Reaching the Diffraction Limit

Differential Speckle and Wide-Field Imaging for the WIYN Telescope

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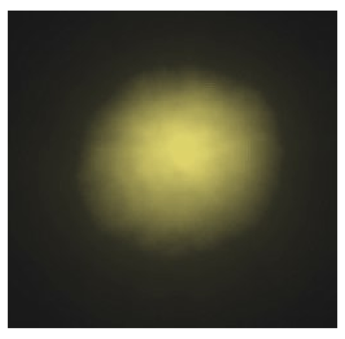
Introduction

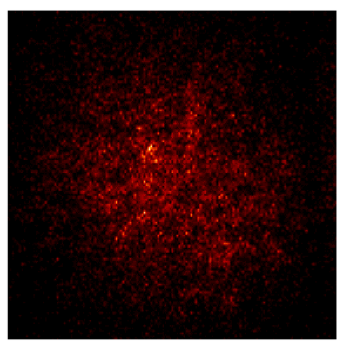
Speckle imaging allows telescopes to achieve diffraction limited imaging performance. The technique requires cameras capable of reading out frames at a very fast rate, effectively 'freezing out' atmospheric seeing. The resulting speckles can be correlated and images reconstructed that are at the diffraction limit of the telescope. These new instruments are based on the successful performance and design of the Differential Speckle Survey Instrument (DSSI) [2, 1].

The instruments are being built for the Gemini-N and WIYN telescopes and will be made available to the community via the peer review proposal process. We envision their primary use to be validation and characterization of exoplanet targets from the NASA K2 and TESS missions and RV discovered exoplanets. Such targets will provide excellent follow-up candidates for both the WIYN and Gemini telescopes [3]. Examples of DSSI data are shown in the figures below. We expect similar data quality in speckle imaging mode with the new instruments.

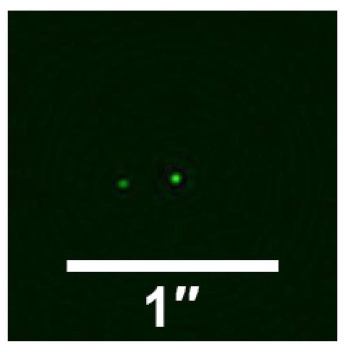
Additionally, both cameras will have a wide-field mode and standard SDSS filters. They will be highly versatile instruments and it is that likely many other science programs will request time on the cameras. The limiting magnitude for speckle observations, will remain around 13-14th at WIYN and 16-17th at Gemini, while wide-field, normal CCD imaging operation should be able to go to much fainter, providing usual CCD imaging and photometric capabilities. The instruments will also have high utility as scoring cameras for telescope engineering purposes, or other applications where high time resolution is needed. Instrument support will be provided, including a software pipeline that takes raw speckle data to fully reconstructed images.



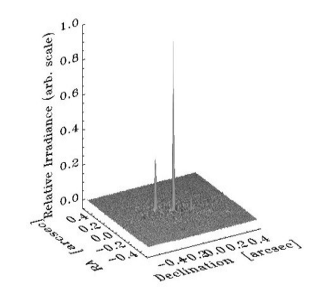
Integrated
1 $''$ image



Speckles



Reconstructed speckle image



Reconstructed speckle image

WIYN

Telescope f/#	6.289
Plate scale	9.374 $''$/mm

WIYNSPKL - Speckle mode

Focal Lengths

L1	30 mm
L2	200 mm

Detector Image Plane

Magnification	6.67x
Pixel Scale	0.0182 $''$/pxl
Unvignetted Circle Dia	22 $''$
Detector FoV	19 x 19 $''$

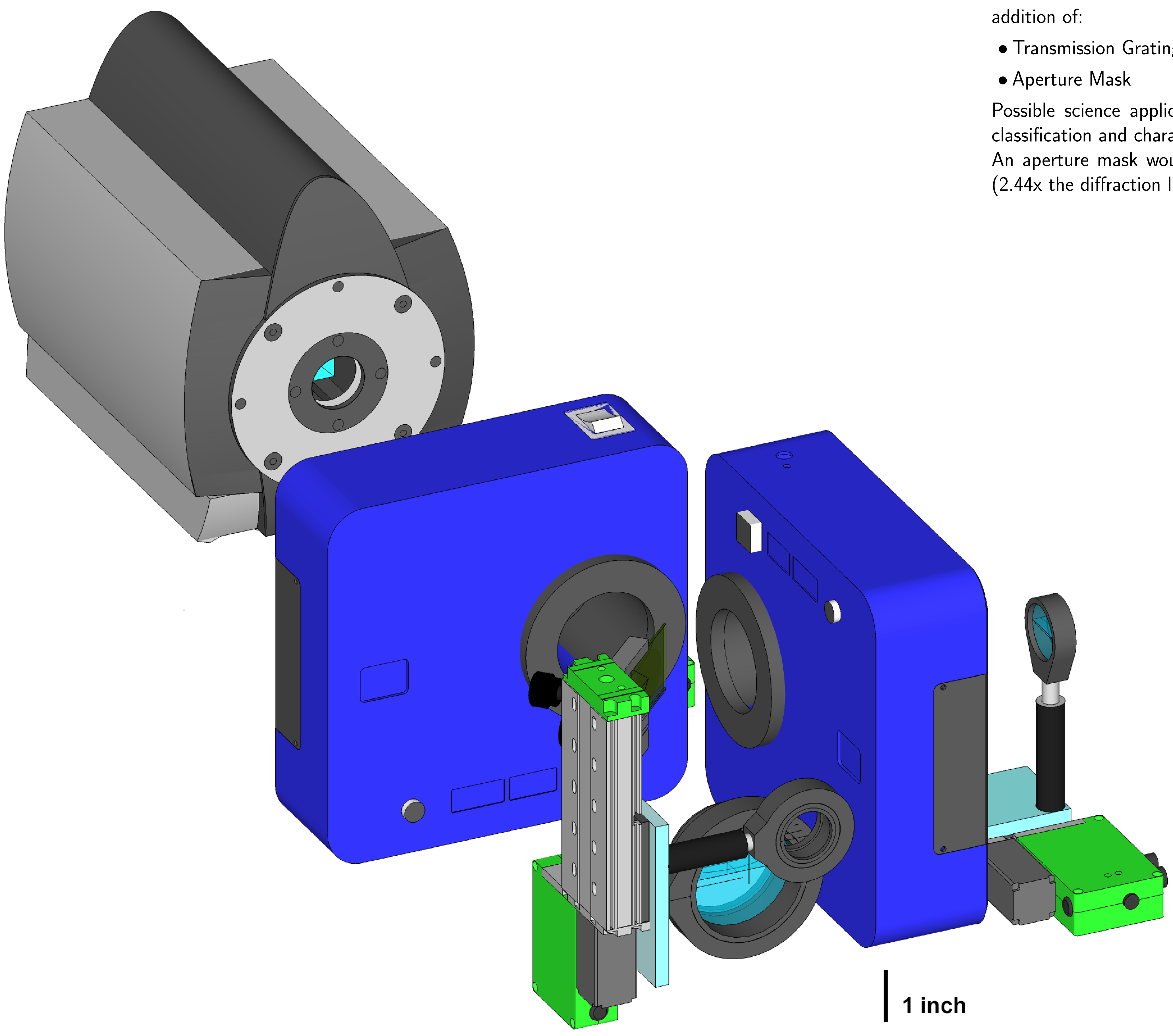
WIYNSPKL - Wide-field mode

Focal Lengths

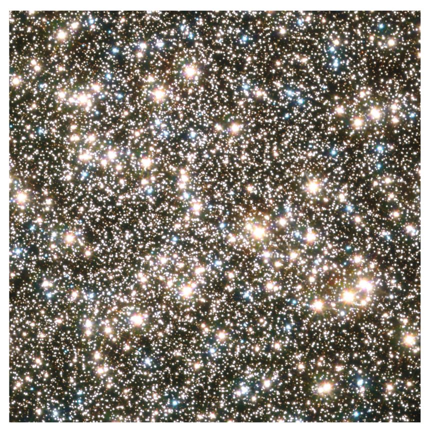
L1	100 mm
L2	150 mm

Detector Image Plane

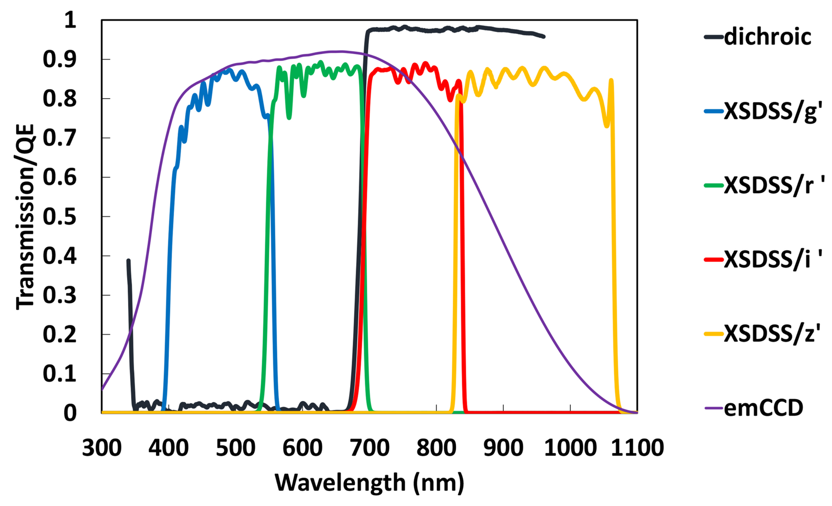
Magnification	1.5x
Pixel Scale	0.0813 $''$/pxl
Unvignetted Circle Dia	56 $''$
Detector FoV	83 x 83 $''$



WIYNSPKL, shown without the enclosure



$\sim$60 $''$ of M13 from the HST archive. This is a scale comparable to what will be available in WF mode.



Detector QE/SDSS Filter Transmission

Dichroic Edge 685 nm

This allows the blue (447nm) and green (562nm) filters in the reflective channel and the red (692nm) and infrared (880 nm) filters in the transmissive channel.

Filter Wheel A	central λ, bandwidth
SDSS/g	480 nm, 140 nm
SDSS/r	625 nm, 140 nm
g-narrow	466 nm, 40 nm
r-narrow	562 nm, 40 nm

Filter Wheel B	central λ, bandwidth
SDSS/i	770 nm, 150 nm
SDSS/z	910 nm, 120 nm
i-narrow	692 nm, 40 nm
z-narrow	832 nm, 40 nm

Detectors

The instrument will use two identical Andor iXon Ultra 888 EMCCD cameras.

- 1024 x 1024 with 13 μm square pixels
- Capable of 26 fps reading out the full chip, higher for subarray readout (speckle mode)
- EX coating, $>$ 80% quantum efficiency from 420 to 780 nm, $>$ 90% QE between 550 and 720 nm.
- Thermoelectrically cooled, require no consumables.
- Data is transferred to the control computer via USB3, no internal cards
- Control computer can be quite small with heat dissipation being minimal.

Maximum Resolution

WIYN	0.036 $''$ FWHM @ 500 nm	0.058 $''$ FWHM @ 800 nm

Discussion

Possible Exoplanet Applications

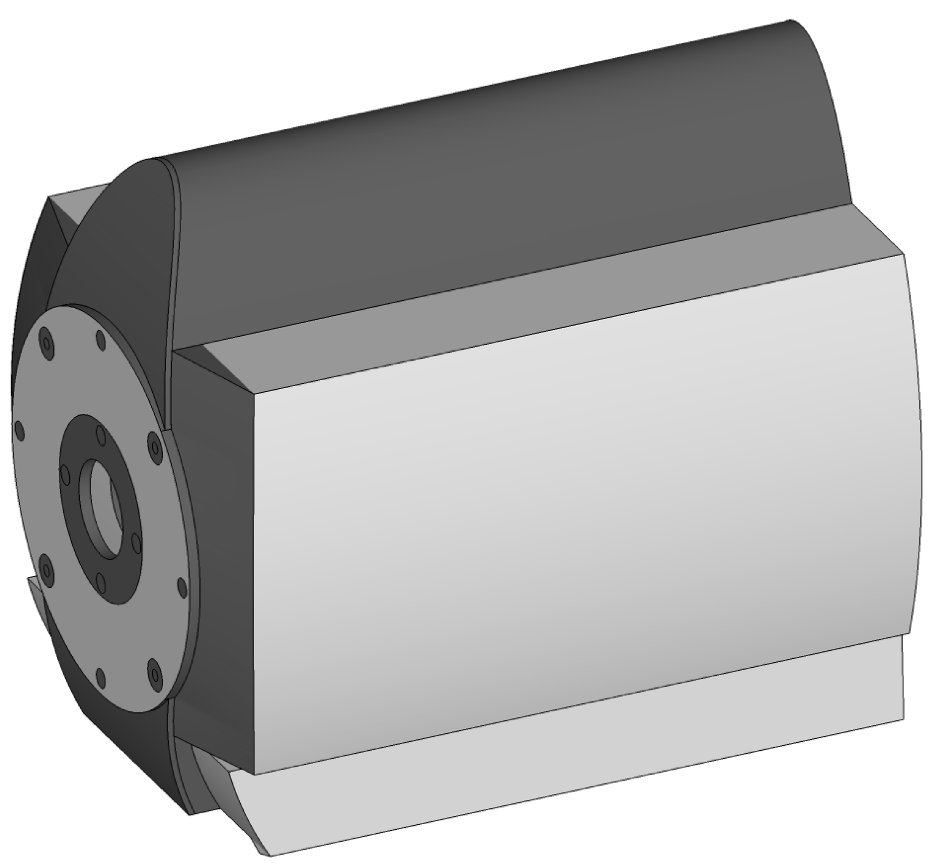
- Simultaneous two color transit photometry yields instant verification (same depth in both channels).
- Standard imaging provides host star photometry
- Speckle imaging assesses binarity and yielding correct exoplanet radius

Future Expansion

The filter wheels each have two remaining empty slots, we are currently exploring possible uses for these including the addition of:

- Transmission Grating - Grism
- Aperture Mask

Possible science application include: exoplanet transit spectroscopy, exoplanet atmosphere detection, transient object classification and characterization.
An aperture mask would allow spatial resolution beyond the diffraction limit! Achieving true interferometric resolution (2.44x the diffraction limit). This could be especially interesting if used on next-generation ELTs.



Acknowledgments

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Notes

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References

[1] E. P. Horch, S. B. Howell, M. E. Everett, and D. R. Ciardi. Observations of Binary Stars with the Differential Speckle Survey Instrument. IV. Observations of Kepler, CoRoT, and Hipparcos Stars from the Gemini North Telescope. *AJ*, 144:165, Dec. 2012.

[2] E. P. Horch, D. R. Veillette, R. Baena Gallé, S. C. Shah, G. V. O'Rielly, and W. F. van Altena. Observations of Binary Stars with the Differential Speckle Survey Instrument. I. Instrument Description and First Results. *AJ*, 137:5057–5067, June 2009.

[3] S. B. Howell, M. E. Everett, W. Sherry, E. Horch, and D. R. Ciardi. Speckle Camera Observations for the NASA Kepler Mission Follow-up Program. *AJ*, 142:19, July 2011.