Spamming the universe:

very long range colonisation and the Fermi question

Anders Sandberg
Stuart Armstrong
Future of Humanity Institute
Oxford University

Fermi explanations

- No aliens
  - Intelligence is short lived
  - Intelligence is exceedingly rare
  - We are the lucky first
- Invisible aliens
  - Human limitations
    - Not been searching long enough
    - Not listening properly
  - Practical limitations
    - Communication is impossible due to problems of scale
    - Intelligent civilizations are too far apart in space or time
    - Communication is impossible for technical reasons
    - They only recently emerged and have not yet had the time to become visible.
    - Civilizations only broadcast detectable radio signals for a brief period of time before moving on to other media.
    - It is too expensive to spread physically throughout the galaxy
- Alien nature
  - They are too alien to be recognized
  - They are non-technological and cannot be detected except by visiting them.
  - They tend to experience a technological singularity becoming unfathomable and invisible.
  - They develop into very fast, information-dense states that have no reason to interact with humans
  - They migrate away from the galactic disk for cooling reasons
  - They tend to (d)evolve to a post-intelligent state
  - They choose not to interact with us
- They are here unobserved
  - Earth is purposely isolated (The Zoo or "Interdict" hypothesis)
  - Earth (and nearby parts of space) are simulated
  - They secretly deal with the government or other groups

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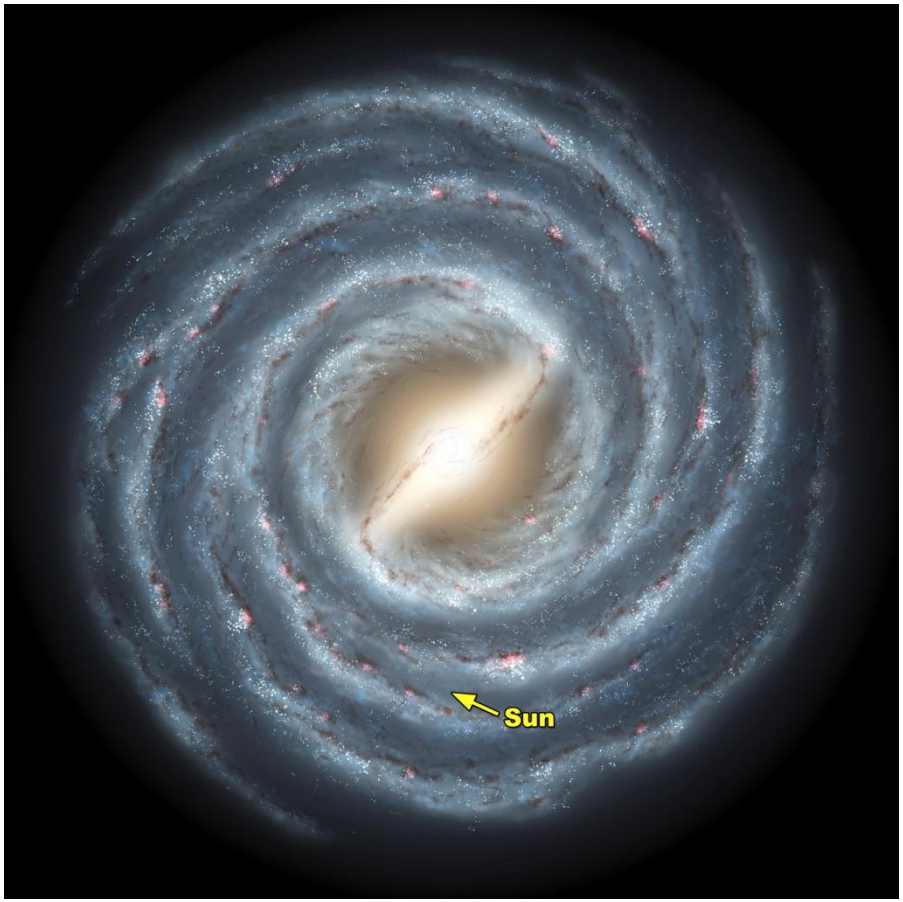
The colonization argument

- 0.01c, 5000 years per generation fills galaxy in a few Myr. Galaxy is over 10 Gyr old.
- Exponential growth even worse
- von Neumann/ Bracewell replicating probes amplify the argument
- Milky Way-o-centric



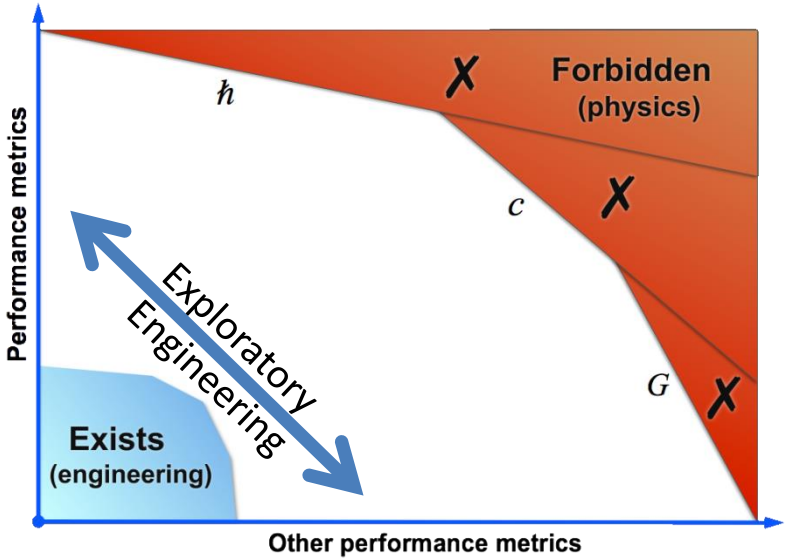
Extragalactic colonization

- What is the minimal resources needed to reach the reachable universe?
- Reachability horizon
  - Speed limited
- Launched relativistic probes
  - Dyson shell powered launch
  - Rocket slow-down
  - Small payload
  - Redundancy to handle dust
- High fan-out
  - Faster, fewer generations (=2)
- Use solar system as example

Exploratory engineering

Compatible with known physics, "plausible" in the future.

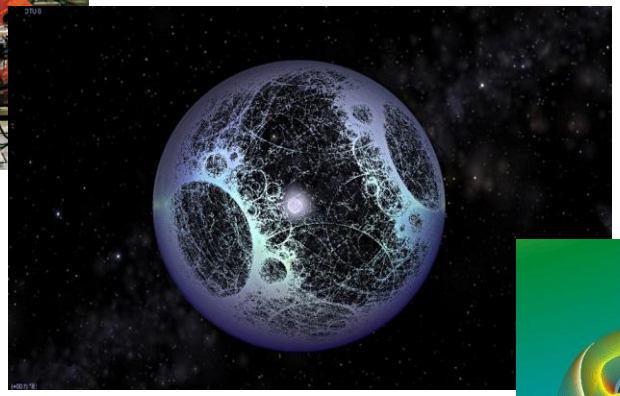
What technologies are "plausible in the future"?



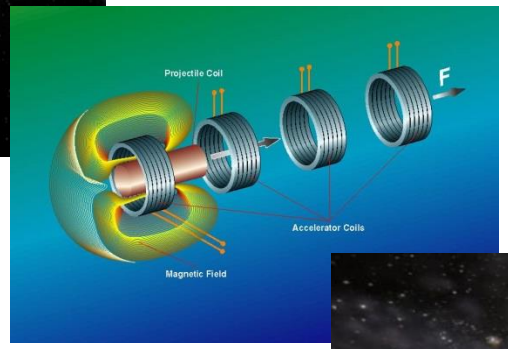
Some guiding principles:

1. If it's been done in nature, we'll probably be able to do it ourselves at some point (AI, replicating cells)
2. Tasks can be automated
3. The building of needed machinery can be automated
4. Hence scale is not in itself an insurmountable barrier
5. The real limiting factors are likely to be resources (energy and material) and time

Automated mining and production



Very large scale energy collection



Coilgun launch

Relativistic rocket deceleration

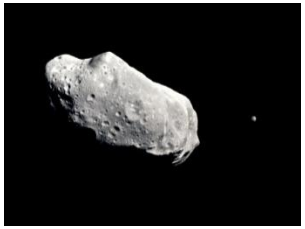
Repeat for all stars in target galaxy

Colony seed in target galaxy

Sorry Mercury, it's nothing personal...

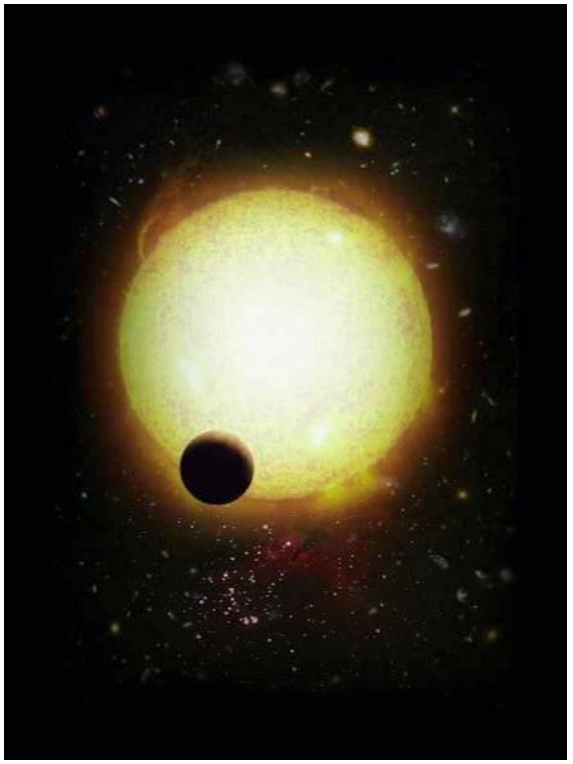
Mine stuff

Get it into orbit



Make solar collectors

Get energy



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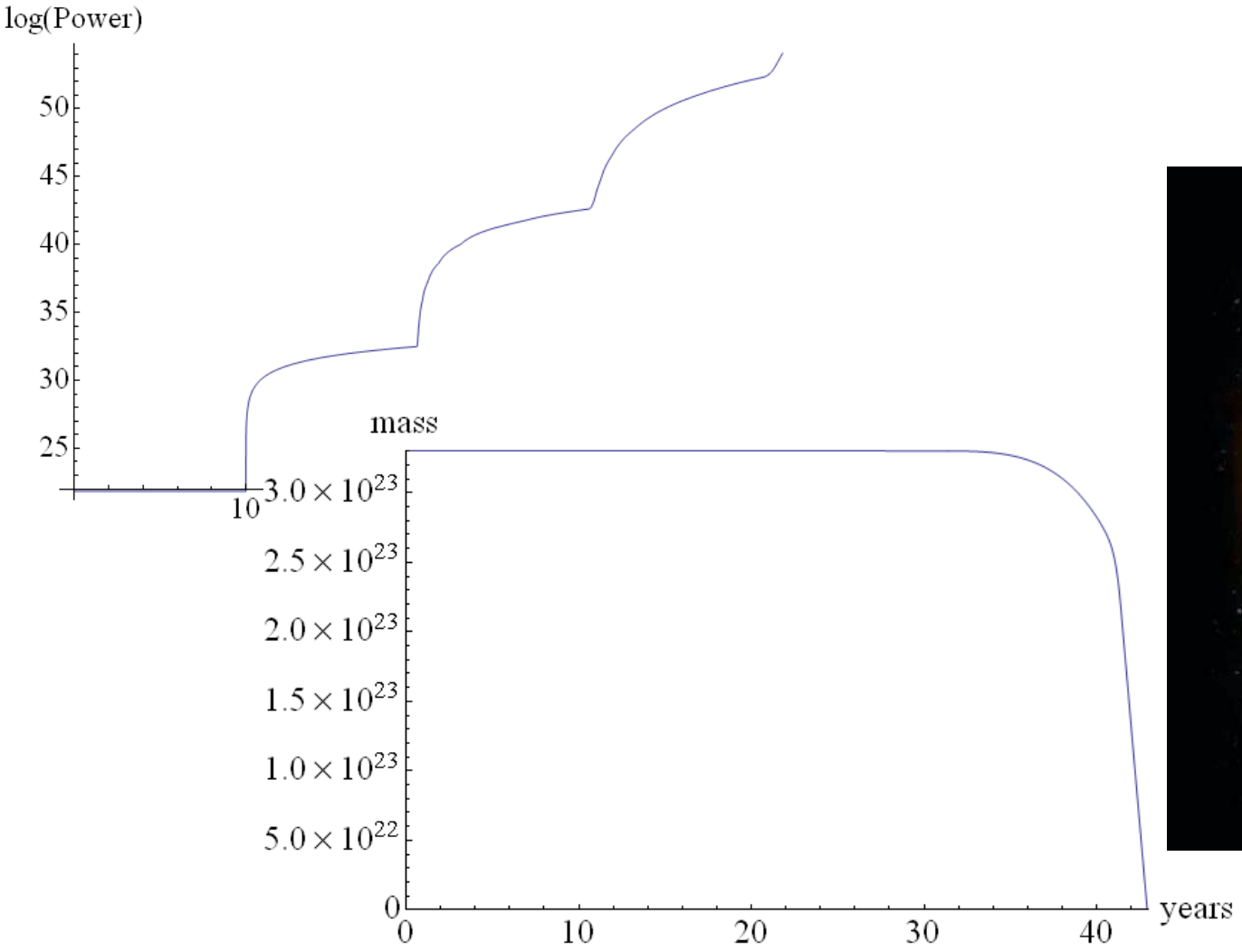
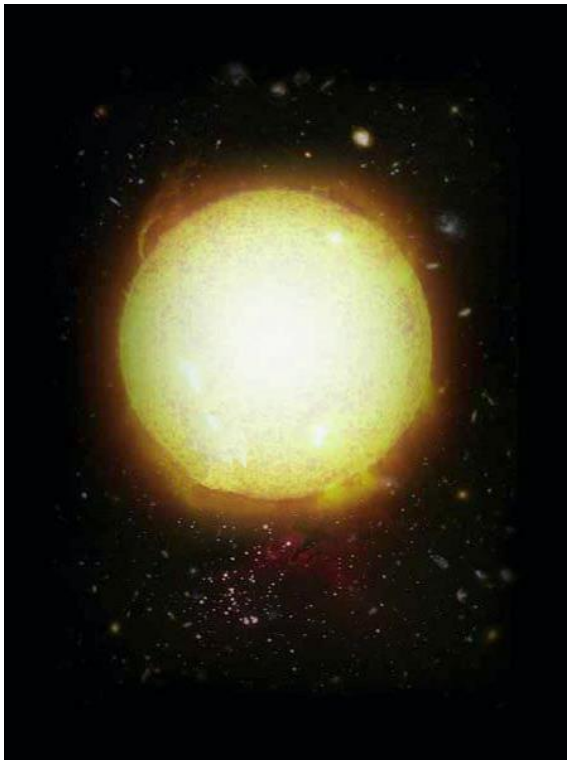




Payloads

- Navigation, energy production, mining, replication
- Freitas: 500 tons (factory)
- Our sketch: 30 grams (big nut)
  - Biological demonstration
  - More than enough information storage

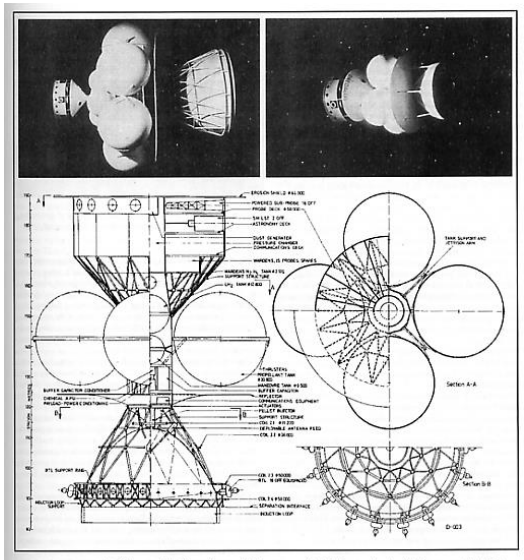


Figure 3.33. Project Daedalus[1022] interstellar flyby probe, modified to carry a self-replicating seed payload.[1014] (courtesy of British Interplanetary Society)

Deceleration rockets

Decelerating: use a rocket (ignore alternative methods)

$$\Delta v = c \cdot \tanh\left(\frac{I_{sp}}{c} \ln \frac{m_0}{m_1}\right)$$

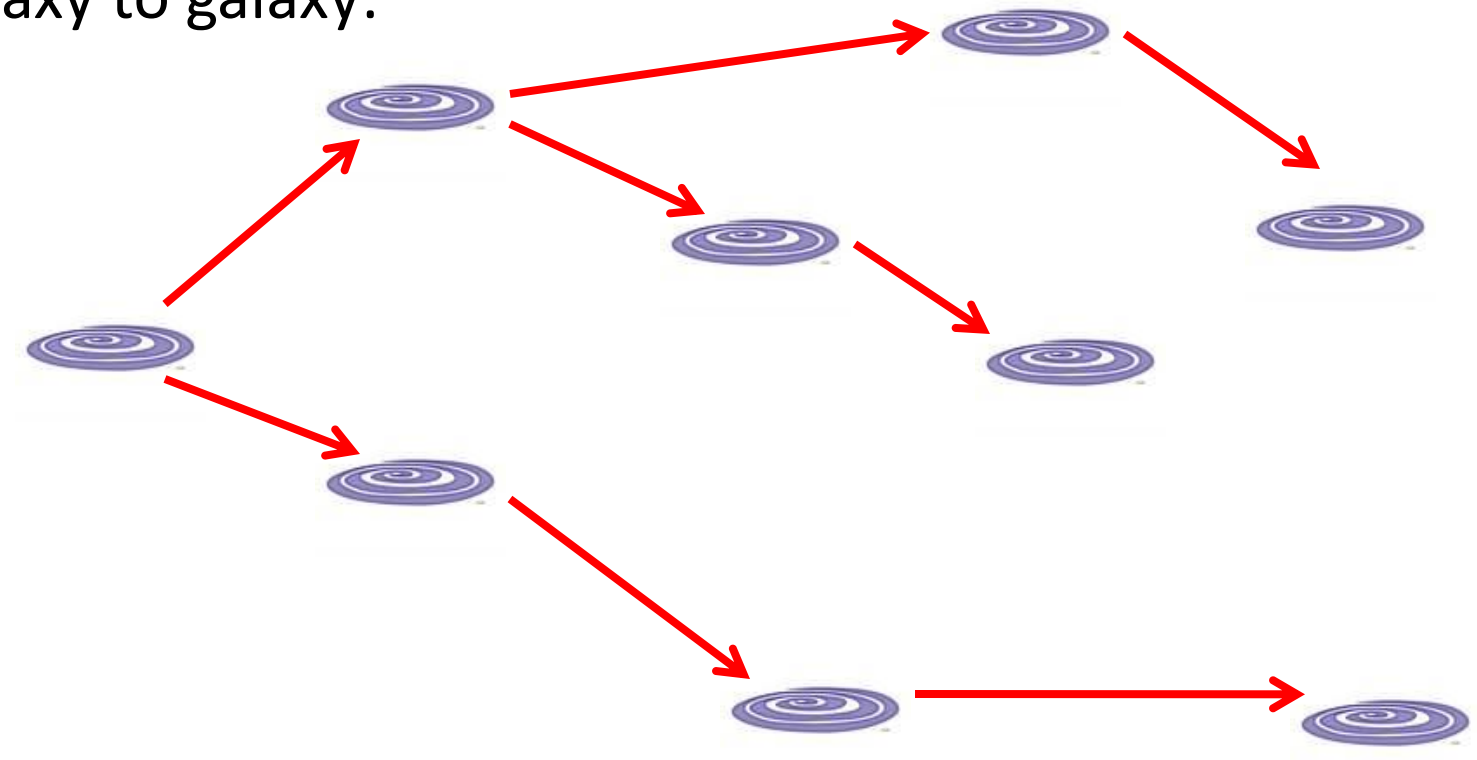
m_0=0.03kg

m_1	Matter-anti matter (I_{sp}/c=0.6)	Fusion (I_{sp}/c=0.119)	Fission (I_{sp}/c=0.04)
50% c	0.075	3.0	28000
90% c	0.35	7080	2.9×10^{14}
99% c	2.5	1.4×10^{8}	1.6×10^{27}

So will model probes of mass 3 kg, 8 tons, and 30 tons.

All dressed up, and somewhere to go

Slow colonisation (Sagan/Newman/Fogg/Hanson model), galaxy to galaxy:



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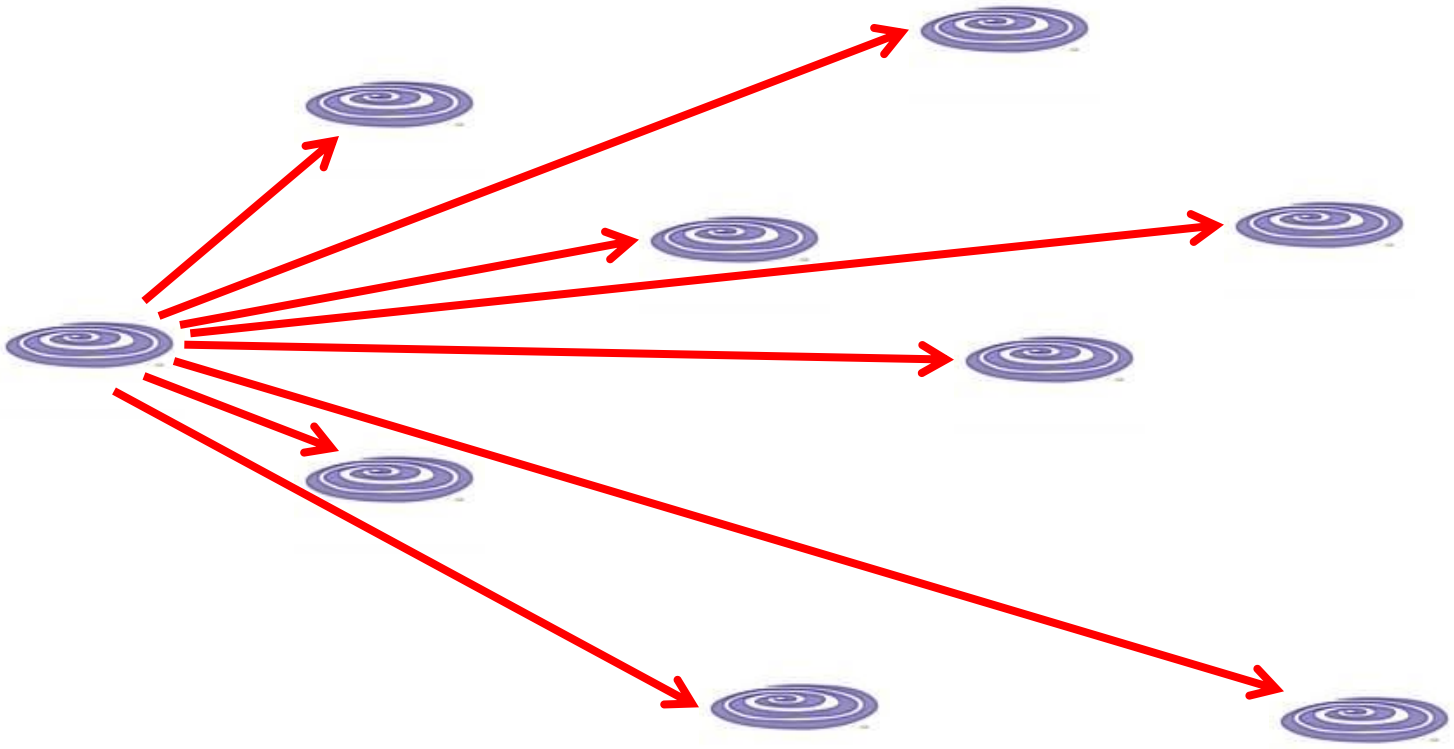
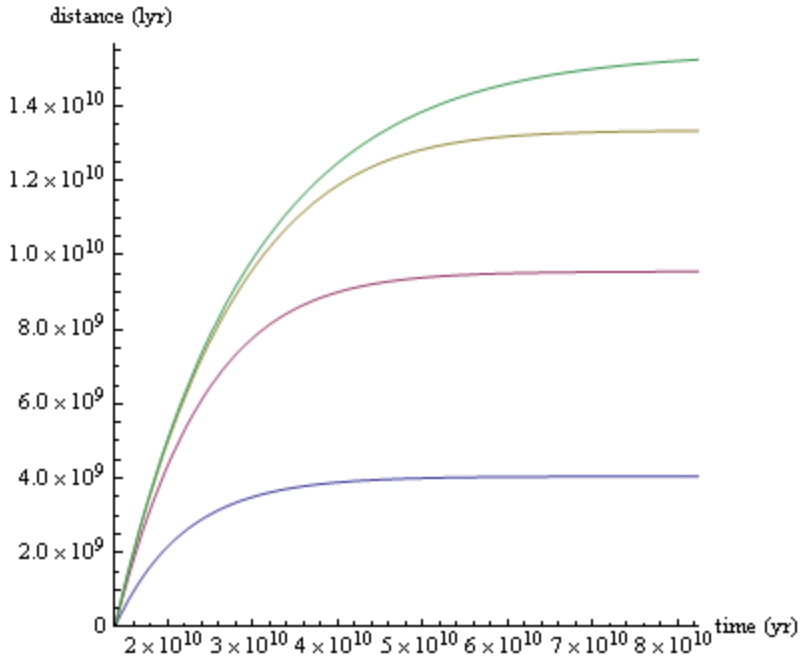
Fast colonisation:



All dressed up, and somewhere to go

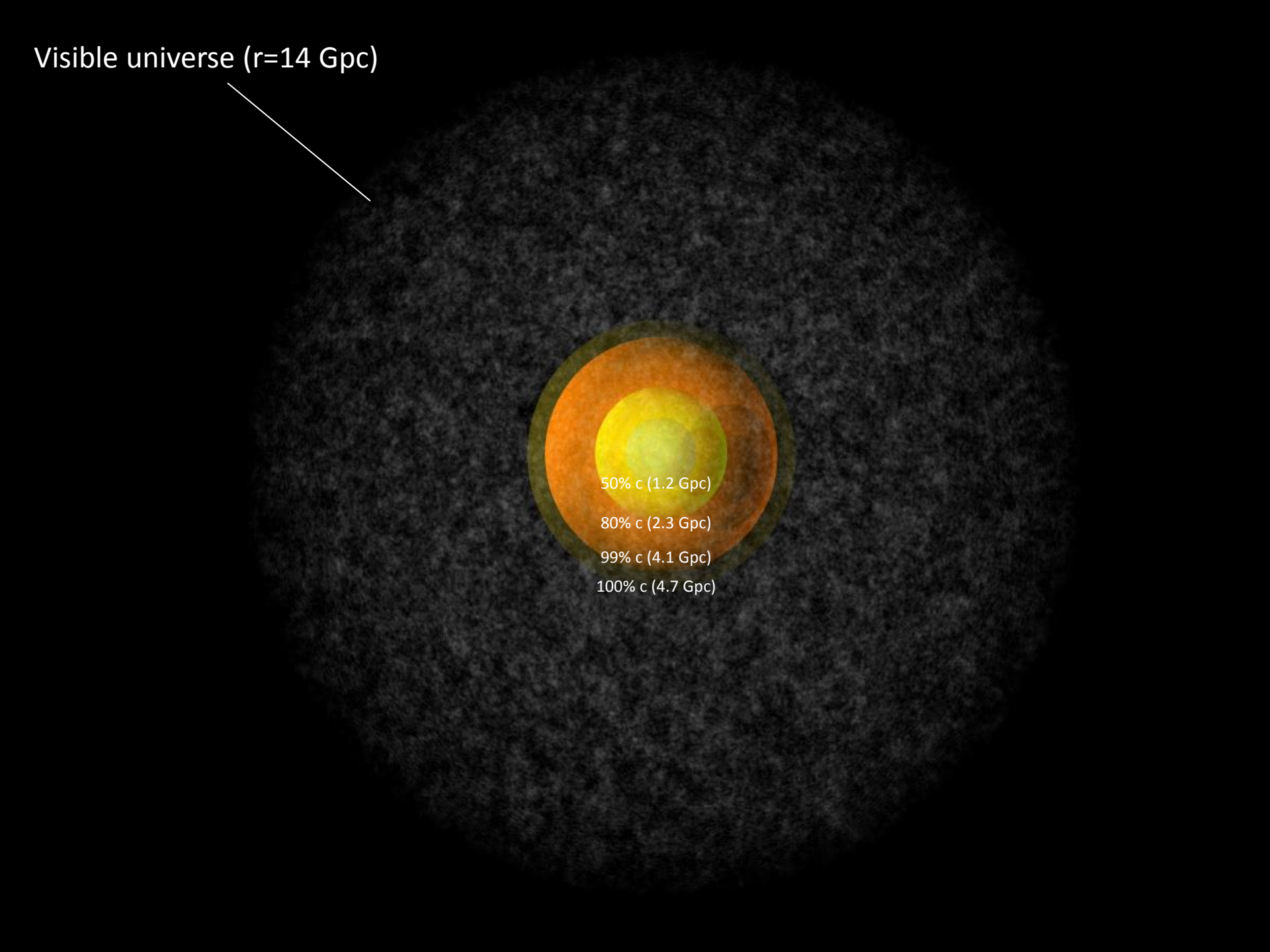
Friedman equation, flat, cosmological constant, WMAP data
Solving the geodesic equations in co-moving coordinates:



At 50% c, 90% c, 99%c, c

Speed	**Galaxies reached**
50% c	130 million
90% c	1.8 billion
99% c	4.8 billion

Delaying launch by even a million years has no impact on these numbers. Best to take our time, then go very fast.


Visible universe (r=14 Gpc)
50% c (1.2 Gpc)
80% c (2.3 Gpc)
99% c (4.1 Gpc)
100% c (4.7 Gpc)

How long to everything?

	Speed	Mass	K energy	Fuel Energy	# probes	Total energy
Fission	50% c	35000	4.87×10^{20}	Negligible	$2(1.16 \times 10^{8})$	
Fusion	80% c	15000	8.99×10^{20}	Negligible	$2(7.62 \times 10^{8})$	
Antimatter	99% c	5	2.74×10^{18}	2.7×10^{17}	$40(4.13 \times 10^{9})$	
No decel	99% c	1	5.47×10^{17}	0	$40(4.13 \times 10^{9})$	

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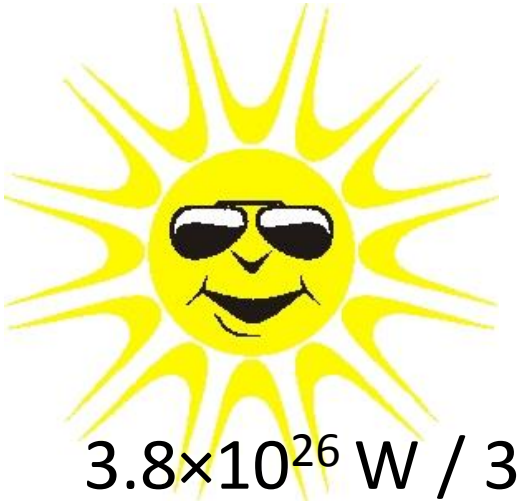

3.8×10^{26} W / 3

	Time taken
Fission	30 min
Fusion	6 hours
Antimatter	2 hours 19 min
No decel	24 min

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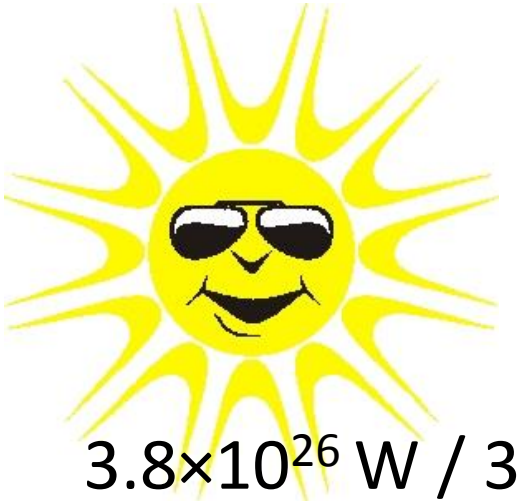
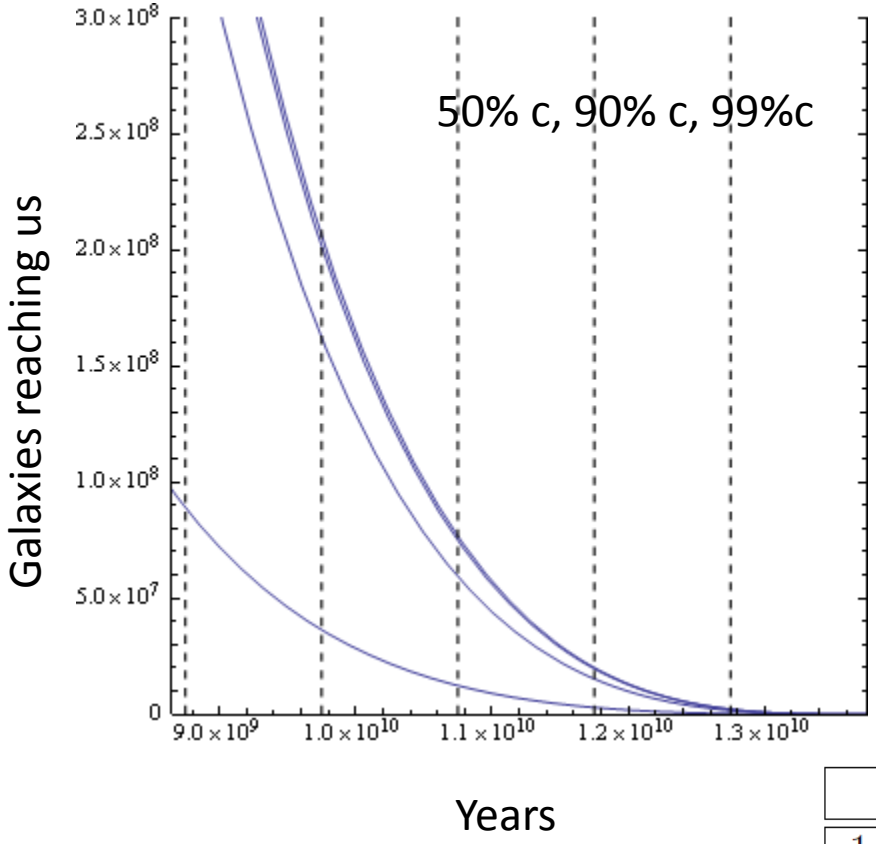
Cosmic scale approximation: **0**



3.8×10^{26} W / 3

	Time taken	Time for 500 ton replicator
Fission	30 min	938 years
Fusion	6 hours	11 400 years
Antimatter	2 hours 19 min	4 390 years
No decel	24 min	754 years

Who could reach us?



Even at just 50% c, 2 billion years in the past, at least 4 million galaxies in reach: 1 million trillion stars

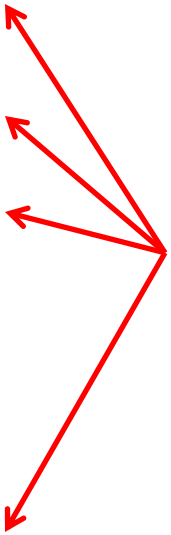
Galaxies that could have reached us:

	$50\%c$	$80\%c$	$99\%c$
1 billion years	2.63×10^5	1.03×10^6	1.89×10^6
2 billion years	2.57×10^6	9.63×10^6	1.67×10^7
3 billion years	1.07×10^7	3.80×10^7	6.46×10^7
4 billion years	3.14×10^7	1.06×10^8	1.74×10^8
5 billion years	7.69×10^7	2.45×10^8	3.88×10^8

What can we conclude?

The silence in the sky is pretty talkative… it is just hard to guess what it is saying:

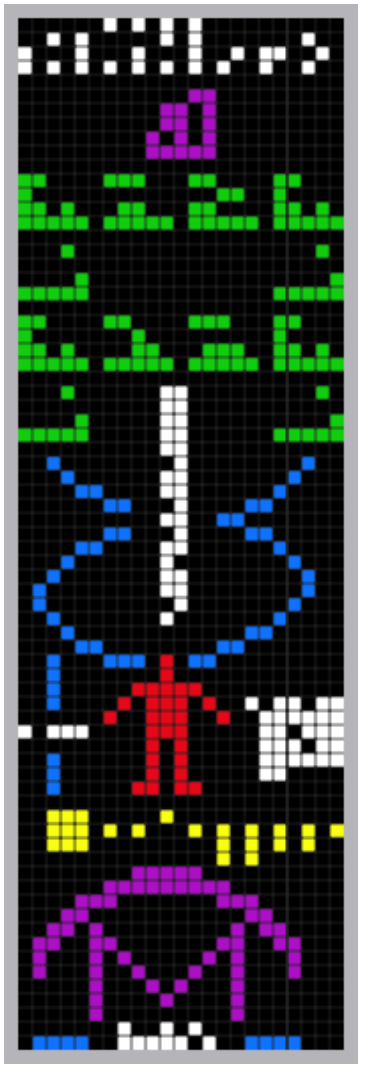
- Either a low technology ceiling
- Or high existential risk
- Or strong convergence
- Or one dominant old species
- Or we are simulations
- Or we are indeed alone

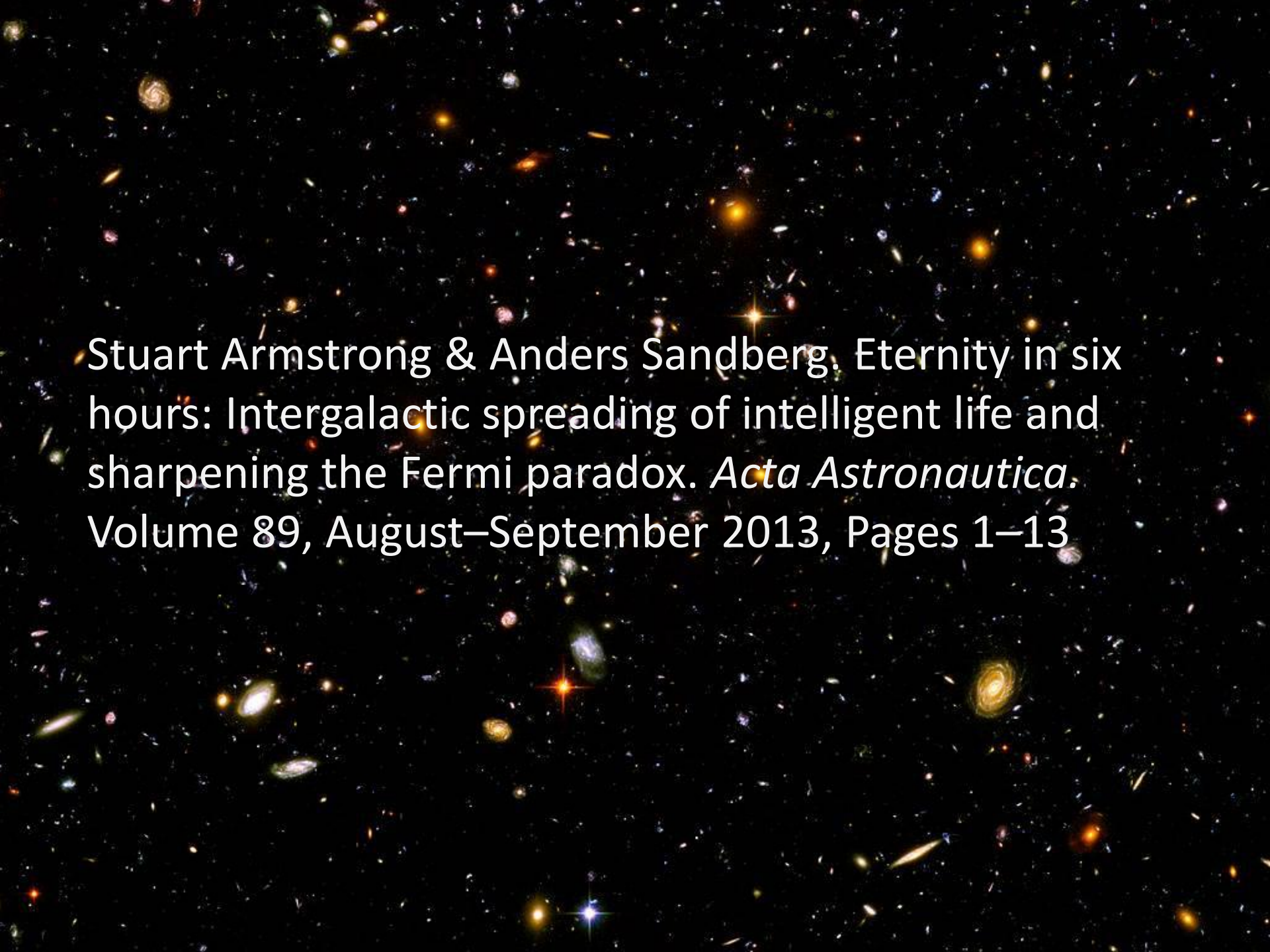


Our result forces these to be much more radical than we usually think!

Each answer implies uncomfortable things

- Low technology ceiling
  - Transhumanists are overoptimistic
- High existential risk
  - We need to figure it out… but it might not help!
- Strong convergence
  - Is this something we want? Is it moral convergence?
- Dominant old species
  - We better figure out the rules
- We are simulations
  - We better be interesting
- We are alone
  - BIG responsibility to safeguard life and consciousness





Stuart Armstrong & Anders Sandberg. Eternity in six hours: Intergalactic spreading of intelligent life and sharpening the Fermi paradox. *Acta Astronautica.* Volume 89, August–September 2013, Pages 1–13