‘Hubble Vision’

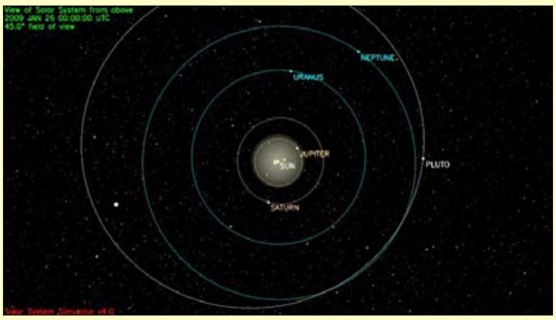
Meeting 3: HST views the solar system

Alec MacKinnon (DACE)

Outline

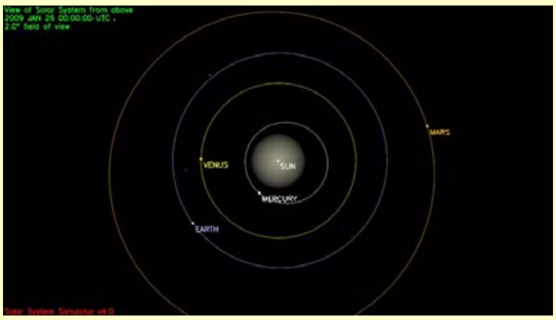
- 'solar system'
  - what are we talking about?
- solar system big questions:
  - what can we do with HST?
- 'simple' discoveries! things never seen before
- inferior planets
- Mars
- gas giants
- comets
- asteroids
- KBO's

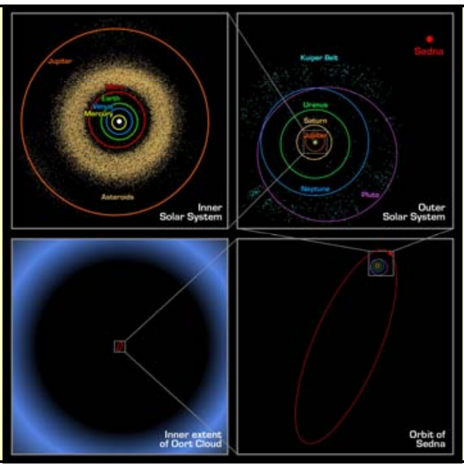
Solar system, 26 Jan 2009



NASA JPL Solar System Simulator – still includes Pluto!!!!!!

Terrestrial planets, 26 Jan 2009





Solar system big questions (1)

- Why do the other solar system bodies look the way they do?
  - Surfaces
  - Interiors
  - Atmospheres
- And what does this teach us about our own planet?
  - History
  - Present-day workings
  - Future fate (in the era of global warming)

Solar system big questions (2)

- is there 'life' anywhere else in the solar system?
- if not now, in the past?

Solar system big questions (3)

- Origin of the solar system
  - how did it start out?
  - how did it subsequently come to look the way it does now?
  - Many of the other questions are only *really* interesting because they help with this one
- likelihood of life existing in solar systems elsewhere?

Solar system: HST cf. space probes

- space probes can go close and reveal unequalled detail....
- ...but only during brief flybys, or at best during the life of a mission (e.g. few months, one or two years)
- landers give very detailed information about very specific locations, not a global view
- HST provides better resolution than anything on the ground (almost!)
- HST can monitor solar system bodies over several years
- can respond to unexpected events

Telescopes and resolving power

- As reviewed already:
  - Bigger telescopes show more detail ….
  - ….turbulent gas in the way allowing
- E.g. human eye *d* = 7 mm
  - Resolve objects 20 *arc seconds* apart (20”)
  - *arc second*?

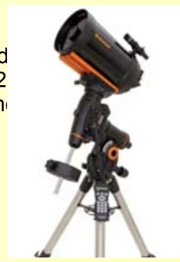
Resolving power

- E.g. human eye *d* = 0.7 cm
  - Resolve objects 20 *arc seconds* apart (20”)
  - *arc second*?

Image: Petr Novak, Wikipedia

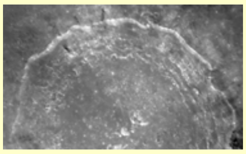
Telescopes and resolving power

- Typical serious amateur telescope *d* = 20 cm
  - Resolve objects 0.7” apart
  - bigger and bigger telescopes give little ad
    above 65 cm (2
    the atmosph



Hubble Space Telescope

- HST *d* = 240 cm, *unimpeded by the atmosphere*
  - Resolve objects 0.06” apart
- 0.06” is:
  - 100 metres on the Moon
  - 170 km on Jupiter, at closest to Earth
  - 1300 km at the distance of Neptune



Lunar crater Copernicus
image: J Caldwell; A Storrs; NASA

Limiting magnitude

- HST's *limiting magnitude* is about 30 (in long time exposure, 'deep field' images)
  - faintest naked-eye stars are mag. 6
  - mag 30 objects are 4 billionths as bright
  - binoculars might take you to mag 9 - 10
- valuable capacity for seeking tiny objects on the edge of the solar system

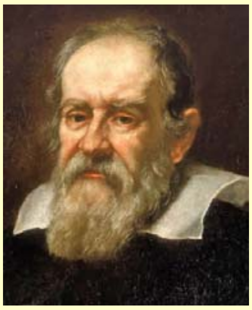
What can HST not do?

- the Sun!
- Mercury (too close to the Sun)
- more generally, anything less than 50º fro the Sun – barring 'special dispensation'

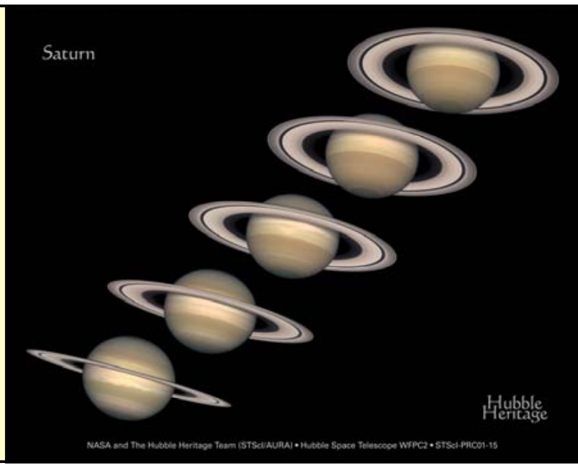
Ring plane crossing (1995)

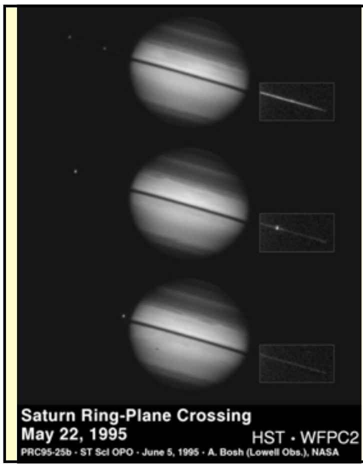
- Saturn orbits the Sun once every 29.5 Earth years
- Axis of rotation tilted 26.7º to plane of orbit
- our view of the ring system changes regularly as we and Saturn travel round the Sun
- pass through the *plane* of the rings once every 13 – 15 years (roughly, around the Saturnian equinoxes)

Galileo



- knew in 1610 there was something weird about Saturn (three bodies?)
- only one body in 1612
- “Has Saturn swallowed his children?”
- ring plane crossing





Saturn ring plane crossing, May '95

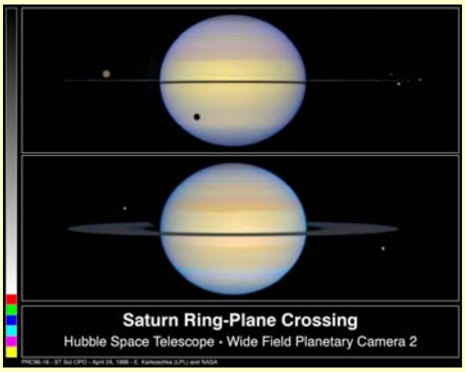
before

during

12 hrs after

Saturn ring plane crossing, Aug '95

Rings revealed here in *edge-on* view; typically 10 m in vertical extent
look for new moons at this time; find clumps in rings



Plane crossings

- Saturn currently in Leo
- ring plane crossing 4 Sep 2009 (but too close to the Sun)
- rings will get difficult to view next few months
- these observations demonstrate the HST capabilities

Terrestrial planets

- Mercury: too close to the Sun
- Venus: has been studied, but shrouded in clouds
- Mars: study seasonal variations, dust storms etc.
  - Viking landers, 1976;
  - Mars Global Surveyor; Mars Pathfinder (both 1996)
  - 20 year period with no space missions

Venus and Mars

- Venus:
  - similar in size to Earth
  - orbit ~ 0.7 AU
  - rotates only very slowly: 243 Earth days
  - 500° hotter than it should be at its distance from the Sun; pressure 90 times greater than on Earth
- Mars:
  - roughly half the size (radius) of Earth
  - 1.5 AU
  - similar length of day
  - pressure about 1% felt on Earth
  - has kept very little atmosphere; 5° of greenhouse warming

Terrestrial planets

Image: NASA

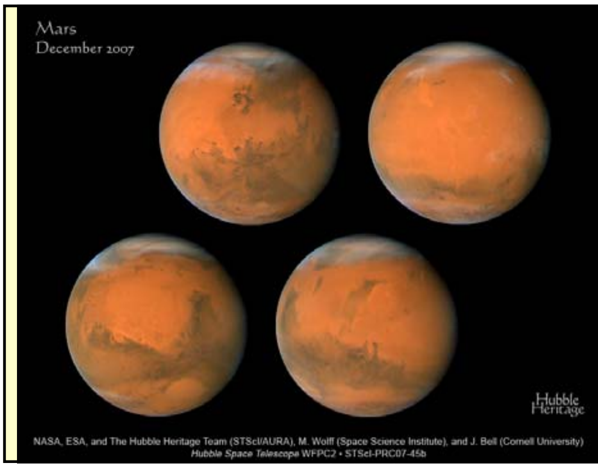
Venus

- the brightest non-stellar object in the sky
- roughly West, immediately after sunset, at the moment

Level of SO_2 in Venus' middle atmosphere has been declining through the 1990s, possibly since a 1958 event

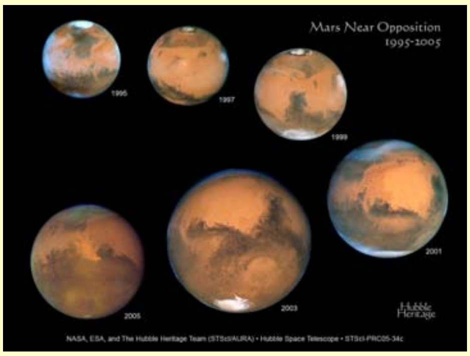
(only one more Venus observation since, in 2003)

Venus needed special exemption from safety regulations!



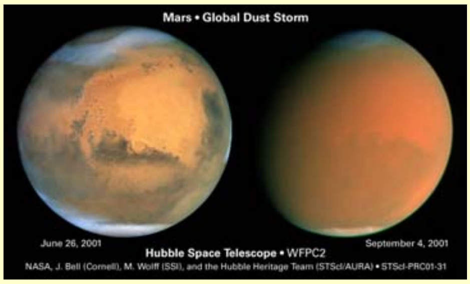
HST Mars

- After Viking, Mars was not revisited by spacecraft until 1996
- HST images were made regularly; thus long-term changes could be studied
- Viking period was exceptionally warm and mild
  - atmosphere was dustier and more opaque
  - implications for habitability of Mars; likelihood of living things



2005 opposition: dust storm

Image: NASA/ESA/STScI/J Bell (Cornell)/M Wolff (Space Science Institute)

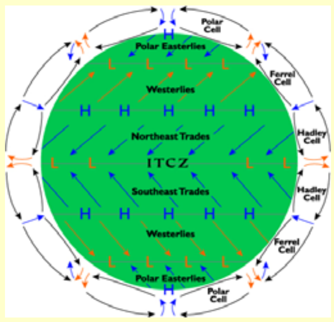


lasted three months

HST Mars

- long-term variation of atmosphere (spectra as well as images)
  - formation of water vapour cloud layer in spring, lasting until after midsummer
  - between -10º and +30º latitude;
  - Martian *Hadley cell*

Hadley cells and trade winds



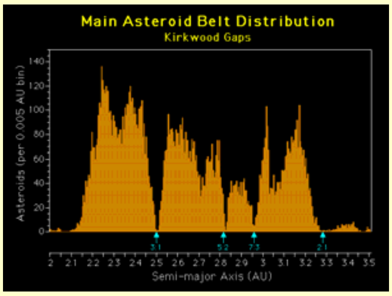
HST Mars

- dust storms and their effects (warming and cooling)
- detailed studies, e.g. tracking clouds to deduce wind speeds
  - 15 – 44 m/sec (roughly 34 – 100 m.p.h)
- (have to stop watching Mars when it gets too close to the Sun)

Asteroids

- …or ‘minor planets’
- Reside in region between Mars and Jupiter; mostly 2 – 3 AU from Sun
- Largest, and first discovered (1801) is Ceres, 457 km radius; now visible, in binoculars, in Gemini
- Maybe 1,000,000 of 1 km or more radius
- first class of 'minor bodies' – links to comets and KBO's?; and to origin of the solar system

Asteroid distribution and Kirkwood gaps



Classes of asteroid

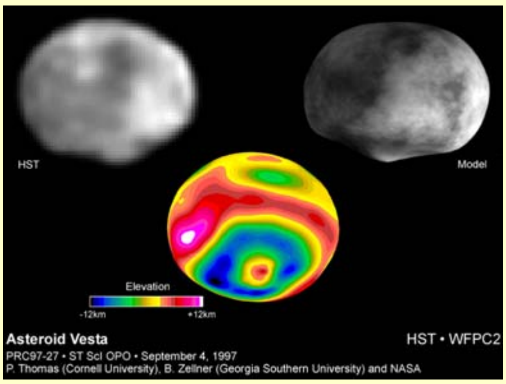
- Reflect classes of meteorite
- C-type: ‘primordial’ mix of elements minus hydrogen, helium and ‘volatiles’; very dark; (‘chondrites’); 75% of asteroids
- S-type: nickel-iron plus silicates; brighter (i.e. more reflective); 17% of asteroids
- M-type: ‘metallic’, nickel-iron; fragments of a larger body, big enough to ‘settle down’ with different chemical substances at different depths; bright

433 Eros

- 'near-Earth' asteroid: comes within 0.15 AU of Earth
- 33 × 13 × 13 km
- Discovered 13/8/1898
- Studied close-up, at length, by the NEAR (Near Earth Asteroid Rendezvous) mission, 14/2/2000 – 28/2/2001
- Soft-landed on Eros 12/2/2001 !

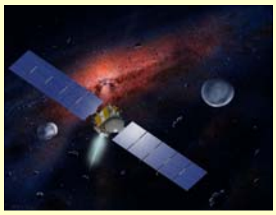
Eros

Image: http://nssdc.gsfc.nasa.gov/planetary/mission/near/near_eros_2.html
See also the movies at http://near.jhuapl.edu/Images/.Anim.html



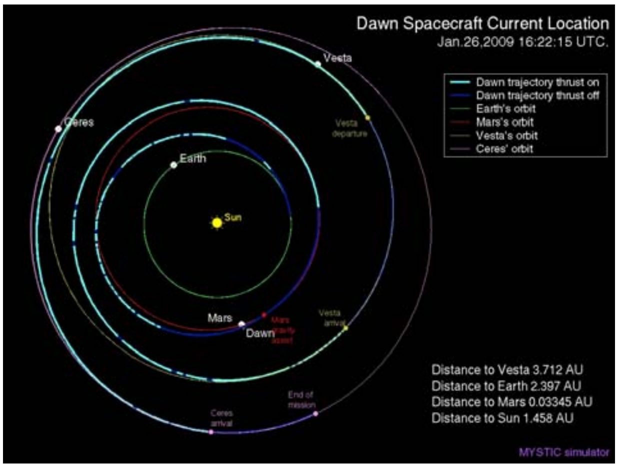
Vesta is 530 km across
impact crater at south is 450 km across

Vesta HST

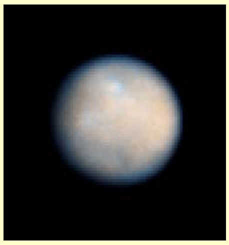


2007 image; in preparation for NASA *Dawn* mission

Image: NASA/ESA/L McFadden



Ceres - HST

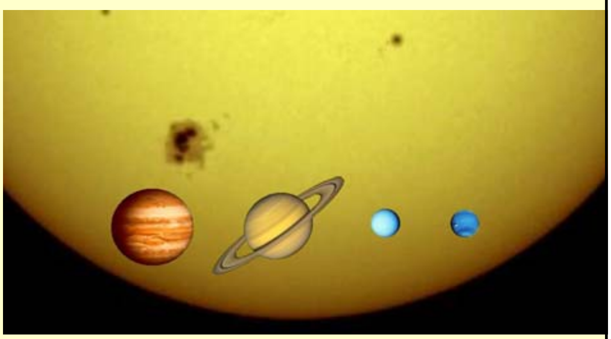


Water ice layer near surface? Subsurface life (as suggested for Europa)?

NASA *Dawn* mission - 2015

Image: NASA/ESA/J Parker

Gas giant planets



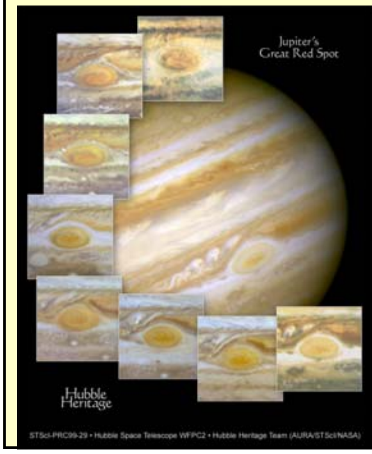
Jupiter

red
white
brown
blue

Image: NASA

Jupiter

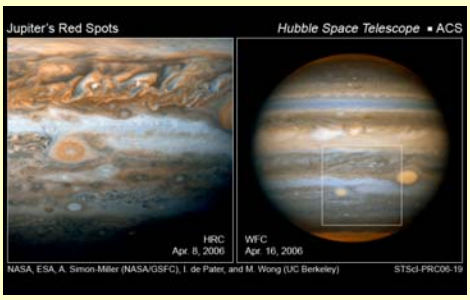
- about 11 times radius of Earth
- orbits the Sun at 5 AU
- rotates once every 10 hours – in spite of its great size
- weather system: rapidly rotating globe of gas, heated by sunlight; and indeed internally heated
- long-lasting features; and transient phenomena
  - vorticity



Changes in the Great Red Spot

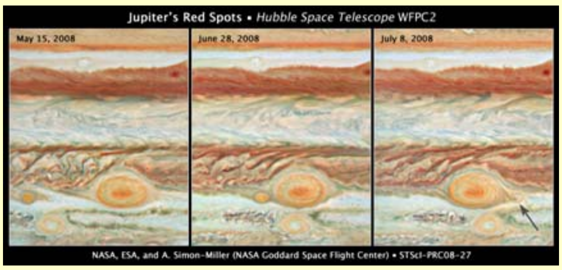
- has existed for 300 years
- 25,000 km in diameter
- persistence reflects lack of solid surface – but not unchanging
- laboratory for fluid dynamics – cf cyclones etc. on Earth

New Red Spot



Global climate change?
(images comparable to Voyager flybys of the 1970s)

Spot mergers



Jupiter and its moons

Image: NASA, ESA, A Karkoschka (U Arizona) (image shows Ganymede)

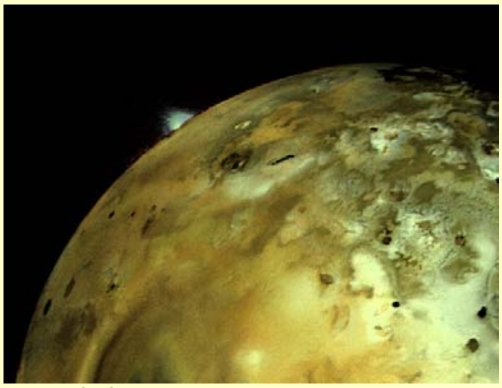
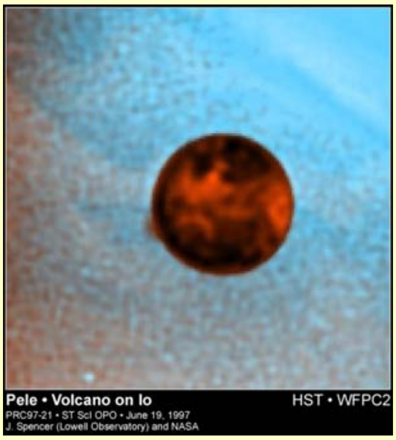


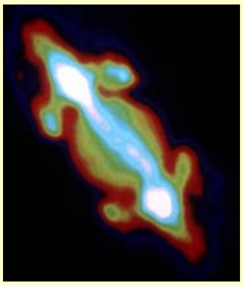
Image: NASA (Galileo mission)

New feature on Io

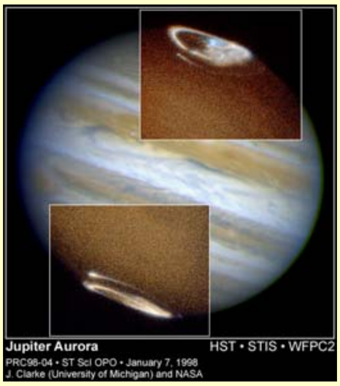


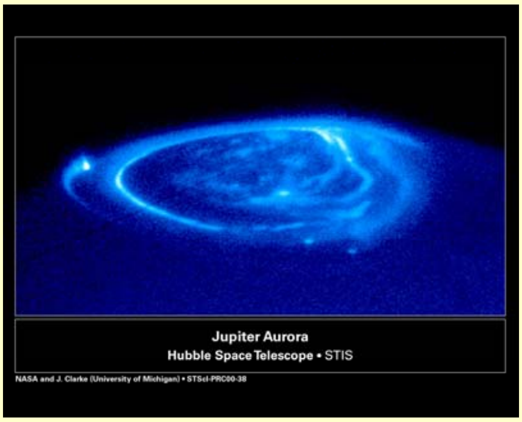
Io volcano from HST!!

Jupiter/Io plasma torus



VLA image courtesy of NRAO/AUI

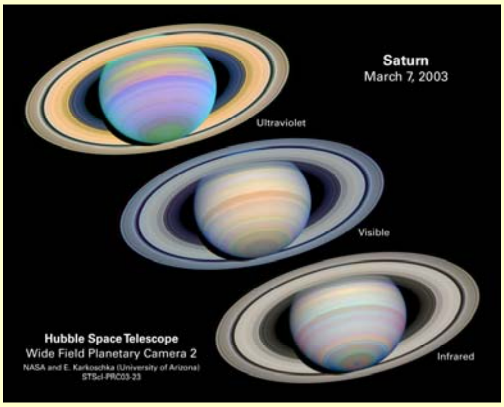




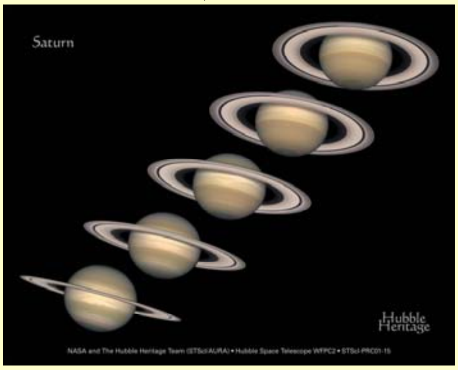
16 – 22 July, 1994

Images:
HST/NASA/ESA

Comet Shoemaker -Levy 9

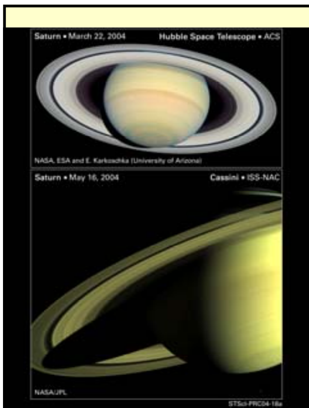


Saturn, 1996-2000



Storm on Saturn

Image: R Beebe, D Gilmore, L Bergeron, NASA



Cassini vs. HST

note detailed banding of rings; Cassini division (Mimas) etc.

William Herschel (1738-1822)

- Runaway Hanoverian army musician!
- Discovered the planet Uranus in 1781
- First planet to be discovered since the time before writing

Uranus

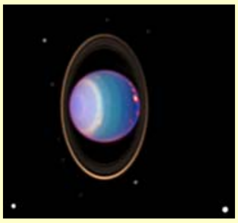


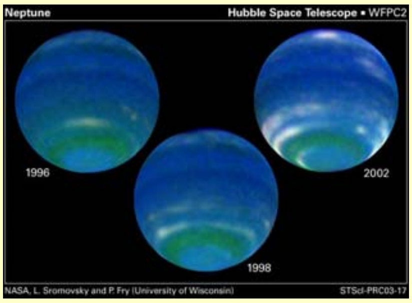
Image: E Karkoschka/NASA

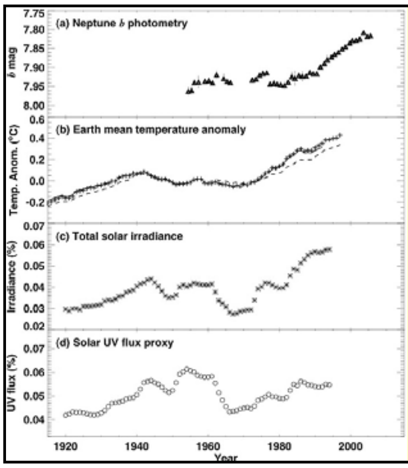
- *Hubble Space Telescope* – infrared - image of Uranus
- Technically naked eye object, but really needs binoculars, and study over many nights
- Rings discovered 1977 in *stellar occultation*

HST Uranus

- colours of satellites! (thought gray from Voyager time)
- cloud features in atmosphere across a range of wavelengths – revealed more clearly than in Voyager (at longer wavelengths)

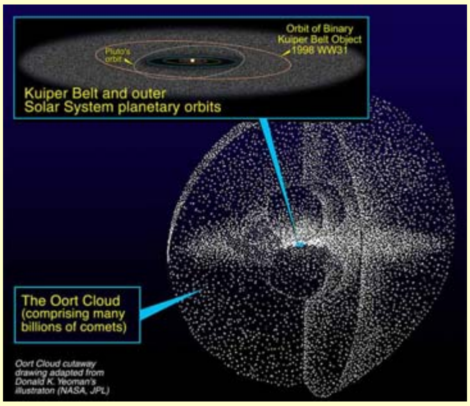
Neptune's changing weather





Neptune, Earth, Sun!!!!

H B Hammel, G W Lockwood, *Geophys. Res. Letts.* vol 34 (2007)



'Trans-Neptunian Objects'

- Objects beyond Neptune (30 AU and beyond)
- 'Kuiper Belt Objects' (KBO's): 30 – 50 AU
- Outer edge at 50 AU appears real
- Pluto! (one of the largest KBO's)
- Eris!
- Sedna!
- Quaoar, Ixion, Varuna,…
- Suffering no tidal interaction with larger bodies (as e.g. the moons of the gas giants do), KBO's should be primeval remnants of the planetary formation process in the early solar system

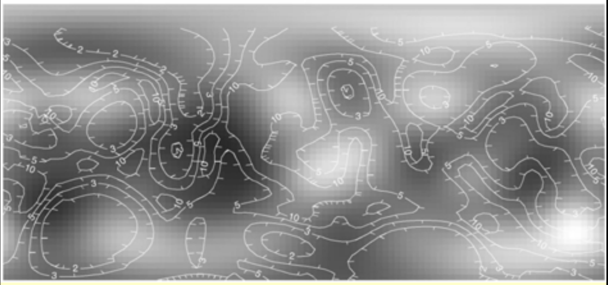
Kuiper Belt

- 70,000 KBO's > 100 km
- *Classical* KBO:
  - 40 – 48 AU
  - Orbits close to *circular*
  - Far enough away from Neptune to be stable in spite of it
- Plutinos:
  - In *3:2 resonance* with Neptune
  - Pluto!
- *Scattered belt objects:*
  - In highly elliptical orbits, perihelion near 35 AU, often highly *inclined* to the ecliptic

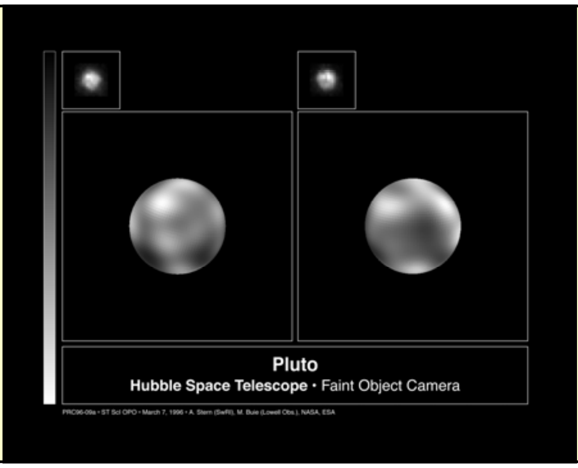
Kuiper Belt

- a site of controversy
- poor old Pluto!
  - now a 'dwarf planet', along with Eris (KBO) and Ceres (biggest and first discovered of the asteroids)

Surface brightness of Pluto



Stern et al. (1997); map constructed using observations from 1994
bright polar regions; dark along equator except at *antipodes* of sub-Charon point
Pluto has higher albedo than most KBO's – frosts condensed from atmosphere



Pluto and Charon: HST

before the repair mission!

Image: ESA/NASA/STScI

Charon

- Discovered June 1978
- Photographic plates of Pluto showed a slight, periodic bulge, synchronous with Pluto's rotation
- 1985-1990: period of mutual eclipses (two intervals per 248 year period)
- 'seen' only by HST
- 6.39 day orbit; 19,571 km
- NB Stephen Baxter, *'Vacuum Diagrams'*

Pluto and Charon

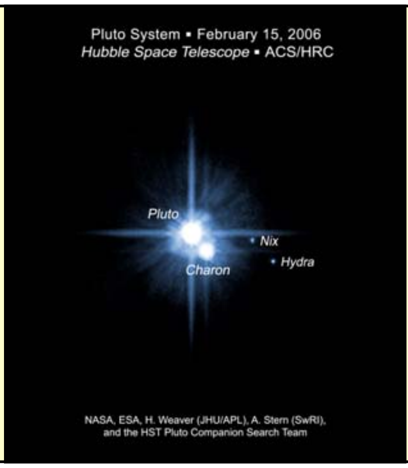
Pluto: r= 2390 km

Charon: r = 1205 km

orbital period 6.387 days

tidally locked

Image: R Albrecht/ESA/ESO/NASA



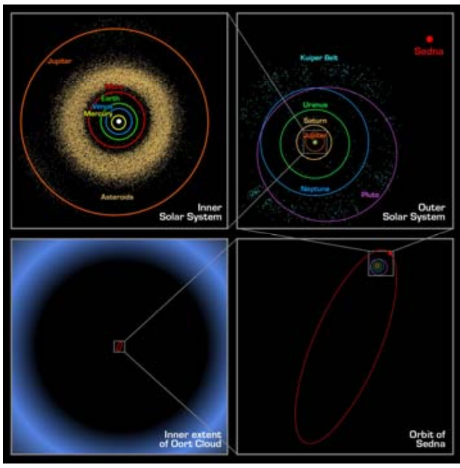
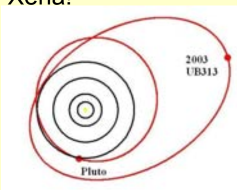


Image: NASA/JPL-Caltech/R Hurt

Eris

- Previously 2003 UB_{313} and... Xena!



Radius of 1300 km (at least 1200) cf. Pluto, 1137 km

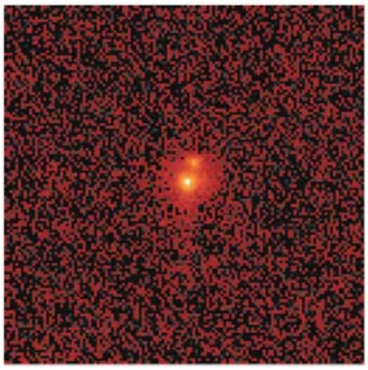


Figure 15 CCD image of the binary KBO 1999 TC_{36} taken with the Hubble Space Telescope, showing the binary and secondary clearly separated by ~0.37 arcsec. Image courtesy of C. Trujillo (Caltech).

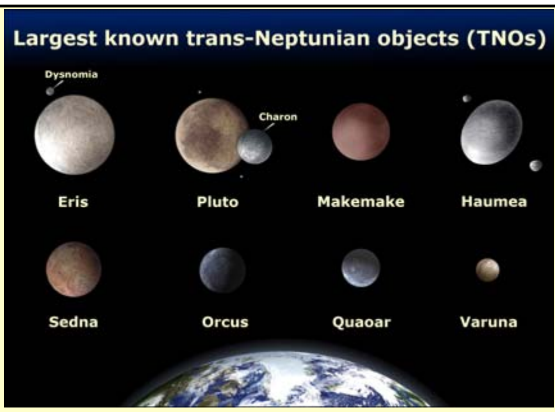
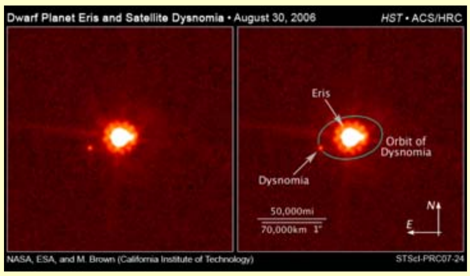


Image: Wikimedia Commons



Phoebe

- outermost moon of Saturn, almost 13,000,000 km mean distance
- 110 km radius
- *retrograde* orbit – so collisions are head-on, ejecting lots of debris
- captured asteroid/'minor body' - KBO?
- Cassini images suggest mostly icy body with dark surface layer
- 'primordial'?

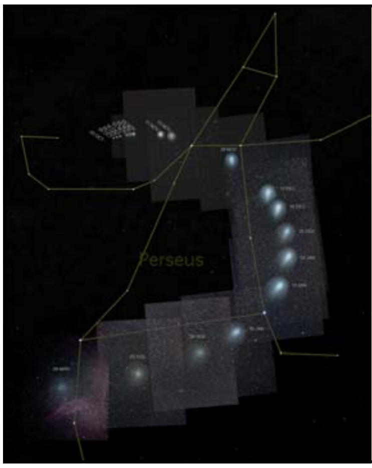
Phoebe from Cassini

impacts reveal bright (icy?) material under dark coating – like Callisto

like outer asteroid belt? KBO's?

comparable in size to Nix or Hydra.....

Image: NASA (Cassini mission)



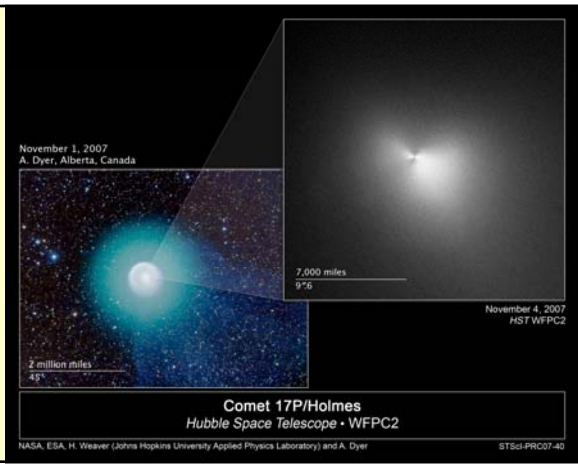
Comet 17P/Holmes

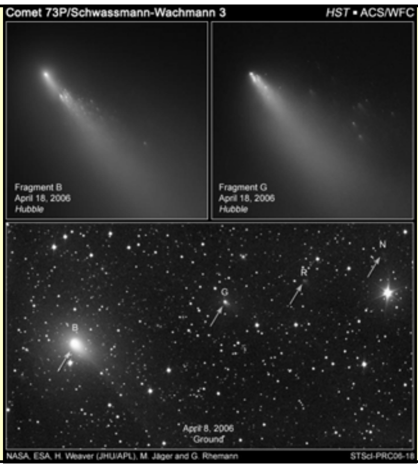
23 – 24 October 2008

brightened by about a factor of about 500,000 in brightness

build-up of heat in porous surface?

Image: Wikimedia Commons





Conclusions

- HST allows long-term survey, at a wide range of wavelengths, of major planets and moons, in detail only exceeded by space probes
- provides a global view of these worlds
- it reveals surface details of bodies that have not been visited
- it is a particularly valuable tool for revealing details of minor solar system bodies – KBO's, comets, asteroids – which may offer vital clues to the events at the origin of the solar system