Searching for proto-brown dwarfs:

Extending near IR spectroscopy of protostars below the hydrogen burning limit

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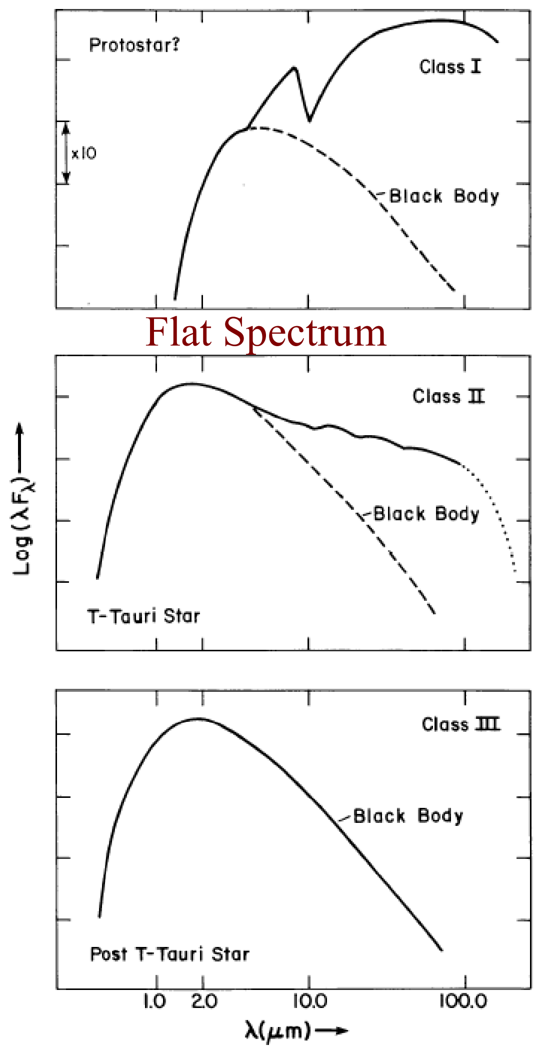
The Big Question…

- What physical mechanisms control the accretion of mass during the star formation process?

- Addressing this question will require measurements of young stars and brown dwarfs during all phases of mass accretion.

Class 0 - Low L_{bol}/L_{submm}

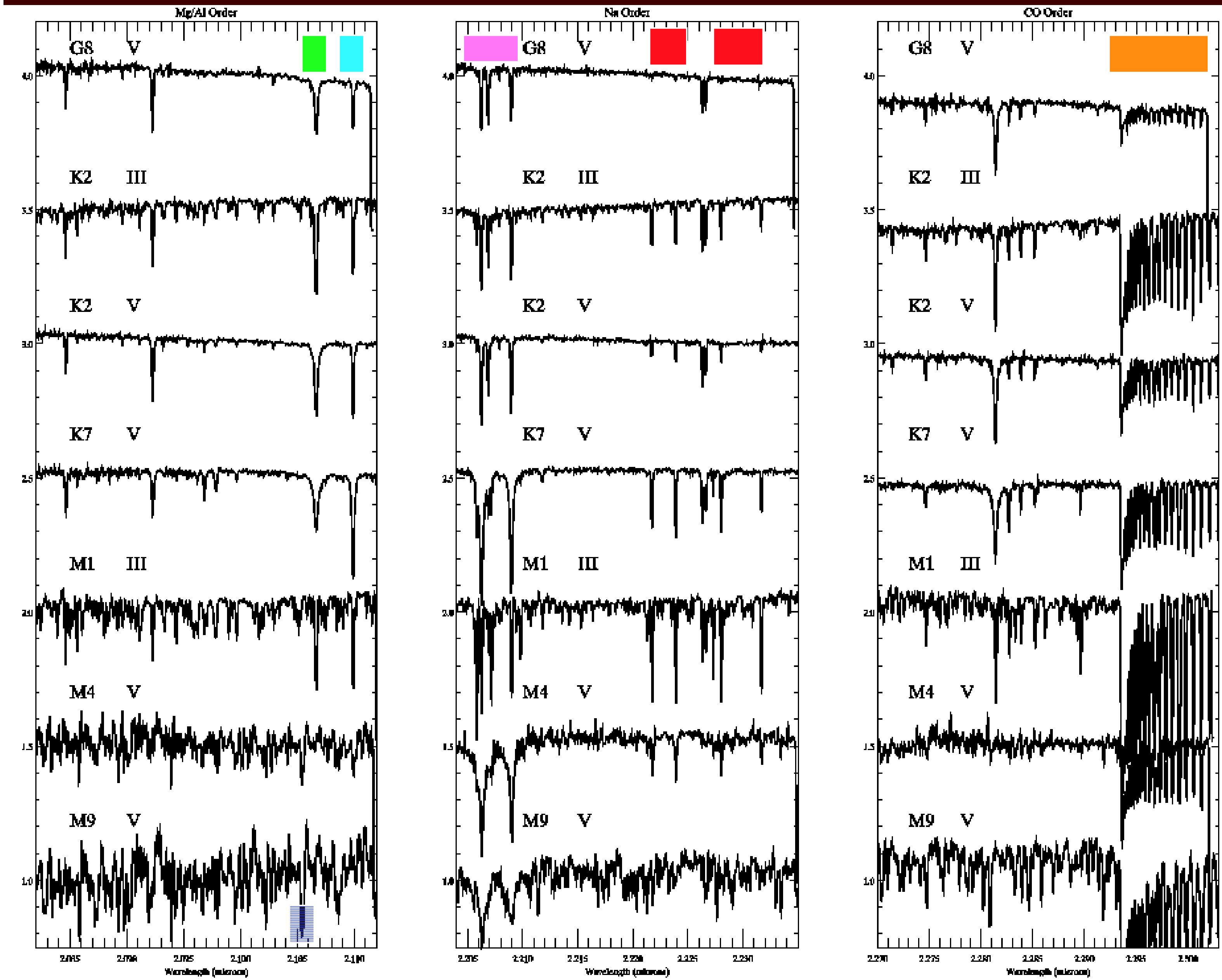


(Lada 1987, Andre et al 1993)

Basic Survey Overview

- 72 targets
  - 52 Class I/Flat Spectrum protostars from Tau-Aur, ρ Oph, Serpens
  - 20 spectral standards
- Observations from NIRSPEC on Keck II
- R ~ 17,000

Standard Atlas



Mg/Al
T_{eff} above 3500

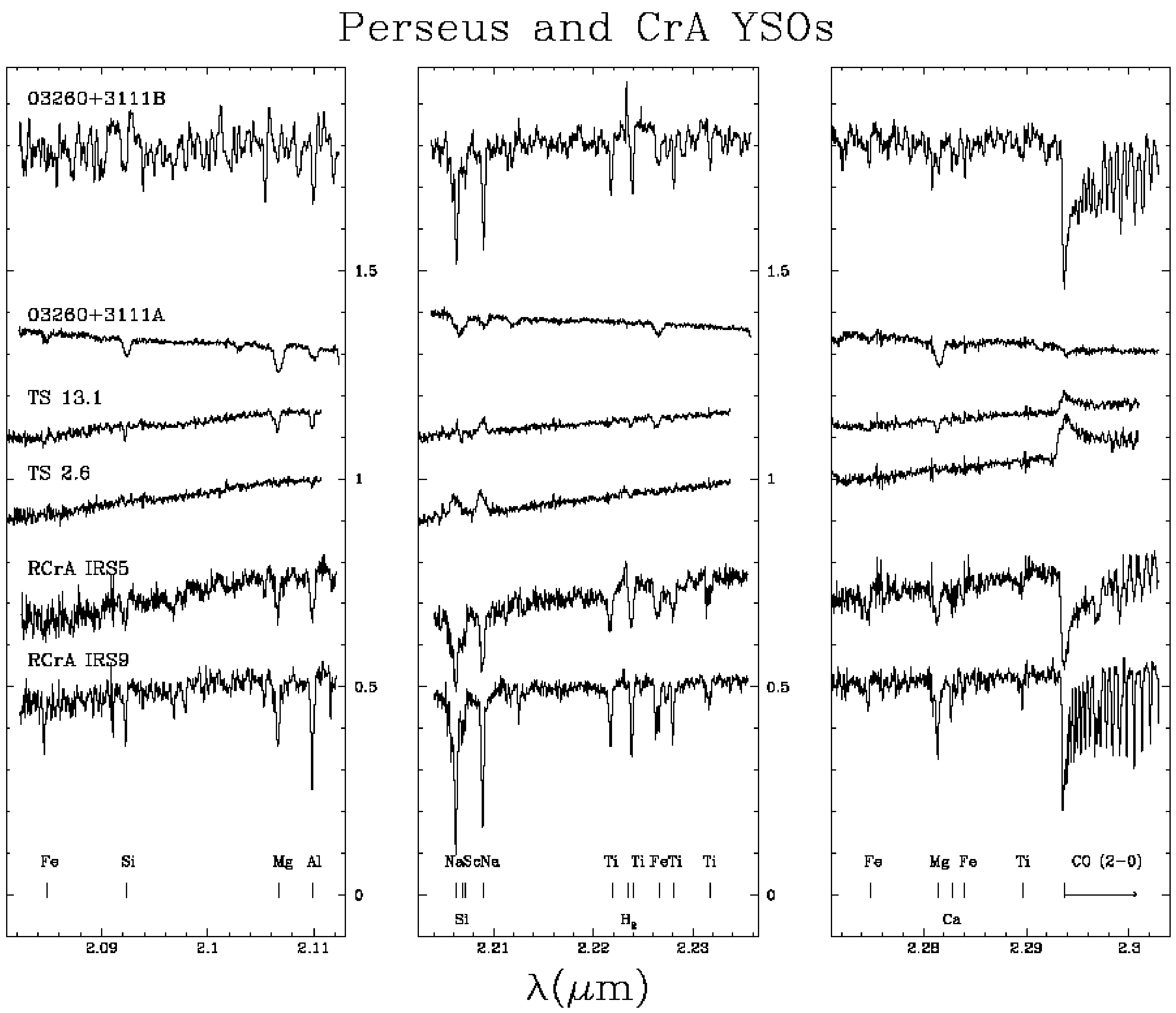
Line X
T_{eff} below 3500

Na
T_{eff}, log g

Ti
B field

CO
T_{eff}, log g, v sin i

Protostellar Spectra



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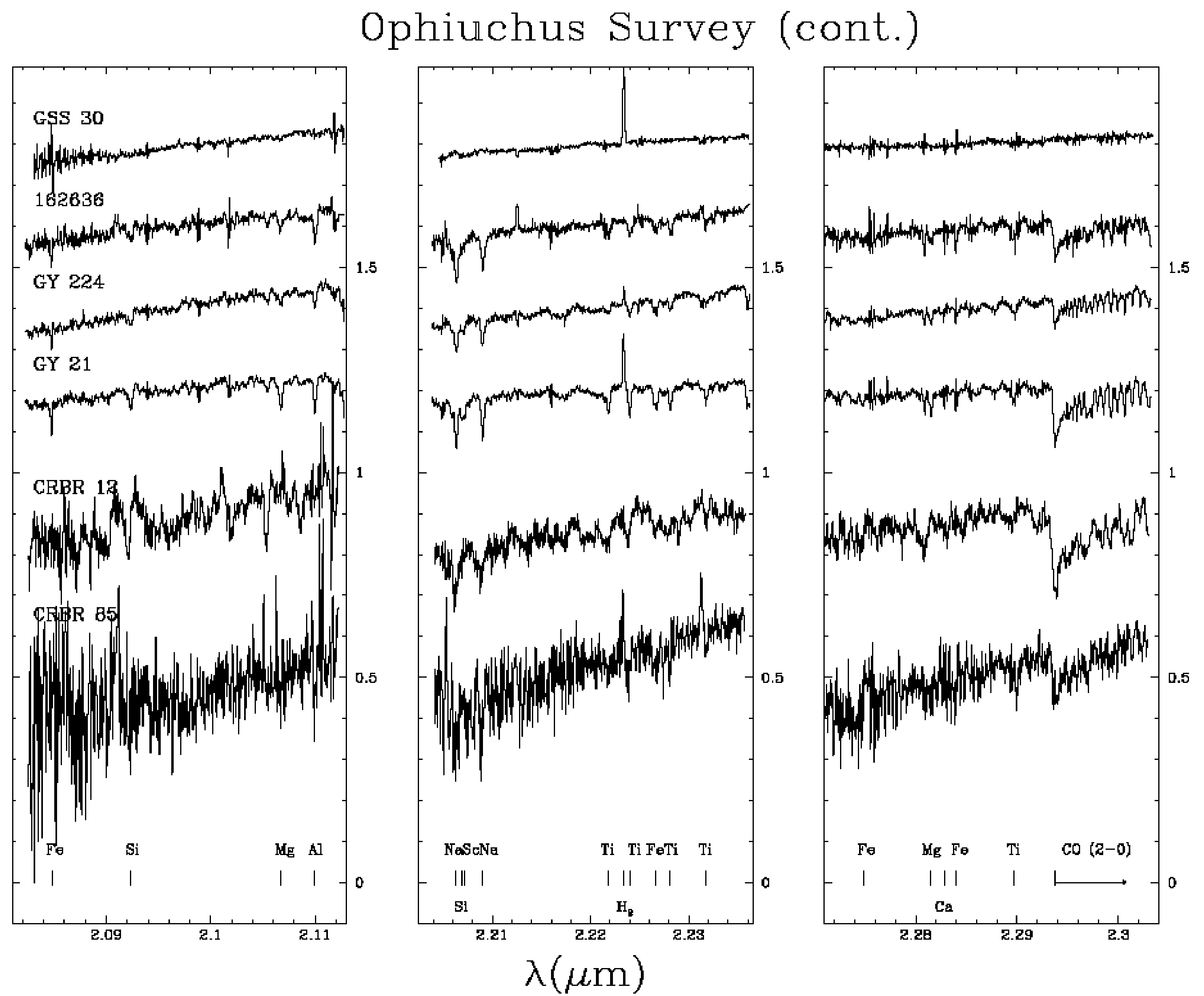
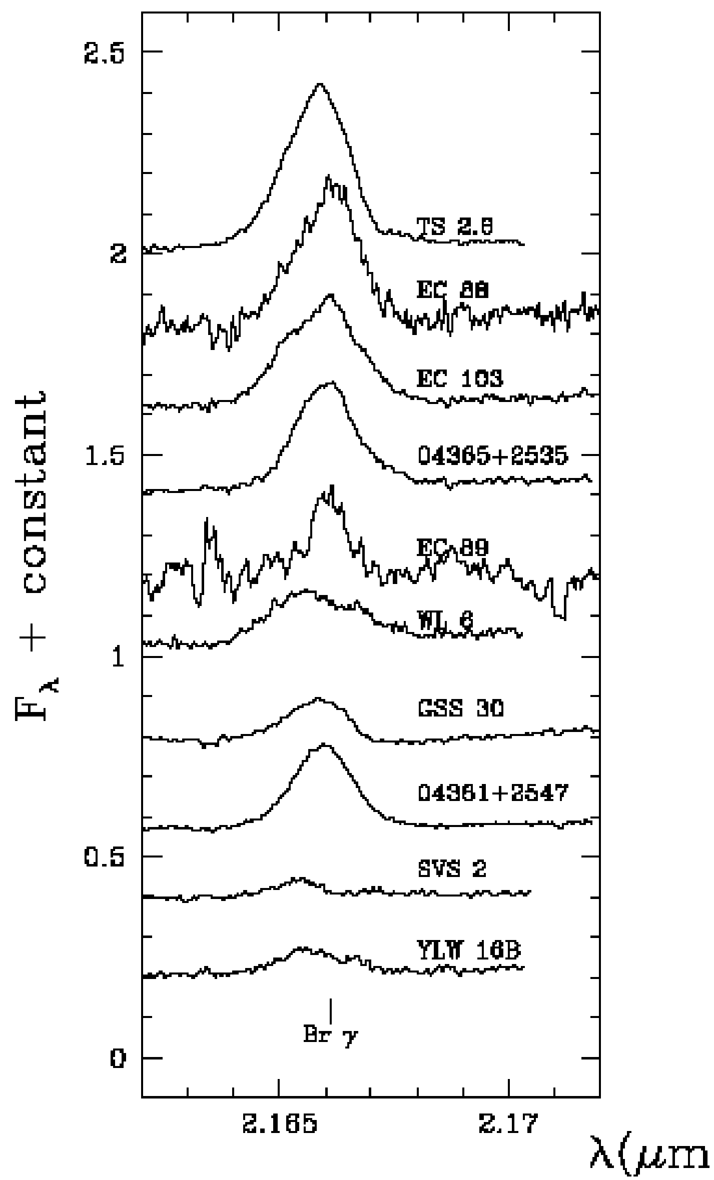


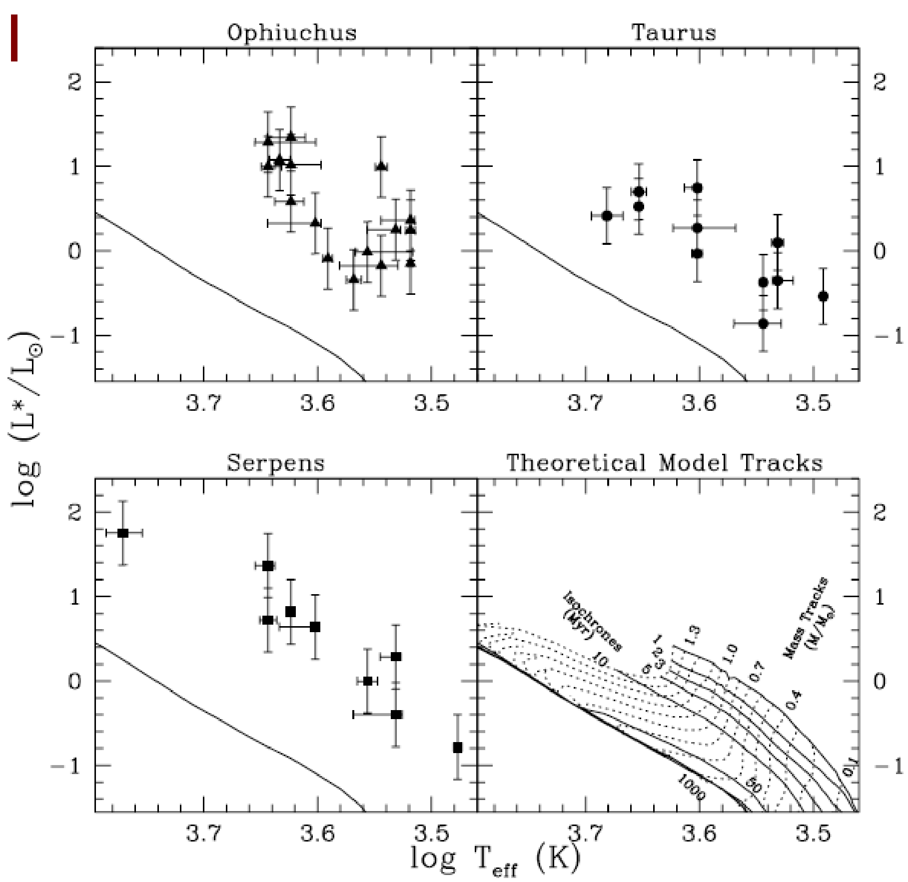
ULMS

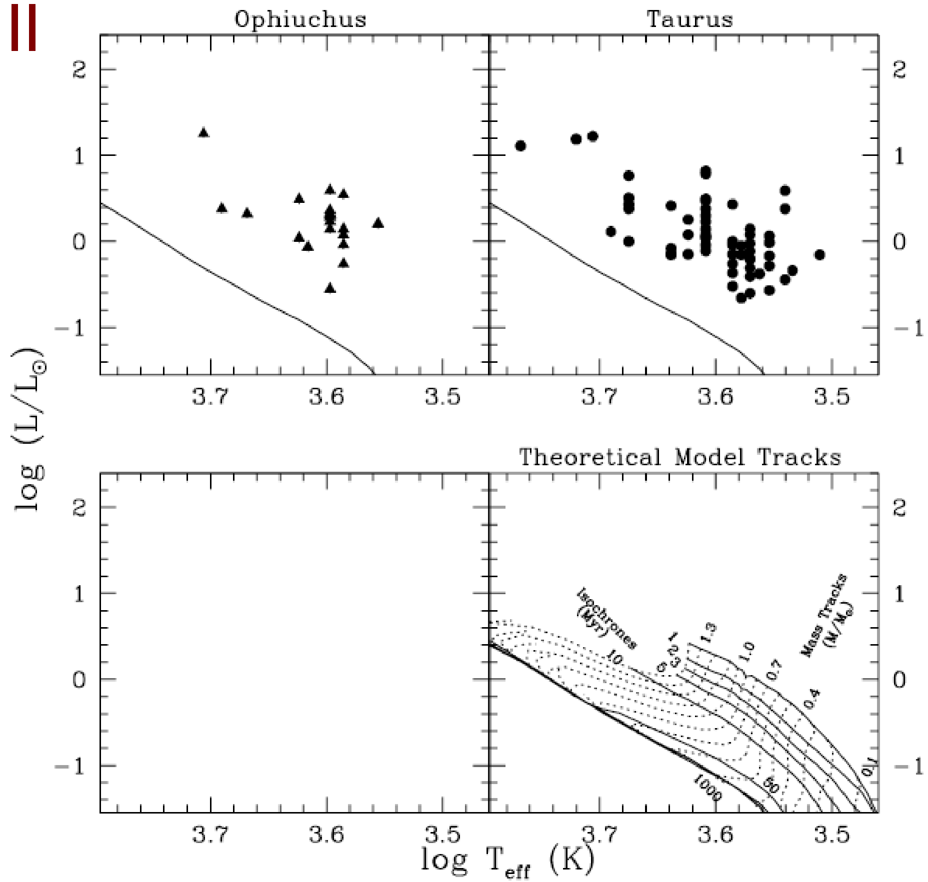
Bulk Sample Properties

- Photospheric lines detected in 80% (40/52) of sample
- Accretion signatures common
  - Brackett γ (34/52)
  - H_2 emission (23/52)
- Disk emission features 15% (8/52)
- Spectral synthesis determines best fit parameters
- Typical veiling $r_K \sim 1.8$



Placing Protostars on HR diagrams





– Significant spread due to uncertainty in scattering / extinction corrections / veiling variability?

Doppmann et al 2005 (astro-ph/0505295)

Protostellar Rotation

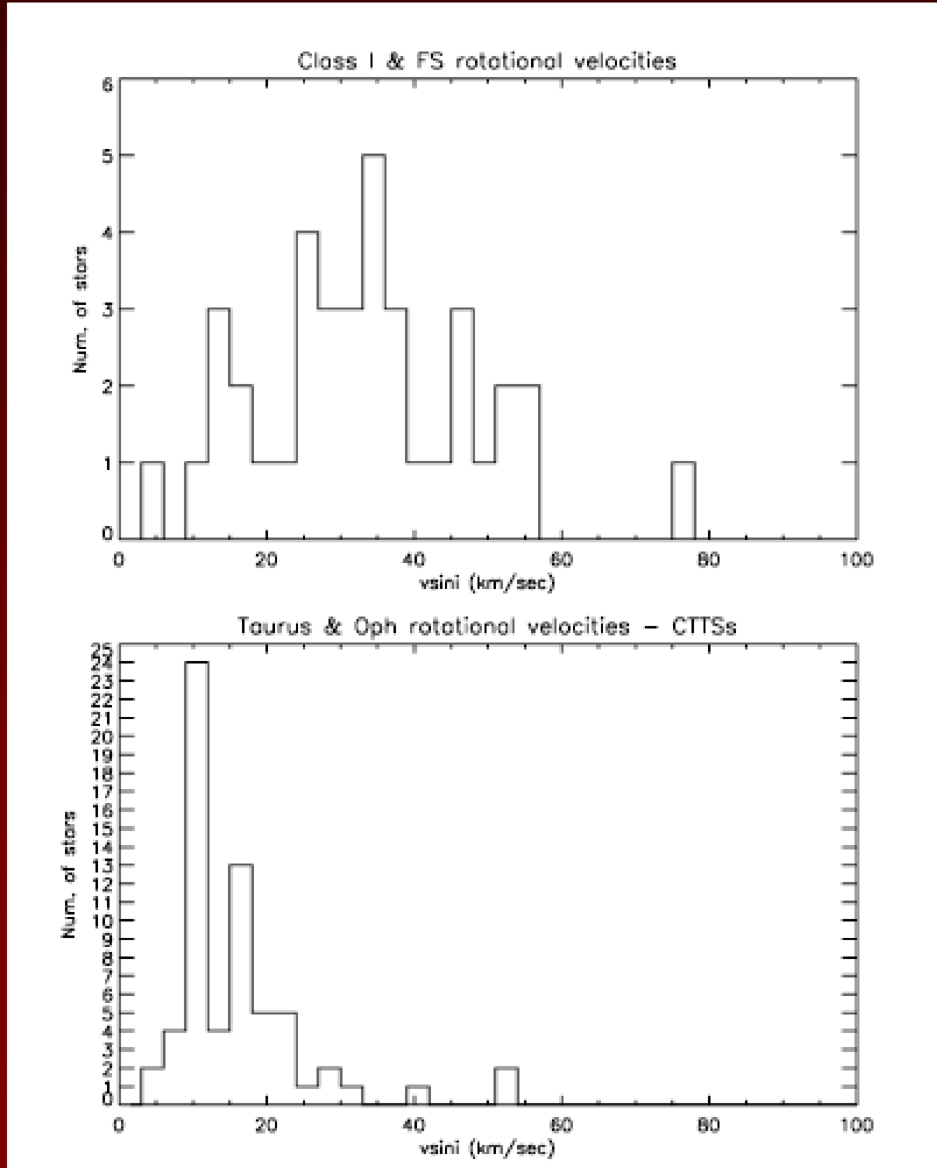
– Median Class I

$v \sin i \sim 38$ km/sec

– Median Class II

$v \sin i \sim 18$ km/sec

Covey et al 2005a
(AJ 129 2765)



Surveying proto-brown dwarfs

- Objects with detected absorption lines near stellar/sub-stellar boundary
  - EC 125 synthetic fits indicate $M \sim 0.07\ M_{\odot}$
  - Eyefit to spectrum (inc. continuum structure)
    M5 -> $M \sim .25\ M_{\odot}$

- Objects without detected lines are possible proto-brown dwarf candidates
  - EC 103 $L \sim 0.24$ $r_K > 3$

- Campaign targeted at low luminosity proto-brown dwarfs initiated Fall 2004
  - NIRSPEC cooling system swap forced observation of bright Class Is

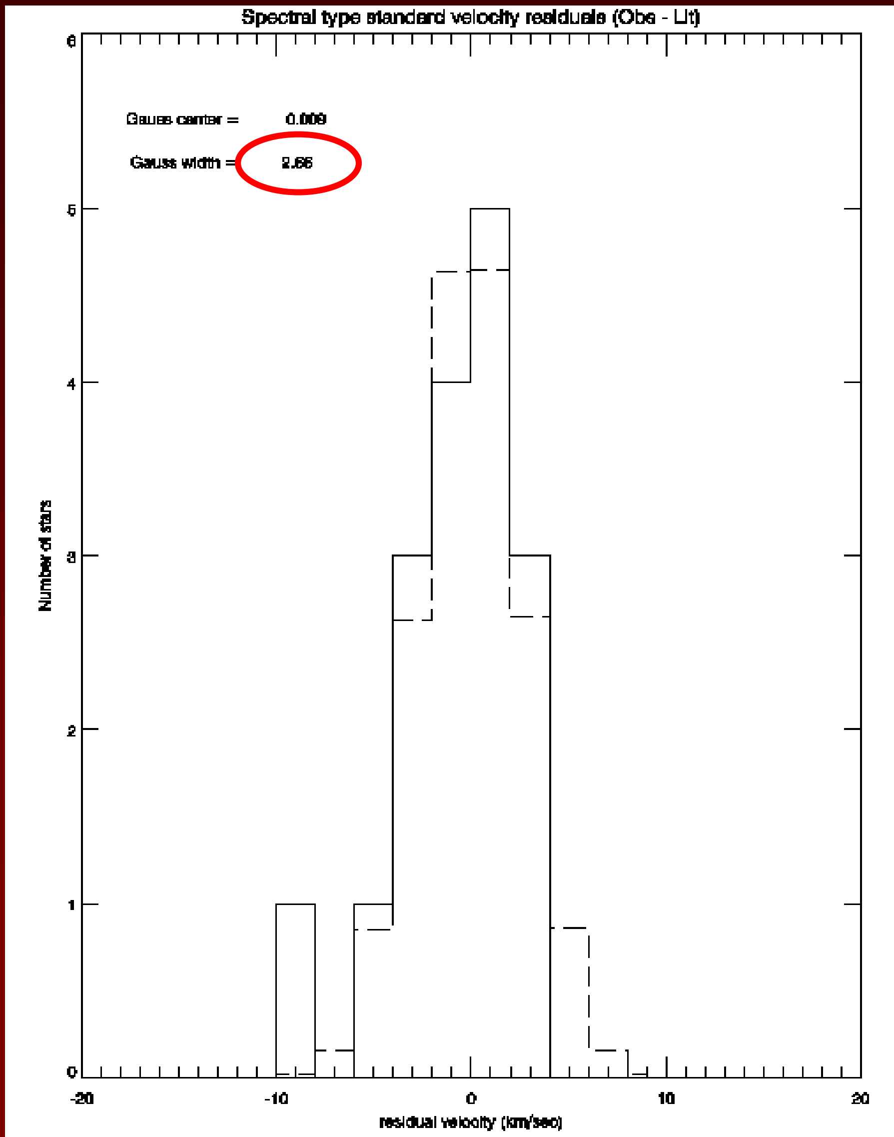
Surveying proto-brown dwarfs

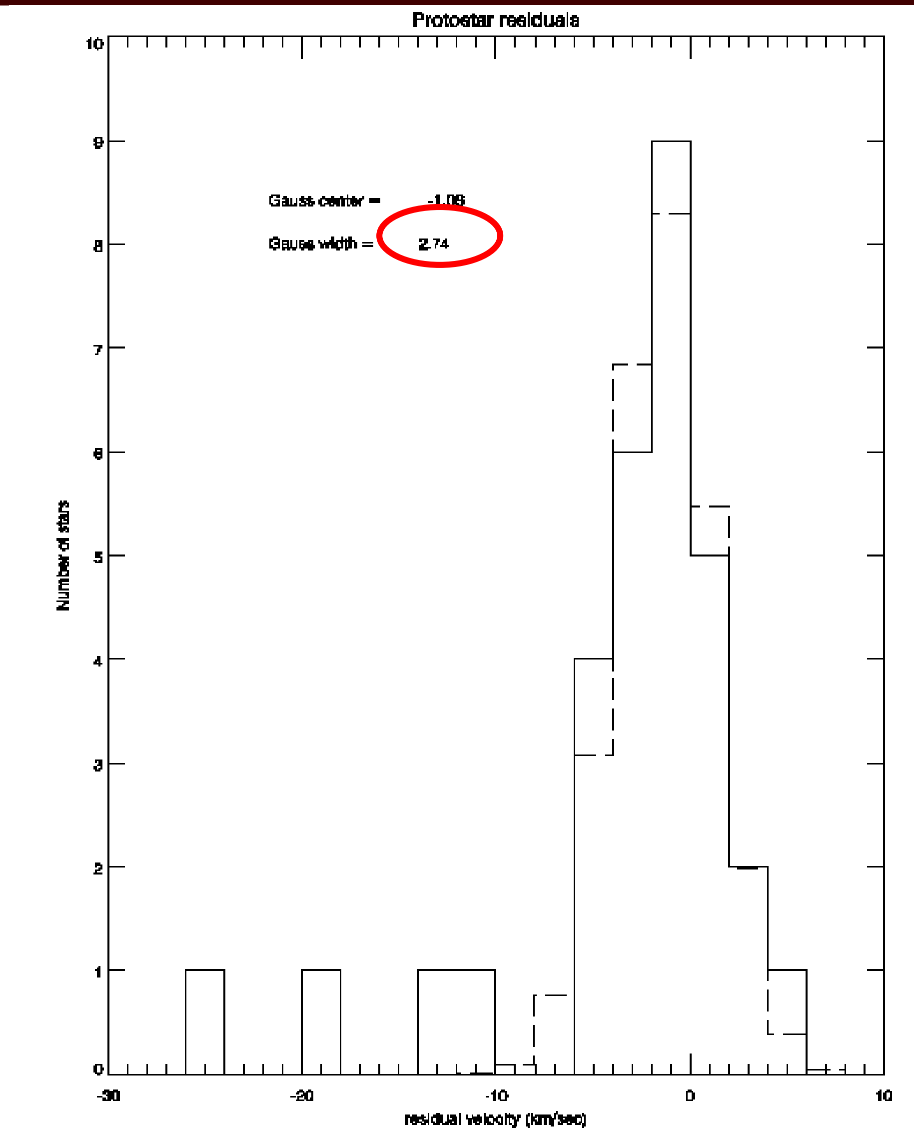
- Obtaining spectra of lowest mass proto-brown dwarfs
  - Baraffe models for 40 M_J brown dwarf at 1 Myr:
    M8 $m_K \sim 12.4$ in Taurus
  - Typical Taurus $A_K \sim 3$ -> $m_K \sim 15.5$
- Getting to $m_K \sim 15$
  - Lower resolution (susceptible to degeneracy)
  - Multi-object capability
  - L or M band (lower reddening)

Summary

- Near IR spectra provide diagnostics of physical state of Class I protostars
- Class I protostars share T_{eff} & Luminosity space with Class II objects, but possess larger veilings, larger v sin *i*
- Low luminosity objects without photospheric lines are possible proto-brown dwarf candidates
- Lowest mass proto-brown dwarfs challenging for current near IR observational limits

Radial Velocity Analysis



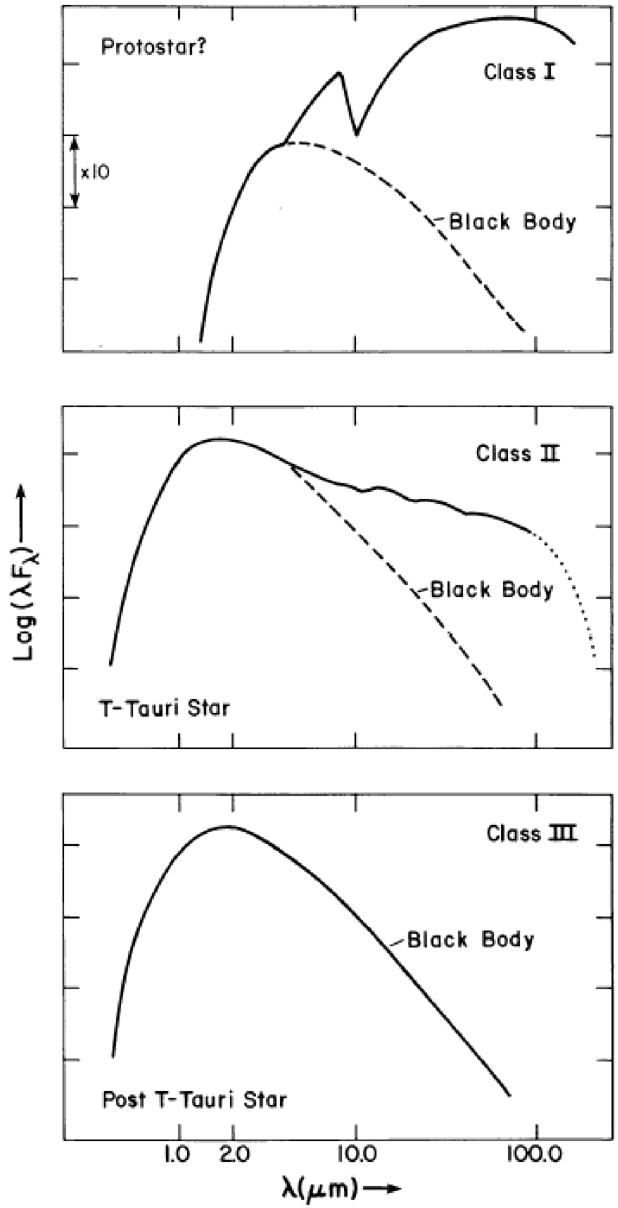


Covey et al 2005b (in prep)

Previous Studies of Class I Objects

- Optical photospheric absorption features in ~1/3 of Class I objects (3 - Kenyon et al 1998, 11 - White & Hillenbrand 2004)
  - S/N ~ 2-20

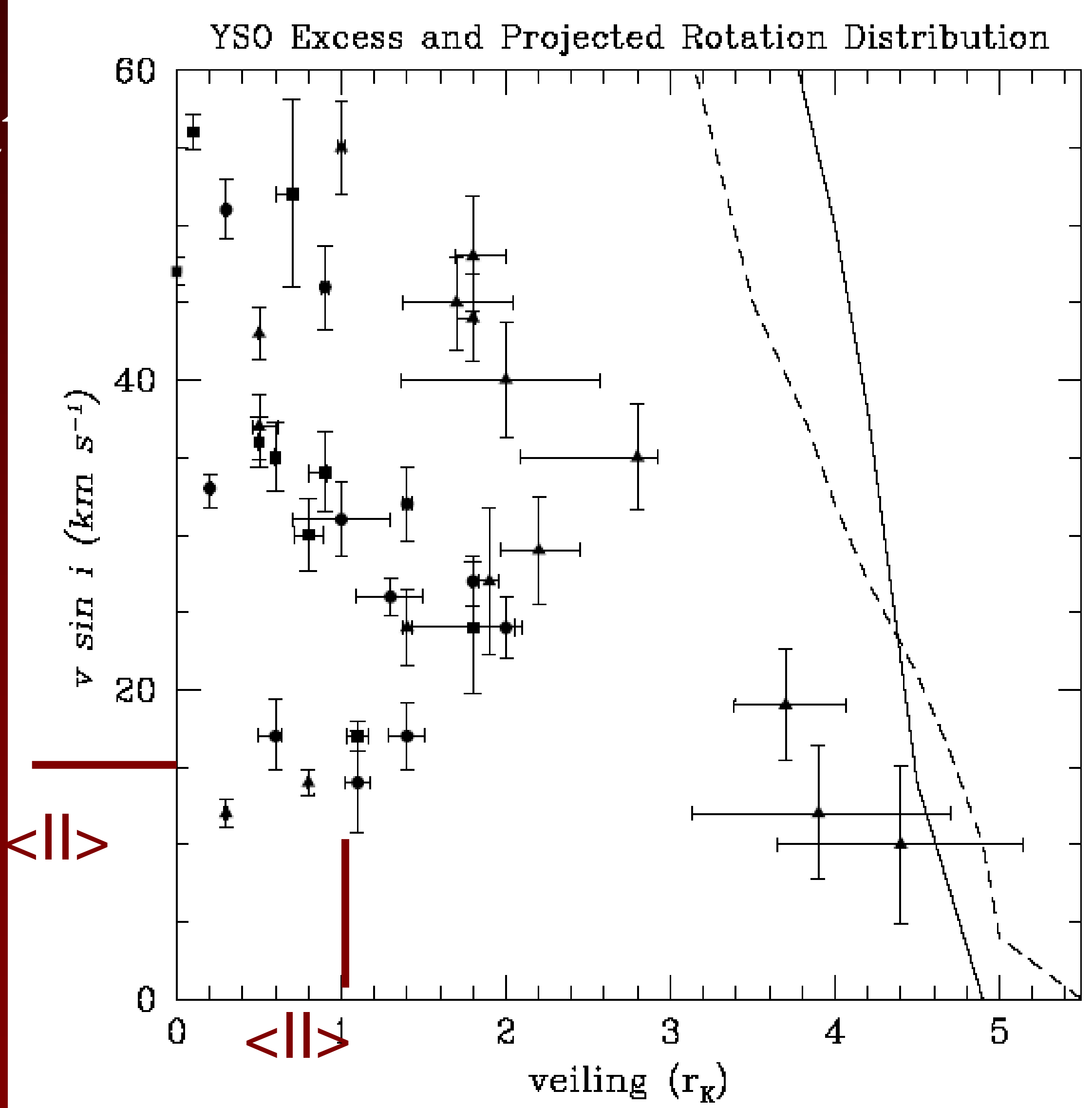
- Higher resolution IR spectra reveal photospheric absorption features (2 - Greene & Lada 2000, 1 - Greene & Lada 2002, 2 - Ishii et al 2004, 3 - Nisini et al 2005)
  - S/N ~ 20-200



(Lada 1987, Andre & Montmerle 1994)

Rotation and Veiling

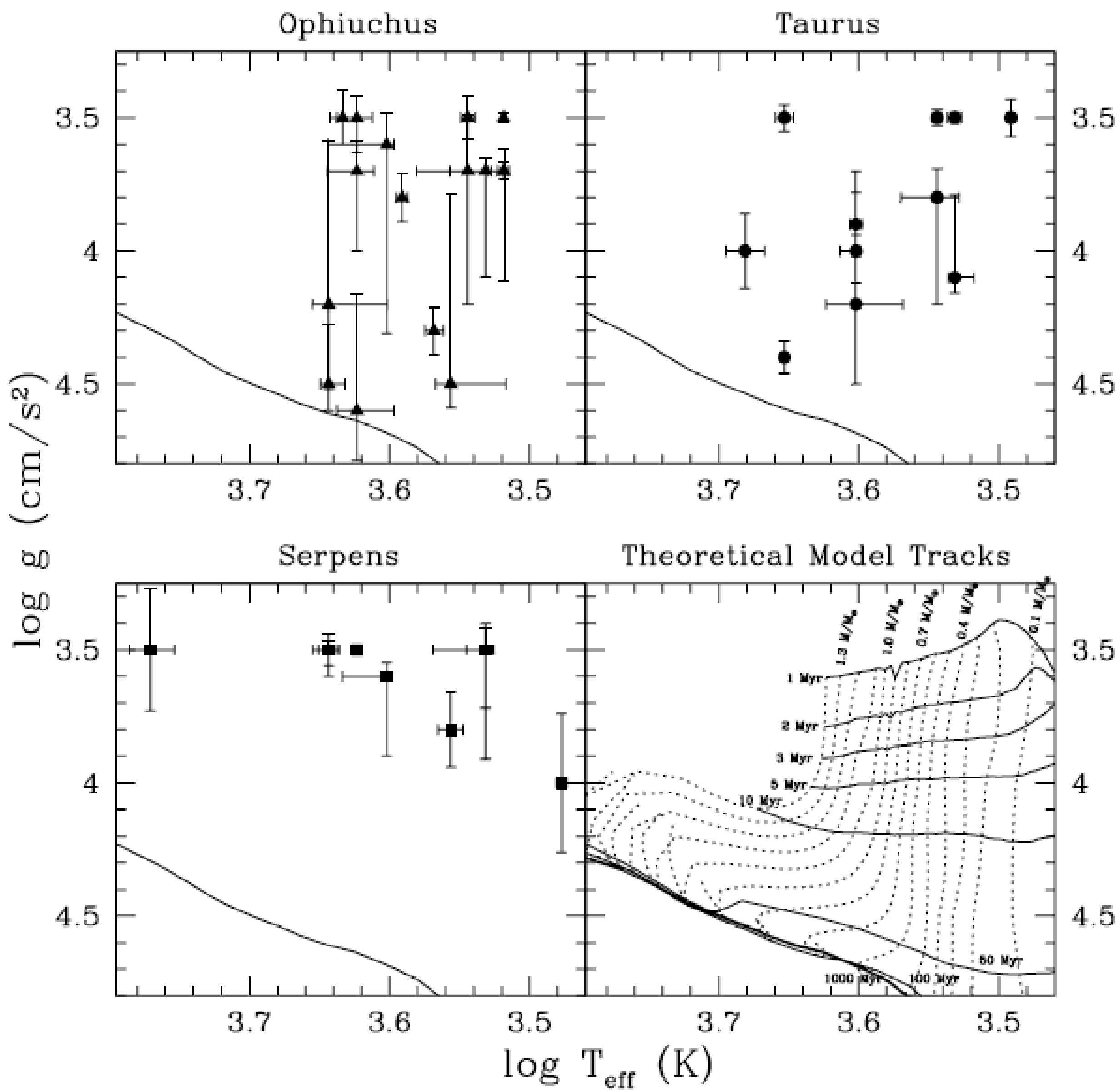
– Class I protostars rota[t] more quickly and are more veiled than CTTSs in the same star formation regions.



Placing Protostars on HR diagram

- Derived T_{eff} and log g allow comparison to models

- log g errors can produce unphysical ages



Previous Studies of Class I Objects

- Optical photospheric absorption features in ~1/3 of Class I objects (3 - Kenyon et al 1998, 11 - White & Hillenbrand 2004)
  - S/N ~ 2-20
  - $2800 < T_{eff} < 5000$, $dM/dt \sim 10^{-(6-8)}\ M_\odot\ yr^{-1}$, $v \sin i \sim 20$

- Higher resolution IR spectra reveal photospheric absorption features (2 - Greene & Lada 2000, 1 - Greene & Lada 2002, 2 - Ishii et al 2004, 3 - Nisini et al 2005)
  - S/N ~ 20-200
  - $2800 < T_{eff} < 5000$, $v \sin i \sim 40$

Looking for answers

- Class I protostars
- Near IR spectroscopic survey of protostars
- Bulk properties of the Class I phase
- Identifying and studying the lowest mass protostars

Spectral Synthesis Details

- Comparison spectra from LTE spectral synthesis via MOOG (Sneden 1973) with solar metallicity NEXTGEN model atmospheres (Hauschildt et al 1999) with line lists from Kurucz (1994) and Goorvitch & Chackerian (1994).
- Additional line constants generated by fitting solar spectra and MK standard grid.