GPU-accelerated Simulations of Misaligned Accretion onto Spinning Black Holes

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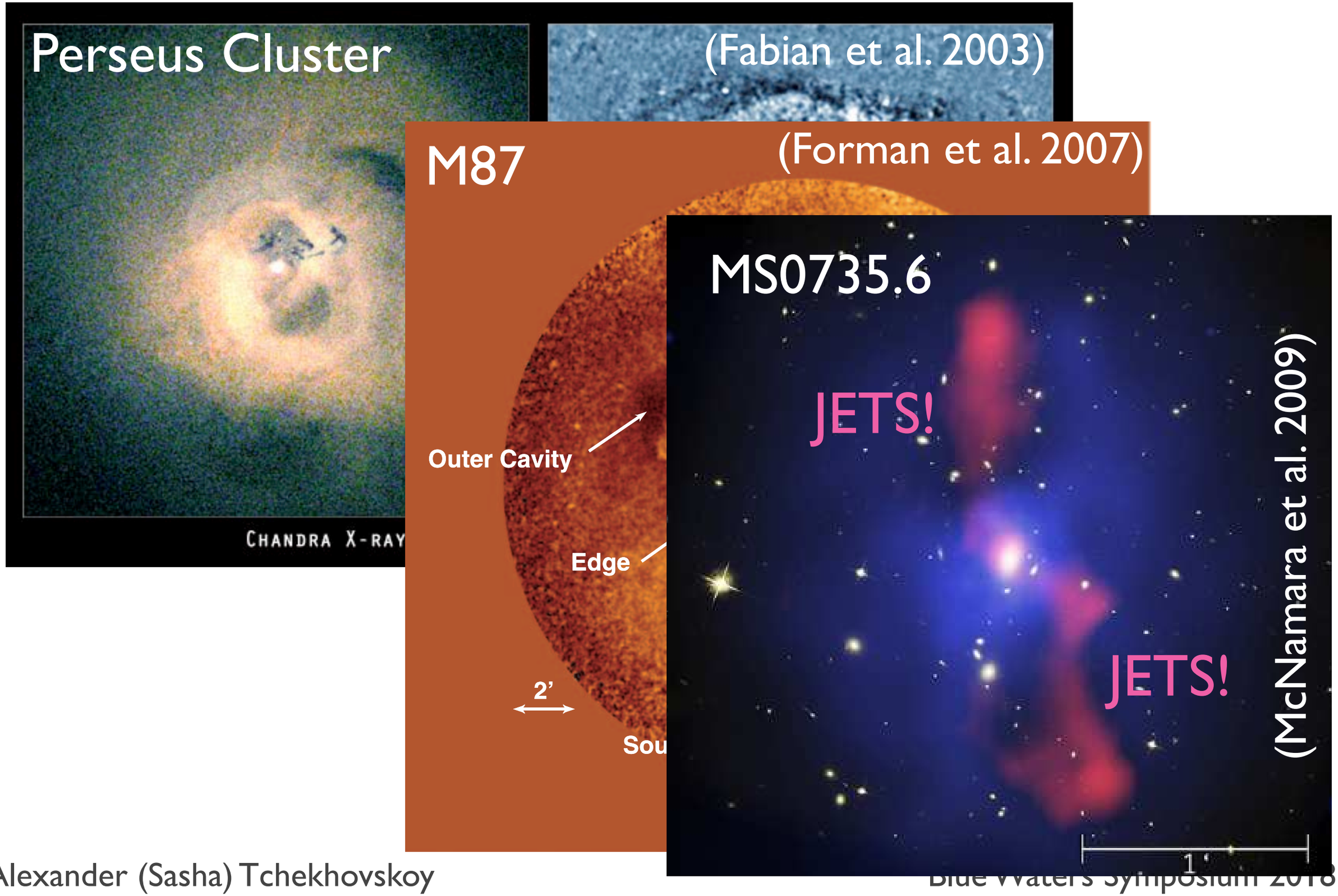
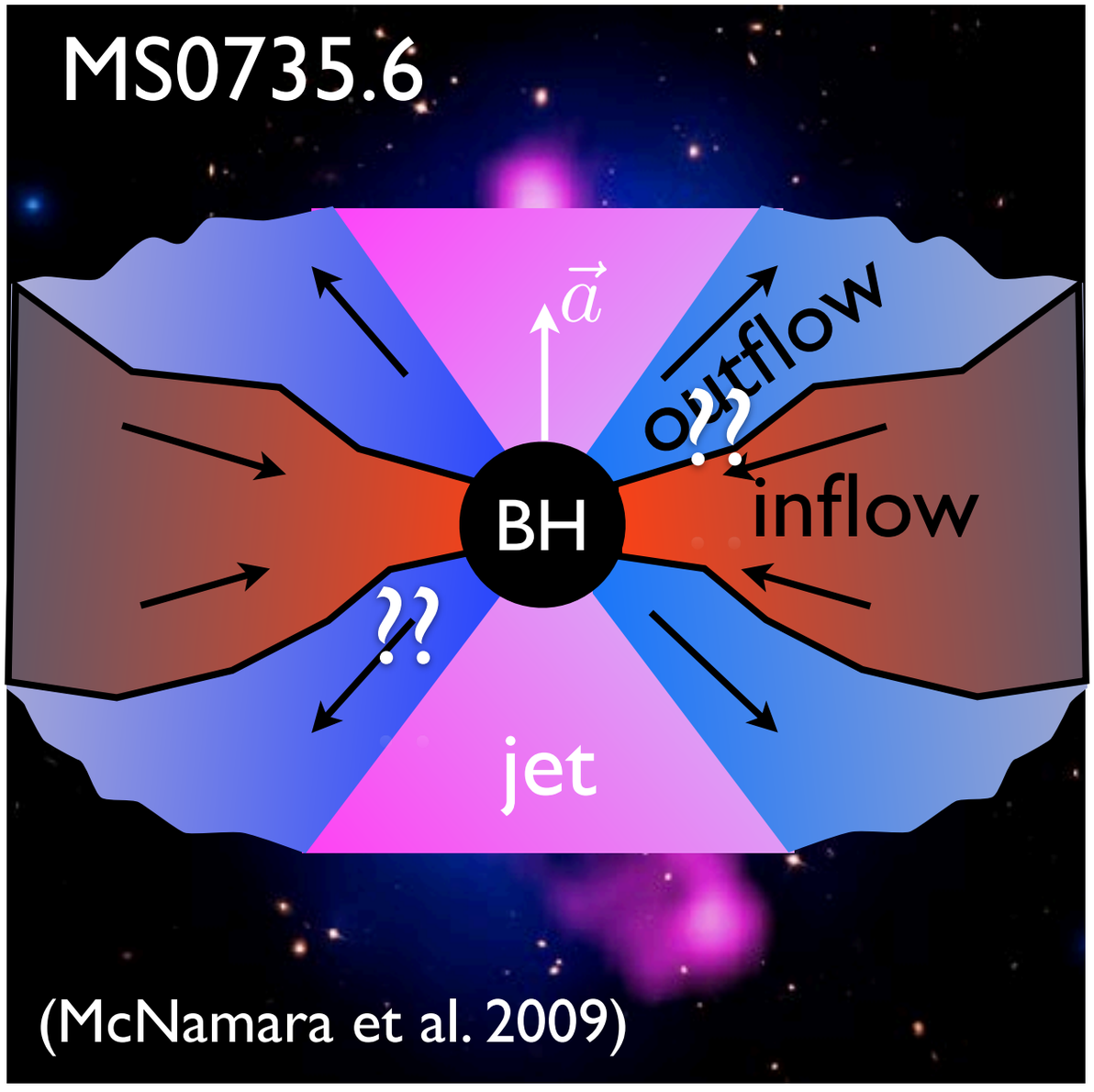
How Do Black Holes Explode Galaxies/Clusters?



We are Missing Something Important!

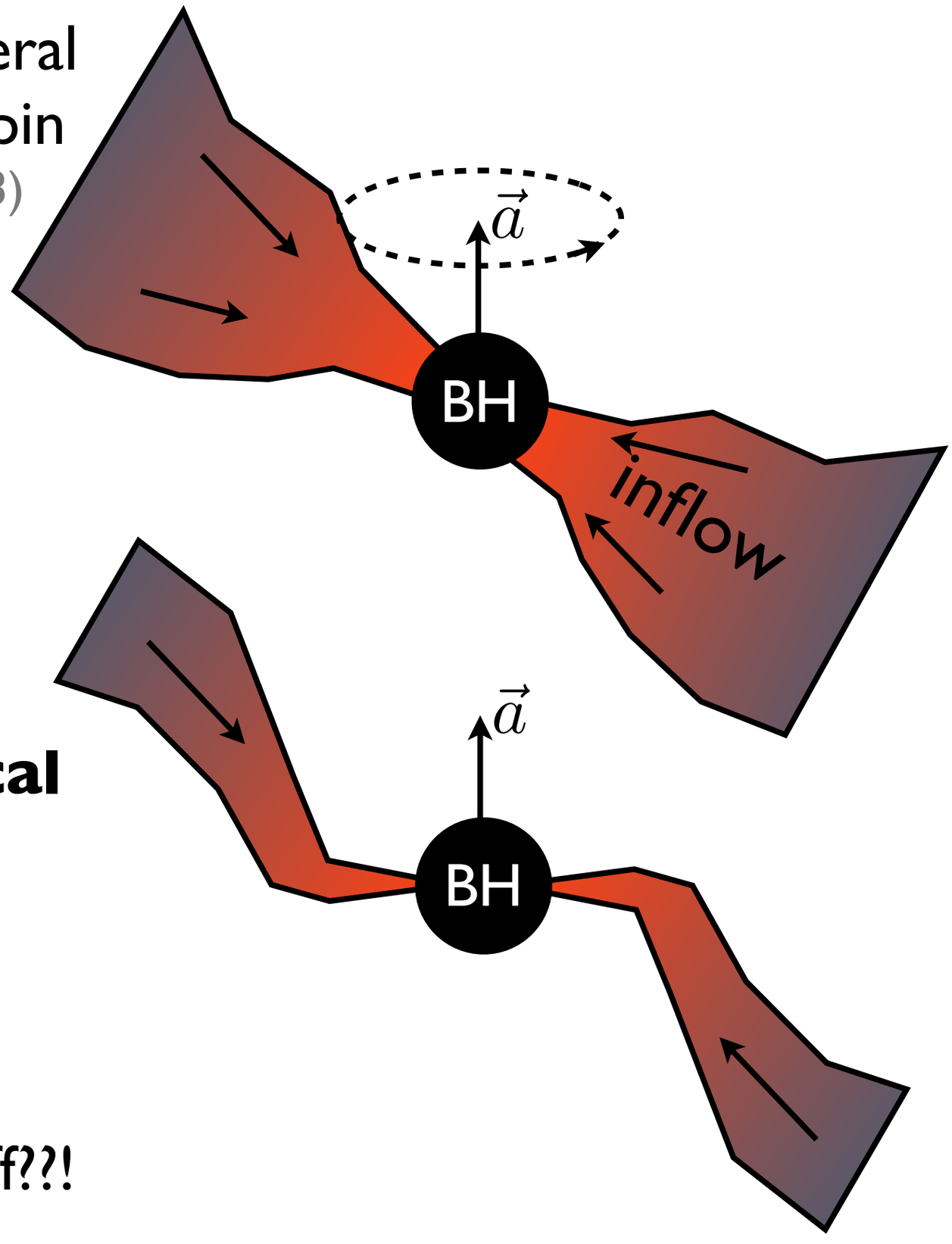


YES: typical disks are **tilted**

No: we do not understand them (yet)

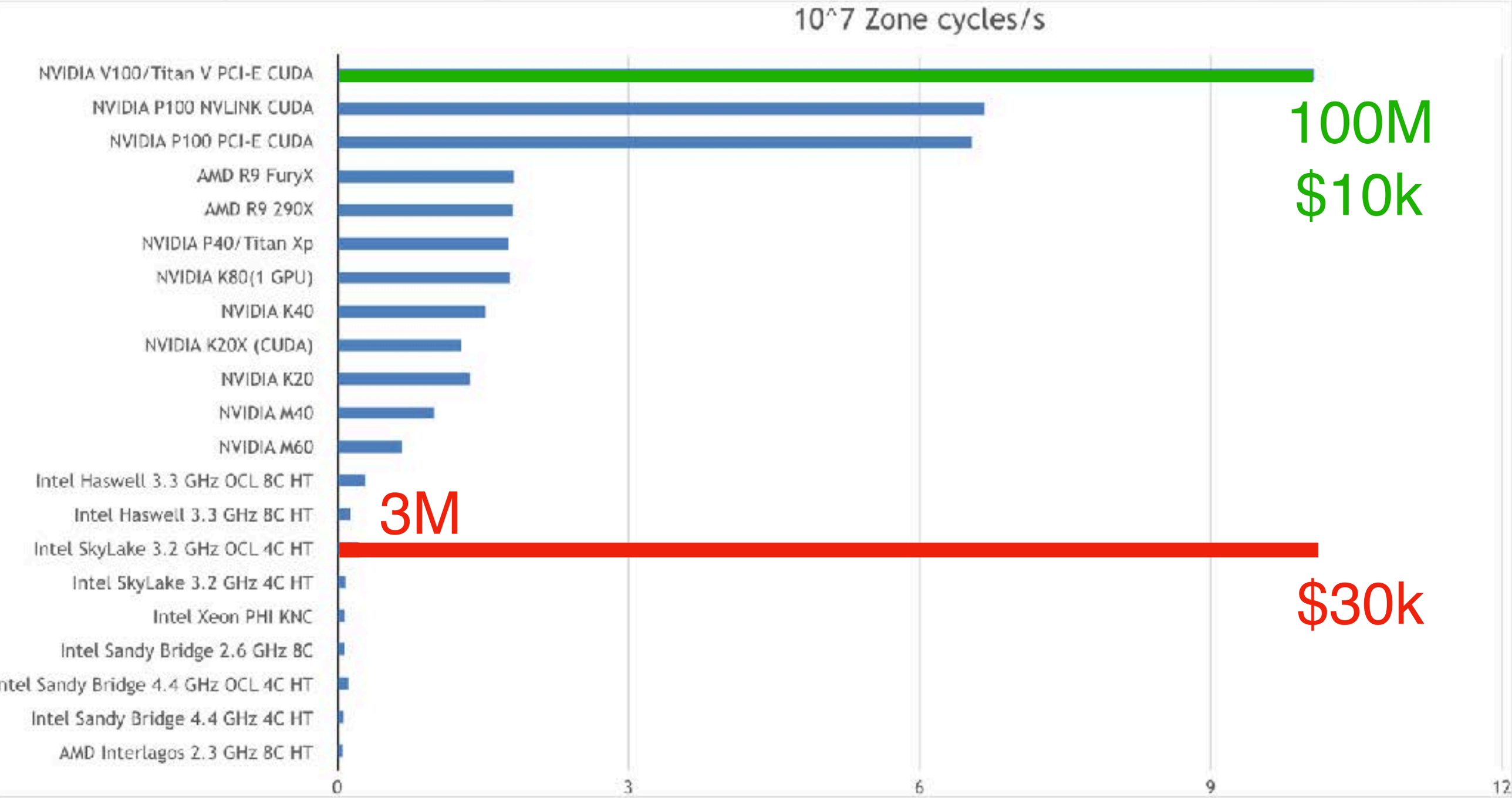
Tilted Disks are Hot

- **Thick disks** precess due to general relativistic frame dragging by BH spin
  (Fragile et al. 2005, 2007; McKinney, AT+2013)
- **Thin disks** can align due to Bardeen-Petterson (1975) effect
  - Seen only in pseudo-Newtonian simulations, not in GR
    (Nixon et al. 2012; Nealon et al. 2015)
    - *Do thin disks align in GR?*
- Challenge: **enormous dynamical range**. Need to resolve thin disk *over* long run times.
- Cost $\propto (h/r)^{-5}$ -- prohibitive!
- How could we possibly pull this off??!



H-AMR: What's Your Nail?

- Multi-GPU 3D H-AMR ("hammer", Liska, AT, et al. 2018):
  - Based on HARMPI
  - 85% parallel scaling to 4096 GPUs (MPI, OpenMP,

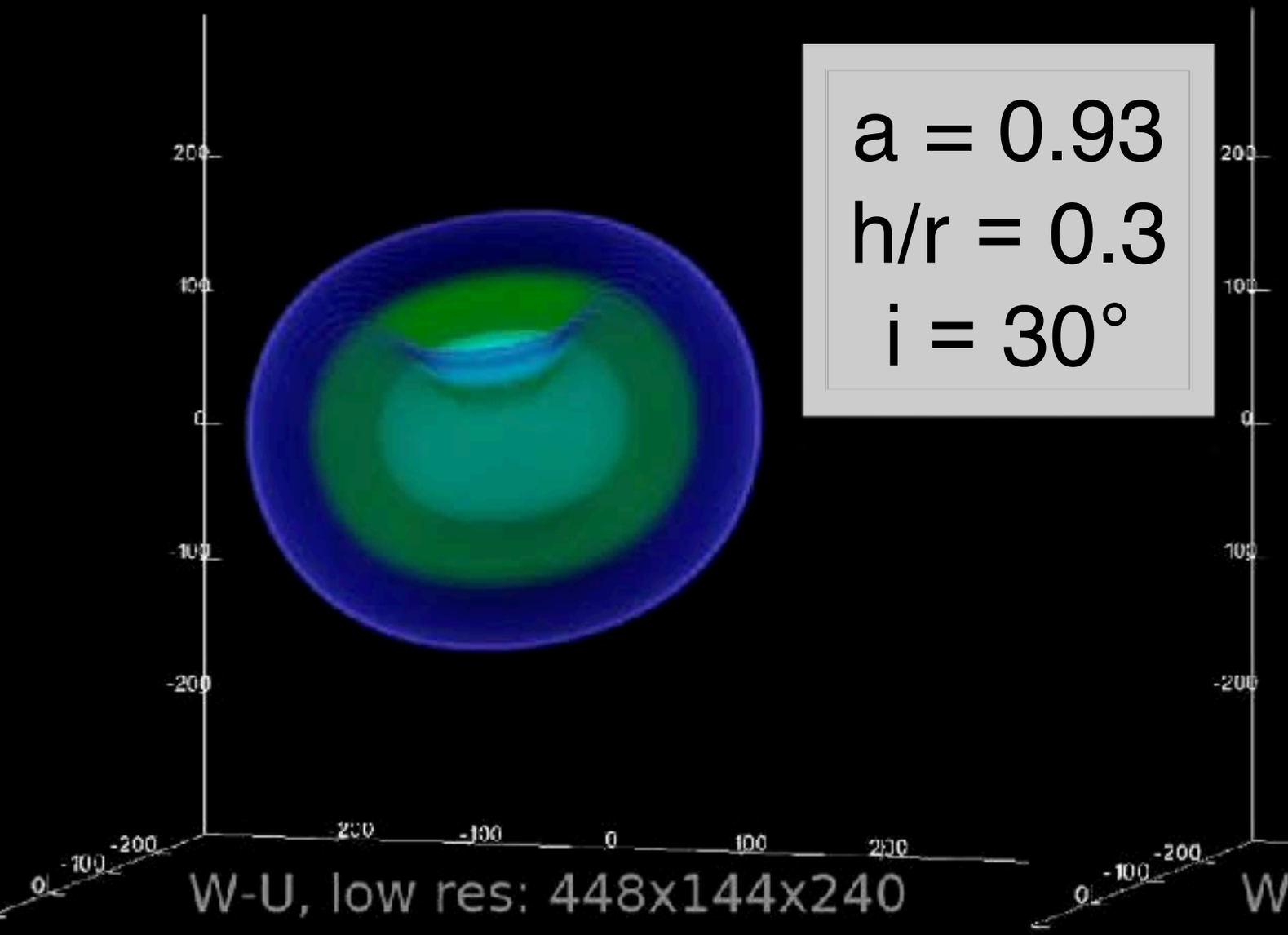


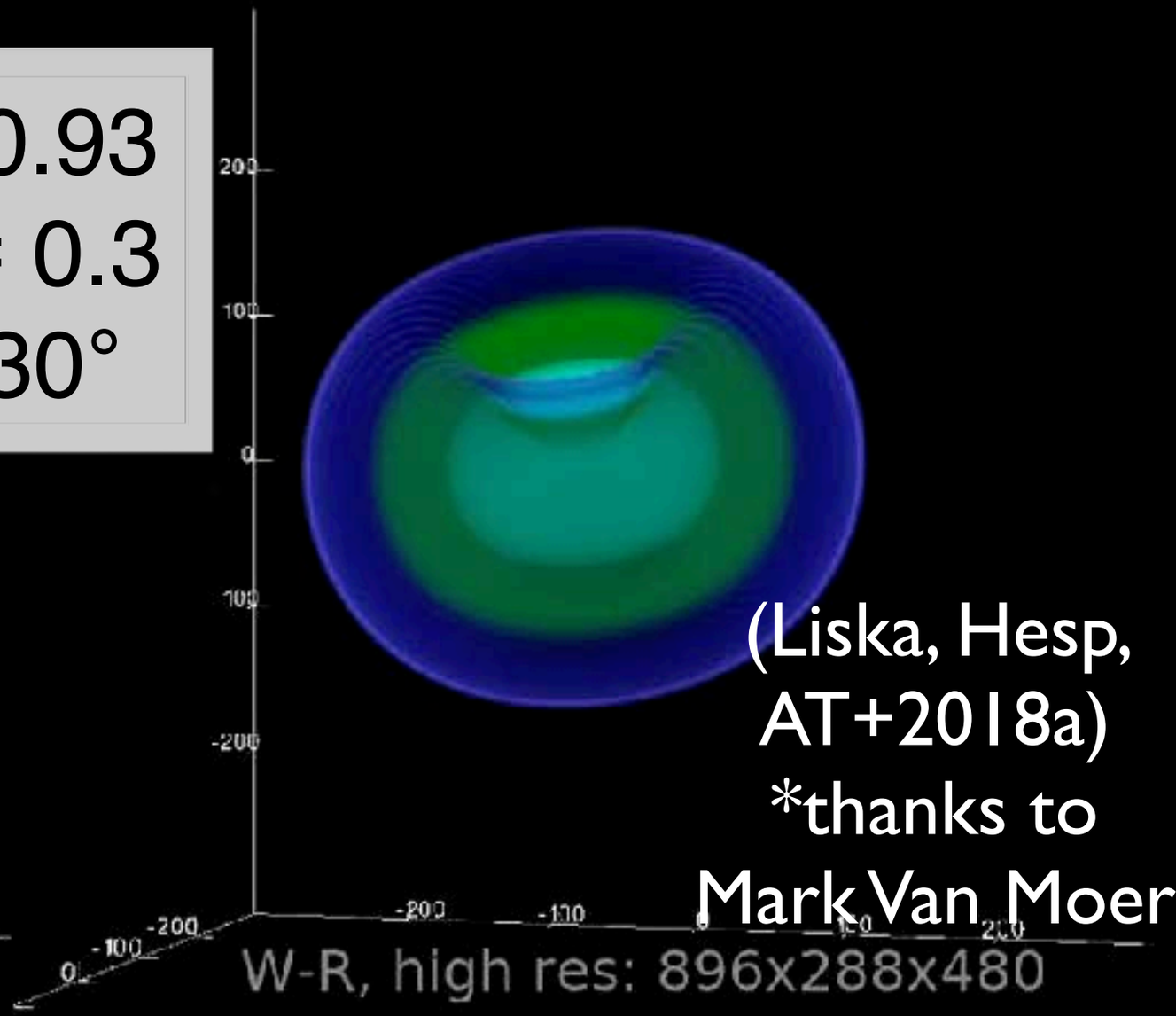
Resolution Matters

1x (low) resolution

2x resolution

a = 0.93
h/r = 0.3
i = 30°





(Liska, Hesp, AT+2018a)
*thanks to Mark Van Moer

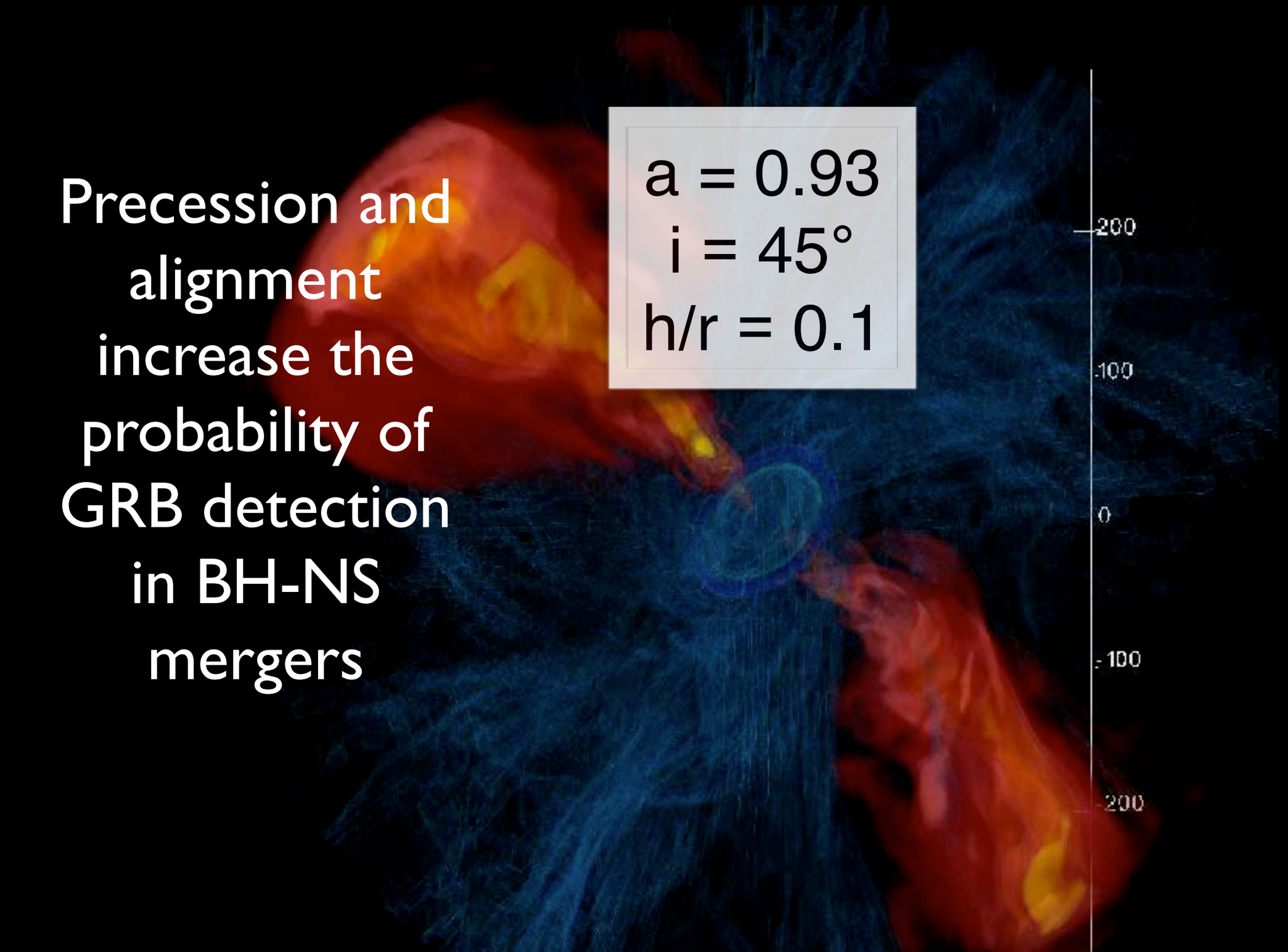
4x resolution is similar to 2x:
results are similar -> convergence

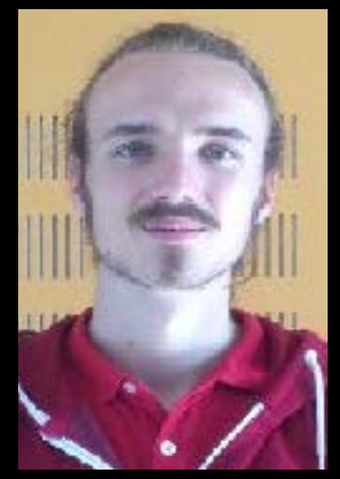
Credit: Z. Younsi, M. Liska, C. Hesp

Thick-ish Disks Precess and Align

Precession and alignment increase the probability of GRB detection in BH-NS mergers

a = 0.93
i = 45°
h/r = 0.1

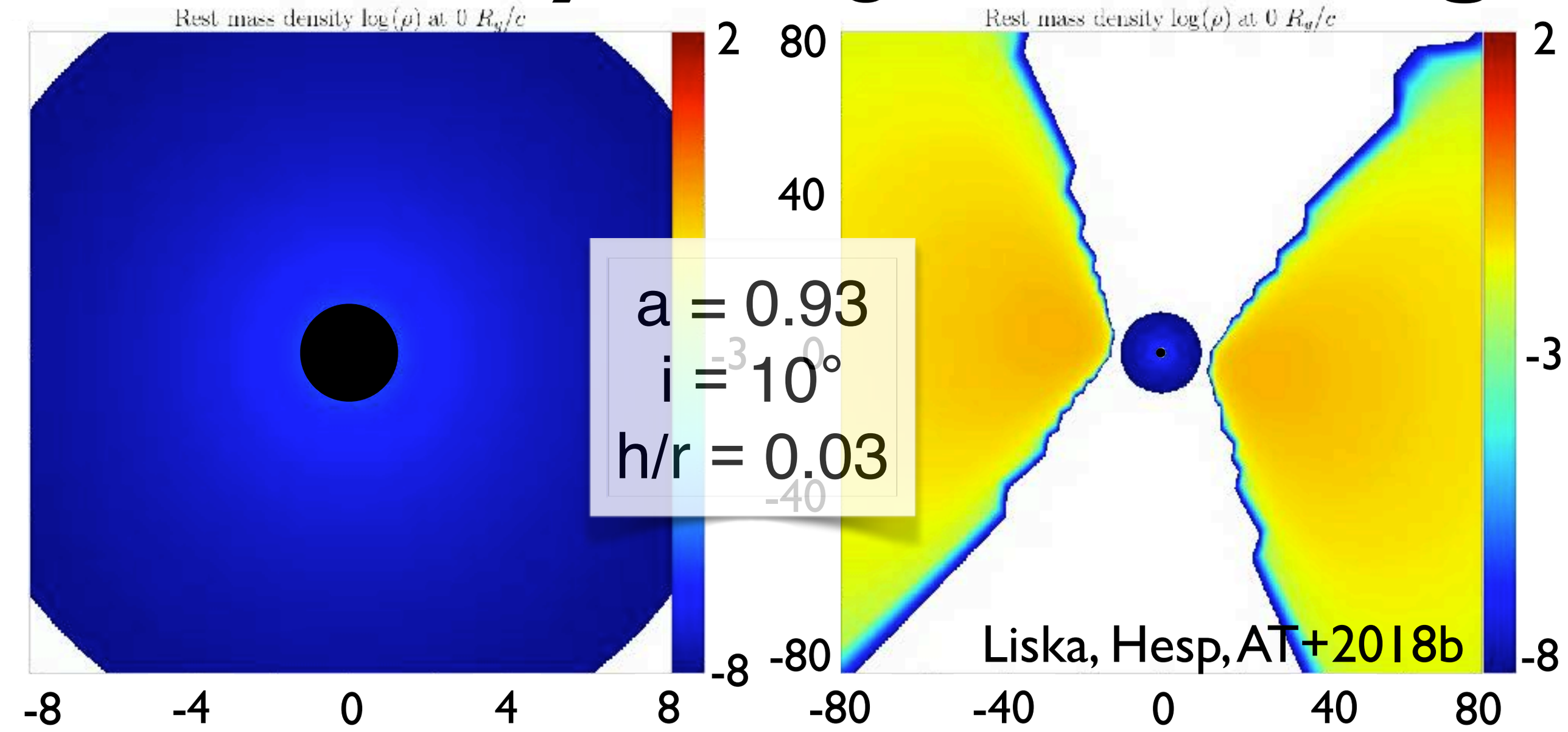




Casper Hesp
(University of Amsterdam)

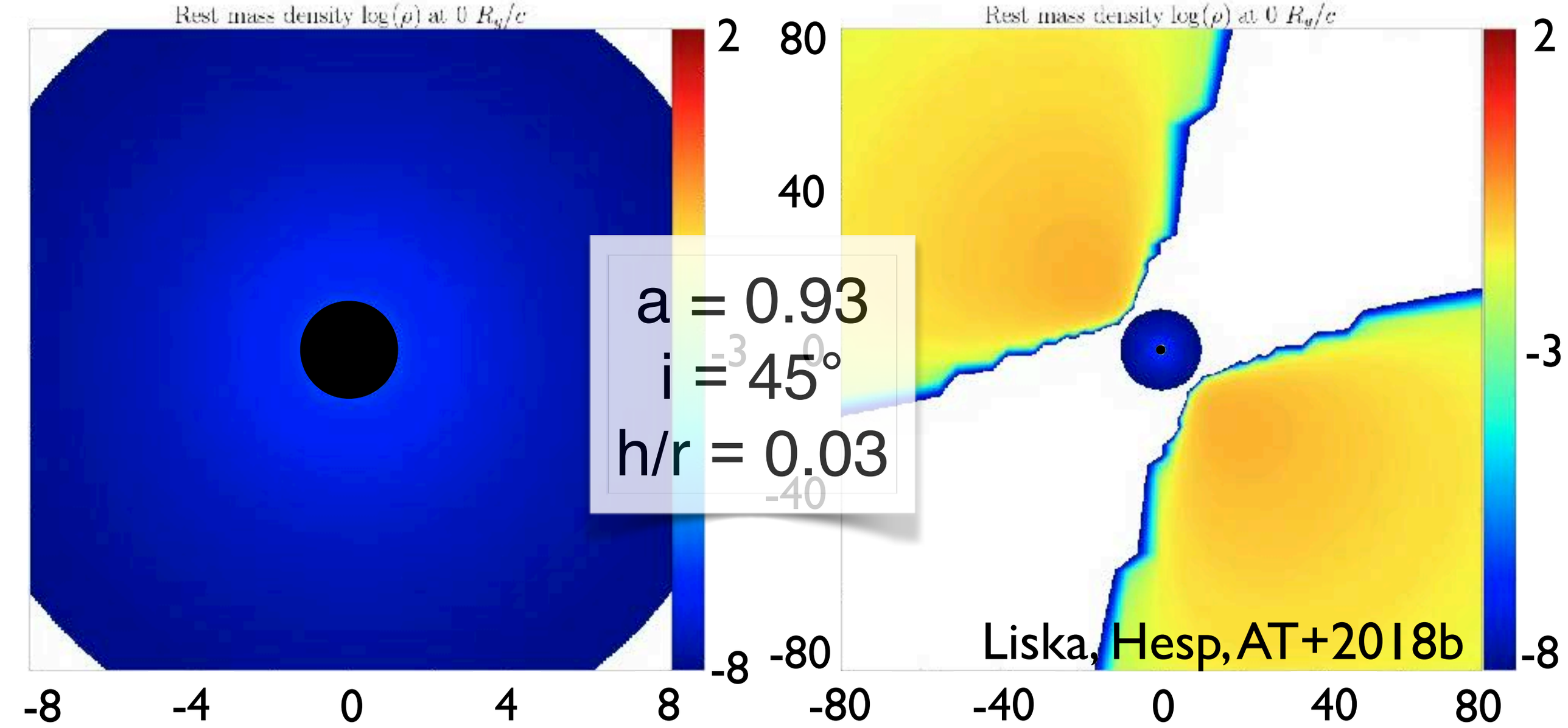
*thanks to Mark Van Moer

Thin **Weakly** Misaligned Disks **Align**



- Thinnest disk simulations to date: h/r = 0.03
- First demonstration of (Bardeen-Petterson?) alignment in a general relativistic MHD simulation of a thin disk
- Effective resolution 2880×860×1200, 3 AMR levels

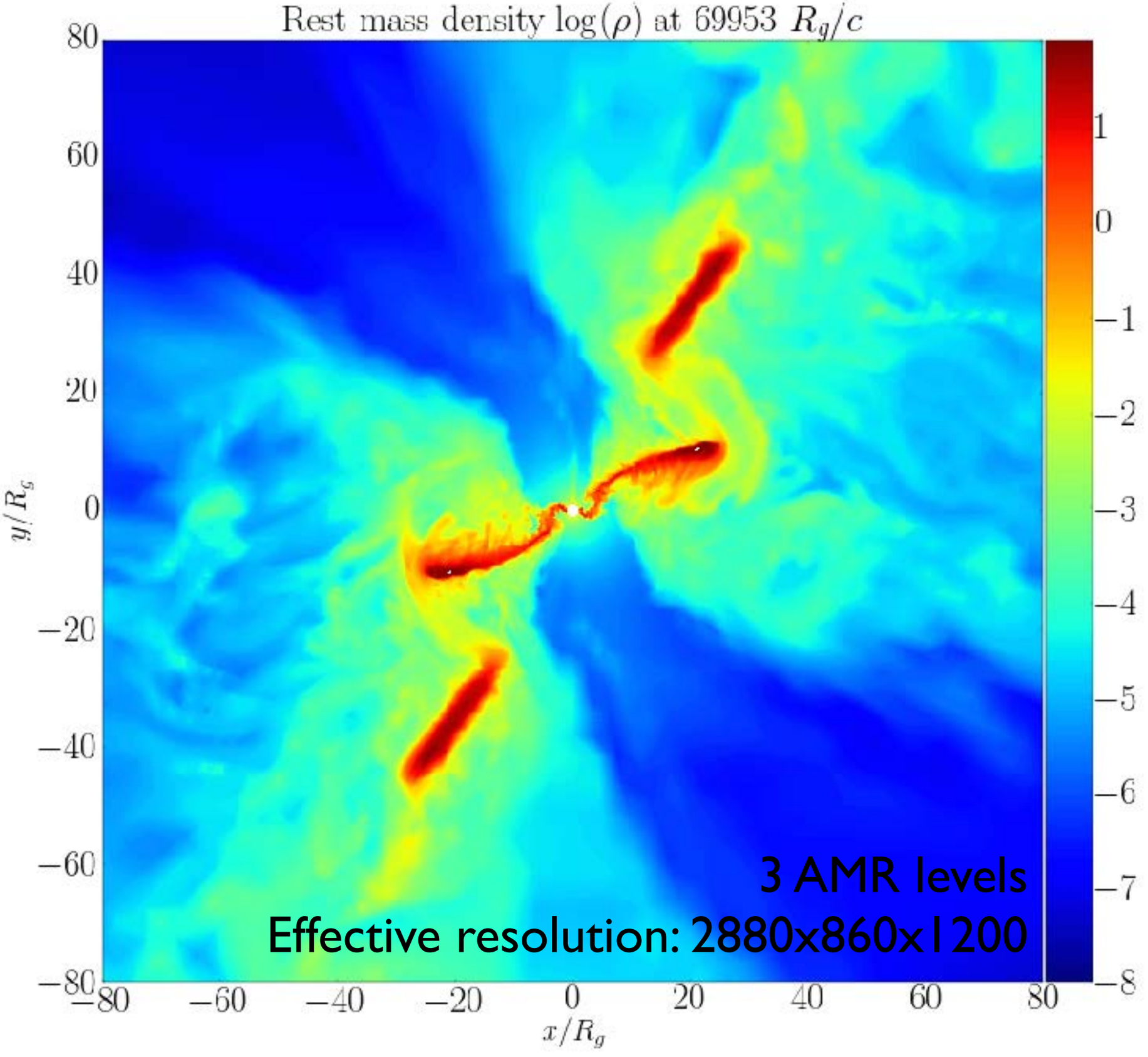
Thin **Strongly** Misaligned Disks **Align** and **Break**



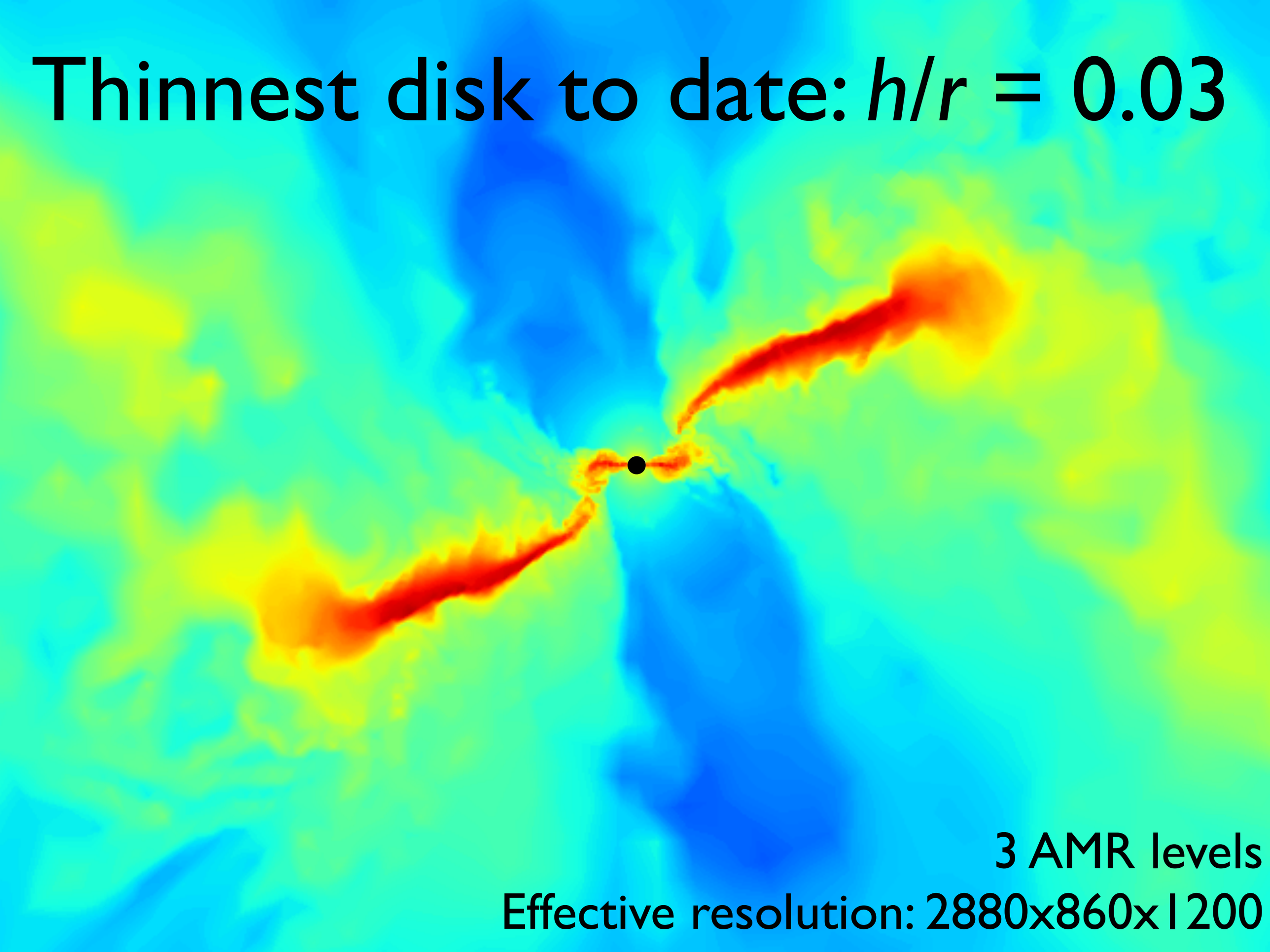
- First demonstration of (Bardeen-Petterson?) alignment and disk breaking in GRMHD!
- Effective resolution 2880×860×1200, 3 AMR levels

Thin **VERY Strongly** Misaligned Disks **Tear**

- Disks can tear up into individual segments
- Extra dissipation and luminosity
- Completely different luminosity profile
- Can affect BH spin measurements
- Larger observed disk size than expected?
  (Blackburn+2011)



Thinnest disk to date: $h/r = 0.03$



3 AMR levels

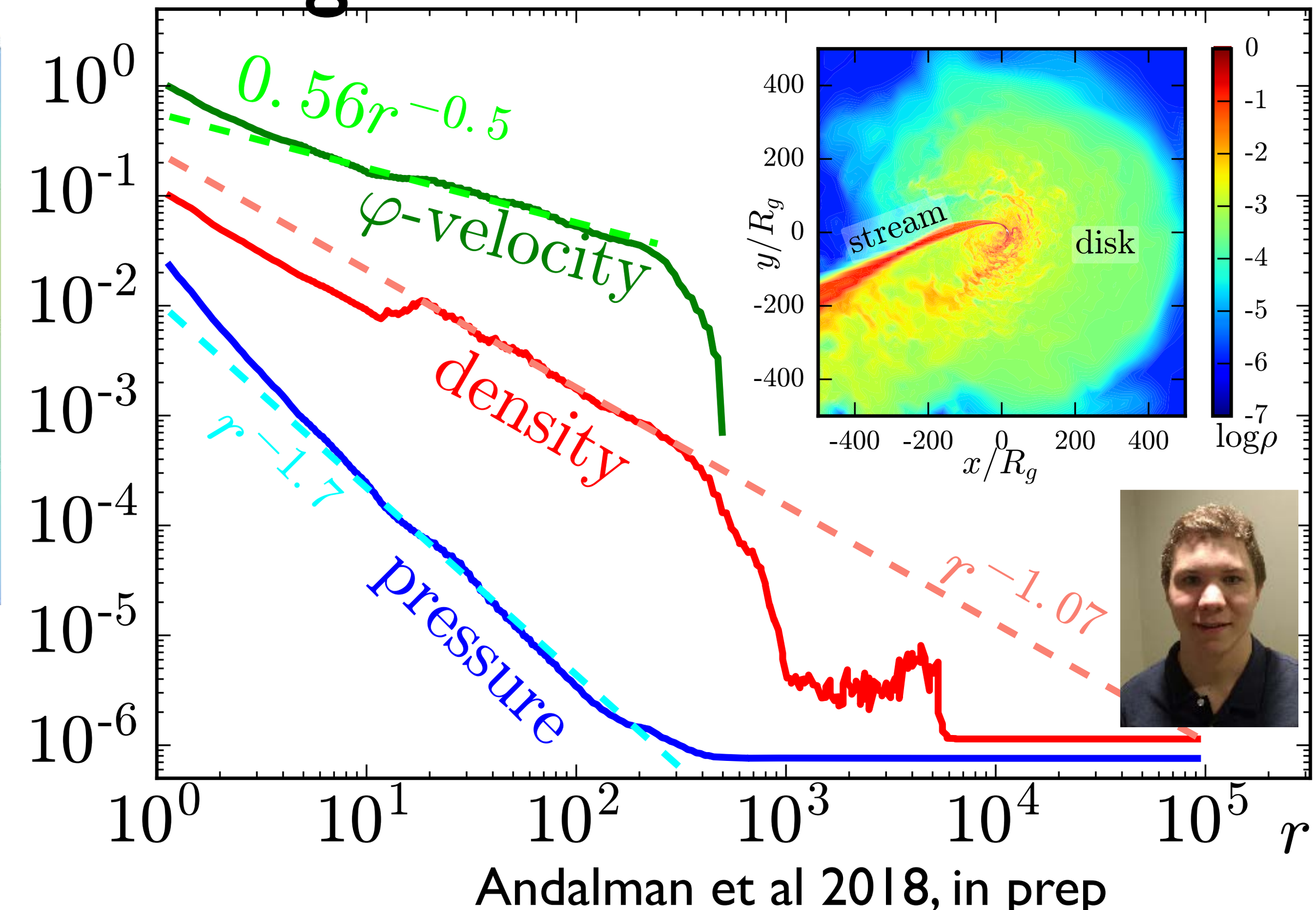
Effective resolution: 2880x860x1200

Ridiculously thin disk: $h/r = 0.015$

4 AMR levels

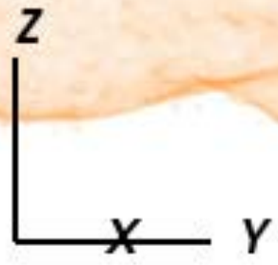
Effective resolution: 5760x1720x2400

Making the Disk from Scratch



Andalman et al 2018, in prep

Disk Appears to Form with a Tilt, Too



*thanks to
Casper Hesp,
Mark Van Moer

Advances Enabled by Blue Waters

Zack Andalman (Evanston Township High School)

- We are beginning to understand **typical, tilted accretion at unprecedented resolutions**
- **Jets** can **precess** together with tilted disks over multiple precession cycles
- Bardeen-Petterson-like ***alignment, breaking, and tearing* of thin disks** first seen in GRMHD ➛ essentially unexplored observational manifestations
- Advances in **making disks from scratch** by pulling stars apart

Matthew Liska (University of Amsterdam)

Casper Hesp (University of Amsterdam)

NSF

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BLUE WATERS
SUSTAINED PETASCALE COMPUTING

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