# NEAR-PERIHELION OBSERVATIONS OF COMET HALLEY FROM SHUTTLE ORBITER

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## Abstract

The goals of cometary research, articulated by several comet science working groups, imply that it would be desirable to (1) observe comets from space, and (2) to make synoptic sequences of comet observations. Intercept missions and the Space Telescope will return unique data on Comet Halley, but will leave important gaps in the observational coverage of the comet's activity, especially around the time of perihelion passage. A cometary instrument package of modest size could be assembled to share space in the Shuttle cargo bay with other payloads; this approach should be economical enough to permit scheduling such a package for several flights during Halley's apparition, and thus partially fill the observational gaps left by ST and the intercept missions.

## Introduction

The goals of cometary research have been articulated by several comet science working groups (for example, reference 1). Lists of goals typically include: (1) Determine the chemical nature and physical structure of cometary nuclei, and characterize changes that occur as functions of time and orbital position; (2) Characterize the chemical and physical structure of cometary atmospheres and ionospheres, and their development as a function of time and orbital position; (3) Determine the nature of comet tails, and characterize their interactions with the solar wind.

I want to emphasize two recurrent themes in this list: first, determination of chemical composition, and second, tracing the evolution of various cometary phenomena as functions of time and orbital position. It is belaboring the obvious to list the advantages of observing comets from space. First, molecular vibrational and electronic bands and atomic resonance lines, which will provide the best data on chemical composition and physical state, are typically in the vacuum ultraviolet and are therefore unobservable from the ground. Second, synoptic sequences of observations aimed at tracing the evolution of cometary phenomena would not have their continuity interrupted by terrestrial weather. In fact, there will be practical limitations on synoptic observations of Halley from space, as I shall discuss later.

## First Digression: Halley Intercept Missions

Observations of Comet Halley from space will fall into two categories: the more-or-less *in situ* observations from intercept missions, and remote observations from Earth orbit. The subject of this paper is clearly the latter category, but I want to digress briefly to emphasize that both categories will be valuable, and complementary, especially if a NASA intercept mission is not flown. The Giotto and Planet A missions will provide "snapshots" of the comet's physical state, returning unique data on the nucleus, fields and particles, and cometary dust *at a particular time and orbital position*. Synoptic sequences of remote observations will be needed *to relate the ground truth returned* by these missions to the evolution of cometary phenomena. A collateral reason for remote observations made in conjunction with intercept missions is that observations from widely separated vantage points may offer a possibility of studying cometary phenomena in three dimensions.

## Second Digression: Space Telescope

Space Telescope (ST) will have an instrument complement with unprecedented spatial resolution and sensitivity (Table 1). It will be on-orbit throughout the 1986 apparition of Halley, and therefore one might expect it to make long sequences of comet observations. However, ST has a

TABLE 1. Space Telescope Instrument Complement with Unprecedented Spatial Resolution and Sensitivity.

| Instrument | | Detector(s) | Wave length range | Field of View | Angular Resolution | Spectral Resolution | Polarimetry | Dynamic Range | Sensitivity |
|---|---|---|---|---|---|---|---|---|---|
| Wide-Angle/Planetary Camera | f/12.9 | Si CCD's with coronene coating | 1150Å to 11,000Å | 2,67 arc-min$^2$ | 1 pixel = 0.10arc-sec | Defined by bandpass filters. (band-passes unspecified) | None | Approx. 7.5 visual magnitude | $m_Y \simeq$ 26 for point srce (S/N $\simeq$ 10 in 3000 sec) |
| | f/30 | | | 68.7arc-sec$^2$ | 1 pixel = 0.043 arc-sec | | | | |
| Faint-Object Camera | f/96 | SIT vidicons coupled to 3-stage intensifiers | 1150Å to "visible" | 11 arc-sec$^2$ | 1 pixel = 0.022 arc-sec | 44 selectable band-pass filters (band-passes unspecified) | Polaroid-type analyzers | Bright limits are a function of read out format. Range from 10.4 to 16.4 $m_Y$/arc-sec$^2$ for selectable formats from 64x64 to 512x512. | |
| | f/48 | | | 22 arc-sec$^2$ | 1 pixel = 0.044 arc-sec | 14 selectable filters (bandpasses unspecified). Also "spectrograph "mode: $\lambda/\Delta\lambda$ approx 2300 in range 1200 Å to 5400Å | Unspecified | | |
| Faint-Object Spectrograph | | "Blue-Biased" Digicon<br>"Red-Biased" Digicon | 1150 to 5800Å<br>2200 to 7500Å | 0.1 arc-sec to 4.3 arc sec, selectable by means of 10 apertures. Each digicon has a special 0.3 arc-sec aperture for spectro-polarimetry. | | $\lambda/\Delta\lambda \simeq 10^3$ or $\simeq 10^2$ (selectable) | Polarization analyzer can measure degree and position angle of linear polarization. Limited to wavelength range 1200 to 3000Å | | Faint limits for blue point sources (AOV-BOV stars) correspond to<br>$m_Y \simeq 22$ for $\lambda/\Delta\lambda = 10^3$<br>$m_Y \simeq 25$ for $\lambda/\Delta\lambda = 10^2$ |
| High-Resolution Spectrograph | | CsI/LiF Digicon<br>CsTe/MgF$_2$ Digicon | 1050 to 1700Å<br>1150 to 3200Å | 0.25 and 2.0 arc sec, selectable by means of two entrance apertures. | | $\lambda/\Delta\lambda \simeq 2\text{x}10^4$ to $1.2\text{x}10^5$ (selectable) | None | | Faint limit of AOV point srce, at 2400Å (S/N $\simeq$ 10) correspond to $m_Y = 14.5$ for $\lambda/\Delta\lambda = 2\text{x}10^4$<br>$m_Y = 11.5$ for $\lambda\ \Delta\lambda = 10^5$ |
| High-Speed Photometer | | S-20 image dissectors (2)<br>Cs-Te image dissectors (2) | 2000Å to 6000Å<br>1150Å to 3000Å | 0.4 and 1.0 arc-sec, selectable by means of two sets of entrance apertures for each detector. | | Defined by band-pass filters (band-passes unspecified) 12 per detector. | None<br>Polaroid-type coating on "some" filters: 4 orientations at 45° increments. | Dynamic range $\simeq 10^8$, with "insignificant" departures from linearity over first 6 decades. | |

Sun-viewing constraint of 45 to 50 degrees: it will be unable to observe Halley for a period extending from about 6 weeks before to about 6 weeks after perihelion passage. This is precisely the part of the apparition when the level of comet activity will be highest, and changing most rapidly. Moreover, competition for ST observing time will be fierce, so it is problematical whether enough time could be committed to make meaningful sequences of observations to follow the evolution of cometary phenomena. The most important contribution from ST will probably be occasional observations of the comet's activity well before and after perihelion passage, out to unprecedented heliocentric distances.

The International Ultraviolet Explorer (IUE) also deserves mention. IUE has already been operational for more than two years, but there is at least a remote possibility that it could be kept operational until 1986. However, IUE suffers from the same Sun-viewing constraint as ST, and would therefore be no more capable than ST of observing Halley near perihelion. There does not appear to be a compelling reason to make heroic efforts to keep IUE operational for another six years.

## Observations from Shuttle

The intercept mission and ST will clearly leave an important gap in the observational coverage of Halley. This gap would be filled most satisfactorily by a free-flying, orbital comet observatory specifically designed to operate even at very low solar elongation angles, near perihelion passage. It is unlikely that such a facility would be in the cards before 1986, however. The next best approach appears to be a package of comet instruments to fly on the Shuttle.

The Shuttle Orbiter is not an ideal platform for synoptic comet observations because each orbital mission will last for only about one week. A comet instrument package would therefore have to be flown on several missions. However, it is unlikely that even one Shuttle mission, much less several, could be dedicated exclusively to comet observations. We should therefore consider a package small enough to share the Shuttle manifest with other payloads, and thereby economical enough to be flown several times during the apparition. A package occupying a single Spacelab pallet segment, or the equivalent, would fit this requirement.

The International Halley Watch Science Working Group discussed the performance specifications that such an instrument package would have to meet in order to return "useful" observations. Their recommendations are summarized in Table 2. I have generated a list (Table 3) of 17 instruments from Spacelab missions 1 and 2 (references 2 and 3), Galileo, and astrophysics instruments for which definition studies are in progress; this list should not be considered exhaustive but merely illustrative. From Table 3, I developed a model instrument package which more or less meets the specifications recommended by the IHW Science Working Group. Table 4 presents a possible set of options for the model package. Each option represents an increase in both cost and in science returned: I believe the science return grows more rapidly than the cost.

## Conclusions

A small package of instruments, which could be scheduled to fly on several Shuttle missions, would be an effective means of extending observational coverage of Comet Halley to include the critical part of the apparition near perihelion passage. This approach would certainly be "second best" to a dedicated orbital comet observatory. However, it would be feasible in the sense that payload space appears to be available for at least two flights during the apparition, and instruments exist, or could be modified, or are being developed, which could be integrated into a package of the required size, and which would return useful physical data on the comet.

## References

1. NASA Technical Memorandum 80432, "Report of the Comet Science Working Group" (1979).

2. NASA Technical Memorandum 78173, "Spacelab Mission 1 Experiment Descriptions" (1978).

3. NASA Technical Memorandum 78198, "Spacelab Mission 2 Experiment Descriptions" (1978).

## TABLE 2

## DESIRED SCIENCE CAPABILITIES *

| | CAPABILITY | ANGULAR FOV/RESOLUTION (radians) | SPATIAL FOV/RESOLUTION (km at 1.2 AU) | SPECTRAL RESOLUTION ($\lambda/\Delta\lambda$) | SPECTRAL RANGE | INVESTIGATIONS |
|---|---|---|---|---|---|---|
| 1) | Wide-Field Multispectral Imaging | $10^{-1}/10^{-4}$ | $1.5x10^{7}/2x10^{4}$ | 10 | 0.115 - 1.10 μm | Gaseous species, particles in outer coma and tail. |
| 2) | High Resolution Multispectral Imaging | $10^{-2}/10^{-5}$ | $1.5x10^{6}/2x10^{3}$ | 10 | 0.115 - 1.10 μm | Parent/daughter species in inner coma. |
| 3) | High Resolution Spectrophotometry | $10^{-2}/10^{-4}$ | $1.5x10^{6}/2x10^{4}$ | $10^{4}$ | 0.115 - 2.0 μm | Band structure of molecular and ionic species. |
| 4) | Infrared Radiometry | $5x10^{-2}/$ ? | $7.5x10^{6}/$ ? | 10 | 2.0 - 100 μm | Particle physical properties in tail. |

* As identified by IHW Science Working Group.

## TABLE 3

## SAMPLE INSTRUMENTATION

| INSTRUMENT | HERITAGE | P.I. | EXISTING CHARACTERISTICS | APPLICABILITY TO DESIRED CAPABILITY | POTENTIAL MODIFICATIONS | COMMENTS |
|---|---|---|---|---|---|---|
| 1) Imaging Spectrometric Observatory | Spacelab 1 | M.R. Torr (U. Mich.) | 0.02 μm - 1.2 μm at $\lambda/\Delta\lambda \simeq 10^3$<br>Can observe within 8° of Sun. | 3 * | ? | Spectral resolution not as good as desired. Instrument pointing partially by Orbiter ACS |
| 2) Microwave Remote Sensing Experiment | Spacelab 1 | M. Herse (CNRS) | Can operate as passive X-band radiometer | - | ? | Electronic rack goes inside pressurized Spacelab module. |
| 3) ATMOS | Spacelab 1<br>Spacelab 3 | C.B.Farmer (JPL) | 2-16 μm at $\lambda/\Delta\lambda \simeq 10^2$ | - | Would require entirely new detectors to observe comet. | Resides in Scientific Airlock of Spacelab pressurized module. |
| 4) Grille Spectrometer | Spacelab 1 | M. Ackerman (ESA) | 2.5 - 12 μm at $\lambda/\Delta\lambda$ = ? | - | Would require entirely new detectors to observe comet. | |
| 5) Waves in OH Emission Layer | Spacelab 1 | M. Herse (CNRS) | 0.758 -0.830 μm (OH emission band) | 1 ? | Filter wheel with range of wavelength coverage. | Uses Orbiter AC3 for pointing. Very limited spectral range. |
| 6) Atmospheric Emission Photometric Imaging | Spacelab 1 | S.B. Meude (Lockheed) | 0.28 μm → ?<br>6° - 20° FOV | 1 ? | Filter wheel with range of wavelength coverage. | Modular LLLTV system with "evolutionary felxibility" |
| 7) FAUST Camera | Spacelab 1 | C.S. Bowyer (UC Berkeley) | 0.11 - 0.2 μm at $\lambda/\Delta\lambda \simeq 10^{-1}$<br>FOV = $1.5x10^{-1}$ rad<br>Res.= $6x10^{-4}$ rad | 1 | ? | Limited wavelength range. Pointing by Orbiter ACS. |

SAMPLE INSTRUMENTATION

| INSTRUMENT | HERITAGE | P.I. | EXISTING CHARACTERISTICS | APPLICABILITY TO DESIRED CAPABILITY | POTENTIAL MODIFICATIONS | COMMENTS |
|---|---|---|---|---|---|---|
| 8) Very Wide Field Camera | Spacelab 1 | C. Gourtes (France) | 0.13 - 0.25 μm<br>FOV = 0.2 - 1.0 rad | 1 ? | ? | Has "spectrometric" and "photometric" modes. Pointing by Orbiter ACS. |
| 9) Small Cooled IR Telescope | Spacelab 2 | G. Fazio (SAO) | 4 μm - 120 μm<br>FOV = 0.05 rad | 4 * | ? | Pointing partially by Orbiter ACS. Requires dedicated pallet segment. |
| 10) Solar Magnetic and Velocity Field | Spacelab 2 | A. Title (Lockheed) | | - | ? | Polarimeter, IPS-pointed. |
| 11) High Resolution Telescope and Spectrograph | Spacelab 2 | G. Brueckner (NRL) | 0.112 - 0.170 μm at $\lambda/\Delta\lambda \simeq 3\times10^4$<br>Angular res. $10^{-5}$ rad | 3 | Would require entirely new detectors to look at comet. | IPS-pointed. Narrow wavelength range. |
| 12) CCD Camera | Galileo | --<br>(JPL) | $\sim$0.3 - 1.0 μm<br>FOV $\simeq 6\times10^{-2}$ rad<br>Res $\simeq 7\times10^{-5}$ rad | 1 * | Coronene-doped CCD's.<br>All-reflecting optics.<br>Appropriate filters. | "Flight Spare" Galileo instrument would need modification for comet observations. |
| 13) UV Spectrometer | Galileo | C. Hord (U. Colo) | 0.115 μm - 0.43 μm<br>$\lambda/\Delta\lambda \sim 2\times10^2$<br>FOV $\simeq 2\times10^{-2}$ rad | 3 * | Baffling to permit observation close to $\odot$. | Would require a modest amount of development for comet observations. Spectral resolution not as good as desired. |
| 14) UV Imaging Telescope | Spacelab | T. Stecher (GSFC) | 0.112 - 0.28 μm<br>FOV = $1.2\times10^{-2}$ rad<br>Res = $1.5\times10^{-5}$ rad | 2 * | Filters appropriate for comet observation.<br>Sun shade. | IPS=pointed. Limited wavelength coverage. |

SAMPLE INSTRUMENTATION

| INSTRUMENT | HERITAGE | P.I. | EXISTING CHARACTERISTICS | APPLICABILITY TO DESIRED CAPABILITY | POTENTIAL MODIFICATIONS | COMMENTS |
|---|---|---|---|---|---|---|
| 15) UV Spectroscopy Experiment | Spacelab | A. Davidsen (Johns Hopkins) | 0.11 - 0.19 μm at<br>$\lambda/\Delta\lambda \simeq 10^2$<br>res $\simeq 6\text{x}10^{-4}$ rad | 3 * | Possible extension of wavelength coverage to 0.3 μm. | IPS-pointed.<br>Limited wavelength coverage. |
| 16) UV Photometry Polarimetry | Spacelab | A. Code (U. Wisc) | 0.14 0.35 μm at<br>$\lambda/\Delta\lambda \simeq 5\text{x}10^2$<br>res $\simeq 3\text{x}10^{-4}$ rad | 3 | | IPS-pointed.<br>Polarimetry of dust grains-all 4 Stokes parameters.<br>Basically a point-source instrument. |
| 17) Schwarzschild Camera | Sounding Rocket | T. Stecher (GSFC) | "UV" instrument<br>FOV = 0.2 rad<br>res = $1.5\text{x}10^{-4}$ rad | 1 * | Interface to Spacelab pallet | Approx. $1 to $3M to develop for Spacelab comet observations. |
| 18) Multichannel Mapping Spectrometer | Instrument Devel. | T. McCord (U. Hawaii) | 0.25 - 4.0 μm<br>Spatial resolution set by "fore-optics" | 3 * | Interface to Spacelab | Approx. $3 to $10M,<br>3 years for development.<br>Unique spectral coverage. |

Table 4

## SAMPLE "MENU" OF SMALL-SCALE INSTRUMENTS

| | | | |
|---|---|---|---|
| Imaging Spectrometric Observatory | Spacelab 1 | Spectrophotometry from 0.02$\mu$m to 1.2$\mu$m at 2 to 6Å resolution. Can view within 8° of Sun. Spatial resolution approx. 2x$10^4$ km at 1 AU. | Hard-mounted to pallet; therefore pointing partly by S/C attitude control, partly by scanning mirror. |
| FAUST Telescope | Spacelab 1 | Spectroscopy from 0.11$\mu$m to 0.20$\mu$m at 30 to 200Å resolution. Photometry over 0.1$\mu$m bandpass. Spatial resolution approx. $10^5$ km at 1 AU. | Hard-mounted to pallet; therefore pointing entirely by S/C attitude control. |
| Ultraviolet Spectrograph | Galileo | Spectroscopy from 0.115$\mu$m to 0.43$\mu$m at 7 to 14Å resolution. Spatial resolution approx. 4x$10^6$ by 3x$10^5$ km at 1 AU. | Requires modification: baffles to permit observation at low Sun angles. |
| CCD Camera | Galileo | Multispectral imaging from 0.40 to 1.0$\mu$m. Spatial resolution approx. $10^4$ km at 1 AU, with $10^7$ km field of view. | Requires modification: Baffles for low-Sun-angle. Desirable further modifications would permit extension of spectral coverage into UV, provide higher spatial resolution. |
| NIMS | Galileo | Photometry/radiometry from 0.7 to 5.2$\mu$m. | Requires $10^5$ sec integration to achieve $S/N = 10^2$. |