The Cosmos
Planets & Life
PHYS 214
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Please start all class related emails with “214:”

The final pop quiz!

- Covers all lectures since last quiz…

- Note there will be no review lecture
  - University is closed on April 6th (Good Friday) – I will post notes
- Solutions for assignment 3 are up in the solutions cabinet of Stirling Hall

Today's Lecture

$$N = R^* p_p n_E p_l p_i p_c T$$

- Constraining p_l, p_i, p_c, T
  - Finalize our look at life & examine the development of intelligence (rather speculative)
  - Issues relating to choosing to communicate
  - Lifetime of communications
- We'll touch on a few SETI details (more later in the week)

p_l – probability of planets in the habitable zone spawning life

- We know on Earth life evolved very rapidly
  - Geological evidence shows fossilized bacteria at 3.8 Gyr ago
  - Complex animal life took far longer to evolve though
- Some people take this to be evidence that life will evolve rapidly elsewhere
  - Which suggests life should be common – perhaps $p_l=1$ (or something close to it?)
  - Is this a reasonable assumption?

Be careful about the statistics

- Just because life evolved quickly on Earth does not have to imply life is common
  - If we were the only habitable planet in the galaxy where life had evolved we would still see life evolving the way we have…
  - However, this would likely mean there is something unusual about Earth (*c.f.* the Rare Earth Hypothesis)
- By considering different scenarios for the time for life to evolve Lineweaver & Davis (2002)* show that for planets older than 1 Gyr the probability of life (*biogenesis*) evolving is > 13% at a 95% confidence level
  - We thus take $p_l \approx 0.1$ as a conservative estimate

**See Nature, http://www.nature.com/news/2002/020513/full/020513-3.html*

Can we hope to constrain p_l more?

- ***YES!***
- Being able to detect Earth-like planets is a driving force behind next generation interferometric missions like the Terrestrial Planet Finder (US, 2020?) or Darwin (ESA, 2015?)
- These missions are generically termed "life finding" as they will look for strong biosignatures like O_2 to O_3

TPF concept

p_i – probability of intelligent life evolving

- Defining intelligence is obviously difficult
  - We have a difficult time defining it for humans
  - We could however, for the purposes of SETI, just suggest intelligence is the capability to make a radio transmitter
- However, as a precursor we know that microbes need to evolve into complex multicellular life
- Once we have reached that stage it is unclear precisely what steps are needed to evolve a level of intelligence capable of building interstellar communication devices
  - Is a sequence of special events required? Do intelligent species need to avoid impact events
  - Dinosaurs did not evolved to the same level as we have within the 160 Myr period they existed for
  - *Homo sapiens* developed high intelligence ~200,000 years after evolving as a distinct species

Encephalization Quotient

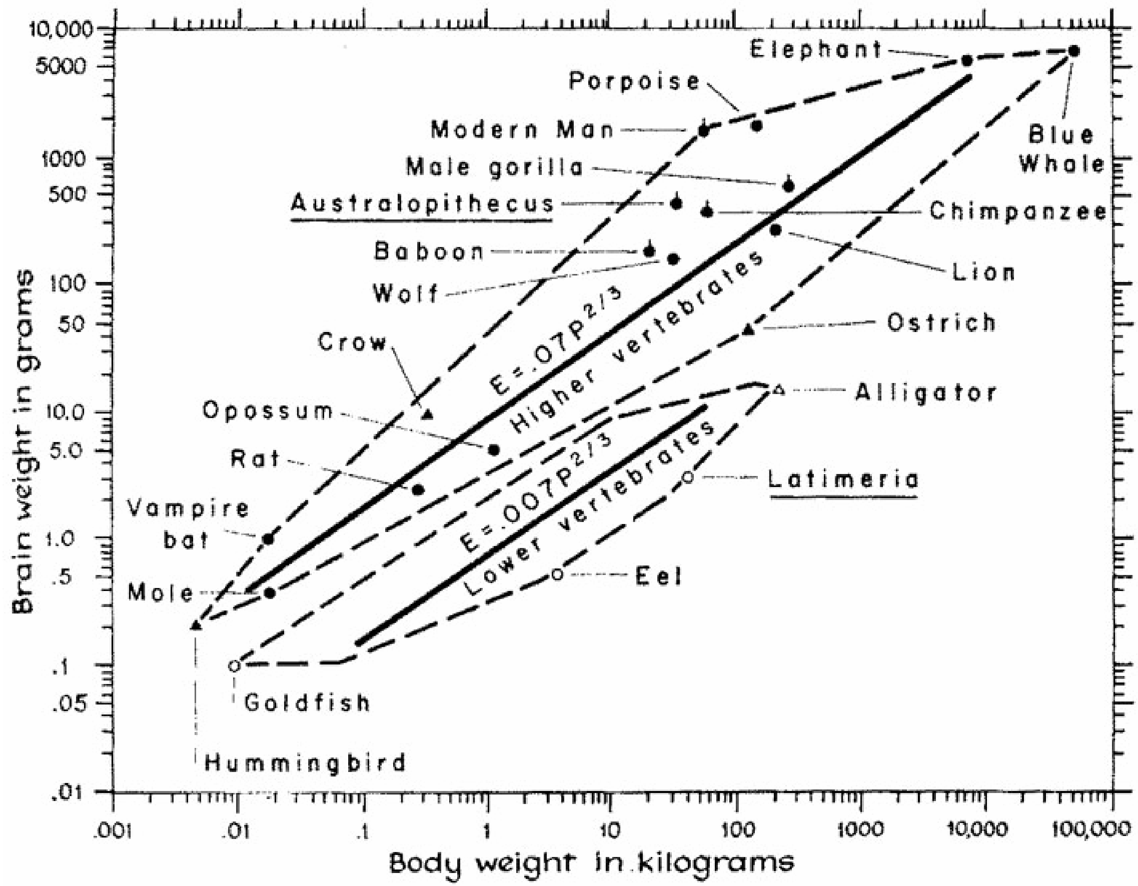
- A simple (*crude*) biological estimate of relative intelligence, it is defined in two steps
- Firstly, *Encephalization* (E) is the ratio of brain mass to body "surface mass"

$$E = \frac{\text{Brain Mass}}{(\text{Body Mass})^{2/3}}$$

- The 2/3 power is used because brains do not seem to grow in proportion to mass

Note some authors define E is being the encephalization quotient by normalizing by a certain value – watch out for this.

Comparison of vertebrates



- Mammals and birds have brains roughly 10x larger than reptiles and fish

Encephalization Quotient

- *Encephalization Quotient* (EQ) measures how "intelligent" a species is relative to other *comparable* life forms

ex. Dolphins compared to similar mass aquatic mammals of a similar mass

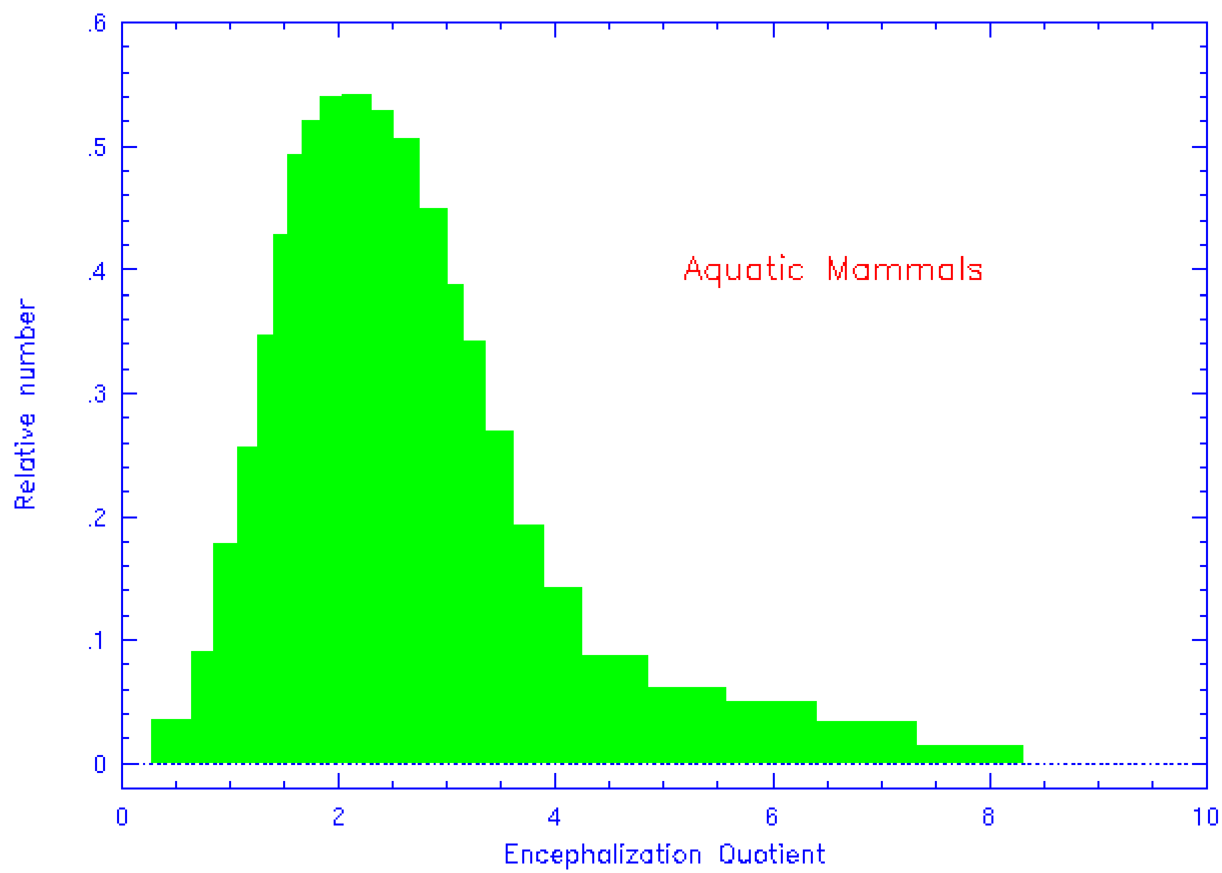
$$EQ = \frac{E(actual)}{E(average)}$$

land mammals

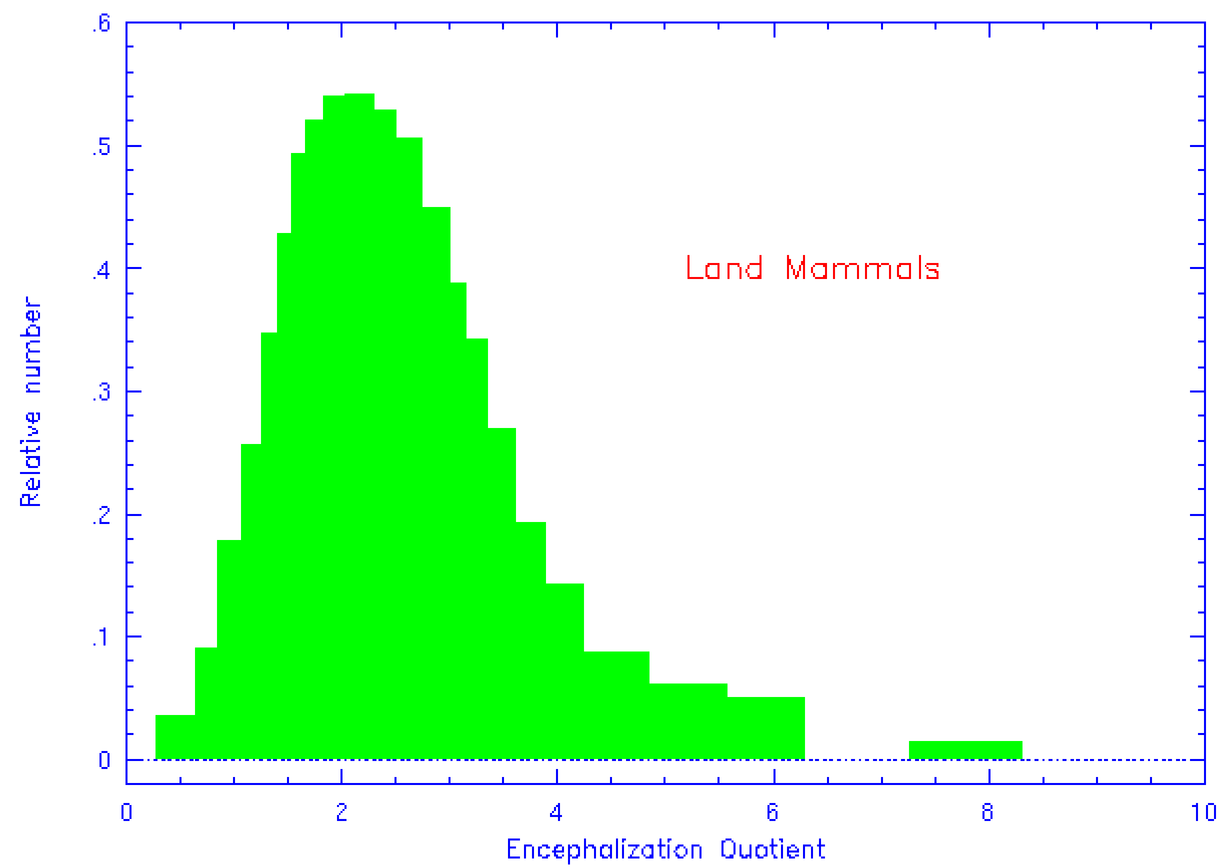
EQ(cows) = 0.2
EQ(dogs) = 1
EQ(chimps) = 4
EQ(humans) = 7-8

The frequently used formula for EQ across mammals/birds is EQ=brain mass/(0.12(body mass)$^{2/3}$)*

Encephalization Quotient – aquatic mammals



Encephalization Quotient – land mammals

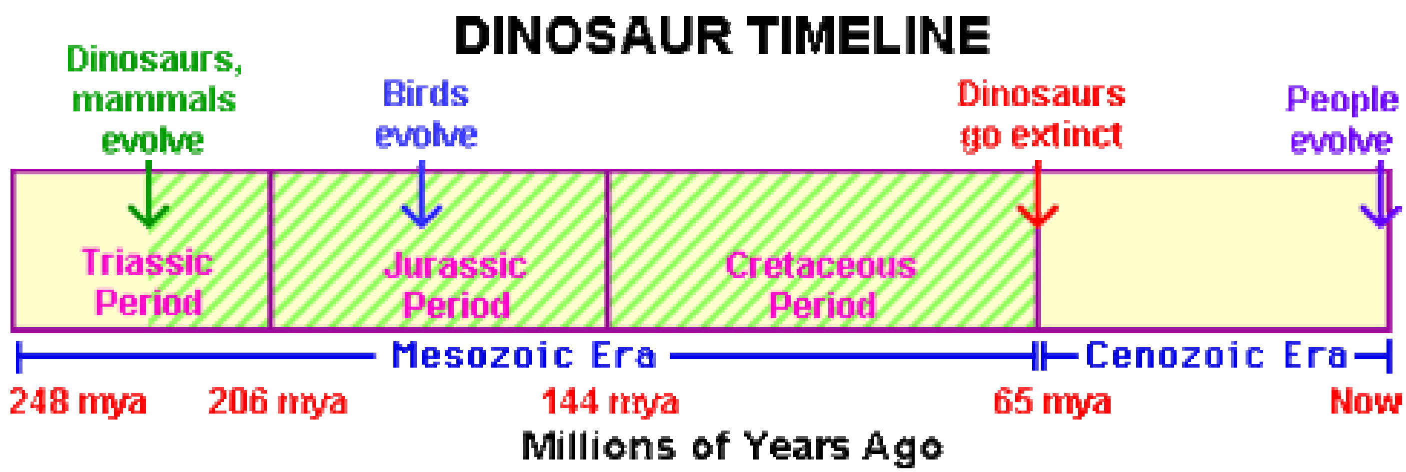


Is the development of the large brains in humans a “freak” event?

- Comparatively recently several studies have been published that attempt to link abnormal brain/cranial development to mutations within a single gene
  - Mutations of the “ASPM” gene are known to produce reductions in the size of the cerebral cortex
  - Gene MYH16 is known to have disabled the production of powerful jaws in early hominids and may have led to larger skulls
- Still, we have little idea exactly how many genes are directly responsible for determining brain size yet alone those which control brain complexity
  - and what about the role of selection effects from the environment?

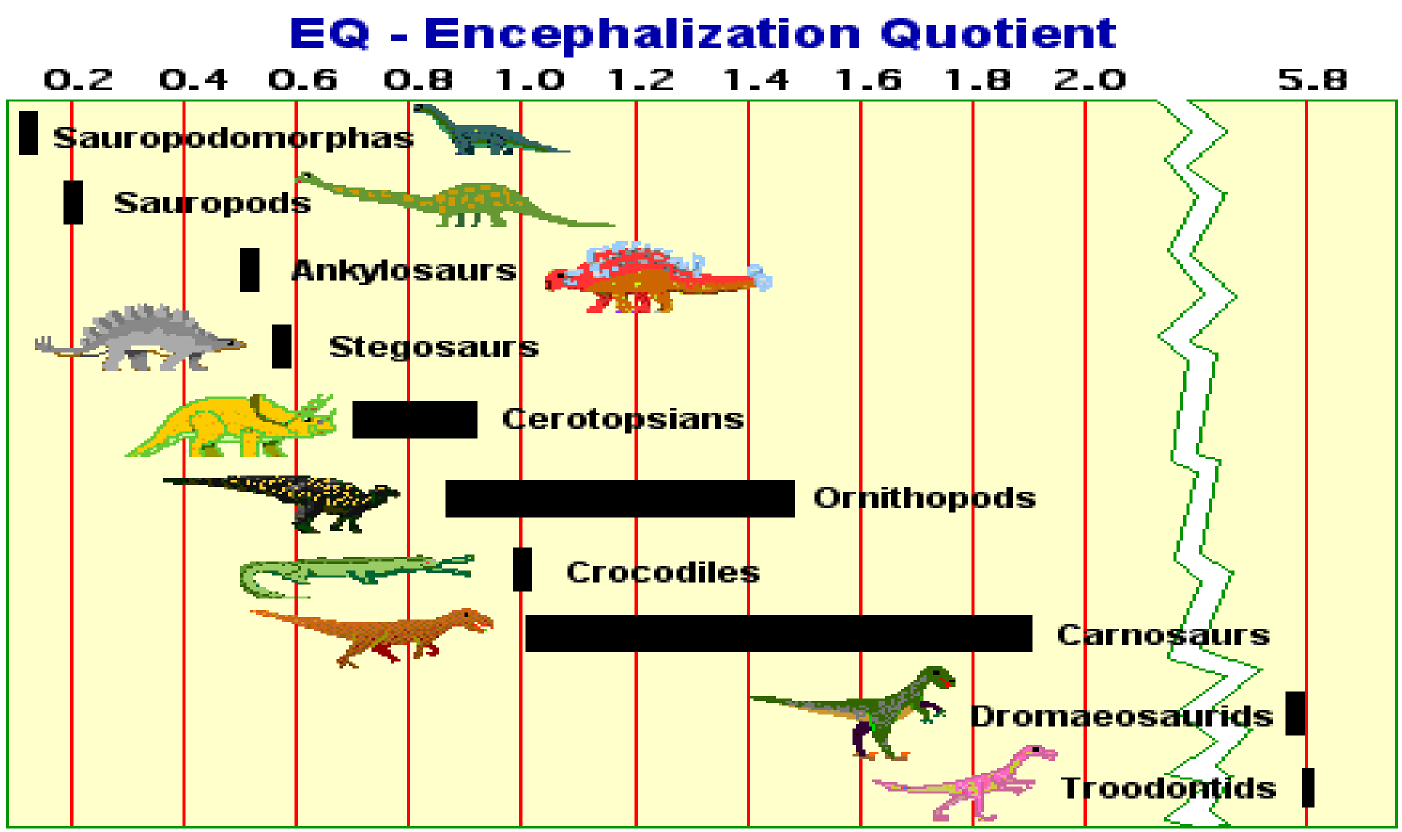
Can we learn anything from dinosaur evolution?

- How smart were the smartest dinosaurs?
- They evolved over 160 million years, whereas humans have been around only 200 thousand years… what was different?



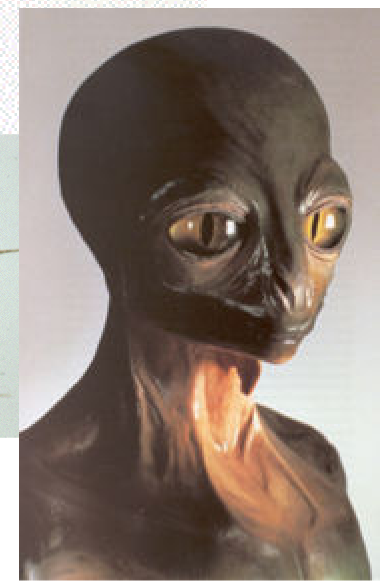
EQ's for dinosaurs

- Some dinosaurs did possess a high EQ (up to ~6)



The most intelligent dinosaur?

- The highest EQ for dinosaurs belongs to *Troodon*
  - Binocular vision (forward facing eyes)
  - Stereoscopic hearing
  - Dextrous "hands"
- However, remember that the brain masses of reptiles & fish is 10x lower than mammals, so in reality *Troodon* was still fairly unadvanced
  - Certainly not close to a chimp!



How might Troodon have evolved?

Constraining p_i

- We are again limited to studying only our own evolution
- Notably, even though we have had mass extinctions there seems to be a clear trend towards higher levels of intelligence
  - This could of course be an unusual event since the Cretaceous extinction paved the way for mammals
- Given the evolutionary record it does not seem like that p_i is extremely small
  - What might have happened to *Troodon*?
- We can (slightly optimistically) set $p_i \approx 0.1$

Constraining p_c - does a civilization actively have to choose to broadcast?

- Couldn't we just detect their radio waves that are "leaking" out of the planet?
- Let's try a very quick calculation:
  - Assumption: Terrestrial radio antenna emits 10^6 W in all directions (bit higher than current values) and we'll try to detect this 1 ly distant
  - Sensitivity of radio telescopes is determined by the flux of incoming radiation (Watts per m^{-2})
  - Flux of signal from terrestrial antenna at that distance

$$F = \frac{L}{4\pi r^2} = \frac{10^6 \text{ W}}{4\pi(9.46\times10^{15} \text{ m})^2} = 8.9\times10^{-28} \text{ W m}^{-2}$$

How does this compare to the sensitivity limits of modern radio telescopes?

Comparison of some SETI searches

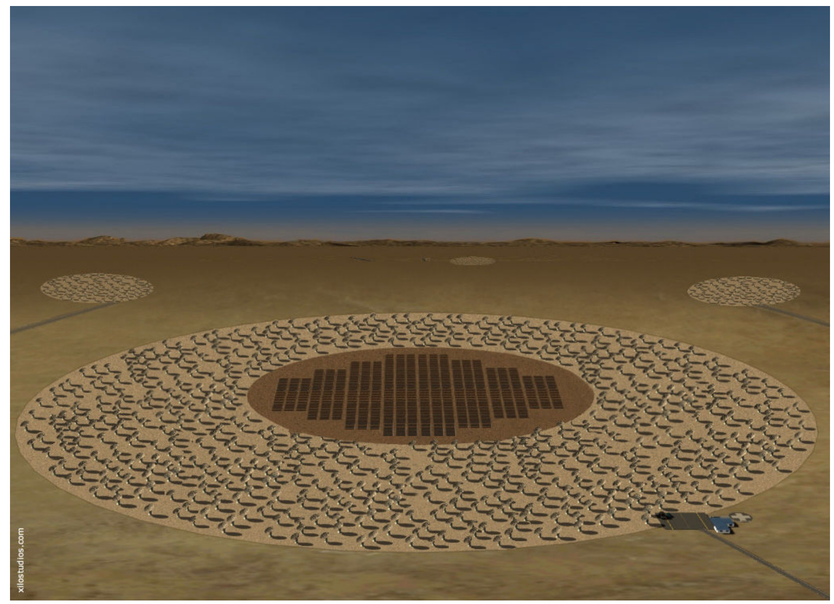
Survey	# of stars	Detection threshold/ W m^{-2}	EIRP at 4 ly / W	EIRP at 1000 ly / W
Arecibo	280	8×10^{-27}	10^{8}	9×10^{12}
Allen Telescope (SETI Inst., 2010?)	100000	$\sim 1 \times 10^{-25}$	2×10^{9}	10^{14}
SKA (2016?)	100000	8×10^{-29}	10^{6}	9×10^{10}

EIRP=Equivalent isotropic radio power, corresponds to the strength of the transmitter

Only the SKA could detect a 10^{6} W antenna at 1 ly away (it could at 4 ly actually)

The Square Kilometer Array

- A truly incredible "next generation" radio telescope
  - Cost 1 billion dollars, 70 million per year to operate
  - International consortium (Canada involved, but not as much as we would like!)
  - It will have a collection area of 1000000 m^2
- SETI will only get a fairly small amount of time on the telescope though



SKA movie

So given we can’t detect “average signals”…

- A civilization might choose to build a massive transmitter 100’s of MW …
  - Many papers have been written on this – SETI “beacons”
  - However, given the huge amount of empty space out there this is a very inefficient way of working
- Most likely scenario: detect civilizations that actively beam a signal toward us
  - If you do this you can actually increase the effective power of your transmitter by many orders of magnitude
  - For example, the Arecibo radio telescope has an equivalent isotropic power of 2×10^{13} W
    - Unfortunately it is speculated that only 3 planetary systems have ever been illuminated by the narrow beam

So what value would p_c take?

- In reality for us, this value is pretty much zero
  - We are quite naturally very concerned about uninvited guests!
- We have actually sent messages (without asking everyone on the planet(!) whether this is OK…)
  - In 1974 a message was beamed towards a distant star cluster known as M13 by Frank Drake, using the Arecibo transmitter
  - It will take 25000 years to get there
- At the time the UK Astronomer Royal wrote to Drake questioning the wisdom of such an act
  - Drake replied we've been leaking radio for decades without worrying about it
  - Is this an acceptable answer in view of what we know about signal strengths?

Another message was sent in 2001 from the Ukraine (different group) with an EIRP of 2×10^{12} W

What about T, the lifetime of the broadcast?

- For the 1974 message, the lifetime of the broadcast was only repeated over 169 seconds
- For the 2001 message the lifetime was 3 hours – still an incredibly short amount of time when you think about it…
- So it is looking more and more like T might also be close to zero as well, but again we have only ourselves to draw this information from…
- This is even before we consider questions of civilization lifetimes, survival *etc.*

Summary of lecture 27

- Depending on whether the Earth is special, we can take p_l=0.1 to a fairly high level of confidence
- p_i is much less clear, and may well have a strong environmental dependence. p_i=0.1 is probably at the upper end of possibilities
- p_c could well be small – it certainly is for us as we have not made a unilateral decision to broadcast
- Lastly, the lifetime of the broadcast, T, is equally poorly constrained
  - Directed terrestrial broadcasts have lasted at most hours

Next lecture

- Drake Equation
  - Putting it all together!