“Low-metallicity ISM”, Goettingen 2012

Star Formation in a low-metallicity gas

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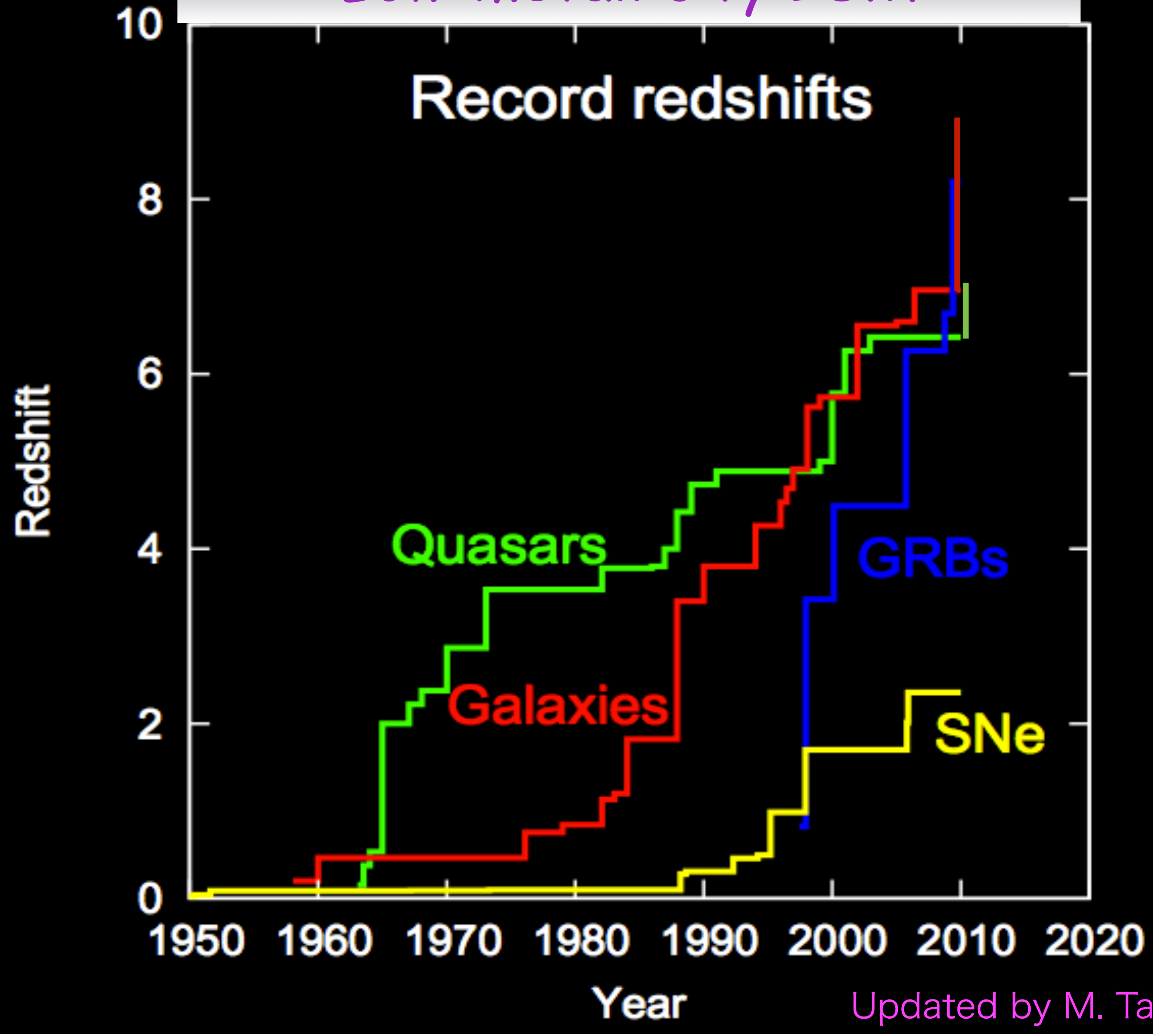
References:
Bromm & NY, 2011, Annual Review of Astronomy & Astrophysics
Hosokawa, Omukai, NY, Yorke, 2011, Science, 2011
Greif, Bromm, Clark, Glover, Klessen, NY, Springel, 2012, MN
Tanaka, Moriya, NY, Nomoto, 2012, MN
Hosokawa, NY, Omukai, Yorke, 2012, ApJL in press
Chiaki, NY, Kitayama, 2012 arxiv:1203.0820 (Talk by Chiaki)

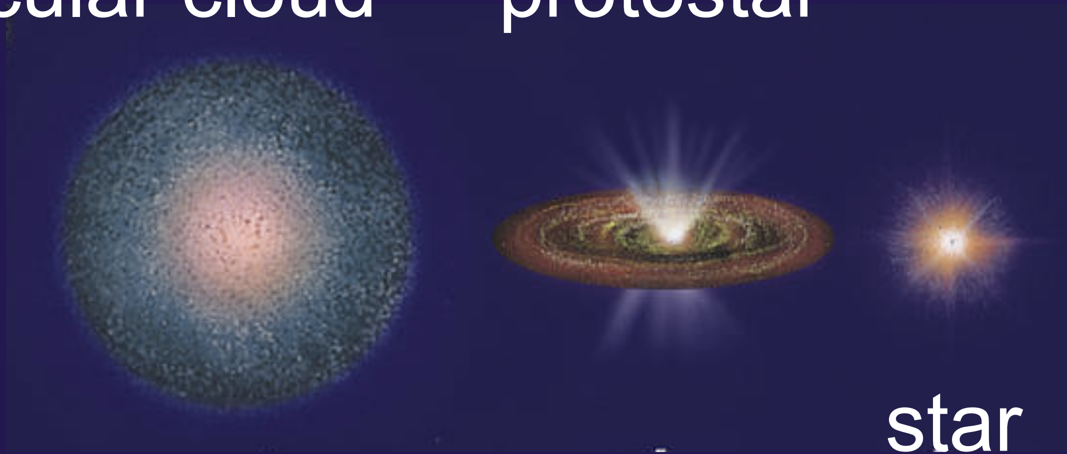
Low-metallicity ISM



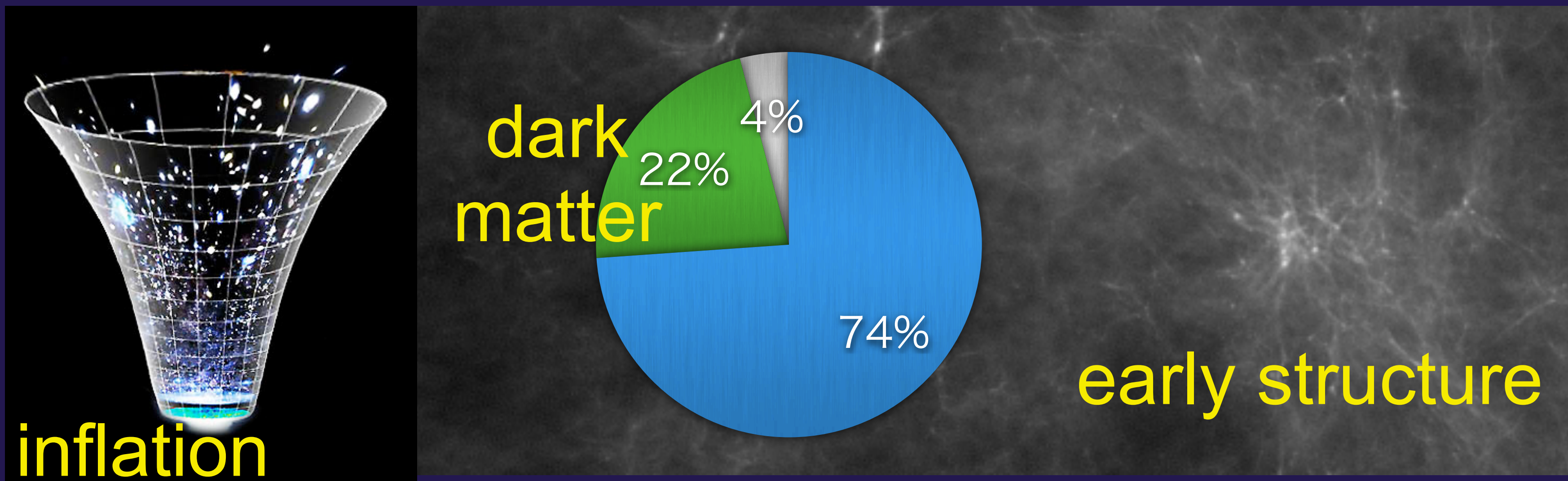
Updated by M. Tanaka

Theory

THEORY OF STAR FORMATION

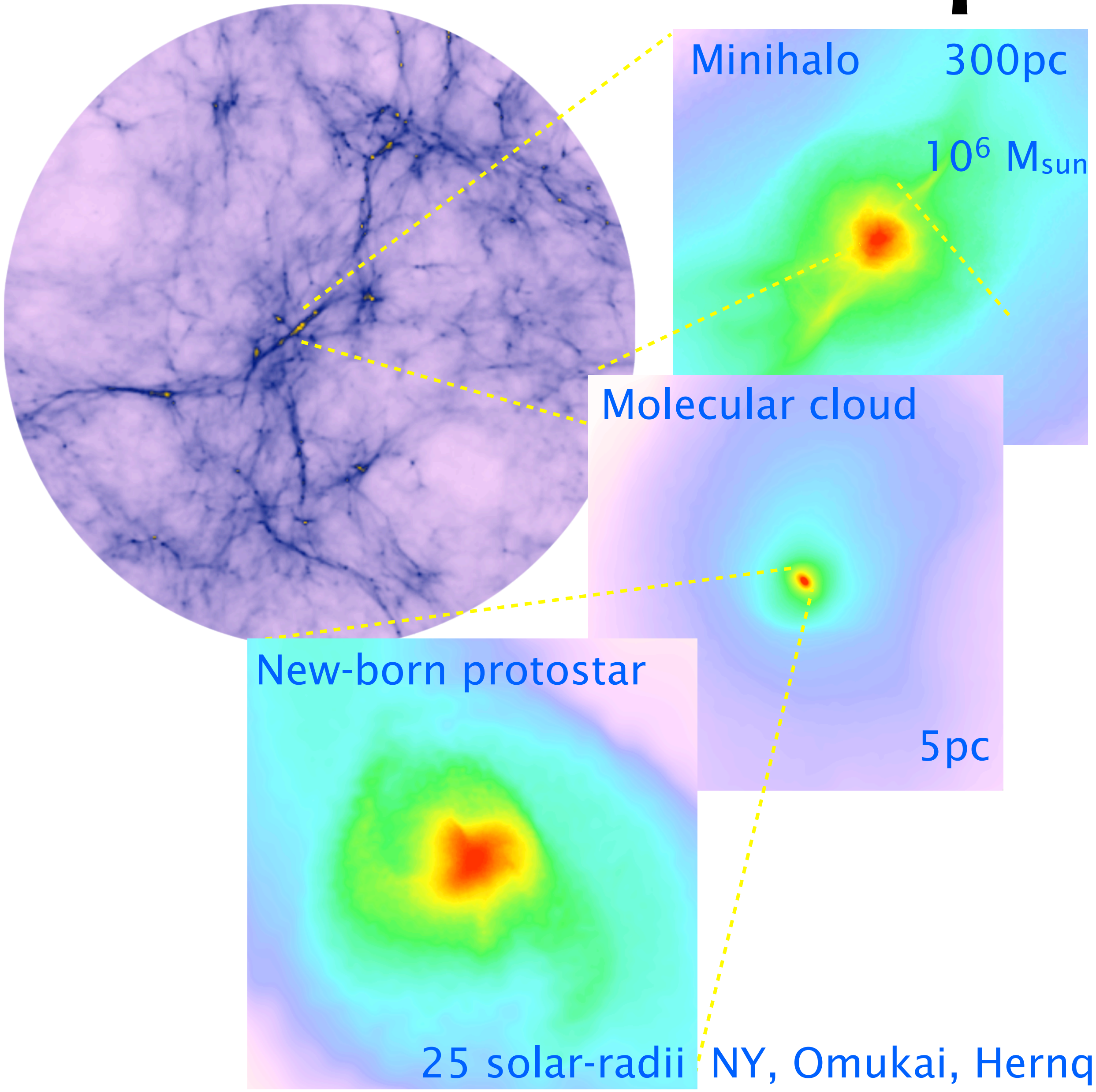


STANDARD COSMOLOGICAL MODEL



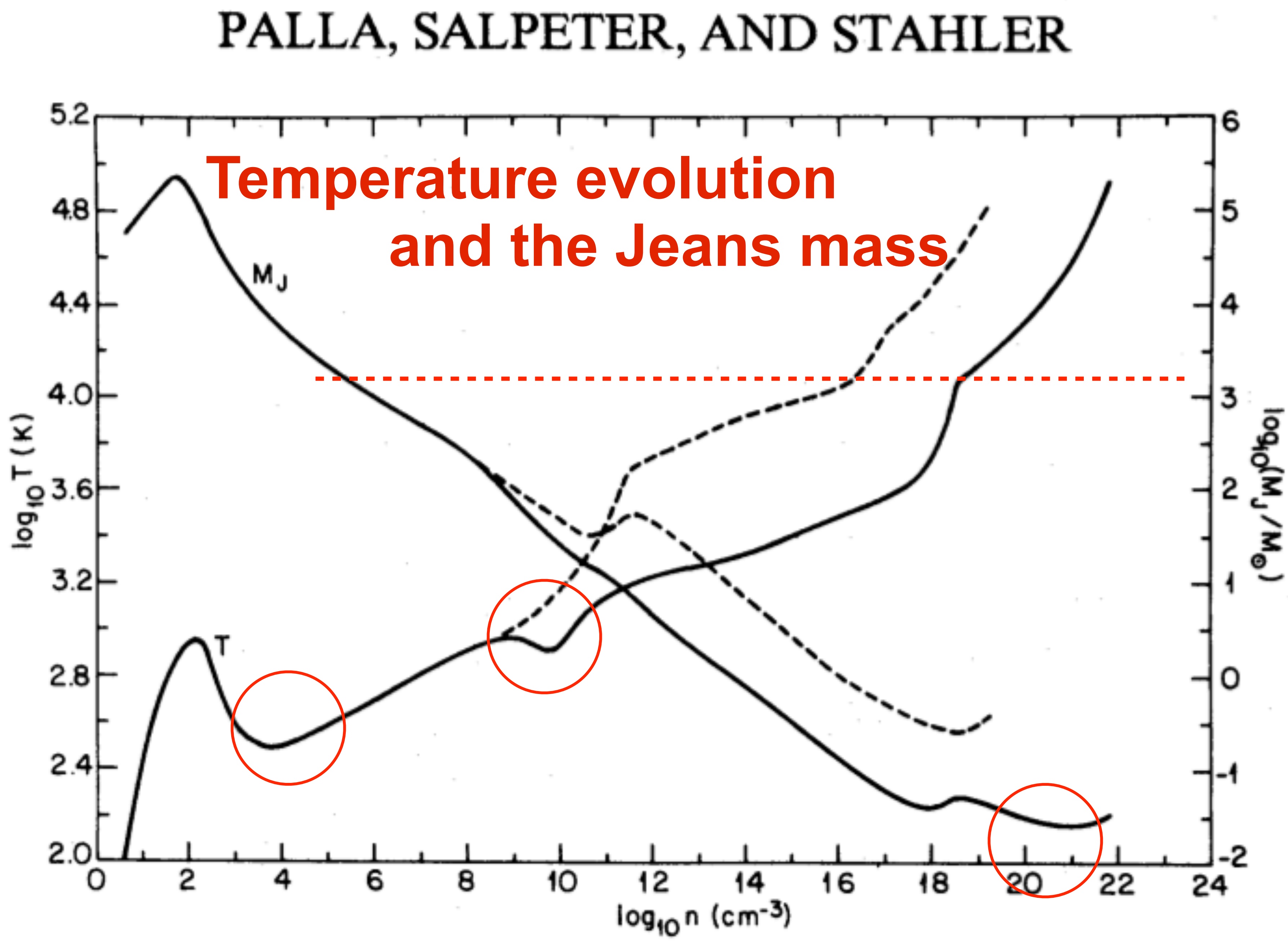
Simple physical state in the early universe

From primeval ripples to a protostar



cosmic web
↓
dark matter minihalo
↓
molecular cloud
↓
cloud core
↓
protostar

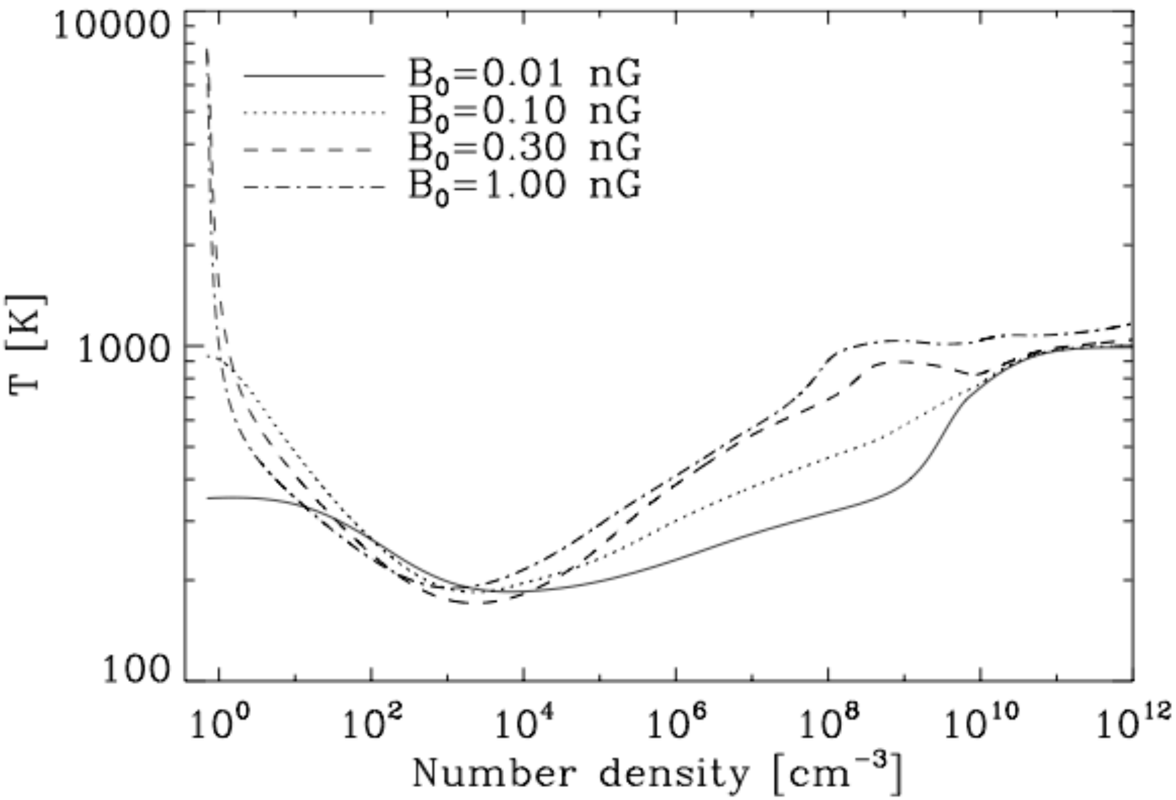
NY, Omukai, Hernquist 2008, Science



PSS83; Omukai 2001

Effect of primordial B

Schleicher+09



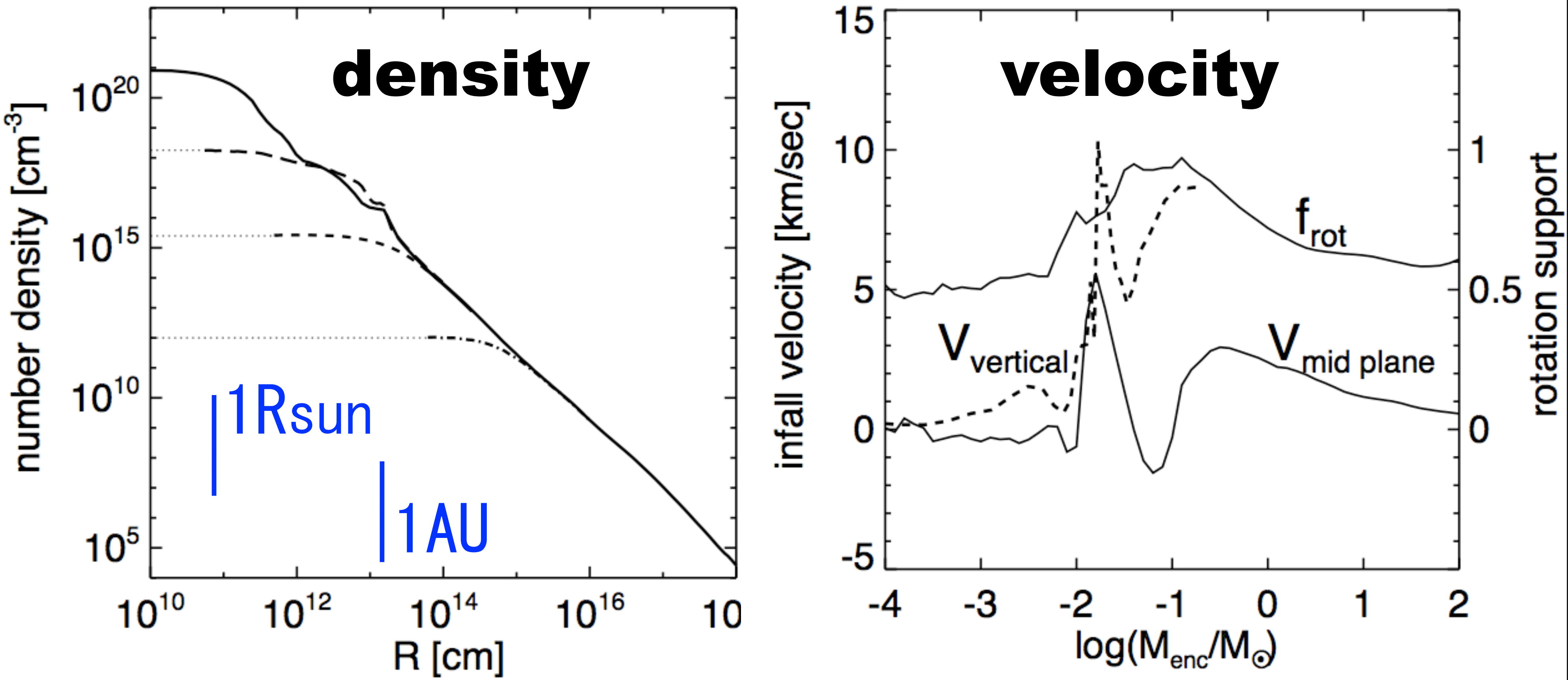
Thermal evolution
at low-densities affected.

Also the magnetic
Jeans mass becomes
larger than minihalo mass:

$$M_J^B = 10^{10} M_\odot \left(\frac{B_0}{3\ nG} \right)^3 ;$$

Influence on PopIII.2 stars.

Pre-collapse phase

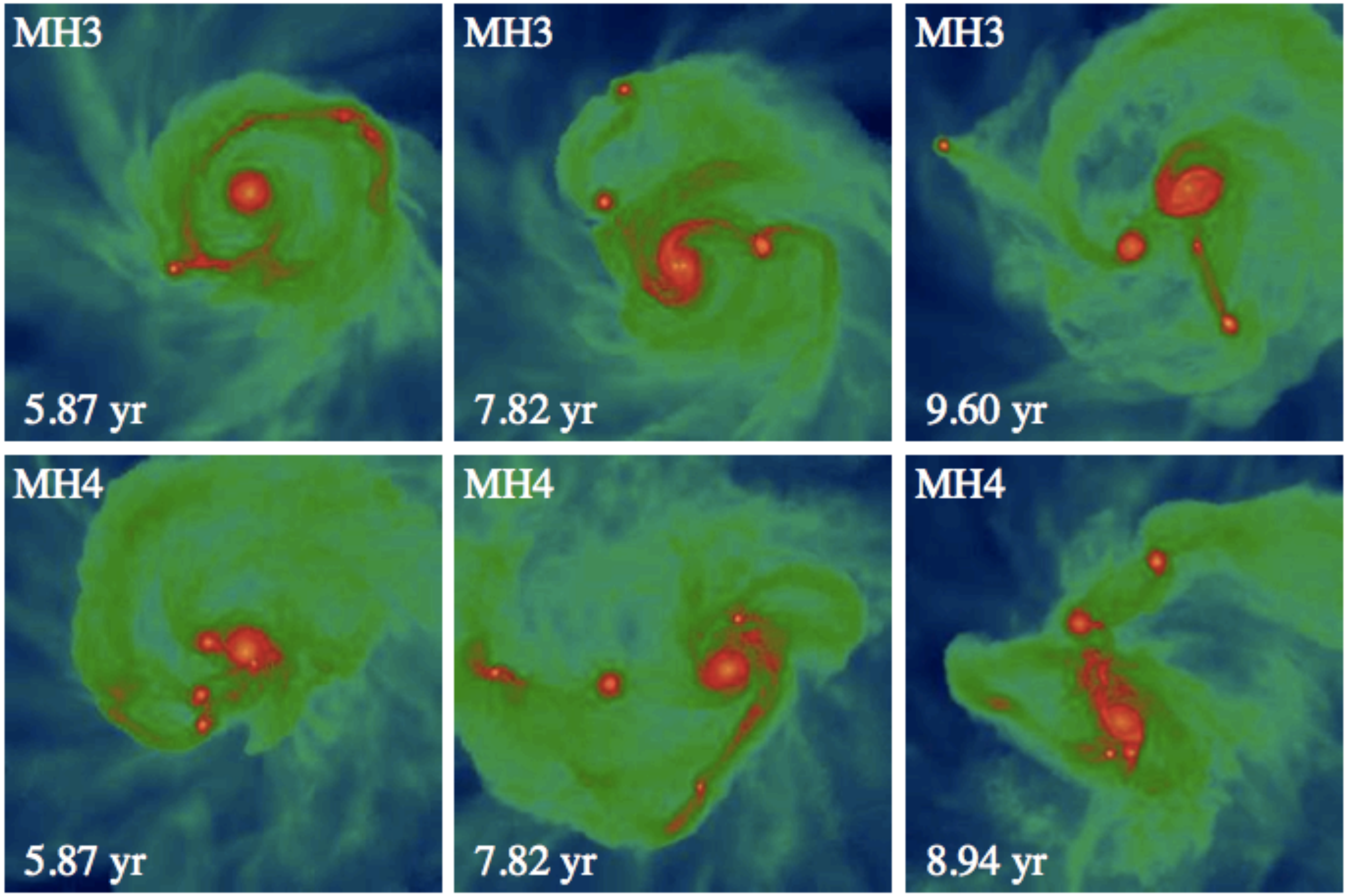


The mass of the new-born protostar ~ 0.01 M_{sun}

Dark matter plays little role
after run-away collapse (unless DM annihilates; Smith+12)

Recent simulations

Early evolution



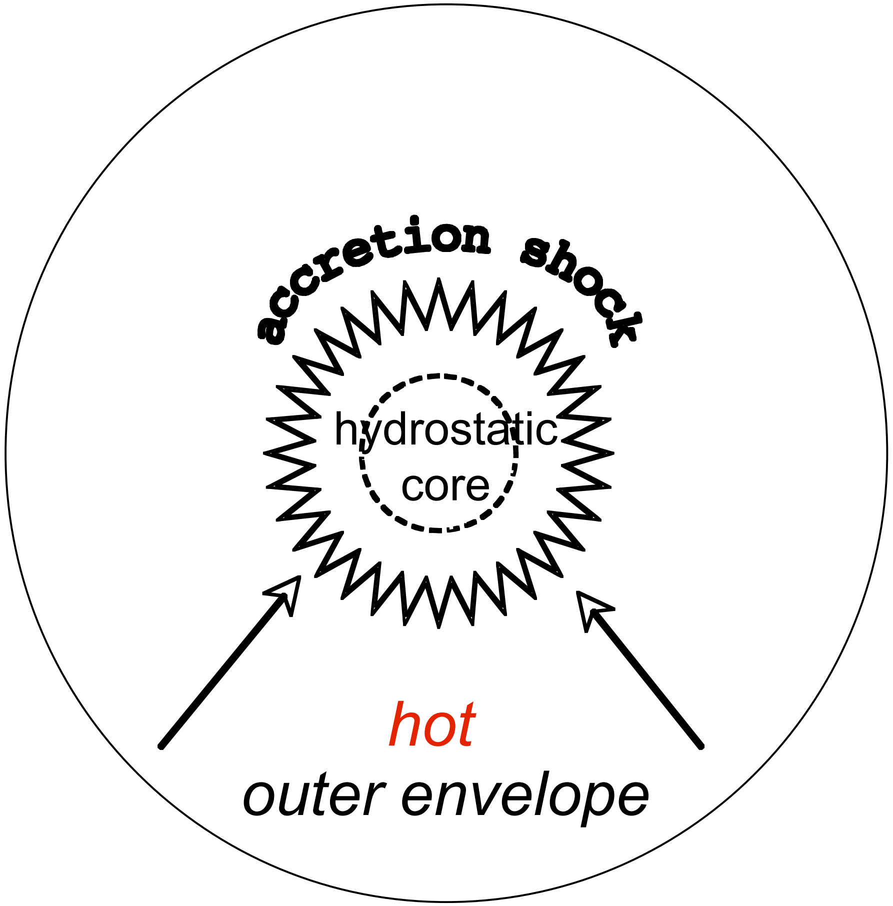
Small fragments are merged onto the central protostar on an orbital time scale

"Gravo-viscous accretion"

Greif, Bromm, Clark, Glover, Smith, Klessen, NY, Springel, 2012

Hyper-accreting protostar

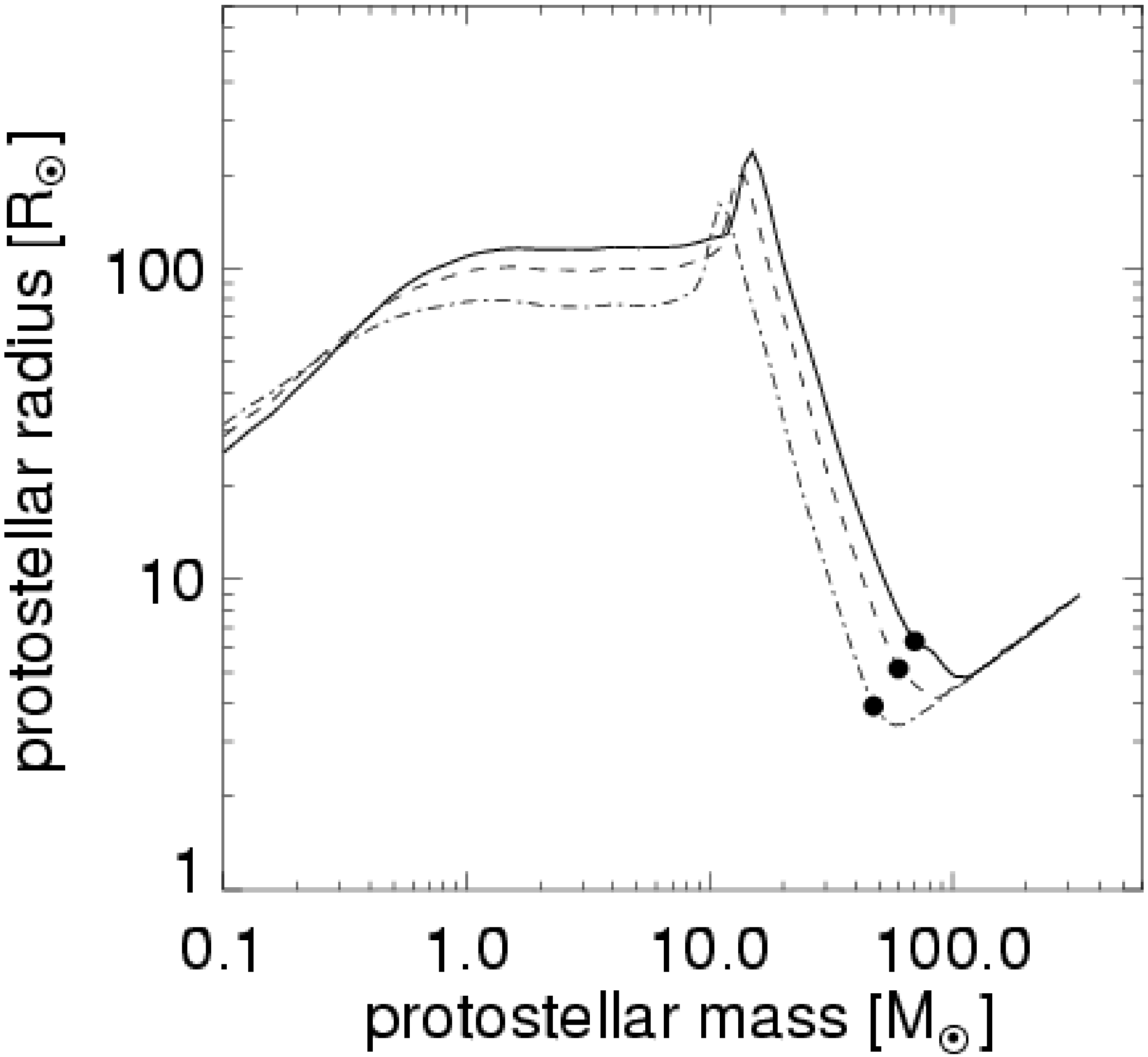
A “classic” picture



The central protostar accretes the surrounding gas at a very large rate:

$$dM/dt \propto T^{1.5}/G$$
$$= 0.01\text{-}0.1\ M_{sun}/\mathrm{yr}$$

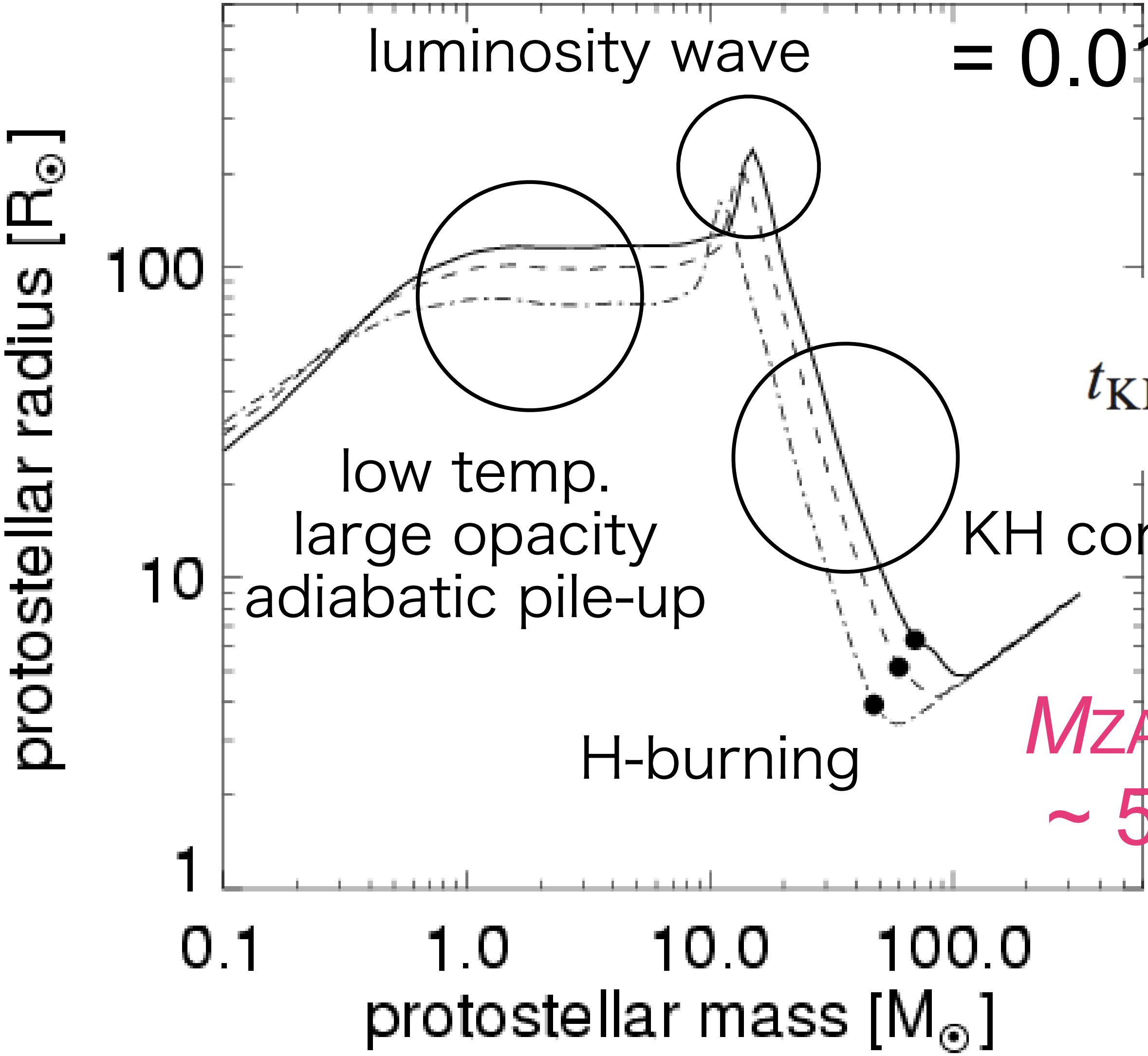
Protostellar evolution



Omukai & Palla 2003; NY, Omukai, Hernquist, Abel 2006

Protostellar evolution

dM/dt = 0.01-0.1 *M*sun/yr



$$t_{\rm KH} = \frac{GM_*^2}{R_* L_*} \propto \frac{1}{M_* R_*}$$

*M*ZAMS ~ 50-100 *M*sun

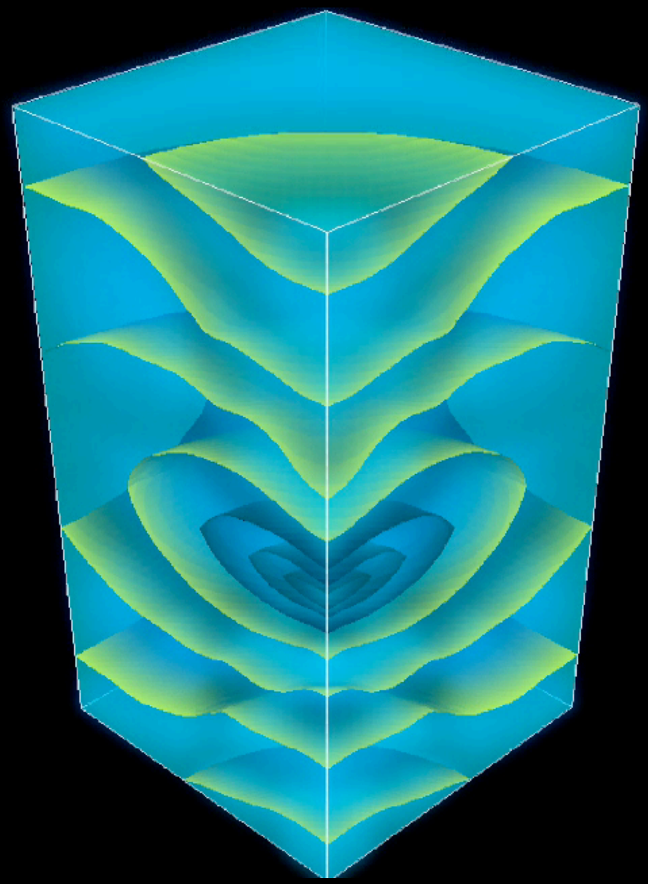
NY+2006

Protostars grow through gas accretion, mergers, plus, protostellar feedback over ~ 100,000 years

The Key Question

How and when does a first star stop growing ?

Protostellar evolution to main-sequence



H_{II} region break-out

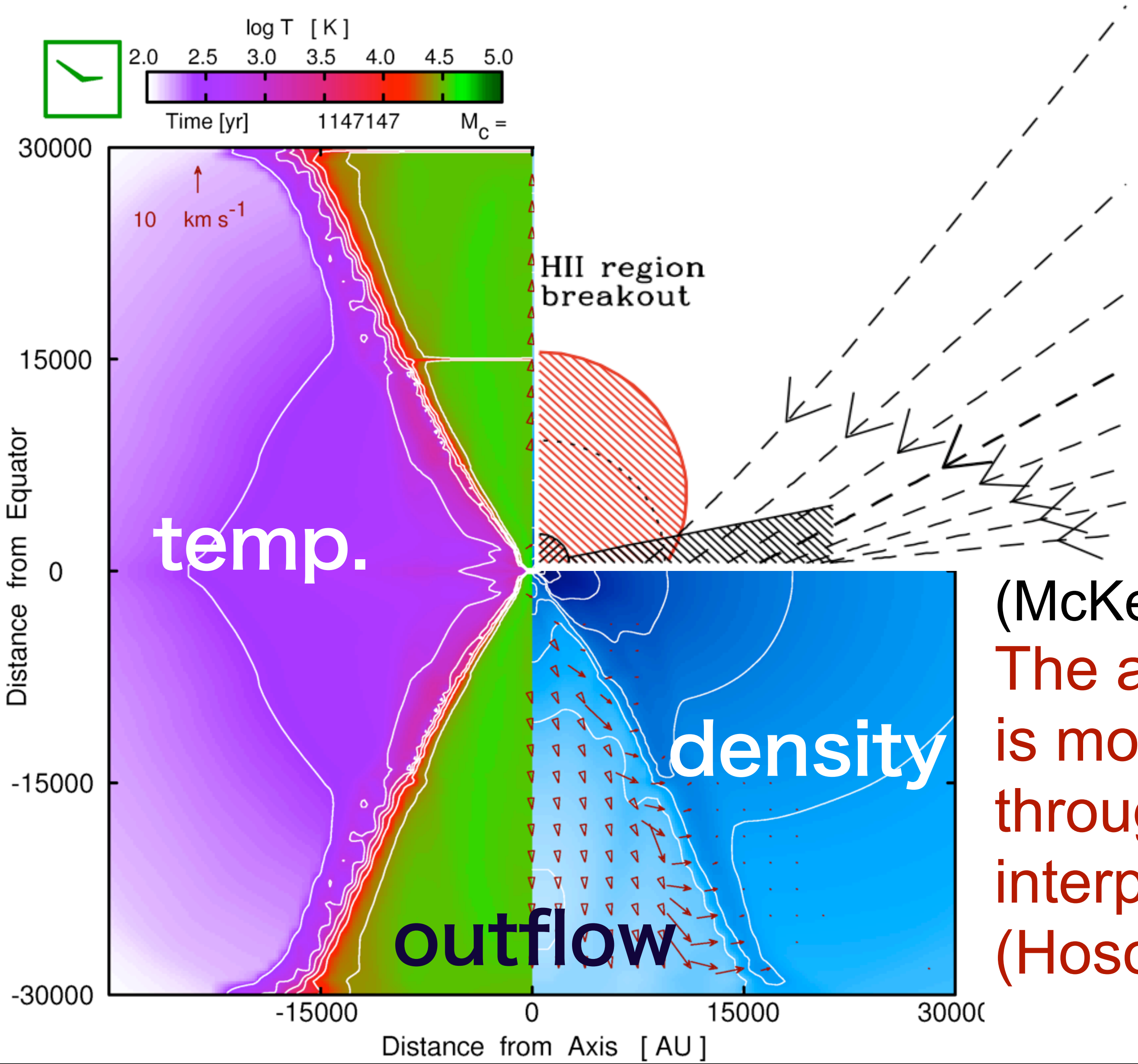
Radiation-hydro. calculation by T. Hosokawa.

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.

Pressure-driven outflow

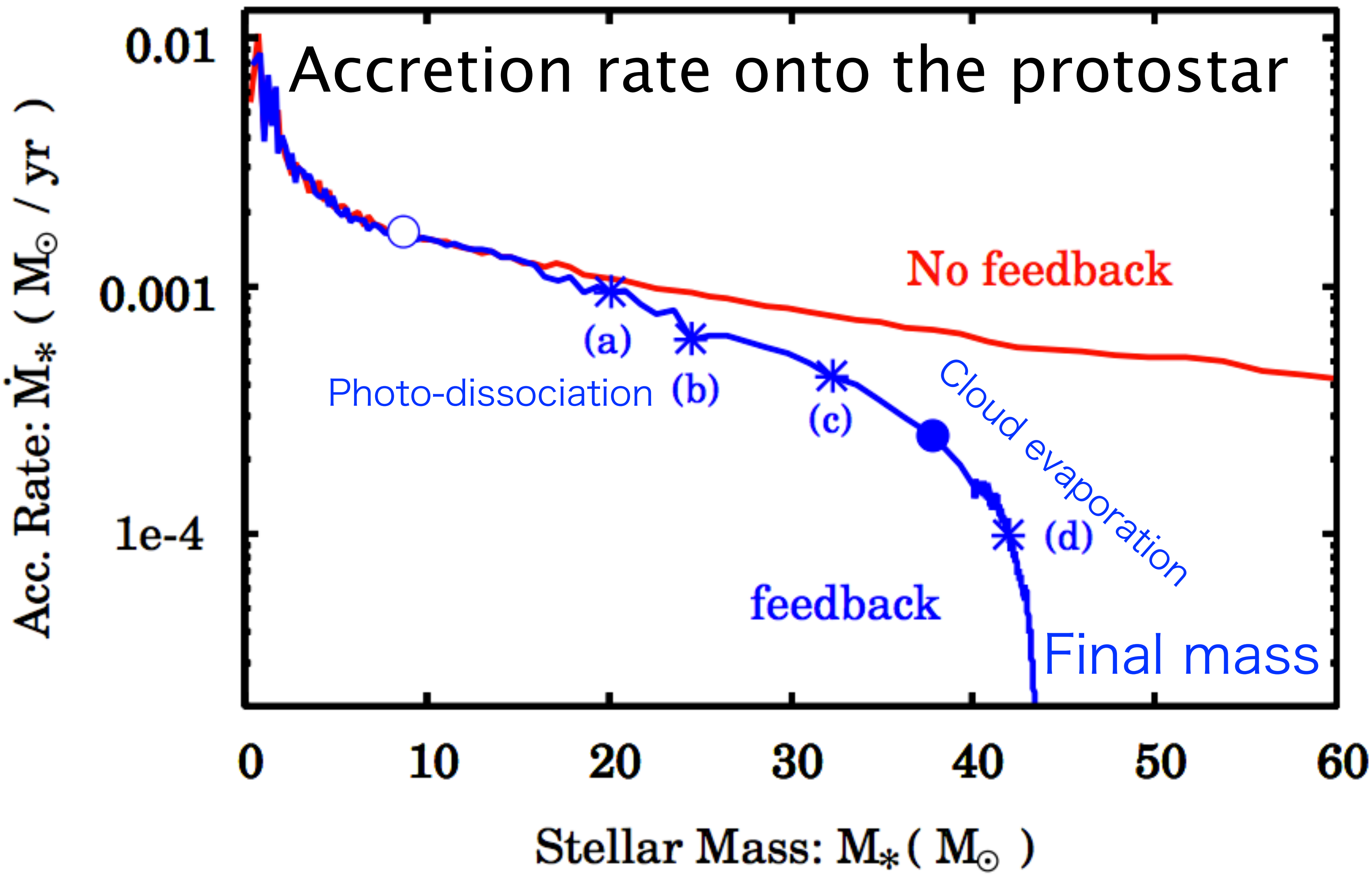


Disk ablation.
(McKee-Tan 08)

The actual evolution is more dynamical through complex interplay.
(Hosokawa+11)

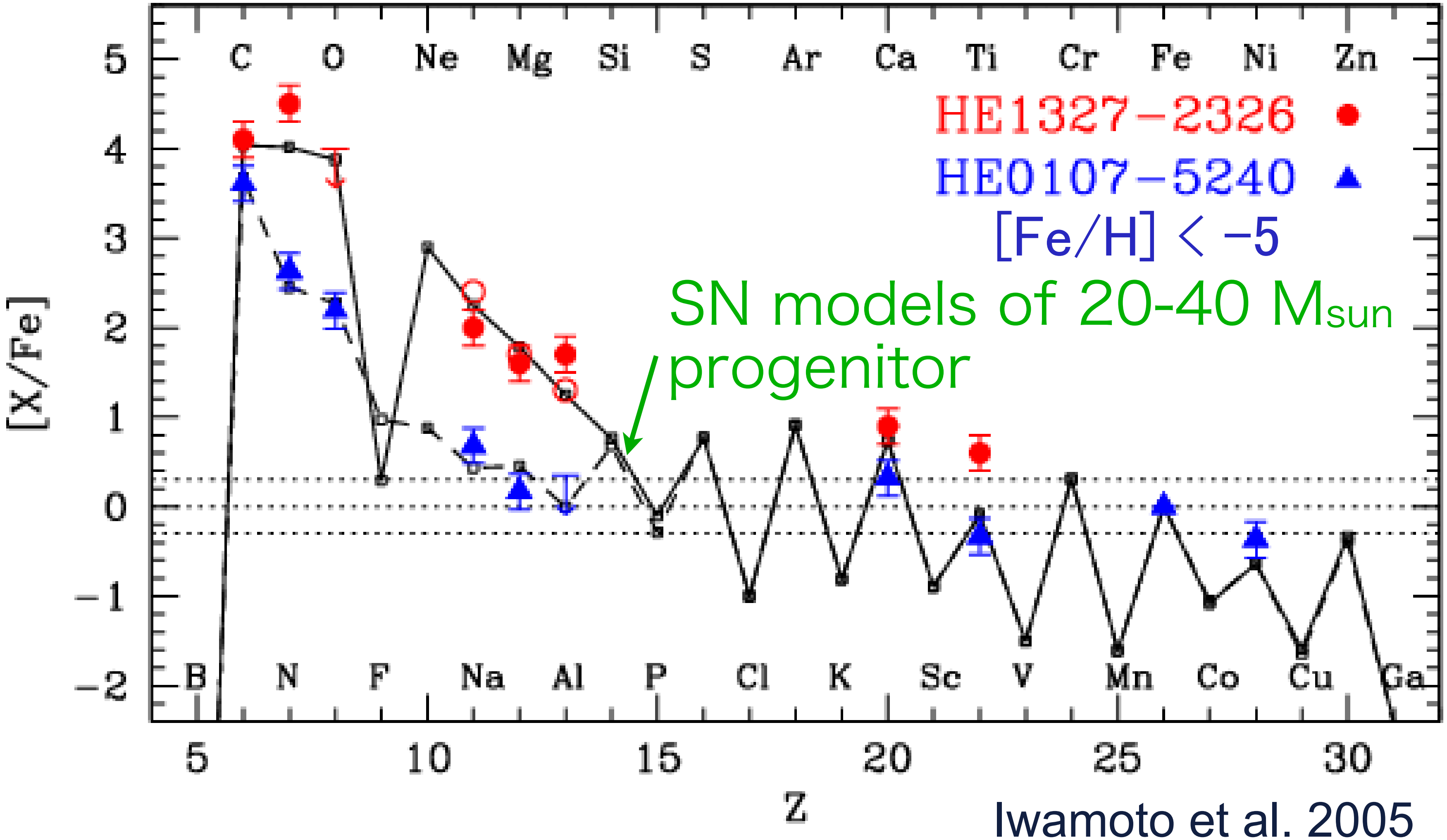
Accretion vs evaporation

Hosokawa, Omukai, NY, Yorke, 2011, Science



Long standing puzzle resolved

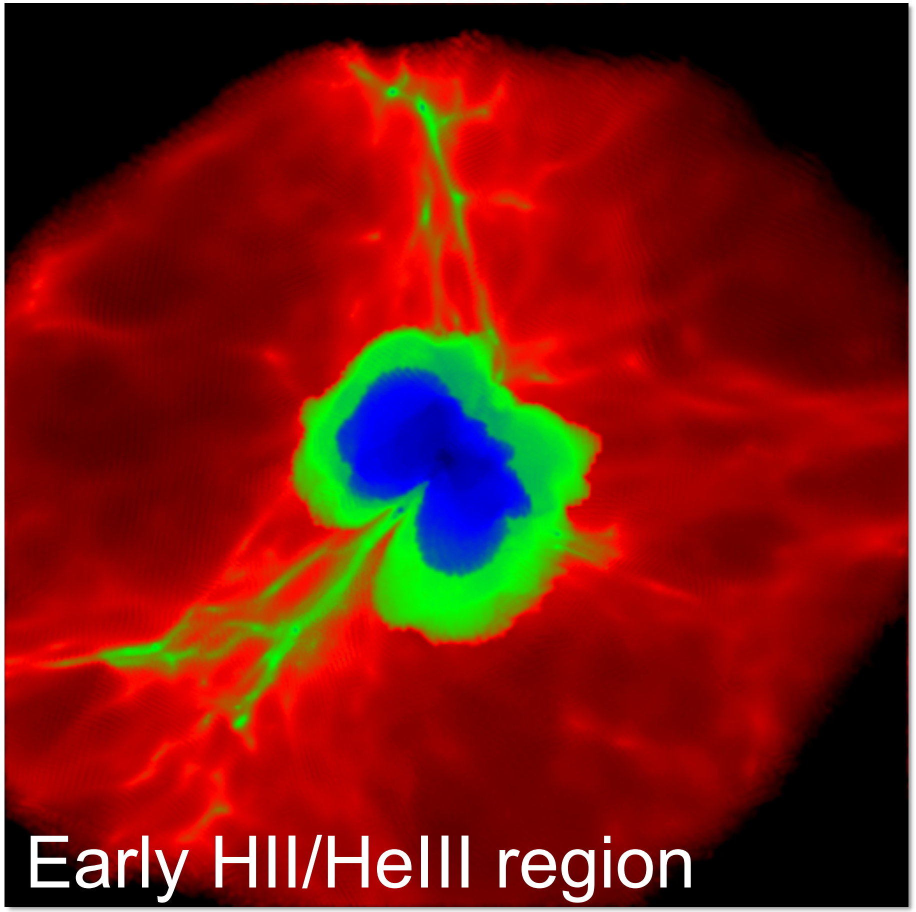
Observed elemental abundances



Iwamoto et al. 2005

PopIII.2 Stars

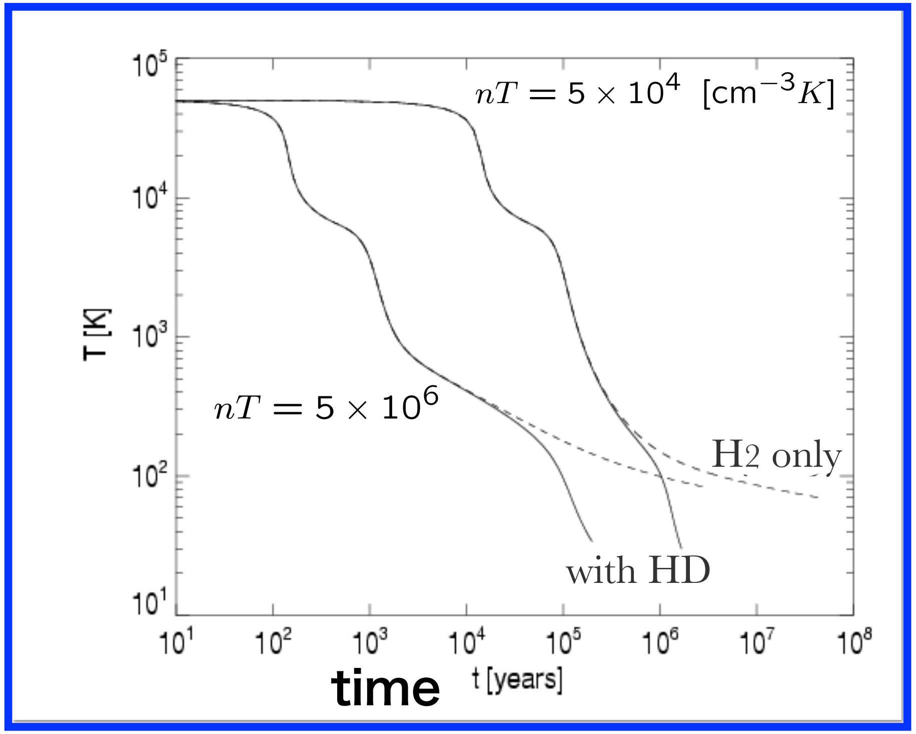
Stars formed in a pre-ionized gas



NY, Omukai, Hernquist 2007, ApJ

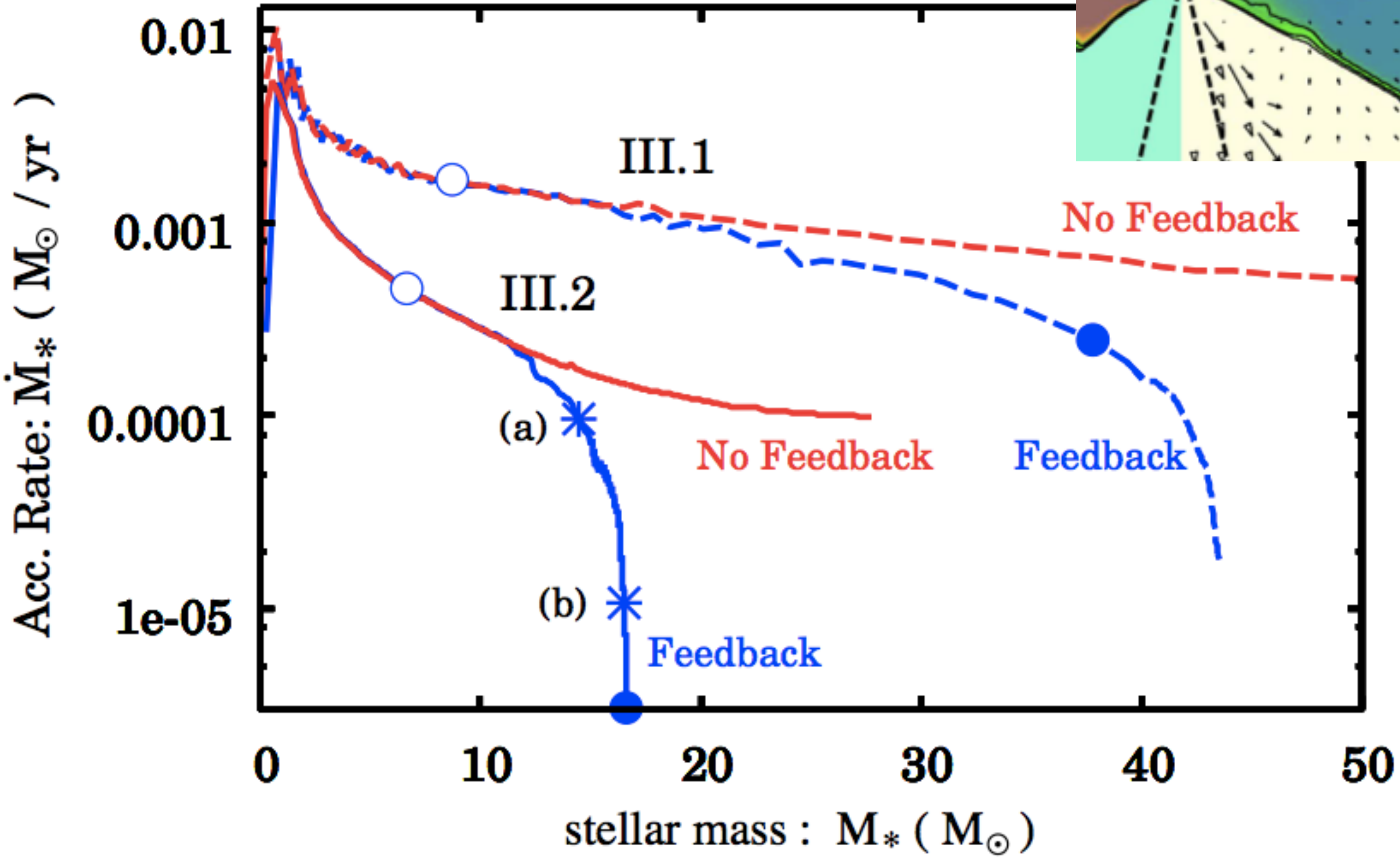
Johnson & Bromm 2006; McGreer & Bryan 2008

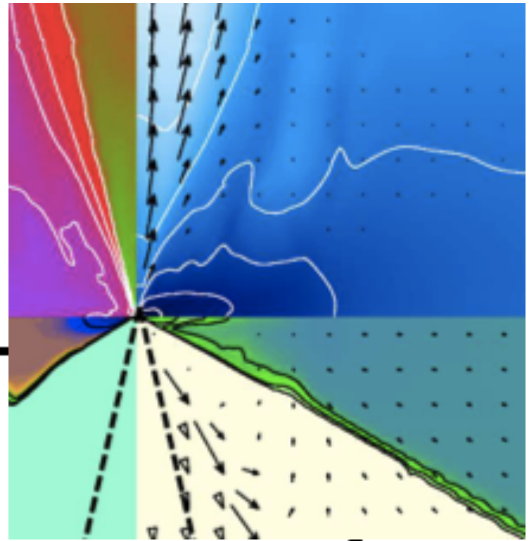
temperature evolution



Primordial stars formed by HD cooling are not very massive ~ 40*M*sun

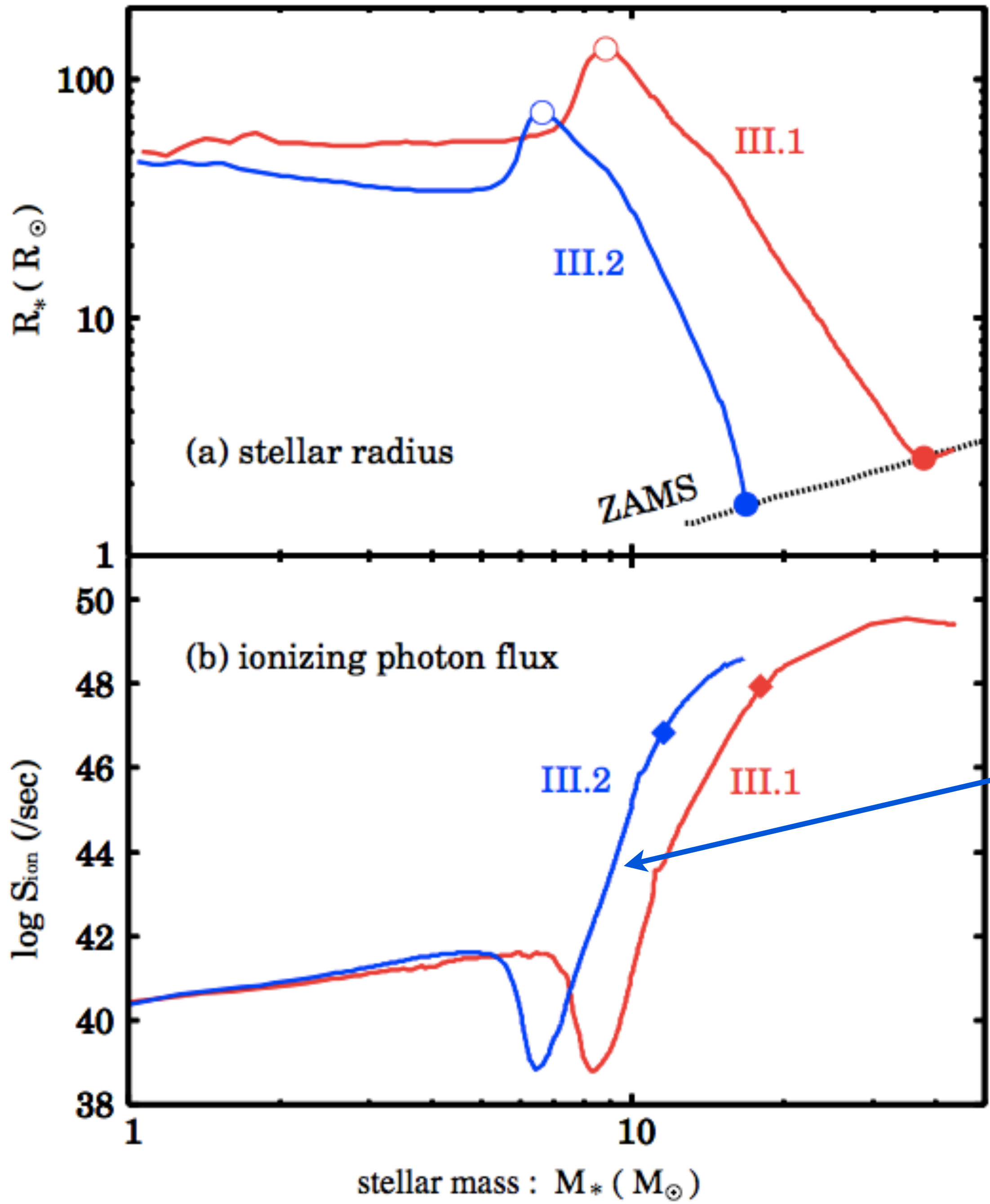
PopIII.2 Stars





Hosokawa, NY, Omukai, Yorke, ApJL in press

III.1 vs III.2

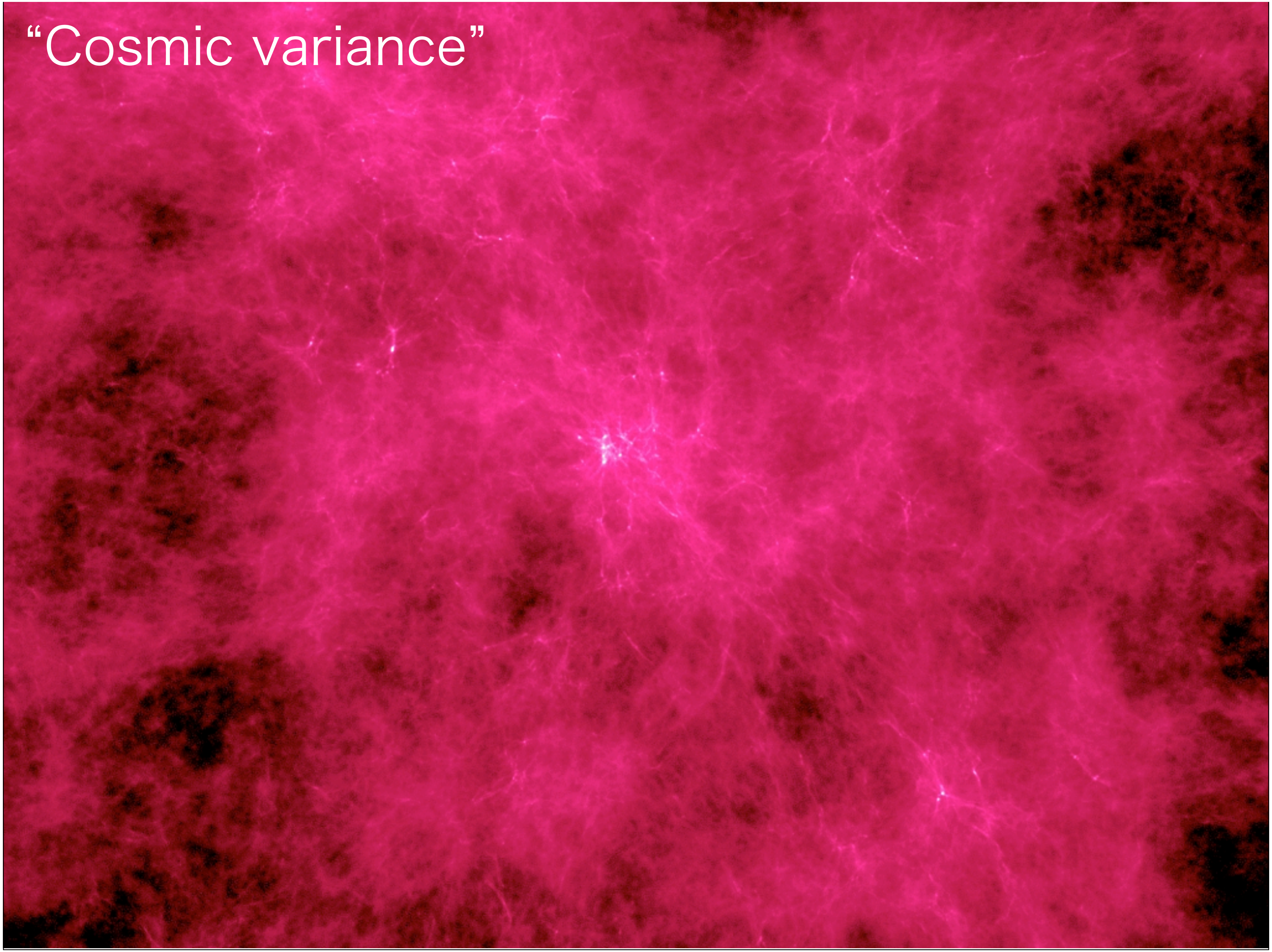


The initial accretion rate is smaller in III.2 (owing to HD cooling).

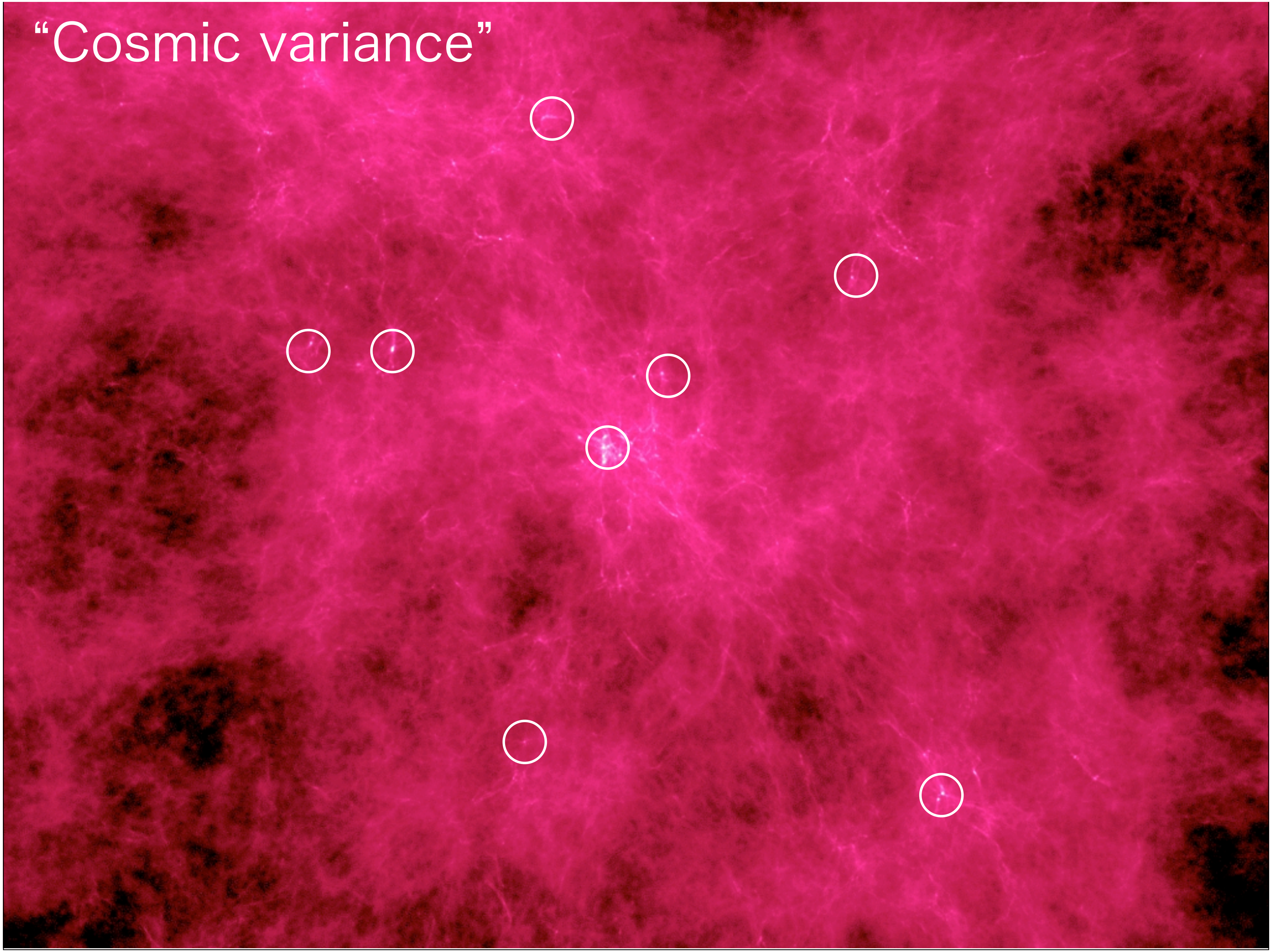
KH contraction begins earlier, at a small stellar mass. But ionizing luminosity increases quickly.
→ Growth halted early at M ~ 10 M_{sun}

Toward Primordial IMF

“Cosmic variance”



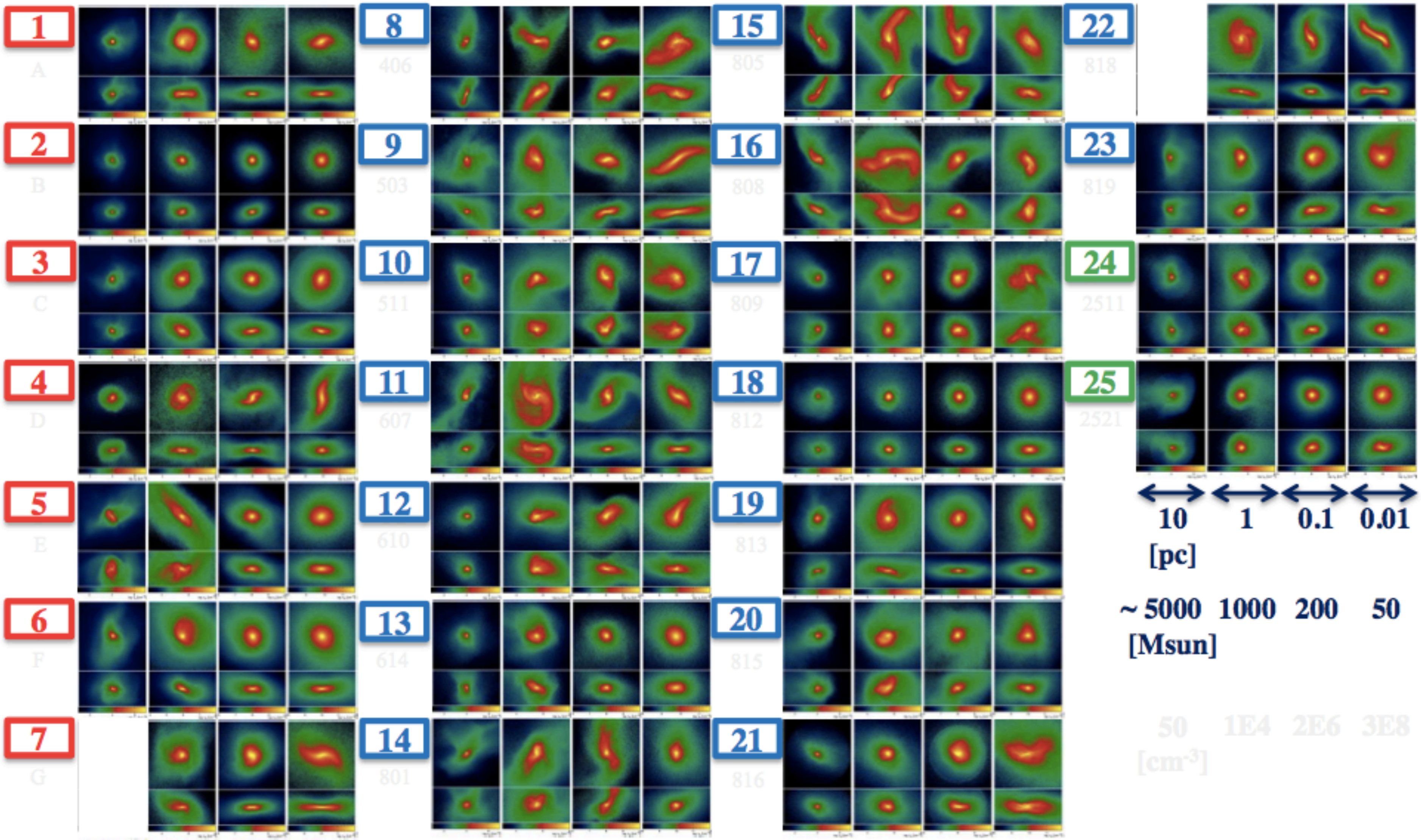
“Cosmic variance”



Toward Primordial IMF

A sample of gas clouds

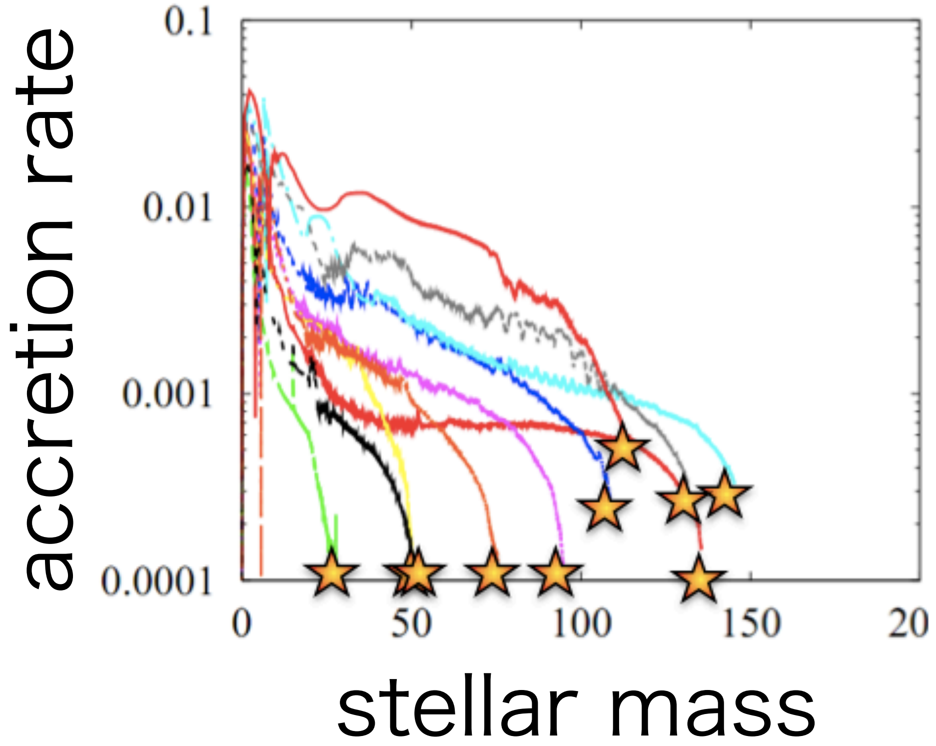
S. Hirano+ in prep.

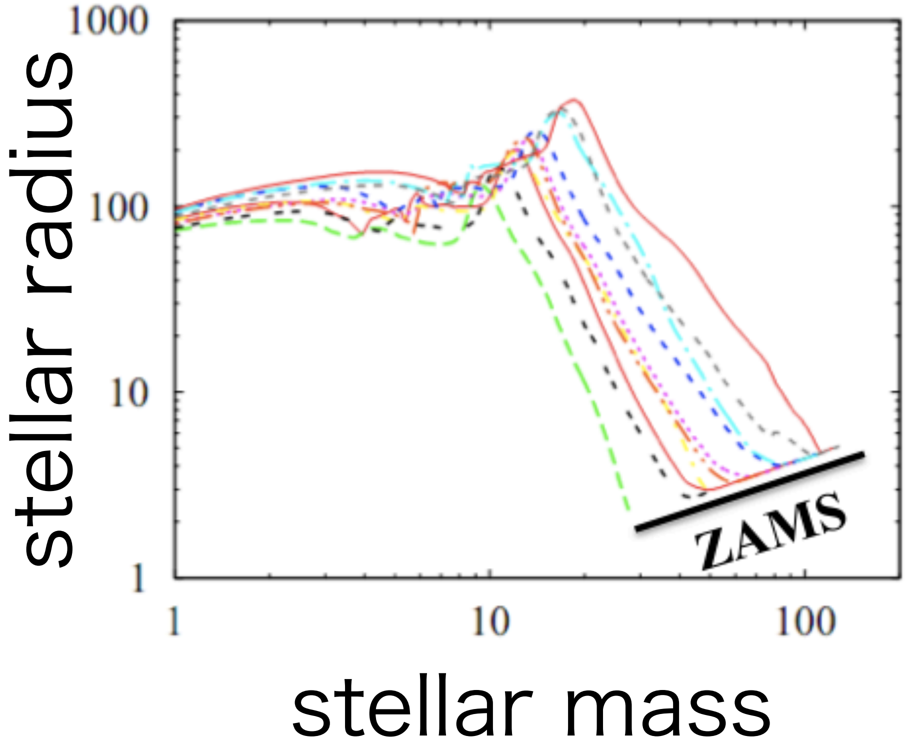


Mass distribution

- $M_{star,min}$ = 27.7 [M_{sun}]
- $M_{star,max}$ ~ 150 [M_{sun}]

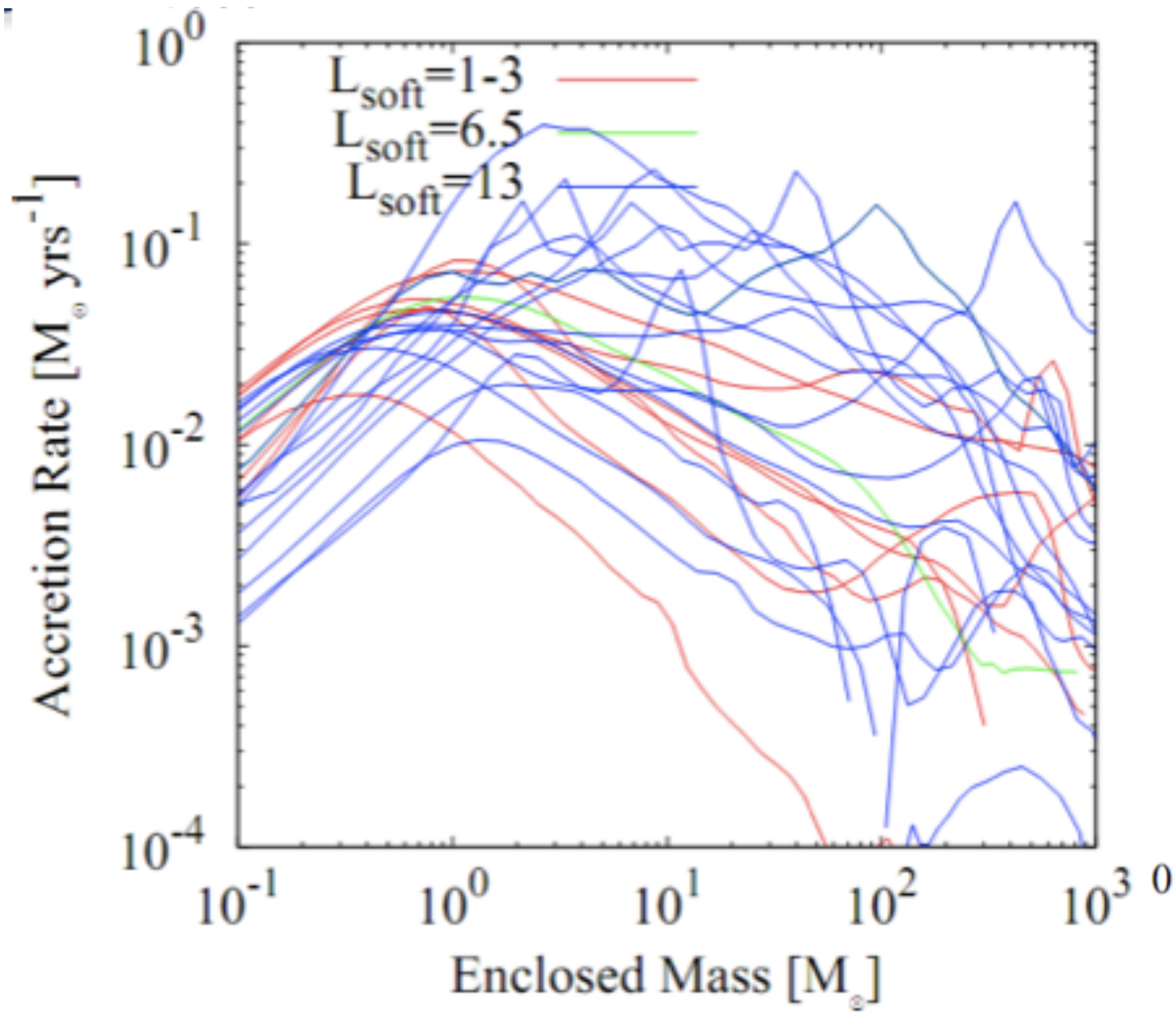
Overall evolution similar to our fiducial cases





S. Hirano+ in prep.

Preliminary results

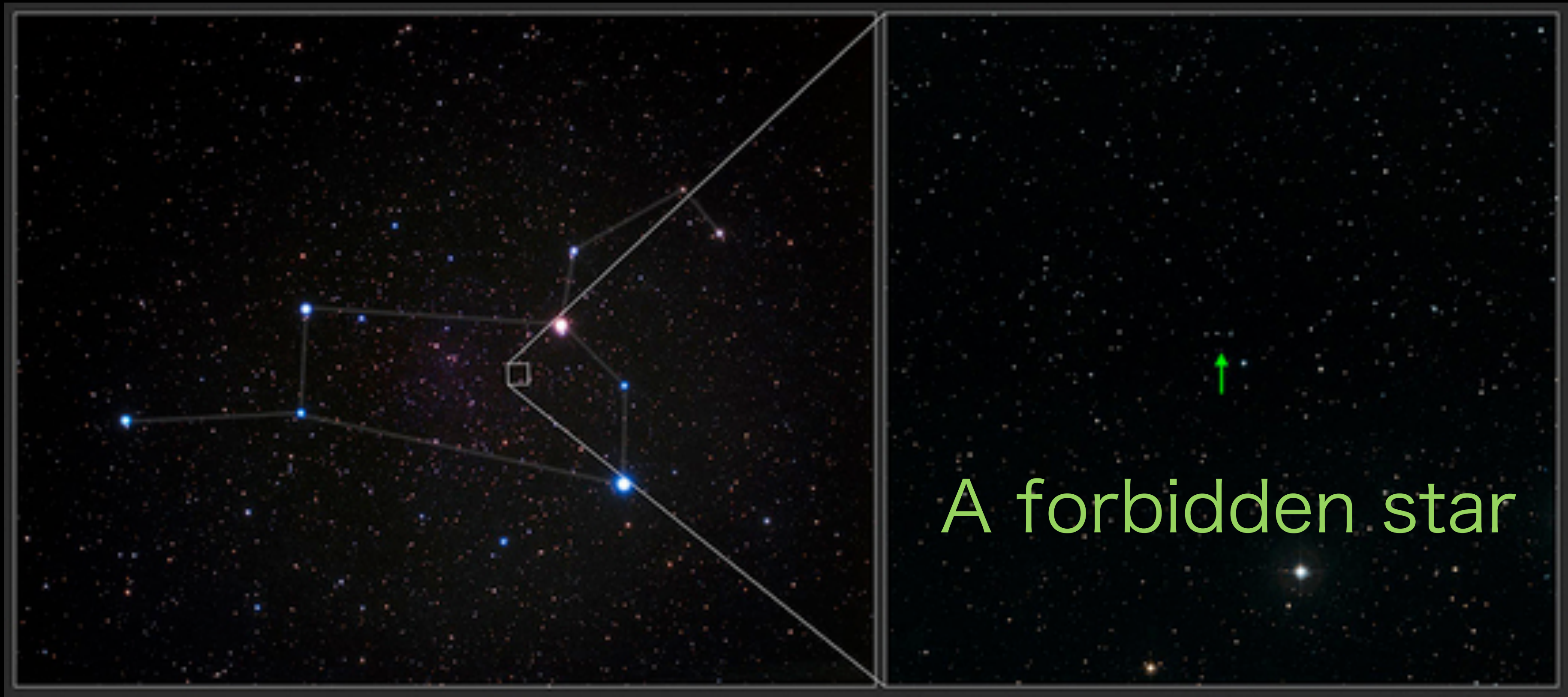


? Cases with large dM/dt cannot be followed for long time.

Very massive stars ?
Binaries ?
(Ring instability)

Formation of low-mass low-metallicity stars

Stellar relics in the MW



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

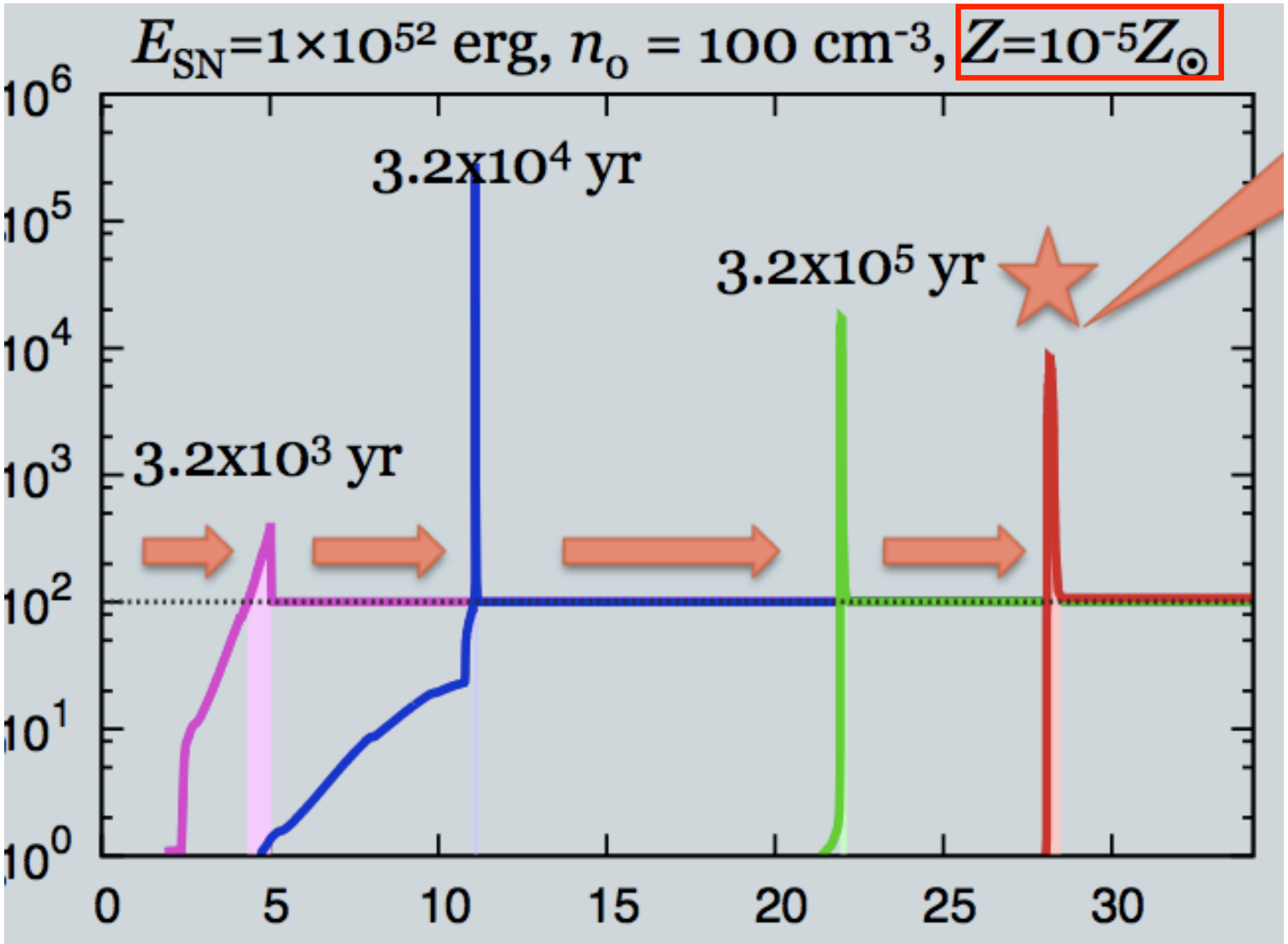
extremely metal-poor (not only iron-poor)

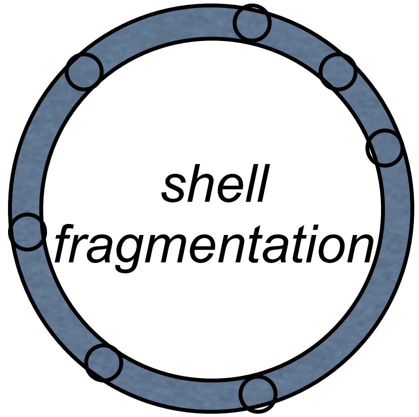
$Z < 4.5 \times 10^{-5} Z_{sun}$

Caffau et al. 2012

Supernova shock

1D hydro calculation of an early SNR

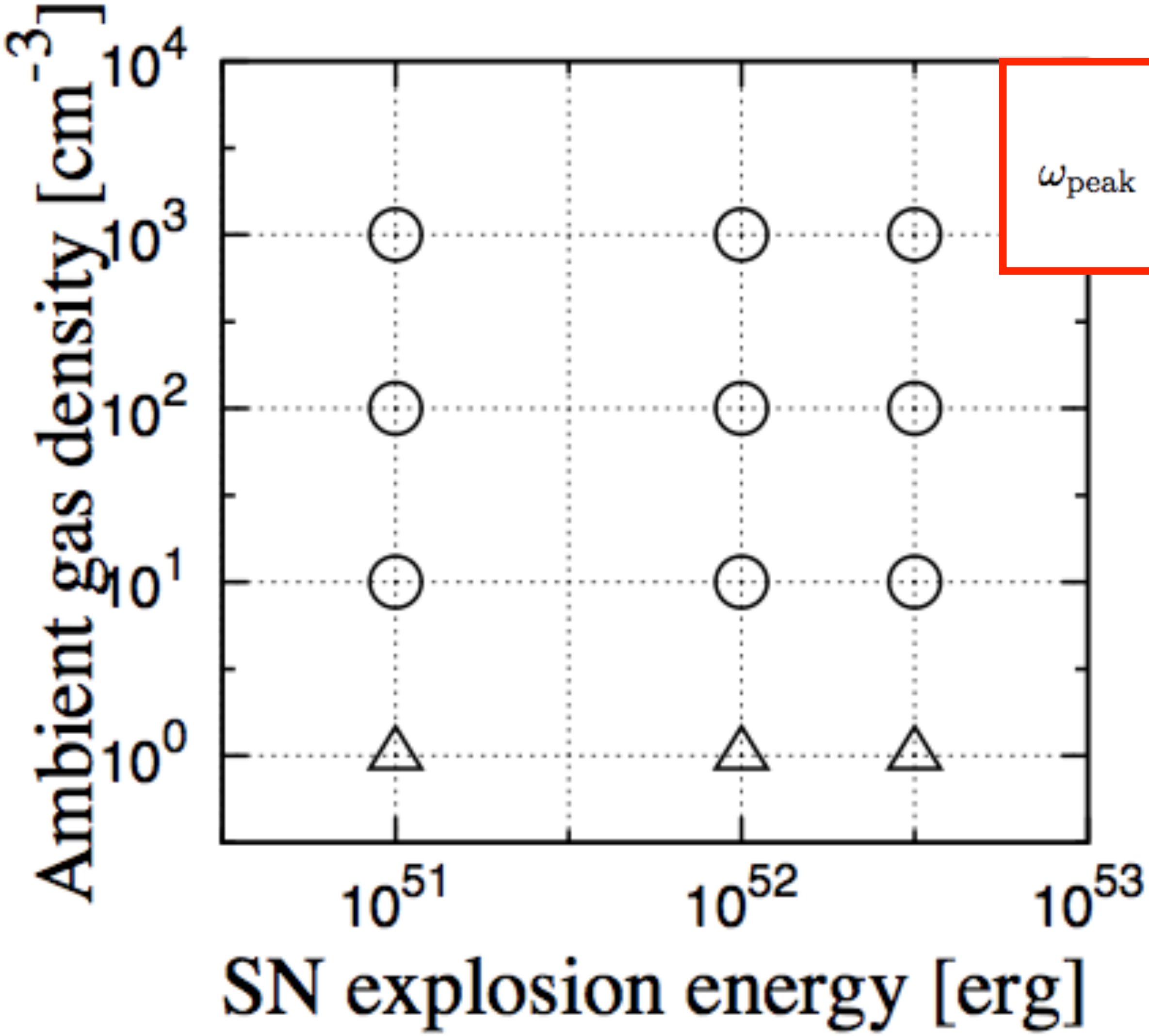




Chemistry
+ cooling
in a low-Z gas

Chiaki, NY, Kitayama 2012

Shell instability



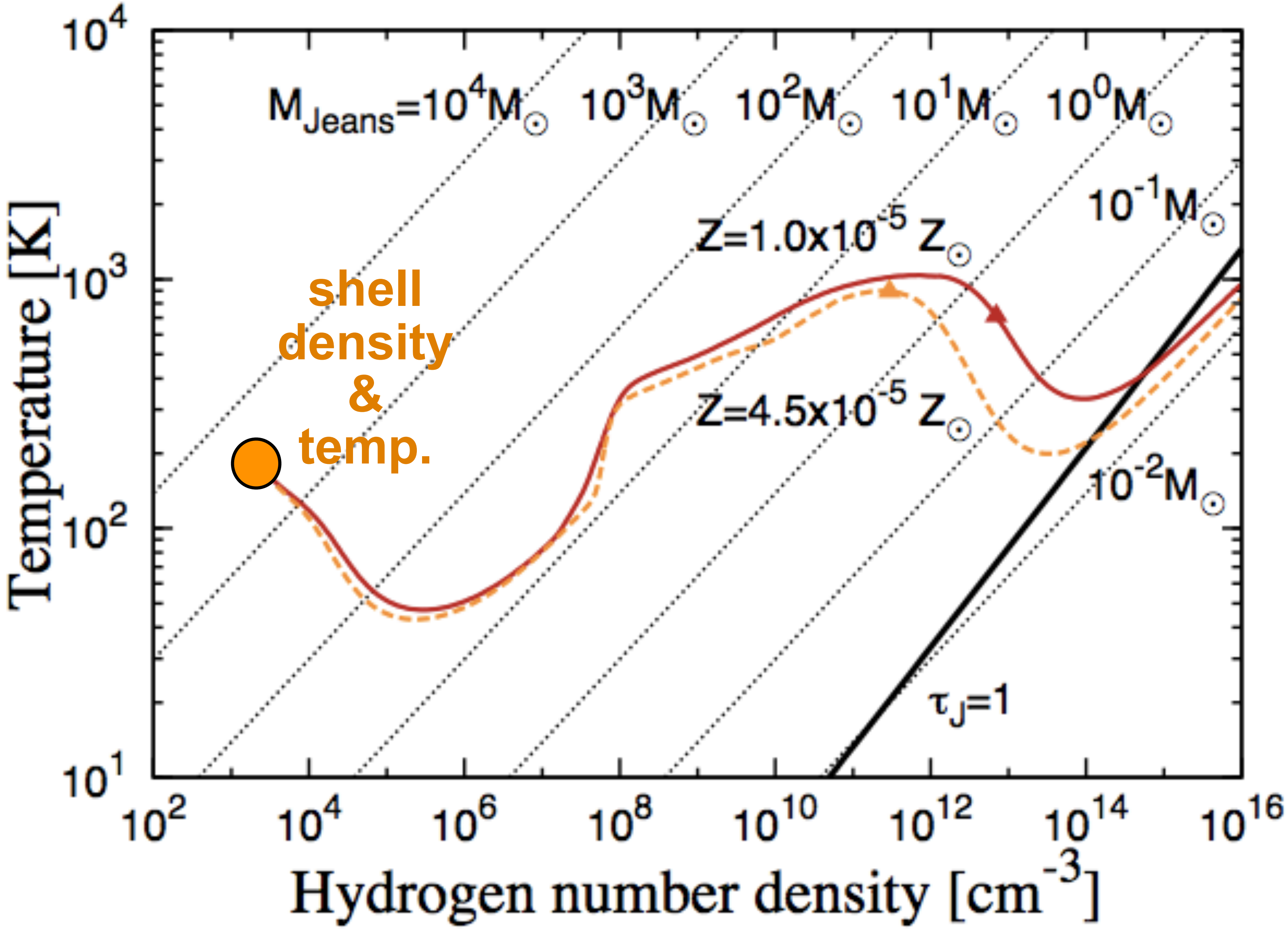
$$\omega_{\rm peak} = -\frac{3V}{R} + \left[\left(\frac{V}{R}\right)^2 + \left(\frac{\pi G \Sigma_0}{c_{\rm eff}}\right)^2\right]^{1/2}$$

Elmegreen, Iwasaki+11

Positive ω:
growing mode
exists

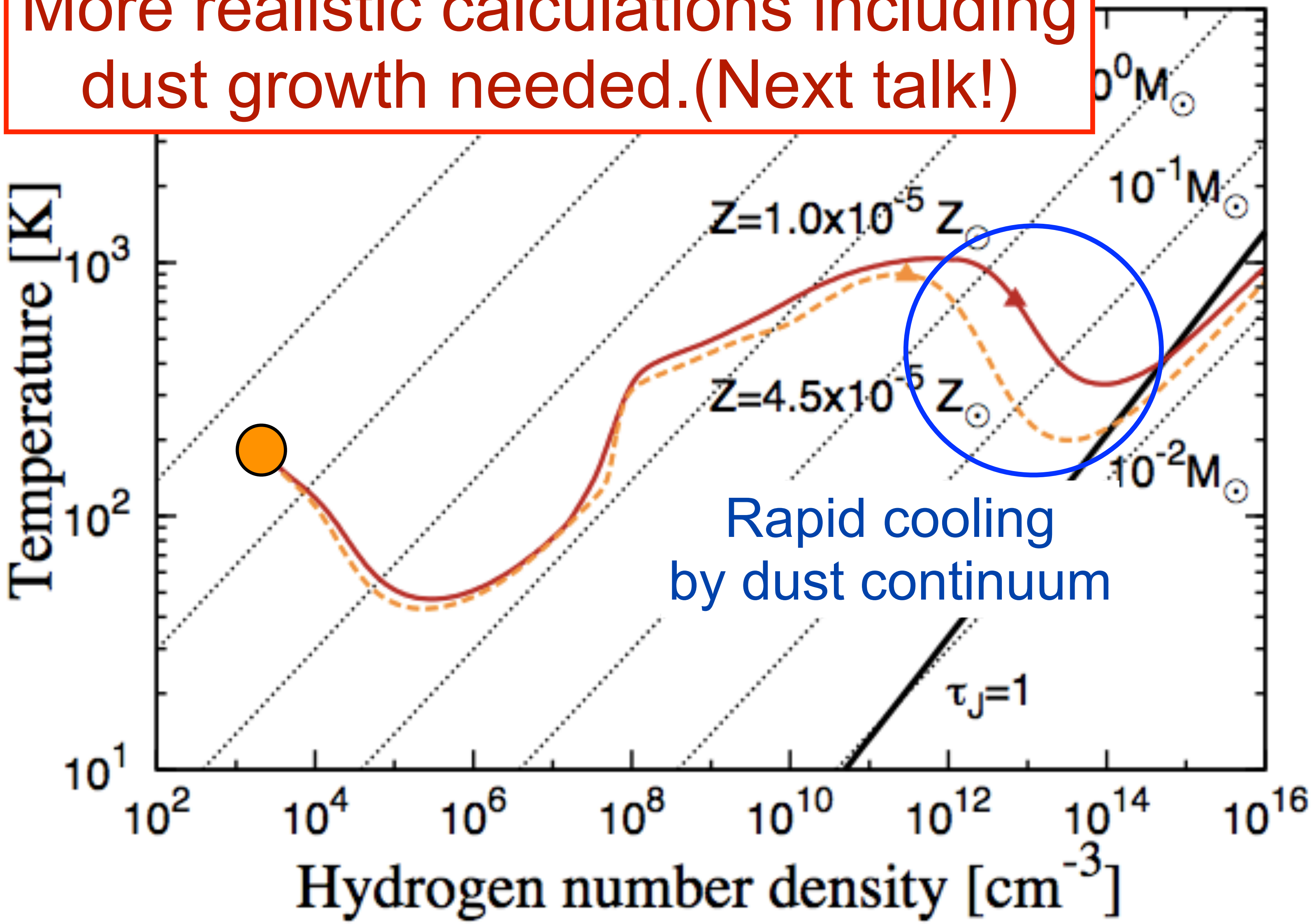
Chiaki, NY, Kitayama 2012

Fragment evolution



Fragment evolution

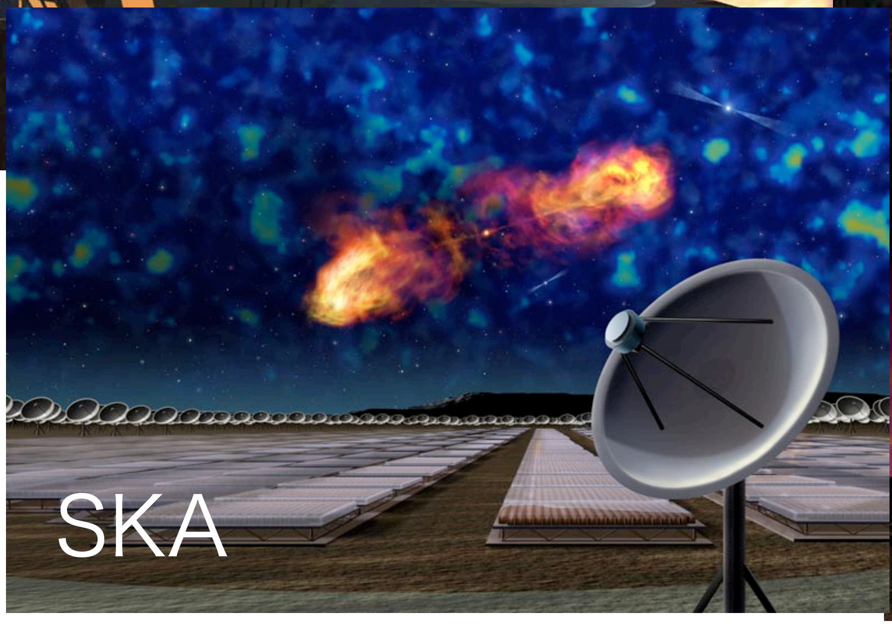
More realistic calculations including dust growth needed.(Next talk!)



Probing the IMF of the early generation stars

The future

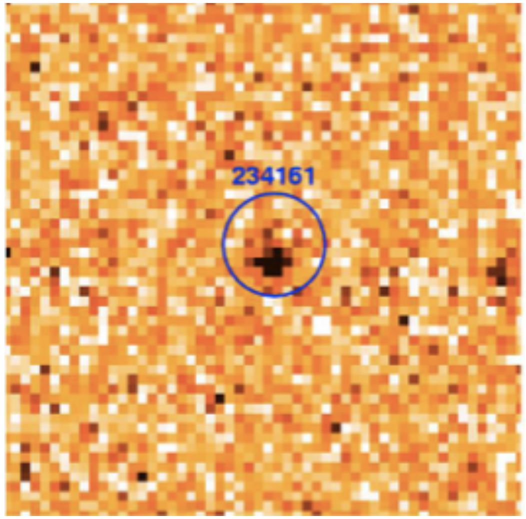
JWST

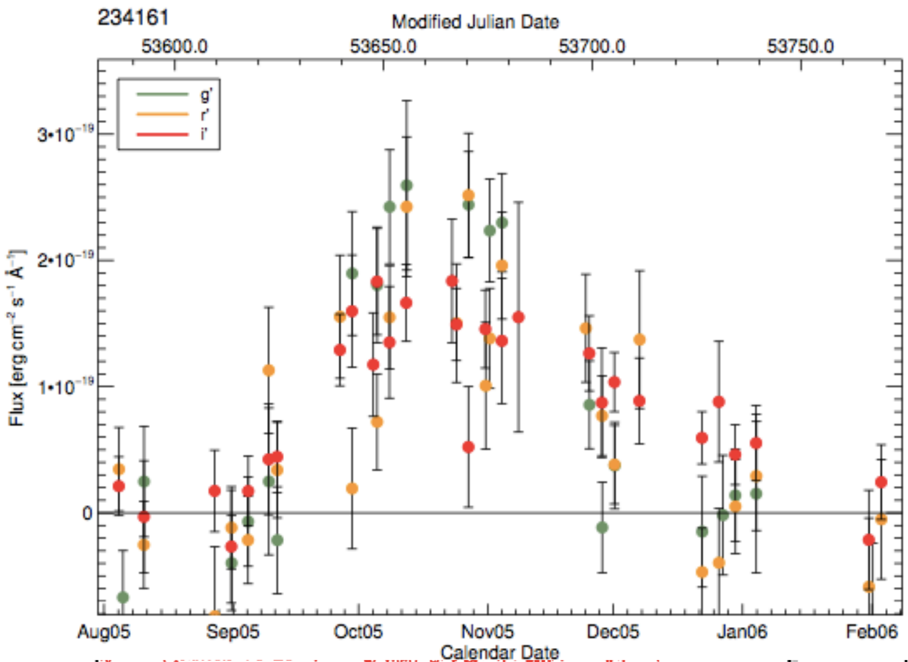


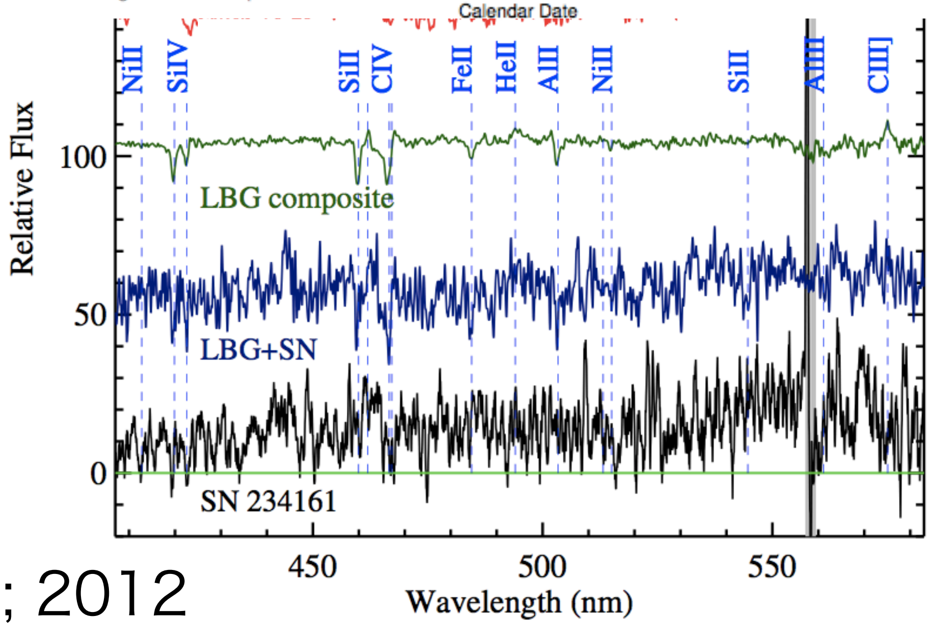
Core-collapse supernovae at very high-z

Highest-z supernova

Type IIn at z=2.4

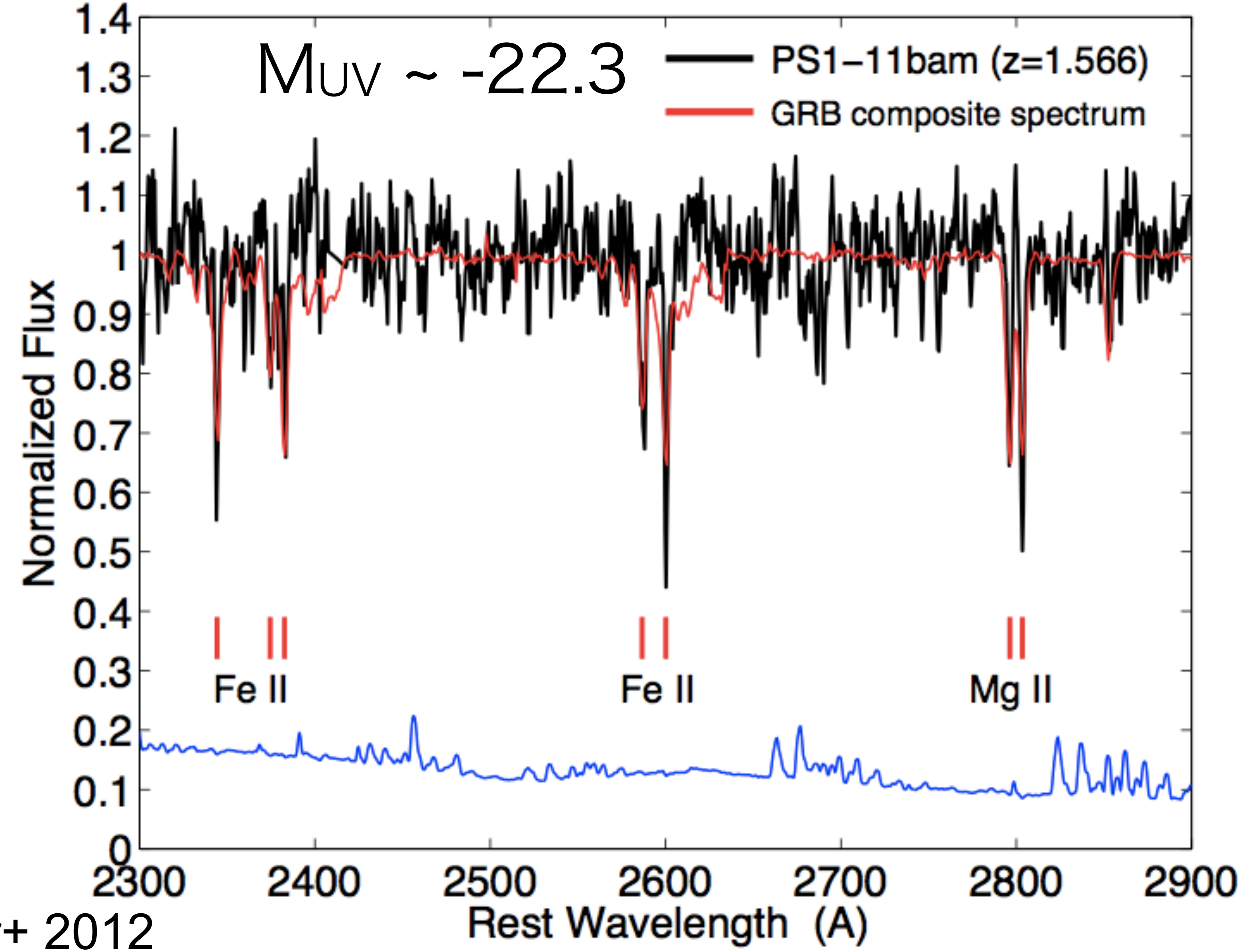






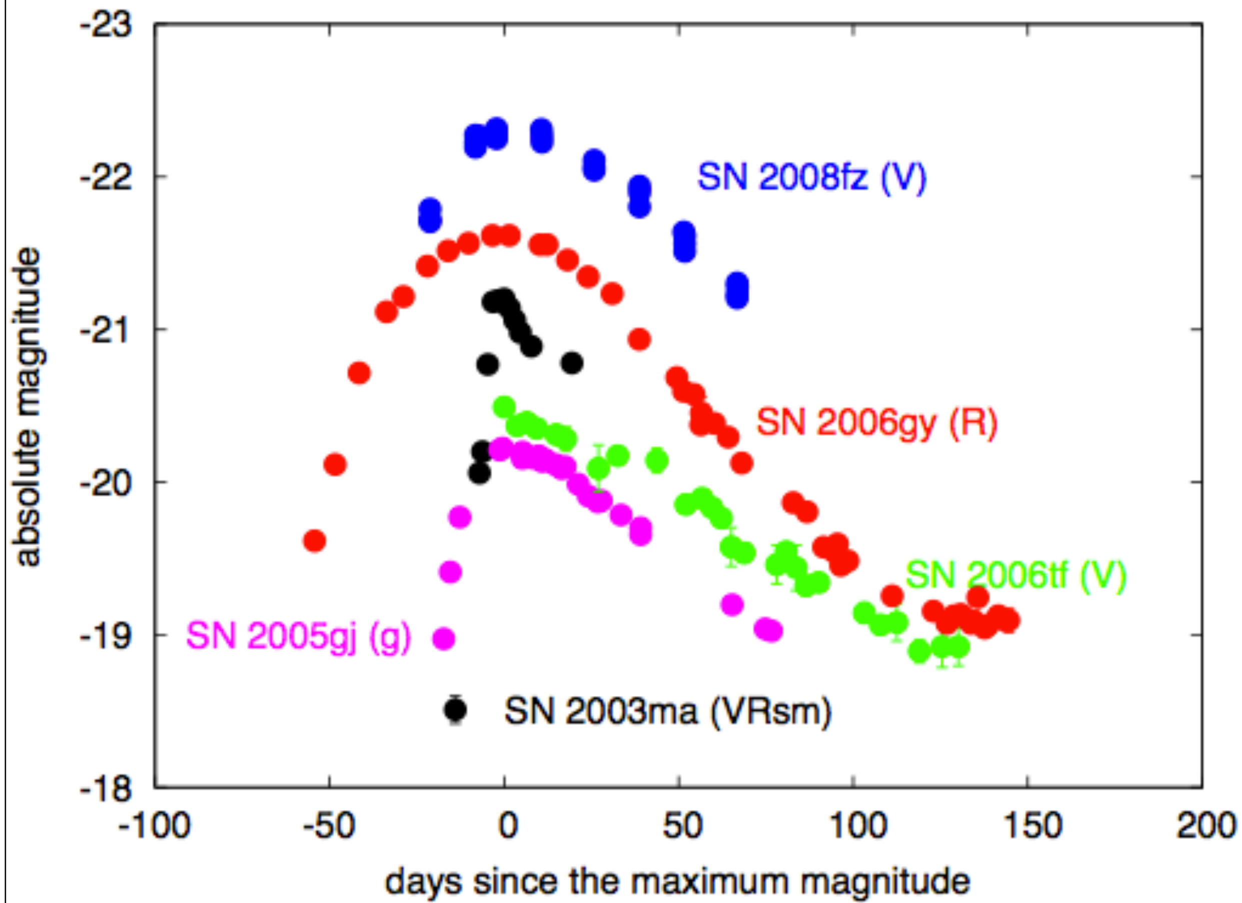
Cooke et al. 2009, Nature; 2012

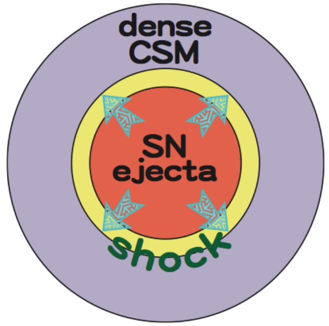
Distant SN as backlight



Berger+ 2012

Super-luminous SN





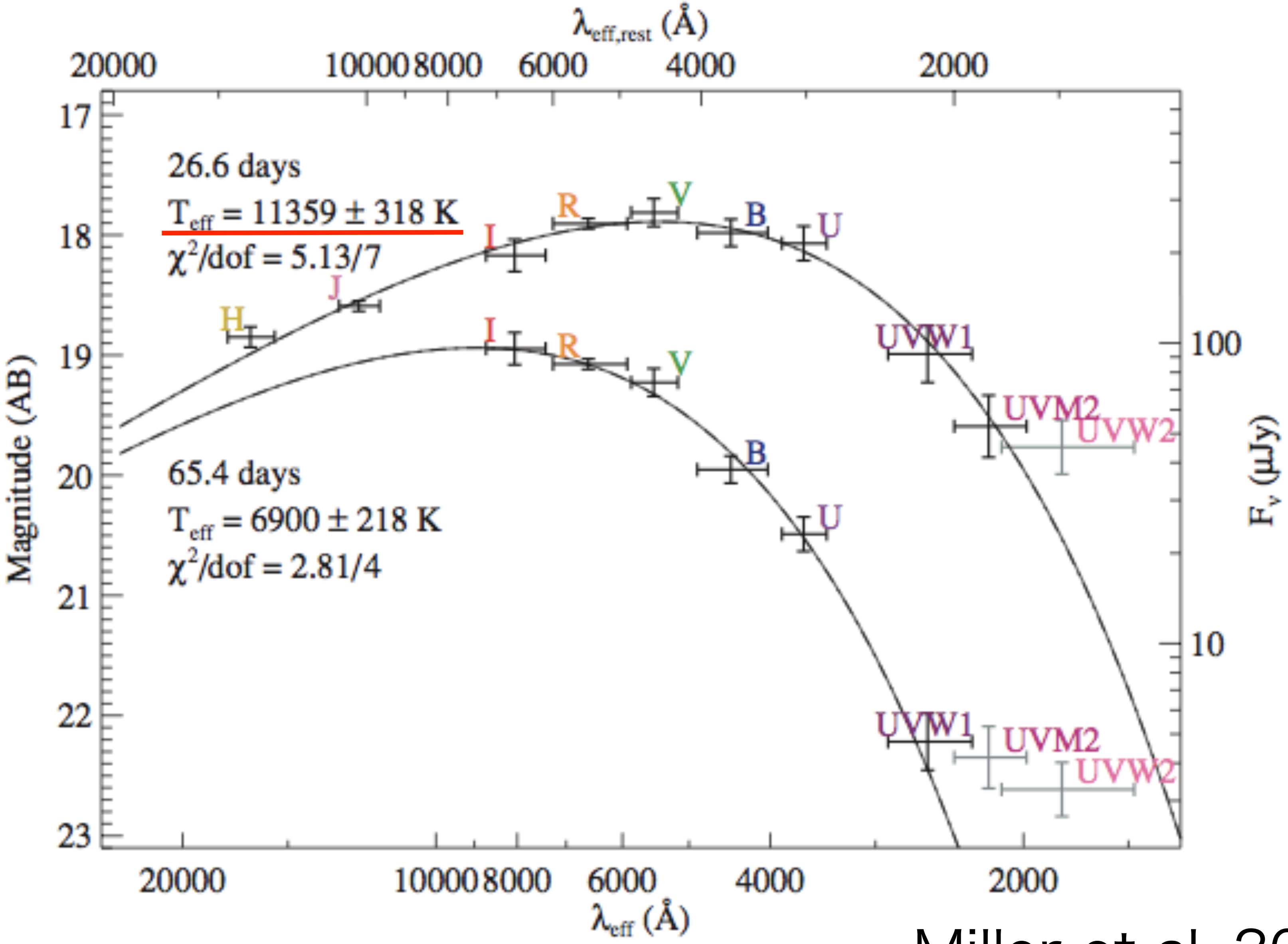
They will be visible to very high-z.

Powered by shock-interaction with dense CSM.

Bright in rest-UV

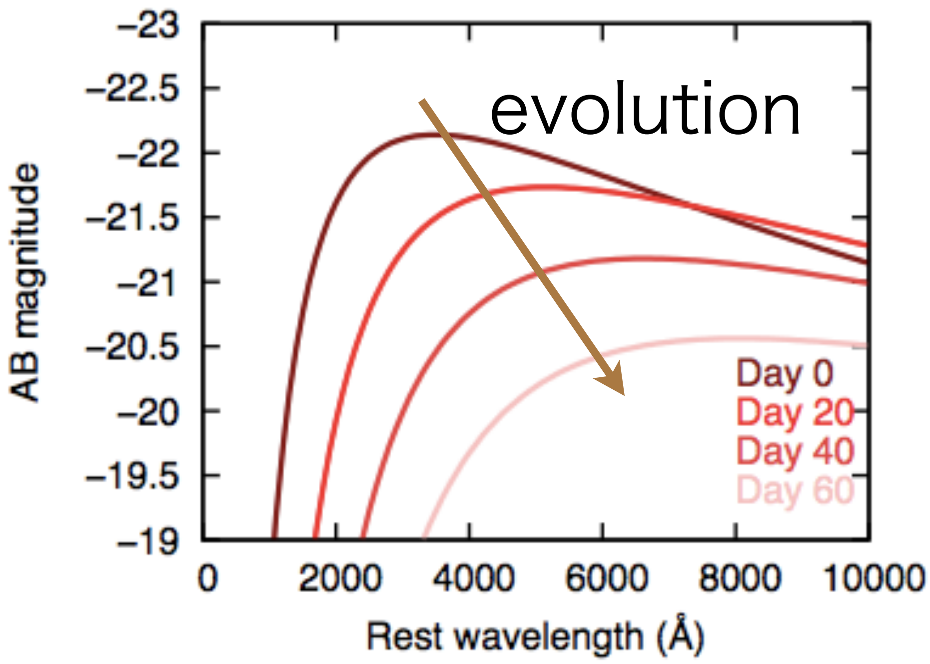
Death of a very massive star (> 50 Msun?)

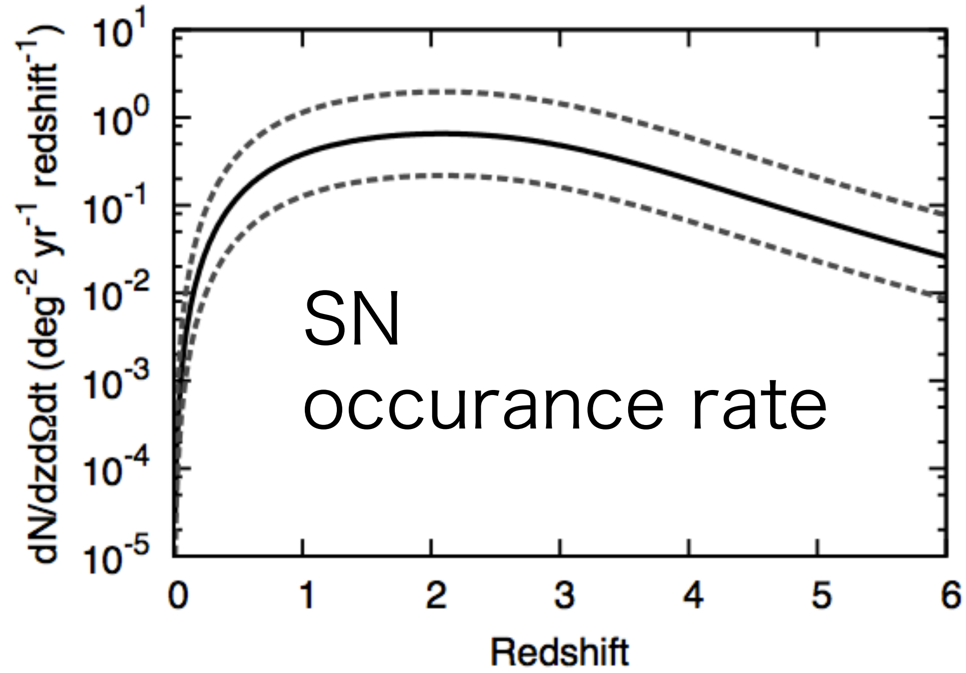
2008es: Bright in UV



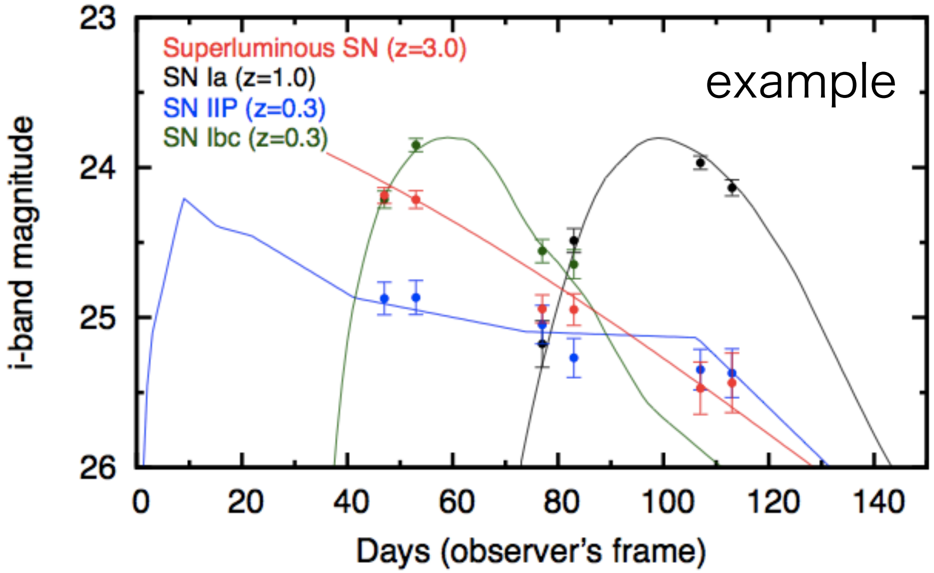
Miller et al. 2009

Model SED and LC





SN
occurance rate

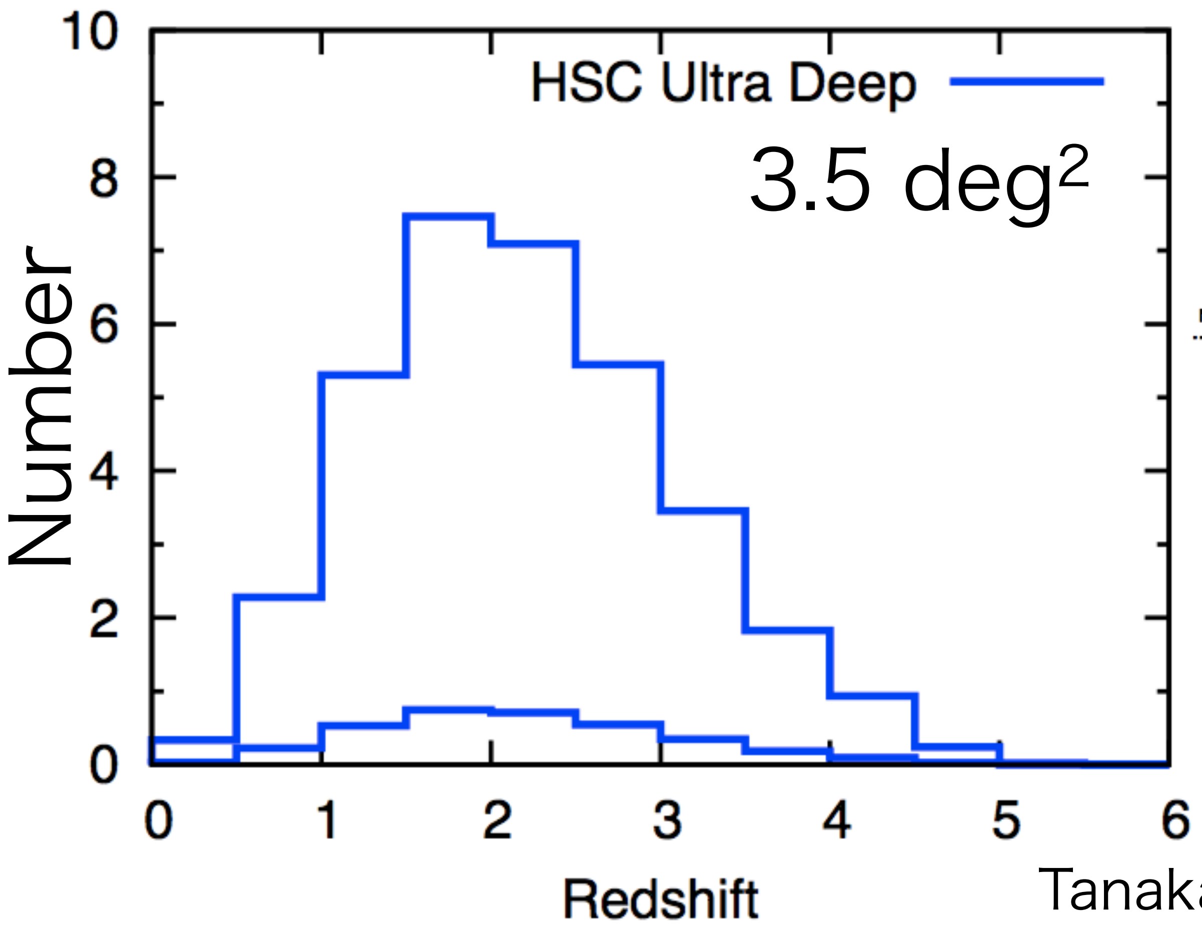


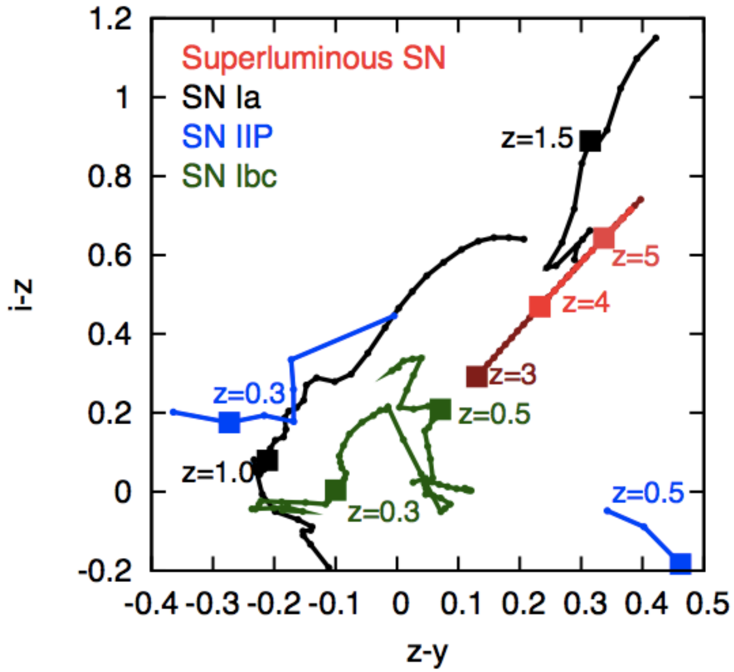
Monte Carlo light curve
+ photometric errors

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



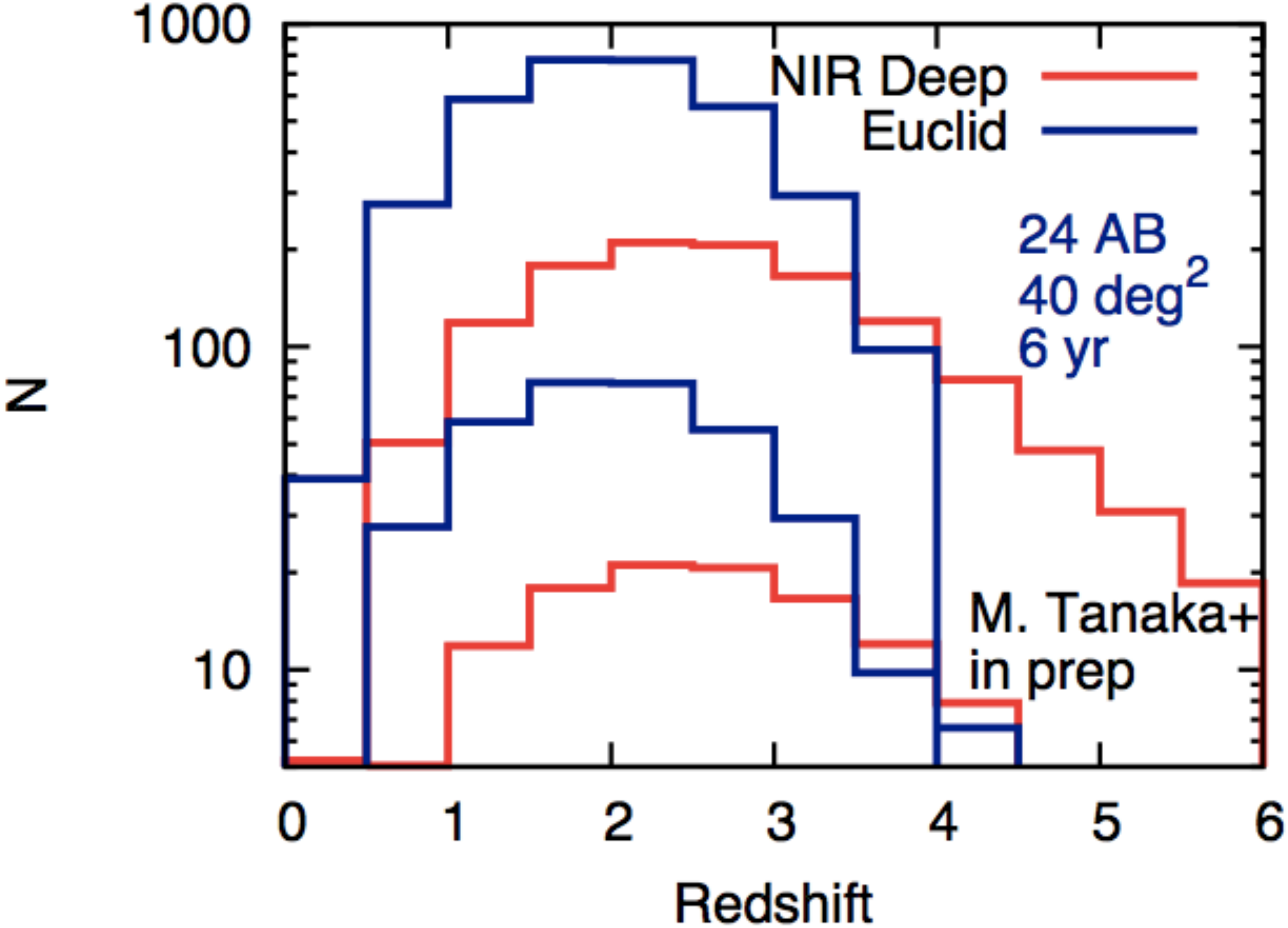


color selection

Tanaka, Moriya, NY, Nomoto, 2012

Euclid as SN finder

~ 1month cadence over 6 years!

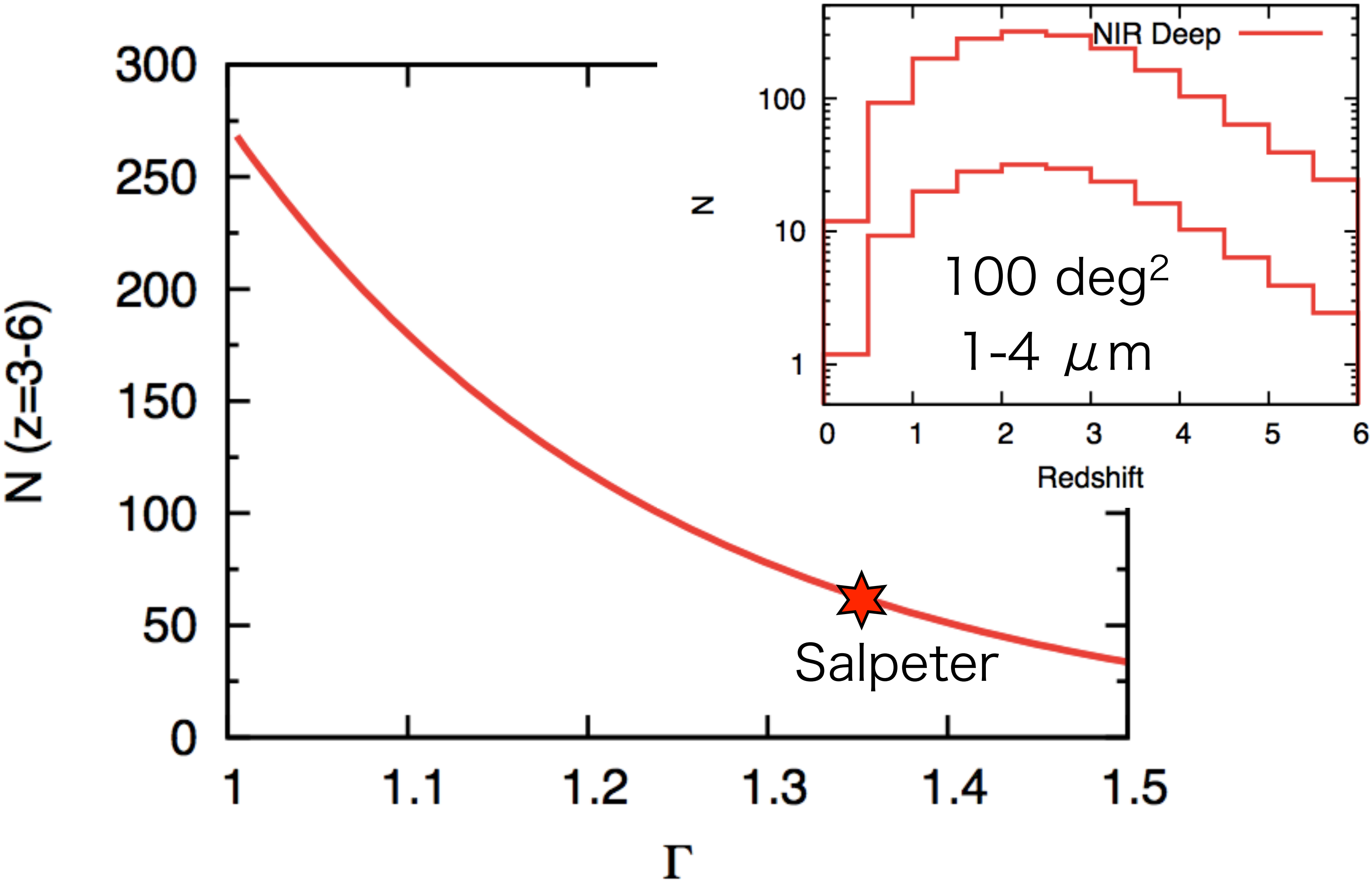


NIR

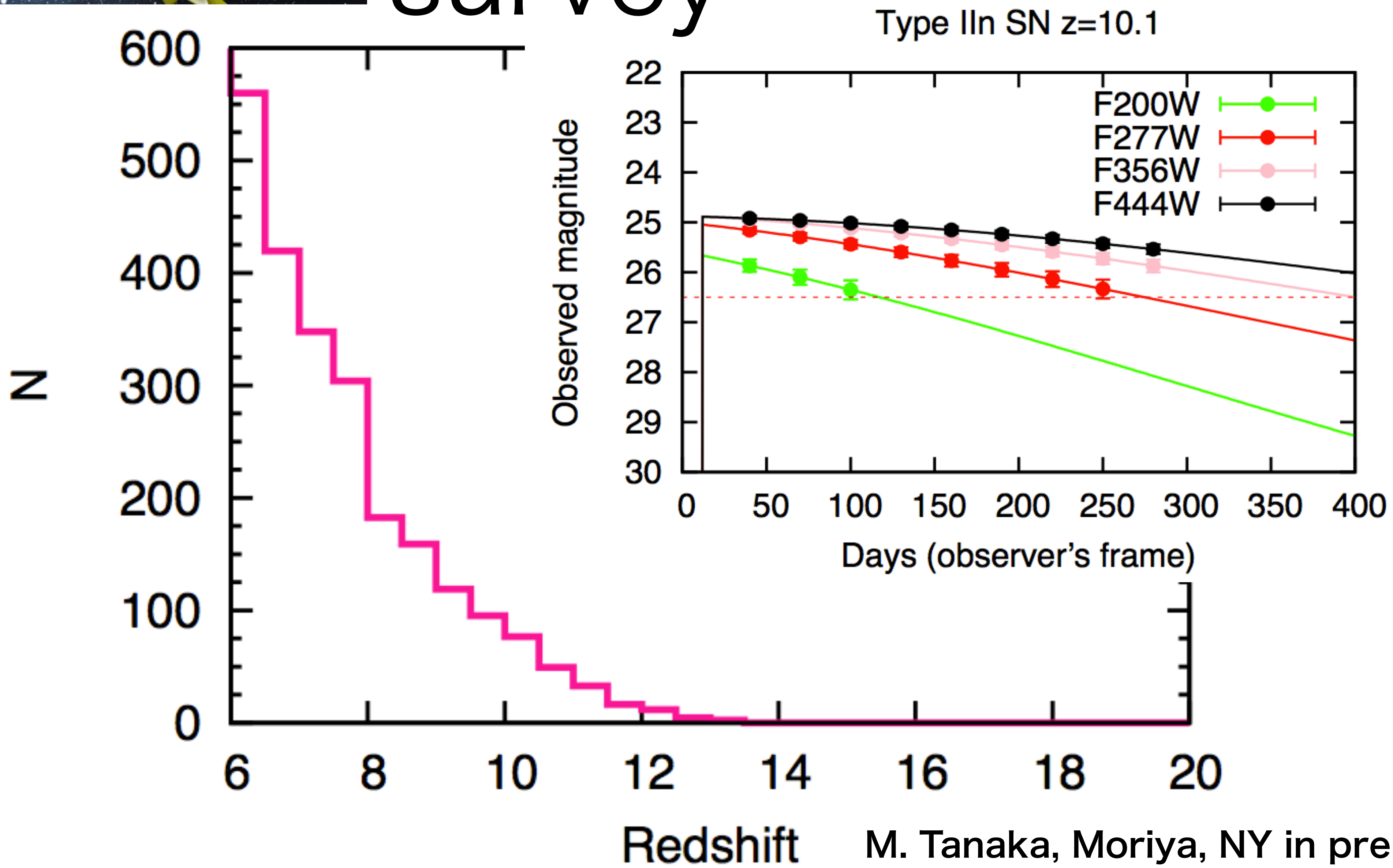
Y, J, H

bands

IMF by NIR survey

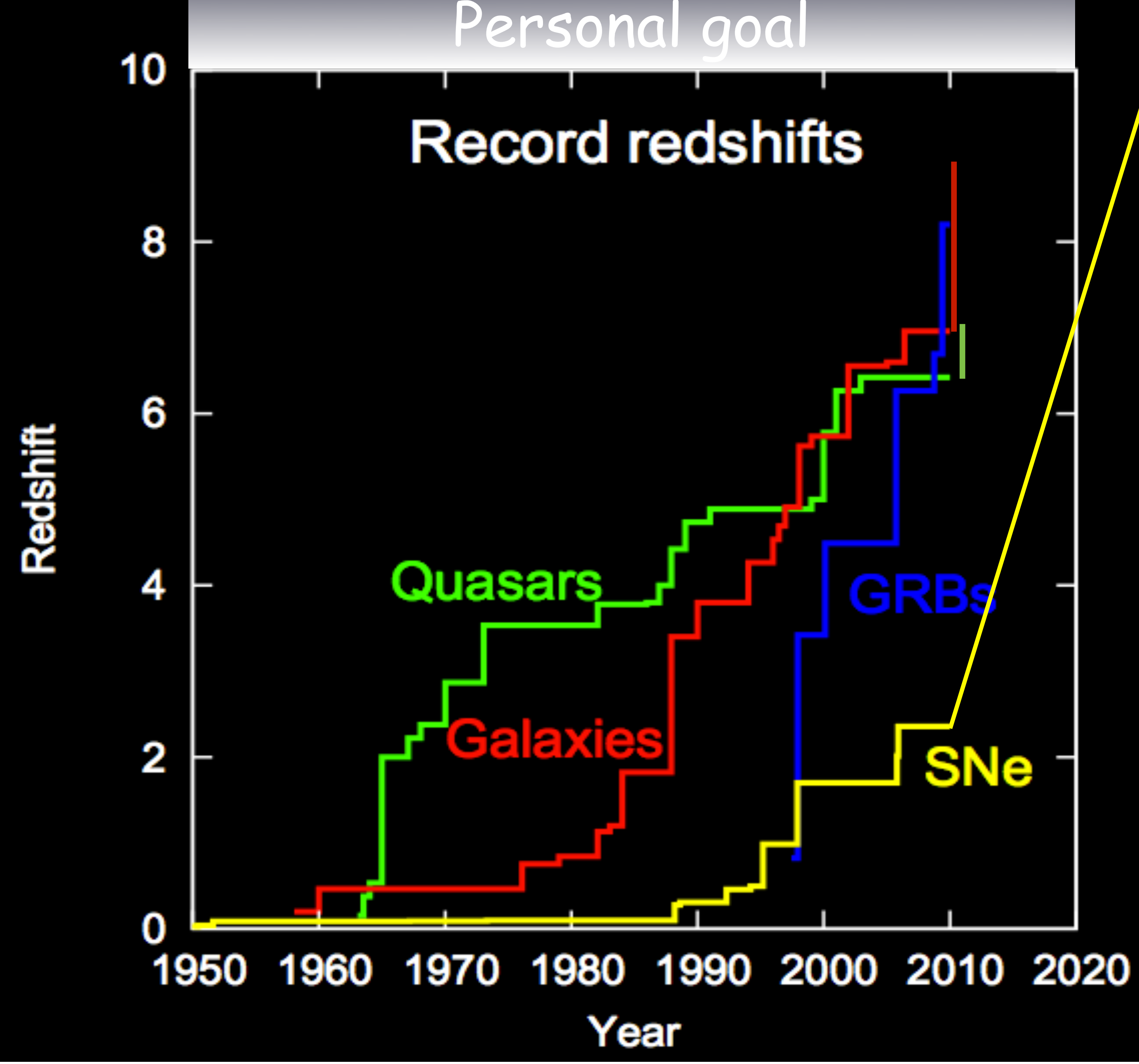


All-sky near-infrared survey



M. Tanaka, Moriya, NY in prep

Personal goal



Summary

- Primordial stars are massive, but mostly not extremely massive
- Likely 10-100 M_{sun} dominant, including Pop III.2 stars
- EMP stars formed in early SNR
- Early Superluminous SNe detectable to z~10