Merger Influence on the Thermal SZ Effect

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1. Model and characteristics: - integrated pressure
   - spectral function
   (transonic merger)

2. An application: maps for subsonic mergers

Why look at mergers?

- increasing observational evidence from X-rays:
  - dimension: r ~ 10-600 kpc
  - Mach number: 0.4 – 2.5
  - (early stage/late stage, subsonic/transonic)
- source of non-thermal physics (spectral fct.)
- reveal the cluster substructure
- information on structure formation

Why look at mergers with SZ?

- compare with X-rays, provide an (independent) tool (in particular for high z)
- observe mergers which are not seen in X-rays (position and direction of motion), possibly extract parameters from a simple model
- investigate (high z) substructure
- source of error for parameters based on SZ flux, e.g. H_0

MODEL: framework

- focus on (common) minor mergers

✡ DM profile not changed (major mergers excluded)

- $r_{sub} \leq 0.6\ r_l$, $M_{sub} \leq 10\text{-}20\ \%\ M_{cl}$
- simple gas dynamics: gas spread around subcluster, redistribution maintaining β-profile

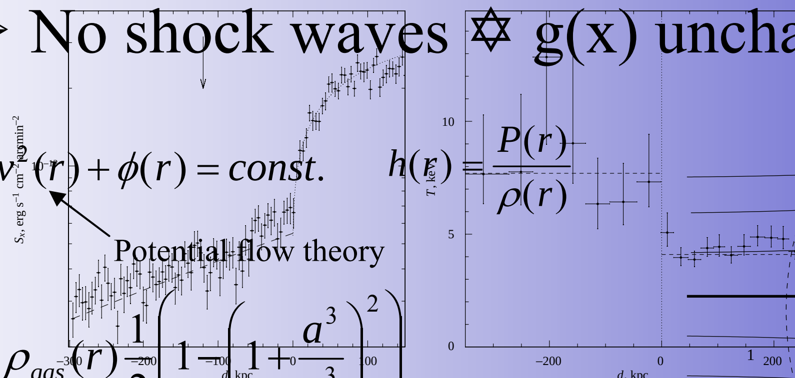
✡ goal: build a model with characteristic merger features

Model and characteristics: subsonic

$$\Delta I(x) \propto g(x)\int_{cl}\left(\frac{k_B T_g}{m_e c^2}\right)\sigma_T n_e dl_{cl}$$

Subsonic:

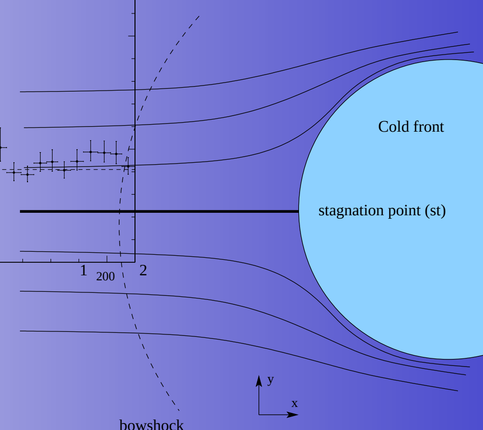
- ~ incompressible, but P_{ex}
- Moving body through gas
- No shock waves ✡ g(x) unchanged

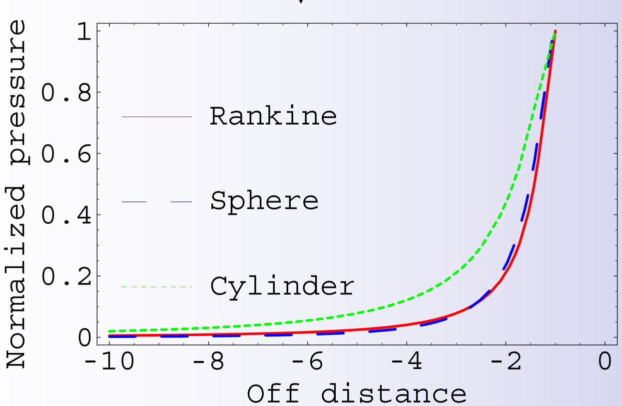


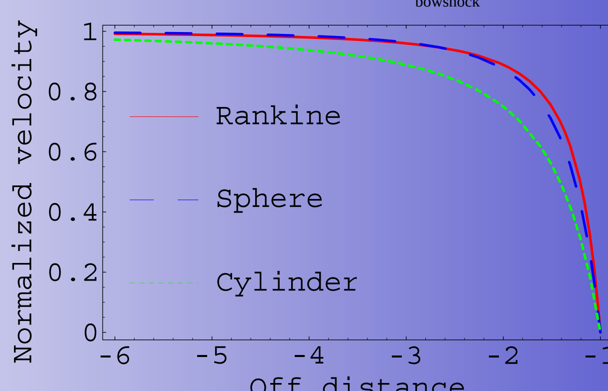
Bernoulli eq. $h(r)+\frac{1}{2}v^2(r)+\phi(r)=const.$ $h(r)=\frac{P(r)}{\rho(r)}$

Potential flow theory

(Stagnation point l.o.s) $P_{ex}(r)\propto \rho_{gas}(r)\frac{1}{2}\left(1-\left(1+\frac{a^3}{z^3}\right)^2\right)$



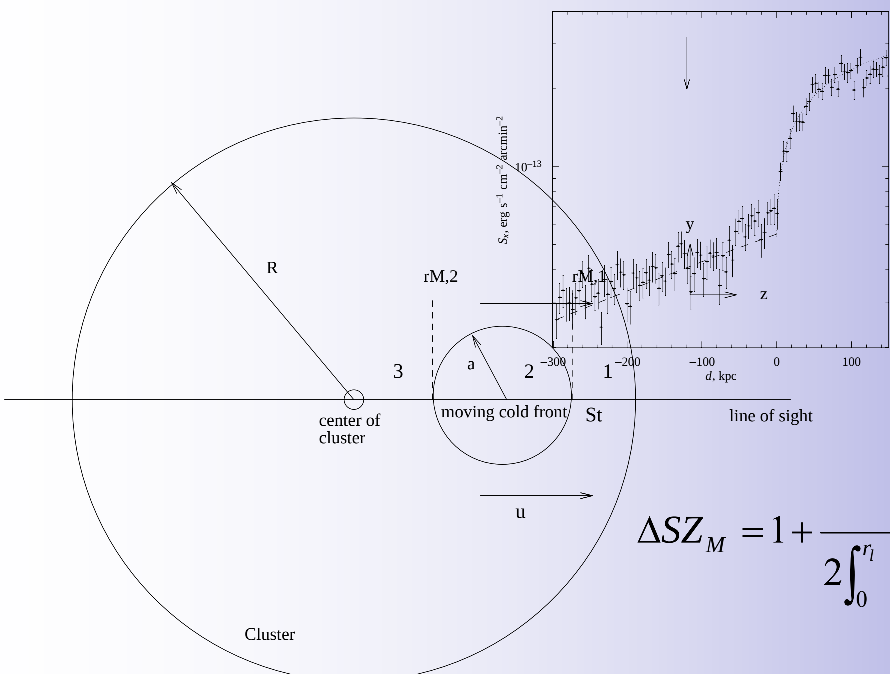


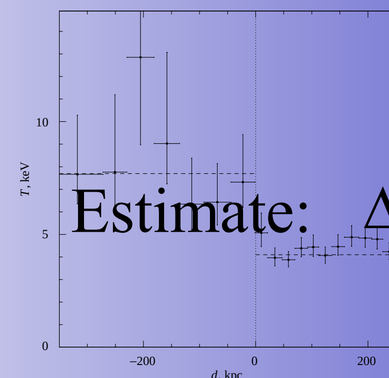


Modified SZ signal (1)

$$\Delta I(x) \propto g(x) \int_{cl} \left(\frac{k_B T_g}{m_e c^2}\right) \sigma_T n_e dl_{cl}$$

- no change in *g(x)*
- 3 regions along l.o.s: P_{ex}, subcluster, turbulent region behind





Estimate: $$\Delta SZ_M = \frac{\Delta I_M(x)}{\Delta I(x)}$$

$$\Delta SZ_M = 1 + \frac{1}{2\int_0^{r_l} f(r)dr}\left[\int_{r_l}^{r_{M,1}} f(r)\frac{1}{2}M^2\left(1-\frac{v(z)^2}{u_\infty^2}\right)dr - \int_{r_{M,1}}^{r_{M,2}} f(r)dr + a\frac{n_{e,M}T_M}{n_{e,0}T}\right]$$

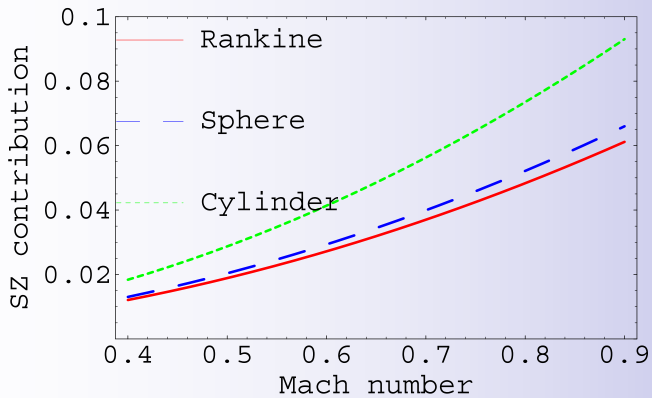
✡ Many parameters: r_c, M, subcluster

Modified SZ signal (2)

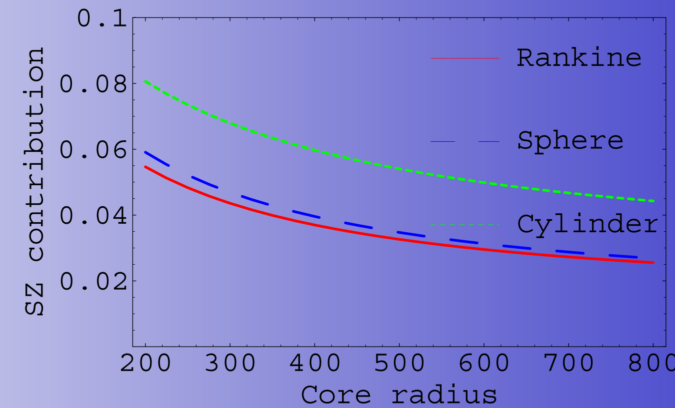
$$\Delta SZ_M = \frac{\Delta I_M(x)}{\Delta I(x)}$$

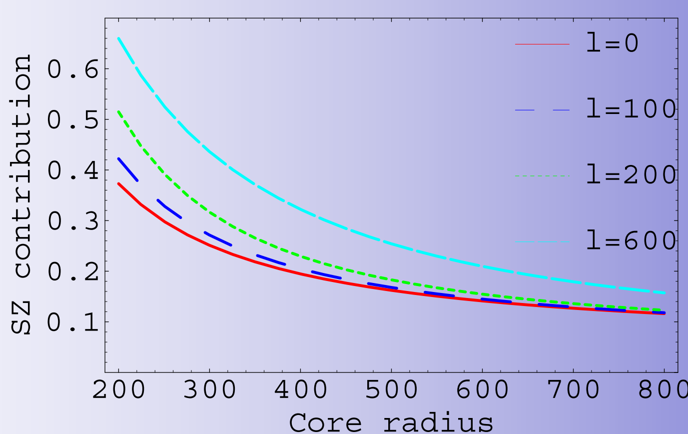
$$\Delta SZ_M = 1 + \frac{1}{2\int_0^{r_l} f(r)dr}\left[\int_{r_l}^{r_{M,1}} f(r)\frac{1}{2}M^2\left(1-\frac{v(z)^2}{u_\infty^{\ 2}}\right)dr - \int_{r_{M,1}}^{r_{M,2}} f(r)dr + a\frac{n_{e,M}T_M}{n_{e,0}T}\right]$$

Excess pressure contribution



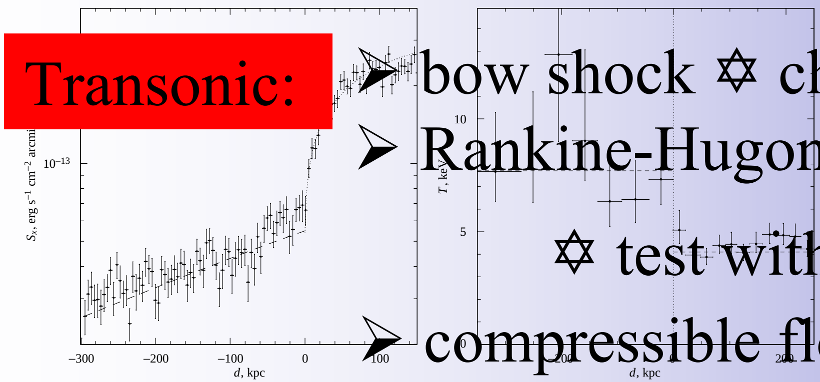
Excess pressure contribution





subcluster contribution
depending on loacation l

Model and characteristics: transonic

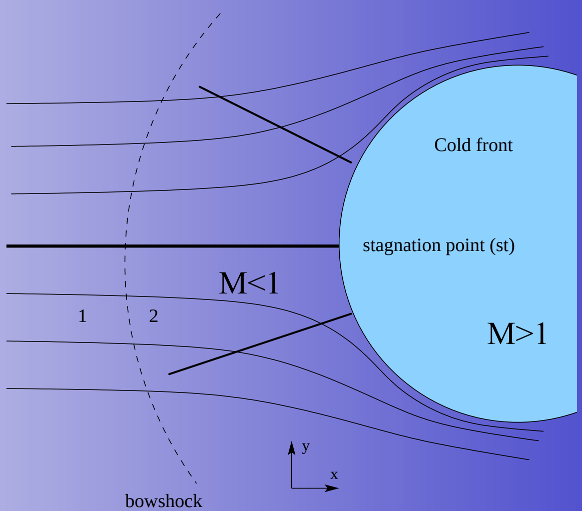


Transonic:

- bow shock ✡ change microphysics, *g(x)*
- Rankine-Hugoniot jump conditions at shock front

  ✡ test with observations: *C*
- compressible flow within shock region

$$\left.\begin{aligned} \rho_1 v_1 &= \rho_2 v_2 \\ P_1 + \rho_1 v_1^2 &= P_2 + \rho_2 v_2^2 \\ h_1 + \frac{1}{2} v_1^2 &= h_2 + \frac{1}{2} v_2^2 \end{aligned}\right\} \quad \begin{aligned} \frac{\rho_1}{\rho_2} &= \frac{2\gamma}{\gamma+1} M^2 + \frac{\gamma-1}{\gamma+1} = \frac{1}{C} \\ \frac{P_2}{P_1} &= \frac{2\gamma}{\gamma+1} M^2 - \frac{\gamma-1}{\gamma+1} \end{aligned}$$



✡Result: additional contribution due to pressure jump

Modified SZ signal (1)

What changes? ✡ g(x)

- shock particle re-acceleration mechanism depending on *C*

  (1st order Fermi acc., stochastic acc. ... Not well known!)

- new emerging electron population
- hybrid electron distribution with high energy power law tail

$$\alpha = \frac{C+2}{C-1}$$

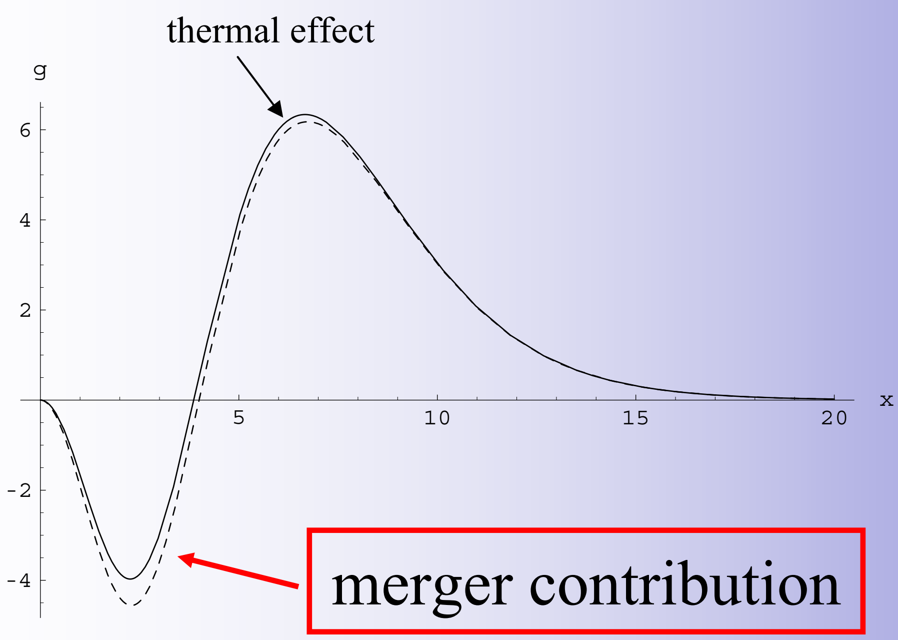
✡ Problem: lower limit p_l for power law!

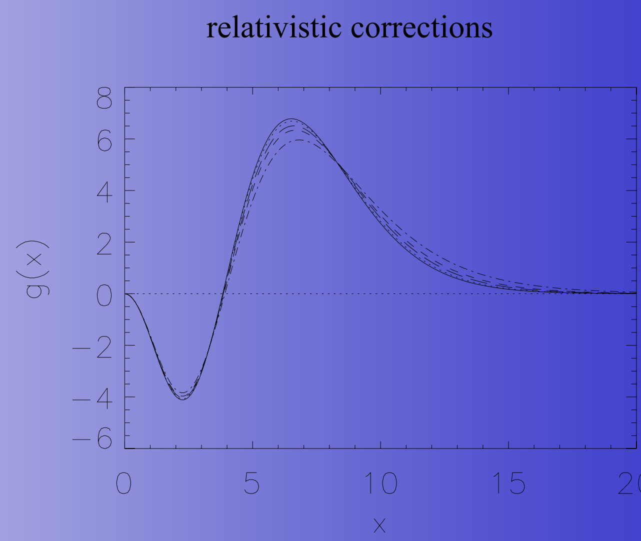
combination of 2 (independent) electron populations:
✡ cross scattering, requires new calculation technique

Colafrancesco et al., 2003

Modified SZ signal (2)

g(x)



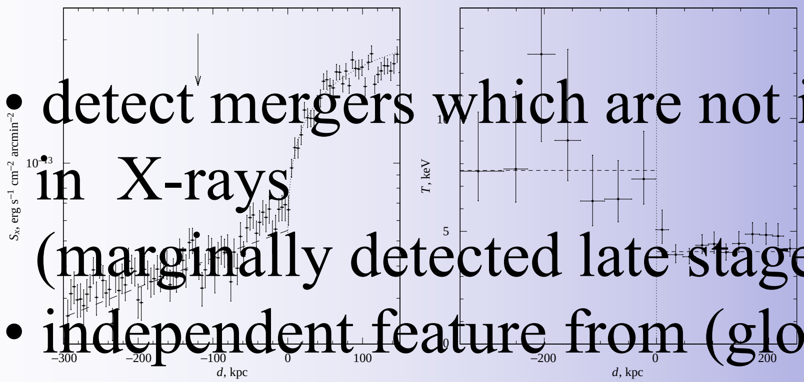


✡ Results:

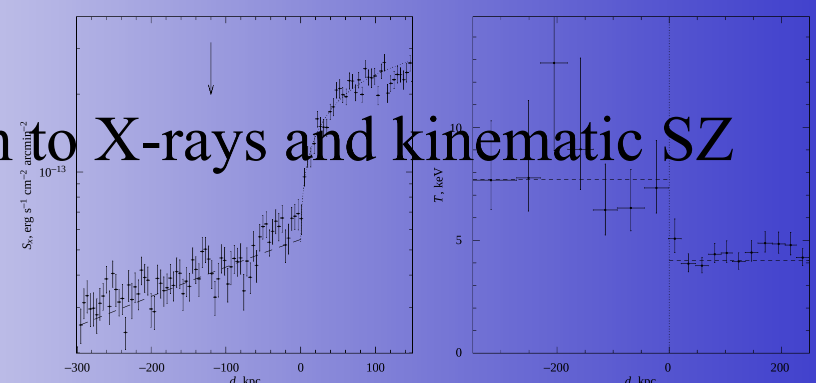
- change in crossover ~ 10 %
- limited to certain regions?

MAPS FOR SUBSONIC MERGERS

Interest:

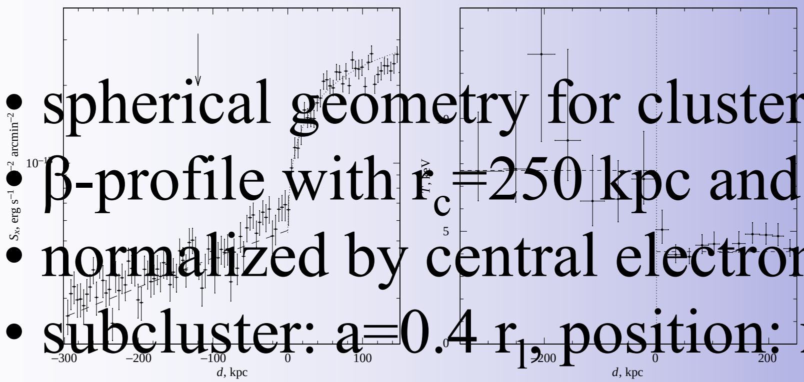


- detect mergers which are not identified by bow shocks in X-rays (marginally detected late stage, cold fronts)
- independent feature from (global) compressibility and heating effects
- look for merger dynamics
- complementary information to X-rays and kinematic SZ

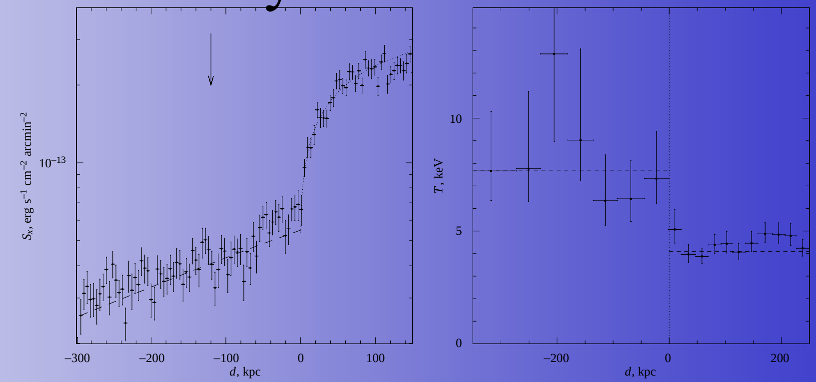


Maps for subsonic mergers

Parameters:

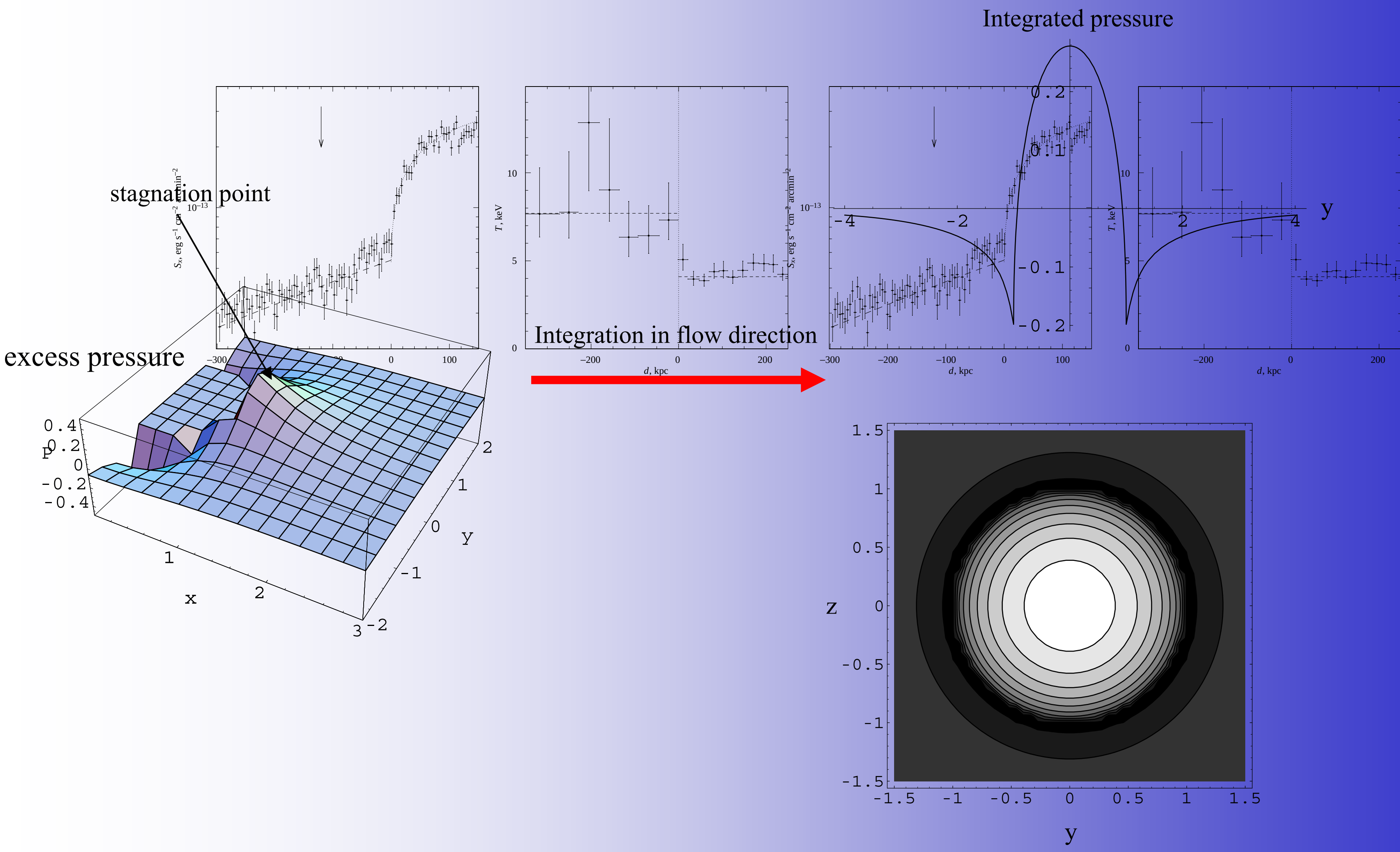


- spherical geometry for cluster and subcluster
- β-profile with r_c=250 kpc and β=2/3, r_l=1 Mpc
- normalized by central electron density and temperature
- subcluster: a=0.4 r_l, position: x=0.5 r_l, y=z=0, M=0.6
- subcluster density=background density
- DM structure not changed



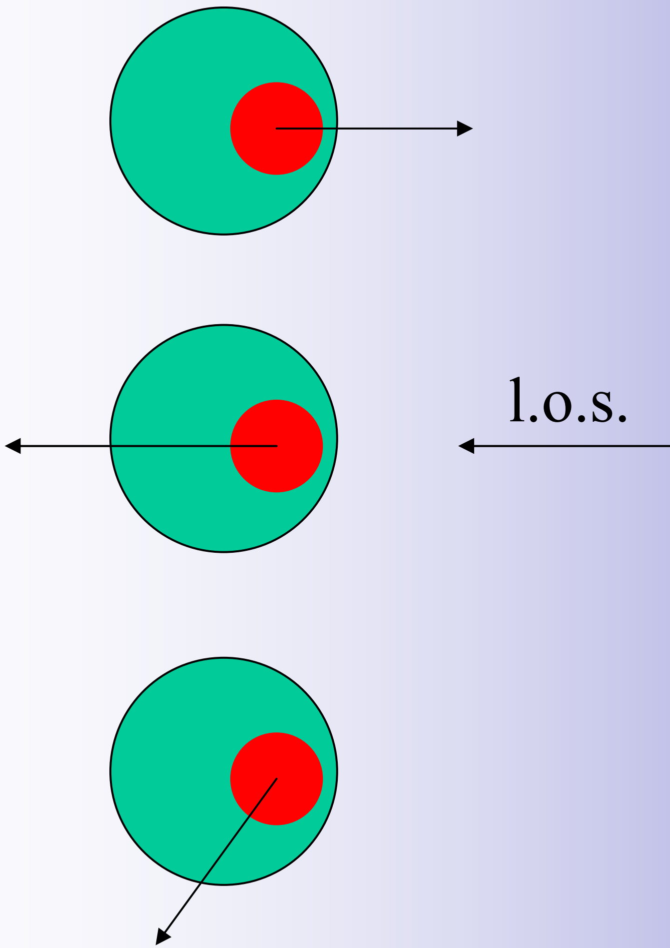
Maps for subsonic mergers

excess pressure feature:



Maps for subsonic mergers

location ✡ direction of movement



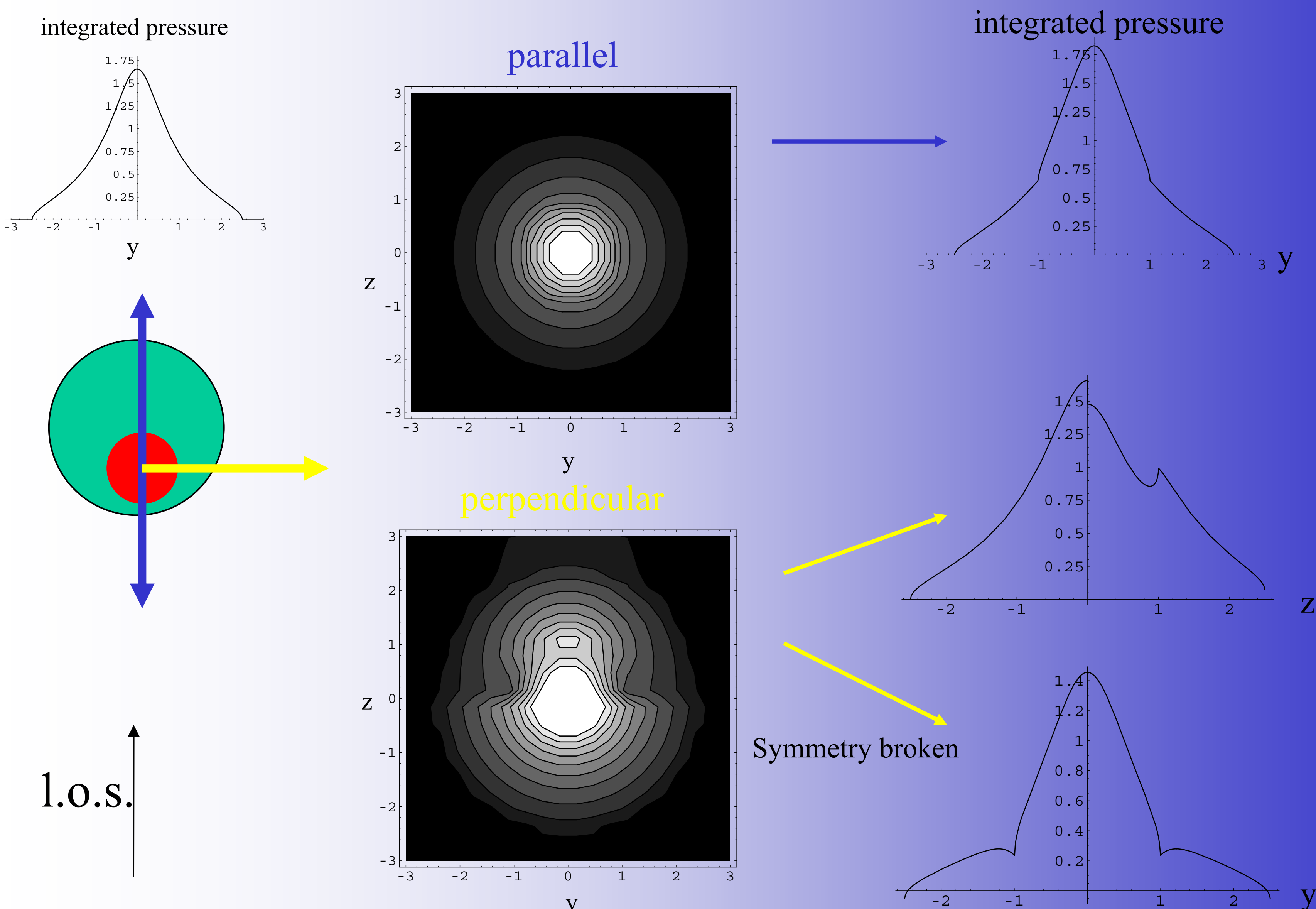
late stage merger, cold front (slowed down)

infalling substructure

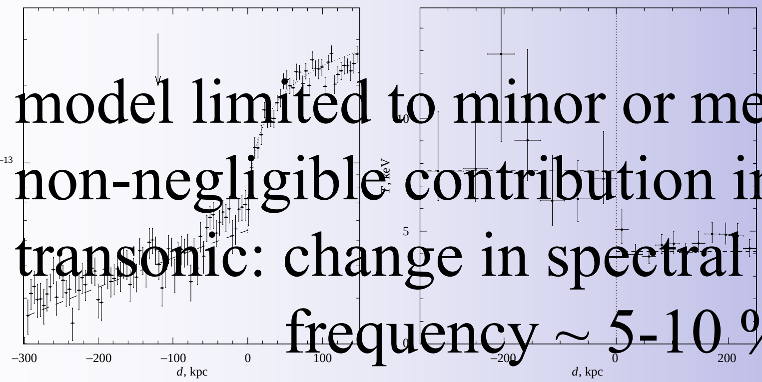
transversally moving substructure

Maps for subsonic mergers

results: excess pressure contribution



CONCLUSION AND SUMMARY



- model limited to minor or medium-scale merger
- non-negligible contribution in intensity: ~ 10-15 %
- transonic: change in spectral function g(x) at crossover frequency ~ 5-10 %
  (Problem: disentangle from relativistic corrections)
- complementary/additional information due to excess pressure compared to X-rays ("invisible merger")
- different features depending on direction of moving substructure (subsonic mergers), change: ~ 5-10 %
- complementary to kinematic SZ
- detect substructures with high resolution SZ mapping (high z)
- SZ-survey: constrain merger rate and structure formation