Small Body Science Enabled with a 30-m Telescope

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TMT Science Forum – Washington DC

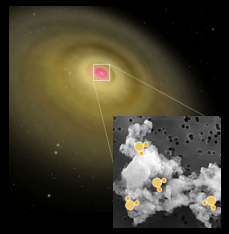
Tues June 23, 2015

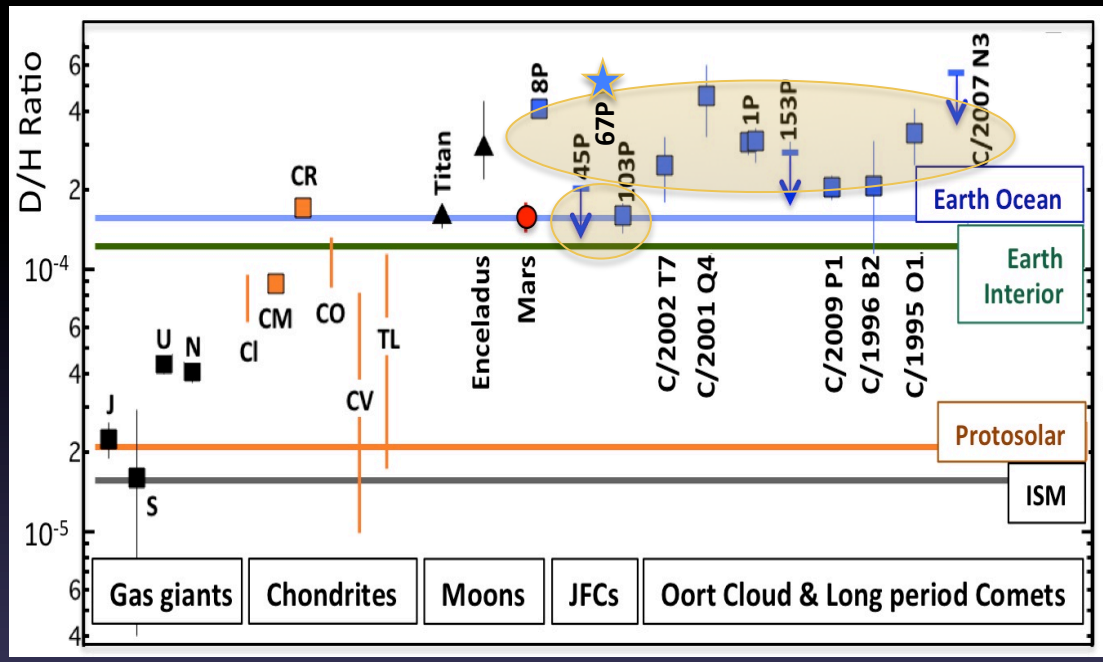
Courtesy: NASA/JPL-Caltech

New Worlds New Horizons: Habitable Worlds

- The inner solar system is dry
- We don't know how Earth got its water
- As of 6/23/15 there are > 5500 extrasolar worlds….

Tracing Origins of H_2O: Habitable Worlds





- Giotto & Halley (1980's)
  - Elevated D/H → source of Earth's water?
  - Low T ion-molecule reactions elevate D/H
  - Comets form in outer disk


- Modern: In-situ, sub-mm, IR
  - Match disk chemistry models for LP comets
  - Herschel: Must revise disk chemistry models
  - Rosetta: Rethink where Earth's water comes from

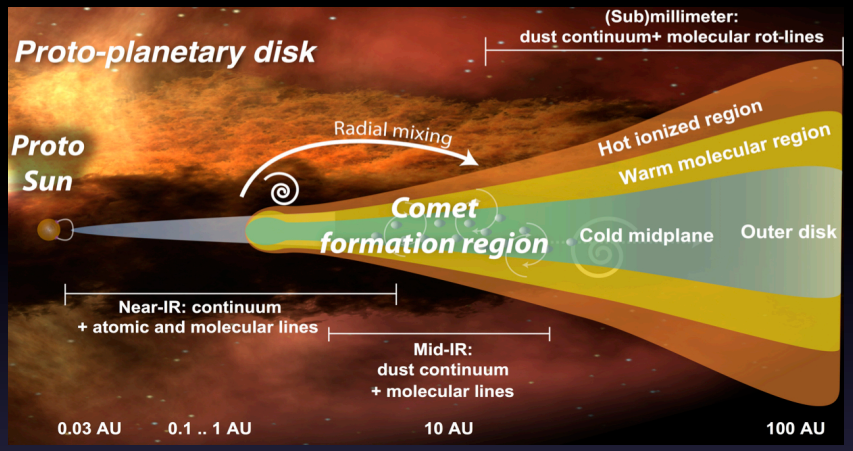
TMT Enables

- D/H for "regular" comets

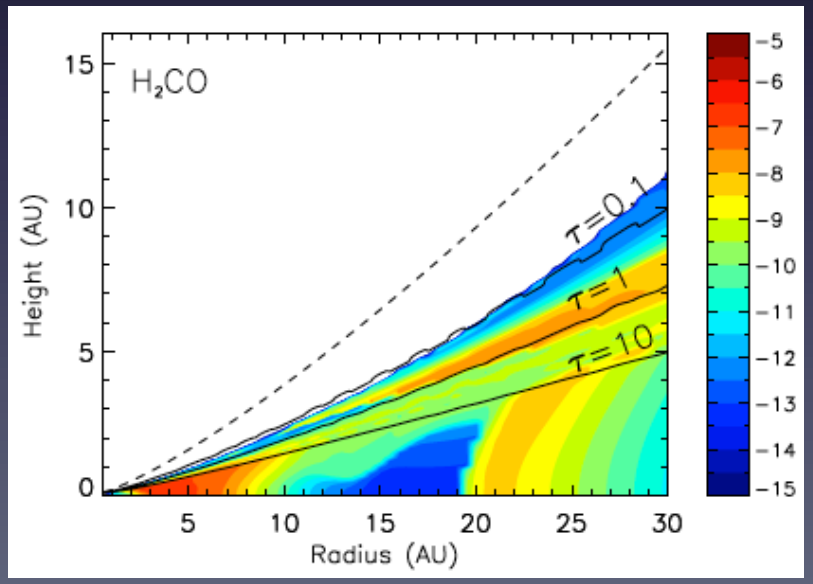
Chemistry in Protoplanetary Disks

- Disk Models
  - Chemical network + hydrodynamic model
  - Heating: H_2 photodissociation, grain formation, C ionization, CR, X-ray, gas-grain collisions
  - Cooling: emission O, C, C^+, CO, CH
- Results
  - Cold midplane: grains, ice condensation
  - Warm molecular layer: gas phase molecules
  - Hot surface: penetrated by UV, X-ray (ions)
- Uncertainties
  - Initial molecular cloud model
  - Angular momentum transport, turbulence, B field
  - Complex model – needs observation constraints…

Synergy TMT & ALMA
- Resolved disk chemical obs: ALMA
- Comet volatile chemistry: TMT

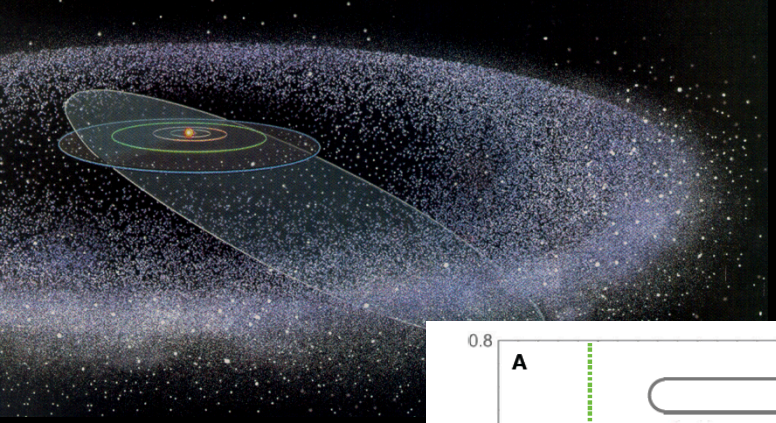


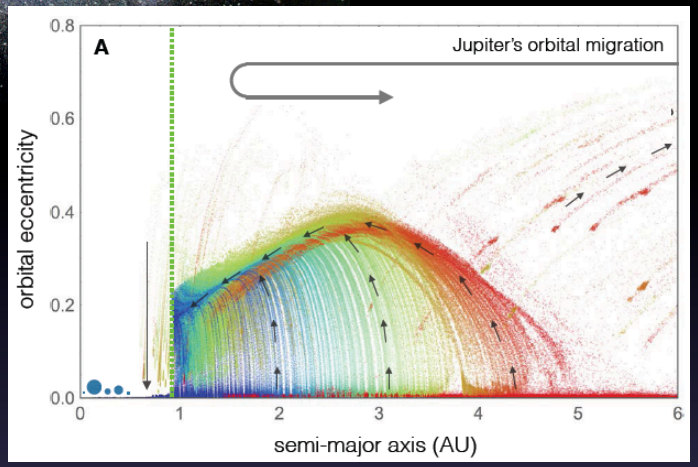
A. Mandell, G. Villanueva, GSFC



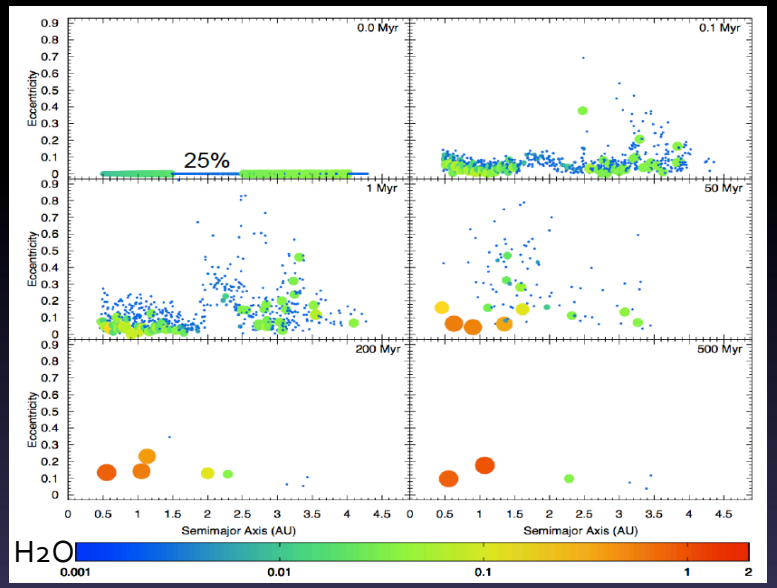
Willacy & Woods 2009, *ApJ* 703, 479

Evolving Solar System Dynamics

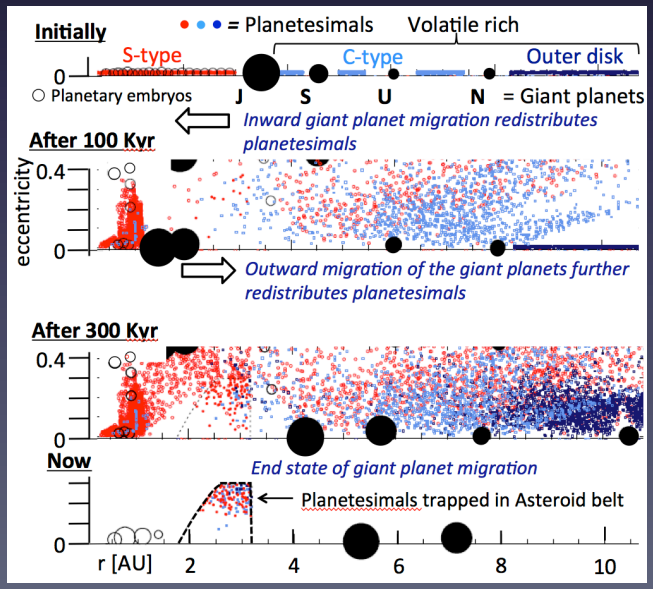




Batygin & Laughlin (2015)



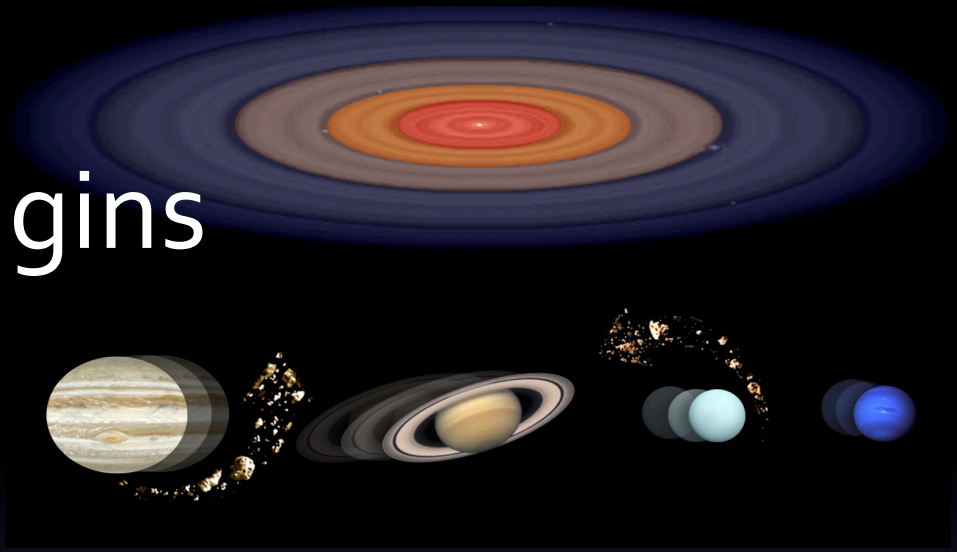
Izidoro & Haghighipour (2014)



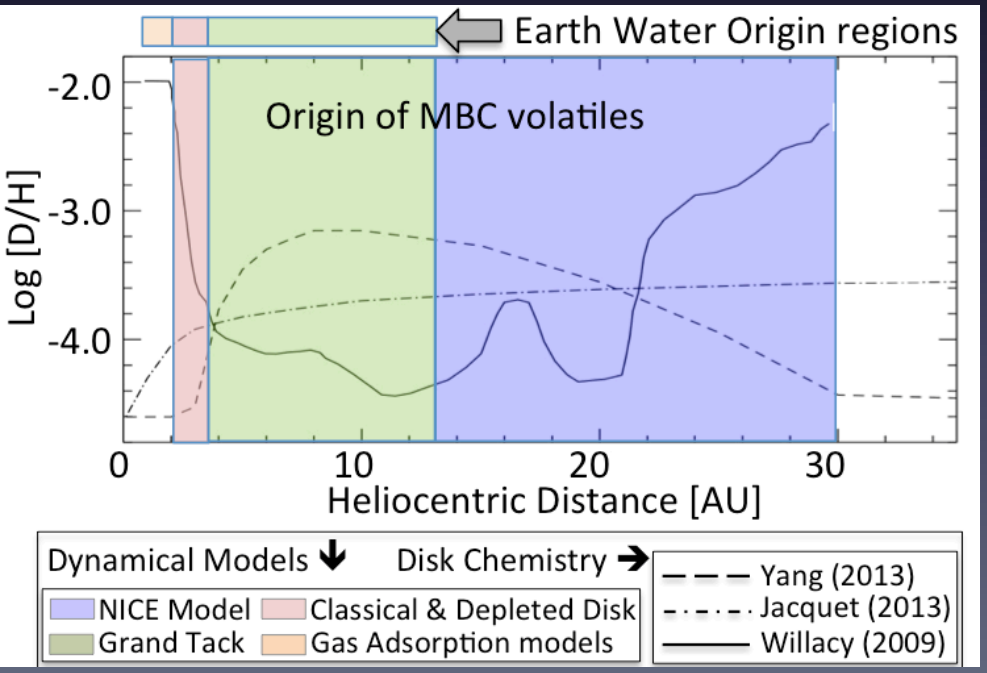
After Walsh *et al.* (2011)

- Many models – planetesimal migration
  - *Planet migration* – formation of giant planets migrating in a gas disks (Grand Tack, Nice)
  - *Depleted mass distribution Disk* – using mostly local materials

Understanding Origins

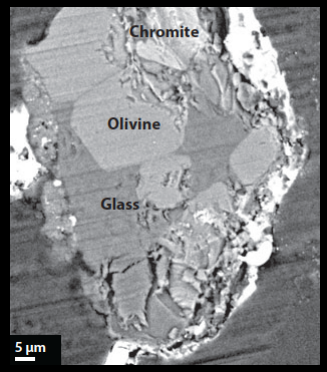


- Disk chemistry
  - Imprints signature on Grains
  - Grains collide and become planetesimals

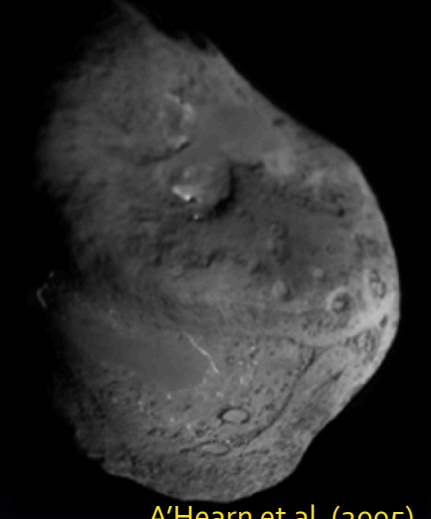


- Dynamics of building planets
  - Planet migration – scatters planetesimals
  - Depleted disk – local materials
  - Scattered planetesimals rearranged

Mission Insights: Unique Obs….

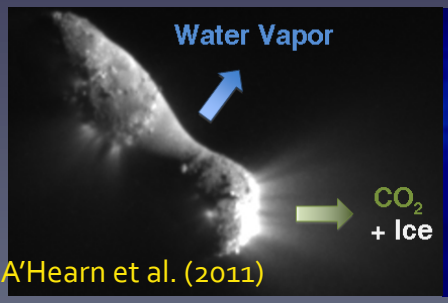


Ogliore (2012)

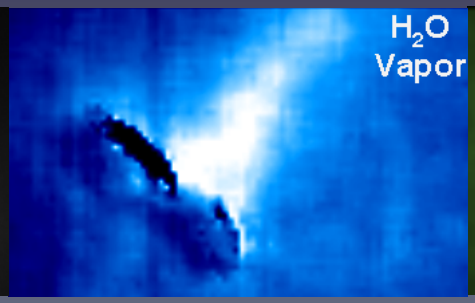

A'Hearn et al. (2005)

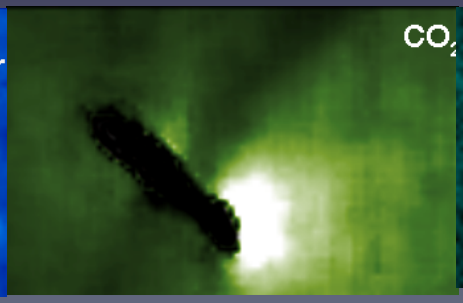
- Stardust (Brownlee 2014, *AREPS* 42)
  - Cold regions in solar system were not isolated
- EPOXI / Akari / WISE (A'Hearn *et al*, 2011 & 2012)
  - Outgassing heterogeneity – distinct nuclei?
  - CO/CO2/H2O ratios – formation location in disk?
- Rosetta (Sierks *et al*. 2015)
  - Can the 3-4m scale "goose bumps" tell us something about the formation location/process?

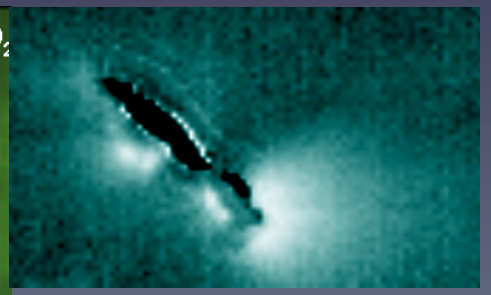
ESA/Rosetta/MPS



A'Hearn et al. (2011)







Tracing Solar System Volatiles

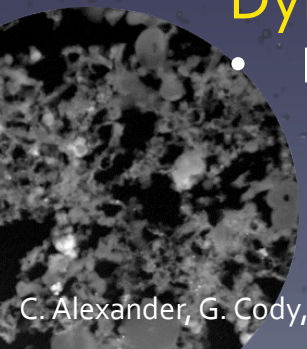
Credit: ESA/Rosetta/MPS

- Meteorites
  - Aqueous alteration
    - Seen everywhere
  - Insoluble Organic Matter, IOM
    - Partly preserved from ISM
    - Some parent body processing

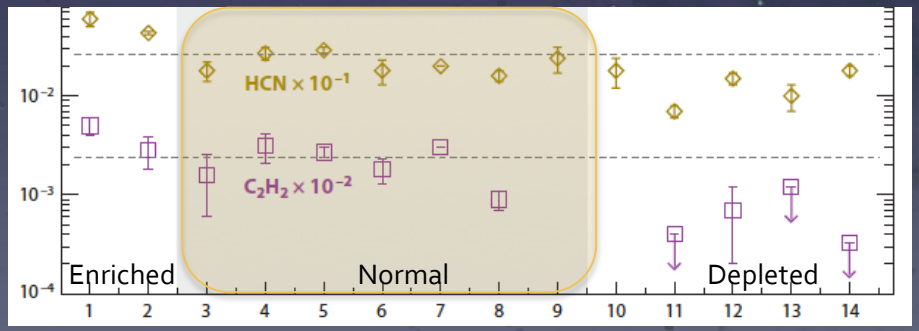
- Comets
  - Ground based – Taxonomies
    - Daughter species (85 comets)
    - Isotopes $^{15}N/^{14}N$, $^{13}C/^{12}C$ (~20)
    - Parent organics (~15 comets)
  - Organic volatiles
    - Depleted, normal, enriched
    - Not correlated with comet type

Dynamical origin: Comets

- Difficult to trace source . . .

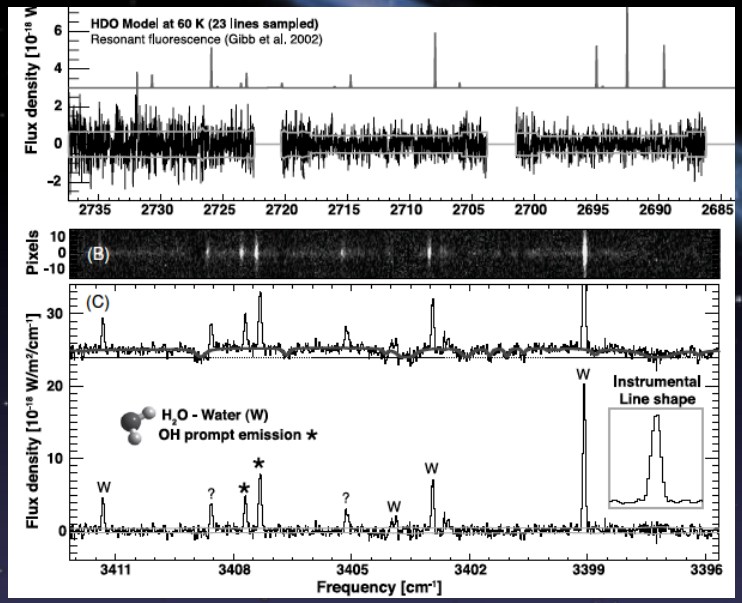


C. Alexander, G. Cody, CIW

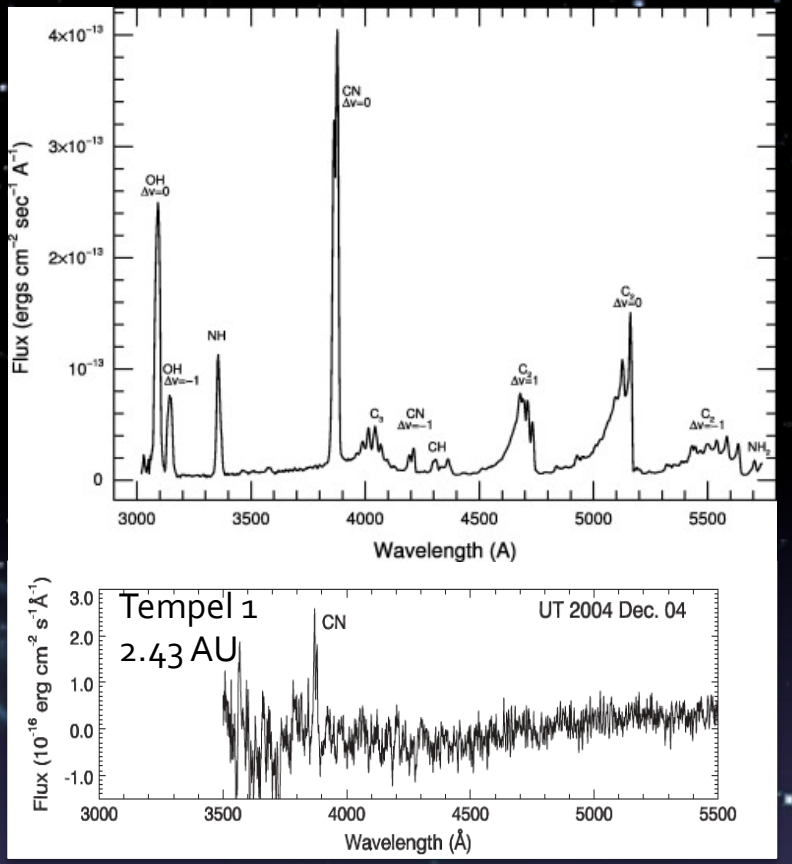


Mumma & Charnley, 2011

Limitations



Villanueva et al 2009



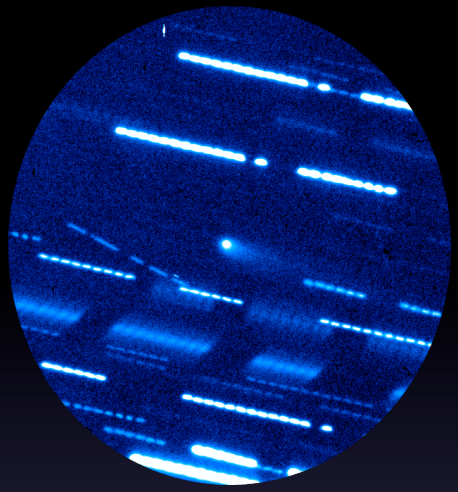
Meech et al 2011

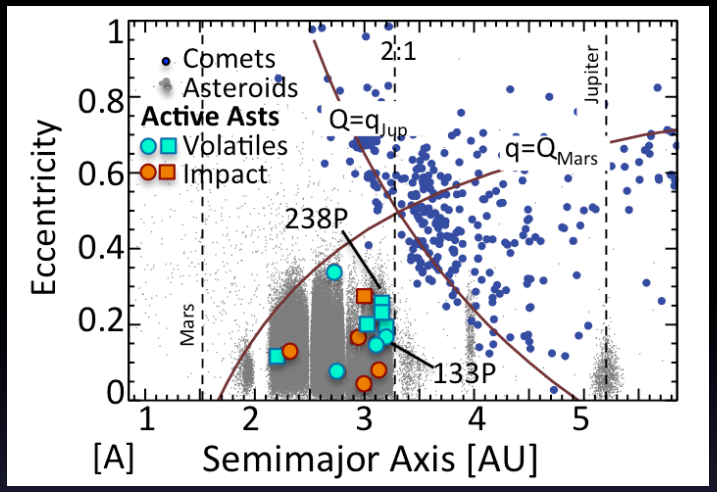
- Key Tracers of volatile history
  - Can't get H2O measurements much into the asteroid belt
  - Can only get isotopes & organic volatiles in "extraordinary" comets

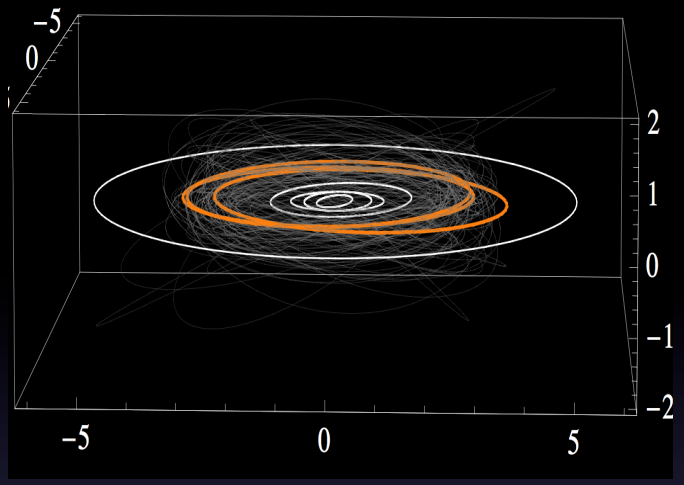
TMT Enables

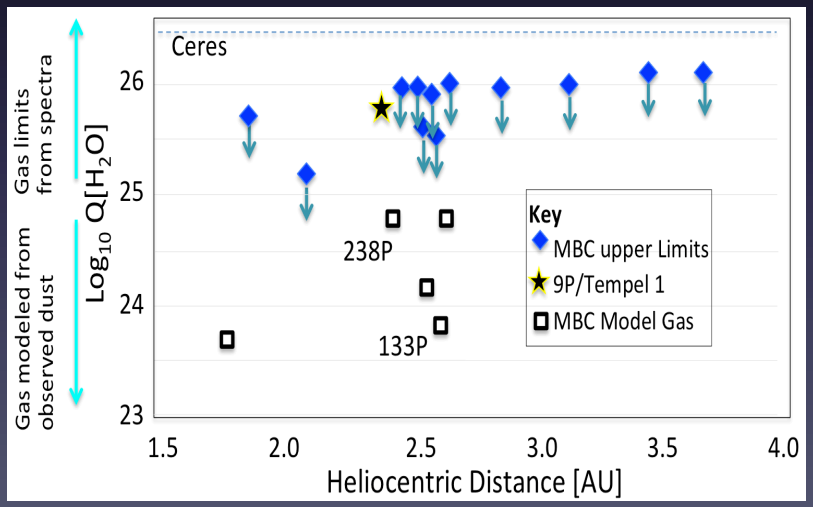
- Isotopes and organic volatiles in typical comets from the ground
- Robust context for in-situ investigations

Origin of Water – Another Place to Look?









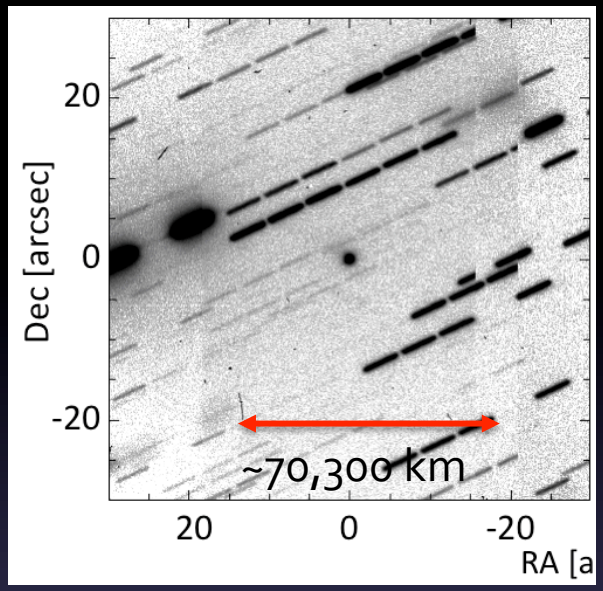
- Objects we have "sampled"
  - Oort Cloud & Kuiper Belt Comets (gnd/space)
  - Small Icy Moons (Cassini)
  - Asteroids (meteorites)
- Main Belt Comets – a New Reservoir
  - Look like comets
  - Orbit in the asteroid belt
  - Well defined origin location constraints

TMT Enables

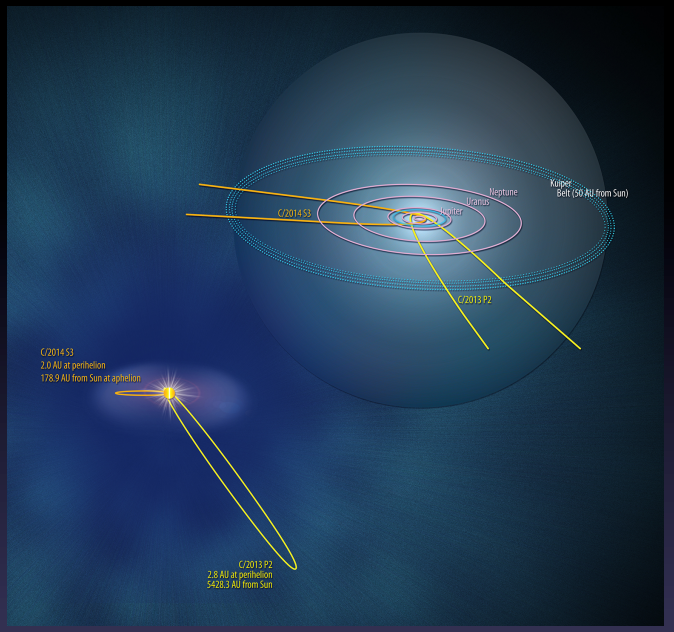
- Direct detection of volatiles in asteroid belt

Synergies: New Constraints . . .

Pan STARRS1, Maui



Data from Gemini N 8m

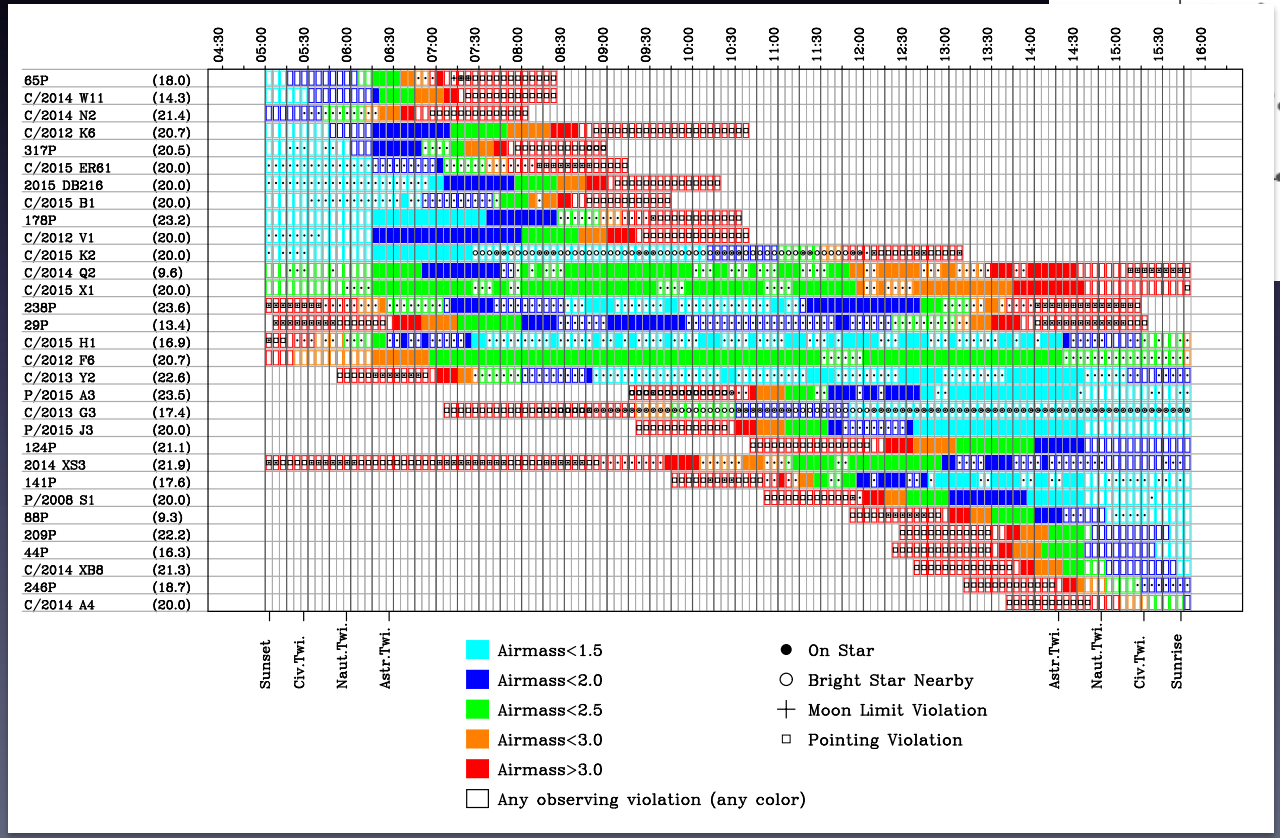


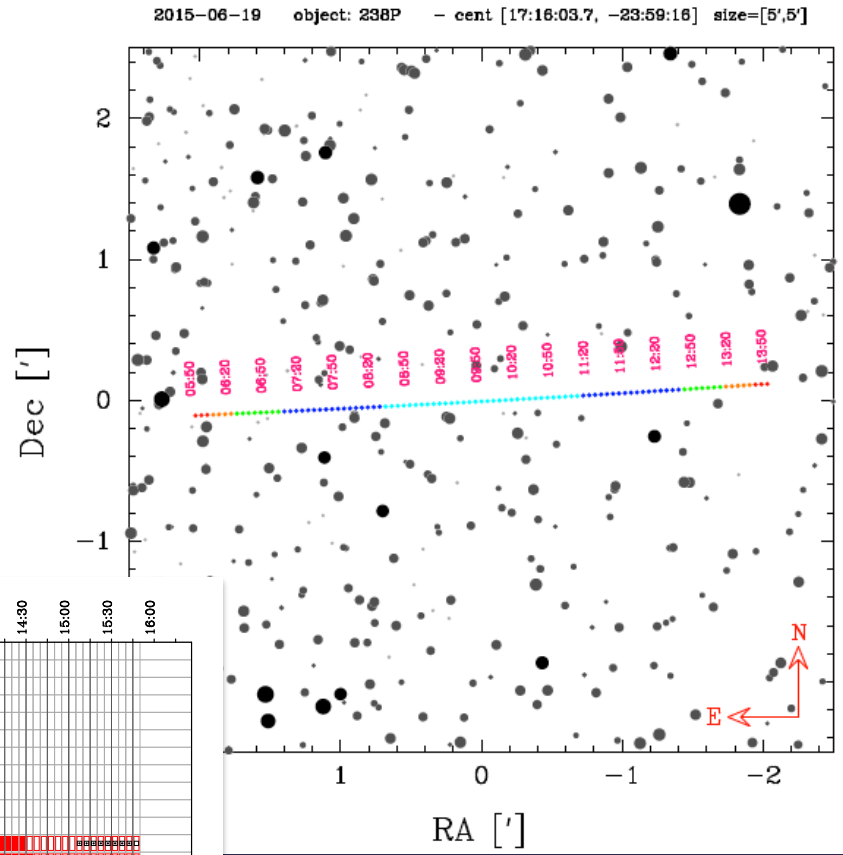
- Discovery
  - Aug 4 Asteroidal object discovered by PS1 on long-period comet orbit
  - Aug 6-8 Deeper images (Faulkes, CFHT 3.6m) no obvious activity
  - Sep 4 Gemini North 8 m telescope
- Characterization
  - Optical + Near IR spectrum – Gemini 8m
  - Faint ~ mag 21

Observing Challenges

Observing planning Tool

- Passing over faint stars / near bright stars
- Airmass, moon & pointing limits

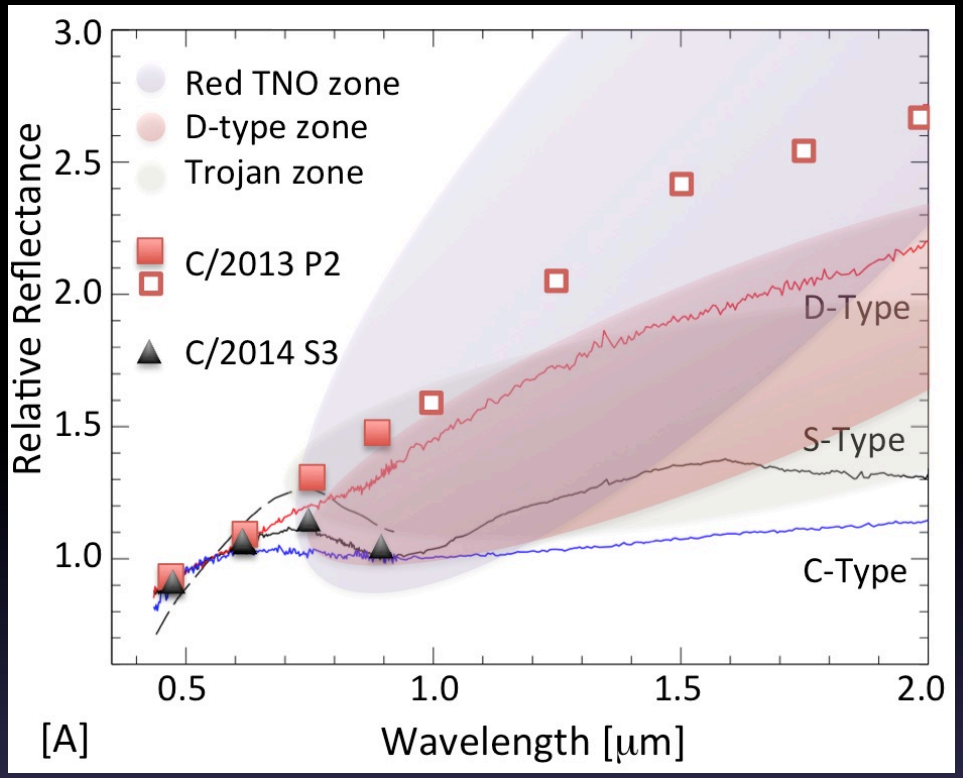


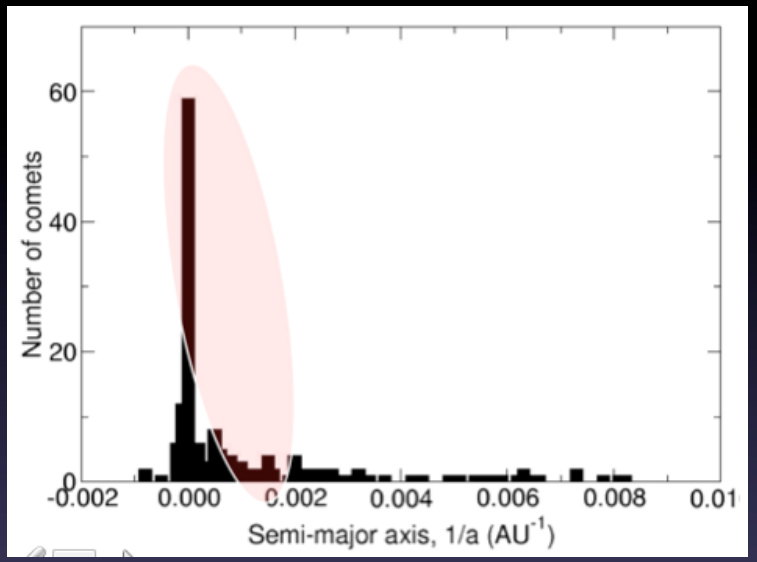


Requirements

- Non-sidereal guiding
- Queue is essential for some cases
- Partial nights

Origins? Composition…





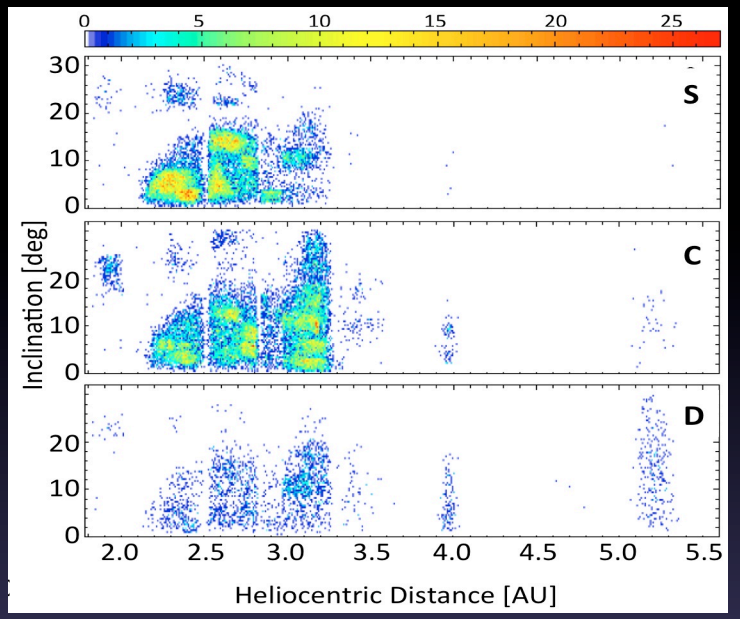
- Extinct Oort comet? Asteroid?
  - Loss of "volatile frosting" (Oort 1950, Jewitt '05)
  - "Dead" comets unlikely (Levison *et al.* '02)
  - 1% of Oort cloud populated with asteroids (Weissman & Levison '97).
- Implications of Oort Asteroids
  - Observational evidence of dynamical models
- Newly Recognized
  - We may now have dozens of these; only a few bright enough to observe

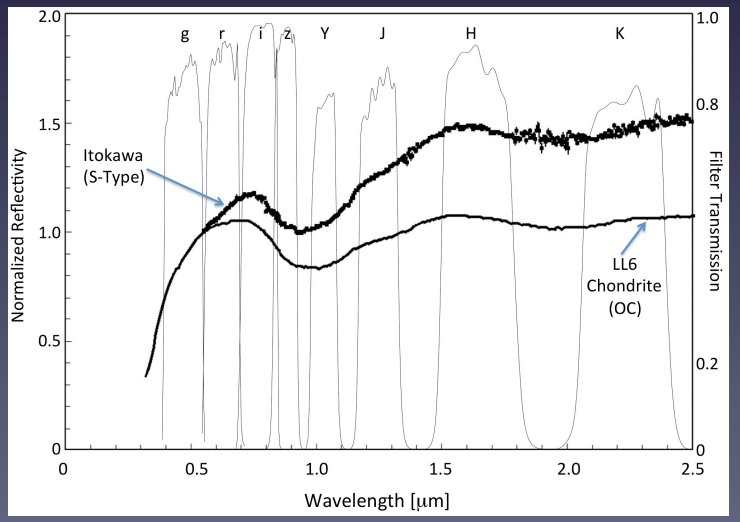
Implications of S-Type Spectrum

- "Fresh" inner solar system material?
  - Ejected into the Oort cloud from inner solar system
  - Evolve in as Oort cloud "asteroids"
- Volatiles on S-types?
  - Linked to ordinary chondrites (OCs) with evidence of aqueous alteration (Doyle, 2015)
  - Consistent with low water-rock ratio
  - Early in solar system history
- Implications
  - Our solar system "snowline"
  - Sample of material that builds habitable world?
- Challenges
  - Faint, barely active
  - z, Y, H band – hard to get for most

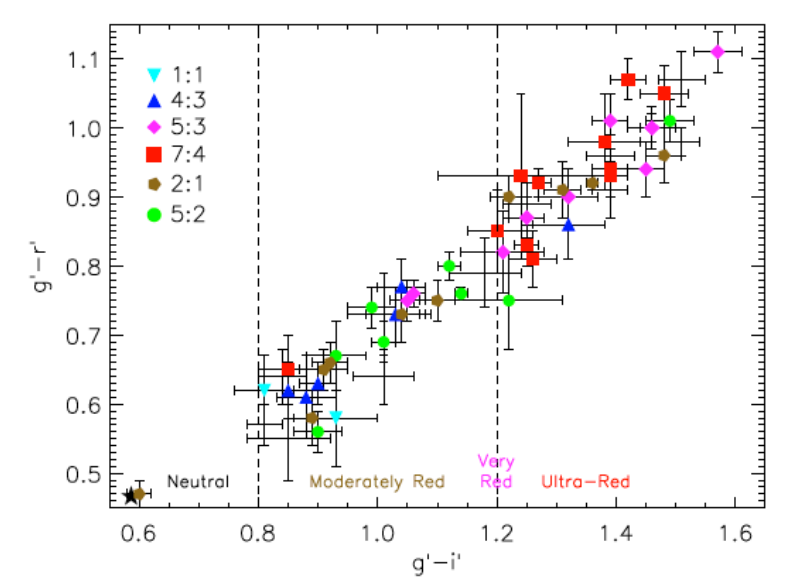
TMT Enables

- Composition class for all new discoveries
- Detection of water

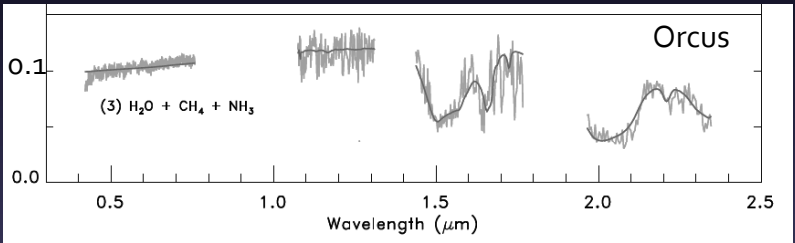




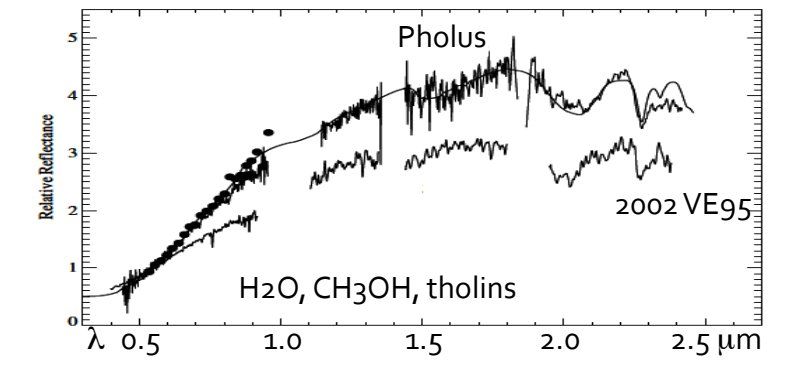
Outer Solar System Colors



Sheppard (2012)



Delsanti et al. (2010)

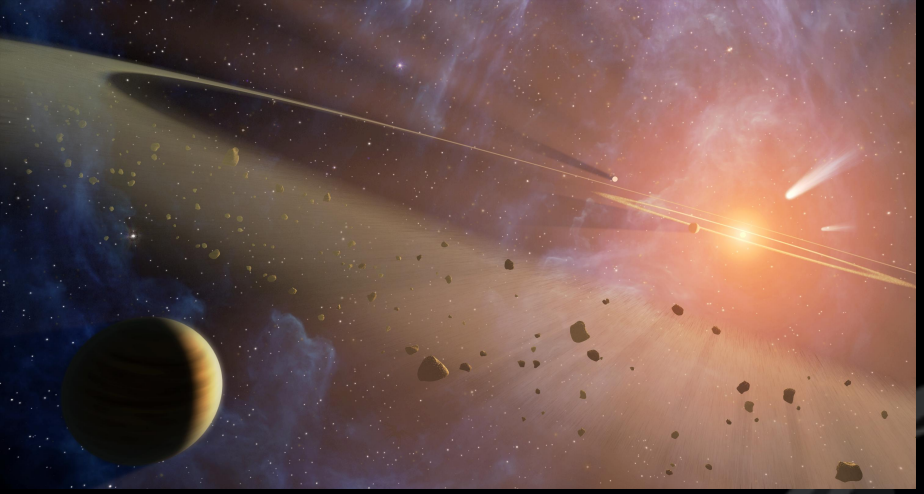


Cruikshank et al (1998); Barucci et al (2006)

- KBOs exhibit a range of colors
  - Differences between resonant groups
  - Relates to origins, evolution?
- Spectroscopy only on a few
  - Some featureless, red
  - Some with deep water ice bands
  - Some have CH_3OH, CH_4, NH_3, tholins …

TMT Enables

- Spectra for a large number of KBOs
- Understanding of chemistry

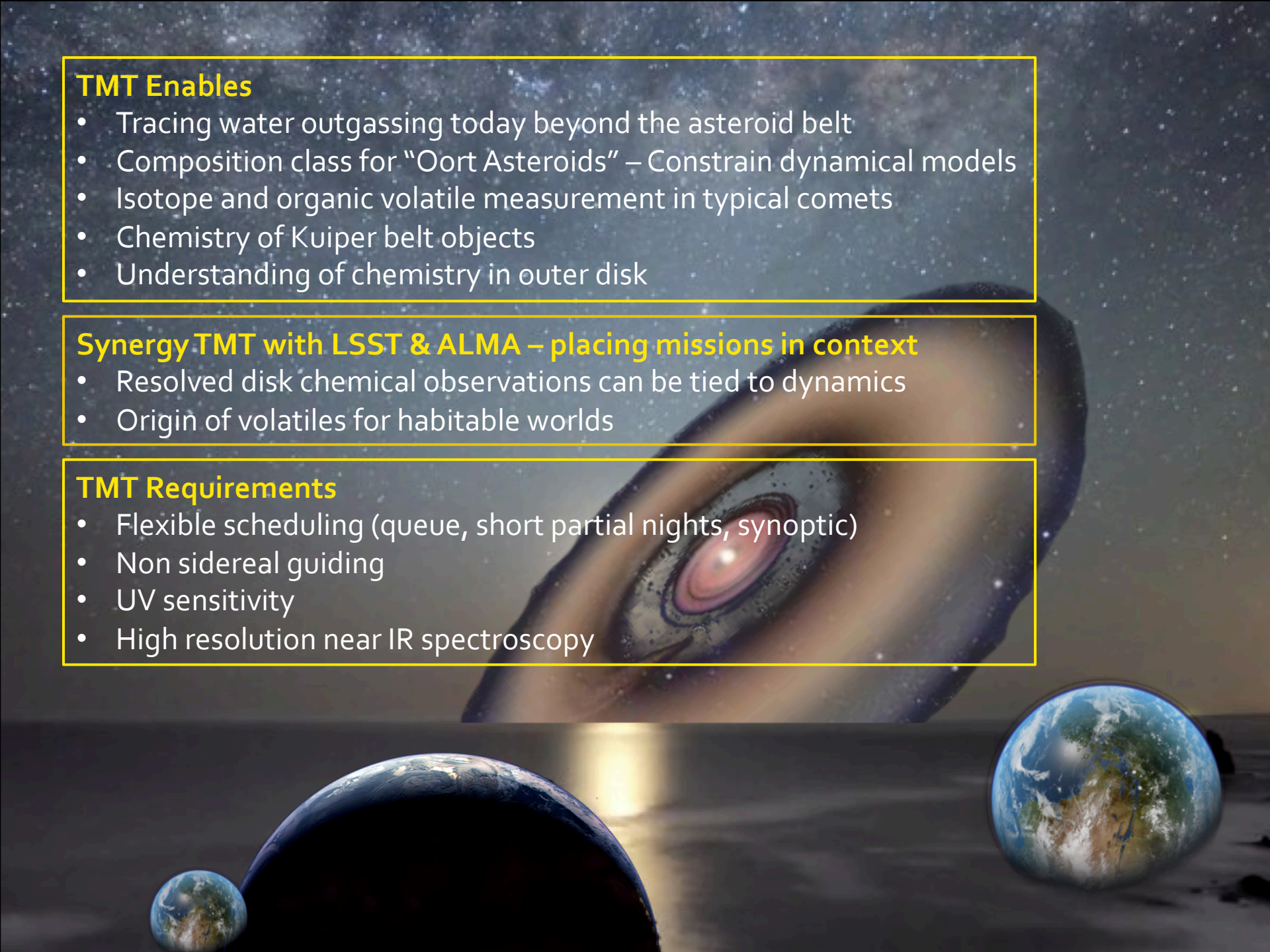


Conclusions

"I used to think the dynamicists had solved the solar system formation, but well, now . . ."

ALMA, C. Brogan (NRAO/ESO/NAOJ)

- Many Dynamical models
  - Most all require migration of planetesimals – constraints Oort asts?
- Many disk chemical models
  - Complex chemistry, needs to couple with transport in disk
  - Comets have ice – so need to form outside of or near "snow line"
  - Where the snow line was changed with time, and position is debated
  - Oort asteroids may help constrain location (LSST)
- Origins of volatiles for habitable Worlds: couple Dynamics & chemistry
  - Volatiles are key ingredients for life



TMT Enables

- Tracing water outgassing today beyond the asteroid belt
- Composition class for "Oort Asteroids" – Constrain dynamical models
- Isotope and organic volatile measurement in typical comets
- Chemistry of Kuiper belt objects
- Understanding of chemistry in outer disk

Synergy TMT with LSST & ALMA – placing missions in context

- Resolved disk chemical observations can be tied to dynamics
- Origin of volatiles for habitable worlds

TMT Requirements

- Flexible scheduling (queue, short partial nights, synoptic)
- Non sidereal guiding
- UV sensitivity
- High resolution near IR spectroscopy