Comets, Centaurs, and Kuiper Belt Objects (KBOs):

**RELEVANCE:** Comets and KBOs are the planetesimal remnants of planet formation in the outer solar system.

**Dynamical:** Comet, Centaur, and KBOs provide information on the orbital evolution of the solar system from number/spatial distribution, apparition frequency, inclination, and eccentricity.

**Compositional:** Comet, Centaur, and KBOs provide information on the density, temperature, composition, and radial distribution (with heliocentric distance) from volatile ratios (CO:OH), isotopic ratios (e.g. D:H, OD:OH, C\textsubscript{12}:C\textsubscript{13}, albedo, and gas to dust ratios.
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Comets:

- Comets preferentially sample the small end of the planetesimal population.

Comets' primary scientific value comes from their solar proximity:

**Two Major (Compositionally Distinct?) Classes:**

- **Long Period:**
  - (Oort Cloud: 5-10 AU)
  - Random Inclinations
  - High Eccentricity (Aphelia > 100 AU)
  - Long Periods
  - Lower Inclination Dispersion
  - Smaller Aphelion (< 100 AU)
  - Shorter Periods

- **Short Period:**
  - (Kuiper/Edgeworth: 40 AU)

・Shorter Periods
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Comet Science Goals for the Coming Decade:

Fundamental Questions:

• What is the (chemical/structural/isotopic/mass fraction) composition of cometary nuclei?
• How does the composition vary among classes of comets (KBO vs. Oort vs. Extra solar?)?
• How do variations in composition respectively reflect formation, evolution, heliocentric distance, or unresolvable characteristics?
• What aspects of comets can be used to constrain models of planetary system formation?
• What is the relationship between comet nuclei and KBOs/Centaurs?

Recommended Approach:

• In situ measurements of comets with robot probes (e.g., CONTOUR, Deep Impact, Rosetta).
• Remote sensing of comets from the Earth and Space.
• Categorization and sampling.
• Exploring the extremes of small and large heliocentric distances.
• Study of evolution over full orbit cycles (inbound to outbound).
• Coordination with probes.
Indirect Scientific Relevance and Goals:

**Relevance:** Comets are natural astrophysical laboratories for photochemistry, fluorescence, gas kinetics, and plasma processes.

- Photochemistry (rates and branching ratios)
- Fluorescence (g-factors, detailed balance)
- Gas kinetics (collisional mixing to exospheric vectorial flow)
- Plasma Interactions (charge exchange, ion-pickup, MHD)

**Relevance:** Comets interact with the Sun and Solar Wind.

- Comet ion interactions with magnetized solar wind
- Charge exchange with highly ionized solar wind component
- Photochemical sensitivity to solar FUV-EUV flux
- Variable sampling of solar latitudes (low cost Ulysses)
Comet Science Targets in the Ultraviolet:

- Spatial distribution, isotope ratios, state structure, temperatures, and production rates of:
  - Primary coma species (H, C, O, S, CS, CO\textsubscript{EUV-NUV}, OH)
  - Trace neutrals (H\textsubscript{2}, S\textsubscript{2}, Ar)
  - Ion Species (CO\textsuperscript{+}, CO\textsubscript{2}\textsuperscript{+}, CN\textsuperscript{+}, O\textsuperscript{+} - Response vs. solar wind activity and EUV flux)

- Advantages:
  - Low background continuum.
  - Ground states.
  - Higher energy interactions.
  - Photochemical end states.

- Detection and mapping of the lower cascade lines of highly state solar wind ions including:
  - O V and C VI near 525Å (H, C, O, S, CS, CO\textsubscript{EUV-NUV}, OH)
  - O VI at 1034 Å
  - C III at 977Å
  - Ne VIII at 448Å
Useful Capabilities for the HST Telescope:

- Spatial Resolution: The HST-STIS performance of 0.06-0.1" is adequate.
- Aperture: HST-Class is enough if we make use of higher sensitivity detectors, more efficient gratings, and high throughput filter designs.
- Bandpass: Ideally, 43.0-310.0 nm (Capture >55 nm in second order).
- Moving Target Guiding.
- Several comet specific filters (OH, CO, CO$_2$, C, S, CS, dust).
- Echelle (or high res.) spectroscopy (5-10 km/sec velocity resolution)
- Field of View: >8 arcminutes nominal. Wide field option of 20 to 30 arcminutes with reduced spatial resolution (focal reducer).
- Wide-Field H Ly-alpha line shape mapping (R > 10$^5$)

Size of the Sun
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Programmatic Requirements:

The Constraint: We have never had the capability to observe comets in the inner solar system where they are most active.

- Observe short and long term changes in individual object properties
- Scale lengths decrease
  - Follow for entire orbits
- Solar wind interaction more pronounced
- Solar wind variations with cycle and solar latitude
- Rapid changes in temperature and activity levels
- Statistical samples of composition
- Outbursts and disruptions (Deep Impact)
Centaurs and the Kuiper Belt:

- KBOs and Centaurs preferentially sample the high end of the Planetesimal population:

- KBOs and short period comets are thought to be parts of the same population:

- KBOs are relatively numerous (50,000-100,000 over 100 km in diameter):

- Centaurs represent bridging bodies, some comet-sized and all close enough to the Sun to have significant gas production.
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Populations and Dimensions:

**Classical Belt:**
- **Plutinos:**
  - Occupies the region between 40-49 AU
  - Clustered in the region near 40 AU
  - Stable orbits with low eccentricity and inclination scatter
  - Stable orbits with a 3:2 orbital resonance with Neptune
  - Remnant of protoplanetary disk
  - Pluto/Charon are members

**Scattered Belt:**
- **Centaurs:**
  - Aphelia out to 100 AU
  - Aphelia of 5-40 AU
  - High inclination scatter
  - Wide size distribution
  - Not consistent with planetary dynamical interaction
  - Unstable orbits require recent injection to the solar system
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Size Distributions:

KBOs:
- Substantial Observational Bias
- Sizes from ~100 km up to Pluto

Centaurs:
- Dynamical Bias?
- Sizes from ~10 km to 200 km
Observational Limitations:

Centaurs:

- Gas production more easily studied in the radio
- Dust coma observable in the visible

KBO Surveys:

- Still in reconnaissance phase where all-sky searches are used
- Available field of view trumps from ground telescopes is greater

Spatial Scales in the Outer Solar System:

- No space telescope conceivable in the next 10-20 years will be able to resolve detailed surface features on Pluto, let alone the rest of the Kuiper Belt.
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Take advantage of the following opportunities:

- Contrast increased relative to comparable ground based apertures
- AO systems limited in target opportunities for field studies and wide-field observations

Program: Individual target observations of KBO properties including:

- Rotation Light Curves
- Satellite Searches
- Size/Albedo relationship (Pluto-25%; Varuna-9%)

NUV Photometry/Spectroscopy:

- Search for signatures of surface ices and atmospheric emissions
- Stellar occultations

Fig 3: Lau & Jewitt, AJ Nov 1996
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Useful Capabilities for the HSL Observatory:

Precision Sensitivity:

• Maximize Aperture for Resolution and Effective Area
• Diffraction Limited Image Quality

Broad Bandpass:

• Seeing and Background Advantages Extend to Visible
• Overlap and Direct Comparison with Ground

Filtering and Spectroscopy:

• 5-10Å Broadband Spectroscopy
• Broadband NUV-Visible Filters; Targeted Narrowband in NUV

Campaign Commitment for Characterization Surveys:
The Interplanetary Medium and Heliosphere:

- The Heliosphere is carved out of the Local Interstellar Medium by the solar wind.

- The ionized component of the LISM interacts with the solar wind at a boundary, the Heliopause.

- The neutral component of the LISM penetrates the solar system, where it scatters H Ly-α, is ionized by solar EUV, and charge exchanges with the solar wind.
**Studies:**

The IPM Ly-α emission line contains information about:

- The Temperature and Density of the LISM
- The Properties of the solar wind/LISM plasma interaction
- The Intensity of the solar ionizing radiation field
- The Density of the solar wind.

**History:**

- The Brightness and All-Sky distribution of the IPM has been mapped
- Existing facilities have not done as well with line shape studies
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Useful Capabilities for the HSL Observatory:

**Precision Sensitivity for Diffuse Targets:**

- Wide-Field Aperture Summation Photometry (also good for certain comet lines)
- Very High ($>10^5$) Spectral Resolution (both wide and narrow field)
  - New Technology for wide field:
    - UV FPI?
    - Reflective SHS?