

Computing the Heavens:

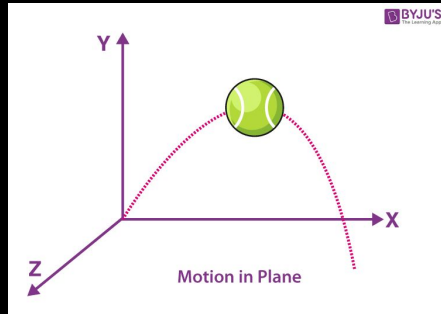
Using Computers to Understand the Chaotic and Complex

Ian Johnson
For SBU WISE

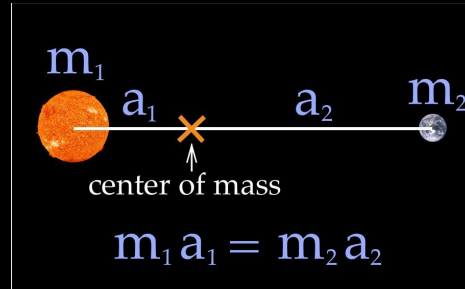
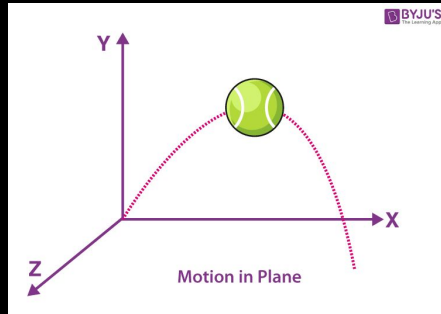
04.08.2025

One, Two, Three, and Infinity

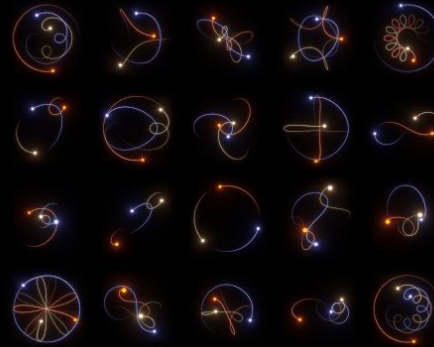
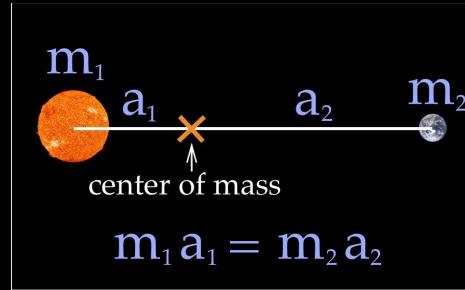
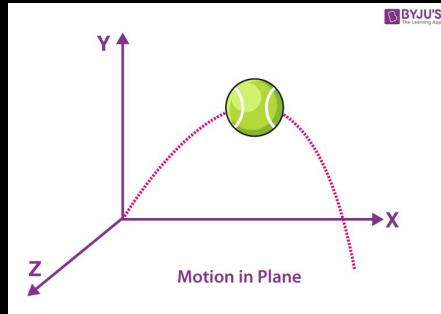
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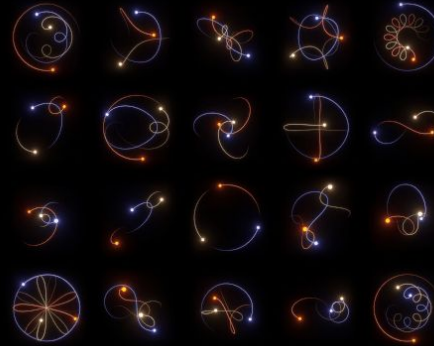
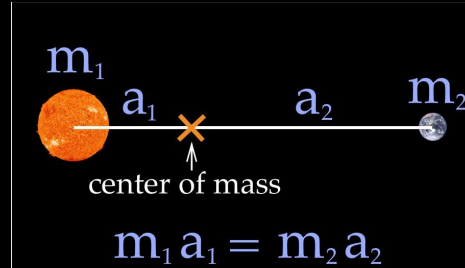
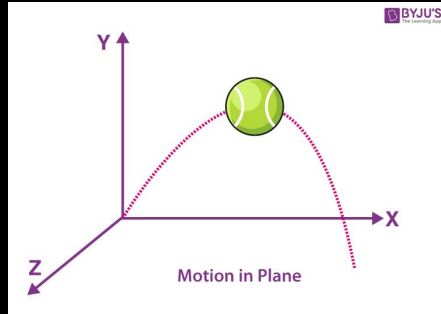
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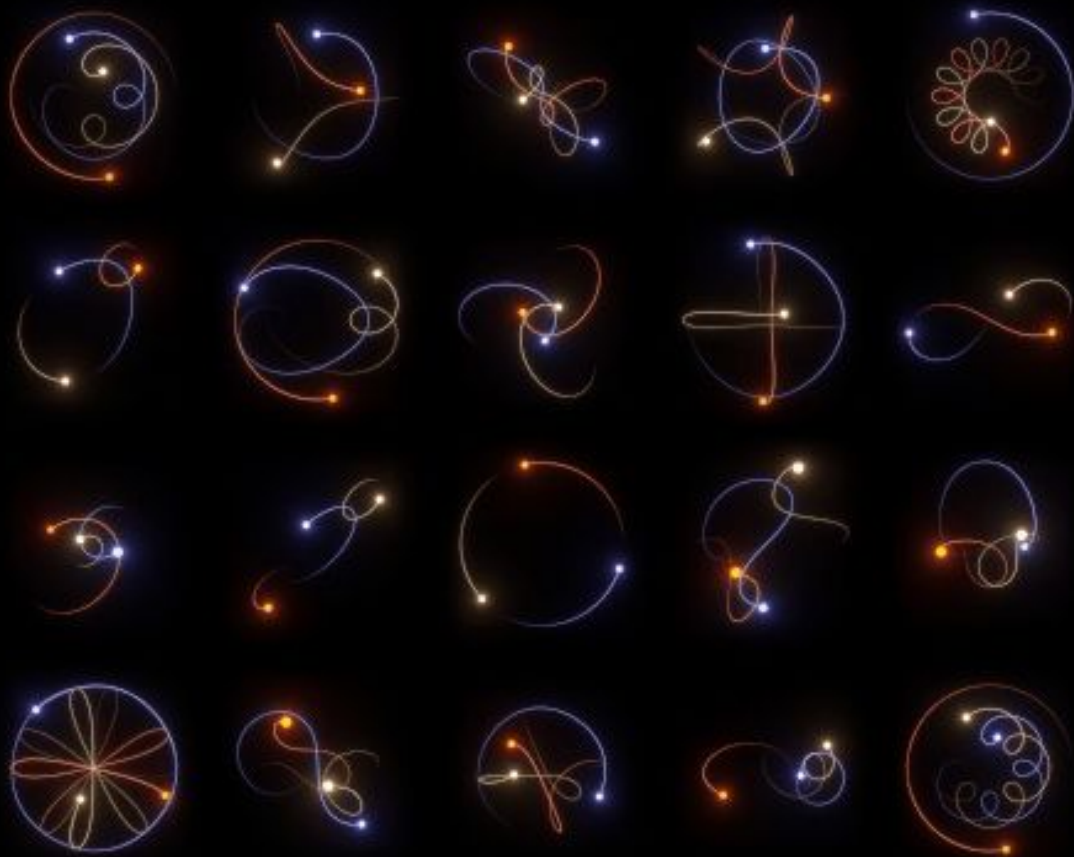


One, Two, Three, and Infinity



One, Two, Three, and Infinity





The 3 “Types” of Dynamic Astrophysical Simulation

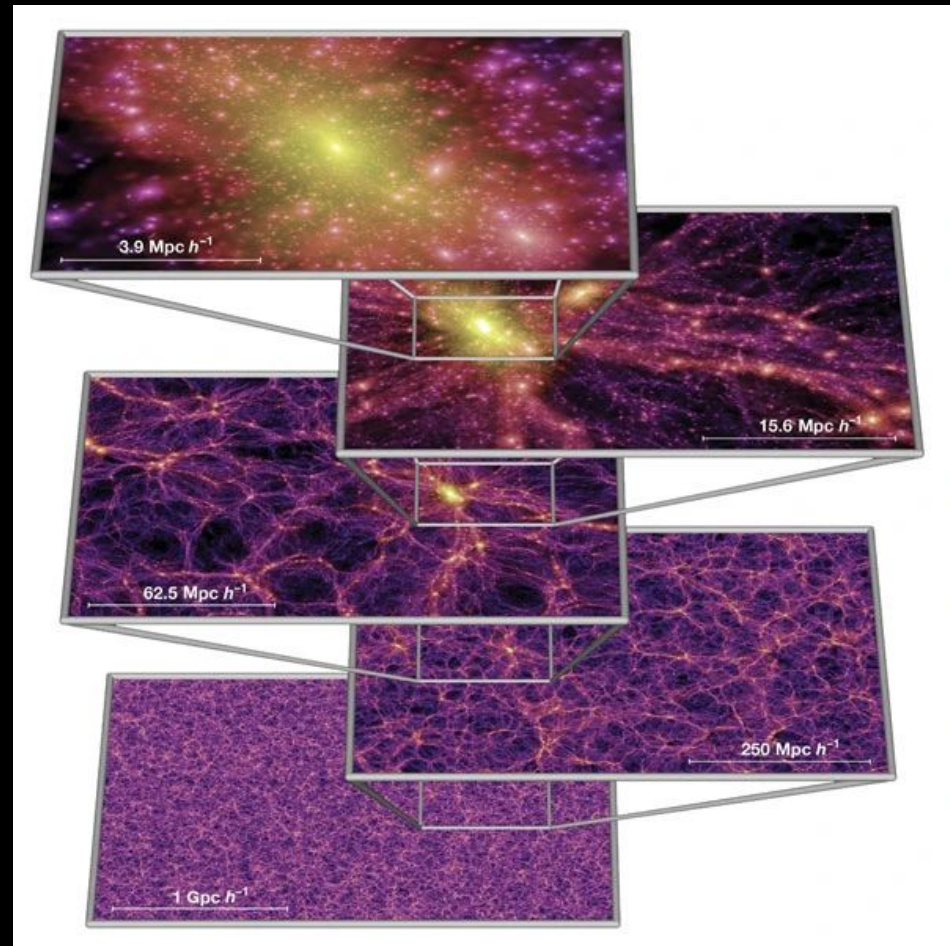
1. N-Body Code
2. General Relativistic Code
3. Hydrodynamic Code

All these specialize in a type of math/problem we as humans struggle to do by hand.

N - Body Code

Simulating the Entire Universe

- How do we know the Big Bang happened?
- The Millennium Simulation shows how large scale structure formed
- Newest version used:
 - 100 TB of Data
 - 300 CPU *years*



Simulations of the formation, evolution and clustering of galaxies and quasars V. Springel et. al.

General Relativistic Code

General Relativity From Literature: The Brothers Karamazov

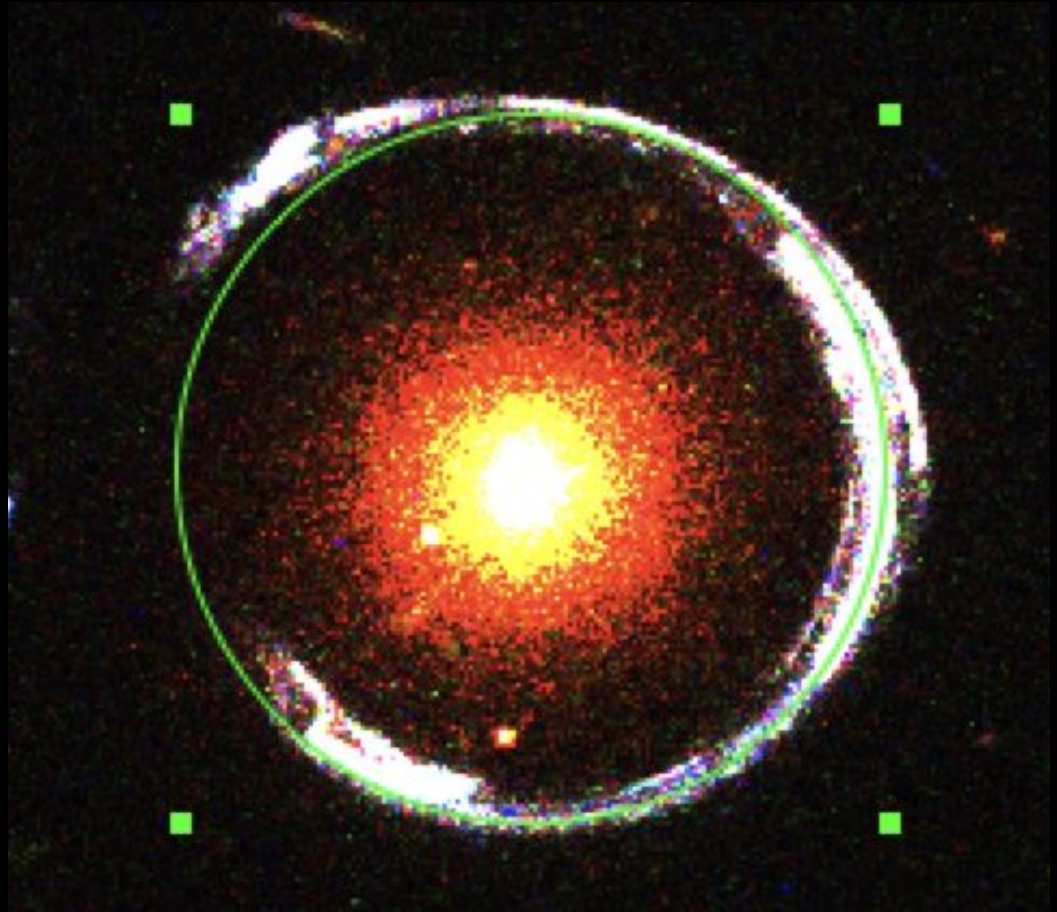
Book V Chapter 3: Translated by Pevear and Volokhonsky (highly recommend):

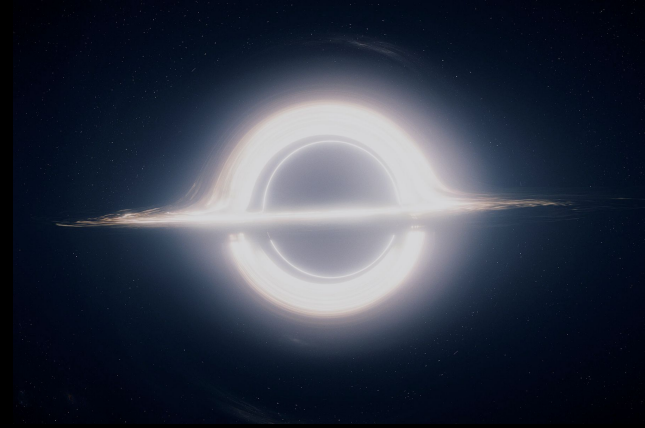
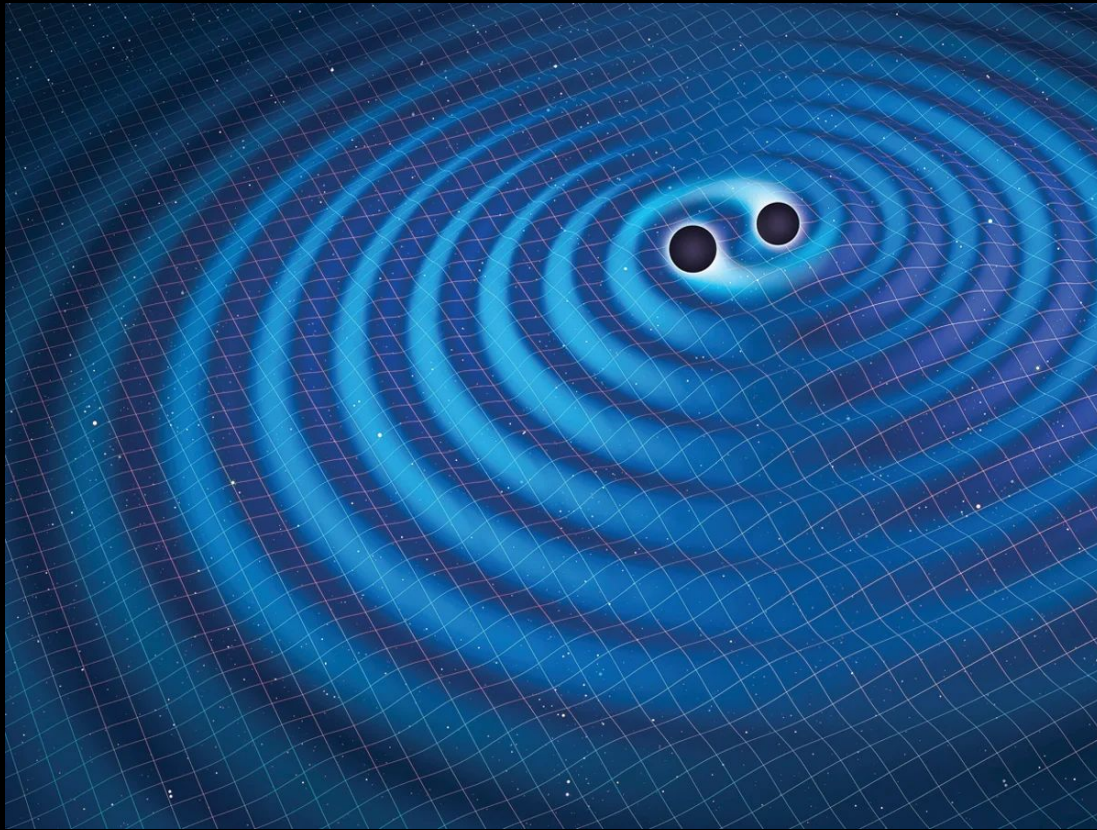
... if God exists and if he indeed created the earth, then, as we know perfectly well, he created it in accordance with Euclidean geometry, and he created human reason with a conception of only three dimensions of space. At the same time there were and are even now geometers and philosophers, even some of the most outstanding among them, who doubt that the whole universe, or even more broadly, the whole of being, was created purely in accordance with Euclidean geometry;

they even dare to dream that two parallel lines, which according to Euclid cannot possibly meet on earth, may perhaps meet somewhere in infinity.

General Relativity

- Describes gravity as a curvature of spacetime rather than a force
- Explains phenomena like:
 - Lensing
 - Black Holes
 - Precession of Mercury
- Non-linear theory
 - Gets singularities
 - Very hard to calculate by hand



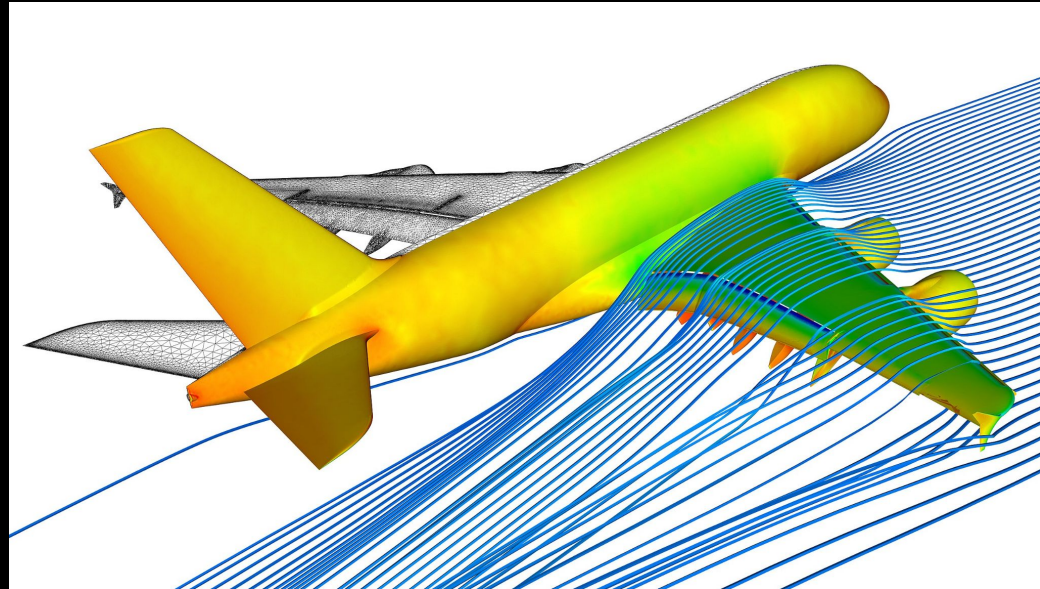


Images: The Black Hole Collision That Reshaped Physics | Scientific American, Interstellar

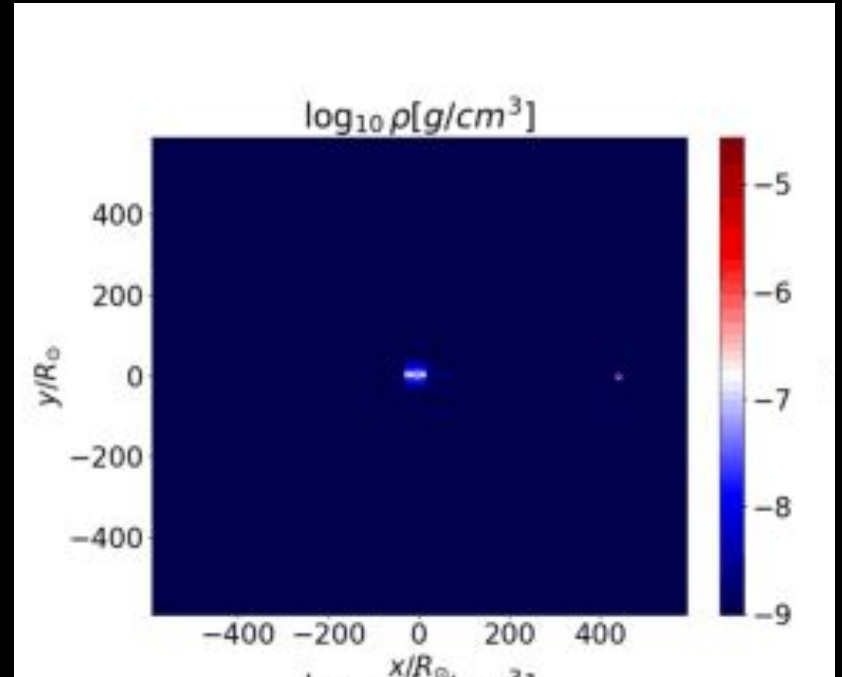
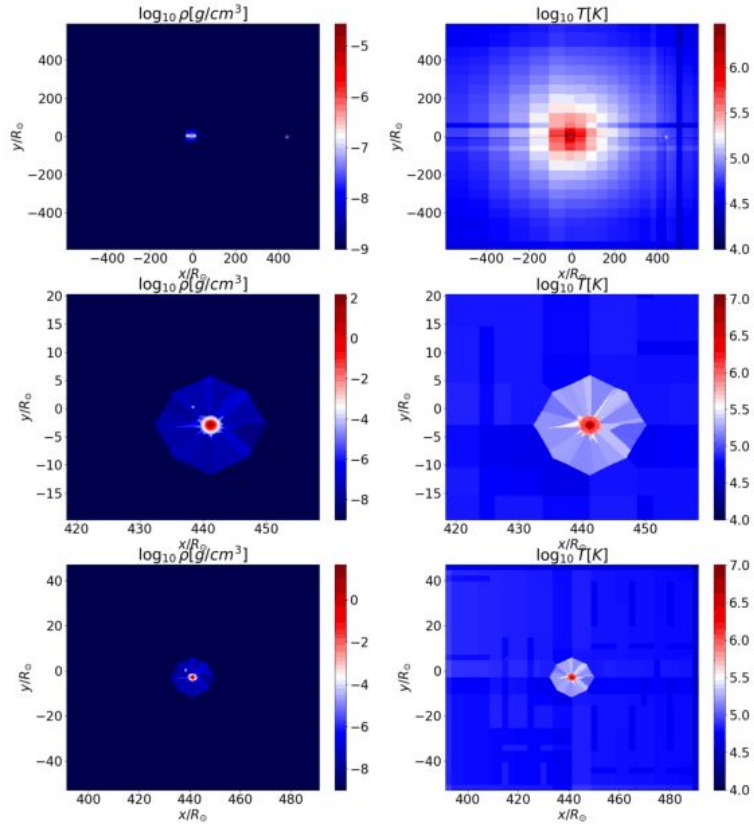
(Magnetohydrodynamic Code

Fluids Are Complicated

- A literal million dollar question (but worth much more)
- Fluids can become “turbulent”
- Even smooth paths are difficult
- Same problems in planes exist among the stars



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What Do Computational Physicists Do?

What I Do:

- Write code in several languages
- Work with high performance computing
- Learn and create new and efficient ways to model
- Astrophysical theory, physics theory, and a wide range of math

But also:

- Design images
- Read and Write
- Communicate with others!

Learn More At My Class's Github:



Additional Topics of Work

- Machine Learning (AI)
 - For detections
 - For cleaning data
 - For simplifying systems
- Public equation solvers
 - Solve initial conditions of the universe
 - Find solutions for stars
 - Refine data
- Other simulations
 - Particle physics simulations
 - Simulate detectors
 - Simulate “fake” data

High Performance Computing (HPC)

- Super computers / computing clusters run our code
- Important for beyond astrophysics
 - Artificial intelligence
 - Engineering
 - Software Companies
 - Fast detectors
 - + More



Image: The growing market for High-Performance Computing (HPC) | Digitalisation World