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**

**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: 
\[ \frac{de}{dt} = h(g)s - g^2 \Lambda(T) \]

Stellar birth function: 
\[ \Psi(g,T) = C_n g^n f(T) \quad \text{with} \quad f(T) = \exp(-T/T_s) \]
One-zone model: self-regulated SF

Evolution of a box model

Involved timescales:

\[ \tau_{\text{heat}} \equiv \frac{e}{h(g_s)} \sim 5 \cdot 10^{-4} \tau_{\text{SF}} \equiv \frac{g}{\Psi(g,T)} \]

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

\Rightarrow \text{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

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

(Pelupessy, van der Werf & Icke 2004)

(M_g=2\cdot10^8 \, M_\odot \, M_s=1.5\cdot10^8 \, M_\odot \, M_{\text{halo}}=15\cdot10^9 \, M_\odot)
One-zone model - II: Adding dynamics

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

2. massive stars:
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stellar birth function:
\[ \Psi(g, T) = C_n g^n f(T) \]

⇒ 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 \( R_s \).

+ description for mean size \( R_s \) of the baryonic mass distribution

+ \( PdV \) term in energy eq.
One-zone model - II: Adding dynamics

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

\[
\frac{d^2 R_s}{dt^2} = \text{Gravity} + \text{Pressure} + \text{Ang. Mom.} + \text{Friction}
\]

1. Gravity:
   \[
   - \frac{d\Phi_{DM}}{dr} \bigg|_{r=R_s} - \frac{1}{2} \frac{GM}{R_s^2}
   \]
   (DM halo: Burkert 1995)

2. Pressure:
   \[
   - C_p \cdot \frac{1}{g} \cdot \frac{dP}{dr} \sim + \frac{T}{R_s}
   \]

3. Angular momentum:
   \[
   + \frac{j^2}{R_s^3} = \left( \frac{C_j \cdot j_{\text{max}}}{R_s^3} \right)^2
   \]

4. Friction:
   \[
   - \frac{v_{\text{rad}}}{\tau_{\text{fric}}} \quad \text{with} \quad \tau_{\text{fric}} \equiv C_{\text{fric}} \cdot \tau_{\text{ff}}(r = r_0)
   \]
An example...

- **Star formation**: non-linear Schmidt law \( (n=1.5) \) with thermal feedback term
- **Dissipation**: radiative cooling
- \( M_{\text{gas}} = 2 \cdot 10^9 M_\odot \) within \( R_{\text{ini}} = 8 \) kpc
- Dark matter: \( r_0 = 8 \) kpc, \( f_{\text{bar}} \approx 10\% \)
An example...

- **mean radius**
- **virial temperature**
- **gas temperature**
- **massive stars**
- **low mass stars / remnants**
- **gas**
- **SFR**

![Graphs showing various parameters over time](image)
An example...

**Graphs:**
- **Model:** Model 004b ($M_g = 2 \times 10^9 M_\odot$, SF($n=1.5$, $C=0.06$, fb))
- **Axes:**
  - **LOG $[M_g, M_e, M_b] (M_\odot)$** vs. **time (Gyr)**
  - **R (kpc)** vs. **time (Gyr)**
  - **LOG [SFR] (M_\odot yr^{-1})** vs. **time (Gyr)**
  - **LOG [$T_{gas}$ (K)]** vs. **time (Gyr)**

**Legend:**
- Gas
- Massive stars
- Low mass stars / remnants
- Mean SFRs
- SFR

**Labels:**
- **mean SFRs**
- **gas temperature**
- **mean radius**
- **virial temperature**
Model with different IMF

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

(Theis & Köppen 2009)
A temporally variable IMF

  - IMF depends on global SFR
  - Influence on stellar heating (number of massive stars; upper mass limit)
  - Correction factor $f_{WK}(\psi)$:

$$f_{WK}(\Psi) = \begin{cases} 
1 - 0.8e^{-x/2} & \text{for } x \geq 0 \\
0.2e^x & \text{for } x < 0
\end{cases}$$

with $x \equiv 3 + \log[\Psi / (M_\odot \text{yr}^{-1})]$
Model with WK-type IMF

- SFR almost independent of IMF
- self-regulation is very efficient!
- however: chemical history might vary strongly (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
  \[ \Psi_{b,in}(g, s, R) \equiv \frac{\eta_i g}{\tau_i} \cdot f_i(R_{sh}(s, g), R) \]

- \( f_i \): volume fraction of galaxy covered by SN shells, estimated by
  \[ f_i(R_{sh}(s, g), R) \equiv 1 - e^{-(R_{sh}/R)^3} \]

- \( \eta_i \): efficiency factor for SF in shell (\( \sim 0.1 \))
Induced Star Formation
Induced Star Formation

(Theis & Köppen 2009)
Models with dissipation by inelastic cloud-cloud collisions

- If ISM is strongly fragmented, kinetic energy (deposited in random motion) is dissipated by inelastic clump-clump collisions

- Dissipation rate scales formally similar to radiative cooling: \( \frac{\text{de}}{\text{dt}} = C_{\text{diss}} g^2 \sim e / \tau_{\text{coll}} \)

- Collisional timescale:

\[
\tau_{\text{coll}} \equiv \frac{1}{n_{\text{cl}} A_{\text{cr}} v_{\text{rel}}} \approx 0.97 \left( \frac{M_g}{10^9 M_\odot} \right)^{-1} \left( \frac{R_S}{5 \text{kpc}} \right)^{7/2} \left( \frac{M_{\text{DM}} (R_S)}{10^{10} M_\odot} \right)^{-1/2} \text{ Gyr}
\]
Dissipation by cloud collisions

model032 \( (M_g = 4.5 \times 10^9 M_\odot, \ r_0 = 8 \ \text{kpc}) \): cloud–cloud collisions

\[ \tau_{\text{diss}} \]

mean radius

\[ \tau_{\text{dyn}} \]

velocity dispersion

"temperature", i.e.

SFR

gas

massive stars

low mass stars
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