MACQUARIE UNIVERSITY
ASTRONOMY, ASTROPHYSICS AND ASTROPHOTONICS RESEARCH CENTRE

The Replicable High-resolution Exoplanet and Asteroseismology (RHEA) spectrograph

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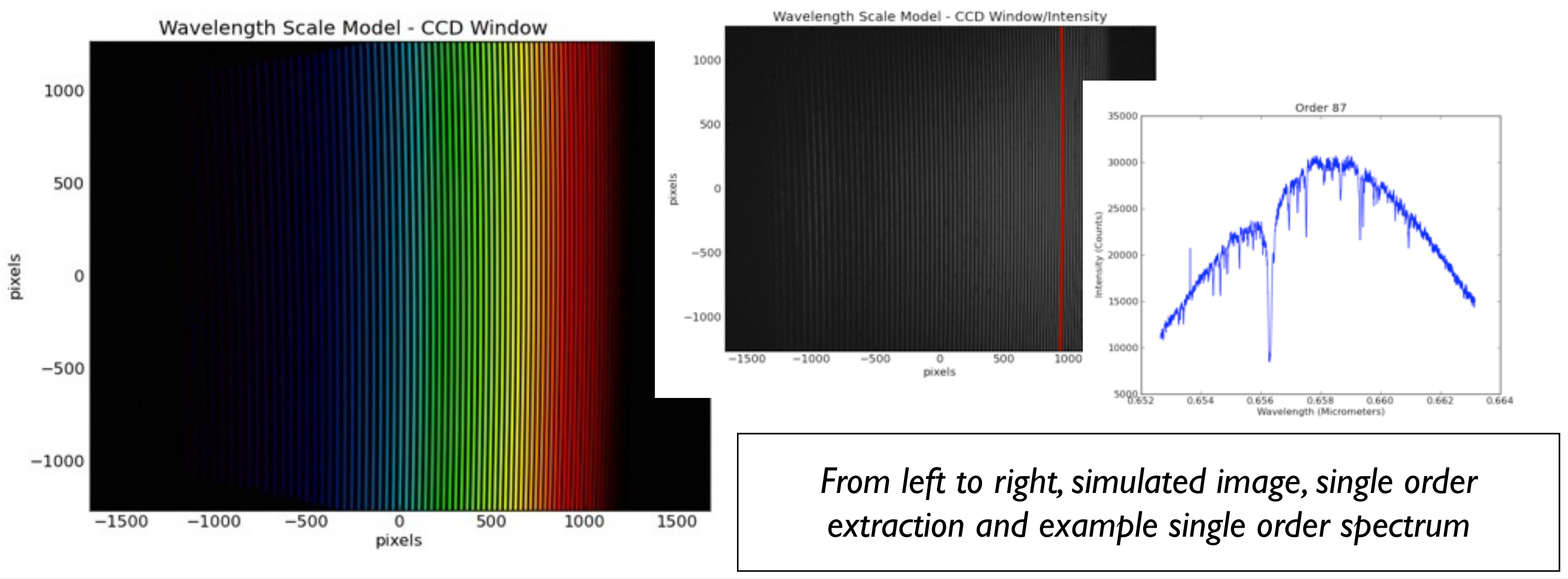
Introduction

The current limitations associated with detecting exoplanets using Radial Velocity (RV) measurements include temperature stability of spectrographs and efficient fibre scrambling in the quest for sub metre/sec precision. However, an astrophysical fundamental limitation is also present, in the form of noise from stellar activity. This is particularly true for giant stars, where the amplitude of pulsations is comparable with RV signals from hot-Jupiters. Long-baseline RV measurements are required to measure the intrinsic pulsations of the host star and de-correlate them to look for the planetary signals. This process uses these data for asteroseismological analysis, which also provides improved precision on the stellar mass and density. This is impractical using large telescopes, but possible to do on bright stars with 0.3-1m class telescopes. This poster presents the current status of the **Replicable High-Resolution Exoplanets and Asteroseismology (RHEA)** spectrograph, a compact single-mode fibre-fed spectrograph being developed at Macquarie University. It will serve the basis of a series of cheap spectrographs, composed of many "off the shelf" items, to be deployed on small telescopes for exoplanet and asteroseismological studies of giant stars, providing accessible technology to address this exciting problem.

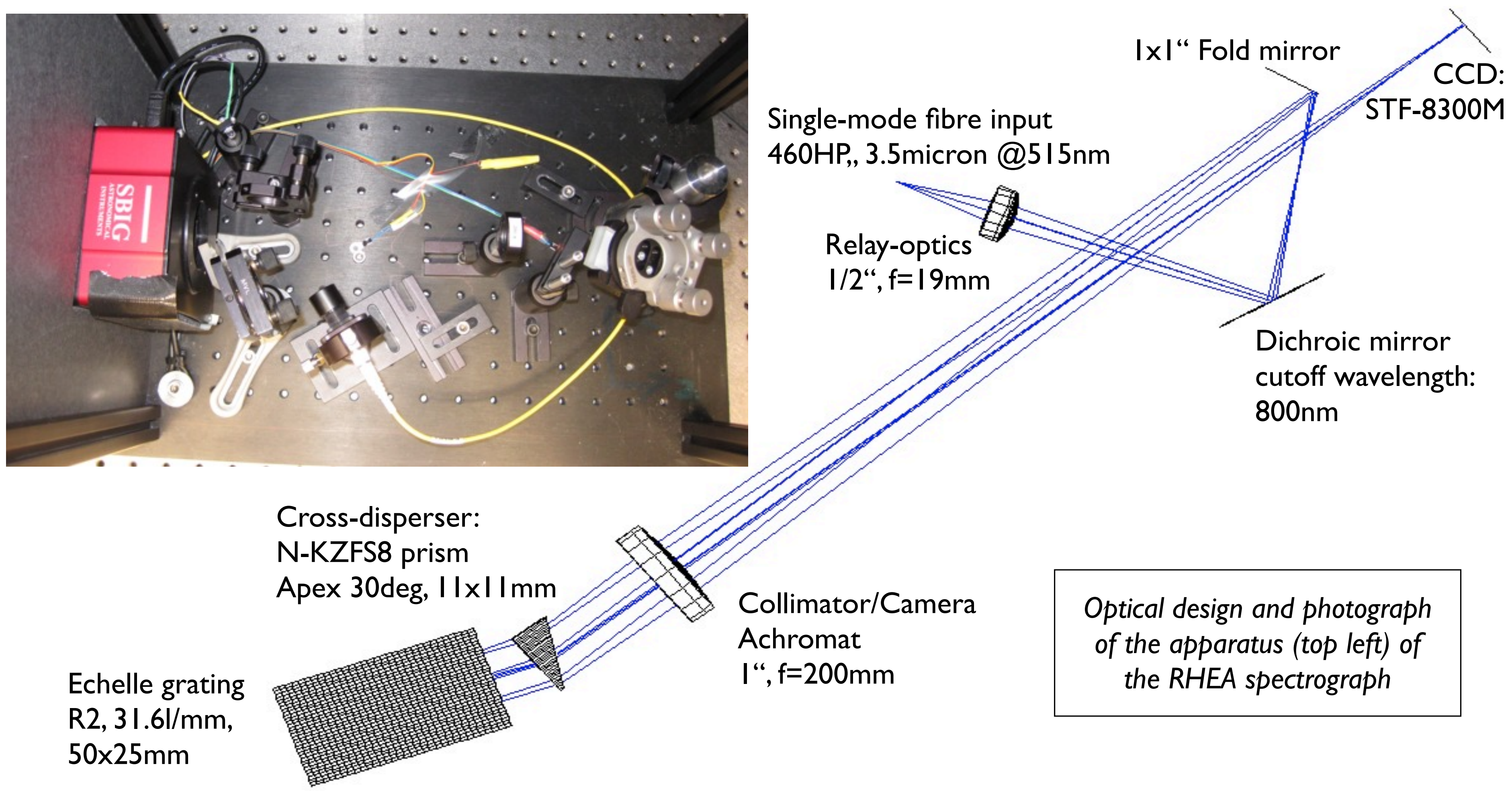
Wavelength scale model

Contrary to traditional methods of spectral extraction, we have developed a physically motivated model of the wavelength dispersion on the CCD chip. From first principles and knowledge of the spectrograph design, we use ray-tracing techniques to create a simulated image that allows the identification of spectral features. The parameters of the model are adjusted using preliminary data, such as a solar spectrum, and a model of the wavelength scale is generated, which is then used for spectral extraction. This will increase the pipeline's ability to measure precise RV variations.



From left to right, simulated image, single order extraction and example single order spectrum

Spectrograph design



Optical design and photograph of the apparatus (top left) of the RHEA spectrograph

The RHEA spectrograph is a compact high-resolution (R~50,000) single-mode fibre-fed echelle spectrograph, build with only off-the-shelf components, designed to be replicable and low cost. It operates at optical wavelengths, in the 400-600nm range. As shown in the figure, the starlight is fed through a fibre and collimated by a 200mm focal length lens. The light is then directed onto a 9mm wide prism and dispersed using an R2 echelle grating with 31.6 grooves/mm. The light is then fed back through the prism again, which acts as a cross-disperser and focussed onto an SBIG STT-8300M camera with a Kodak KAF-8300 3326x2504 chip. The entire optical setup is enclosed in 5mm polystyrene foam with a thermal insulator. The spectrograph also contains a custom thermal stabilization system on an active feedback loop.

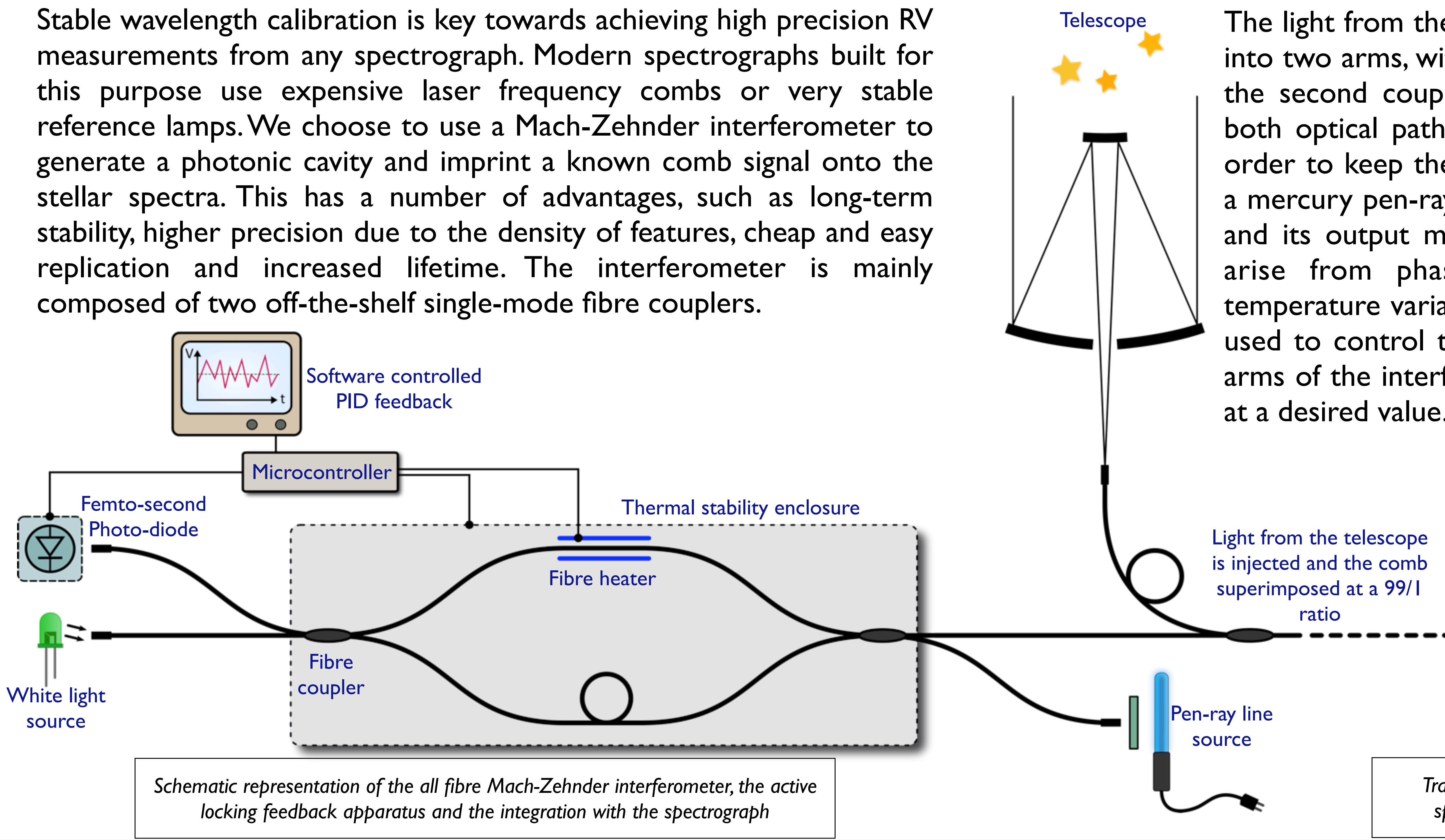
Macquarie Observatory

Macquarie University is ideally suited to build and test a spectrograph of this kind on bright stars. The prototype will be tested at the Macquarie Observatory's Meade LX200 16" telescope, which is sufficiently isolated from background light but within walking distance from the precision mechanical and optical facilities required to provide components and support for the spectrograph. The observatory is in the process of becoming an automated facility employing custom software for the task.

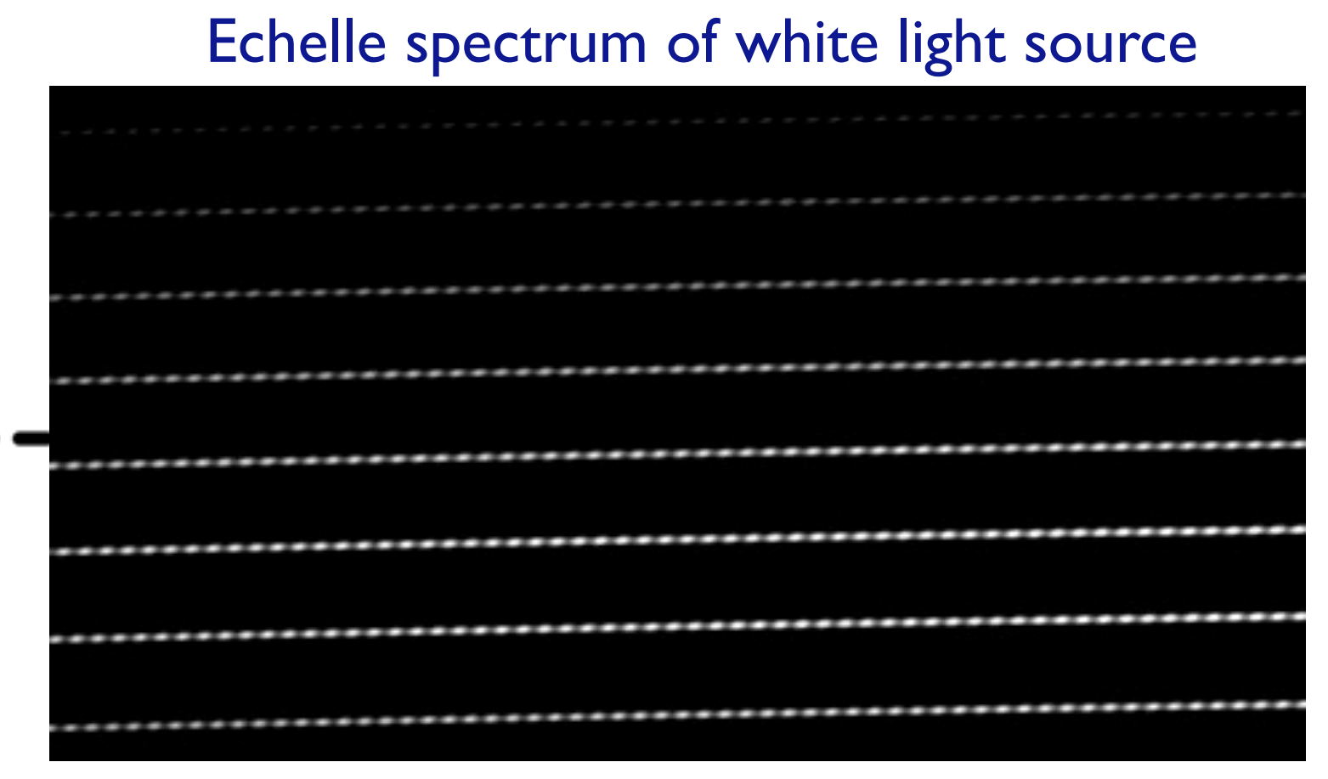
Wavelength Calibration

Stable wavelength calibration is key towards achieving high precision RV measurements from any spectrograph. Modern spectrographs built for this purpose use expensive laser frequency combs or very stable reference lamps. We choose to use a Mach-Zehnder interferometer to generate a photonic cavity and imprint a known comb signal onto the stellar spectra. This has a number of advantages, such as long-term stability, higher precision due to the density of features, cheap and easy replication and increased lifetime. The interferometer is mainly composed of two off-the-shelf single-mode fibre couplers.

The light from the source enters the first coupler and gets split into two arms, with a path length difference, and recombined at the second coupler. The interference between the light from both optical paths generates the desired wavelength comb. In order to keep the comb stable over long timescales, light from a mercury pen-ray lamp is fed back through the interferometer and its output monitored using a photodiode. Flux variations arise from phase shifts due to mechanical stress and temperature variations. A microcontrolled PID feedback loop is used to control the amount of heat to apply onto one of the arms of the interferometer and thereby actively lock the phase at a desired value.



Schematic representation of the all fibre Mach-Zehnder interferometer, the active locking feedback apparatus and the integration with the spectrograph



Transmission spectrum of a green LED taken with the RHEA spectrograph. The peak separation at 550nm is ~0.03nm

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