METEORITEORBITS.INFO – TRACKING ALL KNOWN METEORITES WITH PHOTOGRAPHIC ORBITS. M. M. M. Meier[1], [1]ETH Zurich, Institute of Geochemistry and Petrology, Clausiusstrasse 25, CH-8092 Zurich, Switzerland (matthias.meier@erdw.ethz.ch).

Introduction: As of December 2016, there are 25 meteorites for which the entry fireball was captured by cameras from different angles, and over a sufficient duration, so that a closed solution for a heliocentric orbit of the precursor meteoroid could be calculated and published (Table 1). There are seven more meteorites for which orbits have yet to be published. Historically, photographic orbits (Přibram, “PR” in Fig. 1, fell 1959 [1]; Lost city, LC, fell 1970 [2]; Innisfree, IN, fell 1977[3]) helped to confirm that meteorites originate from the asteroid belt region and not, as some suggested at the time, from interstellar space (e.g., [4]). Today we know of some orbits (Bunburra Rockhole, BR; Buzzard Coulee, BC; and Almahata Sitta, AS) which are dynamically “detached” from the asteroid belt (aphelion <2 AU), likely because they had at least one close encounter with a terrestrial planet [5]. Since 1990, additional meteoroid orbits have been determined at ever faster pace, to more than one per year in recent years (including unpublished orbits). This is primarily due to the growing number of fireball camera networks entering in operation in the last few years [6]. Such orbits are of high importance to meteoriticists interested in the “birth regions” (asteroid/meteorite connections) and delivery mechanisms of meteorites. In order to help the community keep up with the rapid developments in this field, I have decided to create a freely accessible online database.

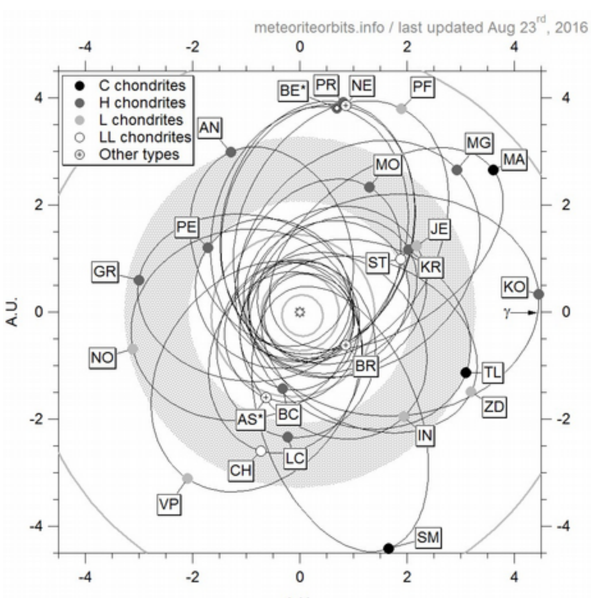

Fig. 1. Meteorite orbits (asteroid belt = shaded area). The γ sign shows the direction of the vernal equinox.

Table 1: all meteorites with photographic orbits

Name	Type	Yr.	a (AU)	e	i (°)	Ref.
Stubenberg	LL6	2016	1.53	0.40	2.1	7
Žd'ár nad Sázavou	L3	2014	2.10	0.68	2.8	8
Annama	H5	2014	1.99	0.69	14.7	9
Chelyabinsk	LL5	2013	1.72	0.57	5.0	10
Novato	L6	2012	2.09	0.53	5.5	11
Sutter’s Mill	CM2	2012	2.59	0.82	2.4	12
Križevci	H6	2011	1.54	0.52	0.64	13
Mason Gully	H5	2010	2.47	0.60	0.83	14
Košice	H5	2010	2.71	0.65	2.0	15
Grimsby	H5	2009	2.04	0.52	28.1	16
Jesenice	L6	2009	1.75	0.43	9.6	17
Maribo	CM2	2009	2.48	0.81	0.11	18,19
Buzzard Coulee	H4	2008	1.25	0.23	25.0	20
Almahata Sitta	Ur.*	2008	1.31	0.31	2.54	21
Bunburra Rockhole	Eu.*	2007	0.85	0.24	9.0	22,23
Villalbeto de la Peña	L6	2004	2.3	0.63	0.0	24
Park Forest	L5	2003	2.53	0.68	3.2	25
Neuschwanstein	EL6	2002	2.40	0.67	11.4	26
Morávka	H5	2000	1.85	0.47	32.2	27
Tagish Lake	C2	2000	2.1	0.57	1.4	28
Peekskill	H6	1992	1.49	0.41	4.9	29
Benešov (a),(b)	LL3.5	1991	2.48	0.63	24.0	30,31
Innisfree	L5	1977	1.87	0.47	12.3	3,30
Lost City	H5	1970	1.66	0.42	12.0	2,30
Přibram	H5	1959	2.40	0.67	10.5	1,26

*Ur. = Ureilite; Eu. = Eucrite; *anomalous within their class*

Methods: *Selection criteria:* I only include falls where a meteorite was eventually recovered (unlike, e.g., the widely observed fireball in the Swiss alps from March 2015, for which an Aten-type orbit was determined, and a terminal mass of a few kg was calculated, but a meteorite remains to be found [32]). I exclude falls for which the orbit is not fully constrained (e.g., the “most probable” orbit of the St. Robert meteoroid [33]), or where no photographic documentation exists (e.g., the orbit of Orgueil [34]). “Photographic documentation” is not restricted to camera networks, and can include footage from private or security cameras, or telescope observations (for Almahata Sitta [21]). Events are also only listed in the database once the orbital elements are published in the peer-reviewed literature, or otherwise documented in a citable form (e.g., on arXiv or in a conference abstract; this is done to dis-encourage the citation of the website as a source for an individual orbit – users should always give reference to the original publication. If you would like to cite the website for its merits of compilation, use reference [6] instead). If more than one orbital solution exists, all sources are mentioned but only the values from the most recent (or most precise) one are listed.

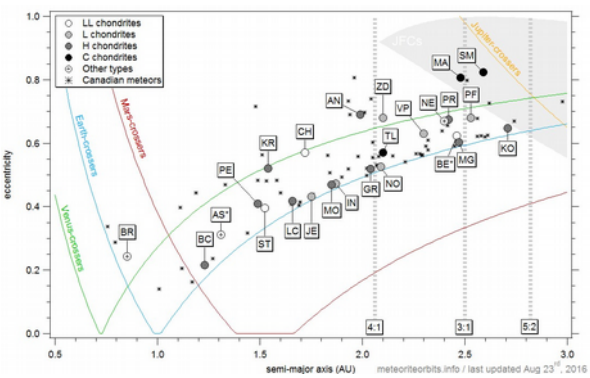

Fig. 2. Eccentricity vs. semi-major axis for all meteorites with orbits. Jupiter family comets plot in the shaded region.

Current status: The database, accessible online at www.meteoriteorbits.info, provides a searchable and sortable list of all meteorites with published photographic orbits. For each entry, I list the name of the meteorite (including a link to the Meteoritical Bulletin Database), a two-letter abbreviation for internal use, the chemical/petrographic type, the country, date and time of the fall, the masses of the meteoroid and the recovered meteorites, the velocity at infinity, and five orbital elements: the semi-major axis, eccentricity, inclination, the argument of perihelion, and the longitude of the ascending node. Diagrams (including Fig. 1, 2) are provided and kept up to date. The website is built with the free content management system Wordpress.

Discussion: Of the 25 meteorites with orbits, 10 are H chondrites, 6 are L chondrites, 3 are LL chondrites, 3 carbonaceous chondrites, 2 are achondrites and 1 is an enstatite chondrite. These numbers are in agreement (within counting statistics) with the overall fall rates (e.g., [35]). With the exception of Bunburra Rockhole, all meteoroids are Mars-crossers, but only five are also Venus-crossers, suggesting that the Earth and Venus are much more efficient in removing meteoroids than Mars is. Interestingly, only the two CM-type samples have a Tisserand parameter (T_{jup}) between 2 and 3, as do the Jupiter family comets, potentially suggesting a connection between the two (see Fig. 2 and [36]).

Outlook: In the near future, I plan to expand the database to include information on the geocentric parameters, intermediate source region determinations [37], and cosmic histories (exposure ages and gas retention ages). Diagrams will be automated, a CSV file with all data points will be available for download, and DOI-links will be given for all publications.

If you are aware of a meteorite for which an orbit has been determined, or where an orbit is about to be published, please let me know so we can add it to the pending list or to the database, respectively.

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