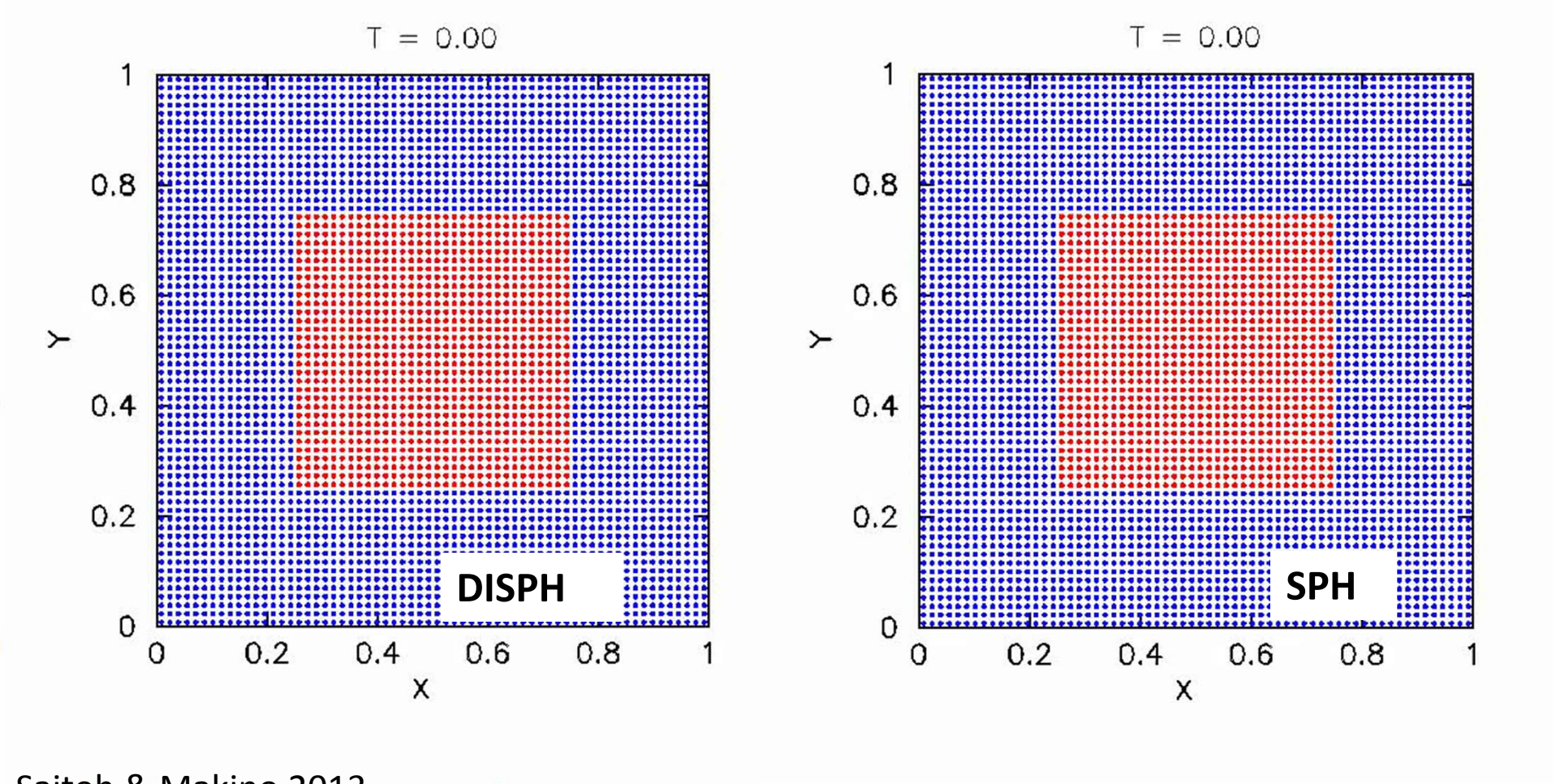
サンタバーバラ クラスターテスト 再訪

斎藤貴之

地球生命研究所 (ELSI)
東京工業大学

DISPH vs SPH



Saitoh & Makino 2013

Santa Barbara Cluster Comparison Test

Frenk+1999

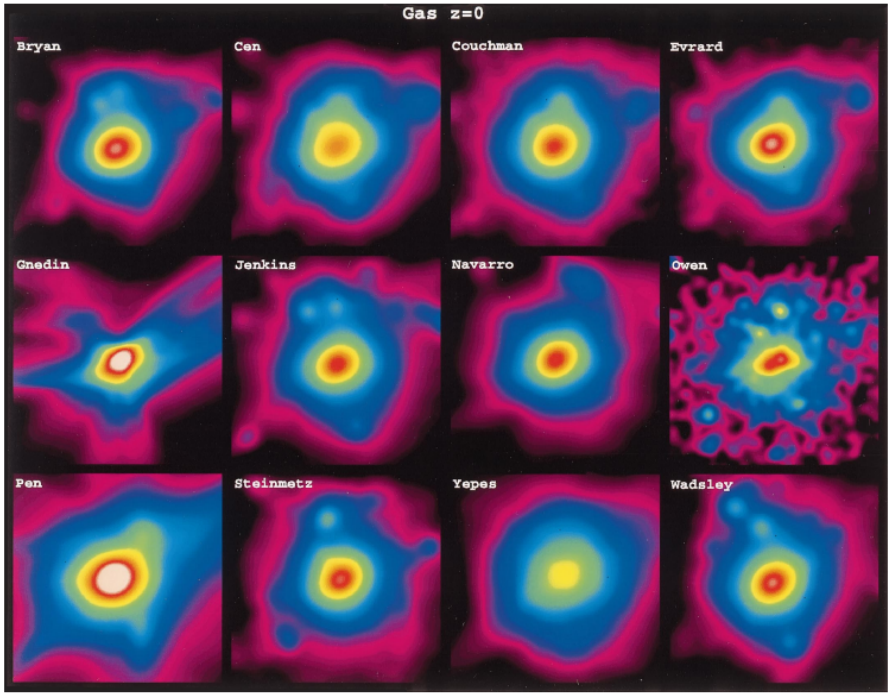


FIG. 3.—Projected gas density at $z = 0$. The images, covering the inner 8 Mpc of each simulation cube, have been smoothed using the standard Gaussian filter of 250 kpc half-width described in the text.

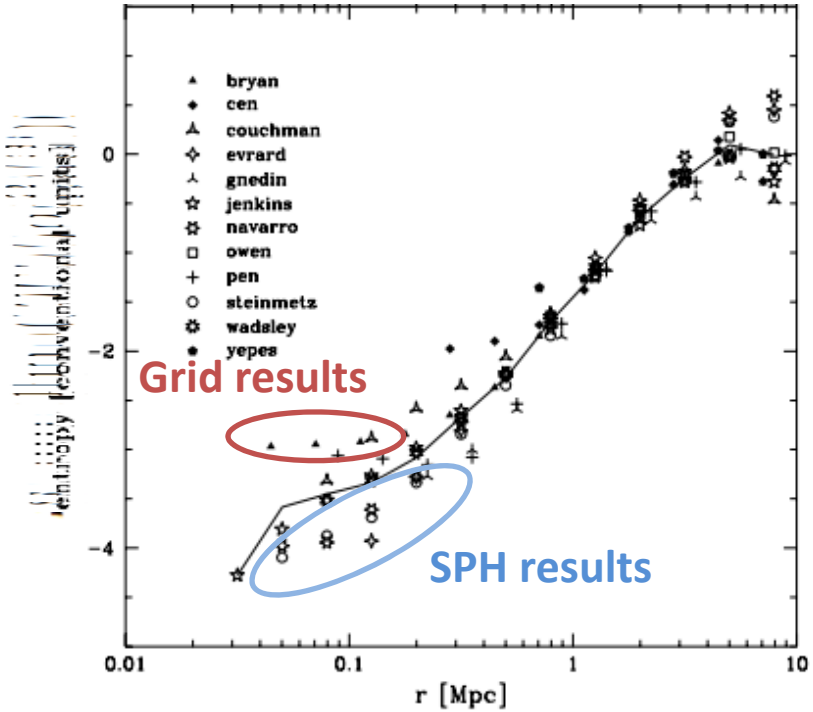


FIG. 18.—Radial variation of the gas entropy. The entropy is defined as $s = \ln(T/\rho_{gas}^{2/3})$. See legend to Fig. 10 for further details.

- エントロピープロファイルに系統的な違い
  - Grid results: **Core at the center**
  - SPH results: **No entropy core**

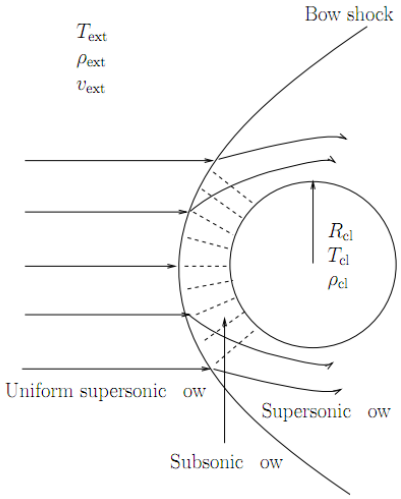
エントロピープロファイルの違いの起源は？

- Frenk+1999 の解釈

> the entropy remains approximately constant within ~200 kpc. This difference might reflect differences in the way in which shocks are treated in the SPH and grid codes; however, the effect is small and occurs at the resolution

- 従来の SPH 法は接触不連続面に非物理的表面張力が発生(e.g., Agertz+2007)
  - クランプ落下時にラム圧・流体不安定性による破壊を免れて低エントロピー成分を中心に供給する可能性
  - Blob test (Agertz+2007) の結果が示唆的
  - See also Power+2014

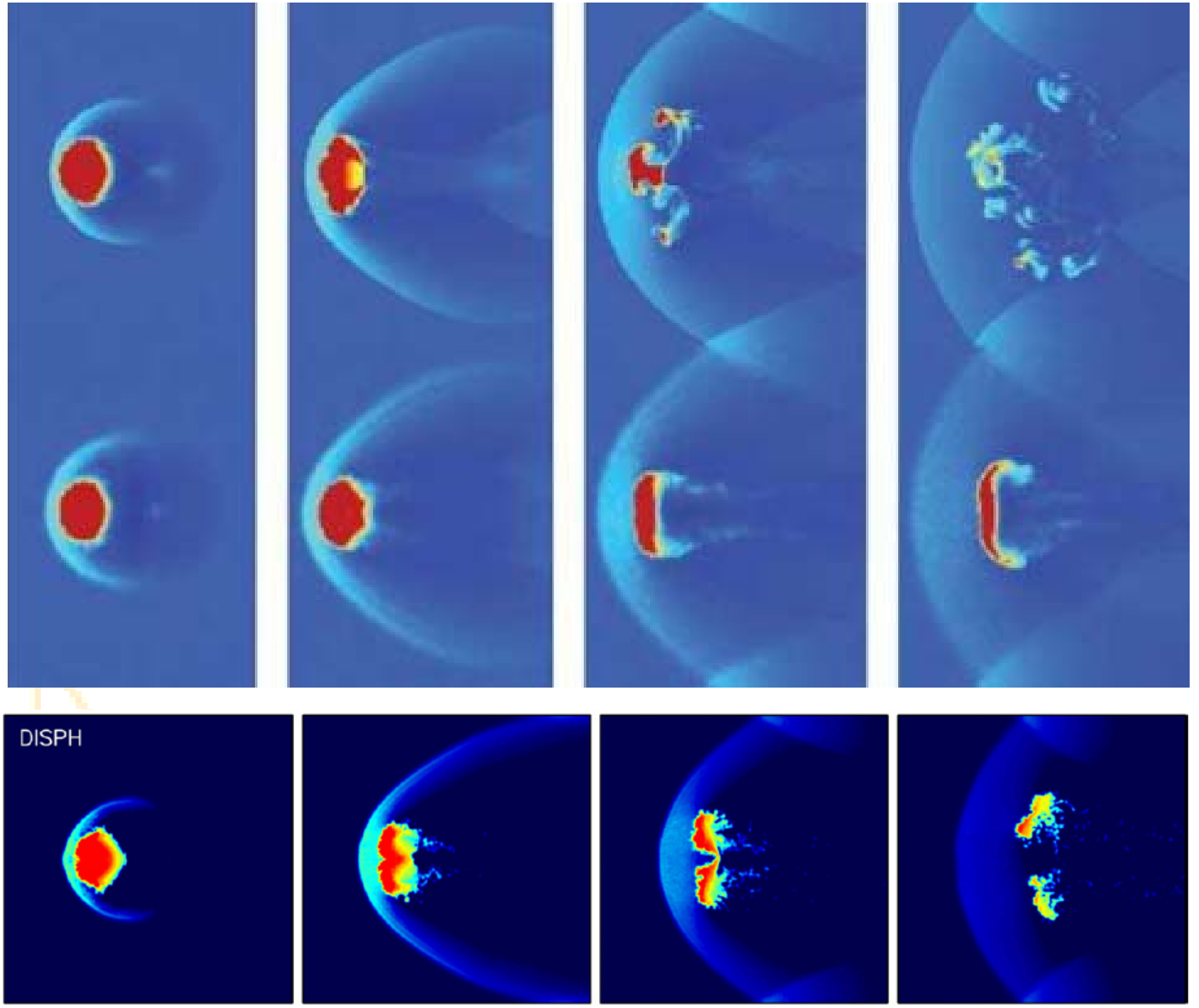
Blob Test



Grid

SPH

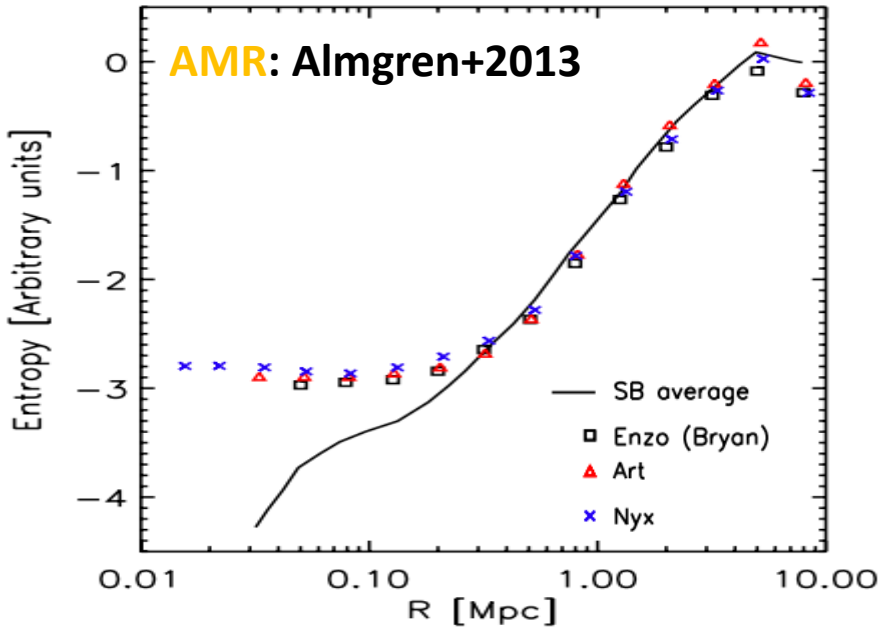
DISPH

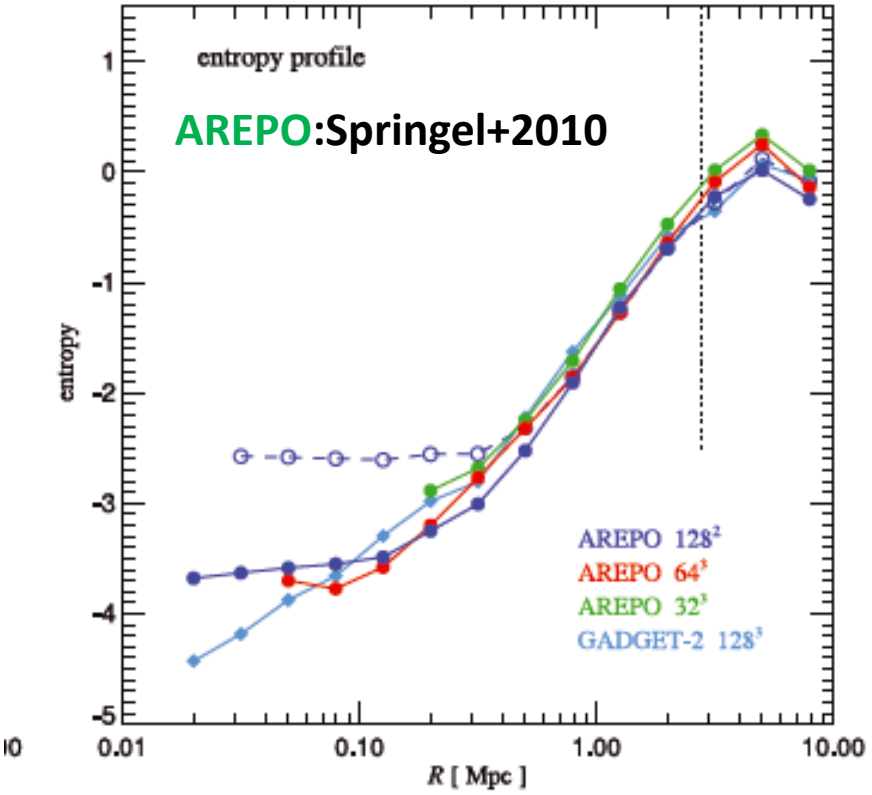


Agertz et al. 2007

Saitoh & Makino 2013

AMR/Moving mesh results





- **AMR** の結果は収束
- **AREPO** は core あり、ただしそのサイズは小さくエントロピーはより低い

Numerical diffusion

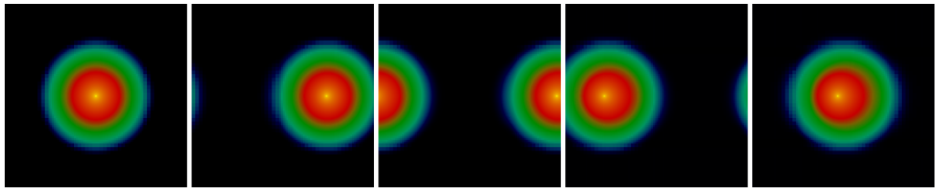


Figure 12. Density projections of the cluster over the course of 1 Gyr in which it moves once around the simulation box. Images taken at 0, 250, 500, 750, 1000 Myr with projected density range $[10^{8.4}, 10^{16.5}]\,M_\odot\,Mpc^{-2}$. Yellow and red shows higher density regions than green, while black is very low density. [Images produced with ENZO (ZEUS).]

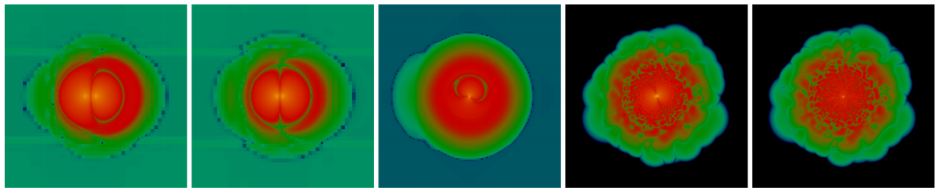
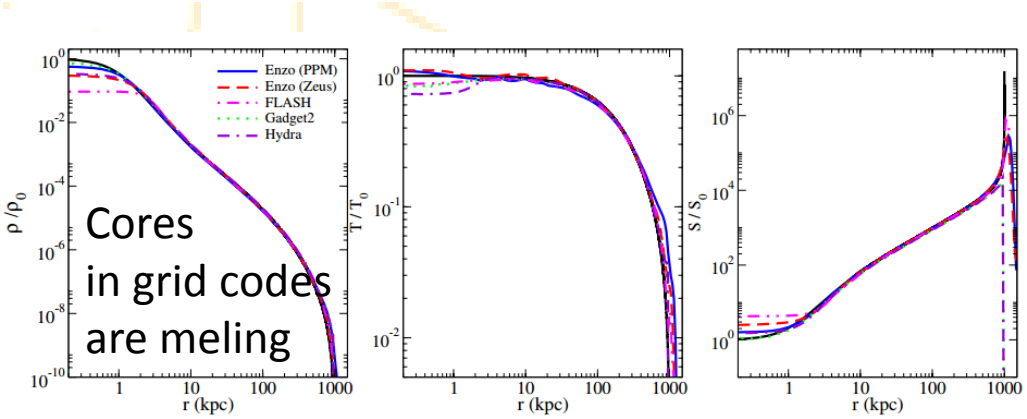


Figure 13. Image subtractions of the density projections at the start and end of the translating cluster test. From left- to right-hand side shows ENZO (PPM), ENZO (ZEUS), FLASH, GADGET2 and HYDRA. The projected density range is $[10^4, 10^{18.6}]\,M_\odot\,Mpc^{-2}$.



Tasker+2008

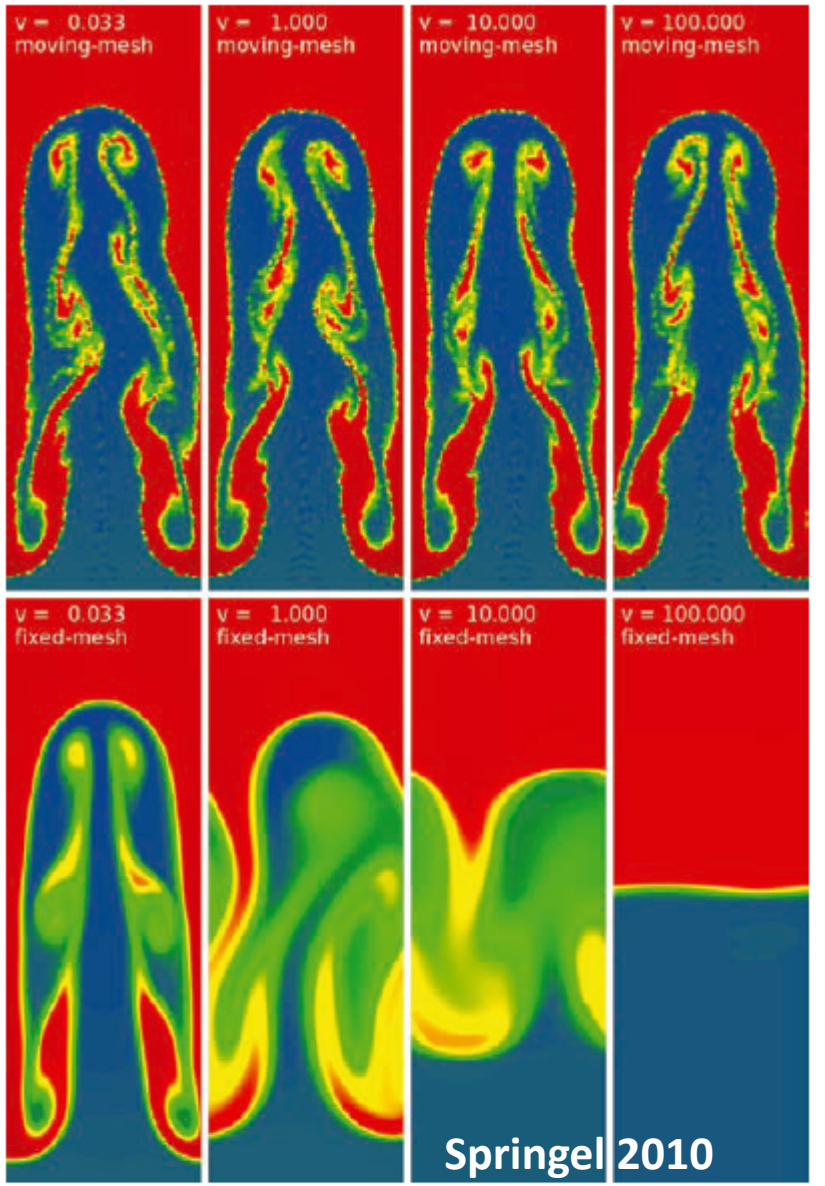
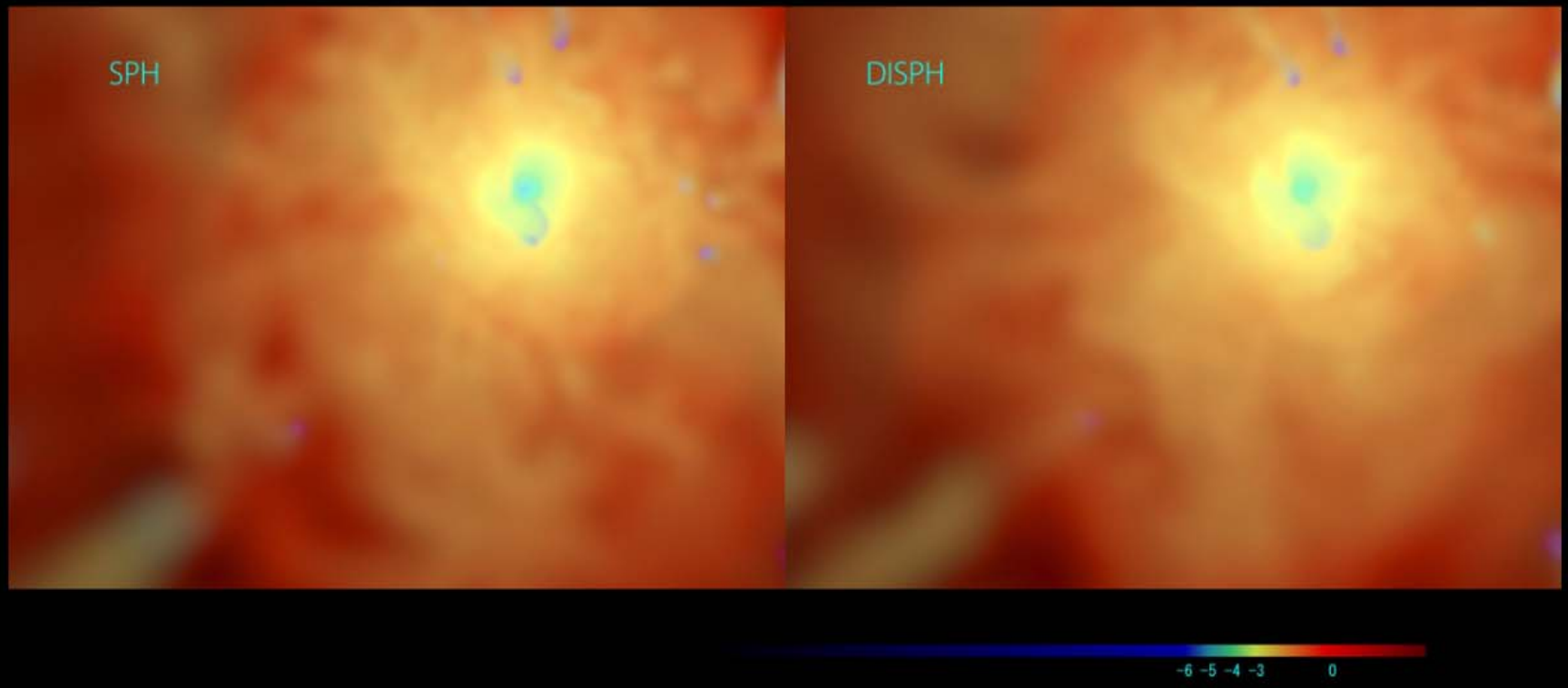


Figure 36. RT instability calculated with different Galilean boosts v_x in the horizontal direction (the simulation domain is periodic in the x-direction). The correct result should in principal be independent of v. The top row shows the result at time $t = 15.0$ computed with our moving-mesh approach, while the bottom row of panels gives the corresponding results for a fixed-mesh calculation with AREPO.

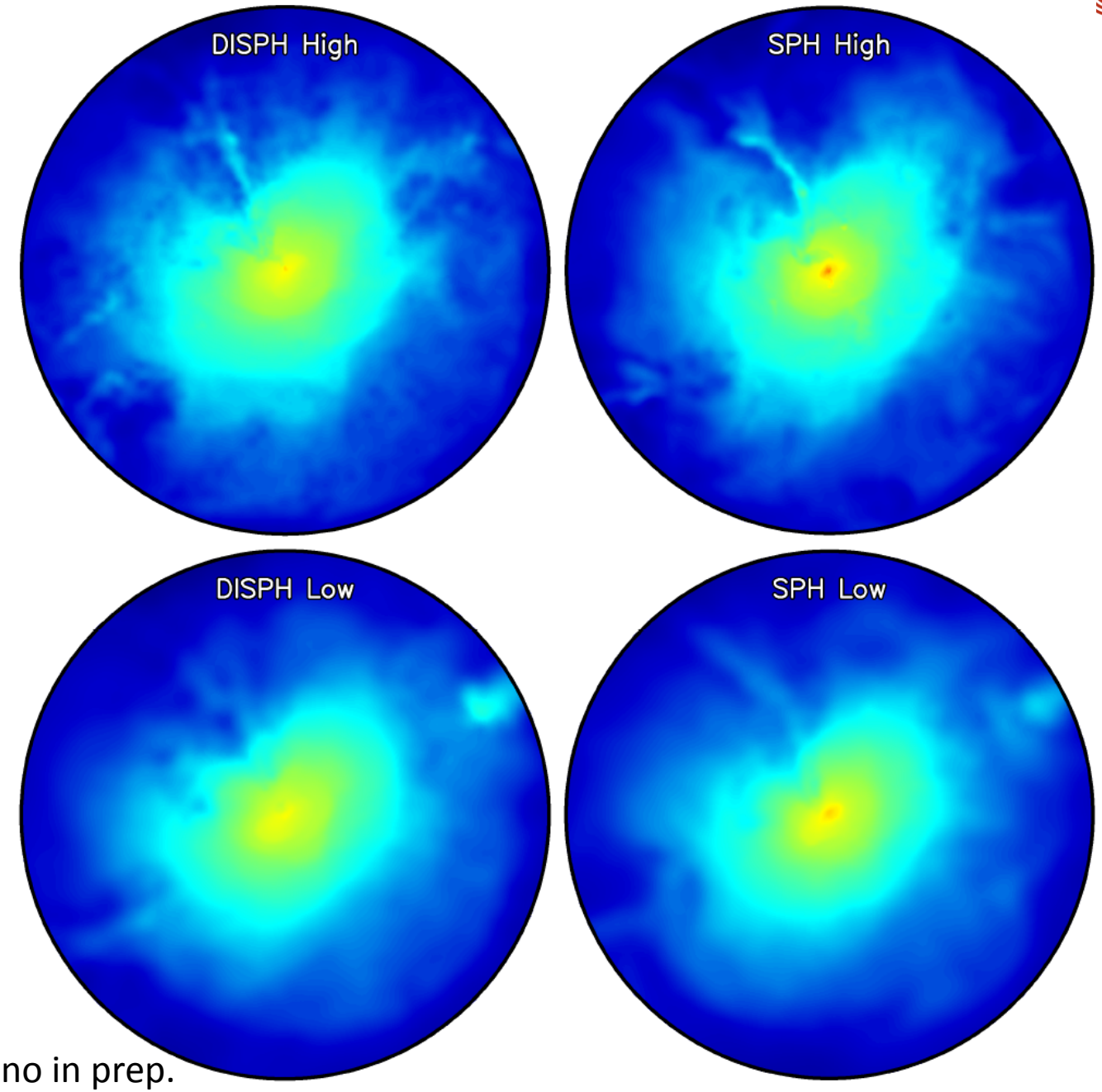
Runs

- Initial condition
  - Cosmology: **SCDM**
  - $2x128^3$ & $2x256^3$ particles (Heitmann+2005)
  - $\Omega_b=0.1$
- Code: **ASURA** (Saitoh+2008/2009)
  - DISPH(Saitoh & Makino 2013)/standard SPH
    - Artificial visc. (Monaghan 1997) with variable α (Morris & Monaghan 1997; Roswogg 2009)
  - Time step limiter (Saitoh & Makino 2009)
  - FAST (Saitoh & Makino 2010)
  - Symmetrized softening for tree (Saitoh & Makino 2012)
  - Phantom-GRAPE (Tanikawa+2012)



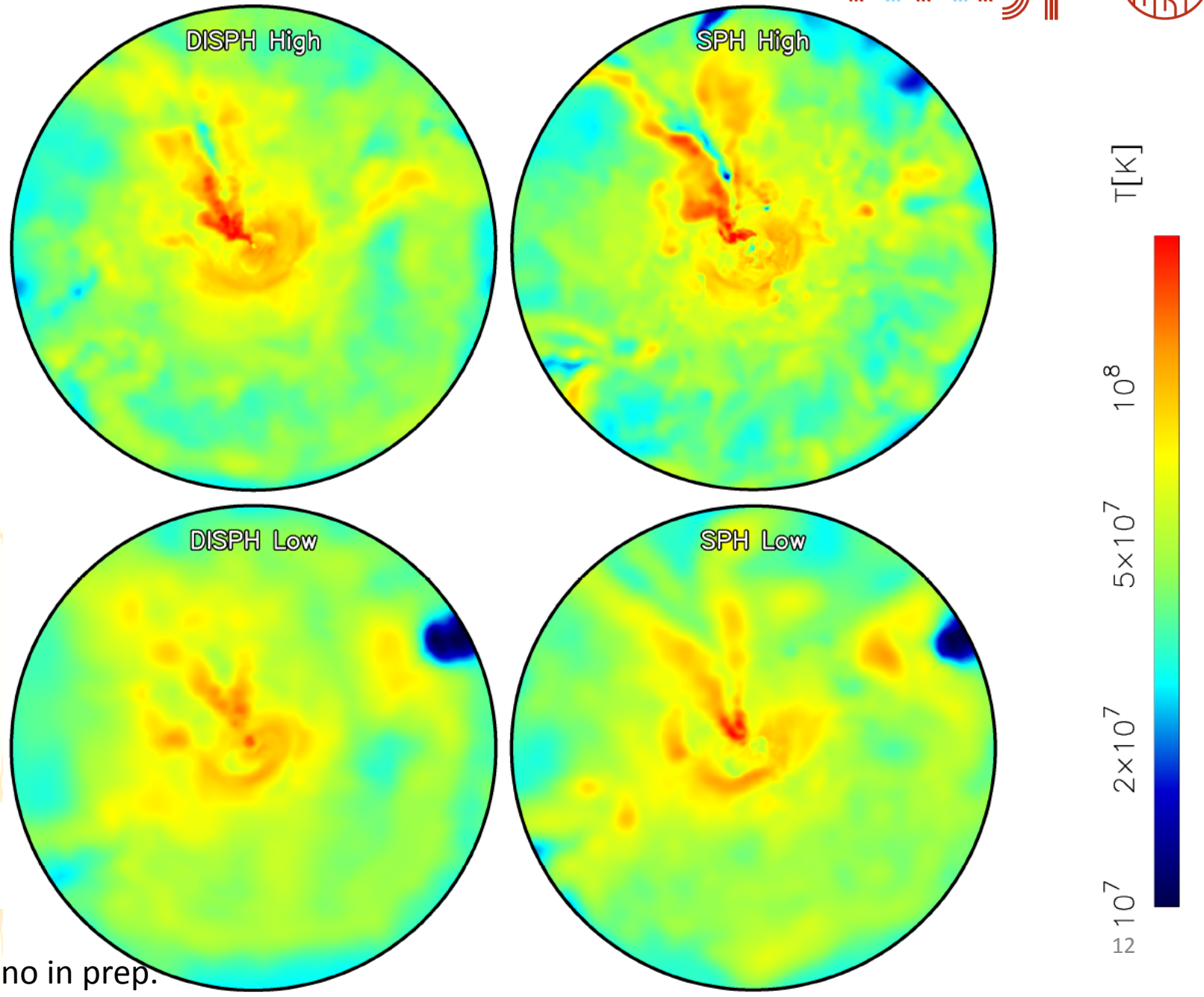
可視化：中山弘敬(国立天文台/ヴェイサエンターテイメント)

Snapshots:Density



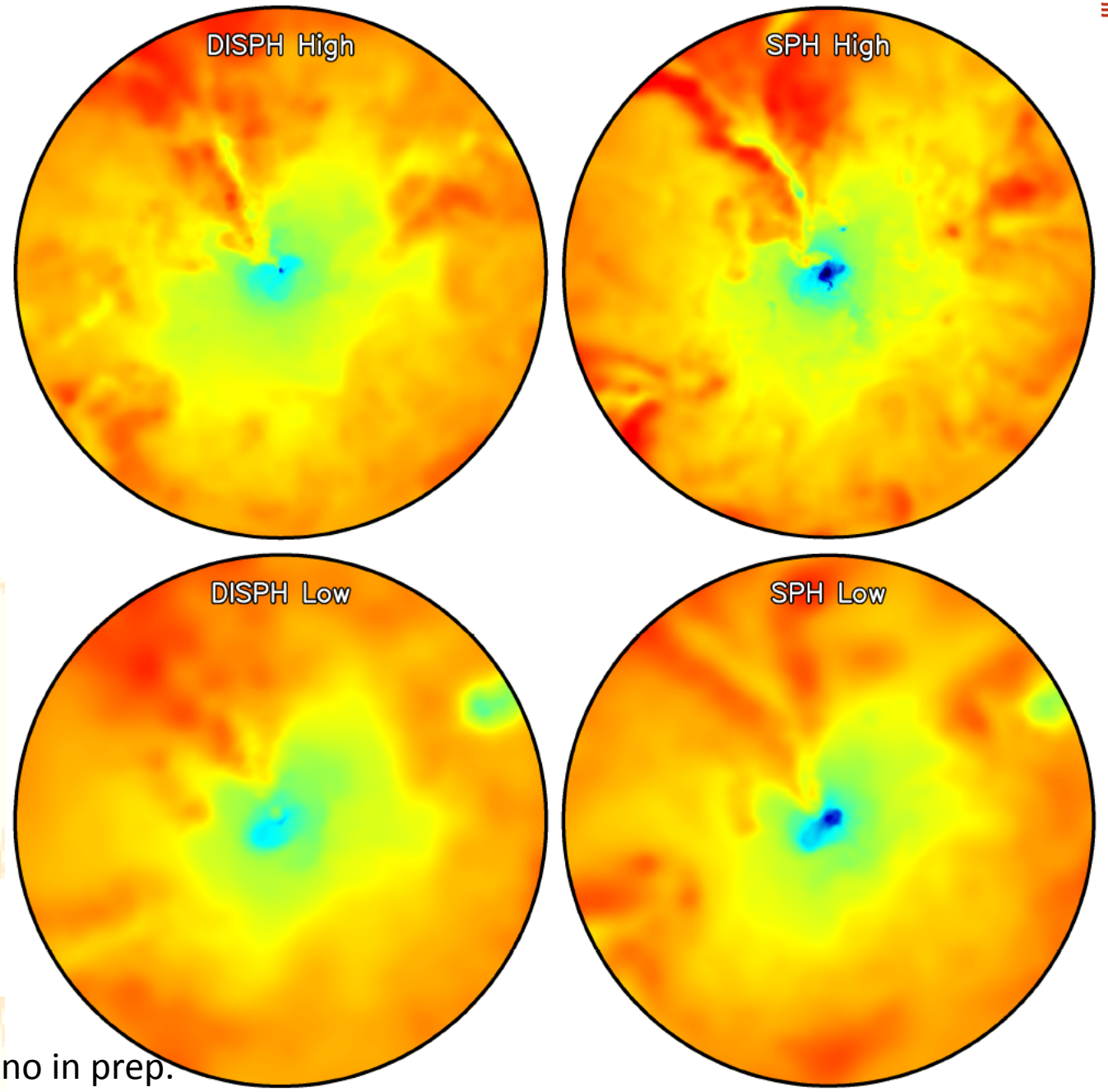
Saitoh & Makino in prep.

Snapshots:Temperature



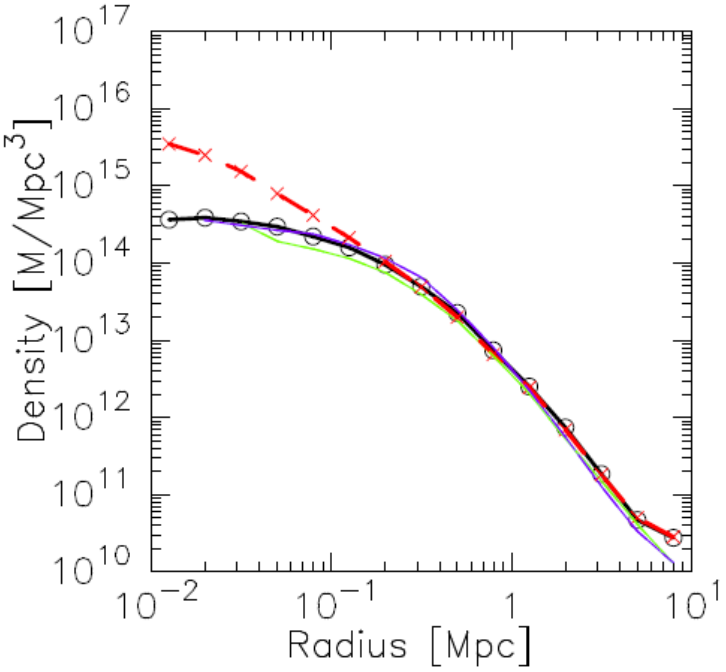
Saitoh & Makino in prep.

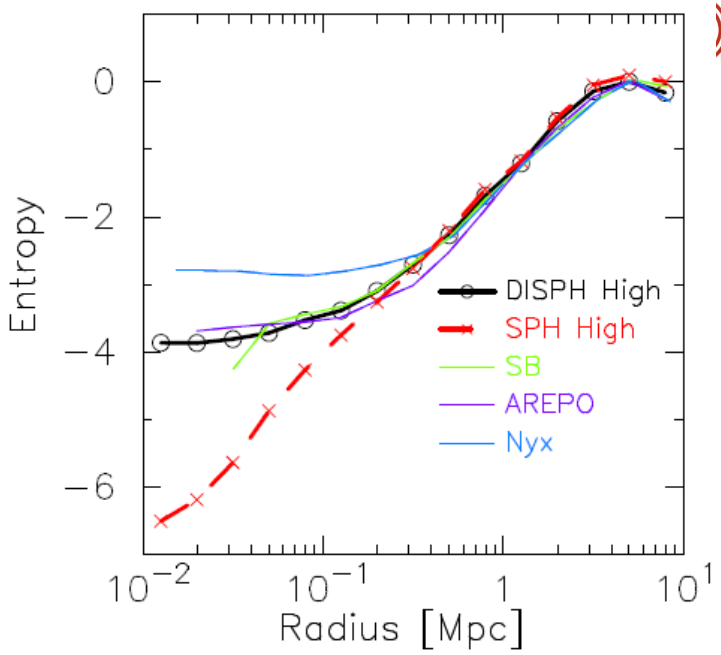
Snapshot:Entropy

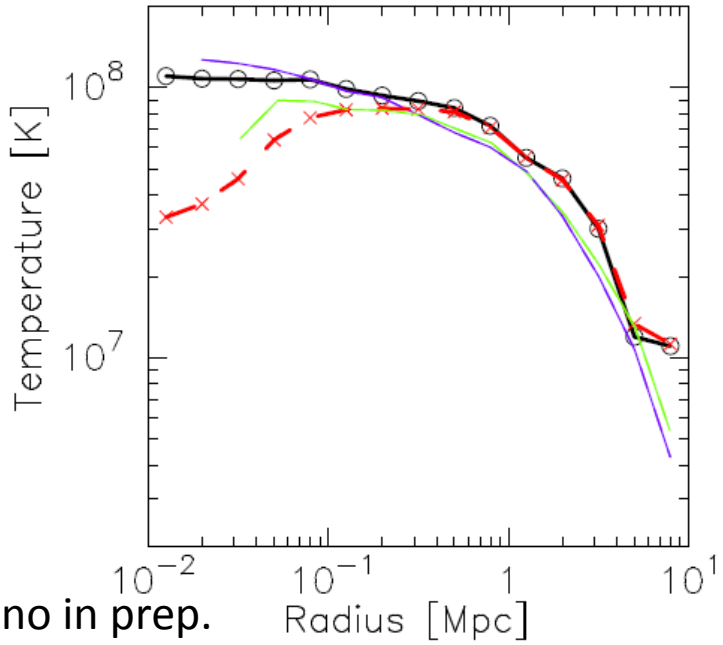


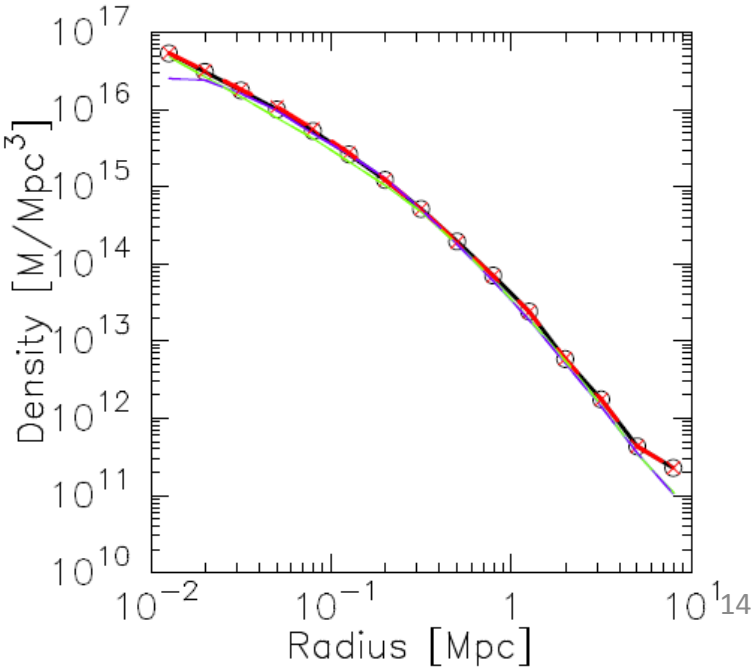
Saitoh & Makino in prep.

DISPH
SPH
SB ave.
AREPO
AMR





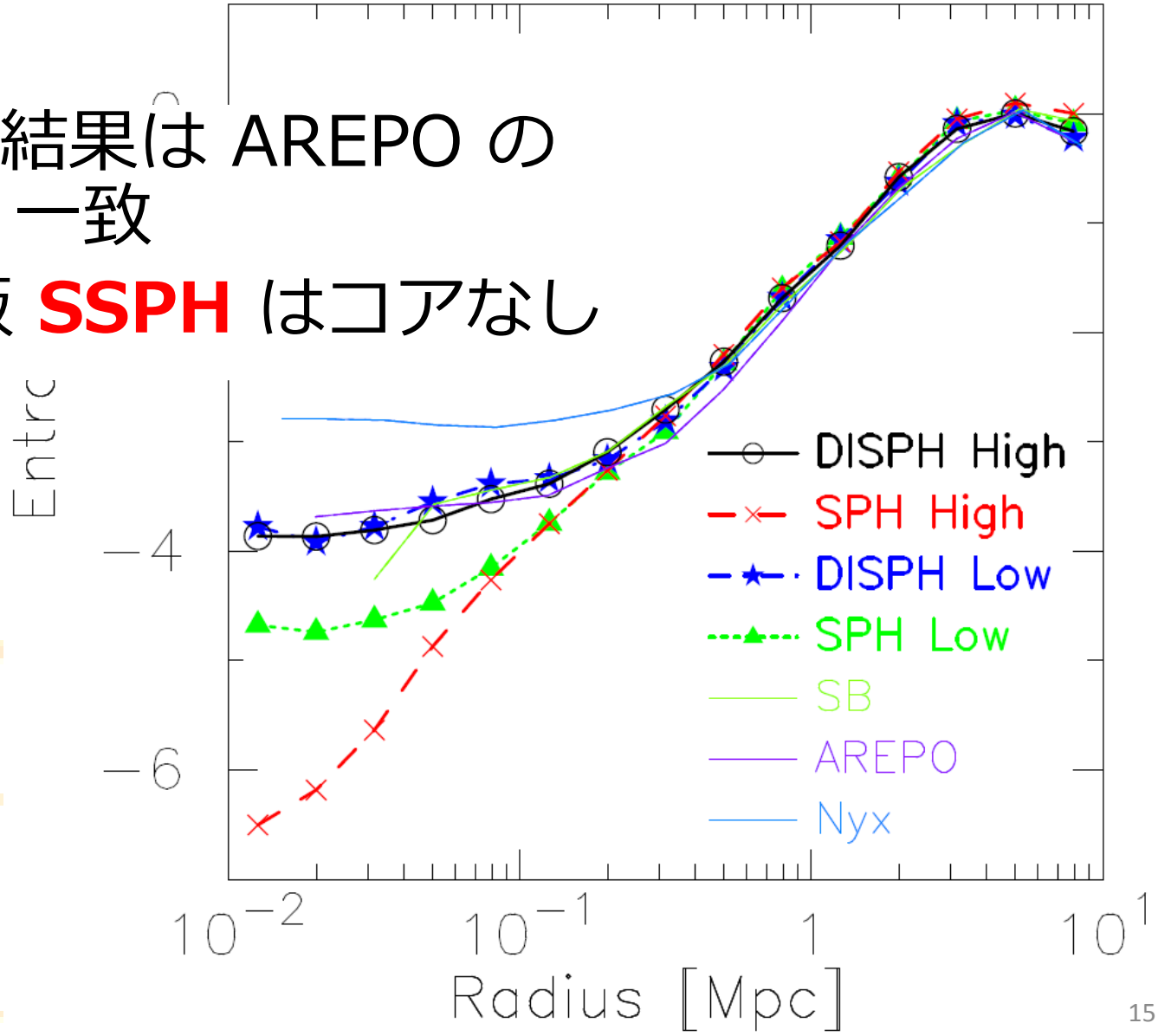




Saitoh & Makino in prep.

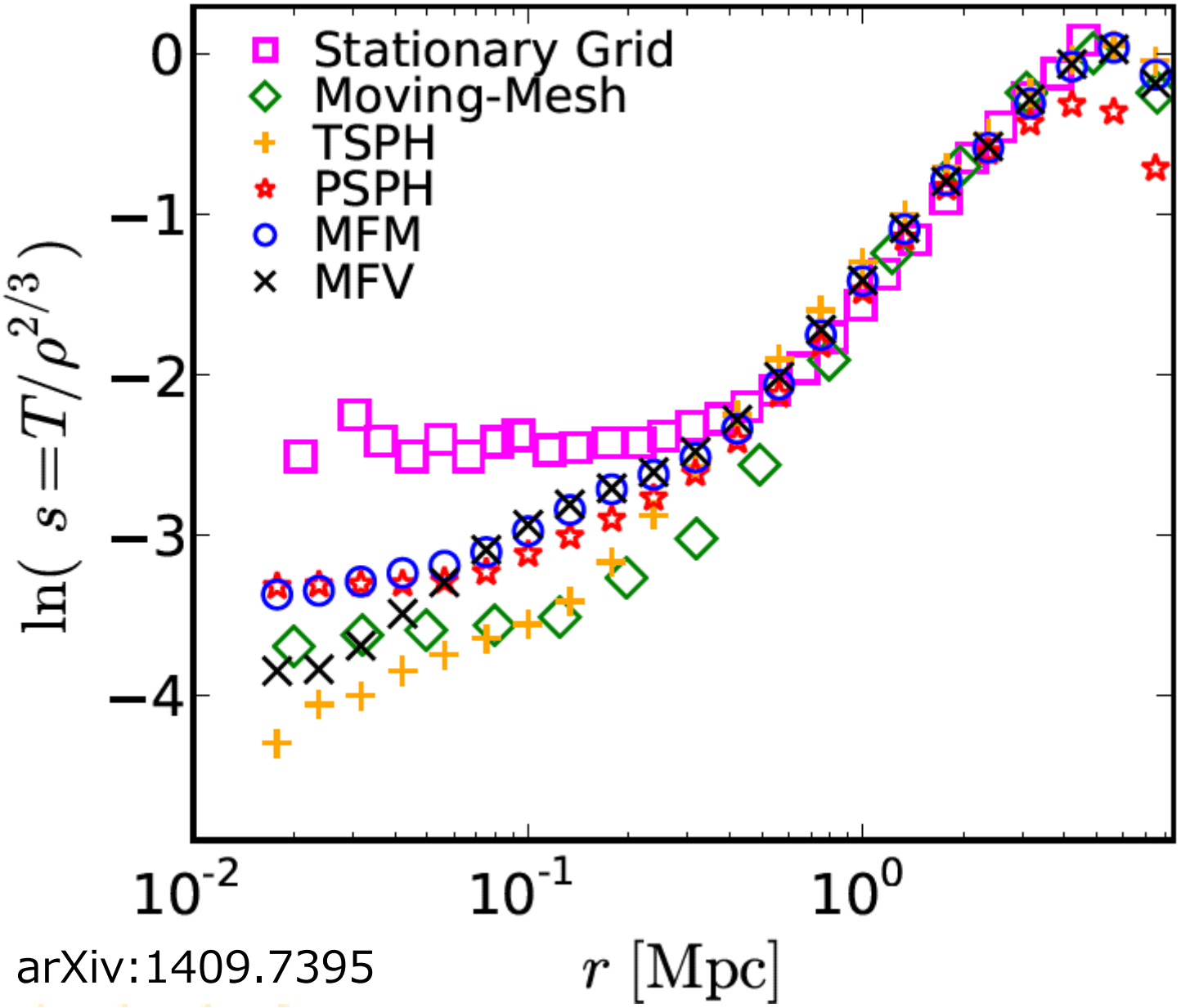
Profiles:Entropy

- **DISPH** の結果は AREPO の結果と良く一致
- 高分解能版 **SSPH** はコアなし



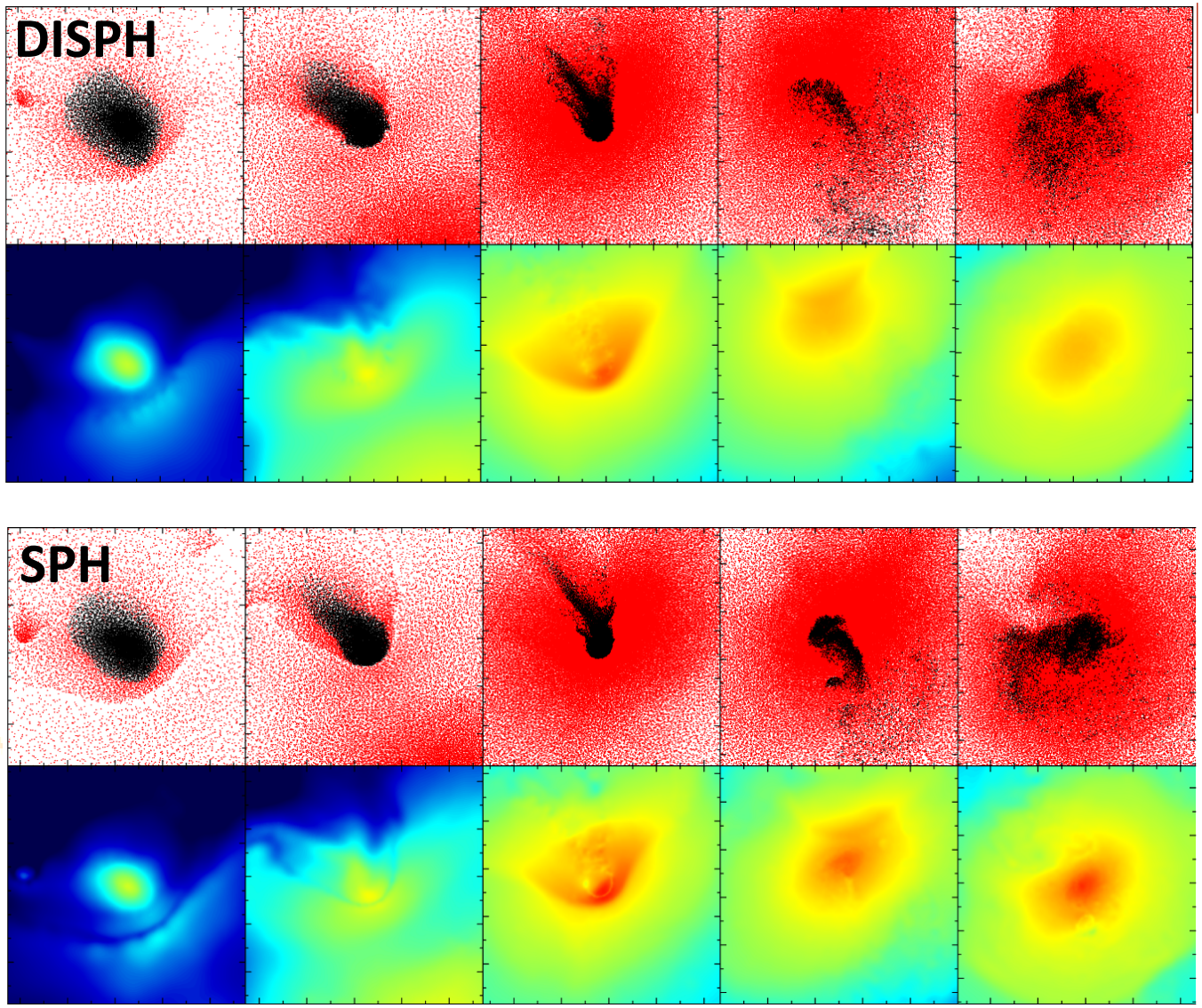
Saitoh & Makino in prep.

GIZMO ?



Hopkins arXiv:1409.7395

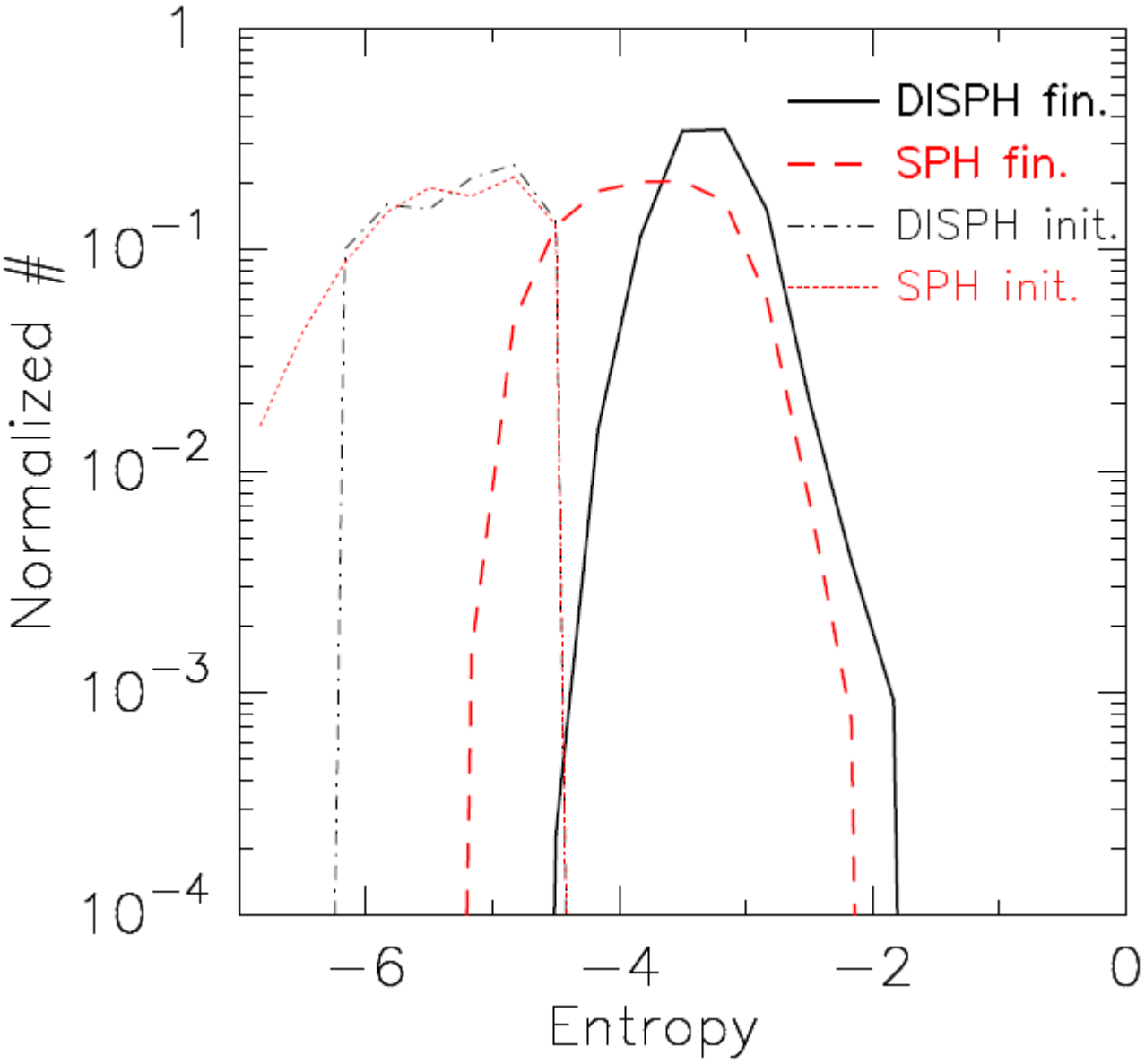
Unphysical Surface Tension around Clumps



- SSPH の計算ではクランプとハローの間にギャップが発生➔ギャップがクランプをラム圧から守る
- DISPH の計算ではギャップはない

Saitoh & Makino in prep.

Entropy Evolution



まとめ

- サンタバーバラクラスターテスト(Frenk+1999)
  - SPH法とメッシュ法で**エントロピープロファイルに系統的な違い**
- 近年の SPH 法の発展は、SSPH 法の定式化そのものが原因の根源であることを示唆
- DISPH と SSPH の結果を比較
  - **DISPH** ではクランプがクラスター中心に落ちるときに破壊されエントロピーが上がる➔**コアを持つ**
    - ただし、コアのサイズはAMRのそれより小さく、また深い
    - おそらく AMR の結果は数値粘性の影響がある
  - **SSPH** では非物理的表面張力のおかげで破壊を免れ、低エントロピー成分を持ち込む➔**コアなし**
  - **DISPH は銀河形成研究でも有用**