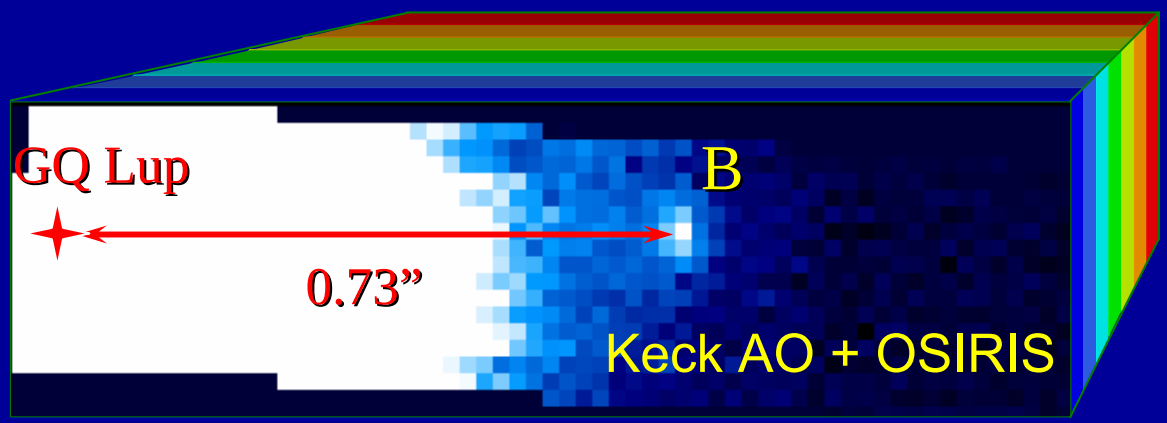
First High-Contrast Science with an IFS: the Sub-Stellar Companion to GQ Lup



- ***Michael McElwain (UCLA)***
- *Stanimir Metchev (UCLA)*
- *James Larkin (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

OSIRIS - A Lenslet Based Integral Field Spectrograph (IFS)

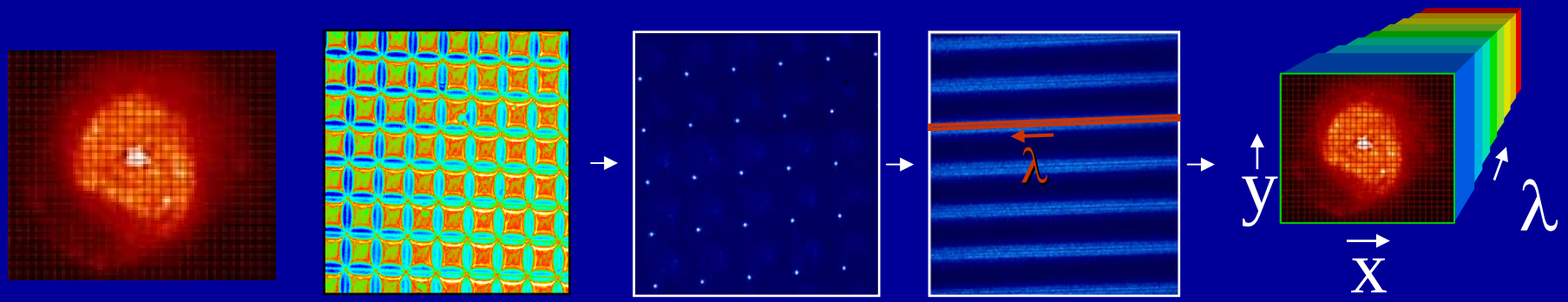
Focus Image onto a Lenslet Array

1. Image on Lenslets

2. Pupil images

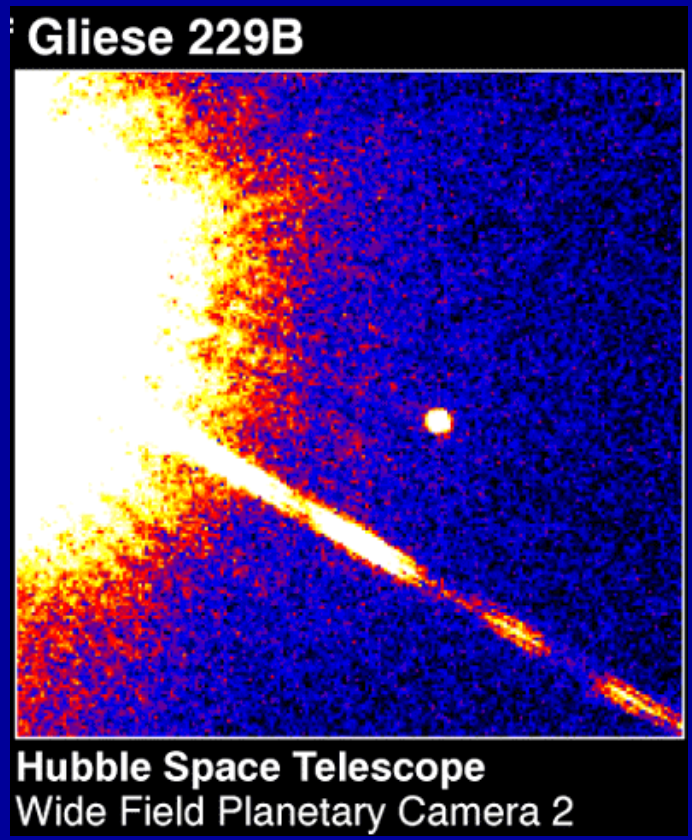
3. Pupil images dispersed

4. Extracted Data Cube



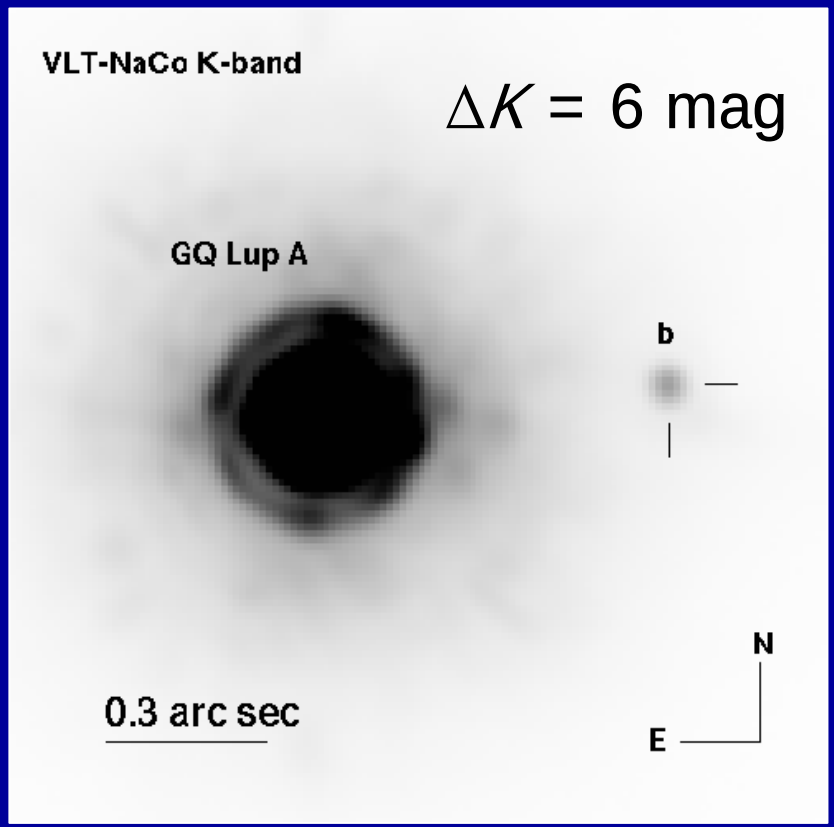
Direct Imaging of Sub-Stellar Companions

- laboratory of sub-stellar astronomy:
  - Compare objects at a fixed age and metallicity
- step toward the future imaging of exoplanets



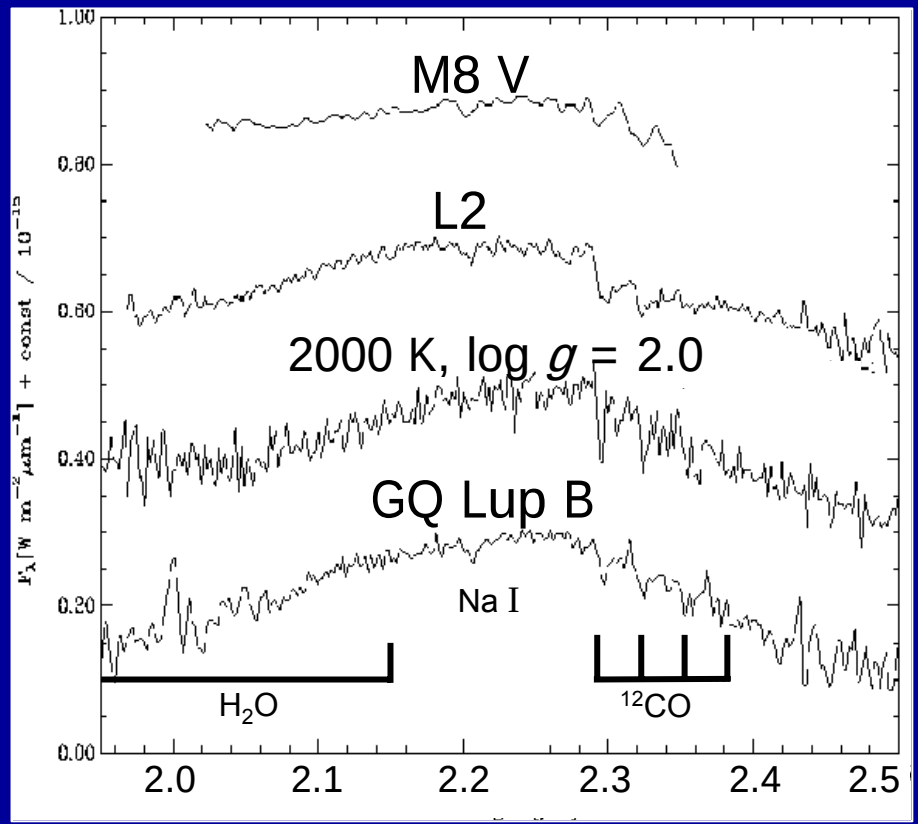
(Golimowski et al. 1998)

GQ Lup A/B



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

Spectral type: M9–L4



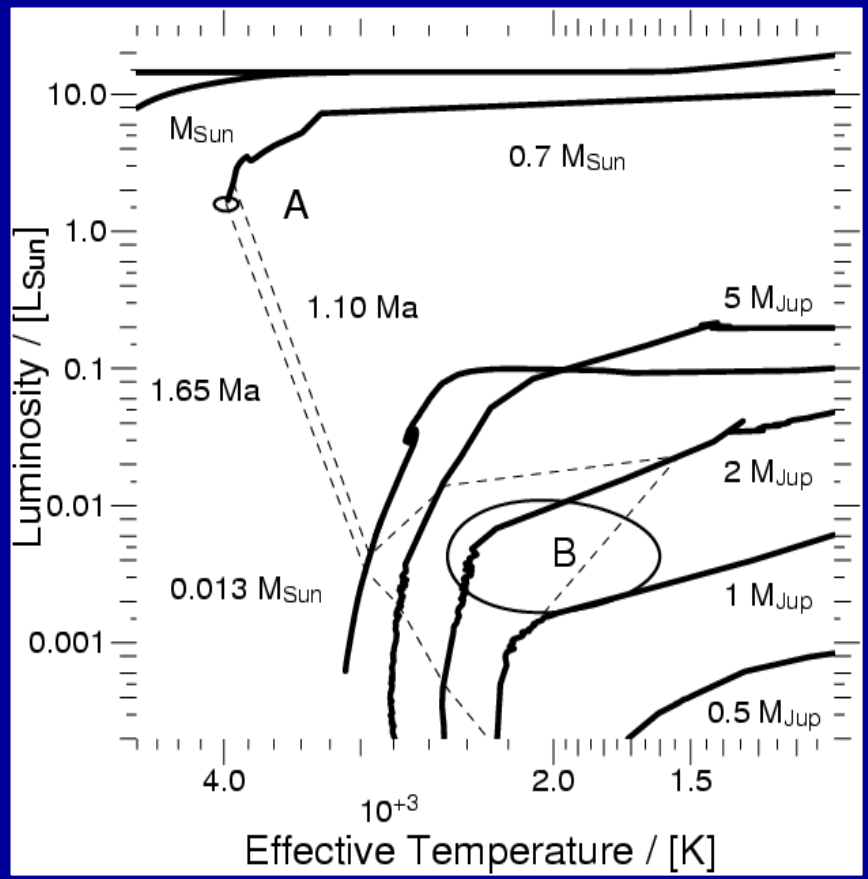
(Neuhaüser et al. 2005)

The Mass of GQ Lup B

- "hot-start" models predict 3–42 M_{Jup}
  - *Burrows et al. (1997), Baraffe et al. (2002)*
  - uncertain at ≤3 Myr ages
- nucleated instability and collapse models predict 1–2 M_{Jup}
  - *Wuchterl et al. (2000), Wuchterl & Tscharnuter (2003)*
  - better at young ages?

Which theoretical models are more accurate?

Is GQ Lup B an exoplanet?

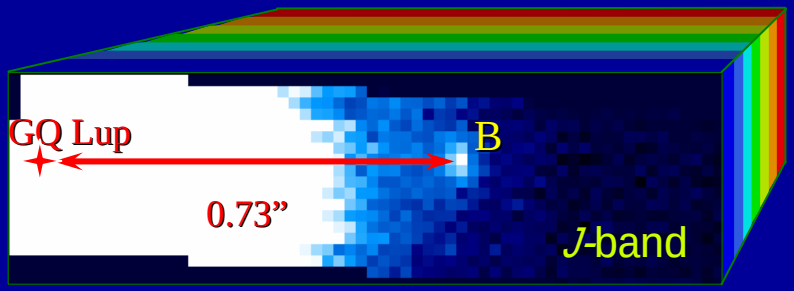


(Neuhaüser et al. 2005)

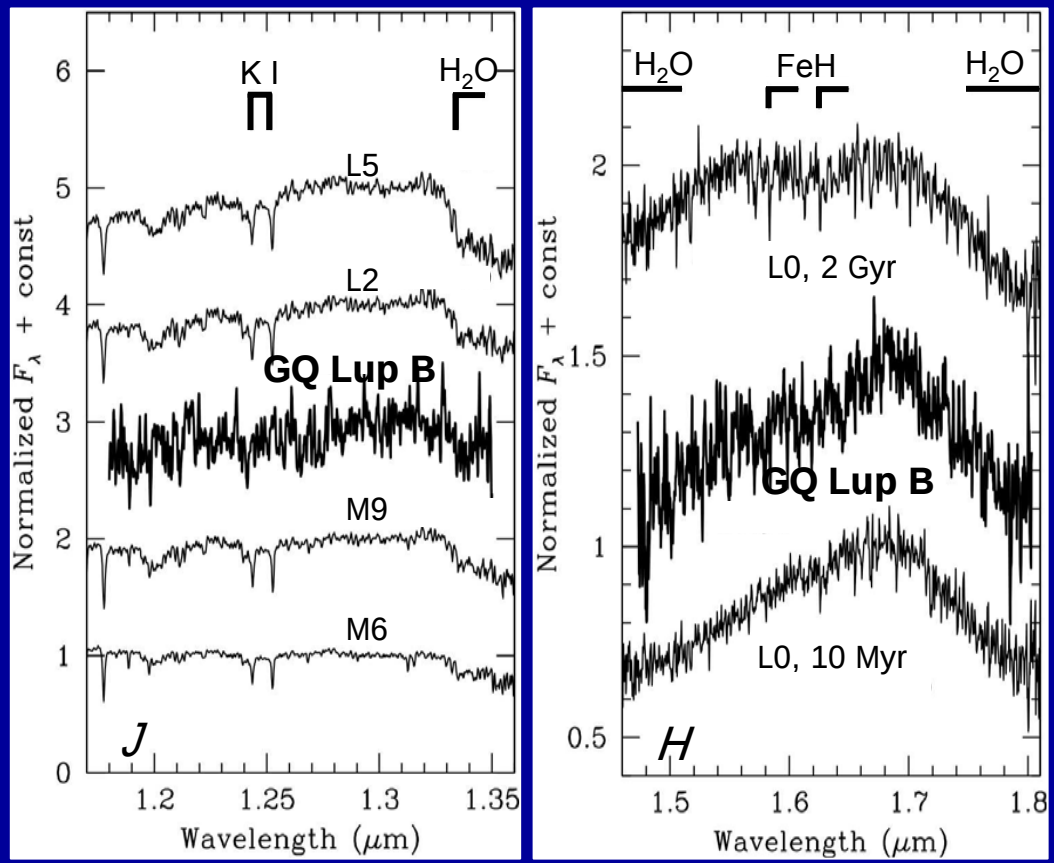
Steps in Characterizing Sub-Stellar Companions

- Determine age and distance
  - from parent stellar association (best) or primary star
- Determine spectral type, effective temperature
  - direct near-IR spectroscopy (with AO)
- Determine mass, surface gravity
  - from evolutionary models

Keck/OSIRIS Spectra of GQ Lup B

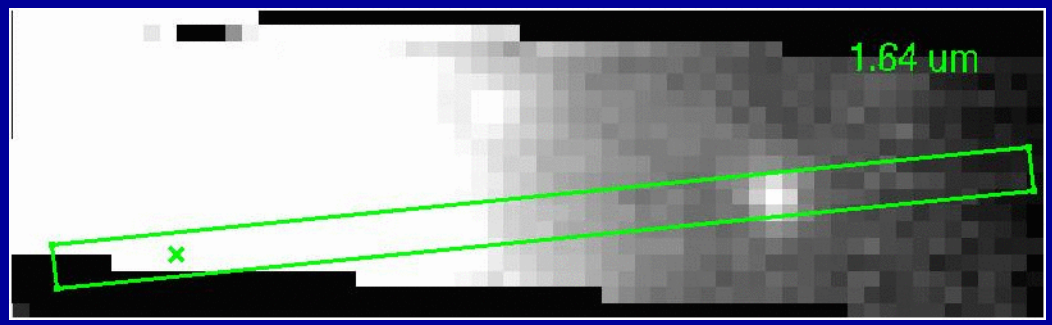


- integral field spectrograph behind Keck II AO system (PI: J. Larkin, UCLA)
- OSIRIS commissioning data (June 2005)



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

AO Integral Field Spectroscopy Is More Reliable Than AO Slit Spectroscopy



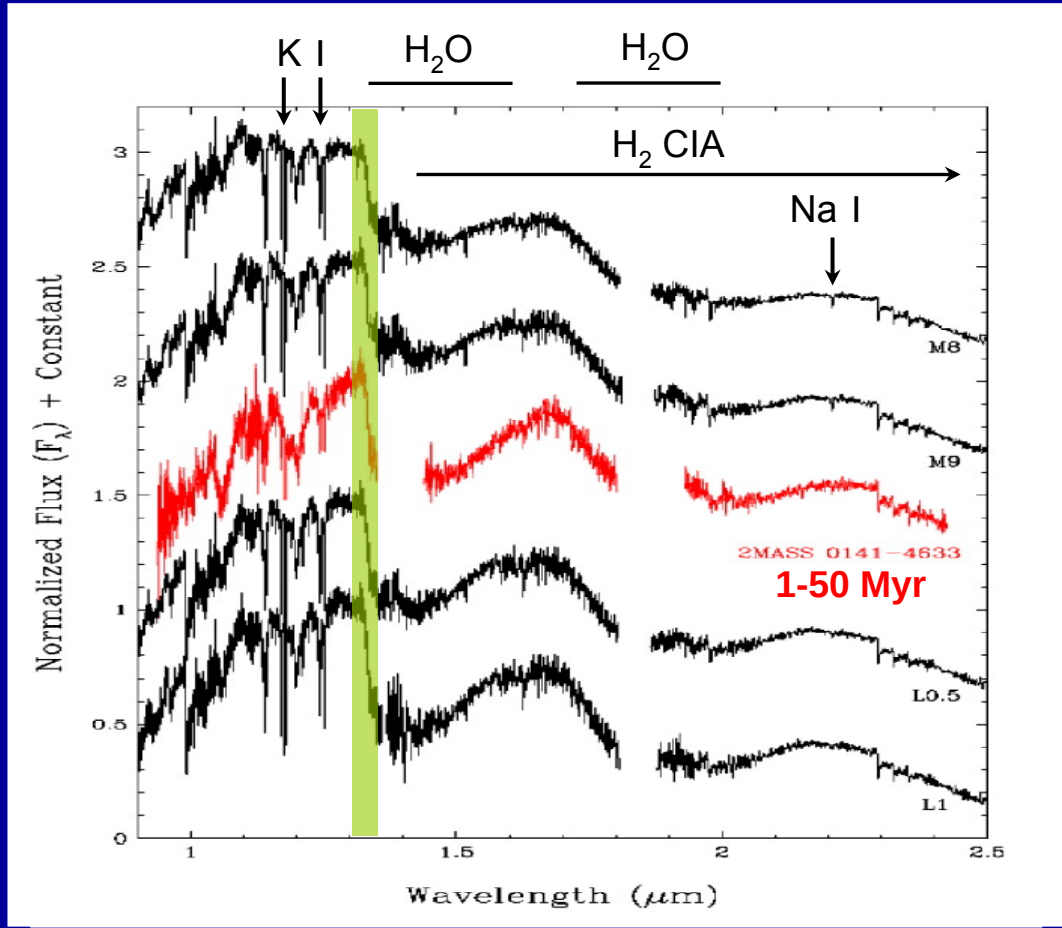
elevation,
differential refraction

H-band
53 mas-wide slit
GQ 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

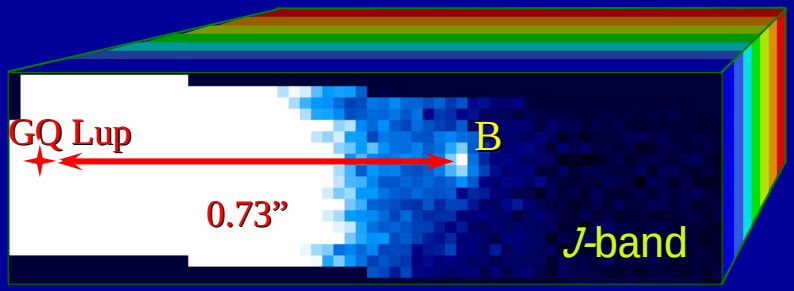
Spectral Classification of Ultra-Cool Objects is Age-Dependent

- spectral type
  - proxy for T_{eff}
  - determined by continuum shape in brown dwarfs
- but: young (<100 Myr) brown dwarfs
  - larger radius
  - lower surface gravity ($g = GM/R^2$)
  - weaker K I, Na I absorption
  - weaker H_2 CIA over 1.5–2.5 μm
- spectral classification most reliable from H_2O dip at 1.3 μm *(Slesnick et al. 2004)*



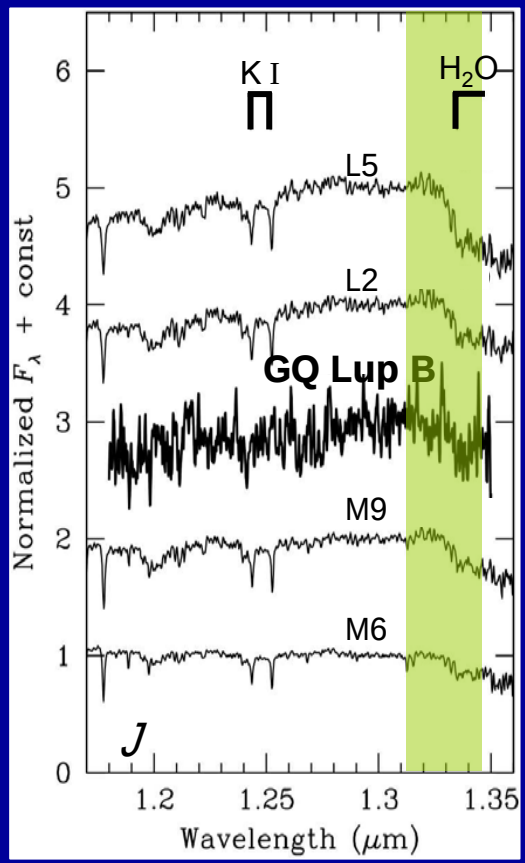
(Kirkpatrick et al. 2006)

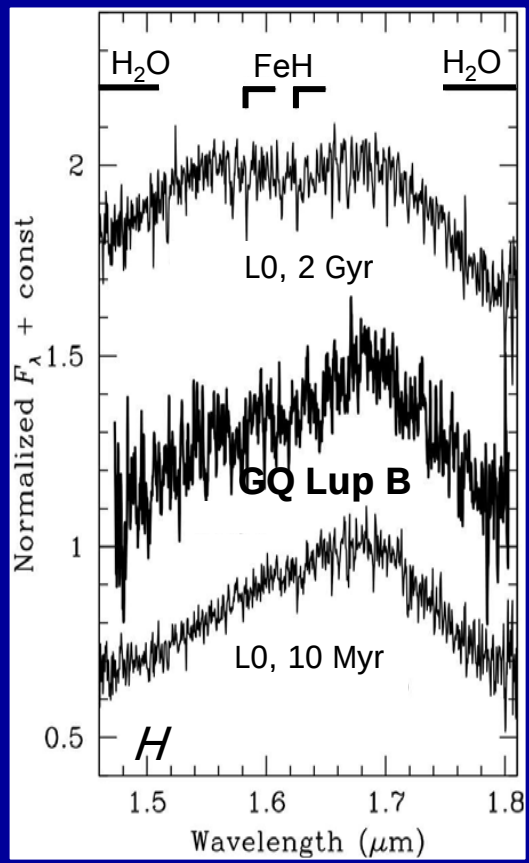
Keck/OSIRIS Spectra of GQ Lup B



- commissioning OSIRIS data (Aug 2005)
- *J*- and *H*-band

- spectral type: **M8 ± 2**
  - *Neuhaüser et al.*: M9–L4



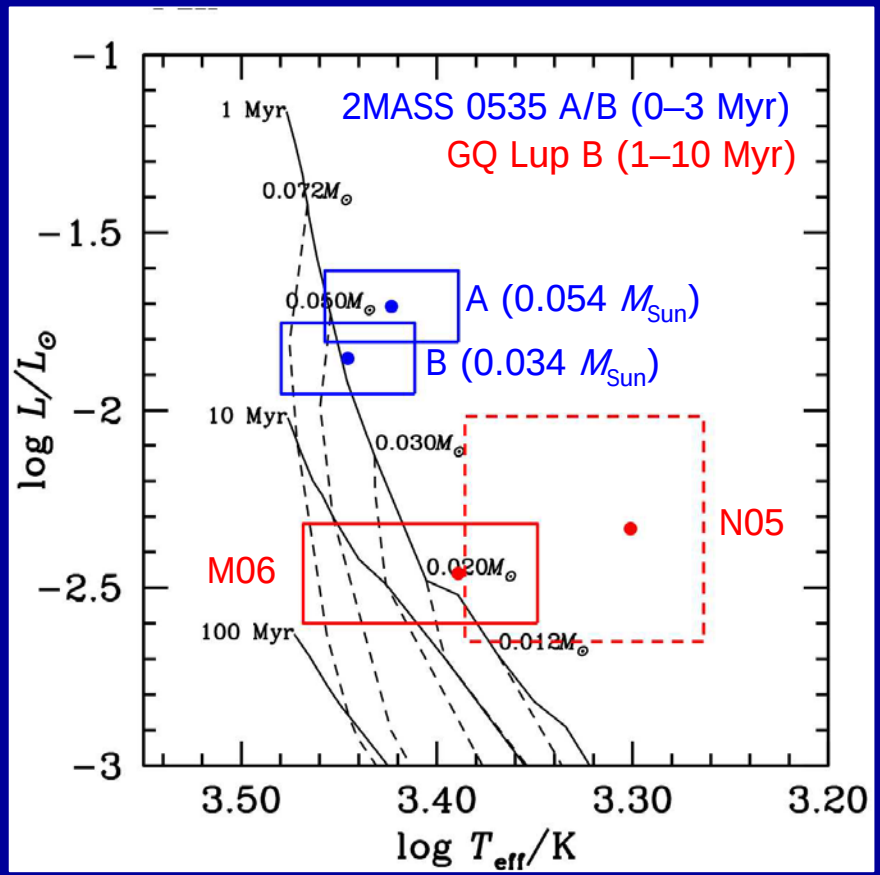


(McElwain, Metchev et al., ApJ, in press)

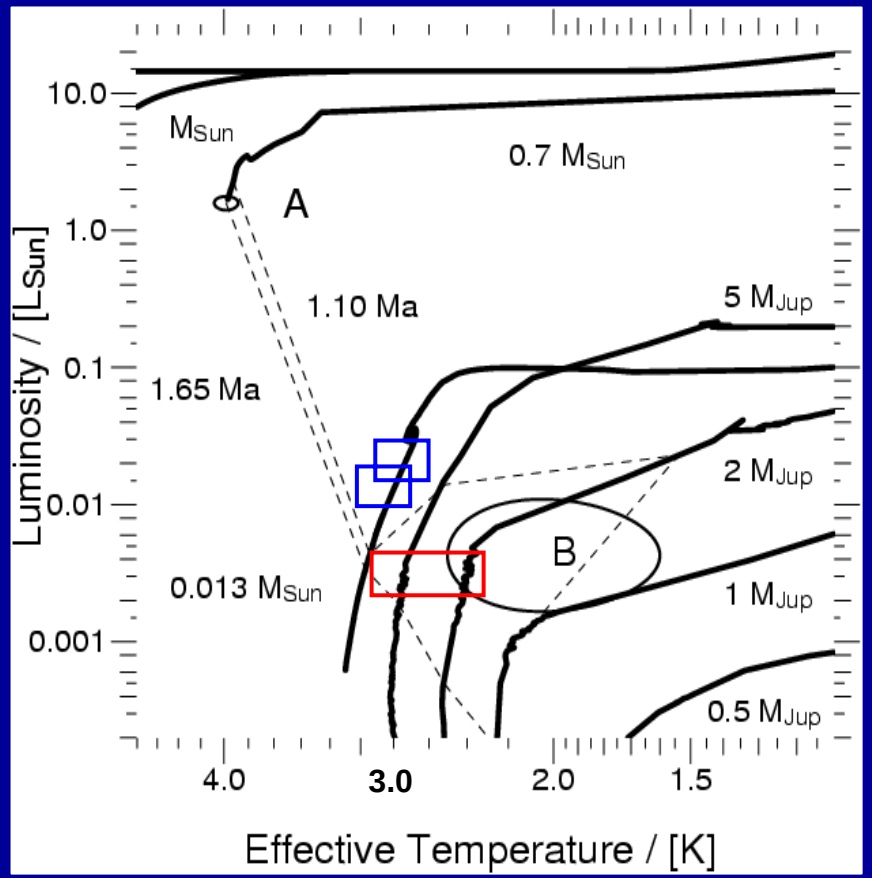
GQ Lup B is Hotter and Older Than Inferred by Neuhaüser et al.

- *McElwain, Metchev et al.:*
  - spectral type: M6–L0 (~2600 K)
  - age: 1–10 Myr
- *Neuhaüser et al. (2005):*
  - spectral type: M9–L4 (~2000 K)
    - AO slit losses affecting *K*-band continuum?
    - weakening H_2 CIA absorption at 1.5–2.5 μm
  - age: 0.1–2 Myr

Testing Evolutionary Models: "Hot-Start" Models Better at ≤3 Myr



(Stassun et al. 2006, Chabrier et al. 2000 models)



(Neuhaüser et al. 2005, Wuchterl & Tscharnuter 2003 models)

GQ Lup B is Probably a Brown Dwarf

- *McElwain, Metchev et al.:*
  - spectral type: M6–L0 (~2600 K)
  - age: 1–10 Myr
- "hot-start" models *(Burrows et al. 1997; Chabrier et al. 2000)*

  ⇒ mass: 10–40 M_{Jup}

- *Neuhaüser et al. (2005):*
  - spectral type: M9–L4 (~2000 K)
    - AO slit losses affecting *K*-band continuum?
    - weakening H_2 CIA absorption at 1.5–2.5 μm
  - age 0.1–2 Myr
- "cold-start" models *(Wuchterl & Tscharnuter 2003)*

  ⇒ mass: 1–2 M_{Jup}

Marois et al. (accepted), 0.6–3.5 μm SED analysis: 9–20 M_{Jup}

Summary

- AO integral field spectroscopy is more reliable than AO slit spectroscopy
- GQ Lup B is hotter (M6-L0) and older (1-10 Myr) than initially reported by *Neuhaüser et al. (2005)*
- Empirical young BD masses are more consistent with the hot start evolutionary models
- GQ Lup B is probably a brown dwarf and not an exoplanet

Thanks to the OSIRIS team

ACADEMIC

- Principal Investigator - James Larkin (UCLA)
- Project Scientist - Andreas Quirrenbach (University of Heidelberg)
- Co-Investigator – Alfred Krabbe (Cologne)
- Research Astronomer – Inseok Song, Christof Iserlohe (Cologne)
- Graduate Students - Matthew Barczys, David LaFreniere*, Michael McElwain, Tommer Wizansky, Shelley Wright
- Close collaboration – Ian McLean, Eric Becklin

ENGINEERING

- Project Engineer - George Brims
- Mechanical – Ted Aliado, **John Canfield**, Nick Magnone, Evan Kress
- Software – Tom Gasaway (UCSD), Chris Johnson, John Milburn, **Jason Weiss**
- Electrical – Ken Magnone, **Michael Spencer**, Gunnar Skulason,
- CARA - Paola Amico, Allan Honey, Junichi Meguro, Grant Tolleth, & others

ADMINISTRATIVE

- CARA Project Manager – Sean Adkins, David Sprayberry*
- Management – Juleen Moon, Jim Kolonko
- Secretarial – Melinda Laraneta

(lead engineer in each area for OSIRIS in **bold**, * denotes non-active team members)