Loop I and underlying super-bubbles

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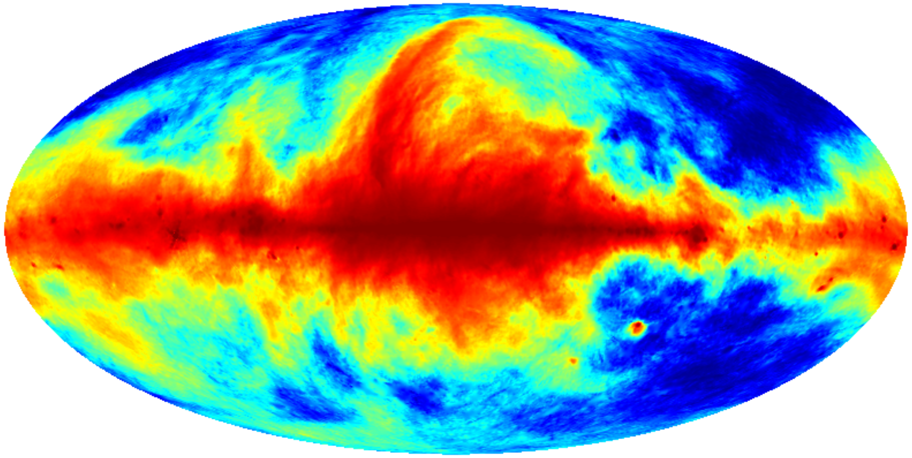
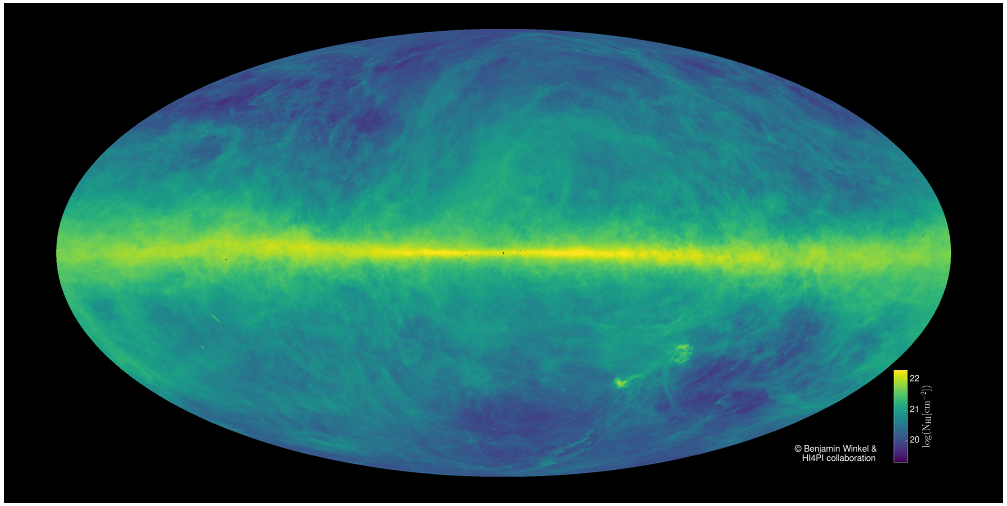
Searching for the Sources of Galactic Cosmic Rays, 11 – 15 Dec 2018, Paris




22
21
20
log(N_HI[cm^-2])
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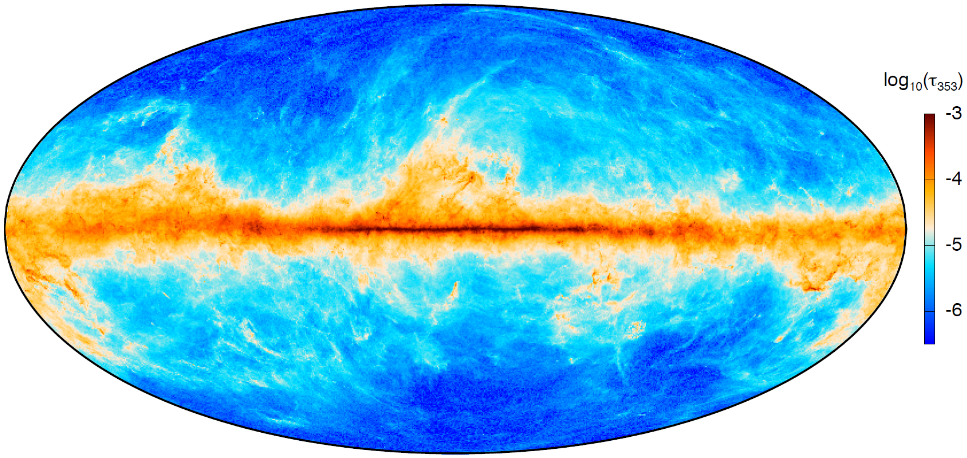
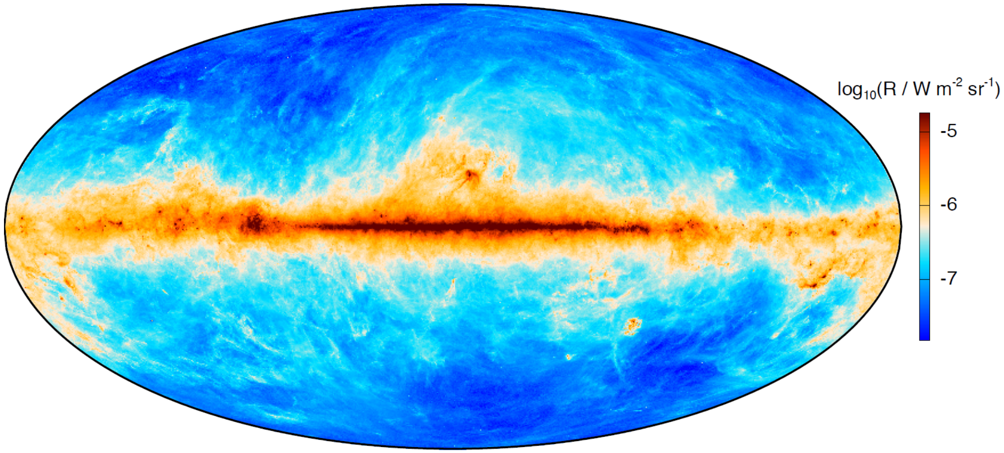
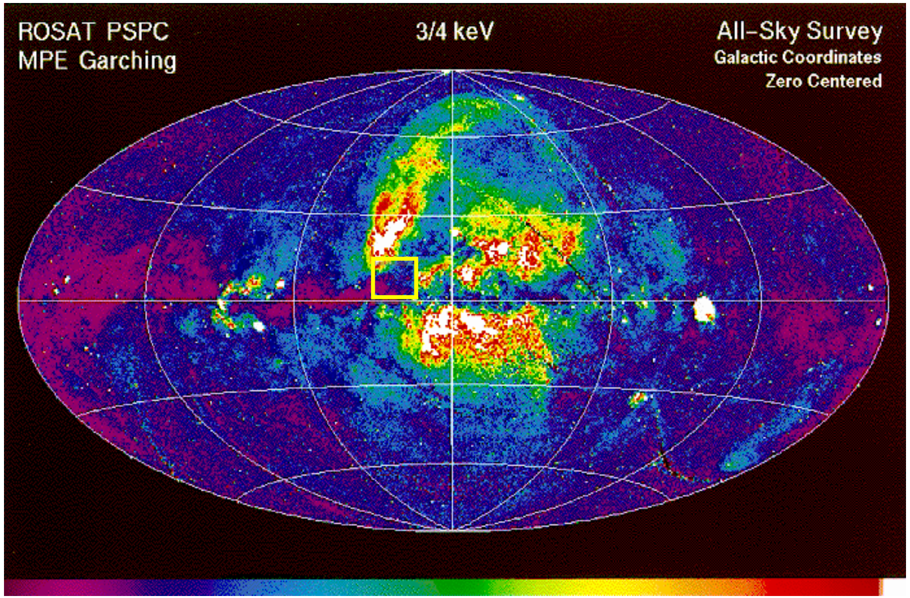
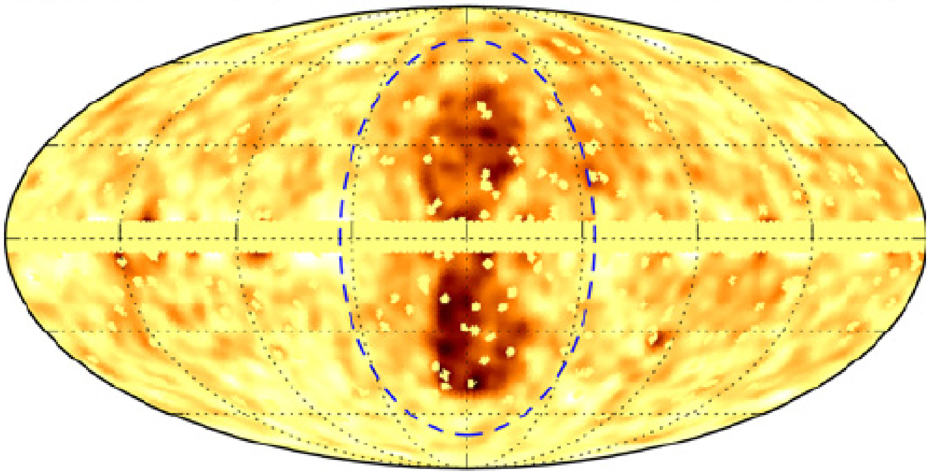

log10(τ353)
-3
-4
-5
-6

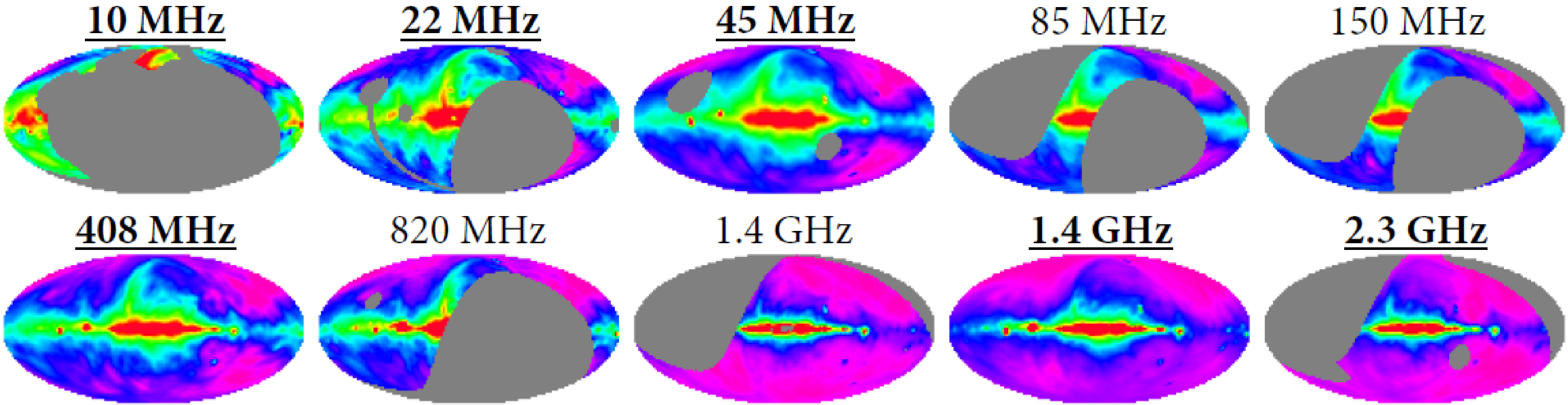

log10(R / W m-2 sr-1)
-5
-6
-7


ROSAT PSPC
MPE Garching
3/4 keV
All-Sky Survey
Galactic Coordinates
Zero Centered



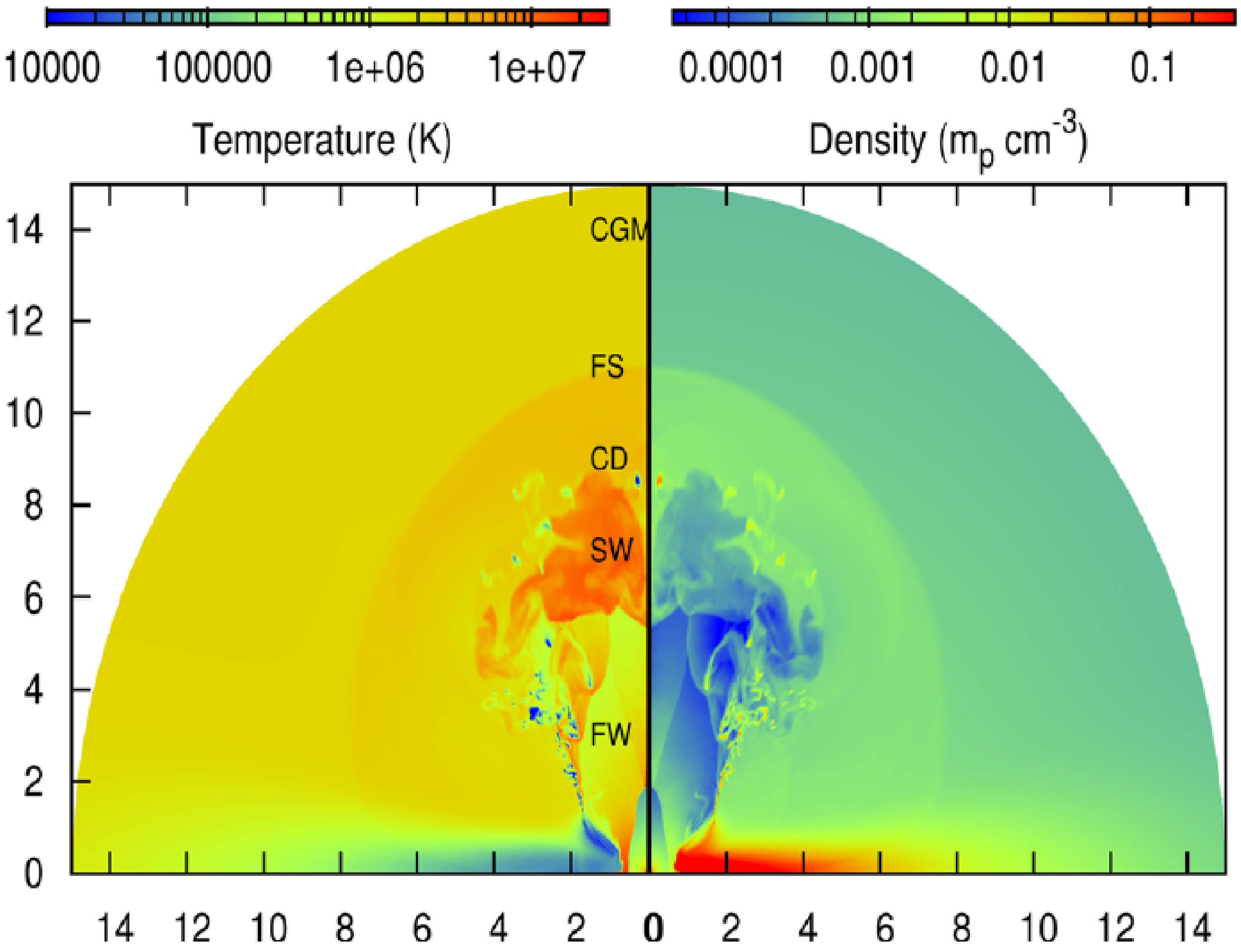
Loop I from 10 MHz to GHz

(H Zheng etal 2016)



Loop I, NPS & FB from GC activity

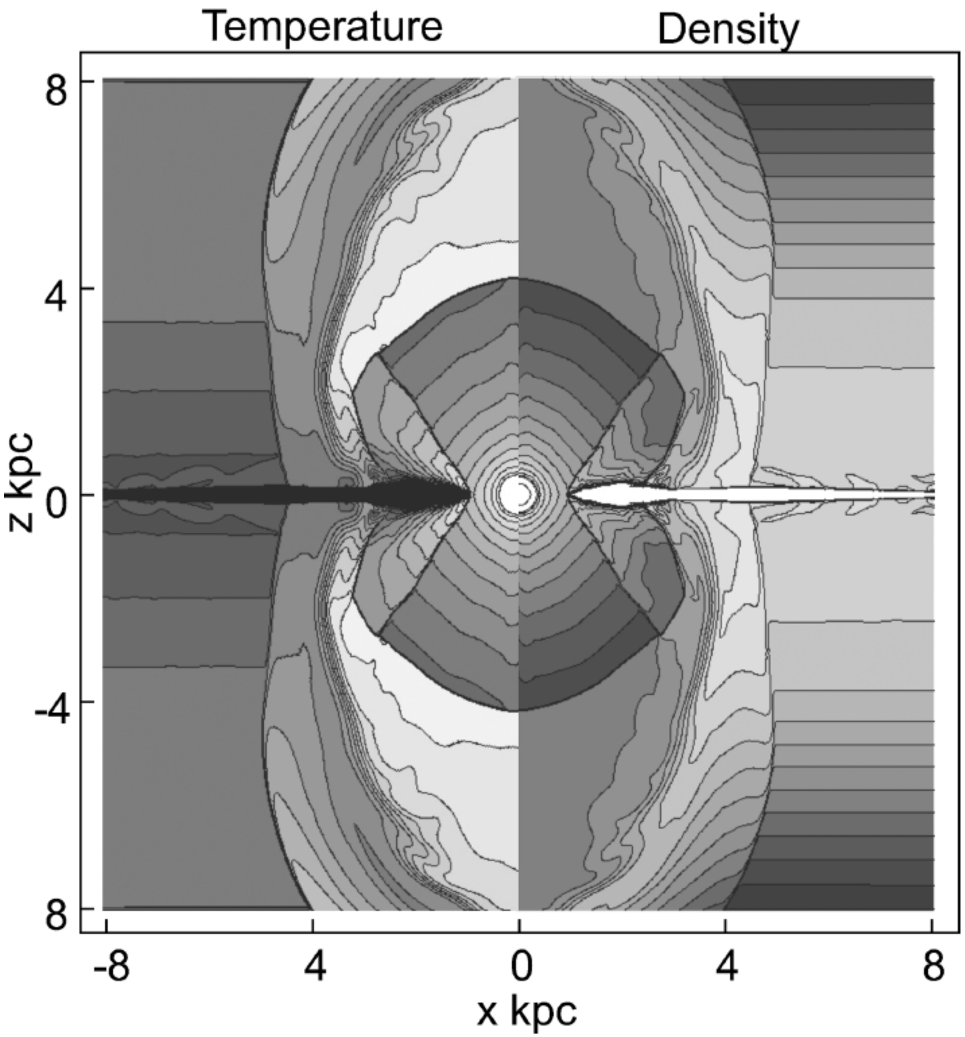
(Sarkar etal 2015, Sarkar 2018)

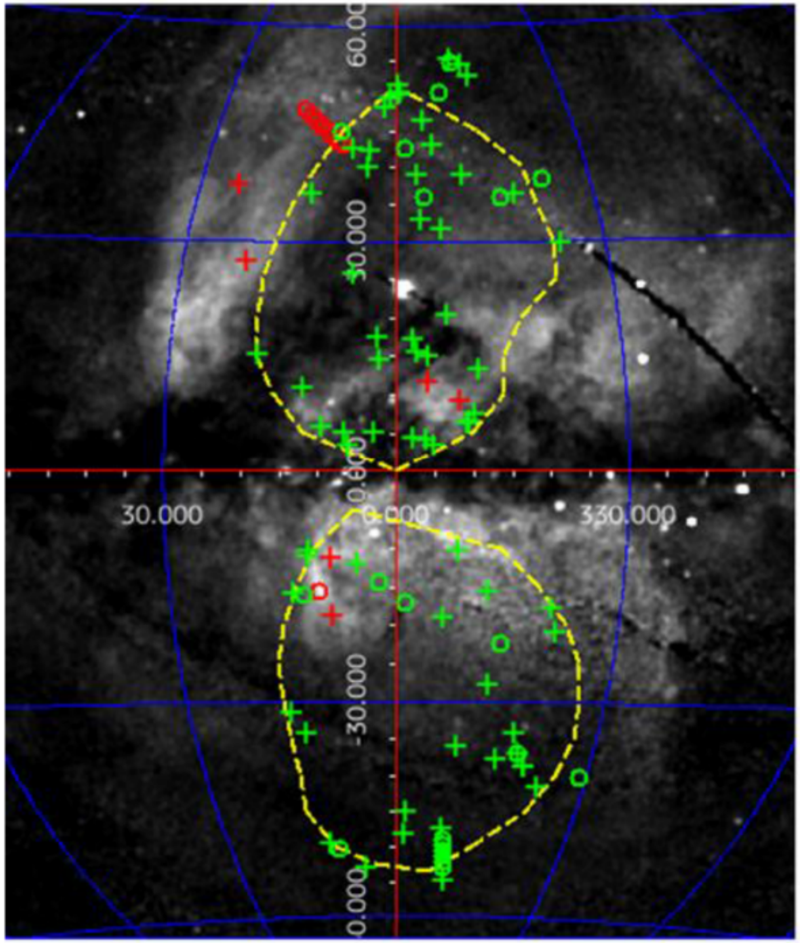


SFR$\simeq$ 0.5 $M_\odot$ yr^{-1} over last 10–20 Myr

Loop I, NPS & FB from GC activity

(Sofue etal 2016, Kataoka etal 2018)

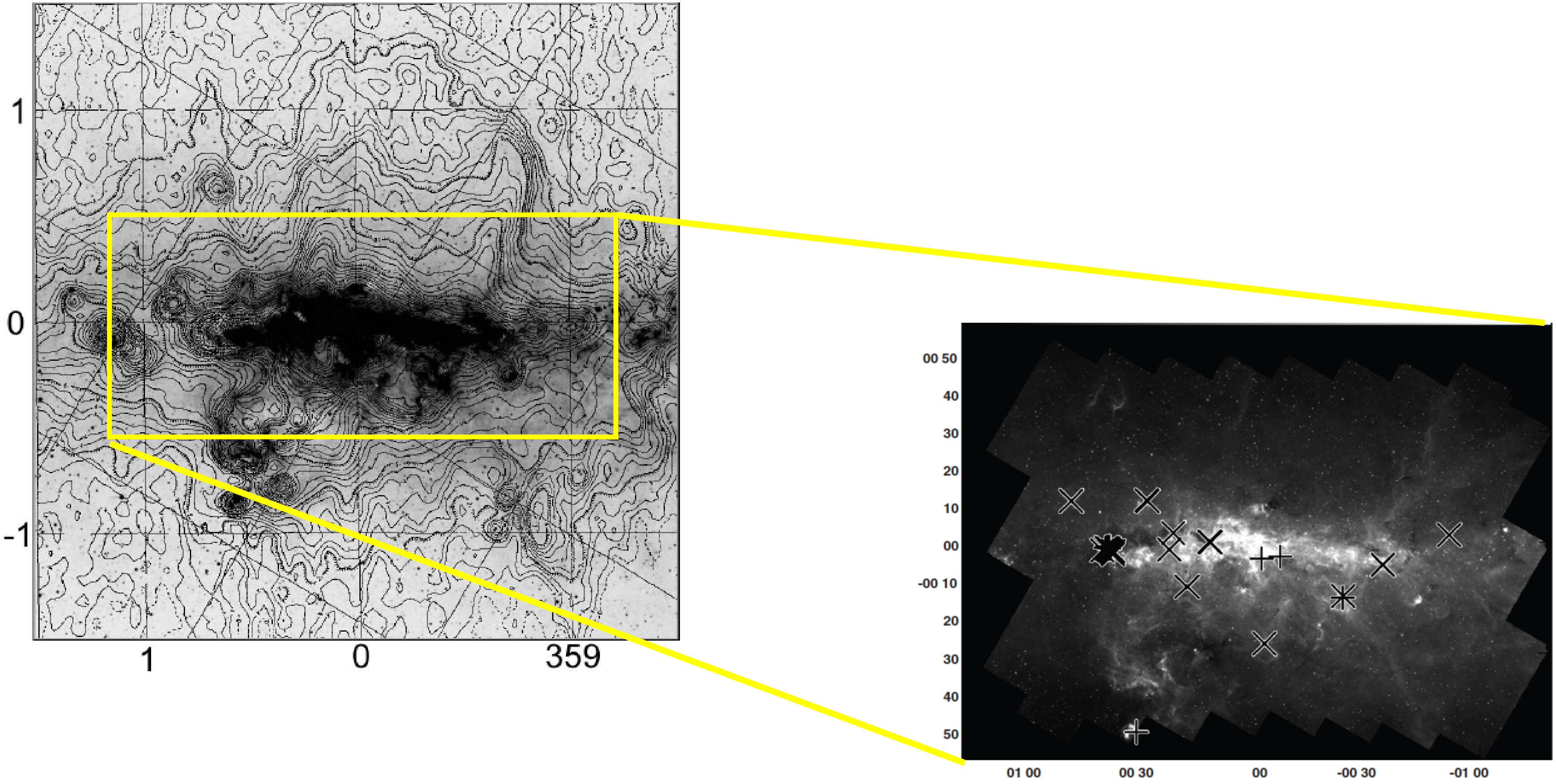




SFR$\simeq$ 0.3–0.5 $M_\odot$ yr^{-1} over last 10 Myr

SFR in the GC: central ~400 pc

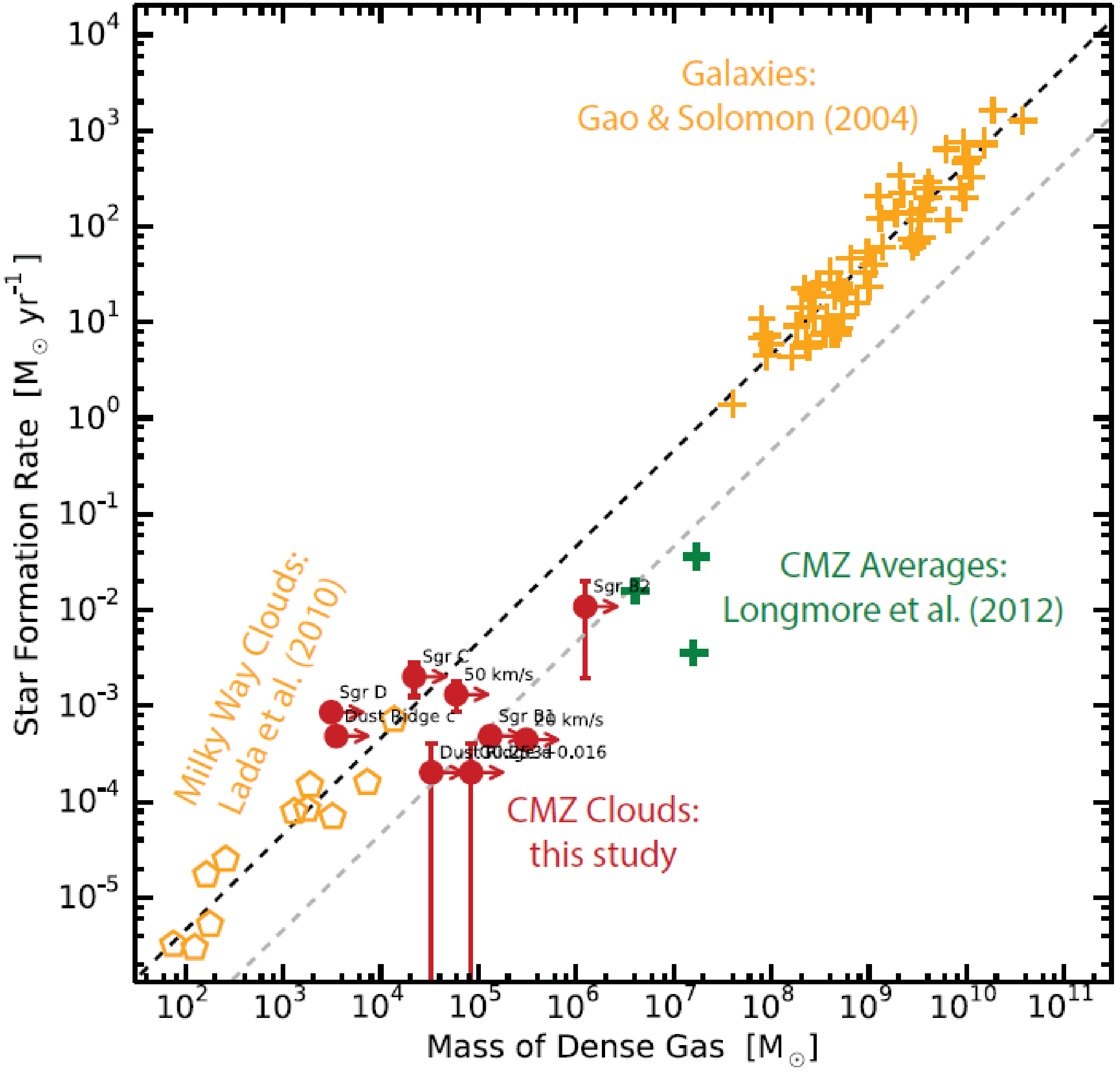
(Yusef-Zadeh etal 2009)



$\langle \mathrm{SFR} \rangle \leq 0.14\ M_\odot\ \mathrm{yr}^{-1}$ over 10 Gyr

$\mathrm{SFR} \sim 0.04\text{–}0.08\ M_\odot\ \mathrm{yyr}^{-1}$ over last 10 Myr

SFR in the GC: central ~200 pc



Longmore etal 2012

Kauffmann 2015

Barnes etal 2017

Winding superbubble in the GC with a low SFR (Vasiliev & YS 2018, in prep)

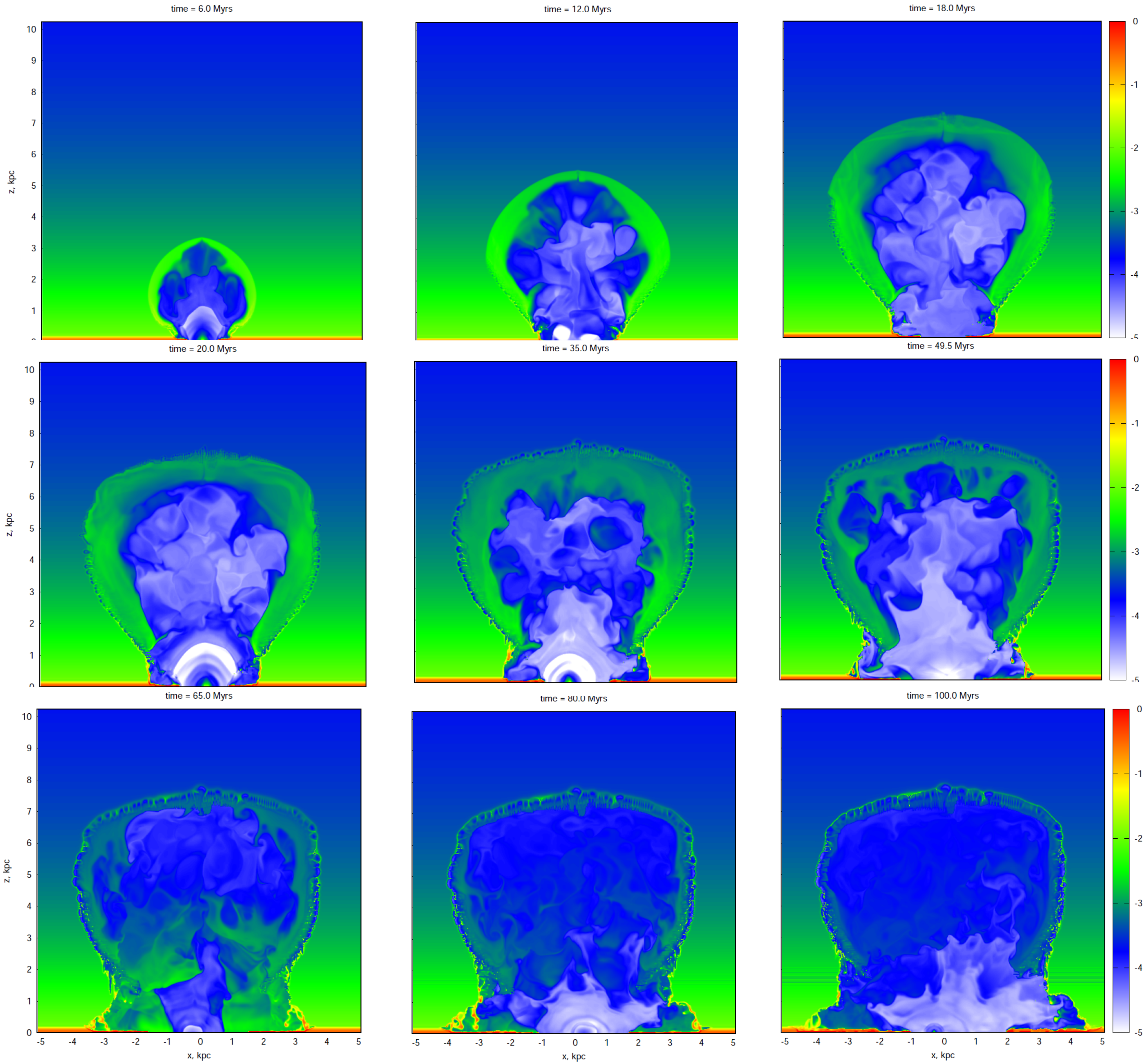
SFR model over 100 Myr

- 0–10 Myr: SFR$= 0.28\ M_\odot\ \mathrm{yr}^{-1}$;
- 10–18 Myr: SFR$= 0$;
- 18–28 Myr: SFR$= 0.028\ M_\odot\ \mathrm{yr}^{-1}$;
- 28–28.5 Myr: SFR$= 0$;
- 28.5–100 Myr: SFR$= 0.0028\ M_\odot\ \mathrm{yr}^{-1}$;

- $\langle \mathrm{SFR} \rangle = 0.033 M_\odot\ \mathrm{yr}^{-1}$

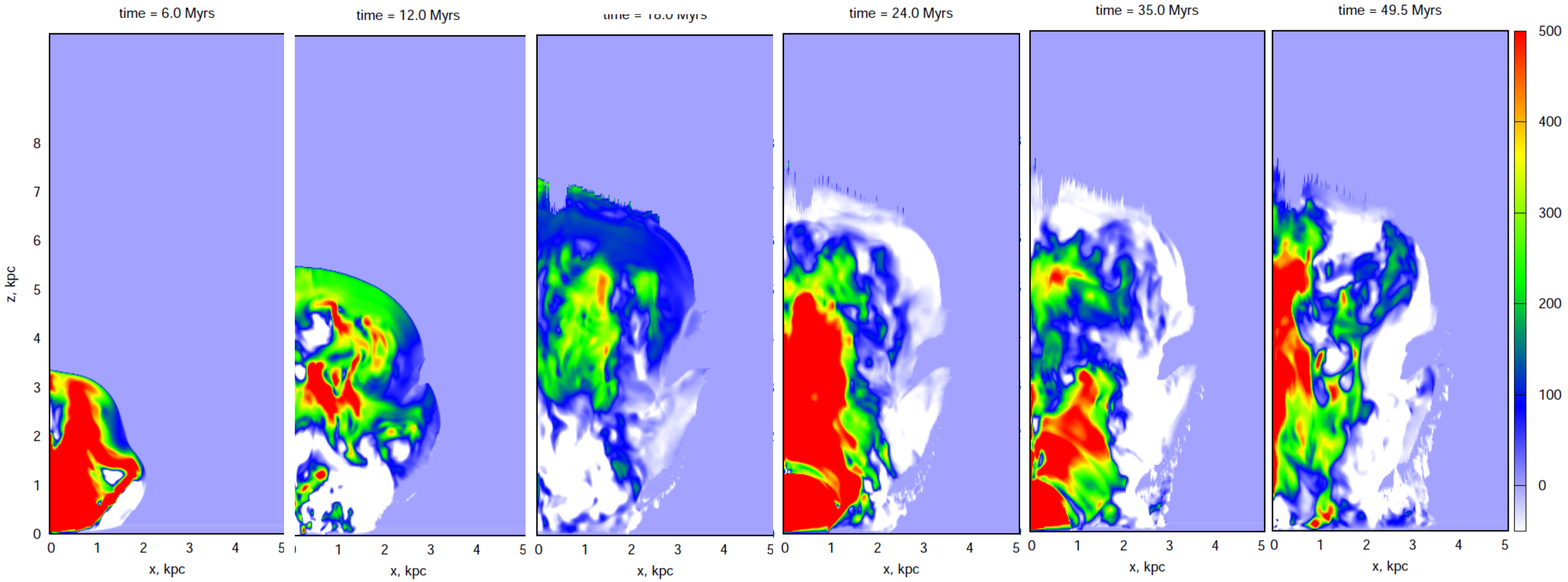
Injection by individial SNe spread within 100 pc

$$L(\mathbf{r}, t) = \sum_i \delta(\mathbf{r} - \mathbf{r}_i)\delta(t - t_i)$$


time = 6.0 Myrs
time = 12.0 Myrs
time = 18.0 Myrs
time = 20.0 Myrs
time = 35.0 Myrs
time = 49.5 Myrs
time = 65.0 Myrs
time = 80.0 Myrs
time = 100.0 Myrs
z, kpc
x, kpc
0
1
2
3
4
5
6
7
8
9
10
-5
-4
-3
-2
-1
0
1
2
3
4
5
0
-1
-2
-3
-4
-5

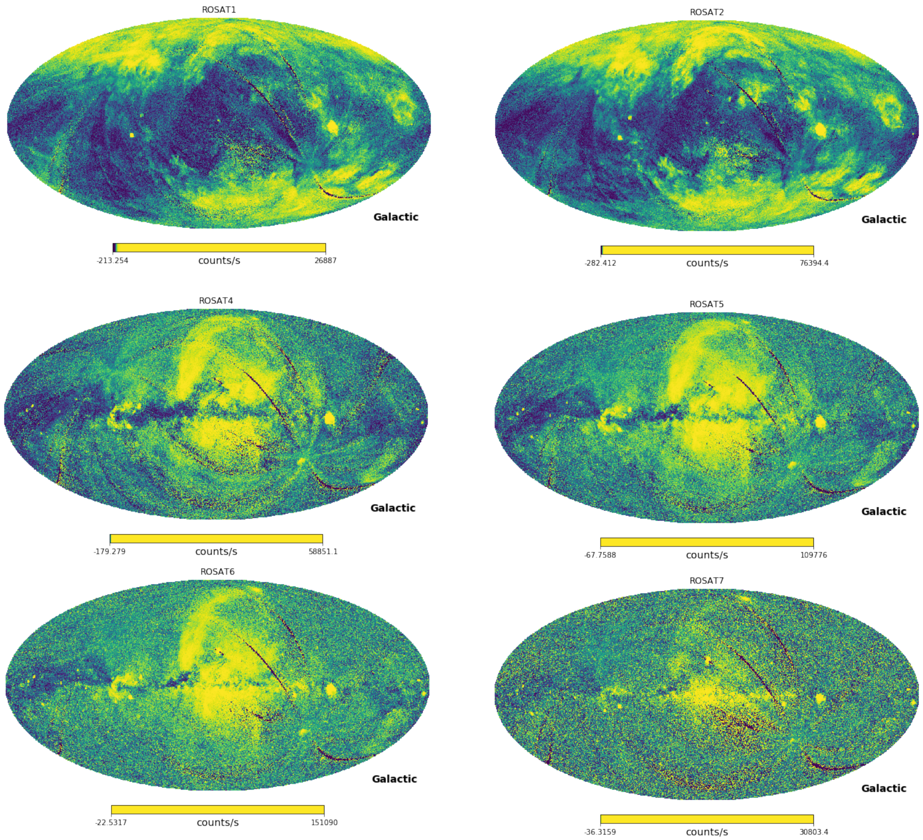
Supebubbling wind in the GC with low SFR

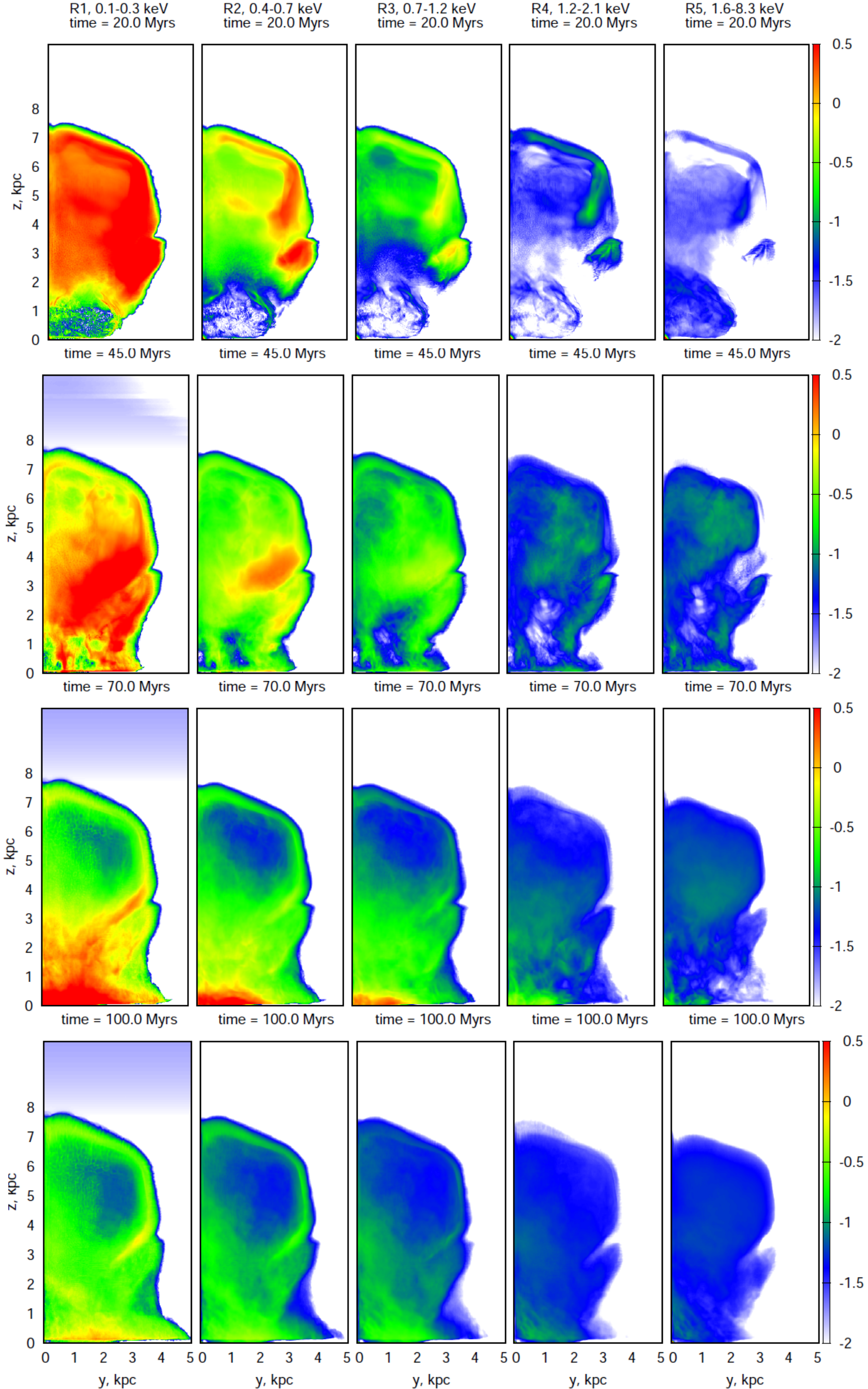
(Vasiliev & YS 2018, in prep)



ROSAT view model

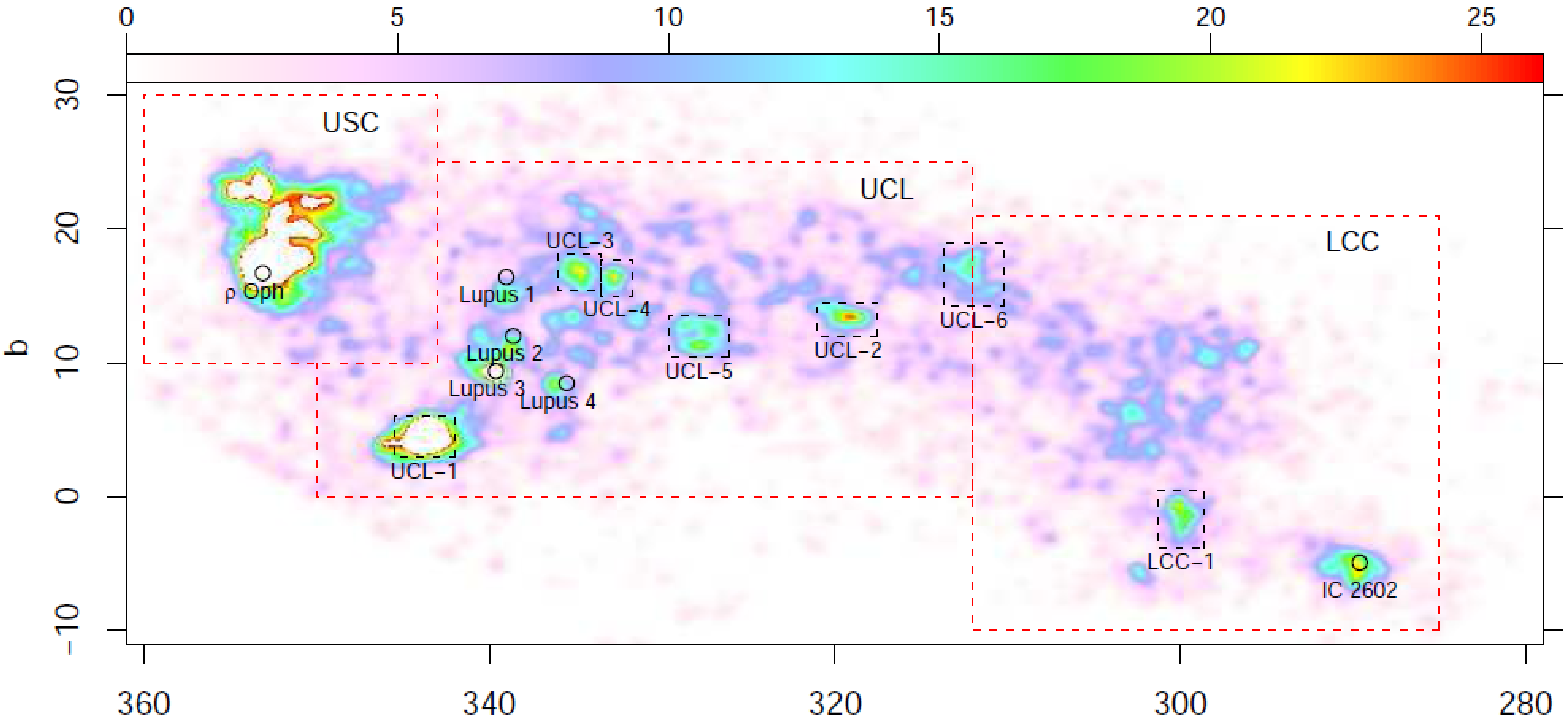
$$\text{At } z \geq 10 z_0 \;\; N_H \leq 10^{19}\ \text{cm}^{-2}:$$
$$\rightarrow \quad \tau(\geq R1) \leq 0.3$$





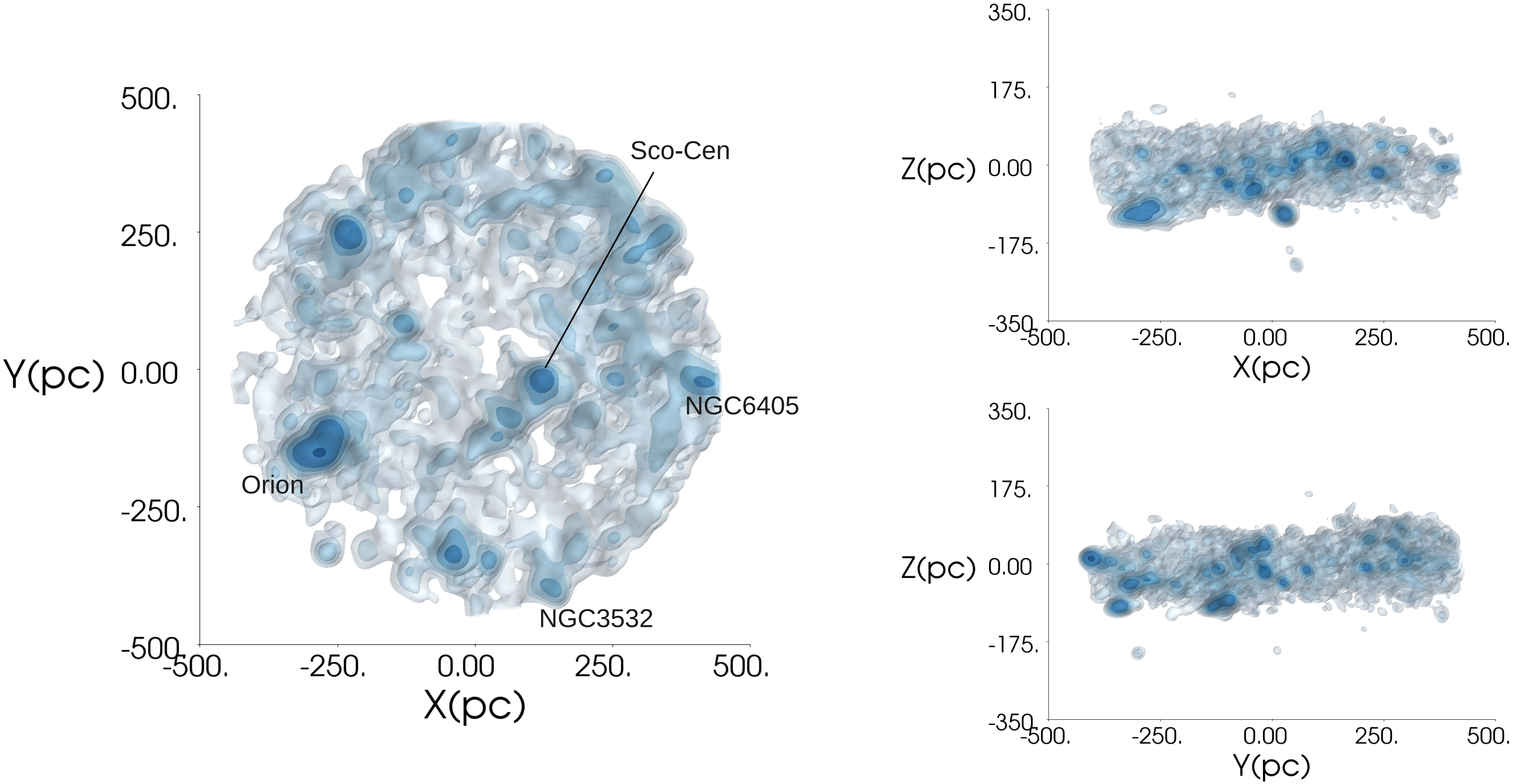
Nearby OB associations: Sco-Cen

(Damiani etal 2018)



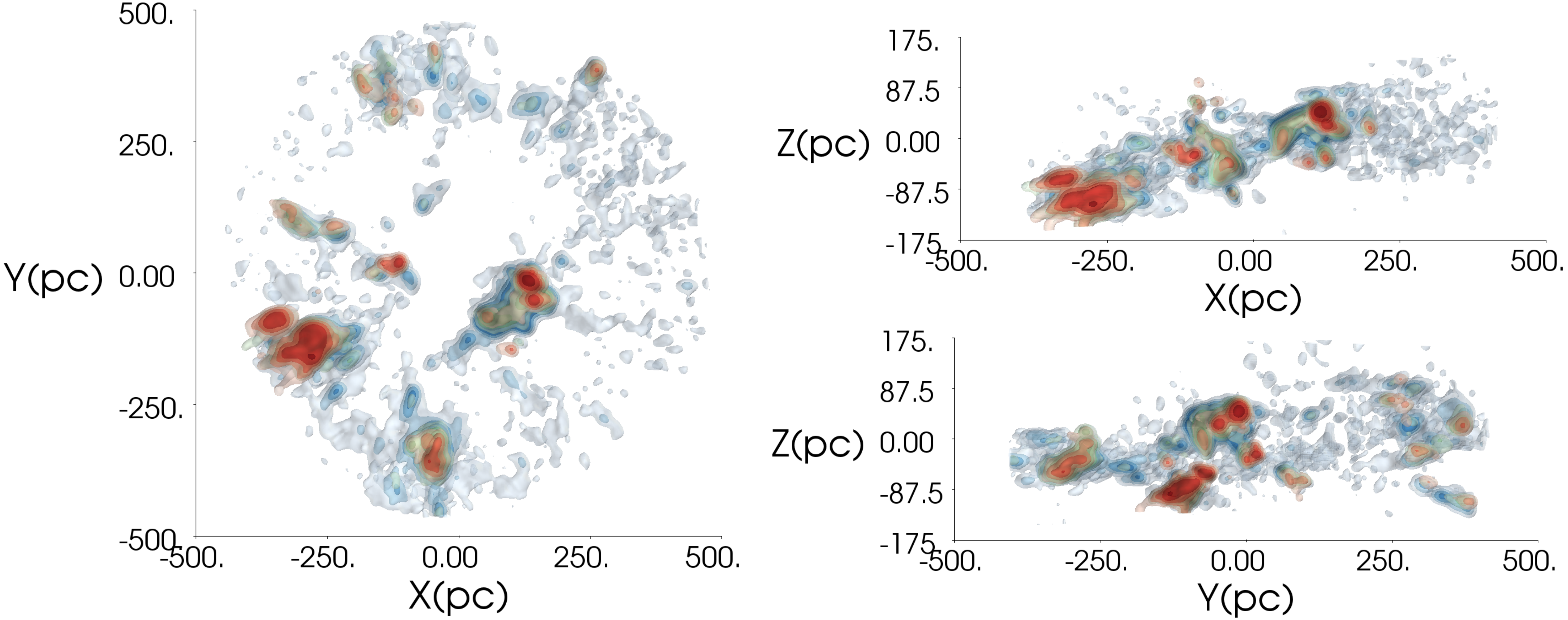
Nearby OB associations: upper main-sequence

(Zari etal 2018)



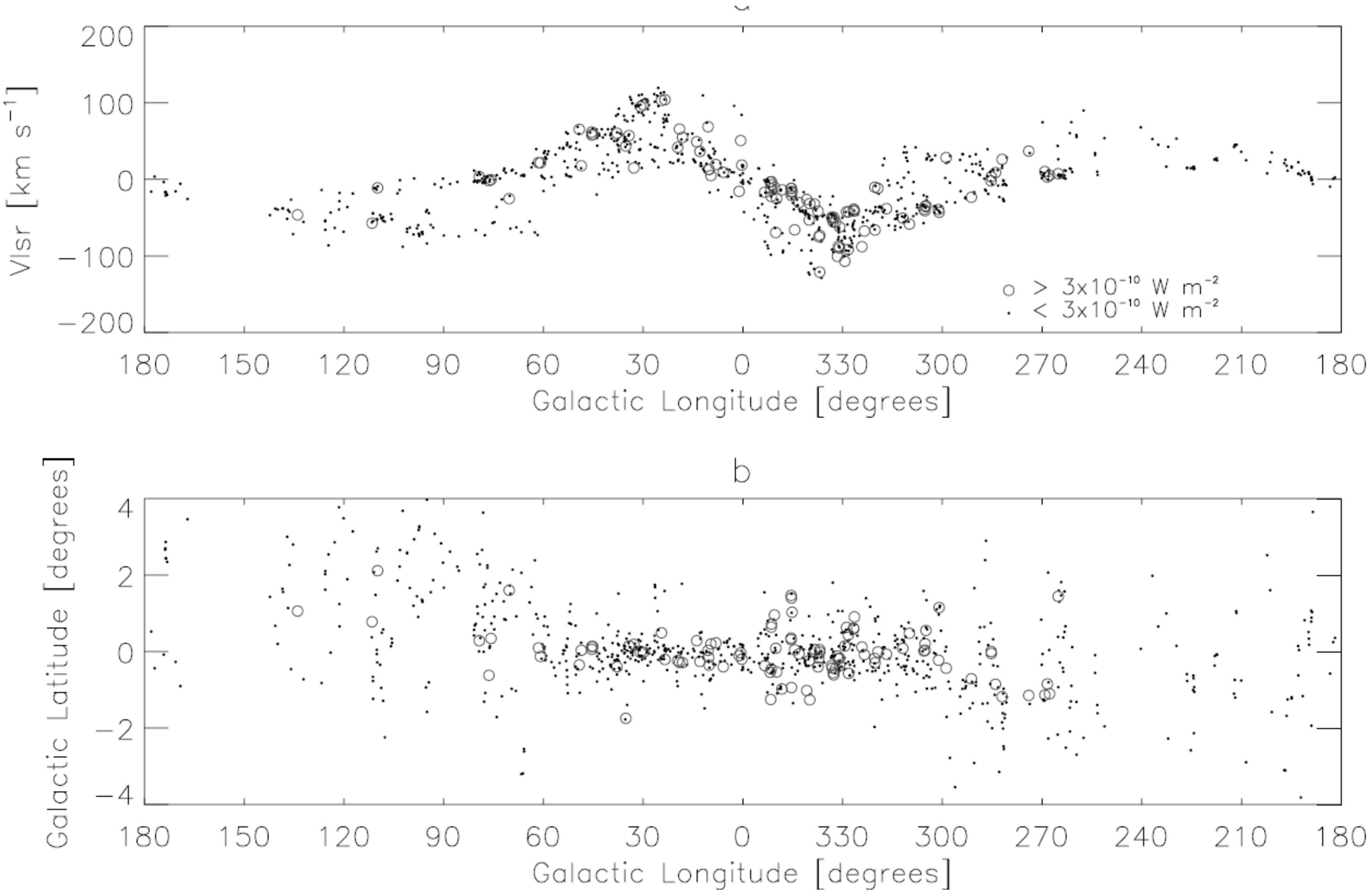
The contours represent the levels 0.2, 0.3, 0.4, 0.6, 0.8, 1 density levels

Nearby OB associations: t<5 (red), 10<t<10, 10<t< 20 Myr



OB associations in the Milky Way

(Bronfman etal 2000)



a) Longitude-Velocity, b) Longitude-Latitude for massive SF regions

OB associations in the Milky Way

- Mass function: $dN/dM = CM^{-\alpha}$ with $\alpha = 1.25$–2.25, $M_{\rm min} \simeq 300\ M_\odot$, $M_{\rm max} \simeq 3 \times 10^7\ M_\odot$;
- Assume mass fraction in clusters $\zeta \sim 0.01$ of MW stellar mass

  $\Rightarrow$ Total number of clusters $N \sim 3 \times 10^5$;
- With radial distribution $N(r) \propto e^{-R/R_o}$

  $\Rightarrow$ covering factor of bubbles from massive $(M > 10^5\ M_\odot)$ clusters

  $f_c(M \geq 10^5\ M_\odot) \simeq 0.2$,

  $f_c(M < 10^5\ M_\odot) \simeq 1$ within longitudes $30^\circ < l < 330^\circ$;

SN explosions in the inner Galactic disk

- Critical energy to break through $E_{cr} \simeq 300 \rho_0 c_s^2 z_0^3$

$$\rho_0 \propto e^{-(R-R_o)/R_g}, \quad z_0 \propto e^{(R-R_o)/R_g}$$

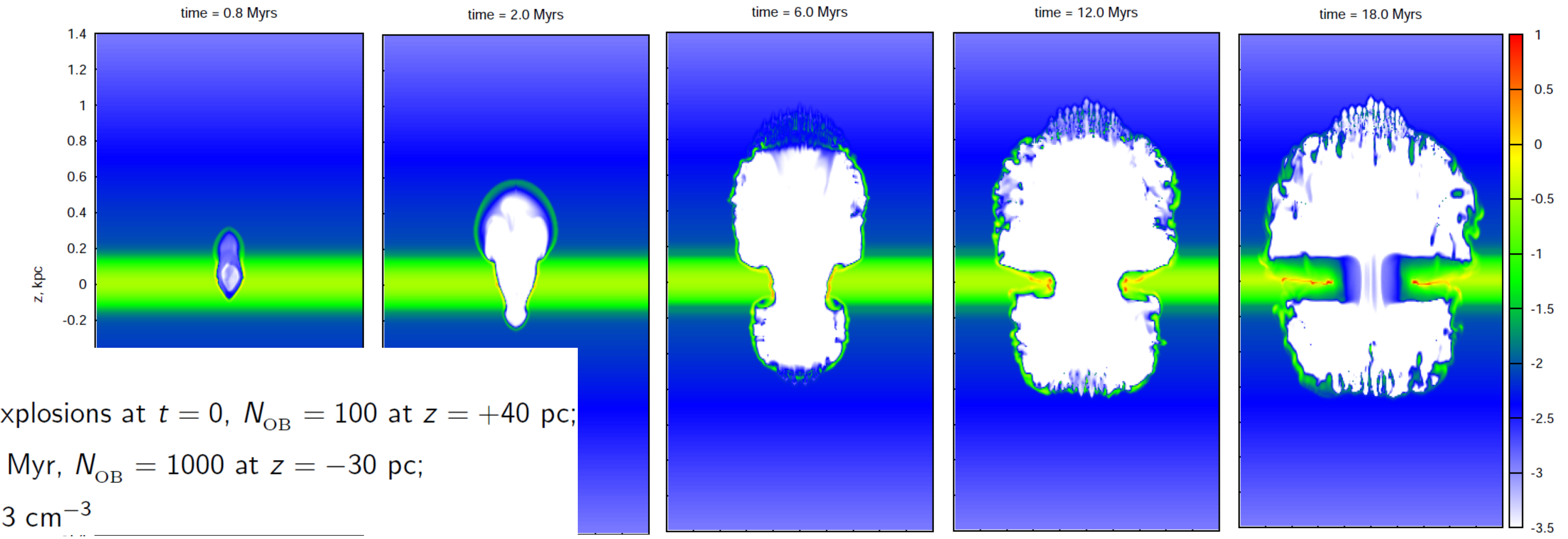
$$E_{cr} \simeq 5 E_B e^{2(R-R_o)/R_g},\ R_o = 8.5 \text{ kpc},\ R_g = 9.8 \text{ kpc}$$

- Extra-planar clusters and stars

$$\rho(z_{\rm OB}) \propto e^{-z_{\rm OB}/z_0-(R-R_o/R_g}, \quad z_0 \propto e^{(R-R_o)/R_g}$$

Few examples of asymmetric superbubbles

YS & Vasiliev 2018, in progr

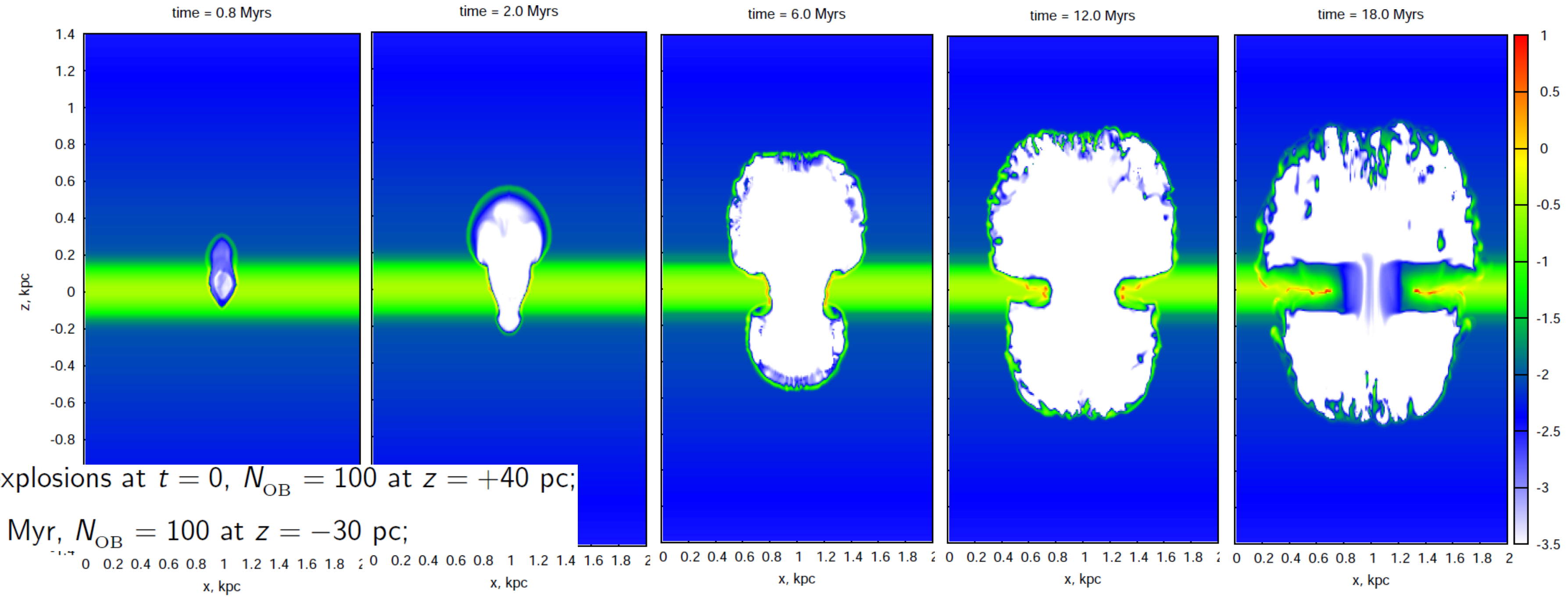


Models parameters

1st cluster gives SN explosions at $t = 0$, $N_{\rm OB} = 100$ at $z = +40$ pc;

2nd cluster at $t = 18$ Myr, $N_{\rm OB} = 1000$ at $z = -30$ pc;

$r_{\rm clstr} = 30$ pc, $n_0 = 0.3$ cm^{-3}

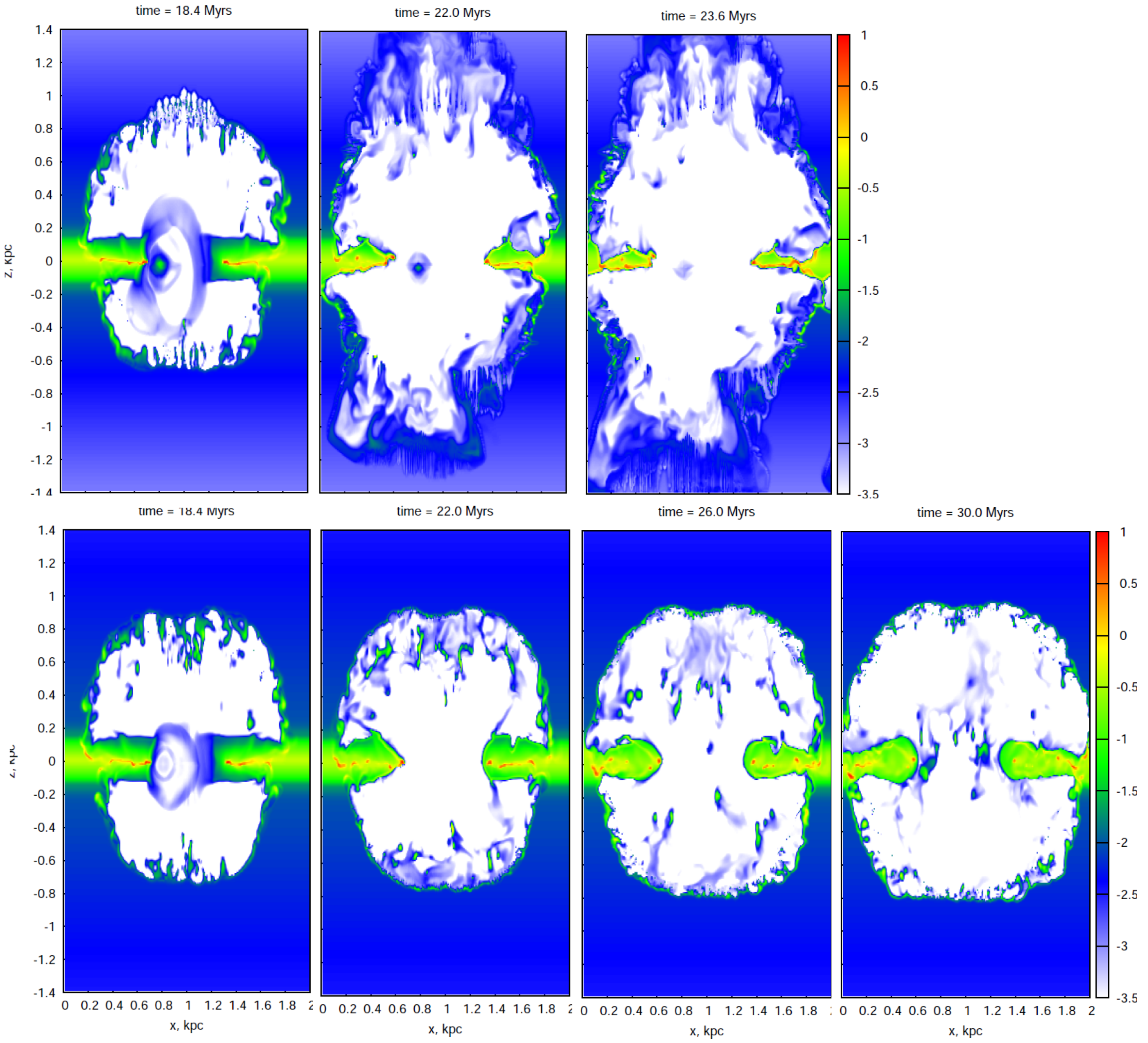


1st cluster gives SN explosions at $t = 0$, $N_{\rm OB} = 100$ at $z = +40$ pc;

2nd cluster at $t = 18$ Myr, $N_{\rm OB} = 100$ at $z = -30$ pc;

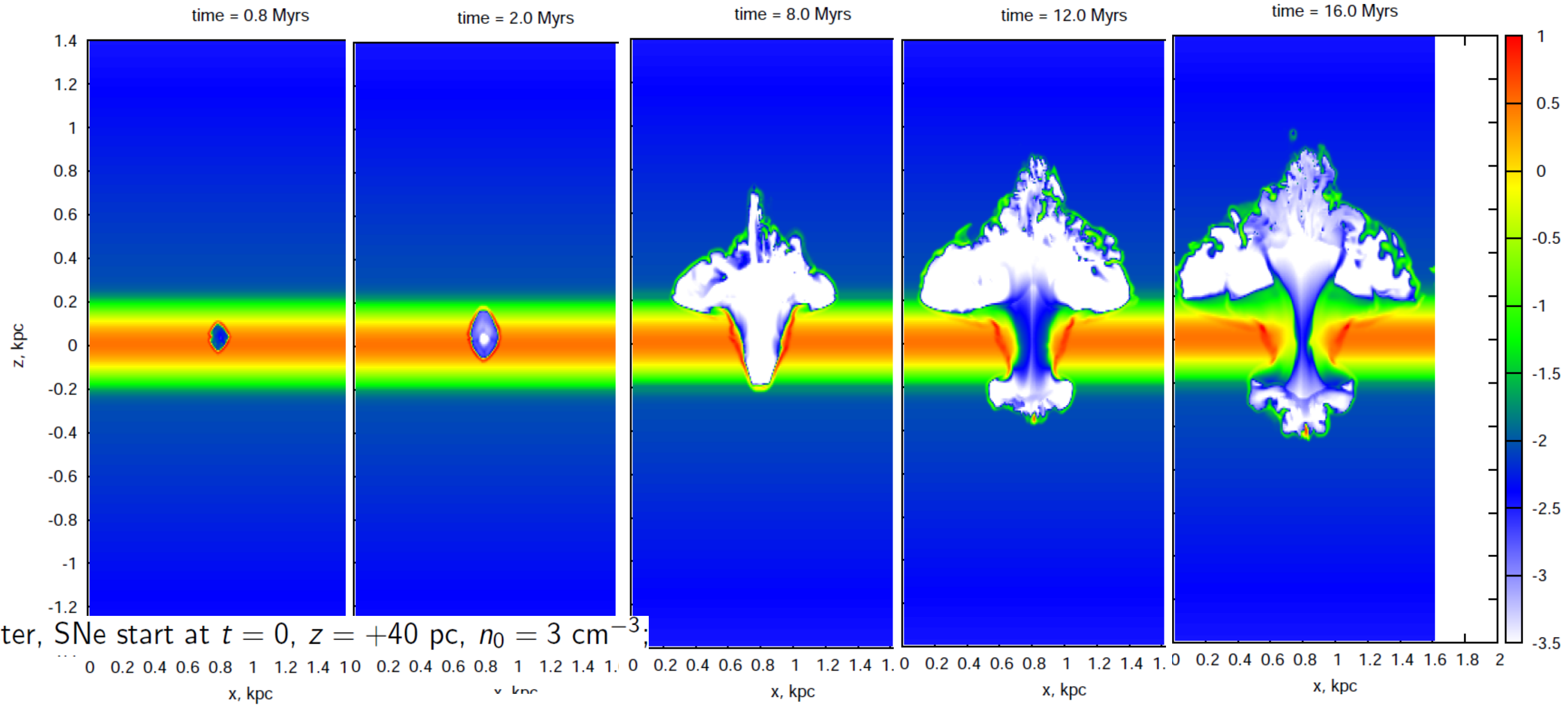
Asymmetric superbubbles at final stages

YS & Vasiliev 2018, in progr



Asymmetric superbubbles in denser envmnt

YS & Vasiliev 2018, in progr



$N_{\rm OB} = 100$-cluster, SNe start at $t = 0$, $z = +40$ pc, $n_0 = 3$ cm^{-3};

Planck dust & ROSAT 1 & 2

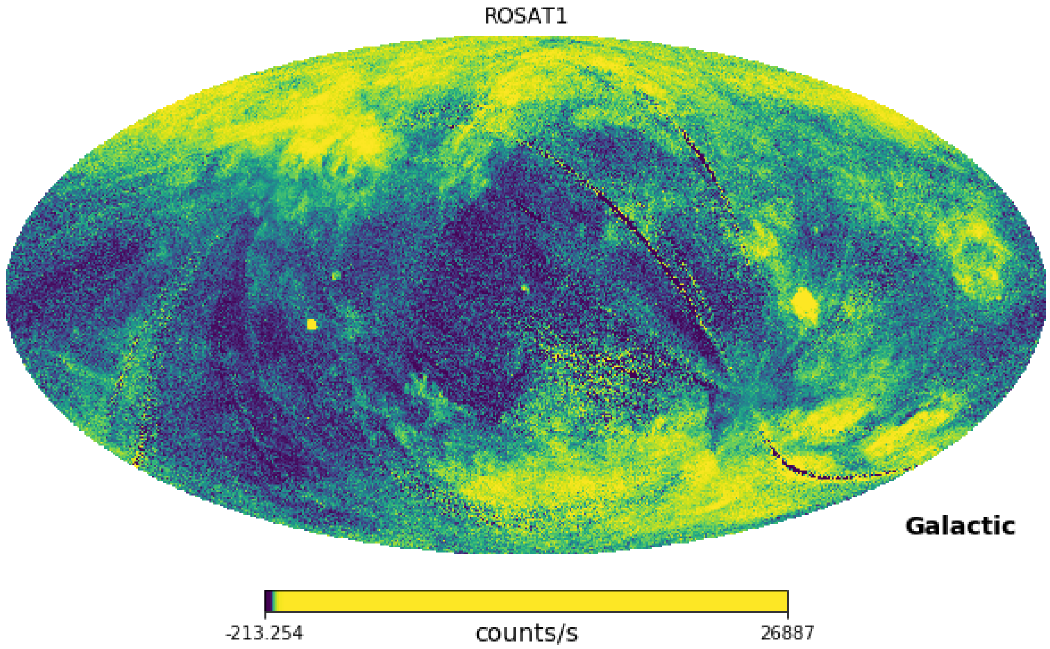
(Pshirkov, Popkova & YS 2018, in prep)

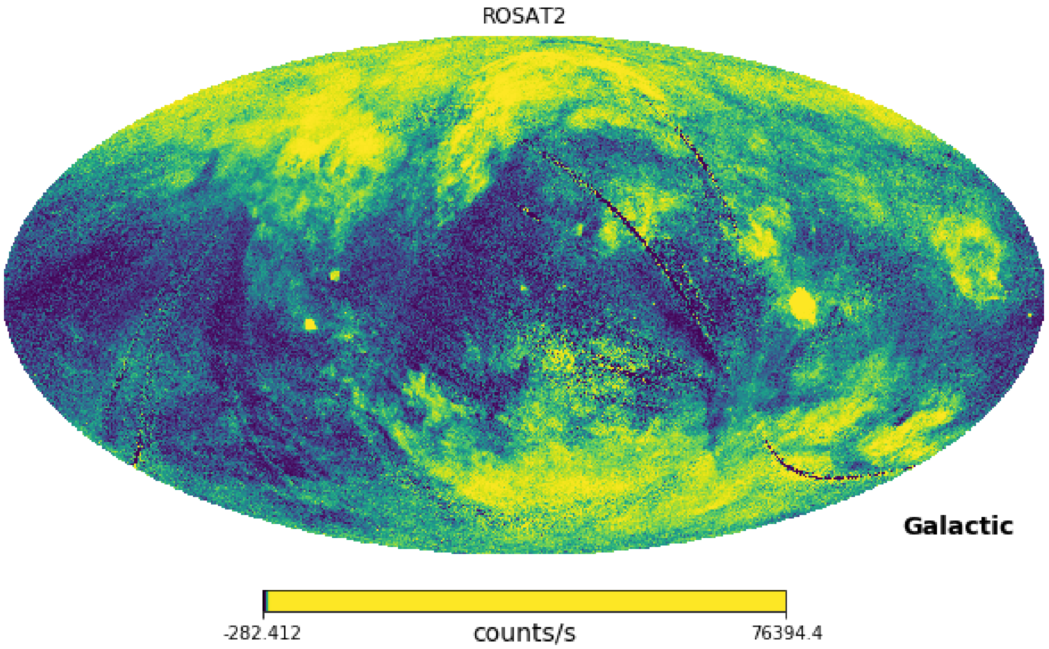
R1 Band: $E = 0.11\text{–}0.264$ keV

R2 Band: $E = 0.14\text{–}0.264$ keV

Mask1: $l = 15\text{–}45^\circ,\ 30^\circ \leq b \leq 90^\circ$

Mask2: $l = 15\text{–}45^\circ,\ -90^\circ \leq b \leq -30^\circ$

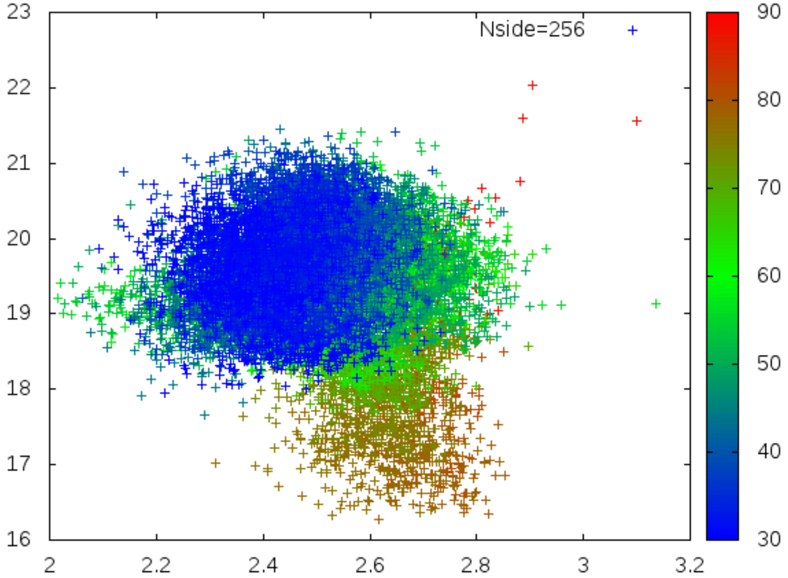




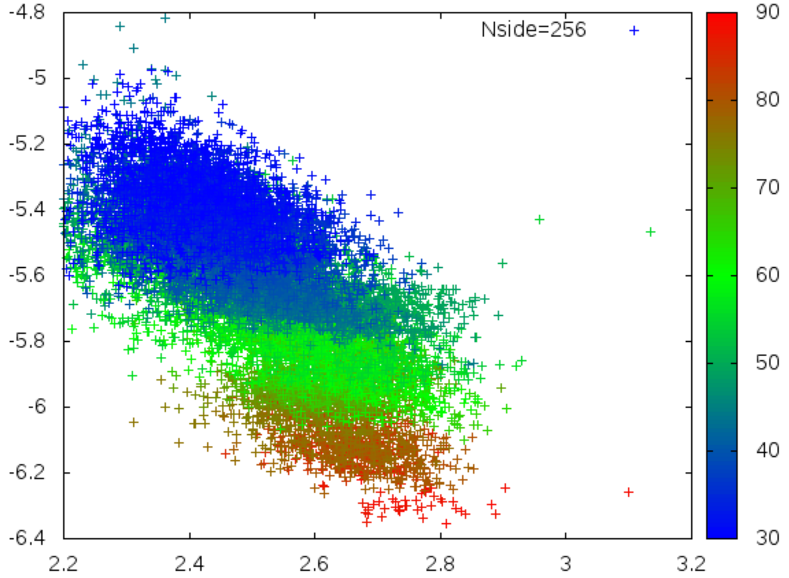
Planck dust & ROSAT 1

(Pshirkov, Popkova & YS 2018, in prep)

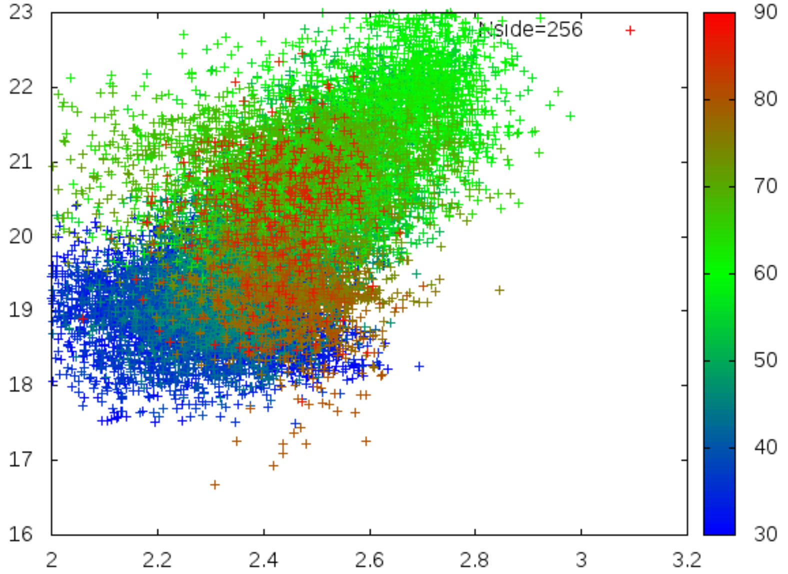
ROSAT1 vs T_{353} Nside=256 MASK1



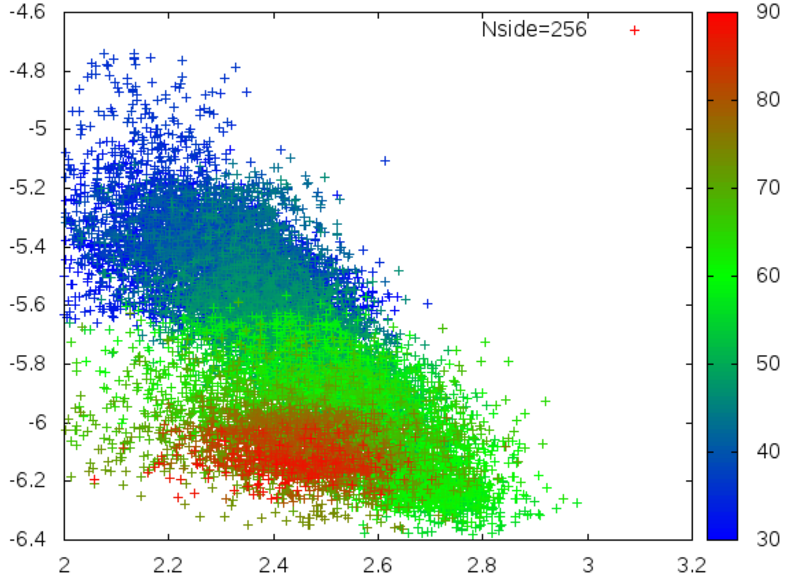
ROSAT1 vs Tau_{353} Nside=256 MASK1



ROSAT1 vs T_{353} Nside=256 MASK2

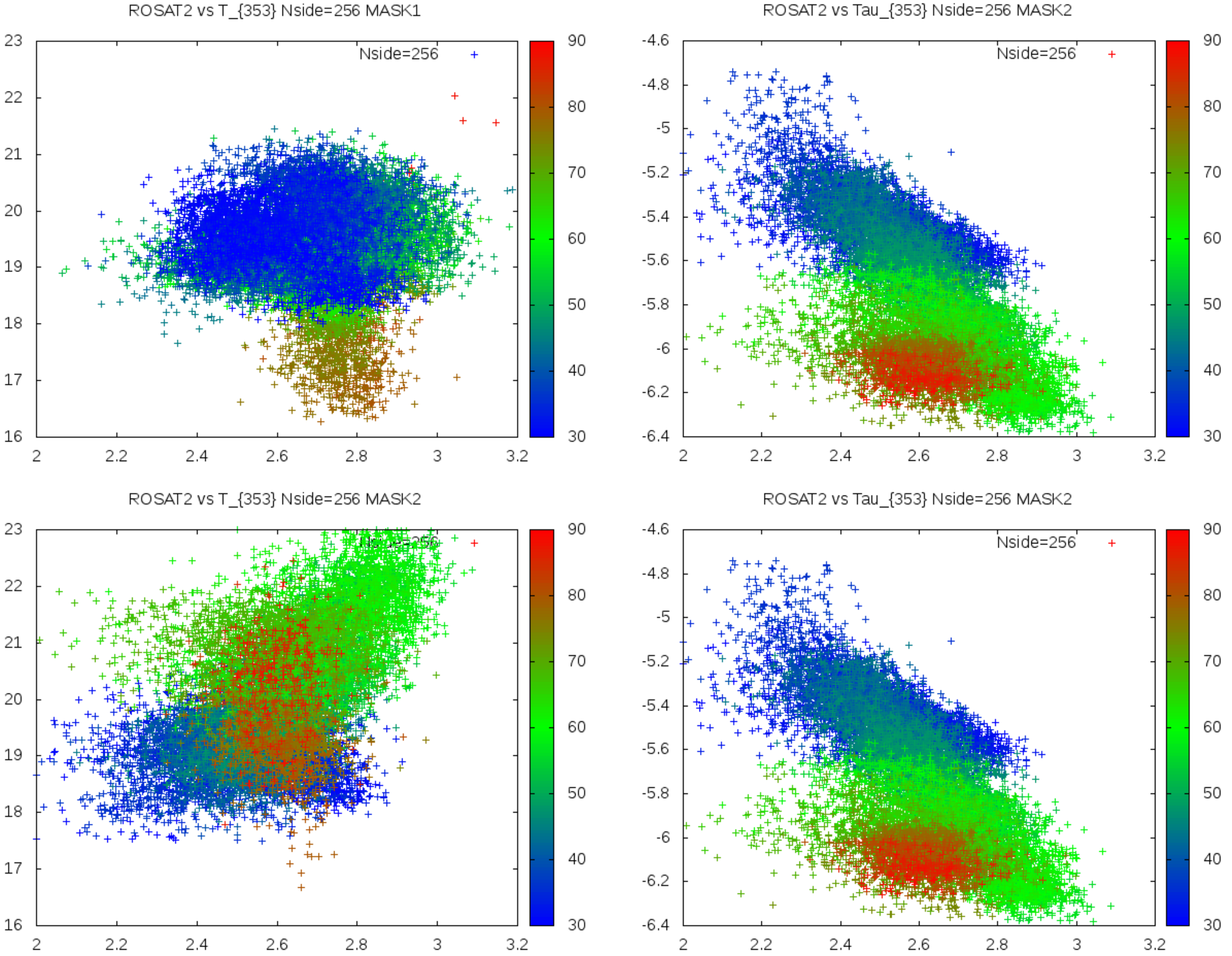


ROSAT1 vs Tau_{353} Nside=256 MASK2



Planck dust & ROSAT 2

(Pshirkov, Popkova & YS in prep)



Dust temperature: Mask 1

(Pshirkov, Popkova & YS in prep)

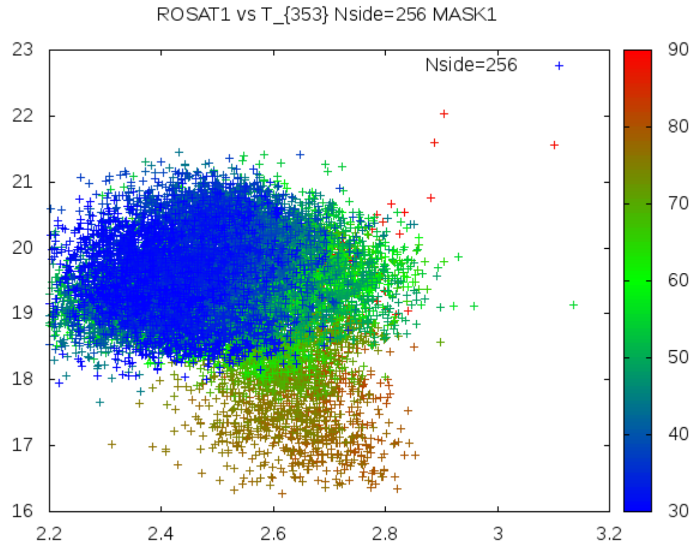
- Photoheating: $T_d \simeq 20\chi^{1/6} a_{0.1\mu m}^{-1/6}$ K

χ is the ISM radiation field in Habing units;

At $z \geq 1$ kpc radiation field $\chi \sim 0.1$

$T_d \simeq 14$ K

Additonal heating needed!



- Collisional heating from hot plasma: $T_d \simeq 13 a_{0.1\mu m}^{-1/6} n_{0.01}^{1/6} T_6^{1/4}$

$T_6 = 3, \Rightarrow \quad T_d \simeq 17$ K

Dust temperature: Mask 2

(Pshirkov, Popkova & YS in prep)

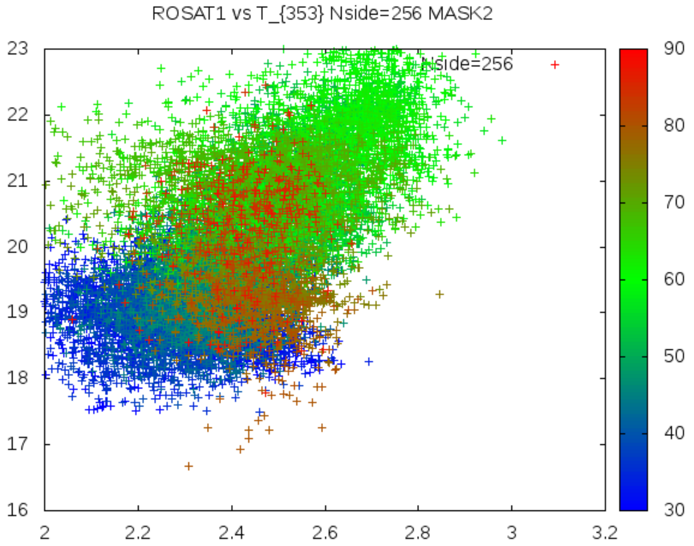
- Photoheating: $T_d \simeq 20\chi^{1/6} a_{0.1\mu m}^{-1/6}$ K

χ is the ISM radiation field in Habing units;

At $z \geq 1$ kpc radiation field $\chi \sim 0.1$

$T_d \simeq 14$ K

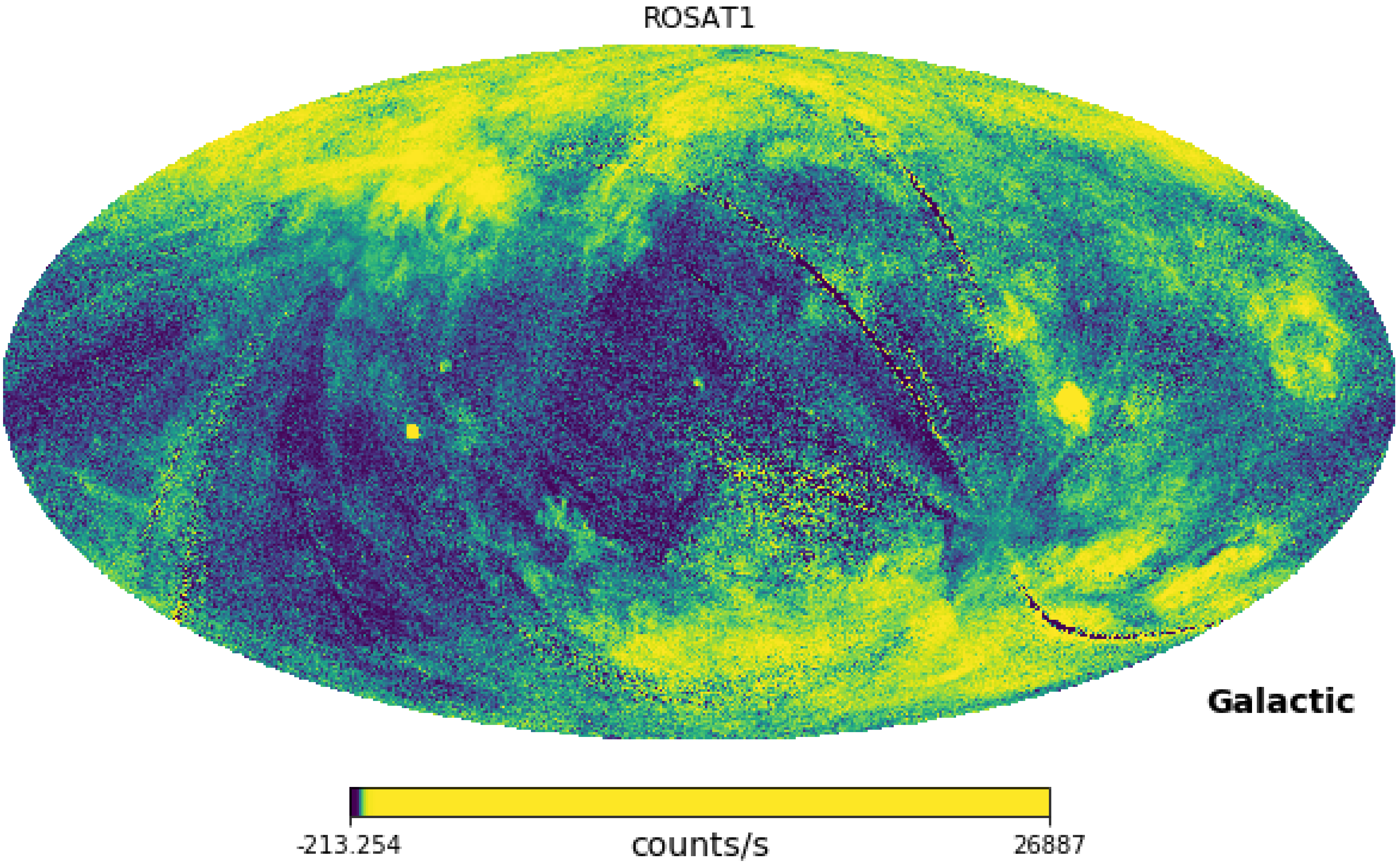
Additonal heating needed!



- Collisional heating from hot plasma: $T_d \simeq 13 a_{0.1\mu m}^{-1/6} n_{0.01}^{1/6} T_6^{1/4}$

$T_6 = 3, \;\; \Rightarrow \;\; T_d \simeq 17$ K

$$\frac{n_{0.01}}{a_{0.1\mu m}} T_6^{3/2} \simeq 30$$


ROSAT1
Galactic
-213.254
counts/s
26887

Conclusions

Galactic center alone cannot explain Loop I and related large scale structures in their interplay

Contaminations from foregrounds matter

Dust – X ray – HI – synchrotron cross-interrelation can hint

Thank you!