

Statement of Research

Introduction

My research interests cover optical & infrared opto- & cryo-mechanical instrumentation, infrared properties of star forming regions, processes of dust formation and variability of brown dwarfs and blazars. I describe below the various instrumentation projects I have participated in over the last eight years, as well as the observational projects I have been involved with in the last four years. In my future research I expect to continue with the dominant emphasis on instrumentation, while also engaging in a wider range of observational astronomy.

Instrumentation

My work in instrumentation has been broad-based, and all of it has been educational, technically and collaboratively. I describe my instrumentation work below chronologically to highlight the progress and expansion of my experience in the natural manner of the learning process.

Engineering Instrumentation

My research in instrumentation began during my undergraduate studies with a project on experimental determination of aerodynamic properties of a supersonic ramjet missile using supersonic wind-tunnel testing of a scaled model. A project of this kind requires gathering an extensive amount of data to determine only a handful of many parameters that need to be well understood to accurately model the test object's behaviour within the entire operational envelope. Even so, the difficulties that arise in the use of experimental results was made evident in the project I undertook for my undergraduate thesis. Firing range tables generated after extensive field trials of a well regarded and commonly used artillery shell were found to be invalid when used in high altitude battlefields. We created a detailed modelling program to simulate all the aspects of the flight of the artillery shell based on the previously measured characteristics of the shell. Having confirmed the model's validity within the experimentally tested flight envelope, it was used to generate suggestions for modifications to the shells to ensure a controlled and predictable flight path for the shells in high-altitude battlefields. These two projects have formed my opinion on the role of experimental science as well as the effort and caution needed in its use.

Seeing at Fan Mountain Observatory

My work in astronomical instrumentation began with a year-long campaign in 2002, along with a fellow graduate student Chan Park, to determine the site seeing at the Fan Mountain Observatory of the University of Virginia. Fan Mountain was one of the locations considered for a new home for the U.S. Naval Observatory during the 1950s (Birney, 1966). It is only 16 miles from the University of Virginia, and when UVa decided to create a second station of the Leander McCormick Observatory, Fan Mountain was chosen as its location based on the study done by the USNO. However, the seeing at the site had not been analysed in nearly 30 years and when UVa decided in 2000 to embark upon a major renovation and upgrade of the facilities, measuring the site seeing became a priority. We devised a Differential Image Motion Monitor based on an 8-inch Meade telescope and an SBIG STV CCD Camera to measure seeing. The setup, observations and data analysis follow Tokovinin (2002). We determined that the seeing at Fan Mountain is $1.52'' \pm 0.47''$ in the astronomical H-band.

A Near-Infrared Camera for Fan Mountain Observatory

The upgrade of the Fan Mountain Observatory, lead by Michael F. Skrutskie at the newly formed Virginia Astronomical Instrumentation Laboratory, envisioned transforming one of the two telescopes at the site, a 31-inch classical Cassegrain, into a state-of-the-art Near-Infrared(NIR) facility for astronomical observations. NSF funding was obtained for an NIR Camera to be designed and built by students. I, along with Chan Park, lead the optical design using ZEMAX optical design software and the mechanical design using Mechanical Desktop. We also performed the assembly of the machined parts, tested and commissioned the NIR camera, christened FanCam.

FanCam is based on a HAWAII-I detector, has a field of view of $8.7' \times 8.7'$ with $0.51''$ pixels, and contains a suite of near-infrared filters in two filterwheels. FanCam optical design has very low distortion and field curvatures, and is confocal for imaging in the Y, J, H & K_s broadband filters used in FanCam. All these qualities allow for excellent astrometric and mosaicing capabilities. Photometric observations with Point Spread Functions(PSF) as low as $0.9''$ have been made on nights with excellent seeing. The quality of the images has consistently been limited the seeing, and our prior determination of typical seeing helped us optimise the design of the camera for best usability. The 10σ limiting magnitude in 10 minutes of on-source observations is 19.0 in J, 18.0 in H and 17.0 in K_s bands(Kanneganti et al, 2009).

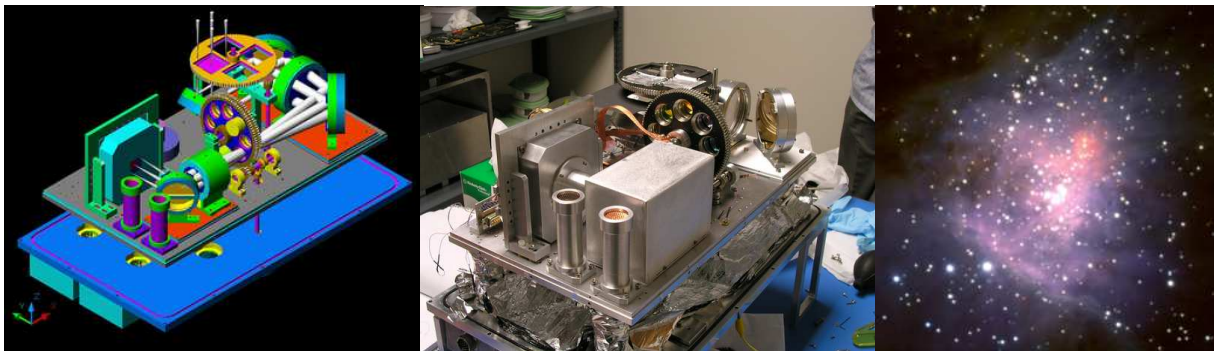


Figure 1: (*left*) FanCam layout, rendered in Mechanical Desktop, (*middle*) the actual layout, ready to be closed up and (*right*) the first light image of the Orion Nebula, 10min in J, H & K_s bands.

The optical layout has a collimated space with a Lyot stop straddled by the two filterwheels. This design feature has allowed us to place two Wollaston prisms and a grism in one of the filterwheels, facilitating linear polarimetric observations and $R \sim 400$ spectral observations of point sources in conjunction with the four broadband filters mentioned above. The Wollaston Prisms were funded by a AAS Small Research Grant and were spec'ed by another collaborator to give about $30''$ separation between the images cast by the ordinary and the extra-ordinary beams. The grism was funded by a Sigma-Xi Grant-in-Aid of Research awarded to me. I designed the grism using analytical ray-tracing and the plotting tool Gnuplot, and verified the final design using ZEMAX. The grism was then ordered from a grating lab, and has recently been installed. Observations are underway to validate the design and performance of the polarizers and the grism. Further information on FanCam can be accessed at <http://www.astro.virginia.edu/research/instrumentation/fancam.php>

A Space-qualified Hand-held Near-Infrared Spectrograph

In the summer of 2005, the astronomical instrumentation group at UVa was approached by Dr. Gregory Olson, a collaborator and an alumnus of UVa, with a request for a scientific instrument he

could take with him on his week-long trip to the International Space Station (ISS). He also stipulated that the instrument use a commercial Sensors Unlimited InGaAs camera and this be detachable so the camera be used independently. After deliberations at a student science committee formed for this instrument, we concluded that the primary astronomical target from the vantage point of the ISS is the Earth, which is also a target only infrequently observed by astronomers. An integrated-light spectral signature of Earth within the $0.85\text{-}1.7\ \mu\text{m}$ spectral range of the specified detector is of great interest due to its applicability in interpreting spectra of yet-to-be discovered terrestrial-mass exo-planets the Terrestrial Planet Finder mission (TPF-I) is expected to study.

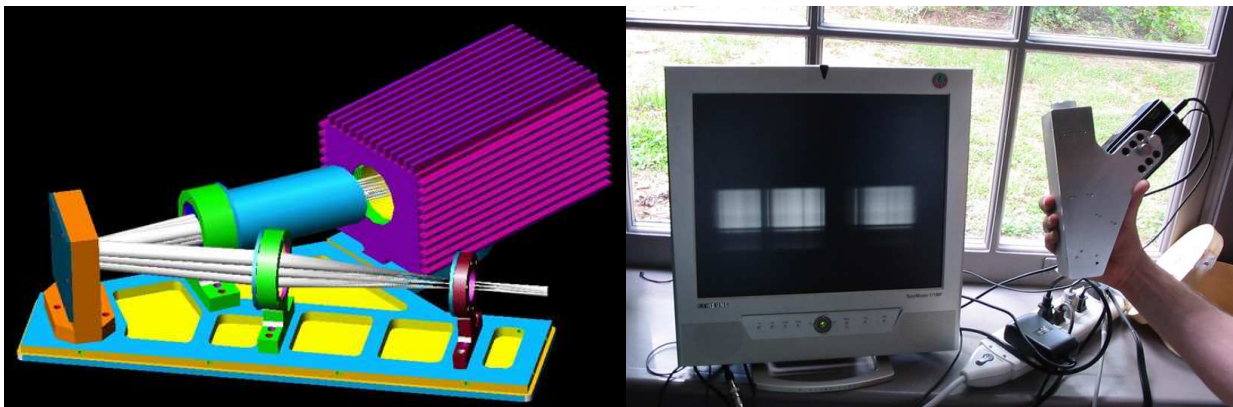


Figure 2: (*left*) The ISSSpec design rendered in Mechanical Desktop. (*right*) A sample observation with the spectrograph. The output is recorded as digital video and converted into FITS images post-observation.

I lead the optical and mechanical design of the instrument and the assembly of the instrument. The demanding aspect of the project was to create three copies of the spectrograph that conform with all the NASA/RSA drawn requirements for equipment designated for human space flight in the short period available - Dr. Olsen flew to the ISS in October 2005, and pass the qualification tests to be done by the Russian Space Agency. We carefully selected all non-machined materials from pre-approved NASA material lists. The short notice also meant all optics had to be ordered off-the-shelf from catalogs. The spectrograph was made as a module and attaches to the camera using thumbscrews and positions the detector at the optical focus of the spectrograph using pre-defined cardinal surfaces. The spectrograph creates a very linear 1st-order long-slit spectrum of the entire spectral range of the detector with an $R \sim 206$ at $1.27\ \mu\text{m}$. After testing determined that the performance of all the three copies of the spectrograph were indistinguishable and consistent with the design (Kanneganti et al, 2006), two of the copies were sent to Russia, where they passed the space-flight qualification tests. One spectrograph was flown to the ISS in October 2005, but was not used for observing as the U.S. Government refused an export license for the InGaAs camera to be sent to Russia. Further information on ISSSpec can be found at <http://www.astro.virginia.edu/~sk4zw/research>.

TripleSpec, a Cross-Dispersed Spectrograph

TripleSpec is an $R \sim 3000$ cross-dispersed near-infrared spectrograph for use as a facility instrument at a large telescope (Wilson et al, 2004). University of Virginia has collaborated with Cornell, JPL and CalTech to design and build three nearly identical copies of the instrument for use at the Apache Point Observatory 3.5m telescope (UVa), Palomar 200-inch telescope (Cornell & JPL) and

The laser system I am in-charge of controls the positioning, quality and stability of the laser beams that will be launched into the sky, and have various diagnostic systems incorporated in it to monitor and maintain the stability of the laser beams that is needed to achieve the demanding requirements on the ARGOS system. The diagnostic systems designed include internal field location measurement, pupil location measurement, laser launch telescope alignment monitor and laser phase monitoring. The system also continually corrects for telescope vibrations and flexure that affect the laser beam launch path. The component procurement phase of this project is rapidly advancing and the laser system will be assembled and tested in the next few months.

Science

Search for Short Periodicity in the Near Infrared Variability of OJ287

OJ 287 is one of the most extensively studied Blazars, with historical observations going back nearly a century, and exhibits complex variability at all wavelengths and at all timescales (Takalo, 1994). The only clearly stable longterm periodic variability detected in its observations is the 2-year separated flares that repeat every 11.6 years. There have been various detections of transient periodicities on 15-30 minute timescales in radio observations (Kinzel et al, 1988) for nearly 25 years at multiple frequencies. A detection of a corresponding intermittent NIR variability, either photometrically or polarimetrically will help better characterize the processes in accretion disks and jets that lead to variability (Marscher, 2006). I have undertaken a two year observational project with FanCam to search for such a variability and also to demonstrate the capabilities of FanCam with regard to long-term multi-epoch variability studies. We have seen some indications of a 22-minute periodicity in J-band linear polarimetry in data taken in the fall of 2007, and more observations are currently underway to try and confirm this periodicity.

Near-Infrared Variability of Young Stellar Objects in Embedded Clusters NGC 1333 and NGC 7129

This project, lead by my close collaborator Chan Park, involves near-infrared photometric monitoring of the embedded clusters NGC 1333 and NGC 7129. Using FanCam, we have obtained photometric data in J, H & K_s data on one $8' \times 8'$ field in NGC 7129 and two fields in NGC 1333 at more than 30 epochs over the time period of November 2005 to October 2007. The photometric depth of these observations is approximately 17 in K_s , 18 in H and 19 in J at a signal-to-noise ratio of 10σ . We have detected and categorized a significant number of new Class I and Class II YSOs in these clusters. We are currently analysing the data to shed light on the physical processes behind the observed variability.

Near-Infrared Cloudshine in CB4

CB4 is an extremely cold (kinetic temperature of 14K) gravitationally stable Bok Globule about $5'$ in diameter and a mean core A_v of 1.9 mag with fully a subsonic velocity field, which makes CB4 a unique case study for molecular cloud modelling (Dickman & Clemens, 1983). Internal structure of molecular clouds is usually discerned using extinction maps or radio line or dust emission maps, but all these techniques have limitations. Scattered light surface brightness has recently begun to be used as an independent method to measure column density to compliment these kind of observations (Juvela et al, 2008). The low extinction present in the case of CB4 allows for the surface brightness to be directly converted into column densities and provide a detailed density profile (Padoan et al, 2006). To this end, I have taken 1-hour long on-target observations of CB4 in Y, J, H & K_s bands

with FanCam to detect its very faint scattered light. We are in the process of extracting a surface brightness profile to compare to the cloud models described in Dickman & Clemens (1983).

Measurement of the Opposition Surge of Triton at True Opposition

Triton is one of the few very active moons in the solar system, and its surface properties are of significant scientific interest. Triton is known to have a strong Opposition Surge (a very dramatic increase in brightness at very low solar phase angles), possibly variable (Herbert et al, 2004), and we availed the opportunity to observe Triton in J, H & K_s bands with FanCam around the opposition of August 13, 2007. Triton reached solar phase angles as small as 0.009 degrees during this opposition, with the Sun's angular radius at its location at only 0.008 degrees. The observations were carried out in two parts - one around opposition, and the other about a month later to provide a baseline for the increase in brightness we seek to detect. We measured the amplitude and angular width of the opposition surge in each near-infrared band, and will compare them to Triton's opposition surge in the visible from Buratti et al (2004), as well as the opposition surge of other icy bodies in the outer Solar System to gather clues to the thermal and weathering histories of these surfaces (Dante et al, 2008).

Variability of L-T transition Dwarfs

The rapid expansion in the observations of L & T dwarfs since the recent adoption of their classification has helped form a moderately coherent description of the general evolution of these objects (Kirkpatrick, 2005). The objects classified type L1 through L8 correspond cleanly with a trend of decrease in their effective temperature, as is also true for classes T4 through T9. In the transitional classes L9 through T3 however, the effective temperature remains constant at around 1500K while the $J - K_s$ color of the object becomes bluer by 2 magnitudes. Also, fewer number of these L-T transition dwarfs are detected in comparison to the other classes. If we accept the most well received explanation for these trends, L1 through T9 form an evolutionary track for brown dwarfs, with some considerable degeneracy caused by variation in mass and metallicity of the objects. In this scenario, the L-T transitional dwarfs would represent a swift transitional phase in the evolution with a rapid shift in color (Knapp et al, 2004). The likely physical explanation for this is rapid condensation of dust in the upper atmospheres of these dwarfs that starts to appear in L8 dwarfs and has completely rained down below the photosphere by the time the dwarfs have evolved to T4 dwarfs (Lodders, 1999). Atmospheric modelling of the low temperature atmospheres of the transition dwarfs have significant degeneracy with regards to metallicity, gravity and possible variations in "weather" and partial "cloud cover" in the photosphere (Burrows et al, 2006). To better constrain these atmospheric models, thorough studies of short and long period variability in these transition dwarfs is needed (Enoch et al, 2003). An observational campaign, with a dozen or more L-T transitional dwarf targets, monitored for variability in the hours to days timescales would make a good contribution to our understanding of Brown Dwarf evolution. I hope to begin such a project in the near future based on the availability of suitable observing opportunities.

Summary

I have worked on a varied set of instrumentation projects which range from small in scale (isspec) to large (ARGOS). All of these projects were very hands-on and allowed the exercise of remarkable independence in decision-making as well as episodes of collaboration, and have proved highly instructional experiences. My interests in observational science to date have primarily been determined by the instrumentation projects in which I have been involved. I expect to continue with

studies similar to the ones at present while continuing to broaden my interests based on the capabilities of the instruments I hope to be involved in designing and building in the future. Inclusion of students has been a significant feature of many of these projects with beneficial results. I intend to actively pursue student mentoring and student involvement in both the instrumentation and science in my work.

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