

A BAYESIAN FRAMEWORK FOR EXPLORING THE EARLY IMPACT HISTORY OF THE ASTEROID BELT WITH METEORITE THERMOCHRONOLOGY

G. H. Edwards¹, C. B. Keller¹, C. Stewart¹, E. R. Newton², ¹Earth Sciences, Dartmouth College, Hanover, NH, U.S.A. (graham.h.edwards@dartmouth.edu), ²Physics & Astronomy, Dartmouth College, Hanover, NH, U.S.A.

Introduction: The collisional history of the solar system provides important constraints on its dynamical and architectural evolution. Episodes of widespread enhancement in impactor flux reflect dynamical instabilities, which, in turn, are thought to be excited by giant planet migration events [e.g. 1,2]. While collisional histories constrained by the lunar and martian cratering record have been used to predict such an event at ~4.0 Ga [2], more recent dynamical models limit the timeframe of giant planet instabilities to within the first ~100 Ma of solar system history [3]. These earlier timescales are corroborated by the radiometric cooling ages of asteroidal meteorites. Since temperature-sensitive thermochronometric systems of meteorites would record the thermal imprint of an enhancement in highly energetic impact events, the apparent absence of widespread resetting of high-temperature thermochronometers contradicts an asteroid-belt-scale instability after 4.48 Ga [4].

We expand on these studies and aim to precisely constrain the timescales of widespread excitement in the asteroid belt within the first several hundred million years of solar system history. The challenge to resolving impact resetting of thermochronologic systems over this timescale is that it overlaps with the primary cooling of radiogenically heated parent planetesimals [e.g. 5]. To overcome this challenge, we implement a Bayesian statistical model to resolve these two processes through comparison of model asteroidal thermal histories to a database of chondrite ⁴⁰Ar-³⁹Ar dates [adapted from 4]. The ⁴⁰K-⁴⁰Ar system (as measured by the ⁴⁰Ar-³⁹Ar method) is particularly well suited to dating impact events given its sensitivity to resetting at moderate temperatures (<700 K).

Methods & Approach: We developed a simple asteroid-scale thermochronologic evolution code, which simulates conductive cooling of a radiogenically heated spherical body [e.g. 5] and near-surface reheating by impacts. Model ⁴⁰Ar-³⁹Ar dates at different depths in the body are calculated from the time of cooling below a closure temperature. Impact resetting of the ⁴⁰K-⁴⁰Ar system is modeled by an exponentially decaying probabilistic impactor flux, for which each “collision” resets the cooling age of an assumed near-surface volume of the model asteroid.

The thermal code is coupled to a Markov chain Monte Carlo inversion that stochastically varies model parameters (e.g. ⁴⁰Ar closure temperature, onset of heightened impact flux) and for each perturbation calculates the likelihood that the observed ⁴⁰Ar-³⁹Ar date distribution is drawn from the age distribution of the thermal model output. This inversion, via the Metropolis algorithm, explores the likelihood space corresponding to the above-mentioned model parameters and converges on a distribution that describes the posterior estimate for the value of each parameter, as constrained by the observed ⁴⁰Ar-³⁹Ar date distribution.

Preliminary Results & Discussion: We report two key observations from preliminary results. (1.) Thermal simulations that do not incorporate impact resetting fail to converge on model parameters that reproduce the observed distribution of >4 Ga ⁴⁰Ar-³⁹Ar dates in chondrites. This indicates that unperturbed conductive cooling alone cannot account for the observed cooling ages. (2.) In contrast, when the simulation incorporates a single bombardment event characterized by an exponential decay in impactors from a peak initial flux, the posterior converges on a mean instability start date of 113 ± 53 Ma (1σ) with local maxima in the posterior distribution at ~60 Ma, 100-130 Ma, and ~190 Ma. These distinct peaks represent higher likelihood regions of the parameter space and may imply multiple instabilities recorded in the chondritic ⁴⁰Ar-³⁹Ar date record.

Limitations & Future Work: We acknowledge several oversimplifications used in the current asteroid thermal codes, including assumptions of (1.) a single bombardment event and (2.) quantitative representation of all original asteroidal material in the meteorite record. We will explore and present on the effects of incorporating multiple bombardment events and differential preservation/delivery of asteroidal material, among other assumptions and model sensitivities, on the posterior estimates of when elevated impactor fluxes occurred in the young asteroid belt.

References: [1] Walsh K. J. et al. (2011) *Nature* 475: 206–209. [2] Gomes R. et al. (2005) *Nature* 435: 466–469. [3] Ribeiro de Sousa R. et al. (2020) *Icarus* 339. [4] Mojzsis S. J. et al. (2019) *The Astrophysical Journal* 881: 13. [5] Miyamoto M. et al. (1981) *Proceedings of the Lunar & Planetary Science Conference* 12B: 1145–1152.