

WEATHER ON SUBSTELLAR WORLDS?

A J-BAND MONITORING PROGRAM FOR WEATHER-INDUCED VARIABILITY ON T-DWARFS

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Abstract

One of the most puzzling behaviors exhibited by cool brown dwarfs is their rapid evolution from very red ($J-K=2$) to very blue ($J-K=0$) near infrared colors at the boundary between L and T spectral types, marking the transition from cloudy to cloud-free atmospheres. It has been suggested that the rapidity of this evolution, accompanied by a J-band brightening, is caused by the fragmentation of photospheric cloud decks, allowing flux from deeper, warmer layers to escape. This hypothesis has testable consequences: such patchy cloud coverage should give rise to rotationally modulated variability. We describe our upcoming J-band monitoring program for photometric variability on ~ 50 T-dwarfs. Our goal is to achieve a continuous time series of high-precision differential J-band photometry for each target over a large fraction of a rotational period. This survey will be conducted over the coming year, using the Wide-field InfraRed Camera (WIRC) on the du Pont 2.5-m telescope at Las Campanas Observatory, with observations commencing in August 2009.

1. THE ROLE OF DUST IN BROWN DWARF ATMOSPHERES:

The brown dwarf (BD) spectral sequence (L0→T9 SpTs) is a cooling sequence, representing the evolution of a BD's spectral energy distribution over time:

1. Below temperatures ~ 2200 K refractory elements (e.g., Mg, Fe, Si, Al, Ca, Ti, V) condense into grains, causing the atmospheres of early-to-mid L dwarfs ($2200 \text{ K} > T_{\text{eff}} > 1700 \text{ K}$) to be shrouded in dust.
2. With further cooling and grain growth, dust grains are no longer supported in the upper photosphere and settle into a layer near the cloud base. The extent of the dust layer represents a fine balance between upward mixing and gravitational settling.^[1]
3. For mid-to-late T dwarfs ($T_{\text{eff}} \sim 1000$ K) the dust cloud layer lies completely below the photosphere, and no longer contributes to the opacity, leading to the re-emergence of a clear, dust-free atmosphere.
4. Dusty L dwarfs typically have very red NIR colors ($J-K \sim 1-2$), while the latest T dwarfs with clear atmospheres have very blue ($J-K < 0$) NIR colors.^[2]

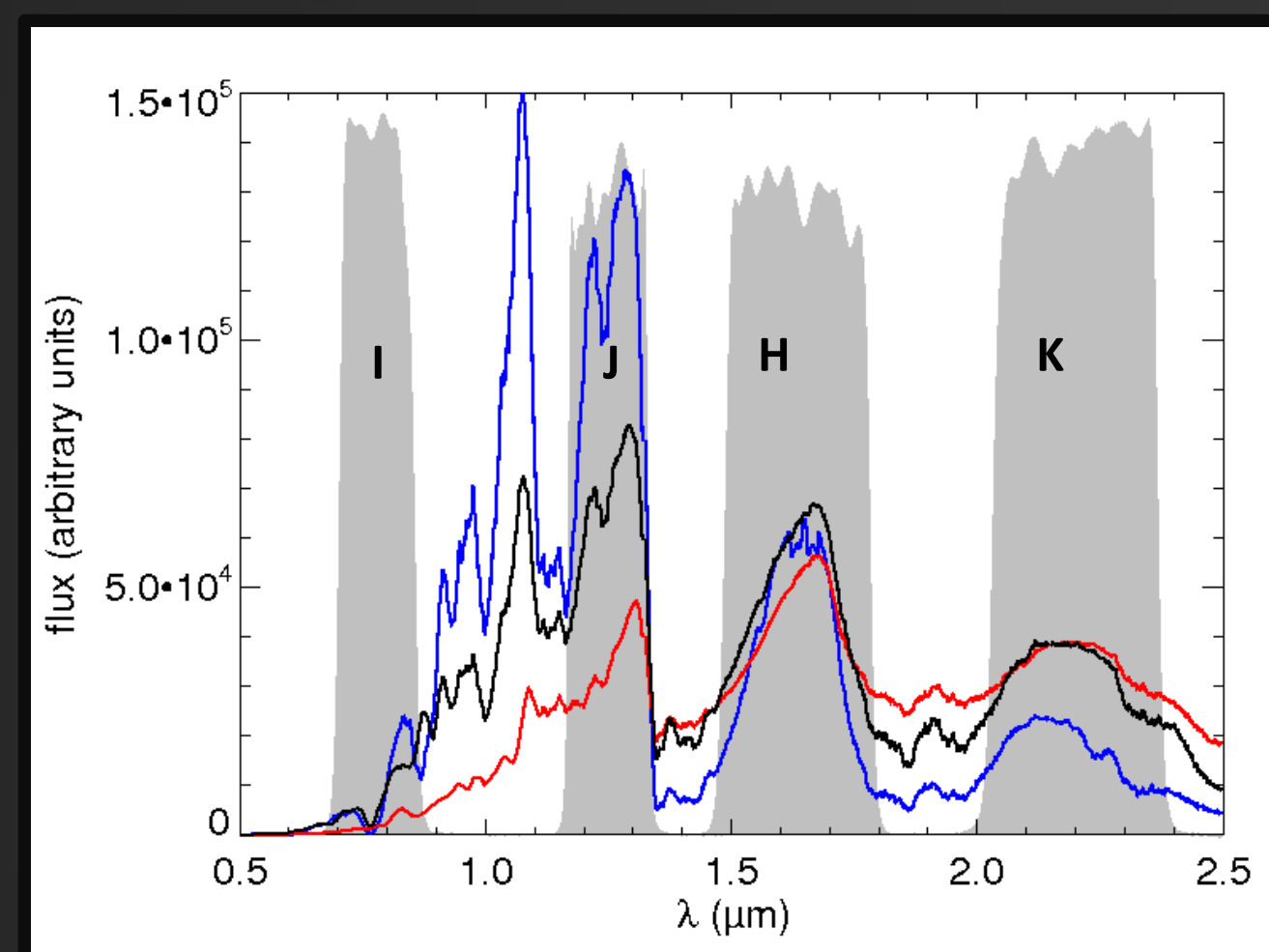


Figure 1: The role of dust in BD atmospheres. PHOENIX model spectra (Allard et al. 2003) for a $T_{\text{eff}}=1700$ K BD with a (i) fully dusty atmosphere (red line), (ii) clear atmosphere (blue line), and (iii) in the case of partial dust settling (black line).

2. CLOUD FRAGMENTATION AT THE L/T TRANSITION?

As clouds begin to clear at the boundary between L and T spectral types—to so-called *L/T transition*—there is a very rapid evolution from very red ($J-K=2$) to very blue ($J-K=0$) near infrared colors. This rapid evolution is accompanied by a counter-intuitive brightening in the J-band with decreasing effective temperature (figure 2)^[3,4]. Although dust grain settling provides a natural explanation for cloud clearing (see part 1), 1D models assuming a single set of parameters (T_{eff} , dust properties) over the entire BD surface are unable to reproduce the rapidity of the L/T transition, nor the strong observed J-band brightening.

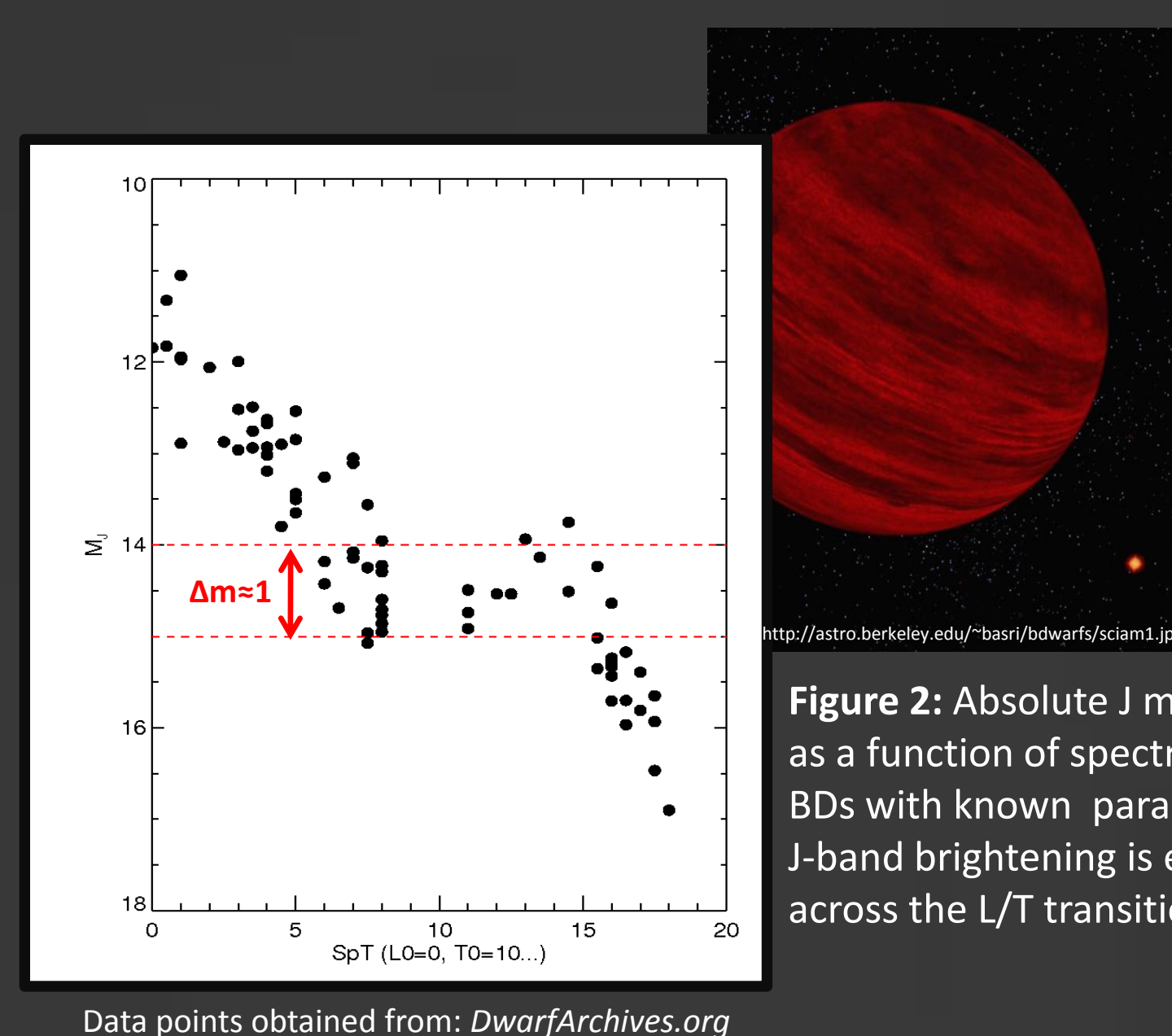


Figure 2: Absolute J magnitude as a function of spectral type for BDs with known parallaxes.^[3,4] A J-band brightening is evident across the L/T transition.

A possible explanation for these phenomena is that the atmospheres of L/T transition objects are inhomogeneous; composed of both dusty and clear regions^[5], similar to the band-like structure and/or spots seen on Jupiter. This scenario explains both the rapid decrease in dust cloud opacity and the temporary resurgence in J-band luminosity, as flux from deeper warmer layers is allowed to escape. This hypothesis has testable consequences: patchy cloud coverage on L/T transition BDs will give rise to rotationally modulated variability.

3. PHYSICAL CONSTRAINTS FOR CLOUD MODELS FROM VARIABILITY STUDIES:

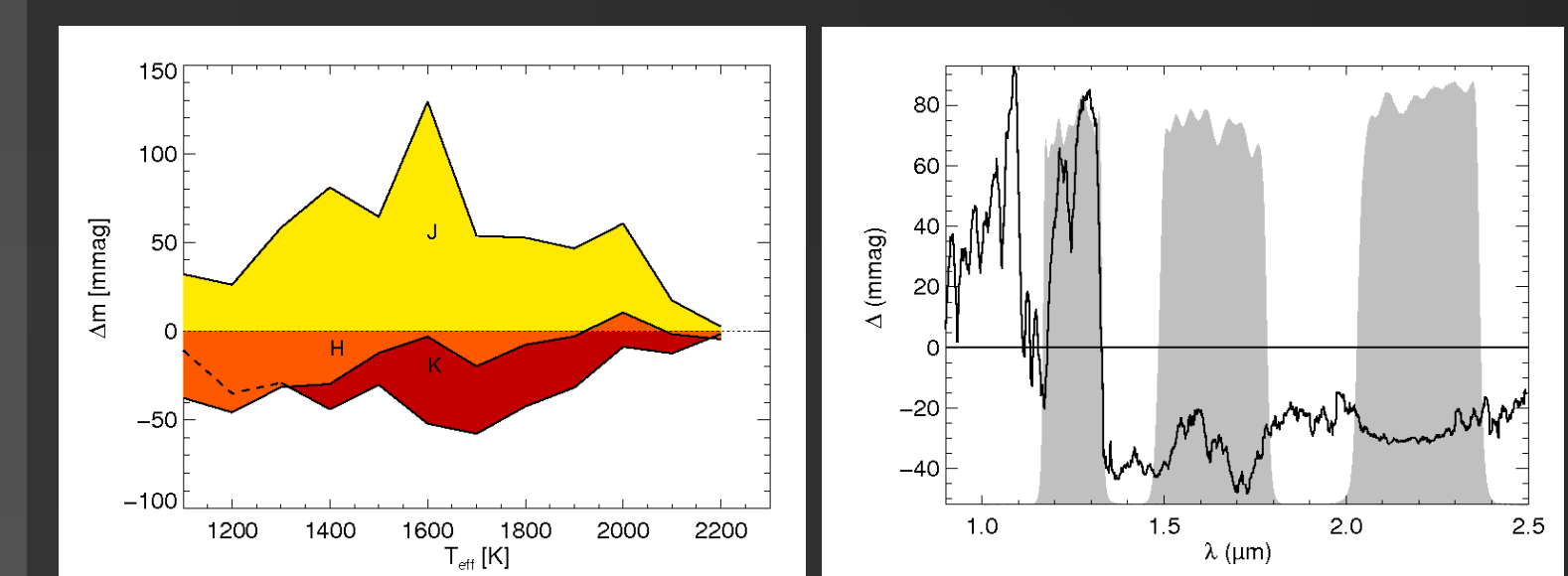


Figure 3: variability for dust-free holes in a dusty atmosphere, with $\Delta T=0$ K. (i) as a function of T_{eff} (left), and (ii) as a function of wavelength (right), $T_{\text{eff}}=1300$ K

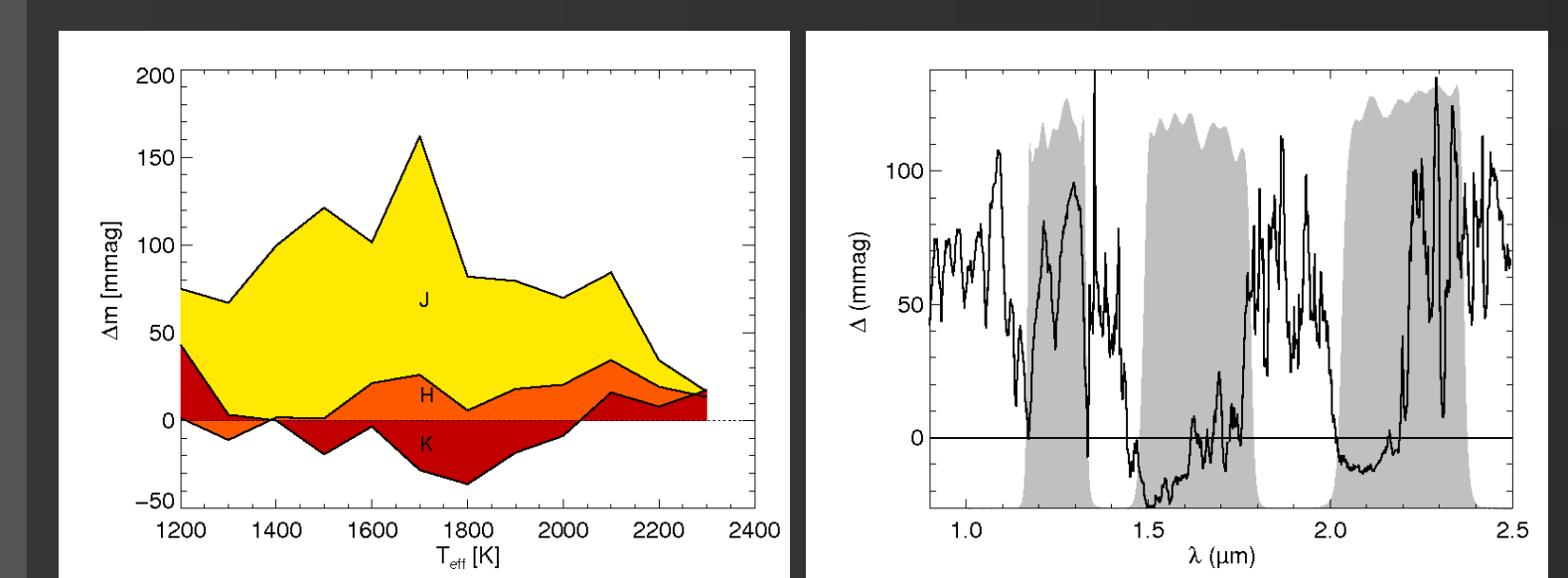


Figure 4: same as above, but for $\Delta T=100$ K

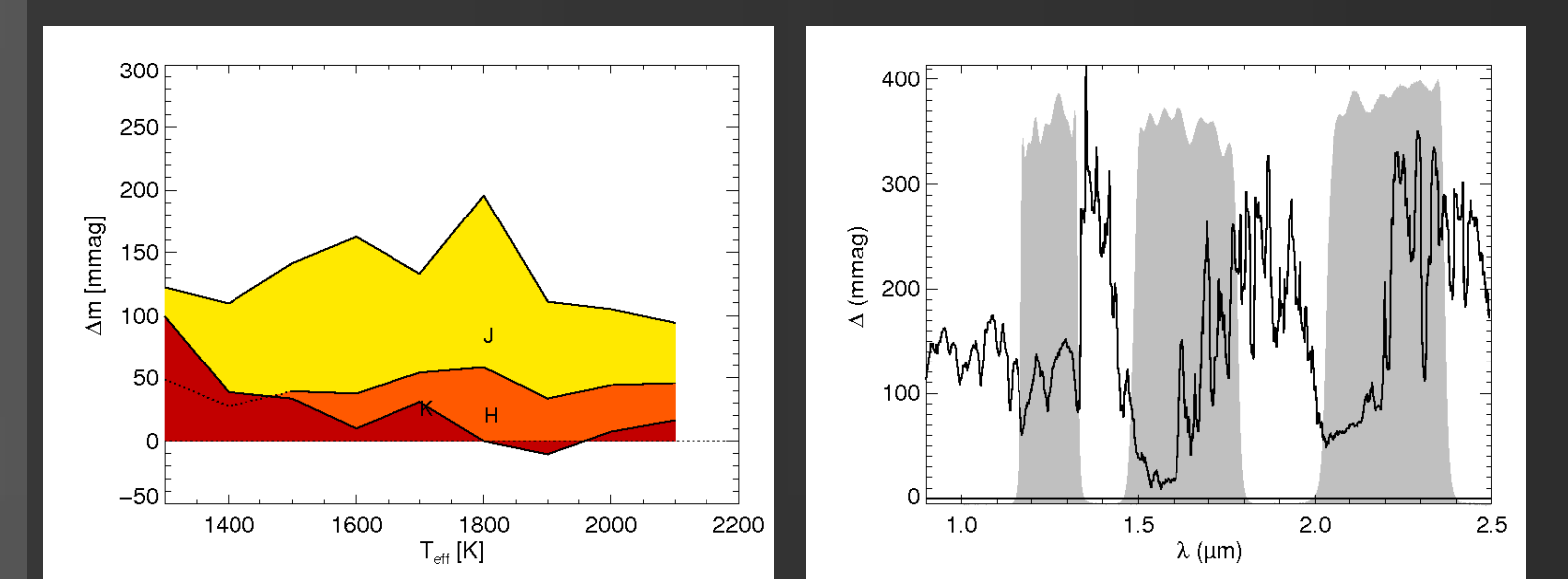


Figure 5: same as above, but for $\Delta T=200$ K

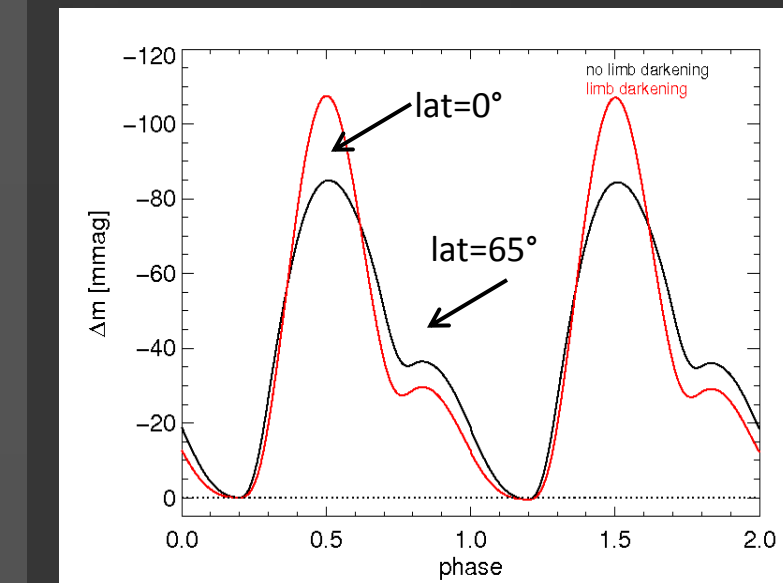


Figure 6: Light curve for two large COND (dust-free) spots (each covering 2.5% of total surface area) at latitudes of 0° and 65° , computed using the spot model of Dorren, 1987^[6]. The affects of spot latitude and limb darkening (red curve) on the amplitude of the observed variability are demonstrated.

Predictions for variability due to inhomogeneous cloud coverage using PHOENIX SETTL (dust cloud settling model) and COND (clear, zero dust opacity) model atmospheres.^[1] Predictions are based on COND holes in SETTL atmospheres, covering a 10% fractional area over the visible disk.

From top to bottom on the left:
(i) $\Delta T(\text{COND-SETTL})=0\text{K}$
(ii) $\Delta T(\text{COND-SETTL})=100\text{K}$
(iii) $\Delta T(\text{COND-SETTL})=200\text{K}$

The relative J/K amplitudes are either correlated or anti-correlated, and with differing amplitudes as a function of T_{eff} , and ΔT

IN SEARCH OF WEATHER ON BROWN DWARFS: THE J(HK)-BAND MONITORING PROGRAM

THE SURVEY:

- A NIR monitoring program for weather-induced variability in ~ 50 late L and T dwarfs in the southern hemisphere.
- 48 nights (24 winter/ 24 summer) with the Wide-field InfraRed Camera (WIRC)^[7] on the du Pont 2.5-m telescope
- Specially purchased MKO J filters to minimize second order telluric extinction residuals
- Continuous time-series J-band differential photometry in search of weather-related variability.
 - 24 nights J-band monitoring
 - 24 nights for long-term/multi-band (J,H,K) follow-up

GOALS:

- High precision (< 10 mmag) time series differential J-band photometry for our targets
- Determination of the frequency of variable late L and T-dwarfs: evidence of increased variability at the L/T transition?
- Follow-up of variable targets: constraints on the physical properties of weather patterns: sizes, natures, and temperatures of dusty/clear spots.

OBSERVING STRATEGY:

To achieve a continuous time series of photometry over a large fraction of a rotational period ($\sim 2-12$ hours for BDs), requires continuous monitoring of each target for ~ 4 hours in order to ensure that observations are obtained, in the worst case scenario, over at least a third of a rotational period. However, recent *vsini* measurements for nearby field T-dwarfs suggest that most are rapid rotators, with periods under ~ 5 hours^[8].

Although this timescale means we may miss other interesting phenomena at longer timescales (e.g. the transit of an earth-size planet would be detectable in our dataset), the probability of observing an eclipsing binary or planetary transit is much less than 1% for the entire dataset given even the most optimistic assumptions. Thus, a continuous monitoring strategy allows for the most stable configuration, without incurring a large risk of missing rare longer-term phenomena.

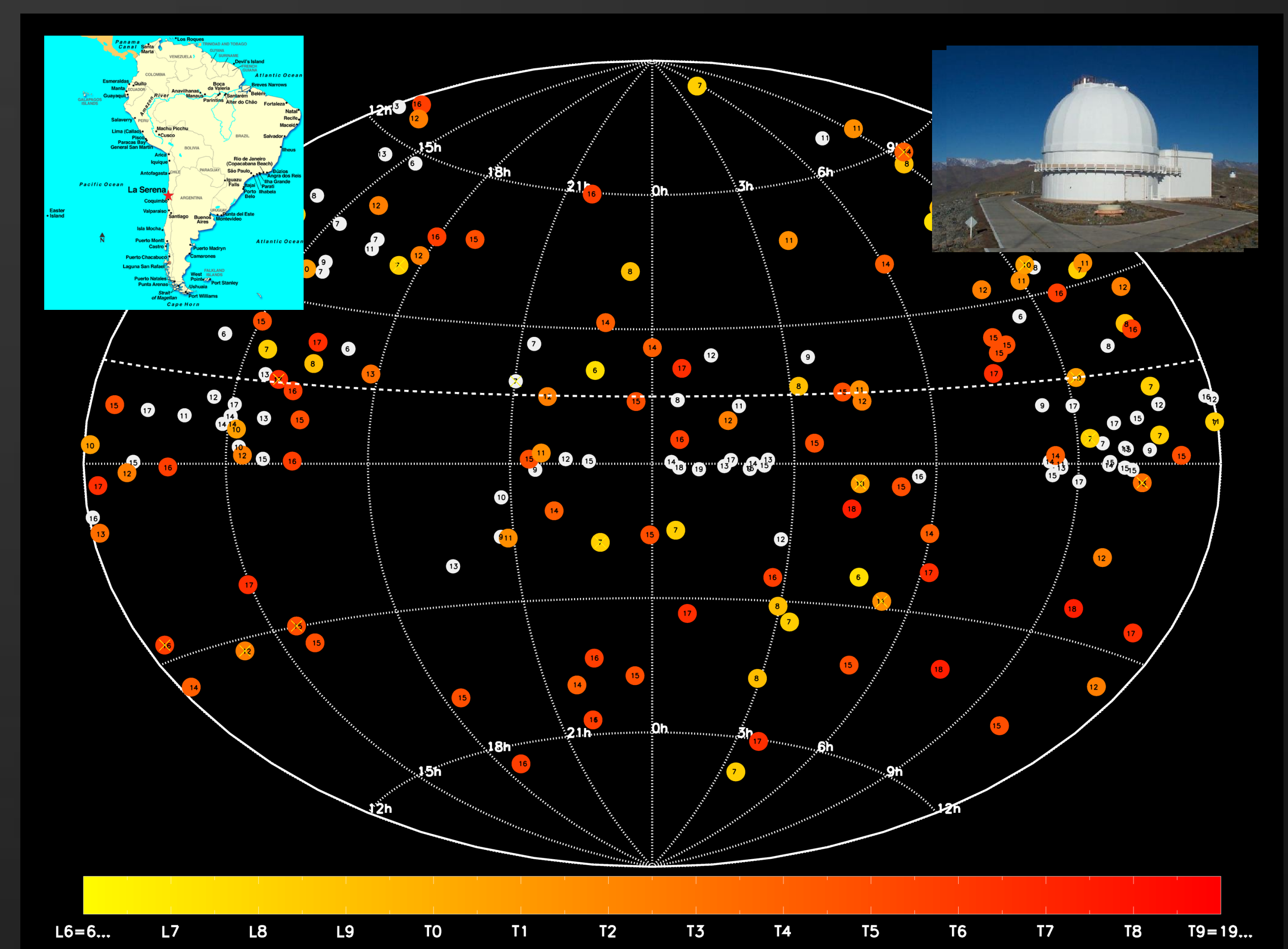


Figure 7: Target selection for our monitoring program. Late L and T dwarfs (L7-T9) bright enough to observe with WIRC from the du Pont 2.5-m telescope ($J < 16.5$) are indicated by colored circles. Fainter late-type BDs are indicated by grey circles. The limiting declination ($+10^\circ$) is indicated by a dashed white line.

REFERENCES:

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