Pueo-Nui Workshop

Solar System Observations

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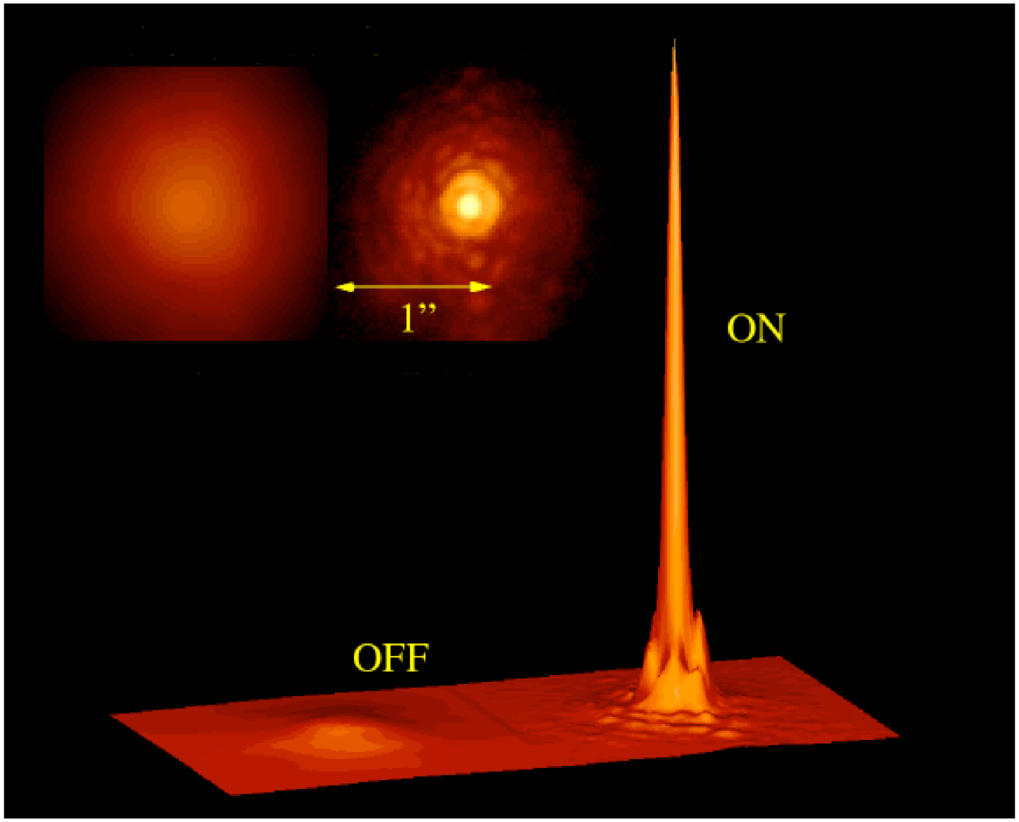
Background information



Pueo-Nui expected performances

- Strehl of ~ 92% at K band (on bright sources)
- Strehl of ~40% at R band, FWHM~40mas
- The CFH telescope would return performances of a 12m telescope at λ=0.6μm!
- Question: Is it worth the effort wrt present competition with large telescopes?
- Description of solar system applications

Telescopes w/ diffraction limited capabilities

- **AO:** CFHT (3.6m), ESO/VLT (8m), Keck (10m), Palomar (5m), Gemini (8m), Subaru (8m), Lick (3m), *Starfire (1.5m), Mt Wilson (2.5m), AEOS (3.6m)*

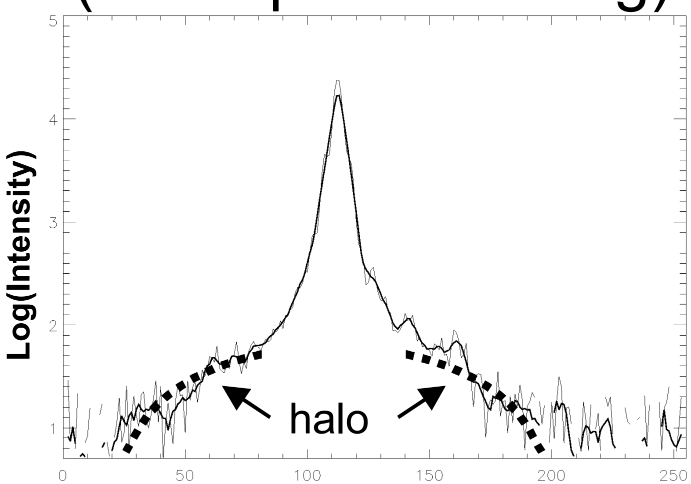
- **Space:** Hubble Space Telescope (2.5m)

Solar system bodies

- Large size & brightness range
  - Terrestrial planets, giant planets
  - Planetary atmosphere, satellites and rings
    - Neptune, Uranus have been observed with AO
  - Asteroids
    - Main-belt asteroids, Near-Earth-Objects, Trans-Neptunians, Centaurs
  - Comets
- Time variable phenomena

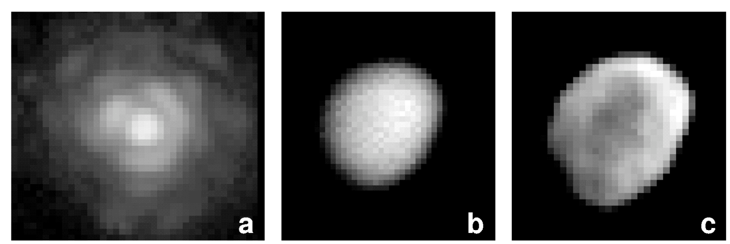
Performances and limitations

- Diffraction limit for the PSF core: image restoration (MISTRAL for solar system objects)
- Uncorrected modes result in a halo with size ~ λ/r_o (atmospheric seeing)



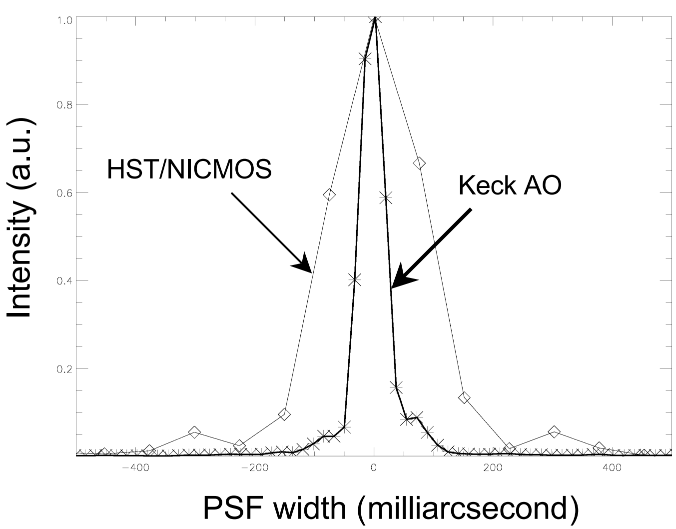
PSF profile (2μm)

Example of image restoration
Asteroid Vesta



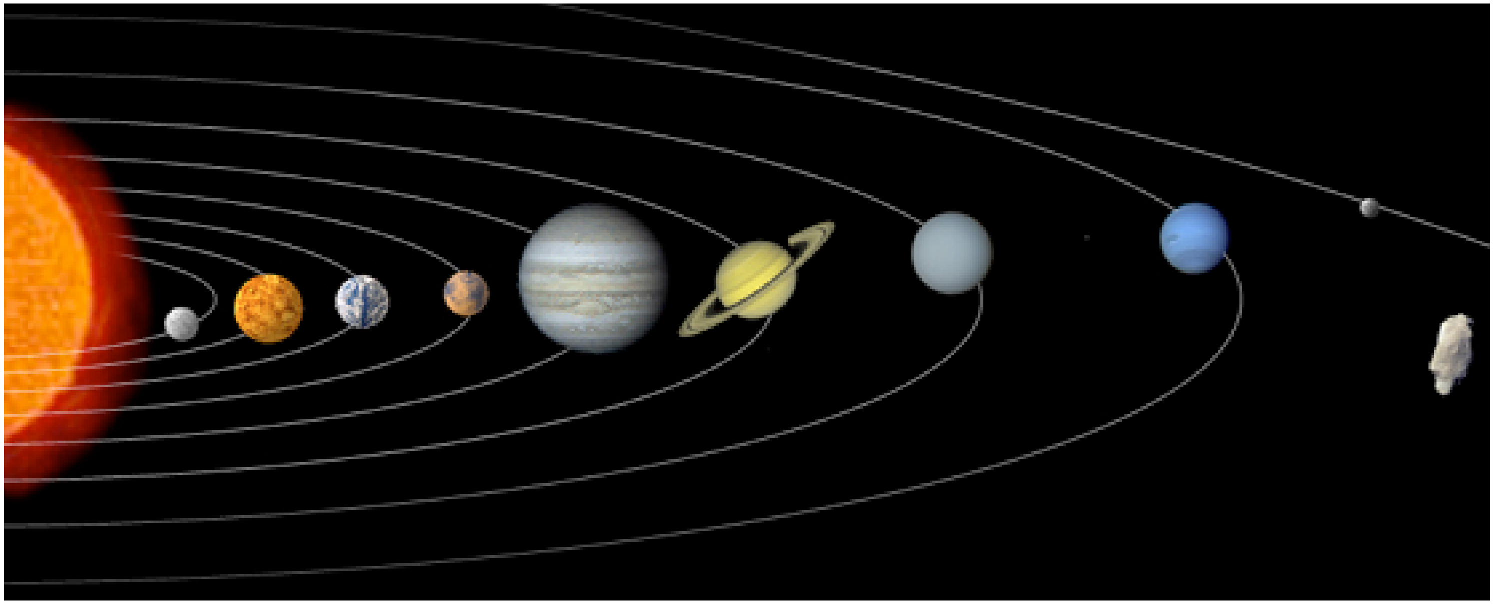
Performances and limitations (Cont’d)

- Stability of the PSF (number of corrected modes) is critical for high-contrast
- Limitation in object brightness (V>11-16) & angular size (20-30” isoplanatic patch at K band)



AO on large telescopes (e.g. Keck) provide 50mas resolution (~ 50km at mid distance through the asteroid main-belt)

Application to solar system sciences



A case for Pueo-Nui?

- Very good optical quality + high-Strehl provide high dynamic range and high-contrast imaging

- Asteroids
  - surface compositional mapping, shape, geology
  - satellites
- Planetary satellites
  - surface mapping (imaging/spectro)
  - study of inner systems (Uranus, Neptune)
- Rings
- Planetary atmosphere
  - Short-time scale and seasonal variability, small scale features

Asteroid studies

Asteroid studies

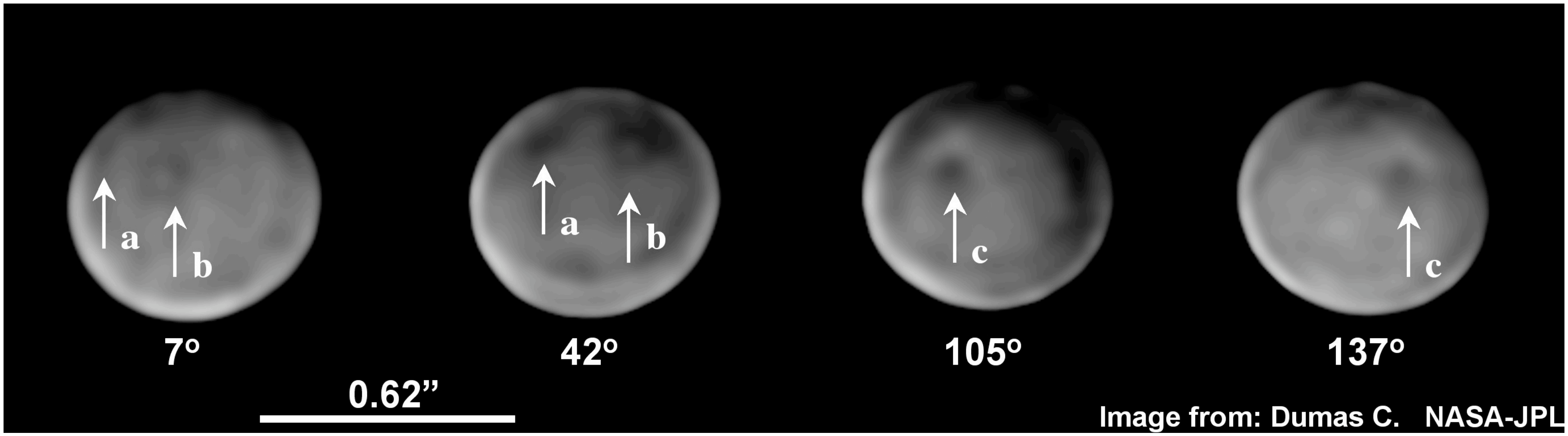
- Mapping of main-belt objects
- ~25 asteroids w/ diameter > 200km
- ~250 asteroids w/ diameter > 100km
- FWHM at 0.6μm: 40mas = 60km at the mid-belt distance
- Shape informs us on formation / collision history

Asteroid studies (Cont'd)

- Albedo features: composition/collisional history
- Pole orientation

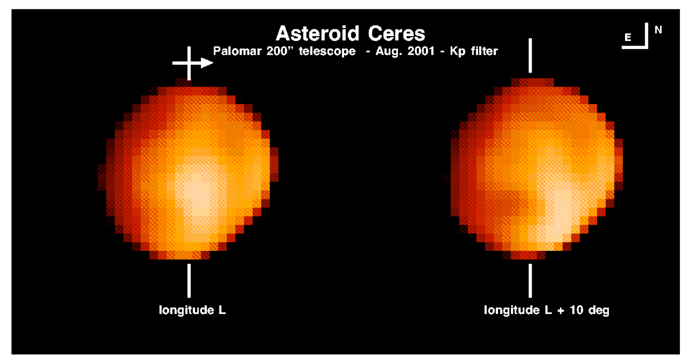
- Would require set of silicate filters (pyroxene, olivine)
- Spectroscopic capabilities (R~200)

Asteroid studies (Cont'd)



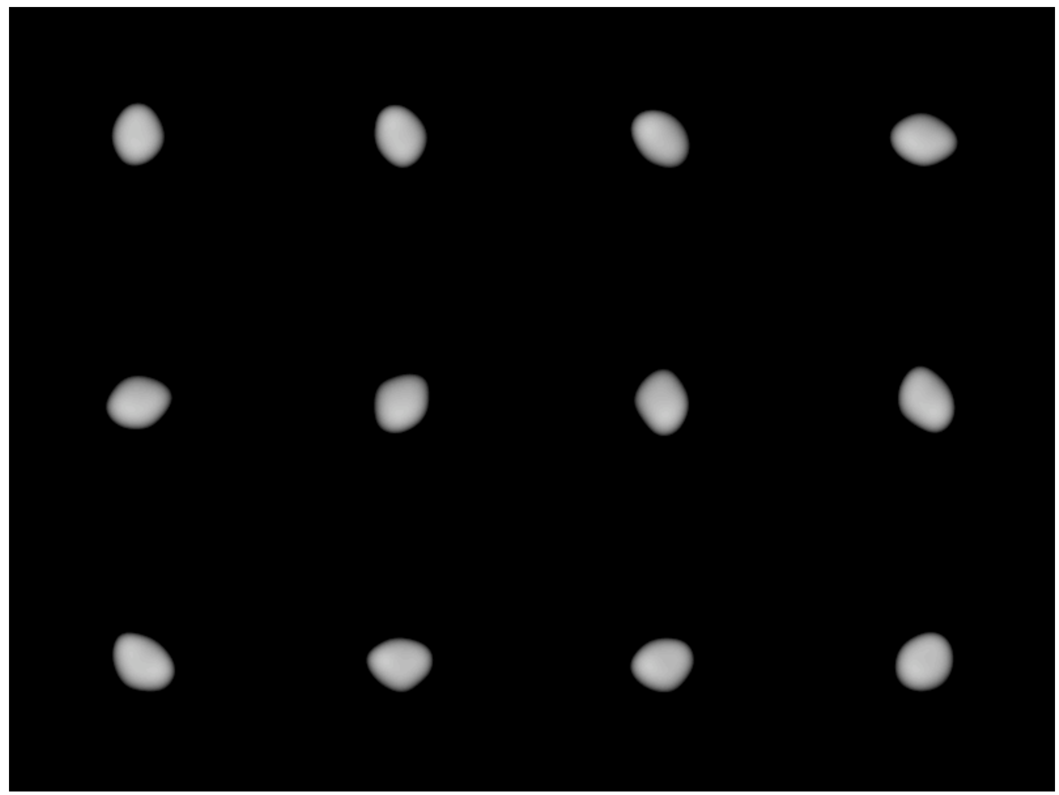
Mapping of Ceres with Keck-AO at 2.2μm

- Shape model
- Geological study (crater counting)
- Pole orientation
- Albedo maps
- Search for small (sub-km) satellites

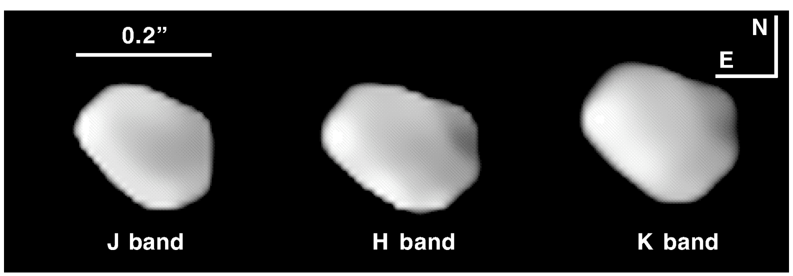


Asteroid studies (Cont'd)

Asteroid Davida from Keck at K band
0.2" diameter. Shape/pole orientation



Asteroid Juno from Keck
0.24" diameter. Shape/albedo features

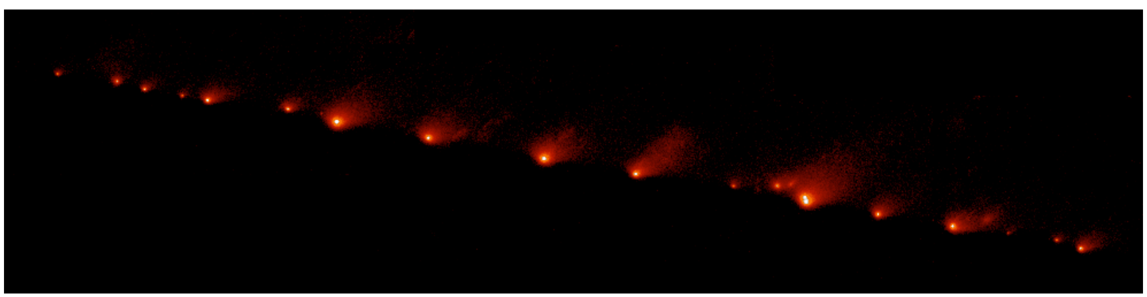


Summary (asteroid mapping)

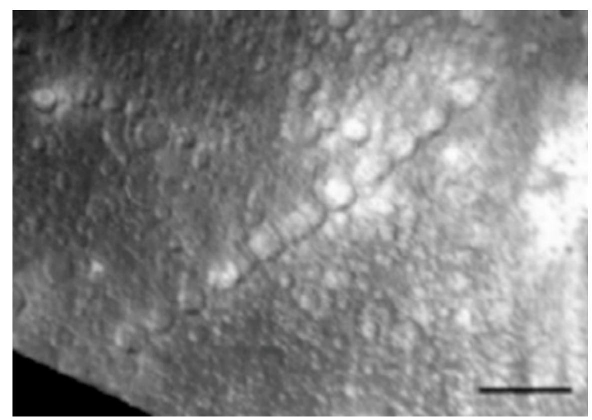
- High-Strehl down to V-R bands would allow study of > hundred of main-belt asteroids
- Less thermal background than near-IR
- Shape/pole/geological/collisional study
- Large telescopes are an alternative at near-IR but oversubscribed
- Low-resolution slit spectroscopy (bands of pyroxene and olivine). Medium-band filters

Asteroid satellites

- Why looking for asteroid satellites?
  - Existence suspected but no direct evidence until 1993 (Galileo's flyby of asteroid Ida)
    - Early report of peculiar lightcurves ('70s)
    - Visual observations of secondary events during star occultations
    - Double/multiple craters on Earth/Venus/Moon
  - New class of objects in the solar system
  - Dynamics/collision in the asteroid main-belt
  - Important physical characteristics: bulk density, internal structure



Comet Shoemaker-Levy 9

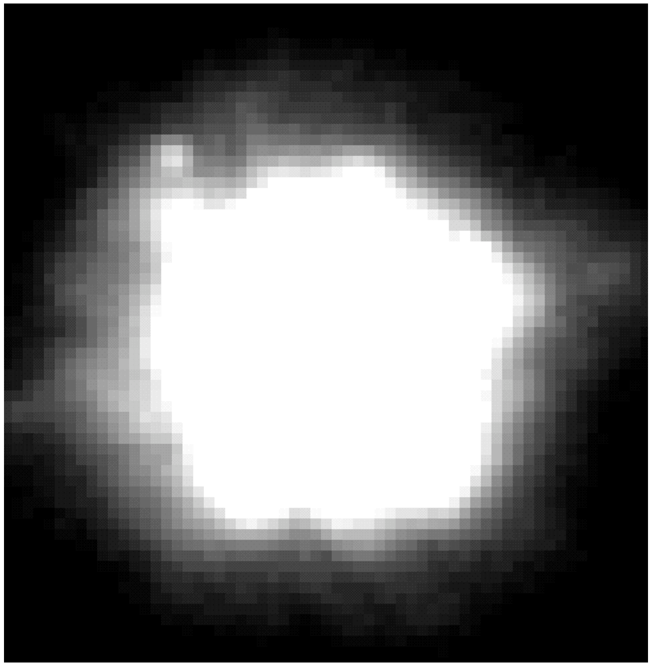


Callisto

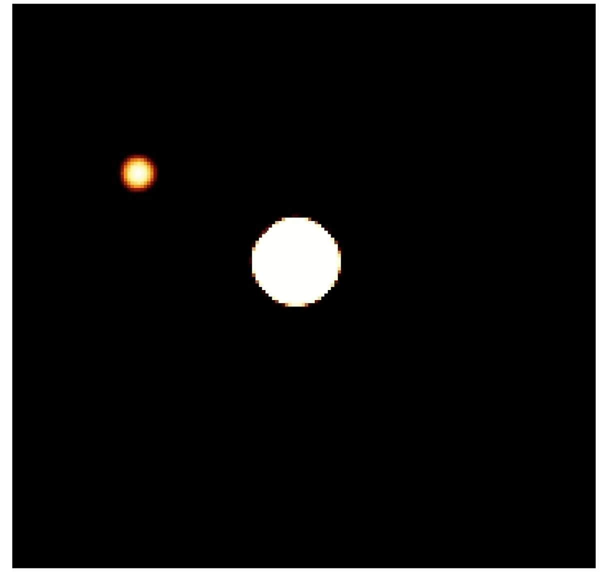
Asteroid Eugenia

- First discovery of a binary asteroid from the ground (November 1998, CFHT)
- ID for 45 Eugenia
  - Type F (primitive, 4% albedo)
  - 2.7AU heliocentric distance
  - ~220km diameter
  - retrograde
- Satellite's ID:
  - 4.7 days rotation
  - 13km diameter
  - 1200km orbital distance

  (i.e. orbit size ~ 11 Eugenia's radii)

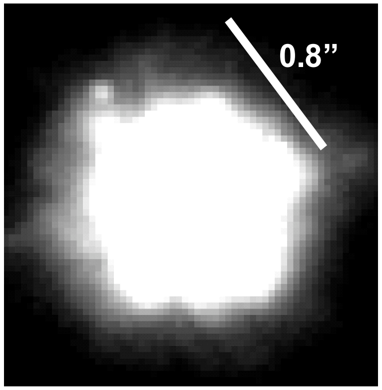


Eugenia (Cont'd)

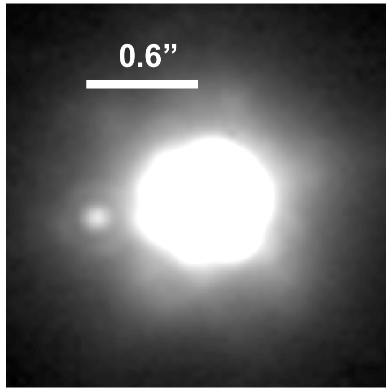


- A typical day on Eugenia
  - One revolution is 4.4 years long
  - One day is 5.7 hours long
  - Apparent motion of Petit-Prince in Eugenia's sky comparable to Earth's Moon (~20 "Eugenian" days)
  - Low gravity: 270 times less than Earth's, 45 times less than on the Moon
  - Petit-Prince's angular size (~0.6deg) similar to the Moon seen from Earth

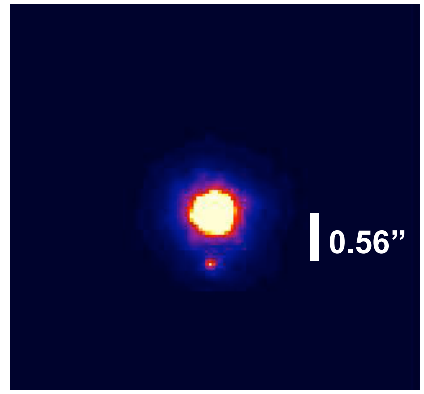
Family portrait



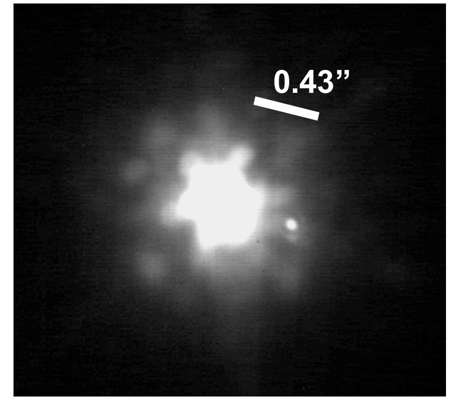
Eugenia from CFHT



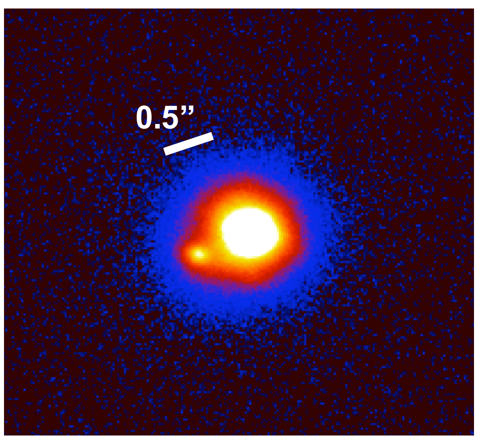
Pulcova from CFHT



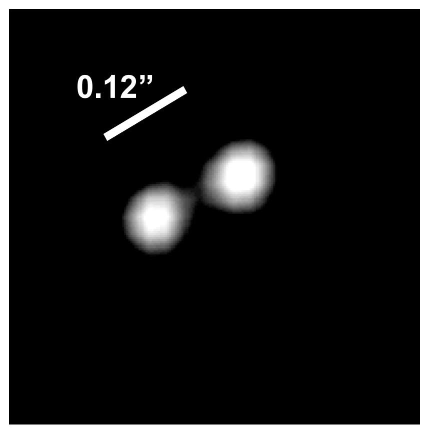
Kalliope from CFHT



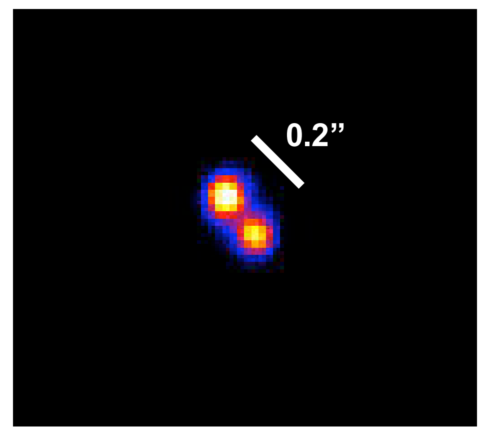
Hermione from Keck



Balam from Gemini



Antiope from Keck



Patroclus from Gemini

Some interesting results & questions

- Satellites might be more frequent among the C/F/P type asteroids (primitive). Observational effect?

- Calculated densities for C/F/P types are low (1.2-1.8g/cc). Not consistent with solid rock. Rubble pile? Hydrated minerals?

- The density for Kalliope (2.3g/cc) is lower than expected for metallic asteroids

- Are double asteroids more prevalent among the Trojan group?

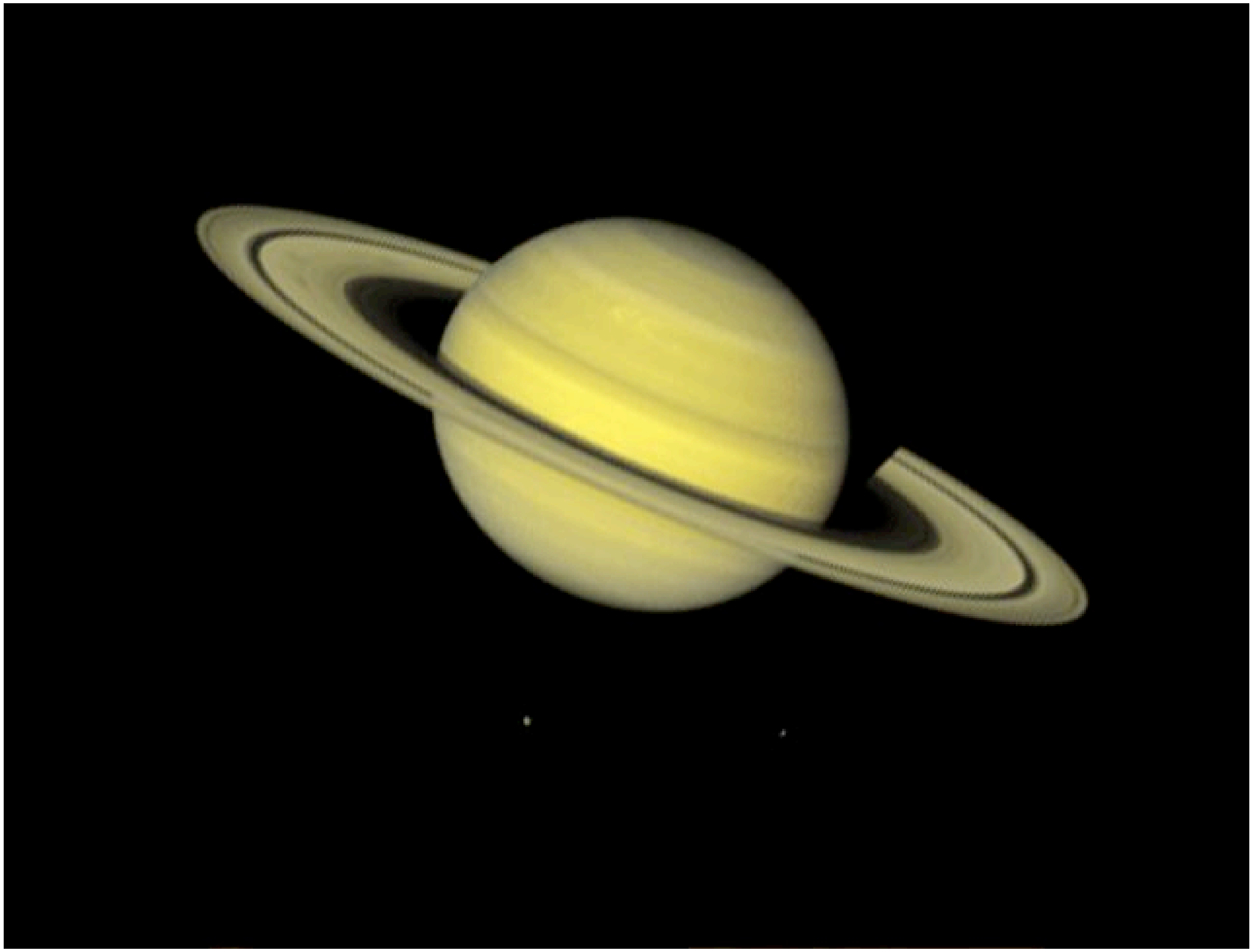
Some interesting results & questions (Cont'd)

- We observed about 500 asteroids and derive a frequency of ~ 2% for binary asteroids (large satellites) in the main-belt
- AO observations of main-belt asteroids only sensitive to "large" satellites (~10km). A detection of Dactyl-like object is (for now) beyond our reach.
- Why is the prevalence larger (~16%) among the Near-Earth Objects population? Different formation mechanisms? What about TNOs? Loosely bound systems?

Summary (asteroid satellites)

- Future will help to study coupling between asteroids families and the diverse formation processes
- Tool to explore the interior, composition and collisional history of asteroids and formation of terrestrial planets in general (impact hazards)
- Higher-contrast and higher resolution means detection of smaller, closer-in satellites (Dactyl type). Exploring size distribution for small objects
- Coronagraphy?
- Access to telescope time is a problem on large telescopes
- Slit spectroscopy would allow detailed compositional study of both components

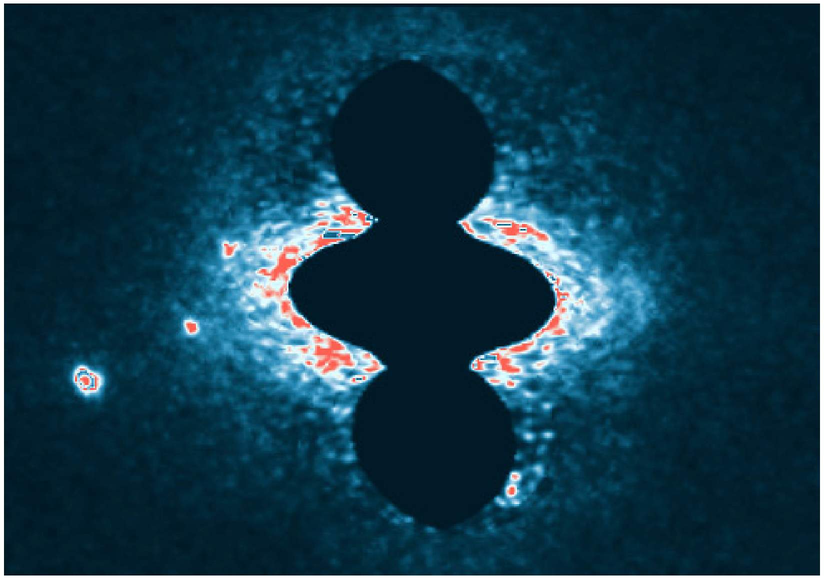
Planetary satellites and rings



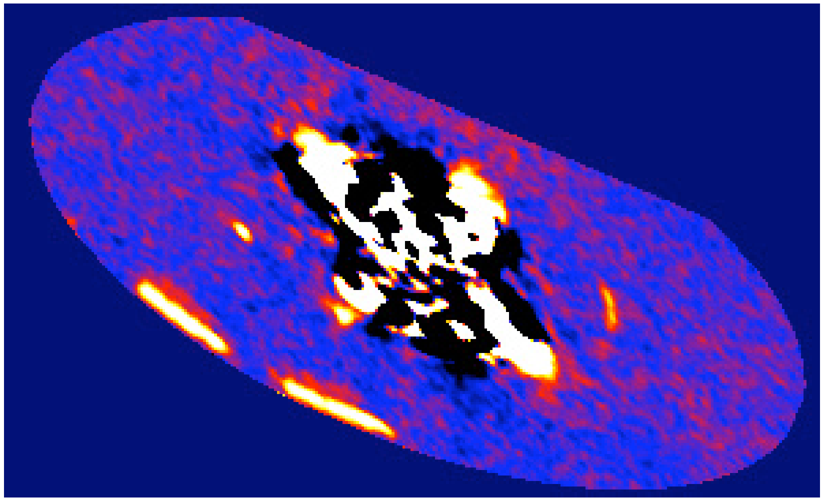
Neptune's ring-arcs

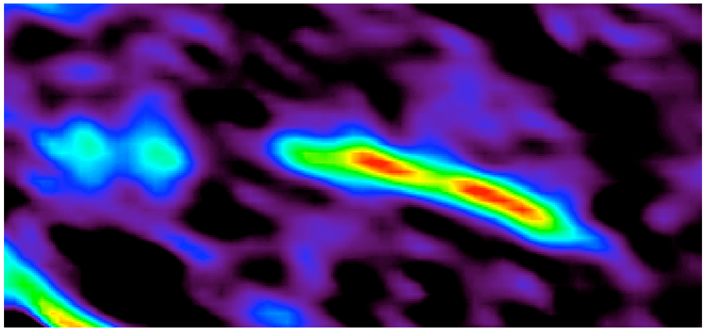
- PSF stability and high-Strehl provide contrast

Ring-arcs w/ Hokupa`a at CFH



With HST-NICMOS

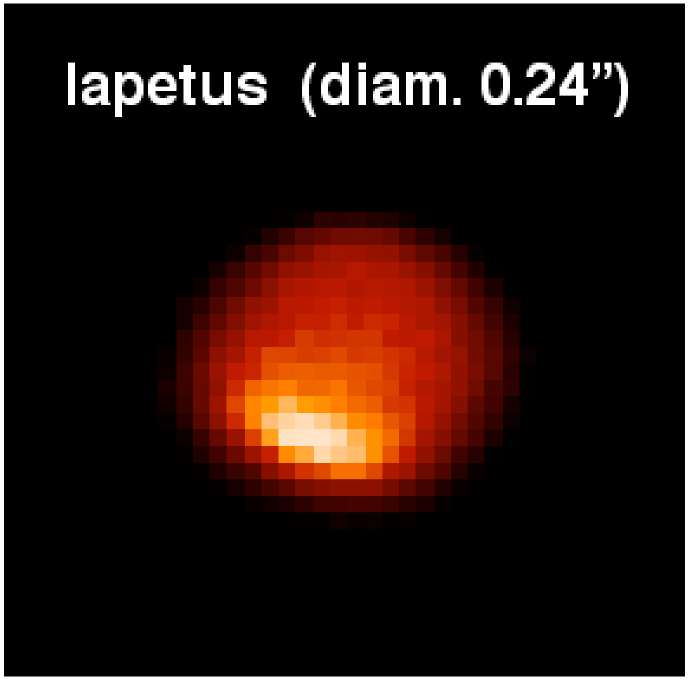




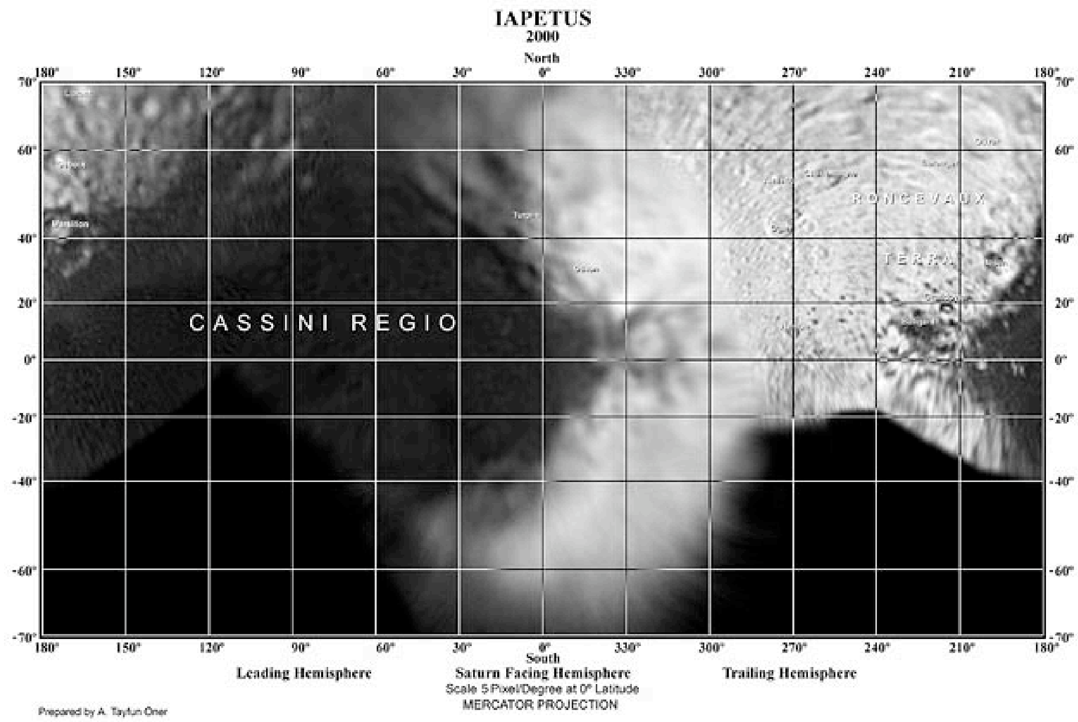
Rings

- PSF stability and high-Strehl provide contrast for diffuse structures such as planetary rings (giant planets)
- Near-IR range is best since planet is fainter (methane bands)
- Pueo-Nui would be unique to carry-out detailed study of ring systems (variability). Neptune's full rings have not yet been observed from the ground.
- Access to telescope time
- Ability to lock on extended objects (Uranus is ~4" diameter). Variable aperture for the wavefront sensor?

Planetary satellites: Iapetus

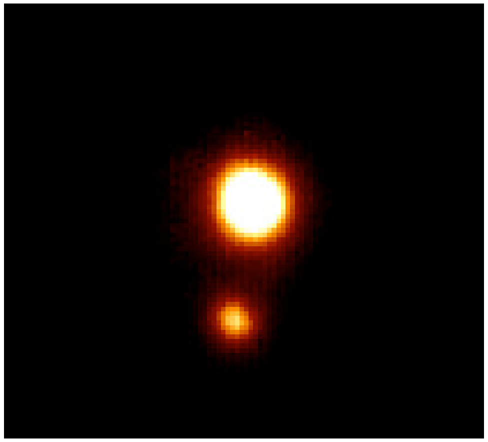


Keck AO+SCAM
Kband



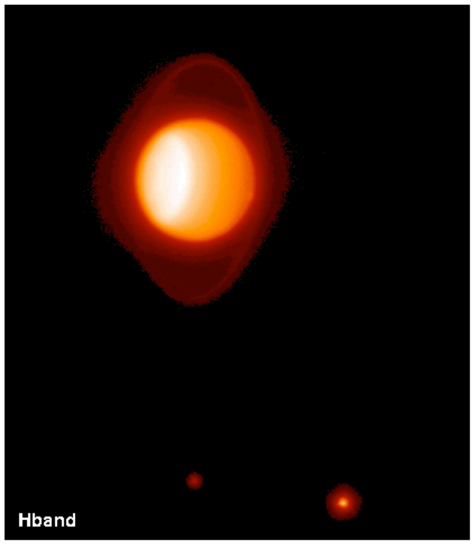
Iapetus map from Voyager

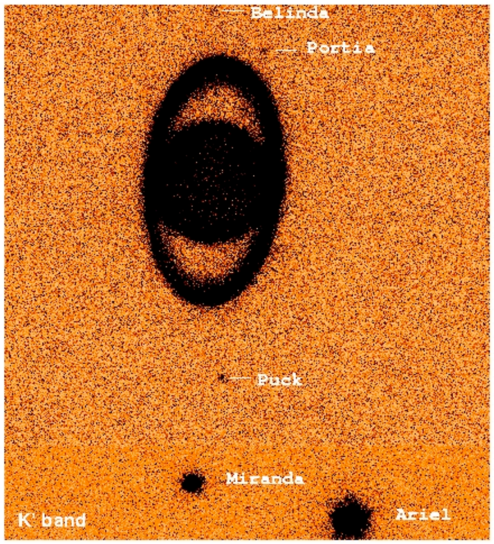
Planetary satellites (Cont'd)



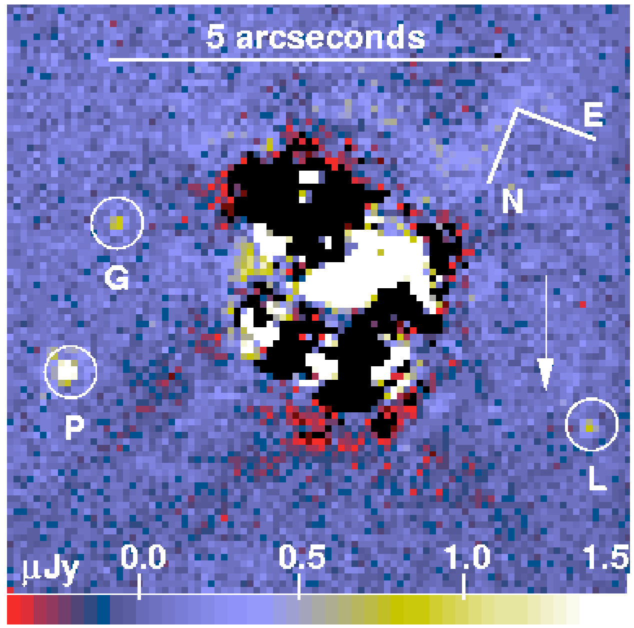
Pluto-Charon with Pueo

Uranus at H & K band (Pueo)





Neptune (HST-NICMOS)



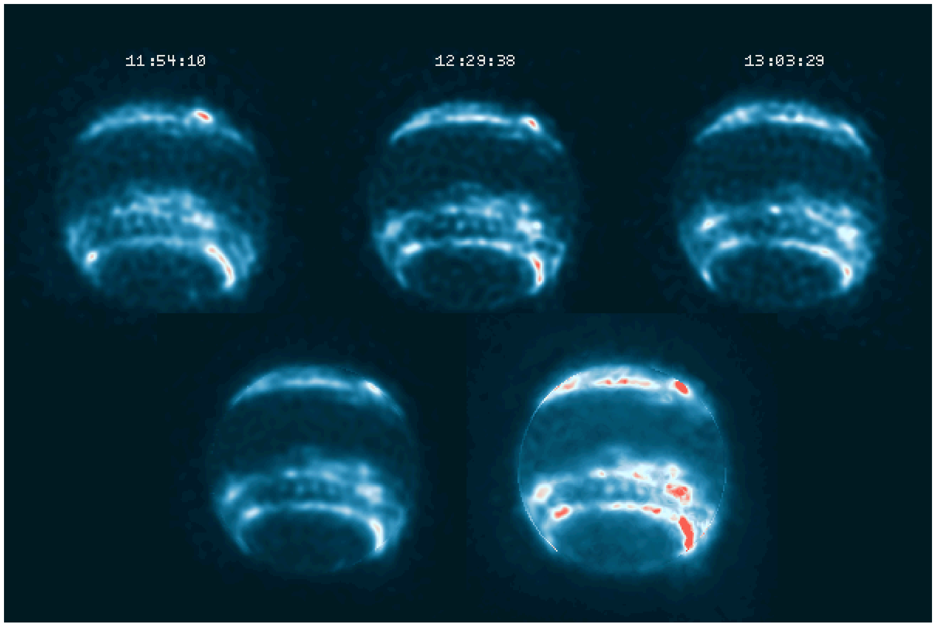
C. Dumas, NASA-JPL.

Pueo-Nui Workshop. LAOG, Grenoble, France, May 22-23, 2003

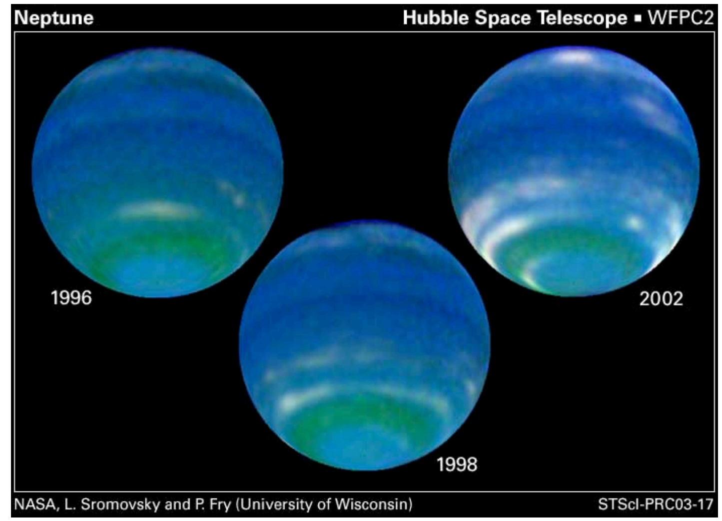
Planetary satellites (summary)

- High-contrast in the near-IR allows detection of the faint inner moons
- Filters in/out bands of main ices (CH_4, H_20)
- Low-resolution slit spectroscopy
- Rotationally resolved spectroscopy (spatial distribution of icy compounds)

Planetary atmospheres



Neptune from Hokupa`a at CFH (deconvolved) in the near-IR



Neptune from HST-WFPC2 (visible)

Daily/seasonal changes in the atmosphere of giant planets

Planetary atmosphere (summary)

- High-contrast in the near-IR allows detection of the faint cloud structures
- Monitor seasonal & short time-scale variations
- Slit spectroscopy at higher resolution (R~2500)
- Access to telescope time
- Study of Jupiter and Saturn would be much more challenging (limited to polar regions or limb w/ satellite conjunction)
- Adjustable aperture for the WFS (Uranus+Neptune)

Summary

- Pueo-Nui would support large numbers of solar system programs
- Working in the “visible” range would provide low background for detection of faint sources
- High-contrast for detection of diffuse sources (rings, cloud features) and faint, close-in objects (asteroid satellites)
- In some cases, program could be equally carried-out on large telescopes but time allocation highly oversubscribed
- Good performances on “faint” guide sources (V>12)

- Pueo-Nui science would benefit from set of “medium” band filters (ices, silicates) for compositional study
- Low to medium resolution spectroscopy highly-desirable (cross-dispersed 0.8-2.5μm?)
- Variable WFS aperture to lock on extended sources