FORMATION AND EVOLUTION OF DUST IN GALAXIES

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Everything gets dusty!

The bad sides:

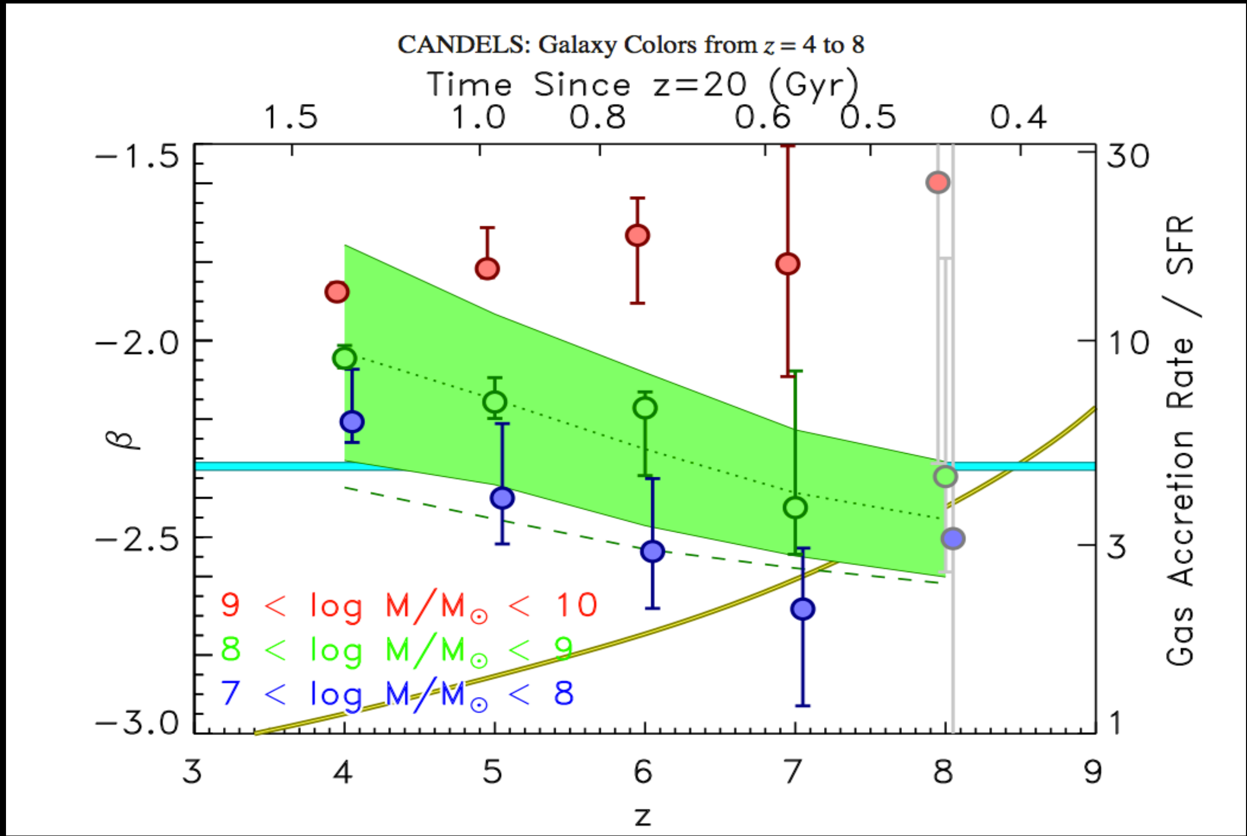
Nuisance for inferring 'true' UV/optical properties of e.g. galaxies, stars, SNe …

The good sides:

Advantage for sub-mm observations of high-z galaxies (thermal dust emission)

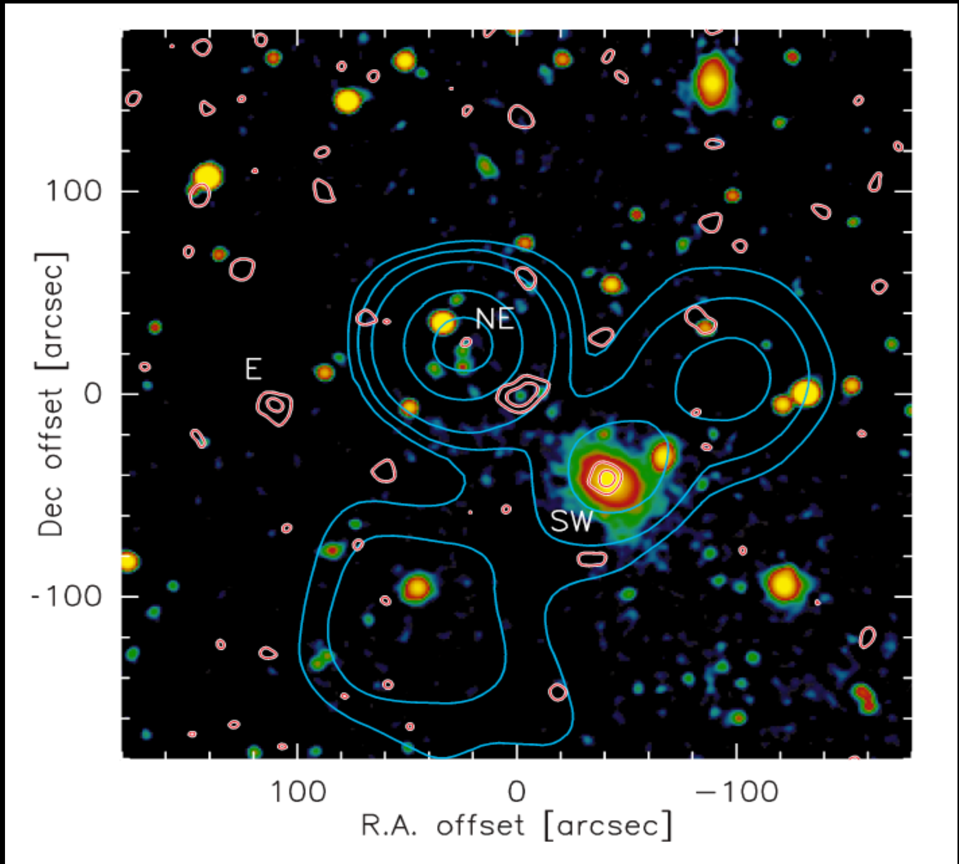
Quick and dirty!

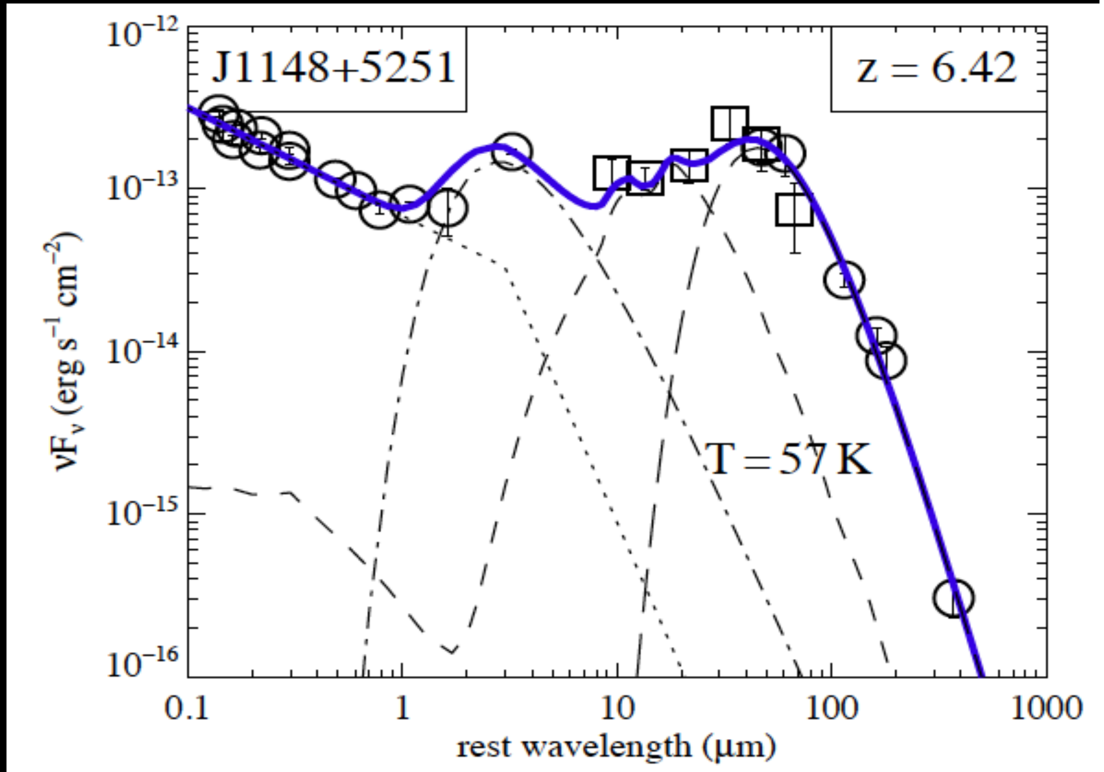
Dust at high redshift - Galaxies at z = 4 - 8



Finkelstein et al. 2012

Quick and dirty!





Leipski et al. 2013

Bertoldi et al. 2003

$$M_\mathrm{d} = \frac{S(\nu_\mathrm{o})\, D_\mathrm{L}^2}{(1+z)\kappa_\mathrm{d}(\nu_\mathrm{r})\, B(\nu_\mathrm{r}, T_\mathrm{d})}$$

$M_d \sim 2 - 8 \times 10^8\, M_\odot$

Large amounts of dust in galaxies!!

Galaxy	SFR ($M_\odot$ /yr)	Dust mass ($M_\odot$)	Stellar mass ($M_\odot$)
E galaxy	0.01–0.1	10^{5-6}	10^{11}
Milky Way	2	5×10^7	2×10^{11}
LMC	0.2–0.3 (1)	2×10^6	10^{10}
SMGs	100–1000	10^{8-9}	10^{11}
QSOs	≥ 1000	10^{8-9}	10^{11}

Quasars at high redshift: $M_d \sim 2 - 8 \times 10^8\ M_\odot$

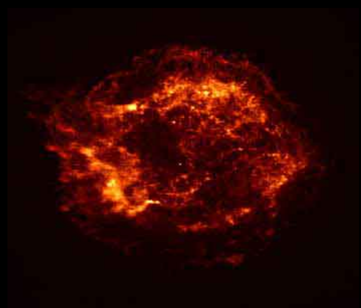
(e.g., Bertoldi et al. 2003, Wang et al. 2010, Michalowski et al. 2010)

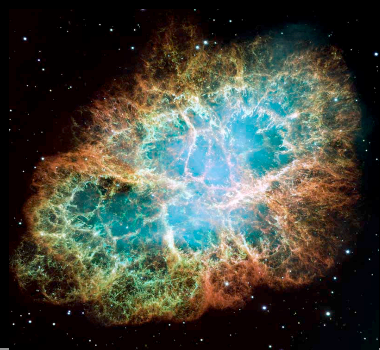
Problem also in MW, SMC, LMC: only 4-10% stellar dust

(e.g., Draine 2009, Matsuura et al. 2009, Boyer et al. 2012)

Dust sources

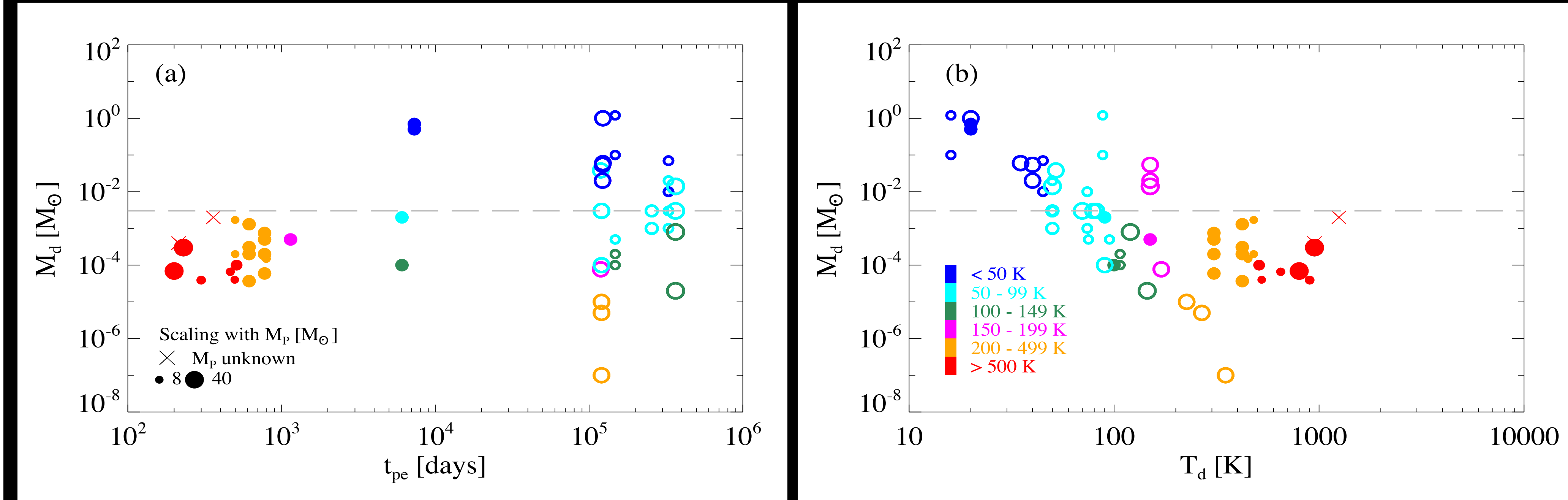
Source	Observed amount of dust	Theoretical predictions	Reference
Pair instability Supernovae		up to 25 $M_\odot$	Nozawa et al. 2003, Cherchneff & Dwek 2009, 2010
AGB stars	up to 1–5 x 10^{-3} $M_\odot$	up to 2 x 10^{-2} $M_\odot$	Groenewegen et al. 1998a, 1998b; Ramstedt et al. 2008 Ferrarotti and Gail 2006
RSG and WR stars	about 1% of AGB stars		
LBV	up to 0.4 $M_\odot$		Gomez et al. 2010
Core collapse Supernovae	up to 1 $M_\odot$	up to 1 $M_\odot$	Matsuura et al. 2011, Nozawa et al. 2007





Gall et al. 2011, A&ARv

Observational evidence of dust from supernovae



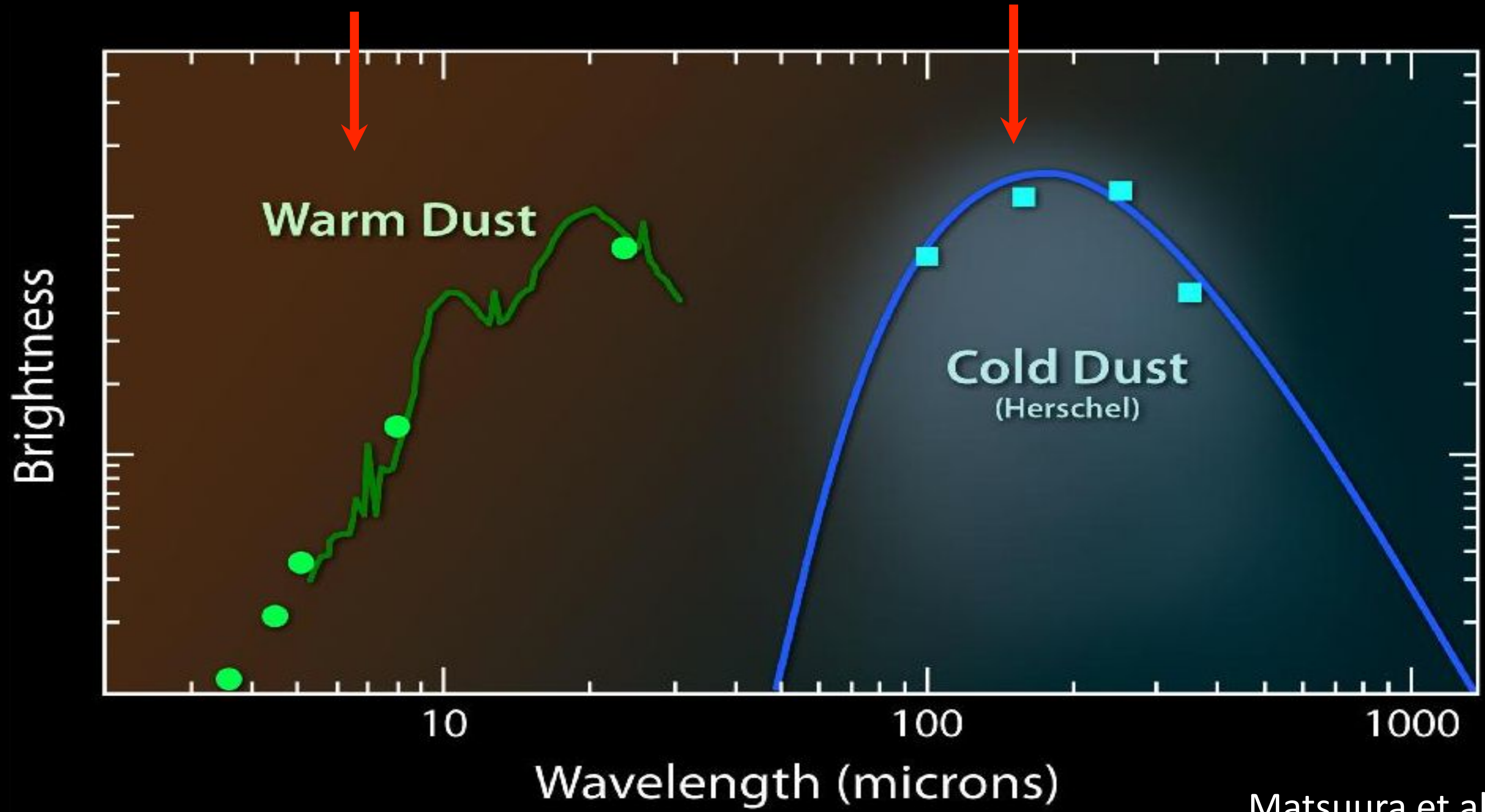
Gall et al. 2011, A&ARv

SN 1987A

~ 20 K

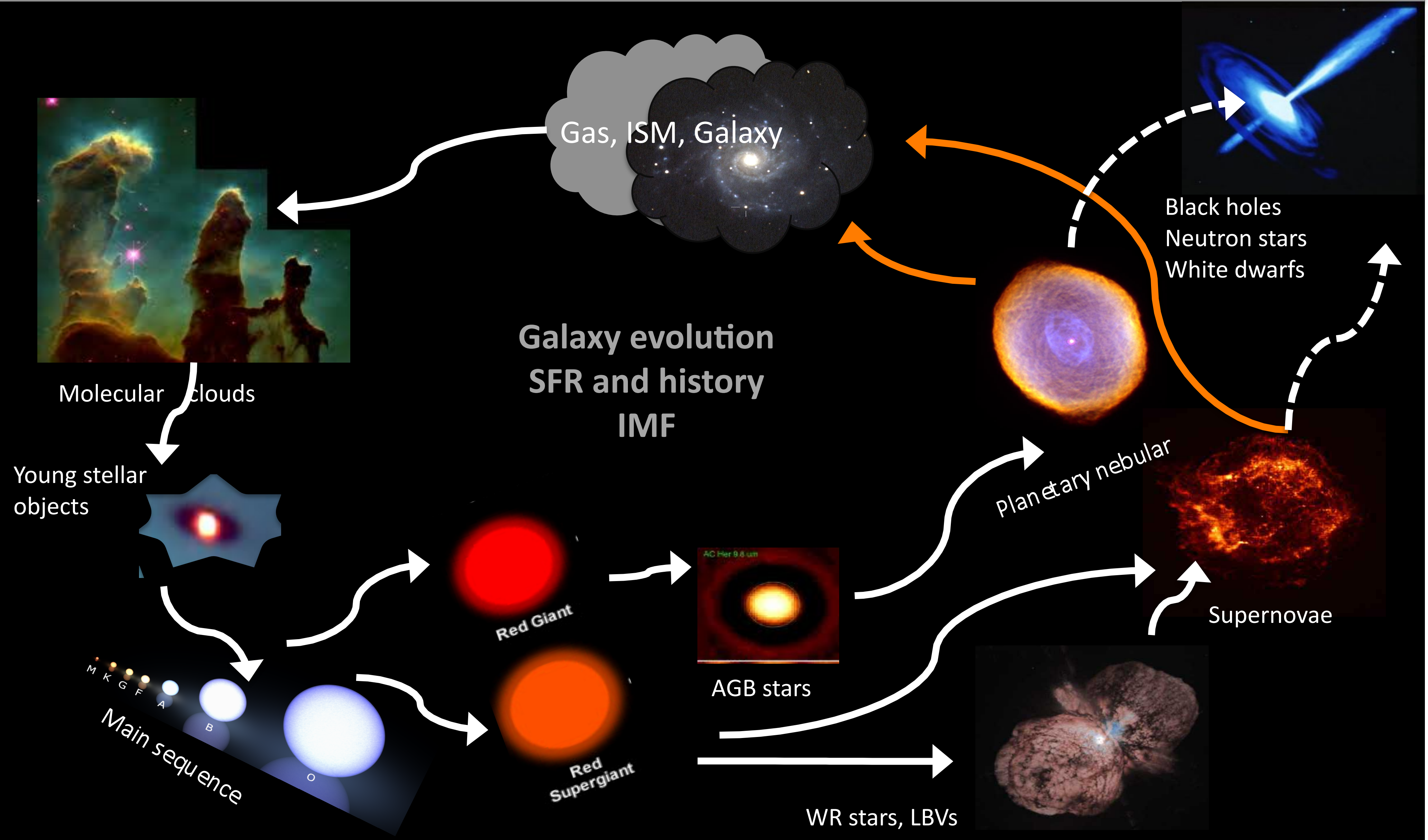
~ 180 K

~ 0.7 M_{sun}



Matsuura et al. 2011

Life cycle of matter



Chemical Evolution models

- Star formation

$$\psi(t) = \psi_{\rm ini}(t)\left[\frac{M_{\rm ISM}(t)}{M_{\rm ini}}\right]^k$$

- IMF

$$\int_{m_1}^{m_2} m\phi(m)dm = 1$$

- AGB, SN rates

$$R_{\rm i}(t) = \int_{m_{\rm L(i)}}^{m_{\rm U(i)}} \psi(t-\tau_m)\phi(m)dm$$

- Injection rates

$$E(t) = \int_{m_{\rm L(i)}}^{m_{\rm U(i)}} Y(m)\psi(t-\tau_m)\phi(m)dm$$

- Dust

$$\frac{{\rm d}M_{\rm d}(t)}{{\rm d}t} = E_{\rm d,SN}(t) + E_{\rm d,AGB}(t) - E_{\rm D}(t)$$

$$E_{\rm D}(t) = \eta_{\rm d}(t)(\psi(t) + M_{\rm cl}(t)R_{\rm SN}(t) + \Psi_{\rm SMBH})$$

- Gas

$$\frac{{\rm d}M_{\rm g}(t)}{{\rm d}t} = E_{\rm g}(t) + \eta_{\rm d}(t)M_{\rm cl}(t)R_{\rm SN}(t) - (1-\eta_{\rm d}(t))(\psi(t) + \Psi_{\rm SMBH})$$

- Metals

$$\frac{{\rm d}M_{\rm Z}(t)}{{\rm d}t} = E_{\rm Z}(t) - \eta_{\rm z}(t)(\psi(t) + \Psi_{\rm SMBH})$$

Chemical Evolution models

Parameters	Value	Unit	Description
$M_{\rm ini}$	5×10^{10}, 1×10^{11}, 5×10^{11}, 1.3×10^{12}	$M_\odot$	Initial mass of the galaxy
$\psi_{\rm ini}$	1×10^{3}	$M_\odot\ {\rm yr}^{-1}$	Star formation rate
$Z_{\rm ini}$	10^{-6}	$Z_\odot$	Initial metallicity
k	1.5		Power for the relation $\psi(t) \propto M_{\rm ISM}(t)^k$
$M_{\rm cl}$	800, 100, 0	$M_\odot$	Swept-up ISM mass per SN
$M_{\rm core}^{\rm crit}$	15	$M_\odot$	Critical He core mass
$\xi_{\rm SN}$	0.93		SN dust destruction factor
$M_{\rm SMBH}$	3×10^{9}, 5×10^{9}	$M_\odot$	Mass of the SMBH
$t_{\rm SMBH}$	4×10^{8}	yr	Growth timscale for the SMBH
$t_{\rm max}$	10^{9}	yr	Maximum computed age of the galaxy
Parameters	**Switch**		**Description**
$Y_{\rm Z}$, $Y_{\rm E}$, $Y_{\rm Q}$ (for SN)	EIT08, WW95, N06, Georgy et al. (2009)		Possibilities for the SN yields
$Y_{\rm Z}$, $Y_{\rm E}$, $Y_{\rm Q}$ (for AGB)	van den Hoek & Groenewegen (1997)		Possibilities for the AGB yields
$\phi(m)$	Salpeter, mass-heavy, top-heavy, Larson 1, Larson 2		Initial mass function
SFR	evolving/constant		Additional switch for the SFR
$\epsilon_{\rm AGB}(m, Z)$	only one case considered		Dust formation efficiency, AGB
$\epsilon_{\rm SN}(m)$	max/low		SN dust formation efficiency
$\xi_{\rm SN}$	considered/not considered		SN dust destruction
BH/SN	SN when BH/no SN when BH		Possibility, if a SN occurs even a BH is formed or not
SMBH	considered/not considered		Growth of SMBH

Gall et al. 2011

Chemical Evolution models

Tuning parameters

Most important:

SFR, IMF, Dust source, SN dust destruction

Good models:

Need to explain observations!

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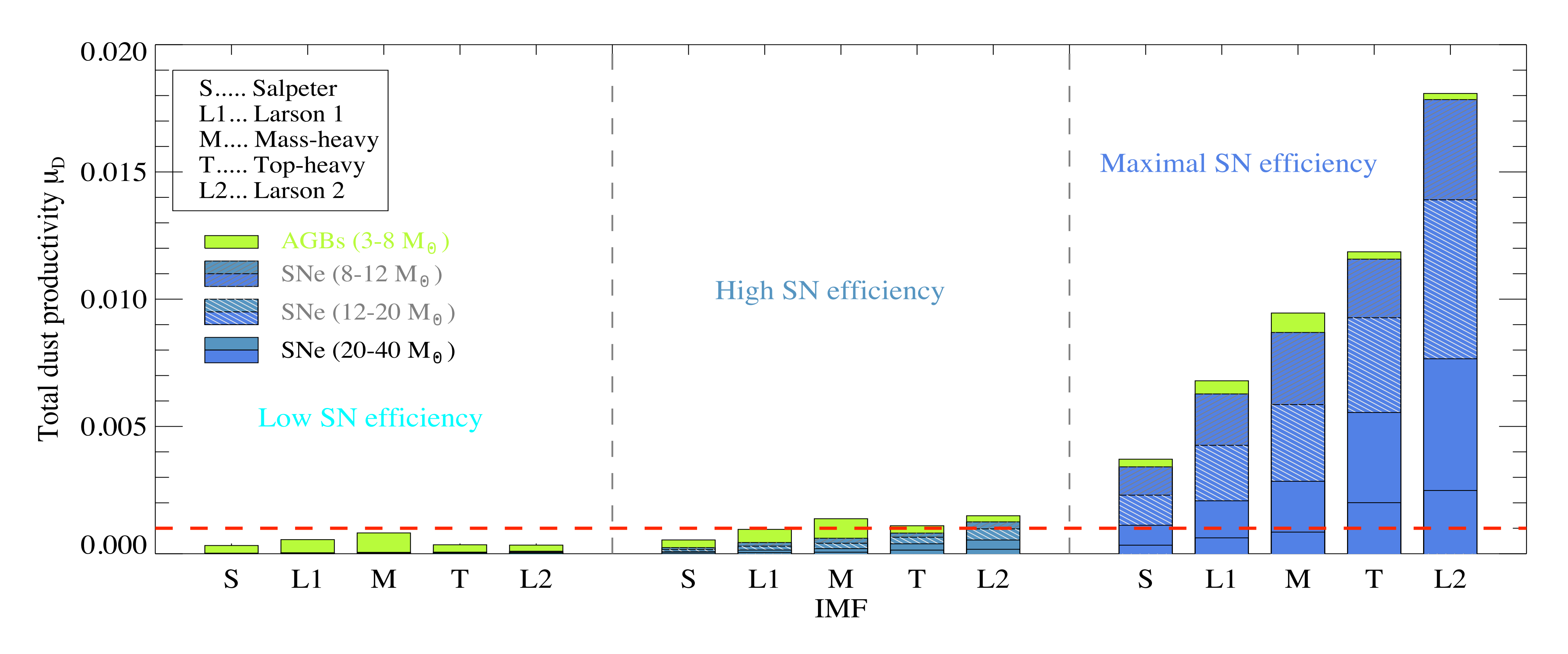
Dust Productivity



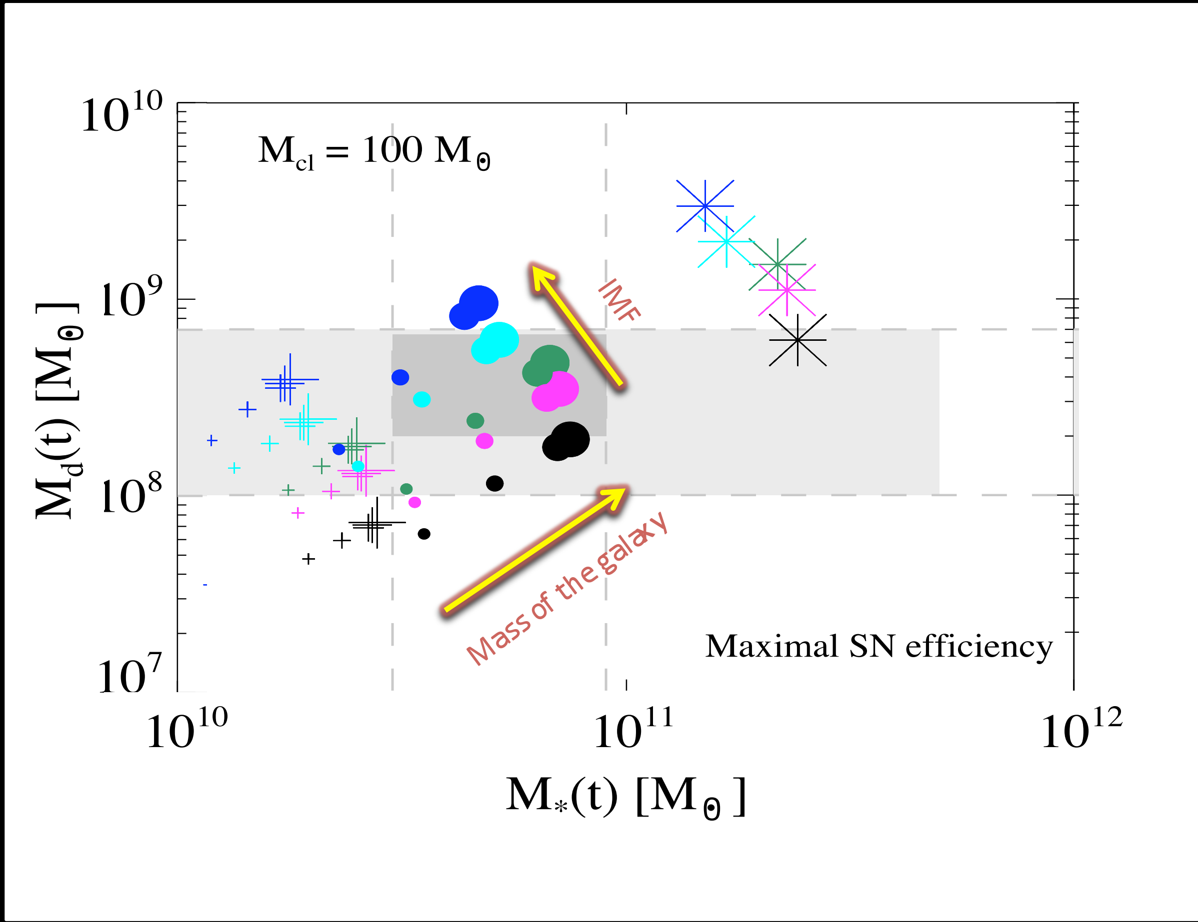
Gall et al. 2011, A&ARv

$$\mu_D = \int_{m_L}^{m_U} \phi(m) M_z(m) \varepsilon(m) dm$$

$$M_{dust} = \mu_D \times SFR \times \Delta t$$

Rapid formation of dust!

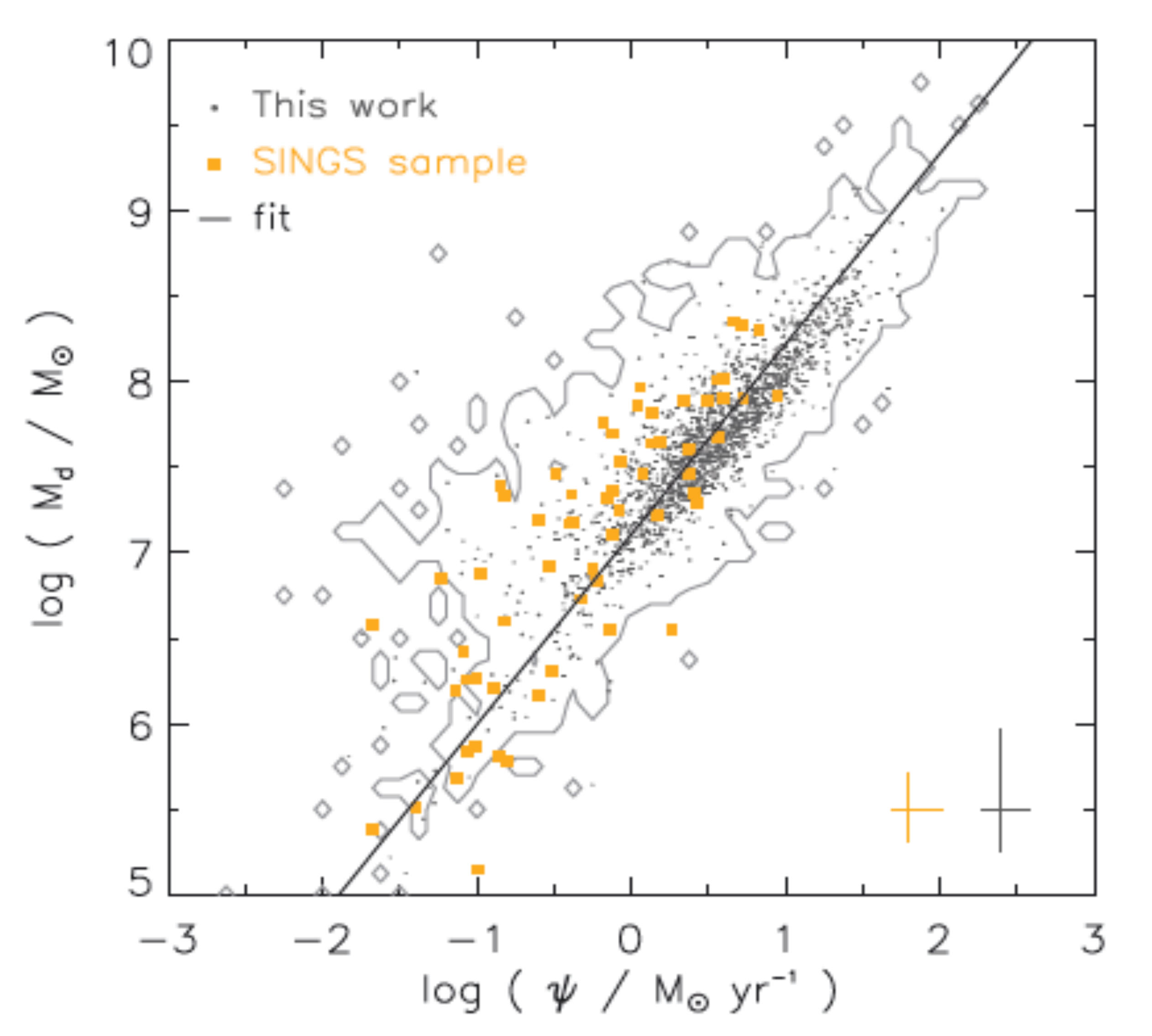
Modeling quasars at $z > 6$



Rapid evolution (30 Myr) with SN ~0.1-1 $M_{\odot}$

Gall et al. 2011A&A,525,13; 525,14

Dust mass and SFR relation

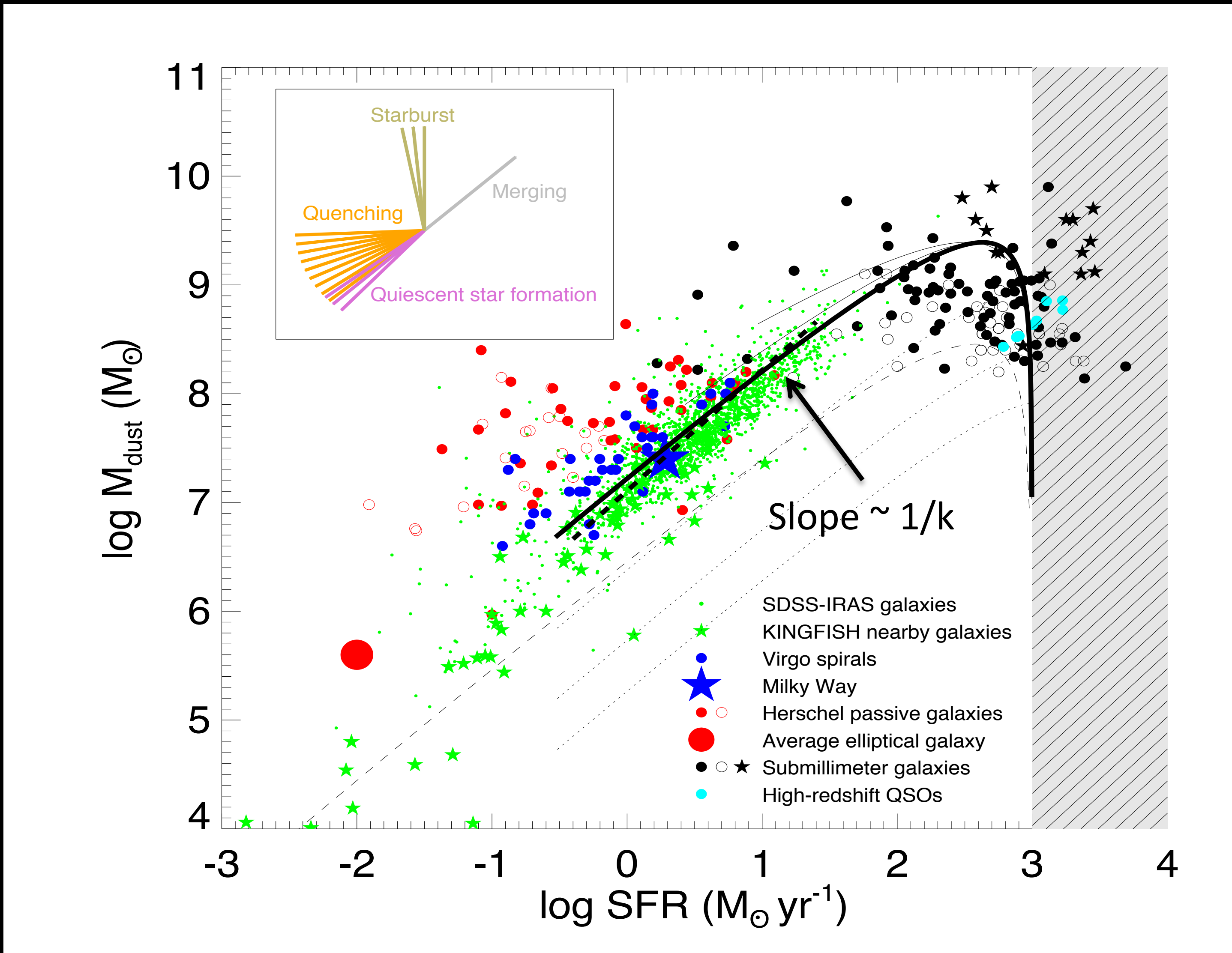


1658 SDSS galaxies

$$M_{\rm dust} \propto {\rm SFR}^{1.11}$$

da Cunha et al. 2010

Dust mass and SFR relation



$$SFR \propto M_{ISM}^{k}$$

Hjorth, Gall & Michalowski, 2013

The Dust Mass Challenge

Who will win the battle?

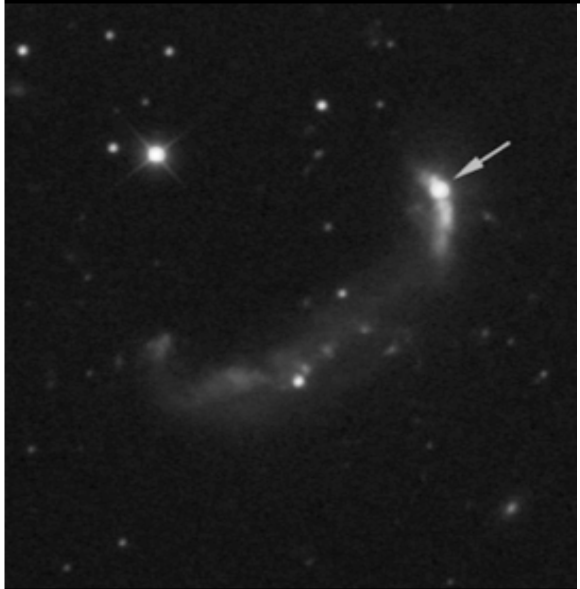
- Supernovae or grain growth?

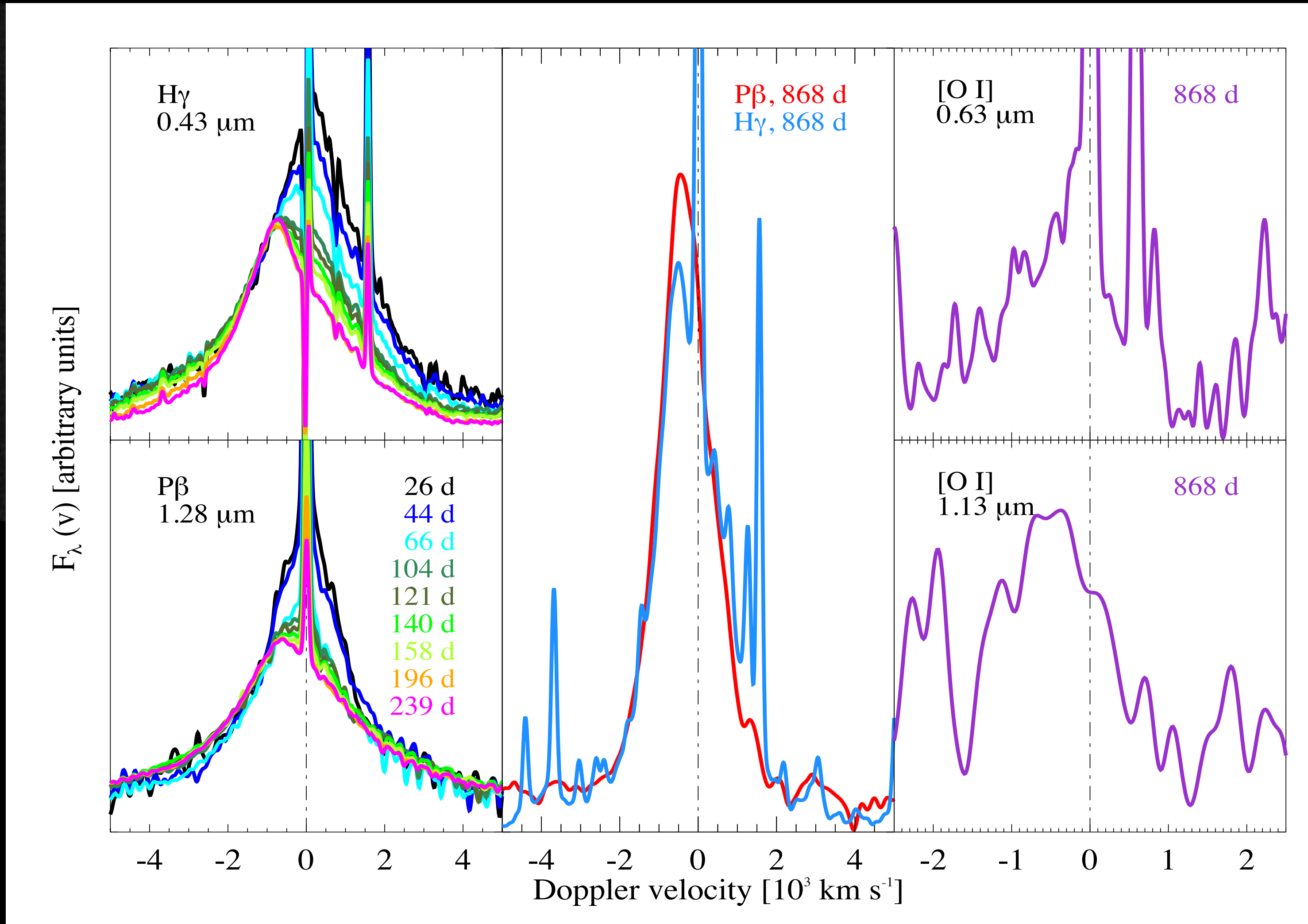
Or

Should we ask another question:

- Is there a balance between dust production and destruction? And what could that be?

Type IIn SN 2010jl, VLT/X-shooter



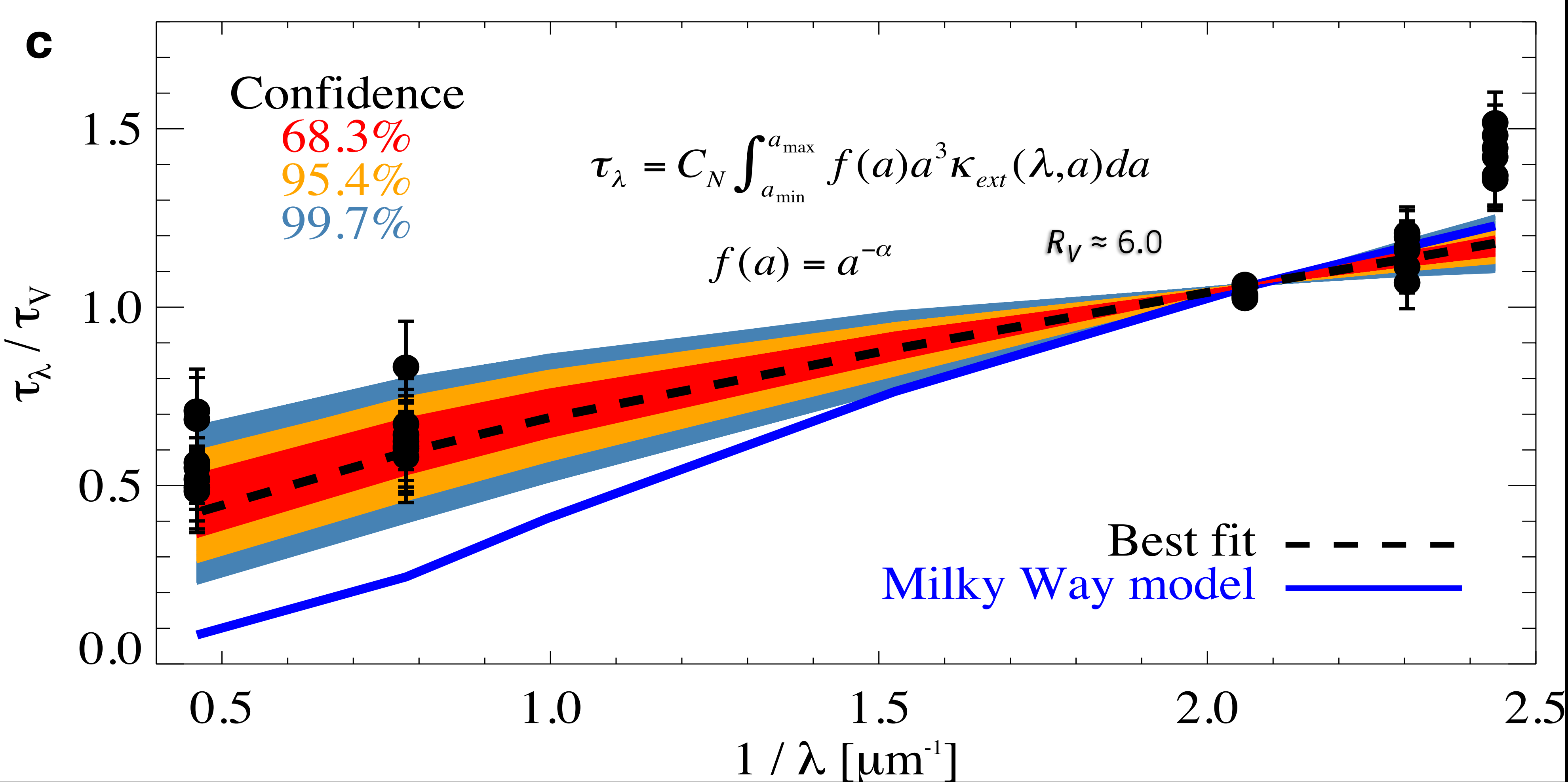


UGC 5189

Redshift of SN
z = 0.01058

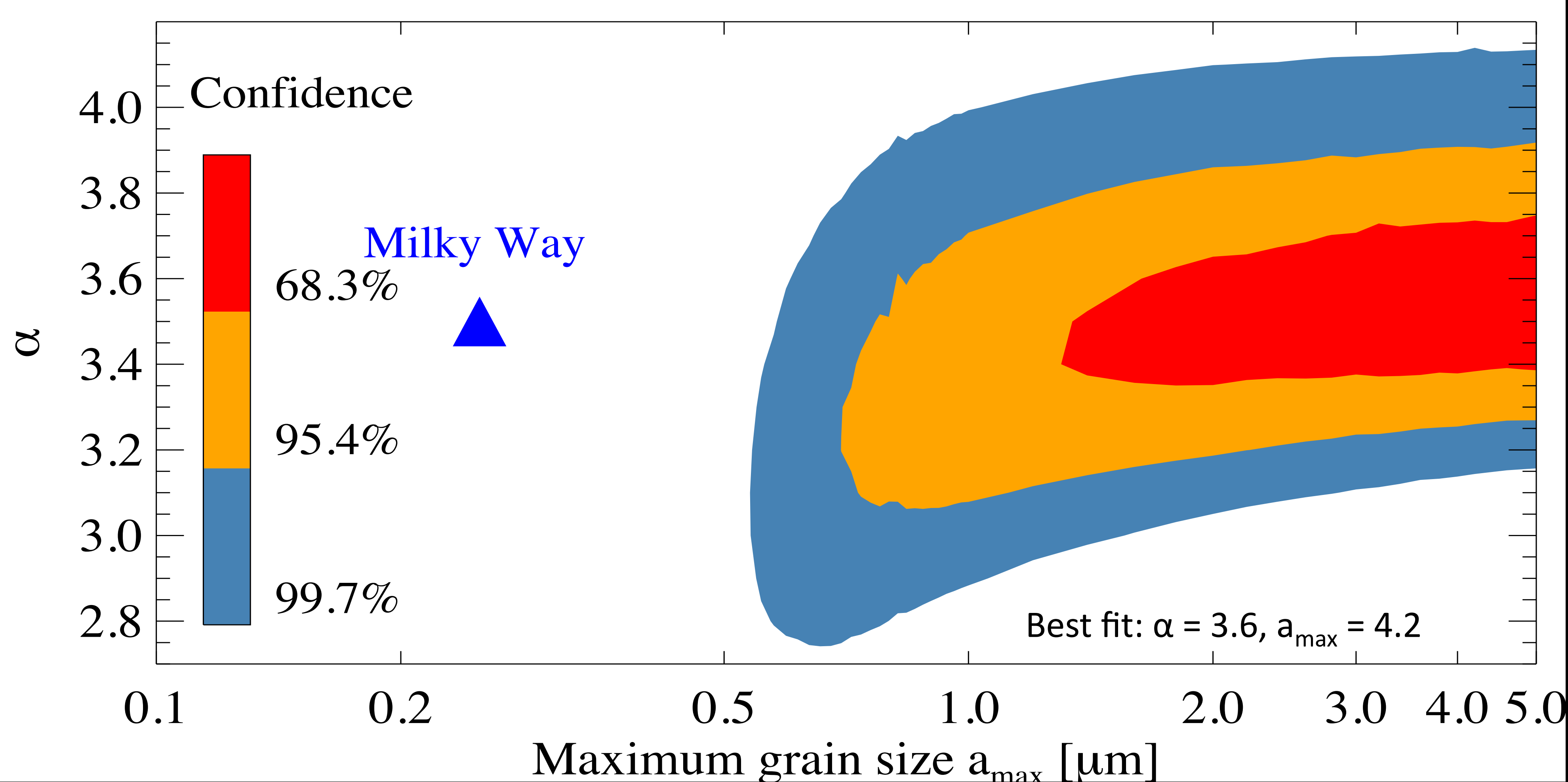
Gall et al. 2013, submitted

Supernova extinction curve



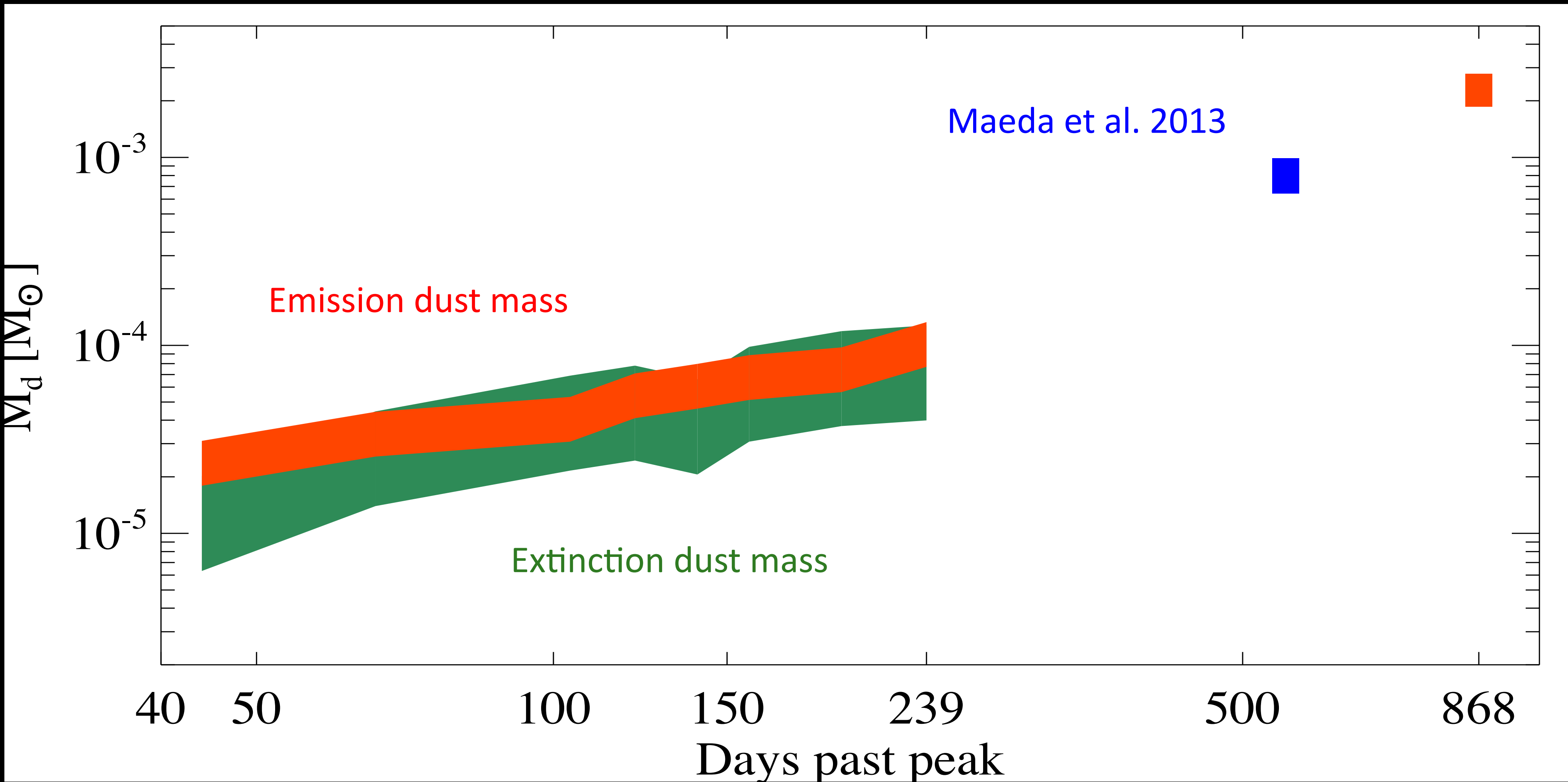
Gall et al. 2013, submitted

Large grains



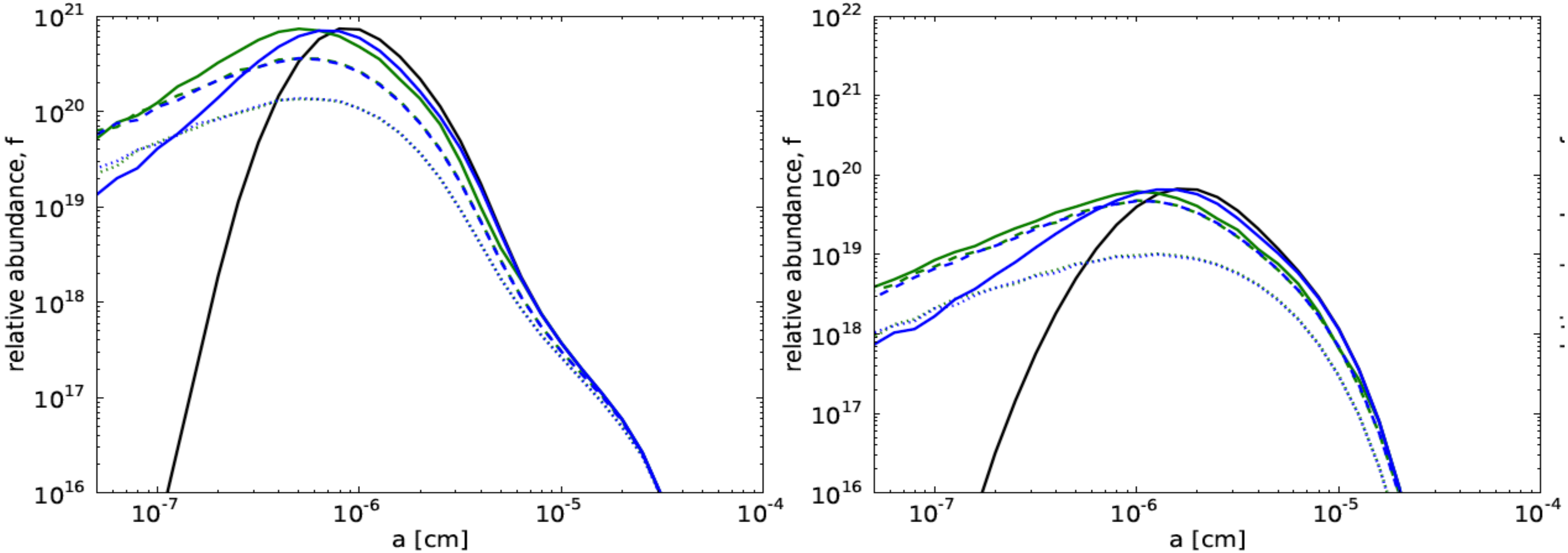
Gall et al. 2013, submitted

Dust mass estimates



Gall et al. 2013, submitted

Large grains are robust against destruction



(a) C (b) Silicates

Silvia et al. 2010

Grains > 0.1 μm have highest survival rate, loosing < 30%

→ SN 2010jl: 80% of dust mass is in form of large grains !!

Summary

How reliable are the observations?

- Dust composition, optical properties, temperature

What are the responsible sources?

- Stellar sources:
  - AGB stars are not major sources at any redshift
  - Progenitors of SNe: dust destruction critical, too little production
  - SNe: Evidence of large and efficient dust production, more observations needed
- None stellar sources:
  - Grain growth likely slow process
  - AGN outflows, winds,…. not major sources

Indication of fast and efficient process of dust formation

- Works with efficient SN dust production
- Dust destruction in the ISM still an issue
- Large grains?

THANK YOU