Meteorite Constraints on the Early Stages of Planetary Growth in the Inner Solar System. N. Haghighipour[1] and E. R. D. Scott[2], [1]Institute for Astronomy and NASA Astrobiology Institute, University of Hawai'i-Manoa, 2680 Woodlawn Drive, Honolulu, HI 96822, nader@ifa.hawaii.edu, [2]Hawai'i Institute of Geophysics and Planetology, University of Hawai'i-Manoa, 1680 East-West Road, Honolulu, HI 96822, escott@higp.hawaii.edu.

We present the results of a study of the delivery of the parent bodies of iron meteorites to the inner part of the asteroid belt through collision, accretion, and scattering of planetesimals, and the subsequent growth of chondritic asteroids at the early stage of planet growth. Our goal is to portray a comprehensive picture of the growth and scattering of meteorite parent bodies in the inner part of the solar system by studying the interactions among protoplanets and planetesimals, and the influence of a growing giant planet on the dynamics of these objects. We have numerically integrated the orbits of several hundred protoplanets and more than one thousand planetesimals, and have studied their collisions, accretion, and scattering while Jupiter's core grows. The results of our simulations indicate a transitional range for the mass of the growing Jupiter (50-100$M_\oplus$) above which the perturbative effect of this object plays a strong role in the scattering of planetesimals, and increases the efficiency of the delivery of the parent bodies of iron meteorites to the asteroid belt. We will present the details of our study and discuss the applicability of our results within the context of the core-accretion and disk instability models of giant planets formation.

Introduction: Being the remnants of the accretion and collision of ~70 planetesimals in our solar system [1-3], iron meteorites provide the best clues to the nature of the collisions among these objects and the initial stage of accretion and growth of small bodies, particularly in the inner part of our planetary system. The parent bodies of iron meteorites were traditionally, assumed to have formed, differentiated, and subsequently been disrupted in the main asteroid belt. Observational evidence, however, is in disagreement with this assumption and indicates that differentiated bodies are not currently common in that area. Also, the parent bodies of iron meteorites, which were probably 20 to >500 km in size [2,3], formed much earlier than the parent bodies of ordinary and carbonaceous chondrites [4,5,6]. In an attempt to overcome these difficulties, Bottke et al [7] have suggested that the iron meteorite parent bodies probably formed inside 2 AU and were scattered into the main belt as a result of the collisions and interactions between the protoplanets in that region and the remaining planetesimals.

Hf-W isotope evidence shows that cores formed in most iron meteorite parent bodies less than 1 Myr after CAI formation [8]. By contrast the evidence from Pb-Pb and Al-Mg dating of chondrules shows that the parent bodies of the carbonaceous and ordinary chondrites accreted 1.5 to 4.5 Myr after CAI formation, presumably in the asteroid belt [e.g., 5].

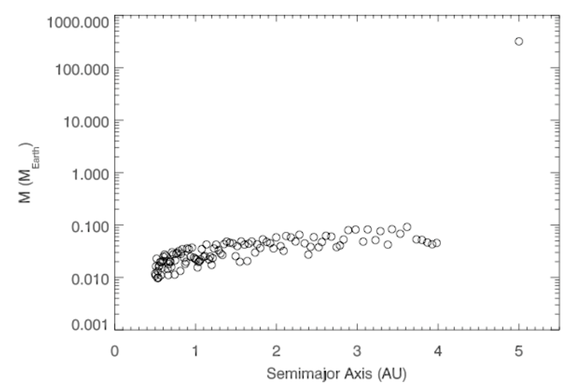

Figure 1: Graph of the distribution of protoplanetary objects. Jupiter is also shown at the upper right corner.

The accretion and scattering of planetesimals through interactions with protoplanets must have occurred during the time that the cores of the giant planets in the outer part of the solar system, were growing. The gravitational perturbations of the growing giant bodies have certainly affected the collision of protoplanets and planetesimals, the scattering of these objects to the asteroid belt, and the growth of bodies in the asteroid belt. How significant this effect has been, and whether it increased the efficiency of the delivery of the parent bodies of iron meteorites to the asteroid belt, or instead prevented them from scattering, are questions that require deep understanding of the dynamics of the bodies at the early stage of planet growth in our solar system.

Numerical Simulations: Since the perturbative effect of the giant planet is a function of its mass, numerical simulations of the dynamical evolution of planetesimals and protoplanets need to be carried out at the presence of this object and during its growth. For this purpose, we considered a system consisting of the Sun, several hundred Moon- to Mars-sized planetary embryos, 1200 planetesimals, and a growing giant planet with the present orbital parameters of Jupiter. The planetary embryos were randomly distributed between 0.5 AU and 4 AU, with mutual separations of 3-6 Hill radii (figure 1). The masses of these objects were chosen to increase with their semimajor axes (*a*) and the number of their mutual Hill radii (Δ) as $a^{3/4}\Delta^{3/2}$. The total mass of the protoplanetary disk was chosen to be approximately 4 Earth-masses, and its surface density, normalized to 8.2 g/cm^2 at 1 AU, was taken to be proportional to $r^{-3/2}$. We considered an eccentricity between 0 and 0.05 for each protoplanet, and assumed that their orbital inclinations were 0.1 degrees.

The planetesimals of our system were mass-less particles randomly distributed in two regions: 0.5-2 AU and 3.5-4 AU. The eccentricities of these objects were also chosen from the range of 0 to 0.05, and their inclination were taken to be 0.1 degrees.

We numerically integrated the orbits of the planetesimals, protoplanets, and proto-Jupiter in our system, for 10 Myr. To examine the effect of the growth of Jupiter on the accretion and scattering of planetesimals, we carried out simulations for different values of the mass of this object, ranging from $0.1M_\oplus$ to $300M_\oplus$. The results of our study are summarized in the following sections.

1) In systems where the mass of the giant planet's core was smaller than $10M_\oplus$, the dynamics of planetesimals were mainly governed by their interactions with the planetary embryos. In these systems, perturbation of the giant planet did not play a significant role. Many of the planetesimals of these systems were accreted by protoplanets, and their scattering to outer distances was slow and less efficient. The scattering of small bodies were more pronounced when the collisional growth of planetary embryos produced larger objects.

2) Systems in which the mass of the growing giant planet was within the range of $50M_\oplus$ to $100M_\oplus$ presented the transitional cases. In these systems, the dynamical effects of the perturbation of the giant planet were detectable approximately 40% through the simulations. The planet in these systems caused close approaches between planetesimals and many protoplanetary embryos (particularly those in the outer region of the asteroid belt), resulting in their ejection from these systems (i.e., their semimajor axes exceeded 100 AU). Many of the planetesimals were also scattered to different orbits throughout the asteroid belt. The efficiency of this scattering process was considerably higher than the previous case.

3) When the mass of the giant planet was larger than $100M_\oplus$, the perturbation of this object was the dominant effect. Figures 2 and 3 show the results of simulations for 2 Myr for one of such systems. The mass of the giant planet in these figures is $300M_\oplus$. As shown here, the outer protoplanets are strongly affected by the giant body and become unstable in a short time. Many of the planetesimals are also ejected from the system. The destabilizing effect of the giant planet extends to large distances from this object with-

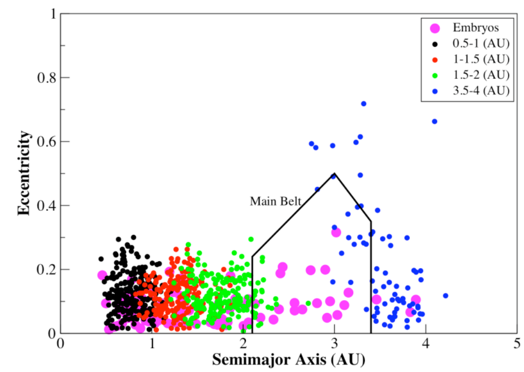

Figure 2: Graph of the scattering and final eccentricity of planetesimals and protoplanets. A $300M_\oplus$ planet, not shown in the figure, is at the place of Jupiter.

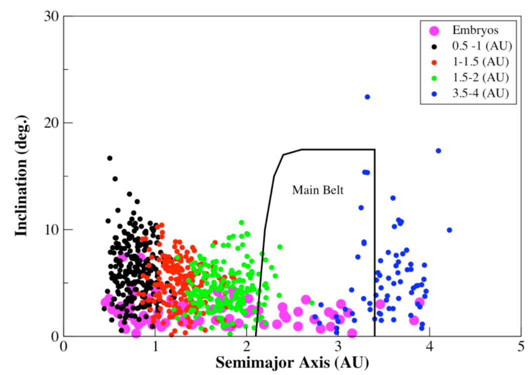

Figure 3: Graph of the scattering and final inclination of planetesimals and embryos. A $300M_\oplus$ planet, not shown in the figure, is at the place of Jupiter.

in the asteroid belt area leaving the inner part of this region less unaffected by this body. Simulations show that in this case, the inner region of the asteroid belt (<2.5 AU) is primarily populated by planetesimals that were back-scattered from the region between 1.5 AU and 2 AU, although some of the inner planetesimals also contributed. The forward scattering of outer planetesimals into this region, was insignificant after 10 Myr.

References:

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