

Abstract

Observed at extreme ultraviolet (EUV) wavelengths, the solar atmosphere is a complex, rapidly evolving system with dynamical timescales ranging from less than one second to many hours. A new instrument concept, demonstrated by the 2006 *MOSES* rocket flight, makes it possible to investigate dynamics through line profile data obtained with each snapshot over a large field of view. Observations in the Lyman alpha line of singly ionized helium (He II $\lambda 30.4$ nm) reveal blue shifted jets and explosive events in great detail. Future plans include observation of the sun's upper transition region (Ne VII $\lambda 46.5$ nm) and development of a more sensitive, yet lighter and more compact, instrument.

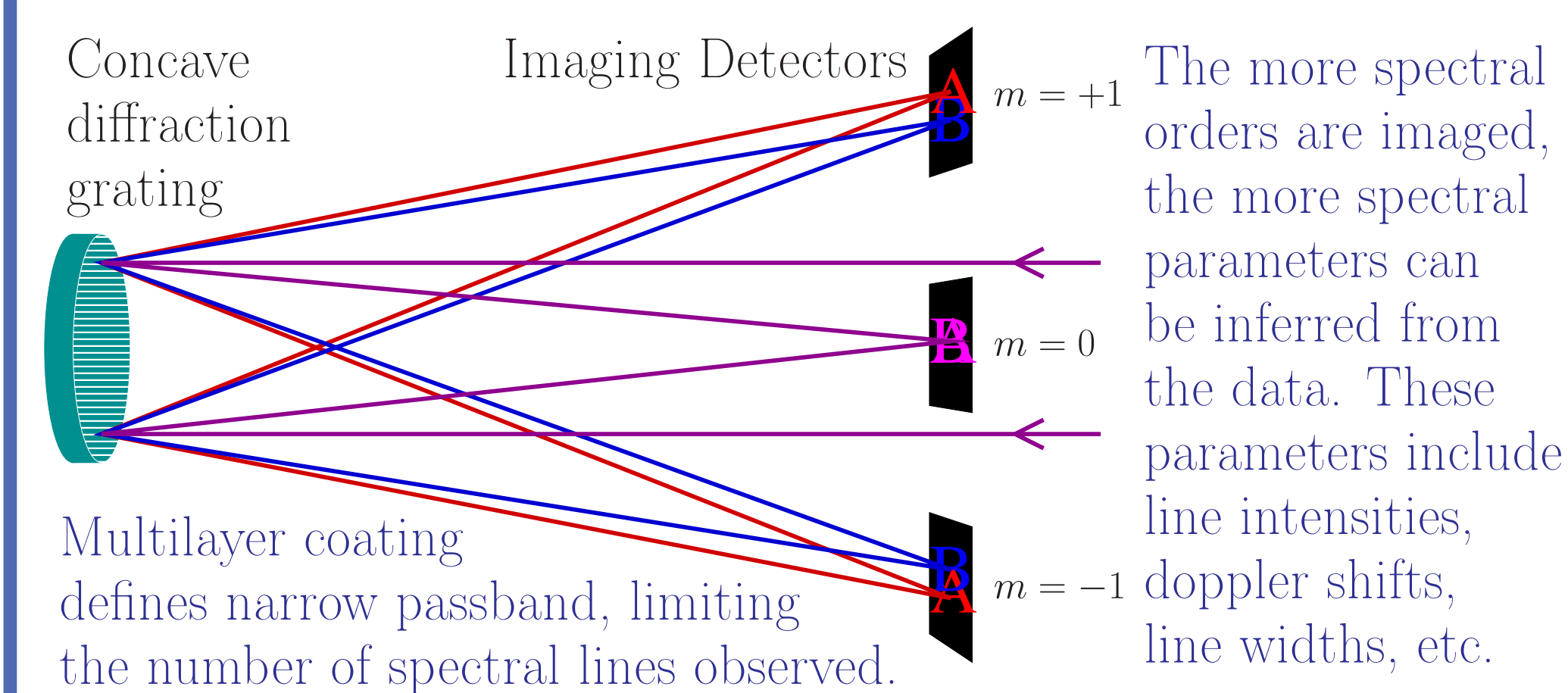
First Launch

The *Multi-Order Solar EUV Spectrograph (MOSES)* was first launched on February 8, 2006 on a NASA sounding rocket. Much of the instrument was designed, built, tested, and calibrated by MSU students.

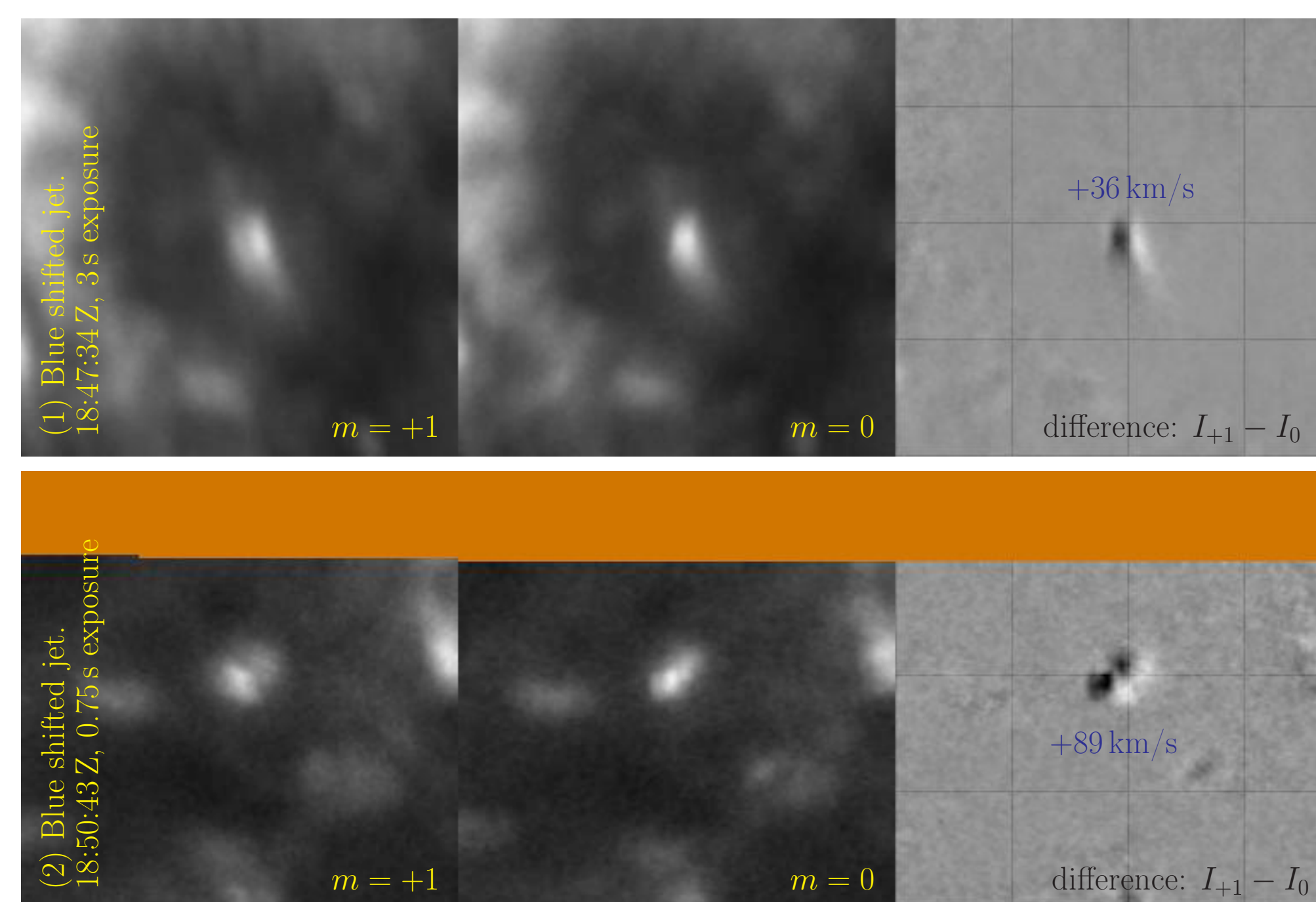
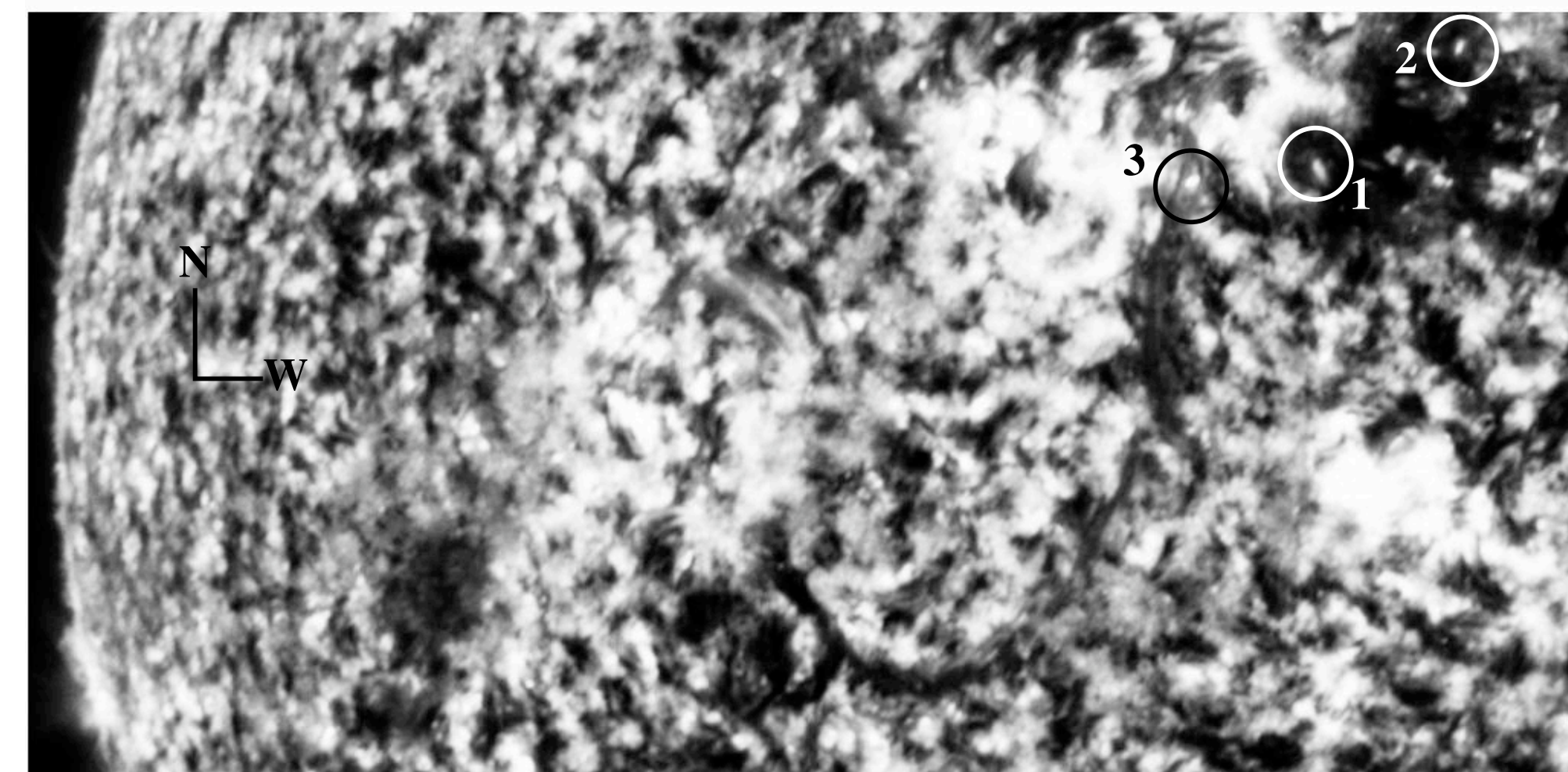


Instrument Concept

A concave reflection grating forms images at several spectral orders simultaneously. Each spectral order presents a different combination of spectral and spatial information [0,1,2,3,4].

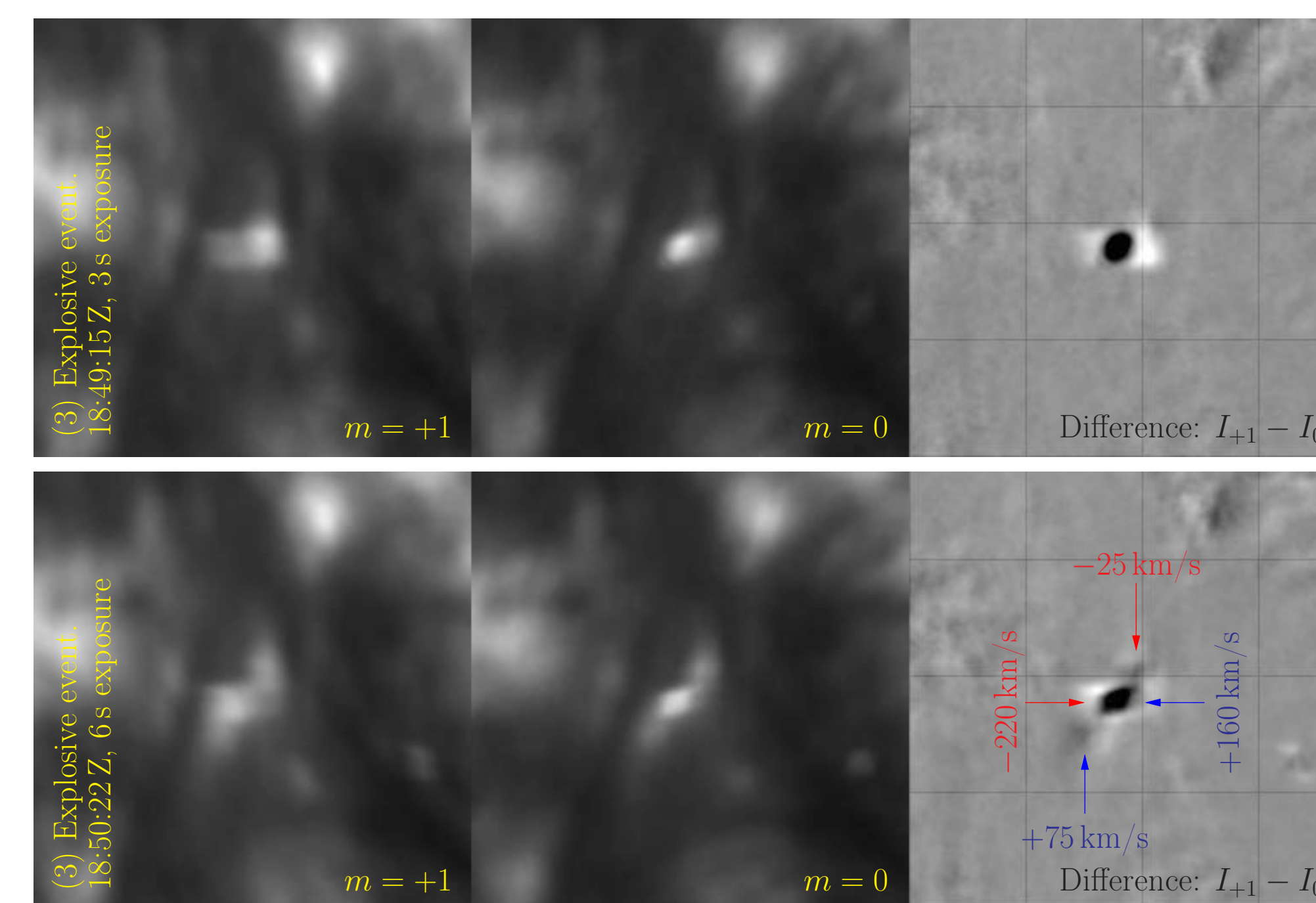


Solar Transition Region Jets and Explosive Events



Blue-shifted jets. The doppler shift provides a lower limit on total velocity, and often exceeds the sound speed (29-47 km/s). The velocities are likely Alfvénic, associated with magnetic reconnection.

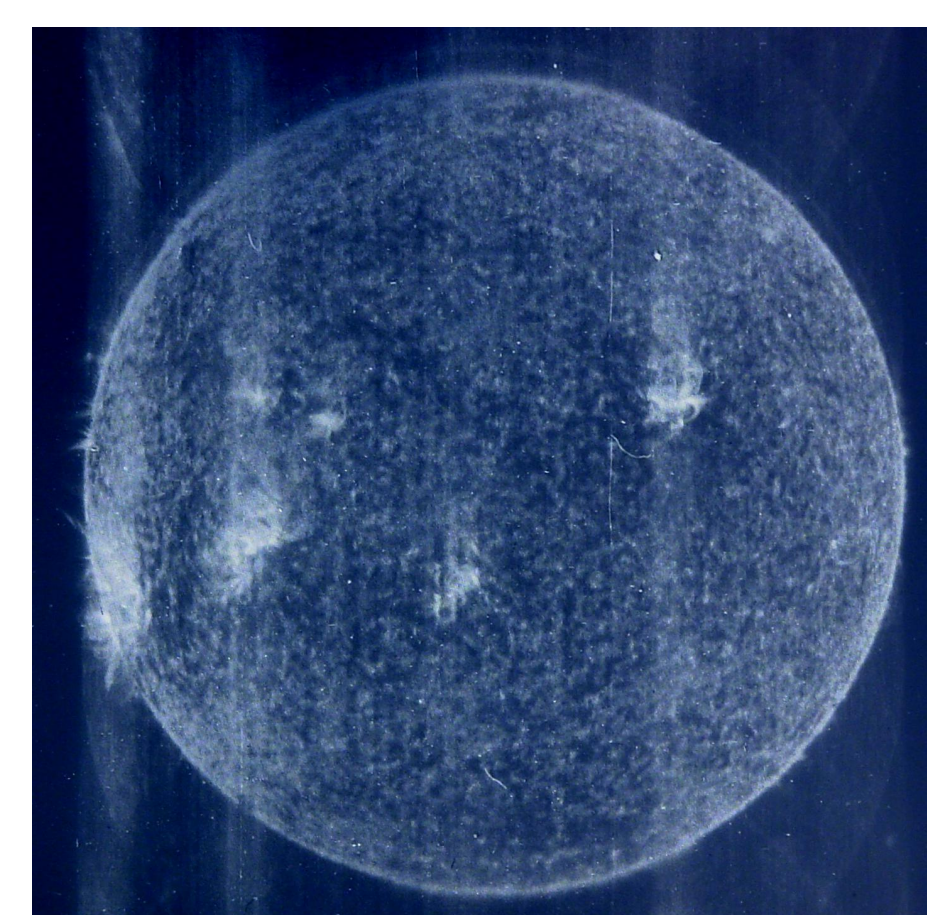
The image At left, captured by the *MOSES* sounding rocket on 8 Feb 2006, shows the solar transition region in the 30.4 nm emission line of He II. The temperature of formation for this line is approximately 30,000-80,000 K. The three labeled events are analyzed below. *MOSES* allows us to measure doppler shifts and line widths over the entire field of view in a single snapshot.



Explosive events are commonly observed by slit spectrographs. This was the first 3D characterization [3]. Our observations contradict the standard model of a bidirectional reconnection outflow.

Next Objective: Ne VII

We plan to launch *MOSES* again in summer 2013, carrying new optics optimized for Ne VII, 46.5 nm.

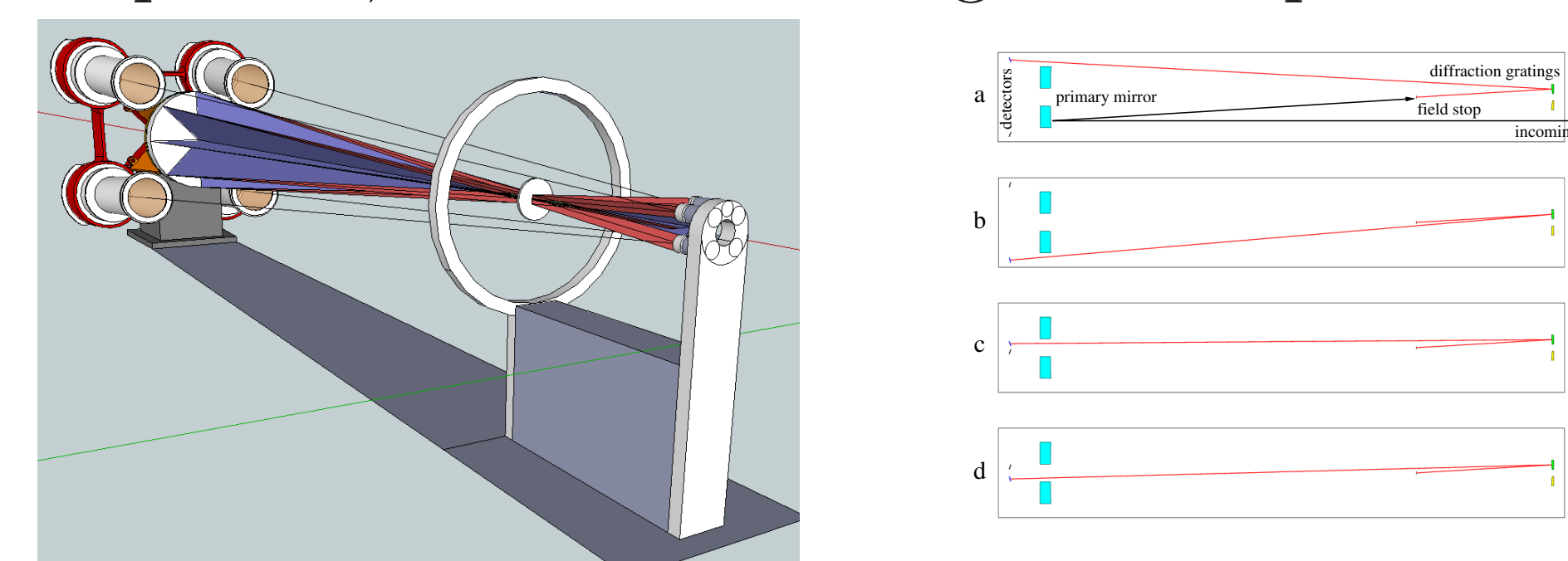


At left is a Skylab image of the Sun in Ne VII, formed at $T \sim 0.5$ MK, where the solar transition zone merges into the corona. No solar images or spectra of Ne VII have been taken since 1974.

In the 46.5 nm line, we expect to find many small-scale transient events. By observing at the roots of the corona, we hope to learn how the lower atmosphere supplies energy and mass to the corona.

EUV Snapshot Imaging Spectrograph

An advanced design offering improved optical performance, compact layout, higher moments of spectral line profiles, and flexible configuration options.



Modified Gregorian	Magnification 4
Primary mirror	150 mm parabola, f/6.7
Secondary mirrors	Ellipsoid ($m = 0$) TVLS gratings, 1 per order 4-8+ spectral orders
Coatings	EUV/FUV Multilayer
Detectors	Rear-illuminated CMOS, $\sim 10 \mu\text{m}$
Spatial resolution	~ 1 arc second
Spectral resolution	$\sim 4-20$ km/s/pixel ($a < c < d < b$)

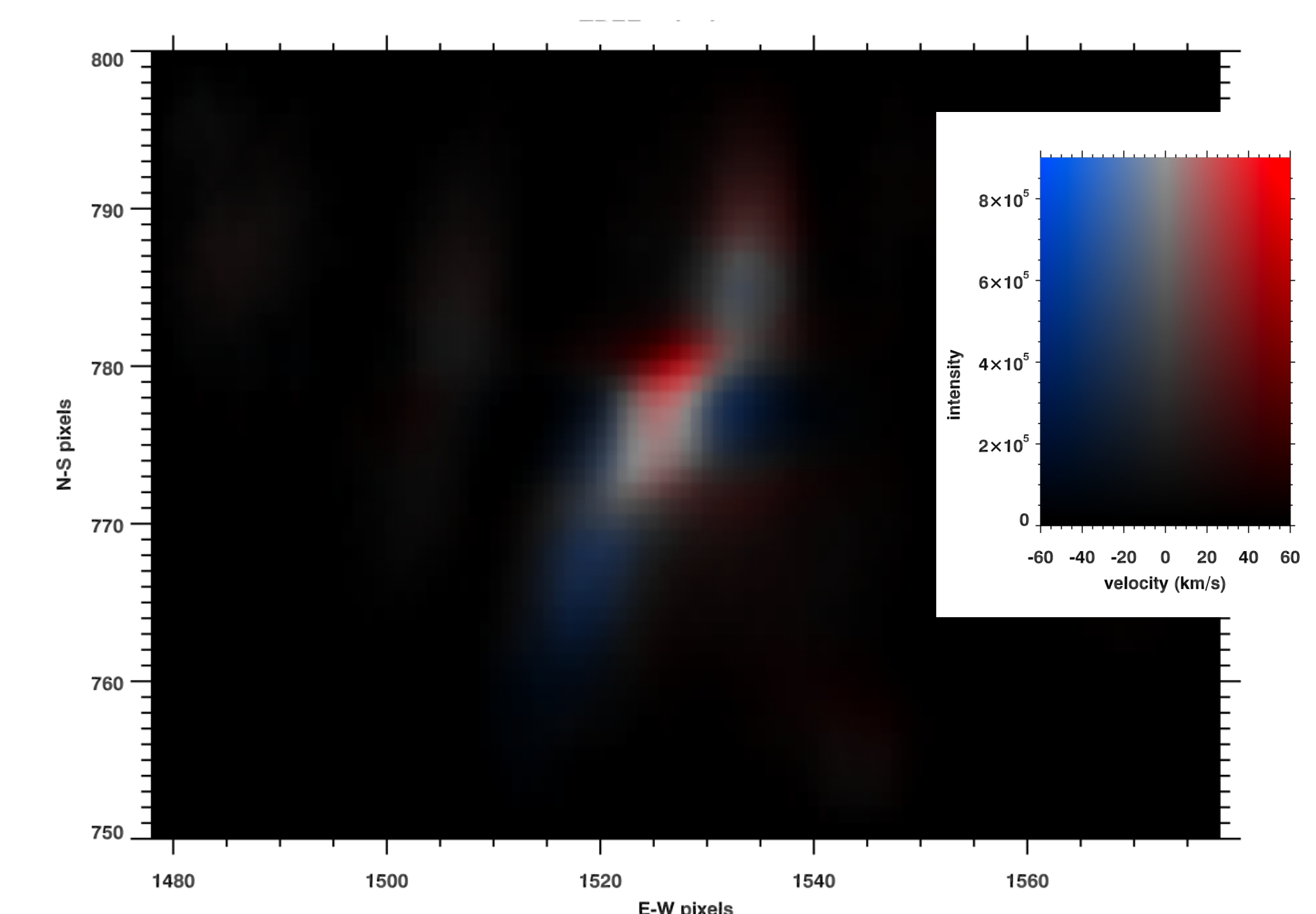
Inversion

Image at spectral order m is formed by projection through the Object, $I_{\odot}(x, y, \lambda)$:

$$d_m(x, y) = \mathcal{P}I_{\odot} \equiv \int_{\lambda_1}^{\lambda_2} I_{\odot}(x + m\lambda, y, \lambda) d\lambda \quad (1)$$

Recover $I_G(x, y, \lambda) \approx I_{\odot}$ by iterative inversion:

1. $d'_m = \mathcal{P}I_G$ (eq. 1)
2. $I_G \leftarrow I_G(x + m\lambda, y, \lambda) \prod_m \left[\frac{d_m(x+m\lambda, y)}{d'_m(x+m\lambda, y)} \right]^{\gamma_m}$
3. Apply smoothing to I_G .
4. Iterate, adjusting γ_m so $\chi^2_{R, m} \rightarrow 1$.



Inversion applied to the explosive event [4].

Acknowledgment

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References

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- [1] Applied to photospheric magnetography: DeForest, C. E., et al. (2004) *Astrophys. J.* 616, 600.
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- [3] Fox, J. L., Kankelborg, C. C., & Thomas, R. J. (2010) *Astrophys. J.* 719, 1132.
- [4] Fox, J. L. (2011) PhD Thesis, Montana State University.