Through the wormhole: using ray-tracing to visualize the wormhole of Interstellar

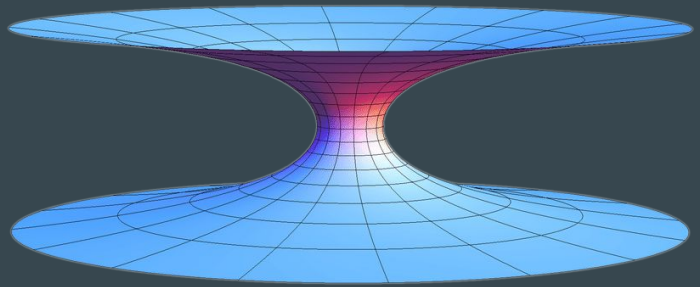
By Chase Hanson, Quinn White, Lily Whitler

The Hans Zimmer Fan Club

github.com/ASU-CompMethodsPhysics-PHY494/final-2020-hans-zimmer-fan-club

Background

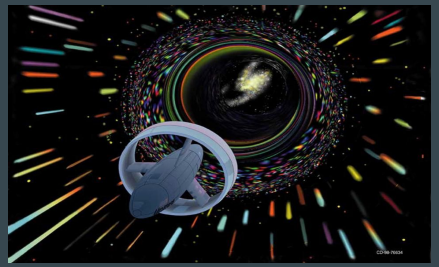
- Wormholes are very interesting differential geometrical objects that connect two distinct points in spacetime.
  - Though they have not (yet) been observed, they have not been disproven. They are physically *not impossible.*
- Ray-tracing is a computational method of accurately re-creating images by tracing a ray of light from a “camera” back in time to its origin, and can be used to visualize a wormhole



The embedding diagram for a wormhole. In lay-terms, a wormhole is a 4d geometrical object, this diagram shows what it would look like if we, the observer, lived in the plane (R3 to R2).

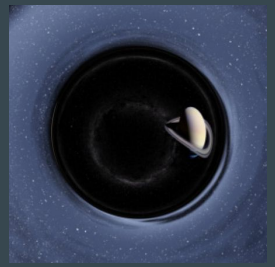
Goals

- Define the geodesic equations, or the *super-Hamiltonian*, for given initial conditions.
- Implement a functioning integrator.
- Implement code that warps input images as near and far sides of the wormhole, or the *upper* and *lower celestial spheres*.
- Recreate the top panel of Fig. 7 in James et al. (2015)



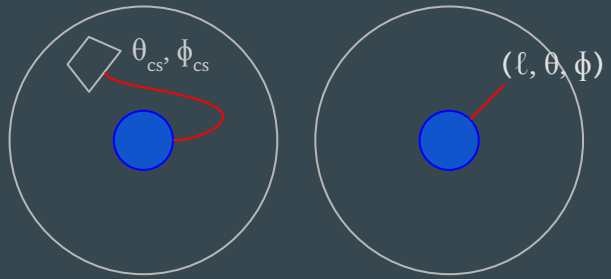
Forbes (left) and Science Magazine (right)

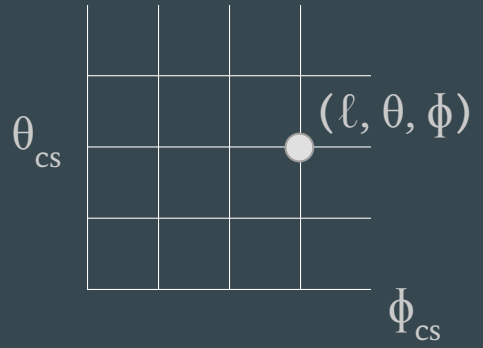
James et al. - theoretically validated



Implementation

- Generated a discrete set of initial conditions on the observer's local sky
- Numerically integrated the ray equations backwards in time to obtain positions (ℓ, θ, ϕ) and momenta (p_ℓ, p_θ) using a `scipy` implementation of RK4
- Interpolated the resulting discrete map from the observer's sky to the celestial sky to produce a general mapping between the observer and the celestial spheres
- Applied the map to an image of Saturn placed on the lower celestial sphere and a star field placed on the upper celestial sphere

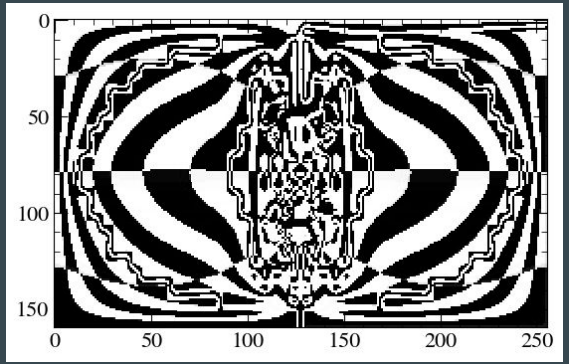


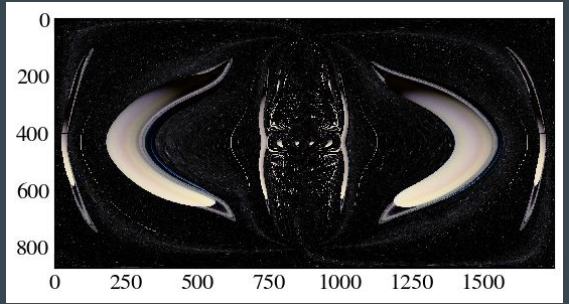


Implementation, and how not to do it

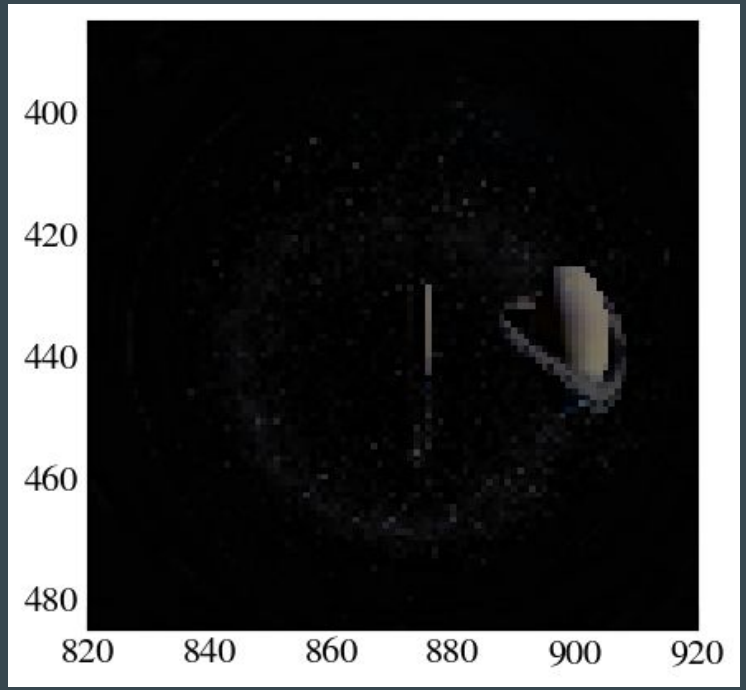
Issues encountered along the way:

- Incorrect angle wrapping
- Inconsistent treatment of the celestial spheres and the interior of the wormhole
- Repeated calculations of conserved quantities
- Numerical artifacts after interpolation
  - Likely due to incorrect interpolation of the celestial spheres





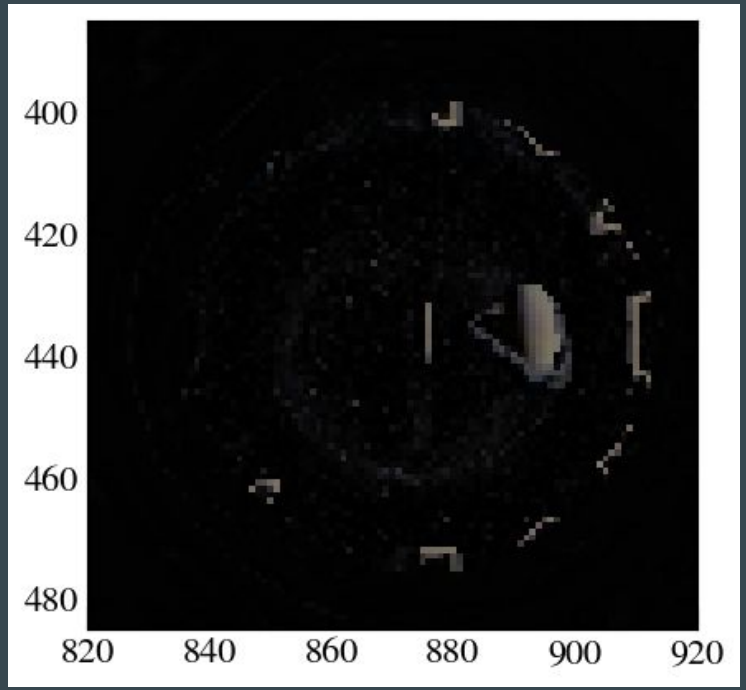
The Warped Images



The Hans Zimmer Fan Club (2020)

James et al. (2015)

The Warped Images



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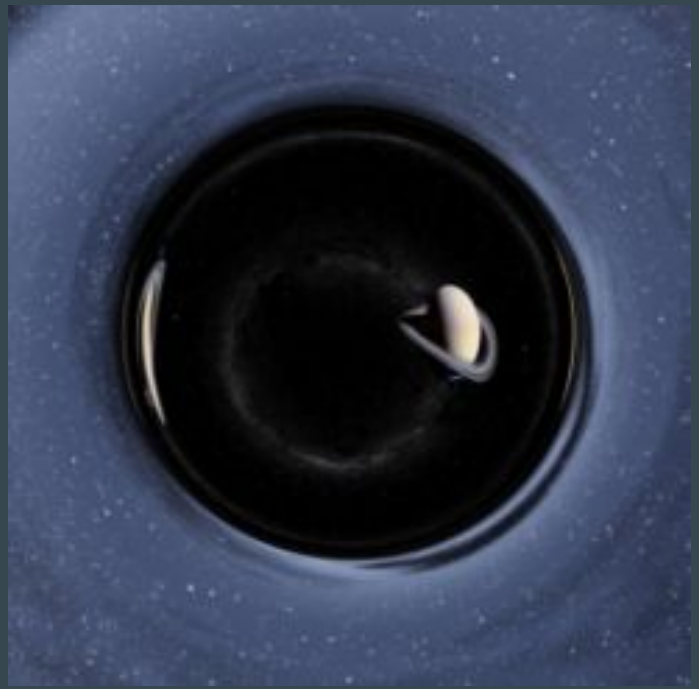
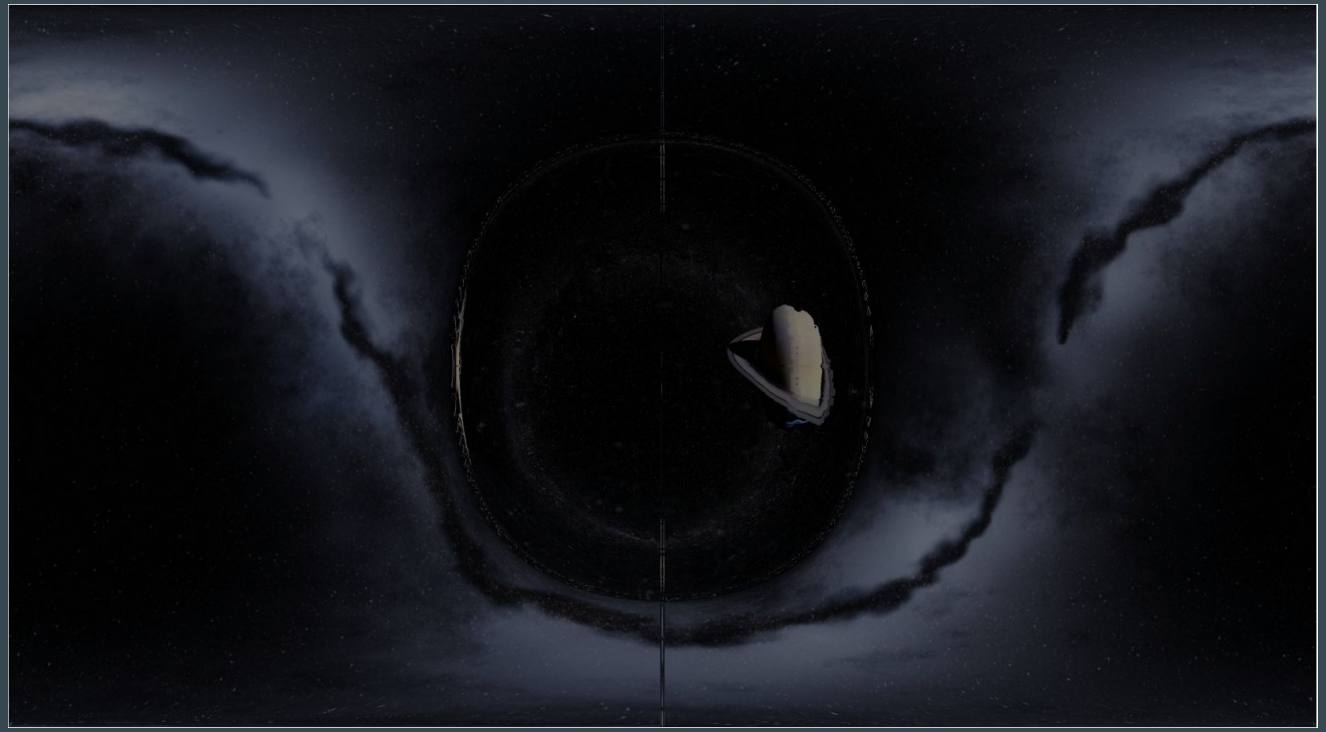
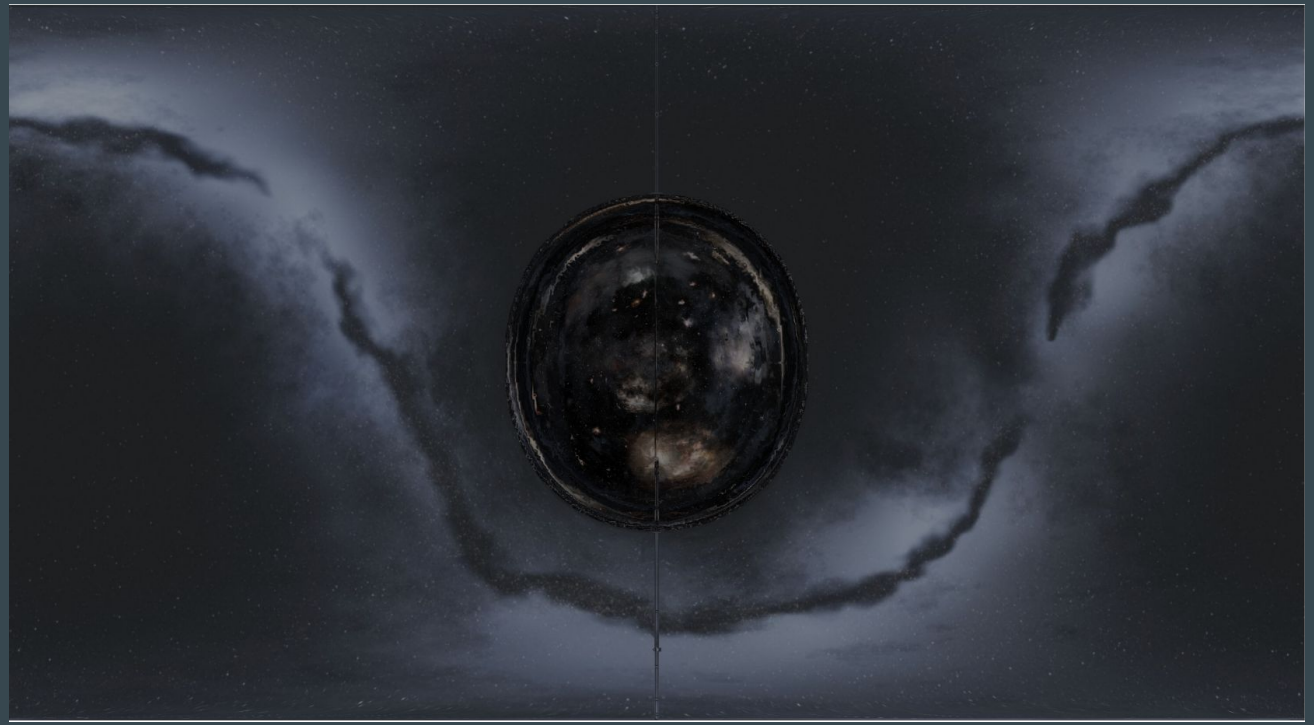


James et al. (2015)

Improving Quality of Warped Images



Improving Quality of Warped Images



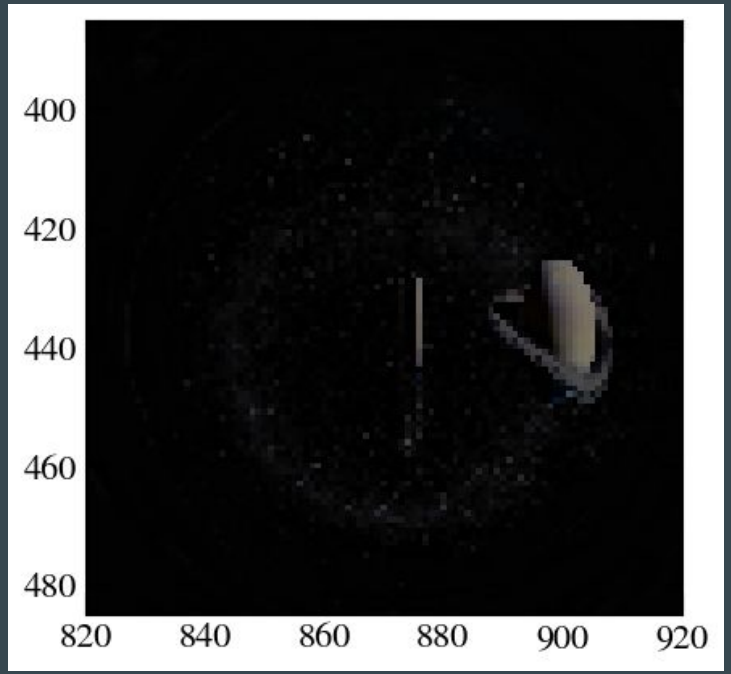
Future Work

- Improve the resolution of the final image
- Parallelize the numeric integration
- Observe Einstein rings around the wormhole
- Make animated passes around and through the wormhole

"Einstein ring" by the gravitational influence of the galaxy cluster SDSS J0146-0929.

Summary

- Ray-tracing is a powerful method to visualize the effects of a wormhole on spacetime
- Numerical integration of the geodesic equation traces a light ray back in time, creating a mapping between observer and the celestial spheres
- Interpolating a discrete map allows us to create a general description of the lensing effects of the wormhole
- Different wormhole geometries (e.g., length, radius) impact the degree of warping



Acknowledgements

We thank the authors of the example code written in Mathematica that we used as guidelines, Jason Biggs and Lennart Rudolph.

Tremendous thanks to Prof. Oliver Beckstein and Chenou Zhang for letting us work on this project, we had a ton of fun with it.

Thank you for such a wonderful course and providing extremely useful and fun lessons, we are very grateful.

References

Jason Biggs. [GIF] Visualizing Interstellar's Wormhole: from article to programming. Mathematica Community, 2016. URL: https://community.wolfram.com/groups/-/m/t/852052.

Oliver James, Eugénie von Tunzelmann, Paul Franklin, and Kip S. Thorne. Visualizing Interstellar's Wormhole. *American Journal of Physics*, 83(6):486–499, 2015. DOI: 10.1119/1.4916949.

Thanks to Lucy too!