# THE PROPOSED COLUMBUS MISSION: HIGH AND LOW RESOLUTION SPECTROSCOPY IN THE 100-2000 Å SPECTRAL REGION

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For the past year a Joint Working Group of NASA and ESA scientists and engineers has been defining the scientific objectives and instrument parameters for a proposed satellite to obtain far and extreme ultraviolet spectra of stars, interstellar gas, solar system objects, and galaxies. The project, now called Columbus, incorporates the scientific goals of the previously proposed NASA Far Ultraviolet Spectrograph Explorer (FUSE) and ESA Magellan missions.

The prime spectral range of Columbus, 900-1200 Å, cannot be observed by IUE or Space Telescope. In this spectral range Copernicus was able to observe bright stars ($m_V \lesssim 6$) with high resolution and the Hopkins Ultraviolet Telescope (HUT) will observe faint sources at low resolution, but Columbus will be the first instrument capable of high spectral resolution observations of faint sources ($m_V \approx 17$). High resolution spectra in the 900-1200 Å region will permit studies of the Lyman lines of atomic H and D, the molecules $H_2$ and HD, resonance lines of C III and O VI, and other species listed in Table 1. Columbus also is being designed to observe the 1200-2000 Å spectral region at high resolution, permitting measurements of many stages of ionization for the same atom (i.e. N I, II, III, V; C II, III, IV; and S II, III, IV, VI). The broad coverage of ionization states is essential for the analysis of interstellar and stellar plasmas where the ionization balance can be quite complex.

Table 1. Important Spectral Lines Observable by Columbus

| Species | log $T_e$ | 912-1216 Å Lines | Species | log $T_e$ | 100-912 Å Lines |
|---|---|---|---|---|---|
| H I, D I | | 1216, 1026, 973...912 | Ne VII | 5.8 | 465 |
| $H_2$, HD | | many lines 912-1120 | Ne VIII | 5.9 | 770, 780 |
| N I | | 951, 964, 1133, 1200 | Mg X | 6.1 | 610, 625 |
| A I | | 1048, 1066 | Fe XII | 6.3 | 187 |
| N II | 4.4 | 916, 1084, 1085 | Si XII | 6.4 | 499, 512 |
| C III | 4.8 | 977, 1175 | Fe XV | 6.5 | 284 |
| N III | 4.8 | 991 | Fe XVI | 6.6 | 335, 361 |
| S III | 4.8 | 1012, 1190 | Fe XVIII | 6.8 | 104 |
| P IV | 5.0 | 951 | Fe XIX | 6.9 | 108 |
| S IV | 5.0 | 1062 | Fe XX | 7.0 | 121 |
| P V | 5.2 | 1118, 1128 | Fe XXI | 7.2 | 103, 138, 150 |
| O VI | 5.5 | 1032, 1038 | Fe XXIV | 7.5 | 192, 225 |
| S VI | 5.5 | 933, 944 | | | |

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Table 2. Prime Science Program of Columbus

| Science objective | Spectral features to be observed | Astronomical targets |
| --- | --- | --- |
| Primordial D/H ratio ratio in unprocessed gas | H, D Lyman lines $H_2$, HD | Interstellar gas in distant regions of galaxies |
| Morphology and kinematics of the hot component of interstellar matter | O VI, Fe XV, Fe XVI etc. | Disks and halos of galaxies |
| Hot ($10^5$–$10^7$ K) gas in active galactic nuclei | C III, O VI, Fe XV?, Fe XVI? | Quasars, Seyfert galaxies |
| Global energy balance of $10^4$–$10^7$ K plasmas in outer atmospheres of stars | C III, O VI, Fe XV, Fe XVI, etc. | A–M main sequence, F–K giants, hot stars, binary systems |
| Energy balance of $10^4$–$10^7$ K plasmas and physical processes during flares | O VI, Fe IX–XXIV | Transient stellar sources and binary systems |
| Evolution and winds of stars (mass loss, acceleration mechanisms, physical properties) | C III, O VI, Fe XV Fe XVI, etc. | Young and old hot stars, cool stars |
| Physical properties of hot evolved stars (temperature, luminosity, evolution, chemical composition) | EUV continuum, EUV absorption edges and lines | White dwarfs, subdwarfs, nuclei of planetary nebulae |
| Physical processes occurring in the magnetospheres of the giant planets and their satellites | $H_2$, S III–VI, O III, etc. | Neptune aurorae, Io torus |



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A novel feature of Columbus will be the capability for moderate resolution spectroscopy in the 100-900 Å region, which permits observations of plasmas hotter than 300,000 K (see Table 1) simultaneously with observations of the cooler plasmas. Since many types of stars, galactic nuclei, and the interstellar medium contain both cool and very hot plasmas, the ability of one instrument to observe all temperature regimes in the same object nearly simultaneously will be a powerful tool for solving many fundamental problems. Table 2 lists some of these scientific objectives; the types of astronomical objects to be studied; and the important spectral features to be observed. A more detailed description can be found in the Final Report of the Science Working Group for the Far Ultraviolet Spectroscopic Explorer.

Interstellar opacity will limit the number of objects which can be observed below the Lyman continuum limit at 912 Å. The opacity decreases as $\lambda^3$, however, and interstellar densities are very low ($n_H = 10^{-2}$-$10^{-3}$ $cm^{-3}$) in the hot phase, which probably represents most of the volume of the interstellar medium. Thus, Columbus should be able to observe objects to considerable distances at 100-300 Å in some directions in the Galactic plane (see Fig. 1) and to larger distances perpendicular to the plane, perhaps even outside the Galaxy. In addition, many nearby objects can be observed above 300 Å.

The scientific goals and spectral features summarized in Table 2 are compatible with the tentative telescope and spectrograph parameters given in Table 3. The high resolution capability in the 900-1200 Å region (spectrograph A) is considered prime with a desired total effective area (telescope and spectrograph) of 100 $cm^2$. Coverage of the full spectral range at one time is highly desirable for each spectrograph. Work is now under way to develop more detailed designs for the scientific instrument, spacecraft, orbit, and operations.

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Table 3. Tentative Instrumentation

**Telescope**

~1 m aperture
grazing incidence optics
1 arcsec imaging
long slit

**Spectrograph Capabilities**

| | | | |
|---|---|---|---|
| Spectral Range (Å) | 900-1200 | 1200-2000 | 100-2000 |
| Spectral Resolution ($\lambda/\Delta\lambda$) | 30,000 | 10,000 | 1,000 |
| Spectrograph Type | Rowland? | Echelle | Grazing Incidence |
| Optical Surface Coatings | SiC, Aℓ, Os? | $MgF_2$ | Au |
| Effective Area Specification | 100 $cm^2$ | --- | --- |



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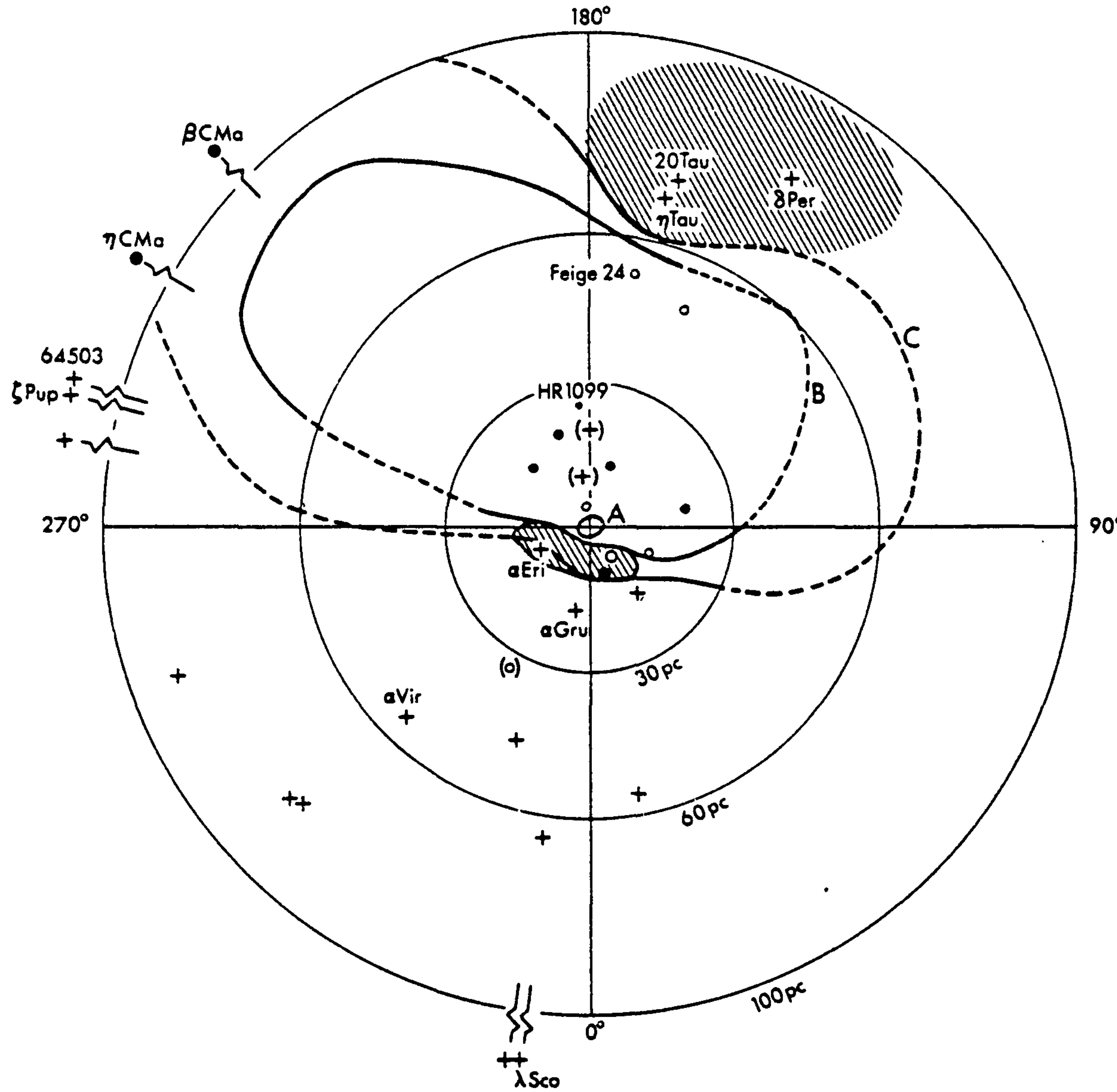


Fig. 1. Neutral hydrogen column density $N_{HI}$ contours projected onto the plane of the galaxy ($b = 0°$). The Sun is at the center of the plot, distances out to 100 pc are indicated, and the direction toward the galactic center ($\ell = 0°$) is at the bottom. Line A is the contour of $N_{HI} \sim 5 \times 10^{17}$ cm$^{-2}$, corresponding to $\tau_{500\ \AA} = 1$, $\tau_{200\ \AA} \approx 0.1$, and $\tau_{100\ \AA} \approx 0.01$. Line B is the contour of $N_{HI} = 25 \times 10^{17}$ cm$^{-2}$, corresponding to $\tau_{500\ \AA} = 5$, $\tau_{200\ \AA} \approx 0.5$, and $\tau_{100\ \AA} \approx 0.05$. Line C is the contour of $N_{HI} \sim 50 \times 10^{17}$ cm$^{-2}$, corresponding to $\tau_{500\ \AA} = 10$, $\tau_{200\ \AA} = 1$, and $\tau_{100\ \AA} \approx 0.1$. All open circles are white dwarfs. Small circles represent stars with $N_{HI} \lesssim 5 \times 10^{17}$ cm$^{-2}$, medium circles represent stars with $5 \times 10^{17} < N_{HI} < 25 \times 10^{17}$ cm$^{-2}$, the large circles represent stars with $25 \times 10^{17} < N_{HI} < 50 \times 10^{17}$ cm$^{-2}$, and the crosses represent stars with $N_{HI} > 50 \times 10^{17}$ cm$^{-2}$. Stars with measured hydrogen column densities but which are located within 10 pc projected distance are not plotted. Data compiled by York and Frisch (from Final Report of the FUSE Science Working Group).



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