# The Cosmos

## Planets & Life

## PHYS 214

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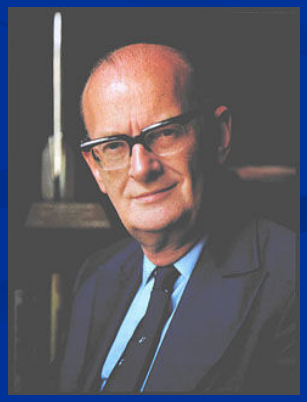
Please start all class related emails with "214:"

# Today's Lecture

- A few exam details
- Classification of Alien civilizations
  - Kardashev classification
  - Possible human futures

*"Any sufficiently advanced technology is indistinguishable from magic"*
Arthur C. Clarke



# Final format

- Mid term format was 30 MC, 2 short answer, 1 hour
- 30 mins for MC implies you had 15 mins per short answer
  - MC and short answer contributed equal marks
  - Not enough time on the short answers for about 1/3 class
- Final will be only 25 MC, but 4 short answer in 2 hours
  - ***Covers all material in course***
  - 25+60=85 total marks
  - For comparison, last years 3 hour exam had 146 marks, if we prorate, that corresponds to 97 in 2 hours
  - 25 mins for MC implies about ~24 mins per short answer question
    - Have quite a bit more time on each question compared to the mid term

# Short answer format

- Choose 4 questions from 6, divided into two sections of three. You must answer at least one question from each section
- Individual question format is same as mid-term
  - One part explanation
  - One part calculation
- This time I have given a clear representation of the marks available in each section, so you can prioritize if you want to

# Advice on short answer

- One sentence is enough to get you 1 mark – provided you explain a concept/fact clearly and succinctly
- The number of marks corresponds to the number of pertinent facts you need to mention/discuss
  - Doesn't hurt to put a couple more if you are not sure you have got everything
  - As with the midterm I'll have a list of possibilities exceeding the available marks
- One short answer question has 2/3 of the weight on the discussion, but most are 60/40 split between discussion/calculation
  - As I mentioned – you will know how many marks are available
- There is also one (and only one) question where there are more marks available for the calculation

# Kardashev Classification

- A scale proposed by the Russian physicist Nikolai Kardashev for classifying the relative advancement of (advanced) civilizations
- The classification works on the basis of the total power that can be utilized by a given civilization
- Although there is some debate, humans are not considered to yet be sufficiently advanced to be measured on the first "rung" of the scale
- So who is interested in this scale?
  - SETI researchers, futurists, science fiction authors!

# ON THE INEVITABILITY AND THE POSSIBLE STRUCTURES OF SUPERCIVILIZATIONS

Nikolai S. Kardashev
Space Research Institute
Academy of Sciences
Moscow, USSR

ABSTRACT. Since civilizations face always problems that require continuously greater activity, it is likely that supercivilizations will undertake activities and construct structures of a very large scale. Properties and means of detections of such superstructures and activities are discussed. We also examine six possible scenarios on the evolution of civilizations.

## 1. WHAT ARE WE SEARCHING FOR?

At present the most important aspect of the problem of searching for extraterrestrial civilizations seems to be the need for a logically consistent agreement on what is it that we are searching for. Unfortunately, such an agreement has not yet been reached. Most experimental searches for extraterrestrial civilizations proceed from a position of "Terrestrial Chauvinism". Thus, in spite of criticism that the probability of finding a civilization at our level of development and - moreover - among the nearest stars is in fact close to zero, the search for Earth-type civilizations is continuing. The solution of the problem has not and will not be advanced until the initial concepts and therefore the search strategies are changed. This is where the situation stands today. No long-term search program has yet been started, and no attempts to search for signals can be regarded as substantial. Extraterrestrial civilizations have not yet been found, because in effect they have not yet been searched for.

# Type 1 Classification

- Type I — A civilization that is able to harness all of the power available on a single planet
- How much power is that exactly?
- Sun outputs $4\times10^{26}$W
- Fraction reaching Earth: $\pi r_p^{\,2}/4\pi d_p^{\,2}$
- So total power= $4\times10^{26}$W $\times$fraction = $1.8\times10^{17}$ W
- 1.8 petaWatts! – that is a lot of power…

# How does our current power consumption compare?

- Humans generate about 15 TW of power $=15\times10^{12}$ W
- Quite a bit lower than a Type 1 civilization
- Can we extrapolate the scale somehow below zero?
- As we'll see, the scale is logarithmic in nature so we can define a continuous scale of Kardashev classification (K) by

$$K = \frac{\log_{10} W - 6}{10}$$

*You can play with the constants a bit, but this is good enough*

# So what value do we derive for Earth?

- $\text{Log}_{10}(15 \times 10^{12}) \approx 13$, hence K=0.7
- How can we increase our energy gathering up to Type I levels?
  - Since we are talking about energy from the Sun this is (at least in theory) a renewable resource
  - Other than coating the entire surface with a manmade structure(!) giant orbiting solar panels are the least invasive approach
- Other suggestions include harvesting energy from ocean thermal currents
  - Seems like an incredibly dangerous idea given the importance of energy circulation in regulating global climate


*These values are down by 0.1 relative to the true K*

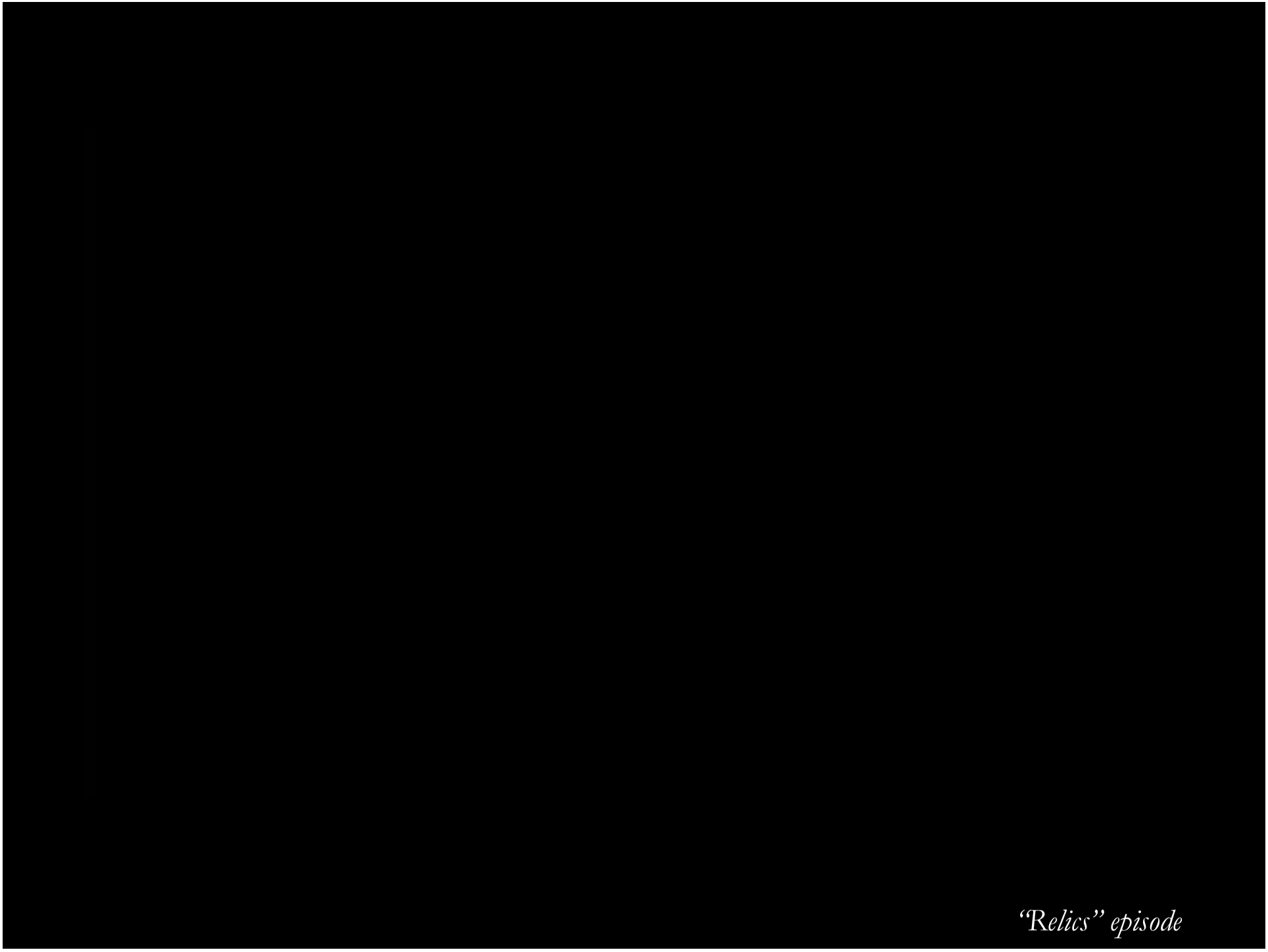
# Fiction versus reality

*Coruscant (Star Wars)*

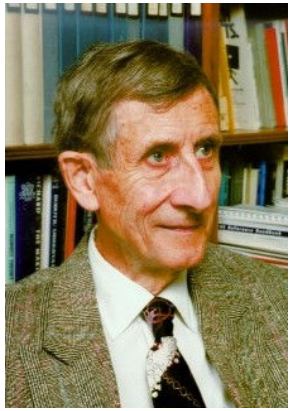
*Earth (Europe)*

# Type II Classification

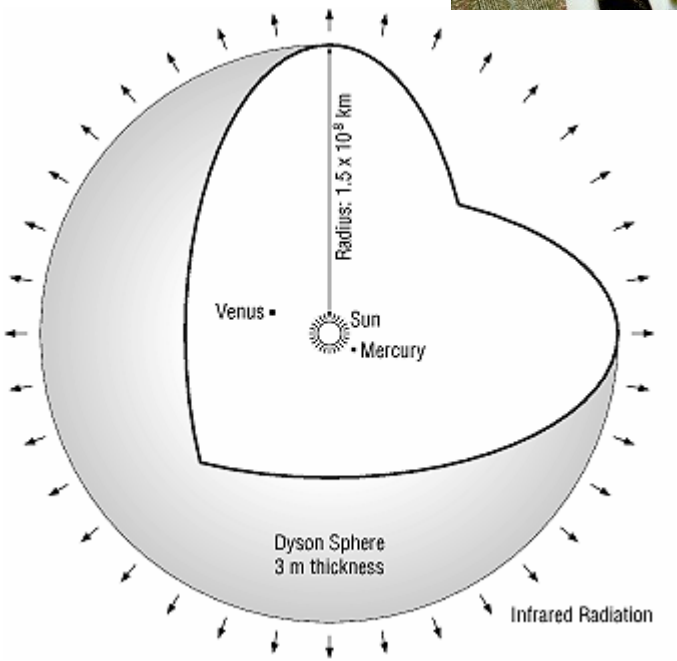
- Type II — A civilization that is able to harness all of the power available from a single star
- For the Sun, that would correspond to $4\times10^{26}$ W
  - $K=\log_{10}(4\times10^{26})-6/10=2$, so our formula works here
- How exactly would you go about capturing this energy….?


*"Relics" episode*

# The Dyson Sphere



- The idea for building infrastructure to encapsulate a star is accredited to the physicist Freeman Dyson
  - Appeared in an article in *Science* in 1959
- Note Dyson did not actually envisage a hard sphere, rather just a sphere of collectors floating in space
  - The original idea has been largely misinterpreted by science fiction authors
  - A rigid body needs to be extremely strong to overcome the gravity if it isn't rotating
    - If it does rotate then there will be great differences in the strains at different parts of the sphere
      - Led author Larry Niven to propose making a ring that rotated "Ringworld" series



# Can we detect Dyson spheres?

- If we imagine a Dyson sphere at the Earth's radius, then its temperature (assuming incident radiation is re-radiated) can be derived in the same way as a planet

$$T_{DS} = \left( \frac{R_*^2 T_*^4}{4 r_{DS}^2} \right)^{1/4}$$

- As you would expect, for a Dyson sphere at the Earth's orbital radius the peak emission is in the infrared

# At first we thought "no"… but maybe!

- Unless a Dyson Spheres looking very similar to collapsing protostars
  - Recall, these systems grow in temperature until nuclear ignition is achieved
- Early studies thought it would be impossible to tell them apart
- Now we think that we can, a true Dyson sphere should have an almost perfect blackbody spectrum (more so than protostars)
- Searches are ongoing, but not promising as yet



## THE INFRARED DETECTABILITY OF DYSON CIVILIZATIONS

In a very stimulating paper, Dyson (1960) has suggested that technical civilizations considerably in advance of our own may rearrange the matter in their planetary systems into spherical shells, so that the emission of the local suns into all $4\pi$ steradians may be gainfully employed. Dyson showed that the mass available for exploitation in a possibly typical planetary system, the luminosities of main-sequence stars of solar spectral type, and the minimum thickness of a habitable biosphere have mutually consistent orders of magnitude. If such solar system re-engineering is a tractable—if, for us, remote—solution to problems of energy acquisition and overpopulation, it may have been attempted by many advanced technical civilizations on planets of other stars.

Whether natural or artificial in origin, a spherical shell a few astronomical units in radius, at a temperature of a few hundred degrees Kelvin, will be a detectable source of

TABLE 1

DETECTABLE RANGE FOR $R = 5.2$ a.u., $\lambda = 8$–$13\ \mu$

| $P_n$ | $10^{-11}$ Watts | | | $10^{-12}$ Watts | | | $10^{-14}$ Watts | | |
|---|---|---|---|---|---|---|---|---|---|
| $D$ (inches) | 20 | 61 | 200 | 20 | 61 | 200 | 20 | 61 | 200 |
| $r$ (pc) | 10 8 | 32 9 | 108 | 34 2 | 104 | 342 | 342 | 1040 | 3420 |
| $N$ (mag.) | − 1 8 | 0 63 | 3 2 | 0 69 | 3 1 | 5 7 | 5 7 | 8 1 | 10 7 |

TABLE 2

DETECTABLE RANGE FOR $R = 1$ a.u., $\lambda = 8$–$13\ \mu$

| $P_n$ | $10^{-11}$ Watts | | | $10^{-12}$ Watts | | | $10^{-14}$ Watts | | |
|---|---|---|---|---|---|---|---|---|---|
| $D$ (inches) | 20 | 61 | 200 | 20 | 61 | 200 | 20 | 61 | 200 |
| $r$ (pc) | 2 06 | 6 46 | 20 6 | 6 58 | 20 1 | 65 8 | 65 8 | 201 | 658 |
| $N$ (mag) | − 1 8 | 0 63 | 3 2 | 0 69 | 3 1 | 5 7 | 5 7 | 8 1 | 10 7 |

infrared emission, seen through the 8–13-$\mu$ window of the Earth's atmosphere, provided that the shell is close enough to us. It is clearly very difficult to estimate from first principles the number of advanced technical civilizations in the Galaxy, and, therefore, the mean distance to the nearest such civilization. Recent estimates for this distance which at least explicitly state the assumptions invoked are 200–1000 pc (von Hoerner 1961), 50–300 pc (Sagan 1963), ~90 pc (Cameron 1963), and 3–300 pc (Pearman 1963). The distance to the nearest 300° K protostar is likely to be less than the distance to the nearest Dyson civilization.

It is possible to determine the range at which detection is feasible of large opaque

Infrared Processing and Analysis Center, Caltech/JPL.
IPAC is NASA's Infrared Astrophysics Data Center.

IAC-04-IAA-1.1.1.06

# SEARCHING FOR DYSON SPHERES WITH PLANCK SPECTRUM FITS TO IRAS


**Dick Carrigan**

**Fermilab**


*http://home.fnal.gov/~carrigan/Infrared_Astronomy/Fermilab_search.htm*

# How much energy would be available to an individual?

- Let's assume that the civilization is modest in size – say the same as the current Earth
- 10 billion individuals sharing $4 \times 10^{26}$ W would mean each individual had a net energy availability of $4 \times 10^{16}$ W, or 4000 times more than the entire world production today
- How much "land" would you have?
  - 28 million square kilometres
    - 20% of the entire land masses on Earth!

# Building Dyson Spheres

- Type I Dyson spheres, constructed from orbiting panels are surprisingly feasible if you can find enough material
- Type II Dyson are much, much harder to build and while you are building them they are quite unstable
- There is a joke "A society capable of building a Dyson sphere doesn't need a Dyson Sphere"

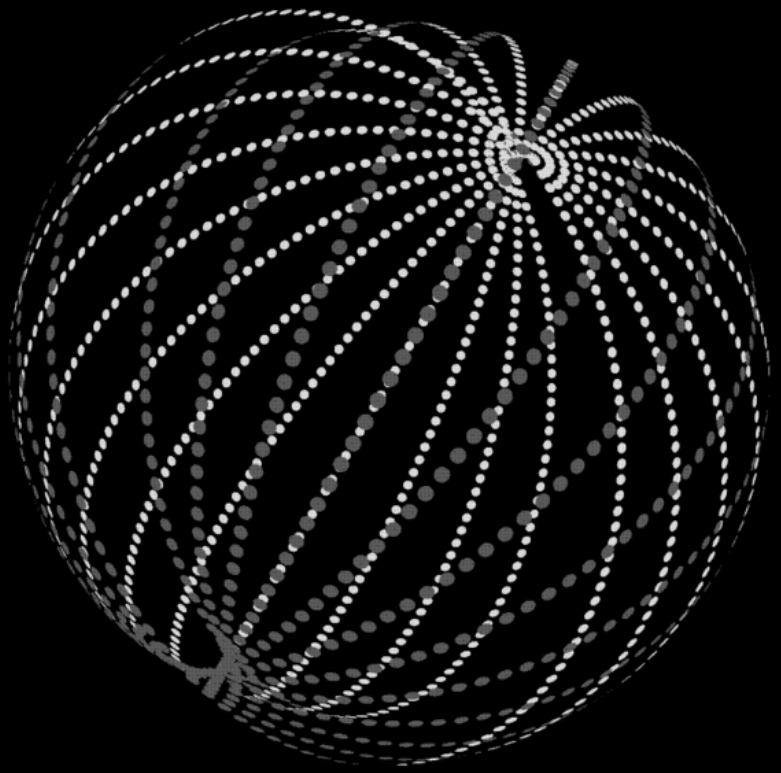
# How thick could a shell be?

- Let's take all the mass in the planets in Solar System as an example (don't ask me how we actually get it all!)
  - about $2.67 \times 10^{27}$ kg
  - Surface area of DS = $2.8 \times 10^{23}$ $m^2$
  - So about 9443 kg per $m^2$
  - At a density of 2000 kg $m^{-3}$ means you could only make the sphere 4.72 meters thick
  - Numerous estimates put the required structure thickness at orders magnitude larger levels than this…

*"A society capable of building a Dyson sphere doesn't need a Dyson Sphere"*

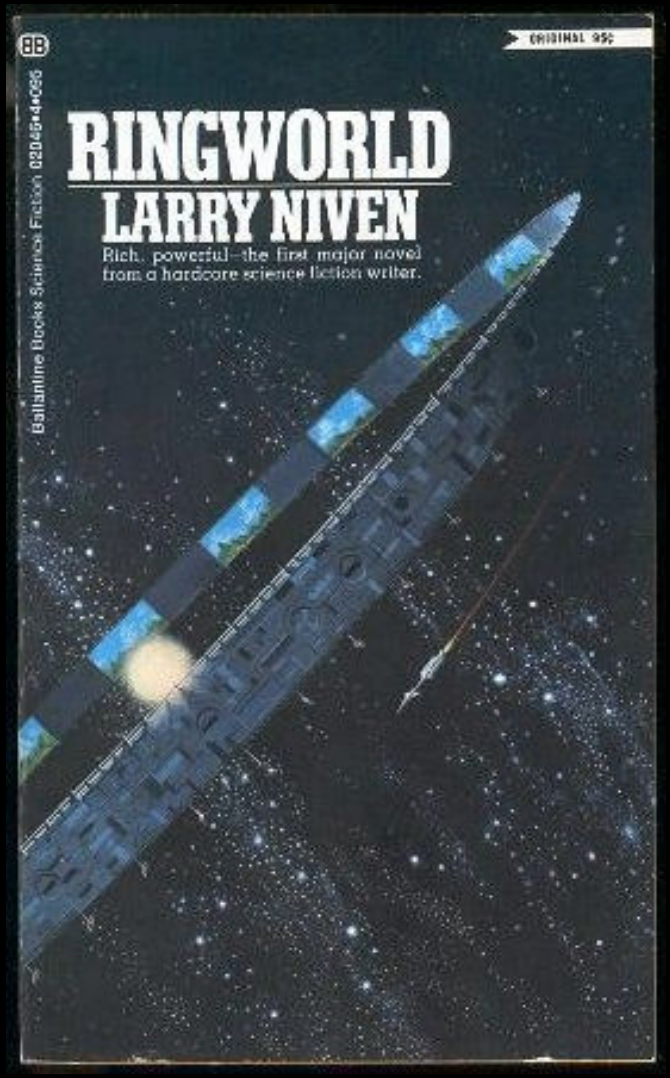
# Dyson's original idea is more "tractable"

- Having many collectors floating around on orbits could theoretically be done
- Don't have to worry about one or two enormous pieces of material
  - Just have to worry about a lot more smaller ones



# Larry Niven - Ringworld

- There are a number of problems with rigid Dyson spheres (sometimes called Type II Dyson spheres)
  - Must be strong enough to resist tidal pull from the Sun (even unobtainium materials would need to be 100s metres thick)
  - If you spin it, you create really enormous strains (top still feels gravitational pull, equator can be balanced by centrifugal force)
    - Needs to rotate at about 1000 km $s^{-1}$ to give Earth-like gravity
- Niven made the sensible suggestion that the easiest thing to do is to build a large ring, and then spin that



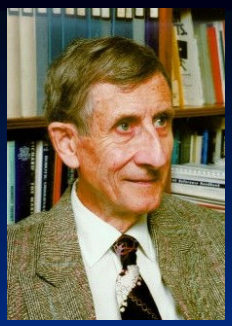
# Type III Classification

- Type III — A civilization that is able to harness all of the power available from a single galaxy
- This power value varies, but was taken by Kardashev to be $4\times10^{37}$ W
  - So $K=\log_{10}(4\times10^{37})-6/10=3.1$
- Such civilizations would have colonized the galaxy and would be harvesting energy from every star in the galaxy
- Presumably this would take an extremely long time…

# Type IV civilizations?

- Suggestions have been made to extend the scale to include
  - utilizing either the power of a supercluster of galaxies $10^{42}$ W
  - harnessing the power of the entire Universe
    - See Frank Tipler's "*The Physics of Immortality*"
  - maybe Type IV classifications should be limited to civilizations that can "control the laws of physics"
    - Perhaps we limit this to civilizations that can spawn new Universe's as in the Biocosm hypothesis
- To us, such civilizations would be indistinguishable from deities

# Kardashev & Dyson's projections



- Kardashev & Dyson made some guesstimates of when humans would transition between each type of civilization
  - Guesstimates assume that energy production grows exponentially, but with a low growth factor
  - Type I – 2200 AD
  - Type II – 5200 AD
  - Type III – 7800 AD
    - However, Kardashev neglects relativity, so in fact Type III must at minimum be millions of years away

*See interview with Michio Kaku* - "How Advanced Could They Be?". *Astrobiology Magazine.*

# Will humans actually get to Type I status?

- Technological Singularity? (Vinge, Kurzweil)
  - If we build systems that are as intelligent as humans are they destined to modify themselves to become increasingly efficient and more intelligent?
  - Runaway growth of intelligence?
- AI pundits suggest this could occur by 2030-2040
  - They assume though that Moore's Law (computer power essentially grows exponentially) will continue – it looks like it won't beyond 2015 (but we don't know yet!)
- Some people are genuinely worried about this
  - Bill Joy (Sun Microsystems co-founder) wrote an extensive article in Wired magazine in 2000 "Why the future doesn't need us"

# Summary of lecture 31

- Kardashev classification classes civilizations according to their power utilization
  - At present humans do not yet rate as a 1 on this scale
  - Type I civilizations utilize all of the power of their star arriving at the planet
  - Type II civilizations utilize all of the power of their star
    - Dyson sphere is one way to do this
  - Type III civilizations utilize all the power of a galaxy
    - Presumably this requires galactic colonization and must take a long long time…


Thank you!

***Good luck in the exam!***