HYPOTHESIS:
A possible role for stochastic radiation events in the systematic disparity between molecular and fossil dates.

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Abstract:
Major discrepancies have been noted for some time between fossil ages and molecular divergence dates for a variety of taxa. Recently, systematic trends within avian clades have been uncovered. The trends show that the disparity is much larger for mitochondrial DNA than for nuclear DNA; also that it is larger for crown fossil dates than stem fossil dates. It was argued that this pattern is largely inconsistent with incompleteness of the fossil record as the principal driver of the disparity. A case is presented that given the expected mutations from a fluctuating background of astrophysical radiation from such sources as supernovae, the rate of molecular clocks is variable and should increase into the past. This is a possible explanation for the disparity. One test of this hypothesis is to look for an acceleration of molecular clocks 2 to 2.5 Ma due to one or more moderately nearby supernovae known to have happened at that time. Another is to look for reduced disparity in benthic organisms of the deep ocean.

Running title: Radiation and Molecular Clocks
1. Introduction
There has been a long acknowledged disparity between ages determined from the fossil record and those derived from molecular divergence dating. The sign of this disparity is nearly always in the direction of much older molecular ages. A variety of effects may cause biases of either sign in the molecular ages, but, due to incompleteness of the fossil record, fossil ages are (aside from outright errors) lower bounds to the age of the taxon, so that the ages of originations are always underestimates. Since this could in principle account for the entire effect, much discussion has centered on this option.

A systematic study of trends within the disparities in avian clades (Ksepka et al. 2014) asserts that variety of patterns, not to be enumerated here, are inconsistent with attributing all of the age disparity to gaps in the fossil record. We are urged to consider any possible systematic biases in molecular dates as well as calibration strategy. At this point it is relevant to mention that the whole basis of molecular dating has been accused of systematic underreporting of errors (e.g. Graur and Martin 2004). However, we shall for the purpose of this paper assume that they have a basis in reality.

One possible bias in molecular dates concerns a variable rate of molecular clocks due to changes in the mutation rate. An unknown but substantial fraction of mutations come from radiation of various kinds (Alpen 1997). The radiation background in the Earth’s environment fluctuates strongly, so that it is expected to find events of increasing strength when looking further back in geologic time (Erlykin and Wolfendale 2009; Melott and Thomas 2011). There is a normal operational assumption that molecular clocks move at a constant rate, but fluctuating radiation backgrounds would vary this rate. In the absence of selection pressures, isolated communities, etc. this variable mutation rate need not correspond to a correlated variable rate of evolution.

I wish to stress the following: this is a physics based hypothesis; there are many other biological explanations that may explain all or part of the phenomenon. I do not intend to claim that it is the best possible explanation, but only to introduce it for discussion.

High energy events can produce air showers which have strong effects on the ground. Since such very strong events are not occurring now (see e.g Overholt et al. 2015), molecular clock rates determined from very recent data would not include this acceleration. The purpose of this note is to suggest further examination of this possibility, with attention to one specific test.

Ksepka et al. (2014) reported that the disparity between fossil and molecular clocks is greater with mitochondrial DNA than with nuclear DNA. This observation is consistent with our hypothesis of a radiation link for the disparity, because mitochondrial DNA is more subject to damage from radiation and to oxidative stress, one of the primary mechanisms of radiation damage to DNA (Yakes and Van Houten 1997; Kam and Bonati 2013).
2. Radiation Events and the Earth
There are a variety of possible types of astrophysical radiation and likely sources for events at the Earth (Melott and Thomas 2011). Dominant among these are the Sun (see Wdowczyk and Wolfendale 1977) and other stars in our galaxy. It has been known for some time that supernovae and gamma-ray bursts from other stars in our galaxy are likely, based on their intensity and frequency of occurrence, causal agents in mass extinction every few 100 Myr. The Sun has X-ray flares, but the dominant form of radiation for biological consideration is in Solar Proton Events. There was in 775 AD an event indicated by 14C in tree rings which exceeds anything in the modern era (Miyake et al. 2012; Jull et al. 2014) and which is probably attributable to the Sun (Melott and Thomas 2012; Usoskin et al. 2013).

All of these are potentially dangerous sources, although interpreting the new data on the Sun and Sunlike stars is an emerging area. Although the atmosphere provides considerable shielding, effects on the ground can still include radiation in the form of muons (Atri and Melott 2011; Marinho et al. 2014) and neutrons (Overholt et al. 2013; Overholt et al., 2015). Most muons are stopped by a kilometer of water, so any potential muon damage would not include benthic organisms in the deep ocean. In addition, the ionizing radiation can deplete the stratospheric ozone layer (Thomas et al. 2013, and references therein), admitting increased damaging and mutagenic ultraviolet-B from the Sun. Nearby supernovae will bombard the Earth with much higher energy cosmic rays (protons) than are likely to come from the Sun.

3. Testing the Idea
Most of the astrophysical radiation including the indirectly increased UVB can be stopped by 10 m of water. However, the DNA of such organisms may be affected in a pelagic larval stage, especially if they are photosynthetic. Organisms which are shielded from the radiation should not show effects of strong fluctuations. In particular, deep-water benthic organisms should display more congruence between the fossil and molecular dating methods.

Kspeka et al. (2014) noted that for very old dates (many times 10 Myr), there is better congruence than for younger dates. This would be consistent with a high rate of mutation in the not too distant past, and a return to a geologic mean rate over longer periods.

There is a large amount of new data in the form of $^{60}$Fe in sediments which suggest that one or more supernovae went off within one or a few hundred light years of the Earth around the beginning of the Pleistocene (Fry et al. 2015; Wallner et al. 2016; Breitschwerdt et al. 2016; Melott 2016; Fimani et al. 2016; Binns et al 2016). This would indicate an enhanced radiation environment persisting for at least several thousands of years for each event. Therefore, if this idea has merit, there should be an acceleration of the molecular clocks relative to the fossil record around 2.5 Ma. The transport
modeling work (Breitschwerdt et al. 2016) was published simultaneously and done without knowledge of the new data from the other studies. Improved modeling is in progress which should better constrain the dates. We have recently done computations of radiation transport in the galaxy and the atmosphere (Thomas et al. 2016) which suggest at least a factor of 10 increase in ionizing radiation at the surface of the Earth, persisting for thousands of years. This also should be further refined in near future. The other test of this idea, as noted, is the expected major reduction in the disparity for deep-sea organisms.

In closing, it should be emphasized that we do not claim that this is better than other existing explanations for this disparity, but that it is a possibility that should be considered, and can be tested by looking for the predicted acceleration near the beginning of the Pleistocene and better agreement between fossil and molecular ages for deep sea organisms.

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