The ExAOC Science Instrument: An Integral Field Unit

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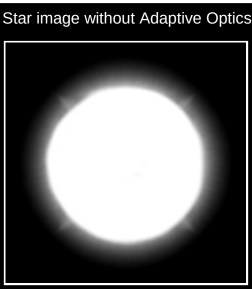
Over 100 planets have been identified outside our Solar System by indirect detection methods such as radial velocity measurements or transit measurements as a planet passes in front of its host star. When trying to directly image a Jupiter-like planet around another star like our Sun, small separations and large contrast in brightness have previously made these observations impossible. The advent of large telescopes and highly efficient adaptive optics (AO) systems has pushed observational sensitivities to remarkable limits.

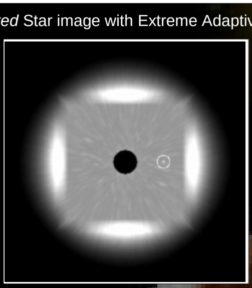
The Extreme Adaptive Optics Coronagraph (ExAOC) is being designed to discover and study extrasolar planets by means of direct detection at the Gemini Observatory. This complex system is comprised of an AO system, coronagraph, and a science instrument. The ExAOC science instrument will be an integral field infrared spectrograph designed to interface with the coronagraph in the ExAOC system. This instrument achieves Nyquist sampling at a wavelength of 1 micron with broad band spectral coverage over a 216 x 216 (2.80“ x 2.80“) grid of spatial elements, while simultaneously acquiring a low resolution spectrum at each element. An infrared transmissive lenslet array is used to sample the image plane early in the optical path, separating field points prior to the spectrograph. This isolation of the field points mitigates the errors induced by the backend optics allowing the instrument to achieve high internal Strehl ratios. This instrument design is ideal for the detection of faint companions because of its high level of speckle suppression and moderate spectral filtering.

Detecting Extrasolar Planets around Nearby Stars

Star image without Adaptive Optics



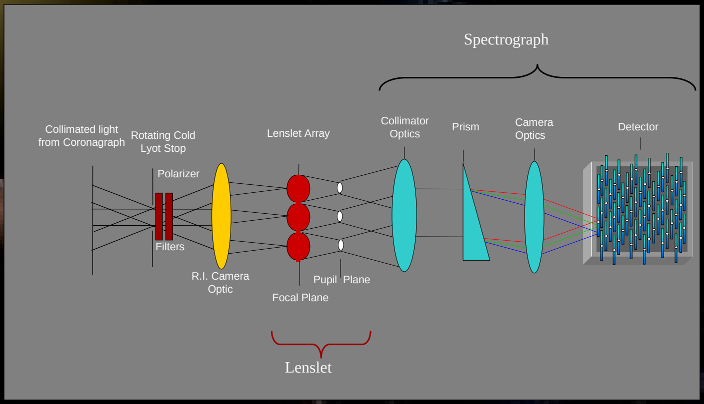
Simulated Star image with Extreme Adaptive Optics



`Macintosh et al., *High Contrast Adaptive Optics: “Extreme” AO*`

Starlight gets distorted as it passes through our atmosphere, and without adaptive optics the light is spread from a diffraction limited spot into a broad “seeing disk” as depicted in the image on the left. With ExAO, corrections are made for these distortions, and roughly 90% of the broad starlight on the left is concentrated into the small region behind the coronagraph – the black dot in the center of the image on the right. The coronagraph suppresses the intense light from the host star, and this allows for high contrast detections of very faint sources at small separations from the star. A planet eight times the mass of Jupiter is circled to the right of the coronagraph in the image on the right. The radial speckles seen in the control area on the right image are a dominant source of noise and limit the detections of faint companions. Using indirect detection techniques, we know that roughly 10% of nearby stars have Jupiter-sized planets at small separations from their parent star. ExAO will be able to explore whether nearby stars have Jupiter-like planets at separations similar to Jupiter's distance from the Sun.

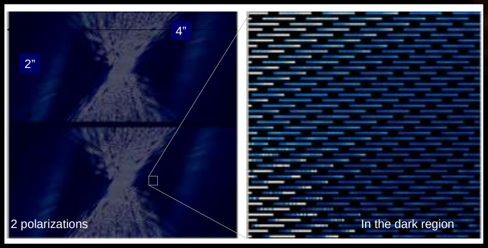
Science Instrument Optical Design



Simulated Raw Data

Image at lenslet array

Dispersed spectra on detector



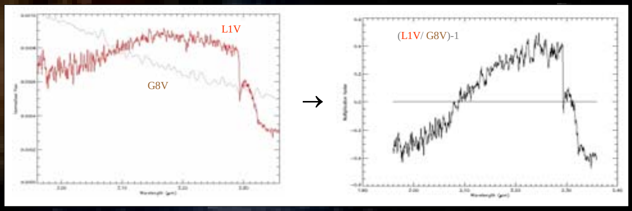
Simulated raw data from the integral field unit was constructed through scaling a PSF by wavelength into a cube and then placing the spectra in their respective positions in a two dimensional raw image. This compact spectral layout is attained by slightly rotating the lenslet array to separate neighboring row lenslets by 3 pixels, and the low spectral resolution means the spectra are sufficiently short (18 pixels) to prevent the overlapping of adjacent spectra. Roughly 46,000 spectra will be taken simultaneously in either the z, J, H, or K broad bands.

Speckle Suppression and Spectral Filtering

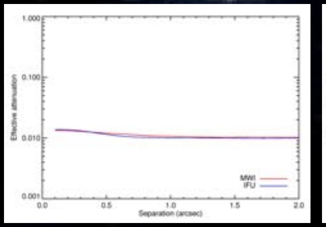
A reconstructed data cube will contain speckle noise from atmospheric phase distortion and aberrations introduced the optical system. The atmospheric phase distortions are short-lived and their spatial location changes rapidly; however, aberrations from the optical system are static errors that dominate the speckle noise in exposures of more than a few seconds. The Speckle Suppression Differential Imaging (SSDI) technique will be used to reduce the contamination from speckles. Speckles are wavelength dependent, which means that speckles will be scattered to varying angles. A radial rescaling of the cube can allow for each speckle to occur in the same spatial location, and then a subtraction of the rescaled channels will significantly reduce the speckle noise. Spectral filtering will be employed as a post processing algorithm to enhance the signal from the planet relative to the background. Signal from the companion is overlaid by the signal from the host star, and knowledge about the differences in spectral information can be used to design a weighted filter which maximizes the contrast between the planet and the parent star. Efficient speckle suppression and spectral filtering can increase the dynamic range by a factor of 100.

Normalized Input Spectra

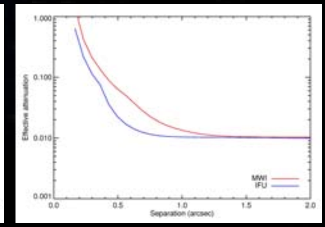
Weighted Digital Filter



Suppression for a companion with a T8 Spectrum



Suppression for a companion with a Flat Spectrum



`LaFreniere et al.`

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Background Image is courtesy of space artist Lynette Cook.