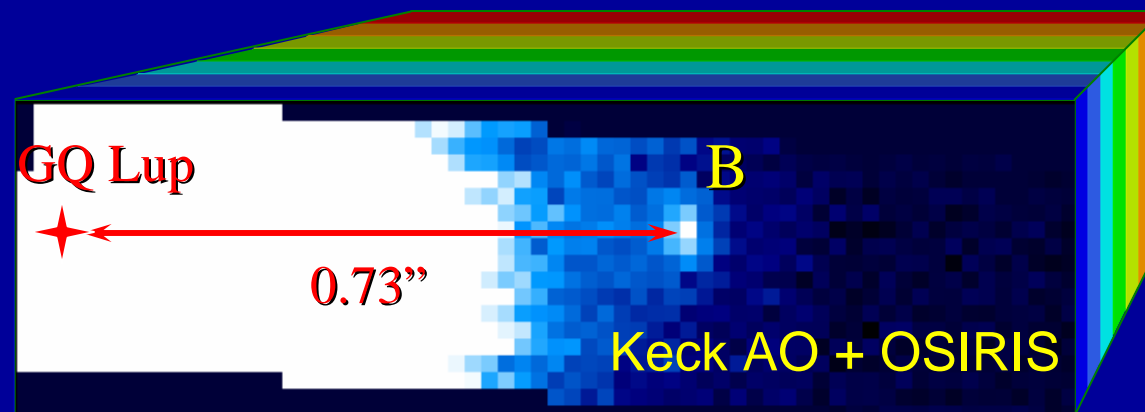


High Contrast Spectral Imaging: the Case of GQ Lup



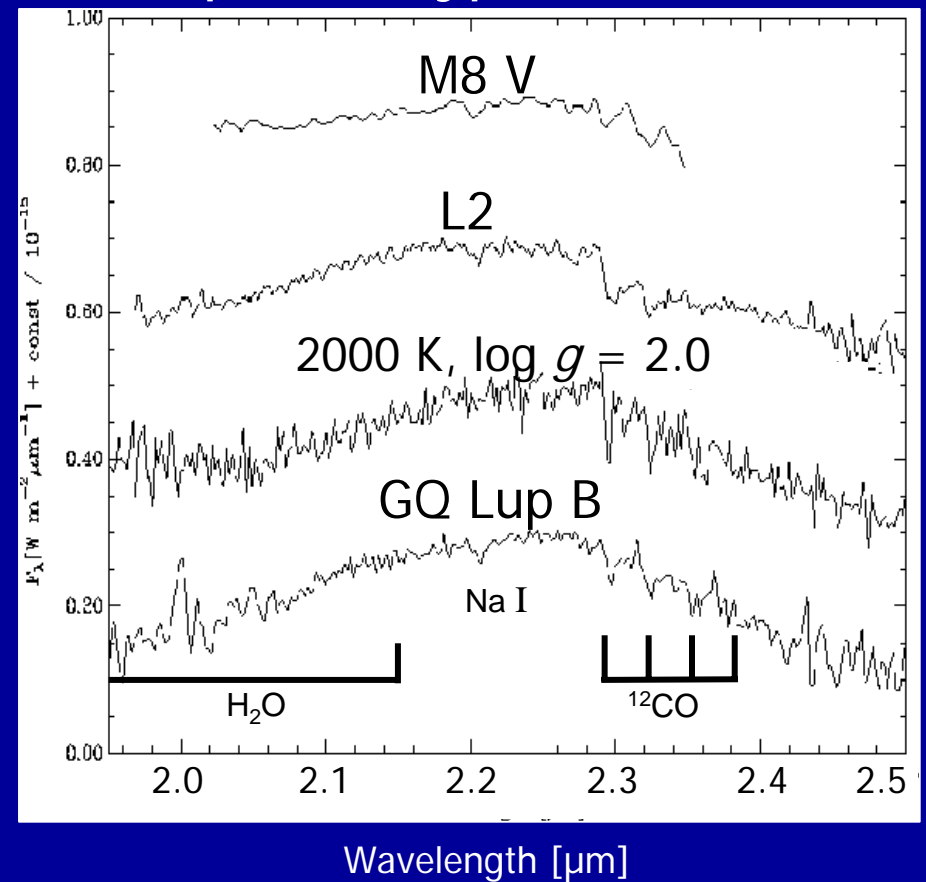
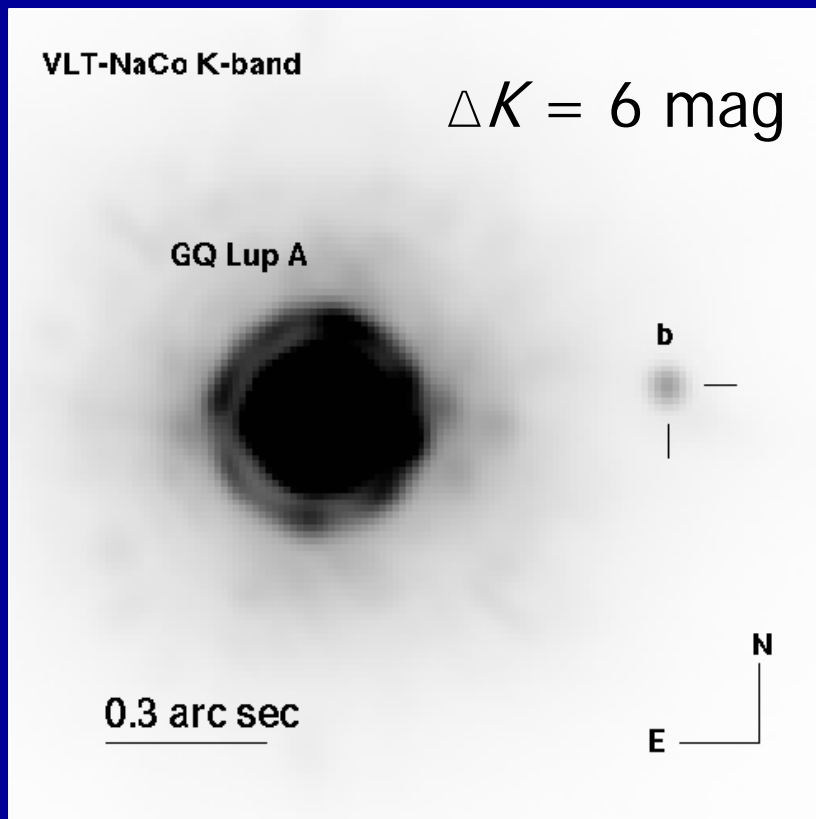
- *Michael McElwain (UCLA)*
- *James Larkin (UCLA)*
- *Stanimir Metchev (UCLA)*
- *OSIRIS commissioning team*

GQ Lup B – An Exoplanet or a Brown Dwarf?

- 1–2 M_{Jup} planet?
 - VLT AO slit spectroscopy
 - Neuhaüser et al. (2005)
- 10–40 M_{Jup} brown dwarf?
 - Keck AO + OSIRIS spectroscopy
 - McElwain, Metchev, Larkin et al., *ApJ*, accepted

Discovery images of GQ Lup A/B

Spectral type: M9–L4

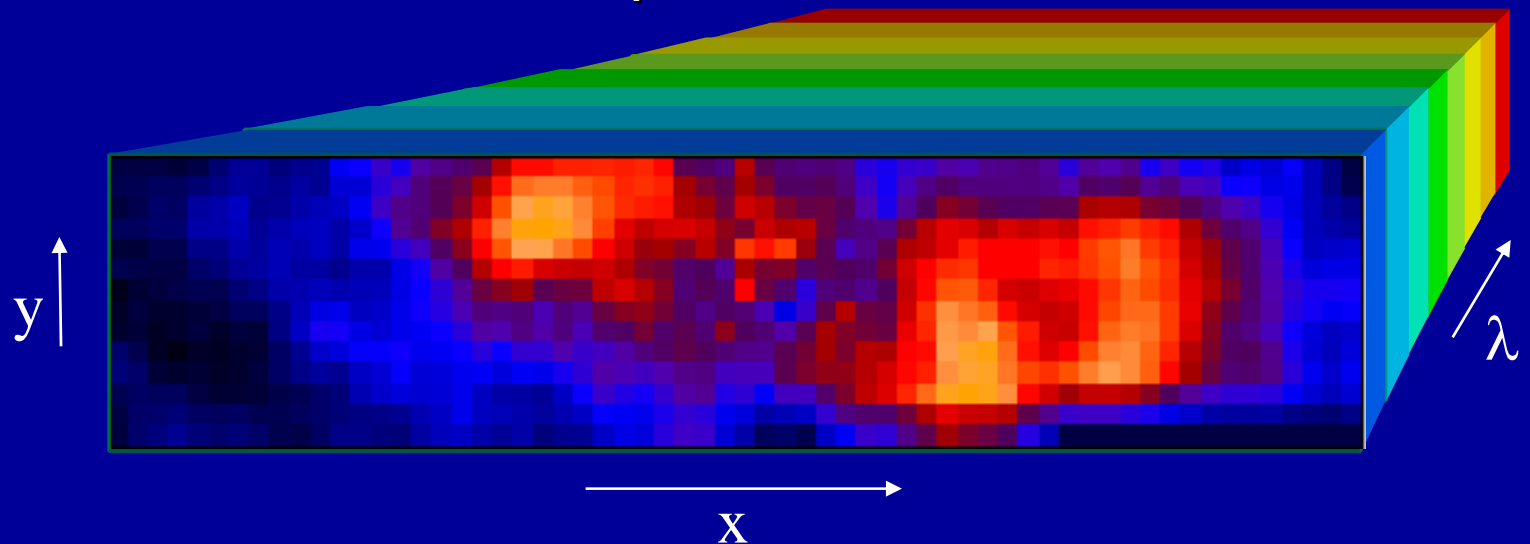


cTTS in Lupus 1; age 0.1–2 Myr
(Hughes et al. 1994)

(Neuhauser et al. 2005)

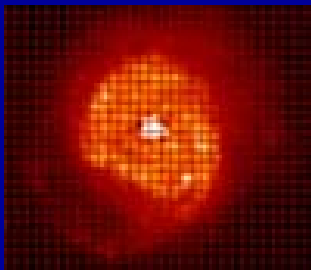
OSIRIS (OH-Suppressing InfraRed Imaging Spectrograph)

- Integral Field Spectrograph
 - Spectra over a contiguous rectangular field.
- Spatial resolution at the Keck Diffraction Limit ($<0.050''$)
- Spectral resolution ($\lambda/\Delta\lambda$) ~ 3800
- Full z, J, H, or K spectra with single exposure (16x64 lenslets)
- Integrated Data Reduction Pipeline

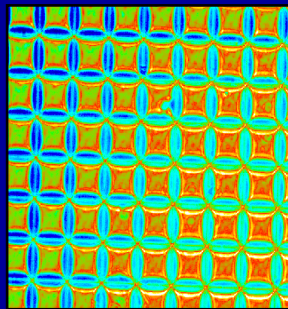


OSIRIS - A Lenslet Based Integral Field Spectrograph (IFS)

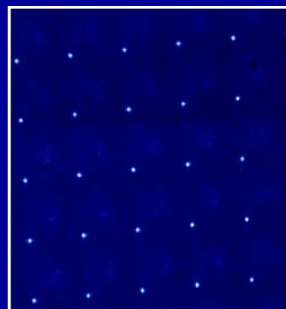
Focus Image onto a Lenslet Array



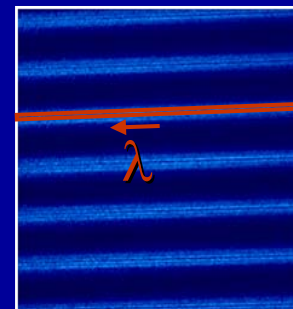
1. Image on Lenslets



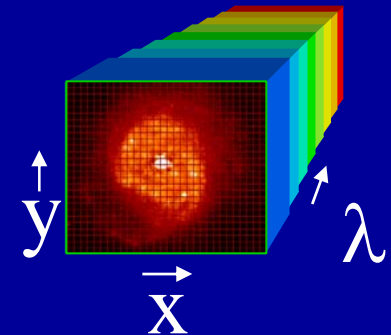
2. Pupil images



3. Pupil images dispersed

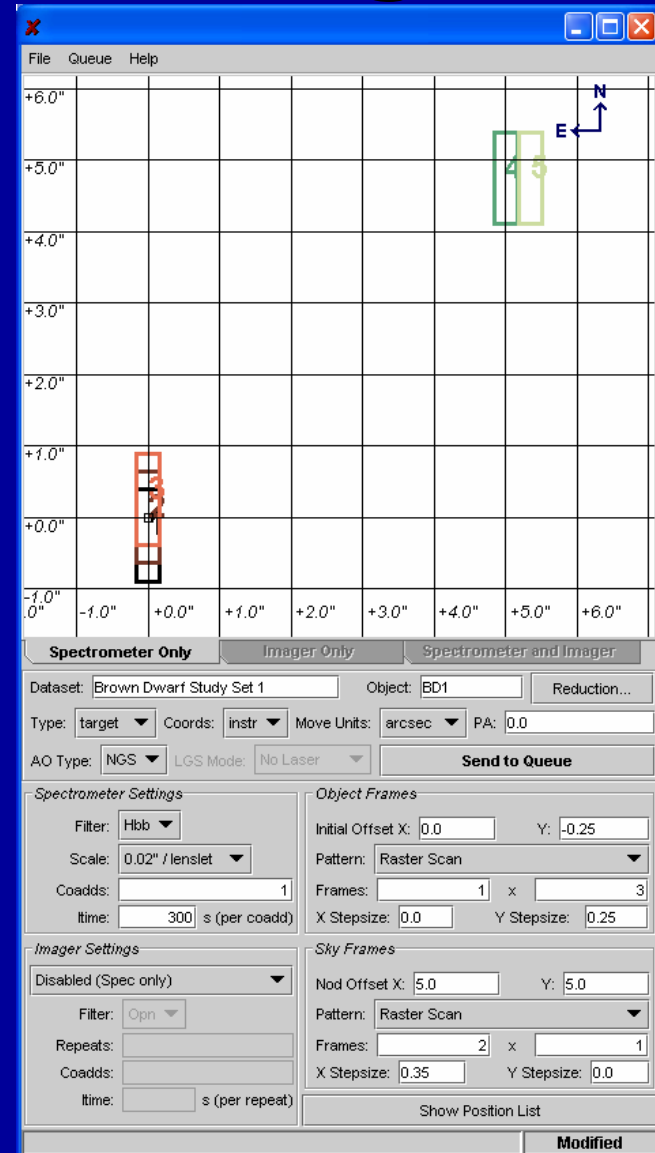


4. Extracted Data Cube

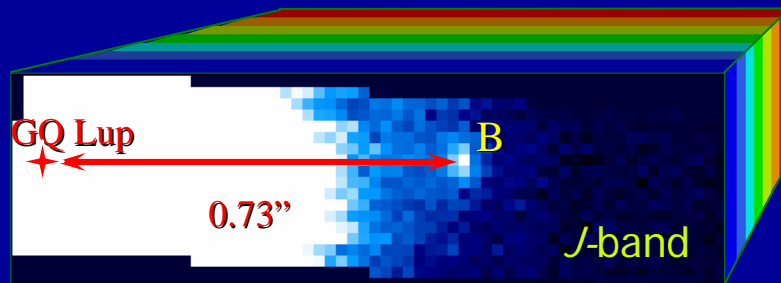


Pre-observing planning checklist

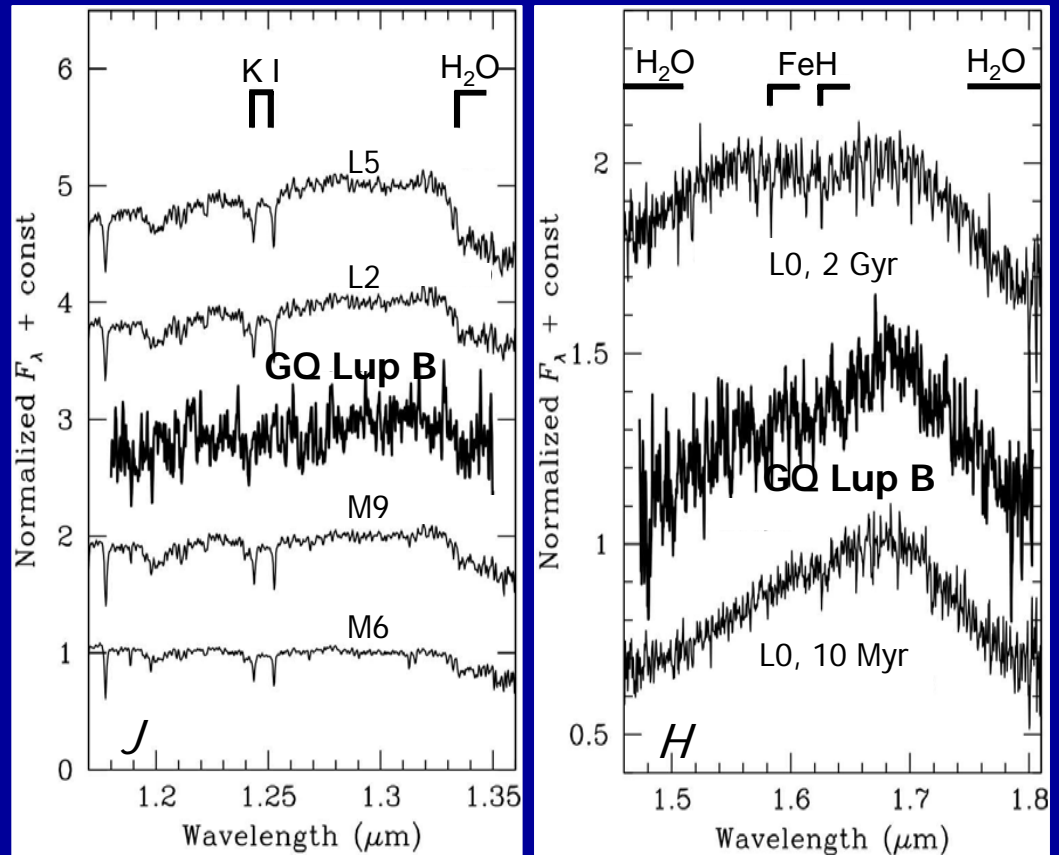
- Natural Guide Star – GQ Lup A
 - R magnitude of 11.0
- Choose scale
 - 0.020"
- Choose integration time for desired sensitivity
 - From instrument zero points
- Determine dither pattern
- Make an execution file



Keck/OSIRIS Spectra of GQ Lup B

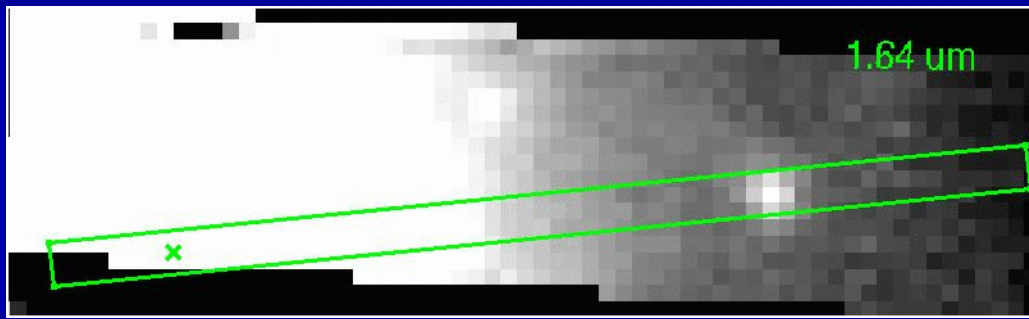


- **integral field spectrograph** behind Keck II AO system (PI: J. Larkin, UCLA)
- OSIRIS commissioning data (June 2005)



(McElwain, Metchev et al., ApJ, in press)

AO Integral Field Spectroscopy Is More Reliable Than AO Slit Spectroscopy

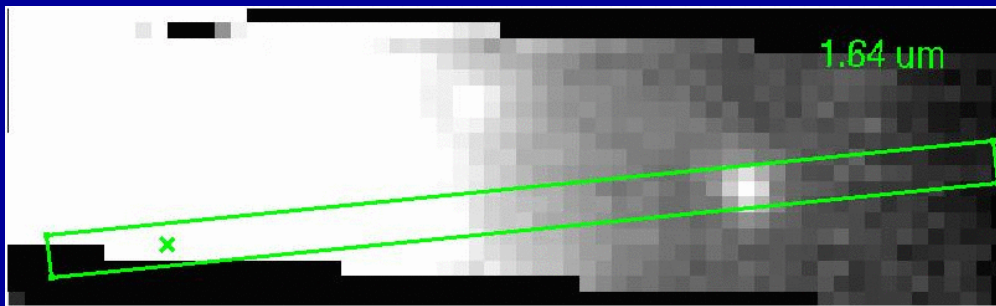


elevation,
differential refraction

H-band
53 mas-wide slit
GO Lup A/B aligned on slit

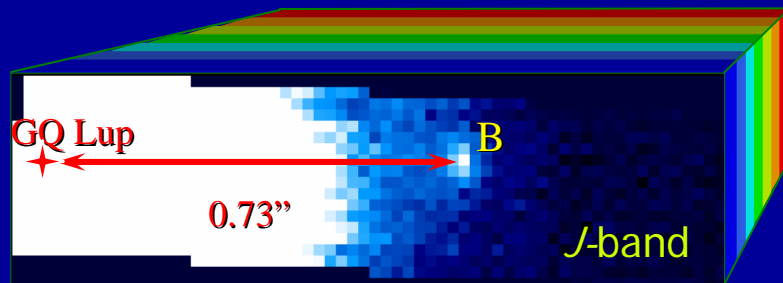
- AO slit spectroscopy:
 - slit width (40–100 mas), PSF (40–80 mas) comparable to pointing precision (~20–40 mas)
 - differential refraction (atmosphere, AO transmission optics)
 - especially important in high-contrast regime
- IFS AO spectroscopy :
 - no slit losses due to centering on slit
 - no slit losses due to differential refraction
 - trace PSF centroid as a function of λ
 - variable extraction aperture as PSF changes?

IFS is Good for Target Extraction and Primary Background Subtraction

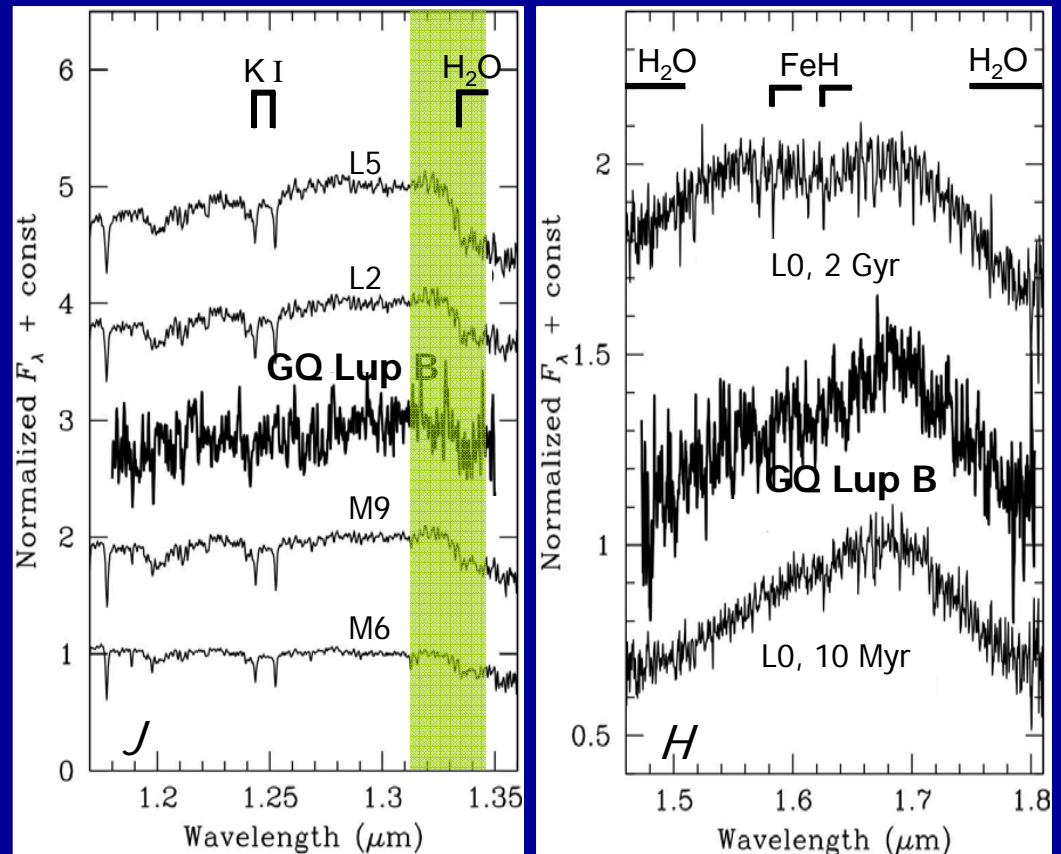


- Correct cube for differential dispersion.
- Extract the companion spectrum.
- Fit host star PSF to estimate the background contribution at the location of the secondary.
- Subtract host background from the companion spectrum.

Keck/OSIRIS Spectra of GQ Lup B



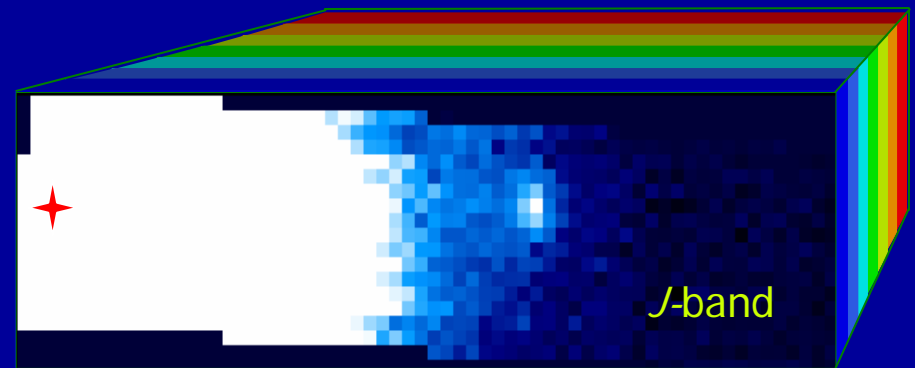
- commissioning OSIRIS data (Aug 2005)
- *J*- and *H*-band
- spectral type: **M8 ± 2**
 - *Neuhauser et al.*: M9–L4



(McElwain, Metchev et al., *ApJ*, in press)

GQ Lup A/B Astrometry & Photometry

- Astrometry
 - Similar to imaging
- Photometry
 - Curve of growth for the telluric and GQ Lup A – find flux ratio and magnitude for GQ Lup A
 - Compare the flux ratios of the same aperture for GQ Lup A/B
 - Determine GQ Lup B magnitude



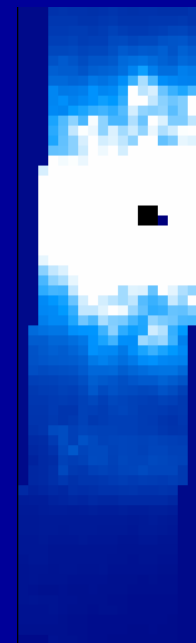
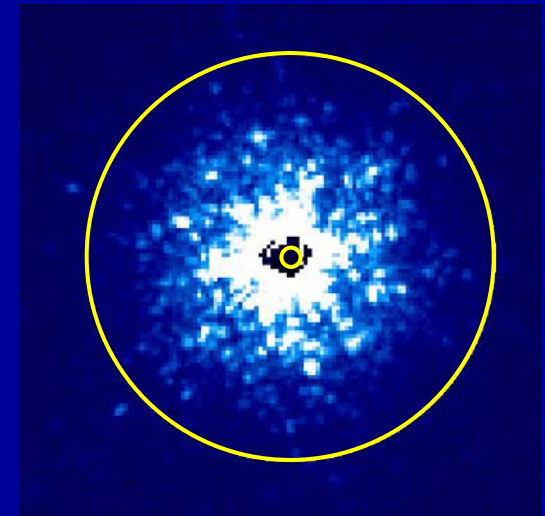
High Contrast Imaging: Speckle Suppression

At moderate Strehl ratios (< 0.95) and small separations ($< 1''$), speckle noise produced by atmospheric wavefront distortion and imperfect optics are the dominate noise source.

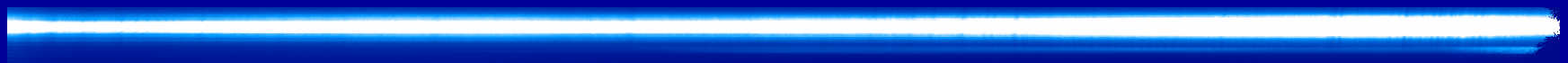
- Innovative techniques for enhancing contrast
 - Simultaneous Differential Imaging
 - Spectral Suppression

Speckles are wavelength dependent and can be modelled for each wavelength.

Typical speckle pattern for Keck II + OSIRIS Imager in the Kn3 filter



Keck II + OSIRIS Spec in the Kbb filter



Summary

- AO integral field spectroscopy is more reliable than AO slit spectroscopy
- An IFS is efficient for halo subtraction.
- Astrometry and photometry procedures are the similar to those for direct imaging.
- An IFS can perform speckle suppression.
- GQ Lup B is probably a brown dwarf and not an exoplanet.