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First results from the science commissioning of the Gemini High Resolution Optical Spectrograph (GHOST)

July 20 2022

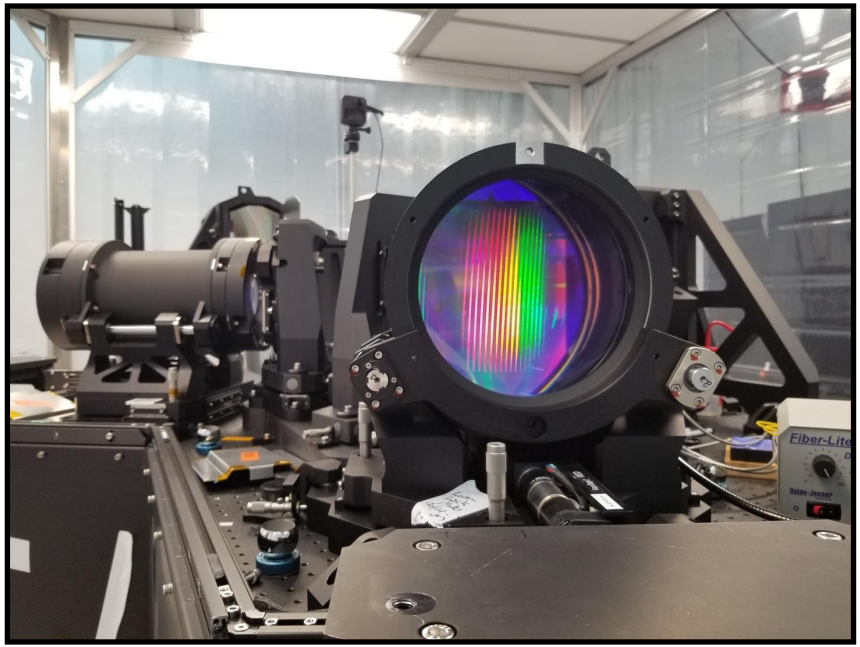
Christian Hayes, Alan W. McConnachie & the GHOST Commissioning Team

NRC Herzberg Astronomy & Astrophysics
Australian National University
Australian Astronomical Optics - Macquarie University
NOIRLab/Gemini

What is GHOST?

GHOST is the next generation fibre fed high resolution optical spectrograph for Gemini

- The original call for proposals was in 2011, followed by competitive conceptual designs
- Preliminary design started in 2014
- Delivered to Gemini in Spring 2020…and then had to sit for 2 years because of Covid



Project is lead by AAO, and is an effective partnership between AAO, ANU, NRC and Gemini

- Cass Unit, fibres, electronics —> AAO
- Software, Data Pipeline —> ANU
- Spectrometer —> NRC HAA

The GHOST Team

Current team members include:

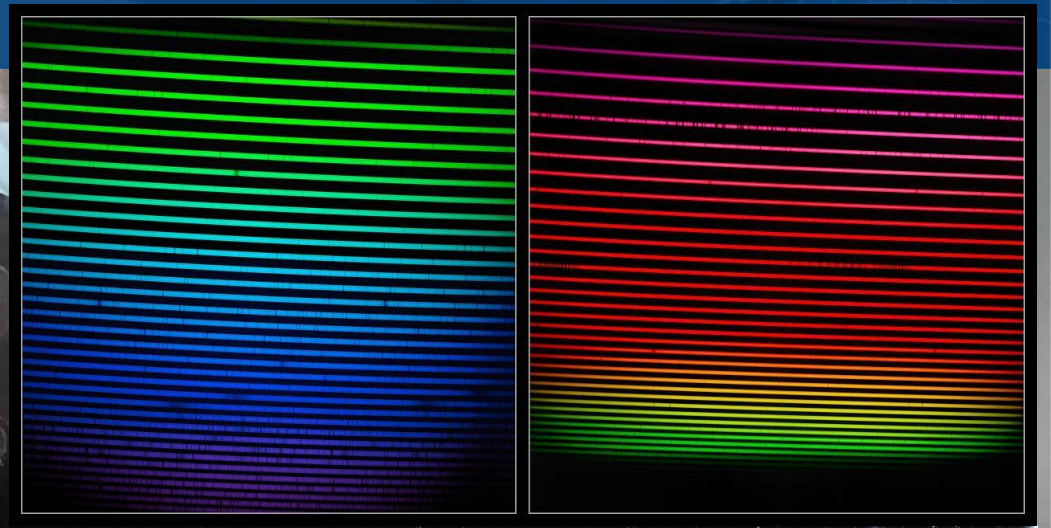
Gemini
John Bassett, David Hendersen, Venu Kalari, Steve Margheim and many others!

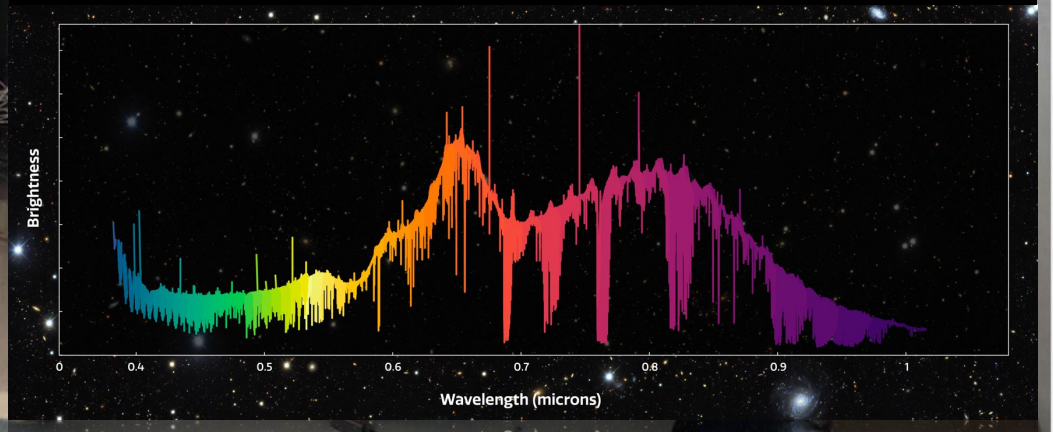
HAA
Andre Anthony, Greg Burley, Ed Chapin, Adam Densmore, Jennifer Dunn, Chris Hayes, Jordan Lothrup, Scott Macdonald, John Pazder

ANU
Michael Ireland, John Neilson, Peter Young

AAO-Macquarie
Vlad Churilov, Tony Farrell, Lew Waller, Ross Zhelem

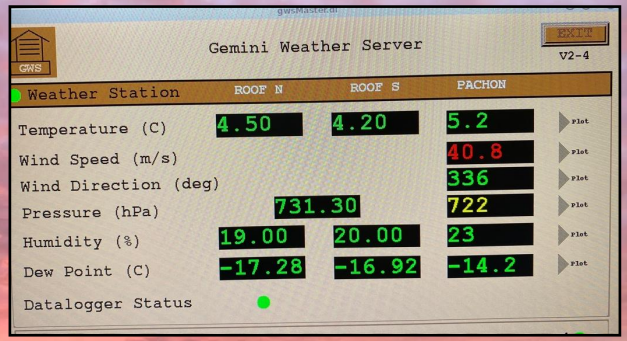
GHOST



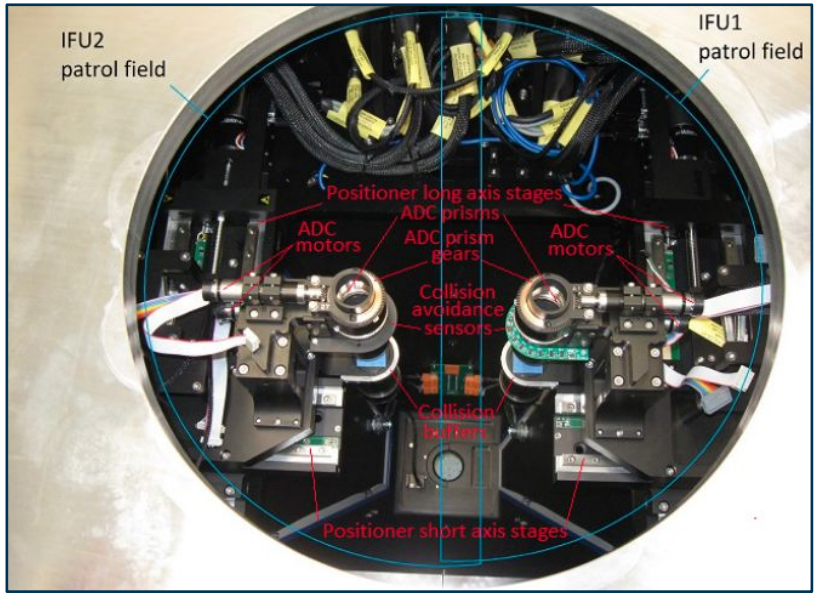


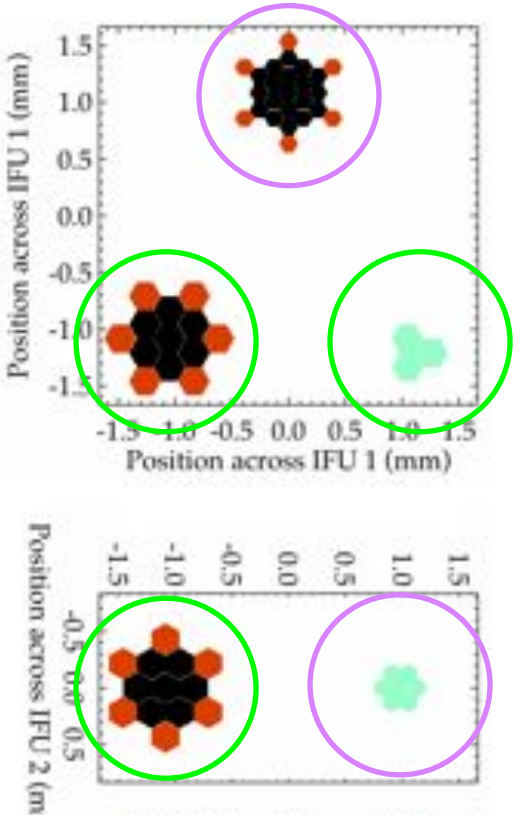
GHOST Commissioning

- GHOST Commissioning originally scheduled for 9 nights, June 20 - 28 2022
- By night 8, we'd opened the telescope on two of those nights, both times with very high winds and very variable transparency
- Extended for three additional nights…only needed two: nights 9, 10 and 11 were superb



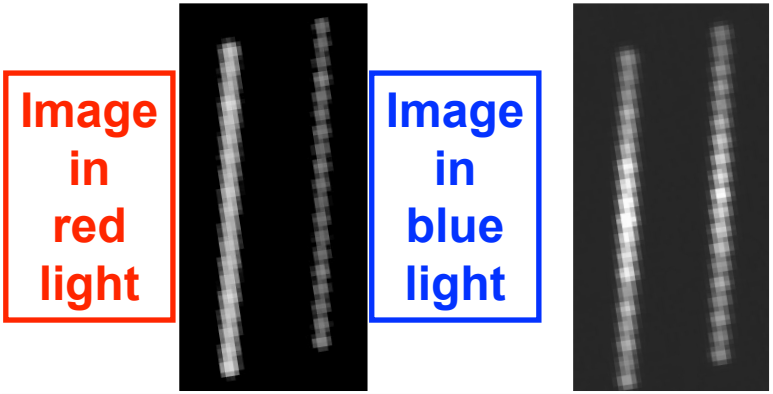
The GHOST Slit Unit

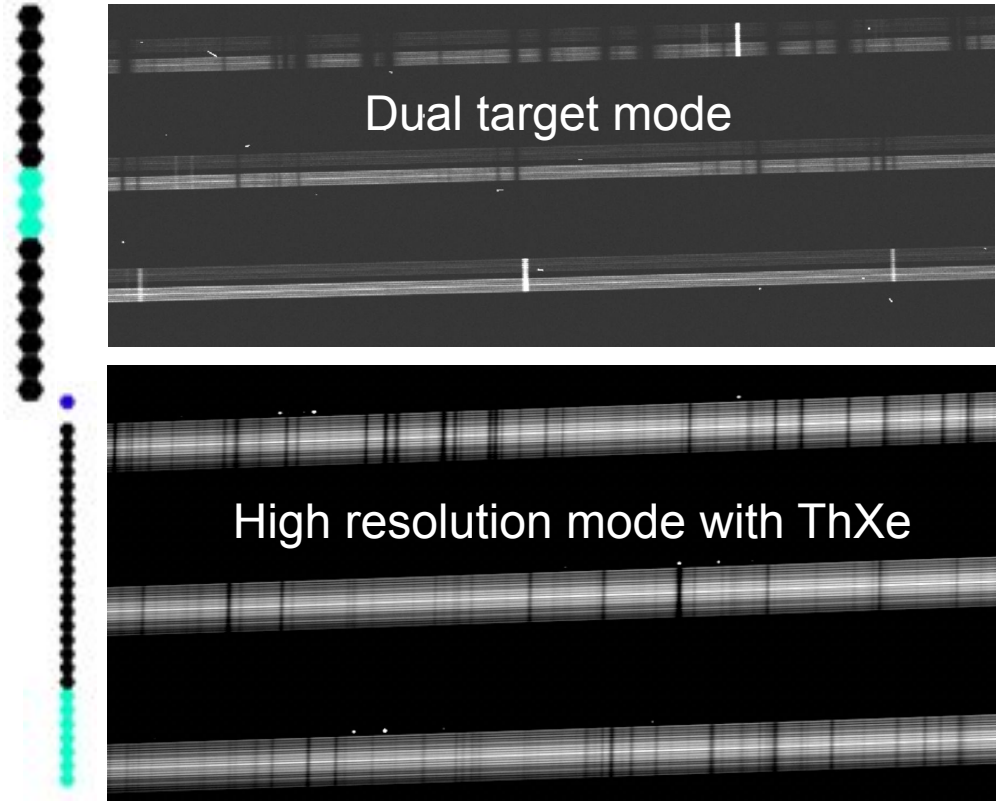




The GHOST Slit Viewer Camera

- GHOST has a slit camera that images the slit throughout a science exposure, producing “blue” and “red” slit images.
- These images are used in the Data Reduction pipeline to optimally extract the spectra, and they are also a good independent check on conditions during an observation



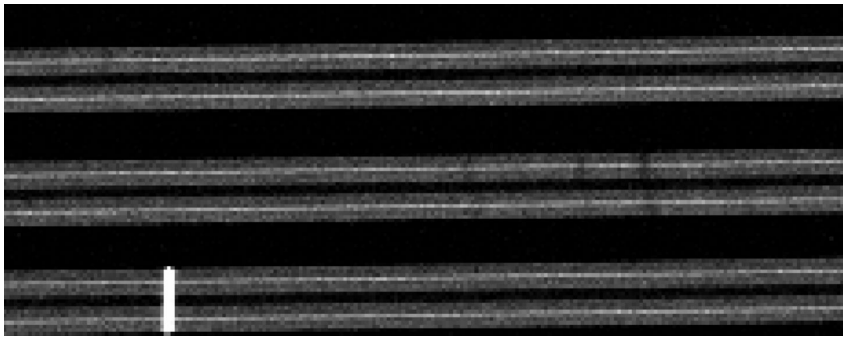


Very poor seeing Good seeing

GHOST Operating Modes

Configuration	Resolution setting	On-chip binning	Notes
Dual	50K	2 x 2	Oversampled with 1 x 1 binning
Dual faint	50K	2 x 4	
Single faint	50K	2 x 8	Balance read noise vs sky
High	75K	1 x 2	
High faint	75K	1 x 4	
PRV	75K	1 x 1	ThXe Agitator
Dual low-res (TBD)	50K	4 x 4	R ~ 25K

- No reason to use 1 x 1 binning modes normally (don't need spatial resolution). But for PRV, want to keep ThXe separate from science target
- GHOST oversampled in standard res, so can bin by 2 in this setting without losing much (any) spectral resolution
- Binning by 4 in spatial direct sensible for very faint targets
- More extreme binning in spatial direction possible; but not advisable in dual mode; even in single object mode, need to weigh reduced read noise with increased contamination from sky

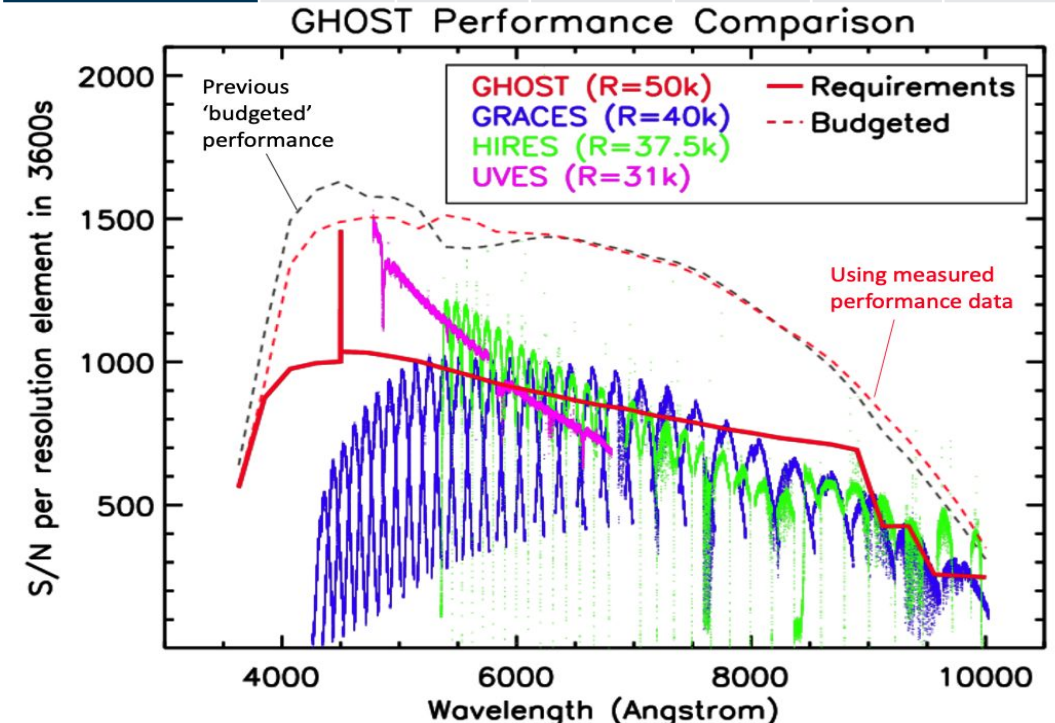


- On-chip binning in spectral direction by 4 now possible, but not yet tested. Should give VLT/FLAMES-like resolution

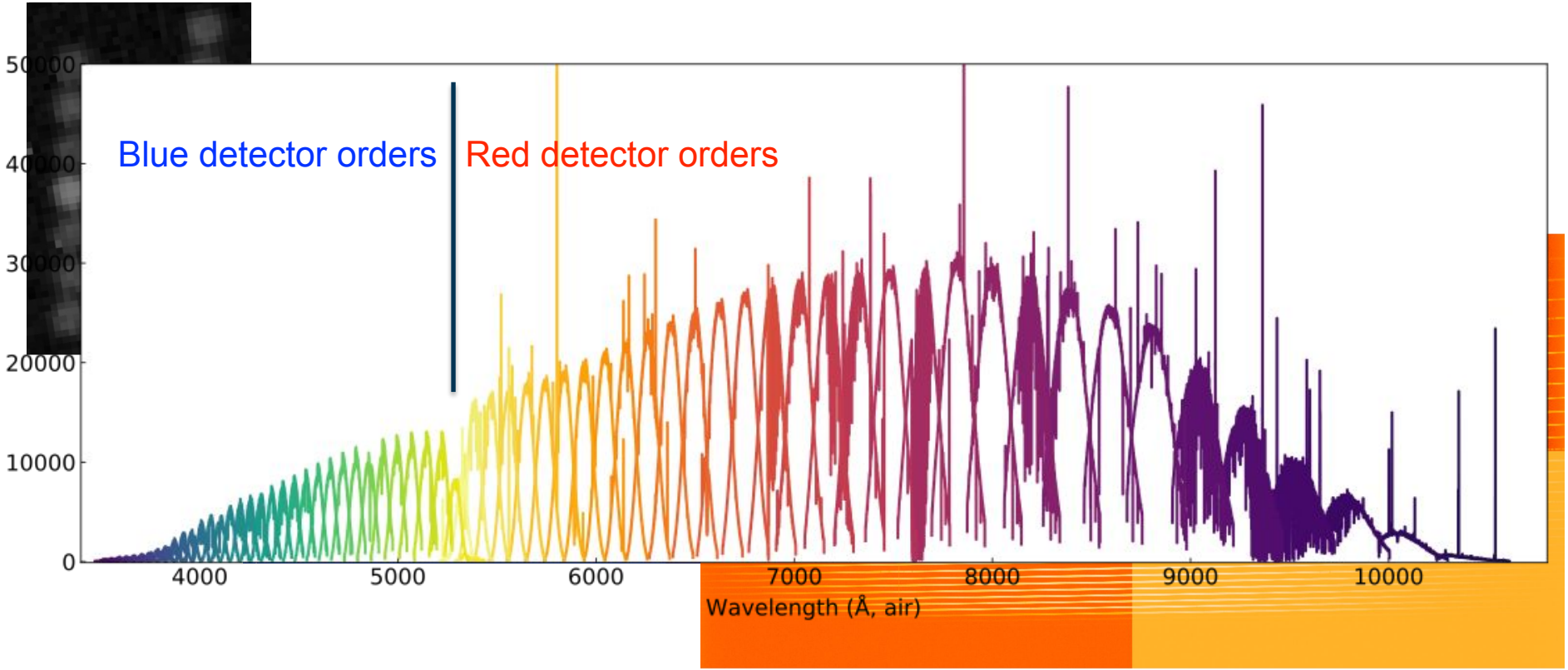
GHOST sensitivity

- GHOST requirements are defined as AB magnitude that has a SNR=30 in 1 hr observation in good conditions
- In-lab performance of GHOST from 2019 showed that we are easily exceeding the requirement
- On-sky measurements are on-going. We want to bullet proof our numbers prior to presenting them. Involves
  - optimal extraction of spectra in binned modes
  - photometric solution for the sky
  - would like to correct for mirror reflectivity degradation in the blue

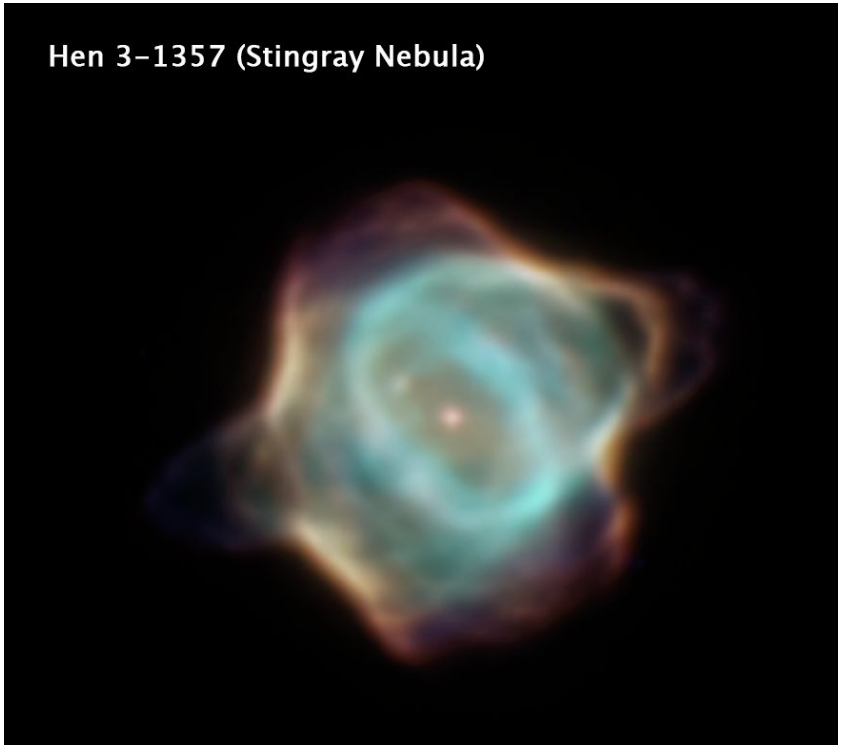
wavelength (nm)	363	375	450	550	900	950
Mag limit*	15.3	16.1	17.5	17.0	17.2	16.2

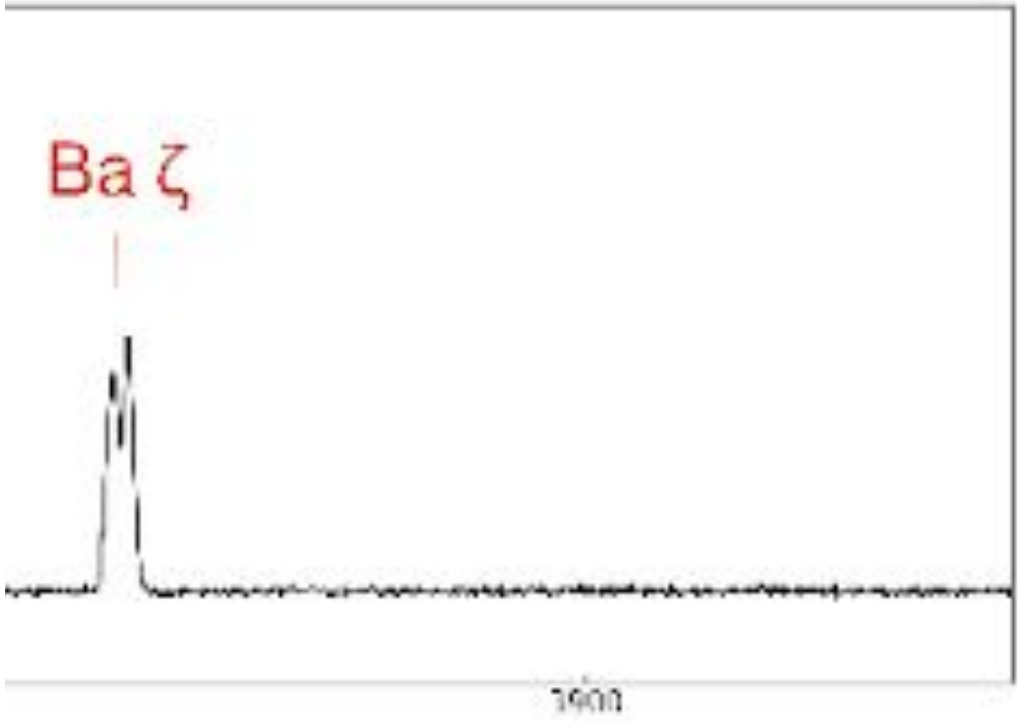


GHOST gallery: LTT6248 - extraction of orders

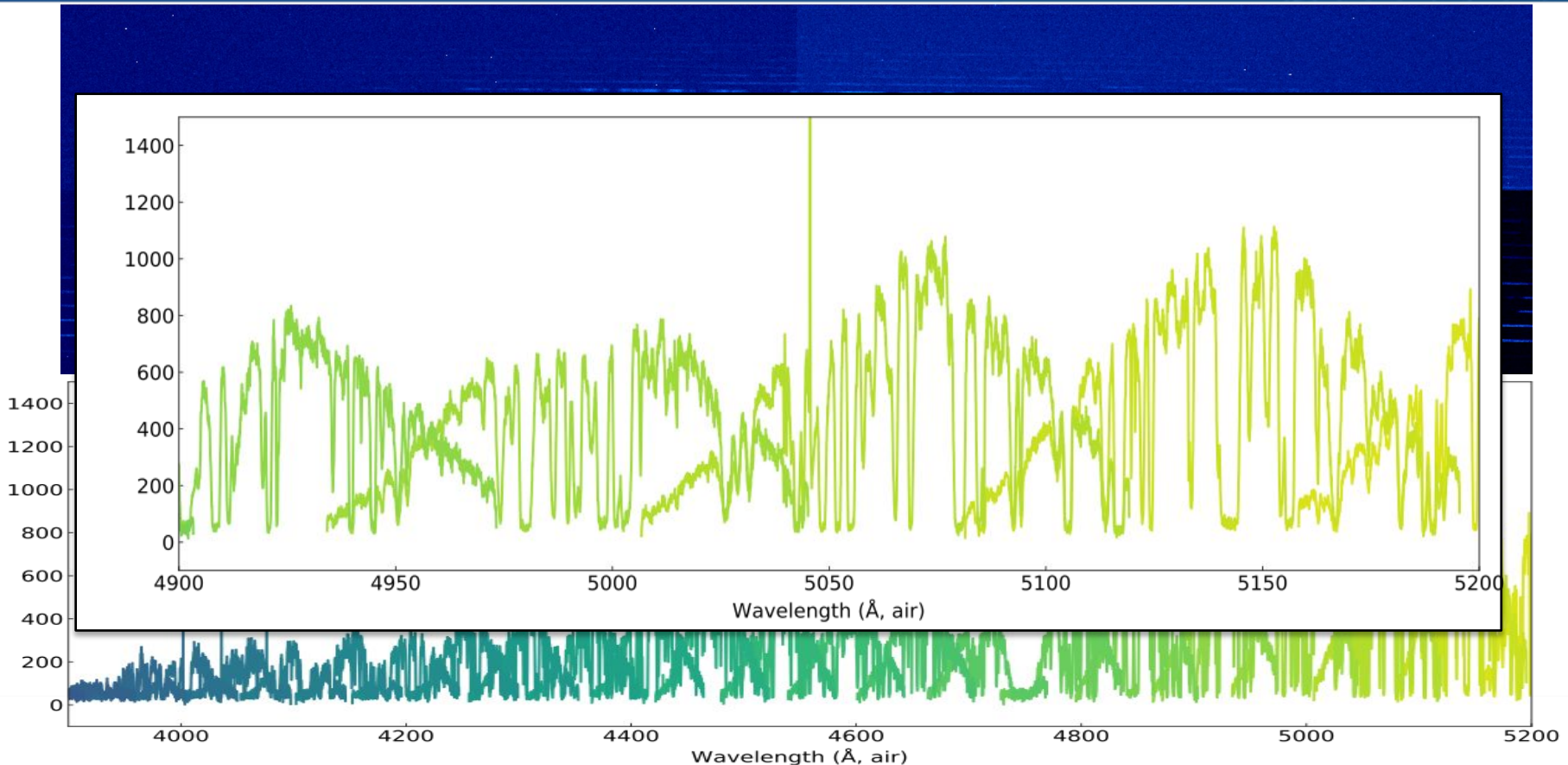


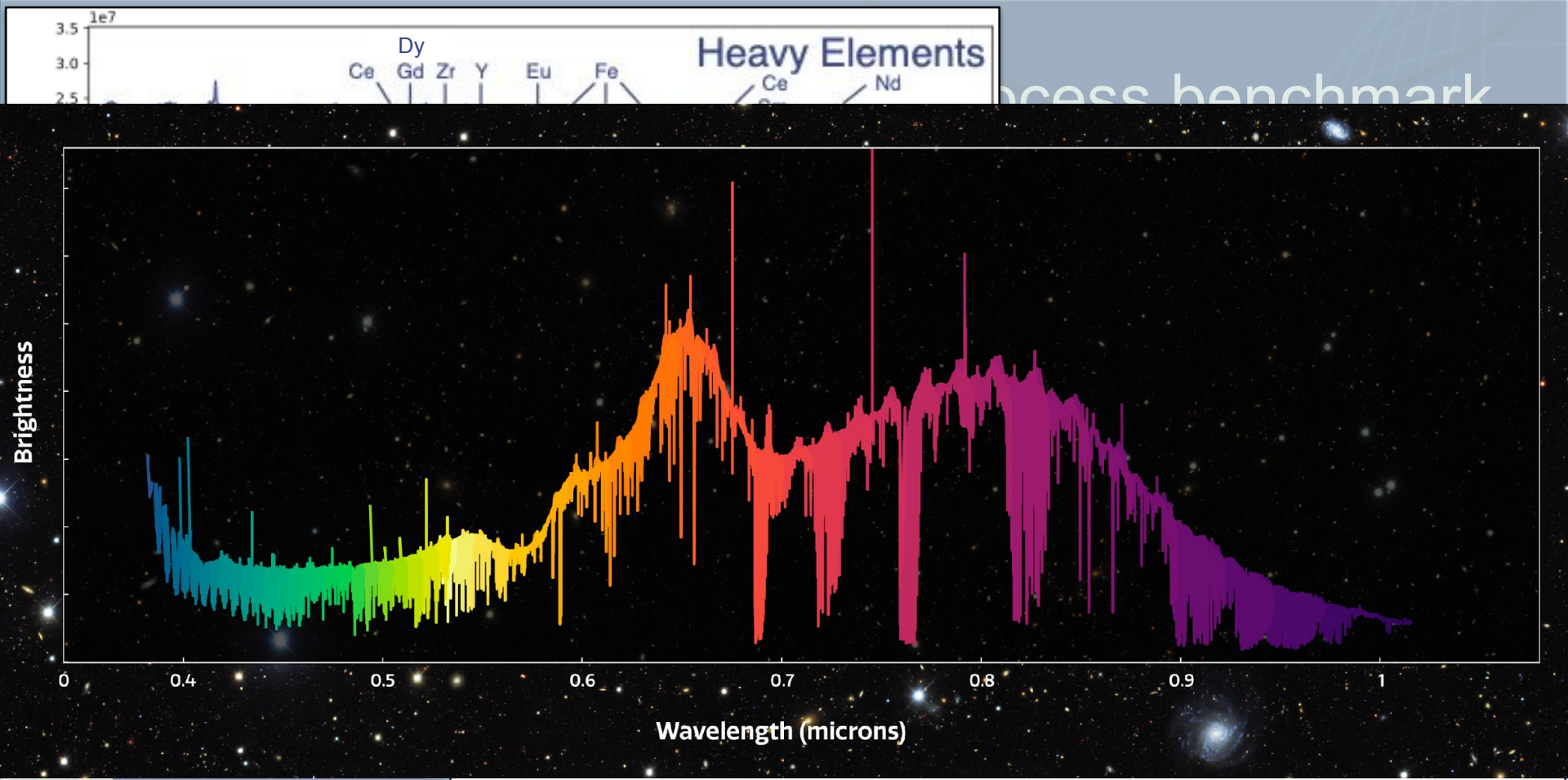
GHOST gallery: the StingRay nebula and the Balmer series





GHOST gallery: a quasar and the Ly-alpha forest

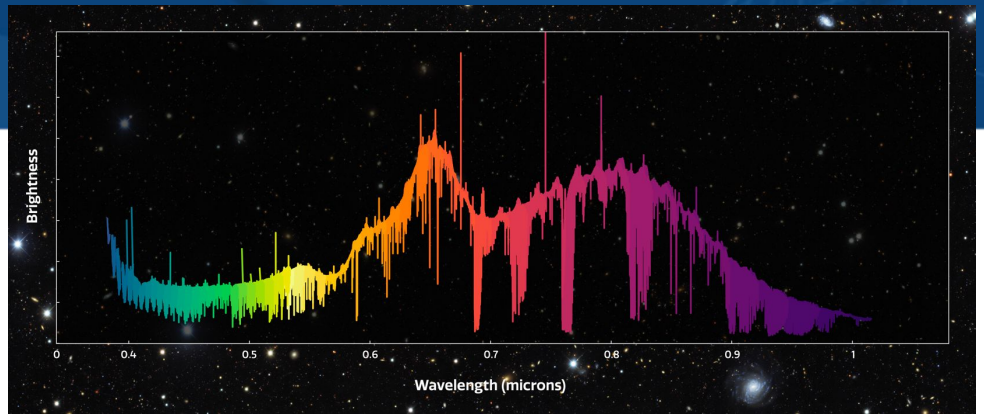




Wavelength (Å)

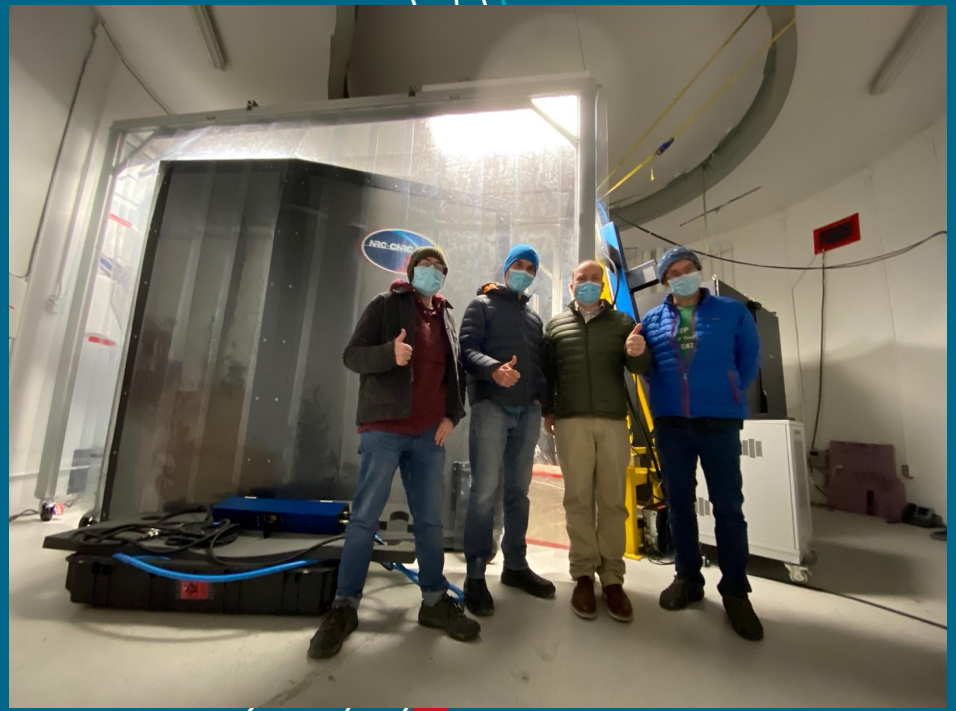
Summary

- GHOST had a successfully commissioning run at the end of June 2022; many thanks to the hard work of many at Gemini for making the whole integration, verification and commissioning so successful!
- GHOST provides high-resolution spectra of the



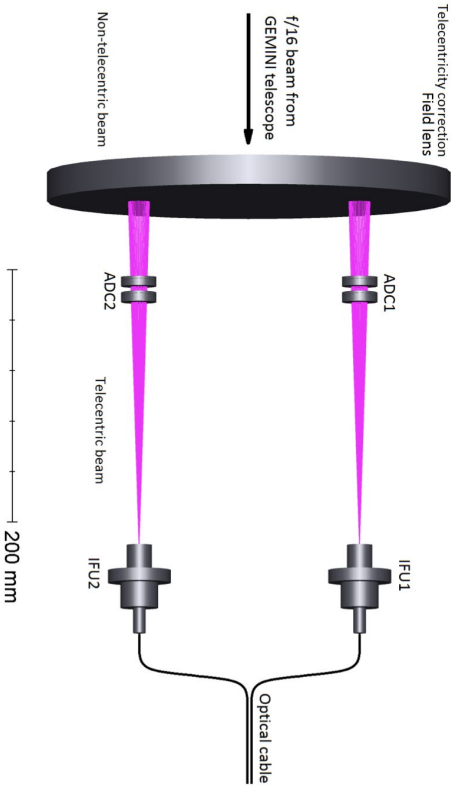
THANK YOU

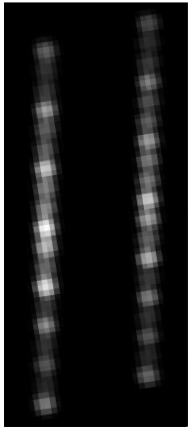
Questions? Comments?

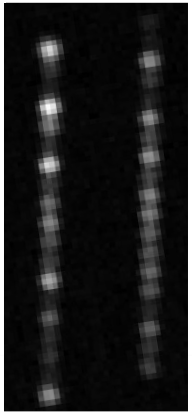


Extra Slides

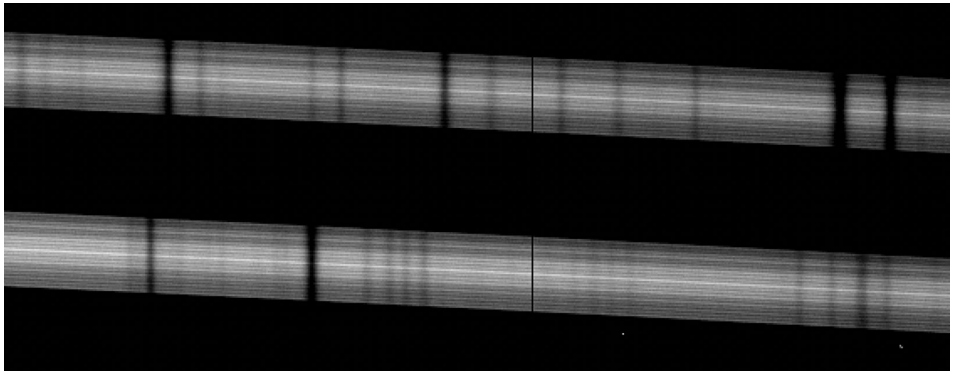
GHOST ADCs



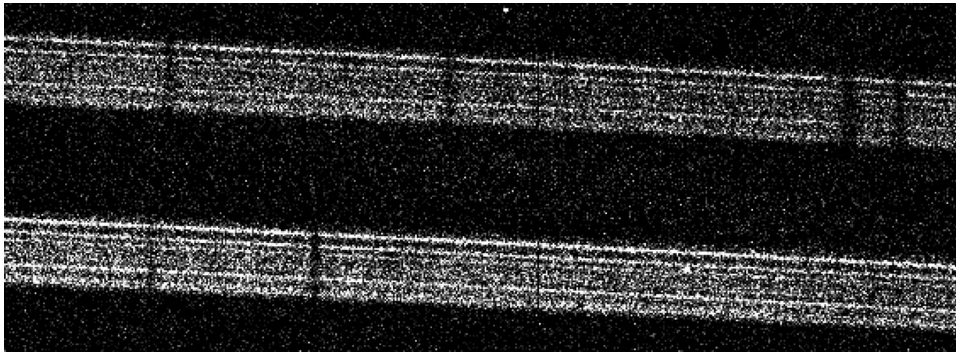




ADCs switched on



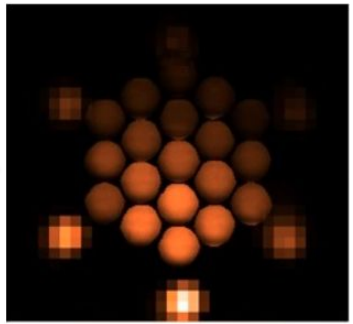
ADCs switched off



Acquisition and Guiding with GHOST I

- Each IFU has guide fibres around the outside 
- GHOST guiding (independent of Gemini guiding via PWFS1/2) keeps targets centred in the IFU by updating IFU position to balance the flux in the guide fibres

Initial reconstructed image: IFU overlapping with source (to within ~1arcsec rms)



- “Direct acquisition” (where the IFU is centred directly on the target) takes only the time necessary for a few images of the guide camera. Can be seconds for a bright star
- During commissioning, **direct acquisition worked for a target with G = 19.7 mag**! (30 sec exposures on guide camera)

Acquisition and Guiding with GHOST II

- Direct acquisition and guiding on a very faint target may not be possible, and certainly might not be the most efficient given long guide camera exposures.
- Also there is a known failure mode of direct acquisition, specifically a faint star within a few arcsecs of a brighter star
- Commissioned two other modes for A&G:
  - Blind offset
    - i.e., acquire and centre on a bright star, then offset to science target
    - No active guiding during science observation
  - Companion guiding
    - Position both IFUs at expected position of stars
    - Center and guide using only one of them (i.e,, use a [brighter] star in a less crowded region to guide with)