ASTRONOMY 420W

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Final Exam Essays:

1. Present and provide some explanation for the complex distribution of orbits and surface compositions of rocky bodies in the Asteroid Belt:

Most asteroids are located in the main asteroid belt, at heliocentric distances between 2.1 and 3.3 AU. The orbits are very eccentric, and can be explained well with a Rayleigh distribution, suggesting some sort of equilibrium situation that is occurring. Several gaps and concentrations of asteroid semimajor axes can be distinguished; these gaps are called Kirkwood gaps. Kirkwood gaps coincide with resonance locations with the planet Jupiter. Perturbations by the giant planet produce chaotic zones around the resonance locations, where asteroid locations can be forced to values high enough to cross the orbits of Mars and Earth. Saturn too causes resonances near the inner edge of the asteroid belt. Saturn's apse precession rate can also excite asteroids onto high eccentricity orbits. In some cases, asteroids are sent plowing into the Sun. In contrast, asteroid population is enhanced at the 3/2 and 4/3 resonances with Jupiter near the outer edge of the belt that actually prevent close encounters with the giant planet. Jupiter's L4 and L5 triangular Lagrangian points contain roughly 700 asteroids. These bodies are known as the Trojan asteroids, and are the most stable between the giant planets. Trojans have low albedos and are further away from the Sun than are the main belt asteroids.

Asteroids are also classified by composition and albedo, most being one of three types. The majority of asteroids (C-type) are similar to carbon-chrondite meteorites with approximately the same composition as the sun (excluding hydrogen) and are relatively dark. Those with a composition of nickel iron mixed with silicates of iron and magnesium (S-type) are relatively bright. The M-type's are composed of nickel iron and are bright. Asteroid surfaces are covered in regolith, much like the moon. Space weathering of asteroids is thought to be the source of the altered surface compositions. Another possibility is interaction with the Solar wind, and cosmic rays.

2. Discuss results and inferences about the solar nebula obtained from study of radioactive isotopes (or their daughter isotopes) in components of ancient meteorites (e.g. long-lived ^{207}Pb/^{206}Pb, short-lived ^{26}Al/^{27}Al or ^{41}Ca/^{40}Ca, oxygen ^{18}O-^{17}O-^{16}O).

Several radioisotopes were present in the early Solar System. Many have ½ lives that are short relative to the age of the Solar System, and are now extinct. For example, the decay of 26Al to 26 Mg with a ½ life of .72 Ma, or the decay of 41Ca to 41K with a ½ life of 0.1 Ma. These isotopes are evident only from the presence of their daughter material, and therefore only allow for relative ages to be determined. The initial relative abundance of radionuclides must have been homogenous throughout the solar nebula. This can be achieved if the radioisotope had a stellar origin, i.e. from a supernova. However, isotopes' forming locally by means of an energetic particle near the young protosun is an alternative forming mechanism. If this were the case, a radial heterogeneity would exits. Thus, the differences in daughter product compositions no longer depend solely on age, but also on position relative to the protosun and cant be used to date objects.

To determine absolute ages, some of the parent isotope must still be present in the object. Thus, long-lived radionuclides with ½ lives on the order of billions of years are needed. Only the Pb-Pb chronometer has been shown to reach high enough precision to have errors of less than a million years. This chronometer is based on the decay of two long-lived radionuclides: 238U which decays to 206Pb with a ½ life of 4.46 Gyr, and 235U which decays to 207Pb with a ½ life of 0.704 Gyr. Since 235U decays faster than 238U, the atomic ratio 235U/238U decreases with time, thus causing the ratio of 207Pb/206Pb to increase with time. Therefore, by measuring the present day isotopic Pb composition, one can get an absolute age of objects. These tools allow us to determine absolute ages of CAI's and chondrule formation.

Most CAI's show a significant excess of 26Mg, suggesting widespread distribution of 26Al in the early Solar System. In contrast, the majority of chondrules show small to undetectable amounts of 26Mg. This implies that chondrules began to form about 2 million years later than CAI's. This is supported by Pb-Pb dating.

3. What melted the chondrules, which constitute much of the mass of meteorites from the Asteroid Belt?

It is not known fully what melted the chondrules; there are several theories to be outlined:

One of the ideas is that chondrules melted as they passed through shock waves in the solar nebula gas. As chondrules melted, they changed from fluffy dust to round, compact spheres, altering their aerodynamic properties and enabling the growth of larger bodies. Because shocks would melt chondrules early in the solar nebula's evolution, the results are consistent with the common idea that chondrule formation was a prerequisite to the formation of planets in general.

Chondrules may have melted by current sheets. Charged particles are accreted by magnetic fields. Gas and dust that enters a sheet is heated by the collisions with charged particles. Magnetic instabilities cause turbulence, leading to a pile up of magnetic field lines, these causes a build up of ions and especially high current. This model may explain the near IR excess observed in young stars, but the early magnetic history of the sun is not well known at all so this model is not of much use.

X-Ray flare shocks may have melted the chondrules as well. High X-ray activity seen in T-Tauri stars may have been the source of the flares. When the sun was young, it was highly active, producing energetic X-ray flares which penetrate deep into protoplanetary disks. Shock waves form where the pressure of the impacting wind is about the same as the pressure from the nebula.

Other models that are out in the scientific community include: meteor ablation in planetary atmospheres, impacts on parent bodies, nebular lightning, FU Orionis outburst, ablation in bipolar outflow, and flash heating.

4. Summarize our current understanding of the populations and origins of minor bodies in the outer solar systems: Plutinos, Trans-Neptunian Objects, Kuiper Belt Objects, Oort cloud cometary nuclei.

A Trans-Neptunian object (TNO) is any object in the solar system with all or most of its orbit beyond that of Neptune. The Kuiper belt and Oort cloud are names for some subdivisions of that volume of space. Due to the changes in the orbits of the known planets in the early 1900s, it was assumed that there was one or more planets beyond Neptune, but not yet identified. The search for these led to the discovery of Pluto, and since then a few other significant objects have been found. These are still too small to explain the perturbations, though, and revised estimates of Neptune's mass showed that the problem was fictitious.

Over 800 Kuiper belt objects (KBOs) (a subset of trans-Neptunian objects (TNOs)) have been discovered in the belt, almost all of them since 1992. The Kuiper belt is a hypothetical massive flattened disc of billions of icy planetesimals supposedly left over from the formation of the solar system. Most KBOs are lumps of ice with some organic (carbon-containing) material, detected using spectroscopy. They are of the same composition as comets and many astronomers believe them to be just comets. KBOs are by (current) definition limited to 30-50 AU from the sun. Some KBOs that also periodically travel inside Neptune's orbit are in 1:2, 2:3 (plutinos), 2:5, 3:4, 3:5, 4:5, or 4:7 orbital resonances with Neptune. Cubewanos form the central region, and scattered disk objects (SDOs) are found in the outer areas of the belt. The belt should not be confused with the Oort cloud, which is not limited to the plane of the solar system and is more distant. The Oort cloud is a postulated spherical cloud of comets situated about 50,000 to 100,000 AU from the Sun. This is approximately 1000 times the distance from the Sun to Pluto or roughly one light year, almost a quarter of the distance from the Sun to Proxima Centauri, the star nearest the Sun. The Oort cloud is a remnant of the original nebula that collapsed to form the sun and planets five billion years ago, and is loosely bound to the solar system.

5. Present evidence and discuss some possible implications for the irradiation of protoplanetary disks by X-rays.

Recent research presents us with evidence of strong X-Ray flares; the weakest of the flares are ~10x stronger than the most powerful flares from the Sun during recent solar cycles. Some COUP sources show periodicity. If optical evidence is accurate, then the X-rays may not arise directly from the stellar surface fields. This may be evidence for flaring at the star-disk corotation radius. COUP has detected the 6.4 keV iron fluorescent line emission in several luminous, hard-spectrum Orion Nebula sources (Prof. Feigelson). It is not yet clear whether this iron line is due to reflection off of protoplanetary disks. This line is not seen frequently, even when there is sufficient signal, this implies that this is a rare occurrence. Reflection from a flattened distribution of dense cold matter is a good model, and this is supported by the fact that the 6.4 keV sources are deeply embedded with near-IR excesses, i.e. young systems with heavy disks.

X-rays can affect the protoplanetary disk in significant ways. Some examples of this are: (1) X-rays penetrate deeply into the disk and ionize material, inducing turbulence which affects accretion, (2) high energy flaring could possibly melt chondrules and solve a problem plaguing astronomy, and (3) X-rays will heat the outer disk layers and will alter the disks chemistry.

6. Describe the growth of solid bodies in a protoplanetary disk from interstellar dust particles to solid planetary embryos.

As a protoplanetary disk cools, microscopic grains begin to condense into larger and larger particles. The coagulation of these particles begins to proceed via mutual collisions. These small grains in the disk begin to become coupled to the gas via their motion. These particles agglomerate into macroscopic bodies (planetesimals) within roughly 10^4 years at 1AU. Once the dust accumulates into cm→km sized planetesimals, they begin to experience disturbances resulting from orbiting slightly faster than they surrounding gaseous disk. The disturbance causes a loss of orbital angular momentum, and consequently the planetesimal spirals in toward the host star. Planetesimal dynamics is a rather complicated field, and is dominated by planetesimal-planetesimal and planetesimal-embryo interactions. Once a body is km sized, mutual contributions from gravitation interactions and collisions lead to accretion. The most massive of the planetesimals have the largest gravitational accretion cross-sections. Random velocities play a vital role in the evolution of planetary embryos. If they remain smaller than the escape speed from the largest bodies, then these planetary embryos grow rapidly.

7. Contrast two views of the formation of gas giant planets with reference to models of Jupiter's interior.

There are two main schools of thought for the formation of gas giant planets. One is the nucleated stability model, and the other is the gravitational disk instability model. They both have their advantages and disadvantages as does every model of planetary formation.

The nucleated instability model involves 3 major phases that simulate the concurrent solid and gas accretion of the giant planets. The first phase is the growth of the solid and almost entirely high metal core. This early growth is thought to have occurred rapidly due to runaway accretion. The second phase lasts much longer, tens of millions of years for Jupiter. During this phase both solids and gasses are accreted slowly. This continues until a critical core mass is reached, then rapid gas accretion is triggered. The final mass is achieved in this phase. This model gained acceptance due to the fact that it can reproduce the present angular momentum of Jupiter. The main disadvantage of this model is primarily the fact that it takes so long to build up the solid core to the critical mass.

Disk instability was initially discarded due to difficulties in forming a solid core, and then it was resurrected in the mid-90’s as a response to the problems of the nucleated instability model. The process of disk instability is very fast, occurring in 100’s of years. After about 150 years, spiral arms begin to develop as do local overdensitities at distances > 10AU. The main advantage to this model is its ability to form gas giants at a great speed. But it is not known whether these masses even last, because the simulations were not continued for longer time periods. Also, this model doesn’t explain our solar system very well. Another advantage is that it can explain the extra solar planets that we have already observed very close to their parent stars.

Both models of giant planet formation have appealing features, but there is a lot to resolve in each. Nucleated instability has grown to be accepted by many astronomers, but difficulties still remain with long timescales of formation. Disk instability resolves the time problem, but is unable to explain many of the aspects of our own solar system.

8. Describe and outline explanations for the diversity of gas giant planetary orbits: hot Jupiters like 51 Peg, cold elliptical Jupiters, and cold circular Jupiters as in our planetary system.

Light was shed on the puzzle of the Hot Jupiters when simulations of protoplanetary disks showed that gas giants like Jupiter could migrate inward towards their stars, either due to drag against disk material or by gravitational perturbations with the disk. Tidal forces and disk clearing near the star would tend to park such migrating planets at orbital distances quite similar to those of the Hot Jupiters. It would appear that 51 Pegasi b and its kin originally formed far from their stars but spiraled inward to their current orbits.

Another explanation for the appearance of hot Jupiters was demonstrated by Dr. Stuart J. Weidenschilling. If a system of three or more giant planets form about a star, their orbits may become unstable as they gain mass by accreting gas from the circumstellar disk; subsequent gravitational encounters among these planets can eject one from the system while placing the others into highly eccentric orbits both closer and farther from the star. The Jupiter that was placed into a highly eccentric orbit far away from the star explains the phenomena of Cold Elliptical Jupiters, and the other Jupiter that was placed into an orbit close to the star is another explanation of Hot Jupiters.

Orbit crossings and global instabilities among planets in the disk can lead to dramatic orbit changes and large eccentricities. Long-lived gas in a proto-planetary disk may lead to circular orbits in such planetary systems. Other systems that lose their gas may suffer dynamical instabilities, leading to eccentric orbits at a variety of semimajor axes. However, the latter scenario, if common, does not explain the apparent paucity of Jupiters from 0.5 to 1.5 AU, and it remains to be seen if Jupiters are common farther out.

9. Summarize the current state of knowledge of extraterrestrial life in the Universe, and briefly present your views on future prospects.

Currently our knowledge of ET life is ZERO! We know absolutely nothing.

In recent years, scientists and the general public have realized that intelligent life may well be found throughout the universe. We are probably not the only civilization in our galaxy; it may even contain dozens or hundreds of civilizations scattered among its 400,000,000,000 stars. If we receive a richly detailed message from one of these civilizations or have some other form of contact with it, the effects on our civilization could be pervasive and profound.

The search for extraterrestrial intelligence (SETI) has now become reasonably mainstream within the scientific enterprise. Radio astronomy's efforts to detect a signal or message from another civilization are increasing rapidly. Cosmology may be shifting toward emphasizing life throughout the universe, not just stars and sterile dust. Recent polls find that 50% of adults believe there is intelligent life beyond the earth.

Sometime in the future of human civilization, contact or interaction with intelligent life from somewhere else in our galaxy will probably occur. It might occur next year, for instance, or 100 years from now. Our rapidly increasing efforts make contact particularly likely within the next 20 or 30 years (wishful thinking). Few events in the entire sweep of human history would be as significant and far-reaching, affecting our deepest beliefs about the nature of the universe, our place in it, and what lies ahead for human civilization. Seeking contact and preparing for successful interaction should be one of the top priorities on our civilization's current agenda.