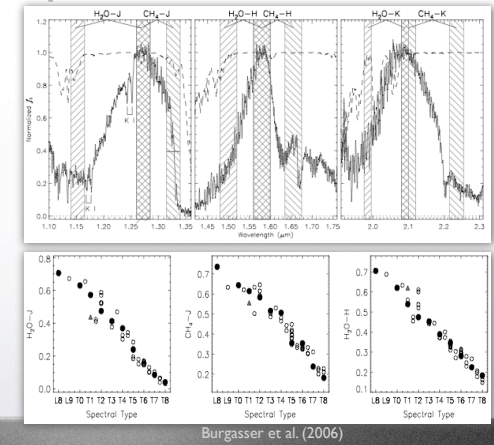


Observational properties of brown dwarfs

T dwarf sequence definition

- Based on IR spectroscopy
- Geballe et al. (2002) superseded by Burgasser et al. (2006)



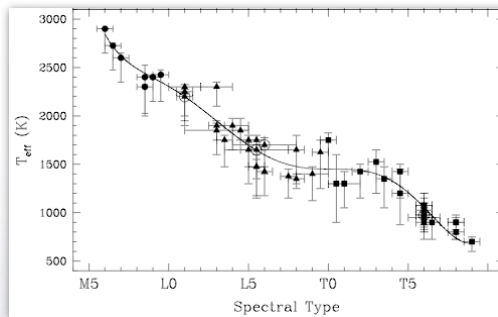
Burgasser et al. (2006)

The L/T transition puzzle

Remember Stefan's law:

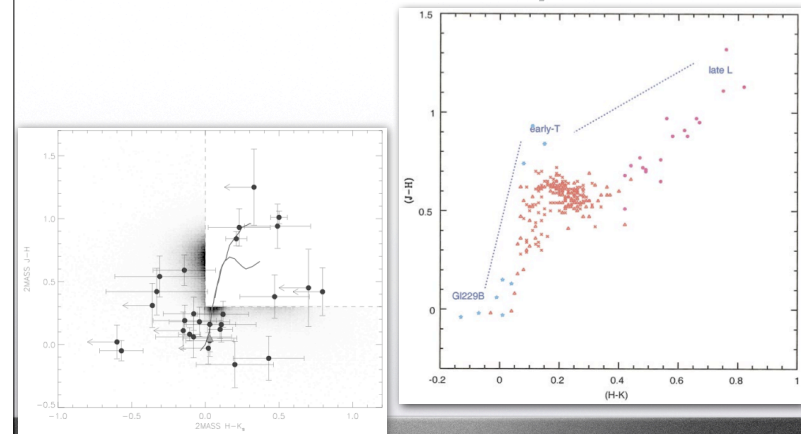
$$L = 4\pi R_{BD}^2 \cdot \sigma \cdot T_{eff}^4$$

- radius (model)
- L_{bol} :
 - larger λ coverage
 - distance (parallax)



Golimowski et al. (2004)

The elusive early Ts

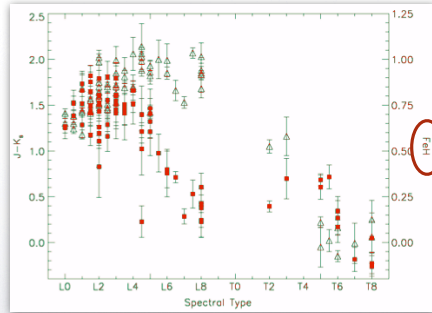


Burgasser et al. (2003)

Reid (2000)

The cloud breaking hypothesis

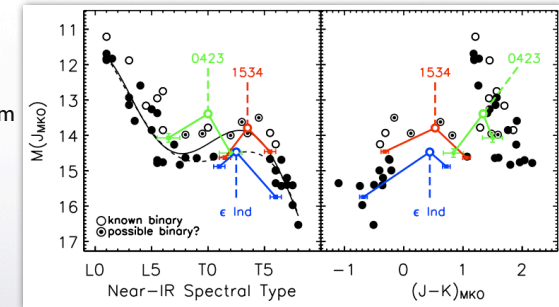
- Re-appearance of FeH for later spectral types, as BDs get bluer
 ⇒ Indication that a deeper, warmer region is probed?



Burgasser et al. (2002)

The binary explanation

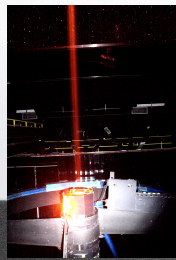
- Are most transition objects binaries?
 would solve the problem of the atmospheric metamorphosis at constant-temperature



Liu et al. (2006)

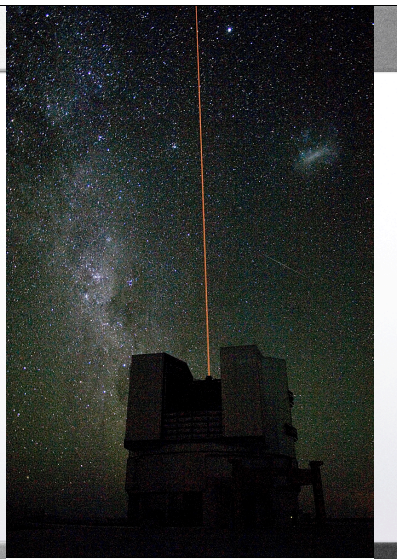
Technical mean: laser guide star

- New method to correct (in real time) atmospheric distortion with a laser guide “star”



ESO-Paranal Feb 2006

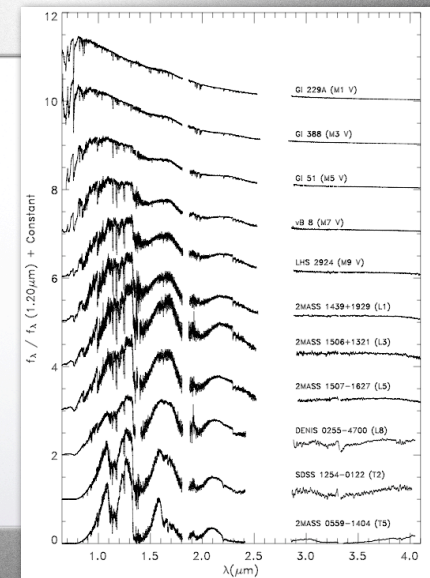
Subaru Oct 2006

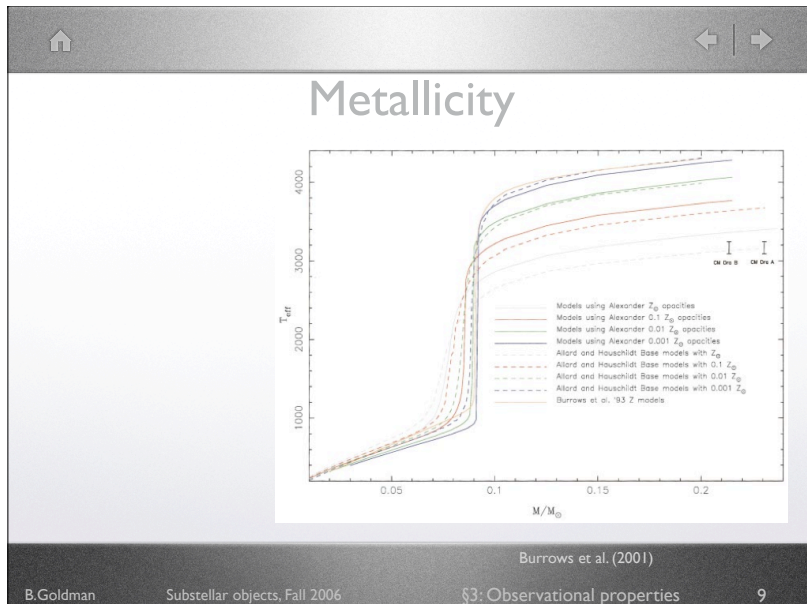


First Light of the VLT Laser Guide Star

Summary

- Two new spectral classes
 - based on molecular absorption strength not seen in earlier (warmer) classes
 - well accepted schemes
- Problems remain
 - L/T transition
 - relation type-temperature
 - additional parameters:





A few words on the Galaxy

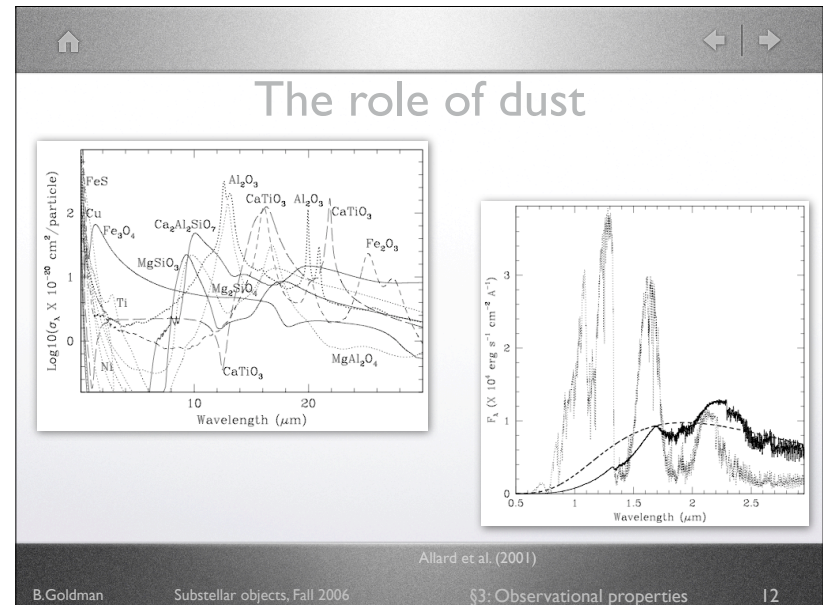
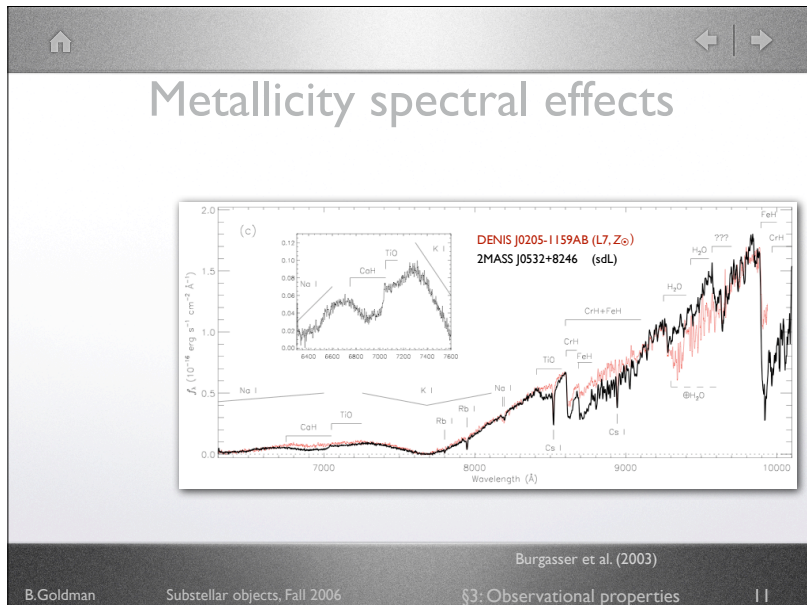
- Thin disk:
 - continuous star formation over the past ~8 Gyr
- Thick disk:
 - sequel of a merging event?
 - low metallicity
- Bulge
- Stellar halo (or spheroid)
 - very low metallicity
- Dark halo (or halo)
 - unknown nature

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Substellar objects, Fall 2006

§3: Observational properties

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Variability

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Rotational velocity

Mohanty & Basri (2003)

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Atmospheric model predictions

- Models predict the temperature of where photons come from (temp. brightness profile)
- Multi- λ observations may constrain cloud location

Ackerman & Marley (2001)

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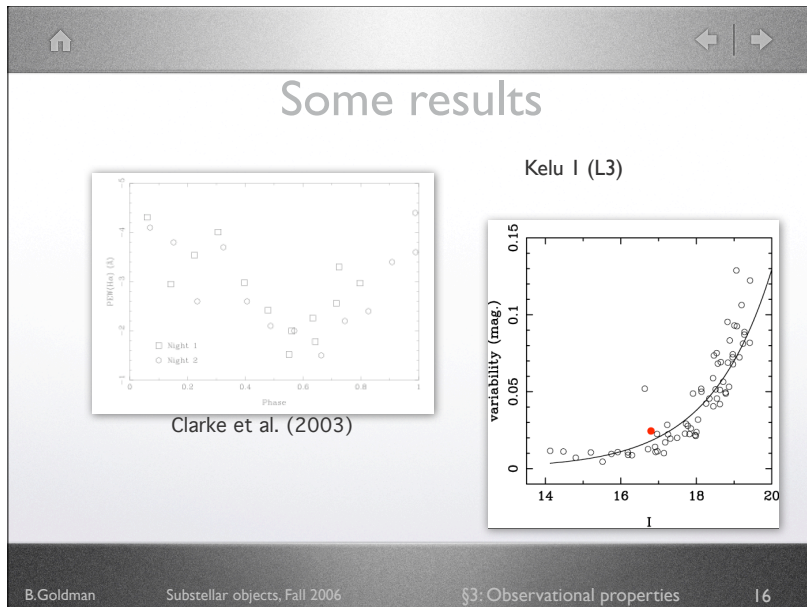
Some results

Kelou I (L3)

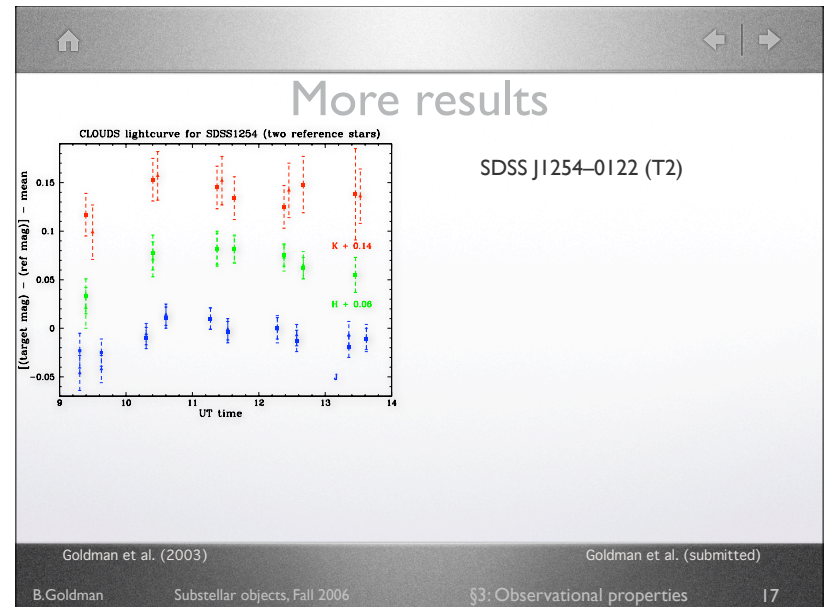
Clarke et al. (2003)

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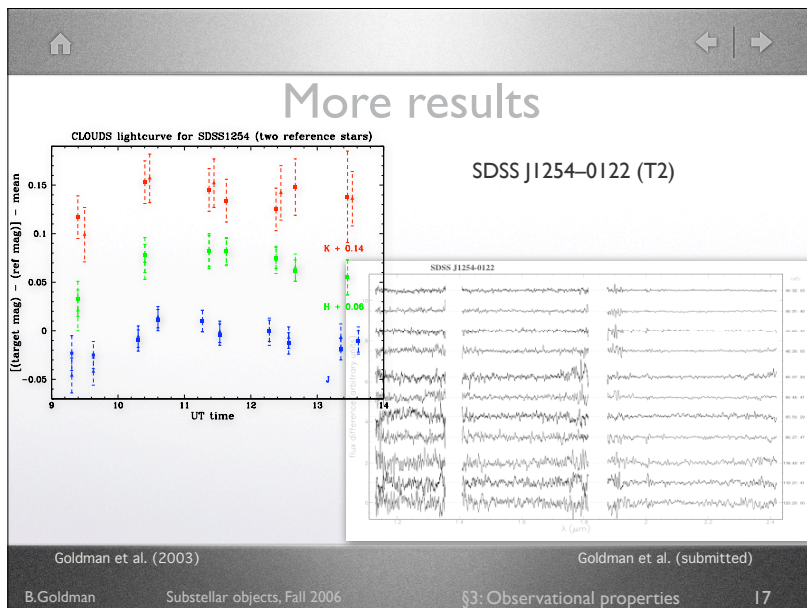
16



16



17



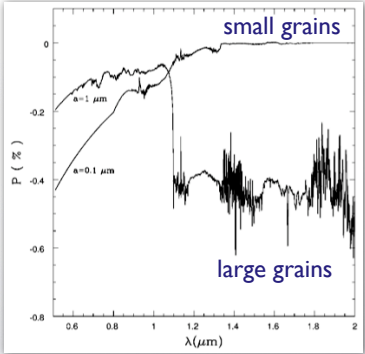
17



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Polarimetry—expectations

- Dust in the photosphere
 - produces scattering
- Non-spherical:
 - Relation eccentricity e —
 - angular velocity ω :
 - uniform density ρ
 - uniform rotation
 - Chandrasekhar (1933)



The graph shows polarization P (%) on the y-axis (ranging from -0.8 to 0) versus wavelength λ (μm) on the x-axis (ranging from 0.6 to 2). Two curves are shown: a solid line for 'small grains' and a dashed line for 'large grains'. The small grain curve shows a positive polarization peak around 1.2 μm , while the large grain curve shows a negative polarization peak at the same wavelength. Labels $a=1 \mu\text{m}$ and $a=0.1 \mu\text{m}$ are present near the curves.

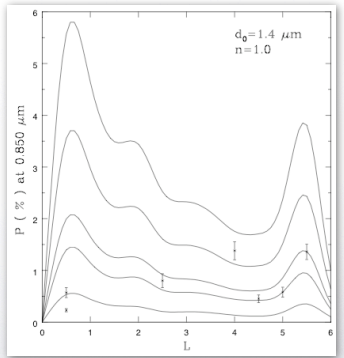
Sengupta & Krishan (2001)

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Polarimetry—expectations

- A lot of assumptions:
 - rotational velocities
 - density profile
 - cloud location
 - particle size distribution
 - single/multiple scattering



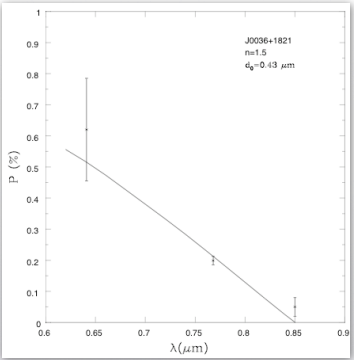
The graph shows polarization P (%) at $0.850 \mu\text{m}$ on the y-axis (ranging from 0 to 6) versus the L parameter on the x-axis (ranging from 0 to 6). Multiple curves are shown, representing different assumptions. Parameters $d_0 = 1.4 \mu\text{m}$ and $n = 1.0$ are noted in the top right.

Sengupta et al. (2005)

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Polarimetry—example



2MASS J0036+1821 (L3.5)

$n=1.5$
 $d_0=0.43 \mu\text{m}$

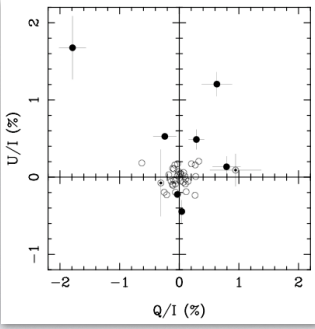
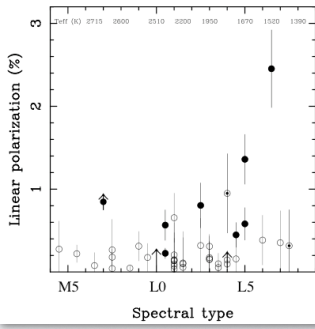
The graph shows polarization P (%) on the y-axis (ranging from 0 to 1) versus wavelength λ (μm) on the x-axis (ranging from 0.6 to 0.9). A single data point with error bars is shown at approximately $\lambda = 0.65 \mu\text{m}$ and $P = 0.55$. A solid line represents a model fit to this point.

Sengupta et al. (2005)

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Polarimetry—results

The left plot shows the ratio of U to I polarization (U/I %) on the y-axis versus the ratio of Q to I polarization (Q/I %) on the x-axis, both ranging from -2 to 2. The right plot shows Linear polarization (%) on the y-axis (ranging from 0 to 3) versus Spectral type on the x-axis (ranging from M5 to L9.5).

Zapatero Osorio et al. (2005)

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The Hebrew University of Jerusalem
The Institute for Advanced Studies

The Victor Rothschild Memorial Symposium

The 24th Jerusalem Winter School in Theoretical Physics
General Director: David Gross

**The Lives of Low-Mass Stars
and Their Planetary Systems**

Directors: Lars Bildsten & Tsvi Piran
December 27, 2006- January 5, 2007

Lars Bildsten > KIPP
Bases of Stellar Structure, Fully Convective Stars and Contraction to the Main Sequence

Adam Burgasser > MIT
Properties and Magnetic Activity of Low-Mass Stars and Brown Dwarfs

Adam Burrows > University of Arizona
Giant Planet Formation and the Atmospheres and Spectra of Extra-Solar Giant Planets

Eugene Chiang > UC-Berkeley
Observation and Theory of Proto-Planetary and Debris Disks Including the Kuiper Belt

Ralf Klessen > Heitberg
Turbulence and Fragmentation during Low-Mass Star Formation

Ralph Pudritz > McMaster University
Hydro-magnetic Outflows and Jets from Low-Mass Stars and Stellar Spin Evolution

Re'em Sari > Caltech
Terrestrial Planet Formation in Disks around Young Stars

Dimitar Sasselov > Harvard
Extra-Solar Planet Observations, Solar Systemology and New Searches

Within the last decade, more than 100 planets have been found around nearby stars, revealing worlds quite different than our own and challenging our notions about planet formation. Simultaneous breakthroughs in our knowledge of distant bodies in our own solar system, the Kuiper Belt Objects, and detailed studies of the lowest mass stars and brown dwarfs provide probes of the environments conducive to star and planet formation. This diversity offers during the formation of a star and the subsequent accumulation of matter in a proto-planetary disk around it. This school brings together lecturers across the breadth of this exciting endeavor, from the properties of the host stars where planets are formed to the studies of the planets themselves.

Participants: the school is intended for advanced graduate students and postdoctoral researchers from all over the world. Cost: Registration fee \$100. Hotel accommodation: \$2500. Financial support will be granted based on requests made during applications. Applications should be made via the web site: www.iaa.huji.ac.il by November 15, 2006.

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Next lecture

- ARI, Monday, November 6th, 15:15 by Thomas Henning
- Internal structure:
 - core gas degeneracy
 - energy transport
 - evolution
- Readings:
 - *New light on dark stars*: §3
 - Chabrier & Baraffe, 2000, ARA&A, **38** 337
 - Burrows et al, 2001, Rev.Mod.Phys. **73** 719 (§§I-IV)

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