Main Belt Comets and Volatiles in the Asteroid Belt

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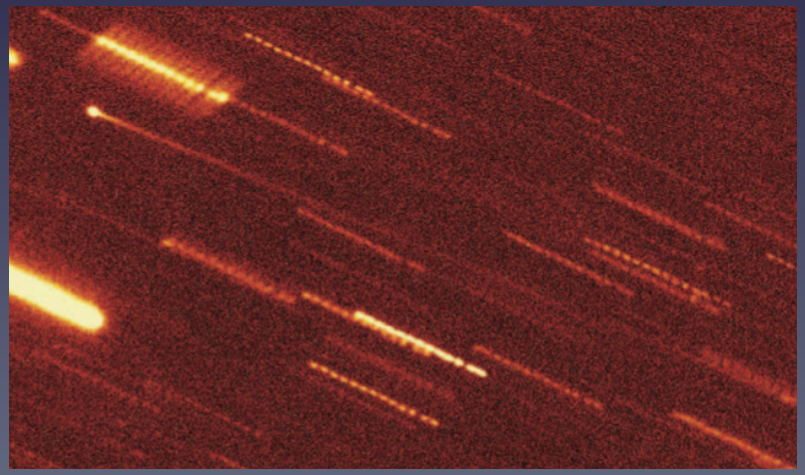
SBAG 9 Meeting

July 11, 2013

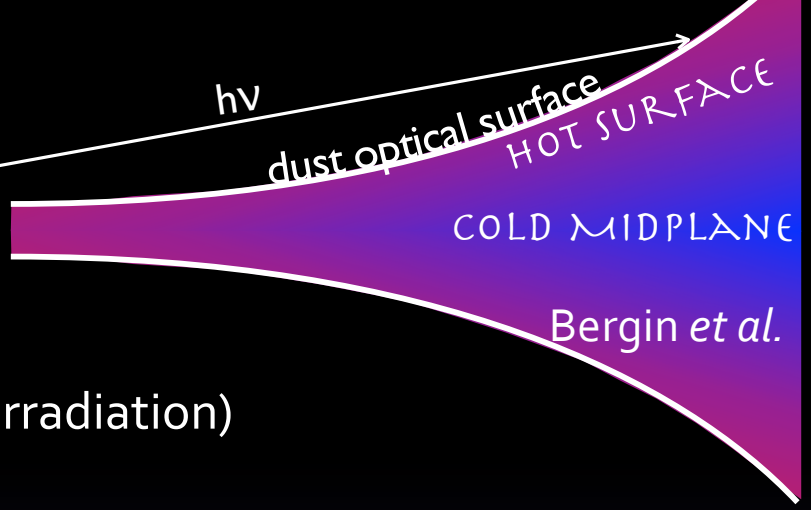


Small Bodies & the Decadal Survey

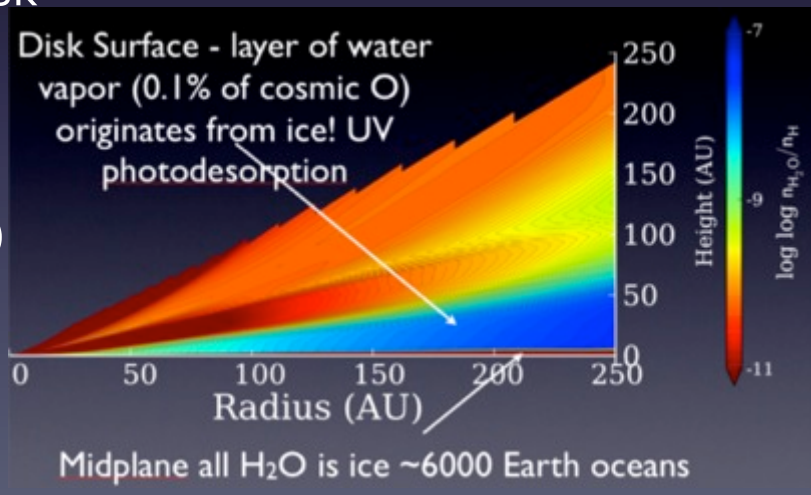
- Goals – Building new worlds & planetary habitats
  - What were the initial conditions, processes & stages of Solar System formation
  - What were the primordial sources of organics and volatiles

- Key Recent Discoveries
  - Insights into disk structure & chemical models
  - Change our paradigm of comet formation
  - Aqueous alteration seen everywhere in primitive meteorites, Ceres outgassing
  - Moon less dry than previously thought
  - Extensive near-surface Ice on Mars
  - Explosion in the number of known exoplanets
  - New discoveries in the asteroid belt related to volatiles
  - New insights into comet chemistry from missions

Disks to Planets

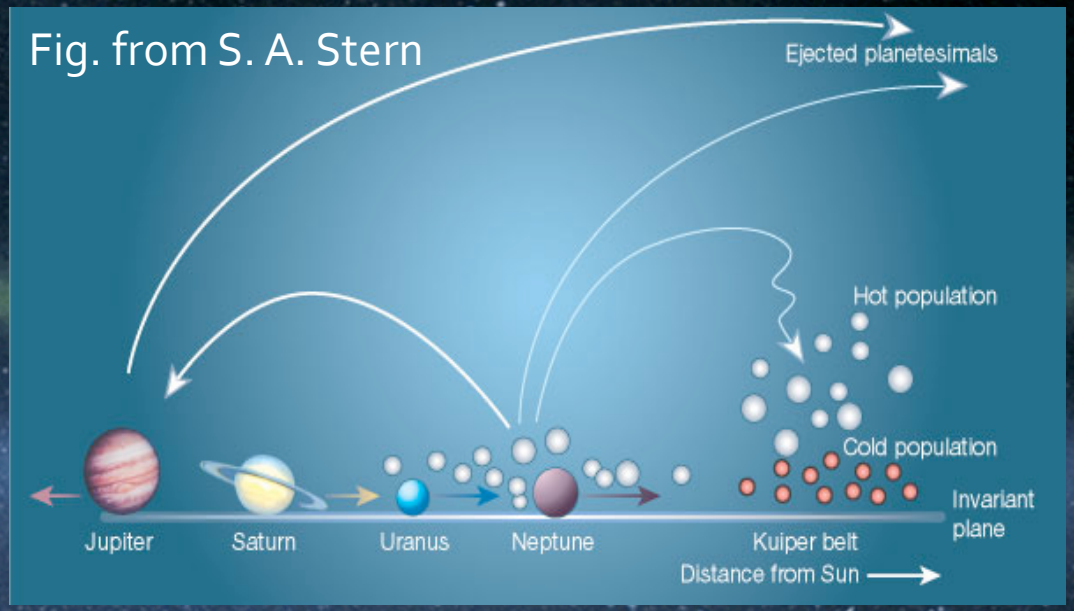


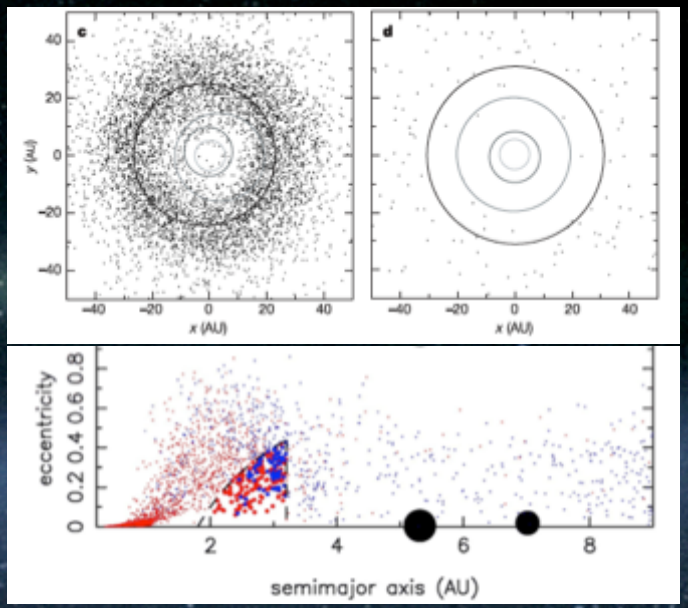
- Planets form in circumstellar disks
  - Disks are flared → higher surface T (UV irradiation)
- Volatiles present as gas and ice
  - Disk chemistry affected by surface UV, X-ray, mixing of materials, disk T and density structure
  - Inside an evaporation front (snow-line) present as gas
  - Comets sample a cold reservoir in the disk
- Snowline Debates & Observation
  - Snowlines change with time
  - Models locations differ (1 AU → Ast belt)
  - Herschel/Spitzer measurement in 1 disk
    - TW Hya – gas density sharp drop
    - Snowline at few AU



Hogerheijde, Bergin et al., *Science* 334 (2011)
IAU Symp 280, (2011)

Planetesimals & Comets: A Changing View



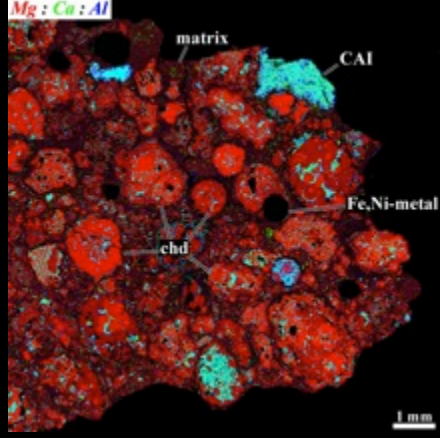


Tsinganis, Morbedelli *et al* 2005
Walsh *et al*, 2011

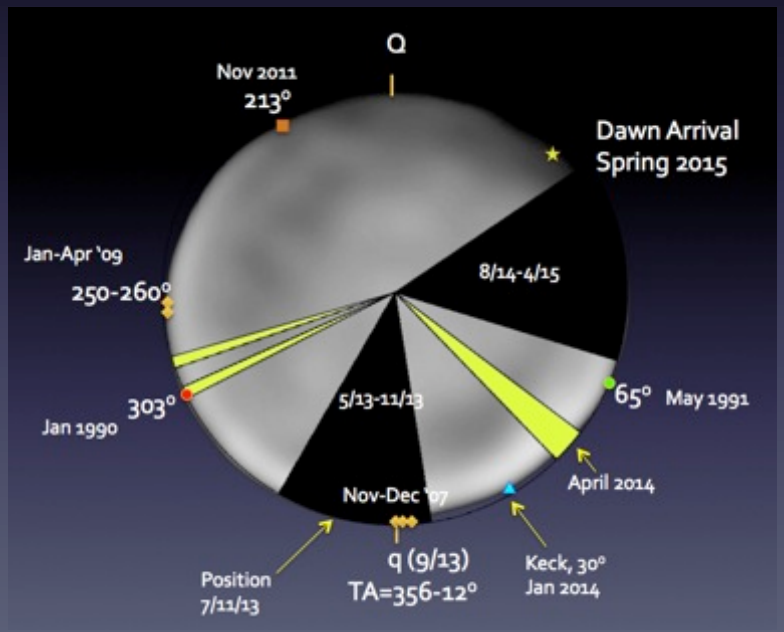
- Old View
  - Long Period Comets (LPCs) form in giant planet region
  - Scattered out to Oort cloud
  - Perturbed inward
- JFCs form in Kuiper belt
  - Migrate in→Centaurs→JFCs

- A changing View
  - *Nice model* – dynamics post-Jup form
    - Water came after Earth formed
    - Easiest to bring water from ast belt
  - *Grand Tack* – formation of giant planets
    - Explains small size of Mars
    - Delivers outer SS icy objects to Belt & Earth
- Implications
  - Significant mixing in nebula

Water in the Asteroid Belt



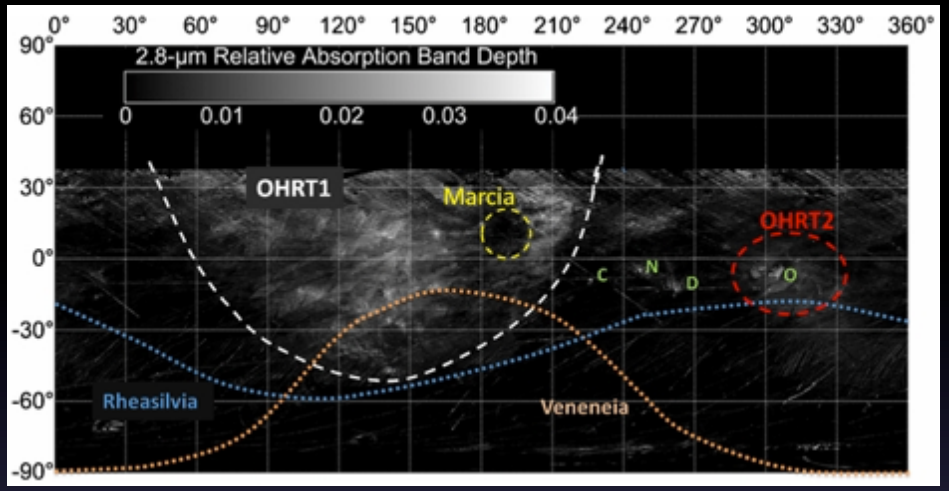
- Aqueous Alteration in Asteroids
  - Chondrites – sampled from ~15 groups
  - Aqueous alteration everywhere during first few Myr
  - Occurred at low to high T (300-1200K) - hydrothermal
  - Parent body formation location not known (ast belt)



- Ceres Outgassing
  - Water detected IUE 1991 (A'Hearn)
  - Ground searches since then, no detections
  - Herschel 11/2011 – upper limits

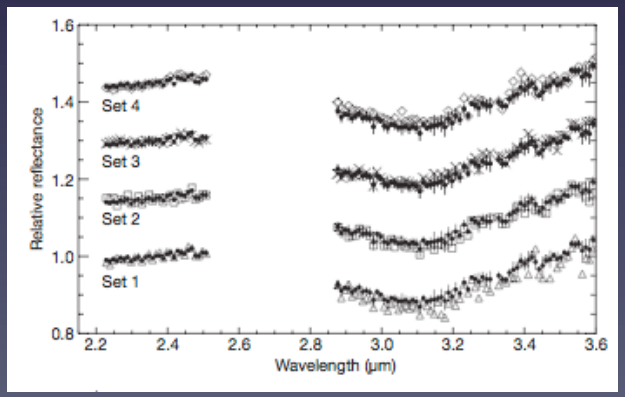
Water in Asteroid Belt & Comets

- Long history of asteroid phyllo-observations (Vilas *et al*)
- Hydrated minerals on 24Themis
- Hydrated minerals on Vesta

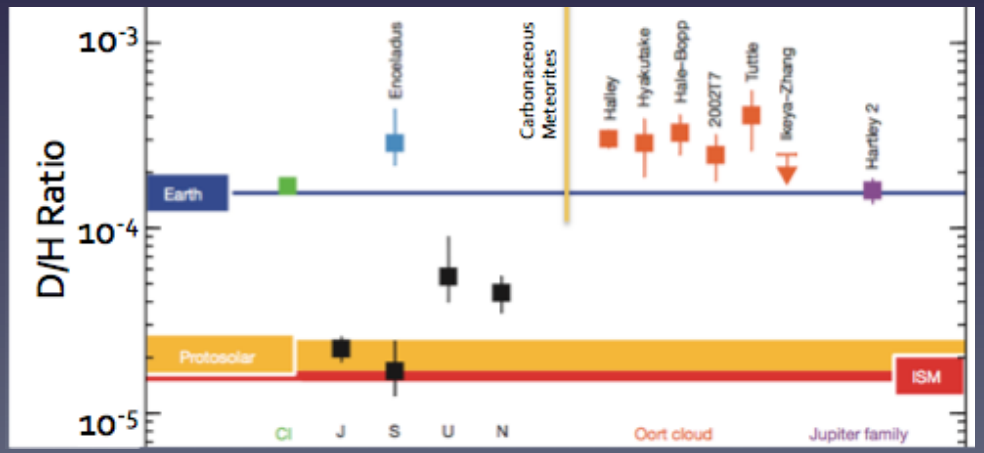


De Sanctis *et al* (2012) *ApJ* 758, L36

- D/H in Hartley 2 → JF comets don't form where we thought



Campins *et al.* (2010) *Nature* 464
Rivkin & Emery (2010) *Nature* 464



Hartogh *et al* (2011) *Nature* 478

Asteroid Belt Discoveries: MBCs

- Characterization
  - Objects dynamically asteroidal, formed in-situ
  - Exhibit comet-like tails
  - Most must be driven by H_2O sublimation
  - Surface H_2O not stable – requires "activation"
- Water not observable from Earth
  - H_2O fluxes needed to lift dust 1-2 orders of mag lower than detection capabilities w/ Keck
  - Characterization → in-situ

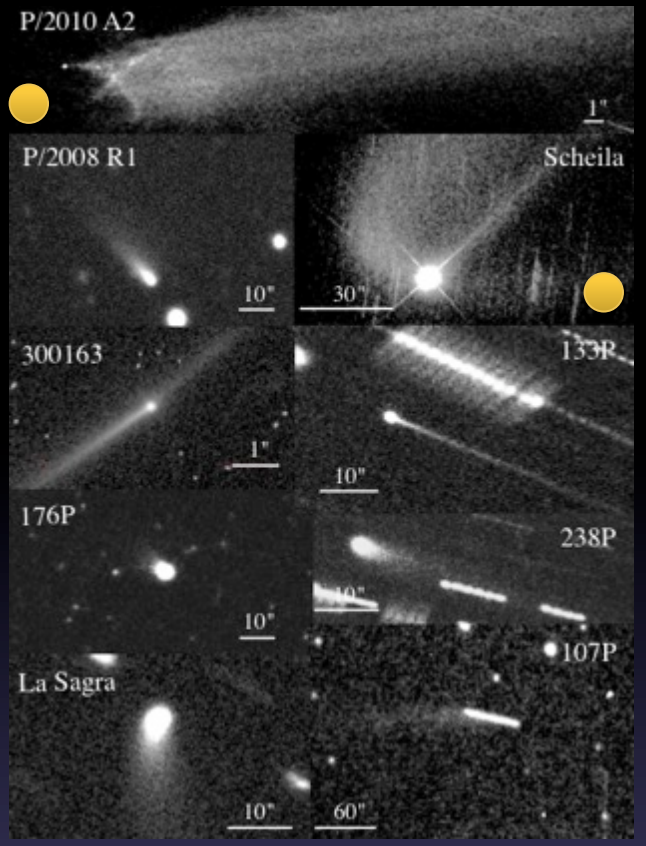
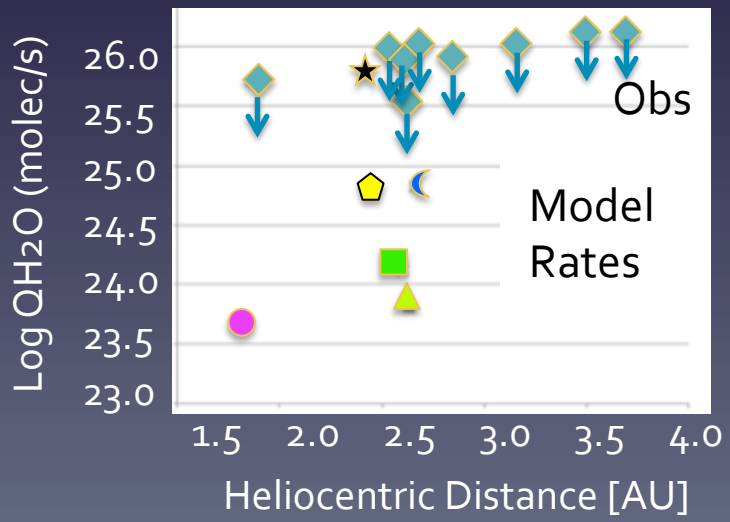


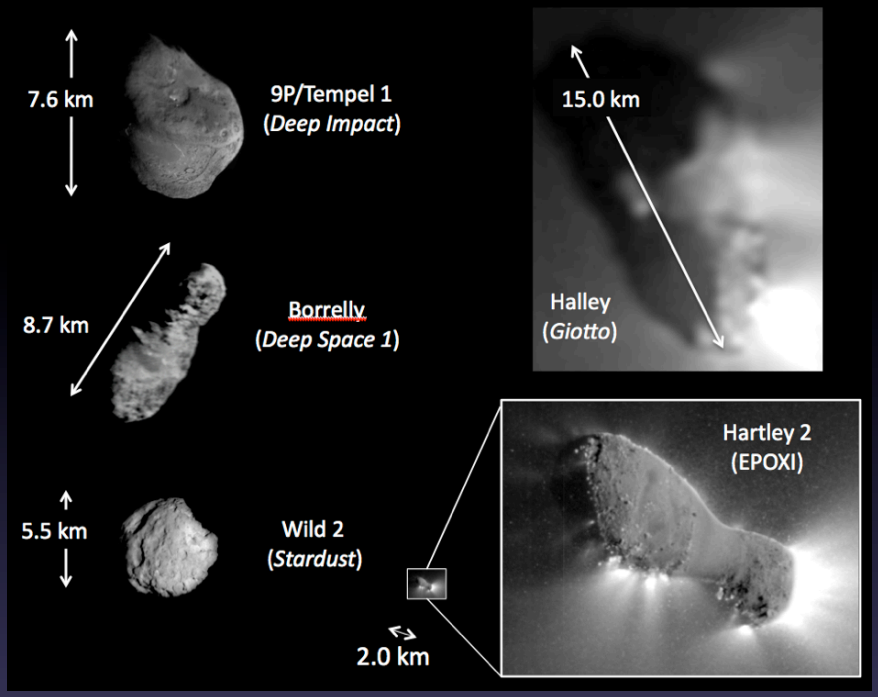
Fig. from D. Jewitt, AJ 143, 66.



MBC limits
9P/Tempel 1

133P
238P
2010 R2
238P
176P

EPOXI Mission



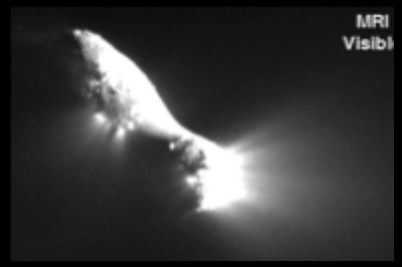
- Nov 4, 2010 Encounter
  - 12.3 km/sec; 700 km flyby
  - 2m / pix best resolution
  - 3 instruments (vis & near IR)
- Known prior to EPOXI
  - Comets a mix of dust & volatiles
  - Comets are physically very diverse
  - Excellent insulators
  - Mixture of high and low-T SS material

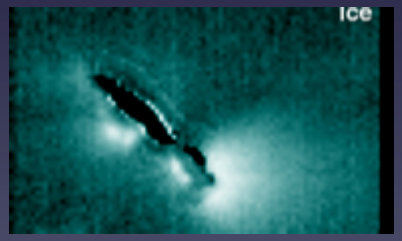
Spacecraft

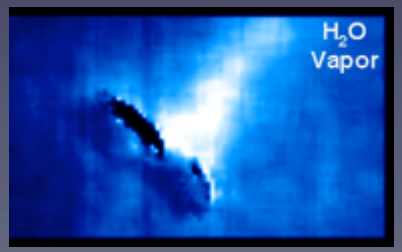
Ball – JPL mission

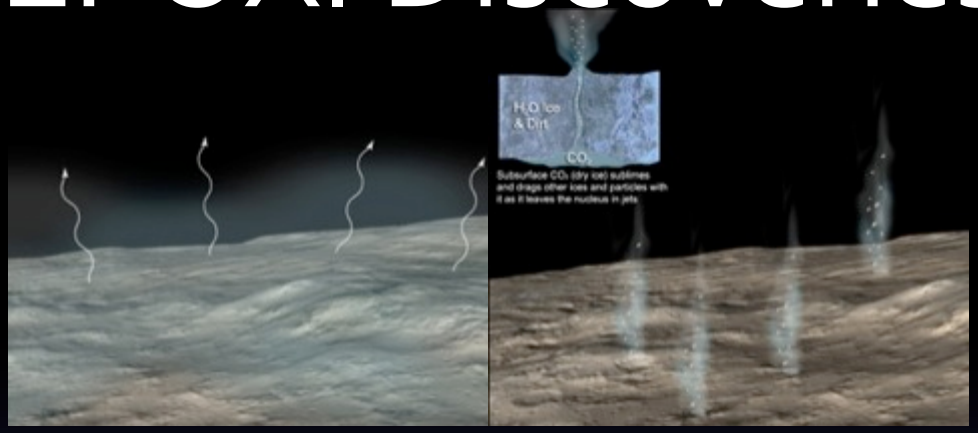
Still operational

EPOXI Discoveries









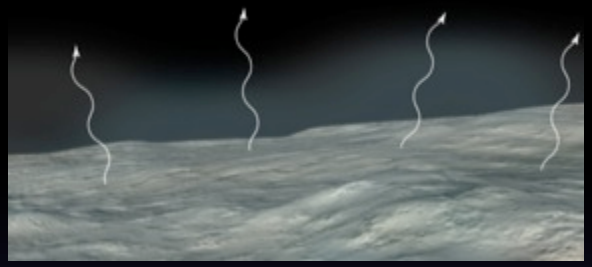
A'Hearn *et al.* 2011, *Science* **332,** 1396

- Nucleus surrounded by swarm of large chunks
  - mm to 10's cm slow moving (ice + dust)
- Dust, CO_2 and water-ice grains flow together
  - New discovery: CO_2 drives jets & activity
  - Water vapor is everywhere – but faint
  - Minimal surface ice – associated with rough morning terminator

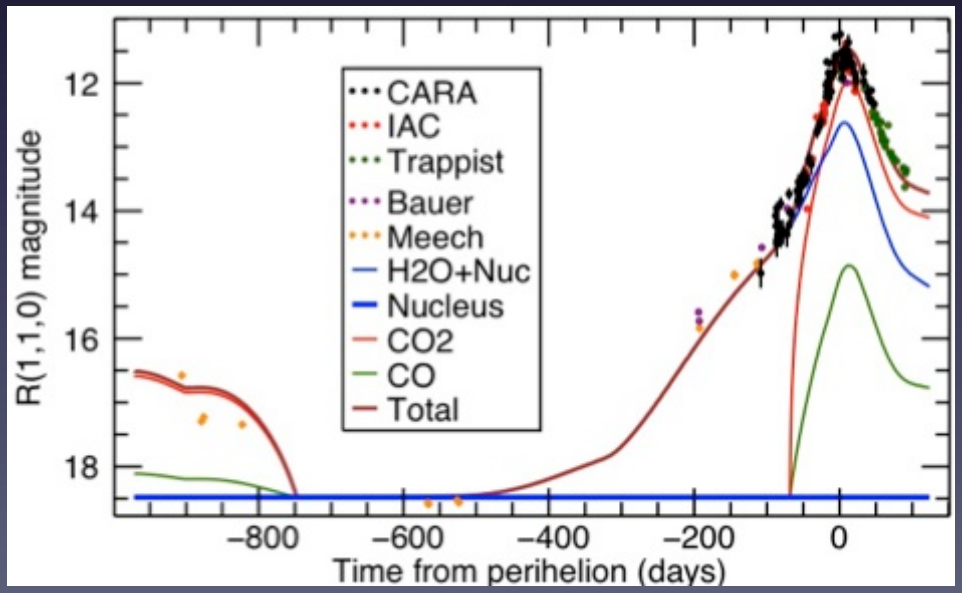
New view of importance of CO2 as a driver of activity in comets

Ground-Based Brightness Data

- Surface sublimation Models
  - Energy balance at surface of nucleus
    - Incident energy
    - Thermal
    - Sublimation
    - Conduction
  - Ices sublimate
    - Drags dust from surface
    - Increased scattering from dust
  - Compute observed total brightness

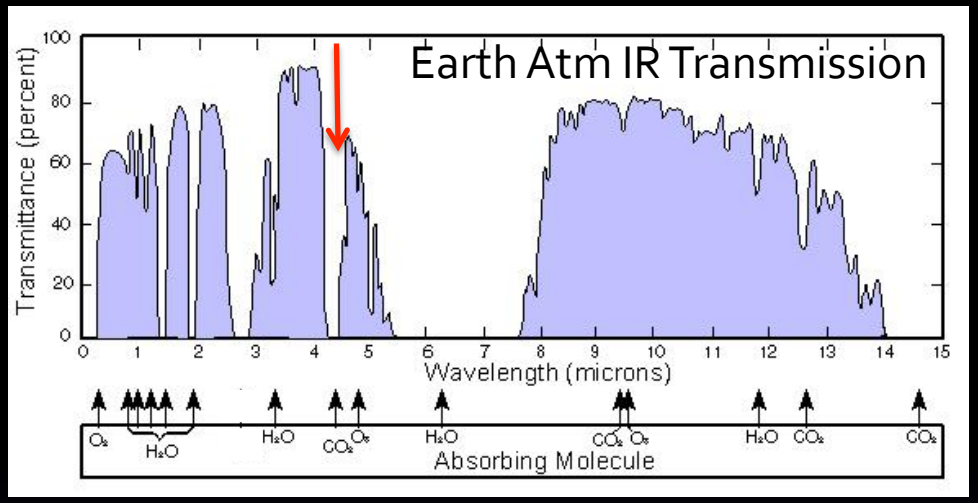


$$F_{\odot}(1\text{-}A) / r^2 = \beta \left[\varepsilon \sigma T^4 + L(T)\, dm_s/dt + \kappa(z,T)\, \partial T/\partial Z\right]$$

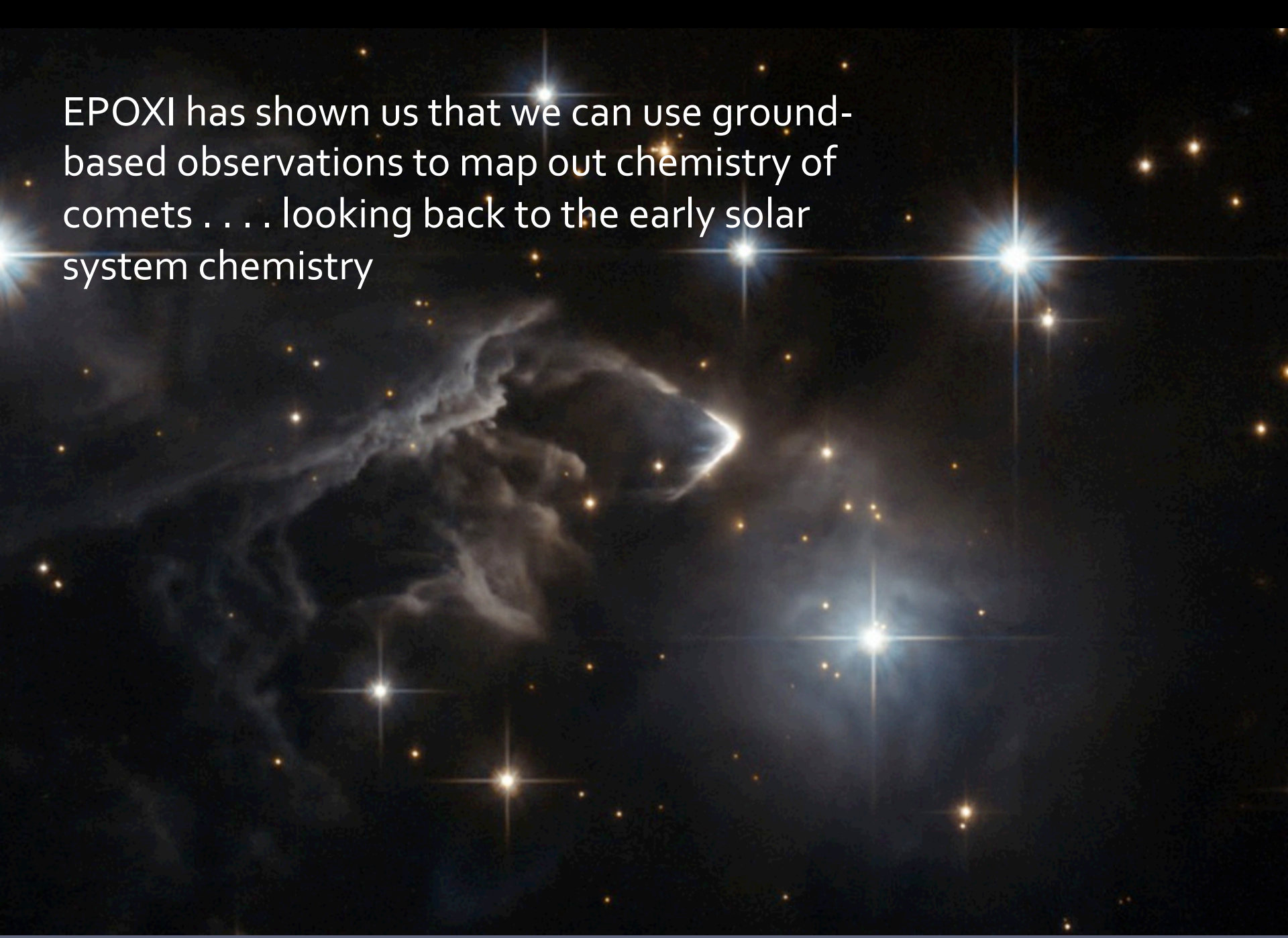


Implications: Can get information about CO_2 abundance from the ground for a large number of comets

Measurements of CO_2 in Comets



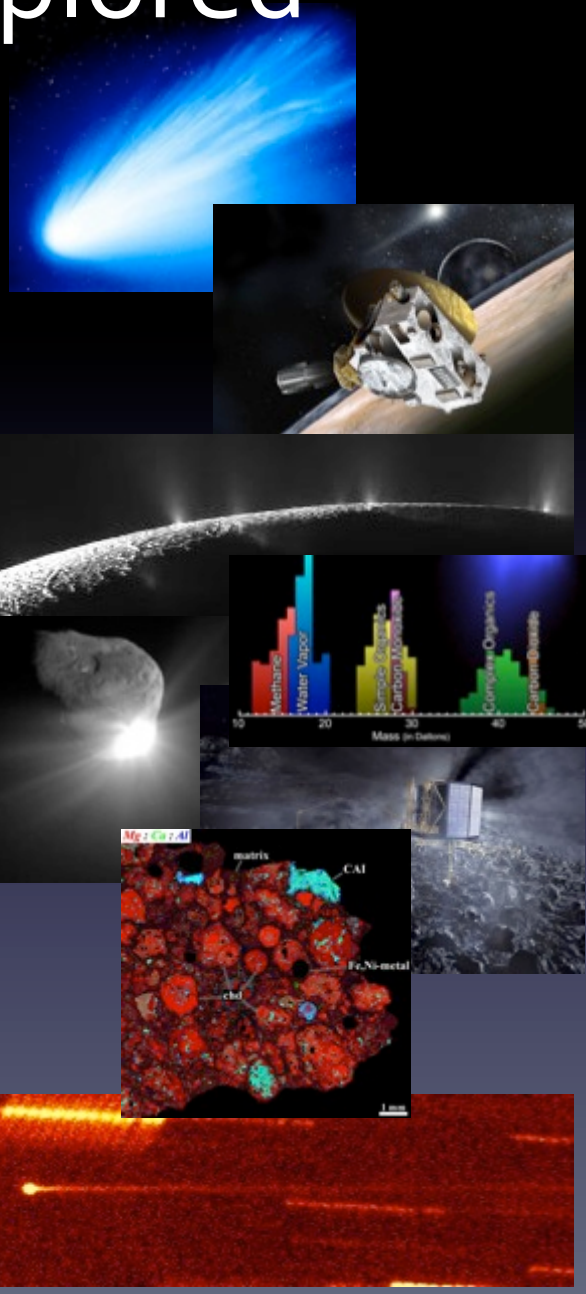
- Earth Atm opaque at 4.26, 15.2 microns
- Direct Observations
  - Giotto in situ – mass spectrometer; EPOXI in situ near IR spectra
  - ISO spectra
  - Spitzer, WISE thermal bands
  - Akari Satellite (~20 comet measurements)
- Indirect
  - Forbidden CO emission during photo-dissociative excitation of CO_2



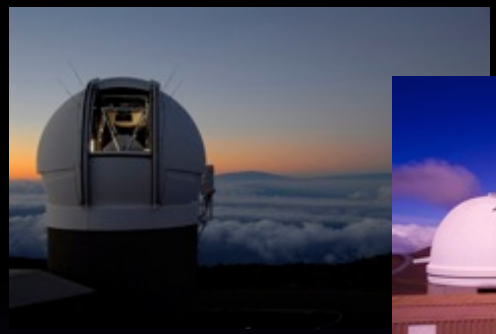
EPOXI has shown us that we can use ground-based observations to map out chemistry of comets . . . . looking back to the early solar system chemistry

Volatile Reservoirs Explored

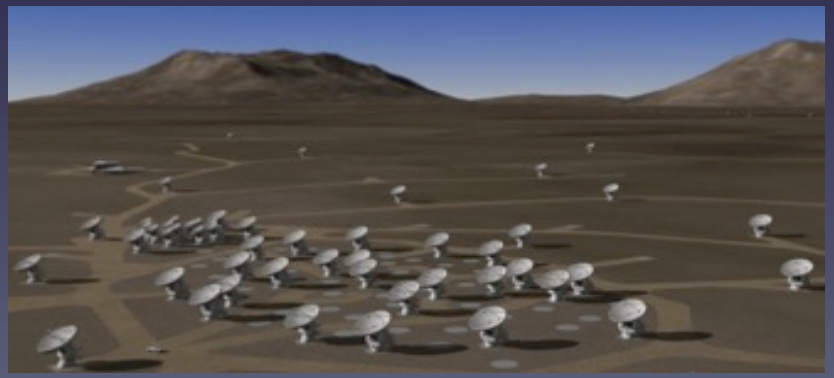
- Explored Small Body Volatile Reservoirs
  - Oort Cloud & Kuiper belt
    - Ground-based observations → Comets
    - New Horizons → Pluto, TNO
  - Outer solar system Satellites
    - Cassini – Enceladus
  - Jupiter family comets
    - Deep Impact, EPOXI, StardustNExT, Rosetta
    - Herschel, Spitzer, Ground based observations
  - Middle – inner asteroid belt (meteorites)
- Unexplored Volatile Reservoirs
  - Outer belt →Main Belt Comets



New Capabilities



- Pan STARRS & LSST
  - Survey for new active objects
- ALMA
  - Disk resolved chemical observations



Meeting the Decadal Goals

- SS Dynamics Model landscape is rapidly changing
  - Models reproduce structure, mass distribution → not chemistry
- Many communities are interested in water in the main belt
  - Cosmochemists – aqueous alteration everywhere in primitive meteorites (don't know dynamical origin)
  - Planetary observations: water in outer belt: Themis family, Ceres . . . .
- The outer asteroid belt is wet . . . .
  - We need in-situ observations to characterize it
  - DAWN is the first step – but Ceres is evolved
- The next decade and how to move forward
  - Need to explore the outer belt . . .
  - If we characterize the water isotopically & combine with dynamical models and new observations (ALMA) → testable hypotheses