Vznik hvězd a vývoj galaxií

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The Star Forming Region: 
Carina Nebula
Key Hole Nebula
Eta Carinae
Figure 7  The four stages of star formation. (a) Cores form within molecular clouds as magnetic and turbulent support is lost through ambipolar diffusion. (b) A protostar with a surrounding nebular disk forms at the center of a cloud core collapsing from inside-out. (c) A stellar wind breaks out along the rotational axis of the system, creating a bipolar flow. (d) The infall terminates, revealing a newly formed star with a circumstellar disk.
A Turbulent Cloud
Piontek & Ostriker 2006
Collect and Collapse

Elmegreen & Lada 1977: ApJ 214, 725, Fig. 1
Instability in the CPS separating I and S fronts
Expanding shells in the Milky Way
Ehlerová & Palouš 2005
RCW 79: Triggered Star Formation

Observations of the HII region RCW79 at various wavelengths:
- in orange (infrared): the dust shell that surrounds the HII region B
- in blue: the ionized hydrogen that fills the HII region
- yellow contours (millimeter wavelengths) show cold dust condensations

Near-infrared image of one condensation (NTT - ESO): This region includes a second-generation HII region.
Orion Molecular Complex GS206-17+013
The region of the Sextant
Dwarf Irregular Galaxy IC 2574
Formation of stars

1. gas form stars
2. gas return from stars
3. mass recycling
4. mixing of products of stellar evolution
5. chemical evolution of galaxies
6. stellar generations
7. first stars
Fragmenting Shell

1. Expansion of the HII region

HII region (10,000 K)

Outer molecular material (< 100 K)

2. Formation of a dense layer surrounding the HII region

Ionization front

Shock front

3. Gravitational collapse layer into dense frag

Newborn star surrounded by a compact HII region

4. New stars forming in the frag
The observed mass spectrum

\[ \xi(m) = \frac{dN}{dm} \]
the number of objects in the mass interval 
\((m, m + dm)\)

power-law approximation: \[ \xi(m) \sim m^{-\alpha} \]

- GMC in the Milky Way
  Solomon & Rivolo (1989): \( \alpha = 1.5 \)

- clouds in the outer Galaxy
  Heyer et al. (2001): \( \alpha = 1.8 \)

- molecular clouds in the LMC
  NANTEN, Fukui et al. (2001): \( \alpha = 1.9 \pm 0.1 \)

- the universal stellar IMF, Kroupa (2001):
  \[ \alpha = (0.3 \pm 0.7; 1.3 \pm 0.5; 2.3 \pm 0.3; 2.3 \pm 0.7) \]
  \[ m = (0.01 - 0.08; 0.08 - 0.5; 0.5 - 1.0; > 1.0)M_\odot \]
The scale-free instability

\[ \omega(k) = \frac{2\pi}{t_{\text{growth}}} = \text{const.} \]

- **the number of fragments within R:**
  \[ N = \omega \frac{R^3}{(\lambda/4)^3} = \frac{8\omega R^3 k^3}{\pi^3}, \text{ where } k = \frac{2\pi}{\lambda} \]

- **the mass of a fragment:**
  \[ m = \frac{4}{3} \pi (\lambda/4)^3 \rho = \frac{1}{6} \pi^4 \rho k^{-3} \]

- **the number of fragments between**
  \[ (k, k + dk): dN = \frac{24\omega R^3 k^2}{\pi^3} dk \]

- **the mass spectrum:**
  \[ \xi_{\text{scale-free}}(m) = -\frac{4}{3} \pi R^3 \rho \omega m^{-2} \]
The Jeans instability

\[ \omega(k) = \sqrt{-c^2 k^2 + 4\pi G \rho} \]

\[ \xi_{\text{Jeans}}(m) = -\frac{16}{9} \frac{R^3}{m} \rho \ m^{-2} \left[ -c^2 \left( \frac{\pi^4 \rho}{6m} \right)^{2/3} + 4\pi G \rho \right]^{1/2} \]

The mass spectrum of the scale-free instability (+) and of the Jeans gravitational instability (x) with \( c = 0.3 \text{ km s}^{-1} \), \( \rho = 1.67 \times 10^{-24} \text{ g cm}^{-3} \).
The mass spectrum of a starburst - analytical solution using thin shell

\[
\omega(\eta, t) = -\frac{3V}{R} + \sqrt{\frac{V^2}{R^2} - \frac{c_{sh}^2 \eta^2}{R^2}} + \frac{2\pi G \Sigma_{sh}}{R} \\
\eta = 2\pi R/\lambda
\]

the fragmentation integral: \( I(\eta, t) = \int_{t_b}^{t} \omega(\eta, t')dt' \)

\[
R(t) = 53.1 \times \left( \frac{L}{10^{51} \text{ erg Myr}^{-1}} \right)^{\frac{1}{5}} \times \left( \frac{\mu}{1.3 \text{ cm}^{-3}} \right)^{-\frac{1}{5}} \times \left( \frac{t}{\text{Myr}} \right)^{\frac{3}{5}} \text{ pc}
\]

\[
V(t) = 31.2 \times \left( \frac{L}{10^{51} \text{ erg Myr}^{-1}} \right)^{\frac{1}{5}} \times \left( \frac{\mu}{1.3 \text{ cm}^{-3}} \right)^{-\frac{1}{5}} \times \left( \frac{t}{\text{Myr}} \right)^{-\frac{2}{5}} \text{ kms}^{-1}
\]

\[
\Sigma(t)_{sh} = 0.564 \times \left( \frac{L}{10^{51} \text{ erg Myr}^{-1}} \right)^{\frac{1}{5}} \times \left( \frac{\mu}{1.3 \text{ cm}^{-3}} \right)^{\frac{4}{5}} \times \left( \frac{t}{\text{Myr}} \right)^{\frac{3}{5}} \text{ M}_\odot \text{pc}^{-2}
\]
The mass spectrum of fragments of an expanding shell at time $5t_b$

$$t_b = 28.8 \times \left( \frac{c_{sh}}{\text{km s}^{-1}} \right)^{\frac{5}{8}} \times \left( \frac{L}{10^{51} \text{ erg Myr}^{-1}} \right)^{-\frac{1}{8}} \times \left( \frac{\mu}{1.3 \text{ cm}^{-3}} \right)^{-\frac{1}{2}} \text{ Myr}$$
AMR: $l = 35$, with internal and external pressure, $t = 5$ Myr

- No pressure confinement: long modes unstable only
- External and internal pressure confinement: short modes are also unstable following the thin shell dispersion relation
- Expansion into a low pressure medium: top heavy IMF
- High pressures result in more fragmentation and low mass fragments
Omega Centauri & NGC 2808
Multiple stellar generations in massive GC

$$ (m-M)_0 = 13.35 $$

$$ E(B-V) = 0.12 $$

$$ Z = 10^{-3}, \ Y = 0.246 $$

$$ Z = 2 \times 10^{-3}, \ Y = 0.248 $$

$$ Z = 2 \times 10^{-5}, \ Y = 0.35 $$

$$ Z = 2 \times 10^{-3}, \ Y = 0.45 $$
Fast rotating massive stars

Scenario I
(Cluster evolution at constant mass)
Formation of globular clusters
Slow winds of massive stars form new stars
Today

Scenario II
(Mass segregation)

Massive stars (1st gene)
Low-mass stars (1st gene)
Low-mass stars (2nd gene)
2D hydrodynamical simulation
Galaxies: Stars + ISM + DM
The Milky Way Galaxy
The Whirlpool Galaxy M51
NGC 1097 and Sombrero Galaxies
Stars

1. $N = 10^9 - 10^{12}$
2. gravitational forces
3. $t_{relax} = 0.1 \ (N/\ln \ N) \ t_{cross} = 10^{17} \ yr$
4. $t_{relax} \gg t_{Hubble}$ - galaxies are collisionless systems
5. rotation + random motions:

$$E_{rotation} \gg E_{random}$$
6. stability of the rotating disk:

$$Q = \frac{\sigma_R \kappa}{3.36 \ G \Sigma}$$
7. $Q < 1$ - disk is locally unstable - formation of spiral arms
The Barred Galaxy NGC 1365

![The Barred Galaxy NGC 1365](image_url)
Bars

1. global instability
2. $Q_B = \frac{E_{\text{rotation}}}{E_{\text{potential}}}$
3. bar formation: $Q_B > 0.14$
4. disk warming - $Q$ increases - disk stabilizes
5. formation of bulge
6. increase of $E_{\text{random}}$ - $Q_B < 0.14$
7. bar destruction
The gas

1. dissipative
2. structures
3. turbulent nature
4. supersonic motions
5. instabilities: increase of random motions
6. energy dissipation: decrease of gas random motions
7. it provokes the instabilities
Groups of Galaxies
Ultraluminous Infrared Galaxies
Hubble Space Telescope • WFPC2

NASA and K. Borne (Raytheon ITSS and NASA Goddard Space Flight Center),
H. Buschouse (STScI), L. Colina (Instituto de Física de Cantabria, Spain) and R. Lucas (STScI)
STScI-PRC88-45
Virgo Cluster of Galaxies
The Tides
Toomre & Toomre 1972

Fig. 4.—A flat direct ($\gamma = 0$) parabolic passage of a quasi-axis companion
Antennae: Galaxies in a collision
The Harassment: CL0939 versus Coma (Moore et al. 1995, Nature)
Abel Cluster of Galaxies  03341
Gas Stripping
NGC 4522 in Virgo
SPH simulation of the ISM stripping
Jáchym & Palouš, 2009, A&A
Galaxies in interaction

1. merging of galaxies
2. tidal fields
3. galaxy harassment
4. gas stripping
5. galactic canibalism
6. number of collisions decreases
7. star formation rate decreases