Winds Driven by Massive Star Clusters

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A self-consistent stationary solution for spherically symmetric winds driven by compact star clusters is presented. The impact of strong radiative cooling on the internal wind structure and its expected appearance in the X-ray and visible line regimes are discussed.

In collaboration with

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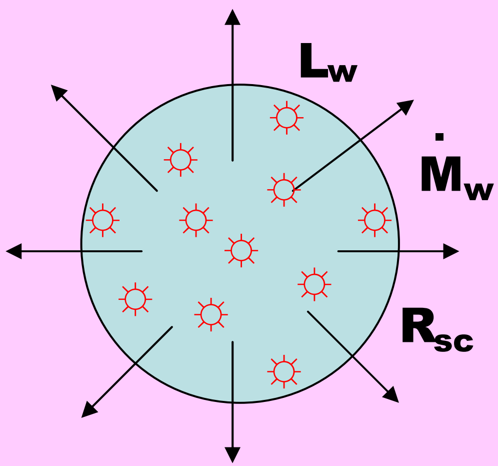
References to:

Silich, Tenorio-Tagle & Muñoz-Tuñon, 2003, ApJ, 590, 791
Tenorio-Tagle, Silich & Muñoz-Tuñon, 2003, ApJ, 597, 279

1. The steady-state wind solution (adiabatic).

Chevalier & Clegg, 1985



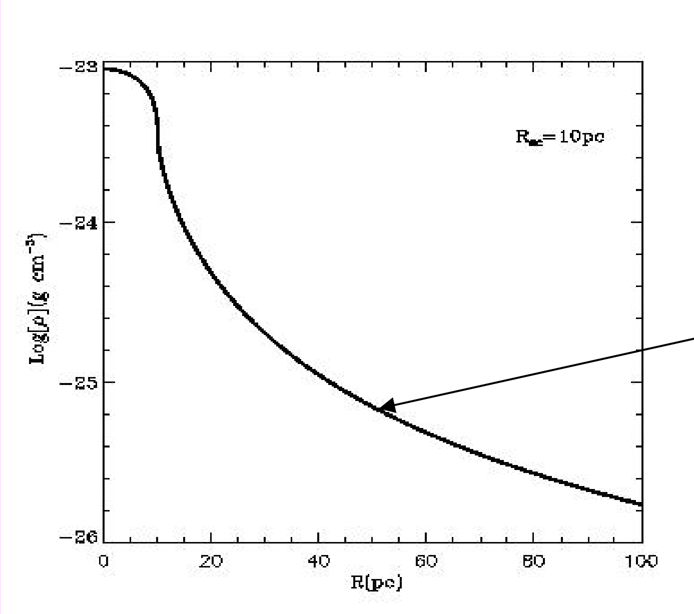
The energy deposited by stellar winds and SNe explosions is fully thermalized via random collisions. This generates the large central overpressure that accelerates the ejected matter out of the star cluster volume.

Three parameters L_w, $\dot{M}_w$ and R_{sc} completely define free wind expansion.
There is an analytic solution (Chevalier & Clegg, 1985; Canto et al. 2000). The wind central density, pressure and temperature are known

$$\rho_c = \frac{\dot{M}_w}{4\, p A\, R_{sc}^2\, V} \; ; \quad P_c = \frac{\gamma - 1}{2\gamma} \frac{\dot{M}_w V_\infty}{4\, p\, A\, R_{sc}^2} \; ; \quad T_c = \frac{(\gamma - 1)\mu}{\gamma k} \frac{L_w}{\dot{M}_w} ; \; V_\infty = (2 L_w / \dot{M}_w)^{1/2} .$$

Using these initial values one can integrate the basic equations numerically and reproduce the analytic solution throughtout the space volume.

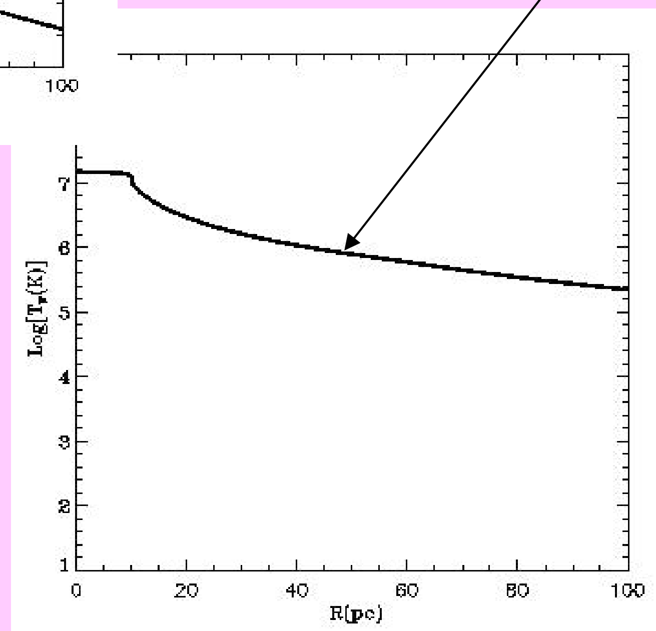
The adiabatic wind density, temperature and velocity distributions.



r^{-2}

Density

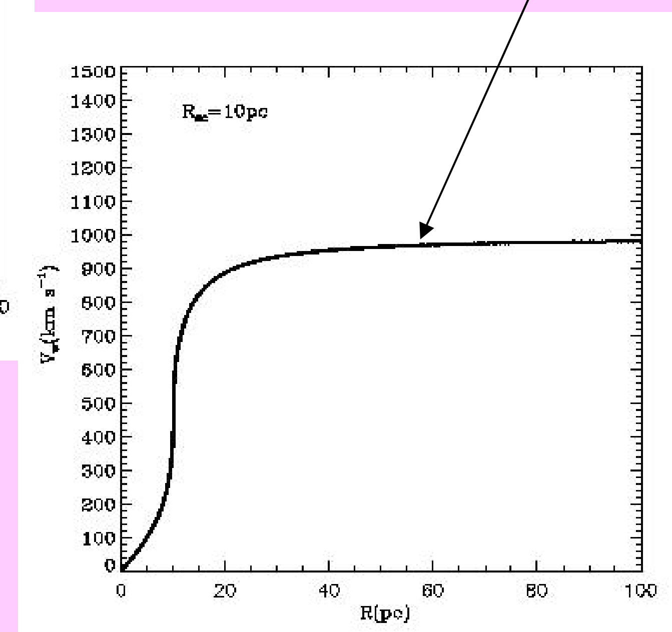
$r^{-4/3}$



Temperature

V_{∞}

Velocity



2. The steady-state radiative solution.

The highly non-linear character of the cooling function inhibits the analytic solution.

The key problem is: how to integrate the basic equations if initial conditions are not known?

$u_c = 0$

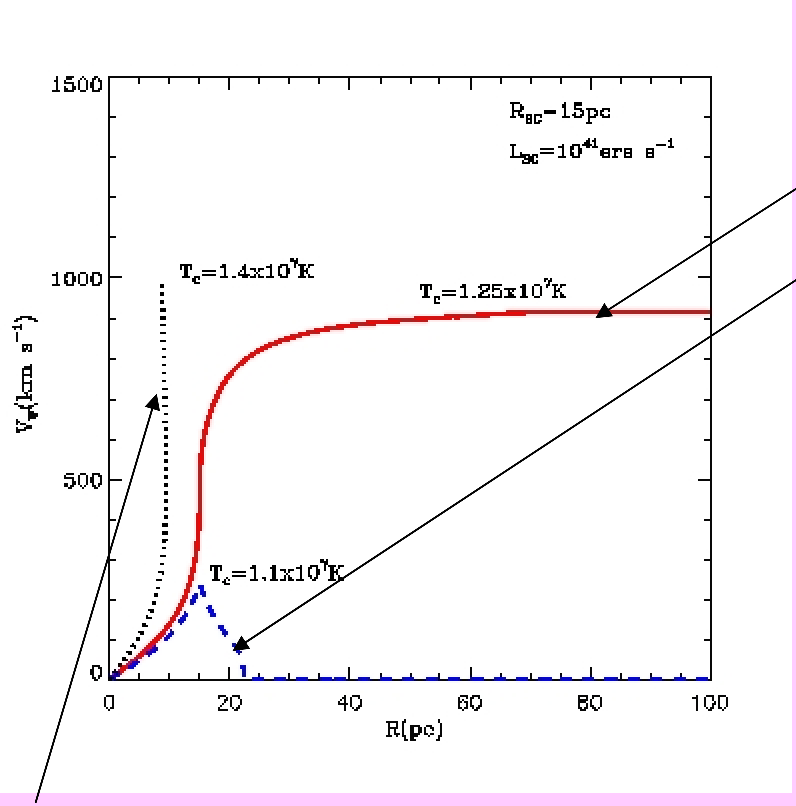
$T_c = ?$

$\rho_c = ?$

How to define the central values?

2. The steady-state radiative solution.

How to integrate the basic equations



Three possible types of integral curves:

1. Wind solution , Rsonic=Rsc

2. Breeze solution, Rsonic>Rsc

3. Unphysical double−valued solution, Rsonic<Rsc

The radius of the sonic point is dependent on the central pressure. To obtain wind solution one has to find Pc that places Rsonic at the star cluster surface.

In the adiabatic case Rsonic = $\frac{6\gamma}{\gamma - 1} \frac{A\,Pc}{\sqrt{2 q_e q_m}}$

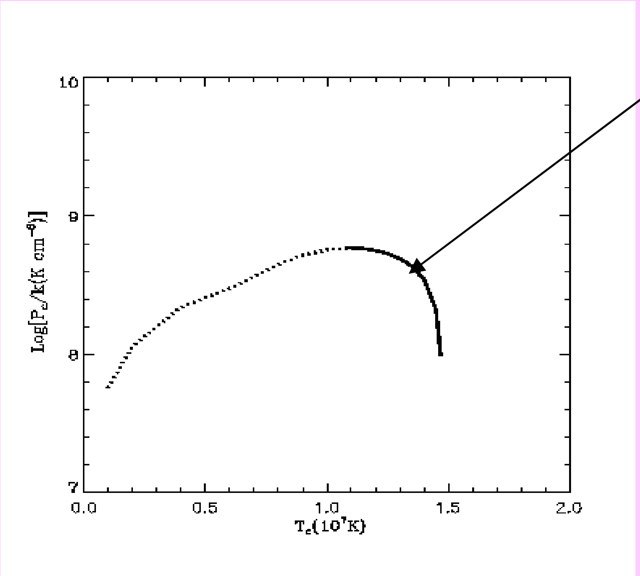
In the radiative case the central density and temperature are not independent

$$n_c = \sqrt{\left(q_e - \frac{q_m}{\gamma - 1} c_c^2\right) / \Lambda(T_c)}$$

q_e and q_m are energy and mass deposition rates per unit volum.
$\Lambda(T)$ is the cooling function.

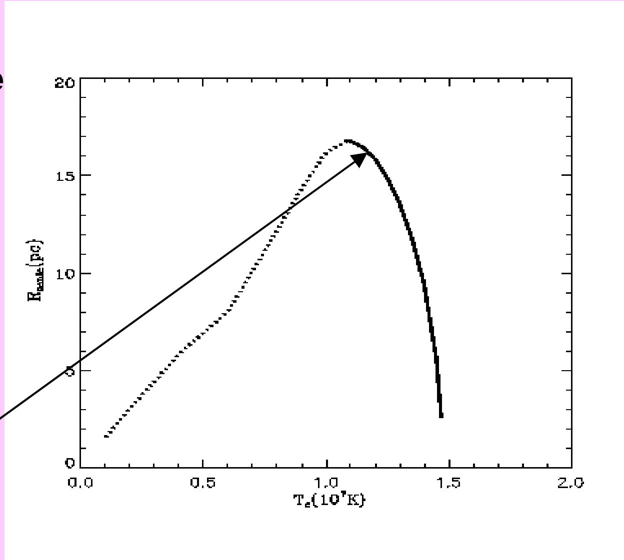
P_c cannot exceed a maximum value, R_{sonic} has a maximum, Rsonic,max, for any given set of star cluster parameters.

The stationary solution does not exist if Rsc > Rsonic,max



The central pressure

The sonic radius



3. The critical energy input rate

For any given ratio $\eta = q_e / q_m$ (in the adiabatic case this ratio defines the terminal wind velocity) there is a **critical energy deposition rate L_{crit} .**

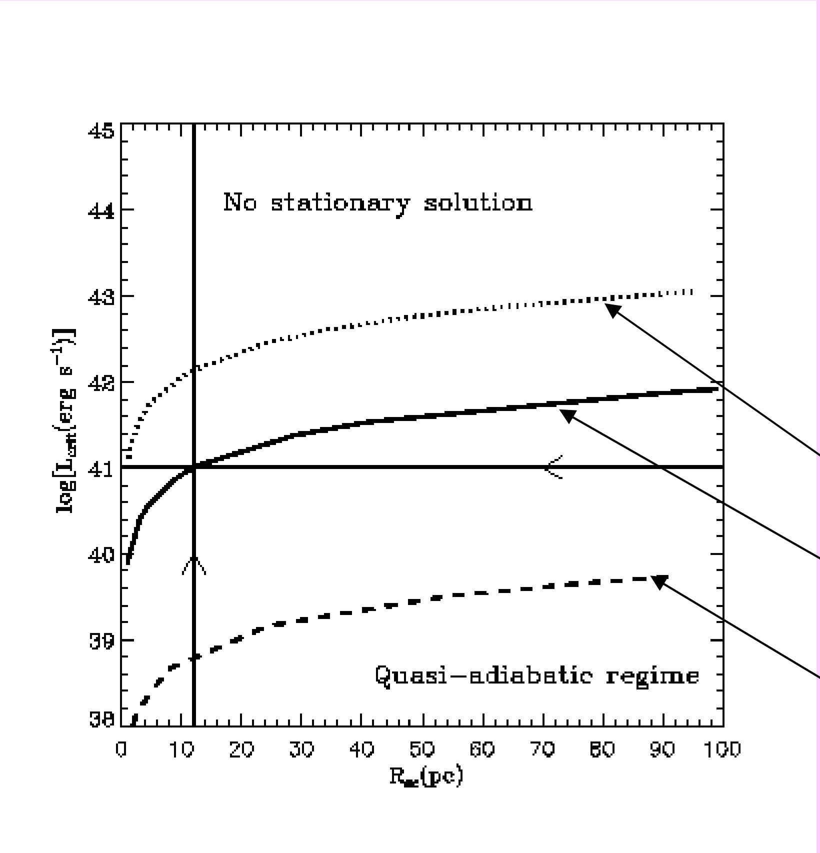


Figure 3. The critical energy input rate.

The stationary solution does not exist if the energy input rate exceeds this limit.

VwA = 1500 km s^{-1}

VwA = 1000 km s^{-1}

VwA = 500 km s^{-1}

4. The internal wind structure

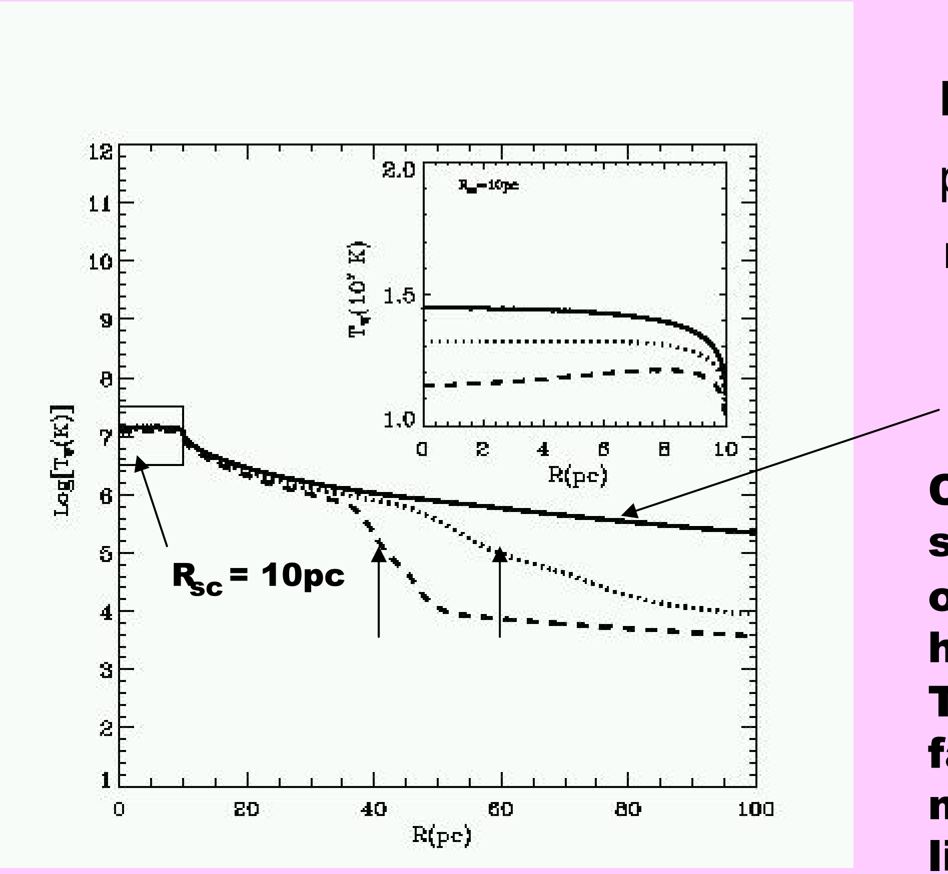


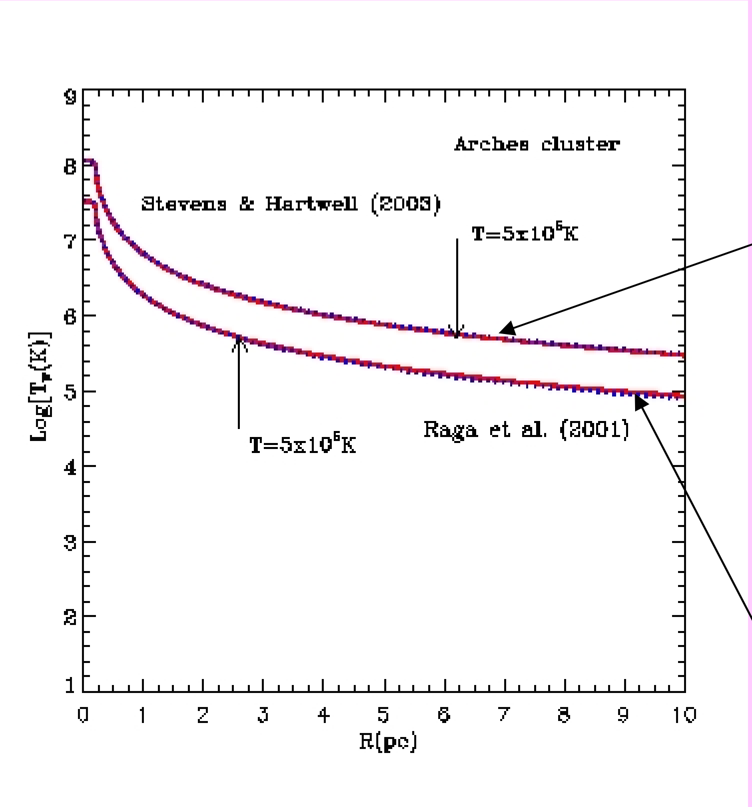
Figure 2. Temperature profiles for progressively larger energy deposition rates (1, 5, 8) × 10^{40} erg s^{-1}, respectively.

Cooling modifies the internal wind structure bringing the boundary of the X-ray zone and low temperature halo closer to the wind center. This promotes the establishment of a fast moving ionized envelope which may be observed as a weak and broad line emission component at the base of much narrower line caused by the central HII region.

No extended X-ray emission

Broad emission line component

The Arches cluster.



Star cluster wind evolves in the quasi−adiabatic regime

Observational properties

(Serabyn et al. 1998 ; Yusef-Zadeh et al. 2002)

$R = 0.2$ pc

Lxray (0.2-10keV) ≈ $4\mathrm{x}10^{35}$ erg s^{-1}

Stevens & Hartwell model (2003):

$L_{sc} = 1.8\mathrm{x}10^{39}$ erg s^{-1}

$\dot{M}_{sc} = 7.3\mathrm{x}10^{-4}$ M_{o} yr^{-1}

$V_w = 2810$ km s^{-1}

$L_{Xray} = 10^{35}$ erg s^{-1}

Raga et al. model (2001):

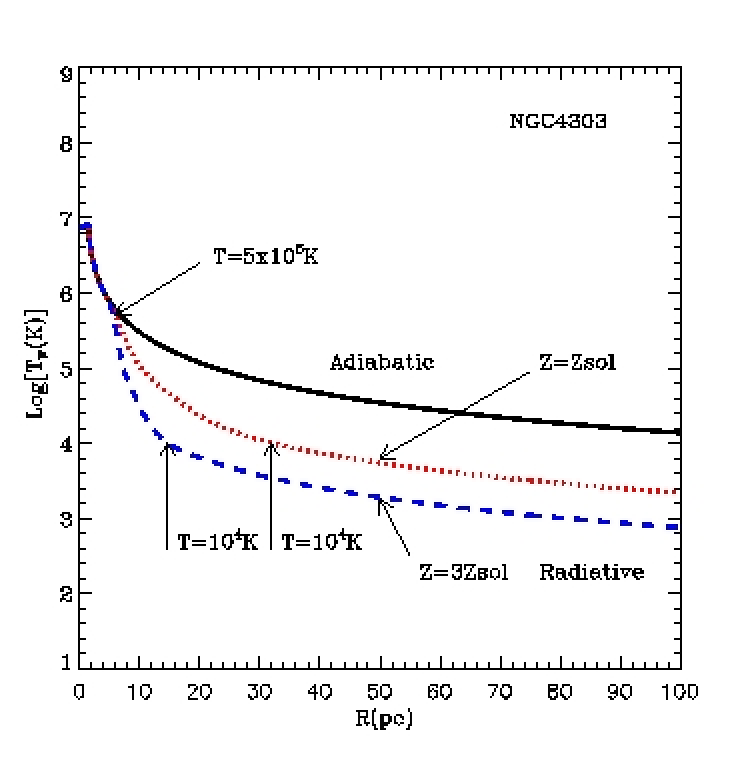
$L_{sc} = 4.25\mathrm{x}10^{38}$ erg s^{-1}

$\dot{M}_{sc} = 6\mathrm{x}10^{-4}$ M_{o} yr^{-1}

$V_w = 1500$ km s^{-1}

$L_{Xray} = 3\mathrm{x}10^{35}$ erg s^{-1}

The nucleus of NGC4303



Observational properties

(Colina et al. 2002; Jimenez−Bailon et al. 2003)

R_{sc} = 1.55 pc

$M_{sc} = 10^5\ M_o$

kTxray = 0.65 keV

$L_{H\alpha} = 1.2\times10^{39}$ erg s^{-1}

Lxray (0.2-2keV) ≈ 1.7×10^{38} erg s^{-1}

Z=Zsol model predictions

$L_{sc} = 3\times10^{39}$ erg s^{-1}

V_w = 715 km s^{-1}

$L_{Xray} = 1.3\times10^{38}$ erg s^{-1}

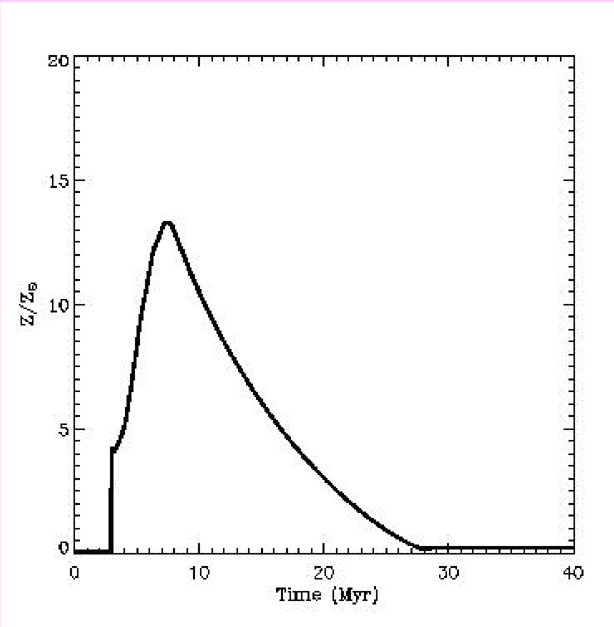
Broad component luminosity :

$L_{H\alpha} = 1.5\times10^{36}$ erg s^{-1} ; $L_{Br\gamma} = 1.4\times10^{34}$ erg s^{-1}

The wind temperature begins deviate from the adiabatic model already at ≈ 6 pc radius.

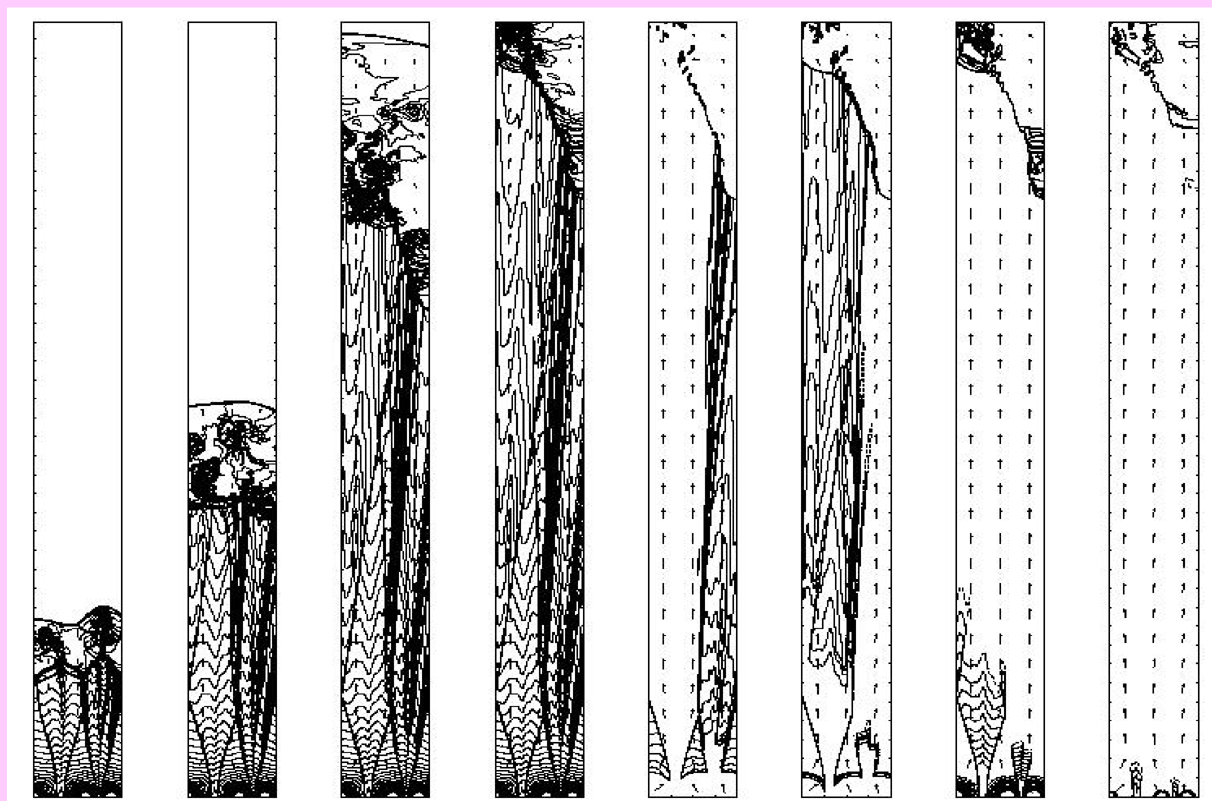
The expected luminosity of the broad component is ≈0.1% of the core Hα emission.

5. Galactic winds driven by multiple SSCs



The interection of winds from neighboring SSCs lead to a collection of oblique shocks that collimate their outflows into a network of dense and cold filaments embedded into a hot X-ray environment.

← Density → ← Temperature →



Each SSC is a source of a high-metallicity supersonic outflow.

Tenorio-Tagle et al. 2003

4. Conclusions

1. We have found a self-consistent stationary solution for radiative winds driven by individual super-star clusters.

2. Our model predicts:

   - An internal wind structure that is radically different from the adiabatic solution. This implies:
   - a much less extended region of X-ray emission ;
   - instead there is a photo-ionized gaseous halo that should be detected as a week and broad emission line component at the base of the narrow component caused by the central HII region ;

3. The interection of multiple winds collimates galactic wind outflows and forms a network of dense and cold filaments embedded into a hot X-ray environment.