Using Monte Carlo Realisation Techniques to Model SETI

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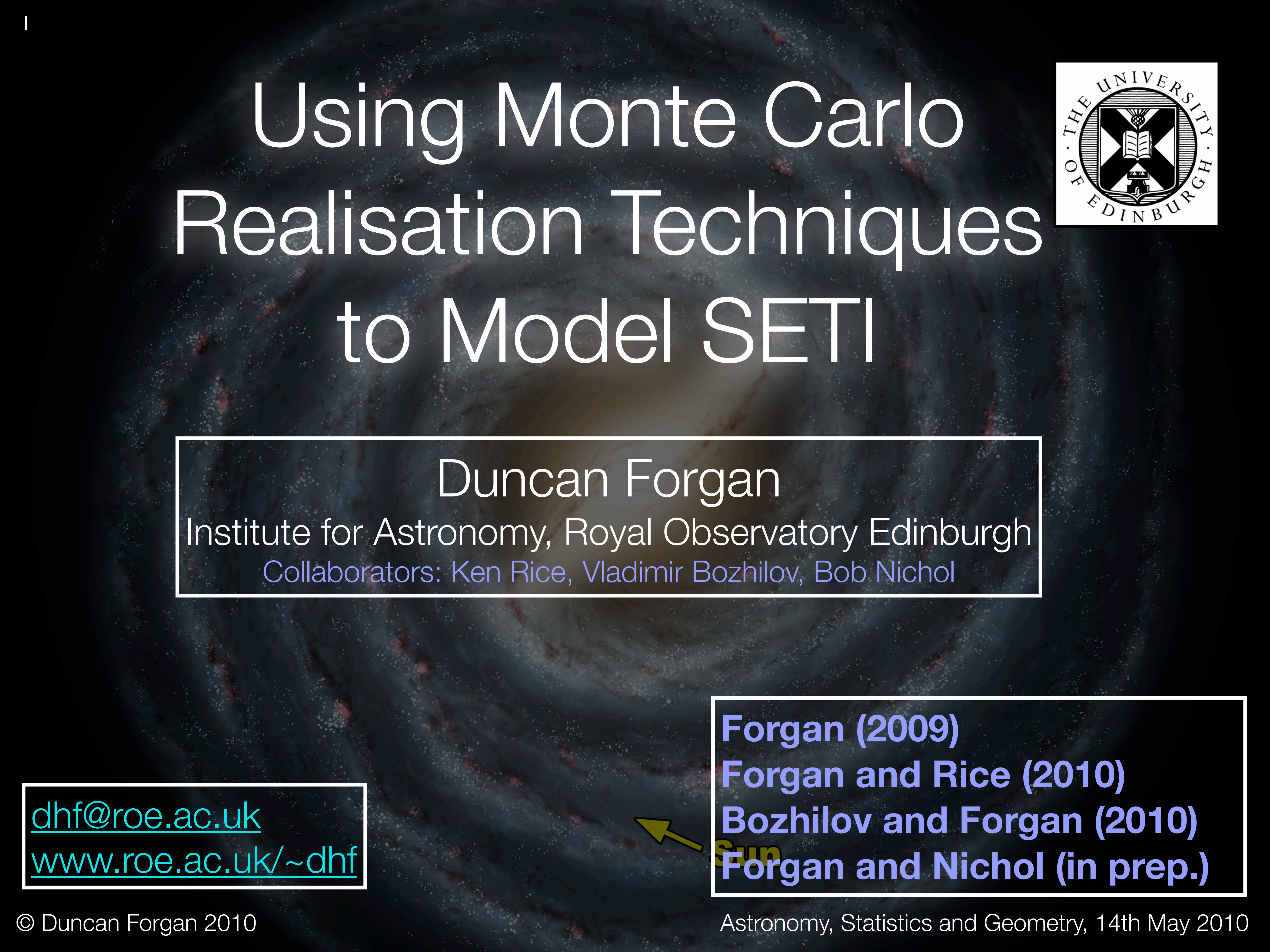

Forgan (2009)
Forgan and Rice (2010)
Bozhilov and Forgan (2010)
Forgan and Nichol (in prep.)

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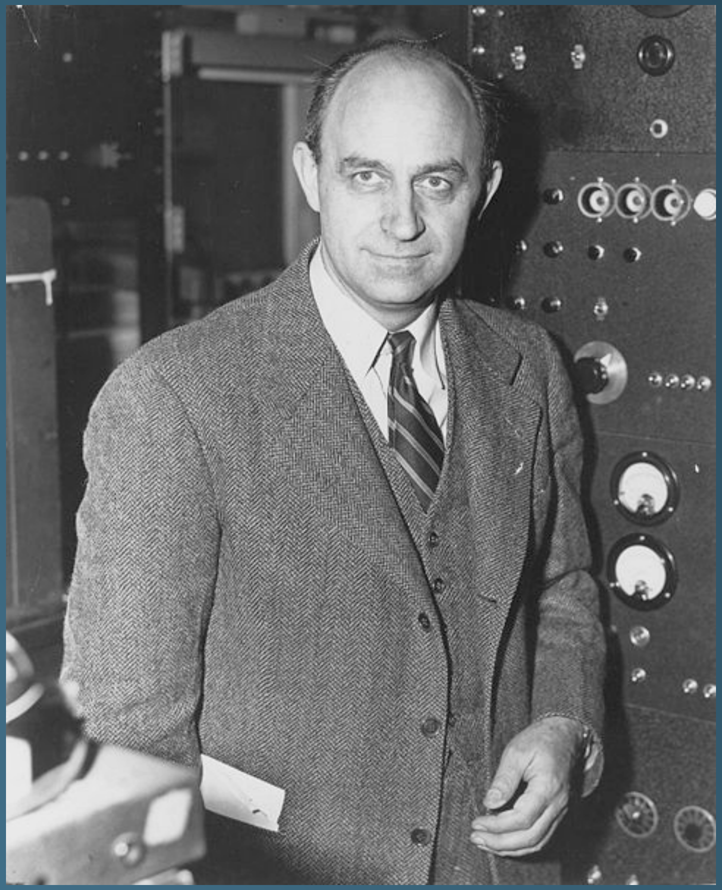
Outline

Introduction

- The SETI program has (so far) been unsuccessful
- Future surveys must be based on quantitative research - what should the strategy be?
- But, one sample statistics is a problem!
- Researchers have traditionally had two model choices

Fermi's Paradox

- A nice "back of the envelope" calculation
- Estimate timescale for civilisations to evolve
- Estimate galaxy crossing time at a modest speed
- Turns out aliens should be here already
- But they're not! So Where Are They?



The Drake Equation

- A simple equation for estimating the number of signals we should expect (over all time):

$$N = R_* f_g f_p n_e f_l f_i f_c L$$

- Good as a first pass: but...
- All terms are mean values
- No information about N as a function of space or time

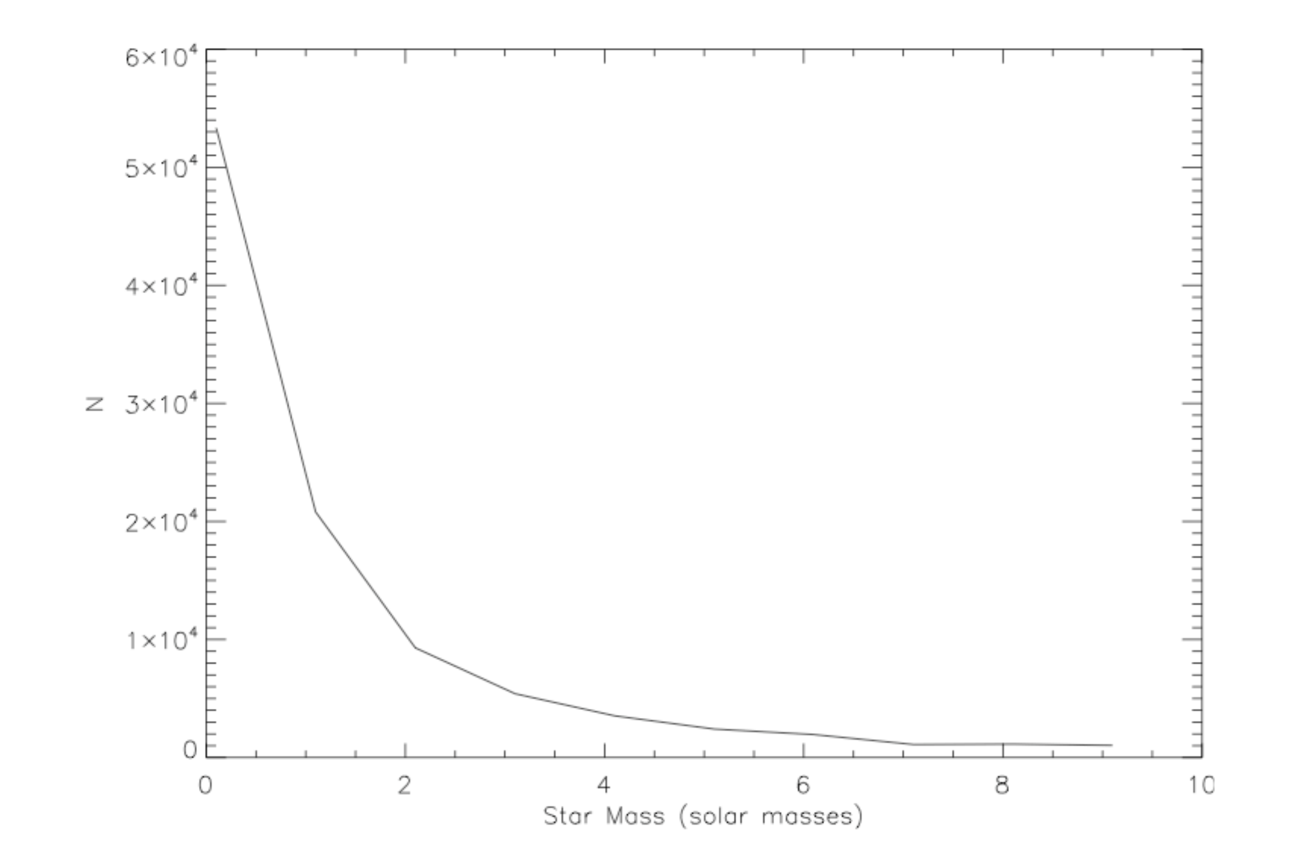
My Method

- Use Monte Carlo Realisation Techniques
(c.f. Vukotic and Cirkovic 2007)
- Generate a mock Galaxy of individual stars and planets
- Seed life according to some hypothesis
- Evolve it by stochastic equations
- Get the history of life in mock Galaxy $\longrightarrow$ One Realisation
- Many Runs $\longrightarrow$ sampling error estimates

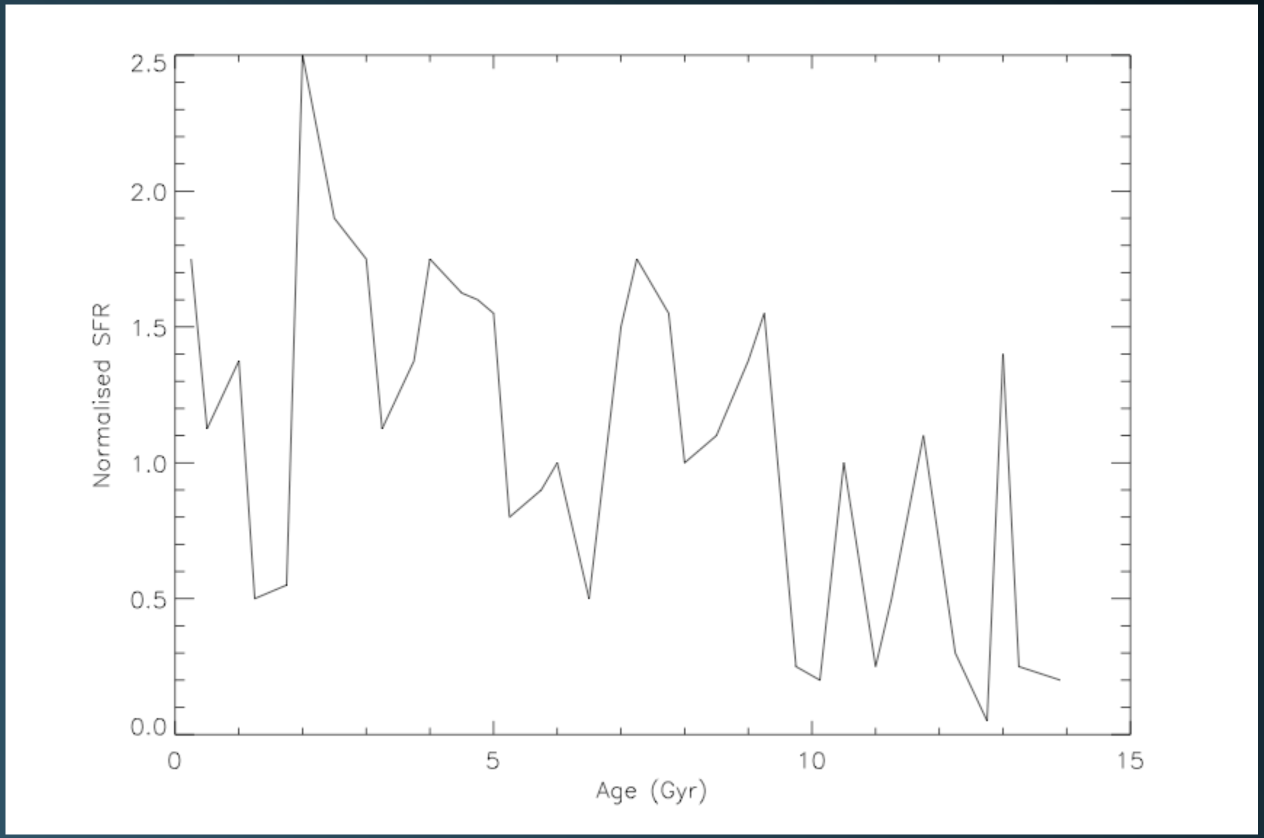
Stellar Parameters

- Assume Main Sequence stars - largely governed by their mass
- Randomly sample masses to reproduce initial mass function
- Place stars at various galactocentric radii to reproduce surface density
- Use star formation history to get stellar ages
- Other properties can also be deduced, e.g. metallicity

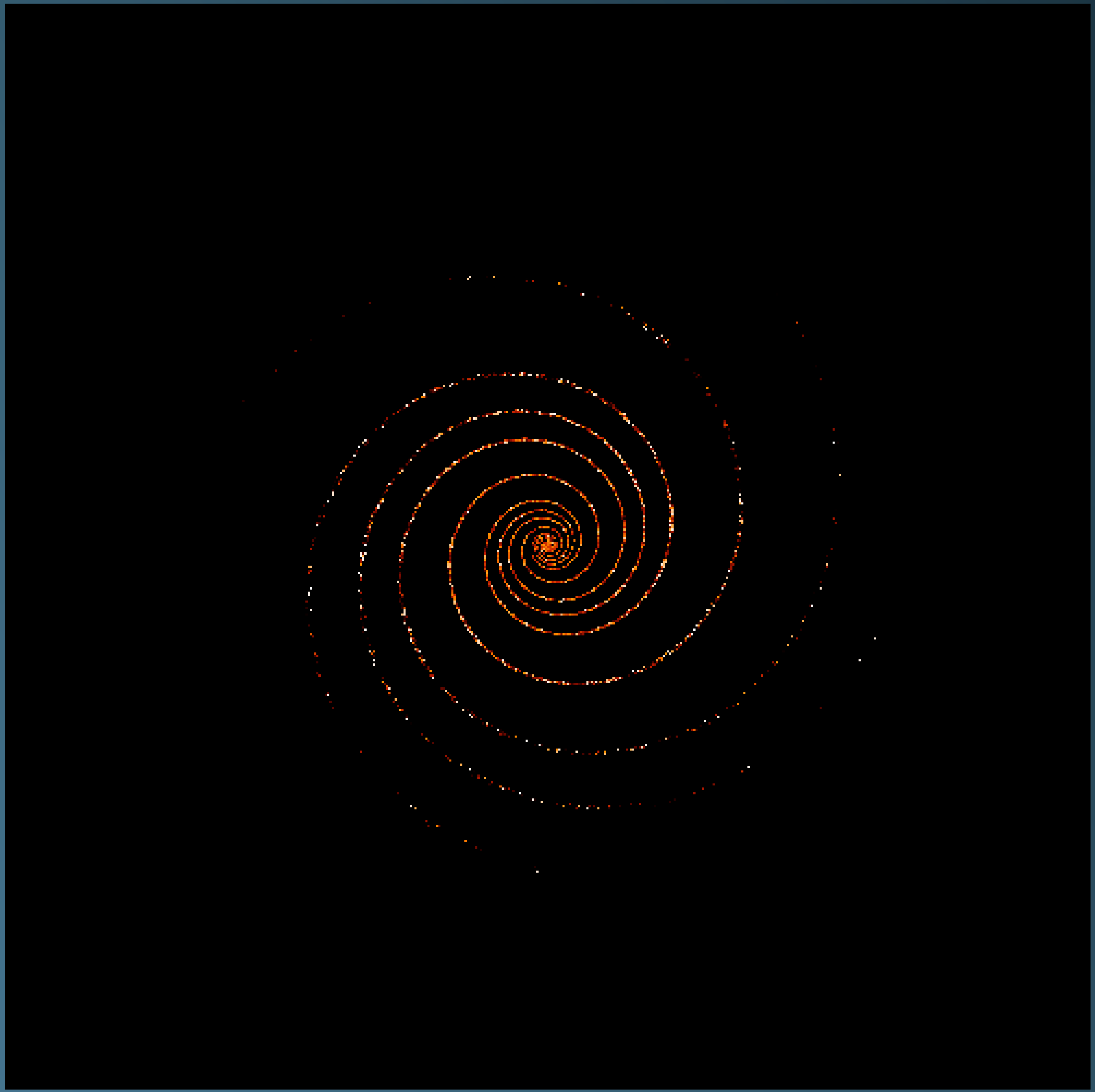
Scalo & Miller (1979)



Rocha-Pinto et al (2000)

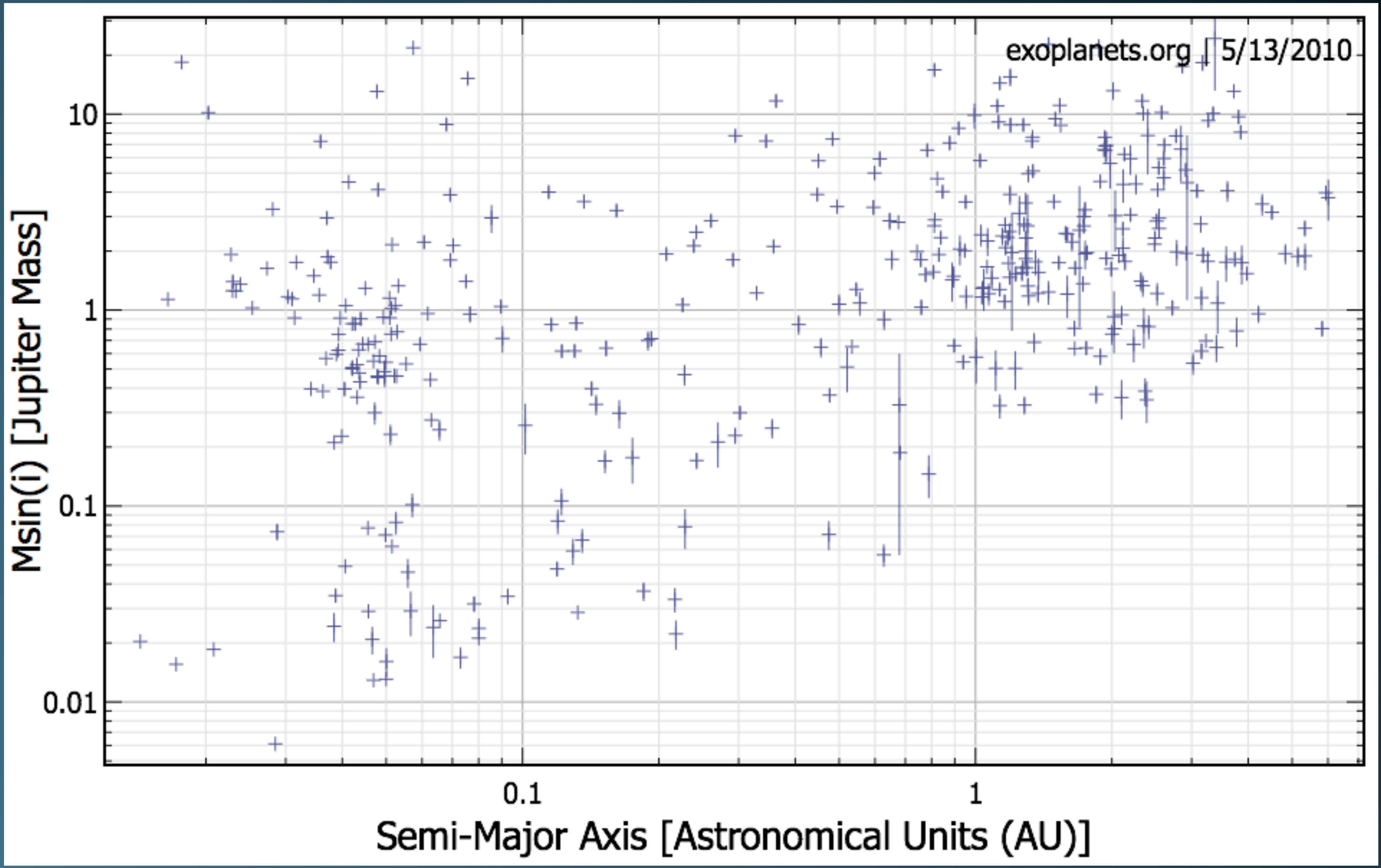


The Toy Galaxy



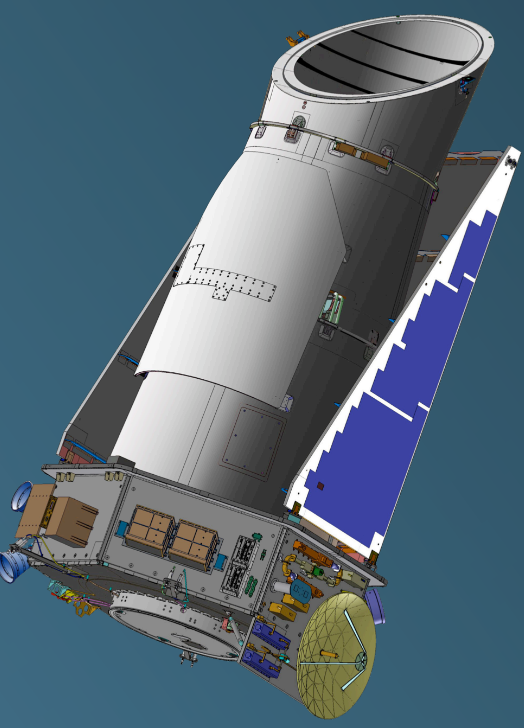
Planetary Parameters

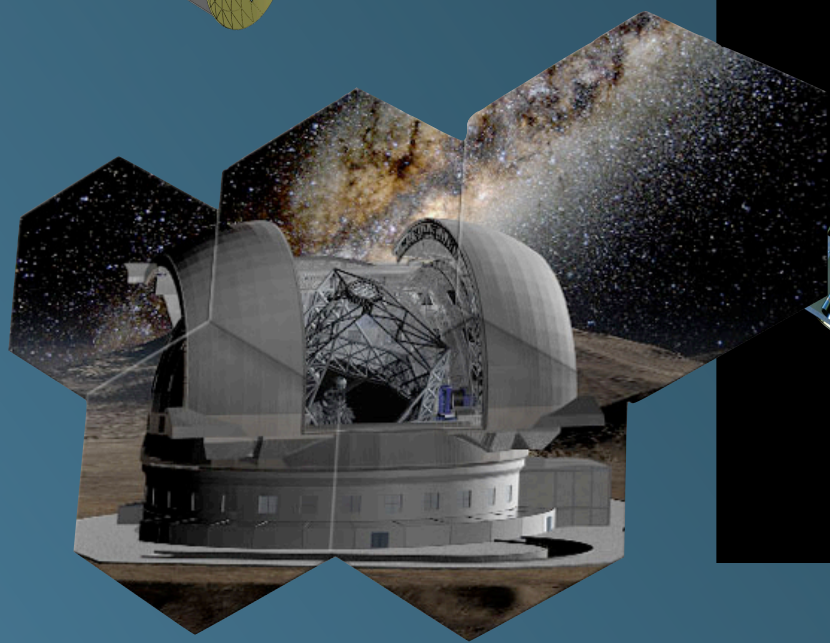
- Go to either exoplanet observations or theory
- Sample parameters to reproduce them

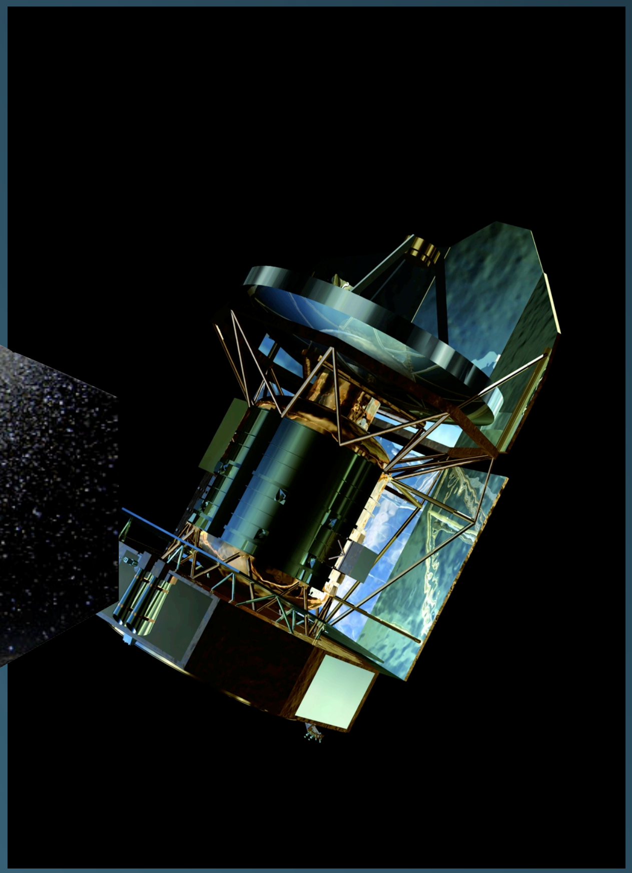


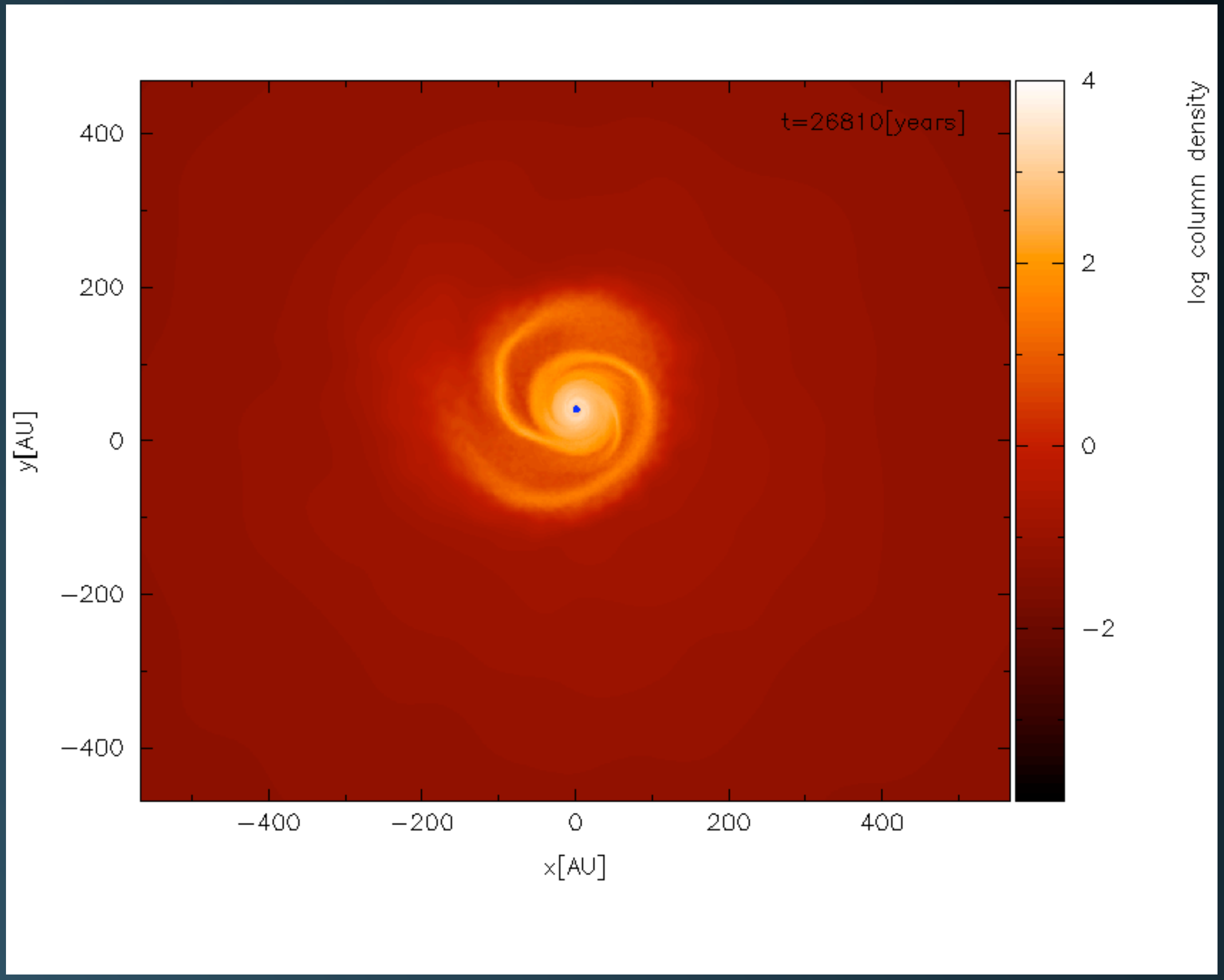
The Problem with Planets

- Observations heavily biased
- Theory has issues too
- Results will be coloured by these problems
- We will just have to be patient!









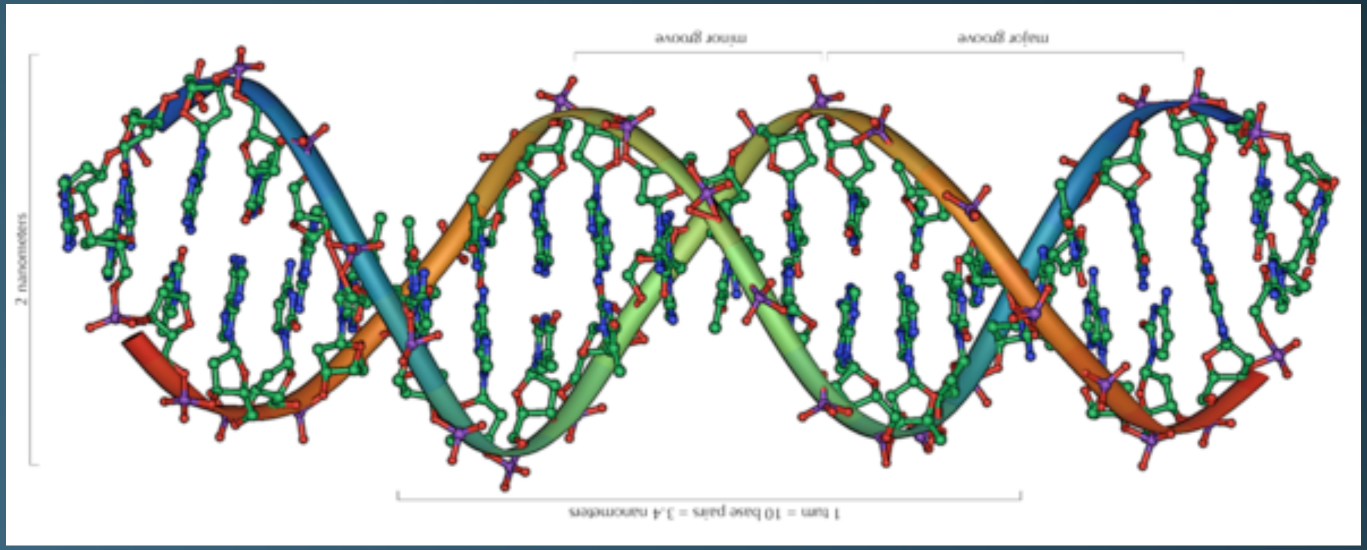
Biological Parameters

- Must rely on single sample statistics

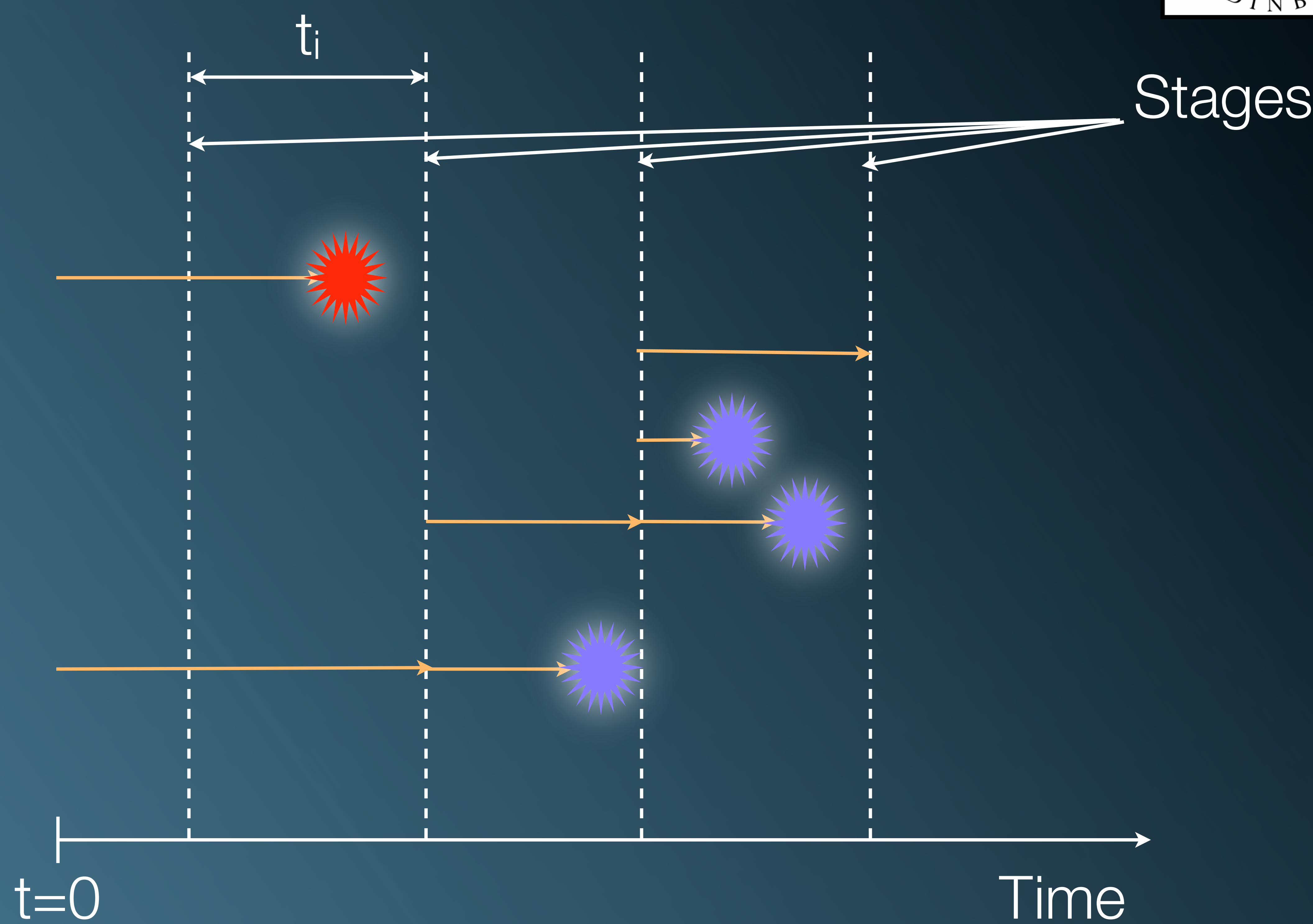
- Postulate: Evolution must achieve N key goals or stages to produce intelligent beings - the “hard step scenario” (Carter 2008)

- At each stage, resetting events can occur (e.g. SNe, comets, GRBs, see Annis 1999)

- Resets can either move life back a stage, or annihilate it

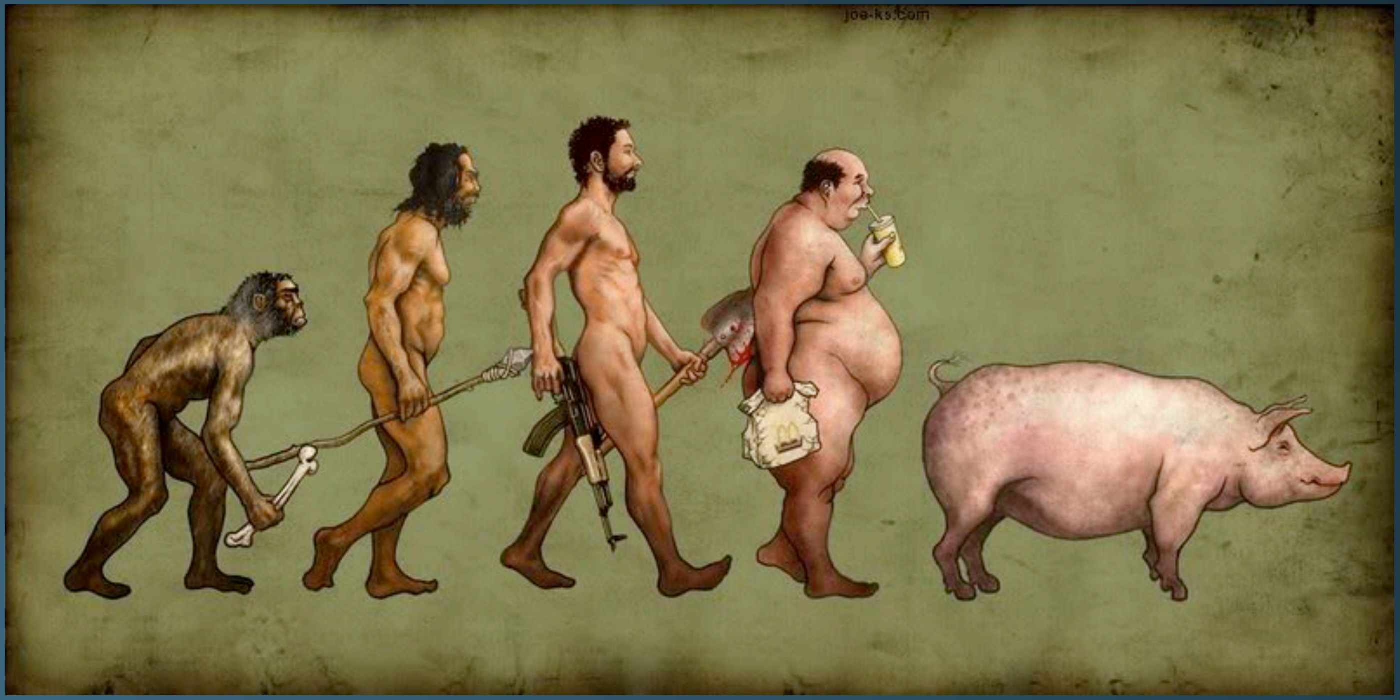


Stochastic Evolution



Civilisation Parameters

- Civilisations start out as “fledgling”
- Two potential futures: self-destruction or advancement (described by a simple probability)
- Whether civilisations destroy themselves or become advanced affects the signal lifetime of the planet



Civilisation Parameters

The Habitation Index:

$$I_{inhabit} = \begin{cases} -1 & \text{Biosphere which has been annihilated} \\ 0 & \text{Planet is lifeless} \\ 0.5 & \text{Planet has microbial life} \\ 1 & \text{Planet has primitive animal life} \\ 2 & \text{Planet has intelligent life} \\ 3 & \text{Planet had intelligent life, but it destroyed itself} \\ 4 & \text{Planet has an advanced civilisation} \end{cases}$$

Communication

- SETI is most interested in this!
- We are tracking individual intelligent civilisations
- We can calculate communication possibilities for intelligent civilisation pairs (ICPs)
- We can calculate separations, communication windows and therefore whether lightspeed communication is possible

$$ds^2 = c^2 dt^2 - dx^2$$

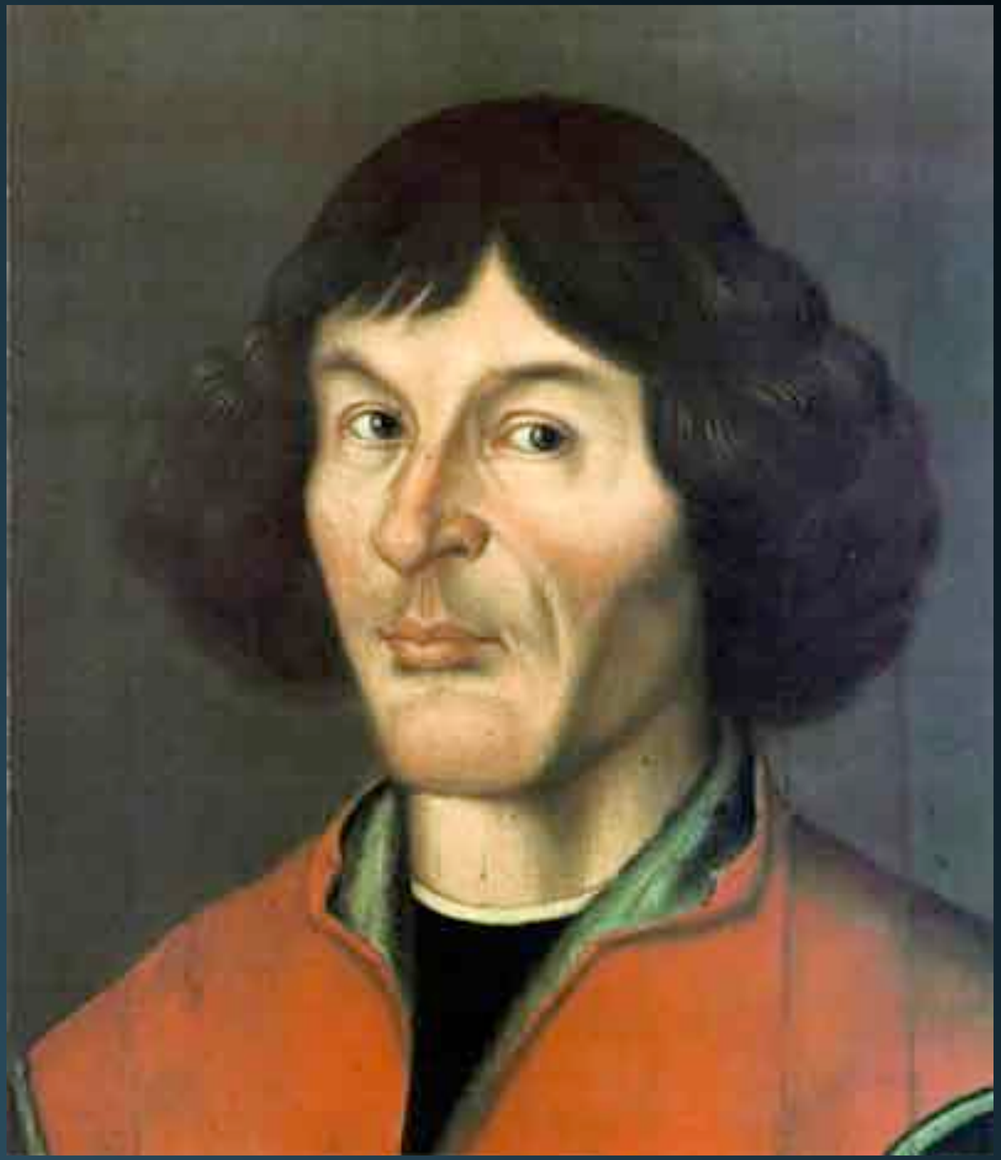
The Biological Copernican Principle

- Have many biological parameters that are not well-constrained

- Assume that life on Earth is not unique or special

- Constrain evolutionary parameters using Gaussian distributions (assuming Central Limit Theorem applies)

- Pick Earth as the mean

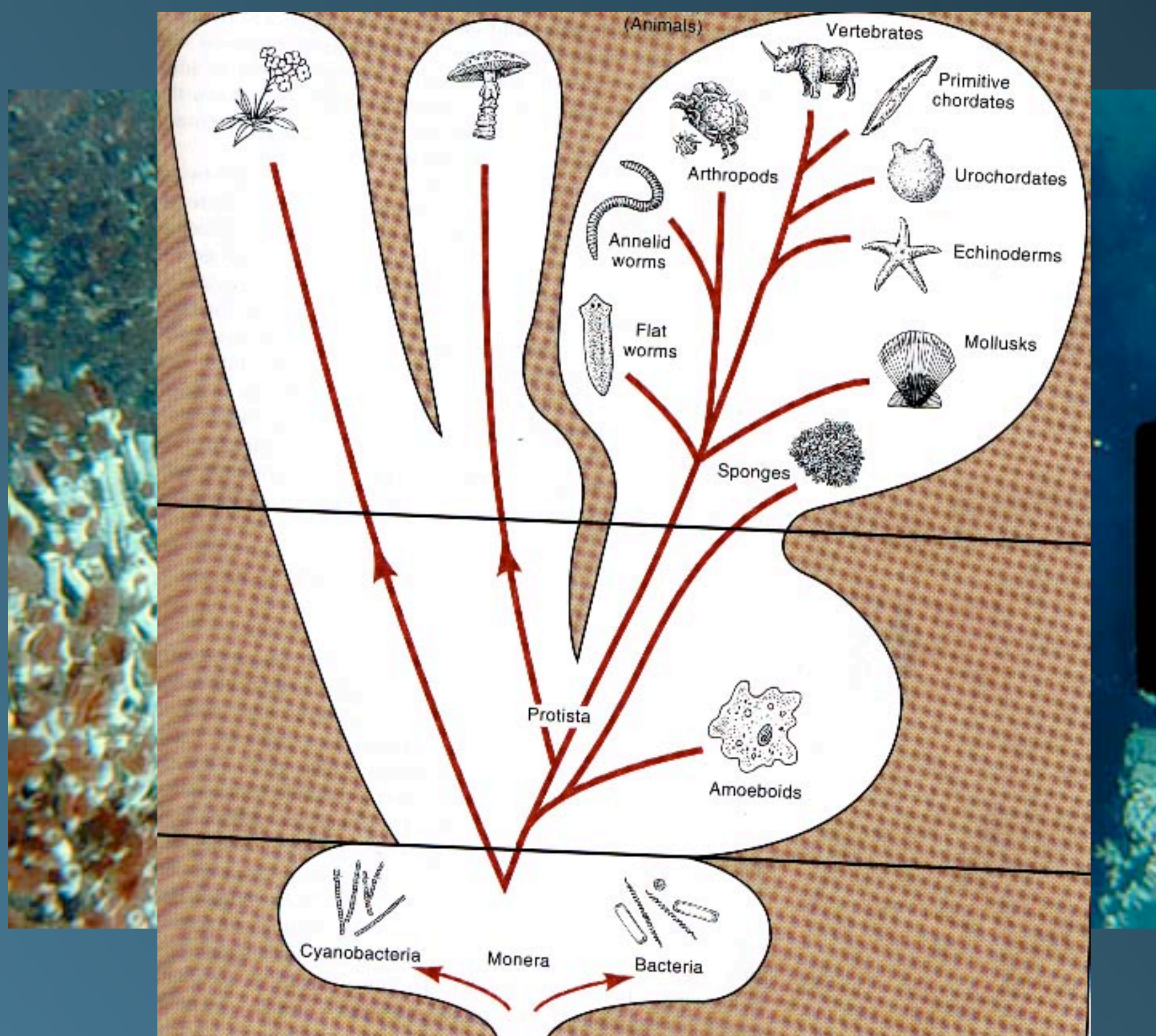


The Rare Earth Hypothesis

Ward and Brownlee (2000)

1. Simple life is everywhere

2. Complex Life is very rare



Putting the Hypothesis in the Model

Complex life can only form on a planet if it meets stringent criteria:

1. The planet's surface temperature is between [4,50] degrees C
2. The planet is between [0.5,2.0] Earth Masses
3. The star mass is between [0.5,1.5] solar masses
4. The planet has at least one moon
5. The planetary system has one "Jupiter" in an outer orbit

Microbial life forms if the planet surface temperature is [0, 100] degrees C

Experimental Control: the Baseline

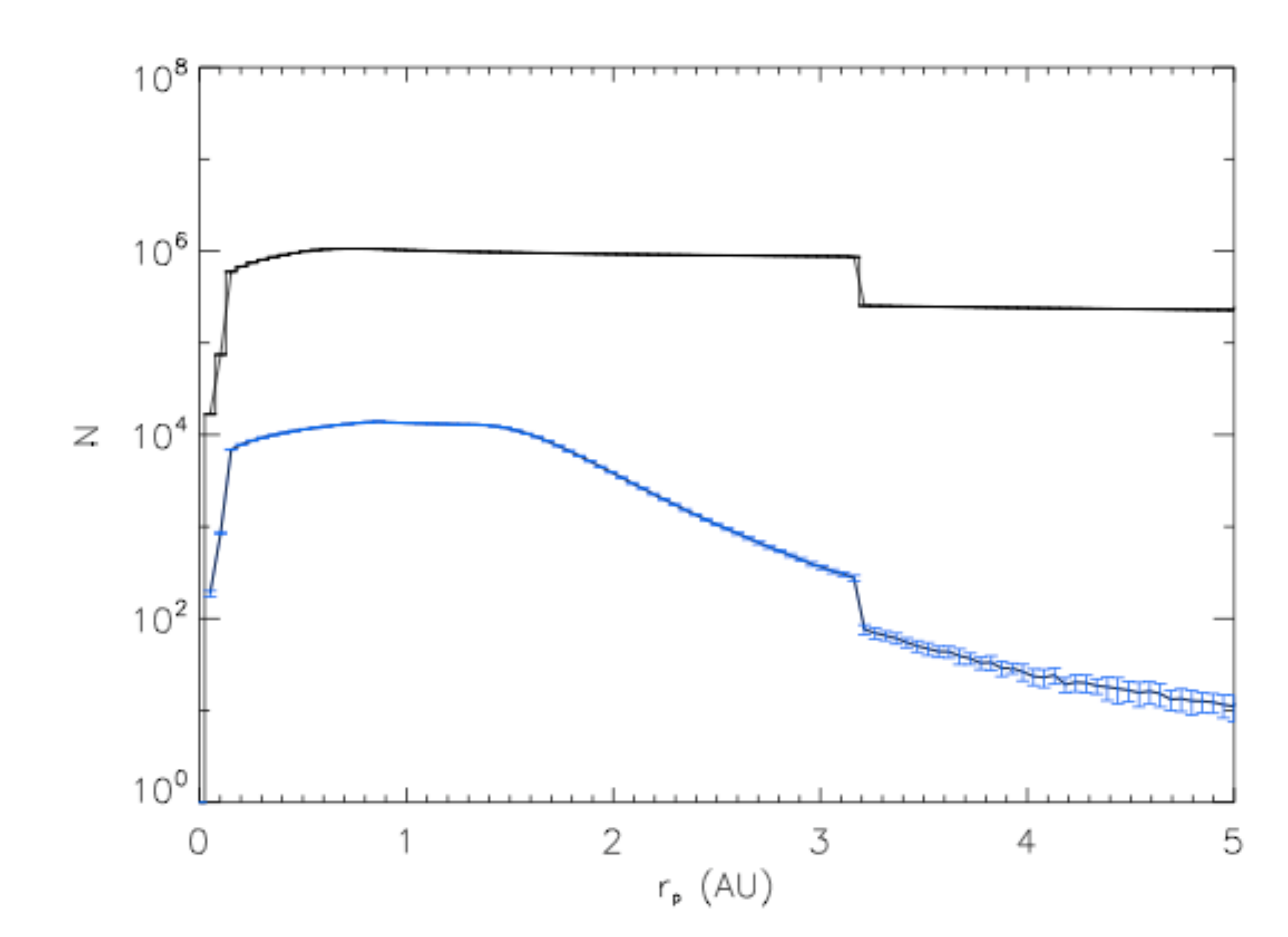
- The method is better at identifying relative trends than absolutes
- We would do better to compare our results with a “neutral” hypothesis

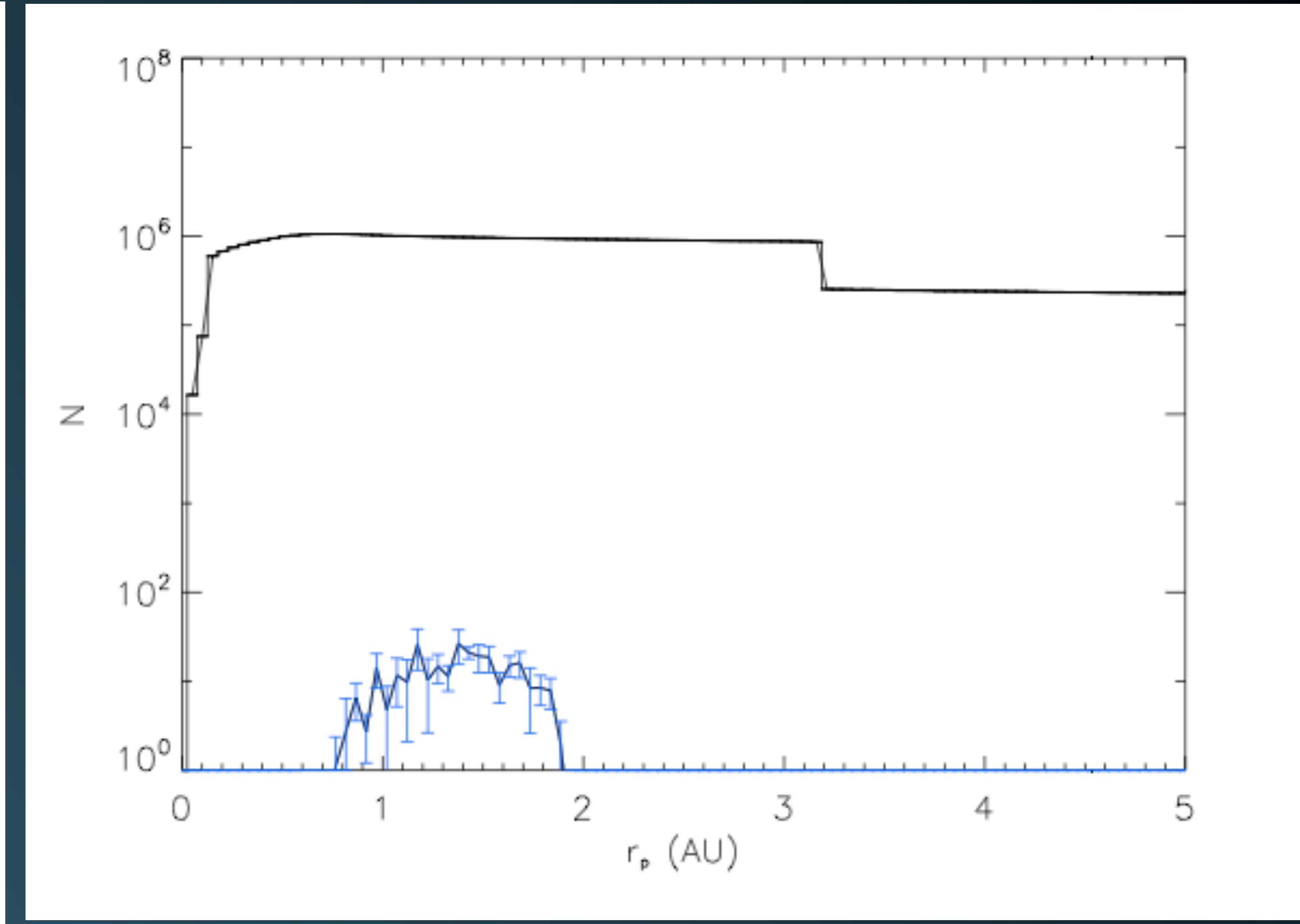
Complex life can form on a planet if

1. The planet’s surface temperature is between [4,50] degrees C

Microbial life forms if the planet surface temperature is [0, 100] degrees C

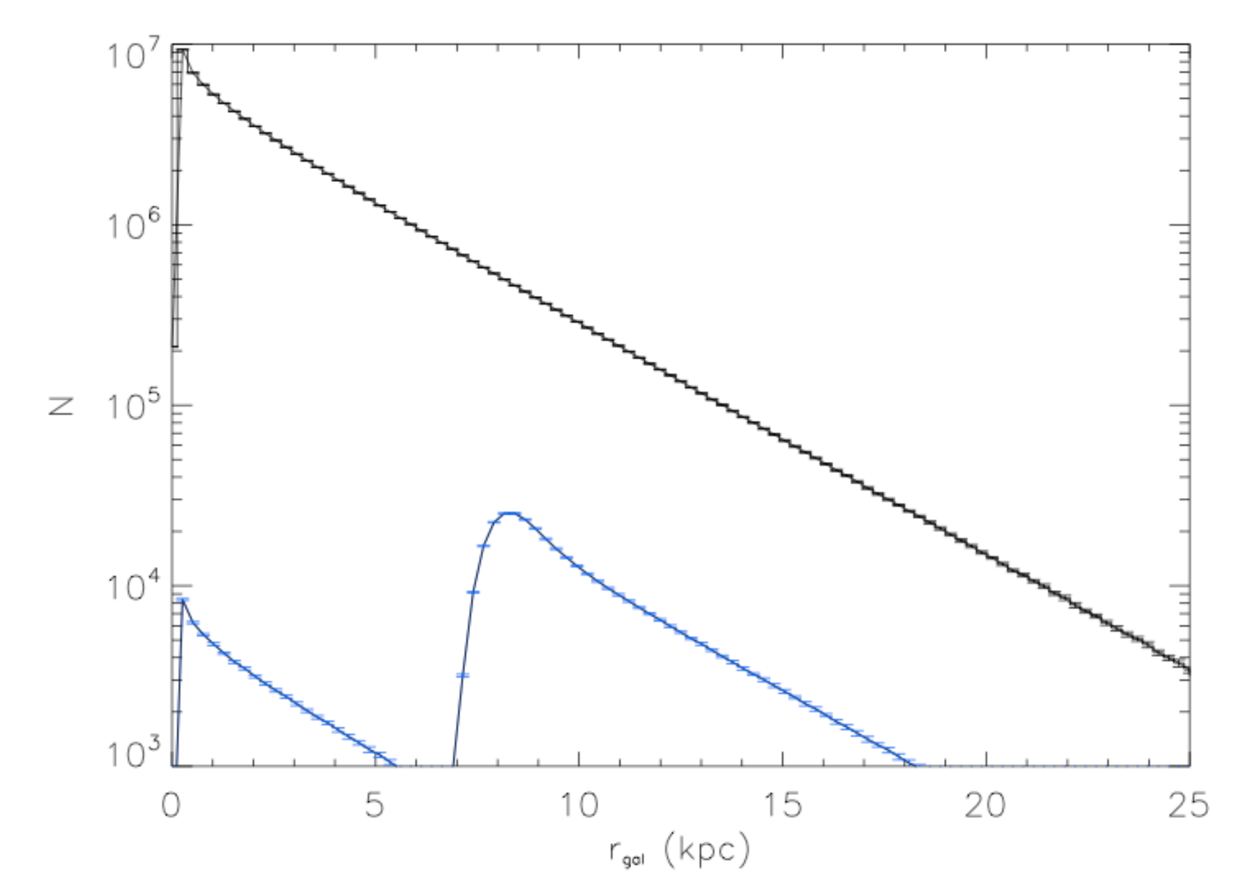
Results

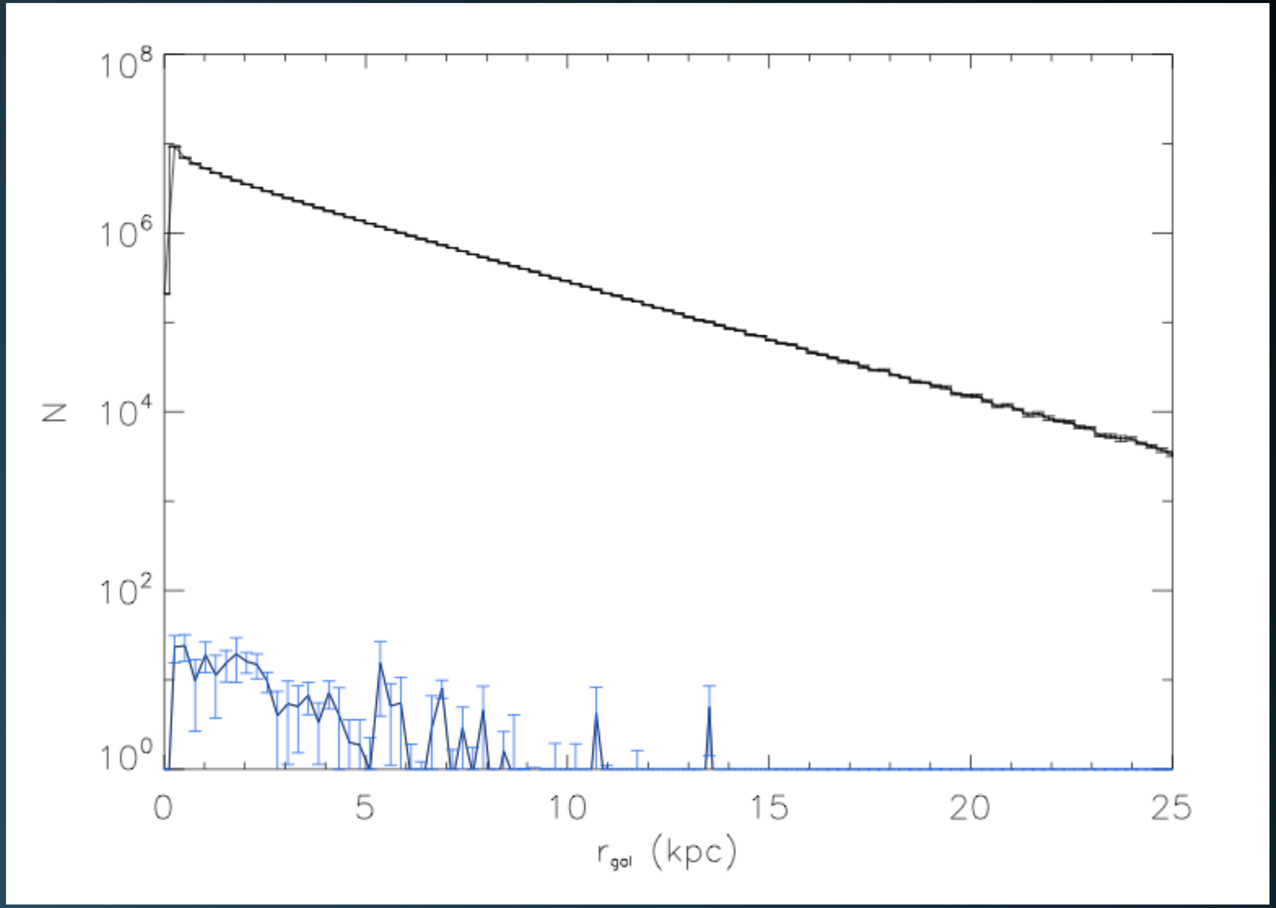




The Baseline (left) has planets at many radii
Constraining the stellar mass requires Earth-like orbits for the Rare Earth Hypothesis

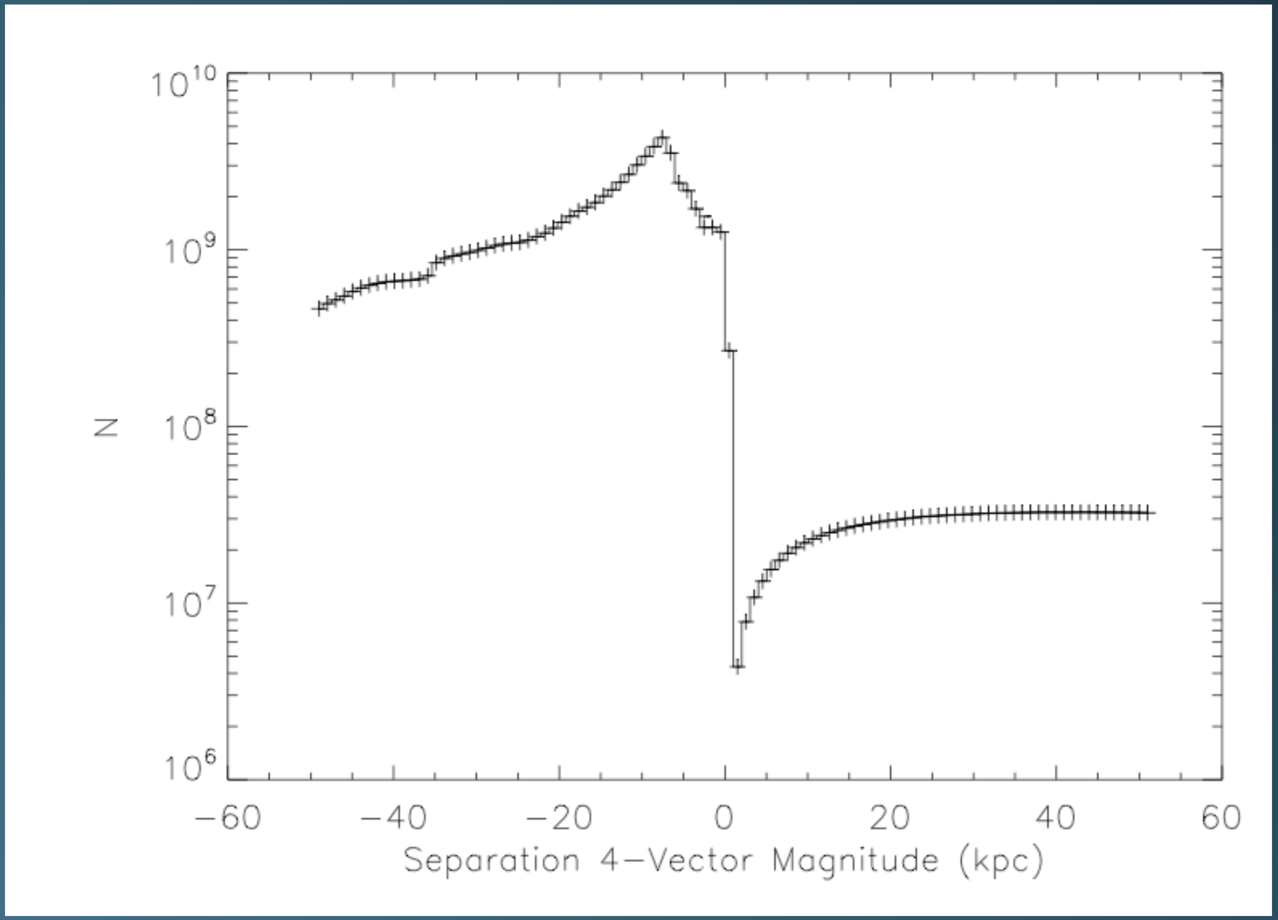
Results

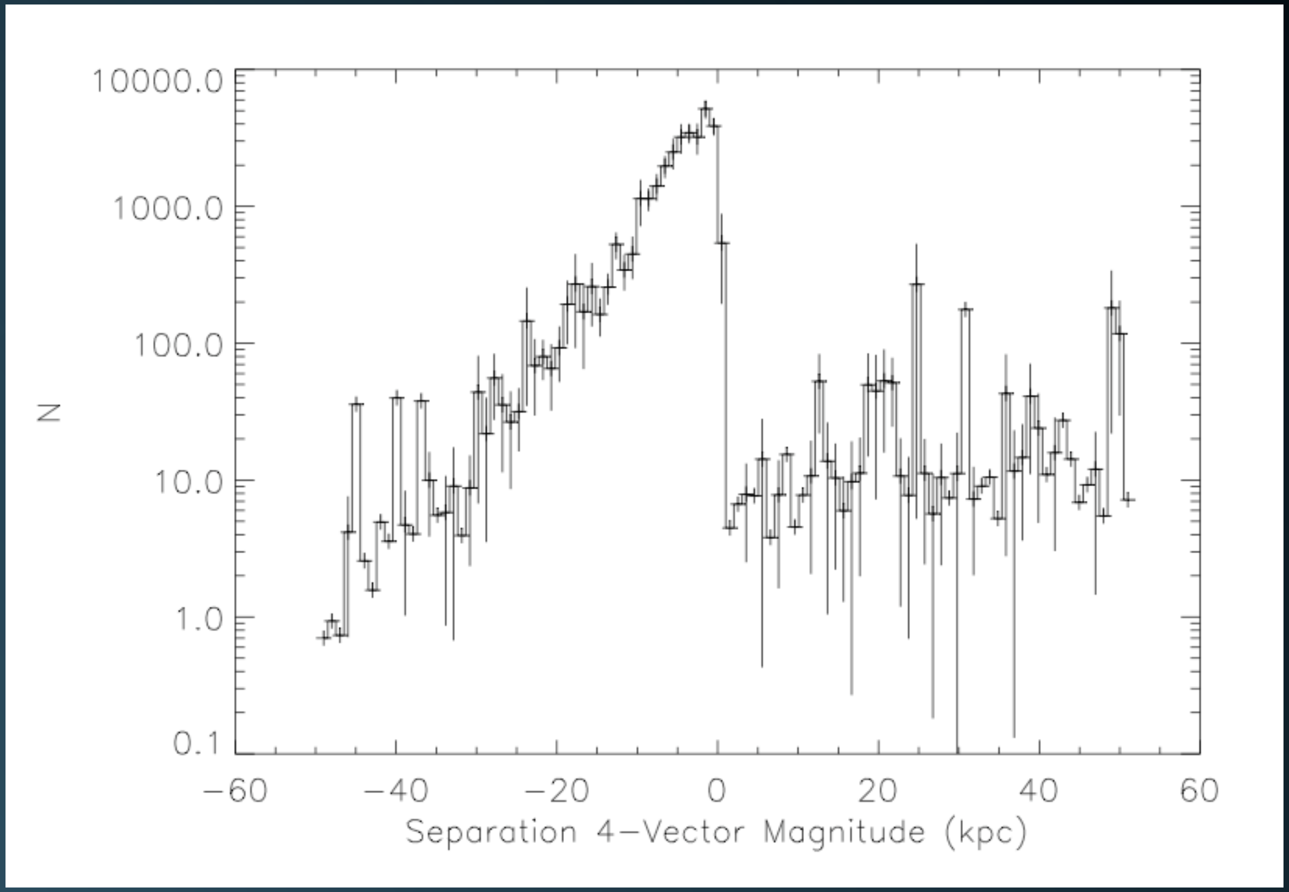




The Baseline (left) shows the Galactic Habitable Zone (from 7-10 kpc)
The Rare Earth Hypothesis does not! Is this significant?

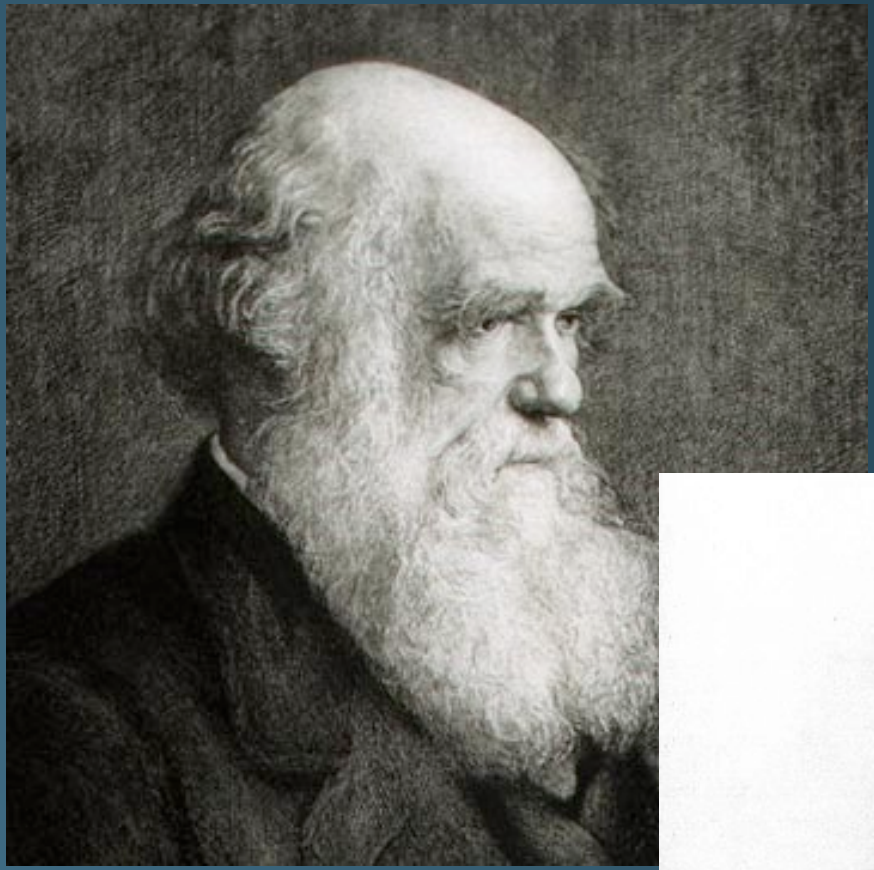
What about Communication?

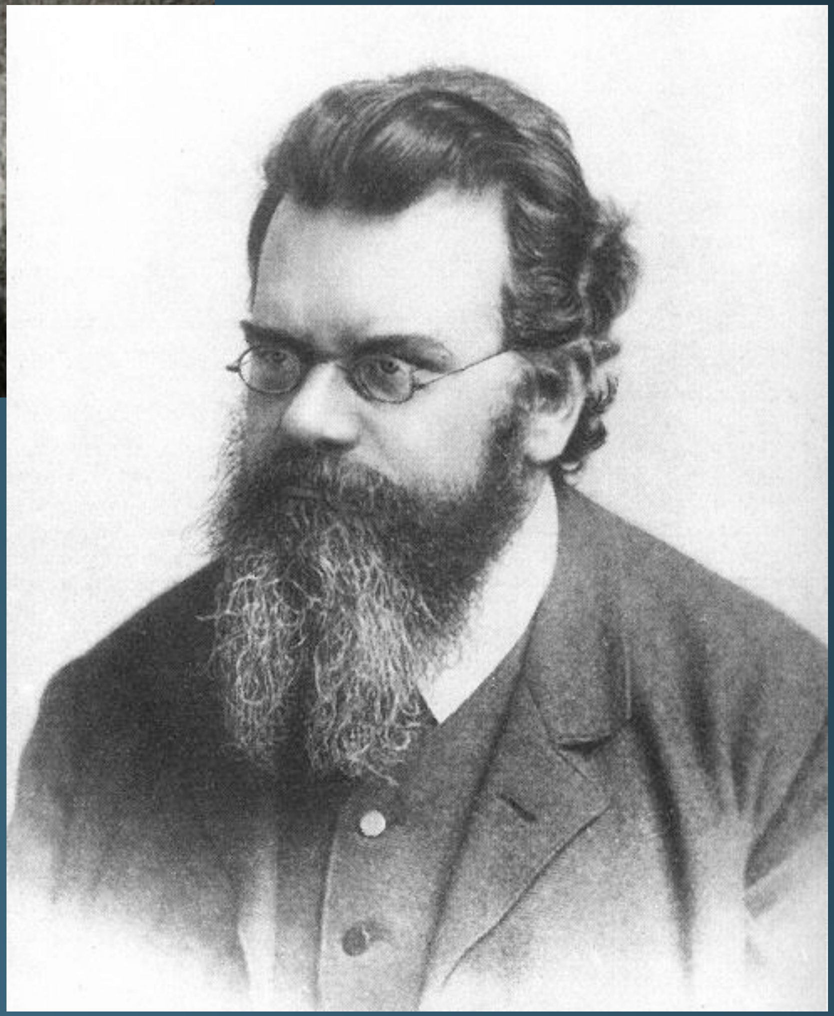




In general, most civilisations are unconnected
But, the ones that are are very connected, with the potential for many messages to be exchanged

The Entropy Principle





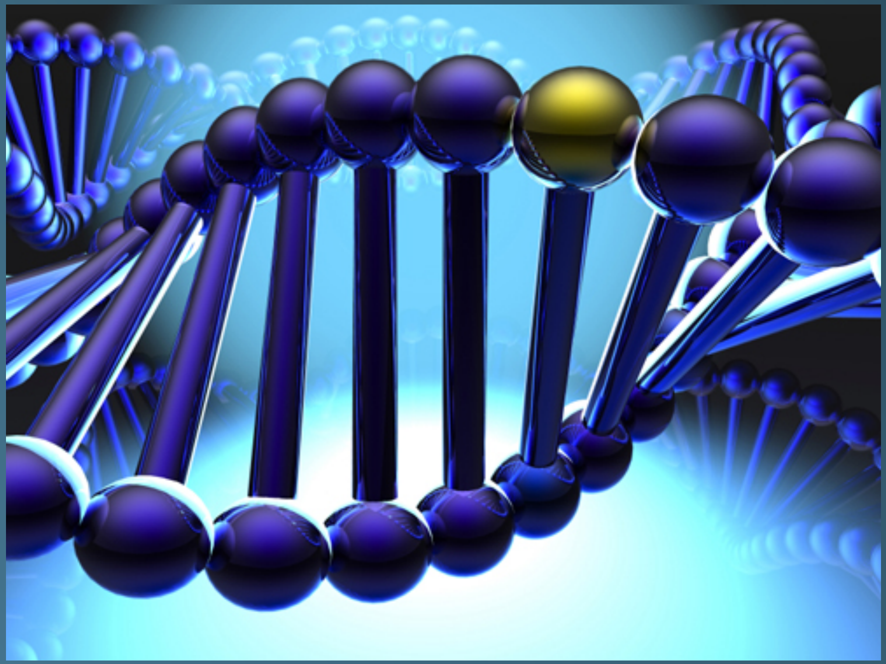
- Natural Selection, and the Principle of Least Action are the founding pillars of Darwinian Evolution

- They can be brought together using the the Second Law of Thermodynamics (Kaila & Annila 2008)

- In this form, it can explain the species-area relation (Würtz & Annila 2008)

The Entropy Principle

- If Entropy plays a role in the evolution of animal life, what about intelligence?
- We postulate that Entropy influences civilisations
- If we think in terms of replicators:



The Entropy Principle

- We could even go as far as a definition for intelligence:

Intelligence is the process by which replicators artificially synthesize a radically new and fundamentally different type of replicator.

Bozhilov and Forgan (2010)

The Entropy Hypothesis

- We adopt the baseline hypothesis, and add the criterion

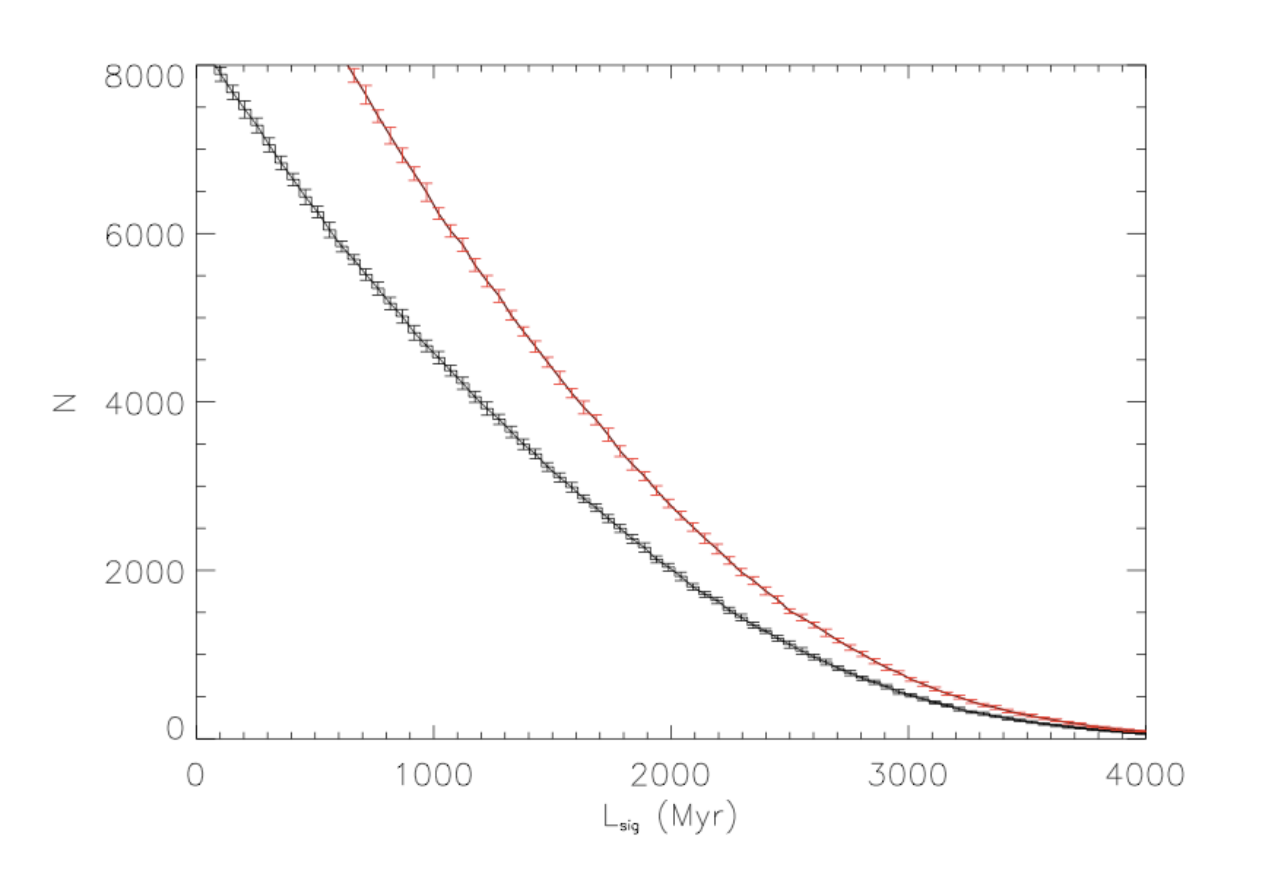
$$P_{destroy} = 1.65 \times 10^{-3} e^{\frac{t_{adv}}{0.056}}$$

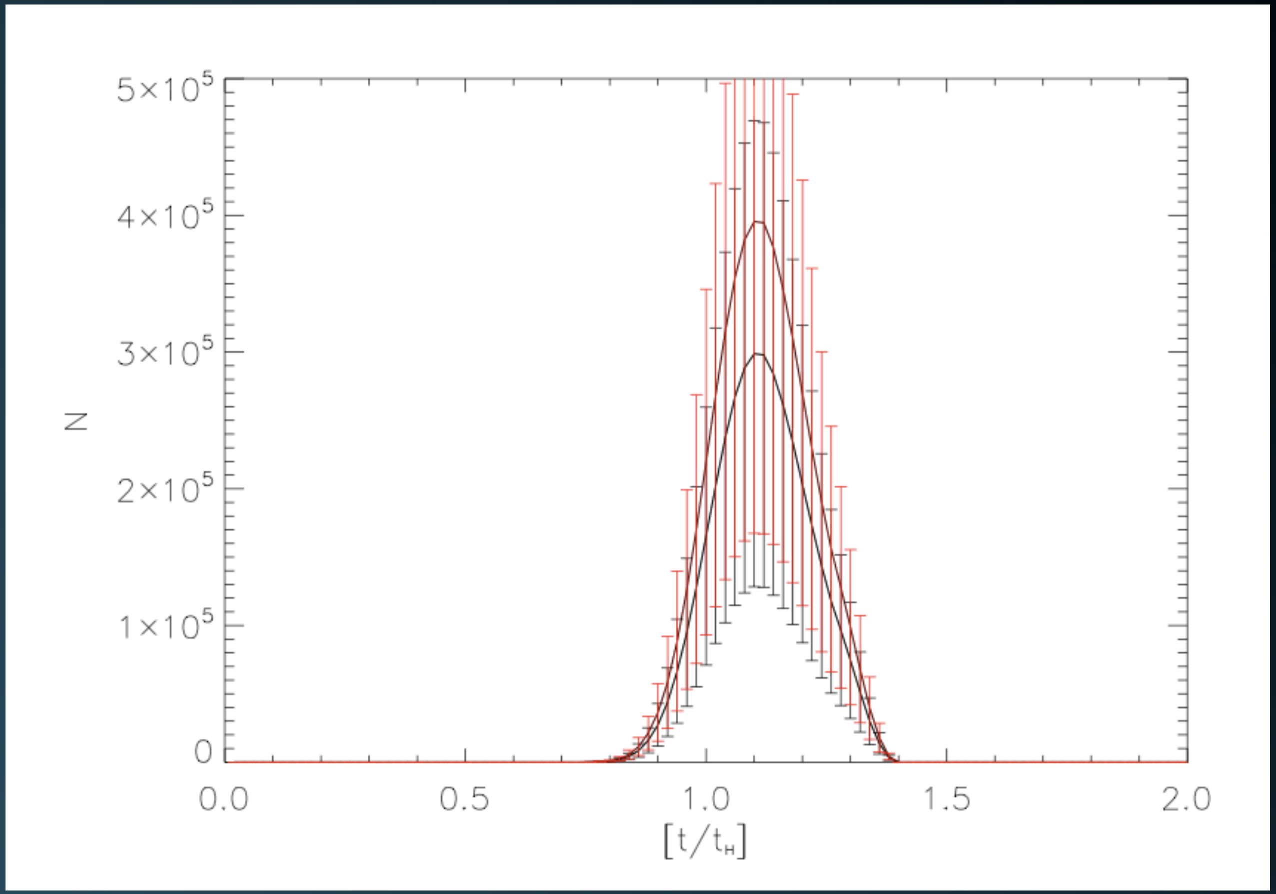
- This is motivated by our own increasing entropy - we assume that a civilisation will in general increase its planet's entropy

- Waiting too long to become advanced and escape self-destruction is therefore increasing the risk of destruction occuring

- This is inherently a sociological pressure - will it be detectable?

Results





- There is a slight change in the signal lifetime of civilisations
- But the observations are practically indistinguishable

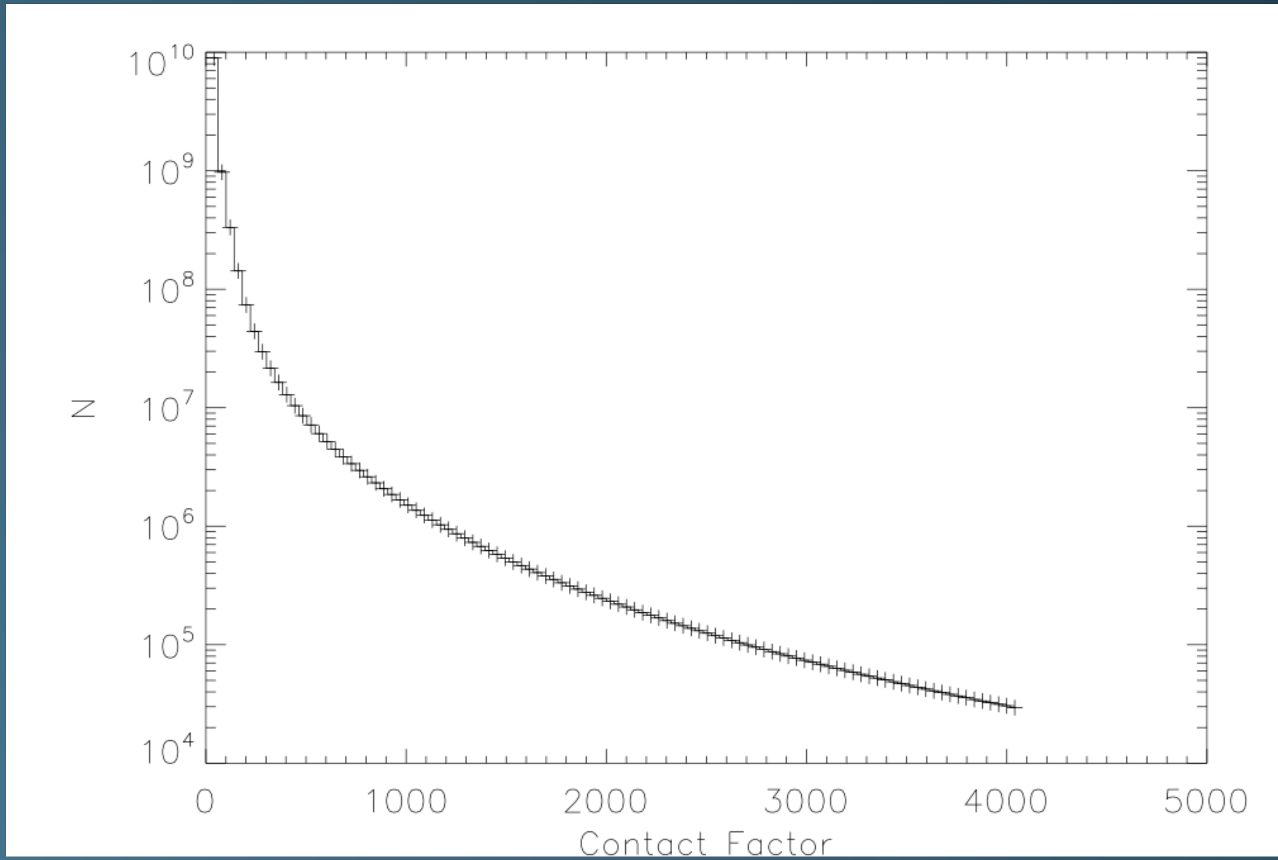
What about the SKA?

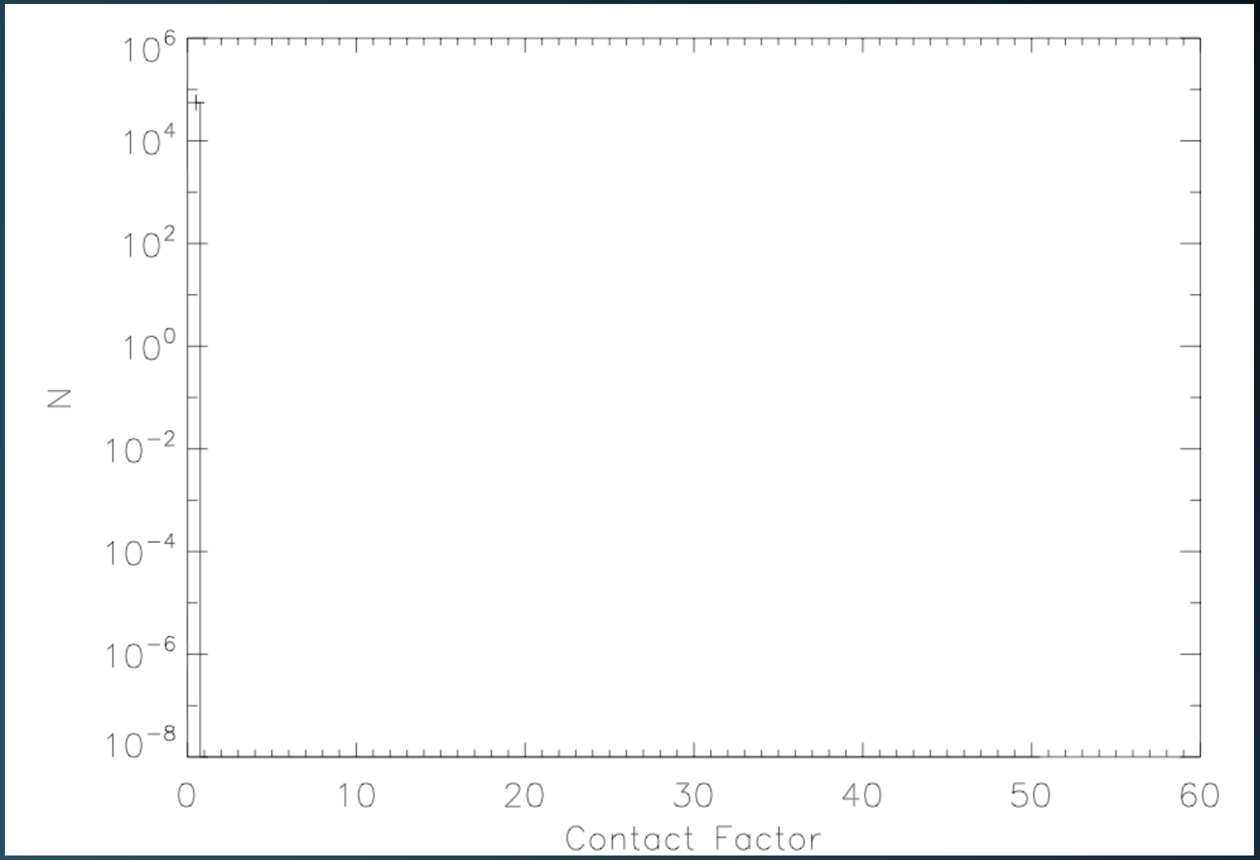
- The SKA will detect humanlike radio signals out to a distance of 300 light years (Loeb and Zaldarriaga 2007)
- But, we've been going radio quiet over the last 100 years
- What if the (10^5) civilisations in the baseline hypothesis were humanlike?

A Failure of Serendipity

- We calculate the contact factor:

$$f = \frac{c\,dt}{2dx}$$





- Contact is extremely improbable, even in the most optimistic case

Summary

- It is possible to make a facsimile of the Galaxy to use as a backdrop for simulating ETI

- Inputs are still a problem: “garbage in, garbage out”

- Method will improve as data improves, and it can still provide detailed output, as well as comparing hypotheses of life and intelligence

- This is a more effective way of quantifying our ignorance!