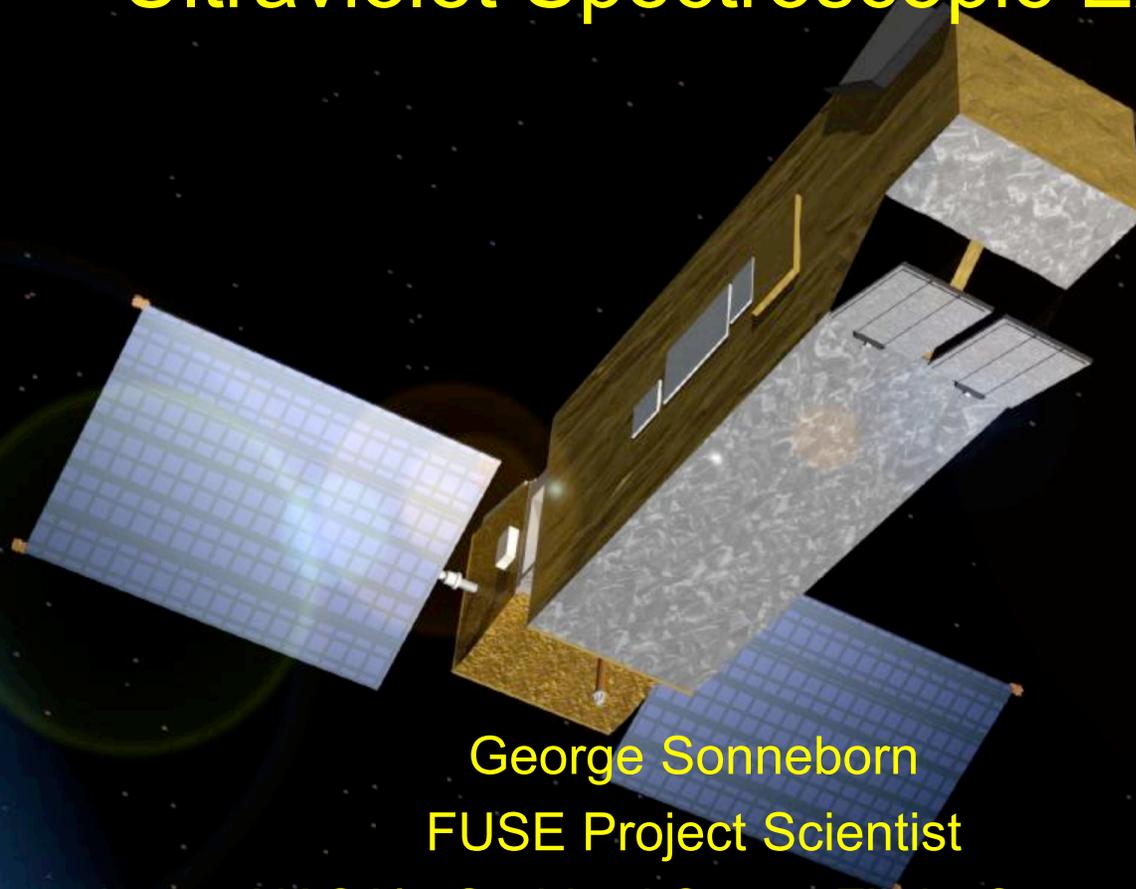


Six Years of Astrophysics with the Far Ultraviolet Spectroscopic Explorer



George Sonneborn
FUSE Project Scientist

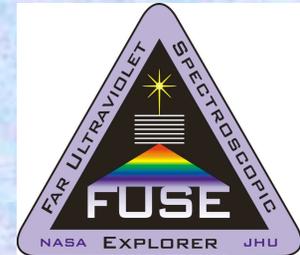
NASA's Goddard Space Flight Center

207th AAS Meeting Washington, DC 12 Jan. 2006

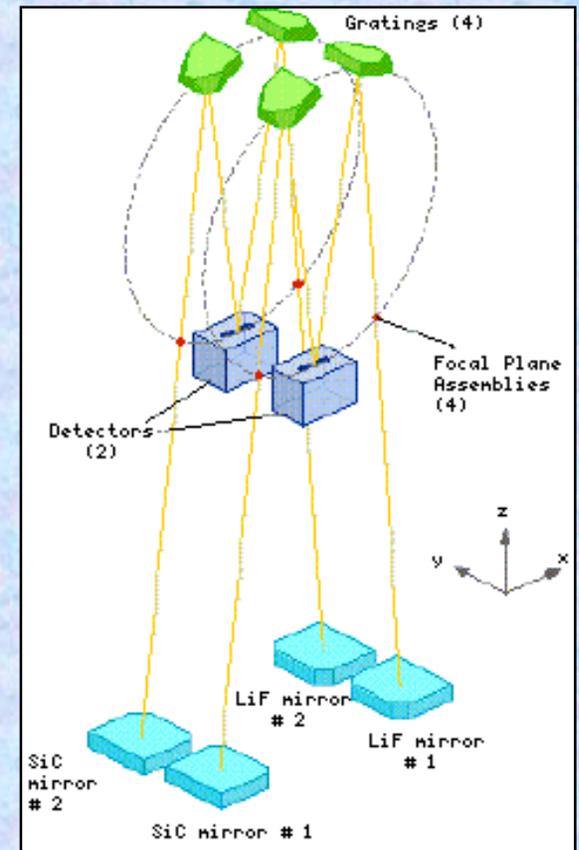
FUSE Mission Background

- 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
 - H₂ 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



- $905 \text{ \AA} \leq \lambda \leq 1187 \text{ \AA}$
- Spectral Resolution
 $\Delta\lambda/\lambda \sim 15 \text{ km/s}$
- Spectrograph apertures
 - 30" x 30"
 - 4" x 20"
 - 1.25" x 20"
- Pointing <math><1'' \text{ rms}</math>
- Time-tag data for
 $F_{\lambda} < 5 \times 10^{-12} \text{ erg/cm}^2/\text{s}/\text{A}$
- 760 km, 25° orbit



12 January 2006

AAS Meeting, Washington, DC

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

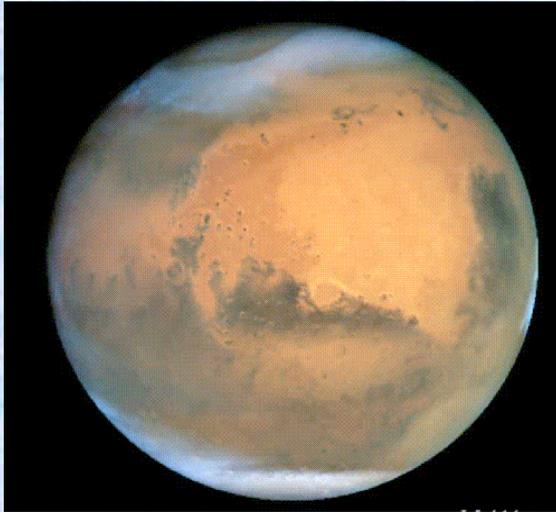
Current Status Under One-wheel mode

- 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

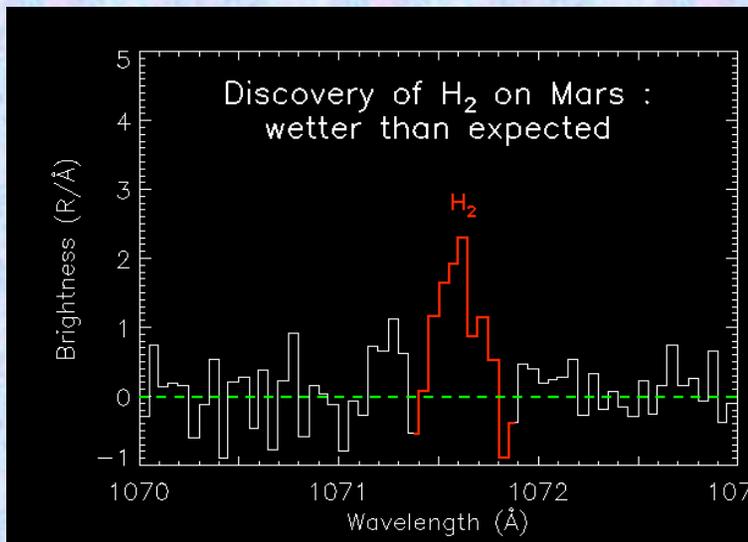
Brief Science Topics not Covered later

- 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_2O , 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 hydrodynamic escape.
- Mars could have had more water, as a proportion of mass, than the Earth.
- Krasnopolsky & Feldman (2001)

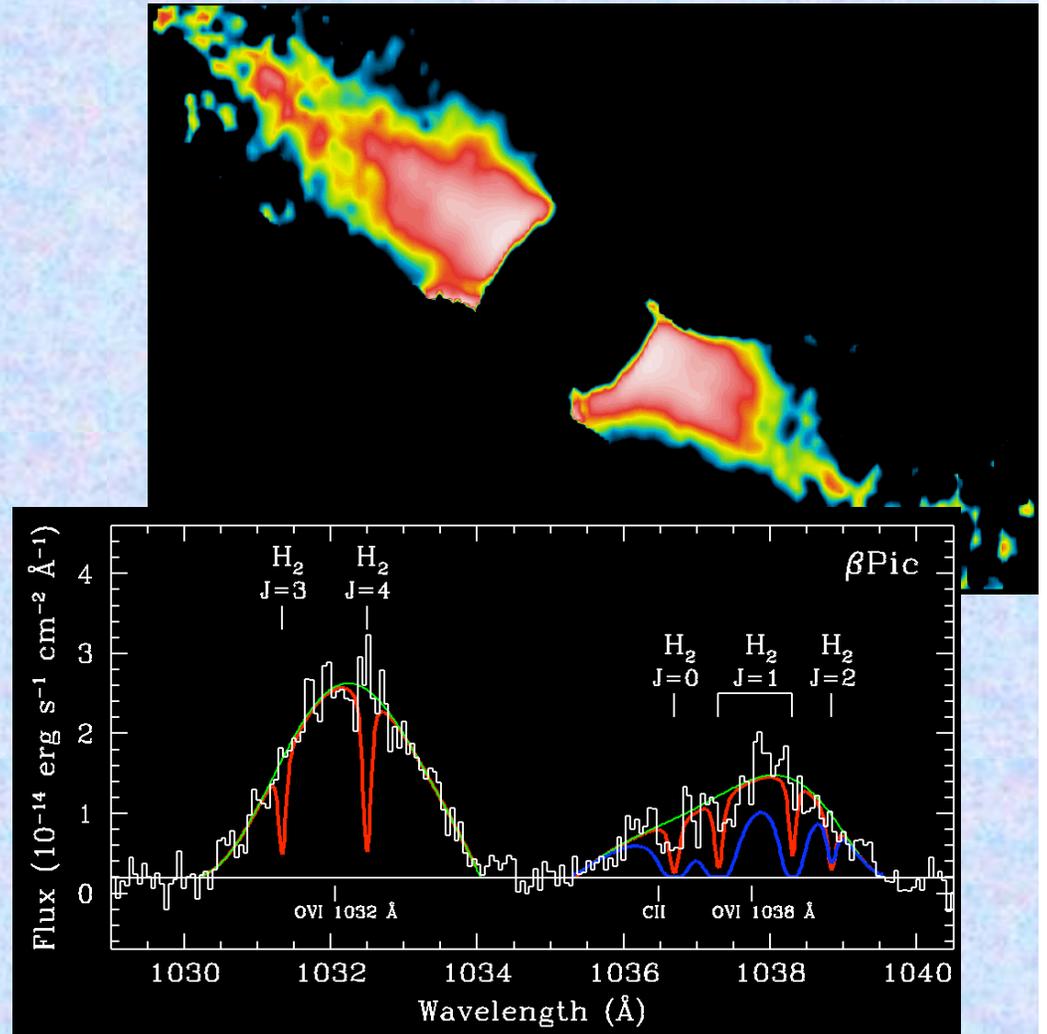


12 January 2006

AAS Meeting, Washington, DC

Debris Disks: β Pictoris

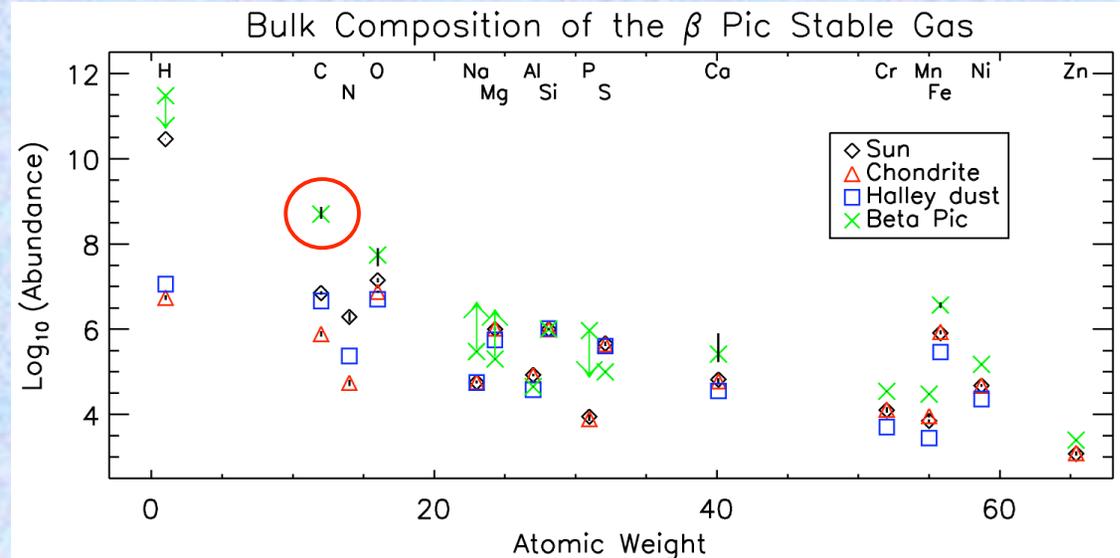
- Beta Pictoris, the prototype young stellar disk system, contains millions of evaporating comets.
- Lack of H_2 FUV absorption (FUSE) plus presence of CO (HST) in β Pic is the signature of ongoing cometary evaporation.
- FUSE measurements of H_2 are important signatures of disk evolution. Complement to Spitzer CS disk programs.
- H_2 IR emission from beta Pic disk seen by ISO may imply H_2 has very clumpy distribution.
- A. Lecavelier, A. Vidal-Madjar, P. Feldman, A. Roberge, *Nature*, August 2001.



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 \sim 10X solar
 - Reflects composition of parent bodies
- $M_{\text{gas}} \sim 0.004 M_{\oplus}$, Gas-to-dust=0.1: $M_{\text{disk}} = 0.03 M_{\oplus}$

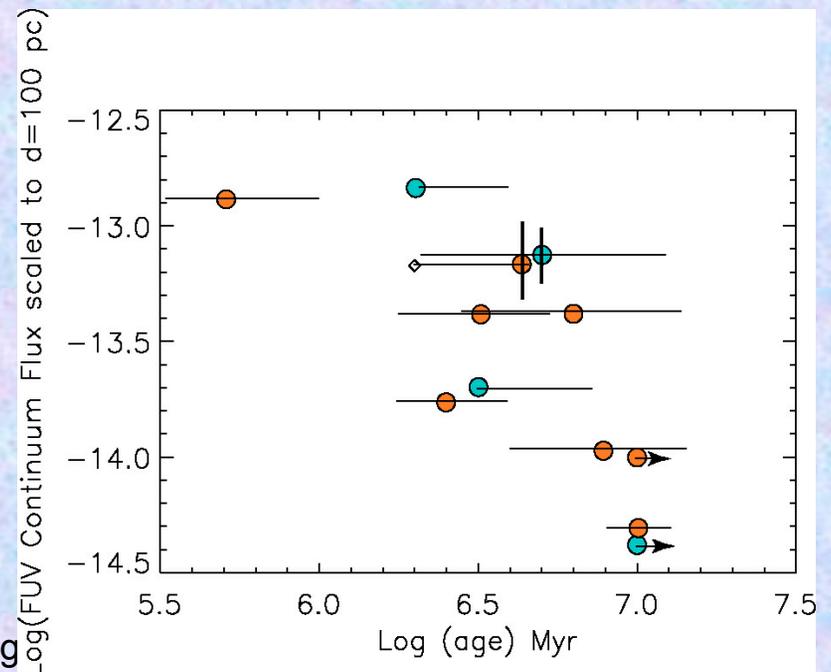
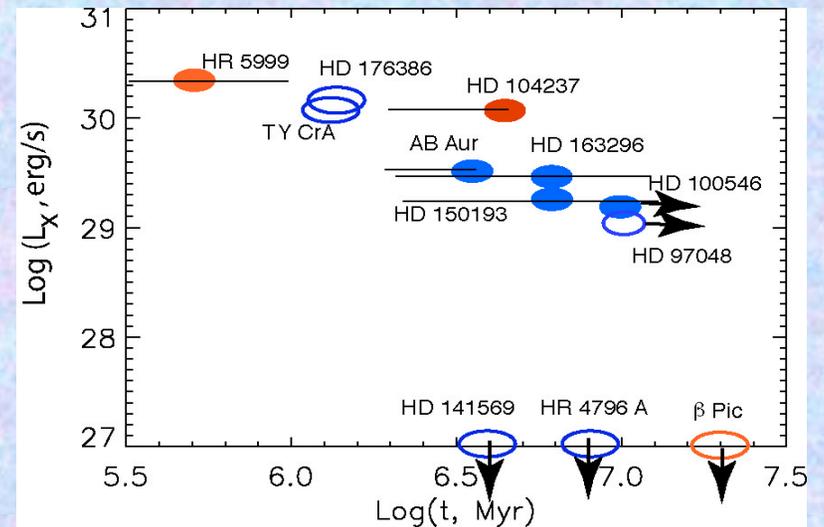


Young A Stars

- 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_{FUV} goes as t^{-2} to t^{-3}

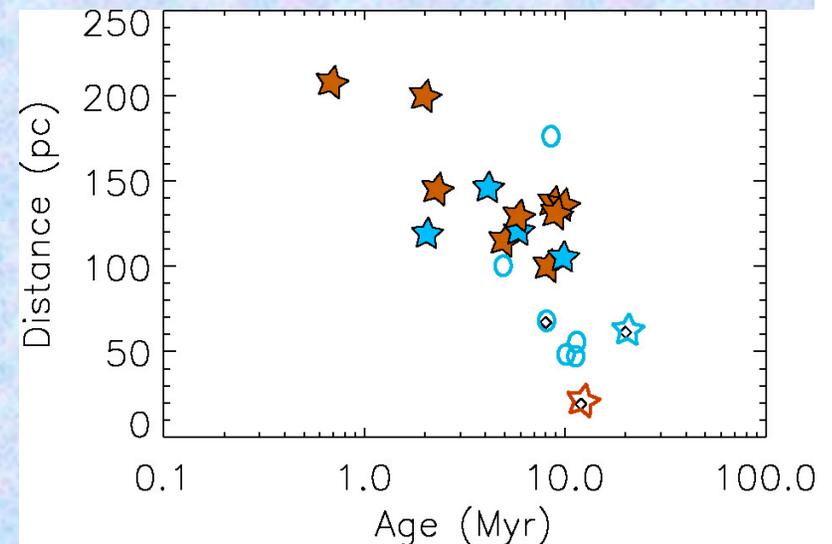
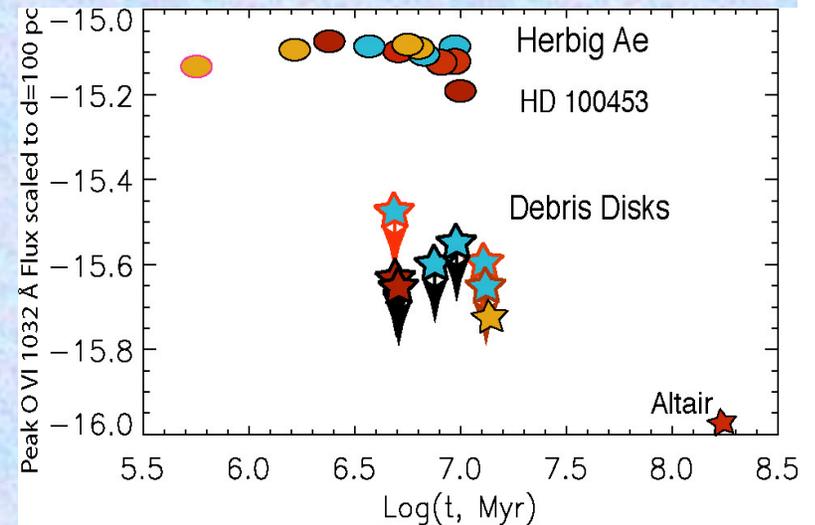
See poster by Williger et al. (Session 175)

Thanks to Carol Grady for this material



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).



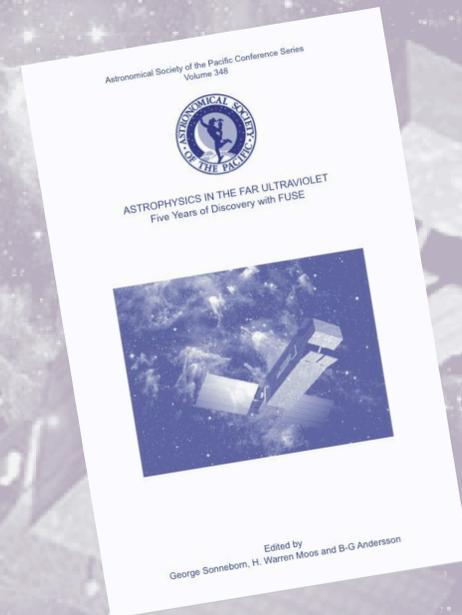
Stay Tuned...

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...

Due Out This Spring!

The Proceedings from the Victoria, B.C. Conference on FUSE Science



Expected publication date: April 2006

12 January 2006

AAS Meeting, Washington, DC