Starbursts in isolated galaxies

(Christian Theis, Vienna)

- Motivation
- Model
- Results
  - IMF
  - spontaneous and induced SF
  - ISM model

in collaboration with *Joachim Köppen* (Strasbourg)

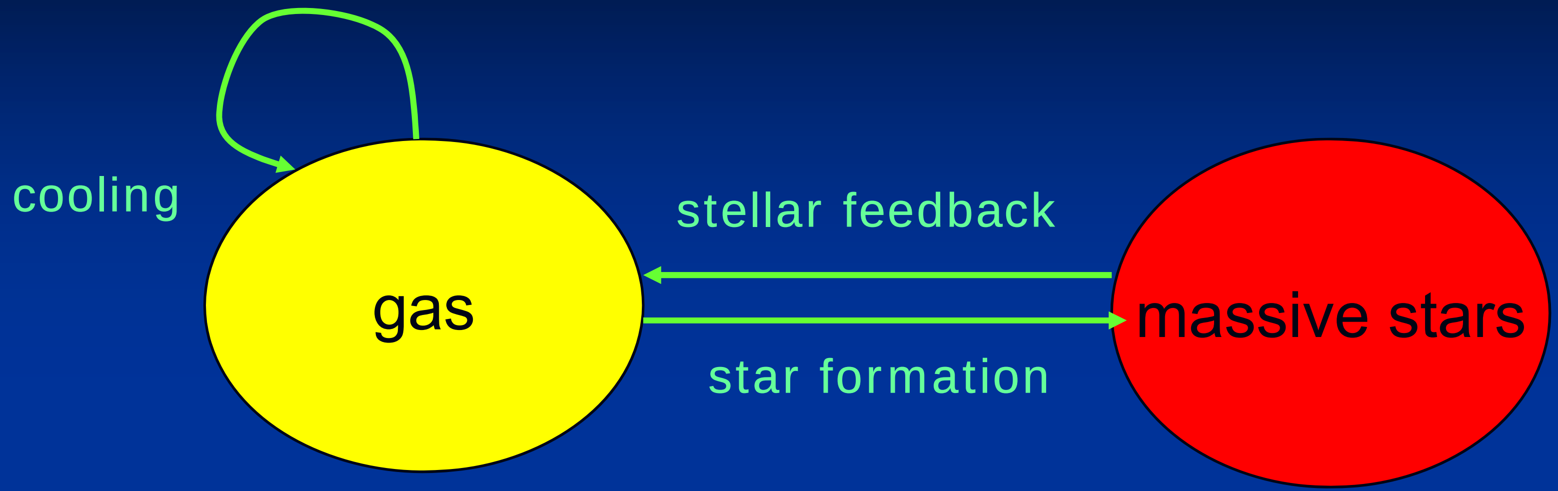
Motivation

- first analysis based on one-zone models
  (e.g. Ikeuchi & Tomita 1983; Ikeuchi, Habe & Tanaka 1984; Scalo & Struck-Marcell 1984, 1986, 1987; Li & Ikeuchi 1989; Köppen, Theis & Hensler 1995, 1997; Hirashita 2000, Quillen & Bland-Hawthorn 2008):

Strong self-regulation

(for immediate feedback)

One-zone model without dynamics



1. gas: $$\frac{dg}{dt} = -\Psi(g,T) + \eta \frac{s}{\tau}$$

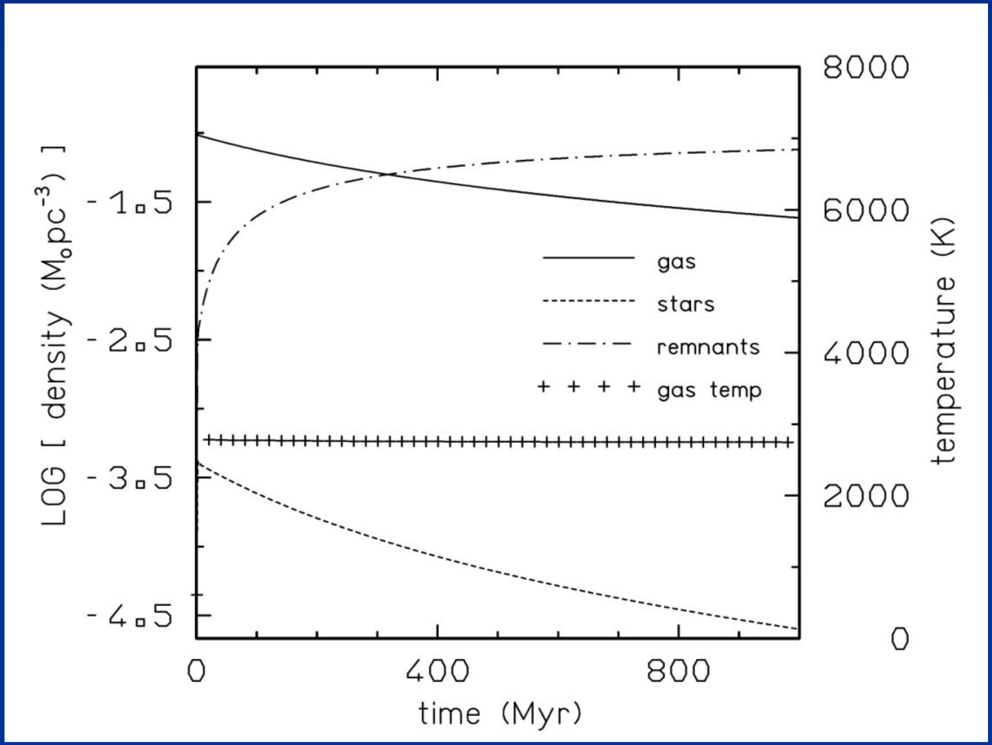
2. massive stars: $$\frac{ds}{dt} = \zeta \Psi(g,T) - \frac{s}{\tau}$$

3. energy of the ISM: $$\frac{de}{dt} = h(g)s - g^2 \Lambda(\mathrm{T})$$

stellar birth function: $\Psi(g,T) = C_n g^n f(T)$ with $f(T) = \exp(-T/T_s)$

One-zone model: self-regulated SF

Evolution of a box model



Involved timescales:

$$\tau_{heat} \equiv \frac{e}{h(g)s} \sim 5 \cdot 10^{-4} \tau_{SF} (\equiv \frac{g}{\Psi(g,T)})$$

$$\tau_{cool} \equiv \frac{e}{\Lambda(T) g^2} \sim 5 \cdot 10^{-3} \tau_{SF}$$

$\Rightarrow$ thermal equilibrium is quickly established

equilibrium star formation rate:

$$\Psi_e(g,T_e) = g^2 \frac{\Lambda(T_e)}{h(g)\xi\tau}$$

(Köppen, Theis & Hensler 1995)

Problems for creating global star bursts

- Stability problem:

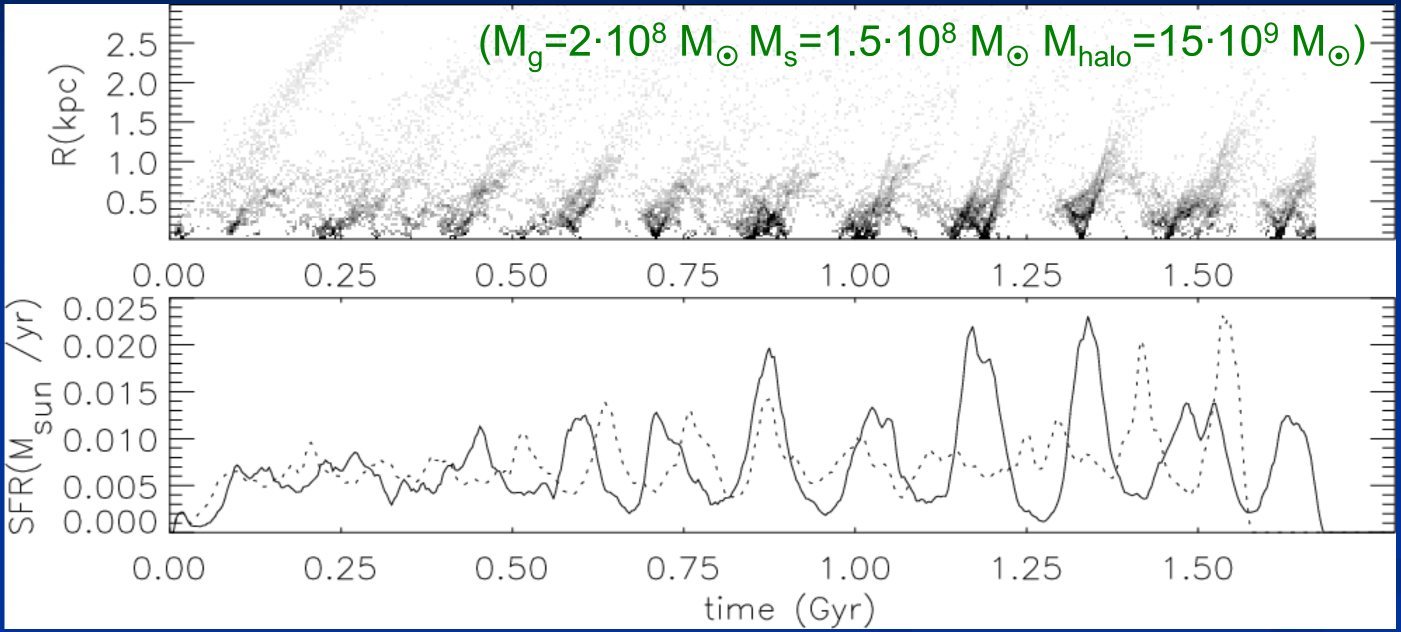
  negative feedback makes many one-zone models very stable

- Coherence problem:

  unstable (small) region will not result in a global burst

- but:
  - Dynamics is missing in most models
  - Different galactic regions are not coupled

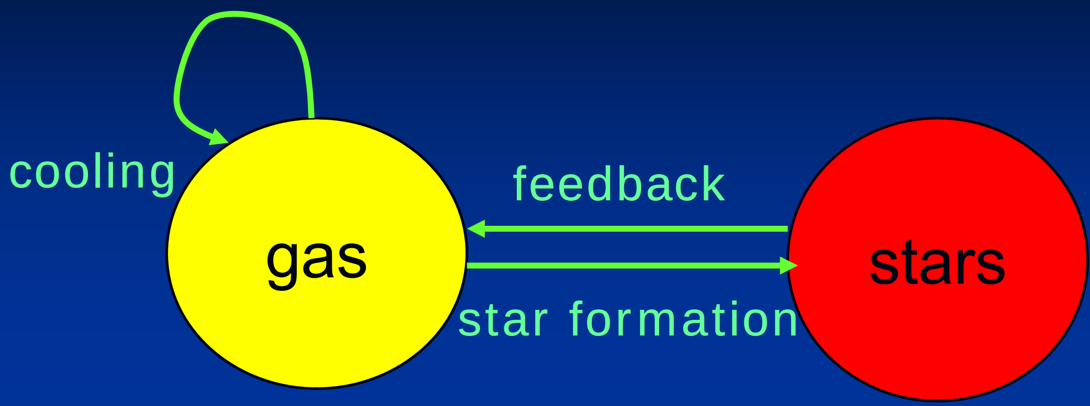
Example from a 3D model



(Pelupessy, van der Werf & Icke 2004)

- 3D Nbody-SPH model for a disk-like dwarf galaxy
- Stellar feedback is included
- Burst period is related to the dynamical timescale

One-zone model - II: Adding dynamics



+ description for mean size R_S of the baryonic mass distribution
+ *PdV* term in energy eq.

1. gas: $$\frac{dg}{dt} = -\Psi(g,T) + \eta \frac{s}{\tau}$$

2. massive stars: $$\frac{ds}{dt} = \zeta \Psi(g,T) - \frac{s}{\tau}$$

3. energy of the ISM: $$\frac{de}{dt} = h(g)s - g^2 \Lambda(\mathrm{T})$$

stellar birth function: $$\Psi(g,T) = C_n g^n f(T)$$

$\Rightarrow$ Quantities like mass density $g=M_g / (4/3\ \pi\ R_s^3)$ depend not only on gas consumption and stellar feedback, but also on dynamical state (R_s).

One-zone model - II: Adding dynamics

Dynamical evolution approximated by motion of a shell in a static dark matter potential:

$$\frac{d^2 R_s}{dt^2} = \mathrm{Gravity} + \mathrm{Pressure} + \mathrm{Ang.\ Mom.} + \mathrm{Friction}$$

1. Gravity: $$-\left.\frac{d\Phi_{\mathrm{DM}}}{dr}\right|_{r=R_S} - \frac{1}{2}\frac{GM}{R_S^2}$$ (DM halo: Burkert 1995)

2. Pressure: $$-C_P \cdot \frac{1}{g} \cdot \frac{dP}{dr} \sim +\frac{T}{R_s}$$

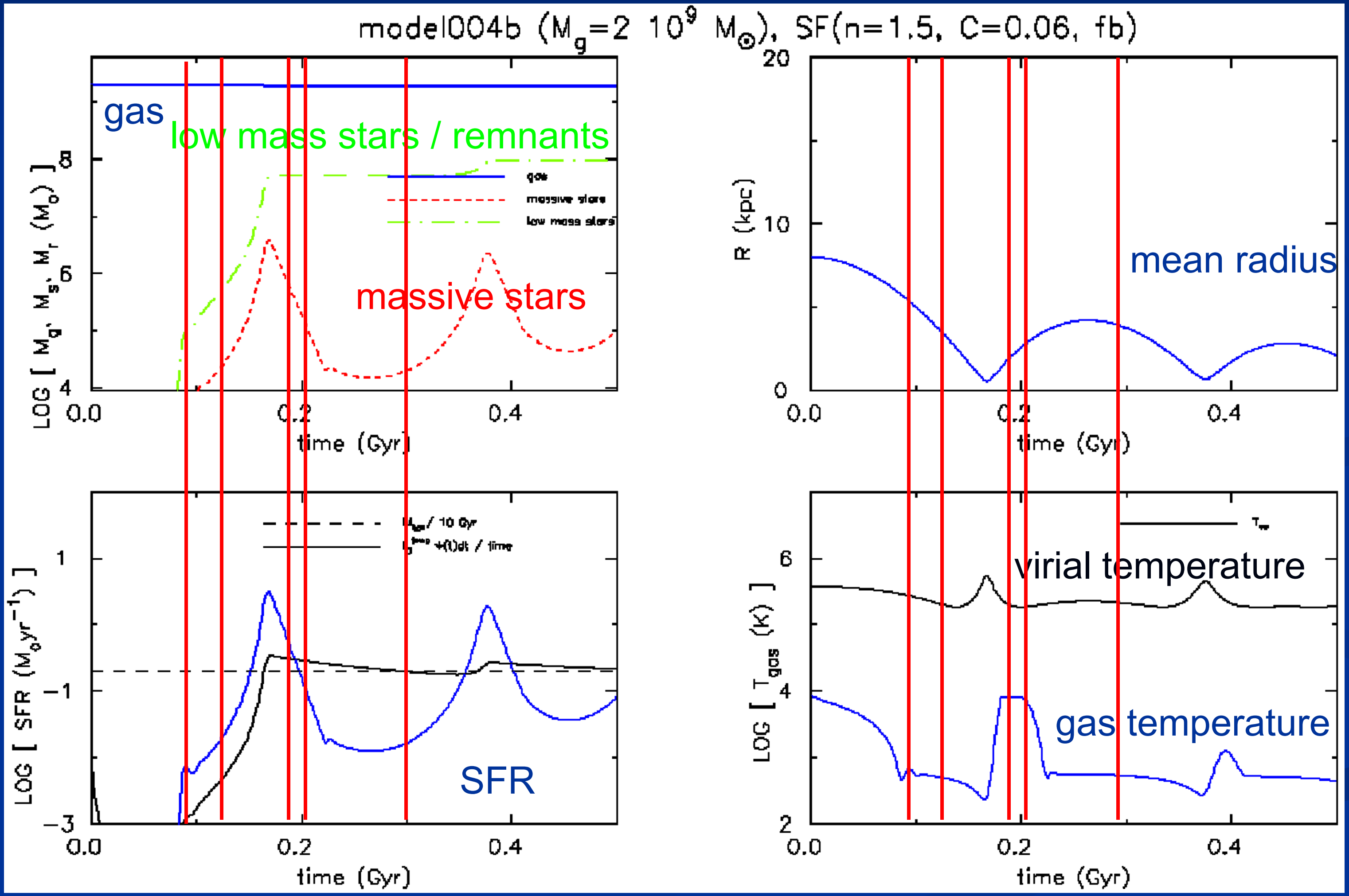
3. Angular momentum: $$+\frac{j^2}{R_S^3} = \frac{\left(C_j \cdot j_{\max}\right)^2}{R_S^3}$$

4. Friction: $$-\frac{v_{\mathrm{rad}}}{\tau_{\mathrm{fric}}} \quad \text{with} \quad \tau_{\mathrm{fric}} \equiv \mathrm{C}_{\mathrm{fric}} \cdot \tau_{\mathrm{ff}}(r = r_0)$$

An example...

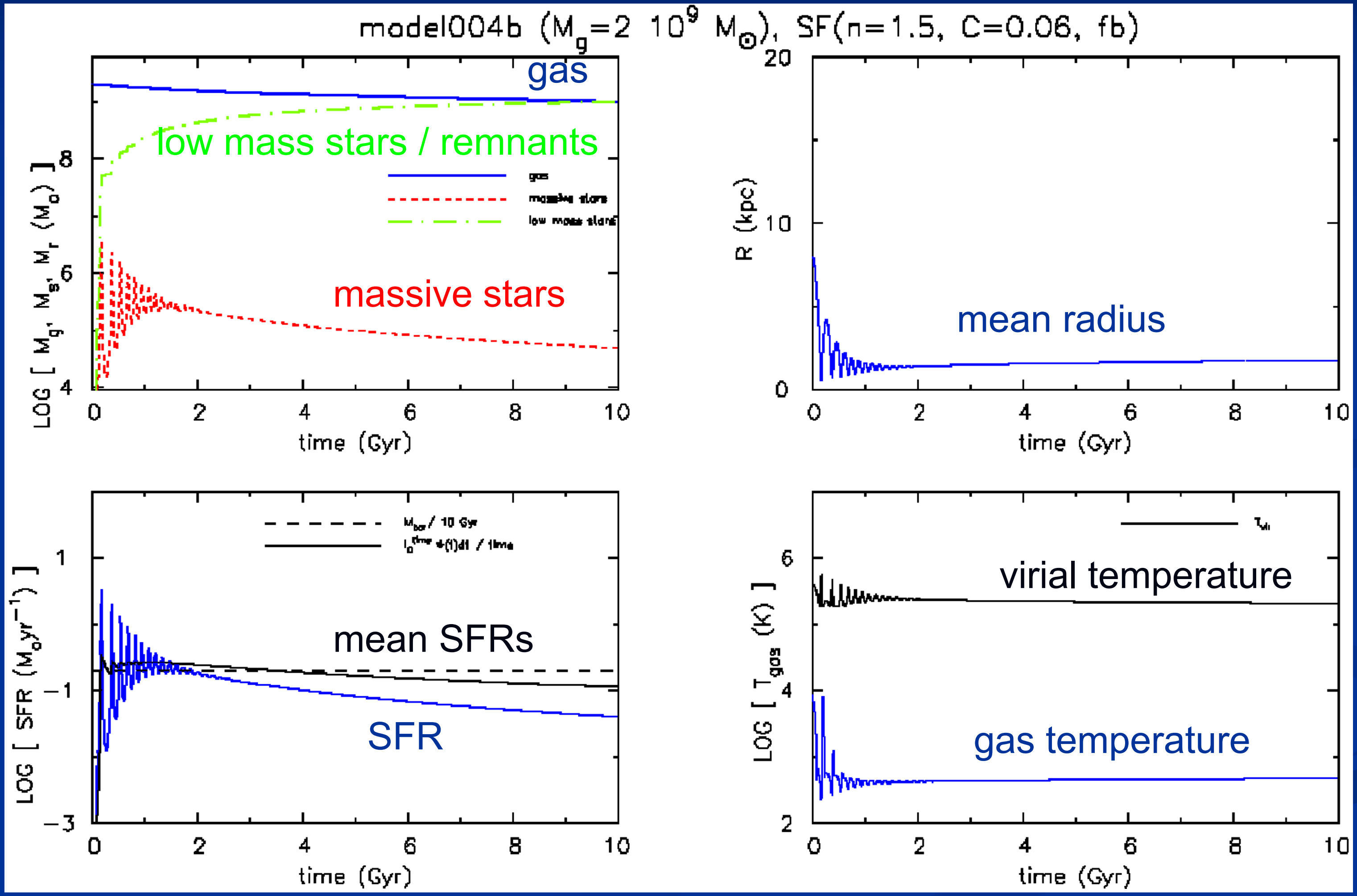
- Star formation: non-linear Schmidt law (n=1.5) with thermal feedback term
- Dissipation: radiative cooling
- $M_{gas}=2\cdot10^9\ M_\odot$ within $R_{ini}=8$ kpc
- Dark matter: $r_0=8$ kpc, $f_{bar}\sim10\%$

An example...



model004b (M_g=2 10^9 $M_\odot$), SF(n=1.5, C=0.06, fb)
gas
low mass stars / remnants
massive stars
gas
massive stars
low mass stars
LOG [M_g, M_s, M_r ($M_\odot$)]
time (Gyr)
R (kpc)
mean radius
time (Gyr)
LOG [SFR ($M_\odot yr^{-1}$)]
SFR
time (Gyr)
LOG [T_{gas} (K)]
virial temperature
gas temperature
time (Gyr)

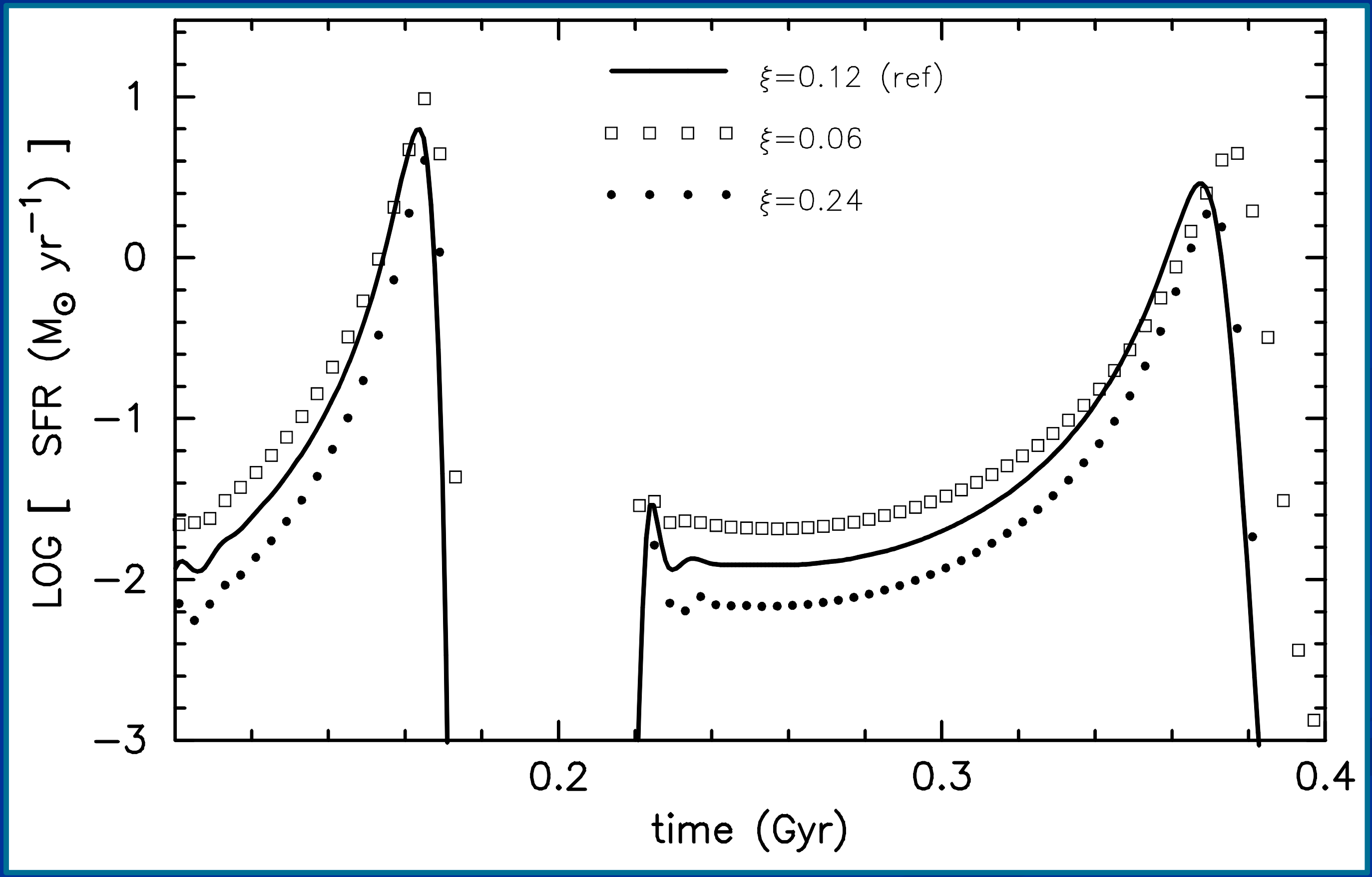
An example...



model004b (Mg=2 10^9 M⊙), SF(n=1.5, C=0.06, fb)
gas
low mass stars / remnants
massive stars
LOG [Mg, Ms, Mr (M⊙)]
time (Gyr)
mean radius
R (kpc)
time (Gyr)
mean SFRs
SFR
LOG [SFR (M⊙yr−1)]
time (Gyr)
virial temperature
gas temperature
LOG [Tgas (K)]
time (Gyr)

Model with different IMF

variation of the mass fraction of massive stars by a factor of 2



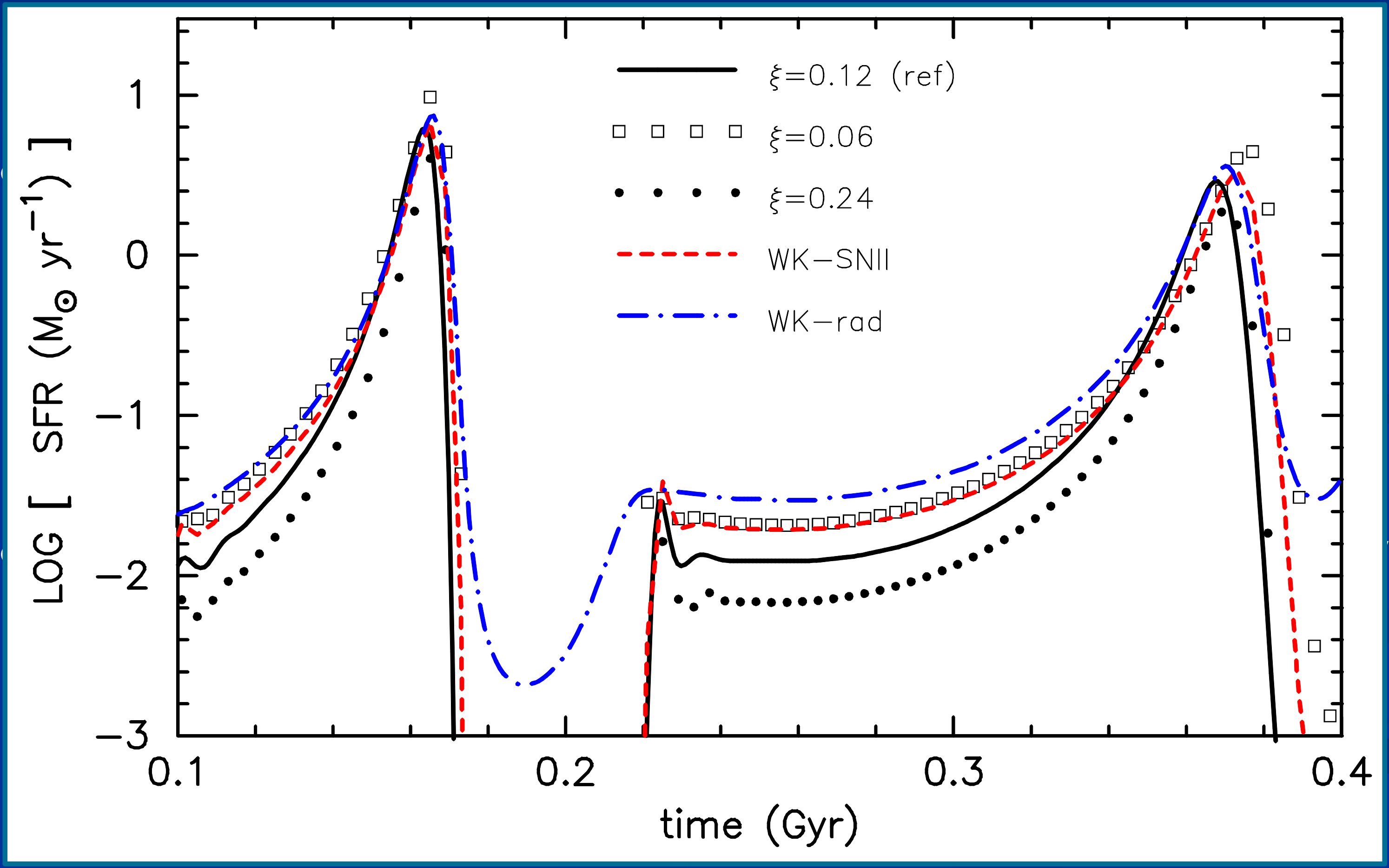
(Theis & Köppen 2009)

A temporally variable IMF

- Weidner/Kroupa-IMF (2005, 2006):
  - IMF depends on global SFR
  - Influence on stellar heating (number of massive stars; upper mass limit)
  - correction factor $f_{WK}(\psi)$:

$$f_{\mathrm{WK}}(\Psi)=\begin{cases}1-0.8e^{-x/2} & \text{for } x \geq 0 \\ 0.2e^{x} & \phantom{\text{for }} x < 0\end{cases} \quad \text{with } x \equiv 3+\log[\Psi/(\mathrm{M}_{\odot}\mathrm{yr}^{-1})]$$

Model with WK-type IMF



(Theis & Köppen 2009)

Induced Star Formation

- extension of stellar birth function:

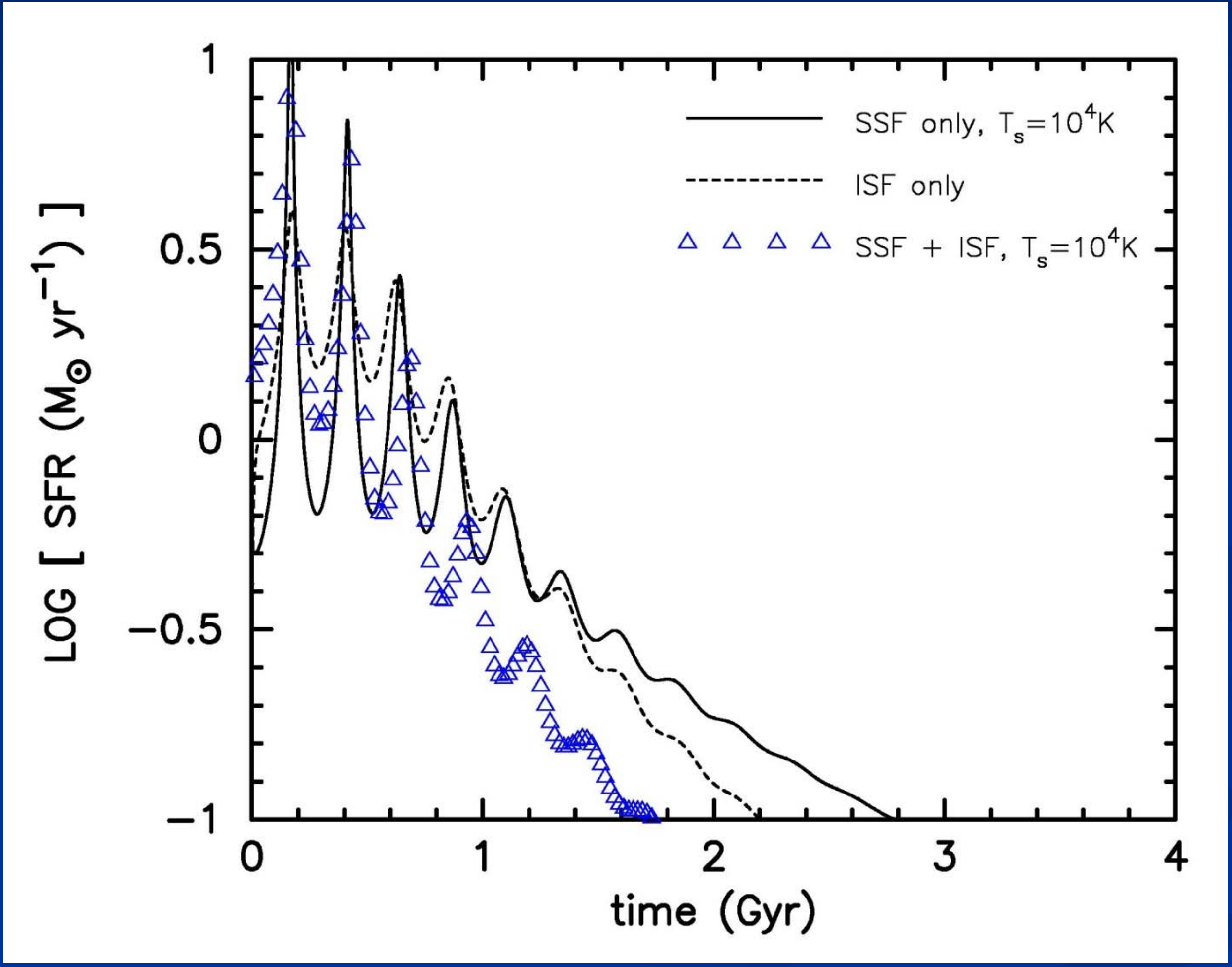
$$\Psi_b(g,T;s,R) = \Psi_{b,sp}(g,T) + \Psi_{b,in}(g,s,R)$$

- new term: SN induced star formation due to material swept up in SN shells

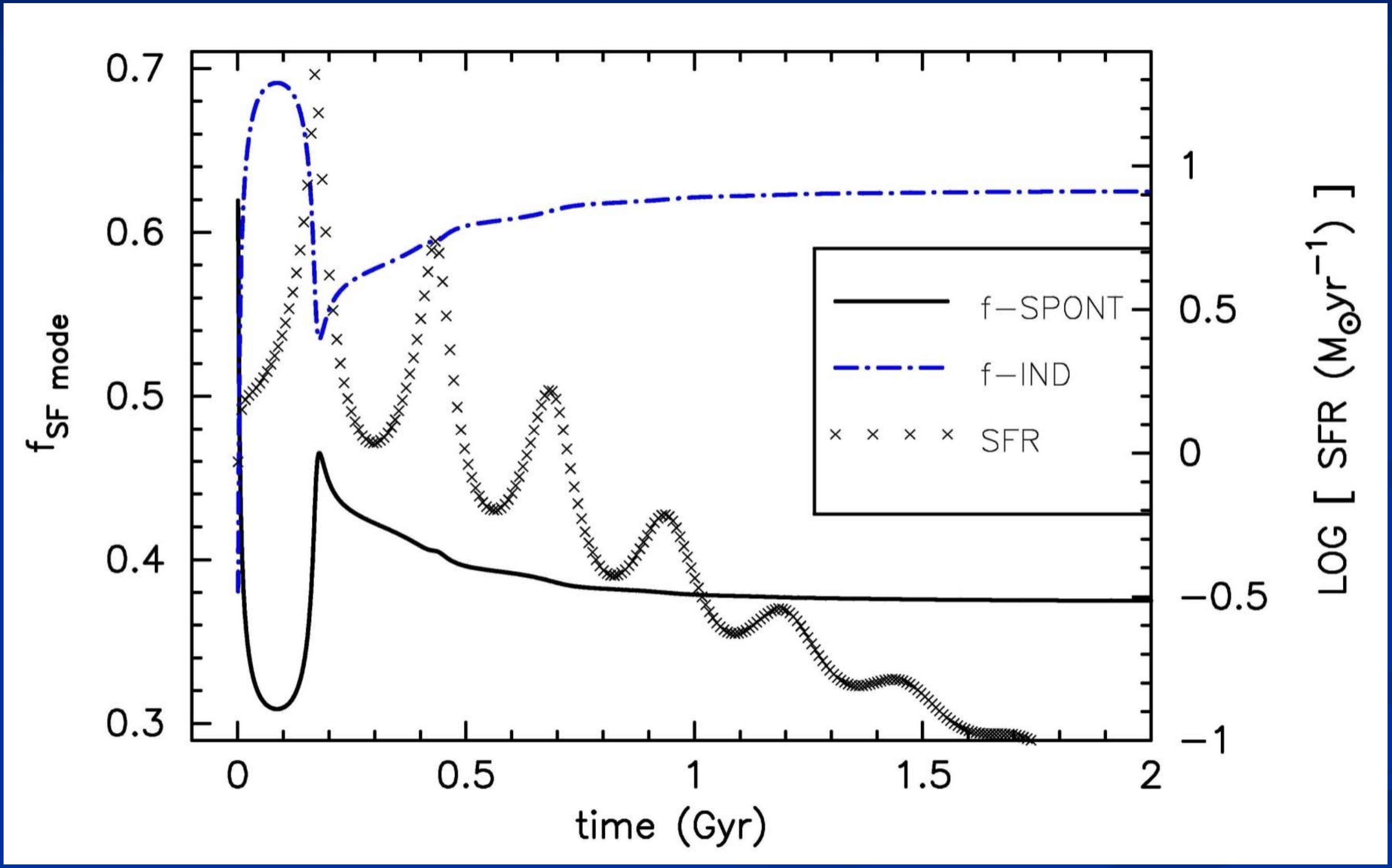
$$\Psi_{b,in}(g,s,R) \equiv \frac{\eta_i g}{\tau_i} \cdot f_i(R_{\mathrm{sh}}(s,g),R)$$

- f_i: volume fraction of galaxy covered by SN shells, estimated by $f_i(R_{\mathrm{sh}}(s,g),\ R) \equiv 1 - e^{-(R_{\mathrm{sh}}/R)^3}$
- η_i: efficiency factor for SF in shell (~0.1)

Induced Star Formation



Induced Star Formation



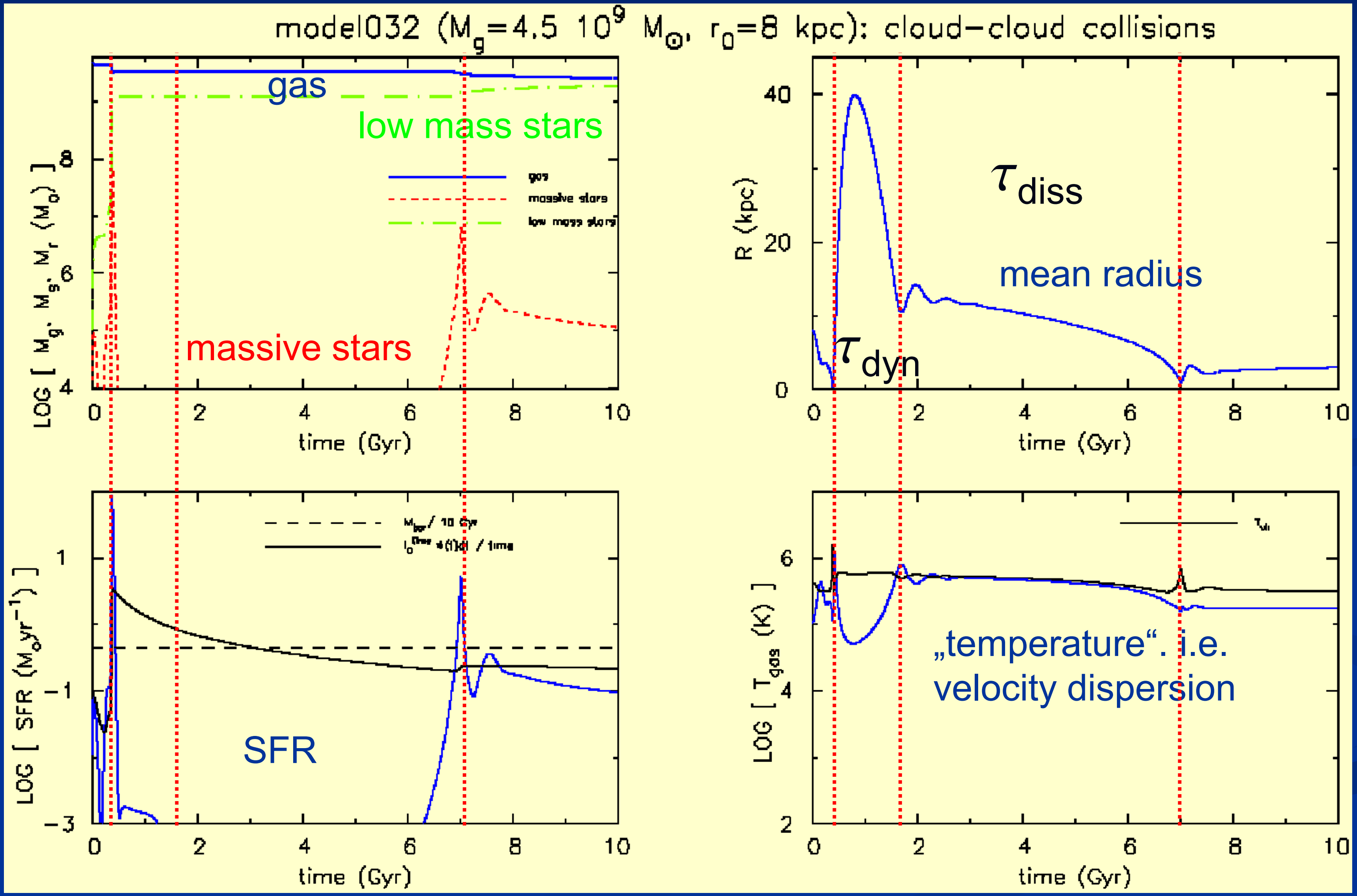
(Theis & Köppen 2009)

Models with dissipation by inelastic cloud-cloud collisions

- If ISM is strongly fragmented, kinetic energy (deposed in random motion) is dissipated by inelastic clump-clump collisions
- Dissipation rate scales formally similar to radiative cooling: $de/dt = C_{diss} g^2 \sim e/\tau_{coll}$
- Collisional timescale:

$$\tau_{coll} \equiv \frac{1}{n_{cl} A_{cr} v_{rel}} \approx 0.97 \left(\frac{M_g}{10^9 M_O} \right)^{-1} \left(\frac{R_S}{5\mathrm{kpc}} \right)^{7/2} \left(\frac{M_{DM}(R_S)}{10^{10} M_O} \right)^{-1/2} \mathrm{Gyr}$$

Dissipation by cloud collisions



Summary

- A) **Dissipation by radiation:**
  - Self-regulated evolution
  - Star formation follows dynamics:
    - ➔ (initial transitory) virial oscillations
  - Global dynamics independent of SF
  - Behaviour very robust w.r.t. SF recipe (parametrization, type of SF, IMF, heating…)
- B) Additional burst type for long dissipational timescales (➔ dependence on nature of dissipation in ISM):
  - long quiescent phases possible