Star formation at low rates - how a lack of massive stars may affect stellar feedback and the evolution of dwarf galaxies

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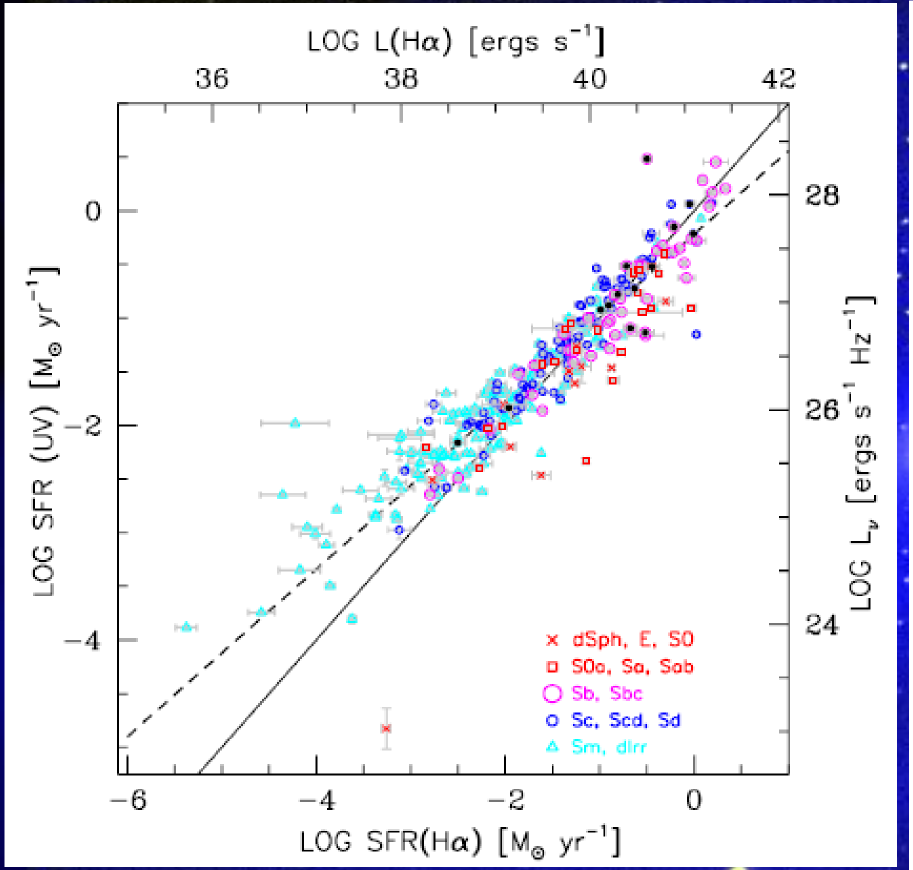
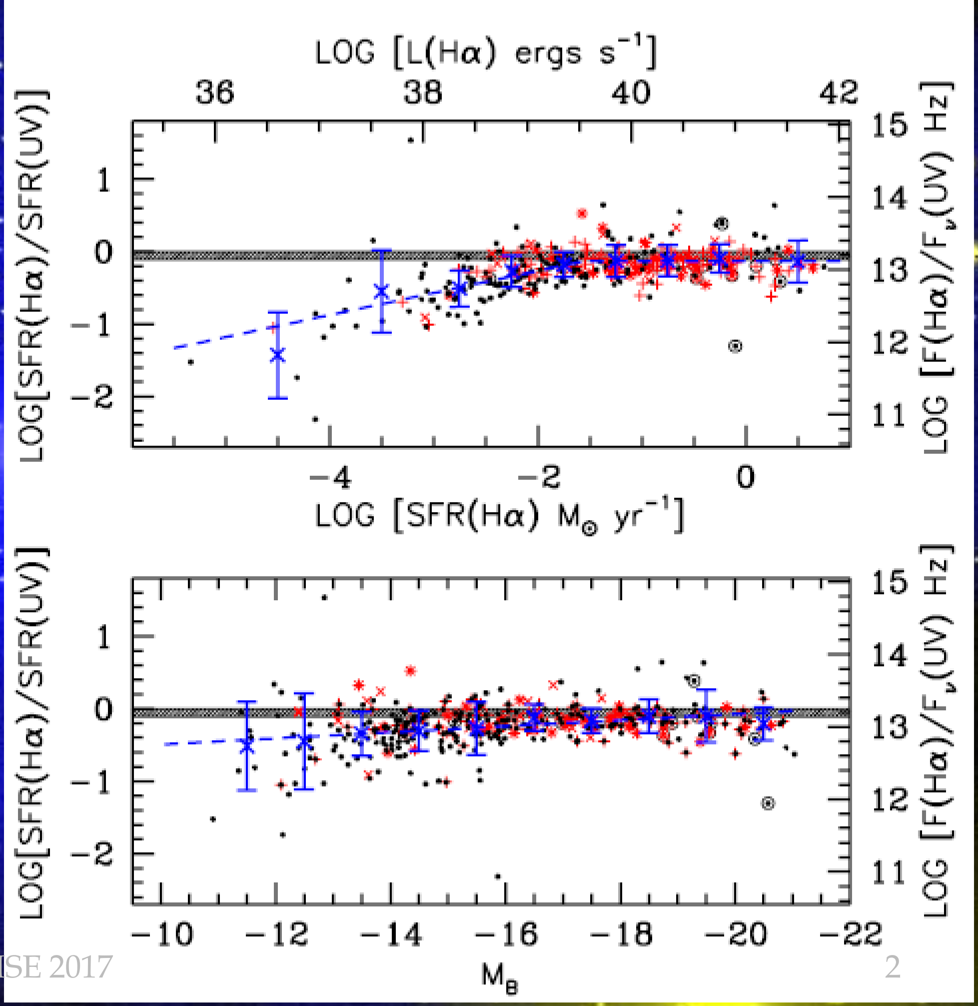
Star formation in DGs mostly at low rates

SFRs derived from indicators, as Hα and UV, resulting from massive stars, normalized to IMF *deviate below ~ 10^{-2} $M_\odot$/yr*

Explanation: Hα preferably stems on average from higher-mass stars than UV

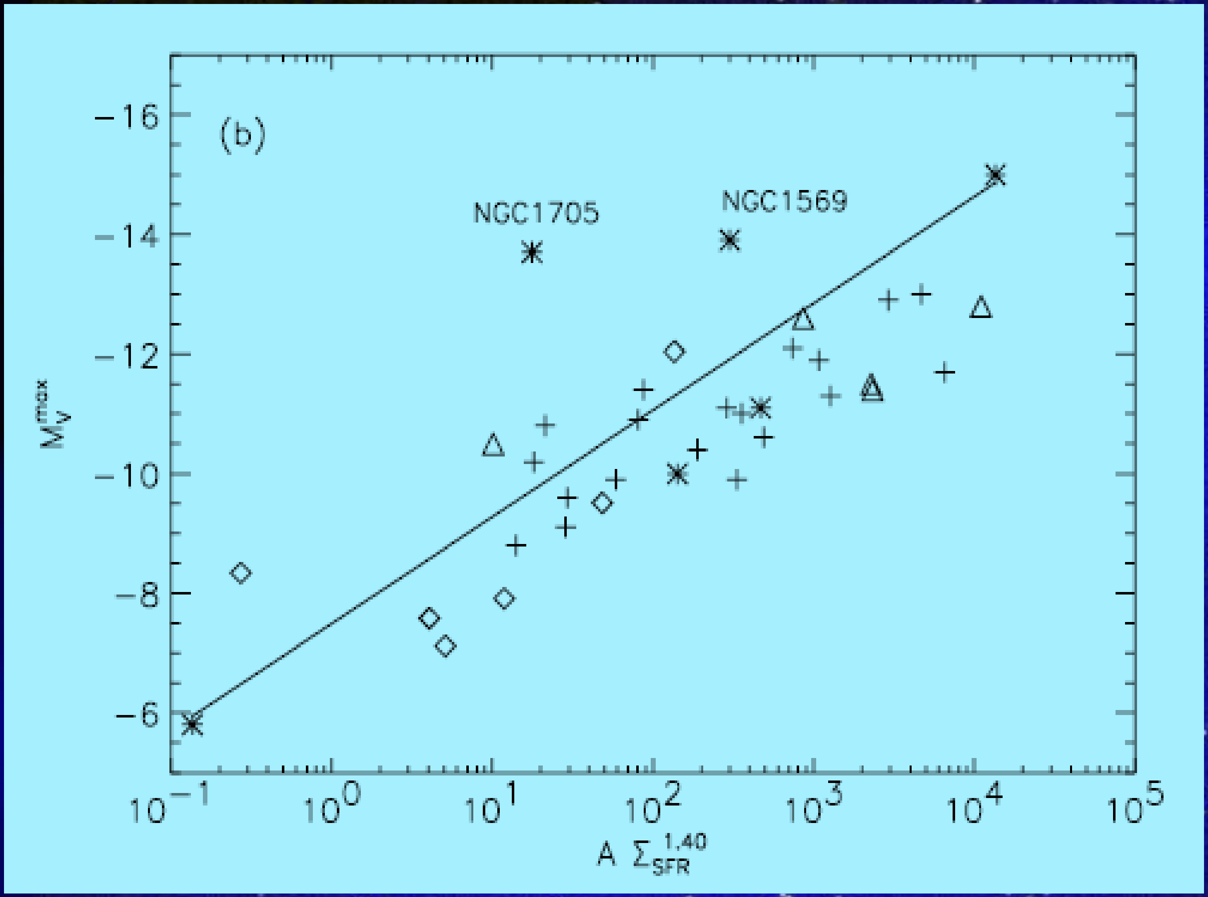
⇒ IMF is not complete in most massive range.





Lee et al., 2009, ApJ, 706

M_V of brightest star cluster vs. column SFR in various galaxies

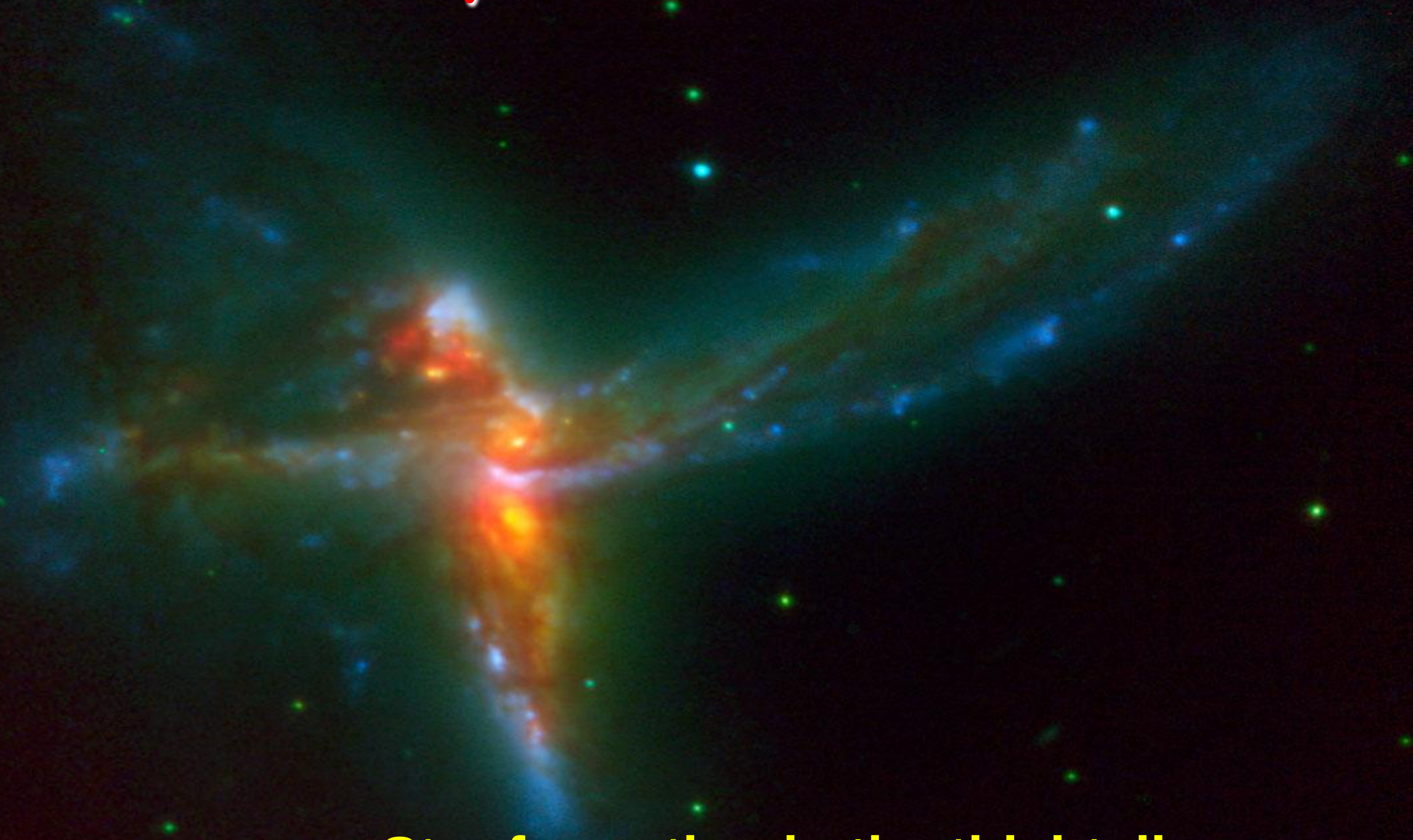


Max. M_V of star clusters in a galaxy is correlated with the SFR K-S law.

Exceptions are starburst galaxies forming super star clusters.

Larsen, 2002, AJ, 124

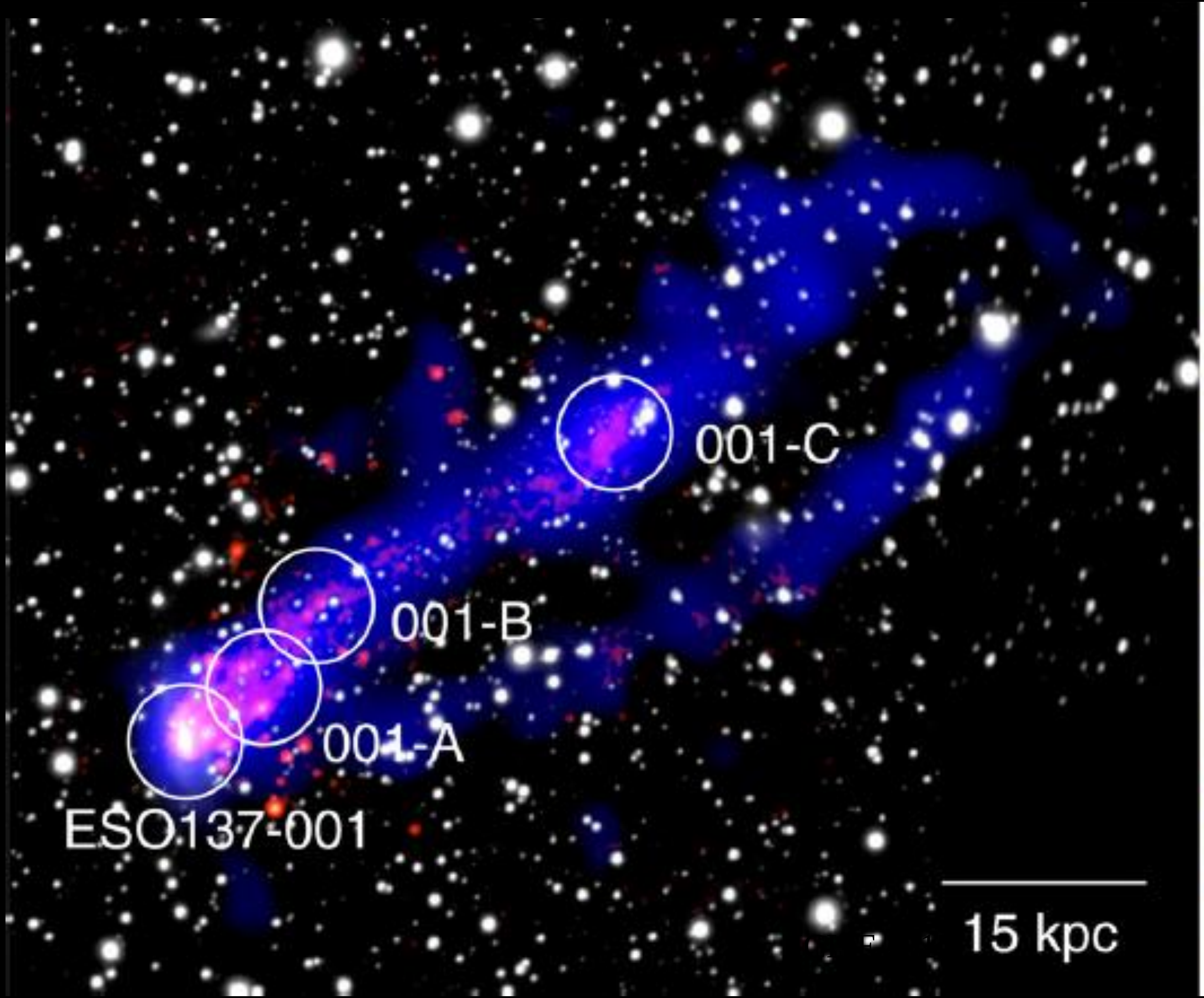
Tinker Bell Triplett: The "Bird" with extremely low SFRs in TDGs



Star formation in the tidal-tail blobs with rates ~ 10^{-4} … 10^{-3} $M_{\odot}$/yr

The detection of ESO 137-001

Star formation in the RPS blobs with rates of ~ 10^{-4} … 10^{-3} $M_{\odot}$/yr



More extreme case: Leo P

$M_V \sim -9.4^m$, $M_* \sim 5.7\ 10^5\ M_\odot$

SFR ~ $4.5\ 10^{-5}\ M_\odot$/yr !!!

Can the IMF be global?

What are the consequences of
low star-formation rates
for the evolution of dwarf galaxies?

How is it treatable in numerical models of
galaxy evolution?

Star-formation param.s in numerical models

- *Star-formation dependence*

  $\dot{\rho}_{SF} \propto \rho_g^k$

  + *physical criteria*
  - *Self-gravity*
  - *Density*
  - $\sim n_{mol}$
  - *Temperature*
  - *Jeans mass*
  - ……
- *SF efficiency* ε

Feedback processes

- *Stellar winds: E + p*
- *Stellar radiation: E +* P_{rad}
- *Supernovae II: E + p(!)*
- *Supernovae Ia: E + p(!)*
- *PNe*

Free parameter:

Energy transfer efficiency ξ

$\xi_{Lyc+SW} \approx$ **0.1 … 1%** **(Hensler 2006)**

$\xi_{SNII} \approx$ **1 … 10%**

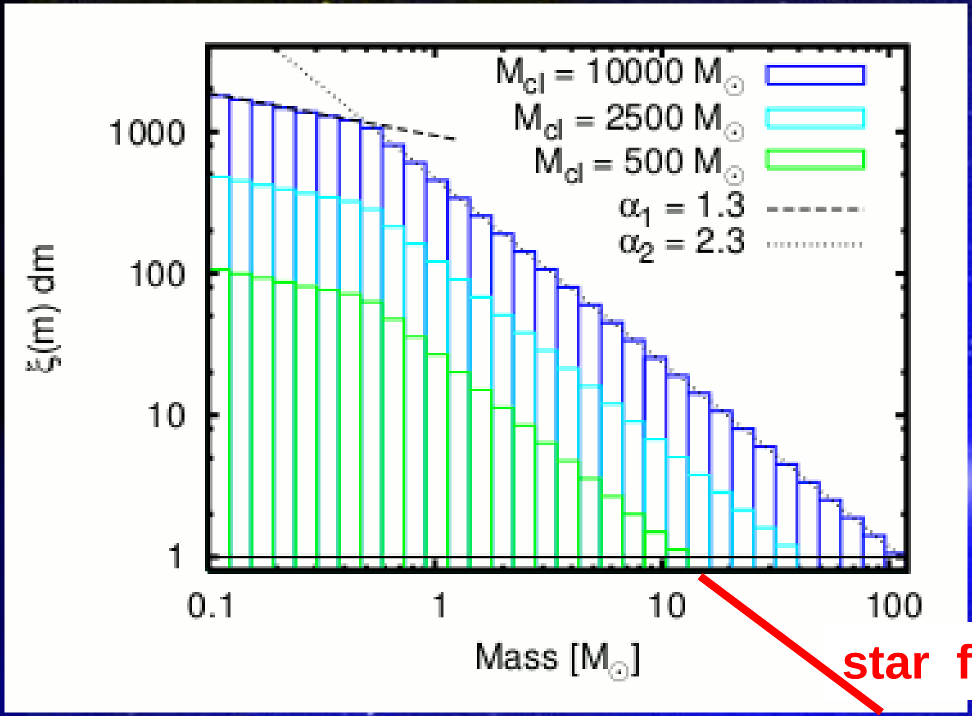
What about the IMF?

SFR of 10^{-2} $M_\odot$/yr over 1 Myr ⇒ 10^4 $M_\odot$ star cluster,
i.e. $SF_{eff} \approx 5\%$ needs M_{cloud} of $2 \cdot 10^5$ $M_\odot$!

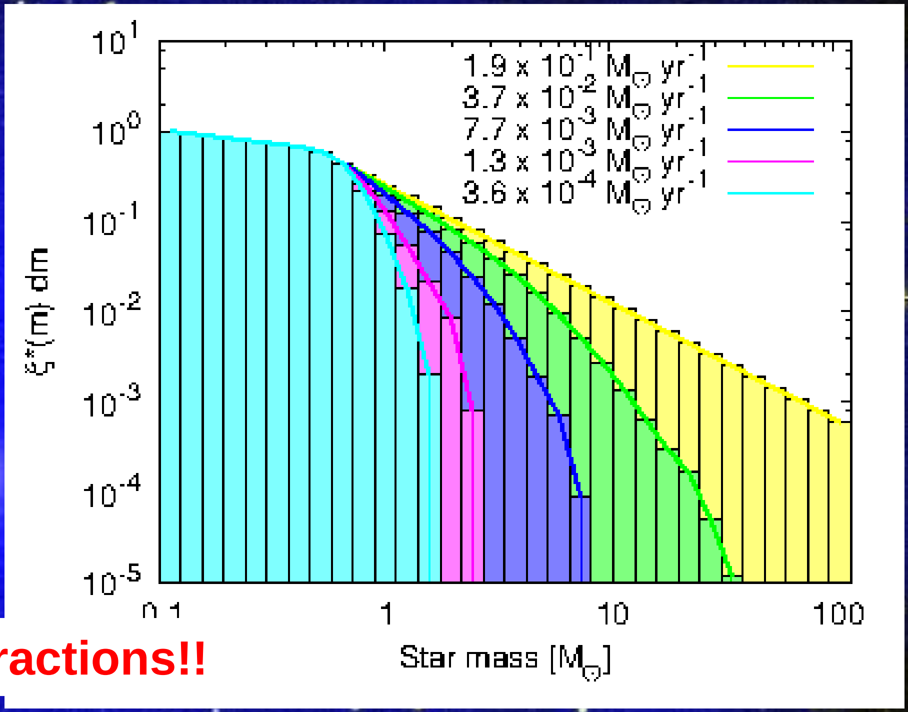
Possibilities to fill the IMF according to the SFR/cloud mass

filled IMF reduced to star fraction

IMF truncated at upper mass interval with N=1



star fractions!!



Ploeckinger, G.H., et al. (2014)

Consequences of low SFR:

- **Filled IMF**: star fractions lead to SNII fractions ⇒ heating?
- **Truncated IMF**: less SF self-regulation? Longer lifetimes of heaviest stars. More low-mass stars! Low SNII rate! But also less SNII energy?

The IMF at low SFR in numerical simulations

At low SFR 3 possibilities emerge:

$$\text{IMF}: \quad \Phi(m) = \frac{dN(m)}{dm} \sim m^{-\alpha}$$

- ***a filled IMF*** **can lead to** ***N(Δm)*** **becoming fractions of 1 only! i.e. for massive stars also** $N_{SNII}(\Delta m)$

$$N(\Delta m) = A \int_{\Delta m} \Phi(m)\, dm = A \int_{m_l}^{m_u} \Phi(m)\, dm$$

$$\text{SFR}: \quad M_*(\Delta m) = A \int_{m_l}^{m_u} m^{-\alpha+1}\, dm$$

- ***The IMF is truncated***

$$\text{condition}: \; N(m_u) \geq 1$$

- ***A stochatic IMF allows for individual massive stars***

Numerical Star-formation recipe

Star-formation self-regulation by stellar feedback

$M_{gas,i} = 1.4 \times 10^8\ M_\odot$; $M_{s,i} = 0$
$M_{DM} = 8.4 \times 10^8\ M_\odot$; $v_{rot} = 30$ km/s

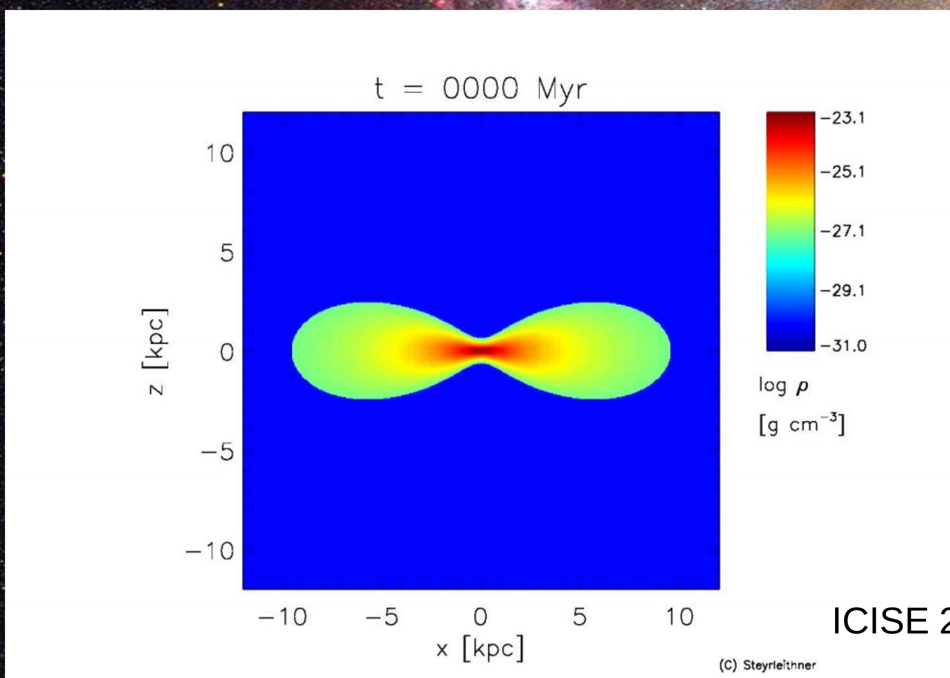
SF as in Köppen, Theis, G.H. (1998, AA, 331)

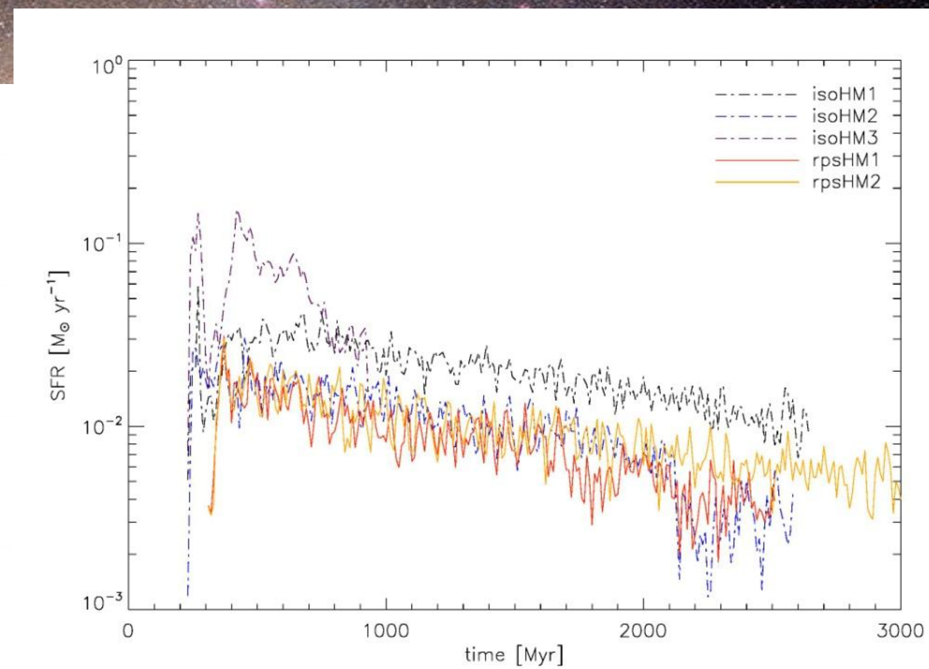
$$\Psi(c,T_c) = C_n c^n \exp\{-T_c / 10^4\, K\}$$

$\xi_{SN} \sim 5\%$

AMR code FLASH

Low star-formation rate;
Massive-star bins not fully with N≥1;
No galactic wind!
SF concentrated to the central part.





Steyrleithner, G.H., et al. (2017)

Numerical IMF recipes and their issues on galaxy evolution

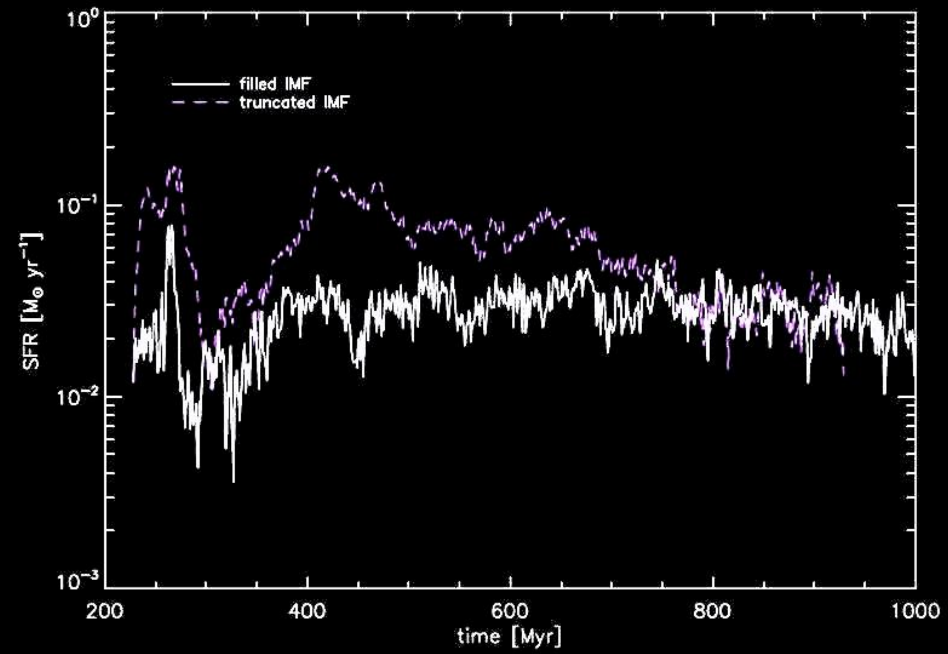
Star-formation self-reg.
stellar radiation+winds
chemistry

Stellar feedback
supernovae II
galactic winds

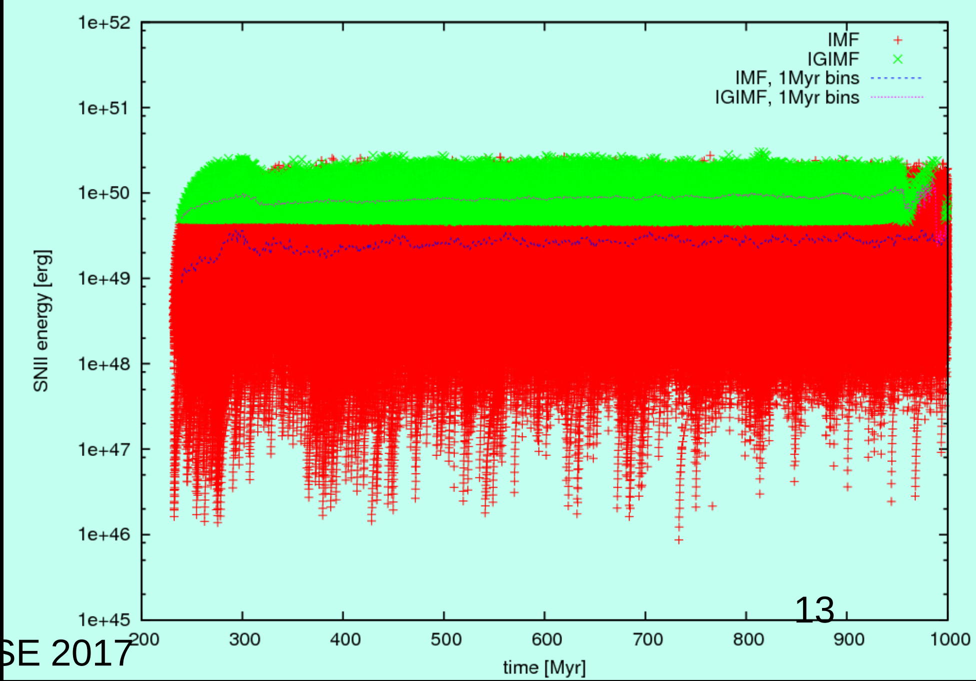
full IMF vs. truncated

Steyrleithner, G.H., et al. (2016)

Energetic feedback by the IMFs



The *truncated IMF* shows higher SFR, i.e. less self-regulation!



The *filled IMF* releases only fractions of SNII energy due to the fractional number of stars in mass bins!
Consequence: Immediate gas cooling!
No sufficient heating to drive a galactic wind.

Steyrleithner, G.H., et al. (2017)

Energetic feedback by the IMFs

For a *truncated IMF* the massive-stars' specific radiative energy feedback is smaller than for a *filled IMF,* because:

$$L_{Lyc,tot} \sim N_{ms}(M)\, L_{Lyc}(M) \sim \int M^{-2.35}\, M^{\beta}\, dM = \int M^{>0}\, dM\ ,\ \beta = 4\ldots6$$

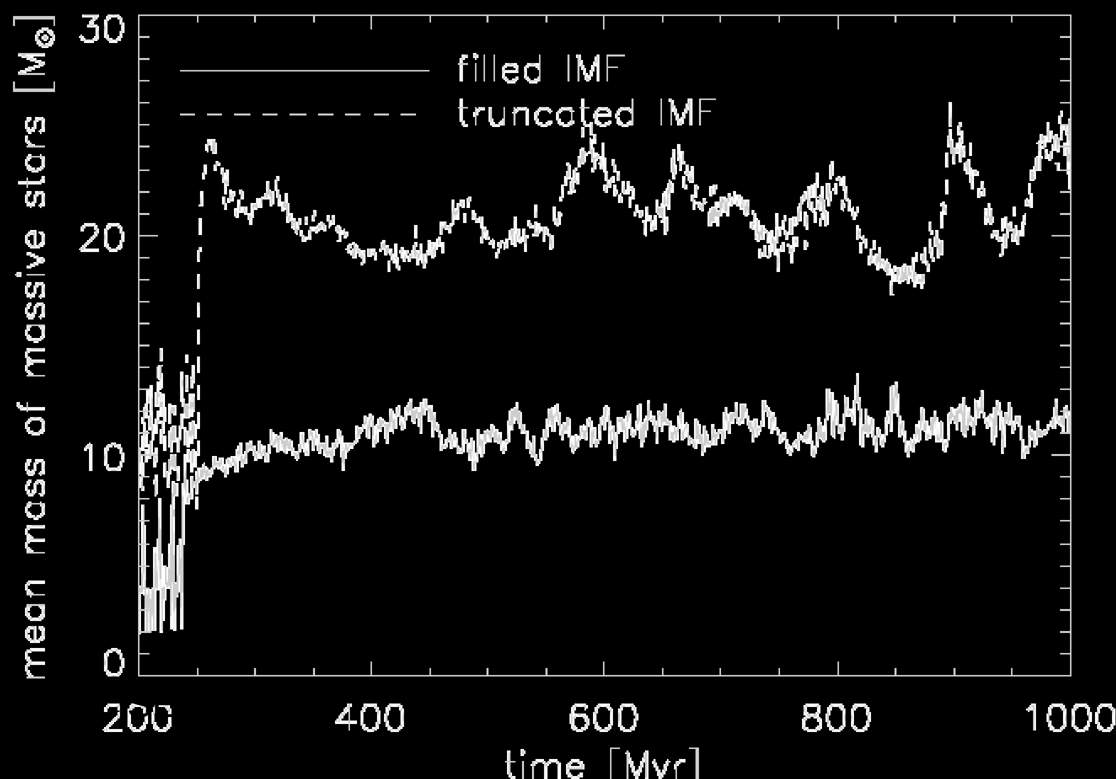
The SNII energy (with an efficiency of $\xi_{SN} \sim 5\%$), however, relates to the star number as $N_{ms} \cdot e_{SN}$

$\Rightarrow$ a *filled IMF* produces

$\leq 1 \cdot e_{SN}$ if

$$M_{ms,tot} = \int^{ms} M\,(M)\, dM \leq \overline{M}_{ms}$$

Then a *truncated IMF* releases more SNII energy than the sum of *filled-IMF* mass fractions.



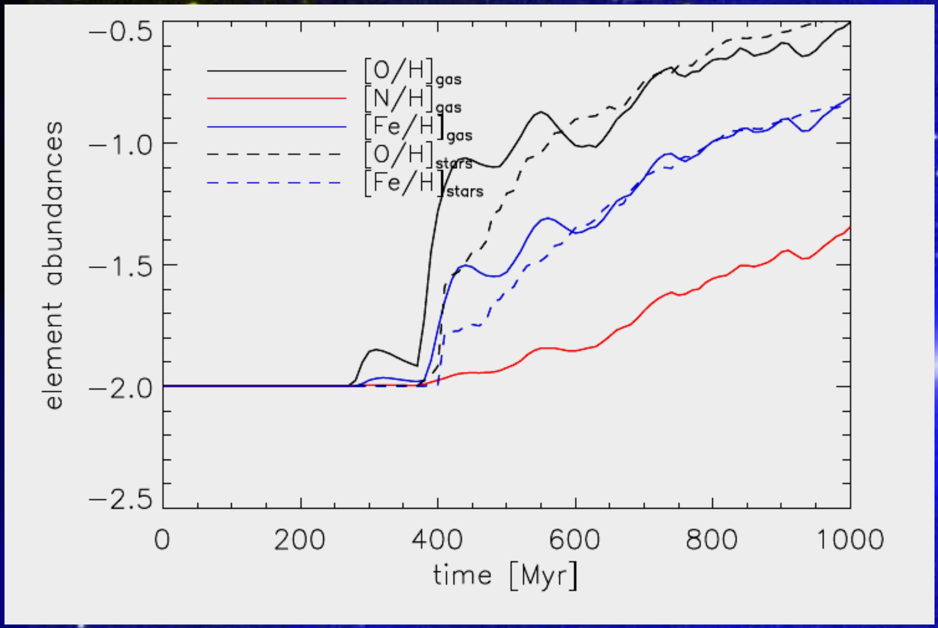
Steyrleithner, G.H., et al. (2017)

Chemical feedback by the IMFs

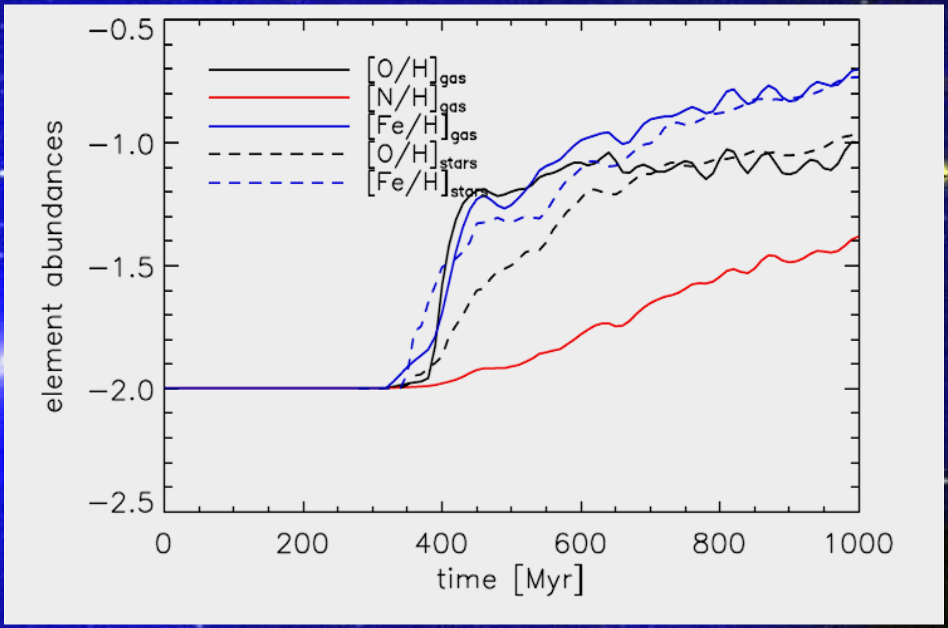
What do we expect?

In the case of lacking massive stars α-element yields should be reduced.

filled IMF



truncated IMF

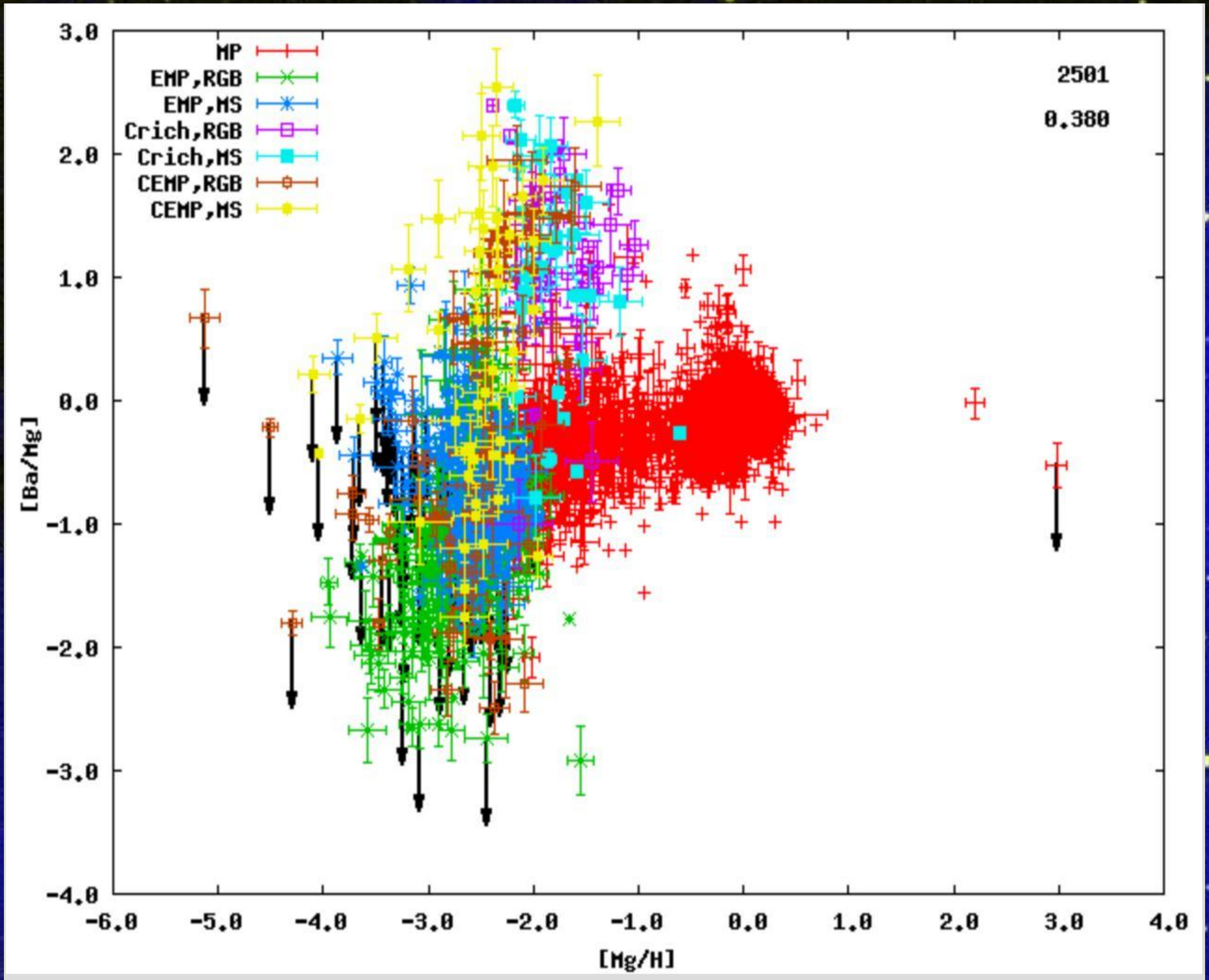


For the *truncated IMF* [O/Fe] becomes < 0; observed e.g. in dSphs.

The same should be studied for Ba vs. Mg!

Steyrleithner , G.H.,et al. (2017)

Ba vs. Mg of MW halo stars



AAS 2017
http://sagadatabase.jp/

Various explanations of the huge Ba/Mg scatter are proposed; the formation of the halo by **disrupted star clusters** (no GCs) of different, but also low masses with various **lack of massive stars** provides a natural explanation.

Summary and Outlook

- ✓ At low SFRs the massive stellar IMF range is not filled!
- ✓ Critical study of their Ha-derived SFR is necessary!
- ✓ At low SFRs the ansatz of *filled IMF* in simulations underestimates the SNII feedback by orders o.m.; leads to too cool bubbles!
- ✓ But efficient SF self-regulation by Lyc and stellar winds!
- ✓ Galactic winds can be driven even by a *truncated IMF*!
- ✓ *Truncated IMFs* change the feedback!
- ✓ The same for *stochastic SF*!
- ✓ Chemical yields of intermediate-mass vs. massive stars change abundance ratios!