Scan for movie clips & paper
https://astrodoo.github.io

Spectral and Imaging Properties of Sgr A* from 3D GRMHD Simulations with Radiative Cooling

RAS Poster Exhibition (Sep. 2020)

Doosoo Yoon[1]
([1]Univ. of Amsterdam)

with Koushik Chatterjee[1], Sera Markoff[1], David van Eijnatten[1], Ziri Younsi (Univ. College London), Matthew Liska (Harvard Univ.), Alexander Tchekhovskoy (Northwestern Univ.)

Event Horizon Telescope

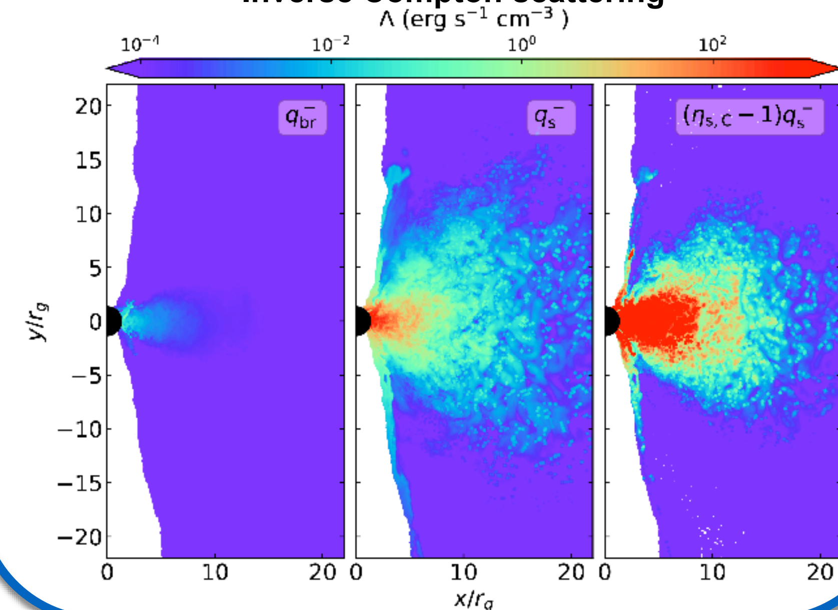
ANTON PANNEKOEK INSTITUUT

Netherlands Organisation for Scientific Research

- **Sagittarius A* (Sgr A*)** is the unique laboratory for testing the theory of general relativity due to its proximity, but many aspects remain unclear yet. It is believed to be fed by a **radiatively inefficient accretion flow (RIAF)**, which is inferred by the low accretion rates: $10^{-9}\,\mathrm{M_\odot\,yr^{-1}} < \dot{\mathrm{M}} < 10^{-7}\,\mathrm{M_\odot\,yr^{-1}}$
→ **Radiative cooling has been ignored for modeling Sgr A*** (e.g., Porth+20, Dexter+20).

- Unanswered questions:
  - how do radiative cooling losses affect the turbulence features of the disk, and thus the angular momentum transport?
  - is the cooling process *indeed* negligible for modeling the spectra from Sgr A*?

Fig 2. Cooling rates for **Bremsstrahlung, Synchrotron, Inverse Compton scattering**



Cooling is applied to the energy equation in GRMHD computation

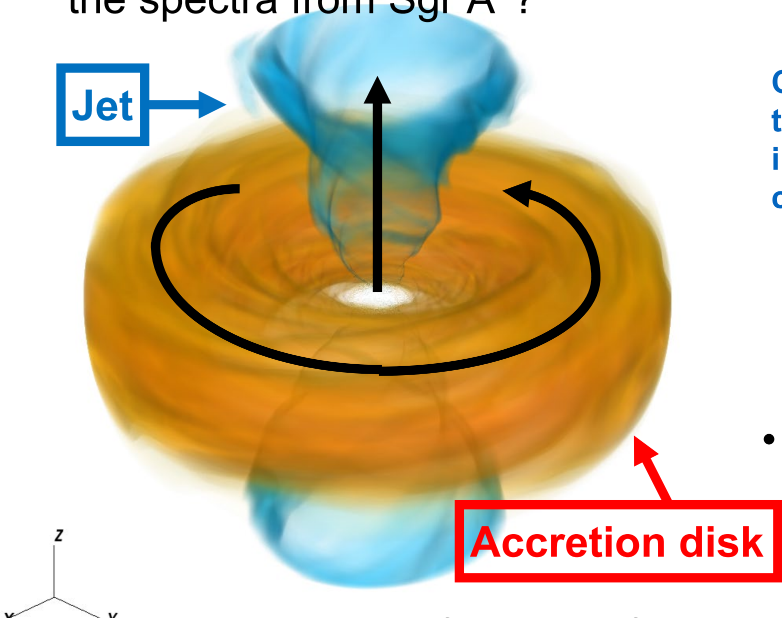
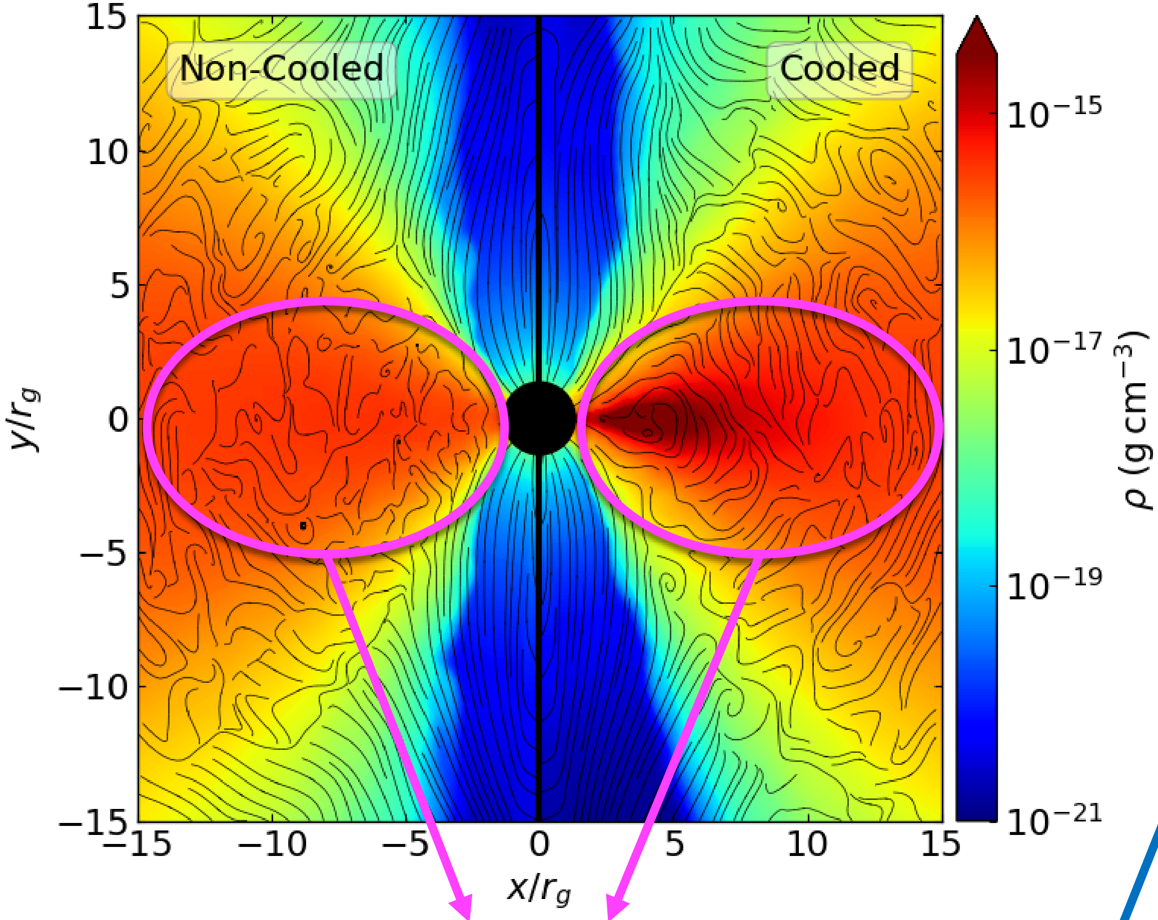


Fig1. 3D volume rendering of gas density from the GRMHD data

- Initial setup in 3D GRMHD Simulations: **H-AMR** code (Liska+18)
  - a single loop of weak magnetic field threaded Fishbone-Moncrief torus: **Standard and Normal Evolution (SANE) disk**
  - jet aligned with the angular momentum of the disk

Fig 3. Time averaged density map w/ magnetic field



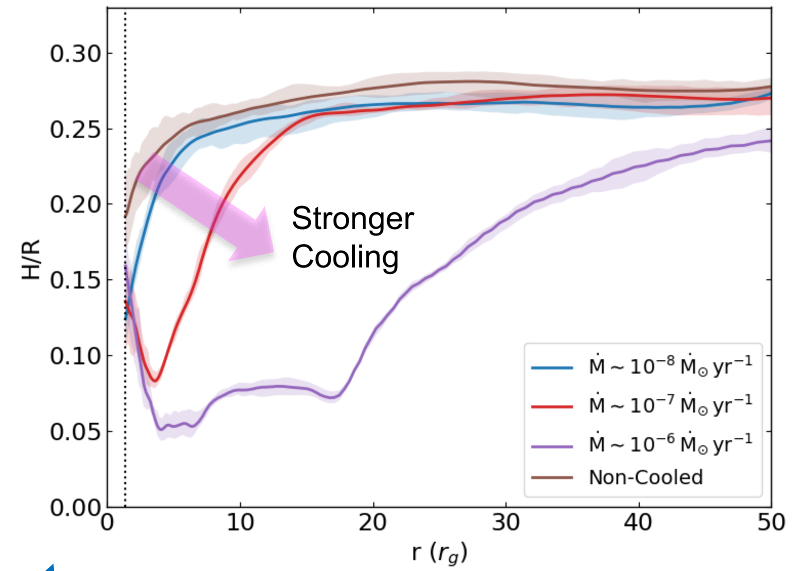


Fig 4. Disk thickness as a function of radius

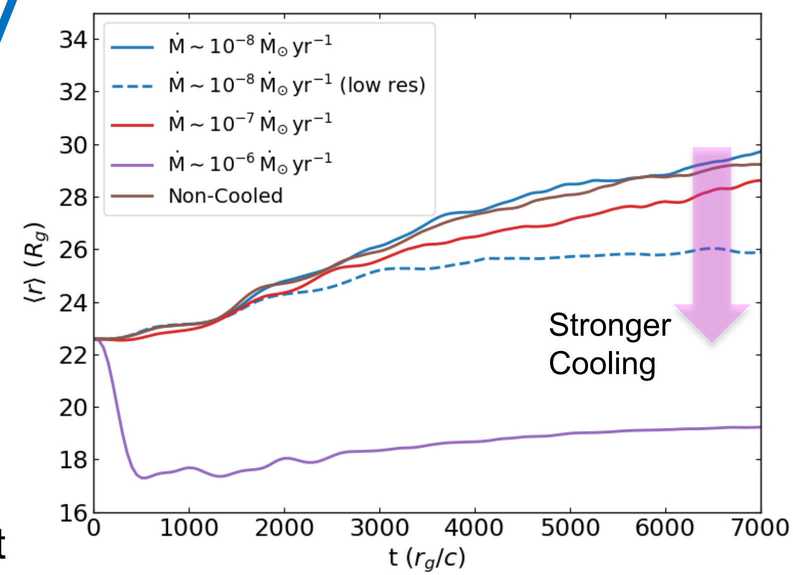


Fig 5. Density-weighted radius as a function of time (i.e., degree of viscous spreading)

When cooling is on: 1) enhanced mid-plane density

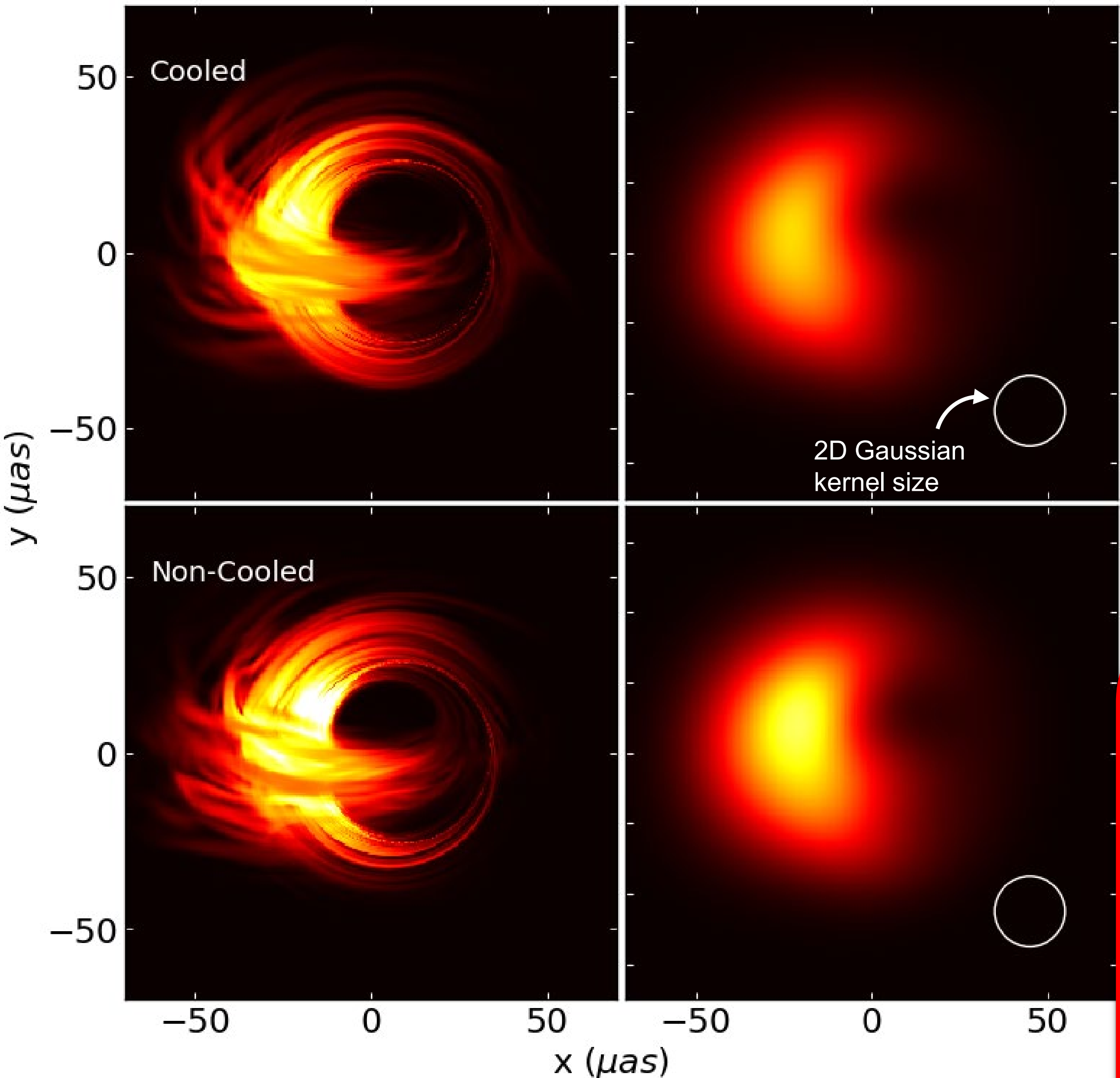
→ thinner disk

2) less turbulent magnetic field

→ reduced angular momentum transport

(i.e., less viscous spreading)

Fig 6. Ray-traced image at 230 GHz for Sgr A* using ray-tracing code **BHOSS** (Younsi+19): direct image from GRMHD data (left) and the blurred image (right) to mimic the Sgr A* image from the **Event Horizon Telescope**



Cooling → 1) dimmer in the peak intensity location (Fig 6.)

2) lower flux over the spectral range (Fig 7.)

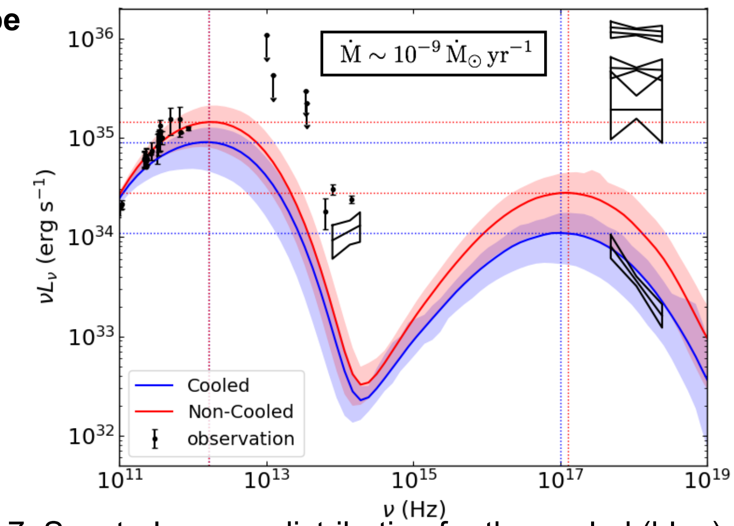


Fig 7. Spectral energy distribution for the cooled (blue) and the non-cooled (red) model, calculated by ray-tracing code **GRmonty** (Dolence+09).

Conclusion

- **The importance of radiative cooling** increases w/ the accretion rate for
  - **dynamical evolution of the accretion flows:** enhanced mid-plane density and less turbulent magnetic field
  - **resulting spectra / images:** slightly dimmer in the peak intensity location and lower flux over the spectral range, but the difference is not significant for Sgr A*.
- In future work, we will study how cooling works when it combines with other physics (e.g., **non-thermal electron / electron heating / MAD disk**).