

Critical Theory &
Interferometric Observation
of the
M87 Photon Ring

strings 2019 Brussels
Andy Strominger

OR

a fun collaboration between theorists/observers,
physicists/astronomers with potential implications
for both our theoretical understanding &
future space VLBI observation of black holes.

M. Johnson, A. Lupasasca, A.S., G. Wong, S. Hadar, D. Kapec, D. Palumbo,
R. Narayan, A. Chael, C. Gamie, S. Doeleman, L. Blackburn, M. Wielgus,
P. Galison, D. Pesce, J. Farah & J. Moran

the talk not given

Asymptotic symmetries give powerful recursion relations for gauge-gravity celestial OPEs

$$\sigma_{\Delta_1}^a(z_1) \sigma_{\Delta_2}^b(z_2) \sim \frac{f^{abc}}{z_1 - z_2} \sigma_{\Delta_1 + \Delta_2 - 1}^c(z_2) \frac{\Gamma(\Delta_1 - 1) \Gamma(\Delta_2 - 1)}{\Gamma(\Delta_1 + \Delta_2 - 2)}$$

in some cases completely determining them!

M. Pate, A. Raclariu, A.S., E. Yuan

to appear
84HoofT conference

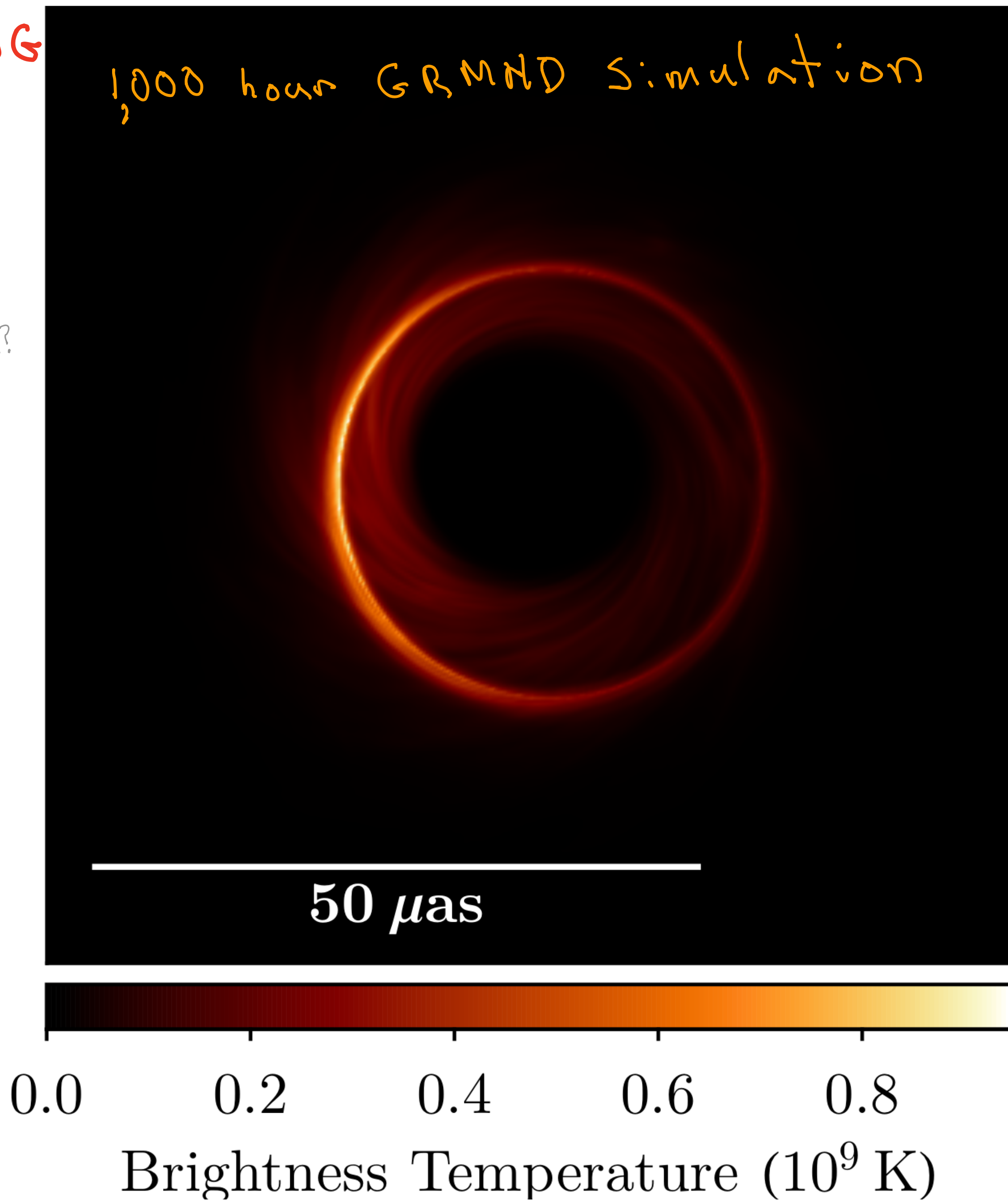


M87, April 10 2019

Event Horizon Telescope Collaboration

Why is the **PHOTON RING** so bright and thin?
Is it a 'brane' or 'holographic screen' of some kind?
Not yet resolved by EHT.
Only ~10% of total flux.

1,000 hour GRMHD simulation

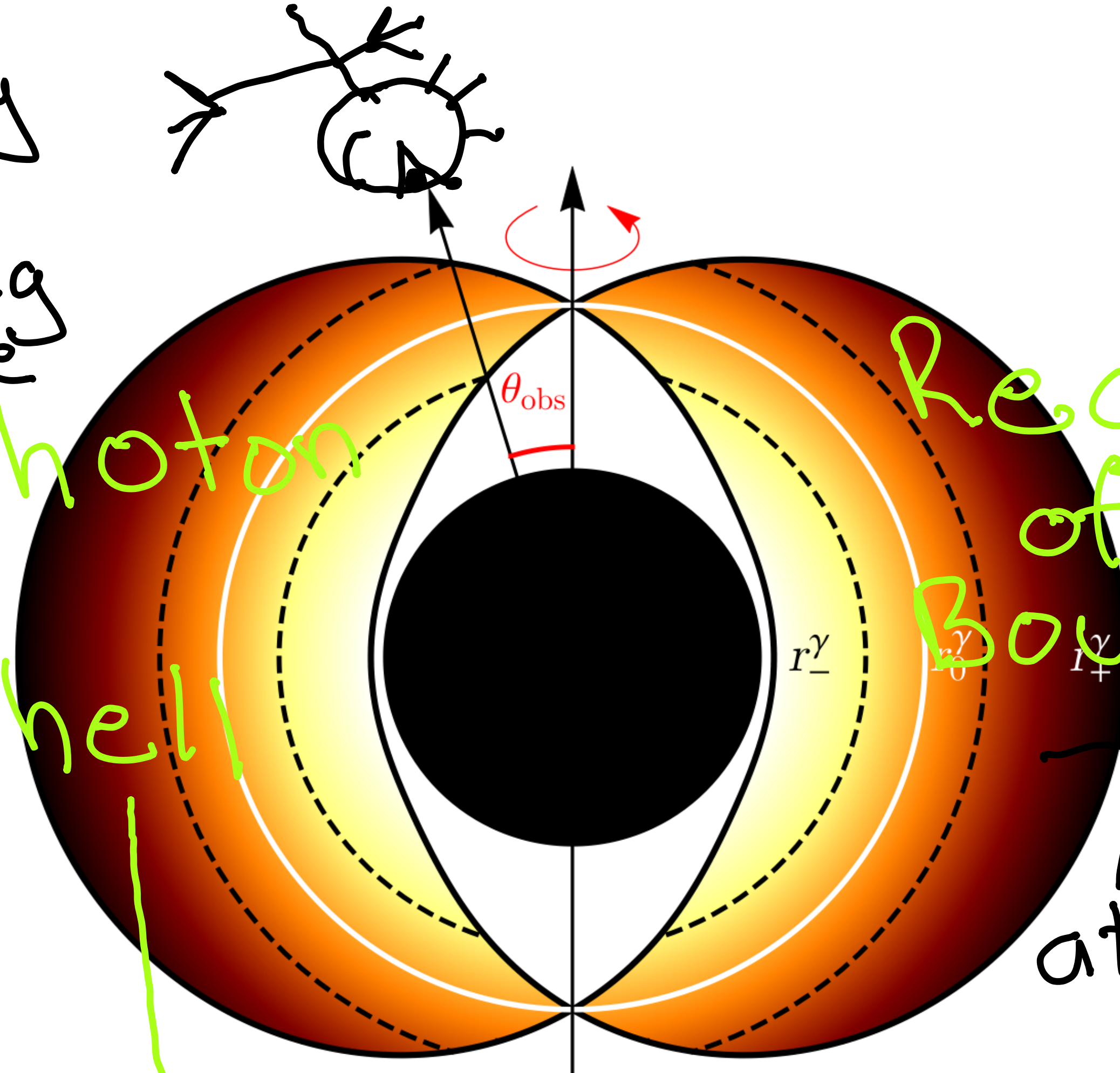


Example of critical phenomena in astronomy. This talk describes its intricate & universal structure proposal to observe with extensions of EHT to moon & LEO, GEO and L2 orbit

The photon ring is produced by multiply-orbiting photons in the photon shell.

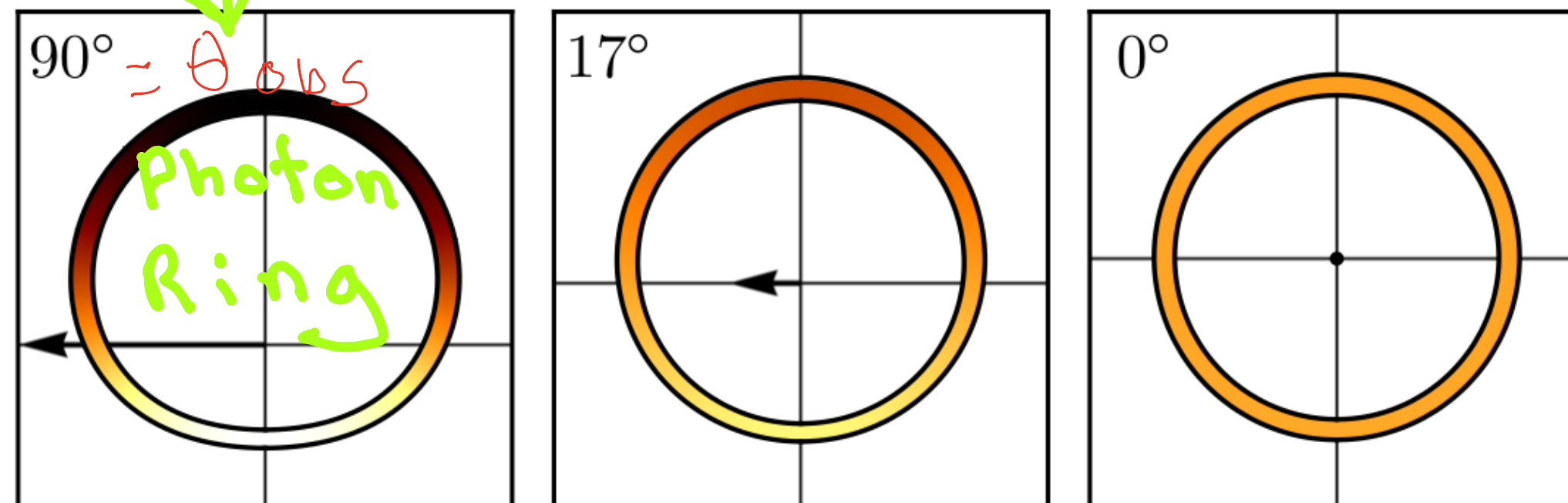
Photon Shell

Region of Bound Orbits



near horizon
AdS region at extremality

Observer Screen



Angle on boundary screen
= radius in bulk
= RG scale

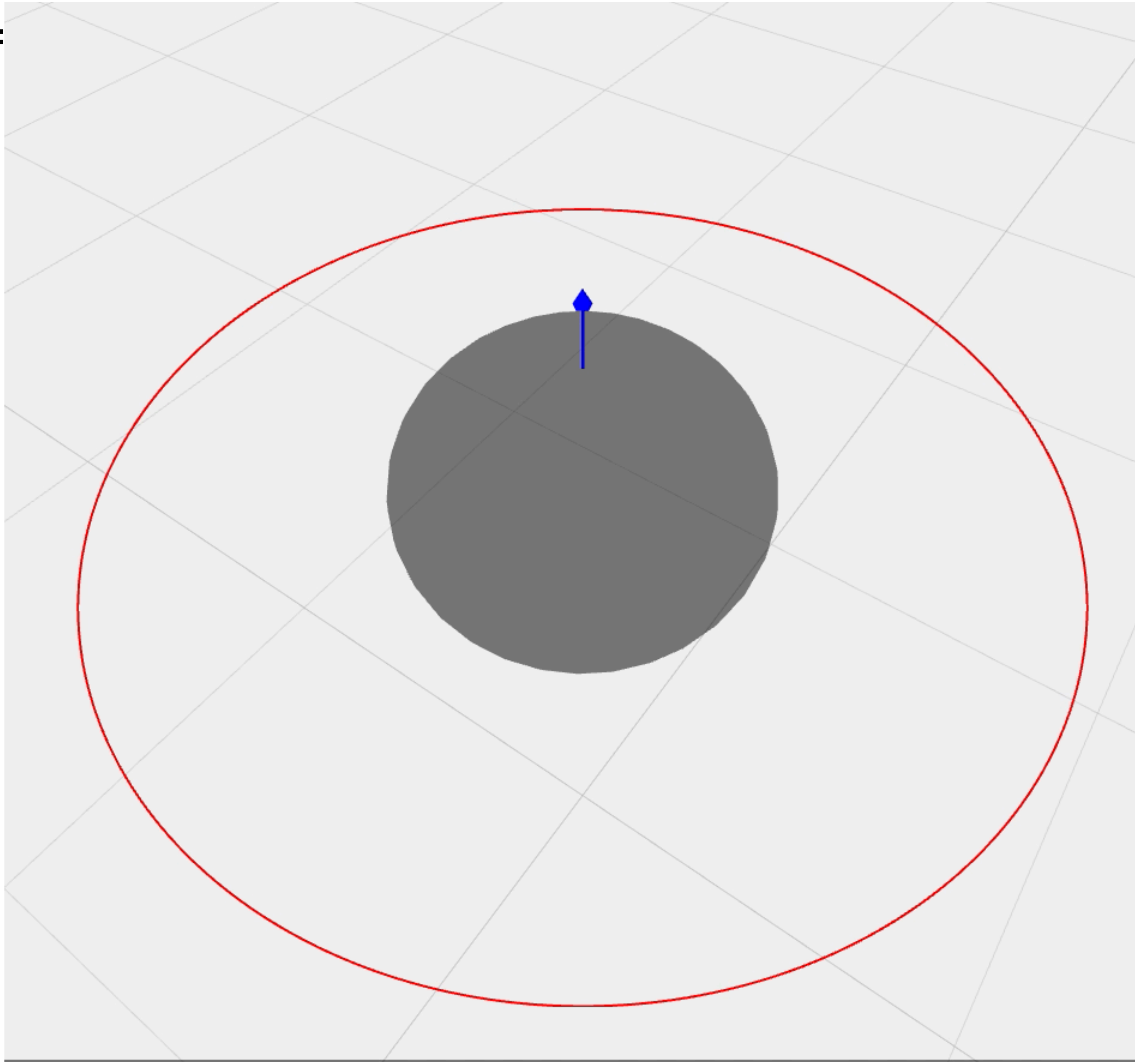
unlike a star image

Much of this was worked out in a different form by Jim Bardeen in the 70's who wrote:

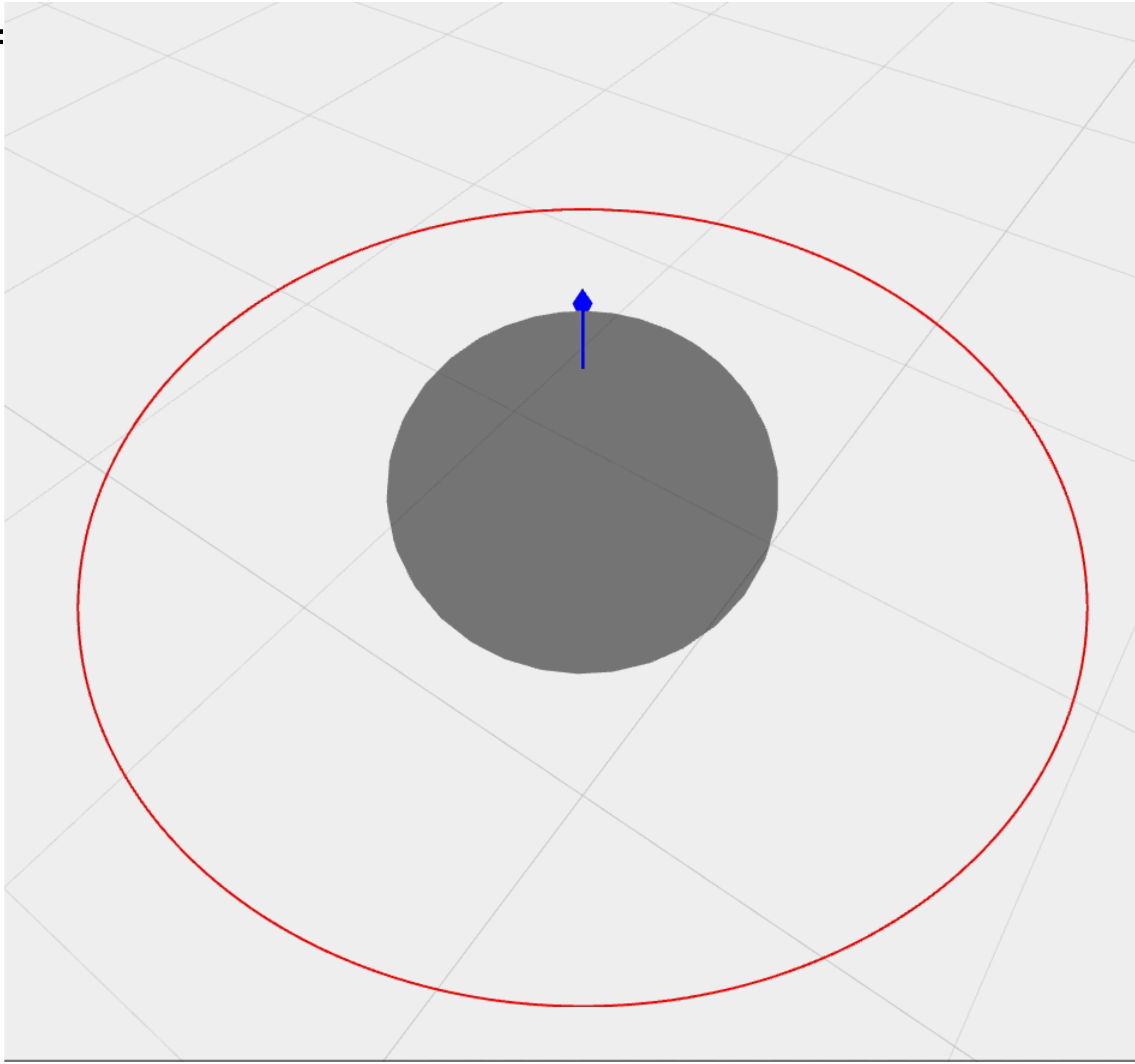
"It is conceptually interesting, if not astrophysically very important, to calculate the precise apparent shape of the black hole... unfortunately there seems to be no hope of observing this effect." J. Bardeen 73-74

Hope for string theorists!!!

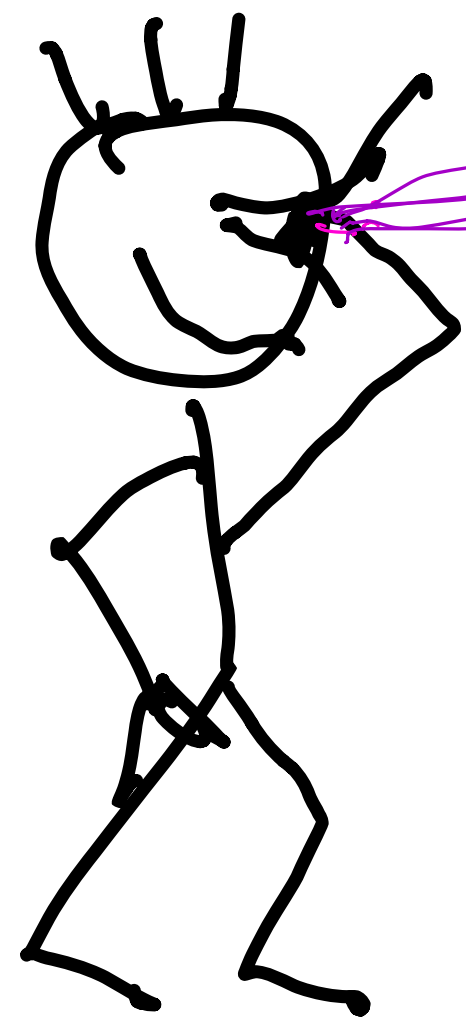
From Leo Stein's Homepage:



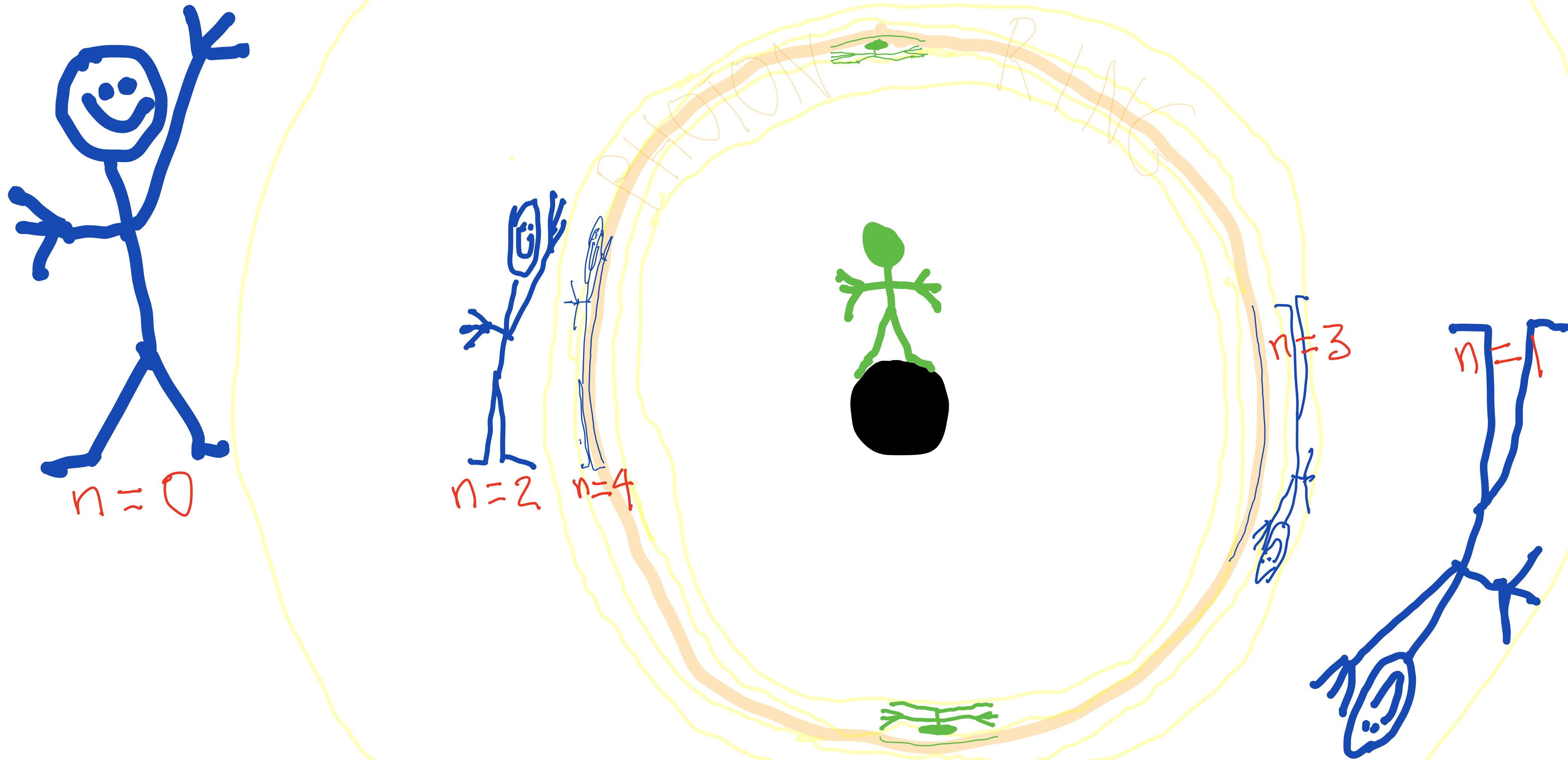
From Leo Stein's Homepage:



Astrophysical computations of observer screen brightness use backward ray tracing & integration



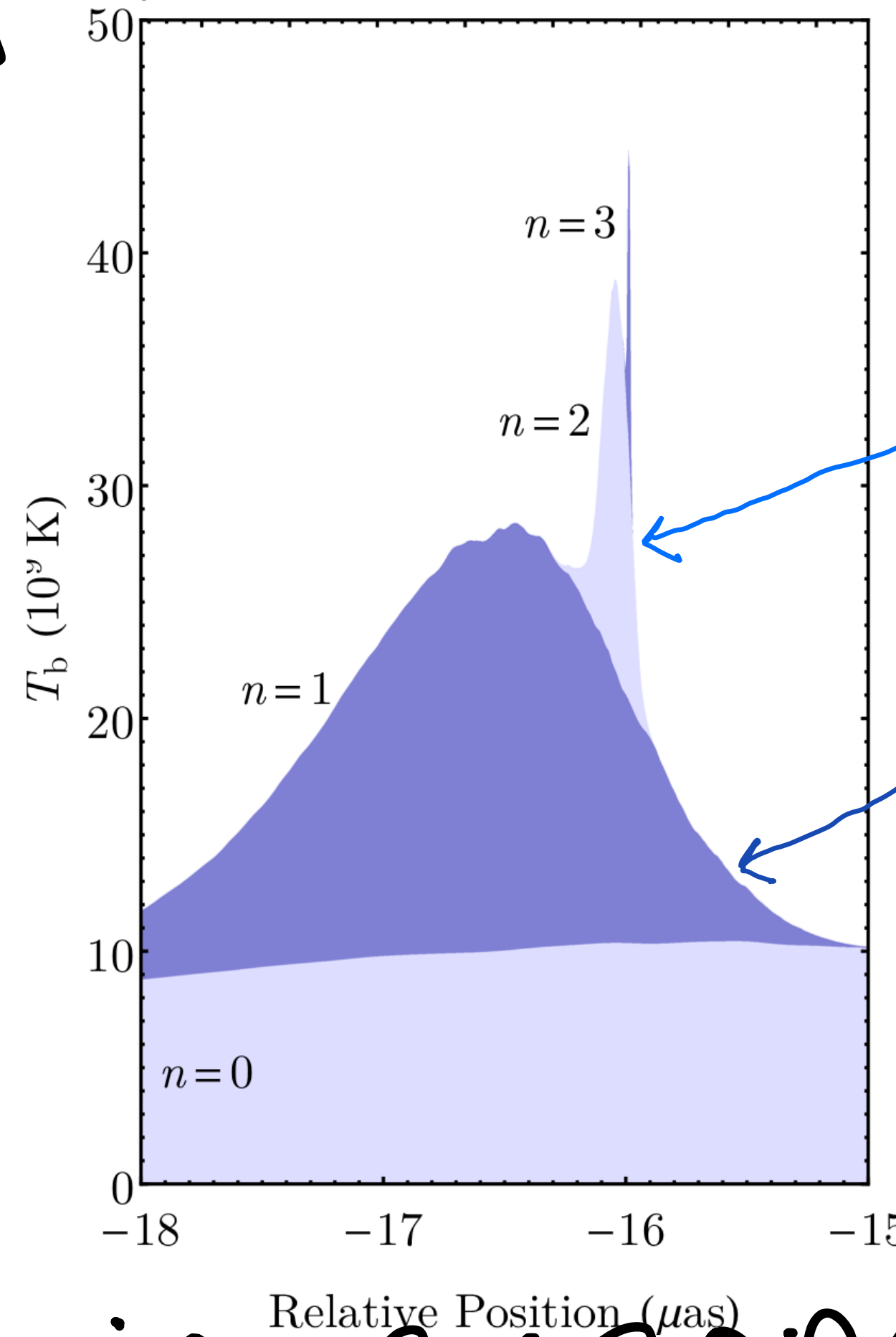
log brightness divergence \sim order parameter
Effective theory of photon ring describes
image ~~GRMHD~~ ~~matter~~ source



Self-similar mirror images of the universe converge in the photon ring.

Photon rings = wedding cake
Layers = photon orbit number

GRMHD:



Mirror image from universal
GR Lyapunov exponent

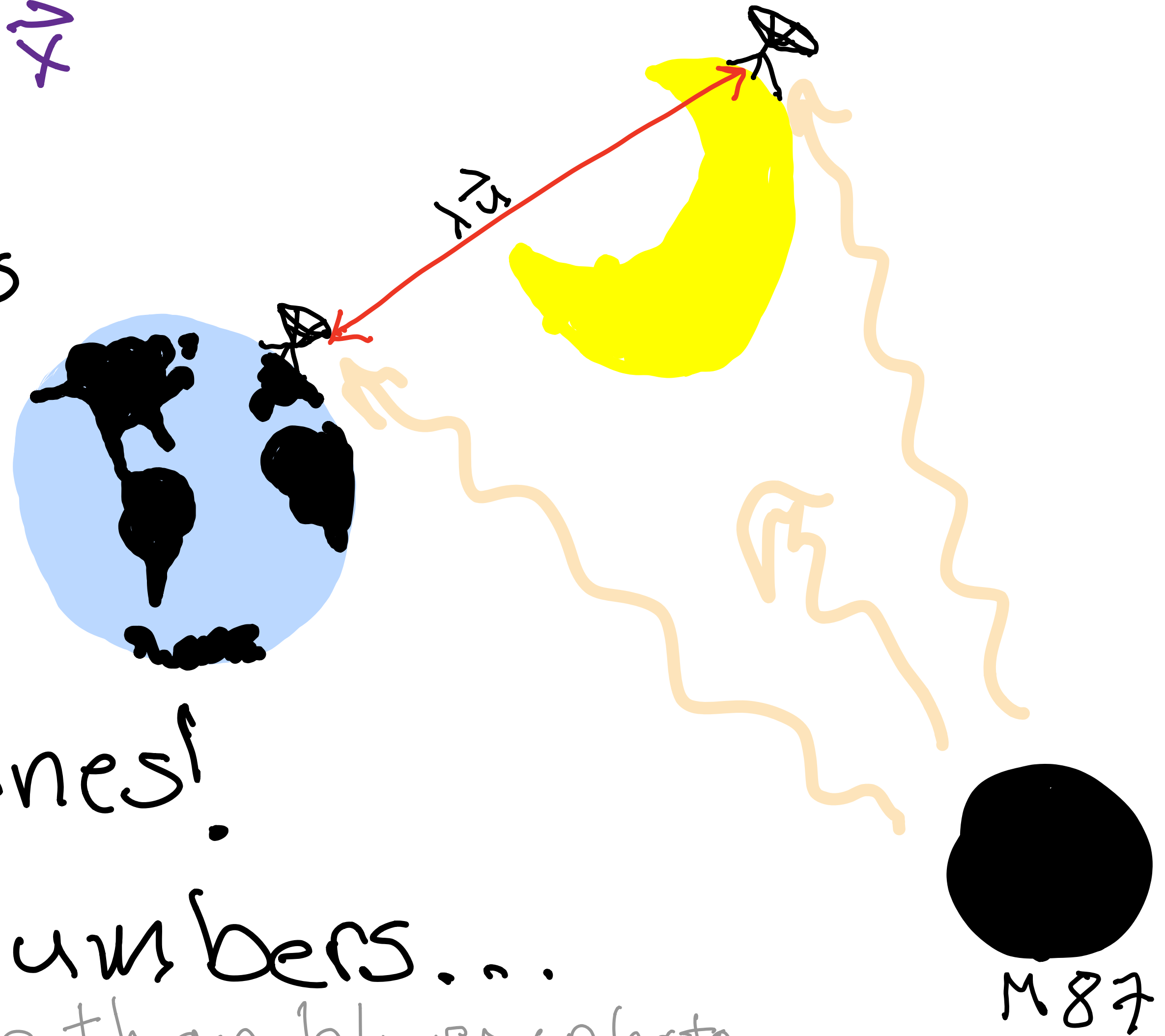
Shape depends on
non-universal matter
distribution

Each layer is exponentially sharper
& dimmer. Can we ever observe?

Possibly YES because long baselines =
high image frequencies

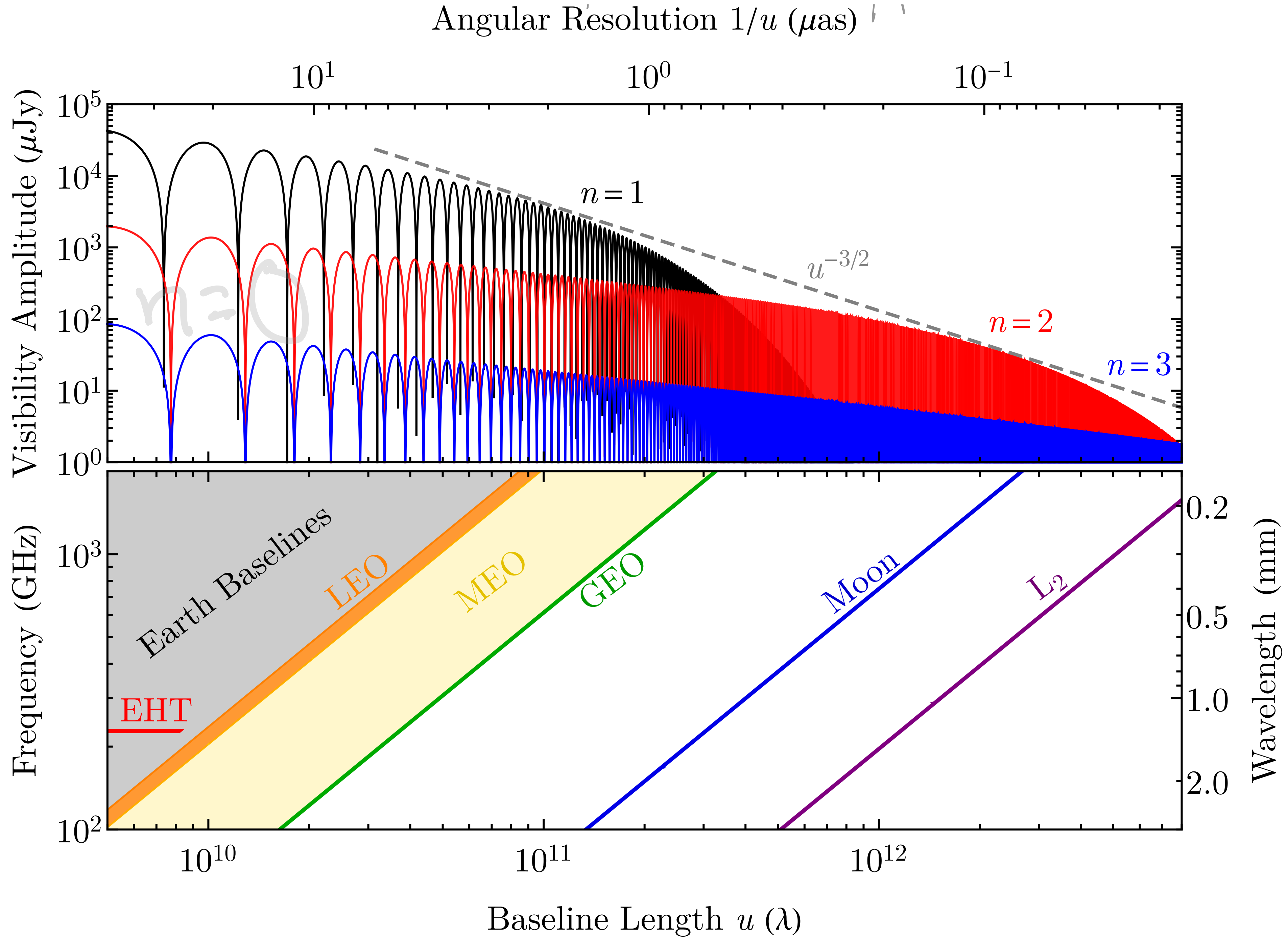
$$V(\vec{u}) = \int dz \vec{x} I(\vec{x}) e^{i\vec{u} \cdot \vec{x}}$$

Ever-sharper features
of higher- n
subrings
dominate
at longer base lines!



Putting in the numbers...

VLBI more like naked eye than blurry photo



Conclusion

The photon shell around a BH and its ring image have a rich & universal structure reminiscent of a critical system. Observing this fine structure requires very long interferometric baselines. This may be possible for next generation EHT extensions with dishes in orbit or on the moon.