High-Speed Spectral Imager
Category: Space Technology/Astrophysics

Overview:

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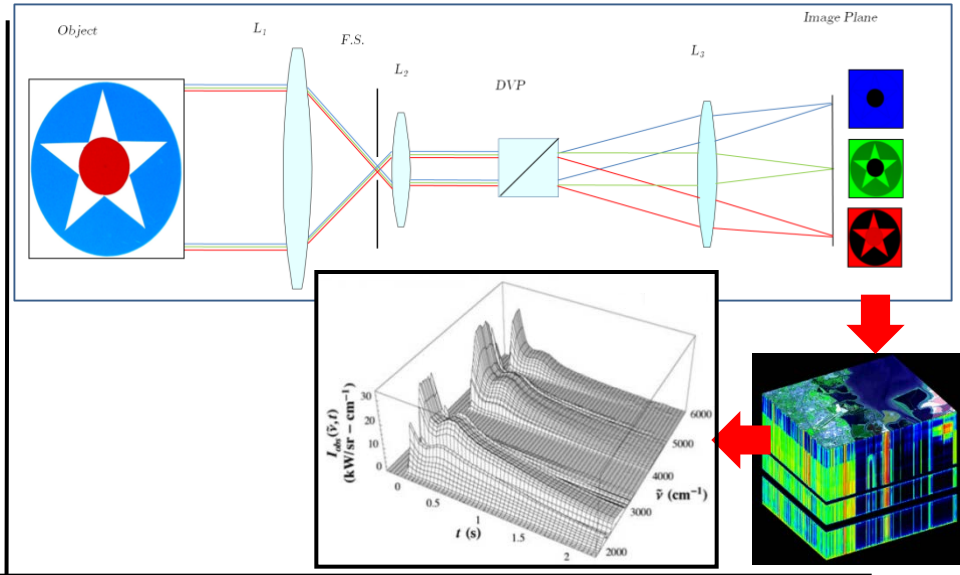
Establish Chromotomographic Imaging (CTI) as a viable technology for extracting spatial and spectral information from rapid-transient events.

Demonstrate versatility of CTI and the ability to design the hardware to meet spatial, spectral, and temporal resolution requirements.

Utilize CTI to observe spectrally- and spatially-diverse rapid transient scenes with resolution not achieved by other space-based spectrometers.

Graphic:



Description:

- CTI images 2D scene through a prism and displays the spectral dimension as a spatial shift. Collecting multiple images per rotation of the prism allows recreation of a spatially-distinct scene at spectral bands over the design spectral range. The prism is rotated and images collected quickly, such that complete spatial and spectral information data is obtained at <0.1 sec intervals
- Observation of wide FOV scenes that have interesting spectral features varied over the FOV and changing quickly. Examples: Solar Flares, Meteorites and Bolides, Planetary Atmospheres.
- Spaced-based CTI as briefed to the Space Experiments Review Board by AFIT is at TRL 3. Following AFIT CTEx mission, TRL 6.
- Possible research collaboration partners: Sandia Labs, National Solar Observatory, Air Force Weather Agency, Air Force Research Labs

Value to NASA:

Demonstrate capability to collect spectrally-resolved images of fast transient events, such as:
- Solar flares & sunspots – support evaluation of models being developed by NASA
- Bolides & meteorites – analyze content, structure, and origin from changes in spectral emissions
- Sprites & aurora – enable micro-scale analysis

Demonstrate technology capable of trading temporal, spectral & spatial resolution for a range of applications

The demonstration of these capabilities advances NASA astrophysics and space technology objectives as outlined in the NASA goals and objectives reference on the SALSO website.

CTEx – Space-based Chromotomography Experiment

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Qualification Statement

This submission is authored by Timothy Coon, a current student at the Air Force Institute of Technology (AFIT) working to advance the CTEx project through thesis research and development. This submission is presented with the full support of physics and aerospace faculty members at AFIT, including those listed above. In addition to many years in academia and advancing the technological readiness of the United States Air Force, many of the faculty members have contributed to space readiness and research in cooperation with various organizations including NASA, Air Force Research Lab (AFRL), Naval Research Lab (NRL), National Air and Space Intelligence Center (NASIC), and The DoD Space Test Program (STP).

Primary Concept

Spectral imaging has been demonstrated to provide valuable information about the composition of complex scenes, but traditional instruments require a significant time to collect the data. The scene is generally divided up into small spatial or spectral bins that are collected one at a time. This generally means the instrument is incapable of measuring a scene that changes over the timescale required to scan through all the bins. The proposed sensor collects spatial and spectral data from the full scene in every frame – no information is missed. A pictorial representation of two spatial dimensions with one spectral dimension collected at one instant in time is shown in the datacube of Figure 1.

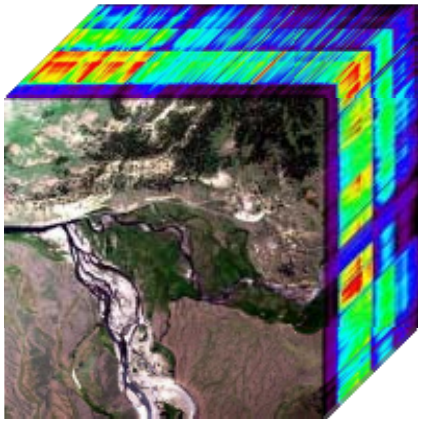

Figure 1 – Datacube consisting of spatial and spectral information

For remote sensing applications, it is typical to understand that the data collected may have increased resolution in the spatial, spectral, or temporal aspects at the expense of the other two. This is most evident in scanning-slit hyperspectral imagers which are able to collect highly-resolved spatial and spectral information by scanning a narrow line of the image space. However, these imagers are unable to combine data of a large, time-varying, two-dimensional field of view (FOV) as they must sweep the image space many times to build a complete image. This means that if the spectral and/or spatial profile of the electromagnetic energy collected from a scene changes rapidly, the scanning-slit imager would be unable to resolve the appropriate information.

Chromotomographic imaging (CTI) is a proposed technology that seeks to allow for remote sensing at high spatial, spectral, and temporal resolution by implementing advanced mathematical algorithms akin to those of medical tomography utilized successfully in the medical industry for decades. Medical tomography is the basis for X-ray computed tomography (CT) scanners, among other devices, and is able to reconstruct three-dimensional images of bones from cross-sectional images. Chromotomography uses similar concepts, except that the three dimensional object is the datacube.

The basic instrument layout is depicted in figure 2. In order to convert the spectral dimension into a spatial dimension that is discernible by image plane sensors, a direct-vision prism (DVP) disperses the energy evenly across the detector plane. As the prism is made to rotate, the image at a particular frequency will translate around the normal of the image plane at a fixed radius. In this way, the spatial and spectral dimensions of the datacube are imaged onto a two-dimensional plane. Tomographic reconstruction algorithms are then implemented to build the datacube from images captured at many projection angles as the prism rotates. Assuming that a datacube can be built for each rotation of the prism, at a reasonable 600 rpm, DVP CTI will build a datacube every 0.1 seconds, quickly enough to observe spectral and spatial changes of most rapidly-changing phenomenon. However, even with moderately-priced equipment, it is not unreasonable to expect the construction of one datacube every 0.01 seconds with high spatial and spectral resolution. In addition to overcoming temporal limitations, CTI is theoretically advantageous when applied to low signal-to-noise imaging as it allows the entirety of the received photons to excite the detector instrument plane.

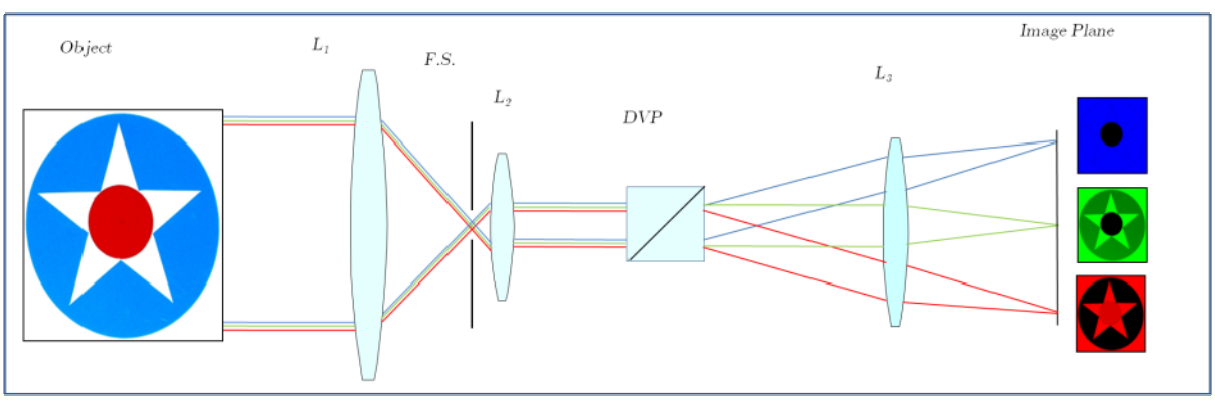

Figure 2 - CTEx Instrument

The applications for spaced-based CTI are many. Even within the scope of observable targets to advance NASA objectives, the possibilities are only limited by our understanding. A few objectives are explored here, but it is noted that the validation of this technology has strong implications for both civil and military applications.

Solar Flares & Sun Spots:
Data could support current efforts to develop physics-based models. For example, comparing the fraction of energy in broadband emissions to the atomic emission line strengths could help to bound estimates of plasma density and support development of flare & sun spot models.

Meteorites and Bolides:
Spectral changes as objects burn up entering the atmosphere could reveal information about their content, structure, and origin.

Planetary Atmospheres:
High spatial and temporal resolution simplifies observation and analysis of limb absorption spectra as planets transit stars.