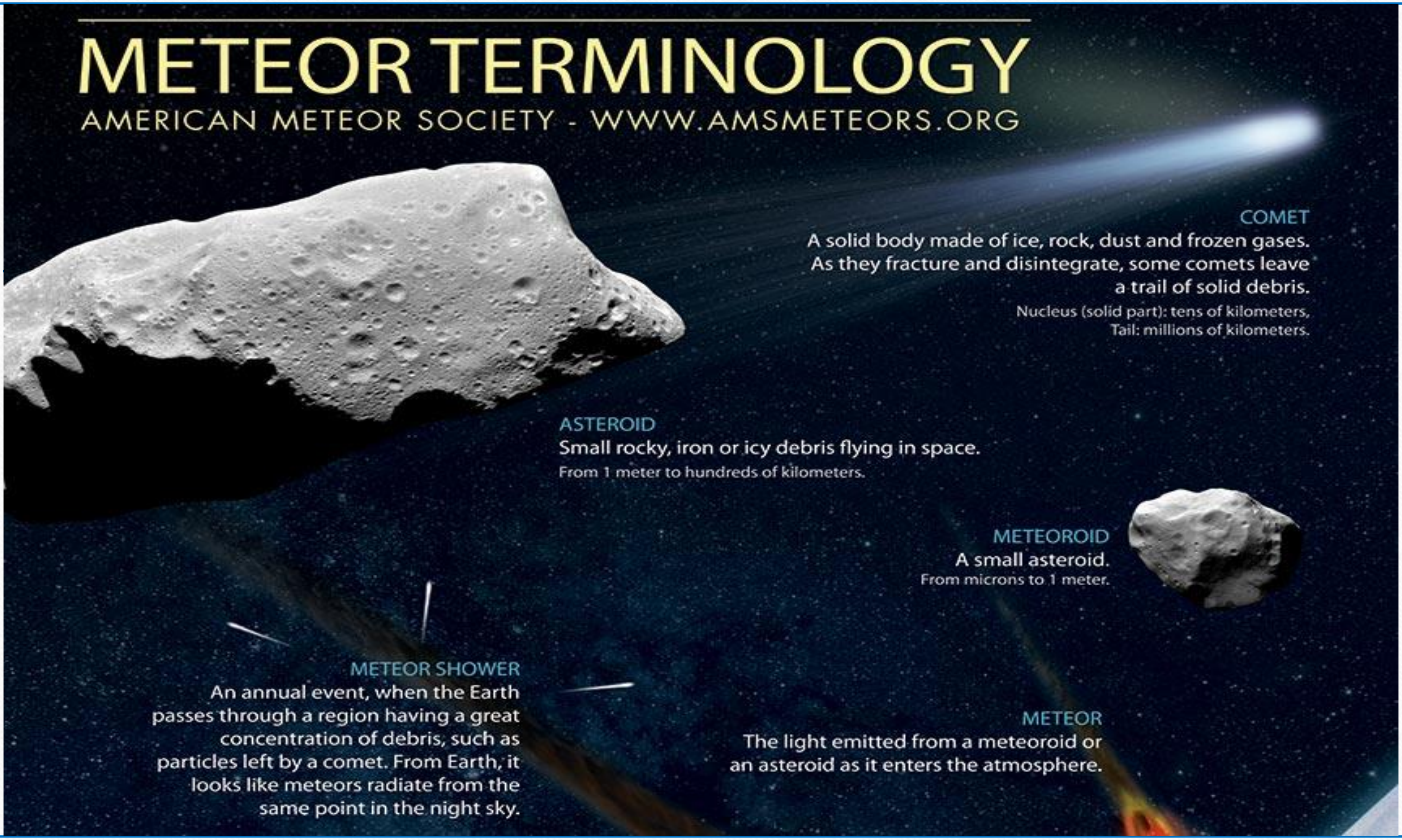
Lo studio di meteore e meteoriti con PRISMA

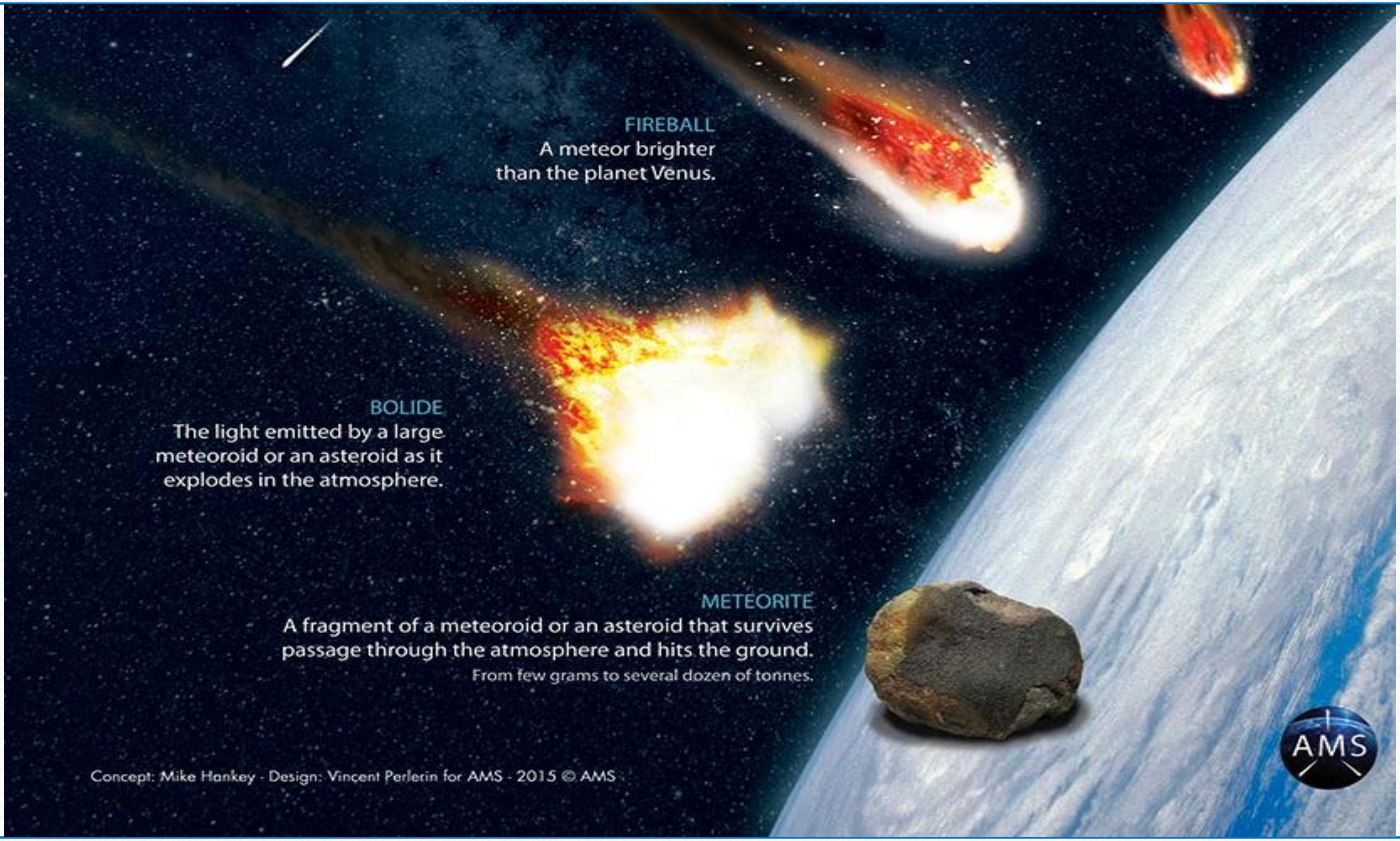
Il ritrovamento della meteorite Cavezzo

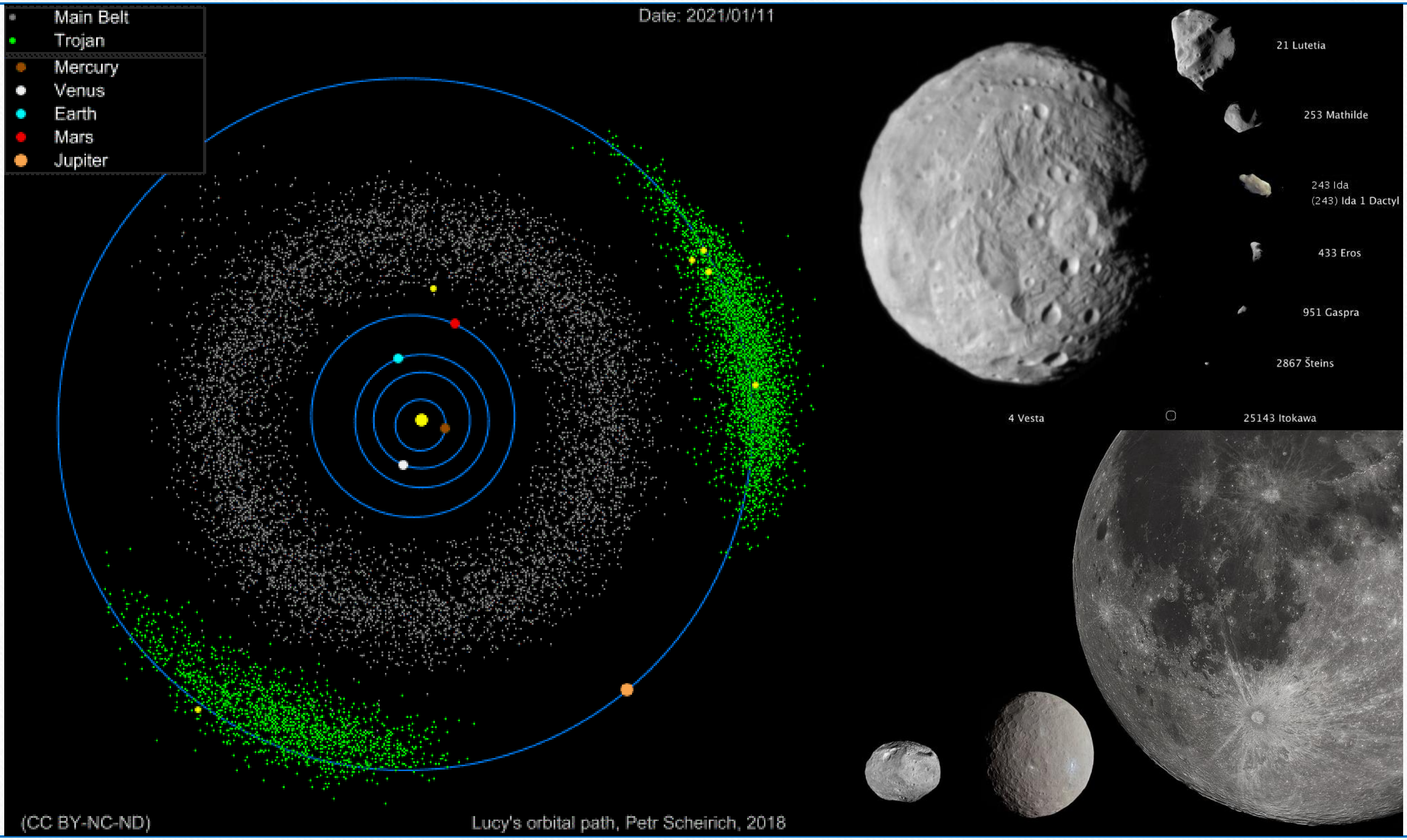
Dario Barghini

Google Meet, 23/03/2021 h 17-19

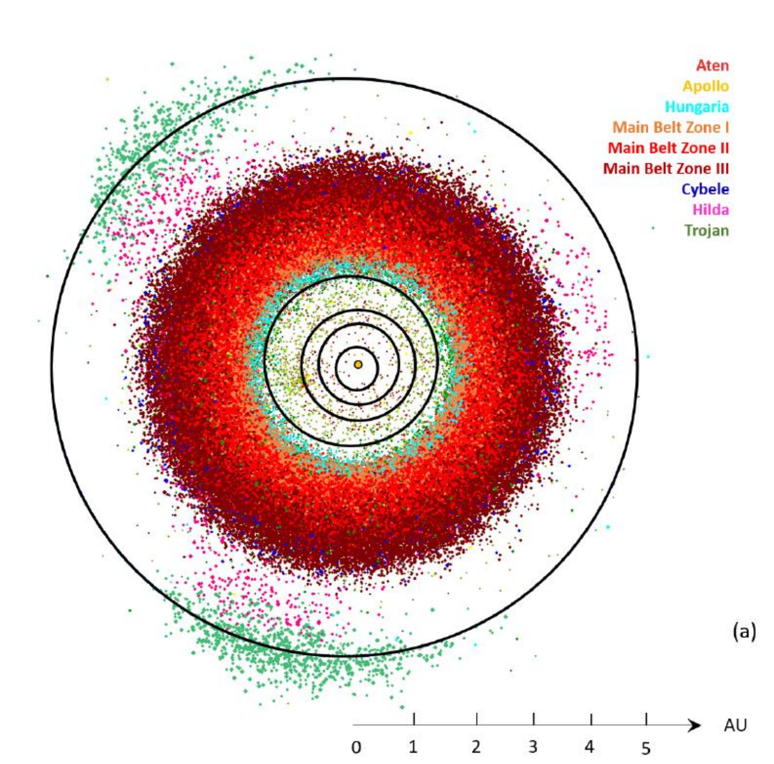
CORSO DI FORMAZIONE IN ASTRONOMIA E ASTROFISICA PER DOCENTI DI SCUOLA SECONDARIA - ANNO 2020 / 2021

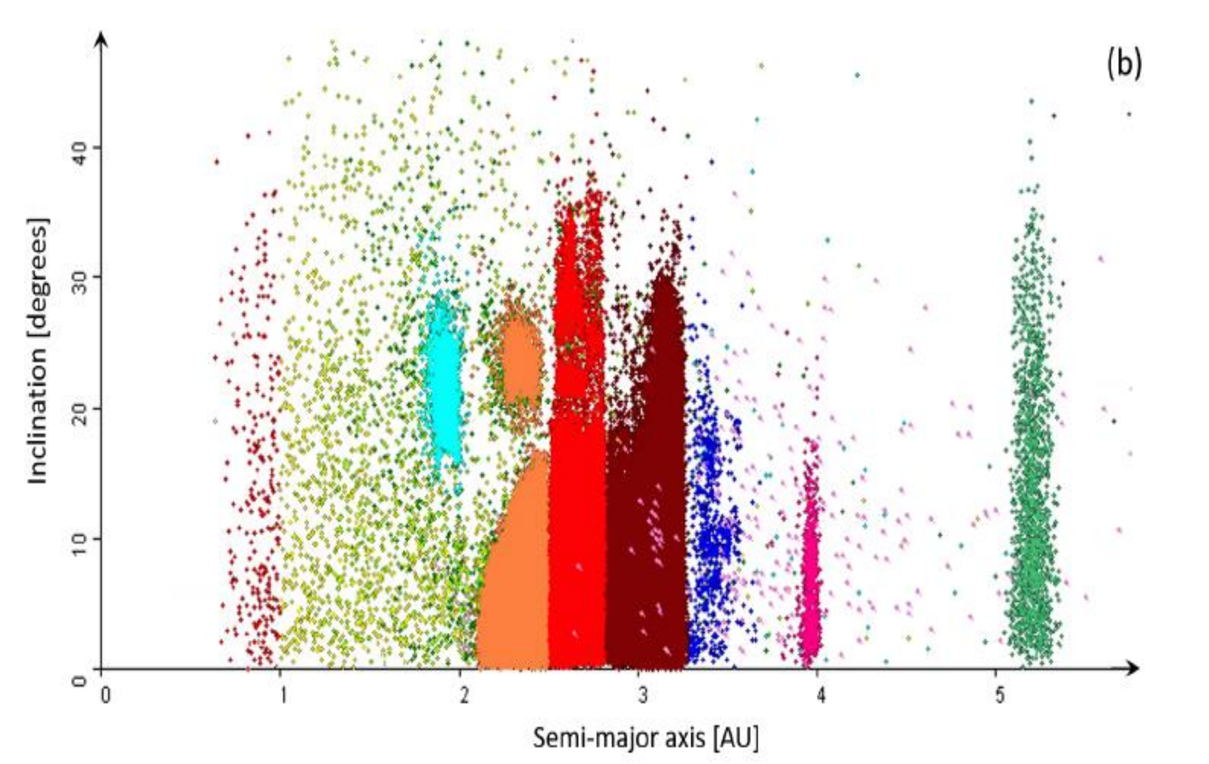

METEOR TERMINOLOGY
AMERICAN METEOR SOCIETY - WWW.AMSMETEORS.ORG
COMET
A solid body made of ice, rock, dust and frozen gases. As they fracture and disintegrate, some comets leave a trail of solid debris.
Nucleus (solid part): tens of kilometers, Tail: millions of kilometers.
ASTEROID
Small rocky, iron or icy debris flying in space.
From 1 meter to hundreds of kilometers.
METEOROID
A small asteroid.
From microns to 1 meter.
METEOR SHOWER
An annual event, when the Earth passes through a region having a great concentration of debris, such as particles left by a comet. From Earth, it looks like meteors radiate from the same point in the night sky.
METEOR
The light emitted from a meteoroid or an asteroid as it enters the atmosphere.

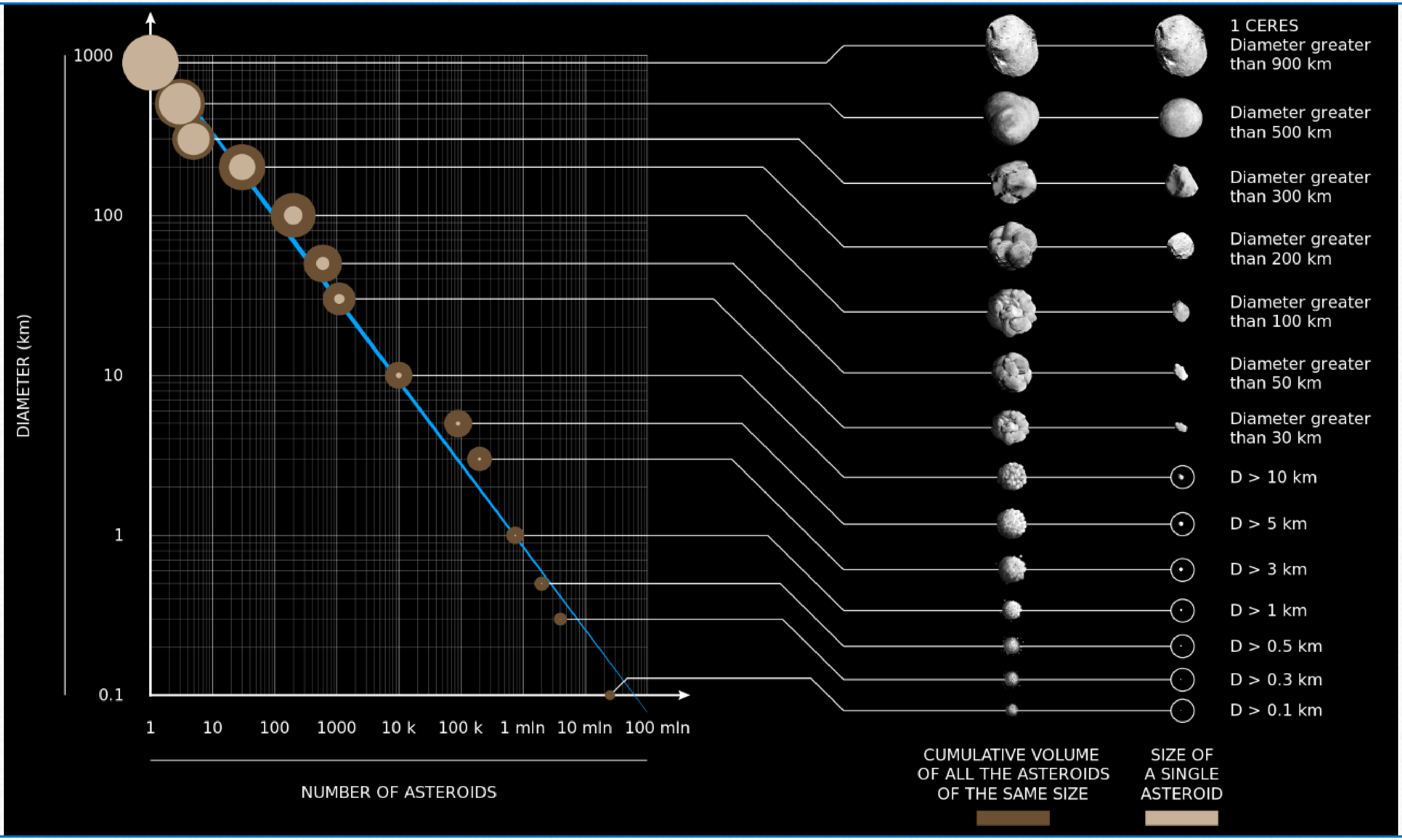

FIREBALL
A meteor brighter than the planet Venus.
BOLIDE
The light emitted by a large meteoroid or an asteroid as it explodes in the atmosphere.
METEORITE
A fragment of a meteoroid or an asteroid that survives passage through the atmosphere and hits the ground.
From few grams to several dozen of tonnes.
Concept: Mike Hankey - Design: Vincent Perlerin for AMS - 2015 © AMS
AMS


Main Belt
Trojan
Mercury
Venus
Earth
Mars
Jupiter
Date: 2021/01/11
21 Lutetia
253 Mathilde
243 Ida
(243) Ida 1 Dactyl
433 Eros
951 Gaspra
2867 Šteins
4 Vesta
25143 Itokawa
(CC BY-NC-ND)
Lucy's orbital path, Petr Scheirich, 2018

Asteroid orbital families







DIAMETER (km)
1000
100
10
1
0.1
1
10
100
1000
10 k
100 k
1 mln
10 mln
100 mln
NUMBER OF ASTEROIDS
1 CERES
Diameter greater than 900 km
Diameter greater than 500 km
Diameter greater than 300 km
Diameter greater than 200 km
Diameter greater than 100 km
Diameter greater than 50 km
Diameter greater than 30 km
D > 10 km
D > 5 km
D > 3 km
D > 1 km
D > 0.5 km
D > 0.3 km
D > 0.1 km
CUMULATIVE VOLUME OF ALL THE ASTEROIDS OF THE SAME SIZE
SIZE OF A SINGLE ASTEROID

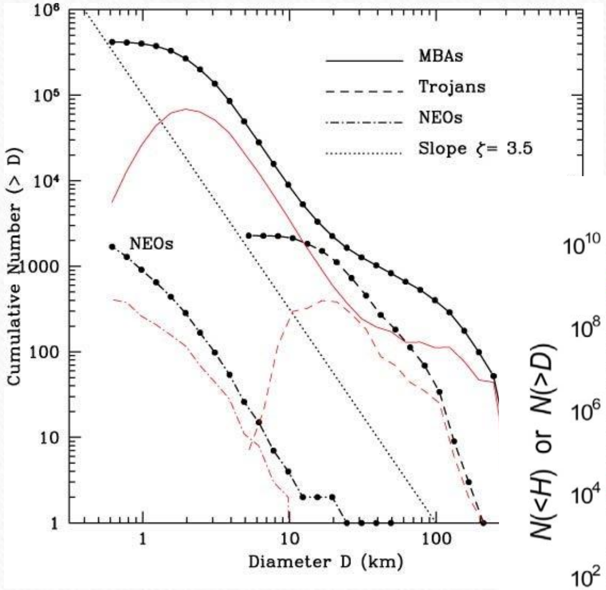
Asteroids size distribution

$$\frac{dn}{dD} \propto D^{-3.5}$$

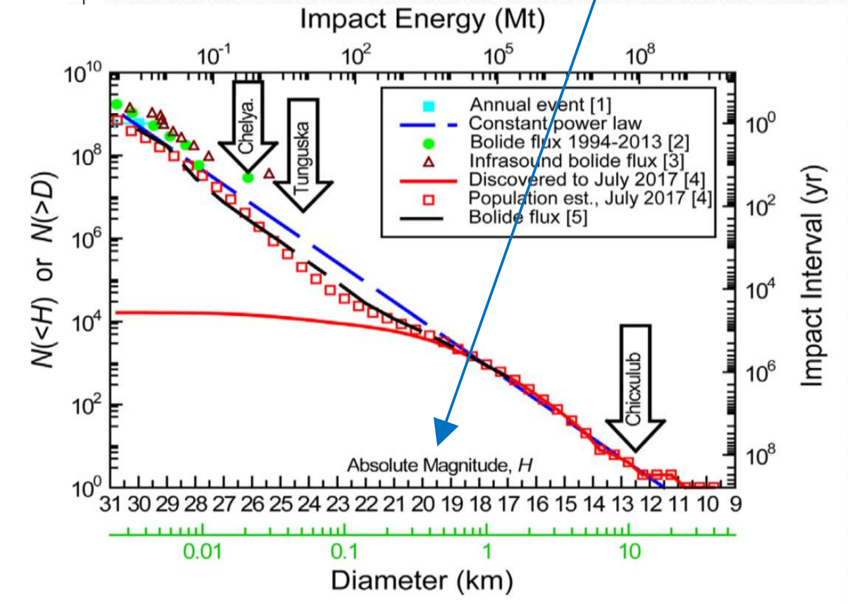
$$n(>D) \propto D^{-2.5}$$

Power law. Why?

→ Collisional equilibrium of asteroidal families



Apparent magnitude when the object is at 1 AU from both the observer and the Sun at a 0° phase angle



Near-Earth Object (NEO)

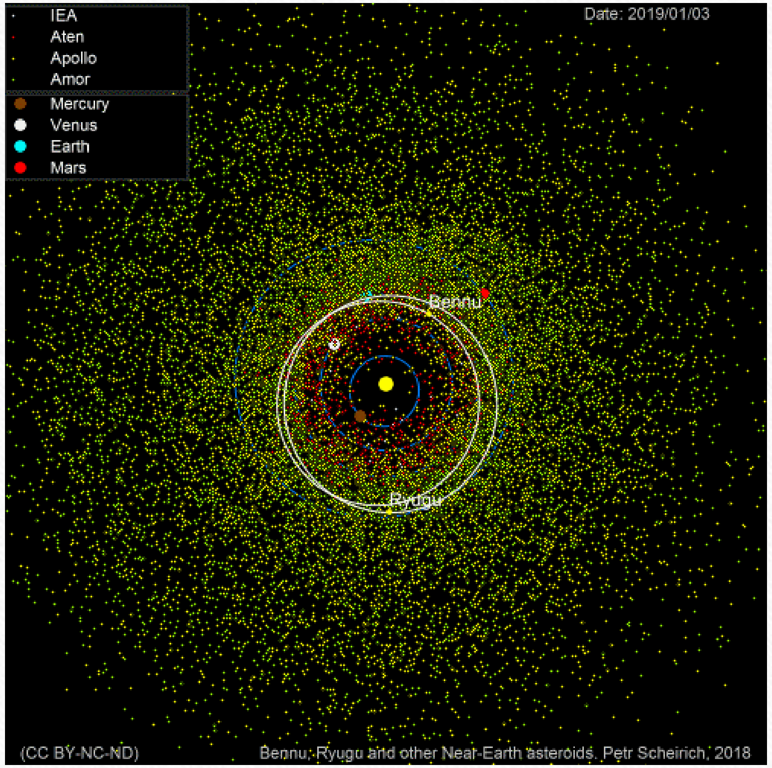
~ 20000

Minor bodies of the Solar system with orbital closest approach < 1.3 AU (1 AU ~ 150 million km)

~ 2000

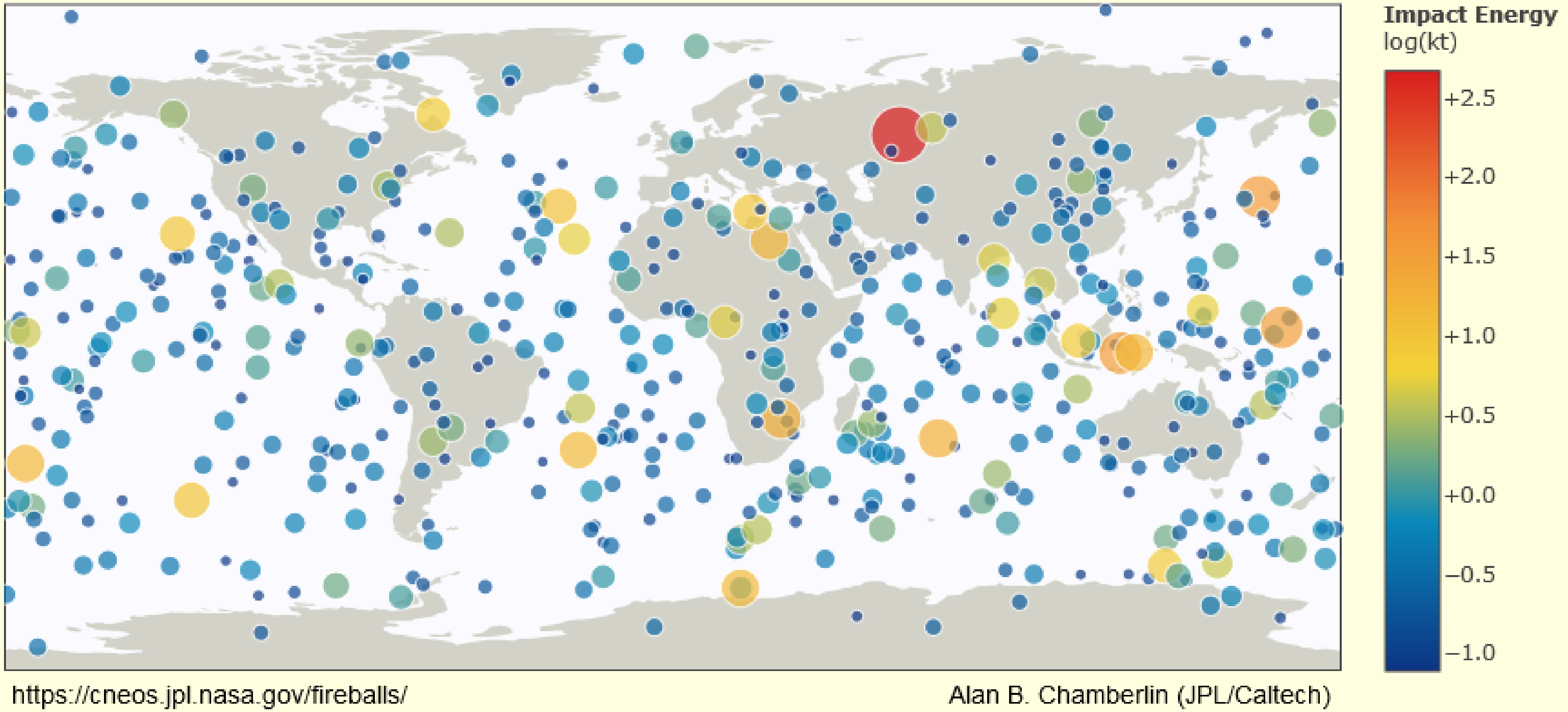
~ 150 with D > 1 km

- **NEA**: Near-Earth Asteroid
- **PHO**: Potentially Hazardous Object (with minimum orbital intersection distance of 0.05 AU and H > 22 / D > 150 m).
- **PHA** (PH Asteroid)



Fireballs Reported by US Government Sensors

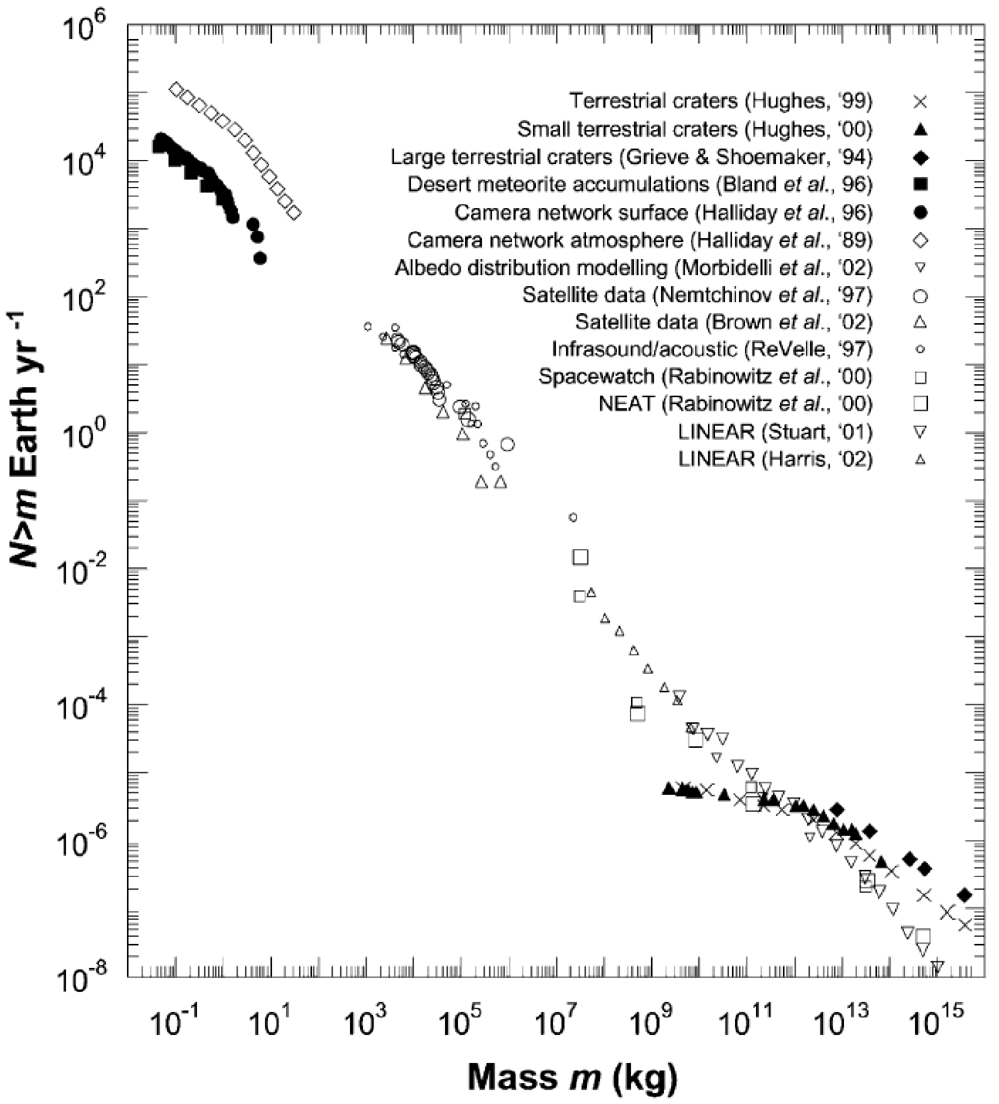
(1988-Apr-15 to 2017-Nov-19)



The rate of small impacts on Earth

TAKE-HOME message:

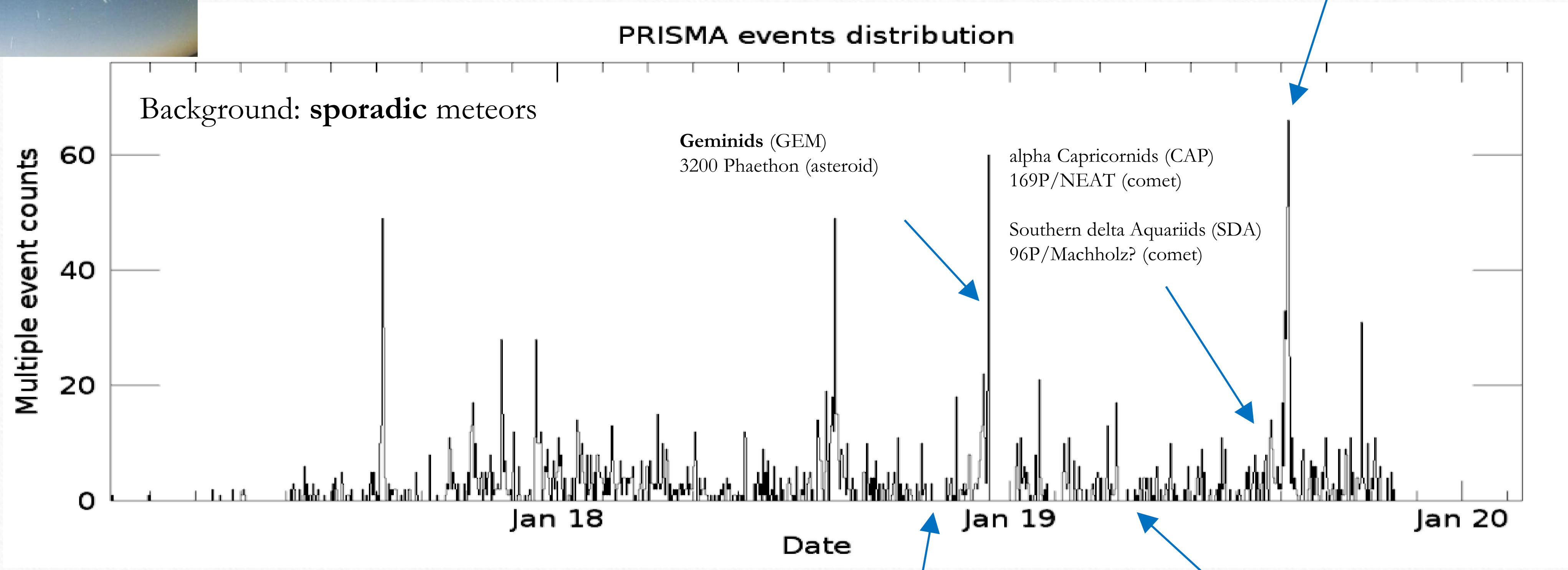
~ 1 potential fall per year over the Italian territory



(apparent) **Radiant** (point)

Meteor showers

Perseids (PER)
109P/Swift-Tuttle (comet)



and many others…

Recurrent (but not strictly) behaviour

Taurids (NTA/STA)
2005 TG10 (asteroid) /
2P/Encke (comet)

Leonids (LEO)
55P/Tempel-Tuttle (comet)

Lyrids (LYR)
C/1861 G1 Thatcher (comet)

Meteor phenomena

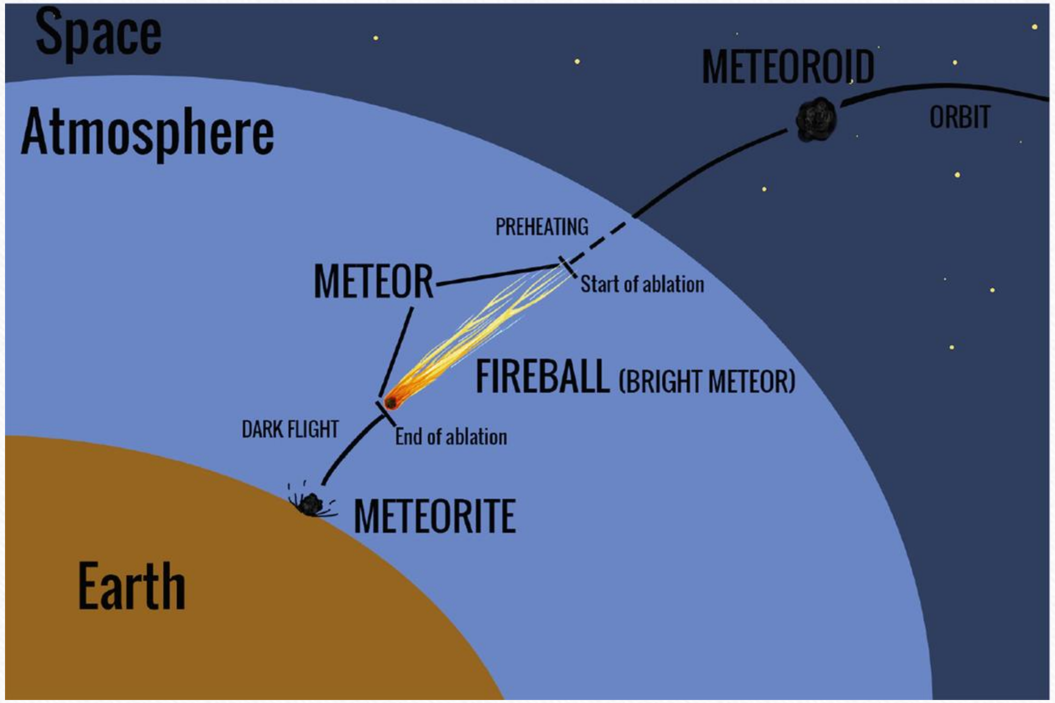
Four «regimes»:

1) Orbital motion:

- perturbation of the orbit of the parent body (gravitational, collisional)
- Intersection of the meteoroid orbit with the Earth

→ Impact velocity (in the Earth's RF) given by the (vectorial) sum of the Earth's speed (V_o~ 30 km/s) and the meteoroid one

… next slide



Meteor phenomena

Four «regimes»:

only Earth's gravity

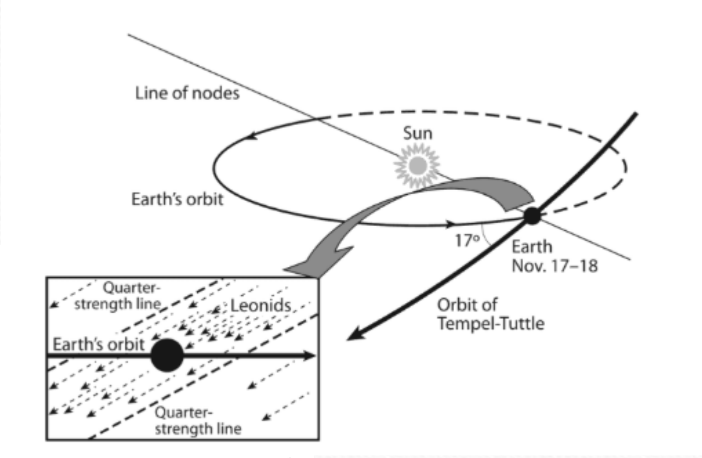
$$\frac{1}{2}mV^2 = \frac{GM_O m}{r} \text{ with } r = R_O + 100 \text{ km}$$

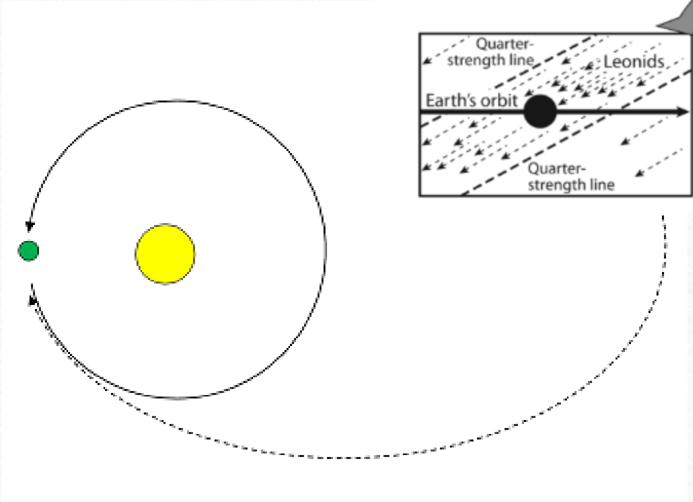
$$\sim V_o + \sqrt{2}\, V_o$$

1) Orbital motion:

Entry velocity between **11 and 72 km/s**

- Asteroids (and meteoroids) tipically have a **prograde orbits**, so that the vectorial sum is tipically a «difference» of modulus
  → asteroidal component – «low» velocity
- Comets can have **retrograde orbits**
  → cometary component – «high» velocity





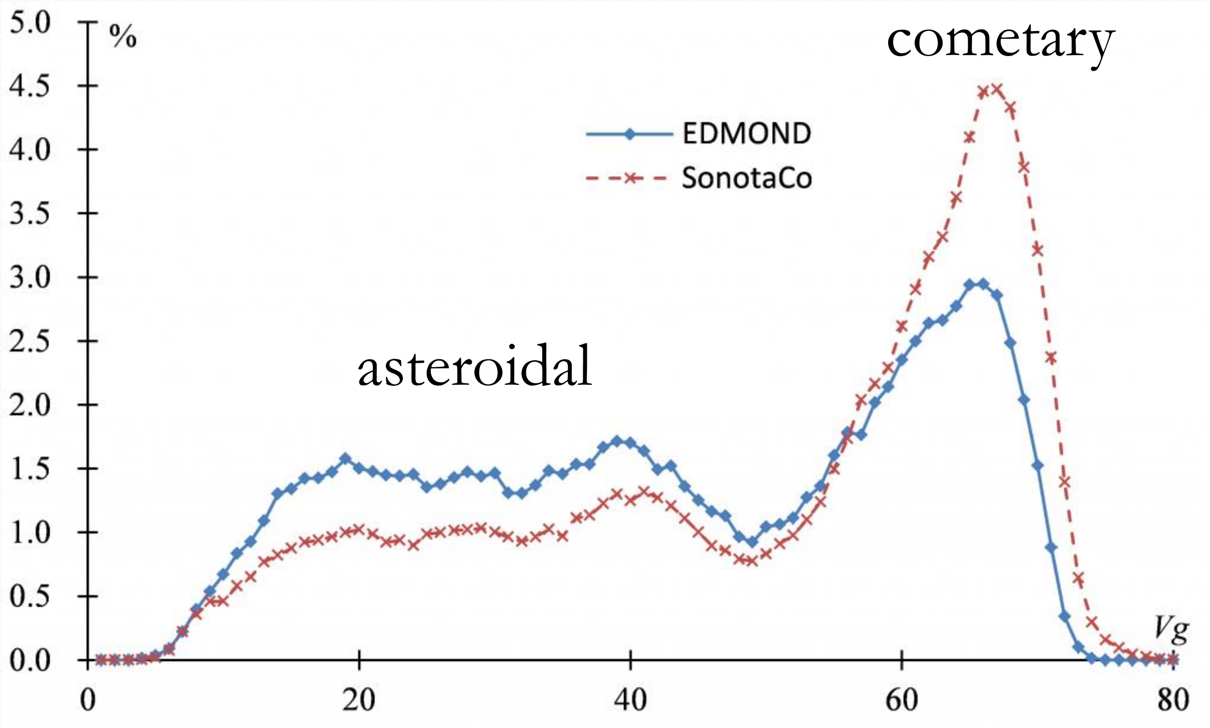
Meteor phenomena

Four «regimes»:

1) Orbital motion:

Entry velocity between **11 and 72 km/s**

- <u>Asteroids</u> (and meteoroids) tipically have a **prograde orbits**, so that the vectorial sum is tipically a «difference» of modulus
  → asteroidal component – «low» velocity
- <u>Comets</u> can have **retrograde orbits**
  → cometary component – «high» velocity

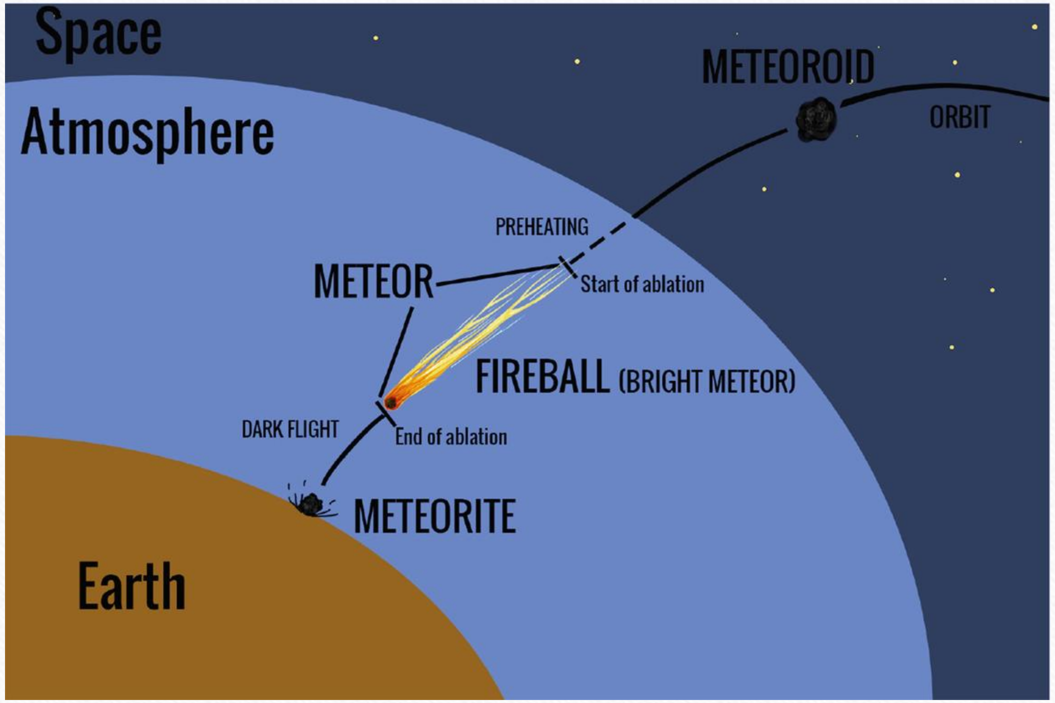


Meteor phenomena

Four «regimes»:

2) Pre-heating:

- From 300 to 100 km of altitude the body starts to «feel» the Earth's atmosphere
- The **surface temperature quickly rise** (500-1000 K) but the inside stays approximately unheated (except for meteor dust)
- Heat conductivity (radiation transfer for small bodies)
- **Surface tension** → spallation



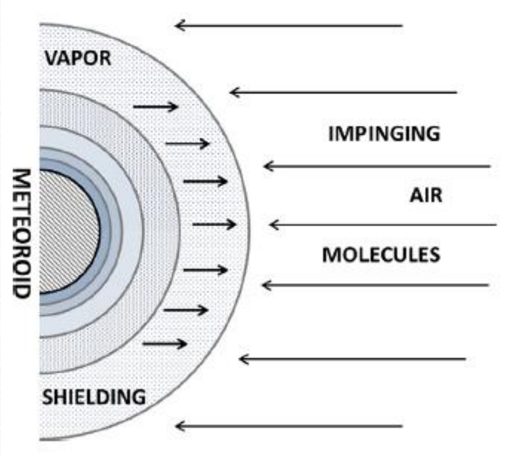
Meteor phenomena

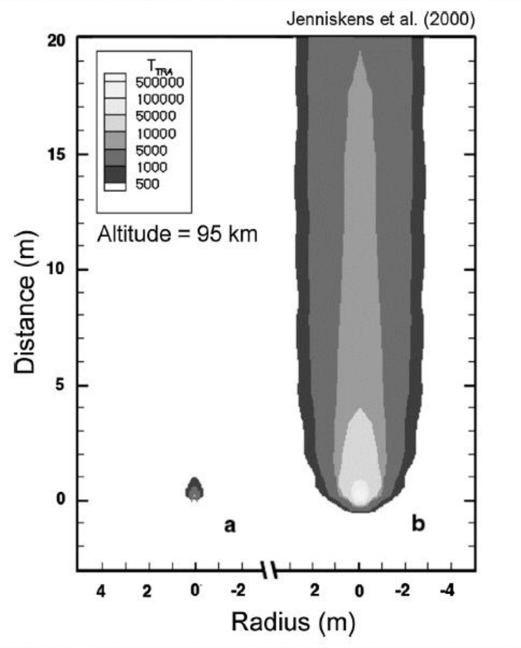
Four «regimes»:

3) Ablation:

- The pre-heating starts to melt the body
- At ~ 2500 K, **evaporation** starts
- **Light emission** due to ionization of elements + black body radiation
- Energy loss due to ablation competes with **deceleration** (relevant only in low atmosphere)
- Possible phenomena: fragmentation and/or flares

If the meteoroid is **slowed down until ~ 10 km/s** and reaches the **low atmosphere** (< 30 km) …



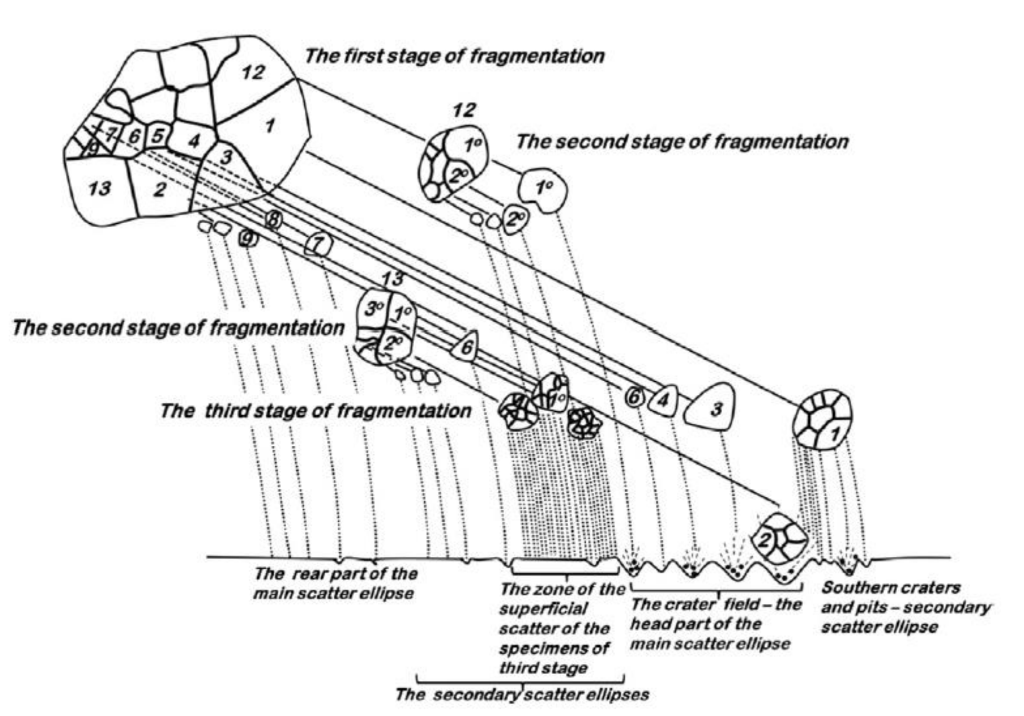


Meteor phenomena

Four «regimes»:

4) Dark-flight:

- The **light emission ceases** because there is not enough kinetic energy to either evaporate or provide heating
- The body decelerate until it begins to «**free-fall**» to the surface of the Earth
- Sensitive to **wind** intensity and direction
- Impact speed between tens to several hundreds of m/s



Meteor phenomena

Five or six «regimes»:

5) Impact crater

(~ 200 identified on the Earth surface)

...

6) Mass extinction

Meteor/Fireball observations

- Meteor **photography** has been used since 1885 (first meteor photograph in Prague by L. Weinek)
- <u>1940</u>: major breakthrough → **rotating shutter** for time marks
- <u>1950</u>: first **multi-station** observation program (Ondřejov Observatory of Czechoslovakia, 30 cameras)
- <u>1960</u>: first **meteorite recovery** from systematic observation survey

Fireball Networks

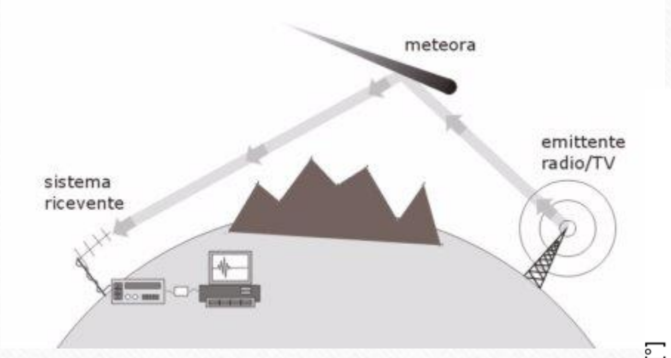
- 1960: start of several **Fireball Networks**. The first one was the Czechoslovakian Fireball Network (now called European Fireball Network).

… In the meanwhile → Technology progress allowed **video observations**

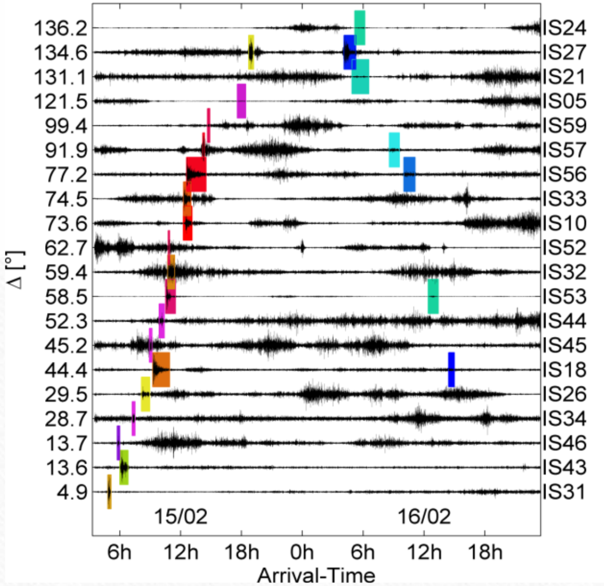
- 2014: **FRIPON** (Fireball Recovery and InterPlanetary Observation Network)
- 2016: **PRISMA** (Prima Rete Italiana per la Sorveglianza Sistematica di Meteore ed Atmosfera)
- Today: ~ **2% of the Earth surface** is covered by Fireball Networks

Alternative methods to observe meteors

- **Meteor scatter** (radio meteors): observe the forward scatter generated by the meteor ionized trail of a radio-frequency signal emitted by a radar source (*e.g.* GRAVES in France)
- **Infrasounds**: detect the low-frequency components of shock waves generated by the meteor impact in the atmosphere
- Observe **meteors from space**



These methods don't suffer from bad atmospheric conditions, as opposed to optical observations



PRISMA

Prima Rete Italiana per la Sorveglianza Sistematica di Meteore ed Atmosfera

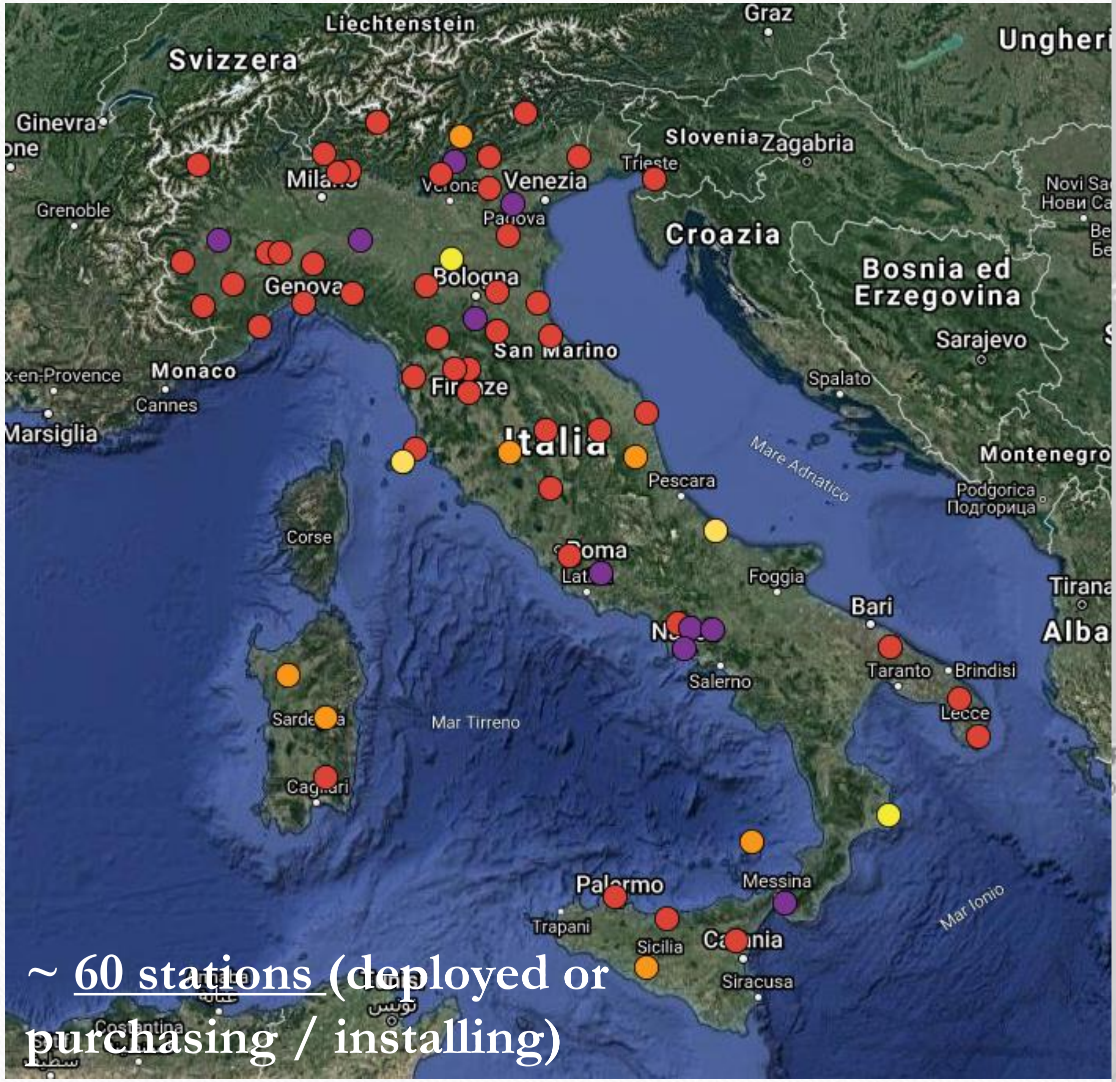
i.e.

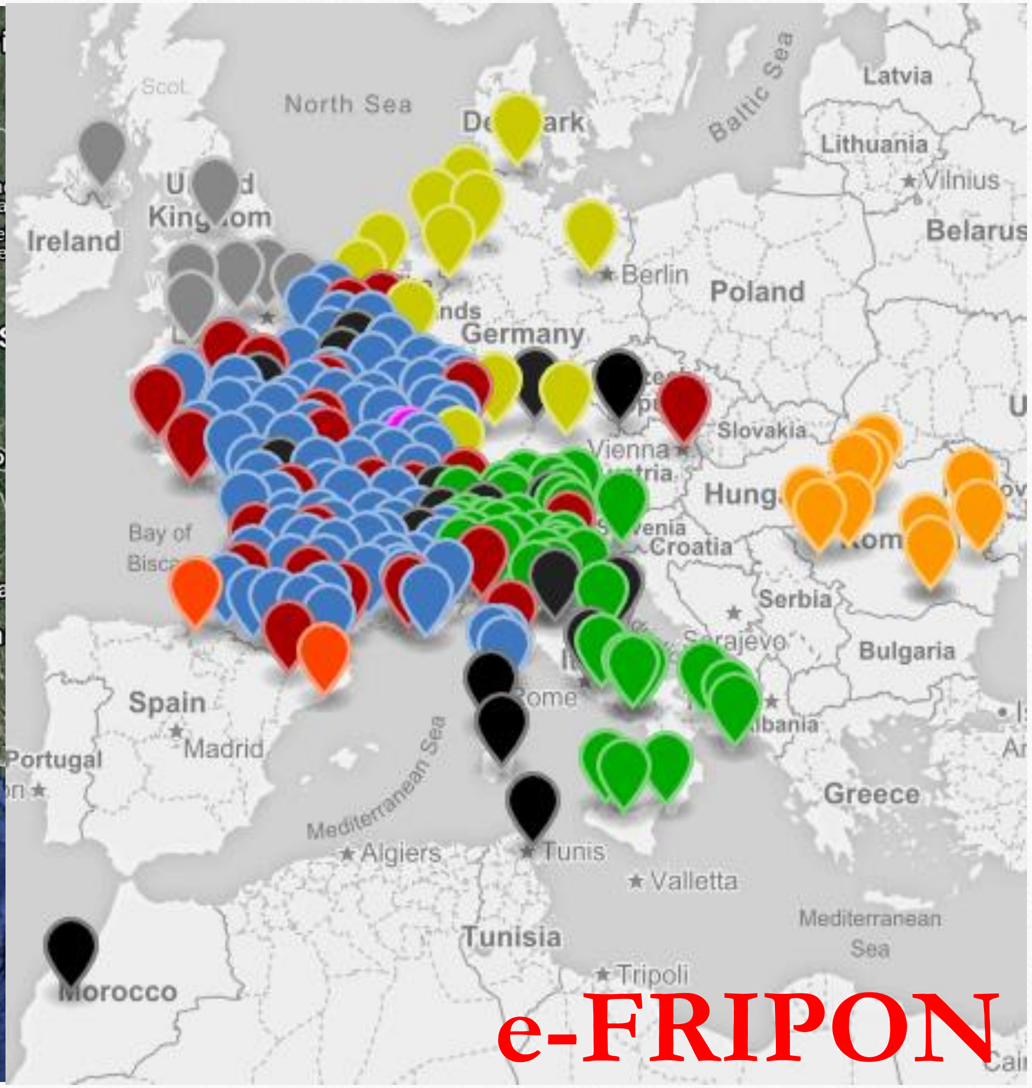
First Italian Network for the Systematic Surveillance of Meteors and Atmosphere

- Started in mid-2016 at the Astrophysical Observatory of Turin - National Institute of Astrophysics (**INAF – OATO**) with the first camera (ITPI01 – Pino Torinese)
- Partnered with the twin-project FRIPON (France)
- Currently **led by INAF** in collaboration with many italian universities, professional/amateur observatories, schools, associations…

Prima Rete Italiana Sorveglianza Sistematica Meteore & Atmosfera

PRISMA


~ 60 stations (deployed or purchasing / installing)
Liechtenstein
Graz
Svizzera
Ungheri
Ginevra
Grenoble
Milano
Verona
Venezia
Padova
Trieste
Slovenia
Zagabria
Croazia
Bosnia ed Erzegovina
Sarajevo
Genova
Bologna
San Marino
Monaco
Cannes
Marsiglia
Firenze
Italia
Spalato
Montenegro
Podgorica
Pescara
Mare Adriatico
Corse
Roma
Latina
Foggia
Bari
Tirana
Alba
Napoli
Salerno
Taranto
Brindisi
Lecce
Sardegna
Mar Tirreno
Cagliari
Palermo
Messina
Mar Ionio
Trapani
Sicilia
Catania
Siracusa

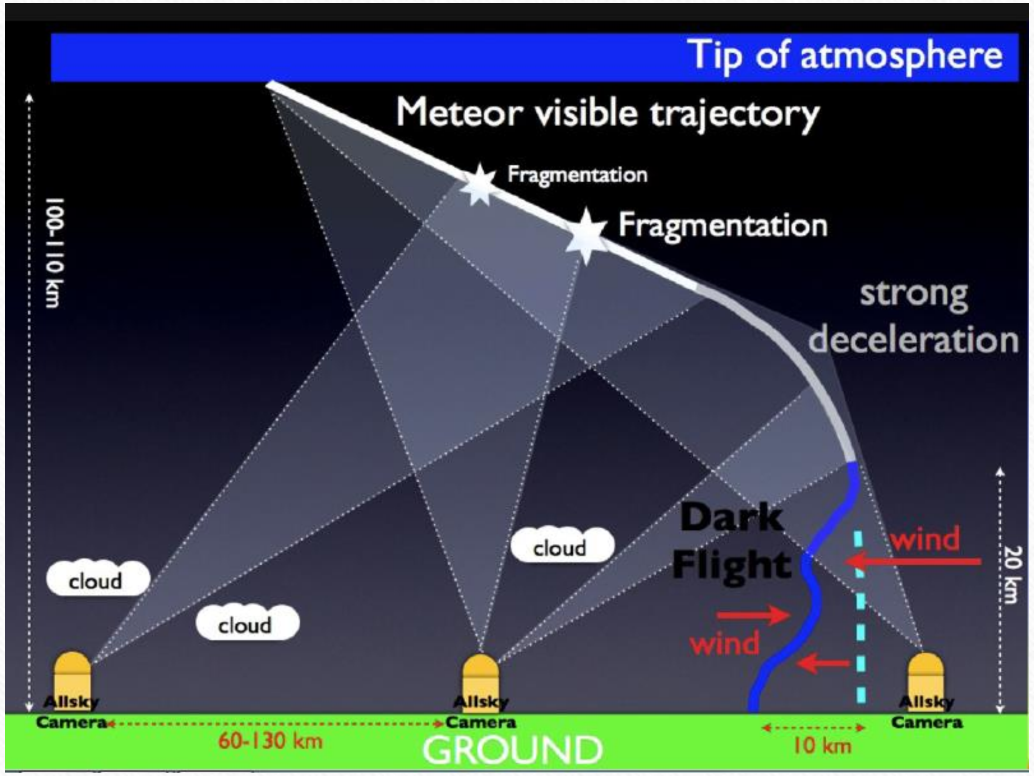

e-FRIPON
North Sea
Denmark
Baltic Sea
Latvia
Lithuania
Vilnius
Belarus
United Kingdom
Ireland
Berlin
Poland
Germany
Slovakia
Vienna
Hungary
Croatia
Serbia
Bay of Biscay
Sarajevo
Bulgaria
Spain
Madrid
Portugal
Rome
Albania
Greece
Mediterranean Sea
Algiers
Tunis
Valletta
Tunisia
Tripoli
Morocco

Observational strategy

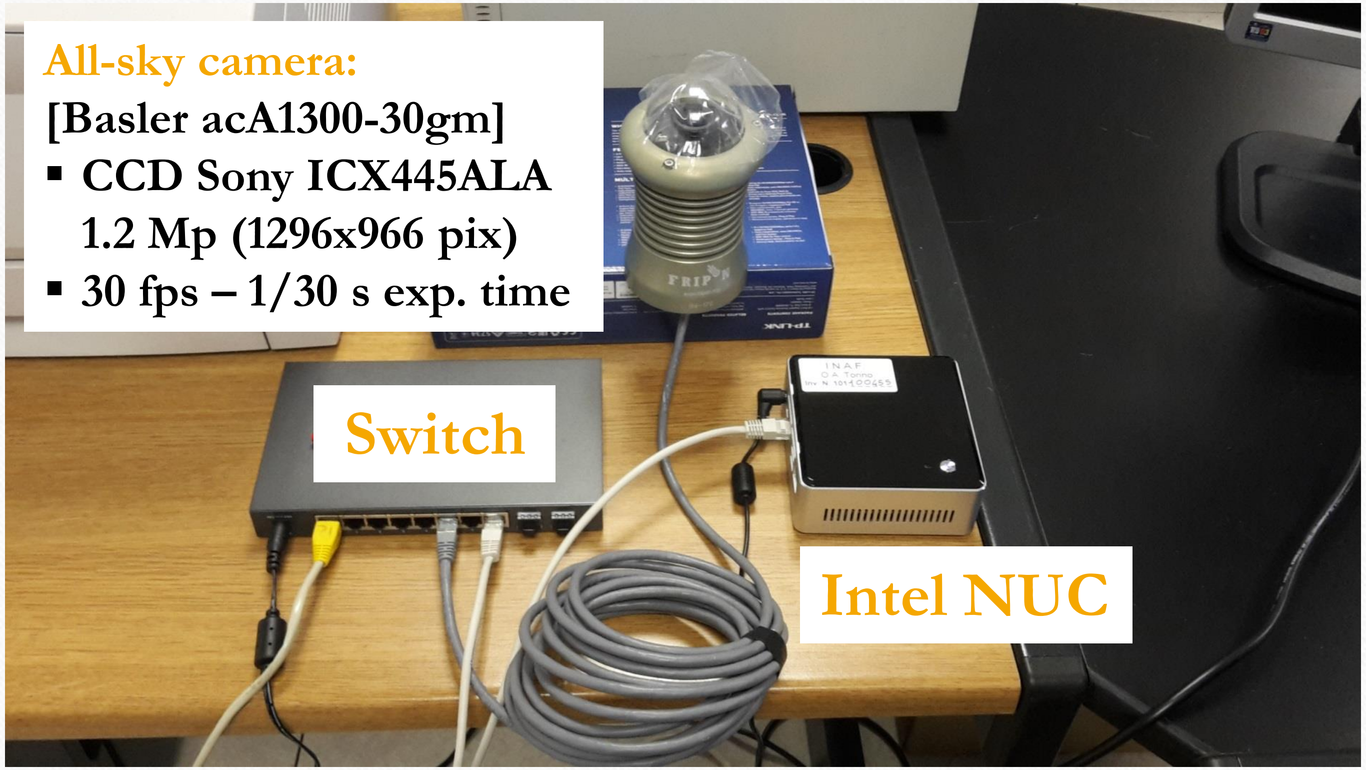
Observe the atmospheric entry of the same event from different stations to reconstruct the 3D trajectory (**triangulation**)

<u>Optimal grid spacing</u>: ~ **80 km**

- trade-off between oversampling and only-single-events case
- also an economical matter (both money and time)
- the denser the network the highest the magnitude detectable, but…

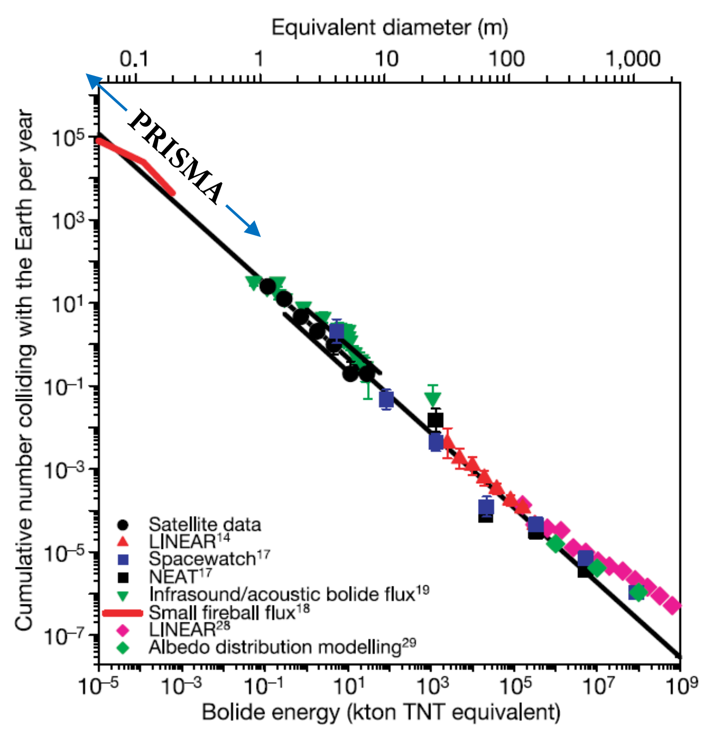


PRISMA Station: ALL-SKY camera
(FISH-EYE)



What PRISMA is looking at?

- **Apparent magnitude $m < 0$** ($m = 0$ for very dark observational sites, usually -1 is the limiting magnitude)
- Diameter greater than **1 cm**, mass greater than few grams
- World-wide, 1-meter meteoroid impacts occur 50 times per years (1 each 10 years over France, even less over Italy). Last «big» recorded events:
  - Almahata Sitta (Sudan, 07/10/2008, 3 m) → 2008 TC3 meteoroid discovered one day before the fall
  - Chelyabinsk (Russia, 15/02/2013, 17 m)
- Realistically speaking, PRISMA looks **between 1 cm and 1 m**

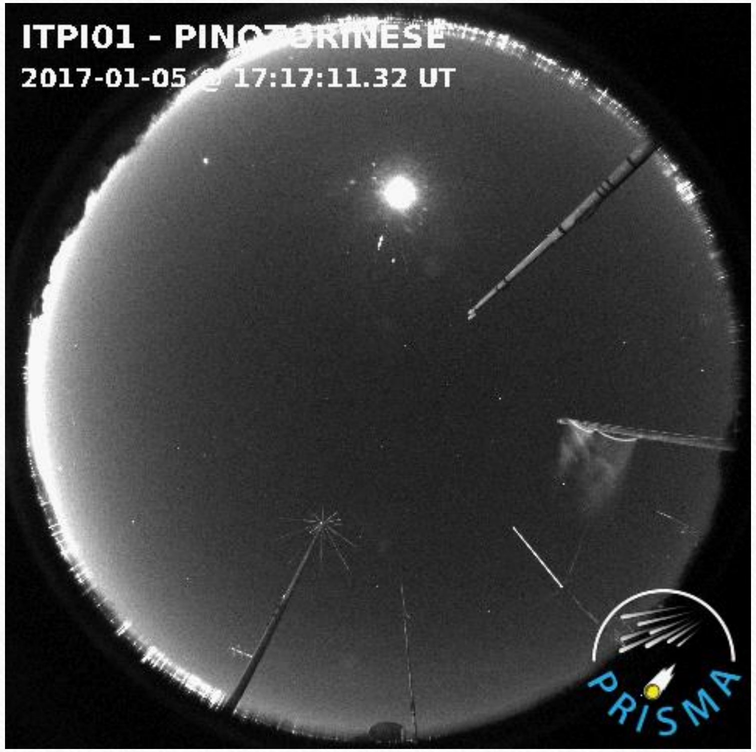


PRISMA calibration data

Astrometry & Photometry

Problem: Almost no stars arise from background on 1/30 s meteor frames

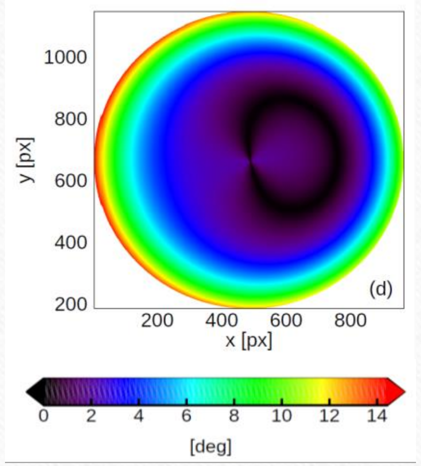
- **Captures**: 5 s exposure images each 10 minutes
- About 140 captures / day, with 100-300 stars / captures

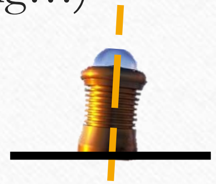


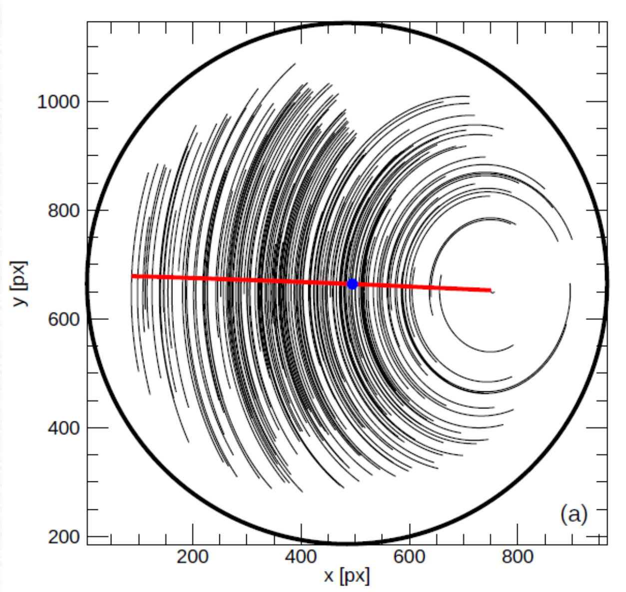
PRISMA calibration data

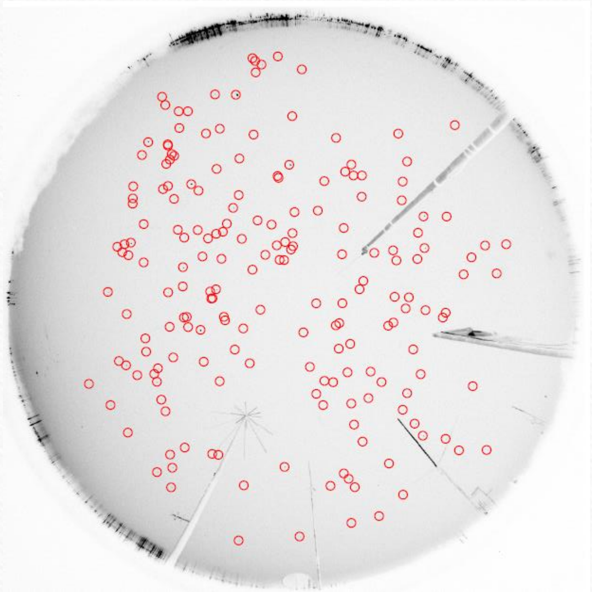
Astrometry (positional calibration)

- Automatic identification of stars and catalogue association
- Distortion correction
  (fish-eye, zenith pointing…)









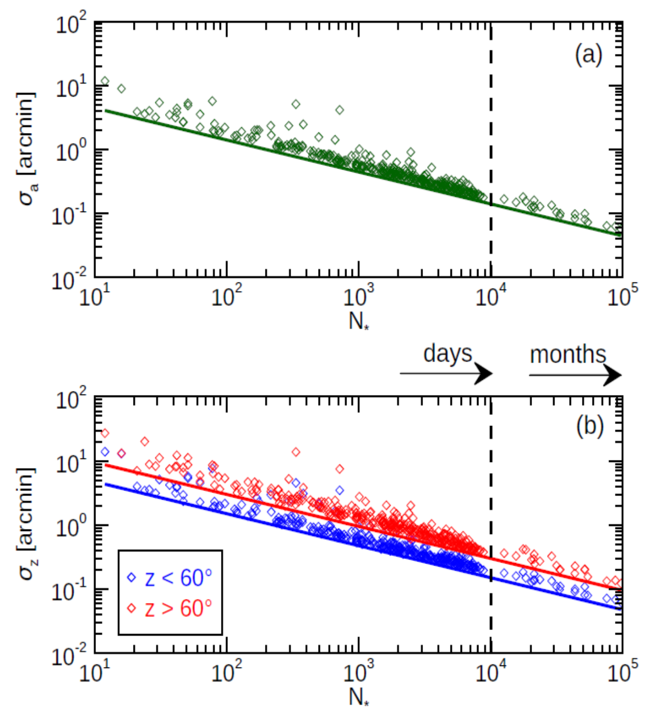
PRISMA calibration data

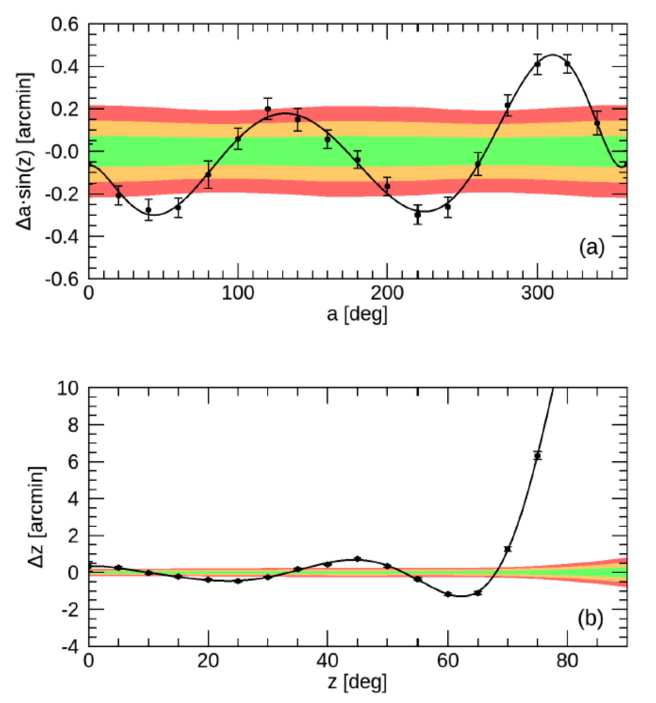
Random projection error

Systematic residuals

Azimuth

Zenith distance



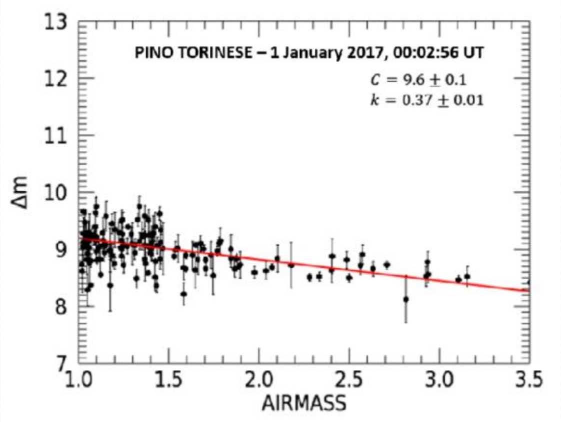


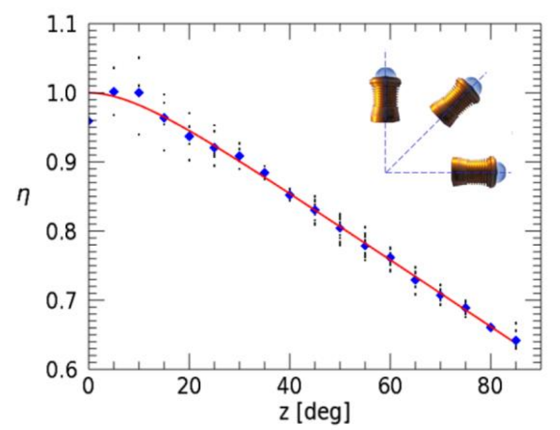
PRISMA calibration data

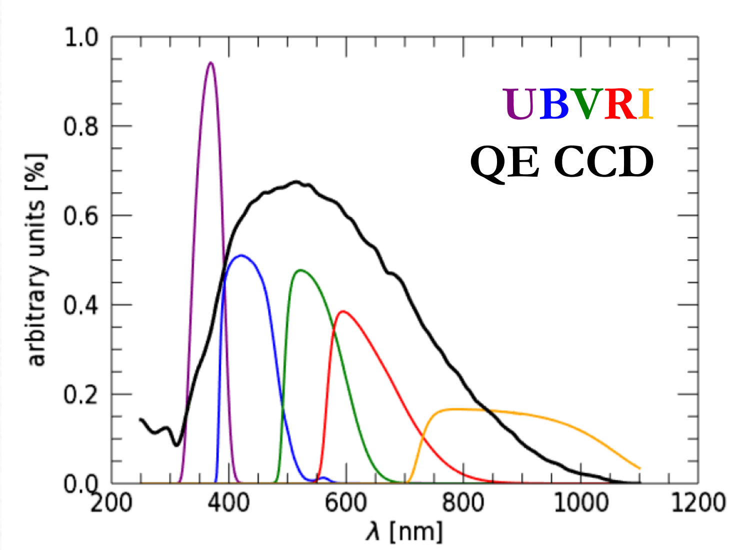
Photometry (intensity calibration)

PRISMA: wide-band photometry

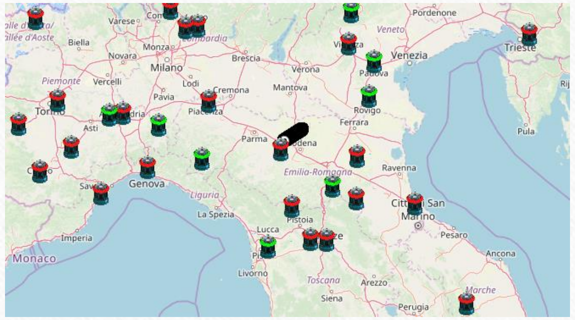
- Radial efficiency loss
- Magnitude zero-point and atmospheric extinction







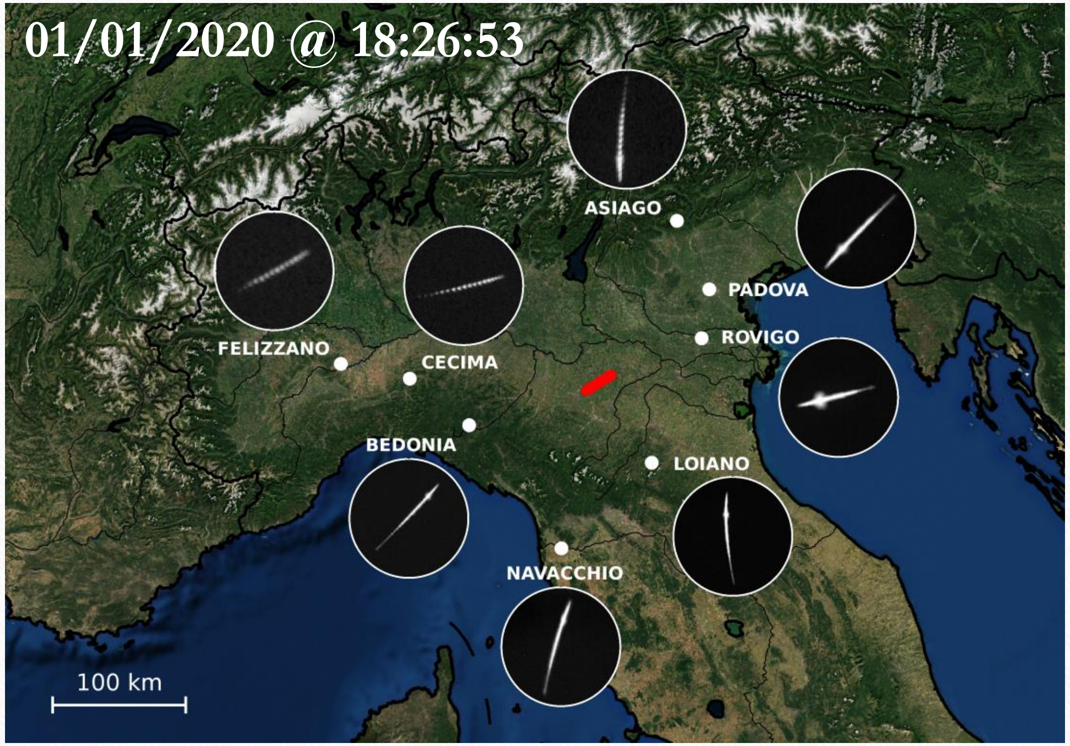
IT20200101
New Year bolide (Cavezzo)



IT20200101
New Year bolide (Cavezzo)

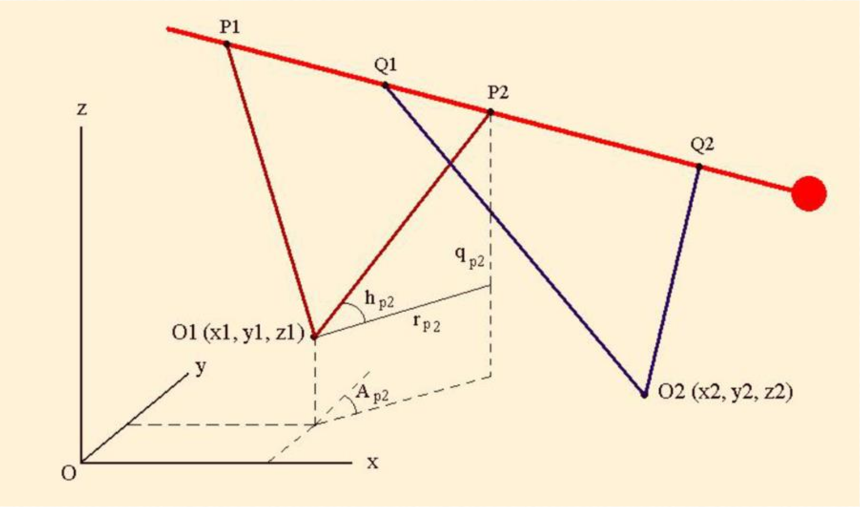
- Captured by 8 PRISMA cameras
  @ 18:26:52.9 – 58.5 (5.6 s)
- Good geographical distribution of cameras
- 75-200 km distance

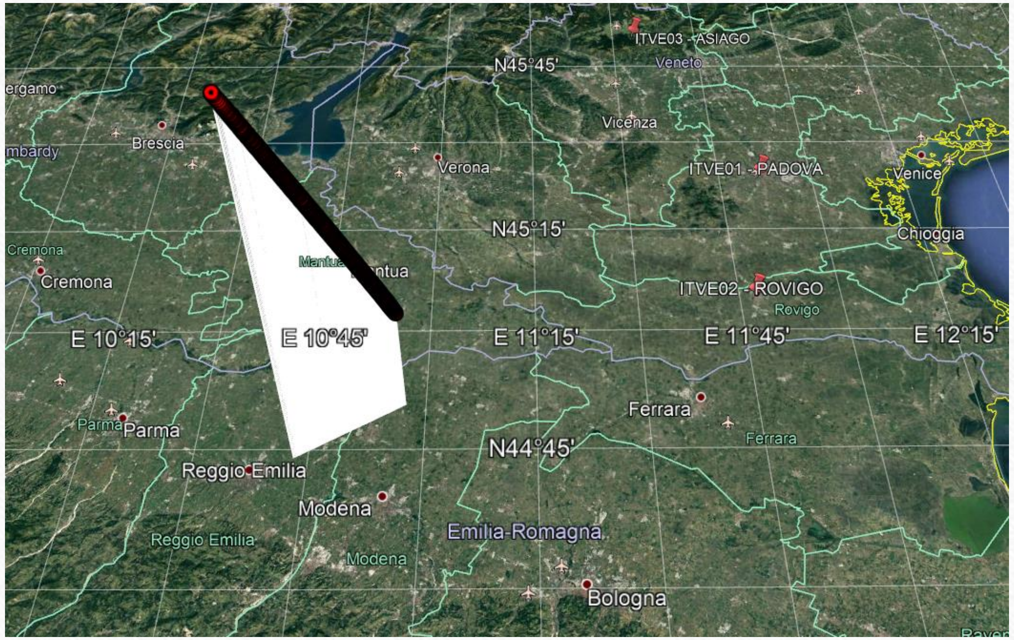
Station name	Lat. N [°]	Long. E [°]	El. [m]
Bedonia (ITER04)	44°30′27.″7	09°37′57.″0	550
Rovigo (ITVE02)	45°04′54.″0	11°47′42.″2	15
Felizzano (ITPI03)	44°54′45.″0	08°26′14.″0	114
Loiano (ITER01)	44°15′23.″7	11°19′54.″4	787
Cecima (ITLO03)	44°48′52.″7	09°04′43.″6	670
Navacchio (ITTO02)	43°40′59.″5	10°29′29.″9	15
Padova (ITVE01)	45°24′07.″0	11°52′06.″7	64
Asiago (ITVE03)	45°50′57.″9	11°34′06.″0	1370



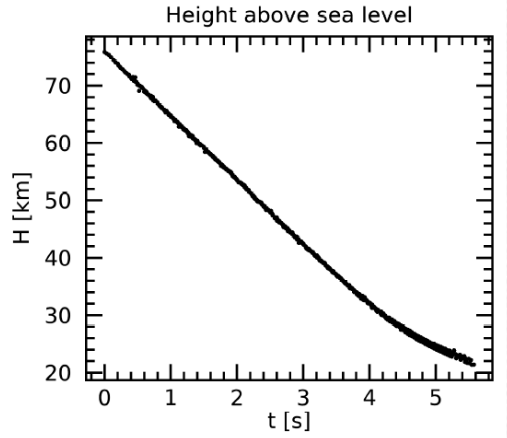
IT20200101
Atmospheric trajectory

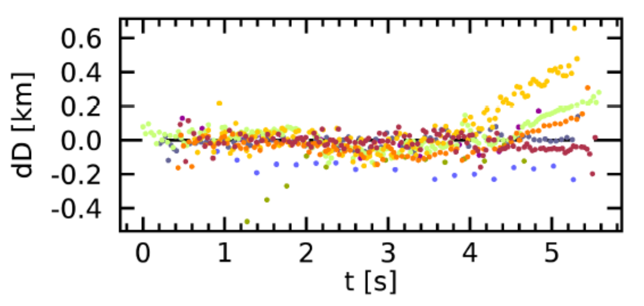
- The 3D atmospheric trajectory is reconstructed with the **triangulation method**

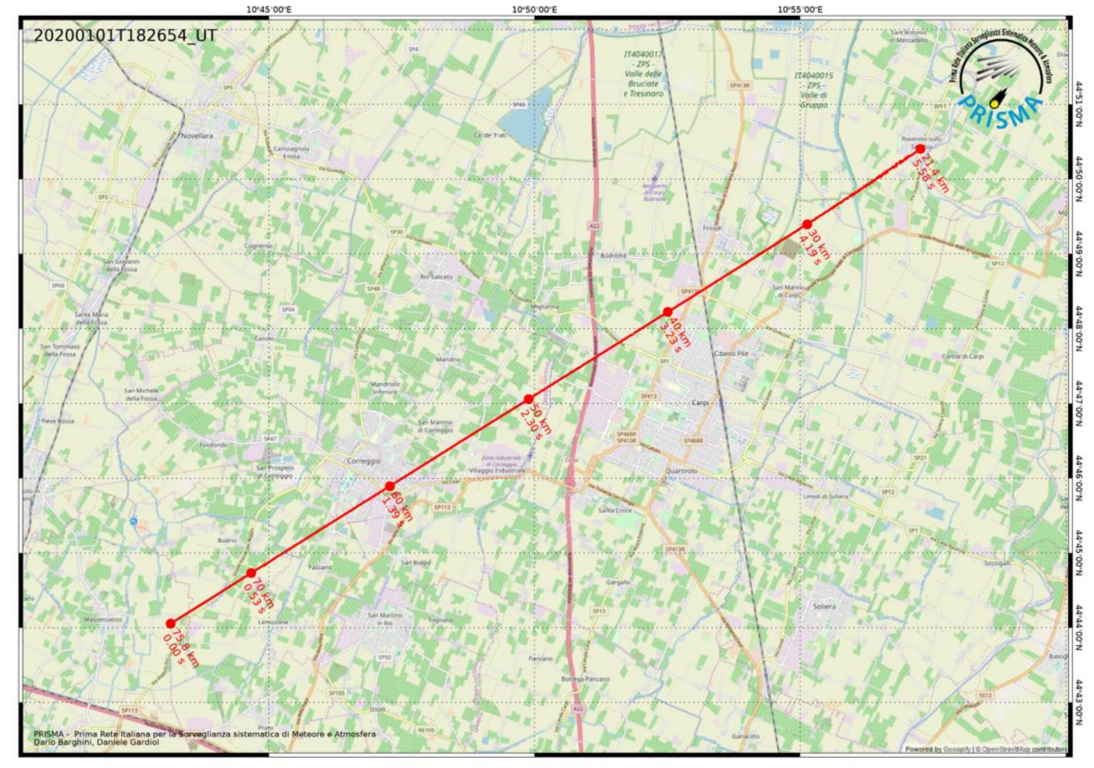




IT20200101
Atmospheric trajectory





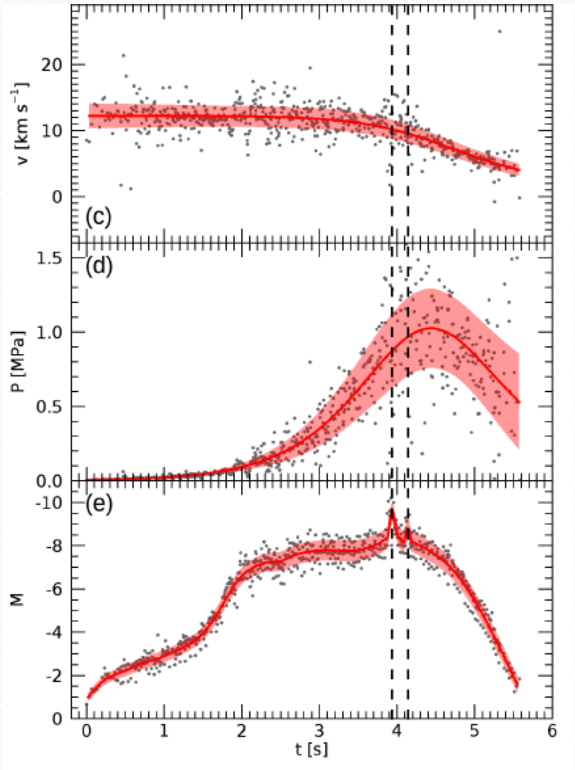


IT20200101
Atmospheric dynamics

From the triangulation results, we compute the **dynamic of the bolide** (velocity, acceleration, mass loss, effective section etc…)

$$\frac{\mathrm{d}v}{\mathrm{d}t} = -\frac{\Gamma \rho_a v^2}{D_\infty} \exp\left(-\frac{\sigma}{6}\left(v^2 - {v_\infty}^2\right)\right)$$
$$\frac{\mathrm{d}\rho_a}{\mathrm{d}t} = \frac{\rho_a v \cos z}{H}$$
$$\frac{\mathrm{d}h}{\mathrm{d}t} = -v \cos z$$

		Beginning	Terminal
Time (UT)	t	18:26:52.9	18:26:58.5
Height (km)	h	75.9 ± 0.2	21.5 ± 0.1
Latitude (N)	ϕ	$44°44'03'' \pm 7''$	$44°50'24'' \pm 7''$
Longitude (E)	λ	$10°43'09'' \pm 7''$	$10°57'25'' \pm 7''$
Velocity ($\mathrm{km\,s^{-1}}$)	v	12.2 ± 0.2	4.0 ± 0.2
Mass–section ratio ($\mathrm{kg\,m^{-2}}$)	D	280 ± 20	210 ± 20
Mass (kg)	m	3.5 ± 0.8	1.5 ± 0.4
Diameter (m)	d	0.13 ± 0.01	0.09 ± 0.01
Luminous path-length (km)	L	59	
Duration (s)	T	5.6	
Trajectory inclination (°)	T_i	68.4 ± 0.3	
Trajectory azimuth (°)	az	238.1 ± 0.2	
Min. absolute magnitude	M	-9.5 ± 0.5 @ 32.6 km	
Pre-atmospheric velocity ($\mathrm{km\,s^{-1}}$)	v_∞	12.8 ± 0.2	
Ablation coefficient ($\mathrm{s^2\,km^{-2}}$)	σ	0.012 ± 0.003	
Max. dynamic pressure (MPa)	P_{max}	1.0 ± 0.3 @ 28.2 km	
Impact Energy (T TNT)	E	0.07 ± 0.02	



Cavezzo:

- low entry velocity (12.8 km/s)
- high inclination (68°)

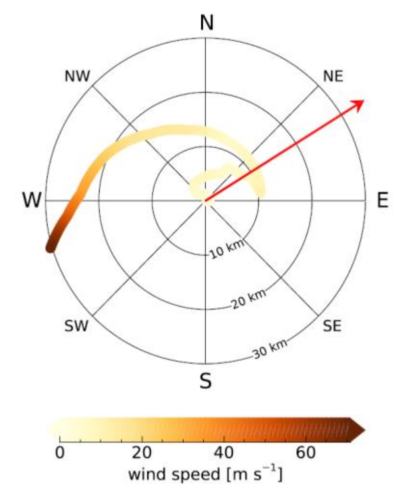
→ **Residual mass ≠ 0 !**

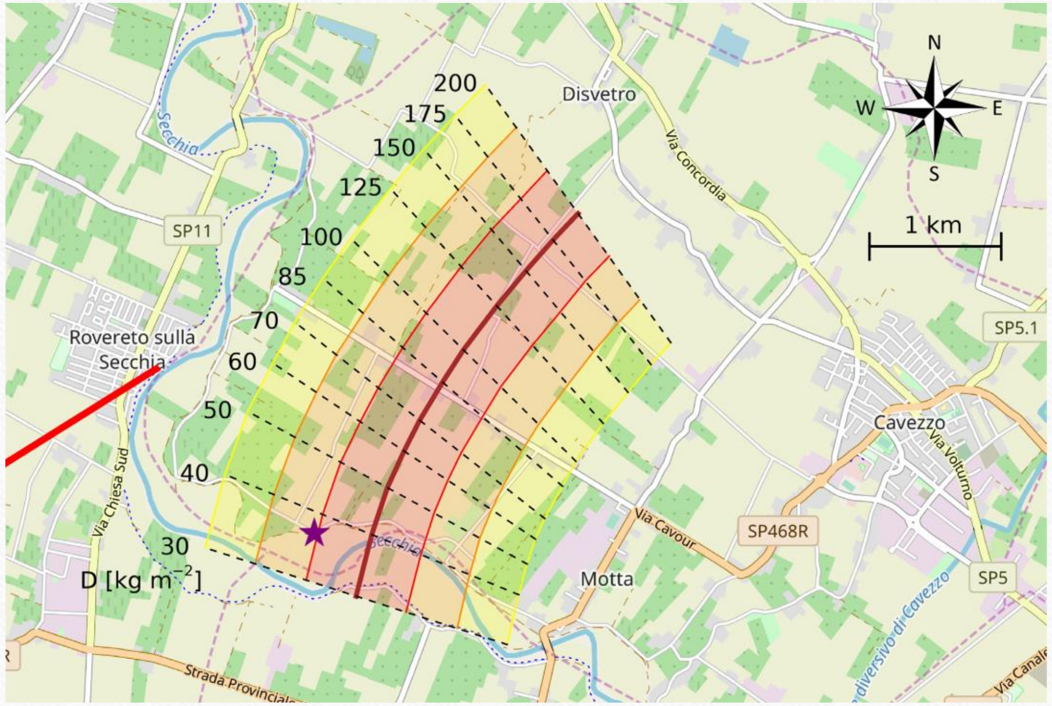
IT20200101
Dark Flight

- The dark flight has to be «extrapolated» from the dynamical model by integrating the system of equation <u>downward to the ground level</u>

- Velocity scale
  km/s → m/s

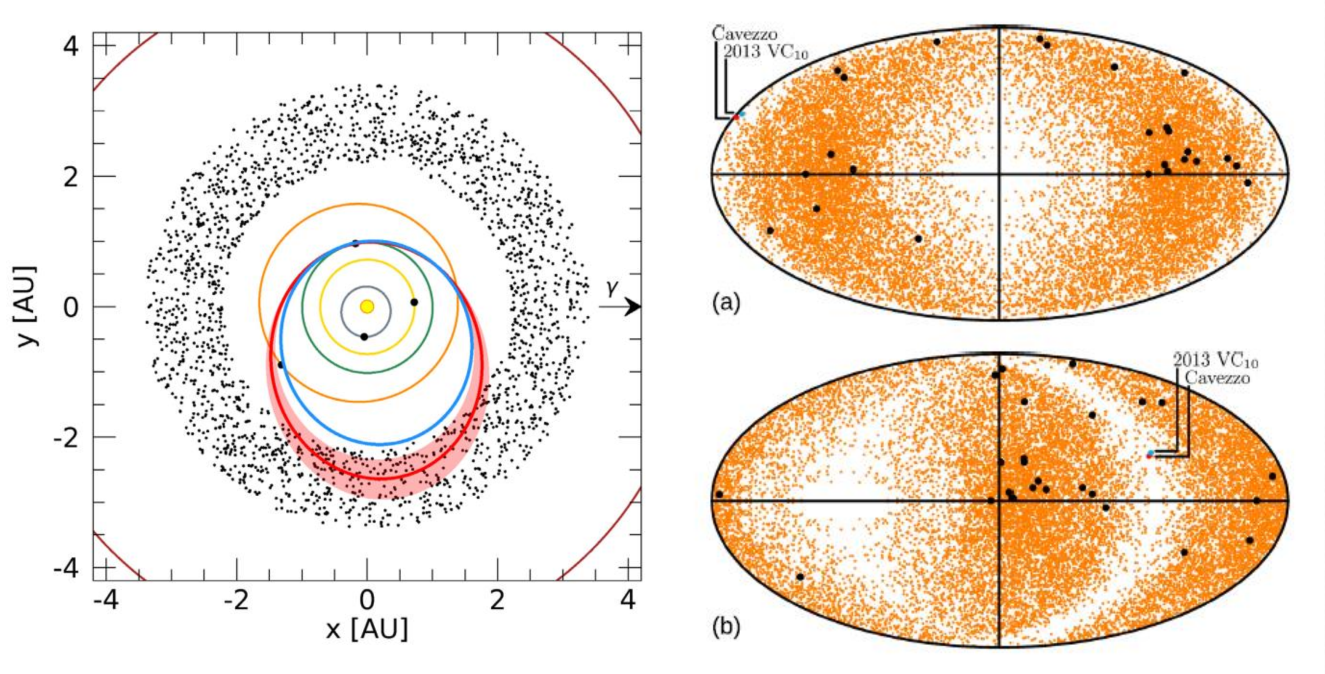
  must account for winds!





IT20200101
Orbit

- The atmospheric trajectory is backward – extrapolated to obtain the heliocentric orbit (orbital elements)
- One can try to identify a **list of parent body candidates** from the computed orbital elements



Cavezzo finding timeline

[Prisma_po] Multiple detection notification 20200101T182654 UT (8 stations)
Robot_FRIPON x

robot@fripon.org tramite inaf.it
a core, prisma_po
mer 1 gen 2020, 20:00

inglese > italiano Traduci messaggio

Stations concerned :
- ASIAGO (01/01/2020 18:26:54 UTC)
- PADOVA (01/01/2020 18:26:54 UTC)
- ROVIGO (01/01/2020 18:26:54 UTC)
- FELIZZANO (01/01/2020 18:26:54 UTC)
- LOIANO (01/01/2020 18:26:53 UTC)
- CECIMA (01/01/2020 18:26:54 UTC)
- NAVACCHIO (01/01/2020 18:26:54 UTC)
- BEDONIA (01/01/2020 18:26:53 UTC)

GENNAIO 2020

1 MERCOLEDÌ
H 19:27 – Evento (Bolide)
H 22:41 – Allerta
Calcolo astrometria

2 GIOVEDÌ
H 13:14 – Risultati definitivi Strewn-field
H 17:04 – Appello alla popolazione sul sito di PRISMA
Serata – Pubblicazione appello su sito MEDIA INAF

3 VENERDÌ

4 SABATO
H 15:02 – email da Davide Gaddi
H 16:00 – Contatto telefonico con Davide Gaddi
H 16:46 – Prima conferma di Romano Serra (sul posto)

Cavezzo finding timeline

[Prisma_po] Meteorite Posta in arrivo ×

Davide Gaddi cikitito@gmail.com tramite inaf.it — 4 gen 2020, 15:13

a prisma_po

inglese italiano Traduci messaggio Disattiva per: inglese ×

Salve.. Ritrovato questo frammento in zona Disvetro_Rovereto sul Secchia in provincia di Modena. Dalle descrizioni si avvicina ad un frammento di meteorite.. O sbaglio? Per informazioni o indicazioni 34 Grazie.Gaddi Davide

____

Prisma_po mailing list

Prisma_po@inaf.it

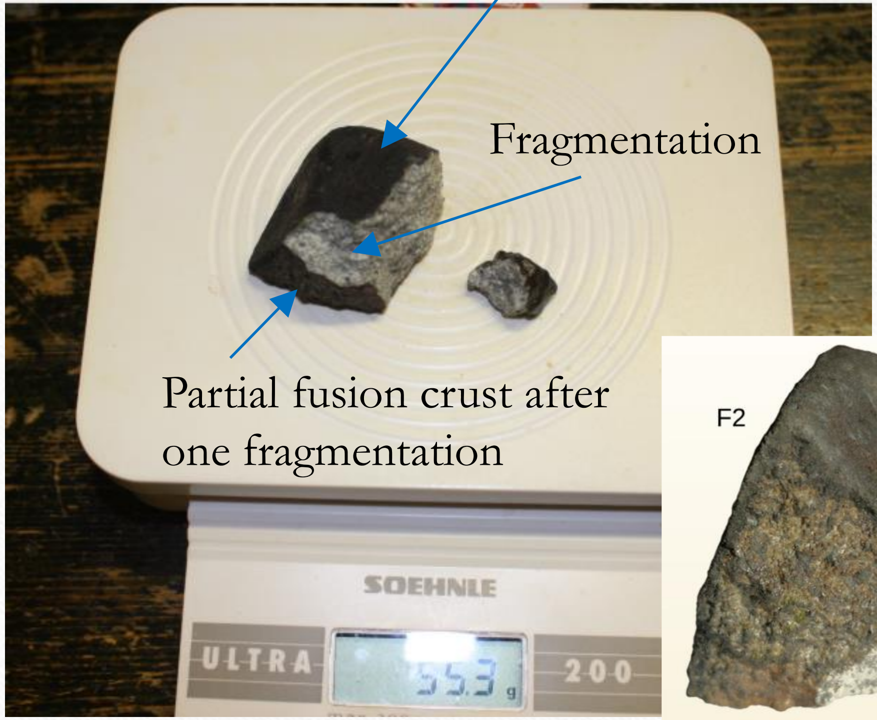
http://www.sedecentrale.inaf.it/mailman/listinfo/prisma_po

2 allegati

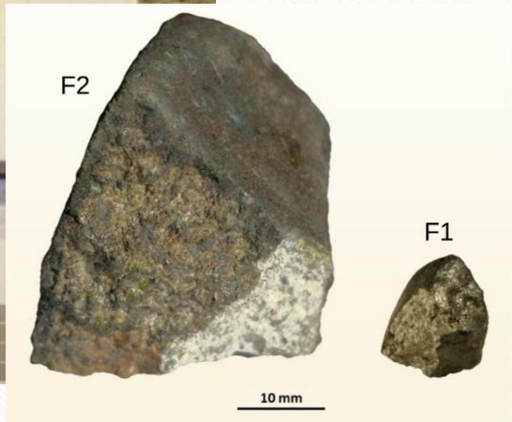
Cavezzo finding timeline

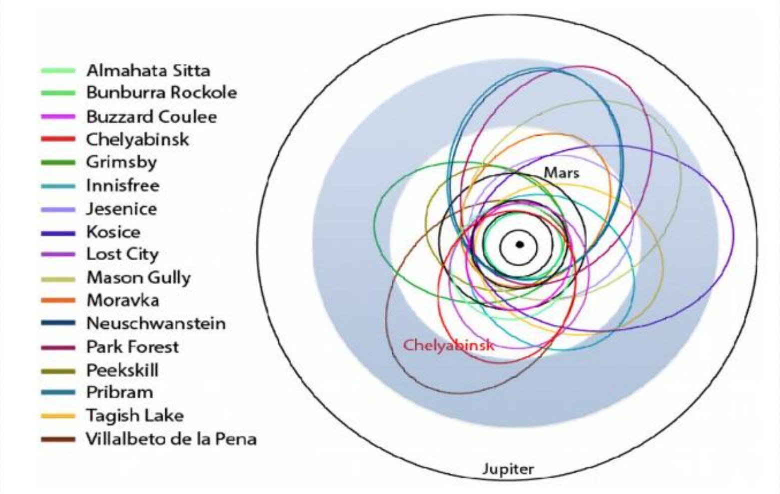



Cavezzo meteorite recovery



- **First Italian meteorite** recovered by an observation survey, just after 3 days from the date of fall
- Just few tens of meteorites recovered in the world with this method from 1960 until nowadays





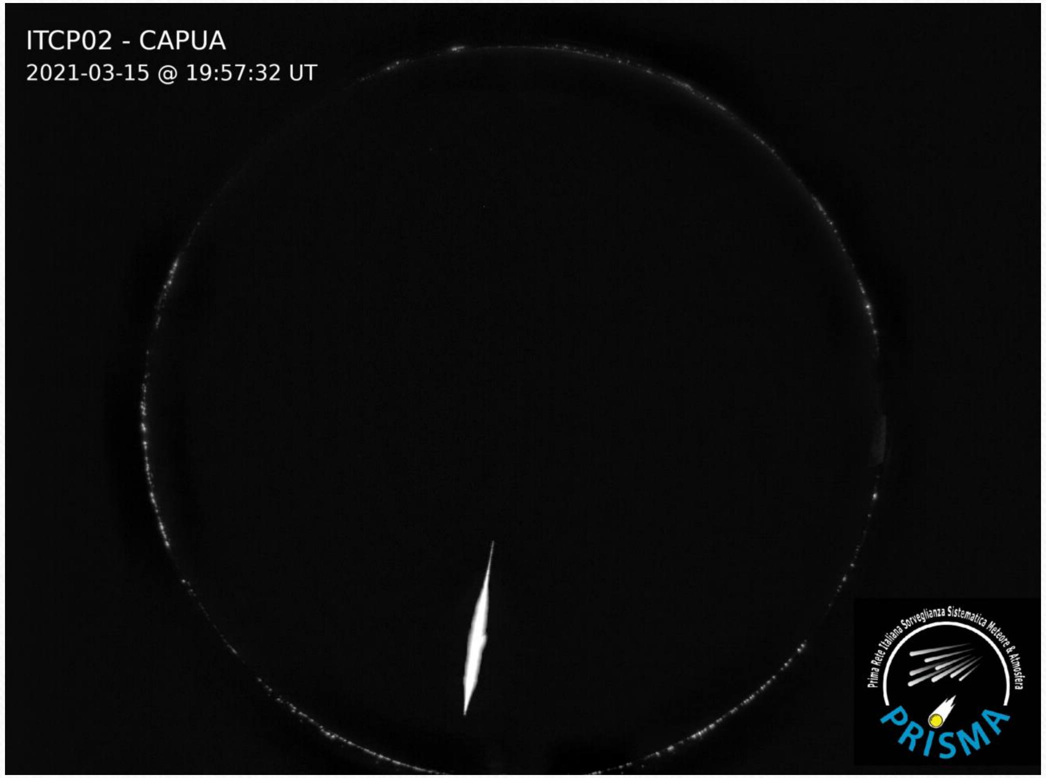
«Pedegree» meteorites

Meteorites originated from meteoroids with observed atmospheric trajectory and reconstructed pre-impact orbit

- Only 36 from 1959
- Only 21 from systematic surveys like PRISMA
- **Cavezzo is the smallest ever recovered**

Name	Date UT	v_∞ (km s^{-1})	m_∞ (kg)	m_{fin} (kg)	TKW (kg)	M[a]	E (T)[b]	Fireball Network[c]
Příbram	07/04/1959	20.9	1300	80	5.6	−19	70	CFN
Lost City	04/01/1970	14.1	165	25	17	−12	4	PFN
Innisfree	06/02/1977	14.7	42	4.9	4.58	−12.1	1	MORP
Benešov	07/05/1991	21.3	4100	300[d]	0.0116	−19.5	200	EFN
Peekskill	09/10/1992	14.7	5000	–	12.4	−16	130	–
Tagish Lake	18/01/2000	15.8	56000	1300	10	−22	1700	–
Morávka	06/05/2000	22.5	1500	100	1.4	−20	90	–
Neuschwanstein	06/04/2002	20.9	300	20	6.22	−17.2	16	EFN
Park Forest	27/03/2003	19.5	11000	–	30	−21.7	500	–
Villalbeto de la Peña	04/01/2004	16.9	600	13	5.2	−18	20	–
Bunburra Rockhole	20/07/2007	13.4	22	1.1	0.339	−9.6	0.5	DFN
Almahata Sitta	07/10/2008	12.4	40000	39	10.7	−19.7	730	–
Buzzard Coulee	21/11/2008	18.0	10000	–	>200	−20	390	–
Maribo	17/01/2009	28.3	2000	<20	0.0258	−20	190	–
Jesenice	09/04/2009	13.8	170	20	3.611	−15	4	SFN
Grimsby	26/09/2009	20.9	30	5	0.215	−14.8	2	SOMN
Košice	28/02/2010	15.0	3500	500	11.3	−18	100	–
Mason Gully	13/04/2010	14.5	40	–	0.0245	−9.4	1	DFN
Križevci	04/02/2011	18.2	50	<5[e]	0.291	−13.7	2	CMN
Sutter's Mill	22/04/2012	28.6	40000	–	0.943	−19	4000	–
Novato	18/10/2012	13.7	80	–	0.363	−13.8	3	CAMS
Chelyabinsk	15/02/2013	19.0	$1.2 \cdot 10^7$	10000	730	−27.3	$5 \cdot 10^5$	–
Annama	18/04/2014	24.2	470	12.5	0.1679	−18.3	30	FFN
Žď'ár nad Sázavou	09/12/2014	21.9	150	>1.3[f]	0.087	−15.3	9	EFN
Porangaba	09/01/2015	–	–	–	0.970	–	–	–
Sariçiçek	02/09/2015	17.3	1700	–	24.78	−16.8	60	–
Creston	23/10/2015	16.0	50	–	0.8523	−12	2	CAMS, SACN
Murrili	27/11/2015	13.7	38	2	1.68	–	0.9	DFN
Ejby	06/02/2016	14.5	120	–	8.982	−14.0	3	–
Stubenberg	06/03/2016	14	600	–	1.473	−15.5	14	EFN
Hradec Králové	17/05/2016	–	–	–	0.134	−11.5	–	EFN
Dishchii'bikoh	02/06/2016	16.6	1000[g]	–	0.07957	−16	30	CAMS, SACN
Dingle Dell	31/10/2016	15.4	40	1.4	1.150	–	1	DFN
Hamburg	17/01/2018	15.8	140	>1	~1	−16.3	5.5	–
Renchen	10/07/2018	20	50[h]	–	1.227	−13.4	2	EFN
Cavezzo	01/01/2020	12.8	3.5	1.5	0.0553	−9.5	0.07	PRISMA

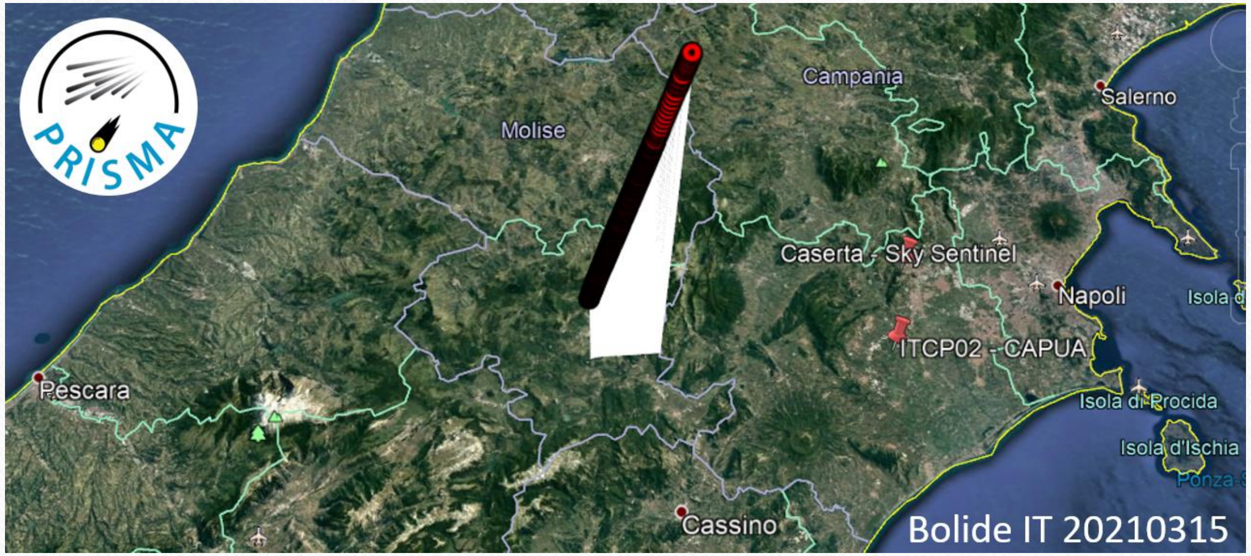
One year later…
IT20210315 bolide



IT20210315 bolide

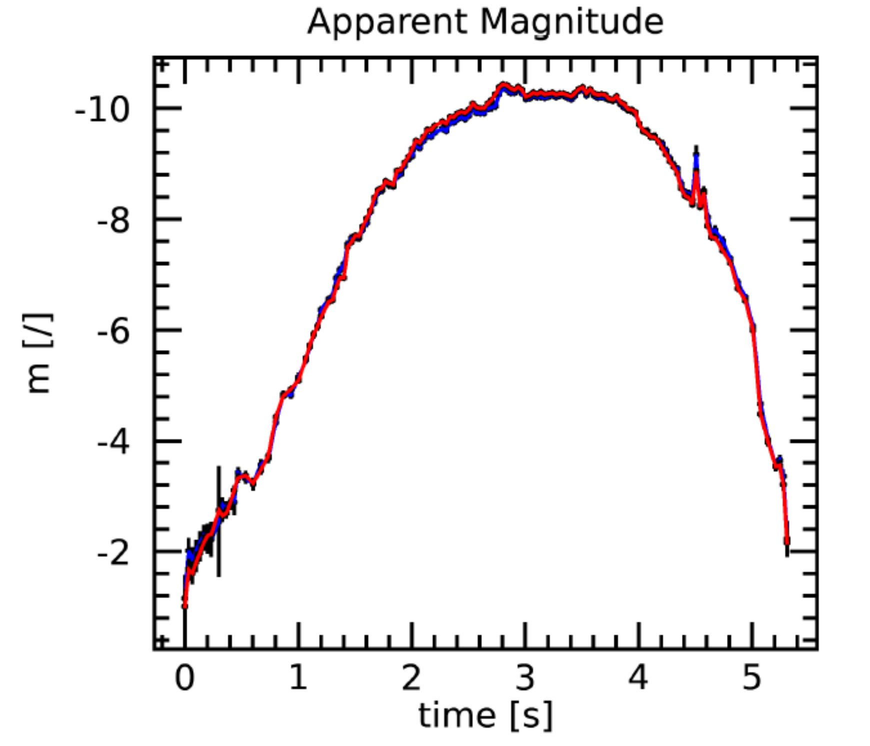
IT20210315 bolide
Atmospheric trajectory

- Only one PRISMA camera was operative that night (**CAPUA @ CIRA** – Centro Italiano Ricerche Aerospaziali)
- Triangulation with two other videos from
  Caserta (AAA – Associazione Arma Aeronautica)
  and **Tortoreto** (IMTN – Italian Meteor and TLE network)



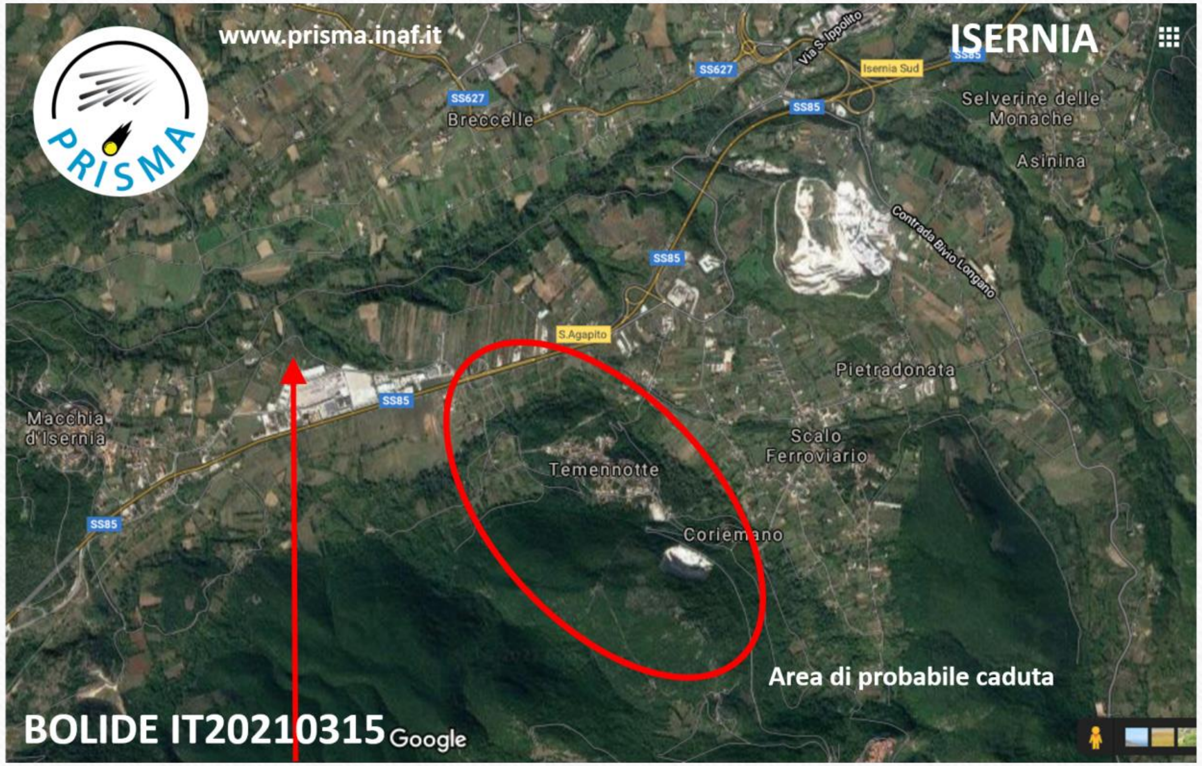
IT20210315 bolide
Atmospheric dynamics

- 80 km beginning heigth @ 14.6 km/s
- 61 km luminous path, in 5.3 s at ~**84° inclination**
- 19.8 km terminal heigth @ 2.8 km/s
- **Terminal mass ~1 kg** / ~ 8 cm size (assuming 3.5 g/cm^3)



IT20210315 bolide
Strewn-field

- Strewn-field over the **Temennotte** locality - Sant'Agapito (Isernia, Molise)
- <u>Strong winds from NW</u>
  ~ 100 km/h @ 10 km



Come comportarsi con una possibile meteorite

Non toccate la meteorite con le mani

Non avvicinate calamite alla meteorite

Non avvolgete la meteorite con plastica/alluminio

Evitate di alitare troppo vicino alla meteorite

Fotografate la meteorite prima di raccoglierla e mappate il punto !!!

Raccogliete la meteorite usando un foglio di carta

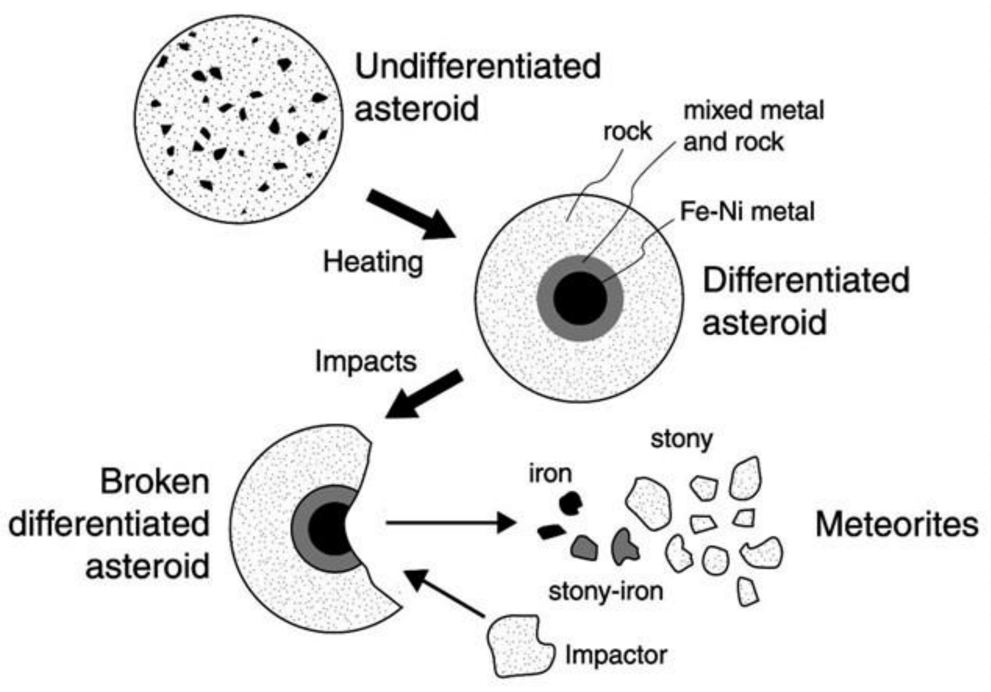
Avvolgetela in un panno di cotone

Riponetela in un vaso PULITO di vetro

Inseritelo in altro vaso a chiusura ermetica e con “assorbi umidità”

What about meteorites?

- **Meteoritic - remnants** of the original meteoroid prior to the atmospheric ablation
- «cheap» extraterrestrial samples (with respect, *e.g.*, to sample-return space missions)



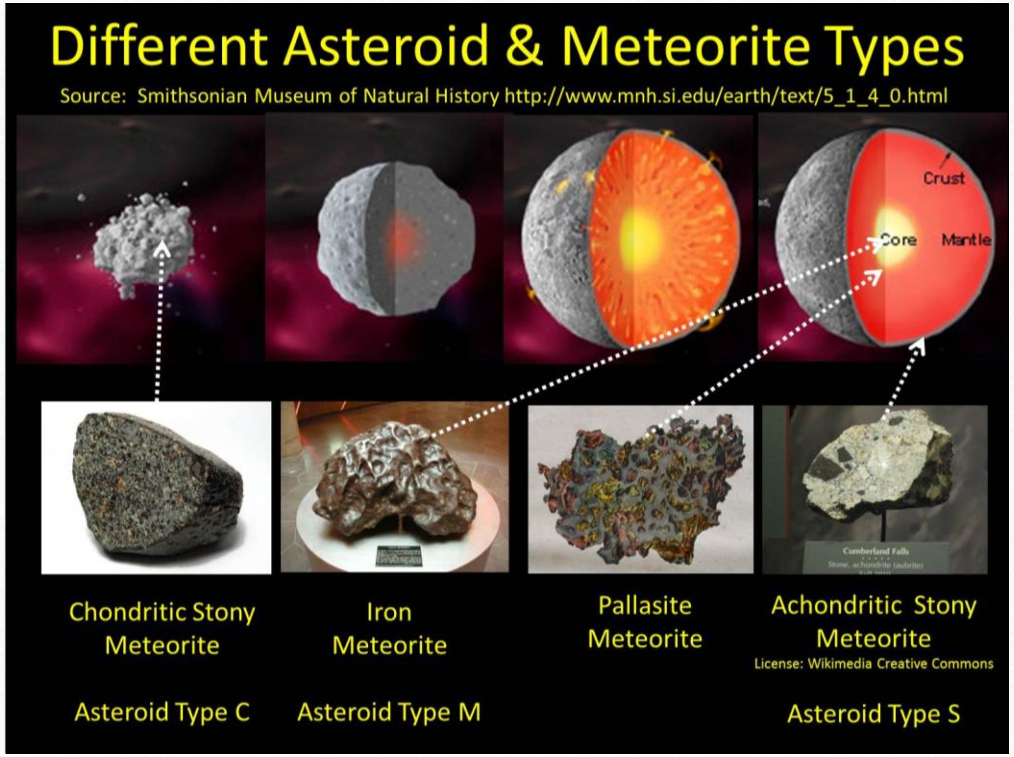
Meteorite classification

Main dinstinction between:

- Unmelted (or undifferentiated): **chondrites**
- Melted (or differentiated): **achondrites**
- Partially melted: **primitive achondrites**

and:

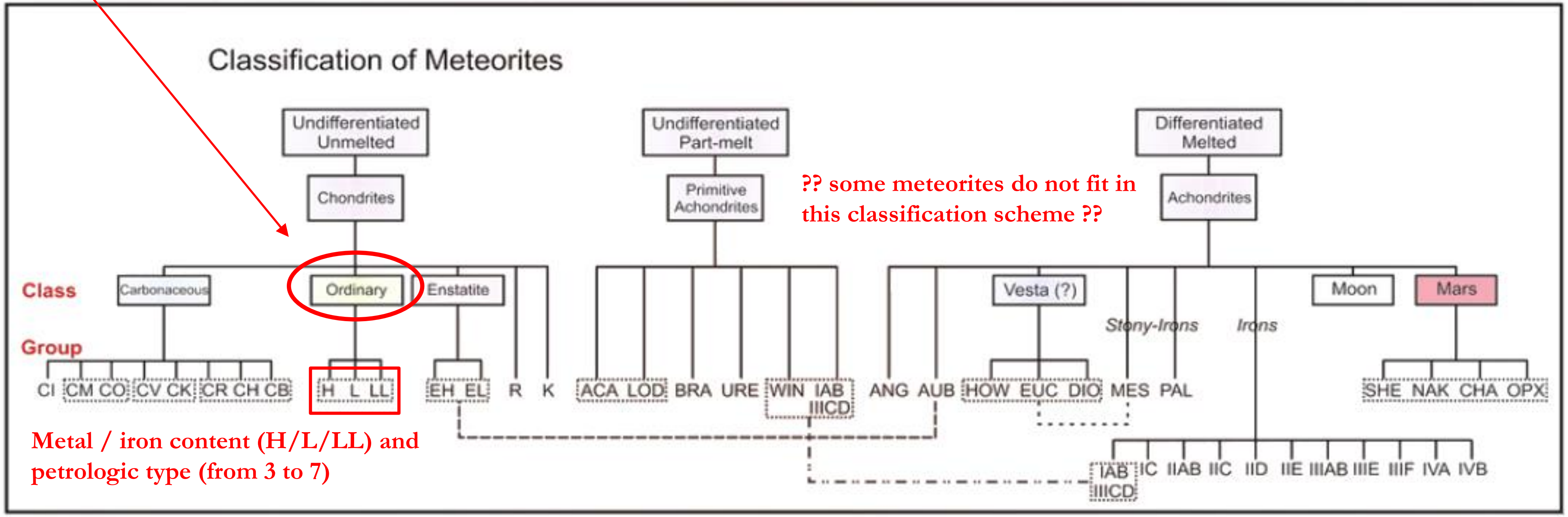
- **Stony** meteorites
- **Iron** meteorites



Classification scheme

86 % of collected meteorites are chondrites
90% of chondrites are OC

This is not the only meteorite classification scheme proposed by the scientific community, it is just the more widely used



THANK YOU FOR YOUR ATTENTION!

References

Bibliography:

Ceplecha et al. (1998), *Meteor Phenomena and Bodies*, Space Science Reviews
Lauretta et al. (2006), *Meteorites and the Early Solar System II*, Arizona University Press
Jennisken (2008), *Meteor Showers and their Parent Comets*, Cambridge University Press
Gradi et al. (2014), *Atlas of Meteorites*, Cambridge University Press
Ryabova et al. (2019), *Meteoroids: Sources of Meteors on Earth and Beyond*, Cambridge University Press
Gardiol et al. (2016), *PRISMA, Italian network for meteors and atmospheric studies*, IMC Proceedings
Barghini et al. (2019), *Astrometric calibration for all-sky cameras revisited*, Astronomy & Astrophysics
Carbognani et al. (2020), *A case study of the May 30, 2017, Italian fireball*, European Physical Journal Plus
Gardiol et al. (2021), *Cavezzo, the first Italian meteorite recovered by the PRISMA fireball network. Orbit, trajectory, and strewn-field,* Monthly Notices of the Royal Astronomical Society

Sitography:

PRISMA website: http://www.prisma.inaf.it/
FRIPON website: https://fripon.org/
IMTN website:: https://meteore.forumattivo.com/
Associazione Arma Aeronautica – sez. di Caserta: http://www.assarmaeronauticacaserta.altervista.org/
International Meteor Organisation (IMO) websit: https://www.imo.net/
American Meteor Society (AMS) website: https://www.amsmeteors.org/
The Meteroritical Society: https://meteoritical.org/
NASA website: https://www.nasa.gov/ (JPL, CNEOS, MEO…)
Wikipedia: http://en.wikipedia.org