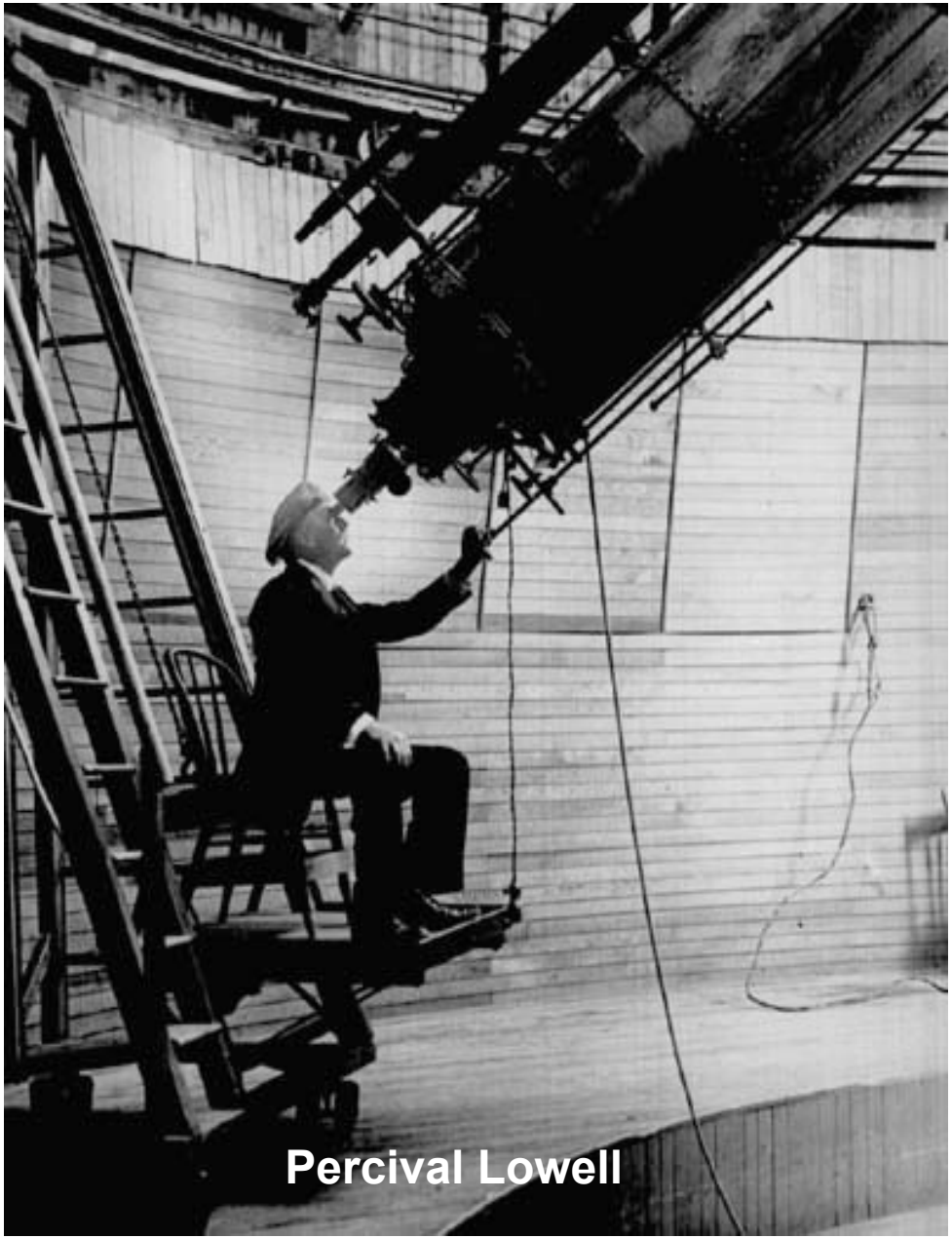
The Story of Pluto and the Kuiper Belt: How Science Progresses

Jane Luu
14 November 2020

1905

Percival Lowell started search for Planet X

Search for Planet X



- Percival Lowell started searching for Planet X in 1905, but died in 1916, before completing his search.

Image credit: Wikipedia

1930

Clyde Tombaugh discovered Pluto

The Discovery of Pluto
February 18, 1930

- Clyde Tombaugh found Pluto near where Lowell predicted it should be

Image credit: Public Domain, https://commons.wikimedia.org/w/index.php?curid=42162321

Science, 21 March 1930

SCIENCE NEWS

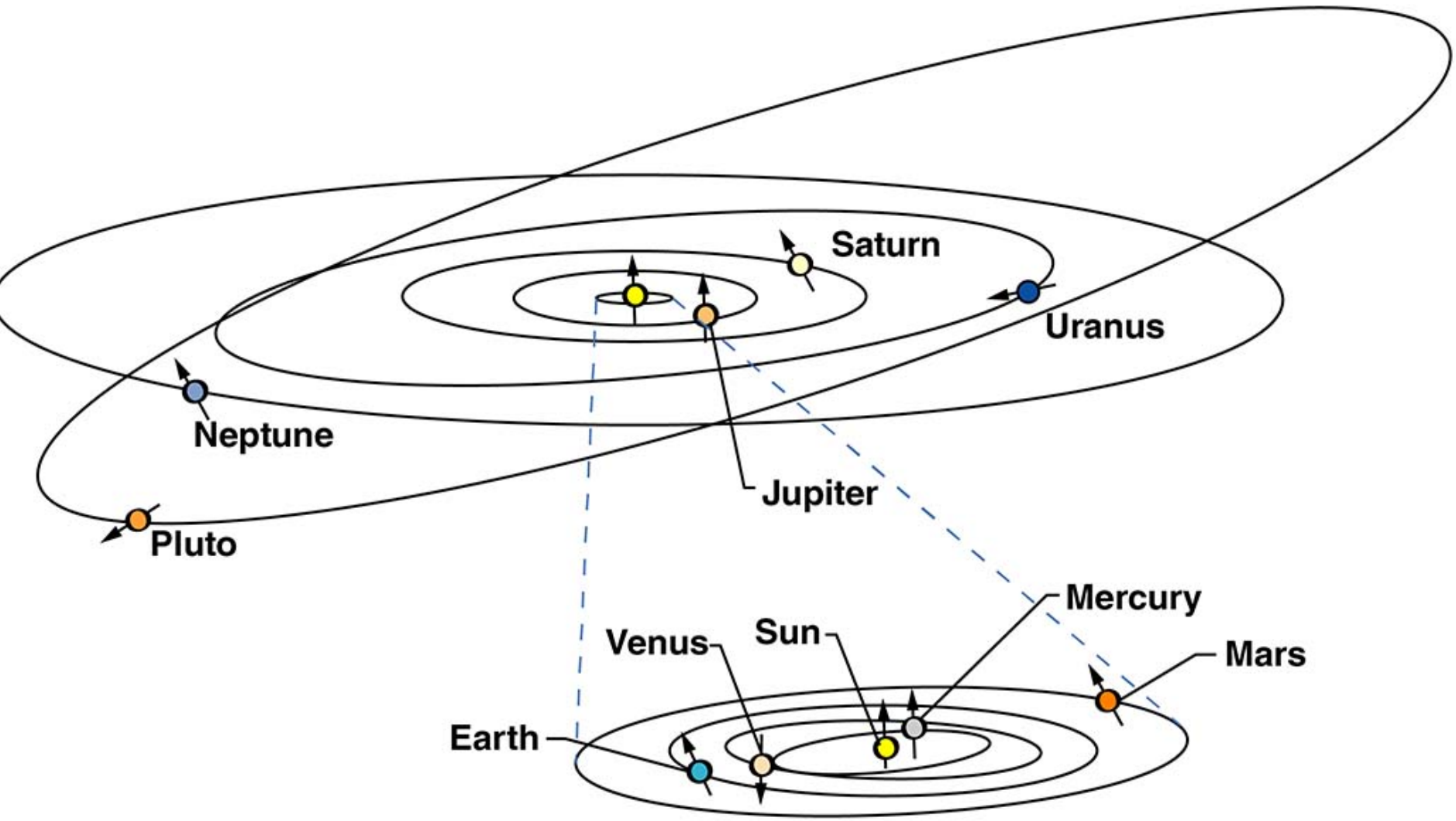
Science Service, Washington, D. C.

A NEW PLANET BEYOND NEPTUNE

CLOSE to the place in the sky where the late Percival Lowell predicted that there was a new and undiscovered

Lowell used the general methods that led in 1846 to the discovery of the planet Neptune, until this year the outpost of the solar system. Lowell began his memoir:

Pluto's highly elliptical, highly inclined orbit



From Duncombe & Seidelmann (1980)

Pluto's Mass Determinations

Date	Investigator	Observations	Mass in terms of the Earth
1848	J. Babinet	Neptune	12
1899	H. Lau	Uranus	9
1908	W. Pickering	Uranus	2
1909	B. Gaillot	Uranus, Neptune	5
1915	P. Lowell	Uranus, Neptune	6.6
1928	W. Pickering	Uranus, Neptune	0.75
1930	J. Jackson	Neptune	1.0
1931	Nicholson and Mayall	Neptune	0.94
1931	E. Brown	Uranus	0.5
1940	V. Kourganoff	Uranus	1.0
1942	L. Wylie	Neptune	0.91
1951	Eckert, Brouwer, and Clemence	Neptune	1.0
1955	Brouwer	Uranus, Neptune	0.82
1968	Duncombe, Klepczynski, and Seidelmann	Neptune	0.18
1971	Seidelmann, Klepczynski, Duncombe, and Jackson	Neptune	0.11
1971	Ash, Shapiro, and Smith	Uranus, Neptune	0.08
1976	Cruikshank, Pilcher, and Morrison	Albedo	0.004
1978	Christy and Harrington	Satellite	0.002

➡ Pluto's mass much too small to perturb Uranus

- Anomalies in Uranus's orbit were due to error

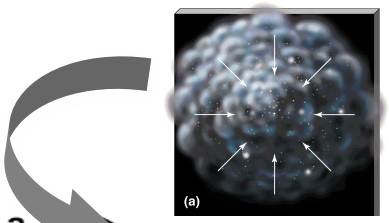
- Tombaugh discovered Pluto not because of predictions, but because he was looking when no one else was.

- Nevertheless, Pluto was accepted as last planet, the edge of planetary system

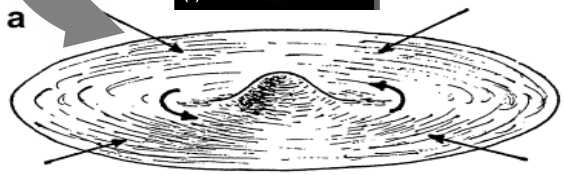
1949 - 1950

- Edgeworth (1949) and Kuiper (1950) questioned edge of planetary system

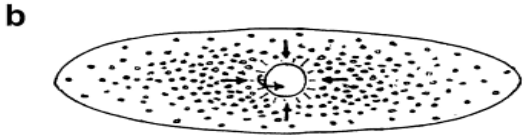
How the Solar System Formed



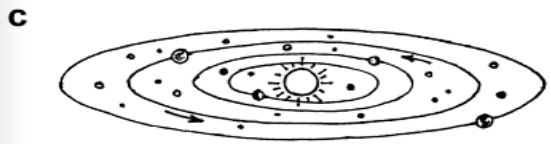
Molecular cloud collapses…



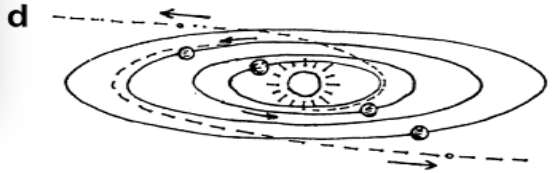
to form thin disk of dust and gas



1 km-size **planetesimals** form



Planetary embryos form (roughly 1000-km in size)



Planetary embryos merge to form planets

- Edgeworth (1949), Kuiper (1951): Small bodies may still exist beyond Neptune

Where do comets come from?

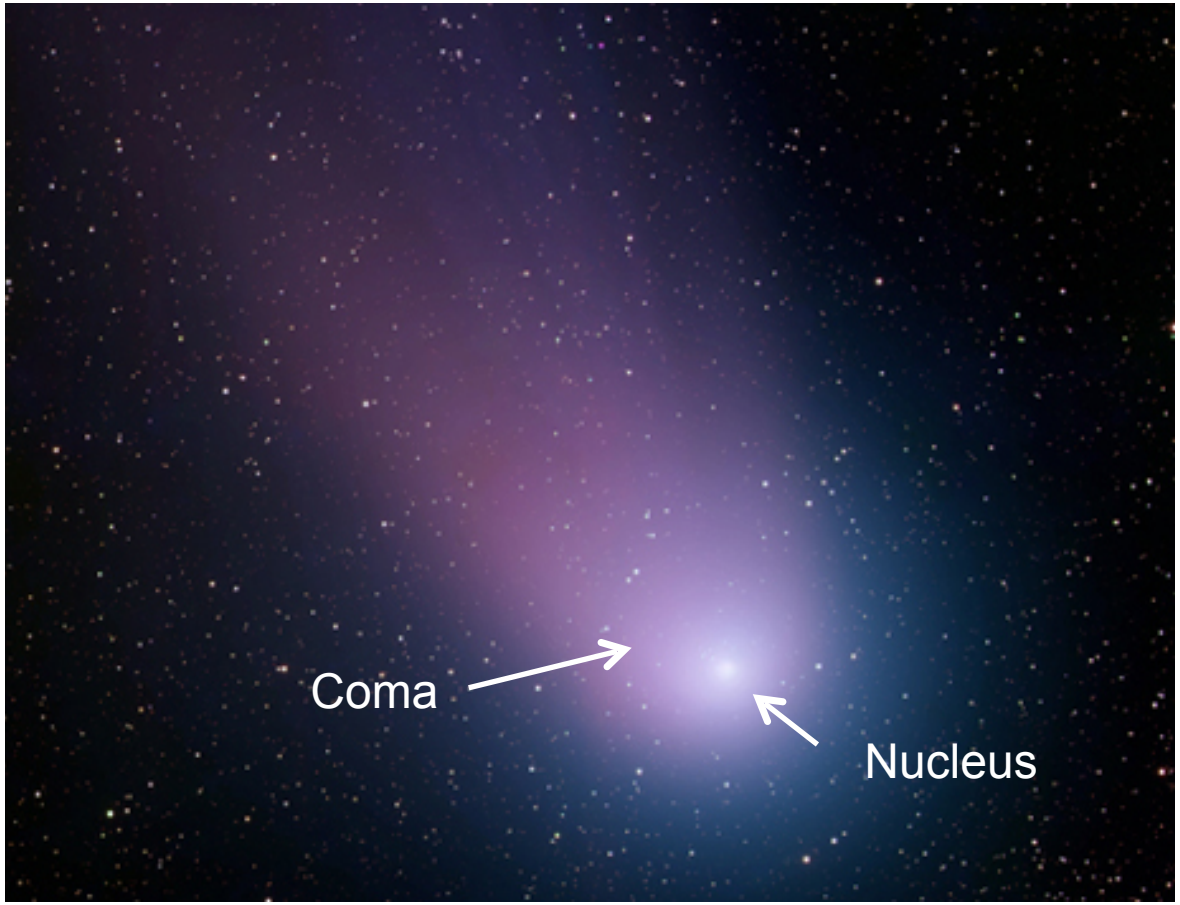


Image credit: NASA

- Comets: small, icy bodies
- Coma appears when comet is warmed by the Sun and its ices evaporate
  - Escaping ice molecules eject dust particles

1. Comets must come from outer solar system
2. Comet loses mass each time it approaches Sun
   - Typical comet exhausts its own mass in a few x 1000 years

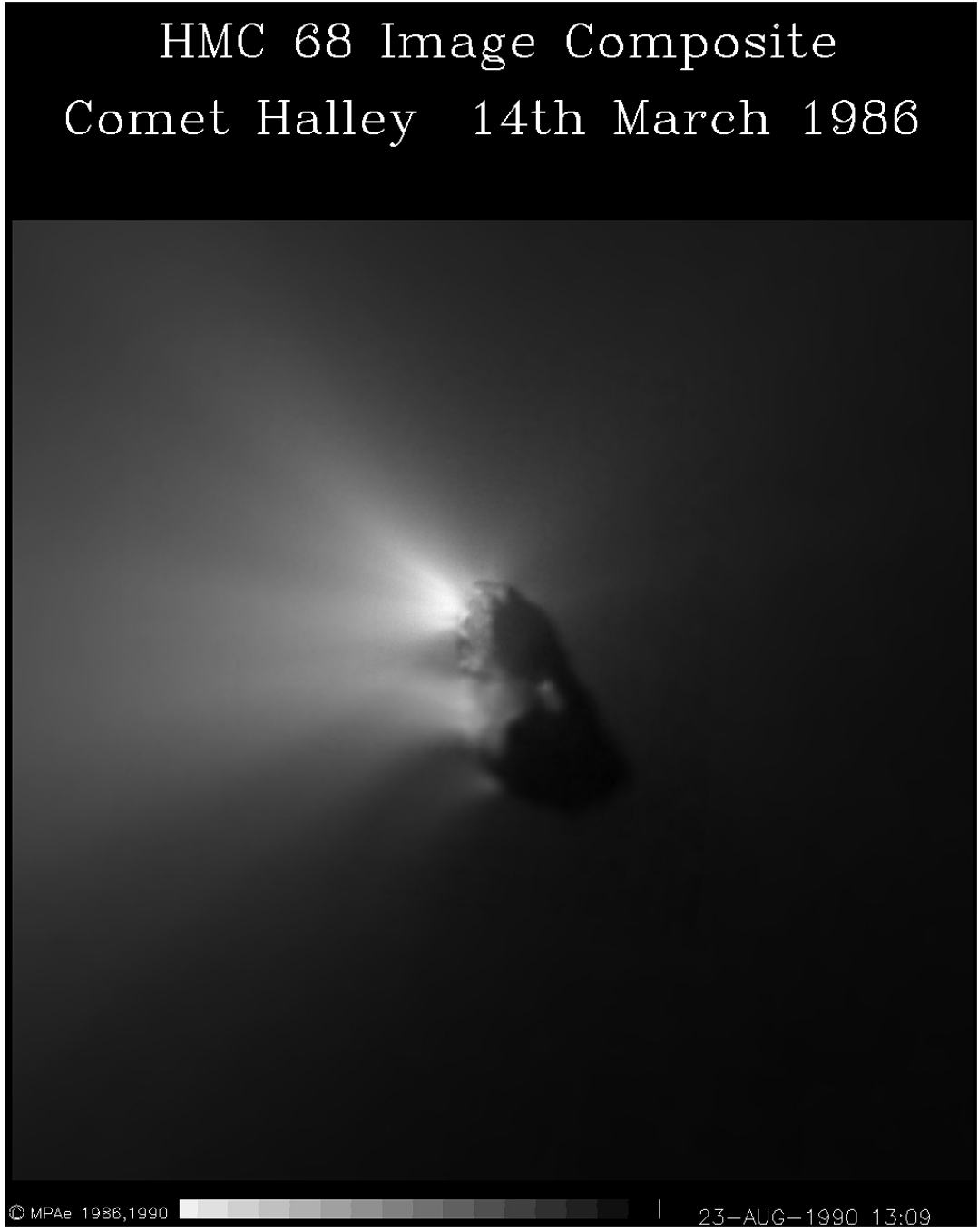


Image credit: ESO

Comet Shoemaker-Levy 9 impacting Jupiter

- Comet also collides with planet or Sun every ~ 10^5 years
- Comets' lifetime much shorter than age of solar system (4.6 billion years)

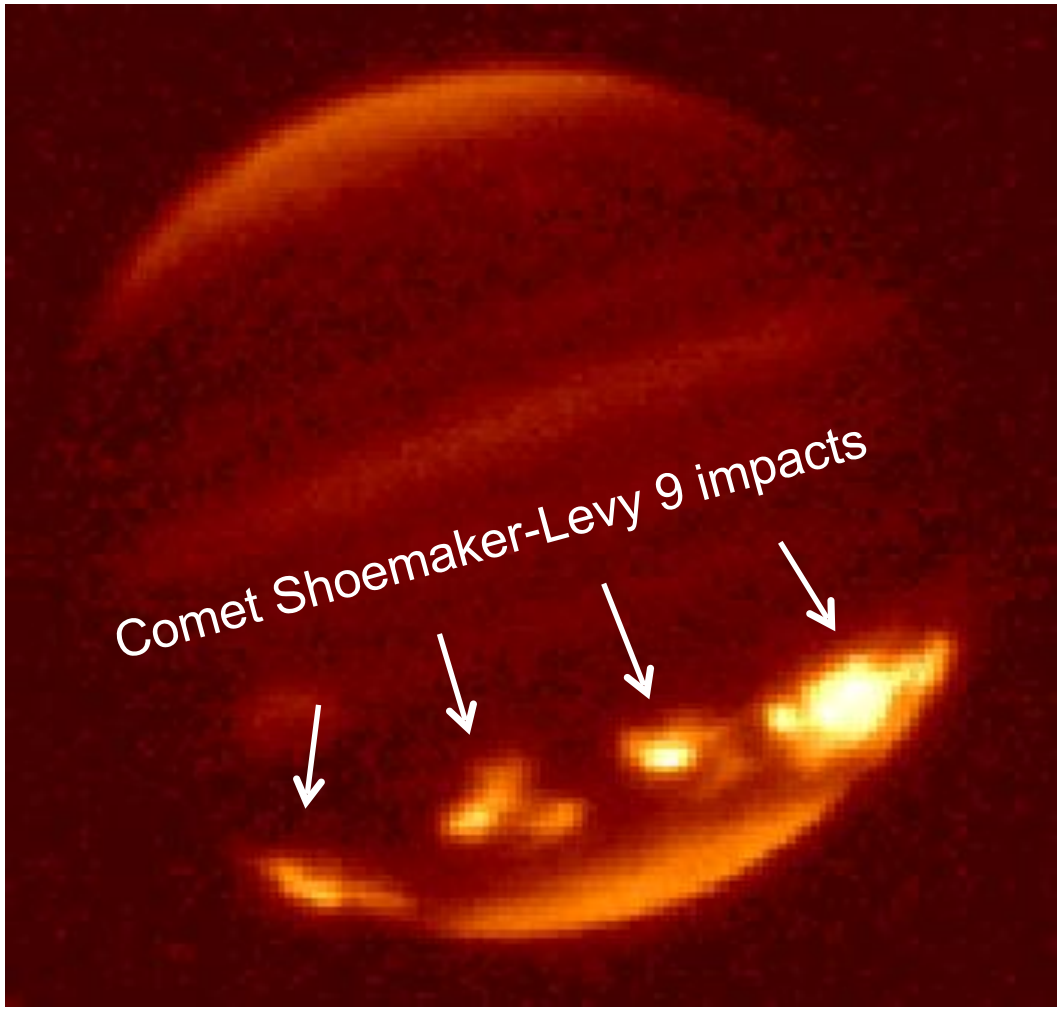
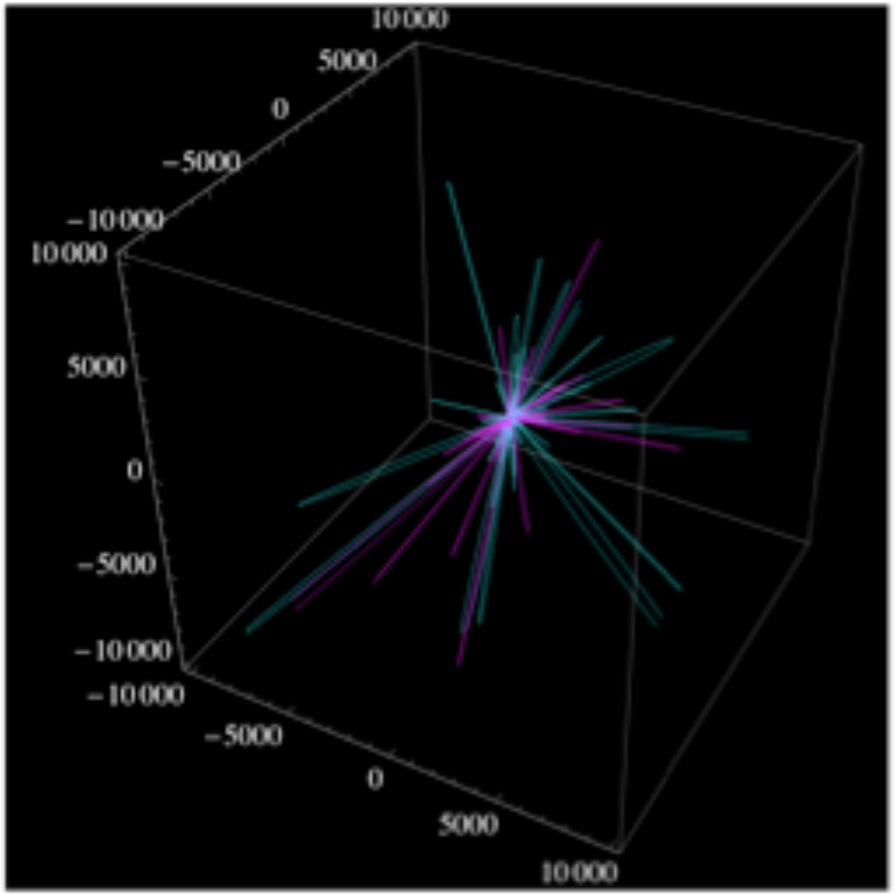


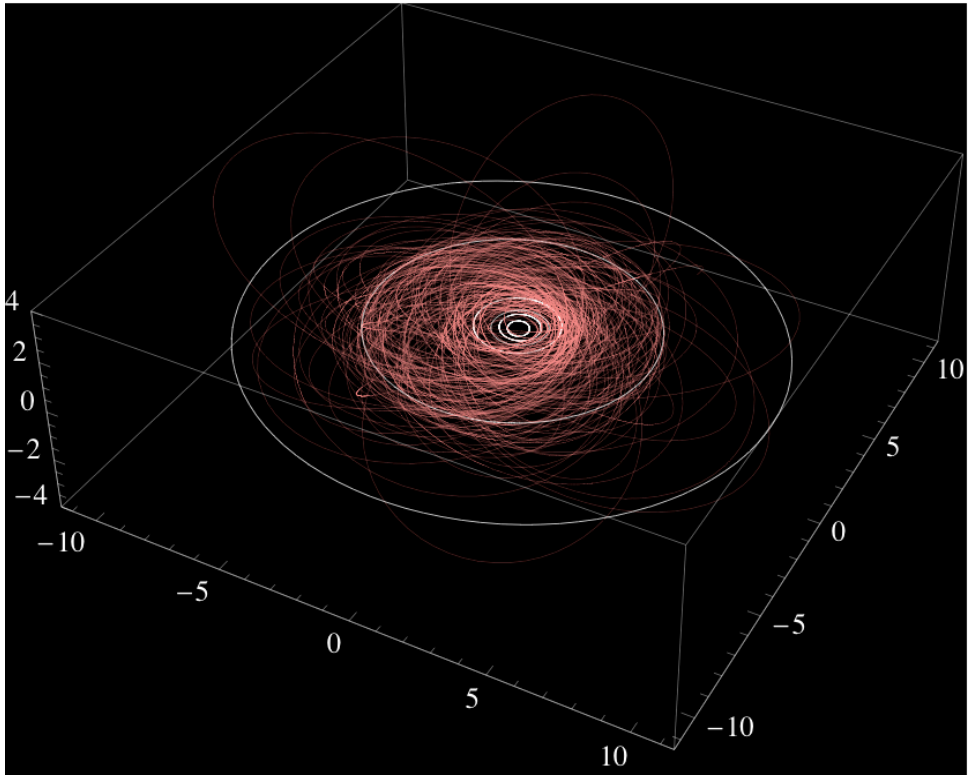
Image credit: NASA

Long-Period Comets



- Period > 200 yrs.
- Semimajor axis ~ 10,000 AU *
- Random orientation
- Source: Oort cloud

Short-Period Comets



- Period < 200 yrs.
- Semimajor axis ~ 5 AU.
- Flat belt
- Does source lie beyond Neptune?

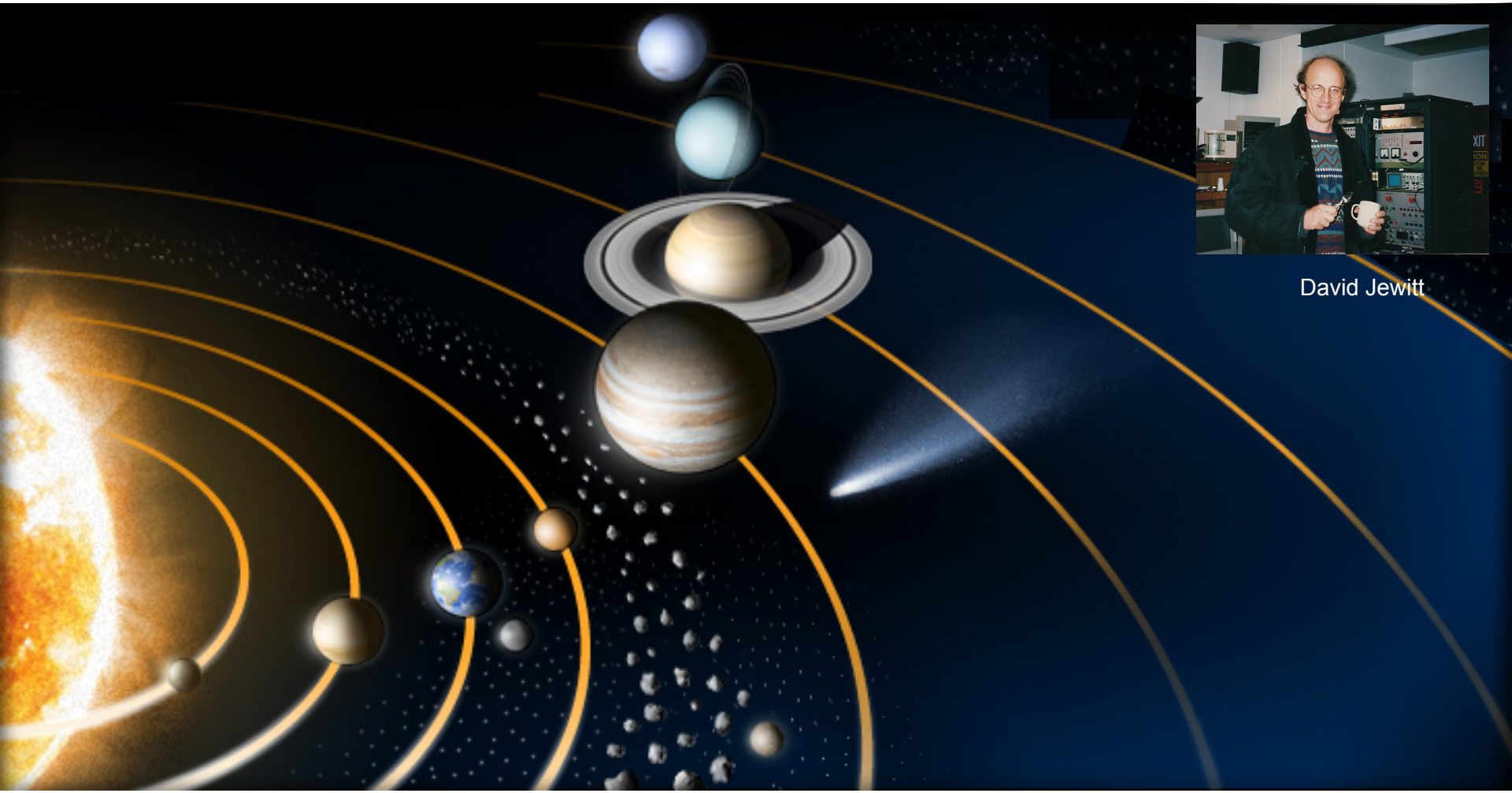
* 1 Astronomical Unit (AU) = Earth - Sun distance = 1.5×10^{11} m

Figures from Jewitt, Moro-Martin, and Lacerda (2008)

1987

Jewitt and Luu started search for outer solar system objects

Why was the outer solar system empty?



David Jewitt

- Could emptiness of outer solar system be simply artifact?

The Search for Slow-Moving Objects

Image credit: KPNO/NOIRLab/NSF/AURA/P. Marenfeld

Which Detector?

Photographic Plate

Image Credit: ESO

- Large field-of-view
- Not very sensitive
- Best suited for bright targets

CCD (Charge-Coupled Device)

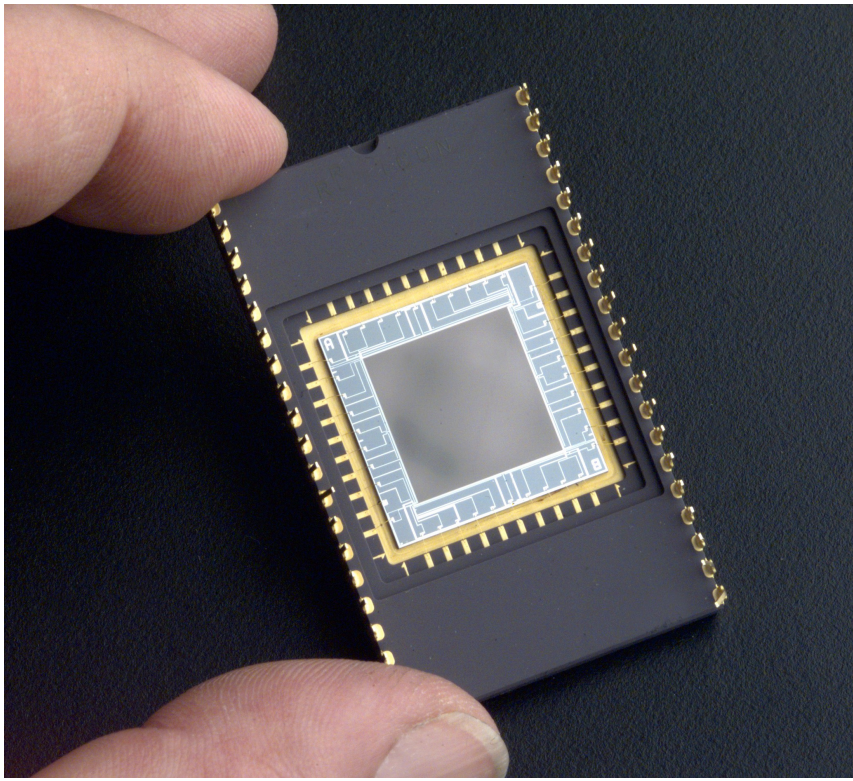
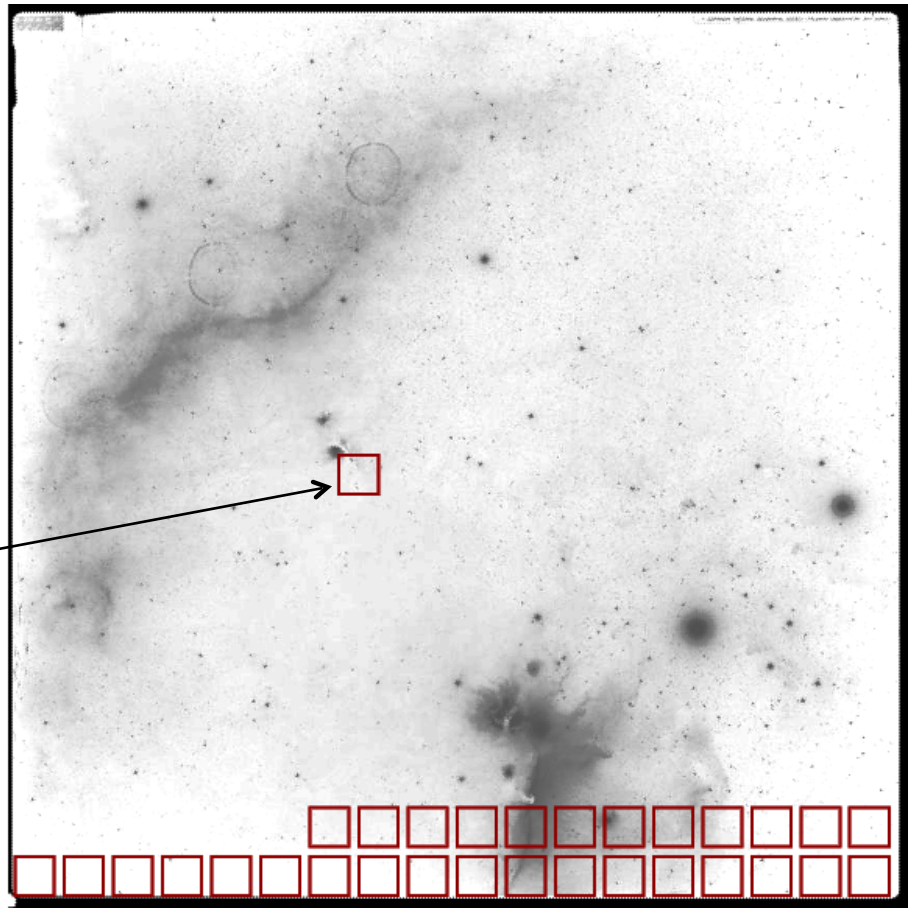


Image Credit: Wikipedia

- Small field-of-view
- Very sensitive
- Best suited for faint targets

Photographic Plate vs. CCD

- Photographic plates for bright objects
- CCD for faint objects
  - 50x more sensitive than photographic plate, but 100x smaller



Photographic plate image

CCD image

Credit: Michael Richmond (http://spiff.rit.edu/richmond/asras/catch_plates/catch_plates.html)

“Blinking”: How to Find Moving Objects

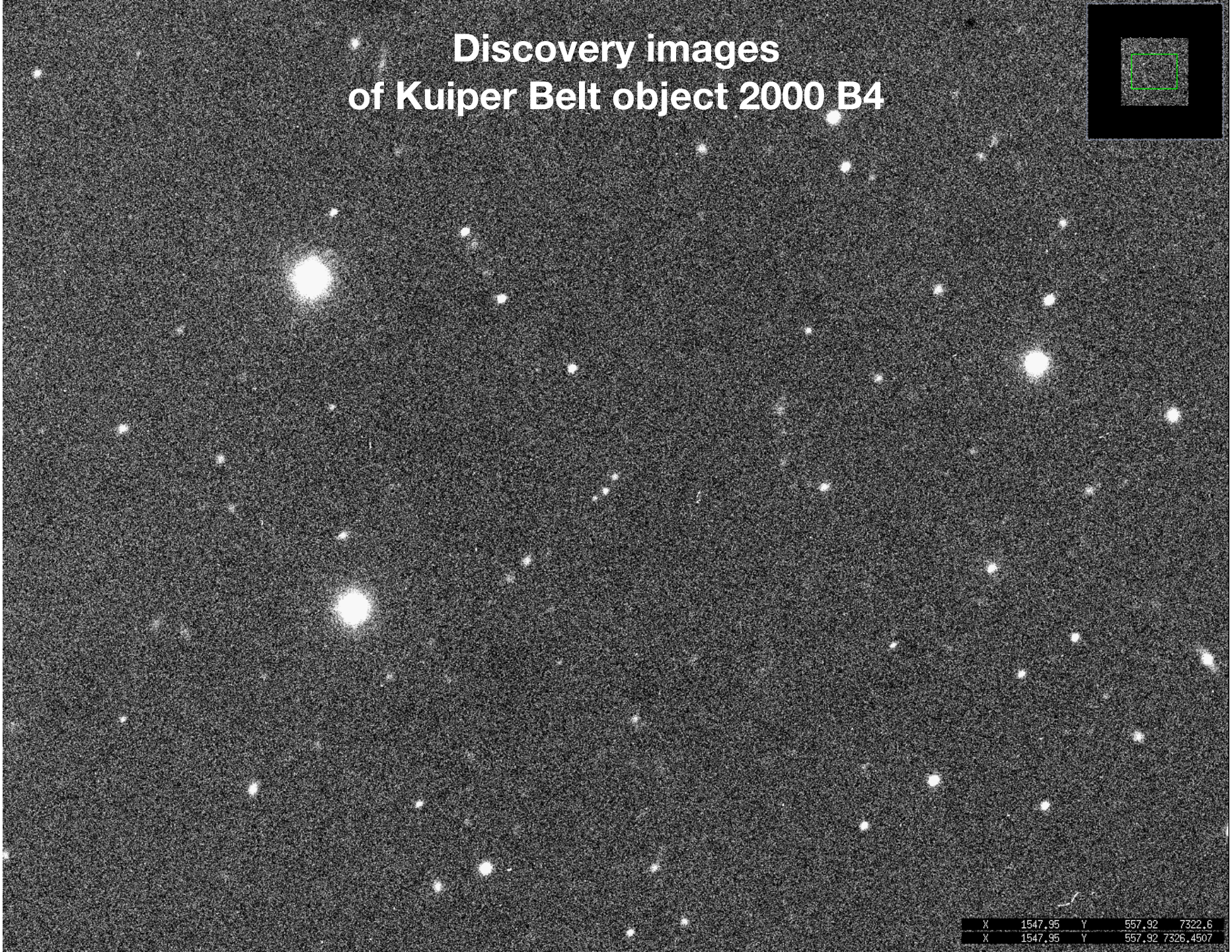
Discovery images of Pluto

http://ircamera.as.arizona.edu/NatSci102/NatSci102/lectures/pluto.htm

Discovery images of Pluto

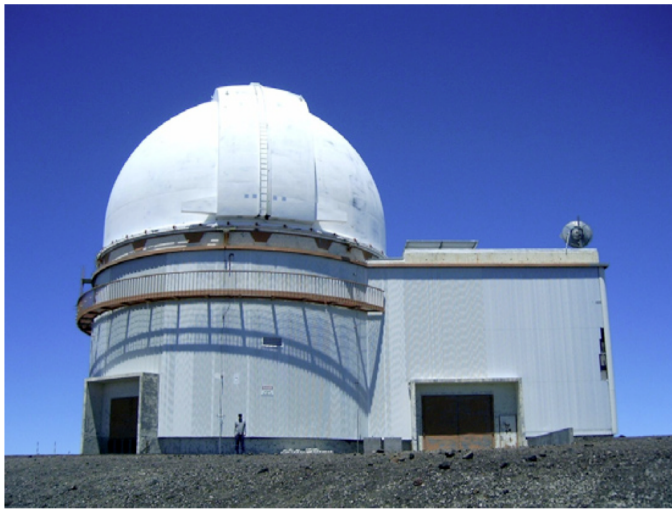
http://ircamera.as.arizona.edu/NatSci102/NatSci102/lectures/pluto.htm

Discovery images of Kuiper Belt object 2000 B4



Mauna Kea Observatory

Image credit: Wikipedia



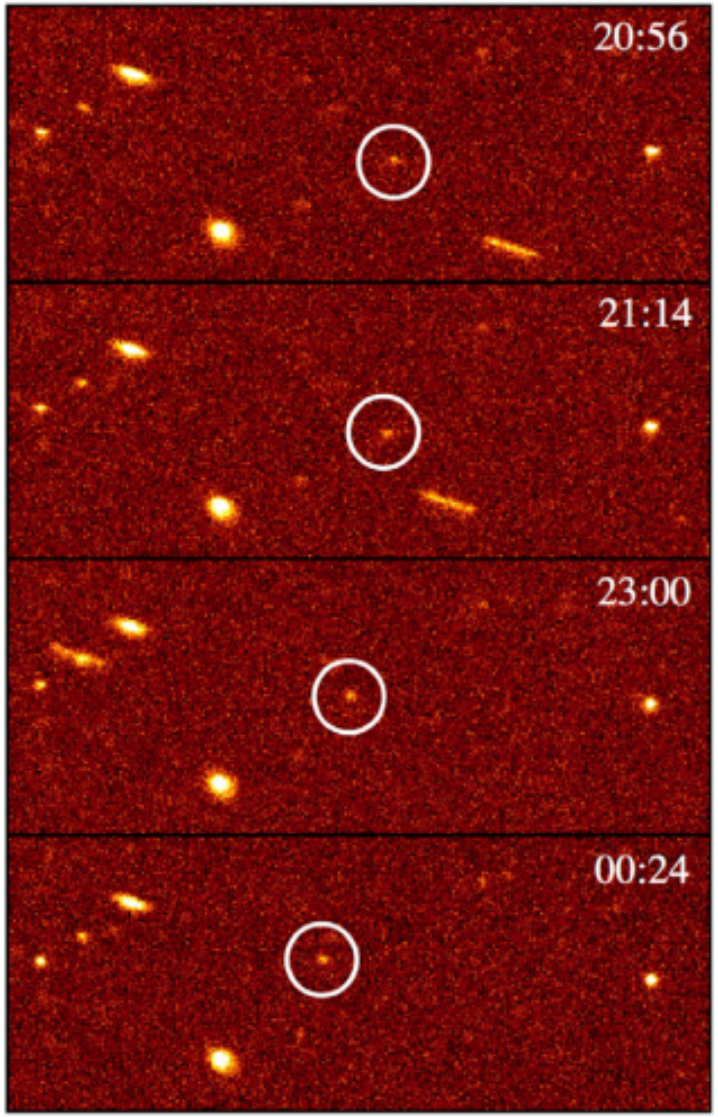
University of Hawaii 88-inch (2.2m) telescope on Mauna Kea, Hawaii

A Night at the Telescope

1992

Jewitt and Luu discovered Kuiper Belt

Discovery of 1992 QB1, First Kuiper Belt Object



Discovery images of 1992 QB1, Aug 30, 1992

Image credit: Jewitt & Luu

- Discovered with new 2048 x 2048 pixel CCD
- Motion: 2.6 arcsec/hr W, 1.1 arcsec/hr S
- Distance: 41 AU (far beyond Neptune and Pluto)
- Diameter: 250 km

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1992 QB_1

D. Jewitt, University of Hawaii; and J. Luu, University of California at Berkeley, report the discovery of a very faint object with very slow (3″/hour) retrograde near-opposition motion, detected in CCD images obtained with the University of Hawaii's 2.2-m telescope at Mauna Kea. The object appears stellar in 0″.8 seeing, with an apparent Mould magnitude $R = 22.8 \pm 0.2$ measured in a 1″.5-radius aperture and a broadband color index $V - R = +0.7 \pm 0.2$.

1992	UT	α_{2000}	δ_{2000}
Aug.	30.45568	$0^h01^m12^s.79$	$+0°08'50''.7$
	30.59817	0 01 12.19	+0 08 46.9
	31.52047	0 01 08.37	+0 08 22.7
	31.61982	0 01 07.95	+0 08 19.9
Sept.	1.35448	0 01 04.90	+0 08 00.6
	1.62225	0 01 03.76	+0 07 53.3

Discovery announcement

Kuiper Belt Orbits — Side View

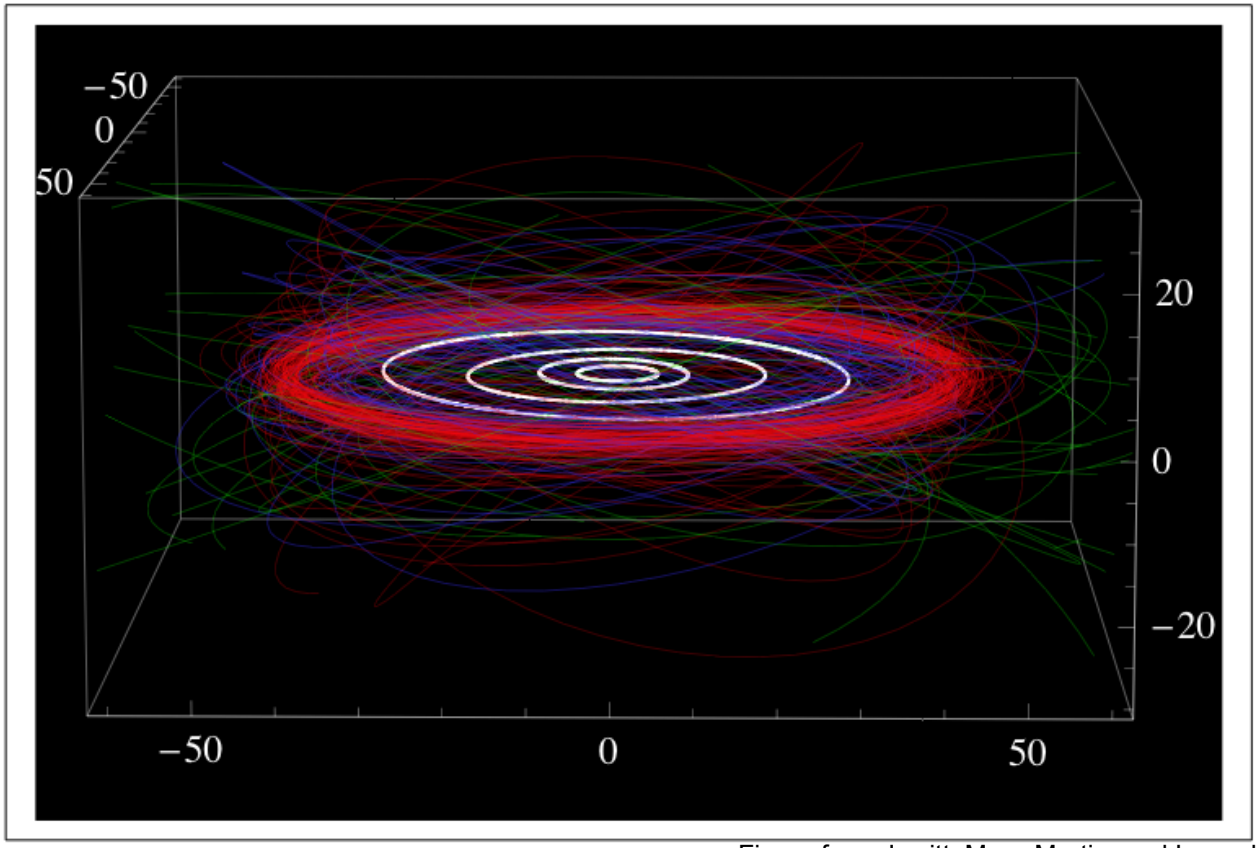


Figure from Jewitt, Moro-Martin, and Lacerda (2008)

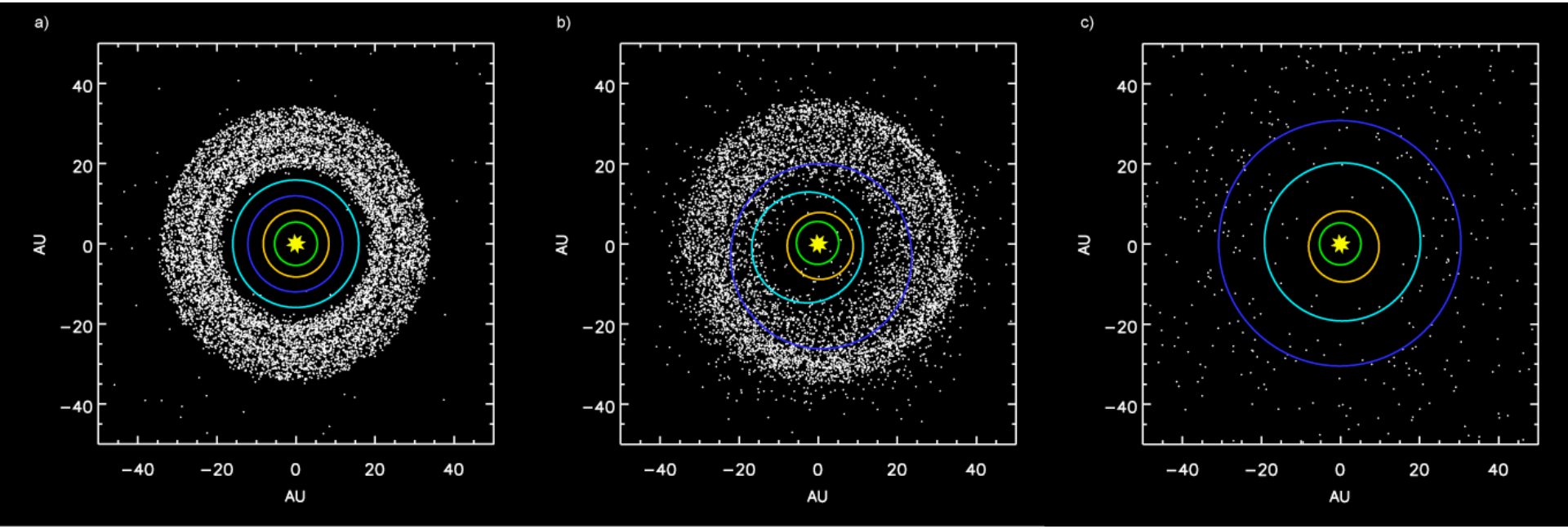
- Kuiper Belt: donut-shape, extending from 40 to >1000 AU
- Current total mass: 0.1 Earth-mass
  - ➡ Original Kuiper Belt: roughly100x more massive

How the Kuiper Belt Moved the Giant Planets
One possible scenario

a) Giant planets and original Kuiper Belt

b) Giant planets scattered Kuiper Belt objects

c) Most of Kuiper Belt scattered away



Adapted from Gomes et al. (2005)

- Orbits of giant planets changed as result of scattering Kuiper Belt objects

Kuiper Belt Orbits — Top View

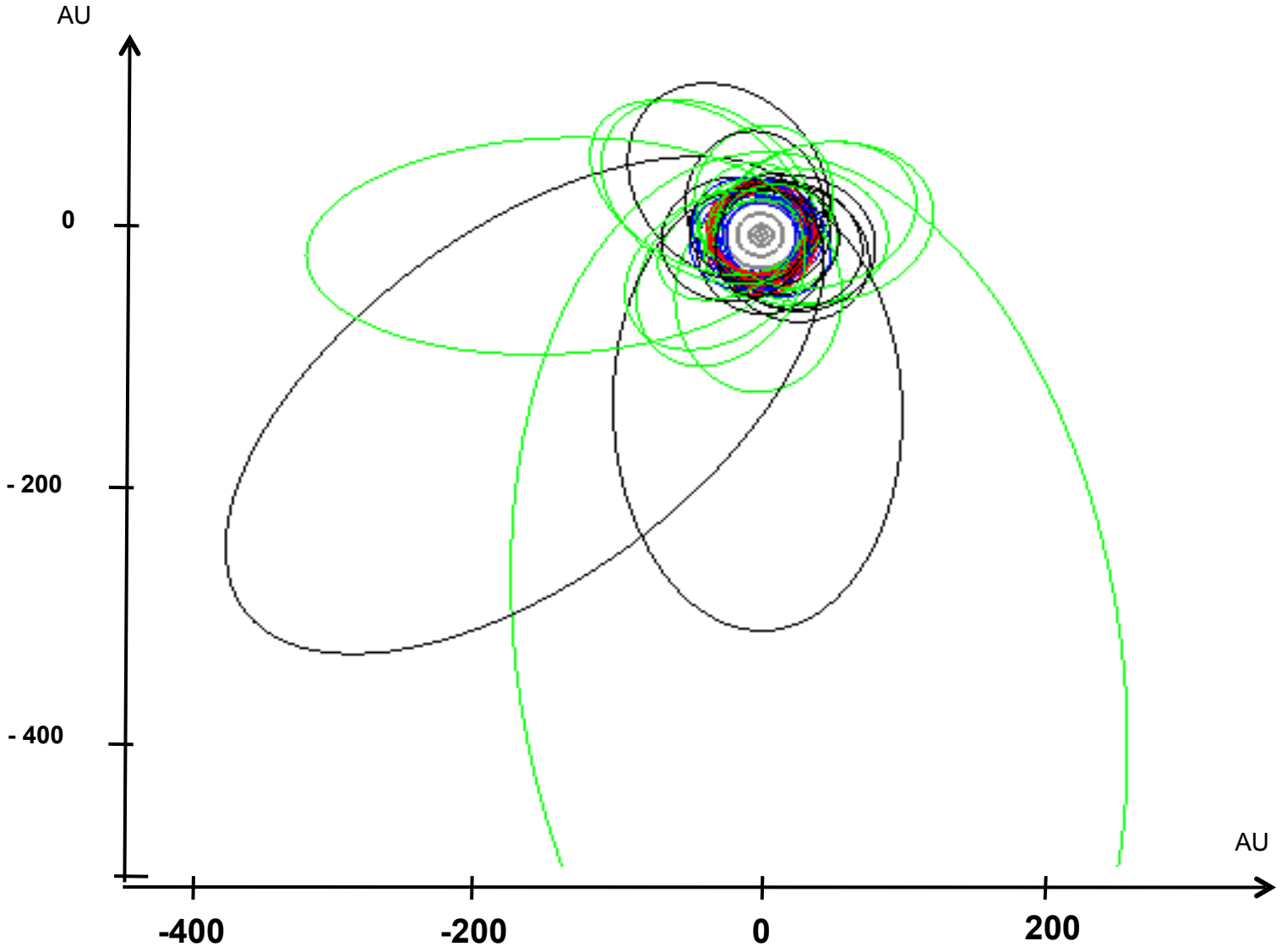
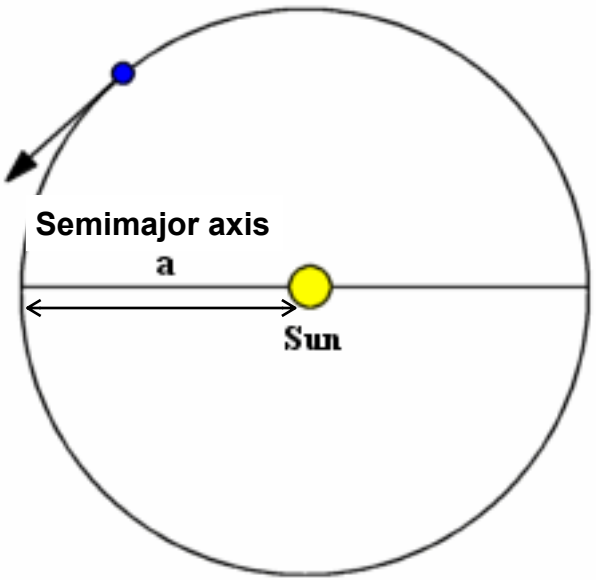


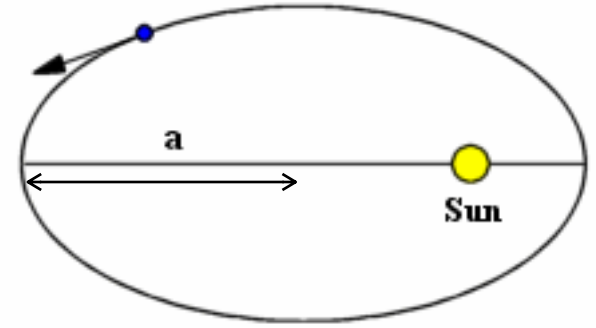
Image credit: Jewitt & Luu

Orbits in Solar System

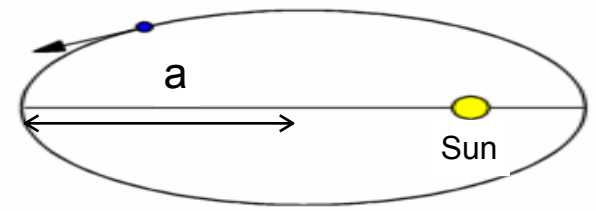


Eccentricity e = 0

- Orbits in solar system are **ellipses**
  - **Semimajor axis a:** how big the orbit is
  - **Eccentricity e:** how elliptical the orbit is



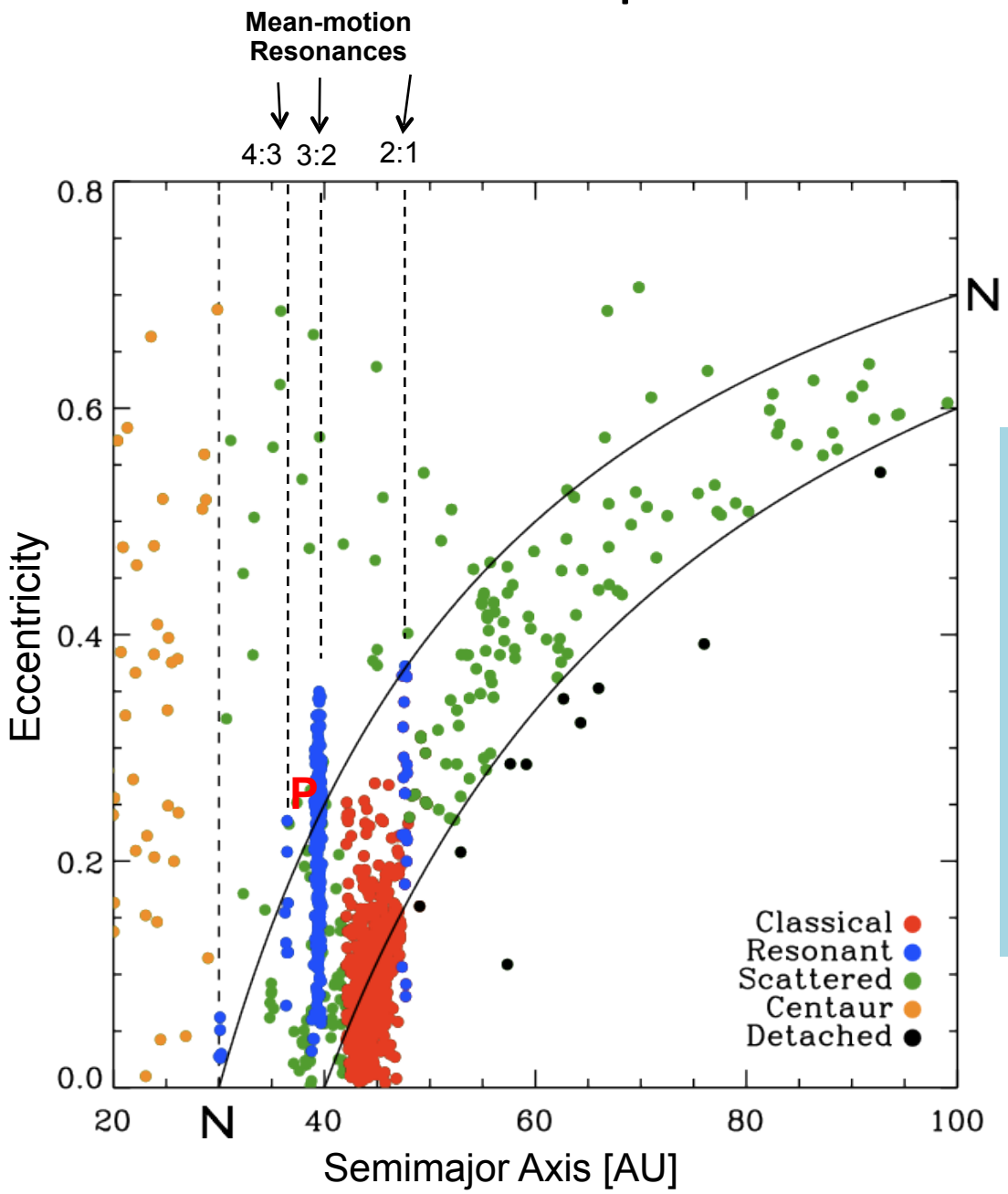
e = 0.6



e = 0.8

Image credit: Wikipedia

Kuiper Belt Orbits



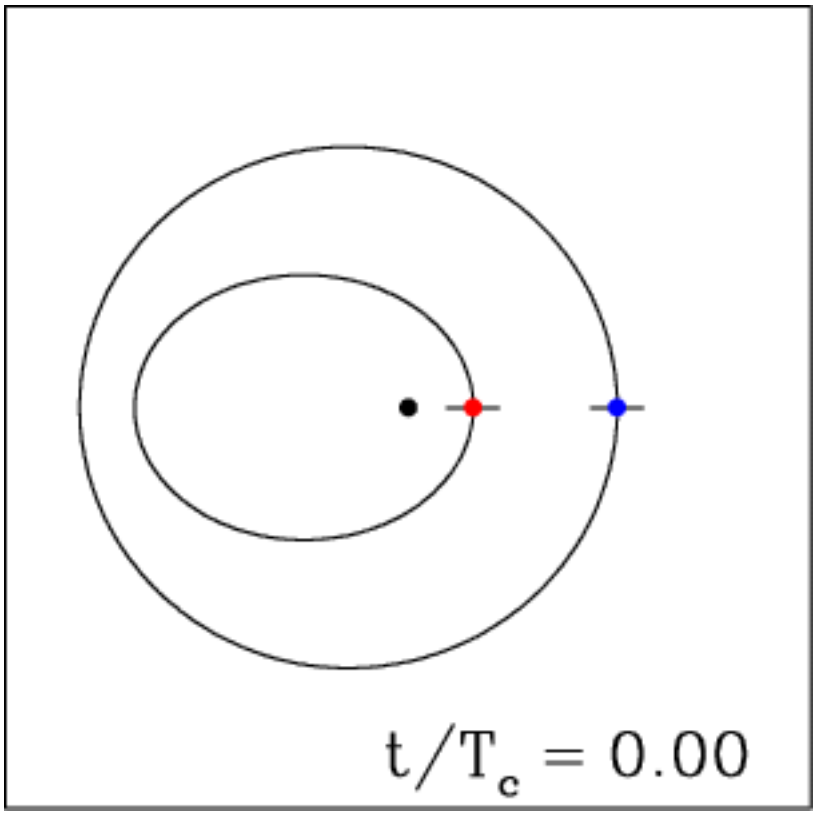
- Kuiper Belt objects have very specific orbits (not random)
- The Scattered objects are precursors of short-period comets
- Many objects are clustered at "mean motion resonances"

Image credit: Jewitt & Luu

Mean Motion Resonance

- Mean motion resonance: when orbital periods of 2 bodies form small ratios, e.g., 2:1, 3:2, etc.
- The 2 bodies receive gravitational "kicks" at the right time (like pushing on swing)

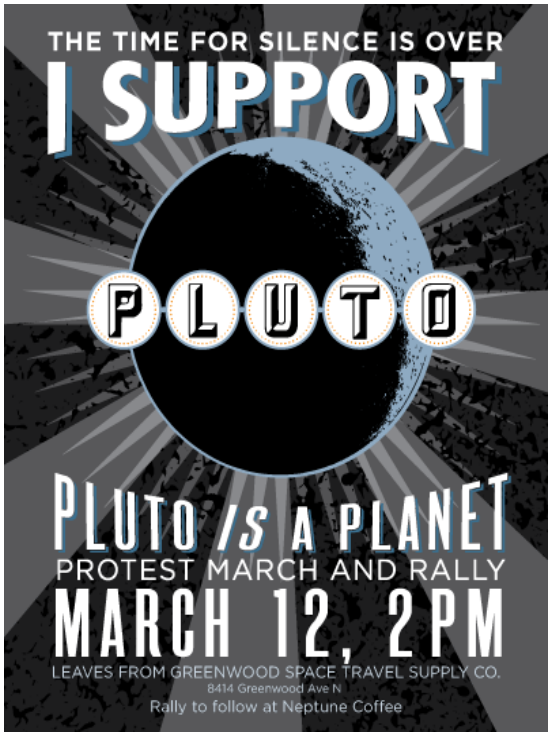
Planets in 2:1 resonance



$$\frac{\text{Blue Period}}{\text{Red Period}} = \frac{2}{1}$$

2006

Pluto officially demoted from planethood



- Scientific progress = change
  - Old ideas replaced with new ones
- Science does not depend on the public's (or children's) feelings

http://www.greenwoodspacetravelsupply.blogspot.com/

Summary

- We found the Kuiper Belt because we looked for it
- Scientic progress = changing old ideas
- Kuiper Belt "trails off beyond Neptune into a far-reaching and richly populated field of objects" - Brian Marsden