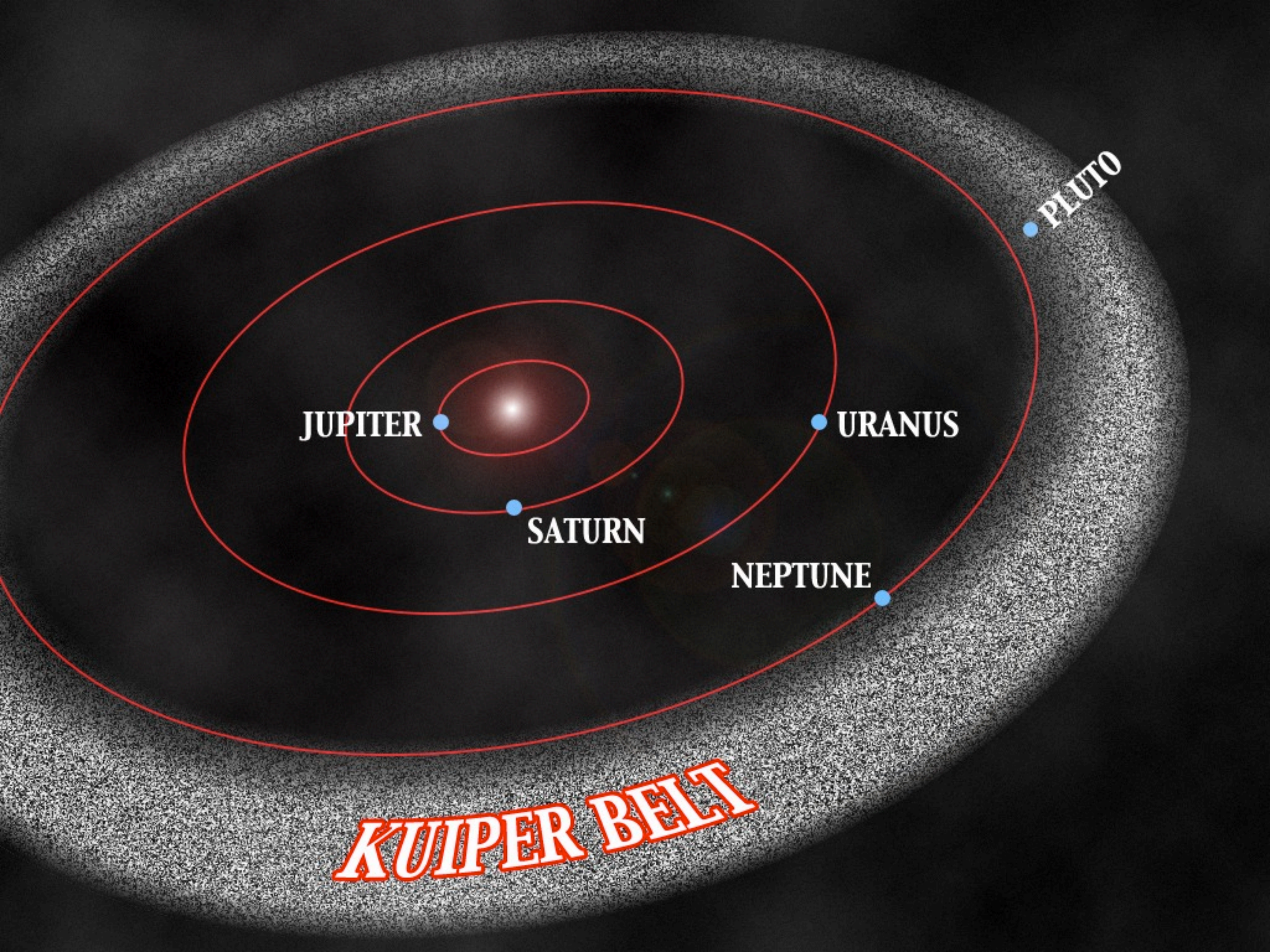
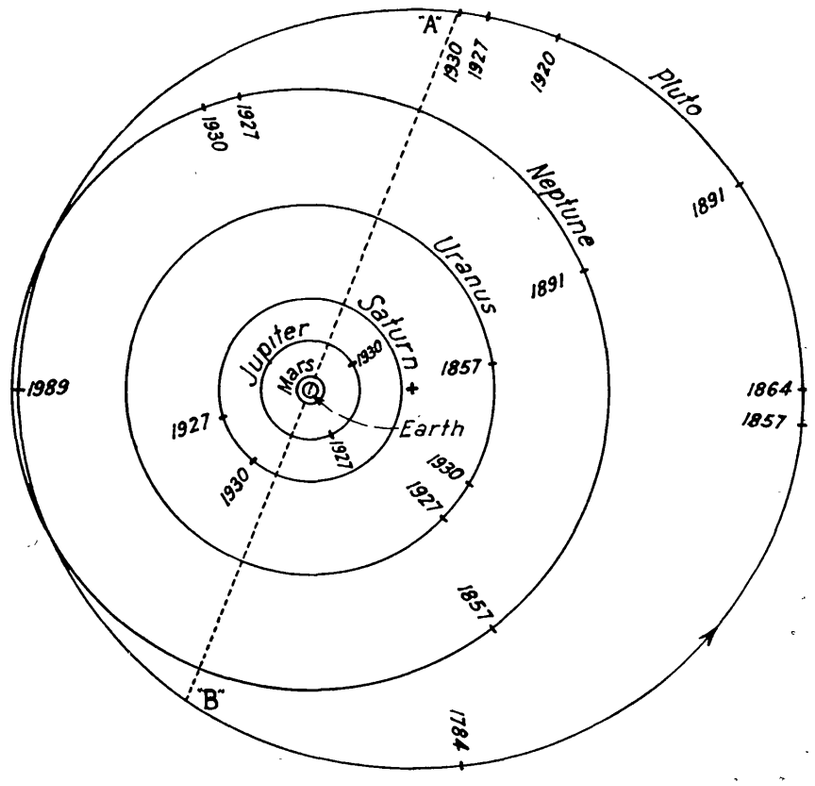
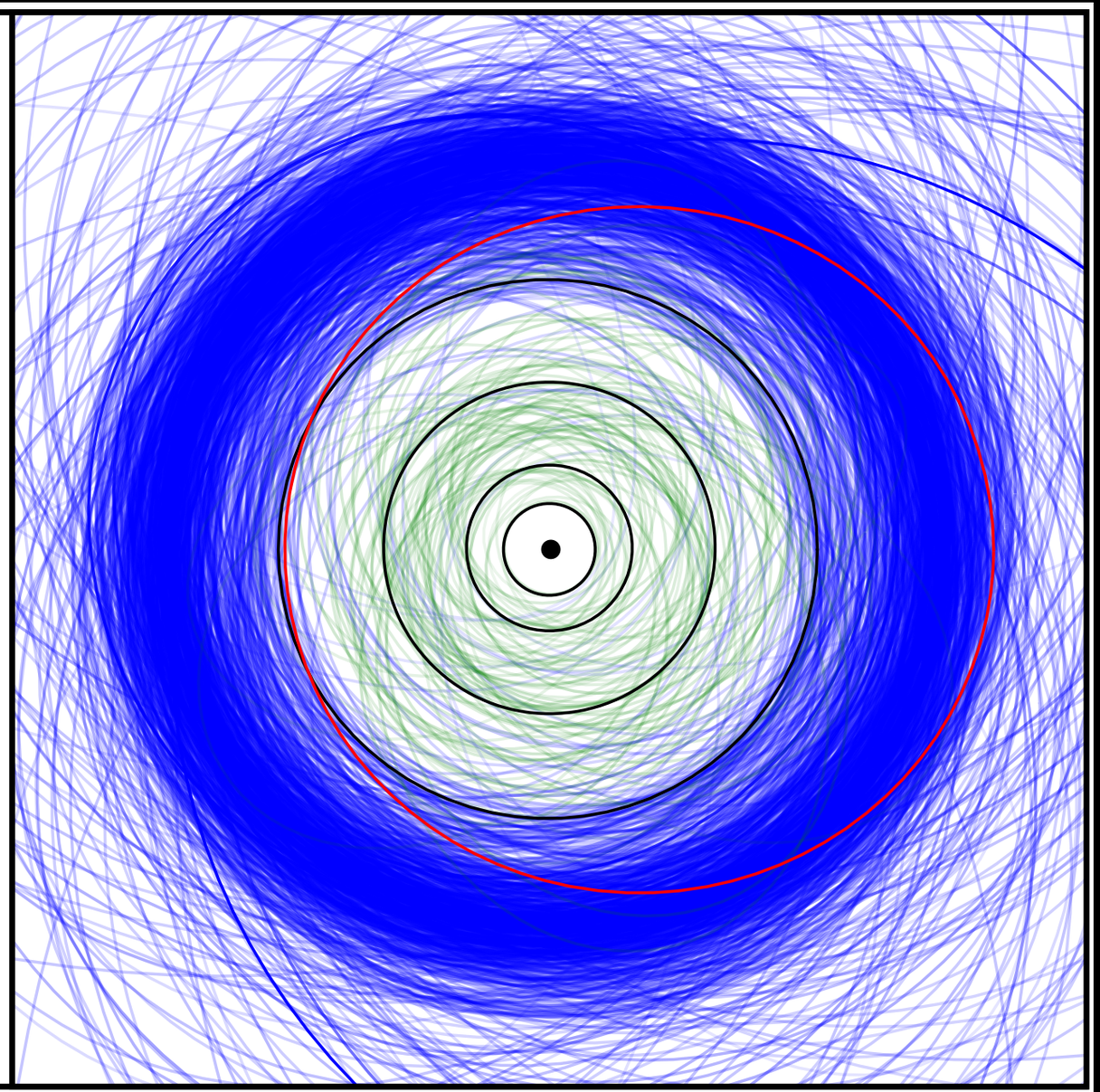
BINARIES IN THE KUIPER BELT

Alex Parker - RASC Talk May 11, 2011

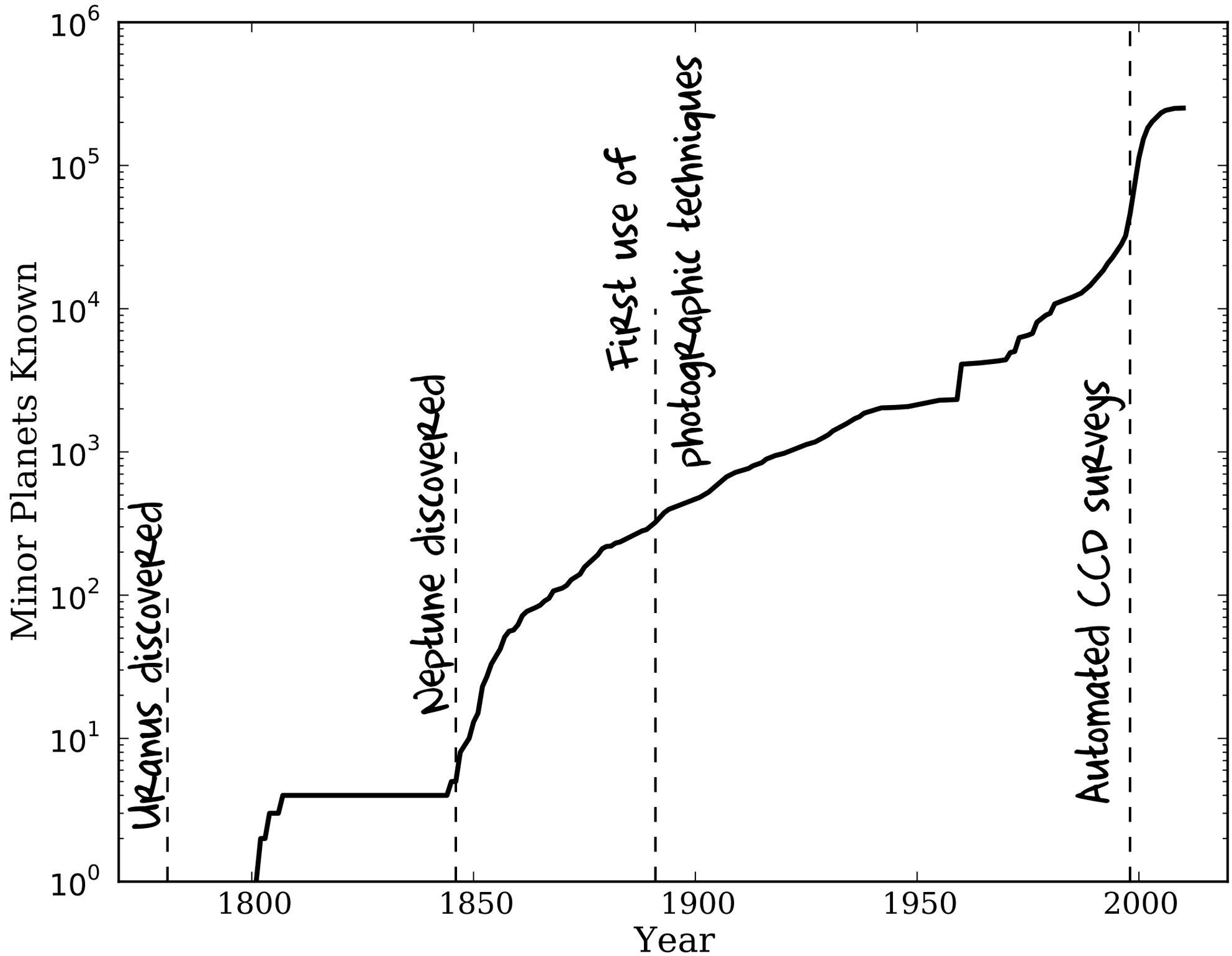

PLUTO
JUPITER
URANUS
SATURN
NEPTUNE
KUIPER BELT


"A"
1930
1927
1920
Pluto
1930
1927
Neptune
1891
Uranus
1891
Saturn
1857
Jupiter
1930
Mars
1989
1927
Earth
1927
1930
1930
1927
1864
1857
1857
"B"
1784

1930



2011


Minor Planets Known
10^0
10^1
10^2
10^3
10^4
10^5
10^6
1800
1850
1900
1950
2000
Year
Uranus discovered
Neptune discovered
First use of photographic techniques
Automated CCD surveys

The Kuiper Belt

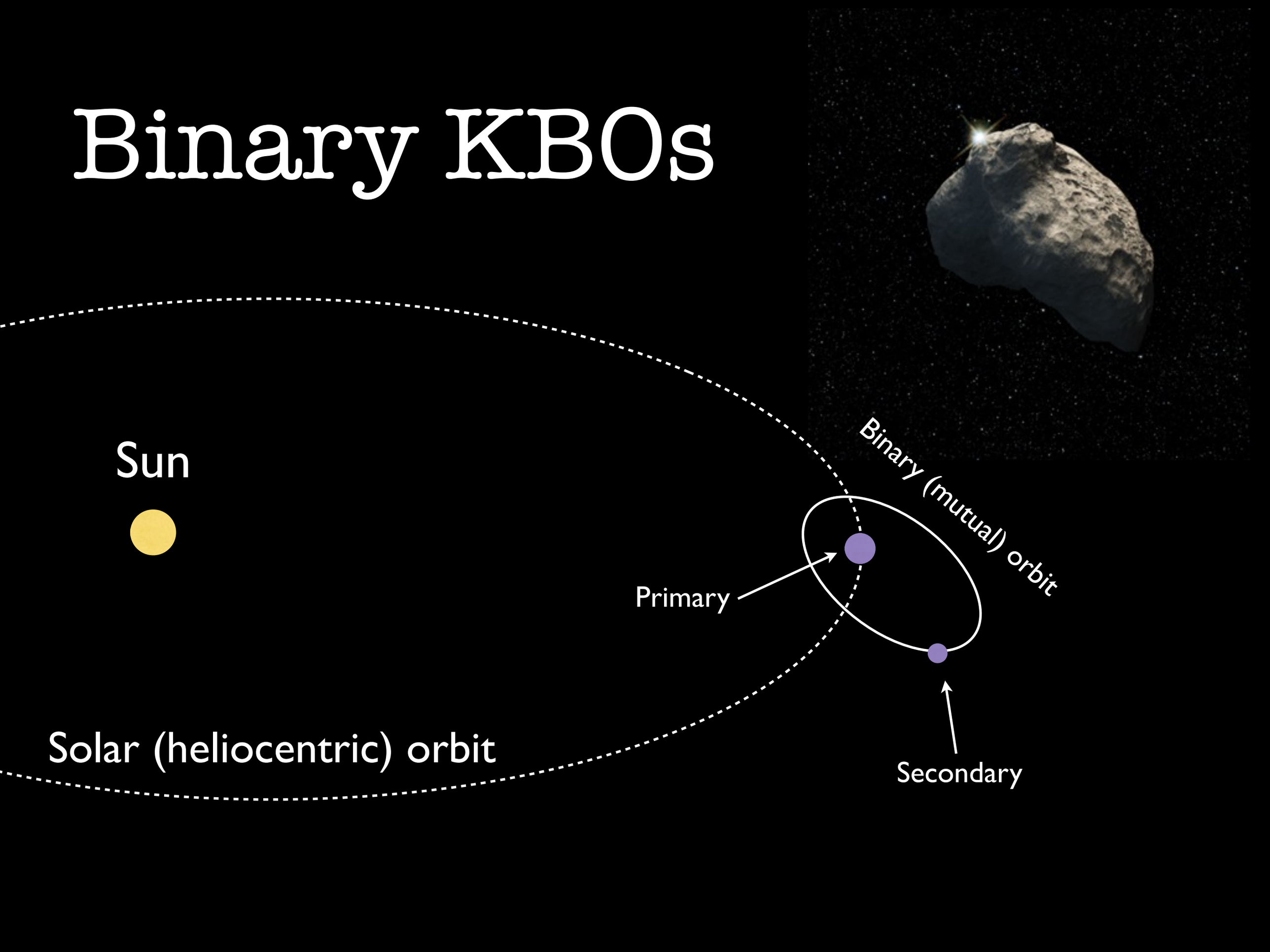
- 5-7 billion km from the Sun
- Fossil remnant of primordial disk of debris
- Helps us understand history of planet formation in the Solar System
- Big question: where did it come from?

=

The Kuiper Belt

- Binaries in the Kuiper Belt:
  - Let us measure mass, density
  - Tell us about dynamics, history, collisions

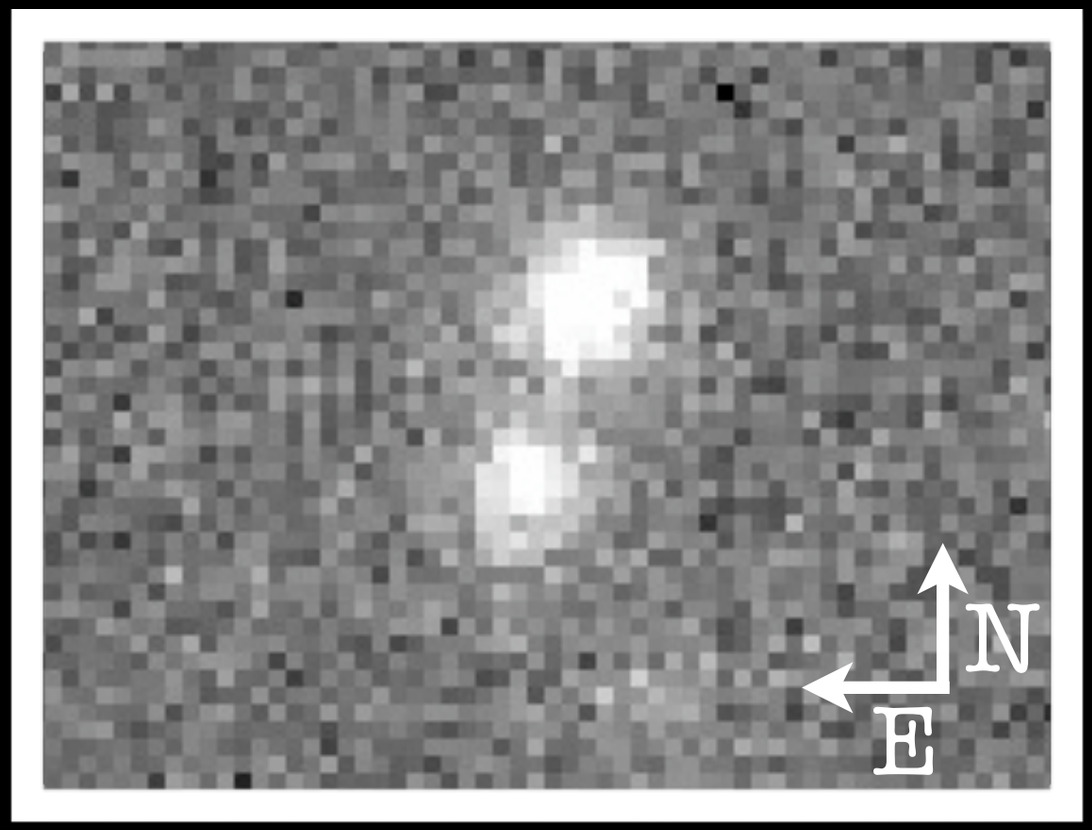
Binary KBOs


Sun
Solar (heliocentric) orbit
Binary (mutual) orbit
Primary
Secondary

Example Binaries

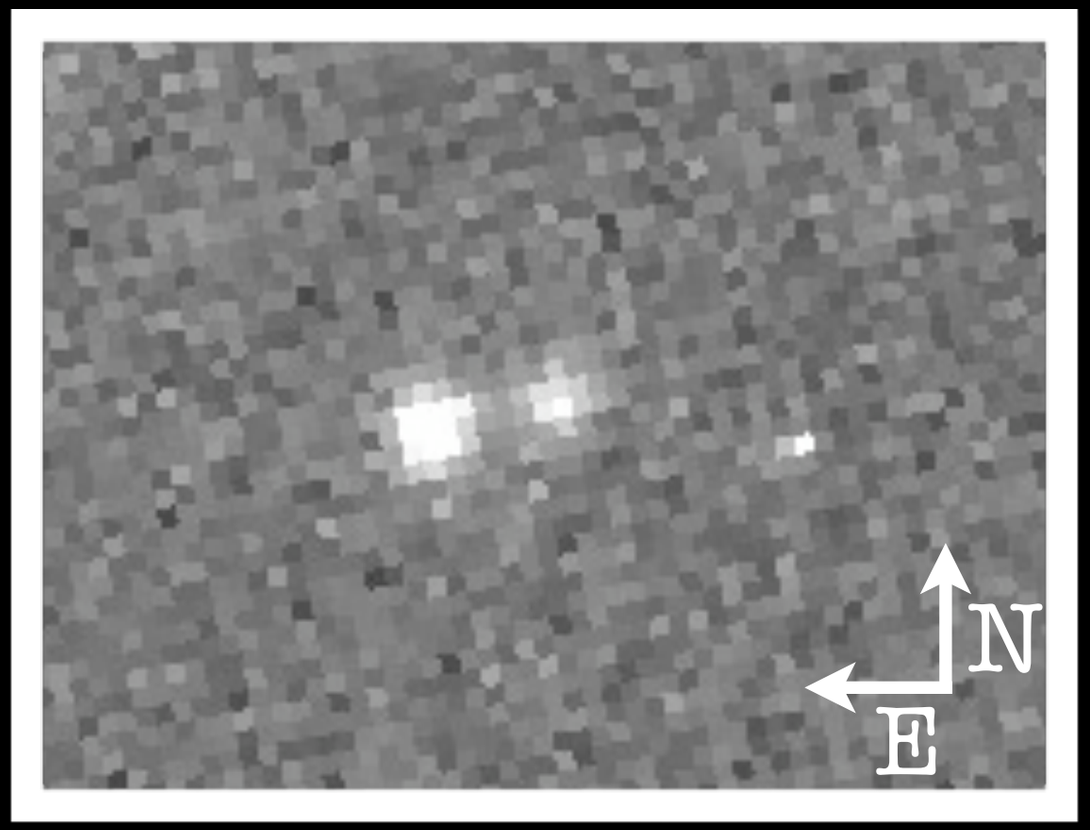
Example Binaries

b7Qa4 - April 2010

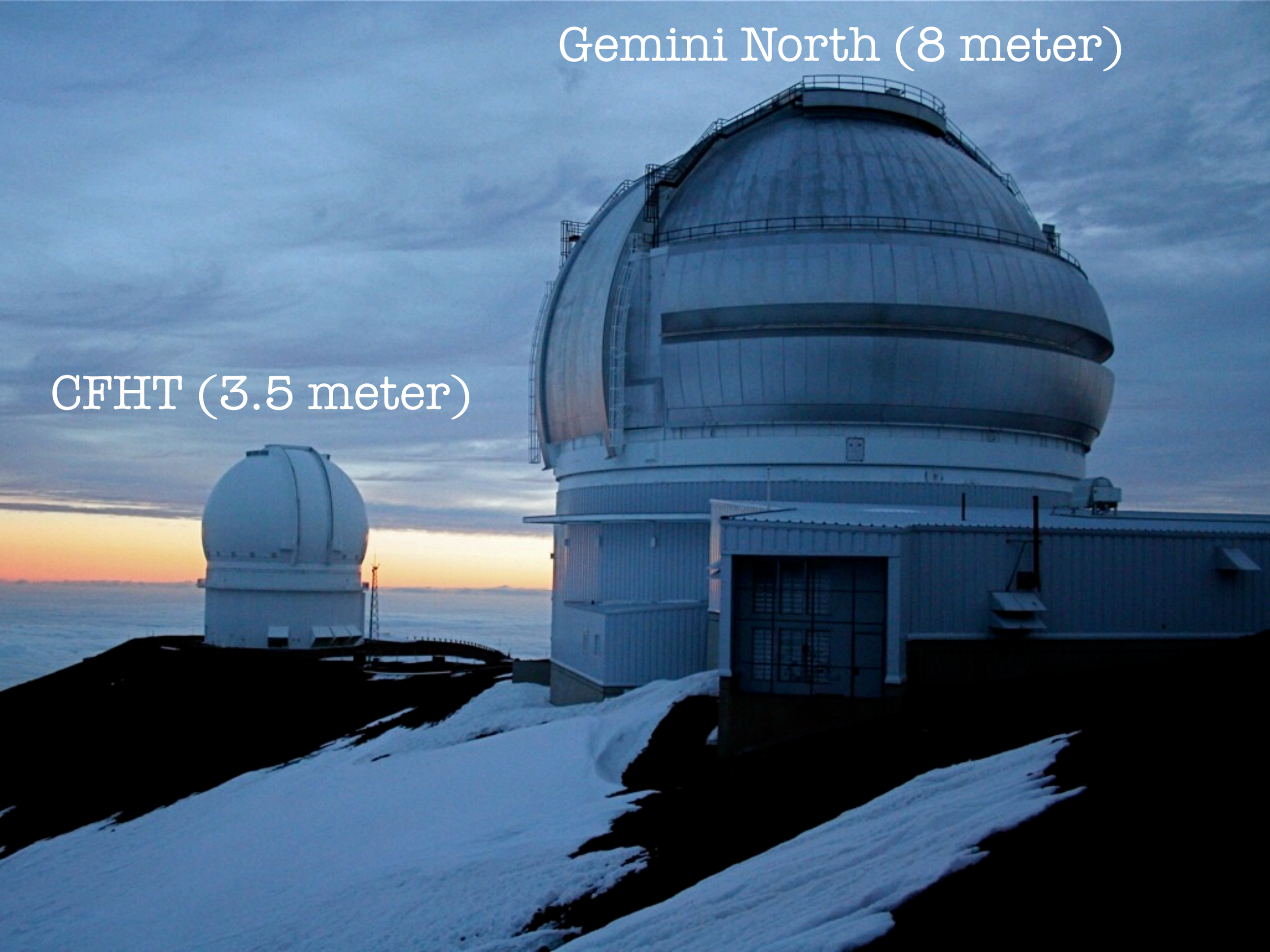


sep ~ 0.82”

2000 CF105 - April 2010



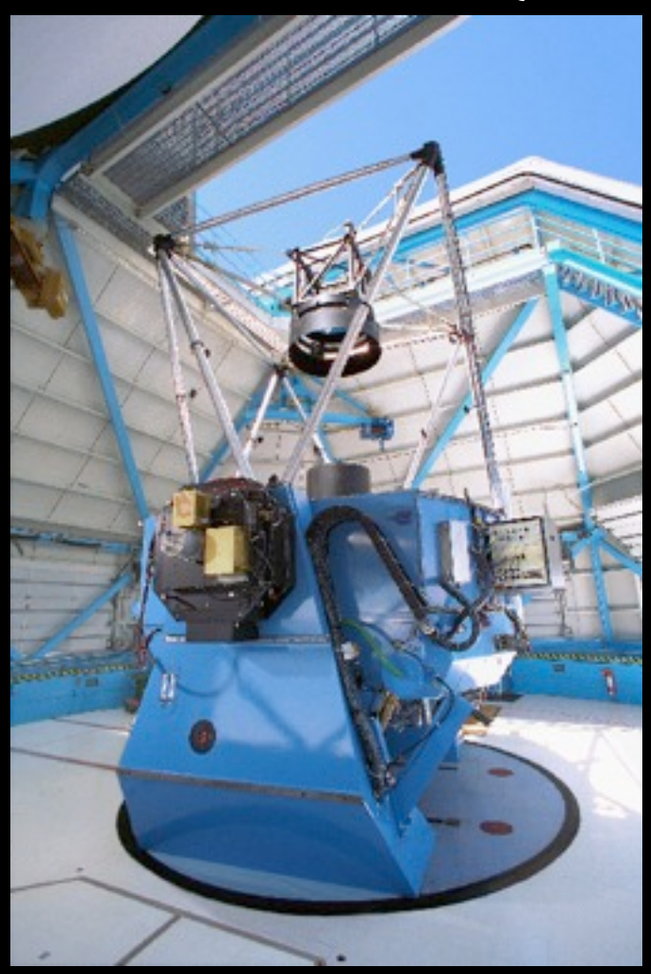
sep ~ 0.95”

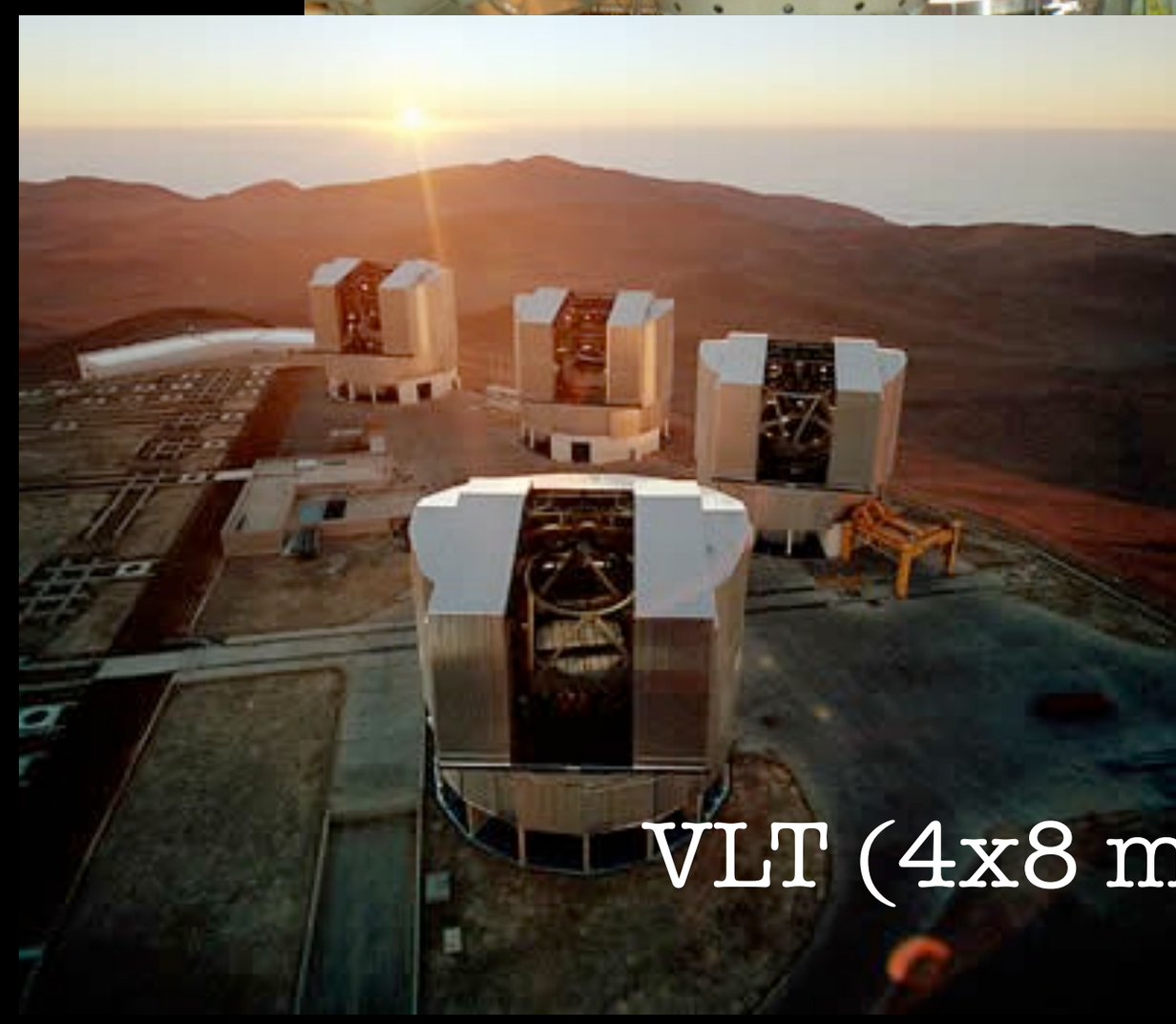

Gemini North (8 meter)
CFHT (3.5 meter)

Hubble (2.4 m)

Palomar (5 m)

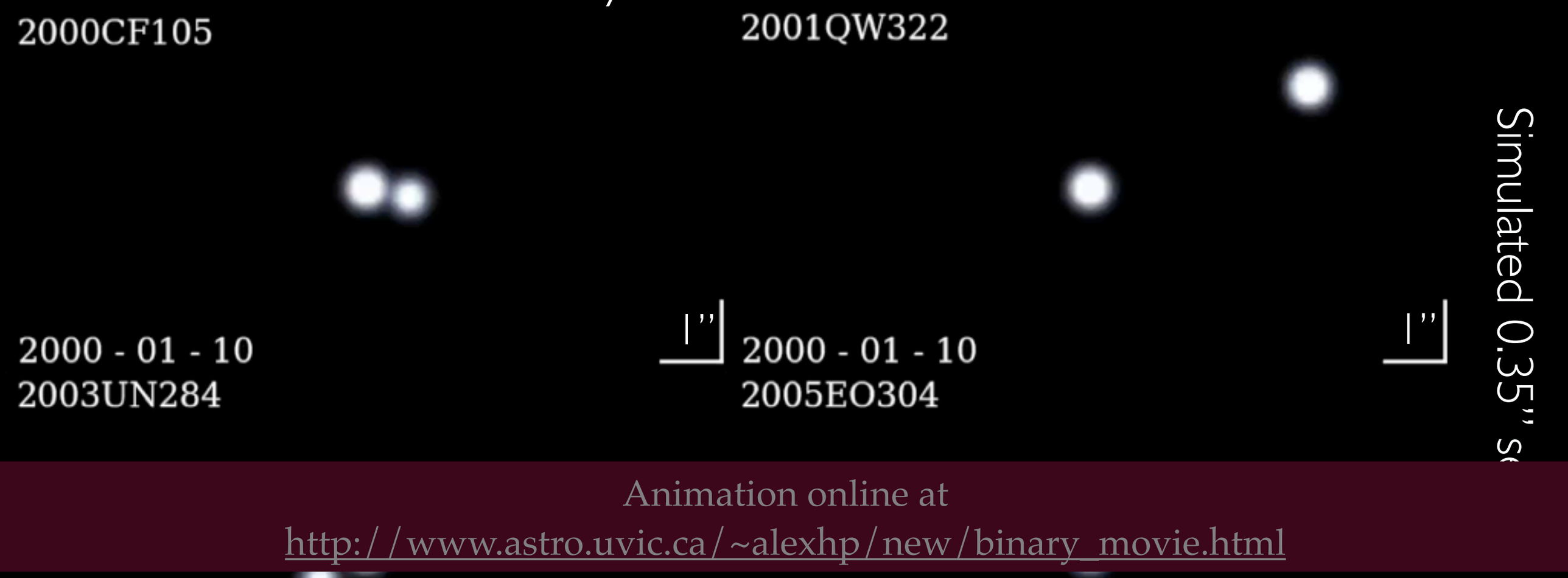
WIYN (3.5 m)



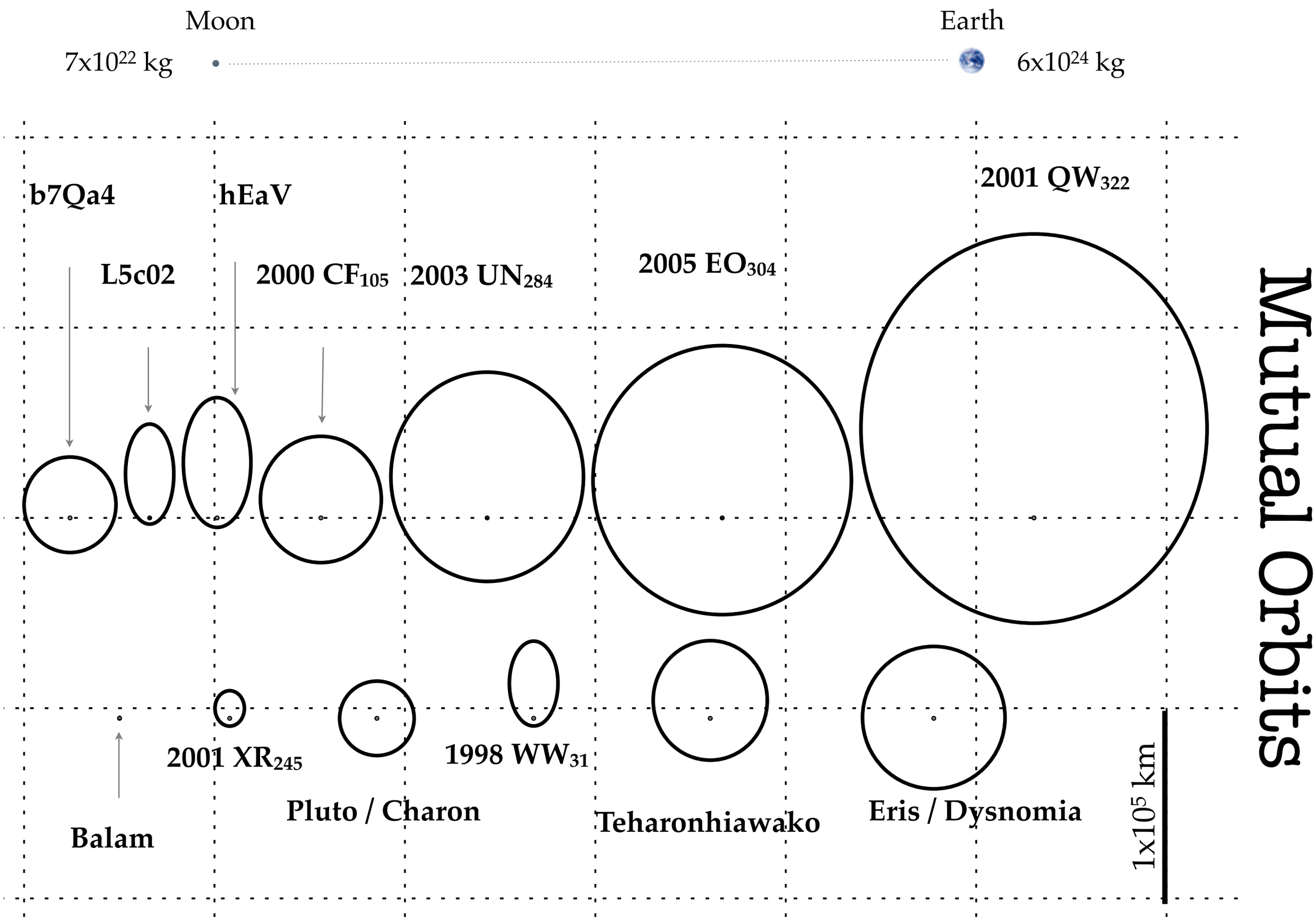


VLT (4x8 m)

Best-Fit Binary Mutual Orbits, 2000-2013



Animation online at
http://www.astro.uvic.ca/~alexhp/new/binary_movie.html


Mutual Orbits
Moon
7x10^22 kg
Earth
6x10^24 kg
b7Qa4
L5c02
hEaV
2000 CF105
2003 UN284
2005 EO304
2001 QW322
Balam
2001 XR245
Pluto / Charon
1998 WW31
Teharonhiawako
Eris / Dysnomia
1x10^5 km

Dynamics

- How can we determine something's mass?
    - Know size and density, calculate.
    - Apply a known force, measure acceleration.
    - Look for effects on nearby objects.
    - Look for bending of light (lensing)
    - Measure surface gravity

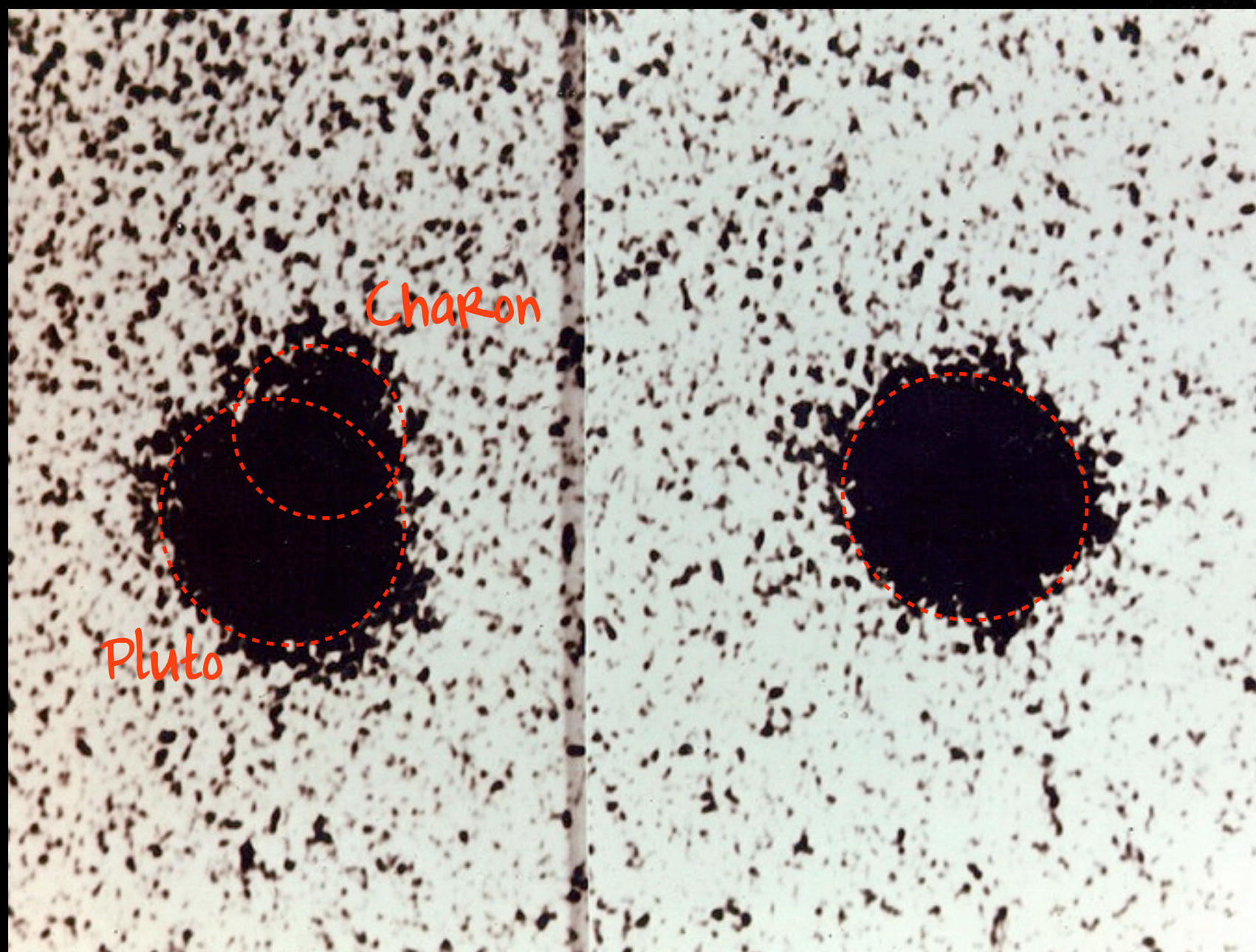
Dynamics

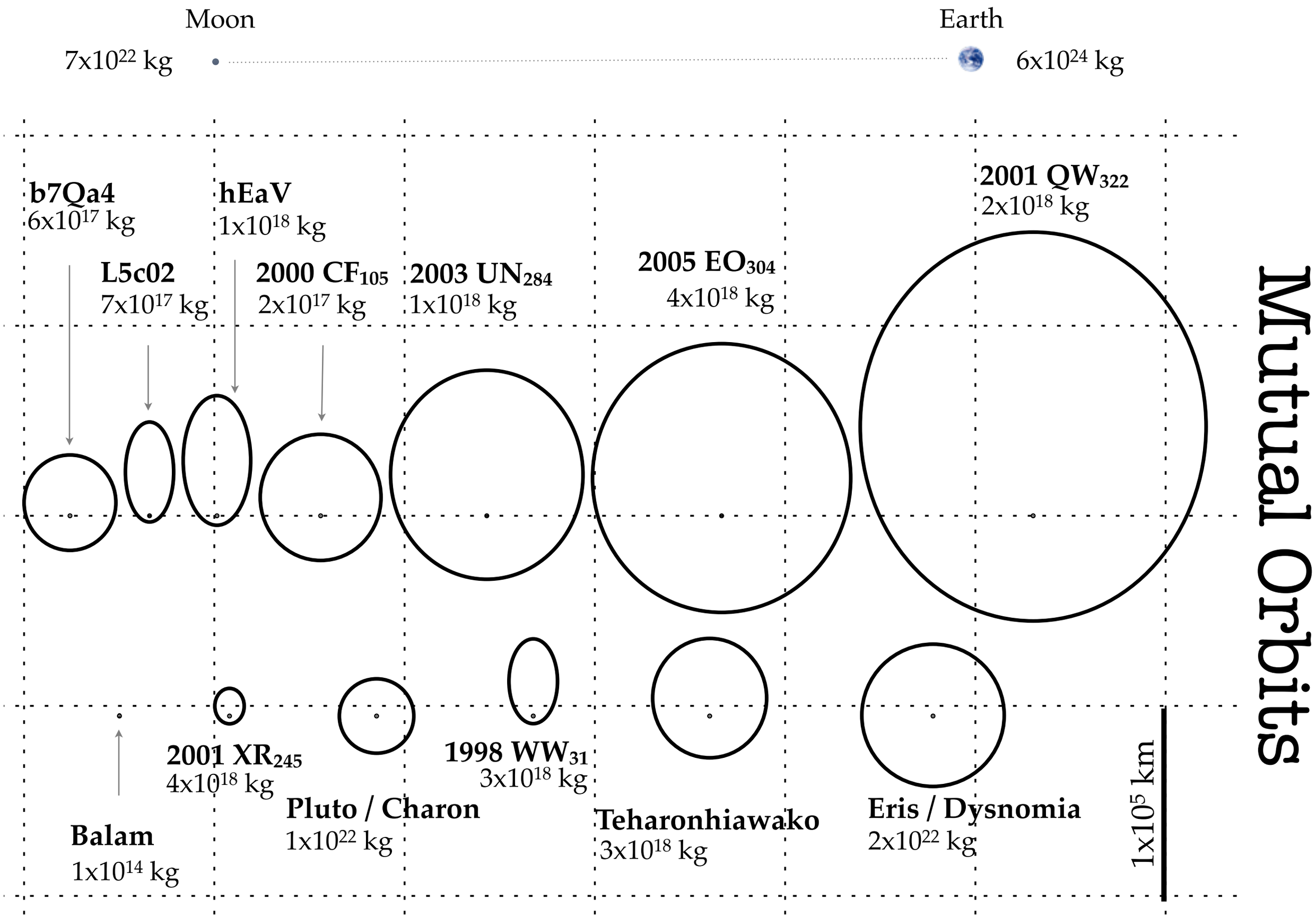
- How can we determine something's mass?
  - From Kepler's Third Law:
    - $M = 4\pi^2 a^3 / (G P^2)$

Dynamics

- Case study: Pluto
  - When discovered in 1930, variations in Neptune's orbit were blamed on Pluto
    - Resulted in mass estimate = Earth
  - In late 1970s, discovery of moon Charon revised mass down by a factor of 500, to less than half a percent of Earth mass

Dynamics




Mutual Orbits
Moon
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2x10^17 kg
2003 UN284
1x10^18 kg
2005 EO304
4x10^18 kg
2001 QW322
2x10^18 kg
Balam
1x10^14 kg
2001 XR245
4x10^18 kg
Pluto / Charon
1x10^22 kg
1998 WW31
3x10^18 kg
Teharonhiawako
3x10^18 kg
Eris / Dysnomia
2x10^22 kg
1x10^5 km

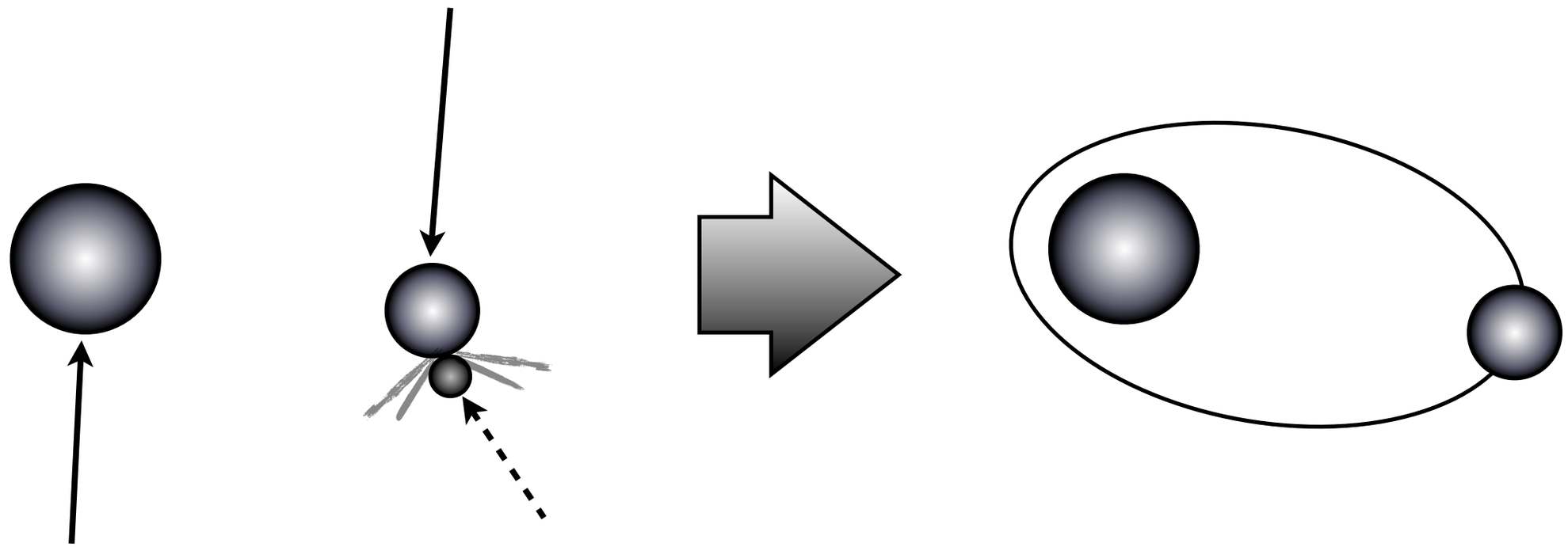
Angular diameter comparison

Animation online at
http://www.astro.uvic.ca/~alexhp/new/figures/moon.mp4

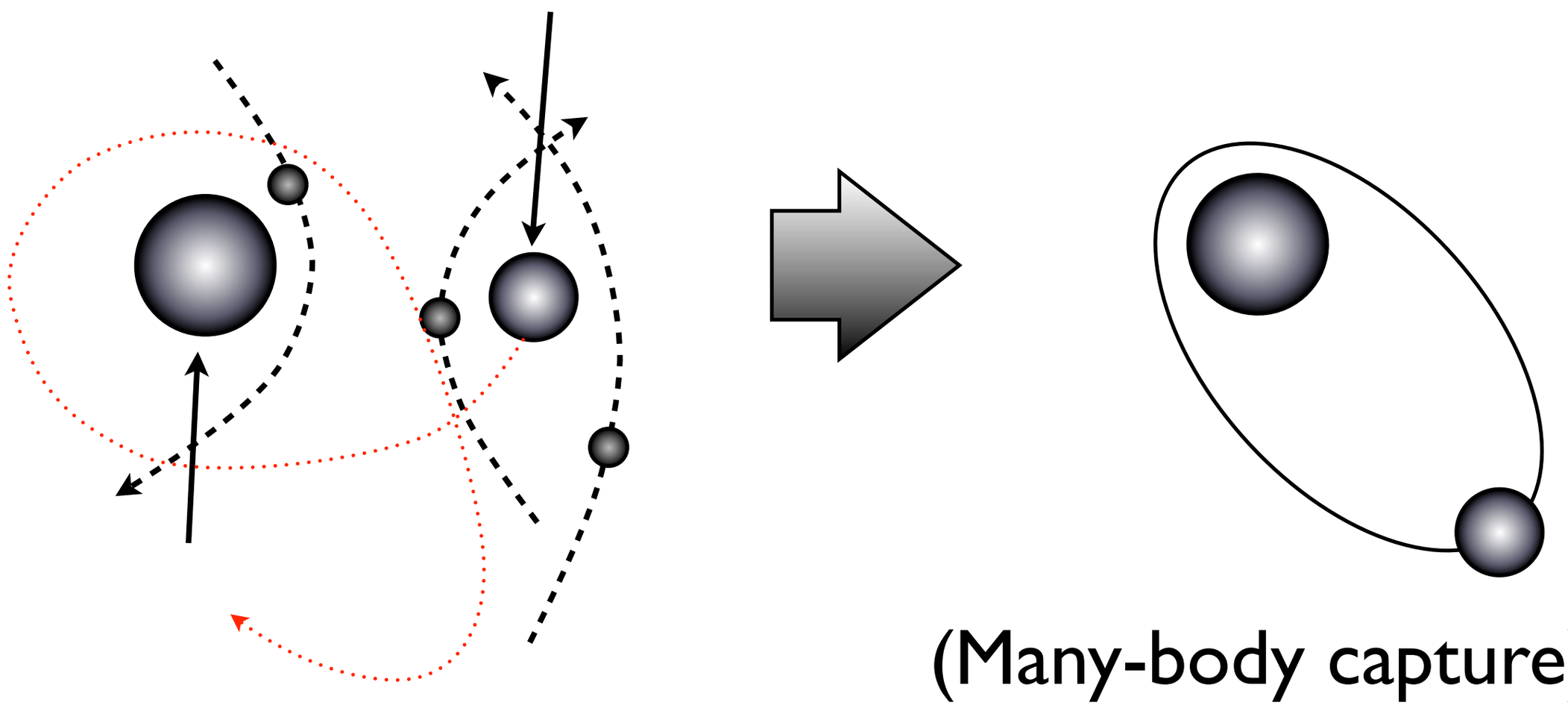
The Moon L5c02-b

Dynamics

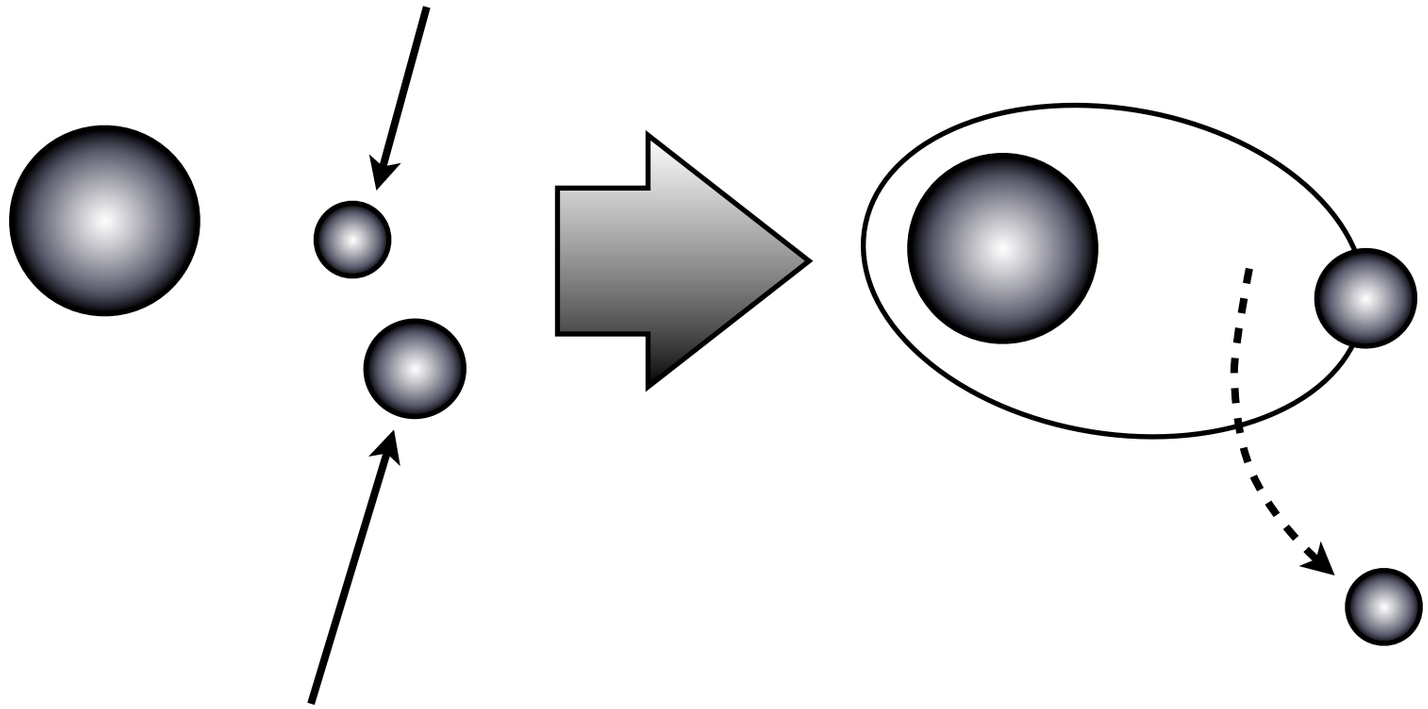
- How did binaries form in the first place?
    - Three-body interactions
    - Collisions
    - Spin-up and fission
    - Many-body interactions
    - “They just formed that way” - gravitational collapse



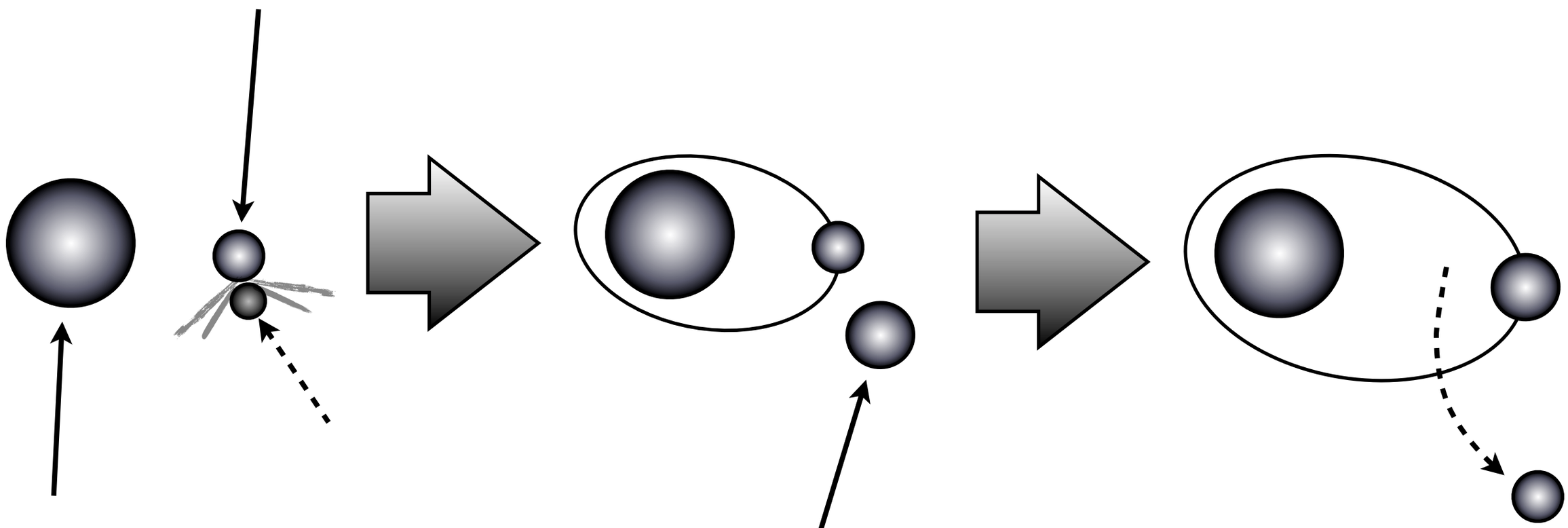
(direct collisional capture)



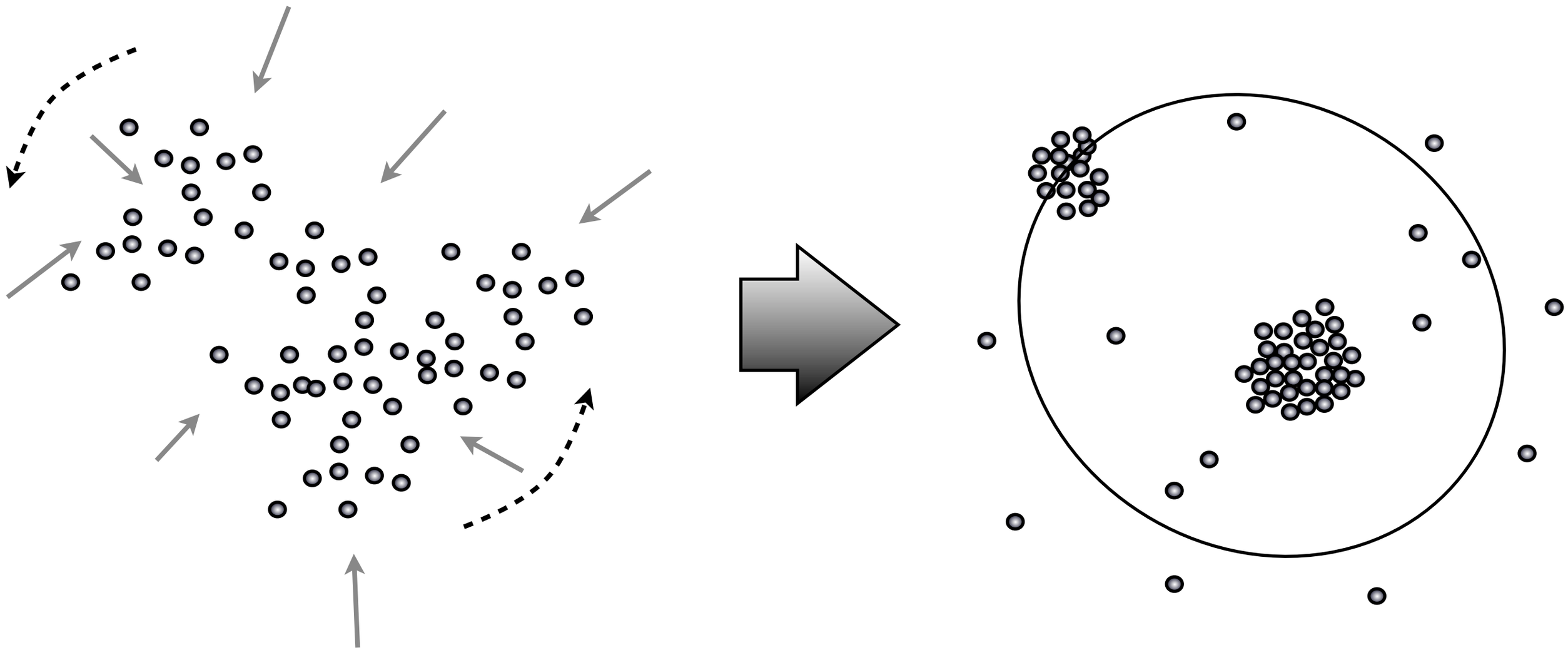
(Many-body capture)



(three-body capture)

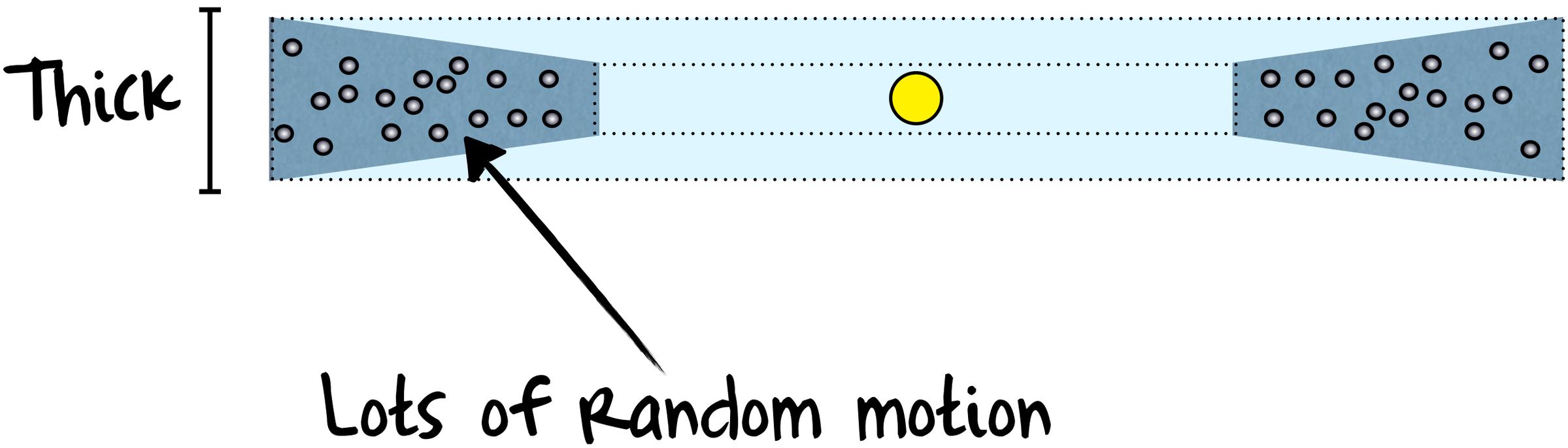


(exchange reactions)



(direct gravitational collapse)

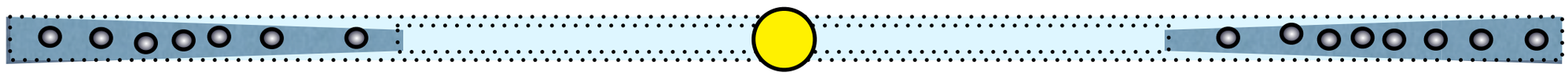
"Hot" disk



- Makes binaries less efficiently
- Only tightly-bound binaries survive
- Random inclinations

"Cold" disk

Thin I



Very little random motion

- Makes binaries more efficiently
- Wide binaries can survive
- Only low inclinations - only retrograde!

The Kuiper Belt

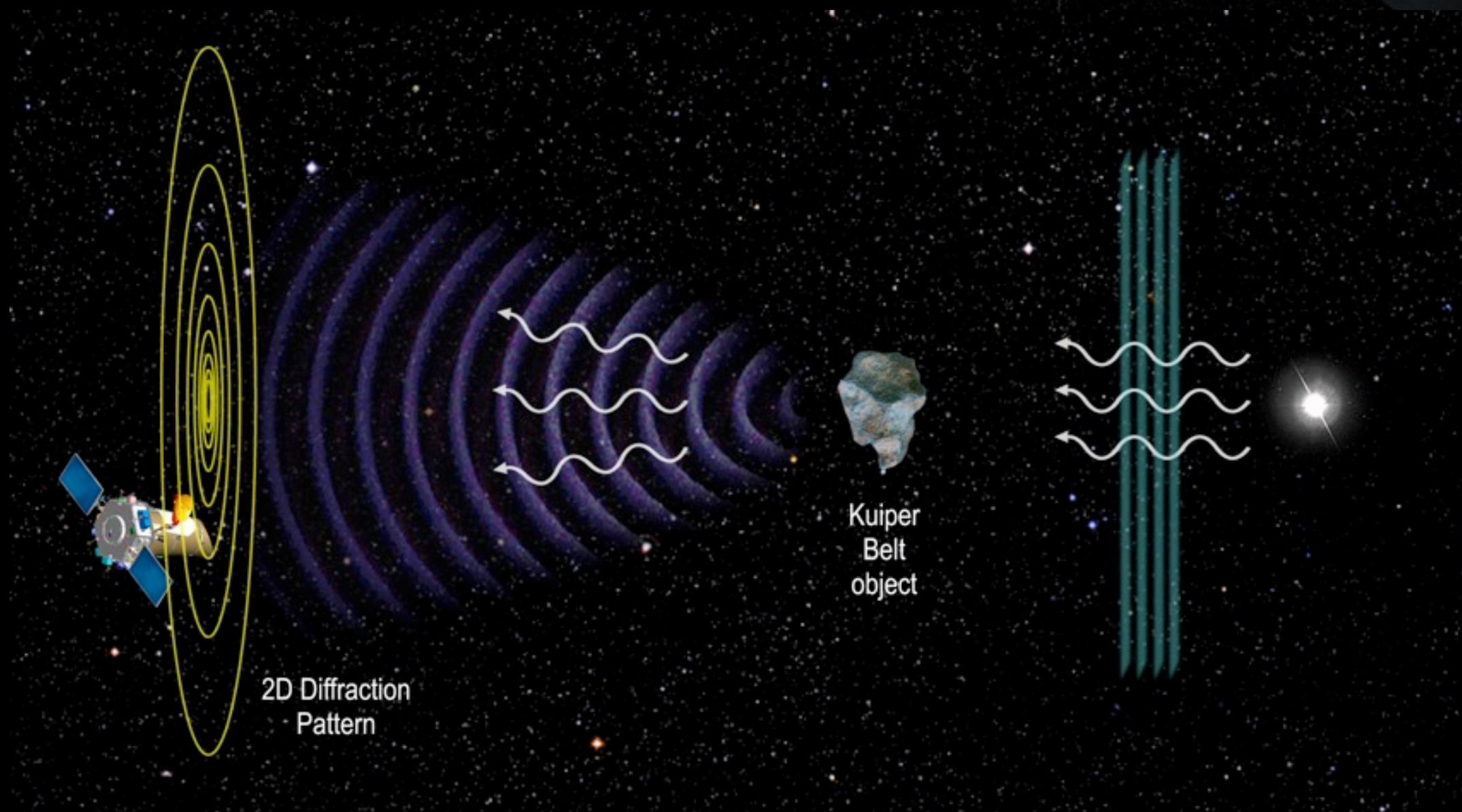
- How can we detect small things?
    - Direct detection (takes a long time)
    - Occultation
    - Craters on large objects
    - Binary survival
    - Explosions!

The Kuiper Belt

- How can we detect small things?
    - Direct detection (takes a long time)
    - 1 km diameter object:
        - 100 million times fainter than Pluto
        - ~40,000 times fainter than first “normal” KBO found (1992 QB1)

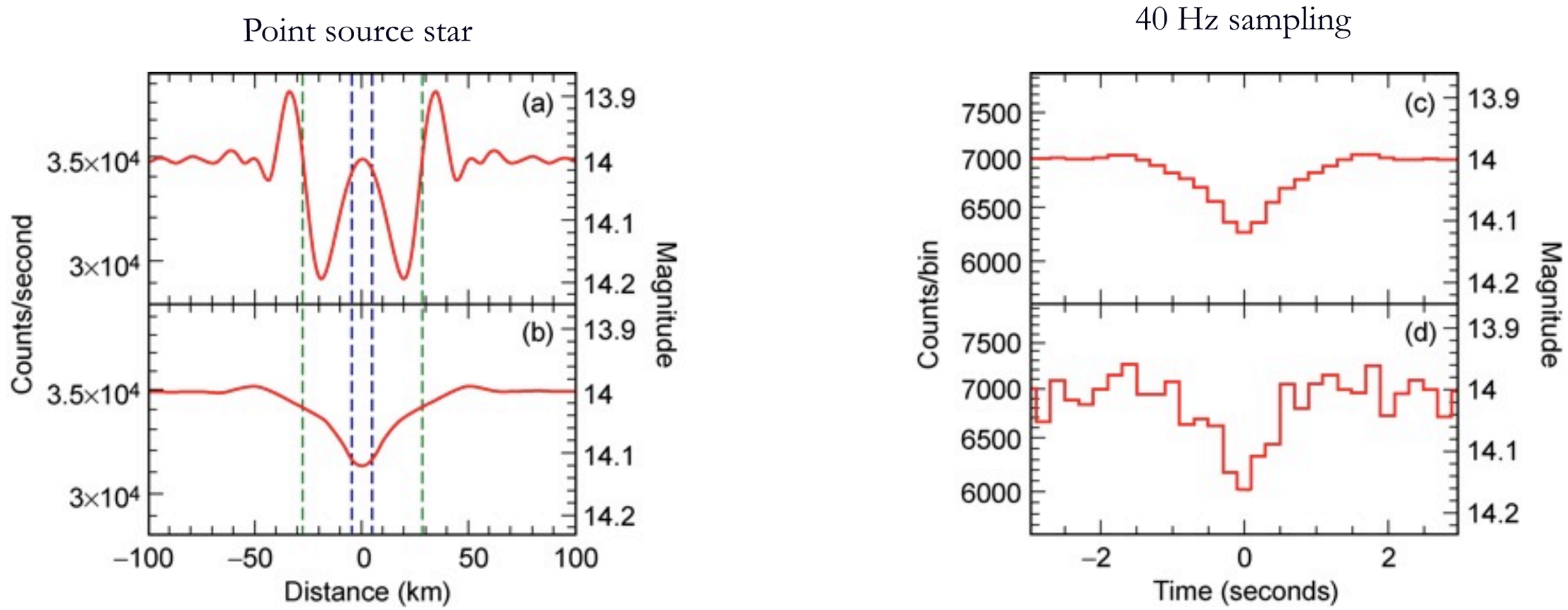
The Kuiper Belt

- Occultations



The Kuiper Belt

- Occultations



The Kuiper Belt

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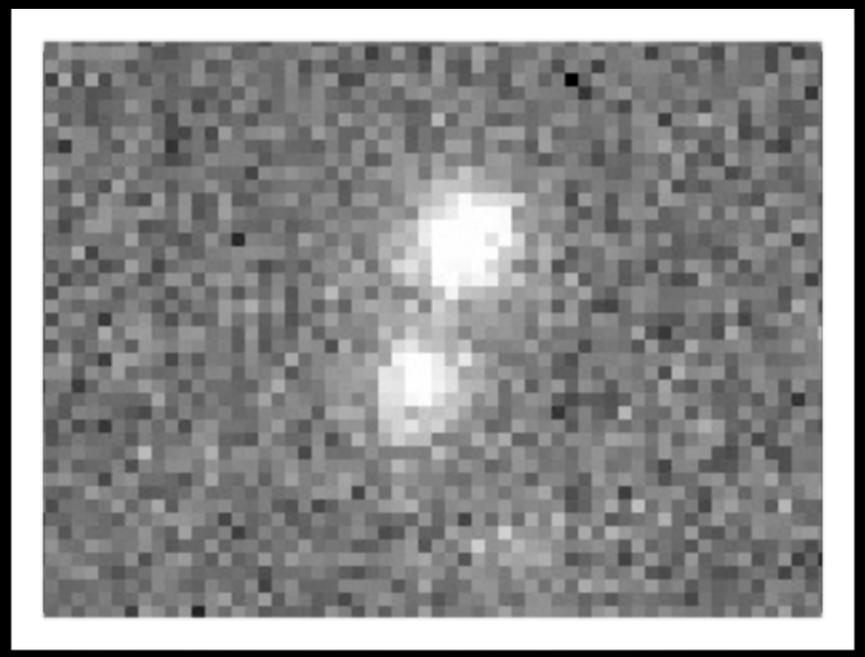

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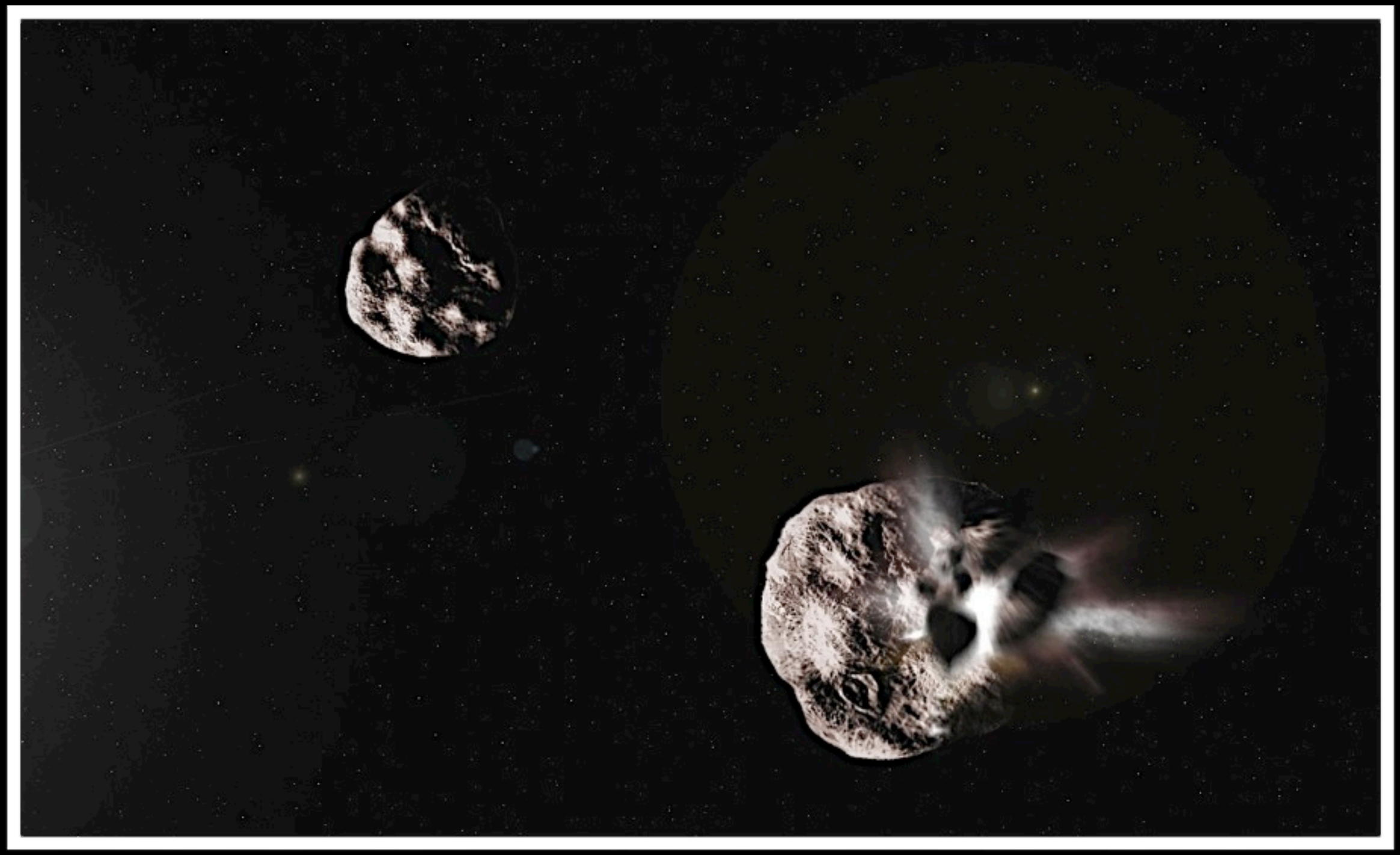
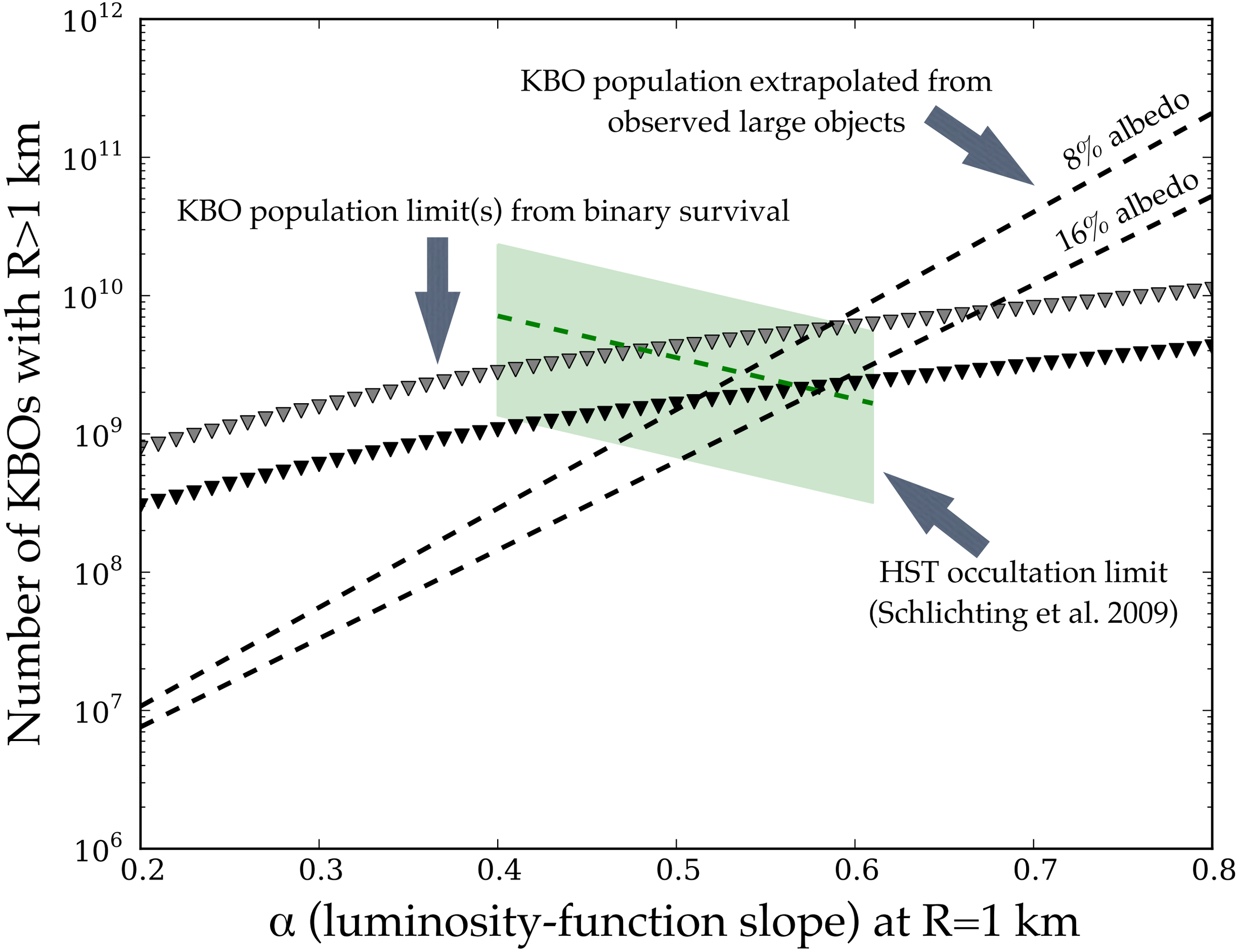
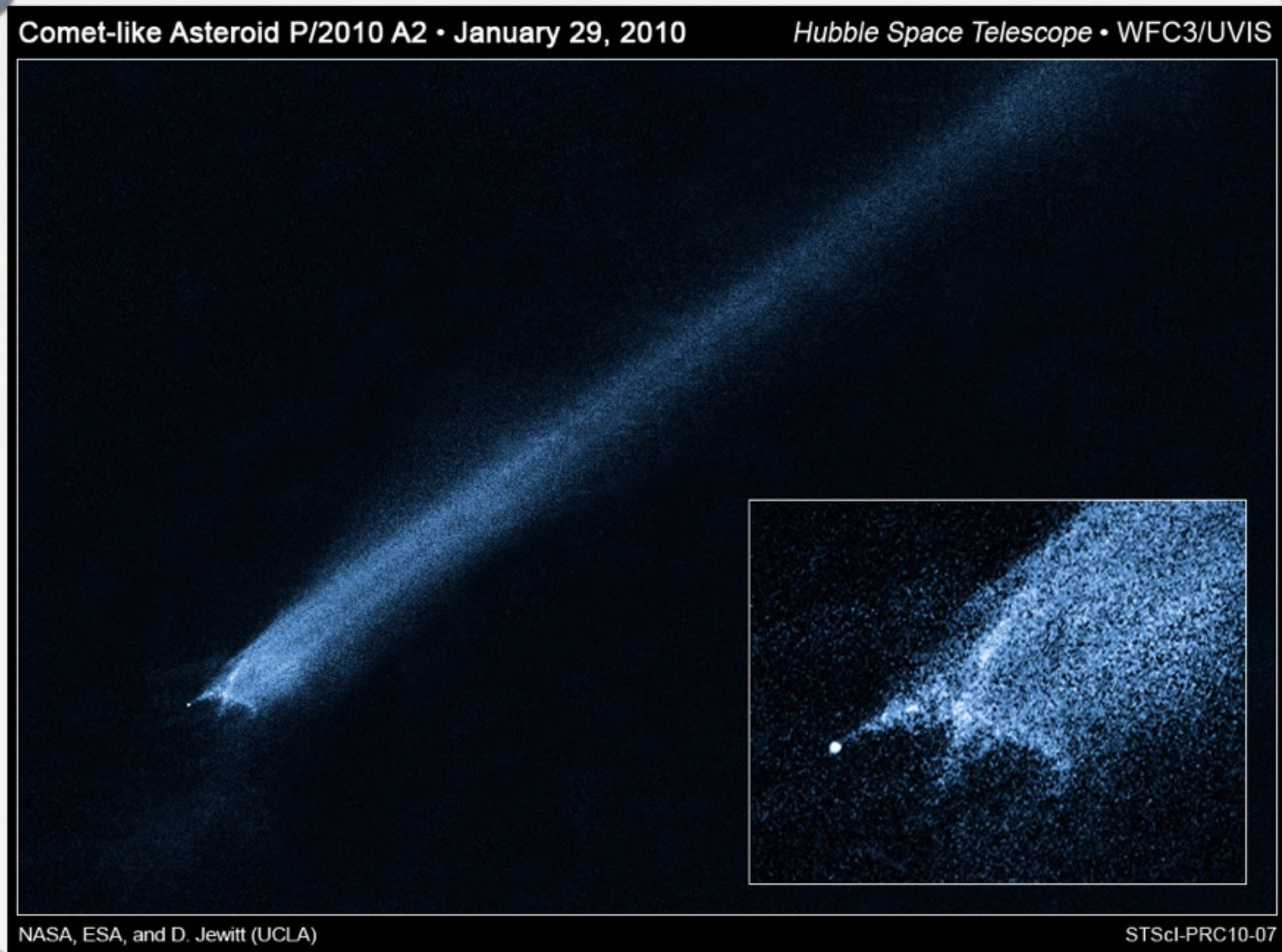
FIRE

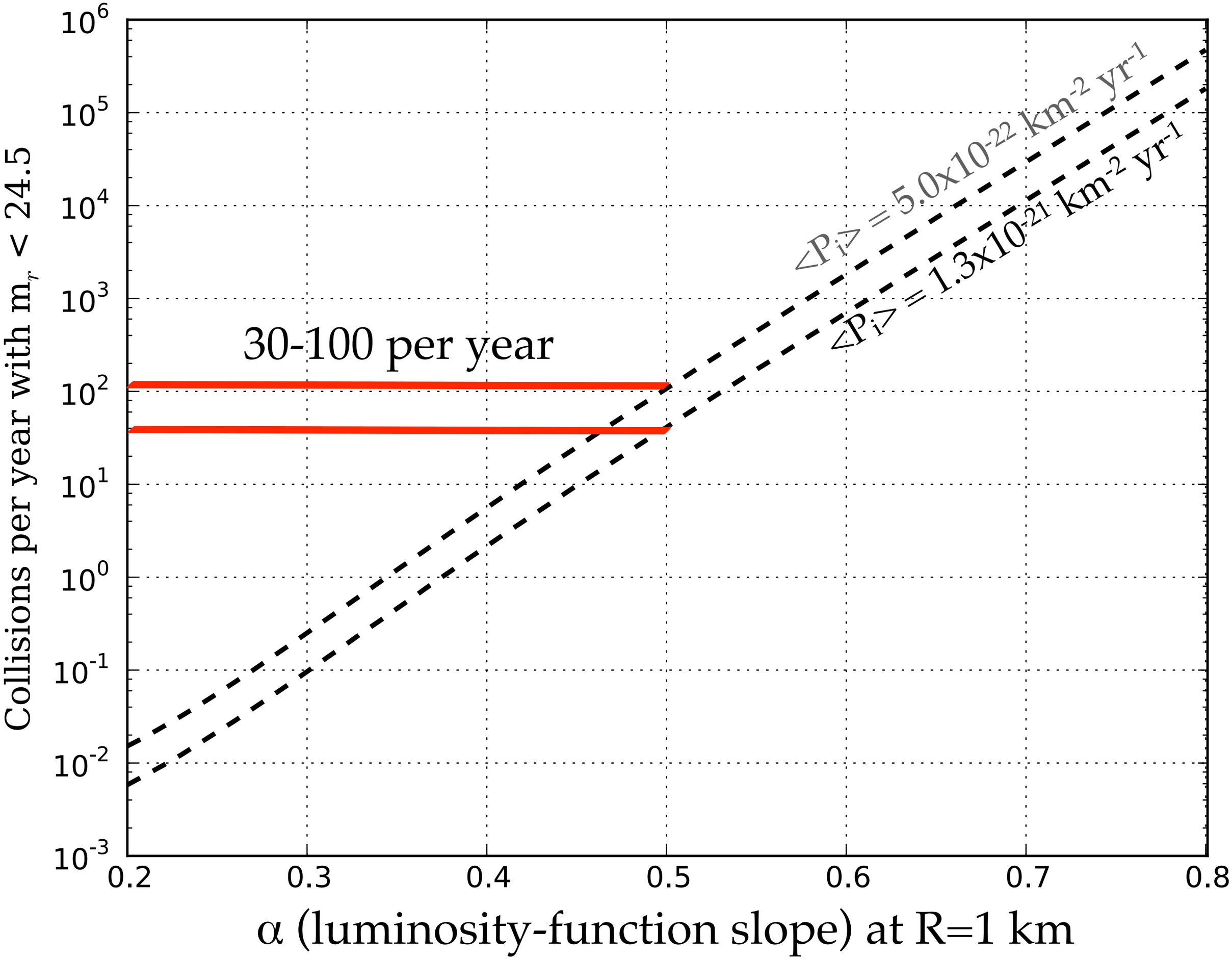
Binary crash-tests




KBO population extrapolated from observed large objects
8% albedo
16% albedo
KBO population limit(s) from binary survival
HST occultation limit (Schlichting et al. 2009)
Number of KBOs with R>1 km
α (luminosity-function slope) at R=1 km
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
0.2
0.3
0.4
0.5
0.6
0.7
0.8

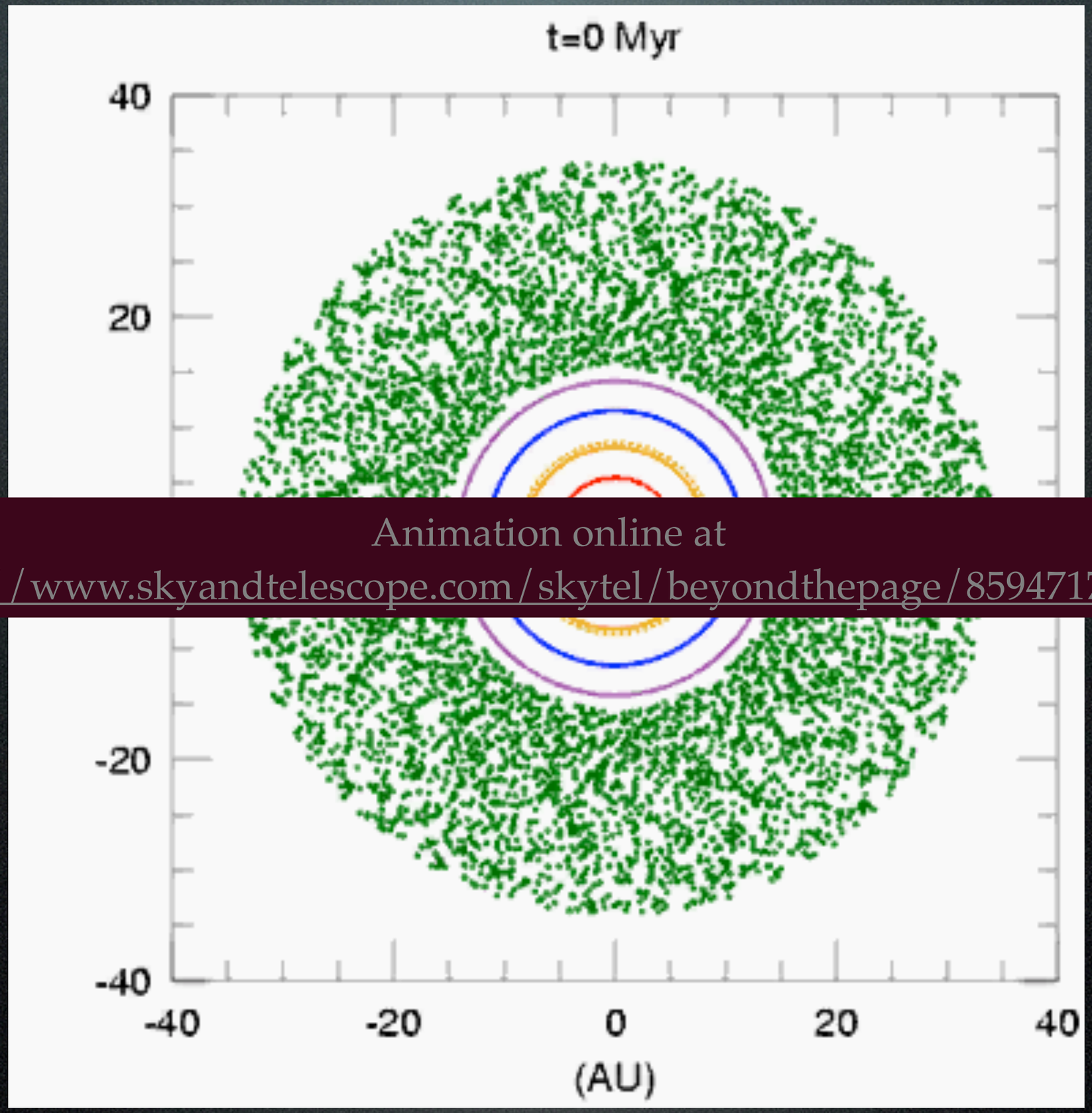


α (luminosity-function slope) at R=1 km


Collisions per year with m_r < 24.5
α (luminosity-function slope) at R=1 km
30-100 per year
$\langle P_i \rangle = 5.0\times10^{-22}$ km^{-2} yr^{-1}
$\langle P_i \rangle = 1.3\times10^{-21}$ km^{-2} yr^{-1}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
0.2
0.3
0.4
0.5
0.6
0.7
0.8

The Kuiper Belt

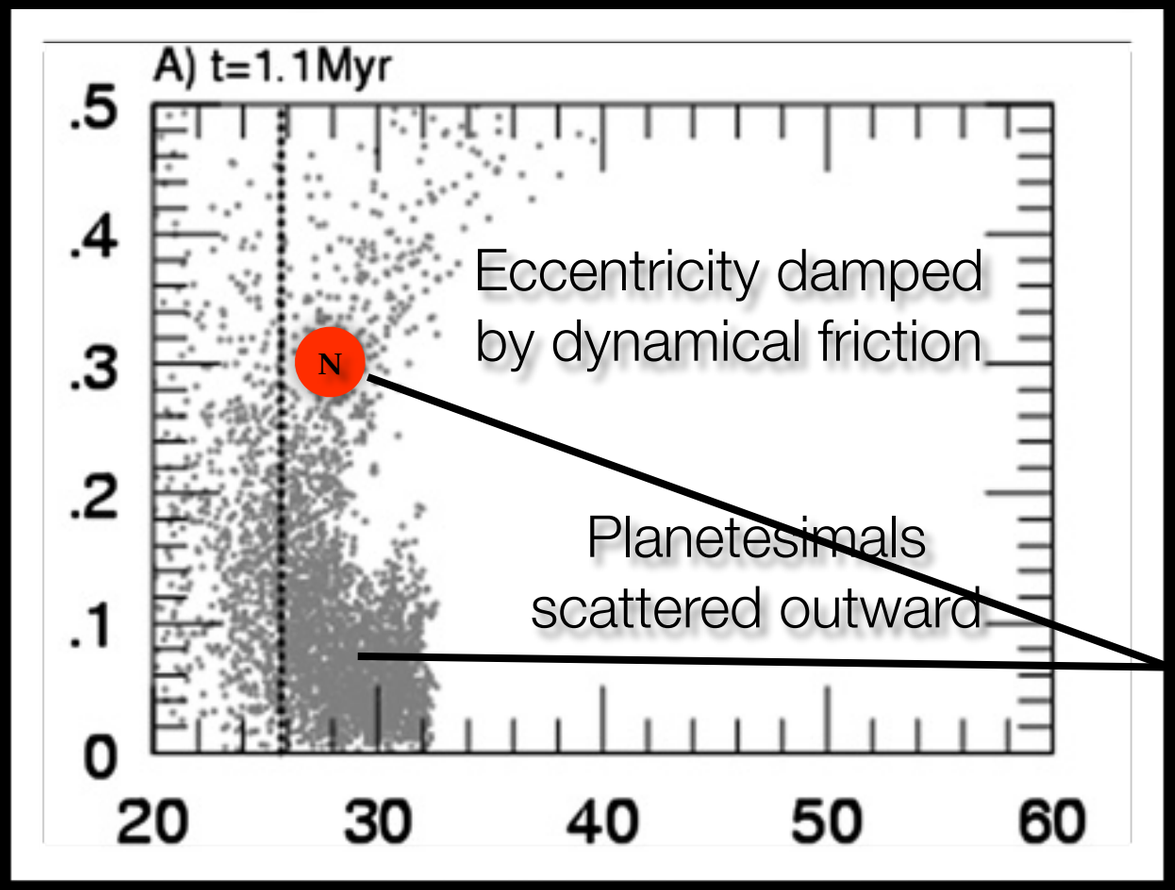
- The “Nice Model”
    - A favored scenario for explaining a number of features in the Solar System: Giant planet orbits, Kuiper Belt and Jupiter Trojans, and Late Heavy Bombardment
- What do binaries tell us about it?



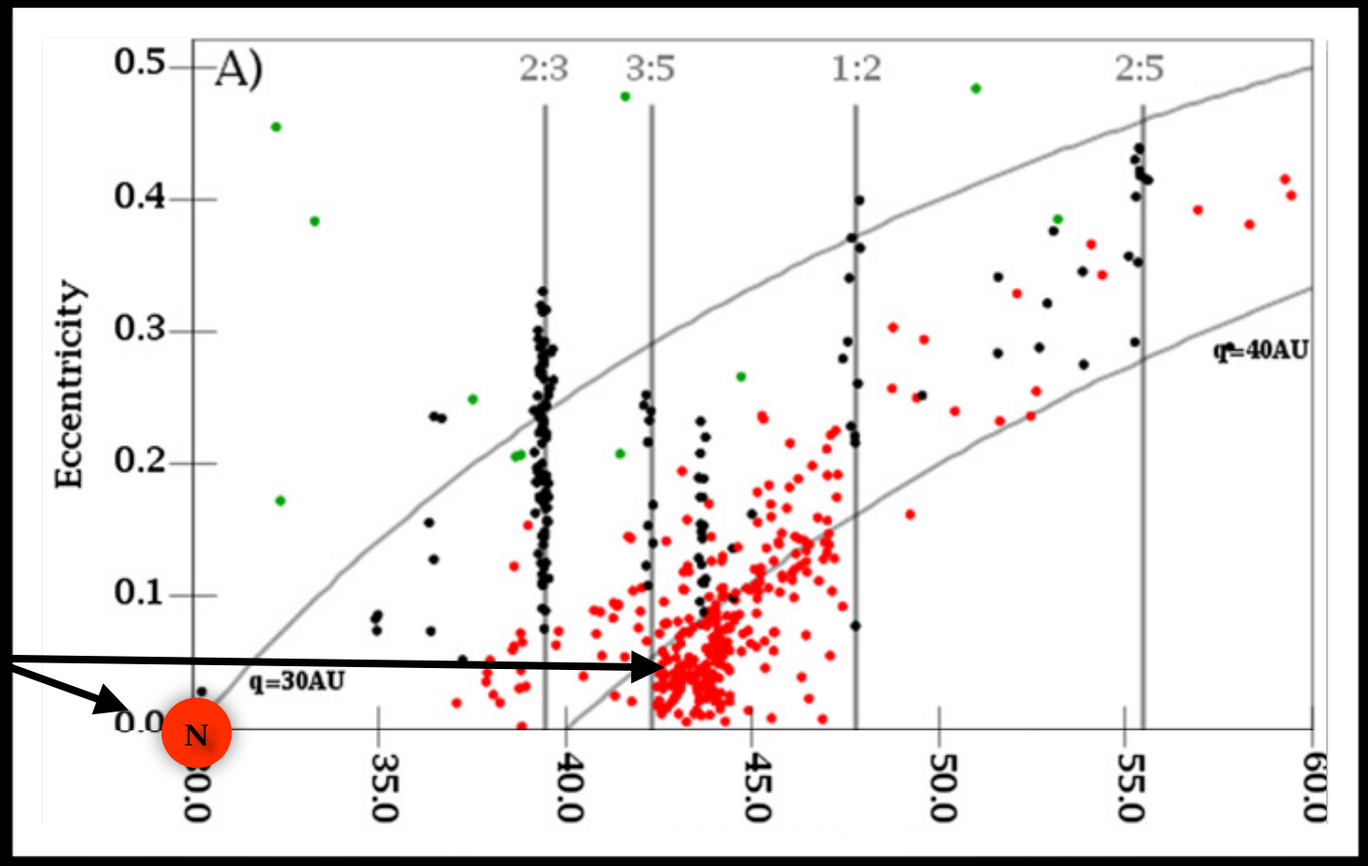
Animation online at
http://www.skyandtelescope.com/skytel/beyondthepage/8594717.html

How did the Kuiper Belt get there?

Post planet-scattering

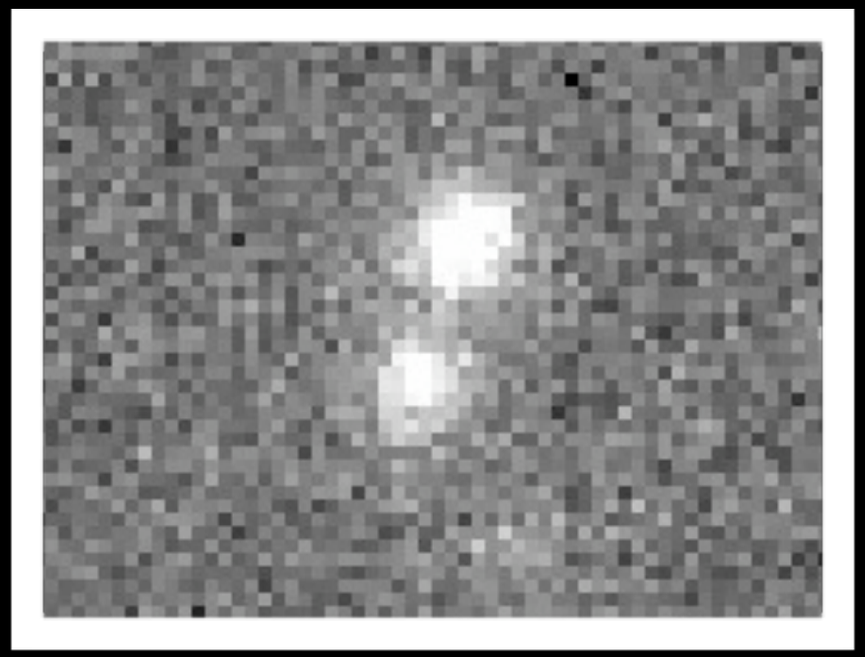


Present-day Kuiper Belt



The Kuiper Belt

- The “Nice Model”
  - What do binaries tell us about it?



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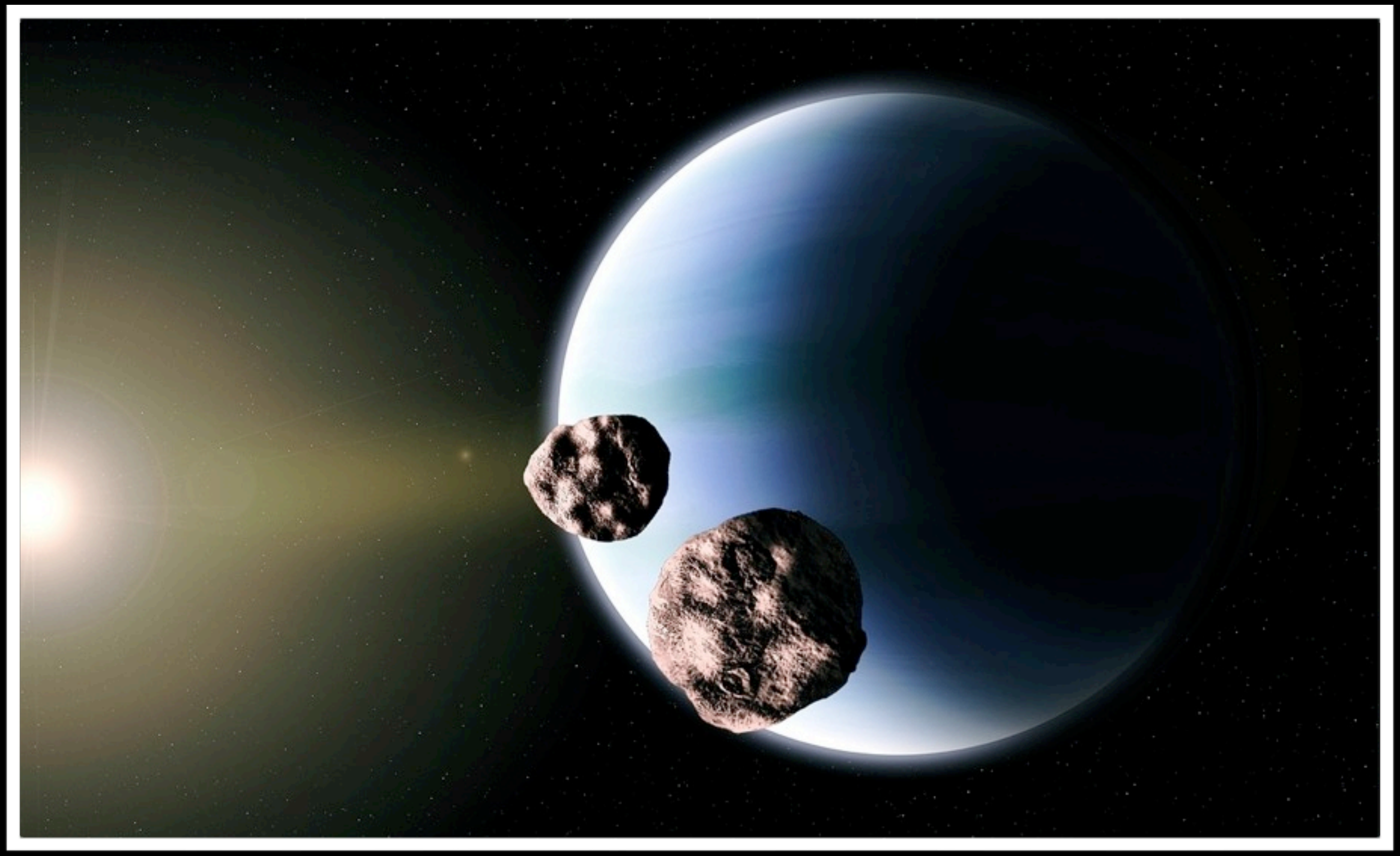
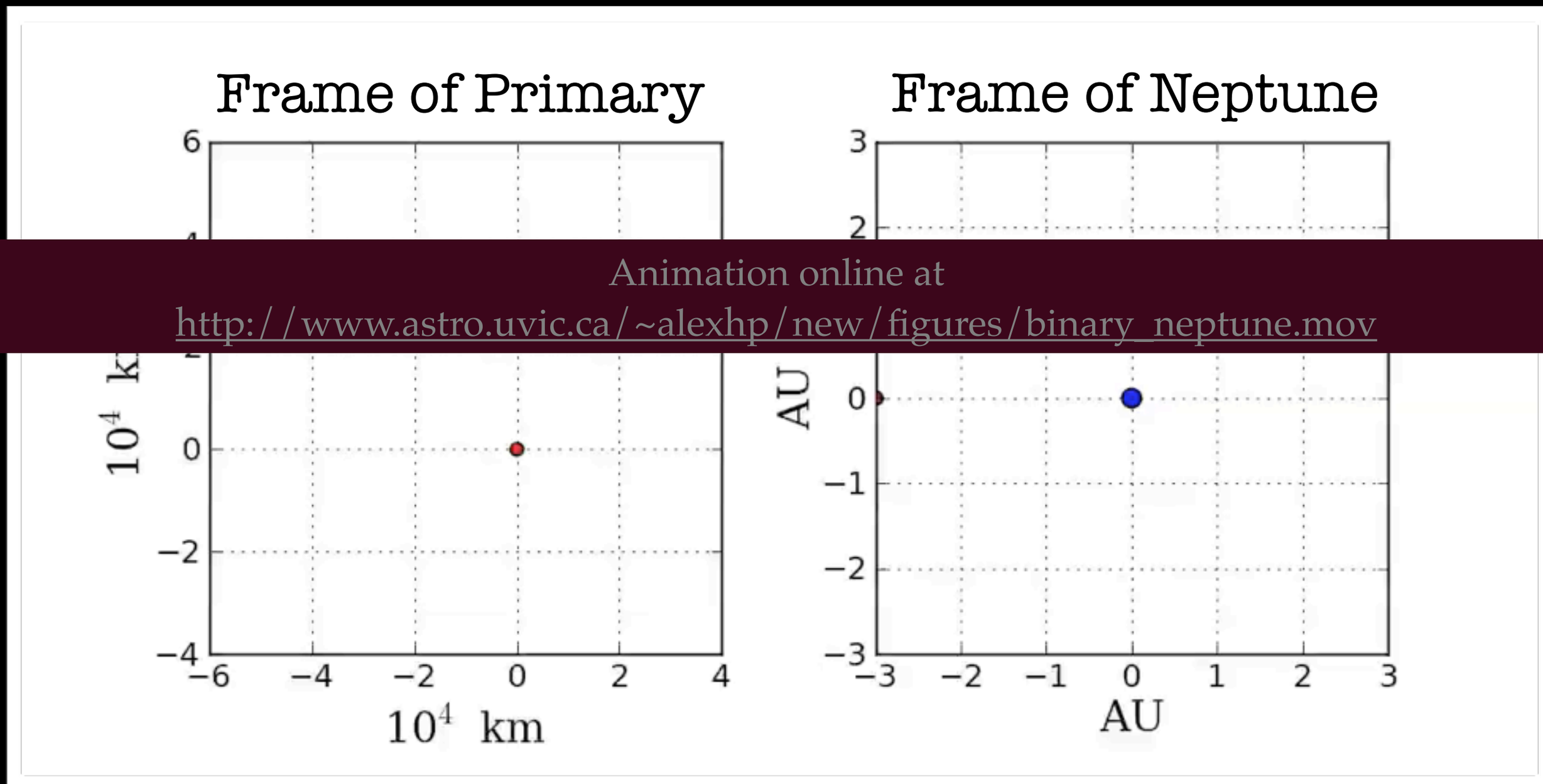
FIRE

Neptune Scattering

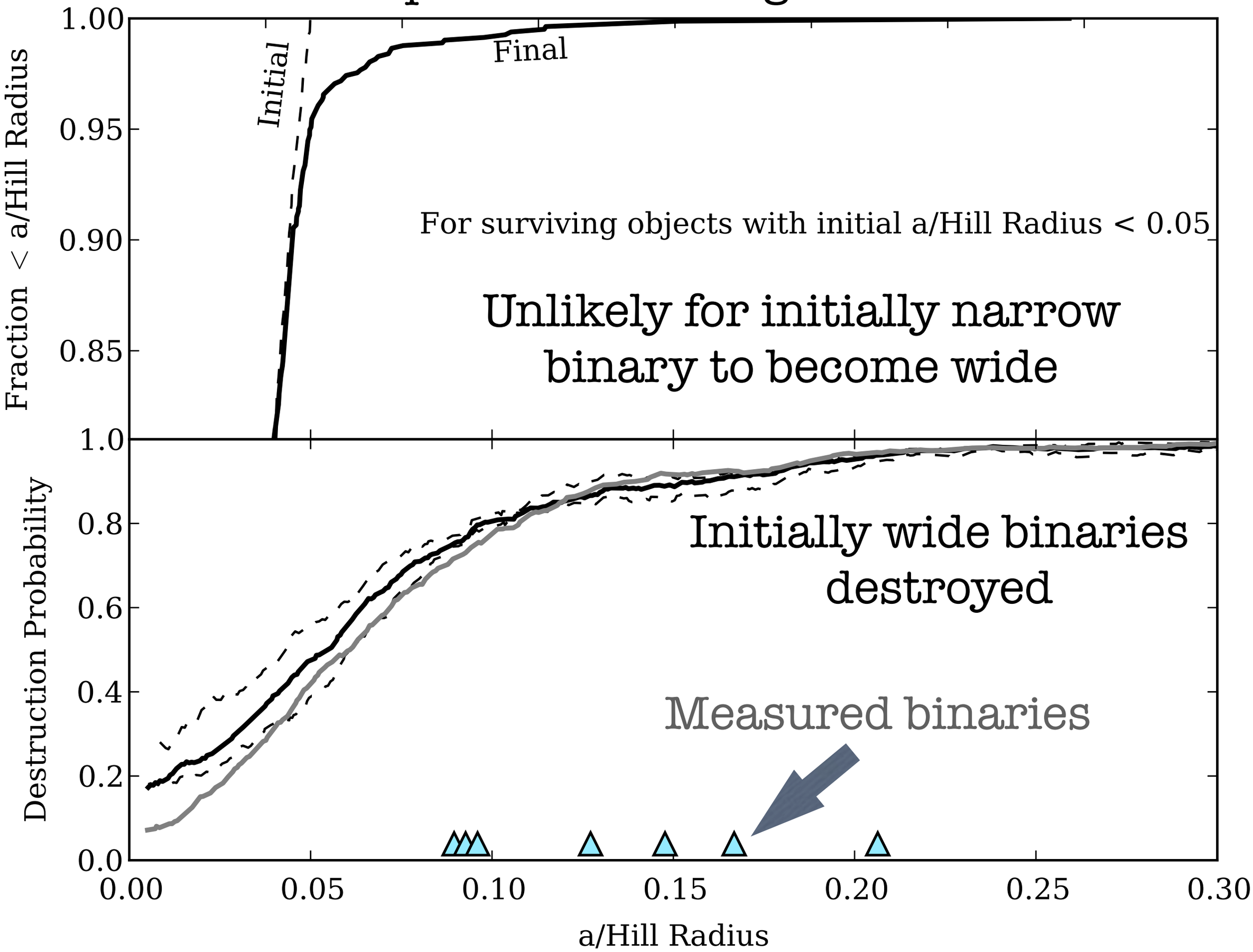


Neptune Scattering



Animation online at
http://www.astro.uvic.ca/~alexhp/new/figures/binary_neptune.mov

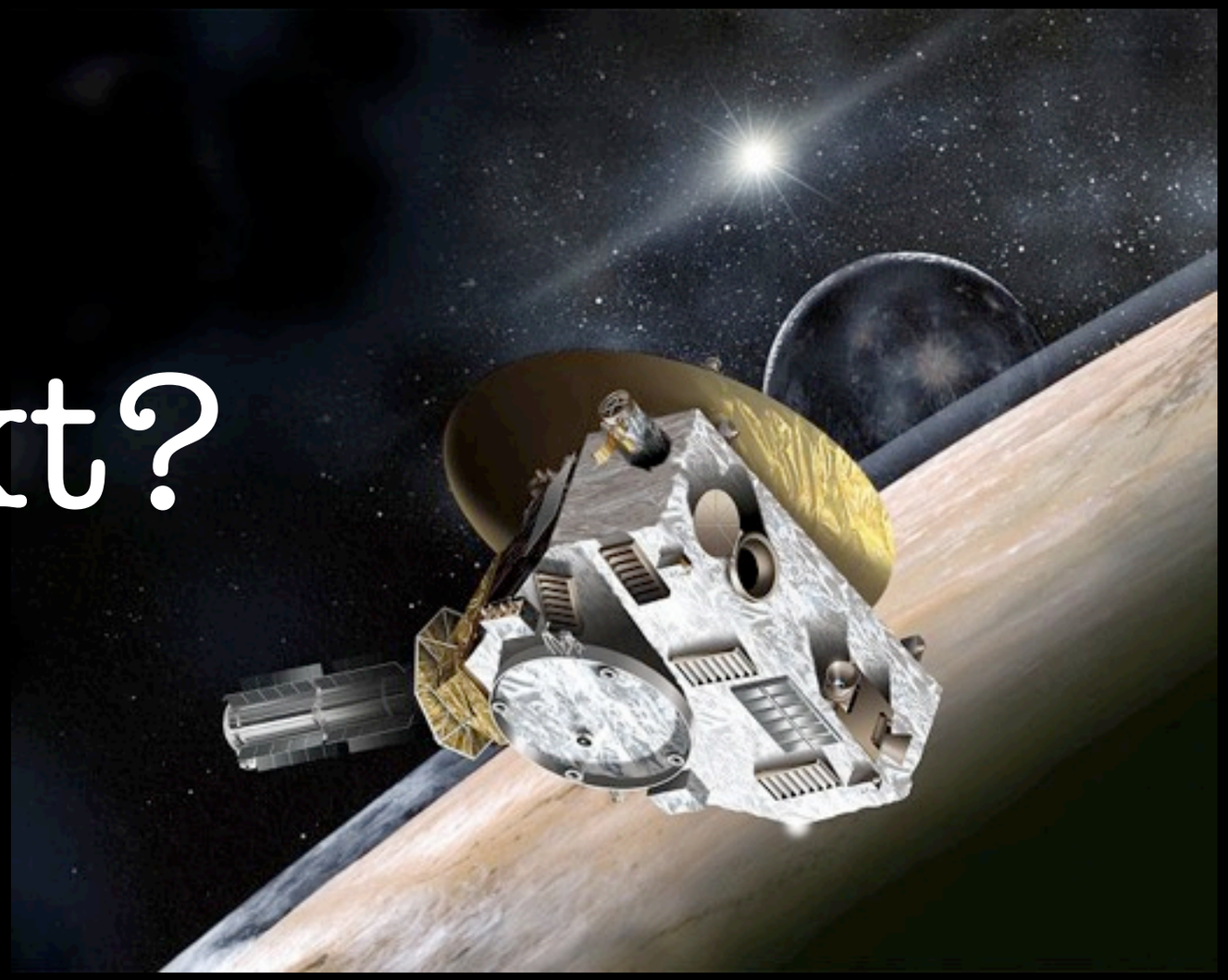
Neptune Scattering: Results



Summary

- Binaries in the Kuiper Belt tell us about the past and present conditions in the outer Solar System
  - Suggest a gentle history, and hint that the classical picture of steady accretion needs to be modified
  - Large collisions are not common on a per-object basis, but we may be able to see them
  - Neptune could not move “cold” classicals

What's next?



- NASA's New Horizons
  - Mission to Pluto: flyby in 2015
  - Flyby of one or more Kuiper Belt Objects in following years
  - Currently searching for candidate KBOs