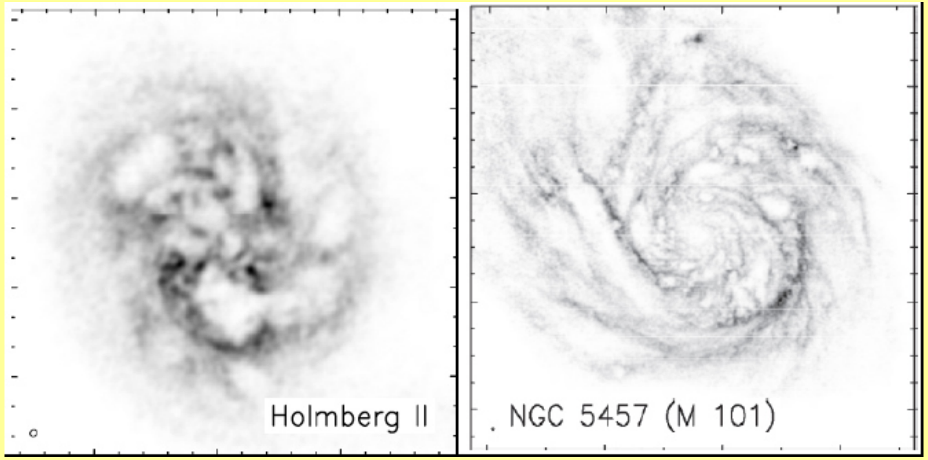
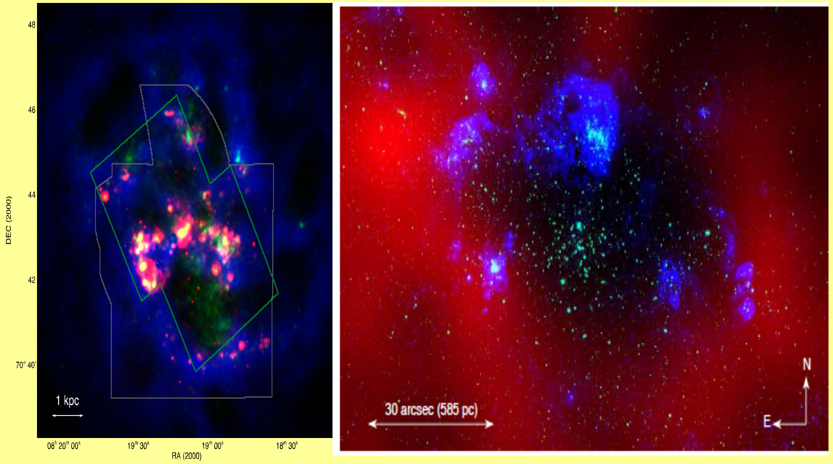
Velocity dispersion of ionized gas behind shockwaves

Evgenii Vasiliev,
Biman B. Nath, Alexei V. Moiseev, Yuri A. Shchekinov

collective SNe: shaping ISM, galactic winds & metal enrichment



Walter+ 2008 (THINGS survey)

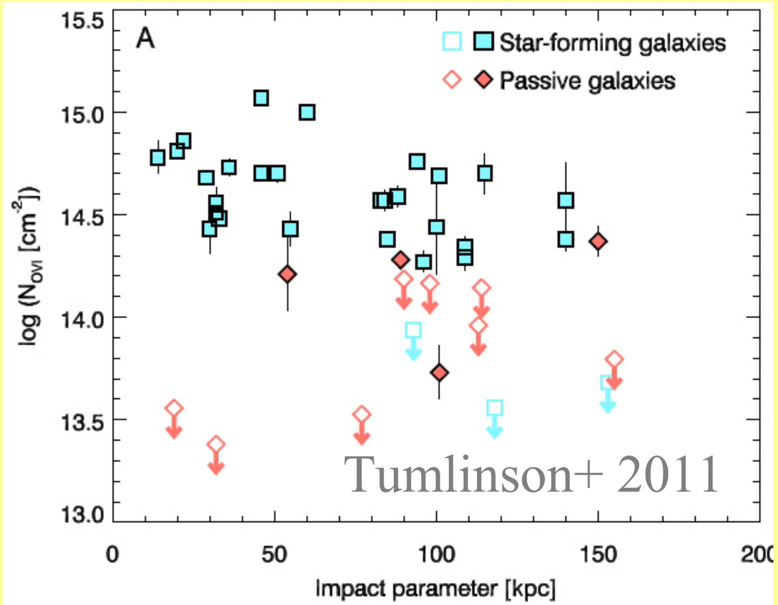


Egorov etal 2014, 2016

metals come from ejection by massive stars
on scales <1pc

shells → supershells → galactic outflows and winds

spread over scales ~1 Mpc (and even in voids)



starbursts → galactic winds

mechanical luminosity (as usual) $L = \nu_{\rm SN} E_{\rm SN}$

multiple SNe explosions (from starburst) $\frac{\partial^2 E}{\partial \mathbf{r} \partial t} = \sum_i \delta(t - t_i)\delta(\mathbf{r} - \mathbf{r}_i)$

understanding conditions for galactic wind launch

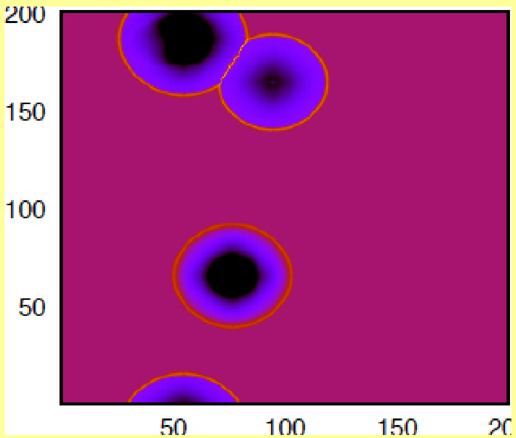
coherency of SNe:

the remnants first overlap (collide), then start cooling

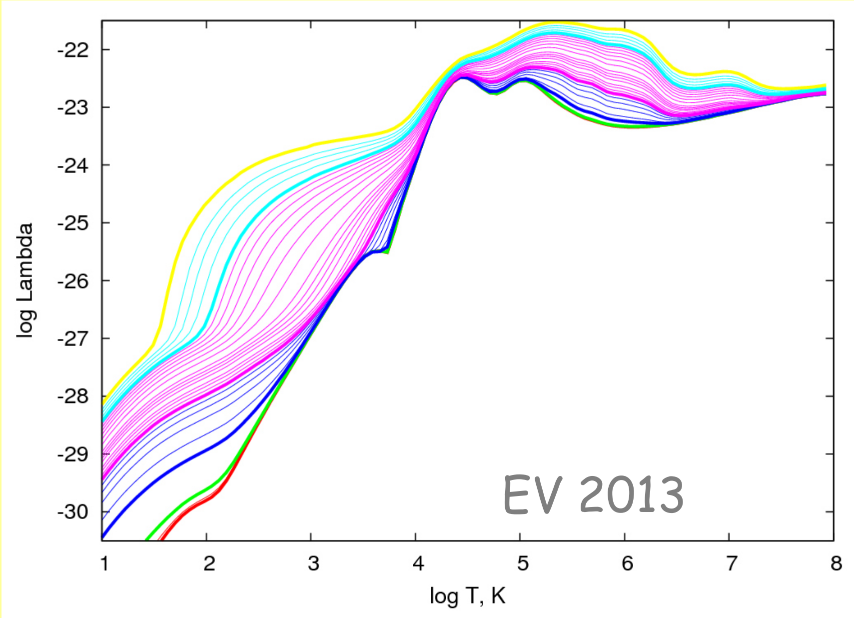
$t_c \leqslant t_r$

Nath & Shchekinov 2013

$$\nu_{\rm SN} \geq \left(\frac{\rho}{E_{\rm SN}}\right)^{4/3} c_h^{11/3} \sim 2 \times 10^{-13}\ {\rm yr^{-1}\ pc^{-3}}$$



nonequilibrium cooling



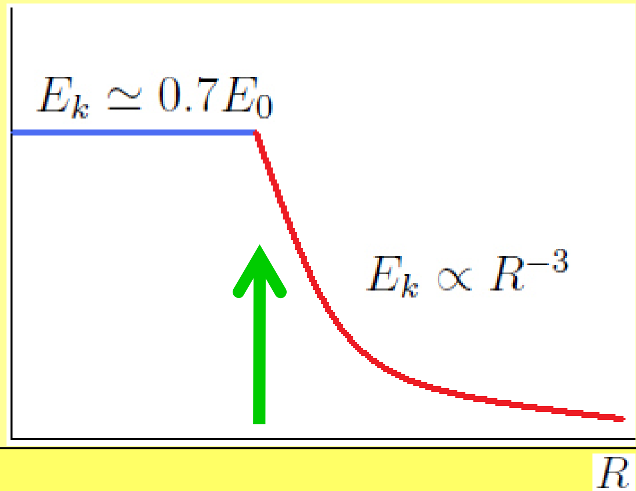
cooling time

dynamical time

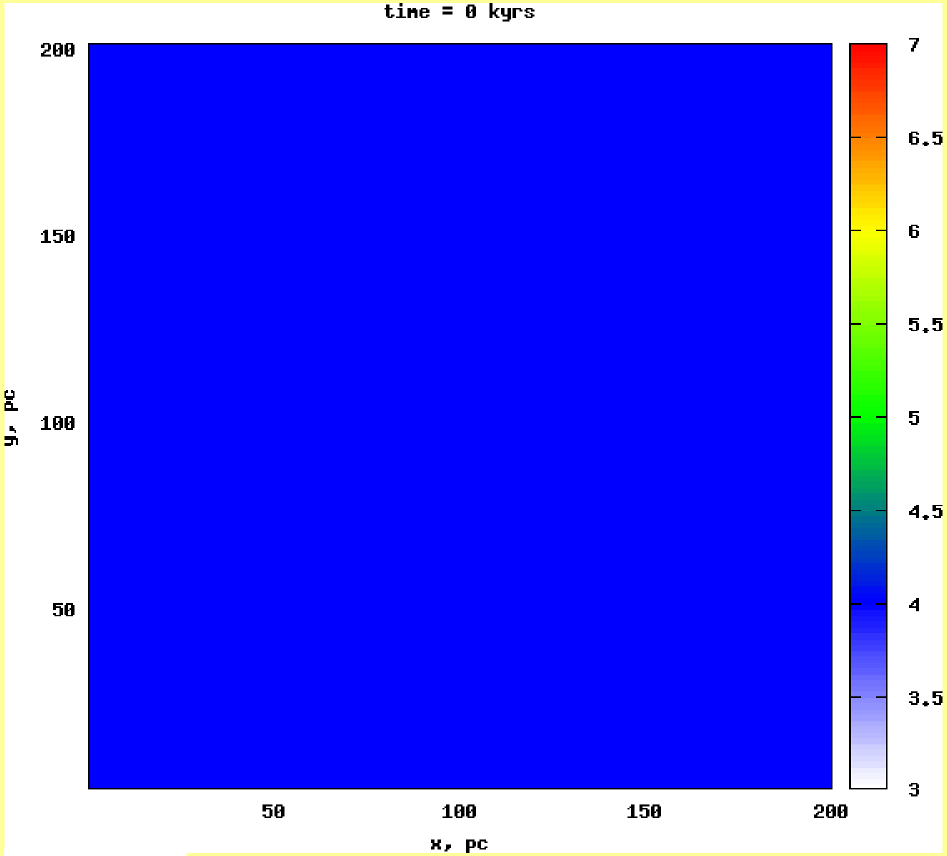
it begins when $t_d = \frac{kT}{4\Lambda n} < \frac{z_0}{3c_s}$

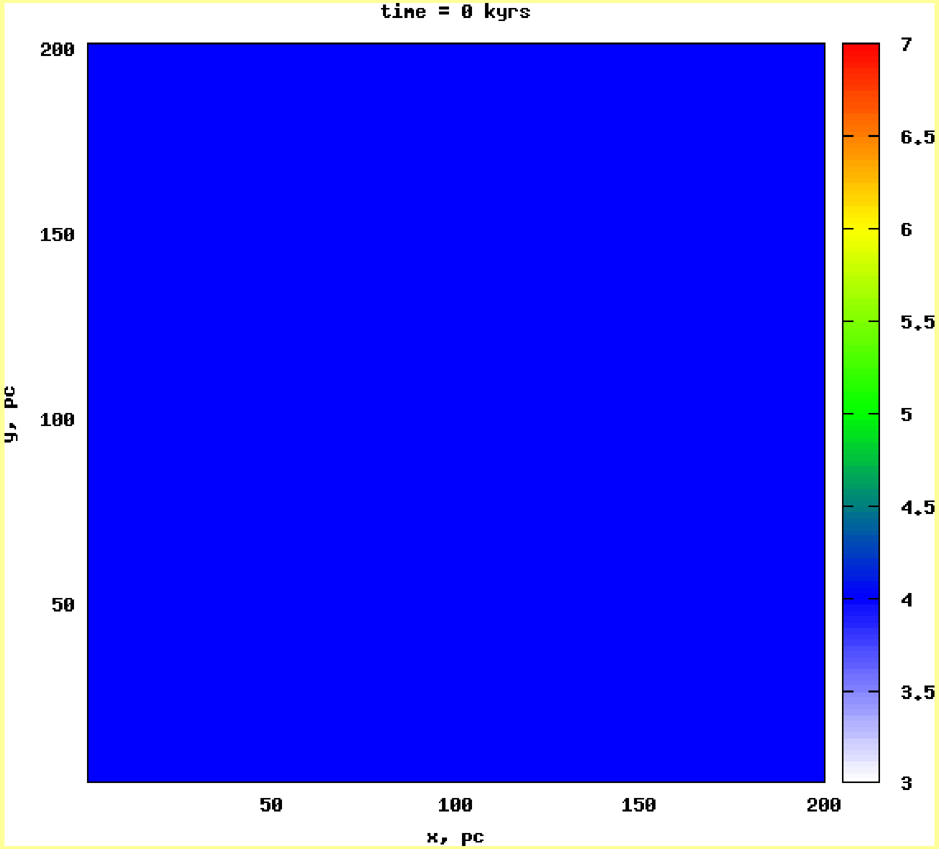
$$\frac{10^{10}}{n}\ \mathrm{s} < 10^{15}\ \mathrm{s}$$

ratio of saved (accumulated) thermal energy to total injected energy is **heating efficiency**



percolating SNe





$\nu_{\rm SN} = 6.25 \times 10^{-12}$ $\quad$ $1.25 \times 10^{-12}\ {\rm pc}^{-3}\ {\rm yr}^{-1}$

time for percolation of hot gas

~ 500 kyr $\quad$ ~1Myr

continuous explosions: heating efficiency

$$\nu_{SN} = 1.2 \times 10^{-10}\ \mathrm{pc}^{-3}\ \mathrm{yr}^{-1}$$

$$1.2 \times 10^{-11}$$

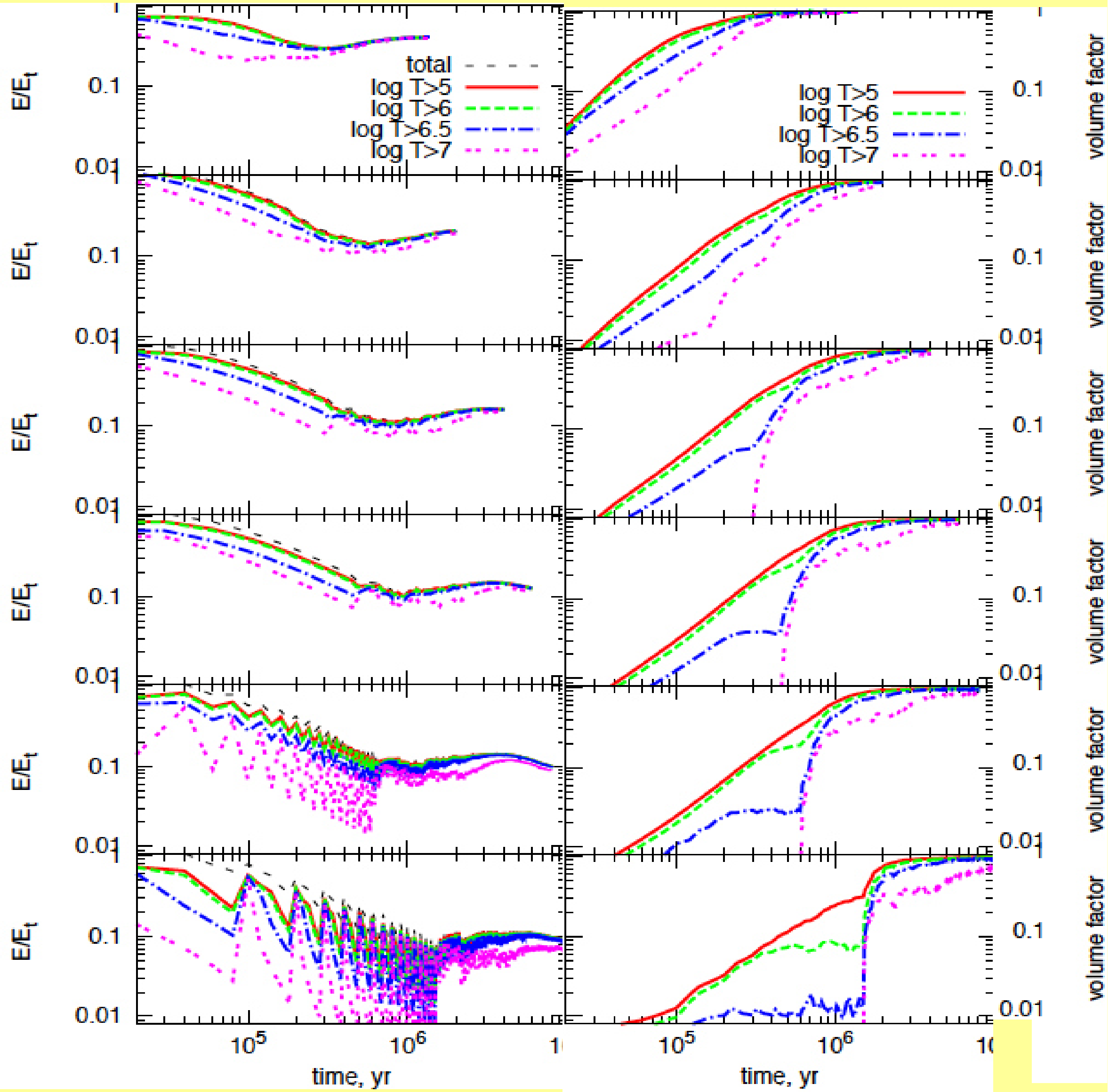
$$6.25 \times 10^{-12}$$

$$3.75 \times 10^{-12}$$

$$3.1 \times 10^{-12}$$

$$1.25 \times 10^{-12}$$

EV, Nath, Shchekinov, 2015



$$\text{Scaling}: \quad \eta_{[10^{6.5}]} \propto \nu_{SN}^{0.2} n^{-0.6}$$

- time for percolation set on

$$t_{\rm perc} \approx 10\,{\rm Myr}\left(\frac{n}{E_{51}}\right)^{4/7}\left(\frac{\nu_{\rm SN}}{10^{-12}\,{\rm pc}^{-3}\,{\rm yr}^{-1}}\right)^{-4/7}.$$

- time for a starburst to exhaust

$$t_{\rm SB} \sim \frac{M_{\rm g}}{\dot{M}_{\rm SF}} \propto \frac{M_{\rm g}}{\nu_{\rm SN}}$$

- SNe start acting collectively (and can launch GW)

$$\frac{\nu_{\rm SN}}{10^{-12}\,{\rm pc}^{-3}\,{\rm yr}^{-1}} < 3\times10^{-4}\,n E_{51}^{4/3}$$

necessary conditions for galactic winds

- time for percolation set on

$$t_{\rm perc} \approx 10\,{\rm Myr} \left(\frac{n}{E_{51}}\right)^{4/7} \left(\frac{\nu_{\rm SN}}{10^{-12}\,{\rm pc}^{-3}\,{\rm yr}^{-1}}\right)^{-4/7}.$$

?!

Long delay (>10 Myr) after starburst initiates before wind launch

(Sharp & Bland-Hawthorn 2010)

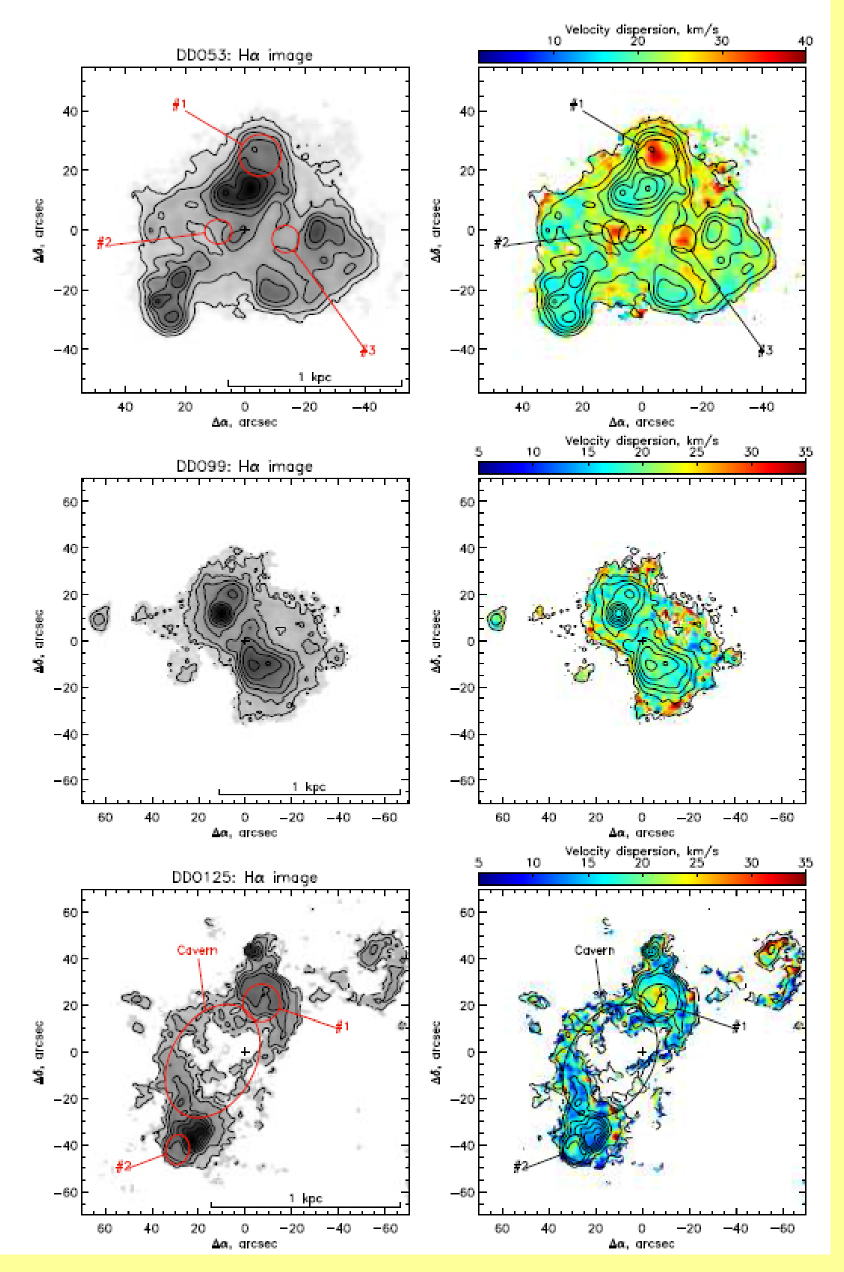
- time for a starburst to exhaust

$$t_{\rm SB} \sim \frac{M_{\rm g}}{\dot{M}_{\rm SF}} \propto \frac{M_{\rm g}}{\nu_{\rm SN}}$$

- SNe start acting collectively (and can launch GW)

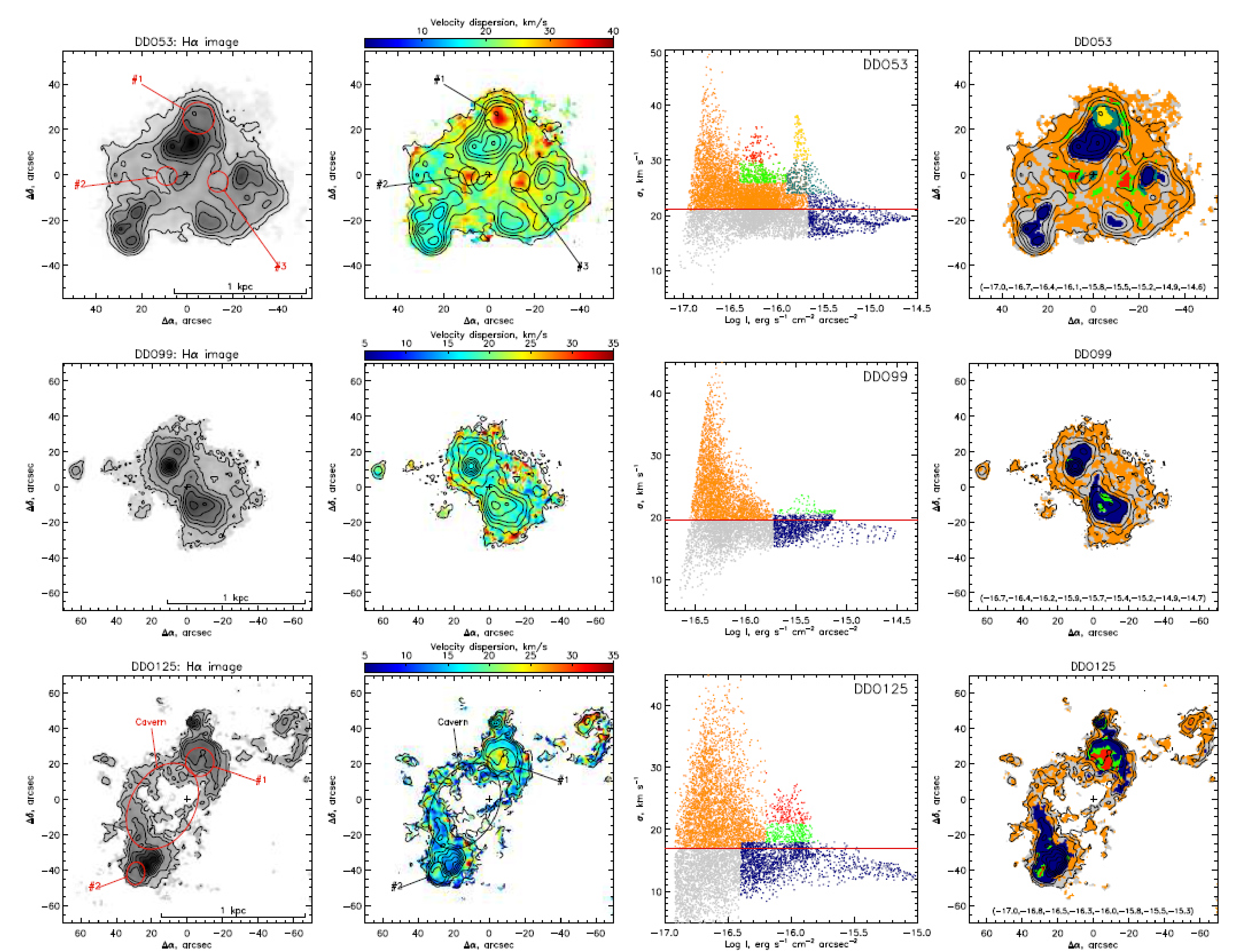
$$\frac{\nu_{\rm SN}}{10^{-12}\,{\rm pc}^{-3}\,{\rm yr}^{-1}} < 3 \times 10^{-4} n E_{51}^{4/3}$$

starformation in dwarf galaxies



Moiseev & Lozinskaya 2012

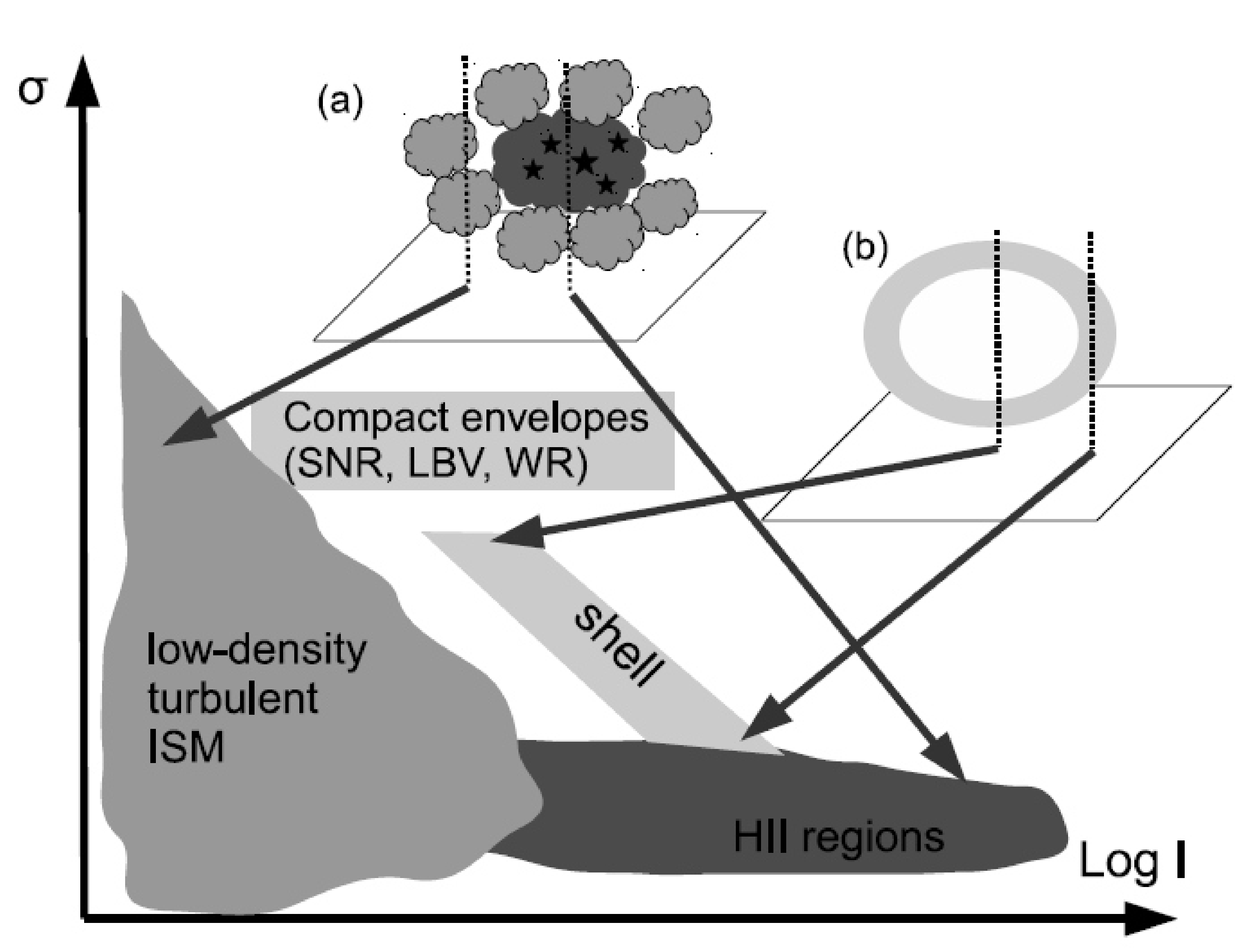
starformation in dwarf galaxies: analysis



Moiseev & Lozinskaya 2012

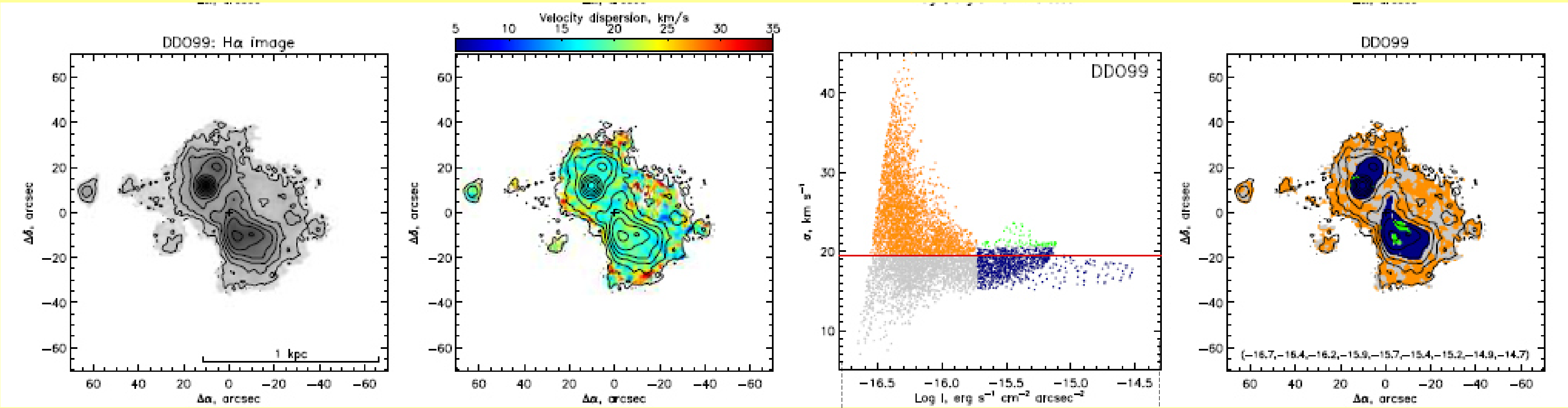
I(Halpha)-sigma diagram

only qualitative analysis



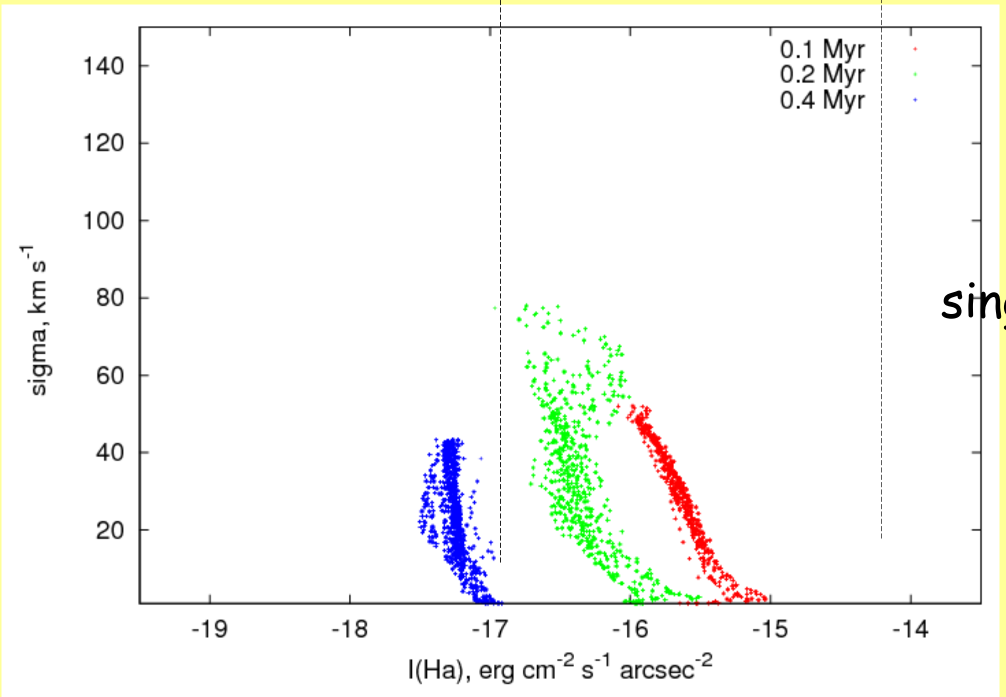
Munoz-Tunon etal 1996, Moiseev & Lozinskaya 2012

I(Halpha)-sigma for a single SN



dispersion along the line of sight

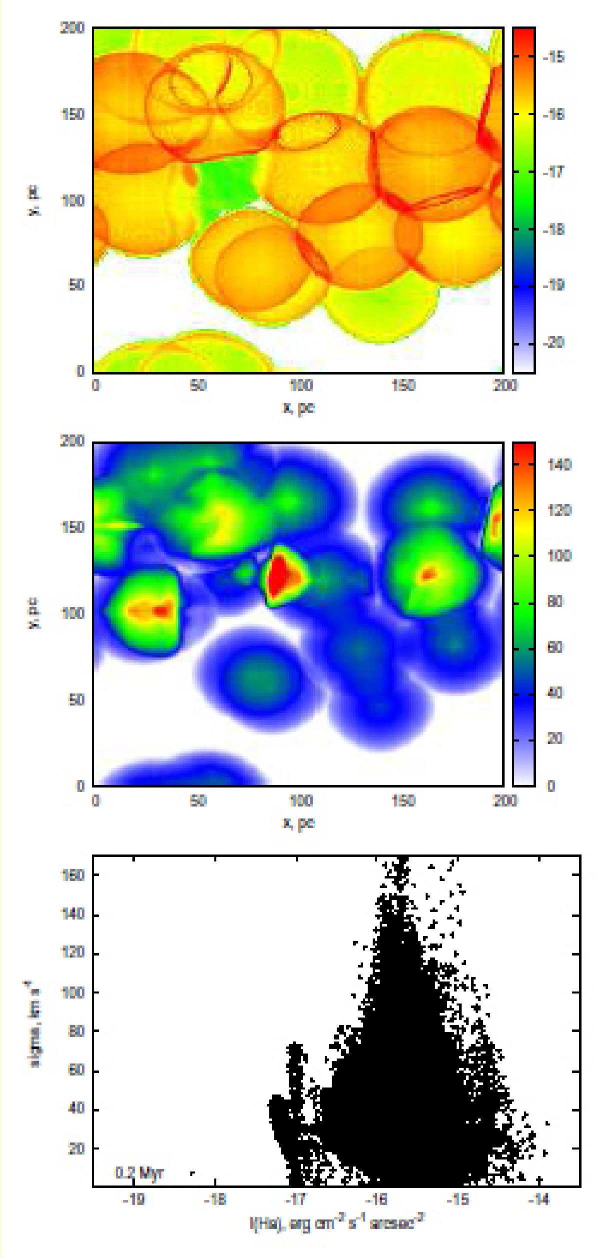
Martinez-Delgado et al 2007
Moiseev et al 2010



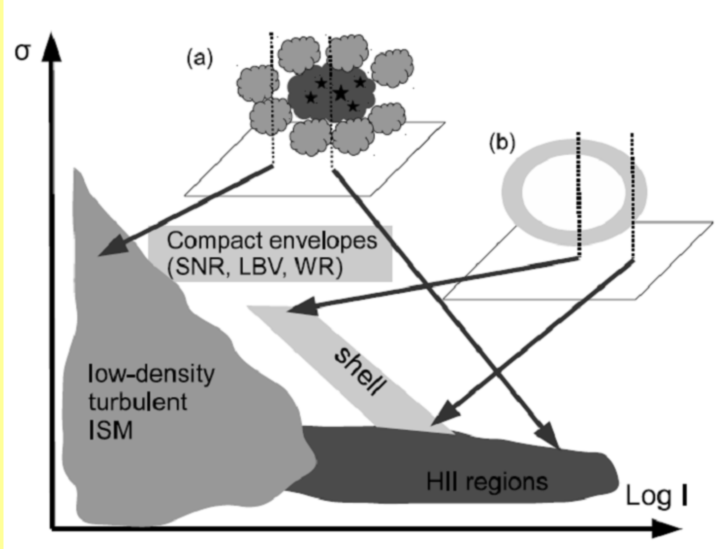
single isolated SN

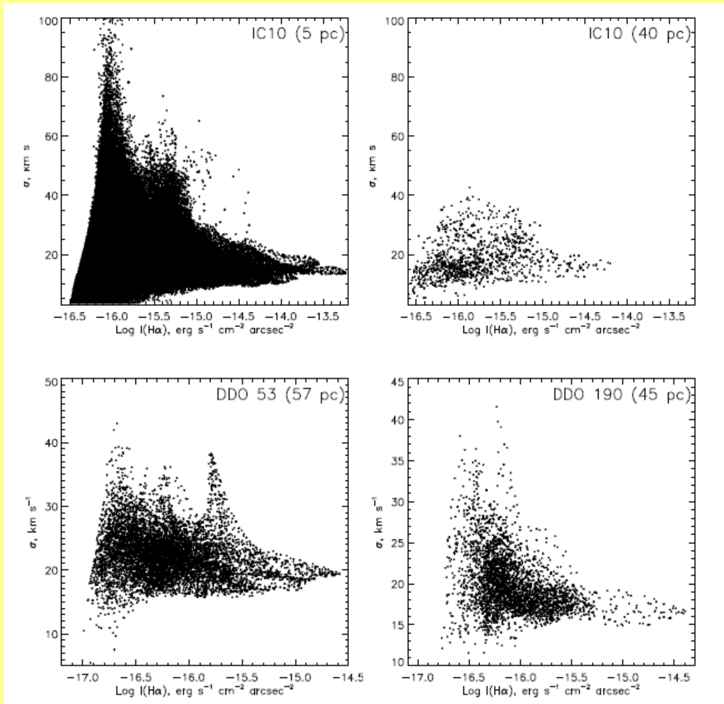
EV, Moiseev, Shchekinov, 2015

I(Halpha)-sigma for multiple SNe



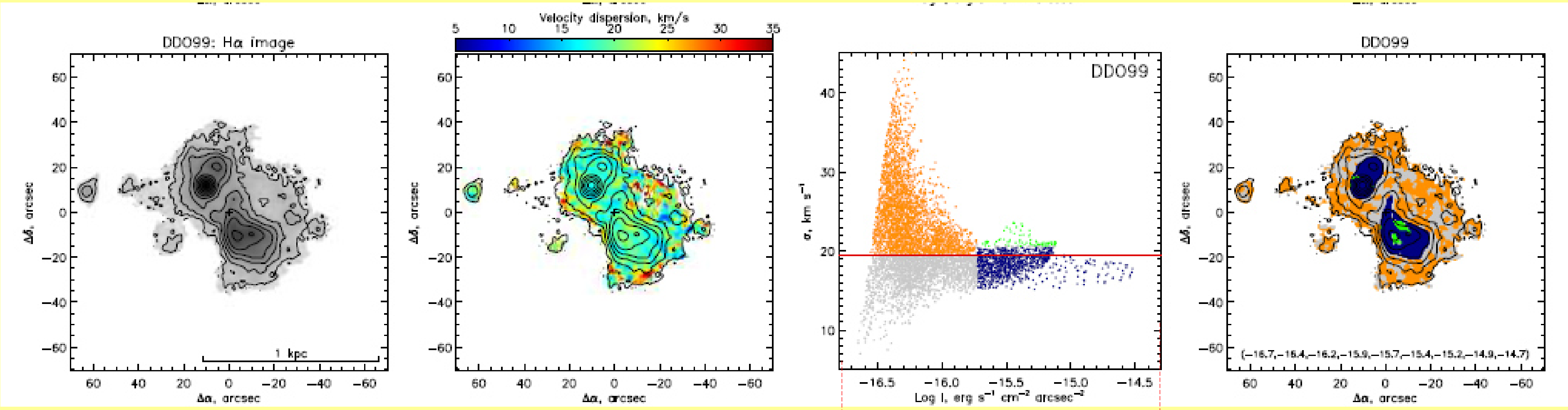
EV, Moiseev, Shchekinov, 2015





Munoz-Tunon etal 1996, Moiseev & Lozinskaya 2012

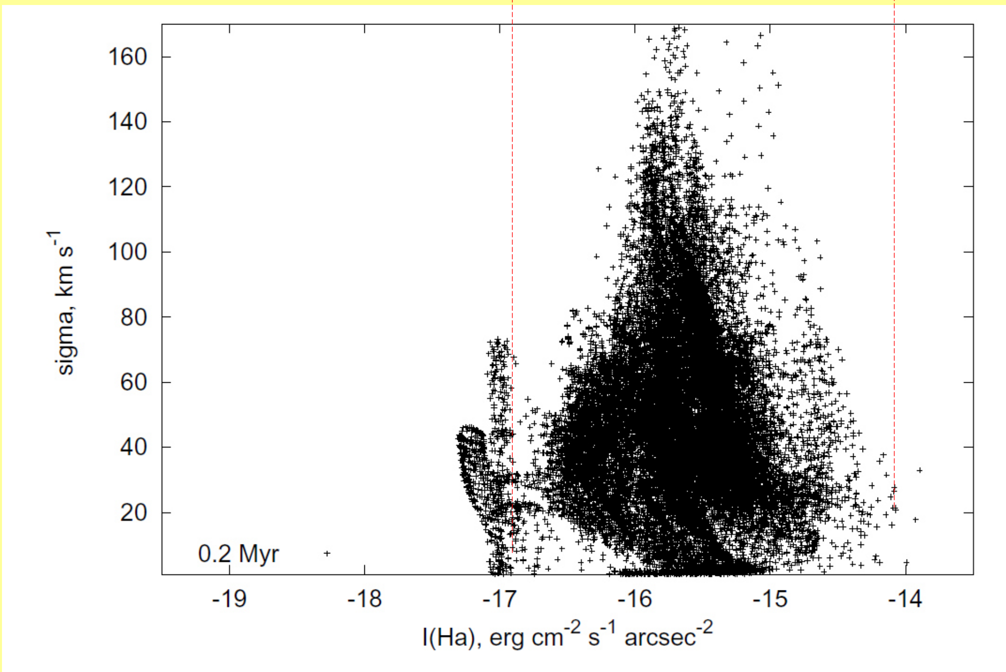
I(Halpha)-sigma for multiple SNe



dispersion along the line of sight

Martinez-Delgado et al 2007
Moiseev et al 2010

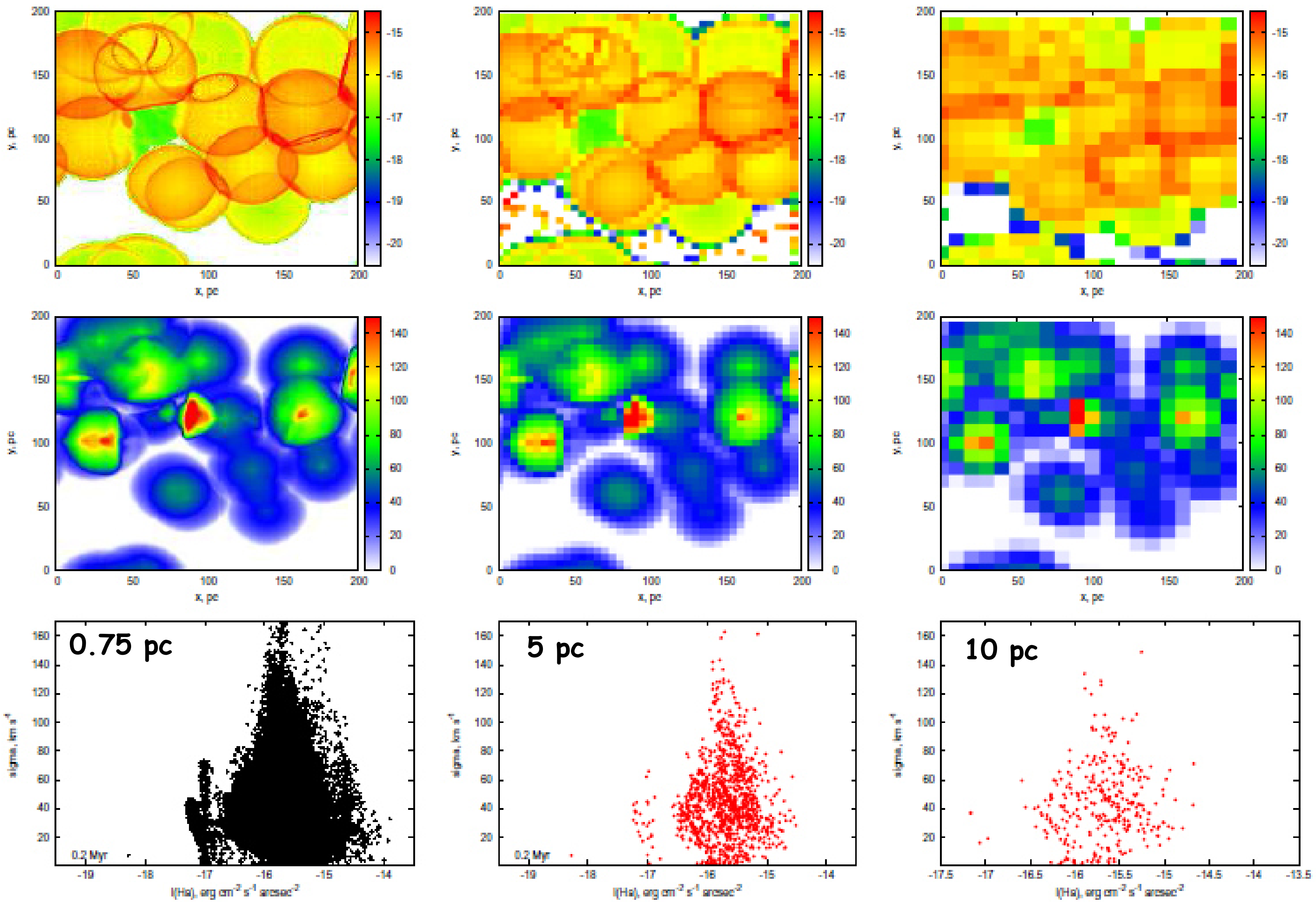
0.75 pc



multiple SN

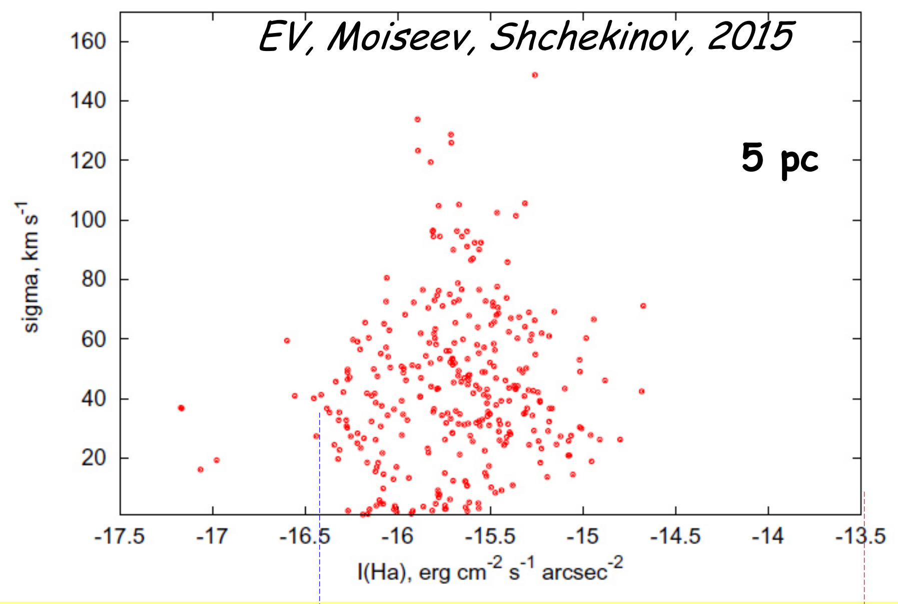
EV, Moiseev, Shchekinov, 2015

I(Halpha)-sigma for multiple SNe: degrading resolution

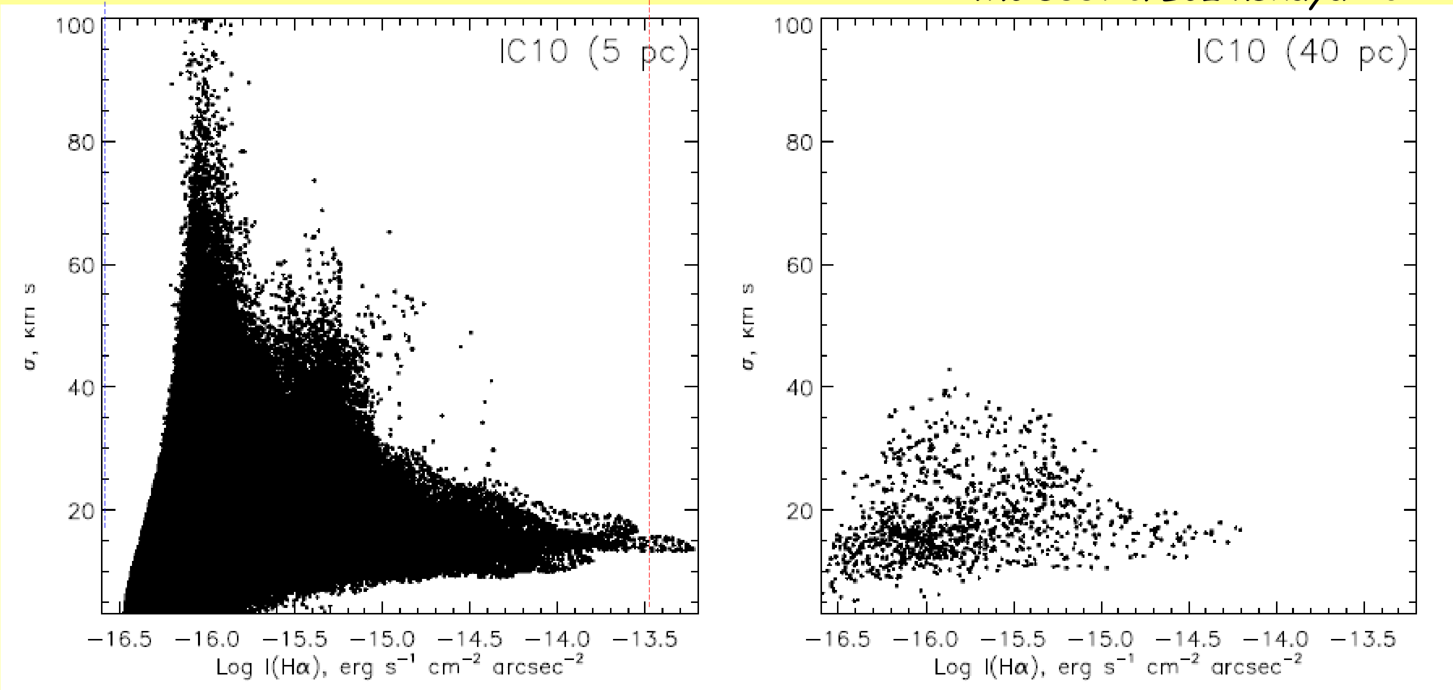


EV, Moiseev, Shchekinov, 2015

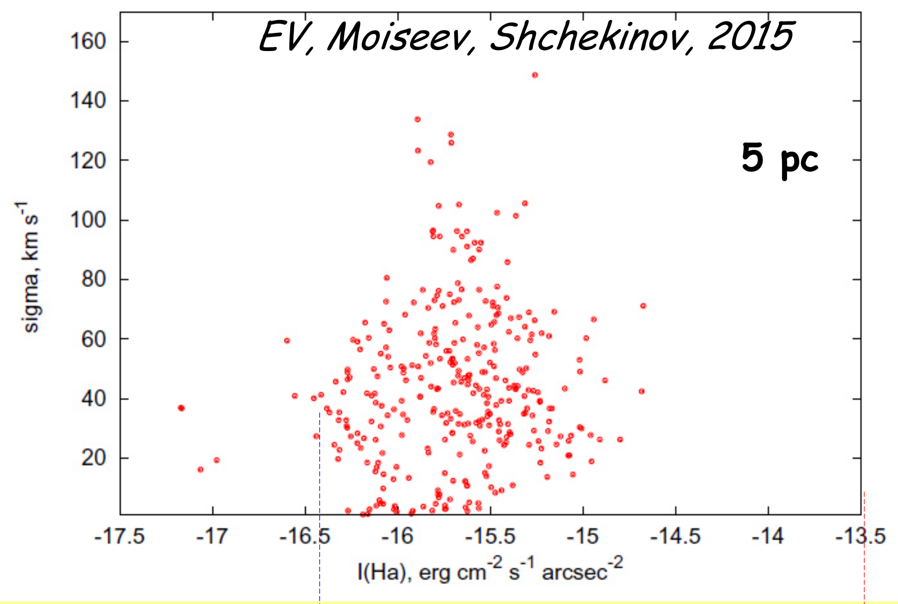
I(Halpha)-sigma for multiple SNe: degrading resolution



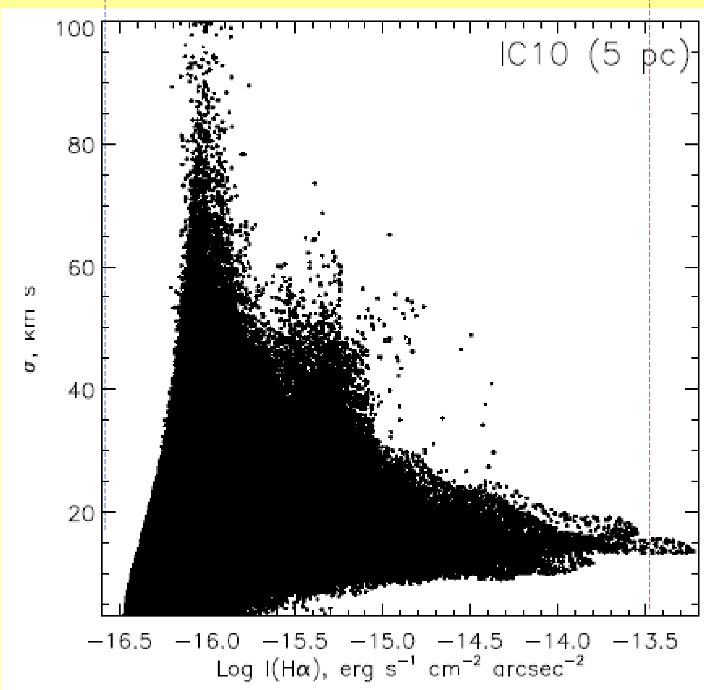
Moiseev & Lozinskaya 2012

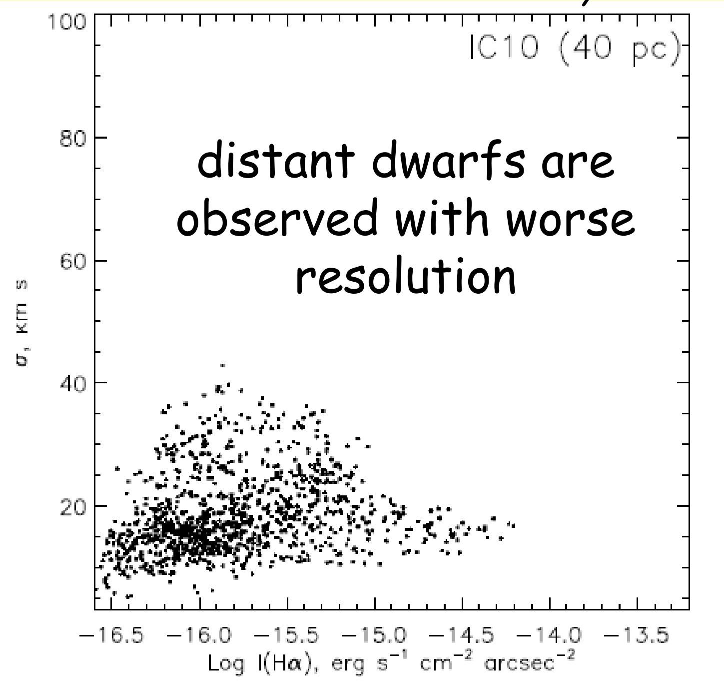


I(Halpha)-sigma for multiple SNe: degrading resolution

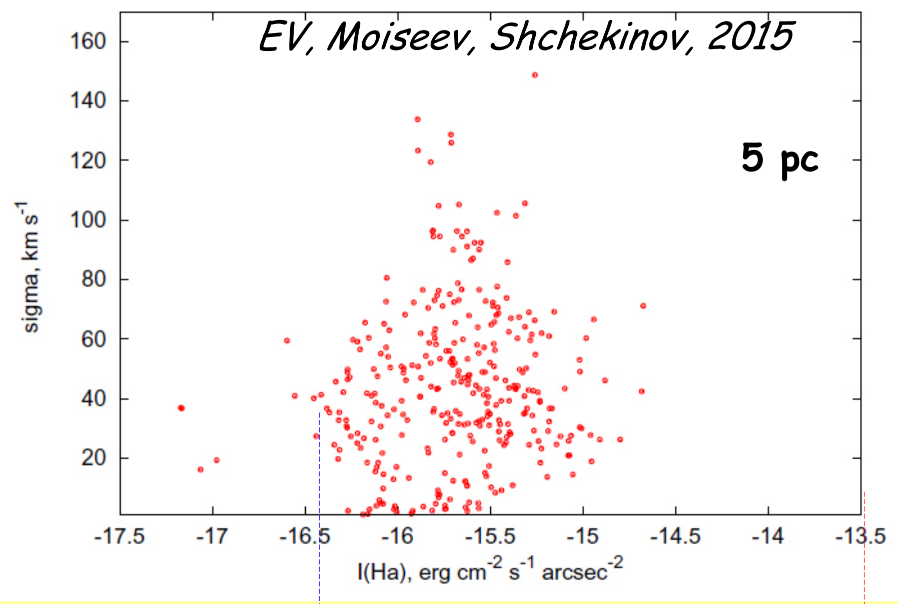


Moiseev & Lozinskaya 2012





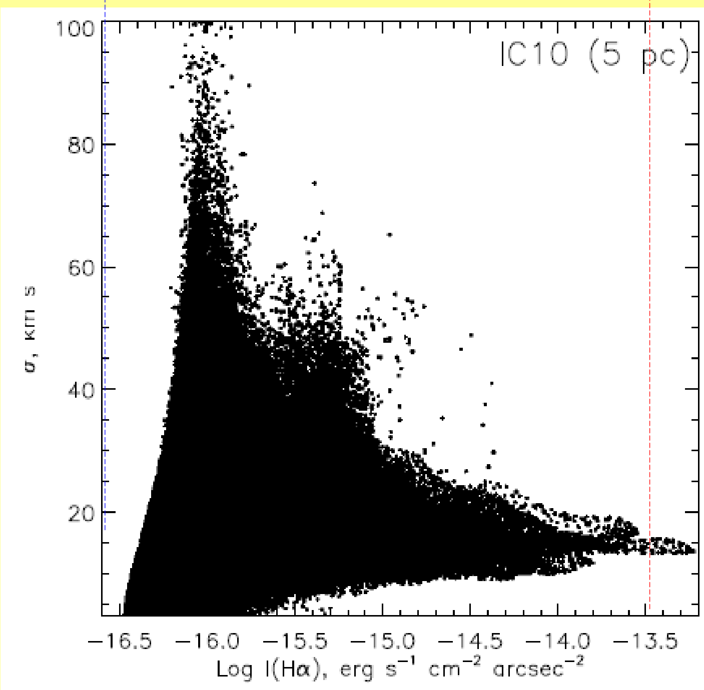
I(Halpha)-sigma for multiple SNe: degrading resolution

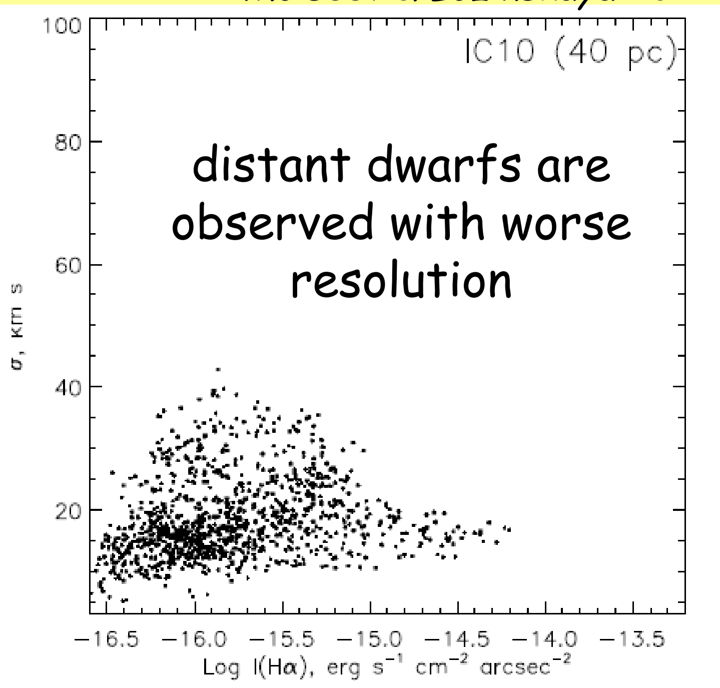


a theoretical view

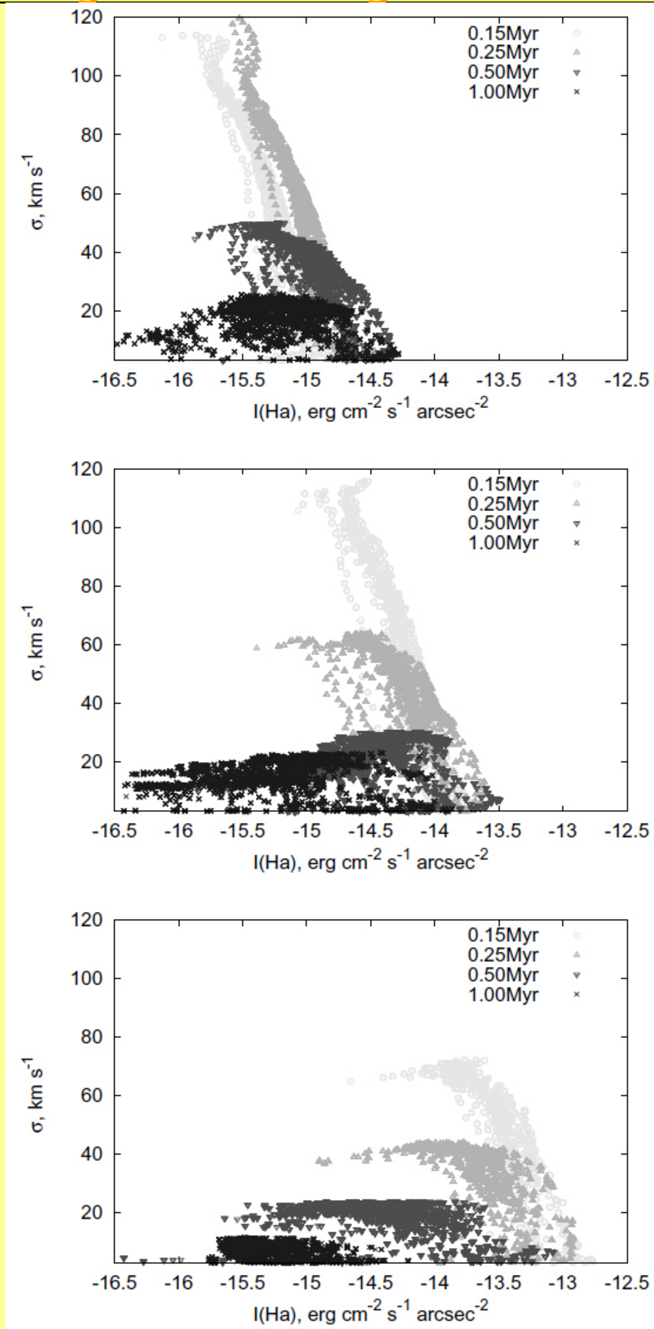
(e.g., dependence on n & Z)

Moiseev & Lozinskaya 2012





I(Halpha) – sigma for a single SN



[Z/H] = 0

1 cm^{-3}

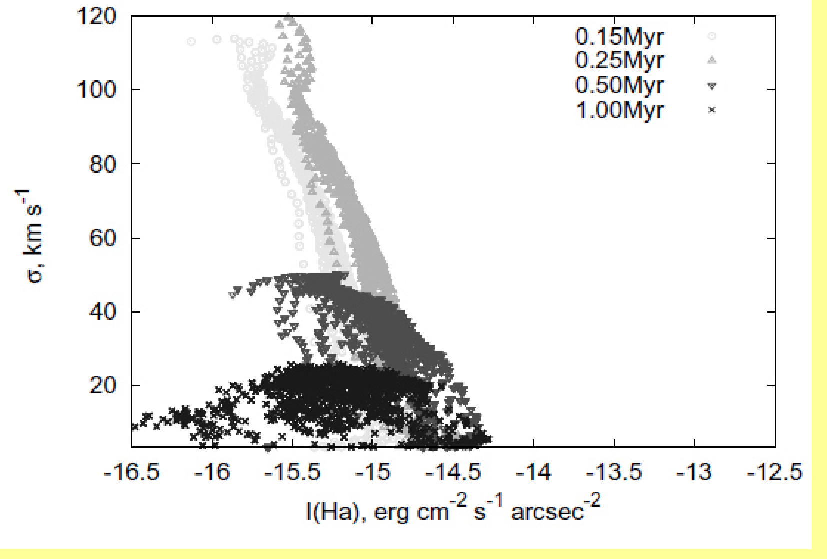
3 cm^{-3}

higher density –
earlier radiative phase –
smaller velocity dispersion
& higher intensity

10 cm^{-3}

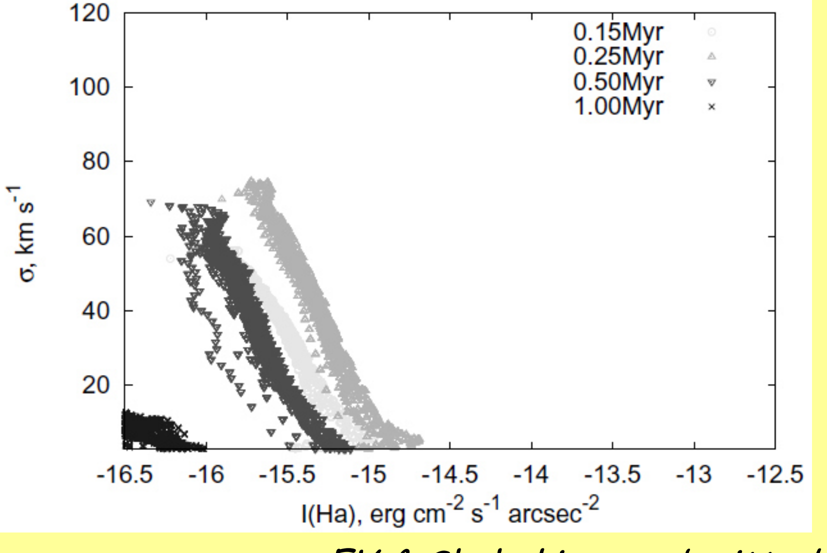
EV & Shchekinov, submitted

I(Halpha) - sigma for a single SN



1 cm^{-3}

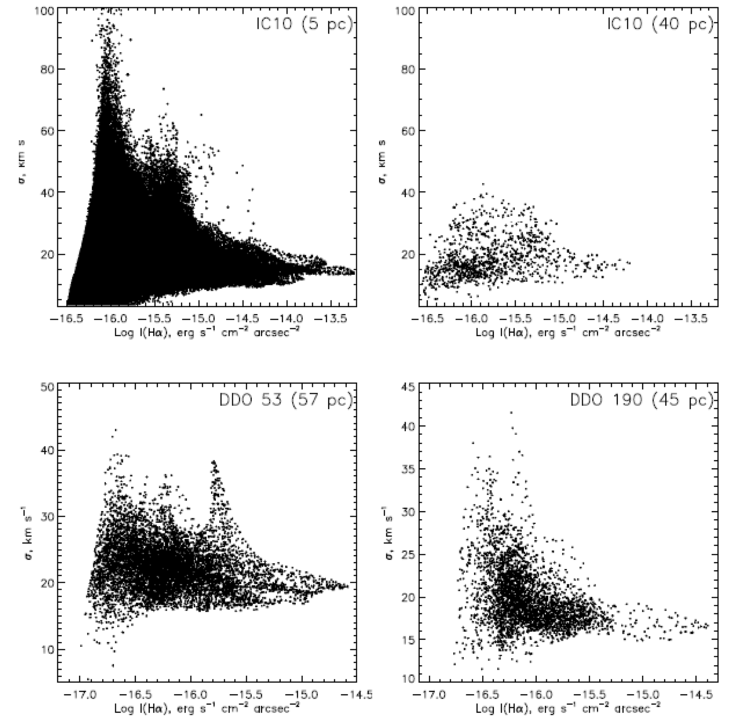
[Z/H] = 0



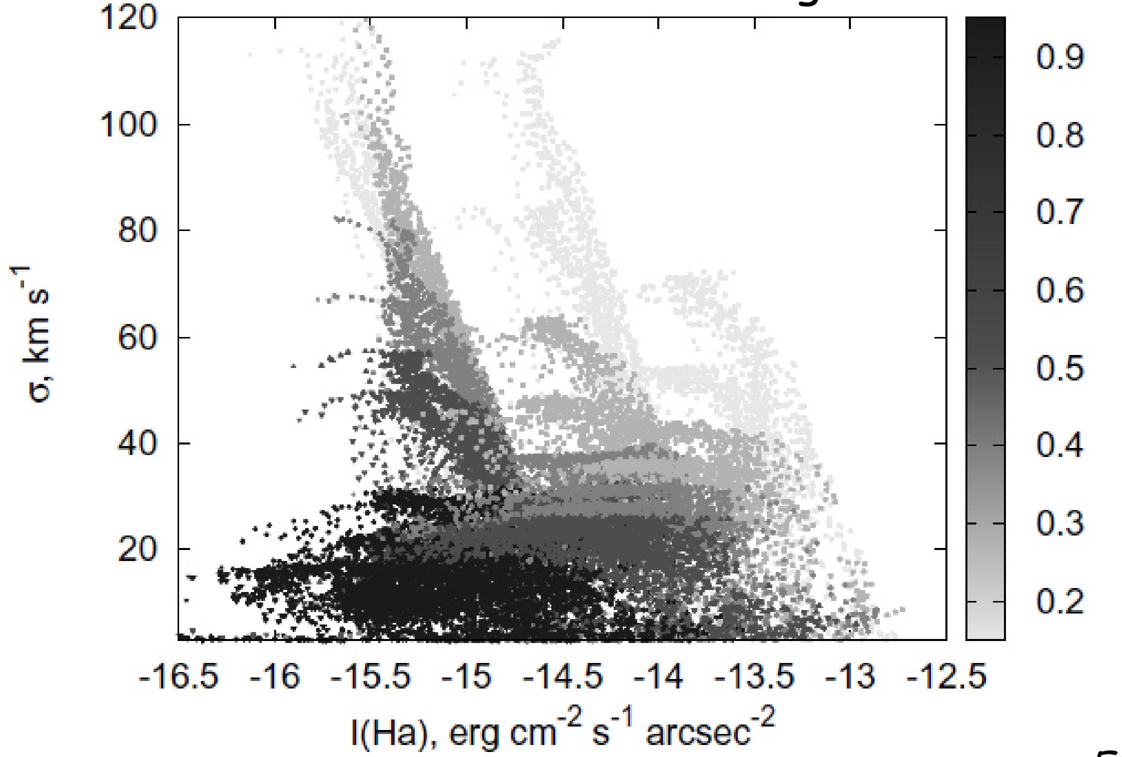
[Z/H] = -1

EV & Shchekinov, submitted

I(Halpha) – sigma for an ensemble of isolated SNe

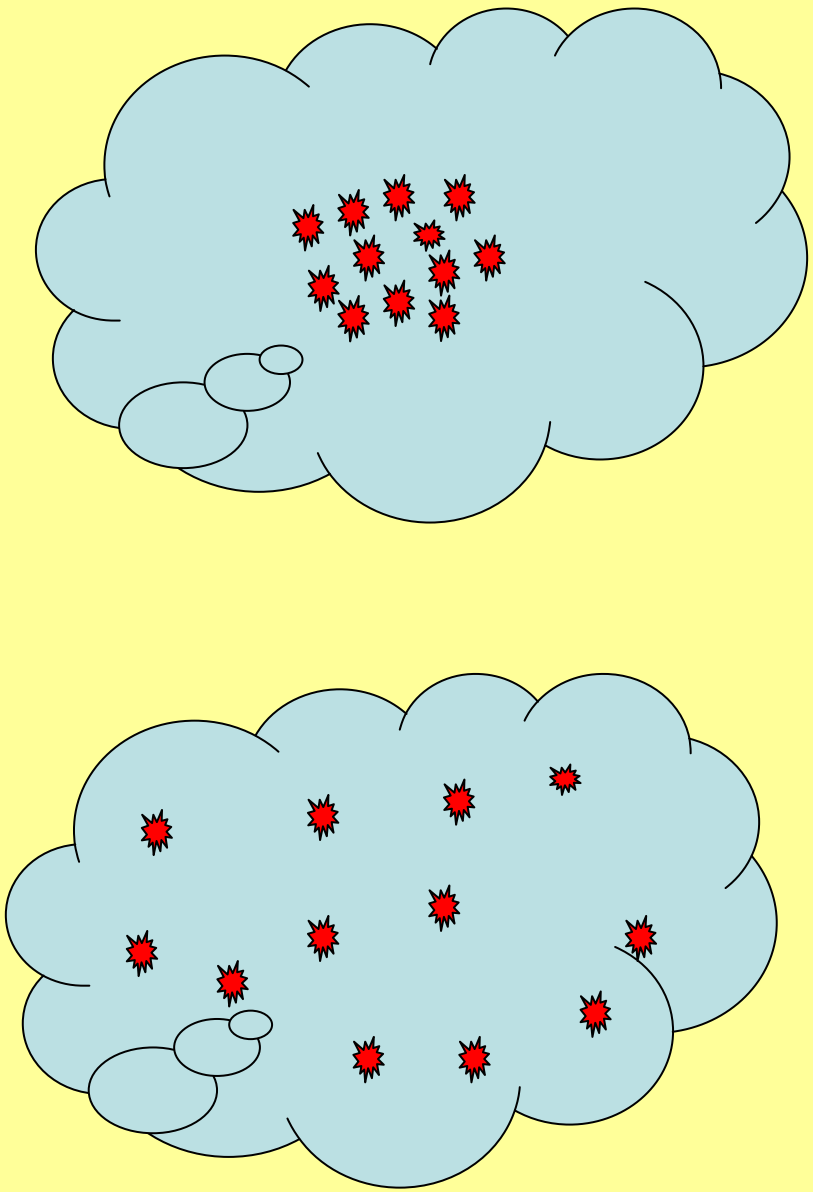


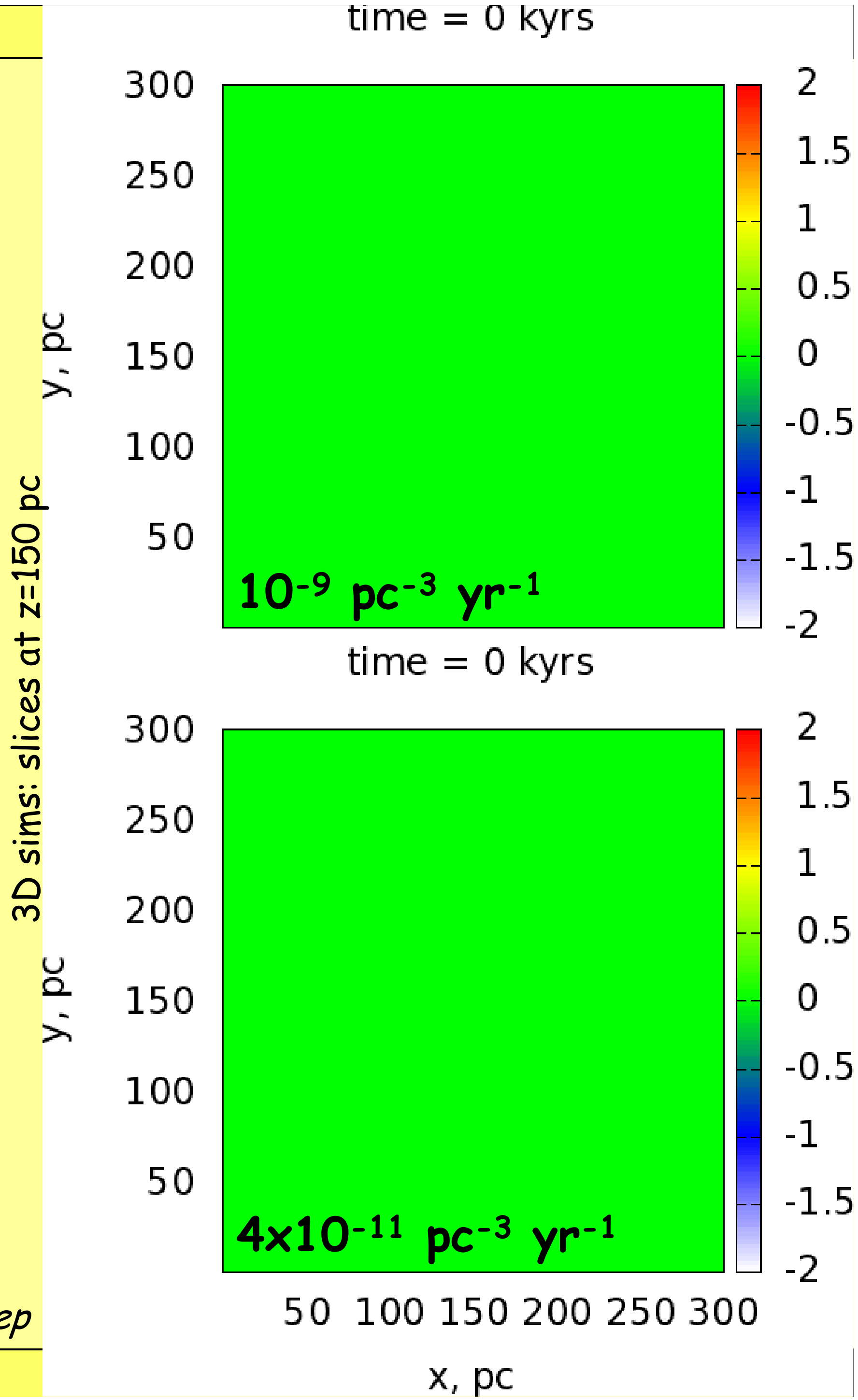
"ensemble" of non-interacting SNe



EV & Shchekinov, submitted

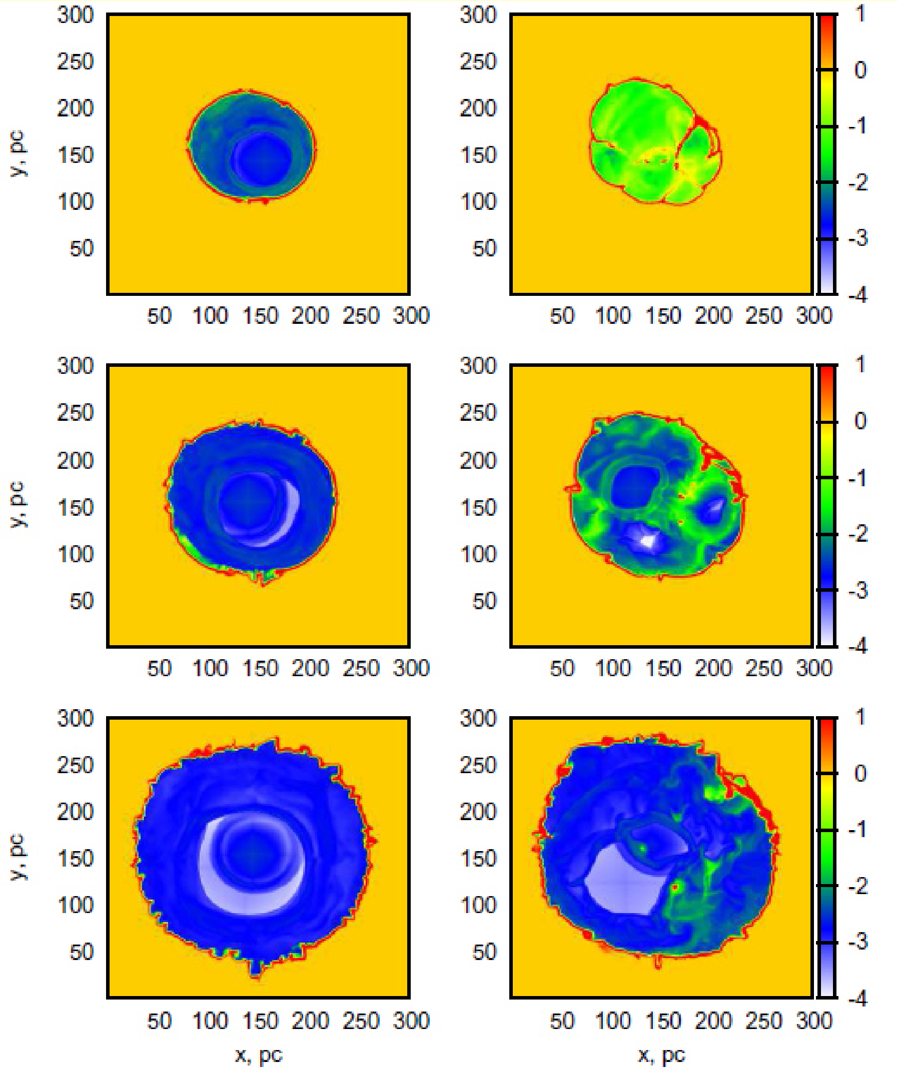
multiple SNe in a cluster





EV, Shchekinov, Nath, in prep

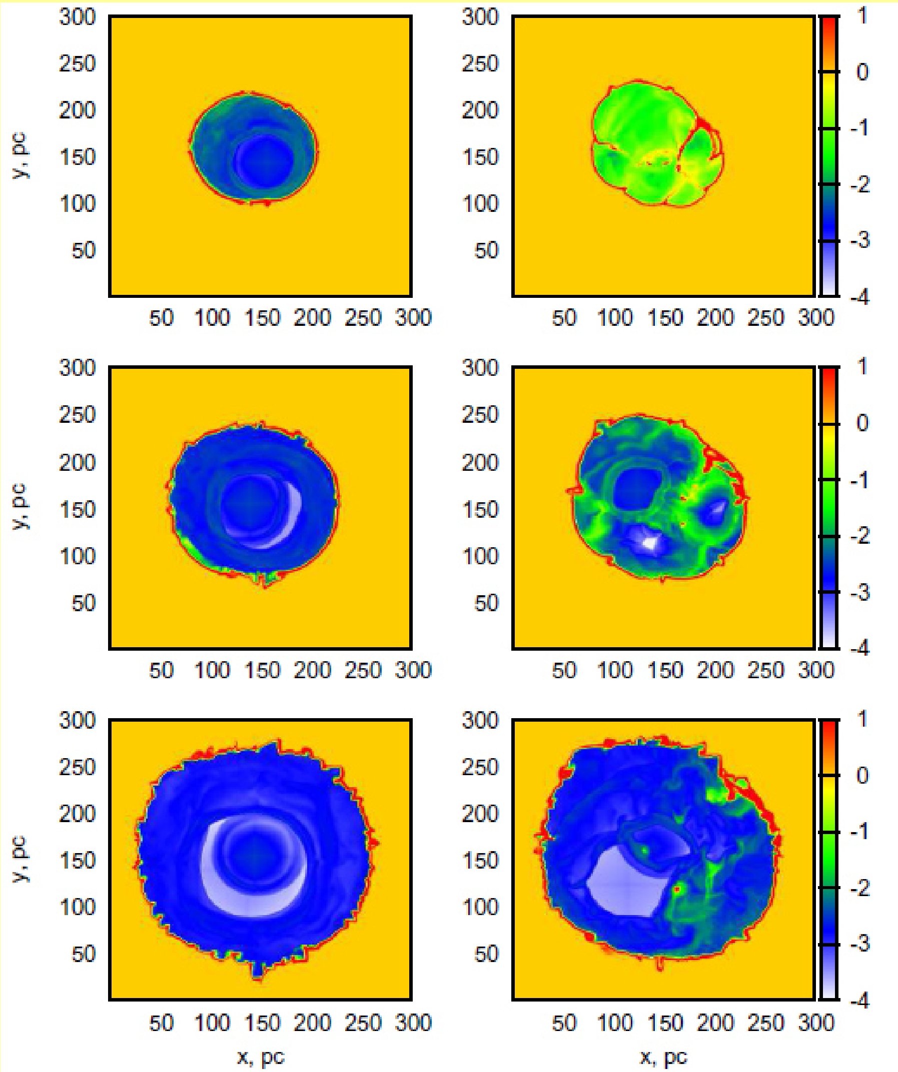
multiple SNe in a cluster: evolution



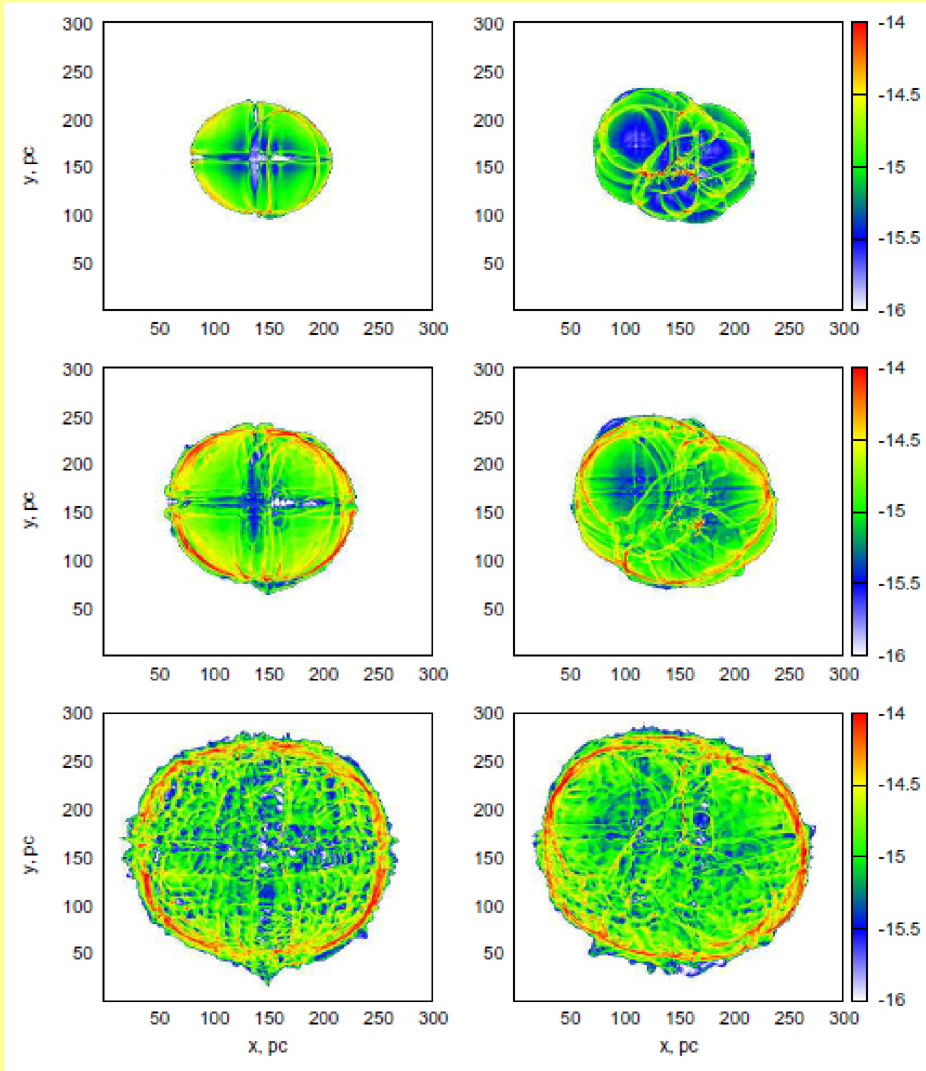
10^{-9} pc^{-3} yr^{-1} 4×10^{-11} pc^{-3} yr^{-1}

EV, Shchekinov, Nath, in prep

multiple SNe in a cluster: H-alpha maps



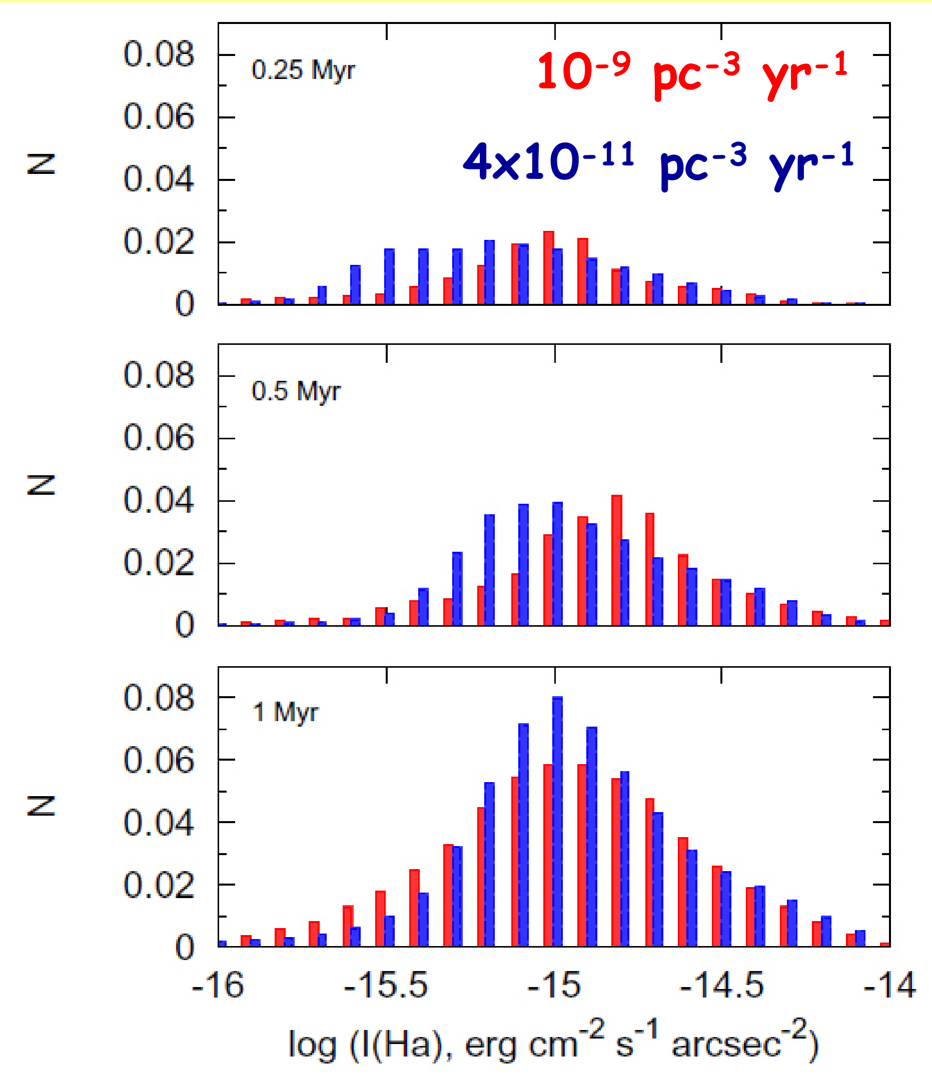
10^{-9} pc^{-3} yr^{-1} 4×10^{-11} pc^{-3} yr^{-1}

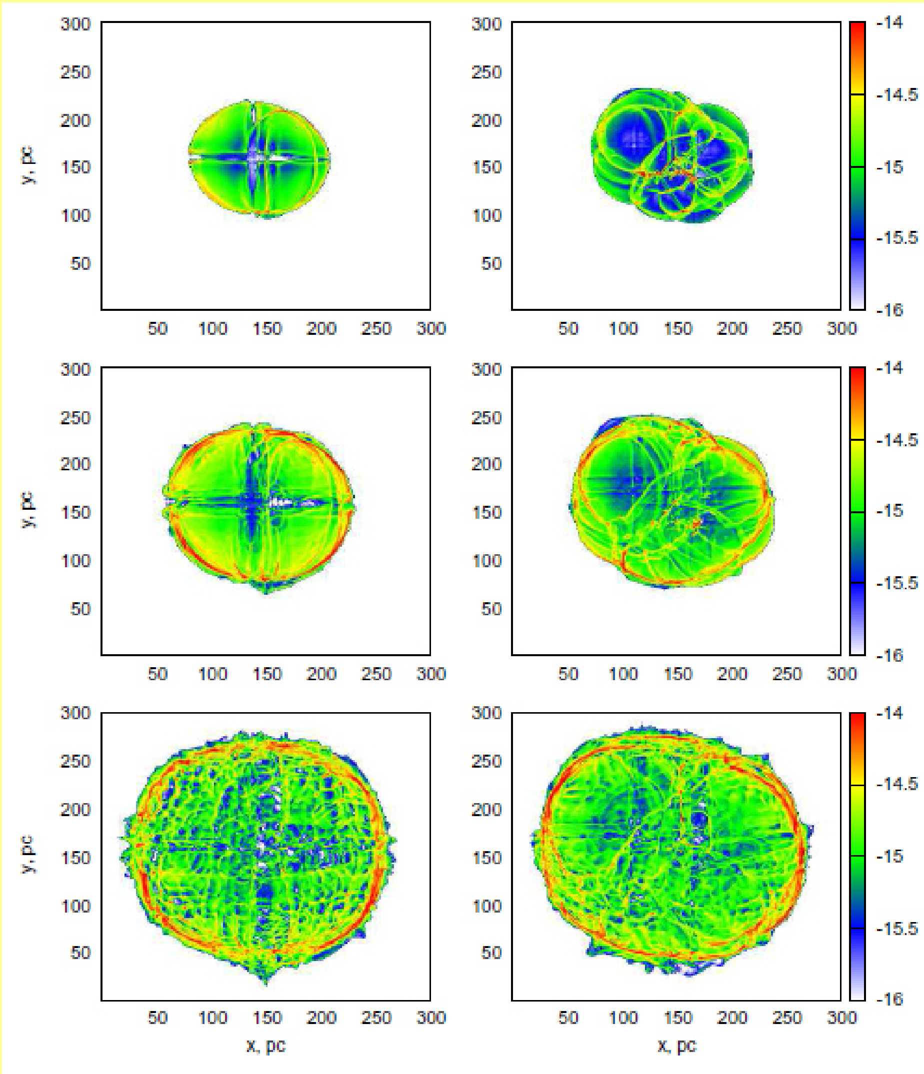


10^{-9} pc^{-3} yr^{-1} 4×10^{-11} pc^{-3} yr^{-1}

EV, Shchekinov, Nath , in prep

H-alpha statistics

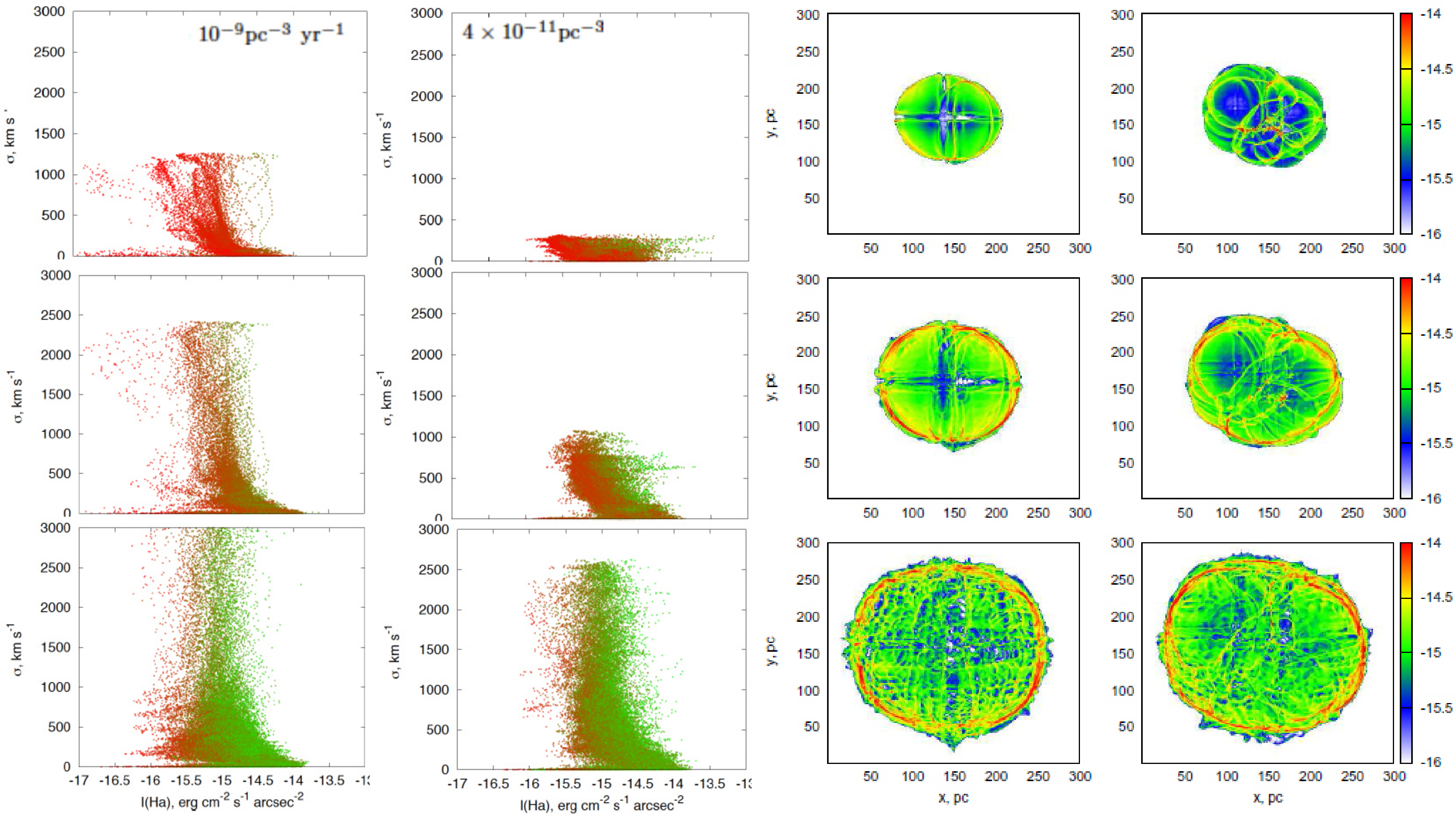




10^{-9} pc^{-3} yr^{-1} 4×10^{-11} pc^{-3} yr^{-1}

EV, Shchekinov, Nath, in prep

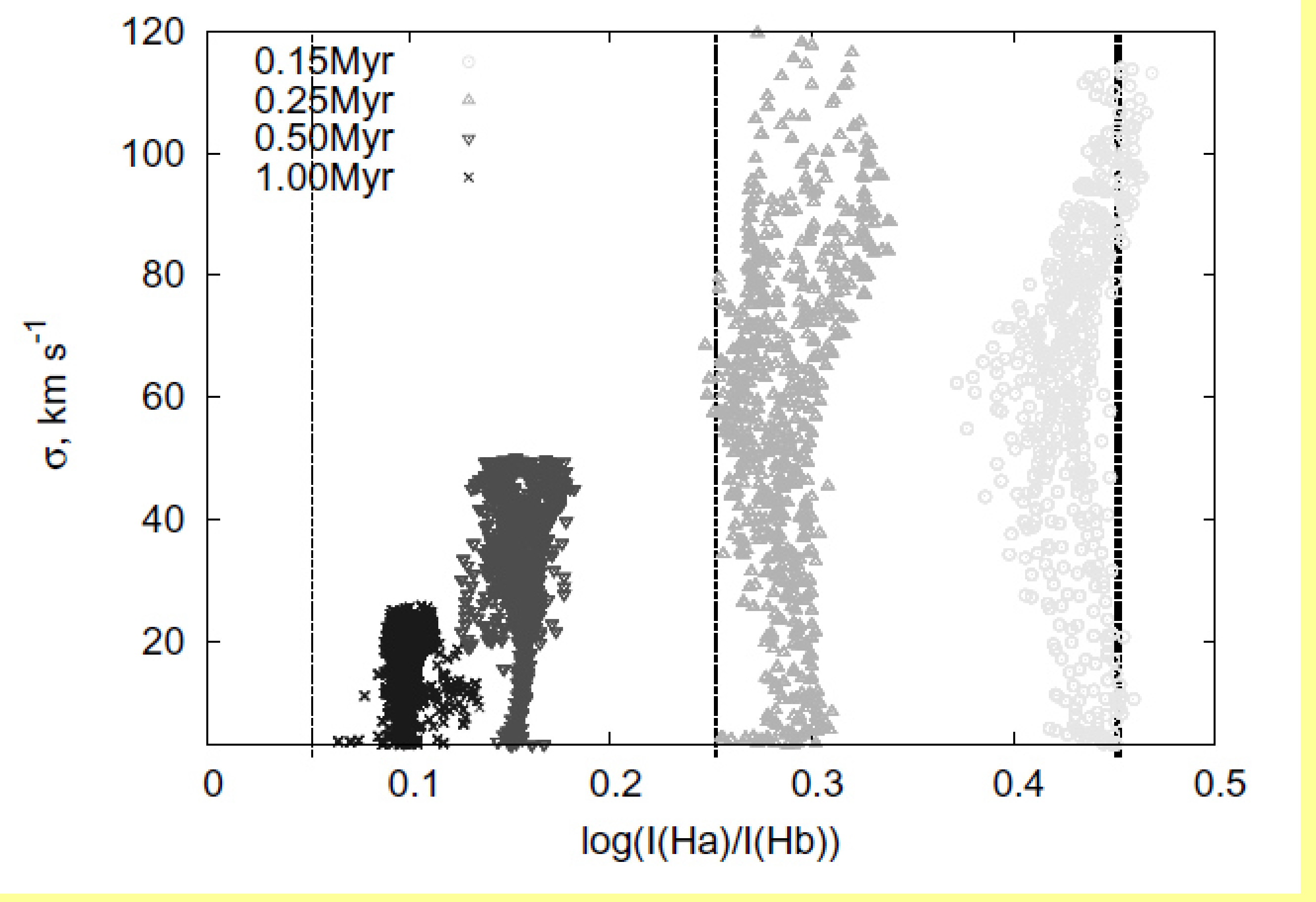
H-alpha intensity – velocity dispersion



10^{-9} pc^{-3} yr^{-1} 4×10^{-11} pc^{-3} yr^{-1} 10^{-9} pc^{-3} yr^{-1} 4×10^{-11} pc^{-3} yr^{-1}

EV, Shchekinov, Nath, in prep

H-alpha/H-beta



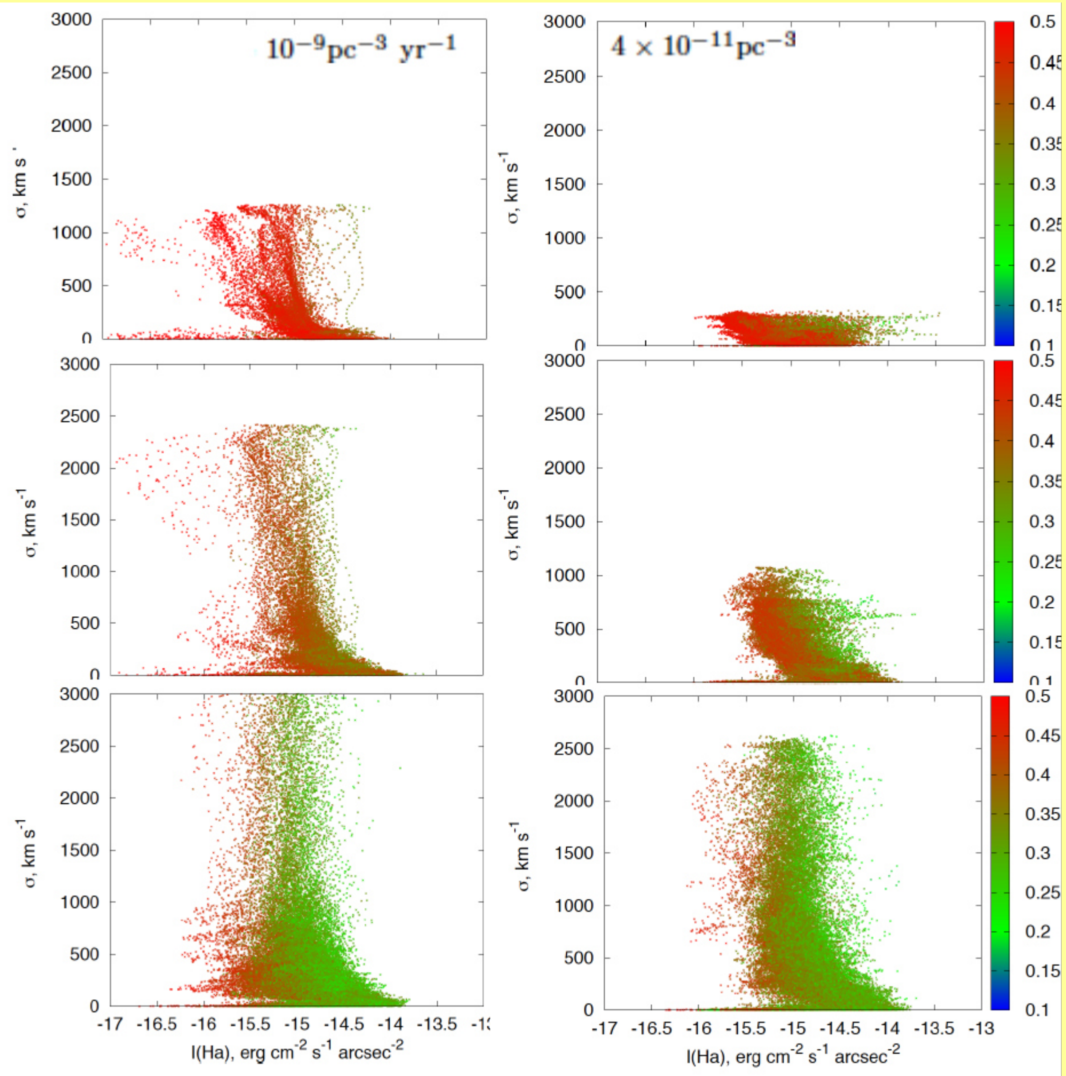
EV, Shchekinov, submitted

$$\frac{H\beta}{H\alpha} \propto T^{0.2}$$

for HII regions ~ 0.4

indicator

H-alpha intensity – velocity dispersion



10^{-9} pc^{-3} yr^{-1} **4×10^{-11} pc^{-3} yr^{-1}**

EV, Shchekinov, Nath, in prep

conclusions (only for the properties of ionized gas)

- the I(Halpha)-sigma diagram obtained for simulated gas flows is similar in shape to that observed in dwarf galaxies.; after the degrading resolution procedure also quantitatively;

- peaks of velocity dispersion on the I(Halpha)-sigma diagram may correspond to several stand-alone or merged SN remnants with moderately different ages;

- Balmer decrement, the ratio of the volume averaged Halpha to Hbeta intensities, seems to be a better indicator of the evolutionary status of the superbubble;

- the locus of points associated to SN shells is close to that for HII regions on the I(Halpha)-sigma diagram.


Thanks!