Solar System Small Body Science with the TMT

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TMT Science Forum, Mysore India

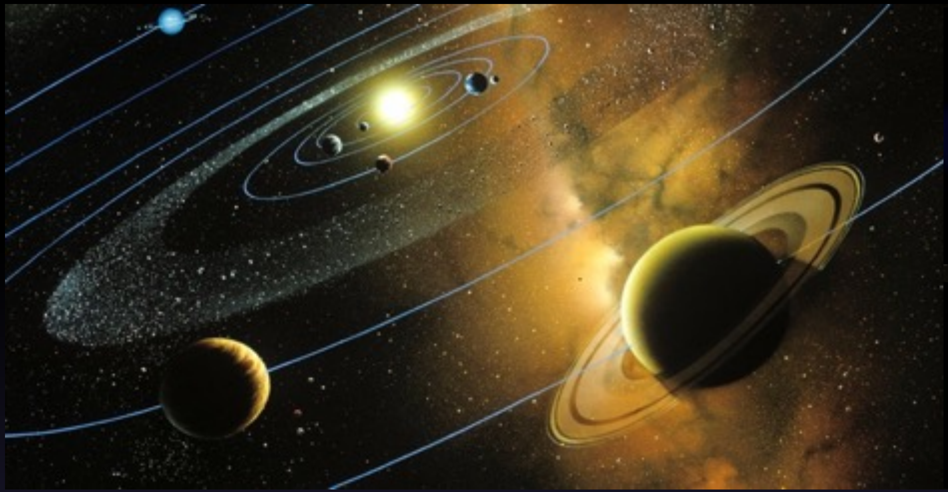
November 7, 2017

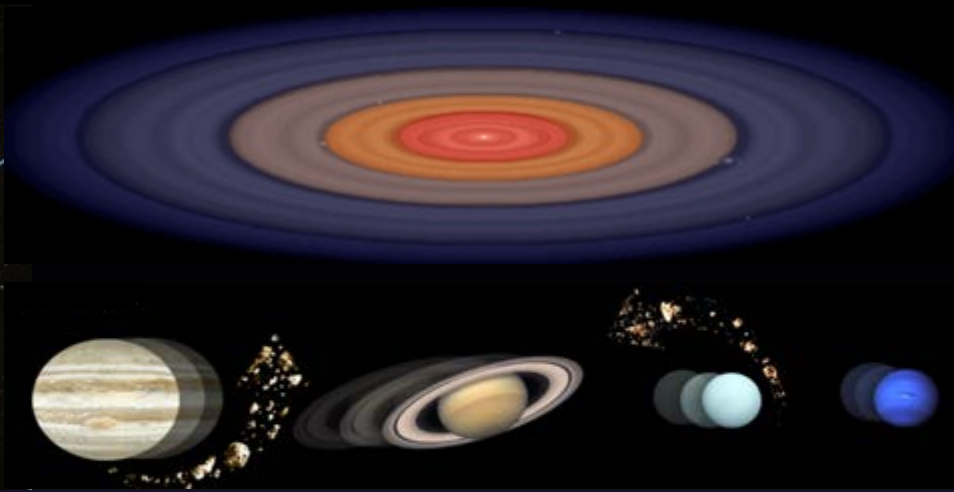
Courtesy: NASA/JPL-Caltech

New Worlds New Horizons: Habitable Worlds

- Decadal goal: understand chemical/physical processes of building habitable worlds
  - Small bodies will provide key constraints – understanding the process in our solar system

Dynamics & Chemistry



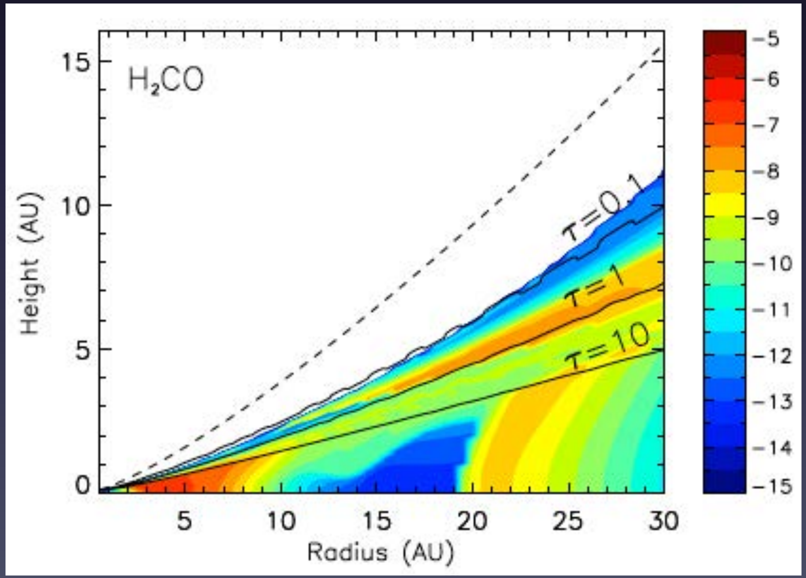


- Disk Chemical Models
  - Chemical network + hydrodynamic model
  - Results in a layered structure
- New Dynamical Models

Key observational constraints

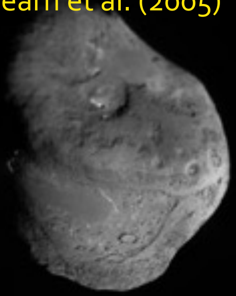
- Resolved disk chemical observations: ALMA
- Comet volatile chemistry: JWST, EELTs, missions
- Characterizing new classes of small bodies→dynamics

Fractional abundances



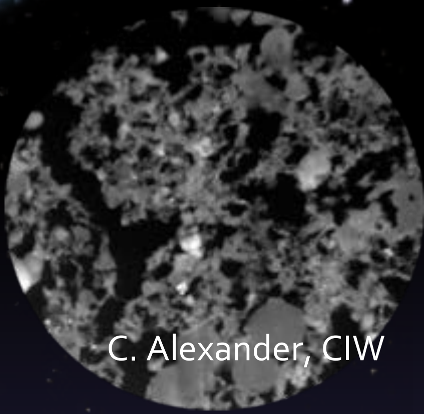
Willacy & Woods 2009, *ApJ* 703, 479

A'Hearn et al. (2005)



Small Body Tracers

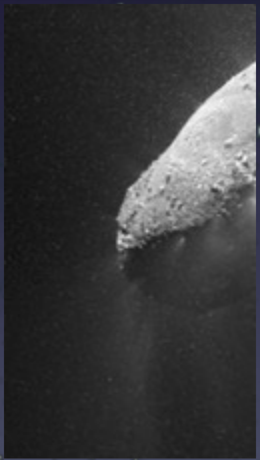
- Comets – Ground Based – 30 years of effort
  - Parent organics & daughter fragments – chemistry uncorrelated with dynamical type
  - Isotopes D/H, $^{15}N/^{14}N$, $^{13}C/^{12}C$ (~20)



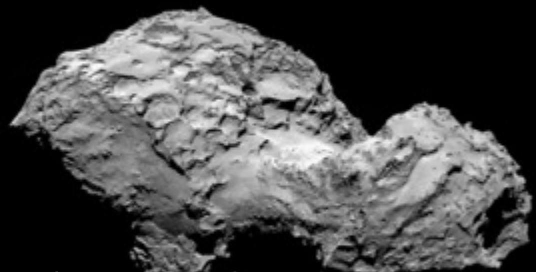
C. Alexander, CIW

- Space Missions (Pre-Rosetta)
  - CO_2 a major driver of activity (uncorrelated with dynamics)
  - Comets are very low density, very low thermal inertia
  - Very dark organic rich surfaces
  - Silicates – nebular processing
  - Stardust – significant nebular mixing

- Meteorites
  - Aqueous alteration (everywhere)
  - Chondrite classes – different zones
  - No Earth feeding zone material



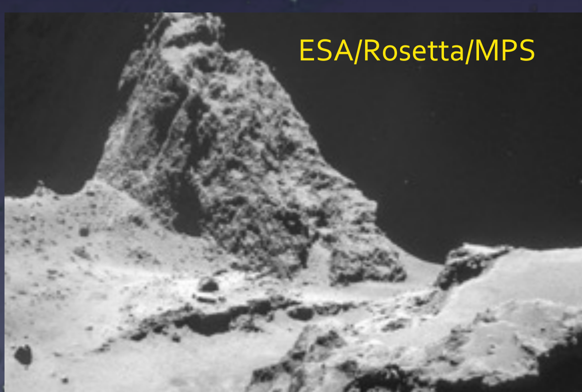
EPOXI: 103P/Hartley 2

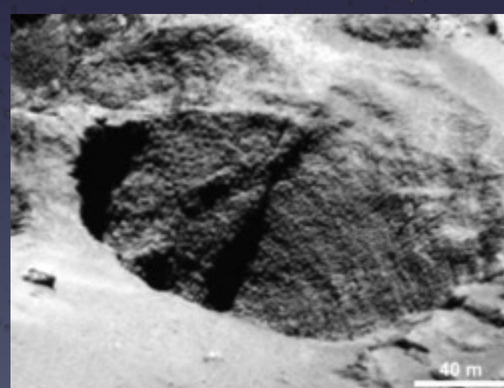


Credit: ESA/Rosetta/MPS

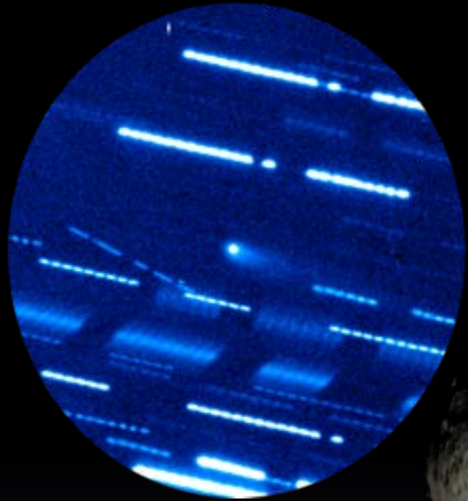
Small Body Volatile Tracers: Comets (Rosetta)

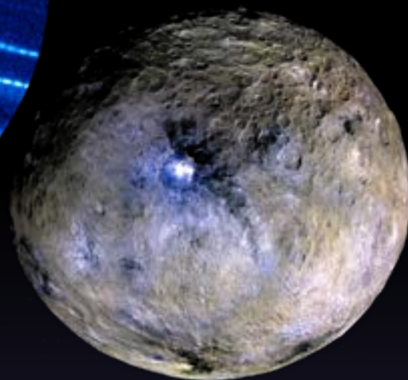
- Formed very cold
  - Abundant supervolatiles: CO (13%), CO_2(8%), O_2 (4%), N_2 (0.07%), noble gases
  - Inheritance from pre-solar cloud . . .
- Little processing since formation
  - Uniform interior
- Structural clues to formation processes
  - "goosebumps" – signature of accretion?
  - Tensile strength very low (3-30 Pa), with harder substrate (kPa-Mpa; snow ~100 Pa)
  - Layering & bilobate structure – gentle collisional growth?

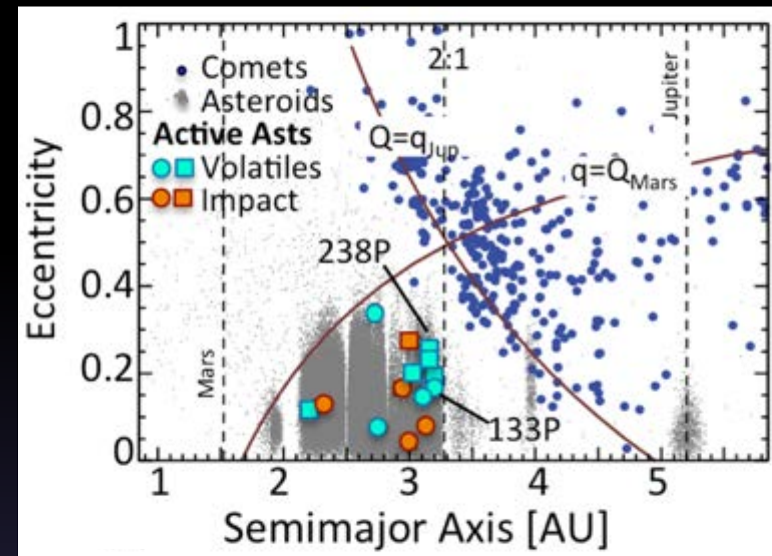


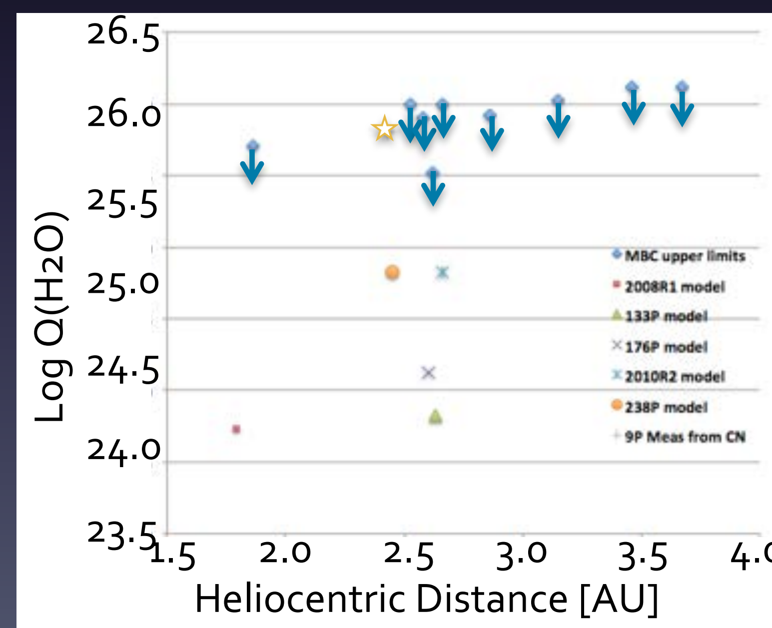


Seeking Water . . . .

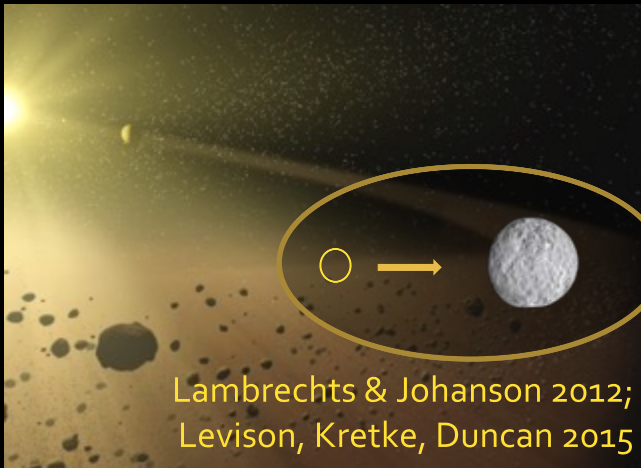


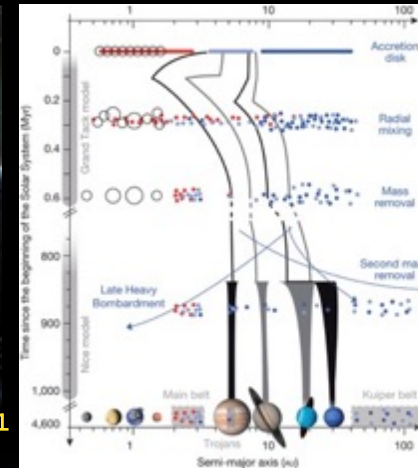






- Relevant Objects
  - Main Belt Comets
  - Ceres
  - NEO as a resource
- Direct Detection not possible yet
  - Sensitivity with Keck / Herschel 1-2 orders of mag too low

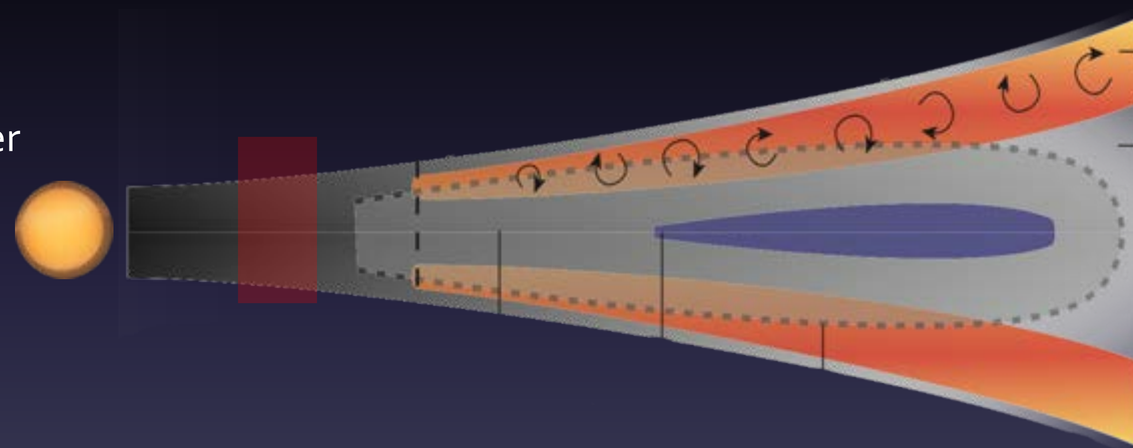




DeMeo & Carry (2014)

- Solar System formation modeling challenges
  - Exo solar system architecture
  - Small size of Mars
  - Overcoming the m-scale barrier

- A Suite of Models
  - Pebble Accretion
  - Grand Tack / Nice Model
  - Depleted disk

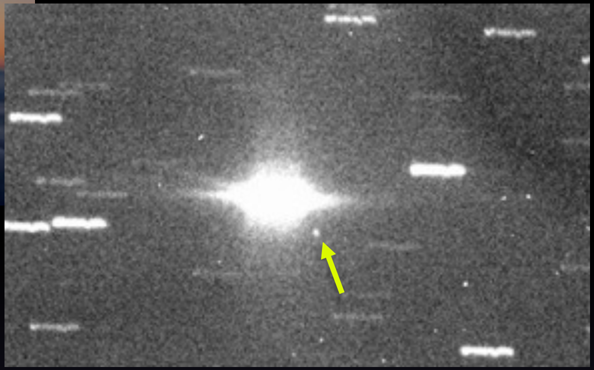


Izidoro, 2013

- New classes of small bodies provide constraints / tests of models
  - Manx comets, Interstellar objects
  - Challenging to observe

An Unusual Discovery – 2013

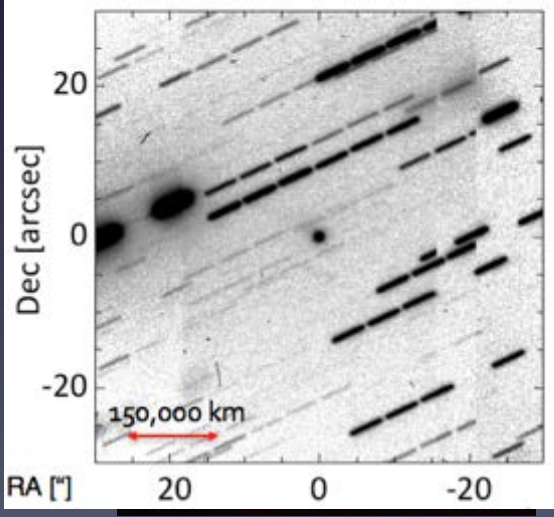
Pan STARRS1, Maui



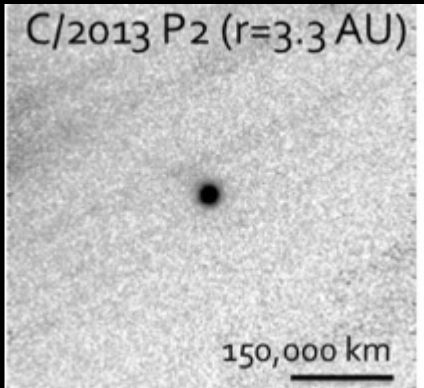
Data from Faulkes 2m

Data from CFHT 3.6m (MKO)

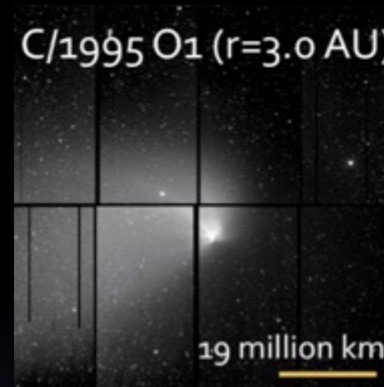
- Aug 4 Asteroidal object discovered by Pan-STARRS1 (2m)
- July-Aug Pre-discovery images gave it a long period (LP) comet orbit
- Aug 6 Amateurs report activity using a 0.4m telescope
- Aug 6 Faulkes telescope (Maui) no comet activity
- Aug 7 CFHT image no obvious activity, but nebulosity
- Aug 8 Deeper image from CFHT (1560 sec) → activity?
- Sep 4 Gemini 8m 26 min → faint coma



Why is this so unusual?



r=3.3 AU, Tail < 1 x 10^4 km
26 min, 8 m telescope



r=3.6 AU, Tail > 3.6 x 10^5 km
4″ telescope, 8 min,

Comet	AU	TA
C/1995 O1	> 13	210
C/2009 P1	>10.7	224
ISON	>9.3	185
C/2012 K1	>8.8	220
C/2011 L4	>7.9	202
C/2013 A1	>7.2	232
C/2012 F6	>6.9	217

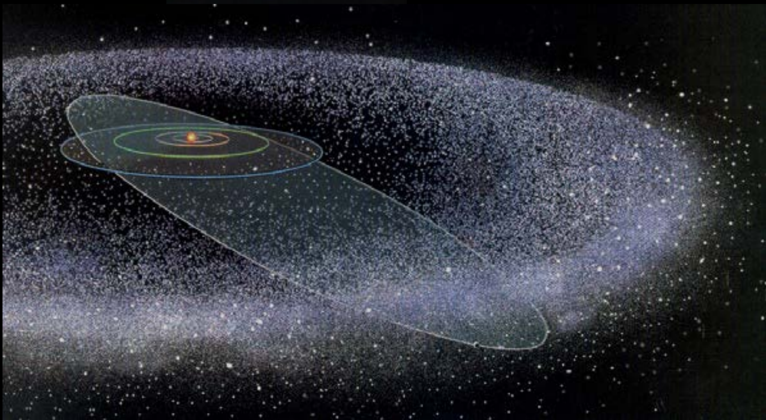
"Manx"

r=3.2 AU, Tail > 1 x 10^6 km
16″ telescope, 8 min

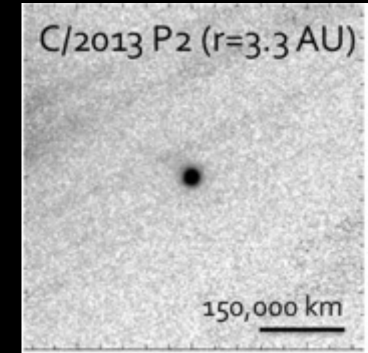
r=3.4 AU,
20″ telescope, 5 min

r=5.3 AU,
20″ telescope, 10 min

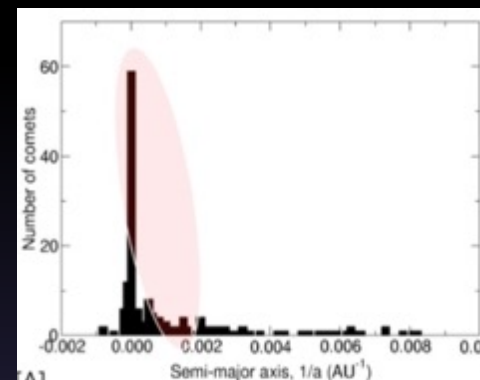
r=2.8 AU,
20″ telescope

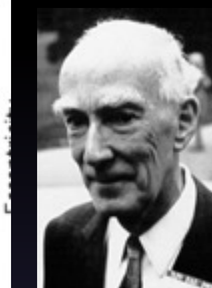


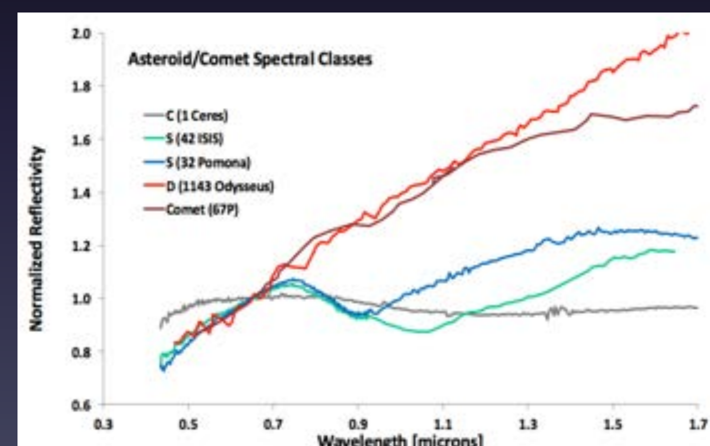
So What is a Manx?

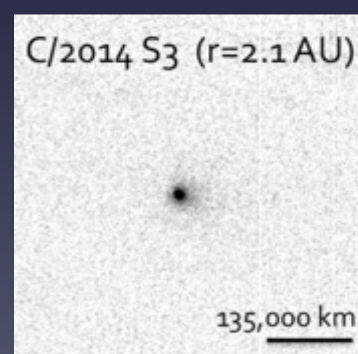


- Possibilities
  - – Nearly dead comet? (Oort's Frosting)
  - – A modern asteroid ejected outward?
    - Predict < 1 per million years
- Spectroscopy to identify what these are
  - – Working to analyze spectrum of the first one
  - – C/2014 S3 (PANSTARRS) discovered 9/22/14





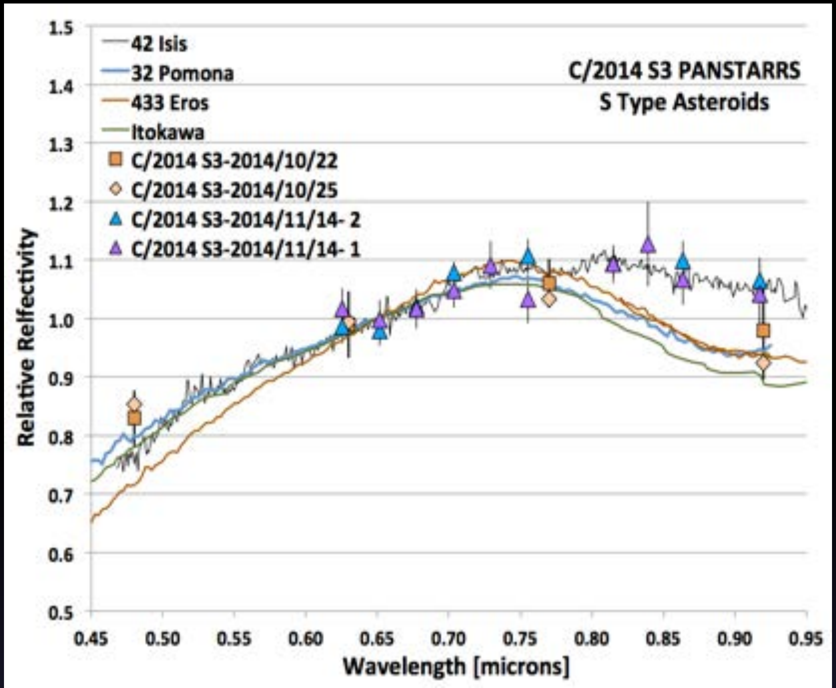




The Race to get its composition

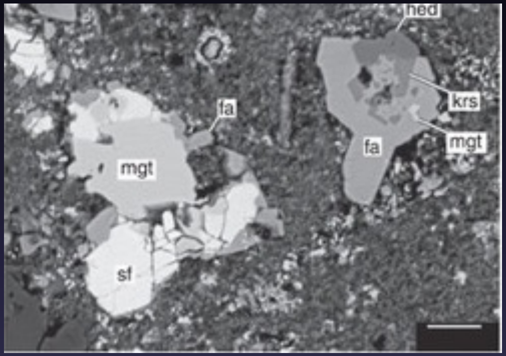
- CFHT: Manx is very faint →need a big telescope
- Ask for time on Maunakea – Gemini
  - No time available
- Request time on the VLT in Chile
  - 6 hrs from proposal to approval, late on a Friday
  - Telescope observed the comet 2 days later (11/18)

A Spectrum & Colors



Reference spectra from SMASS – Binzel et al

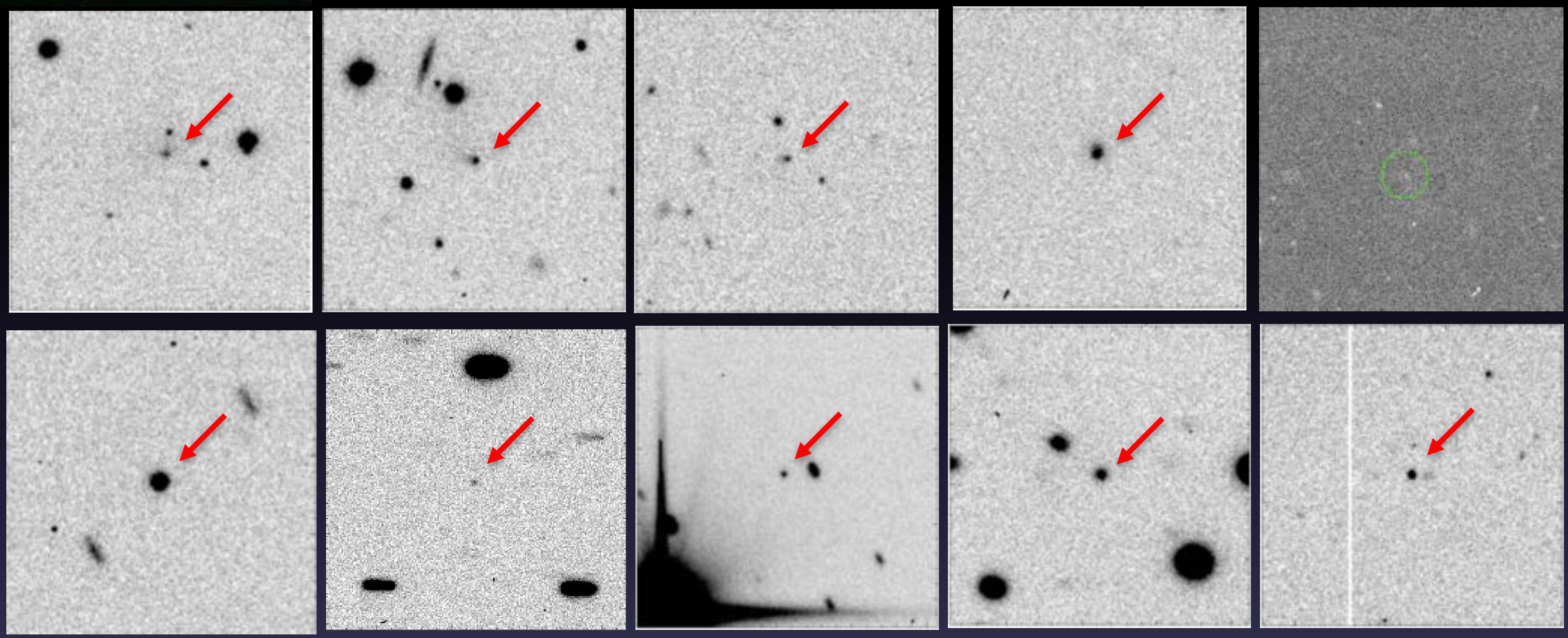
- C/2014 S3
  - Spectrum is inconsistent with primitive C, P, D types
  - Statistically consistent with rocky inner solar system material (S-type)



- S type asteroids
  - In the inner asteroid belt today – no ice
  - S types are related to ordinary chondrites (OC)
  - Shallow 1 μm band associated with most primitive least heated OCs (UOCs)
- Information about OC's past
  - New work showing aqueous alteration (Doyle, Krot, 2015)
  - Consistent with low water:rock (0.1-0.2)

We may be seeing fresh "preserved" Earth building material

A Clowder of Manxes . . .

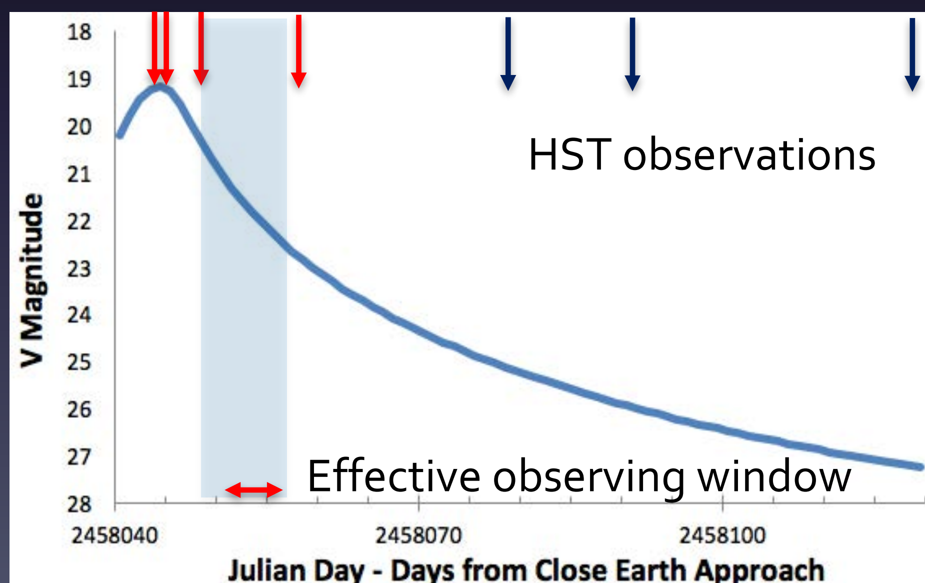


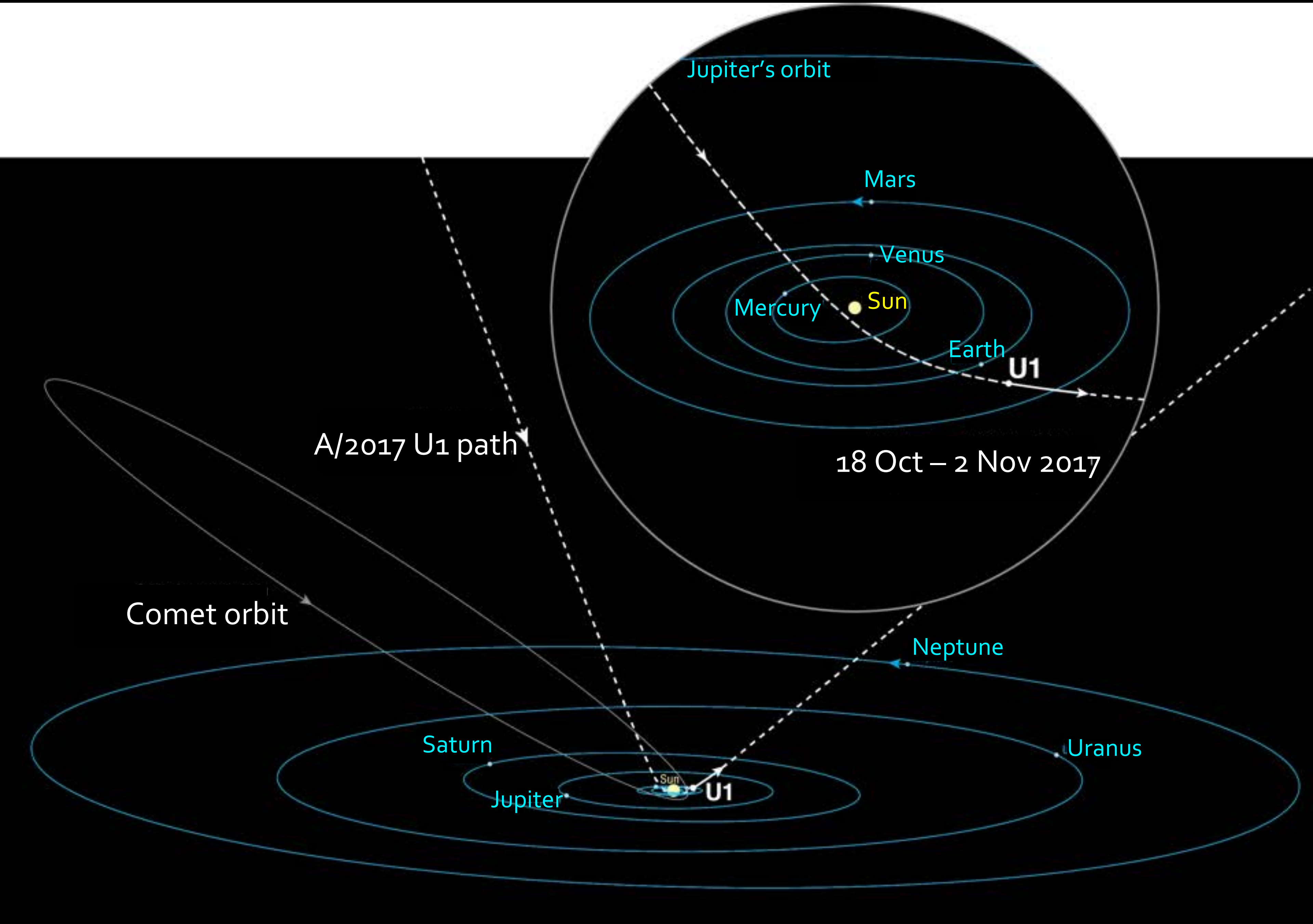
- Distinguishing dynamical models
  - Different solar system forming models make different predictions
  - Need to observe ~50-100 to begin to rule out models

A Case Study: A/2017 U1

Sun	Mon	Tue	Wed	Thu	Fri	Sat
← Sep 9 Perihelion						14- Close Earth approach, CSS Pre-covery
15	16	17	18-PS1 Pre-covery	19- PS1 Discovery	20	21
22- Hyperbolic orbit confirmed	23-DD prop VLT, GS; VLT Approve	24- GS prop Approved	25-VLT Obs, HST prop sub, UKIRT DD award; ☆	26- VLT, GS obs; HST Approve ☆	27- GS,CFHT, UKIRT, Keck obs	28- UKIRT obs ☆
29	30- ☆	31- Nature paper submit	1	2	3	4

☆ = other observations

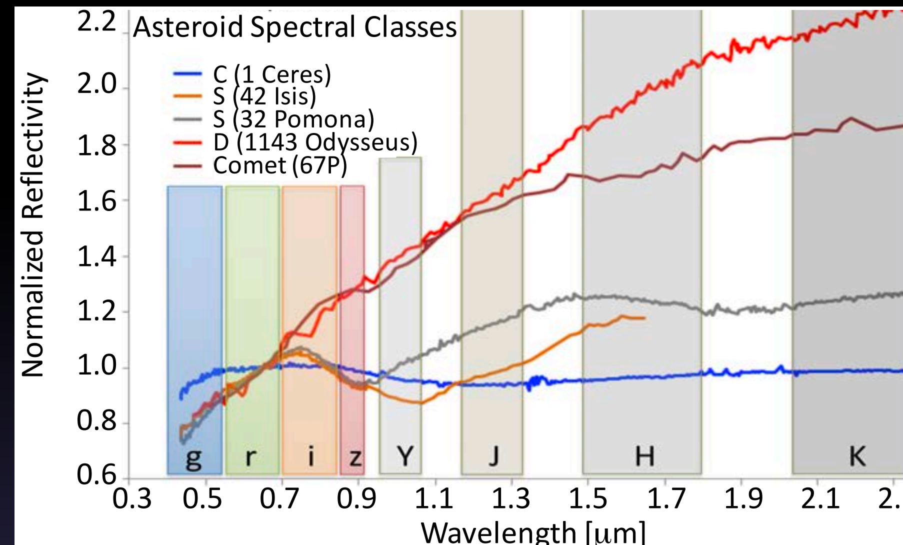


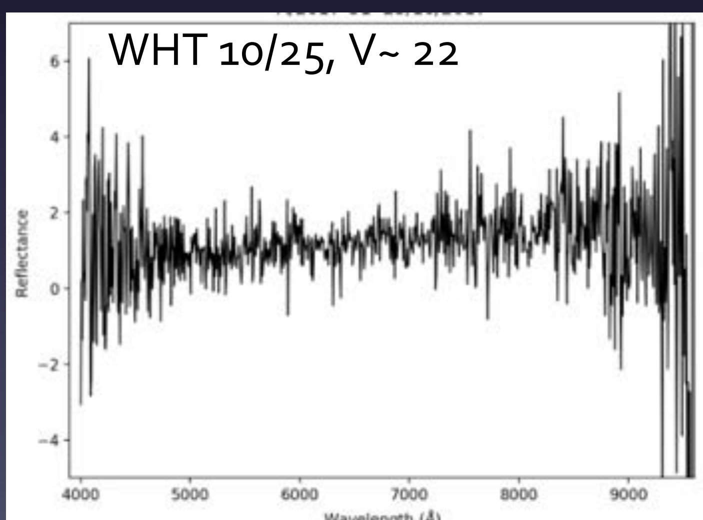

Jupiter's orbit
Mars
Venus
Mercury
Sun
Earth
U1
18 Oct – 2 Nov 2017
A/2017 U1 path
Comet orbit
Neptune
Saturn
Uranus
Jupiter
Sun
U1

What could be done now . . .

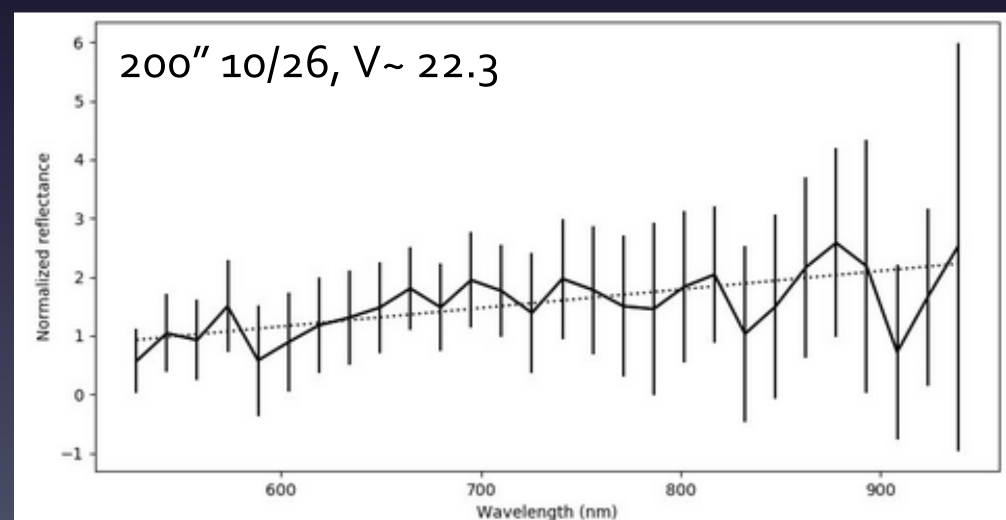
What was done

- Spectral reflectivity (photometry)
- Spectrum
- Rotation, shape, size
- Astrometry





A. Fitzsimmons



J. Masiero

LSST+TMT

- LSST Expectations
  - Now that we have seen the first and understand search strategies – many will be seen
  - Characterization has implications for planet formation models
- TMT-EELT capabilities
  - Interstellar objects
    - WFOS S/N ~ 100 for mag 26 in 300 sec → light curve
    - Many lightcurves spread in time → shape
    - We can get high quality low resolution spectra in vis-near IR
  - Other small bodies
    - Sensitive searches for water from the ground
    - Statistically significant D/H measurements on comets
    - Solar system insights require investigations of ensemble properties

Enabling Capabilities

- Operational
  - Full queue scheduling for rapid ToO response
  - Rapid instrument switching
  - Ability to guide at non-sidereal rates
- Instrument capabilities
  - Optical + near IR low resolution spectra (surface mineralogy)
  - High resolution $\lambda/\Delta\lambda$ near IR spectra (organic parent volatiles, isotopes)
  - High resolution $\lambda/\Delta\lambda$ optical spectra (isotopes)
  - Low resolution Spectroscopy in visible - UV
    - OH 308 nm, CN 388 nm – water detection