The Magnetic Reconnection Explorer (MAGREX)

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Abstract

The MAGREX experiment is designed to investigate the role of magnetic reconnection in producing (a) solar activity, such as flares, coronal mass ejections, and other transient phenomena, and (b) heating of active region loop structures. Subsidiary goals are to understand the flow of mass and energy in active region and flare loops and the evolution of these loop structures. MAGREX accomplishes its goals by obtaining an unprecedented combination of high spatial, spectral, and time resolution data covering temperature regions from the chromosphere to the tops of soft X-ray emitting flare loops. The MAGREX payload consists of a high spectral resolution EUV spectrometer, a multilayer high spatial resolution EUV telescope, and a coarsely collimated transient event X-ray sensor.

1. Science Investigation

1.1. Summary

We propose an experiment with the prime objective of understanding the role of magnetic reconnection in flares, coronal mass ejections (CMEs), and other major forms of solar energy release. The Magnetic Reconnection Explorer (MAGREX) consists of an imaging EUV spectrometer, a multilayer EUV telescope, and an X-ray transient sensor, constructed to observe reconnection in solar activity with unprecedented spatial, spectral, and temporal resolution.

Magnetic reconnection is widely believed to be the most important process for converting magnetic energy into thermal and kinetic energy in both solar and space plasmas. Due to its unique capability for rapid, localized energy release, reconnection has been proposed as the mechanism underlying almost all major manifestations of solar activity, including flares, CMEs, active region and coronal hole heating, solar wind acceleration, and chromospheric explosions. Reconnection plays the central physical role in producing the solar drivers of space weather as well as the EUV and X-ray irradiance variations responsible for key aspects of global change. Reconnection also couples the heliospheric fields to planetary magnetospheres, producing geomagnetic activity. Understanding magnetic reconnection on the Sun would not only advance basic space science, but also would yield better understanding and prediction of the Sun-Earth connection.

Two basic reconnection configurations generally have been applied to solar and space phenomena: \textit{X-point reconnection} and \textit{current sheet reconnection}, as illustrated by the simplified two-dimensional models shown in Figure 1. In both cases, antiparallel magnetic field lines (dashed lines) are carried inward by flows converging on a central current sheet.


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In the X-point configuration shown at left in Fig. 1, ohmic dissipation in a small region at the center of the "X" allows field lines to slip through the plasma. Each field line entering this diffusion region is effectively cut, then each segment reconnects with a segment from a corresponding field line on the opposite side. Immediately afterwards, the bent reconnected field lines experience a strong magnetic tension force which pulls them away from the X-point. Plasma attached to these bent field lines accelerates to form an opposing pair of outflows, as indicated by the long oppositely directed arrows in the figure.

The resulting localized high-speed outflows, or jets, are the primary signature of X-point magnetic reconnection.

Although the reconnection jets and the inflows shown in Fig. 1 have been postulated to be a fundamental feature of solar flares for over 30 years, they have never been conclusively observed. MAGREX has been designed explicitly to observe these features and measure their properties.

Under circumstances, once the field is stressed, the X-point may elongate into a current sheet. Under continued forcing, the sheet lengthens until it becomes tearing-mode unstable and forms many discrete plasmoids which are accelerated toward the ends of the sheet by the well-known melon seed effect. The net effect is a time-variable bidirectional outflow travelling at sub-Alfvénic speeds, which could appear as quasi-steady jets if the time resolution is inadequate.

We refer to this process, illustrated on the right side of Fig. 1, as current sheet reconnection, a driven form of Sweet-Parker reconnection. No slow shocks are formed, so the plasma isn’t heated to the degree found in the X-point scenario. However, the density in the sheet and in the plasmoids is several times greater than in the inflowing plasma. The current sheet reconnection process yields cooler, slower, time-variable bidirectional outflows than X-point reconnection.

Better observations and models are needed to understand the forms of reconnection and their relation to specific solar phenomena. By observing the magnitudes of reconnection outflows and whether they are steady or episodic, for example, MAGREX will allow us to distinguish between the X-point and current sheet varieties in specific events.

1.2.2. Scientific Objectives: Nonflaring Active Region Studies

Besides observing the direct consequences of magnetic reconnection in the solar atmosphere, the instruments on MAGREX will provide a powerful tool for investigating many important problems in active region structure, dynamics, and composition. By combining high spatial resolution imaging with high spectral resolution EUV emission-line studies, MAGREX will measure the essential physical characteristics of active regions more accurately and directly than previously achieved.

1.3 Instrumentation

We have designed a payload with two primary instruments, an EUV telescope and an EUV spectrometer, and one technologically simple secondary instrument, an X-ray transient sensor. The telescope records images with 1 arcsec resolution (0.5 arcsec pixel size) and is cadenced in four energy bands that cover emission temperatures from $10^3$ to $10^6$ K. Its purpose is to record high resolution images of active regions and transient events such as flares, and to provide necessary information to the EUV spectrometer. For example, it detects the onsets of transient events and precisely determines their locations. The location and flux level are passed from the telescope to the spectrometer, whose scanning mirror is positioned to record high-resolution spectra of the events. Similarly, the telescope can be programmed to locate other features of interest in active regions under quiescent conditions.

The EUV spectrometer is capable of recording spectra simultaneously in two selected energy bands with a temporal cadence of 1 s, a spatial resolution of 1 arcsec, and a spectral resolution sufficient for measuring Doppler velocities as small as 2 km s$^{-1}$. Both the telescope and spectrometer are
capable of recording partial-frame images and spectra with a cadence of less than 1 s when a flare or other interesting solar feature is rapidly evolving in time.

The secondary instrument, the X-ray transient sensor, has sensitivity and a temporal resolution of 10 ms. It will provide a transient event alert signal to the two primary instruments and will provide flux level information to the telescope and spectrometer cameras so that transient event onsets can be recorded with proper exposure times.

1.3.1. EUV Telescope. Figure 2 shows the EUV telescope layout. Its design is based on the EIT multilayer instrument that has been successfully flown on the SOHO mission (Delaboudiniere et al. 1995, Moses et al. 1997).

The telescope Cassegrain optical system consists of two spherical mirrors: a concave primary mirror and a convex secondary mirror. Each quadrant of the two mirrors will have a different multilayer coating to reflect four spectral transitions spanning emission temperatures from $10^5$ to $10^7$ K. A rotating mask with a quadrant aperture will select the channel to be recorded.

The images are recorded on a backthinned CCD detector with 1024x1024 pixels and 14 μm pixel spacing. The effective focal length is 5.786 m. Each pixel covers 0.5x0.5 arcsec$^2$, resulting in an 8.5x8.5 arcmin$^2$ field of view.

Increased signal-to-noise can be obtained by binning pixels and/or by increasing exposure times. The ultrahigh resolution of MAGREX, however, allows for meaningful new observations even if pixel binning is required for maintaining cadence.

The combination of the high-temperature Fe XV, Fe XVIII, and Fe XV/XXIII lines with the lower temperature He II line allows us to cover both the very hot plasma expected as a result of reconnection phenomena and to locate that emission with respect to cooler structures such as loop footpoints and magnetic structures observed from the ground or other satellites.

1.3.2. The EUV Spectrometer is the backup flight model of the SUMER/SOHO spectrometer with modifications for the MAGREX mission. A sketch of the EUV spectrometer is shown in Figure 4. Our proposed instrument is not, however, simply a refit of SUMER. New detectors will be used to observe bright active region structures and transient events with high time resolution.

To observe solar activity we will modify the existing spectrometer to use integrating intensified CCD (ICCD) detectors, rather than the photon counting detectors flown on SUMER/SOHO, modify the data handling electronics to simultaneously record spectra in two energy bandpasses, i.e., use both detectors simultaneously. The use of CCD detectors transforms the existing SUMER spectrometer into a new science instrument, capable of observing solar phenomena not possible with SUMER/SOHO.

The total wavelength range accessible to the spectrometer extends from 500 to 1610 Å. Each camera consists of a microchannel plate (MCP) intensifier that is optically coupled by fiber-optics to a CCD detector.

1.3.3. X-Ray Transient Sensor. The X-ray transient sensor consists of a filtered X-ray photodiode and a collimator that observes the same field of view (8.5x8.5 arcmin$^2$) as the EUV telescope. The X-ray flux is continuously monitored and provides a transient event flag to the two primary instruments, the EUV telescope and the EUV spectrometer. The flux level recorded by the X-ray transient sensor will be used to adjust the sensitivity of the telescope and spectrometer cameras so that the transient onset can be recorded with a proper exposure time. The transient X-ray sensor package is 2.5 cm x 3.8 cm x 3.8 cm, has a mass of 70 gm and draws 0.33 W power.
1.4. Observing Strategy. Detecting the effects of magnetic reconnection requires high time resolution images with temperature, density, and Doppler information. For transient events, coverage of the events should be from onset until well into the decay phase. Even for quieter active region loop structures, observations need to be made for as long as possible.

For transient event observations several observing modes have been defined. These are the baseline Quiescent Mode (QM), the Transient Onset Mode (TOM), and the Transient Event Mode (TEM). The telescope and spectrometer are normally in QM. In this mode, the telescope records synoptic images of active regions within its field-of-view. During this time, the X-ray transient sensor continuously records the X-ray flux within the telescope’s field of view. When this flux exceeds a pre-determined level, a transient event flag is sent to the telescope and spectrometer, and the instruments transition to the TOM. The flux level is sent to the telescope and spectrometer cameras so that their integration times can be adjusted for proper exposure. The telescope filter and sector wheels move to a pre-selected channel, e.g., the Fe XXIII/XX transition with $10^7 \, \text{K}$ temperature for a flare observing program. This movement takes place within 0.5 s of receiving the event flag. The centroid of the pre-selected channel emission is determined and sent to the spectrometer telescope mirror mechanism. This mirror then slews to the centroid position within 2.5 s, and the detectors record a spectrum. This spectrum covers two energy bandpasses that were already under observation before the mode change took place. The first full-frame image and spectra are thus recorded within 3 s after the onset of the event and with the proper exposure levels as determined using the X-ray transient sensor.

As the transient activity evolves, full-frame EUV images and spectra are recorded in TEM, or partial-frame images and spectra can be recorded with a faster cadence. Spectra covering the event and the surrounding region are recorded as the spectrometer telescope mechanism moves the solar image on the slit to a new position. Camera integration times are actively adjusted for the best exposure.

Because the entire SUMER spectral range cannot be observed simultaneously, it is necessary to define observing sequences with various spectral line combinations, depending on the particular science objective. The wavelength range accessible to the spectrometer is so large that many possible combinations exist.

For example, one possible wavelength range lies between 668.5 and 713.8 Å. This wavelength interval is available to the spectrometer with a single wavelength setting. It contains chromospheric temperature emission lines from C II, N II, and O II, transition region temperature lines from ions such as N III, O III, Na IX, Mg VIII, S III, S VI, and Ar VIII, and coronal lines from ions such as Mg IX, Al IX, Al X, Si IX, and Ar XII.

Payload Configuration

The primary load-bearing structural member for the payload is a rigid slab forming a common baseplate for the telescope and spectrometer. Radiators for the instruments’ precision optics and detectors will be placed viewing in the S/C Z axis direction for optimal viewing of deep space. The constant thermal environment for these radiators furnishes a high level of thermal stability for the instrument packages.

The MAGREX X-ray transient sensor and fine Sun SISS sensor will be mounted to the aperture end of the instrument baseplate adjacent to the telescope, with its field of view aligned parallel to the longitudinal axes of the telescope and spectrometer. The total weight of the payload including contingency is estimated at $200 \pm 40$ kg.