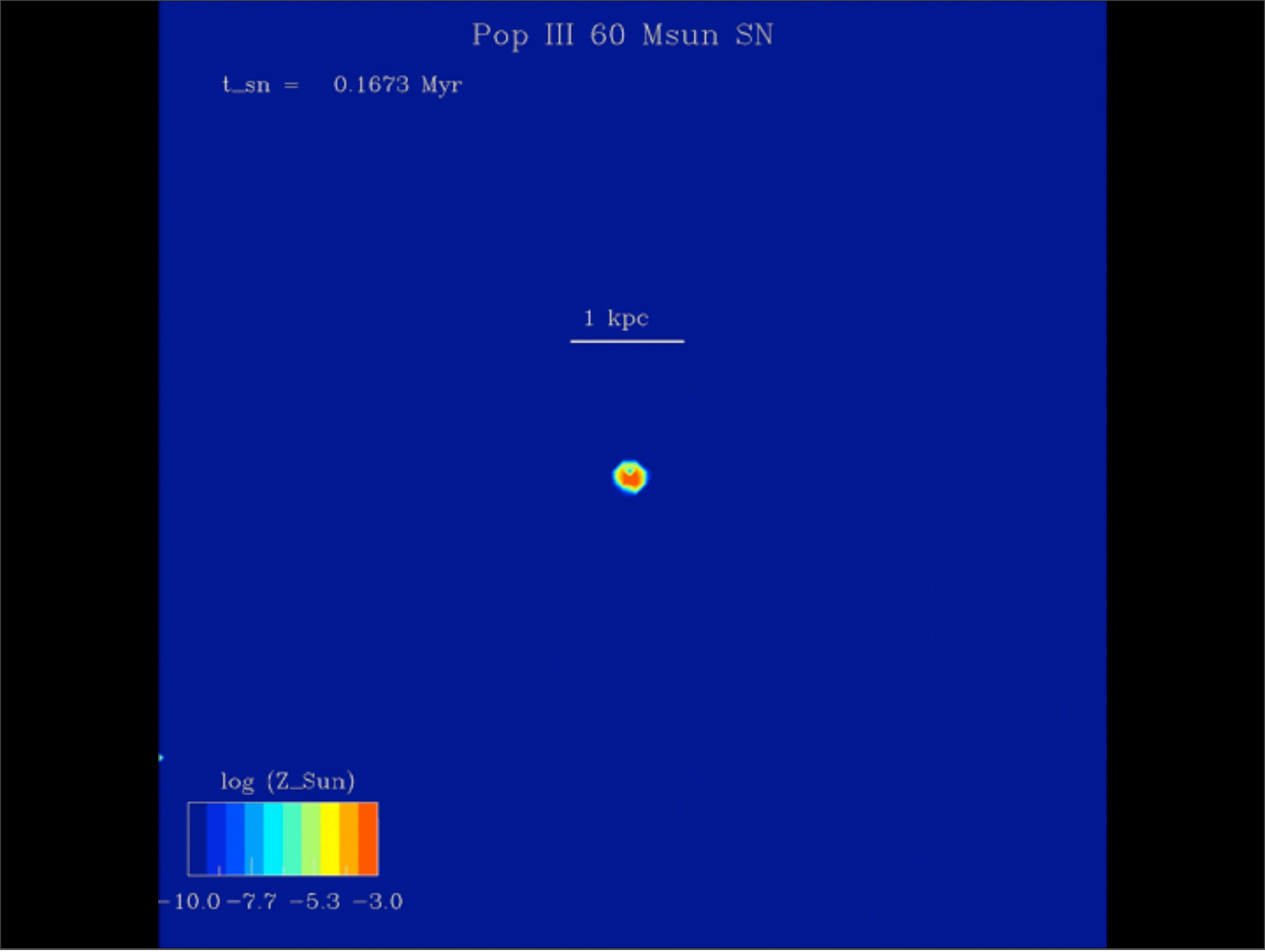
z ~ 28

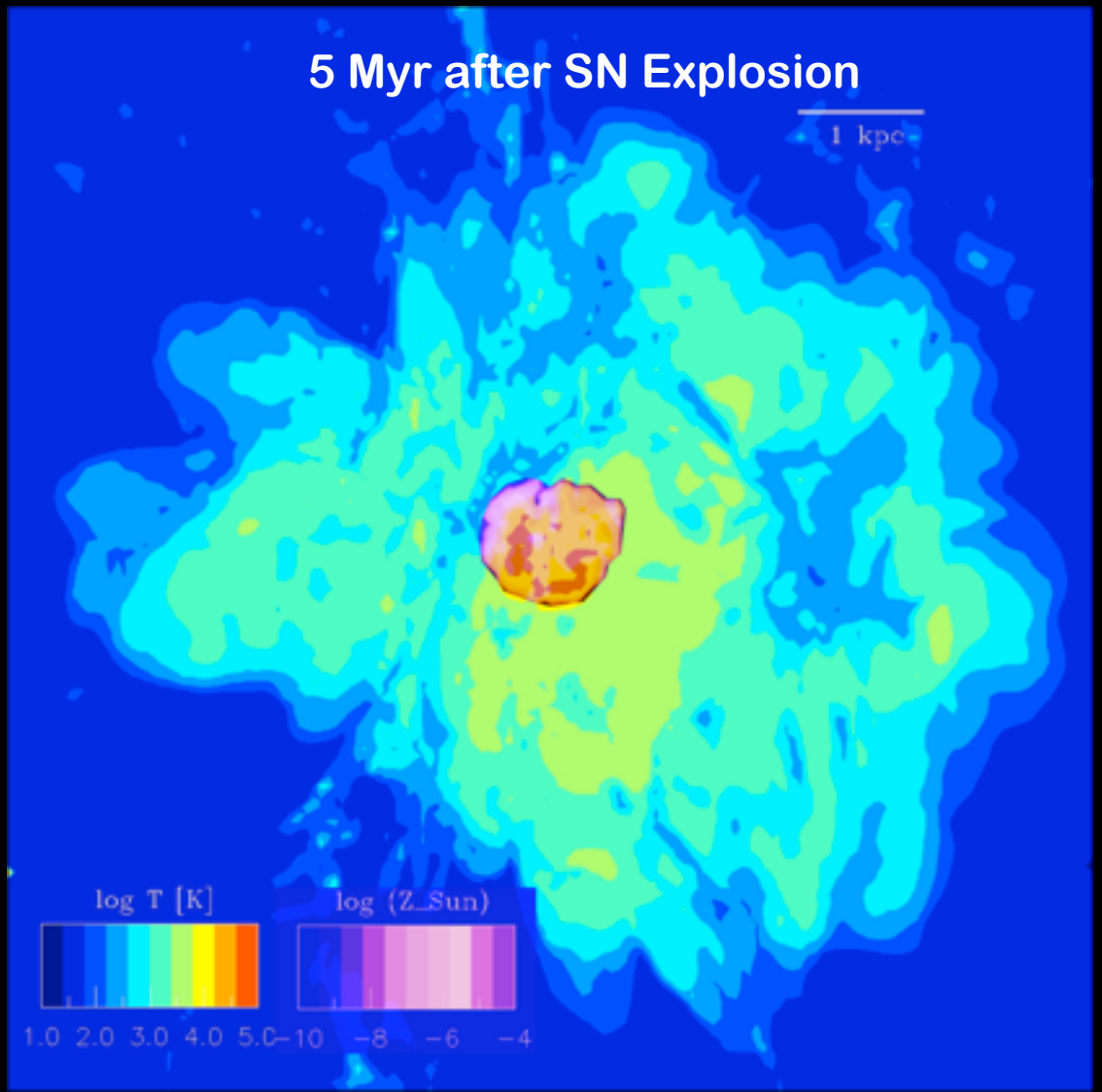

Pop III 60 Msun Star
z ~ 28
t = −0.0337 Myr
t* = 3.7717 Myr
1 kpc
log T [K]
1 2 3 4 5



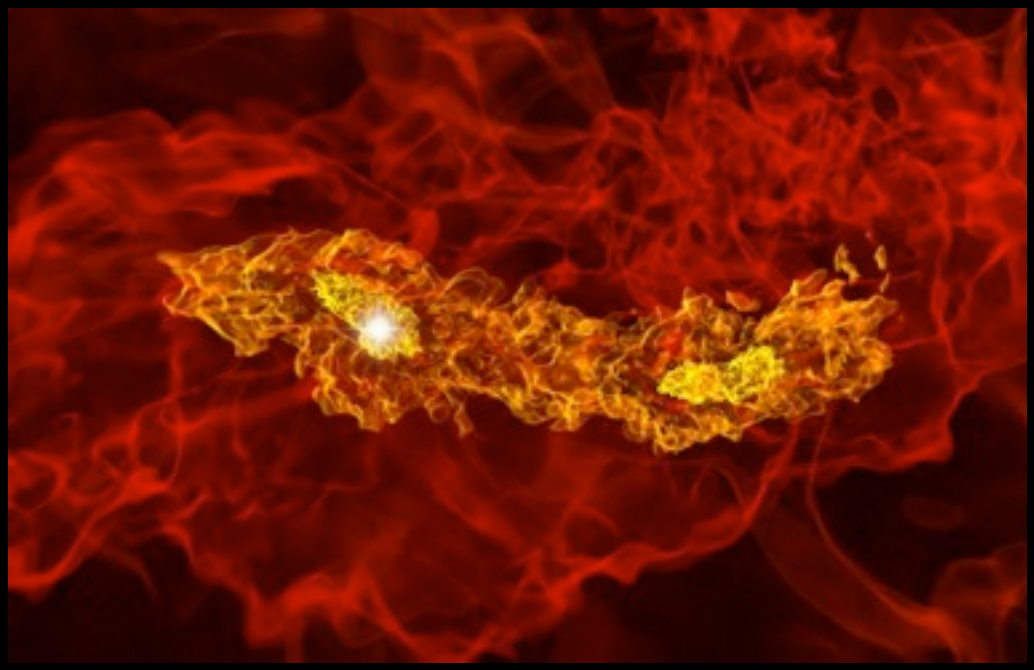

Pop III 60 Msun SN
t_sn = 0.0000 Myr
1 kpc
log T [K]
1.0 2.4 3.7 5.1 6.5

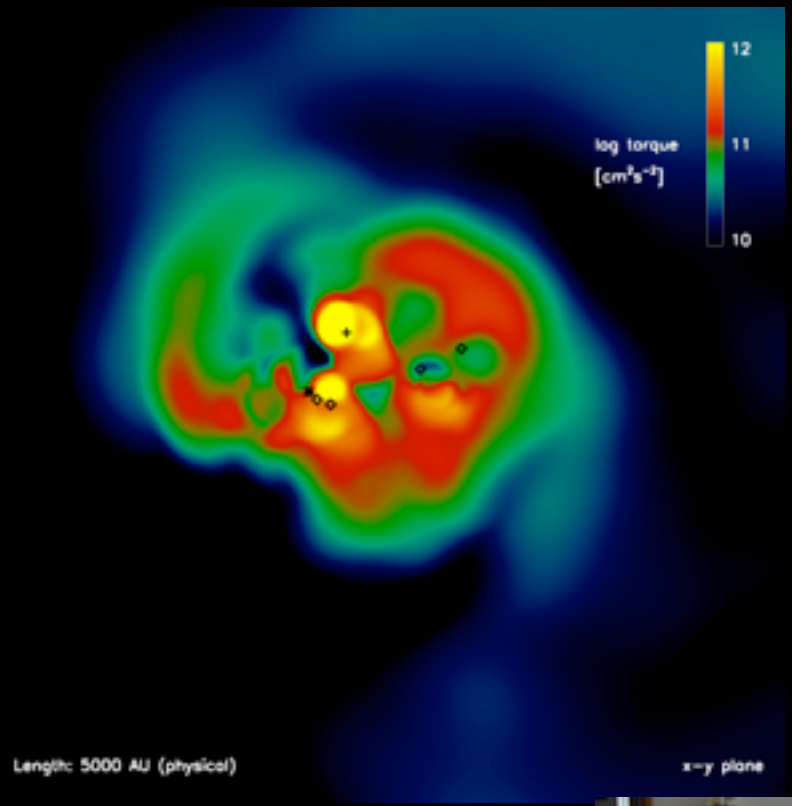



Pop III 60 Msun SN
t_sn = 0.1673 Myr
1 kpc
log (Z_Sun)
−10.0 −7.7 −5.3 −3.0


5 Myr after SN Explosion
1 kpc
log T [K]
1.0 2.0 3.0 4.0 5.0
log (Z_Sun)
−10 −8 −6 −4

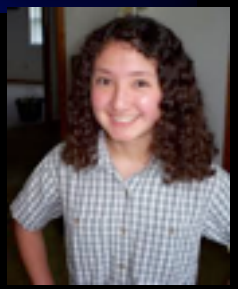
The First Binaries



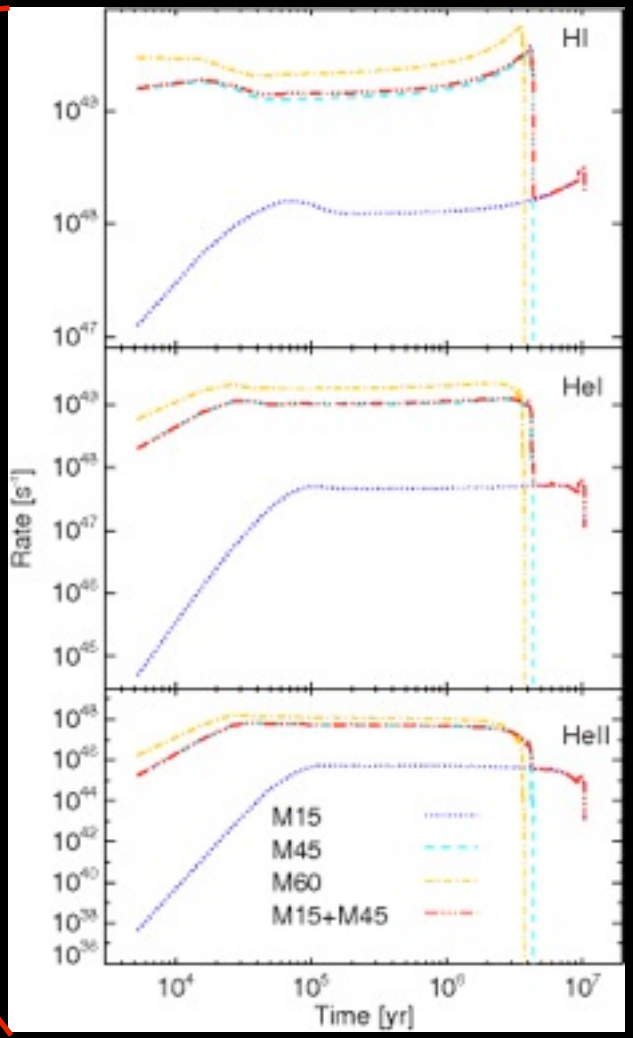


Turk+ (2009)

Stacy+ (2011)

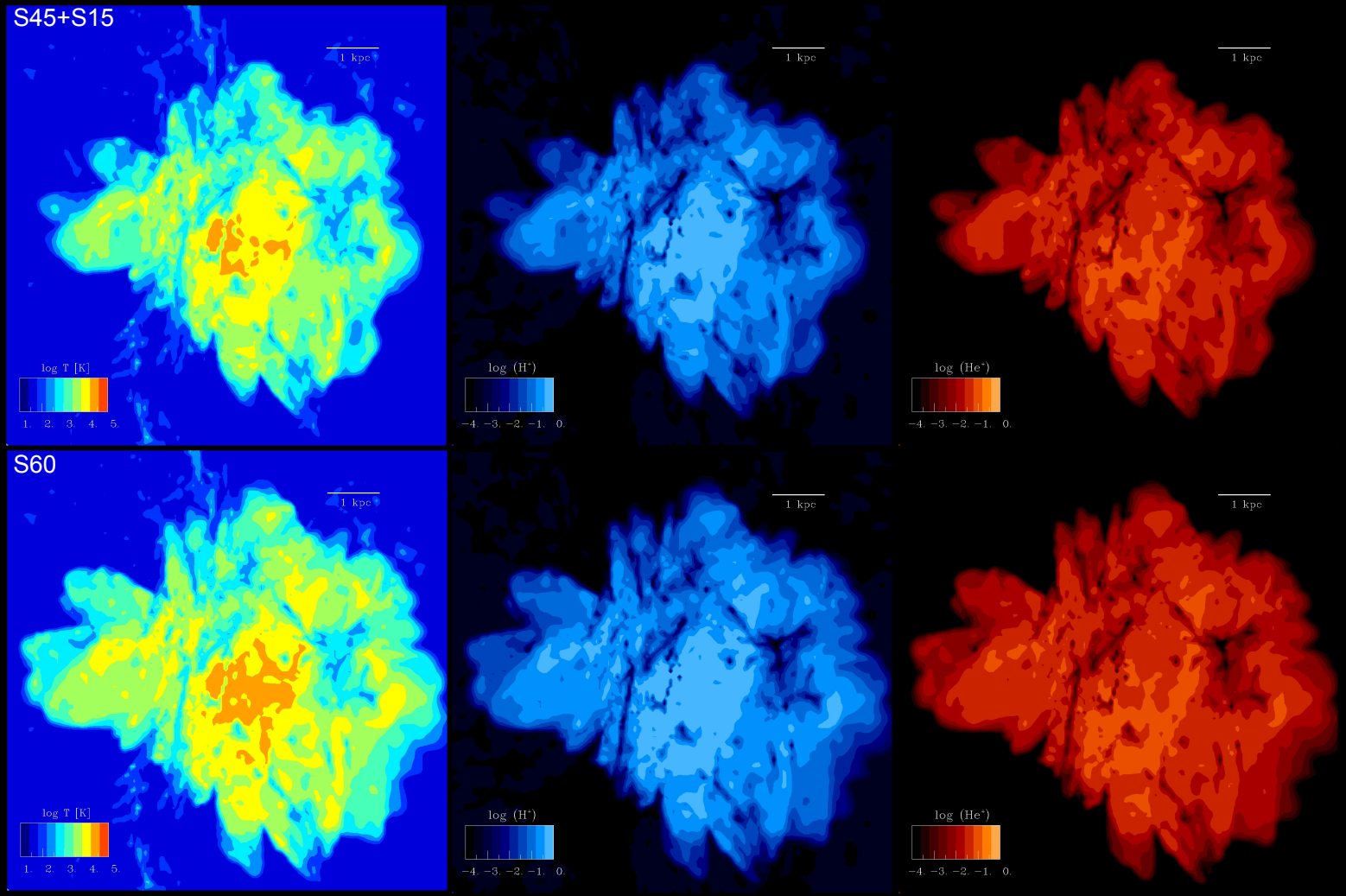


Name	H II [10^{63}]	He II [10^{63}]	He III [10^{61}]	t_* [Myr]
M15	0.64	0.16	0.10	10.51
M45	2.98	1.45	4.34	4.39
The first binary (M15+M45)	3.62	1.61	4.43	10.51
M60	4.18	2.21	8.31	3.77

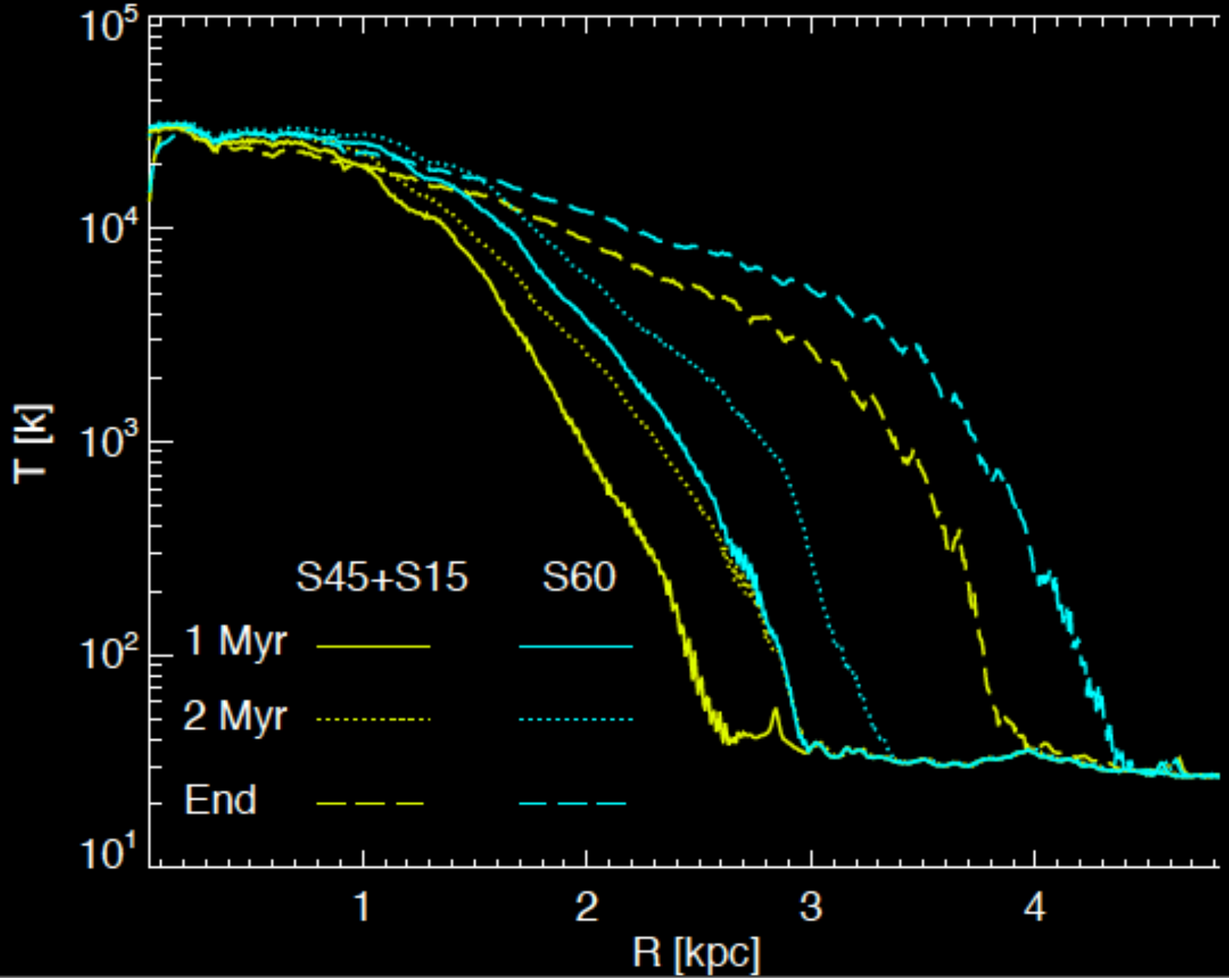


Chen+ in prep

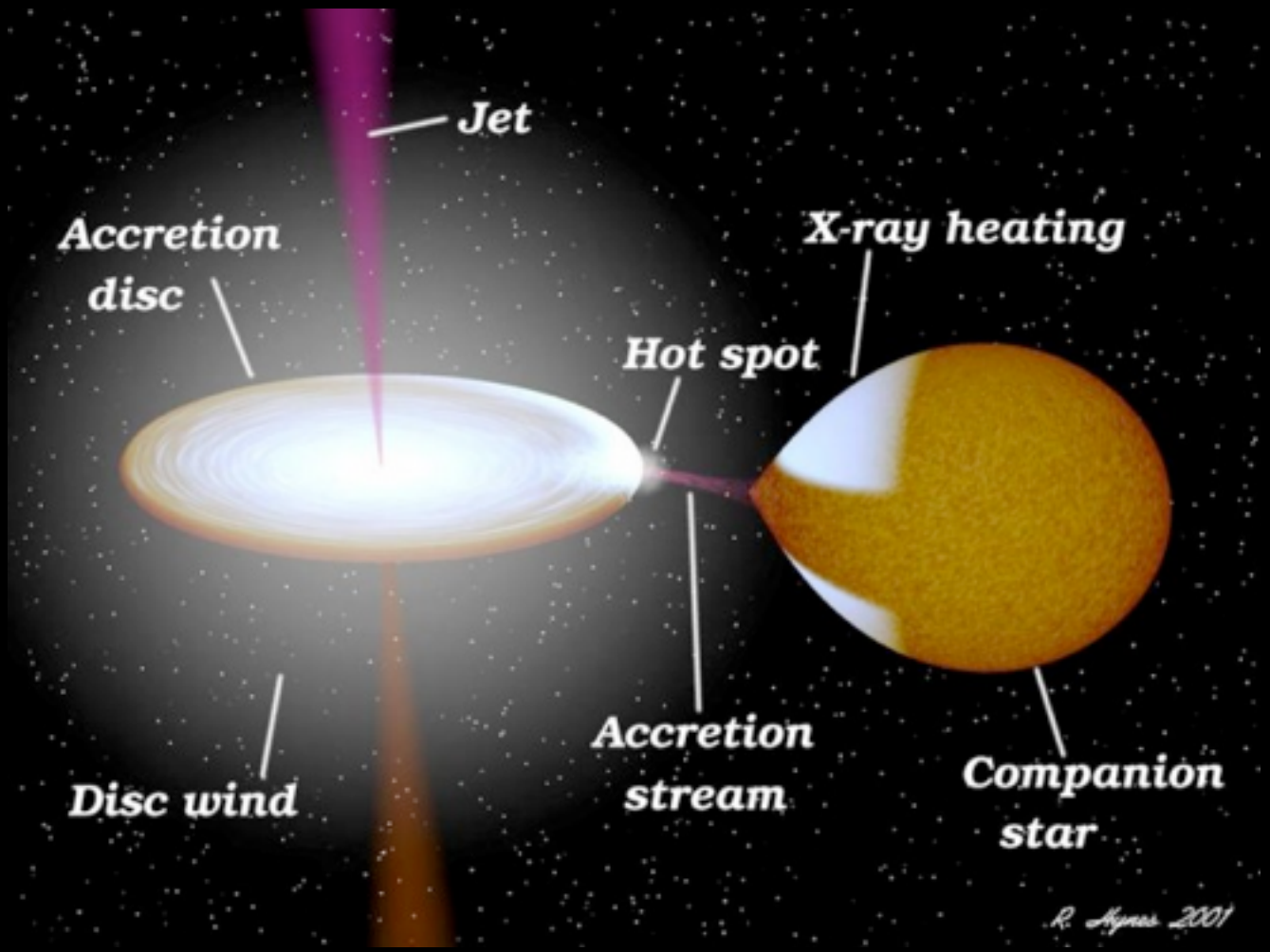
Physical Properties of IGM



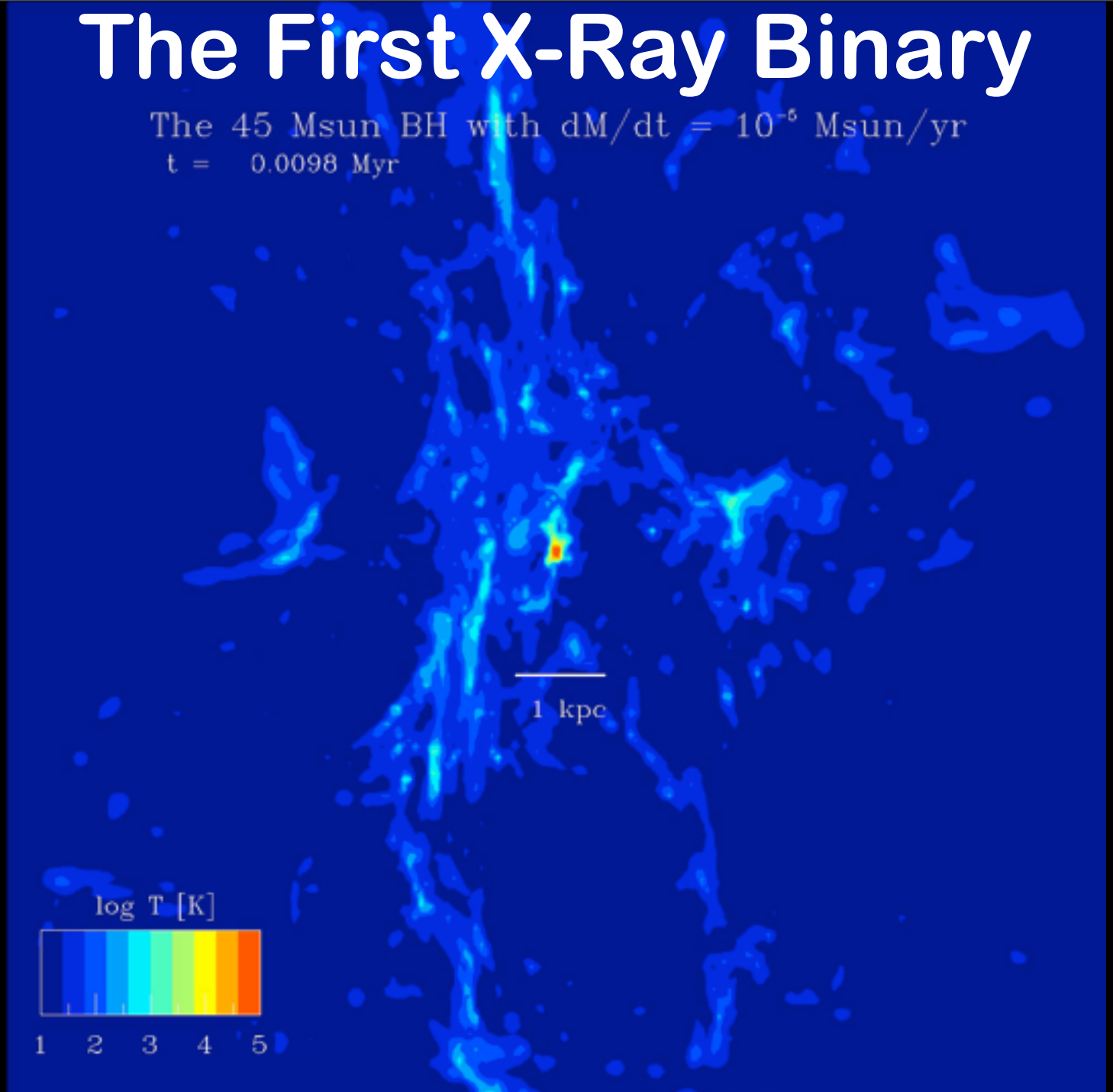
Physical Properties of IGM



The First X-Ray Binary



The First X-Ray Binary



Conclusions

- **All possible radiative feedbacks**
  1. Ionizing photons
  2. SN shock reheating
  3. X-Ray Binaries
- **Chemical enrichment**
  1. SN feedback
  2. Pop III to Pop II transition (Talk: Klessen, Schneider)

Mass of the first stars does matter !!!

Future Work

Future Work

The First Galaxies


TMT


LSST


GMT


JWST

Many thanks for your attention

This work has been strongly supported by:

National Energy Research
Scientific Computing Center