Meteorites: Revealing the history and evolution of our Solar system

Prof. Alan Fitzsimmons
Astrophysics Research Centre
Queen's University Belfast

Credit: NHM

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- What is a meteorite? Or a meteor?
- Types of meteorite.
- Where do they come from?
- What type of object do they come from?
- Dating meteorites (not the Love Island kind!).
- The history of meteorites (dating part 2).
- Future investigations.

Meteorites: Revealing the history and evolution of our Solar system

There are some real experts out there!

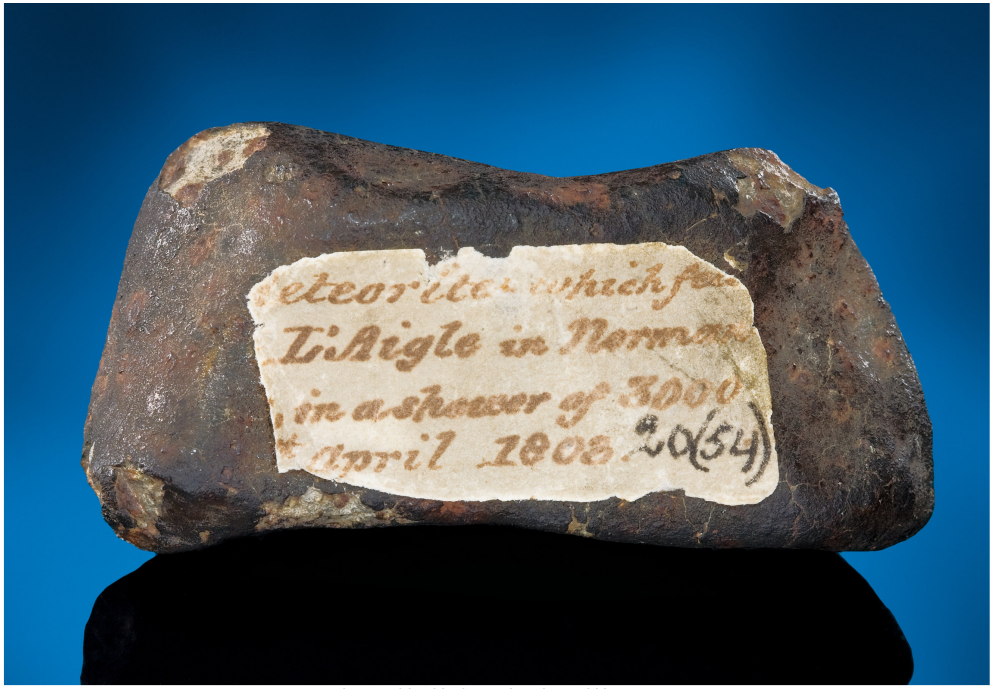
UK Meteor Observation Network (https://ukmeteornetwork.co.uk)
UK Fireball Alliance (https://www.ukfall.org.uk)
BAA Meteor Section (https://britastro.org/section_front/19)

Natural History Museum (including UK National Meteorite Collection)
University of Manchester
Imperial College London
Open University
University of Leicester
…and many more!

Meteorites: Revealing the history and evolution of our Solar system

Meteorites - rocks from elsewhere in the Solar system

Jean-Baptiste Biot
(1774-1862)

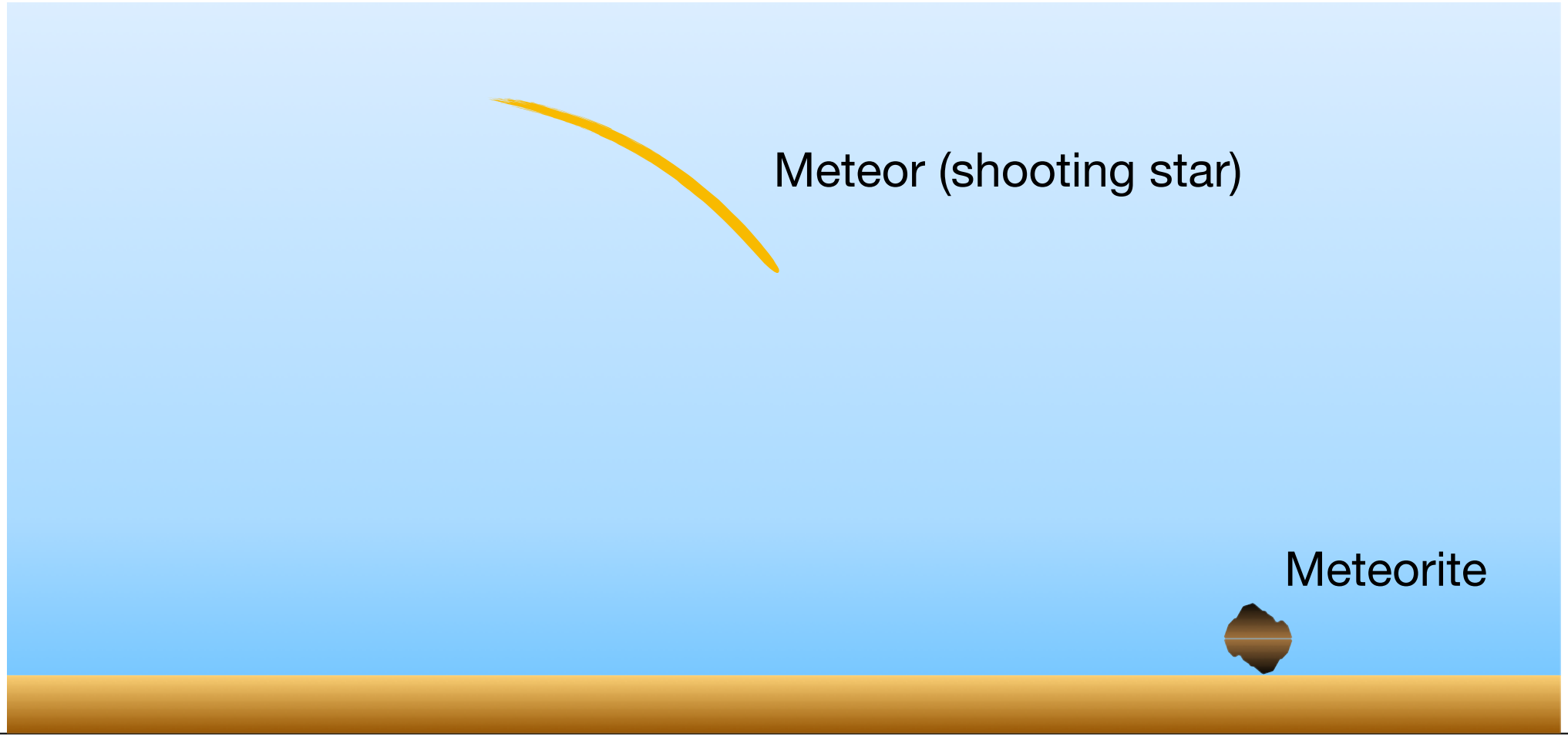


Imaged by Heritage Auctions, HA.com

L'Aigle meteorite
26th April 1803

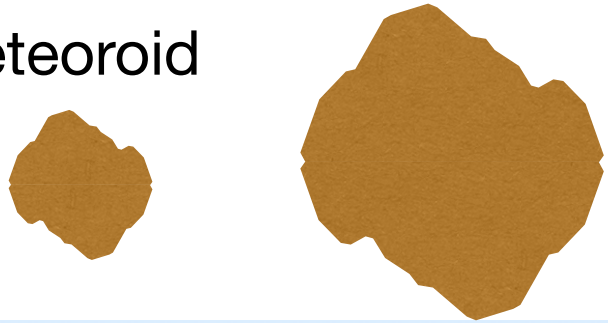
Definitions

Meteoroid

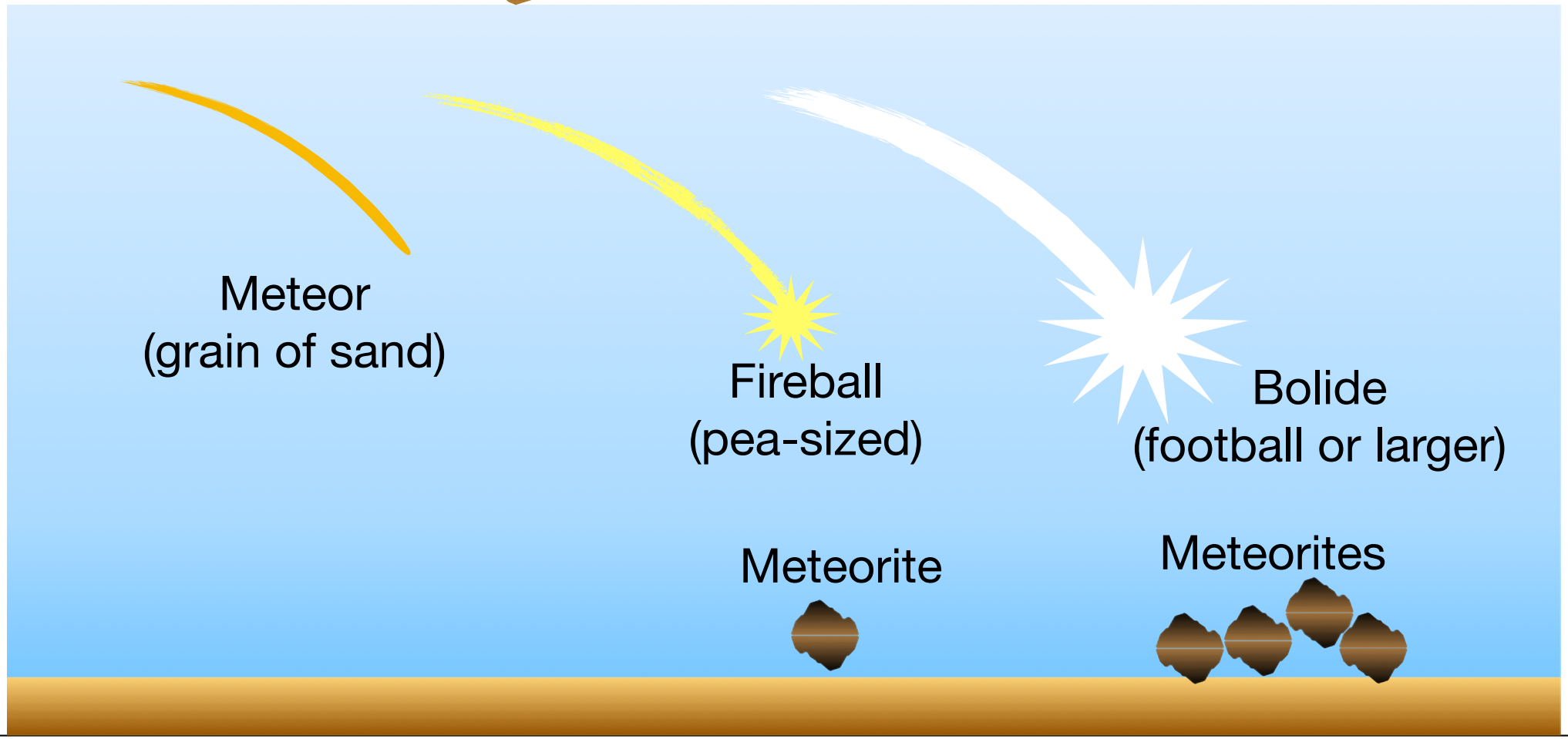


Definitions

Meteoroid



Asteroid (1 metre across or larger)

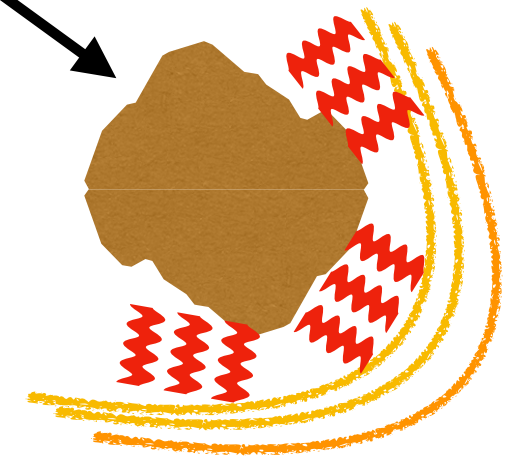


What causes the meteor/ fireball/bolide?

15-20 km/sec
(33,000 to 45,000 mph)

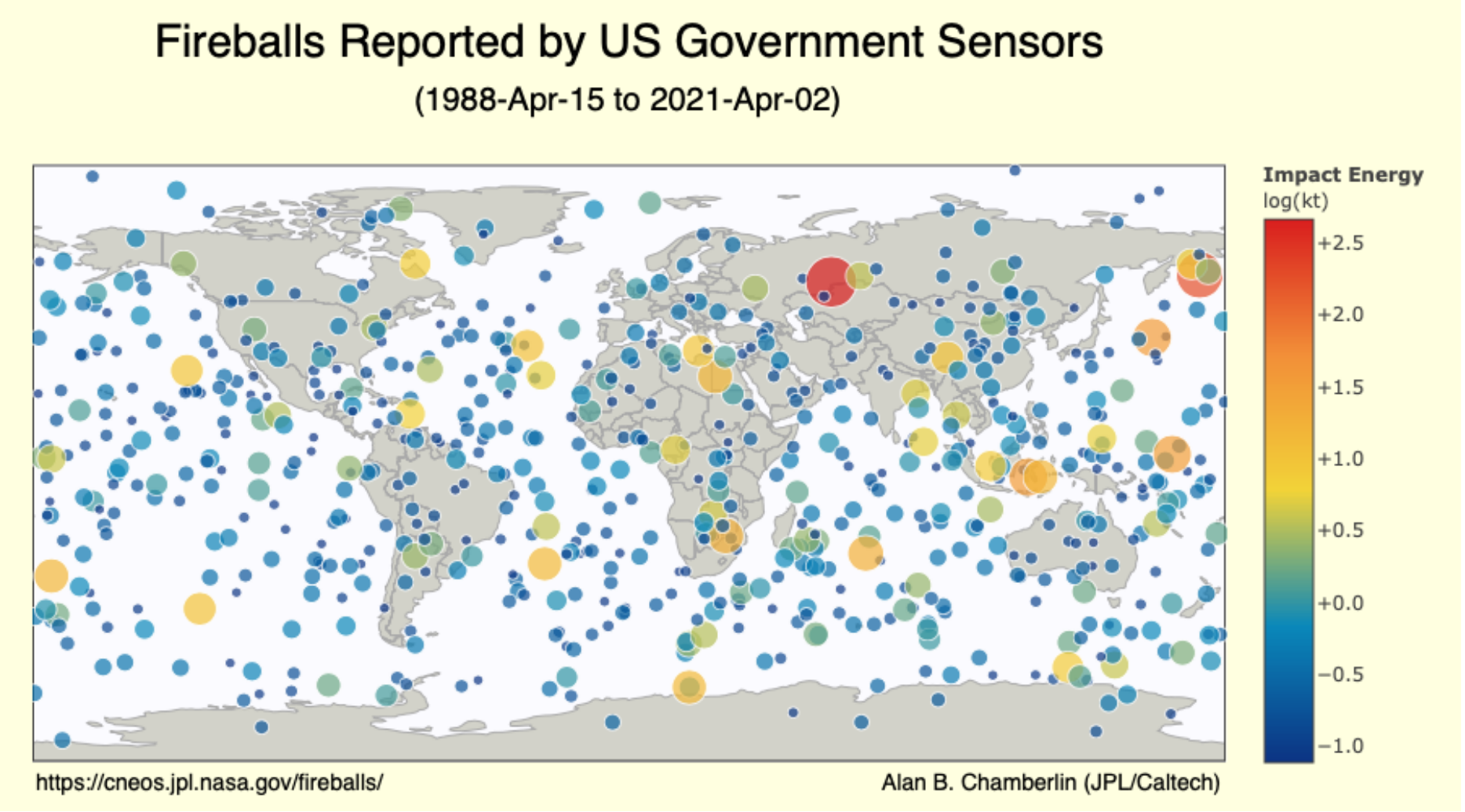
Kinetic Energy -> Friction+Ablation -> Light, Heat

15-20 km/sec
(33,000 to 45,000 mph)

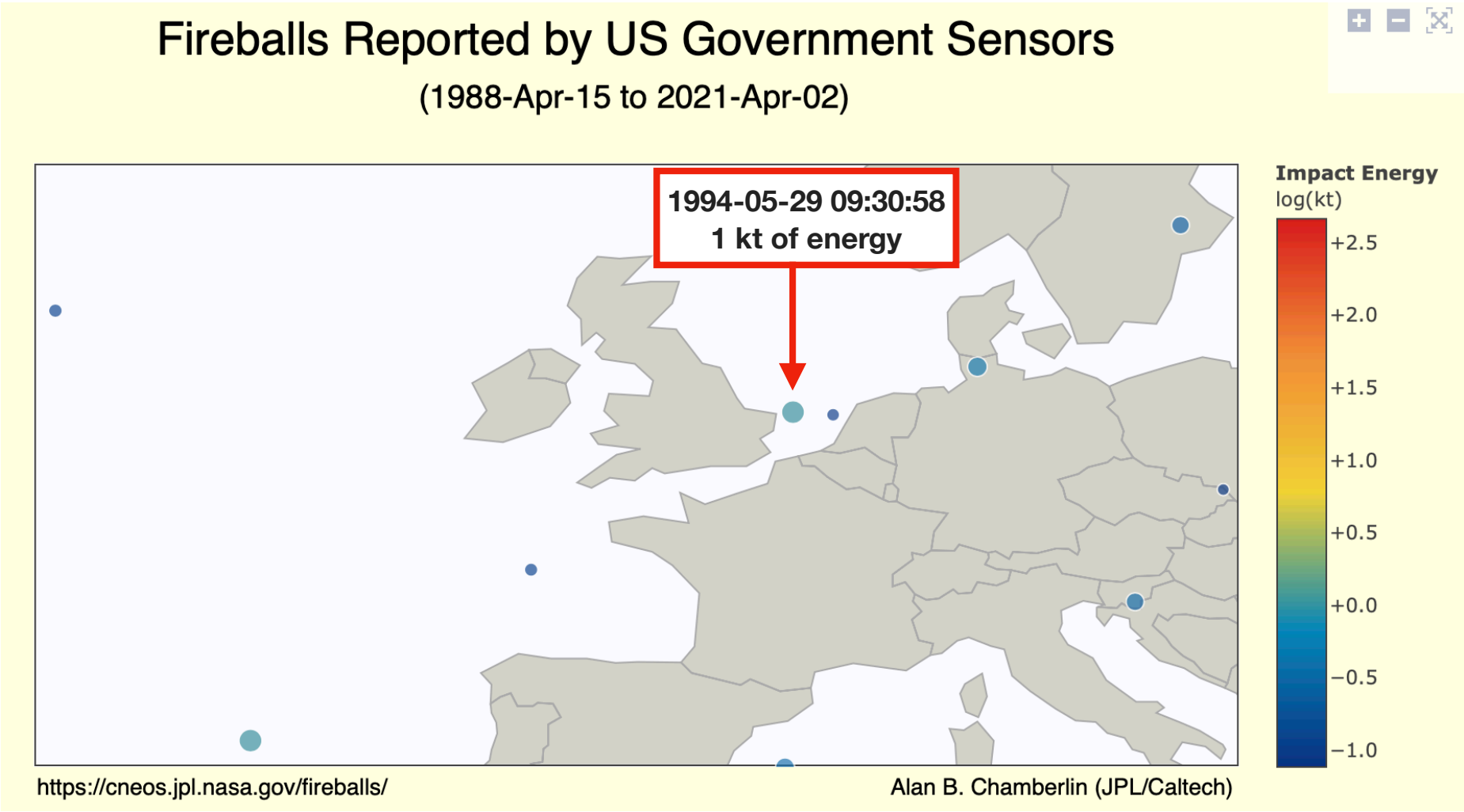


Shock Waves-> Light, Heat -> Ablation

33 years of biggest fireballs



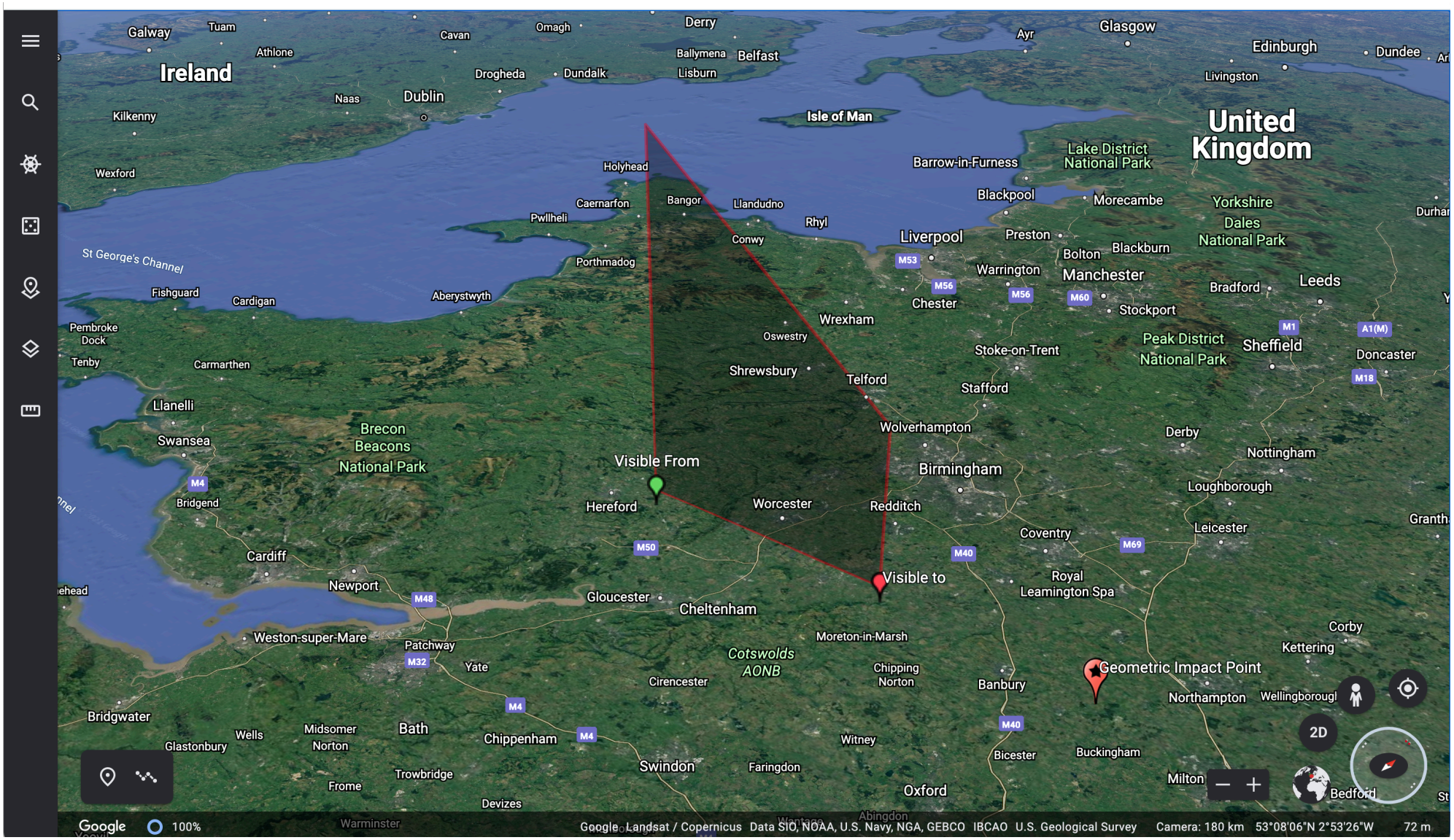
33 years of biggest fireballs



Connecting meteorites to the Solar system 1. Orbits

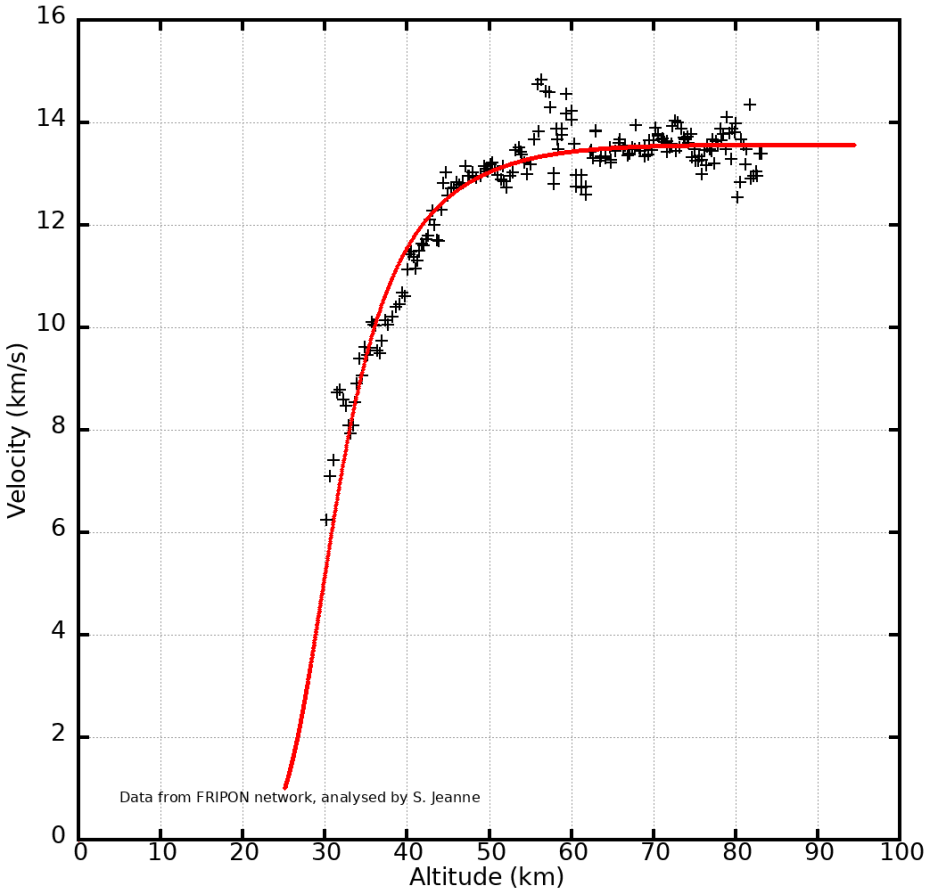
Credit: Ben Stanley/Markus Kempf

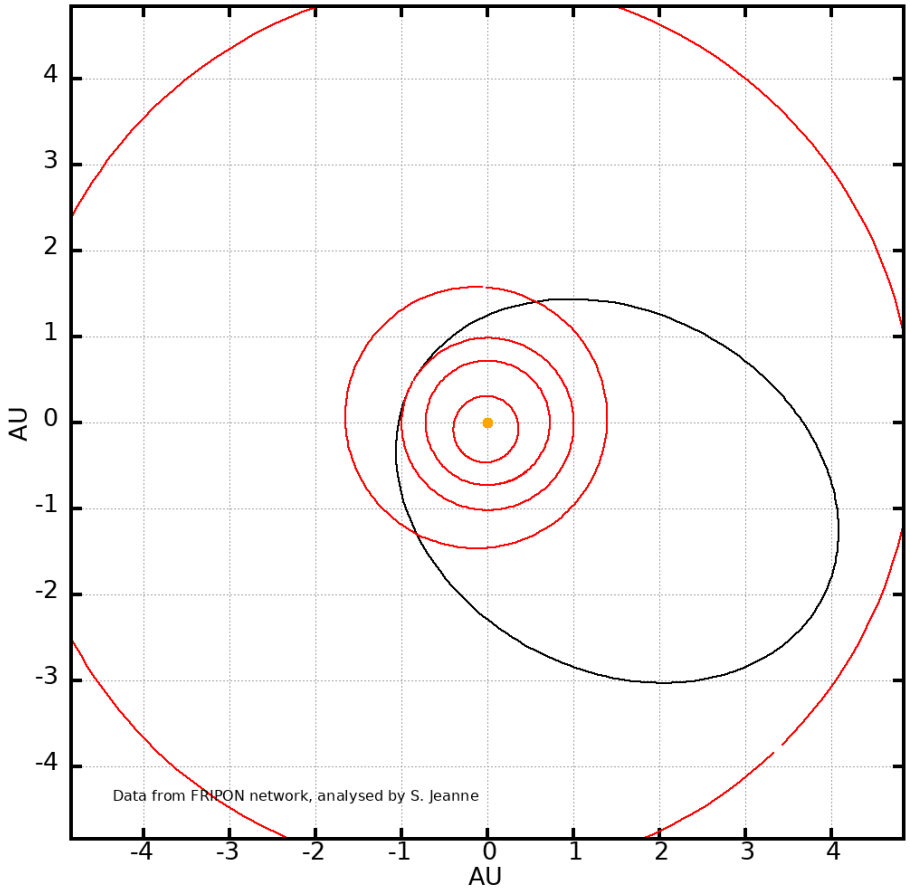
The Winchcombe Fireball



Credit: International Meteor Organisation

The Winchcombe Fireball



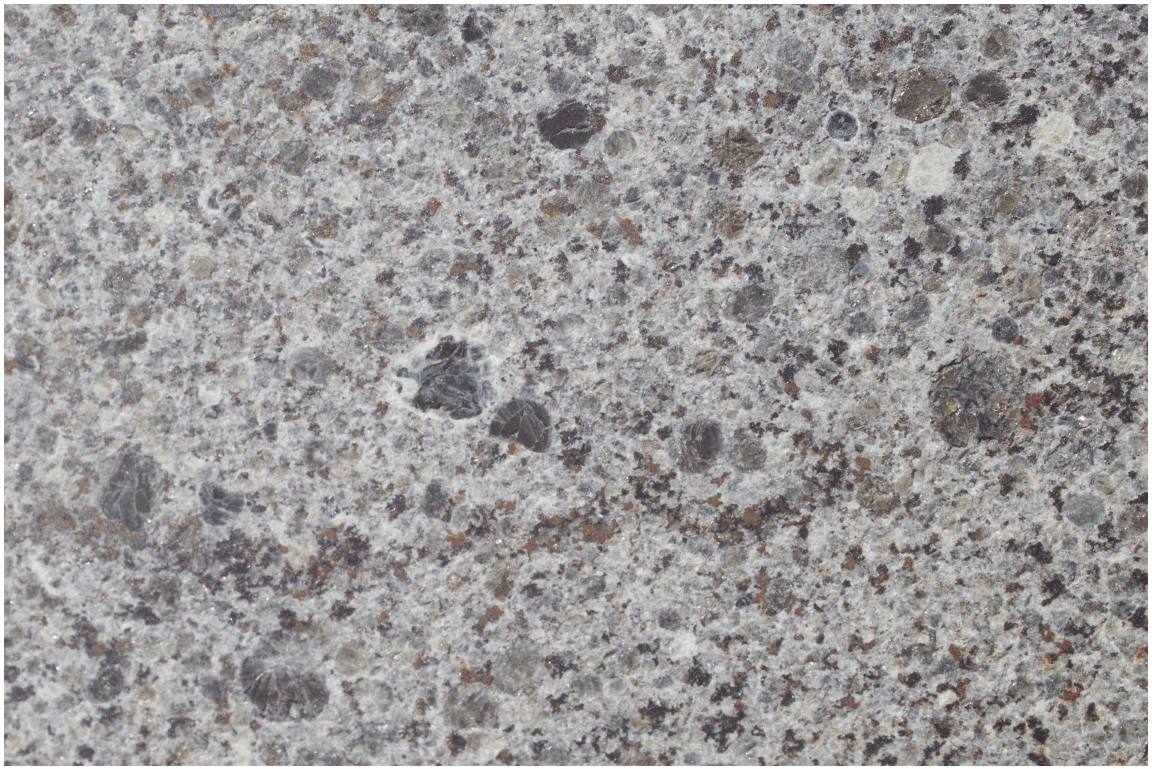


Trajectory and original orbit of the Winchcombe Meteorite
Credit: Fireball Recovery and InterPlanetary Observation Network (FRIPON)
https://fireball.fripon.org/displaymultiple.php?id=15214

Connecting meteorites to the Solar system 2. Composition

Connecting meteorites to the Solar system 2. Composition

Ordinary Chondrite



“Ordinary” - common, **80%** of all witnessed falls are OC meteorites.

“Chondrite” - containing chondrules, spherical concentrations of silicate (rocky) minerals.

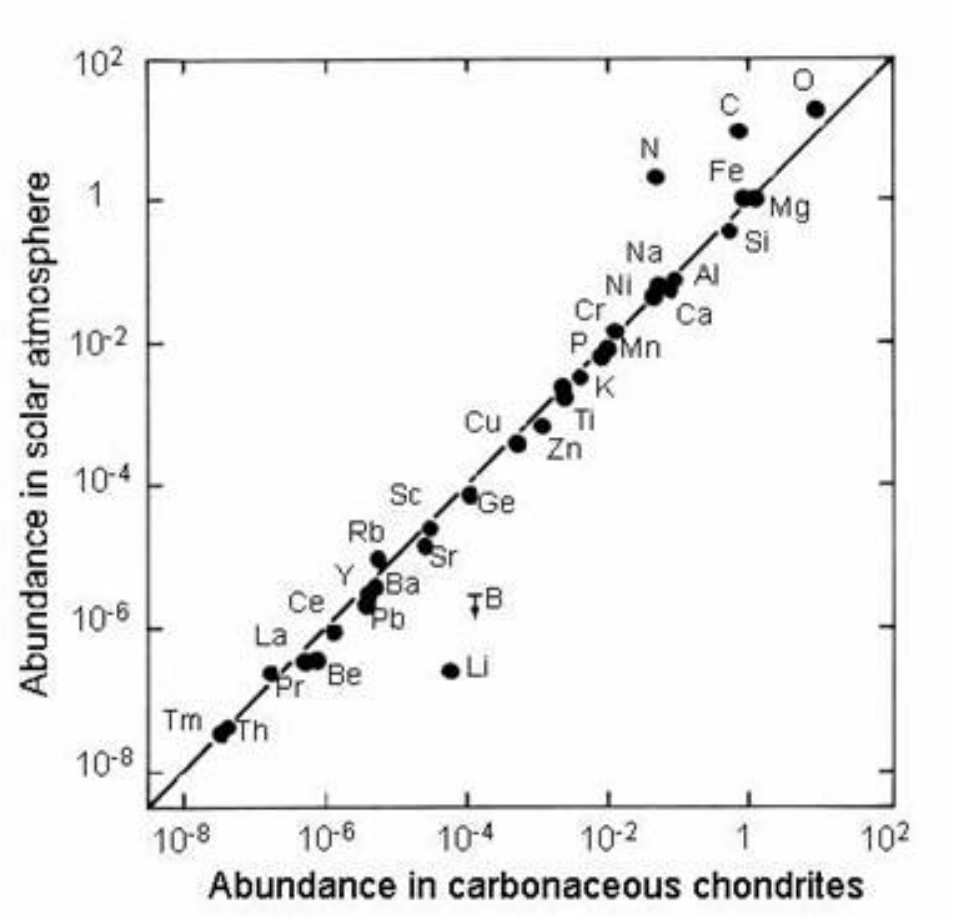
Carbonaceous Chondrite

“Carbonaceous” - carbon rich.
5% of all witnessed falls are C-chondrites.

“Chondrite” - containing chondrules, spherical concentrations of silicate (rocky) minerals.

Contain many more light elements (H,C,O,N) than OC meteorites, implying a more “primitive” composition.

Carbonaceous Chondrite



Credit: Ringwood 1979

"Carbonaceous" - carbon rich.
5% of all witnessed falls are C-chondrites.

"Chondrite" - containing chondrules, spherical concentrations of silicate (rocky) minerals.

Contain many more light elements (H,C,O,N) than OC meteorites, implying a more "primitive" composition.

Achondrites

“Achondrite” - Igneous meteorites from from melting or partial melting of ordinary chondrite material.

8% of all witnessed falls are achondrites.

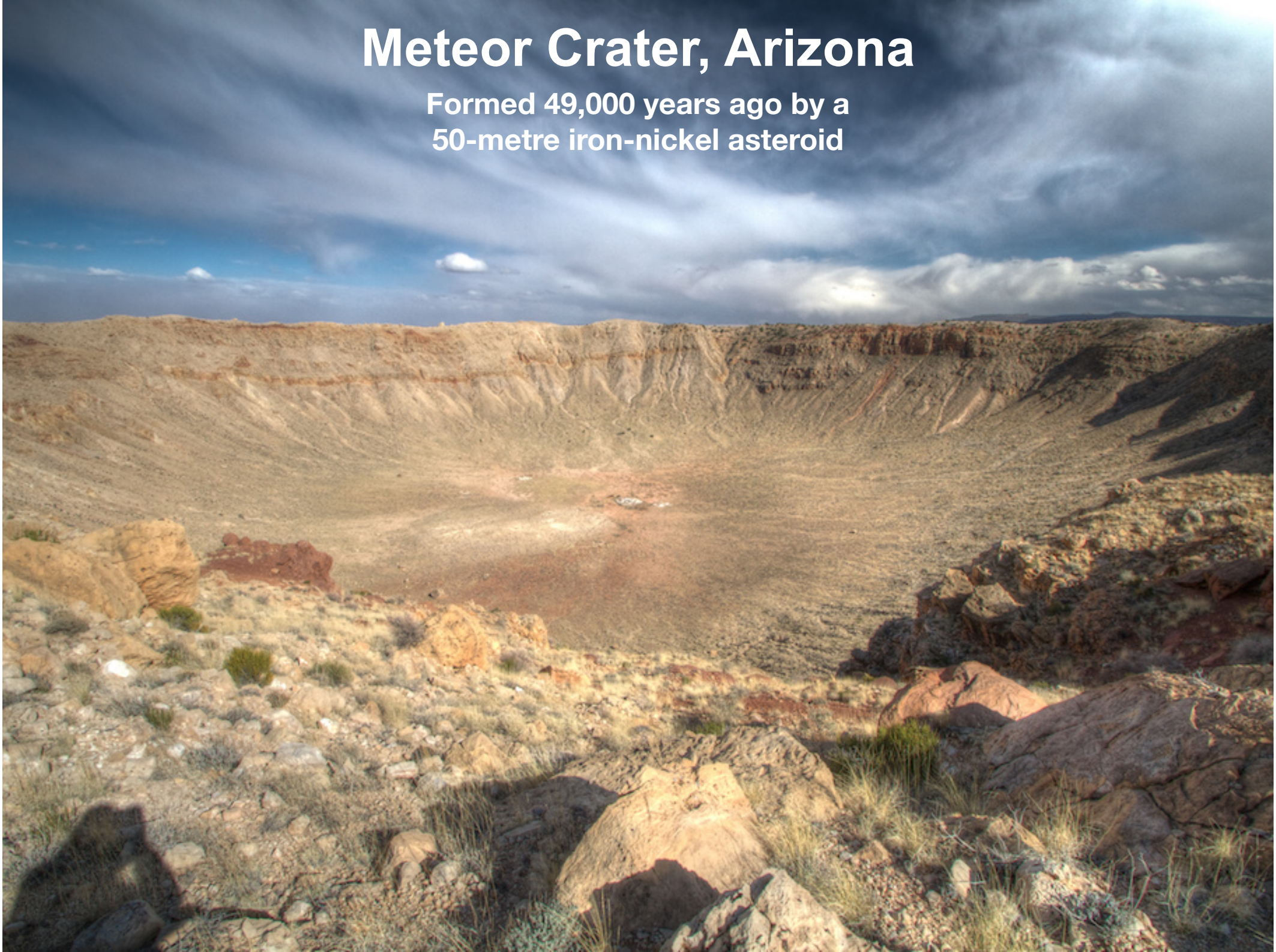
Must come from asteroids where physical processes (heating and collisions) have destroyed the original structure.

Irons

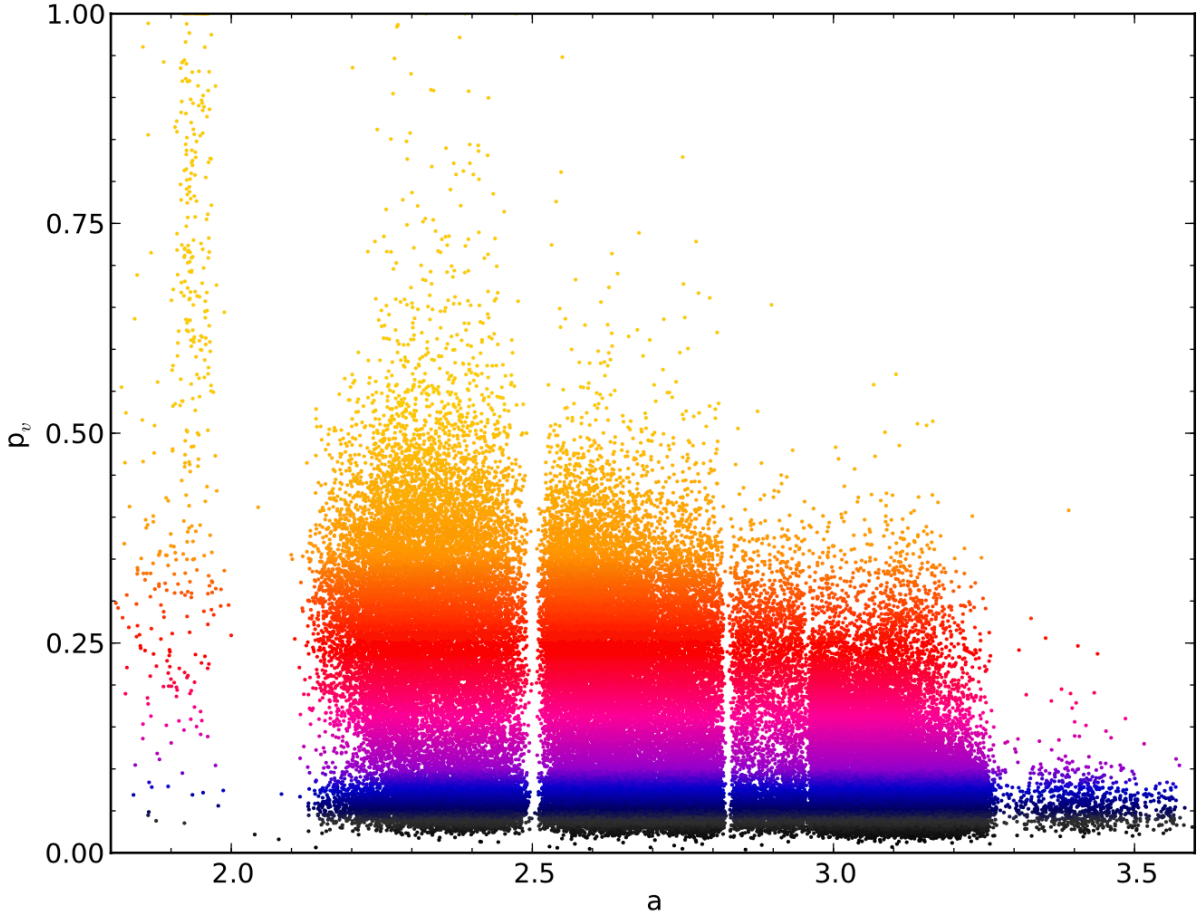
“Achondrite” - Almost pure iron/ nickel (metallic) meteorites.

5% of all witnessed falls are irons.

Must come from asteroids large enough to form an iron core!

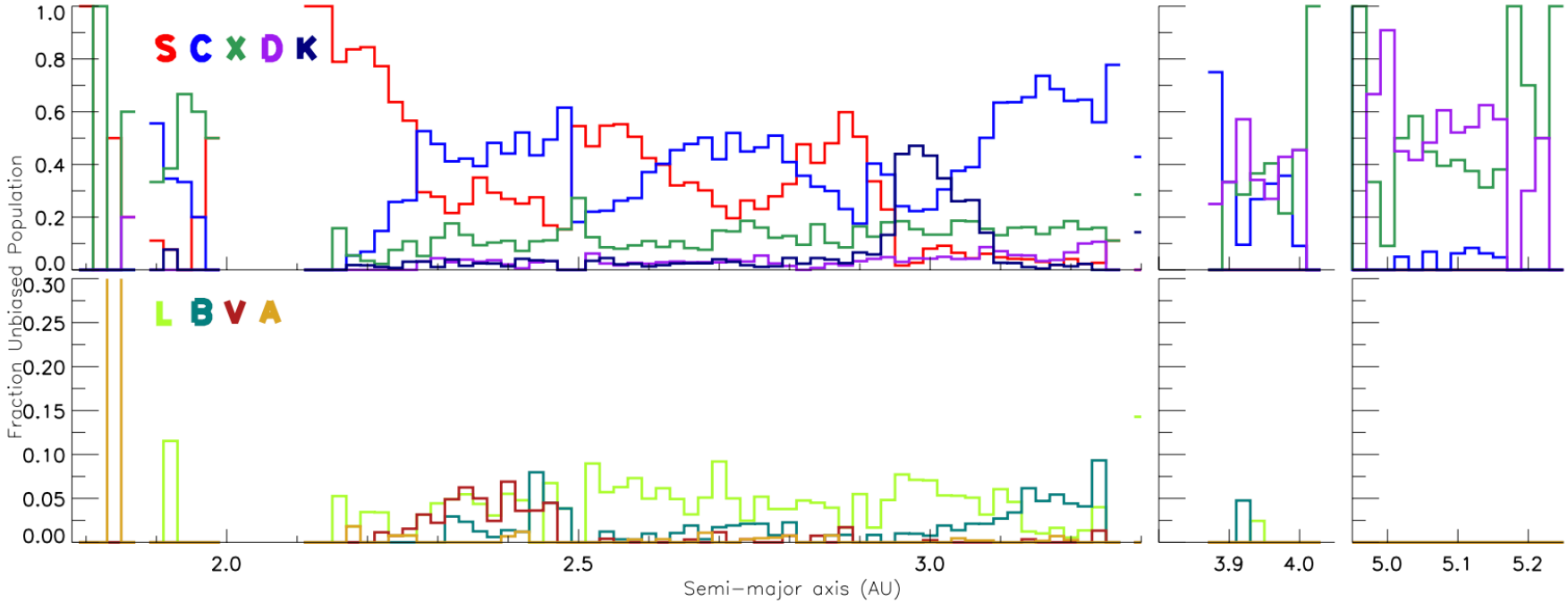

Meteor Crater, Arizona
Formed 49,000 years ago by a
50-metre iron-nickel asteroid

Connecting meteorites to the Solar system 2. Composition



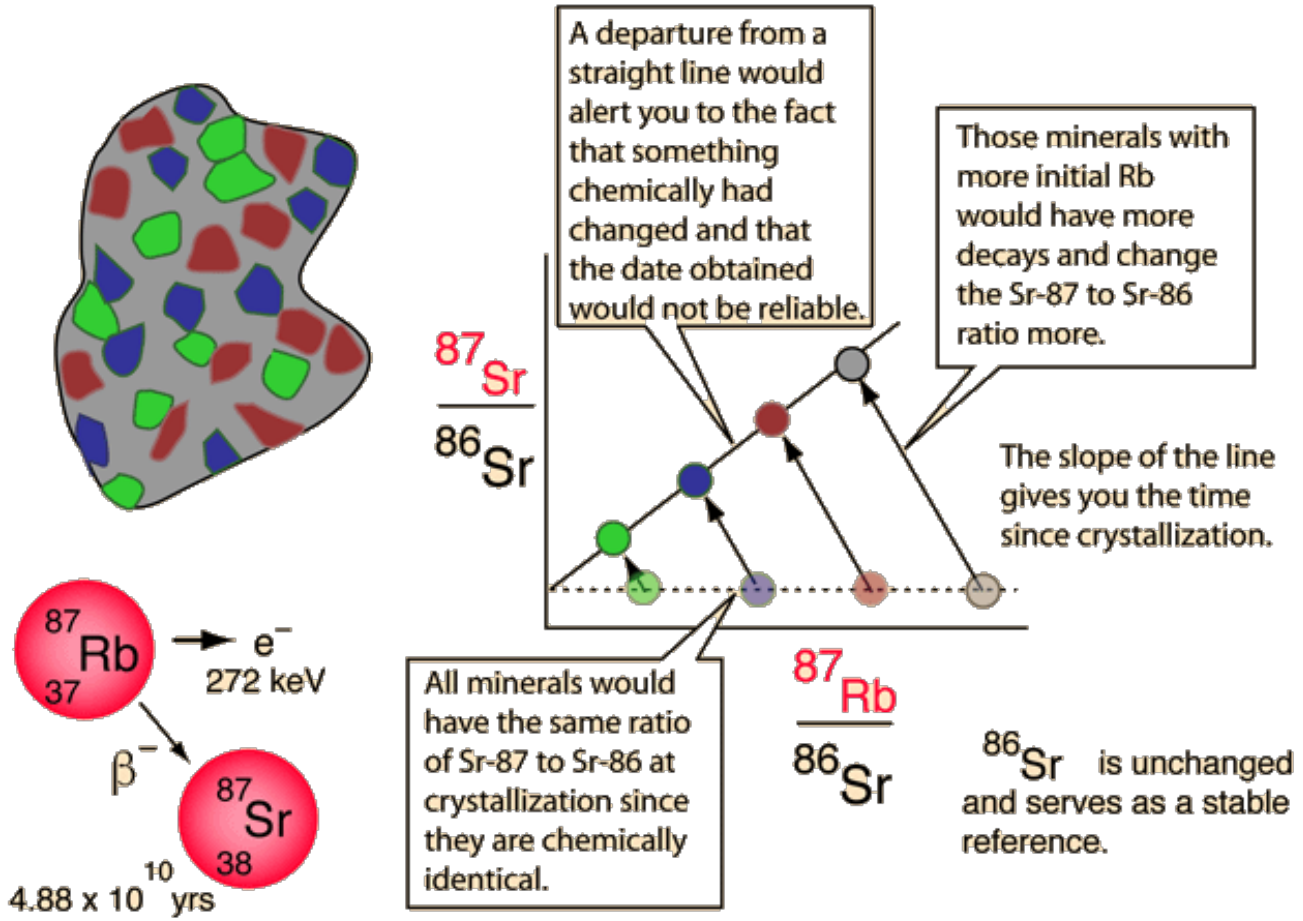
Credit: Masiero et al. 2011

Connecting meteorites to the Solar system 2. Composition



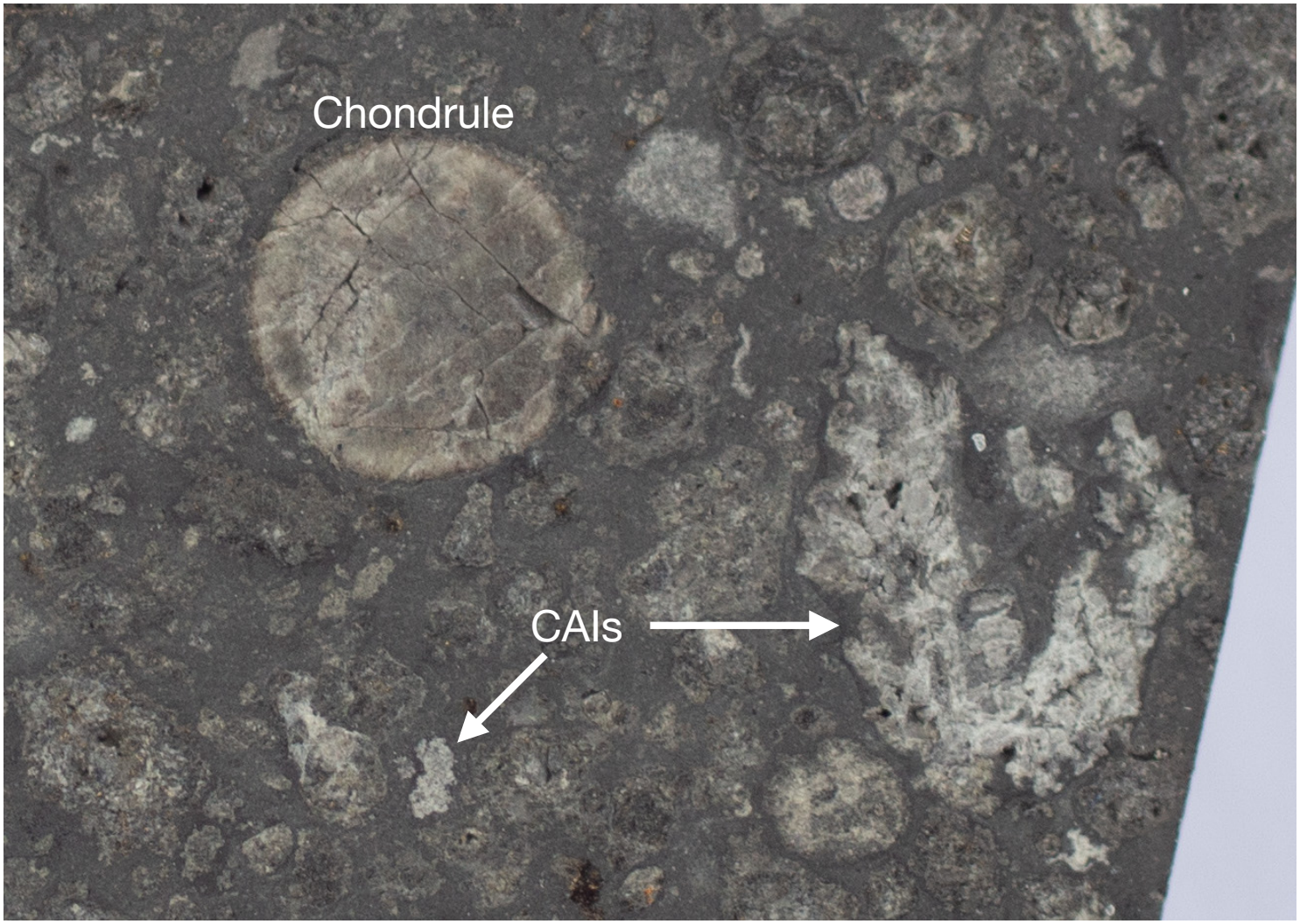
Credit: DeMeo & Carry 2013

Meteorite Ages - Radioactive Dating

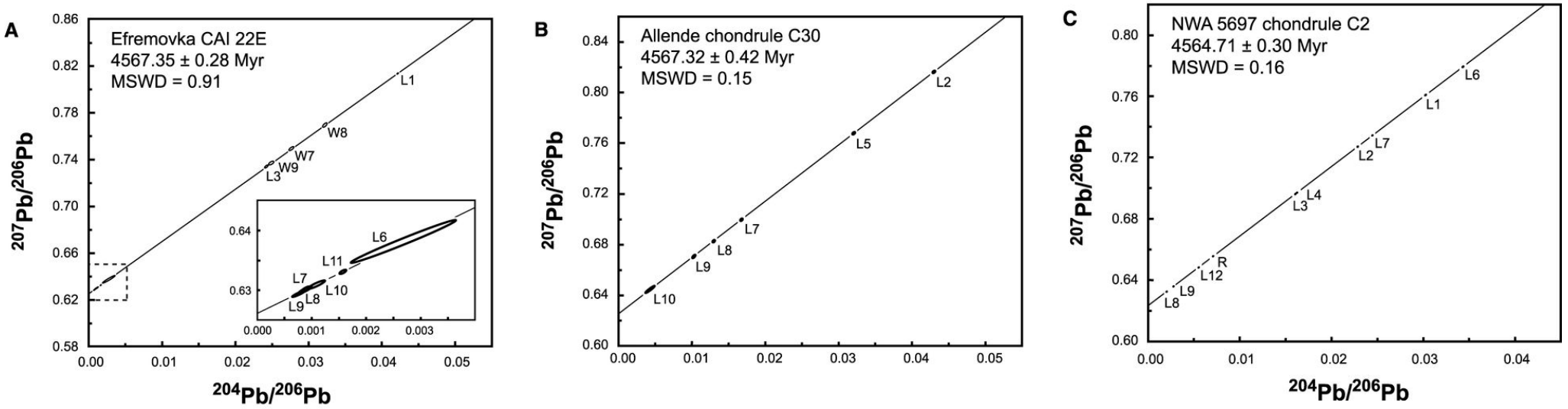


Credit: hyperphysics.com

Calcium-Alminimum-rich inclusions (CAIs)



Meteorite Ages - Radioactive Dating

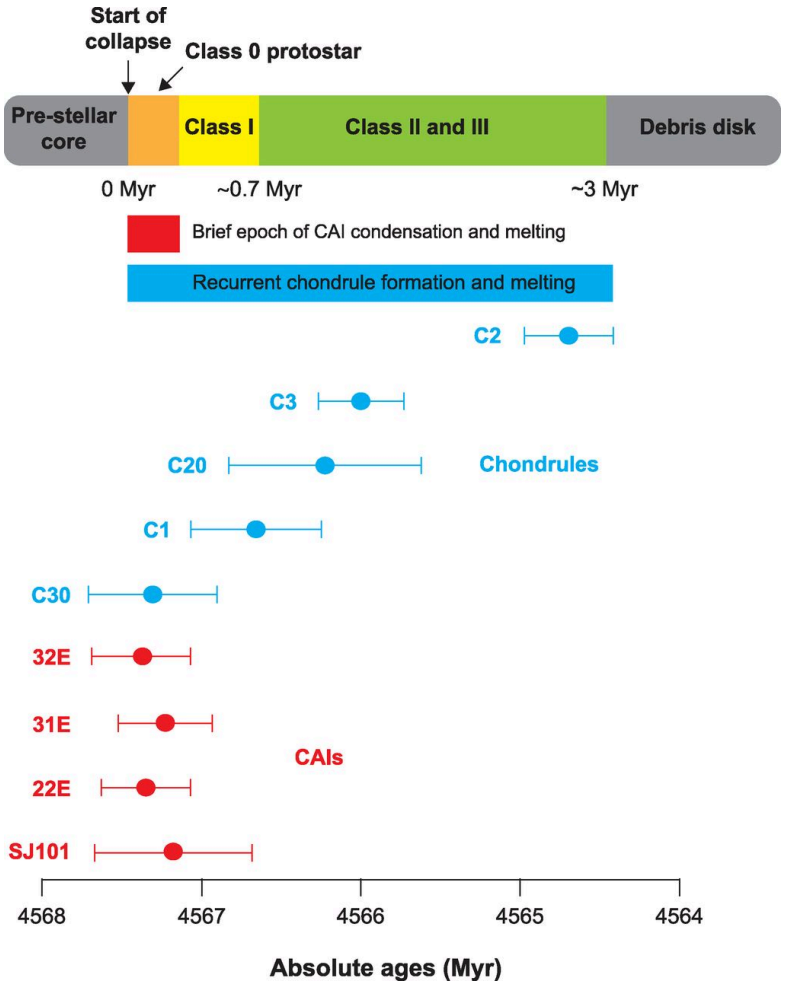


Age of CAIs - 4.567 billion years
Age of chondrules - 4.567 to 4.564 billion years

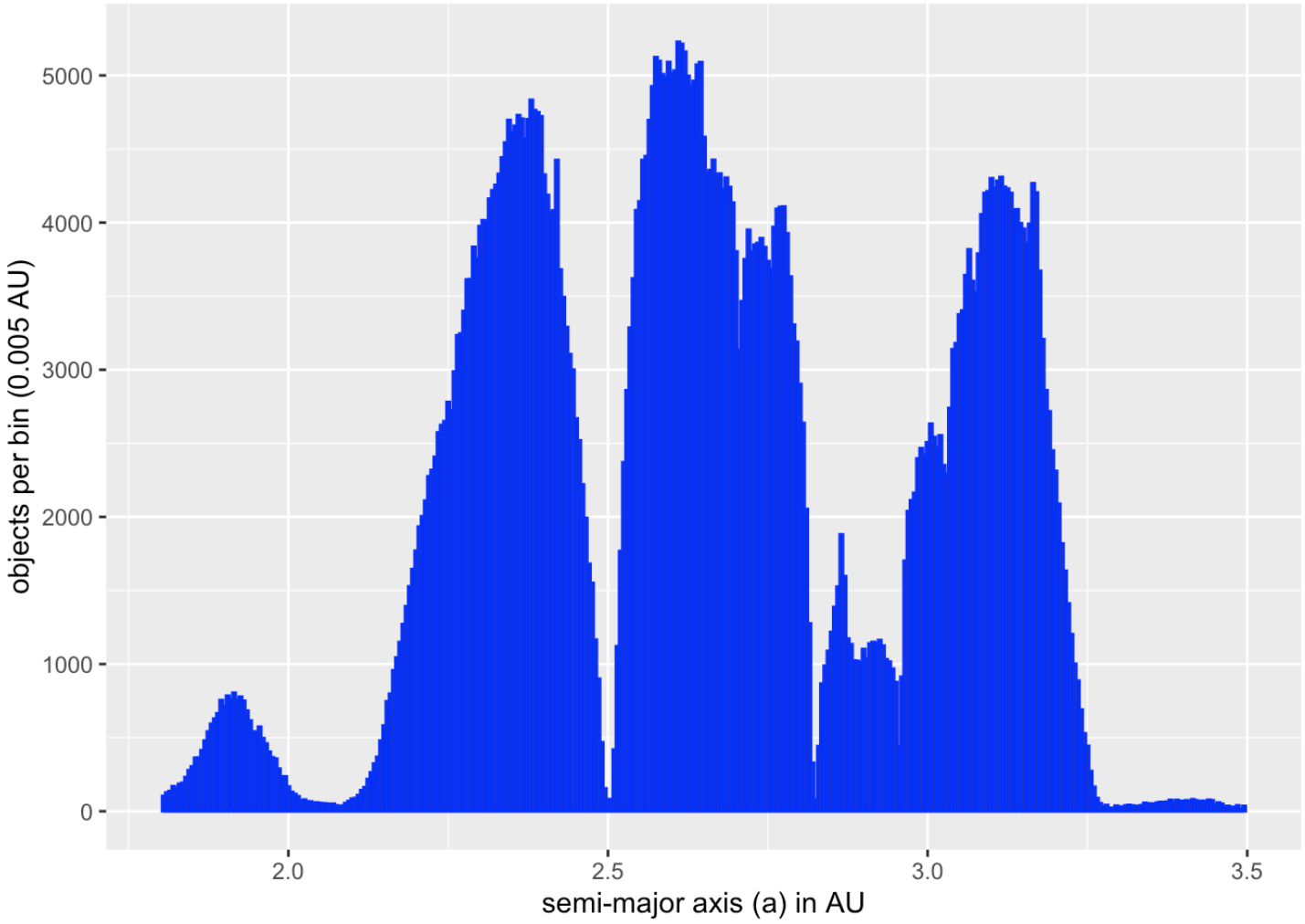
Meteorite Ages - Radioactive Dating

HI Tau Protoplanetary Disk

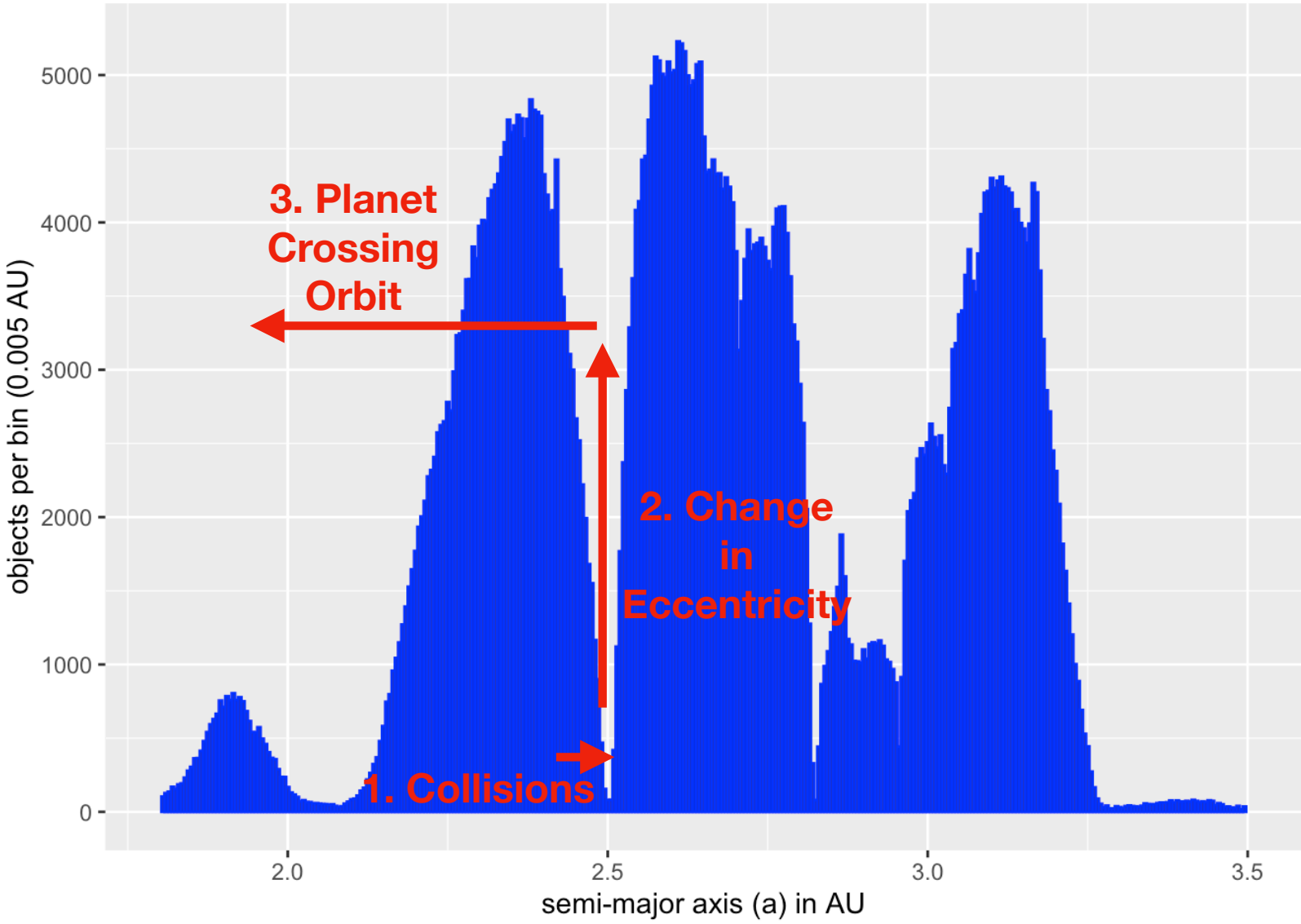
Credit: ALMA/ESO/NRAO



Connecting meteorites to the Solar system 3. Lifetimes

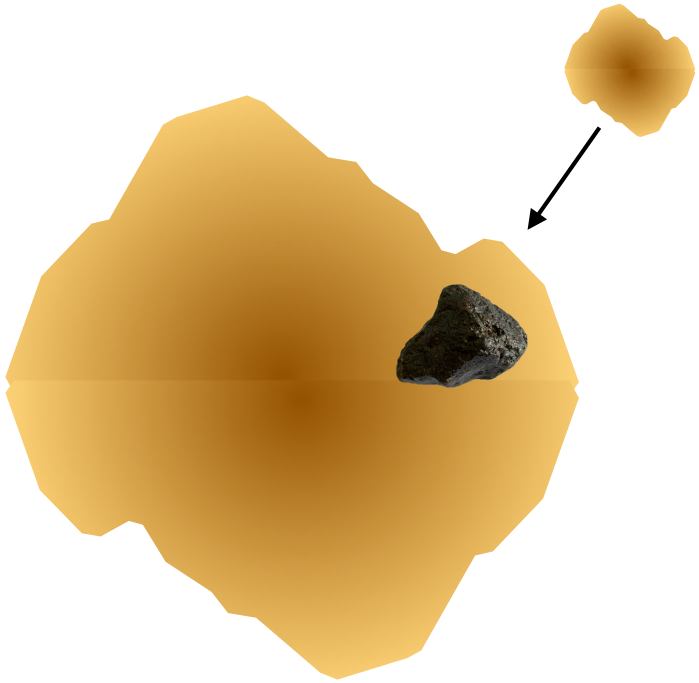


Getting from the Asteroid Belt to Earth.



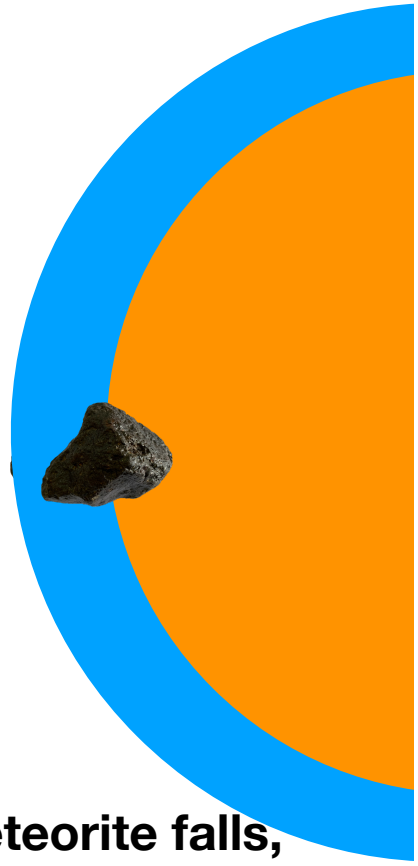
QUEEN'S UNIVERSITY BELFAST
Alan Fitzsimmons
Astrophysics Research Centre

Meteorite Ages - Cosmic Ray Dating



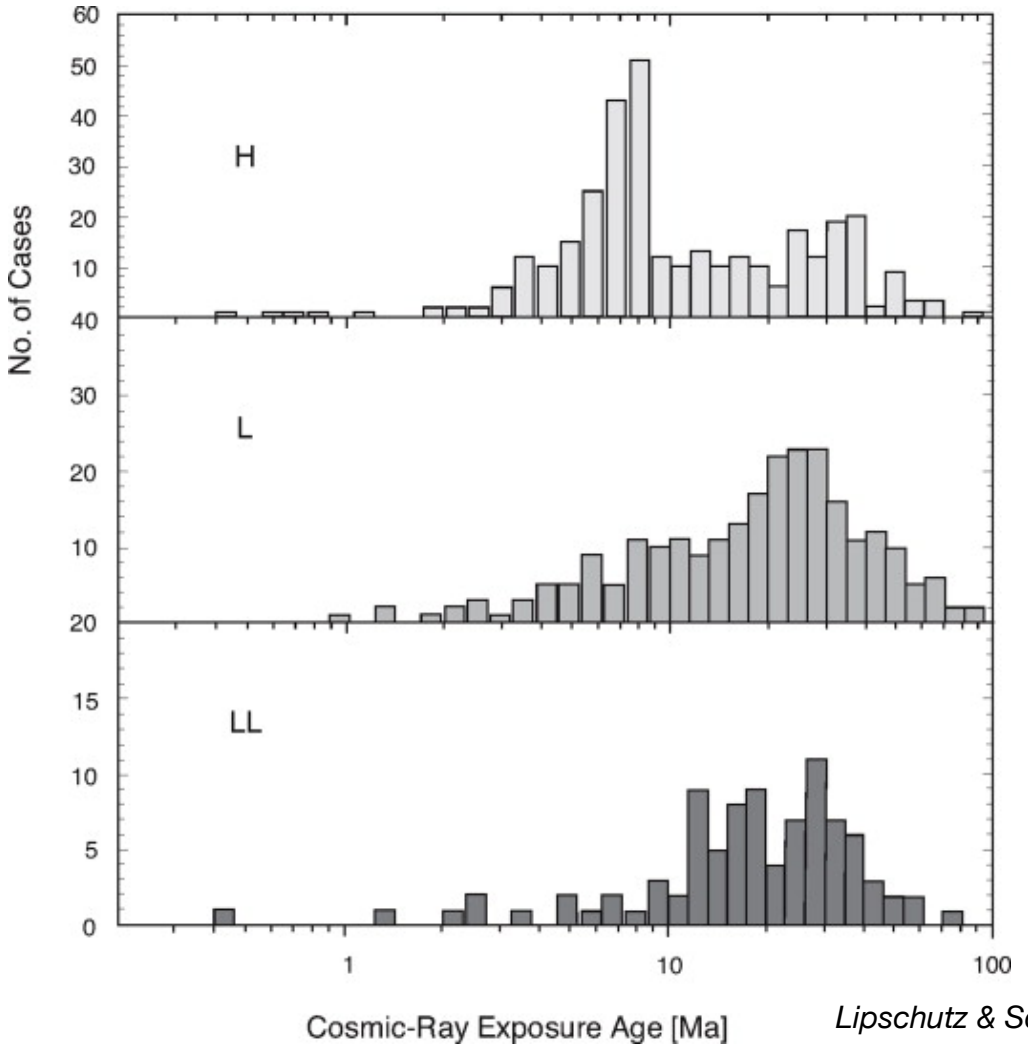
Collision excavates meteoroids

Cosmic rays create new isotopes of elements (^{3}He, ^{21}Ne, ^{38}Ar)



Meteorite falls, analysed

Meteorite Ages - Cosmic Ray Dating



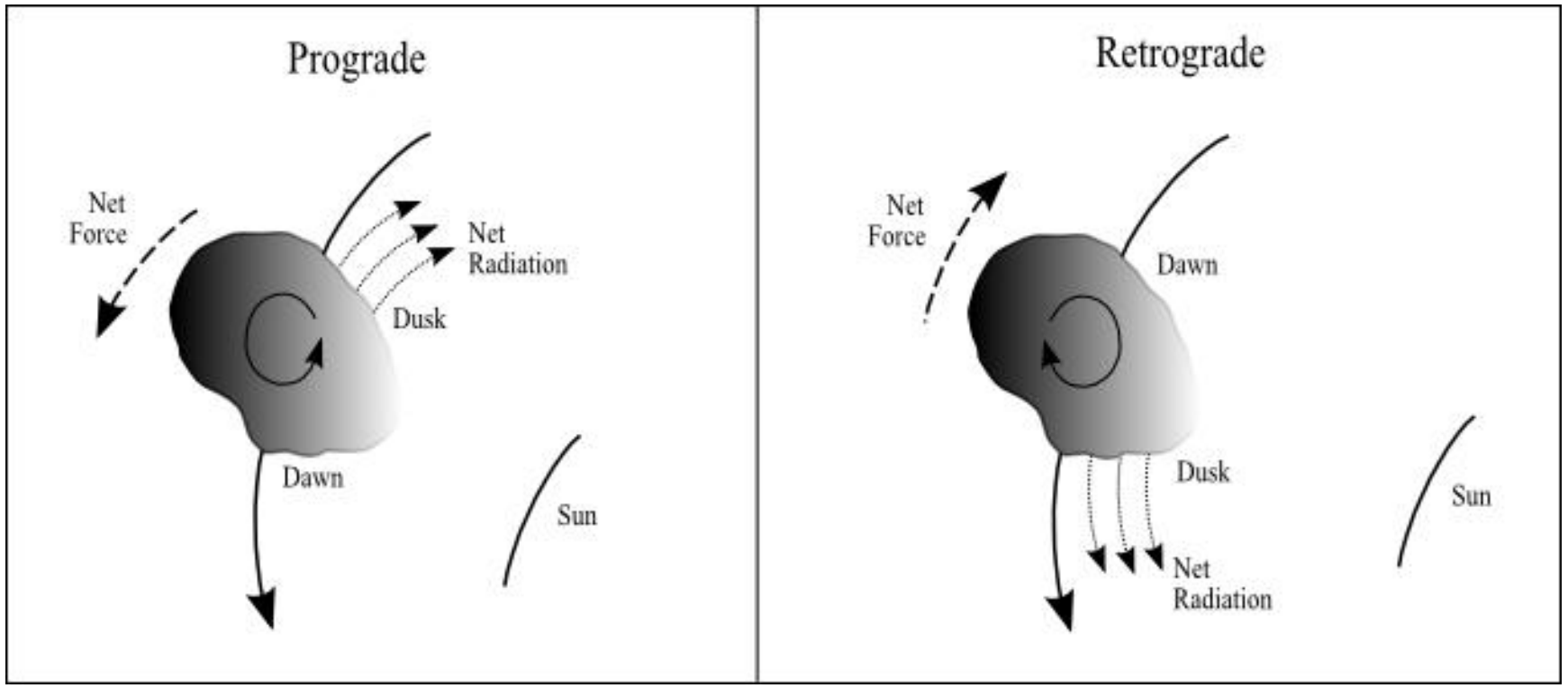
Lipschutz & Schultz 2007

There was a breakup of a High iron content (H) chondritic asteroid 7-8 million years ago.

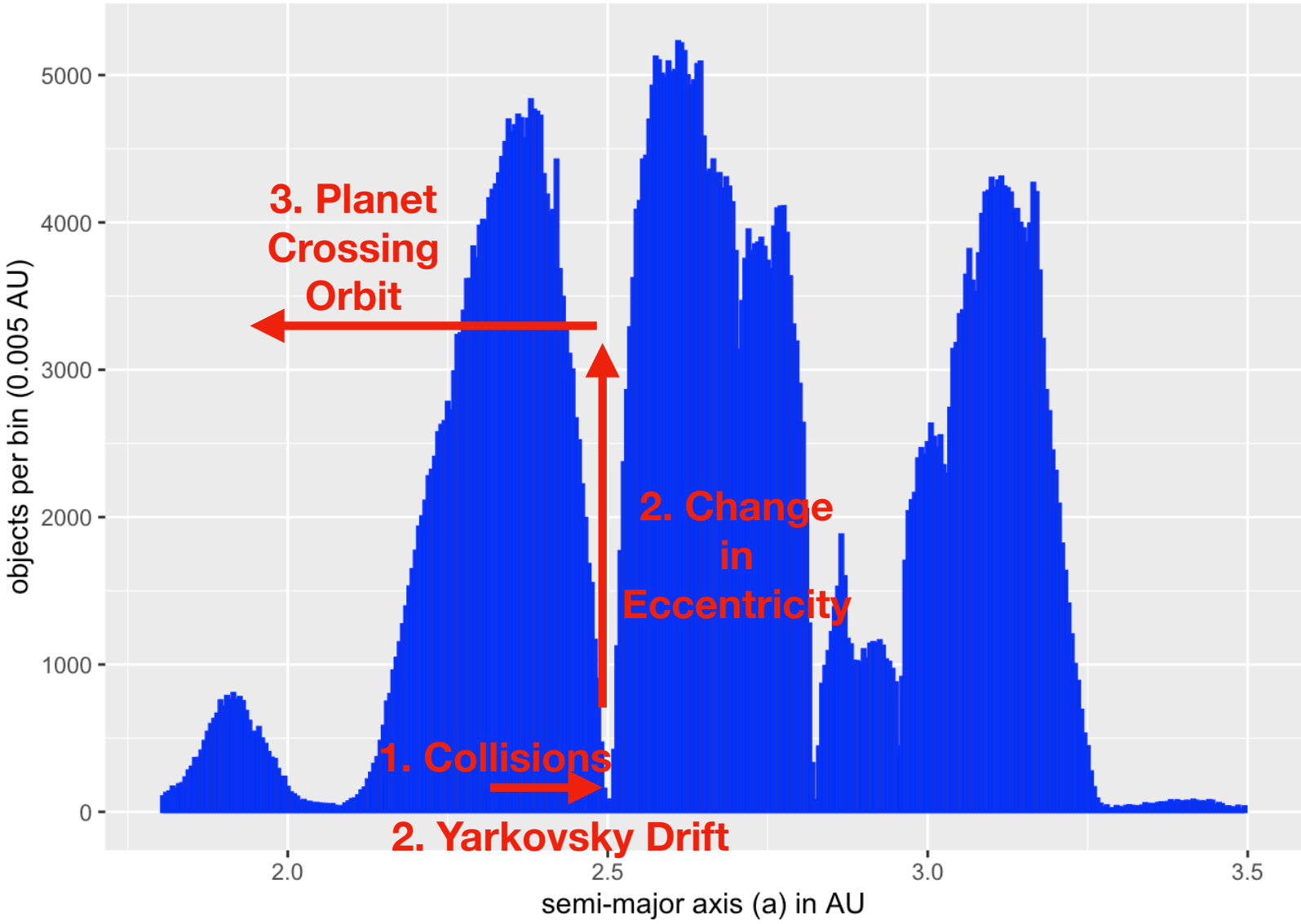
There was a breakup of a Low iron content (L) chondritic asteroid about 25 million years ago.

But ages < 10 million years do not fit match calculations using just gravity to move asteroids!

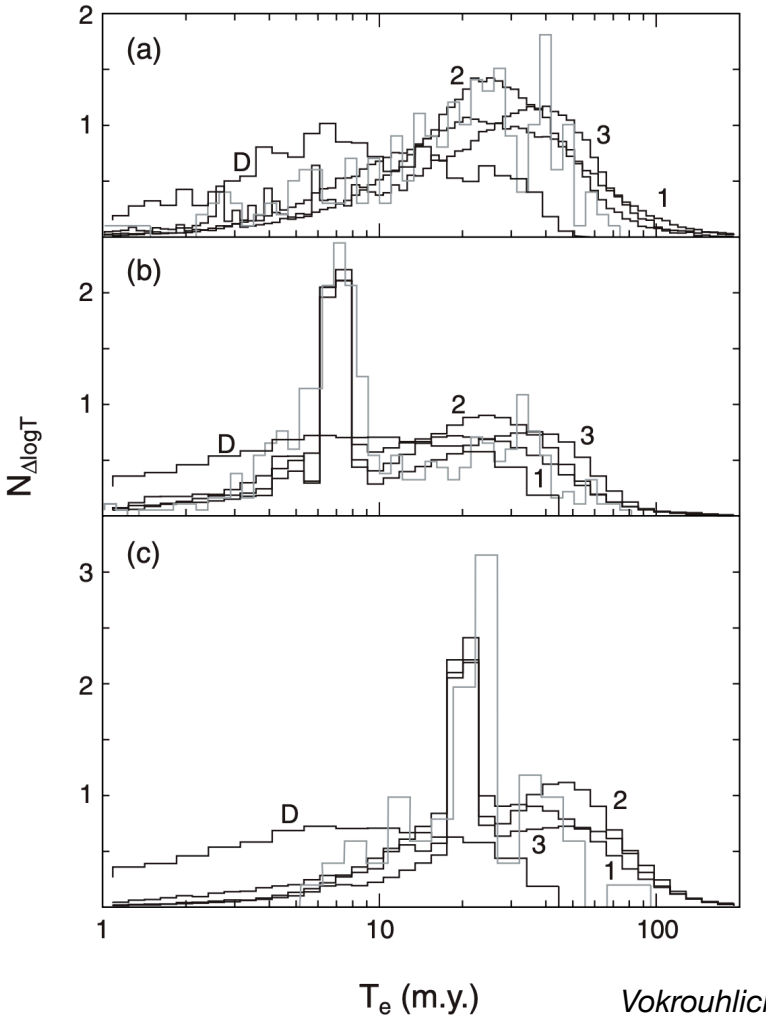
The Yarkovsky effect



Getting from the Asteroid Belt to Earth.



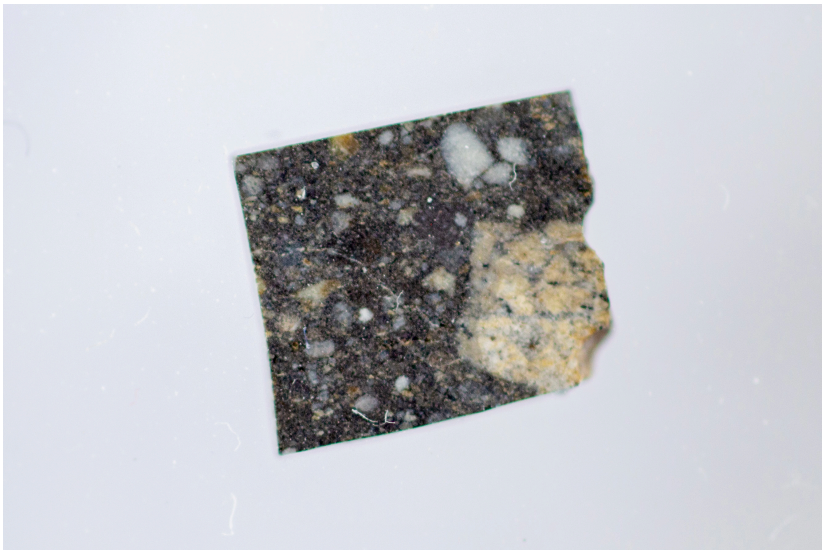
Meteorite Ages - Cosmic Ray Dating

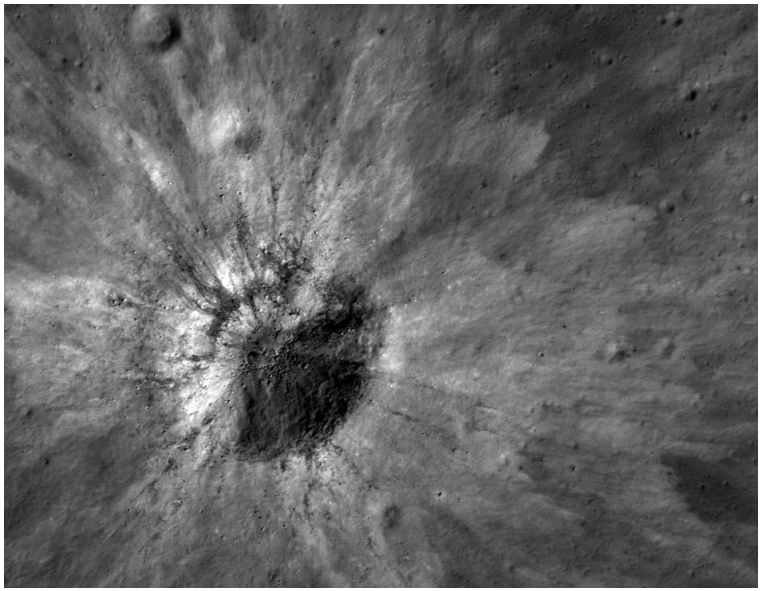


Including the Yarkovsky effect can **match** predicted age distributions to meteorite ages.

Vokrouhlicky & Farinella 2000

Meteorites from other places…



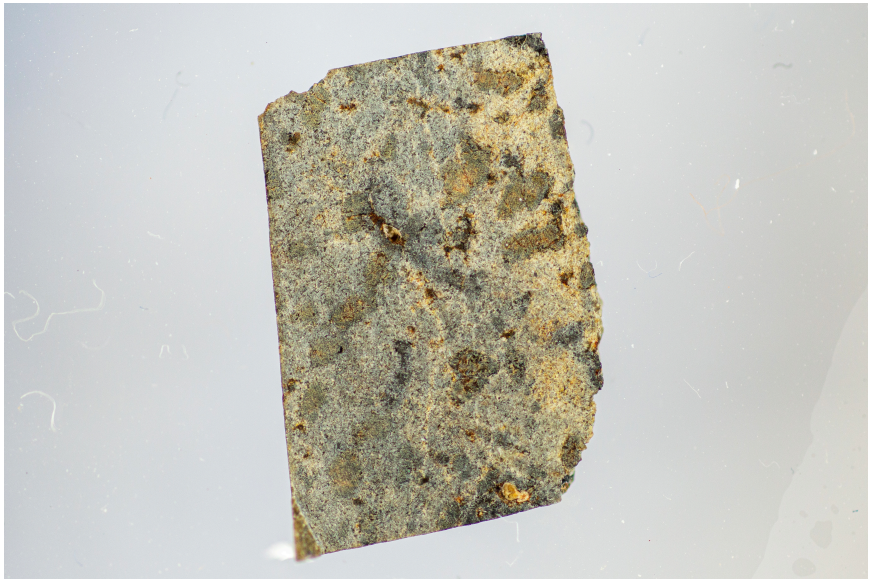


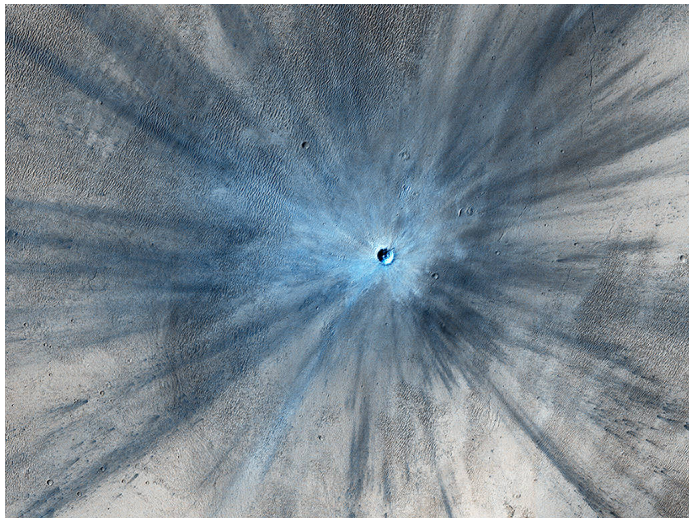
NASA/LRO

Rocks from lunar surface can be ejected via impacts of asteroids.

Lunar Meteorites can be identified by unique mineral composition, plus appearance of compacted rocks of different identity (lunar regolith).

Meteorites from other places…





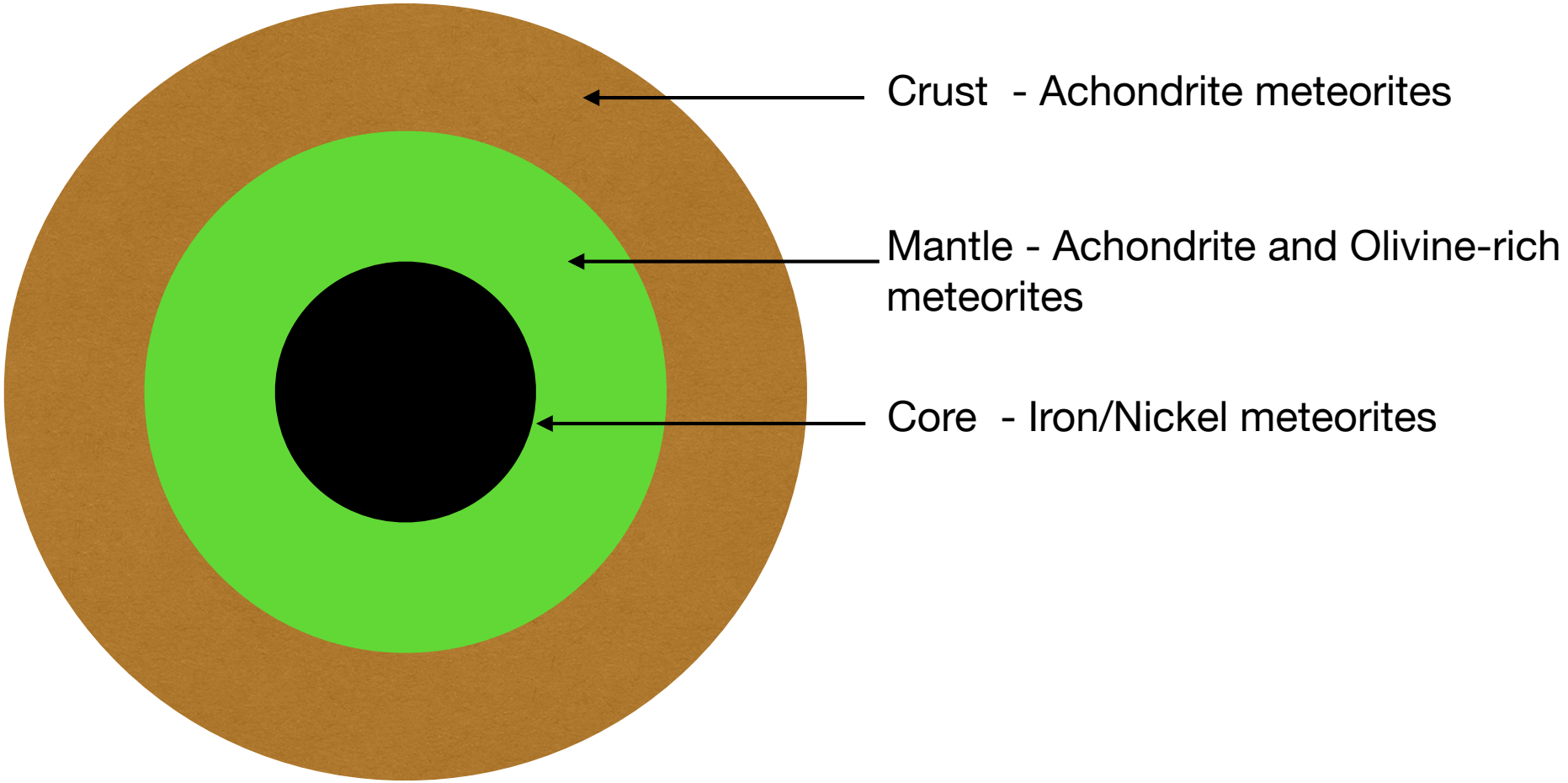
NASA/MRO/MARS2020

Rocks from Martian surface can be ejected via impacts of asteroids.

Martian Meteorites can be identified by mineral composition, age and composition of trapped atmospheric gases.

Outstanding Questions:
1. Where are all the “green” asteroids?

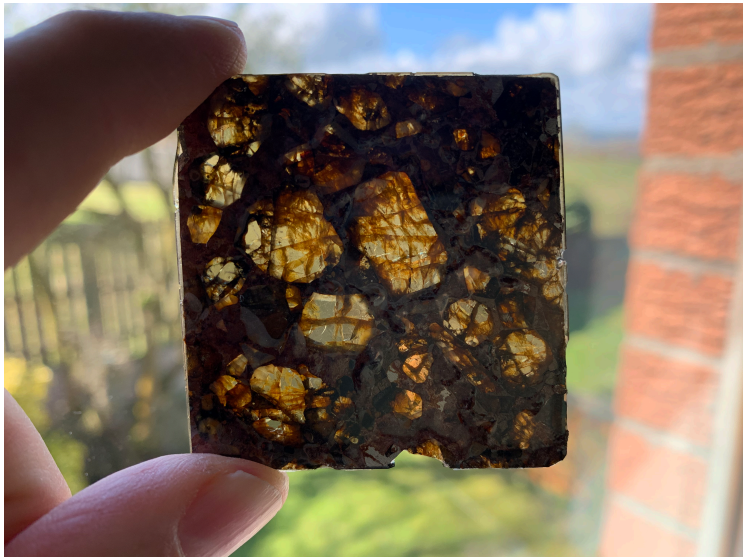
“Primordial” Asteroids more than 300km across
will be differentiated like a terrestrial planet.



Outstanding Questions:
1. Where are all the “green” asteroids?

Brenham Pallasite Meteorite

Photograph by Geoffrey Notkin © Aerolite Meteorites. In the Monnig Meteorite Gallery.

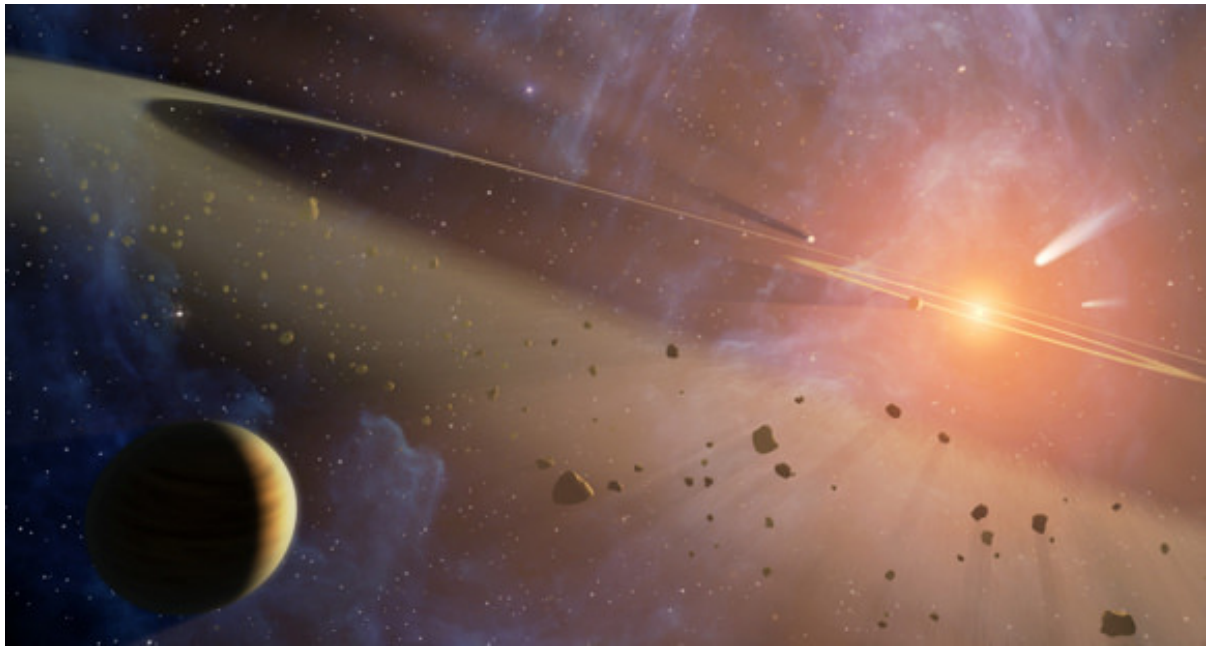


Pallasite meteorites come for the core-mantle boundary of large differentiated asteroids.

There should be roughly as many mantle asteroids as iron/nickel asteroids, but they are missing from surveys.

Recent work has found a number of small olivine-rich asteroids, but is this the answer?

Outstanding Questions:
2. How did chondrules form?

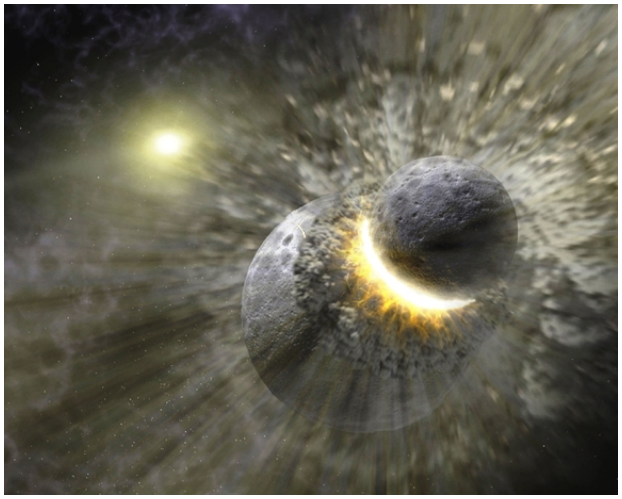


In the first 3 million years, chondrules were created as the Solar System was forming planets.

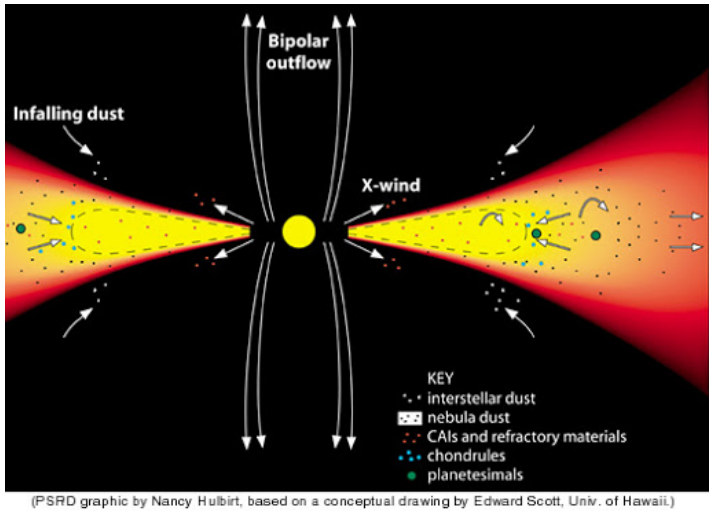
Some mechanism was able to heat primordial material to > 1000 degrees to form molten droplets, which cooled to form chondrules.

Chondrules are within C-chondrite meteorites, which have not been heated!

Outstanding Questions:
2. How did chondrules form?



Collisions?

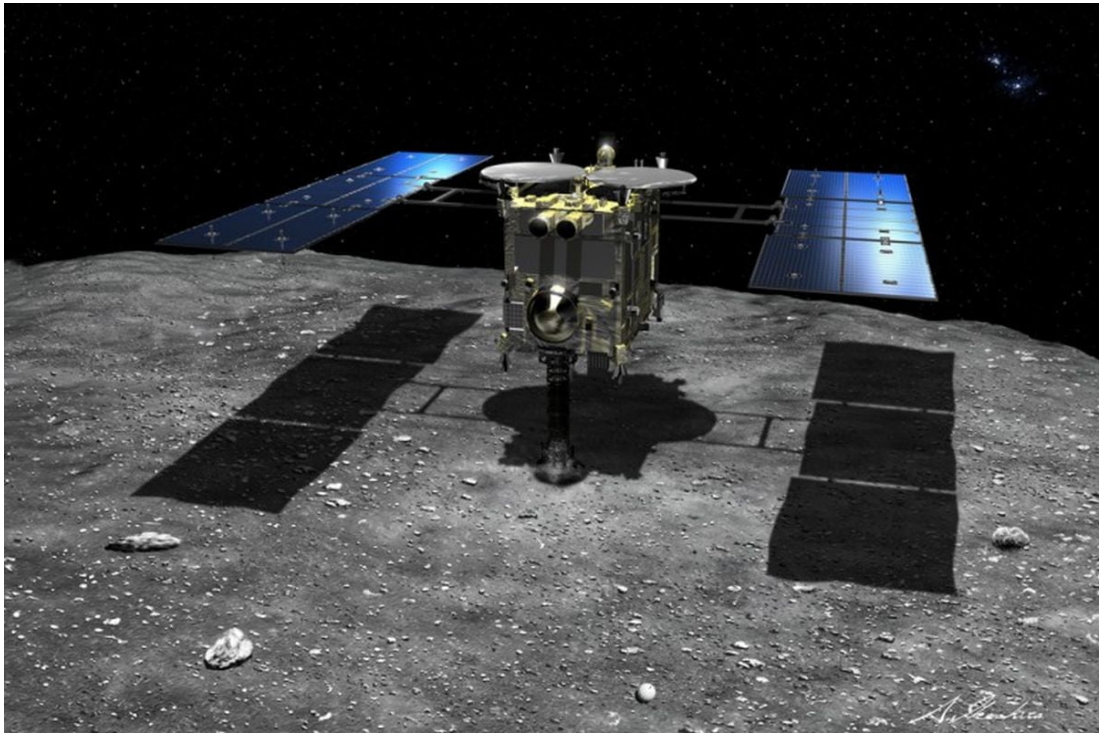


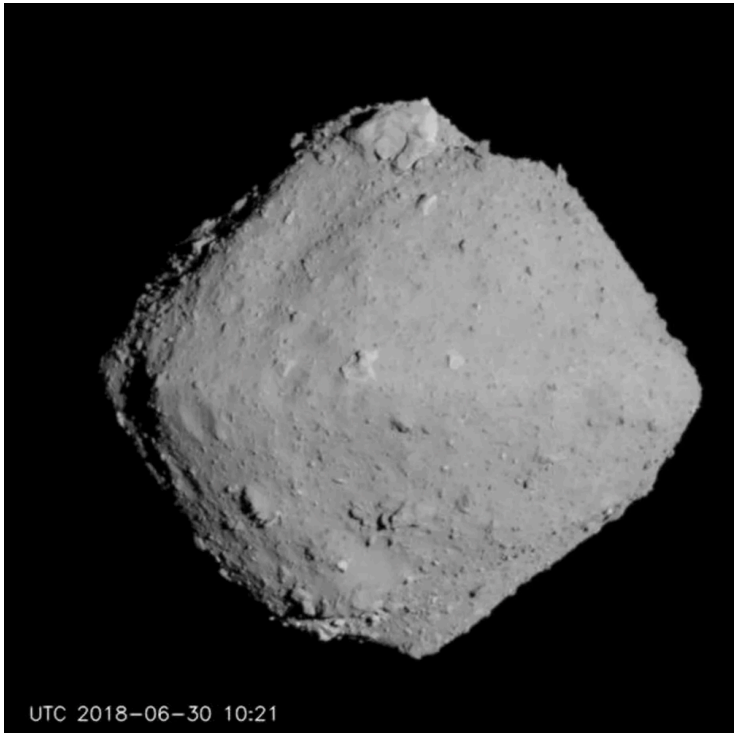
(PSRD graphic by Nancy Hulbirt, based on a conceptual drawing by Edward Scott, Univ. of Hawaii.)

Outflows near the new Sun?

Electrical discharges?

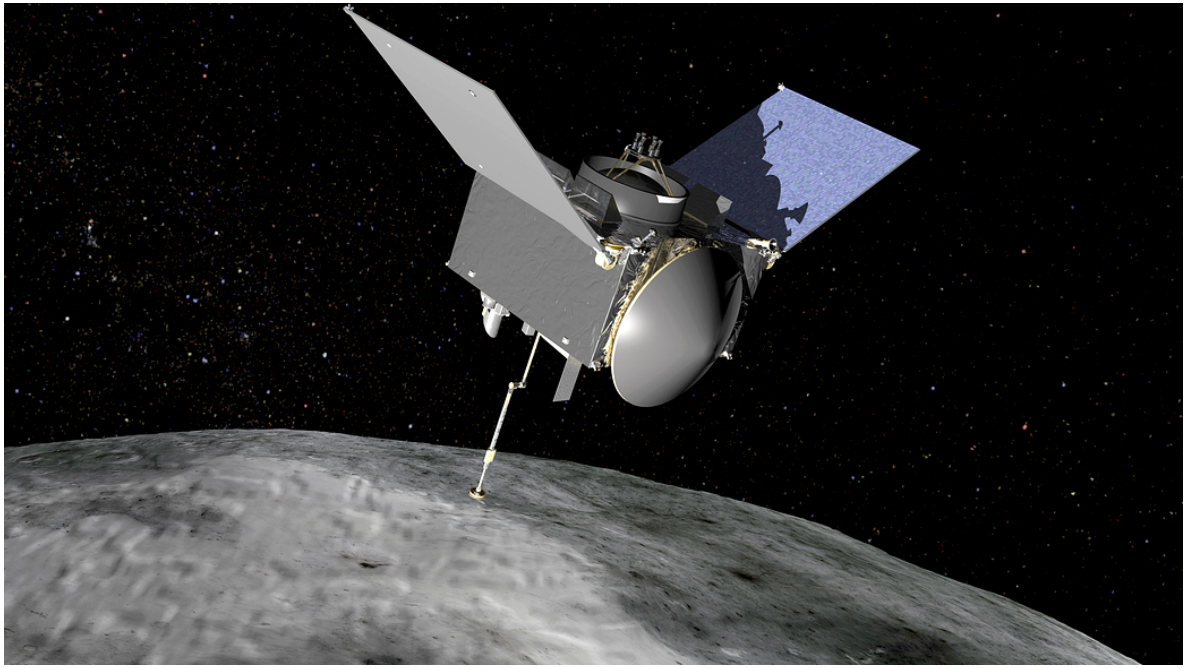
Going to the Source: Missions to Asteroids

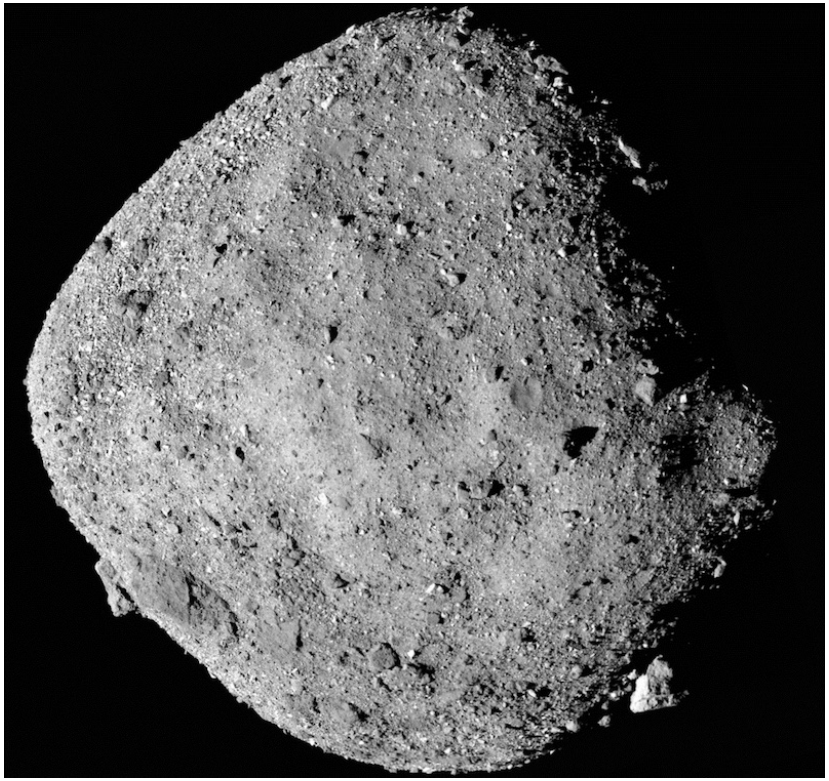




JAXA Hayabusa 2— Sample Return from (162173) Ryugu
Launch: 3rd December 2014
Rendezvous: 27th June 2018
Departure: 13th November 2019
Return: 5th December 2020

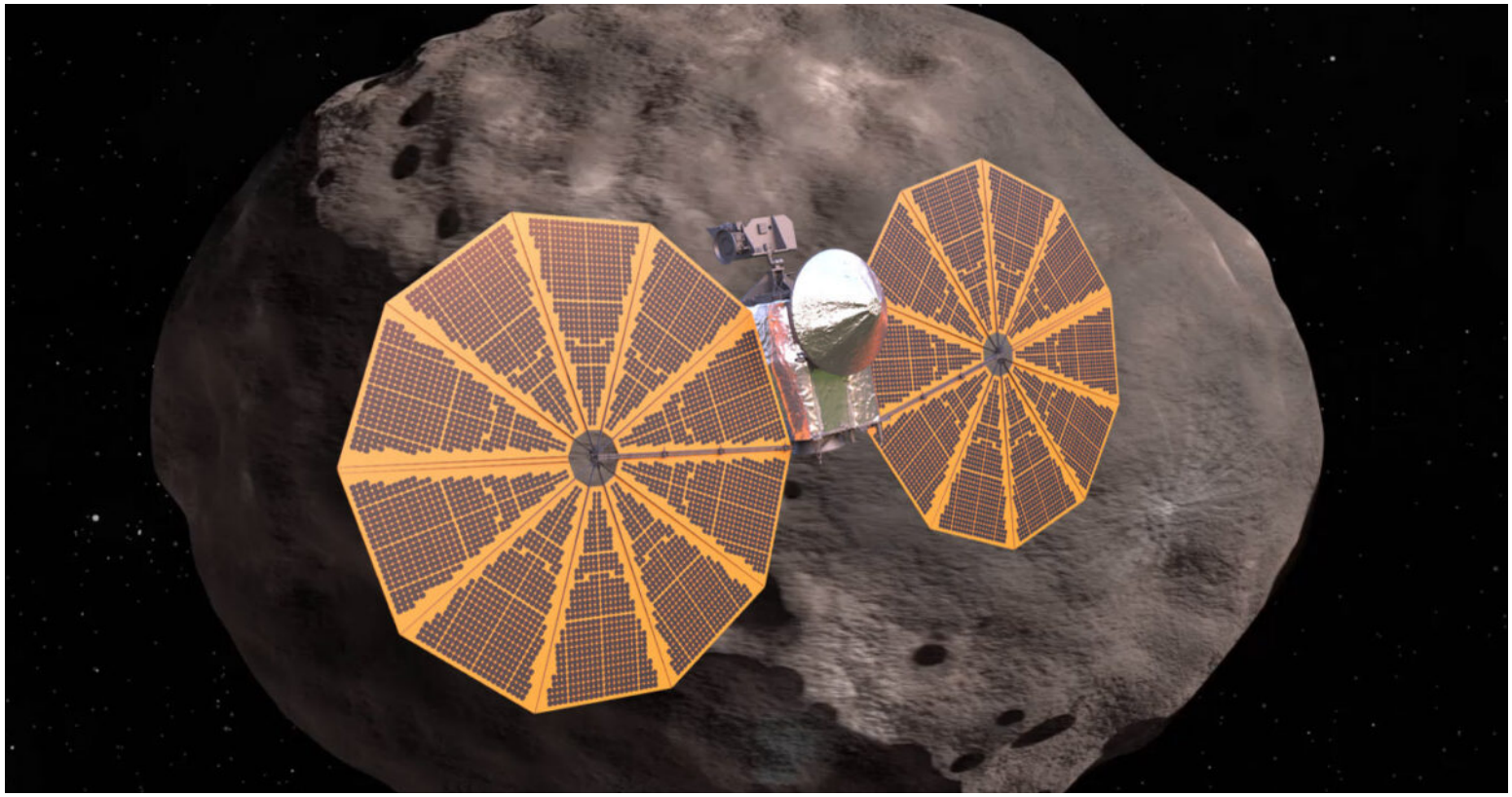
Going to the Source: Missions to Asteroids





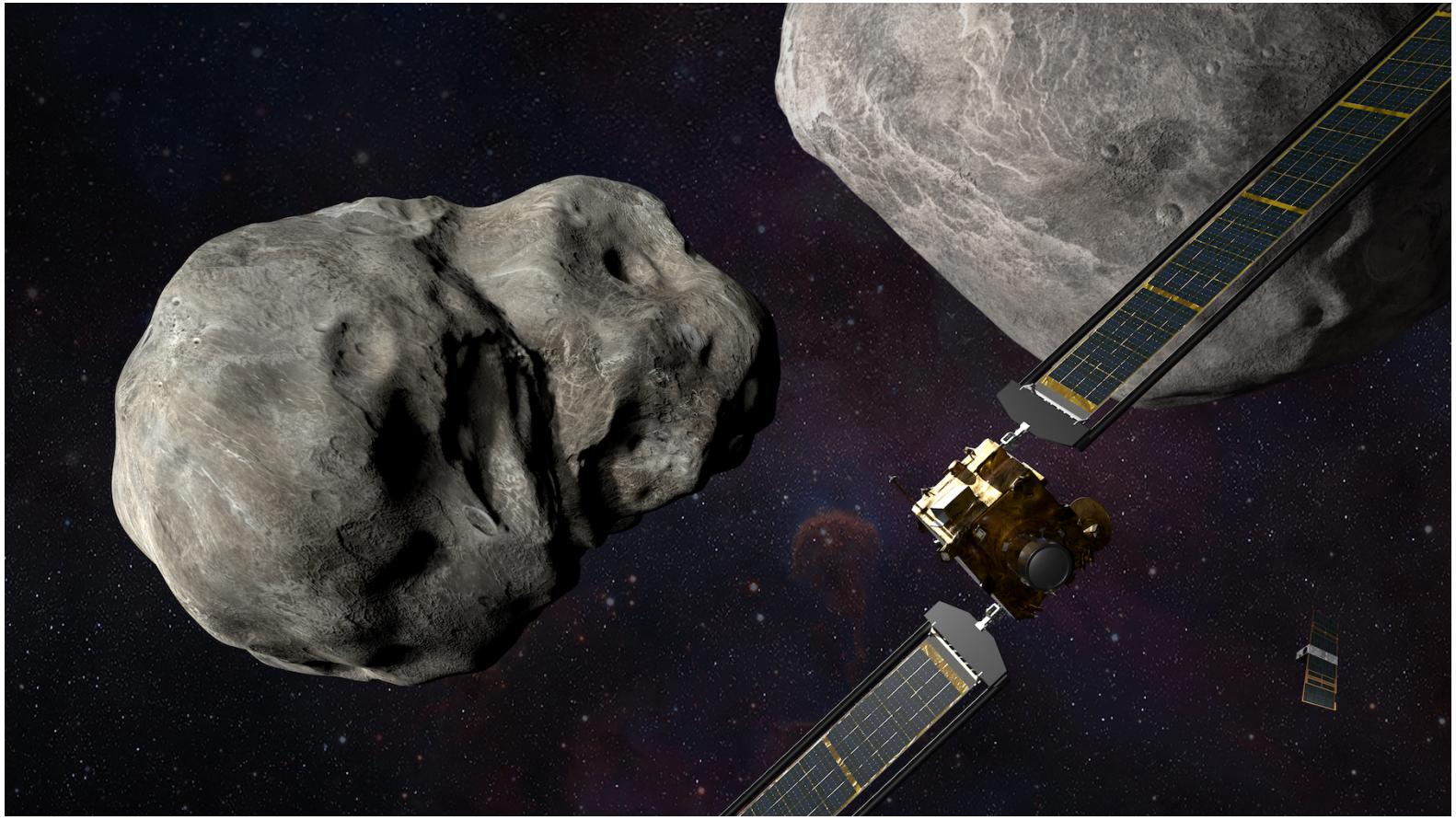
NASA OSIRIS- REx— Sample Return from (101955) Bennu
Launch: 8th September 2016
Arrival: 3rd December 2018
Departure: 10th May 2021
Return: 24th September 2023

Going to the Source: Missions to Asteroids



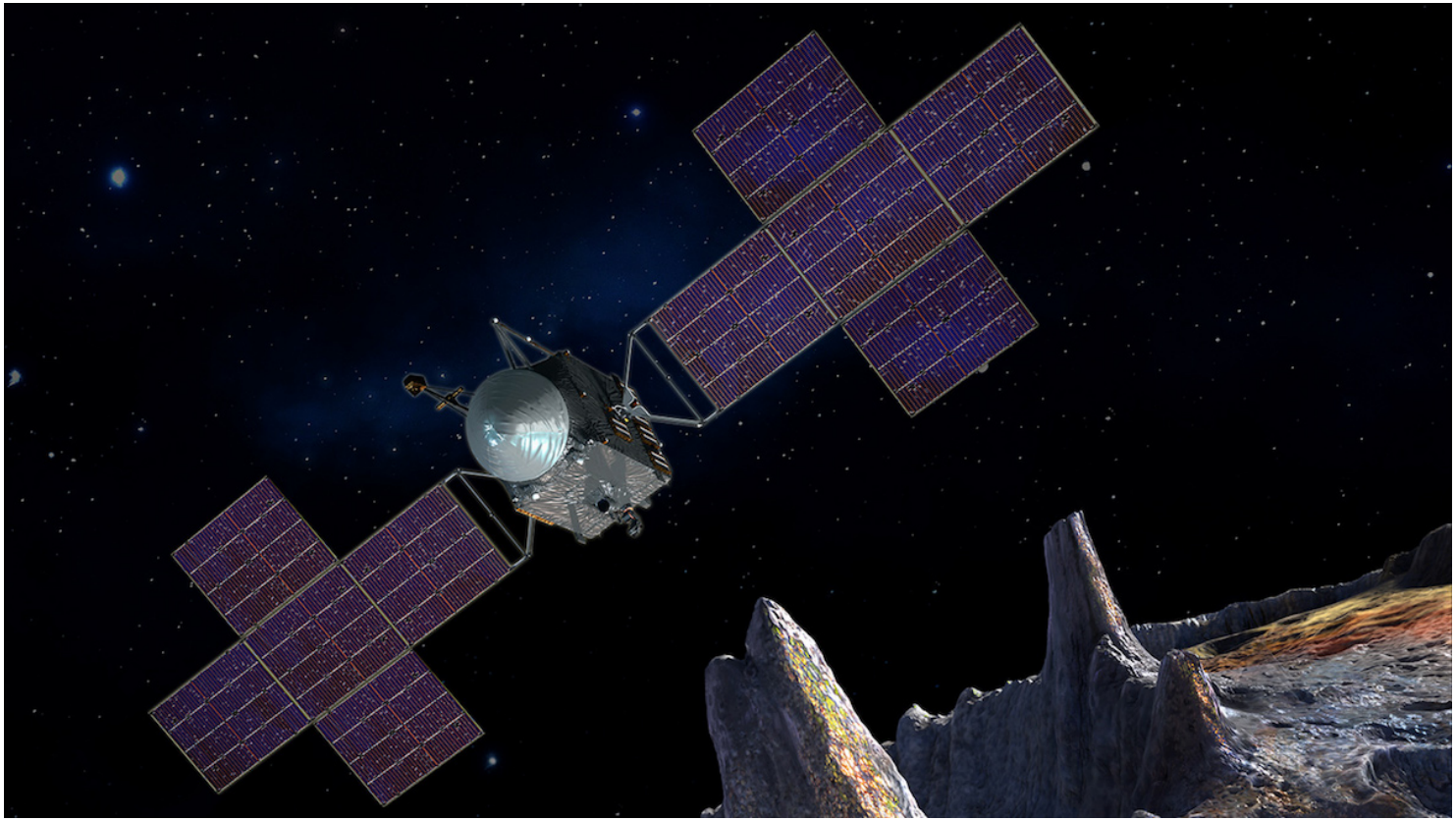
NASA LUCY— Flyby with 7 Trojan Asteroids
Launch: 16th October 2021
Arrival: 12th August 2027 – 2nd March 2033

Going to the Source: Missions to Asteroids



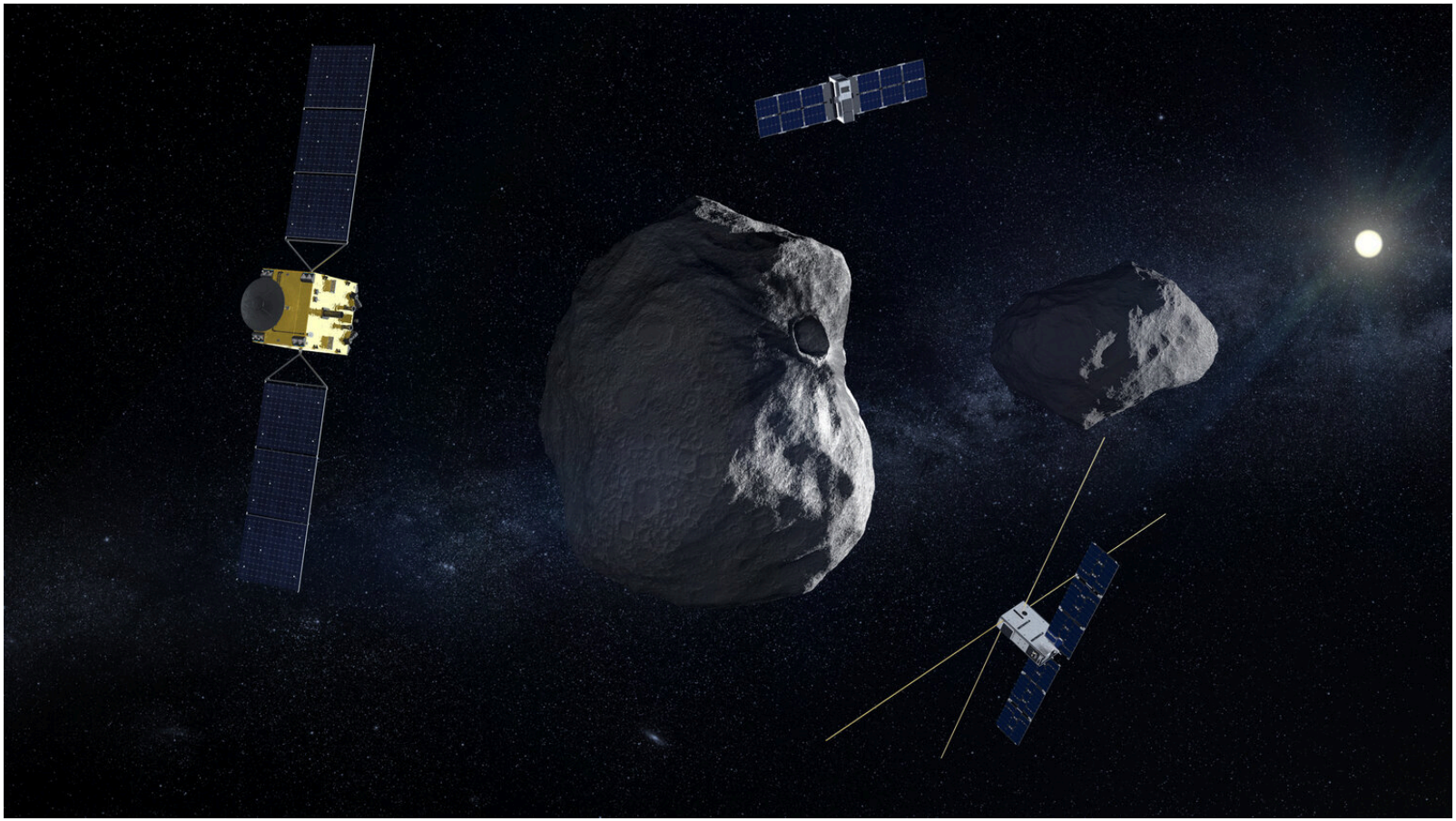
NASA DART+LiciaCube— Planetary Defence Test Mission to Didymos+Dimorphos
Launch: 24th November 2021
Impact: 30th September 2022

Going to the Source: Missions to Asteroids



NASA Psyche— Rendezvous with largest metallic asteroid (16) Psyche
Launch: 19th August 2022
Arrival: 31st January 2026

Going to the Source: Missions to Asteroids



ESA Hera+Juventas+Milani— Planetary Defence Test Mission to Didymos+Dimorphos
Launch: 8th October 2024
Rendezvous: 20th December 2026