Approach To The Cosmic Coincidences

Last Update: 5 July 2006

Incomplete – Needs Chapter numbers adding – when they're written!

1. Classification of the Coincidences

We define four classes of cosmic coincidence:-

(A) Type A coincidences involve a truly stupendous numerical coincidence, i.e. to an accuracy of 1 part in 10^N where N is a big number like 20 or 120.

(B) Type B coincidences are those for which the numerical coincidence is within a few percent, perhaps a fraction of a percent (but excluding Type A).

(C) Type C coincidences are those for which the numerical coincidence is within a few tens of percent (excluding Types A and B).

(D) Type D coincidences are those for which the coincidence is in terms of order of magnitude only, i.e. within a factor of ten or so (and we will stretch this rather further).

Type A coincidences are qualitatively different from the others, and are examined separately in Chapter ?. Whilst some people might regard the extreme nature of the numerical coincidence as making them the most impressive of the coincidences, I am inclined to think the opposite. Their extreme precision implies some mechanistic explanation or symmetry principle which makes them mandatory. They may be better regarded as 'laws' rather than coincidences. Examples include the flatness parameter (Ω_{TOT}) and the vacuum energy density, or cosmological parameter (Λ).

Type B, C and D coincidences are arranged with the most impressive first (B). Detractors might think that Type D, a mere order of magnitude coincidence, is not really a coincidence at all. One perspective on this is that , *a priori*, the universal constants might take any values whatsoever. Consider for example the dimensionless gravitational constant, α_G, whose value is ~6 x 10^{-39}. If we found this to be anthropically constrained to lie in the range 10^{-39} to 10^{-37} then this would be a coincidence from the point of view that it could equally well have been 10^{-5} or 10^{-70}. This makes Type B and Type C coincidences all the more impressive.

We distinguish between a double-sided and a single-sided coincidence. Types B, C and D refer to double-sided coincidences which restrict a universal constant to a finite range of values (i.e. with a lower bound and an upper bound). A single-sided coincidence imposes only a lower bound or an upper bound but not both. These will be denoted $\tilde{B}, \tilde{C}, \tilde{D}$ and are clearly far less impressive.

2. Categories of Coincidence

To attempt to make a wide ranging discussion more coherent, the coincidences are grouped into categories. Each example in each category is discussed in its own chapter, as follows.

(The list is rough & ready at present – needs tidying up…)

Type A Coincidences:
- The flatness parameter (Ω_{TOT})
- The vacuum energy density, or cosmological parameter (Λ).

Weak Force Coincidences:
- The hydrogen:helium ratio
- Stars: Type II Supernovae
- Stars: The first reaction of the pp sequences
- Is the weak force necessary? The Weakless Universe. The possible role of Type I supernovae and novae.

The Stability and Diversity of Matter:
- Constraints on M_n, M_p, m_e for nuclear and atomic stability: $\Delta = (M_n - M_p)/m_e$ is >1 but <3 or so (actually 2.5).
- The relative magnitudes of the strong and electromagnetic force for nuclear stability (and radioactivity): $f \approx 1/3\sqrt{\alpha}$
- The number of stable elements ~1/α. (If this is ~100 then this also defines the absolute size of the strong force through the above relation).
- Rees's $\alpha M_\pi \approx M_n - M_p$ (the electrostatic energy of small nuclei equals the nucleon mass difference) – but why is this required / what does it mean?
- The derived relation $m_e/M_p = 10\alpha$
- The requirement $m_e << M_p$ (Kahn argument, or mine).
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The Strong Force Coincidences:
- The strong force is just strong enough to bind the deuteron; Rees expresses this as $f^2 \approx 2M_n / M_\pi$ (demonstrate!).
- Strong force narrowly misses binding the diproton (but it doesn't matter!)

Recombination, Transparency and Matter-Radiation Equality
- Not clear why recombination = transparency is required, but if so it constrains photon:baryon ratio
- Rough equality of all three times is odd – is there any requirement for it?
- Freeze-out of recombination: May be essential to provide ions for formation of the first stars

The Anthropic Requirements of Stars:
Need to consider this as yet. Anthropic constraints are,
- Stars must form (constraint on Q – and absolute density, hence G ?)
- Stars must produce the chemical elements (see Hoyle)
- Stars must have lifetimes of order Byrs + (for chemical elements to be forged, then solar systems to form; then life to evolve)
- Stars must have luminosity of the right order
- Stars must have surface temperatures of the right order cf biological bond energies
- Smolin's Probability of such stars = 10^{-229} argument – Reprise & examine

The Hoyle Coincidence: Chapter ?
The best one of all!

3. A Brief Note on Life
Despite being based on the emergence of life, anthropic arguments rarely become very biological. The great disadvantage is that sufficient conditions for the emergence of life are unknown. It is hard to be absolutely definitive as regards any necessary conditions for life either. Inevitably, what we take as anthropic requirements are known to be necessary only in the case of terrestrial life. To avoid constantly re-iterating what we are assuming as our minimal requirements for life, we set them down here once and for all:-

- The production of the elements hydrogen, carbon, oxygen and nitrogen;

- The formation of stars with lifetimes of around a billion years or more;

- The same stars to have surface temperatures in the range 3000K to 9000 K and luminosities sufficient to keep planets within the temperature range 0^{o}C to 100^{o}C.

We are not suggesting for a moment that these conditions are sufficient. Other elements could be added to the list as being required for terrestrial life. There is little point, however, since production of the elements up to iron is unlikely to be challenged in any scenario which creates carbon, oxygen and nitrogen. The absence of a requirement to produce elements heavier than iron potentially allows universes with no Type II supernovae to be consistent with life. In this respect note that the major elements of life are all below iron in the periodic table. However, roughly half the trace elements of life on Earth are heavier than iron. Essentially, we are assuming that they are not crucial in general.

The requirement that 'typical' stars (whatever that means) live for around a billion years or more is a crude estimate of the time required for life to evolve. There appears to be a consensus that the first life on Earth was microbial and appeared when the Earth was about 0.7 Byrs old, approximately 3.8 Byrs ago. Given that up to that time the Earth's environment was harsh as regards high temperatures and heavy bombardments, it may be that life actually emerged in only a fraction of this time. Alternatively, it could be that life was seeded from outside the planet. But even then, it must have emerged somewhere else within 13.7 – 3.8 = 9.9 Byrs. As regards intelligent life, our one data point is that this emerged roughly 4.5 Byrs after the formation of the host star. It is difficult to do better than a crude guess that ~1 Byrs is a reasonable lower bound for the emergence of intelligent life.

The suggested planetary temperature range is a soft requirement, chosen so that water is liquid – at least roughly speaking since we have not specified what the pressure might be. A liquid environment is important in providing a medium for transport of pre-life molecules. A gaseous environment might do, but will be at a disadvantage if the density is lower. The specific focus on water may appear Earth-centric. However, water has unique chemical and physical properties which appear to make it peculiarly well suited to supporting the emergence of life. This has been discussed elsewhere and we will not repeat the arguments. Another reason to stipulate temperatures not too much greater than $100^{o}C$ is that proteins lose their internal mobility and denaturise at or just above this temperature (i.e. cooking temperature). Perhaps this is a little *too* specific to terrestrial, DNA-protein based life, however.

The surface temperature of a host star is a requirement quite independent of the star's luminosity or the temperature of the environment on the planet. The star's surface temperature determines the typical energy of individual quanta of radiation. It is necessary that these quanta have sufficient energy to break relevant chemical bonds on the planet, otherwise the radiation will be unable to provide sustenance to life (i.e. photosynthesis, or whatever its counterpart might be). The weakest bonds, and ones particularly important in terrestrial life, are the hydrogen bonds with energies of about $0.01\alpha^2 me = 0.27$ eV. However, it is also necessary to be able to break molecular bonds. Molecular bonds have energies of around $0.05\alpha^2 me = 1.35$ eV. Equating this to the average black body photon energy, 2.7kT, implies surface temperatures need to be ~5,800 K (almost exactly that of the sun). However, temperatures somewhat lower will be adequate since the Planck distribution provides numerous photons with higher energies than the mean. Higher radiation temperatures are obviously 'adequate' also, in this sense. However, if the radiation temperature is too high then all molecular bonds become vulnerable, and life is jeopardised rather than assisted by the radiation. There is another fine-tuning here, since the radiation temperature must not differ too much from ~6000 K. We have not considered in any detail what "too much" might mean. Our value of +/-3000 K is merely a guess which the reader may well be able to improve upon.

Finally, you might think that the assumption that life must originate on a planet is spectacularly lacking in imagination. Maybe so, but there is some rationale for it. We have essentially pinned our colours to the mast of carbon based life forms already. So we can ignore environments in which the relevant chemistry cannot exist. This rules out stars, which have no chemistry since everything is fully dissociated and ionised (except within the photosphere, where there are atoms but not molecules). It also rules out wacky things like life on neutron stars. What about life on comets or asteroids? Essentially these are little different from planets apart from two major disadvantages. They are too light to maintain an atmosphere, and they tend to spend long periods of time out in the cold depths of space. Planets are simply a much better bet. Finally, what about life evolving in gas clouds or other diffuse interstellar media? The main disadvantage here is that, whilst a 3D fluid is jolly good for transport of reactants, chemical reactions prefer a nice two dimensional surface to accumulate on. Reaction rates within a low density inter-stellar gas or dust cloud are not likely to be fast enough to encourage the formation of life in any sensible timescale.