GPI: Basic Instrument Properties

Instrument configuration

GPI is a high contrast, near-IR imaging spectrograph with a selectable dual channel polarimetry mode. High contrast is enabled by a combination of wavefront control and diffraction suppression. A high-bandwidth (1.5 kHz), AO system measures and corrects seeing using two deformable mirrors—a low spatial frequency "woofer" and a high spatial frequency "tweeter" MEMS mirror (18-cm sub-apertures). GPI operates only with on-axis, natural guide stars. The coronagraph is an apodized pupil Lyot coronagraph that employs three optical masks to control diffraction: in sequence a pupil apodizer, a hard-edged occulting spot, and a final pupil stop. An optimized, custom triplet of stops is available for each science wavelength. A slow, accurate, interferometric wavefront sensor monitors the light delivered to the coronagraph spot in real time and reports residual wavefront errors to the AO system for correction. An atmospheric dispersion corrector can be deployed for operation away from the zenith. Representative data is illustrated in Figure 1.

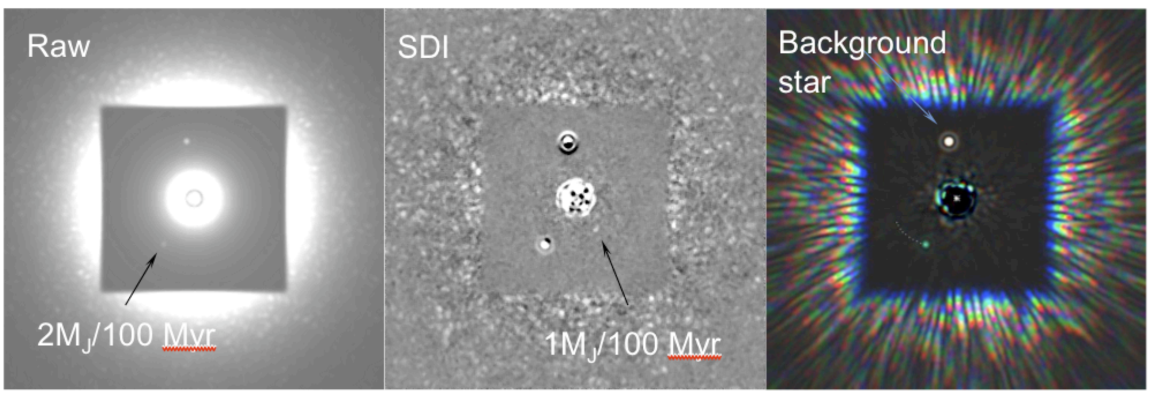

Figure 1: GPI simulation of a 100 Myr old K star at 17 pc. The northern object is a background star. 1 and 2 M_J objects are identified. The white dots near the 2 M_J planet show orbital motion over 10 years (1 dot/year). Credit: C. Marois (HIA/DAO).

Instrument modes

The principal mode is as a low resolution ($R = \lambda/\delta\lambda \approx 45$), lenslet-based, integral field spectrograph sampled with 14 mas pixels over a field of view of 2.8×2.8 arc sec^2. The spectrograph uses a prism and R is a function of wavelength. A broadband filter ($\Delta\lambda/\lambda \approx$ 15%) must be selected to prevent spectral overlap on the detector. The throughput from top of the atmosphere to photoelectrons is about 15%. The inner and outer working angles, approximately $3\lambda/D$ and $\lambda/2d$, respectively vary with wavelength. These angles are listed in Table 1 (D = 7.7 m and d = 18 cm) along with the available filters. Beyond the outer working angle wavefront errors are uncontrolled, and poor contrast is achieved. For non-coronagraph imaging the occulting spot may be removed. Light short ward of the Y band is used by the AO system and not available for science.

Table 1: Filters, spectral resolution, and radius of inner & outer working angles

Filter	Wavelength (μm)	Bandpass (%)	Spectral Resolution	IWA (mas)	OWA (mas)
Y	0.95-1.14	18	34-36	80	600
J	1.12-1.35	19	35-39	100	700
H	1.50-1.80	18	44-49	130	900
K1	1.9-2.19	14	62-70	160	1200
K2	2.13-2.4	12	75-83	180	1300

In dual channel polarimetry mode, the dispersing prism is replaced with a Wollaston prism and spectral resolution is traded for sensitivity to two orthogonal polarization states. Linear Stokes polarimetry, which is sensitive to *I*, *Q*, & *U* is achieved by modulating the astronomical signal with a rotating half-wave plate.

GPI is designed to remain stationary with respect to the telescope pupil during science exposures—it does not rotate to correct for sidereal rotation.

Performance

Achieved contrast is a strong function of guide star magnitude. A bright guide star ($I \leq 8$ mag.) is required for high performance operation, although operation superior to conventional AO systems will be maintained for $I \leq 9.5$ mag. For bright stars, quasi-static speckles set the noise floor, while for dimmer stars, photon shot noise of the uncorrected seeing halo limits sensitivity.

We predict the contrast performance of GPI using integrated models, which include the AO performance, the operation of the coronagraph, and residual speckle noise cancelling using angular and spectral differencing. The resultant performance is depicted in Figure 2. In differential polarimetry mode unpolarized speckles are suppressed by a factor of 100.

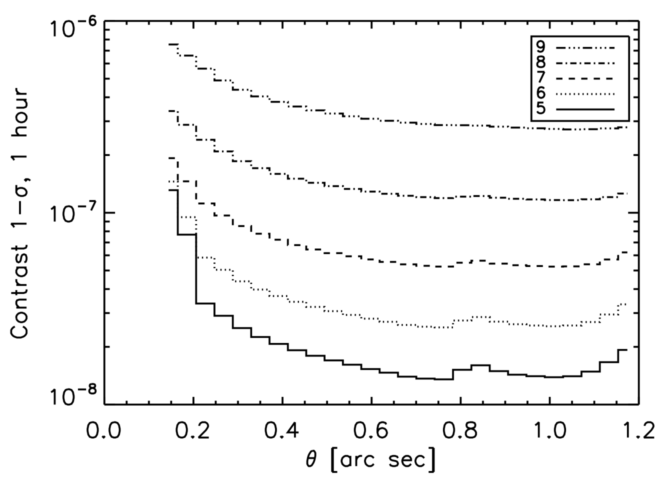

Figure 2: H-band contrast vs. separation for guide star magnitudes of *I* = 5–9 mag. This calculation includes speckle noise, photon shot noise, and speckle suppression using elementary angular and spectral differencing techniques assuming a T dwarf spectral signature.