Dark Star

Research Question

How will interstellar bodies of different masses entering the Solar System affect the probability for life on Earth to go extinct?

Hypothesis

If an interstellar object enters the Solar System, then the Earth's orbit will be affected the most by the bodies of at least one solar mass because those are as great as that of the sun, so they will affect the Earth the most.

Introduction

Theory

$$F_i = G\frac{Mm_i}{|r_i|^3}r_i$$

$$F = \sum_{i=0}^{n} F_i = GM\sum_{i=0}^{n}\frac{m_i r_i}{|r_i|^3}$$

$$F = Ma$$

$$a = G\sum_{i=0}^{n}\frac{m_i r_i}{|r_i|^3}$$

$$\Delta V = a\Delta t$$

$$\Delta P = V\Delta t + \frac{a\Delta t^2}{2}$$

(F_i, F, a, ΔV, and ΔP are vectors)

Types of Stars

The Hertzsprung-Russell (H-R) diagram is a star chart that classifies stars by temperature and luminosity. It defines different types of stars:

- Main sequence stars
- Giants
- White dwarfs
- Brown dwarfs

The stars that are used in this project are:

- Brown dwarf
  - 0.01 to 0.05 Solar masses ($M_\odot$)
- Black dwarf - 1 Solar mass
- Stellar black hole - 5 Solar masses

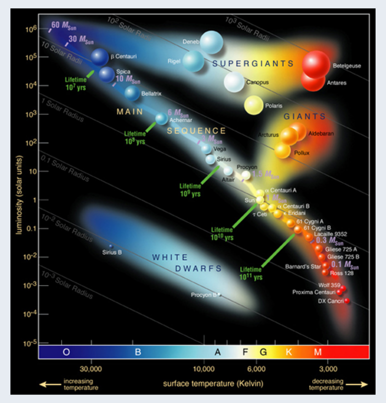

Figure 1: Hertzsprung-Russel Diagram[1]

Solar System

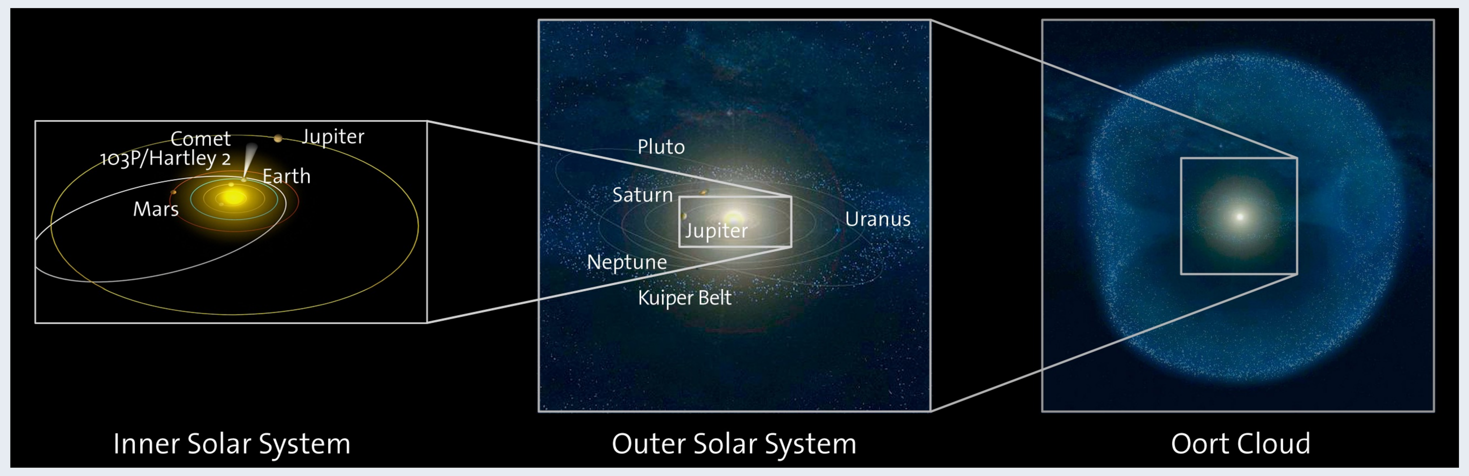

Figure 2: The Solar System[2]

Solar System Regions

- Inner planets
  - Rocky, warm, small planets
  - 'Habitable Zone' - zone in which life can survive (0.8 AU - 2 AU from the Sun).
- Asteroid belt: area of asteroids that separates the inner from the outer planets
- Outer planets: gaseous, cold, massive planets
- Kuiper belt: belt of asteroids, comets, and dwarf planets past the orbit of Neptune
- Heliosheath: region of space in which solar wind is stopped by interstellar wind
- Oort cloud: hypothetical region of space thought to contain the long term comets that orbit the Sun

Velocities

Body	AU/day
Mercury	0.028
Venus	0.02
Earth	0.017
Mars	0.014
Jupiter	0.0075
Saturn	0.0056
Uranus	0.0039
Neptune	0.0031
Oumuamua	0.015
Luhman 16	0.012
Proxima Centauri	0.013
Barnard's Star	0.063

Interstellar Neighborhood

Single Stars

- Barnard's Star - 5.9 light years ($0.144M_\odot$)
- WISE 0855-0714 - 7.3 light years ($0.003 - 0.01M_\odot$)
- Wolf 359 - 7.8 light years ($0.09M_\odot$)
- Lalande 21185 - 8.3 light years ($0.46M_\odot$)

Binary Systems

- Alpha Centauri - 4.3 light years
  - Alpha Centauri A ($1.1M_\odot$) and Alpha Centauri B ($0.907M_\odot$)
- Luhman 16 - 6.5 light years
  - Luhman A ($0.033M_\odot$) and Luhman B ($0.027M_\odot$)
- Sirius - 8.6 light years
  - Sirius A ($2.063M_\odot$) and Sirius B ($1.018M_\odot$)

Earth's life can be destroyed in several ways. One way is if asteroids or comets collide with Earth. This can be caused by the interstellar object disrupting the Oort cloud or the Kuiper or asteroid belt.
Another reason for life's extinction can be if the gravitational force of the interstellar body (or one of the planets) knocks off the Earth out of the Habitable Zone. **This event will be the focus for my project.**

N-body Simulator: Rebound[3]

- N-body simulator
- Python and C extensible
- Good documentation and examples
- Can show the planets and stars trajectories while the simulation is running

Python Code

```
for theta in range(0, 180, 8):
    for phi in range(0, 360, 8):
        for vtheta in range(0, 180, 7):
            for vphi in range(0, 360, 7):
                # convert to radians
                theta = (theta * math.pi) / 180.0
                phi = (phi * math.pi) / 180.0
                vtheta = (vtheta * math.pi) / 180.0
                vphi = (vphi * math.pi) / 180.0

                # run the simulation
                outhz = run_simulation(mass, radius,
                                  velocity, theta, phi,
                                  vtheta, vphi, tmax)
                if  outhz == 0.0:
                    print "safe"
                else:
                    print "destroyed"
```

```
def run_simulation(mass, radius, velocity, theta,
                               phi, vtheta, vphi, tmax):

    # create the Rebound simulation
    sim = rebound.Simulation()
    sim.G = 1.4880826e-34 # (AU^3/kg/day^2)
    sim.dt = 0.02
    sim.heartbeat = heartbeat
    add_solar_system_bodies(sim)

    # add the dark star
    sim.add(hash=100, m=mass,
        x=radius * math.sin(theta) * math.cos(phi),
        y=radius * math.sin(theta) * math.sin(phi),
        z=radius * math.cos(theta),
        vx=velocity * math.sin(vtheta) * math.cos(vphi),
        vy=velocity * math.sin(vtheta) * math.sin(vphi),
        vz=velocity * math.cos(vtheta))

    # set the center of momentum to be at the origin
    sim.move _to_com()

    # run the simulation
    sim.integrate(tmax)
```

**Not all code is shown. Complete code can be found in logbook.*

Approach

1. Create an N-body gravitational simulator.
2. Add the bodies of the solar system to the simulation.
3. Add the different dark stars to the program.
4. For each simulation, change the position and the trajectory of the dark star.
5. After using all the velocities assigned to one dark star, change the mass.
6. Repeat Steps 4 and 5 for the all three types of dark bodies.
7. Find probability of Earth leaving the Habitable Zone, maximum distance that the star can get to the Sun while affecting Earth, and the minimum distance that the star can get to the Sun that does not affect Earth.

Testing Parameters

Simulated time: 200 years
Dark star masses(in $M_\odot$):

- Brown dwarf - 0.05
- Black dwarf - 1
- Stellar black hole - 5

Starting position:

- Distance = 50 AU
- φ and θ change by 8 degrees.

Starting trajectory:

- Velocities (AU/day): 0.001, 0.003, 0.005, 0.01, 0.015, 0.02, 0.025, 0.06
- Direction: φ_v and θ_v change by 7 degrees.

Spherical coordinate system:

- Uses φ, θ, and radius instead of x, y, and z.
- Varying φ and θ form a sphere around the center.

$$x = r\sin\theta\cos\varphi$$
$$y = r\sin\theta\sin\varphi$$
$$z = r\cos\varphi$$

Simulations:

- Approximately 700,000 simulations for each velocity on each mass.
- Total of 16,800,000 simulations.

Results

Probability of Earth's Life Extinction

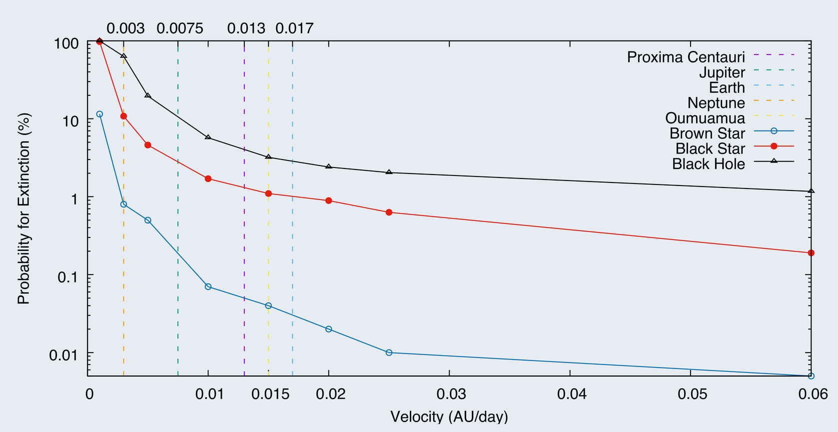

Figure 3: Effect of velocity on probability of Earth's life extinction for simulated dark stars

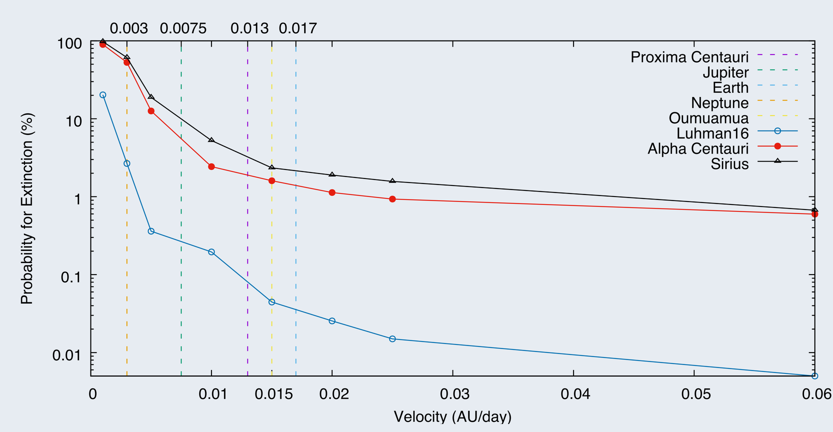

Figure 4: Effect of velocity on probability of Earth's life extinction for three neighboring binary systems

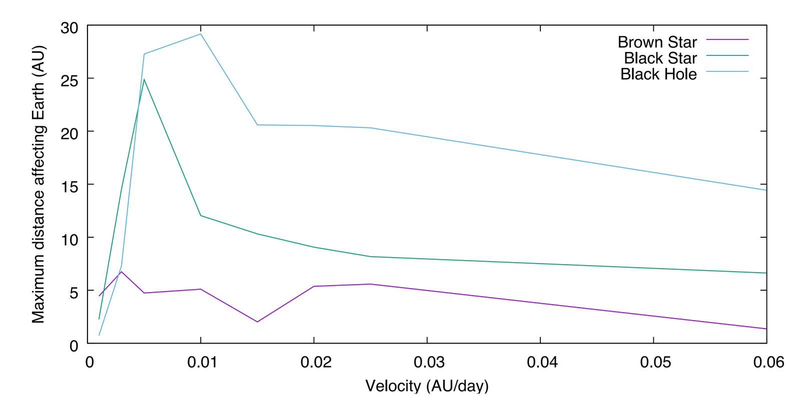

Figure 5: Maximum distance from the Sun that still affects the Earth for simulated dark stars

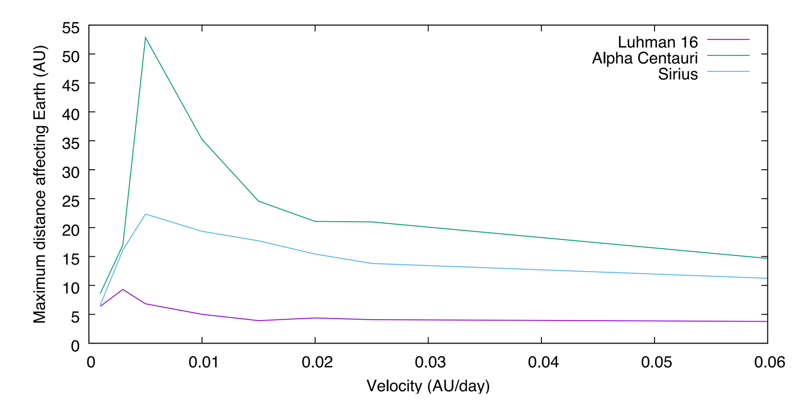

Figure 6: Maximum distance from the Sun that still affects the Earth for binary systems

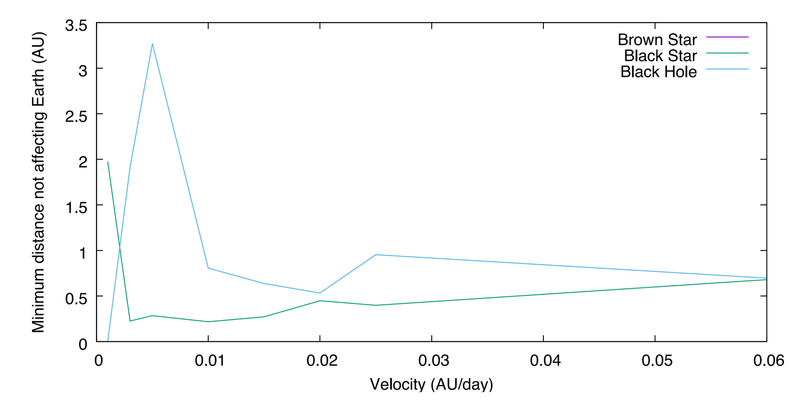

Figure 7: Minimum distance from the Sun that does not affect Earth for simulated dark stars

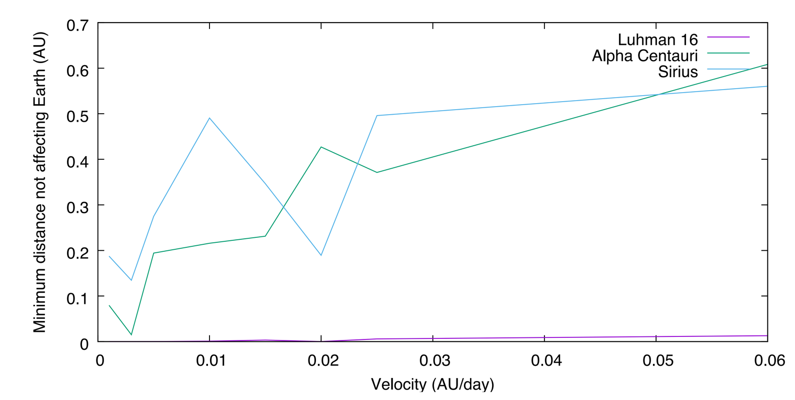

Figure 8: Minimum distance from the Sun that does not affect Earth for binary systems

Brown Dwarf: Effects on Earth's Orbit

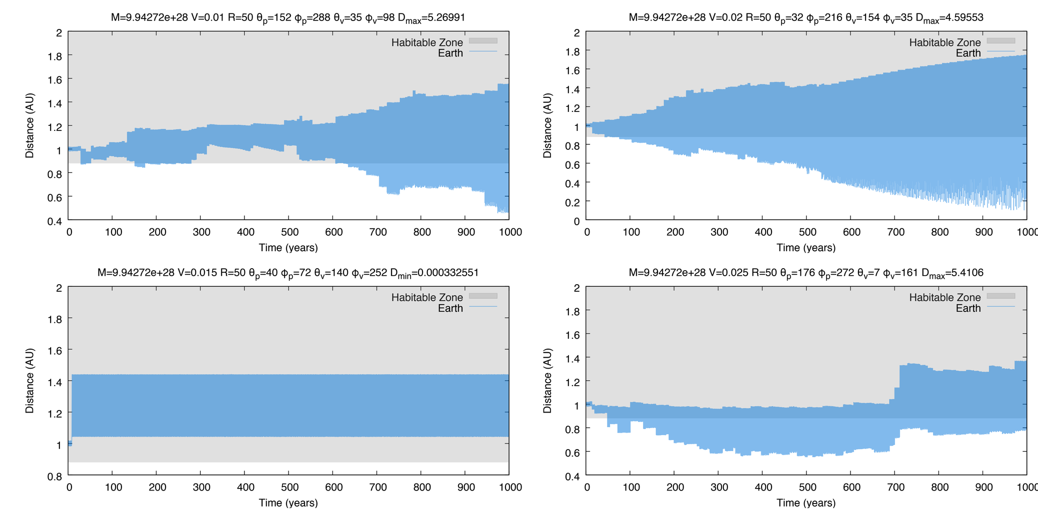

Figure 9: Examples of the Earth's orbit in relation to the habitable zone with the Brown Dwarf

Black Dwarf: Effects on Earth's Orbit

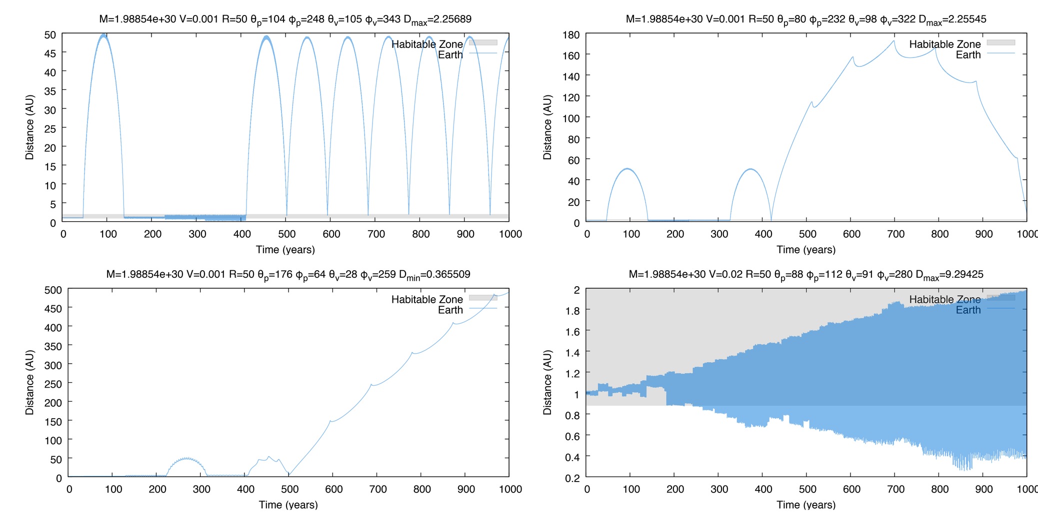

Figure 10: Examples of the Earth's orbit in relation to the habitable zone with the Black Dwarf

Black Hole: Effects on Earth's Orbit

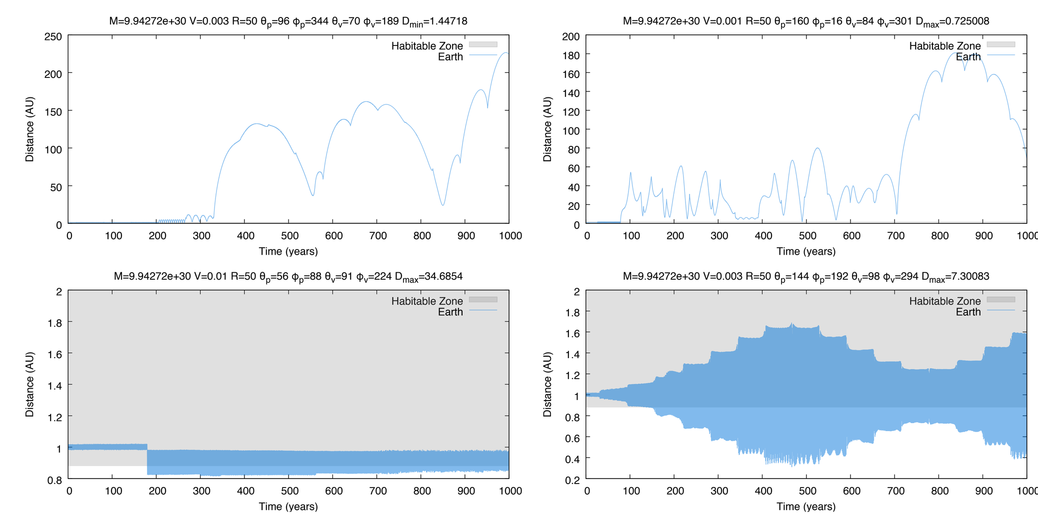

Figure 11: Examples of the Earth's orbit in relation to the habitable zone with the Black Hole

Conclusions

- Probability for life extinction depends on the mass and velocity of the incoming celestial body.
- Brown star can get as close as Jupiter's orbit before knocking the Earth out of the habitable zone.
- Stellar black hole can get closer than Earth's orbit to the Sun without knocking the Earth out of the habitable zone.
- Future steps include finding the average amount of time the Earth has before all life is killed.

References

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