EFFICIENT SEARCHES FOR GALACTIC STREAM INTERSTELLAR ASTEROIDS T. Marshall Eubanks[1], [1]Space Initiatives Inc, Clifton, VA 20124 USA; tme@space-initiatives.com;

Introduction: The recent discovery of the first high velocity hyperbolic object passing through the Solar System, 1I/'Oumuamua (henceforth, 1I), opens the potential for a near term missions to interstellar objects. 1I has a v_∞ (the hyperbolic excess velocity) on both ingress and egress from the solar system of ∼26.3 km s^{-1}, consistent with it being a long term resident of the galactic thin disk. 1I was not detected until after perihelion; any mission to 1I would thus have to have a considerably larger v_∞ to catch up with it. An 1I mission with existing technology, although possible, would thus be expensive and require decades of travel time [1]. If interstellar asteroids could be detected early, before perihelion passage, a "launch-on-detection" mission would be possible [2] with a quick flyby or rendezvous near the Earth, instead of in the outer solar system.

1I: A Member of the Pleiades Stream: *Feng & Jones* [3] showed that 1I is kinematically likely to be part of the "local association" (or Pleiades Moving Group, or in this paper the Pleiades Dynamical Stream), concluding that it was likely to be a relatively young asteroid ejected during recent star formation. Figure 1 shows the Galactic U and V components of velocity for 1I, the Local Standard of Rest (LSR) and two of the dynamical streams found in the solar neighborhood. Figure 2 shows an expanded view of the local kinematics including the five largest streams. The close association between the 1I velocity and the Pleiades stream is unlikely to have occurred by chance; there is no reason to assume a kinematic association with the LSR. A more detailed examination shows 1I had, upon entry to the Solar System, the velocity of an object moving with the older S1 (or "Supercluster") substream [4, 5] of the Pleiades dynamical stream, indicating that its age may be substantially older than the Pleiades star forming region.

Dynamical Streams in the Galaxy: Many stars in the solar neighborhood (in this context, roughly within 1000 pc of the Sun), belong to one of several dynamical streams, the five principle ones being the Coma Berenices, Pleiades, Hyades, Sirius and Hercules streams [16]. The Pleiades stream is associated with the familar open star cluster bearing the same name, and for a long time it was thought that it was simply due to cluster evaporation (the gradual loss of stars over time), implying that the stars in the stream should be no older than the cluster itself (∼80 million years). As more accurate astrometry became available this was shown not to be so, with over half of the stars in the Pleiades stream being substantially older than the age of the cluster, rendering the evaporation model untenable and suggesting

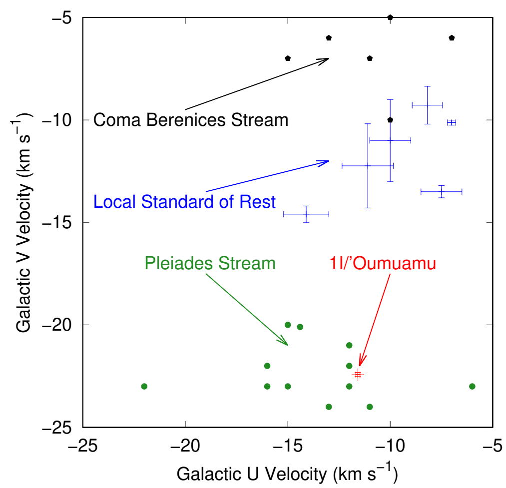

Figure 1: Figure 1 shows U and V velocity component estimates in the galactic U, V, W system, where U is radial (towards the Galactic Center), V is along the direction of galactic rotation, and W is orthogonal to the galactic disk. The stream velocity estimates are for the centroids of the respective streams using the data and compilations in [6], supplemented by [4, 7, 8]; the LSR velocity estimates are from [9, 10, 11, 12, 13, 14]. The 1I inbound velocity is the average of the five 1I velocity solutions using anomalous acceleration models used by [15], with errors inflated to account for scatter in those solutions.

dynamical models for these features [4, 17, 18]. Recent work has focused on the creation and maintenance of galactic streams as a response to a variety of galactic resonances [19]. Resonances can trap particles gravitationally [20], indicating that the mere fact of the capture of asteroid in an dynamical stream is not be proof of non-gravitational drag or acceleration of that body.

Deep Searches for Interstellar Asteroids: Table 1 shows the mean radiant for each of the five major streams shown in Figure 2. Except for the Sirius stream, these streams are all flowing away from the center of the galaxy and have negative U and V velocities. This means that the stream radiants (the directions of their approach before solar perturbations) are at positive declinations (δ) and 16 - 18 hours of Right Ascension (R.A.), as was noted by *Seligman & Laughlin* [2]. However, while their Figure 3 has a very broad distribution of radiants, in reality radiants from dynamical stream asteroids will come from a small number of relatively small locations on the celestial sphere. It will thus be

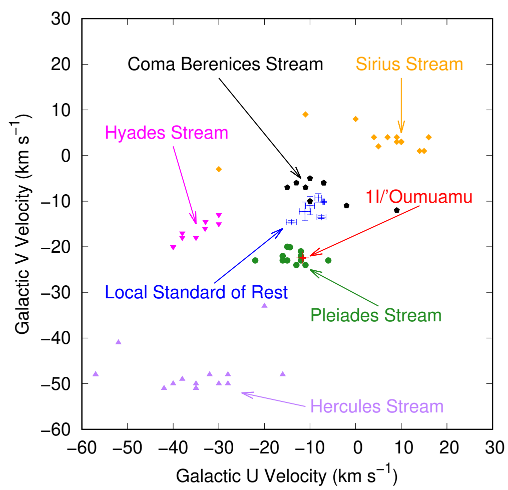

Figure 2: The U and V components of velocity as for Figure 1, expanded to show the five largest local dynamical streams. These streams provide the likely radiants for a substantial fraction of incoming interstellar asteroids; these radiants could be searched for their early detection.

Stream	R.A.	δ	Stellar Fraction
Coma Bern.	16h 24m 41.1s	27° 55' 52"	7.9%
Hyades	18h 46m 34.3s	0° 22' 49"	3.2%
Pleiades	18h 29m 41.3s	30° 12' 22"	3.2%
Sirius	10h 8m 28.5s	21° 51' 56"	2.7%
Hercules	18h 29m 41.3s	23° 11' 50"	1.4%
13 Minor Streams	-	-	3.1%

Table 1: Radiants of the 5 largest dynamical streams in the solar neighborhood. Stellar fraction estimates from [16], who found that 18.3% of the stars the solar neighborhood are in one of these 5 streams. Note that only the Hyades radiant will be within the current Northern declination limit of the LSST.

possible to conduct deep surveys for interstellar asteroids using existing telescopes.

A dedicated deep search for interstellar asteroids would benefit from the ability to predict both the magnitude and direction of incoming stream asteroids, allowing images to be shifted to account for fast motions, for example using synthetic tracking [21]. A 4 meter optical telescope with a modern wide-field camera looking for Pleiades stream asteroids should have been able to find 1I, for example, in June, 2017, 3 months before its perihelion and 4 months before its discovery. providing several months of advance lead time before the launch of the hypothetical fly-by mission descrubed by [2].

Conclusions: The orbital data for 1I seems to be at least as accurate as stellar characterizations of dynamical streams in the Galaxy. The much larger and more accurate stellar data sets being made available by Gaia DR2 and later releases, and by large scale radial velocity surveys, should make it possible to refine the linkage between the 1I orbit and substreams in the Pleiades stream. Improved linkages will both increase the confidence in the asteroid-stream associations and make it possible to connect 1I and future interstellar asteroids to particular stellar populations.

As dynamical streams transport material from different parts of the Galaxy, direct *in situ* exploration of interstellar asteroids from specific dynamical streams and substreams would make it possible to sample the Galaxy and possibly even date structures such as the galactic bar. A mission to a body from a galactic stream would be not just an early interstellar mission, but a galactic mission, providing scientific returns it might otherwise take millennia to obtain, even if fast interstellar travel became routine.

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