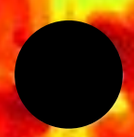
GPU-based Simulations of Tilted Black Hole Accretion and Jets



Sasha Tchekhovskoy (PI, Berkeley ➛ Northwestern)
Matthew Liska and Casper Hesp (Amsterdam),
Eric Coughlin (Berkeley),
Nick Stone (Co-PI) and Brian Metzger (Columbia)

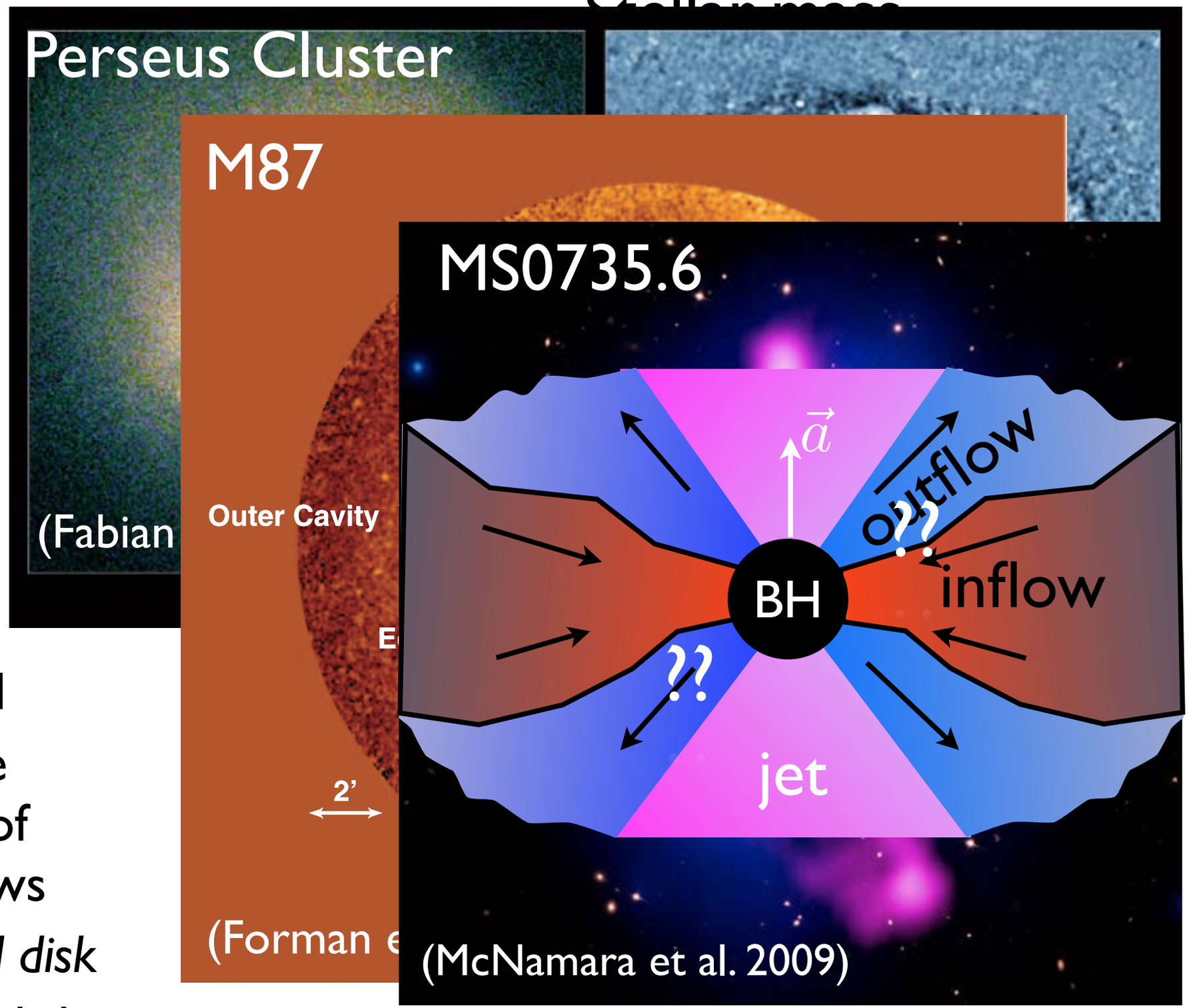
Tidal Disruptions as Probes of Black Hole Astrophysics

Supermassive

$M \sim 10^{6-10} M_\odot$

Quasars/AGN

Stellar mass



- How black holes produce outflows is poorly understood
- Tidal Disruptions are unique laboratories of accretion and outflows
- Expectation is a *tilted disk*
- Challenge: understand the physics of the *most common*, *tilted*, accretion flows from *first principles*

BW + H-AMR = BH Revolution

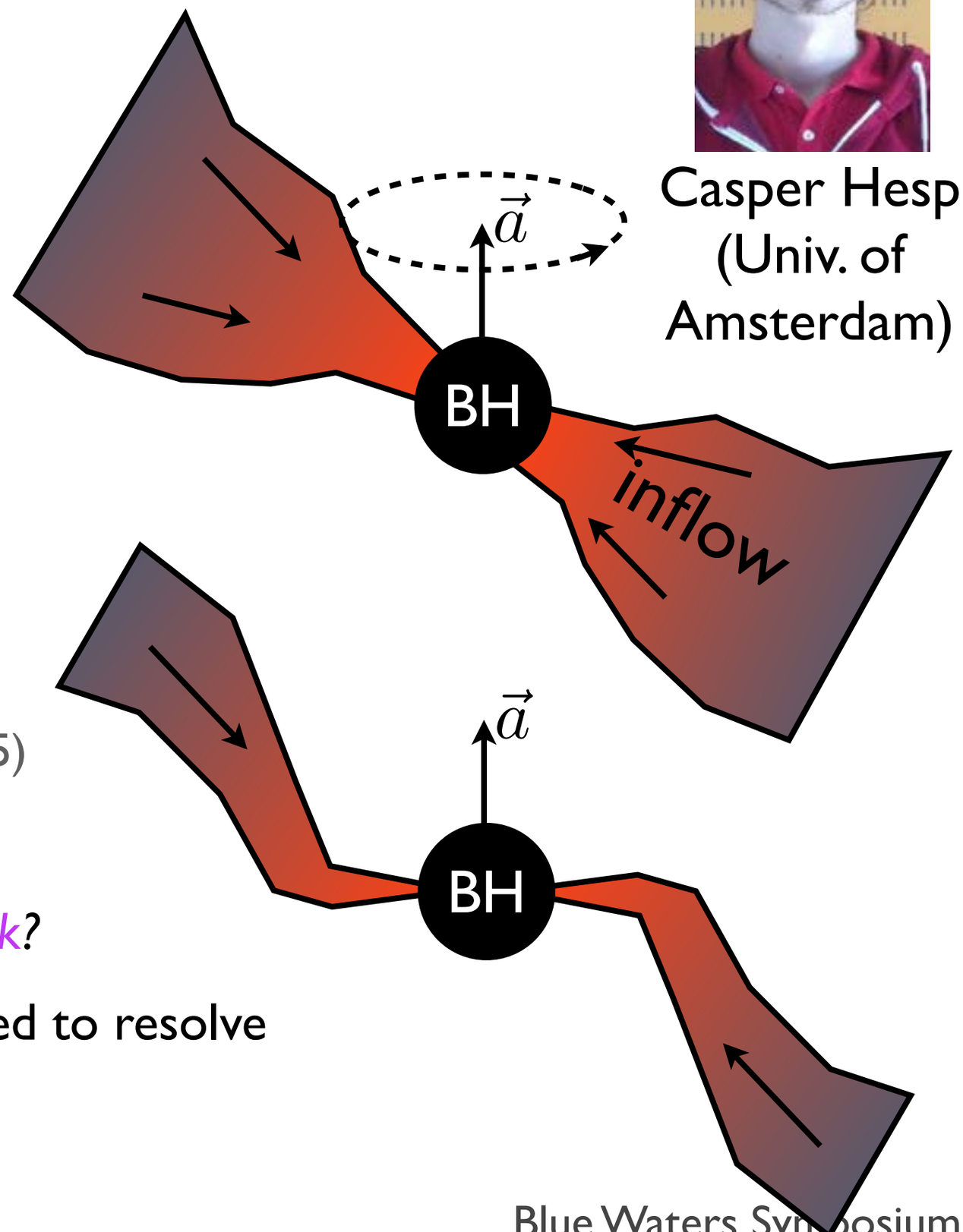
Matthew Liska
(U of Amsterdam)

- Multi-GPU 3D H-AMR ("hammer", Liska, AT, et al. 2017):
  - Based on Godunov-type code HARM2D (Gammie et al. 2003). **See Matthew Liska's poster.**
  - 85% parallel scaling to 4096 GPUs (MPI, OpenMP, OpenCL)
  - 100-450x speedup compared to a CPU core
- Features *on par with state-of-the-art* CPU codes (e.g., Athena++): Adaptive Mesh Refinement (AMR) with local adaptive time stepping

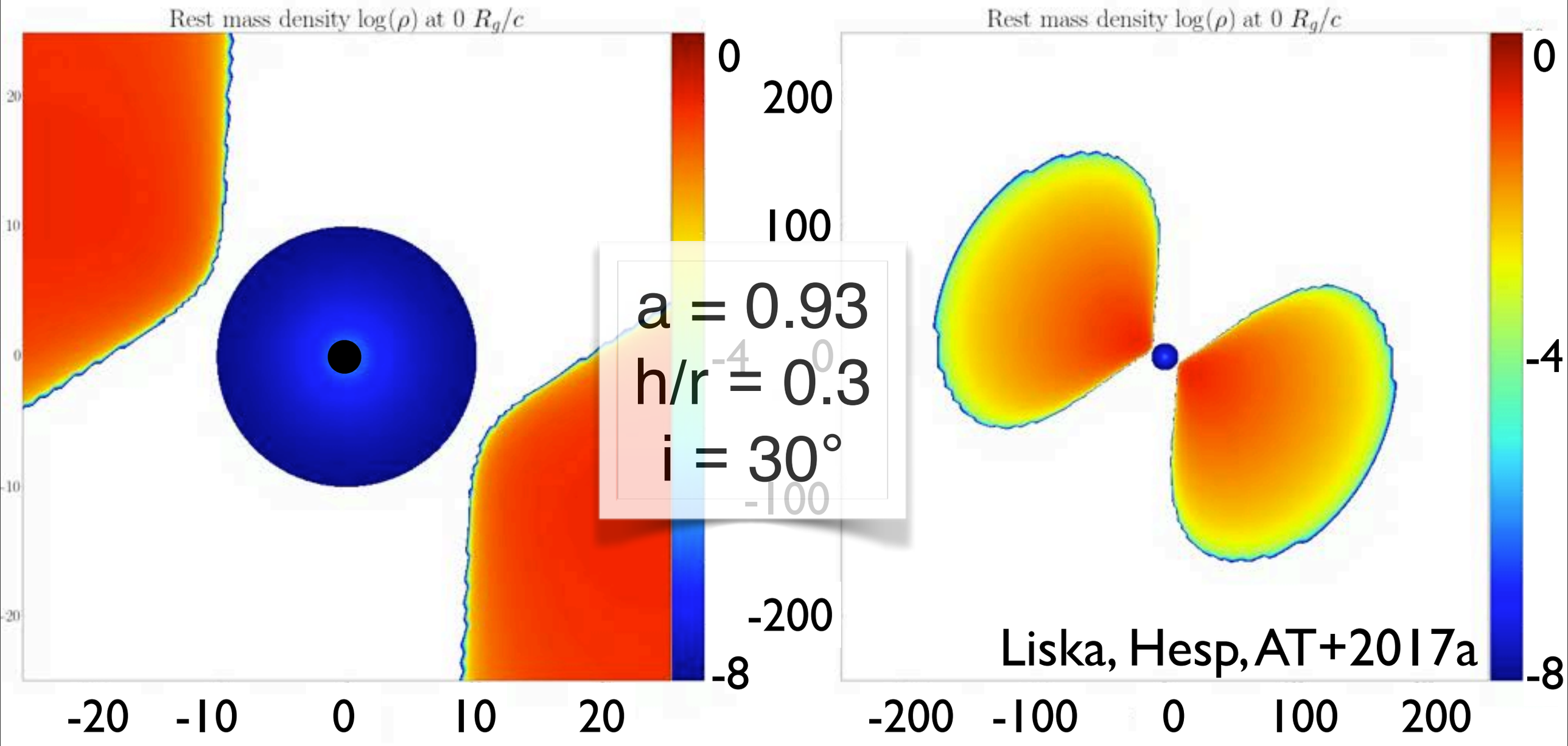
Tilted Disk Physics

Casper Hesp (Univ. of Amsterdam)

- **Thick disks** precess due to general relativistic frame dragging by BH spin
  - precessing tilted disk sims could not handle jets (Fragile et al. 2005, 2007)
  - *Do tilted disks produce jets at all? Do jets precess or point along BH spin?* (McKinney, AT+2013)
  - **See Casper Hesp's poster**
- **Thin disks** can align due to Bardeen-Petterson (1975) effect
  - Seen only in pseudo-Newtonian simulations and at small inclinations (Hawley and Krolik 2015)
  - At larger inclinations disks predicted to break (Nixon et al. 2012)
  - *Do thin disks align in GR? Or do they break?*
- Challenge: enormous dynamical range. Need to resolve thin streams *over* long run times.

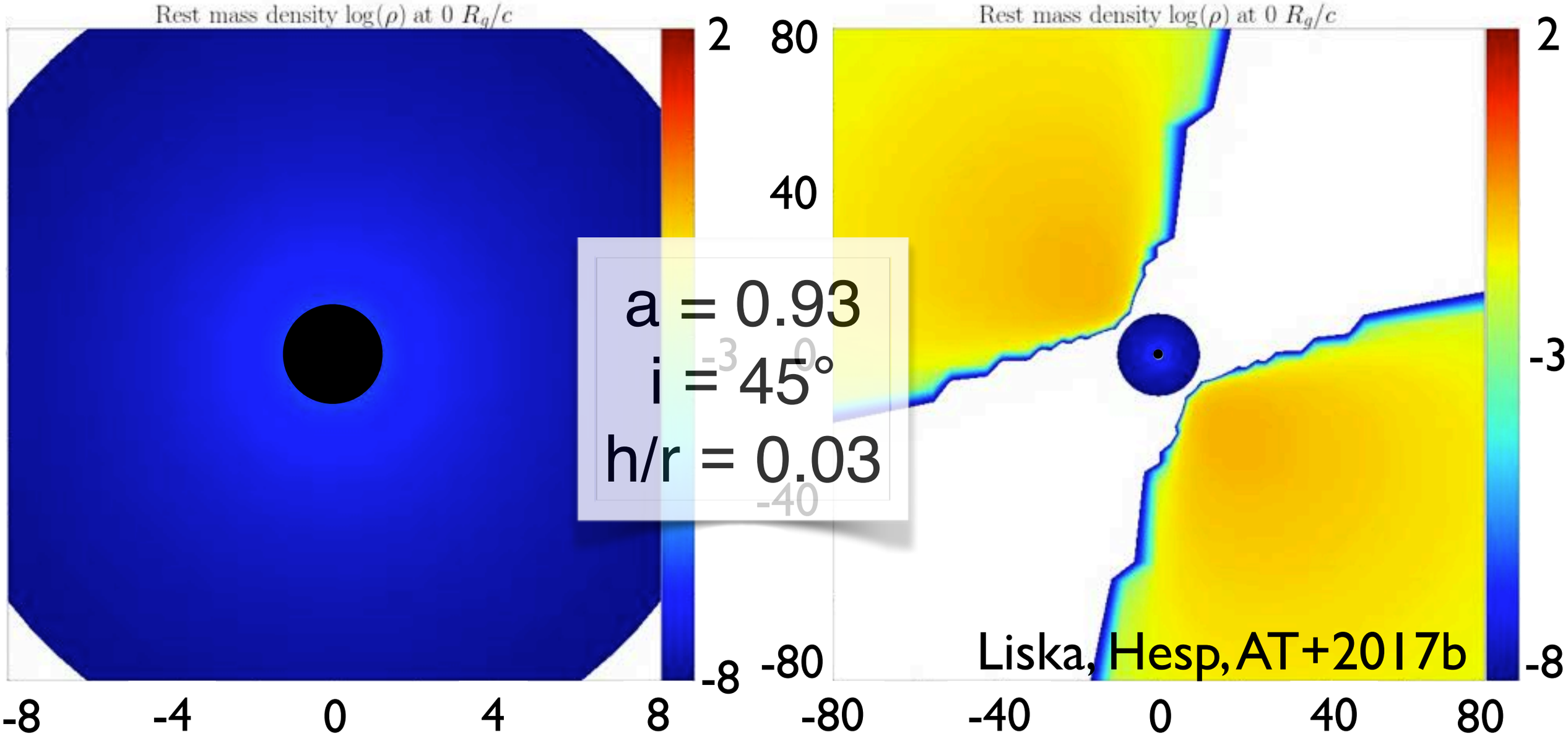


Thick Disks Precess



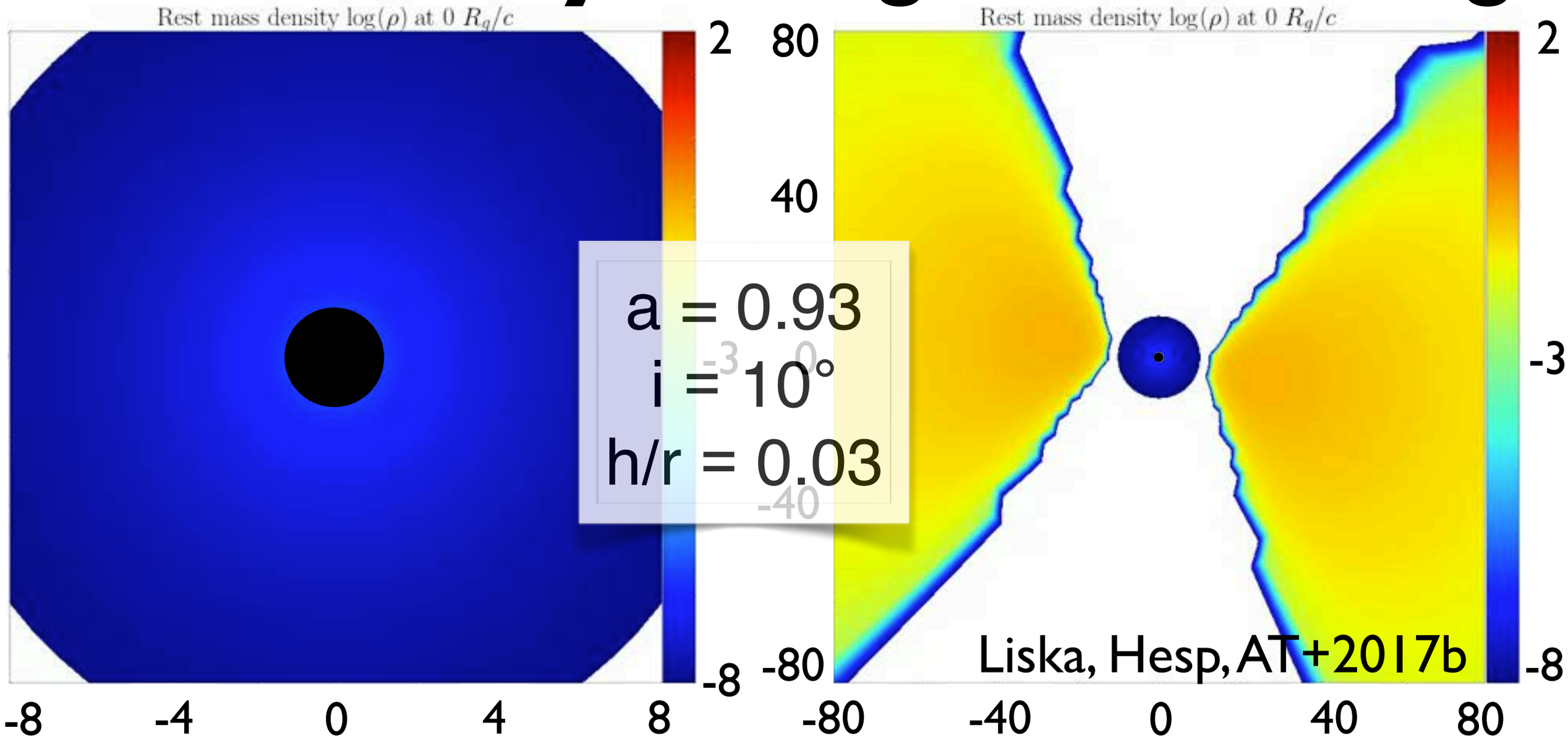
- BW enabled the first demonstration that
  - tilted thick disks produce tilted jets
  - tilted jets precess
- Longest GRMHD tilted disk simulation, 120,000 r_g/c
- Highest resolution GRMHD simulations: 896×288×480
  - convergence verified at 2x resolution: *first ever billion cell run*

Thin Strongly Misaligned Disks Do NOT Align



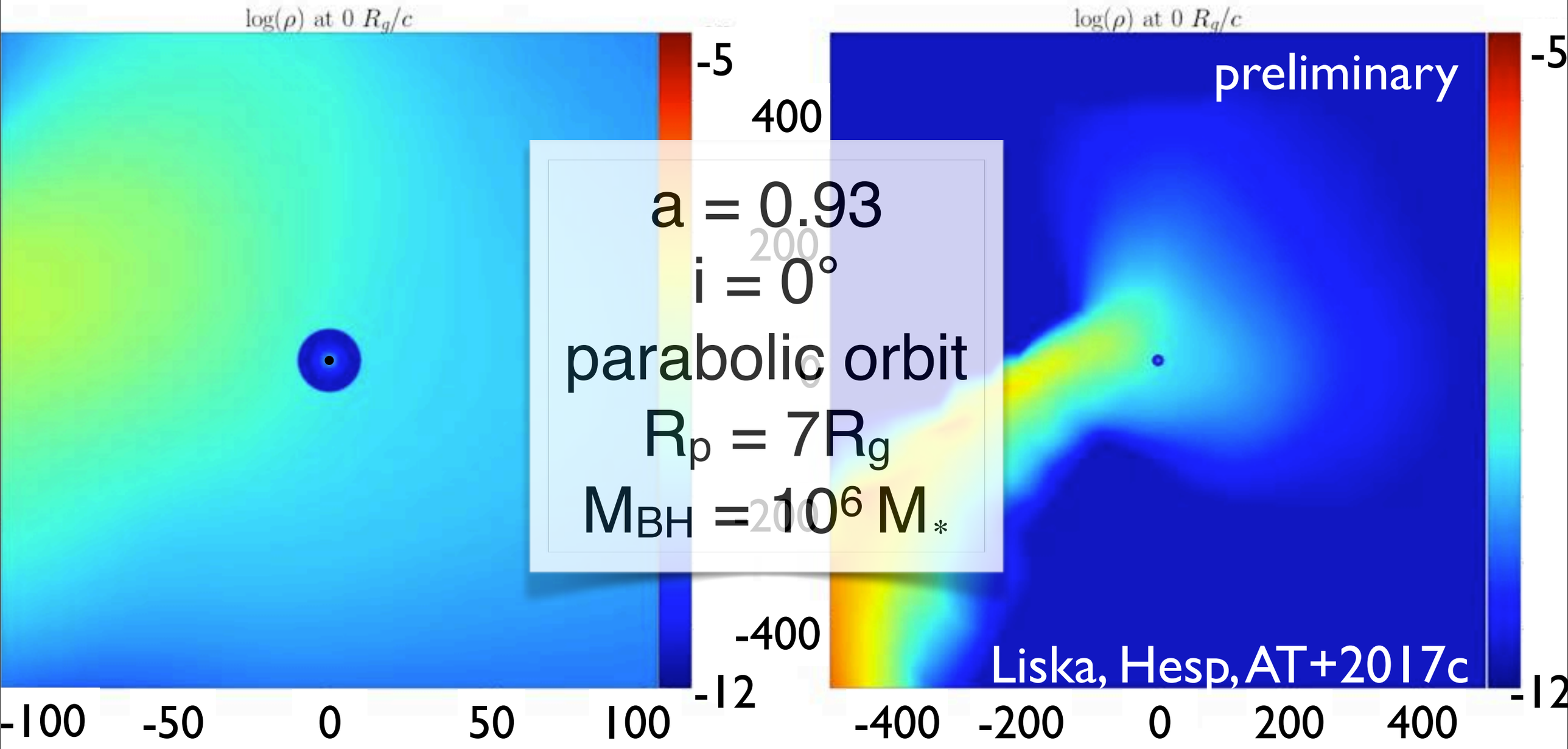
- BW enabled the thinnest disk simulations to date (h/r = 0.03)
  - first tilted disk simulation in non-linear tilt regime (i » h/r)
  - effective resolution 1792×860×1200, 3 AMR levels
  - *preliminary*: even thinner disk, h/r = 0.015, does not appear to align

Thin **Weakly** Misaligned Disks Align



- BW enabled first demonstration of (Bardeen-Petterson?) alignment in a general relativistic MHD simulation of a thin disk
- Effective resolution 1792×860×1200, 3 AMR levels

Making the Disk from Scratch



a = 0.93

i = 0°

parabolic orbit

$R_p = 7R_g$

$M_{BH} = 10^6\ M_*$

- Initial conditions computed by the phantom code by Eric Coughlin
- BW enabled first simulation in GR of a star on a parabolic orbit tidally disrupted by supermassive BH, $M_{BH} = 10^6\ M_*$ (≫ 500M_*, Shiokawa+15)
- effective resolution 1792×860×1200, 3 AMR levels

Broader Impacts

- Giving public talks
- Lecturing at summer schools:
  - PiTP (IAS, Princeton, NJ, July 2016)
  - SPSAS-HighAstro (Sao Paulo, Brazil, May 2017)
  - SOMA-2017: http://astrosoma.ru (Moscow, Russia, July '17)
- Mentoring undergraduate and graduate students
- Addressing long-standing problems in BH accretion

Black Hole Revolution

Matthew Liska
(U of Amsterdam)

- GPU-accelerated AMR general relativistic MHD code
  - perfect match for Blue Waters GPU capabilities
- Groundbreaking science enabled by Blue Waters:
  - *first* billion cell black hole disk-jet simulation
  - *first* jets from tilted precessing thin and thick disks
  - *first* (Bardeen-Petterson?) alignment of thin disk in general relativity
  - *first* simulation in GR of a star on a parabolic orbit tidally disrupted by a supermassive black hole
- Involvement of students from around the world
- I soon move to Northwestern University: please direct interested students and postdocs my way

Casper Hesp
(U of Amsterdam)

NCSA

BLUE WATERS
SUSTAINED PETASCALE COMPUTING

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Modern GPUs Give H-AMR a Boost