The New Horizons Mission: Pluto and Beyond

Susan D. Benecchi
Carnegie DTM & Planetary Science Institute
19 April 2013
Artifacts in the Solar System

• Planet X ~ Pluto: discovered before its time
• Charon
• Nix, Hydra, P4 and P5
• Our current understanding of the Pluto System
• Discovery of the Kuiper Belt
• What small bodies tell us about our Solar system
• The New Horizons Mission
Discovered in January-February 1930, by Clyde Tombaugh at Lowell Observatory, Arizona.

- <1% Mars’s Max Apparent Diameter (0.1 arcsec)
- 50,000 times fainter than Mars (V~14)

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The Pluto system is located at 30 AU (semimajor axis ~ 40 AU), and it has a 249-year orbit with $i = 17^\circ$ and $e = 0.25$.  

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Heliocentric Orbit
Charon 1978

- Charon is ~ $17 \, R_{pl}$ from Pluto ($\sim 1''$), and they are in synchronous rotation with a period of 6.4 days.
- Charon’s $V$–magnitude is 16.8, compared to Pluto’s 15.1 (1/5 as bright).

[Discovery image of Charon, from a USNO photographic plate (James Christy).]

[Ground Based vs HST/FOC images of Charon and Pluto.]

http://www.solarviews.com/eng/pluto.htm
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Nix and Hydra

- Distances of 1.85” and 2.09”
- A few 1000x fainter than Pluto (V~23)
- 1/2000 - 1/100000 Pluto’s mass
- Neutral in color (like Charon)

18 April 2013  Buie et al. 2006
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- Estimated diameter of 8 to 21 miles (13 to 34 km)
- Orbits between Nix & Hydra in the same plane
P5

- Irregular in shape
- 6 to 15 miles across
- In a 58,000-mile-diameter circular orbit around Pluto, assumed to be co-planar with the other satellites in the system.
Size, Surface and Color

Verbiscer et al. 2007

Buie et al. 2006

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Occultation of C313.2 by Charon as recorded by POETS mounted on the 6.5-m Clay telescope at Las Campanas Observatory.


For movie see: http://occult.mit.edu/research/C313OccMovie.php

- Charon does not have a substantial atmosphere.
- Pluto has a Nitrogen atmosphere.

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Pluto is a primarily rocky, not icy body!

From the Densities of Pluto and Charon, One Can Derive Crude Interior Models.

INTERIOR MODELS
(McKinnon & Mueller 1988; Simonelli et al. 1989)

Pluto is a primarily rocky, not icy body!
Perspective

1700s — Halley’s Comet (short period comets)

1801 — 1st Asteroid, Ceres

1930 — Pluto discovered

1932/1950 — Opik & Oort theorize about Oort cloud (long period comet reservoir)

1949/1951 — Edgeworth & Kuiper theorize about the Kuiper Belt

1992 — First Kuiper Belt Object discovered

2002 — First binary Kuiper Belt Object, 1998 WW₃₁
Dust Disks & Exo-plaanet Systems

Beta Pictoris
Hubble Space Telescope - ACS/HRC

Fomalhaut
HST ACS/HRC

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The First KBO: 1992QB1

- 1992–Jewitt & Luu found a 100 km sized object in a near-circular orbit, well beyond Pluto.
- 1993–4 more KBOs found.
- 1994–10 KBOs found.
- 2007 - over 1600 KBOs are observed.
- We expect ~70,000 KBOs > 100 km in diameter.

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Deep Ecliptic Survey Observations

Near Earth: ≥75 "/hr
Main Belt: 30-40 "/hr
Centaurs: 5-15 "/hr
Kuiper Belt: ≤5 "/hr

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Millis et al. 2002
THE OUTER SOLAR SYSTEM

This animation shows the motion of the outer part of the solar system over a 100-year time period. The sun is at the center and the orbits of the planets Jupiter, Saturn, Uranus, and Neptune are shown in light blue (the locations of each planet are shown as large crossed circles).

Comets: blue squares (filled for numbered periodic comets, outline for other comets)
High-e objects: cyan triangles
Centaurs: orange triangles
Plutinos: white circles (Pluto itself is the large white crossed circle)
"Classical" TNOs: red circles
Scattered Disk Objects: magenta circles

The individual frames were generated on a Sun-OS RISC workstation using the PGLOT graphics library. The animation was produced on a RISC OS 4.03 system using !InterGif.

Current KBO Population
Focus on End-Members

✦ Objects in dynamically interesting locations
✦ Cold Classical Kuiper Belt
✦ Resonance populations
✦ Centaurs (transition objects)
✦ Large Objects
✦ Binaries

Face-on
~1600 Objects

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Current KBO Population
Focus on End-Members
✦ Objects in dynamically interesting locations
    ✦ Cold Classical Kuiper Belt
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Face-on

~1600 Objects

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Large Kuiper Belt Objects

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Binaries

✧ binary orbit -> system mass. Kepler’s 3rd law
\[ (m_p + m_s) = \frac{4\pi^2 a^3}{GP^2} \]

✧ diameters assuming (or measuring) an albedo, \( p \).
\[ d = \frac{2r\Delta}{R\sqrt{p}} 10^{-0.2(m_{kbo} + \alpha\beta - m_{sun})} \]

✧ Density -> Suggest composition.
\[ \rho = \frac{m_p + m_s}{4\left[\left(\frac{d_p}{2}\right)^3 + \left(\frac{d_s}{2}\right)^3\right] \pi} \]

McKinnon et al 1997
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Binary Orbits

- HST/WFPC2 and HST/ACS programs (also some Keck LGS AO)
- 4 observations per HST orbit, 5 or more orbits per object
- Filter: F606W ~ V, F814W ~ I
- 18+ objects
- Analyzed data with standard HST pipeline and iterative PSF fitting of binary images with Tiny Tim models.

Science Motivation: Measure system mass for objects in the Kuiper Belt to learn about density/composition. Also to learn about scattering in the Kuiper Belt.

2001 QL$_{251}$, 5 HST visits with WFPC2, Grundy et al. 2009 Icarus
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A Formation Scenario

Gomes 2003, EMP; Figure from West 2003
New Horizons: Launched January 19, 2006
Pluto System Arrival: July 2015

Some of the slides that follow are extracted from presentations made by New Horizons Scientists and can be found on the New Horizons website.

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Great Progress is Fundamentally Limited Until We Visit

This is the fundamental exploration lesson of planetary science.

Pluto at Best HST Resolution

Triton at Best HST Resolution

Earth’s Moon at the Same Resolution

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NEW HORIZONS

The Initial Reconnaissance of The Solar System’s “Third Zone”

KBOs  Pluto-Charon  Jupiter System

Launch
19 Jan 2006
A Mission to Pluto Has Been Worked In the Science Community Since 1989

PERSISTENCE

Now That We’ve Exhausted All Possibilities... Let’s Get Started.

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Toward New Horizons

The Highest Priority New Frontiers New Start
Recommendation of the Planetary Decadal Survey

A Reconnaissance Expedition To the Kuiper Belt & Pluto-Charon

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Launch: 19 January 2006
Leaving Home

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Project Philosophy

Offer early and highly-leveraged science. Do so on time, within budget, and at low risk.
Provide Intensive Public Outreach
Keep It Simple

New Horizons
Shedding Light on Frontier Worlds

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Launch Vehicle: Atlas V 551 With A STAR-48 Upper Stage

- Centaur Interstage Adapter (12.5 ft Dia)
- CCB Cylindrical Interstage Adapter
- RD-180 Engine Common Core Booster™ (CCB)
- Single RL10 Engine
- Centaur Conical Interstage Adapter
- Solid Rocket Boosters
- 5-meter Short Payload Fairing (68 ft)
- Centaur Forward Load Reactor
- Payload Adapter (PLA)
- 5-Meter Payload Fairing Boattail
- Centaur Aft Stub Adapter
- Aft Transition Skirt/Heat Shield
- RD-180 Engine

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# NASA-Specified Pluto-Charon Measurement Objectives

<table>
<thead>
<tr>
<th>Group 1 Objectives: <strong>Required</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Characterize the global geology and morphology of Pluto and Charon</td>
</tr>
<tr>
<td>Map surface composition of Pluto and Charon</td>
</tr>
<tr>
<td>Characterize the neutral atmosphere of Pluto and its escape rate</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group 2 Objectives: <strong>Important</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Characterize the time variability of Pluto's surface and atmosphere</td>
</tr>
<tr>
<td>Image Pluto and Charon in stereo</td>
</tr>
<tr>
<td>Map the terminators of Pluto and Charon with high resolution</td>
</tr>
<tr>
<td>Map the composition of selected areas of Pluto &amp; Charon at high resolution</td>
</tr>
<tr>
<td>Characterize Pluto's ionosphere and solar wind interaction</td>
</tr>
<tr>
<td>Search for neutral species including H, H₂, HCN, and CₓHᵧ, and other hydrocarbons and nitriles in Pluto's upper atmosphere</td>
</tr>
<tr>
<td>Search for an atmosphere around Charon</td>
</tr>
<tr>
<td>Determine bolometric Bond albedos for Pluto and Charon</td>
</tr>
<tr>
<td>Map the surface temperatures of Pluto and Charon</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group 3 Objectives: <strong>Desired</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Characterize the energetic particle environment of Pluto and Charon</td>
</tr>
<tr>
<td>Refine bulk parameters (radii, masses, densities) and orbits of Pluto &amp; Charon</td>
</tr>
<tr>
<td>Search for magnetic fields of Pluto and Charon</td>
</tr>
<tr>
<td>Search for additional satellites and rings</td>
</tr>
</tbody>
</table>

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New Horizons Spacecraft
Instrumentation

- **SWAP**: Solar wind analyzer
- **PEPSSI**: Energetic particle detector
- **LORRI**: Long-range visible imager
- **REX**: Radio science & radiometry
- **SDC**: Student dust counter (under spacecraft)
- **Alice**: UV imaging spectrometer
- **Ralph**: Visible pan. and color imager, IR spectrometer

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Student Dust Counter:
A New Kind of EPO

- **EPO Goal:** Give students a chance to design, build, operate, & study data from a planetary flight experiment.

- **Science Goal:** Make the first dust density & size spectrum observations beyond 18 AU.

- **Students have the primary responsibility** for the design and development of the SDC; over 35 “first Generation” students presently involved at CU, Dozens more across the U.S.

- **Science CoI:** Mihaly Horanyi.

- **Four-to-Five Generations of Students To Be Directly Involved.**

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Current Location/Itinerary

New Horizons Current Position

Distance from Sun (AU): 25.96  Heliocentric Velocity (km/s): 15.01

Distance from Earth (AU): 25.85
Distance from Pluto (AU): 6.80
Round-Trip Light Time (hh:mm:ss): 7:10:03
8 Apr 2013 18:00:00 UTC

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Jupiter Flyby Priorities

- Gravity Assist (Speed Trajectory to Pluto)
- Encounter Ops Practice, Instrument Calibrations
- Jupiter System Science: include studies of Jovian meteorology, satellite geology and composition, auroral phenomena, and magnetospheric physics

C/A Date 28 Feb 2007
Range $38 \, R_{\text{Jupiter}}$

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Jupiter Science: Working as Planned

Jupiter's Moon Io
Tvashtar's Plume
February 28, 2007

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New Horizons in Flight
LORRI High Resolution Imager

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Pluto-Charon Encounter Geometry
14 July 2015

Charon-Earth Occultation
14:37:44

Pluto-Earth Occultation
13:10:47

Charon-Sun Occultation
14:35:37

Pluto-Sun Occultation
13:09:57

• S/C trajectory time ticks: 10 min
• Charon orbit time ticks: 12 hr
• Occultation: center time
• Position and lighting at Pluto C/A
• C/A distances are to body centers

Pluto C/A
12:20
11,095 km
13.78 km/s

Charon C/A
12:34
26,700 km
13.88 km/s

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Targeting Kuiper Belt Objects

- Ground-based campaign to locate candidate KBOs along the spacecraft nominal trajectory up to 55 AU from Sun.
- On-board ΔV is capable of reaching multiple KBOs with size > 40 km.
- Execute a TCM at P+14d to alter trajectory towards first KBO.

- Obtain OpNav image of targeted KBO as early as 3-5 weeks out.
- Refine KBO encounter accuracy with a trim TCM incorporating OpNav data.
- KBO flyby velocities of 8 km/s to 14 km/s.

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• This Europa image is at 300 m/pixel resolution, the same resolution as the New Horizons images taken with the PERSI/MVIC panchromatic imager at Pluto closest approach.
• The Europa inset image is at 50 m/pixel resolution, the same resolution as the New Horizons high-resolution strips taken with the LORRI imager at Pluto closest approach.
Final Stop:
The Kuiper Belt

Images from the 4-m telescope at Cerro Tololo Int. Observatory

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Search Area

- Search area shrinks with time as it converges on the spacecraft trajectory
  - Defined by KBO velocity dispersion, not available delta-V

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Telescopes Used for Our Search

The Magellan Telescopes
Las Campanas Observatory, Chile

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Subaru Telescope
Mauna Kea, Hawaii
KBO Search

Potential candidate

July 2013 Megacam Search Grid

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<table>
<thead>
<tr>
<th>Name</th>
<th>DB-ID</th>
<th>a (AU)</th>
<th>e</th>
<th>i (deg)</th>
<th>Mag</th>
<th>Date of CE</th>
<th>Range at CE (AU)</th>
<th>Δv (m/s)</th>
<th>Obs Arc (days)</th>
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<tbody>
<tr>
<td>2011HM102</td>
<td>VNH001</td>
<td>30.1</td>
<td>0.081</td>
<td>29.4</td>
<td>22.2</td>
<td>2013/11/02 — 2013/11/02</td>
<td>1.22 — 1.22</td>
<td>pre-Pluto</td>
<td>355</td>
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<td>VNHO002</td>
<td>VNH002</td>
<td>51.0</td>
<td>0.223</td>
<td>6.4</td>
<td>—</td>
<td>2018/03/31 — 2019/06/14</td>
<td>0.21 — 0.44</td>
<td>360 — 560</td>
<td>66</td>
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<td>VNHO003</td>
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<td>0.345</td>
<td>5.4</td>
<td>—</td>
<td>2017/01/15 — 2017/11/01</td>
<td>0.18 — 0.40</td>
<td>320 — 850</td>
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<td>VNHO004</td>
<td>VNH004</td>
<td>39.0</td>
<td>0.355</td>
<td>3.8</td>
<td>23.5</td>
<td>2014/10/08 — 2016/03/01</td>
<td>0.34 — 1.14</td>
<td>&gt;5000</td>
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<td>VNHO005</td>
<td>VNH005</td>
<td>51.5</td>
<td>0.455</td>
<td>3.1</td>
<td>24.5</td>
<td>2017/04/25 — 2018/03/11</td>
<td>0.48 — 0.94</td>
<td>880 — 2200</td>
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<td>50.8</td>
<td>0.016</td>
<td>2.5</td>
<td>26.0</td>
<td>2021/02/13 — 2022/03/30</td>
<td>0.17 — 1.13</td>
<td>140 — 810</td>
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<td>2011JW31</td>
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<td>1.9</td>
<td>25.2</td>
<td>2018/05/30 — 2018/12/26</td>
<td>0.14 — 0.21</td>
<td>230 — 290</td>
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<td>2011JY31</td>
<td>VNH008</td>
<td>44.0</td>
<td>0.041</td>
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<td>25.0</td>
<td>2018/07/19 — 2018/10/27</td>
<td>0.14 — 0.16</td>
<td>220 — 240</td>
<td>358</td>
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<td>0.107</td>
<td>3.3</td>
<td>24.5</td>
<td>2020/06/18 — 2020/06/28</td>
<td>0.41 — 0.42</td>
<td>390 — 400</td>
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<td>VNH010</td>
<td>43.2</td>
<td>0.004</td>
<td>2.4</td>
<td>25.4</td>
<td>2018/09/07 — 2019/01/15</td>
<td>0.15 — 0.20</td>
<td>210 — 280</td>
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<td>VNHO011</td>
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<td>42.3</td>
<td>0.161</td>
<td>14.5</td>
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<td>2016/03/11 — 2016/09/07</td>
<td>1.33 — 1.44</td>
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<td>2011HE103</td>
<td>VNH012</td>
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<td>2019/08/13 — 2021/04/24</td>
<td>0.90 — 0.96</td>
<td>850 — 1000</td>
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<td>13.0</td>
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<td>2015/05/16 — 2016/03/21</td>
<td>0.93 — 1.14</td>
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<td>2017/06/24 — 2018/08/28</td>
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<td>690 — 870</td>
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<td>25.3</td>
<td>2020/08/07 — 2020/08/06</td>
<td>1.35 — 1.37</td>
<td>720 — 1270</td>
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<td>VNH019</td>
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<td>0.021</td>
<td>2.7</td>
<td>24.7</td>
<td>2016/12/06 — 2024/12/14</td>
<td>0.38 — 1.96</td>
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<td>54.0</td>
<td>0.020</td>
<td>18.1</td>
<td>—</td>
<td>2017/12/31 — 2024/07/27</td>
<td>1.20 — 4.32</td>
<td>&gt;1000</td>
<td>2</td>
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<td>VNH021</td>
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<td>0.085</td>
<td>3.3</td>
<td>—</td>
<td>2014/07/30 — 2019/03/26</td>
<td>0.07 — 0.45</td>
<td>&gt;1000</td>
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<td>VNH022</td>
<td>44.5</td>
<td>0.044</td>
<td>6.2</td>
<td>—</td>
<td>2016/03/21 — 2020/07/08</td>
<td>0.38 — 0.98</td>
<td>860 — 1180</td>
<td>3</td>
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<td>VNHO023</td>
<td>VNH023</td>
<td>38.8</td>
<td>0.011</td>
<td>19.3</td>
<td>—</td>
<td>2015/08/04 — 2019/12/21</td>
<td>1.28 — 2.58</td>
<td>&gt;1000</td>
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<td>VNH024</td>
<td>41.8</td>
<td>0.155</td>
<td>4.5</td>
<td>—</td>
<td>2015/05/06 — 2017/05/25</td>
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<td>0.021</td>
<td>2.9</td>
<td>—</td>
<td>2019/08/03 — 2019/11/01</td>
<td>0.96 — 1.18</td>
<td>&gt;1000</td>
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<td>0.022</td>
<td>9.1</td>
<td>—</td>
<td>2018/06/19 — 2019/06/24</td>
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<td>3.0</td>
<td>—</td>
<td>2018/01/10 — 2019/08/03</td>
<td>0.73 — 1.82</td>
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<td>2.8</td>
<td>—</td>
<td>2025/03/04 — 2029/12/18</td>
<td>0.19 — 5.36</td>
<td>80 — 1840</td>
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<td>VNHO031</td>
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<td>0.199</td>
<td>6.6</td>
<td>—</td>
<td>2012/08/09 — 2018/01/30</td>
<td>0.39 — 2.33</td>
<td>&gt;5000</td>
<td>6</td>
</tr>
</tbody>
</table>
• Determine KBO orbit to high precision.
• Color information
• Is the object binary?
New Horizons: Exploring the Third Zone

Thanks for listening… Questions?

For more information (including technical papers), see http://pluto.jhuapl.edu
Thanks for listening
Questions?