DOES LATE PROCESSING OF PRIMITIVE CHONDRITES RECORD THE DISSIPATION OF A SOLAR SYSTEM DEBRIS DISK? J. D. Gilmour and M. Filtness, School of Earth, Atmospheric and Environmental Sciences, University of Manchester, Manchester, M13 9PL, UK. jamie.gilmour@manchester.ac.uk

Introduction: A significant fraction of newly-formed (<100 Myr old) sun-like stars in stages following the disappearance of protoplanetary disks show evidence in 24 μm excesses of dust attributed to debris disks within a few AU of the stars [1,2]. A similar structure in our solar system may have evolved to form the asteroid belt [3].

Here we show that the I-Xe [4] record of material in a primitive meteorite that escaped metamorphic processing on its parent planetesimal is consistent with a declining rate of collisional resetting during dissipation of a debris disk, and use the data to propose a constraint on the time dependence of the impact flux in this inner region of the early solar system over the first ~100 Myr.

Late Resetting of Primitive Material: Broadly speaking, two classes of chondritic material exhibit late closure in the I-Xe system. For individual phosphate grains from high petrologic type samples [5] these are attributable to extended cooling after high temperature metamorphism, consistent with deep burial on a parent body. However, other late ages are associated with individual chondrules from type 3 LL chondrites, especially Chainpur [6,7]; these have not experienced high temperature metamorphism. Various processes have been proposed to account for these late ages, including shock, aqueous alteration and recrystallisation [6,7], but all have in common that they require an input of energy contemporaneous with or immediately preceding the time associated with the isochron. At this stage of evolution of the solar system impacts seem the only feasible energy source, especially for material that has not been processed to high temperature and so must have remained close to the surface of the parent body. We also propose that, since adjacent chondrules in the samples have isochron ages varying over 10s of millions of years, the rock present today was assembled after the last impact from material that had sampled diverse parts of the parent body's surface. We therefore think it worthwhile to investigate the implications of considering the I-Xe record of chondrules from this sample as a random sample of the timing of impacts on the parent body.

Impact Flux Model: It is necessary to have a model relating the probability that a sample preserved an isochron age from a given time to the time dependence of impact flux. We write the probability that a sample has preserved an I-Xe isochron age between t and $t + \Delta t$ as $P(t)\Delta t$, where $P(t) = P_i(t)P_s(t)D(t,t_c)$. In this expression $P_i(t)$ accounts for the probability of setting the I-Xe system at time t, $P_s(t)$ for the probability that the system survived from time t to the present day without being reset, and $D(t)$ accounts for cessation of detectable resetting events due either to the detection limit of the I-Xe system being reached or an abrupt end to the collisional flux.

$P_i(t)$ is quantified as the fraction of the surface area of the parent asteroid that experienced events capable of resetting the I-Xe system in unit time. A power law dependence is assumed, with $P_i(t) = Ct^{-n}$ where C is a constant. The form of $P_s(t)$ follows from this, corresponding to the fraction of the surface present at time t that remains unaffected by subsequent setting/resetting events. Thus

$$P_s(t) = 1 - \exp\left(\frac{C\left(t^{(1-n)} - t_e^{(1-n)}\right)}{(1-n)}\right) \qquad \left[= 1 - \left(\frac{t}{t_e}\right)^C \text{ for n} = 1 \right]$$

where t_e is the time at which the exposure to the resetting events parameterised by $P_i(t)$ comes to an end.

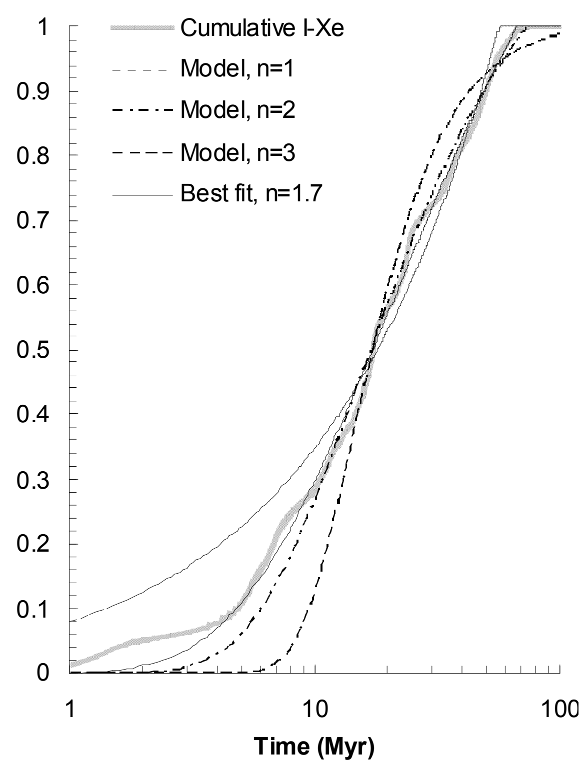

Fig 1. Cumulative dataset constructed by summing unit area Gaussians corresponding to each I-Xe age and associated error in the dataset, compared to models where the impactor flux declines with t^{-n}.

$D(t,t_c)$ is required to be 1 for an early period of evolution and 0 later, with a transition region centered on $t=t_c$, where t_c is a cut off time To meet these requirements while preserving an analytic form for *P(t)* to allow fitting of models to data we adopted $D(t,t_c) = (1-\mathrm{erf}(t-t_c))/2$. Where the cessation of recorded resetting is due to the exhaustion of the supply of impactors $t_e = t_c$; this is not the case where cessation is due to ^{129}I concentrations having declined below those required for an isochron age to be above the detection limit.

The cumulative distribution of data is shown in Fig. 1 and compared to best fit models. For this purpose, the start of the integration was chosen 10 years before the arbitrary zero of the iodine xenon system to ensure that it included the entire contribution from the Gaussians associated with the earliest data points. Models express the expected number of age measurements corresponding to times earlier than *t*. The curves are not sensitive to choice of t_e,, which was set to 4567 Myr during the fitting process corresponding to a continuously declining impact flux to the present day. The best fit is obtained with n = 1.7 and a cut off time t_c = 67 Myr.

Discussion: Models of debris disks [2,8] suggest that they are fed by destruction of a population of large parent planetesimals and that the declining rate of these collisions is responsible for the declining disk mass. During dissipation, the size distribution of disk particles remains in quasi steady state defined by the collisional cascade. If so, it is reasonable to assume that, throughout the debris disk lifetime, the size and energy distributions of the declining impactor flux remained the same. In this case, the time dependence of $P_i(t)$ reflects the dissipation of the debris disk.

Models of debris disk evolution have focused on accounting for the statistics of detectable dust disks around young stars but can be readily adapted for comparison with the decline in impactor flux suggested by the I-Xe data. Mass is fed into the disk by collisions among a population of N_p parent planetesimals, leading to $N_p = kt^{-1}$ [8]. Impactors capable of delivering sufficient energy to reset the I-Xe system are assumed to be larger than can be affected by solar wind pressure or Poynting-Robertson drag, so it is expected that their population decline would be dominated by collisional loss, leading to an expected decline in impactor flux with t^{-1}. This is a reasonable match to the data for times >10 Myr since solar system formation, but overestimates the impact rate in the earlier period. Higher values of *n*, as suggested by our treatment, can be produced in simple models if the debris disk is continuously stirred [8] while our data are reminiscent in the implied depletion rate of the simulations of the early evolution of our asteroid belt [3]. The data thus indicate that the parent debris disk of the asteroid belt was continuously stirred.

Values of the constant *C* are best seen as quantifying resetting rates as a function of time. For the best fit model, 12%/Myr of the asteroid's surface material experienced events capable of resetting the I-Xe chronometer 10 Myr after solar system formation. While the incorporation of $D(t,t_c)$ leads to curve shapes that are insensitive to choice of t_e the fraction of the parent planetesimal that has survived unscathed to the present day in the model are sensitive to this parameter. In the best fit model, when t_e = 4570 Myr, only 65% of material survived from t_c =67 Myr, corresponding in this case to an assumed detection limit for I-Xe) without further resetting. For t_e = 100 Myr, 92% of material survived unmodified from t_c, while for $t_e = t_c$ of course the value is 100%. For n = 1, only 7% of material survives from t_c if t_e = 4570 Myr, rising to 72% when t_e = 100 Myr.

Swindle et al. [6] found only one chondrule from 18 that failed to produce a set of correlated releases from which an initial iodine ratio could be inferred. Holland et al. [7] identified correlated releases in only 5 of the 10 chondrules studied, and no samples yielded low temperature isochrons. This may be a consequence of differences in the heating mechanism by which gas was extracted (furnace vs laser step heating) or sample size. However, all samples had excesses of ^{129}Xe indicating the preservation of ^{129}Xe from ^{129}I decay, suggesting low preservation rates are not compatible with the data and this that the bombardment terminated early in solar system history.

I-Xe model ages of nanodiamonds from other primitive meteorites show late resetting was widespread among the least processed samples (Gilmour, accompanying abstract), while I-Xe ages for carbonaceous chondrite chondrules also record late resetting. Analyses of material form the CV3r chondrite Vigarano [9] and preliminary analyses of the LL3.1 chondrite Krymka (unpublished Manchester data) suggest they too preserve a range of I-Xe ages in adjacent material, opening the possibility that this model can be tested (other sample should produce similar values of *n* for a solar system-wide phenomenon) and the record further examined in other parent bodies.

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