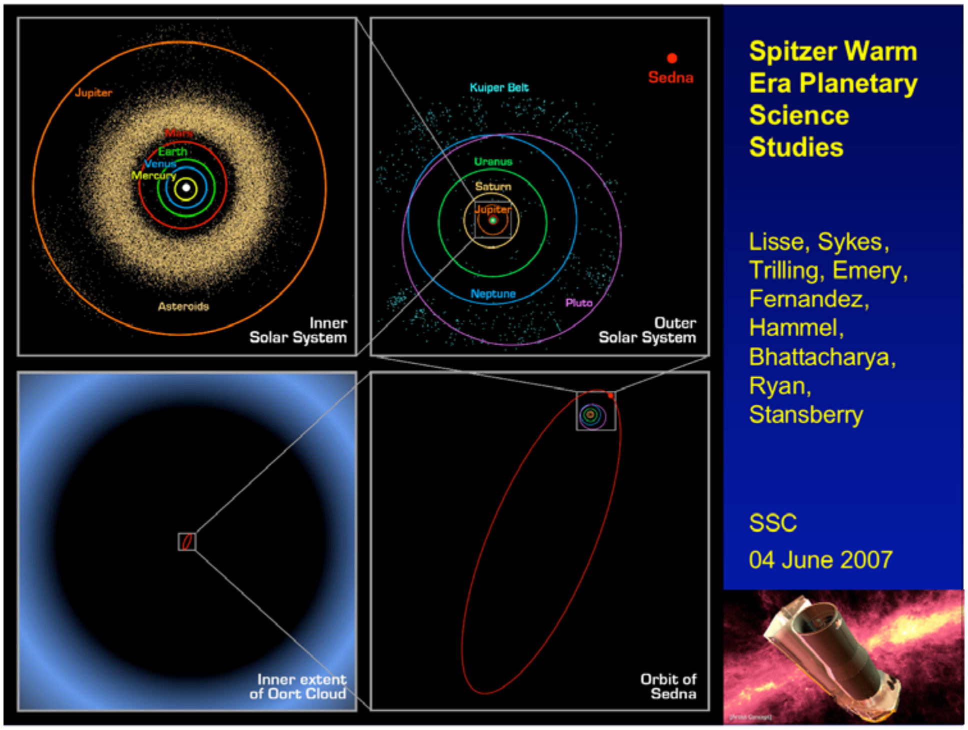
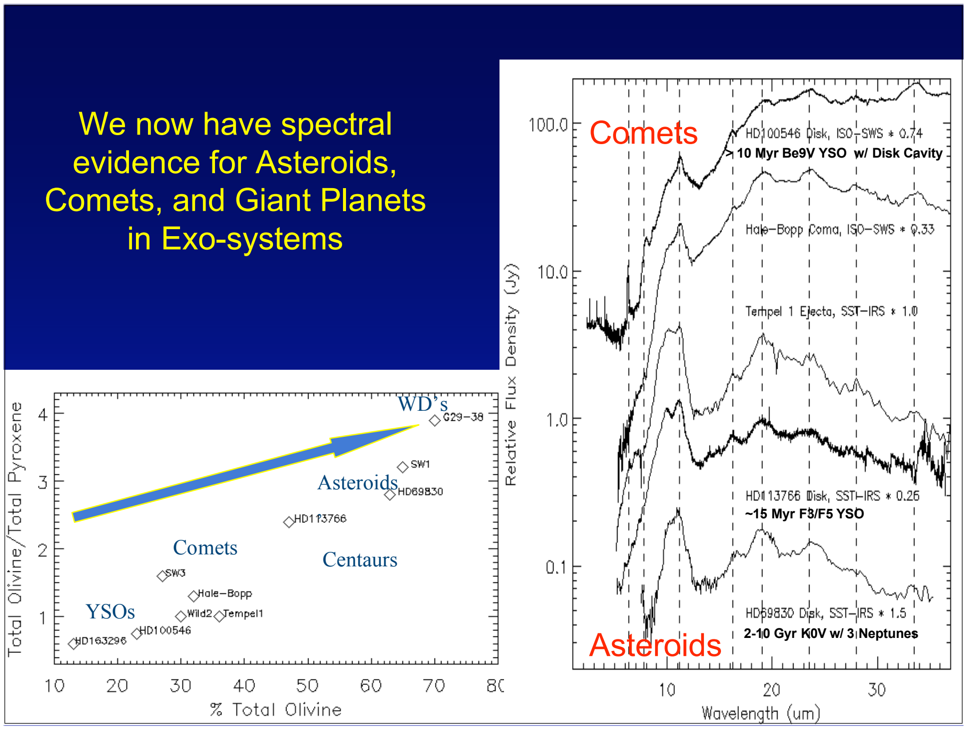


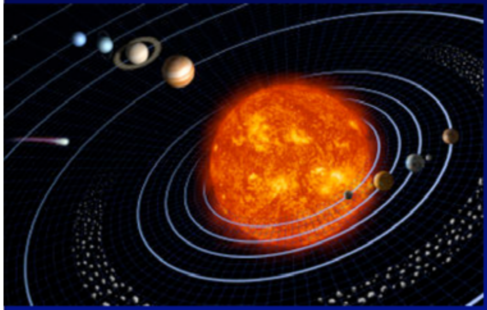
Spitzer Warm Era Planetary Science Studies

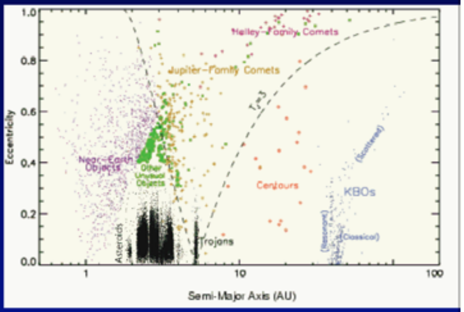
Lisse, Sykes, Trilling, Emery, Fernandez, Hammel, Bhattacharya, Ryan, Stansberry

SSC
04 June 2007



We now have spectral evidence for Asteroids, Comets, and Giant Planets in Exo-systems





What best to study amongst the plethora of solar system objects with Spitzer in the Warm Era? We have identified 6 key questions which we believe make the cornerstone of a very major study, directly relevannt to astrophysical studies of exo-planets and dusty debris disks, which fits in well with Spitzer's abilities to be highly sensitive to point sources in the 3-4 μm range.

Key SWE Planetary Science Questions (I)

***(1) What is the dynamical history of the Solar System, and what role has giant-planet migration played?* There is substantial theoretical work suggesting that giant planets (in our Solar System and in others) undergo significant radial migration before the system settles into its final configuration, but there is still little direct evidence for this hypothesis. A Warm Spitzer can provide observational tests of specific predictions made by those theories by observing various small bodies in the Solar System.** *[Trojans, Outer Main Belt Asteroids (MBAs), Kuiper Belt Objects (KBOs)]*

***(2) What is the distribution of water and organic components in the Solar System?* It has been proposed that water and organic material was delivered to the Earth by impacting comets and asteroids. With a Warm Spitzer, we can map the distributions of water and organic material in the asteroid belt and constrain the consequent flux rate of this life-giving material to the early Earth**. *[Main Belt Asteroids]*

***(3) What are the physical properties of potential Earth-impacting asteroids?* An impact 65 million years ago eliminated the dinosaurs and allowed mammals to rise to prominence. There are thousands of asteroids known in near-Earth space. With a Warm Spitzer, we can understand the physical properties of these bodies and help evaluate the potential impact hazard onto the Earth.** *[Near-Earth Asteroids]*

Key SWE Planetary Science Questions (II)

(4) What is the nature of the refractory and carbonaceous material incorporated into comets from the proto-solar nebula? *Comets -- as leftover planetesimals from the era of Solar System formation -- contain important details of the mechanism of aggregation of ISM dust and gas into planets. Carbon is critical to the beginnings and evolution of life, as well as being an important component of the Earth's crust. The major reservoir of carbon in comets is in the gaseous volatile organic and CO/CO_2 ices, not in the refractory state, and is poorly studied. With a Warm Spitzer, we can better measure both the amount of refractory material emitted by comets into the IPD today, and the amount of carbon contained in volatiles in the PSN.* *[Comets]*

(5) Are the structures we see in mature exo-disks explainable by the erosional and collisional processes supporting the Solar System zodiacal cloud? *Can the model timescales for these processes (10 - 10^6 yrs for cometary emission processes, 10^6 - 10^7 yrs for asteroid fragmentation events, 10^5 yrs for dust-dust collisions, 10^3 - 10^6 yrs for PR drag, < 10^6 years for radiation pressure blowout) be reconciled with Spitzer zody cloud studies?* *[Zodiacal Cloud]*

(6) Is the major energy source driving the dynamics of the icy giant planets Uranus and Neptune gravitational contraction, insolation, or dynamical friction? *Answering this question is crucial for understanding the energy budgets of exoplanet atmospheres. Current observations of Uranus suggest that seasonal insolation changes are more significant than predicted by models, and that Neptune's atmosphere may be more sensitive to insolation than expected. By extending observations of Uranus and Neptune over the five years of the Warm Era -- through major events in the seasonal cycles of the two planets -- we can determine which effects are paramount.* *[Ice Giants]*

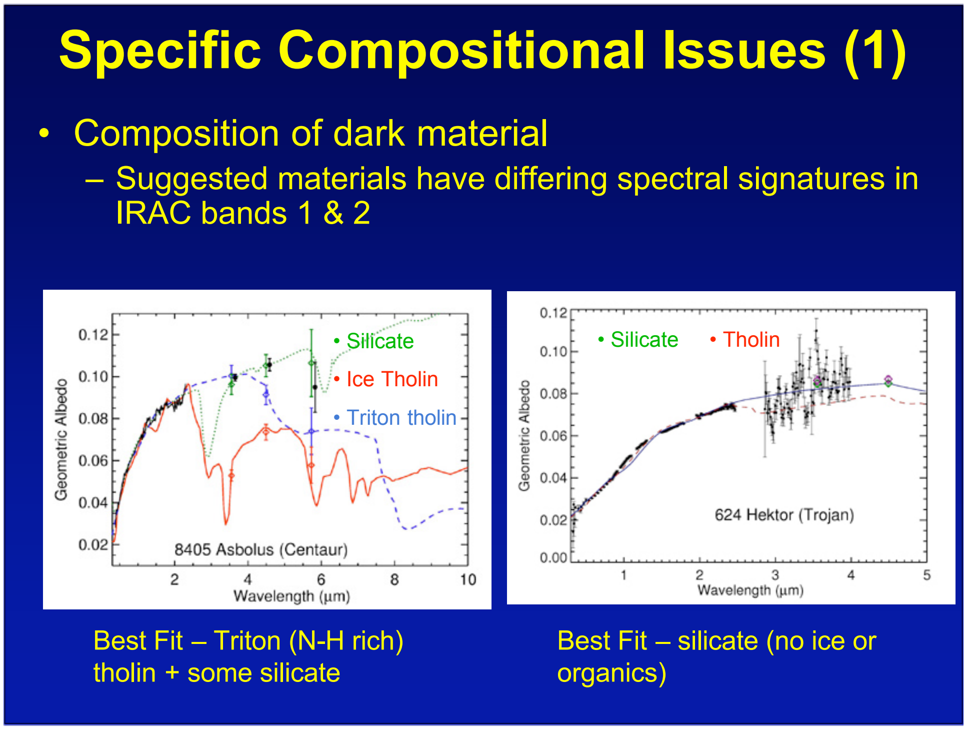
Small Outer Solar System Bodies :

KBOs, Trojans, Centaurs

(1) What is the dynamical history of the Solar System, and what role has giant-planet migration played? *There is substantial theoretical work suggesting that giant planets (in our Solar System and in others) undergo significant radial migration before the system settles into its final configuration, but there is still little direct evidence for this hypothesis. A Warm Spitzer can provide observational tests of specific predictions made by those theories by observing various small bodies in the Solar System.* *[Trojans, Outer Main Belt Asteroids (MBAs), Kuiper Belt Objects (KBOs)]*

Small Outer Solar System Bodies

- 2 Popular General Models for the Solar System
  - *Quiescent* – most primitive bodies formed in current locations
  - *Migration* – dynamical eruption from giant planet migration moved things around
- Models make ***very*** different predictions
  - Trojans (outer-belt asteroids) either formed at ~ 5 AU (quiscent) or at ~30 AU (migration)?
  - What mechanism(s) are responsible for the various Kuiper Belt sub-populations?
- *Observations of primitive bodies to determine their composition provide **direct** tests of dynamical models*

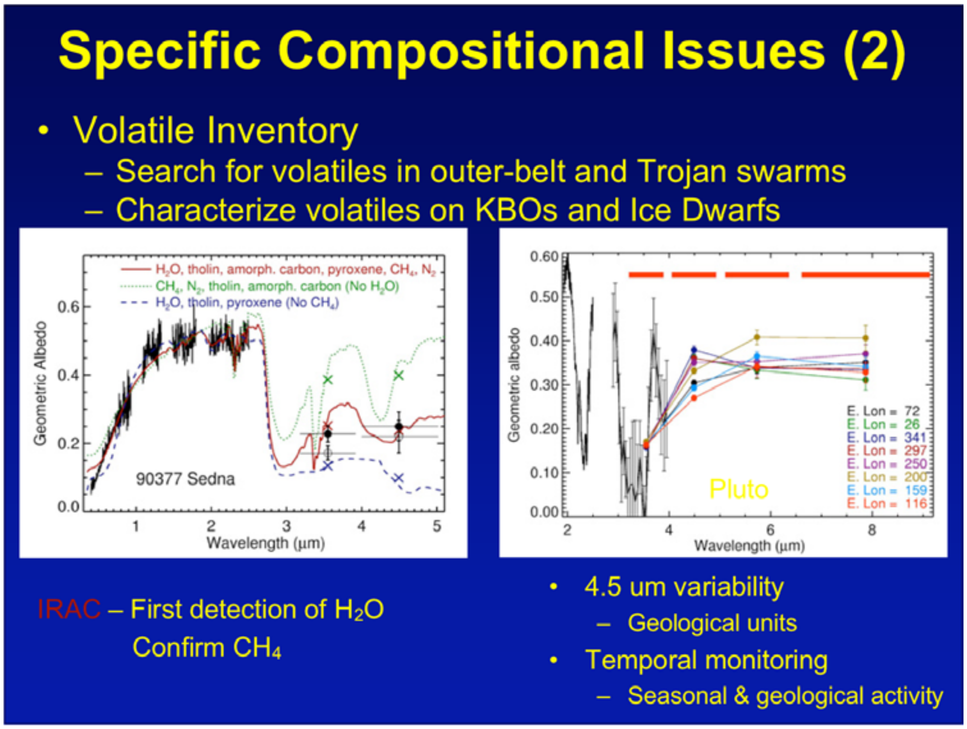


Specific Compositional Issues (1)

- Composition of dark material
  - Suggested materials have differing spectral signatures in IRAC bands 1 & 2

Best Fit – Triton (N-H rich) tholin + some silicate

Best Fit – silicate (no ice or organics)



Specific Compositional Issues (2)

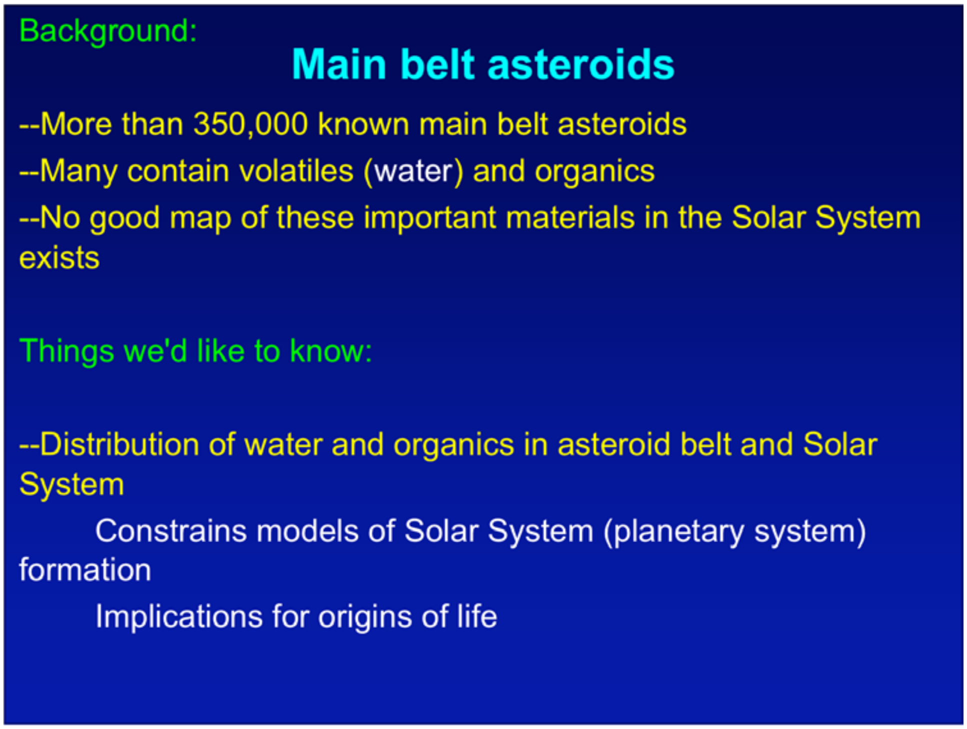
- Volatile Inventory
  - Search for volatiles in outer-belt and Trojan swarms
  - Characterize volatiles on KBOs and Ice Dwarfs

IRAC – First detection of H_2O
Confirm CH_4

- 4.5 um variability
  - Geological units
- Temporal monitoring
  - Seasonal & geological activity

Main Belt Asteroids (MBAs)

***(2) What is the distribution of water and organic components in the Solar System?** It has been proposed that water and organic material was delivered to the Earth by impacting comets and asteroids. With a Warm Spitzer, we can map the distributions of water and organic material in the asteroid belt and constrain the consequent flux rate of this life-giving material to the early Earth.* *[Main Belt Asteroids]*



Background:

Main belt asteroids

--More than 350,000 known main belt asteroids

--Many contain volatiles (water) and organics

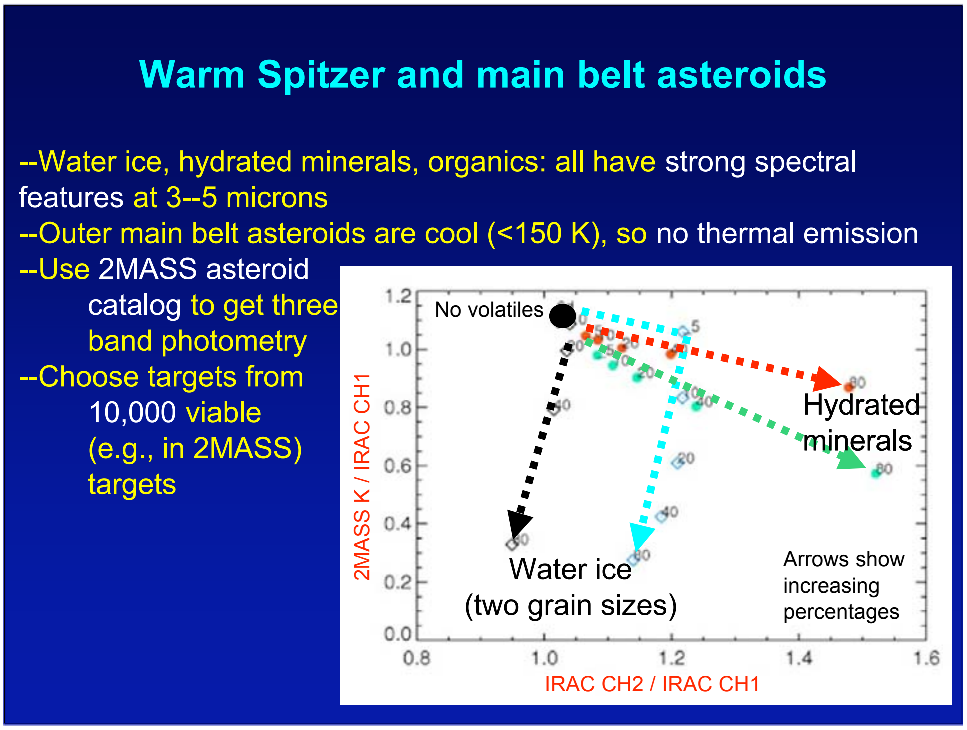
--No good map of these important materials in the Solar System exists

Things we'd like to know:

--Distribution of water and organics in asteroid belt and Solar System

Constrains models of Solar System (planetary system) formation

Implications for origins of life



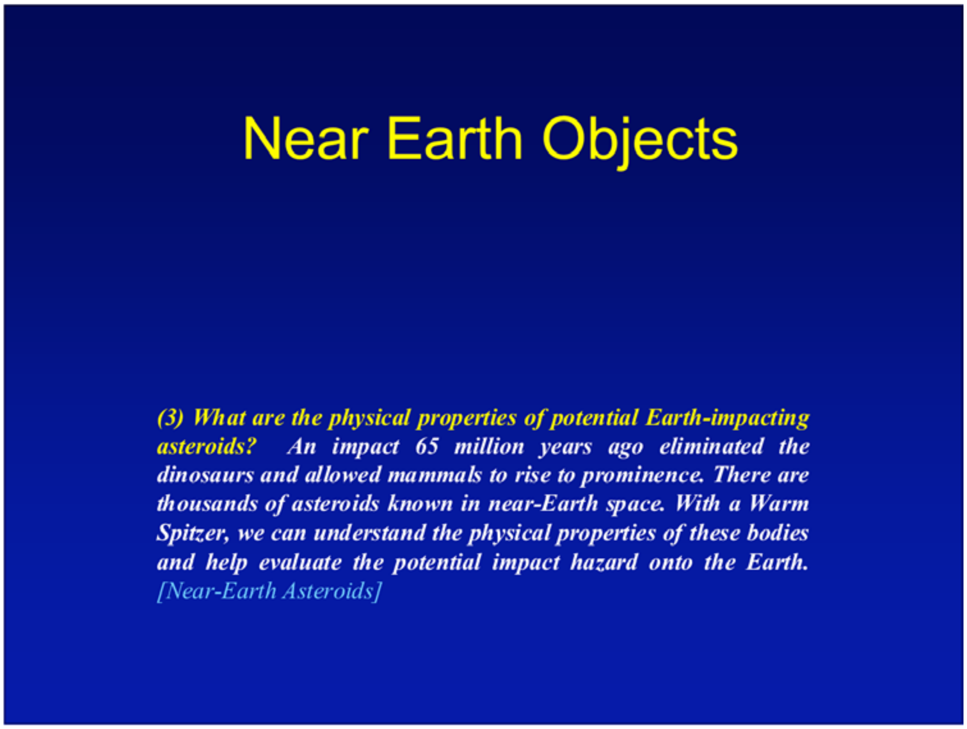
Warm Spitzer and main belt asteroids

--Water ice, hydrated minerals, organics: all have strong spectral features at 3--5 microns

--Outer main belt asteroids are cool (<150 K), so no thermal emission

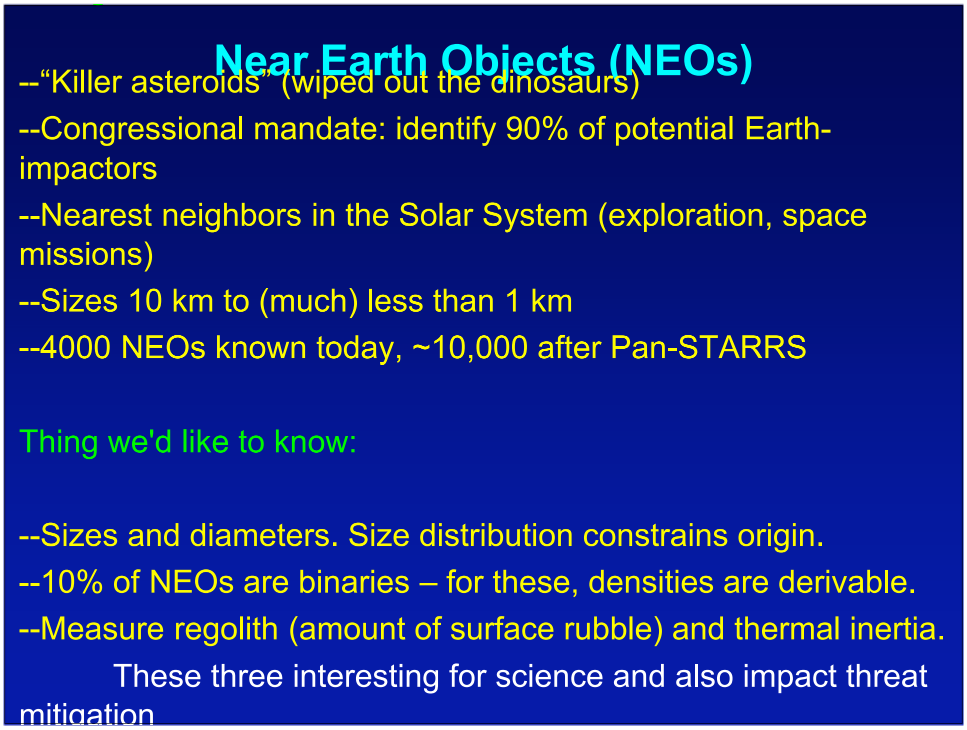
--Use 2MASS asteroid catalog to get three band photometry

--Choose targets from 10,000 viable (e.g., in 2MASS) targets



Near Earth Objects

(3) What are the physical properties of potential Earth-impacting asteroids?   An impact 65 million years ago eliminated the dinosaurs and allowed mammals to rise to prominence. There are thousands of asteroids known in near-Earth space. With a Warm Spitzer, we can understand the physical properties of these bodies and help evaluate the potential impact hazard onto the Earth. *[Near-Earth Asteroids]*



Near Earth Objects (NEOs)

--“Killer asteroids” (wiped out the dinosaurs)

--Congressional mandate: identify 90% of potential Earth-impactors

--Nearest neighbors in the Solar System (exploration, space missions)

--Sizes 10 km to (much) less than 1 km

--4000 NEOs known today, ~10,000 after Pan-STARRS

Thing we'd like to know:

--Sizes and diameters. Size distribution constrains origin.

--10% of NEOs are binaries – for these, densities are derivable.

--Measure regolith (amount of surface rubble) and thermal inertia.

These three interesting for science and also impact threat mitigation

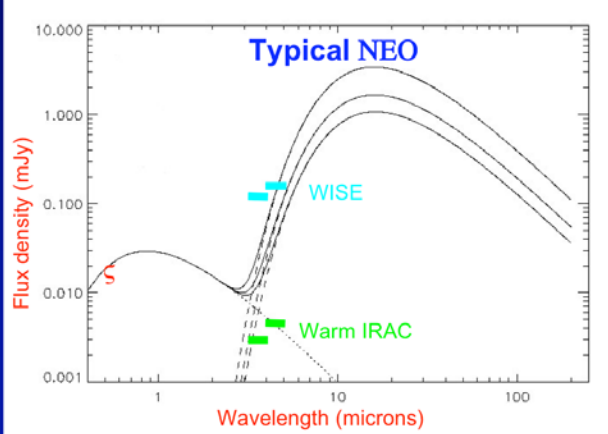
Warm Spitzer observations of NEOs

--NEOs are warm (T~250+ K), so IRAC CH1, CH2 is thermal emission

--Funny visibility windows (because of Spitzer-NEO orbit geometries)

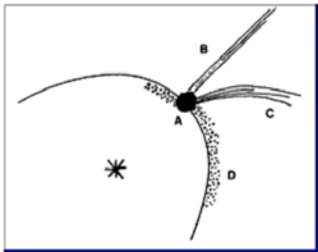
--But all known NEOs visible and bright some time during Warm mission

Albedo	Radius
10%	210 m
20%	150 m
30%	120 m

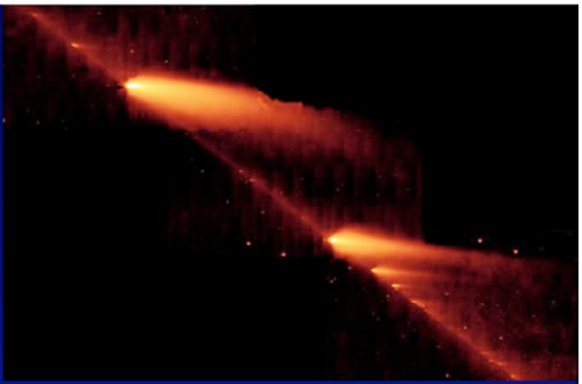


Comets

***(4) What is the nature of the refractory and carbonaceous material incorporated into comets from the proto-solar nebula?** Comets -- as leftover planetesimals from the era of Solar System formation -- contain important details of the mechanism of aggregation of ISM dust and gas into planets. Carbon is critical to the beginnings and evolution of life, as well as being an important component of the Earth's crust. The major reservoir of carbon in comets is in the gaseous volatile organic and CO/CO_2 ices, not in the refractory state, and is poorly studied. With a Warm Spitzer, we can better measure both the amount of refractory material emitted by comets into the IPD today, and the amount of carbon contained in volatiles in the PSN.* *[Comets]*



Schematic of comet morphological structures. *(A) Coma, (B) Ion Tail, (C) Dust Tail, (D) Dust Trail (adapted from Sykes and Walker 1992).*



The P/Schwassmann-Wachmann 3 dust trail and fragmented nucleus form a number of small comets, *obtained at 24 μm by Spitzer MIPS. Here the comae are the bright white regions surrounding each fragment, the dust tail the yellowish to reddish extensions directed away from the Sun to the right, and the comet trail is the thin red line running from upper left to lower right, connecting all the fragments. After Reach et al. (2006). ~1/2 the apparent mass is contained in the trail dust.*

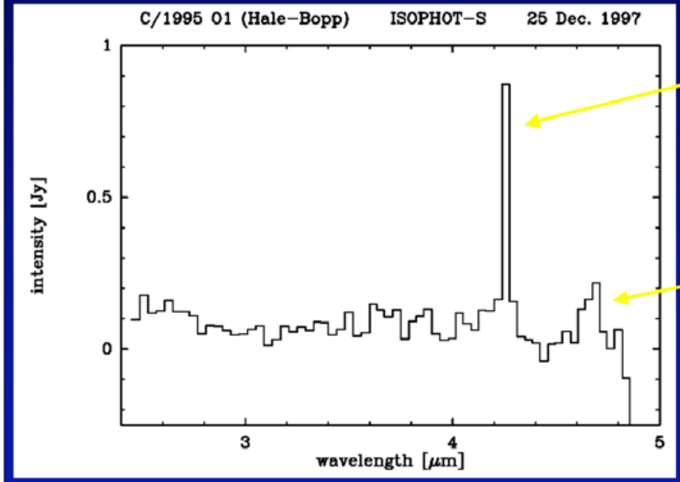
Comet Trails - Where All the Refractory Mass Loss Really Is!
IRAC Ch1/2 allows a continuation of the Dust Trail Survey of Reach,Kelley et al.

Carbon Budget in Comets

- CO_2 and CO are the most abundant volatiles in cometary nuclei aside from H_2O.
- Yet they are generally **only** observable in **bright long-period** comets
  - (e.g. C/Hale-Bopp, C/Hyakutake)
- For a “typical” comet, we are **missing** a huge fraction of the mass in carbon!

A previous example: C/Hale-Bopp

- ISO PHT-S spectrum (Leech 1999):



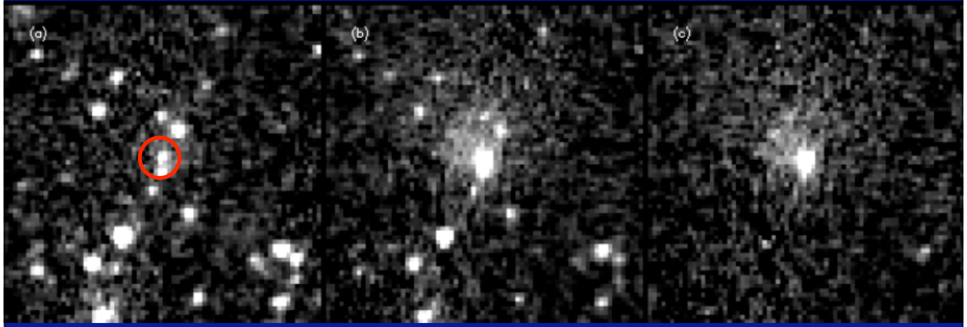
CO_2 ν_3
(4.25µm)

CO v(1-0)
(4.67µm)

But! These emission bands lie within the IRAC Channel 2 bandpass!

Possible Example:

Comet 2P/Encke (via PID 119; SST Archive)



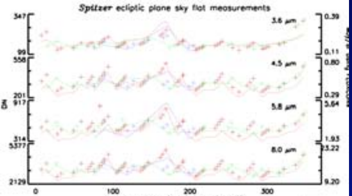
Ch 1 **Ch 2** **Ch 2 - Ch 1**

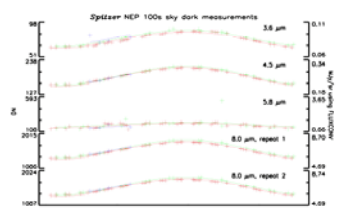
Zodiacal Cloud

(5) Are the structures we see in mature exo-disks explainable by the erosional and collisional processes supporting the Solar System zodiacal cloud? Can the model timescales for these processes (10 - 10^6 yrs for cometary emission processes, 10^6 - 10^7 yrs for asteroid fragmentation events, 10^5 yrs for dust-dust collisions, 10^3 - 10^6 yrs for PR drag, < 10^6 years for radiation pressure blowout) be reconciled with Spitzer zody cloud studies? *[Zodiacal Cloud]*

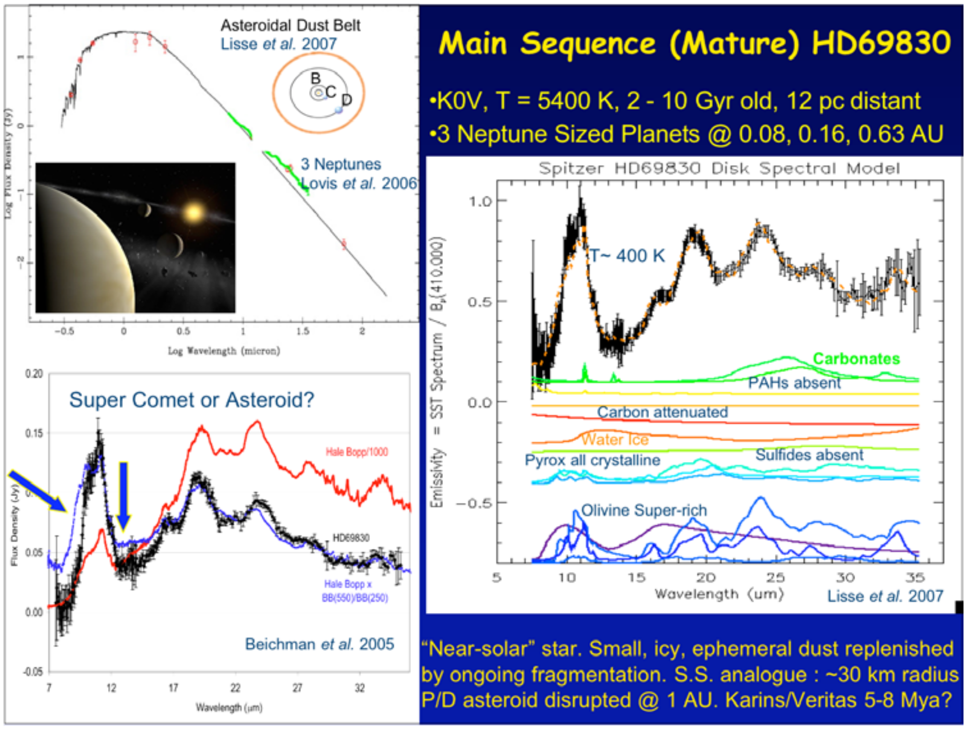
Exo-clouds of > 100 Zodys have been found. But where are the fainter systems?

The Solar System zodiacal dust cloud at 10 μm, as it would appear 1 pc from the Sun with 0.25 AU resolution, 30° above the ecliptic plane. *The stretch is logarithmic, and the density profile used for the image is derived from the IRAS model of Good et al. (1986). Jupiter can be seen at the upper left, and Saturn at the lower right.*





North Ecliptic Pole zodiacal background observed by IRAC. Note the annual variability due to tilt of the circumsolar dust ring relative to Spitzer's orbital plane. (Right) The ecliptic plane zodiacal background observed by IRAC. *Note the biannual variability as Spitzer's line of sight passes through the galactic plane.*



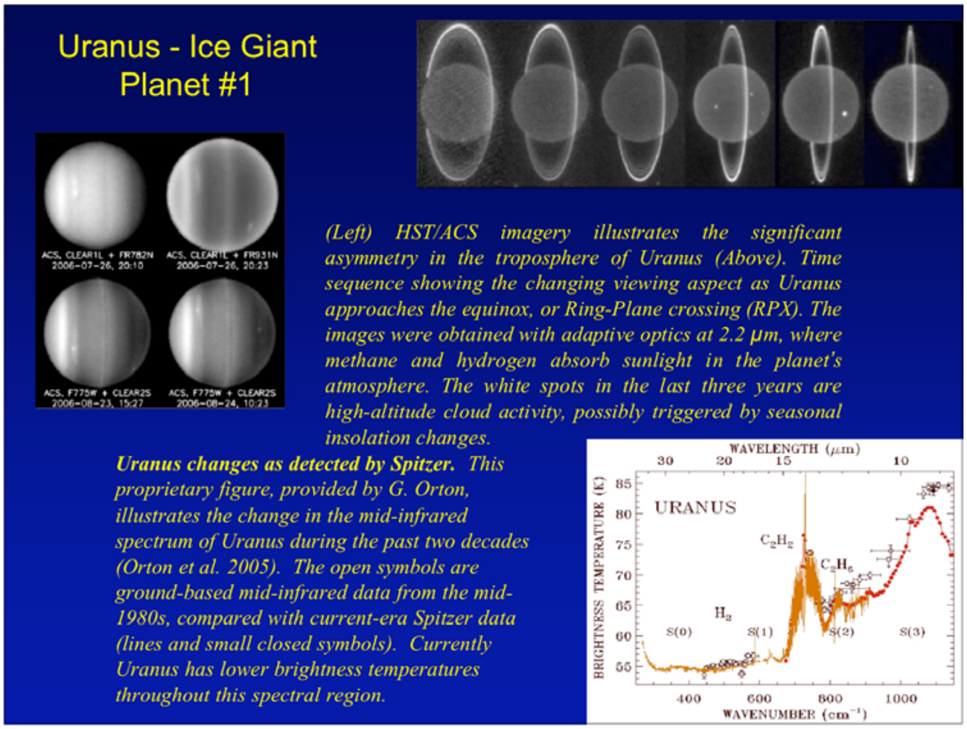
Main Sequence (Mature) HD69830

- •K0V, T = 5400 K, 2 - 10 Gyr old, 12 pc distant
- •3 Neptune Sized Planets @ 0.08, 0.16, 0.63 AU

"Near-solar" star. Small, icy, ephemeral dust replenished by ongoing fragmentation. S.S. analogue : ~30 km radius P/D asteroid disrupted @ 1 AU. Karins/Veritas 5-8 Mya?

Ice Giant Planets

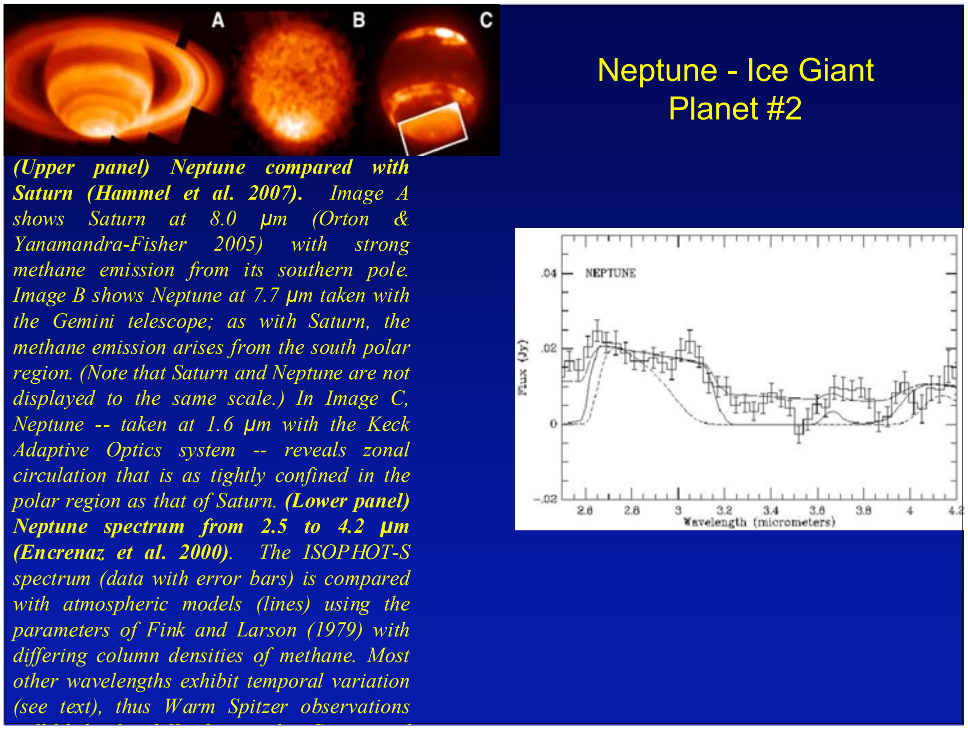
(6) Is the major energy source driving the dynamics of the icy giant planets Uranus and Neptune gravitational contraction, insolation, or dynamical friction? Answering this question is crucial for understanding the energy budgets of exoplanet atmospheres. Current observations of Uranus suggest that seasonal insolation changes are more significant than predicted by models, and that Neptune's atmosphere may be more sensitive to insolation than expected. By extending observations of Uranus and Neptune over the five years of the Warm Era -- through major events in the seasonal cycles of the two planets -- we can determine which effects are paramount. [Ice Giants]



Uranus - Ice Giant Planet #1

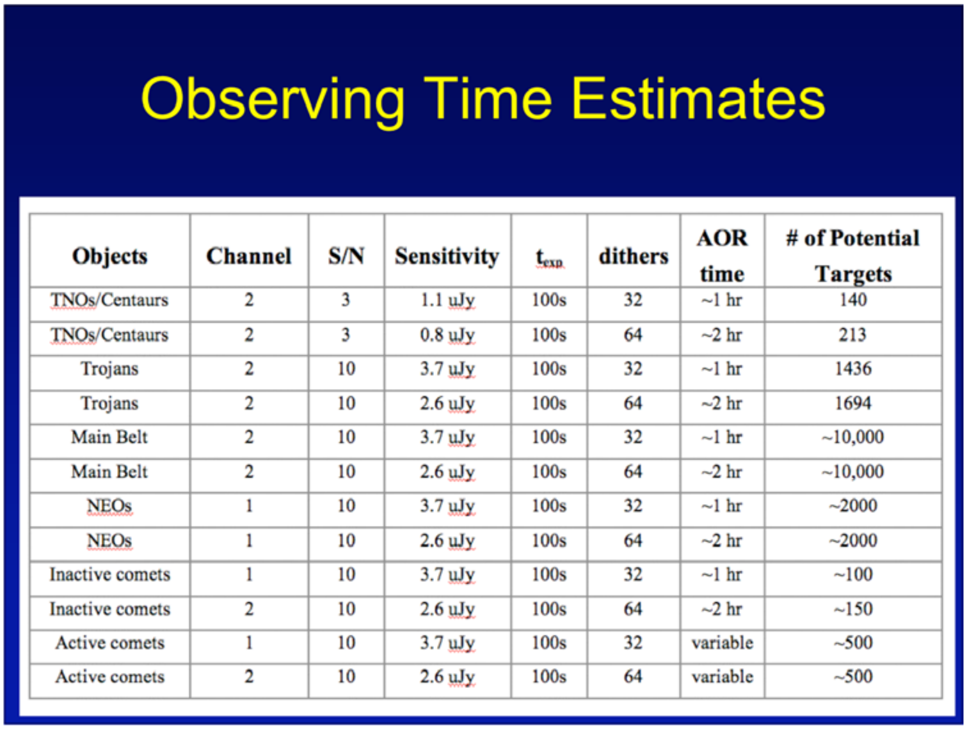
(Left) HST/ACS imagery illustrates the significant asymmetry in the troposphere of Uranus (Above). Time sequence showing the changing viewing aspect as Uranus approaches the equinox, or Ring-Plane crossing (RPX). The images were obtained with adaptive optics at 2.2 µm, where methane and hydrogen absorb sunlight in the planet's atmosphere. The white spots in the last three years are high-altitude cloud activity, possibly triggered by seasonal insolation changes.

Uranus changes as detected by Spitzer. *This proprietary figure, provided by G. Orton, illustrates the change in the mid-infrared spectrum of Uranus during the past two decades (Orton et al. 2005). The open symbols are ground-based mid-infrared data from the mid-1980s, compared with current-era Spitzer data (lines and small closed symbols). Currently Uranus has lower brightness temperatures throughout this spectral region.*



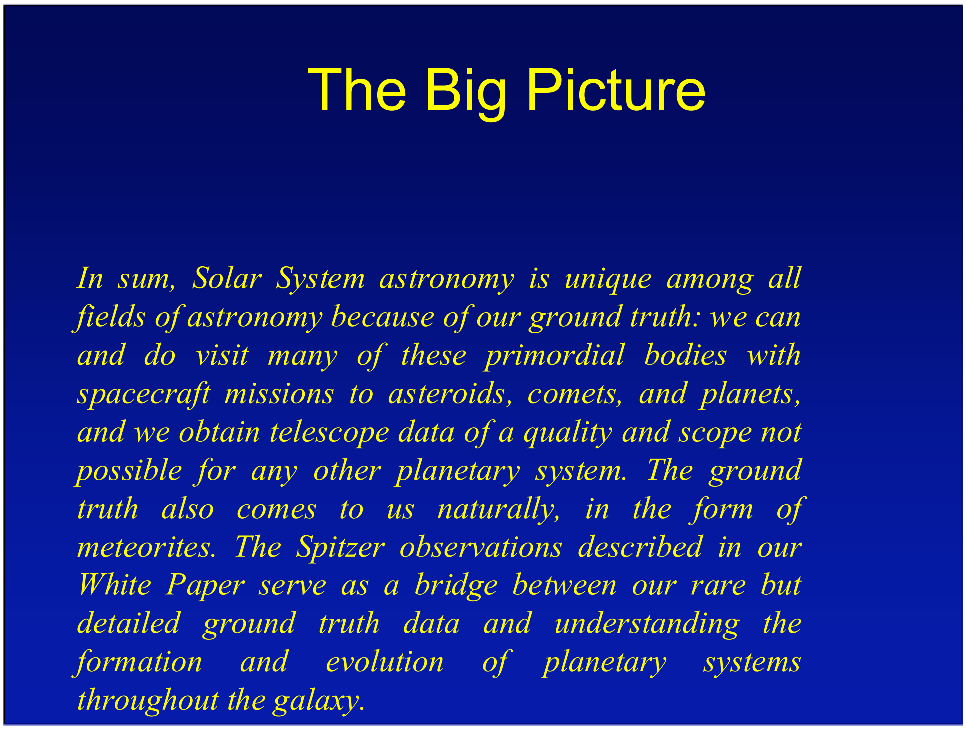
Neptune - Ice Giant Planet #2

(Upper panel) Neptune compared with Saturn (Hammel et al. 2007). *Image A shows Saturn at 8.0 µm (Orton & Yanamandra-Fisher 2005) with strong methane emission from its southern pole. Image B shows Neptune at 7.7 µm taken with the Gemini telescope; as with Saturn, the methane emission arises from the south polar region. (Note that Saturn and Neptune are not displayed to the same scale.) In Image C, Neptune -- taken at 1.6 µm with the Keck Adaptive Optics system -- reveals zonal circulation that is as tightly confined in the polar region as that of Saturn.* ***(Lower panel) Neptune spectrum from 2.5 to 4.2 µm (Encrenaz et al. 2000).*** *The ISOPHOT-S spectrum (data with error bars) is compared with atmospheric models (lines) using the parameters of Fink and Larson (1979) with differing column densities of methane. Most other wavelengths exhibit temporal variation (see text), thus Warm Spitzer observations*



Observing Time Estimates

Objects	Channel	S/N	Sensitivity	t_{exp}	dithers	AOR time	# of Potential Targets
TNOs/Centaurs	2	3	1.1 uJy	100s	32	~1 hr	140
TNOs/Centaurs	2	3	0.8 uJy	100s	64	~2 hr	213
Trojans	2	10	3.7 uJy	100s	32	~1 hr	1436
Trojans	2	10	2.6 uJy	100s	64	~2 hr	1694
Main Belt	2	10	3.7 uJy	100s	32	~1 hr	~10,000
Main Belt	2	10	2.6 uJy	100s	64	~2 hr	~10,000
NEOs	1	10	3.7 uJy	100s	32	~1 hr	~2000
NEOs	1	10	2.6 uJy	100s	64	~2 hr	~2000
Inactive comets	1	10	3.7 uJy	100s	32	~1 hr	~100
Inactive comets	2	10	2.6 uJy	100s	64	~2 hr	~150
Active comets	1	10	3.7 uJy	100s	32	variable	~500
Active comets	2	10	2.6 uJy	100s	64	variable	~500



The Big Picture

In sum, Solar System astronomy is unique among all fields of astronomy because of our ground truth: we can and do visit many of these primordial bodies with spacecraft missions to asteroids, comets, and planets, and we obtain telescope data of a quality and scope not possible for any other planetary system. The ground truth also comes to us naturally, in the form of meteorites. The Spitzer observations described in our White Paper serve as a bridge between our rare but detailed ground truth data and understanding the formation and evolution of planetary systems throughout the galaxy.