Catastrophic disruption of asteroid 2023 CX1

and implications for planetary defence

Auriane Egal

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Definitions

Parent body

Meteoroid

Meteor

Meteorite

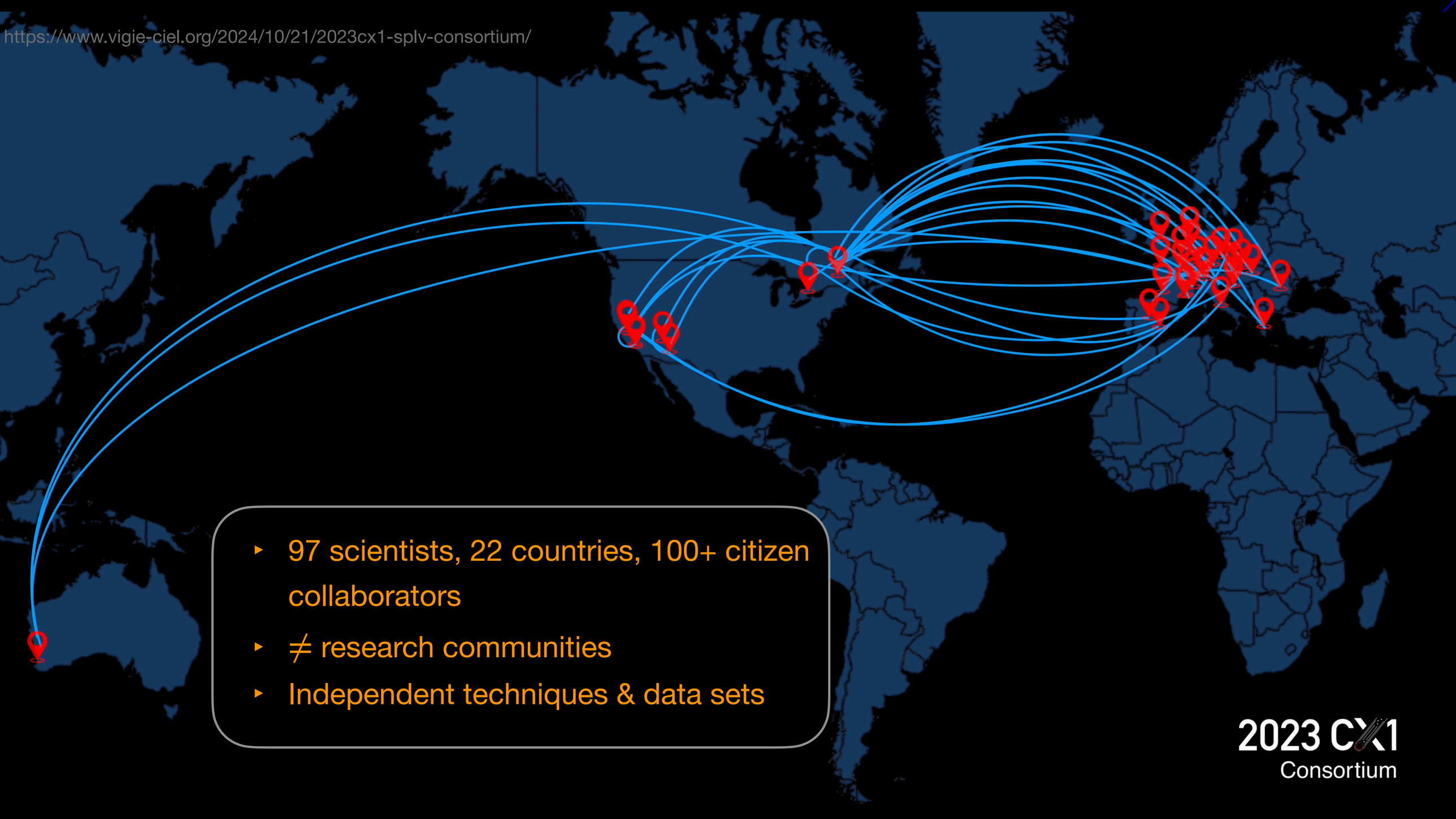
Meteoroid:

From 30 μm to 1 m

Asteroid:

A large meteoroid!

https://www.vigie-ciel.org/2024/10/21/2023cx1-splv-consortium/



- 97 scientists, 22 countries, 100+ citizen collaborators
- ≠ research communities
- Independent techniques & data sets

2023 CX1
Consortium

nature astronomy

Article

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Catastrophic disruption of asteroid 2023 CX1 and implications for planetary defence

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Check for updates

A list of authors and their affiliations appears at the end of the paper

Mitigation of the threat from airbursting asteroids requires an understanding of the potential risk they pose for the ground. How asteroids release their kinetic energy in the atmosphere is not well understood due to the rarity of large impacts. Here we present a comprehensive, space-to-laboratory characterization of an impact of an L chondrite, which represents a common type of Earth-impacting asteroid. Small asteroid 2023 CX1 was detected in space and predicted to impact over Normandy, France, on 13 February 2023. Observations from several independent sensors and reduction techniques revealed an unusual but potentially high-risk fragmentation behaviour. The nearly spherical 650 ± 160 kg (72 ± 6 cm diameter) asteroid catastrophically fragmented at a dynamic pressure of 4 MPa around 28 km altitude, releasing 98% of its total energy in a concentrated region of the atmosphere. The resulting shock wave was spherical, not cylindrical, and released more energy closer to the ground. This type of fragmentation increases the risk of substantial damage at ground level. These results warrant consideration for a planetary defence strategy for cases where a >3–4 MPa dynamic pressure is expected, including planning for evacuation of areas beneath anticipated disruption locations.

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I
Discovery
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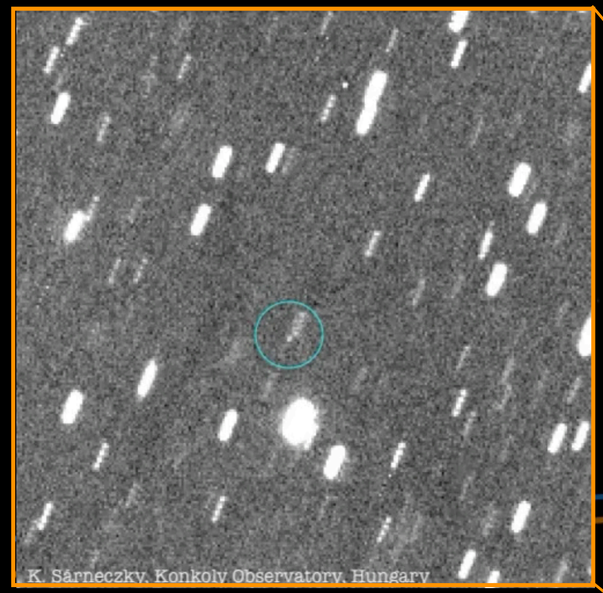
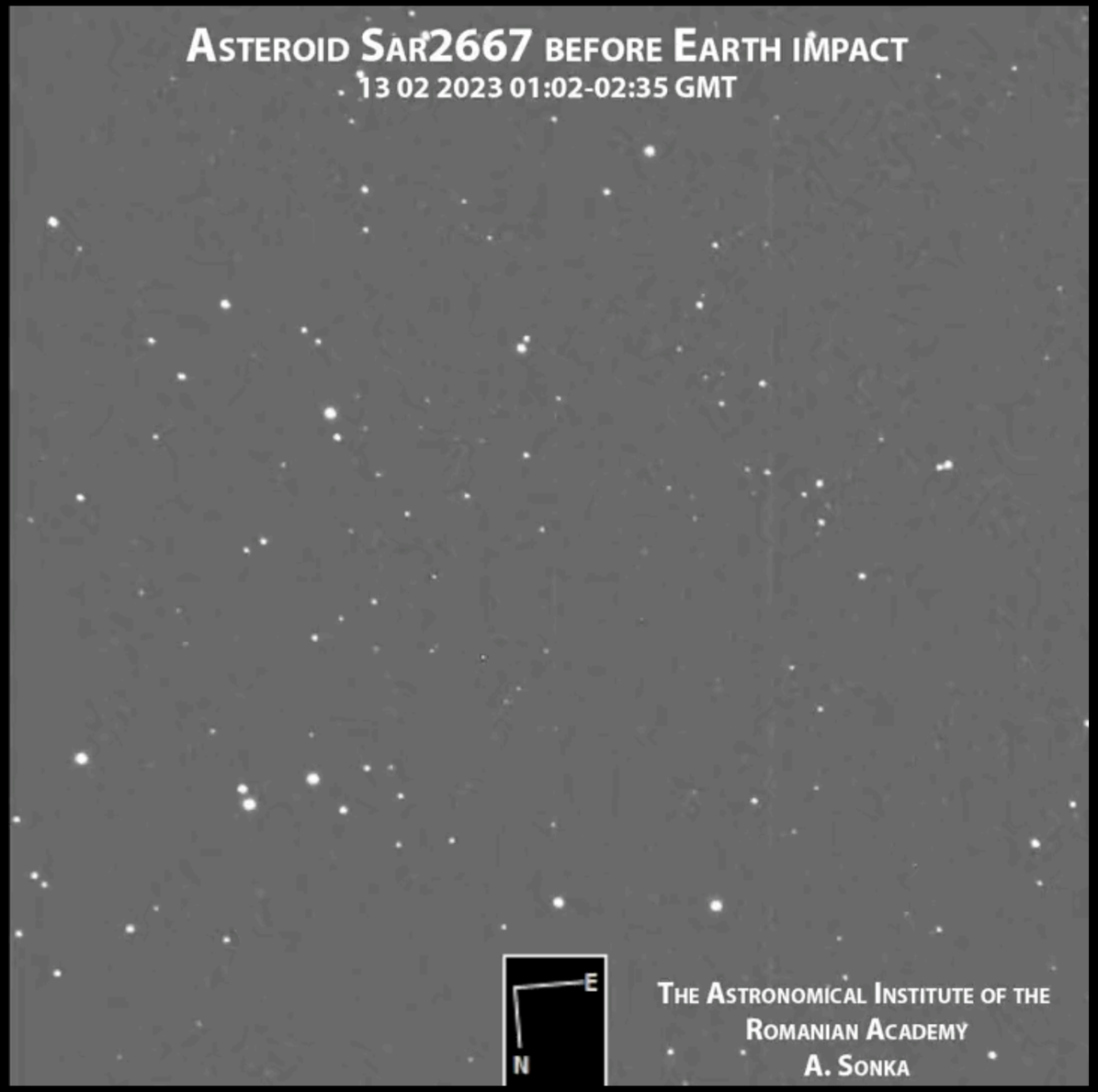
Discovery



- Discovered on Feb. 12, 2023 at 20:18:07 UTC
- About 0.61 times the Earth-Moon distance

Discovery



ESA Operations @esaoperations · 12 févr.

A 1-meter meteoroid (small #asteroid) has been detected and is expected to *safely* strike Earth's atmosphere over northern France between 3:50-4:03 CET.

ESA Operations @esaoperations · 12 févr.

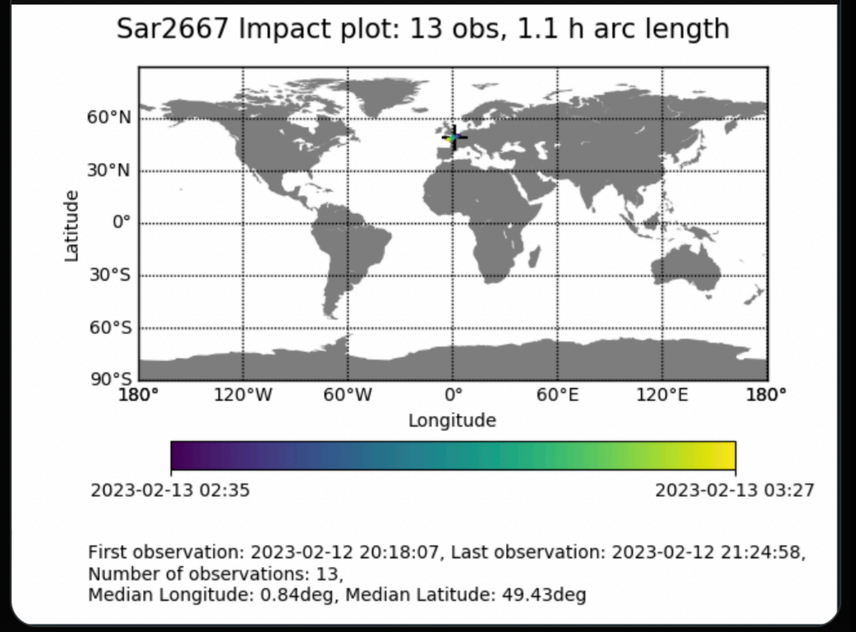
Last estimation shows #Sar2667's point of impact getting much closer to the #Rouen area.

Safe #AsteroidImpact
#ShootingStar☄️

People of Rouen - send us your photos if you get any!🇫🇷

@ESA_fr

Afficher cette discussion



Discovery

Vigie Ciel FRIPON

FRIPON ET VIGIE-CIEL | COMPRENDRE | SE FORMER | PARTICIPER | COMMUNAUTÉ | LOGIN

ENTRÉE IMMINENTE D'ASTÉROÏDE AU-DESSUS DE LA MANCHE !

12 février 2023 *Non* *Par* KARL ANTIER

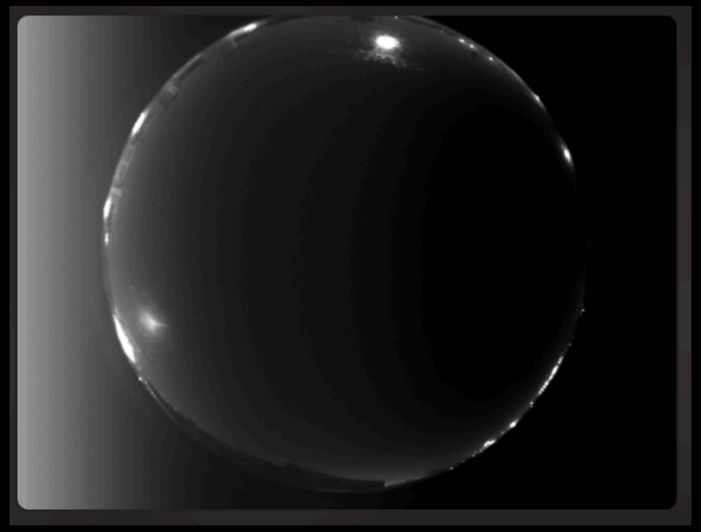
Un petit astéroïde d'environ 1 m de diamètre découvert aujourd'hui a une trajectoire qui devrait l'amener à pénétrer dans l'atmosphère terrestre dans quelques heures… au-dessus de la mer de la Manche ! Pas d'impact au sol prévu, car l'objet est trop petit pour survivre à une telle entrée atmosphérique. Mais un joli bolide devrait être observé depuis le Nord de la France… et des météorites pourraient également atteindre le sol (ou le fond de la mer) ! C'est la 7ème fois depuis le début des observations astronomiques qu'un astéroïde est découvert avant son entrée dans l'atmosphère.

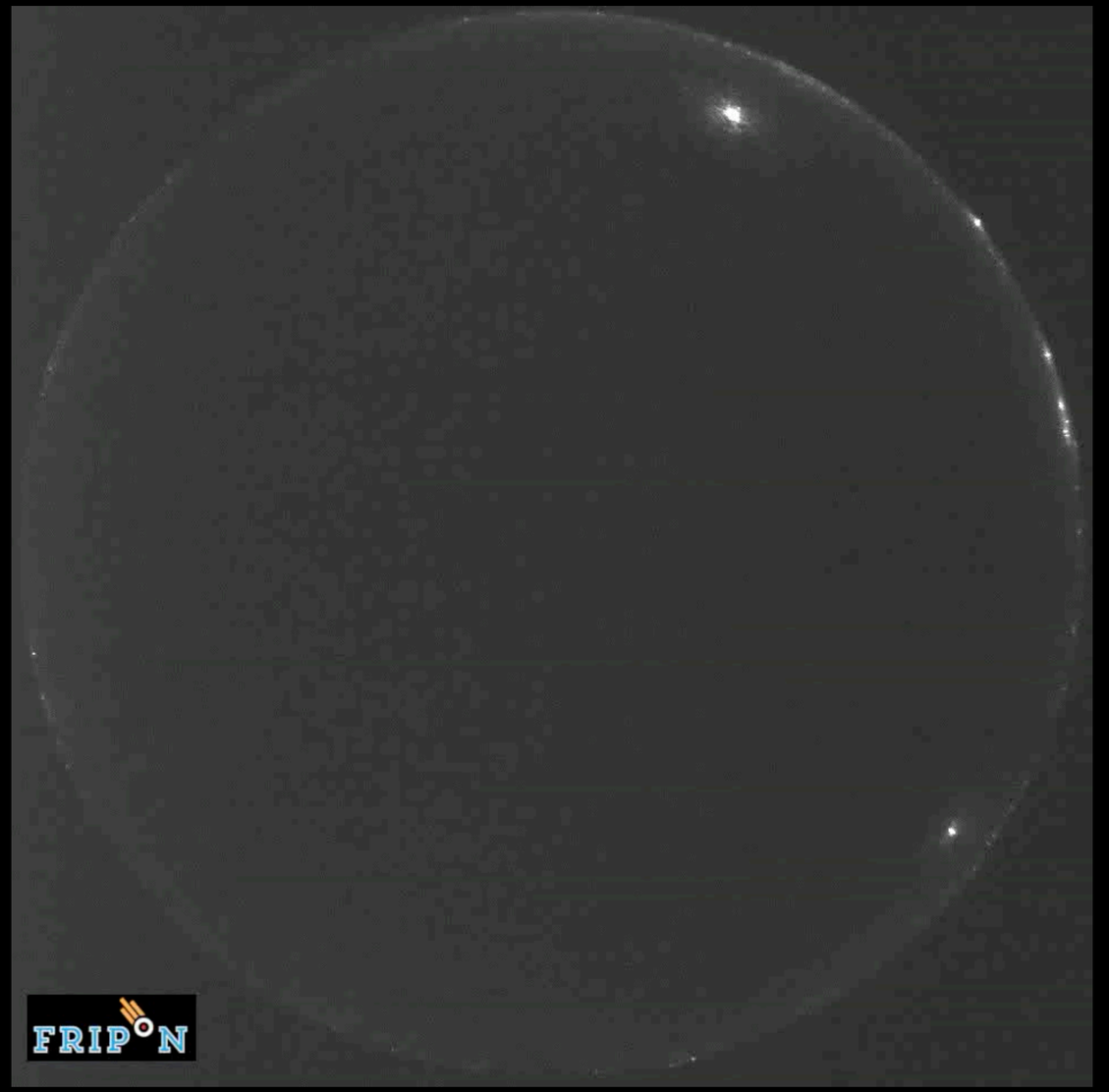
SAR2667, 7ÈME ASTÉROÏDE DÉCOUVERT AVEC UNE TRAJECTOIRE D'IMPACT AVEC LA TERRE

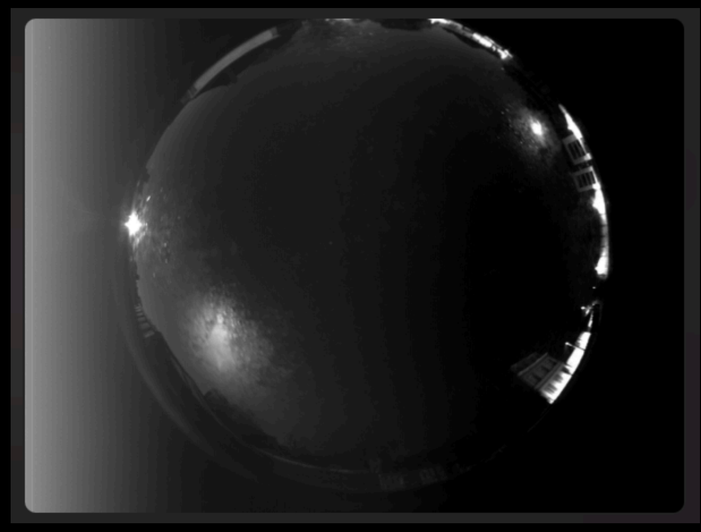
Le petit astéroïde (magnitude absolue de 32.7, soit environ 1 m de diamètre) a été découvert aujourd'hui, par le programme GINOP KHK (K88, à Piszkéstető, Hongrie), et confirmé quelques heures plus tard par l'observatoire de Visnjan (L01, à Tican, Croatie). Actuellement désigné par l'appellation provisoire Sar2667, sa trajectoire l'amène à rencontrer notre planète, la Terre. Heureusement, sa petite taille fait qu'il ne résistera pas à son entrée dans l'atmosphère. Néanmoins, cela devrait naissance à un bolide, c'est-à-dire une étoile filante très lumineuse, et les fragments de l'astéroïde qui survivront potentiellement à cette entrée atmosphérique peuvent être retrouvés sous forme de météorites au sol. C'est la 7ème fois que les astronomes découvrent un astéroïde avant qu'il ne pénètre notre atmosphère. La première date de 2008, avec l'astéroïde 2008 TC3, tandis que le dernier événement similaire est bien plus récent, avec l'entrée atmosphérique de 2022 WJ1 (1,5 m de diamètre) au-dessus du Canada le 19 novembre dernier.

Atmospheric entry

On February 13, at 02:59 UTC, a bright fireball was captured by FRIPON!







Credit: @tymlaly76700

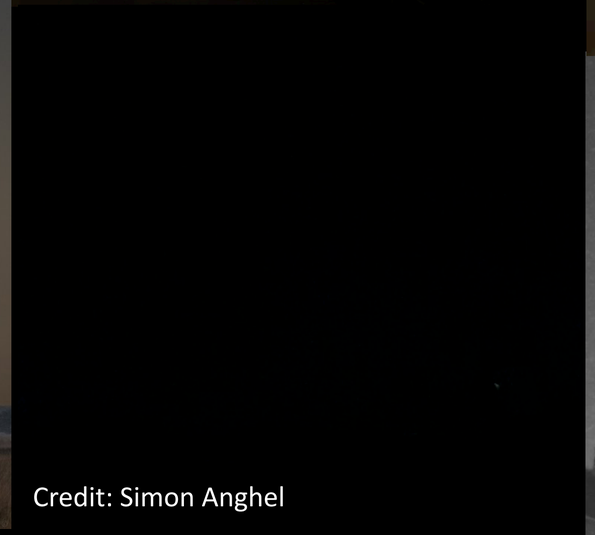
Credit: Nick Russell

Credit: Mike Rushton

Credit: Simon Saunders

Credit: @MegaLuigi

Credit: Gijs de Reijke



Credit: Simon Anghel

Credit: Jamie Olver

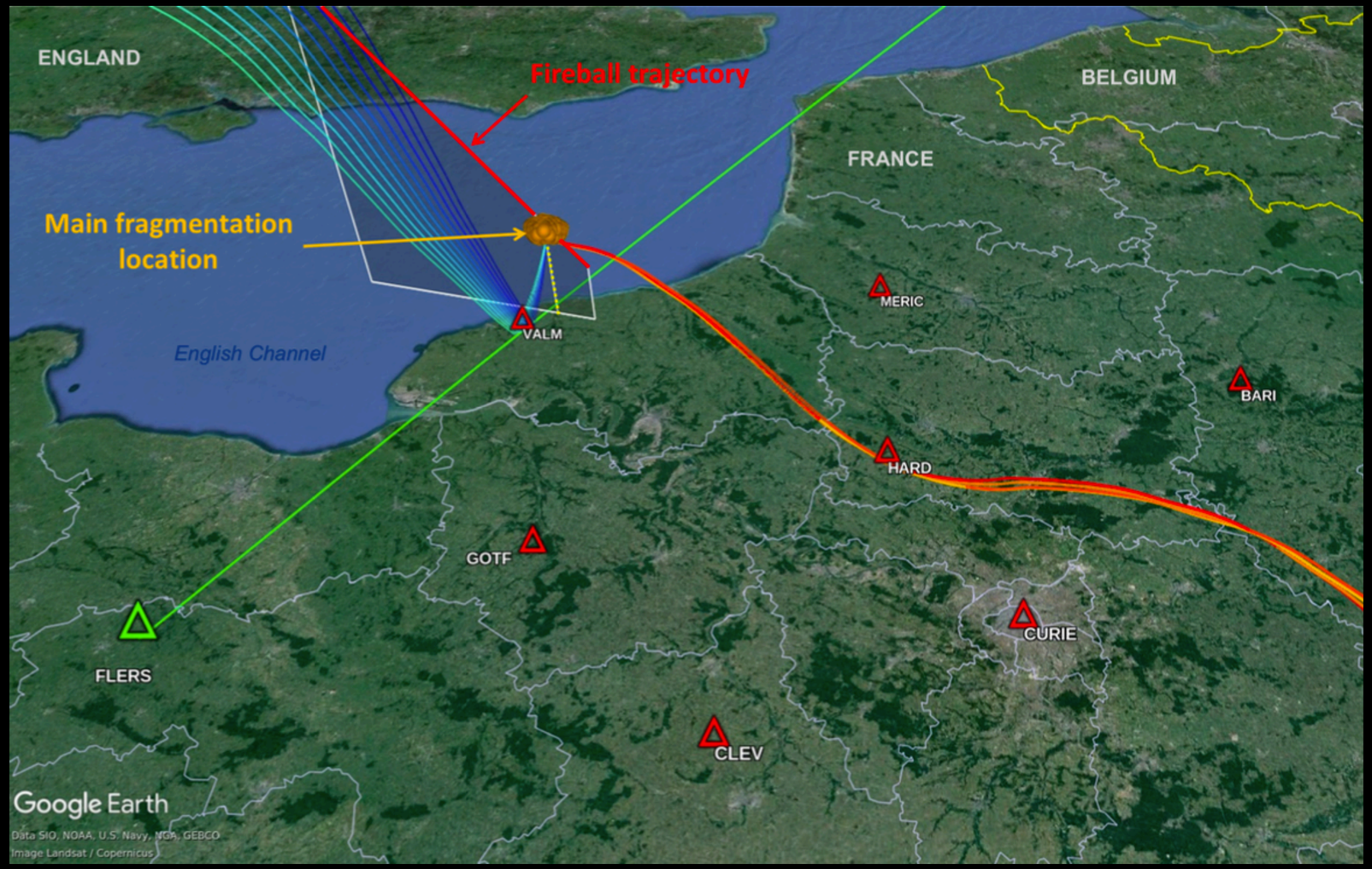
Credit: Josselin Desmars

A worldwide observation effort

Credit: Hadrien Devillepoix

Seismo-acoustic signal

- A seismo-acoustic signal was detected as far as ~5500 km away in Russia!



Credit: Julien Vergoz

Accurate data from

- several CTBTO stations, KNMI, the CEA
- RESIF (Réseau Sismologique et Géodésique Français), the Great Britain Seismograph Network
- the Raspberry Pi Shake & Boom citizen science initiative


I
Discovery
II
Recovery
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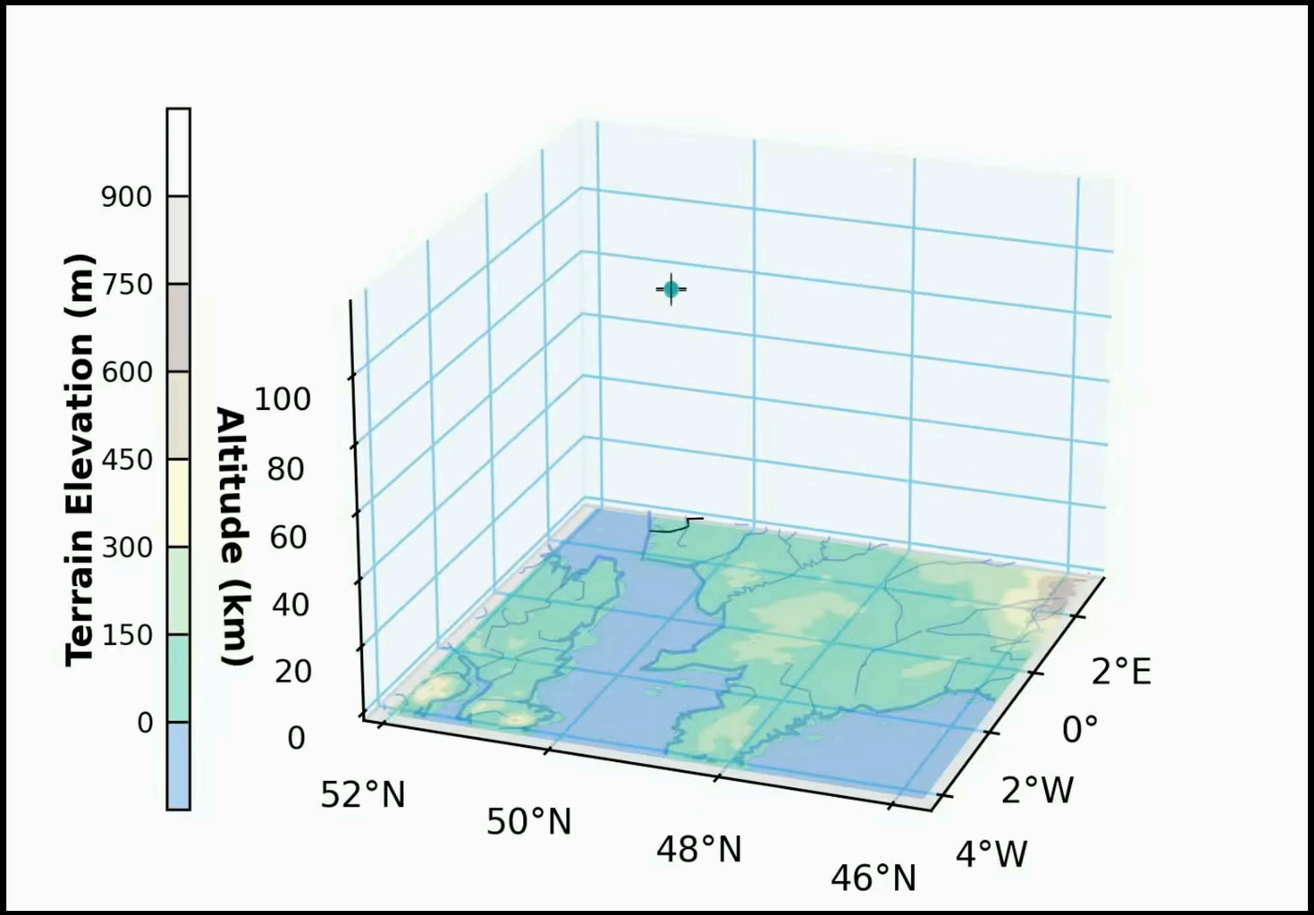
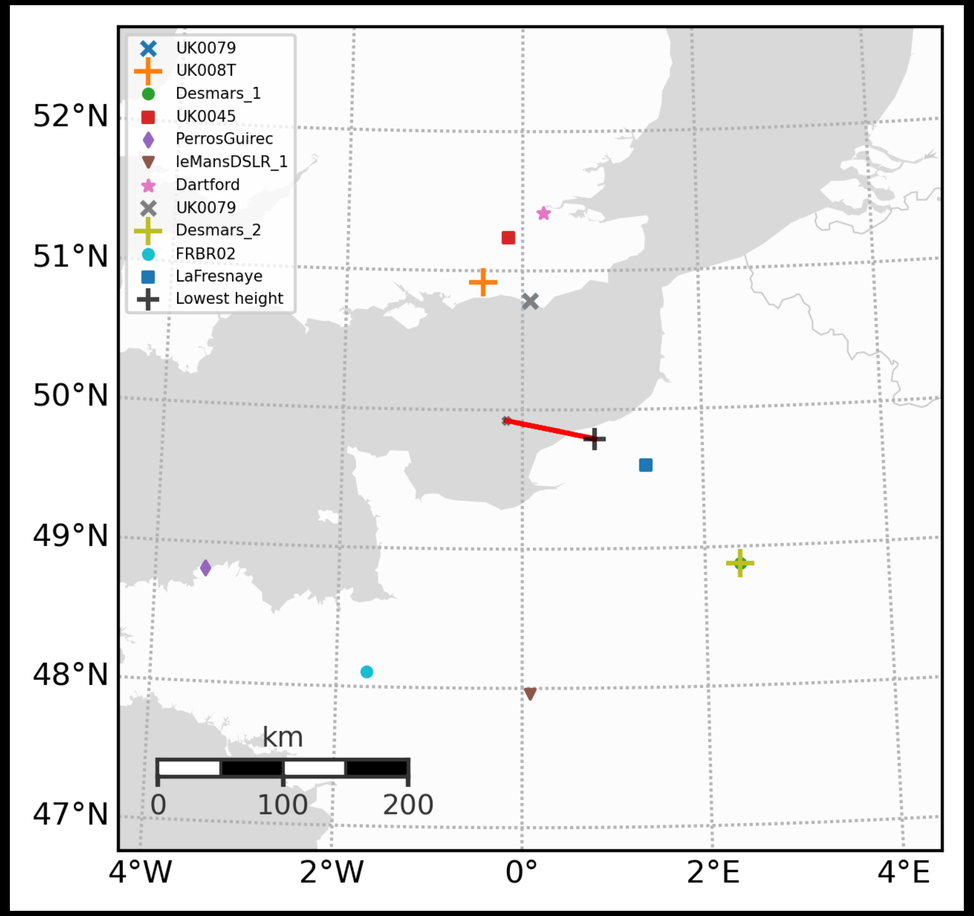
Trajectory

High-resolution photographs and videos from the public
+ GMN/UKMON & FRIPON data



Credit: Simon Anghel



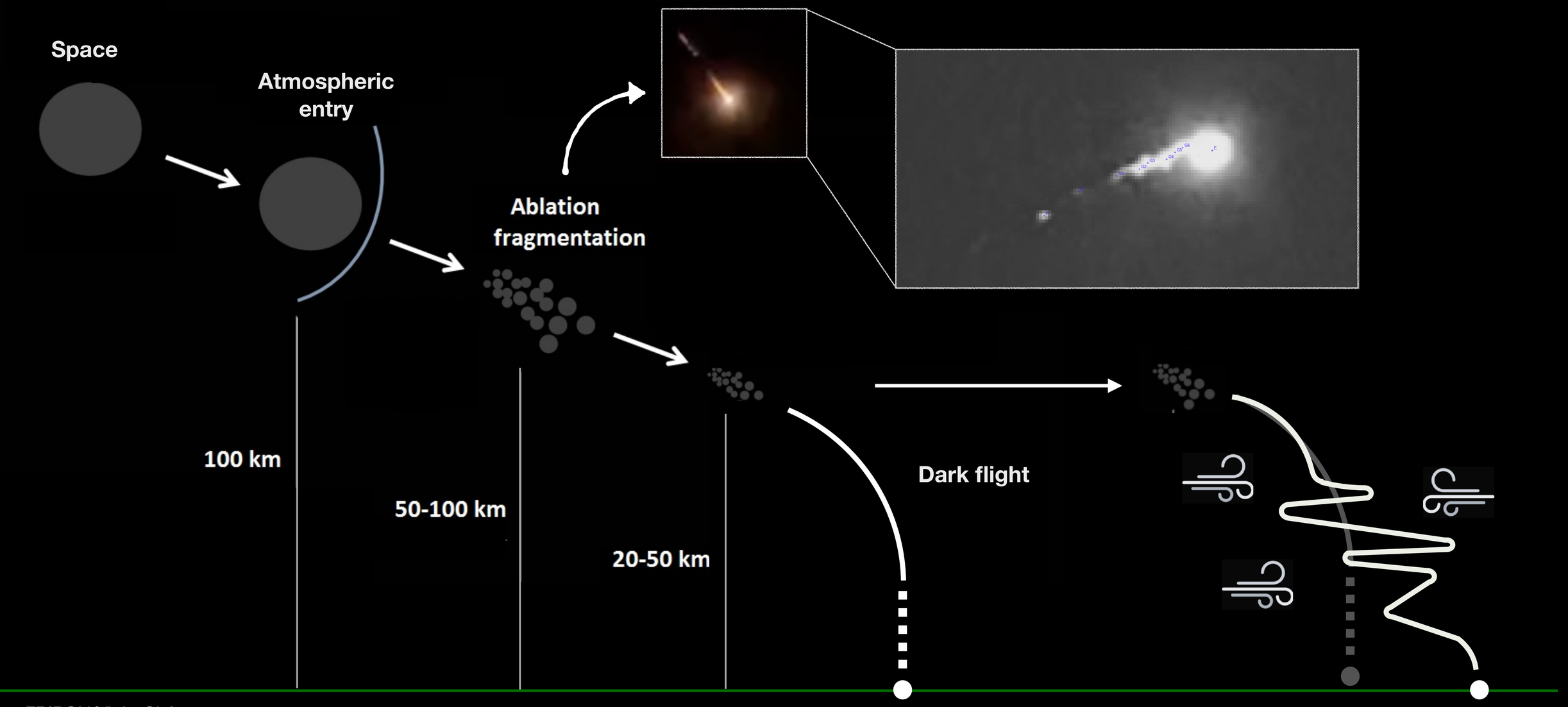
Credit: Denis Vida

Dark flight


Petit-Caux
Dieppe
Martin-Église
Envermeu
Sotteville-sur-Mer
Saint-Valery-en-Caux
Veulettes-sur-Mer
Paluel
Fontaine-le-Dun
Sassetot-le-Mauconduit
Cany-Barville
Ourville-en-Caux
Doudeville
Yerville
Terres-de-Caux
Yvetot
Allouville-Bellefosse
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2024 Airbus
Google Earth
Imagery Date: 6/21/2024 49°43'59.45" N 0°50'56.27" E elev 0 m eye alt 57.02 km

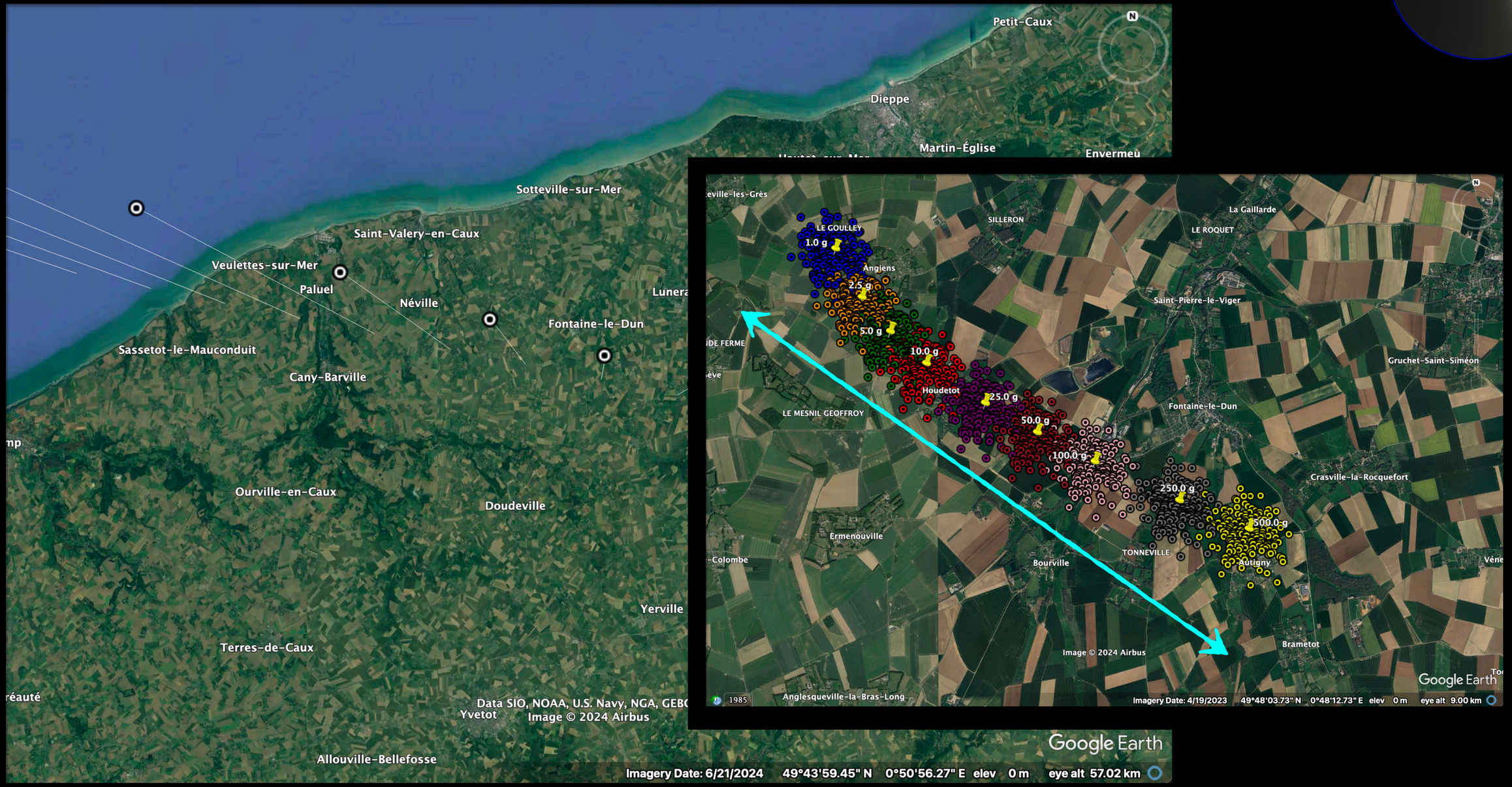
LE GOULLEY
SILLERON
La Gaillarde
LE ROQUET
Angiens
Saint-Pierre-le-Viger
Gruchet-Saint-Siméon
Houdetot
LE MESNIL GEOFFROY
Fontaine-le-Dun
Crasville-la-Rocquefort
Ermenouville
TONNEVILLE
Bourville
Autigny
Brametot
Anglesqueville-la-Bras-Long
Image © 2024 Airbus
Google Earth
1985
Imagery Date: 4/19/2023 49°47'28.20" N 0°52'15.44" E elev 0 m eye alt 9.00 km

Dark flight



Credits: FRIPON/Vigie-Ciel

Strewn field



Credit: Denis Vida

Field search

Credit: Vigie-Ciel

Field search

Credit: Vigie-Ciel

Meteorite recovery

Credit: Vigie-Ciel

Vigie-Ciel
23 h ·

Feb 15, 2023 ···

🤩☄️ FRIPON/Vigie-Ciel retrouve un fragment de l'astéroïde 2023CX1 en Seine Maritime !!! La découverte a été faite par Loïs Leblanc, étudiante de 18 ans, faisant partie de l'équipe de recherche sur le terrain.

Muséum national d'Histoire naturelle Observatoire de Paris - PSL Université Paris-Saclay OSU Institut Pythéas Institut Origines Laboratoire d'Astrophysique de Marseille SETI Institute NASA Ames Research Center CNRS Société Astronomique de France , Western University, Espace pour la vie Luc Labenne, Association Perche Astronomie Association Pilotes et Cie Institut d'astrophysique de Paris.

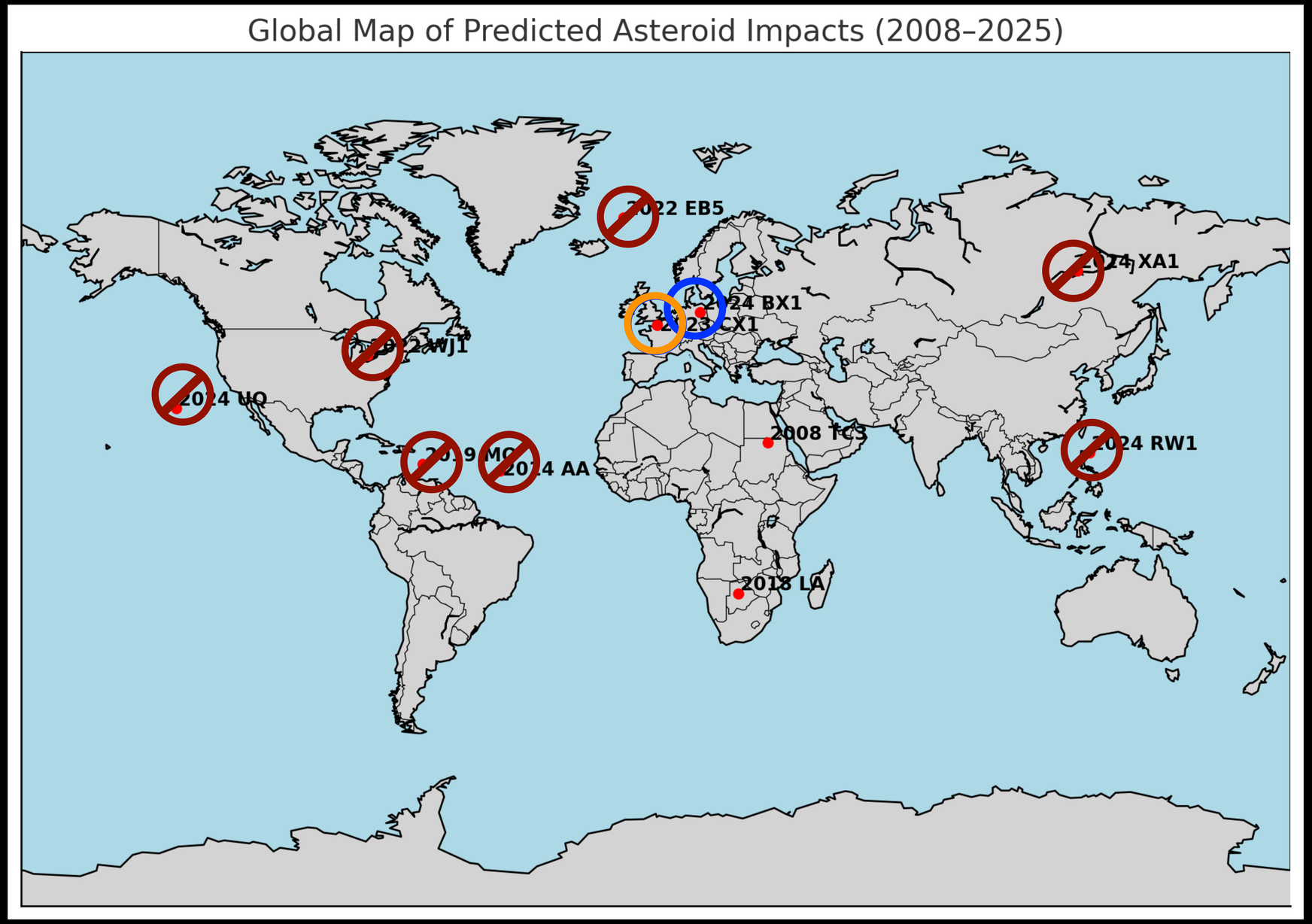
Plus d'infos bientôt sur Vigie-Ciel.org

Meteorite recovery

Saint-Pierre-Le-Viger meteorite

- >100 fragments were recovered along a line of ~8 km
- Recovered mass of ~1.34 kg
- L5–6 chondrite breccia
- S3 shock stage

Predicted asteroid impacts



11 predicted impacts:

- 4 led to meteorite recovery
- 2 provided accurate atmospheric data
- Only one L-chondrite fall: 2023 CX1!

Laboratory measurements

Petrography, bulk density

Bulk chemistry

Credit: Bill Bungay

Noble Gas Spectrometry

^{3}He,^{21}Ne, ^{38}Ar (Kr, Br)

Non-destructive Gamma-Ray Spectrometry

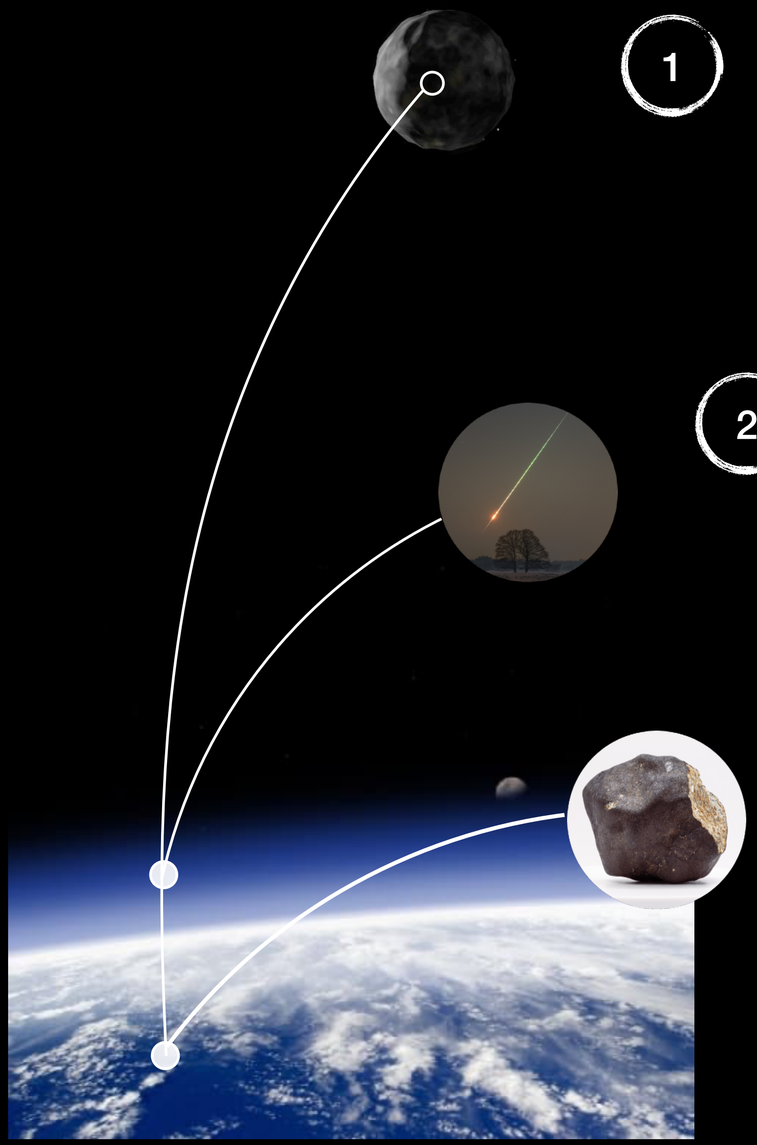
^{22}Na, ^{26}Al, ^{54}Mn, ^{57}Co, ^{60}Co, ^{48}V (16 d)

Destructive Accelerator Mass Spectrometry

^{26}Al, ^{41}Ca

- Classification, structure
- Size, collisional history

A Multi-disciplinary investigation



1 **In space**

Asteroid: size, shape, orbit and origin

2 **In the atmosphere**

Fireball : size, energy, trajectory, fragmentation, strewn field

3 **In laboratory**

Meteorites: size, shielding depth, composition, structure, collisional history

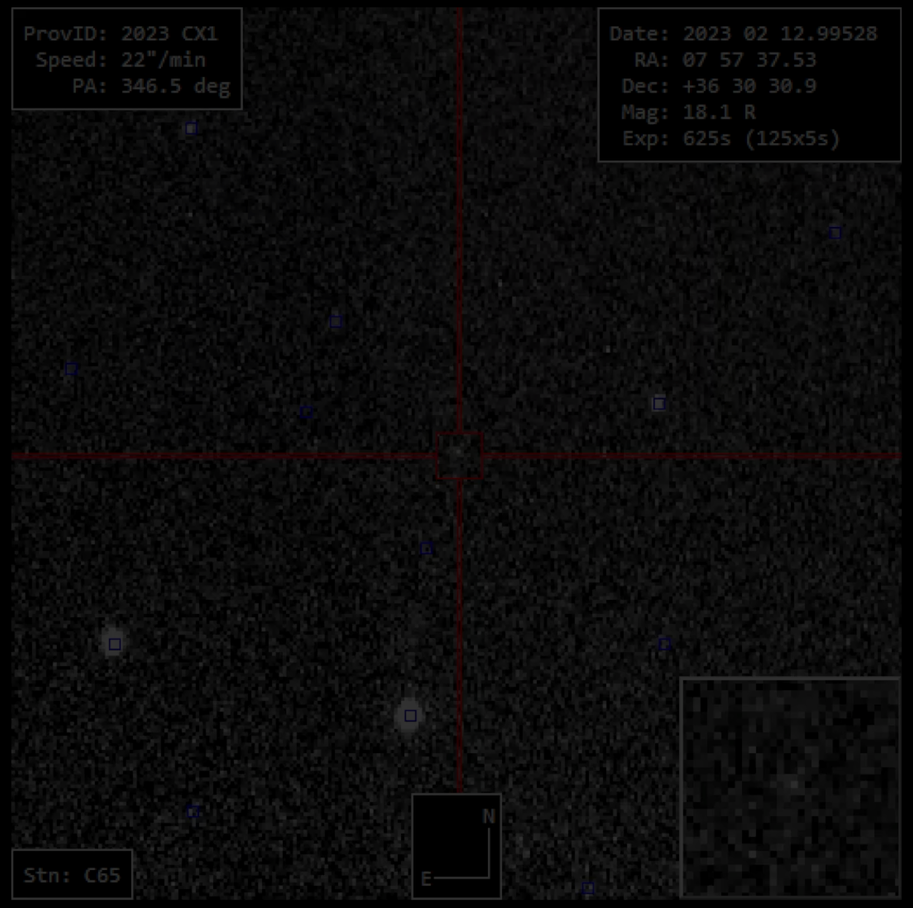
- Multi-technique & complementary analyzes

Telescopic observations

- 22 observatories targeted 2023 CX1
- Careful (re)processing of 11 datasets

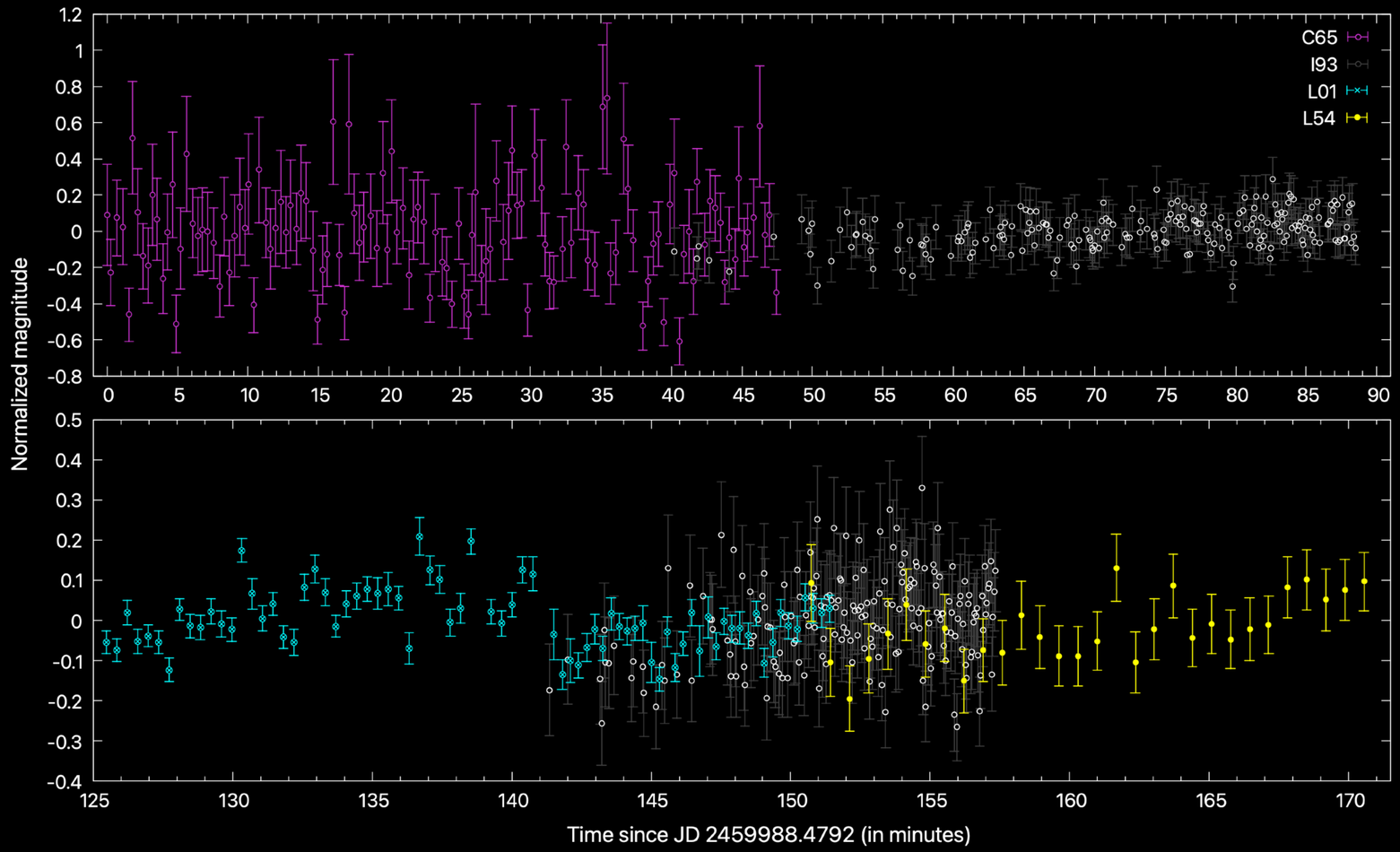
Shape

Photometry



Credit: TJO observatory, Toni Santana-Ros

- Flat light curve (t_{res} < 2s)



- 2023 CX1 was likely spherical

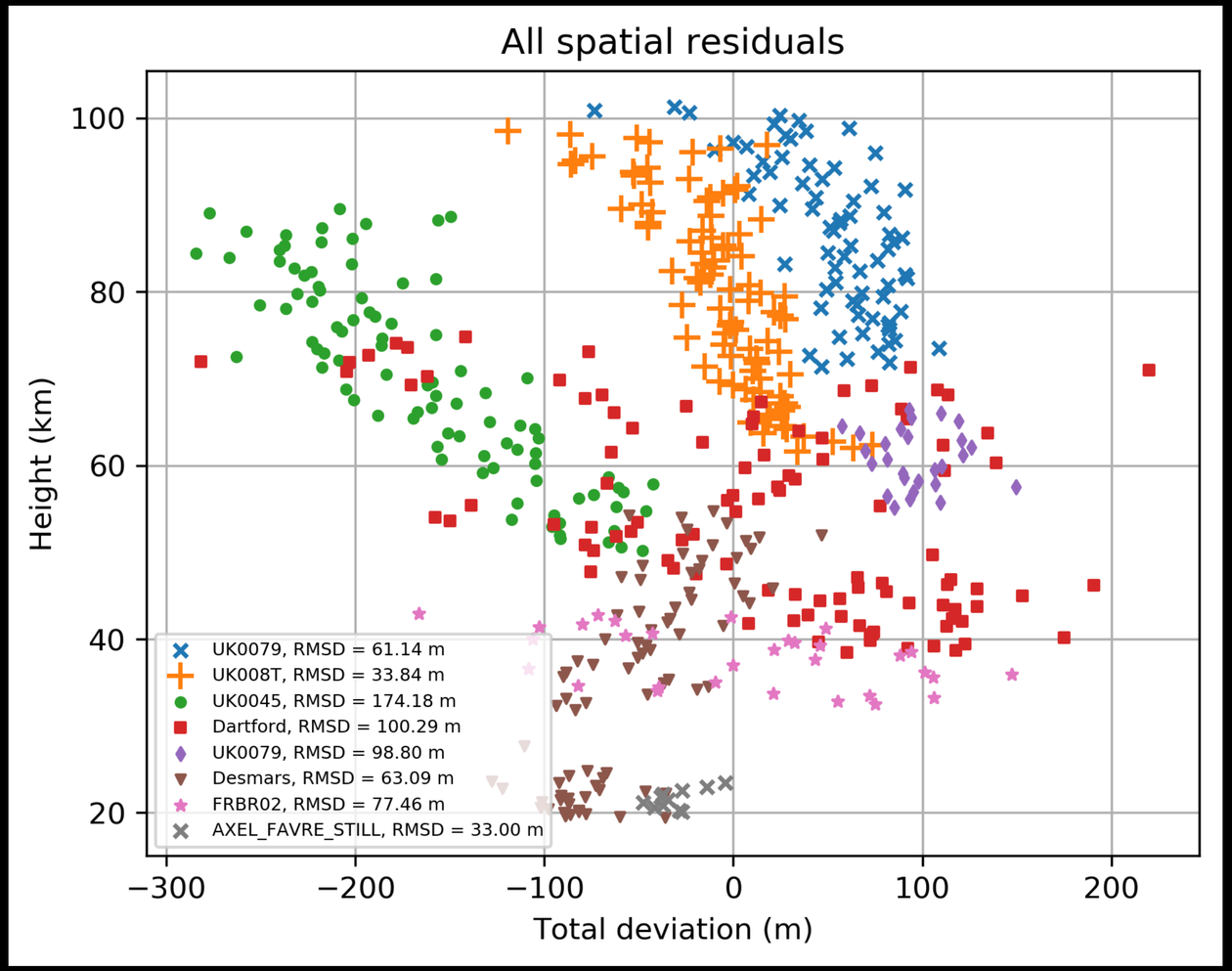
Orbit

Astrometry

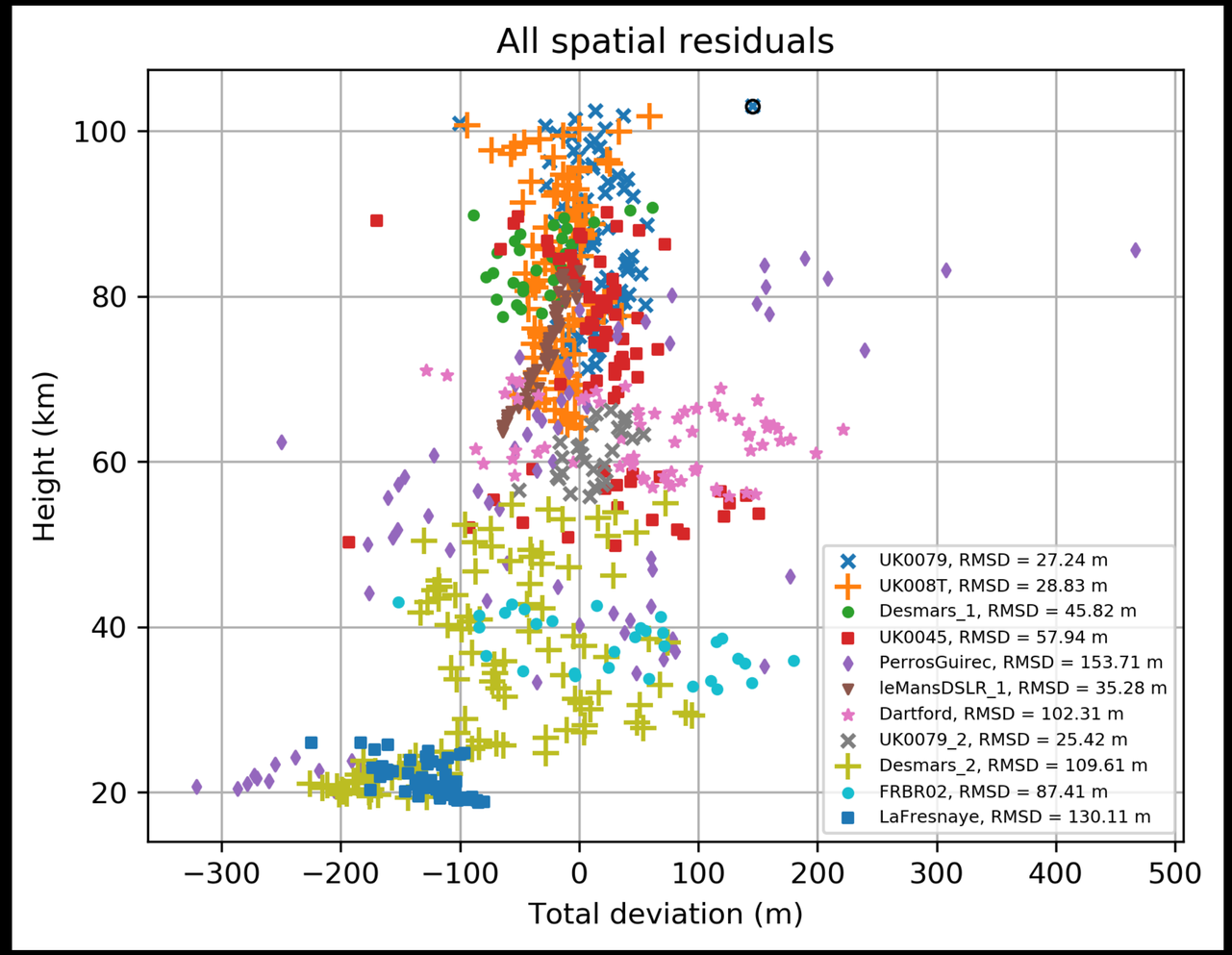
- Trail-fitting techniques
- Timing bias
- Geographic coordinates

Refining the trajectory

First estimate:



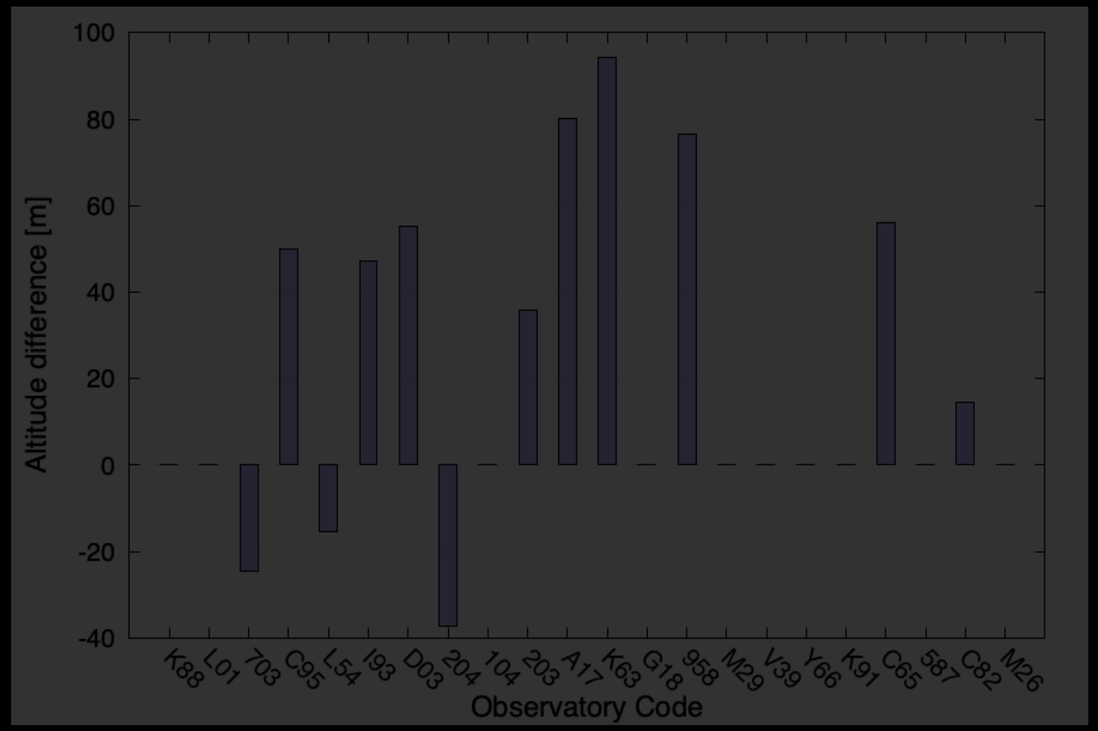
Post-impact processing:



Orbit

Investigating differences:

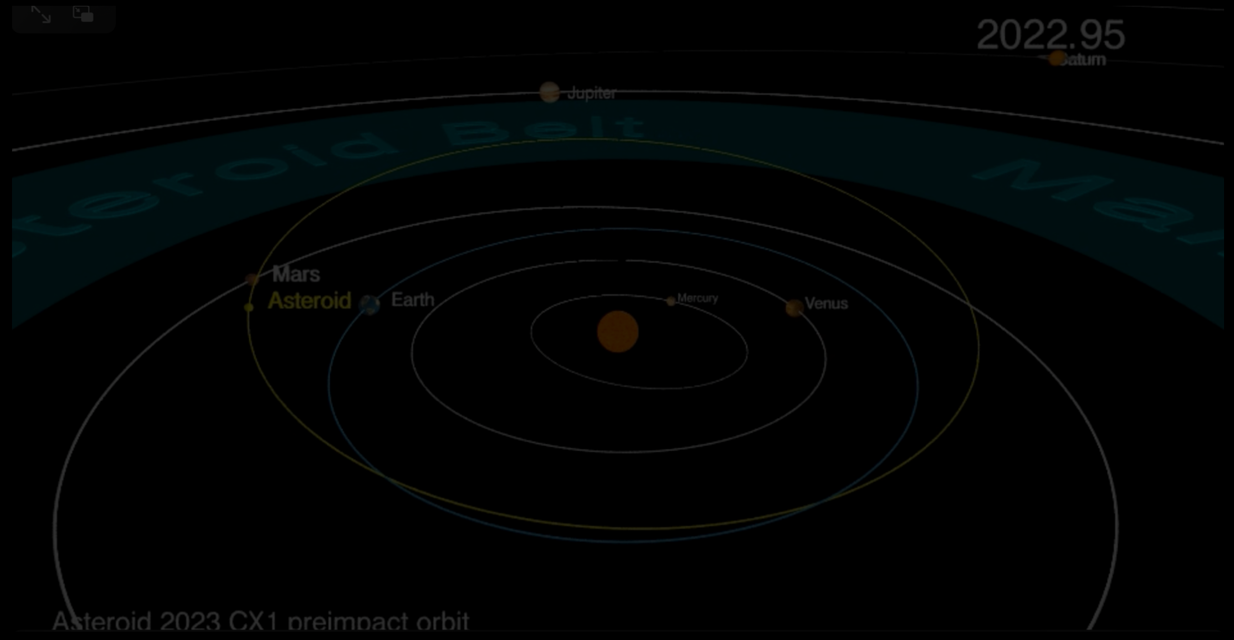
- Significant errors in the observatory coordinates sent to the Minor Planet Center



- ~55% of the heights reported were MSL and not above the ellipsoid

Dynamical origin

- 2023 CX1's orbit indicate an origin in the Inner Asteroid Belt

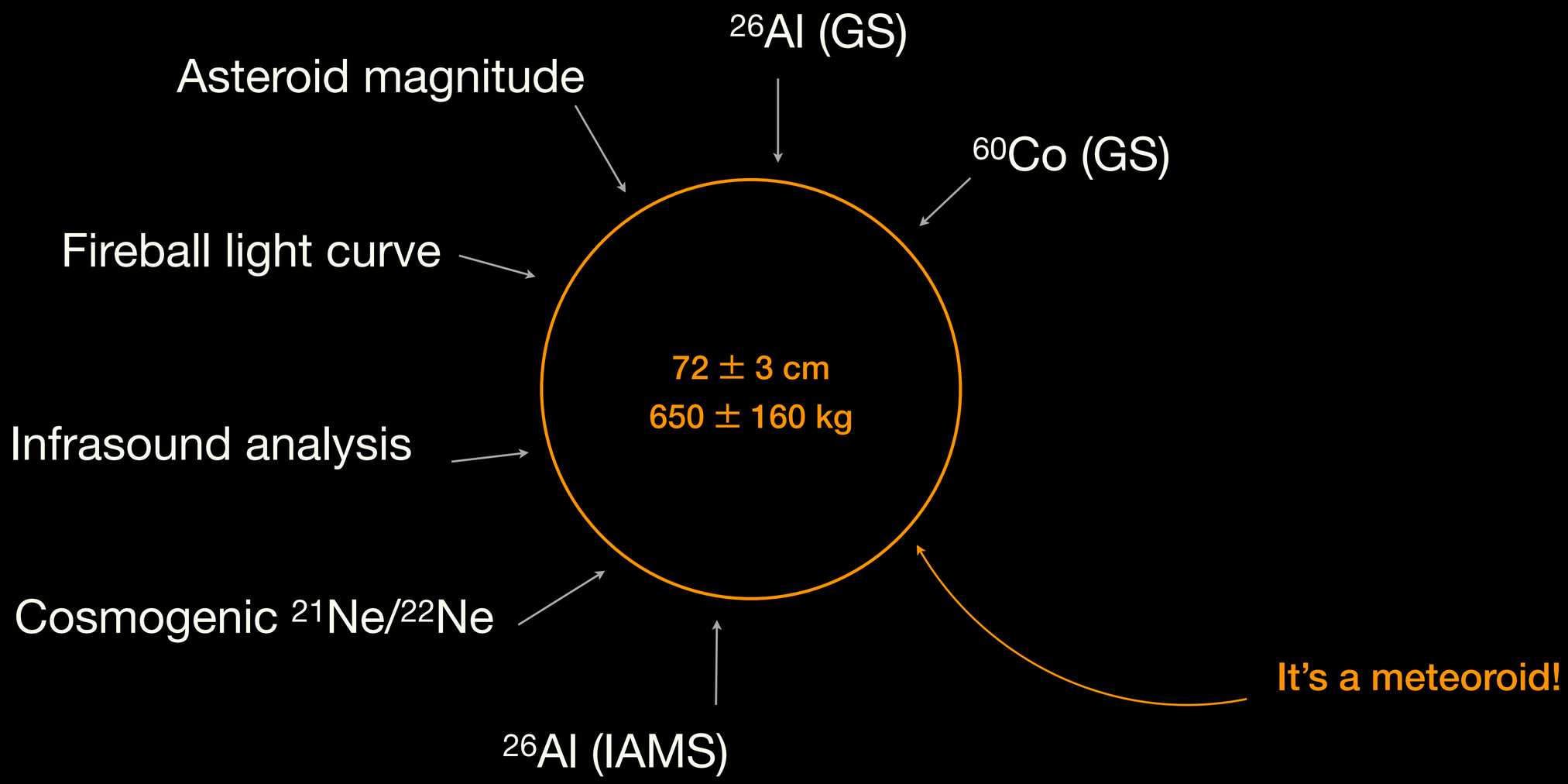


Credit: P. Wiegert

- CX1 was ejected from its parent ~30 Ma ago

Initial size

- Initial mass computed from 7 independent methods



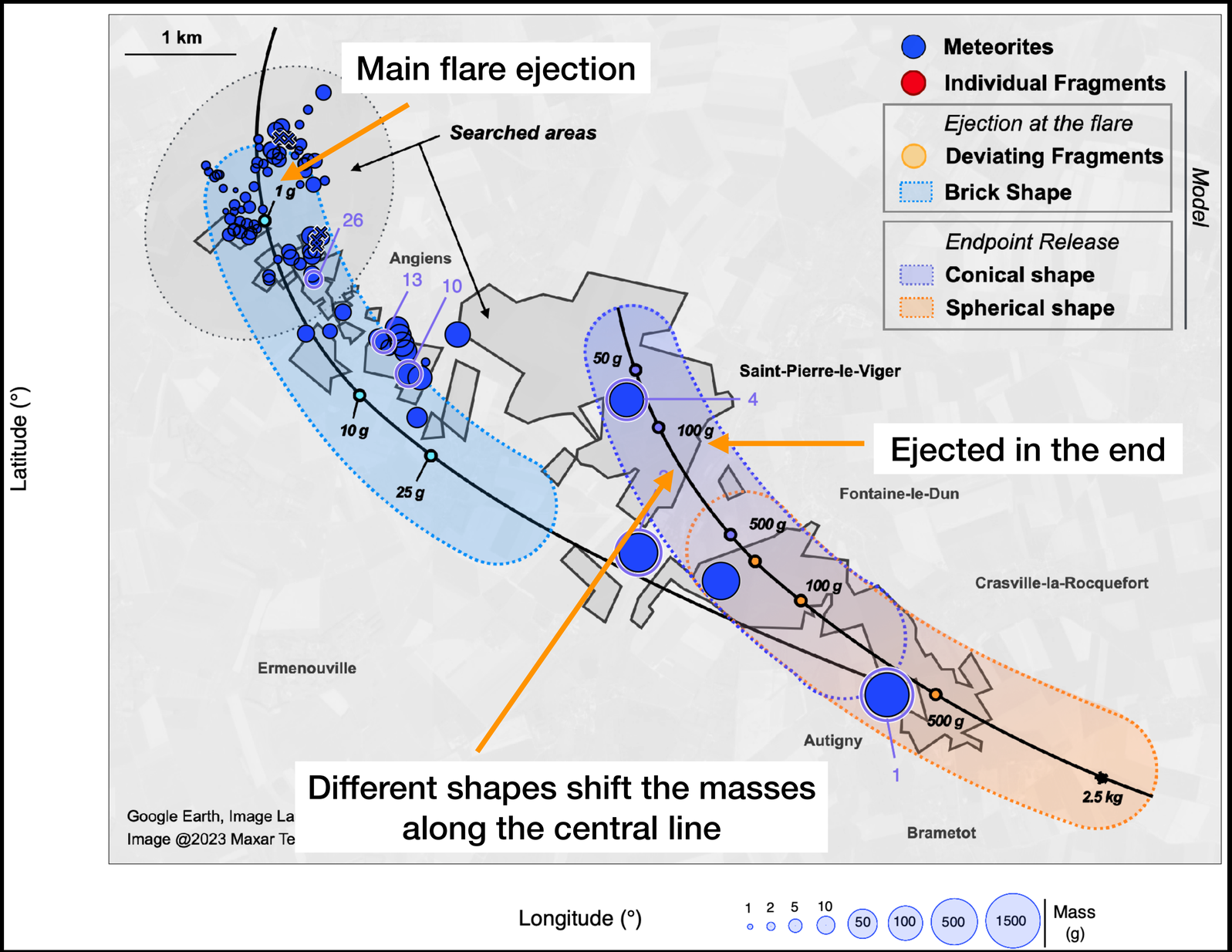
Strewn field

Credit:Denis Vida

Dark flight

- From the observed trajectory, speed, height, and direction

Strewn field



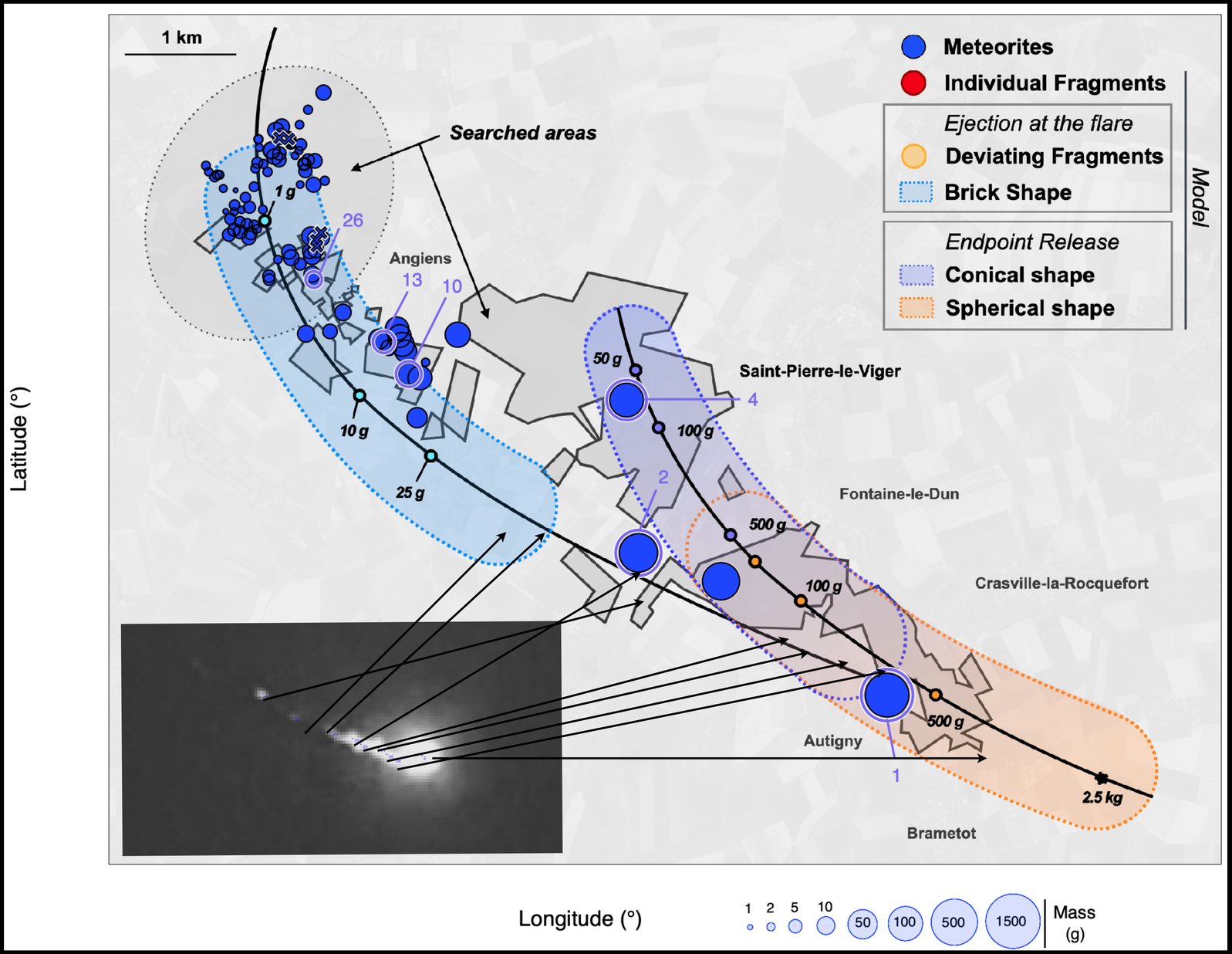
Dark flight

- From the observed trajectory, speed, height, and direction
- Unknown parameters that modify the dark flight:

1) The meteorite's shape
   - changes the drag for each rock
2) The "ejection" (release) point
   - At the end of the trajectory (V < the ablation limit at 4 km/s)
   - At a fragmentation point

- Usually, main mass at the end and smaller pieces at fragmentation points

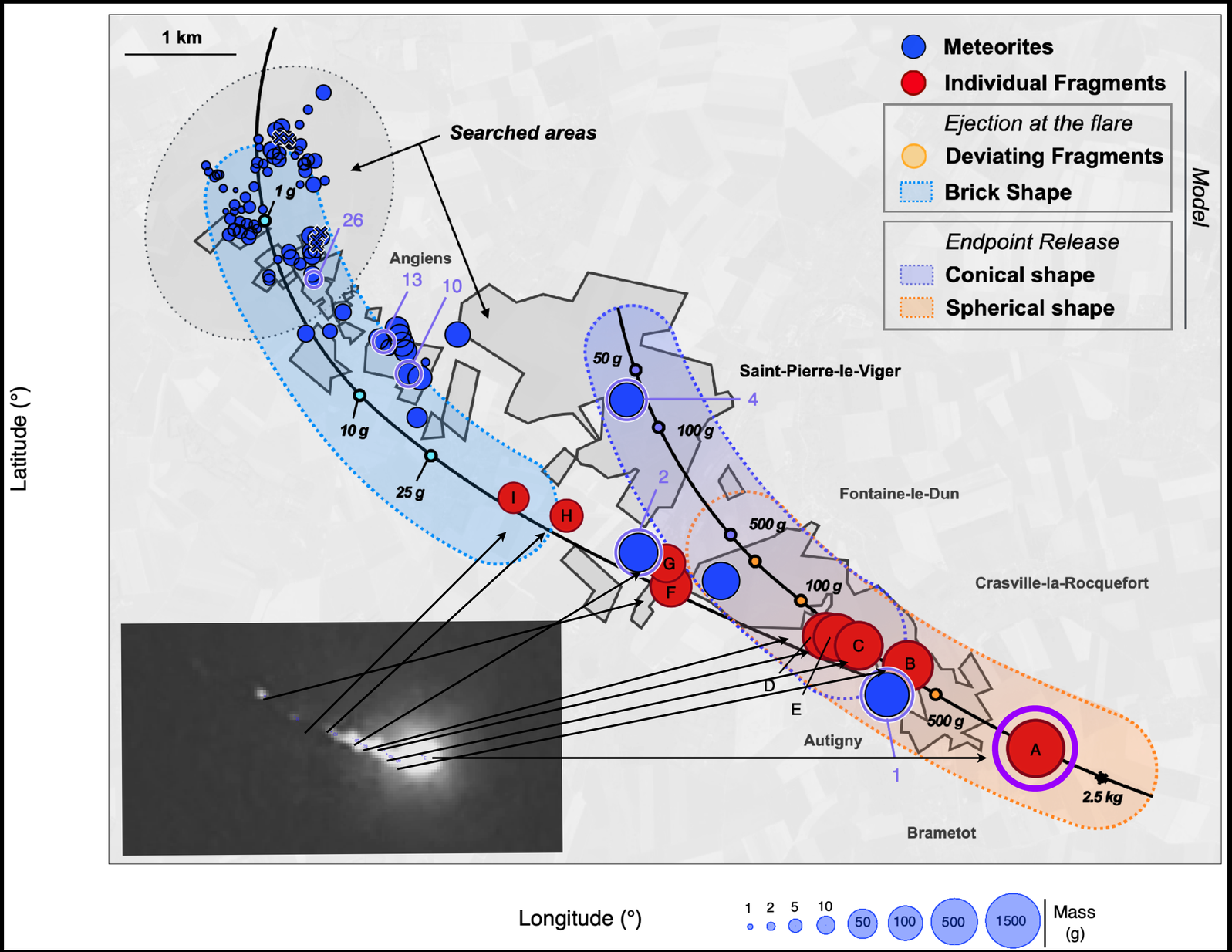
Strewn field



Dark flight

- Small meteorites
  - Ejected at the flare, high drag

Strewn field



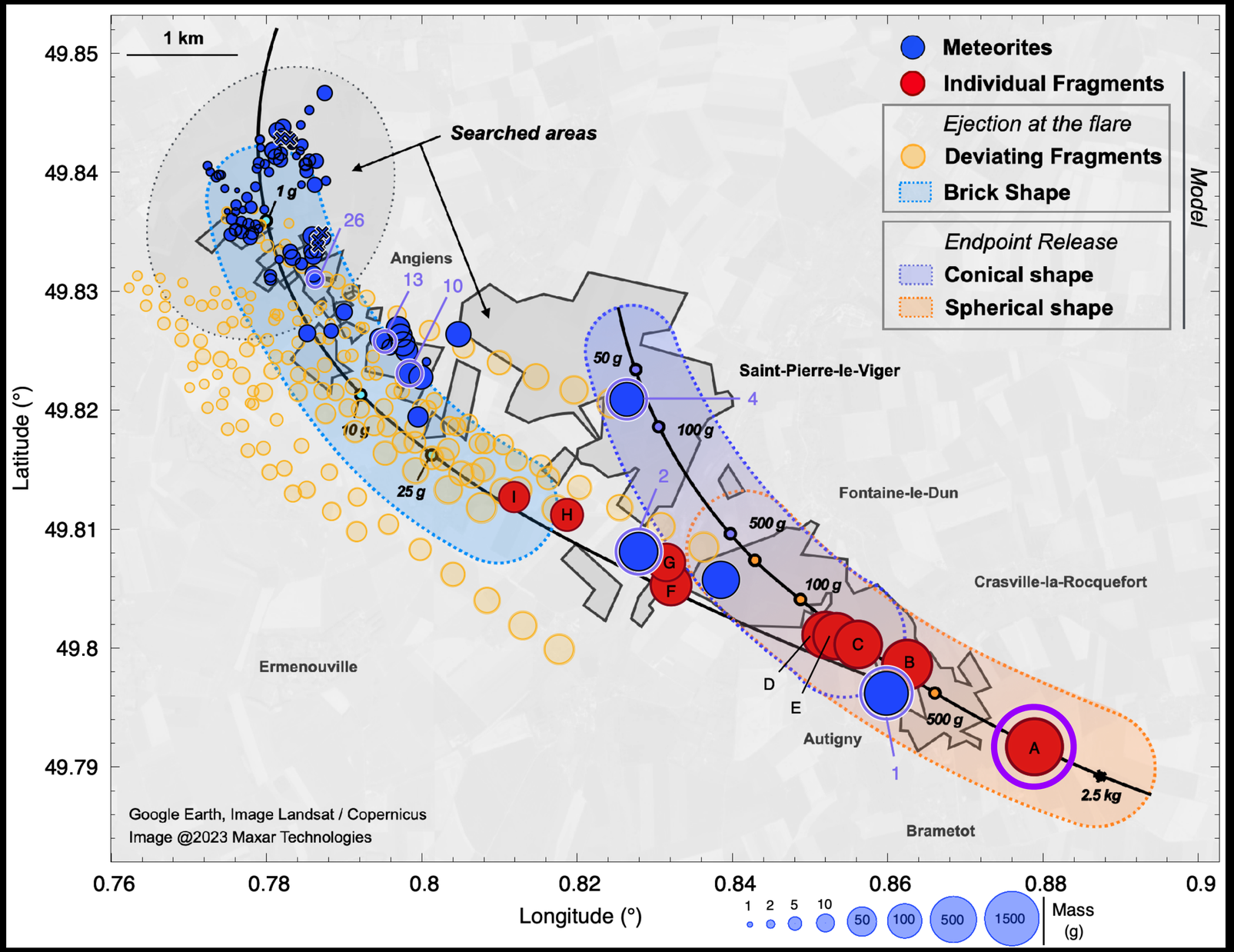
Dark flight

- Small meteorites
  - Ejected at the flare, high drag

- Large masses match the individual fragments identified in the video records

- Fragment #4 and meteorites SE of Angiens

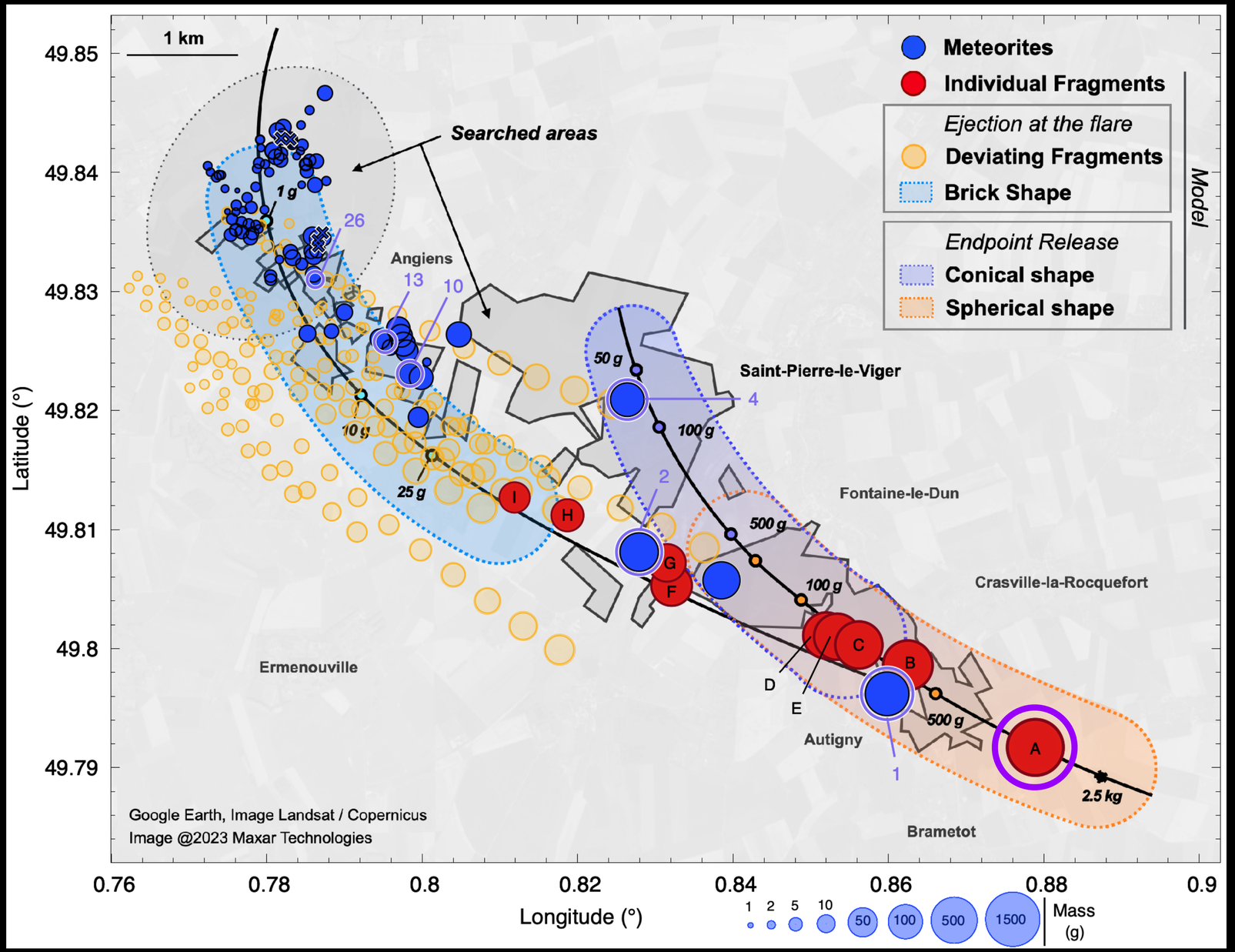
Strewn field



Dark flight

- Small meteorites
  - Ejected at the flare, high drag
- Large masses match the individual fragments identified in the video records
- Fragment #4 and meteorites SE of Angiens
  - A <5° northward deviation after the flare
  - A late separation + strong drag

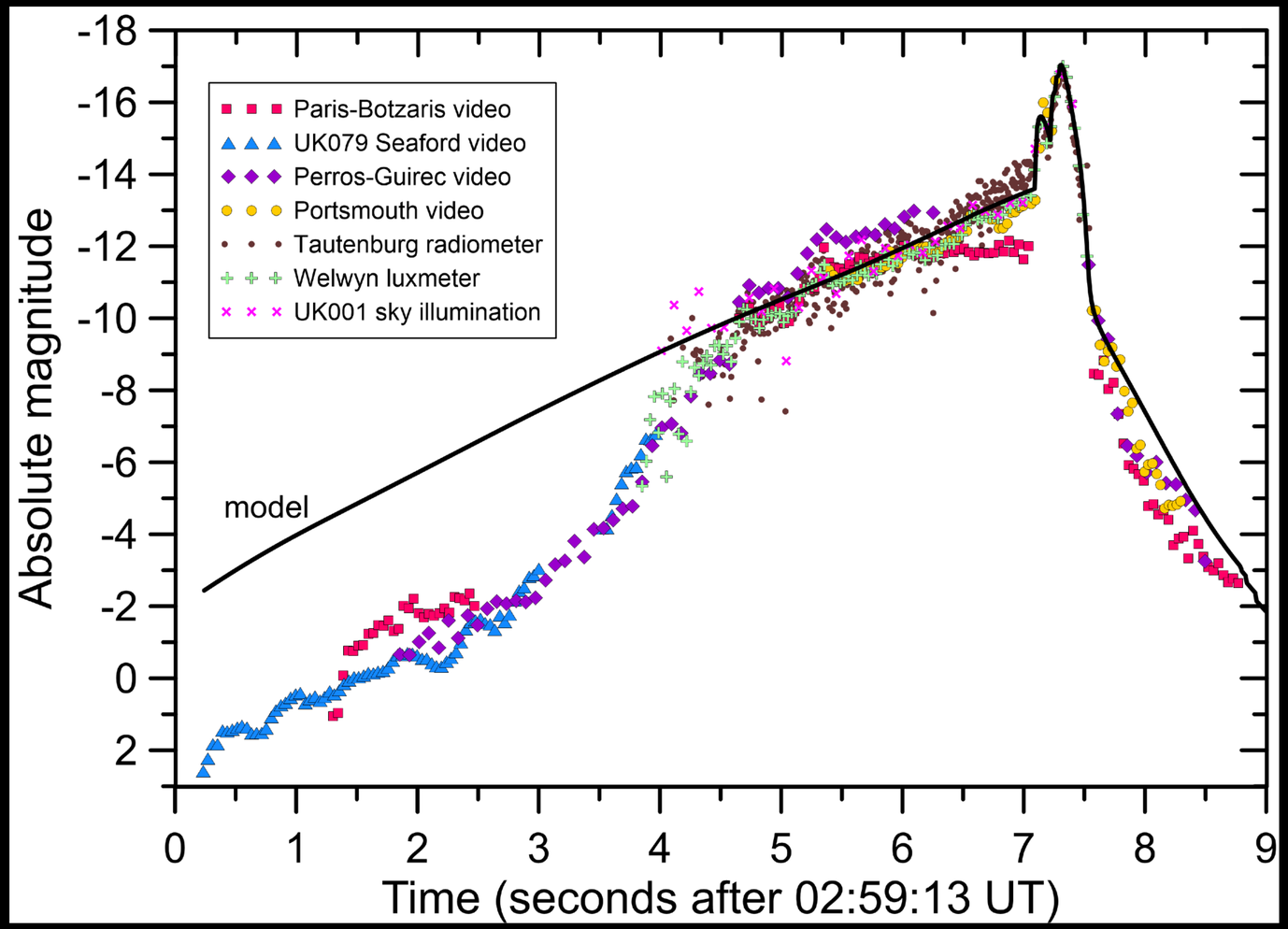
Strewn field



Cosmogenic nuclides concentrations:

- Remarkable homogeneity among the samples
- No correlation with the meteorites' position
  - 2023 CX1 was small
  - Complex & unusual fragmentation behavior

Atmospheric fragmentation



- Two consecutive flares at heights of 27-29 km

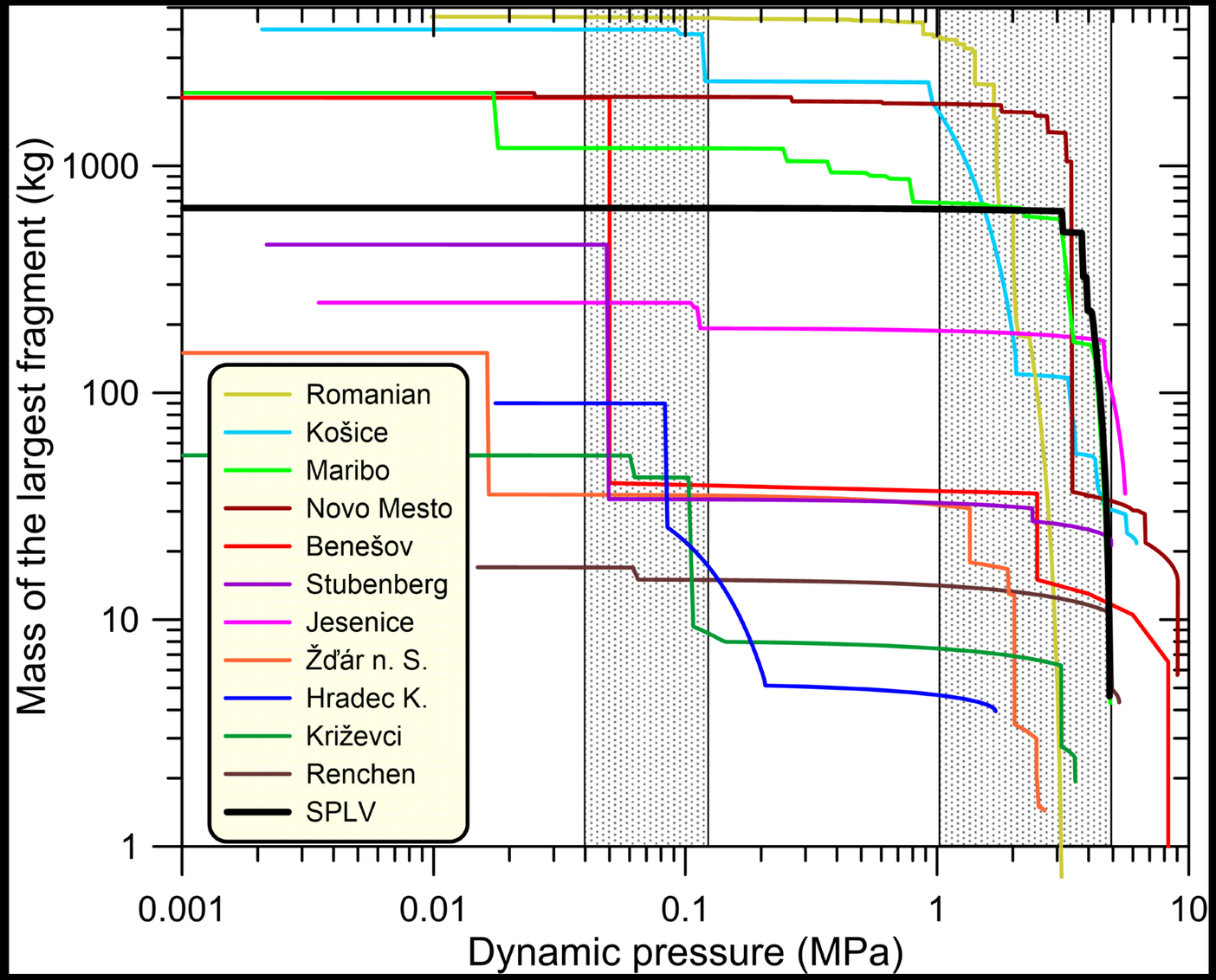
  ⇒ Confirmed by seismo-acoustic analysis!

- Peak absolute magnitude of -17

- No fragmentation nor significant mass loss measured before the flares

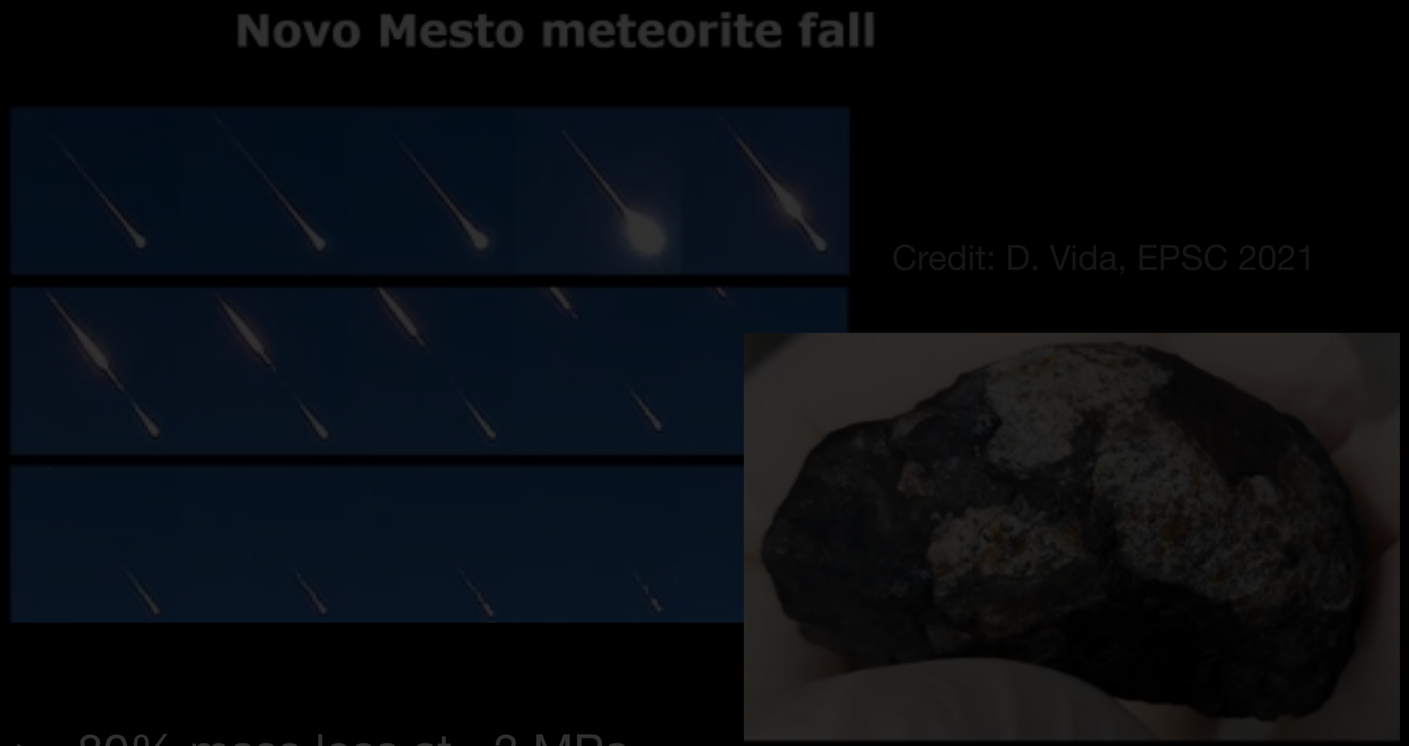
⇒ 2023 CX1 lost ~98% of its mass during a single, catastrophic disruption around 4 MPa

Unusual behavior



- No significant fragmentation at low dynamic pressures
- ≠ from the 22 meteorite-dropping events analyzed by Borovicka et al., 2020
- Only 4 known events that resisted disrupting to such high pressures
  - Prairie Network (Ceplecha et al., 1993, 5 MPa, sparse data)
  - Carancas in Peru (H4-5, 13 m-wide crater, no unique trajectory solution)
  - 2015 superbolide over Romania (3 MPa, no meteorite)
  - Novo Mesto, 2020 (3 MPa).

A new class of risky L-chondrites?



Credit: D. Vida, EPSC 2021

- 80% mass loss at ~3 MPa
- 0.3 kt airburst, minor earthquake on the ground
- Also delivered heavily shocked L5 chondrites
- ~96% probability of originating from Massalia

NM & 2023 CX1

- Both are L-chondrite-like m-sized bodies
- They deposited all their energy in a single, catastrophic event
- Possibility of causing greater ground damage than gradually fragmenting bodies (e.g., Chelyabinsk).

⇒ A new class of L-chondrite-like asteroids capable of producing disproportionately large airbursts?

Conclusion

1. Extremely accurate impact prediction
   - Novel observational strategy deployed by ESA
   - Timing accuracy of a few seconds
2. Efficient media communication
   - First large-scale, targeted observations of a fireball
   - Comprehensive dataset of 2023 CX1 atmospheric entry
3. Efficient ground search & SF computation
   - First meteorite recovered within 2 days of the fall
   - Analyzed in laboratory within a week
4. Best characterized L-chondrite fall
   - Multi-disciplinary analysis
   - Validation & improvements of reduction techniques

Credit: J. Desmars

Conclusion

5

- A new class of risky L-chondrite-like asteroids?

2104 / 10 h

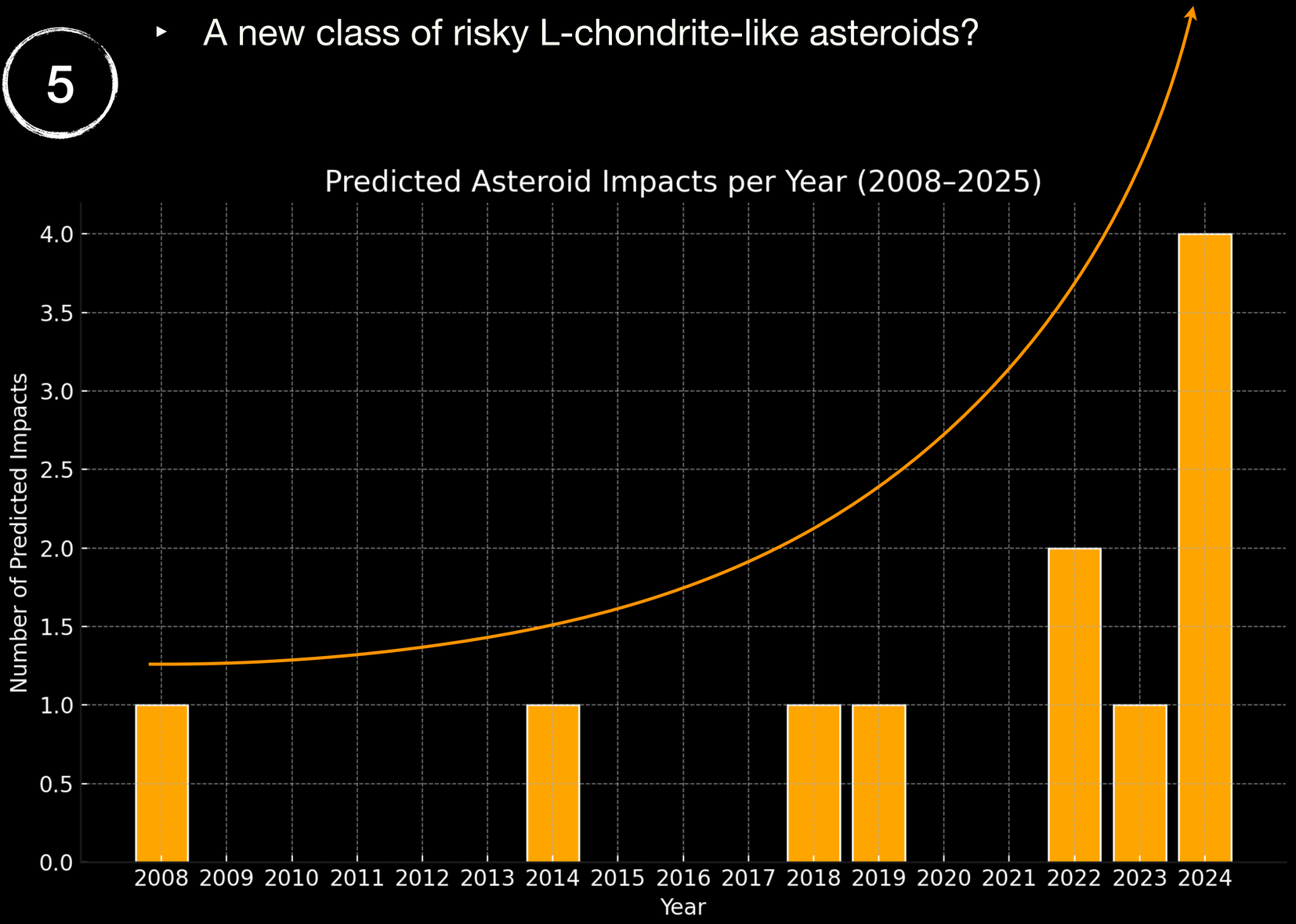
vs

20 000 / yr

Conclusion

5

- A new class of risky L-chondrite-like asteroids?



<u>Imminent impactor checklist:</u>

- Meter- & decameter-sized bodies
- Origin consistent with the inner main belt
- Spectra / color similar to L-chondrites
- Particular caution below the 3-4 MPa pressure threshold


Thank you for your attention!
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