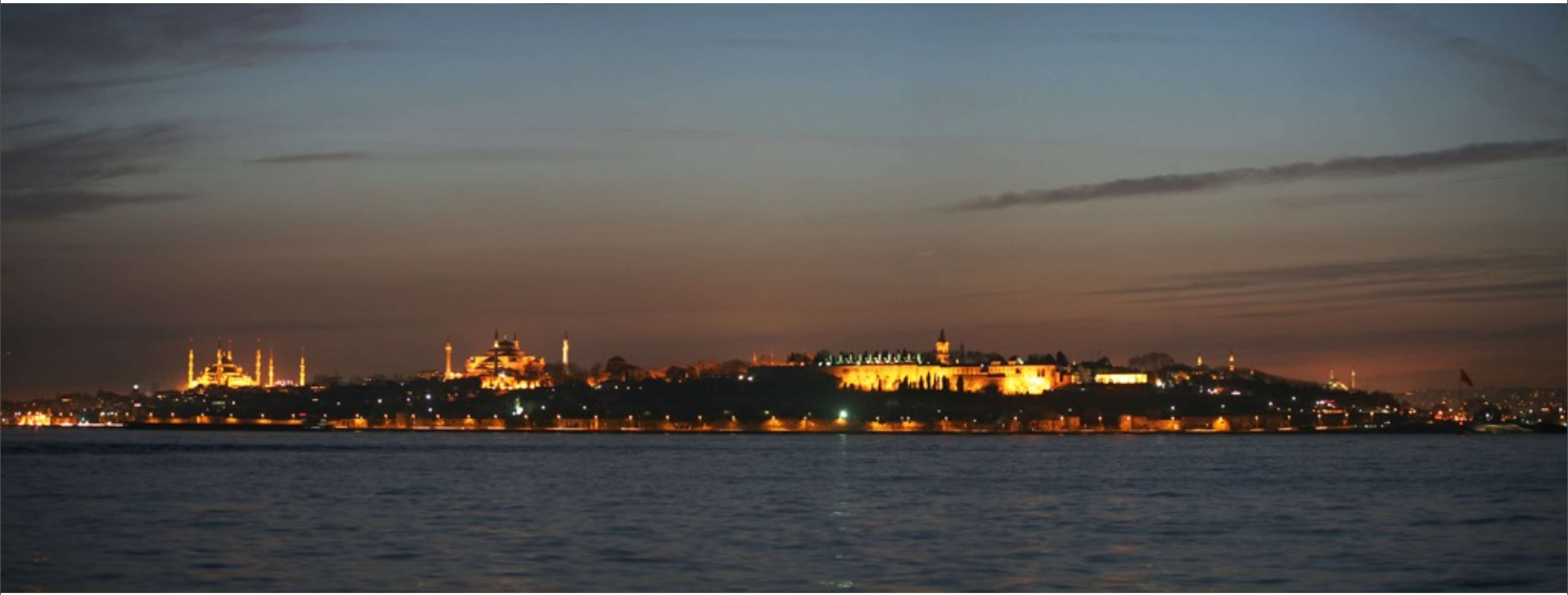
Salomé Dibi   ITN meeting Istanbul

Advisor: Sera Markoff, Co-Advisors: Phil Uttley and Stéphane Corbel



P10: Constraining jet physics and formation

Current work:

1. GRMHD simulations

2. Semi analytical model

Outline:

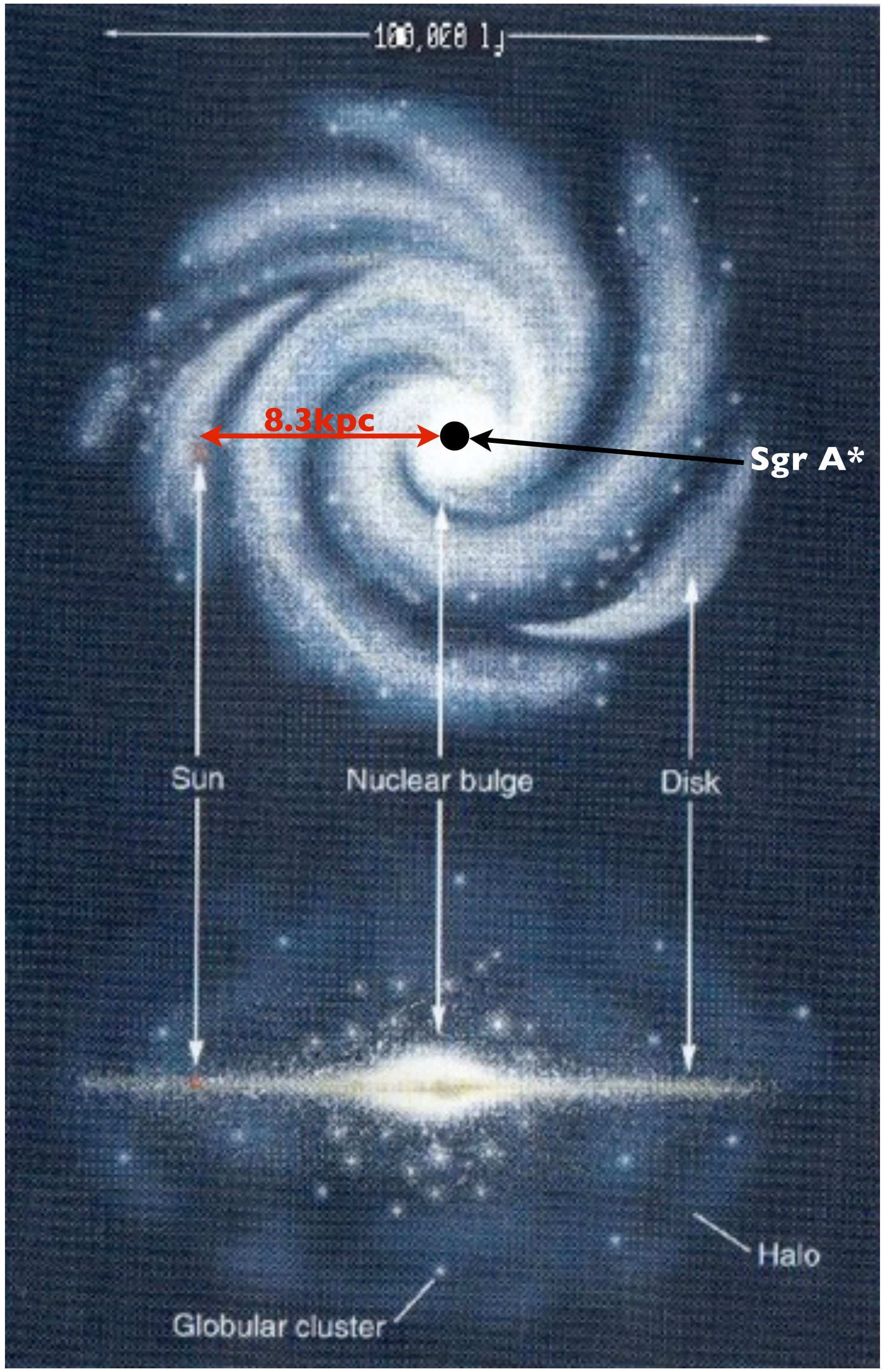
1. Numerical theory of accretion flow and jet launching: A Study on the Galactic center. (S. Dibi, S. Drappeau, S. Markoff, C. Fragile)

- Introduction to SgrA*

- Our modeling of Sgr A*
  - The model
  - Results
  - Spectra

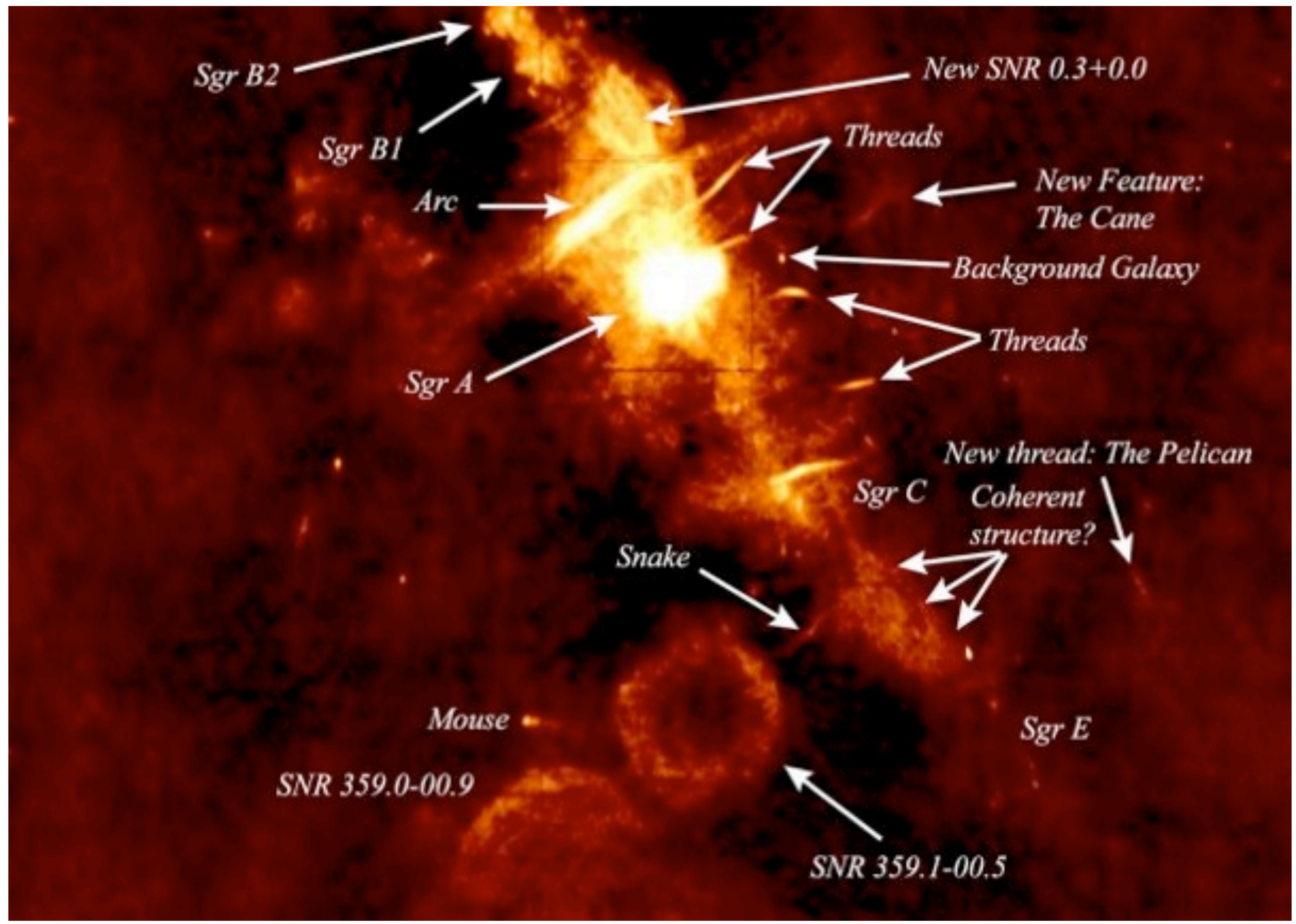
2. A time dependent jet model

Sgr A* = Our Galactic Center



Schematic view of the Milky Way

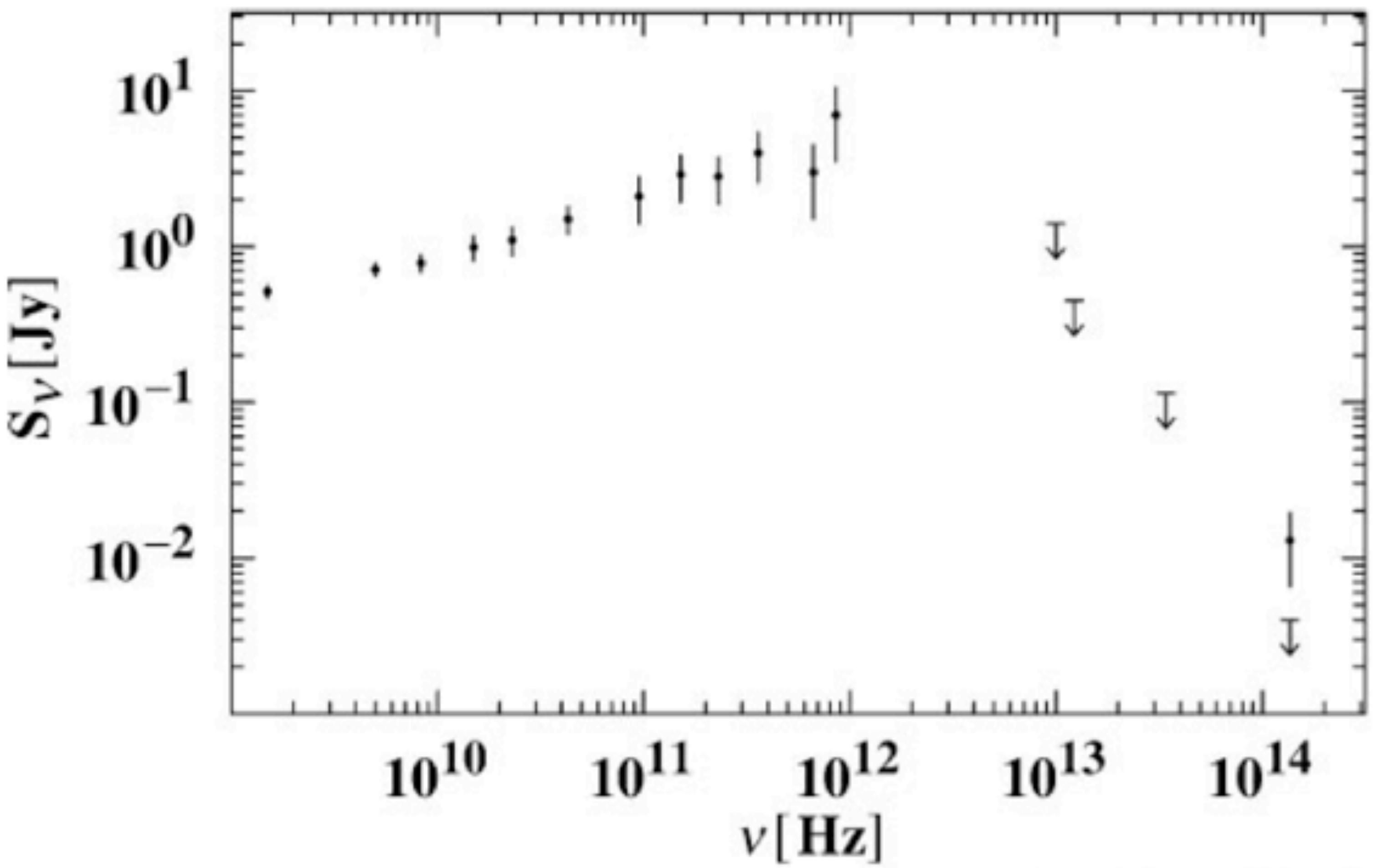
A Compact radio source
1974: Bruce Balick & Robert Brown
(baseline interferometer of the NRAO).



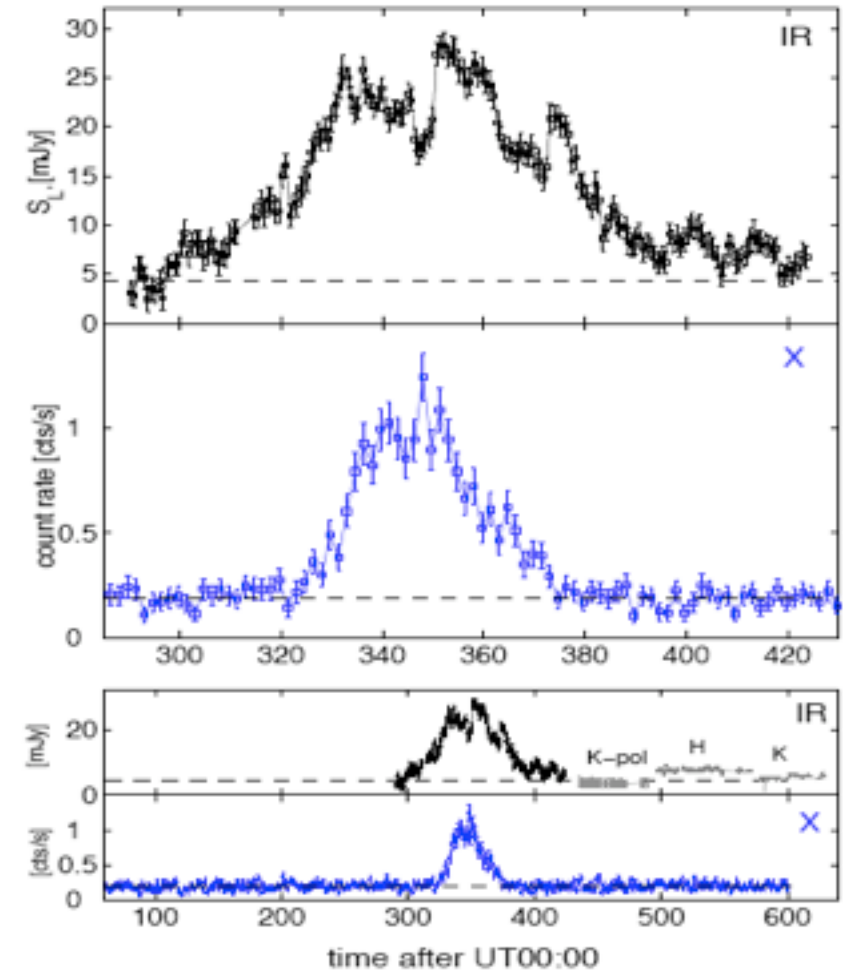
4x4 degree radio region ($\lambda \approx 1$m) around the galactic center, VLA.

Sgr A* Spectrum

Underluminous at all wavelenghts ($L_{bol} \approx 100 L_\odot \approx 10^{-9} L_{edd}$)



Melia & Falcke (2001, ARA&A)



Dodds-Eden et al. (2009)

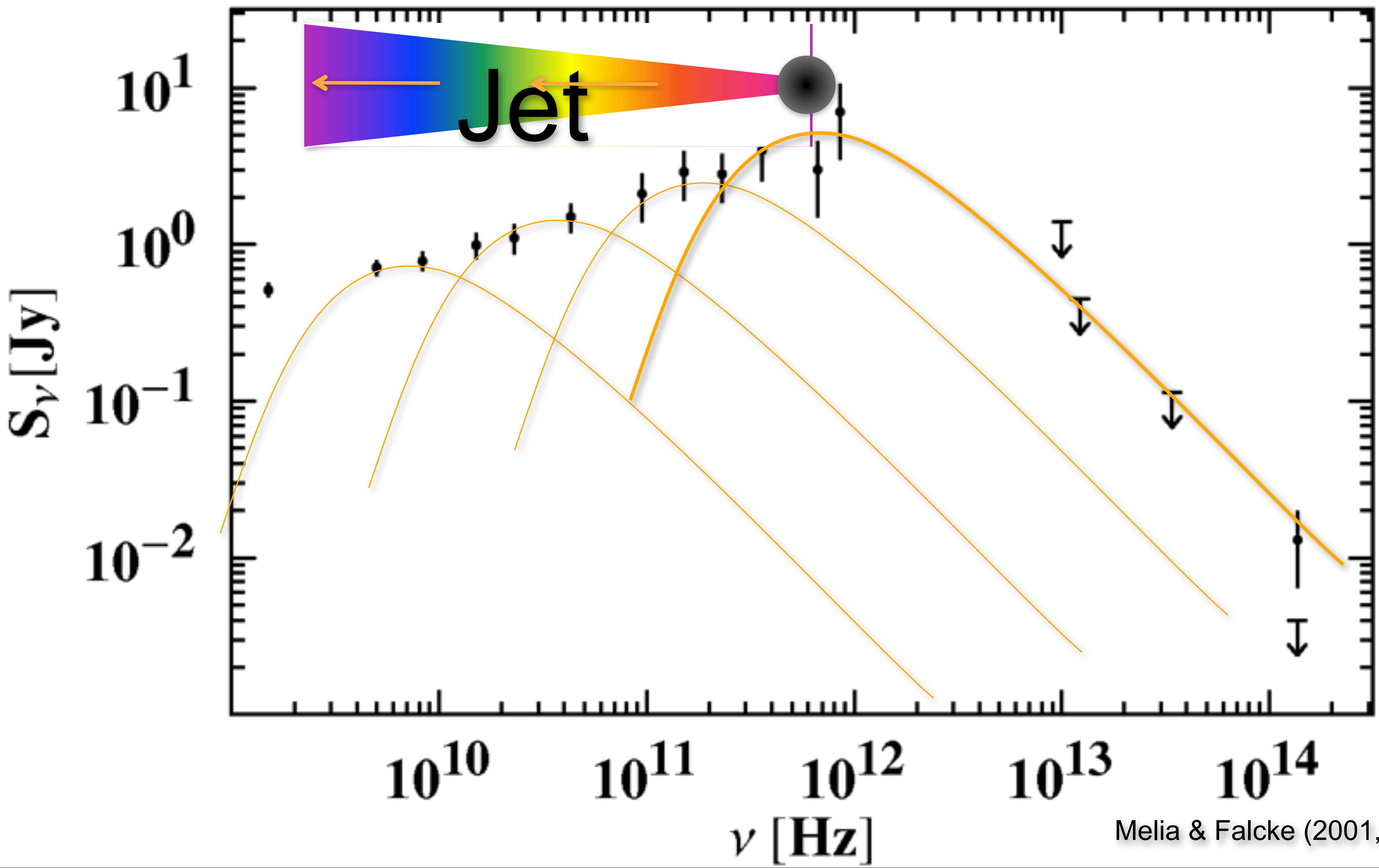
- Is the radio emission of Sgr A* produced in
  - an accretion flow (ADAF/RIAF)? Melia (1994), Narayan+ (1998), Yuan+ (2004), Quataert & Gruzinov (2000)
  - or a moderately relativistic jet? Falcke, Mannheim, Biermann (1993), Falcke (1996), Falcke & Markoff (2000)

- Sgr A* has frequent X-ray & NIR flares on 1h time scales (Baganoff, Pourquet, Genzel, Eckart, Ghez, ….)
- No clear correlation to radio/submm (maybe IR/X-ray leading by hours?)

Sgr A*: Radio-submm-NIR Spectrum

Stratified emission model:

≠ frequencies are dominated by ≠ regions where the optical depth approaches unity.



Melia & Falcke (2001, ARA&A)

Modeling Sgr A*

Why?

- Closest AGN (good test)

- Study the accretion flow

- Predict jet launching

Cosmos ++

GRMHD code developed by Anninos, Fragile and Salmonson (2005)

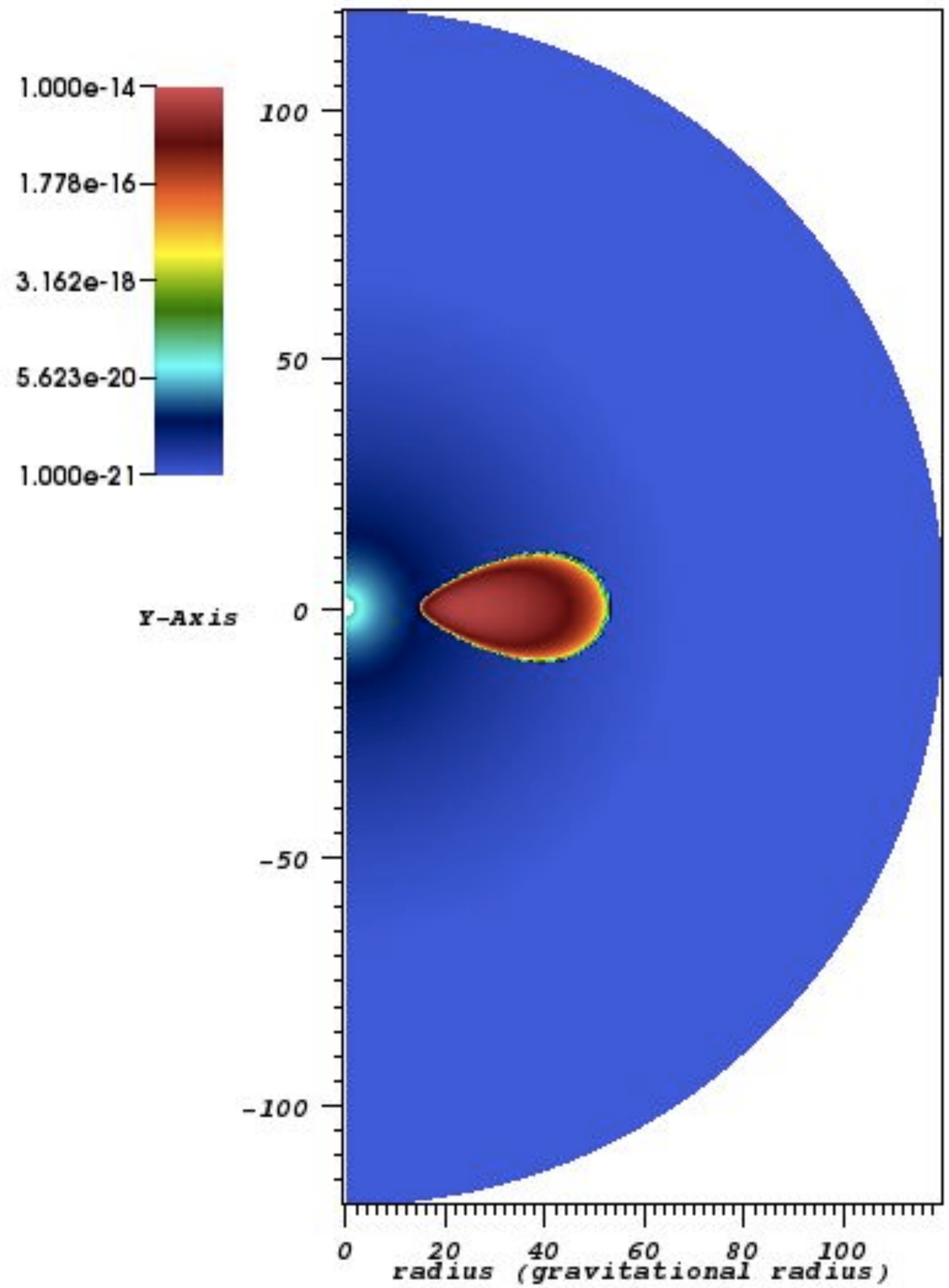
Relativistic MHD on unstructured grids with local adaptative mesh refinement. (ApJ)

Our model:

main-SgrA.cc

Initial mater configuration (rho in g/cm^3)

Torus



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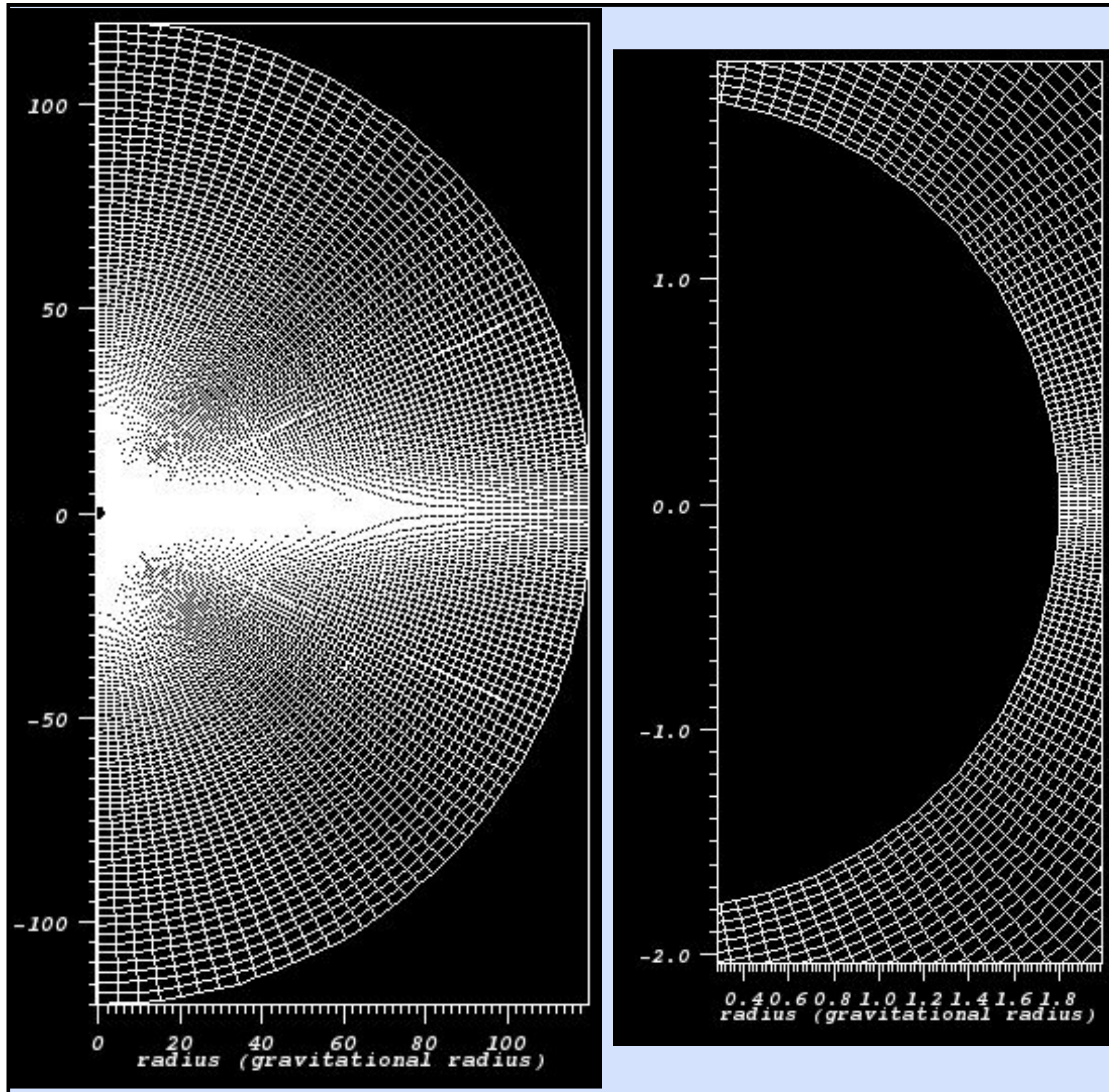
Grid resolution

GRMHD equations solved in each cell



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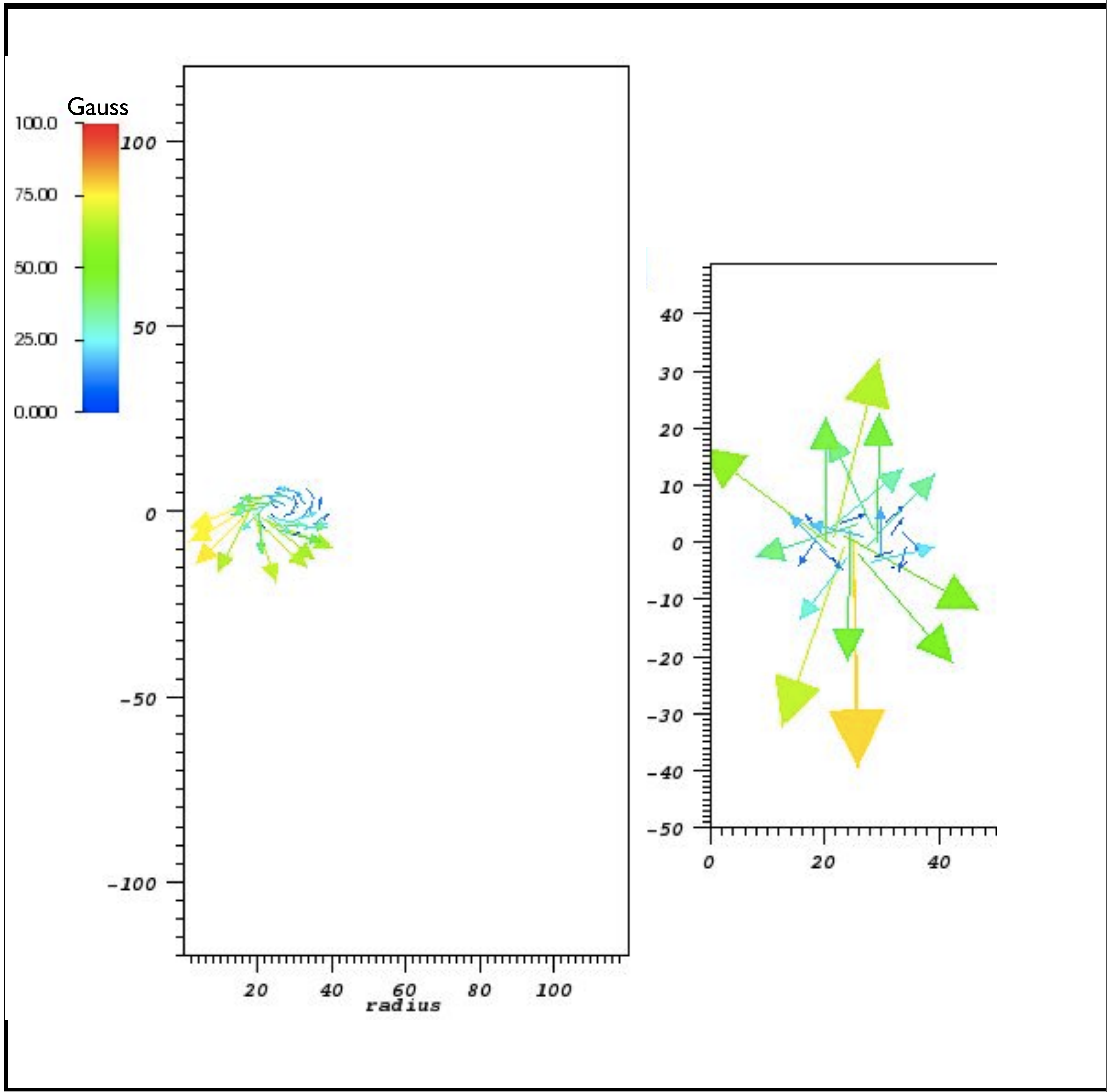
Initial Magnetic field configuration

1 or 4 poloidal loop(s) in the accretion disk

Very low (~50 Gauss)

No external field

Accretion driven by MRI



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Very low (~50 Gauss)

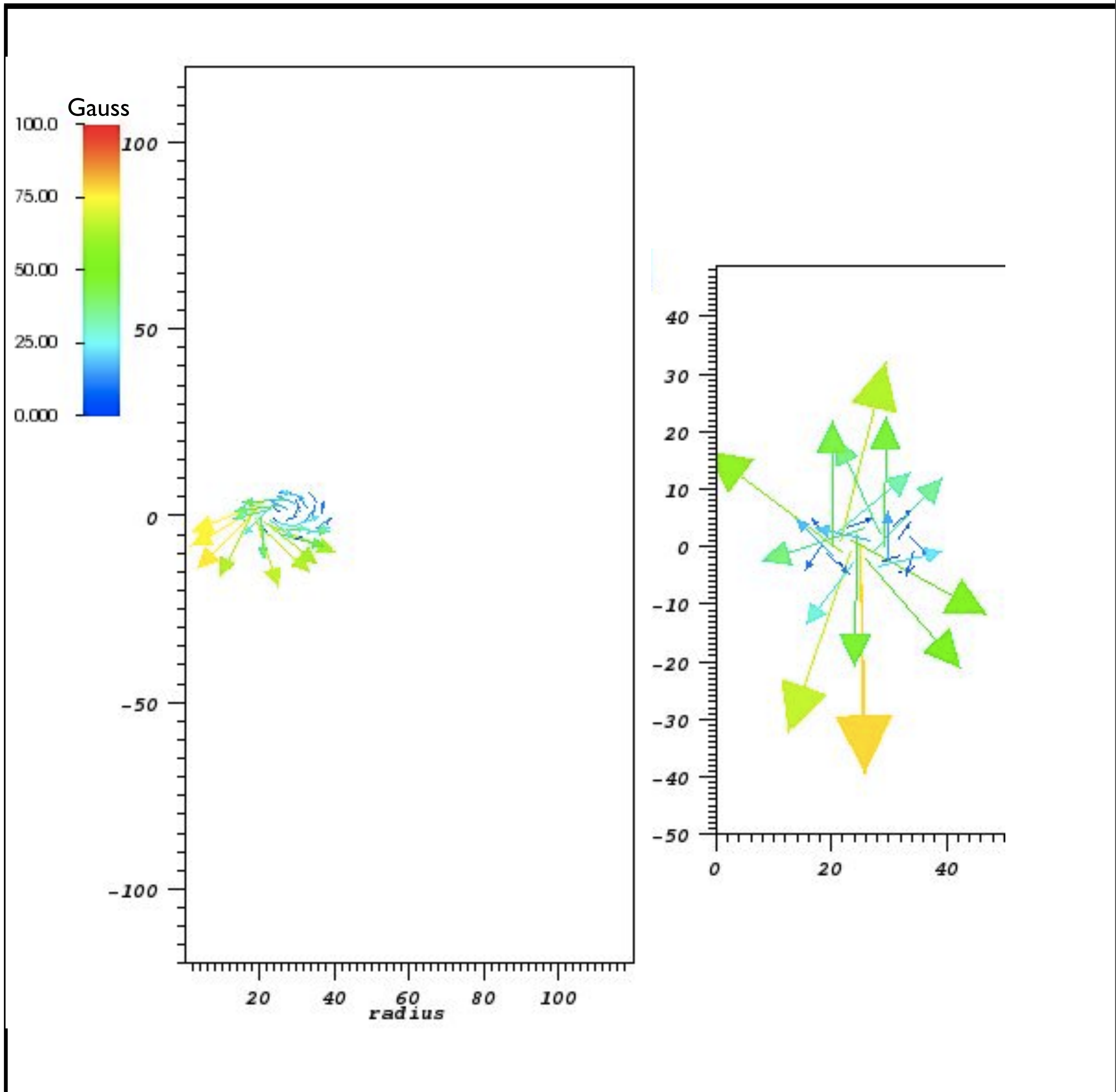
No external field

Accretion driven by MRI

Allow radiative cooling

Thermal Synchrotron, Bremmstrahlung, and Compton

Optically thin assumption



16 free parameters! :

- bhmass
- bhspin
- rin
- rout
- rcenter
- rmin
- rmax
- bhtilt
- angmom
- qpar
- u_in
- deltaw
- kpar
- gamma
- rhoScale
- pressureScale

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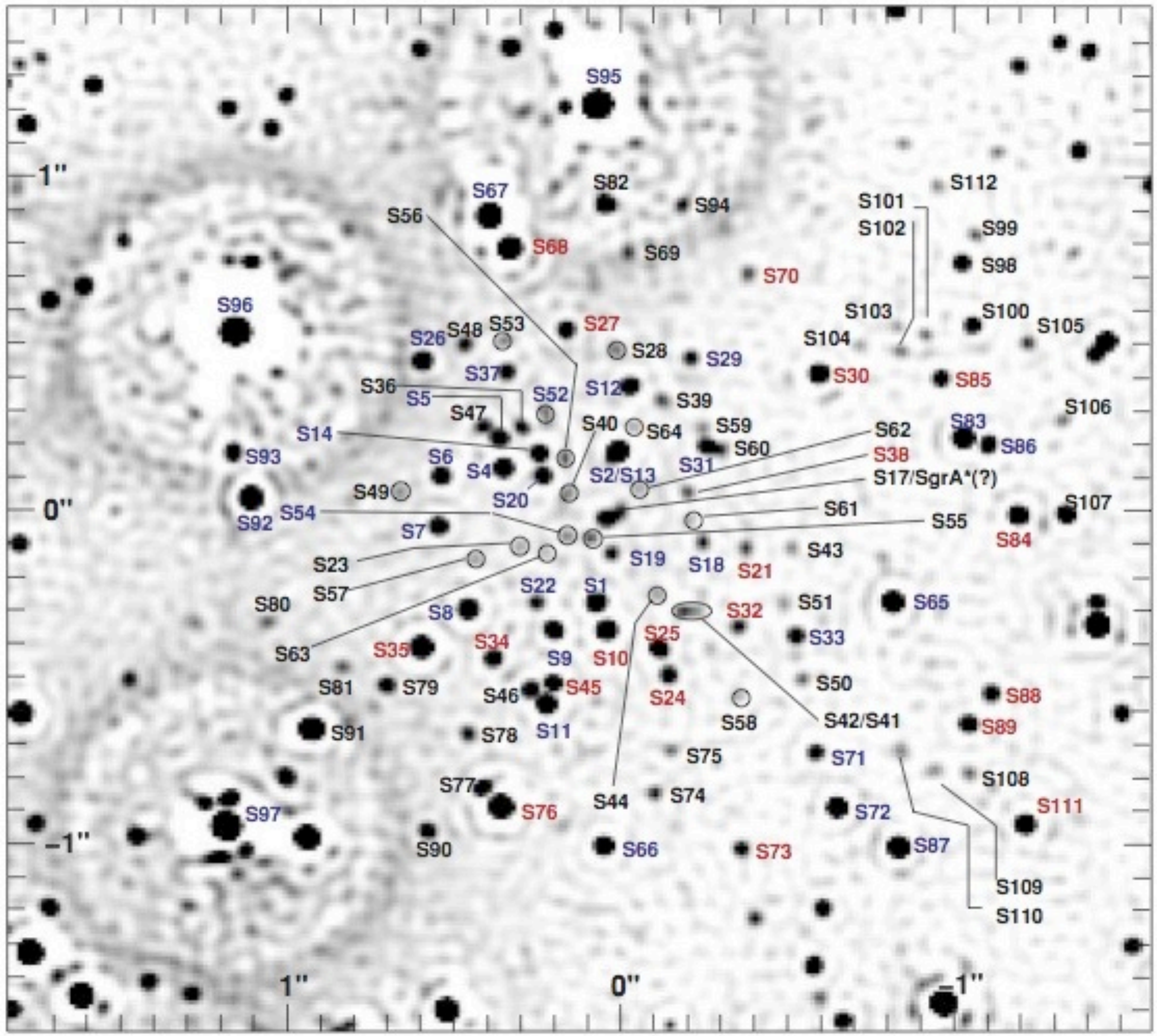
Constrain on the Mass of Sgr A*: NIR imaging

$M = 4.31 \pm 0.06_{|stat} \pm 0.36_{|R0} * 10^6 M_\odot$



1"≈0.04pc

Gillessen et al. 2009 ApJ

16 free parameters! :

- ~~bhmass~~ $4.3*10^6\ M_\odot$
- bhspin ??? a=0, a=0.99
- rin
- rout
- rcenter
- rmin
- rmax
- bhtilt
- angmom
- qpar
- u_in
- deltaw
- kpar
- gamma
- rhoScale
- pressureScale

16 free parameters! :

Constrain on the accretion rate of Sgr A*

$M_{dot} < 2*10^{-7}\ M_\odot\ yr^{-1}$

- ~~bhmass~~ 4.3*10^6 $M_\odot$
- bhspin ??? a=0, a=0.99
- rin 15 r_g
- rout 100 r_g
- rcenter 25 r_g
- rmin 0.9 r_g
- rmax 120 r_g
- bhtilt 0
- angmom 4.5
- qpar 1.68
- u_in -9.8
- deltaw 0
- kpar
- gamma
- rhoScale
- pressureScale

Marrone, 2006, ApJ ::

Simultaneous measurements with the sub-millimeter array

Polarization $\beta = RM\lambda^2$, with $\mathrm{RM} = \frac{e^3}{2\pi m^2 c^4} \int_0^d n_e B\, ds$

16 free parameters! :

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- bhtilt 0
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- qpar 1.68
- u_in -9.8
- deltaw 0
- ~~kpar~~ $0.01 \approx 10^{-8}\ M_\odot/y$
- gamma 5/3
- rhoScale
- pressureScale

EOS: $P=(\text{gamma}-1)\rho\varepsilon$

16 free parameters! :

- ~~bhmass~~ $4.3*10^6\ M_\odot$
- bhspin ??? a=0, a=0.99
- rin 15 r_g
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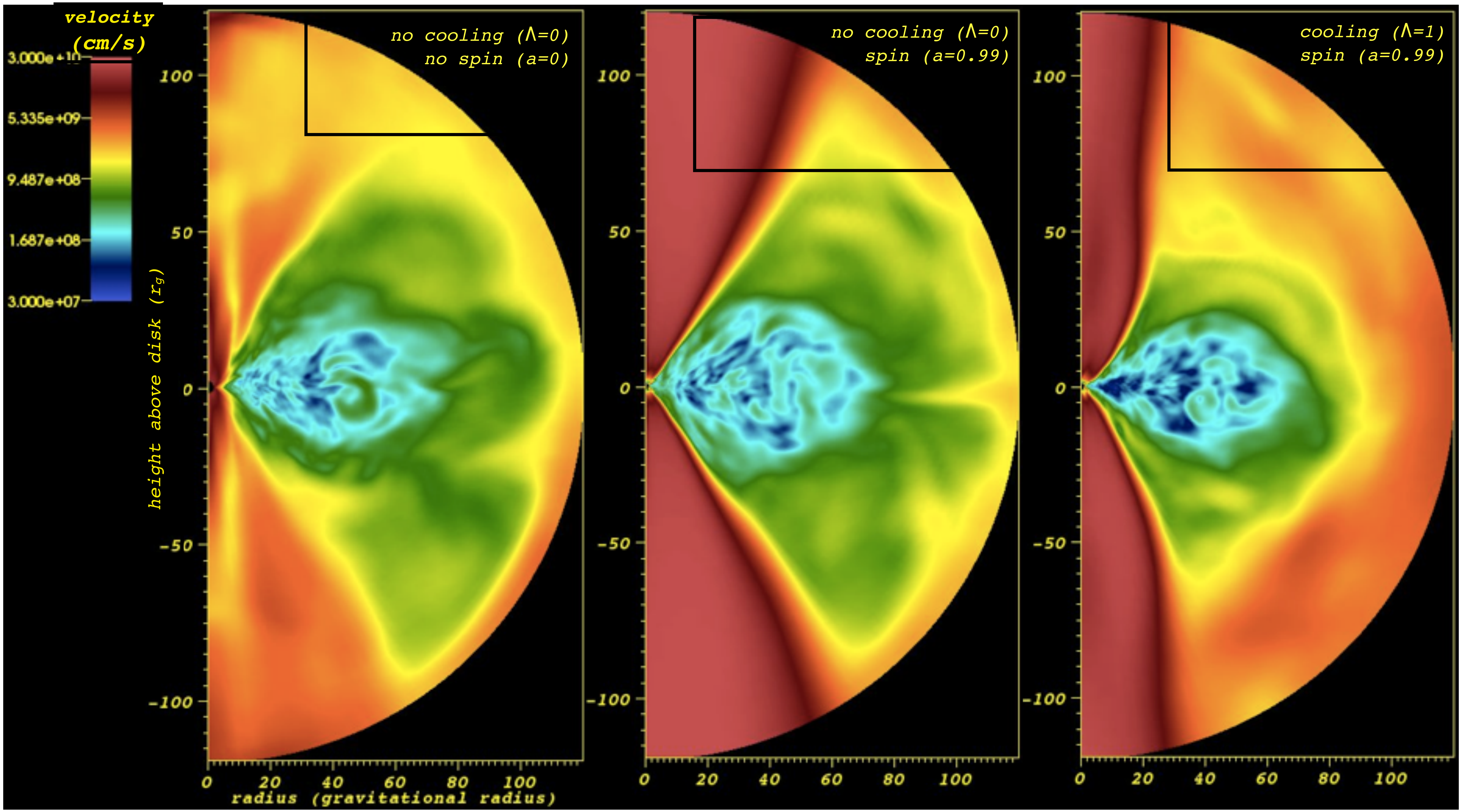
- bhtilt 0
- angmom 4.5
- qpar 1.68
- u_in -9.8
- deltaw 0
- ~~kpar~~ $0.01 \approx 10^{-8}\ M_\odot/y$
- gamma 5/3
- rhoScale $1*10^{-4}$
- pressureScale $1*10^{-6}$

Some results after 7 orbits ...

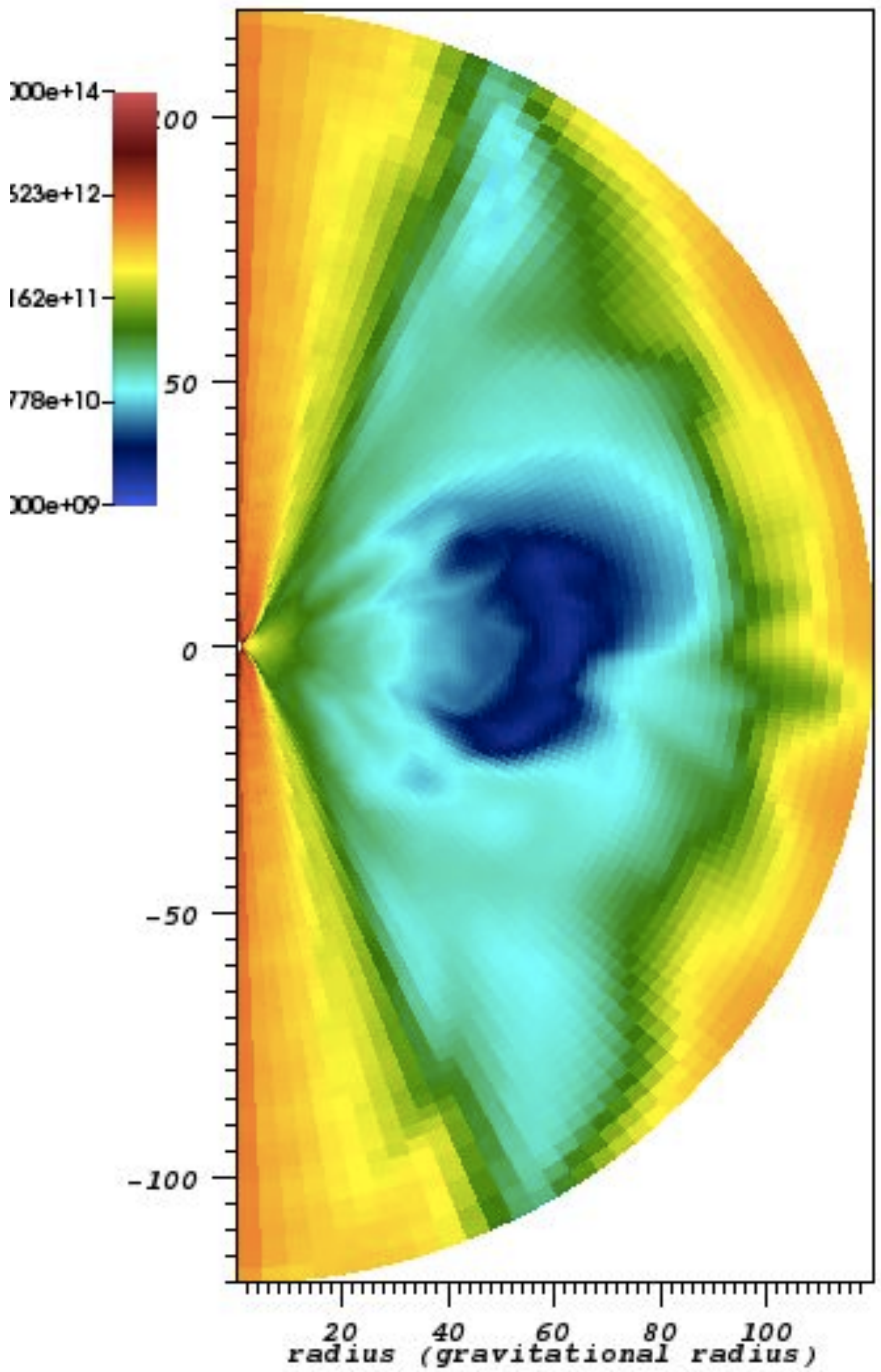
Spin and cooling influence on the velocity magnitude of the outflows



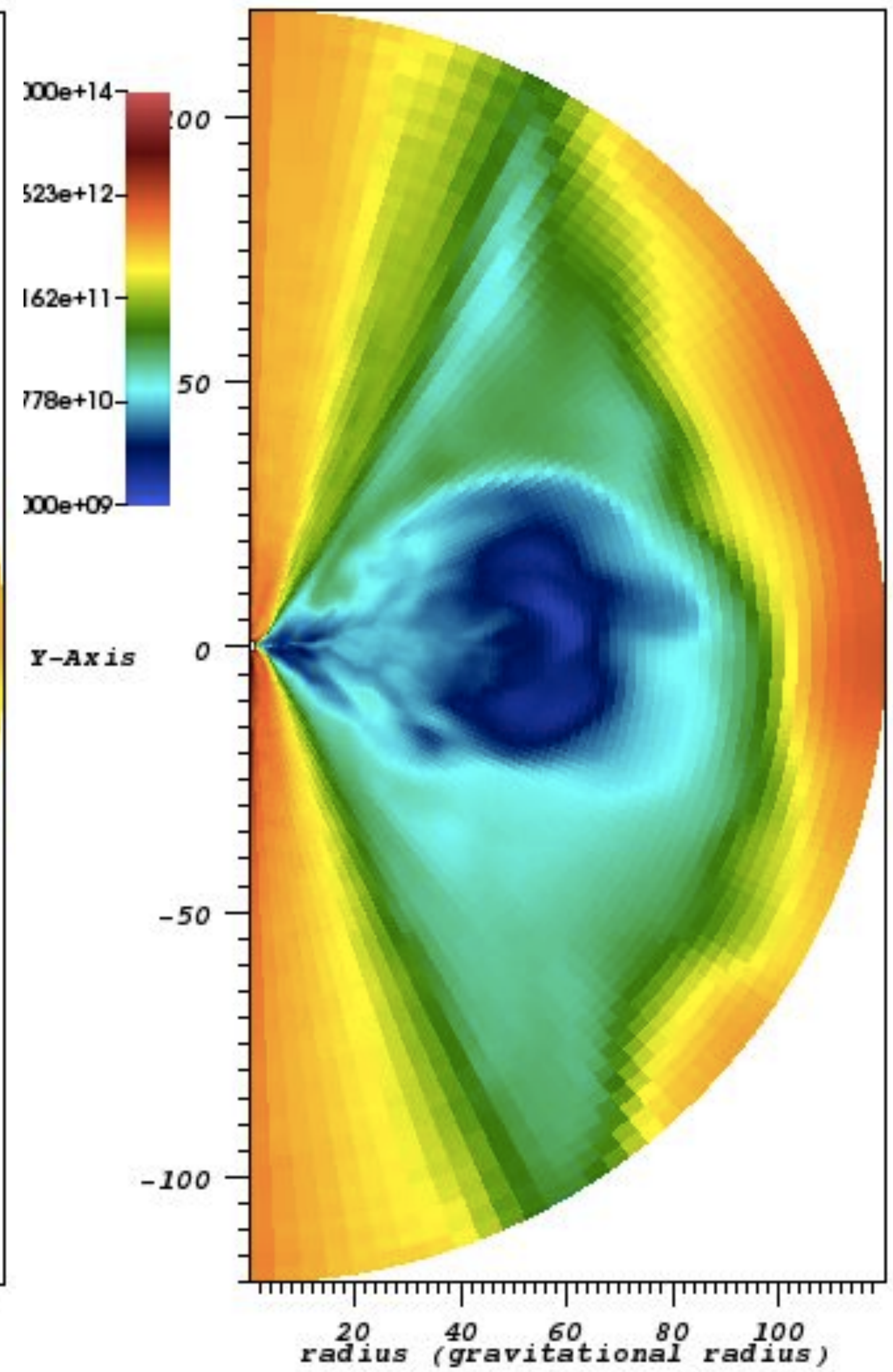
Time averaged velocity on the last 2 orbits

Averaged temperature

spin, no cooling

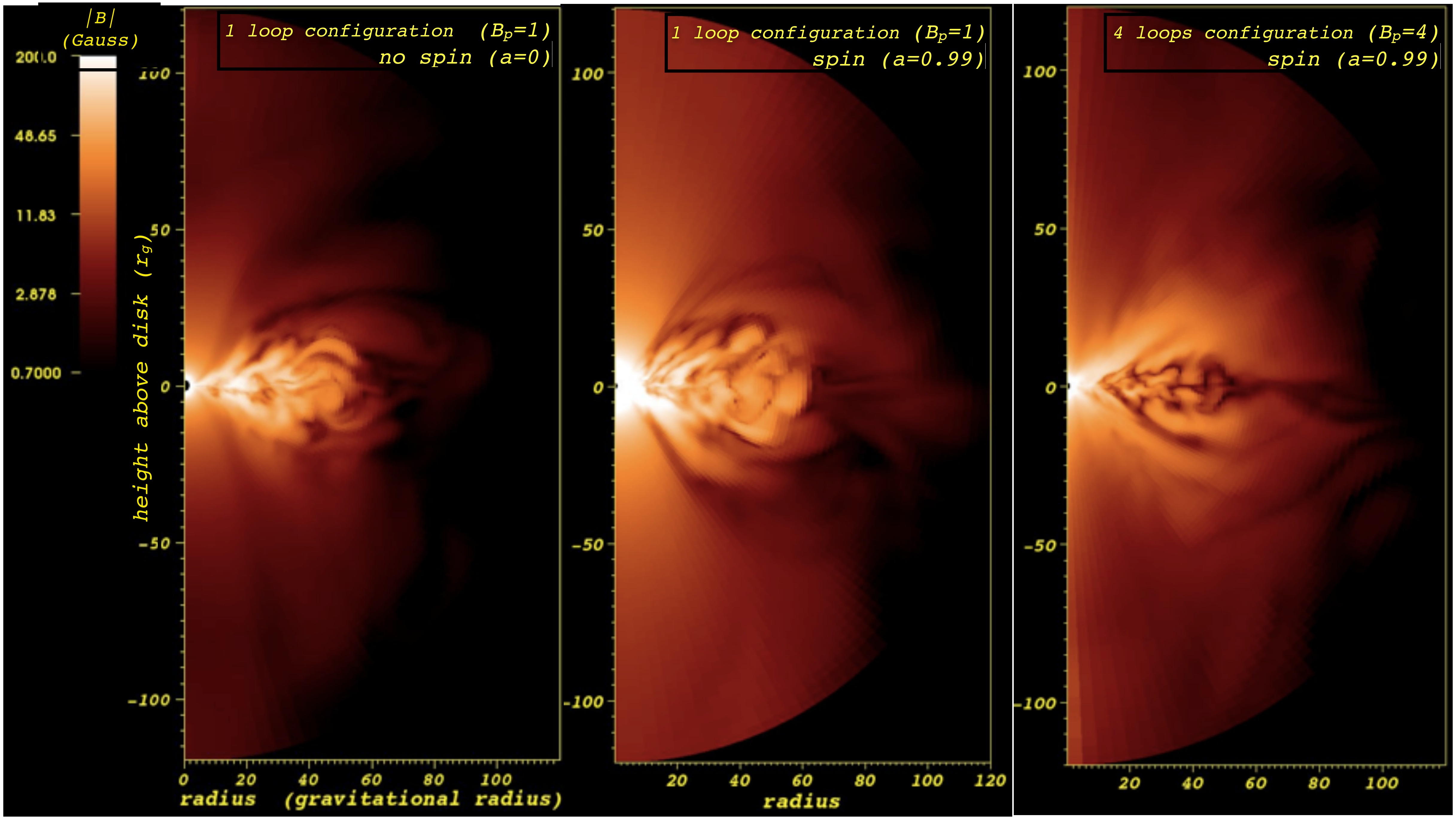


spin, cooling



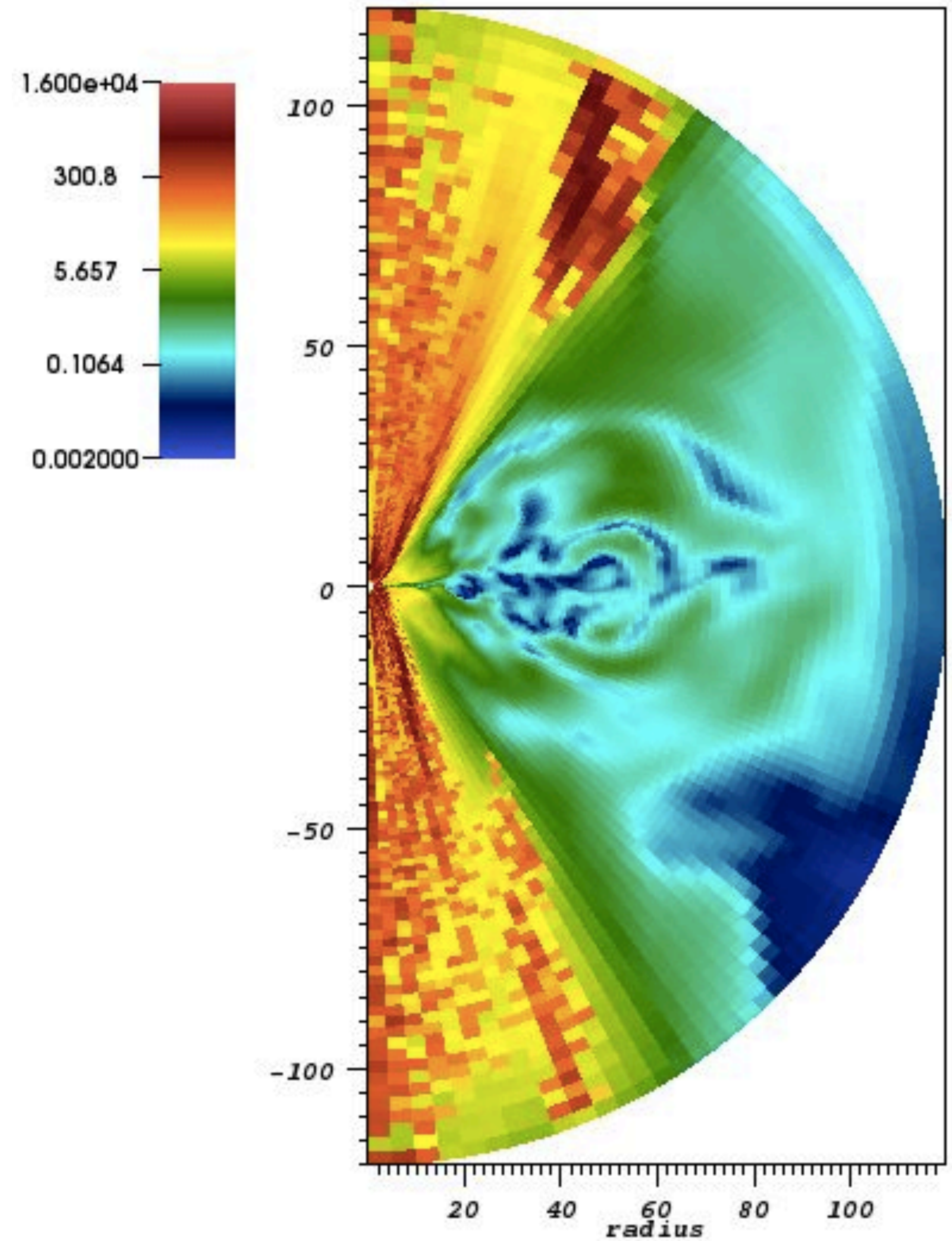
Averaged magnetic field magnitude

without cooling



Nature of the jet?

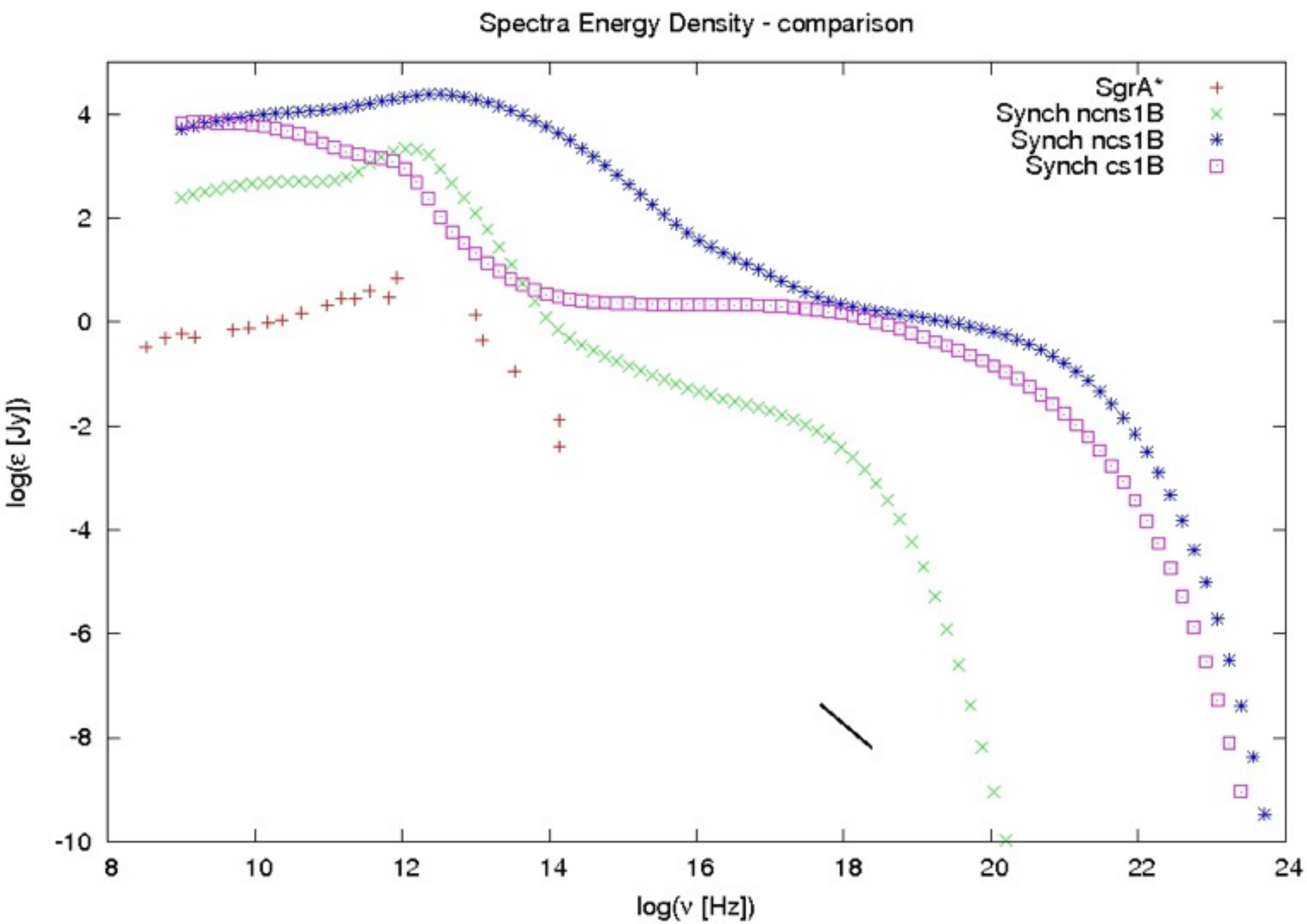
Sigma= magnetic pressure/gas pressure



Time averaged sigma (on the last 2 orbits)

Consequences on the spectrum

Cooling makes quite a big difference!
(~2 order of magnitude) in the IR



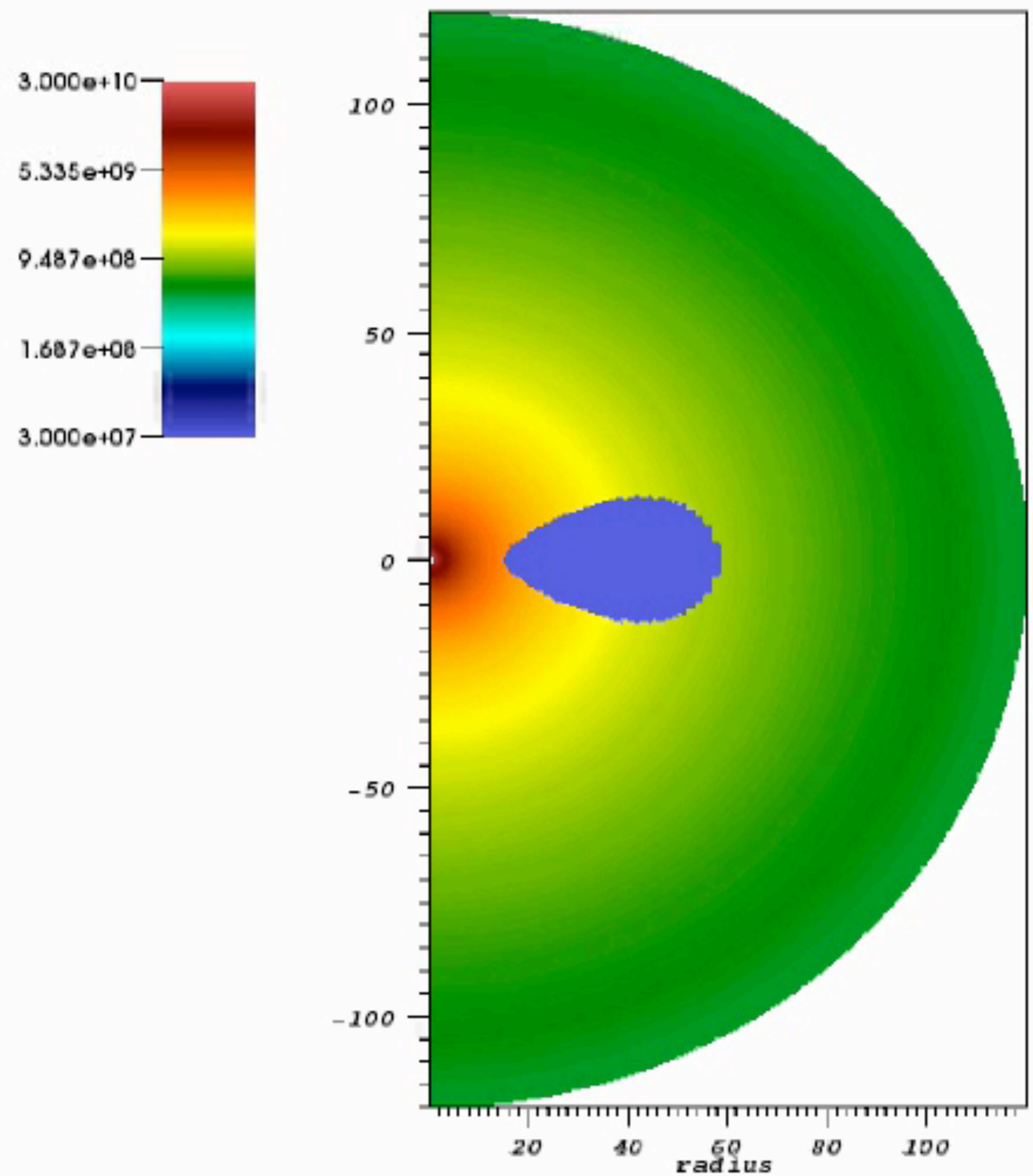
Velocity (in cm/s)

Spin=0.99

Steady state model

Do not believe anything further than 50 Rg

Study on the accretion flow

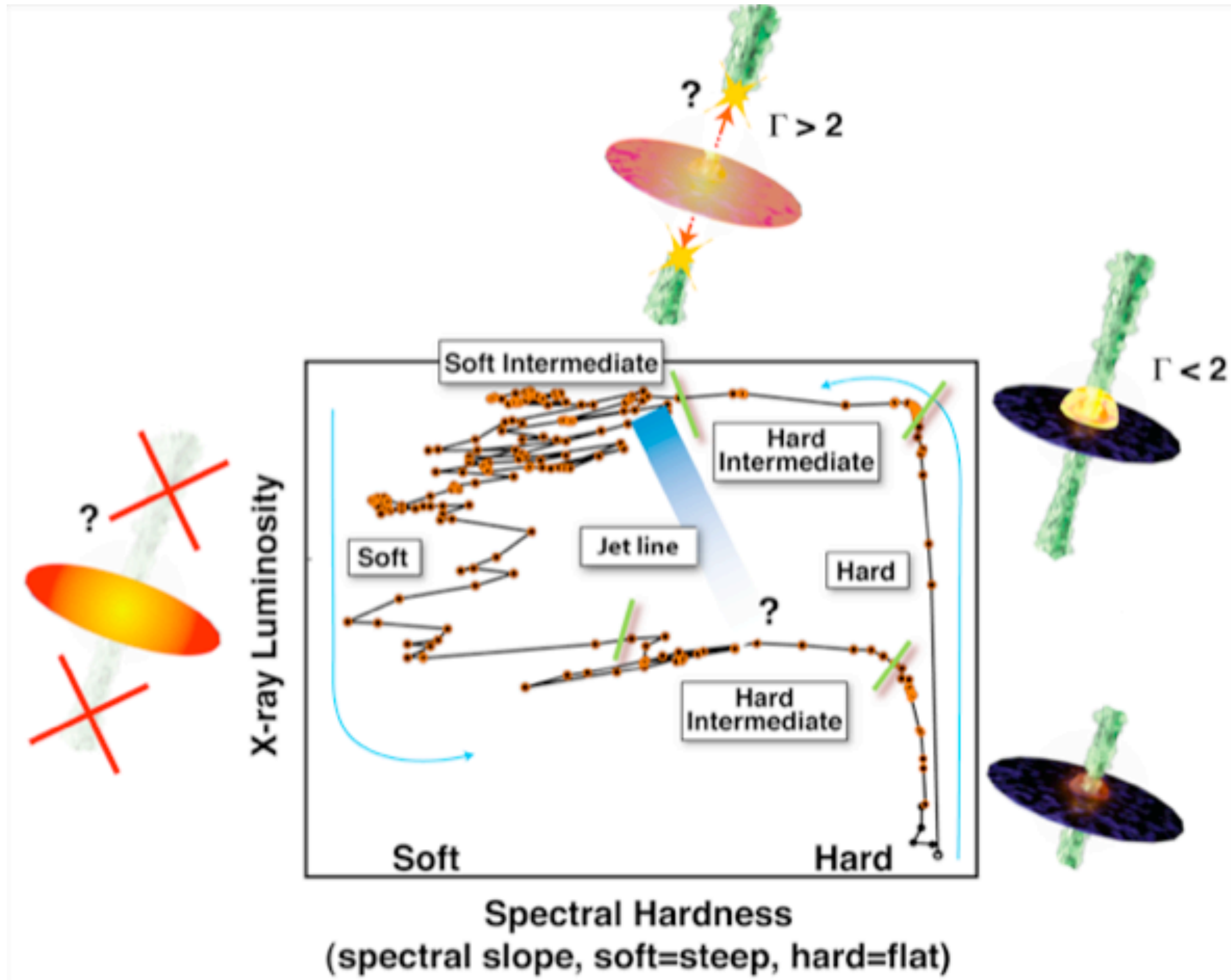


A time dependent jet model to study transitional states
Observations vs Theory

N. Kyfalis: Simple jet model for the low/hard state

Pieter: Sera's model to fit broad band emission from GRS 1915+105

Dipankar Maitra: time dependent jet model



BHB GX 339-4

Time dependent jet model

- Semi-analytical:

Simpler but no “black boxes”
better understanding of the physics and better interpretation of the results of the simulations

- Plasma injected at the base of the jet. Feeding of the jet ≡ matter accretion from disk

Thermal or non thermal distribution
Radiative cooling

So far only Synchrotron cooling...: $\dot{\gamma}_{Syn} = \frac{4}{3}\frac{\sigma_T c}{m_e c^2} U_B \gamma^2$

Analytical solution exists: $$\gamma\beta(t) = \frac{\gamma\beta(t_0)}{1 + \frac{\sigma_T B_0^2 t_0}{6\pi m_e c(2a_{\rm jet}-1)}\gamma\beta(t_0)[1-(t/t_0)^{1-2a_{\rm jet}}]}$$ (A. Pe’er, 2009)

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$$\frac{\partial N(\gamma,t)}{\partial t} = \frac{\partial}{\partial \gamma}\left[\dot{\gamma}(\gamma,t)N(\gamma,t)\right]$$

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Numerical Scheme to solve “Fockker-Planck like” equation

Developing a Chang & Cooper algorithm (A Practical Difference Scheme for Fokker-Plank Equations, Chang and Cooper 1968)
- Conserve particle number
- Conserve energy
- Allow relatively big binning in gamma and time

Ma & Summers (A numerical scheme for Fokker-Planck wave-particle interactions in plasmas 2000) With diffusion

Chiaberge & Ghisellini (Rapid variability in the synchrotron self-Compton model for blazars 1997)

Numerical Scheme to solve "Fockker-Planck like" equation

$$\frac{\partial N(\gamma,t)}{\partial t} = \frac{\partial}{\partial \gamma}\left[\dot{\gamma}(\gamma,t)N(\gamma,t)\right] + Q_{inj}(\gamma,t) - \frac{N(\gamma,t)}{t_{esc}} \qquad \dot{\gamma} = \dot{\gamma}_{Syn} + \dot{\gamma}_{Com} + \dot{\gamma}_{Ad}$$

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Future/current work

1. Cosmos ++

- negative spin ?
- more cooling models
- 3D simulation
- different mater configuration ?

2. Implementation of Chiaberge & Ghisellini in C

- adding other radiative processes
- input of particles, acceleration ?

...

Thank you!