Physics in Science Fiction

SPACE Program (20)

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Science Fiction

- What is science fiction?
- A genre of fiction dealing with imaginative concepts such as:
  - Futuristic technology
  - Space travel
  - Time travel
  - Extraterrestrial life
  - And many others.
- Often when we read (or watch) science fiction, we have to suspend our belief (especially as scientists)

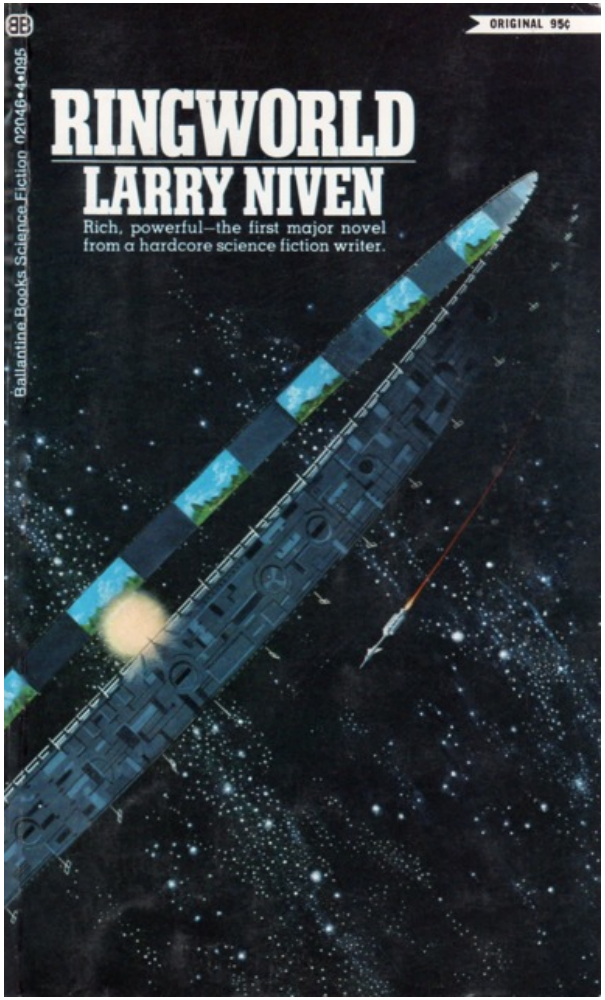
Hard Science Fiction

- There is a special brand of science fiction, called hard sci-fi, which attempts to keep a solid scientific basis.
- Authors try to accurately portray settings and situations using known science, usually physics, chemistry and biology.
- Sometimes elements beyond our science are included (such as faster than light travel, communication).

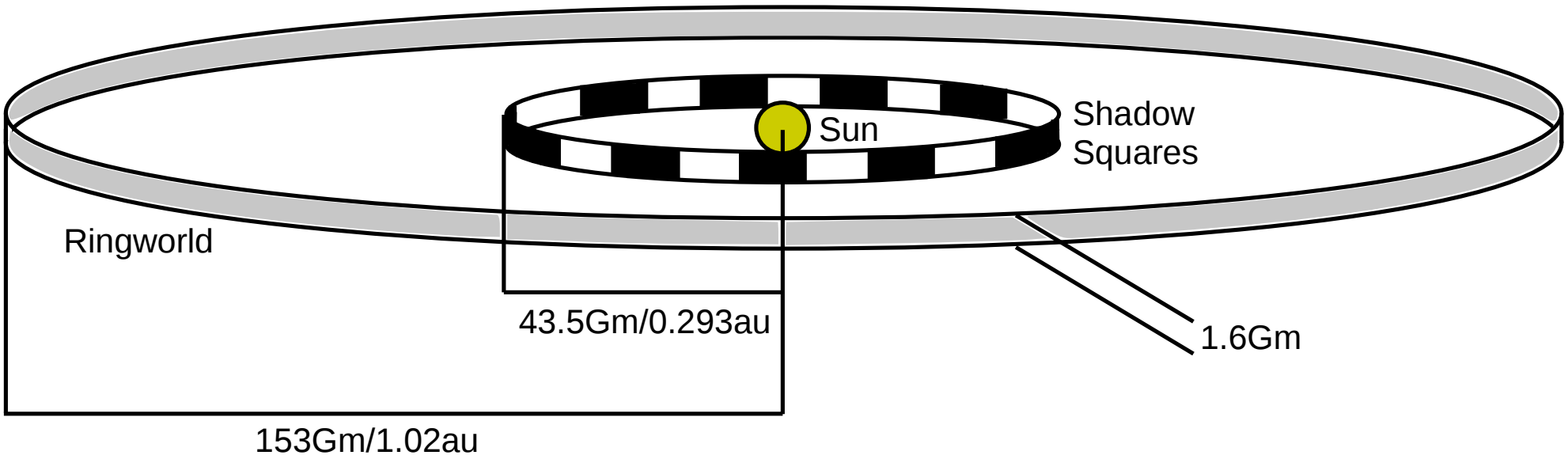
- I've taken the settings of 4 science fiction books:
  - Ringworld by Larry Niven.
  - The Integral Trees also by Larry Niven.
  - Rendezvous with Rama by Arthur C. Clarke.
  - Mission of Gravity by Hal Clement.
- I've attempted to the physics calculations behind these settings to see if they make any sense.

Ringworld

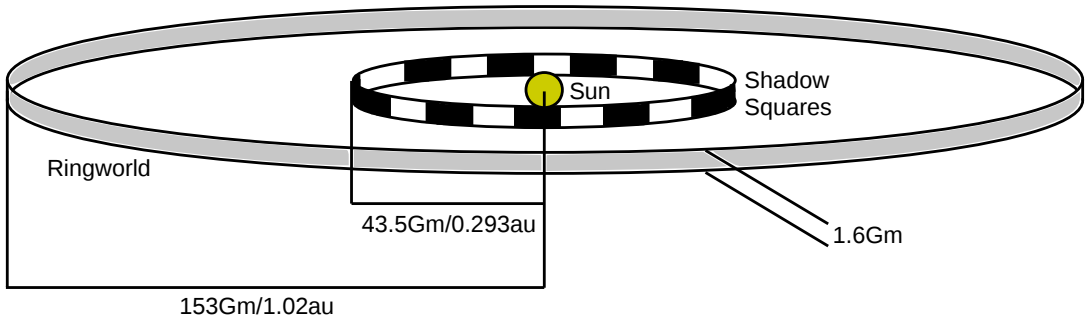
- Written by Larry Niven.
- First published in 1970.
- Won both the Hugo and Nebula awards.
- Follows the adventures of a human, Louis Wu, as he is recruited to explore the Ringworld.



The Ringworld



- The Ringworld is massive:
  - 153 million km in radius.
  - 1.6 million km wide.
  - Surface area of $1.5 \times 10^{15} km^2$

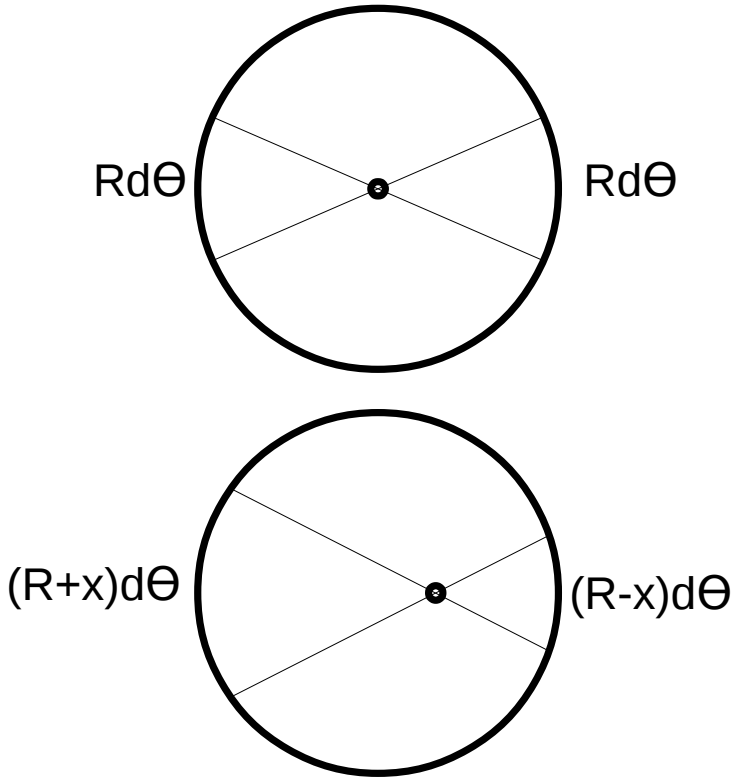


  - 3 million times the surface area of earth!
  - 20 Shadow squares orbiting the sun at a radius of 43.5 million km produce day/night cycle of 30 hours.
  - Mass of $350 M_{earth}$, thickness of 30m.

- The whole ring spins at a rate fast enough to produce a centripetal acceleration of 0.992g
  - Using $a = v_t^2/R$, this corresponds to a velocity of 1,146km/s
- One rotation of the ring takes 9.7 days.

- The tensile stress in Pa of a thin rotating ring is given by $T = \rho\omega^2 r^2 = \rho g R$ where g is the centripetal acceleration.
- The ringworld has a density of $146 kg/m^3$.
- The tensile stress on the ringworld is 194TPa or 194 TRILLION Pascals!
- Structural steel has a tensile strength of 400MPa.
- Carbon nanotubes have a measured tensile strength of 62GPa and a theoretical limit of 300GPa - still well below the requirement for building a ringworld.

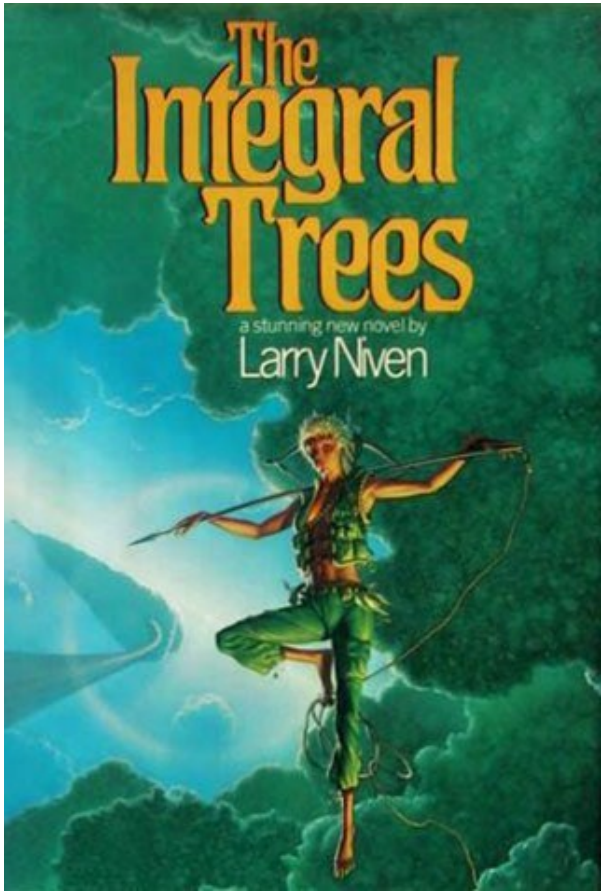
- The ringworld is unstable!
- If perfectly centered on the sun:
  - Force from each side of the ringworld is proportional to $Rd\theta$.
  - Divided by R^2.
- If the the ringworld is moved off center:
  - Force on one side is proportional to $(R+x)d\theta$.
  - Divided by $(R+x)^2$.
  - Force on other side is proportional to $(R-x)d\theta$.
  - Divided by $(R-x)^2$.
- Ringworld is pulled further off-center, eventually crashing into the sun.

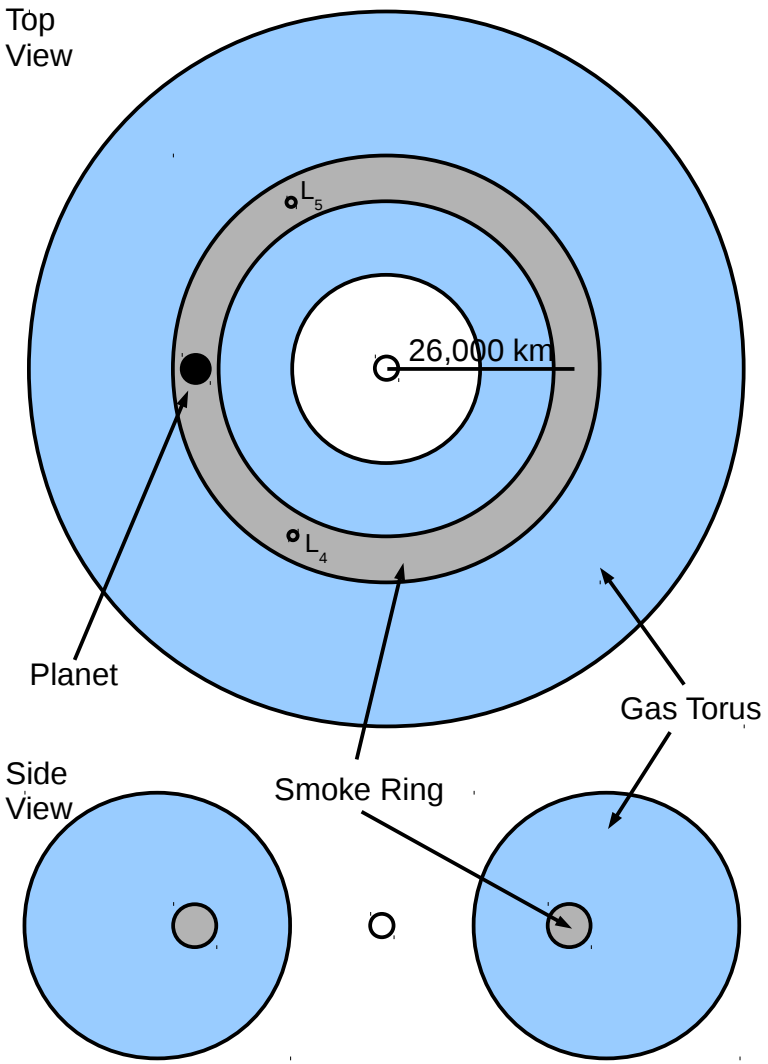


- The tensile strength required to hold the ringworld together is absurdly high.
- Attitude jets would be required to keep the ringworld centered on the sun - any deviation would cause it to fall into the sun.
- If the civilization on the ringworld were to collapse, it would be difficult to rebuild - few natural resources.

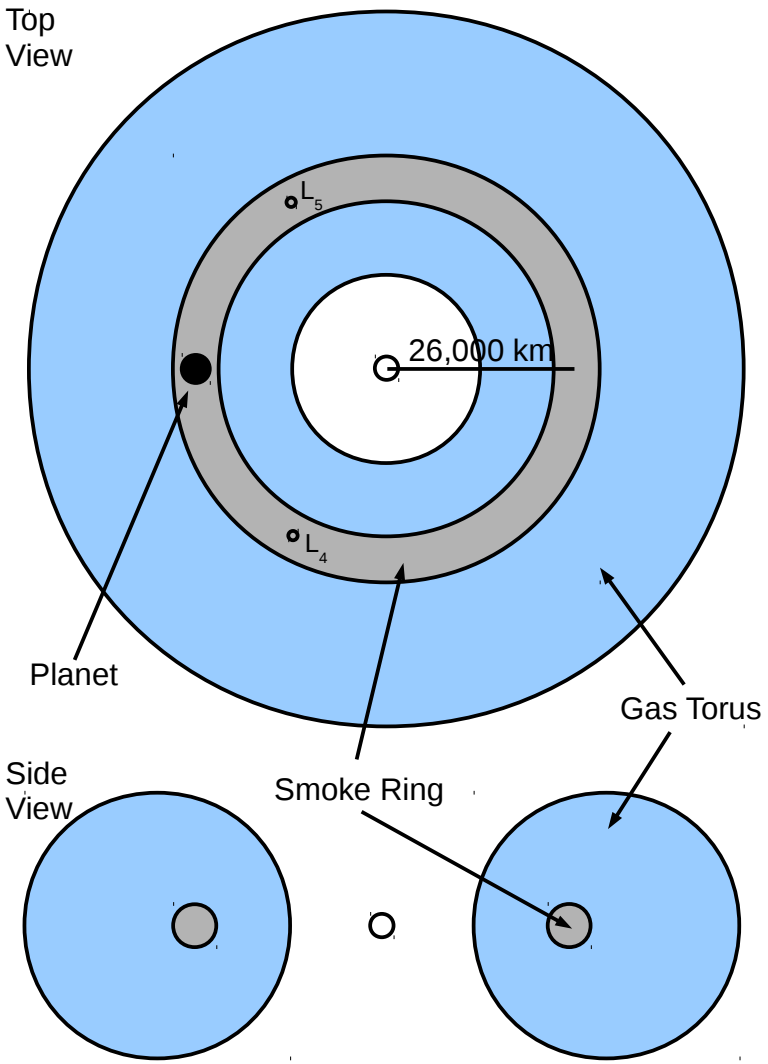
The Integral Trees

- Also written by Larry Niven.
- Published in 1984.
- Nominated for both Hugo and Nebula awards.
- Sequel, The Smoke Ring, published in 1987.
- Follows the inhabitants of an integral tree as they are exiled.

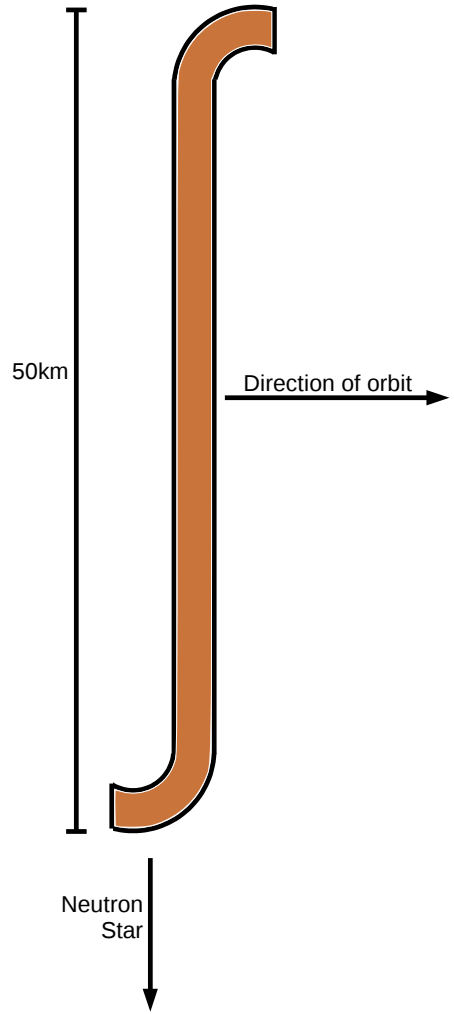




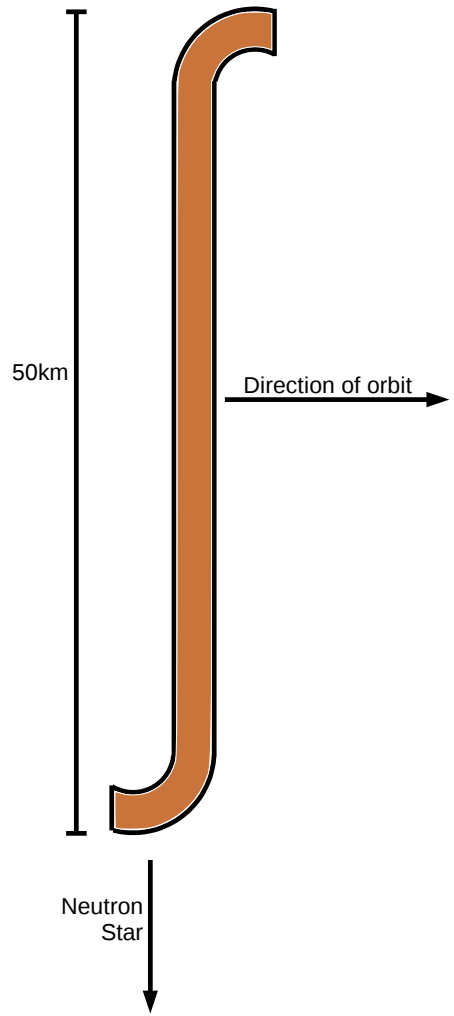
- Consider a binary system consisting of a sun like star and a neutron star with a mass of $1.5 M_{Sol}$
- A gas giant orbits the neutron star just outside it's Roche limit.



- The gas giant's atmosphere has been pulled into a torus which surrounds the neutron star.
- The Smoke Ring is the center of the torus, where pressure is high enough to support life.
- Indigenous plants and animals have evolved to live in constant free fall.



- One of these indigenous plants is the integral tree.
- The story claims these are 50km in length, and point toward the neutron star.
- Tides are created on the ends, since they are in the ‘wrong’ orbit.
  - The story claims these tides produce 1/5 of a g.
- The ends are bent in opposite directions due to the constant wind, producing ‘integral’ shape.

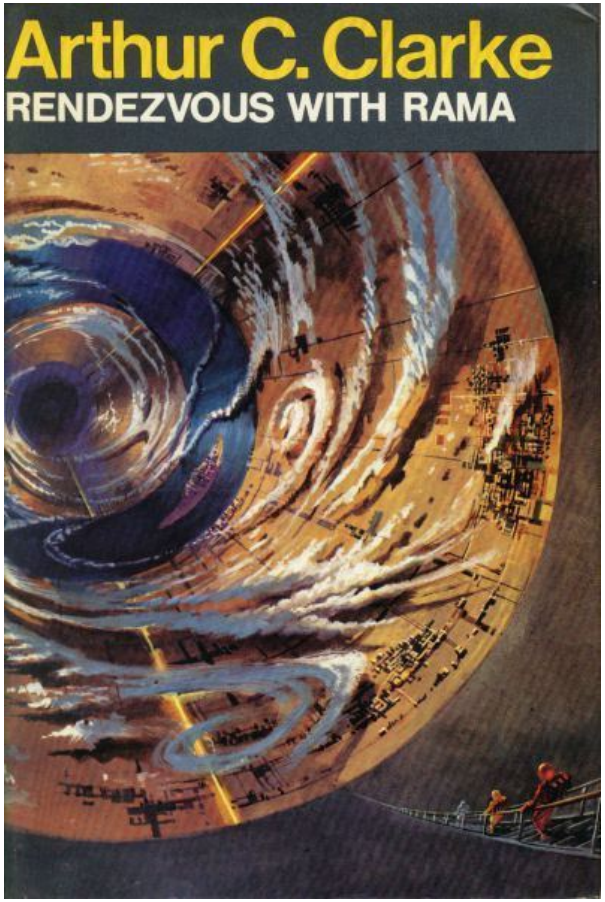


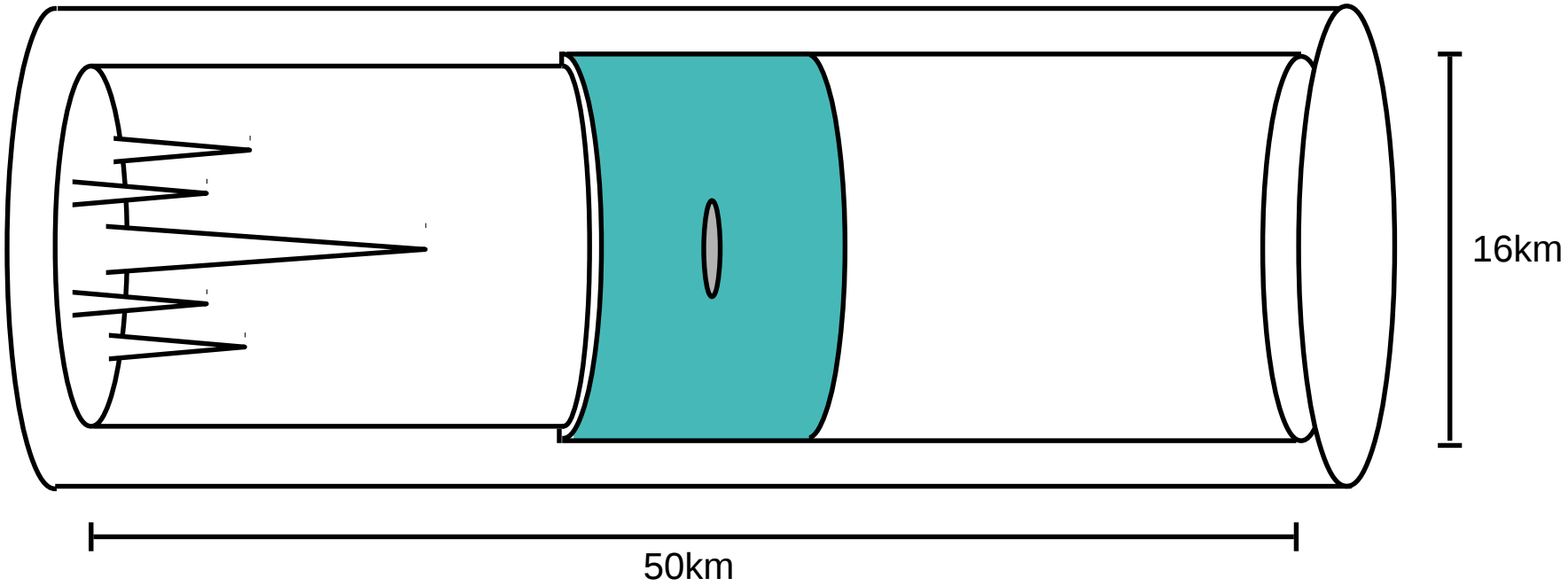
- The tidal acceleration on the ends of the tree is given by $a_{tide} = \frac{2GMr}{R}$, R being the radius of the orbit, and r the distance from the center of the tree
- Using r=25km and R=26,000km with M=1.5M_{Sol}, this produces a tidal acceleration of 19g!
- If orbital radius is doubled to 52,000km and the length of the tree is reduced to 4km, the tidal acceleration becomes a much more manageable 1/5 of a g.
- Scifi writers sometimes make mistakes...

- Niven's calculation of the integral tree tidal acceleration is incorrect.
- The setting seems to be rather unlikely.
- Improbability aside, the idea, if not the numbers, makes sense.
- Scarcity of resources is still problematic.

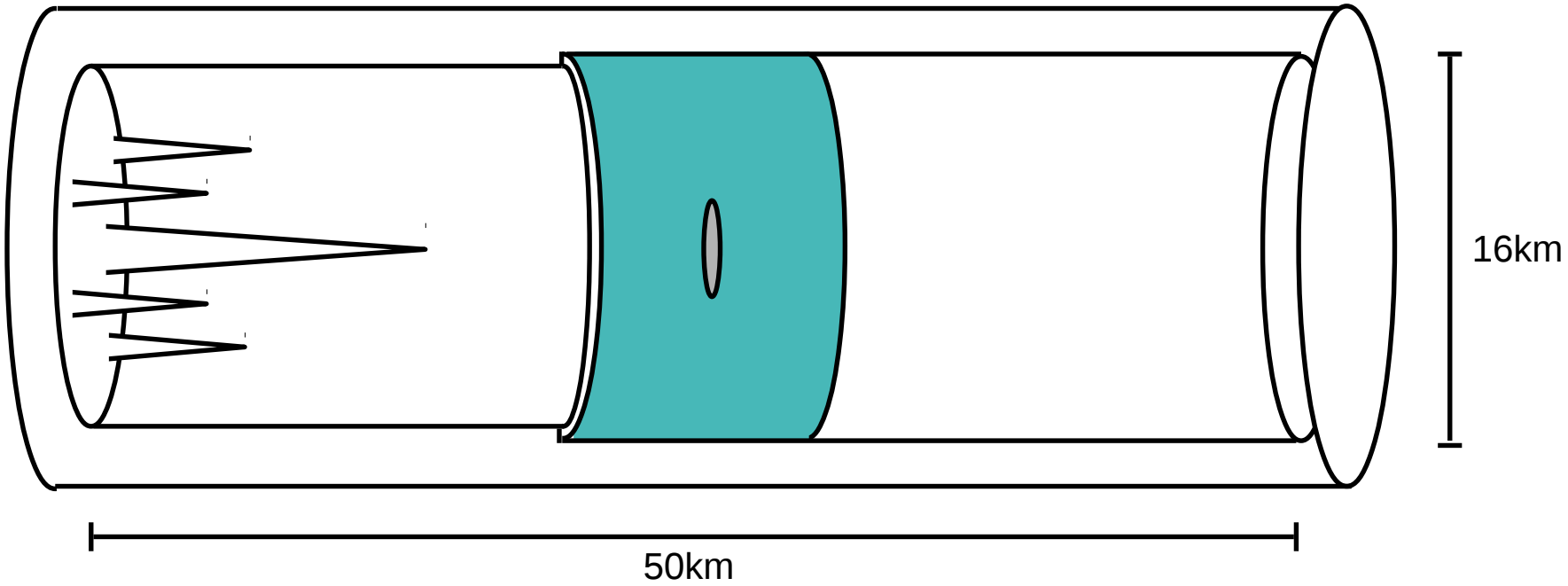
Rendezvous with Rama

- Written by Arthur C. Clarke.
- First published in 1973.
- Won both the Hugo and Nebula awards.
- An obviously artificial object is passing through the solar system, and a ship happens to be close enough to explore it.



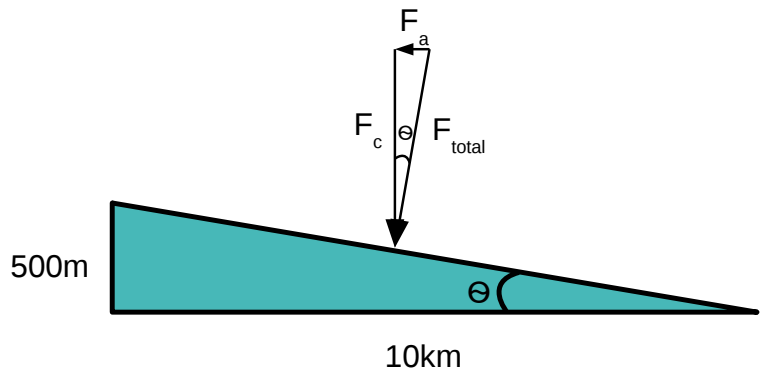


- Rama is a 54km long cylinder with a diameter of 20km.
- The chamber inside is 50km long, 16km across.
- There is a 10km wide “Cylindrical Sea”.
  - The front cliff is 50m tall, and the aft cliff is 500m tall.
- Aft end has a series of cones, which is speculated to be part of the propulsion system.



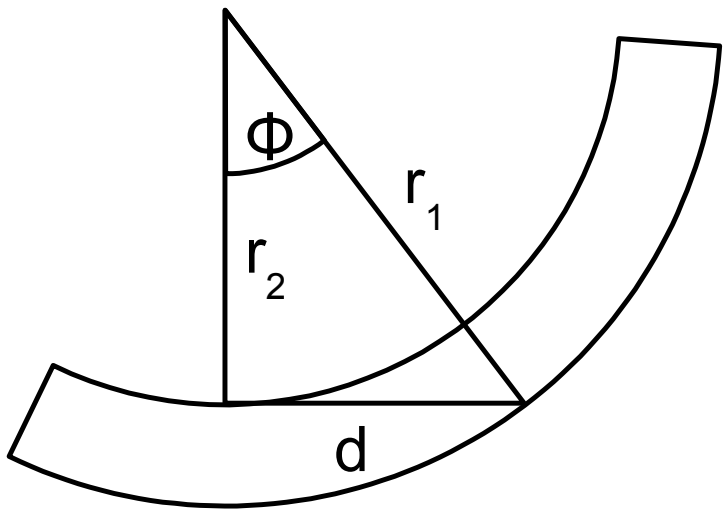
- Rama rotates once every 4 minutes.
- This produces a rotational velocity of $209 m/s$, and a centripetal acceleration of $5.48 m/s^2$, or 0.56g.
- What is the purpose of the higher aft seashore?
- During acceleration, it prevents the cylindrical sea from spilling over

- How much can Rama accelerate given the height of the aft cliff?
- Combined centripetal force and acceleration force vector must be perpendicular to a line connecting each shore



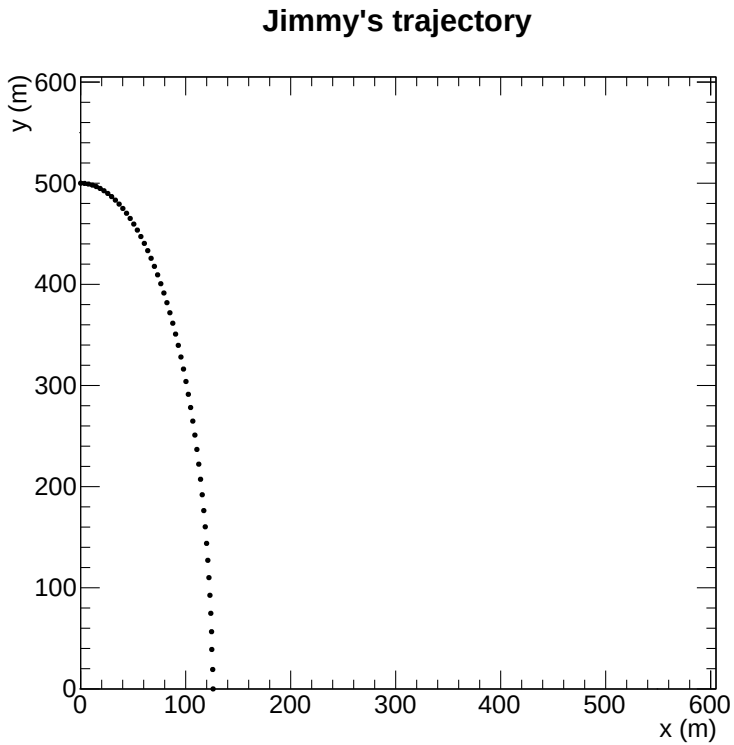
- $tan(\theta) = \frac{500m}{10{,}000m} = \frac{F_a}{F_c} \rightarrow F_a = \frac{500m \times F_c}{10{,}000m}$
- $F_c = ma_c$ and $F_a = ma_a$, so mass cancels.
- Maximum acceleration of Rama is $\frac{0.56g \times 500m}{10{,}000m} = 0.0225g$

- At one point in the story, a character (Jimmy) is at the top of the 500m cliff and needs to jump down into the water.
- Where will he land?
- His Tangential velocity will be 196m/s, since he is at a smaller radius



- He will travel a distance of $d = \sqrt{r_1^2 - r_2^2} = 2.784km$, taking $t = v/d = 14.2s$.
- He will subtend an angle of $\cos^{-1}(r_2/r_1) = 20.36°$, which moves him 2.843km along the circumference.

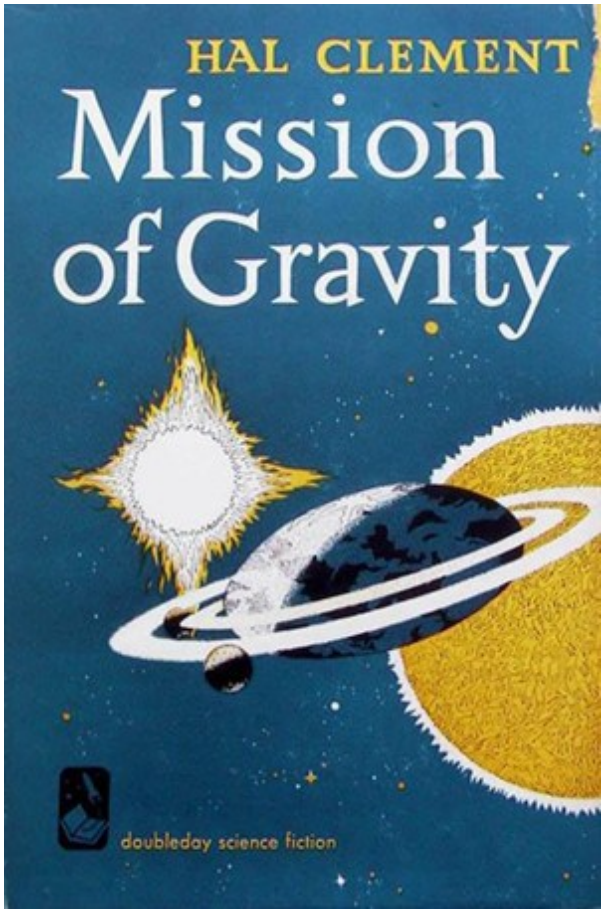
- In 14.2s, Rama rotates $\omega \times t \times r_1 = 2.969km$.
- Jimmy ends up $2.969km - 2.843km$ antispinward of where he was.
- From the perspective of someone on Rama, he is 126m behind where he should be.



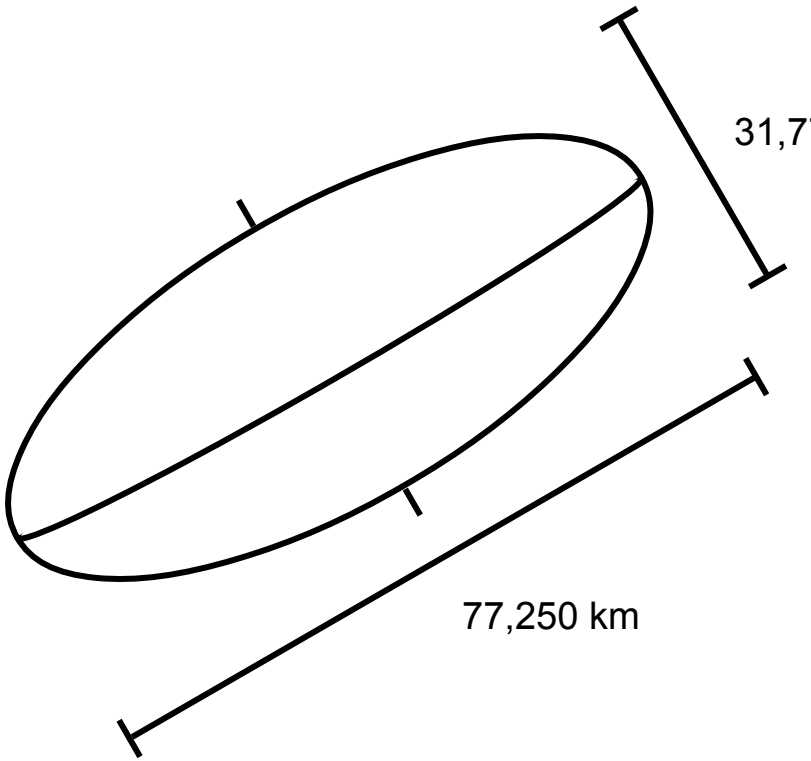
- Probably one of the most realistic settings I've read.
- Everything about Rama has some purpose that makes sense based on real physics.
- Avoid the sequels...

Mission of Gravity

- Written by Hal Clement.
- Published in 1953.
- Nominated for the Hugo award.
- Humans enlist the aid of aliens to retrieve an important device from their strange planet.



Mesklin



- It was thought at the time of writing that there was an object in the 61 Cygni system.
- Mesklin is based on that object.
- From the observations at the time, a mass of $16.2 M_{Jupiter}$ was calculated.
- The author decided to spin it very fast: rotating once every 17.75 minutes.
- As a result, it is a very oblate spheroid.

- On the equator, the gravitational acceleration is 140.3g inward.
- However, due to it's fast rotation, the centripetal acceleration is 137.2g outward.
- These add up to a nice mild 3.1g at the equator.
- As you travel away from the equator, the centripetal force decreases and the gravity increases (in a complex way).
- The author attempted to calculate the polar gravity, but found it difficult. The result he got was 275g.
  - My own attempt yeilded 897g, assuming constant density.
- Humans can visit the equator, but not the poles.

- It turns out that the planet in the 61 Cygni system doesn't exist.
- How would the planet get such a high spin?
- Calculation of the polar gravity is difficult due to the oblateness of the planet. Clement's initial calculation yielded $\sim$700g, but later calculations produced 275g.

- If you like interesting applications of physics, you might like hard sci-fi.
- Hard science fiction stories often have poorly developed characters.
- It's fun to imagine what kind of scenarios might be possible with our knowledge of physics.

- I run a science fiction book club, where we read a book every month.
  - Look us up on goodreads.com under “Victoria BC science fiction book club”
  - URL: https://www.goodreads.com/group/show/113905-victoria-bc-science-fiction-book-club

Title	Author	Description
Dragon's Egg	Robert Forward	Life on a neutron star.
The Mars Trilogy	Kim S. Robinson	Colonization and terraformation of Mars.
The Black Cloud	Fred Hoyle	A dust cloud surrounds the sun.
Tau Zero	Poul Anderson	Relatavistic ship stuck in acceleration mode.
The Fountains of Paradise	Arthur C. Clarke	Construction of a space elevator.
Neutron Star	Larry Niven	A series of short stories with accurate physics.
Raft	Stephen Baxter	Set in a universe where gravity is much stronger.
The Martian	Andy Weir	Astronaut gets stranded on Mars.

book club