# Hubble's Exploration of the Solar System

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### Outline

#### • Minor Bodies, including *Dwarf Planets*

- Comets, Asteroids, TNOs, Pluto System

#### Transient Events

- Comet breakups, Asteroid collision, Jupiter impacts

#### Giant Planet Atmospheres

- Weather and Auroral processes

#### Galilean Satellites

- Atmospheres

#### Ring systems

– Uranus

#### • Mars

- Global imaging

# **Minor Bodies**

- Comet nucleus sizes and D/H
- Resolved imaging of Asteroids
- TNOs: Eris and Haumea
- TNO binaries
- Pluto system





• "Photometrically resolved" cometary nuclei

• Size distribution deviates substantially from "collisionally relaxed" population

Lamy et al.

1 km

### **D/H in Comets**

#### STIS/E140H (Weaver et al.)

#### **Did Comets deliver Earth's water?**





#### Deuterium in the Solar System

**Fig 1:** D in the solar system is divided into primitive (left) and reprocessed (right) reservoirs. The current value of D/H in the Local Interstellar Medium (LISM) reflects the continual decrease in D during the past 4.6 <u>Gyr</u> owing to <u>nucleosynthesis</u> by stars in our galaxy. The Jupiter D/H presumably reflects the value in the solar nebula gas where Jupiter formed. The D/H values for Earth SMOW, the Mars rocks and atmosphere, and the atmospheres of Uranus, Neptune, and Titan are enhanced relative to Jupiter, at least partly due to impacts from primitive bodies, including comets. The D/H value derived from our Hubble observations of C/NEAT is preliminary but appears to be consistent with the values derived from observations of <u>deuterated</u> water in three other comets. (Fig adapted from Owen & Bar-Nun [1])

### **Resolved Asteroids**



STScI-PRC07-27a

Parker, McFadden, Thomas, et al.

### Eris : *Pluto Killer*



Brown et al.

ACS/HRC Images : Dec 2005



Eris is ~5% larger and ~30% more massive than Pluto

Brown et al.



### Mutual Event season for Haumea and Namaka!

Brown et al.



#### Pluto • Hubble Space Telescope ACS/HRC







Buie et al.

### Pluto is a Quadruple System!



ACS/HRC Image: 2006 Feb 15.6 UT

Weaver et al.

# **Transient Events**

- Comet breakups
- Collisions in asteroid belt
- Jupiter impacts

### Shoemaker-Levy 9 : String of Pearls WFPC2, January 1994

/ G, G,

#### C/1999 S4 (LINEAR) : 2000 Aug 5

#### C/Hyakutake : 1996 Mar 26



#### **Comet Breakups : Natural and Not**





NASA, ESA, and D. Jewitt (UCLA)

STScI-PRC10-07

Jewitt et al.

### **SL9-like Impacts on Jupiter**



NASA, ESA, M. Wong (University of California, Berkeley), H. B. Hammel (Space Science Institute, Boulder, Colo.), I. de Pater (University of California, Berkeley), and the Jupiter Impact Team

Wong, Hammel, de Pater, et al.

STScI-PRC10-16

SL9 impacts in July 1994 showed effects of km and sub-km objects plunging into Jovian atmosphere

Frequency of events *thought* to be every ~300 years

Amateur observed new event in July 2009 and Hubble followed evolution

## **Giant Planet Atmospheres**

- Jovian weather, storms, and color changes
- Rare major storm on Saturn
- Aurorae on Jupiter and Saturn



### **Jovian Weather**

March 25, 2007



Jupiter Hubble Space Telescope • WFPC2

NASA, ESA, A. Sanchez-Lavega (University of the Basque Country), and A. Simon-Miller (NASA Goddard Space Flight Center) STScl-PRC07-25

Oval BA (LRS) formed in 2002 from merger of three 65 yr old storms and turned red in 2006

*Global Upheaval* started in 2006 and continues to this day

Simon-Miller, de Pater, Sanchez-Lavega, et al.



### Major Storm on Saturn

 Hubble captured major storm outbreak on Saturn

- Rare, roughly every two Saturn years (last was 1933)
- Cassini will not see this





### **Hubble Observations of UV Auroral Emissions**

Observations made with every camera and UV spectrograph on Hubble

Large programs to study Jupiter during New Horizons flyby (2007) and Saturn during Cassini campaign (2007-2008) Emission energy, morphology, and variations : changes with solar wind

Improved understanding of internal magnetic fields and magnetospheric interactions : apply to exoplanets

# **Galilean Satellites**

• UV emissions from atmospheres

### **STIS/MAMA Spectral Imaging of Satellites**







Both icy satellites have  $O_2$  atmospheres. Ganymede has aurorae + surface  $O_3$ .

Ganymede



Feldman, McGrath, et al.



# **Ring Systems**

Rings and small satellites of Uranus

### **Rings of Uranus**



- Perdita: Detected by Voyager 2 but unconfirmed until HST
- Cupid: ~ 9 km radius, only 850 km interior to Belinda
- Mab: ~ 12 km radius, isolated between Puck and Miranda

#### Showalter et al.

### **Rings of Uranus**



- Further enhancement and co-adding of these images reveals two faint, dusty, outer rings
- Mab is clearly associated with Ring µ, and it's probably the primary source
- Ring v orbits between Portia and Rosalind but is not associated with any known moons

Showalter et al.

# Mars

High resolution, global color imaging

### Mars

 Major Hubble target since earliest days

 Unique global color imaging during all oppositions from 1995-2005



### **Closest Mars-Earth View in 60,000 years**

2003 Mars Closest Approach

August 26, 2003 23:00 UT

Hubble Space Telescope • WFPC2

August 27, 2003 10:00 UT

NASA, J. Bell (Cornell University) and M. Wolff (Space Science Institute) STScl-PRC03-22a

Bell, Wolf, et al.

### **Hubble View of 2001 Dust Storm**



June 26, 2001

September 4, 2001

#### Mars • Global Dust Storm Hubble Space Telescope • WFPC2

NASA, J. Bell (Cornell University), M. Wolff (SSI), and the Hubble Heritage Team (STScI/AURA) • STScI-PRC01-31

Bell, Wolf, et al.

### **Mission Support**

- Hubble has provide valuable support to multiple NASA planetary missions
  - Galileo (Jupiter)
  - Deep Space 1 (Comet 19P/Borrelly)
  - Cassini (Saturn)
  - Rosetta (Comet 67P/Cheryumov-Gerasimenko, Asteroid 21 Lutetia)
  - Deep Impact (Comets 9P/Tempel 1 and 103P/Hartley 2)
  - New Horizons (Jupiter and Pluto)
  - Dawn (Asteroids Vesta and Ceres)

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Backup





### Pluto has two new satellites!

### **ACS/WFC Images of Pluto System**



#### Combination of 4 Images

Combination of 4 Images

### Provisional Names : S/2005 P 1 and S/2005 P 2

