Floating Orbits and Ergoregion Stability of an Exotic star–Black hole system

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What are they?

A floating orbit is a metastable orbit around dense rotating astrophysical bodies wherein the orbiting body avoids orbital decay by stealing rotational energy from the central body.

Why are they important to science?

If a floating orbit can be shown to exist theoretically and if one is discovered in nature, then the system would emit gravitational waves at a regular frequency. With a constant source of waves interacting with the detectors, random noise and other anomalies can be eliminated and the general trend of the radiation would be easier to detect and study. And the confirmation of gravitational radiation would further confirm Einstein's Theory of General Relativity.

How do we get them?

The Penrose Process
The Hartle Approach

The Penrose Process:

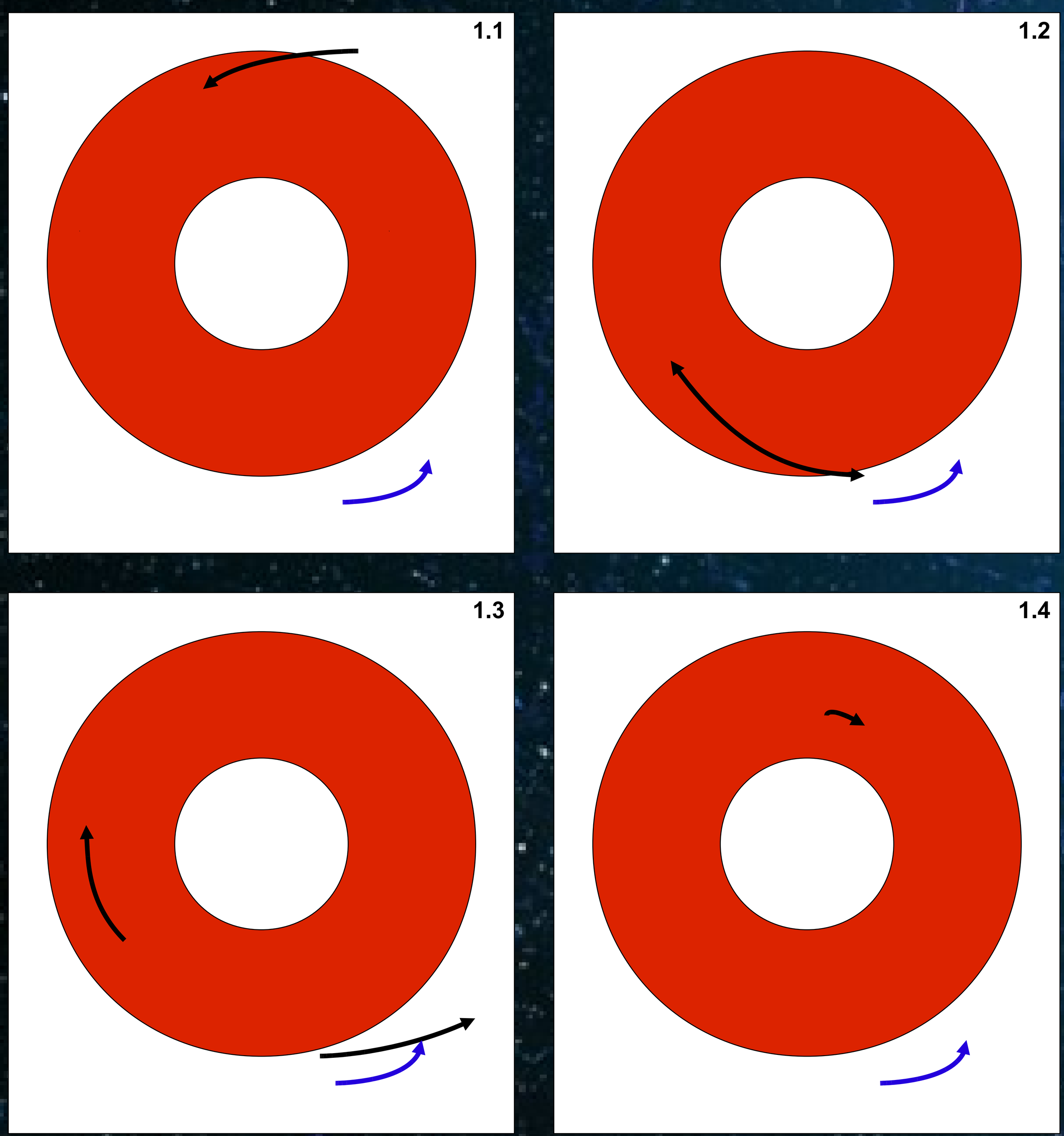

Figure 1.1-1.4
The figures above show the evolution of an incoming object or wave in a prograde orbit entering the ergosphere(red area) and the eventual splitting of that object in two, with one wave traveling in a prograde orbit and escaping the star and the other in a retrograde orbit angled toward the central star's horizon(black hole case) or center(exotic star case).

Acknowledgments:

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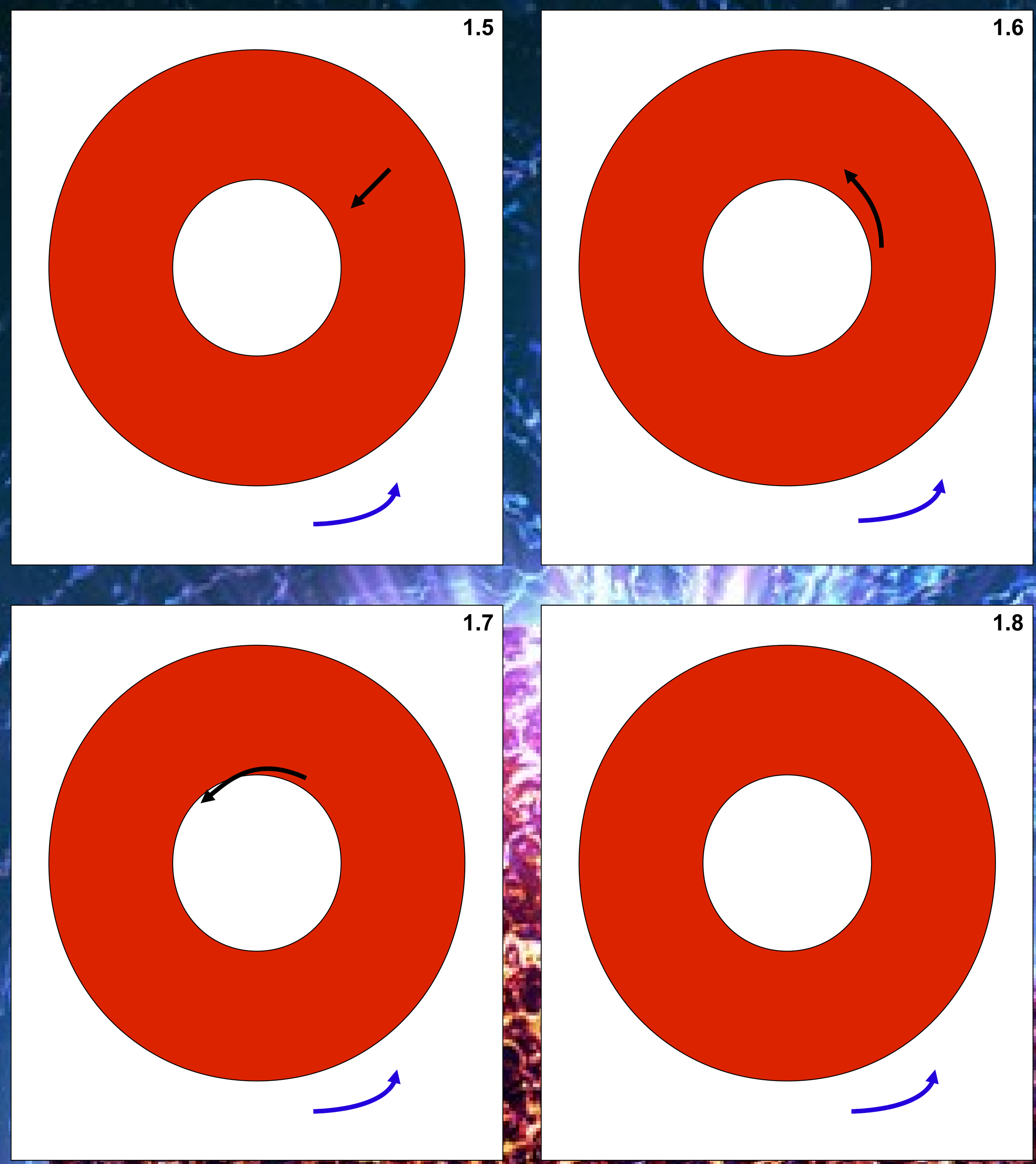

Figure 1.5-1.8
The figures above continue to show the evolution of the inward traveling object, which by Figure 1.6 has been dragged into a prograde orbit and has been passed the horizon by Figure 1.8 in the black hole case.

The Hartle Approach:

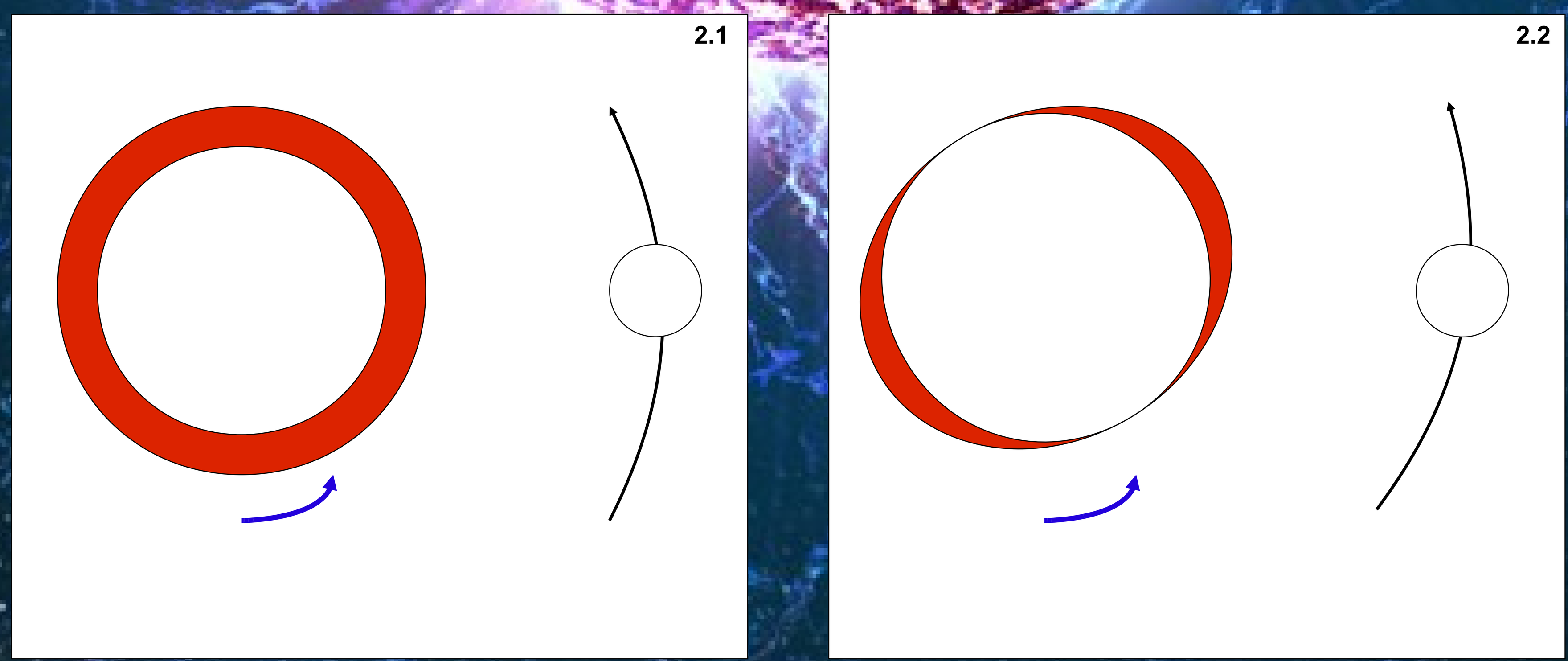

Figure 2.1-2.2
Figure 2.1 shows the initial positions of the central body, the ergosphere(red part) and the orbiting body. As the orbiting body continues to circle the central body it pulls on the ergosphere and the central body, which raises a tide. Since the central body is rotating at a velocity greater than the orbiting body the tide is displaced some an angle in the prograde direction and this displaced tide pulls on the orbiting body as the star rotates; thereby accelerating the orbiting body and decreasing the rotation of the central body

Exotic stars vs. Black holes

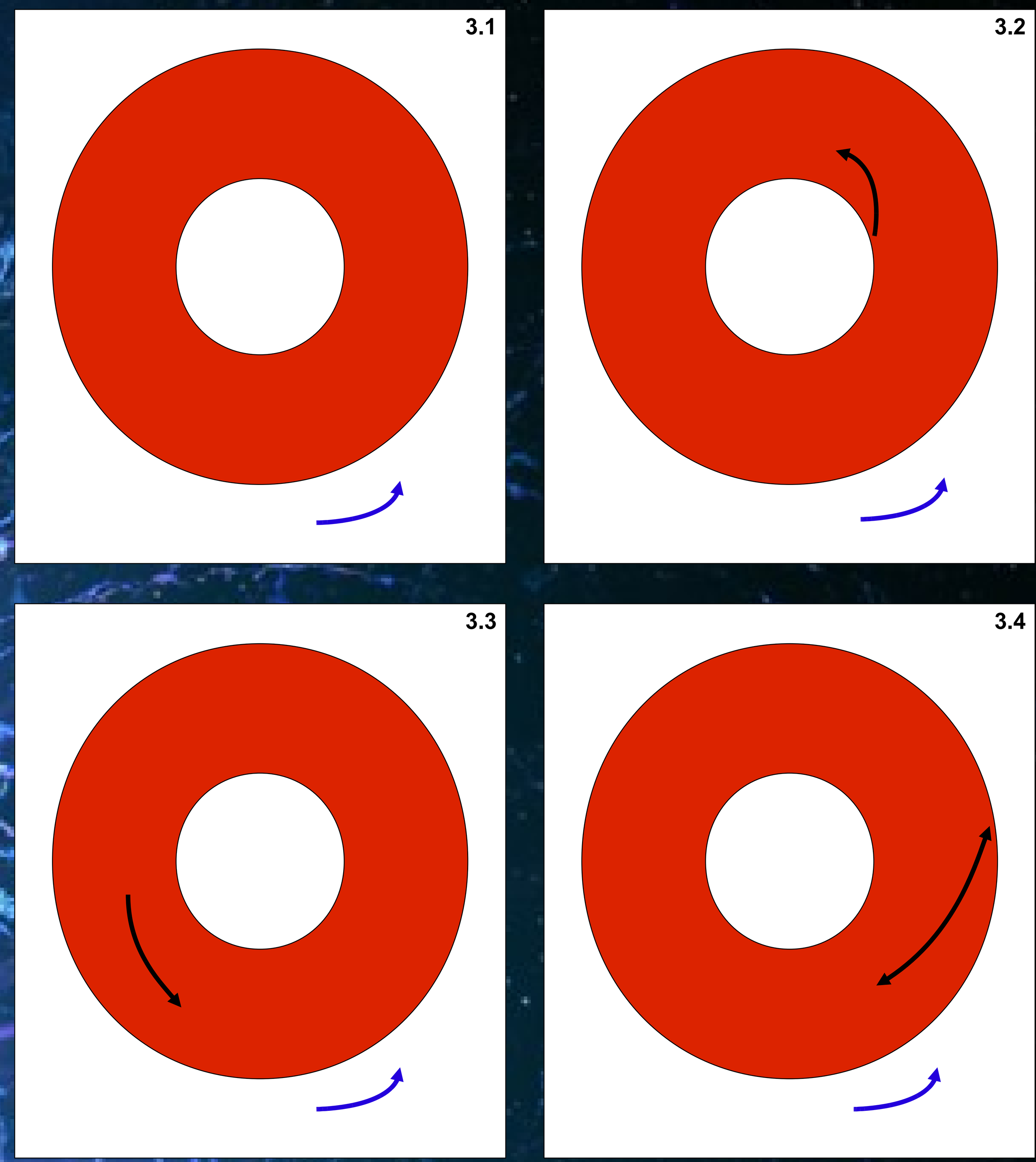

Figure3.1-3.4
Since an exotic star does not have an horizon the inward going wave cannot be absorbed and travels out of the center of the star toward the ergosphere in the prograde direction. Then this initially inward going wave undergoes the Penrose process and splits. The outward wave travels outside the star, while the inward one travels back toward the center of the star to restart this process. The process is called ergoregion instability and can liberate more energy than a similarly massed black hole.

Results and Future Research:

Richartz et.al. devised a test for superradiant scattering(SRS). Wherein a version of Klein Gordan equation is solved and the Wronskian of those solutions has to be negative. Our solutions which describe an exotic star do emit SRS for the solution at infinity:

$$|R|^2 = 1 + C^{out}(a^4 - M^4) \qquad r \to r_+$$

$$|R|^2 = 1 + 2(B^{in} + A)r^2 \quad for\ n=1$$
$$1 + B^{in} r^2 \quad for\ n>1 \qquad r \to +\infty$$

Furthermore, our exotic star would liberate more energy due to ergoregion instability than a similarly massed black hole and, if we use the trend of faster rotating stars having longer instability time scales as shown by Cardoso et. al., we expect our star to have sufficient rotation to sustain a floating orbit. Future research will involve investigating the physical structure needed by our star to exist and the running of the code developed by Kennefick and Glampedakis to see if our star actually can possess a floating orbit.

References:

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