Primer on disk simulations



INIVE

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New York, Mar 11th, 2019

A cartoon AGN



Disks in Astrophysics



Protoplanetary

Galaxies

AGNs

Turbulence and Accretion in 3D Global MHD Simulations of Stratified Protoplanetary Disk

State of the art in pp-disk modeling

- MHD (ideal and non-ideal MHD)
- Selfgravity
- Dust
- Chemistry
- Radiative Transfer
 - Post-processing
 - Radiation hydrodynamics
 - Flux-limited diffusion
 - Ray tracing (long or short characteristics) usually done for solar atmospheres but not for disks.

3D Hydro

Scattered light post-processing



Radiative Transfer

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 - Flux-limited diffusion
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Codes

Grid-based (Eulerian)

- Geometry of flow and grid align
- Self gravity usually a problem in 3D
- GPUs vs CPUs
 - CPU speed-limited but memoryefficient
 - 10^3 few x 10^4 procs
 - Resolution 1024³
 - GPU fast but memory limited
 - 4 GPUs 20 orbits/hr, low resolution 3D (128³)
- Examples
 - Pluto / Athena++ / Pencil / Fargo

Lagrangian

- SPH
- Free boundaries
- Contact discontinuities not well captured (instabilities Not well modeled)
- Particles adaptively trace Dense regions.
- Excellent for gravity
- Examples:
 - Phantom / Gadget

Why can't we simply sed 's/protoplanetary/AGN/g'

Fully ionized

• ppdisks poorly ionized

Relativity

- Unimportant in ppdisks,
- But even for AGNs only important for the central engine

Retrograde and highly inclined orbiters

• Inexistent in ppdisks

Feeback

• Stellar (SN) / sBH

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Relativity (GRMHD)



Retrograde and Highly Inclined orbiters



Satellite-disk interaction leads to angular momentum exchange (migration)



Migration Traps: a simple example



Migration of a single object



"Crowded" Migration in pp-disks



Migration and merger of two objects

- $\bullet~50~M_{\odot}$ BH and $~~30~M_{\odot}$ BH
- Form a binary upon reaching trap



Secunda et al. submitted

Retrograde/Inclined Orbiters

Possible Pitfalls

- Crowded migration?
 - Planet migration theory applied to AGNs Extrapolation from a few (<10 orbiters) to 10⁵ (*Dangerous!*)
 - Unexplored regime.

Intuition: As long as they do not overlap corotational regions it is okay to consider they are migrating in isolation.

• Question: Would circularization would lead to heating?



Feedback

Supernovae



sBH / IMBH accretion disks



Relatively well-known from galactic disk and star formation models.

unexplored (?)

Can such source terms be important in disk heating?

Conclusions

- State of the art in ppdisks
 - MHD / Selfgravity / Dust / Chemistry / Radiative Transfer
- Types of modeling
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 - Lagrangian (meshless, good for free boundaries/gravity)
 - CPU vs GPU
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- Differences between ppdisks and AGNs
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