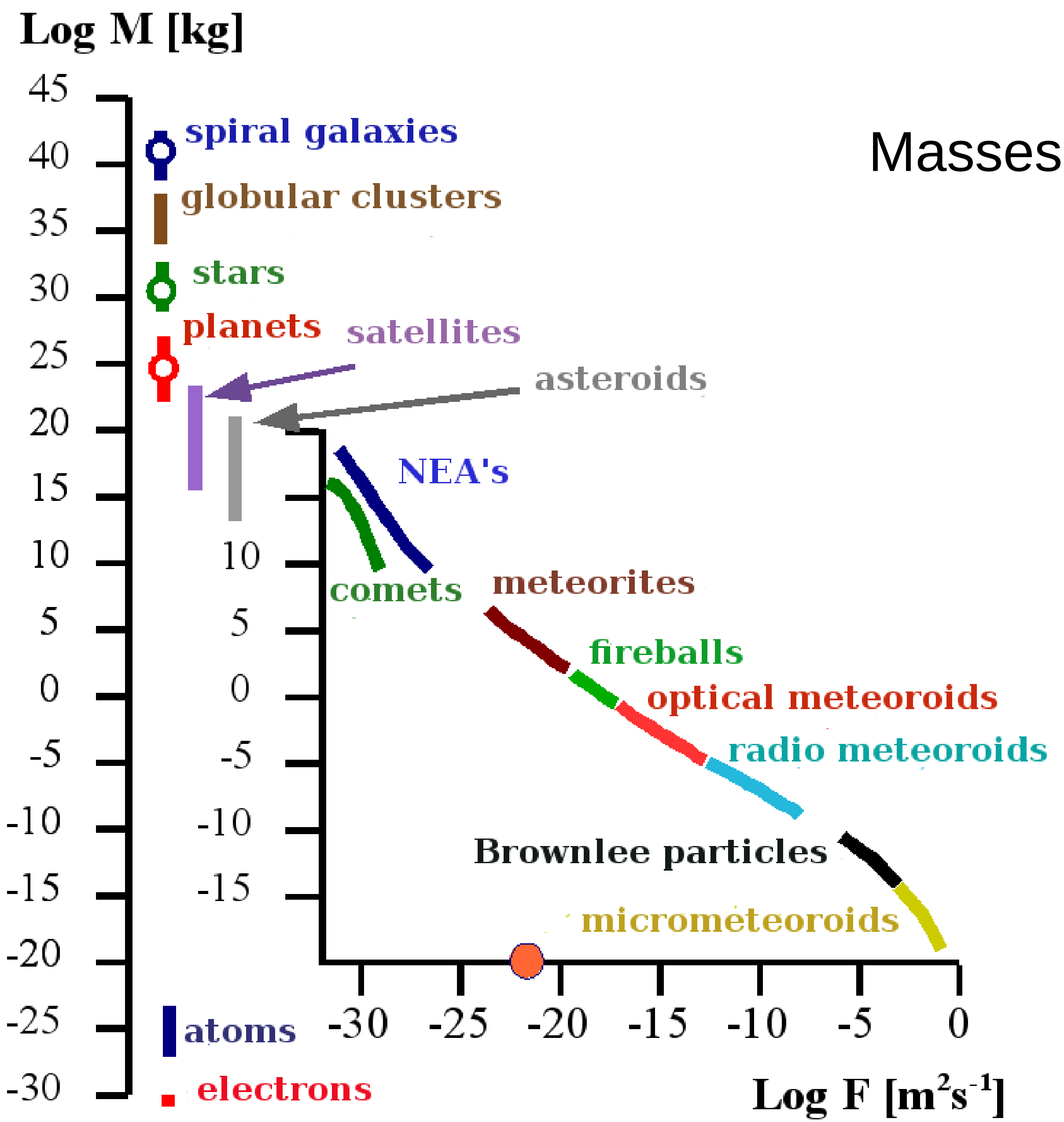
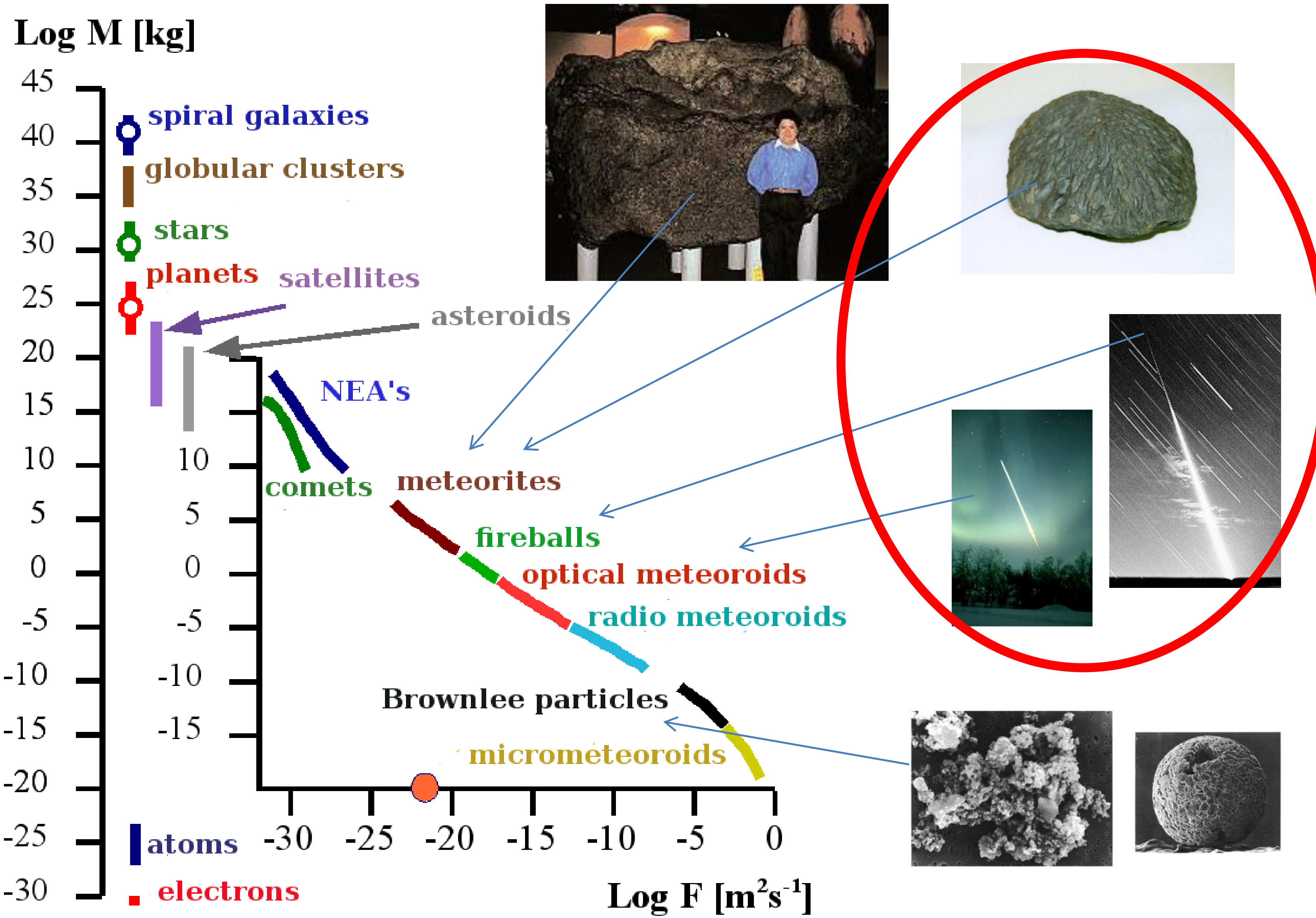
Meteoroid streams and their parent bodies

Tadeusz Jan Jopek
Astronomical Observatory
Poznań, Poland

Masses in the Universe

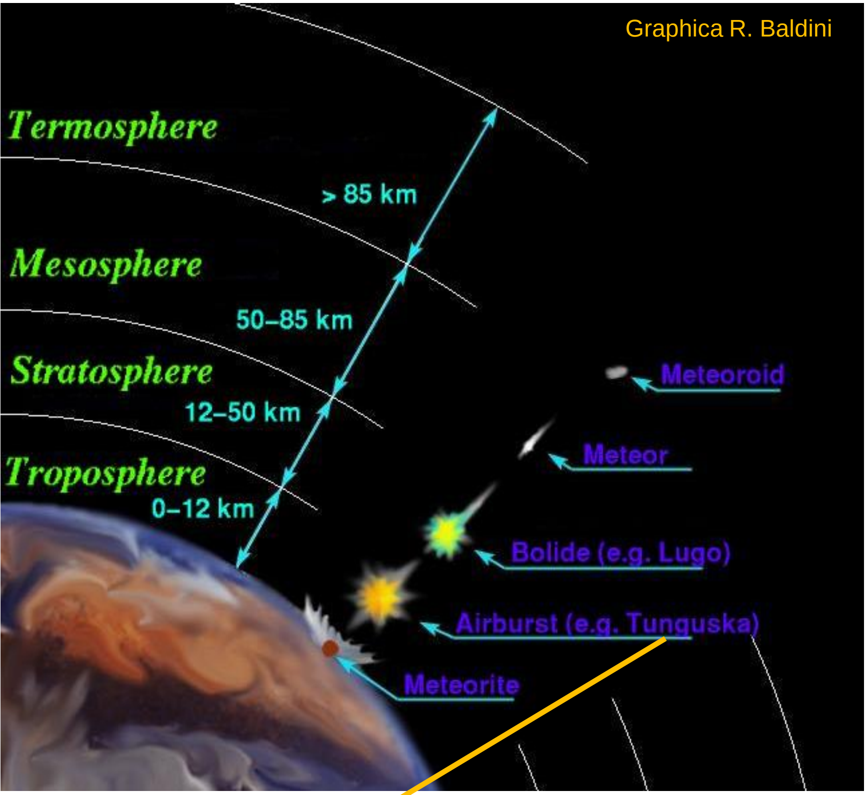


(Kresak 1985)


Log M [kg]
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
spiral galaxies
globular clusters
stars
planets
satellites
asteroids
NEA's
comets
meteorites
fireballs
optical meteoroids
radio meteoroids
Brownlee particles
micrometeoroids
atoms
electrons
10
5
0
-5
-10
-15
-30
-25
-20
-15
-10
-5
0
Log F [m^2s^{-1}]

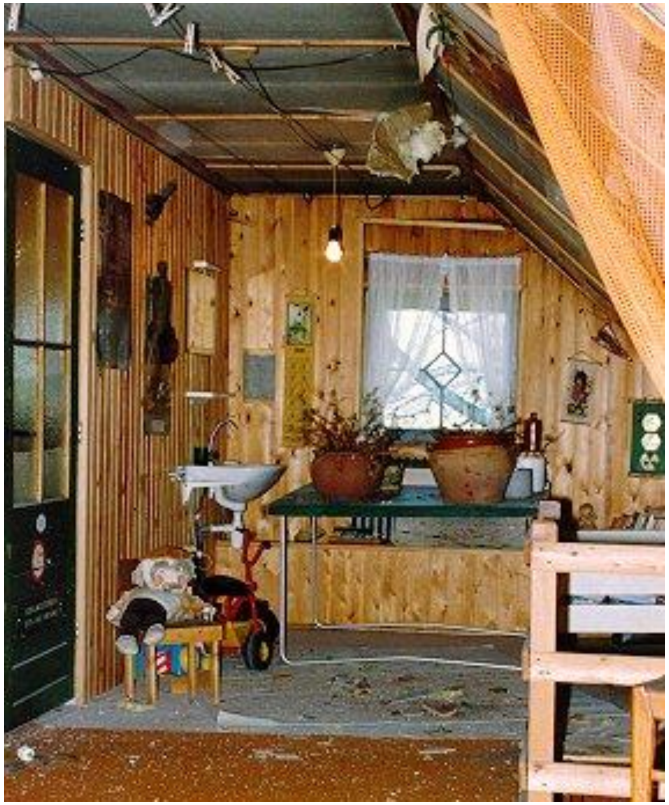
170 Mkg/year of meteoroids falls into the Earth atmosphere

(Ceplecha, Z.: 1992, in Proc. Of the Intern. Astron. Symp., Smolenice, Slovakia, July 6-12, 1992, 165



$E_T \sim 1000\ E_H$

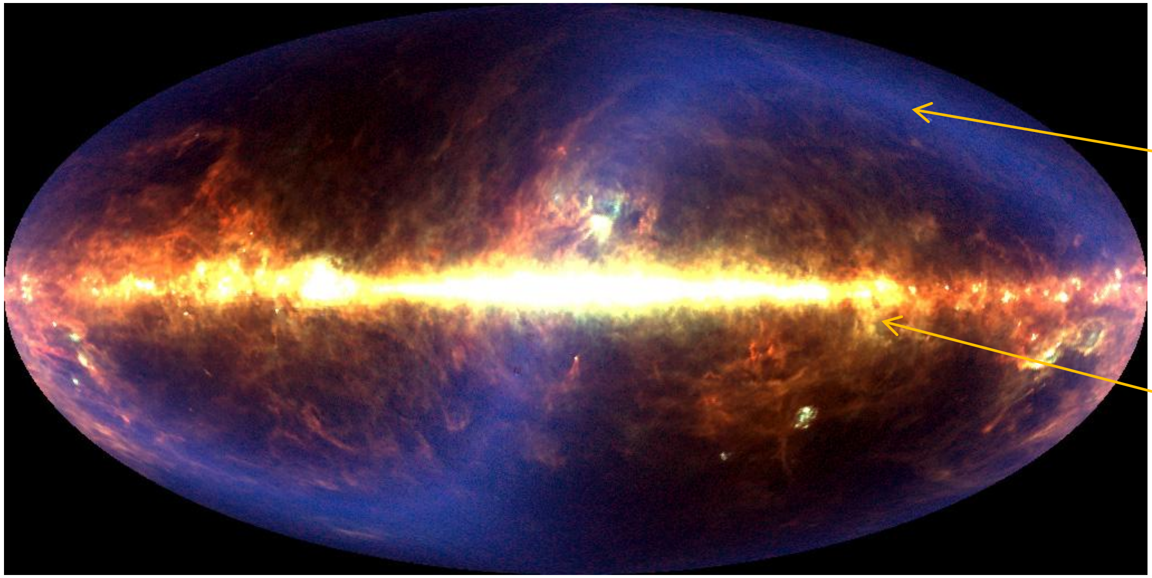
Fot. Pierre Thomas (LST), ENS Lyon



Fot. Policja Municypalna w Enschede

Mass contribution in the Solar System

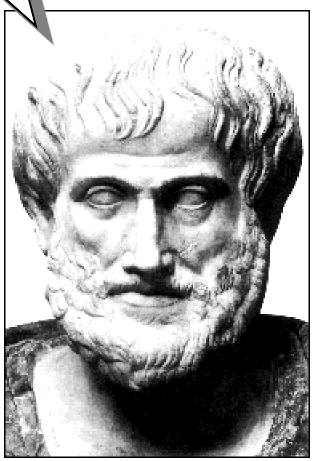
• **Sun:**	**99.85 %**
• **Planets:**	**0.135 %**
• **Comets:**	**~0.01 %**
• **Moons:**	**0.00005 %**
• **Asteroids:**	**~0.0000002 %**
• **Meteoroids:**	**~0.0000001 %**
• **Interplanetary dust:**	**~0.0000001 %**



COBE/DIRBE – infrared sky

Cosmic nature, origin of meteors, meteorites

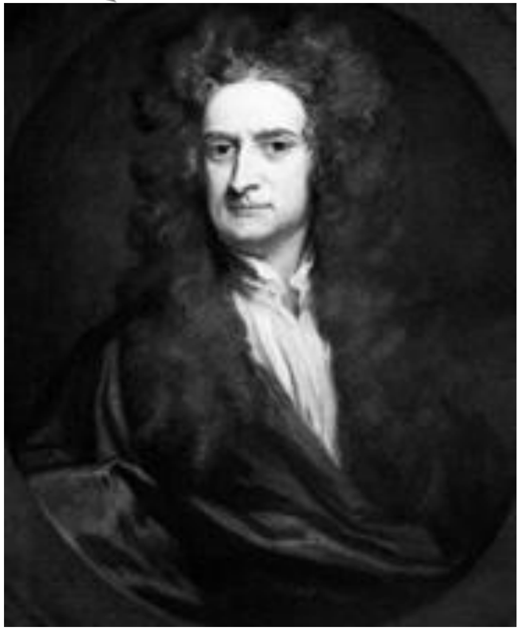
Nonsens!



Well, perhaps …?

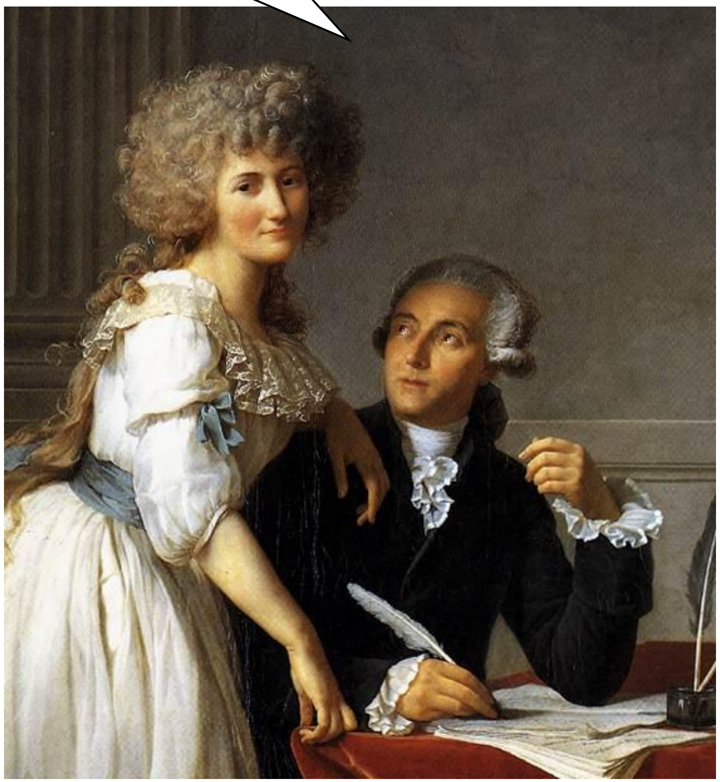
...the interplanetary space has to be free of matter, for not to disturb the course of planets and comets ...

Baroque



Izaak Newton (1642-1727)

Darling, you know everything…



Honey, there are no stones on the sky, so stones can’t fall from the sky!

Age of Enlightenment

Antoine-Laurent Lavoisier

(1743-1794)

Age of Enlightenment

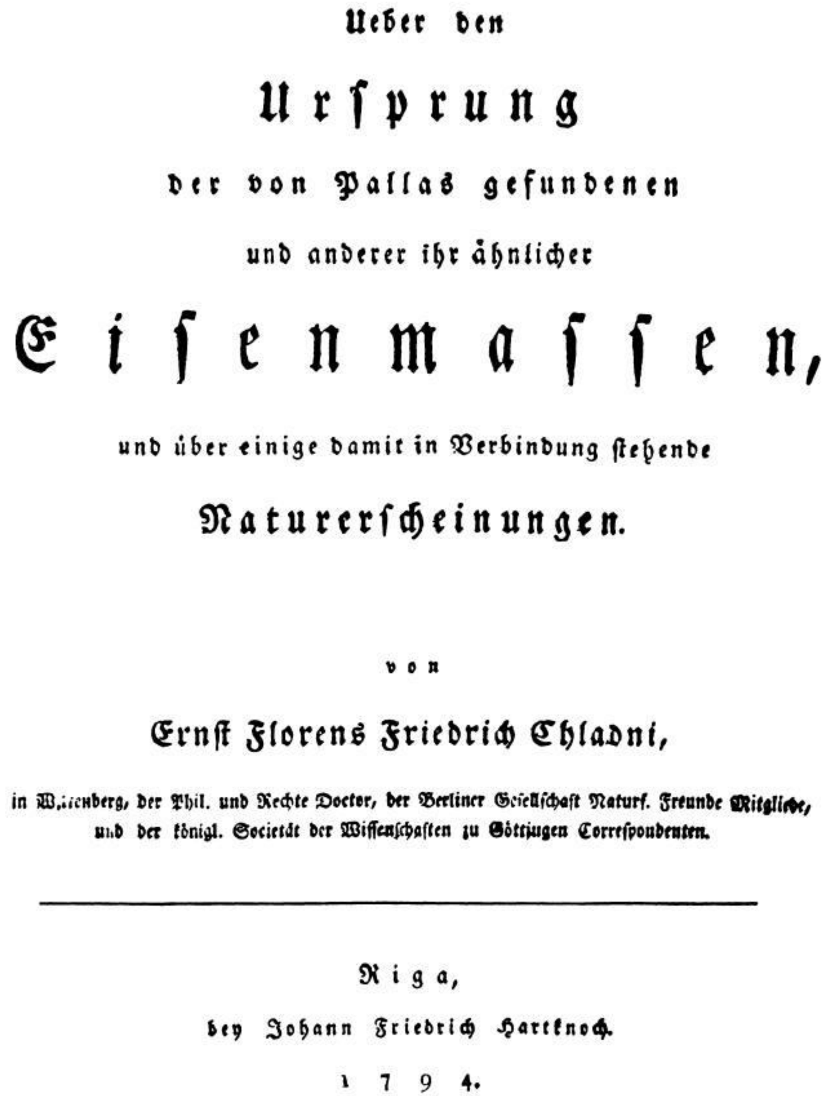
Peter Simon Pallas
(1741-1811)

700 kg iron mass fallen from the sky in Siberia near Krasnoyarsk

Age of Enlightenment

AD 1794

Ernst Florens Friedrich Chladni
(1756-1827)



Ueber den

Ursprung

der von Pallas gefundenen

und anderer ihr ähnlicher

Eisenmassen,

und über einige damit in Verbindung stehende

Naturerscheinungen.

von

Ernst Florens Friedrich Chladni,

in Wittenberg, der Phil. und Rechte Doctor, der Berliner Gesellschaft Naturf. Freunde Mitgliede,
und der königl. Societät der Wissenschaften zu Göttingen Correspondenten.

Riga,

bey Johann Friedrich Hartknoch.

1794.

Age of Enlightenment

AD 1794

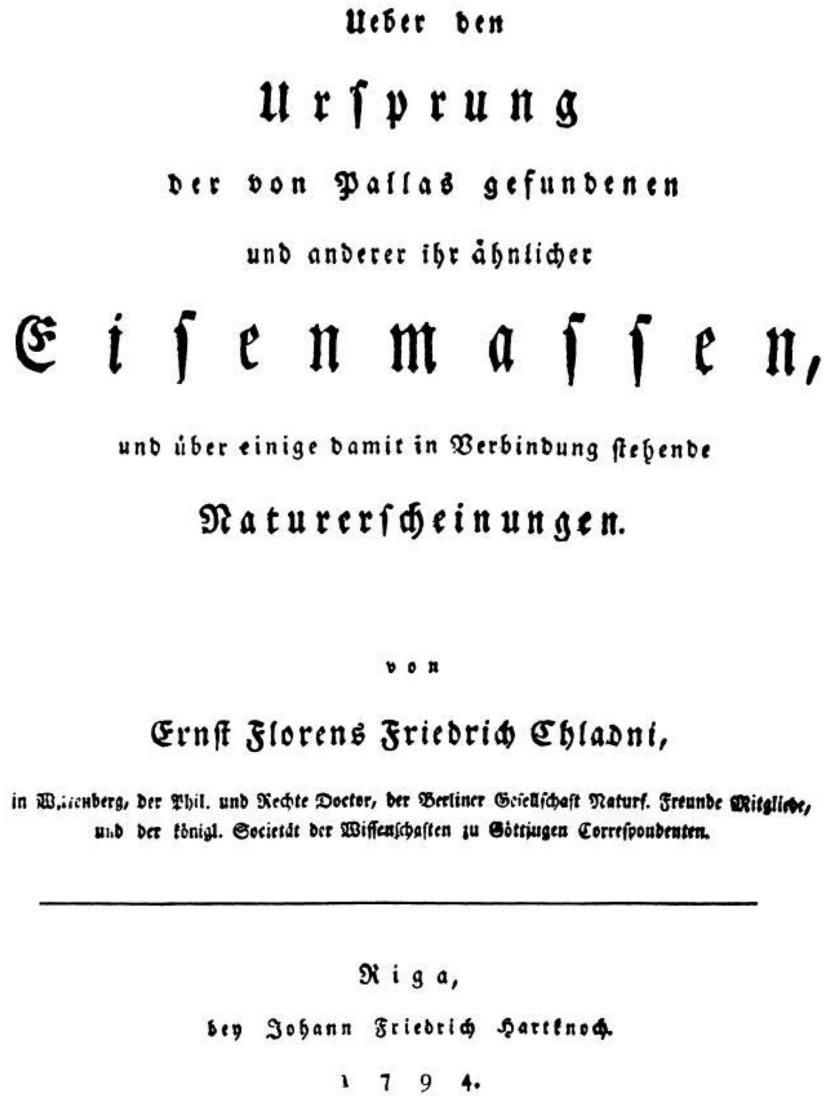
Ernst Florens Friedric[illegible]ni

(1756-1827)

This book is a shame!

Friedrich Heinrich Alexander Humboldt

(1769-1859)



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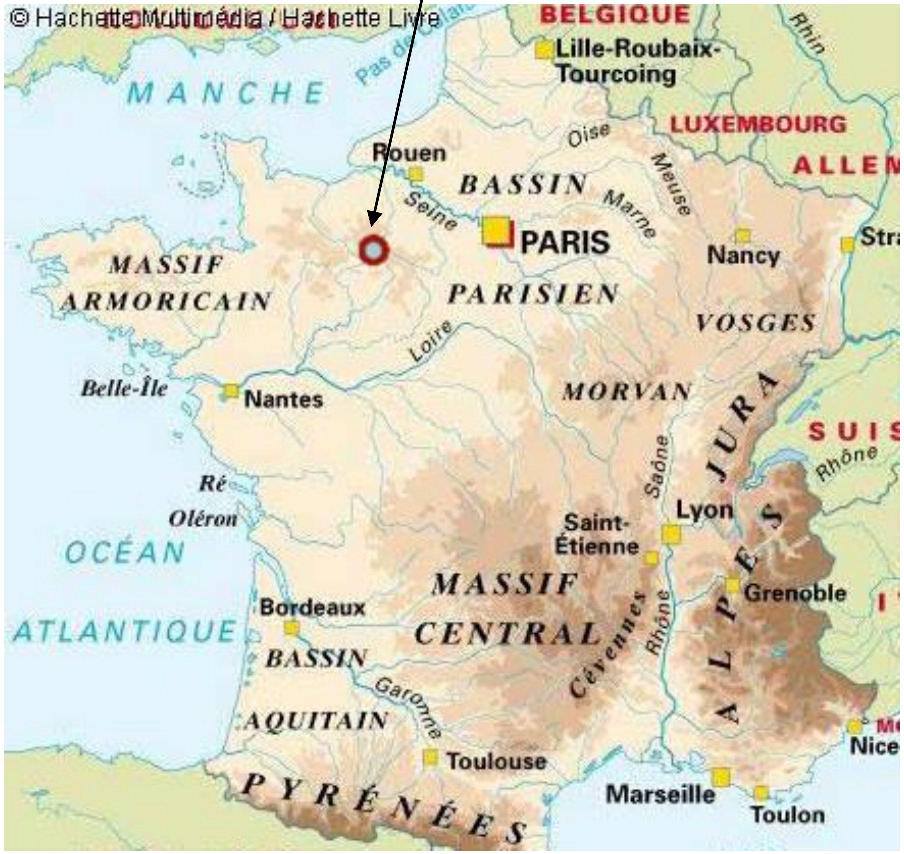
Riga,

bey Johann Friedrich Hartknoch.

1794.

L'Aigle (Orney, Normandie, F)

1803, April 26
Stony meteoritic shower



Cuisine normande

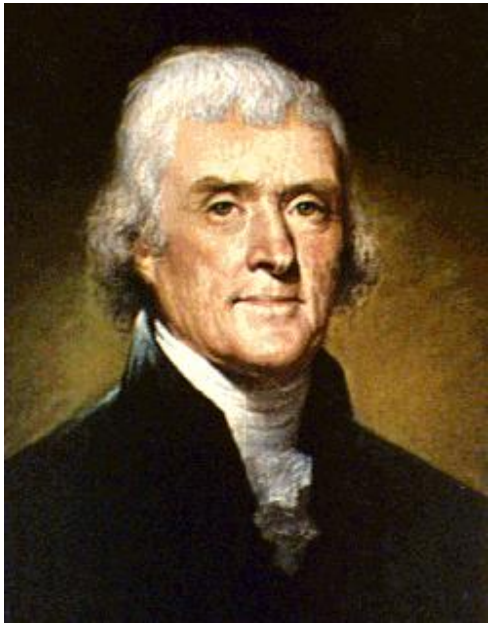
L'Aigle 1803, April 26 Meteoritic shower

A first strewnfield mapping. .

Jean-Baptiste Biot
(1774-1862)

AD 1807

Politicians and meteorite fall

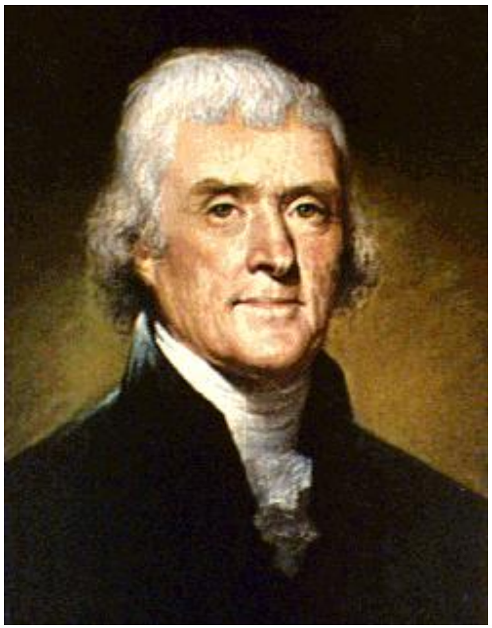


Gentlemen, I would rather believe that two Yankee professors would lie than believe that stones fall from heaven.

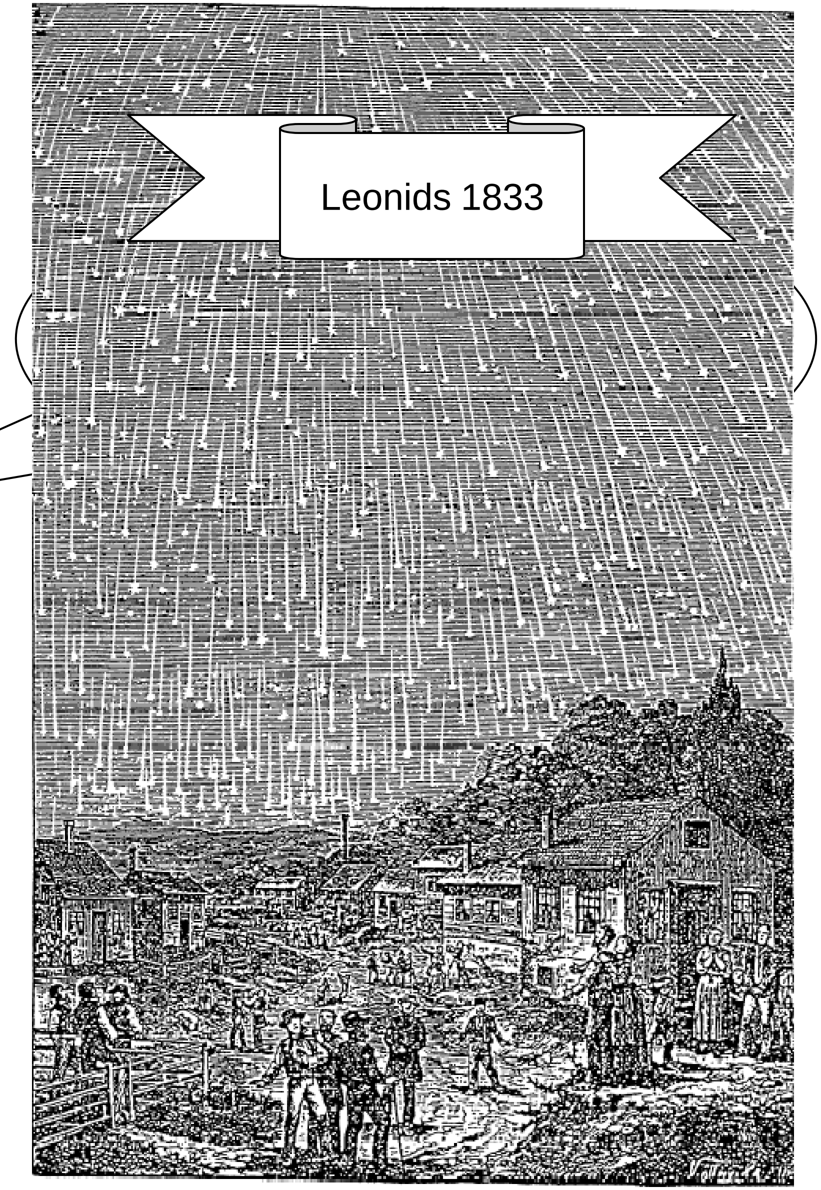
Thomas Jefferson (1743-1826)

AD 1807

Politicians and meteorite fall



Thomas Jefferson (1743-1826)



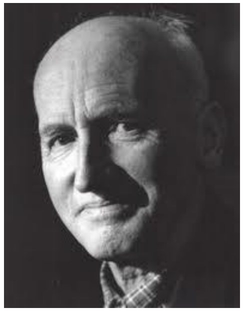

Denison Olmsted
(1791-1851)

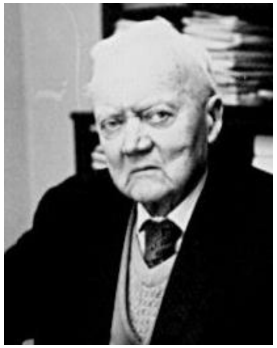

Johann G. Galle
(1812-1910)


Hubert A. Newton
(1830-1896)

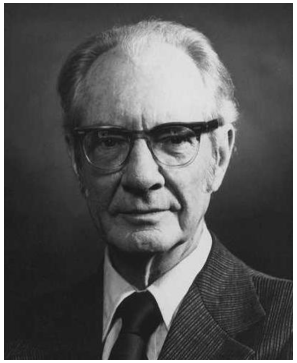

Giovanni V. Schiaparelli
(1835-1910)


William F. Denning
(1848-1931)

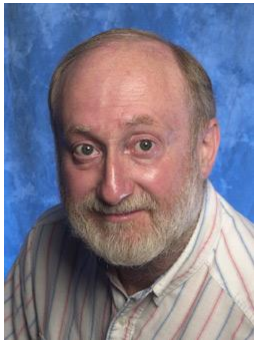

Cuno Hoffmeister
(1892-1968)


Ernst Jujlius Öpik
(1893-1985)


Lubor Kresak
(1927-1994)


Fred L. Whipple
(1906-2004)

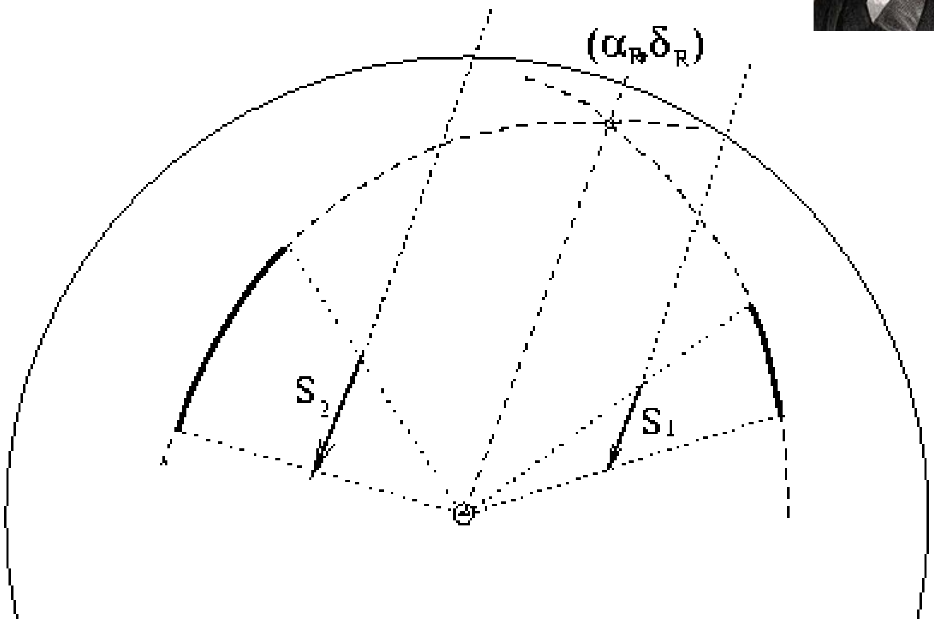

Zdenek Ceplecha
1929-2009


Douglas O. ReVelle
(1945-2010)

Meteor astronomers

Radiant concept

Radiant concept



Geocentric parameters $\mathbf{V_G, \alpha_G, \delta_G, T_{obs}}$

Visual observations of meteors

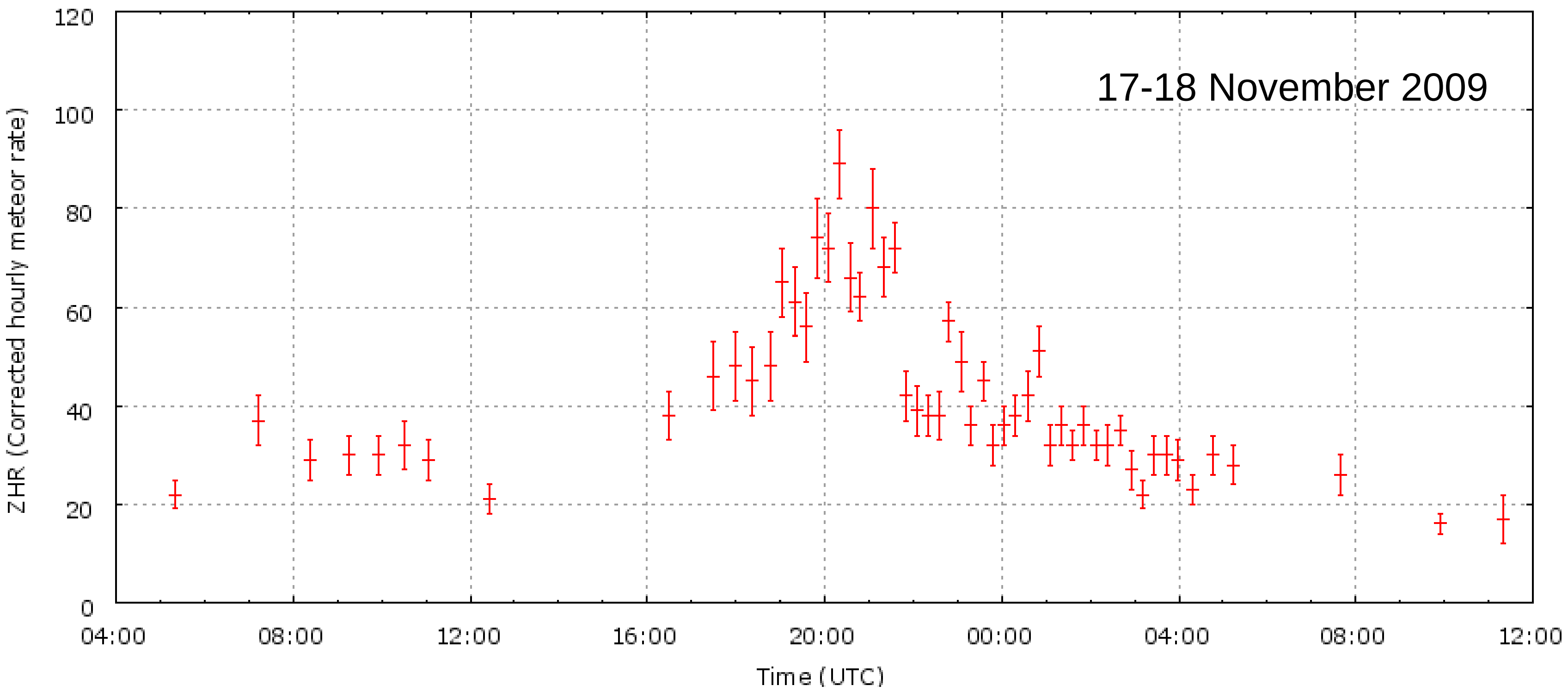
Sternberg Observatory (Germany)

Meteors Division of the Israeli Astronomical Association

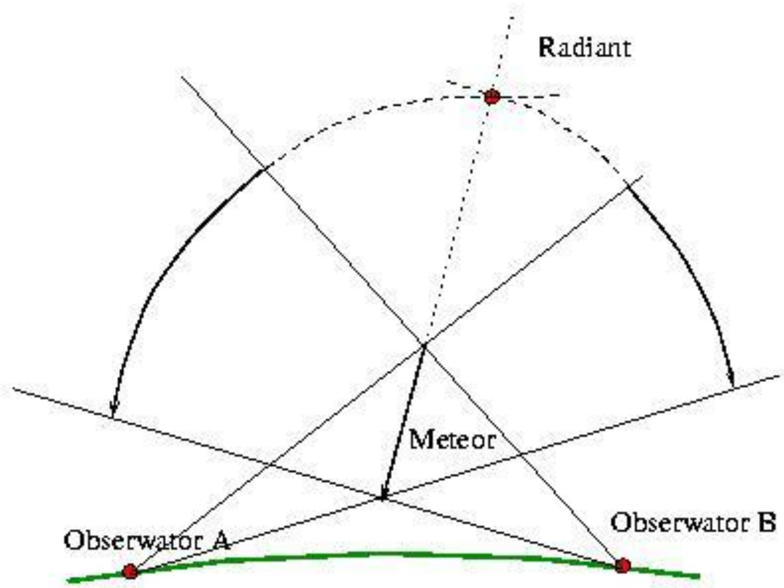
IMO

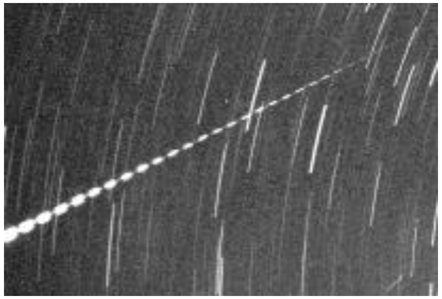
Campain – Leonids 2009

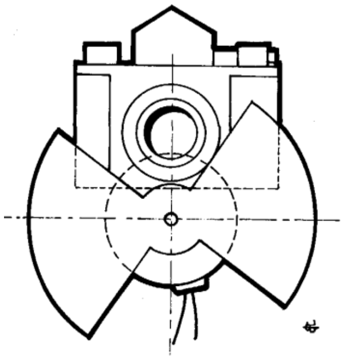
Leonids 2009 (IMO (2010)

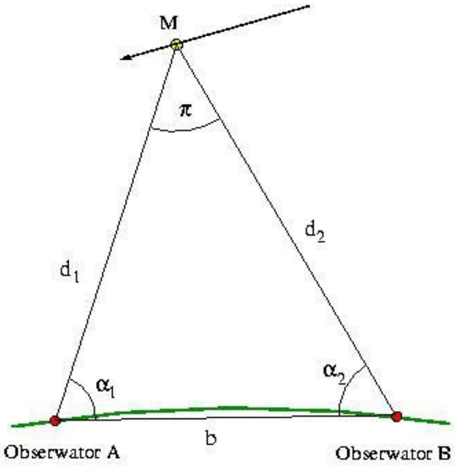


Double station photographic meteor observations







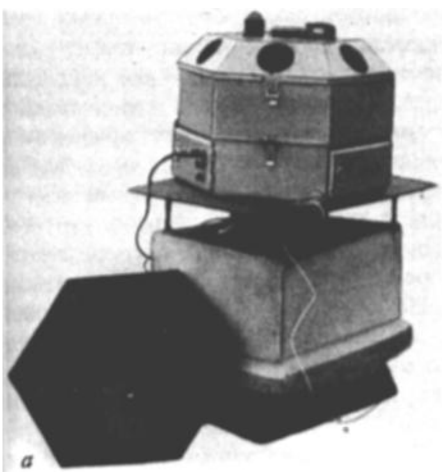


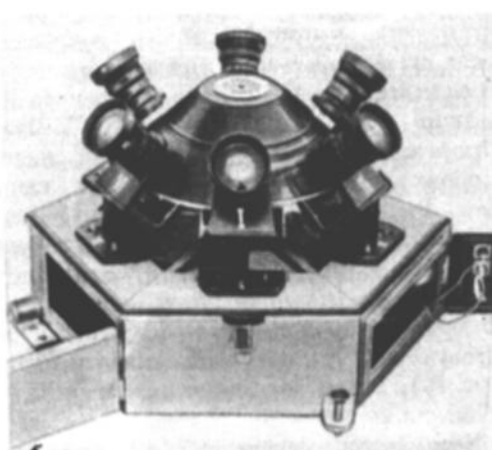
$$\vec{\mathbf{r}}, \dot{\vec{\mathbf{r}}}, t_{Obs} \Rightarrow e, a, \omega, \Omega, i$$

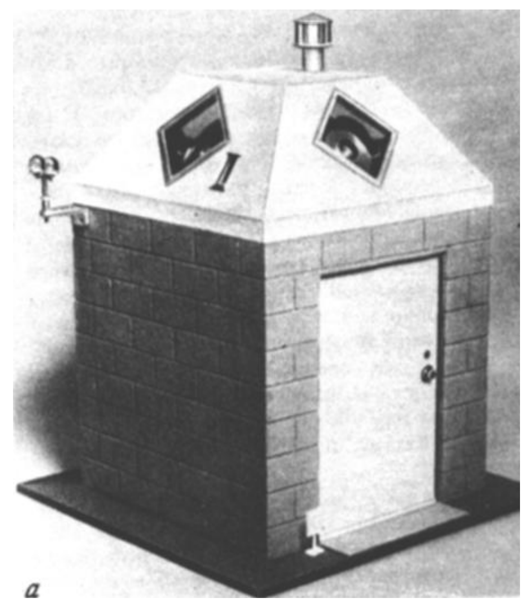
All-sky EN (Czechoslovakia)

MORP
Canada

CCCP

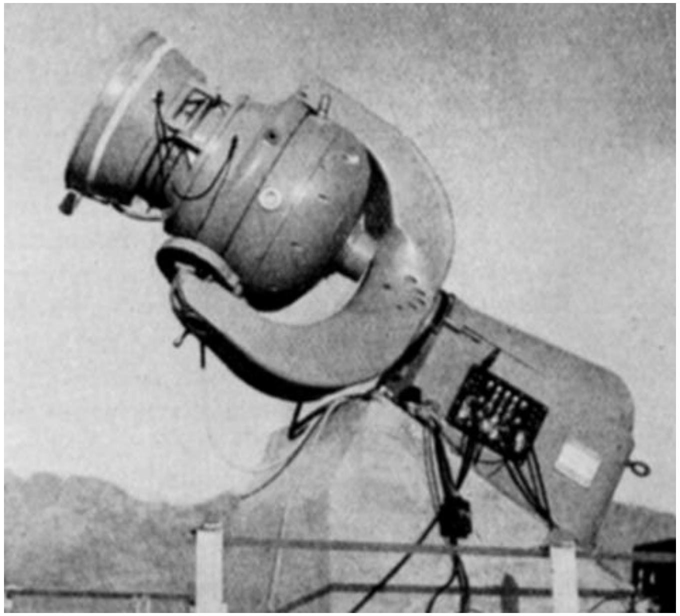


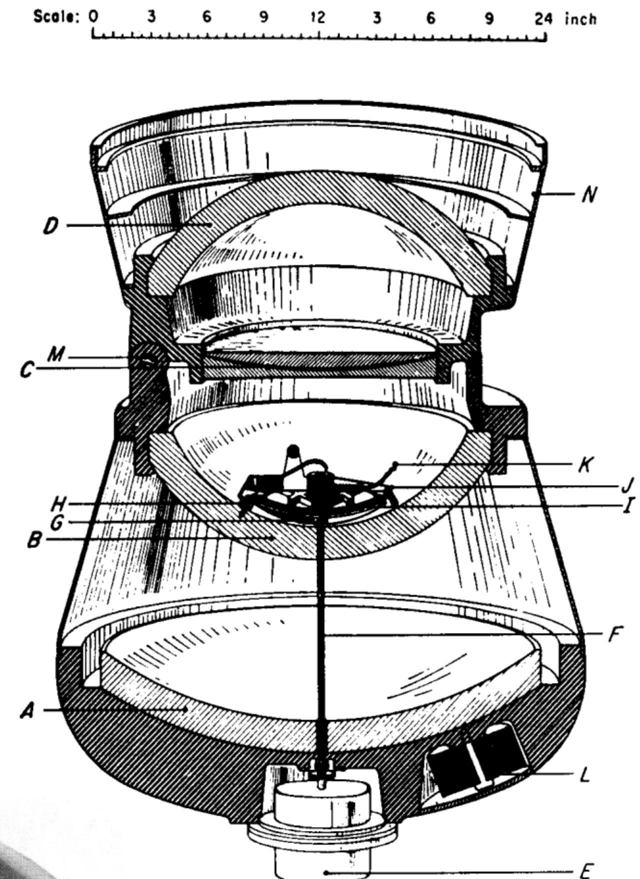


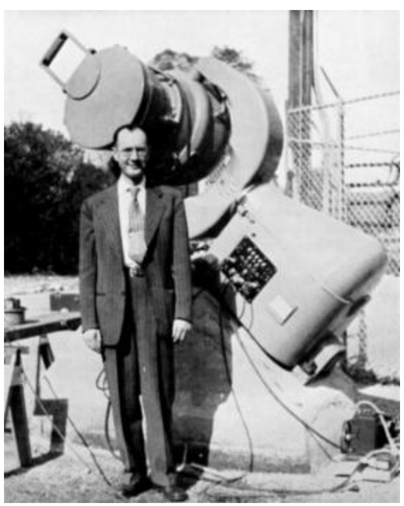


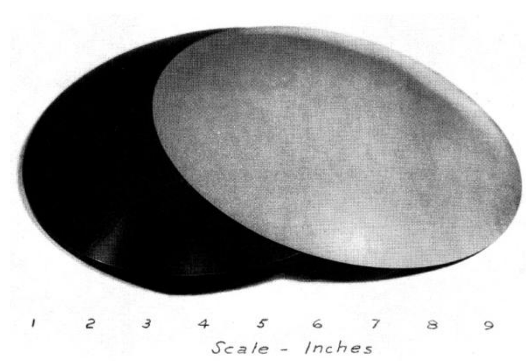
PN
USA

Baker-Schmidt meteor camera









A curved film for the Baker Super-Schmidt meteor cameras.

F =20 cm
F- number - F/0.65
Field of view - 55 deg

Jacchia, Whipple: 1957, SCoA, 1, 183

Automatic bolide photographic camera

(Ondrejov, Cz)

Detectors: sound, clear sky, light up, rain, snow

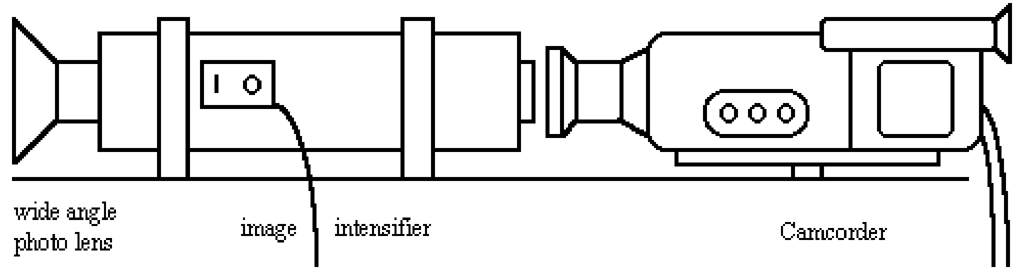
3.5/30 mm Zeiss Distagon

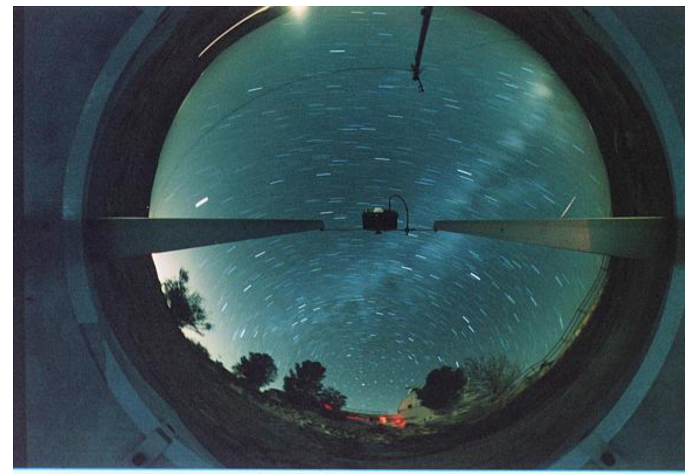
Pentuim II, Linux,
RAM 128 MB, HD 40 GB,
Modem, Internet card
video grabber,
Cards A/D i D/A ,
S/W
Receivers: DCF 77, GPS
UPS

32 flate films
Rotating shutter

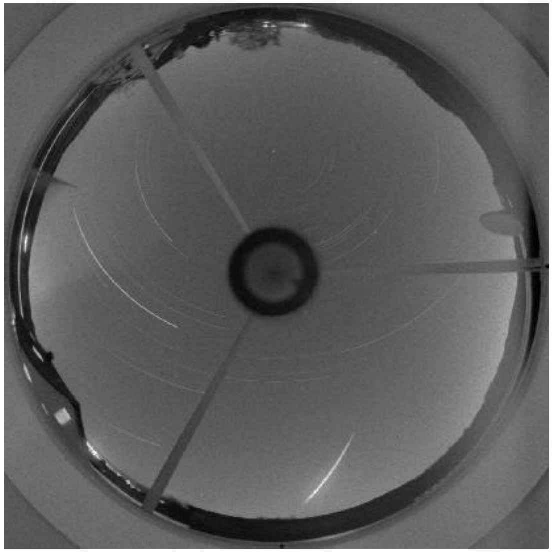
©. P. Spurny

Video meteor cameras





European Fireball Network

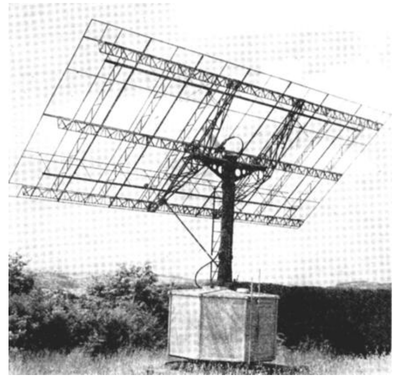


© http://www.dlr.de/pf/desktopdefault.aspx/tabid-623/1043_read-1425/

http://www.pkim.org/?q=pl/node/200

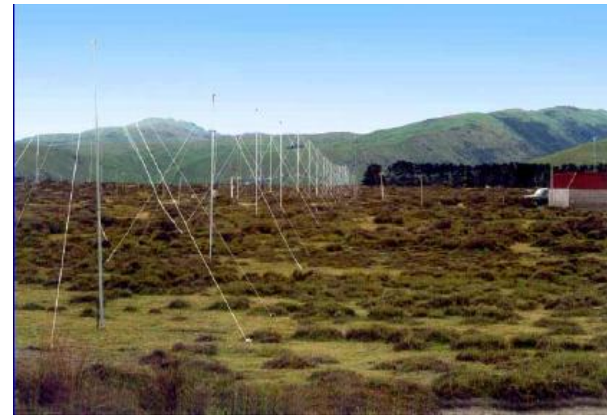
Meteor radio observations

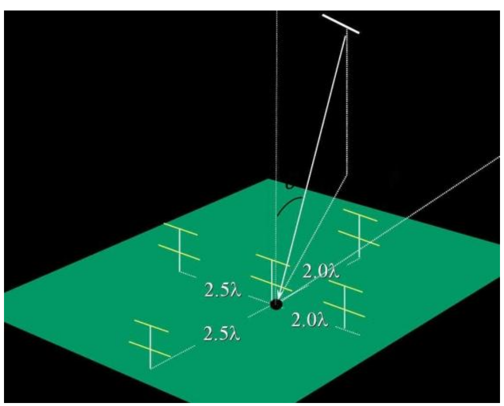
B. Lovell
Jordel Bank



Meteor Radar in Ondrejov n. Prague

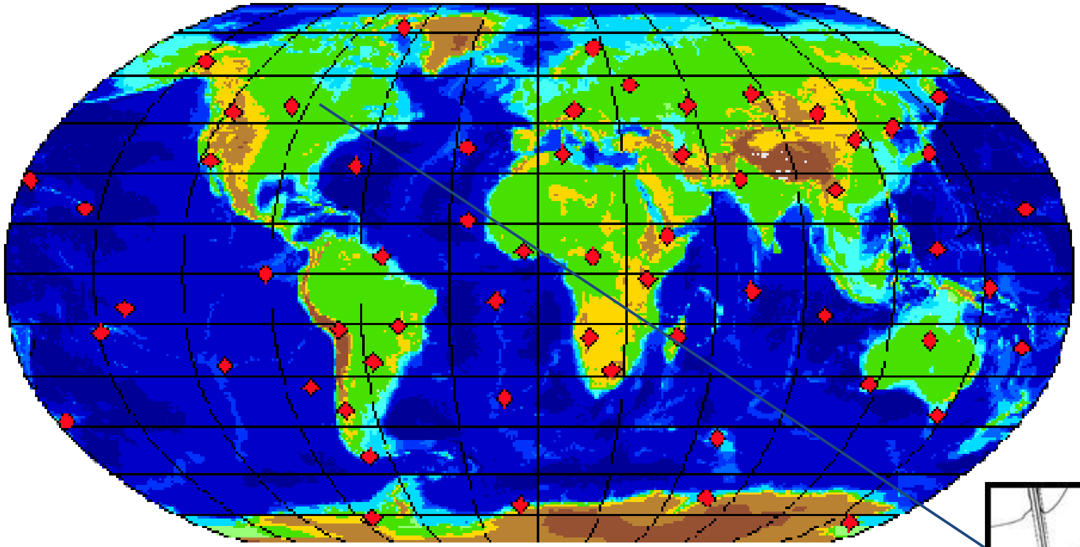
AMOR
Christchurch, NZ

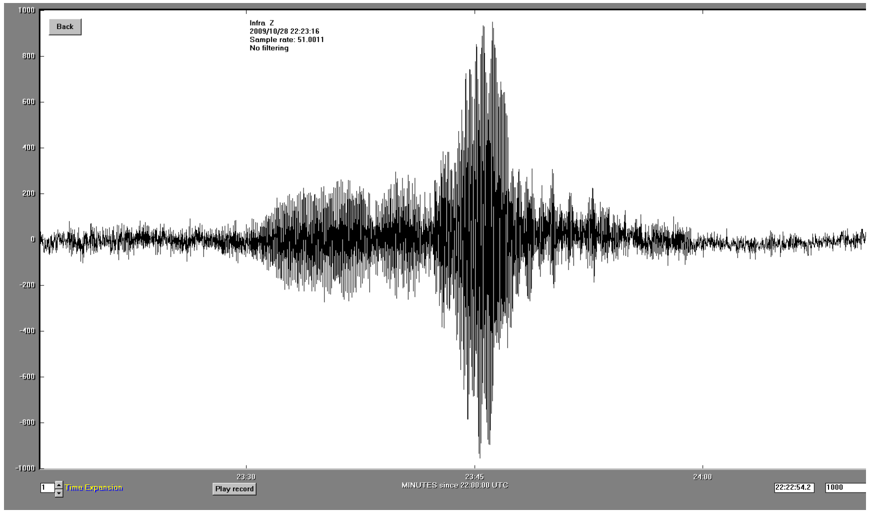


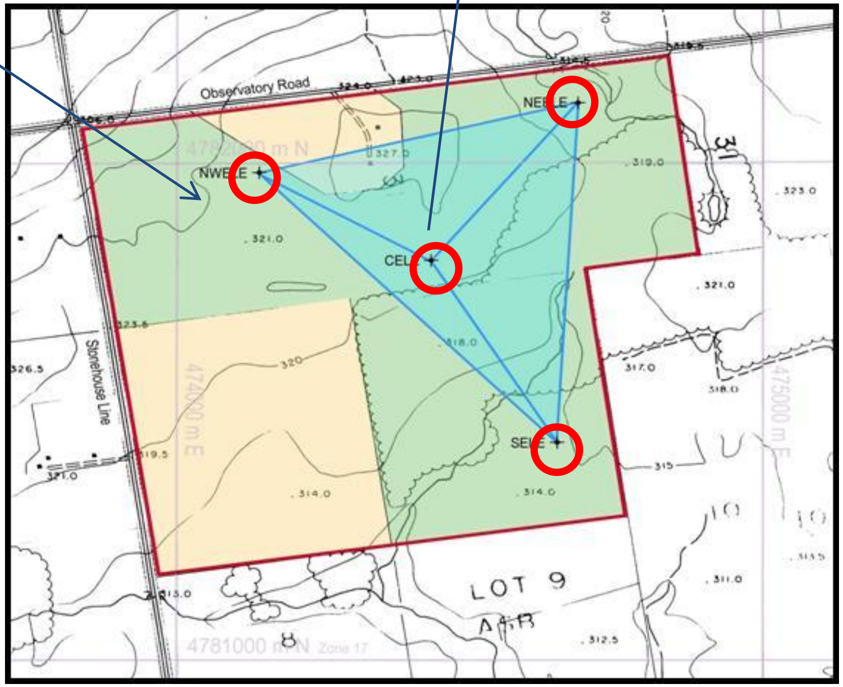


Meteor radar station
on the South Pole

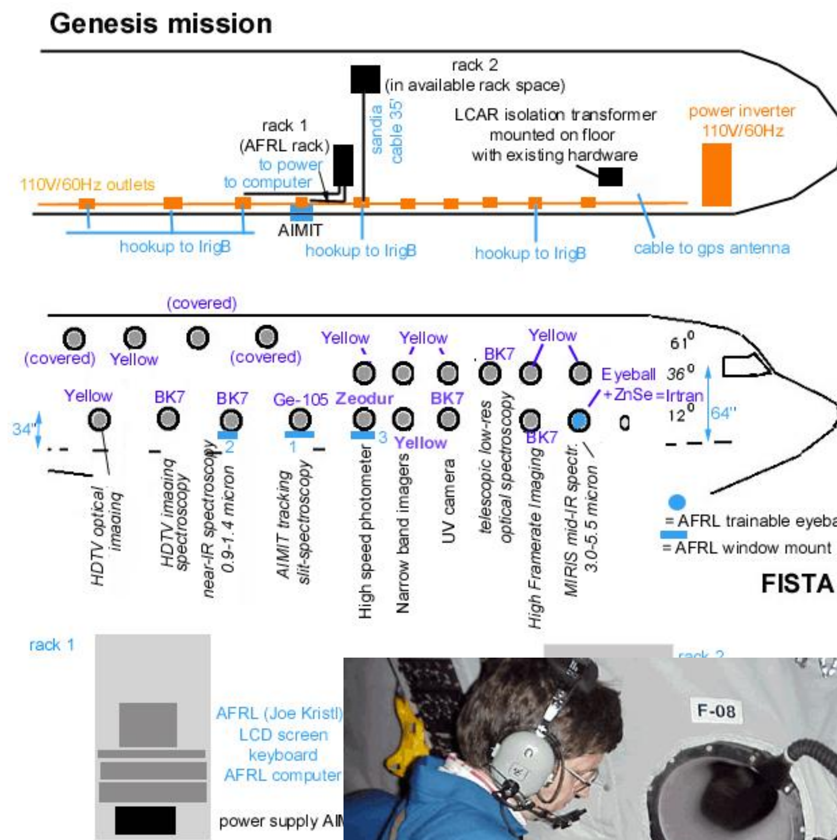
Infrasound meteor network

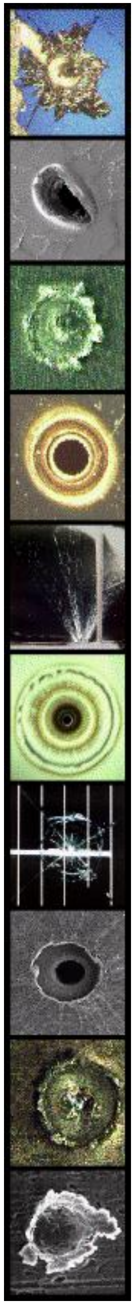




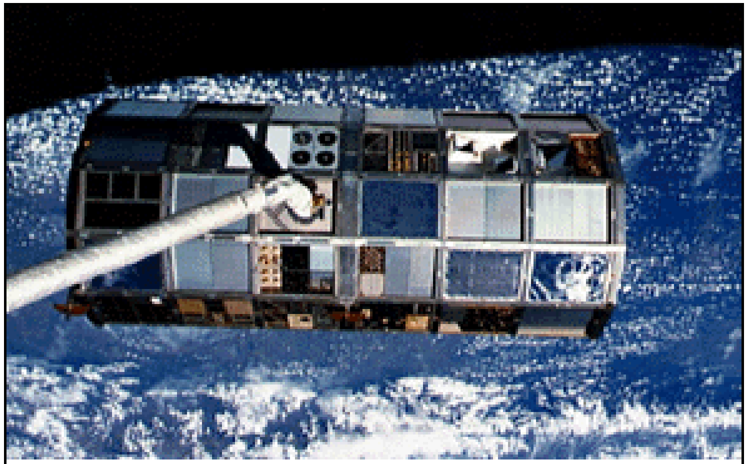


The airplane meteor detections. P.Jenniskens

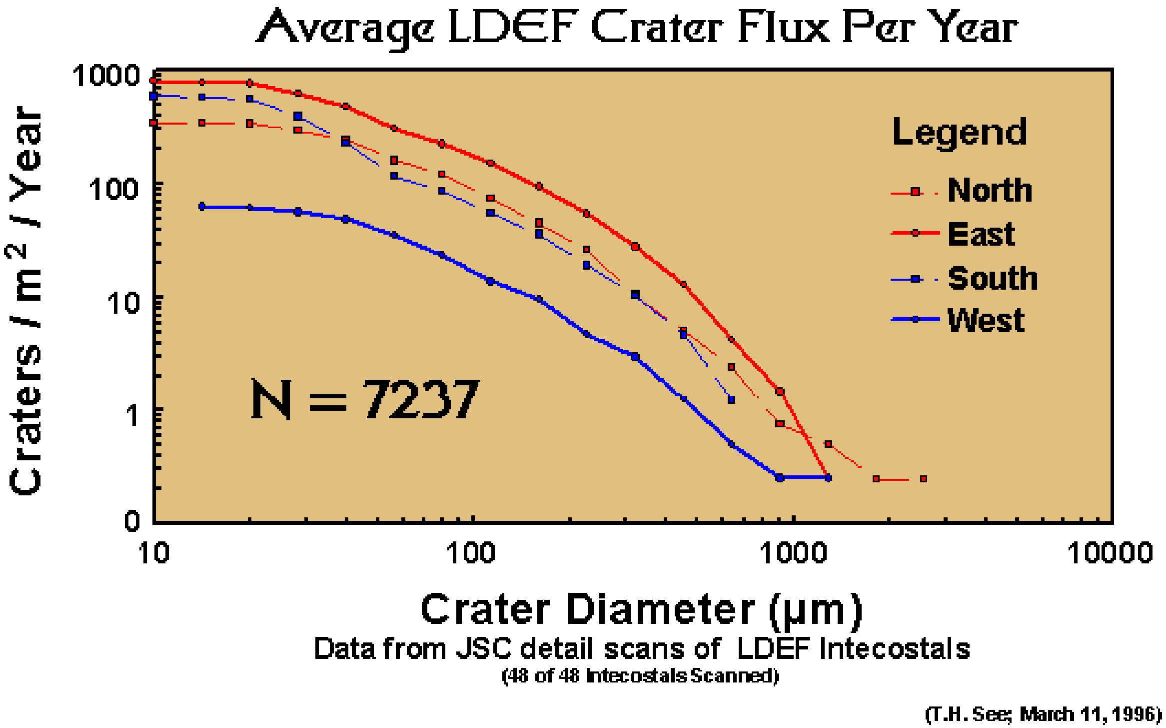




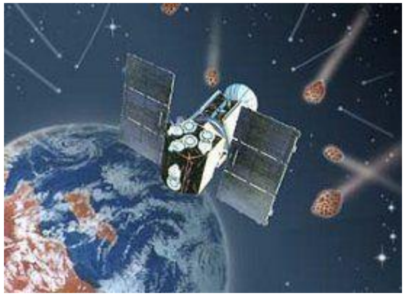
Śmieci w przestrzeni kosmicznej



Long Duration Exposure Facility (LDEF) being retrieved by Space Shuttle after 5.7 years in orbit.

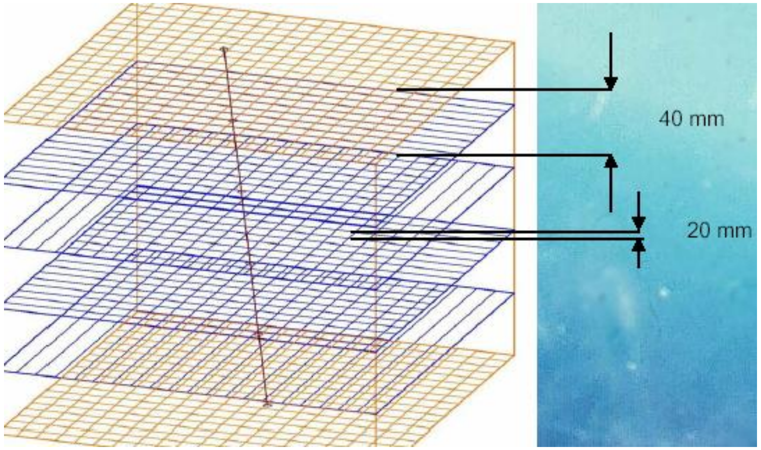


E. Gruen, R. Srama, M. Rachev, A. Srowig, D. Harris, T. Conlon, S. Auer

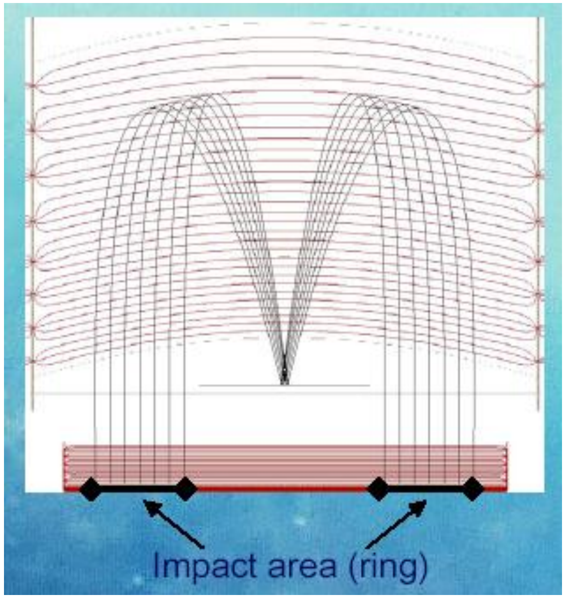


Dust Telescope

Combination of a **Dust Trajectory Sensor** and a **Chemical Composition Analyzer**.

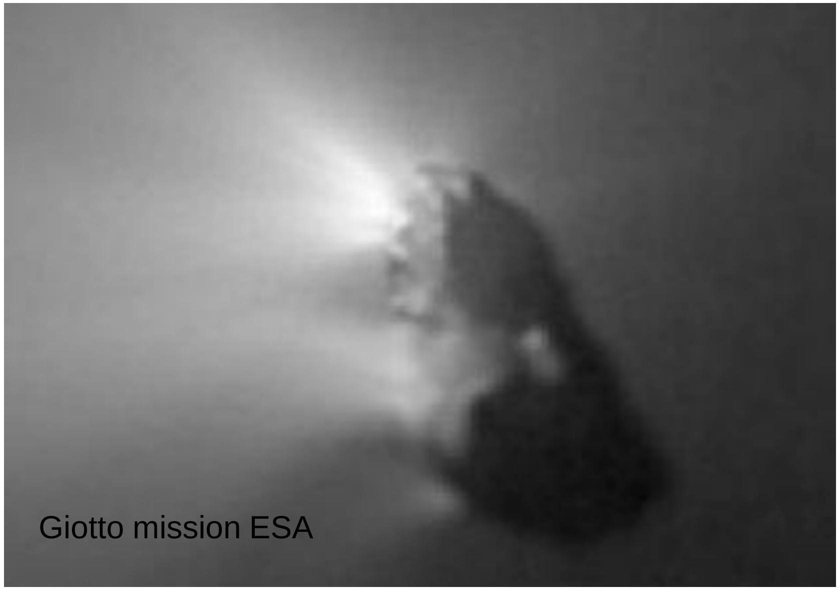


Trajectory sensor configuration

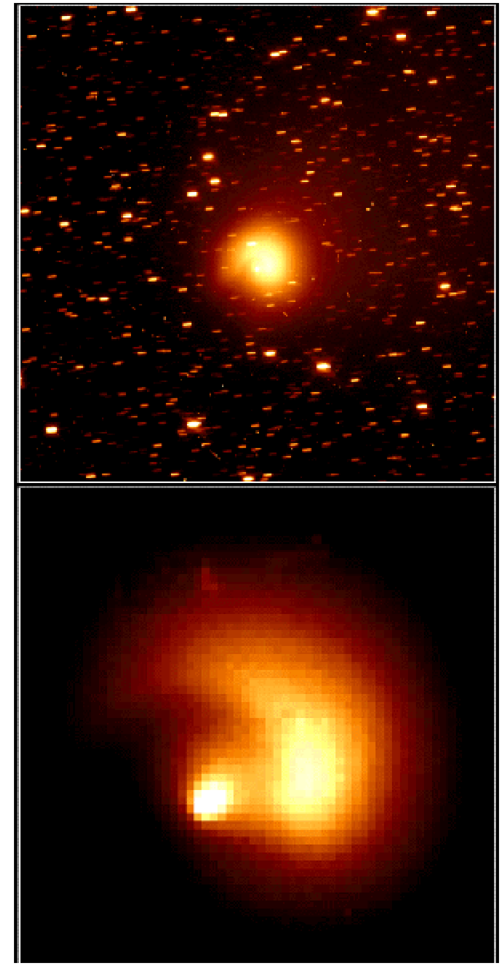


Impact mass analyzer

Origin of meteoroids



Giotto mission ESA

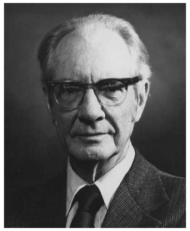


Hale-Bopp, at 7 AU

Gaseous ejection from the comet.
Often and regular mechanism.

Physics of the meteoroid ejection from comet

Energy balance



$$E_{Sun} = E_{Used}$$

$$E_{Sun} = E_{Reradiation} + E_{Sublimation} + E_{Conductivity}$$

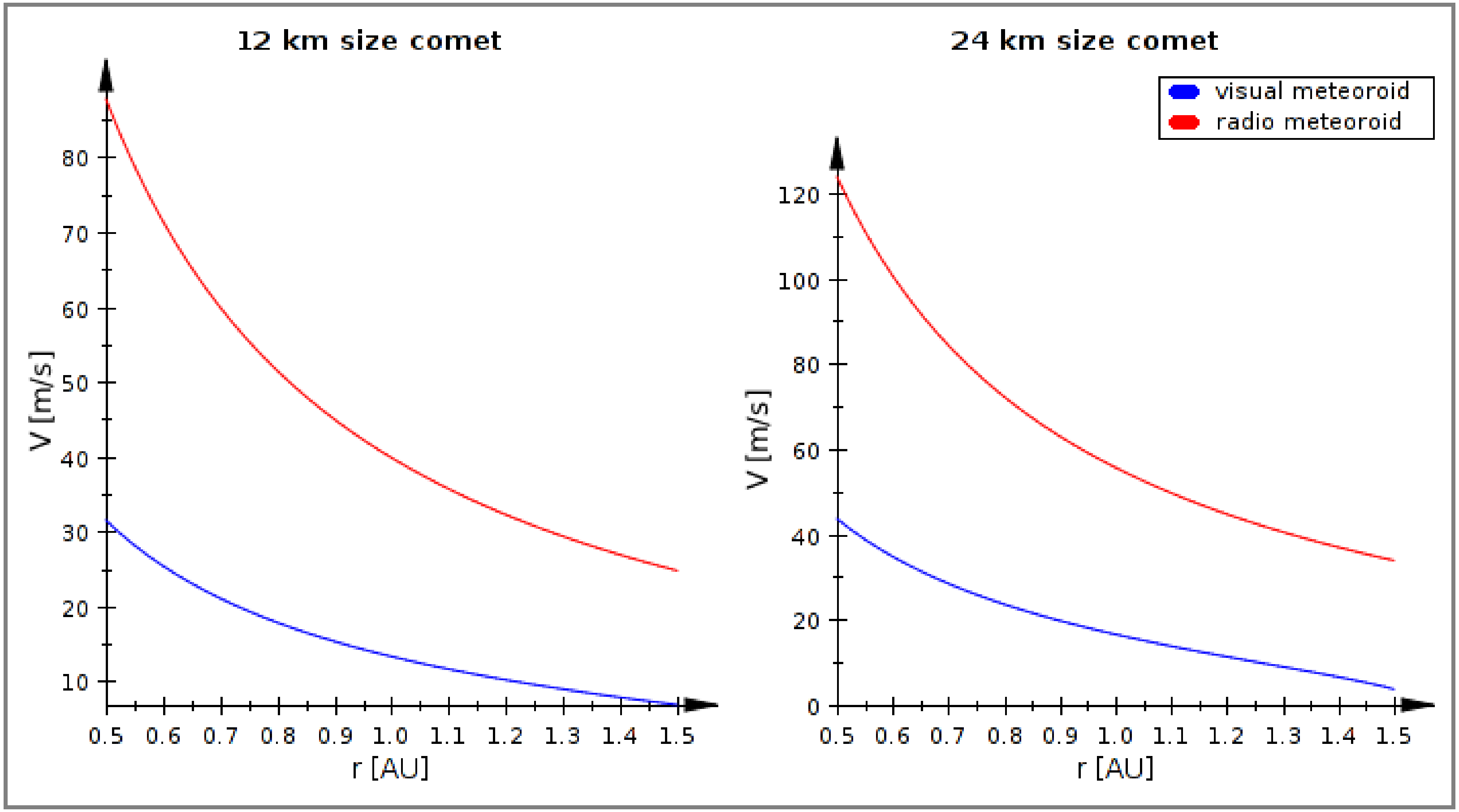
Forces acting on the meteoroid particle

$$\mathbf{F}_m = \mathbf{F}_p + \mathbf{F}_{gc} + \mathbf{F}_{sp} + \mathbf{F}_{gs} \ldots$$

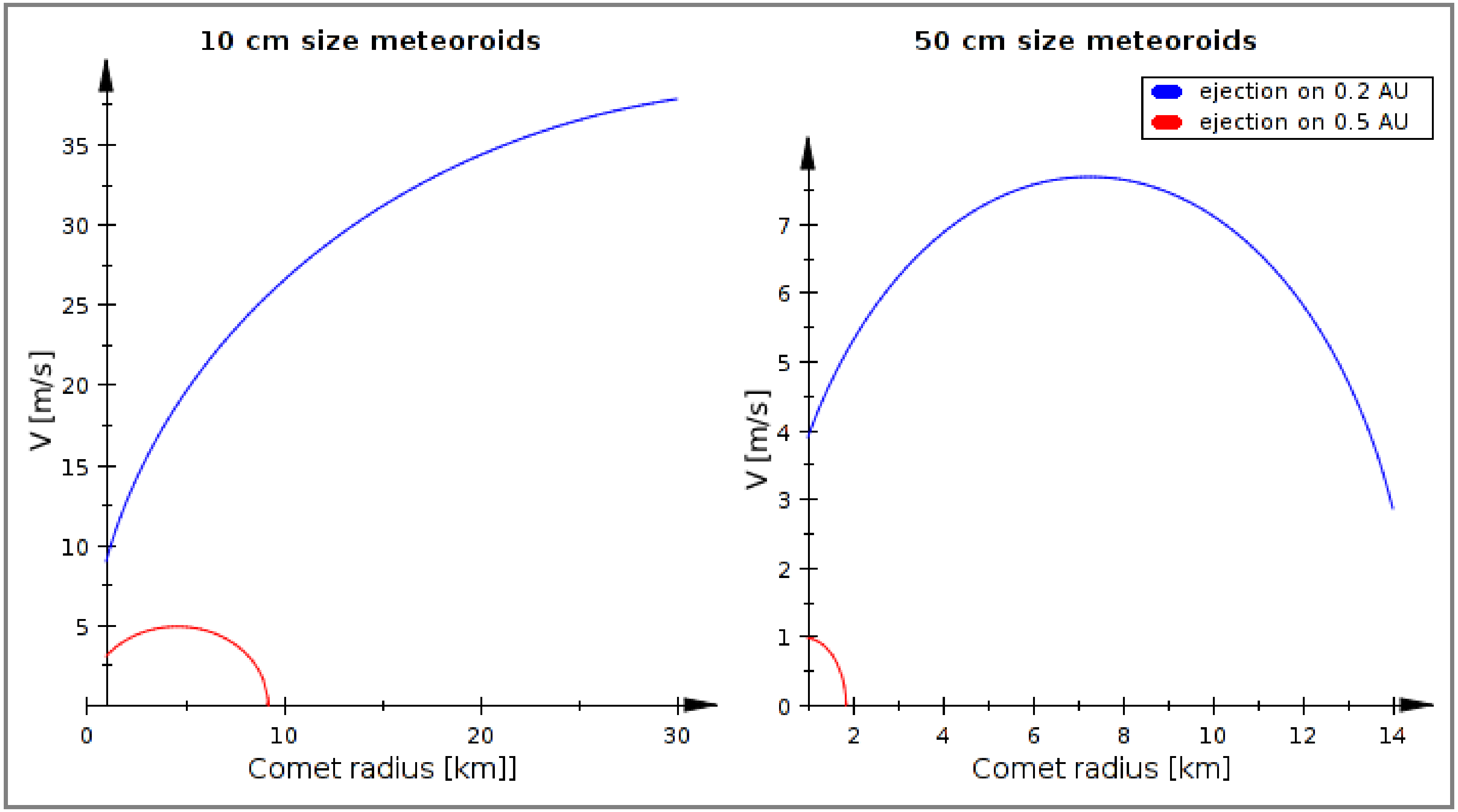
Meteoroid ejection velocity (Whipple 1951)

$$V(R_c, R_m, r) = \sqrt{\frac{F}{r^2}\frac{\pi R_c}{nH}\left(\frac{8kT}{\pi m_0}\right)^{0.5} r^{-0.25}\frac{3\Gamma}{4\pi R_m \rho_m} - \frac{8}{3}\pi G R_c \rho_c}$$

Meteoroid ejection velocity

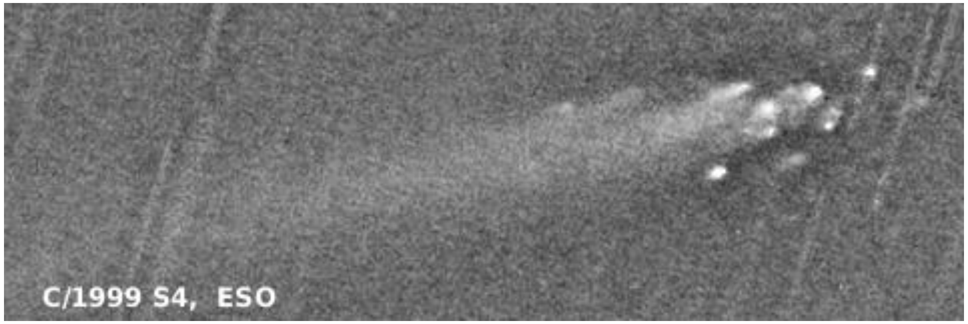


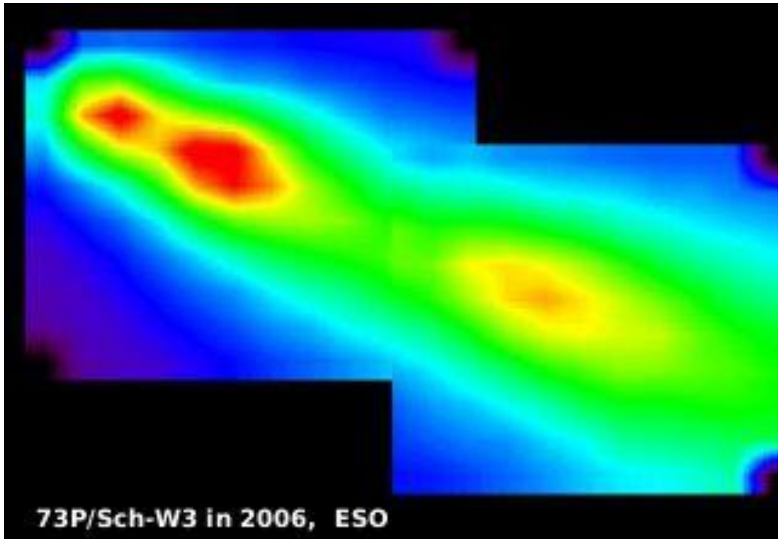
Meteoroid ejection velocity



$$F_m = F_p - F_{gc}$$

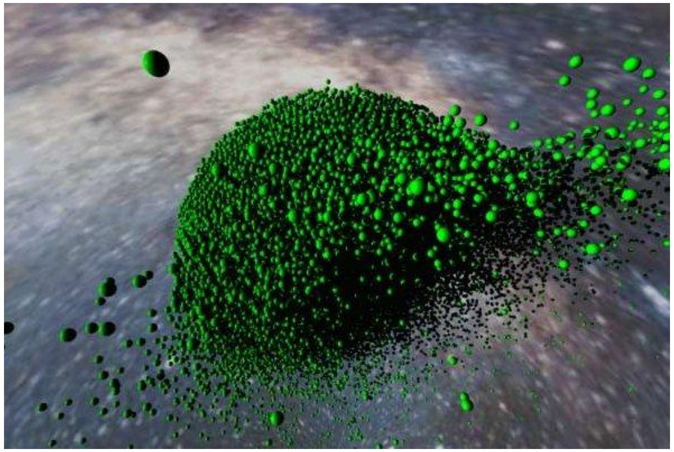
Origin of the meteoroids: disruption of comet





- ~40 cases of comet split
- splitting velocity 0…10 m/s

Origin of meteoroids: destructive collisions between asteroids, comets



Science P. Michel, P. Tanga

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Vol. 5, EPSC2010-634, 2010
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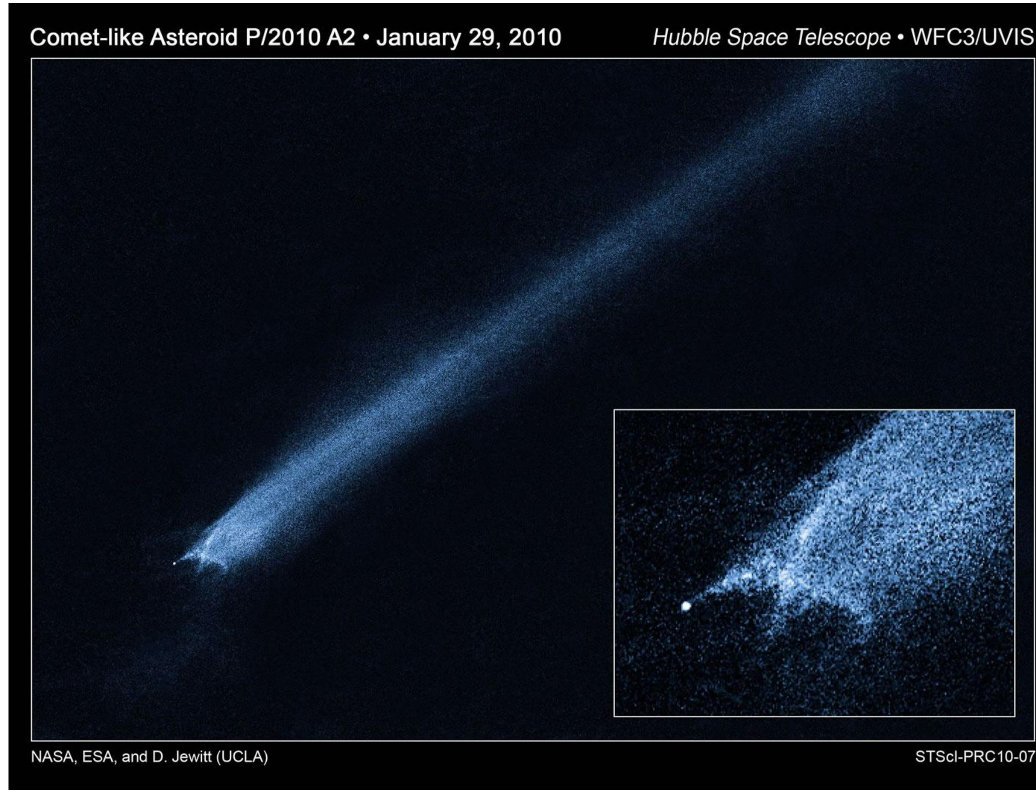
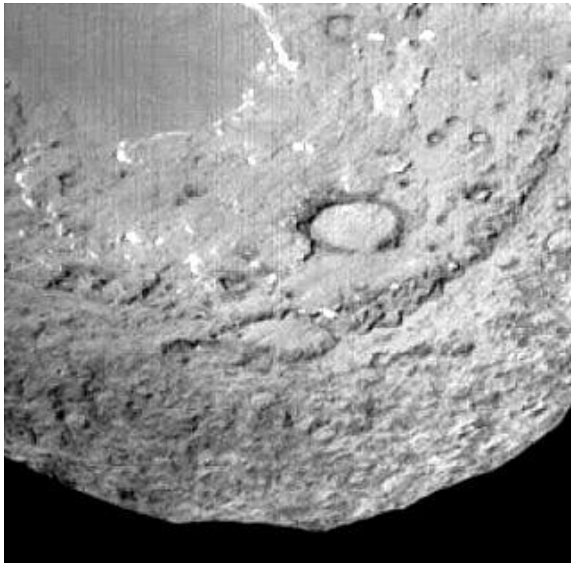


Asteroid collision confirmed by Rosetta/OSIRIS observations

J-B. Vincent (1), C. Snodgrass (1,2), C. Tubiana (1), H. Sierks (1), S. Hviid (1), R. Moissl (1), H. Böhnhardt (1), C. Barbieri (3), D. Koschny (4), P. Lamy (5), H. Rickman (6,7), R. Rodrigo (8), B. Carry (9), S. C. Lowry (10), R. J. M. Laird (10), P. R. Weissman (11), A. Fitzsimmons (12), and the OSIRIS team.

Origin of meteoroids: cratering of comets, asteroids …



9P/Tempel (Deep Impact NASSA)

951 Gaspra (Galileo NASSA)

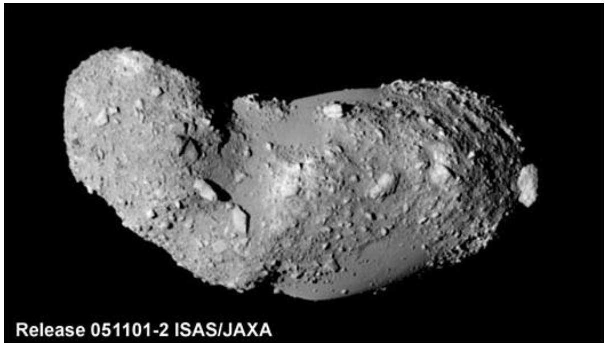
21 Lutetia (Rosseta mission)

Cratering - more frequent than destructive collisions, less efficient

Origin of meteoroids: planetary close encounters

ShL9 after
tidal disruption

25143 Itokawa

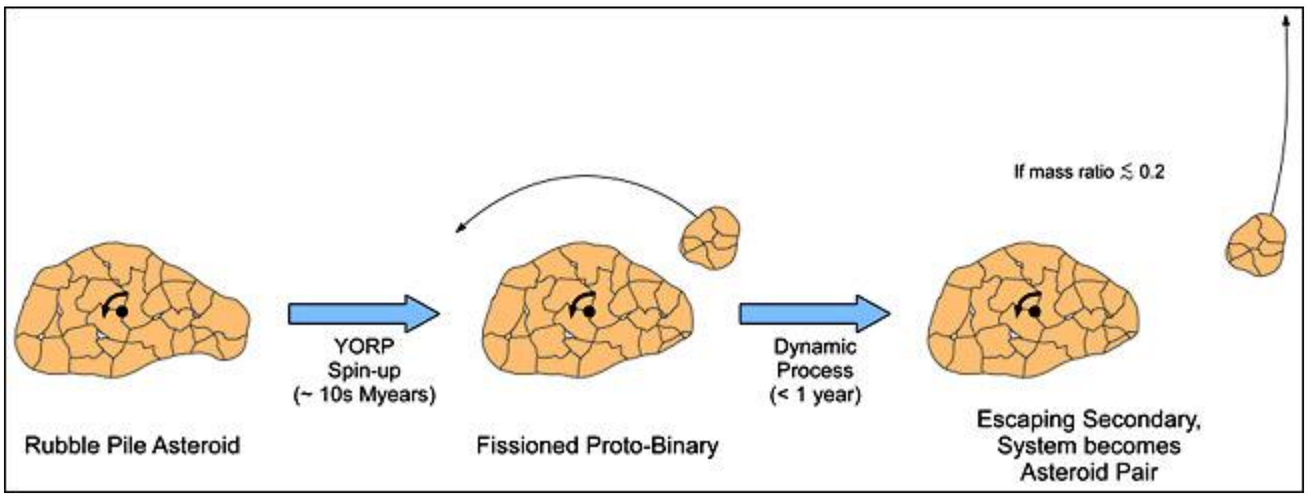


Boulders on
433 Eros surphace

- tidal mechanism (Veres et al. 2008)
- more often than collisions

Origin of meteoroids: YORP effect

- YORP induced spin-up and rotational fisson



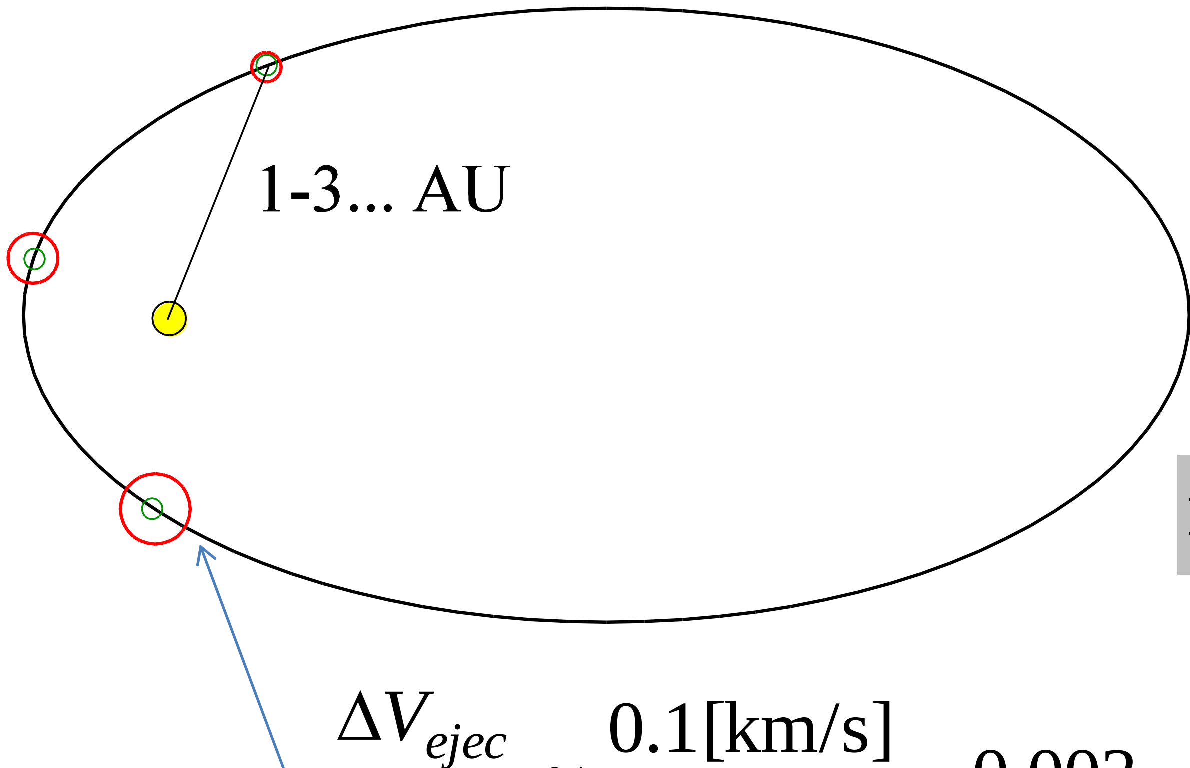
Over tens of millions of years, a rubble-pile asteroid less than 10 kilometers in diameter can spin up to a speed that allows the asteroid to split in two, forming a proto-binary system. If the smaller companion is less than 60 percent the size of the larger asteroid, they will gently separate from one other at a relatively low velocity. The system will eventually become an asteroid pair, or "divorced" asteroid. (Image: Pravec, et al.)

Definition of a meteoroid stream

Meteoroid stream: a set of particles originated from a comet, an asteroid as result of:

- ejection from the comet surface,
- comet explosion, disruption,
- collision between asteroids, comets
- cratering of the comets, asteroids,
- tidal splitting during close encounters,
- YORP rotational fission.

Evolution of a meteoroid stream



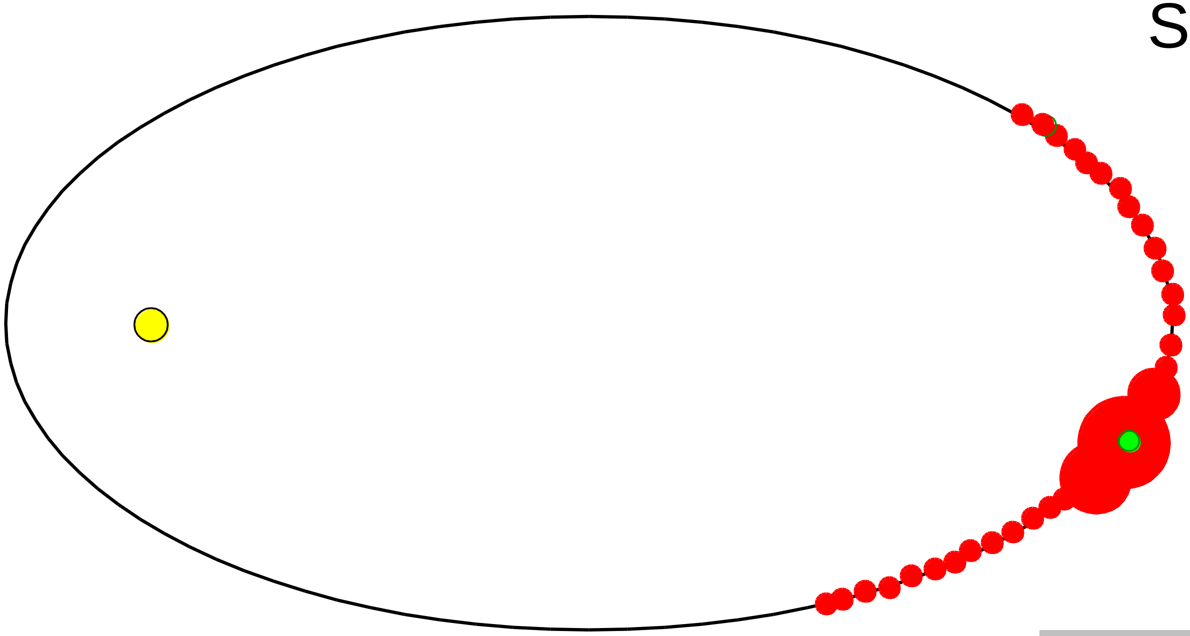
Stage I.

Swarm of meteoroids

$$\mathbf{r}_m \approx \mathbf{r}_c; \quad \dot{\mathbf{r}}_m \approx \dot{\mathbf{r}}_c$$

$$\frac{\Delta V_{ejec}}{V_{orb}} \approx \frac{0.1\,[\mathrm{km/s}]}{30\,[\mathrm{km/s}]} = 0.003\ldots$$

Evolution of a meteoroid stream

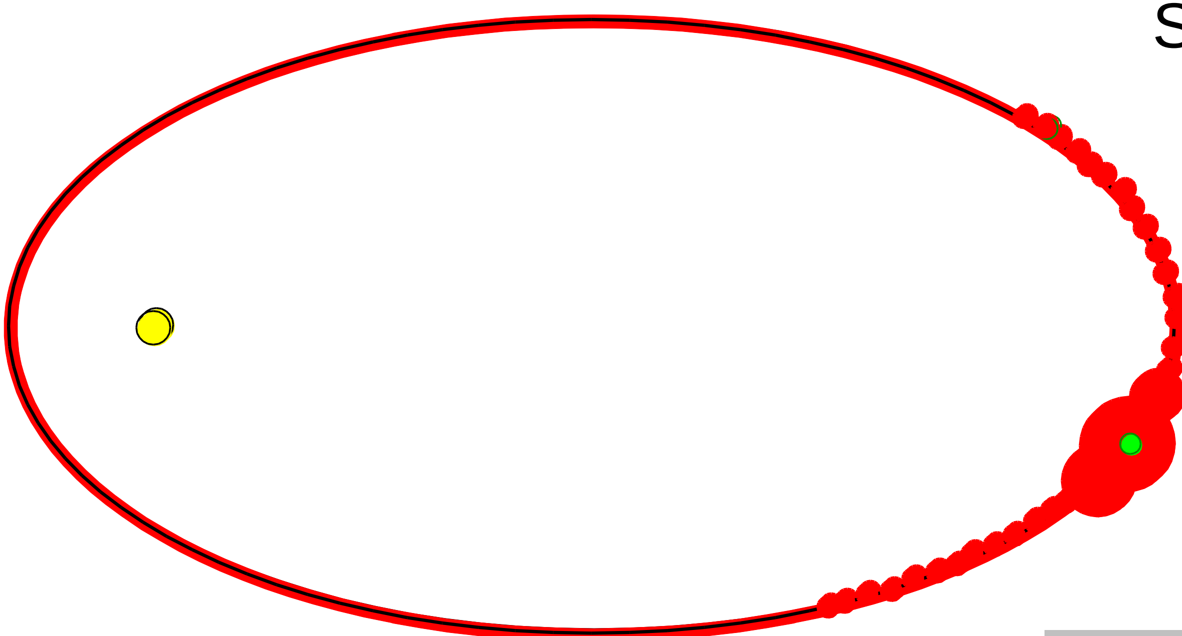


Stage II.

Stream of meteoroids

$$\mathbf{r}_m \neq \mathbf{r}_c; \quad \dot{\mathbf{r}}_m \neq \dot{\mathbf{r}}_c$$

Evolution of a meteoroid stream

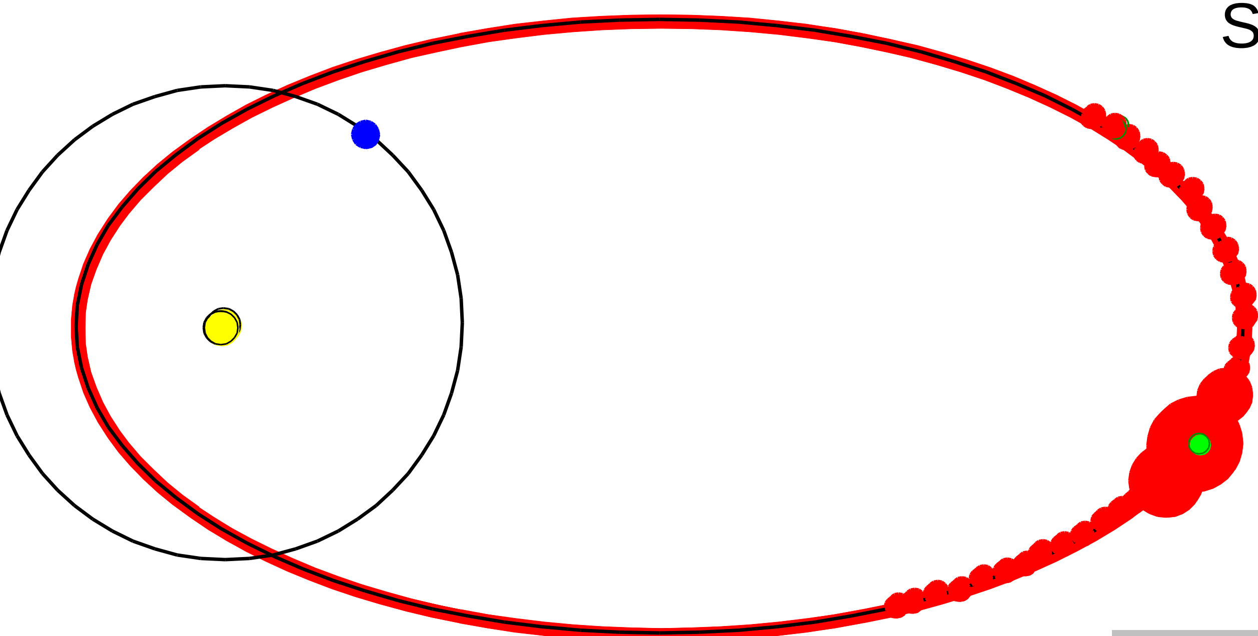


Stage II.

Stream of meteoroids

$$\mathbf{r}_m \neq \mathbf{r}_c; \quad \dot{\mathbf{r}}_m \neq \dot{\mathbf{r}}_c$$

Evolution of a meteoroid stream



Stage II.

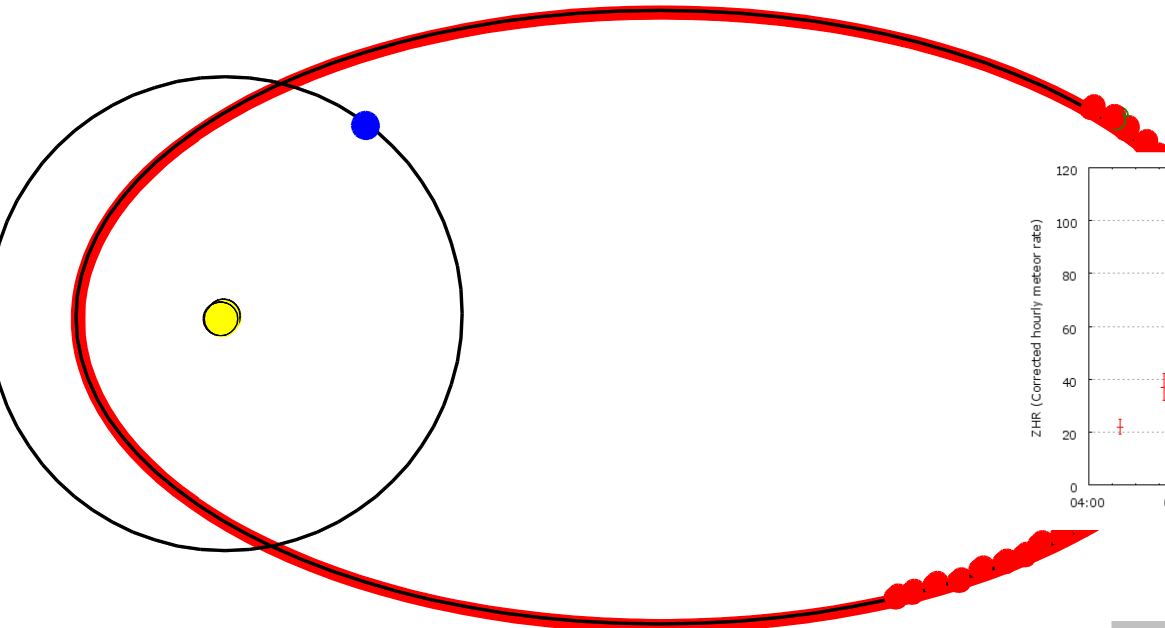
Stream of meteoroids

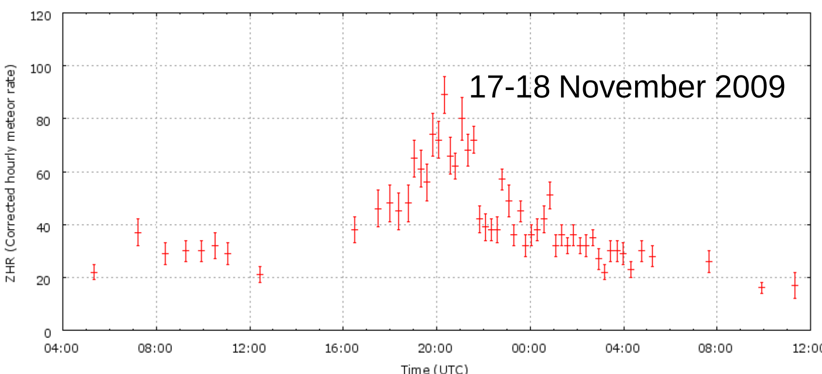
$$\mathbf{r}_m \neq \mathbf{r}_c; \quad \dot{\mathbf{r}}_m \neq \dot{\mathbf{r}}_c$$

Evolution of a meteoroid stream

Stage II.

Stream of meteoroids

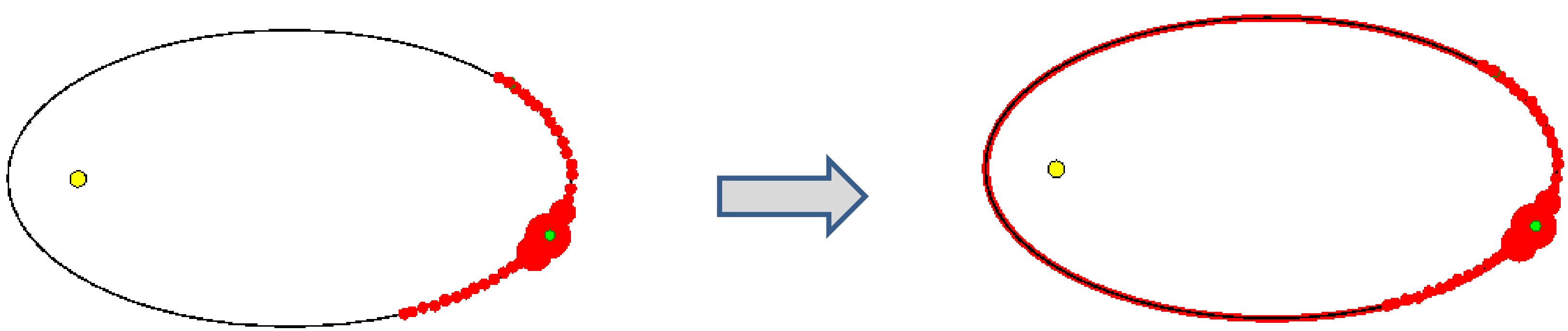


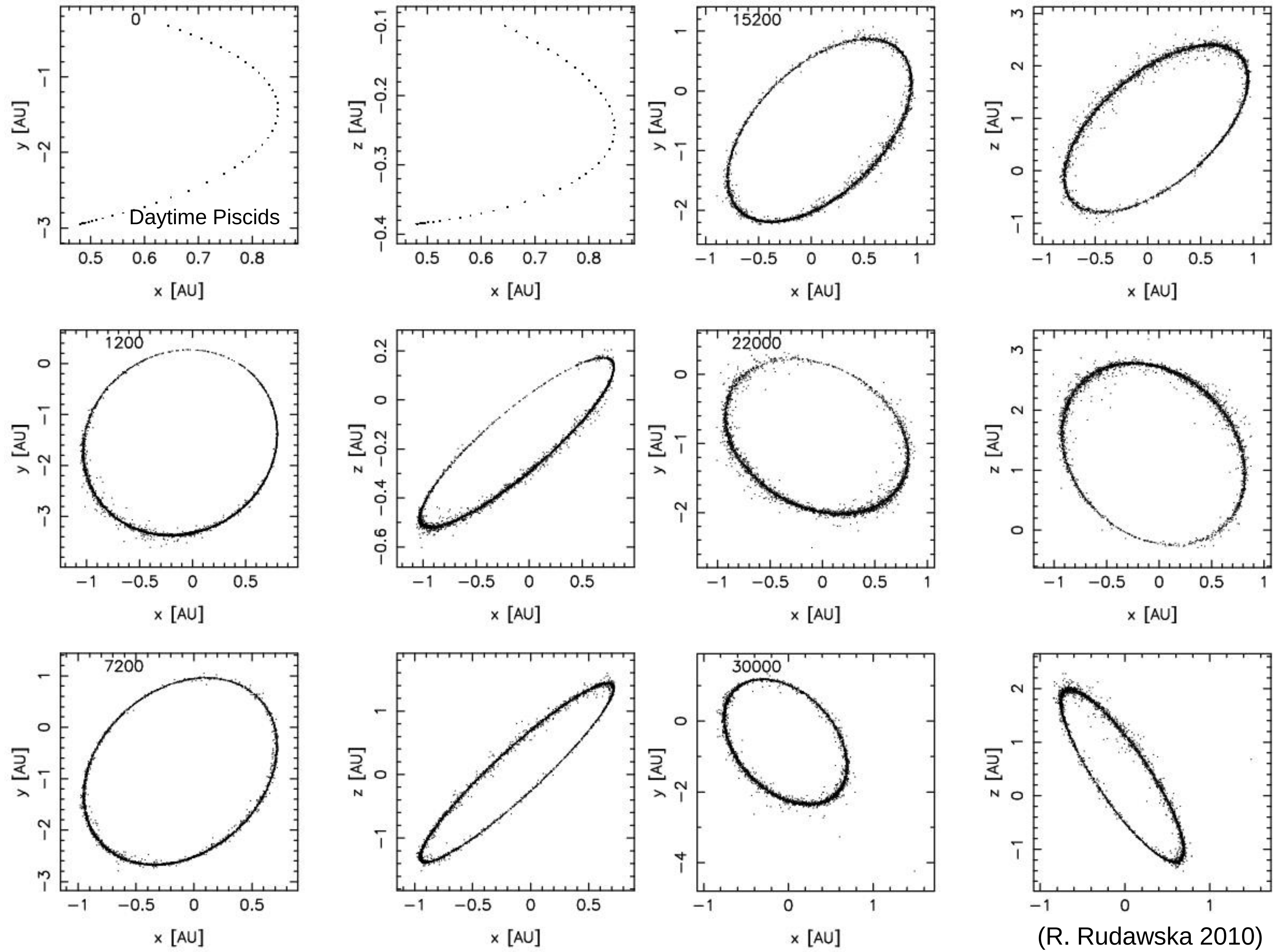


$$\mathbf{r}_m \neq \mathbf{r}_c; \quad \dot{\mathbf{r}}_m \neq \dot{\mathbf{r}}_c$$

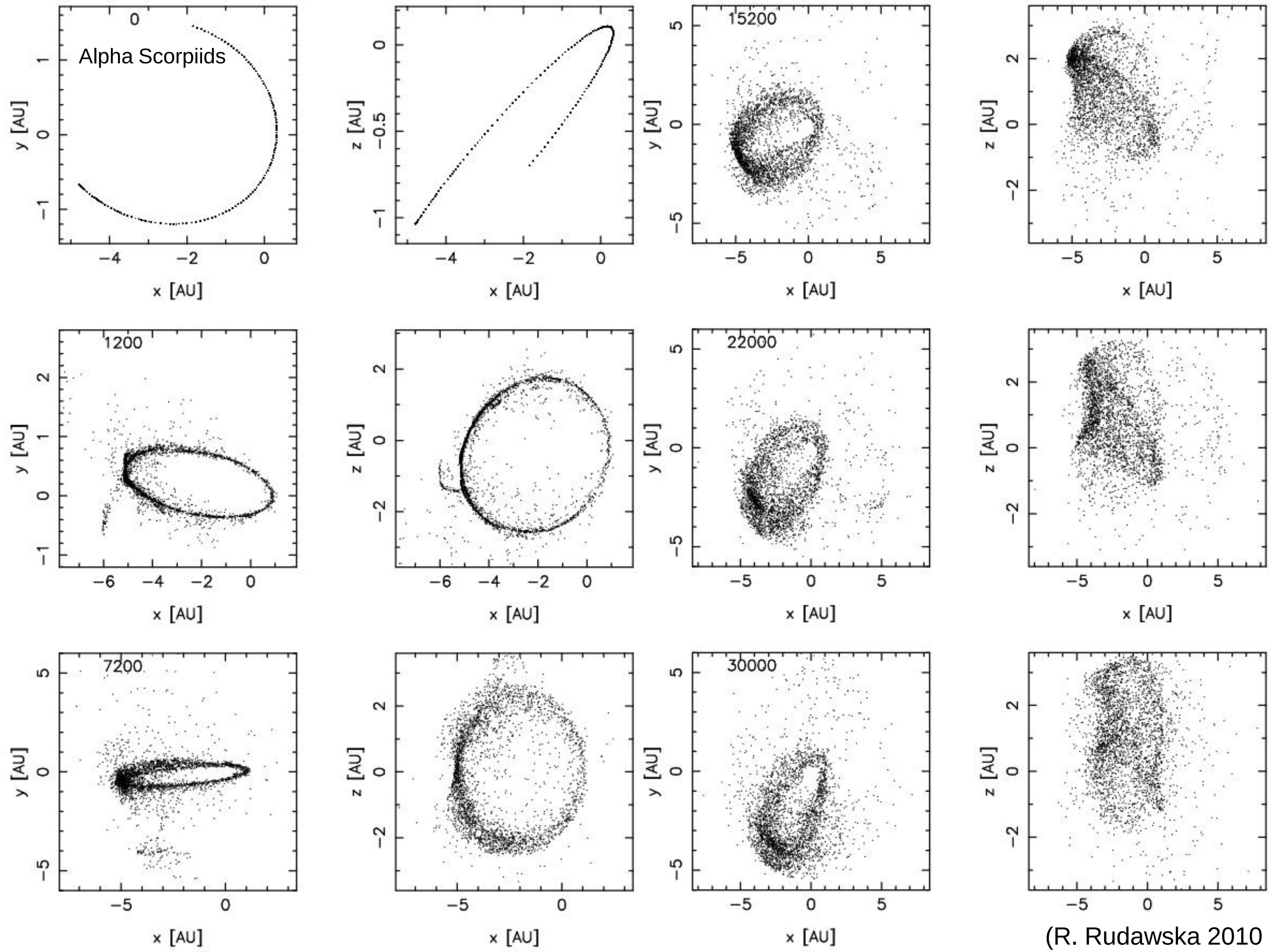
Stage II. Stream of meteoroids (Plavec 1954)

Stream	a [AU]	q [AU]	P [y]	Rotations
Geminids	1.4	0.14	1.66	96
Draconids	3.5	1.0	6.55	108
Leonids	10.3	0.99	33.1	35
Orionids	18	0.59	76.4	15
Lyrids	56	0.92	419	6
Aurigids	153	0.68	1983	2

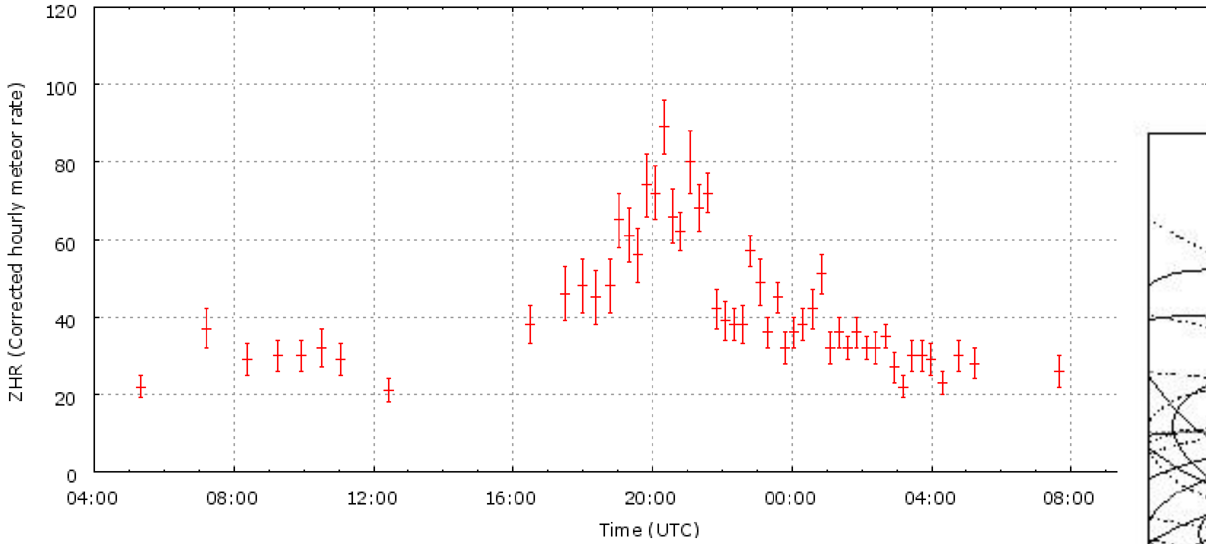


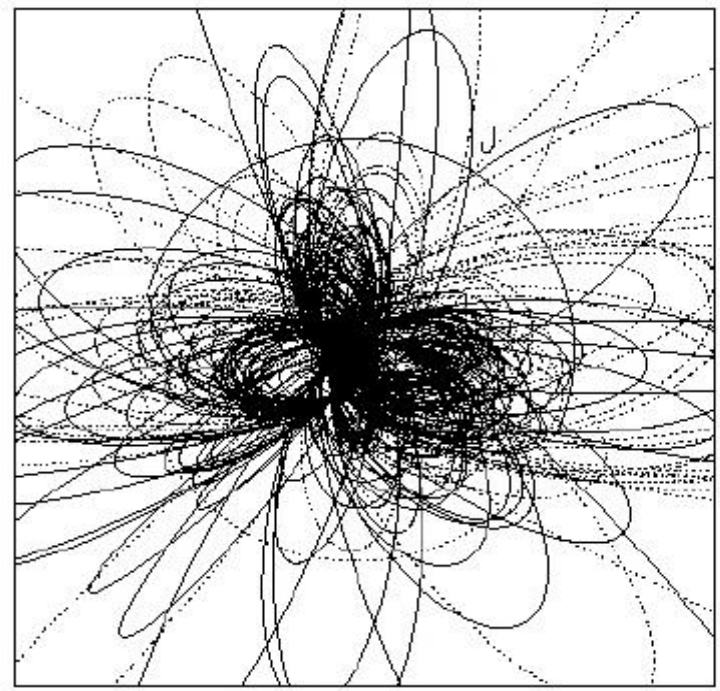


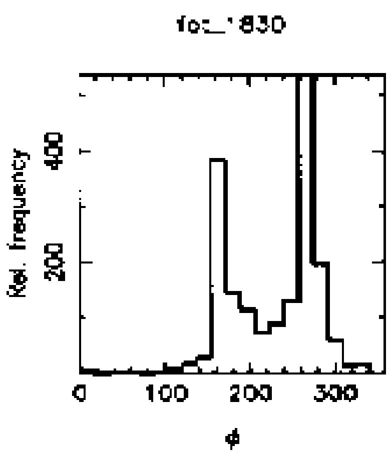
(R. Rudawska 2010)

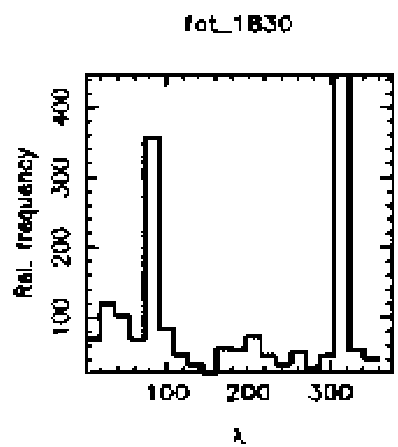


(R. Rudawska 2010



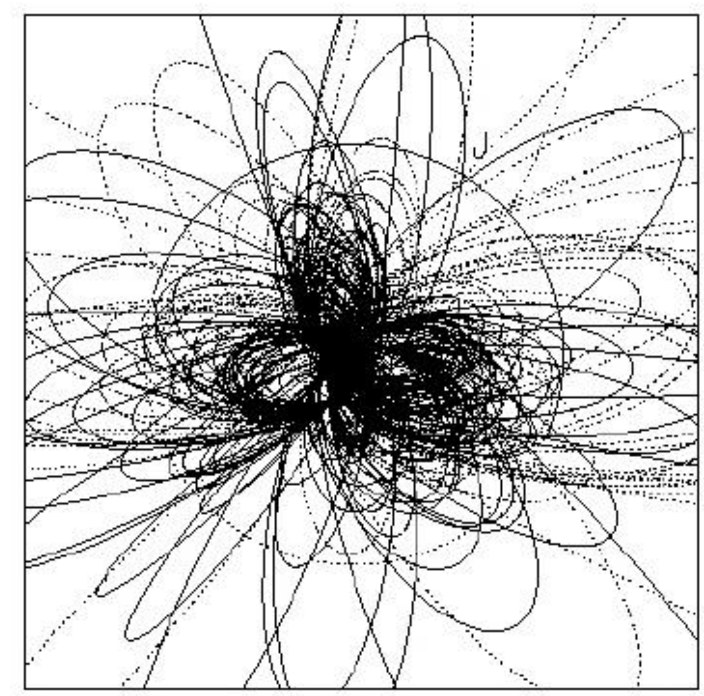






Stream and sporadic meteoroids

Searching for meteoroid streams and their parent bodies



Bringing up a problem:

- given: ~10^3-10^4 orbits of meteoroids (sporadic, stream component) and NEO's, .

- find all streams, their members + their parent bodies,

- probability to identify group of 2, 3, 4, …members by chance should be smaller than 5 %. (reliability level 95%)

Meteoroid streams and their parent bodies

- C/1861 - Lyrids (Pape (1861),Galle (1867),Weiss (1867)),
- 109P/1862 - Perseids (Schiaparelli 1866),
- 55P/1866 - Leonids (Schiaparelli 1866).

Comet 55P/1866 and Leonids meteor stream

G.V. Schiaparelli

The following are the two orbits on which Schiaparelli based his proof, as given in *Sternschnuppen*, p. 57:

	LEONIDS	COMET 1866 I
Perihelion passage................	Nov. 10.092	Jan. 11.160
Longitude of perihelion...........	56° 25.9′	60° 28.0′
Ascending node................	231 28.2	231 26.1
Inclination.....................	162 15.5	162 41.9
Perihelion distance.............	0.9873	0.9765
Eccentricity.....................	0.9046	0.9054
Semi-major axis................	10.34	10.344
Period.........................	33.25	33.176

Ch. P. Olivier, 1925, Meteors, Williams & Wilkins Company

Meteoroid streams and their parent bodies. History.

- C/1861 - Lyrids (Pape (1861),Galle (1867),Weiss (1867)),
- 109P/1862 - Perseids (Schiaparelli 1866),
- 55P/1866 - Leonids (Schiaparelli 1866).

433 Eros -- in AD 1898 first NEA was observed,

- meteoroid showers may be associated width asteroids:
  Olivier(1925), Hoffmeister (1937), Whipple (1938),

Searching for meteoroid streams

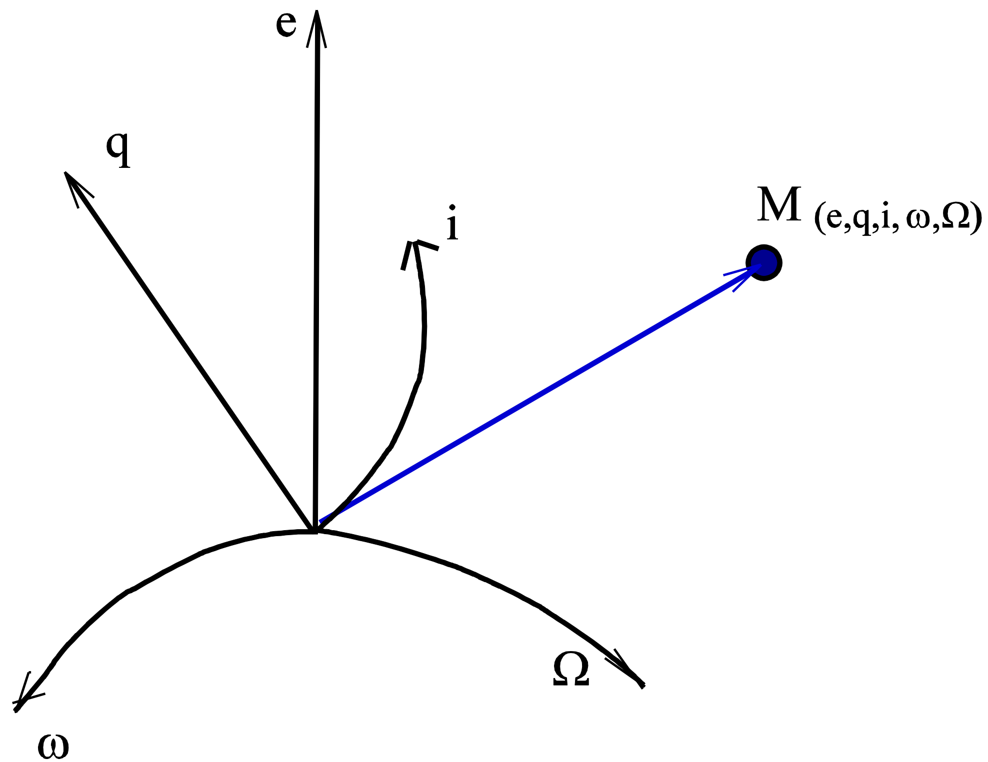
$$\mathbf{M} = \left(\mathbf{r}_m, \dot{\mathbf{r}}_m\right)$$

$$\mathbf{M} = \left(e, q, \omega, \Omega, i\right)^T$$

$$\mathbf{M} = \left(\mathbf{h}, \mathbf{e}, E\right)^T$$

$$\mathbf{M} = \left(U, \theta, \varphi, \lambda\right)^T$$

$$\mathbf{M} = \left(C_1, C_2, C_3\right)^T$$

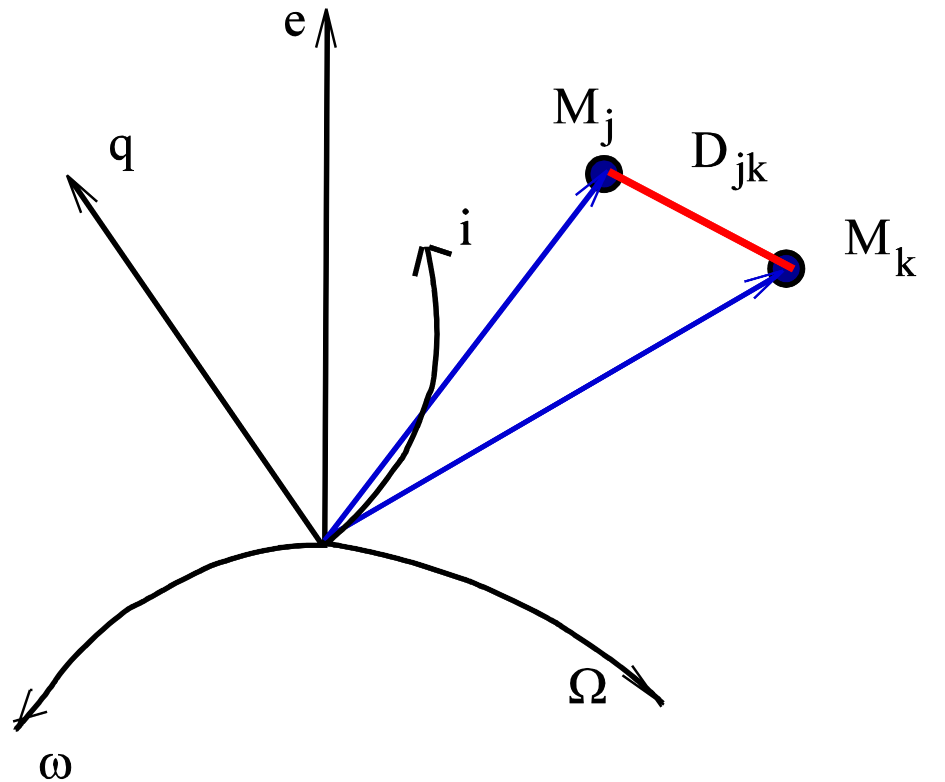


A quasi phase-space concept

Searching for meteoroid streams

A distance between meteoroids $\mathbf{M_j}$ and $\mathbf{M_k}$

$$D_{jk} = F\left(\mathbf{M}_j, \mathbf{M}_k\right)$$



Searchind for meteoroid streams

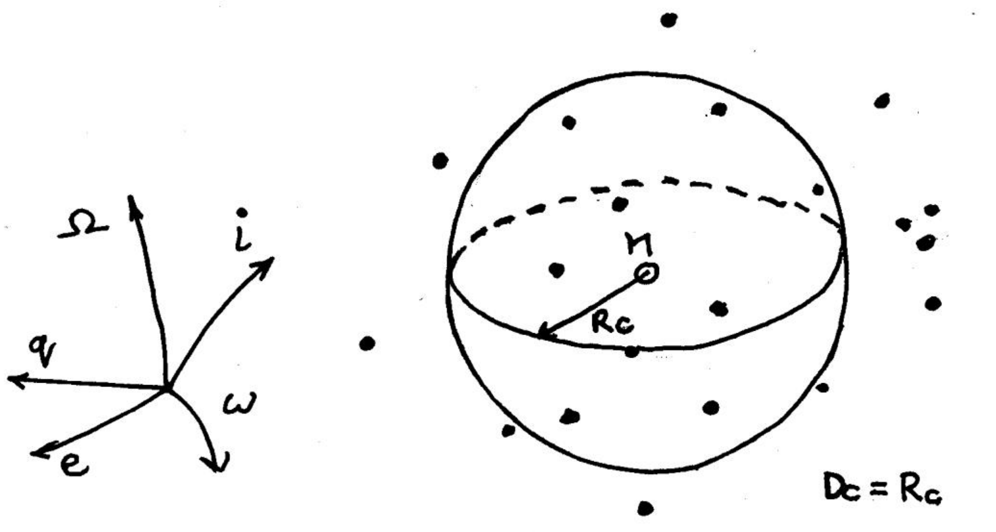
Orbital (dynamical) similarity between $\mathbf{M_j}$ and $\mathbf{M_k}$

$$D_{jk} = F(\mathbf{M}_j, \mathbf{M}_k)$$

$$D_{jk} \le D_C$$

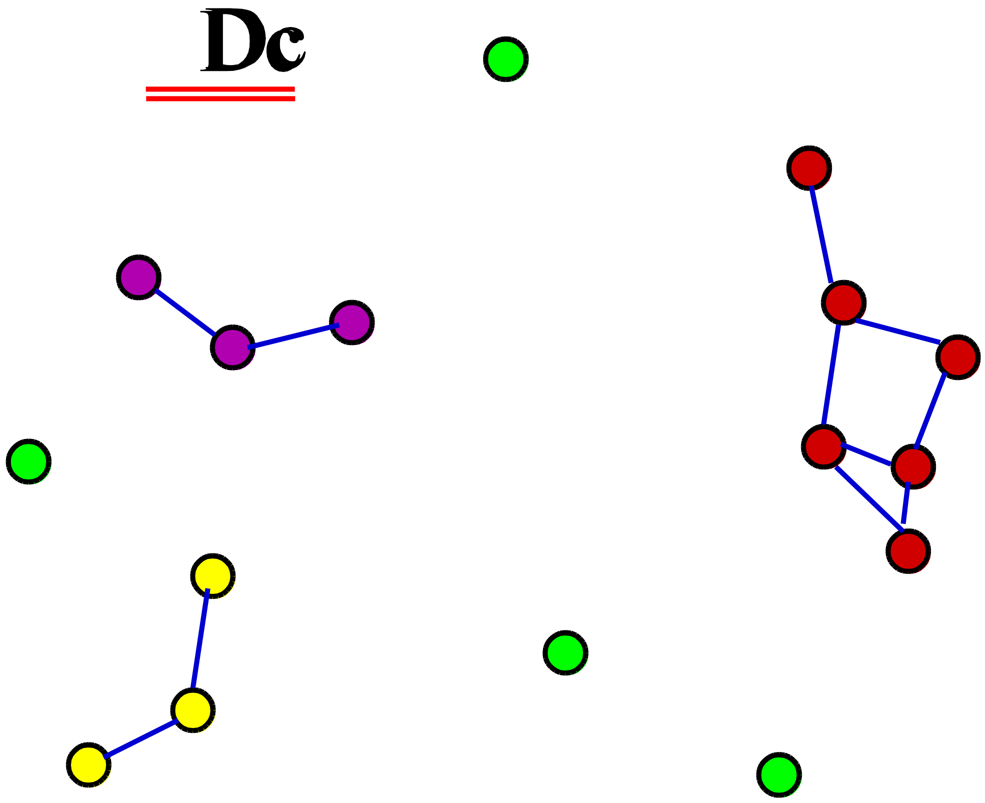
Searching for meteoroid streams

Cluster analysis algorithm



$$D_{Mk} = F\left(\mathbf{M}_M, \mathbf{M}_k\right) \leq D_C$$

Cluster analysis – single linkage algorithm



Searching for meteteoroid streams

How to find similarity threshold **D_C** ?

- using magic value 0.15,
- by democratic approach,
- using formula (Southworth and Hawkins 1963)

$$D_C = 0.2 \cdot \left(\frac{N}{360} \right)^{0.25}$$

- by statistical approach

Operational definition of a meteoroid stream

Meteoroid stream: a set of particles identified by a searching method:

- a distance function,
- a similarity threshold D_C,
- a cluster analysis algorithm.