The New Horizons Mission: Pluto and Beyond

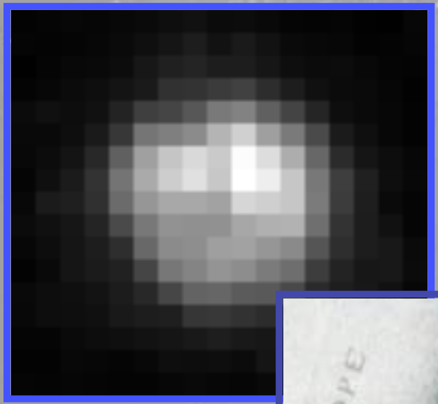
Susan D. Benecchi
Carnegie DTM & Planetary Science Institute
19 April 2013

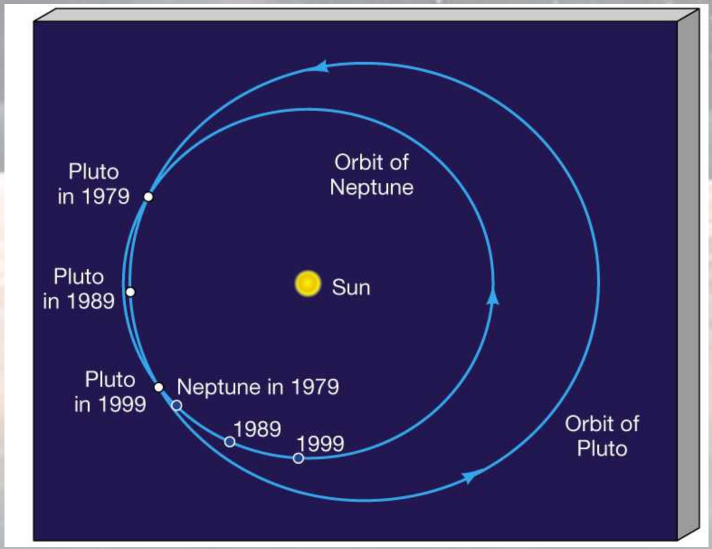
Artifacts in the Solar System

- 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

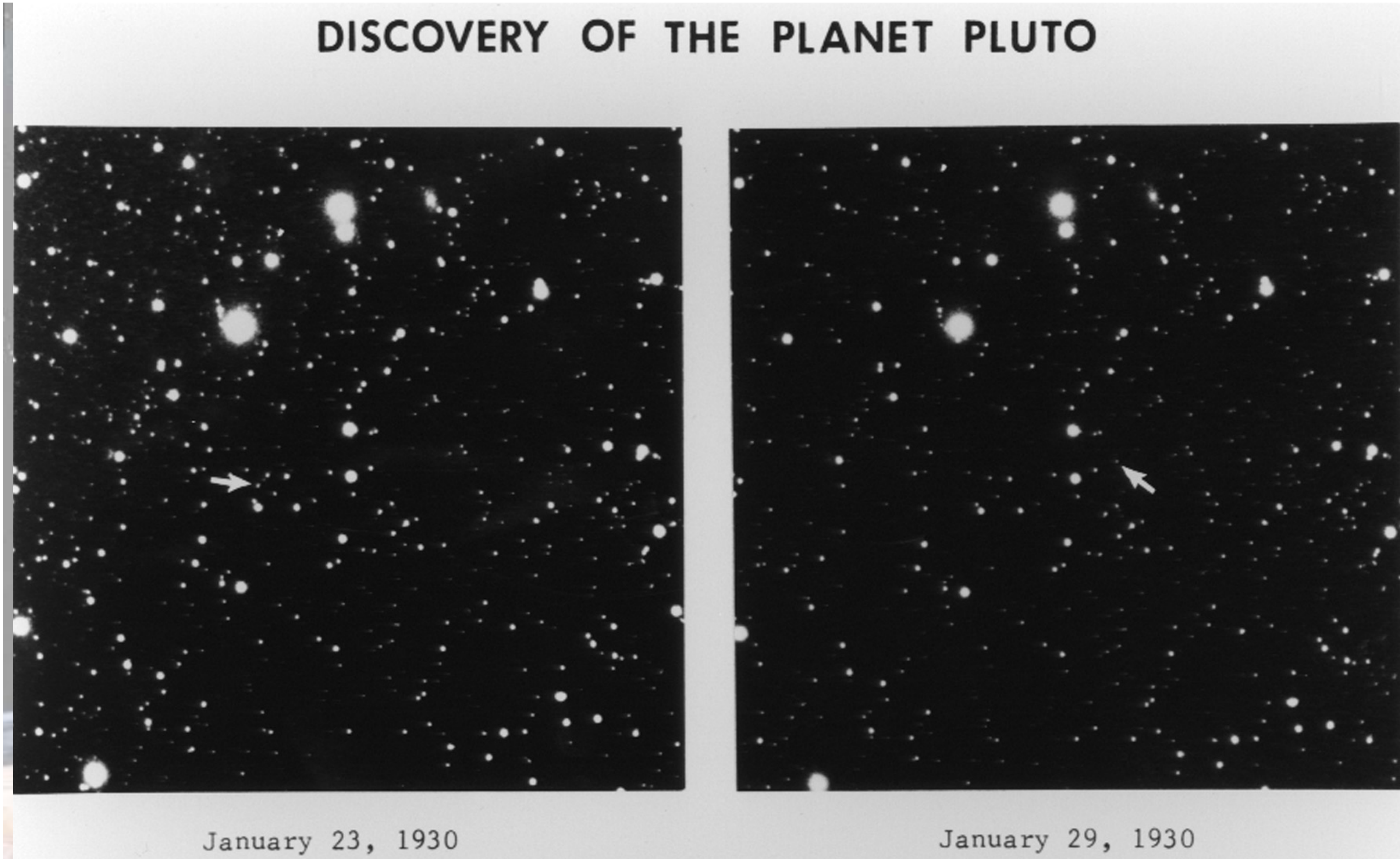
Pluto

Discovered in January-February 1930, by Clyde Tombaugh at Lowell Observatory, Arizona.



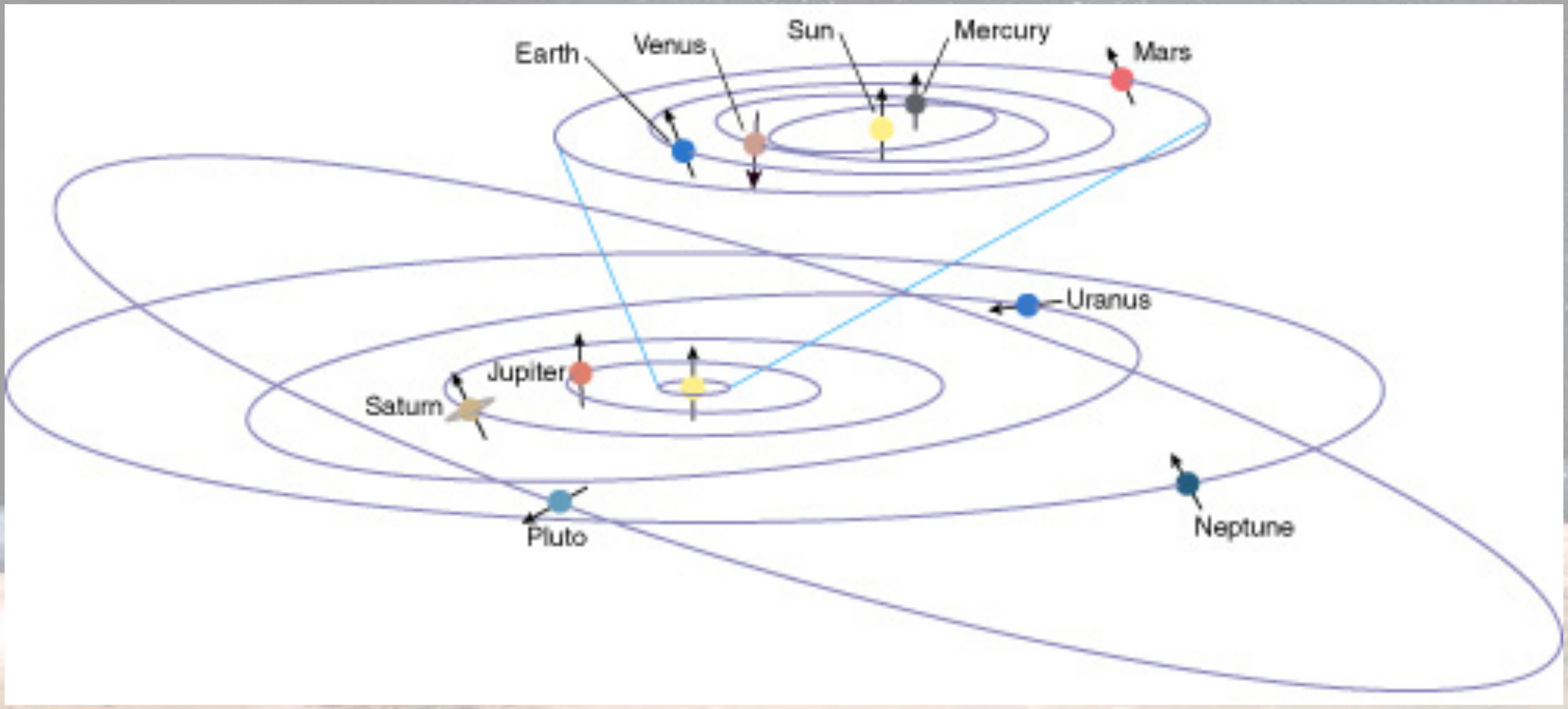


- <1% Mars's Max Apparent Diameter (0.1 arcsec)
- 50,000 times fainter than Mars (V~14)

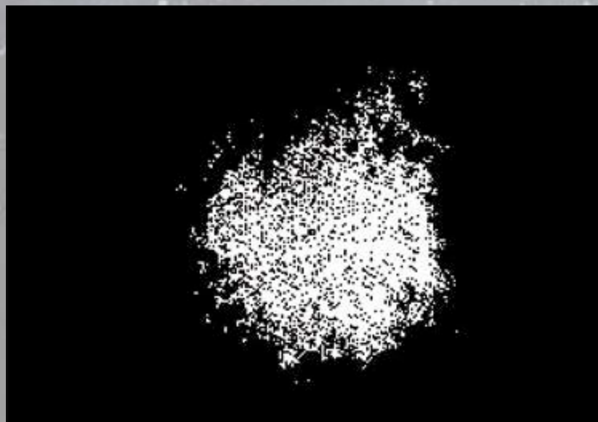


- The Pluto system is located at 30 AU (semimajor axis ~ 40 AU), and it has a 249-year orbit with $i = 17^{\circ}$ and $e = 0.25$.

Heliocentric Orbit

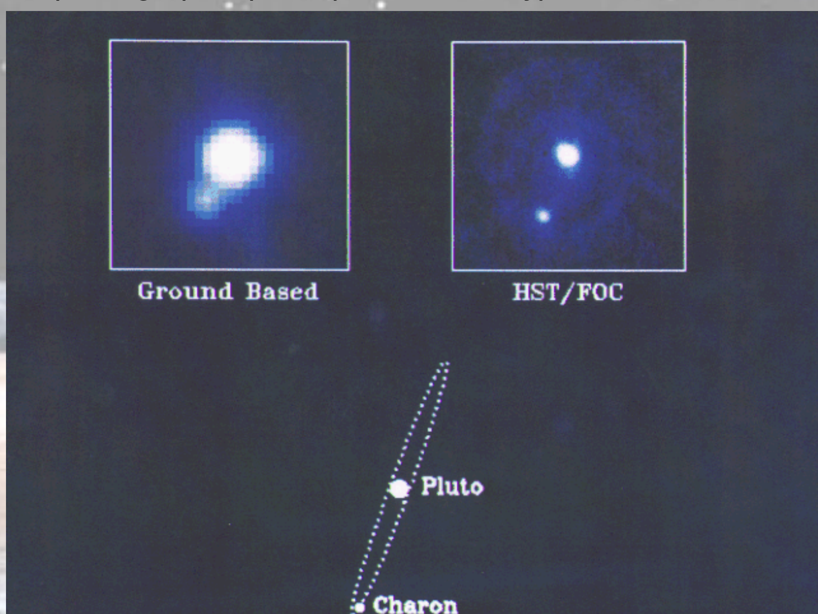


Charon 1978

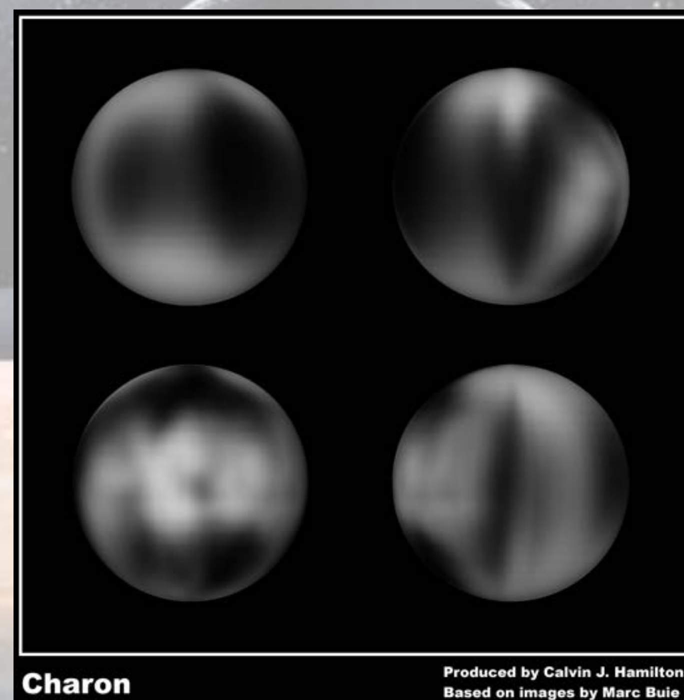


Discovery image of Charon, from a USNO photographic plate (James Christy).

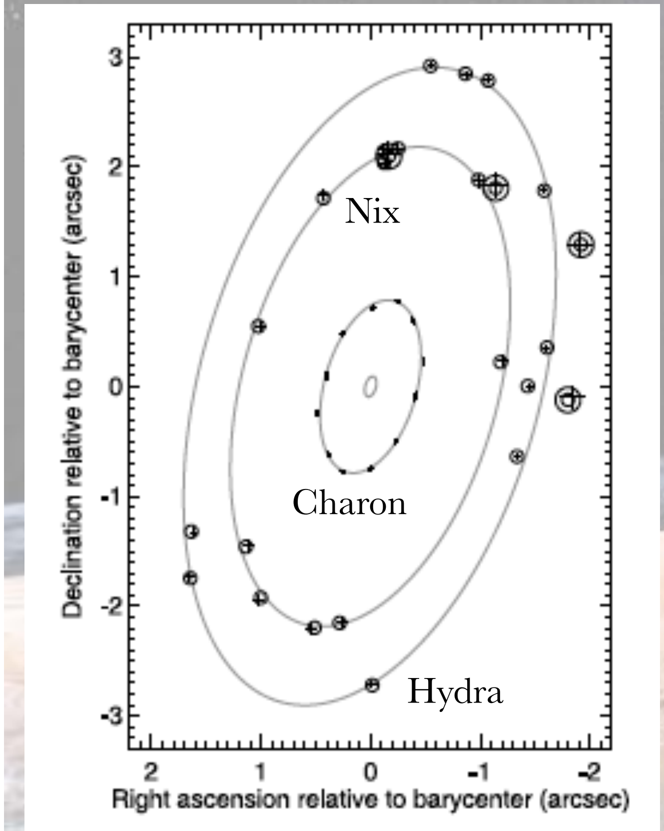
- Charon is ~ 17 R_{pl} from Pluto (~ 1″), and they are in synchronous rotation with a period of 6.4 days
- Charon's *V*–magnitude is 16.8, compared to Pluto's 15.1 (1/5 as bright)



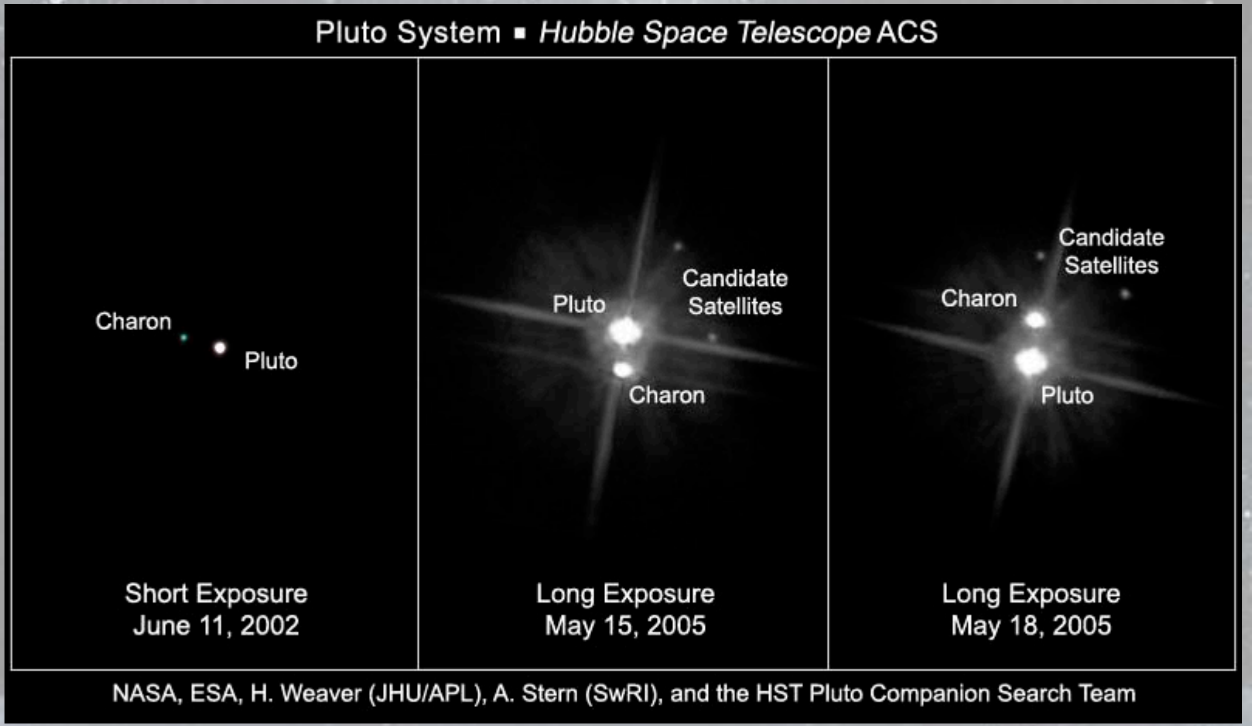
http://www.solarviews.com/eng/pluto.htm



Nix and Hydra

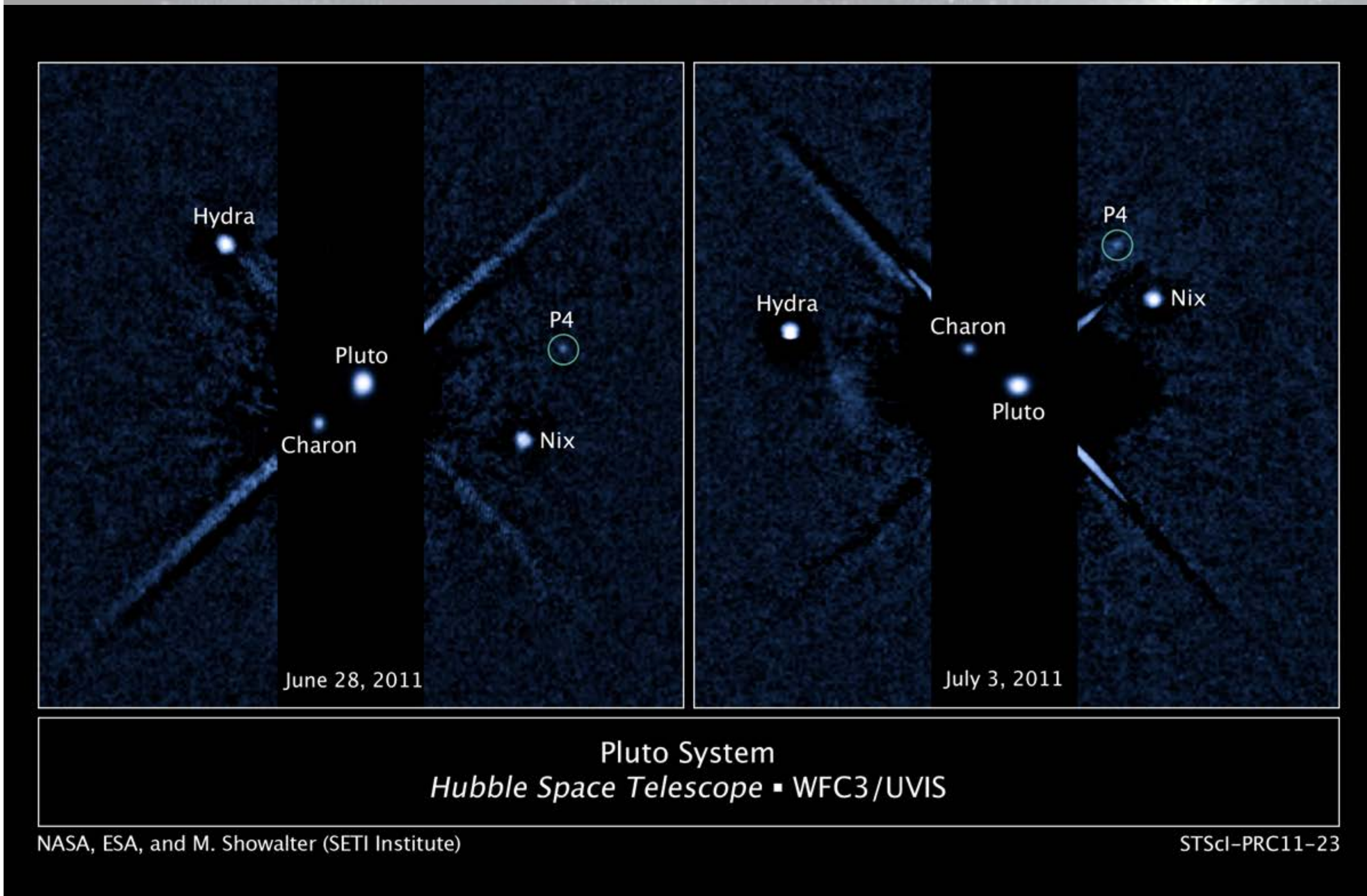


Buie et al. 2006

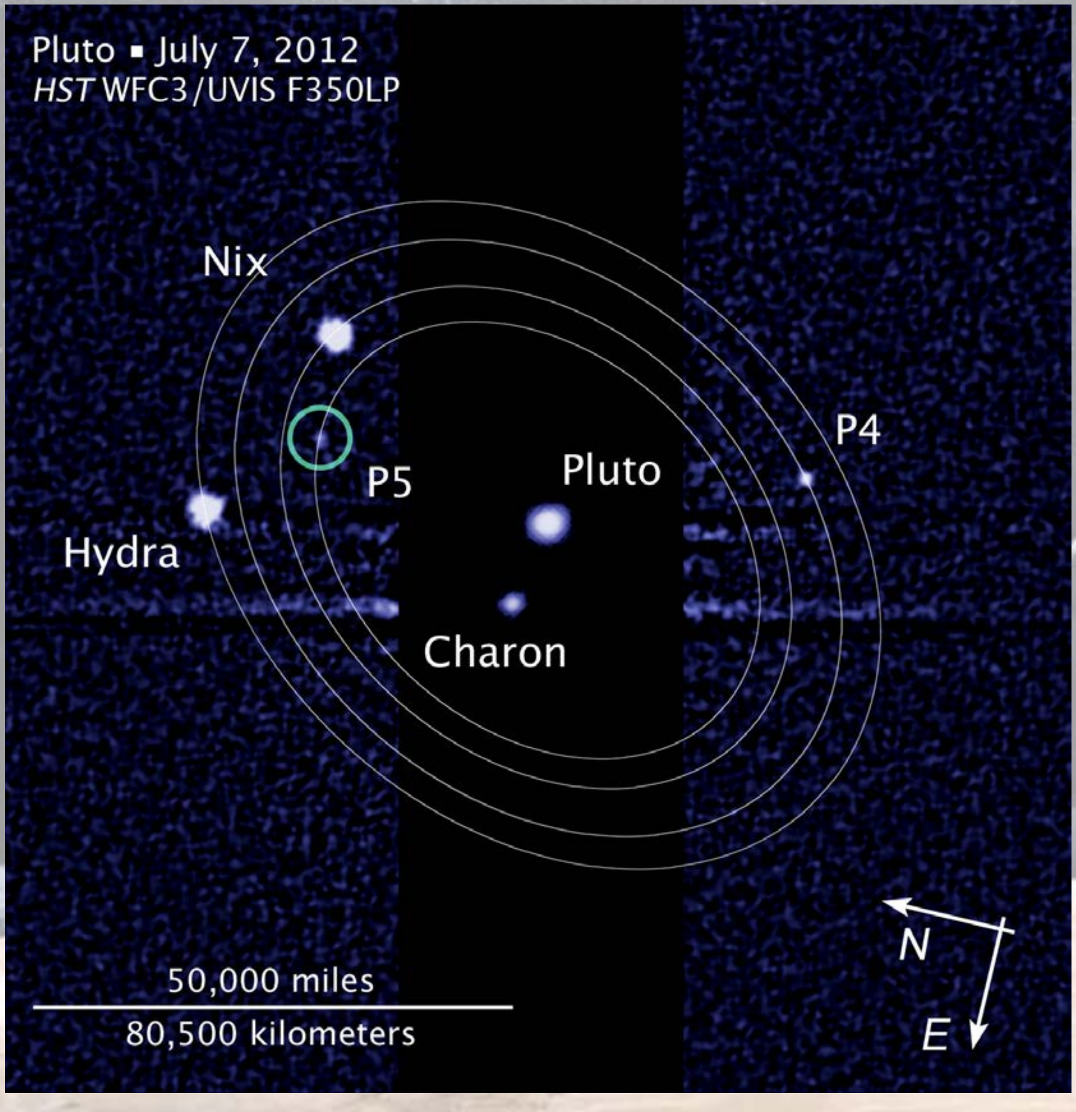


- 2 small moons discovered in 2005 ("S/2005 P1" & "S/2005 P2")
- Distances of 1.85" and 2.09"
- A few 1000x fainter than Pluto (V~23)
- 1/2000 - 1/100000 Pluto's mass
- Neutral in color (like Charon)

P4



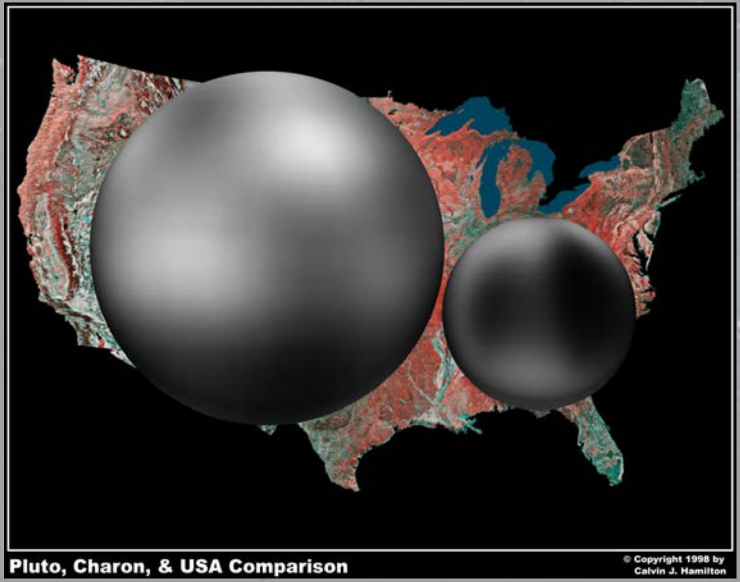
- Estimated diameter of 8 to 21 miles (13 to 34 km)
- Orbits between Nix & Hydra in the same plane

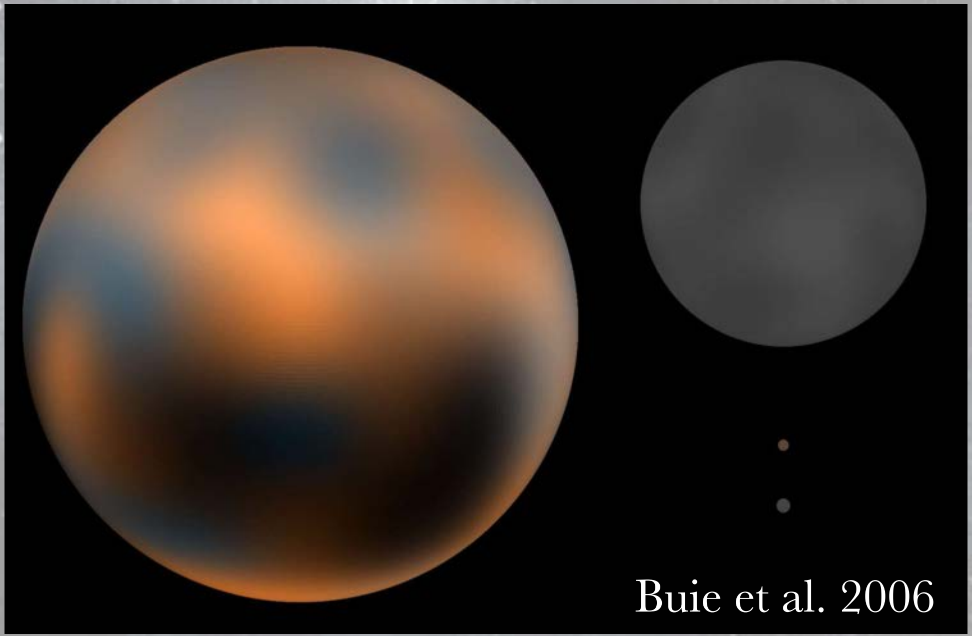


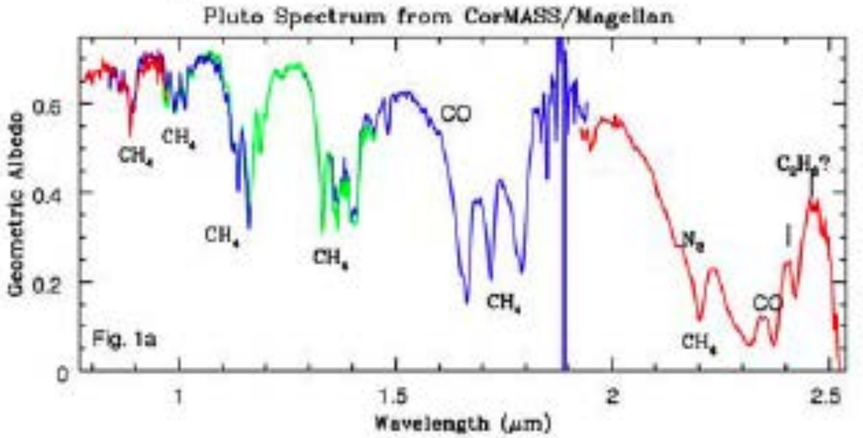
P5

- 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.

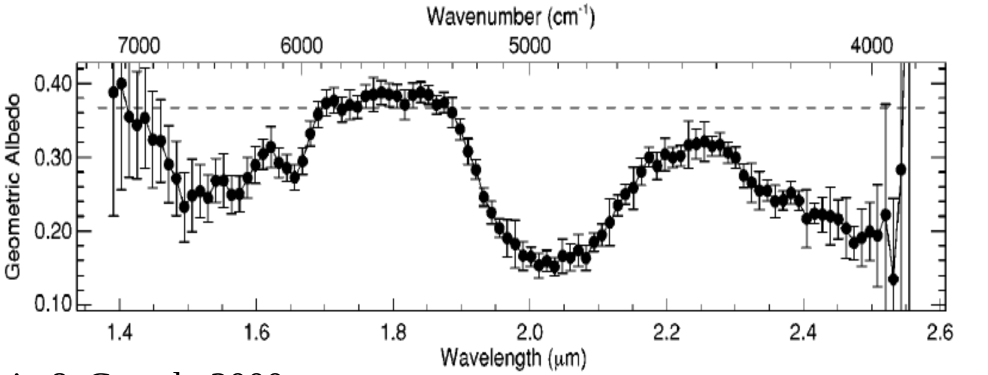
Size, Surface and Color





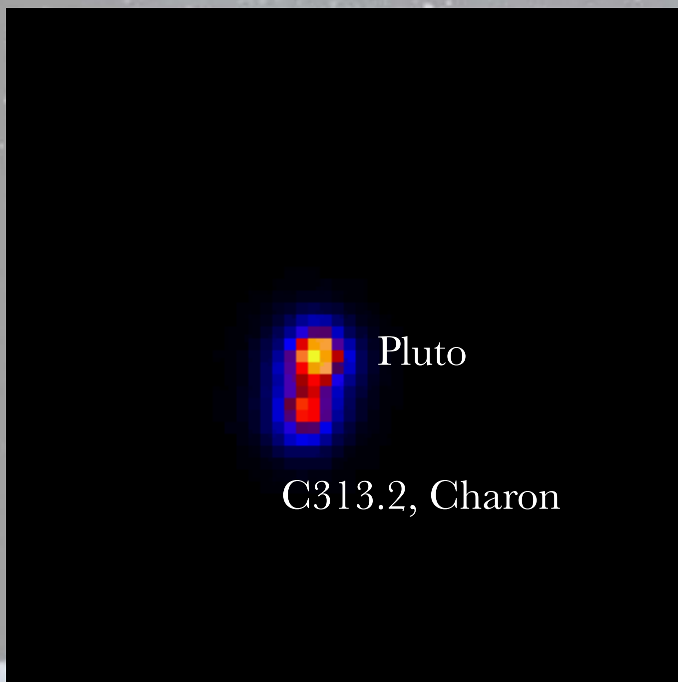


Verbiscer et al. 2007



Buie & Grundy 2000

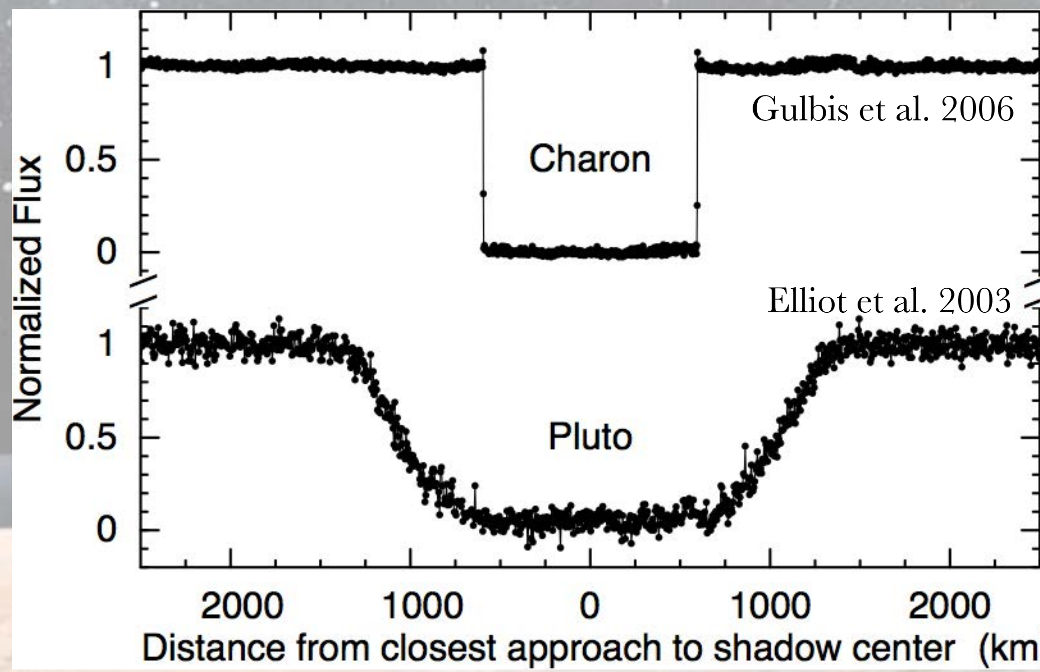
Pluto and Charon: Atmospheres



Observers: J.L. Elliot and E.R. Adams,
Movie: D. Osip *Not real time.

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

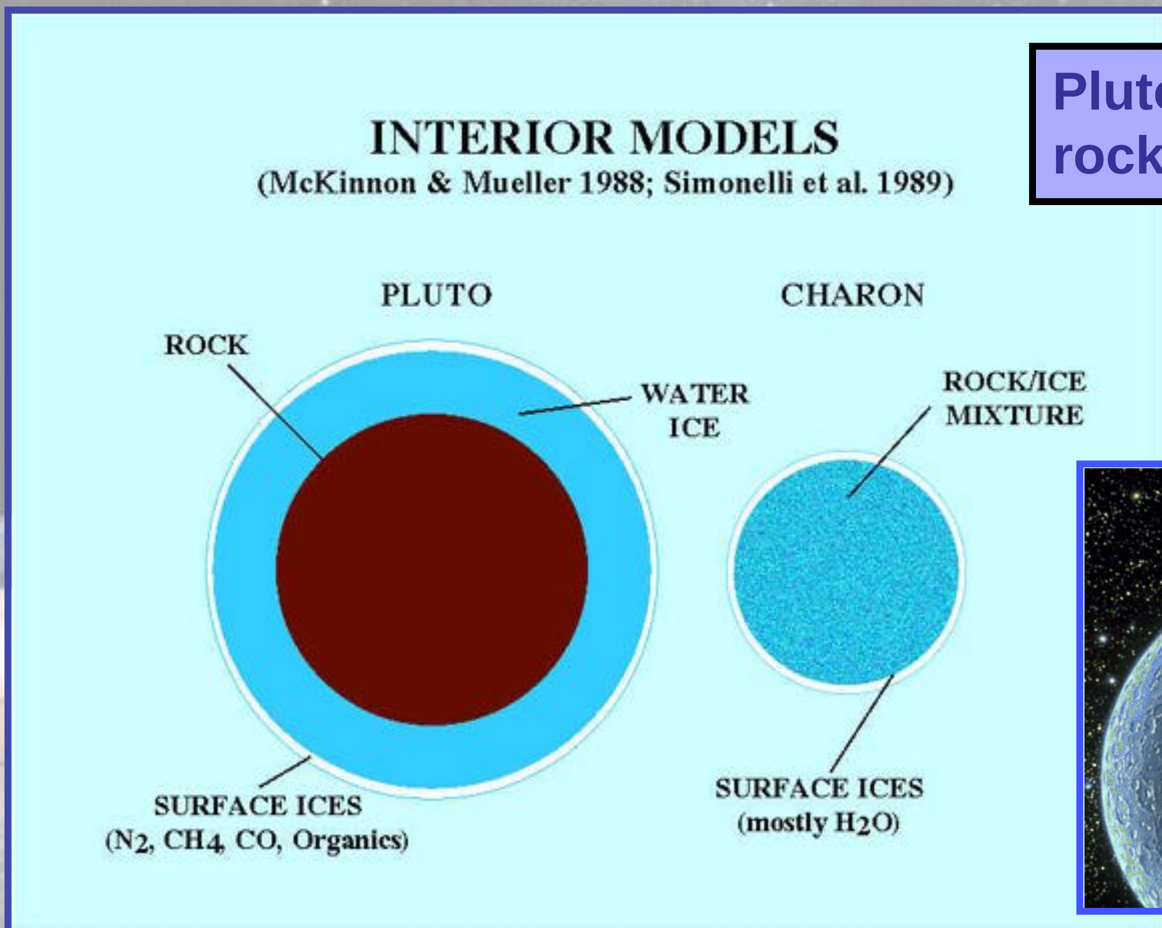
For movie see:
http://occult.mit.edu/research/C313OccMovie.php



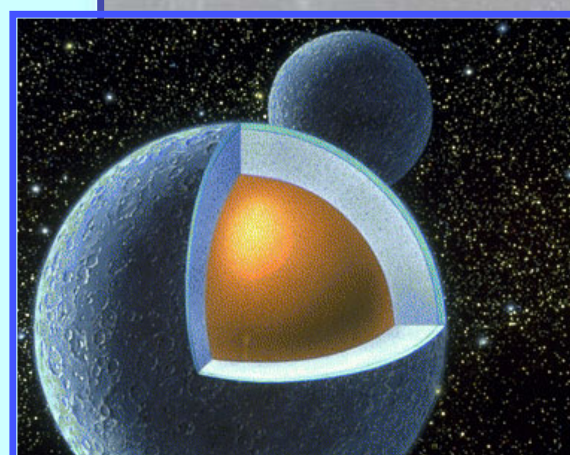
- Charon does not have a substantial atmosphere.
- Pluto has a Nitrogen atmosphere.

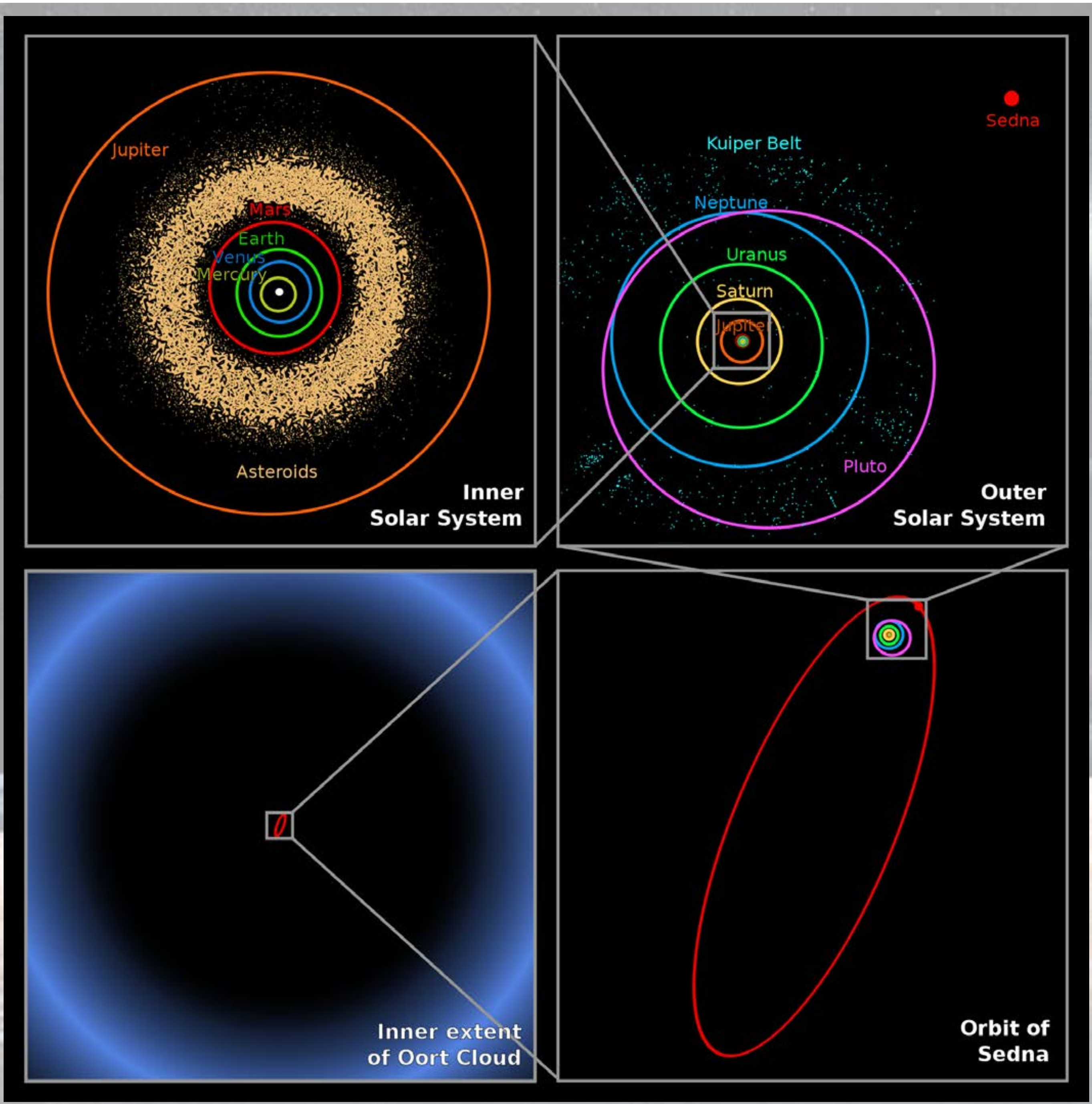
And Do Not Judge This Book By Its Cover

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



Pluto is a primarily rocky, *not* icy body!





Perspective

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

1801 — 1st Asteroid, Ceres

1930 — Pluto discovered

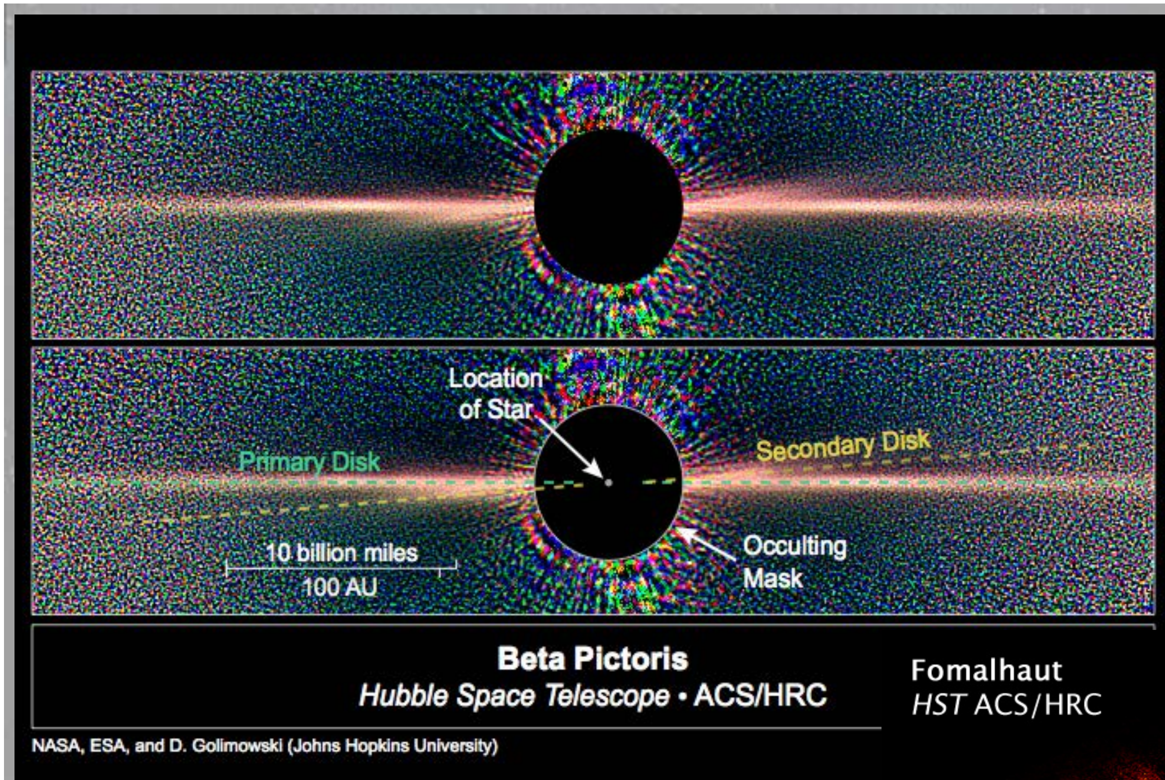
1932/1950 — Opik & Oort theorize about Oort cloud (long period comet reservoir)

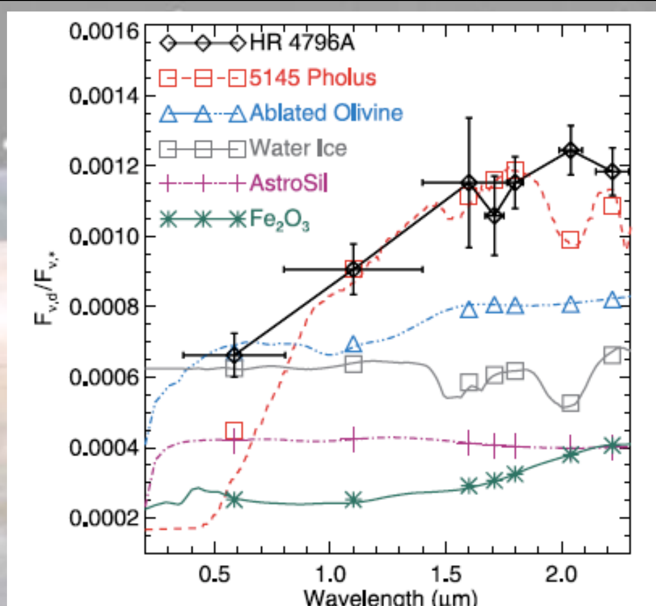
1949/1951 — Edgeworth & Kuiper theorize about the Kuiper Belt

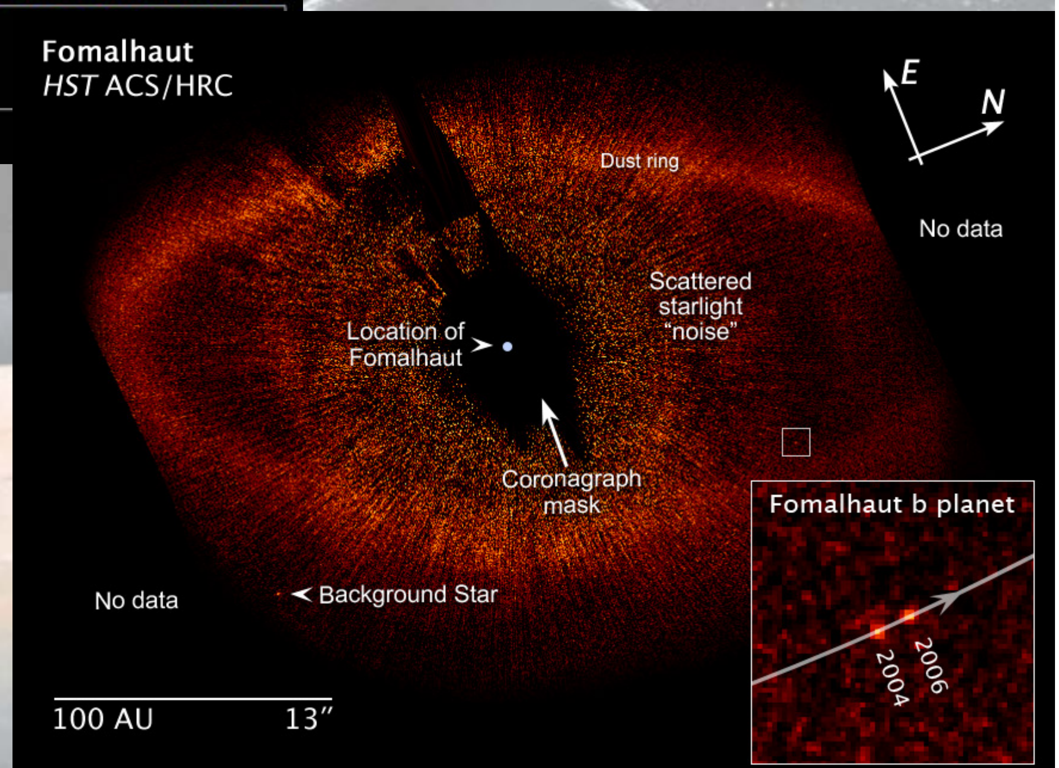
1992 — First Kuiper Belt Object discovered

2002 — First binary Kuiper Belt Object, 1998 WW_{31}

Dust Disks & Exo-plaanet Systems

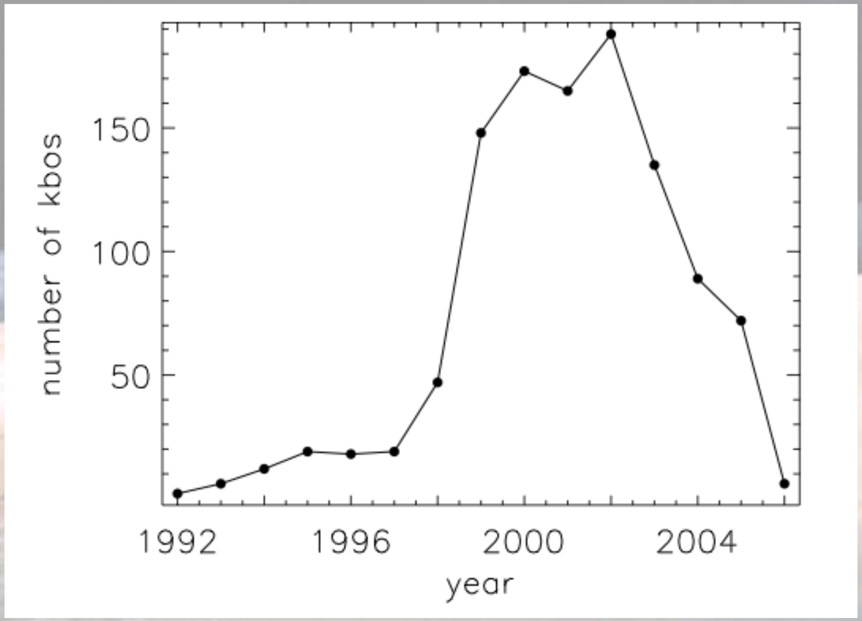


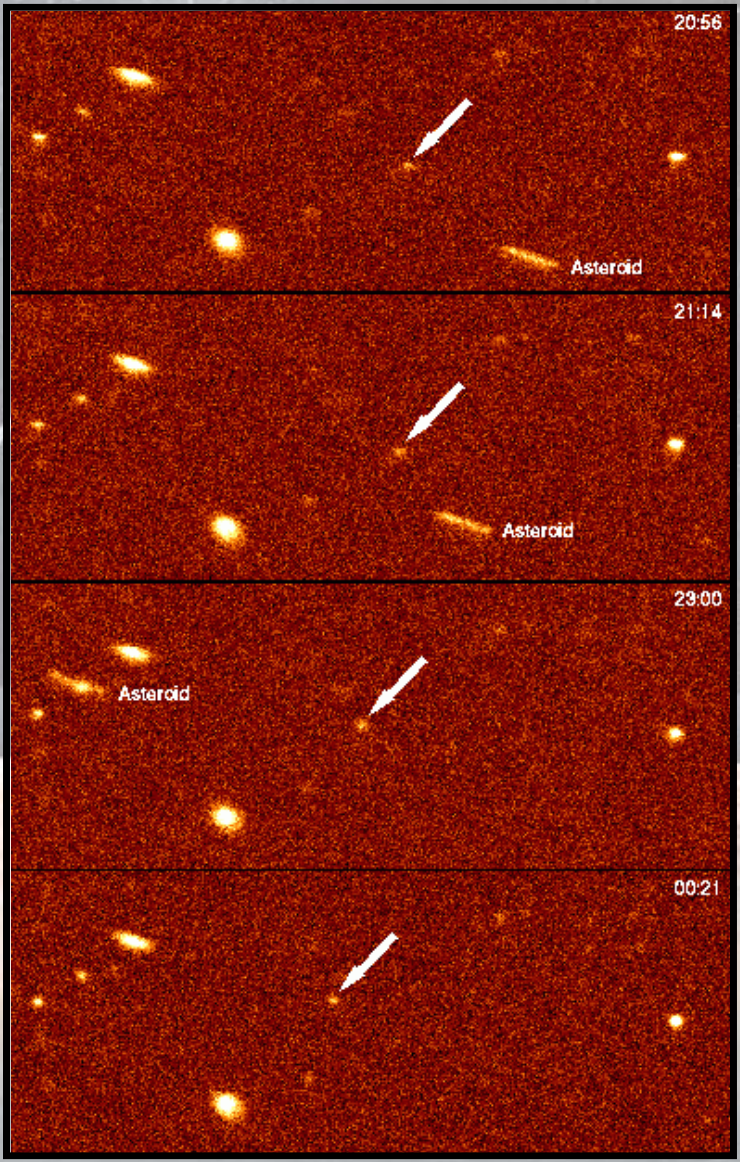




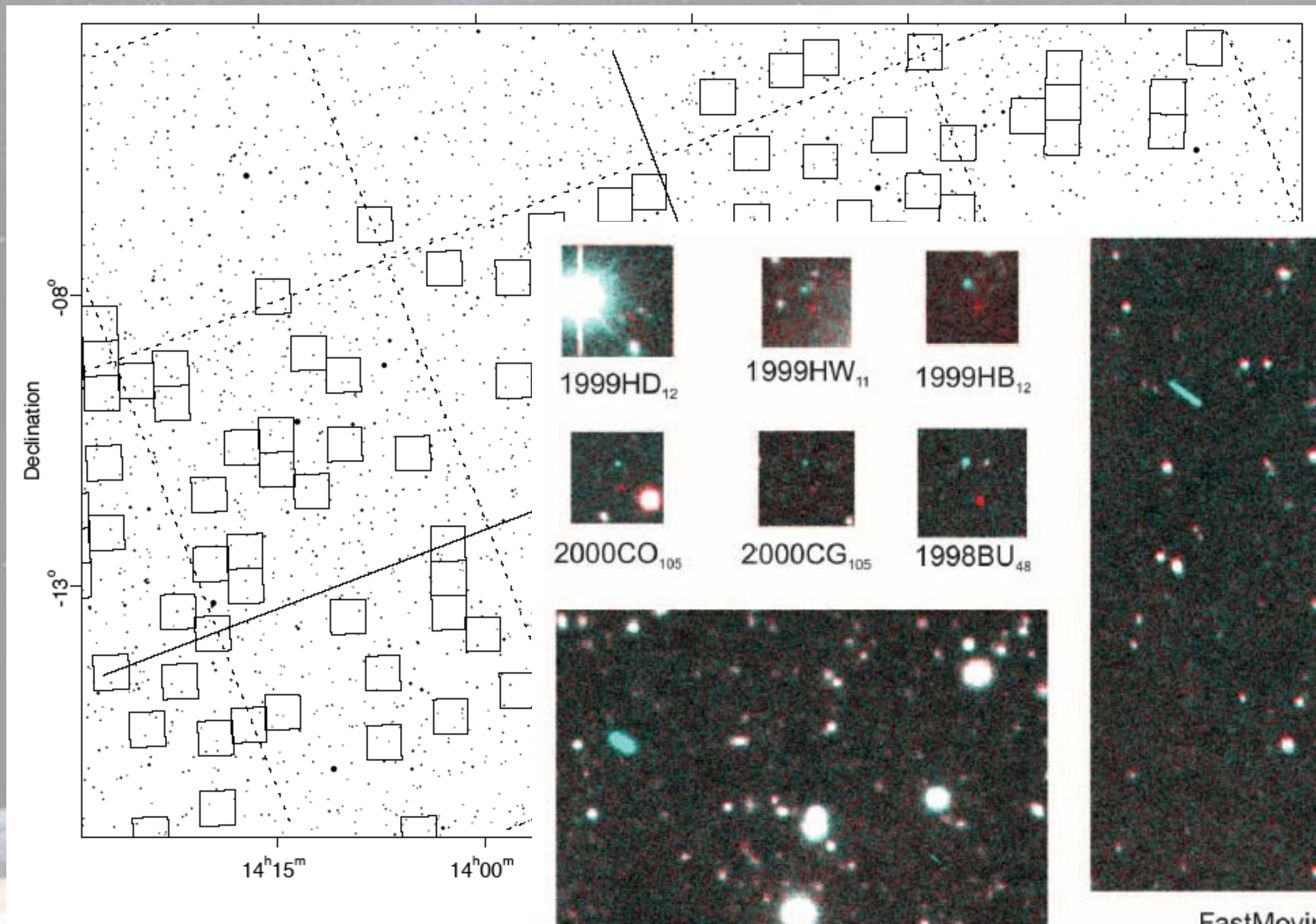
The First KBO: 1992QB1

- 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.

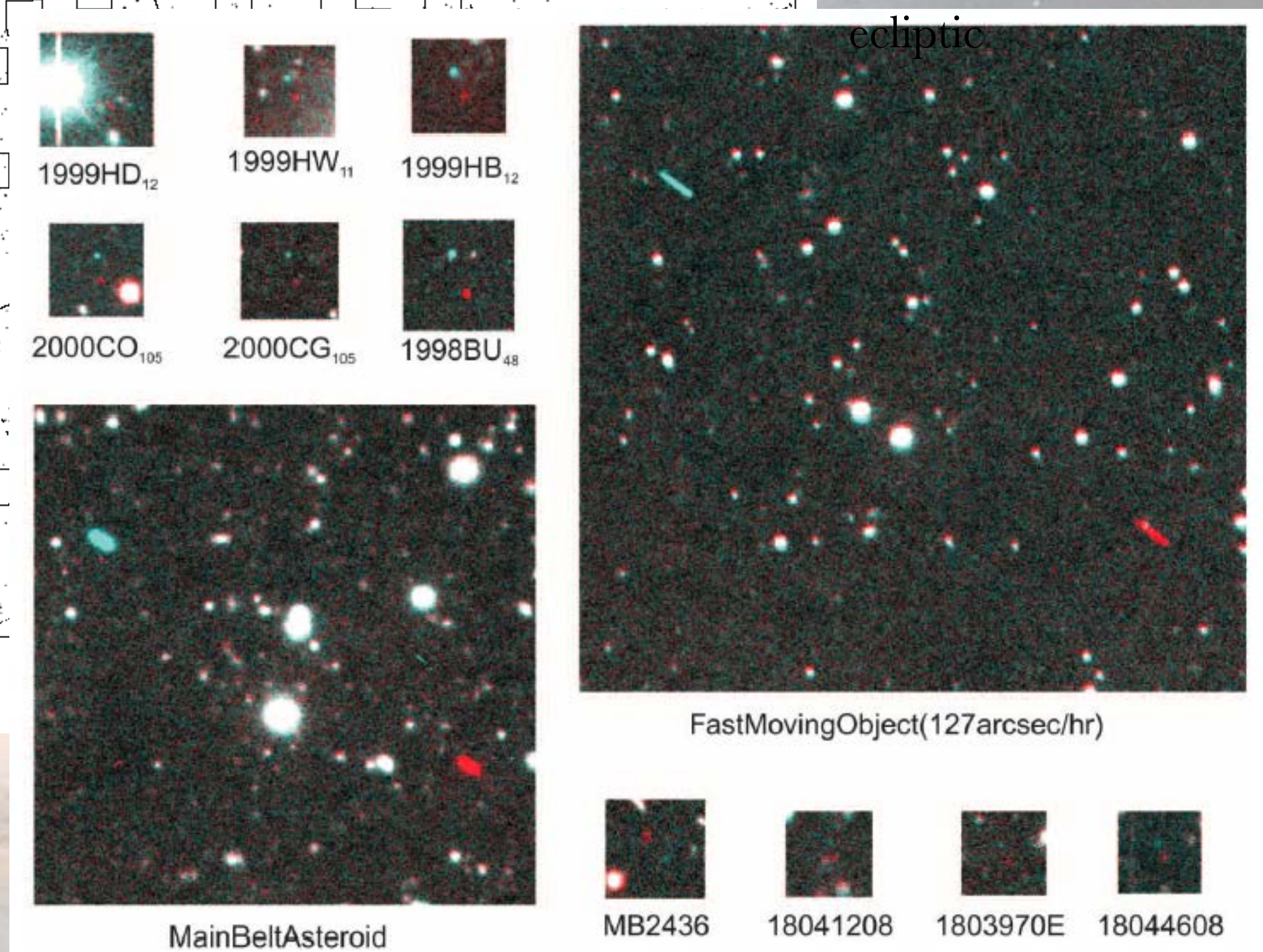




Deep Ecliptic Survey Observations



- Box=0.6°x0.6° on the sky
- ±6.5° of the ecliptic



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

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

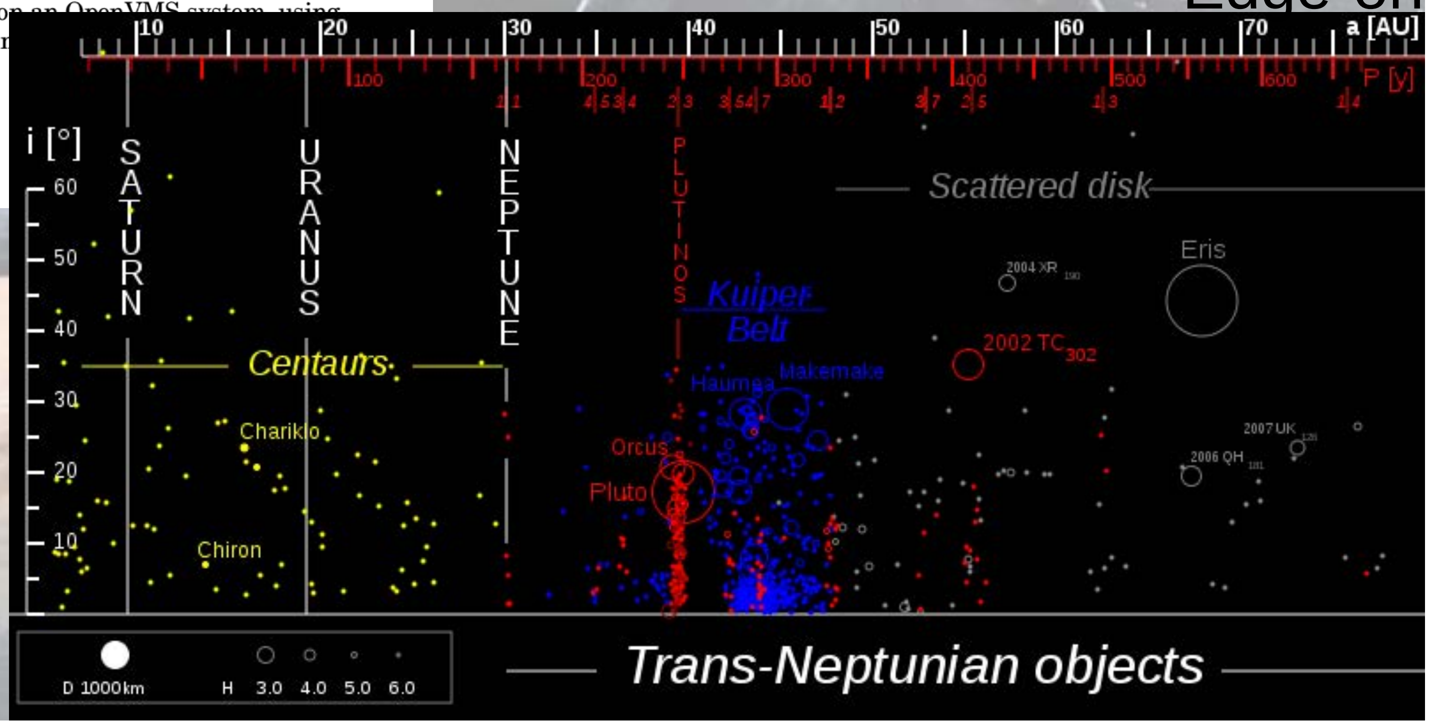
The individual frames were generated on an OpenVMS system, using the PGPLOT graphics library. The ani
RISC OS 4.03 system using !InterGif.

Current KBO Population

Focus on End-Members

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

Edge-on



Face-on

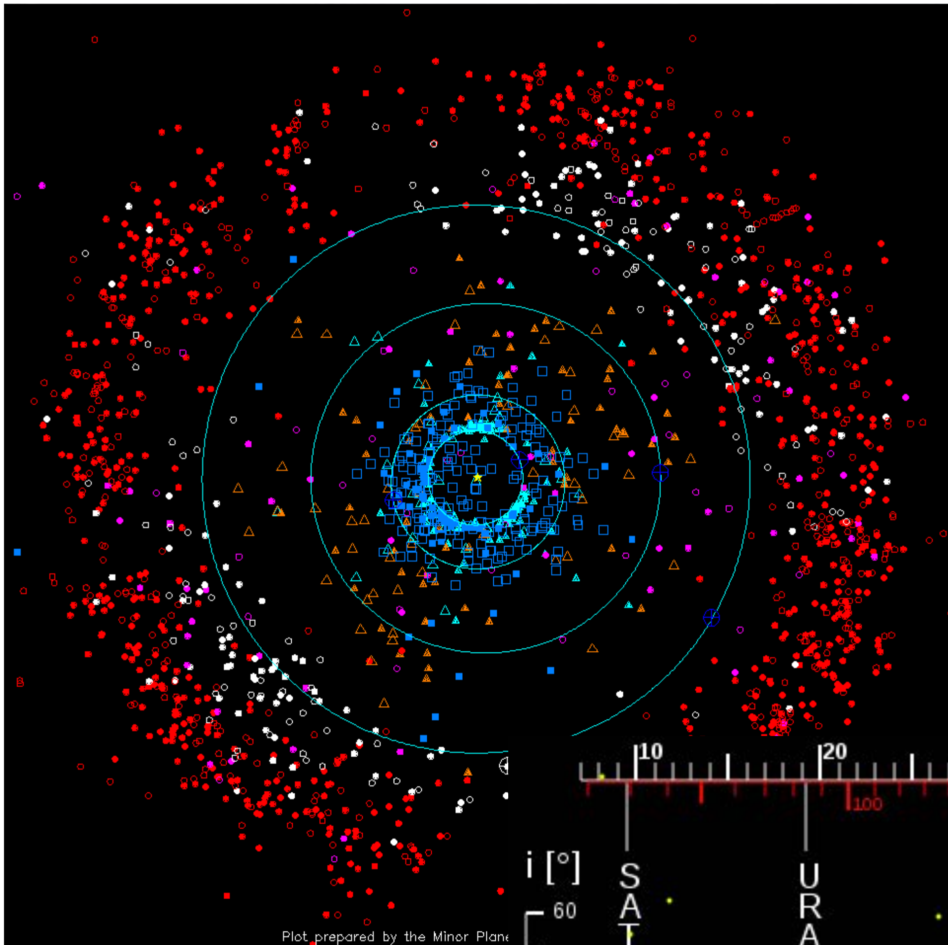
~1600 Objects

18 April 2013
S. D. Benecchi

Current KBO Population

Focus on End-Members

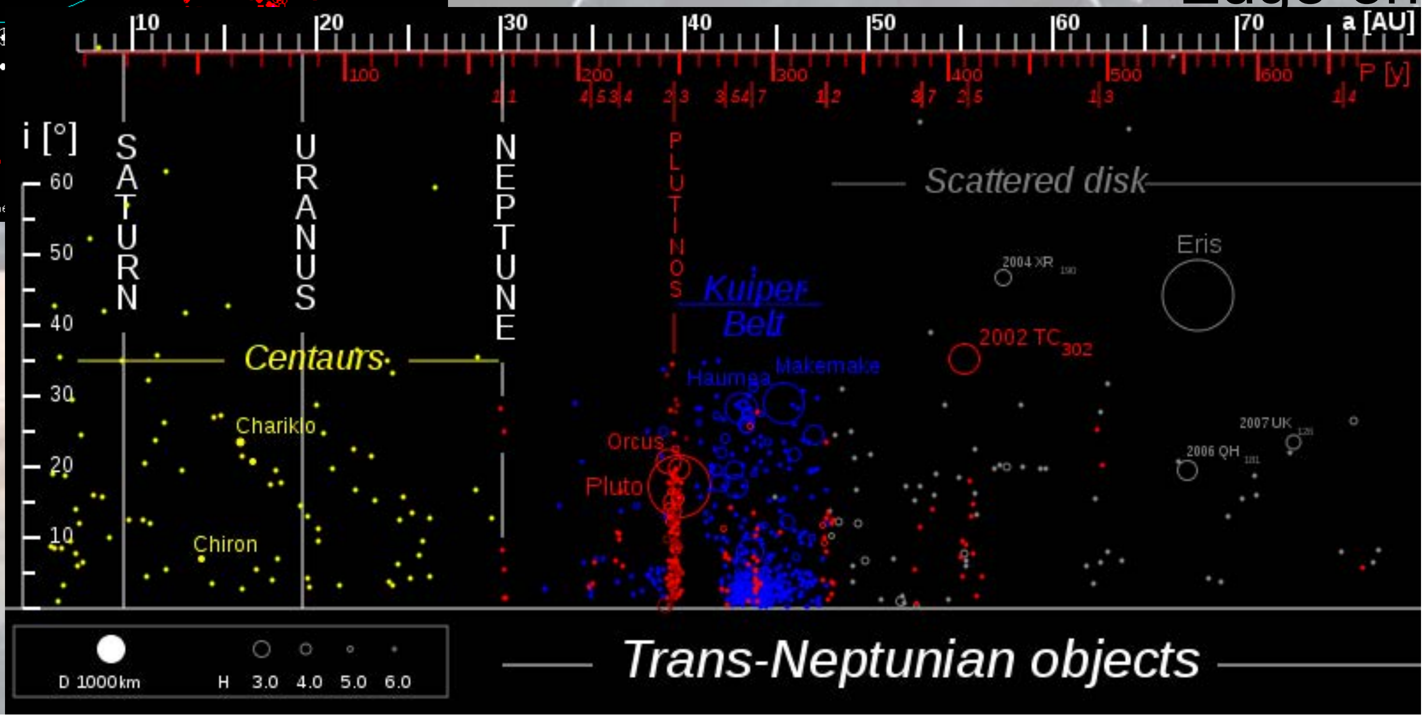
- ✧Objects in dynamically interesting locations
  - ✦Cold Classical Kuiper Belt
  - ✦Resonance populations
  - ✦Centaurs (transition objects)
- ✧Large Objects
- ✧Binaries



Face-on

~1600 Objects

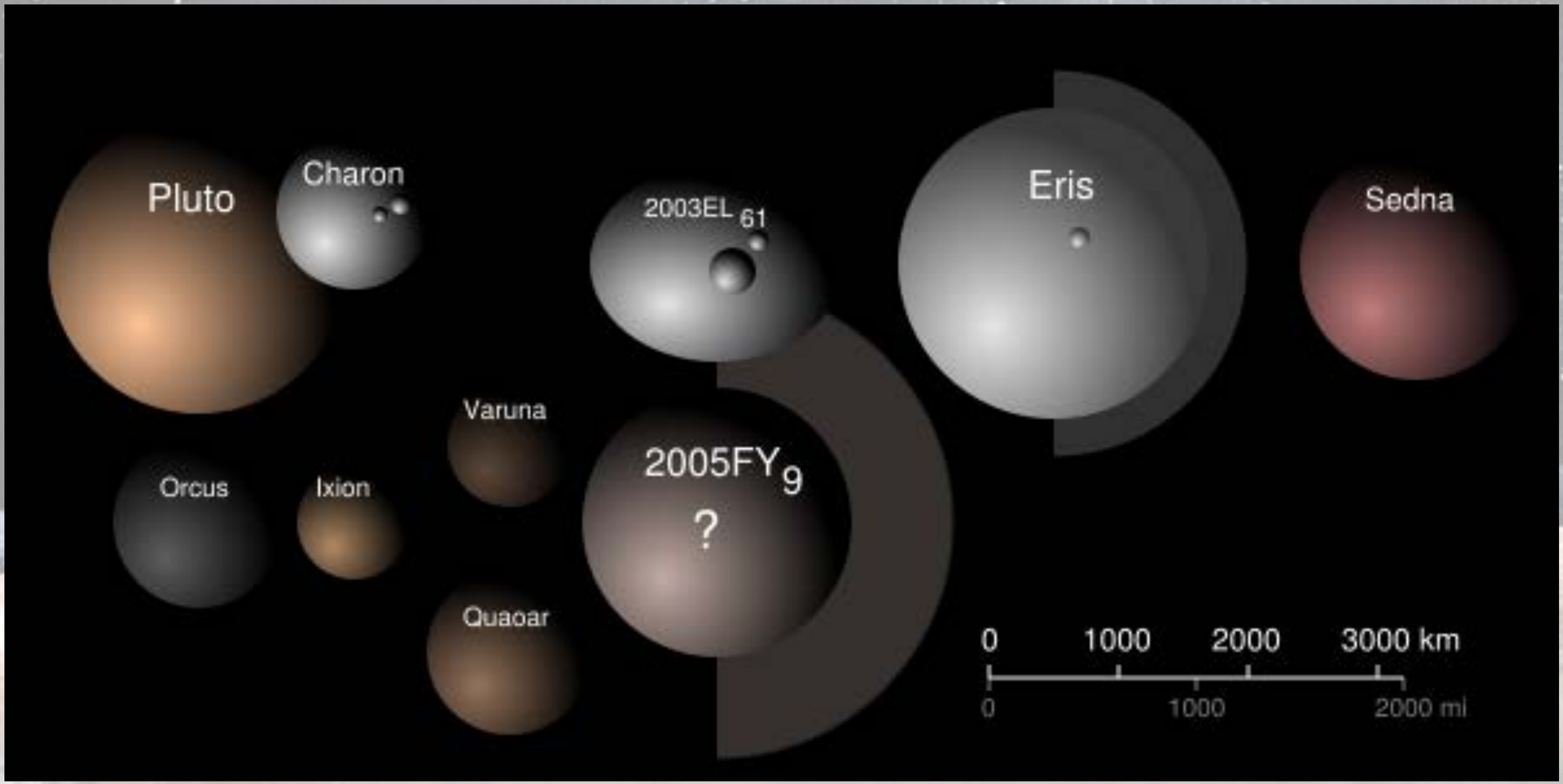
Edge-on



18 April 2013

S. D. Benecchi

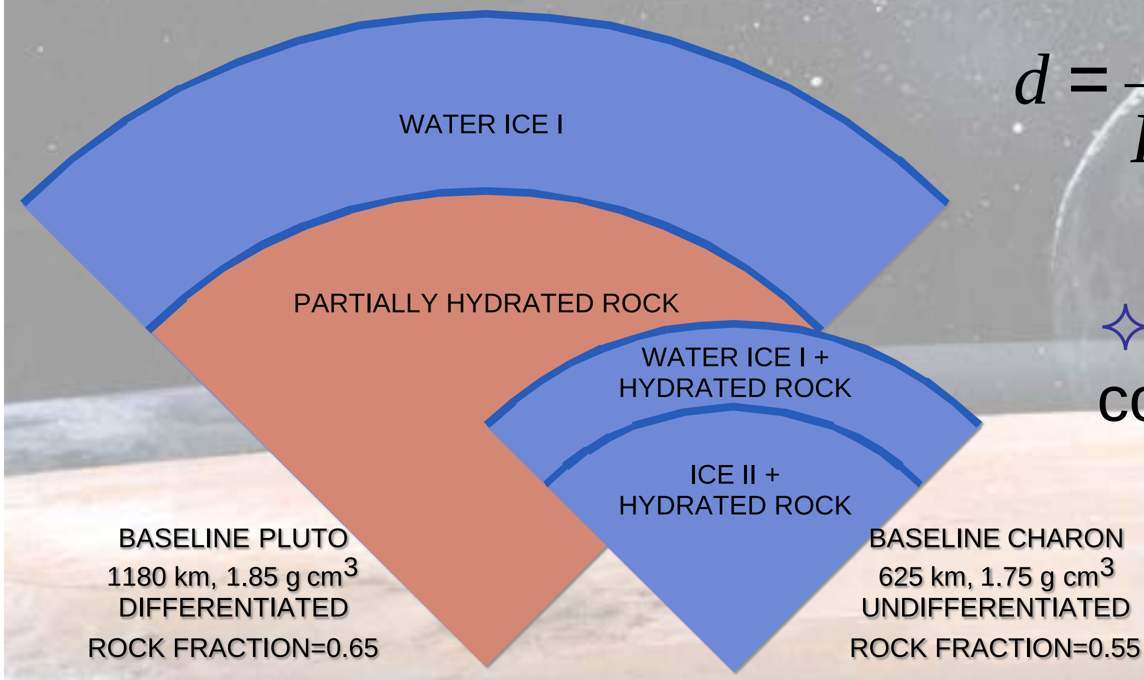
Large Kuiper Belt Objects



Binaries

- binary orbit -> system mass. Kepler’s 3rd law $\left(m_p + m_s\right) = 4\pi^2 a^3 / GP^2$
- diameters assuming (or measuring) an albedo, *p*.

$$d = \frac{2r\Delta}{R\sqrt{p}} 10^{-0.2\left(m_{kbo} + \alpha\beta - m_{sun}\right)}$$



McKinnon et al 1997

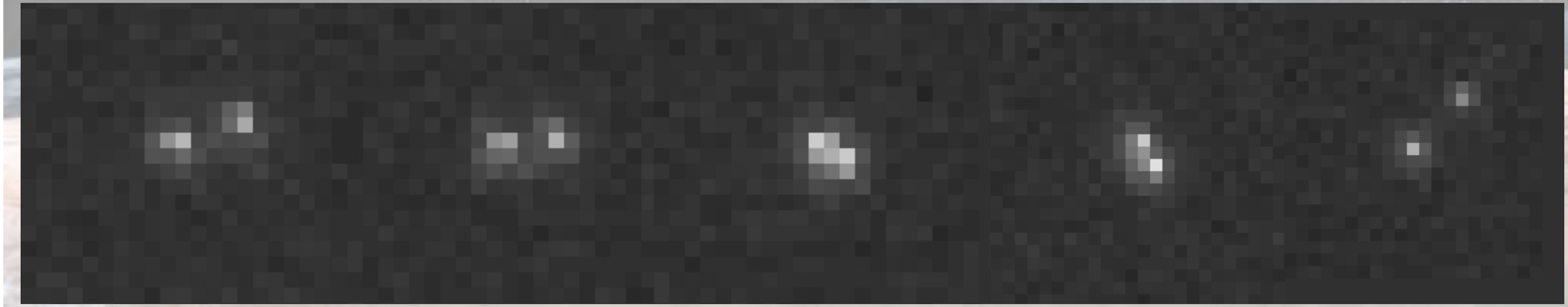
- Density -> Suggest composition.

$$\rho = \frac{m_p + m_s}{\frac{4}{3}\left[\left(\frac{d_p}{2}\right)^3 + \left(\frac{d_s}{2}\right)^3\right]\pi}$$

Binary Orbits

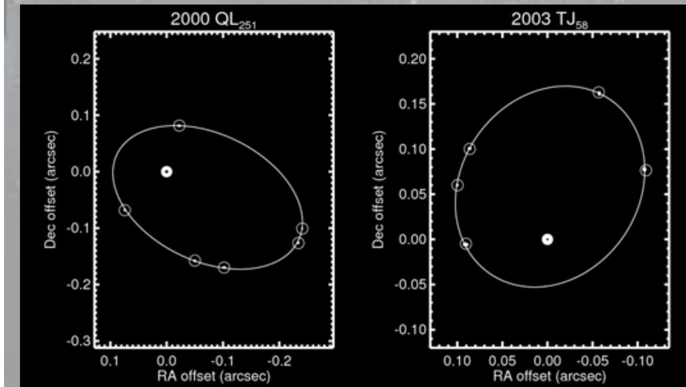
- HST/WFPC2 and HST/ACS programs (also some Keck LGS AO)
- 4 observations per HST orbit, 5 or more orbits per object
- Filter: F606W ~ V, F814W ~ I
- 18+ objects
- Analyzed data with standard HST pipeline and iterative PSF fitting of binary images with Tiny Tim models.

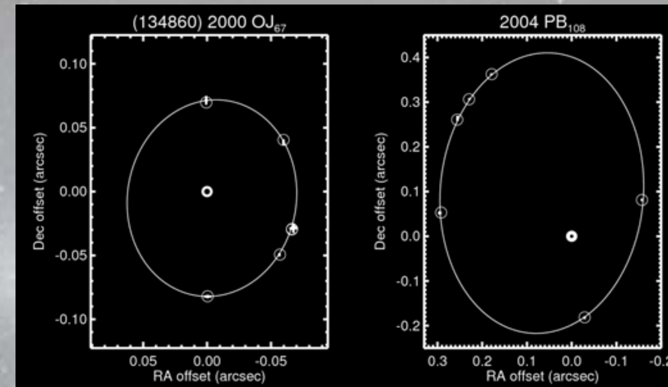
Science Motivation: Measure system mass for objects in the Kuiper Belt to learn about density/composition. Also to learn about scattering in the Kuiper Belt.

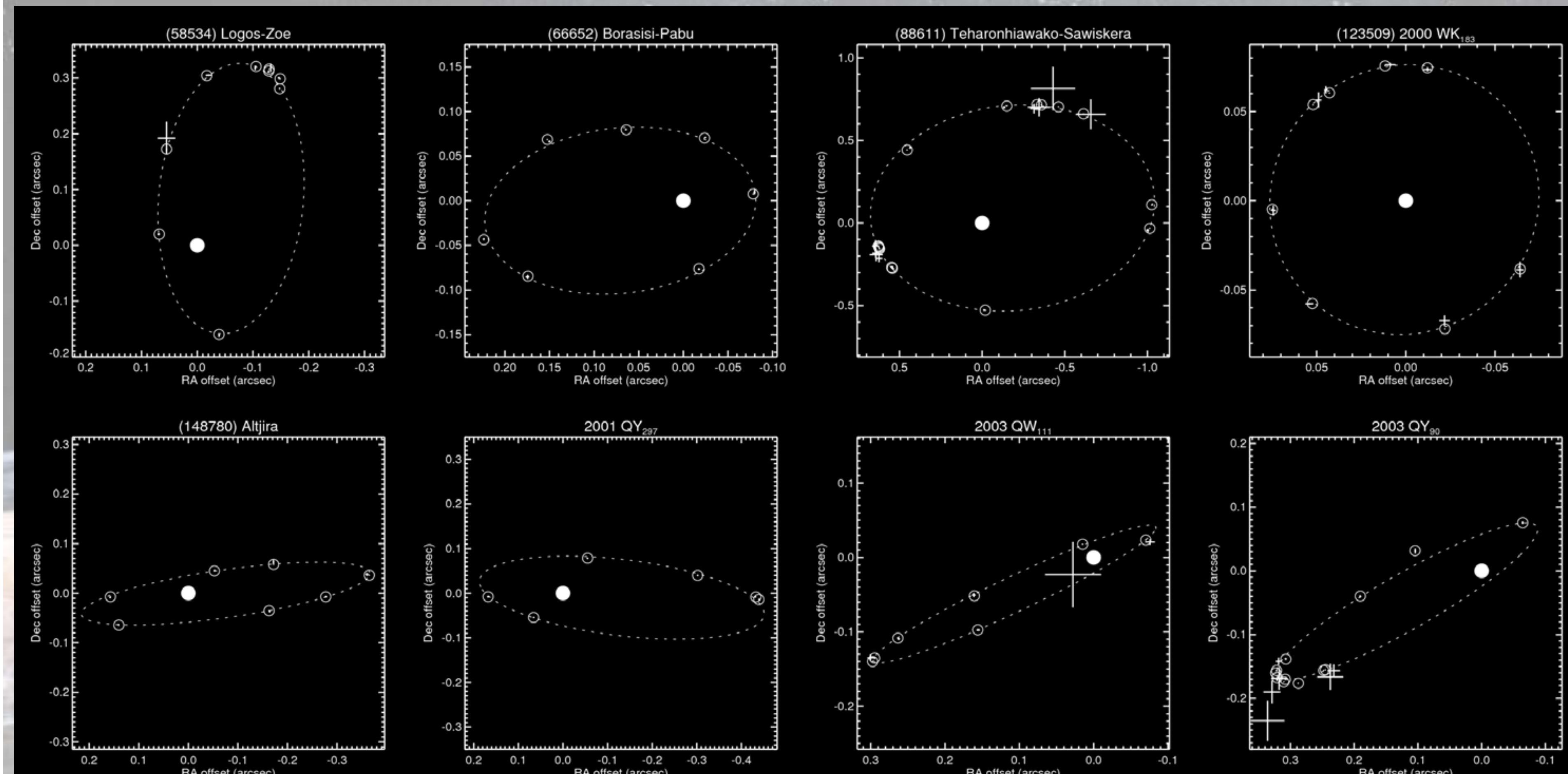


2001 QL_{251}, 5 HST visits with WFPC2, Grundy et al. 2009 Icarus

Orbits

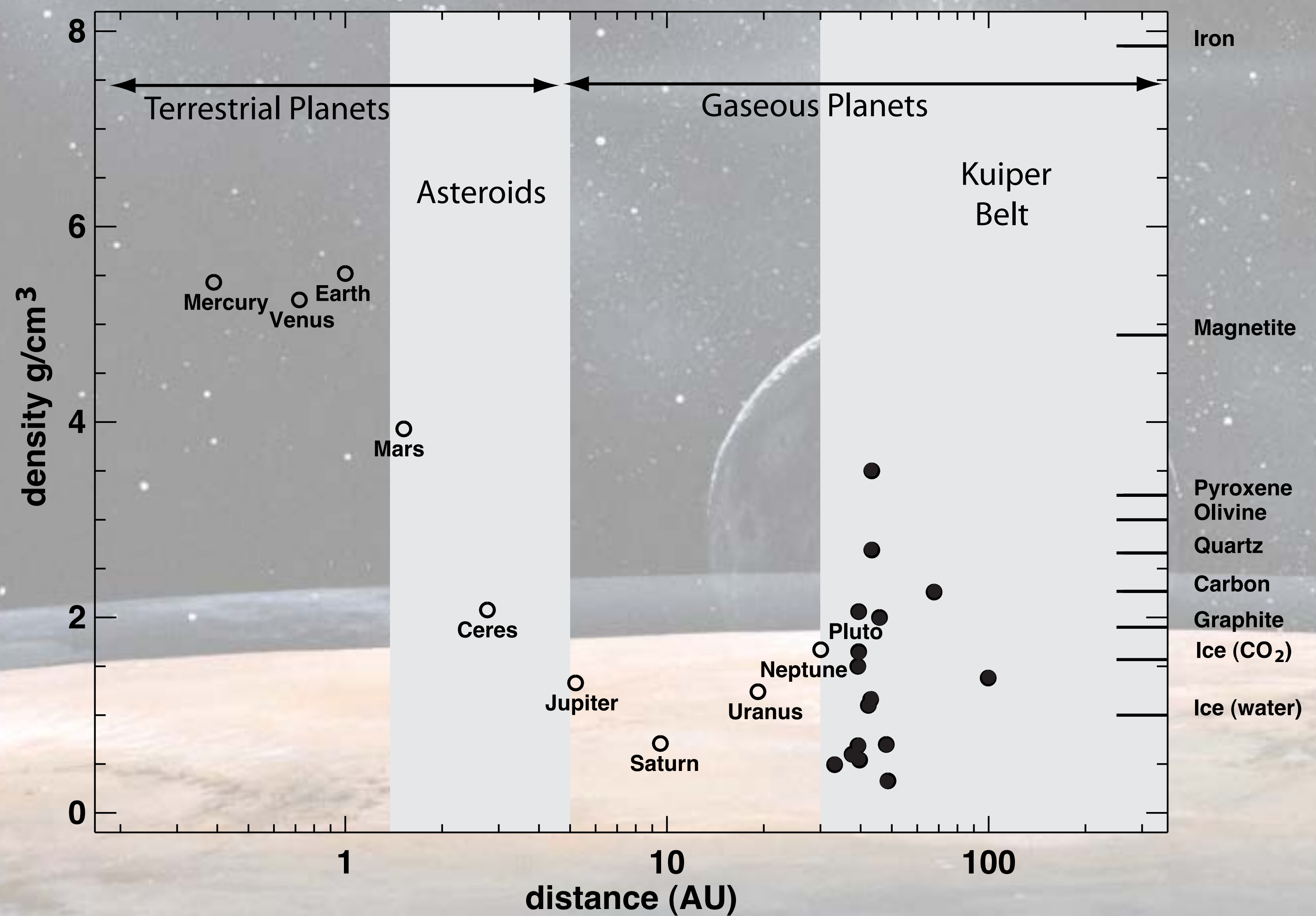






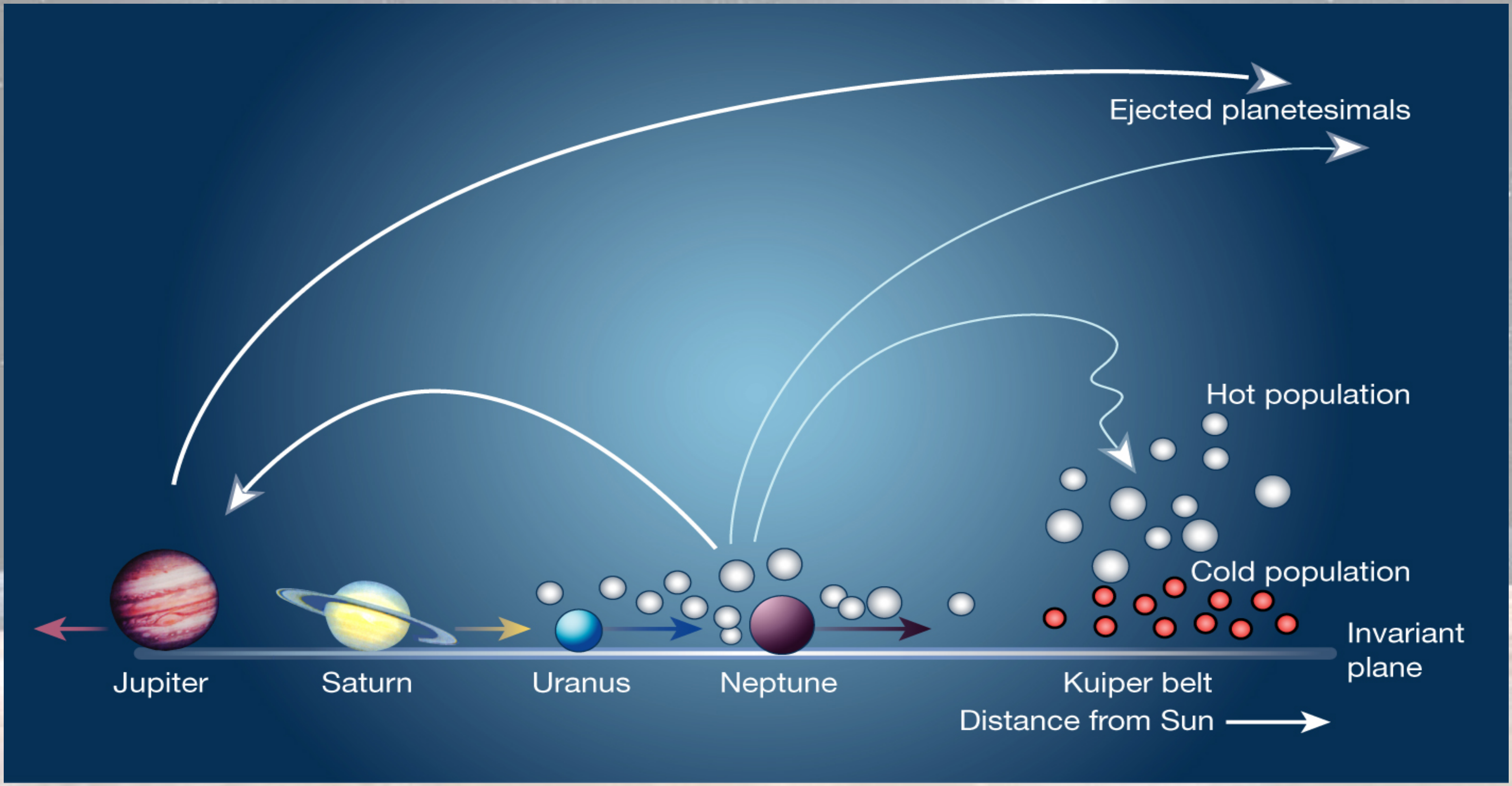
Grundy et al. 2009, 2011

Density in the Solar System



18 April 2013 S. D. Benecchi

A Formation Scenario



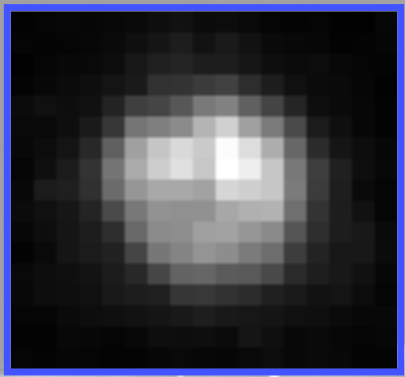
Gomes 2003, EMP; Figure from West 2003

New Horizons: Launched January 19, 2006
Pluto System Arrival: July 2015

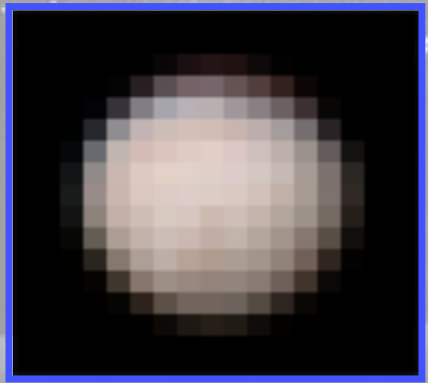
Some of the slides that follow are extracted from presentations made by New Horizons Scientists and can be found on the New Horizons website.

Great Progress is Fundamentally Limited Until We Visit

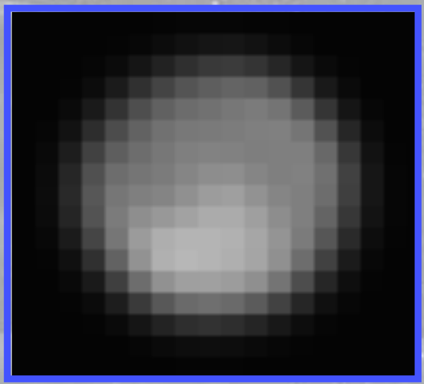
This is the fundamental exploration lesson of planetary science.



Pluto at Best HST Resolution



Triton at Best HST Resolution



Earth's Moon at the Same Resolution

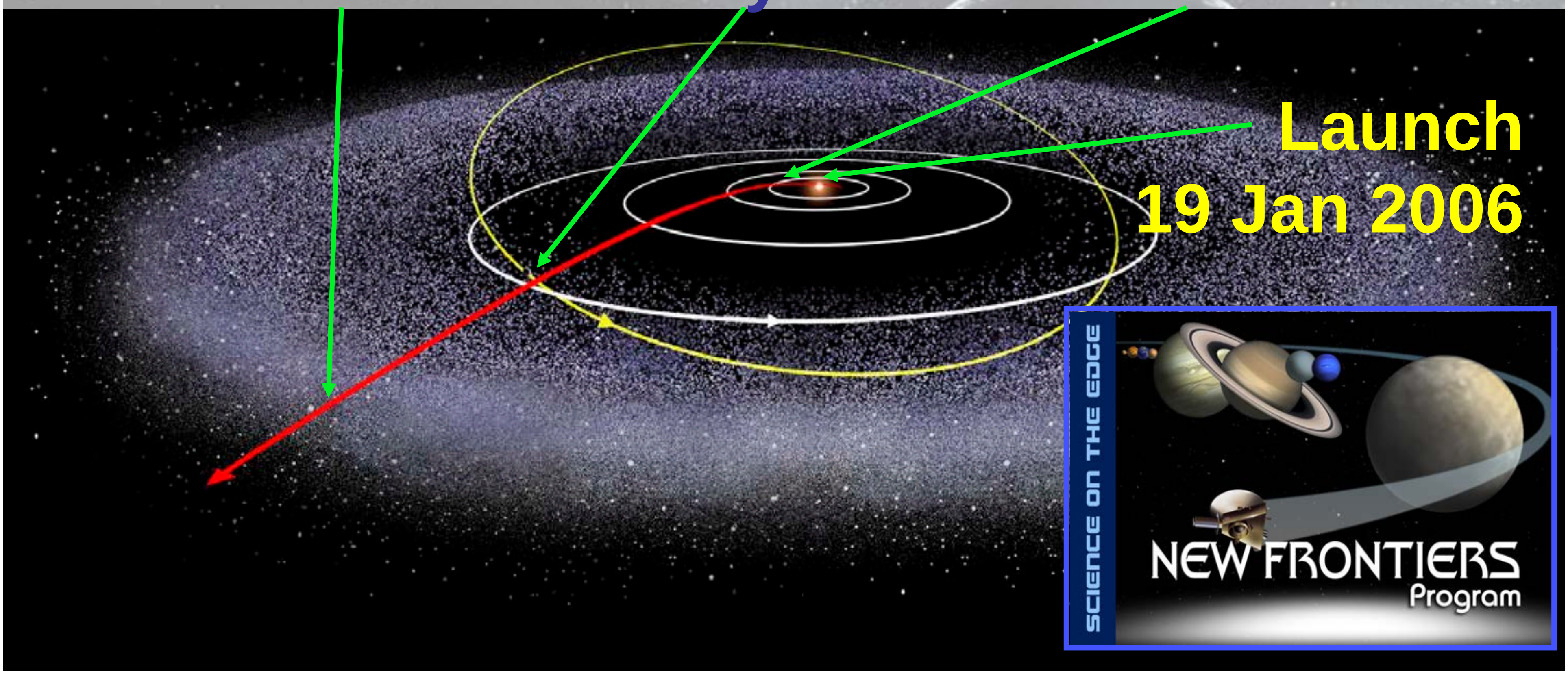
NEW HORIZONS

The Initial Reconnaissance of The Solar System's "Third Zone"

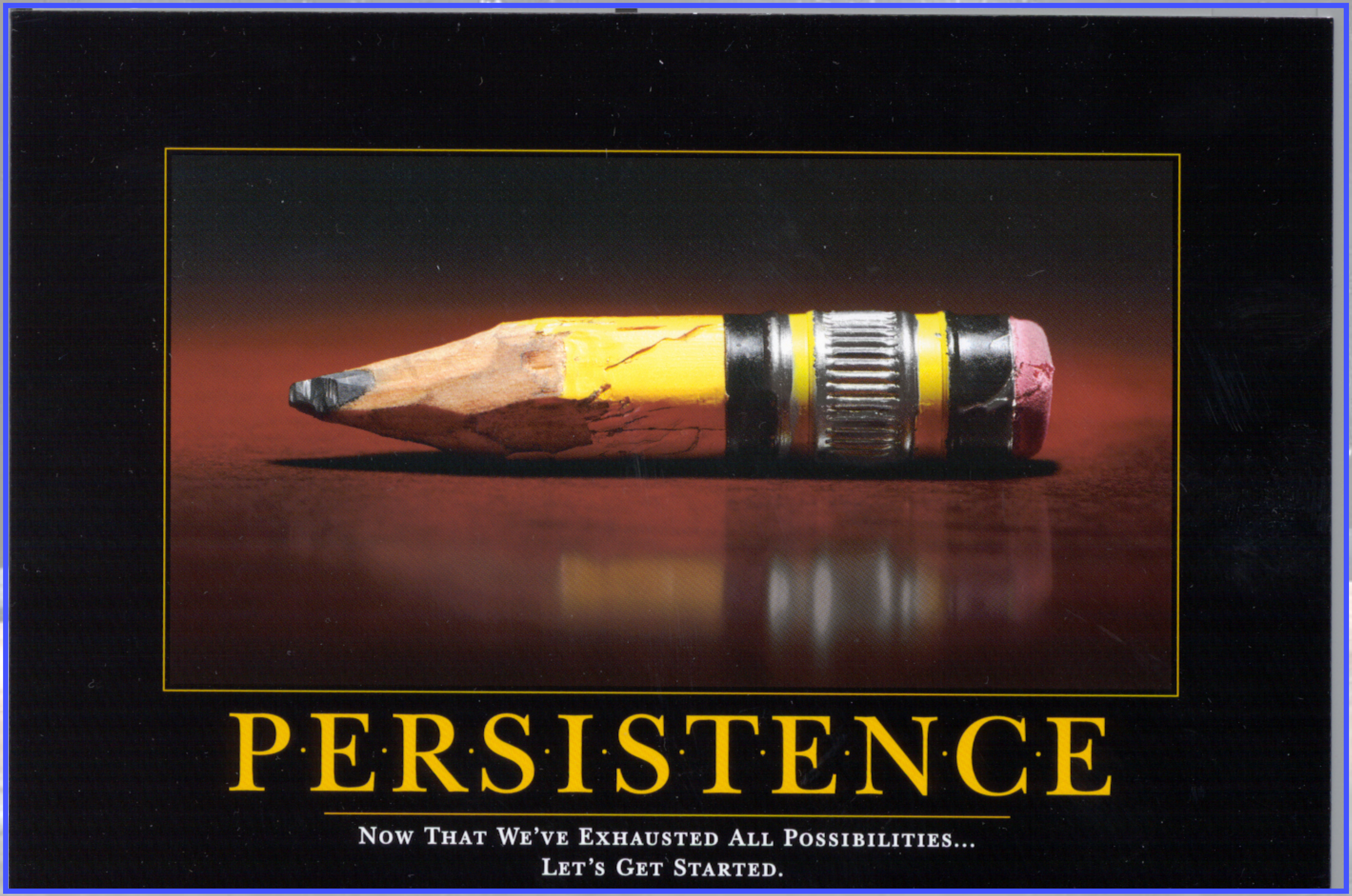
KBOs 2016-2020

Pluto-Charon 14 July 2015

Jupiter System 28 Feb 2007



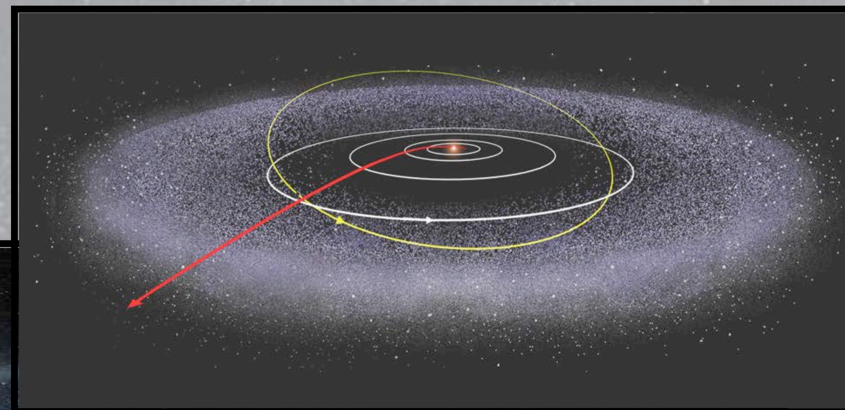
A Mission to Pluto Has Been Worked In the Science Community Since 1989

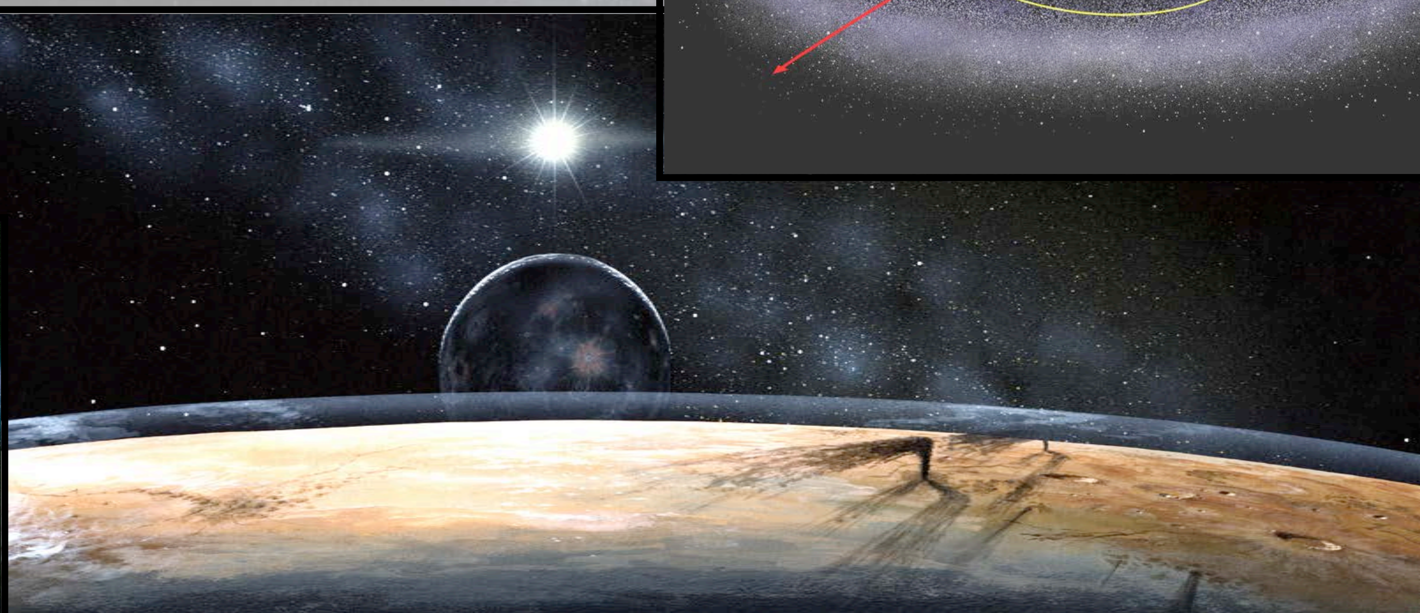


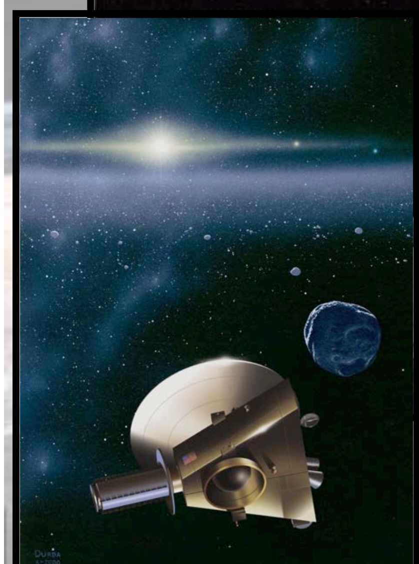
Toward New Horizons

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

A Reconnaissance Expedition To the Kuiper Belt & Pluto-Charon





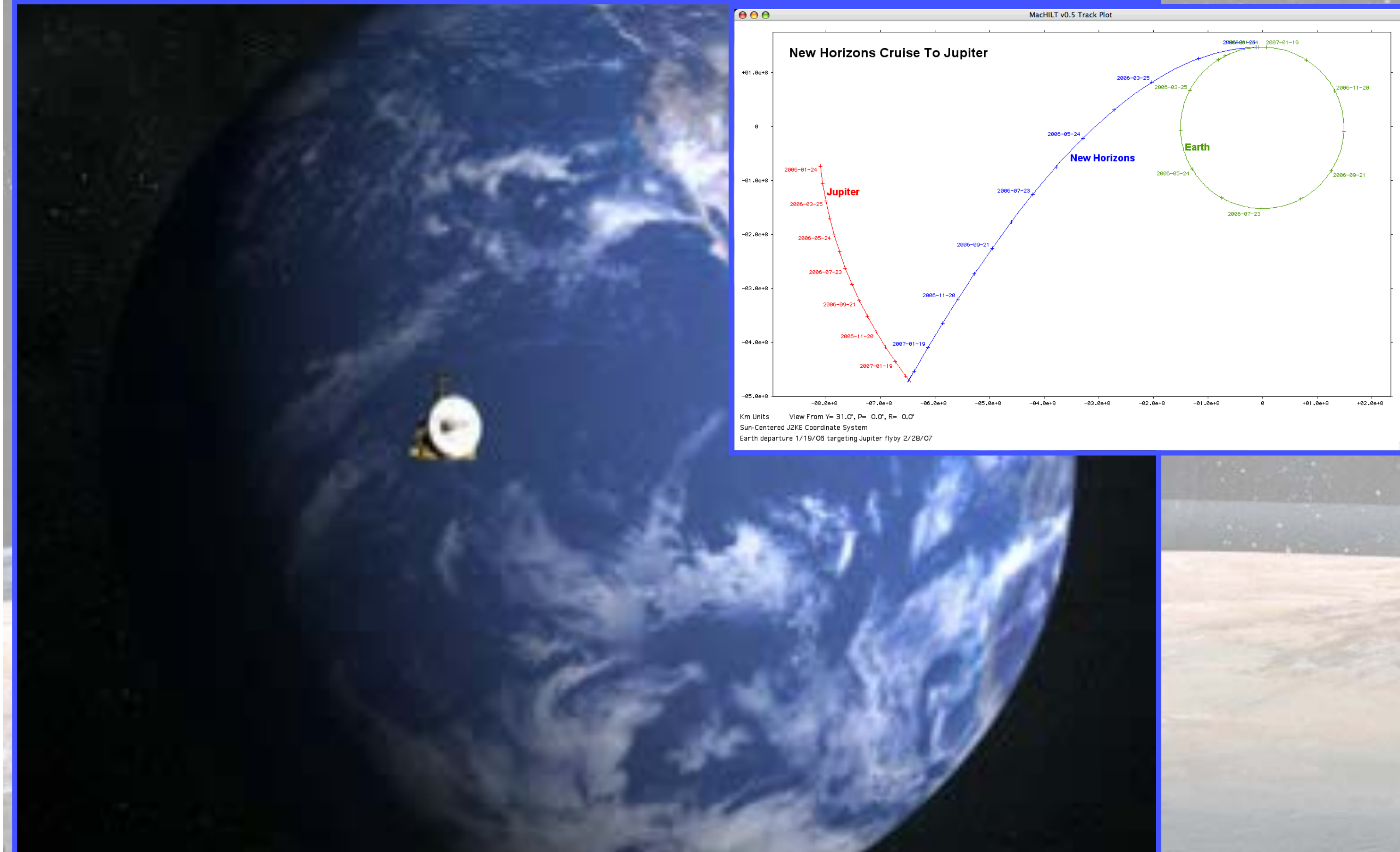


18 April 2013

S. D. Benecchi

Launch: 19 January 2006

Leaving Home



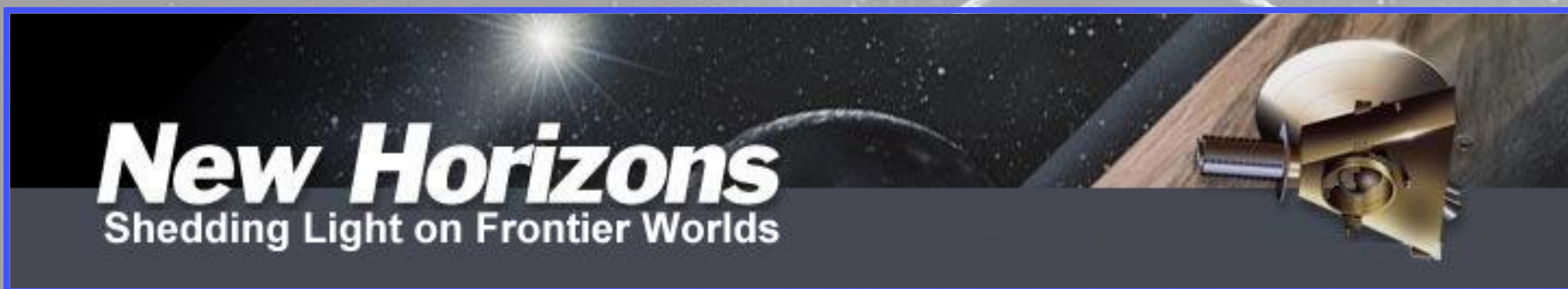
Project Philosophy

Offer early and highly-leveraged science.

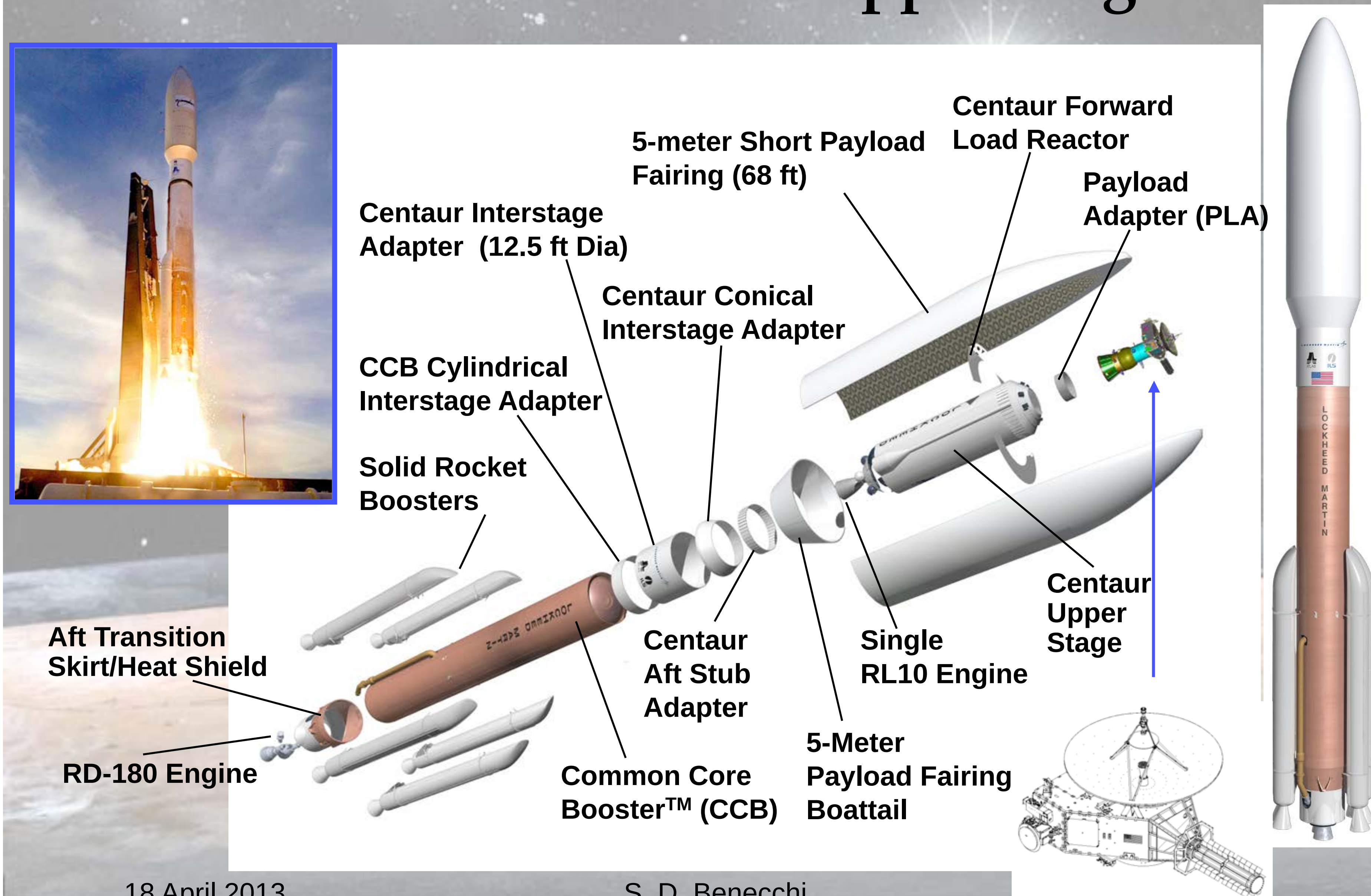
Do so on time, within budget, and at low risk.

Provide Intensive Public Outreach

Keep It Simple



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

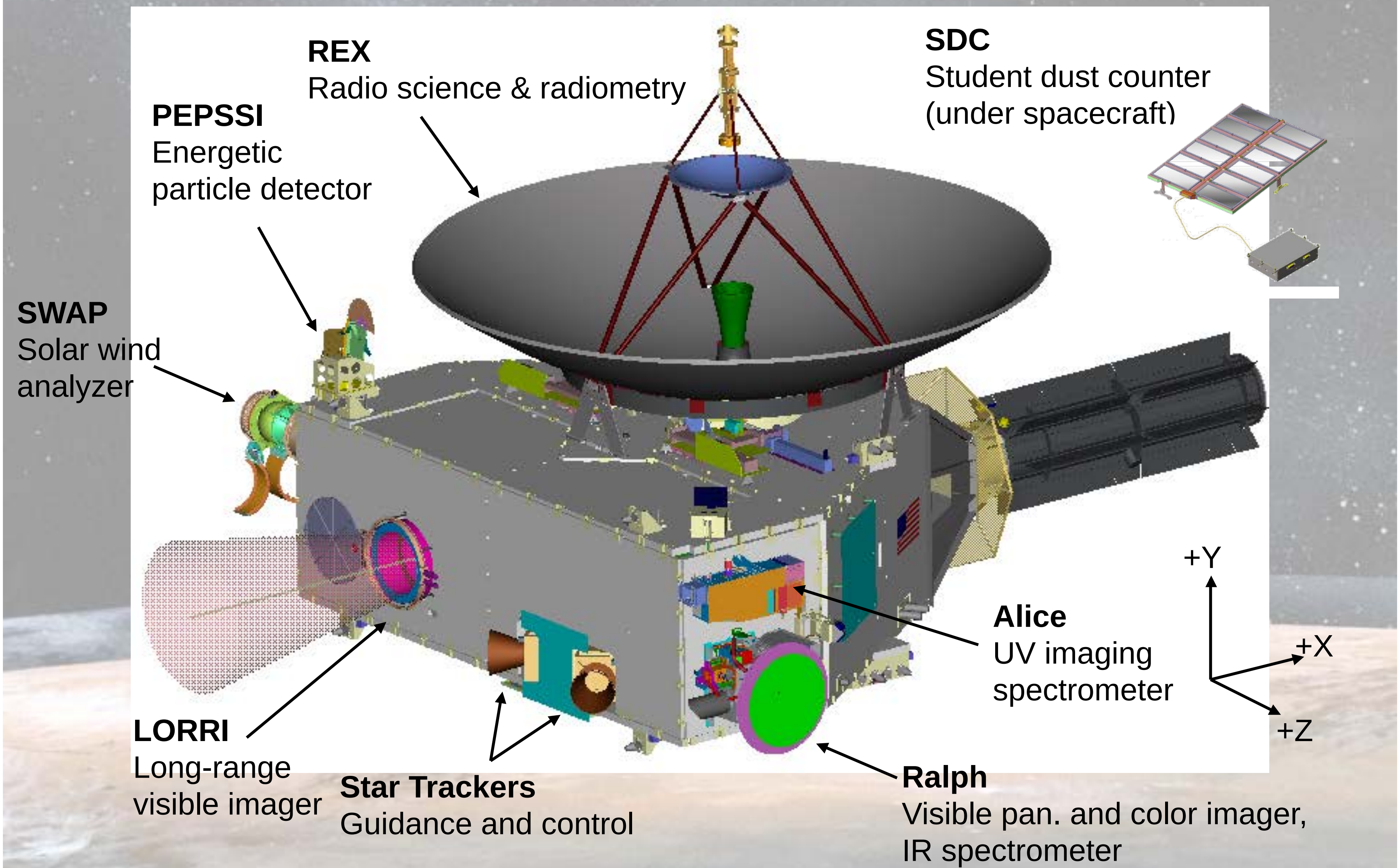


NASA-Specified Pluto-Charon Measurement Objectives

Group 1 Objectives: Required
Characterize the global geology and morphology of Pluto and Charon
Map surface composition of Pluto and Charon
Characterize the neutral atmosphere of Pluto and its escape rate
Group 2 Objectives: Important
Characterize the time variability of Pluto's surface and atmosphere
Image Pluto and Charon in stereo
Map the terminators of Pluto and Charon with high resolution
Map the composition of selected areas of Pluto & Charon at high resolution
Characterize Pluto's ionosphere and solar wind interaction
Search for neutral species including H, H_2, HCN, and C_xH_y, and other hydrocarbons and nitriles in Pluto's upper atmosphere
Search for an atmosphere around Charon
Determine bolometric Bond albedos for Pluto and Charon
Map the surface temperatures of Pluto and Charon
Group 3 Objectives: Desired
Characterize the energetic particle environment of Pluto and Charon
Refine bulk parameters (radii, masses, densities) and orbits of Pluto & Charon
Search for magnetic fields of Pluto and Charon
Search for additional satellites and rings

New Horizons Spacecraft

Instrumentation



Student Dust Counter: A New Kind of EPO

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

- ❑ **<u>Science Goal:</u> Make the first dust density & size spectrum observations beyond 18 AU.**

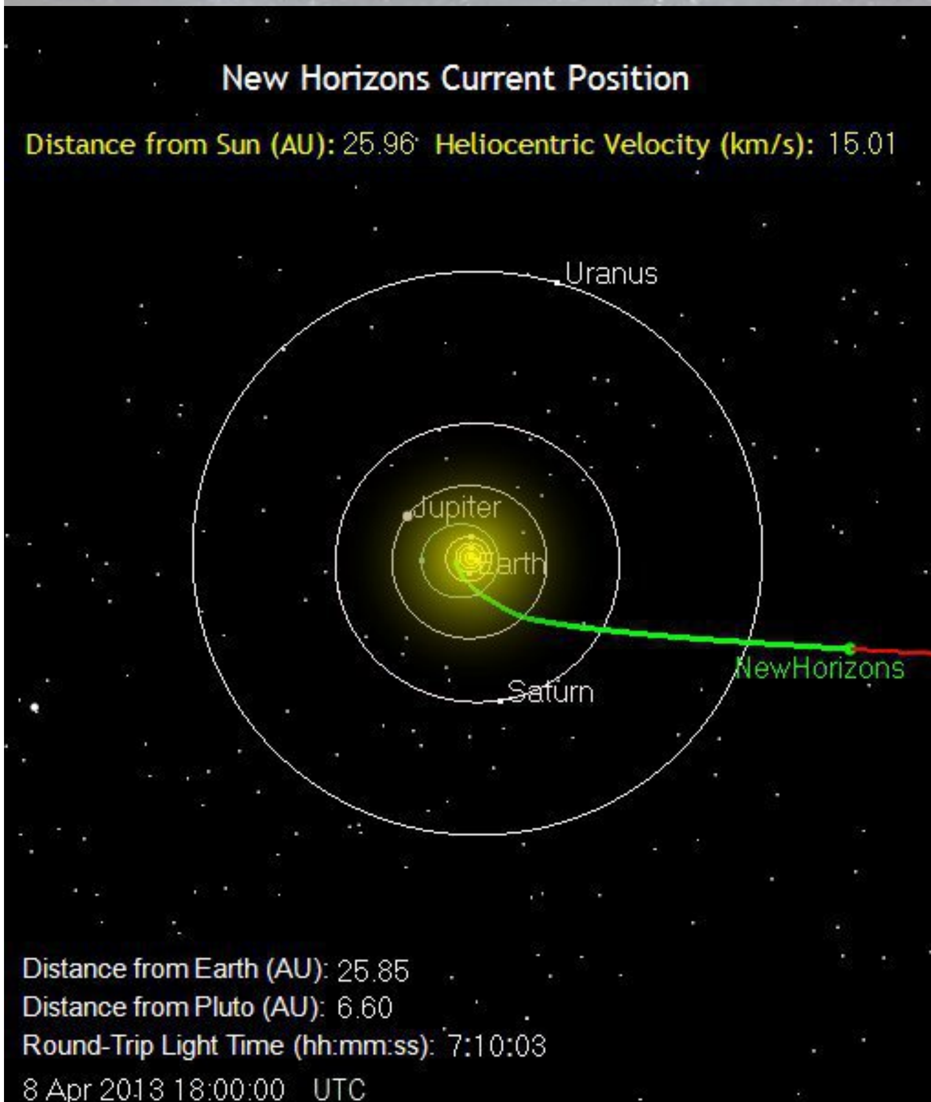
- ❑ **<u>Students have the primary responsibility</u> for the design and development of the SDC; over 35 "first Generation" students presently involved at CU, Dozens more across the U.S.**

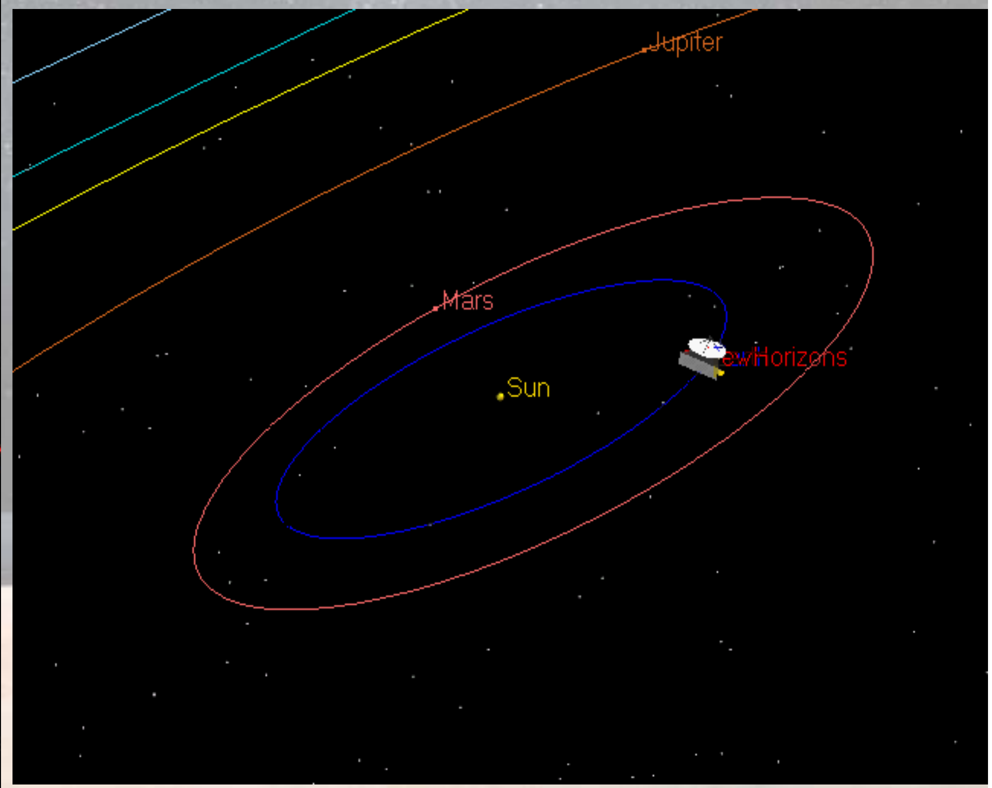
- ❑ **<u>Science CoI:</u> Mihaly Horanyi.**

- ❑ **<u>Four-to-Five Generations of Students To Be Directly Involved.</u>**

SDC Student Team Leaders

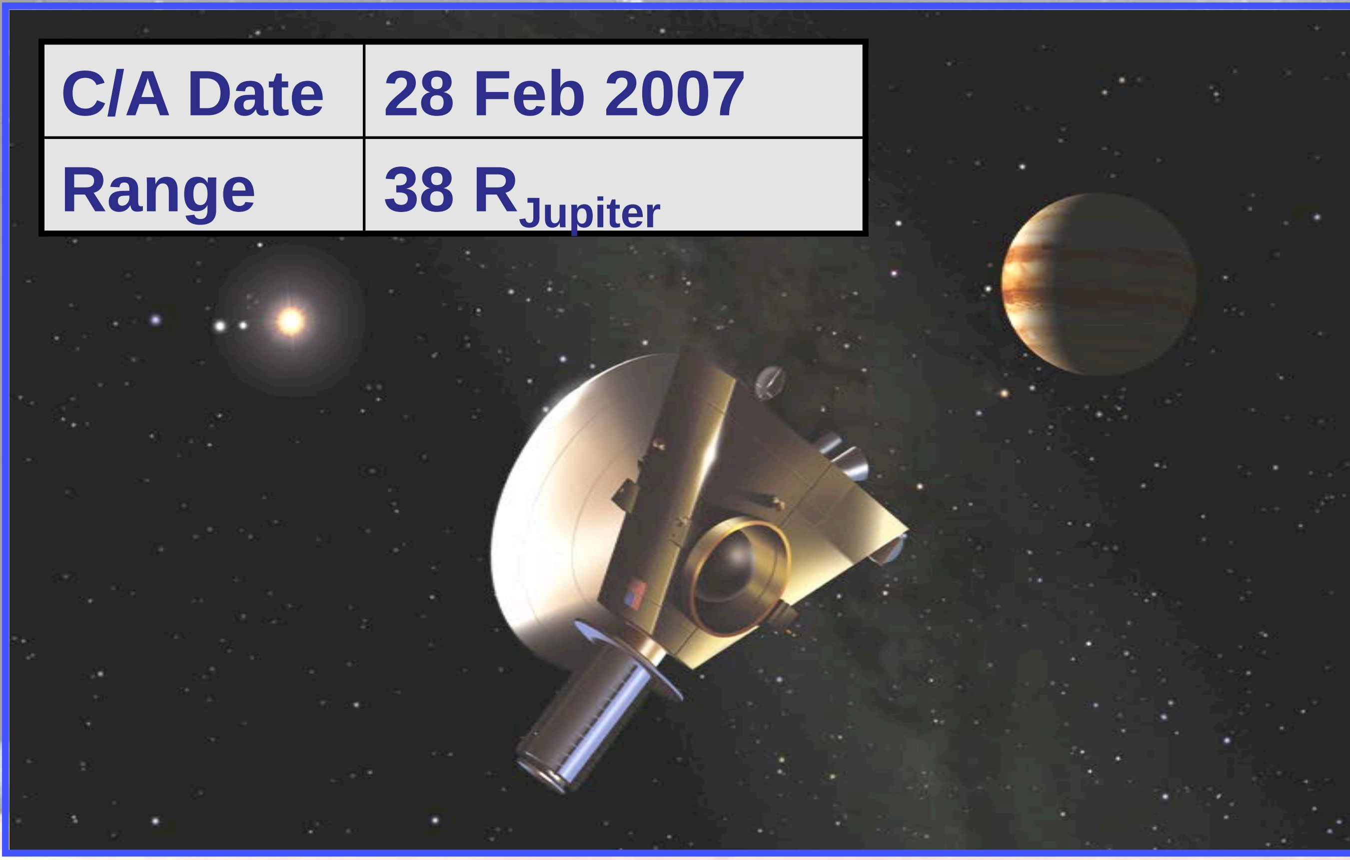
Current Location/Itinerary

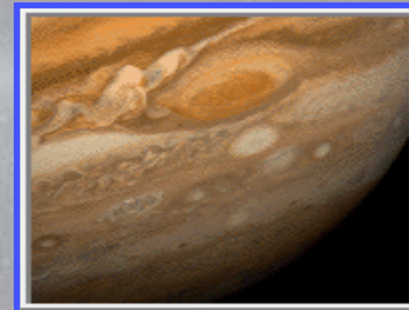


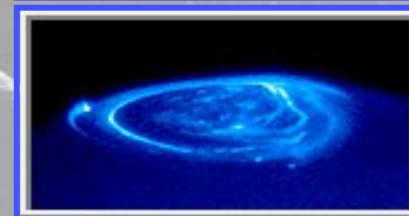


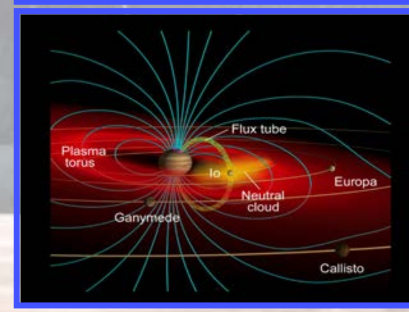
Jupiter Flyby Priorities

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





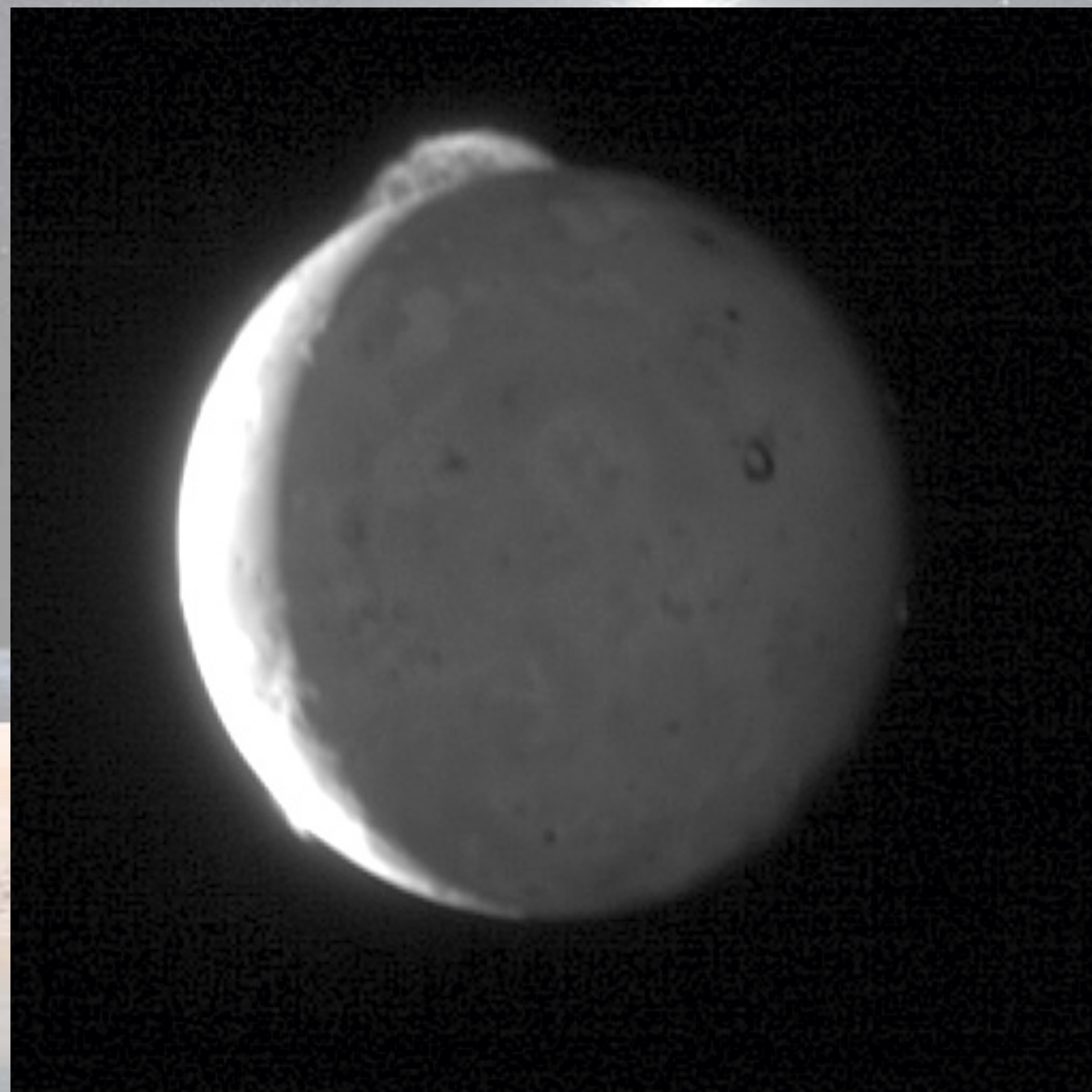




- Gravity Assist (Speed Trajectory to Pluto)
- Encounter Ops Practice, Instrument Calibrations
- Jupiter System Science: include studies of Jovian meteorology, satellite geology and composition, auroral phenomena, and magnetospheric physics

Jupiter Science: Working as Planned

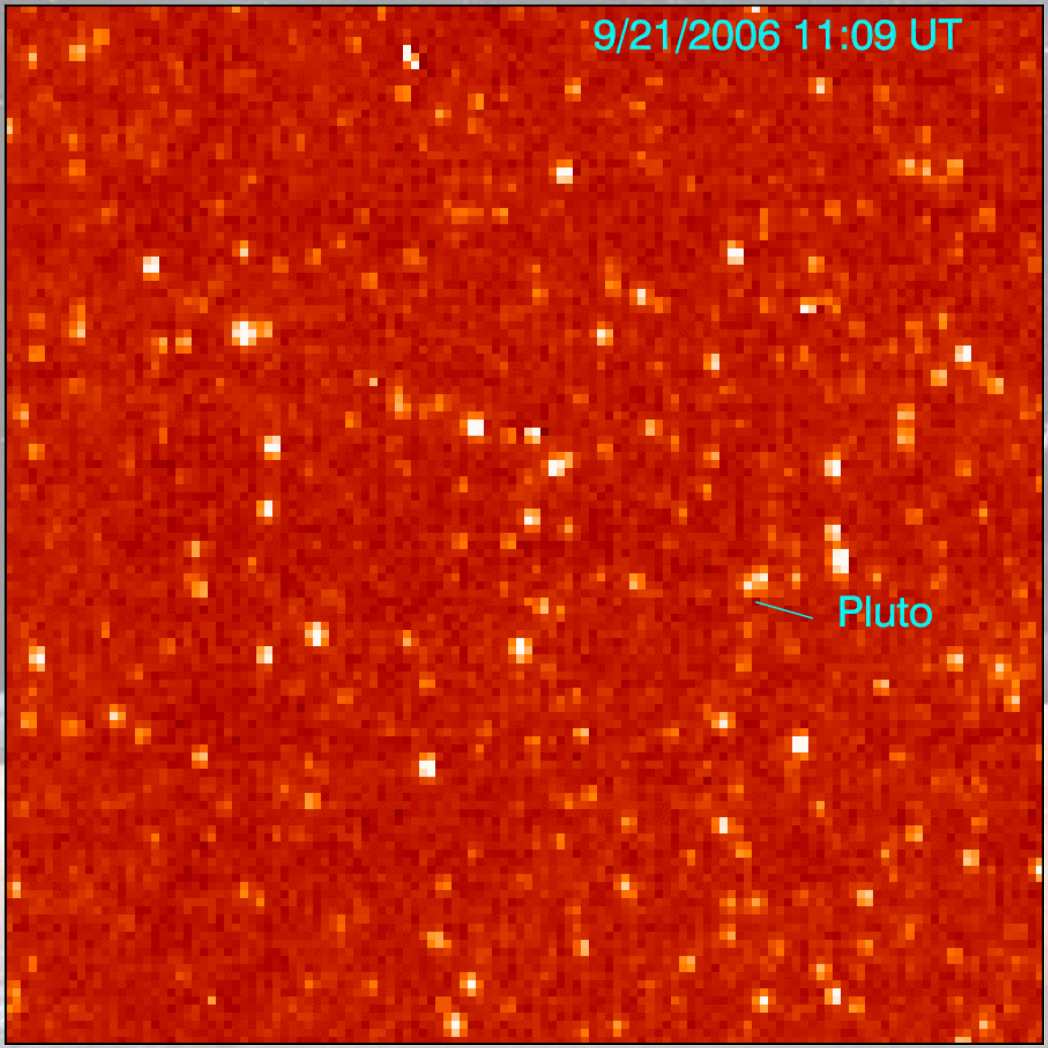
Jupiter's Moon Io
Tvashtar's Plume
February 28, 2007

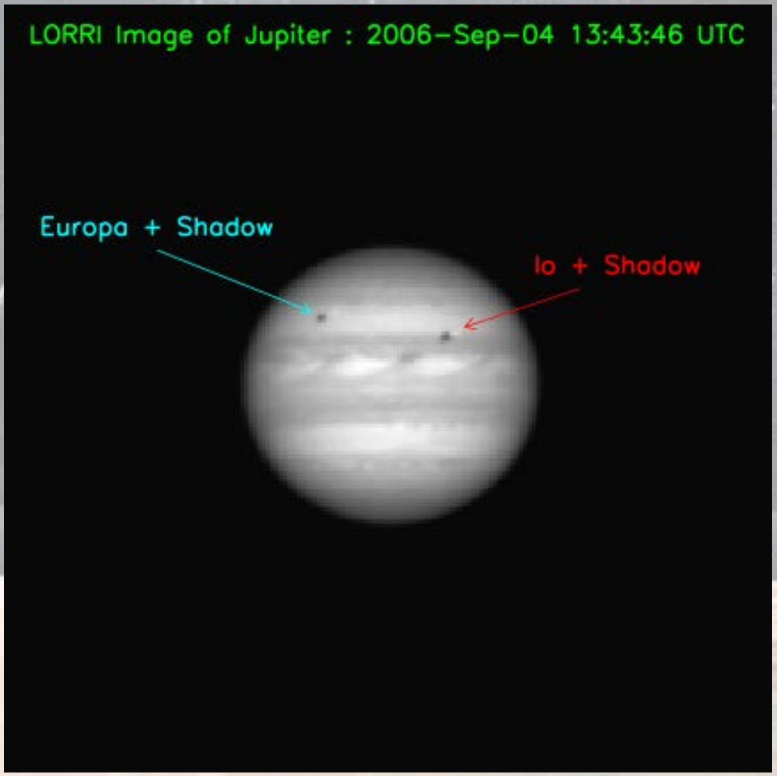


18 April 2013

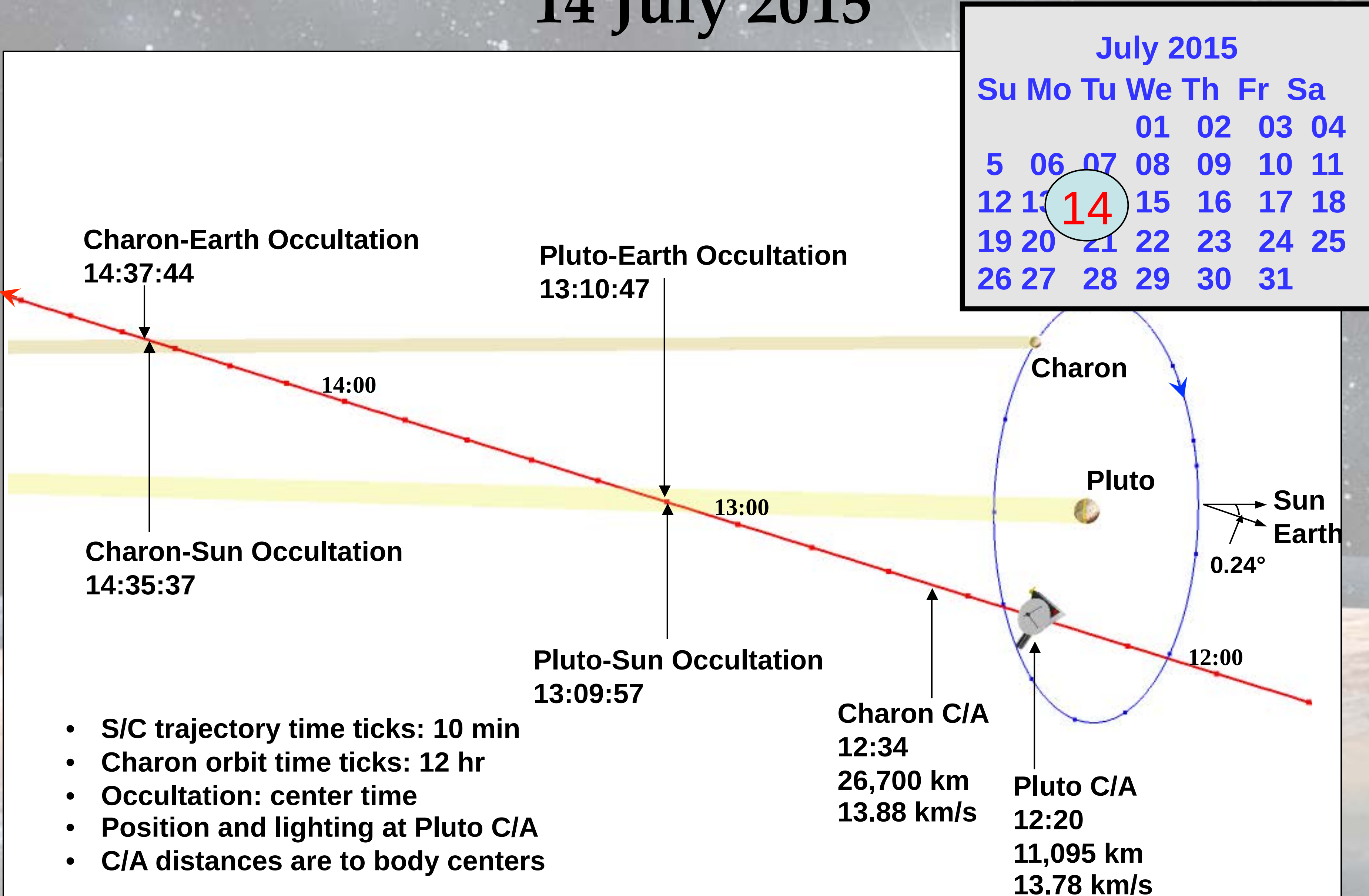
S. D. Benecchi

New Horizons in Flight
LORRI High Resolution Imager





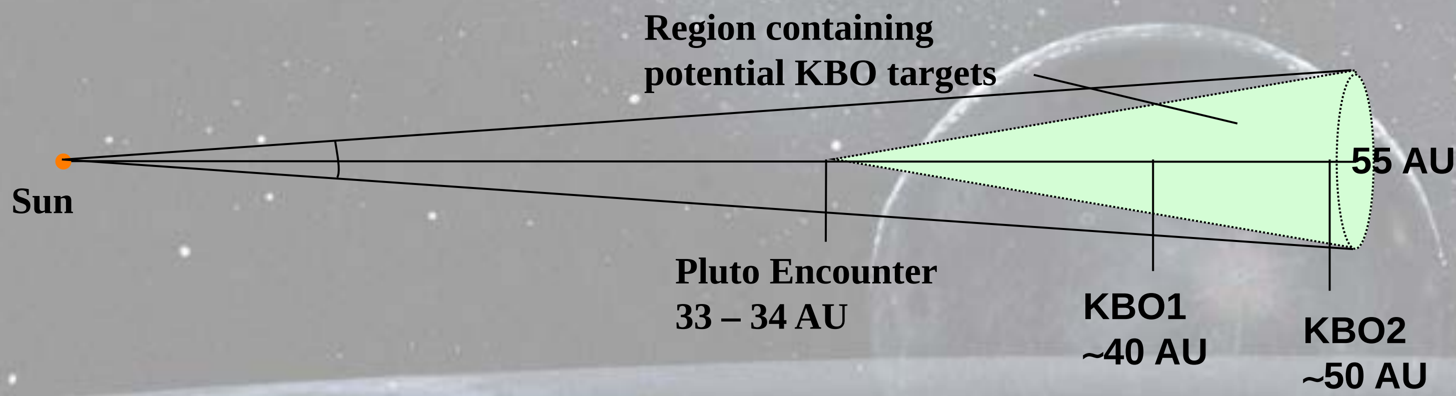
Pluto-Charon Encounter Geometry
14 July 2015



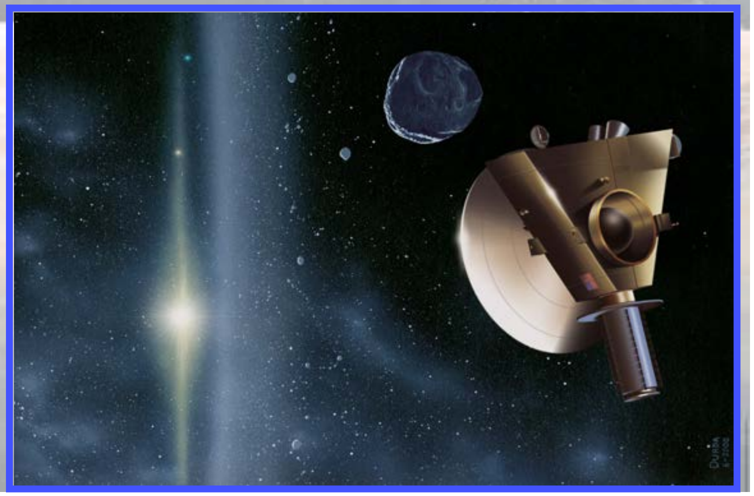
- S/C trajectory time ticks: 10 min
- Charon orbit time ticks: 12 hr
- Occultation: center time
- Position and lighting at Pluto C/A
- C/A distances are to body centers

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.

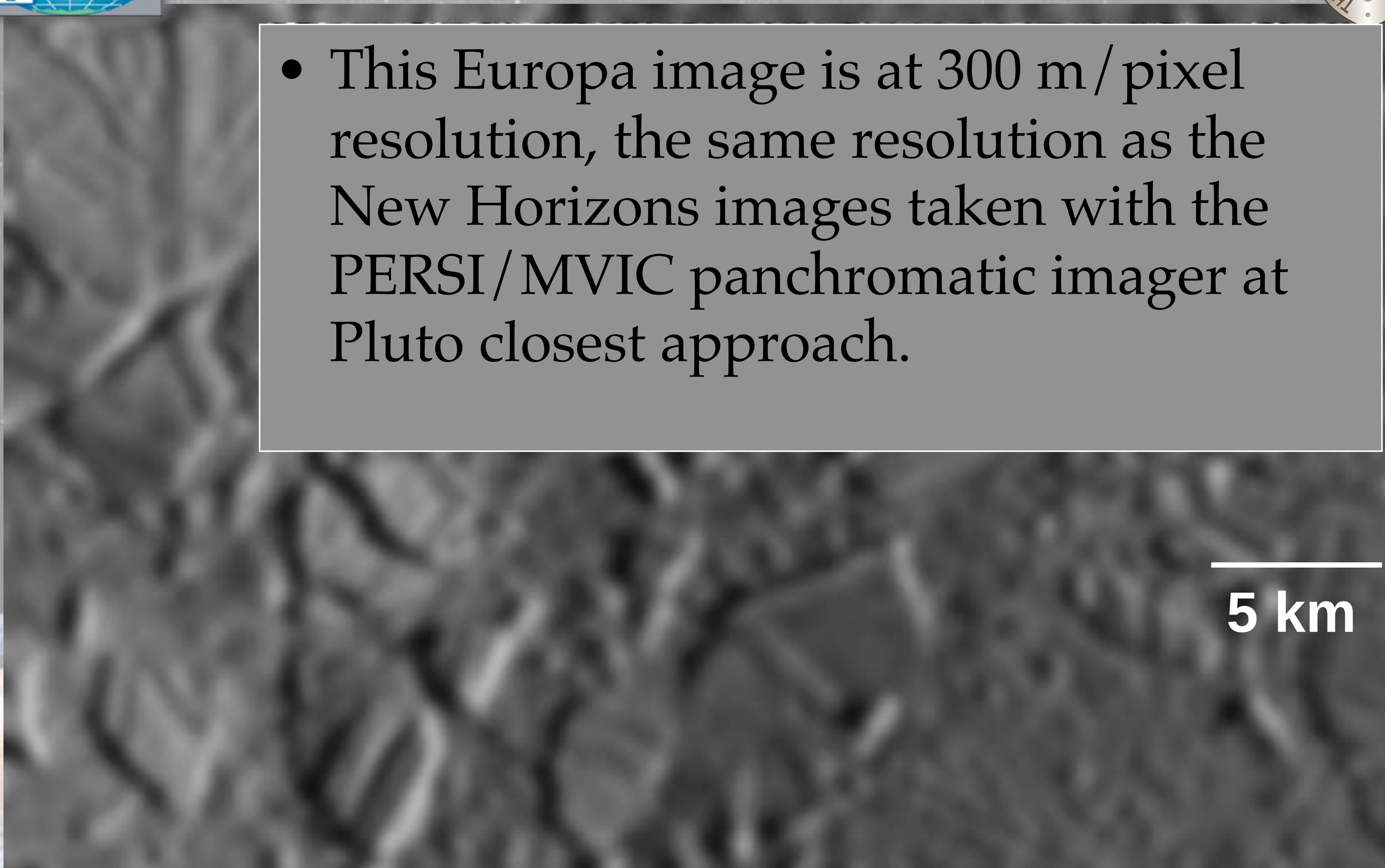


- Obtain OpNav image of targeted KBO as early as 3-5 weeks out.
- Refine KBO encounter accuracy with a trim TCM incorporating OpNav data.
- KBO flyby velocities of 8 km/s to 14 km/s.

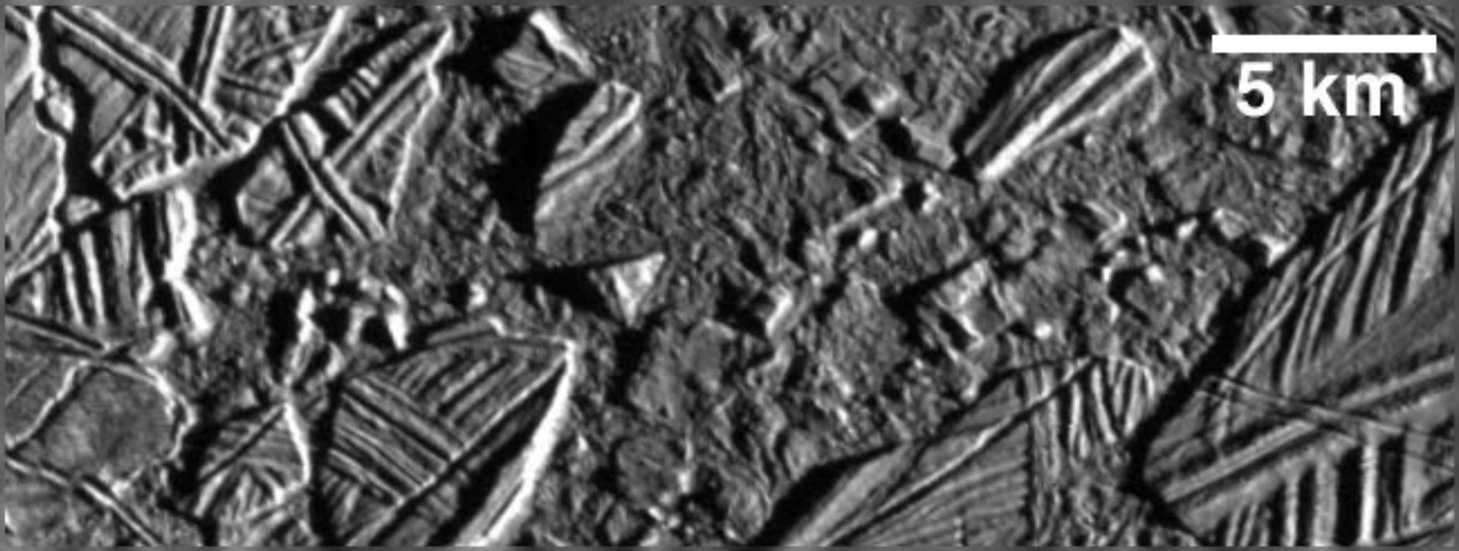


MVIC and LORRI Resolution

- 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.

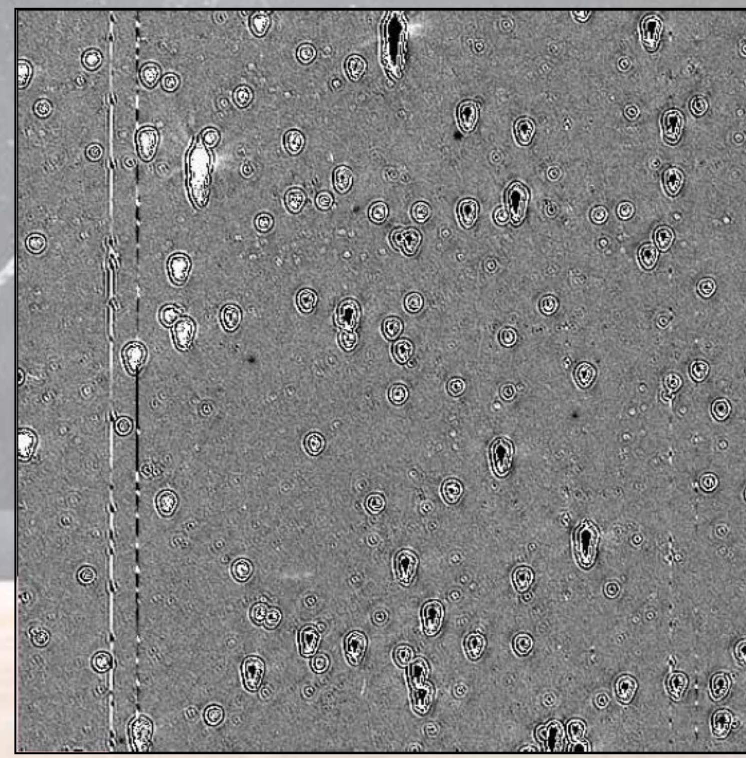


MVIC and LORRI Resolution



- 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.

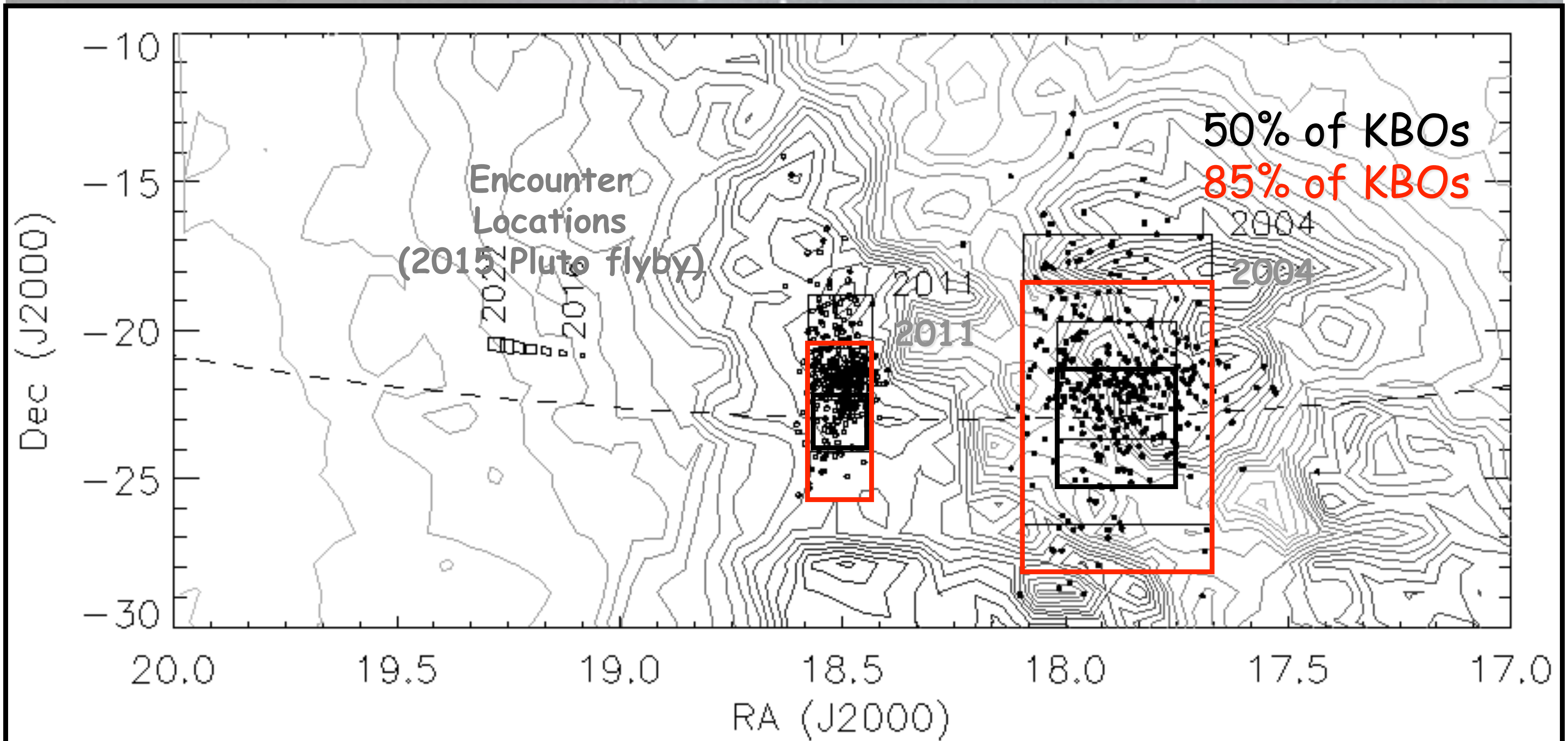
Final Stop: The Kuiper Belt



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

Search Area

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

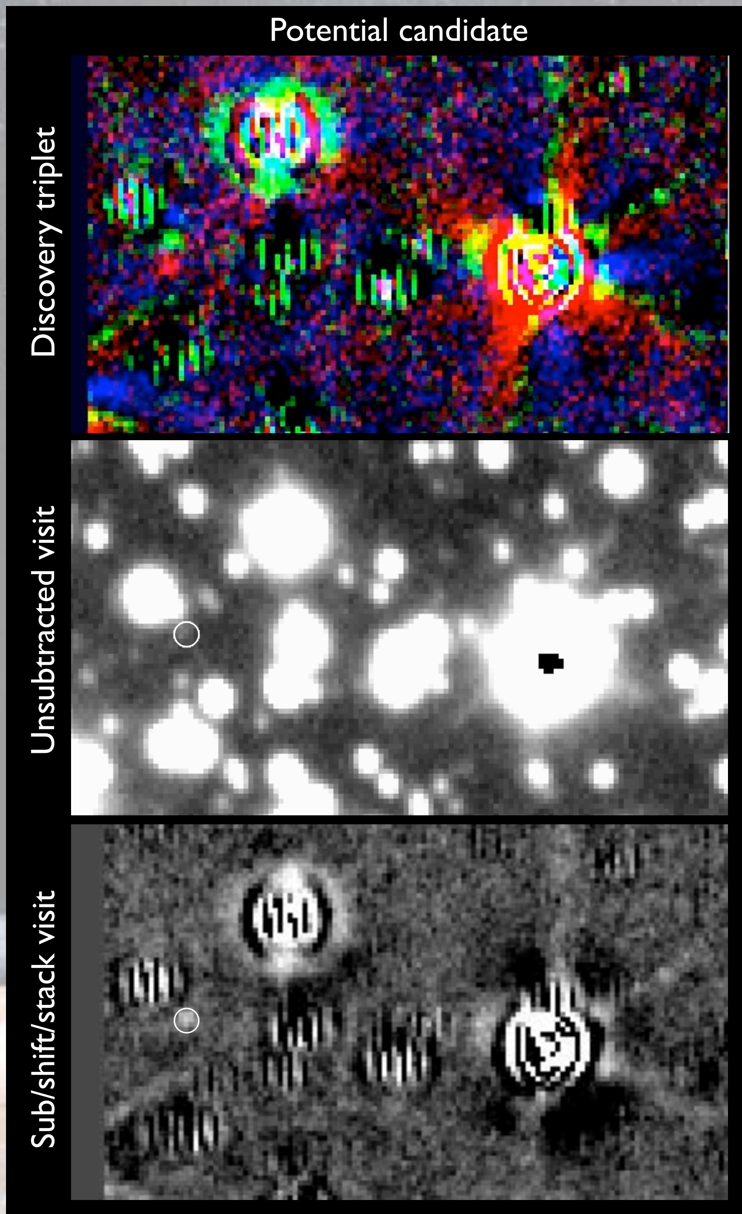


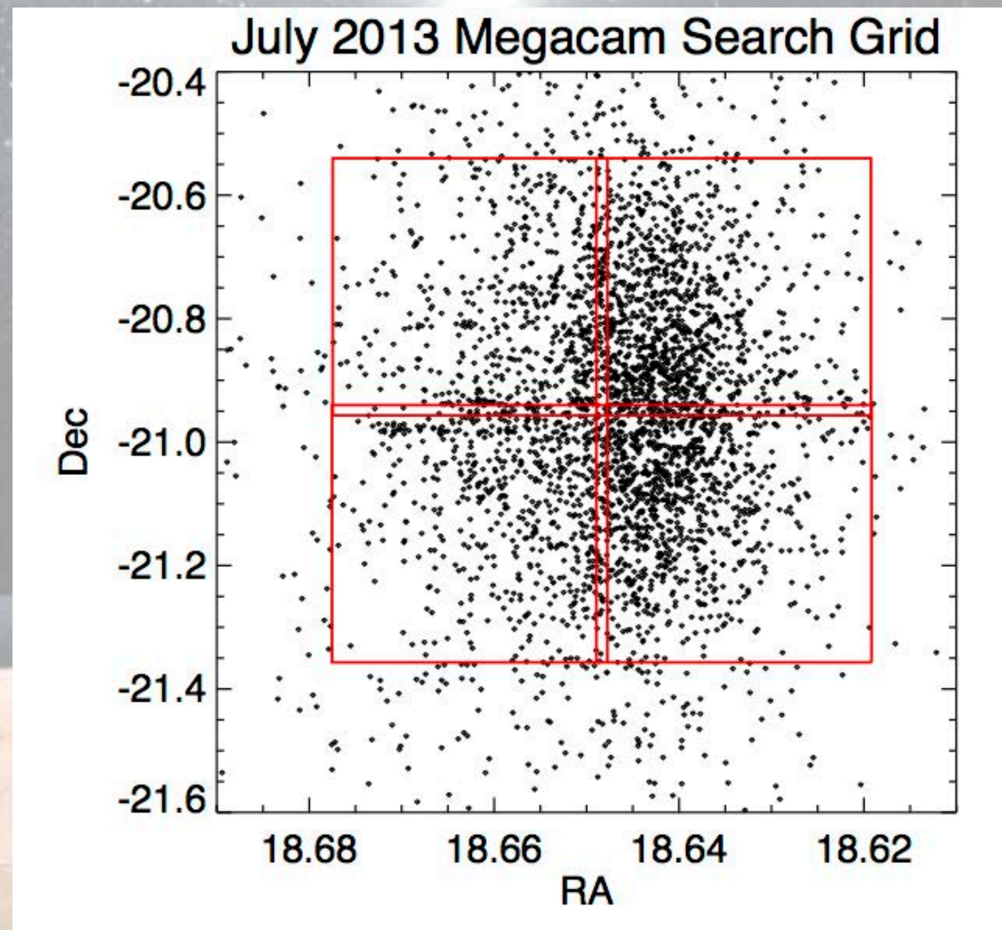
Telescopes Used for Our Search

The Magellan Telescopes
Las Campanas Observatory, Chile

Subaru Telescope
Mauna Kea, Hawaii

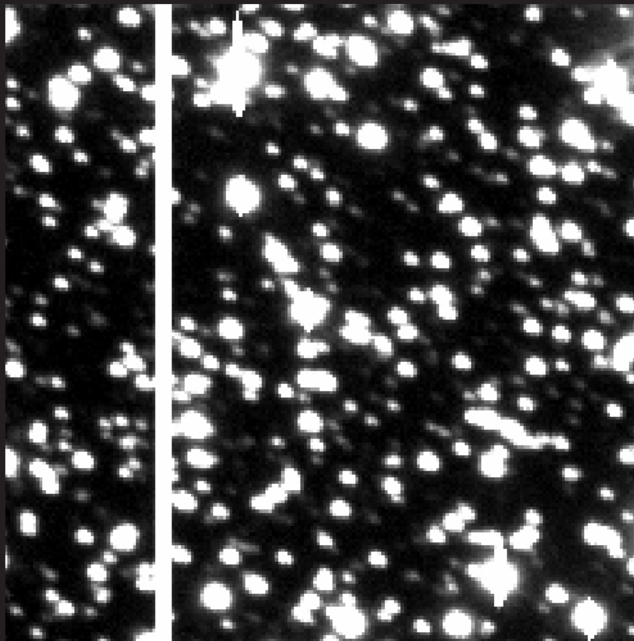
KBO Search


Potential candidate
Discovery triplet
Unsubtracted visit
Sub/shift/stack visit

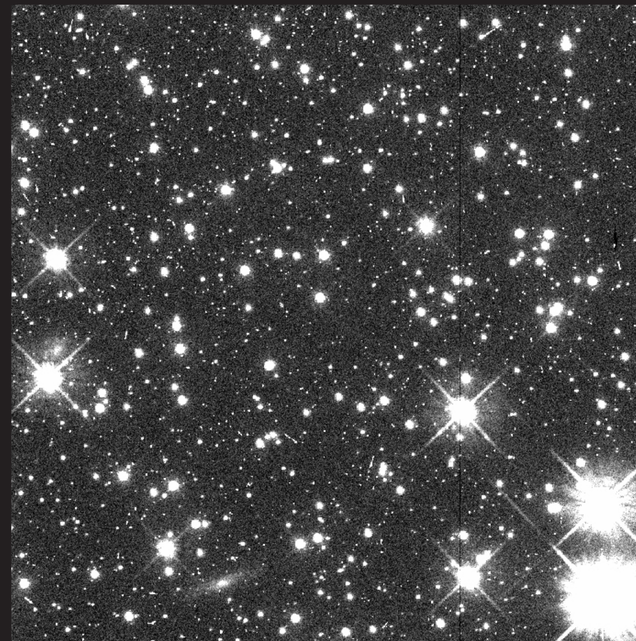

July 2013 Megacam Search Grid
Dec
-20.4
-20.6
-20.8
-21.0
-21.2
-21.4
-21.6
RA
18.68
18.66
18.64
18.62

Discoveries

Name	DB-ID	a (AU)	e	i (deg)	Mag	Date of CE	Range at CE (AU)	Δv (m/s)	Obs Arc (days)
2011HM102	VNH0001	30.1	0.081	29.4	22.2	2013/11/02 — 2013/11/02	1.22 — 1.22	pre-Pluto	355
VNH0002	VNH0002	51.0	0.223	6.4	—	2018/03/31 — 2019/06/14	0.21 — 0.44	360 — 560	66
VNH0003	VNH0003	50.4	0.345	5.4	—	2017/01/15 — 2017/11/01	0.18 — 0.40	520 — 850	66
VNH0004	VNH0004	39.0	0.355	3.8	23.5	2014/10/08 — 2016/03/01	0.34 — 1.14	>5000	34
VNH0005	VNH0005	51.5	0.455	3.1	24.5	2017/04/25 — 2018/03/11	0.48 — 0.94	880 — 2200	65
VNH0006	VNH0006	50.8	0.016	2.5	26.0	2021/02/13 — 2022/03/30	0.17 — 1.13	140 — 810	4
2011JW31	VNH0007	46.0	0.142	1.9	25.2	2018/05/30 — 2018/12/26	0.14 — 0.21	230 — 290	358
2011JY31	VNH0008	44.0	0.041	2.6	25.0	2018/07/19 — 2018/10/27	0.14 — 0.16	220 — 240	358
2011JX31	VNH0009	44.9	0.107	3.3	24.5	2020/06/18 — 2020/06/28	0.41 — 0.42	390 — 400	448
2011HZ102	VNH0010	43.2	0.004	2.4	25.4	2018/09/07 — 2019/01/15	0.15 — 0.20	210 — 280	358
VNH0011	VNH0011	42.3	0.161	14.5	23.2	2016/03/11 — 2016/09/07	1.33 — 1.44	>5000	66
2011HE103	VNH0012	43.7	0.083	6.8	—	2019/08/13 — 2021/04/24	0.90 — 0.96	850 — 1000	358
VNH0013	VNH0013	56.9	0.467	13.0	24.0	2015/05/16 — 2016/03/21	0.93 — 1.14	>5000	64
2011JA32	VNH0014	62.6	0.536	3.2	25.8	2017/06/24 — 2018/08/28	0.35 — 0.42	690 — 870	356
VNH0015	VNH0015	34.8	0.034	18.8	25.4	2012/06/30 — 2017/01/15	0.55 — 2.59	>5000	6
2011HD103	VNH0016	53.1	0.490	5.8	25.3	2020/08/07 — 2024/08/06	1.35 — 1.37	720 — 1270	359
VNH0019	VNH0019	46.4	0.021	2.7	24.7	2016/12/06 — 2024/12/14	0.38 — 1.96	420 — 1420	3
VNH0020	VNH0020	54.0	0.020	18.1	—	2017/12/31 — 2024/07/27	1.20 — 4.32	>1000	2
VNH0021	VNH0021	44.2	0.085	3.3	—	2014/07/30 — 2019/03/26	0.07 — 0.45	>1000	3
VNH0022	VNH0022	44.5	0.044	6.2	—	2016/03/21 — 2020/07/08	0.38 — 0.98	860 — 1180	3
VNH0023	VNH0023	38.8	0.011	19.3	—	2015/08/04 — 2019/12/21	1.28 — 2.58	>1000	3
VNH0024	VNH0024	41.8	0.155	4.5	—	2015/05/06 — 2017/05/25	0.18 — 0.48	>1000	3
VNH0025	VNH0025	46.5	0.021	2.9	—	2019/08/03 — 2019/11/01	0.96 — 1.18	>1000	2
VNH0026	VNH0026	45.4	0.022	9.1	—	2018/06/19 — 2019/06/24	1.02 — 2.17	>1000	1
VNH0027	VNH0027	44.3	0.023	3.0	—	2018/01/10 — 2019/08/03	0.73 — 1.82	900 — 2440	1
VNH0029	VNH0029	67.1	0.022	2.8	—	2025/03/04 — 2029/12/18	0.19 — 5.36	80 — 1840	6
VNH0031	VNH0031	23.8	0.199	6.6	—	2012/08/09 — 2018/01/30	0.39 — 2.33	>5000	6



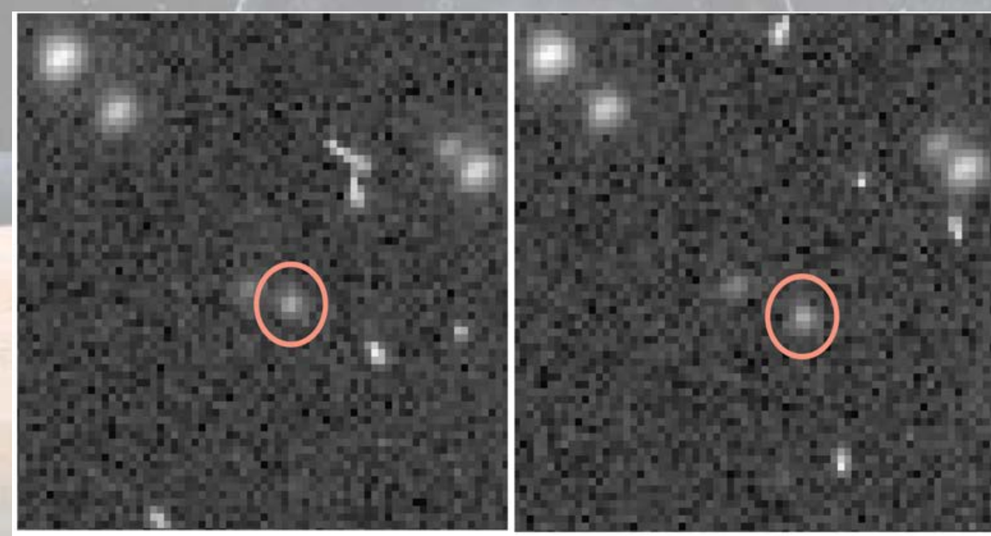
Subaru in NH region



HST, WFC3 in NH region

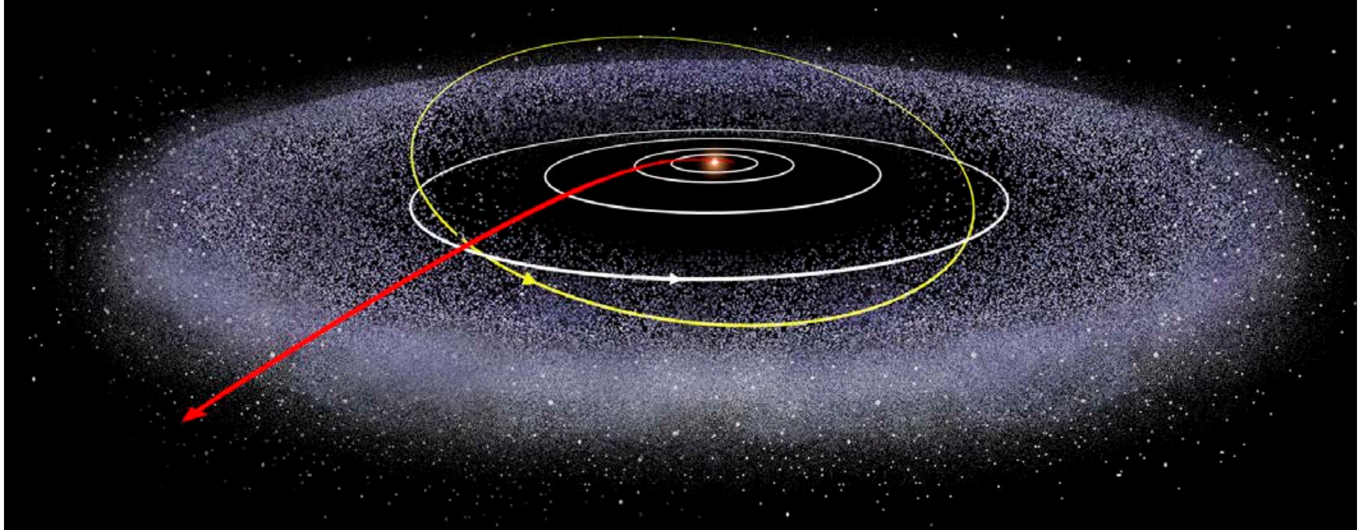
HST Follow-up

2011 JY_{31}



- 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?