A KUIPER BELT SOURCE FOR SOLAR FLARE TRACK-RICH INTERPLANETARY DUST PARTICLES. L. P. Keller[1], and G. J. Flynn[2]. [1]ARES, Code XI3, NASA-JSC, 2101 NASA Parkway, Houston, TX 77058, USA (Lindsay.P.Keller@nasa.gov), [2]Dept. of Physics SUNY-Plattsburgh, 101 Broad St., Plattsburgh, NY 12901.

Introduction: The presence of solar flare particle tracks in mineral grains within interplanetary dust particles (IDPs) has long been accepted as proof of their extraterrestrial origin [e.g. 1]. The 10-20 µm diameter IDPs released by dust producing objects in the solar system (mainly comets and asteroids) spiral in towards the Sun under the influence of Poynting-Robertson (P-R) drag forces [2] and accumulate solar flare energetic particle tracks during their journey.

The number of IDPs with well-constrained track density measurements is small, owing to the difficulty in the measurements and the lack of appropriately-sized crystals in which to image them. In order to use track densities as a chronometer of space exposure, the track production rate must be known. All previous work relied on track production rates determined by chemical etching techniques [e.g. 3], but tracks in IDPs are measured using TEM imaging. Here we report measurements of track densities in IDPs from both the anhydrous and hydrated IDP groups. Using the track production calibration determined from TEM observations of anorthite and olivine in lunar rock 64455 [4] we estimate space exposure times for these IDPs to constrain their parent body sources.

Methods: We used a combination of brightfield and darkfield imaging in a scanning and transmission electron microscope (STEM) to image tracks in microtome thin sections of IDPs. For the IDPs in Table 1, we imaged tracks in multiple grains, and where possible, in multiple phases within the same particle. It is known that anorthite and olivine record the same track density for the same exposure time [4], and here, we assume pyroxene behaves similarly. One limitation to this data is that the mineral grains in IDPs are typically sub-µm in size, which limits the lowest track densities than can be observed (e.g. 1 track in 1 µm^2 equates to 10^8 tracks/cm^2). Chattering and fracturing from microtomy also complicate these measurements. Another issue is that surviving anhydrous silicates in hydrated IDPs are rare.

Results and Discussion: In Table 1 we present our observations to date from 14 IDPs, 10 from the anhydrous group and 4 from the hydrated group showing a range in track densities from ~$2x10^{10}$ up to $5x10^{11}$/cm^2, consistent with previous measurements.

Modeling suggests most of the Zodiacal dust inside of 5 AU is produced by Jupiter family comets (JFCs) and Main Belt Asteroids (MBAs), with lesser contributions from Edgeworth-Kuiper belt objects (EKBOs) and Oort Cloud comets (OCCs) [5]. The latter two sources however, dominate beyond ~10 AU. For pure P-R drag forces, dust released by JFCs and MBAs reaches 1 AU in ~60,000 y, while dust produced by collisions of EKBOs are estimated to take 10^7 y [6]. Sandford [7] used a numerical approach to calculate the expected track densities in 10 µm IDPs from JFCs and MBAs using a track production rate of $6.5x10^5$/cm^2/y (2π) (from chemical etching, [8]), which gave track densities up to $1x10^{10}$/cm^2. We used the same numerical approach of Sandford [7] to calculate the expected track density from these objects, except that we used the new track production rate TEM calibration from [4] ($4.4x10^4$ cm^2/y). From these calculations, we derive track densities for IDPs released by JFCs and MBAs in the mid-10^8/cm^2, two orders of magnitude less than the typical observed track densities in IDPs.

IDPs from MBAs may also be exposed to solar flare particles in regoliths before they are released to space and subjected to P-R drag. The age of the optical surface (exposed surface) of main belt asteroids is poorly constrained, however, several workers using relationships among asteroid families have predicted surface residence times (direct exposure to the Sun) of 10^4-10^6 years. The only firm data point in this regard is from asteroid Itokawa, where solar flare track densities in returned mineral grains indicate typical surface residence times of <10^5 y [4]. We calculate a track density of ~$8x10^8$/cm^2 for an IDP with a regolith residence time of 10^5 y at 3 AU using a $R^{-1.5}$ model for the heliocentric decay of the solar flare flux, a 2π irradiation, and the track production rate from [4]. Even by combining the track density accumulated in a particle residing in an MBA regolith with the those during its transit from 3 to 1 AU, the resulting track density is still 1 to 2 orders of magnitude less than that observed in our IDPs (Table 1). If the track-rich IDPs are from MBAs, then their track densities imply very long (and probably unrealistic) surface residence times (up to 60 My).

The other potential sources of track-rich IDPs include OCCs and EKBOs. Particles from OCCs arrive at 1 AU with high entry velocities and undergo strong heating effects (mineral alteration, track erasure, etc.). Most of the dust produced by EKBOs is ejected from the solar system by the giant planets, but ~20% of the

~10 μm dust survives to 1 AU, although disagreement exists about their Earth encounter velocities [9,10]. Liou *et al*. [9] proposed that EKB dust arrived at 1 AU with low velocities and circularized orbits, while Moro-Martin and Mehlotra [10] suggested that the EKB particles arrive at 1 AU with essentially cometary velocities and eccentricities. We calculate the expected track density for 10 μm diameter, spherical, EKB IDPs using our track production rate, two models for the heliocentric decay of the flare flux, using falloff proportional to $R^{-1.5}$ and $R^{-1.25}$, 4π irradiation, and transit times for IDPs evolving under pure P-R drag (Table 2). Our calculated EKB particle track densities are still an order of magnitude lower than that in the track-rich IDPs implying that an additional source of tracks needs to be considered or that resonance trapping is increasing the exposure time of the IDPs to the solar flare flux.

EKB IDPs spend the large majority of their time in the outer Solar System, where the track production rate from solar flare ions is much lower than at 1 AU, but the track production rate from galactic cosmic rays is much higher. This increases the expected track densities for EKB IDPs over the values shown in Table 2, but measurements of galactic cosmic ray (GCR) tracks are from chemical etching rather than TEM observation, so the expected track densities from GCRs cannot be modeled at this time. It is also unclear if high energy GCRs would produce tracks in 10 μm particles given that GCRs only produce tracks near the end of their trajectory after penetrating to ~meter depths. The track-rich IDPs may have accumuled GCR tracks while part of a larger body and these would be in addition to the solar flare tracks added after its release from an parent body.

Large (~100 μm) EKB particles can be trapped in mean motion resonances (MMRs) with Neptune [5] resulting in longer residence times and hence higher track densities, although the trapping probability is extremely low for small particles (~10 μm) because of their rapidly evolving orbits. One possibility is that our track-rich IDPs accumulated some of their tracks when they were part of larger particles that were trapped in an MMR with Neptune and subsequently fragmented by collisions.

Conclusions: Solar flare track densities in anhydrous and hydrated IDPs are ~two orders of magnitude higher than expected if they were derived from main belt asteroids or Jupiter family comets. Instead, we propose that these track-rich IDPs likely originate in the outer solar system, probably from EKBO sources. An additional source of tracks are required, either through residence in MMRs or possibly from GCRs. The presence of high track densities in some hydrated IDPs is consistent with parent body aqueous alteration in at least some Kuiper belt objects.

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IDP	Tracks/cm^2	host
L2011*B5	6x10^{10}	pyx
L2005*A3	8 x10^{10}	Ol
L2036*C11	6 x10^{10}	An
L2036*B61	10 x10^{10}	pyx
L2036*C46	7 x10^{10}	An
L2011B10	3 x10^{10}	pyx
L2036*C41	8 x10^{10}	pyx
L2005F31	3 x10^{10}	pyx
L2005Q4	5 x10^{10}	pyx
L2006O15	7 x10^{10}	pyx
L2005Q1	50 x10^{10}	pyx, ol
L2009O4	6 x10^{10}	pyx
L2009H11	2 x10^{10}	pyx
L2079C35	6 x10^{10}	pyx

Table 1. The IDPs analyzed in this work, observed track densities, and the host phase(s). IDPs in red (*B5, O15, Q1, and C35) are hydrated IDPs, the others are anhydrous IDPs.

Initial Distance	Falloff Model $R^{-1.5}$	Falloff Model $R^{-1.25}$
	Tracks/cm^2	Tracks/cm^2
50 AU	6.2x10^9	12.6x10^9
40AU	5.4x10^9	10.6x10^9
30 AU	4.6x10^9	8.4x10^9
20 AU	3.6x10^9	6.0x10^9
10 AU	2.2x10^9	3.2x10^9
5 AU	1.2x10^9	1.6x10^9
3 AU	0.8x10^9	0.8x10^9

Table 2. Modeled track densities for density 1 g/cm^3 spherical particles starting in near-circular orbits and evolving under P-R Drag to 1 AU