Lab characterization & on-sky Commissioning of FiberPol for the SAAO 1.9 m Telescope

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Overview: We are offering a Masters project at the SAAO to work on the development and on-telescope commissioning of an upcoming new polarimetric instrument called FiberPol at the SAAO's Instrumentation Lab. It will the first fiber-based 2D spectropolarimeter in astronomy and will be novel technology.

Supervisors

1. Dr. Siddharth Maharana (SAAO, Cape Town)
2. Dr. Sabyasachi Chattopadhyay (SAAO, Cape Town)
3. Prof. Matt Bershady (Univ. of Wisconsin-Madison, Wisconsin, USA)

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Context & Motivation

Polarimetry, as the name suggests, refers to measurement of the state of polarization of light coming from a source. It entails ascertaining the amount and direction/sense of any preferred polarization state in the light beam. Polarimetry is a powerful tool which has been used by astronomers to understand the physics of myriad kinds of astrophysical objects, such as active galactic nuclei, supernovae, proto-planetary systems and dust clouds in the interstellar medium (ISM). In particular, it is useful in study of objects that have an inherent asymmetry in their light emission or propagation mechanism. In fact, often, polarimetry is the only method to find the geometry of an astrophysical object/system and it cannot be obtained by other methods such as imaging and spectroscopy. To carry out such studies, astronomers have been building polarimeters with ever-increasing precision and accuracy, with most current day instruments reaching accuracies of the order of 0.1% or better.

Most modern polarimeters in astronomy come in two broad kinds: imaging polarimeters and spectropolarimeters. As the name suggests, imaging polarimeters create the polarization image of a sky field in different broadband filters, while spectropolarimeters enable polarization measurement as a function of wavelength across a large wavelength range. In general, spectropolarimeters are a more powerful way to probe the physics of astronomical sources, just as the spectra of a source has more encoded information than only the intensity information obtained through images.

All spectropolarimeters built to date operate as long slit or point-source instruments, i.e, usually only point sources can be observed with them. As expected, they are not efficient for spectro-polarimetric measurements of 2D/extended objects. For example, with current day spectropolarimeters, we are unable to efficiently map the polarization of extended objects such as galaxies. This has severely limited the objects studied through polarimetry.

Thus, 2D spectro-polarimetry is one of the next challenges in astronomical polarimetry, along with its promise of rich scientific dividends. Today, 2D spectroscopy, also referred to as Integral Field Spectroscopy (IFS), is an advanced and mature technology used in many of the major telescopes and instruments around the world. 2D spectro-polarimetry, also known as Integral Field SpectroPolarimetry

(IFSP), which aims to combine IFS and polarimetry, will open up a new parameter space of information mining from astrophysical objects and can potentially transform the study of many classes of objects by providing hitherto unavailable data.

Project Details

At SAAO, we are developing an IFSP front end FiberPol for the existing SpUpNIC spectrograph on the SAAO 1.9 m telescope (SpUpNIC). FiberPol will be mounted on the Guiding and Acquisition Module (GAM) of SpUpNIC on the 1.9m telescope. SpUpNIC is the workhorse instrument on the 1.9m SAAO telescope at the Sutherland Observatory that has been working successfully over many years. It is a conventional long-slit spectrograph that can obtain medium to low resolution spectra over the entire optical wavelength range of 350 to 1000 nm using various gratings.

The primary science targets with FiberPol are the study of dust properties in the ISM of nearby galaxies, galactic nebulas, molecular clouds and star forming regions, supernova remnants, asteroids and comets. Even for point objects such as supernovae and active galactic nuclei, the 2D field will be helpful and efficient in correction for ISM introduced polarization by simultaneous observation of field stars, thus allowing the astronomers to accurately estimate the inherent polarization of a source.

Masters Project Description:

FiberPol will perform the tasks of polarimetric analysis like that of a conventional polarimeter along with the 2D functionality of an integral field unit (IFU). The IFU will consist of two bundles of fibers that will sample sky areas of 20 by 10 arc-seconds. These two fibre bundles will collect light of the sky field corresponding to orthogonal polarization states, enabling measurement of each of the Stokes parameters in a single measurement. The switching between the different Stokes parameters will be done using

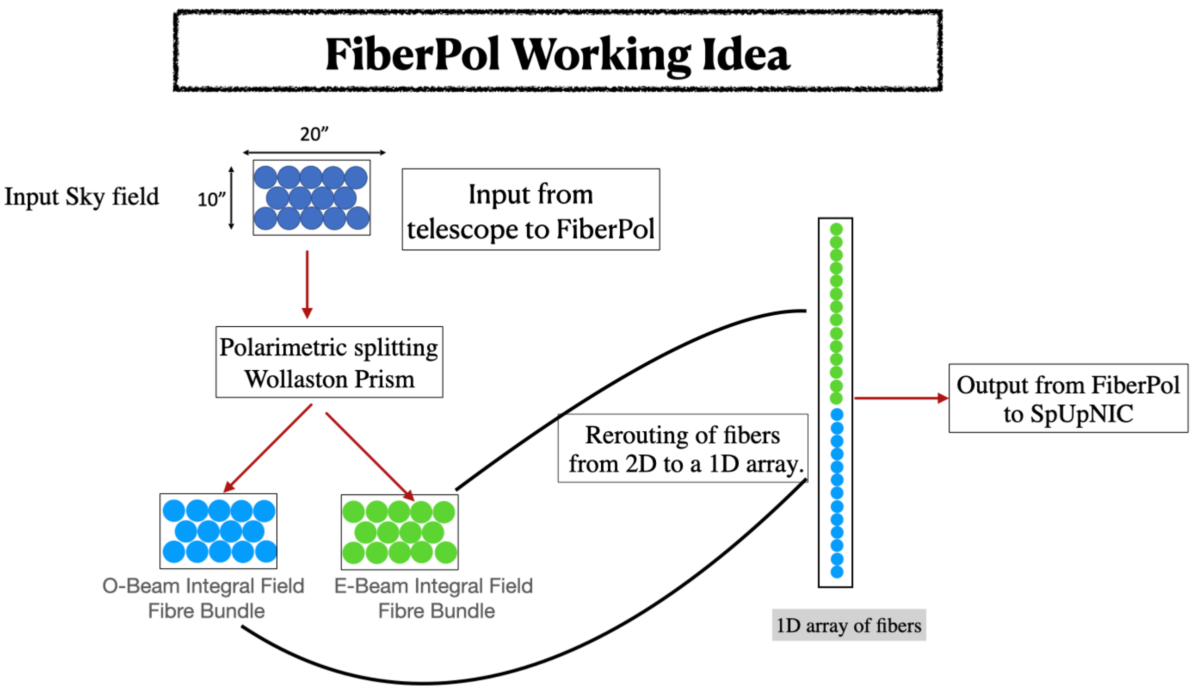

Figure 1. Top level working idea of FiberPol system.

rotating half-wave plate in the optical system. Figure 1 shows the top-level working of the FiberPol instrument. The technical goal is to obtain 0.1 % polarimetric accuracy of the field of view of FiberPol.

The instrument design and development is being carried out by Dr. Siddharth Maharana, Dr. Sabyasachi Chattopadhyay and Prof. Matt Bershady at the SAAO. Together, their research expertise spans both on polarimetry and fiber-based IFS.

Currently, the instrument design has been completed and work is on going on the instrument assembly and fibre-IFU development. Following this, testing, characterization of the instrument and commissioning is scheduled for later part of this year. The key challenges for the instrument development in future are as follows:

a. Accurate assembly and alignment of the optical system, including the fibre IFUs.

b. Measurement of the various polarimetric and spectroscopic systematics of the coupled fibre IFUs and polarimetric system such as its dependance on the length of fibre, temperature etc.

c. Develop the calibration strategy to measure the instrument induced polarization (instrumental polarization) and a methodology to correct for it, both in the lab and the sky.

d. Performance characterization of FiberPol in the lab.

e. Development of the data reduction pipeline for the instrument.

f. Commission on sky and early science and publications.

<u>The Masters project will consist of working on some or all of the above sub-projects, depending on the interest of the student. Please contact us to know more details of the work.</u> The final choice of topics will depend on the student's interests, supervisor and co-supervisor availabilities and the requirements of the program. We request the potential students to contact the supervisors to discuss the options before submitting their applications.

Research Impact:

FiberPol will be the first of its kind of instrument in astronomy and is expected to break new grounds in both technical aspects of polarimetric instrument development as well as the new and unique science capabilities it will provide to astronomers. Further, successful commissioning of FiberPol will be act as a technology demonstrator for IFSP modes on bigger telescopes such as the SALT, Thirty Meter Telescope.

Skillset to be acquired through the project:

This project will provide the student hands-on and first-hand experience on designing and developing cutting edge astronomical instrumentation, in particular working optical systems, data and image analysis techniques. During the project, the student will also get training in writing scientific publications to disseminate the progress made. These skills will find use in any STEM research field as well as general technology industry.

Required Skillsets:

While there is no strict prerequisite skillset needed for the project, during the course of the work, the student will need to spend a substantial amount of their time in the lab, in particular with optical systems. Although no prior programming knowledge is needed, it is expected that the students will need to learn it during the course of the project depending on the requirements.

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