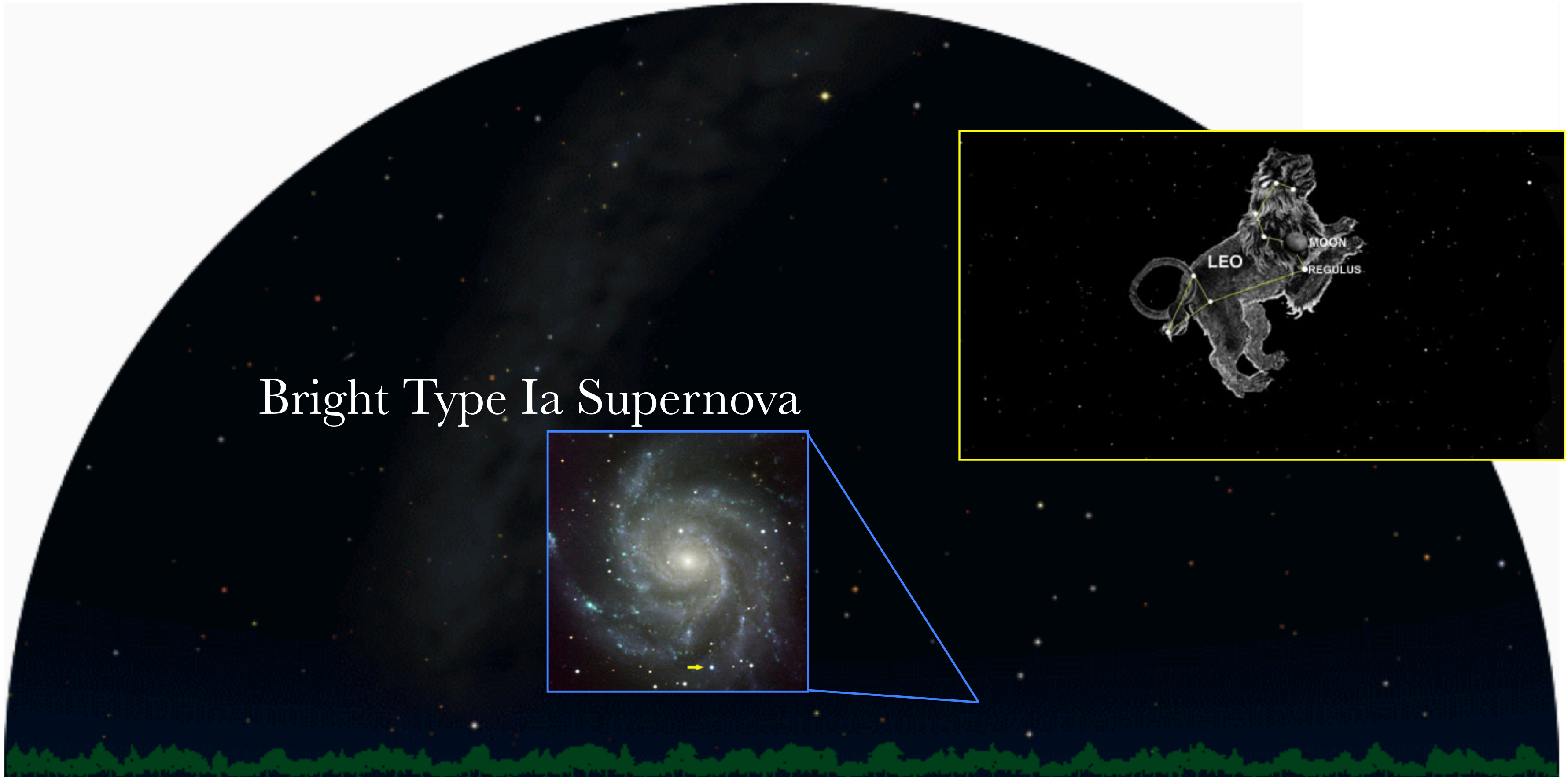
Heidelberg Colloquium, October 25, 2011

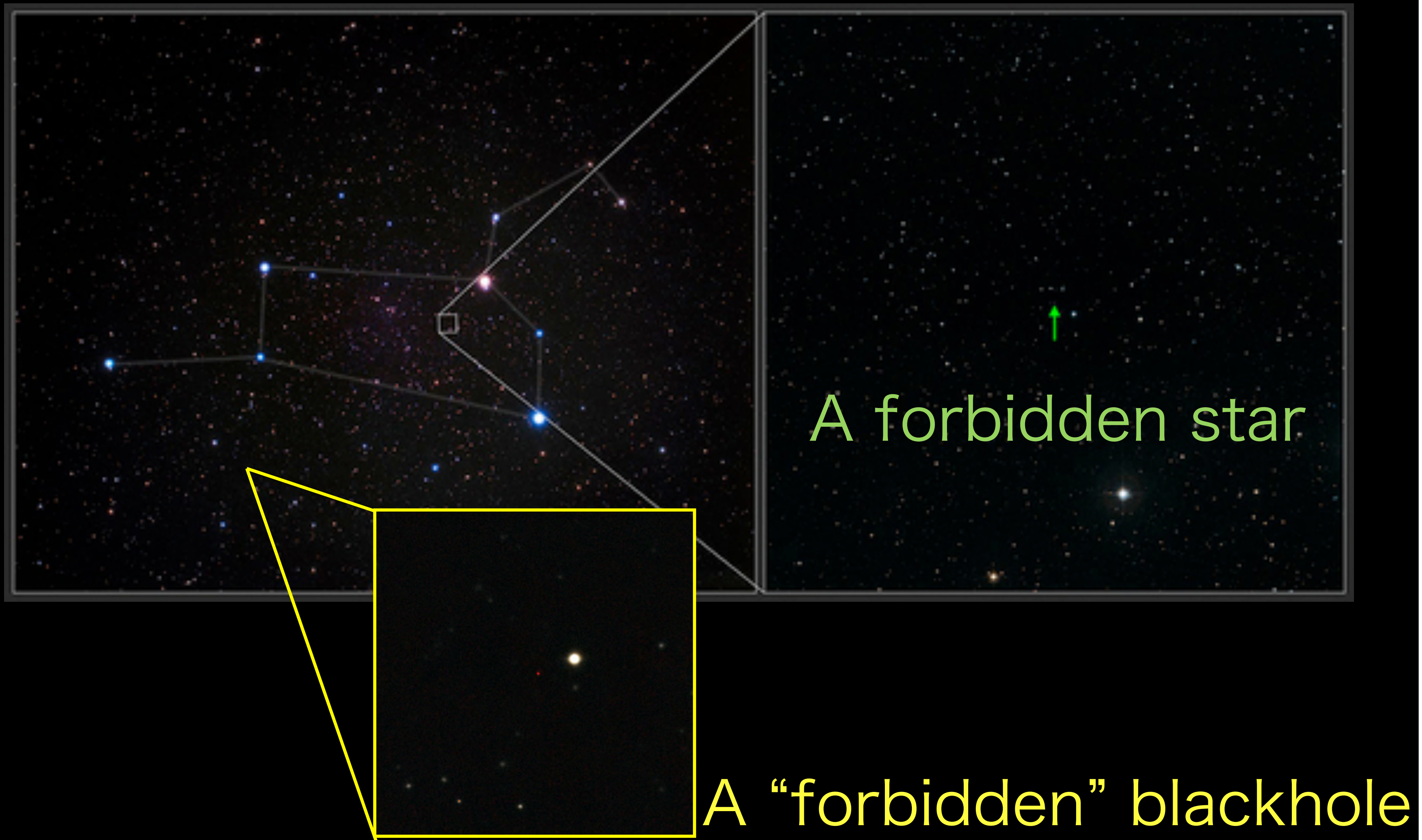
Simulating the structure formation in the Universe

by Naoki Yoshida (IPMU)

October, early morning...



Leo brings mysteries

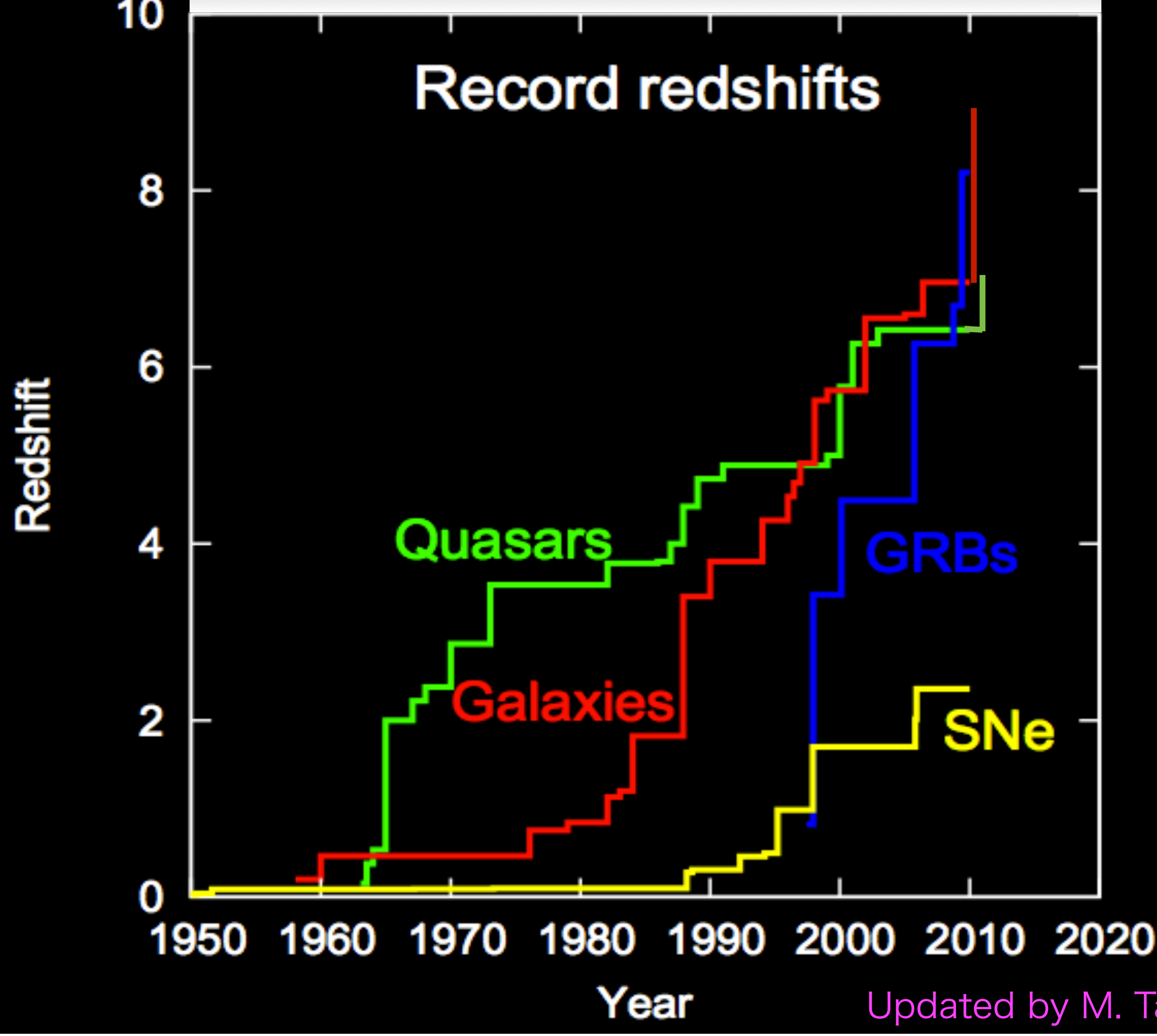


Contents

- ✦ **Star formation in the early universe**
  - from big bang ripples to first stars
  - Hunting for the first stars
- ✦ **Star-forming galaxies at high redshift**
  - LAEs, LBGs, and sub-millimeter gal.
- ✦ **Cosmological simulations: The future**

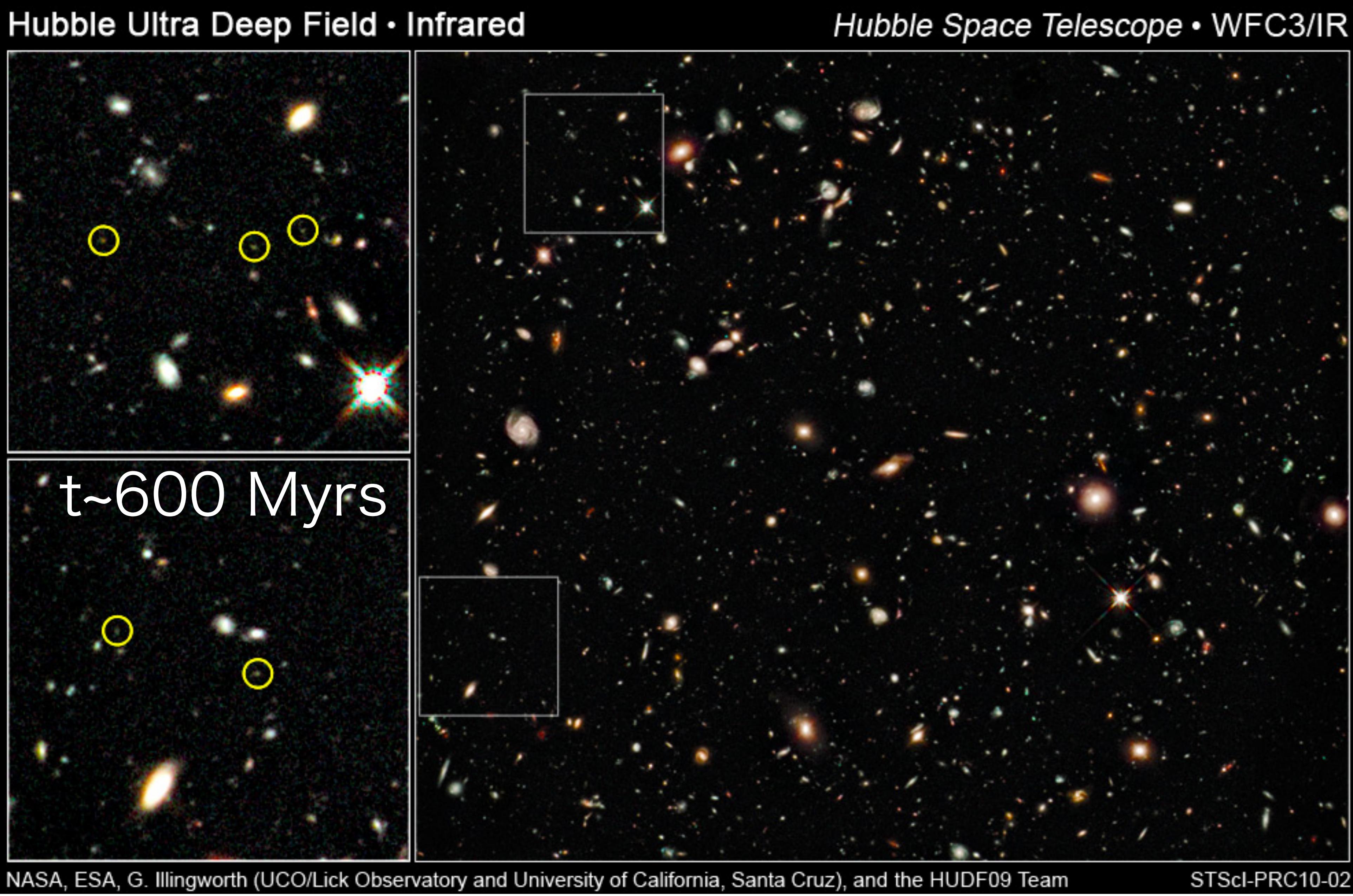
References:
Bromm, NY, McKee, Hernquist, 2009, Nature
Bromm & NY, 2011, Annual Review of Astronomy & Astrophysics
Shimizu, NY, Okamoto 2011, MNRAS

Final frontier

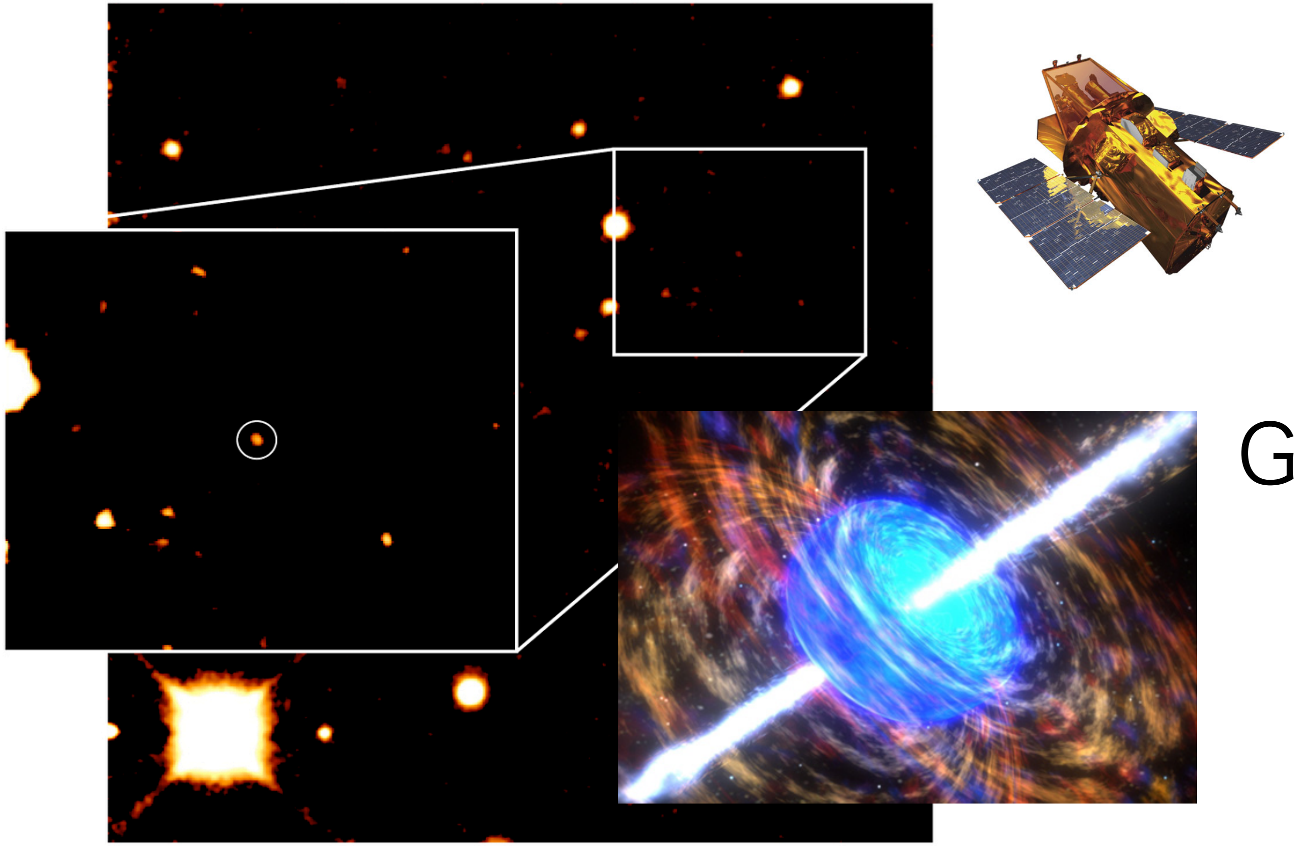


Updated by M. Tanaka

Most distant galaxies



A very high-z GRB



OAO-ISLE　J band　　　　国立天文台　岡山天体物理観測所

GRB 090423

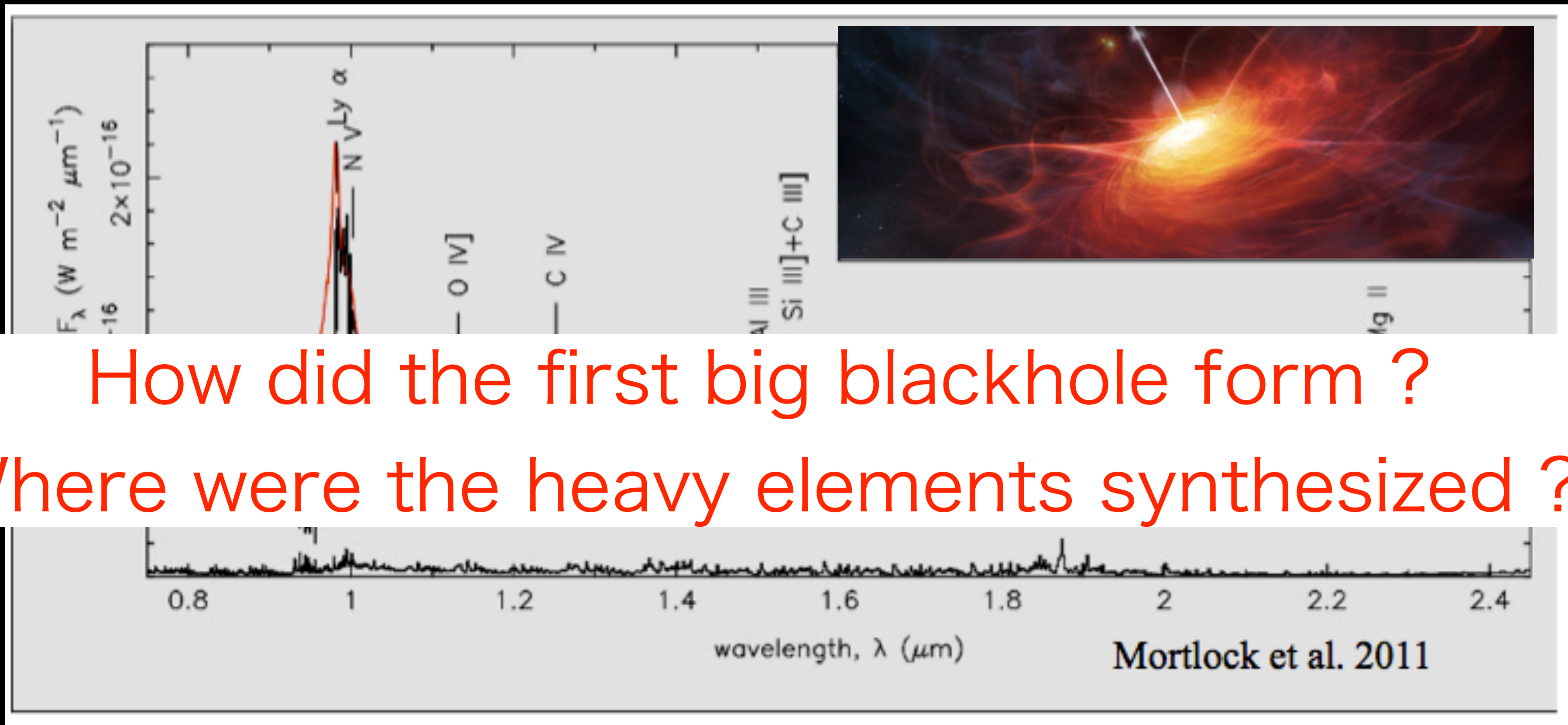
@z=8.3

A massive star's death just 600 million years after the Big Bang!

A YOUNG BUT BIG! BLACKHOLE

2 billion times heavier than the sun

t_age ~ 700 million years

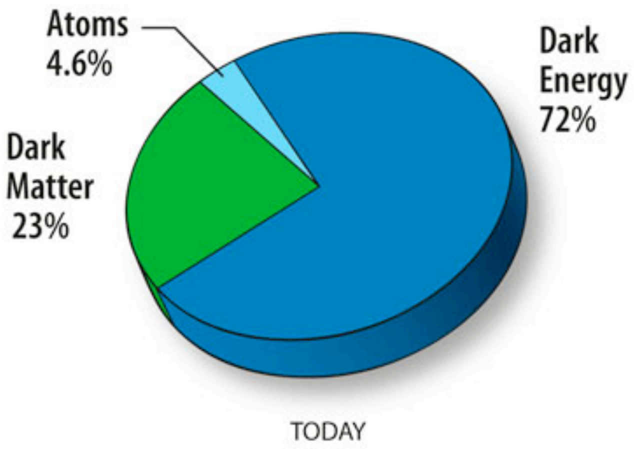


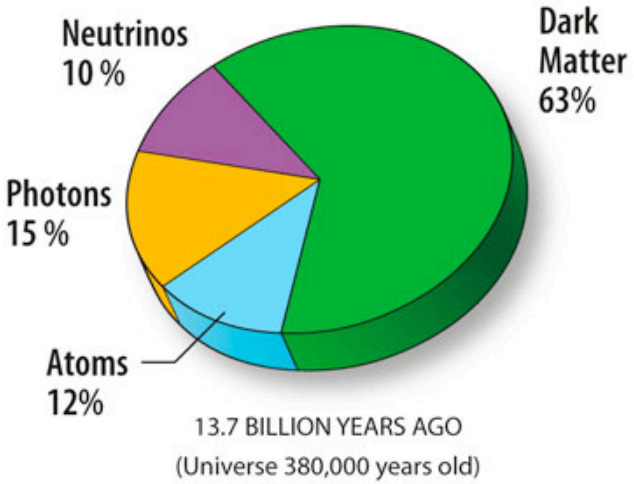
How did the first big blackhole form ?

Where were the heavy elements synthesized ?

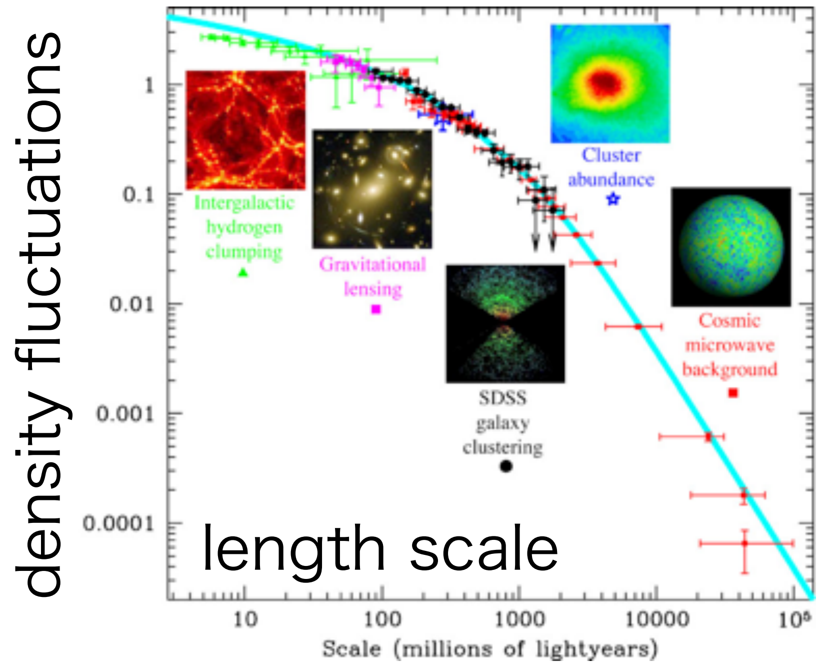
Theory

The Standard Cosmology

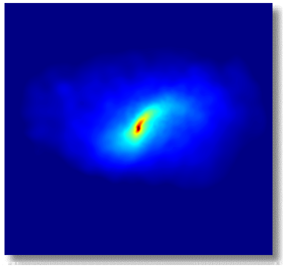




An *ab initio* approach is possible



CMB + LSS + SNe
tell us about the initial state of the universe, and the energy content now and then *precisely*.



Primordial Star Formation

A Simple Problem

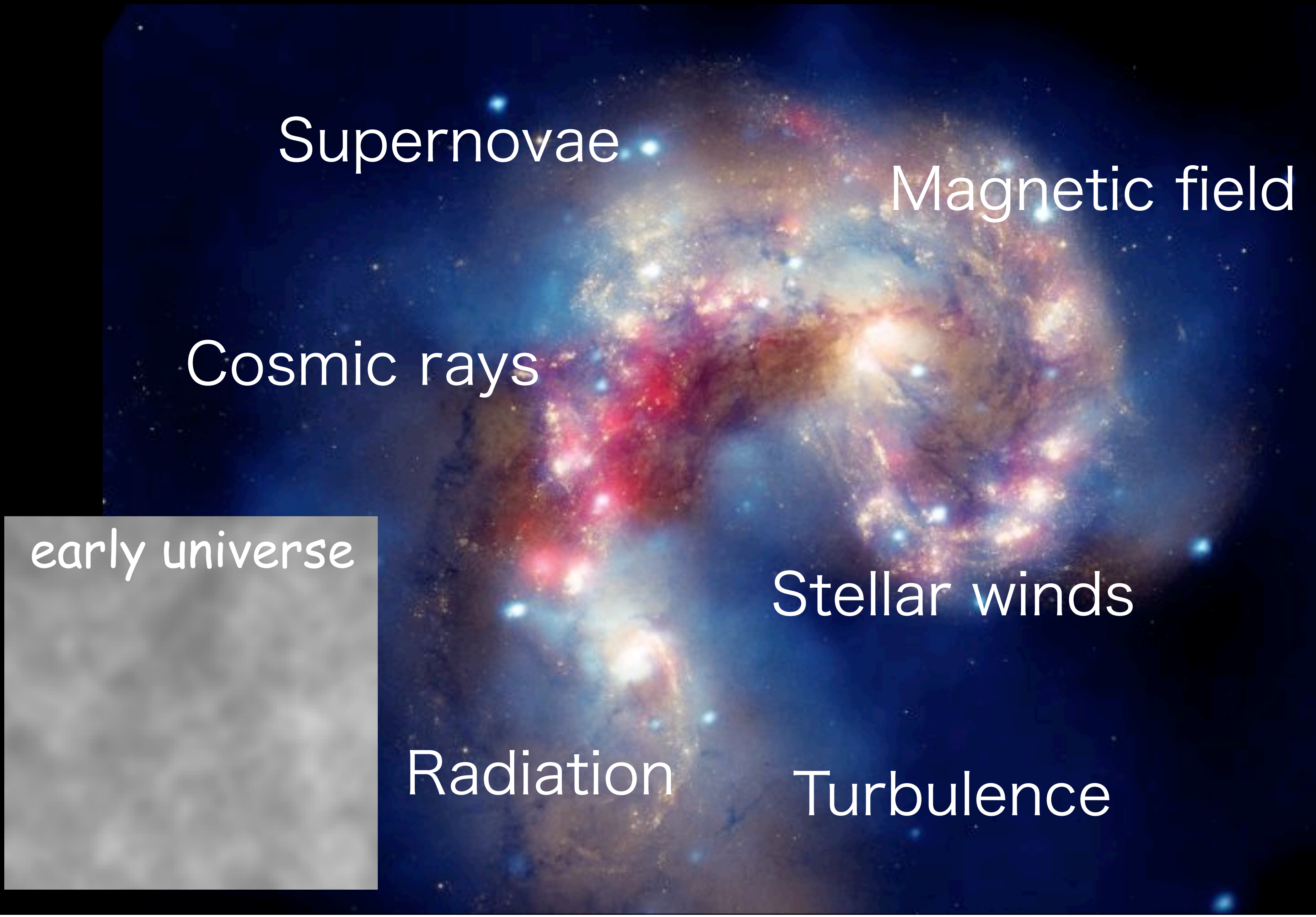
The Initial Condition - “observed”

LCDM model, Gaussian random field,
dark matter + hydrogen-helium gas + CMB

The Physics - understood

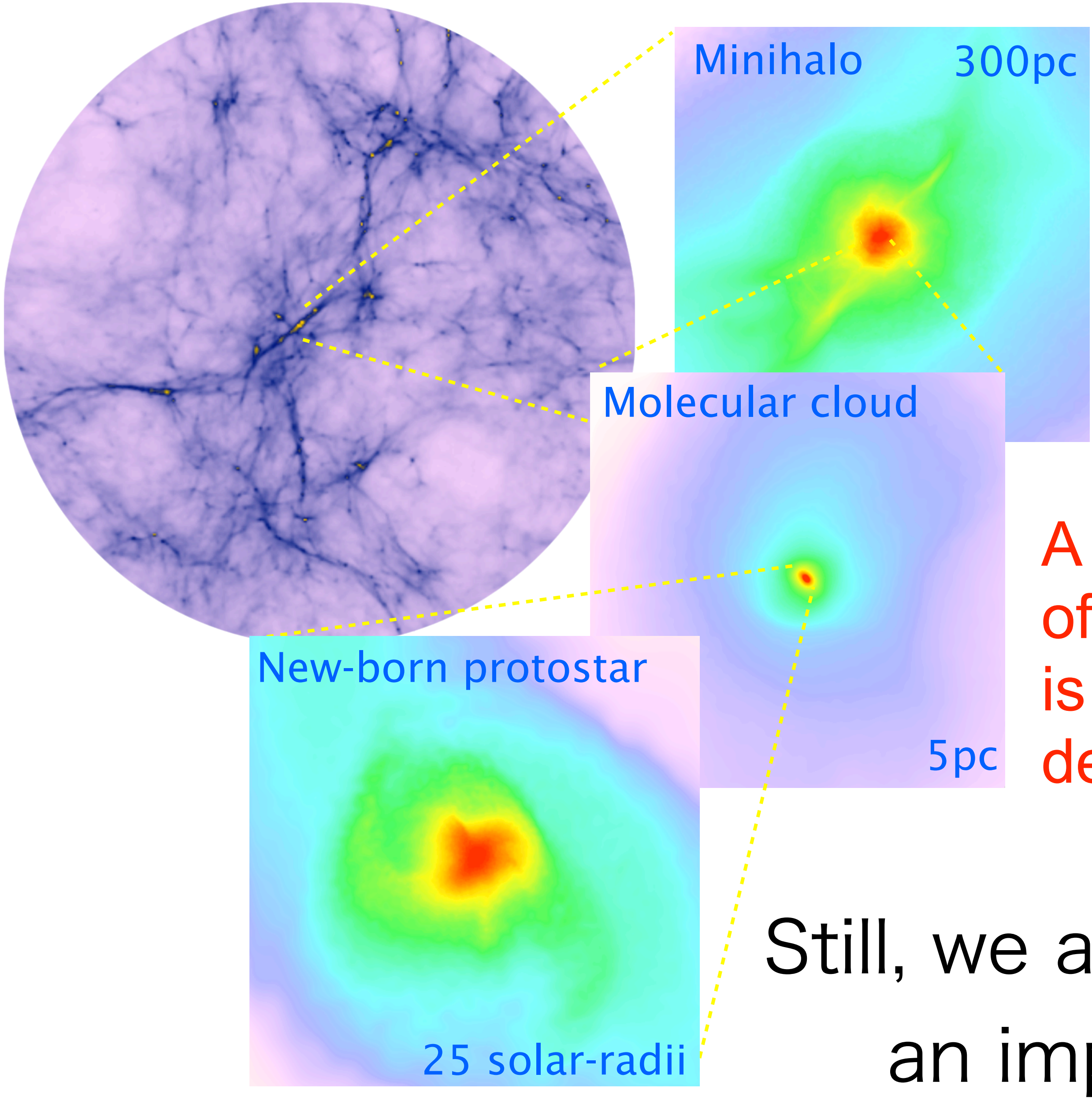
Gravity, hydrodynamics,
atomic/molecular processes
14 species (H, He, D, ions)
~50 important reactions
+ many radiative processes
Density evolution to ~10^{21}/cc

Present-day universe



In the beginning,
there was a sea of light elements
and dark matter...

An early universe “experiment”



Resolving planetary scale structures in a cosmological volume!

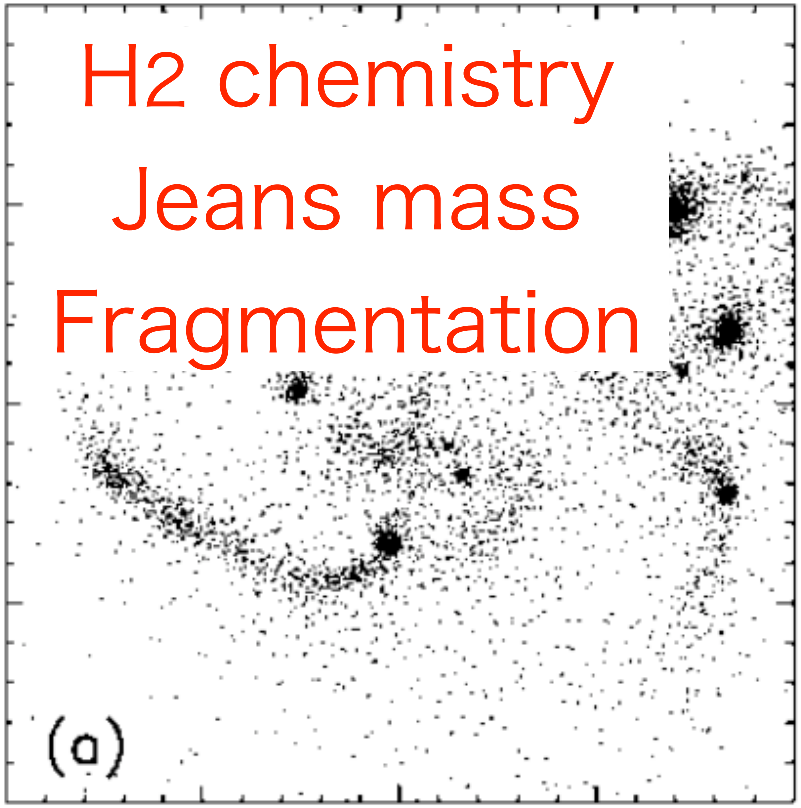
A complete picture of how a protostar is formed from tiny density fluctuations.

Still, we are left with an imporant question...

NY, Omukai, Hernquist 2008, Science

Primordial Stars

Bromm, Coppi, Larson 1999



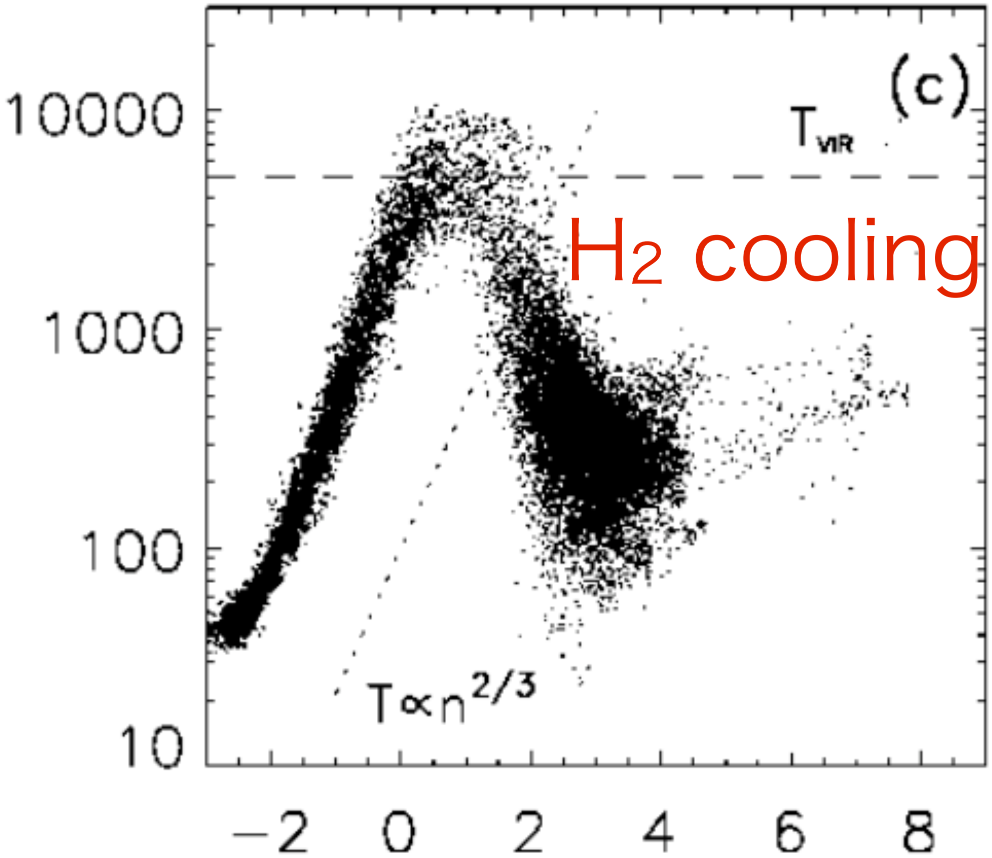
H_2 chemistry

Jeans mass

Fragmentation

Gas cloud mass

~1000 M_{sun}



H_2 cooling

The primordial IMF: History

Long time ago Massive (no PopIII in MW)   Possibilities (Silk)

~2000 Very massive (>100M_{sun}) (Abel, Bromm)

Jeans mass, accretion time

2003-2006 Very very massive (~100-600) (Omukai, NY)

Proto-stellar calculation, 1D

2006-2007 PopIII.2: ordinary massive (~ 40 M_{sun})

HD cooling (Yoshida, Johnson)

2008 Very massive, ~140 M_{sun} (McKee-Tan)

Disk evaporation

2009 Very very very massive (Ohkubo), Binary (Turk)

Core evolution with accretion, BH formation   Rotation ?

2011 Ordinary massive (Hosokawa), Low-mass (Greif)

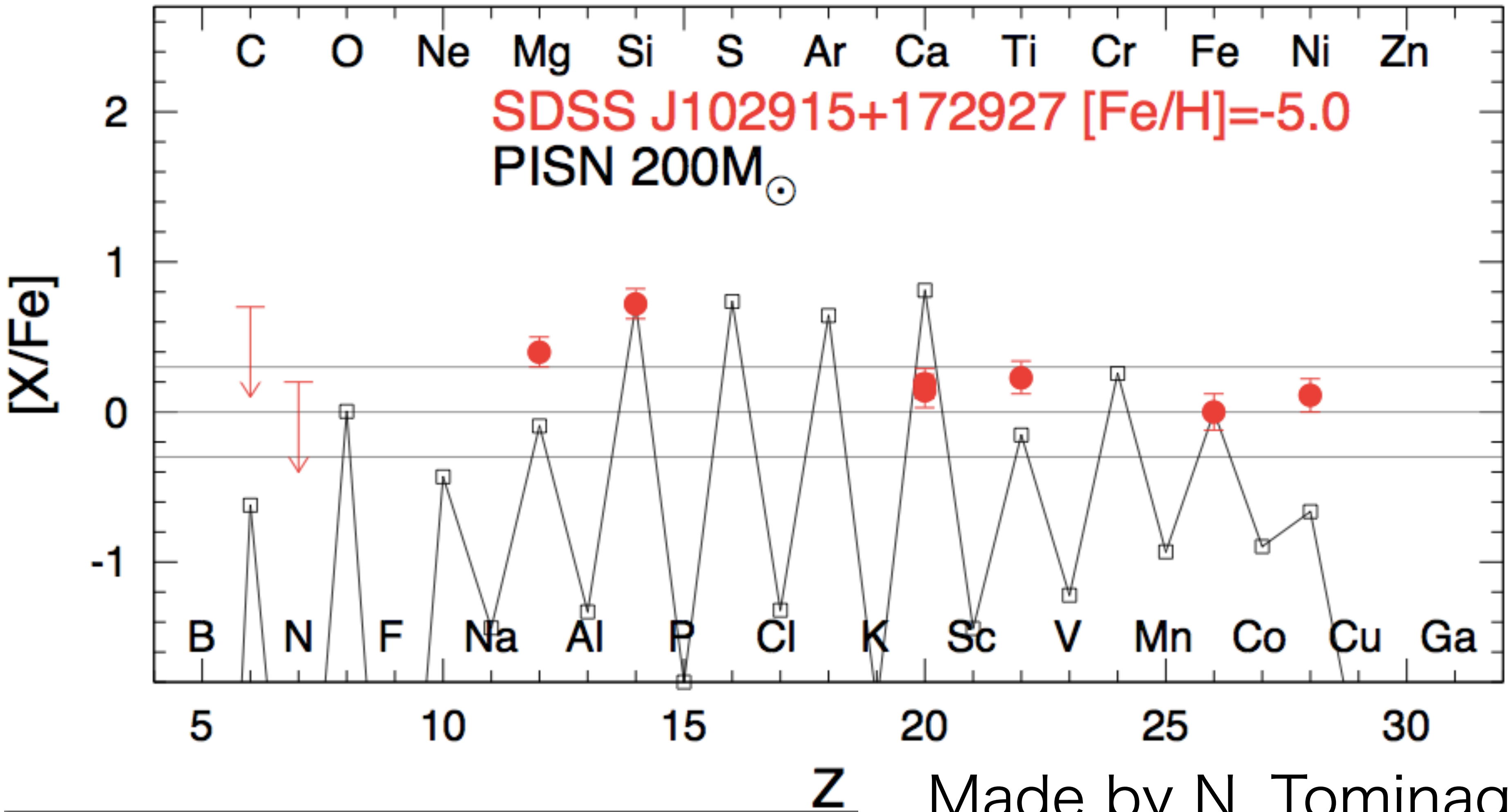
"Cosmo" IC + disk evaporation   Accretion disk fragmentation

Sink particles

Massive PopIII Stars

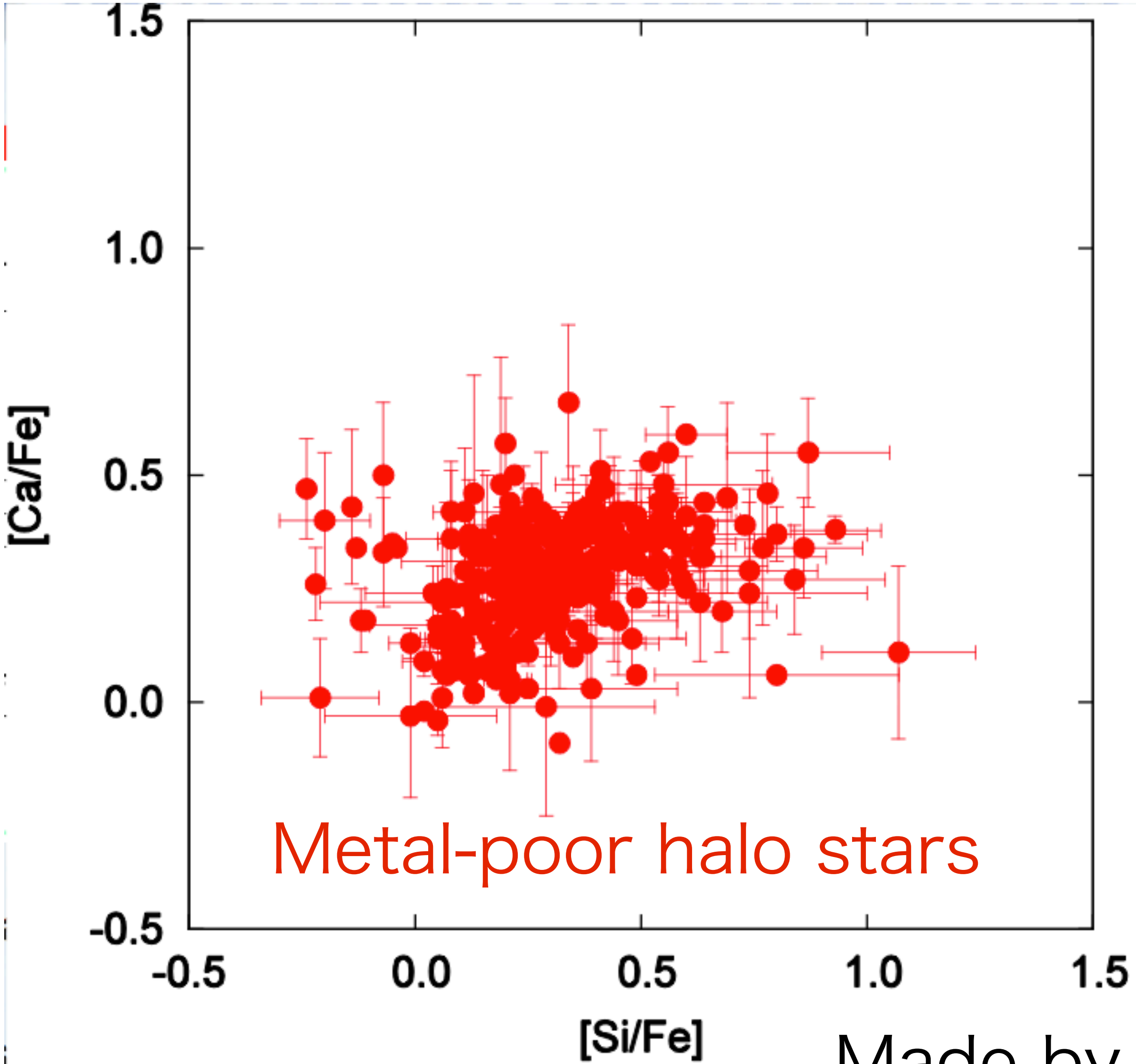
A forbidden SN

Elemental abundance of Caffau's star



Made by N. Tominaga

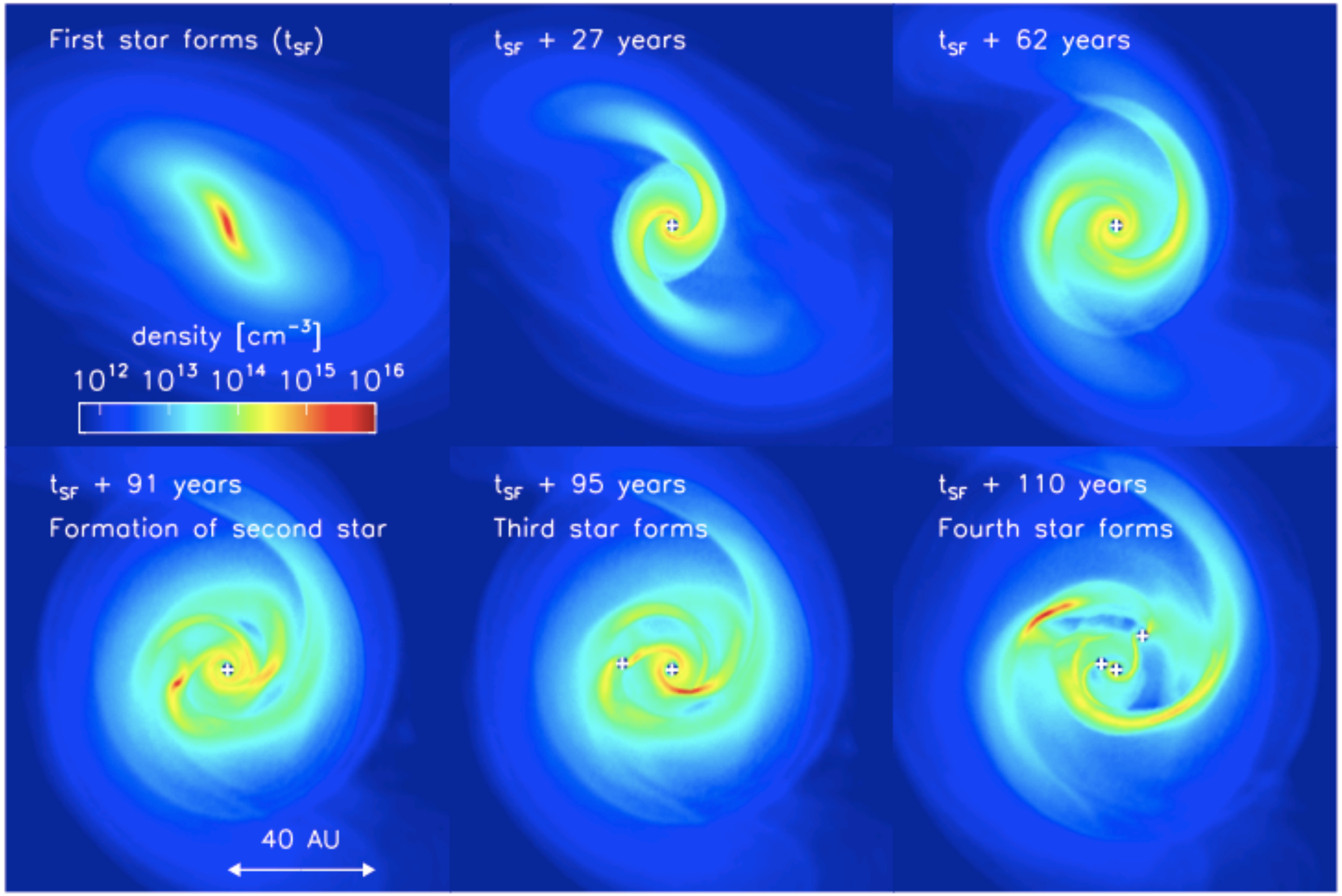
Monster star, we don't need



Made by N. Tominaga

Post-collapse simulations

Disk evolution using sink particles



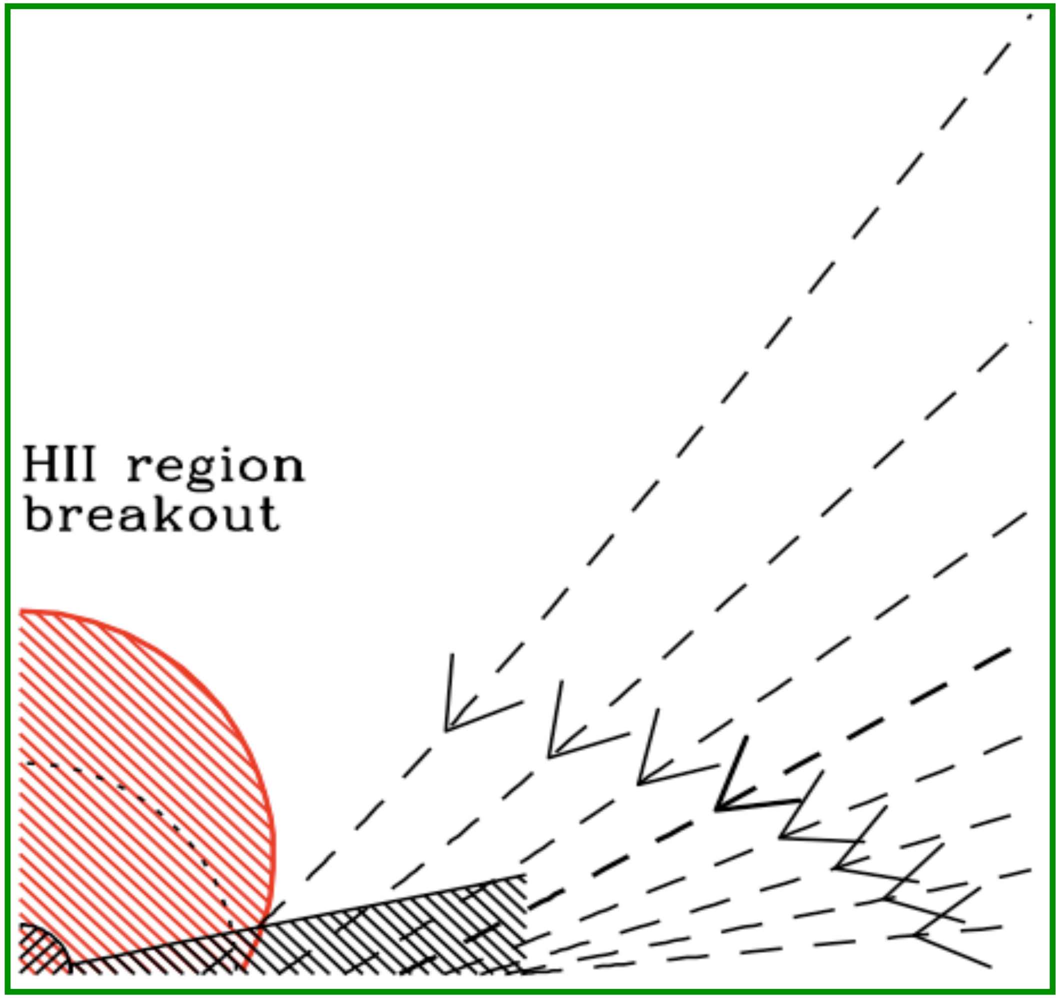
Clark et al. 2011; Greif et al. 2011

The key question

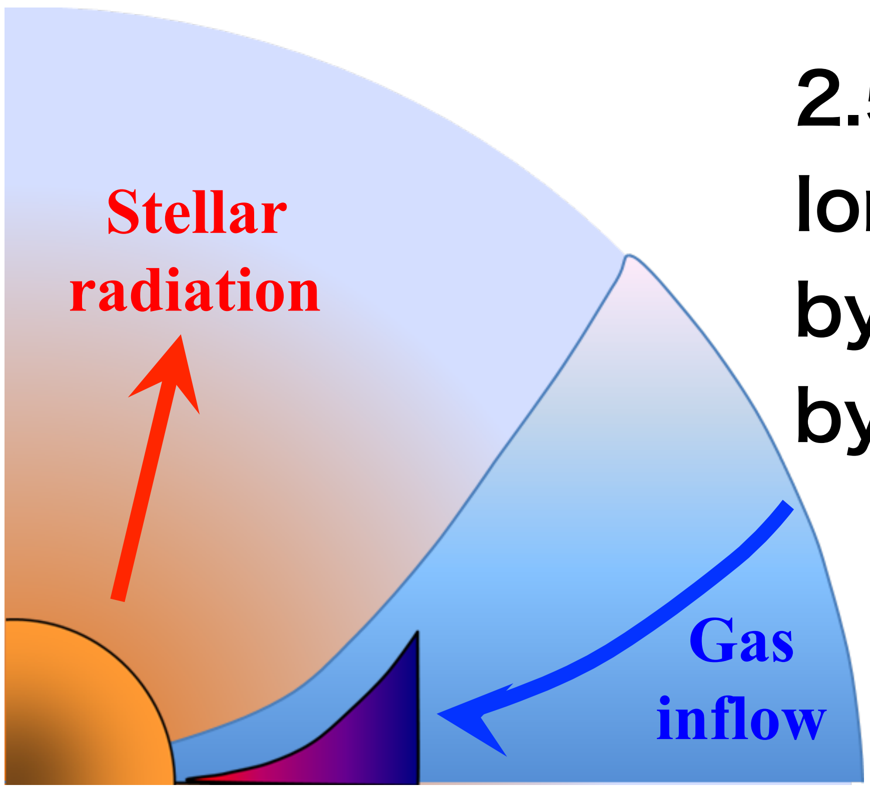
How and when
does a first star
stop growing?

Disk evaporation

McKee-Tan 08
UV photons from the central star ablate the accretion disk, before the star grows extremely massive.



Radiation-hydrodynamics

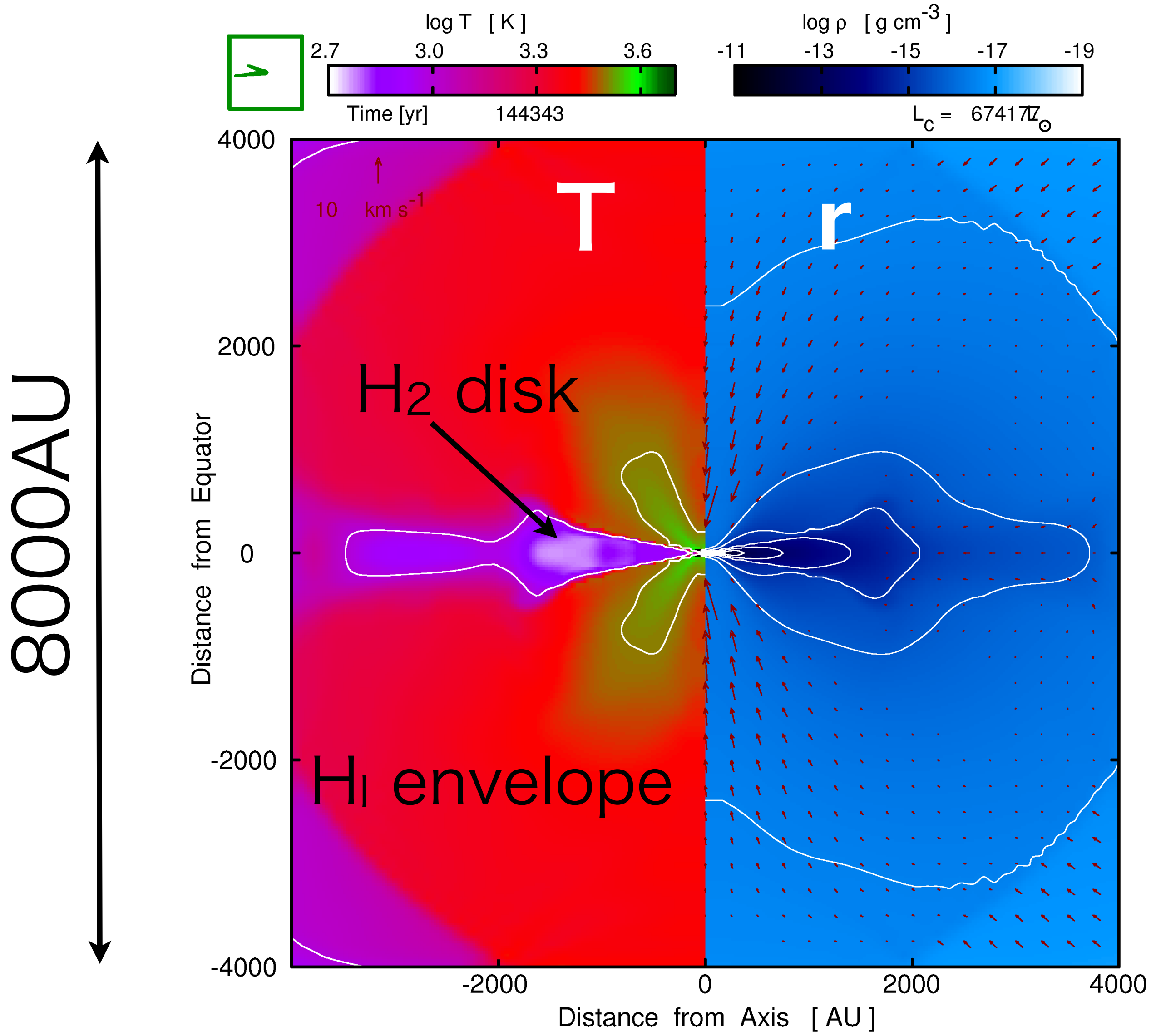


Radition-hydro. calculation
by Takashi Hosokawa (JPL)

2.5D configuration:
Ionizing photon transfer
by ray-tracing, continuum (H^-)
by FLD.
H. Yorke's code + chemistry.

Initial condition taken from
our cosmological run.

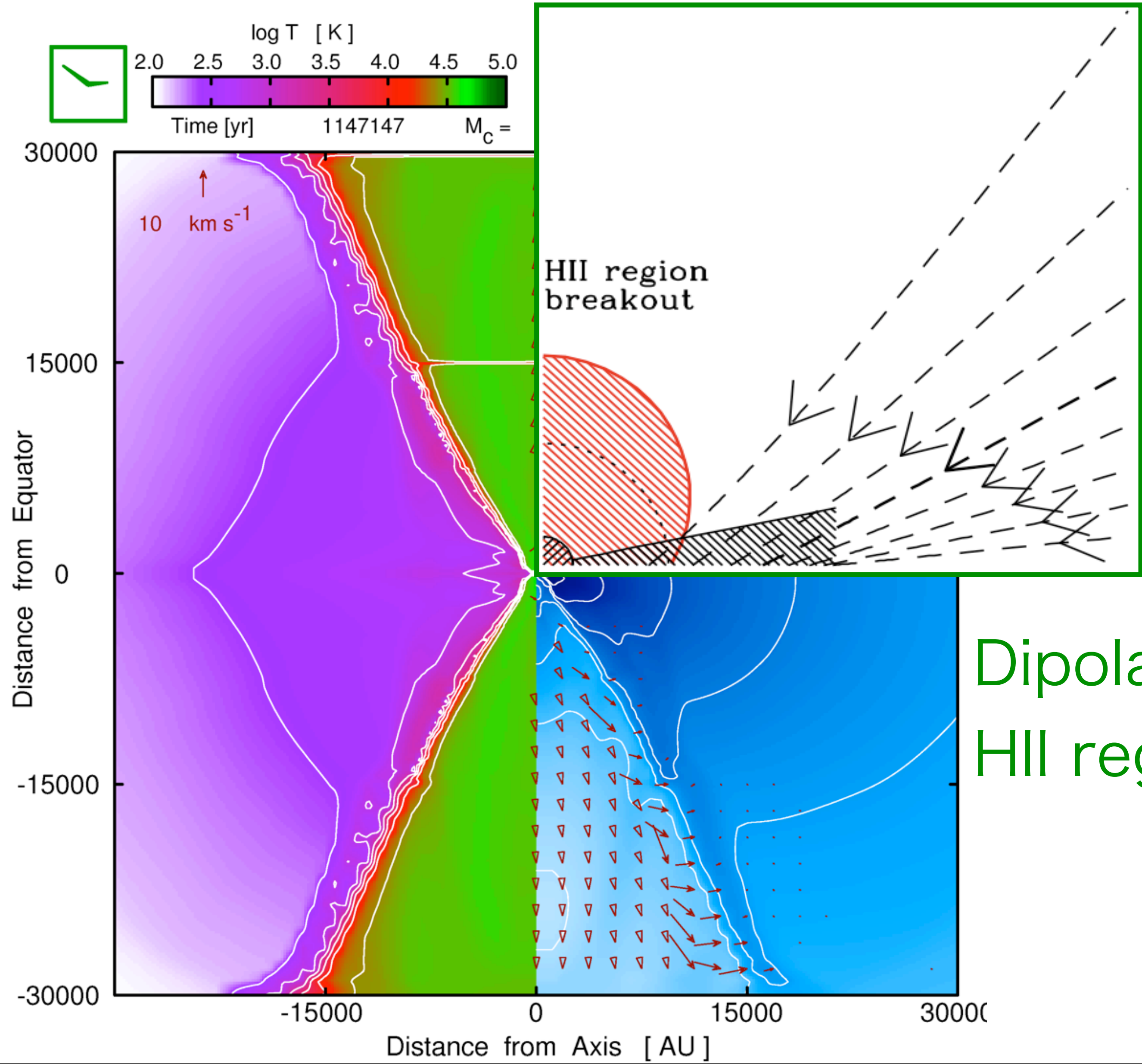
Protostellar feedback



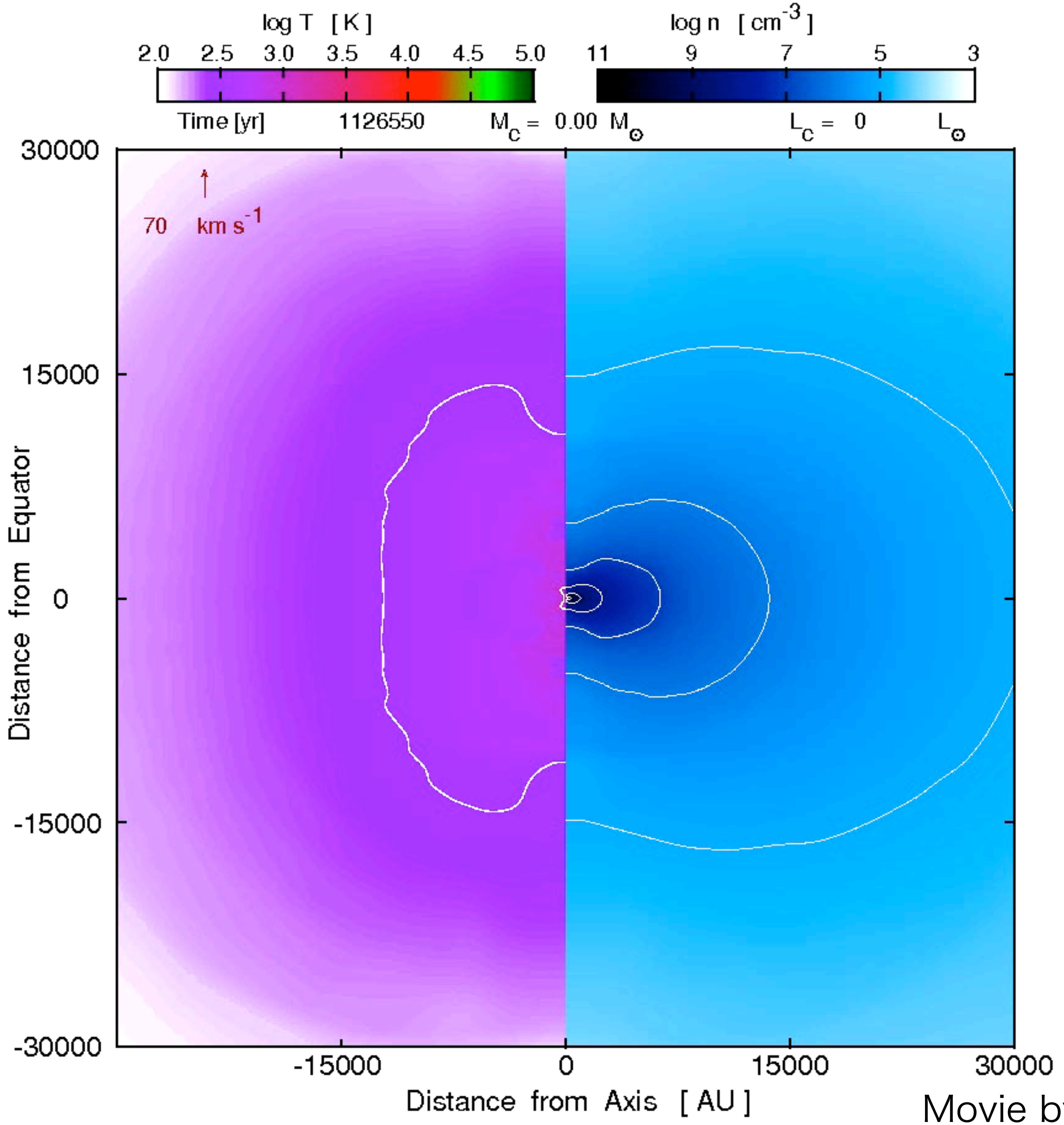
$M_* = 20 M_{sun}$

Hosokawa, Omukai, NY, Yorke

HII region break-out!

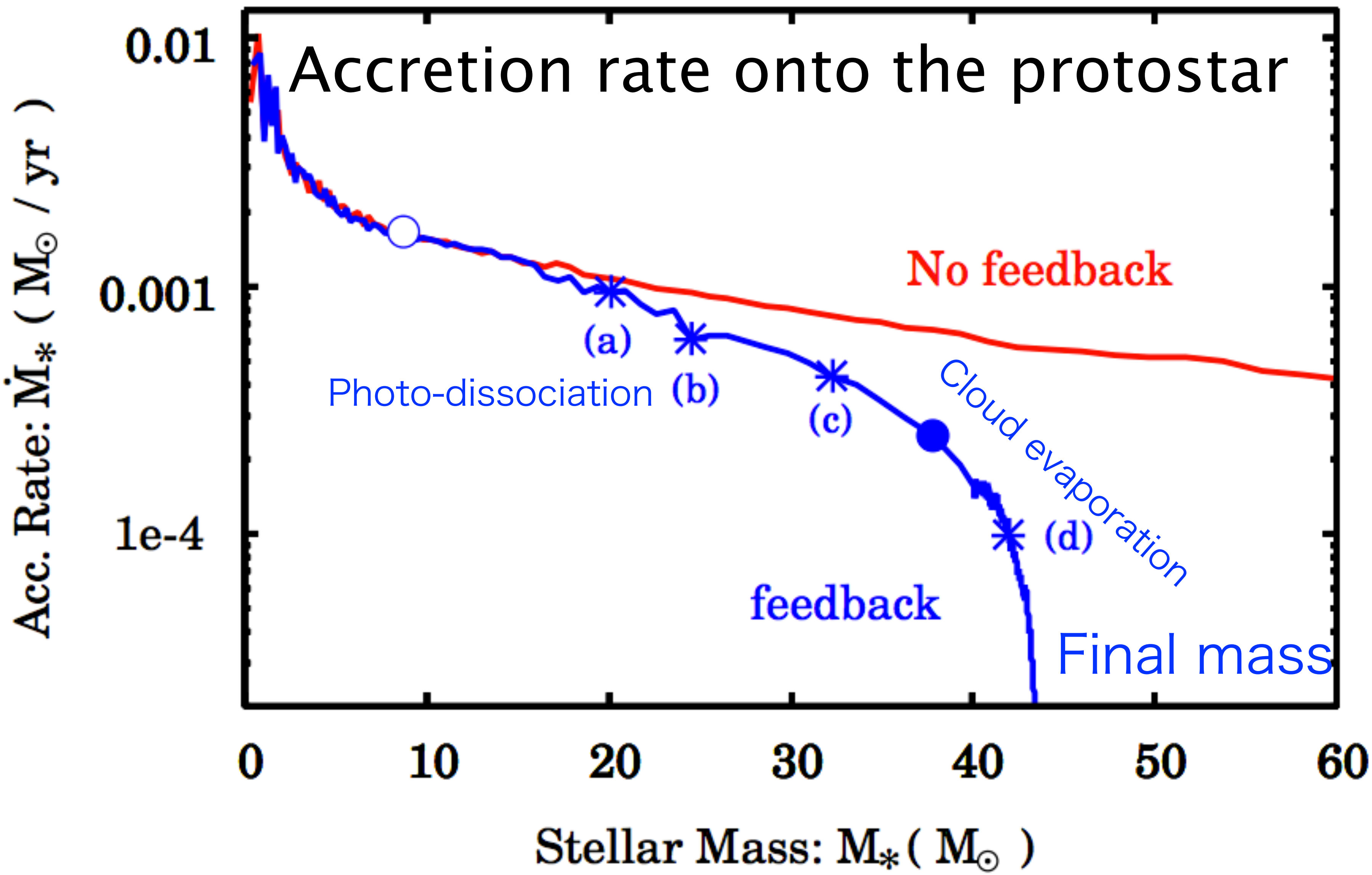


Dipolar
HII region



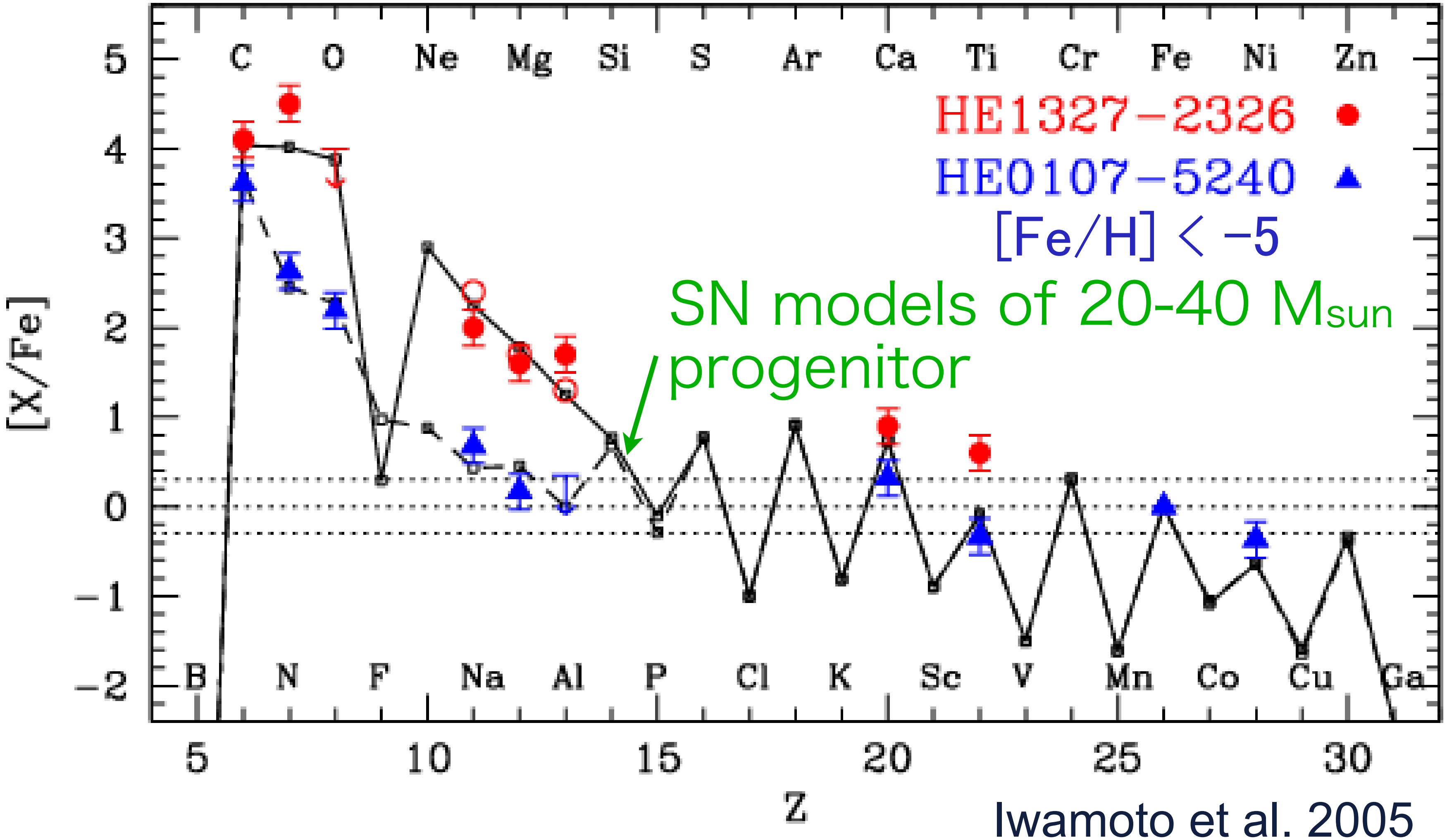
Movie by T. Hosokawa

Accretion vs disk evaporation



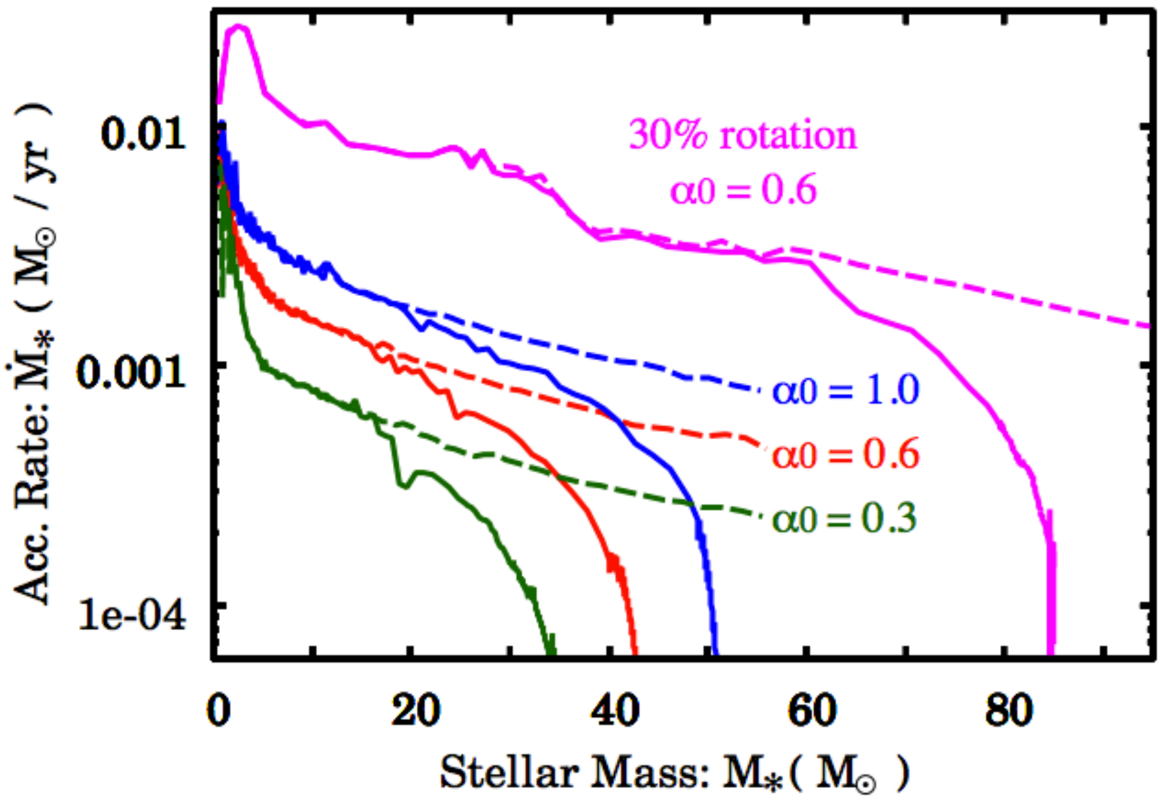
Early chemical evolution

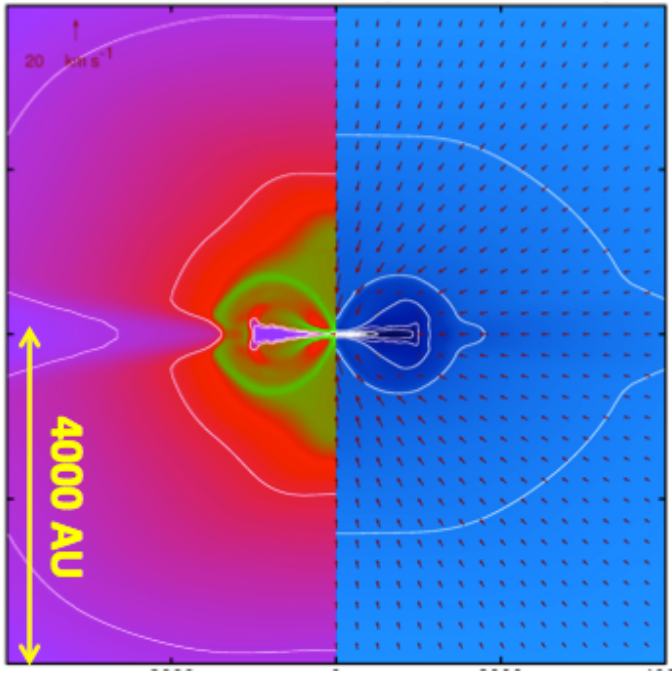
Observed elemental abundances



Iwamoto et al. 2005

Effect of rotation



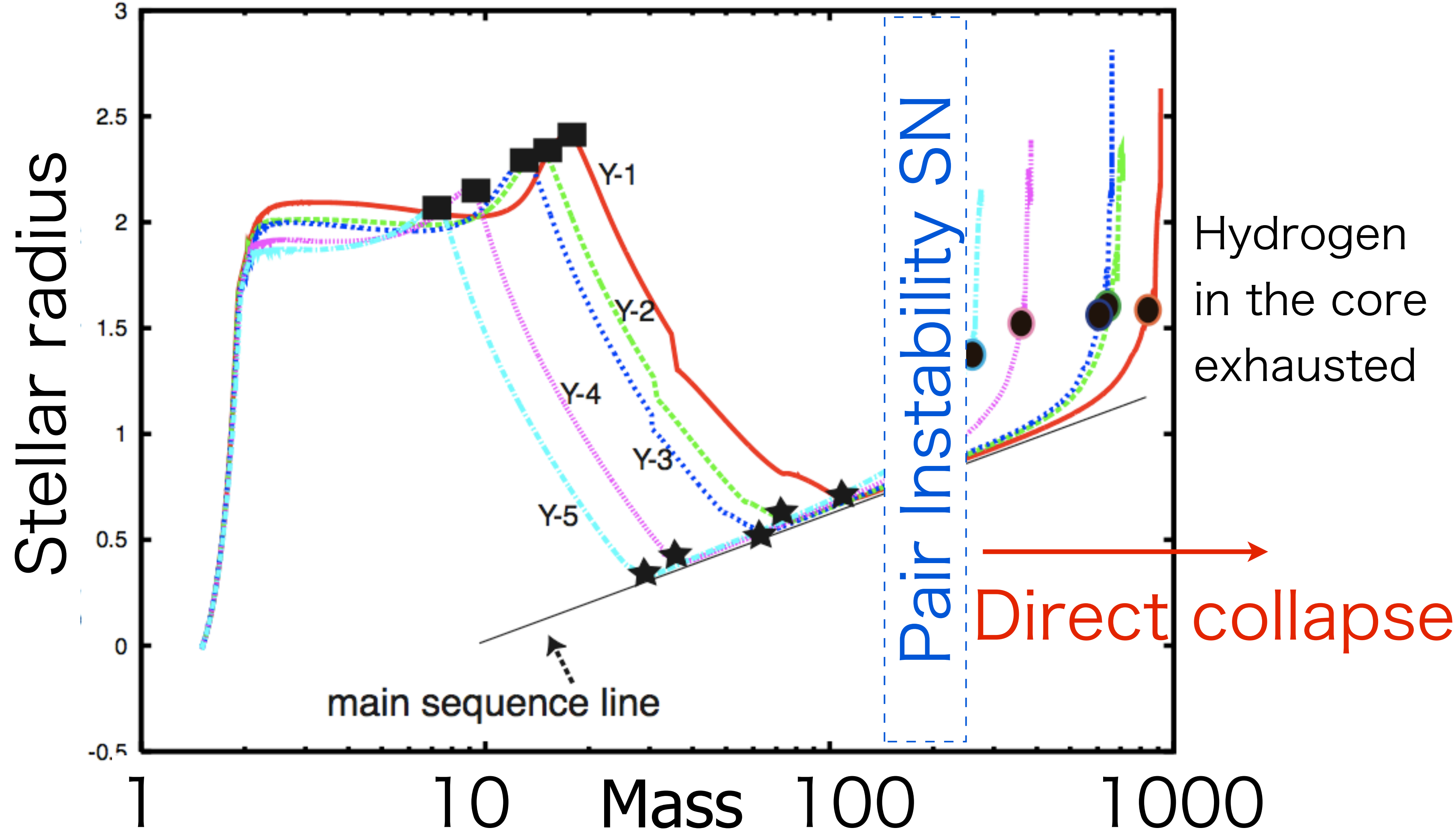


The degree of rotation and the accretion efficiency determines the final mass, but rarely produces M > 100 Msun.

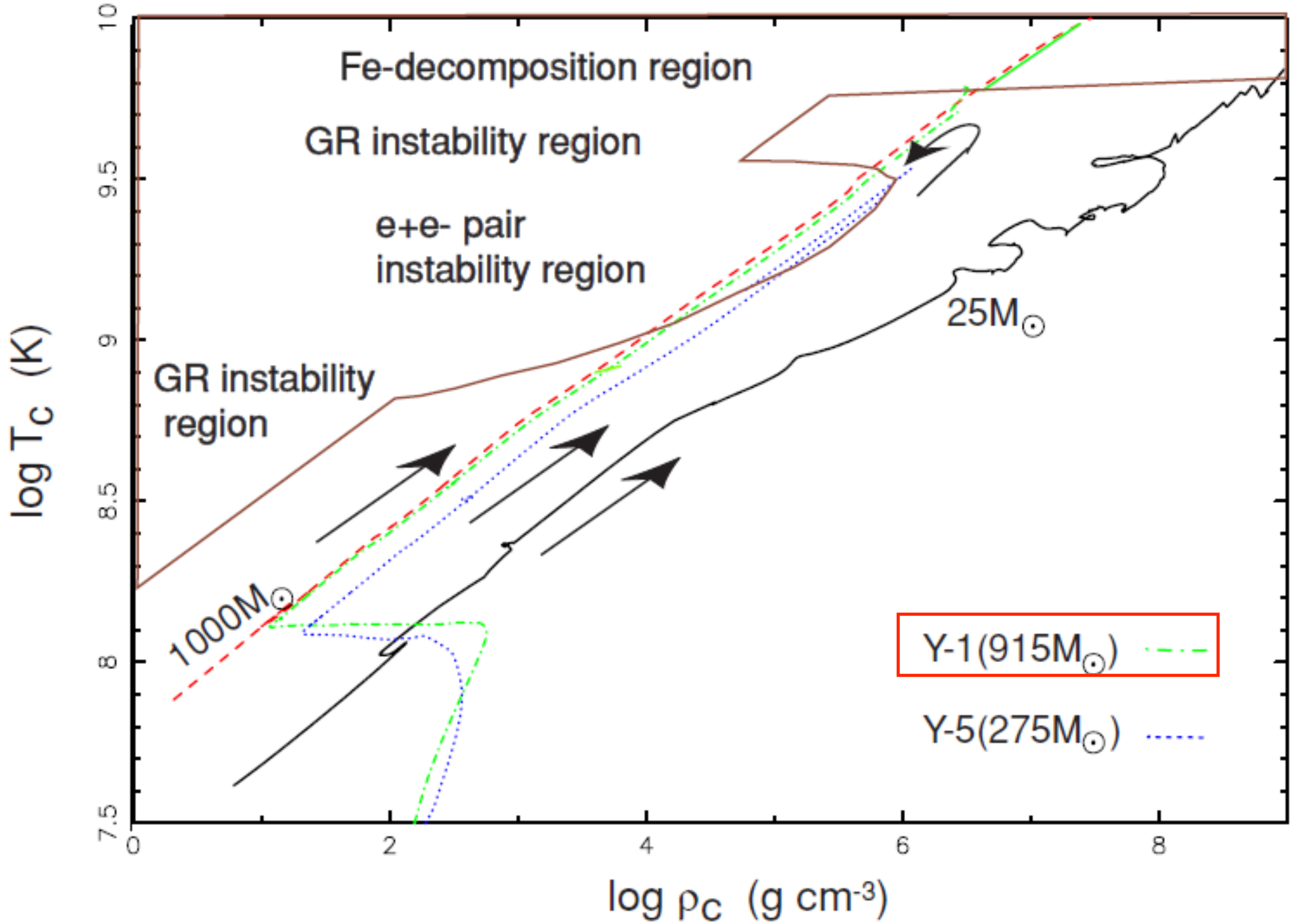
Seeding the formation of SMBH

For a very low spin case

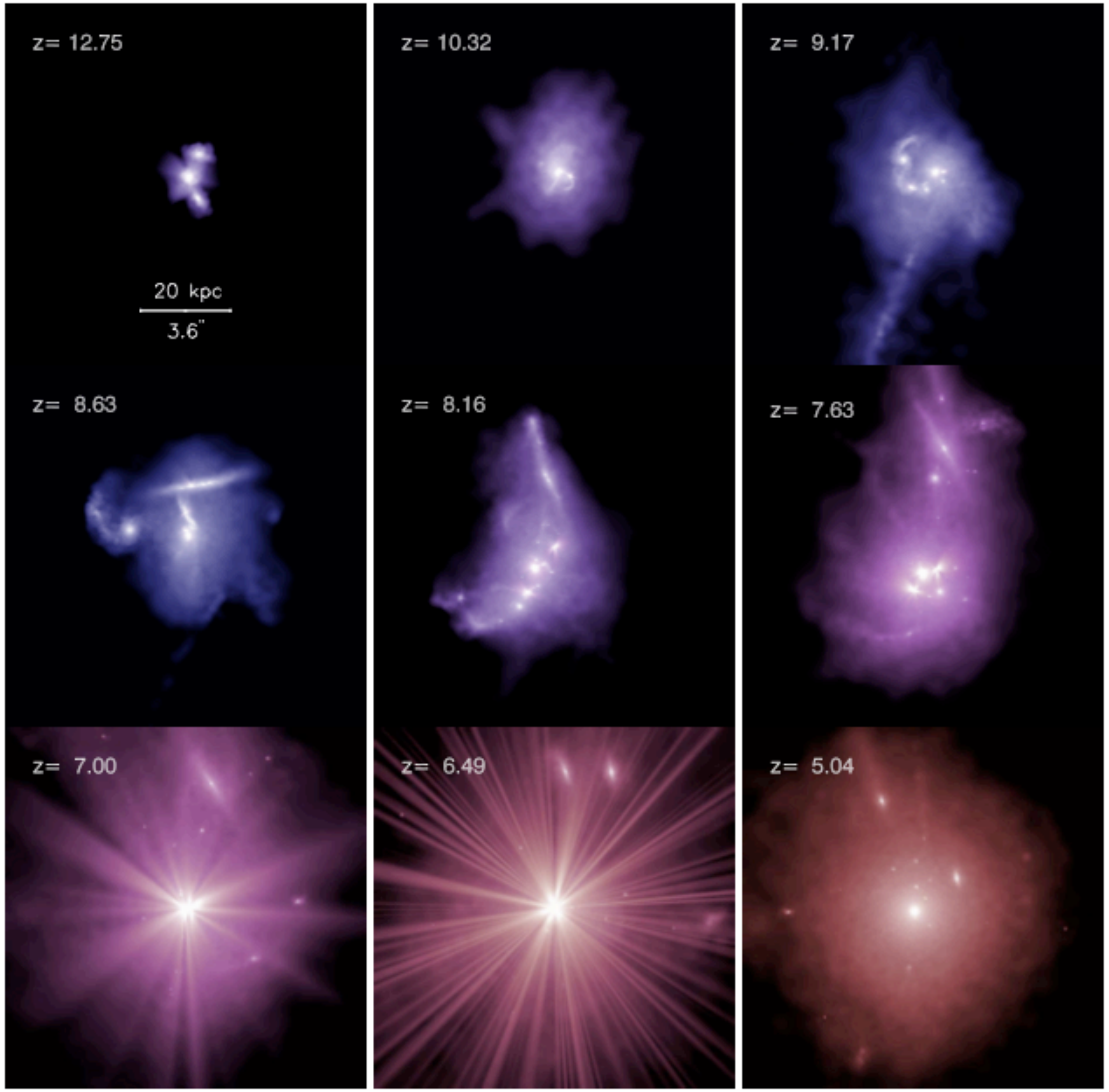
Ohkubo, Umeda, Nomoto, NY, Tsuruta 2009 ApJ



Core evolution



SMBH formation @ z>6



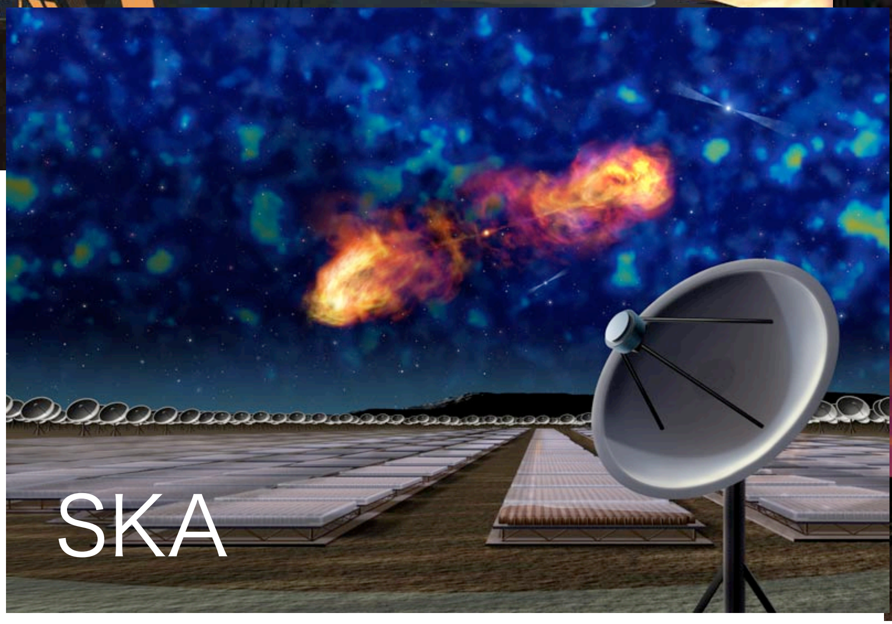
Li et al. 2007
Merging and gas accretion onto PopIII remnants

Other models suggest direct collapse in large halos (Haiman, Voronteri+)

Hunting for the First Stars

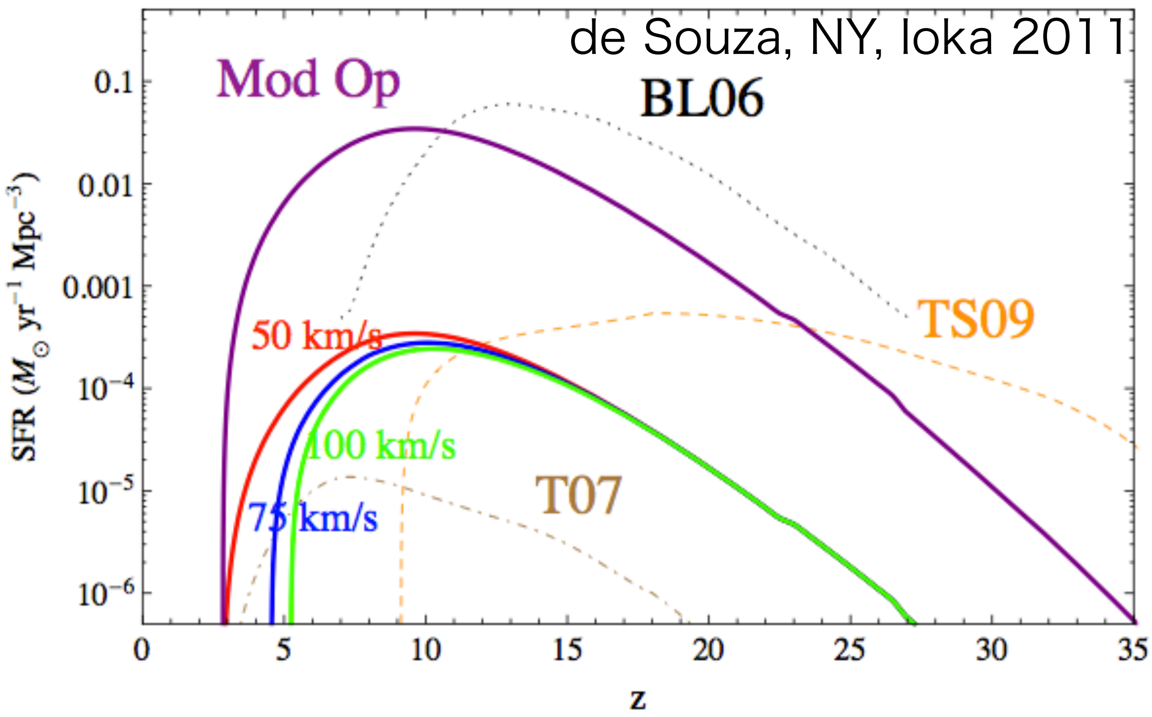
The future

The Webb



PopIII Gamma-Ray Burst

Cosmic star formation rate density



Optimistic model:
Very high star-formation efficiency (~10%), and slow chemical enrichment.

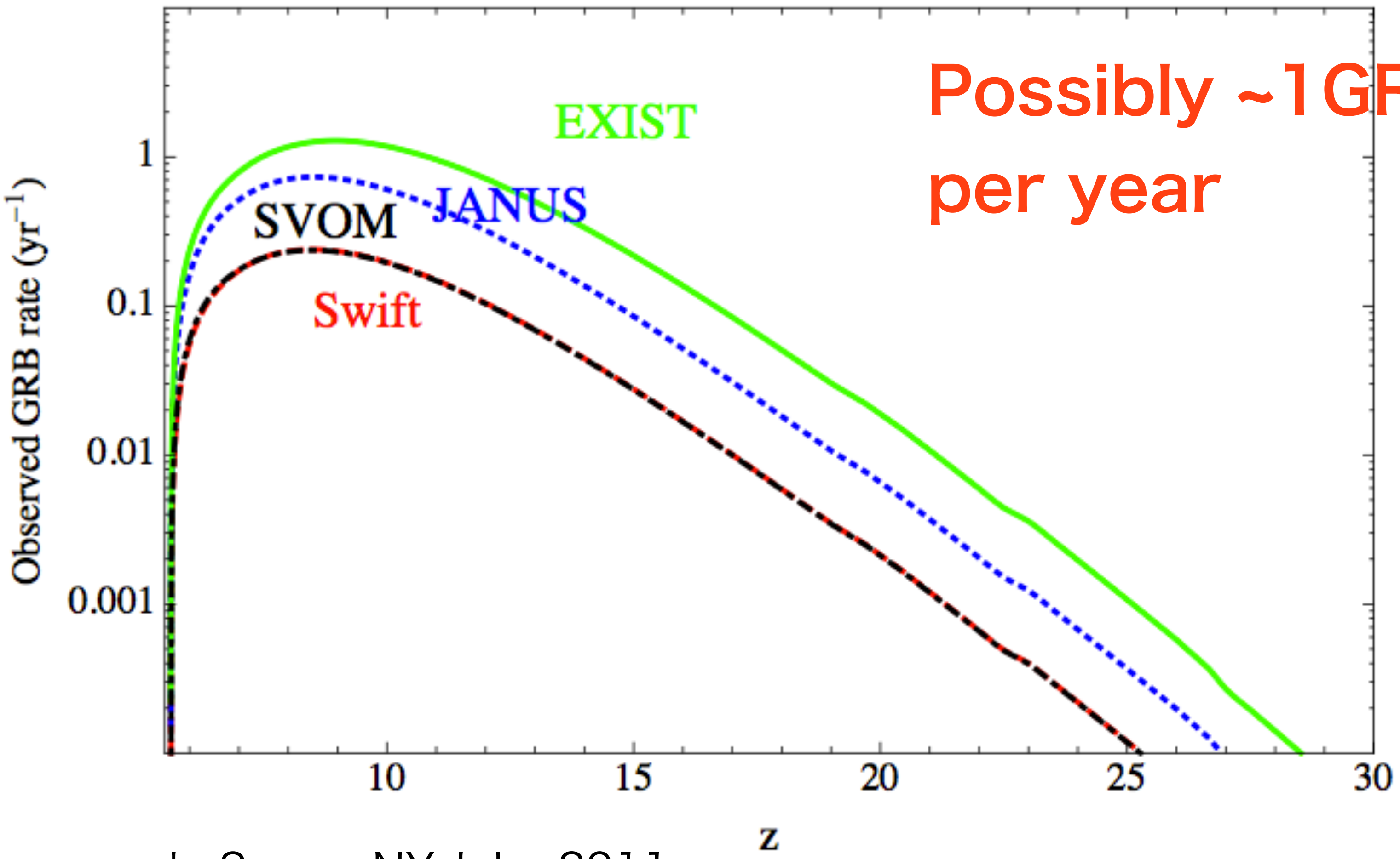
Model:
inhomogeneous metal-enrichment and reionization.

Conservative SFR compared with previous works.

Optimistic models already inconsistent with existing radio-transient surveys.

PopIII Gamma-Ray Burst

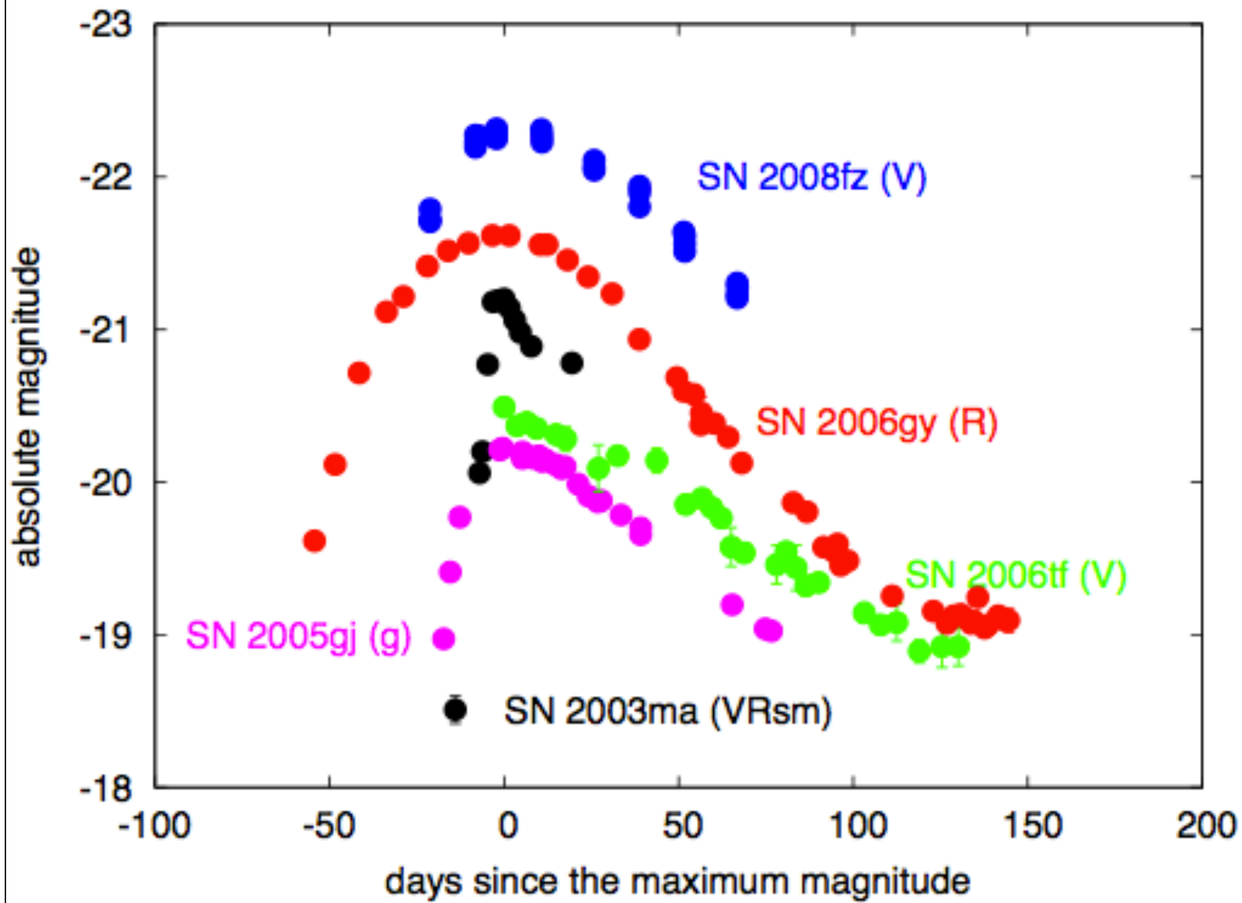
GRB rate to be detected by future satellite missions



Possibly ~1GRB@z=10!
per year

de Souza, NY, Ioka 2011

Luminous TypeIIn SN



Powered by shock-interaction with dense CSM.

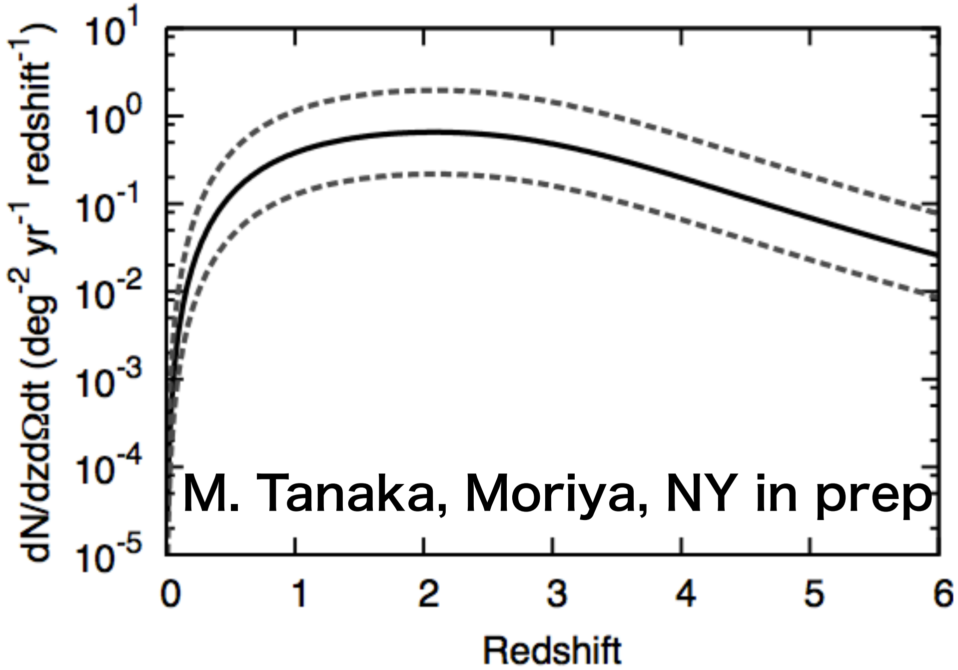
Bright in rest-UV

Death of a very massive star (> 50 Msun?)

If a PopIII triggers TypeIIn, it will be visible to very high-z.

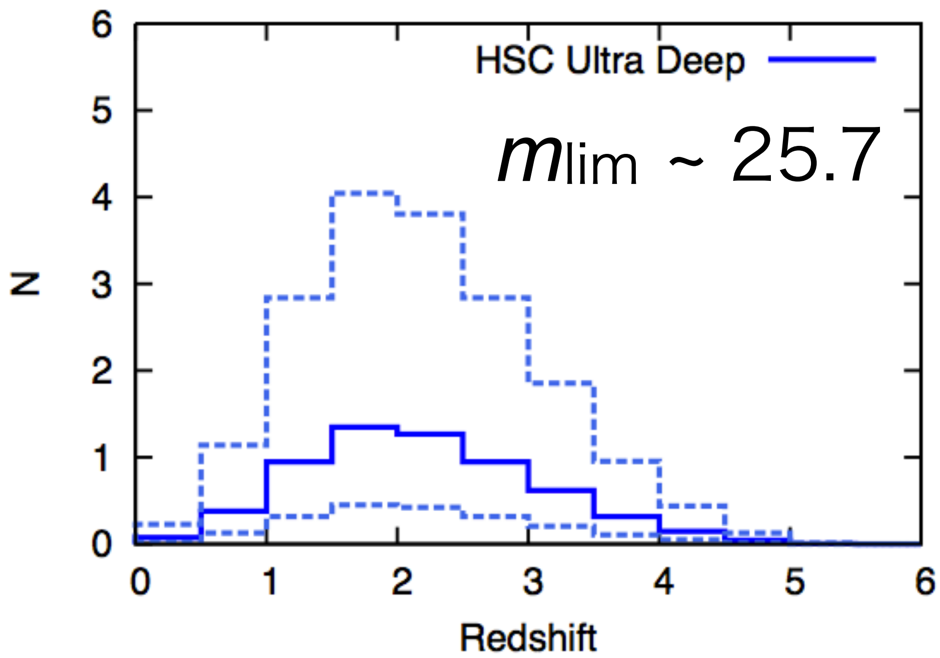
Realistic estimate: Subaru-HSC

Type IIn rate per FOV



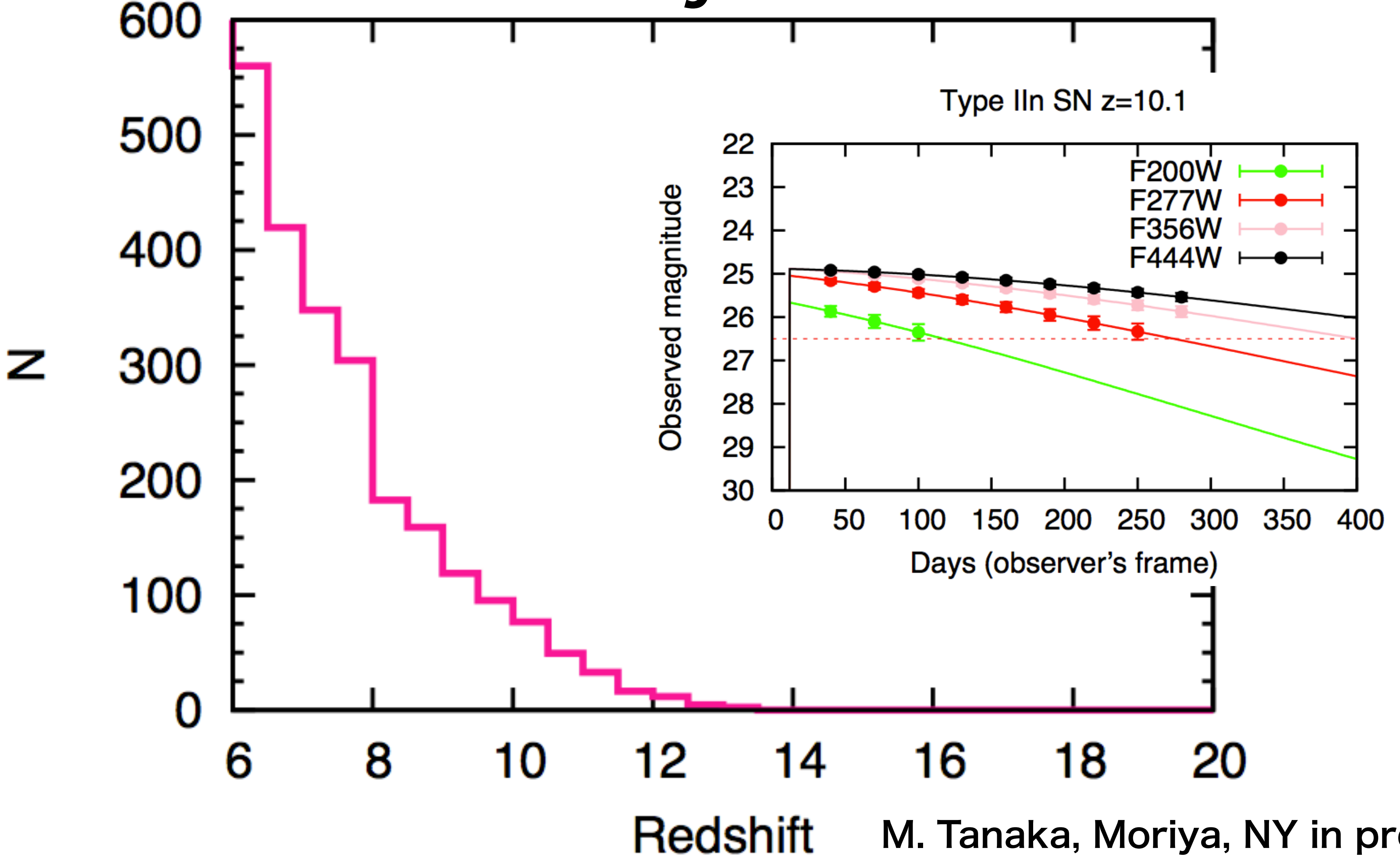
Calibrated to the local rate and LF.

in 7 deg^2



1 month cadence.
Redshift record will be extended to z=4-5

All-sky near-infrared survey



M. Tanaka, Moriya, NY in prep

Summary so far

- Primordial stars are massive, but mostly not extremely massive
- In very limited cases, MBH (~1000Msun) can form, to seed SMBH
- Population III Gamma-ray bursts at z~10 detectable by future X-ray missions
- Population III TypeIIn detectable to z~10