Planetary Protection and Studies of Comets

Lori M. Feaga
(University of Maryland)

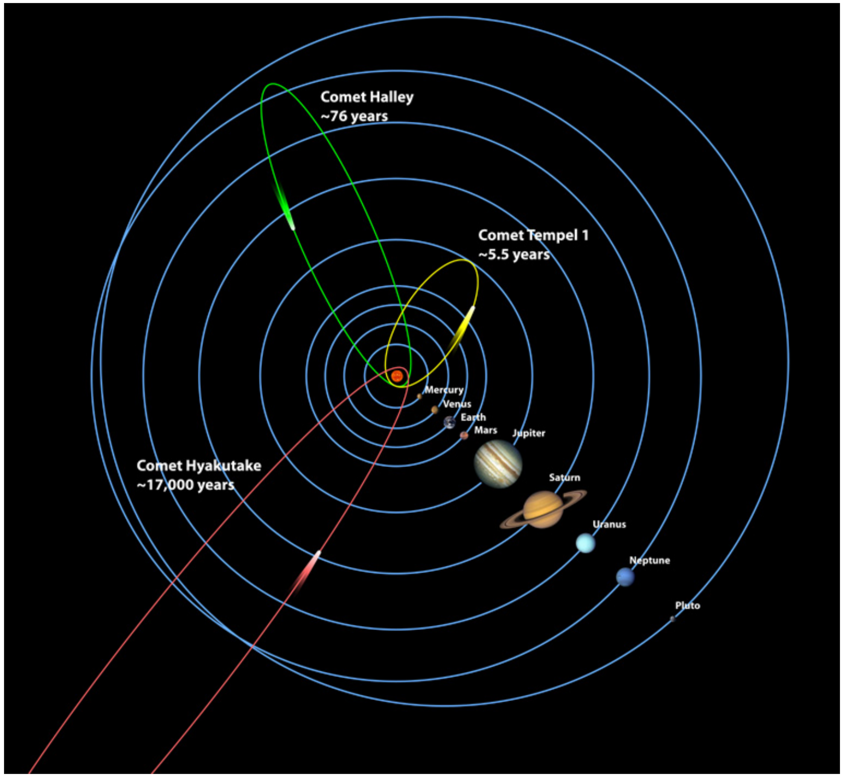
Committee on Planetary Protection
2021 Fall Meeting

Statement of Task – What if all comets/comet missions are assigned to Planetary Protection Category I?

- Are there identifiable populations that are sufficiently:
  - numerous?
  - chemically similar?
  - accessible?
- Would new information indicating more diversity or very unique objects warrant reassessment?
- Want to preserve the capability to perform future scientific investigations and retain scientific integrity.

Cometary orbits & dynamical classifications

- Short period (every 5-10 years)
  - Originate in the Kuiper Belt
  - Disturbed by the gravity of the planets
  - Orbit between ~Jupiter and the Sun
  - Relatively close to the Ecliptic plane
  - Most accessible to spacecraft
- Halley type (every 50-100 years)
  - Halley is the prototype
  - Orbit between ~Neptune and the Sun
- Long period (> 200 years)
  - Originate in the Oort cloud
  - Disturbed by a passing star
  - Isotropic source, high inclinations



Known comet population

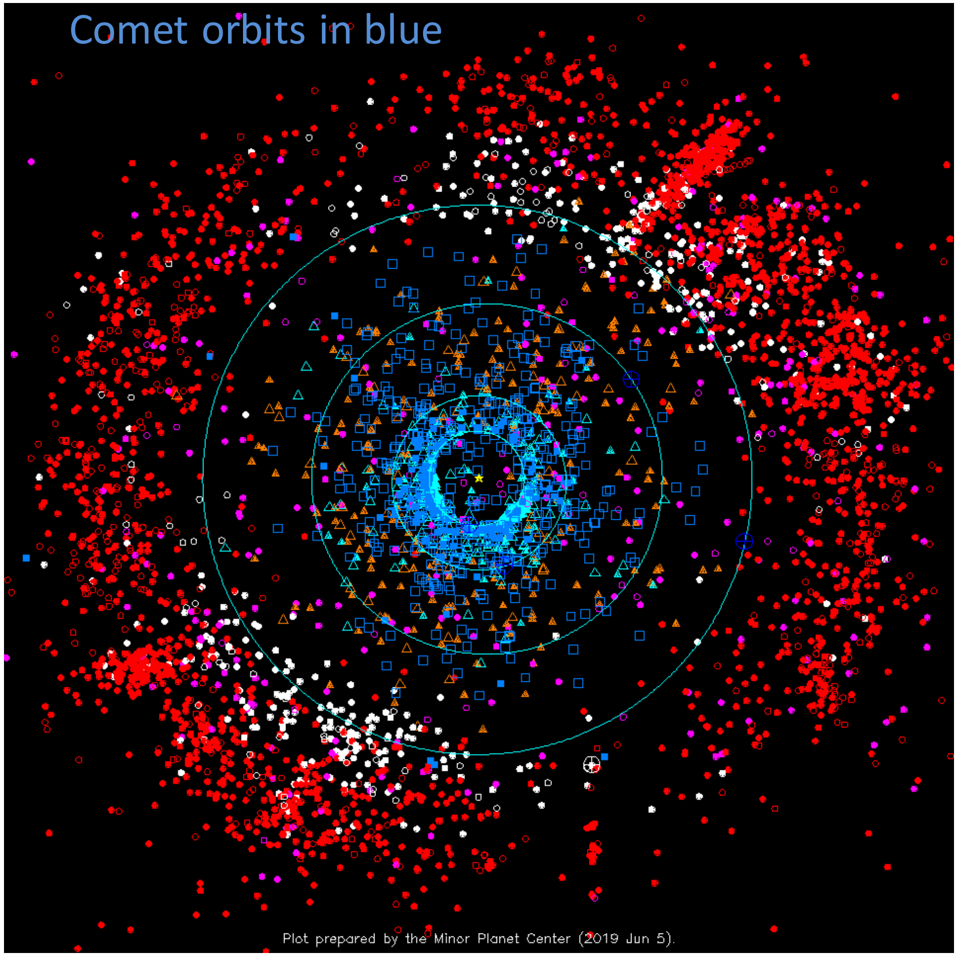


Image credit: Minor Planet Center

As of November 2021:

- 4,429 comets discovered
- 68 comets discovered in 2021
- 436 periodic comets total
- Estimates of 1 billion – 1 trillion comets in Oort cloud
- Debiased LPC population indicates ~7 comets > 1 km within 1.5 AU of the Sun in 1 yr (Bauer et al. 2017)

Why study comets?

Feb. 15, 2013
AP Photo/Nasha Gazeta

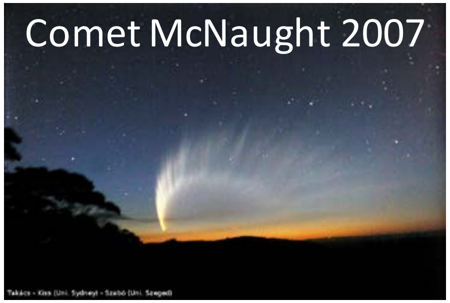
- Old and wise
  - Some of the oldest bodies in the Solar System
  - Record conditions during formation
- Building blocks
  - They are what planets are made of: dust, ices, organics
  - Have been stored in the deep freeze of the Solar System

- Hazardous to life on Earth
  - Impacts could bring mass extinctions
- Publicly accessible
  - Interaction with the Sun is beautiful and humans can witness

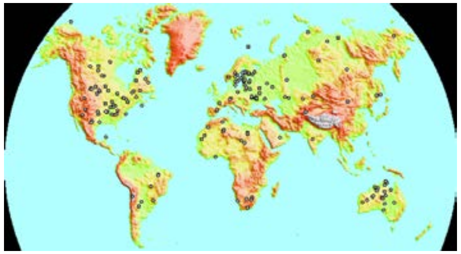
Shoemaker-Levy 9
1994

Image Credit: HST Comet Team & NASA

Comet Hale-Bopp 1997
Image Credit: Philipp Salzgeber

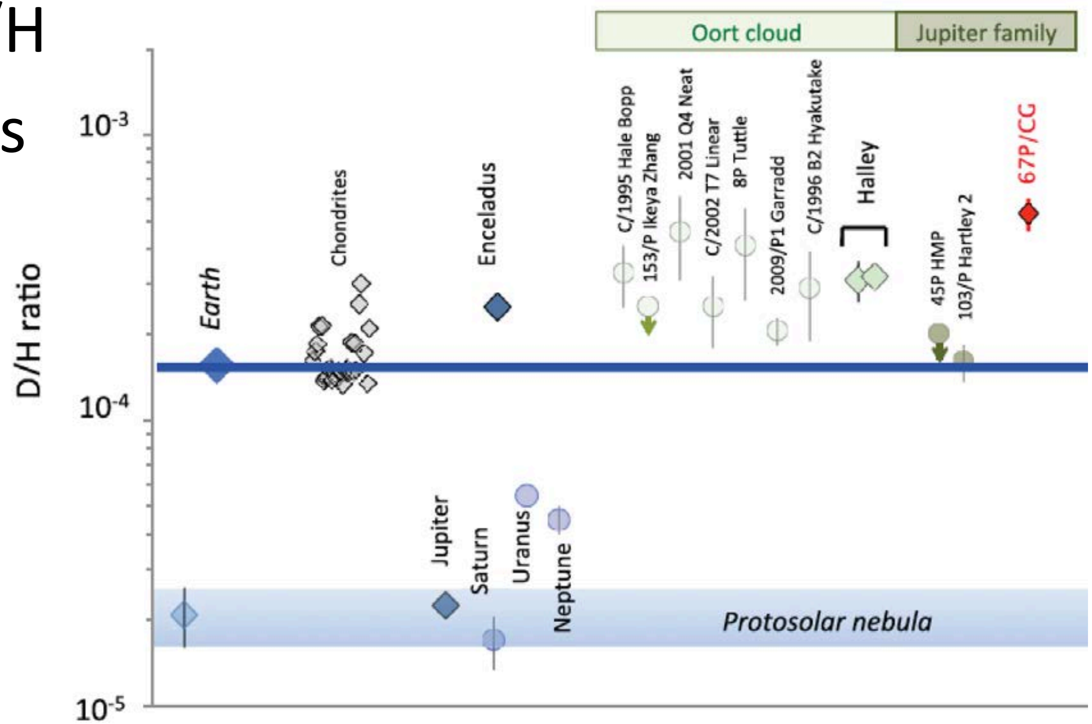


Comet McNaught 2007



Delivery of H_2O and organics to the Earth

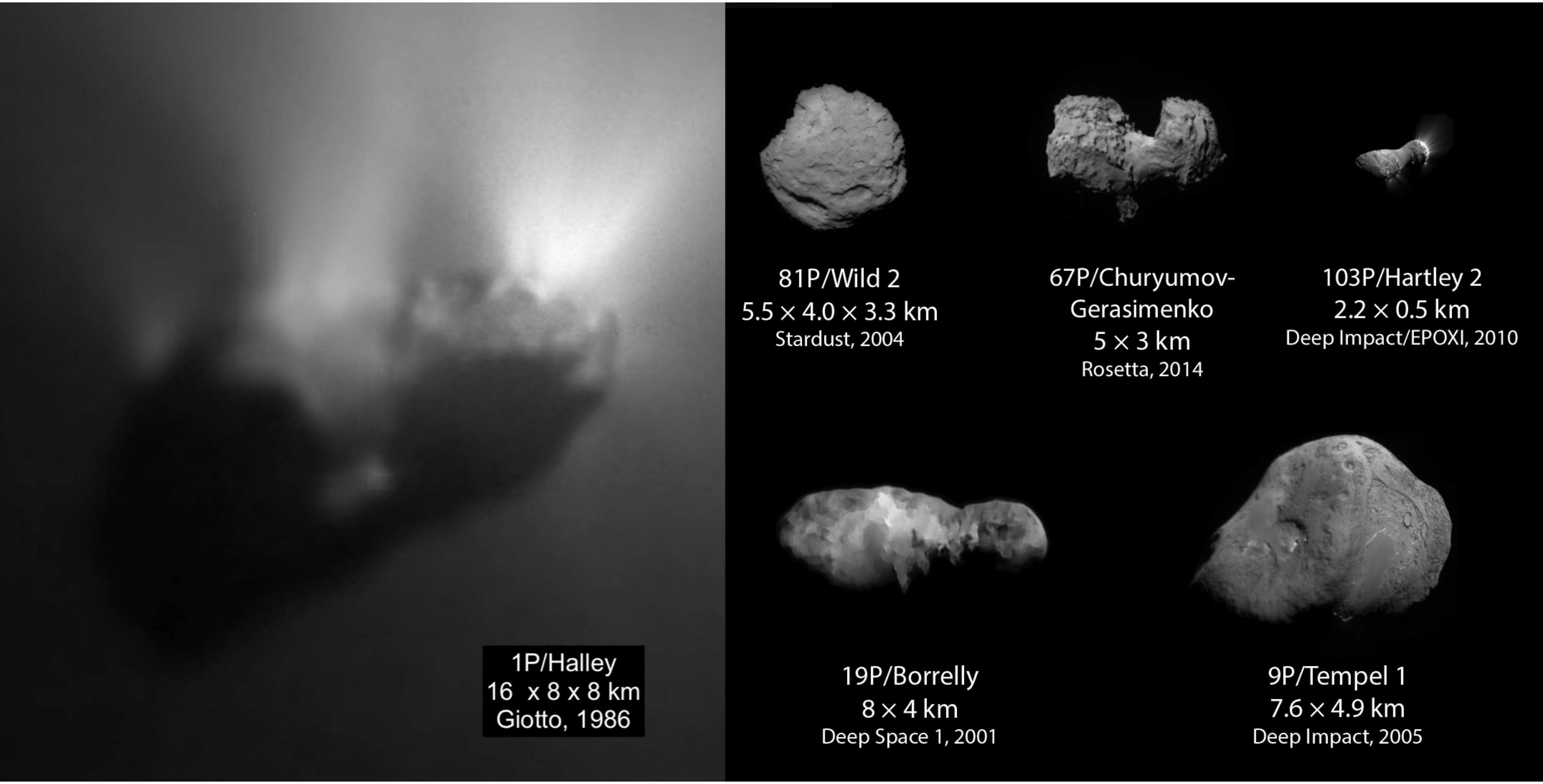
- Most comets have D/H larger than Earth's SMOW
- Oort cloud comets higher D/H than Earth, slightly less scatter than JFCs
- JFCs largest range of D/H and bound Oort comets
- Hyperactive comets most closely match Earth
- May be measuring pristine ice in the coma of hyperactive comets



Altwegg et al. 2015

Diversity among Jupiter-family comets

Cometary nuclei imaged by spacecraft

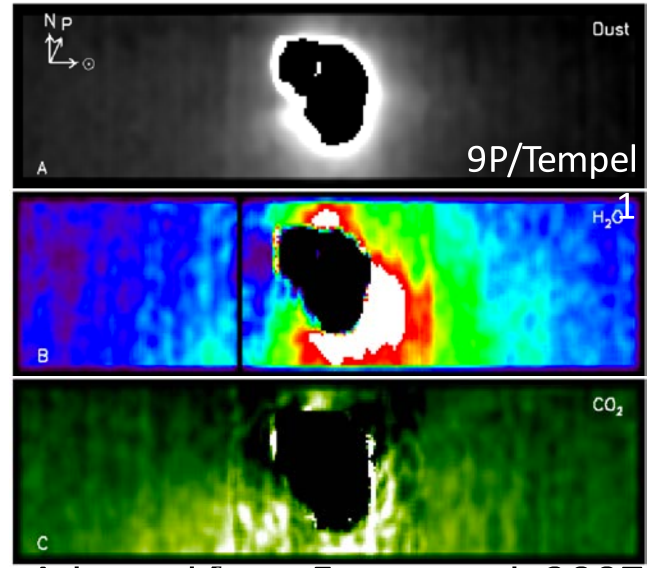


Adapted from E. Lakdawalla

Credit for individual images: 1P – ESA/MPS; 9P – NASA/JPL/UMD; 19P – NASA/JPL/Stryk; 67P – ESA/Rosetta/NavCam/Lakdawalla; 81P – NASA/JPL; 103P – NASA/JPL/UMD

Asymmetric outgassing, jets, and activity

- Activity of two main volatiles in 9P/Tempel are not correlated
  - H_2O mainly sunward
  - CO_2 nightside jets
- 103P/Hartley 2 is CO_2-rich and hyperactive
  - Primary volatiles are not correlated
  - Ice dragged out of interior by CO_2 gas provides secondary coma source of H_2O
- 67P/Churyumov-Gerasimenko had large seasonal asymmetries
  - Summer outbursts and collimated jets
  - Southern hemisphere more abundant in CO_2 and CO



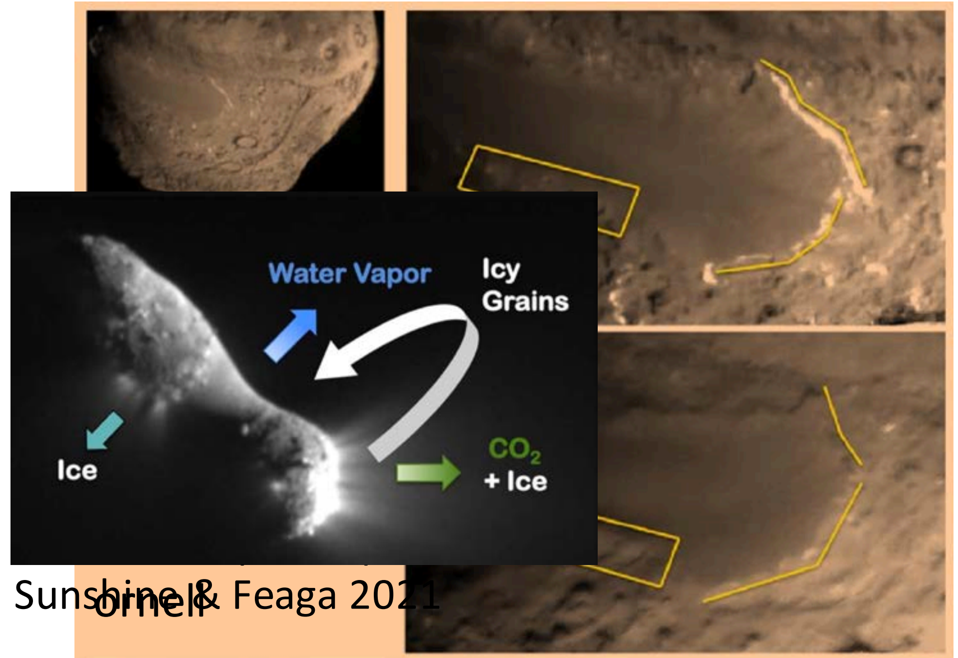
Adapted from Feaga et al. 2007


Vincent et al. 2016

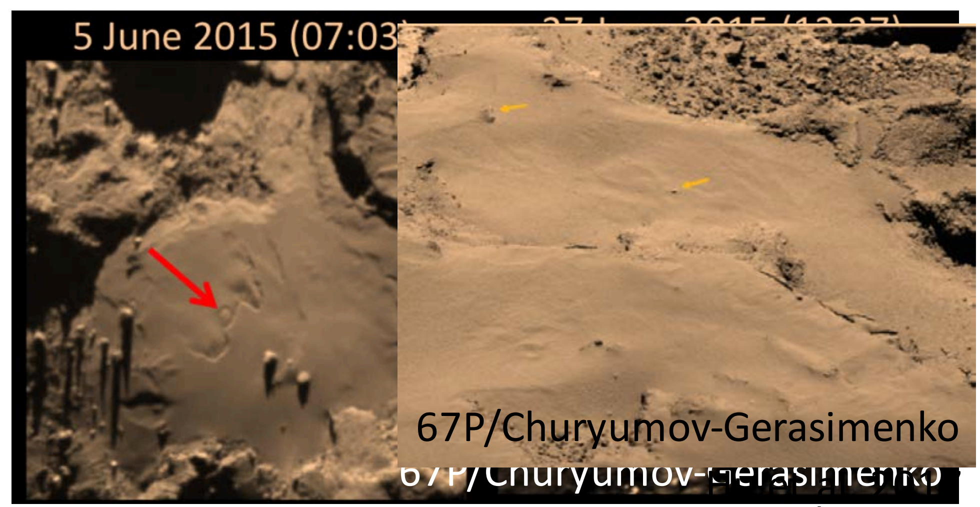
Adapted from A'Hearn et al. 2011

Examples of comet surface processing

- Cosmic ray irradiated (and devolatilized) crust
- Sublimation driven erosion during each perihelion passage (~meter/apparition)
- Fallback of material/transport of material (both ice and dust)



Sunshine & Feaga 2021



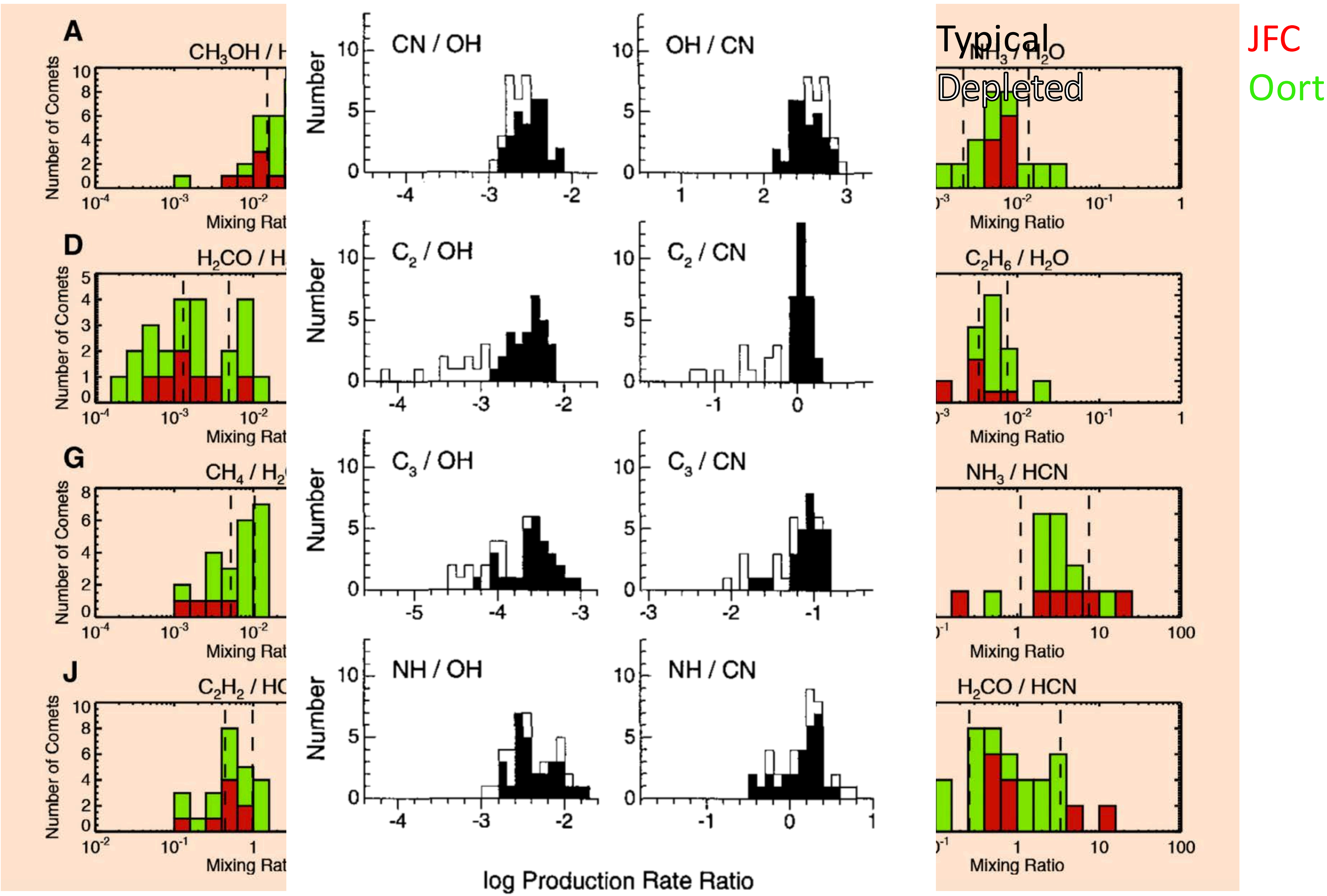
Groussin et al. 2015

Compositional studies and shared characteristics across taxonomies

Composition sheds light on formation

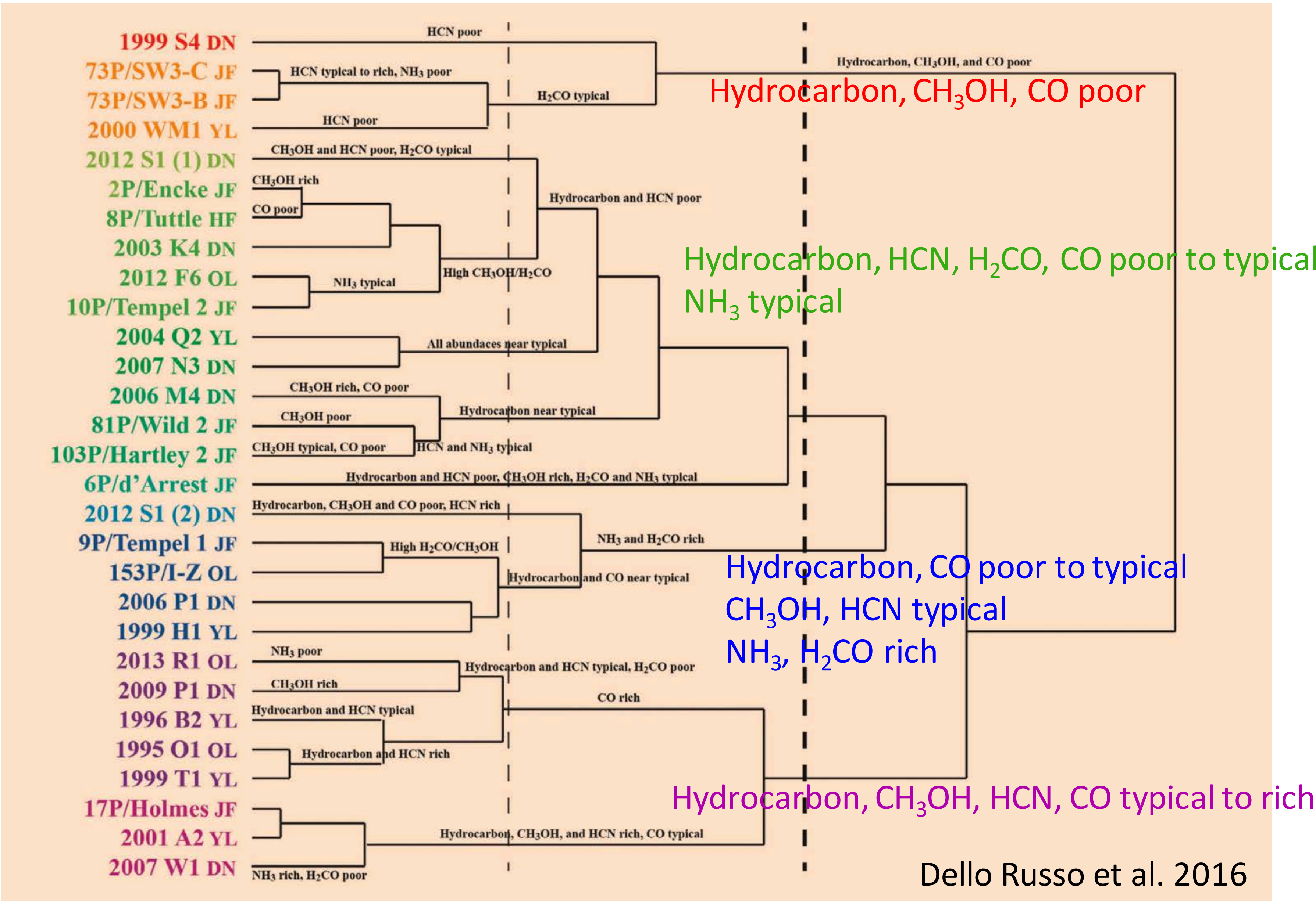
- Temperature constraints from volatiles, especially CO, N_2 which require cold temps
- Evidence for a high degree of mixing in the disk from low and high temperature materials/volatiles as seen in Stardust samples
- Heterogeneities within a nucleus informs mixing and accretion process

Mixing ratios for different comet reservoirs

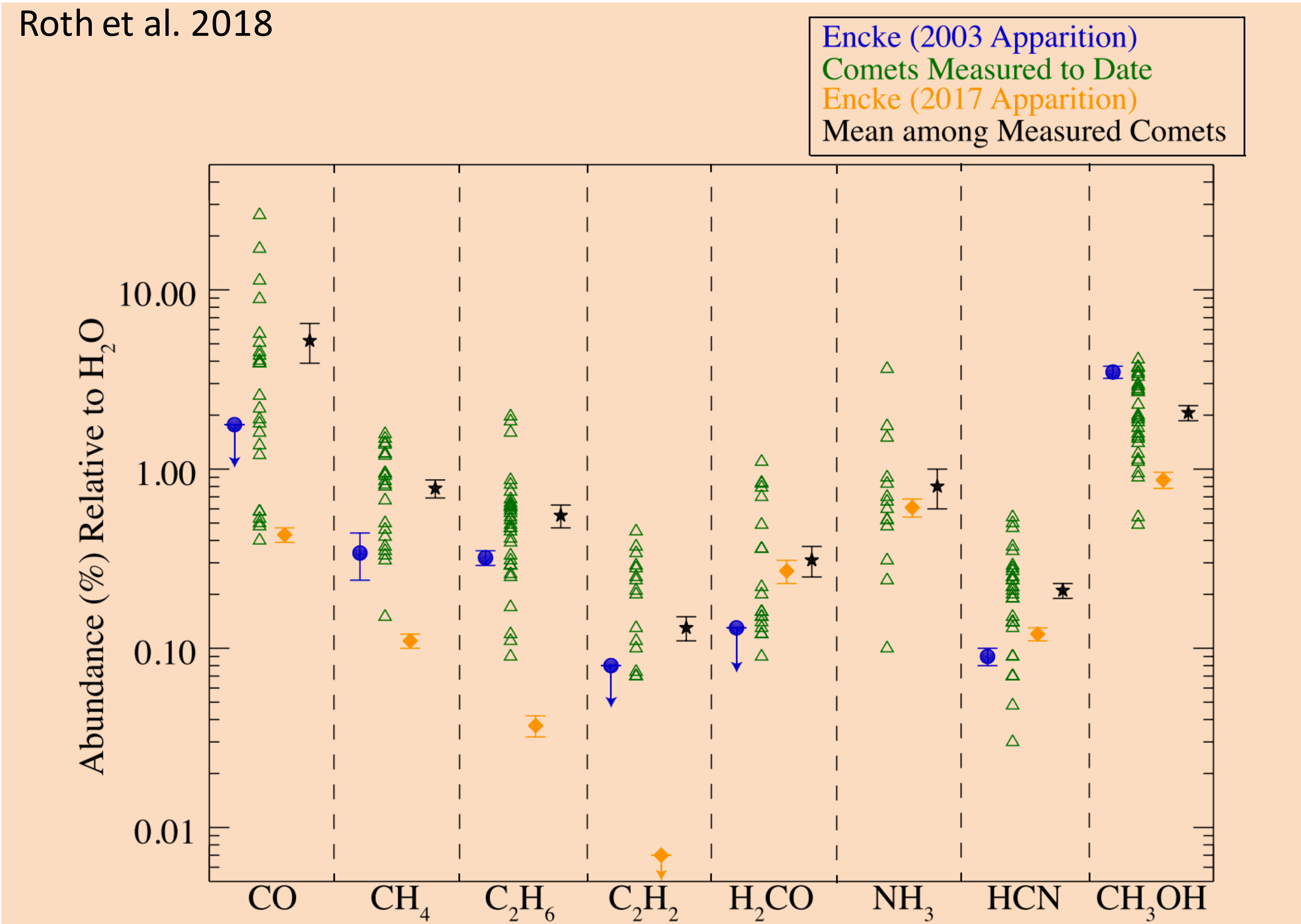


A'Hearn et al. 1995

Compositional taxonomies

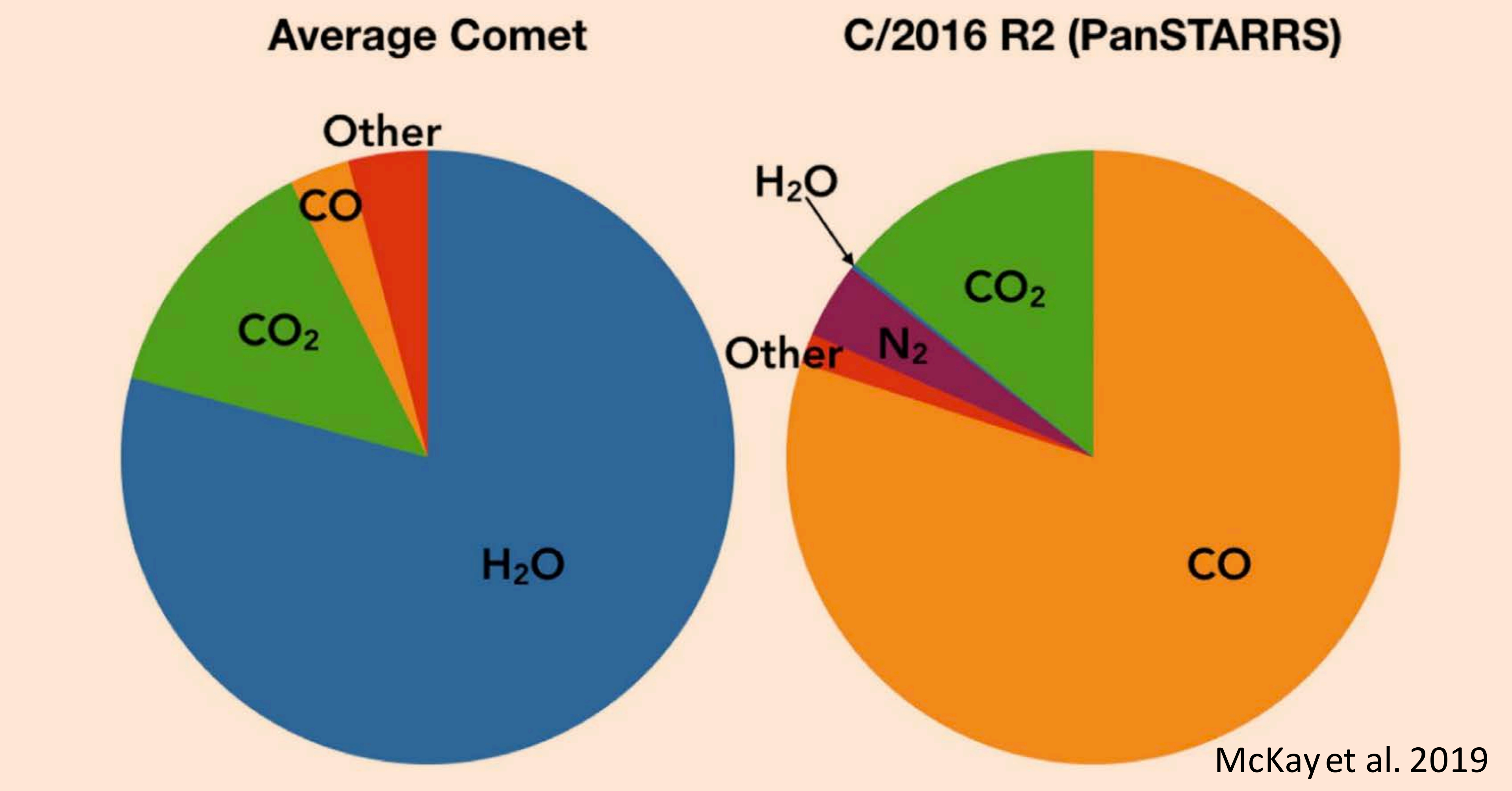


Compositional diversity among comets

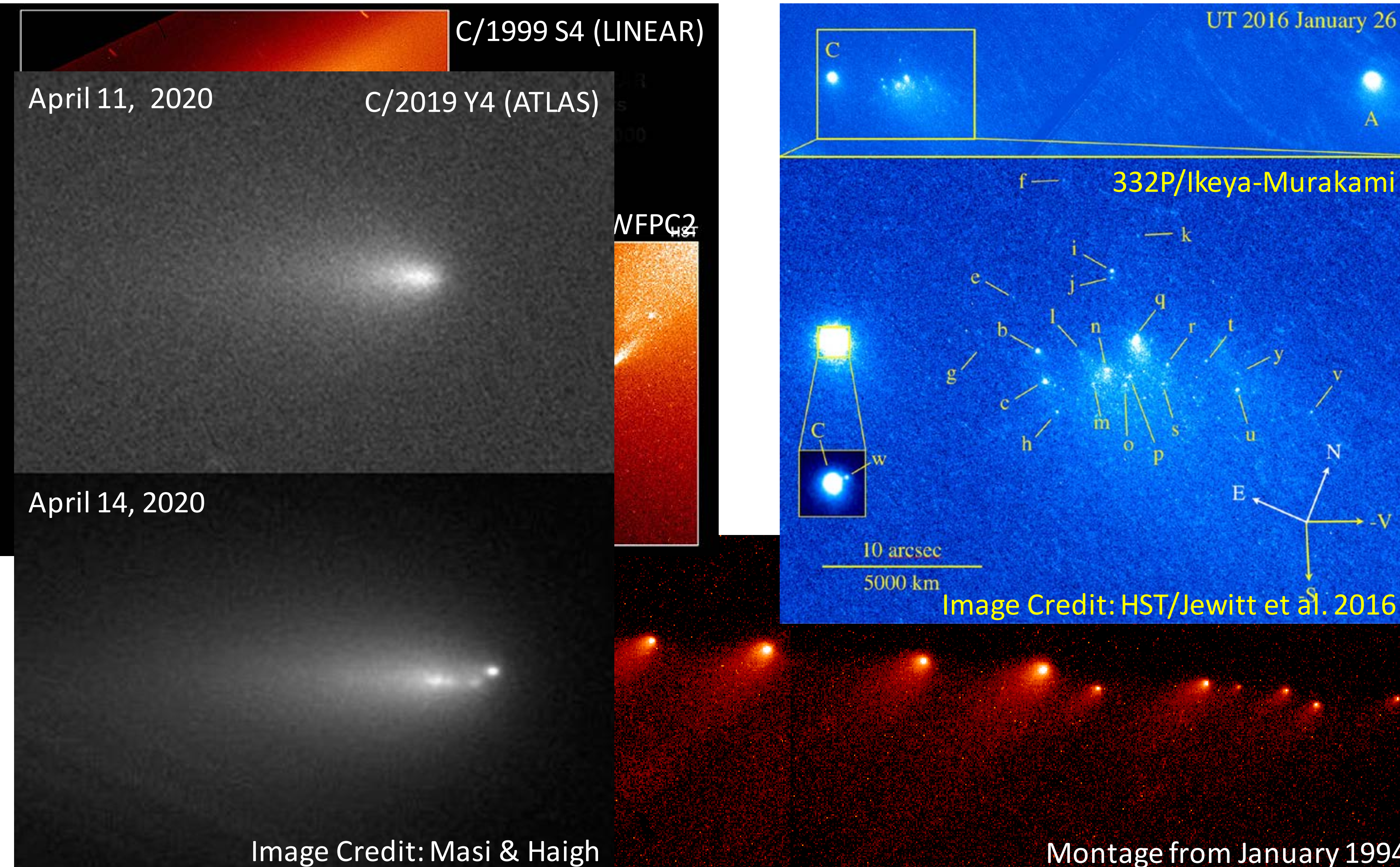


Uniqueness in the comet population to be aware of

C/2016 R2 (PanSTARRS) a 1st of its kind: CO dominated, N_2 rich comet inside 3 AU



High resolution images of fragmented comets

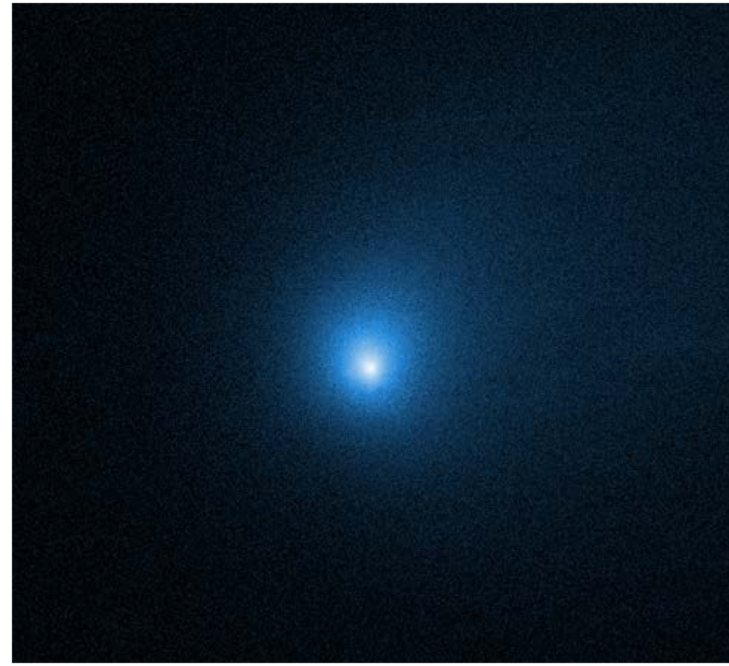


Comet fragmentation is not uncommon

- Fragmentation occurs due to tidal disruption after close encounter (e.g., SL9 with Jupiter), thermal stresses near the Sun (e.g., Kreutz sungrazers), rapid rotation, and explosive outburst of sublimating volatile gases
- Observations catch a glimpse of an outburst or brightening followed by multiple fragments trailing behind the original optocenter
- Often have a principal remnant/s that survive perihelion passage with mini fragments that disintegrate much faster
- Fresh pristine interior material is now exposed
- Some fragmented interiors are compositionally similar and homogeneous (e.g., 73P, C/2001 A2)
- Fragmenting events do not favor location in orbit (perihelion vs. aphelion, inbound vs. outbound) or dynamical type (JFC or Oort cloud comet)
- Mechanism could be a key in evolution to terminal state of a comet

Interstellar objects

Artist's concept of 1I/2017 U1 ('Oumuamua)
Image credit: ESO/Kornmesser



HST image of 2I/Borisov
Image credit: NASA/ESA/Meech/Jewitt

1I/2017 U1 ('Oumuamua)

- Discovered post-perihelion in 2017
- Eccentricity > 1 (1.2)
- No coma/activity, asteroid-like
- Aspect ratio 10:1 unlike any Solar System object
- Color similar to Solar System objects
- Spectra imply organically rich surface

2I/Borisov

- Discovered pre-perihelion in 2019
- Eccentricity > 3
- Coma, comet-like
- Higher CO than any Solar System object
- C_2 depleted, HCN normal
- D spectral type and polarization normal

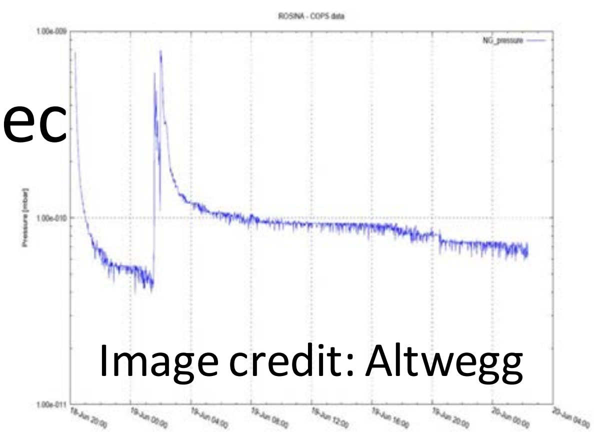
How rare/unique are interstellar comets?

- 2 discovered in span of 3 years
- Assume with dynamical evidence that each originate from a different stellar system
- Each unique formation history
- Calculations range from 0.03 ISO within 6 AU (Hands & Dehnen 2020) to 50 > 50 m in size within 50 AU (Borisov & Shustov 2021) at any given time
- More will be discovered with new deep surveys coming online, this will help refine the statistics

Missions and contaminants

- DI implemented a copper impactor
  - Science results would not suffer confusion by vaporized impactor

- Rosetta saw effects of trajectory maneuver burns
  - Hydrazine and H_2O spikes in mass spec
  - Volatiles that could potentially condense back on surface of comet



Future missions

- Interacting with the surface
  - Landers
  - Sample return
  - Cryogenic sample return (*Holy Grail*)
  - Retain sample integrity is a high priority

- Small sats/cube sats
  - New PIs
  - Next generation of scientists forming small teams
  - If categorization > Cat I, requirements may be onerous
  - Most likely flybys due to mass and trajectory constraints