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Leela E. Koutsantoniou

Black holes, radiation and the accretion disk

MAGNETIC FIELDS IN THE UNIVERSE

- We do not know where they come from and how they are created.
- In every process they are present, we assume they are primordial or pre-existing.
- We also add a lot of ad hoc assumptions about them. (structure, magnitude, etc.)
- Can we do better?

→ We examine the Cosmic Battery model:

we run simulations in GR in order to find out if this mechanism can produce significant magnetic fields.

THE

COSMIC BATTERY MODEL

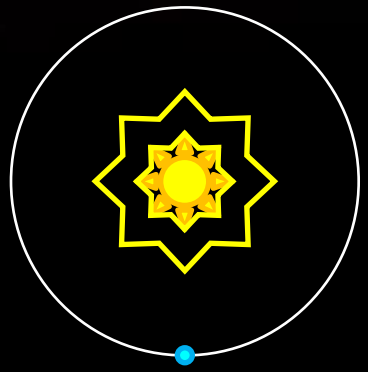
THE COSMIC BATTERY

- Consists of a photon source and an accretion disk.
- The emitted photons are absorbed by the plasma electrons of the disk and that radiation pressure exerts a drag force on them.
- Protons do not perceive the radiation pressure since it is $\propto (m_e/m_p)^2$. They only perceive electromagnetic forces due to a possible charge separation.
- The above causes the electrons and protons to move at a different speed, giving rise to a ring current. From Maxwell's equation we then have the generation of a poloidal magnetic field.
- A simple mechanism that functions everywhere creating magnetic fields from scratch and diffusing them outwards.

POYNTING – ROBERTSON DRAG

POYNTING-ROBERTSON DRAG

- The process by which solar radiation causes dust grains orbiting the Sun to lose angular momentum and slowly inspiral into the star.



- A purely relativistic effect caused by the aberration of light.
- Classical approximation for the force: $F_{PR} = \frac{u}{c^2} W = \frac{\sigma L}{4\pi R^2 c} \frac{u_\varphi}{c}$

GENERAL RELATIVITY

WHY, HOW & WHAT?

- General relativistic effects: $u = 0.75\ c$

No relativistic effects

Aberration

Aberration & Doppler

Aberration & Intensity

- Black hole + accretion disk: strong gravity & axisymmetric spacetime.

$$ds^2 = -\left(e^{2\nu} - \omega^2 e^{2\psi}\right)dt^2 - 2\omega e^{2\psi} dt d\phi + e^{2\psi} d\phi^2 + e^{2\mu_1} dr^2 + e^{2\mu_2} d\theta^2$$

- We solve the photon equations of motion (null geodesics), find “visible” light rays and throw away the rest.

OMEGA CODE INTERFACE

Disk model: Cone

Obscuration: ☑

λmax: 50

spin rate: 0.7

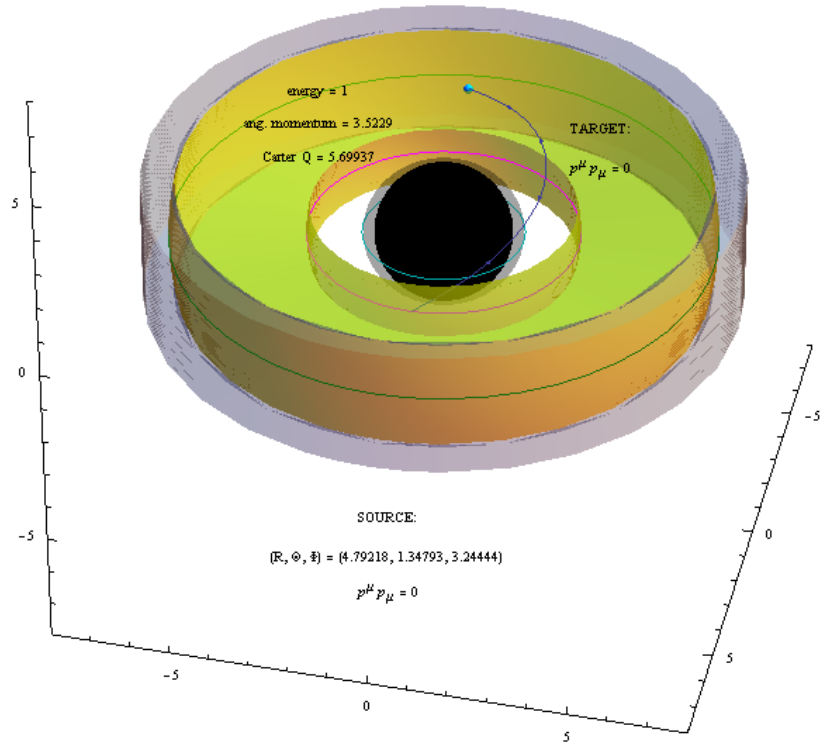
radius: 3.39313

band height: 0.75

polar angle ã: 115

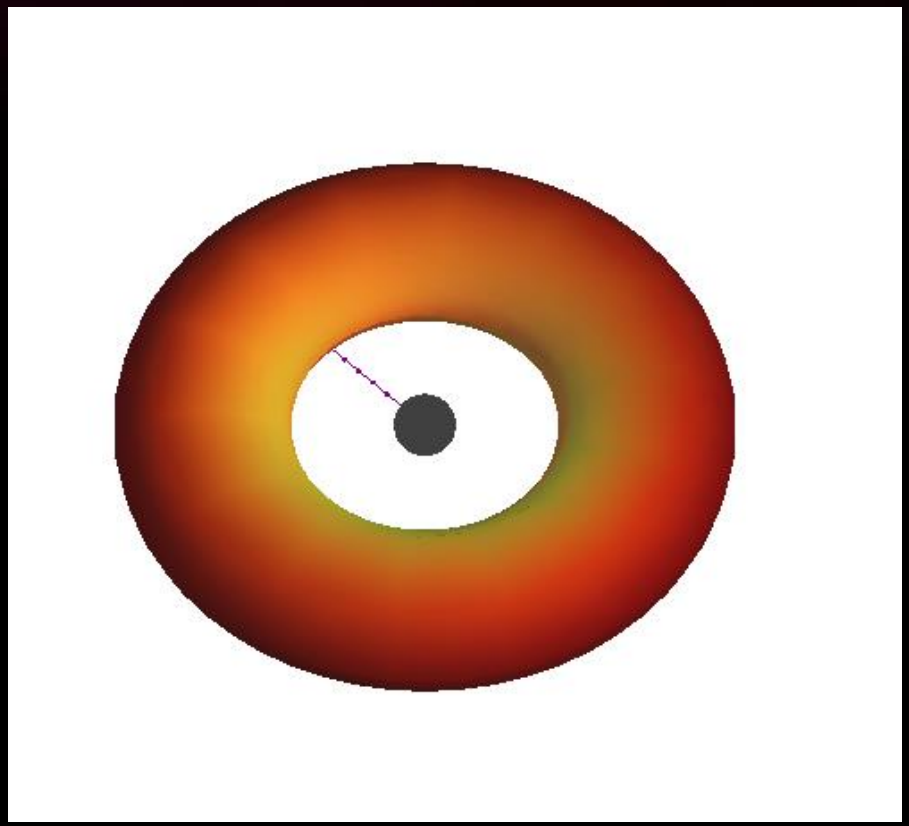
azimuthal angle b̃: 125

zoom: 4



GENERAL RELATIVITY: HOW?

- We scan the whole sky around the target electron:



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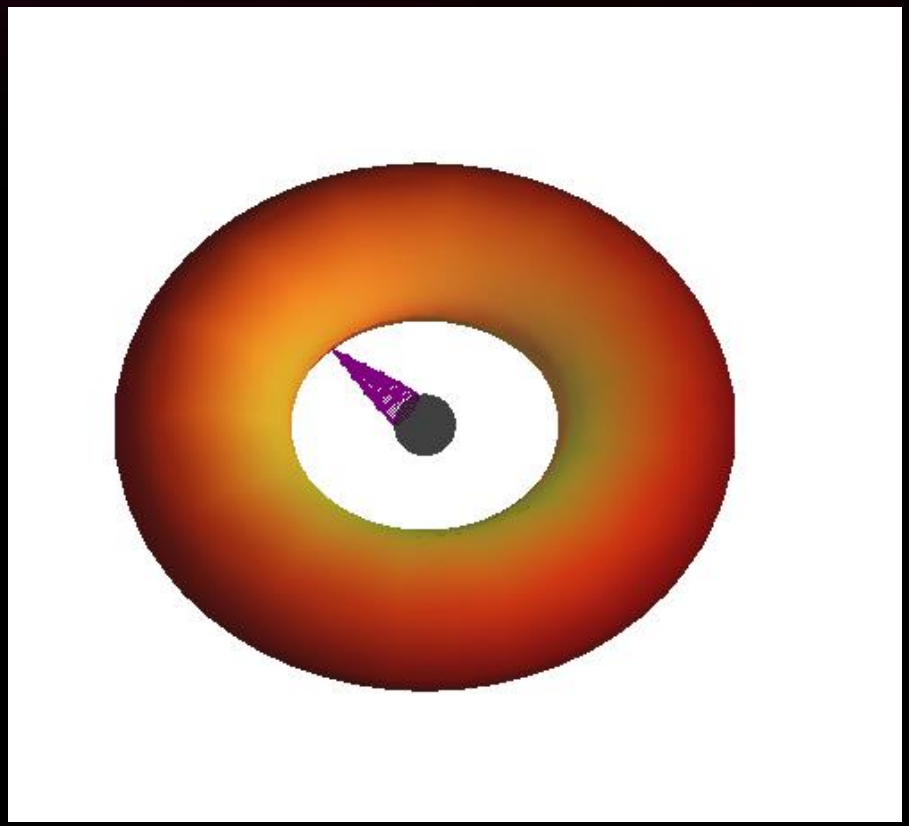

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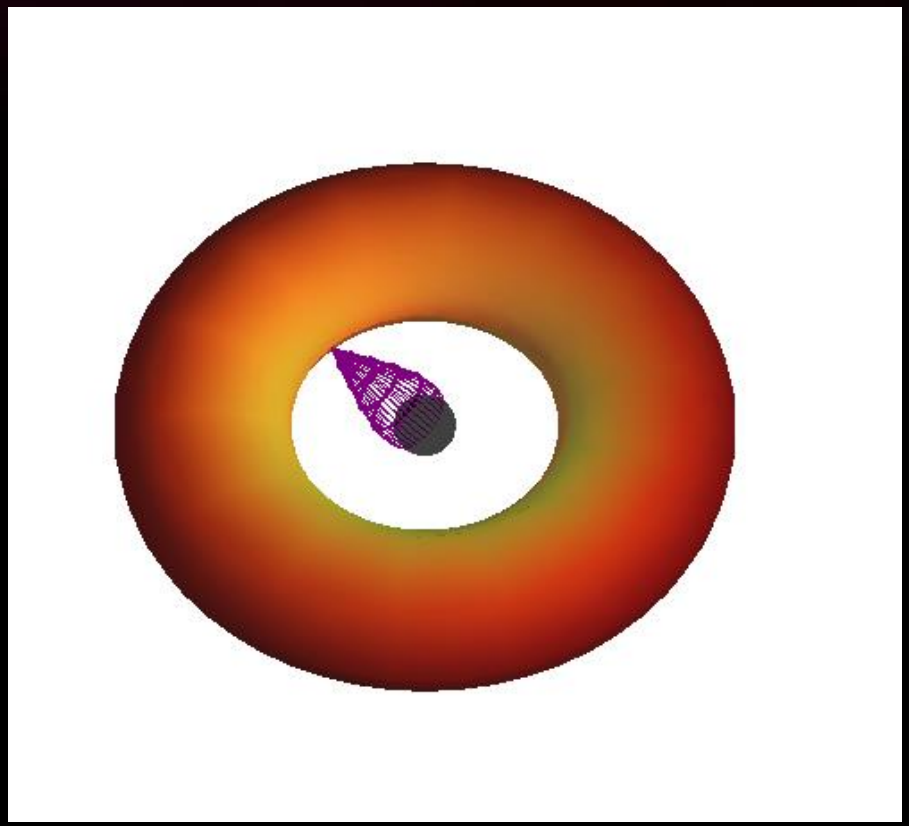

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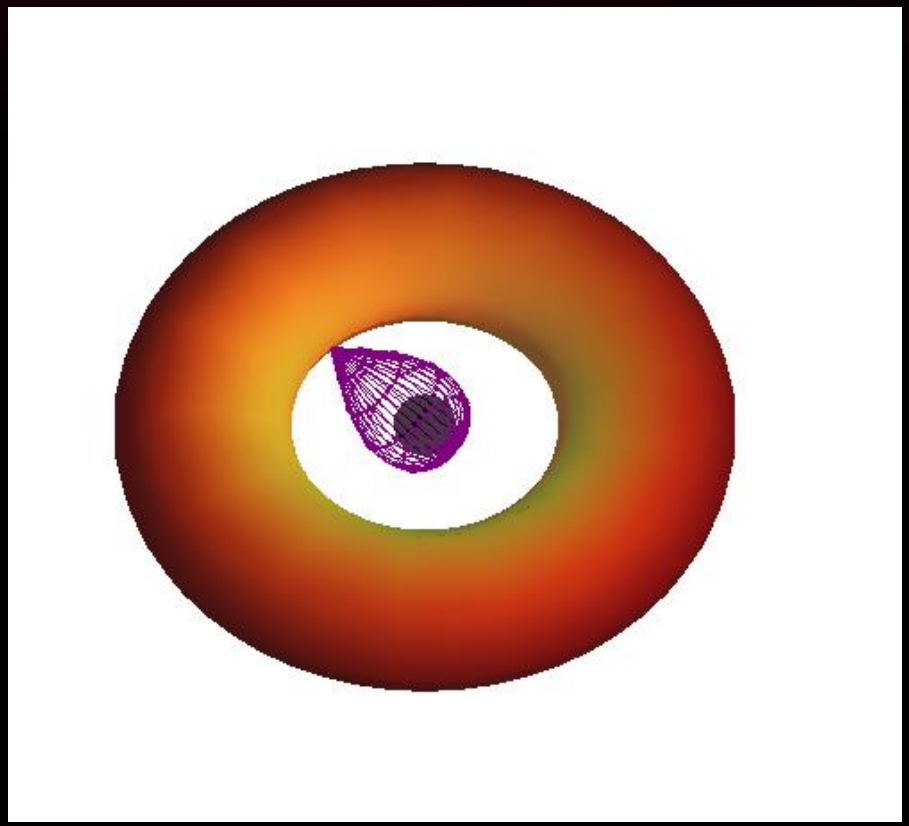

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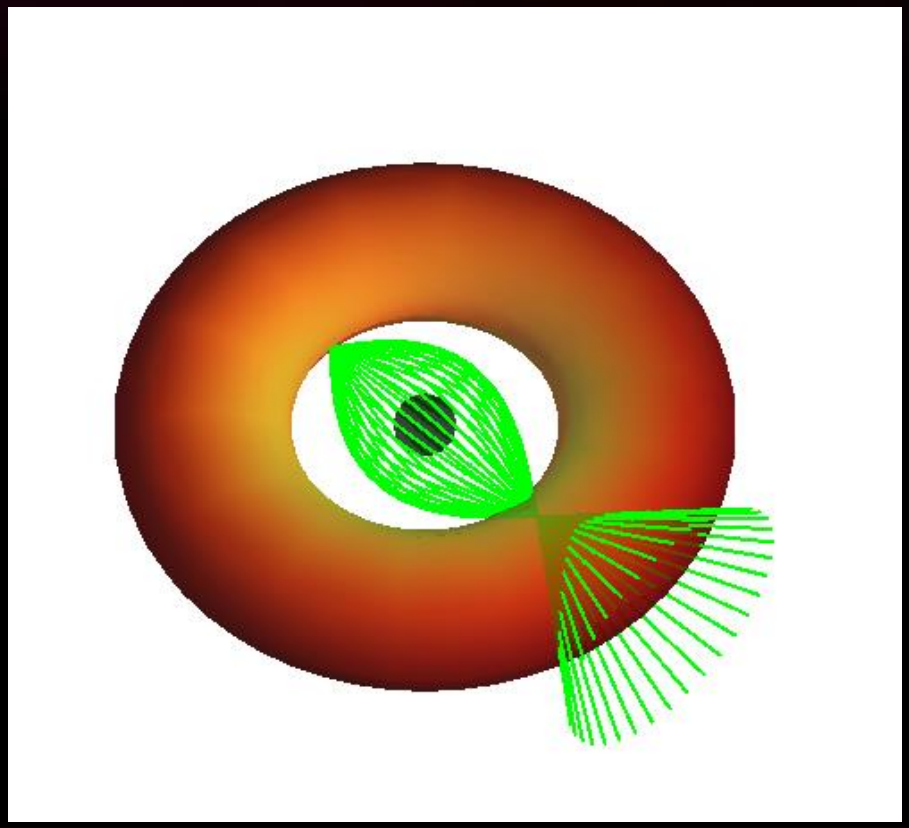

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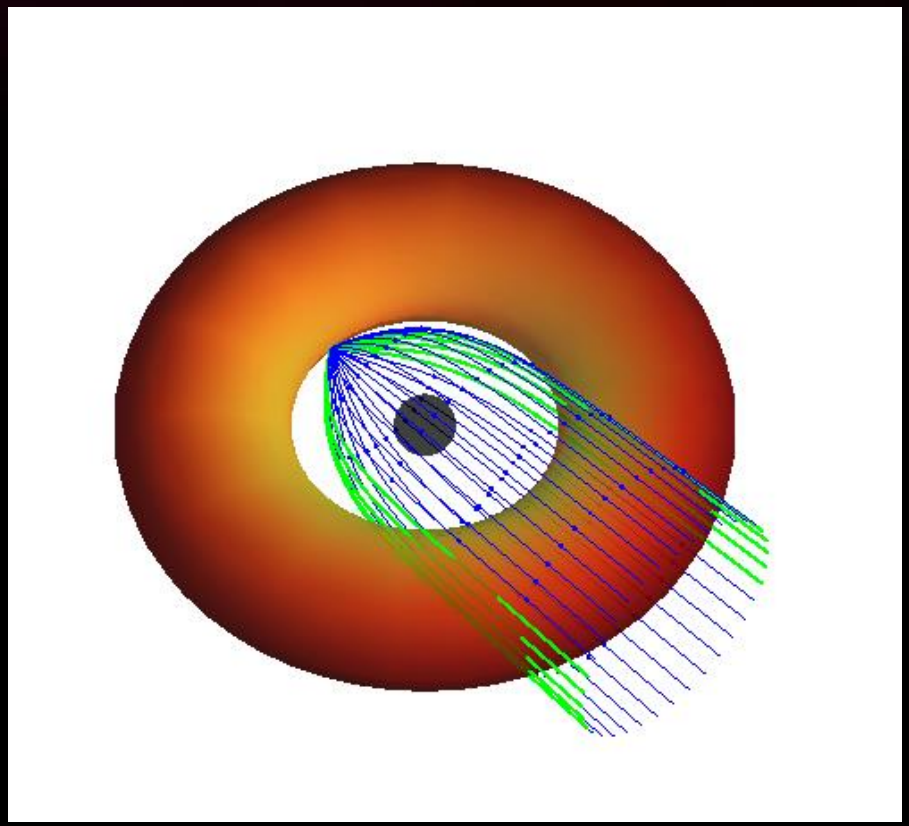

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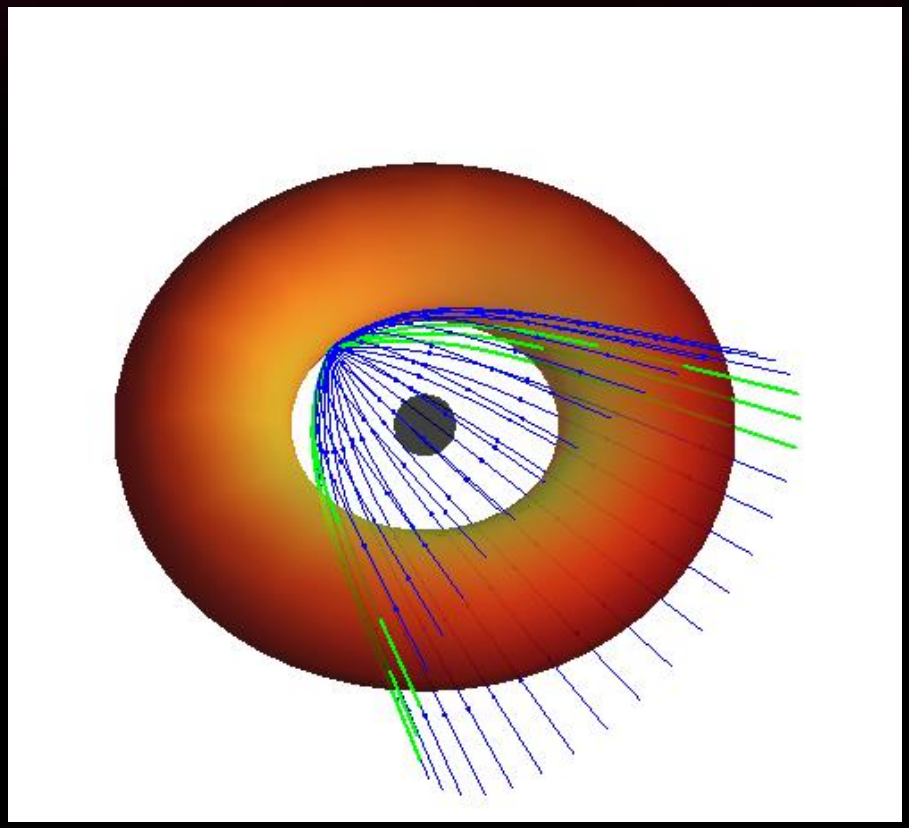

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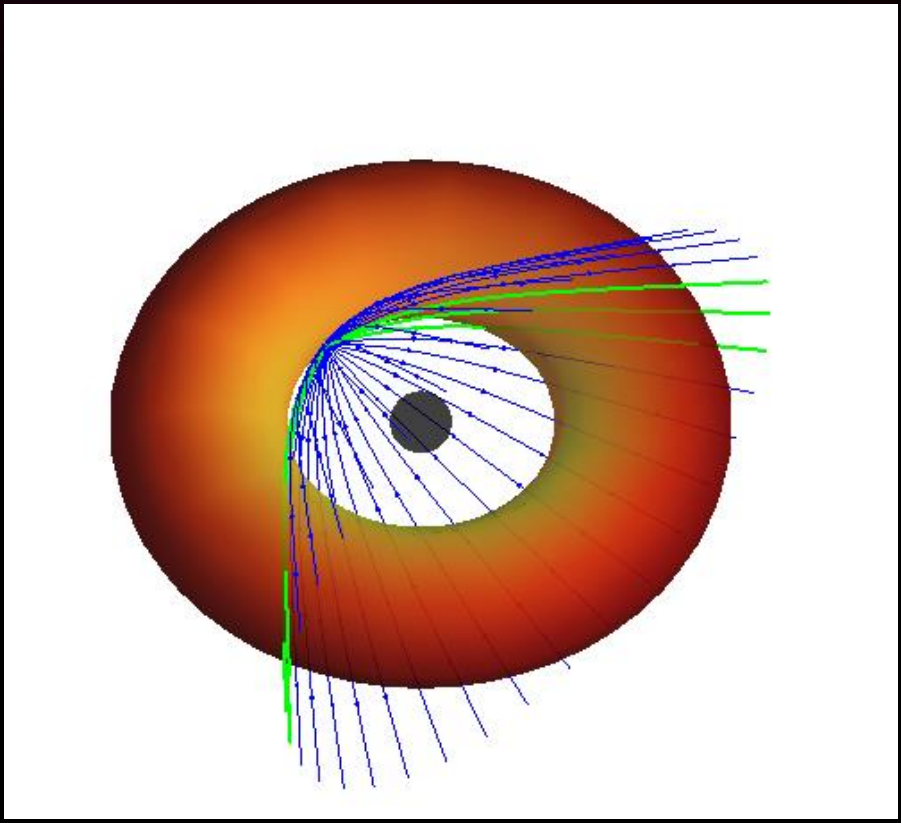

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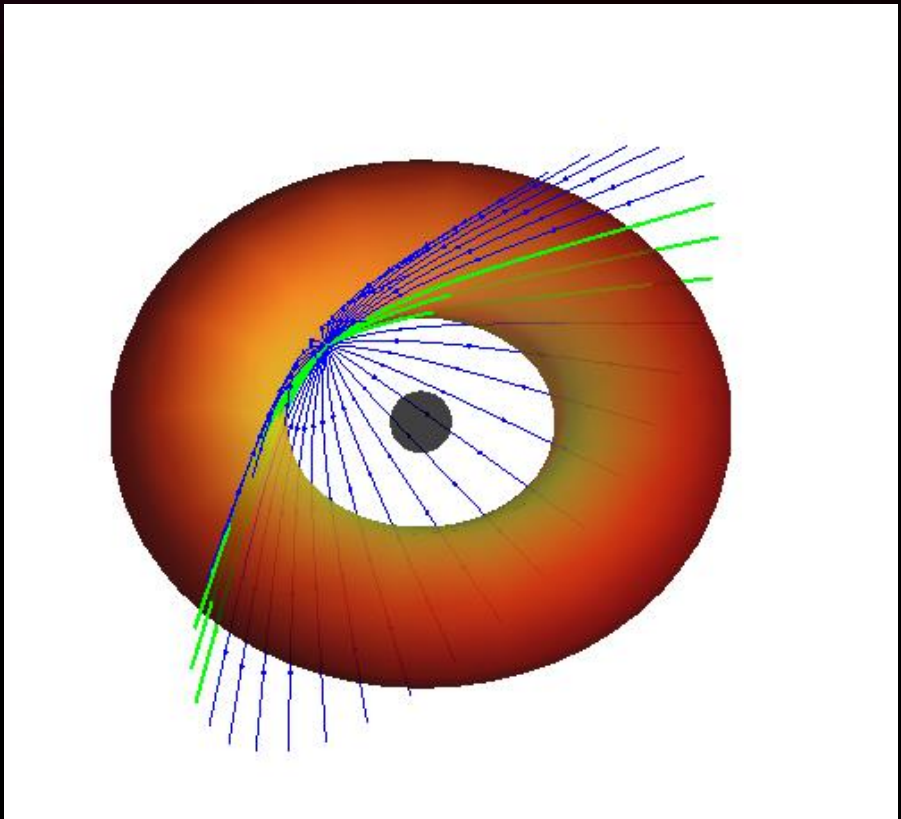

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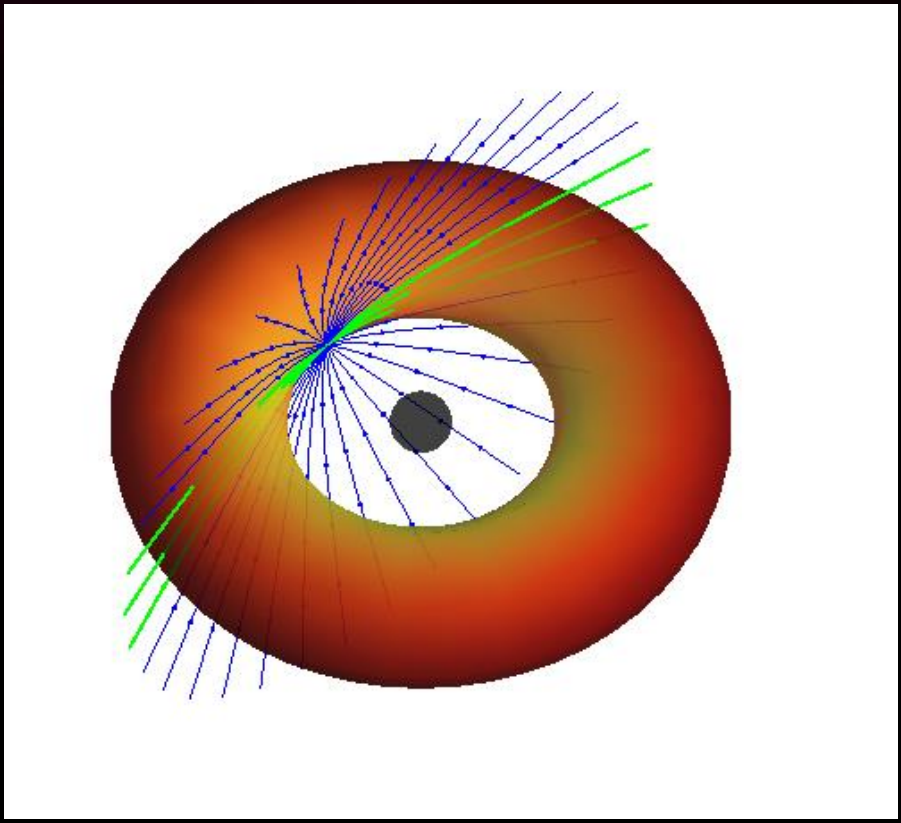

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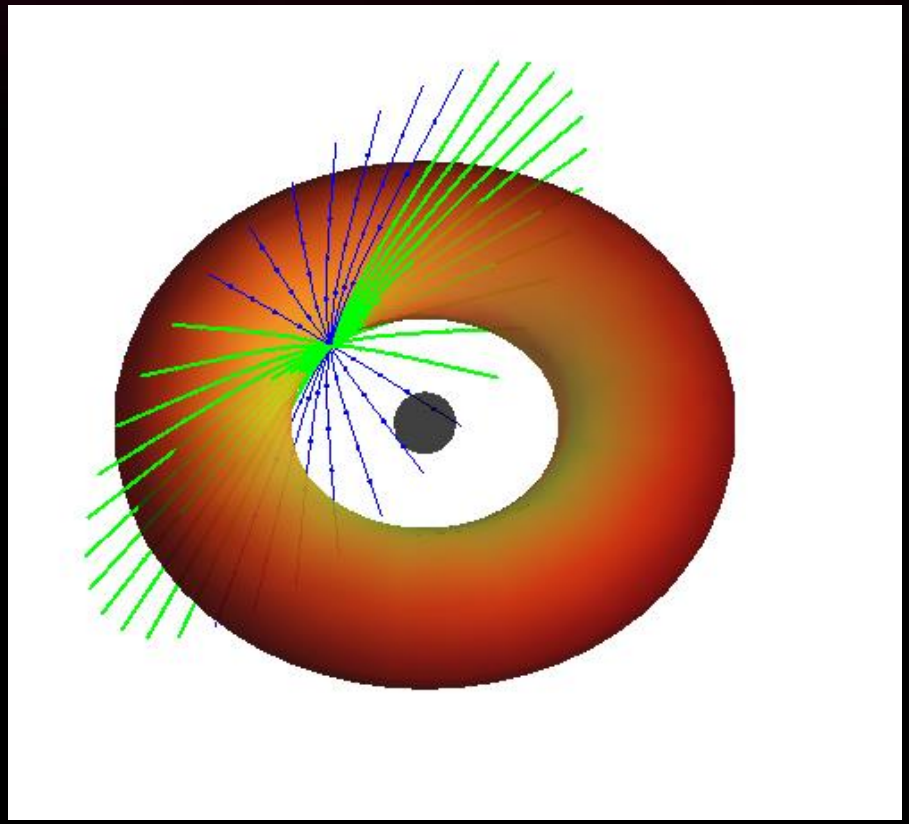

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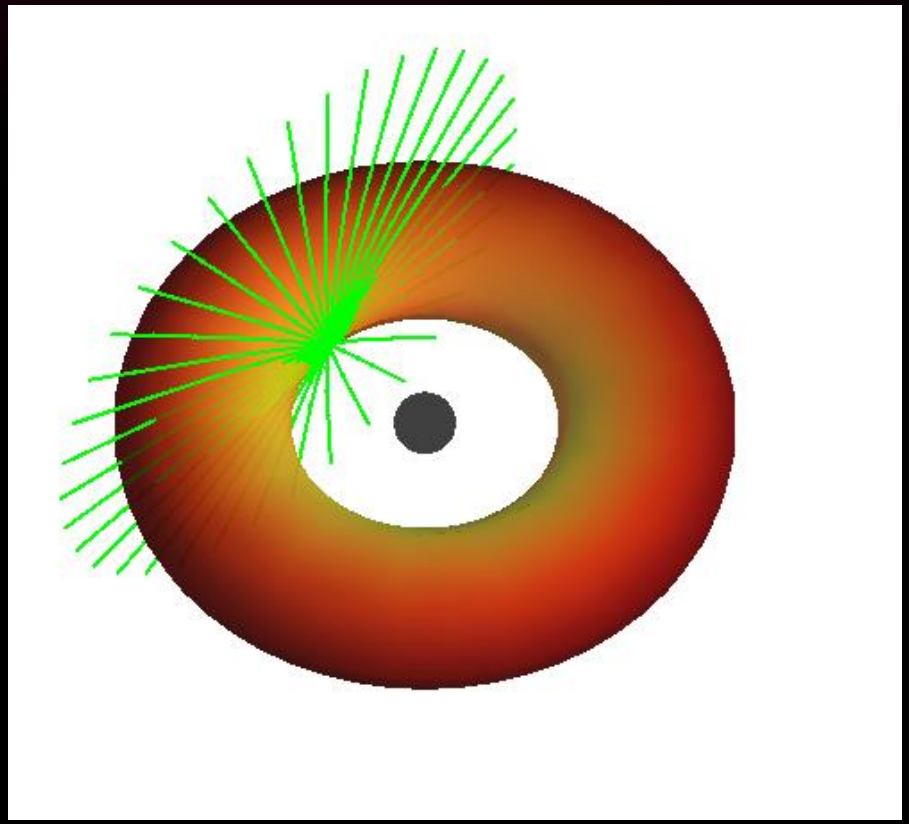

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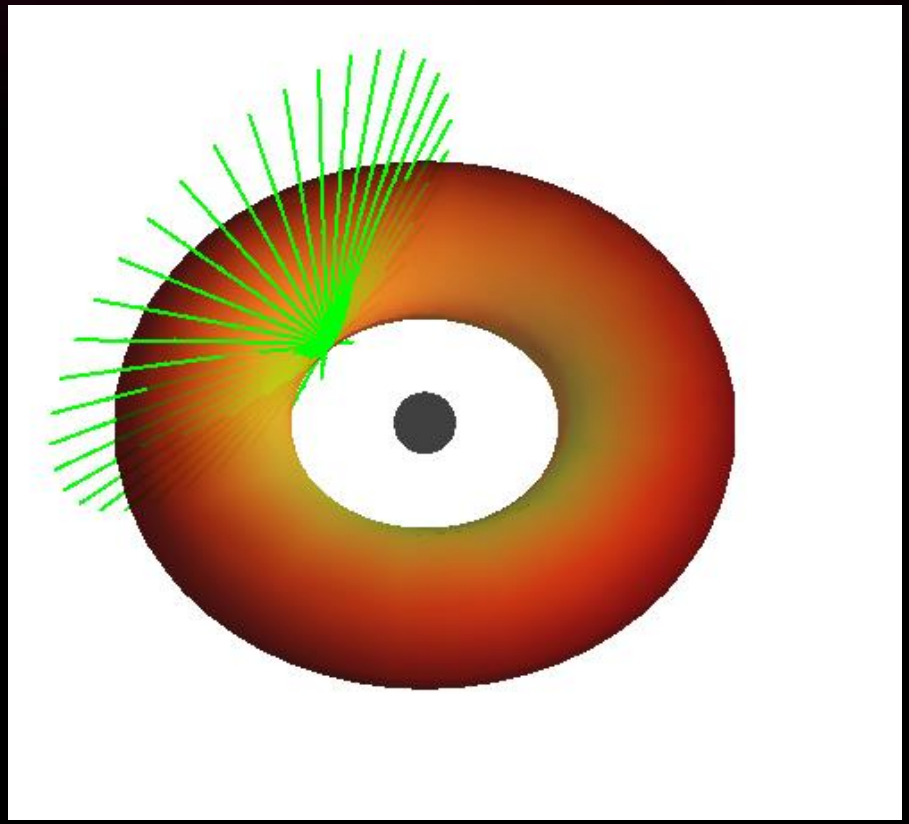

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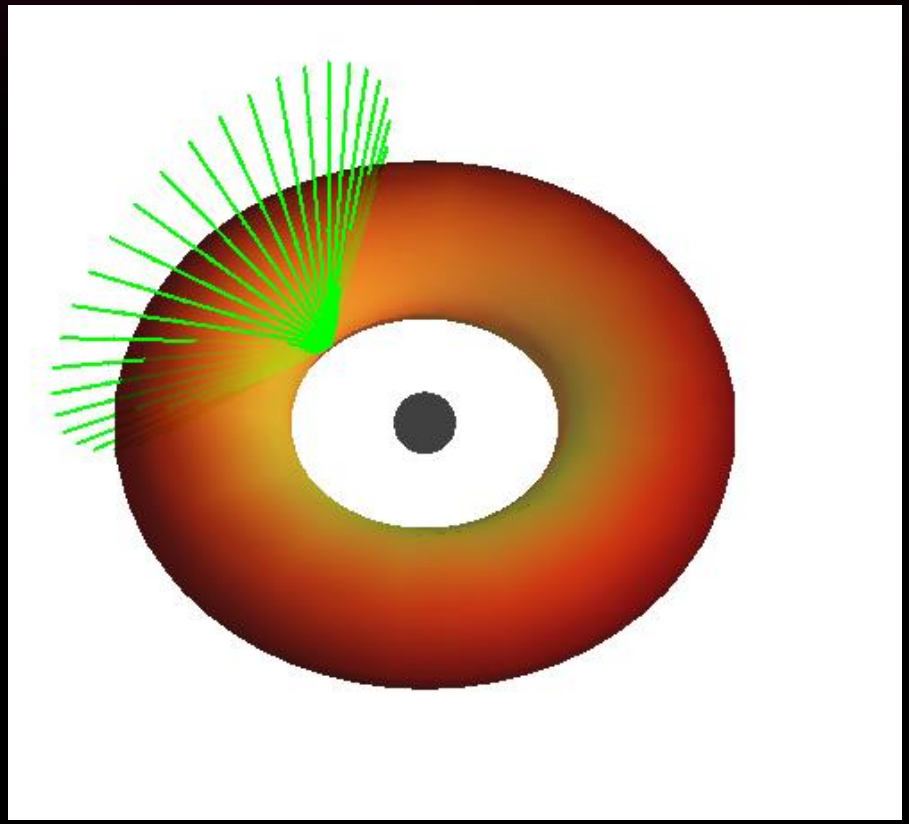

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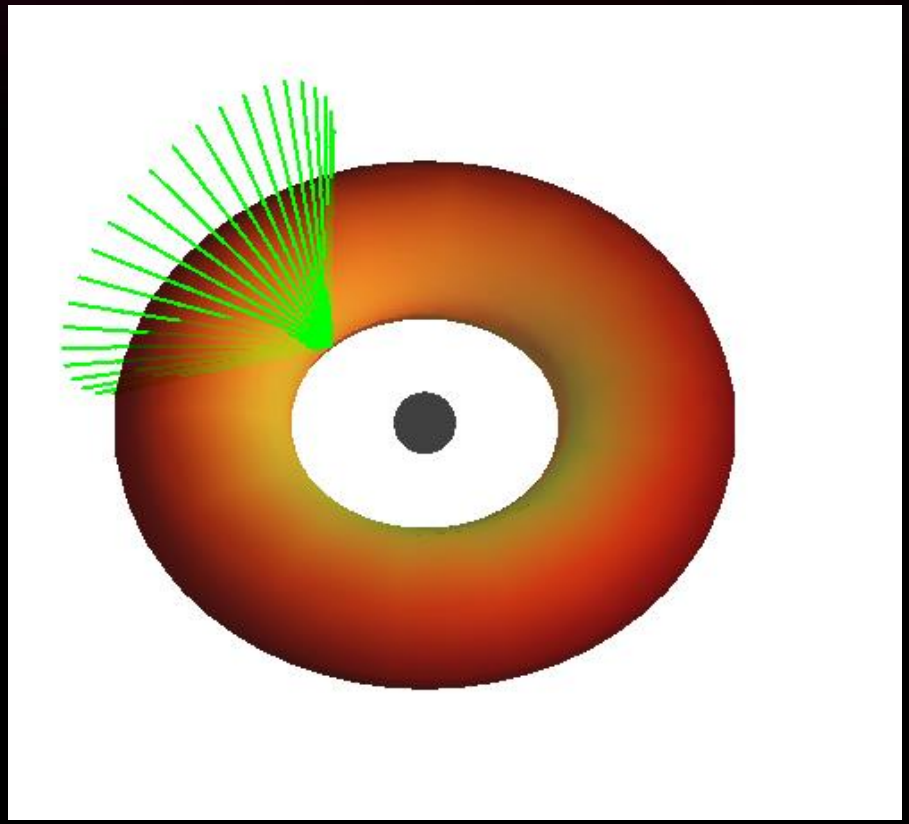

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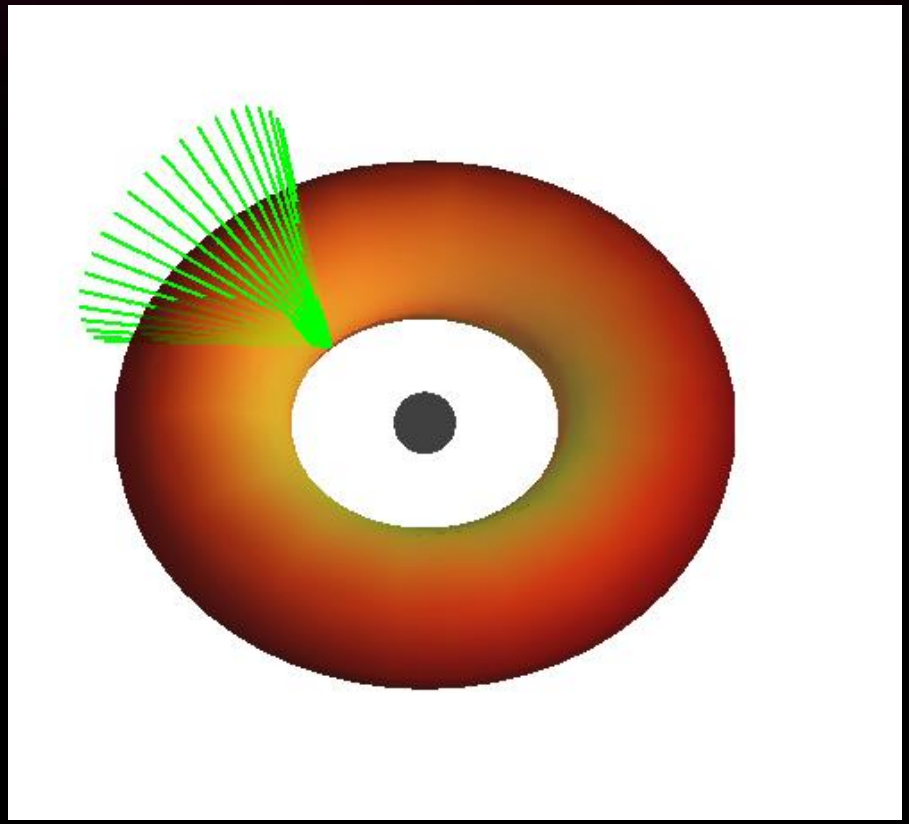

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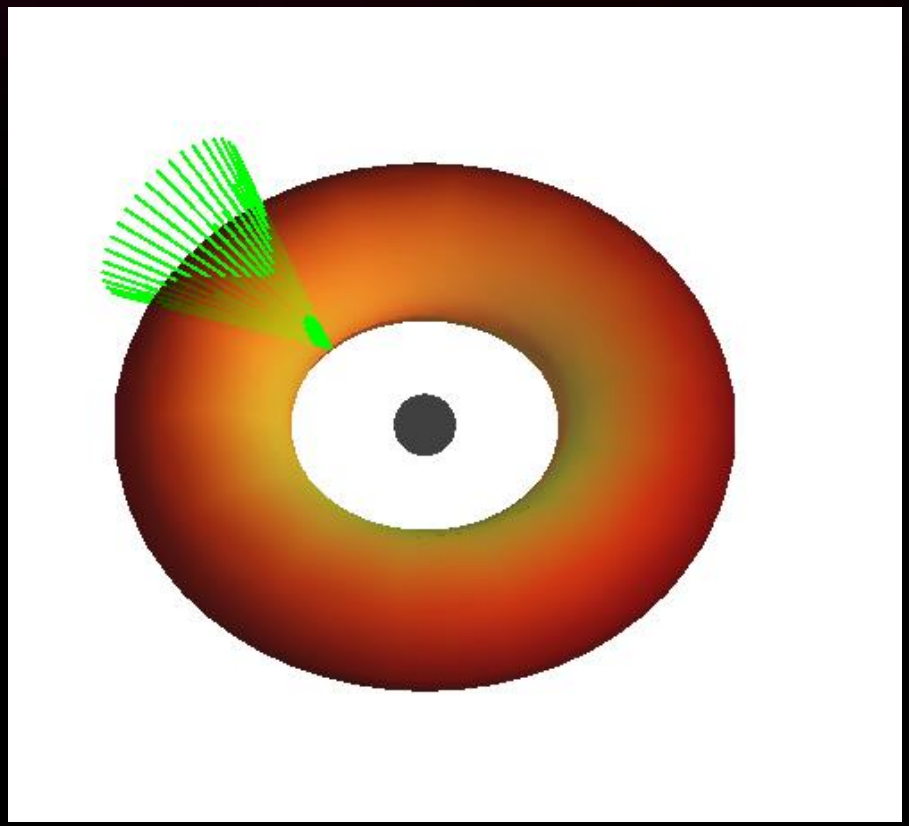

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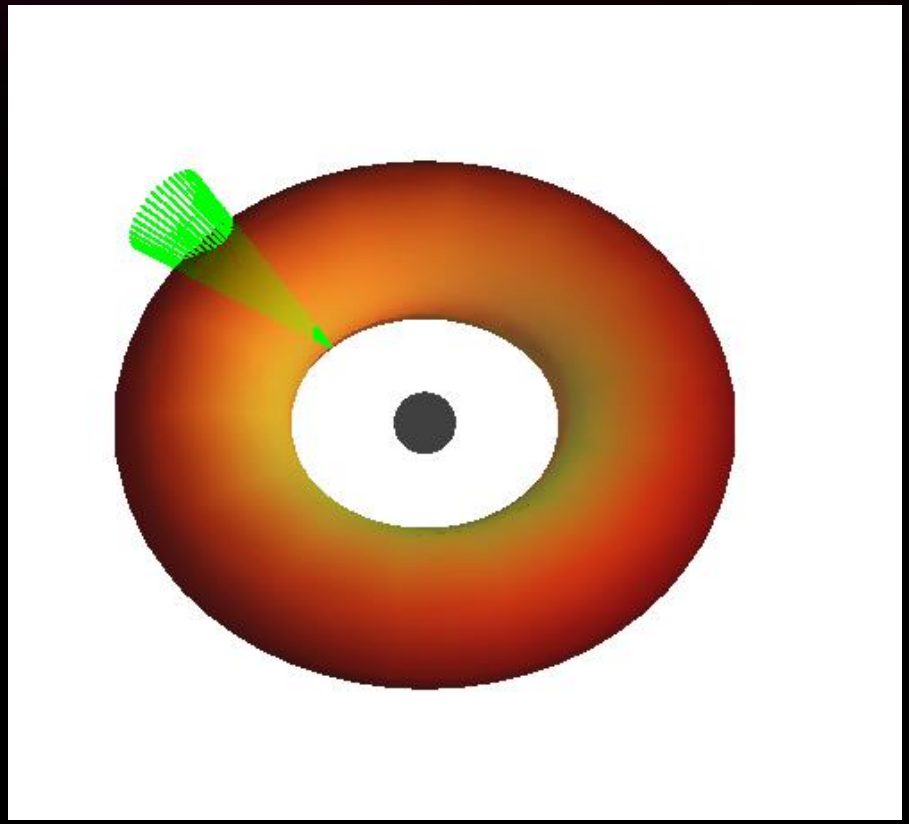

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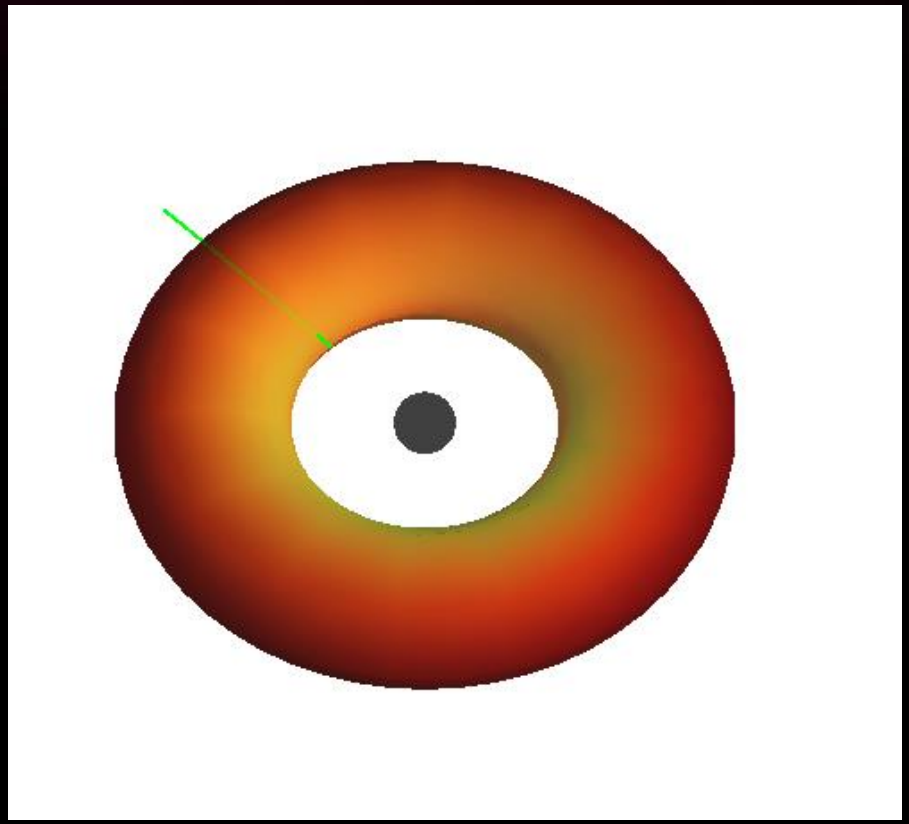
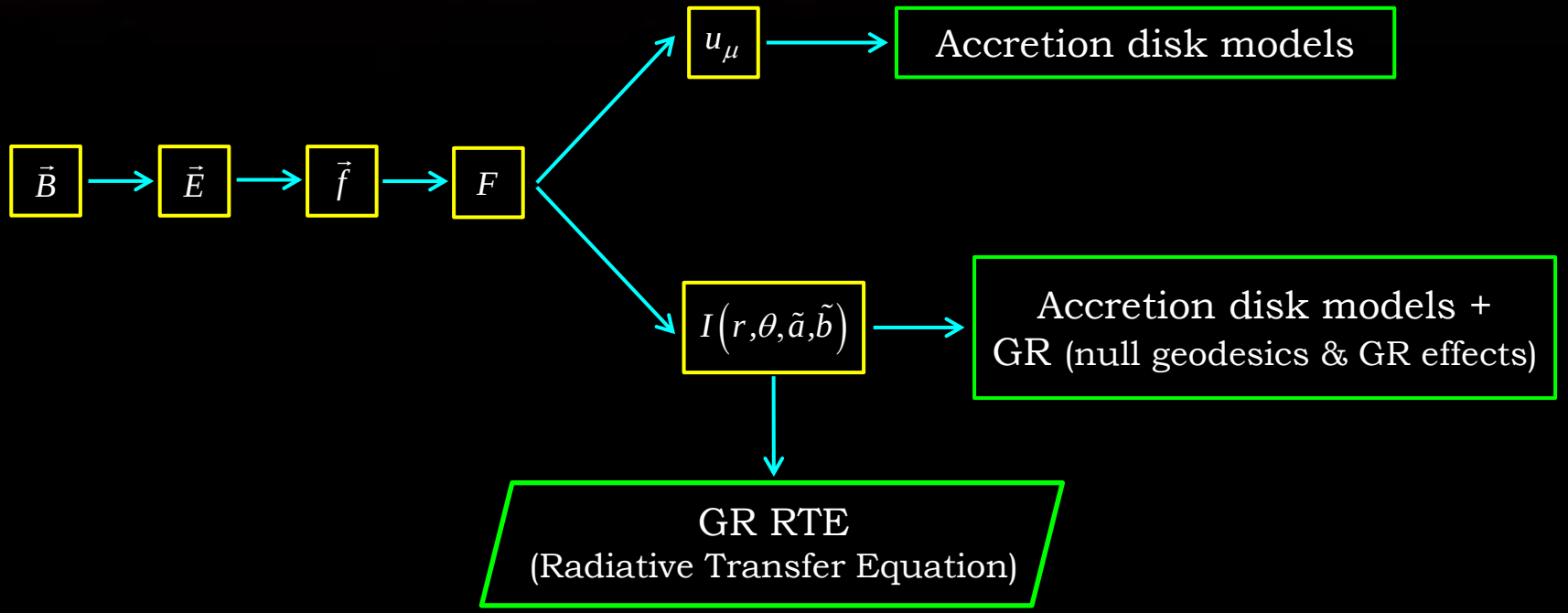
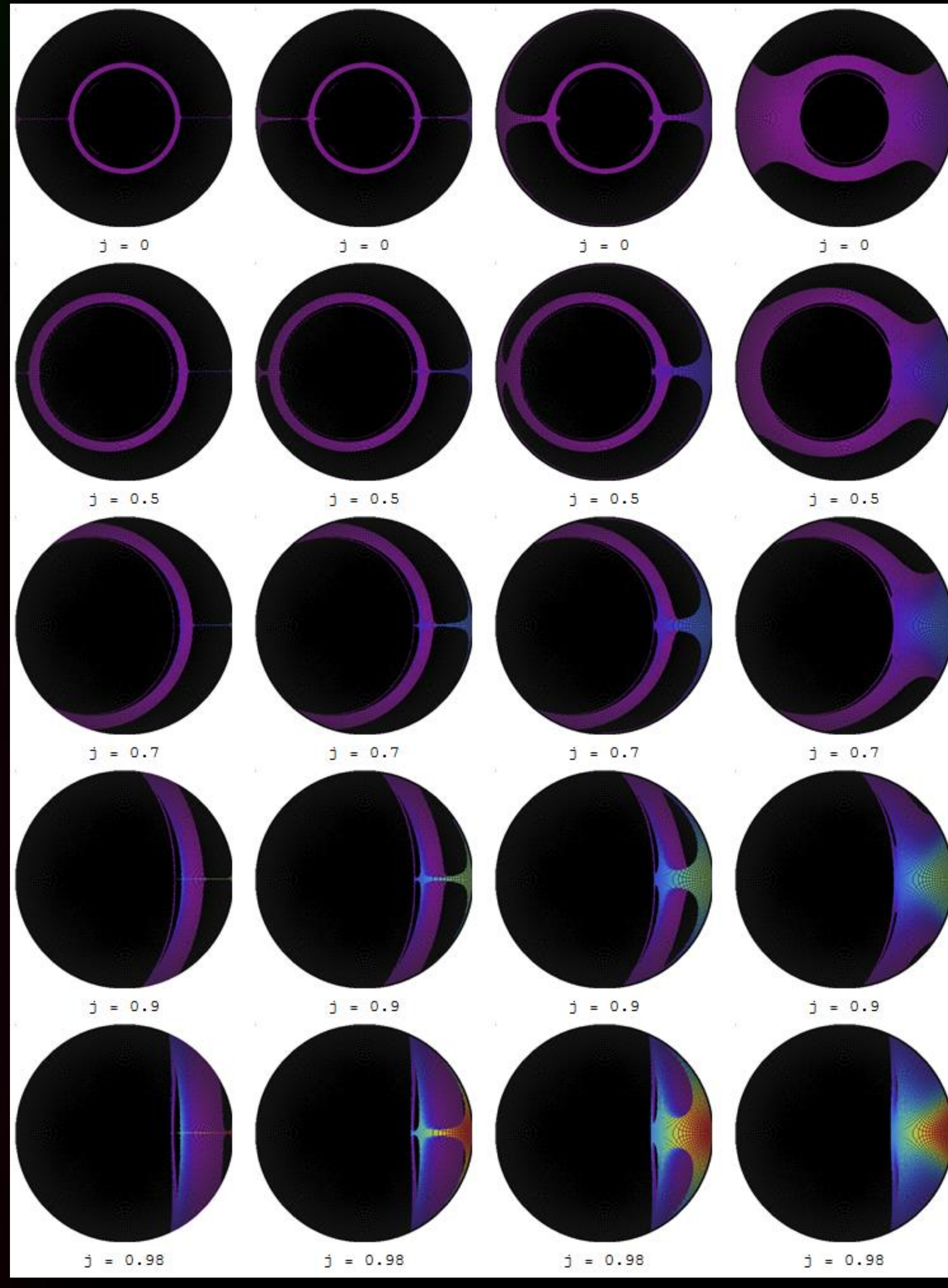


- In order to examine the Cosmic Battery model we need:



RESULTS

SKY MAPS – optically thick disk



Koutsantoniou, Contopoulos 2014

AZIMUTHAL FORCE & TIMESCALE

Table 2
Normalized Azimuthal Radiation Force $f^{\phi}_{\rm rad}/(GMm_{\rm p}/r^2_{\rm ISCO})$

$j = a/M$	$r_{\rm ISCO}(M)$	Inf. Disk	Thin Disk	Thick Disk	Torus
0	6.000	-0.007	0.003	0.037	0.111
0.1	5.669	−0.008	0.003	0.041	0.122
0.2	5.329	−0.010	0.004	0.047	0.135
0.3	4.979	−0.012	0.004	0.054	0.153
0.4	4.614	−0.014	0.005	0.066	0.178
0.5	4.233	−0.016	0.008	0.083	0.214
0.6	3.829	−0.019	0.017	0.117	0.275
0.7	3.393	−0.020	0.053	0.194	0.382
0.8	2.907	−0.019	0.115	0.344	0.589
0.9	2.321	0.002	0.307	0.833	1.187
0.92	2.180	0.016	0.405	1.075	1.459
0.94	2.024	0.040	0.567	1.464	1.870
0.96	1.843	0.092	0.863	2.179	2.576
0.98	1.614	0.242	1.638	3.979	4.171

Azimuthal force / "gravity"

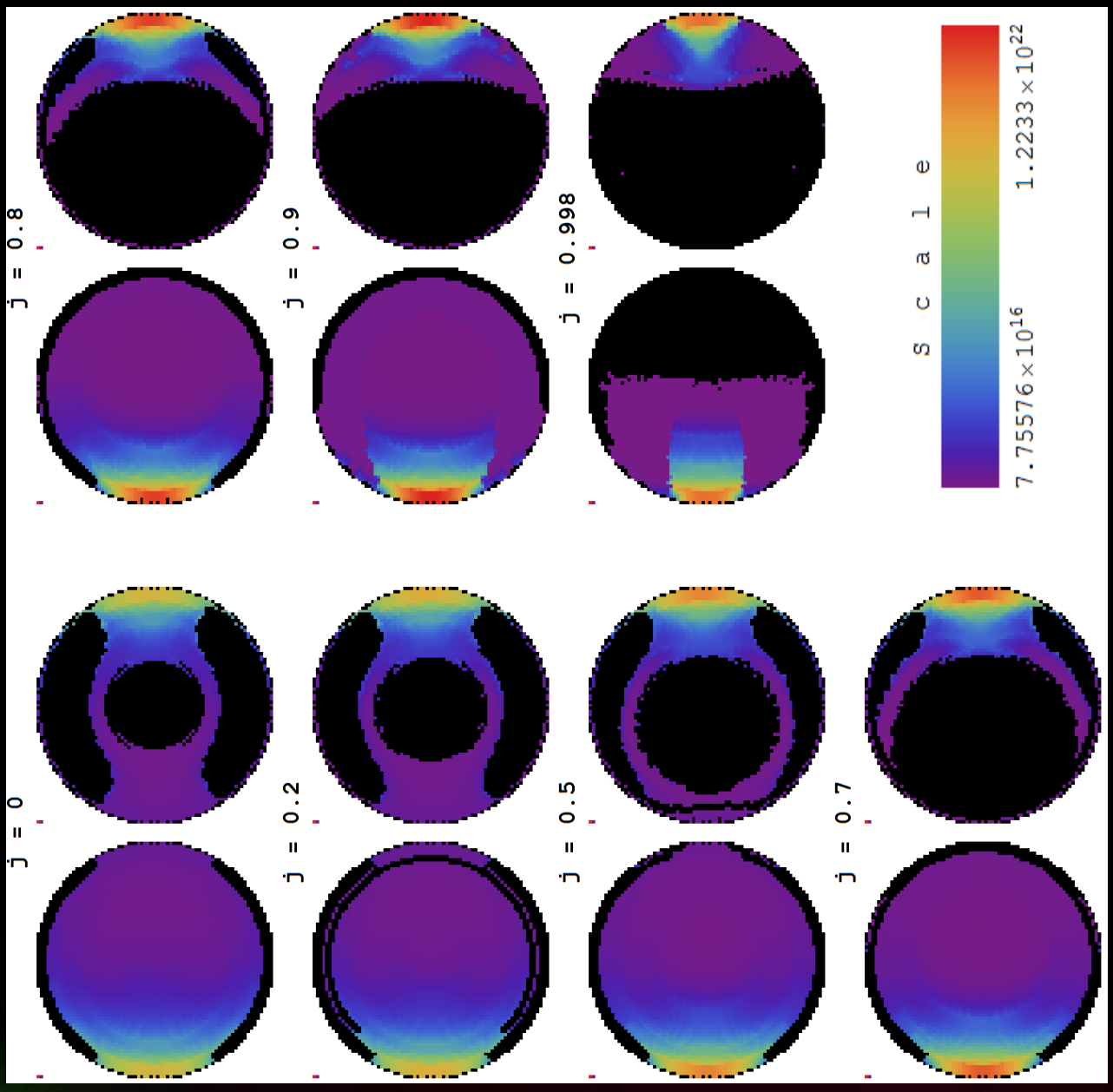
Table 4
Cosmic Battery Timescales $t_{\rm CB} = (e\mathcal{B}_o r_{\rm ISCO}/\alpha_{\rm ISCO} f^{\hat{\phi}}_{\rm rad} c)$ (in hours)

$j = a/M$	$r_{\rm ISCO}(M)$	Inf. Disk	Thin Disk	Thick Disk	Torus
0	6.000	625	1532	115	39
0.1	5.669	440	1282	92	31
0.2	5.329	301	1130	72	25
0.3	4.979	213	1348	55	19
0.4	4.614	143	1610	40	15
0.5	4.233	93	2796	29	11
0.6	3.829	58	537	19	8
0.7	3.393	34	46	10	5
0.8	2.907	18	19	5	3
0.9	2.321	7	8	3	2
0.92	2.180	5	6	2	2
0.94	2.024	4	5	2	1
0.96	1.843	3	4	1	1
0.98	1.614	2	3	1	1

Timescale in hours for generation of $B = 10^7$ G around a 5 $M_\odot$ black hole

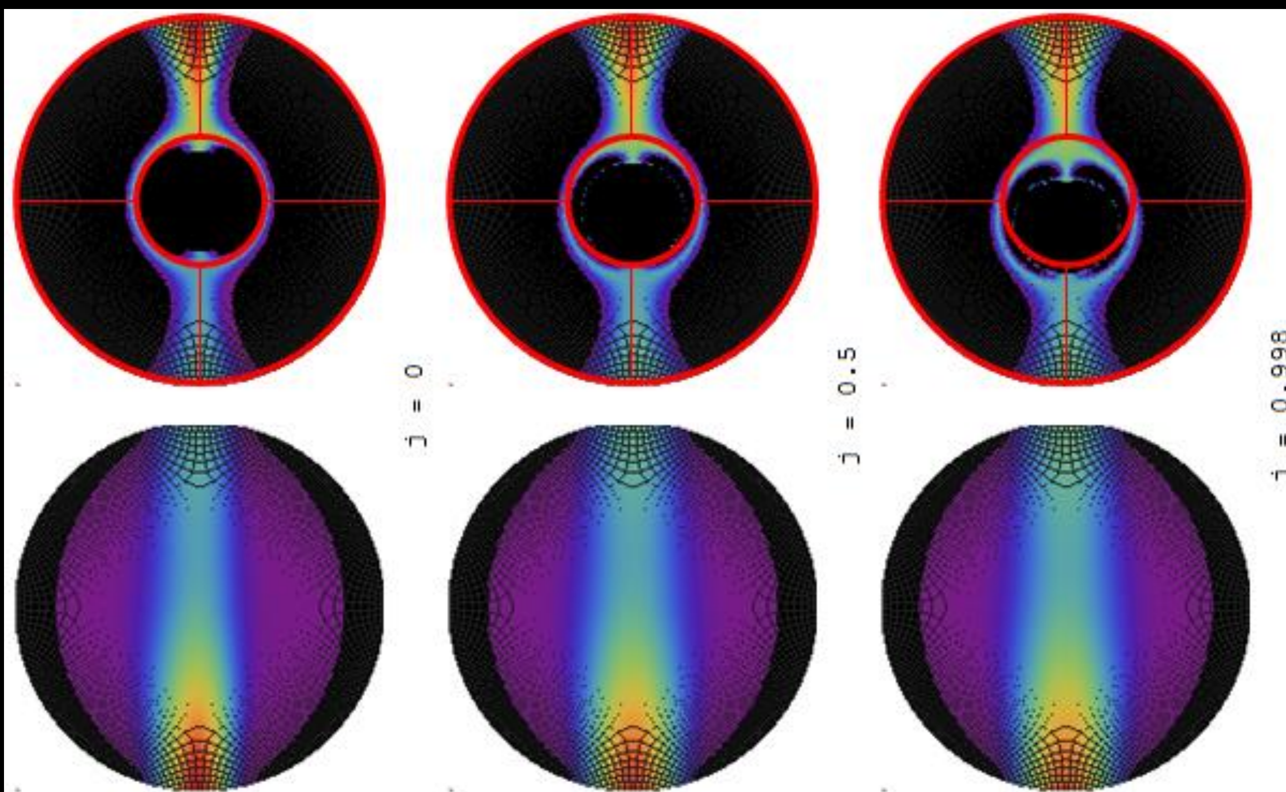
Koutsantoniou, Contopoulos 2014

SKY MAPS – optically thin disk



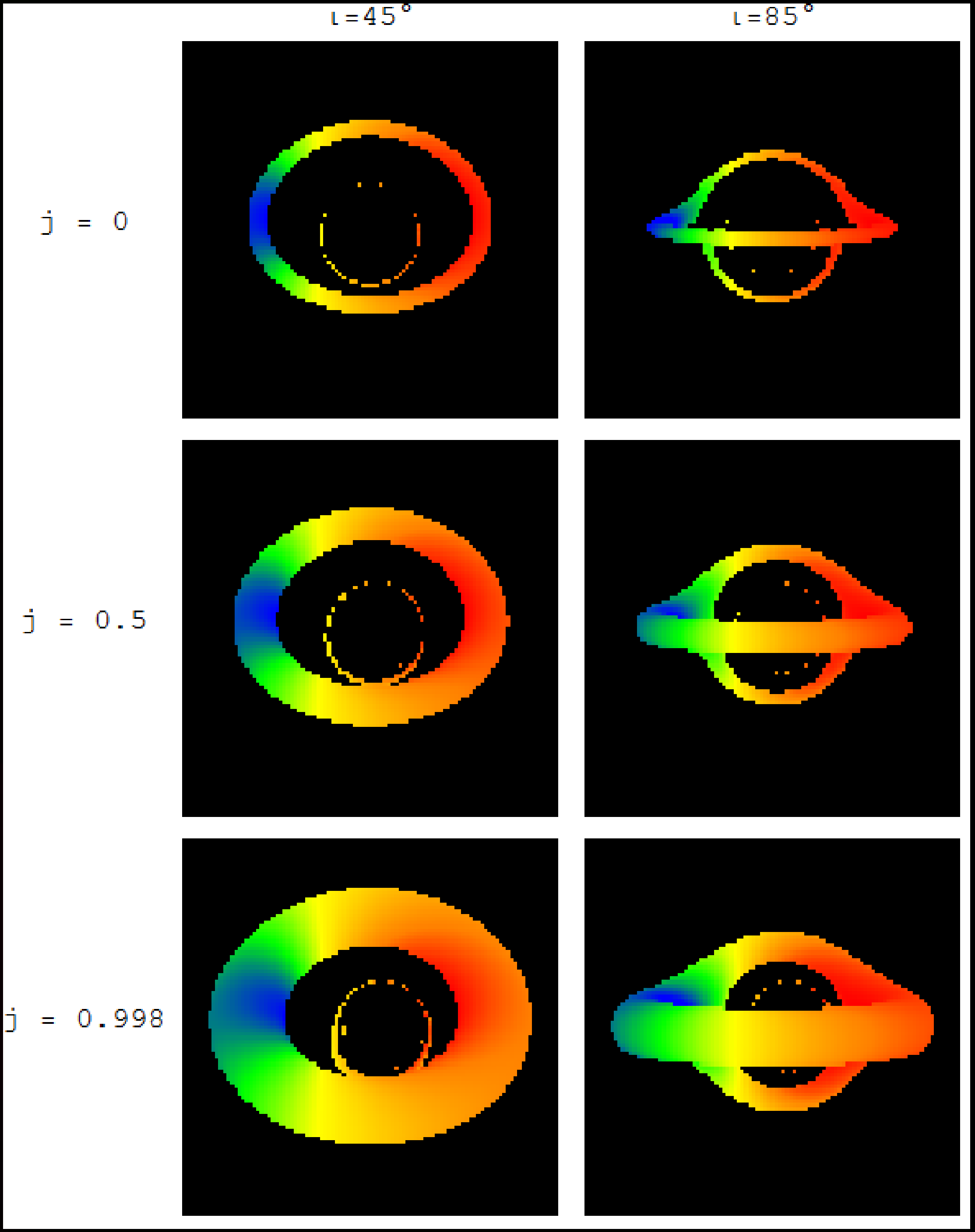
Koutsantonίou, Contopoulos 2015, in prep.

SKY MAPS – polish donut



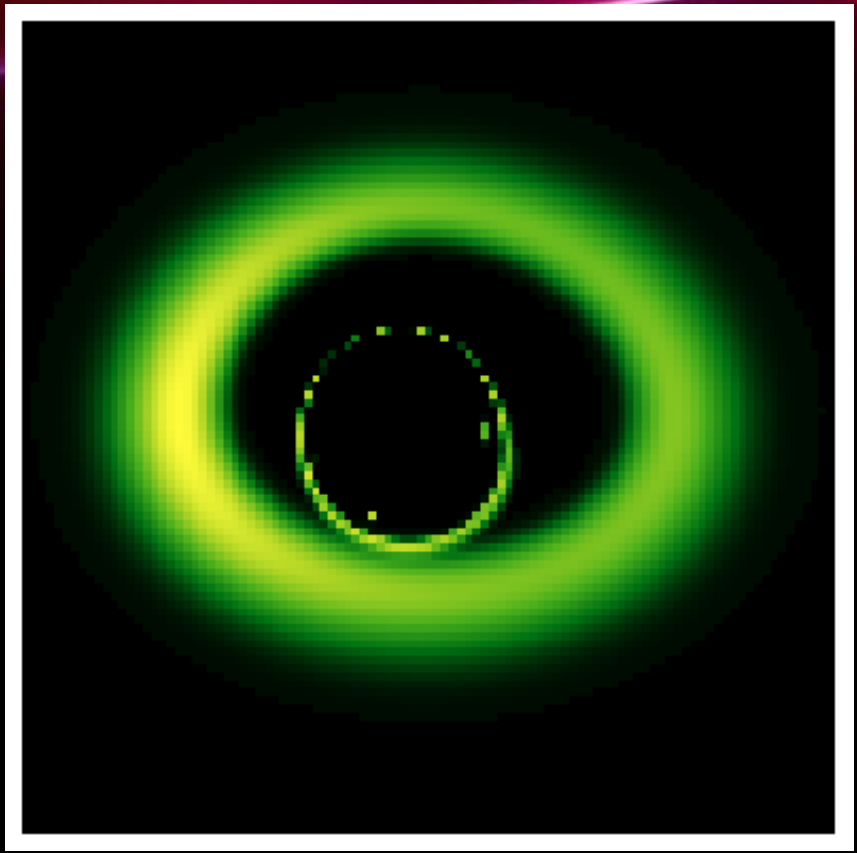
Koutsantoniou, Contopoulos 2015, in prep.

EHT – optically thick disk

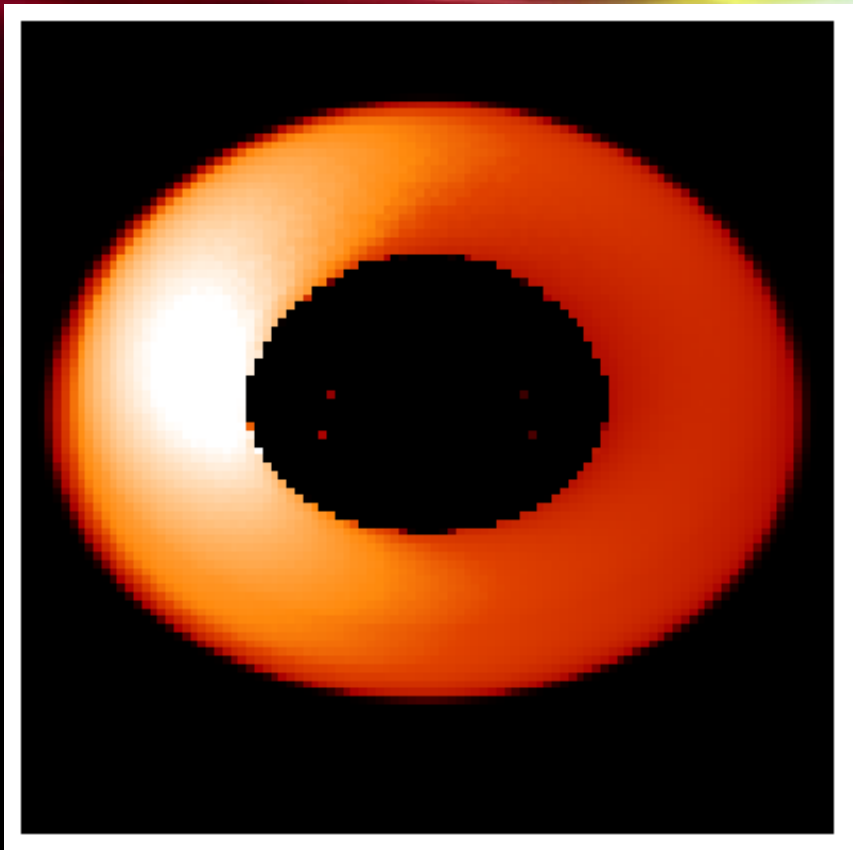


Koutsantoniou, Contopoulos 2015, in prep.

EHT – disk with optical depth



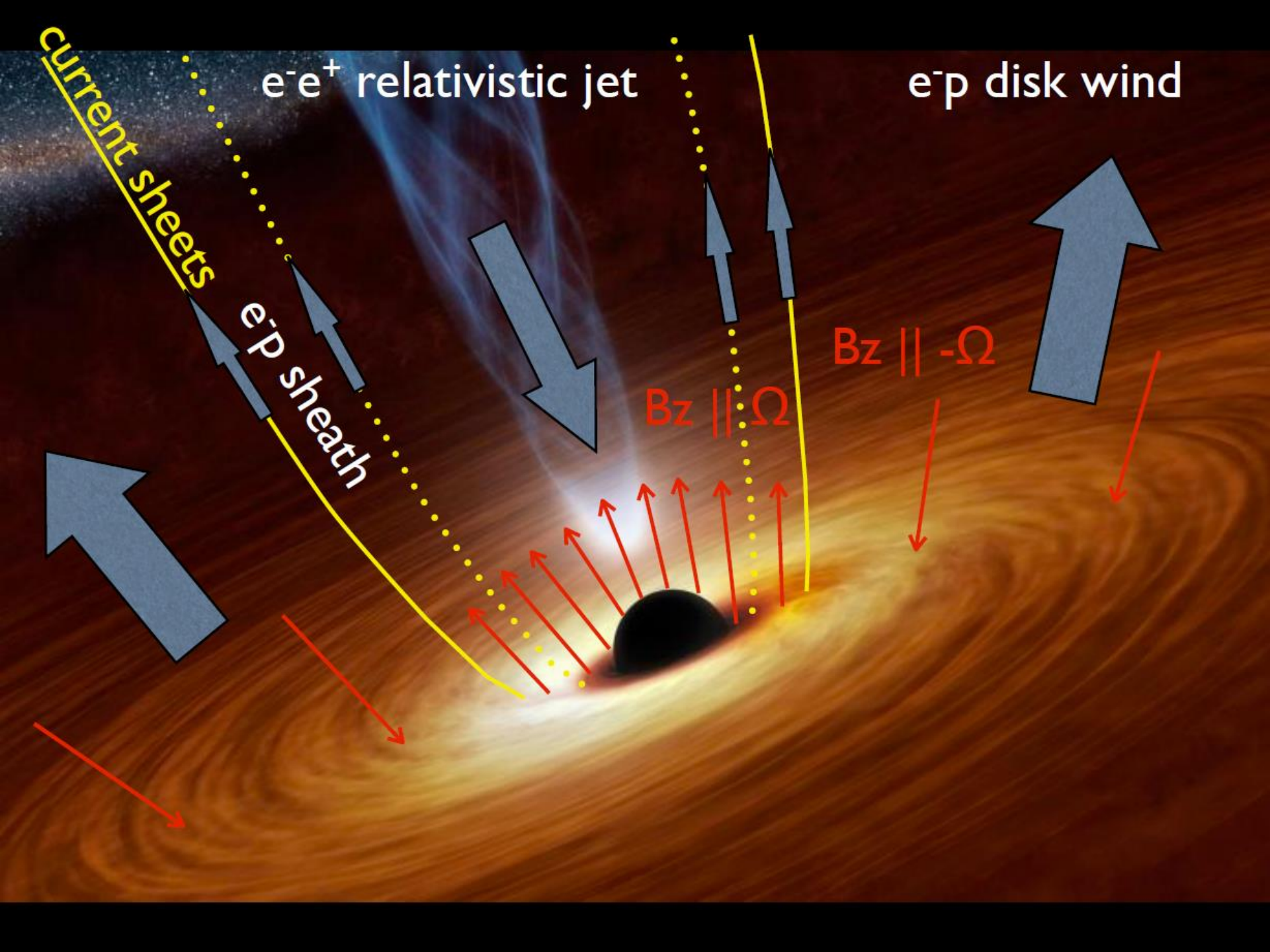
Translucent disk (no absorption)



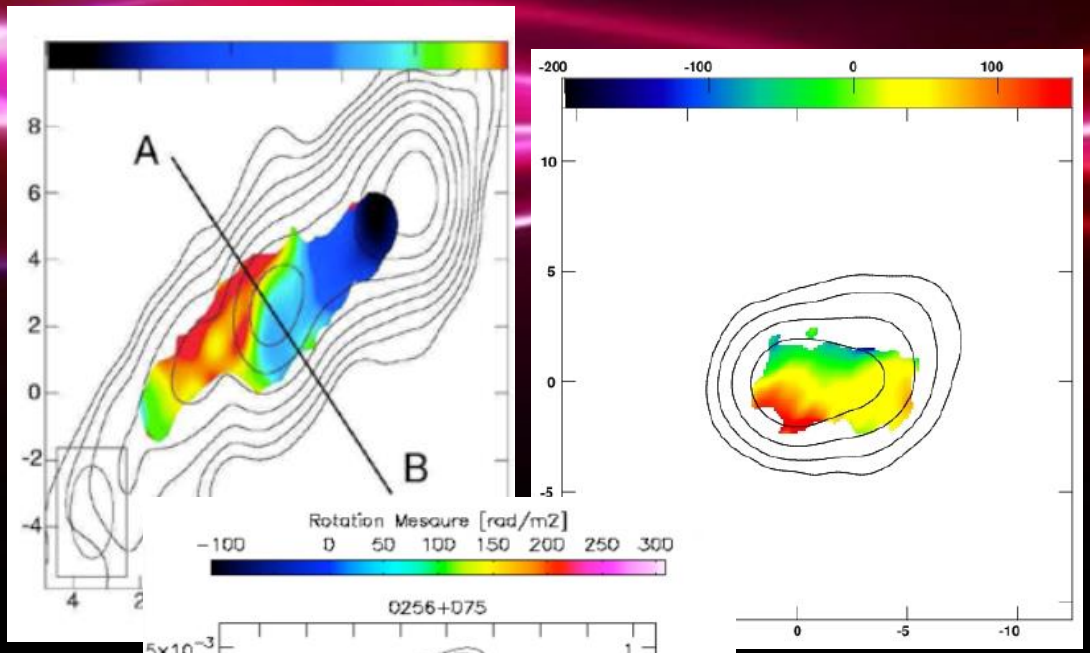
Disk with finite absorption

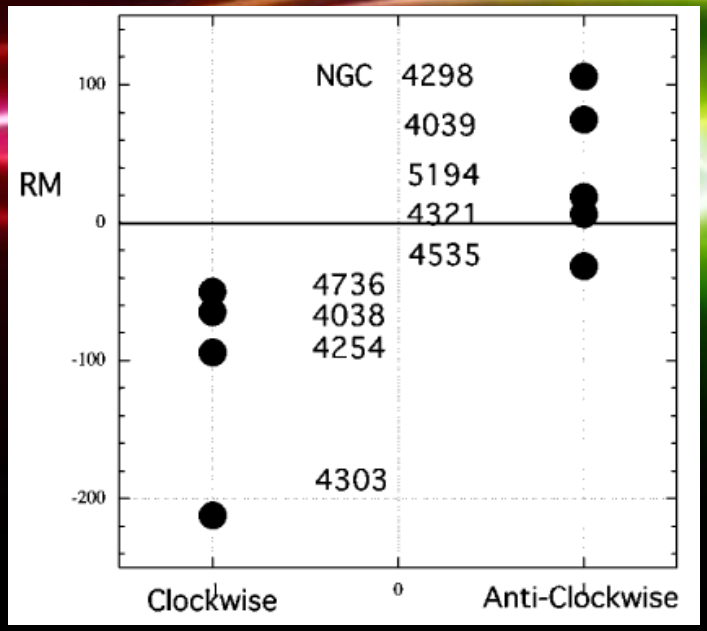
Koutsantoniou, Contopoulos 2015, in prep.

OBSERVATIONS

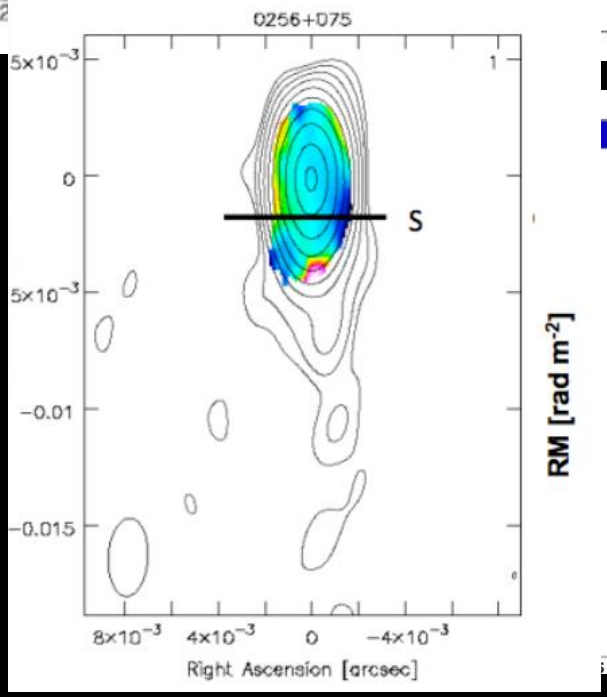

current sheets
e⁻e⁺ relativistic jet
e⁻p disk wind
e⁻p sheath
Bz || Ω
Bz || -Ω

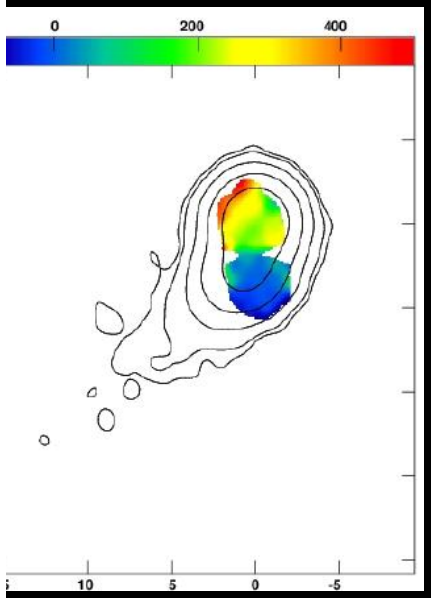
OBSERVATIONS





Lynden-Bell 2013:
"Magnetism along spin"



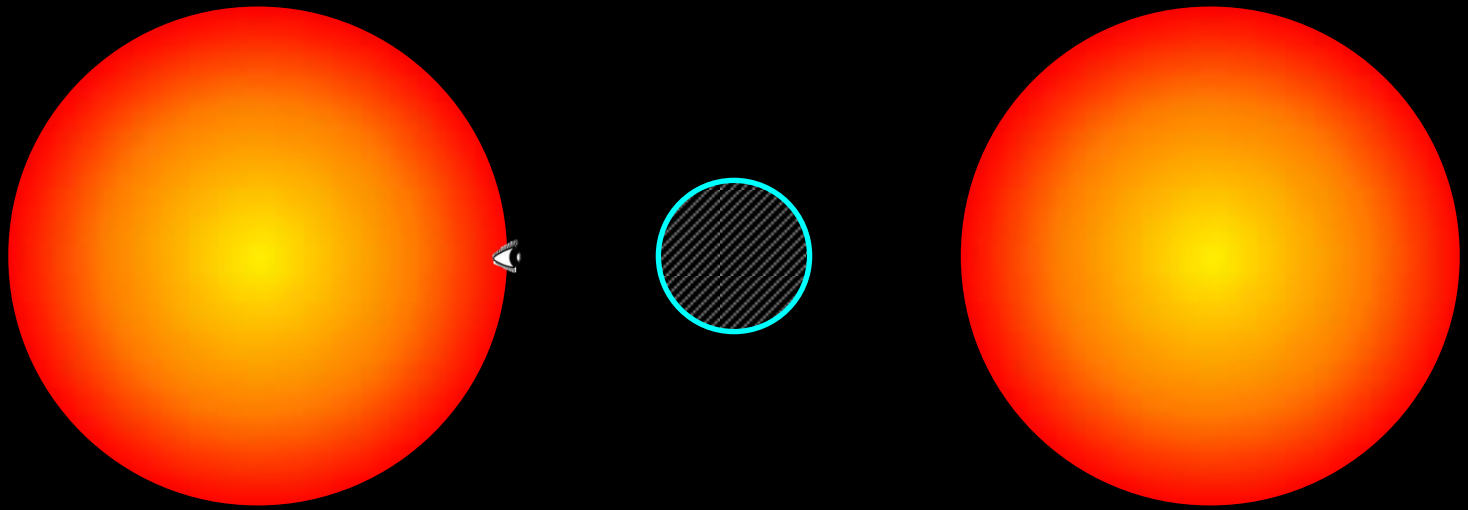


Gabuzda & collaborators

Universal mechanism for the MF generation!

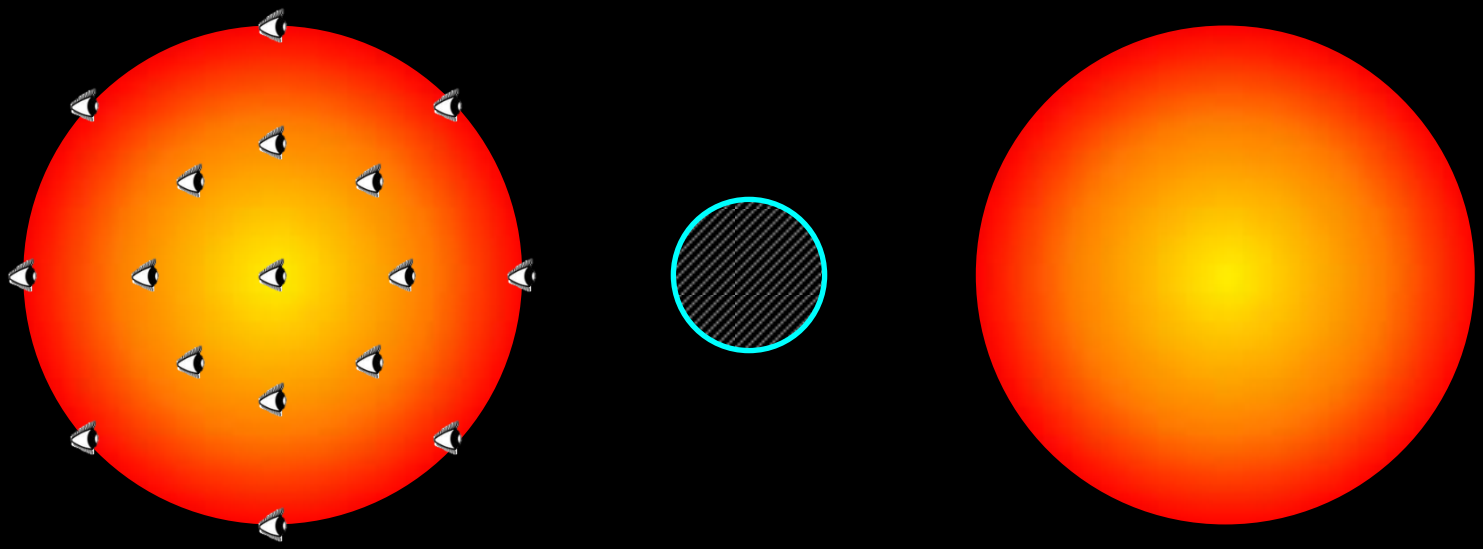
CURRENT & FUTURE WORK

- Running simulations with finite optical depth and the target particle at the ISCO.



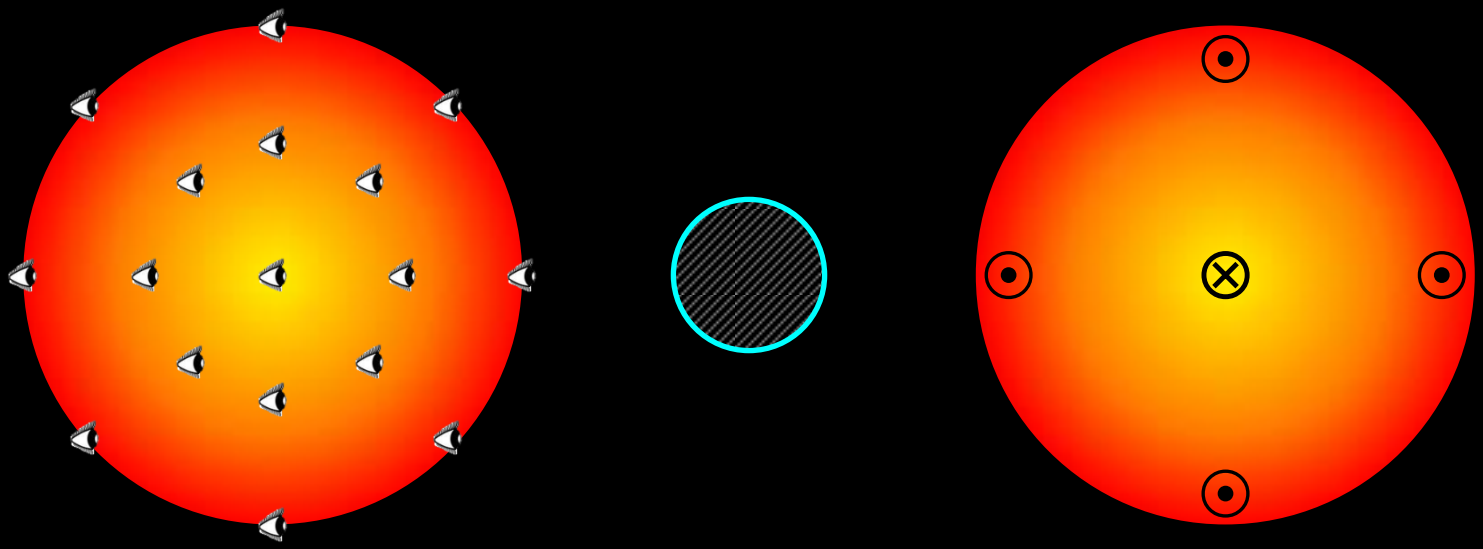
CURRENT & FUTURE WORK

- Running simulations with finite optical depth and the target particle at the ISCO.
- Run the same simulations for various parts inside the disk.



CURRENT & FUTURE WORK

- Running simulations with finite optical depth and the target particle at the ISCO.
- Run the same simulations for various parts <u>inside</u> the disk.
- Observe time evolution of the magnetic field growth and lines.



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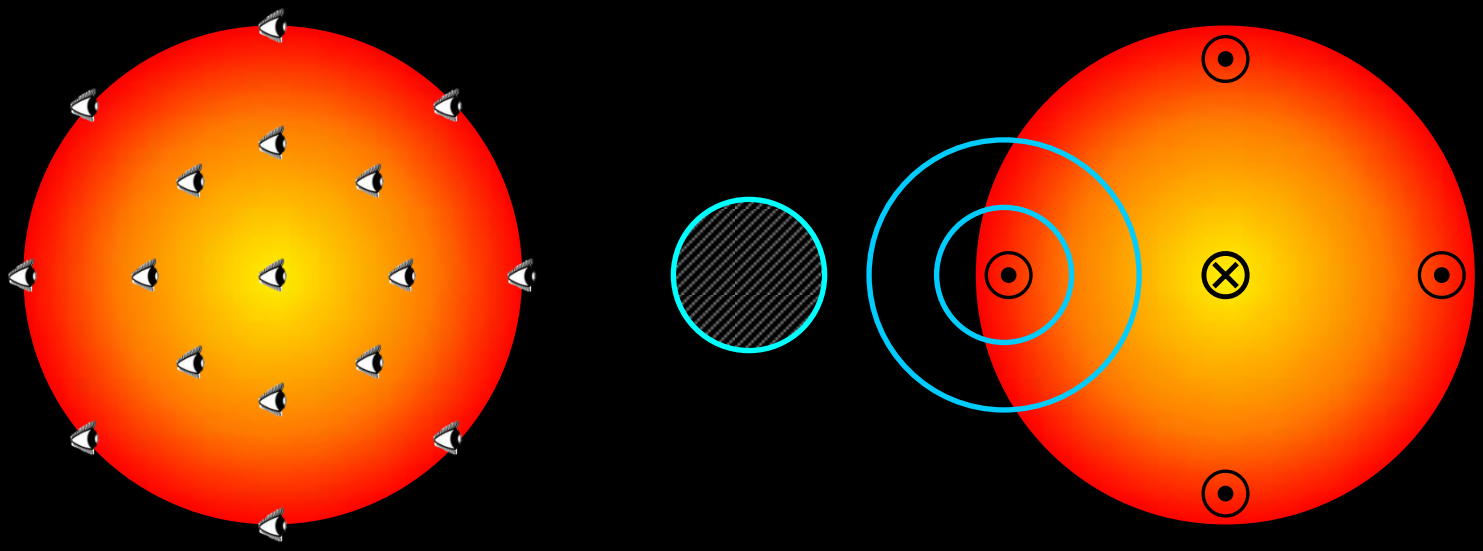

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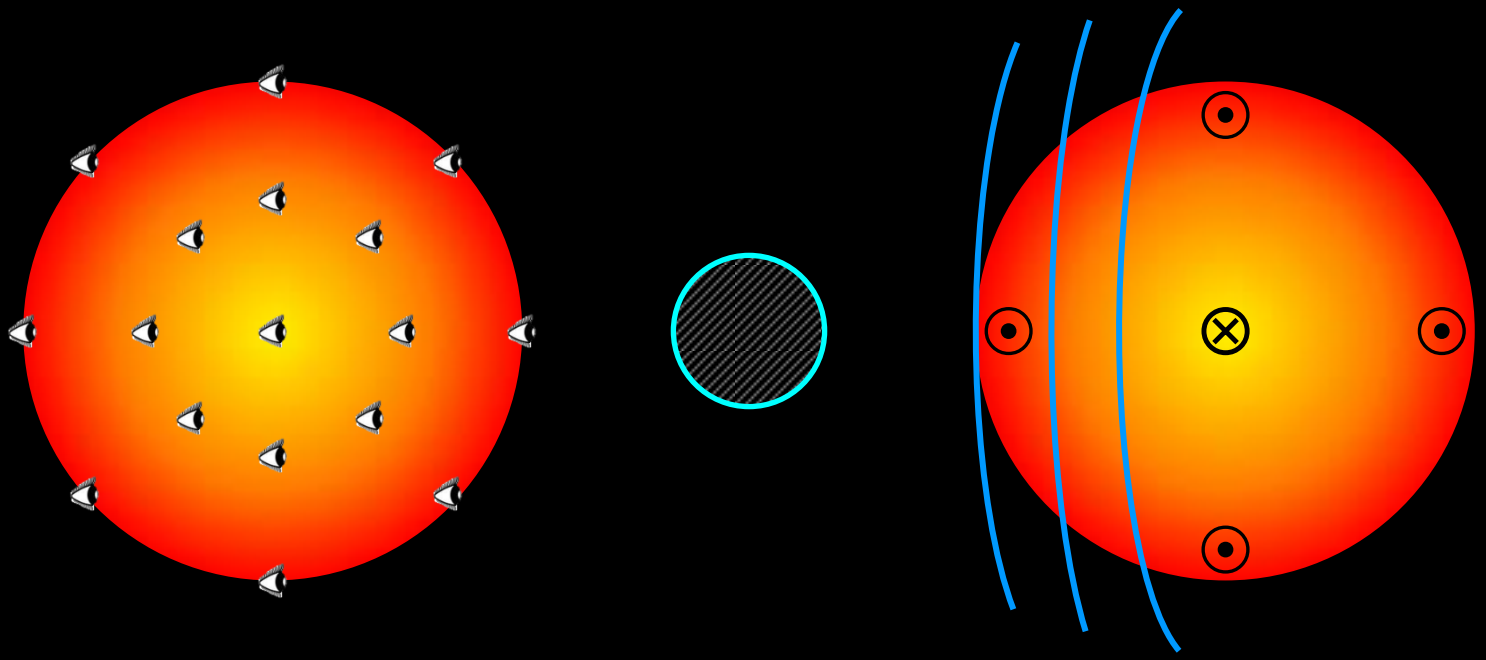

CURRENT & FUTURE WORK

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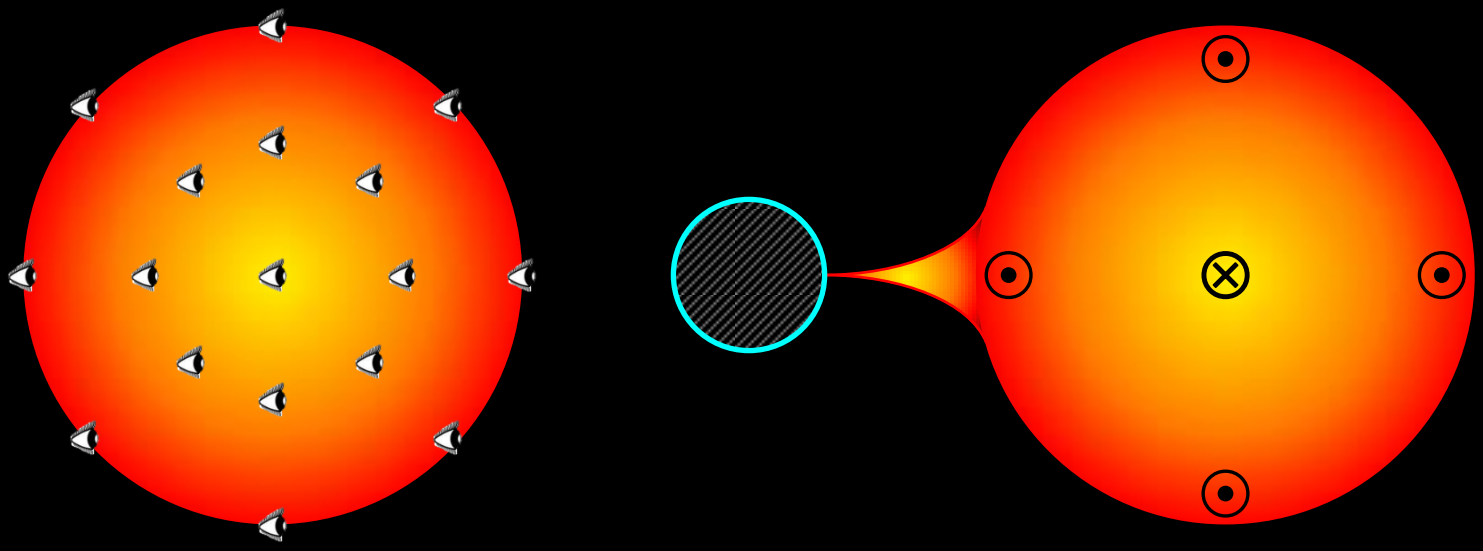
- Run the same simulations for various parts inside the disk.
- Observe time evolution of the magnetic field growth and lines.
- Calculate the impact of the radiation & magnetic field on the disk dynamics.



COMMENTS & CONCLUSIONS

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- It appears that the Cosmic Battery mechanism could produce astrophysically important magnetic fields from scratch and diffuse them outwards.
- Even if in some environments it's not as effective, it can still provide the seed magnetic field required for a dynamo process to kick in.
- Observational data are in favor of a global battery-like mechanism that produces magnetic fields in the Universe. (FRM, spin – magnetization alignment, …)
- Agrees and could(?) explain the HID (q-diagram) along with the existence and destruction of jets in X-ray binaries or similar set-ups.
- Depending on the spin parameter, the phenomenon may change sign! Cases where $f \sim 0$ are particularly interesting.
- Still a lot of work to be done: General Relativity, Plasma Astrophysics, Radiation, 3D simulations (inside the disk, over & under the disk), time evolution, …

THANK YOU

leelamk@phys.uoa.gr

Curving on the edge of daylight
Till it slips into the void
Waited in the long night dreaming
Till the Sun is born again
Stretch the fingers of my hand
Covered country with my span,
Just a lonely satellite
Spec of dust and cosmic sand

Over borders that divide
the earthbound tribes,
No creed and no religion
Just a hundred winged souls…
We will ride this thunderbird
Silver shadows on the Earth
A thousand leagues away
Our land of birth

THANK YOU

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