

# The Sun, Multilayers and *MOSES*

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PXRMS 2008

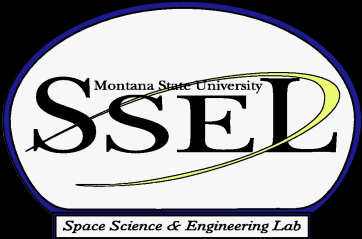
Big Sky, Montana



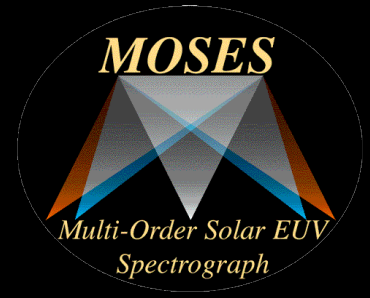
# Abstract



Multilayer coatings have opened up a new window on the solar atmosphere. The first part of my talk will touch on some highlights in the history of solar EUV observation. In the second part, I will report observations of the solar transition region with the *Multi-Order Solar EUV Spectrograph (MOSES)*, a novel telescope design that uses a multilayer grating for simultaneous imaging and spectroscopy over a wide field.



# Outline



1. The solar atmosphere

2. Observations with multilayers in space!

(a) Sounding rockets

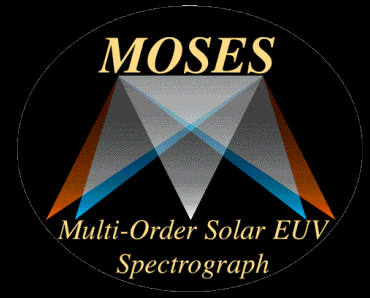
(b) Satellites

3. The *MOSES* sounding rocket

I'll just be hitting the highlights. I apologize in advance if I have left out **your** favorite mission!

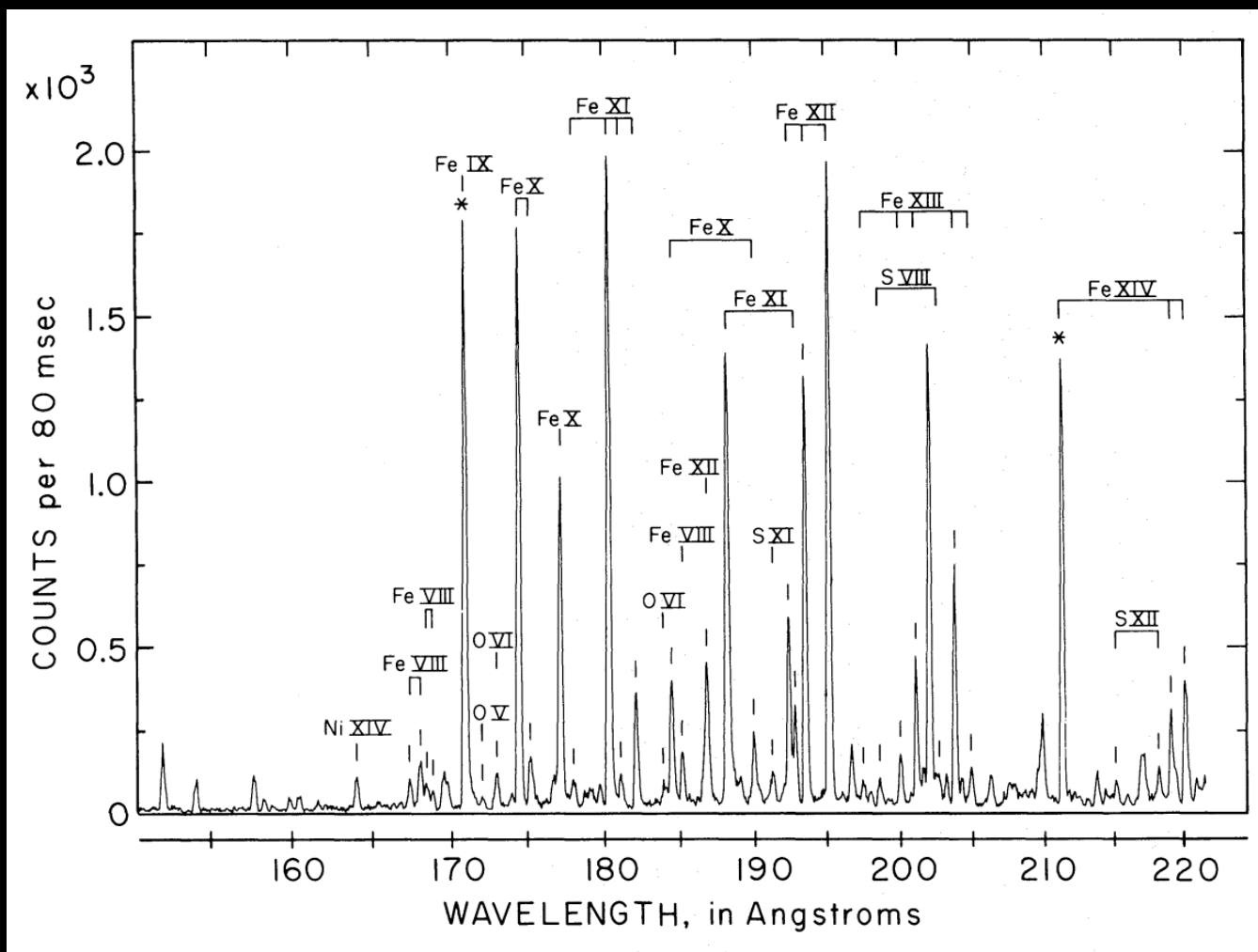


# 1. The Solar Atmosphere



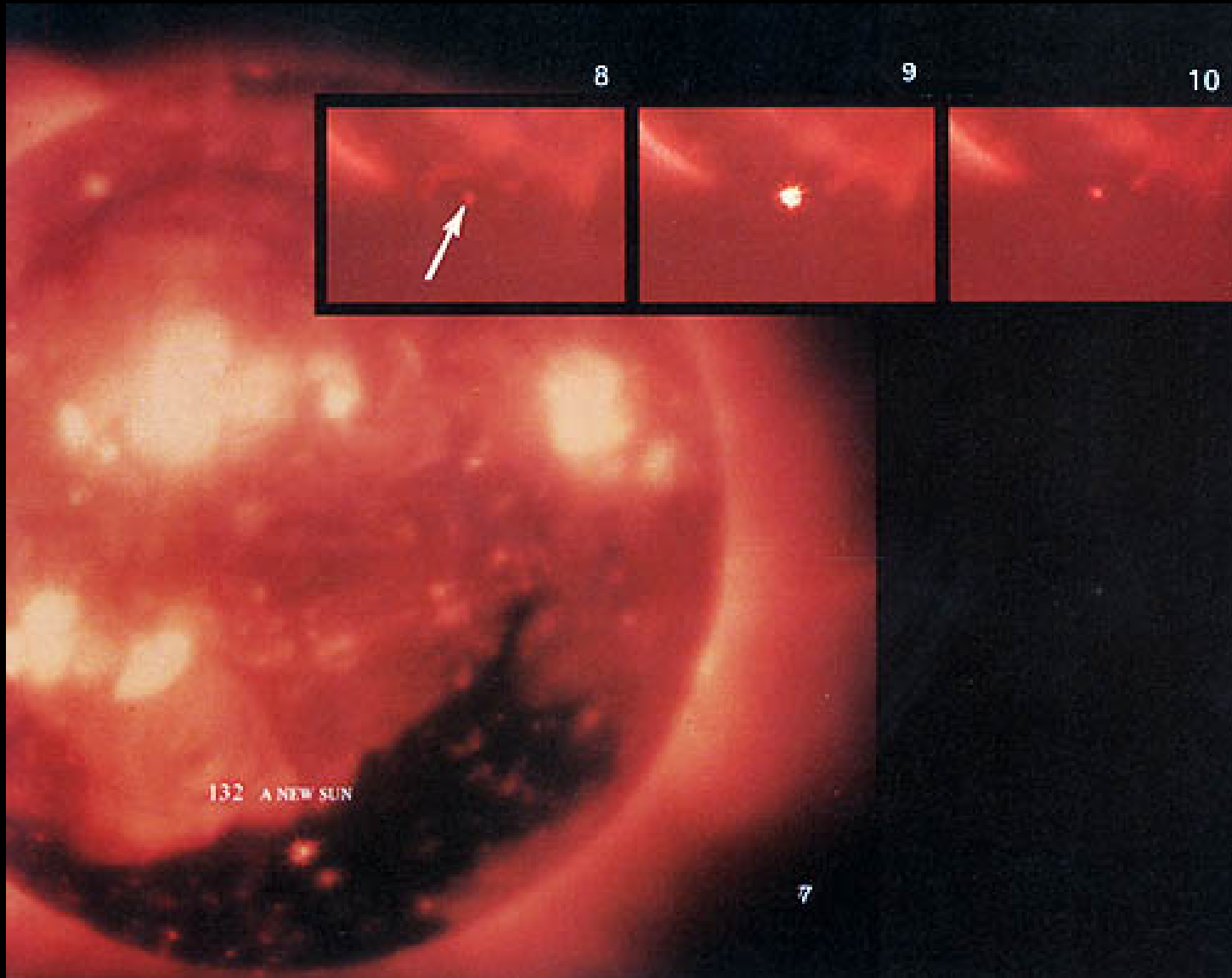
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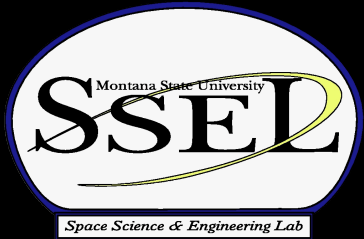
# Hot Atmosphere: EUV emission lines



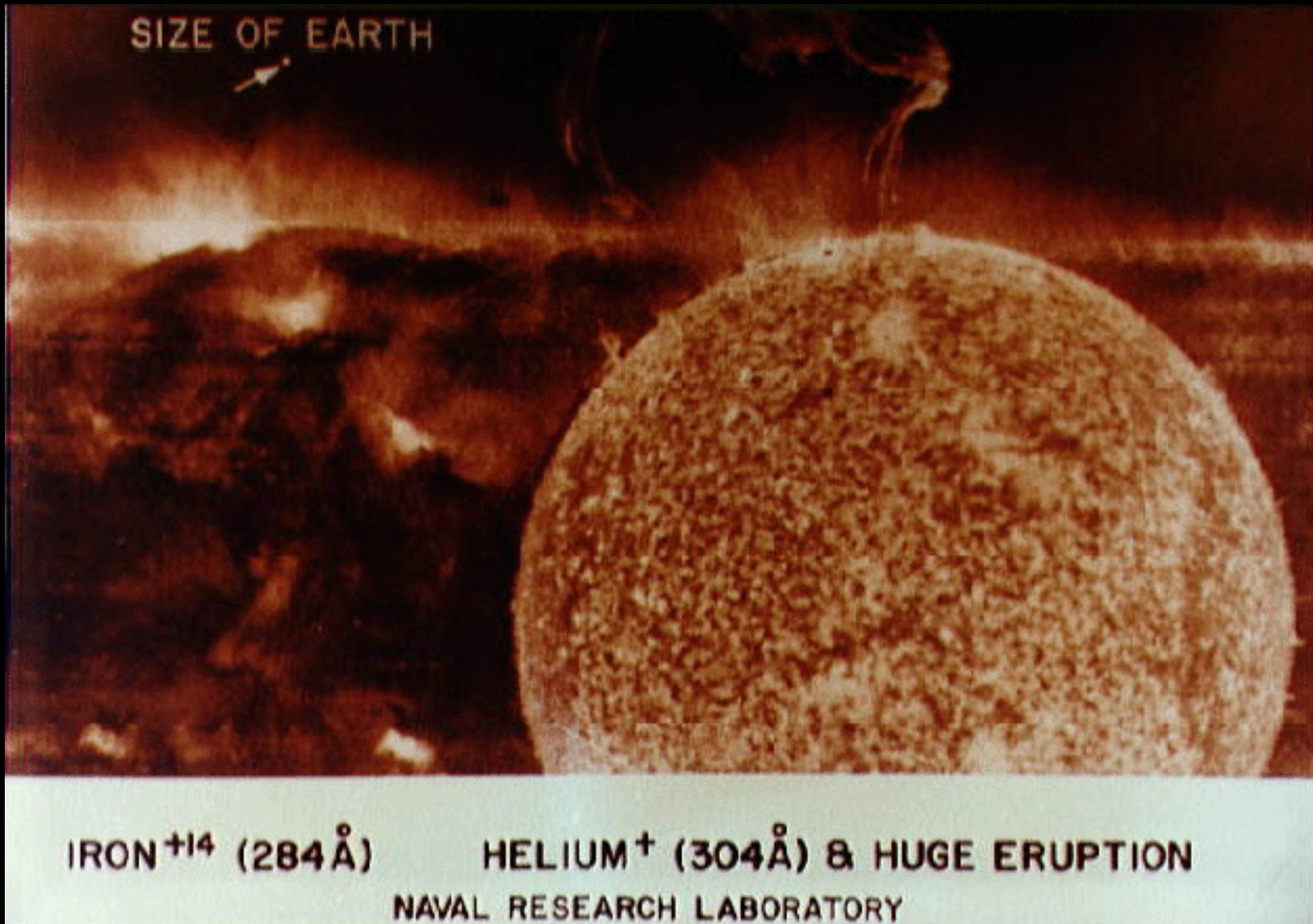
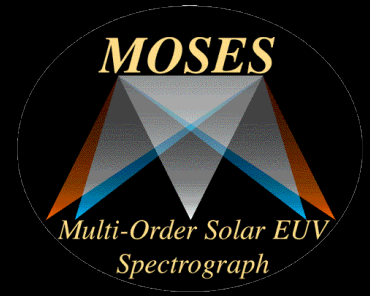
Malinovsky & Heroux (1973)

# Skylab SXR Imaging





# Skylab EUV (S082A)



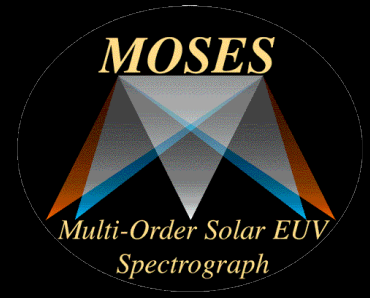
IRON<sup>+14</sup> (284Å)

HELIUM<sup>+</sup> (304Å) & HUGE ERUPTION

NAVAL RESEARCH LABORATORY



## 2. Multilayers in space!



- EUV/SXR enable observation of the Sun's atmosphere.
- Early instruments had low sensitivity.
- The Sun changes rapidly at all observed length scales!
- Solution: **multilayers**.

Groups at Lockheed, Stanford, Harvard and others worked on ML EUV instruments in the 1980's.

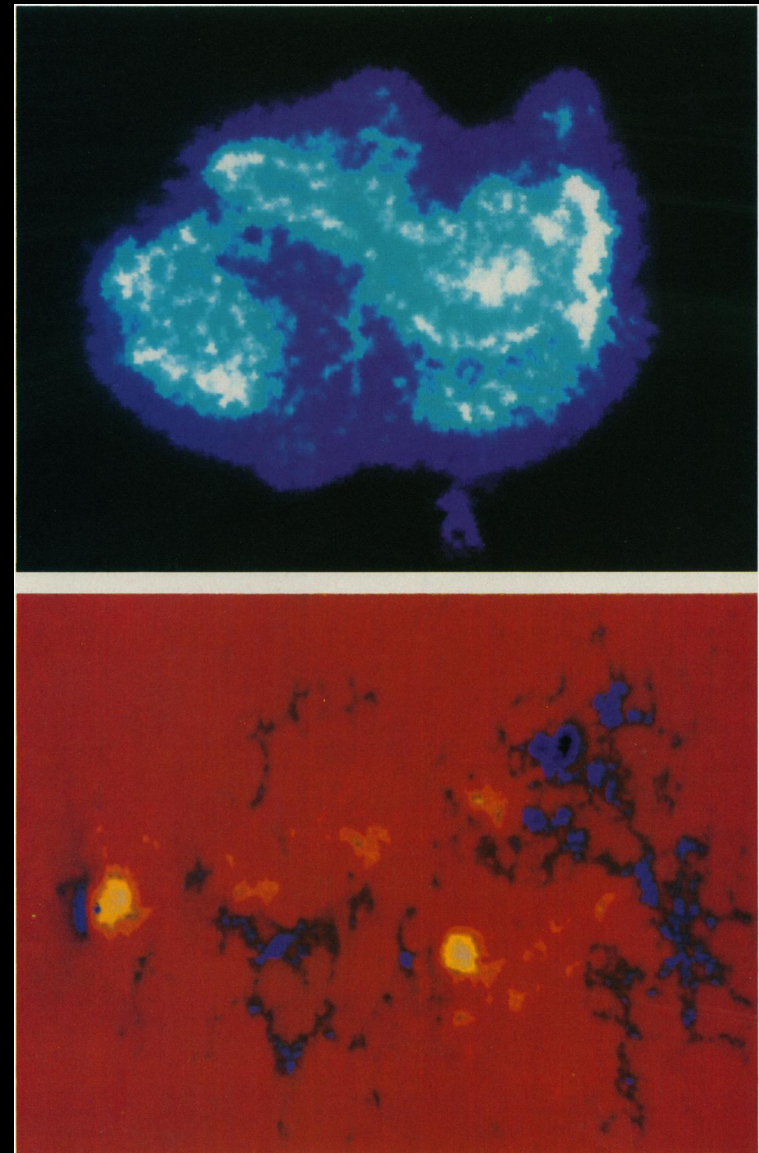


# Multilayers on Rockets

Underwood et al. (Lockheed group) first reported ML image of an astronomical object.

- 25 October 1985
- W/C sputtered ML by ECDC
- Si XII  $\lambda$  44Å
- Resolution 5-10 arcsec

AR 4698/99. EUV above,  
magnetogram below (*Science*, 2 Oct 1987, p. 61)





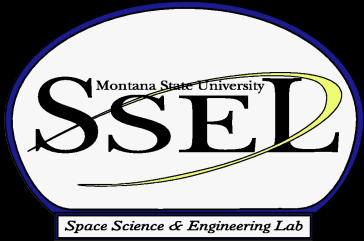
# Stanford/MSFC



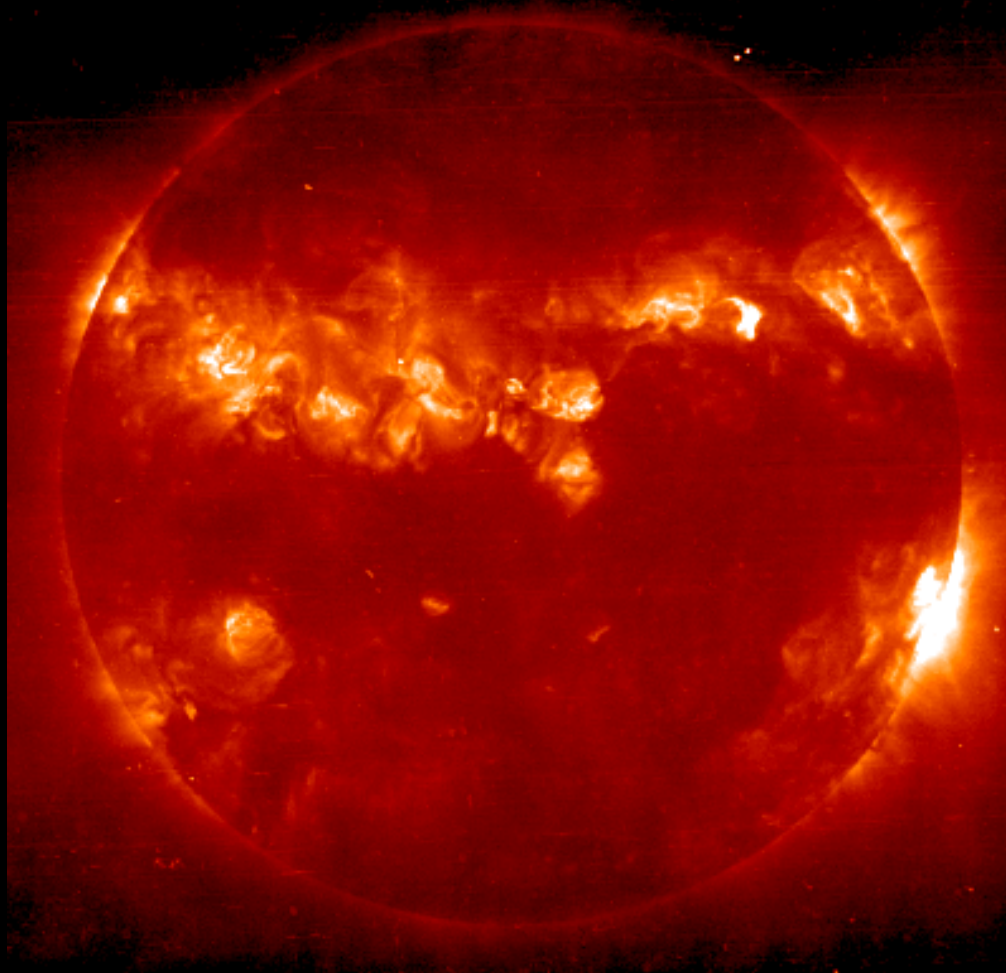
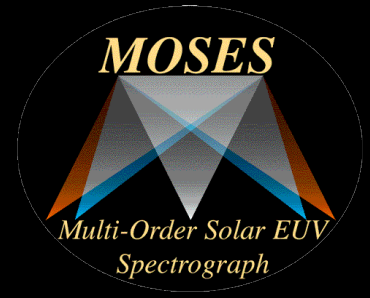
Walker et al. high resolution  
ML images

- 23 October 1987
- Cassegrain telescope
- Mo/Si sputtered ML's by Barbee/LLNL
- Fe IX/x  $\lambda 173\text{\AA}$
- Resolution 1-2 arcsec





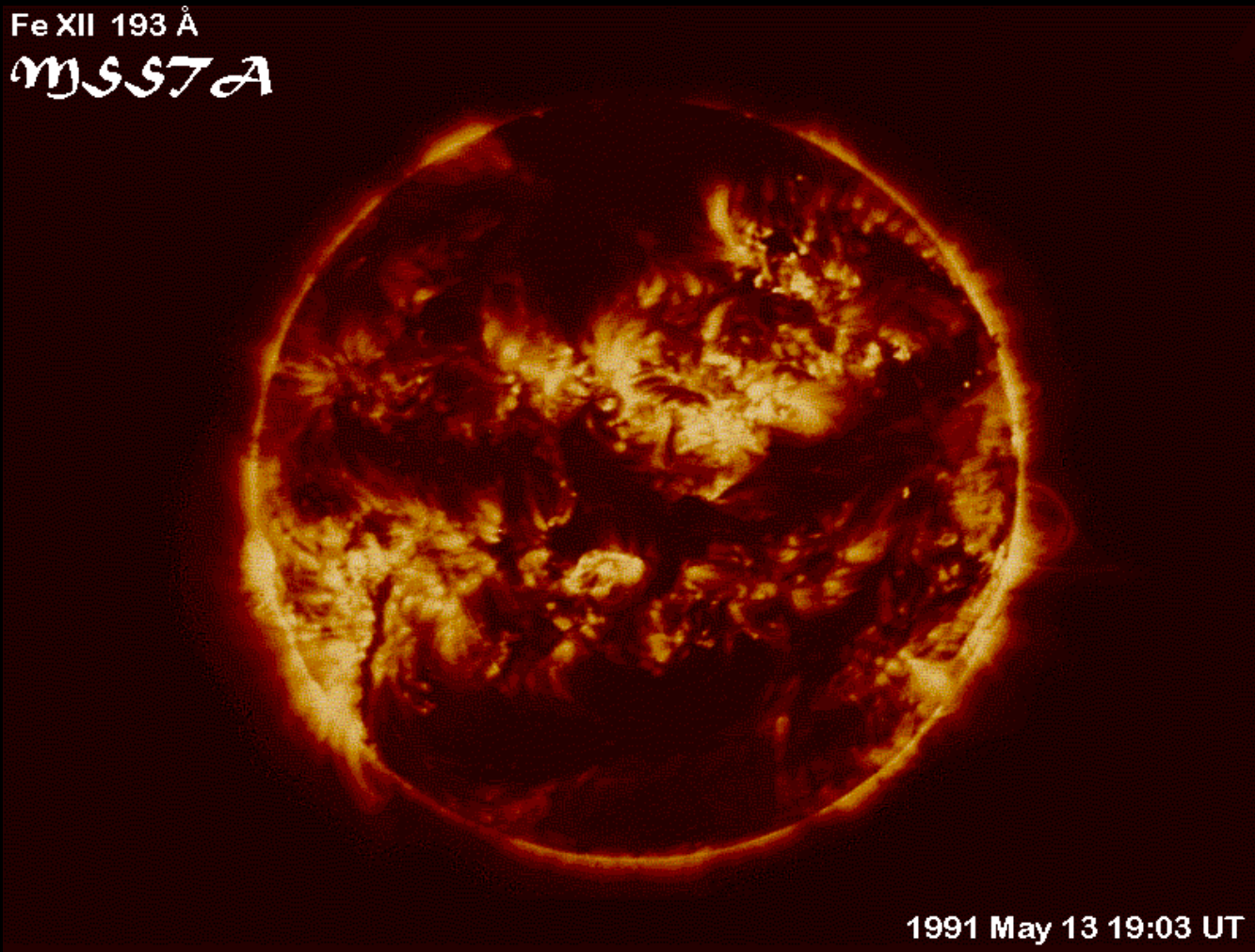
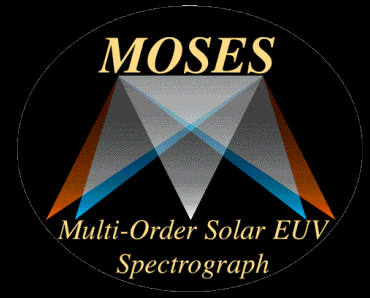
# NIXT (SAO)



Sept, 1989. Forerunner of the *TRACE* satellite!



# MSSTA—19 telescopes!



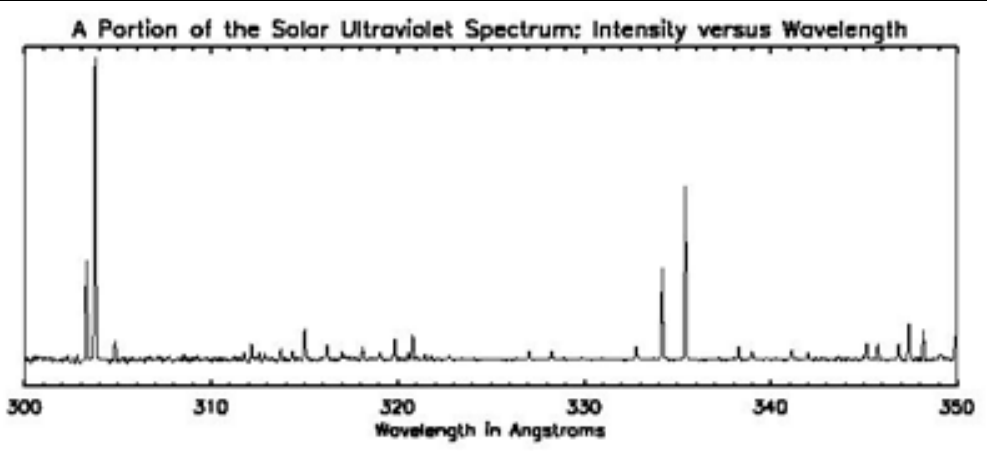
Stanford/MSFC *Multi-Spectral Solar Telescope Array*



# SERTS (GSFC)



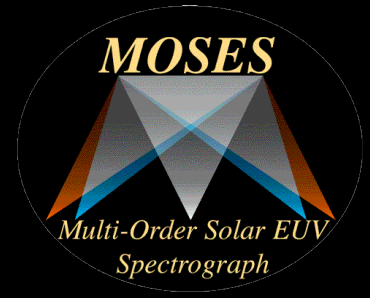
- 1991 May 7
- First ML grating!
- Ir/Si ML by R. Keski-Kuha at GSFC



SERTS-93 active region spectrum, 300-355 Å.



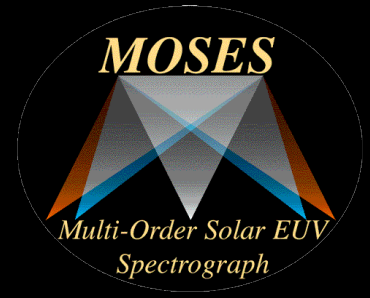
# Multilayers on Satellites



Satellite/instrument	wavelengths (Å)	type	launch
<i>SOHO</i> /EIT	171, 195, 284, 304	imager	1995
<i>TRACE</i>	171, 195, 284	imager	1998
<i>STEREO</i> /EUVI	171, 195, 284	2 imagers	2006
<i>Hinode</i> /EIS	170-210, 250-290	spectrometer	2006



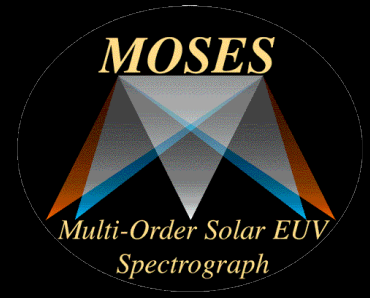
# TRACE Flare Observations



X-flare in 195 Å (Fe XII, Fe XXIV)



## 3. *MOSES*

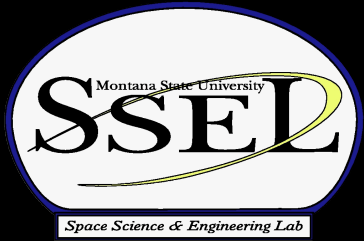


### Motivation:

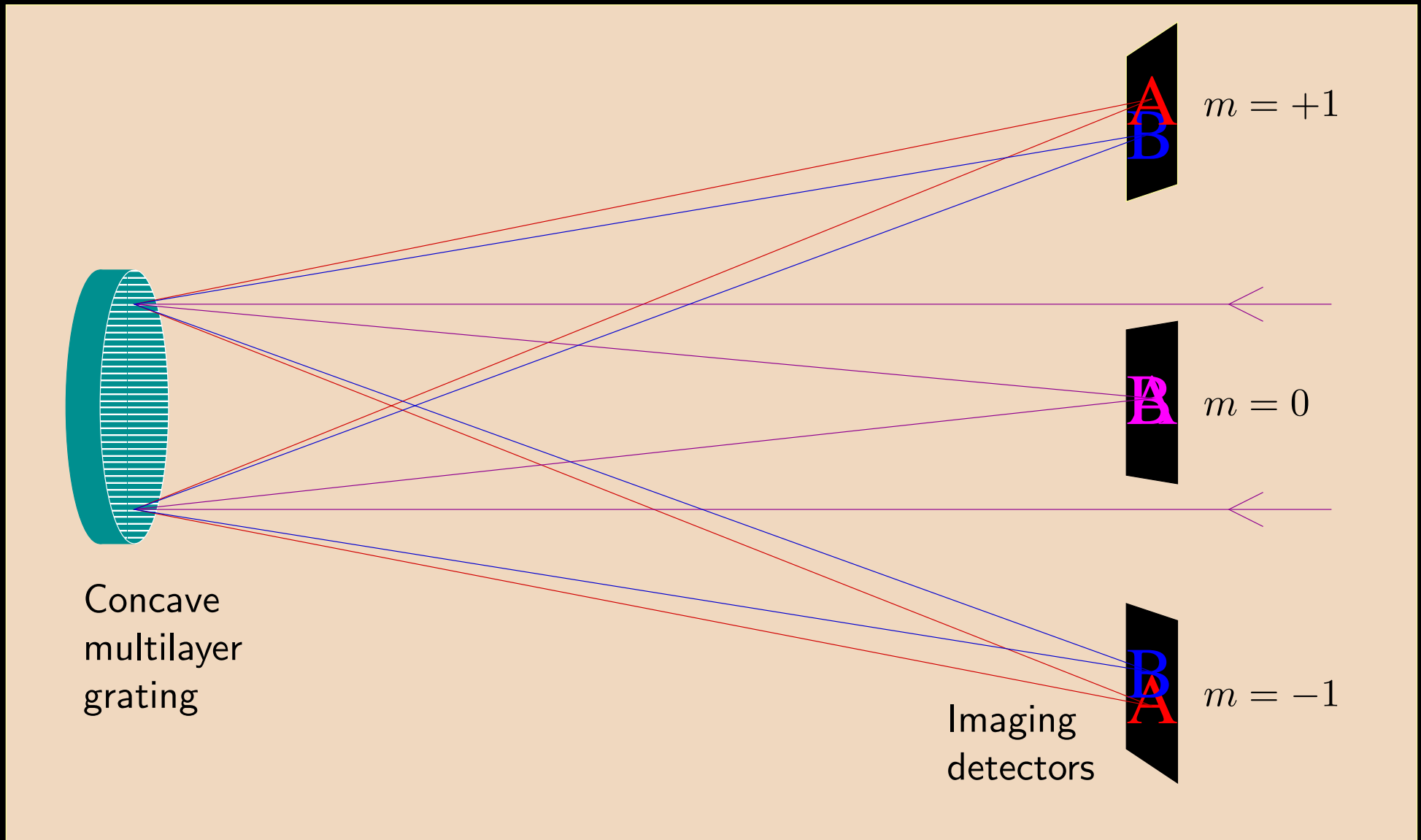
- Multilayer telescopes (MSSTA, NIXT, EIT, TRACE, EUVI) are pure imagers with **several lines** in the passband.
- Slit spectrometers (SERTS, CDS, EUNIS, EIS) build up a field of view slowly by **rastering**.
- The Skylab slitless spectrograph (SO82A) data had many **overlapping** line images.

What's missing is **simultaneous** imaging and spectroscopy.

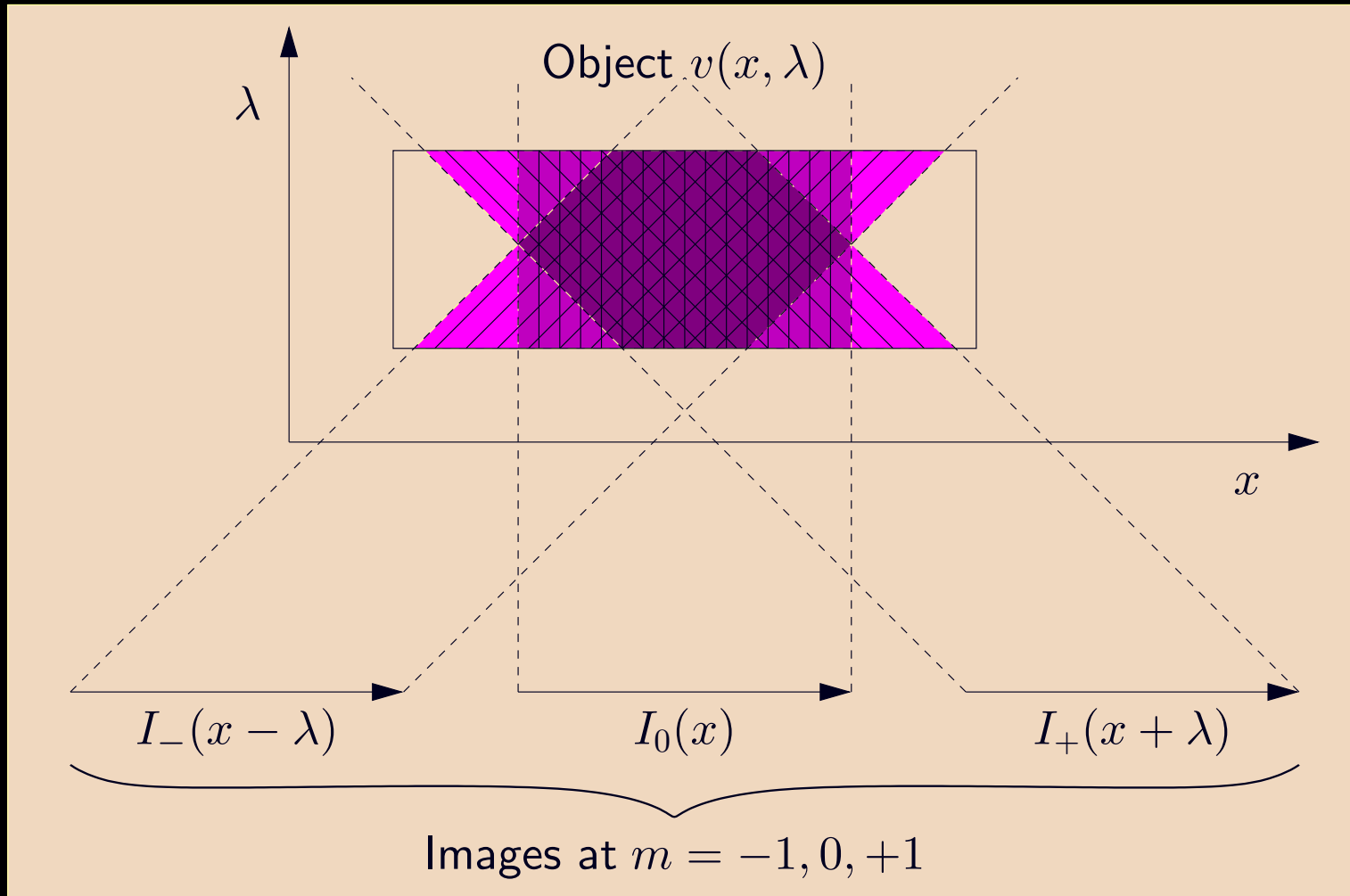




# MOSES: Multi-Order Solar EUV Spectrograph



# Hybrid space analogy





# MOSES Parameters



Optics:  $8 \times 8$  cm spherical grating and flat mirror

Coatings:  $B_4C/Mg_2Si$  multilayer,  $R \sim 0.4$  (GSFC)

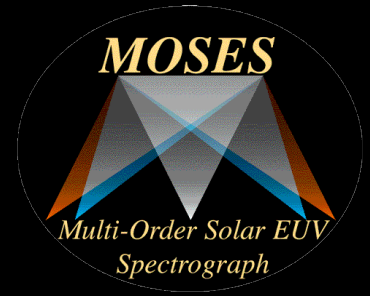
Lines: He II 303.8 Å, Si XI 303.3 Å

Detectors: three  $2048 \times 1024$ , rear-illuminated  
CCDs at  $m = -1, 0, +1$

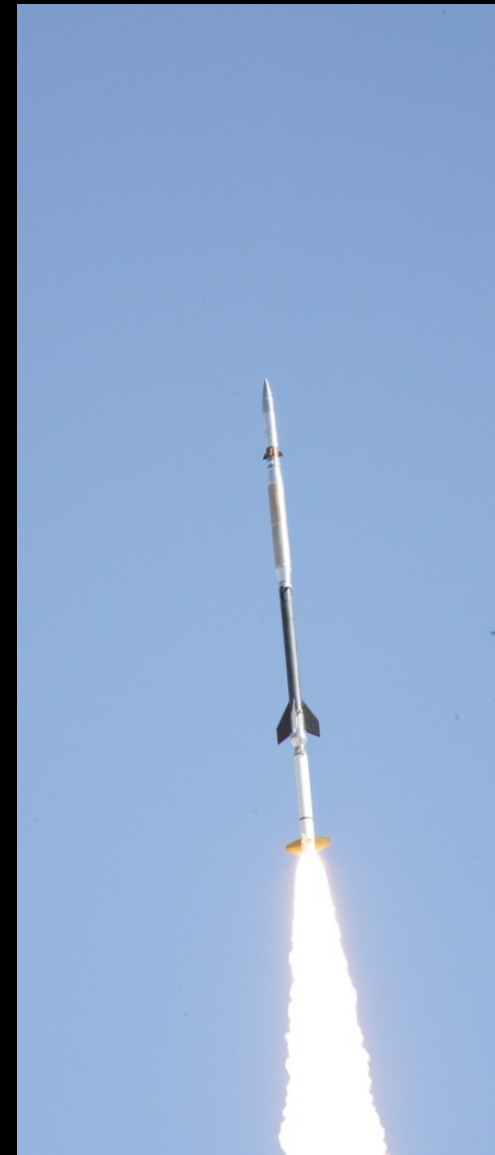
Pixel size: 0.59", 29 mÅ, 29 km/s



# Launch 2006 Feb 8

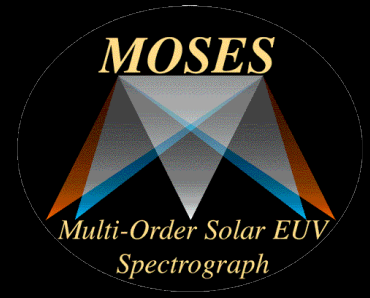


- Launch 2006 Feb 8, 18:44 UT
- ~ 5 minutes of observation above 160 km
- Apogee 260 km
- 27 science exposures, ~ 10 s cadence
- Recovered intact





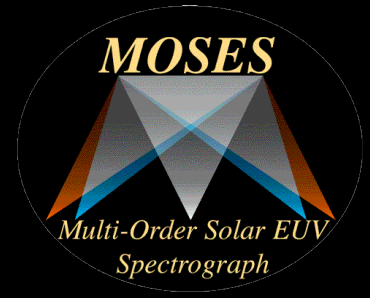
$m = 0$  movie



- 27 exposures (0.25 s – 24 s), 5 min. total, FOV  $> 1R_{\odot}$
- Quiz: Where are the Doppler shifts?



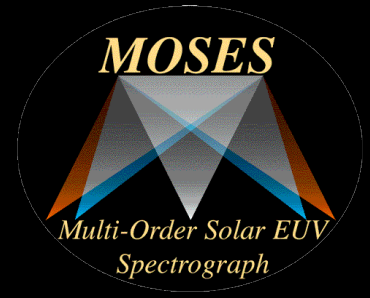
# Movie 1 — Jet



- 20'' grid
- Blue shift
- Context of unshifted brighter features
- Loop flow?



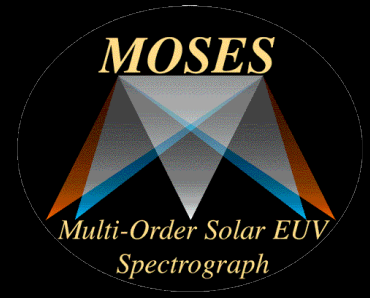
# Movie 2 — Jet



- Bifurcation into two lobes
- Blue shift
- Again, surrounding features are unshifted.



# Movie 3 — Explosive event



- Explosive event (broadening)
- Bidirectional jets





# What is *MOSES* telling us?



- **Simultaneous**, high cadence imaging and spectral information over a wide FOV
- Jets with supersonic doppler shifts, implying acceleration by magnetic reconnection.
- Explosive event, non-aligned jets (contrary to all models!).



# Acknowledgments



The success of *MOSES* owes much to:

- Roger Thomas, Jeff Gum, Scott Owens, Maria Nowak at GSFC
- Lewis Fox, and the MSU *MOSES* student team
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- Marilyn Bruner, LMSAL
- SPARCS team at WSMR
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