AO 101: Considerations for Designing AO Observing Programs of Resolved Stellar Systems

T. J. Davidge Dominion Astrophysical Observatory January 6, 2016

Outline

- PSF considerations for studies of resolved stellar systems.
- Looking to the future
- Background frame strategies (time permitting)

The PSF

- In classical NGS AO systems anisoplanicity limits knowledge of the PSF at locations in the science field where there is not a point source.
- Techniques have been developed to monitor the PSF, and these work at the 10 20% level (Steinbring et al. 2002, PASP, 114, 1267; Steinbring et al. 2005, PASP, 117, 847)
- PSF variations are reduced in MCAO (and now MOAO) systems but can still be a source of noise.

Guide Star Selection

One guide star

Two guide stars

Three guide stars



S=9.8+/- 17.5 Range: 3.8 – 16

S=4.2+/-16.5 Range: 1.7 – 5.3 S=16+/-0.1 Range: 15.9 – 16.0

GeMS can use up to three guide stars. Two guide stars may not mean better correction for making photometric measurements when compared with one.

Finding the Best Asterism for Photometry





Auto GS S=16+/- 0.1 Manually Selected S=16+/-0.2

Don't be afraid to experiment with different asterisms – the auto GS algorithm may not find the best asterism for your needs.

<u>PSF Variations and the Performance of an MCAO</u> <u>system during mediocre seeing conditions.</u>

- MCAO systems will be used extensively on VLOTs, and there will be demand to use these systems over a range of conditions. <u>How well will</u> <u>these systems perform</u> <u>during `soft' seeing</u> <u>conditions?</u>
- The GeMS SV program was designed to investigate MCAO performance during 85%ile IQ conditions.
- FWHM in K is stable to within +/- 10%.



GeMS PSF Variations: J, 85%ile IQ



10 arcsec

First order variation (var=1 in DAOPHOT)

15 arcsec

GeMS PSF Variations: Ks, 85%ile IQ



10 arcsec

Fixed PSF

First order variation (var=1 in DAOPHOT)

15 arcsec

PSF Size



An AO-corrected PSF can extend over many arcsec.

Have used a 50 pixel (1.2 arcsec) radius PSF with MCAO data, and have achieved reasonable agreement with 2MASS measurements.

PSF Size (J; 85%ile IQ)



PSF Size (Ks; 85%ile IQ)



Globular Cluster GeMS

- NGC 1851 was observed in J and K as part of the GeMS + GSAOI science verification process.
- The primary science goals are:
 - to measure proper motions. This will help identify cluster members and – when a number of clusters are observed – provide insights into the Galactic potential.
 - Examine the color vs effective temperature calibration by combining their data with HST data.
 - To assess the performance of MCAO systems.
- Data were recorded during 70%ile IQ conditions, and show a stable FWHM in K.

For more information see Turri et al. 2015, ApJ, 811, L15





<u>Open Clusters: GeMS + GSAOI Observations of</u> <u>Haffner 16 and NGC 3105</u>

- Young clusters are important for studying low mass star formation and cluster disruption.
- Haffner 16 and NGC 3105 have not been extensively studied, but existing data indicates that:
 - Haffner 16 has an age of ~10 Myr, and is not centrally concentrated, indicating that it may be dynamically evolved.
 - NGC 3105 has a poorly determined age (20 100 Myr).
 Also, it has one of the largest RGC of any known open cluster. Hence, mechanisms that are different from those in the solar neighborhood may influence its evolution.

CMDs and Clustering Properties

- The PSF variations can be modelled using the variable PSF option in DAOPHOT.
 - CMD morphology does not depend greatly on PSF variation properties.

SCIENCE RESULTS:

- The (K,J-K) CMDs show sequences that can be matched by isochrones from Bressan et al. (2012).
 - The CMDs are well-matched by models.
 - Haffner 16 has an age ~ 10 Myr, and the models agree with the observations, even in the PMS phase of evolution.
 - NGC 3105 has an age of 25 Myr, and there is excellent agreement with the isochrones.
- The TPCFs of both clusters show signs of dynamical evolution, in that low mass stars are less centrally clustered than high mass stars.
 - In both clusters the age amounts to a few dynamical crossing times, so there has been time for mass segregation to progress.
 - Large coverage on the sky such as is delivered with GeMS is required to study cluster structure.



Looking to the Future: AO at Red Wavelengths

GeMS Observations of NGC 5139 in I



5 k		5.6						
23 -	44	66	87	109	131	152	174	195

Looking to the Future: L'

- Sirius has an age of 100 200 Myr, and is the member of a moving group (Ursa Major?). It has one known companion (Sirius B), and there are hints of another companion with a mass <= 0.1 solar.
- Sirius was imaged with NICI on Gemini South in L', which is a filter that is favourable for the detection of low mass companions. A very stable correction was obtained across the 20 arcsec NICI field of view.

SCIENCE RESULT:

- A brown dwarf of the mass suggested by kinematic studies would have a brightness comparable to or brighter than that of the Sirius A ghost shown in the image. No such object is present. The failure to detect a companion is consistent with the surveys by Bonnet-Bidaud et al. (2008 –> K) and Thalmann et al. (2011 –> M').
 - Could the companion be out of the field of view, on a high-eccentricity orbit?



RAVEN

- Multi-Object Adaptive Optics (MOAO) demonstrator used on the Subaru telescope. Collaboration between UVic, HIA, NAOJ, and Tohoku University.
- Turbulence properties over a 3.5 arcmin FOV are monitored with up to three NGSs. Can work in classical AO mode, GLAO, and MOAO modes.
- Two pick-offs with 4 arcsec FOVs patrol the science field
 - An 11 x 11 DM in each pick-off runs in open loop mode to correct for turbulence at the probe location
- The distortion-corrected signal is fed to IRCS where either images or spectra can be generated.
- The system runs at ambient temperature, and is not optimized for the thermal regime.

Why Do We Care About Narrow-band Imaging in the 3 – 4μm Region?

- Can study the SEDs of stars with circumstellar envelopes (e.g. PMS and TP-AGB stars).
- C star detection.



Figure 34 of Rayner et al. 2009

Glimpse C01: Narrow-band Imaging with RAVEN at 3.2 μm



Thermal Emission: What is Left After Flat Fielding



Note subtle variations in background level.

Flat Fielded

Raw Data

Thermal Background

- Two ways to construct a calibration frame to remove the thermal background:
 - 1. ABBA sequences.
 - Can be inefficient, since spend 50% of the time off source.
 - 2. Experience with GSAOI indicates that one can combine background and/or science frames obtained over a longish time span to create nightly thermal signature frames.
 - Flexure in the instrument causes variations in the optical path that can affect the thermal signature. Hence, should combine observations made at similar airmasses. This is a condition that is automatically imposed during LGS runs.



The End