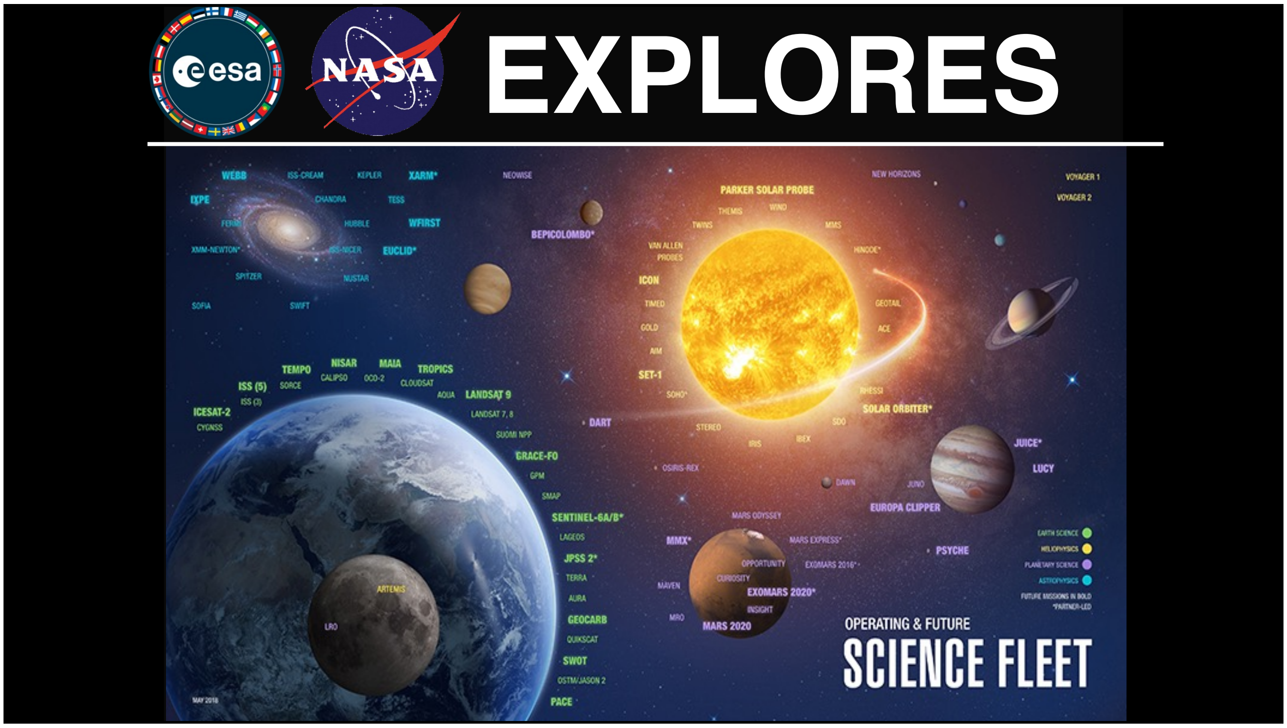

Asteroid Exploration
From Telescopic Discovery to Spacecraft Investigation
Richard P. Binzel
Professor of Planetary Science [Teaching Retired]
Joint Professor of Aerospace Engineering
MacVicar Faculty Fellow
EAPS
Earth, Atmospheric and Planetary Sciences
MIT AEROASTRO
NASA
NEW HORIZONS
Shedding Light on Frontier Worlds
OSIRIS-REx
ASTEROID SAMPLE RETURN MISSION
UNIVERSITY OF ARIZONA/LPL • NASA/GSFC • LOCKHEED MARTIN
LUCY
PSYCHE

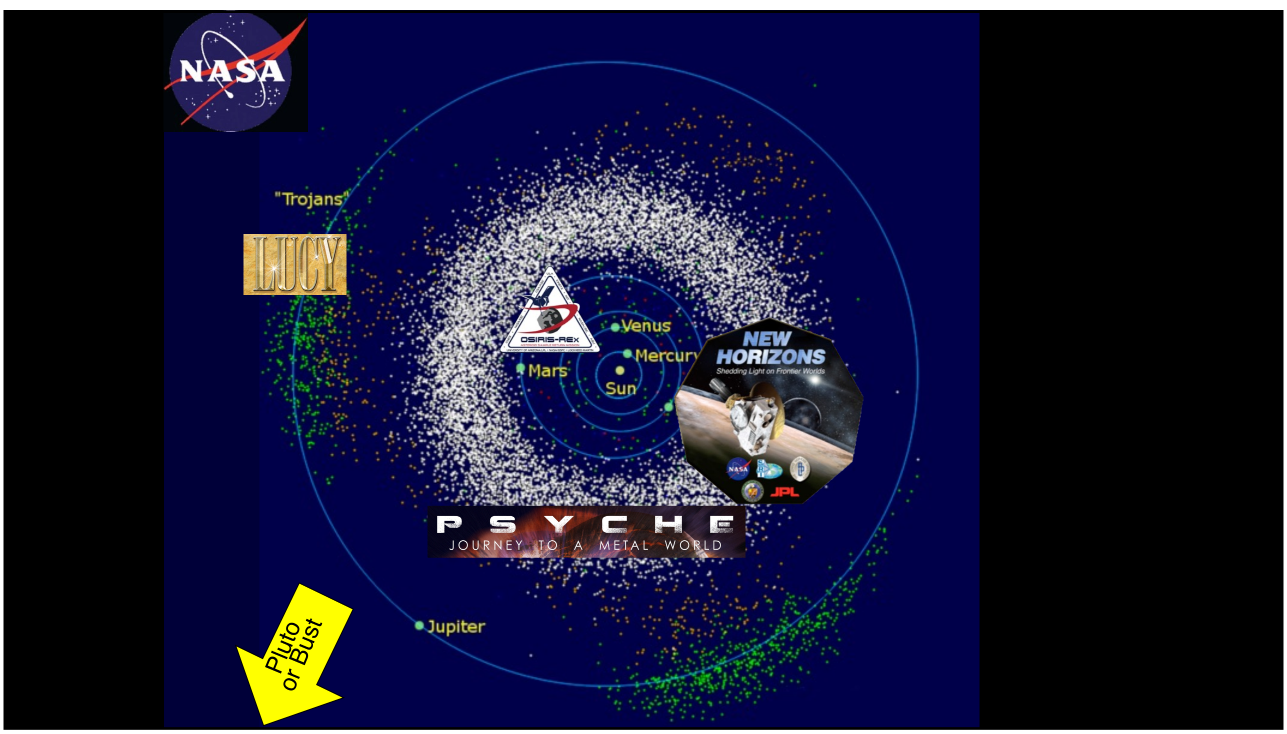
1


Exploration is a basic human instinct rooted to our survival.

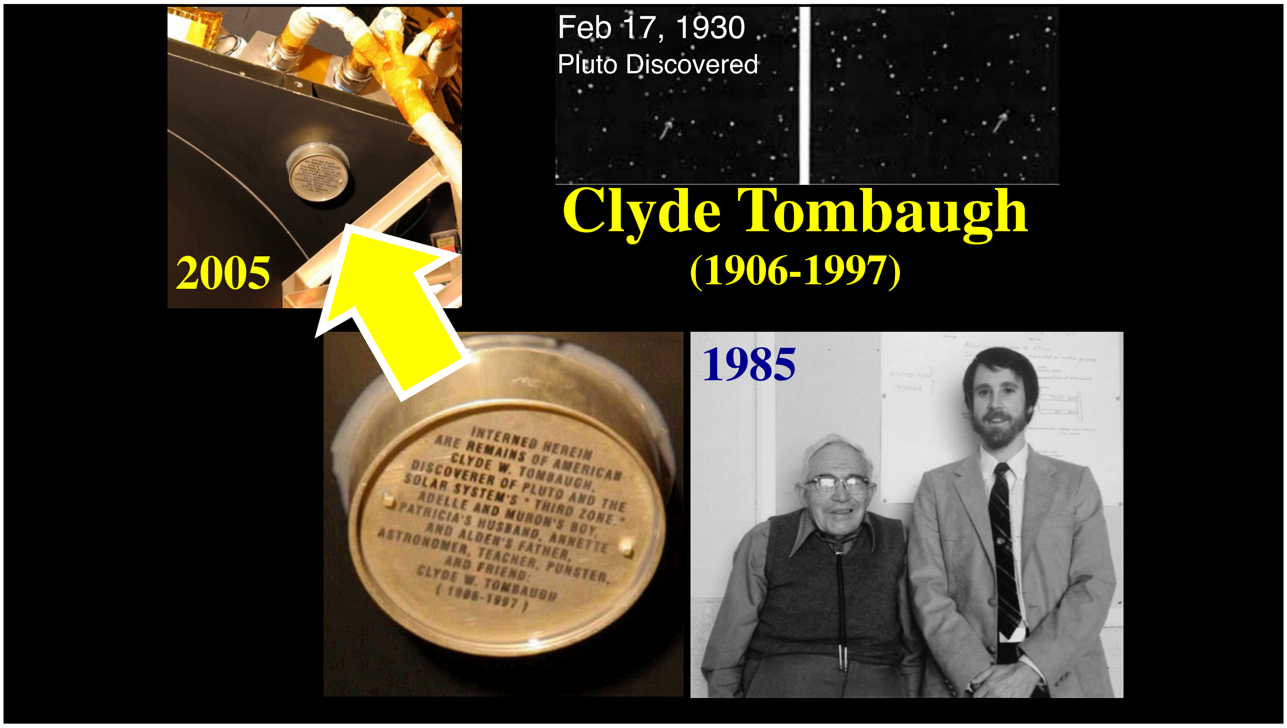
2


esa
NASA
EXPLORES
WEBB
KEPLER
XARM*
WFIRST
EUCLID*
NEOWISE
BEPICOLOMBO*
PARKER SOLAR PROBE
NEW HORIZONS
VOYAGER 1
VOYAGER 2
ICON
SET-1
TEMPO
NISAR
MAIA
TROPICS
ISS (5)
ICESAT-2
LANDSAT 9
DART
GRACE-FO
SOLAR ORBITER*
JUICE*
LUCY
SENTINEL-6A/B*
EUROPA CLIPPER
MMX*
PSYCHE
JPSS 2*
EXOMARS 2020*
GEOCARB
MARS 2020
SWOT
PACE
OPERATING & FUTURE
SCIENCE FLEET

3

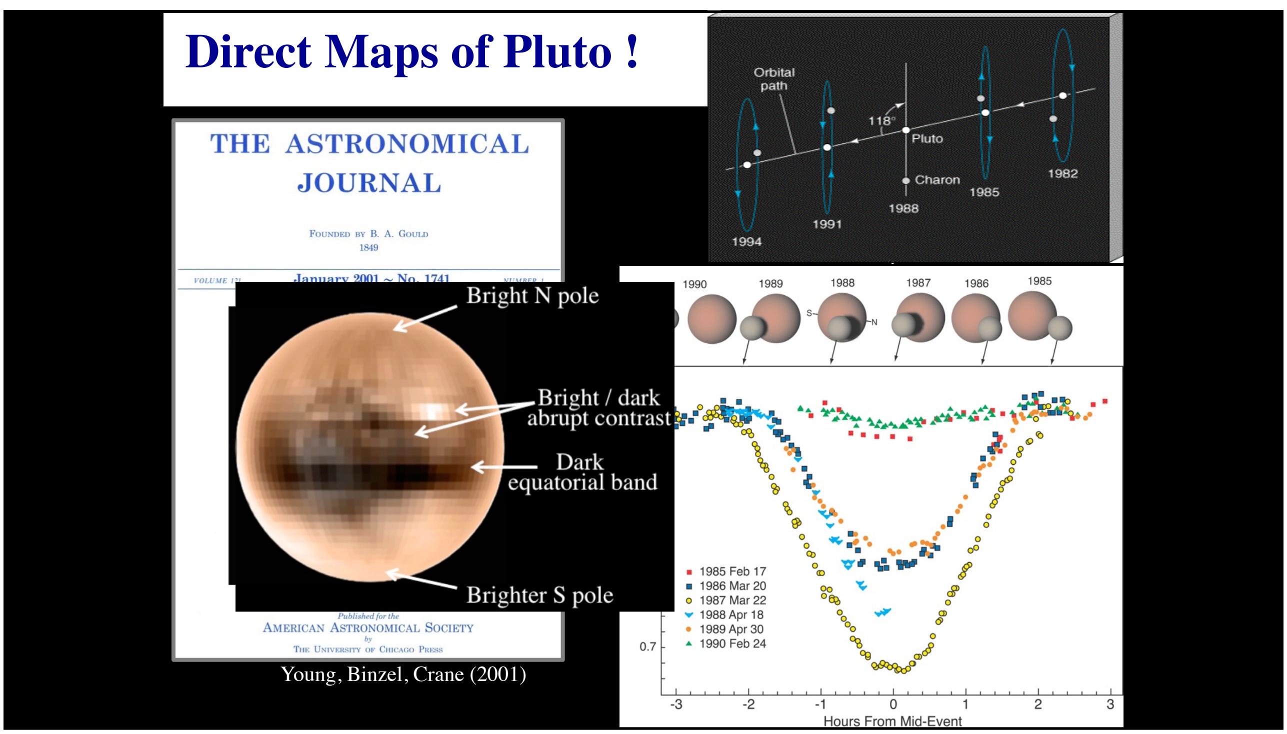

NASA
"Trojans"
LUCY
OSIRIS-REX
Venus
Mercury
Mars
Sun
NEW HORIZONS
Shedding Light on Frontier Worlds
JPL
PSYCHE
JOURNEY TO A METAL WORLD
Jupiter
Pluto or Bust

4



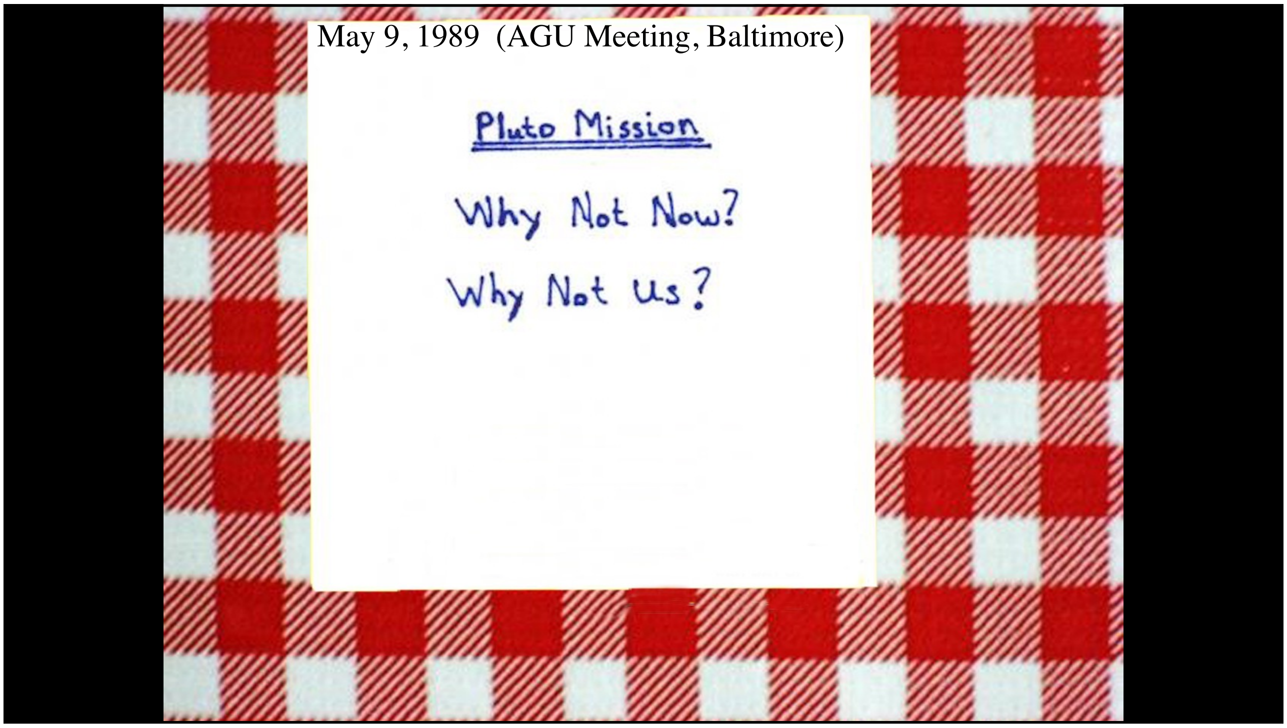
Feb 17, 1930
Pluto Discovered
Clyde Tombaugh
(1906-1997)
2005
1985
INTERNED HEREIN ARE REMAINS OF AMERICAN CLYDE W. TOMBAUGH, DISCOVERER OF PLUTO AND THE SOLAR SYSTEM'S "THIRD ZONE." ADELLE AND MURON'S BOY, PATRICIA'S HUSBAND, ANNETTE AND ALDEN'S FATHER, ASTRONOMER, TEACHER, PUNSTER, AND FRIEND: CLYDE W. TOMBAUGH (1906-1997)

5



Direct Maps of Pluto !
THE ASTRONOMICAL JOURNAL
Founded by B. A. Gould
1849
January 2001 ~ No. 1741
Published for the
American Astronomical Society
by
The University of Chicago Press
Bright N pole
Bright / dark abrupt contrast
Dark equatorial band
Brighter S pole
Young, Binzel, Crane (2001)
Orbital path
118°
Pluto
Charon
1994
1991
1988
1985
1982
1990
1989
1988
1987
1986
1985
1985 Feb 17
1986 Mar 20
1987 Mar 22
1988 Apr 18
1989 Apr 30
1990 Feb 24
0.7
-3
-2
-1
0
1
2
3
Hours From Mid-Event

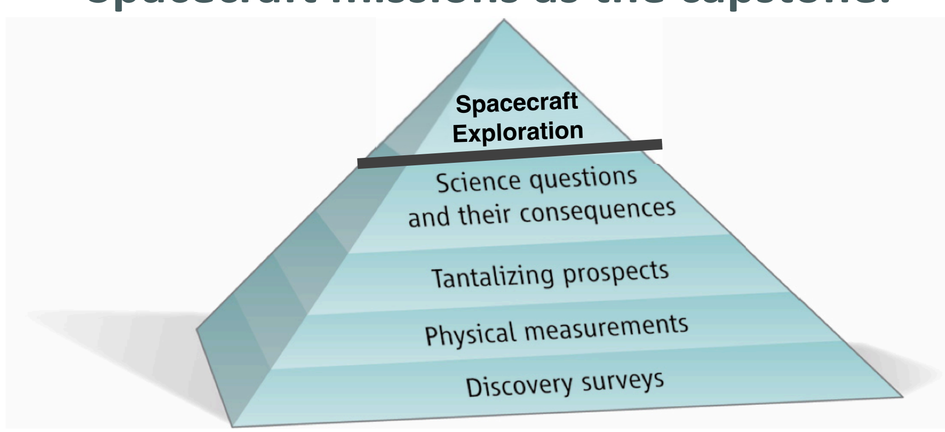
6



7

Pyramid of Planetary Exploration:

Basic research as the foundation.
Spacecraft missions as the capstone.



Richard P. Binzel
SCIENCE VOL 338 12 OCTOBER 2012
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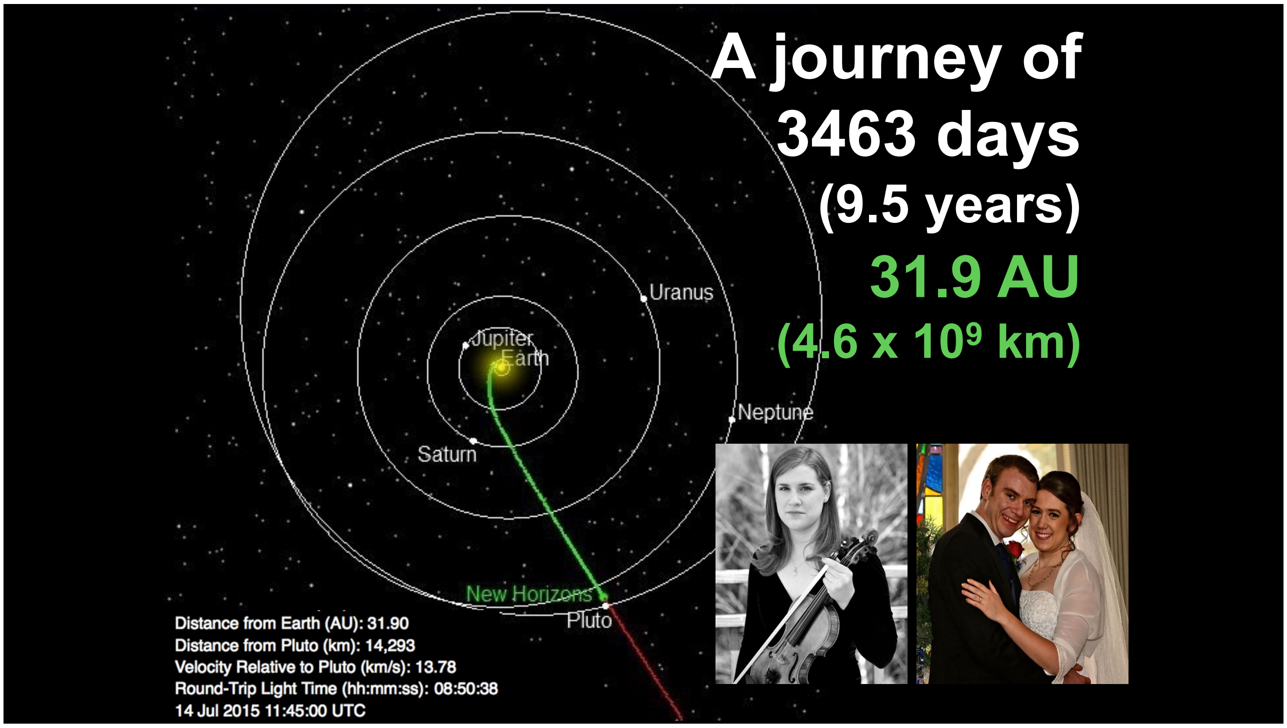
8


1978 – 2006:
Journey to the
launch pad

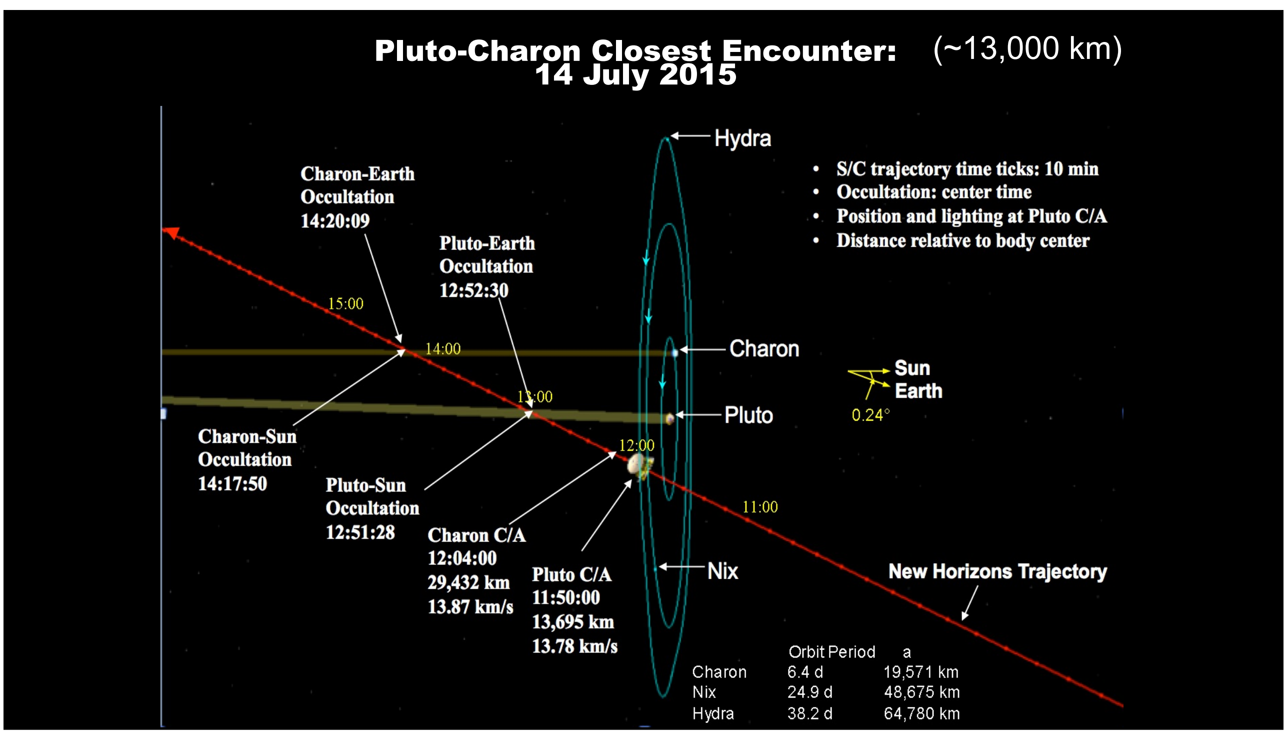
9


January 19, 2006   14:00:00 EST

10

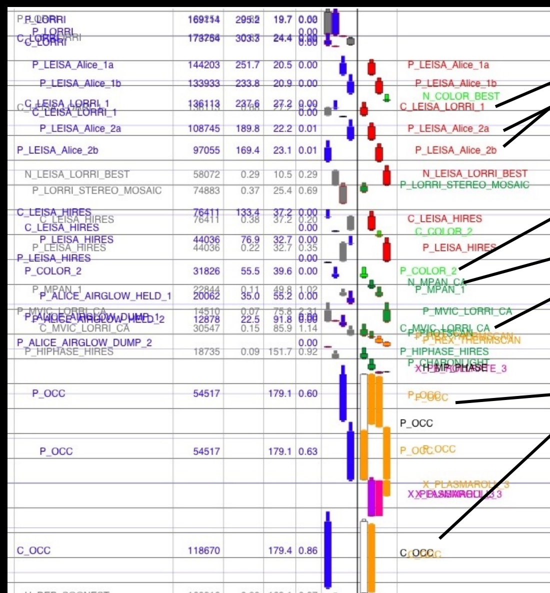

A journey of
3463 days
(9.5 years)
31.9 AU
(4.6 x 10⁹ km)
Uranus
Jupiter
Earth
Neptune
Saturn
New Horizons
Pluto
Distance from Earth (AU): 31.90
Distance from Pluto (km): 14,293
Velocity Relative to Pluto (km/s): 13.78
Round-Trip Light Time (hh:mm:ss): 08:50:38
14 Jul 2015 11:45:00 UTC

11


Pluto-Charon Closest Encounter: 14 July 2015
(~13,000 km)
Hydra
S/C trajectory time ticks: 10 min
Occultation: center time
Position and lighting at Pluto C/A
Distance relative to body center
Charon-Earth Occultation 14:20:09
Pluto-Earth Occultation 12:52:30
15:00
14:00
13:00
12:00
11:00
Charon
Pluto
Sun
Earth
0.24°
Charon-Sun Occultation 14:17:50
Pluto-Sun Occultation 12:51:28
Charon C/A 12:04:00 29,432 km 13.87 km/s
Pluto C/A 11:50:00 13,695 km 13.78 km/s
Nix
New Horizons Trajectory
Orbit Period a
Charon 6.4 d 19,571 km
Nix 24.9 d 48,675 km
Hydra 38.2 d 64,780 km

12

Timeline near Closest Approach



Pluto global pan maps at 0.9 km/pix
Charon global pan maps at 0.9 km/pix
Pluto global IR at 9 km/pix
Nix global color maps at 2 km/pix
Charon global IR at 9 km/pix (+ pan at 0.6 km/pix)
Pluto global IR at 6 km/pix
Nix IR at 4 km/pix & pan at 0.3 km/pix
Pluto pan images at 0.4 km/pix
Charon IR at 5 km/pix (+ pan at 0.4 km/pix)
Charon global color at 1.4 km/pix
Pluto IR at 3 km/pix
Pluto global color at 0.7 km/pix
Nix pan at 0.5 km/pix
Pluto global pan at 0.5 km/pix, strip at 0.12 km/pix
Pluto pan at 0.3 km/pix, strip at 0.08 km/pix
Charon global pan at 0.6 km/pix, strip at 0.16 km/pix
Pluto (smeared) at 110 deg phase
Pluto radiometry at 230 km/pix
Pluto at 0.34 km/pix, 146 deg phase
Pluto in reflected Charonlight, 0.44 km/pix
Pluto solar and earth occultation
Plasma roll
Charon solar and earth occultation

- Timeline addresses all group 1 (required) and 2 (strongly desired) goals, and all but one group 3 (desired) goal.
- All group 1, and most of group 2 and 3 are addressed redundantly
- P-7 days to P+2 days has already been sequenced and reviewed by the science team, with the final delivery due in November.

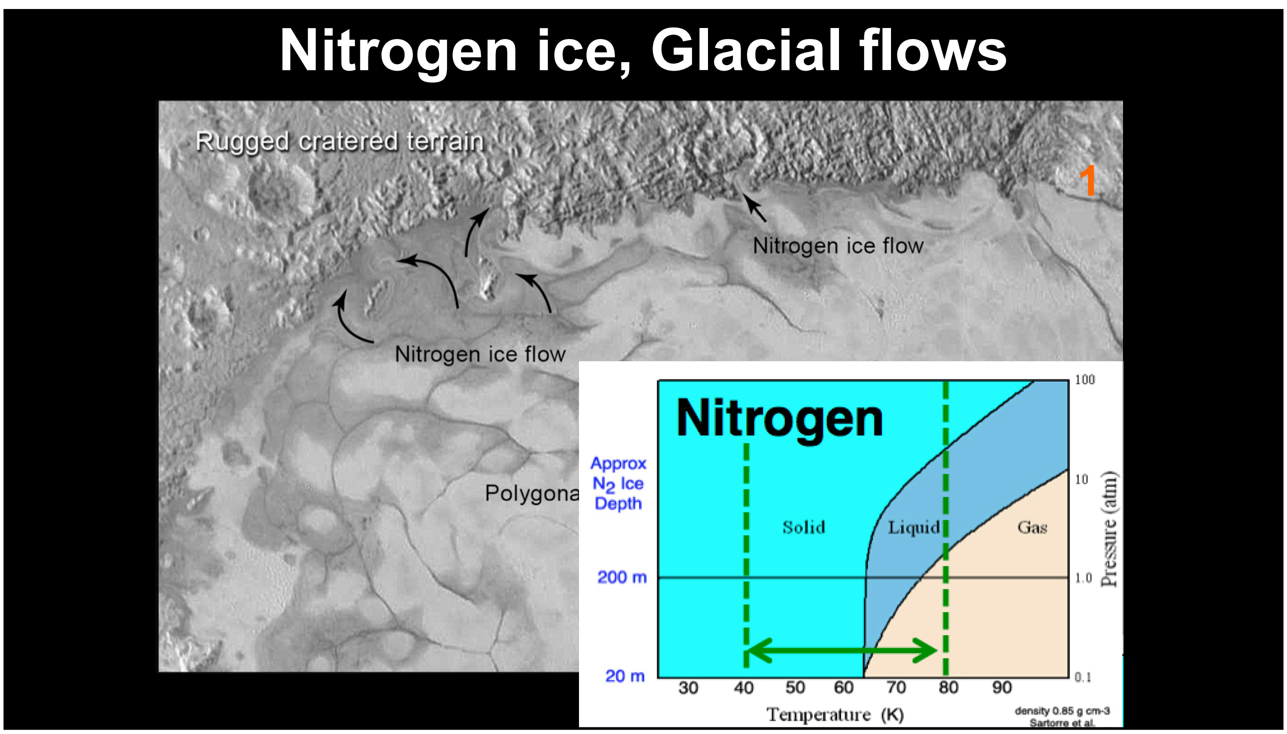
13

After 9.5 years of flight, with a spacecraft that must work autonomously, and 4.5 hours of light-travel to wait, there was only one thing we could do . . .

14


WE
DID IT !

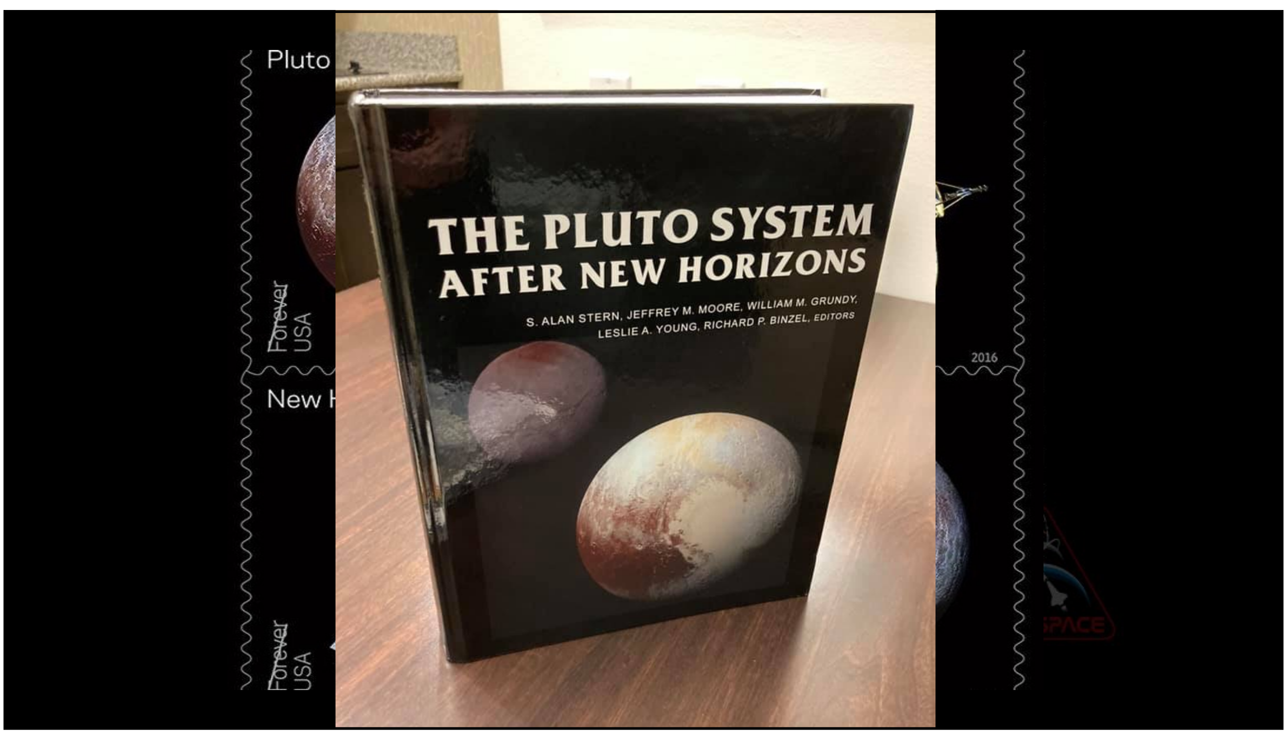
15


Nitrogen ice, Glacial flows
Rugged cratered terrain
1
Nitrogen ice flow
Nitrogen ice flow
Polygona
Nitrogen
Approx
N2 Ice
Depth
200 m
20 m
Solid
Liquid
Gas
30
40
50
60
70
80
90
Temperature (K)
100
10
1.0
0.1
Pressure (atm)
density 0.85 g cm-3
Sartorre et al.

16

Farewell to Pluto

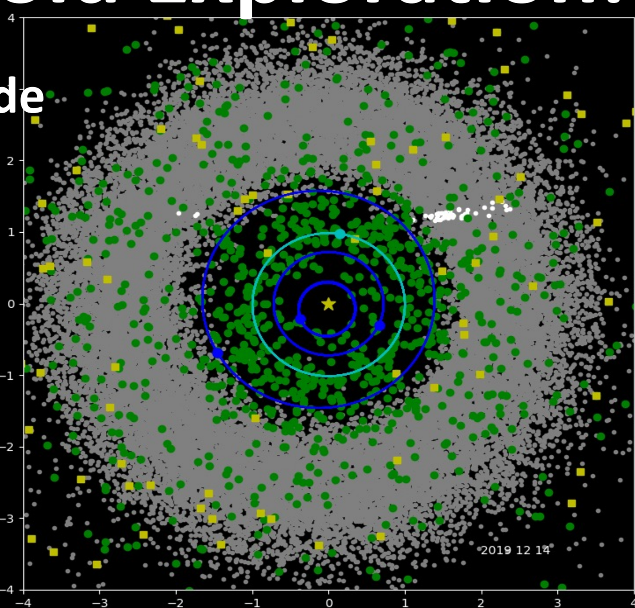
17



18

Asteroid Exploration:

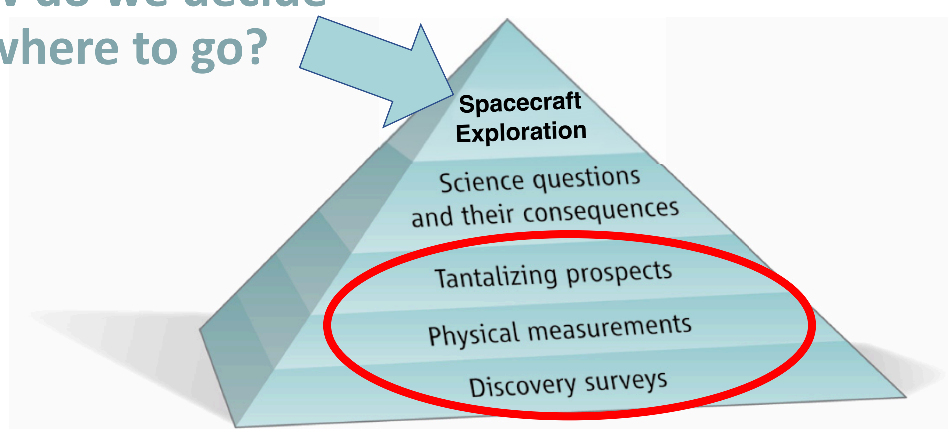
How do we decide where to go?



19

Asteroid Exploration:

How do we decide where to go?



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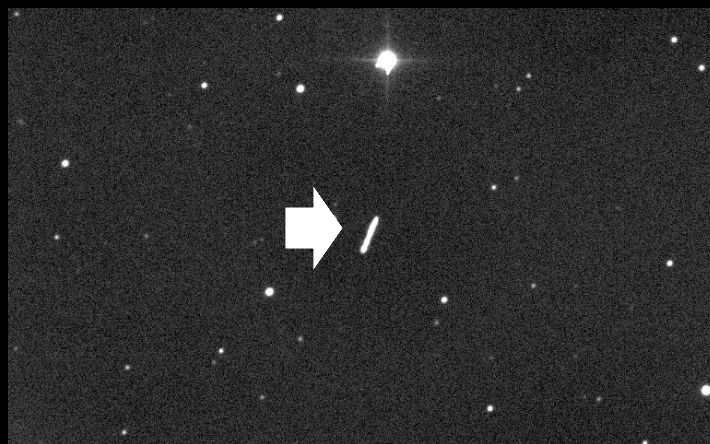
20

Our Challenge:

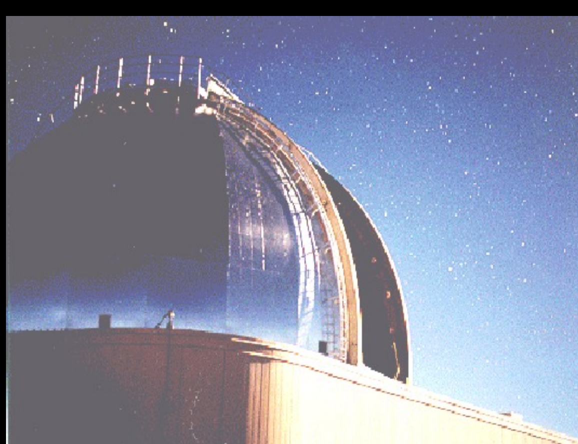
- How do we know what asteroids are?



21

How do we know what asteroids are?

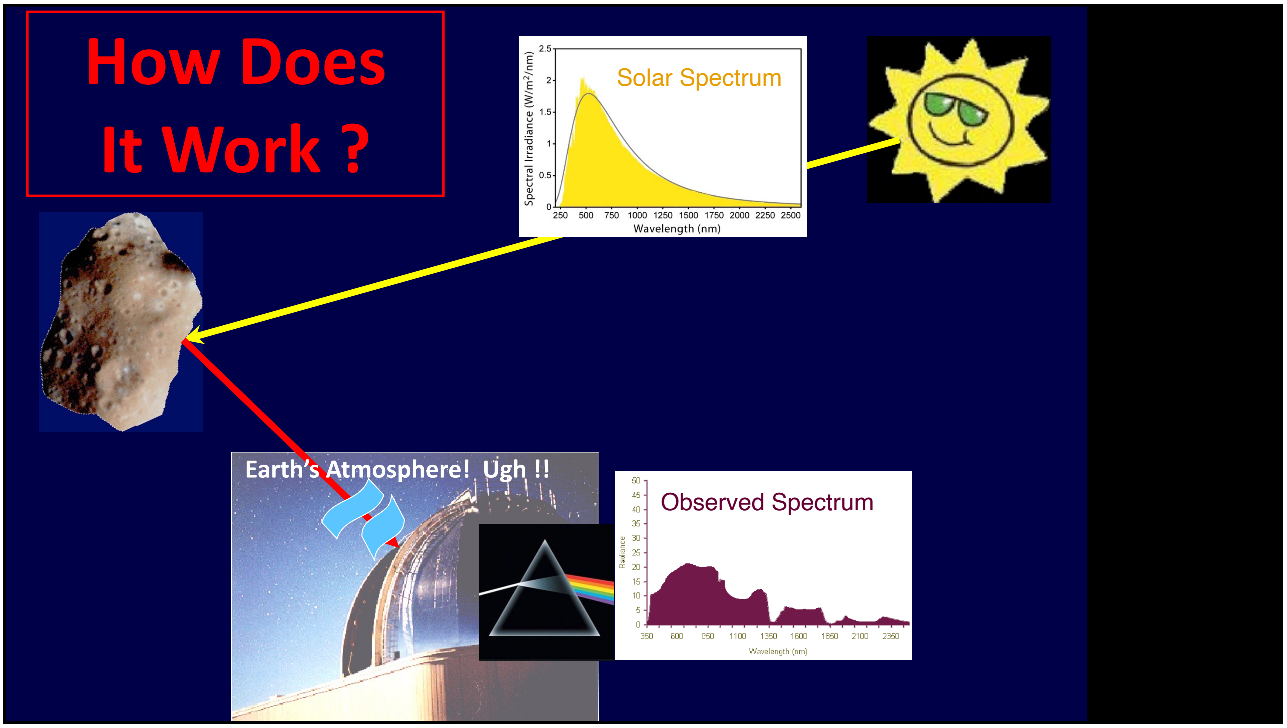
Large Telescopes; Spectroscopic Analysis



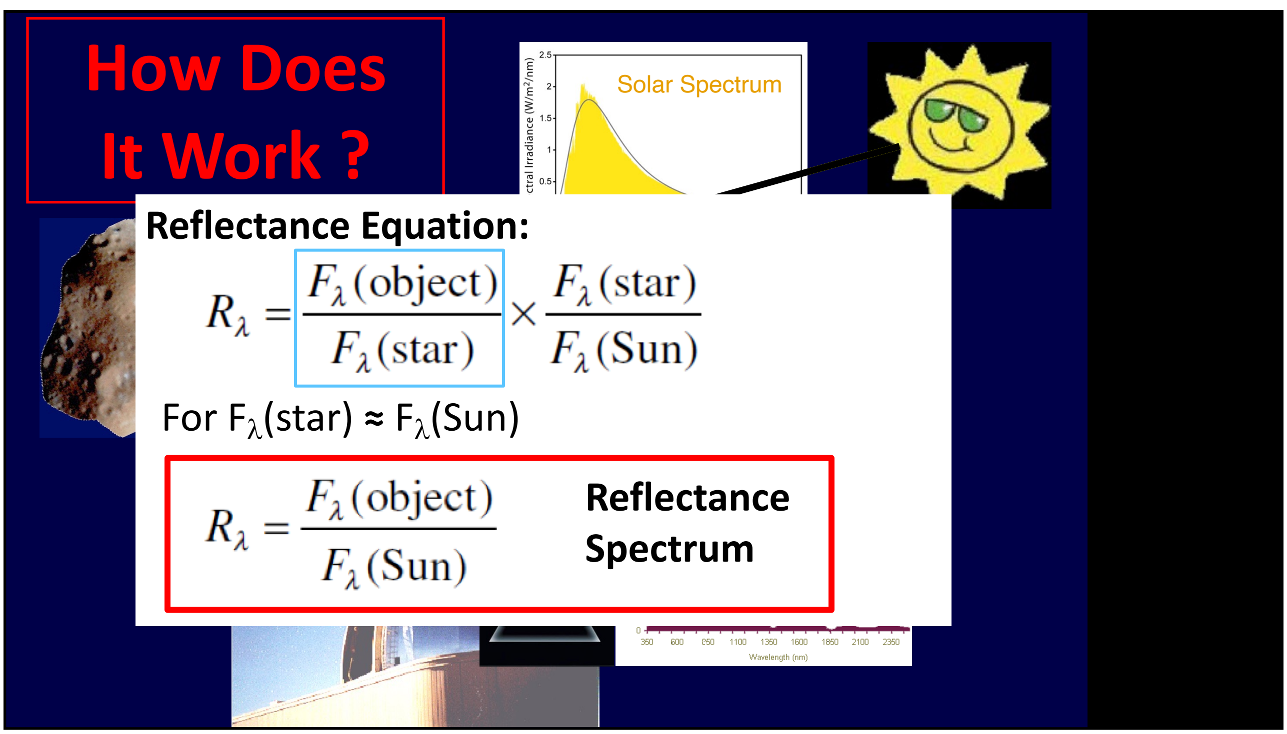
IRTF 3.0m
Mauna Kea, Hawaii

Meudon
Binzel, Birlan et al. 2004

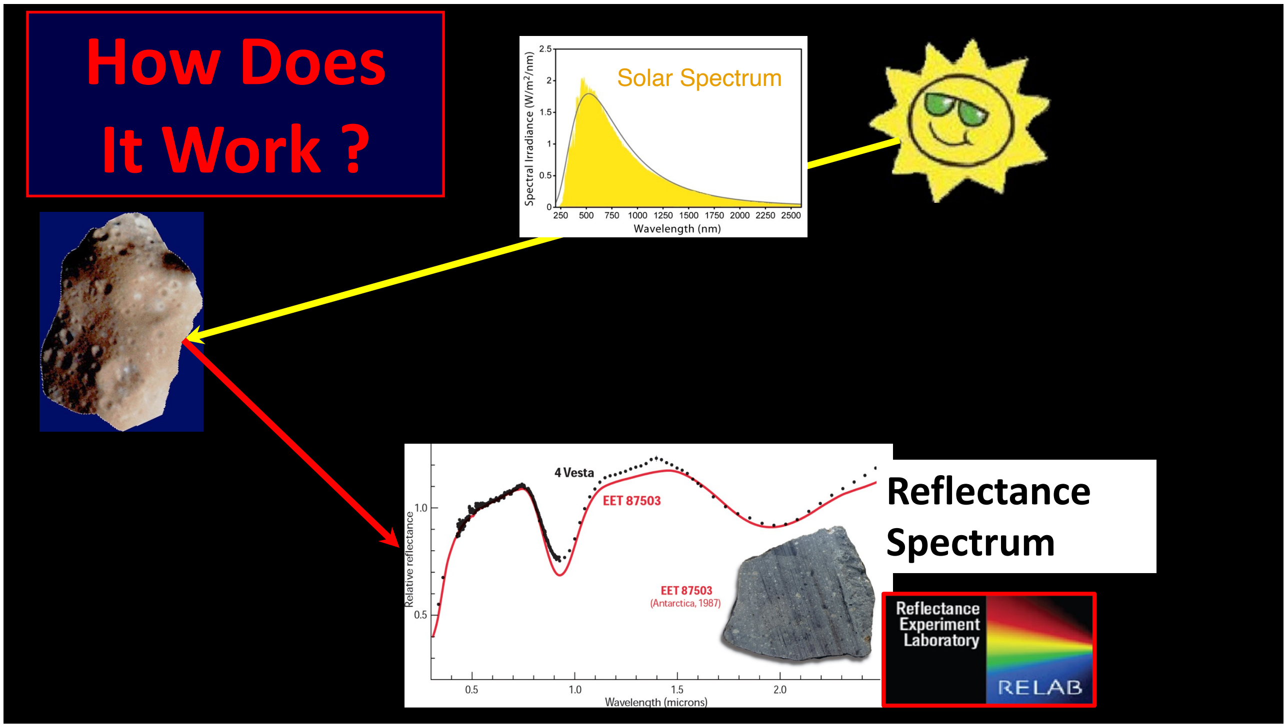
22


How Does
It Work ?
Solar Spectrum
Spectral Irradiance (W/m²/nm)
Wavelength (nm)
Earth's Atmosphere! Ugh !!
Observed Spectrum
Wavelength (nm)

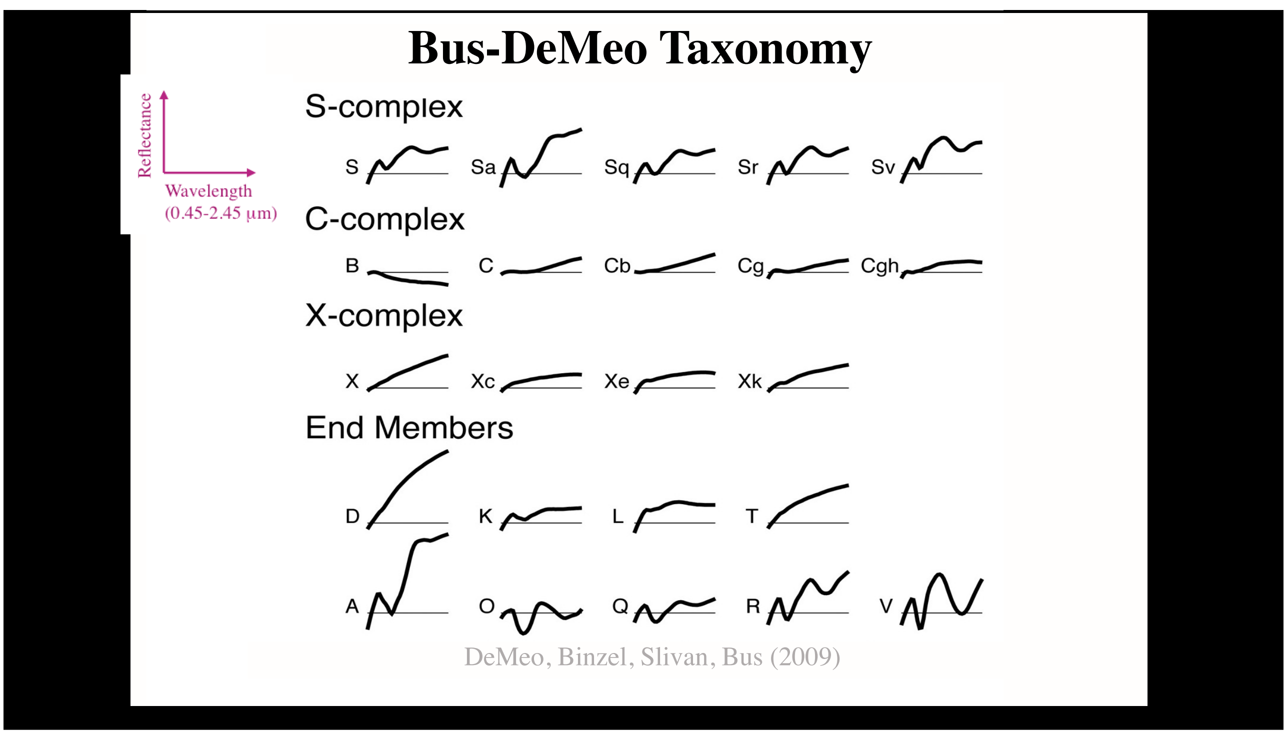
23


How Does
It Work ?
Solar Spectrum
Reflectance Equation:
$$R_\lambda = \frac{F_\lambda(\text{object})}{F_\lambda(\text{star})} \times \frac{F_\lambda(\text{star})}{F_\lambda(\text{Sun})}$$
For $F_\lambda(\text{star}) \approx F_\lambda(\text{Sun})$
$$R_\lambda = \frac{F_\lambda(\text{object})}{F_\lambda(\text{Sun})}$$
Reflectance
Spectrum

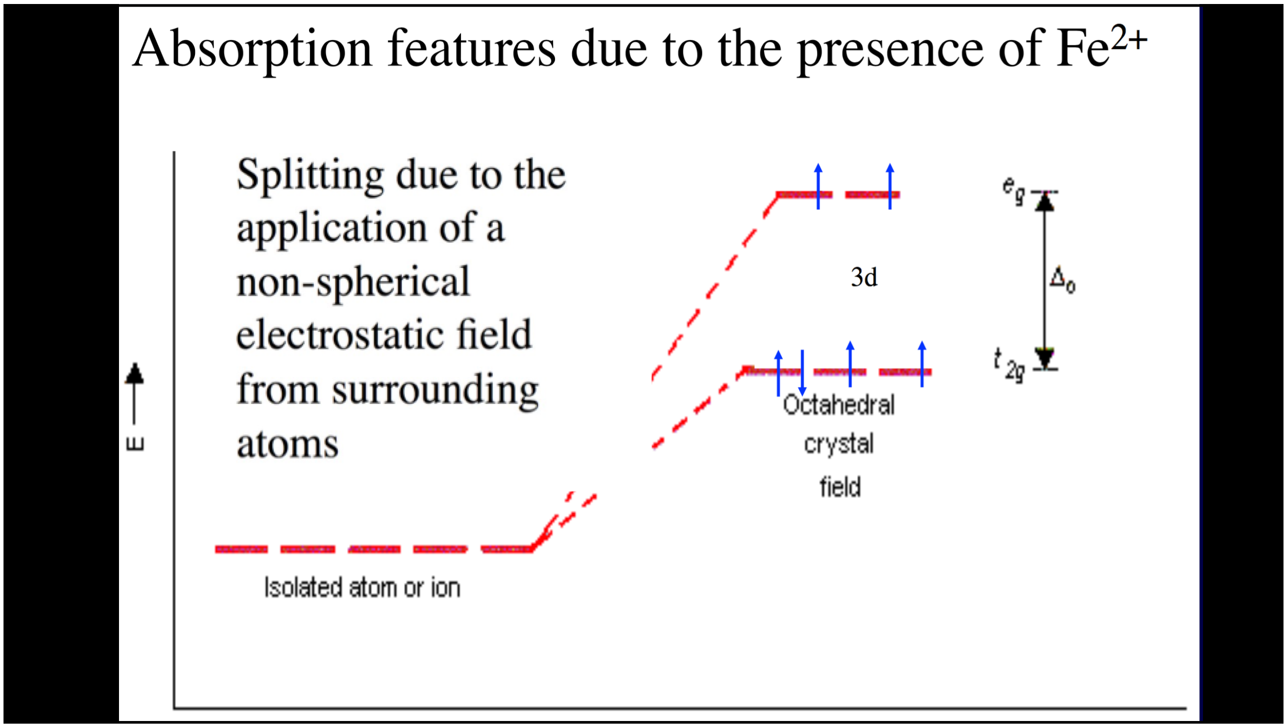
24


How Does It Work ?
Solar Spectrum
Spectral Irradiance (W/m²/nm)
Wavelength (nm)
4 Vesta
EET 87503
EET 87503
(Antarctica, 1987)
Relative reflectance
Wavelength (microns)
Reflectance Spectrum
Reflectance Experiment Laboratory
RELAB

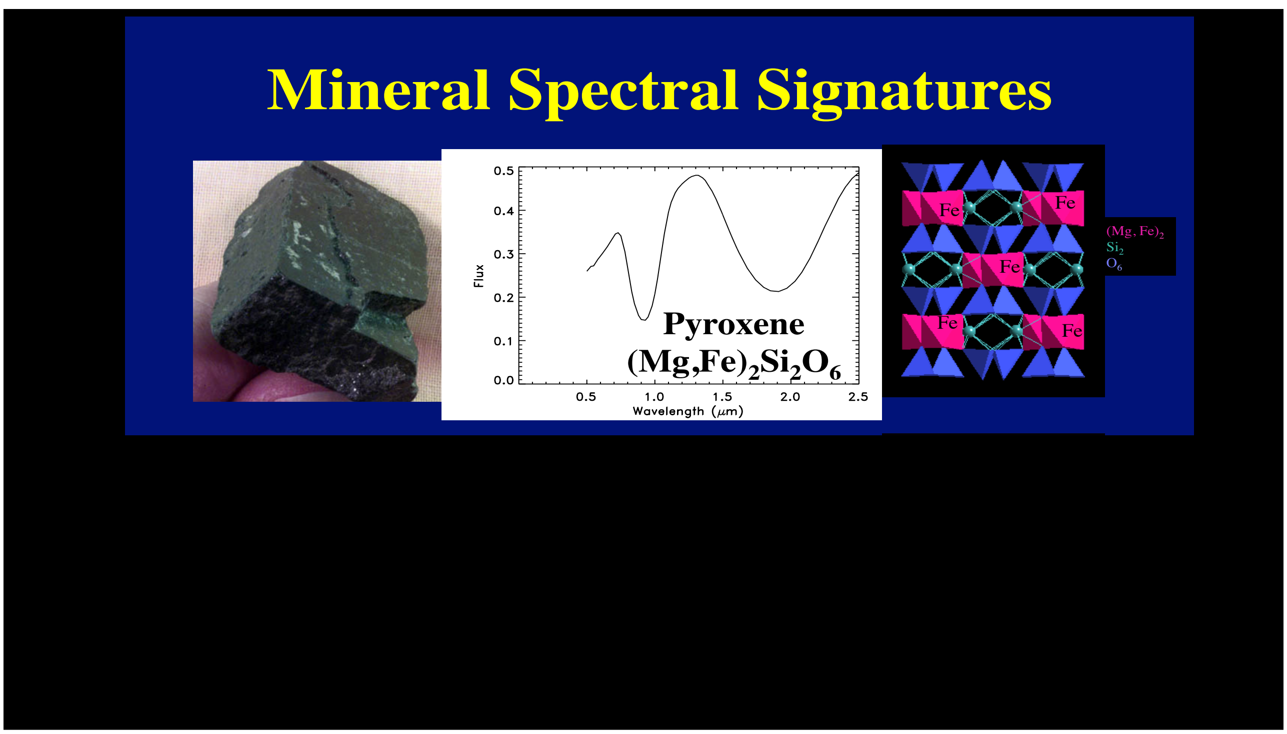
25


Bus-DeMeo Taxonomy
Reflectance
Wavelength
(0.45-2.45 µm)
S-complex
S Sa Sq Sr Sv
C-complex
B C Cb Cg Cgh
X-complex
X Xc Xe Xk
End Members
D K L T
A O Q R V
DeMeo, Binzel, Slivan, Bus (2009)

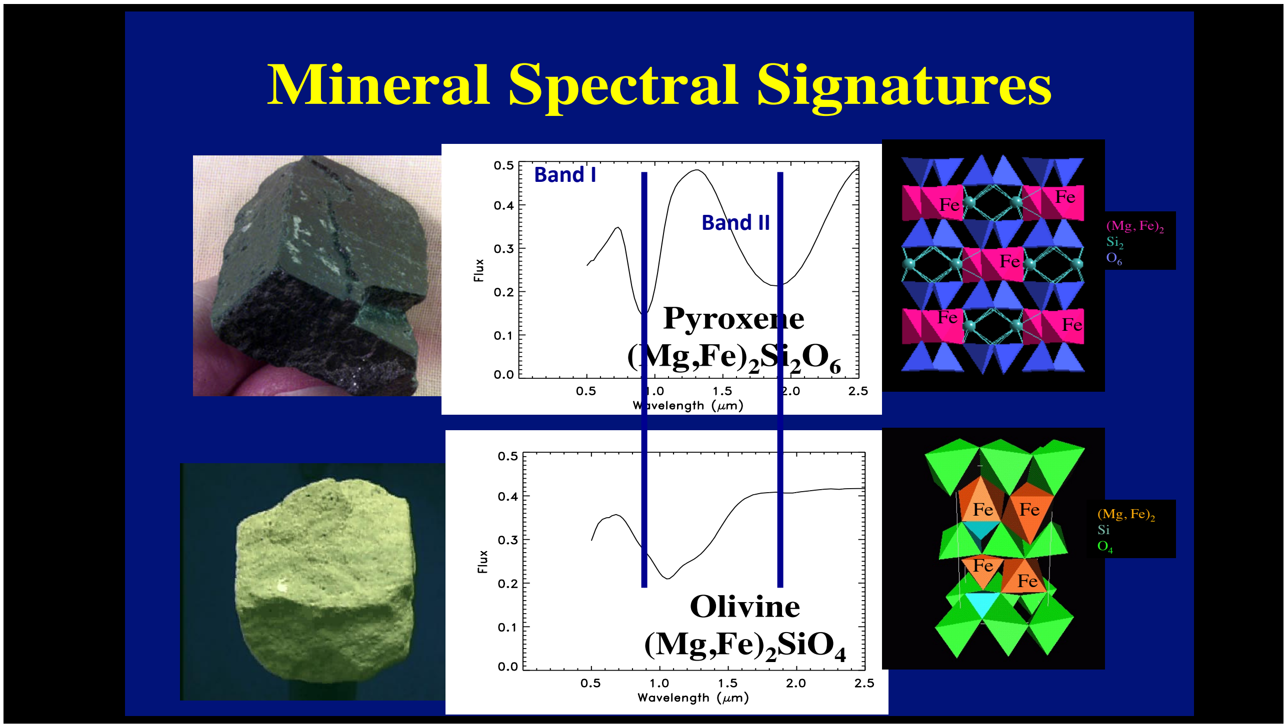
26


Absorption features due to the presence of Fe2+
Splitting due to the application of a non-spherical electrostatic field from surrounding atoms
E
Isolated atom or ion
3d
Octahedral crystal field
eg
Δo
t2g

27


Mineral Spectral Signatures
Pyroxene
(Mg,Fe)2Si2O6
Flux
0.0
0.1
0.2
0.3
0.4
0.5
0.5
1.0
1.5
2.0
2.5
Wavelength (μm)
Fe
Fe
Fe
Fe
Fe
(Mg, Fe)2
Si2
O6

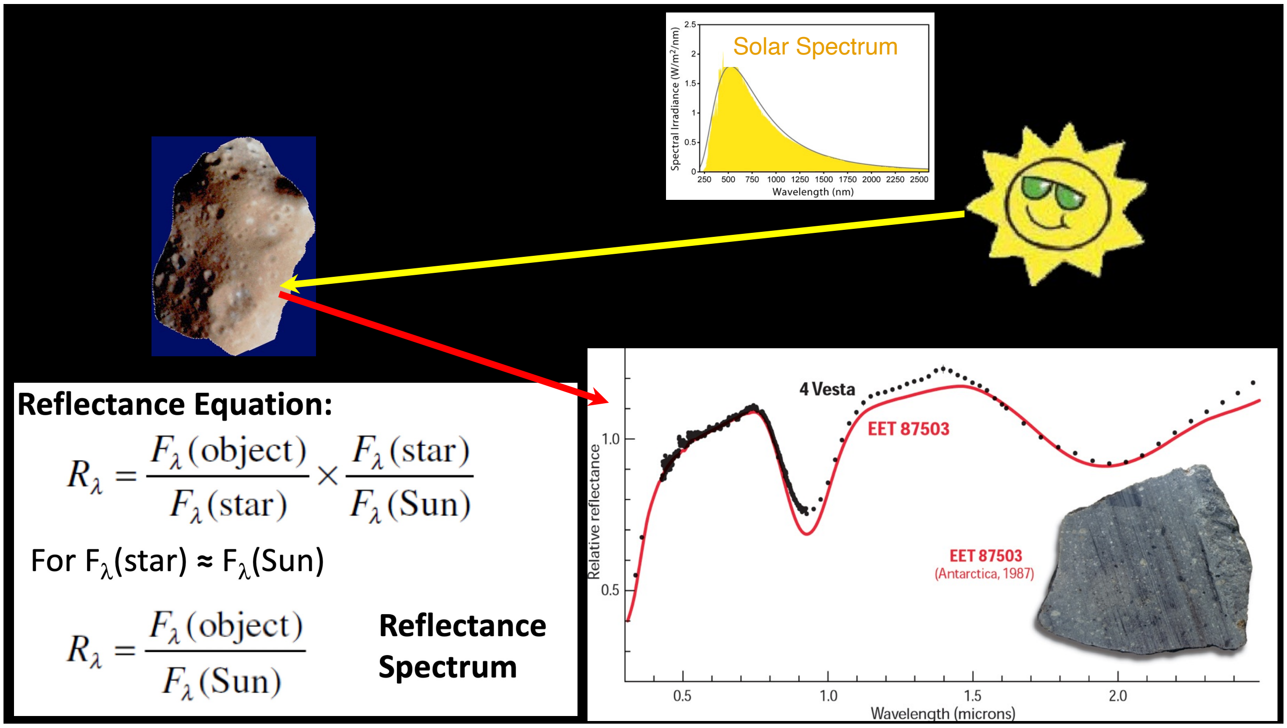
28



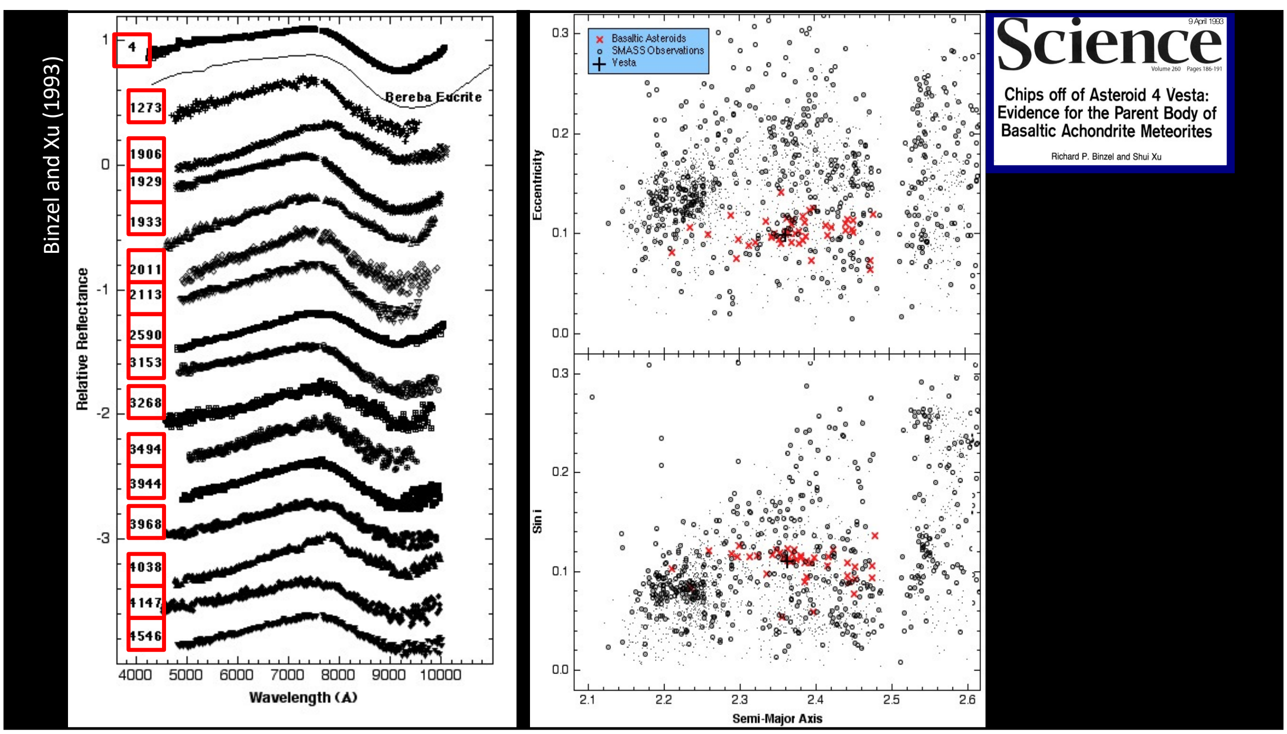
29

Does It Work ?

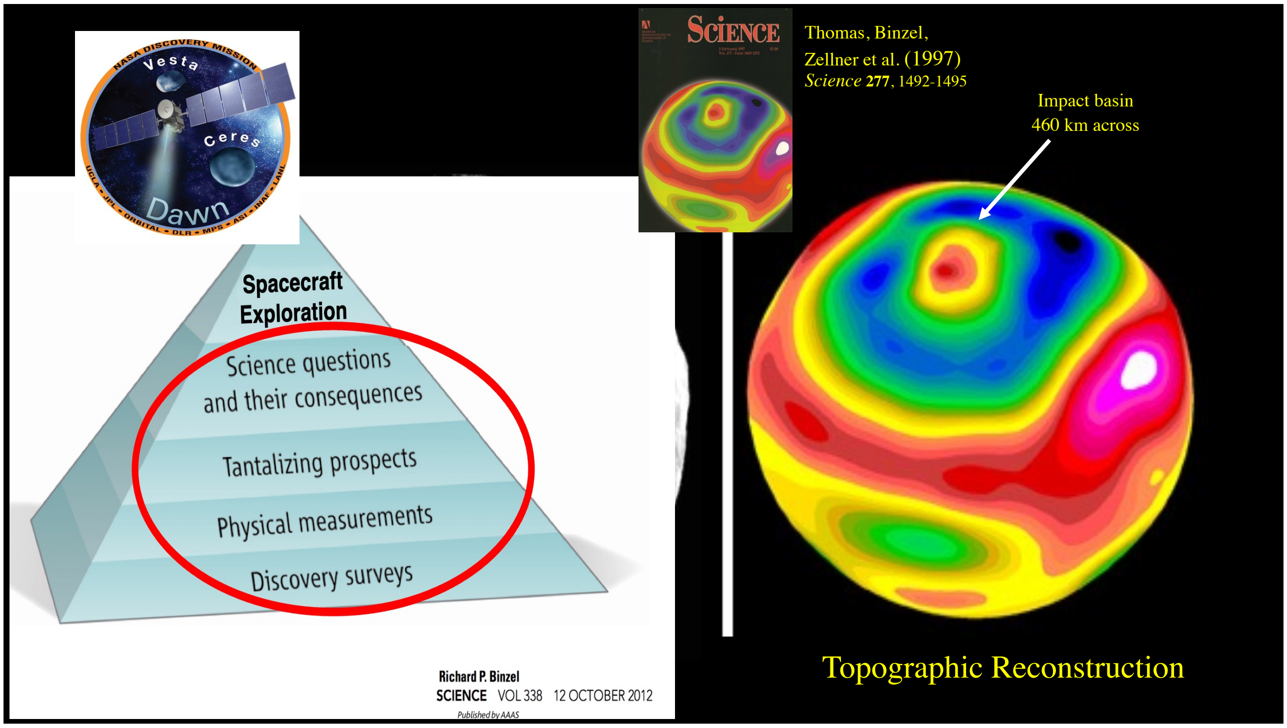
30


Solar Spectrum
Spectral Irradiance (W/m²/nm)
Wavelength (nm)
Reflectance Equation:
$$R_\lambda = \frac{F_\lambda(\text{object})}{F_\lambda(\text{star})} \times \frac{F_\lambda(\text{star})}{F_\lambda(\text{Sun})}$$
For $F_\lambda(\text{star}) \approx F_\lambda(\text{Sun})$
$$R_\lambda = \frac{F_\lambda(\text{object})}{F_\lambda(\text{Sun})}$$
Reflectance Spectrum
4 Vesta
EET 87503
EET 87503
(Antarctica, 1987)
Relative reflectance
Wavelength (microns)

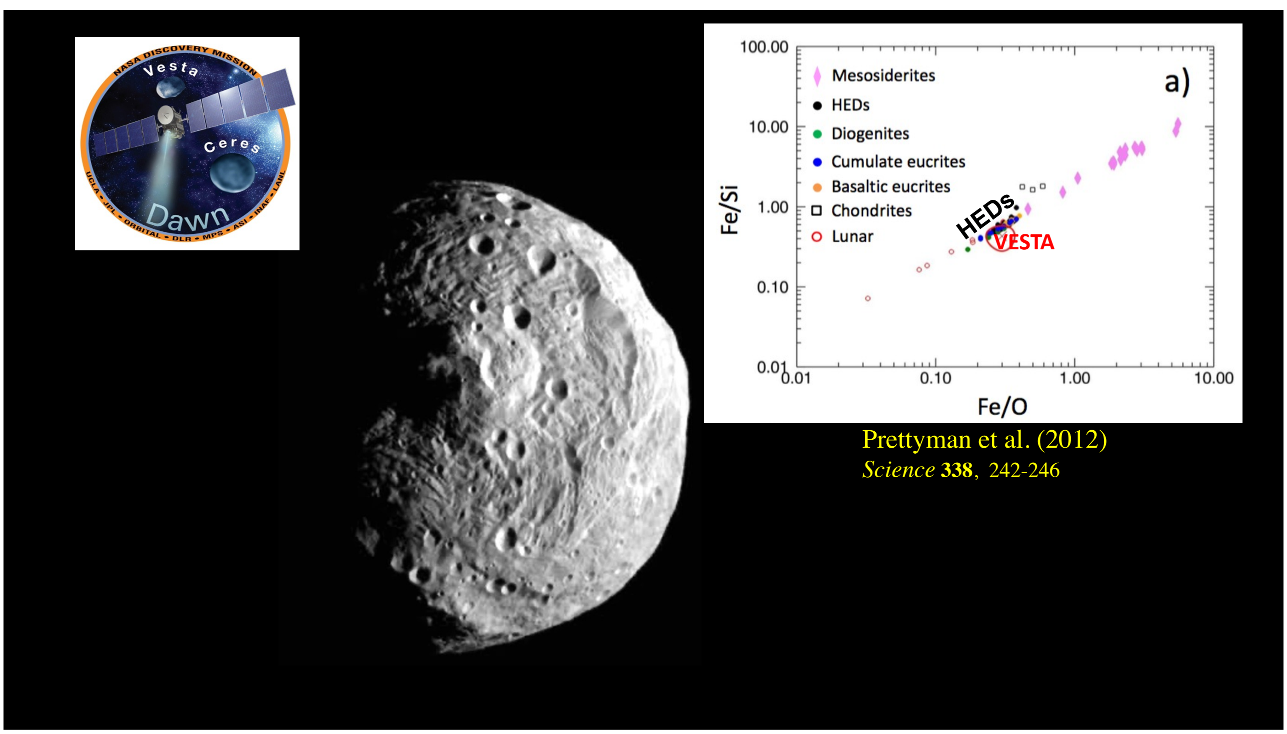
31


Binzel and Xu (1993)
Relative Reflectance
Bereba Eucrite
4
1273
1906
1929
1933
2011
2113
2590
3153
3268
3494
3944
3968
4038
4147
4546
Wavelength (Å)
Basaltic Asteroids
SMASS Observations
Vesta
Eccentricity
Sin i
Semi-Major Axis
Science
9 April 1993
Chips off of Asteroid 4 Vesta: Evidence for the Parent Body of Basaltic Achondrite Meteorites
Richard P. Binzel and Shui Xu

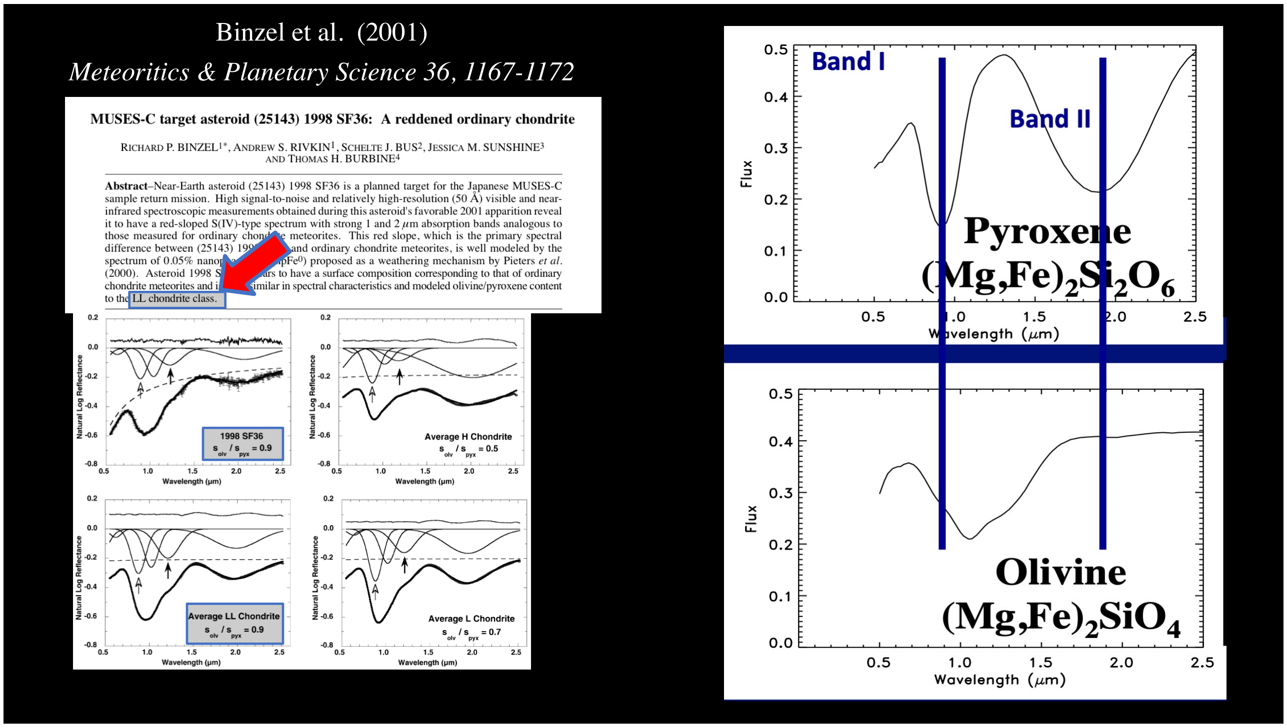
32


NASA DISCOVERY MISSION
Vesta
Ceres
Dawn
Spacecraft Exploration
Science questions and their consequences
Tantalizing prospects
Physical measurements
Discovery surveys
Richard P. Binzel
SCIENCE VOL 338 12 OCTOBER 2012
Published by AAAS
SCIENCE
Thomas, Binzel, Zellner et al. (1997)
Science **277**, 1492-1495
Impact basin
460 km across
Topographic Reconstruction

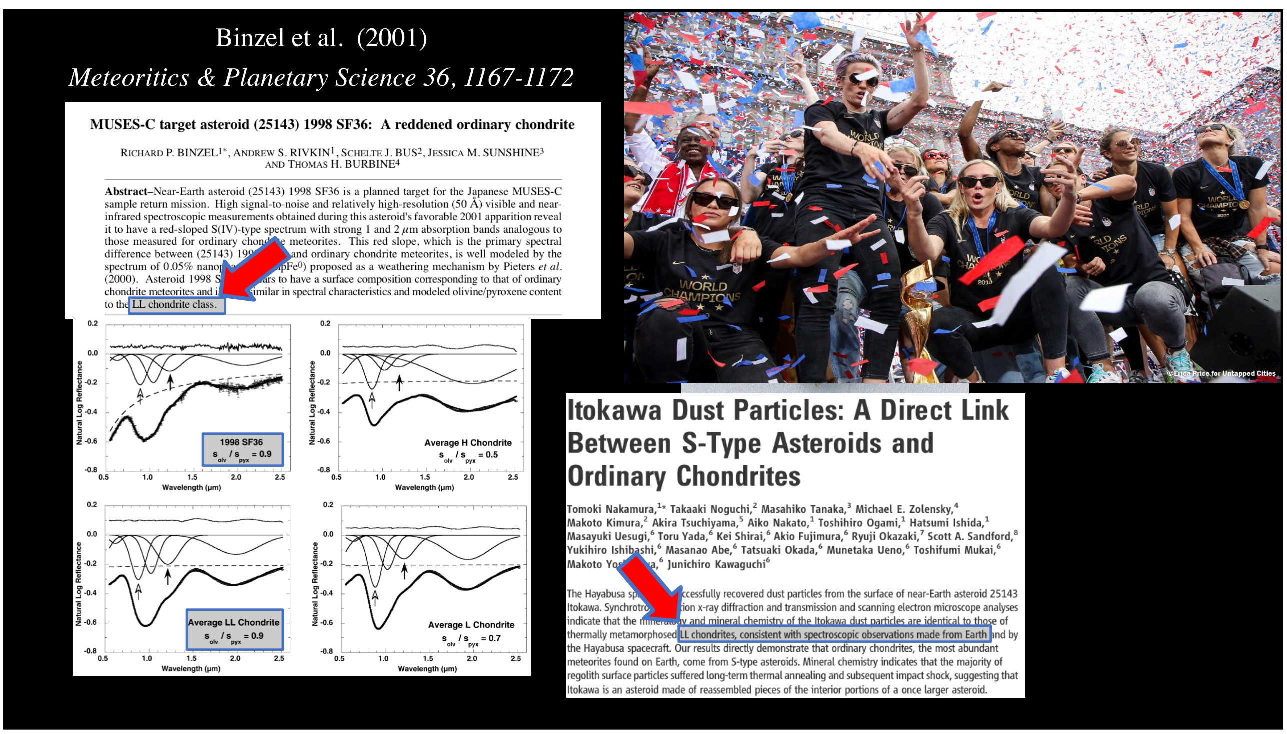
33


NASA DISCOVERY MISSION
Vesta
Ceres
Dawn
100.00
10.00
1.00
0.10
0.01
Fe/Si
0.01
0.10
1.00
10.00
Fe/O
Mesosiderites
HEDs
Diogenites
Cumulate eucrites
Basaltic eucrites
Chondrites
Lunar
a)
HEDs
VESTA
Prettyman et al. (2012)
Science **338**, 242-246

34


Binzel et al. (2001)
Meteoritics & Planetary Science 36, 1167-1172
MUSES-C target asteroid (25143) 1998 SF36: A reddened ordinary chondrite
RICHARD P. BINZEL1*, ANDREW S. RIVKIN1, SCHELTE J. BUS2, JESSICA M. SUNSHINE3 AND THOMAS H. BURBINE4
Abstract–Near-Earth asteroid (25143) 1998 SF36 is a planned target for the Japanese MUSES-C sample return mission. High signal-to-noise and relatively high-resolution (50 Å) visible and near-infrared spectroscopic measurements obtained during this asteroid's favorable 2001 apparition reveal it to have a red-sloped S(IV)-type spectrum with strong 1 and 2 μm absorption bands analogous to those measured for ordinary chond e meteorites. This red slope, which is the primary spectral difference between (25143) 199 and ordinary chondrite meteorites, is well modeled by the spectrum of 0.05% nano pFe0) proposed as a weathering mechanism by Pieters et al. (2000). Asteroid 1998 S ars to have a surface composition corresponding to that of ordinary chondrite meteorites and i similar in spectral characteristics and modeled olivine/pyroxene content to the LL chondrite class.
1998 SF36
Average H Chondrite
Average LL Chondrite
Average L Chondrite
Natural Log Reflectance
Wavelength (μm)
Band I
Band II
Flux
Pyroxene
(Mg,Fe)2Si2O6
Olivine
(Mg,Fe)2SiO4
Wavelength (μm)

35


Binzel et al. (2001)
Meteoritics & Planetary Science 36, 1167-1172
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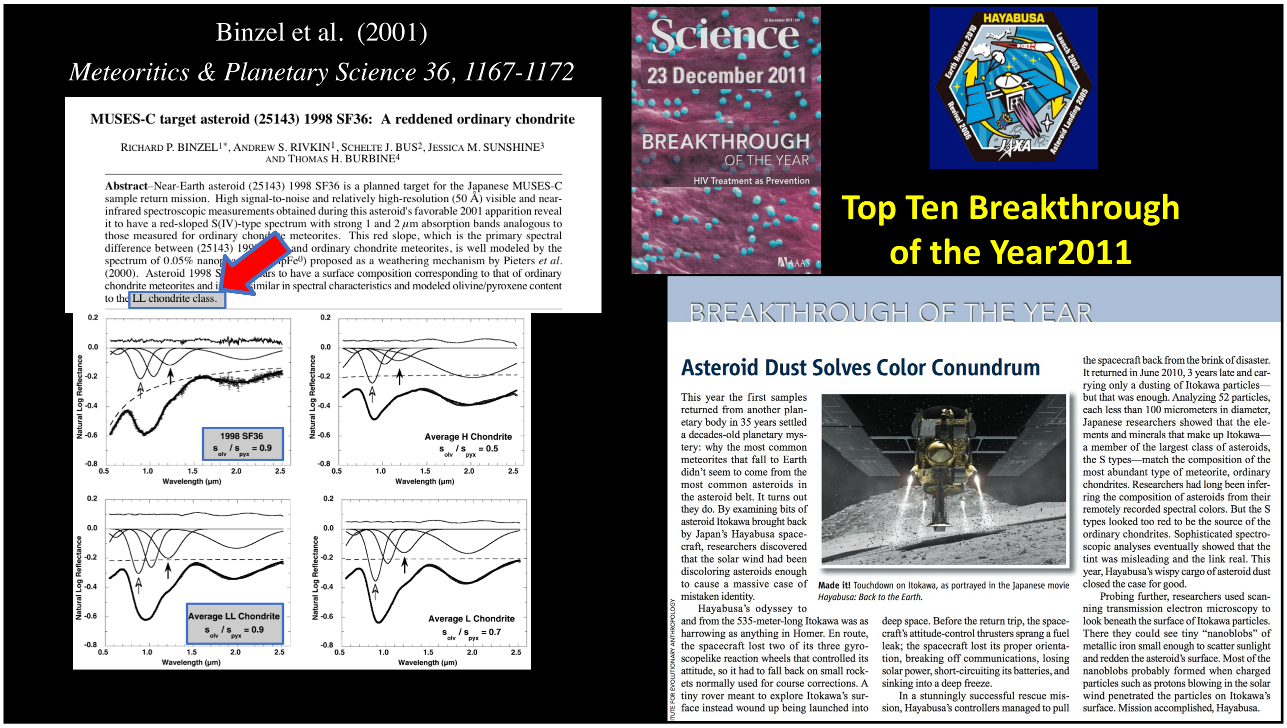
1998 SF36
Average H Chondrite
Average LL Chondrite
Average L Chondrite
Natural Log Reflectance
Wavelength (μm)
WORLD CHAMPIONS
Itokawa Dust Particles: A Direct Link Between S-Type Asteroids and Ordinary Chondrites
Tomoki Nakamura,1* Takaaki Noguchi,2 Masahiko Tanaka,3 Michael E. Zolensky,4 Makoto Kimura,2 Akira Tsuchiyama,5 Aiko Nakato,1 Toshihiro Ogami,1 Hatsumi Ishida,1 Masayuki Uesugi,6 Toru Yada,6 Kei Shirai,6 Akio Fujimura,6 Ryuji Okazaki,7 Scott A. Sandford,8 Yukihiro Ishibashi,6 Masanao Abe,6 Tatsuaki Okada,6 Munetaka Ueno,6 Toshifumi Mukai,6 Makoto Yo a,6 Junichiro Kawaguchi6
The Hayabusa sp ccessfully recovered dust particles from the surface of near-Earth asteroid 25143 Itokawa. Synchrotro tion x-ray diffraction and transmission and scanning electron microscope analyses indicate that the y and mineral chemistry of the Itokawa dust particles are identical to those of thermally metamorphosed LL chondrites, consistent with spectroscopic observations made from Earth and by the Hayabusa spacecraft. Our results directly demonstrate that ordinary chondrites, the most abundant meteorites found on Earth, come from S-type asteroids. Mineral chemistry indicates that the majority of regolith surface particles suffered long-term thermal annealing and subsequent impact shock, suggesting that Itokawa is an asteroid made of reassembled pieces of the interior portions of a once larger asteroid.

36



MUSES-C target asteroid (25143) 1998 SF36: A reddened ordinary chondrite

Richard P. Binzel[1*], Andrew S. Rivkin[1], Schelte J. Bus[2], Jessica M. Sunshine[3] and Thomas H. Burbine[4]

Abstract–Near-Earth asteroid (25143) 1998 SF36 is a planned target for the Japanese MUSES-C sample return mission. High signal-to-noise and relatively high-resolution (50 Å) visible and near-infrared spectroscopic measurements obtained during this asteroid's favorable 2001 apparition reveal it to have a red-sloped S(IV)-type spectrum with strong 1 and 2 µm absorption bands analogous to those measured for ordinary chond[illegible]e meteorites. This red slope, which is the primary spectral difference between (25143) 199[illegible] and ordinary chondrite meteorites, is well modeled by the spectrum of 0.05% nanop[illegible]pFe⁰) proposed as a weathering mechanism by Pieters *et al*. (2000). Asteroid 1998 S[illegible]ars to have a surface composition corresponding to that of ordinary chondrite meteorites and i[illegible]similar in spectral characteristics and modeled olivine/pyroxene content to the LL chondrite class.

BREAKTHROUGH OF THE YEAR

Asteroid Dust Solves Color Conundrum

This year the first samples returned from another planetary body in 35 years settled a decades-old planetary mystery: why the most common meteorites that fall to Earth didn't seem to come from the most common asteroids in the asteroid belt. It turns out they do. By examining bits of asteroid Itokawa brought back by Japan's Hayabusa spacecraft, researchers discovered that the solar wind had been discoloring asteroids enough to cause a massive case of mistaken identity.

Made it! Touchdown on Itokawa, as portrayed in the Japanese movie *Hayabusa: Back to the Earth.*

Hayabusa's odyssey to and from the 535-meter-long Itokawa was as harrowing as anything in Homer. En route, the spacecraft lost two of its three gyroscopelike reaction wheels that controlled its attitude, so it had to fall back on small rockets normally used for course corrections. A tiny rover meant to explore Itokawa's surface instead wound up being launched into deep space. Before the return trip, the spacecraft's attitude-control thrusters sprang a fuel leak; the spacecraft lost its proper orientation, breaking off communications, losing solar power, short-circuiting its batteries, and sinking into a deep freeze.

In a stunningly successful rescue mission, Hayabusa's controllers managed to pull the spacecraft back from the brink of disaster. It returned in June 2010, 3 years late and carrying only a dusting of Itokawa particles—but that was enough. Analyzing 52 particles, each less than 100 micrometers in diameter, Japanese researchers showed that the elements and minerals that make up Itokawa—a member of the largest class of asteroids, the S types—match the composition of the most abundant type of meteorite, ordinary chondrites. Researchers had long been inferring the composition of asteroids from their remotely recorded spectral colors. But the S types looked too red to be the source of the ordinary chondrites. Sophisticated spectroscopic analyses eventually showed that the tint was misleading and the link real. This year, Hayabusa's wispy cargo of asteroid dust closed the case for good.

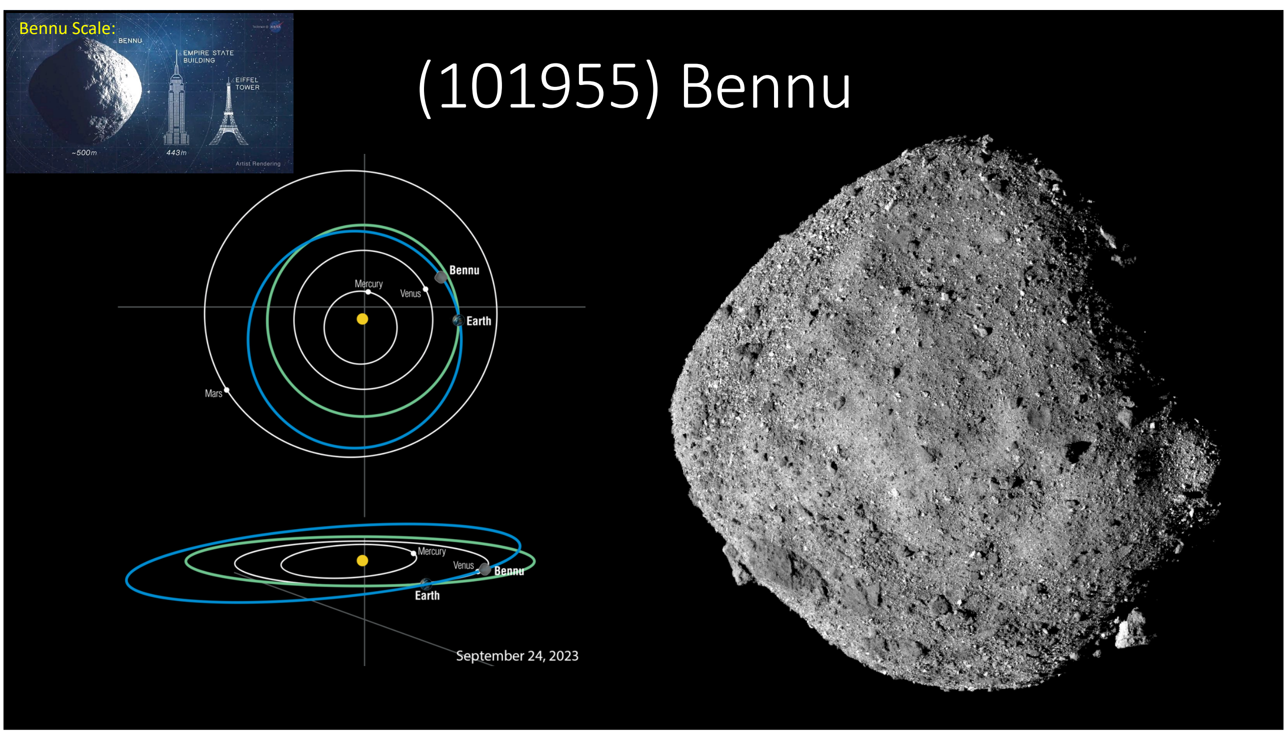
Probing further, researchers used scanning transmission electron microscopy to look beneath the surface of Itokawa particles. There they could see tiny "nanoblobs" of metallic iron small enough to scatter sunlight and redden the asteroid's surface. Most of the nanoblobs probably formed when charged particles such as protons blowing in the solar wind penetrated the particles on Itokawa's surface. Mission accomplished, Hayabusa.

37

38


REXIS
Massachusetts Institute of Technology
Sept. 8, 2016

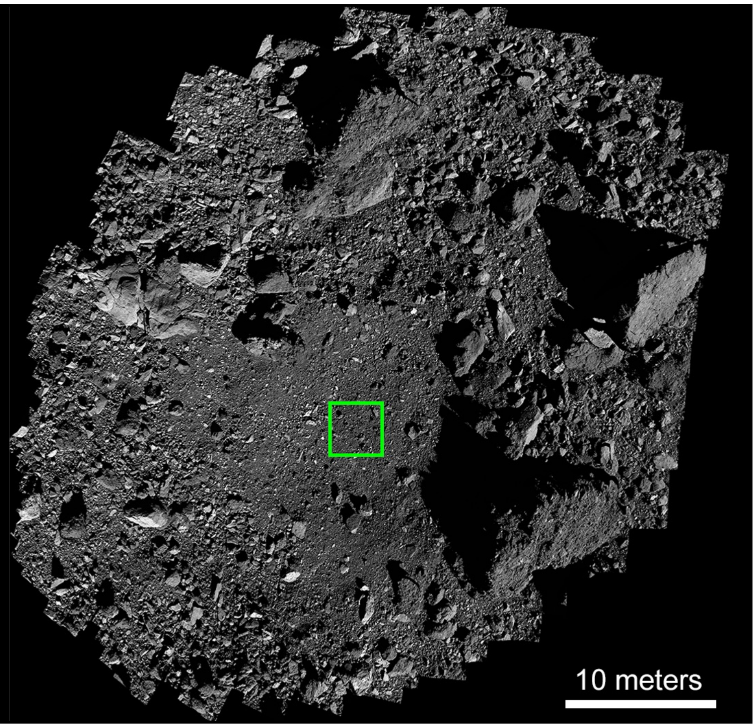
39


Bennu Scale:
BENNU
EMPIRE STATE BUILDING
EIFFEL TOWER
~500m
443m
Artist Rendering
(101955) Bennu
Bennu
Mercury
Venus
Earth
Mars
September 24, 2023

40

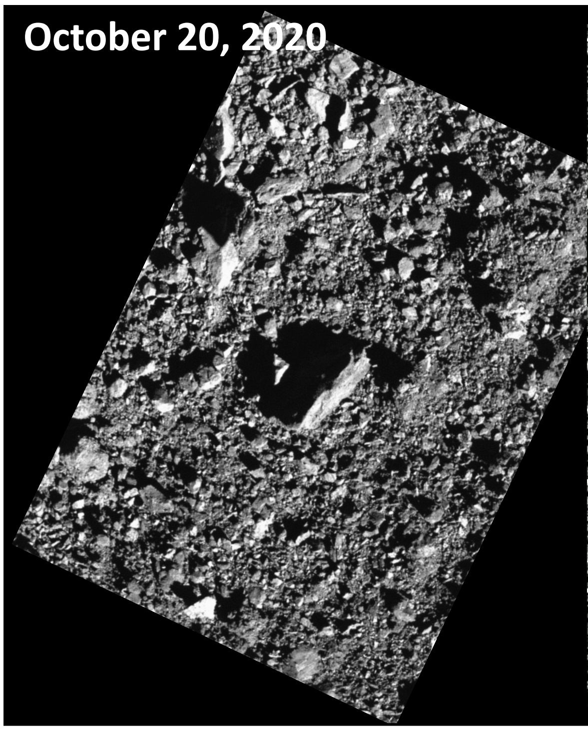
Nightingale Site

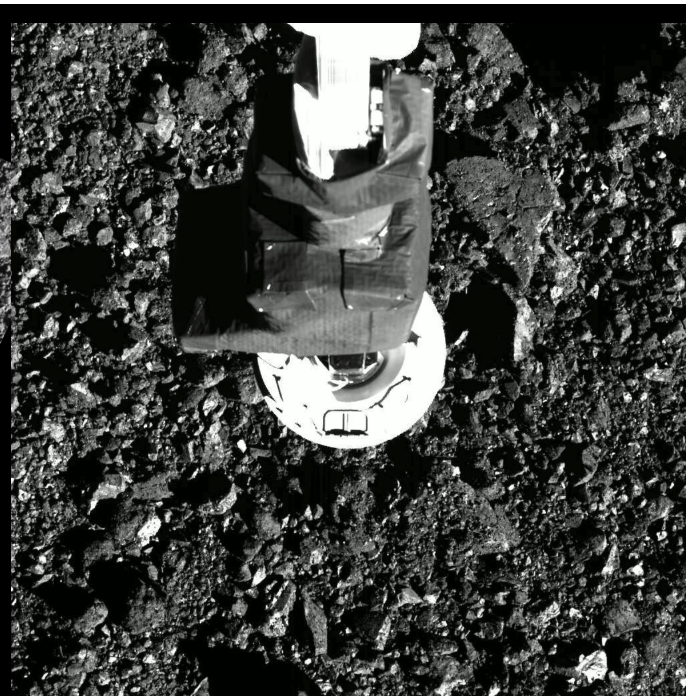
- Within the 20-m-diameter Hokioi crater
  - Spectrally redder in VISNIR than the average surface
  - Among the youngest impact features
  - Mid-latitude (56˚,43˚) location
  - Limited peak T ~360 K (versus ~390 K at equator)
- Selected based on
  - Navigation and safety considerations
  - Expected higher abundance of particles <2 cm in diameter
  - Spectroscopic observations
    - hydrated phyllosilicates
    - iron oxide magnetite
    - organic molecules
    - carbonates



41

October 20, 2020





42

Sample Stowed

- Size range from sub-micron to 3 cm
- Expected Mineralogy and Chemistry:
  - Hydrated phyllosilicates
  - Carbonates
  - Magnetite
  - Sulfides (not spectrally active – but inferred from analog meteorites)

    Organic compounds
- The sample will contain multiple lithologies
  - Similar to type-1 CI and CM chondrites
  - Non-chondritic and igneous in nature, like HED meteorites
  - Some with properties distinct from known meteorites
  - Monomineralic cm-scale carbonates
  - Ejected cm-scale platy particles

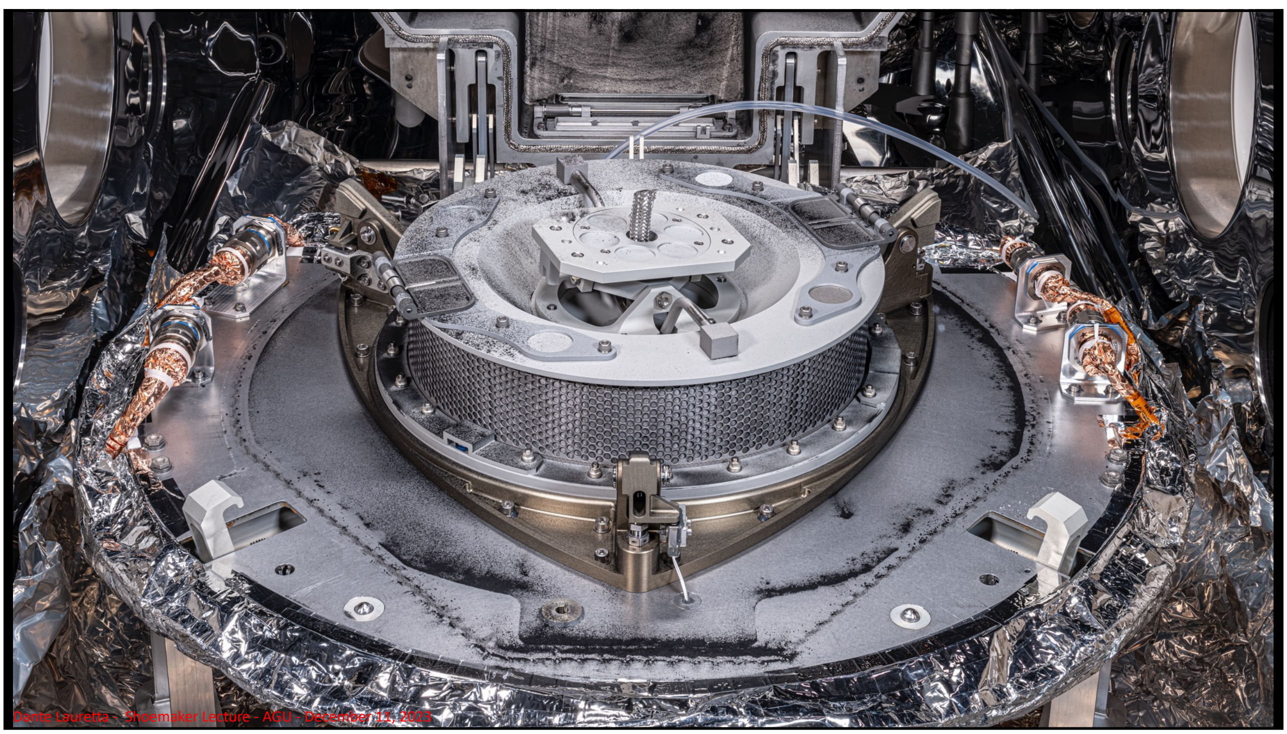
Lauretta et al. 2022 – Science

43

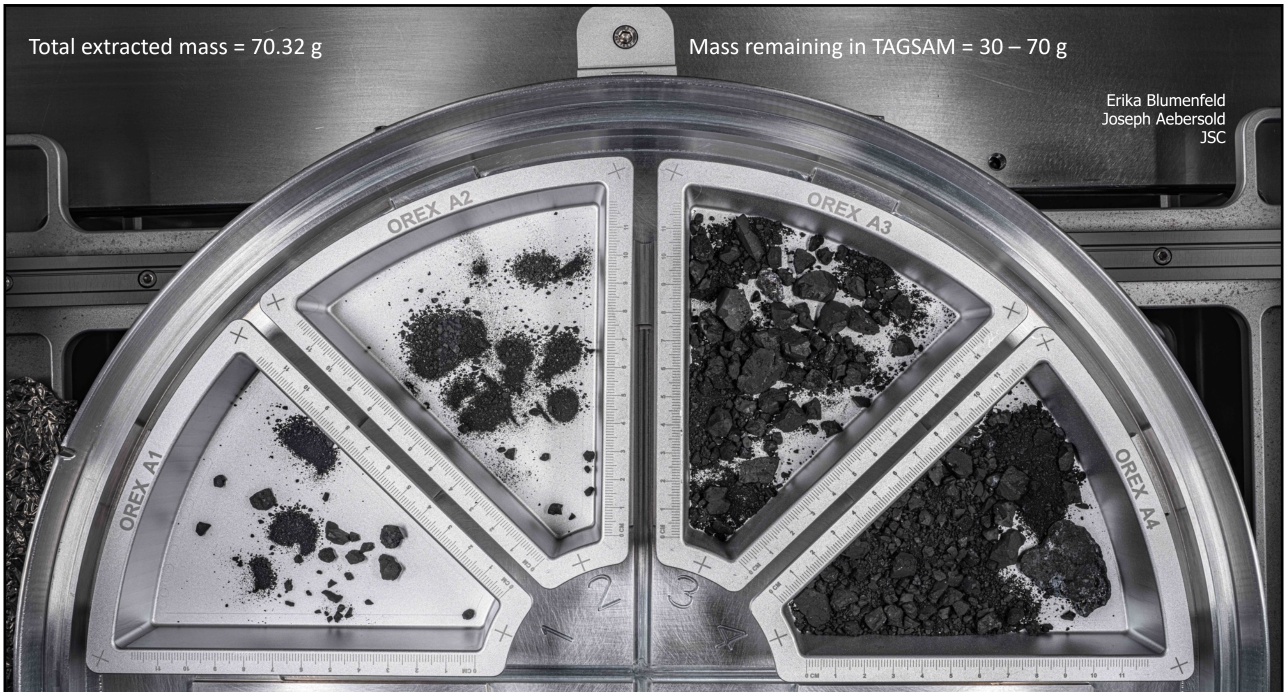
44


Dante Lauretta
OSIRIS-REx P.I.

45


Dante Lauretta - Shoemaker Lecture - AGU - December 11, 2023

46



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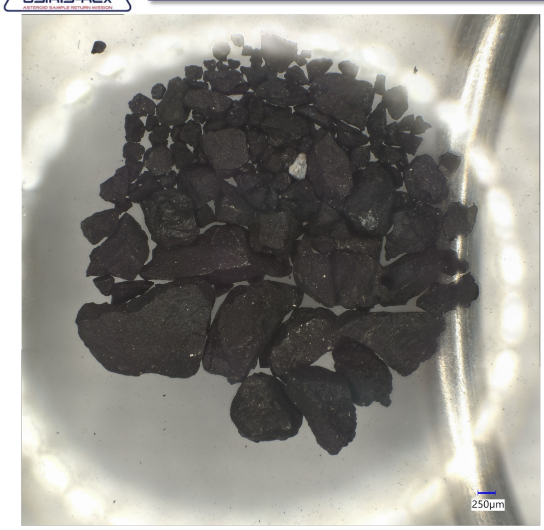
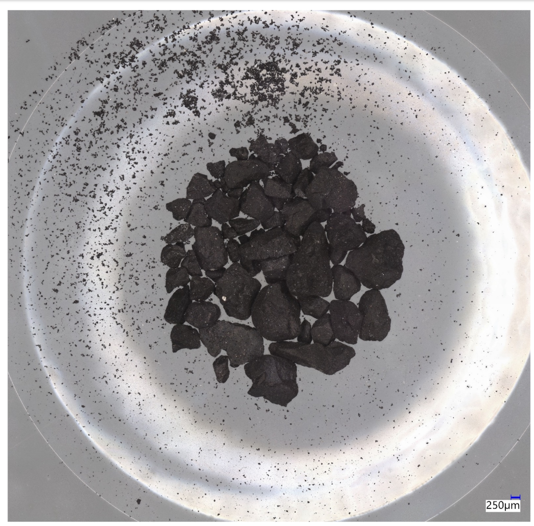
47

Optical Imaging: OREX-500003-0 & OREX-500007-0



OREX-500003-0



OREX-500007-0

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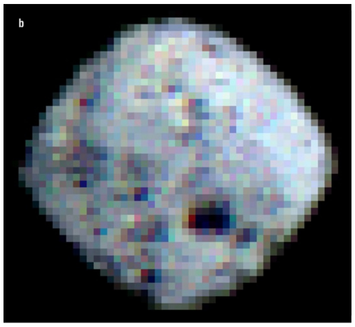
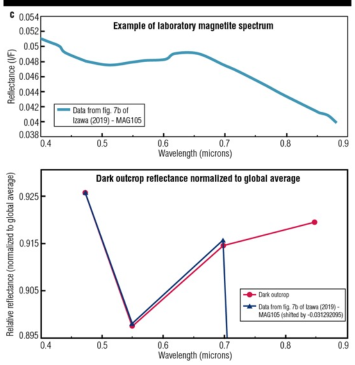
48

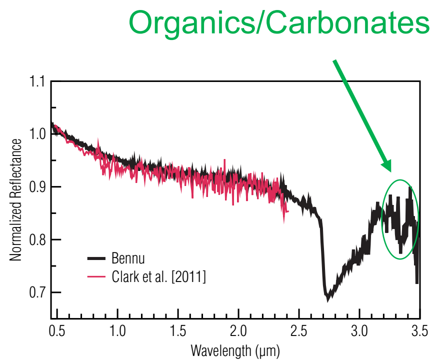
Abundant Hydrated Minerals and Magnetite

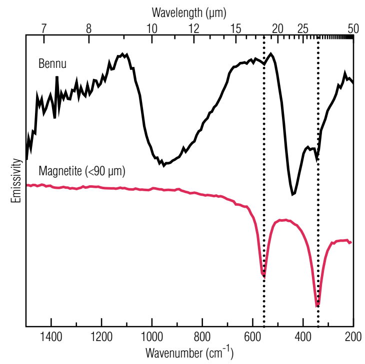


- The VIS-NIR spectrum has a blue (negative) slope, confirming the B-type taxonomy. A 2.7-μm spectral absorption band is present, consistent with the hydrated phyllosilicates
- Thermal emission spectra contain a spectral feature at 23 μm, also consistent with phyllosilicates and CM1 chondrites
- The darkest material show a spectral absorption at 0.55 μm, suggestive of magnetite (Fe_3O_4)
- This interpretation is consistent with OTES spectra, which show features at 18 μm and 29 μm that may be due to magnetite

Lauretta et al. 2019a – Nature; Hamilton et al. 2019 - Nature Astronomy







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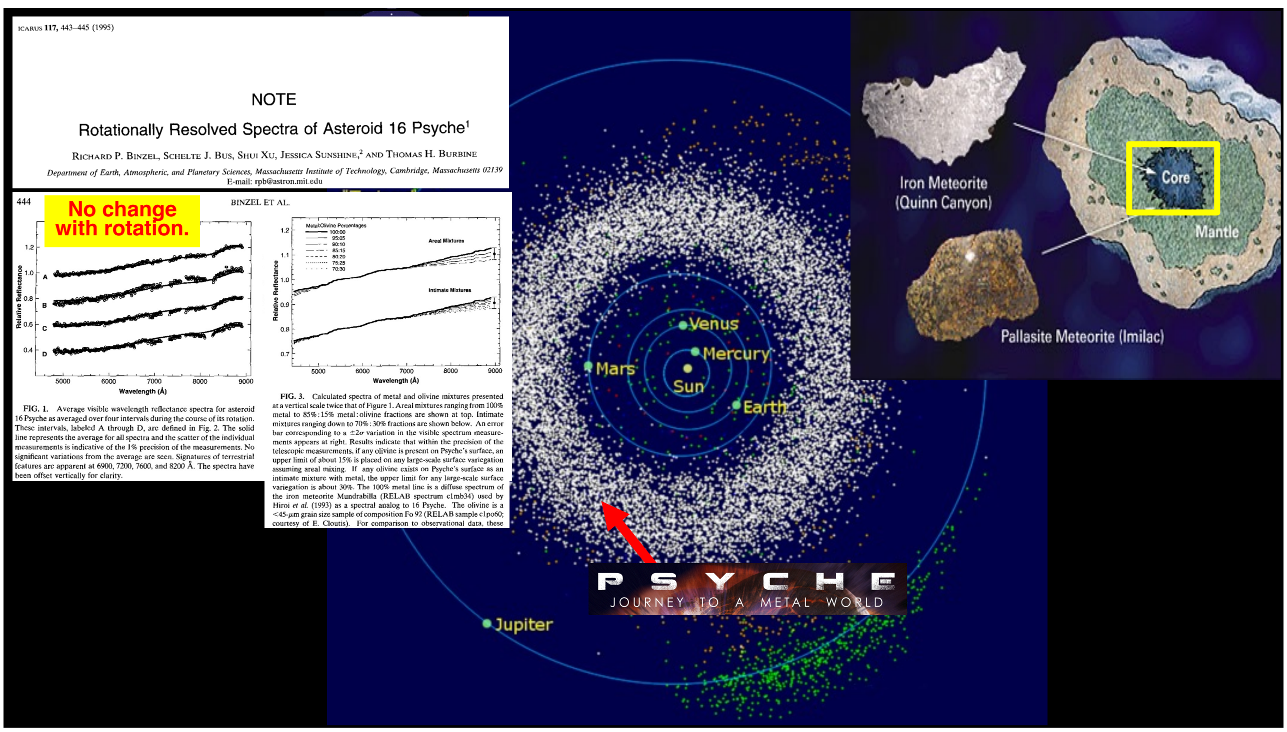
49



ICARUS 117, 443–445 (1995)

NOTE

Rotationally Resolved Spectra of Asteroid 16 Psyche[1]

RICHARD P. BINZEL, SCHELTE J. BUS, SHUI XU, JESSICA SUNSHINE,[2] AND THOMAS H. BURBINE

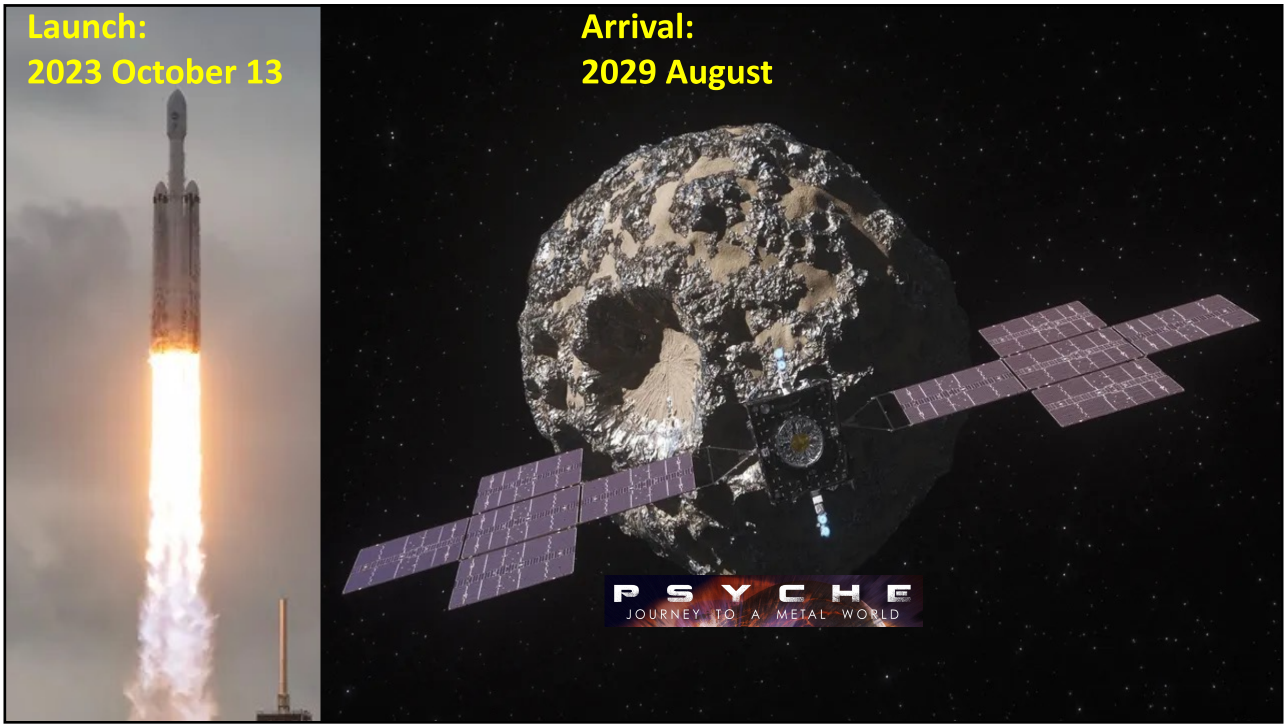
Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139
E-mail: rpb@astron.mit.edu

444 BINZEL ET AL.

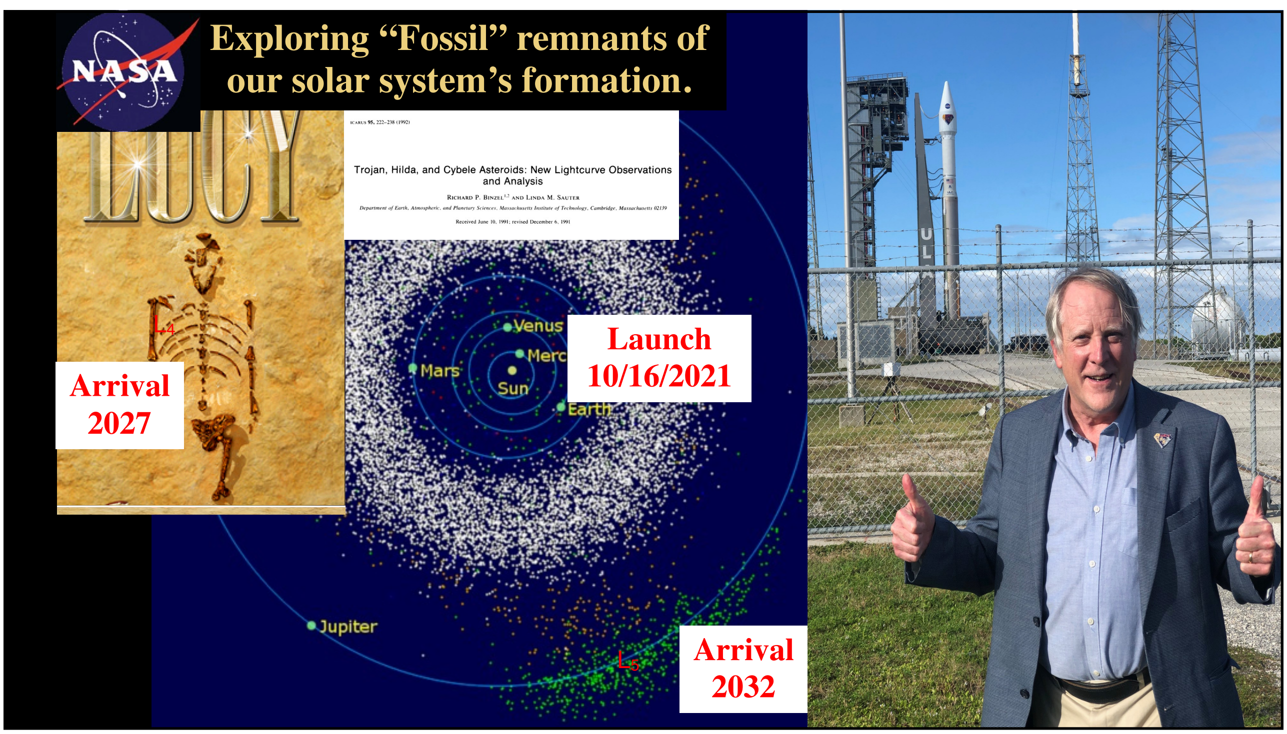
FIG. 1. Average visible wavelength reflectance spectra for asteroid 16 Psyche as averaged over four intervals during the course of its rotation. These intervals, labeled A through D, are defined in Fig. 2. The solid line represents the average for all spectra and the scatter of the individual measurements is indicative of the 1% precision of the measurements. No significant variations from the average are seen. Signatures of terrestrial features are apparent at 6900, 7200, 7600, and 8200 Å. The spectra have been offset vertically for clarity.

FIG. 3. Calculated spectra of metal and olivine mixtures presented at a vertical scale twice that of Figure 1. Areal mixtures ranging from 100% metal to 85%:15% metal:olivine fractions are shown at top. Intimate mixtures ranging down to 70%:30% fractions are shown below. An error bar corresponding to a $\pm 2\sigma$ variation in the visible spectrum measurements appears at right. Results indicate that within the precision of the telescopic measurements, if any olivine is present on Psyche's surface, an upper limit of about 15% is placed on any large-scale surface variegation assuming areal mixing. If any olivine exists on Psyche's surface as an intimate mixture with metal, the upper limit for any large-scale surface variegation is about 30%. The 100% metal line is a diffuse spectrum of the iron meteorite Mundrabilla (RELAB spectrum c1mb34) used by Hiroi *et al.* (1993) as a spectral analog to 16 Psyche. The olivine is a <45-μm grain size sample of composition Fo 92 (RELAB sample c1po60; courtesy of E. Cloutis). For comparison to observational data, these

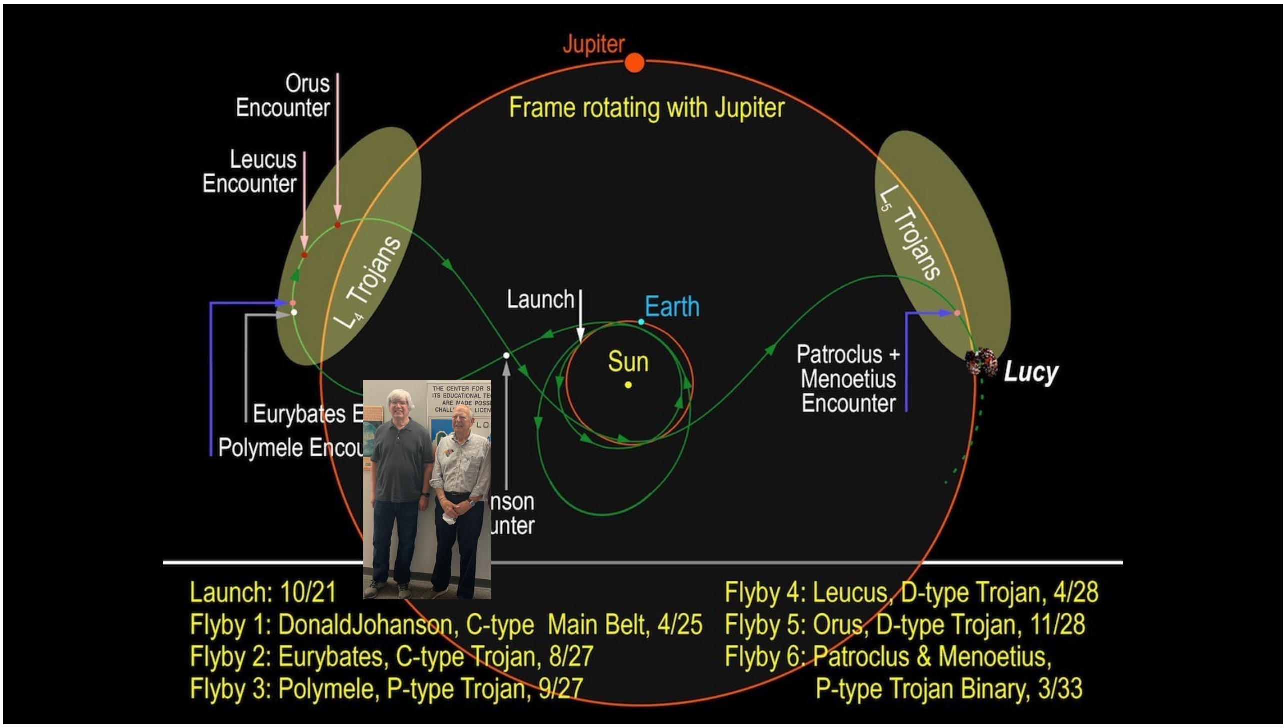
50


Launch:
2023 October 13
Arrival:
2029 August
PSYCHE
JOURNEY TO A METAL WORLD

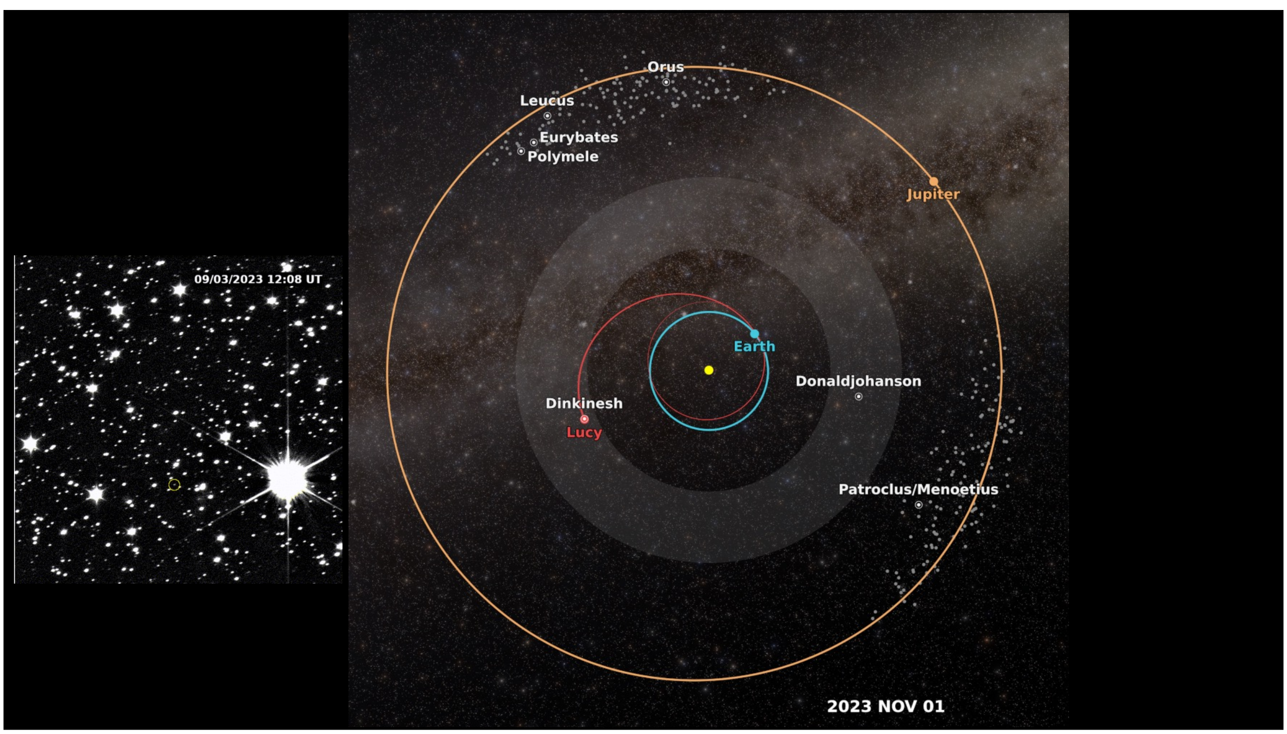
51


NASA
Exploring "Fossil" remnants of our solar system's formation.
LUCY
Trojan, Hilda, and Cybele Asteroids: New Lightcurve Observations and Analysis
RICHARD P. BINZEL AND LINDA M. SAUTER
L4
Arrival 2027
Venus
Merc
Mars
Sun
Earth
Launch 10/16/2021
Jupiter
L5
Arrival 2032

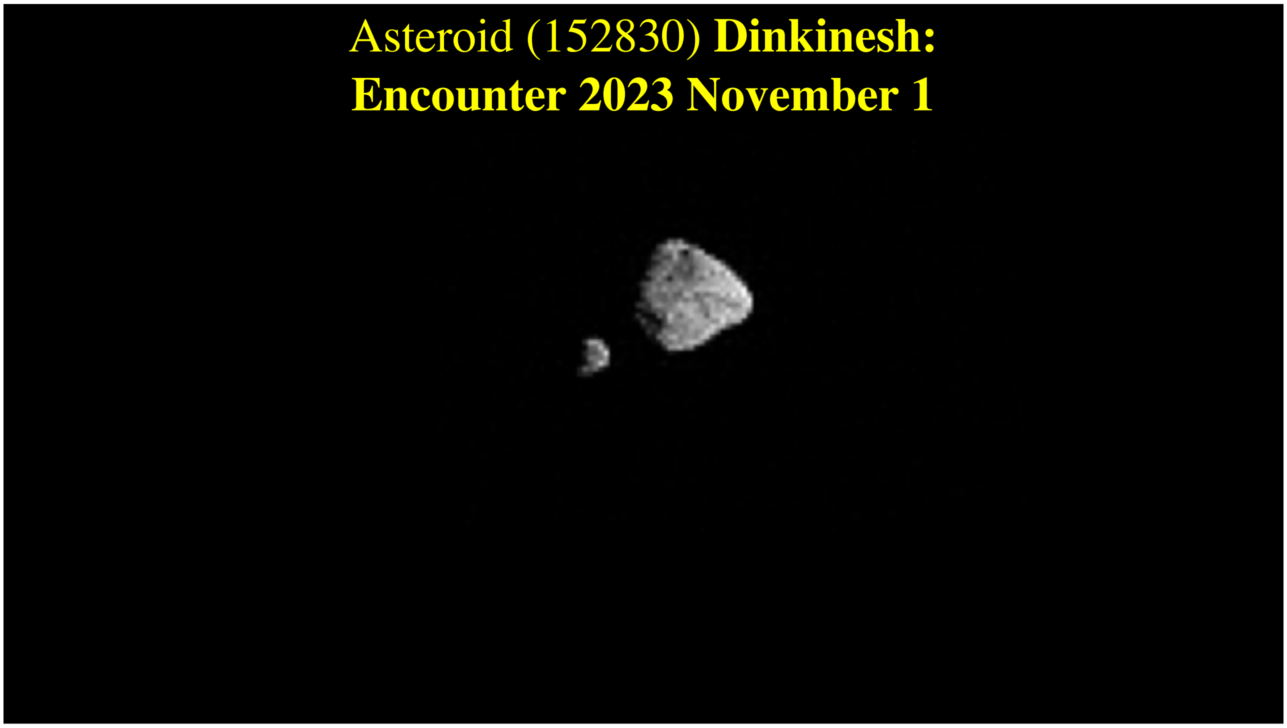
52


Jupiter
Frame rotating with Jupiter
Orus Encounter
Leucus Encounter
L4 Trojans
L5 Trojans
Launch
Earth
Sun
Patroclus + Menoetius Encounter
Lucy
Eurybates E
Polymele Encou
nson
unter
Launch: 10/21
Flyby 1: DonaldJohanson, C-type Main Belt, 4/25
Flyby 2: Eurybates, C-type Trojan, 8/27
Flyby 3: Polymele, P-type Trojan, 9/27
Flyby 4: Leucus, D-type Trojan, 4/28
Flyby 5: Orus, D-type Trojan, 11/28
Flyby 6: Patroclus & Menoetius, P-type Trojan Binary, 3/33

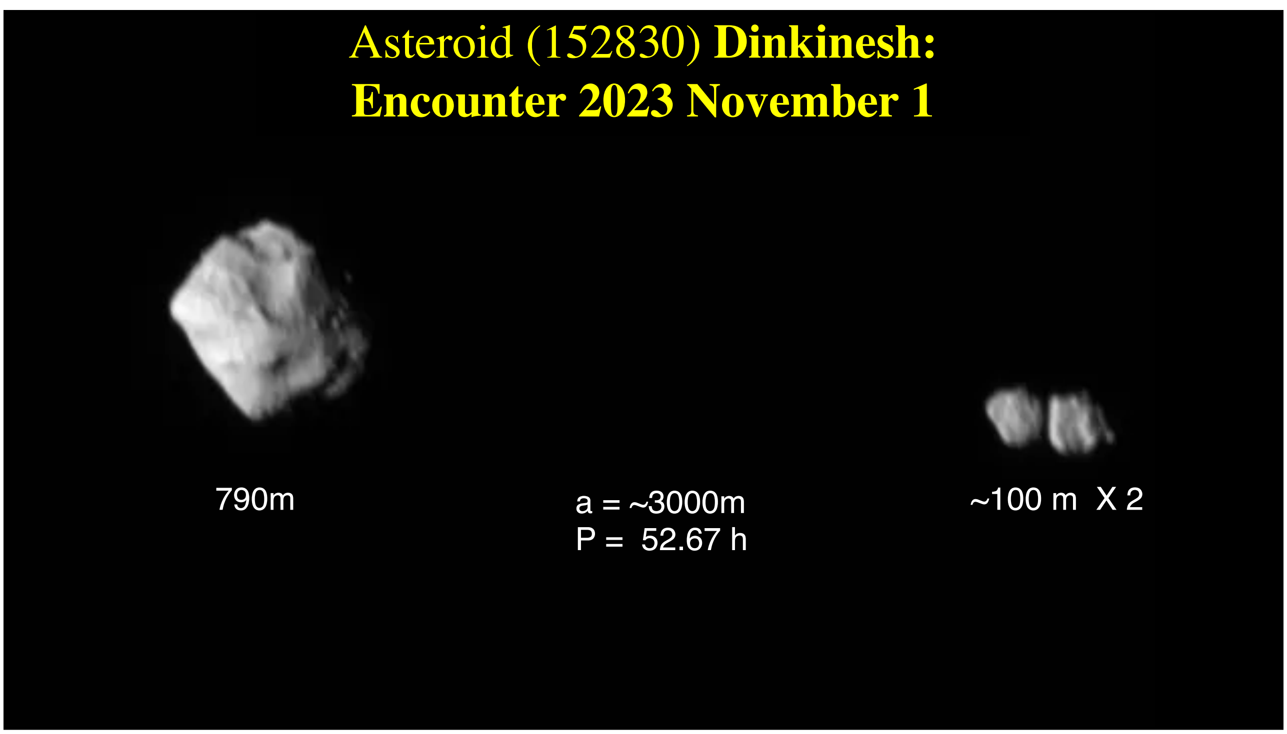
53


09/03/2023 12:08 UT
Orus
Leucus
Eurybates
Polymele
Jupiter
Earth
Donaldjohanson
Dinkinesh
Lucy
Patroclus/Menoetius
2023 NOV 01

54


Asteroid (152830) **Dinkinesh:**
Encounter 2023 November 1

55


Asteroid (152830) **Dinkinesh:**
Encounter 2023 November 1
790m
a = ~3000m
P = 52.67 h
~100 m X 2

56

Apophis 2029

340m asteroid passing within 5.8 Earth-radii.
"A once-per-thousand year natural experiment."

- 300 X More massive than Tunguska body.
- 5000 X More massive than Chelyabinsk body.

Knowledge opportunity for the science of planetary defense.

Key Science Questions / Uncertainties:

- *Will tidal stresses by Earth induce any measurable effects?*
  -Seismic shaking? -Surface landslides? -Shape reconfiguring?
- *Can measurements of effects produce significant scientific advances in planetary geophysics ?*
- *How would measurements be implemented ?*

Comet Shoemaker-Levy 9 (1994)

57

FIN

58