Six Years of Astrophysics with the Far Ultraviolet Spectroscopic Explorer

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FUSE Mission Background

• Designed for absorption spectroscopy of point sources between Lyman limit and Lyman alpha
  – D/H, O VI and other species in the Milky Way disk and halo
  – \( \text{H}_2 \) in wide range of environments
  – Wider range of science anticipated
• PI-led Explorer mission: Warren Moos, Johns Hopkins University
• Launched 24 June 1999
• Key partnerships critical to mission success
  – University of Colorado - spectrograph
  – University of California Berkeley - detectors
  – Canadian Space Agency - Fine Error Sensor
  – Centre National Études Spatiales (France) - gratings
• PI-team and Guest Investigators split observing time for first 3-years; 100% GI program thereafter
FUSE Overview

- 905 Å ≤ λ ≤ 1187 Å
- Spectral Resolution
  \[ \Delta \lambda / \lambda \sim 15 \text{ km/s} \]
- Spectrograph apertures
  - 30" x 30"
  - 4" x 20"
  - 1.25" x 20"
- Pointing <1" rms
- Time-tag data for
  \[ F_\lambda < 5 \times 10^{-12} \text{ erg/cm}^2/\text{s}/\text{Å} \]
- 760 km, 25° orbit
Mission Performance

- GI and PI-team programs have addressed a wide range of stellar, galactic, Magellanic Cloud, extragalactic, and planetary science
  - >2300 unique targets
  - >3600 observations
  - 52 Msec science exposure time
  - 340 refereed papers through 2005
- Instrument performance remains excellent
  - No change in spectral resolution
  - Only 10-30% sensitivity loss since launch
- Serious attitude control system problems have been overcome
  - 4 gyro failures (2 remain)
  - 3 reaction wheel failures (1 remains)
  - Sub-arcsec science mode pointing maintained
  - Sky coverage affected
Current Status Under One-wheel mode

- Science observations presently limited to $|\delta| \geq 50^\circ$
- Cycle 7 proposals (Sept 2005) oversubscribed available time by 3.5X
  - Successful proposals announced last month
- Observing efficiency increasing since science operations resumed Nov. 1, 2005 (~500 ksec obtained in December).
- Principal impediment to better science productivity has been a lack of targets at high declinations
  - Cycle 7 programs will substantially remedy this situation
- Further improvements in one-wheel science operations are expected in coming months
- FUSE Project plans to continue operations at least through 2008
  - Cycle 8 proposals will be due in September 2006
Brief Science Topics not Covered later

- Mars and solar system science
- Debris disk of beta Pictoris
- Activity in young A stars
FUSE Finds Evidence of Early Martian Oceans

- Molecular hydrogen in Mars is excited by the Sun’s chromosphere and is seen in emission in FUSE spectra.

- From the derived density of H$_2$ and observations of D/H, HD/H$_2$, and DHO/H$_2$O, a photochemical model indicates a global ocean 1.25 km deep 3.5 Gyr ago.

- Only 4% of the initially accreted water remained on Mars at the end of hydodynamic escape.

- Mars could have had more water, as a proportion of mass, than the Earth.

- Krasnopolsky & Feldman (2001)
Debris Disks: $\beta$ Pictoris

- Beta Pictoris, the prototype young stellar disk system, contains millions of evaporating comets.
- Lack of $\text{H}_2$ FUV absorption (FUSE) plus presence of CO (HST) in $\beta$ Pic is the signature of ongoing cometary evaporation.
- FUSE measurements of $\text{H}_2$ are important signatures of disk evolution. Complement to Spitzer CS disk programs.
- $\text{H}_2$ IR emission from beta Pic disk seen by ISO may imply $\text{H}_2$ has very clumpy distribution.

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Gas in the β Pic Disk
(Roberge et al. - paper 39.05 & in preparation)

- CS dust continuously replenished ($\tau_{\text{dust}} < t_\star$) from solid planetary bodies (collisions)
- Molecular gas has been hard to detect
- C II, C III, O I from FUSE against emission lines
  - C I, Fe I-II... from HST
- New compilation of mid-plane composition
- C >50X, O ~10X solar
  - Reflects composition of parent bodies
- $M_{\text{gas}} \sim 0.004M_\oplus$, Gas-to-dust=0.1: $M_{\text{disk}} = 0.03M_\oplus$
Young A Stars

- Herbig Ae stars are now routinely detected in X-rays
- \( L_x \sim t^{-1} \) for well-dated systems
- FUSE finds excess FUV light and emission lines in Herbig Ae stars that are driving jets.
- Similar features characteristic of majority of Herbig Ae stars.
- Temporal evolution in \( L_{\text{FUV}} \) goes as \( t^{-2} \) to \( t^{-3} \)

See poster by Williger et al. (Session 175)
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Activity in Young A Stars

- O VI and C III emission not limited to Herbig Ae stars; also seen in debris disks (β Pic and HD 9672)
- Temporal evolution is uncertain.

- Young, nearby stellar associations only partially surveyed by FUSE
- Accessible associations include
  - HD 141569 Moving Group (5 Myr)
  - η Cha (8-10 Myr),
  - TW Hya (8-10 Myr)
  - β Pic (12 Myr),
  - Tuc-Hor (30 Myr),
  - AB Dor (late-type stars only, 50 Myr).
Stay Tuned…
There’s More Science to Come!

• Talks in this session
• Poster session 175
• Proceedings of FUSE conference (August 2004) are due out this Spring.
• Still more papers
• Cycles 8, 9…