Observing the Moon:

A large-scale hypervelocity impact laboratory

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Noordwijk, NL

Outline

- Impacts in the Solar System
- Impacts on the Moon
- Impacts in Lab
- Implications
- Future
- Conclusions

Impacts in the Solar System: Disruptive

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Cratering & regolith

Formation of planetary

Pluto

New Horizons

Asteroid

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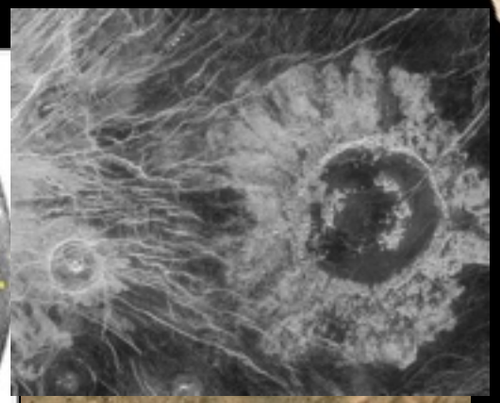

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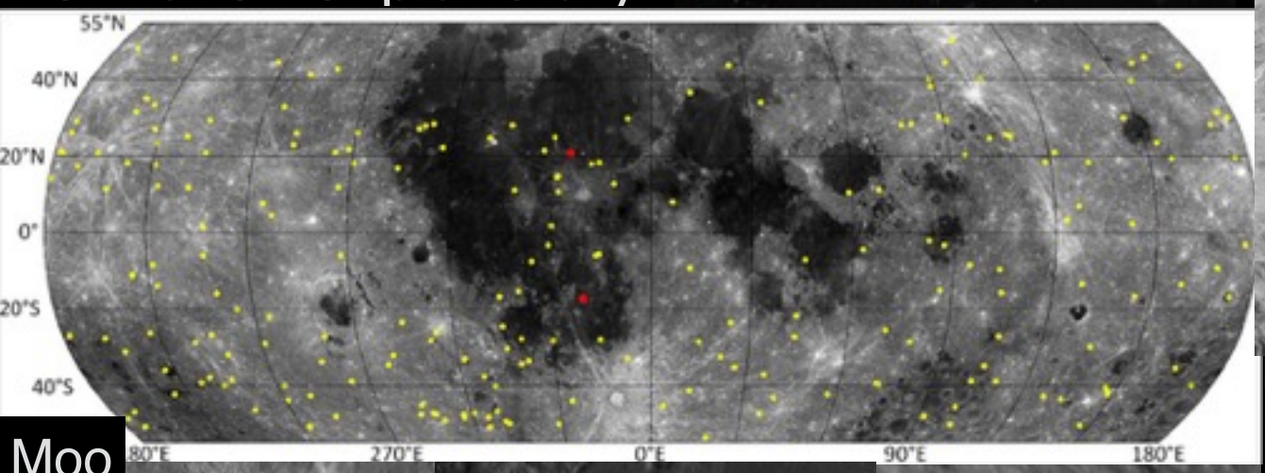

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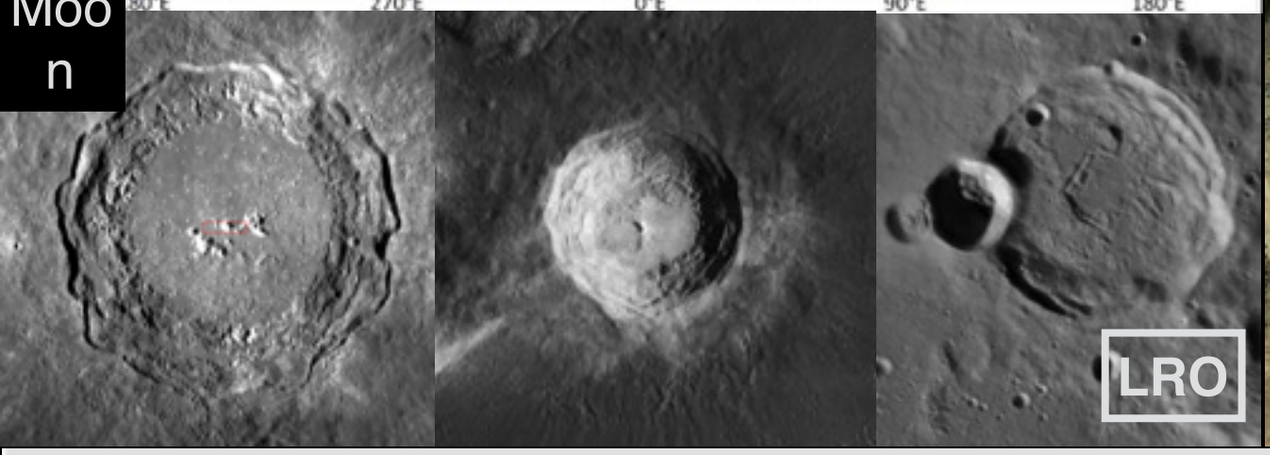
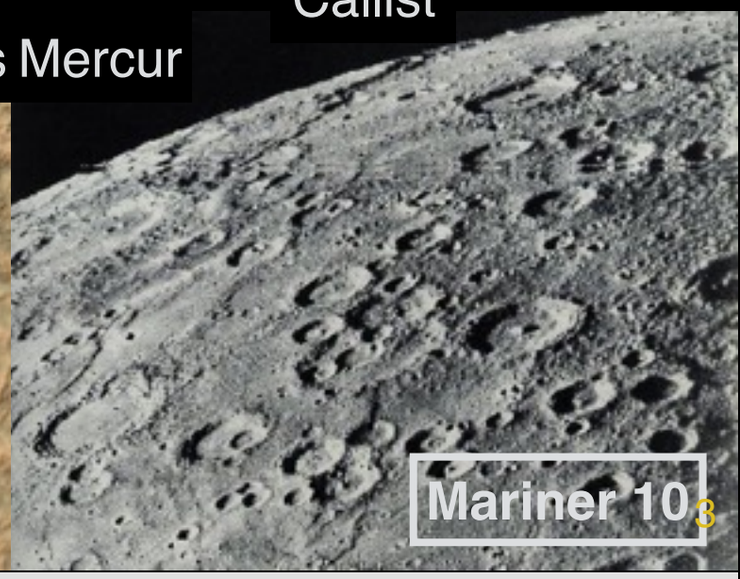


LRO

MRO

Mars Mercur



Mariner 10

Impacts in the Solar System: Disrupti

We make wishes when we see “shooting

But the case is not always this!

Impacts in the Solar

Disruptive

Panels of HST

Space assets suffer micrometeorite bombardment

Impacts in the Solar Syst

Catastrophic events ti

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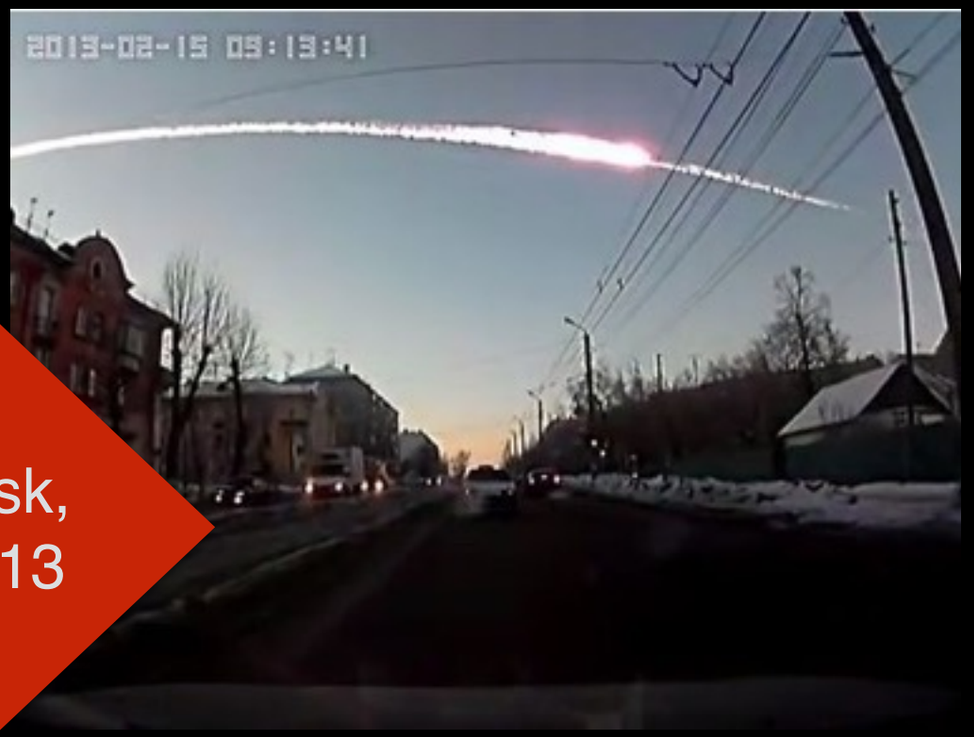
Tunguska,
Russia,1908



Chelyabinsk,
Russia,2013

We should
study their effect
and get ready!

United States

Gulf of Mexico

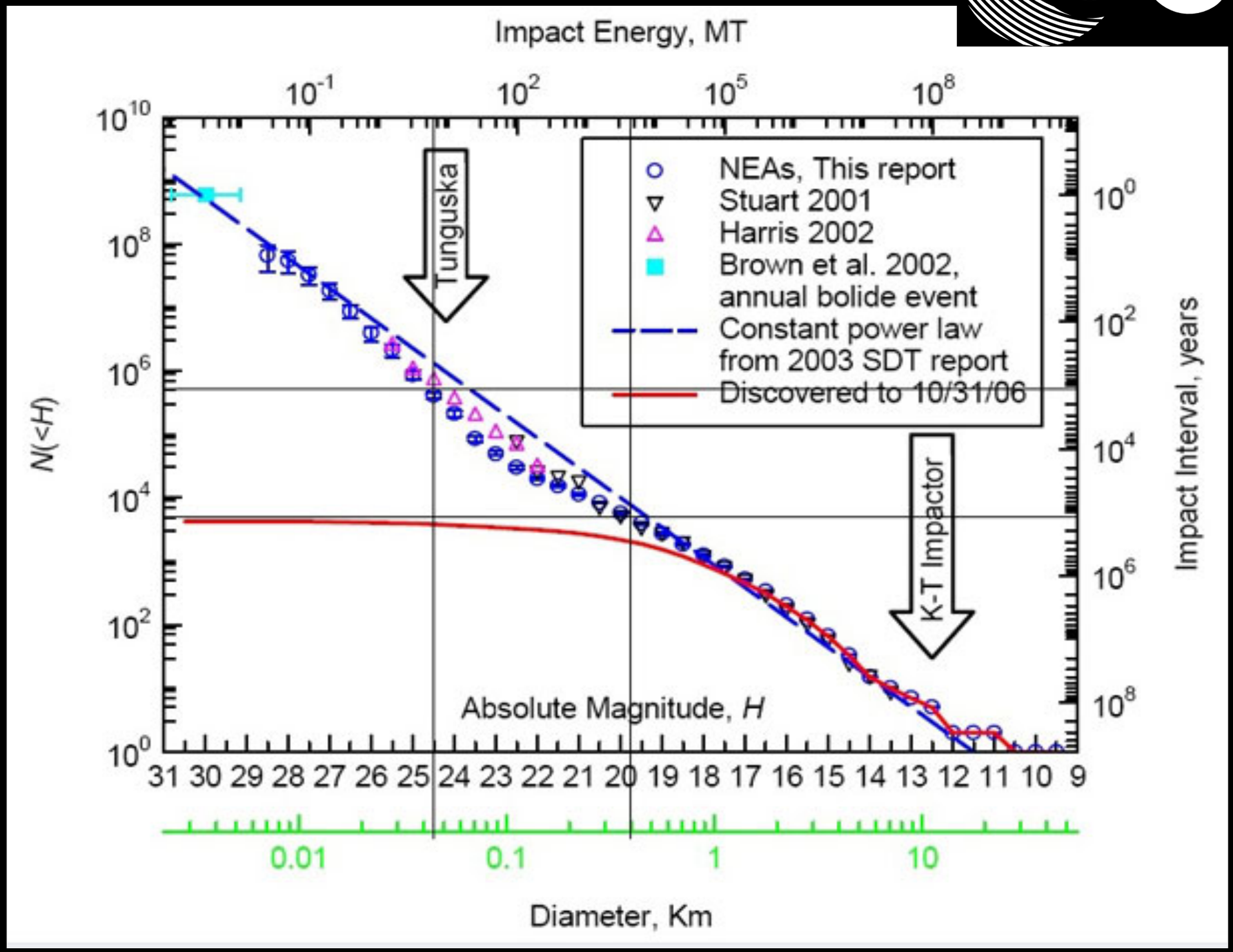
Chicxulub Crater

Mexico

Yucatan

Size matters!!!!

Impactors



Harris+2015

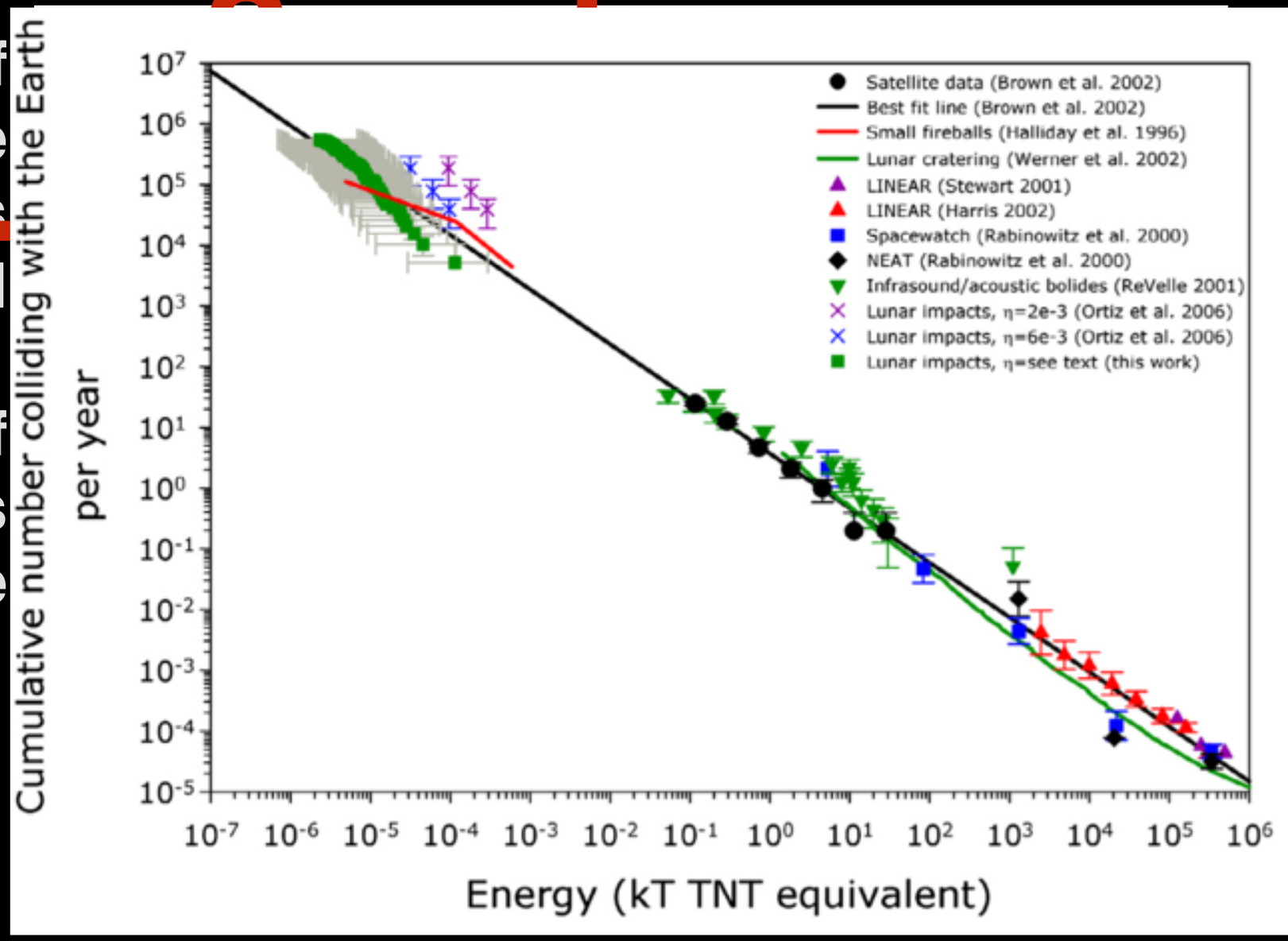
Motivation

Size frequency distribution

- Flux densities of meteoroids in the mass range of gr/kg is not very well constraint.
- The knowledge of small impactors is important for space assets.

Lunar observations

- ✓ Large area for survey - no atmosphere
- ✓ Idea by Melosh 1993
- ✓ ~20 years of lunar



Suggs

Impacts…live (?)

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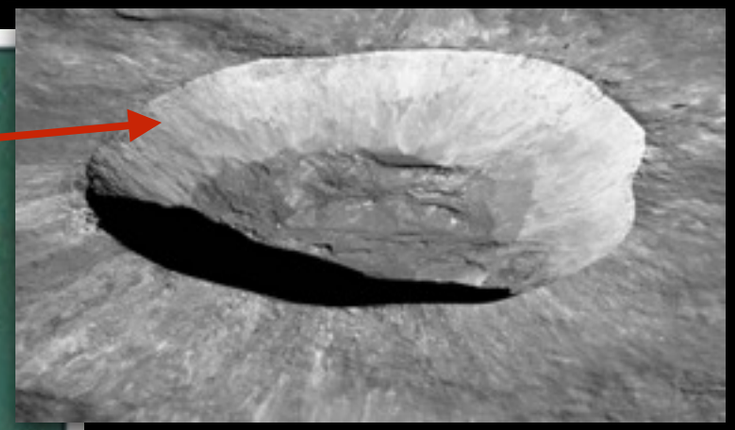
A ‘Canterbury tale’: 1st flash (?) 1178 AD

crater Giordano Bruno



Credits: NASA/
Goddard Space Flight Cente
Arizona State University

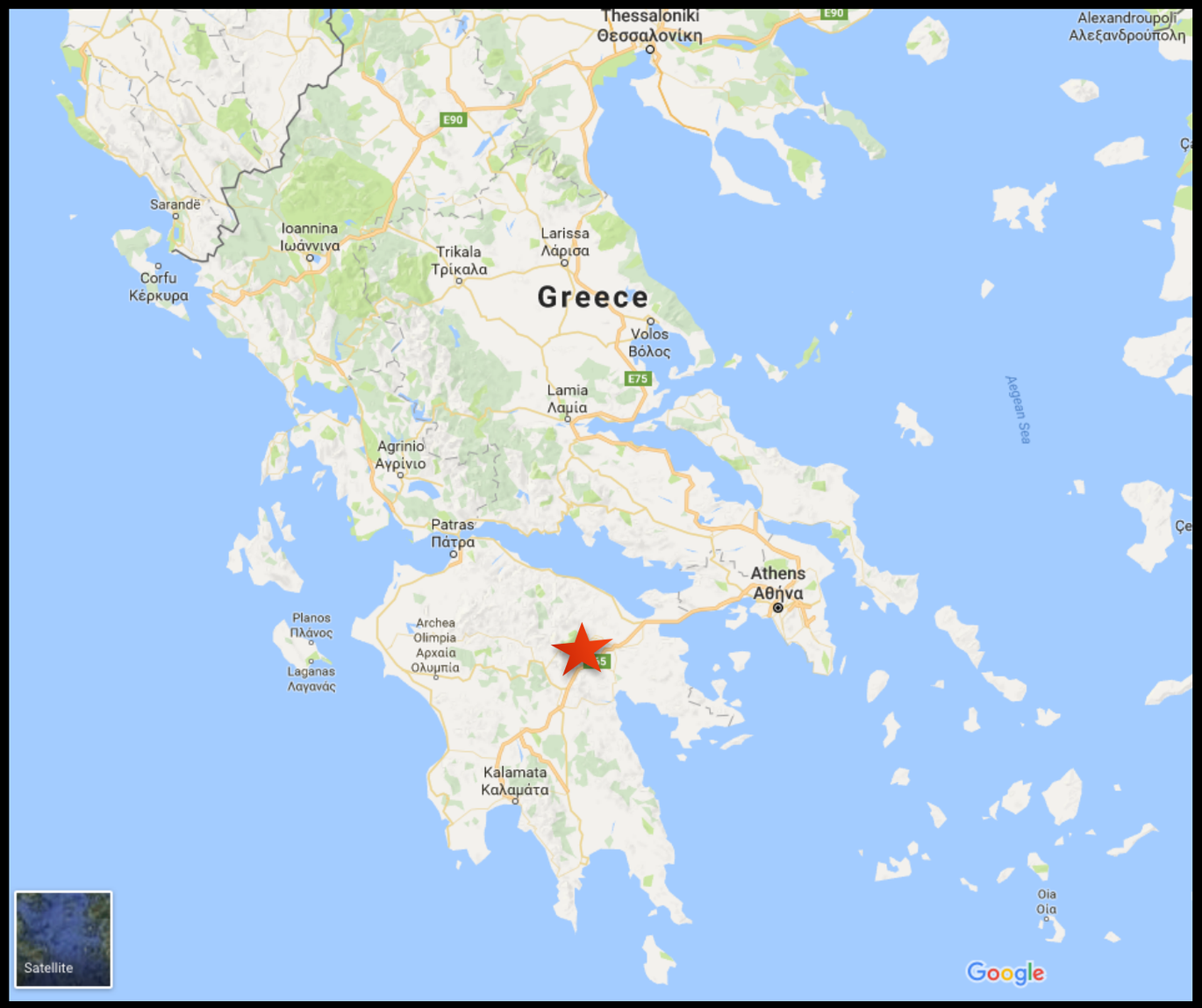
Impacts…live

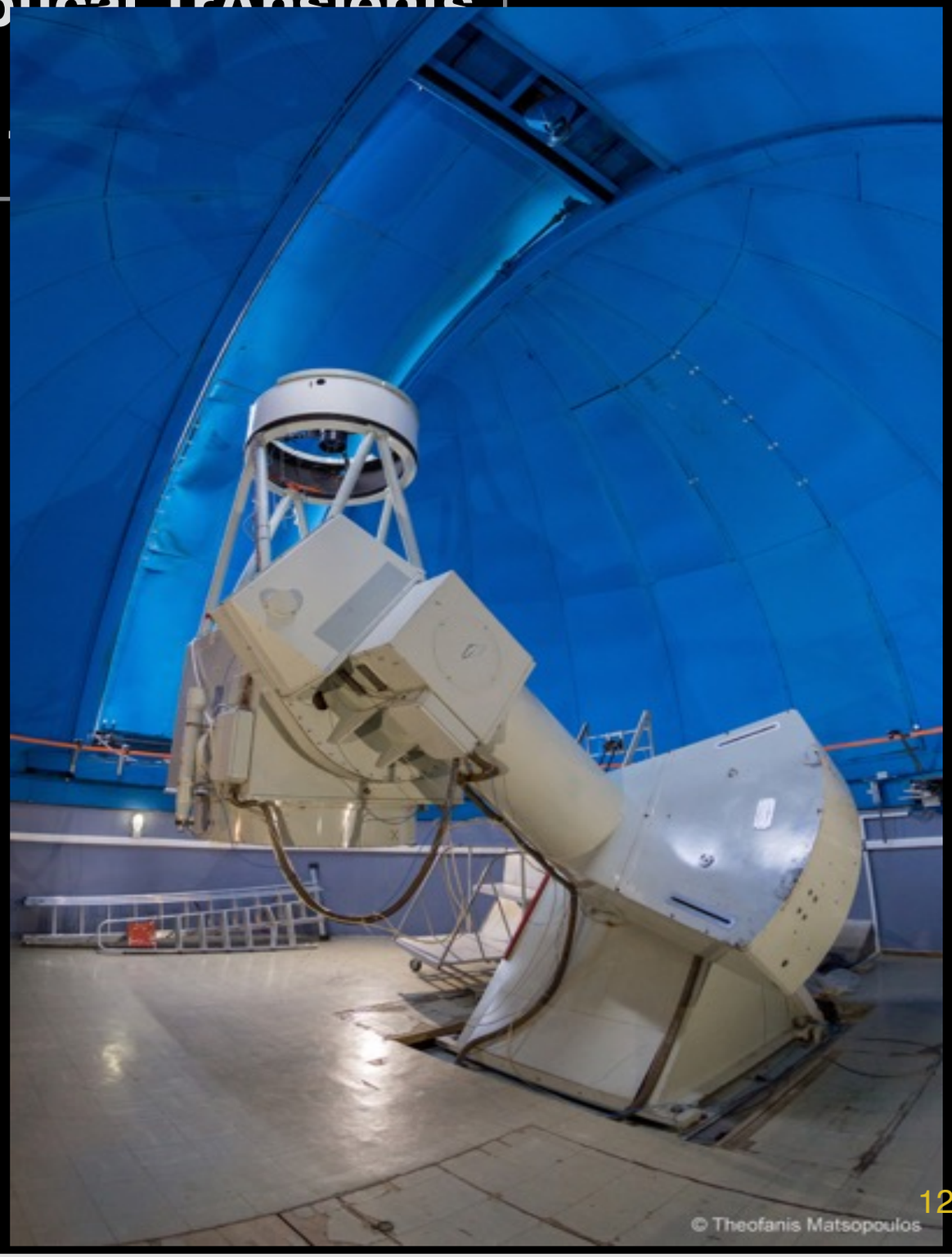
Credits: NOA

Project

NELIOTA = NEO Lunar Impacts and Optical TrAnsients

- **ESA-funded project**
- **22 months of operations (March 201**





Instrumentation

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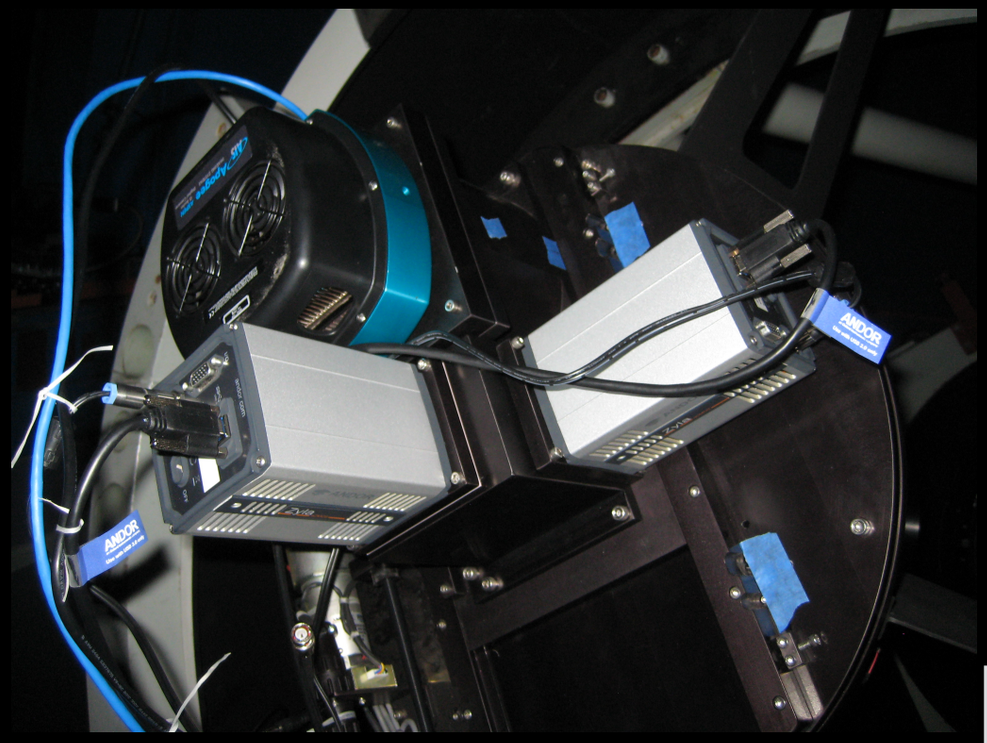
Technical setup

- ✓ 1.2 m telescope
- ✓ two Zyla sCMOS cameras with dichroic beam splitter
- ✓ 30 fps
- ✓ R= 641 and I=798
- ✓ FoV: 16.6x14.0 arcmin
- ✓ res: ~750 m



I. Observation Pl

- ✓ science frames
- ✓ standard stars
- ✓ calibration fra
- ✓ data stored

II. Data Reductio

- ✓ subtraction of the
- ✓ detection of even

III. Archiving & Va

Xylouris+ (in prep.)

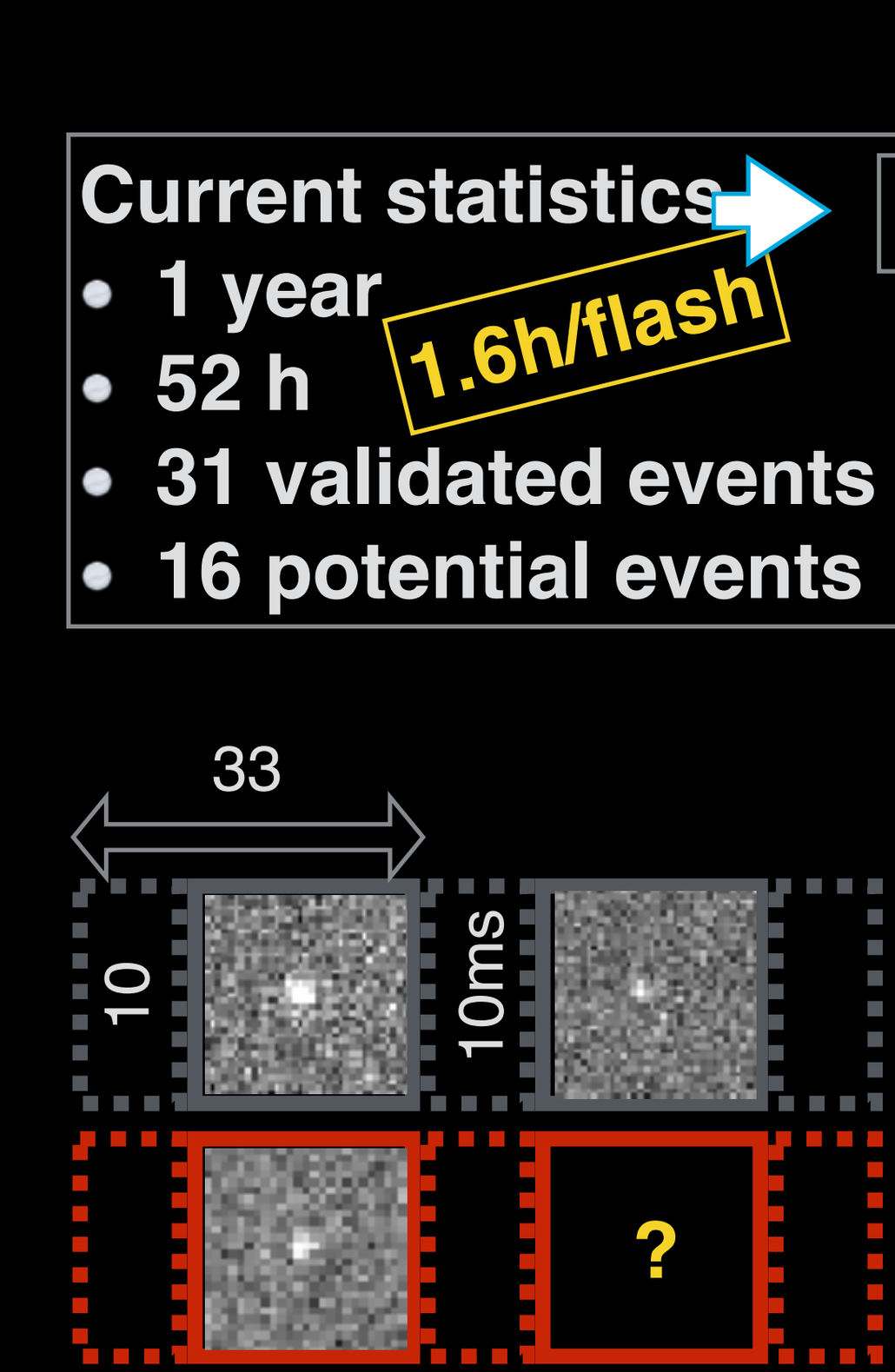
Detections

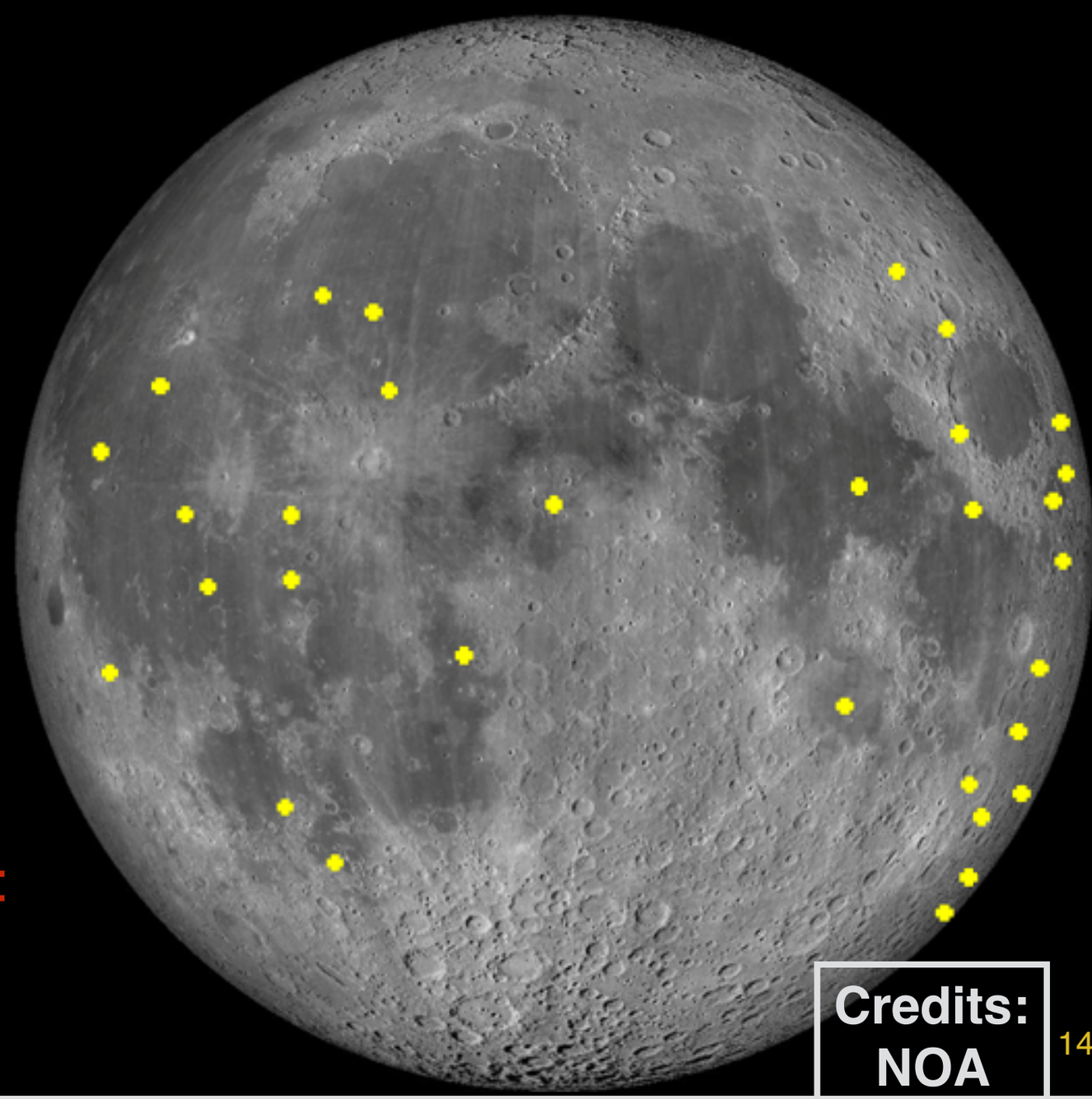
Current statistics

- 1 year
- 52 h
- 31 validated events
- 16 potential events

1.6h/flash

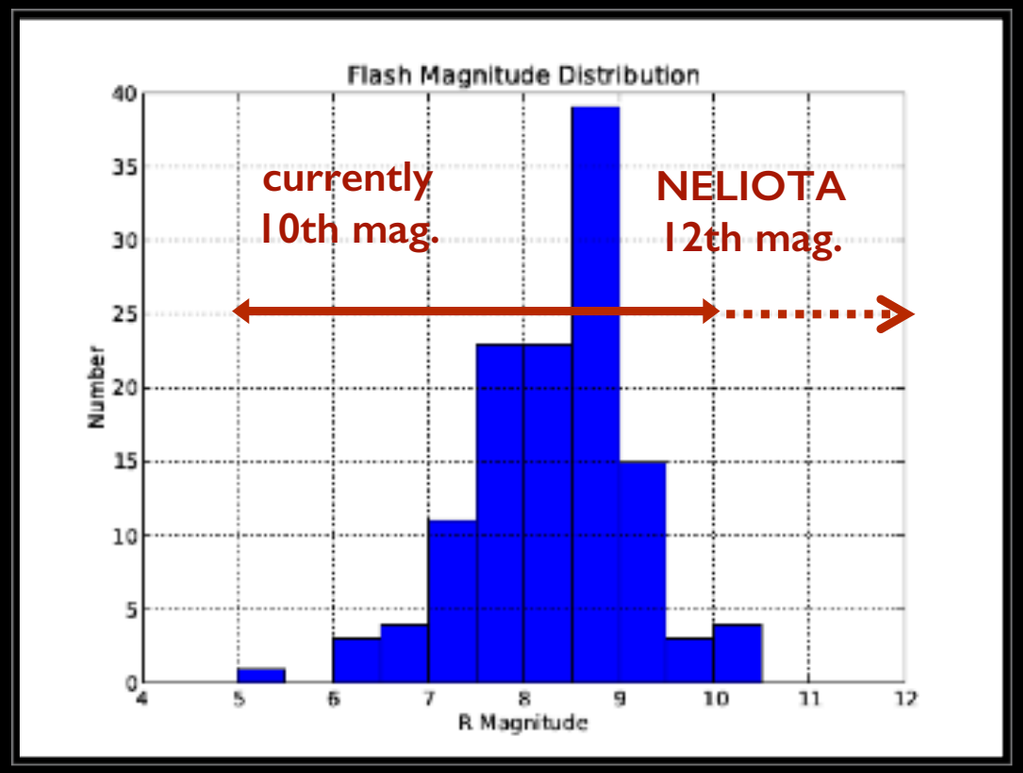
Duration Range: 43- 182 ms

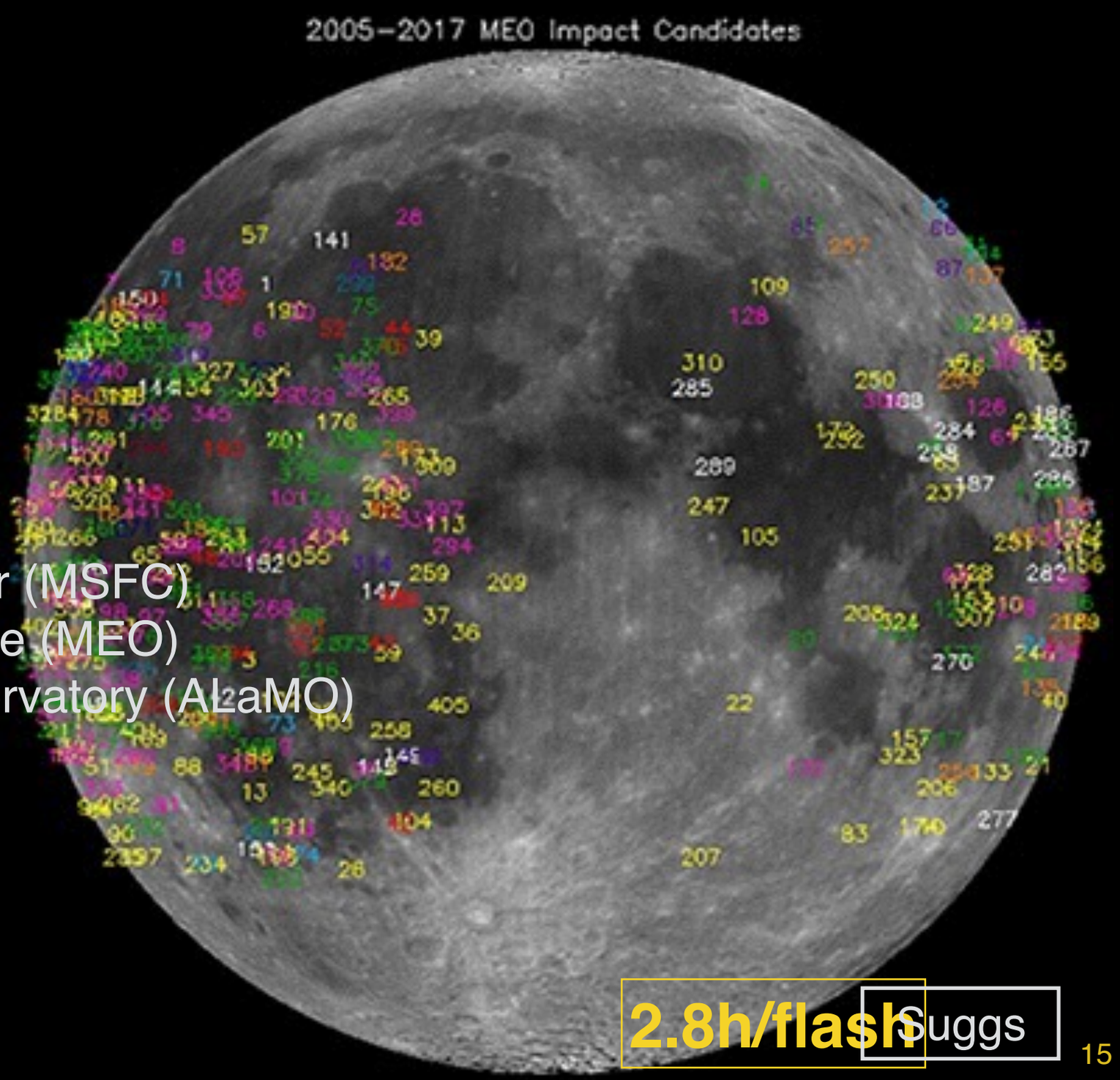




Credits: NOA

Comparison with other surveys





NASA Marshall Space Flight Center (MSFC)
NASA Meteoroid Environment Office (MEO)
Automated Lunar and Meteor Observatory (ALaMO)

Ortiz+1999,2000, 2002, 2006, 2015
Madiedo+2014,2015
Suggs+2014,2017

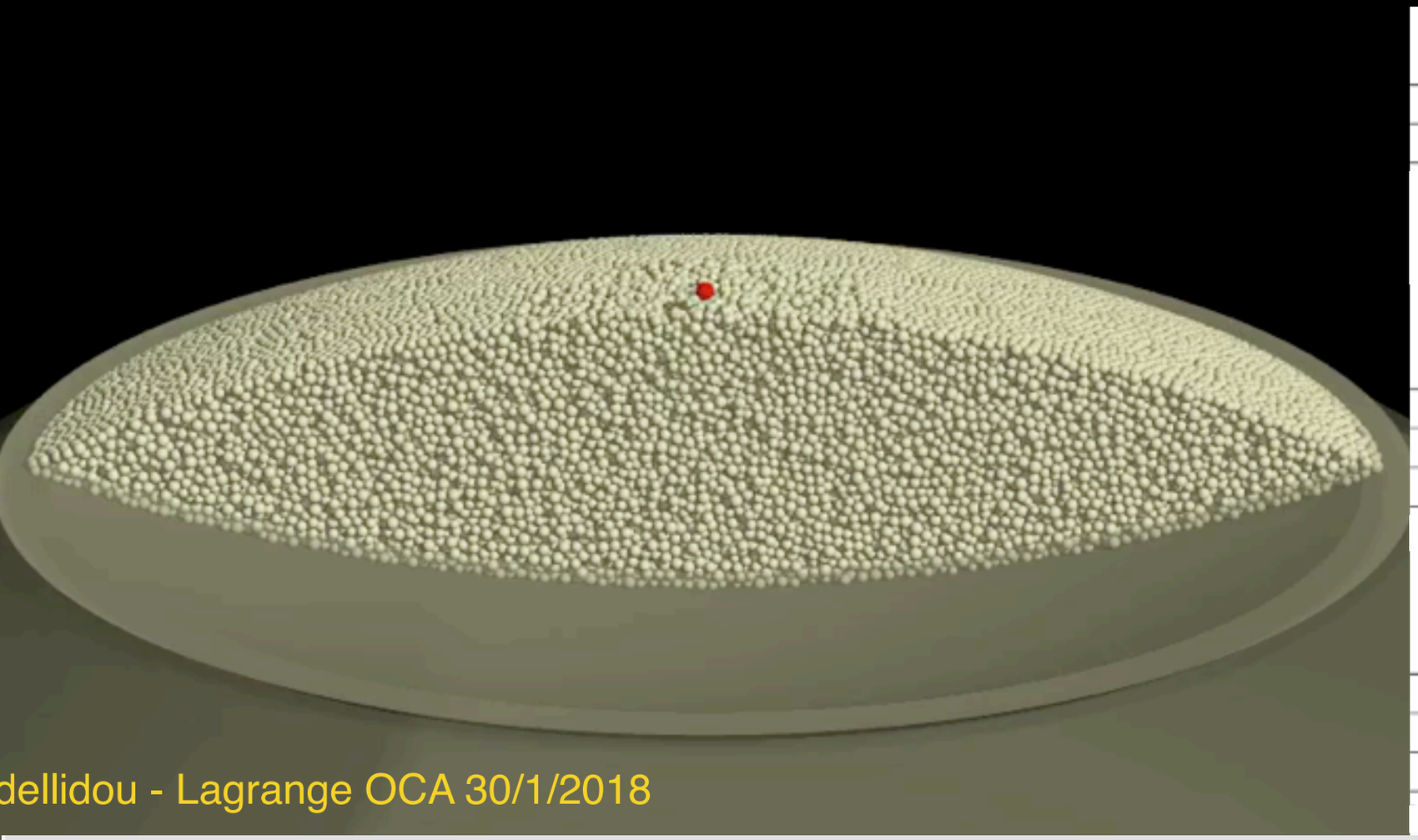
2.8h/flash Suggs

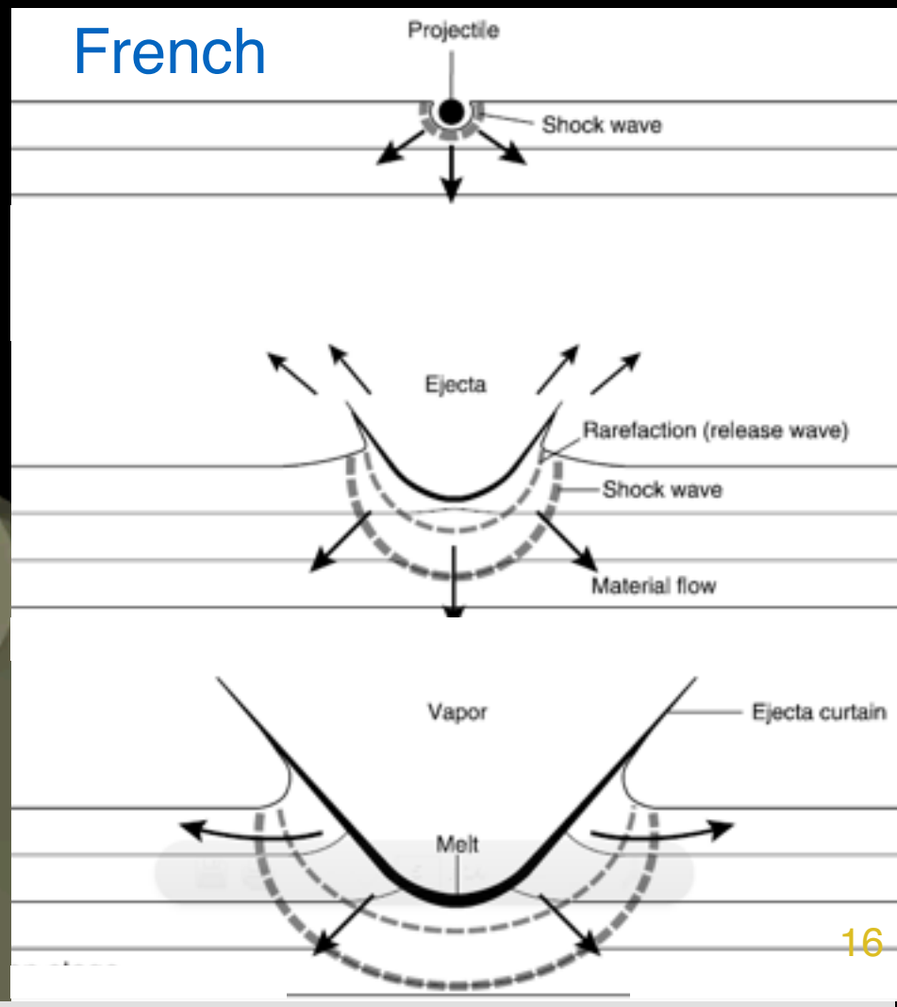
Impact Event

Credits:
Stephen Schwartz
niversity of Arizona

esa

Go a step further to study th





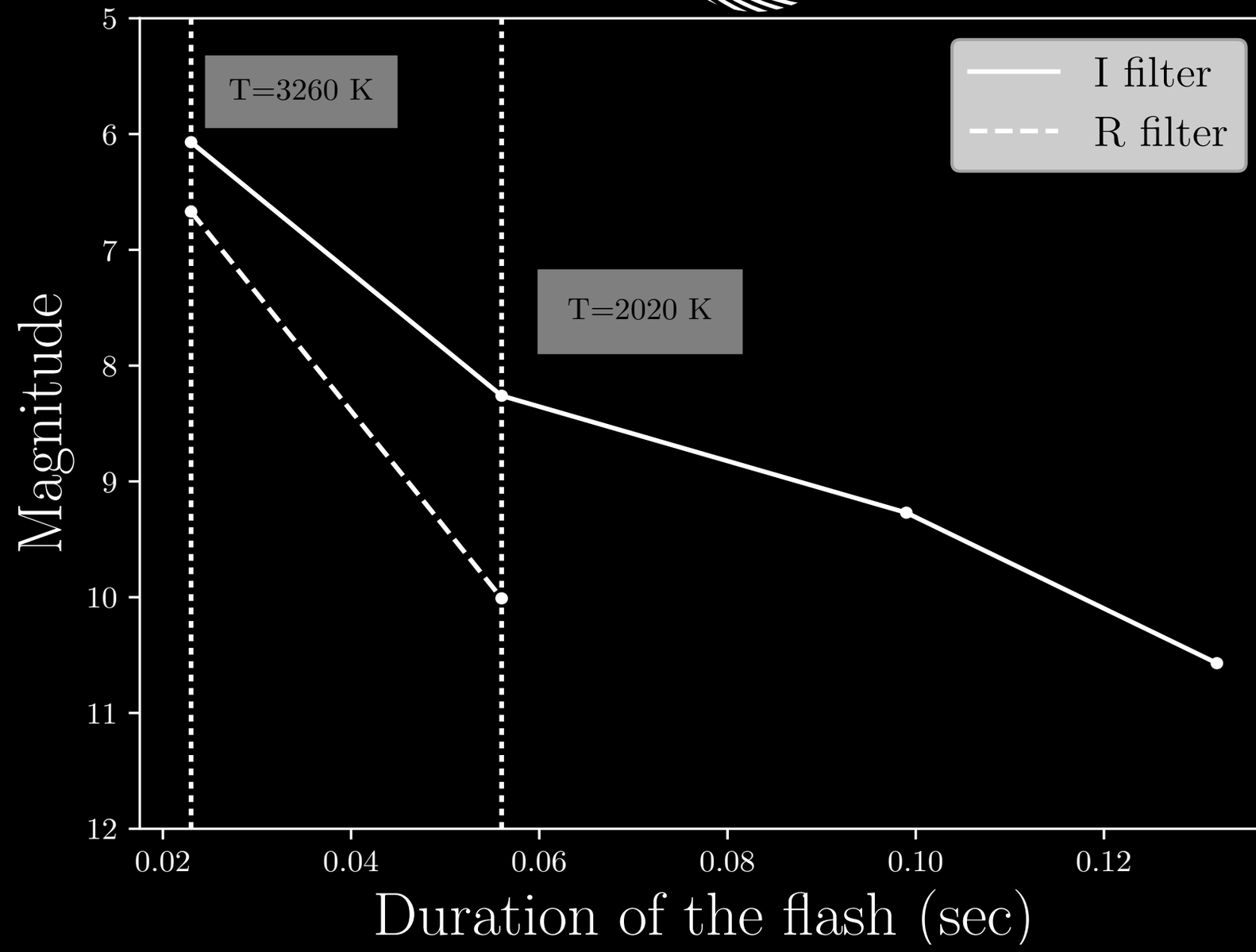
Temperatures of flashes & masses

Black Body behaviour

$$B(T,\lambda) = \frac{dN}{d\lambda} = \frac{2c}{\lambda^4}\,\frac{1}{\exp\left(\frac{hc}{\lambda k B T}\right)-1}$$

- T: temperature
- A: area of the flash
- η: luminous efficiency
- assume an impact velocity (V)
- calculate the mass

$$\frac{1}{2}mV^2 = \frac{\sigma A T^4 t}{\eta}$$



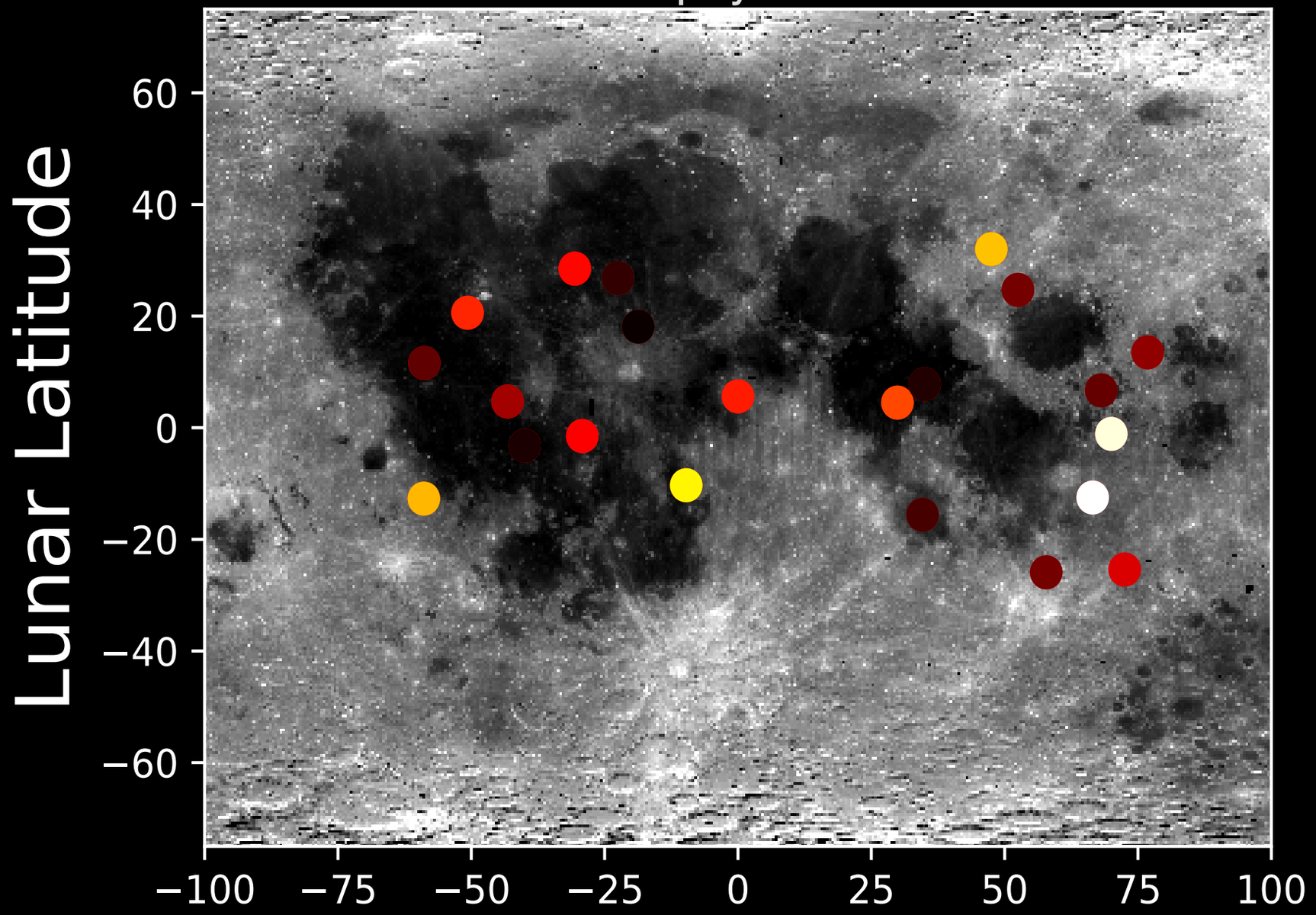
Bonanos, Avdellidou

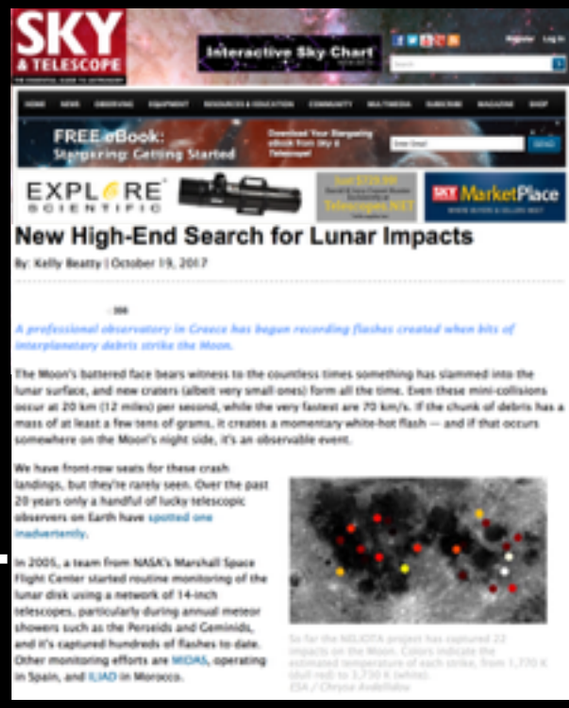
Evolution of the flash
Cooling time will help to understand the

Avdellidou(in

Temperatures vs. Locations

Lunar monitoring campaigns work towards the understanding of impact physics.

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New High-End Search for Lunar Impacts

By: Kelly Beatty | October 19, 2017

A professional observatory in Greece has begun recording flashes created when bits of interplanetary debris strike the Moon.

The Moon's battered face bears witness to the countless times something has slammed into the lunar surface, and new craters (albeit very small ones) form all the time. Even these mini-collisions occur at 20 km (12 miles) per second, while the very fastest are 70 km/s. If the chunk of debris has a mass of at least a few tens of grams, it creates a momentary white-hot flash — and if that occurs somewhere on the Moon's night side, it's an observable event.

We have front-row seats for these crash landings, but they're rarely seen. Over the past 20 years only a handful of lucky telescopic observers on Earth have spotted one inadvertently.

In 2005, a team from NASA's Marshall Space Flight Center started routine monitoring of the lunar disk using a network of 14-inch telescopes, particularly during annual meteor showers such as the Perseids and Geminids, and it's captured hundreds of flashes to date. Other monitoring efforts are MIDAS, operating in Spain, and ILIAD in Morocco.

So far the NELIOTA project has captured 22 impacts on the Moon. Colors indicate the estimated temperature of each strike, from 1,770 K (dull red) to 3,730 K (white).

ESA / Chryssa Avdellidou

Avdellidou (in prep.)

Search for Craters!

Search for the craters using Lunar Reconnaissance Orbiter (LRO) data
We are looking for a student for a summer

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LEAPS 2018
FAQ
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esa

The Leiden/ESA Astrophysics Program for Summer Students (LEAPS) 2018

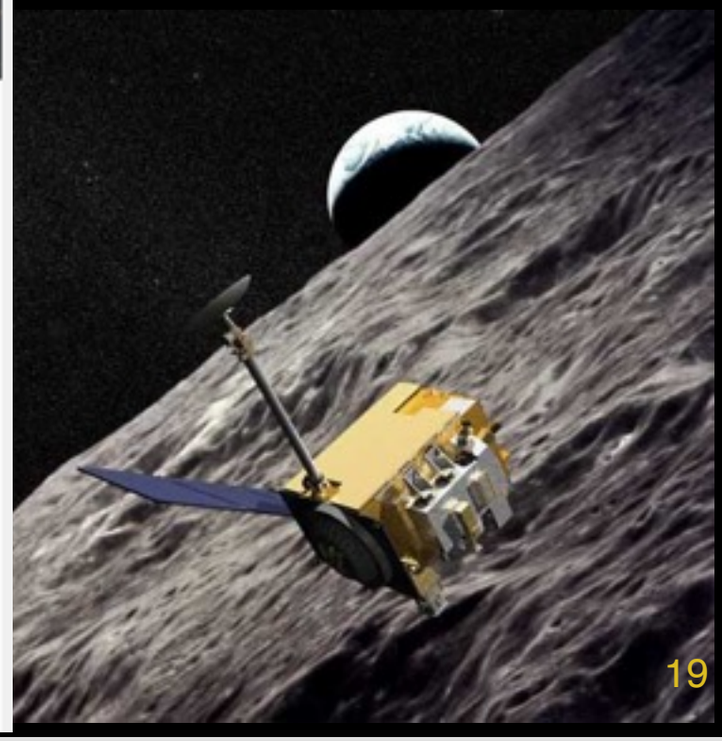
Update: January 15th, 2018

New projects have been posted! Also the new application deadline is Feb 23.

Leiden Observatory and ESA are pleased to welcome applications for the sixth edition of the LEAPS program. Application are carried out through this application form and the deadline is scheduled for **February 23, 2018**. If you have any questions about the application process or the program, please email us . If you want to know more about the projects on offer, please email the project supervisor directly by clicking on their name below.

LEAPS is an opportunity for students with an interest in astronomy and astrophysics to perform a 10-12 week summer research project in collaboration with a research scientist from Leiden Observatory or ESA. The program is open to all students not currently engaged in a Ph.D. program, although most past participants have been senior-undergraduate or masters' students who are enthusiastic about research in astrophysics.

Students will be selected for the program based on their academic achievements and research potential, and will be matched to staff projects based on what they indicate their scientific interests to be. Research at Leiden Observatory and ESA takes place on



Credits: NASA/GSFC/Arizona State Univer

Smart-1

Stooke & Foing 2017

Credits: LRO

Lunar impact Flashes

I. T-estimations:
1,770-3,730 K in the

II. Mass-estimations:
gr-kg
Strong dependence

III. Size-estimations:
Tricky, the origin of the

Plume T is affected by:

- target's material
- target's T

Questions

What is the dependence of an impact on th materials?

Can we infer the type of impactor from the re of an impact?

What is the fate of the impacting body

Let's reproduce.

Laboratory Studies: Light-Gas Gun

esa

University of Kent

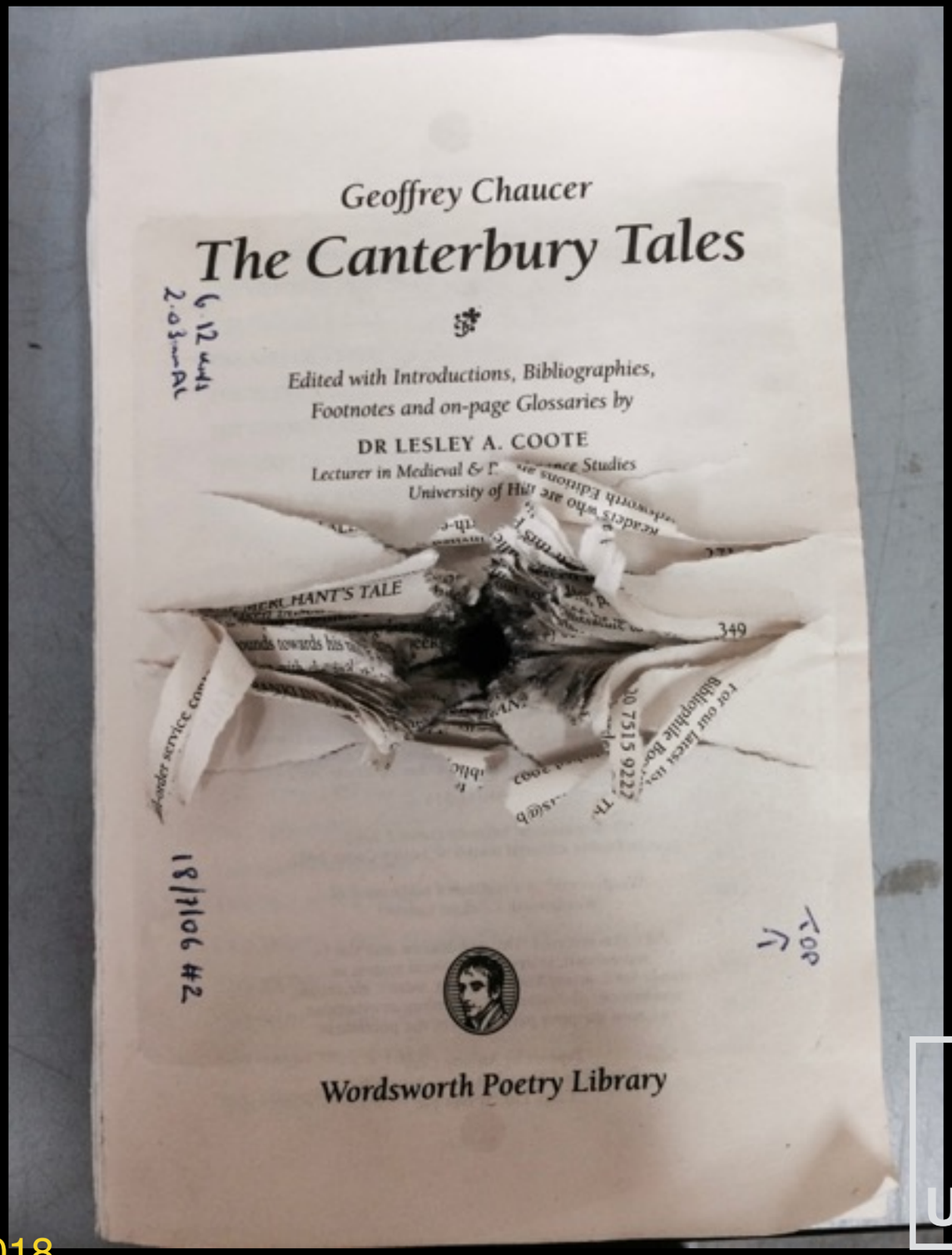
Centre for Astrophysics and Planetary Science

- ✓ V = 7.5 km/s
- ✓ It fires: dust, glass, metals, ice, rocks
- ✓ Targets: hot, cold, rotating, inclined, creatures
- ✓ New vertical gun

Laboratory Studies: Light-Gas Gun

Crucial for habitability, delivery of

Laboratory GAMES: Light-Gas Gun



Credits:
Impact Lab
University of Kent

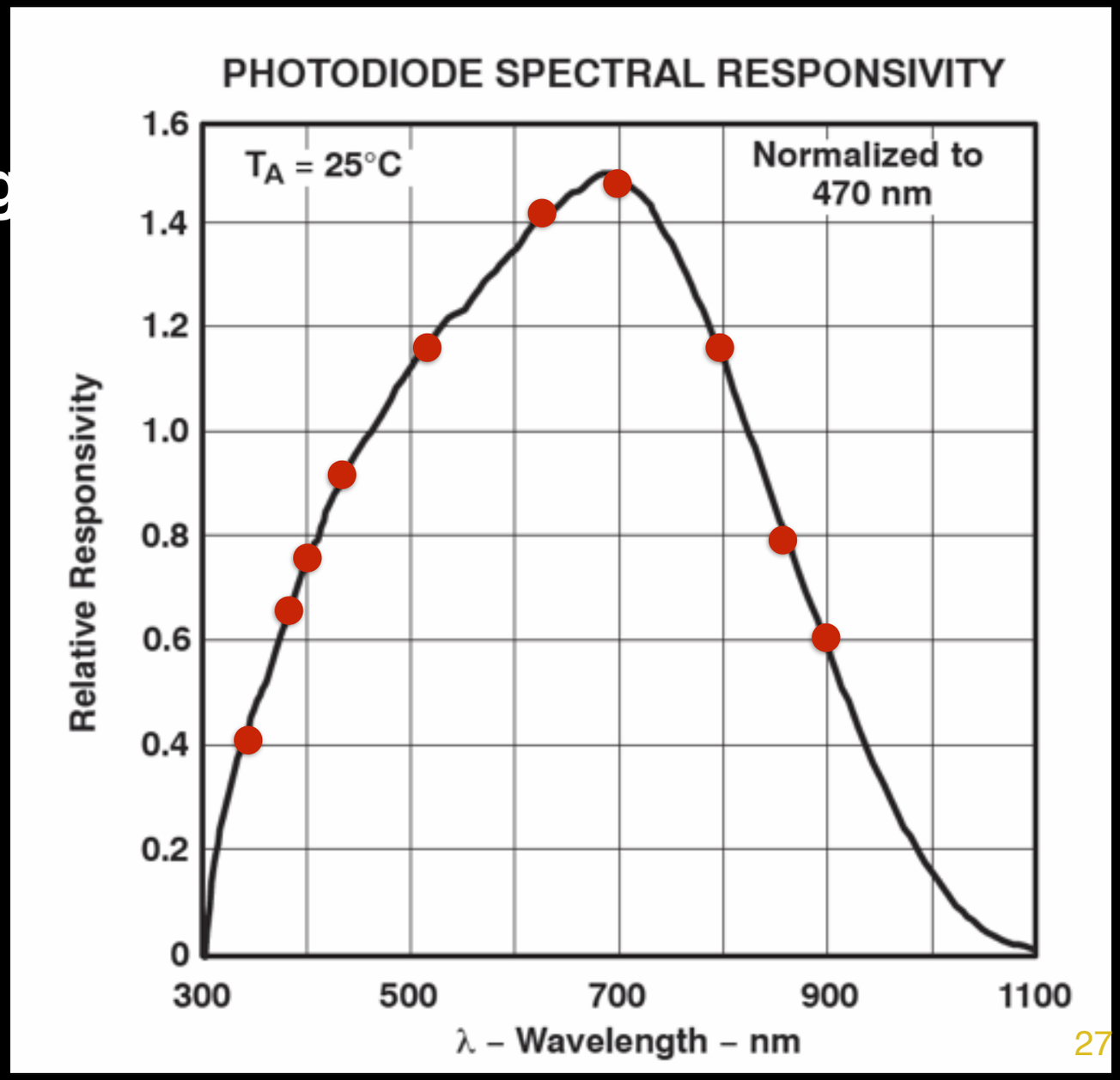
Laboratory Experiments

Catch the flash

- ✓ photomultipliers in R and I
- ✓ speed range: 1-6 km/s
- ✓ projectile: synthetic basalt
- ✓ targets: natural basalt/ lunar reg

› **Photomultipliers in many wavelengths**

Avdellidou, Price and Cole (in prep.)

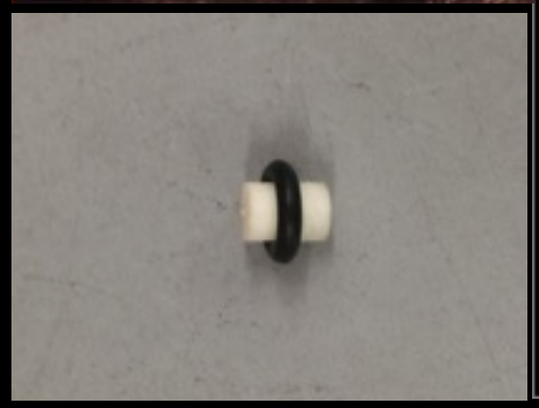


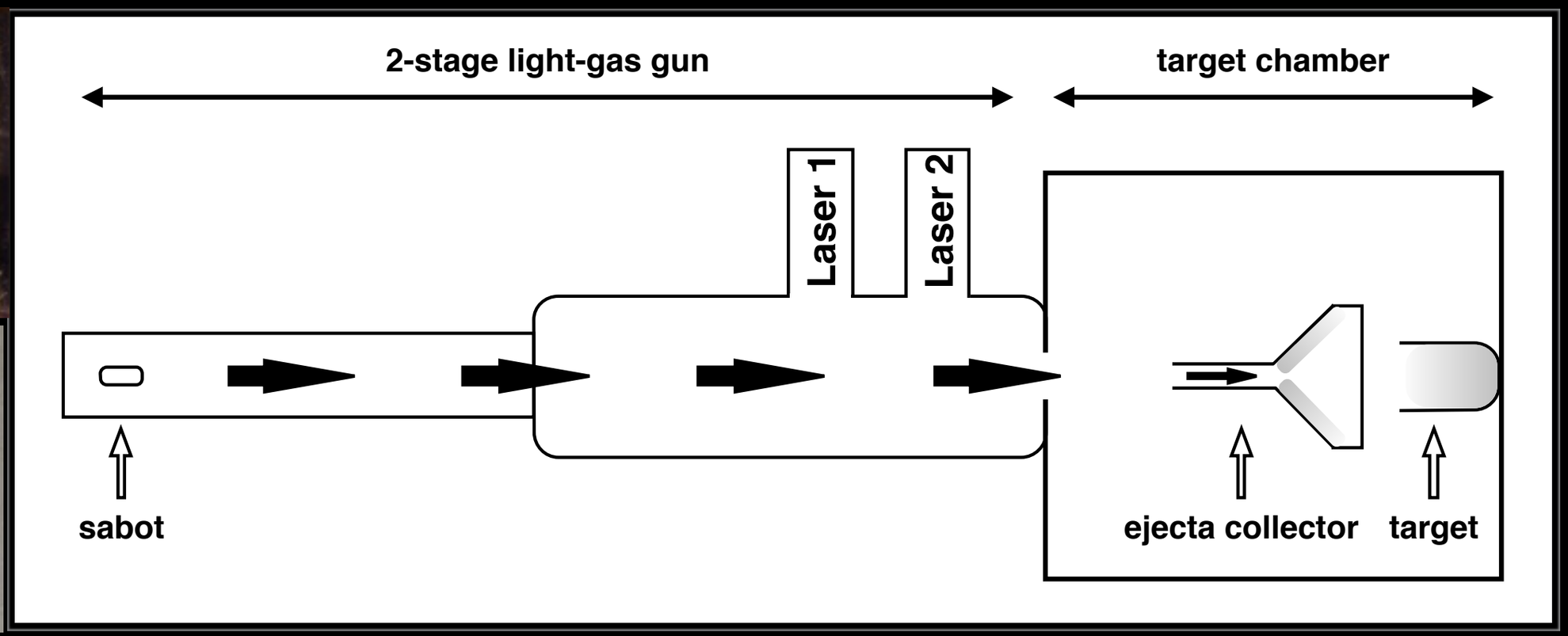
Laboratory Experiments

Credits:
Impact Lab
University of Kent

esa

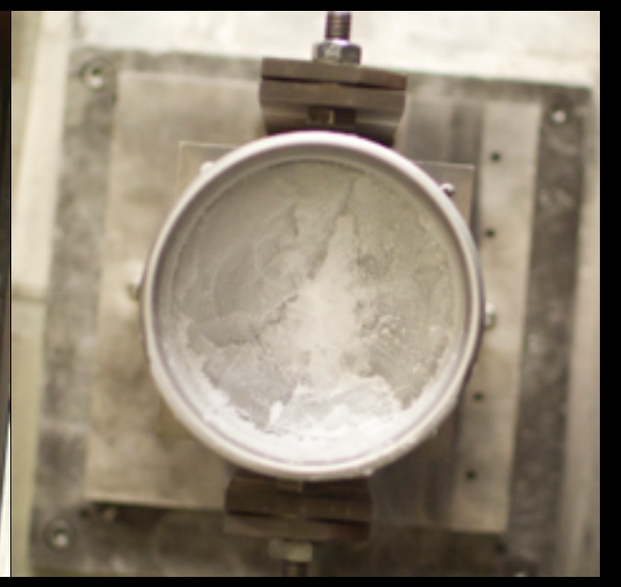
Laboratory Studies: Light-Gas Gun

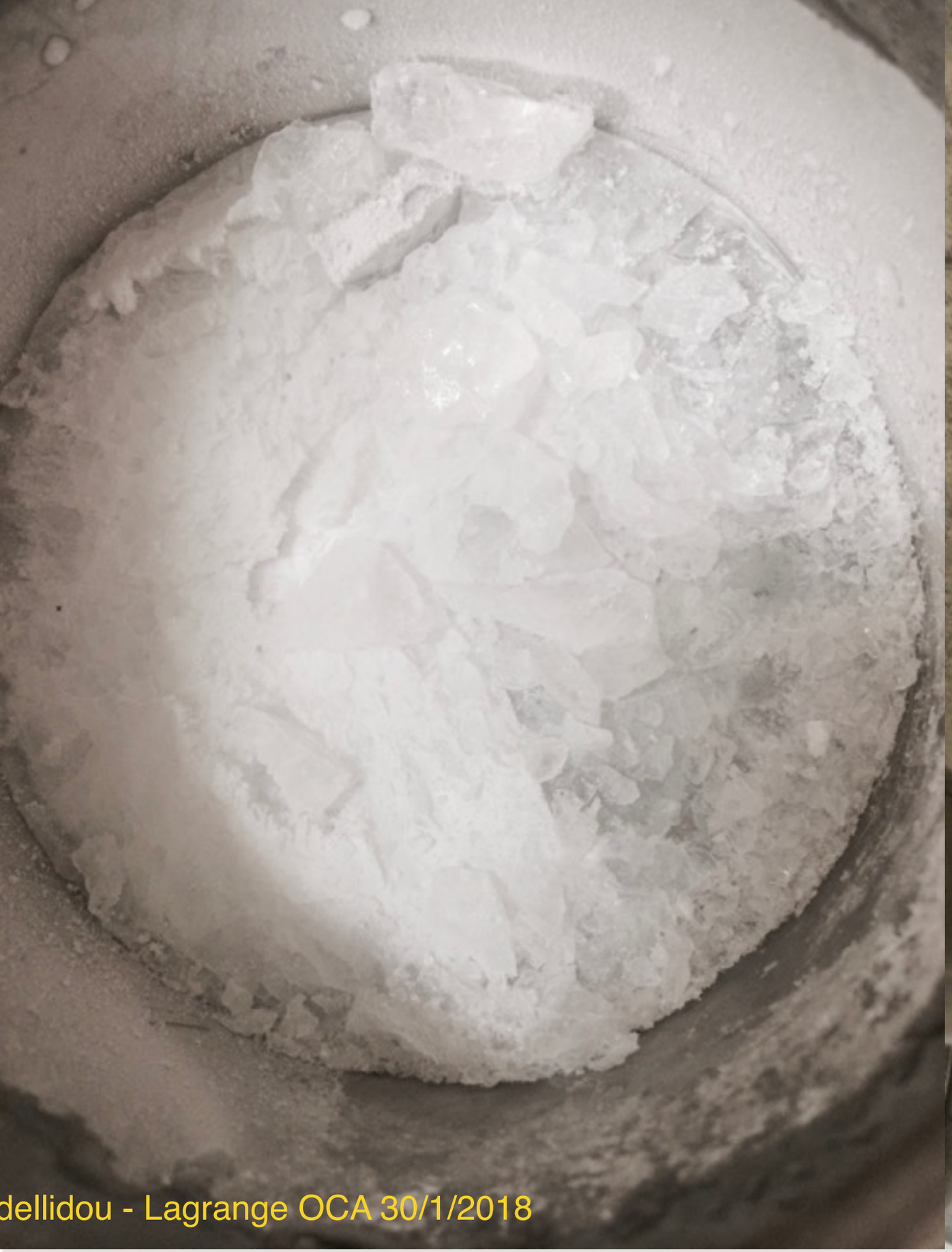




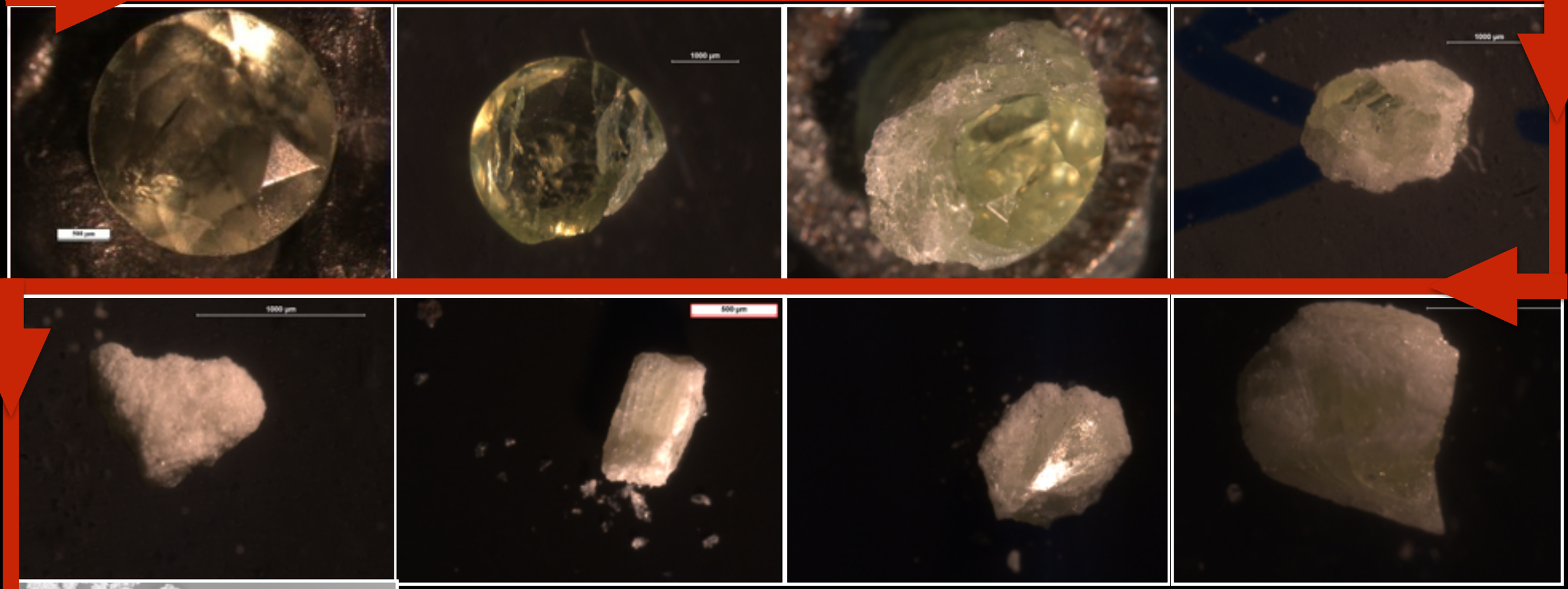
- ✓ Olivine projectiles
- ✓ 2 types of targets: water-ice and CaCO3
- ✓ 3 porosities

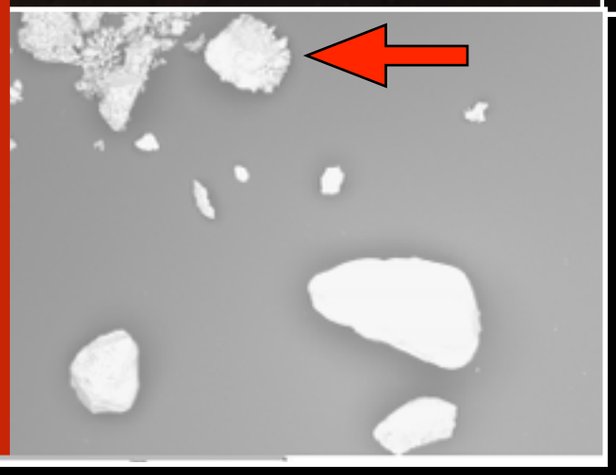
- > mass
- > SFD
- > sta





Laboratory Studies: Light-Gas Gun

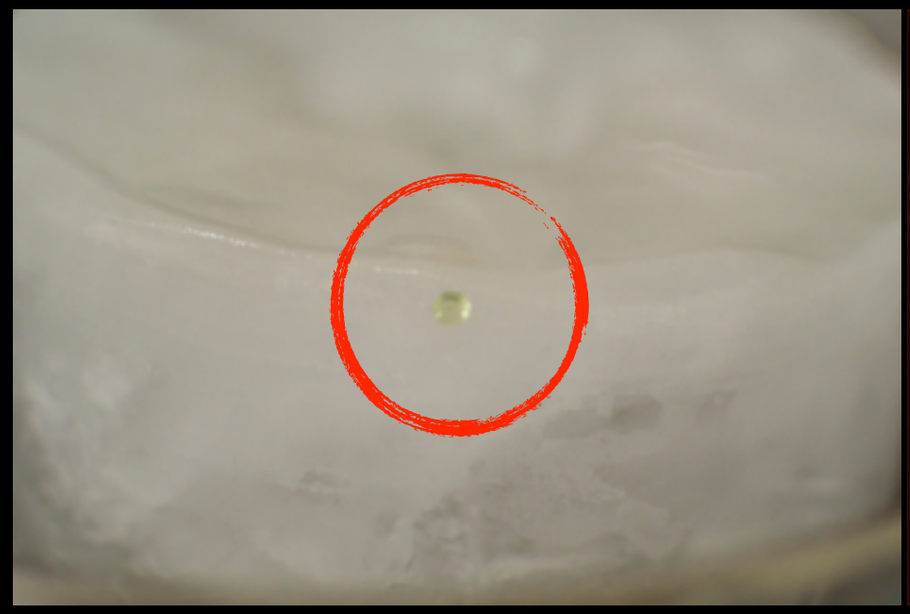


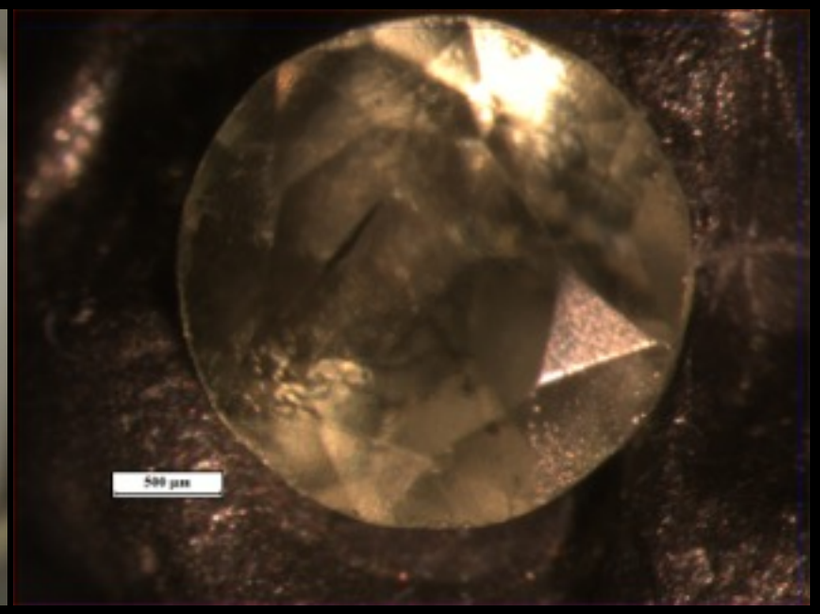


Increasing speed.

Laboratory Studies: Light-Gas Gun

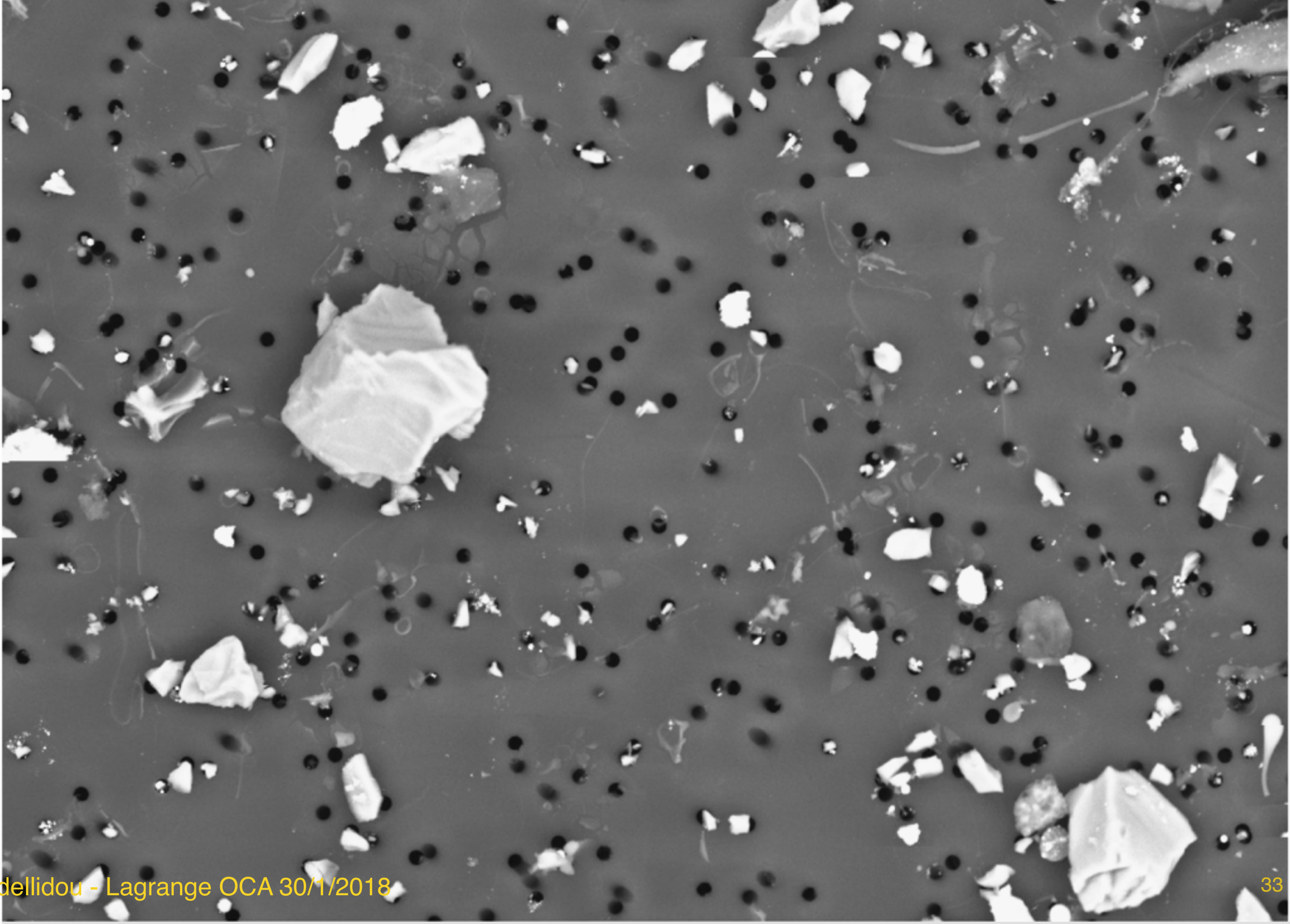
The large fragments were retrieved immediately from the target or ejecta





But how we measure ALL the fragments?

- ✓ melt/dissolve targets
- ✓ filter
- ✓ use SEM



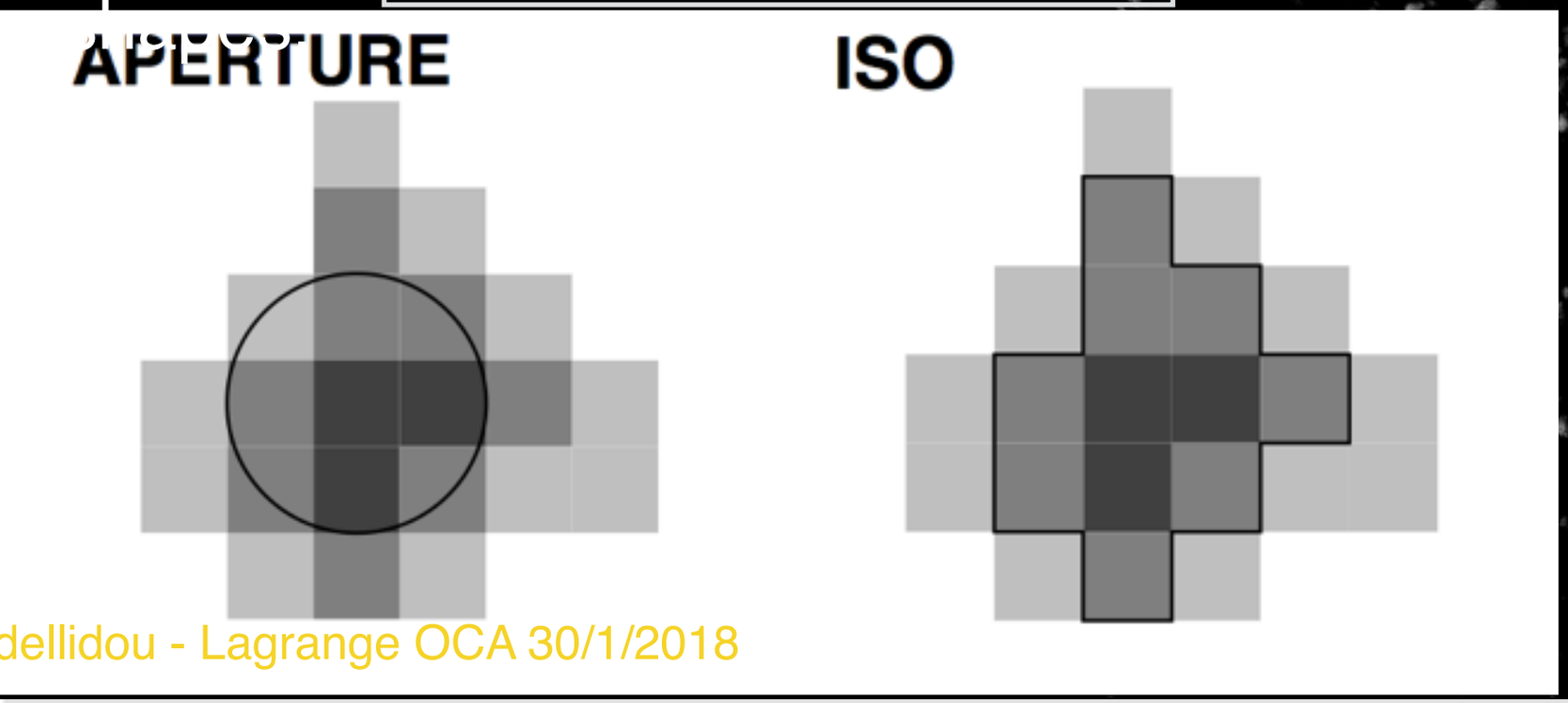
Laboratory Studies: Light-Gas Gun

- Consider fragments as light sources.

- Apply **astronomical photometry** by choosing a desirable threshold above background noise and a threshold in pxl to set the min area per fragment.

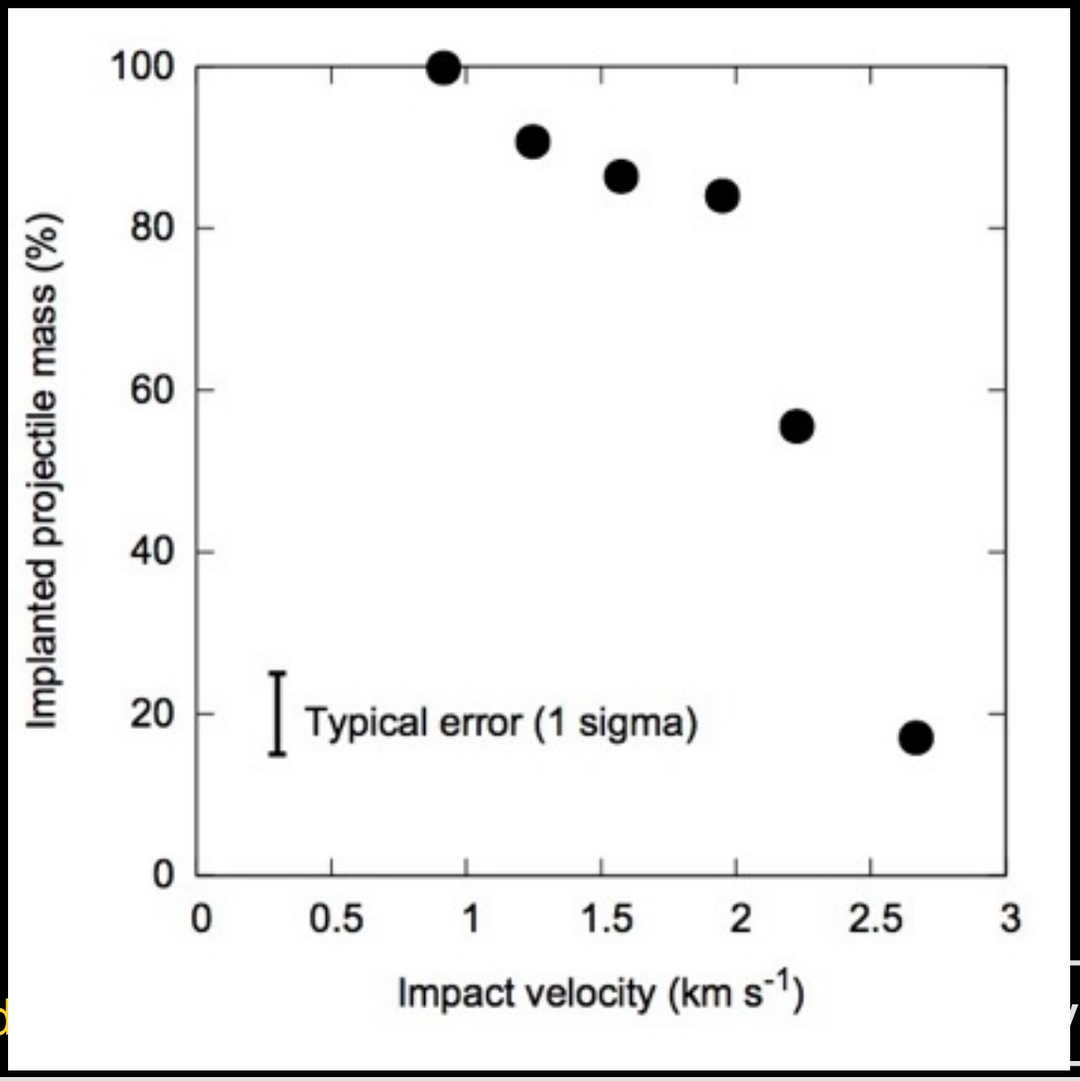
- Identification of irregular

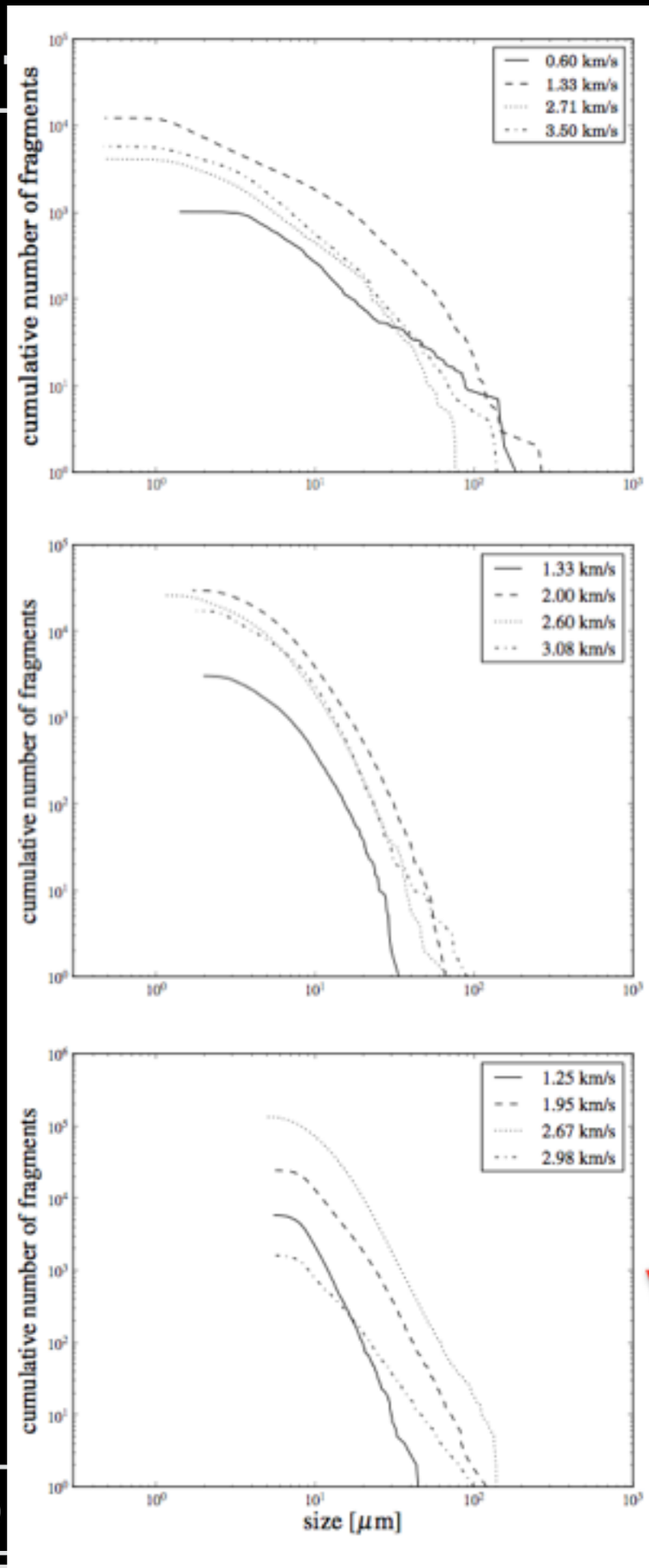
Avdellidou 2016, PhD Thesis



Laboratory Studies: Main Resul

- ✓Projectile survives.
- ✓Material is implanted.
- ✓Dependence on speed, target material and grain size.
- ✓Size distributions of fragments changes with target porosity.





ydellidou+ 2016, 20

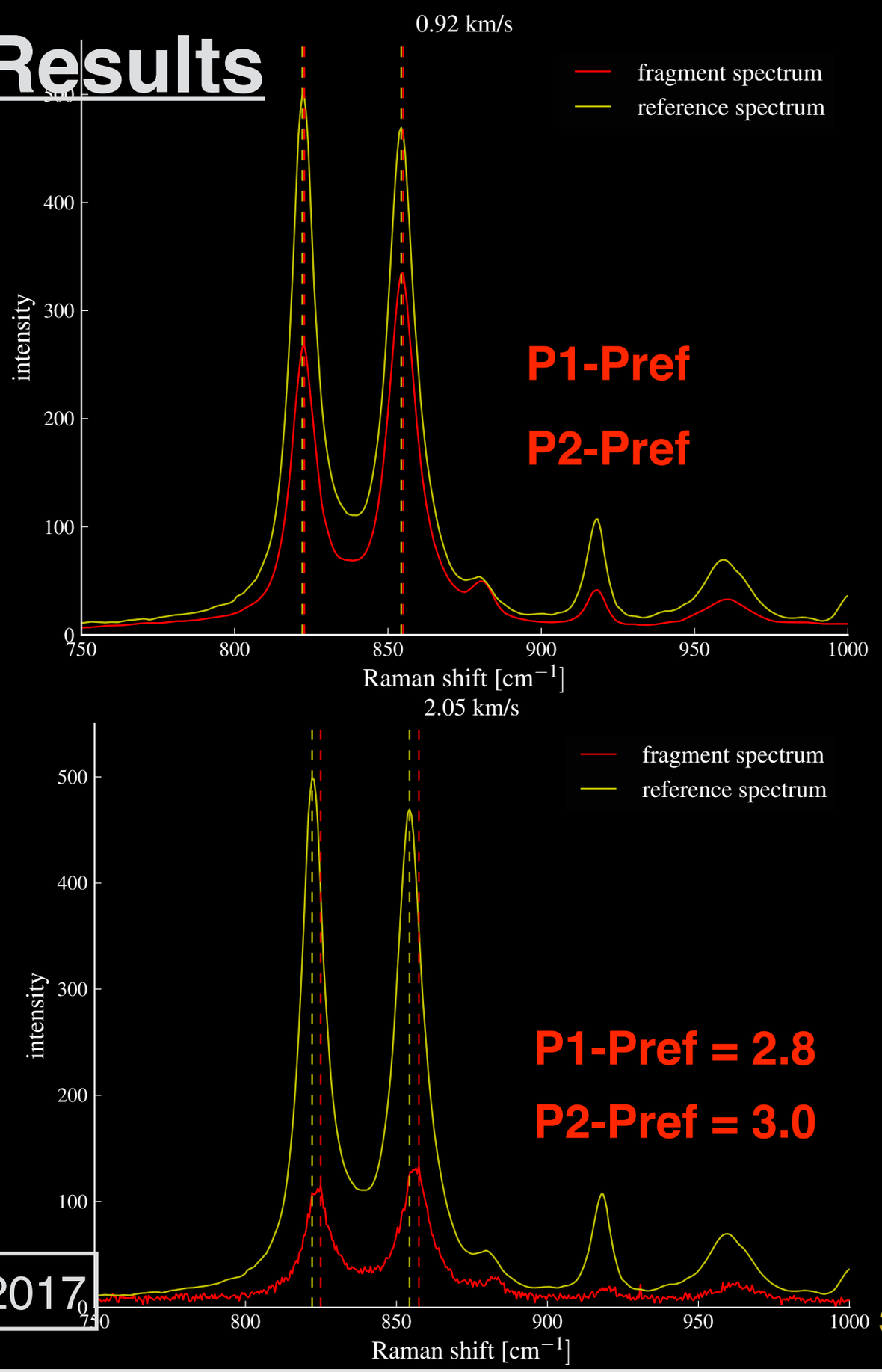
Laboratory Studies: Main Results

At higher speeds projectile suffers from stronger shock during impact.

RAMAN spectroscopy

- ✓Gives the shifts of lines.
- ✓Measure the shift from the reference peaks (P1-Pref, P2-Pref).
- ✓Measure the mutual difference of P1-P2.
- ✓We can understand if the geometry of molecules has been changed.

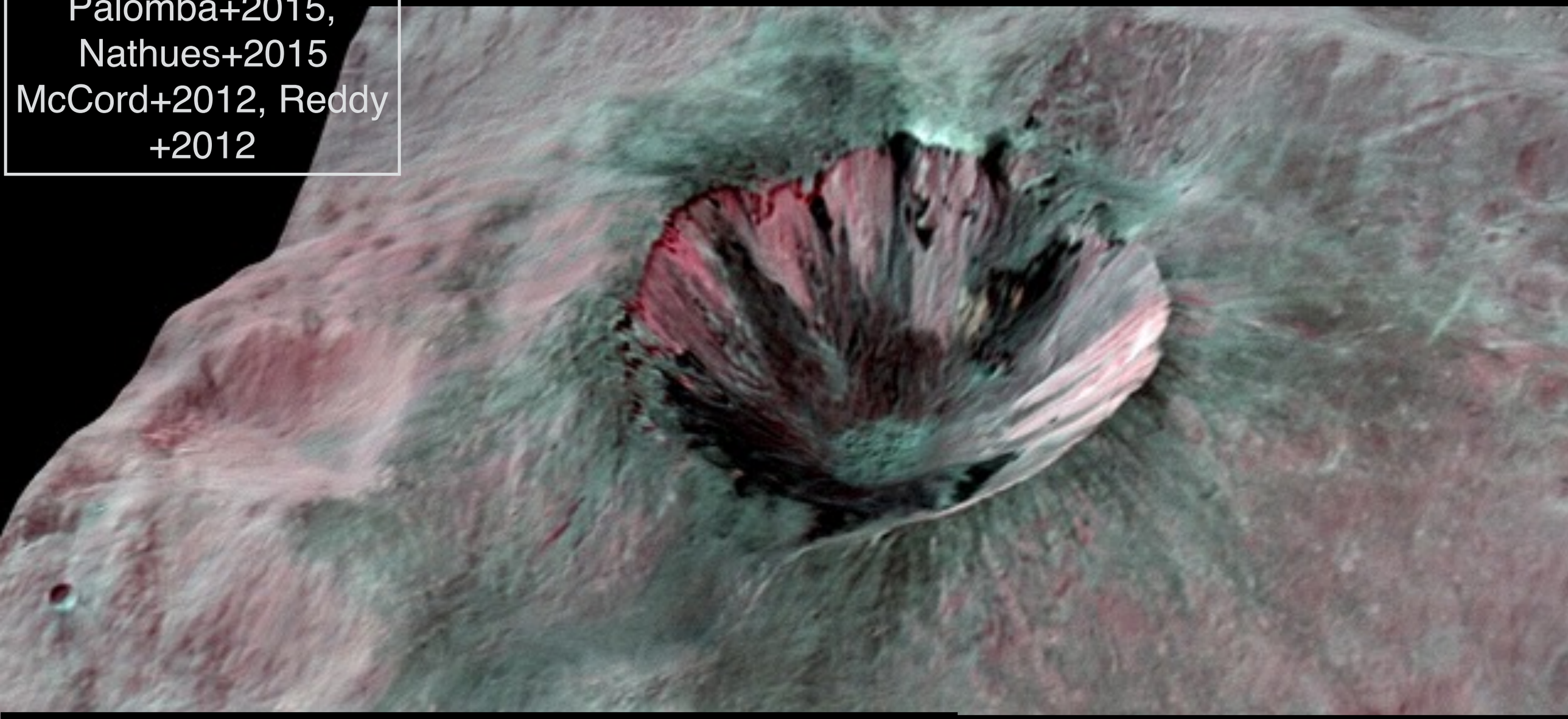
Avdellidou+ 2016, 2017



Implications

Palomba+2015,
Nathues+2015
McCord+2012, Reddy
+2012

Dark material on Vesta (Dawn).



There was a debate about the origin of the dark regions (olivine).

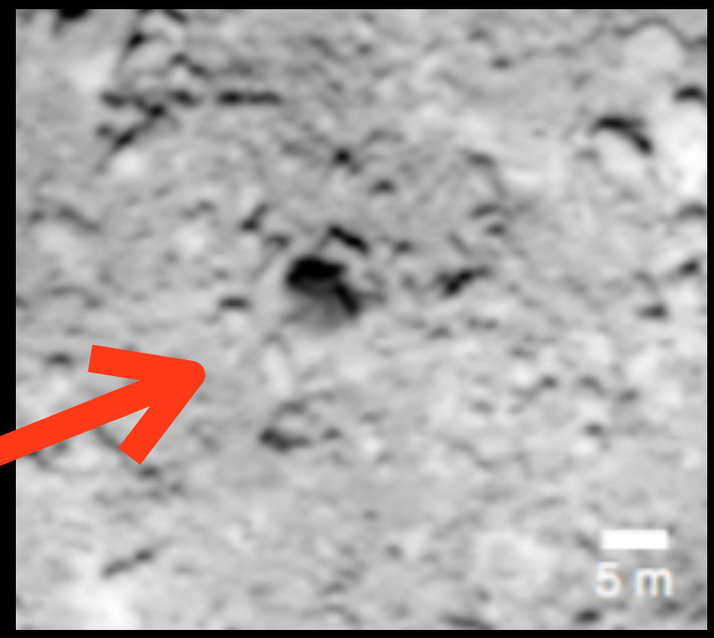
1. ~~endogenous~~
2. exogenous

The impacts related to this craters could not excavate so deep to reach the olivine mantle.

Turrini

Implications

Black boulder on asteroid Itokawa (Hayabusa, JAXA)



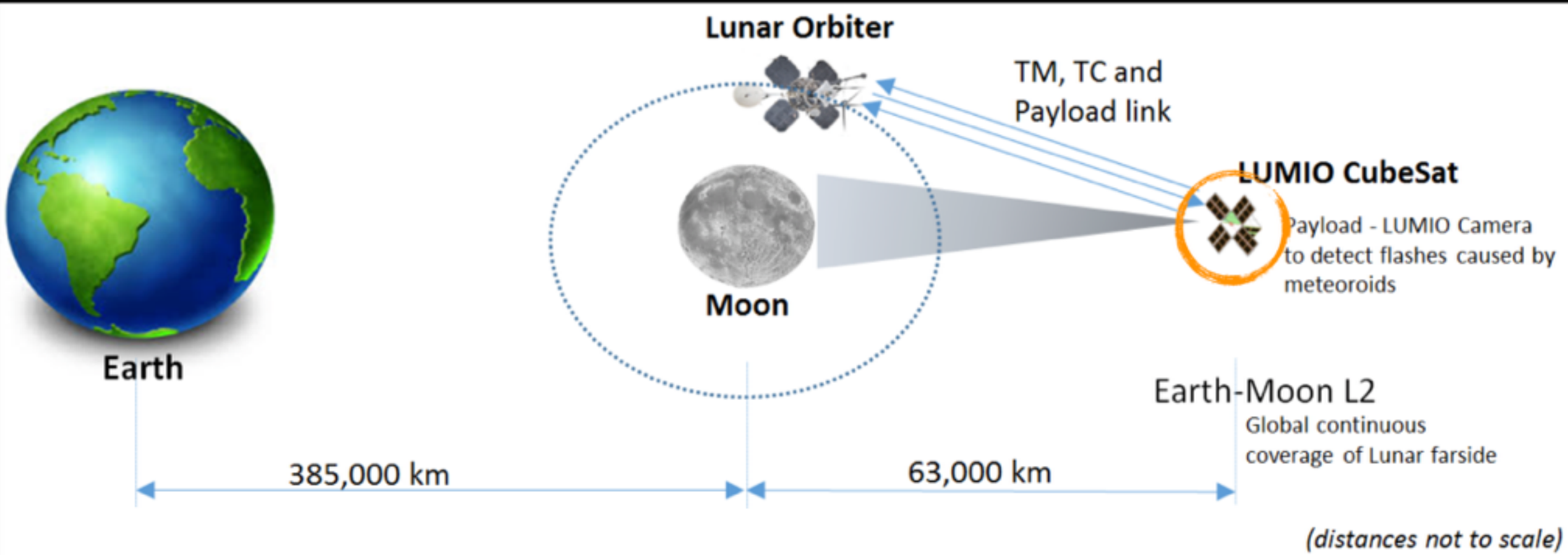
Hirata&Ishiguro 2011

The Future

LUMIO:
LUnar Meteoroid Impact Observer

The Future

Funded under ESA's SYSNOVA competition:
Lunar CubSats for Exploration (LUCE)



Conclusions

- ✓ **Impacts is an important process in the Solar System. Deep study leads to the understanding of the evolution of the Solar System.**
- ✓ **For this we need we need to investigate the dependence on the parameters (speed, impact angle, mass and type of material)**
- ✓ **Implications for the protection of the space assets (e.g. satellites)**
- ✓ **Lunar studies at the forefront of future ESA programs (MoonVillage, Lunar Situation Awareness)**
- ✓ **We need combination of methods to explore large regime of speeds.**