First Light and Faintest Dwarfs, KITP, UCSB, 2012

Primordial Star Formation

Physics, simulations, and the prospects for observation

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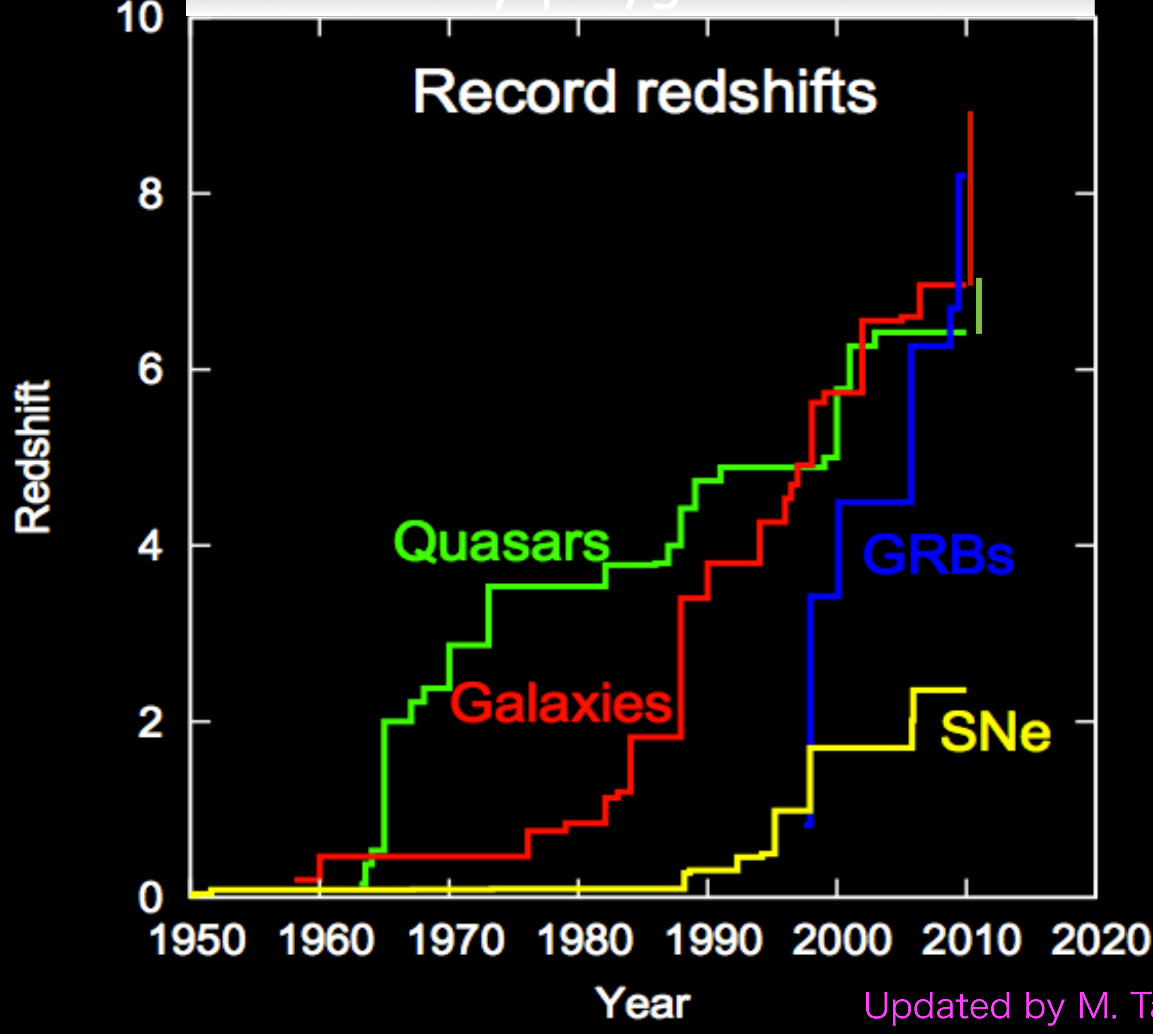
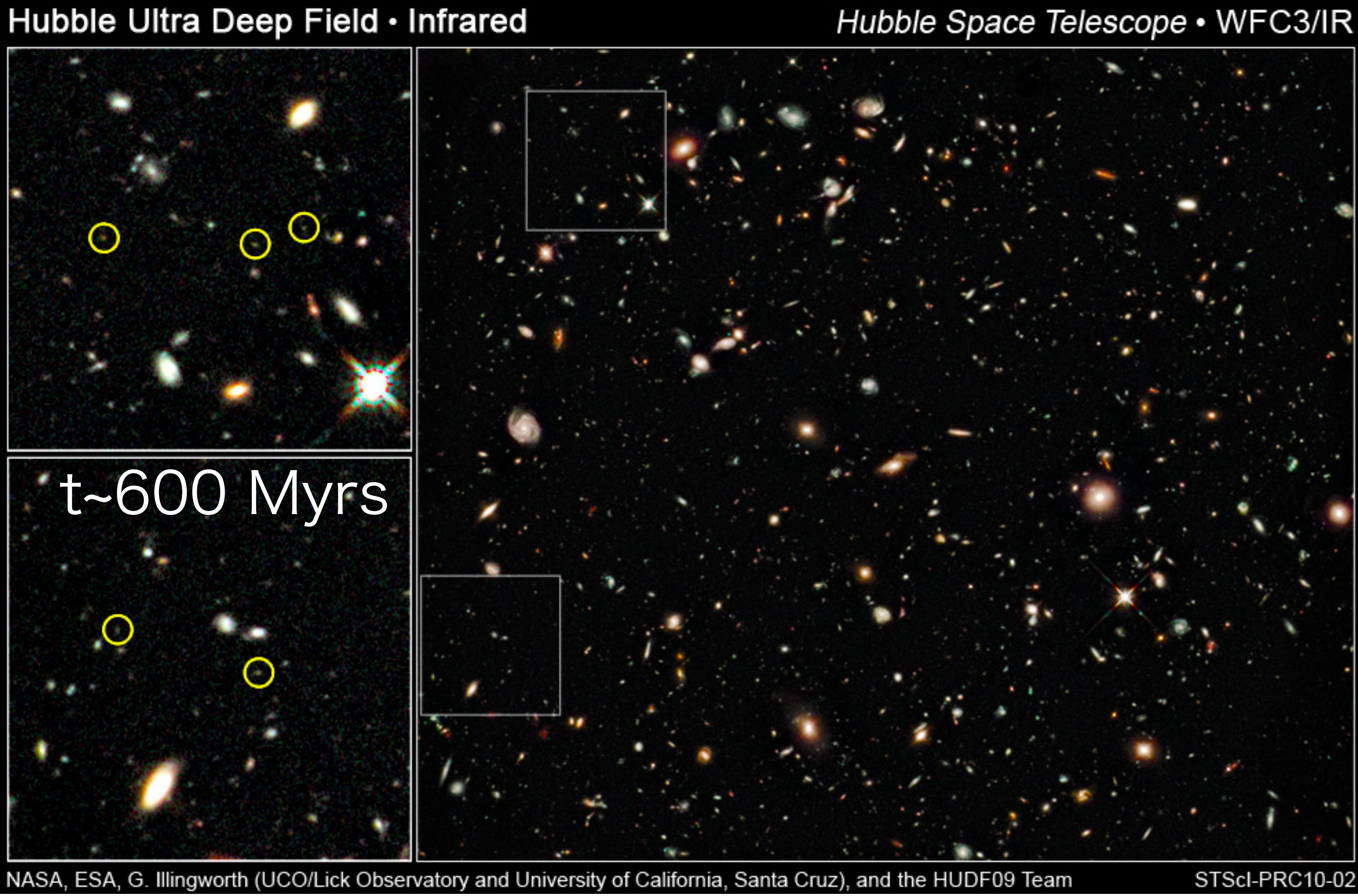
References:
NY, Omukai, Hernquist, 2008, Science
Bromm, NY, McKee, Hernquist, 2009, Nature
Ohkubo, Umeda, Nomoto, NY, Tsuruta, 2009, ApJ
Bromm & NY, 2011, Annual Reviews A&A, 49
Hosokawa, Omukai, NY, Yorke, 2011, Science
De Souza, NY, Ioka, 2011, A&A
Tanaka, Moriya, NY, Nomoto, 2012, MN submitted

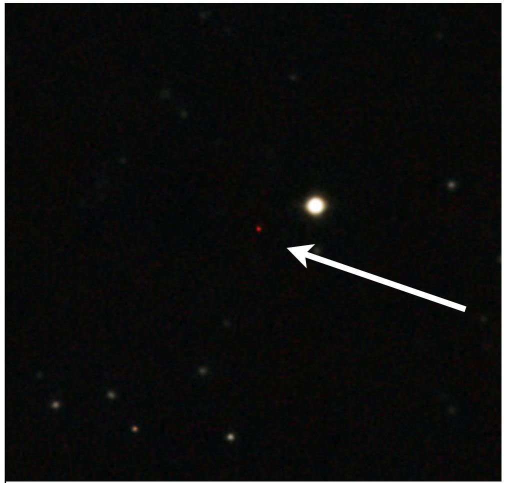
My playground



Updated by M. Tanaka

Most distant galaxies

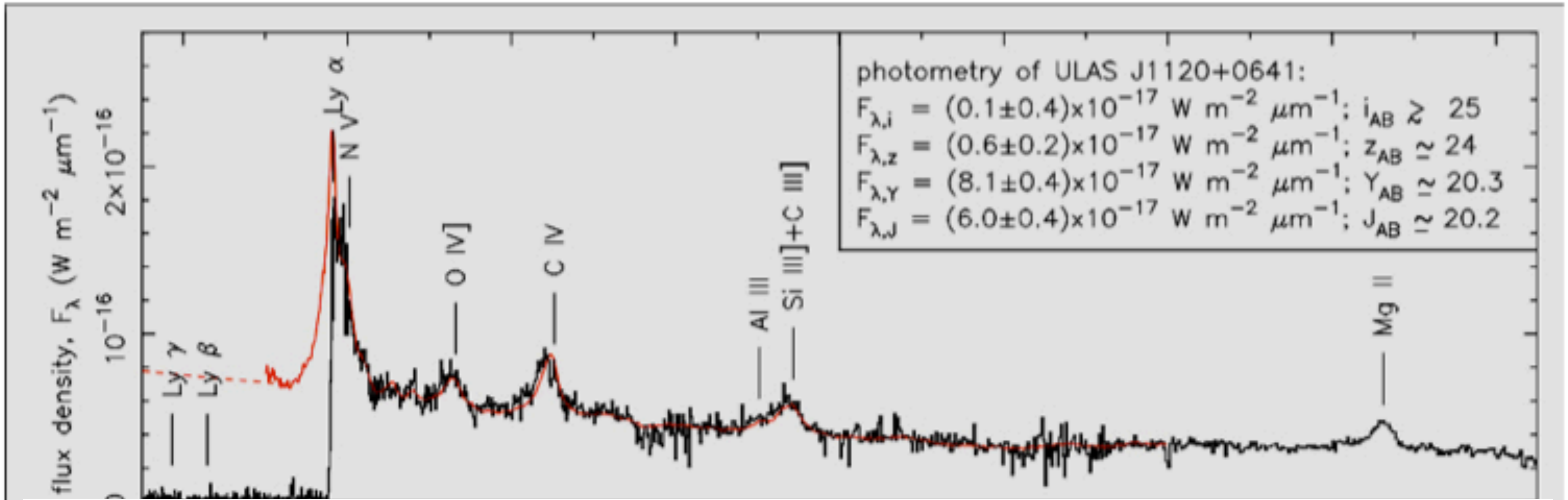




z=7 quasar

2 billion solarmasses

at t~700 million years

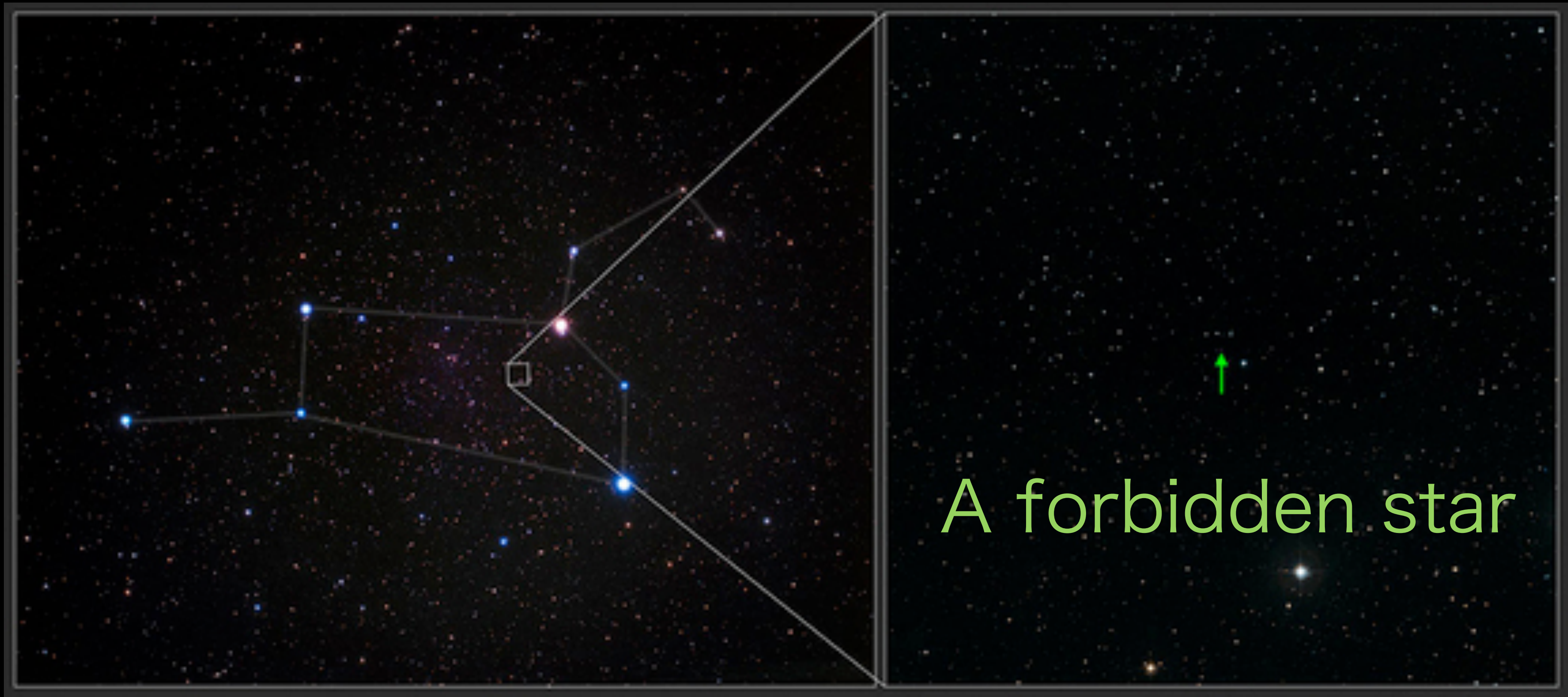


The origin of the SMBH ?

The origin of the heavy elements ?

VLT FORS + Gemini NIRS

Stellar relics in the MW



Low-mass ($<1 M_{sun}$),

extremely metal-poor (not only iron poor)

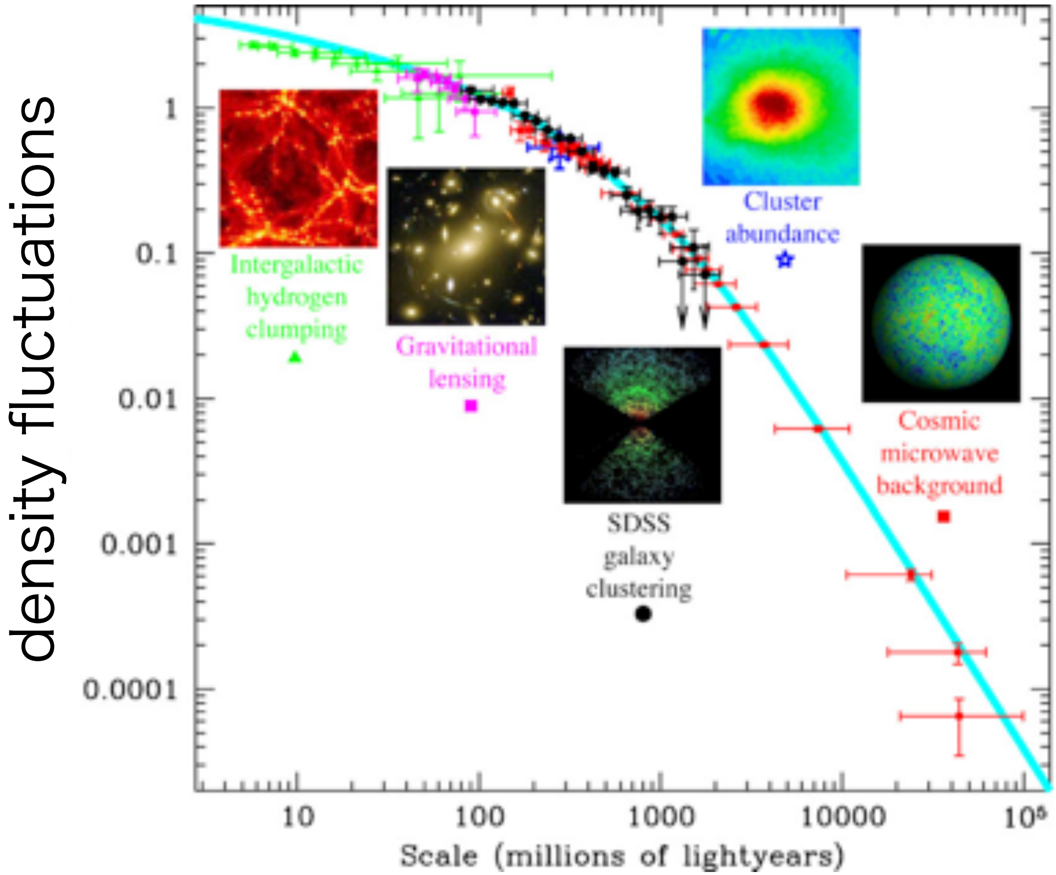
$Z < 4.5 \times 10^{-5} Z_{sun}$

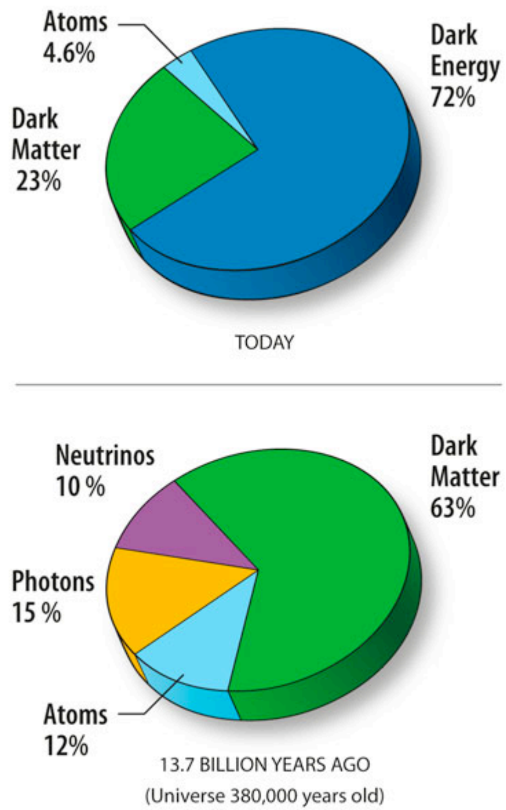
Caffau et al. 2012

Theory

The Standard Cosmology

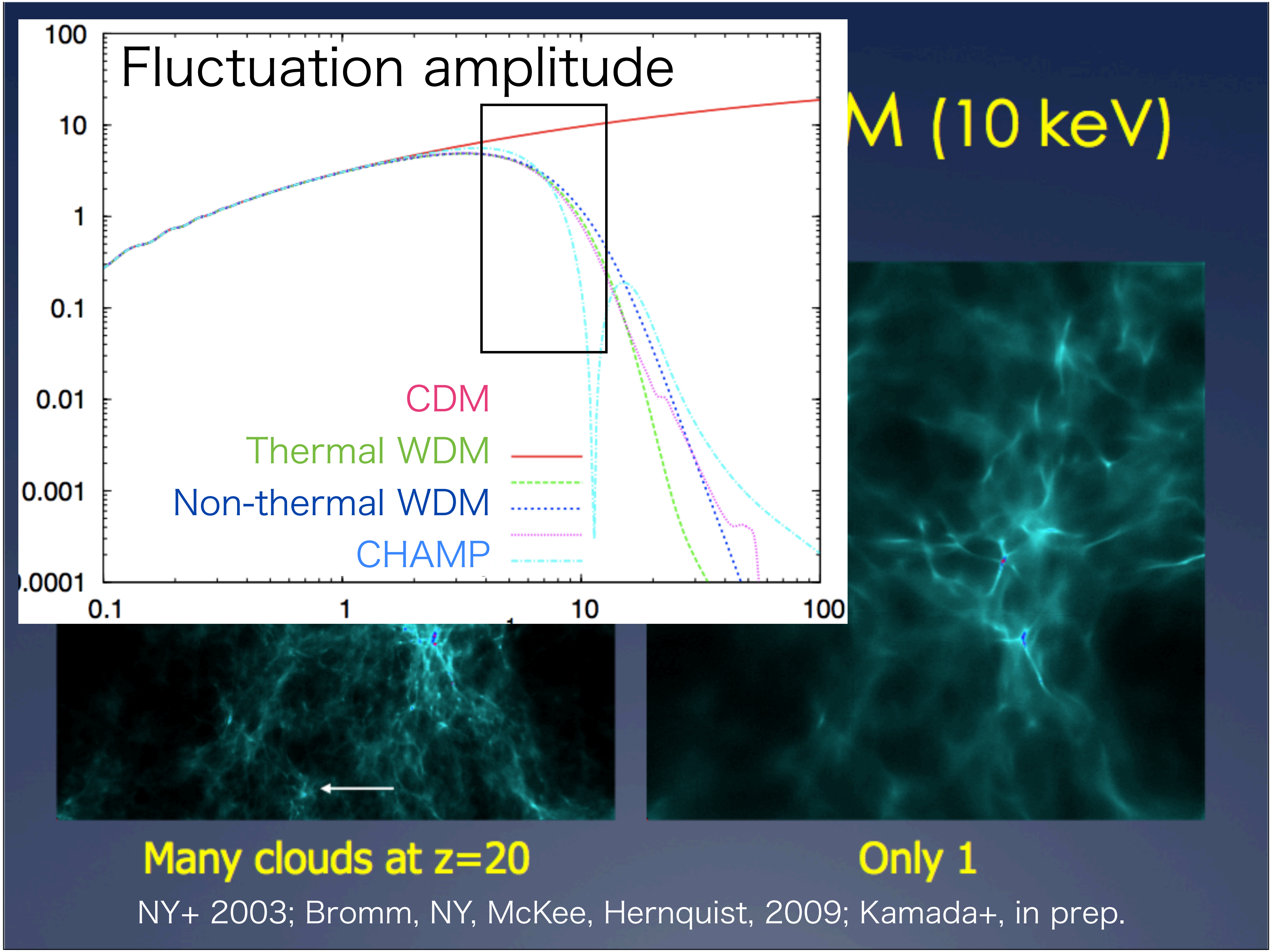
An *ab initio* approach is possible

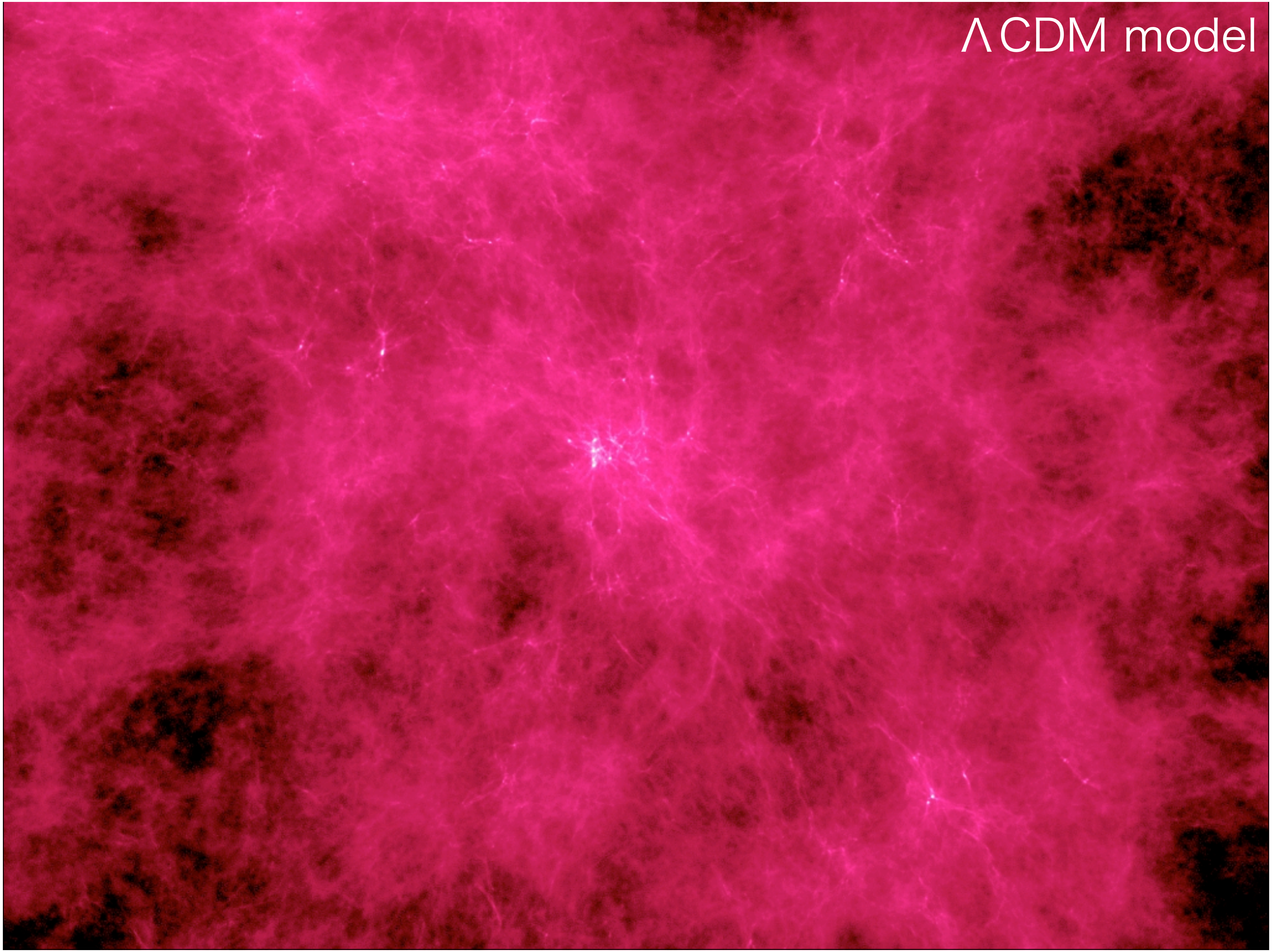




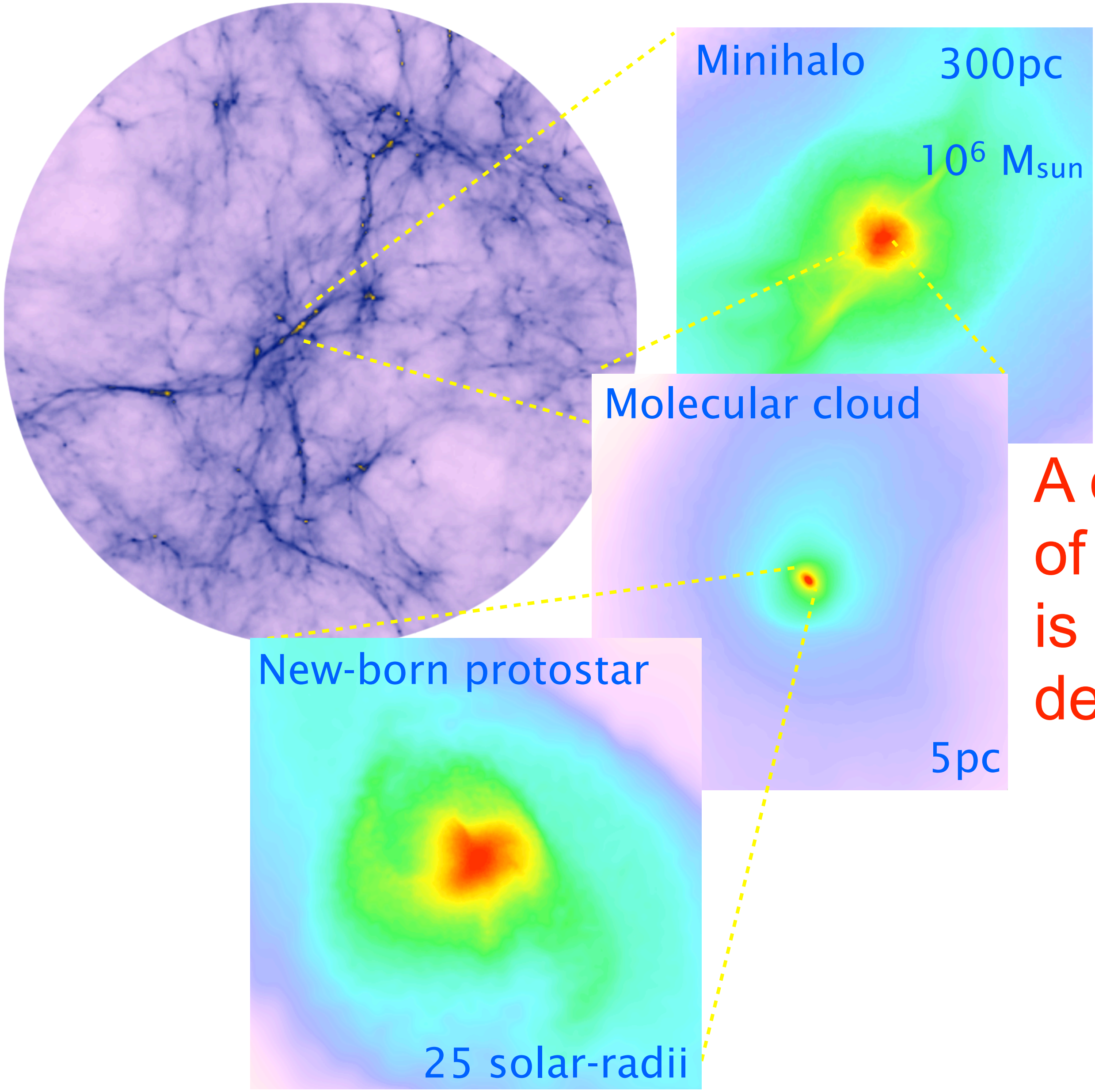
CMB + LSS + SNe tell us about the initial state of the universe, its expansion history, and the energy content now and then *precisely*.

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


Fluctuation amplitude
100
10
1
0.1
0.01
0.001
.0001
0.1
1
10
100
CDM
Thermal WDM
Non-thermal WDM
CHAMP
M (10 keV)
Many clouds at z=20
Only 1
NY+ 2003; Bromm, NY, McKee, Hernquist, 2009; Kamada+, in prep.


ΛCDM model

From a minihalo to a protostar

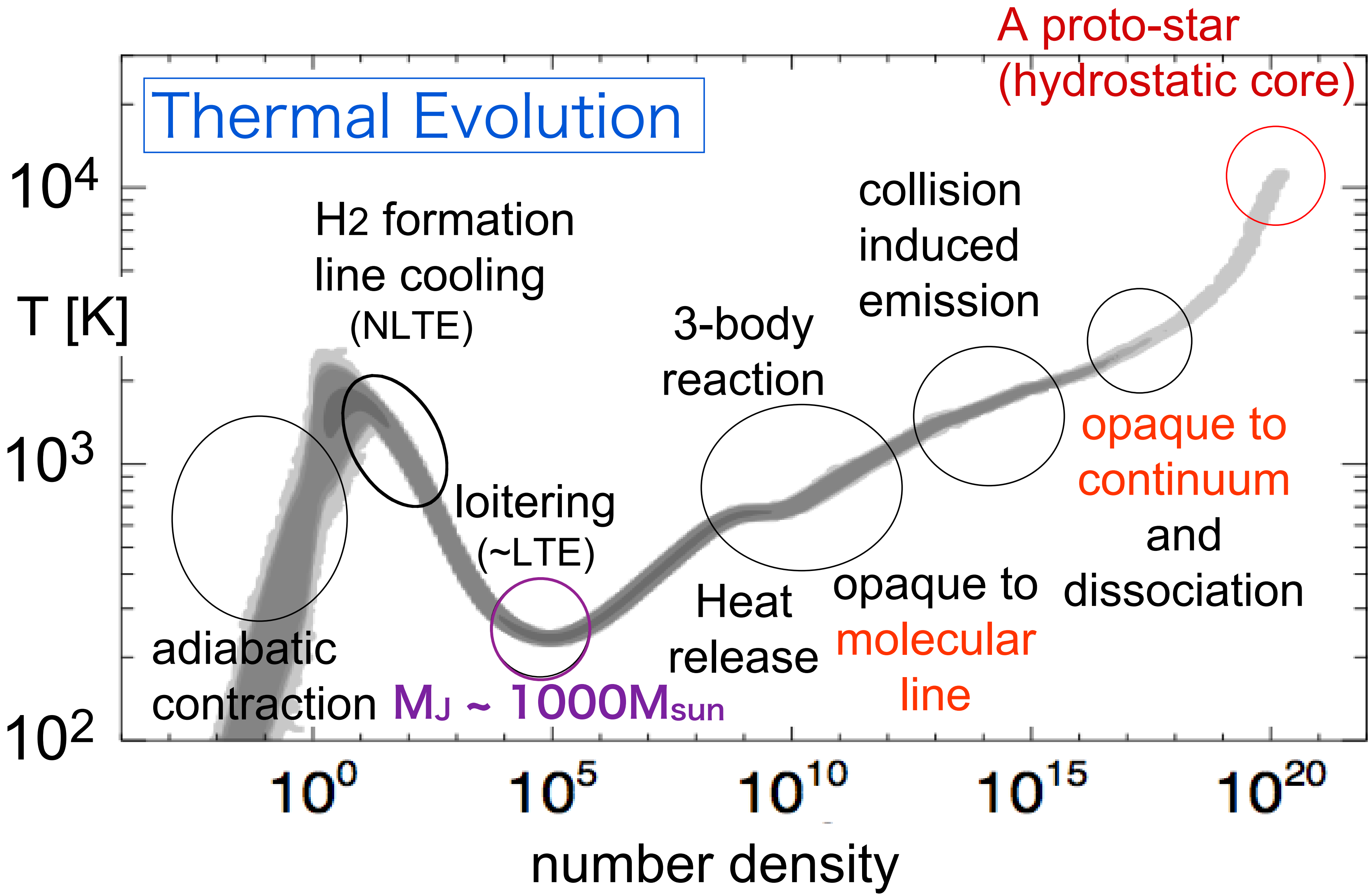


Resolving planetary scale structures in a cosmological volume!

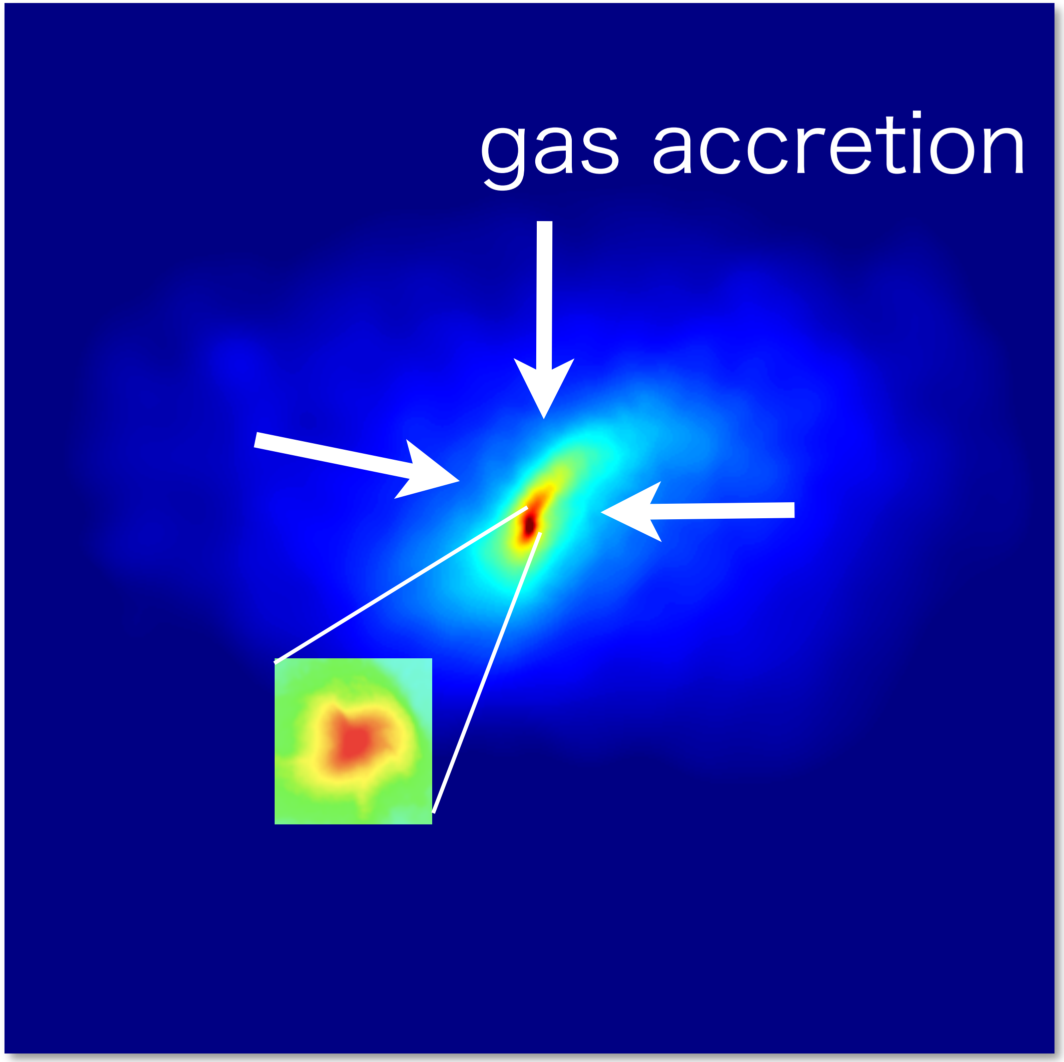
A complete picture of how a protostar is formed from tiny density fluctuations.

NY, Omukai, Hernquist 2008

Physics at a glance



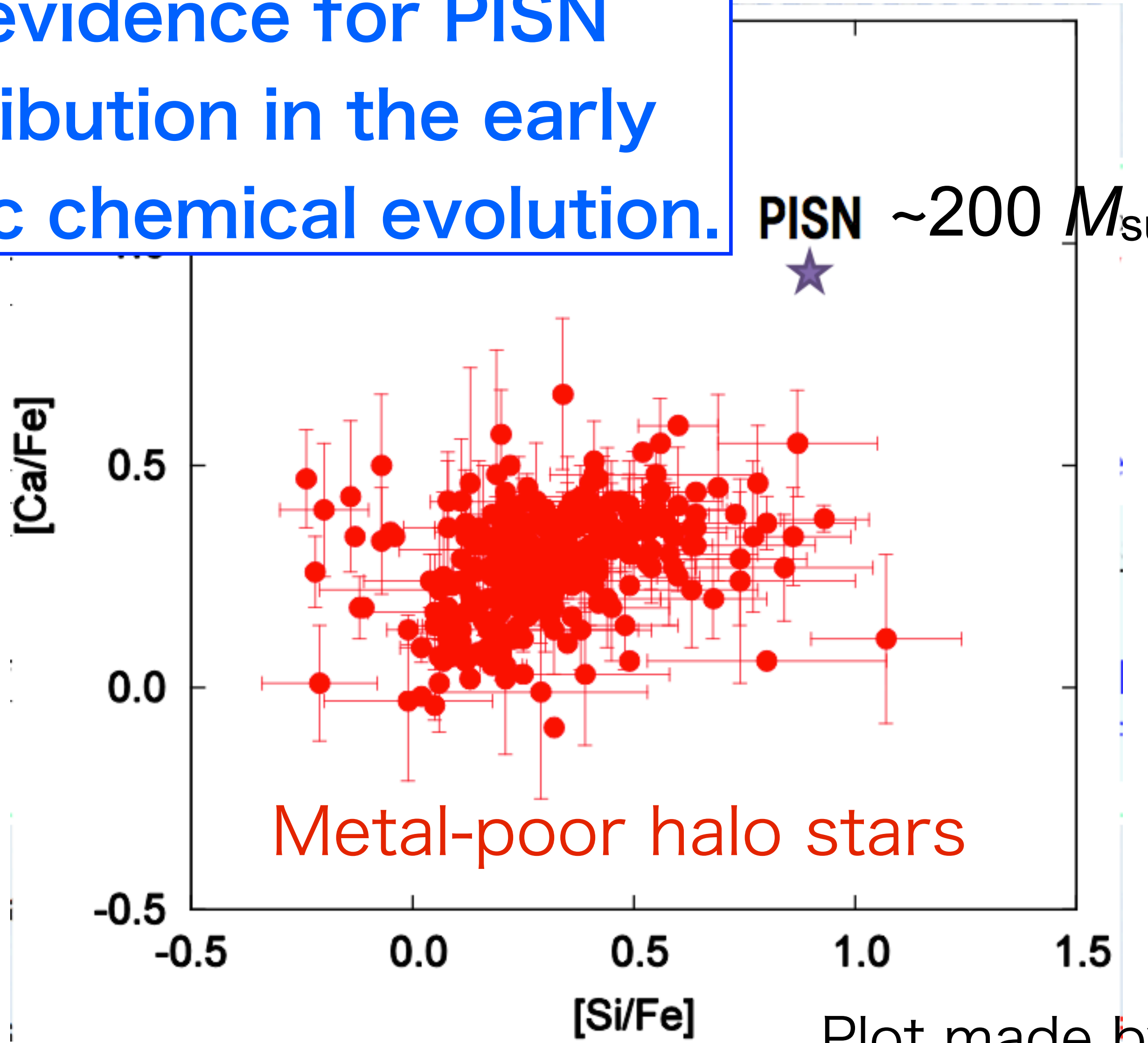
From a protostar
to main-sequence



Massive PopIII Stars

Observations tell...

No evidence for PISN contribution in the early Galactic chemical evolution.



Plot made by N. Tominaga

Theorists said...

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

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

Jeans mass, accretion time

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

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 (Clark)

"Cosmo" IC + disk evaporation   Accretion disk fragmentation

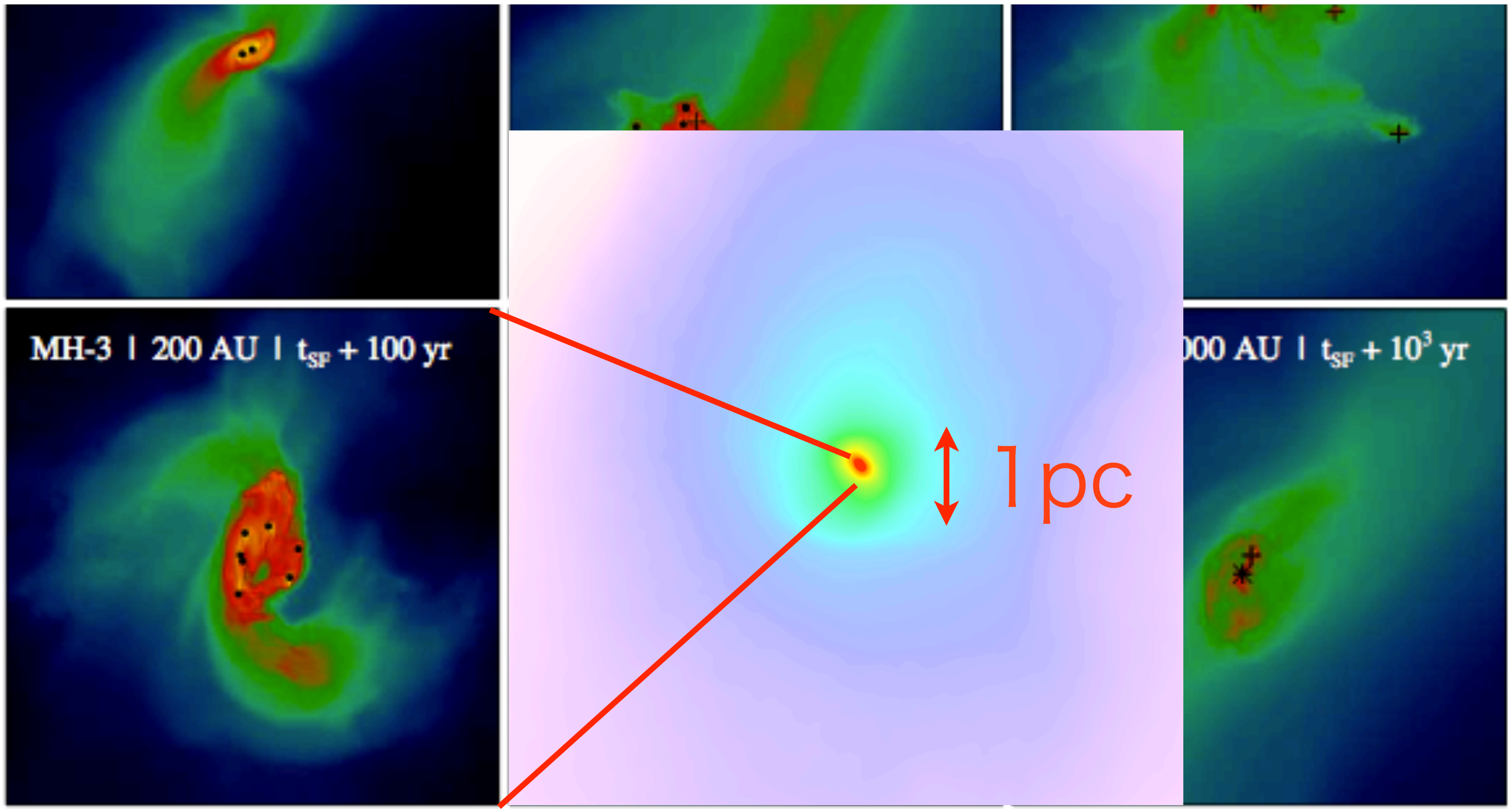
Sink particles

Post-collapse simulations

Disk evolution using sink particles

Follows only 100-1000 years

~ 1% of the entire evolution.

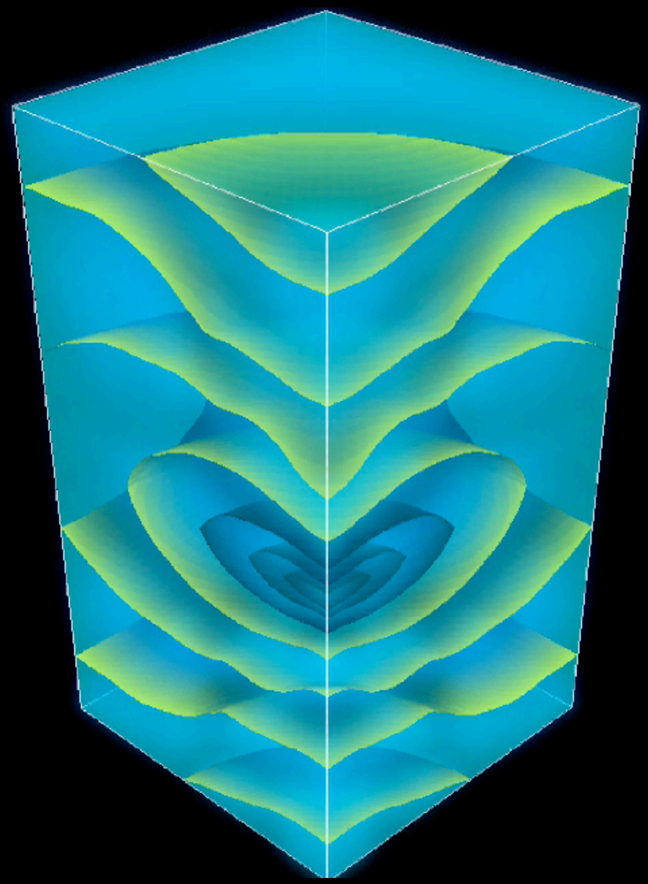


Clark et al. 2011; Greif et al. 2011

The key question

How and when
does a primordial star
stop growing?

Protostellar evolution to main-sequence



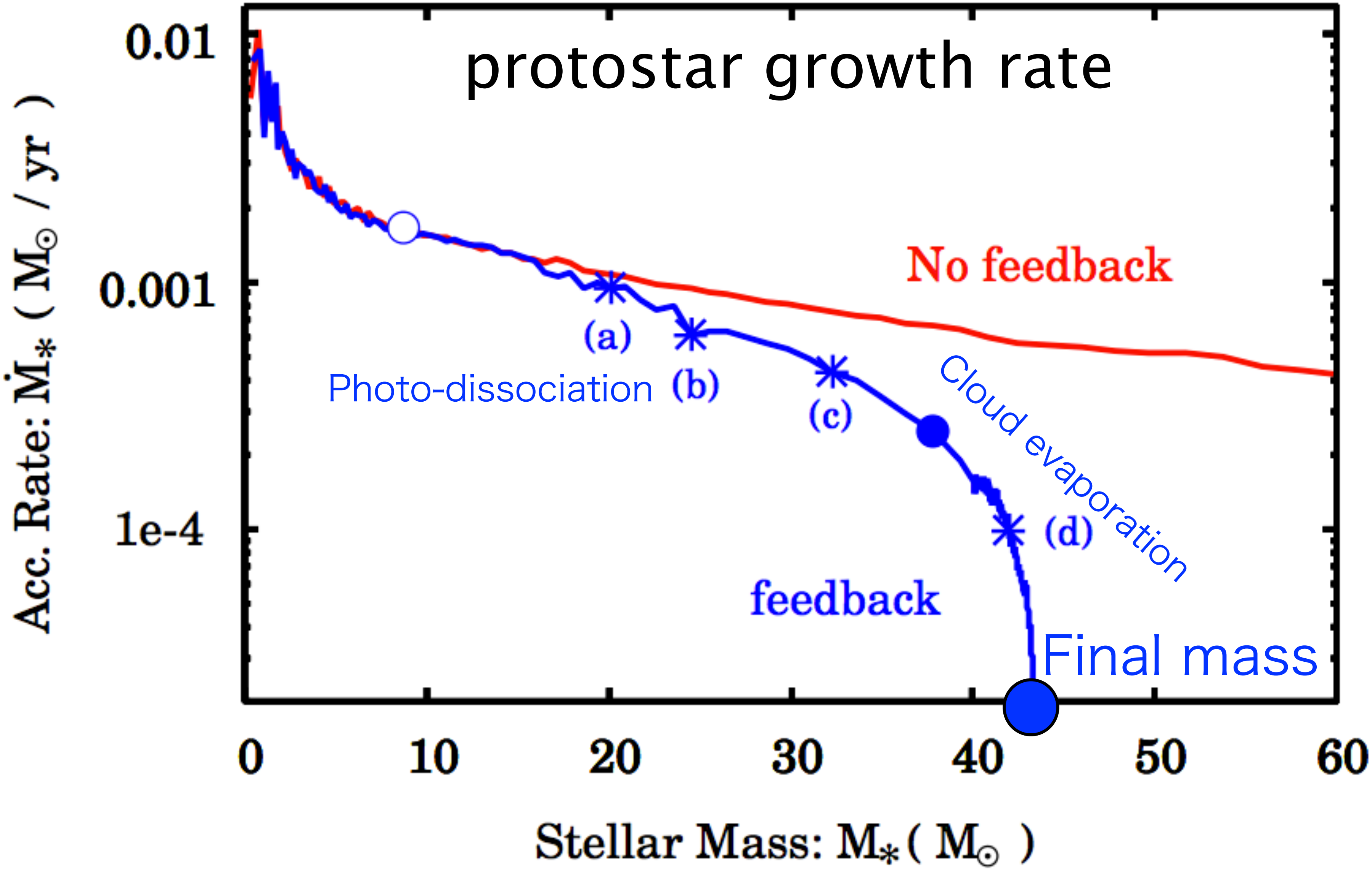
H_{II} region break-out

Radiation-hydro. calculation
by T. Hosokawa (JPL).

Ionizing photon transfer
by ray-tracing, continuum (H^-)
by Flux Limited Diffusion.
H. Yorke's code
+ non-eq. chemistry.
Initial condition taken from
our cosmological run.

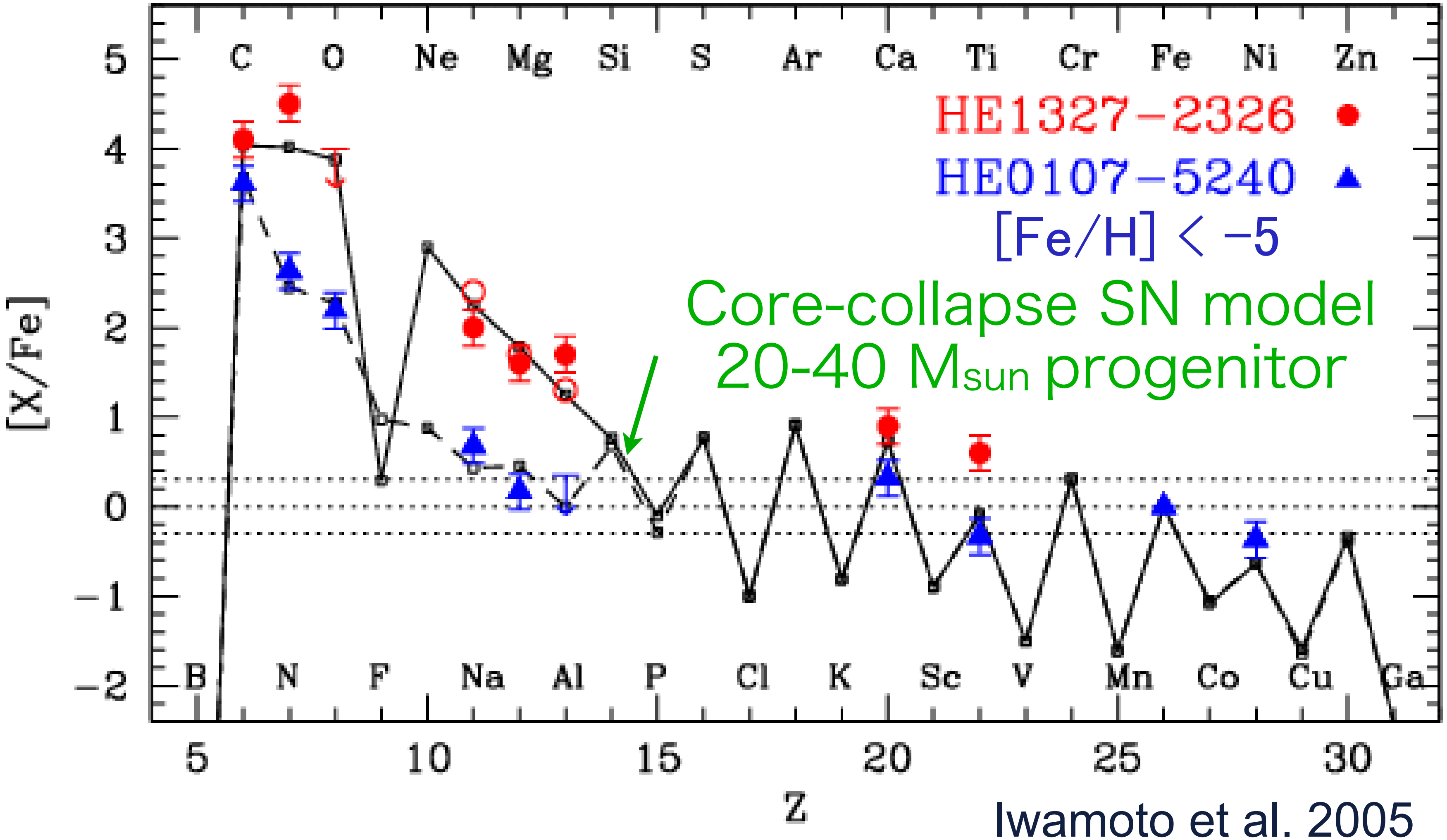
Accretion vs photo-evaporation

Hosokawa, Omukai, NY, Yorke 2011, Science



Long standing puzzle resolved

Observed elemental abundances



Iwamoto et al. 2005

PopIII to PopII

Is there a "critical metallicity" for cloud fragmentation ?

If so, what's the physics behind it ?

Bromm et al.
atomic cooling
by C, O
@low-density

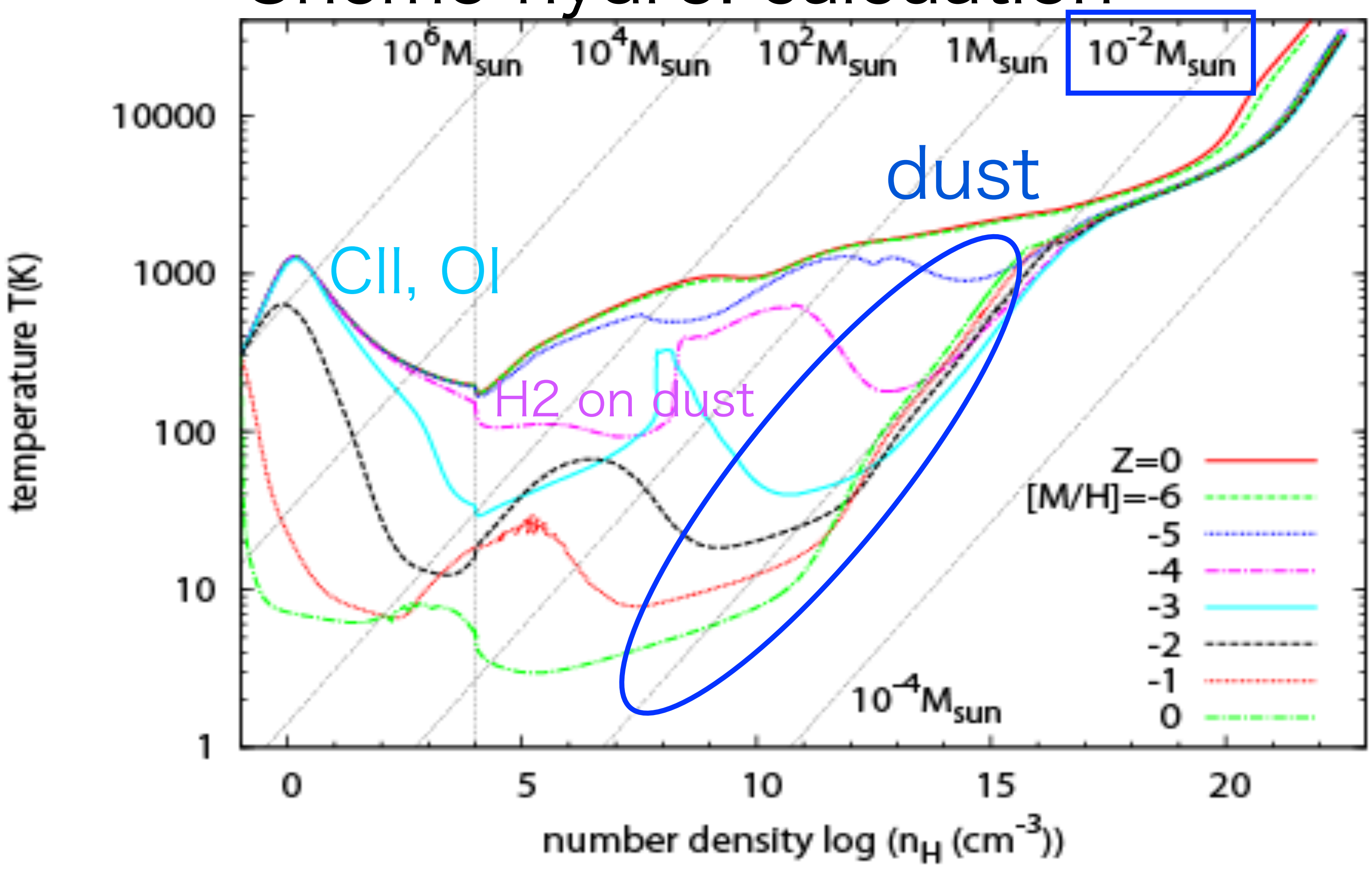
vs.

Omukai, Schneider
cooling by dust
@high density

Recall talks by M.Trenti, O. Gnedin, J. Wise

“Dusticity” 10^{-6} -1Z_{sun}

Chemo-hydro. calcuation



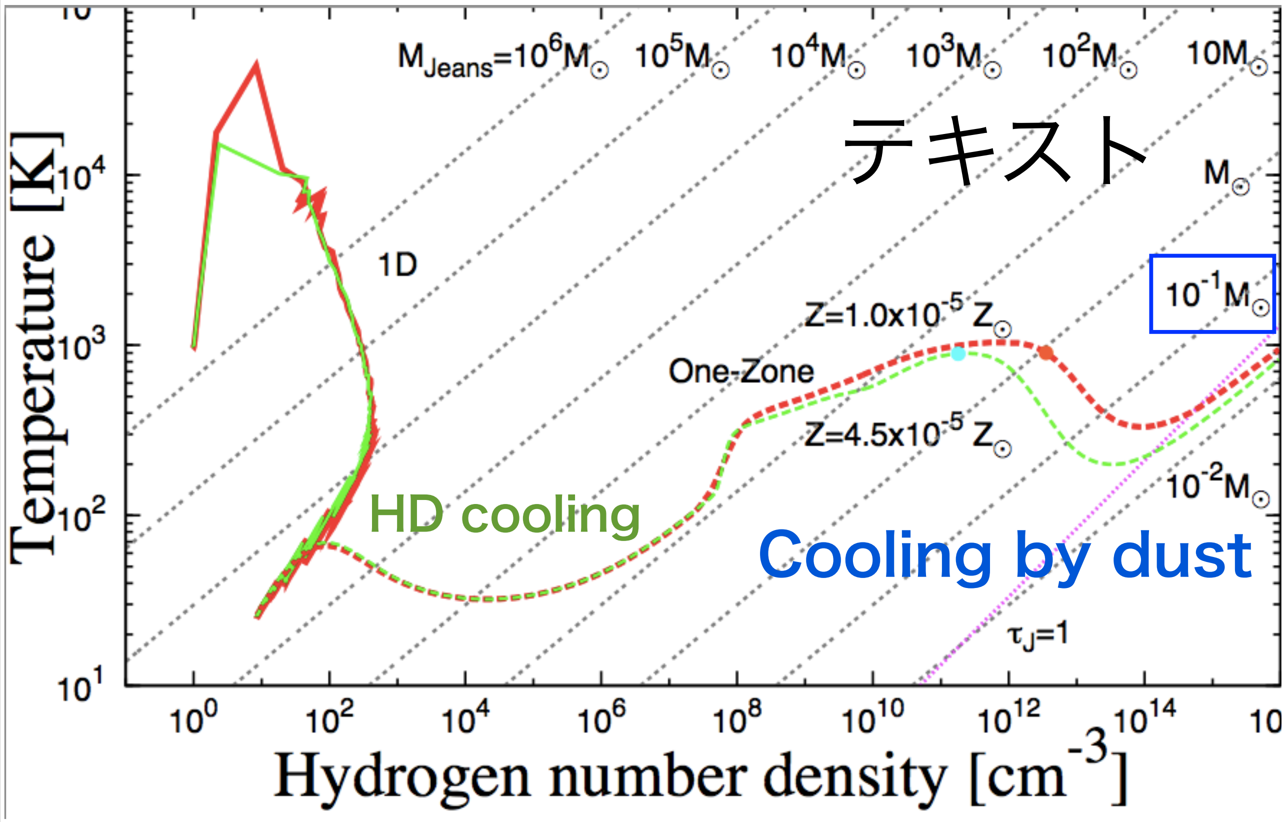
Omukai+2005; Omukai, Hosokawa, NY, 2010

Formation of Caffau's star

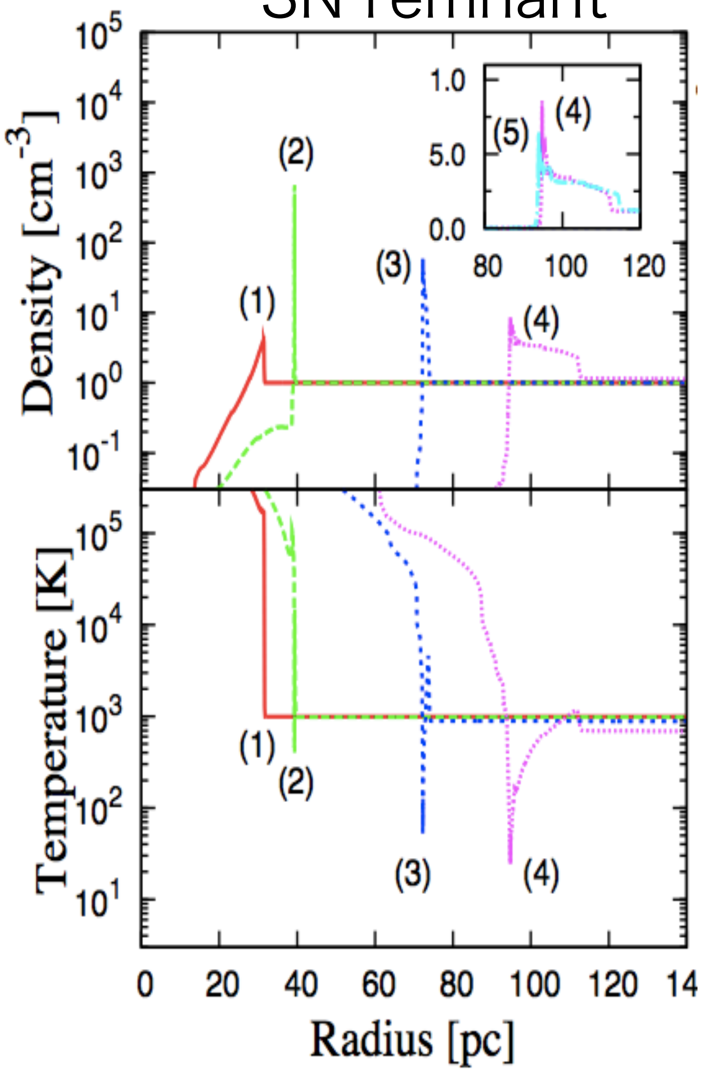
Triggered star-formation by the first supernova

Early SN remnant with 10^{-5} Z_{sun}

Fragmentation of a cooling shell



SN remnant

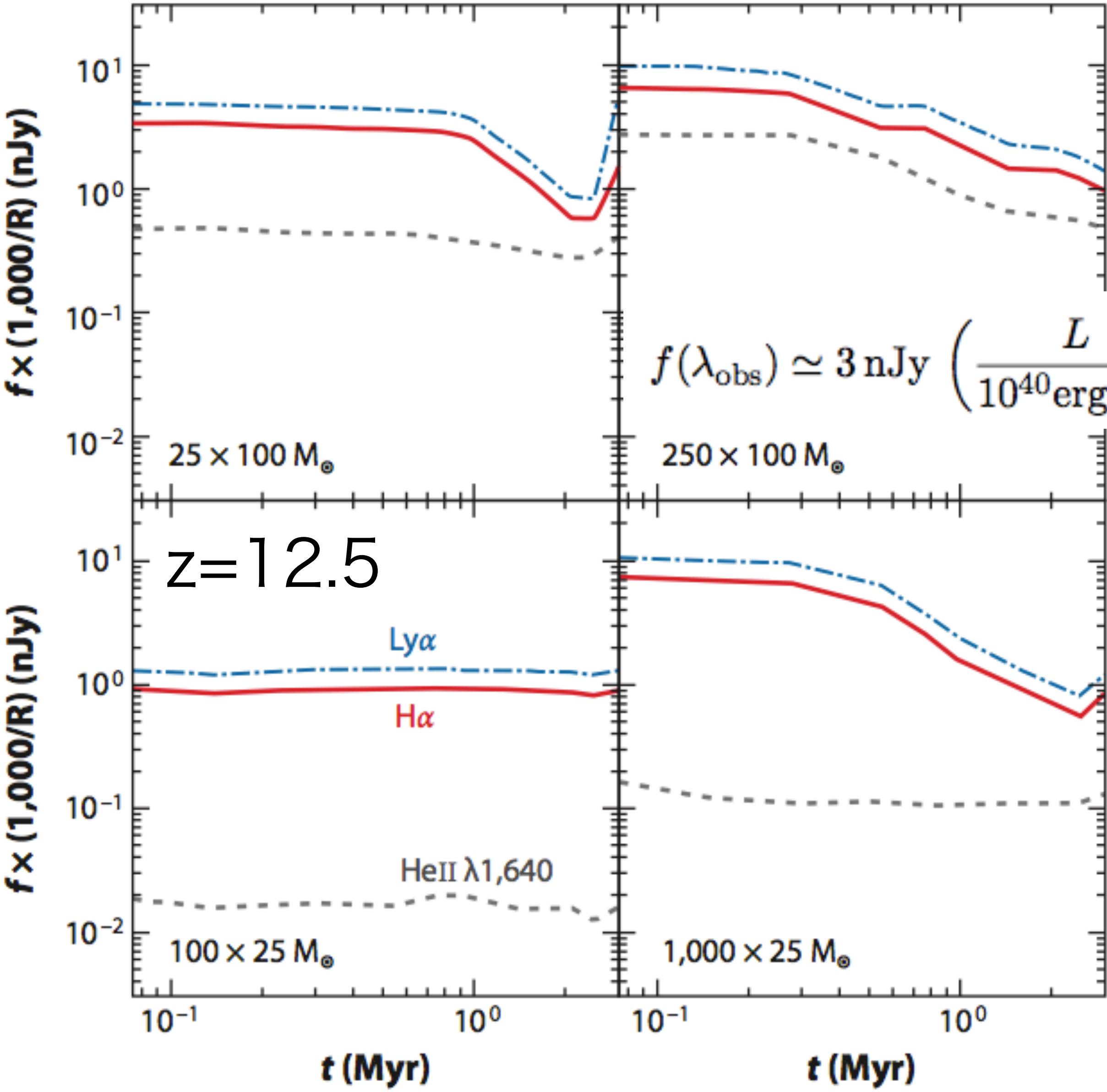


Chiaki, NY, Kitayama, 2012; see also Dopke et al. 2011, Klessen et al. 2012

Hunting for high-z supernovae

The future

Individual star...impossible!

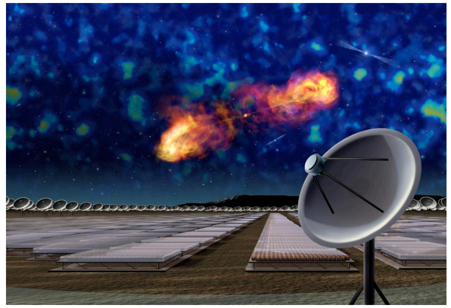


$$f(\lambda_{\rm obs}) \simeq 3\,{\rm nJy}\left(\frac{L}{10^{40}{\rm erg\,s^{-1}}}\right)\left(\frac{\lambda_{\rm em}}{1216{\rm \AA}}\right)\left(\frac{R}{1000}\right)\left(\frac{1+z}{11}\right)^{-1}$$

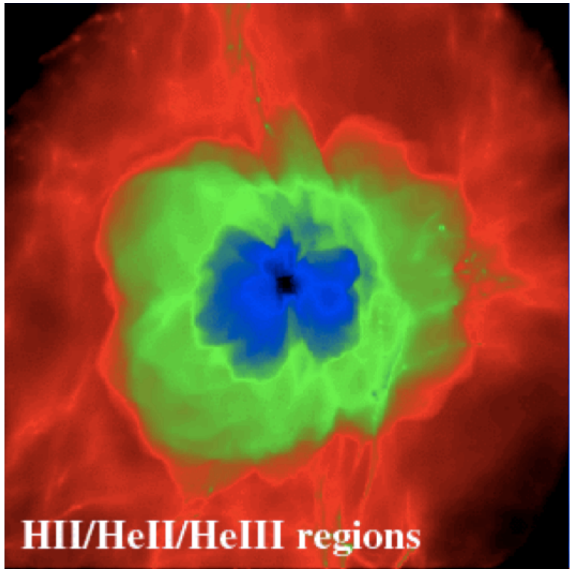
Only clusters of PopIII can be detected by recom. lines.

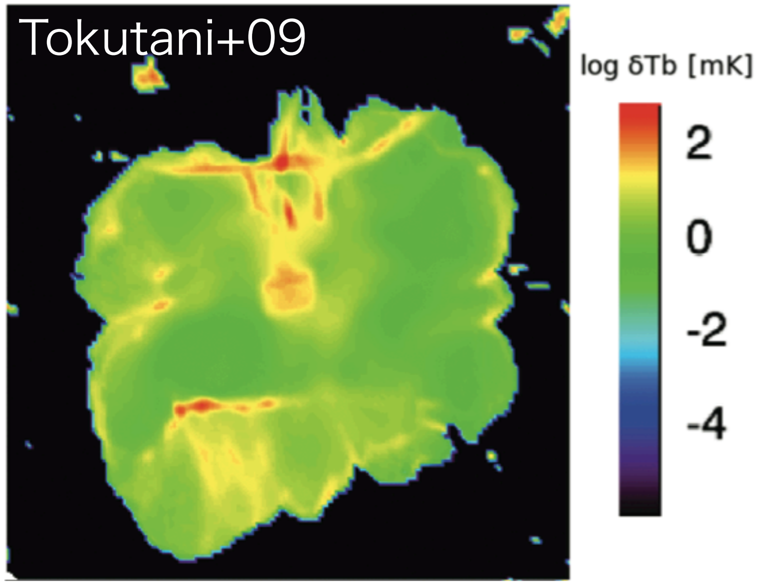
Bromm, NY, ARAA 2011

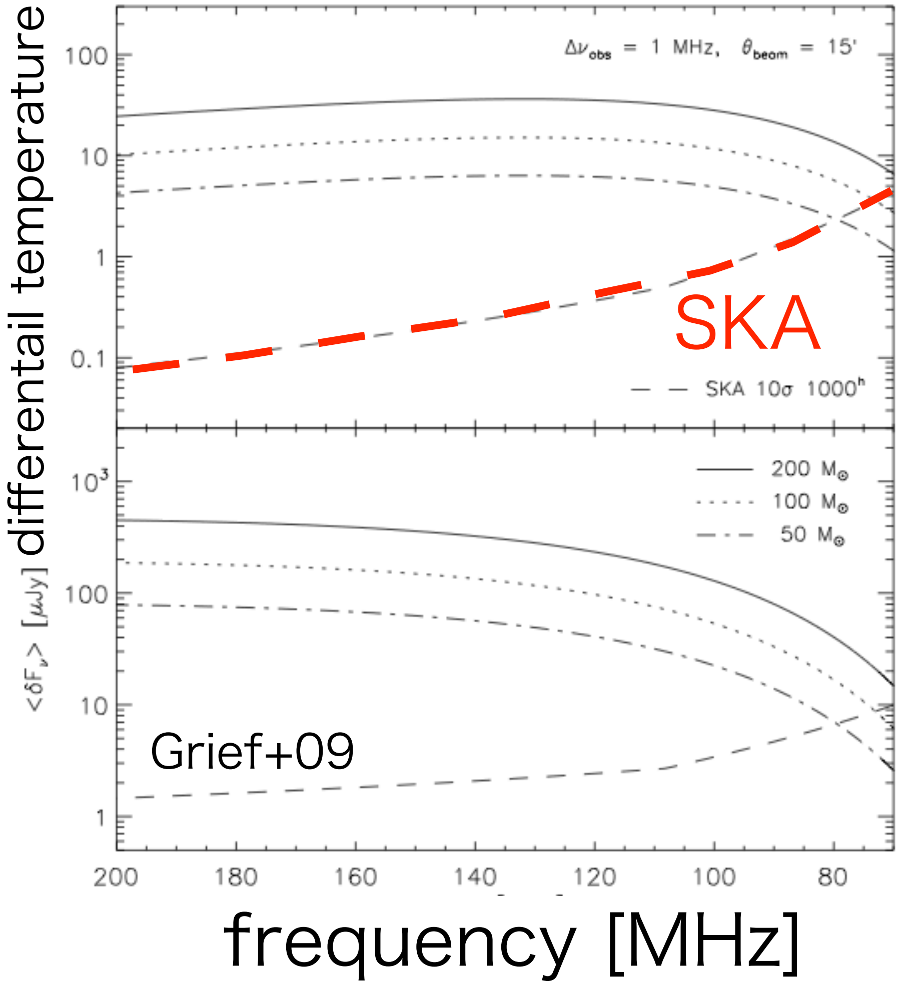
Hope for SKA



Relic HII regions bright in 21cm



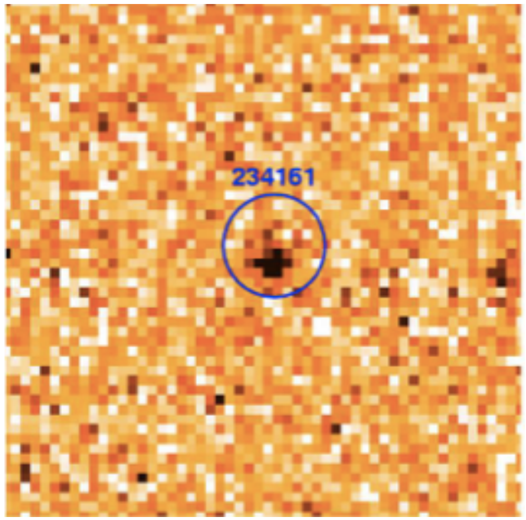


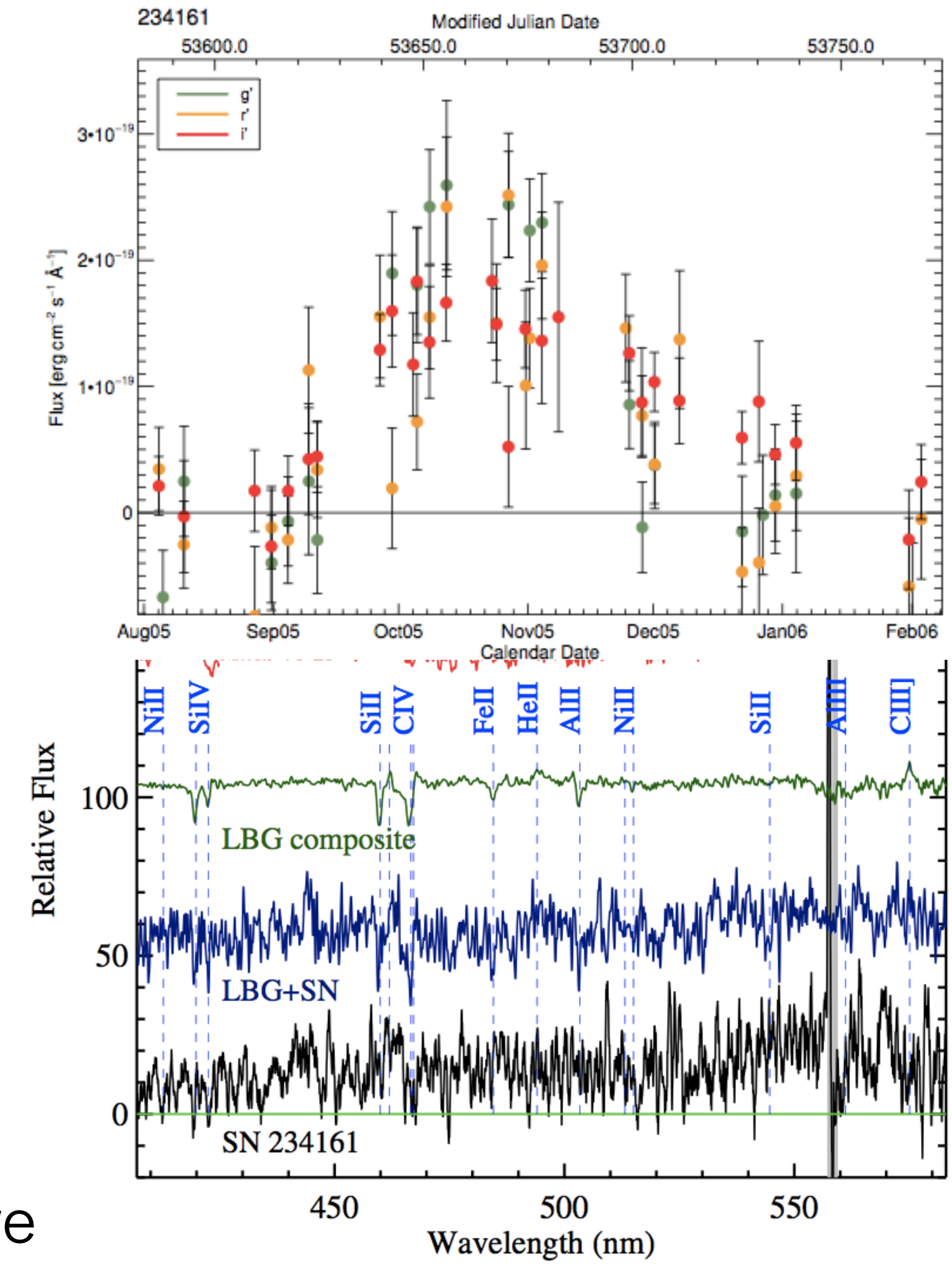


Core-collapse supernovae at very high-z

Highest-z supernova

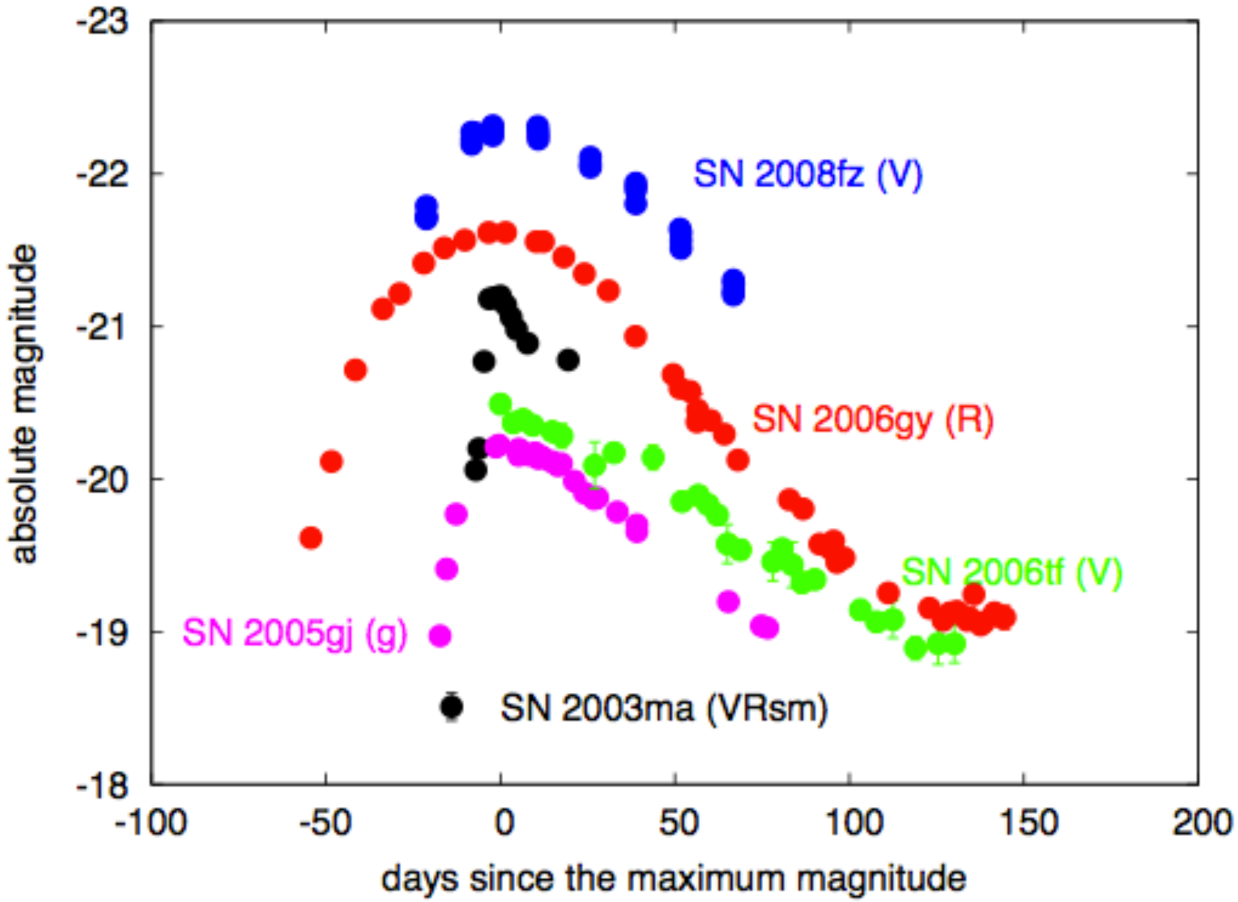
Type IIn at z=2.4





Cooke et al. 2009, Nature

Super-luminous SN



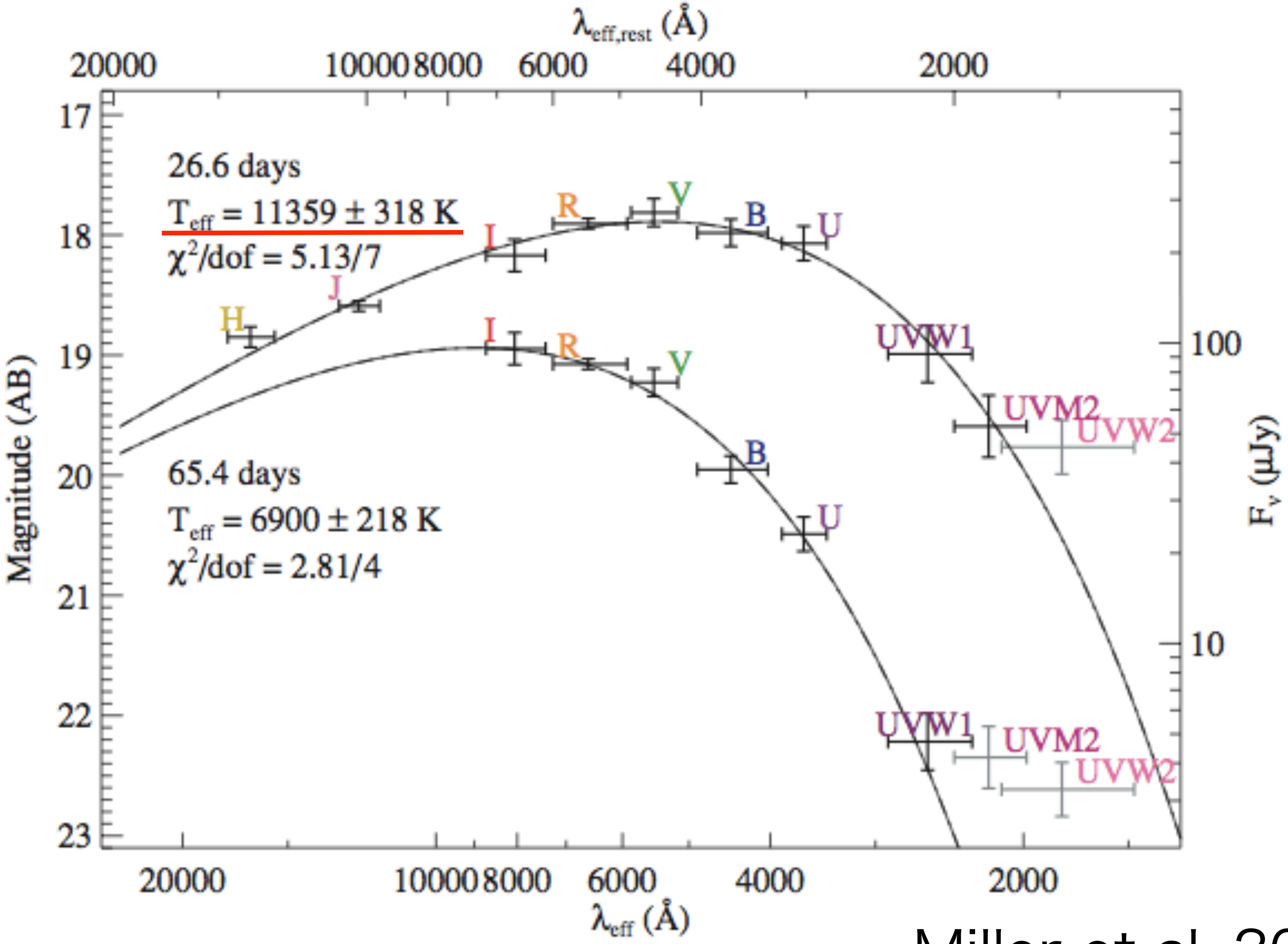
Powered by shock-interaction with dense CSM.

Death of a very massive star (> 40-50 Msun)

Bright in rest-UV

They are visible even at very high-z.

2008es: Bright in UV

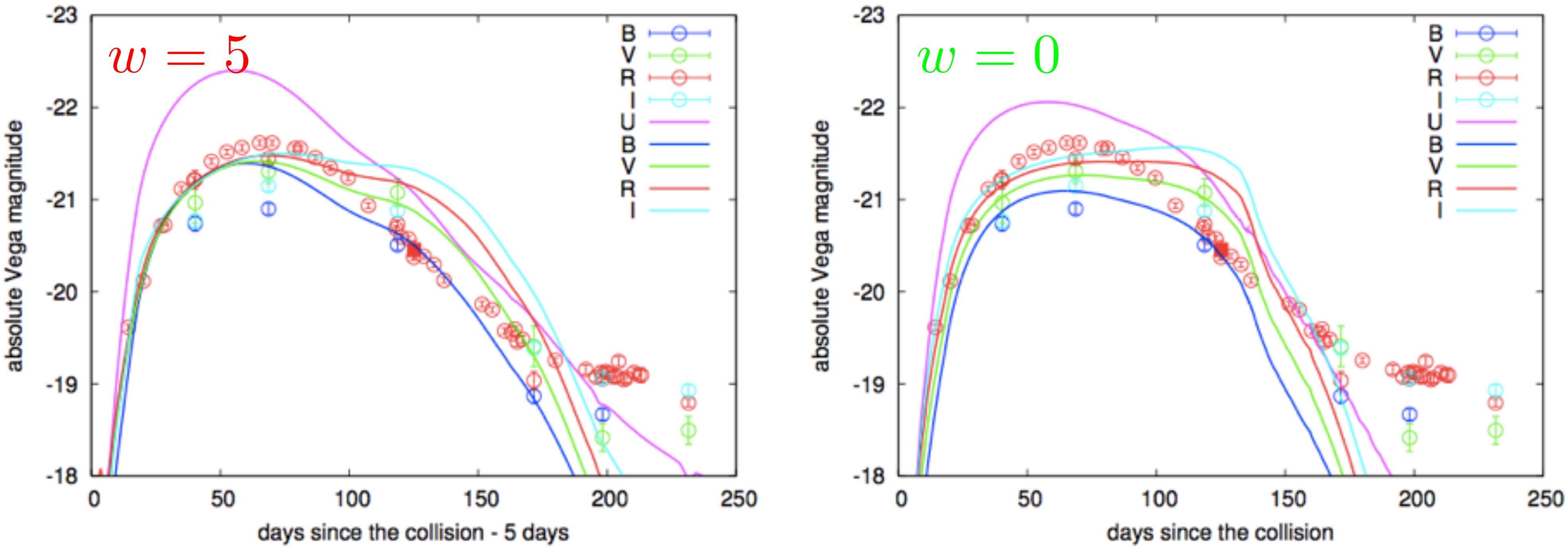


Miller et al. 2009

SN 2006gy

Lightcurve sim. by STELLA

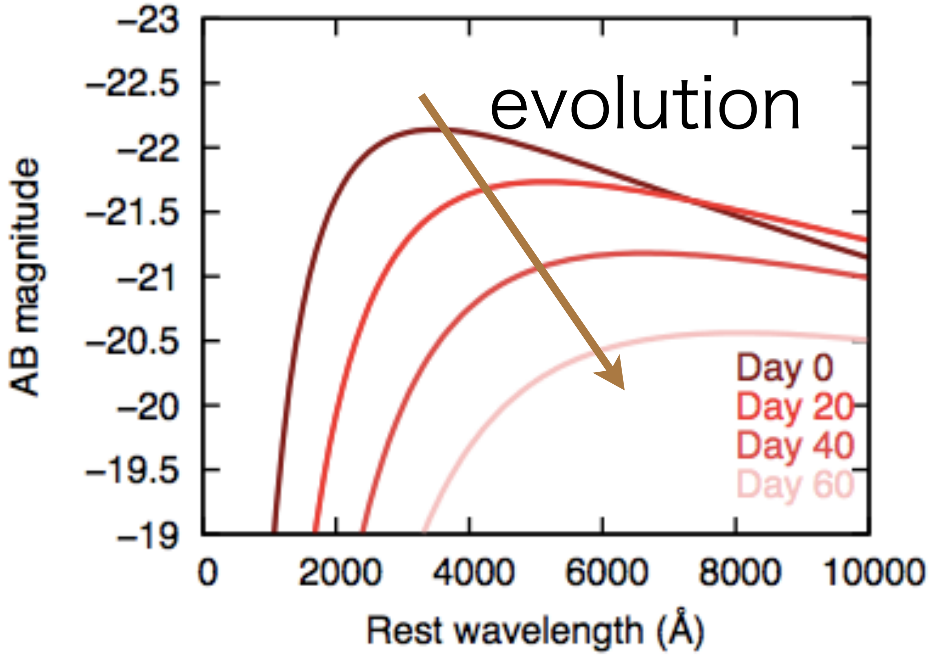
Moriya, Blinnikov, et al., in prep.

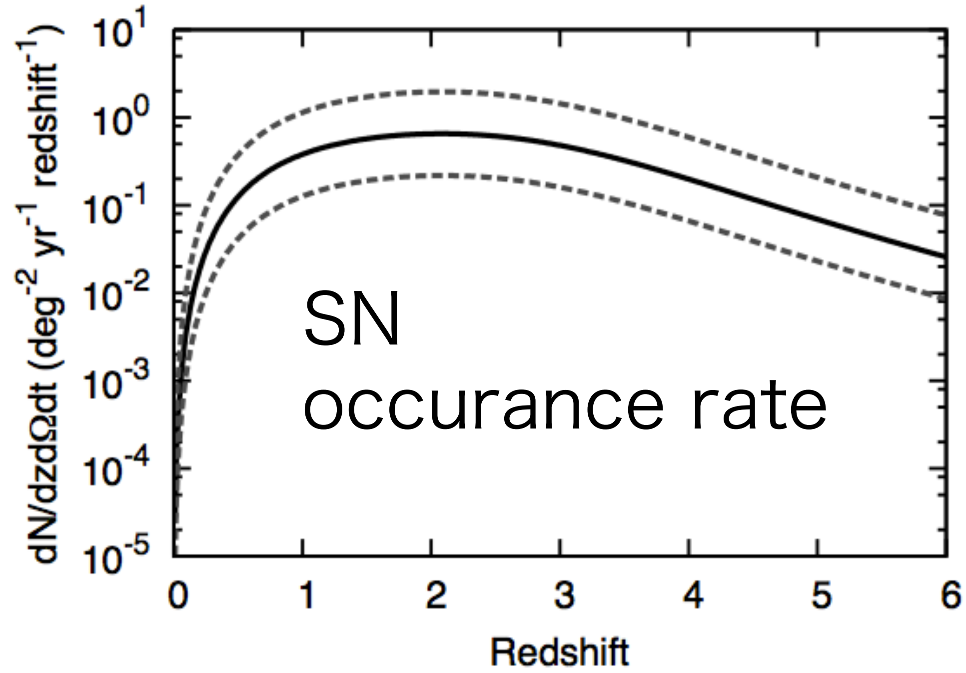


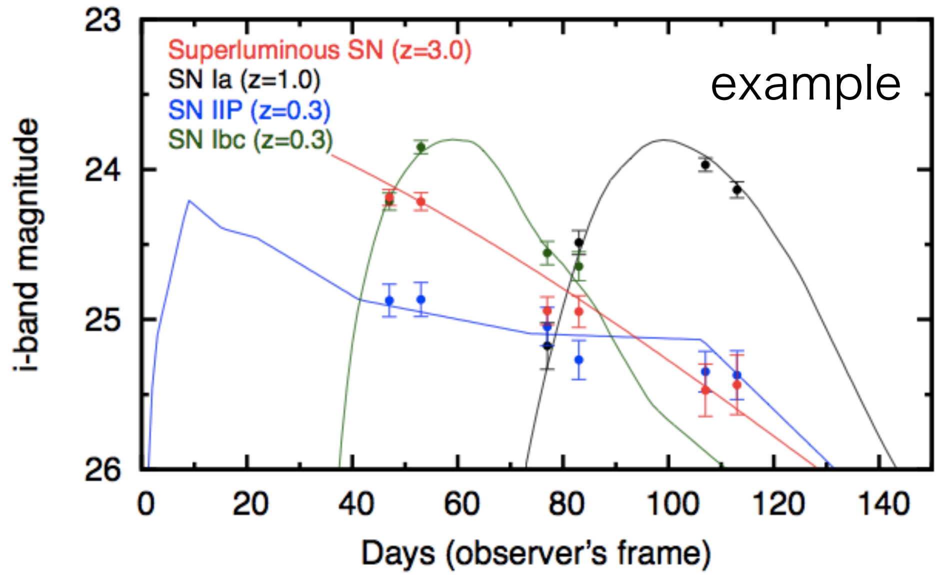
Best model:

E = 10^{52} erg, ejecta mass = 20 M_{sun}

Model SED and LC







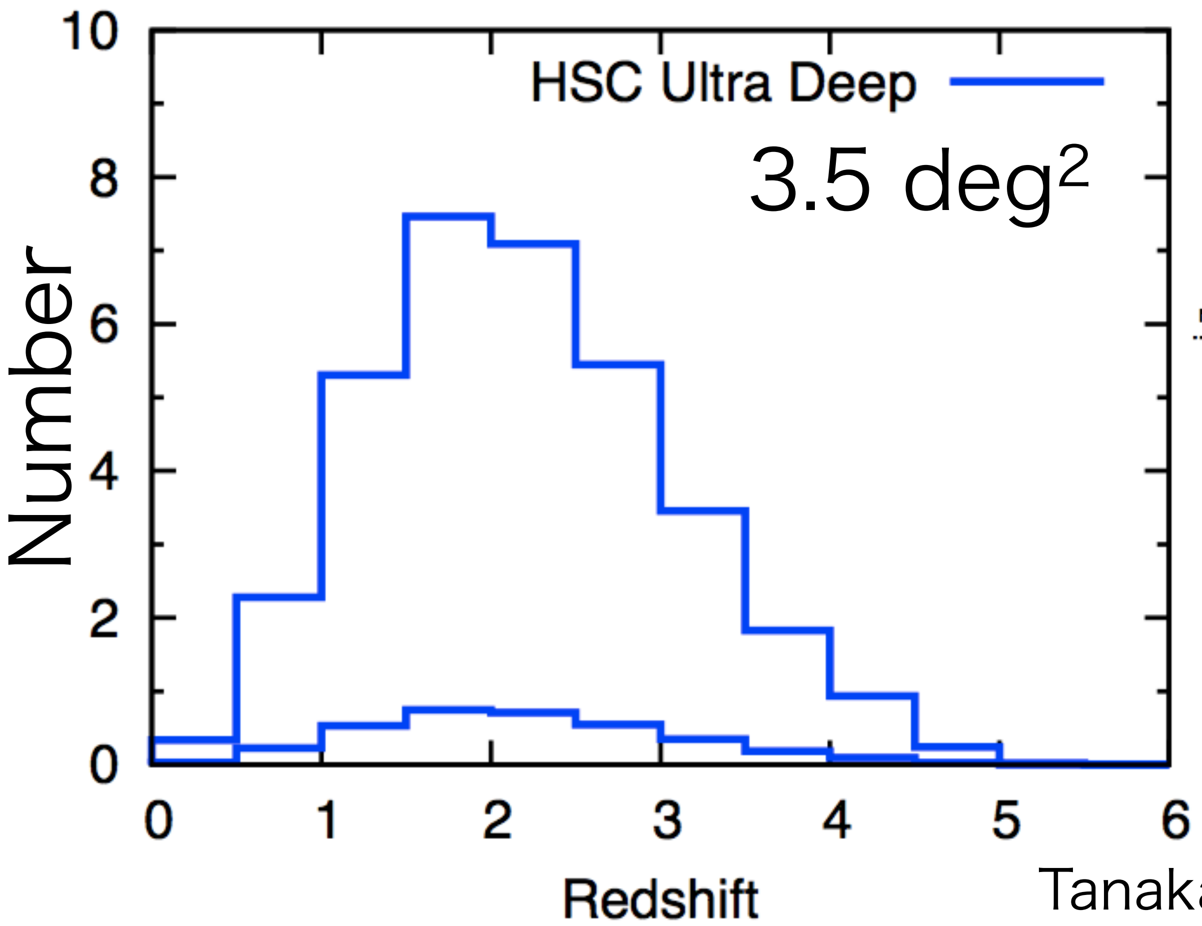
Monte Carlo light curve

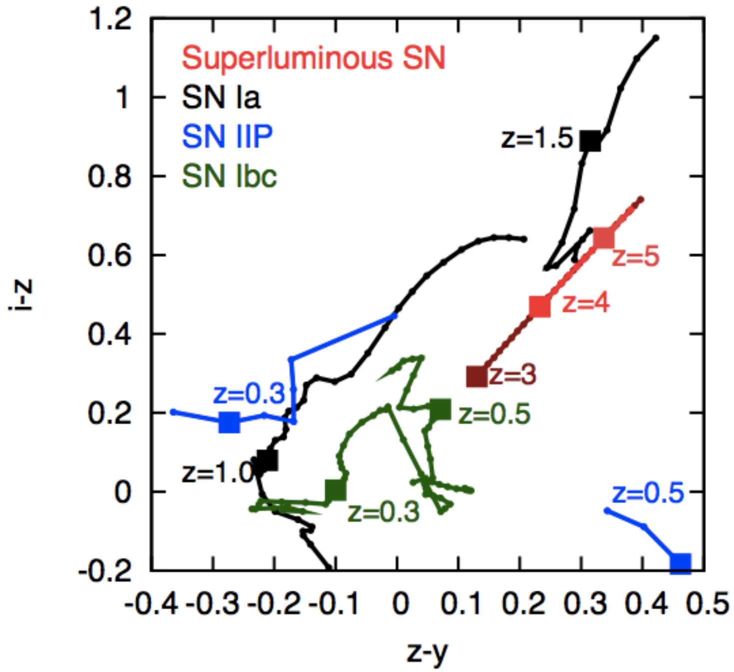
+ photometric errors

Distinguished from low-z SN

Subaru-HSC 2012-

	Area (deg^2)	Δt (day)	n_1	n_2	Limiting magnitude* m_g	m_r	m_i	m_z	m_y
Subaru/HSC Deep	30	6	2	3	26.1	25.8	25.6	24.5	23.2
Subaru/HSC Ultra Deep	3.5	6	3	4	26.9	26.6	26.6	25.6	24.3

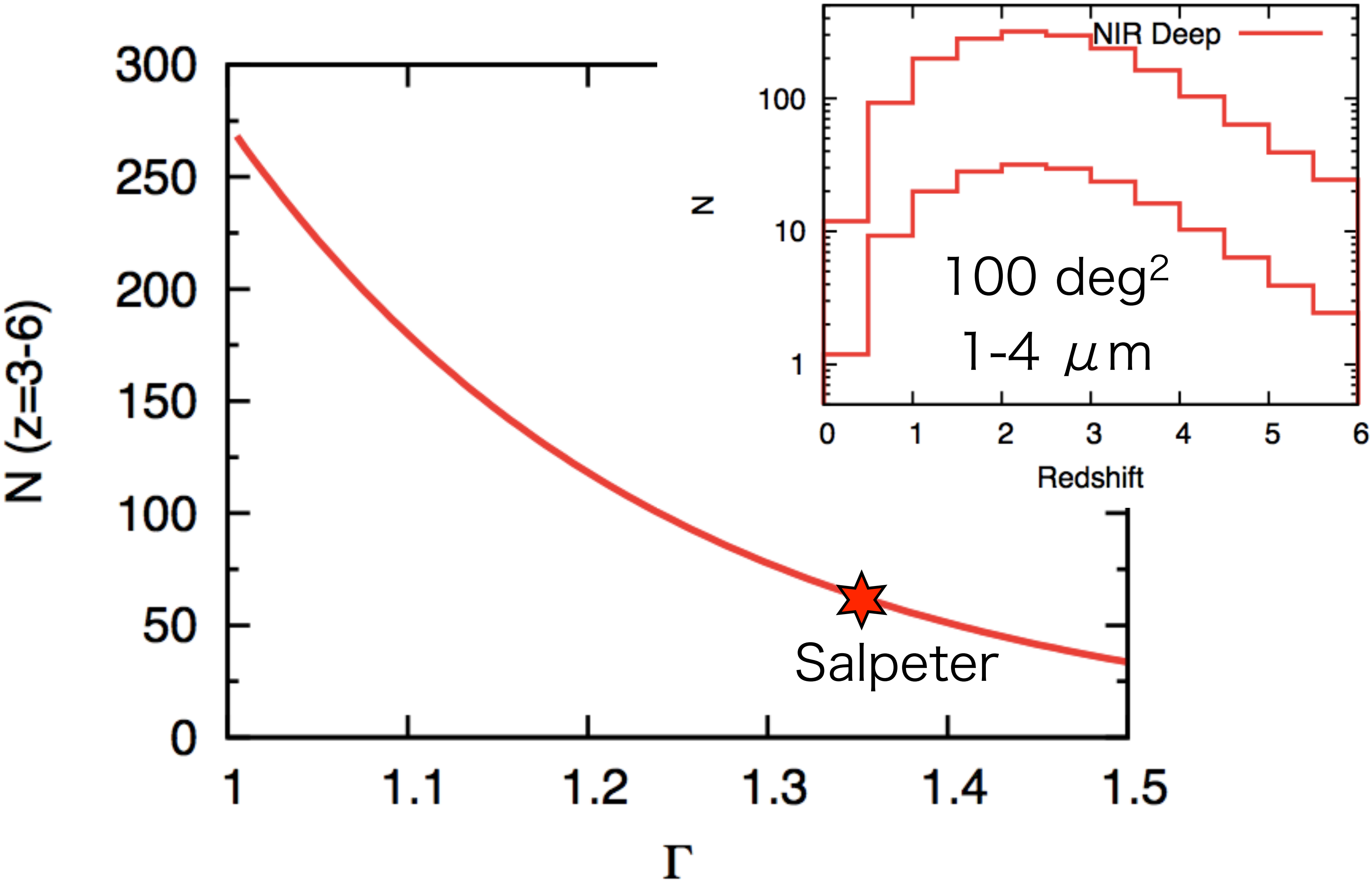




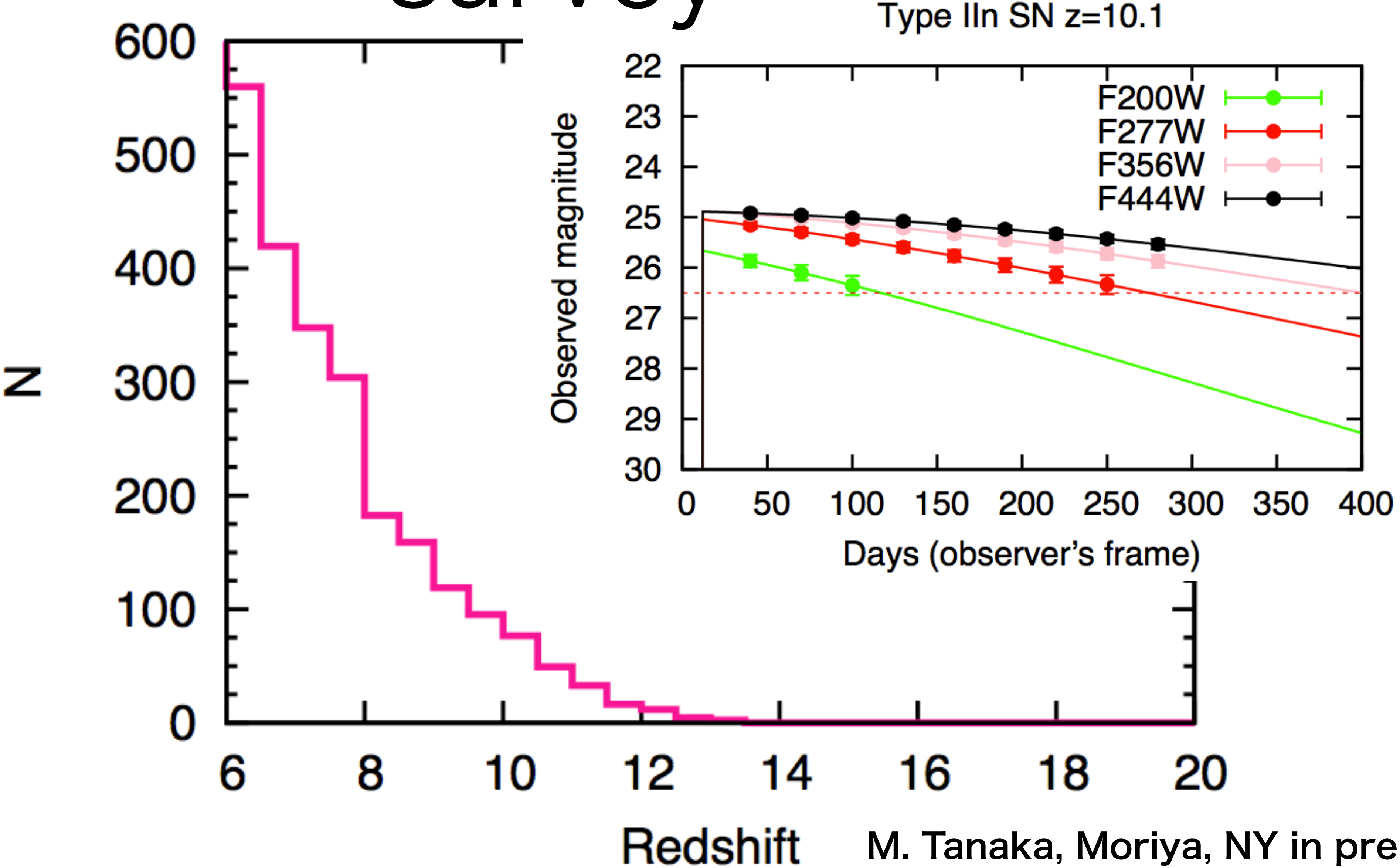
color selection

Tanaka, Moriya, NY, Nomoto, 2012

IMF by NIR survey

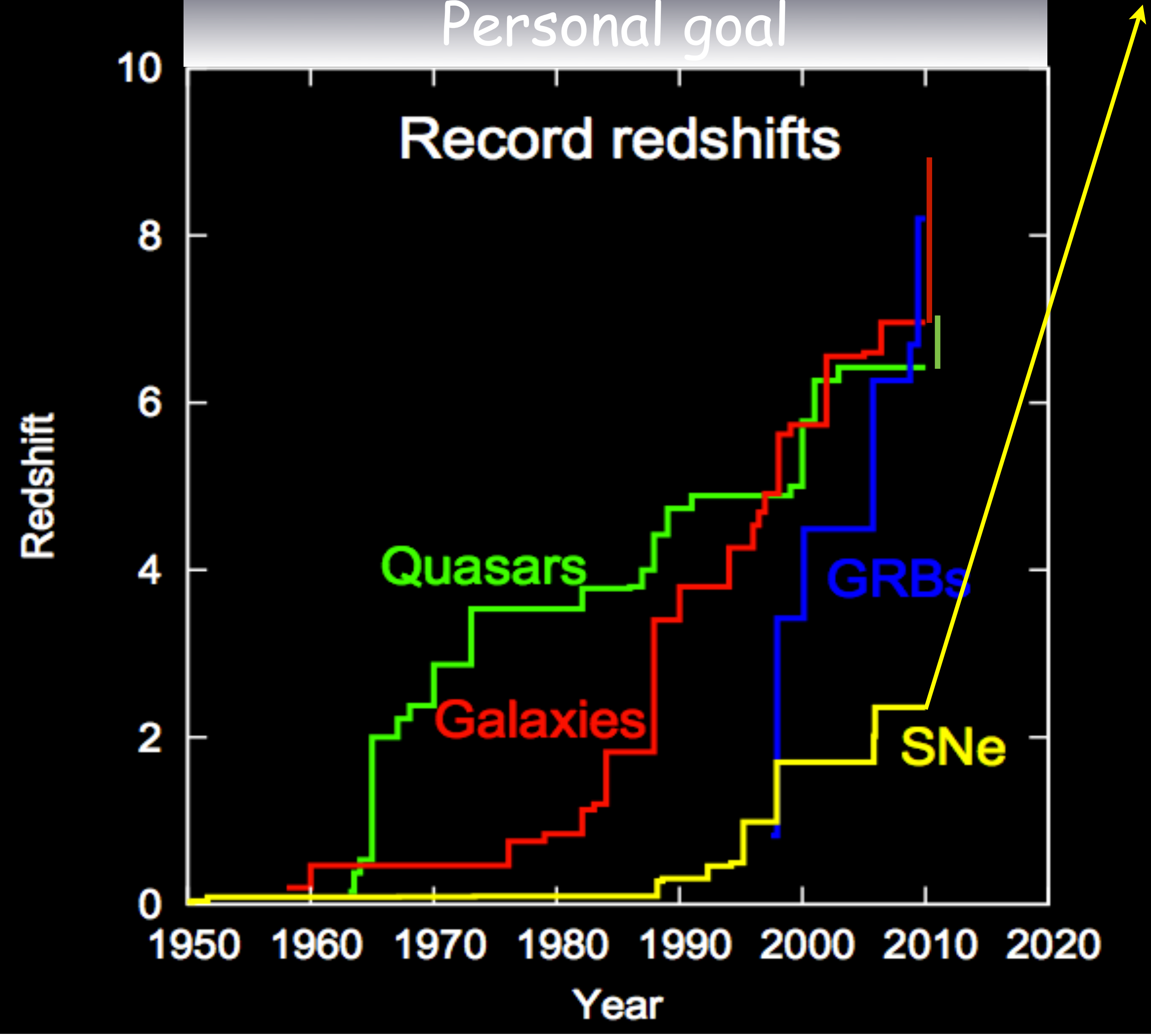


All-sky near-infrared survey



M. Tanaka, Moriya, NY in prep

Personal goal



Summary

- Primordial stars are massive, but mostly not extremely massive
- First supernova as a plausible mechanism for low-mass, low-metallicity star formation.
- Population III Gamma-ray bursts at z~10 detectable by future X-ray missions
- Early TypeIIn detectable to z~10