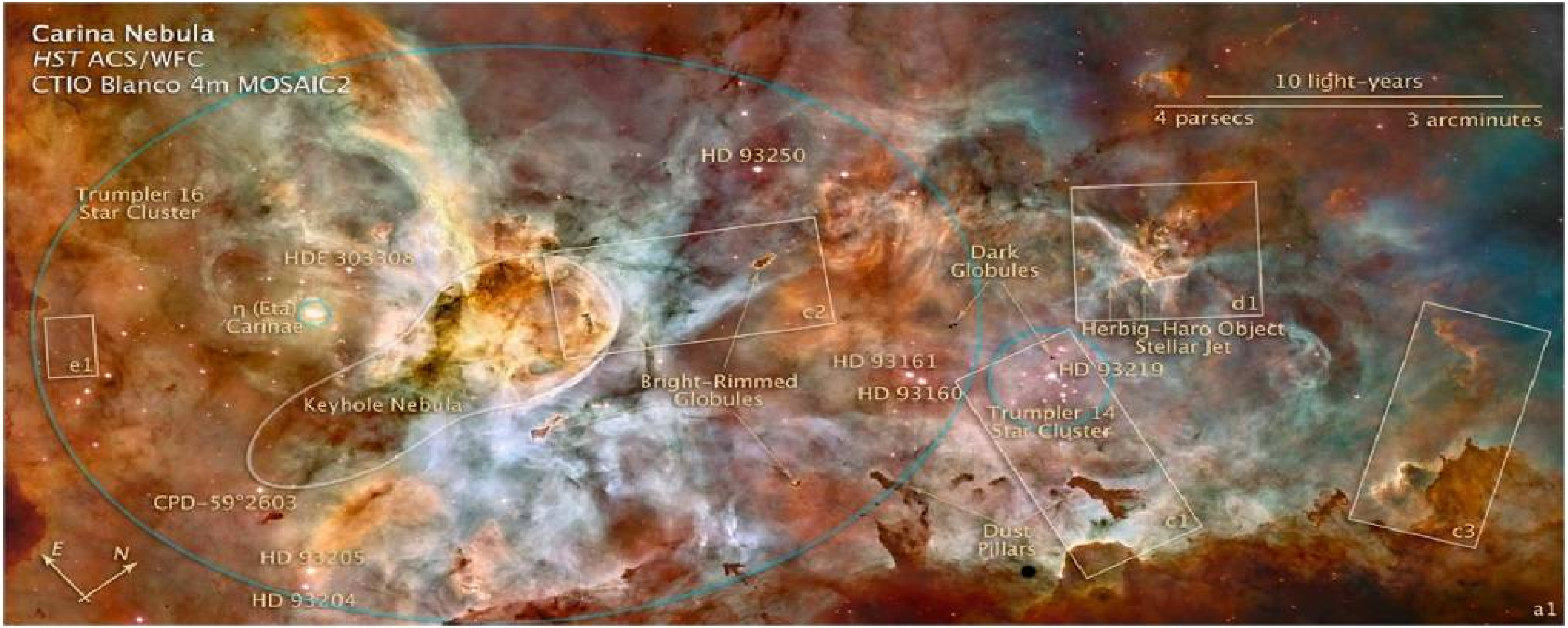
Vznik hvězd a vývoj galaxií

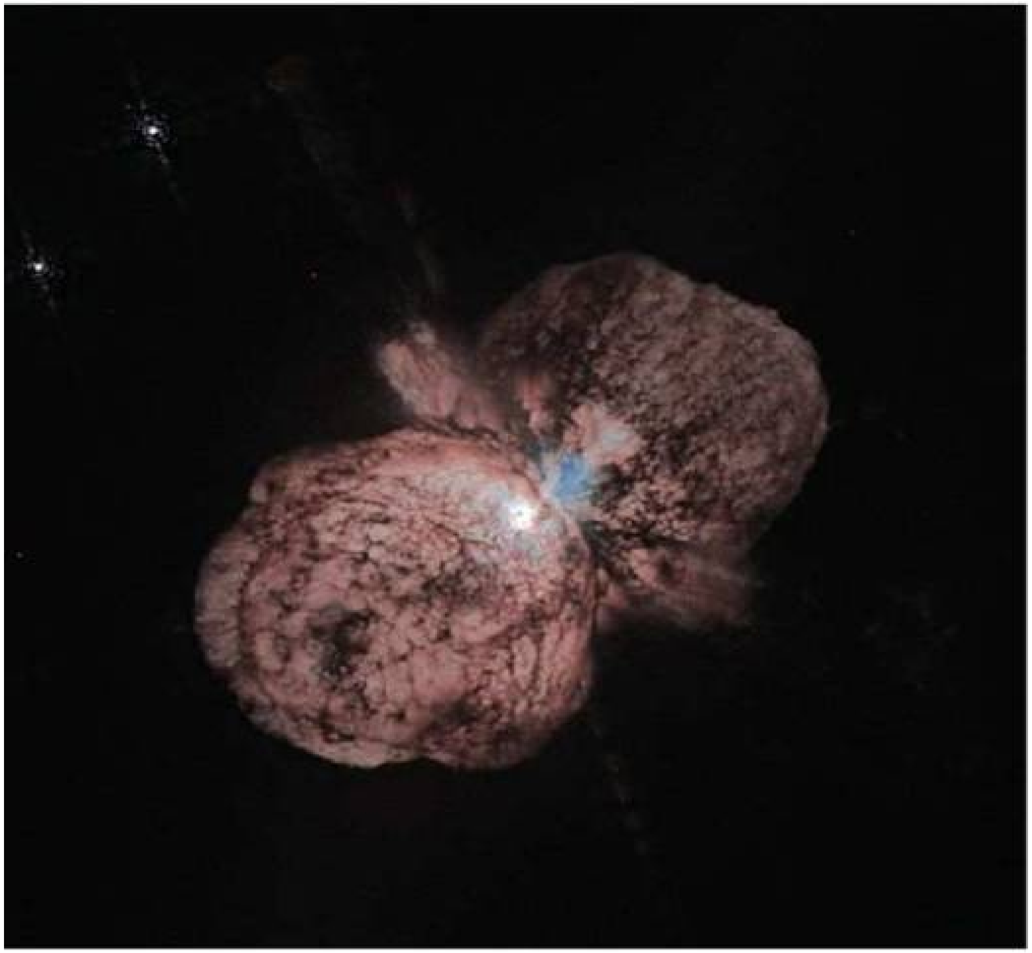
Jan Palouš

The Star Forming Region: Carina Nebula



Key Hole Nebula

Eta Carinae



Shu, Adams & Lizano 1987 ARA+A

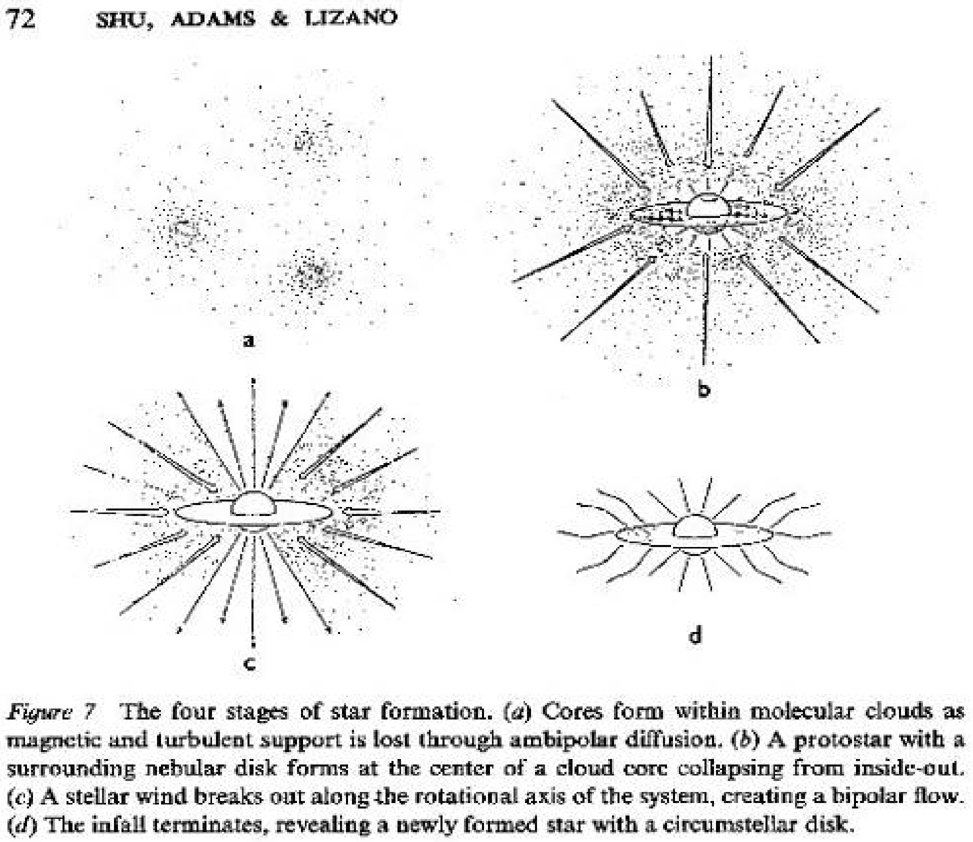
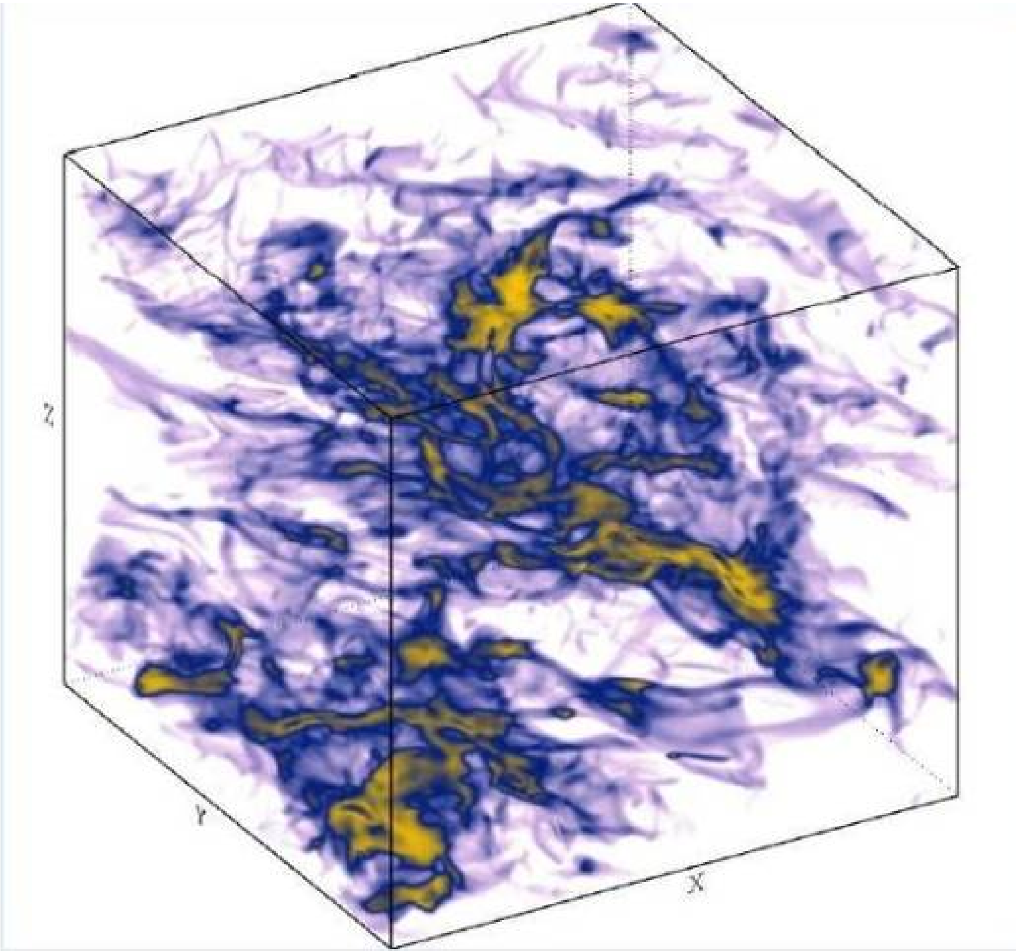
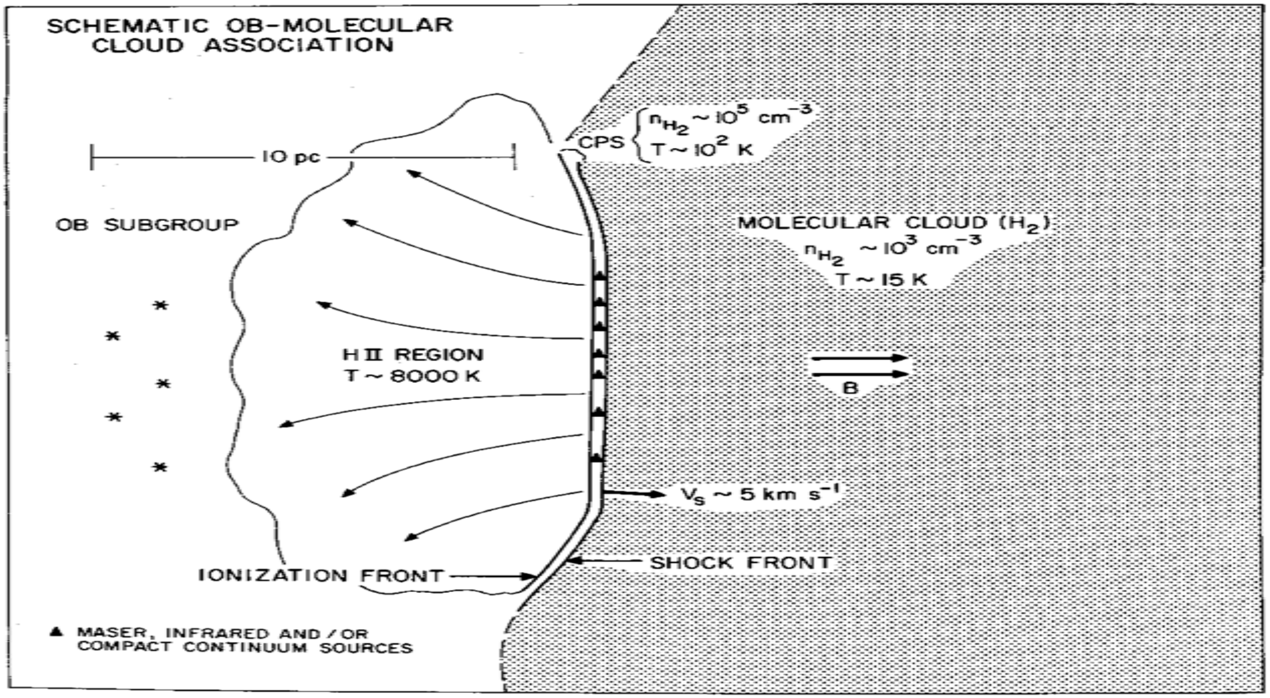

72 SHU, ADAMS & LIZANO

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

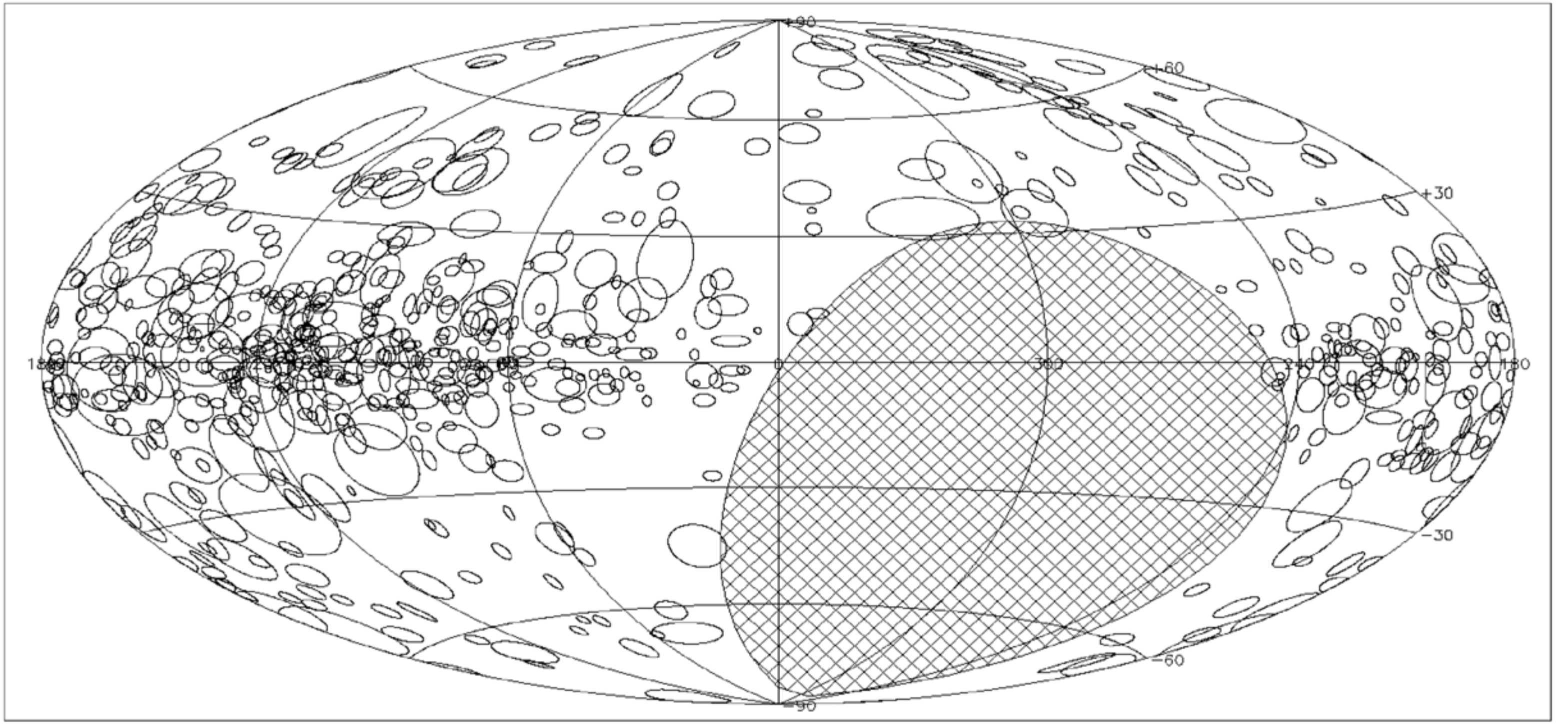


Collect and Collapse



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

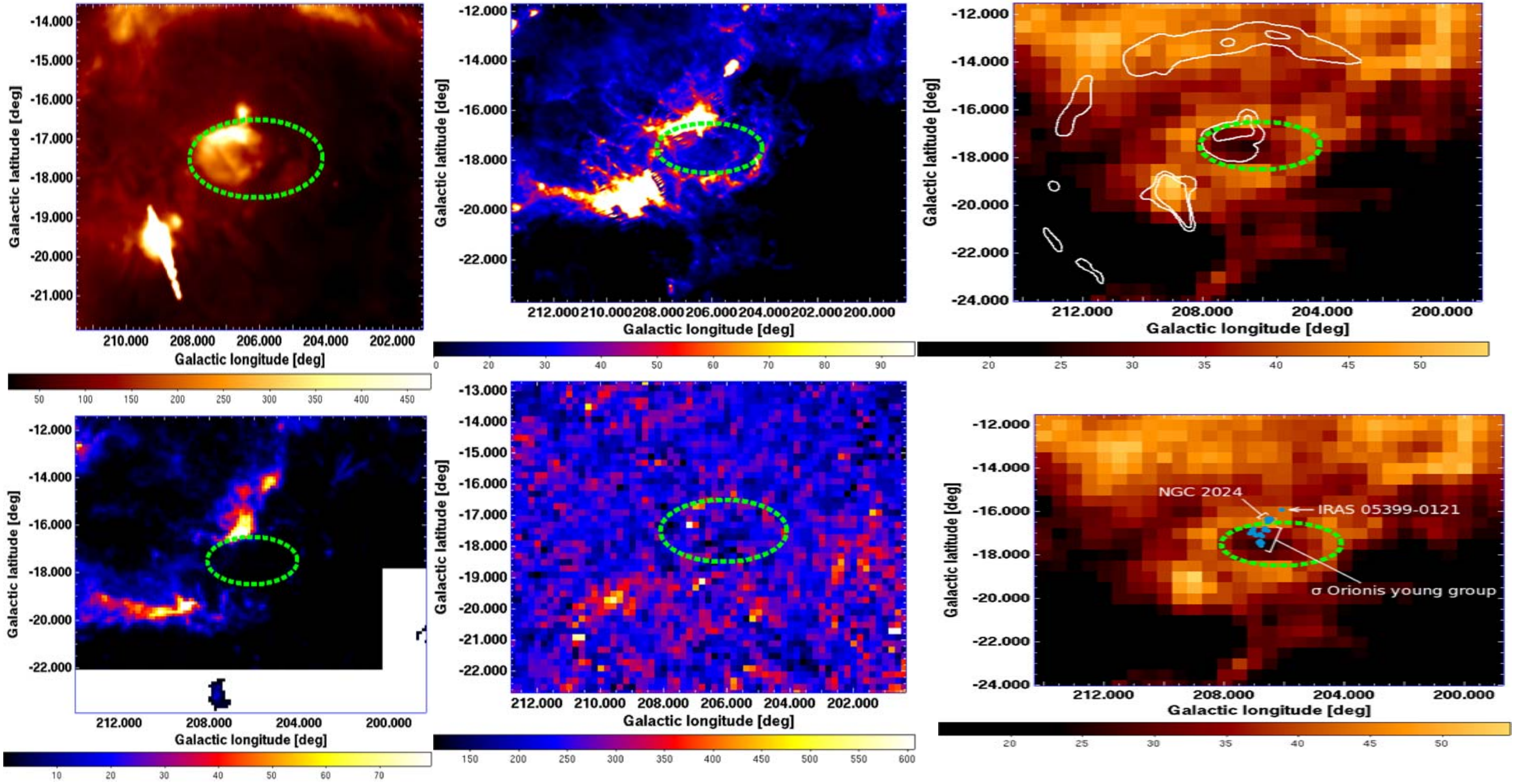
- in orange (infared): the dust shell that surrounds the HII region F

- in blue: the ionized hydrogen that fills the HII region

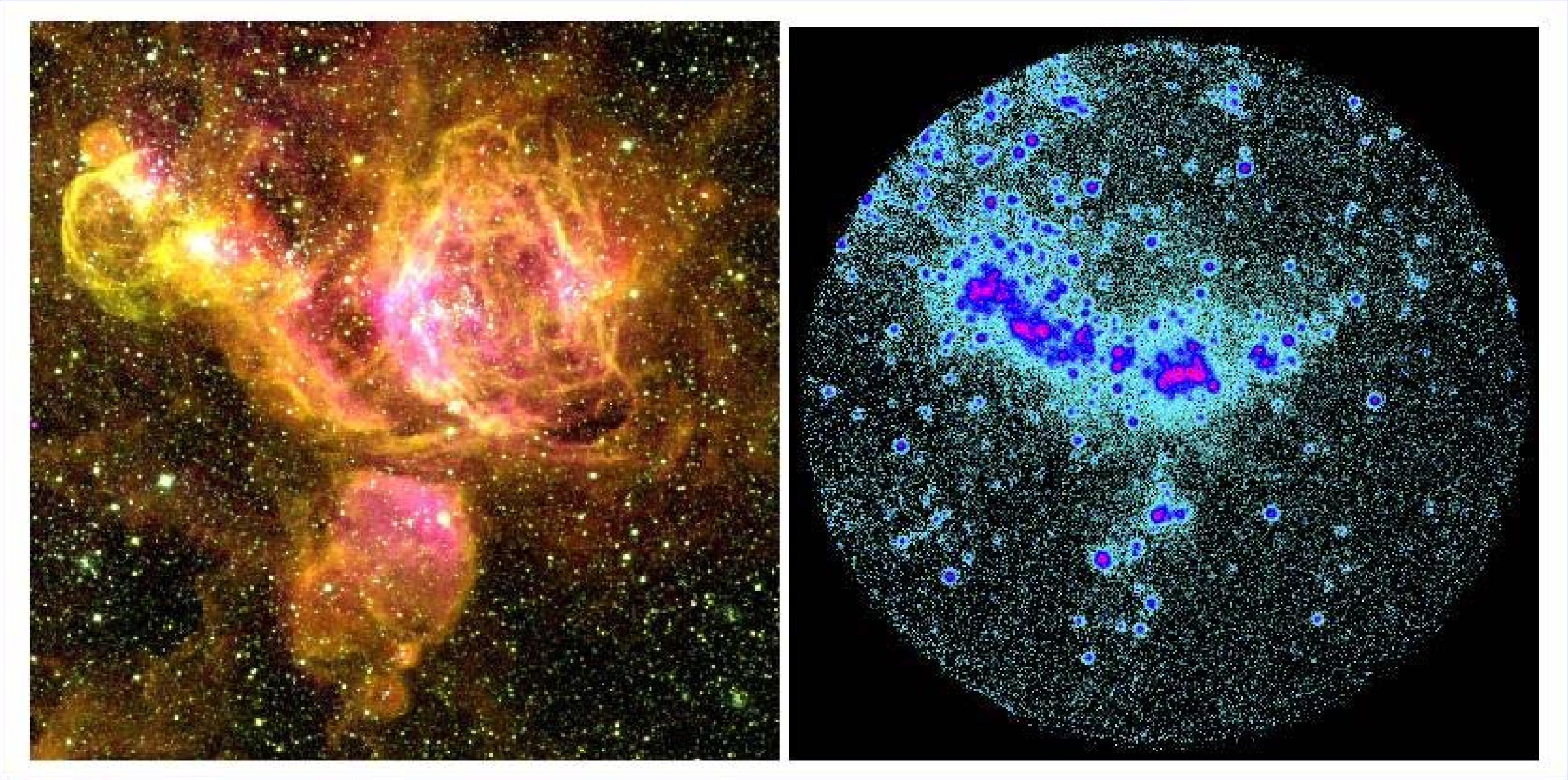
- the yellow contours (millimeter wavelengths) show cold dust cond

Near -infared image of one condensation
(NTT - ESO) - This region includes
a second-generation HII region.

Orion Molecular Complex GS206-17+013

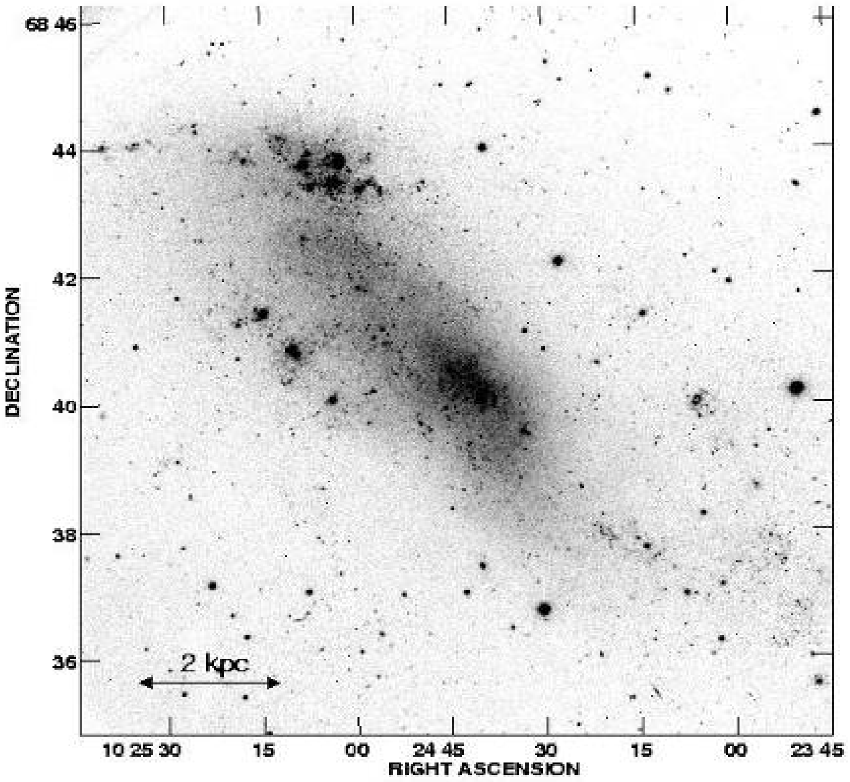


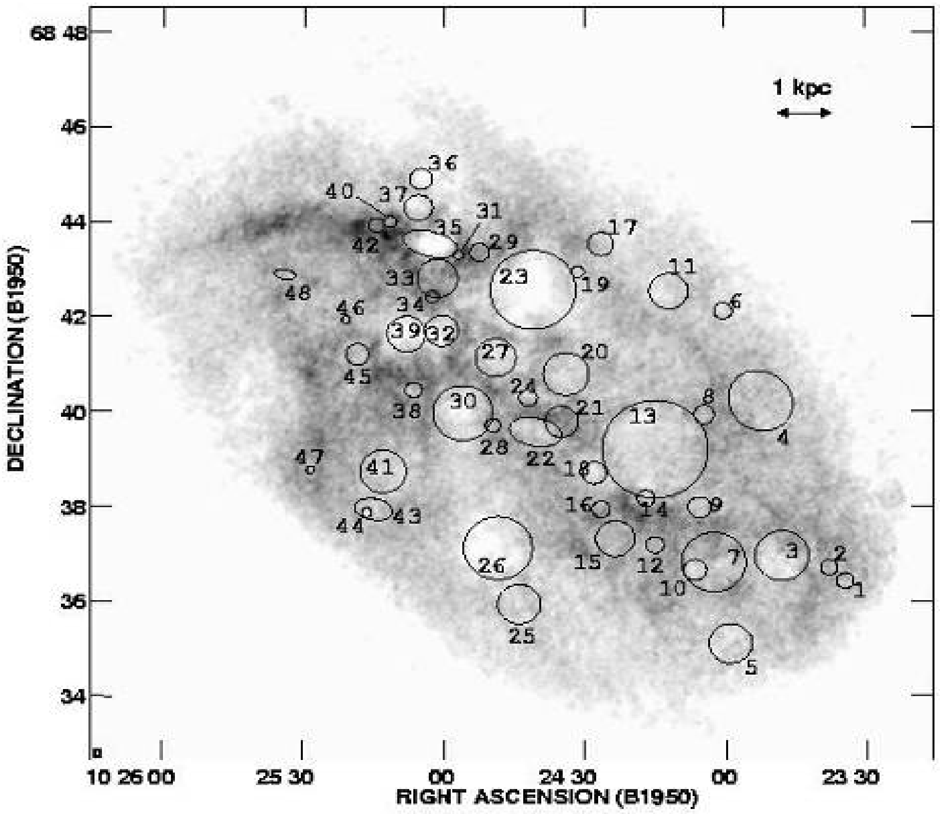
Turbulent Interstellar Medium



The region of the Sextant

Dwarf Irregular Galaxy IC 2574

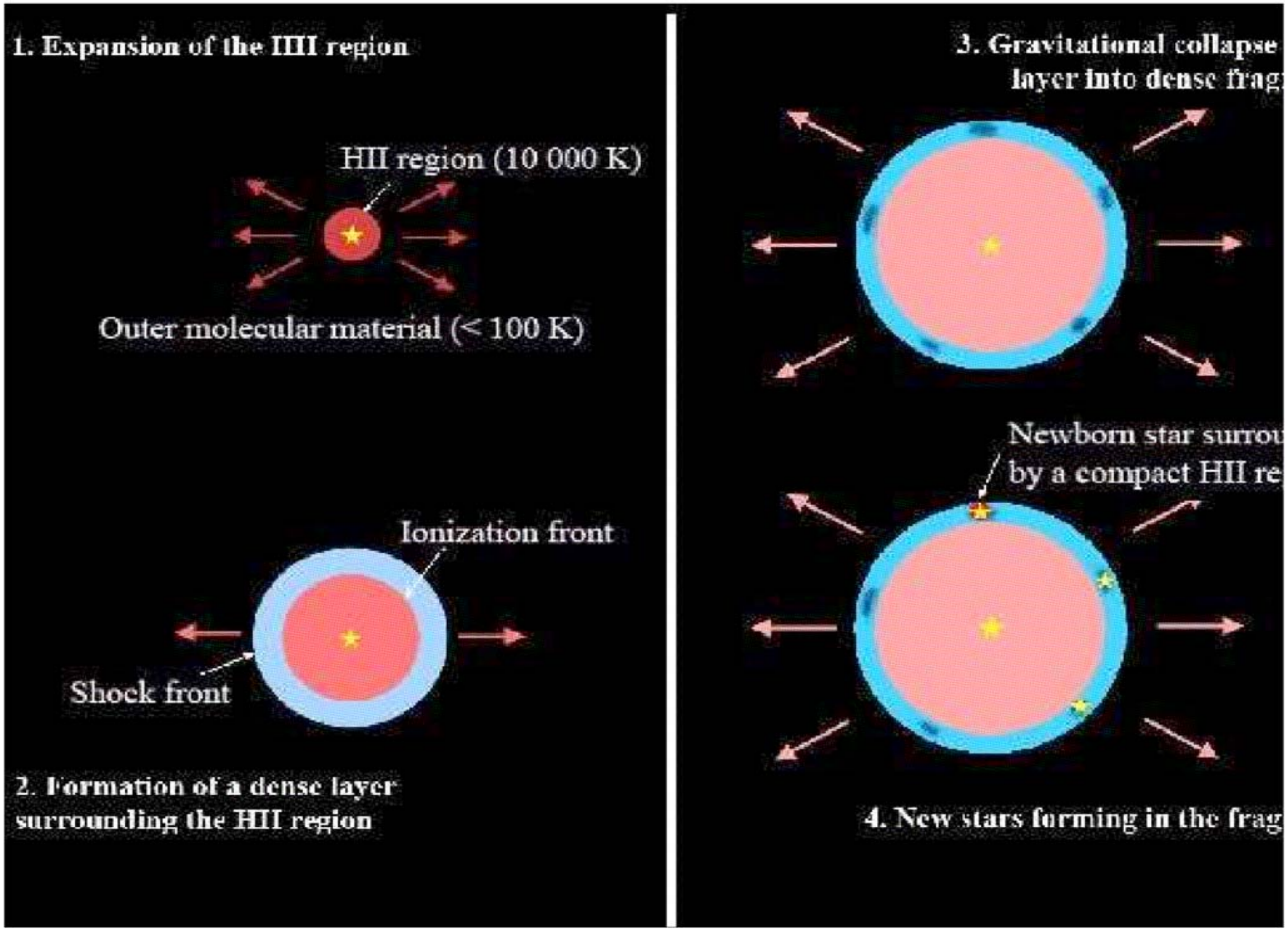




Formation of stars

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



The observed mass spectrum

$$\xi(m) = dN/dm$$

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

$$\omega(k) = \frac{2\pi}{t_{growth}} = const.$$

- **the number of fragments within R:**

$N = \omega \frac{R^3}{(\lambda/4)^3} = \frac{8\omega R^3 k^3}{\pi^3}$ **, 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**

$(k, k+dk)$**:** $dN = \frac{24\omega R^3 k^2}{\pi^3} dk$

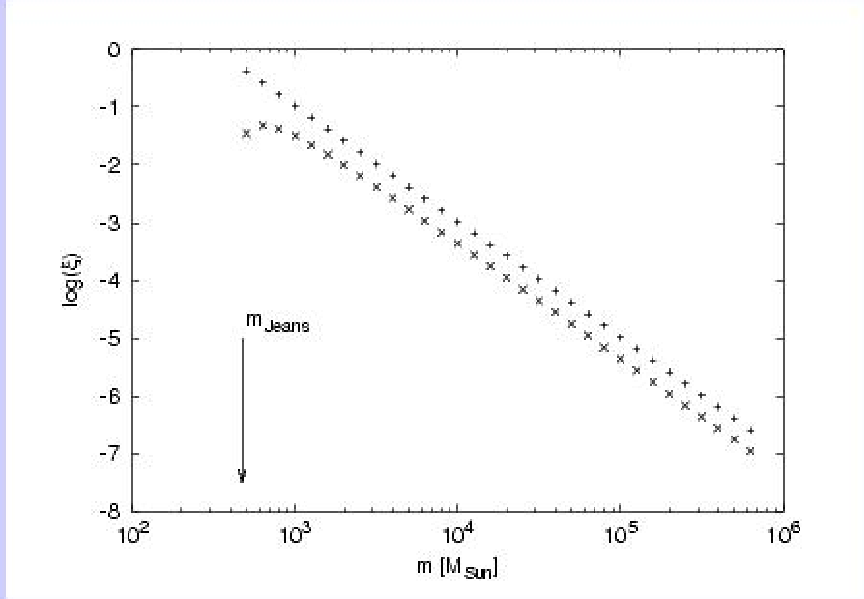
- **the mass spectrum:**

$\xi_{scale-free}(m) = -\frac{4}{3}\pi R^3 \rho\omega m^{-2}$

The Jeans instability

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

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



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

The mass spectrum of a starburst - analytical solution using thin shell

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

$$\eta = 2\pi R/\lambda$$

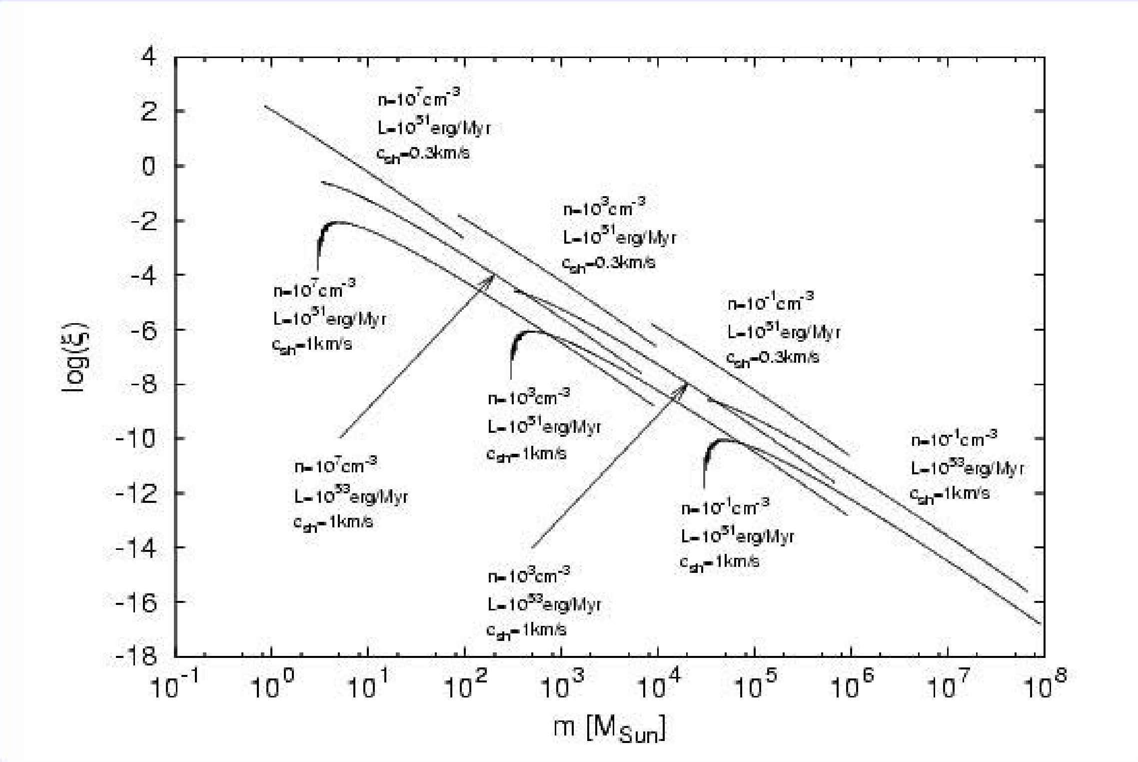
the fragmentation integral: $I(\eta,t) = \int_{t_{\mathrm{b}}}^{t} \omega(\eta,t')dt'$

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

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

$$\Sigma(t)_{\mathrm{sh}} = 0.564 \times \left(\frac{L}{10^{51}\ \mathrm{erg\ Myr^{-1}}}\right)^{\frac{1}{5}} \times \left(\frac{\mu}{1.3}\frac{n}{\mathrm{cm^{-3}}}\right)^{\frac{4}{5}} \times \left(\frac{t}{\mathrm{Myr}}\right)^{\frac{3}{5}}\ \mathrm{M_{\odot}pc^{-2}}$$

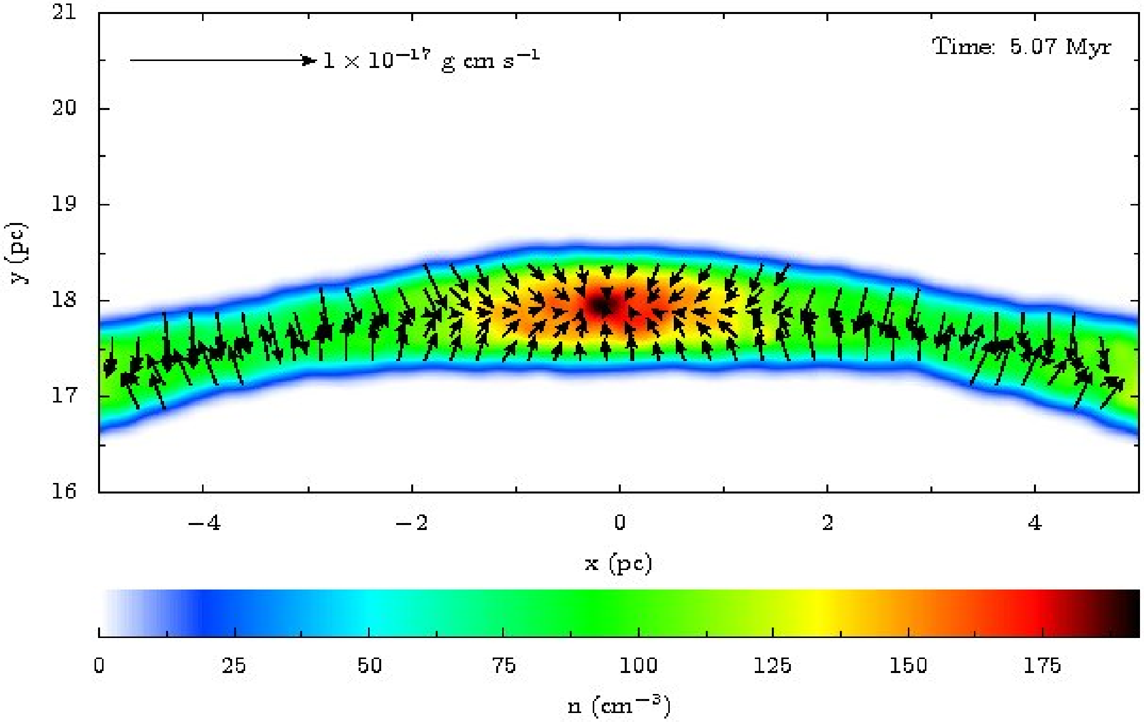
The analytical solution



The mass spectrum of fragments of an expanding shell at time $5t_{\mathrm{b}}$

$$t_{\mathrm{b}} = 28.8 \times \left(\frac{c_{\mathrm{sh}}}{\mathrm{km\ s^{-1}}}\right)^{\frac{5}{8}} \times \left(\frac{L}{10^{51}\ \mathrm{erg\ Myr^{-1}}}\right)^{-\frac{1}{8}} \times \left(\frac{\mu}{1.3}\frac{n}{\mathrm{cm^{-3}}}\right)^{-\frac{1}{2}} \mathrm{Myr}$$

AMR: l = 35, with internal and external pressure, t = 5 Myr

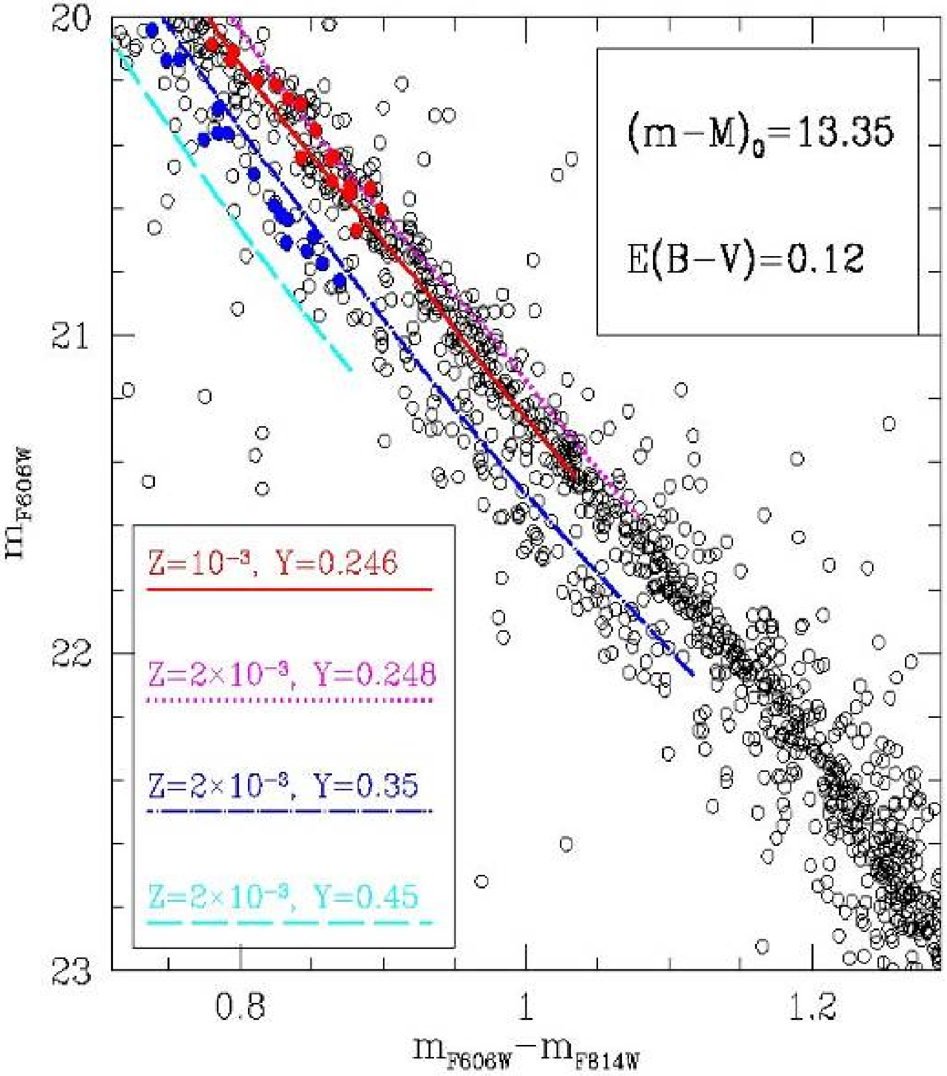


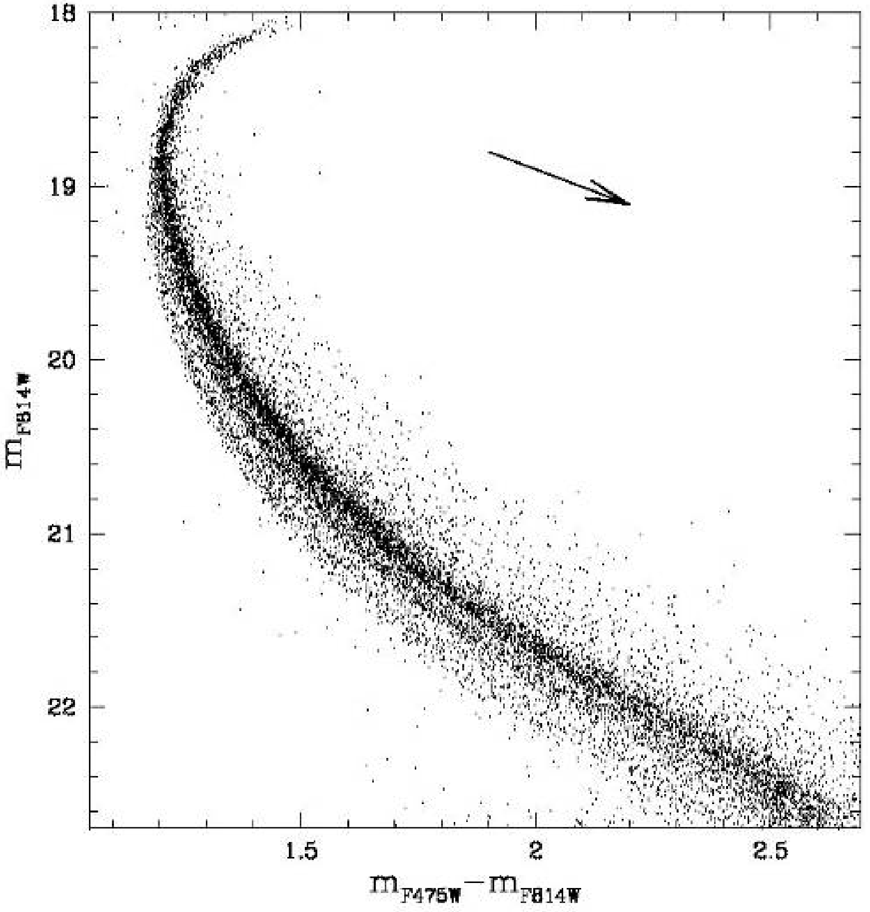
Conclusions (Dale, Wünsch, Whitworth & Palouš, MNRAS, 2009, submitted)

- No pressure confinment: long modes unstable only
- External and internal pressure confinment: 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

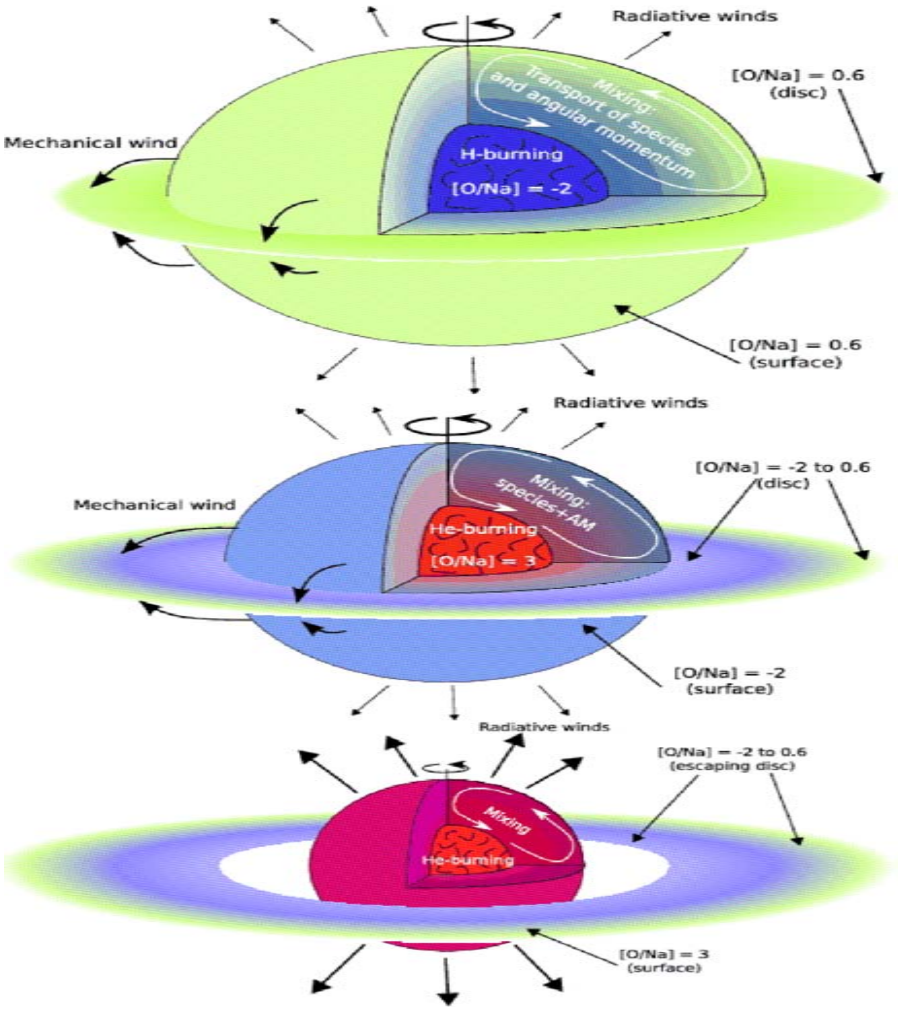
Omega Centauri & NGC 2808

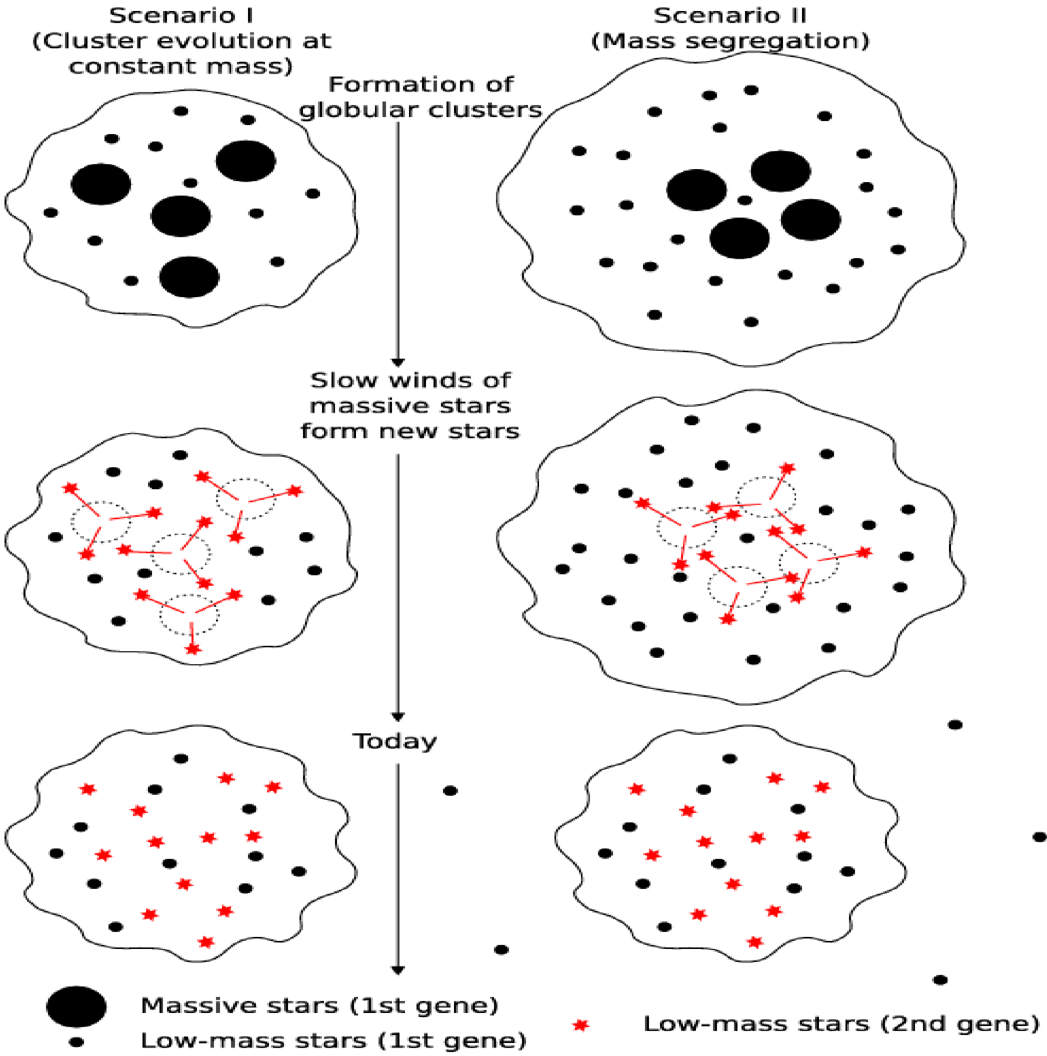
Multiple stellar generations in massive GC



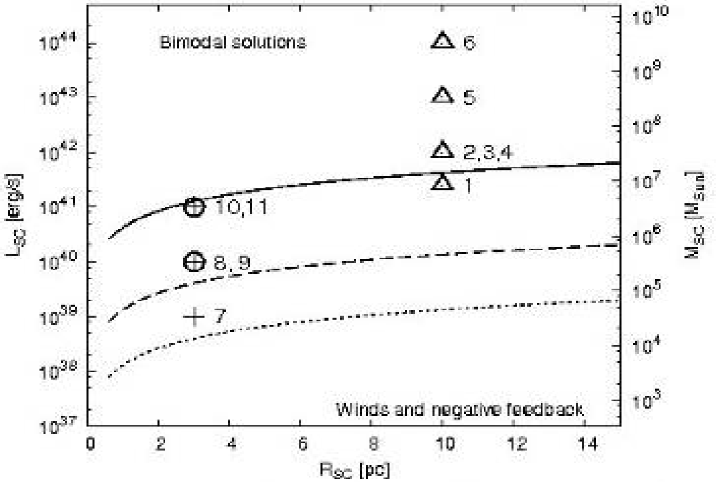


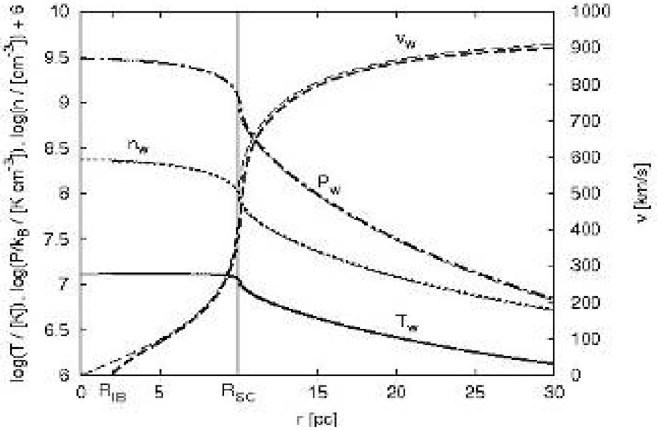
Fast rotating massive stars

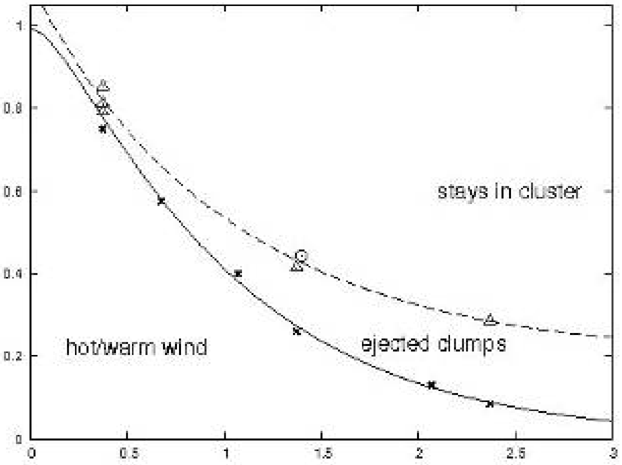


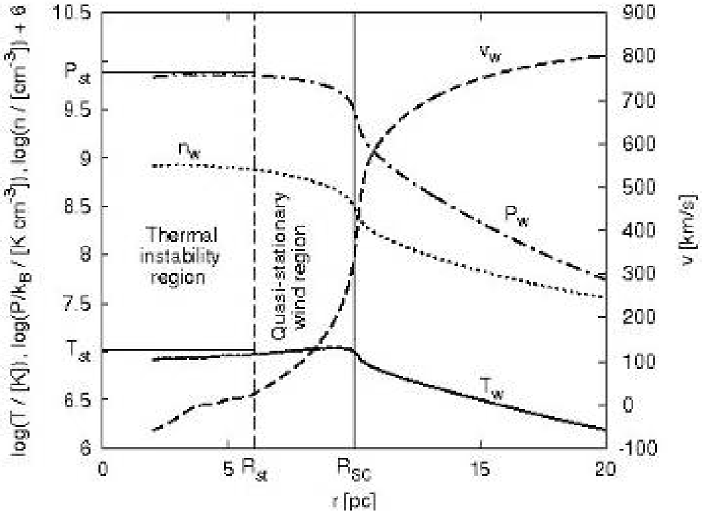


Thermal instability inside of massive GC (Wunsch, Palouš 2008, ApJ 684

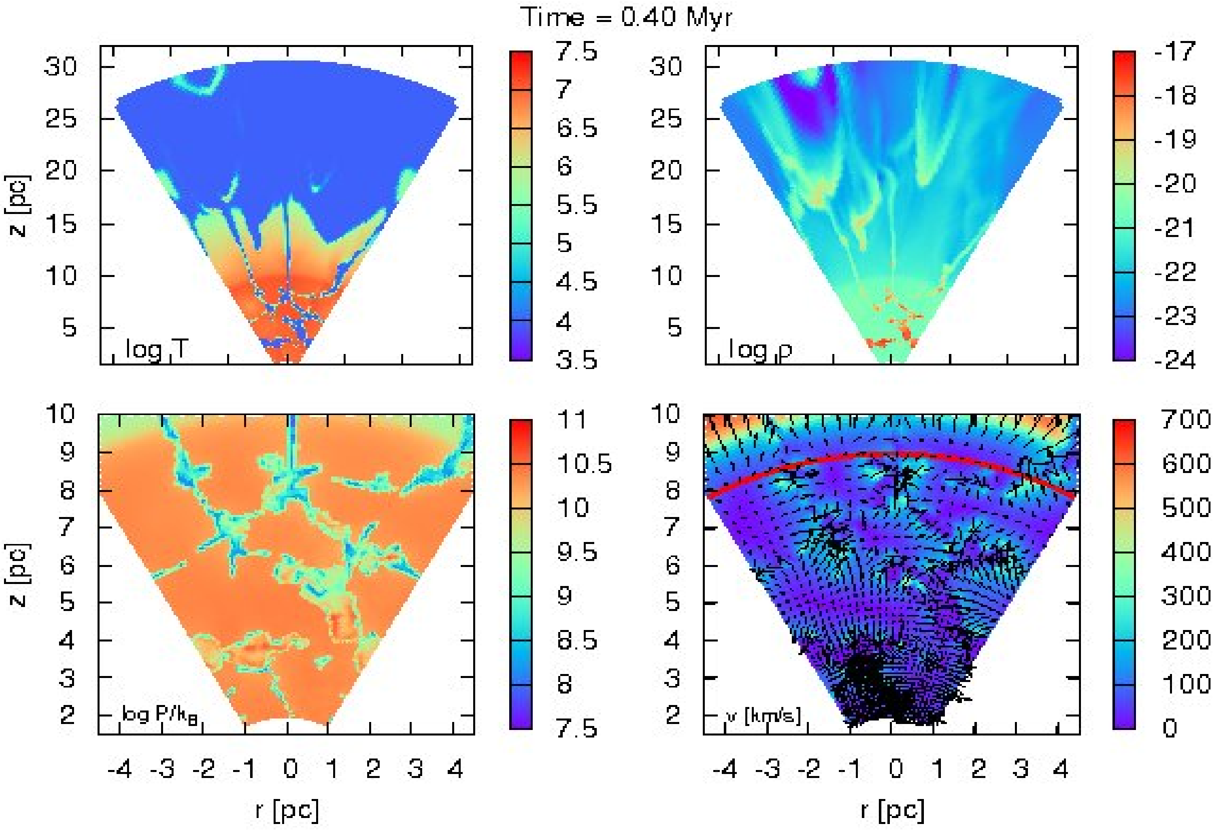








2D hydrodynamical simulation



Galaxies: Stars + ISM + DM

The Colossal Cosmic Eye NGC 1350
(FORS/VLT)

ESO PR Photo 31a/05 (September 27, 2005)

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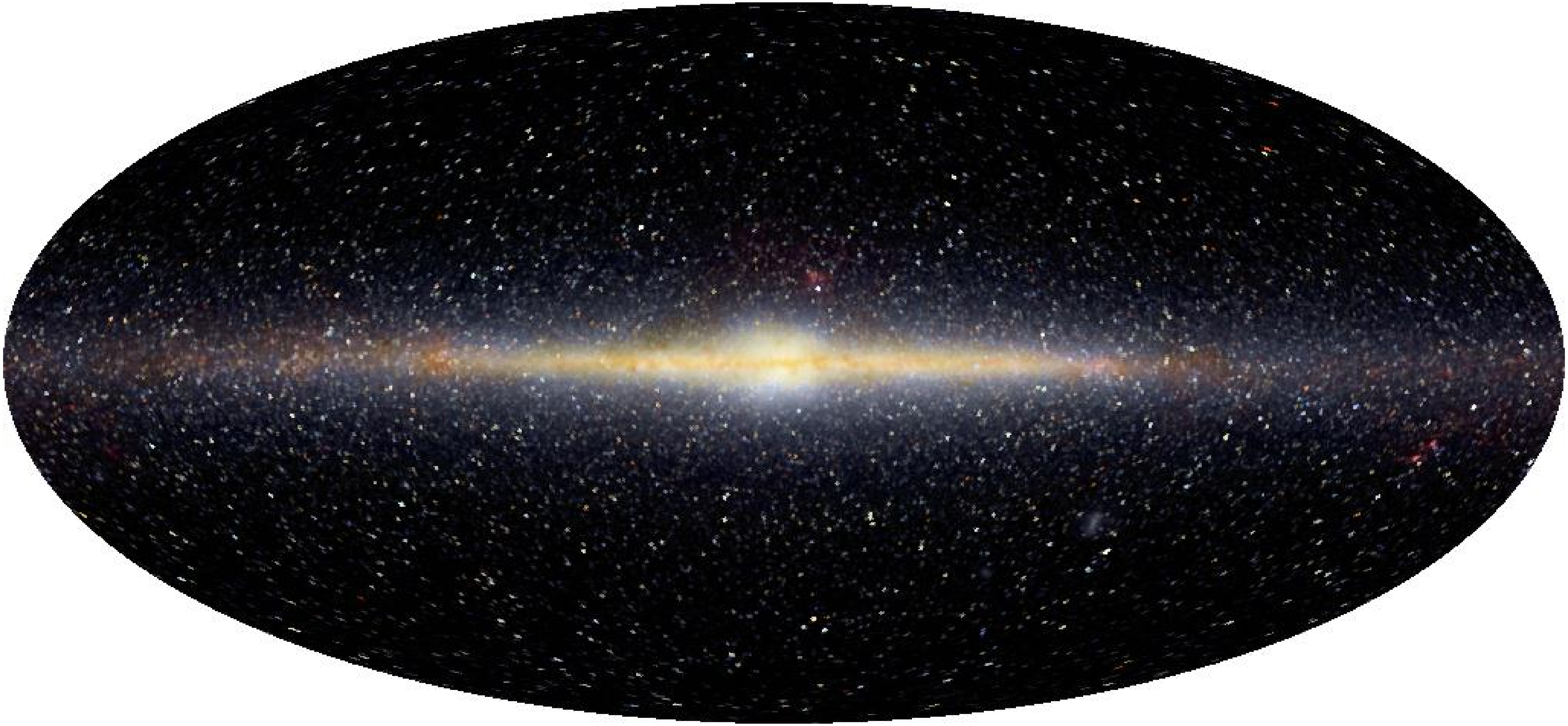
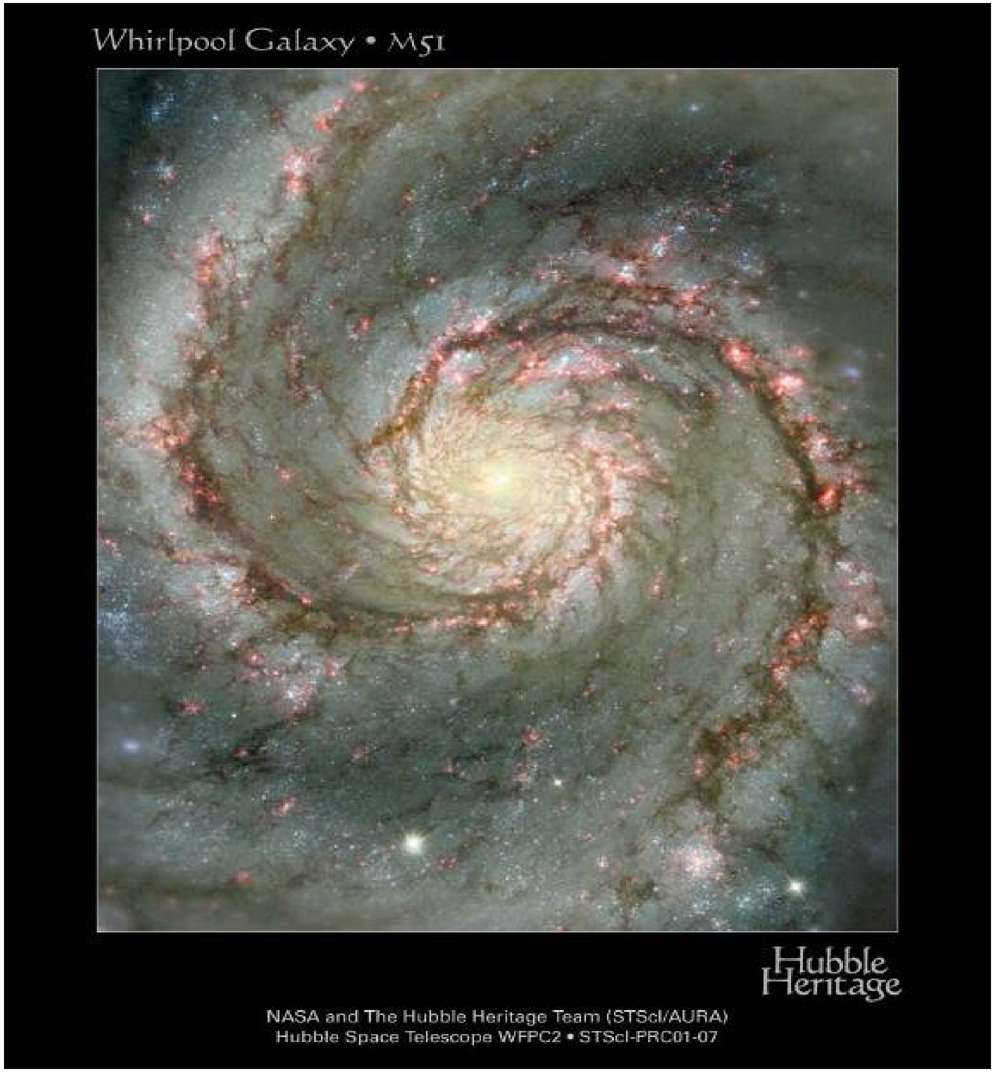
M87 © Anglo-Australian Observatory
Photo by David Malin

The Milky Way Galaxy



The Whirlpool Galaxy M51



NGC 1097 and Sombrero Galaxies

The Centre of the Active Galaxy NGC 1097
(NACO/VLT)

ESO PR Photo 33a/05 (October 17, 2005) © ESO

Stars

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

   $E_{rotation} >> E_{random}$
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

Barred Galaxy NGC 1365
(VLT UT1 + FORS1)

ESO PR Photo 08a/99 (27 February 1999)

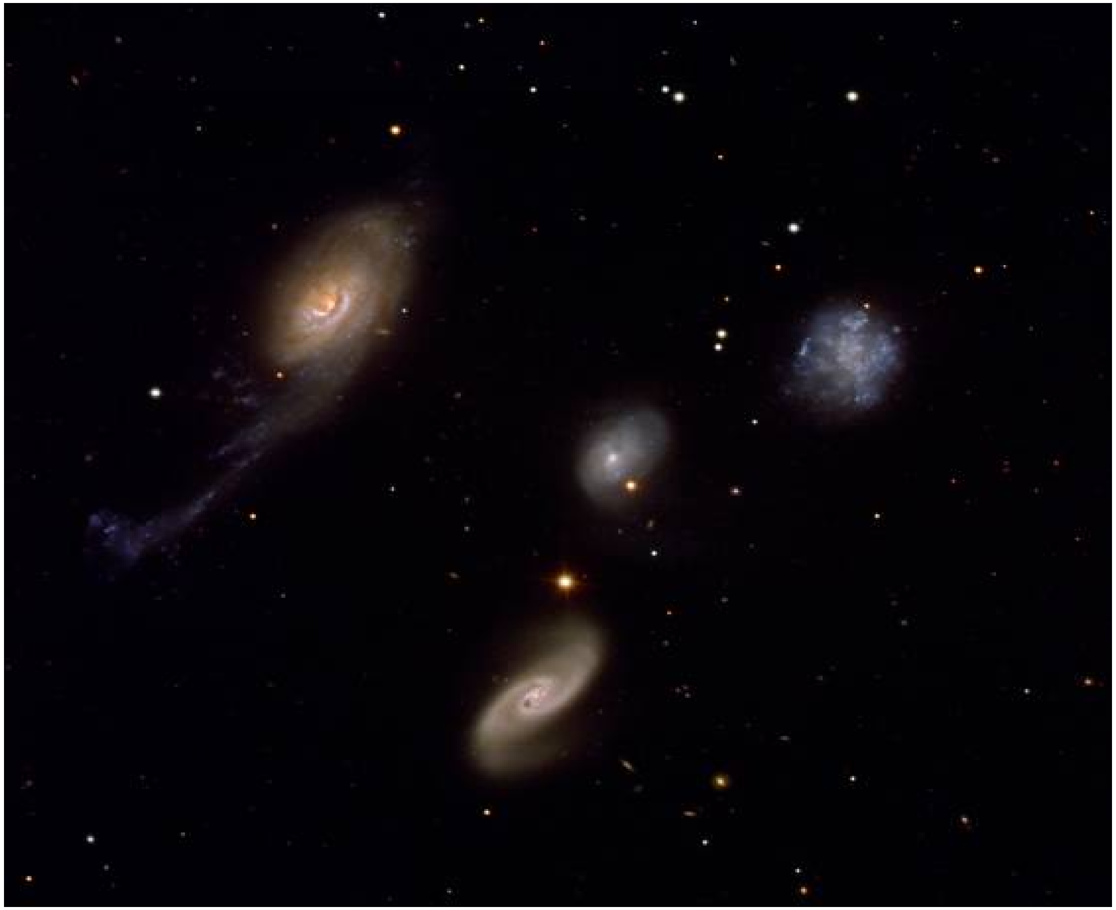
Bars

1. **global instability**
2. **$\mathbf{Q}_B = E_{rotation}/E_{potential}$**
3. **bar formation: $\mathbf{Q}_B > 0.14$**
4. **disk warming - Q increases - disk stabilizes**
5. **formation of bulge**
6. **increase of E_{random} - $\mathbf{Q}_B < \mathbf{0.14}$**
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



Robert's Quartet
(FORS2/VLT)

ESO PR Photo 34/05 (November 4, 2005)

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Ultraluminous Infrared Galaxies
Hubble Space Telescope • WFPC2

NASA and K. Borne (Raytheon ITSS and NASA Goddard Space Flight Center),
H. Bushouse (STScI), L. Colina (Instituto de Fisica de Cantabria, Spain) and R. Lucas (STScI)
STScI-PRC99-45

Virgo Cluster of Galaxies

The Tides
Toomre & Toomre 1972

1972ApJ...178

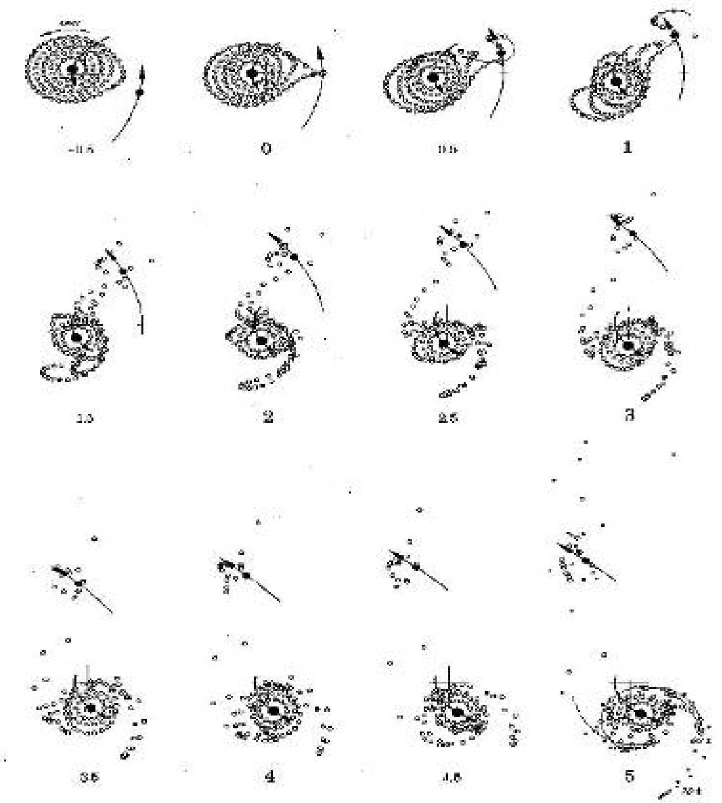

FIG. 4.—A flat direct (i = 0°) parabolic passage of a quarter-mass companion

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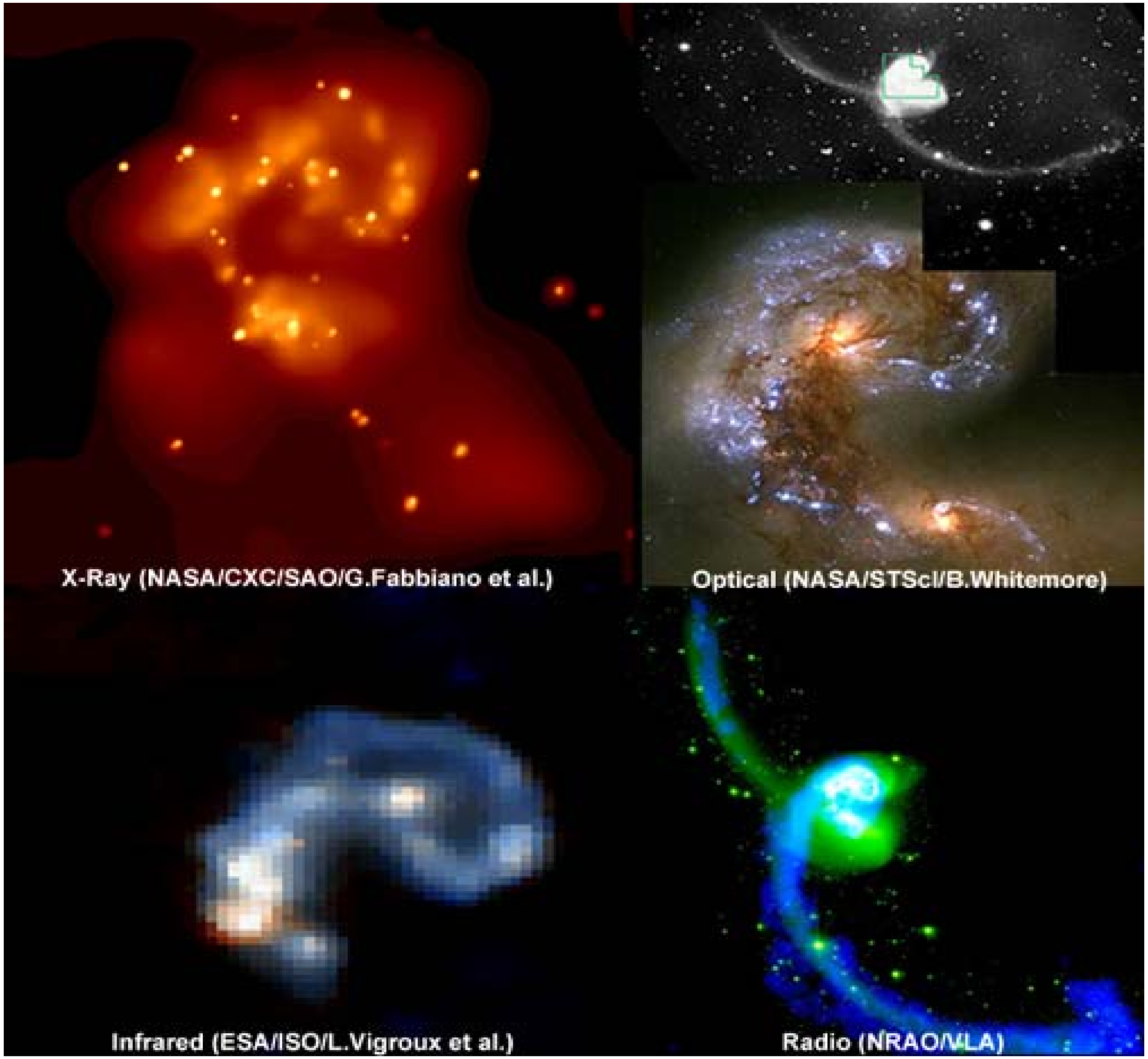
Antennae: Galaxies in a collision



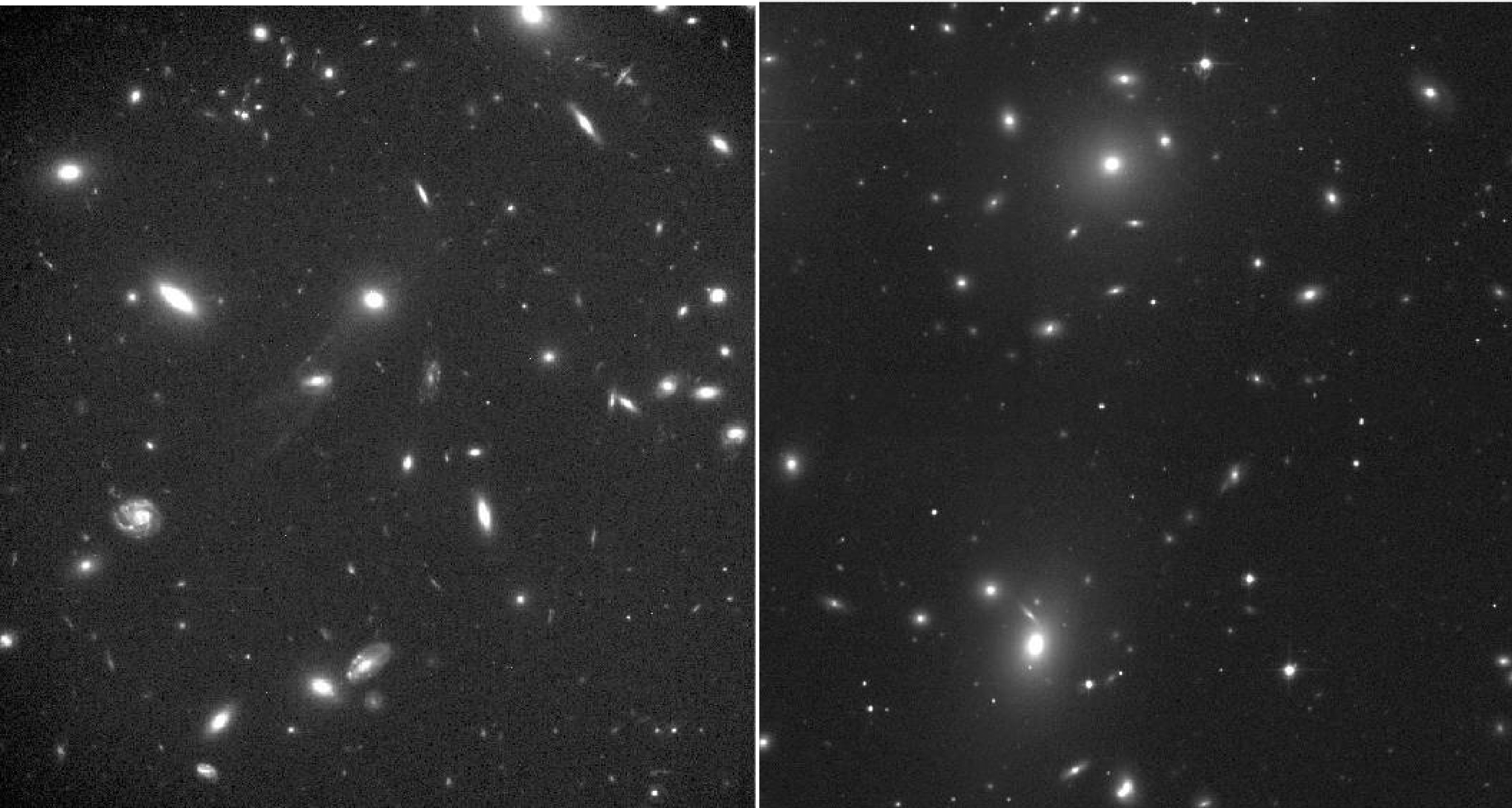
X-Ray (NASA/CXC/SAO/G.Fabbiano et al.)

Optical (NASA/STScI/B.Whitemore)

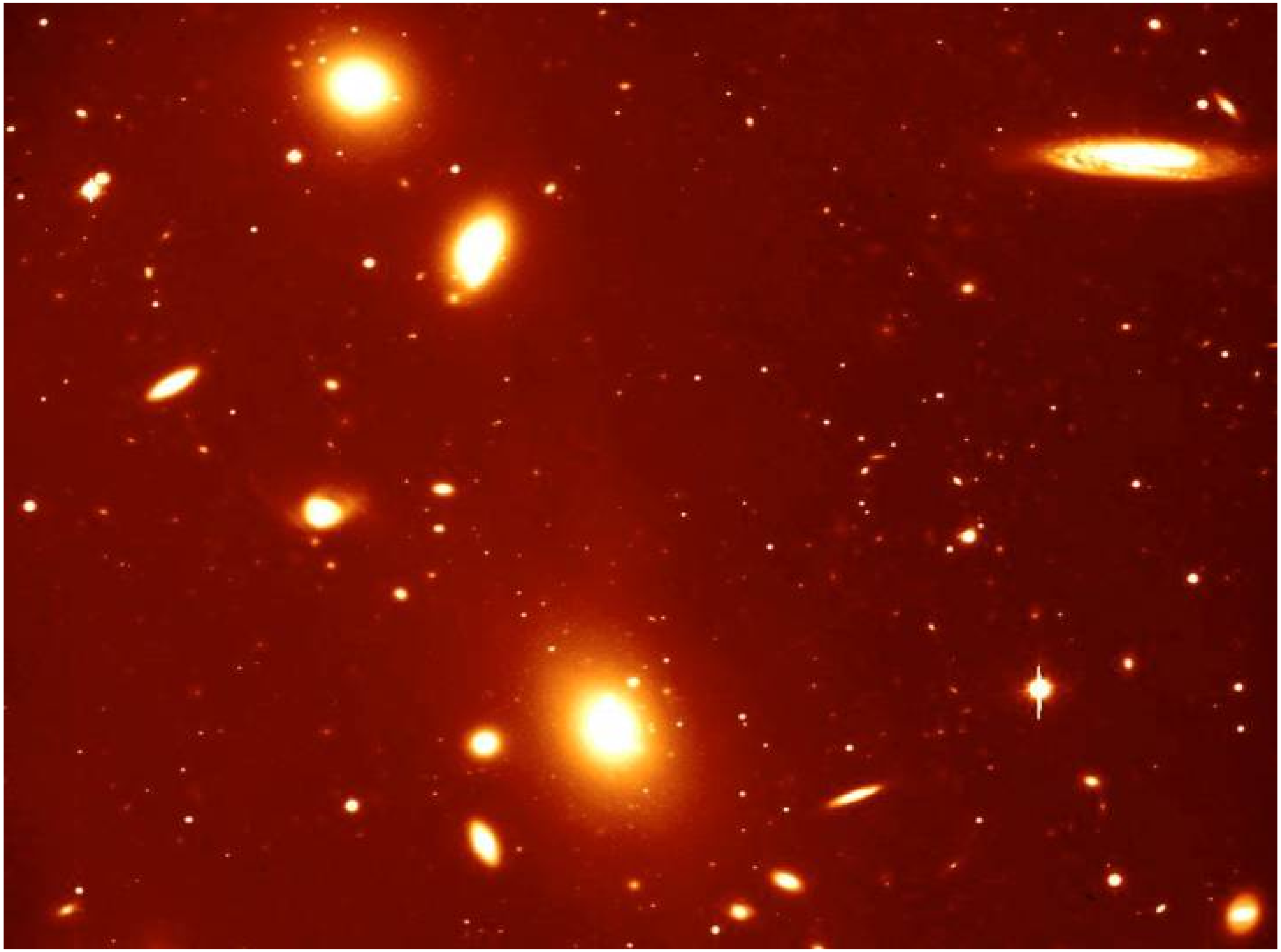
Infrared (ESA/ISO/L.Vigroux et al.)

Radio (NRAO/VLA)

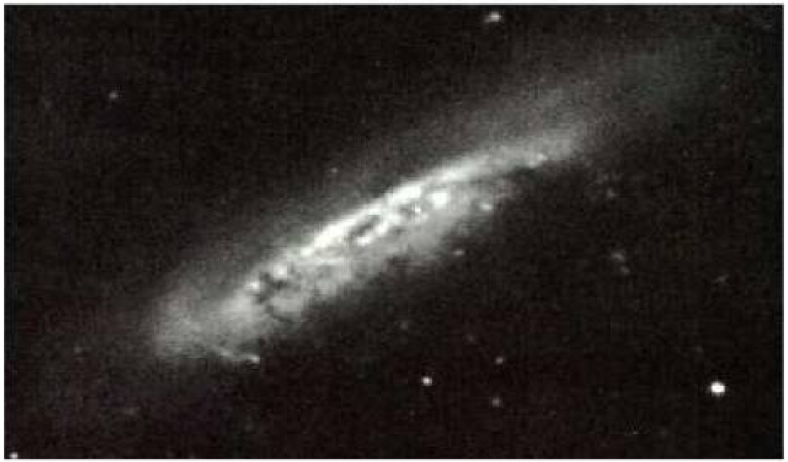
The Harassment: CL0939 versus Coma (Moore et al. 1995, Nature)



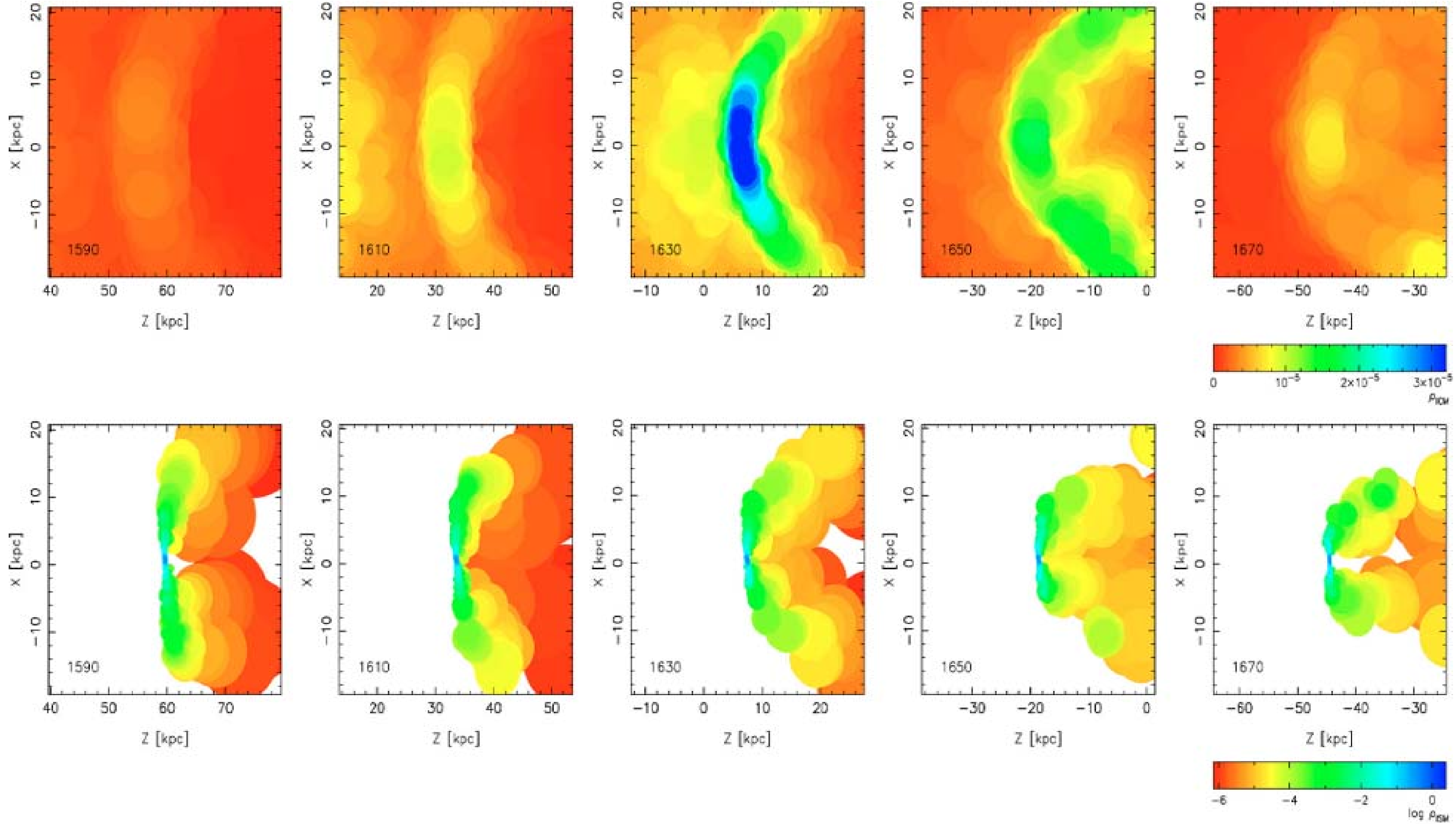
Abel Cluster of Galaxies 03341



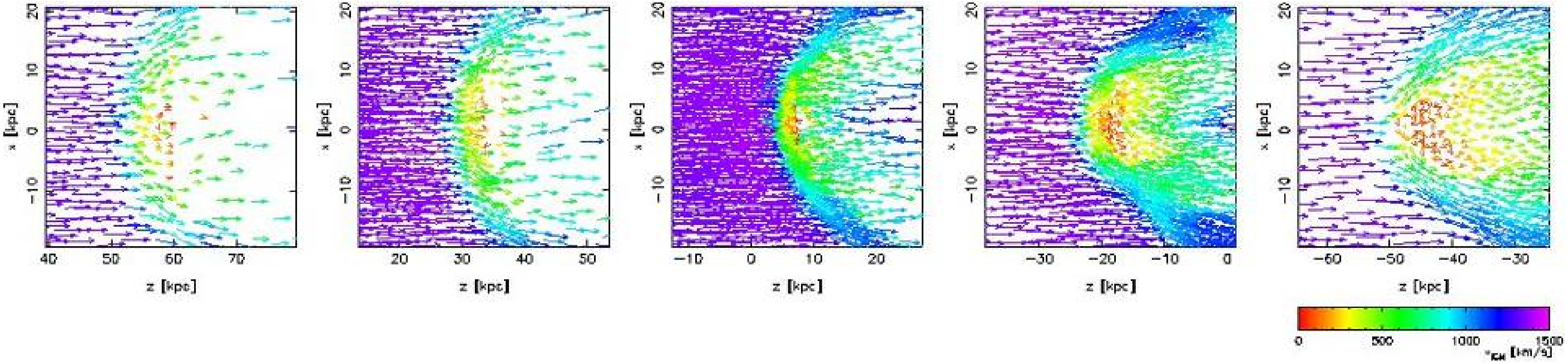
Gas Stripping
NGC 4522 in Virgo



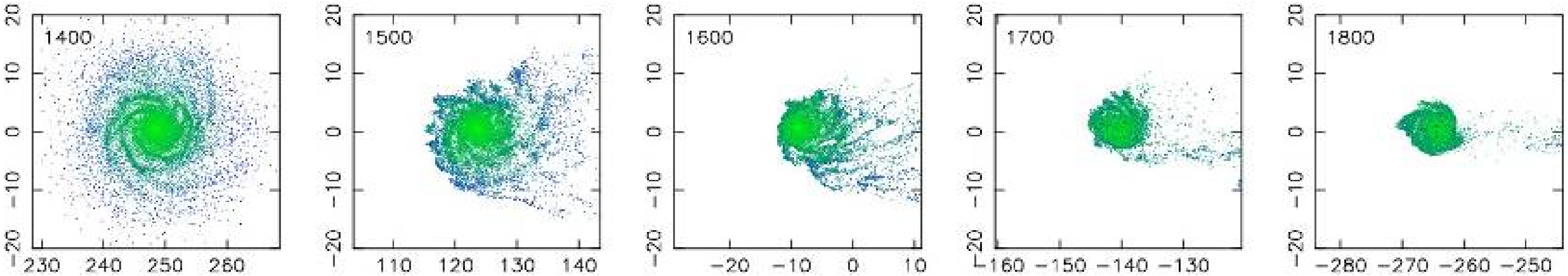
SPH simulation of the ISM stripping



Jáchym & Palouš, 2007, A&A



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