Exoplanets and Low-Mass Objects with DECam

Rachel Street, LCOGT.net

Exoplanets: current state of play

- Microlensing in the IR

Low-mass objects in the solar neighborhood

Exoplanets: Current Understanding

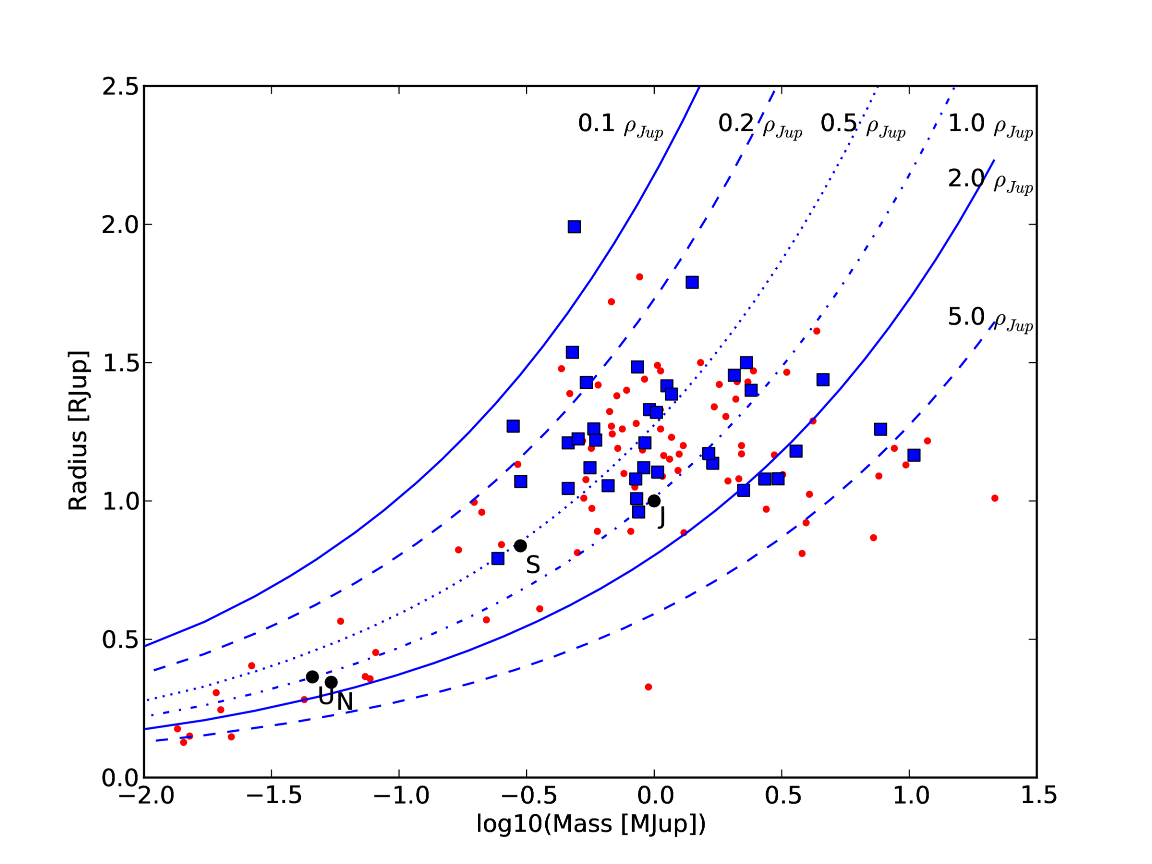
Known planets to date: 573 planets

• 144 transiting - well characterized

• Mostly M_P=~tens M_{Earth} - tens $M_{Jupiter}$
Space missions pushing down to Earth mass

• Long timebase observations to detect planets with orbits in HZ

Some of the many surprises:
• Hot Jupiters
• Bloated radii
• Planetary exospheres
• Migrating planets



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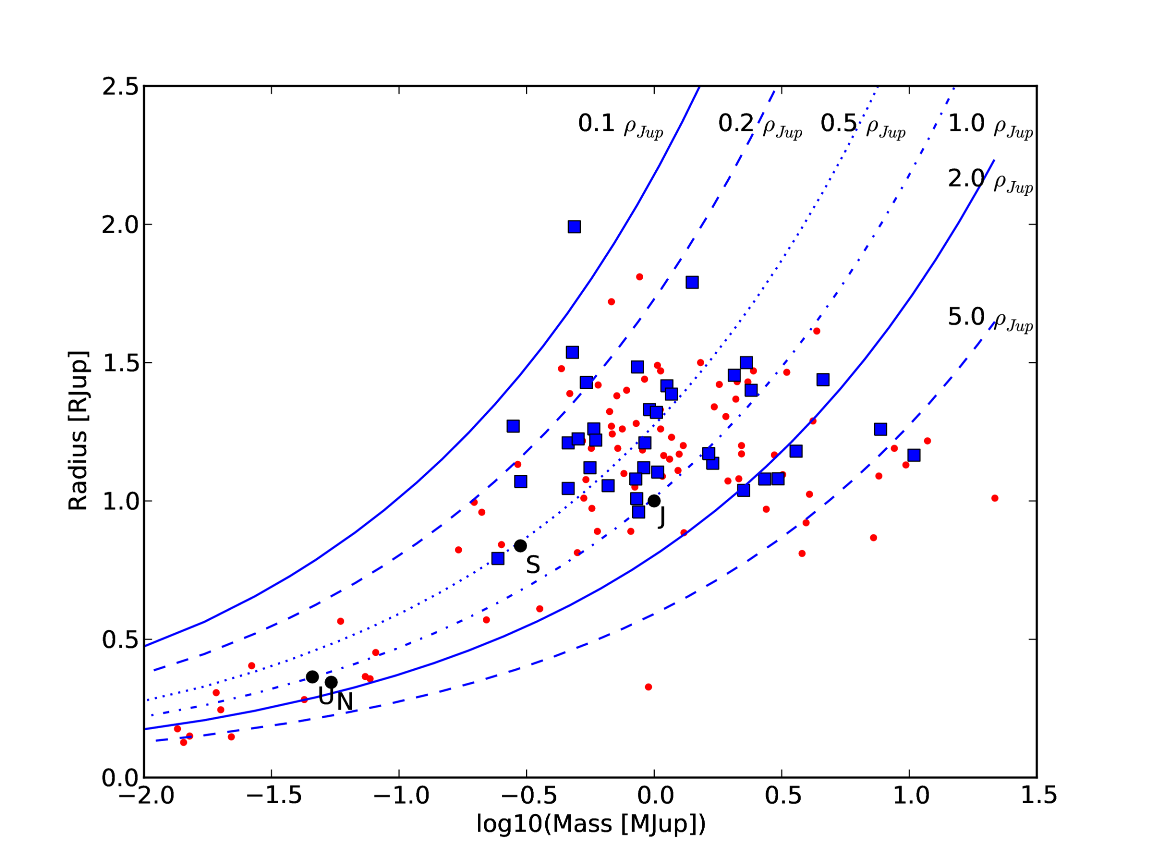


Some outstanding questions:

Frequency and distributions of terrestrial planets

Distribution of planets beyond the snowline

Atmospheric structure and composition

Existence of planets within the habitable zone

Distinctions between planets, brown dwarfs and stars

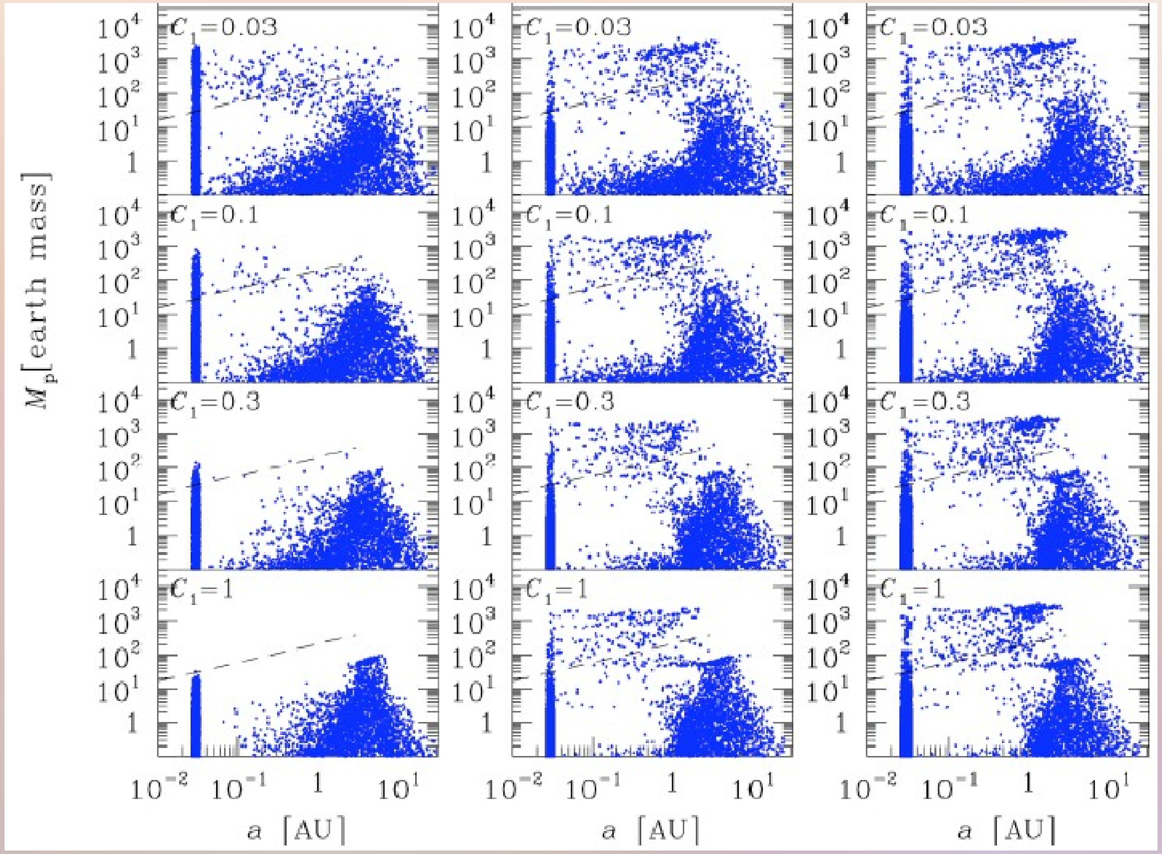
Migration of planets

Exoplanets: Current Understanding

Some outstanding questions:

- Frequency and distributions of terrestrial planets
- Distribution of planets beyond the “snowline”

Models based on core accretion vs. disk instability predict various distributions of planet's mass and semi-major axis.



E.g., from Ida & Lin 2008.

Exoplanets: Current Understanding

Some outstanding questions:

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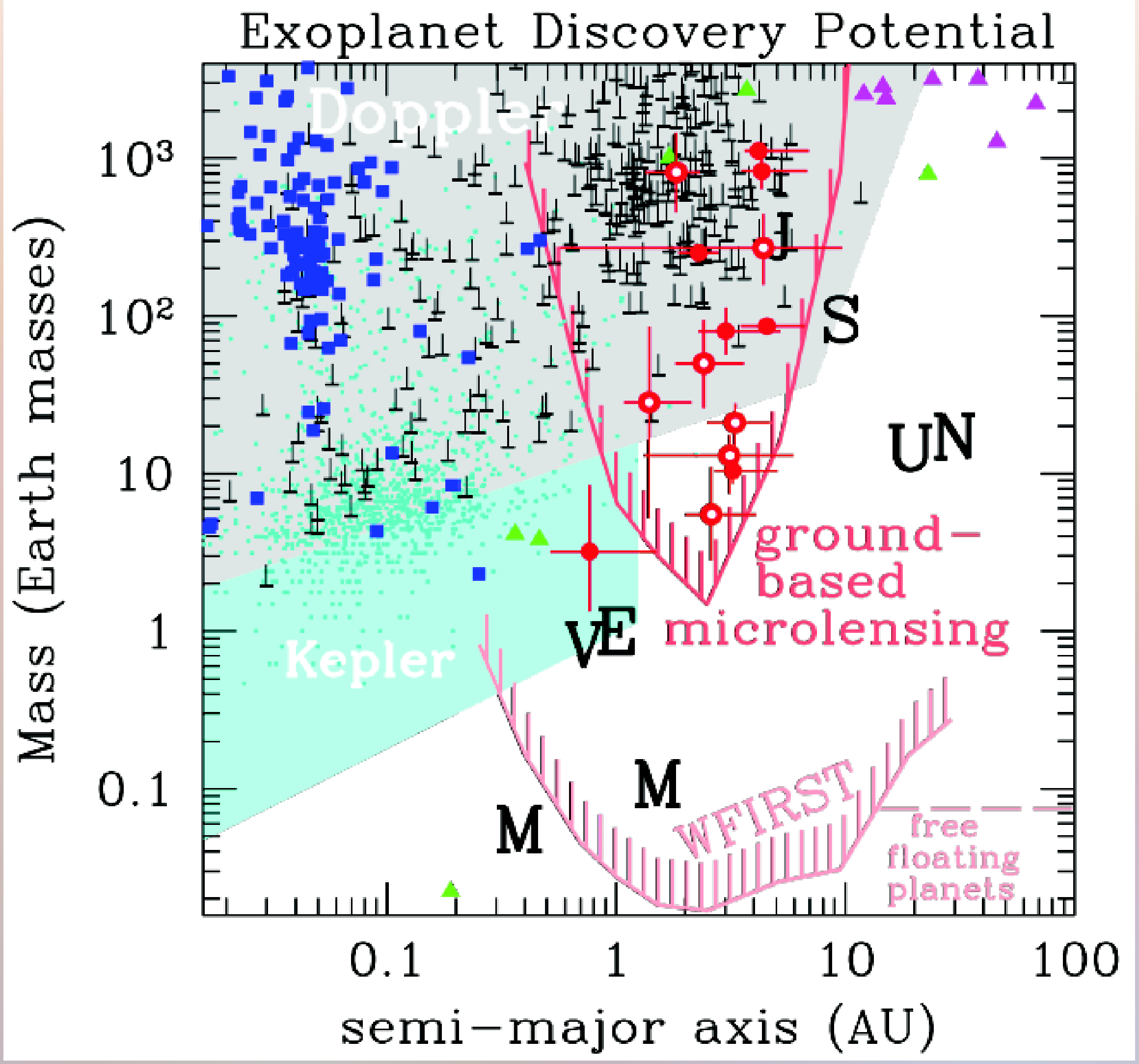
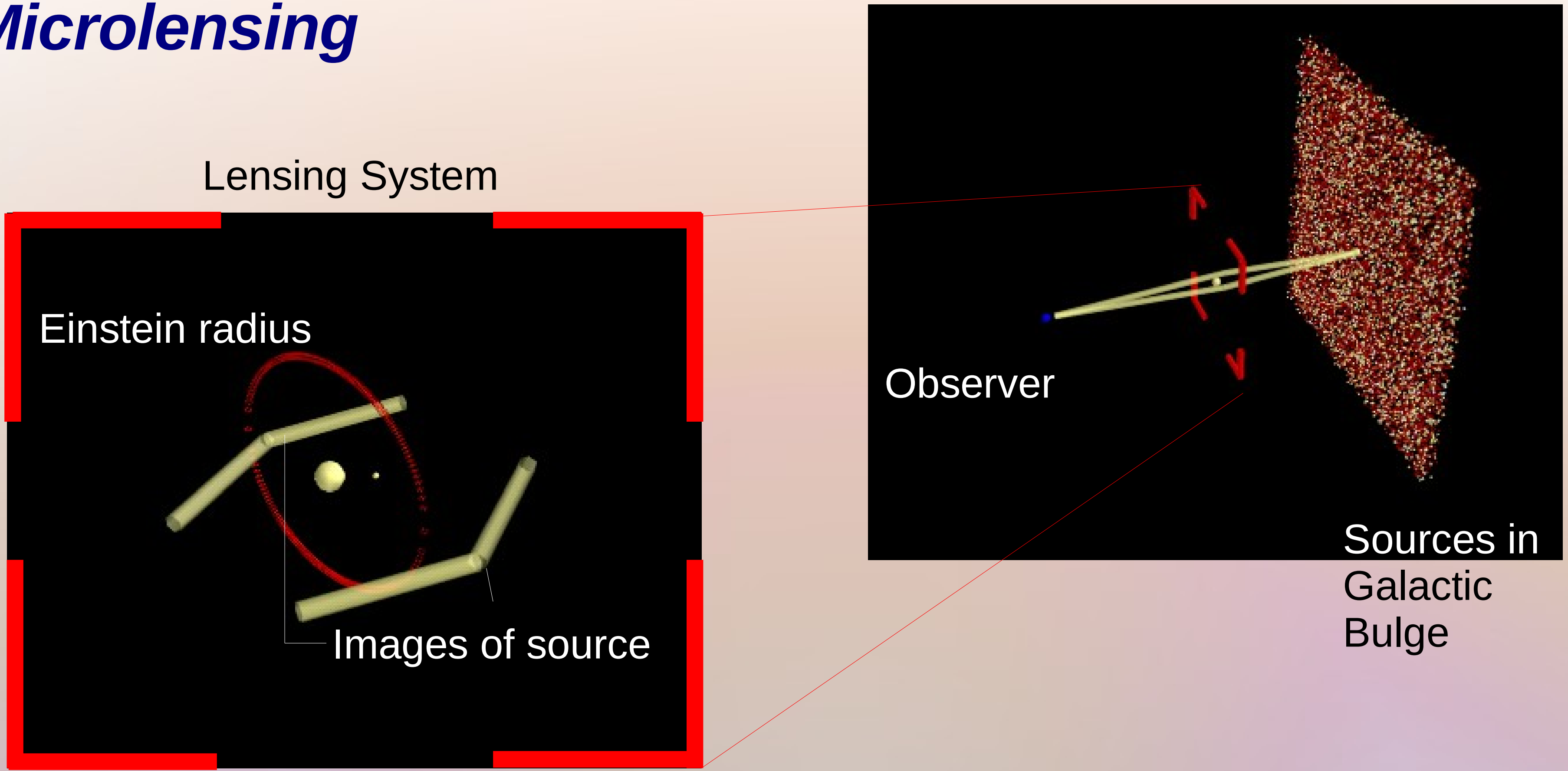
Microlensing offers the most efficient way to explore planets down to Earth masses beyond the snowline.

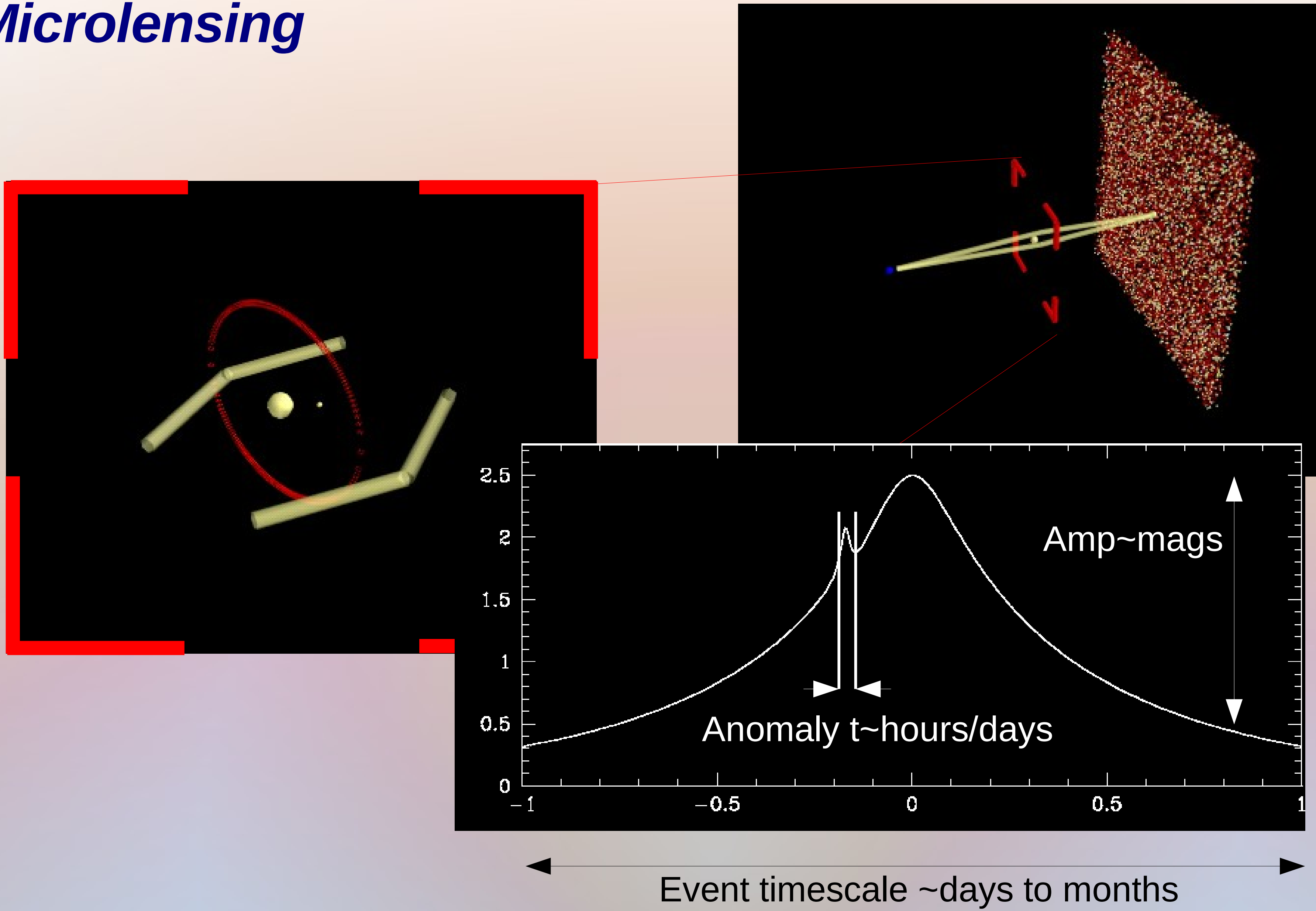


Microlensing



Chance alignment of foreground object (lens) with background source
Lens gravity causes smooth amplification of light from source as relative motion of objects carries them passed one another

Microlensing



Microlensing - present

Microlensing events are discovered by surveys targeting the Galactic Bulge
...1100 events and counting this season!

OGLE

OGLE-IV wide-field camera
on 1.3m Warsaw Telescope, Las Campaňas
Field of view 1.4 sq. deg.
Filters: V, I
Resolution 0.26 arcsec/pixel

MOA

1.8m Mt. John Telescope, New Zealand
Field of view 0.92 x 1.38 deg.
Filters: 400-630nm and 630-1000nm
Resolution 0.81 arcsec/pixel

Microlensing - present

Microlensing events are discovered by surveys: OGLE & MOA

Problem:
Multiple, simultaneous planetary anomalies
Cannot follow them all → selection biases

Need a wide-angle but high-resolution survey and continuous observations

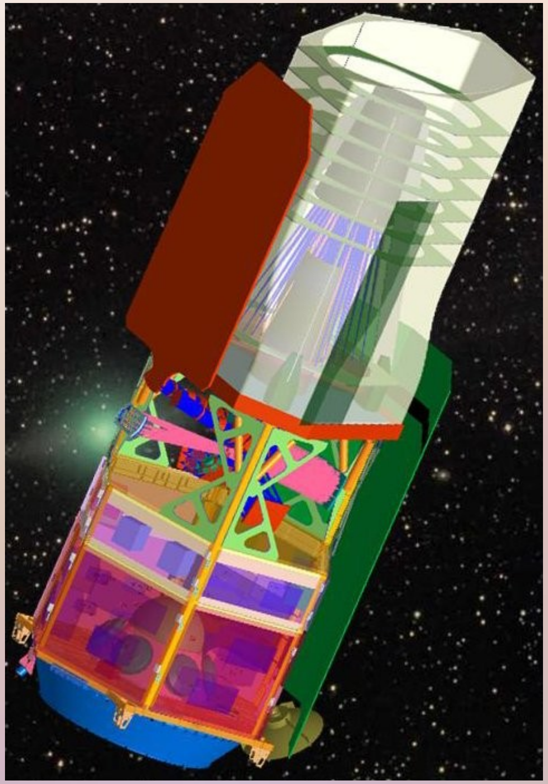
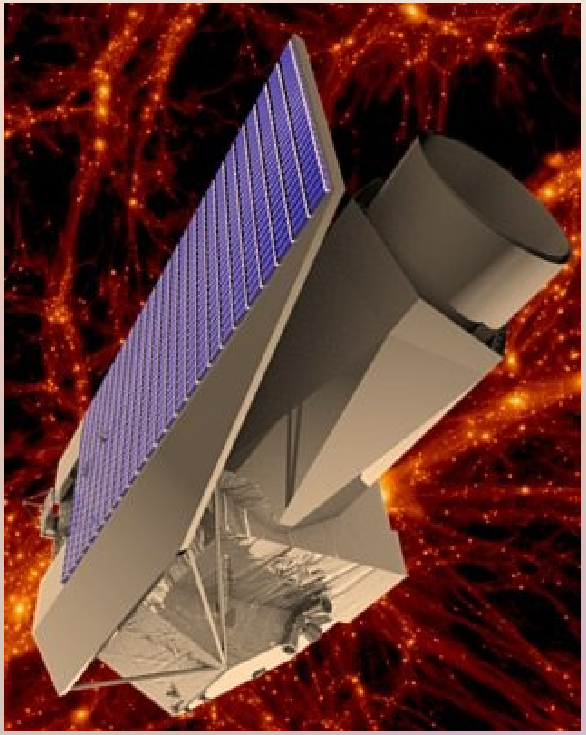
Microlensing - future

Majority of source stars in Galactic Bulge are late-type dwarfs
Ground-based surveys currently at optical wavelengths but would prefer IR...

Galactic Bulge at optical wavelengths...

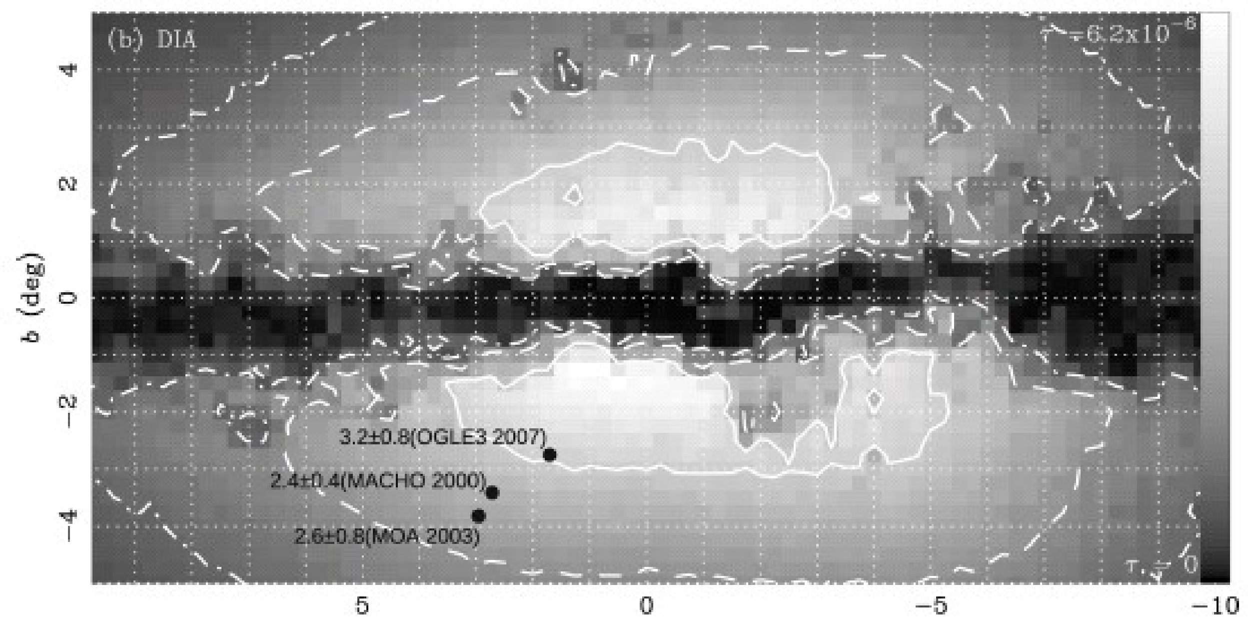
...and in the IR...

Microlensing - future

WFIRST	*Euclid*
	
NASA mission proposal Recommended by Decadal survey ~1.5m telescope Field of view ~2 sq.deg. Pixel scale ≤ 0.3”/pixel Passbands ~1.0-2.0μm	ESA proposed mission 1.2m telescope at L2 Field of view ~0.48 sq.deg Pixel scale ~0.3”/pixel Filters: (R+i+z), Y, J, H

Microlensing - future

Stare strategy for continuous observations
...but where to point?



Microlensing optical depth measures the probability of a microlensing event

Map of optical depth in I-band
Kerins et al. 2009

→ Position dependent

Microlensing - future

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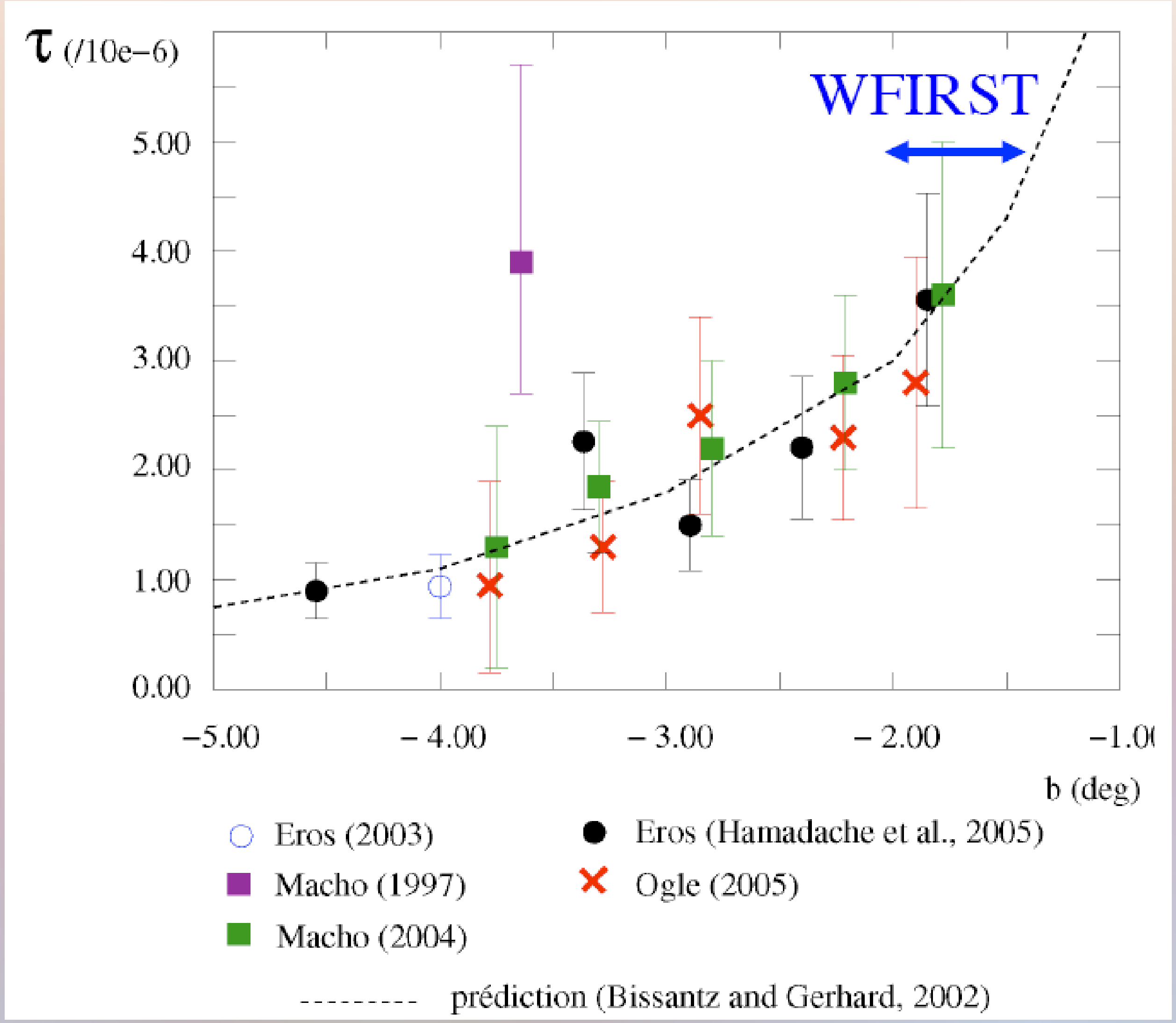


→ Likely underestimated by optical observations

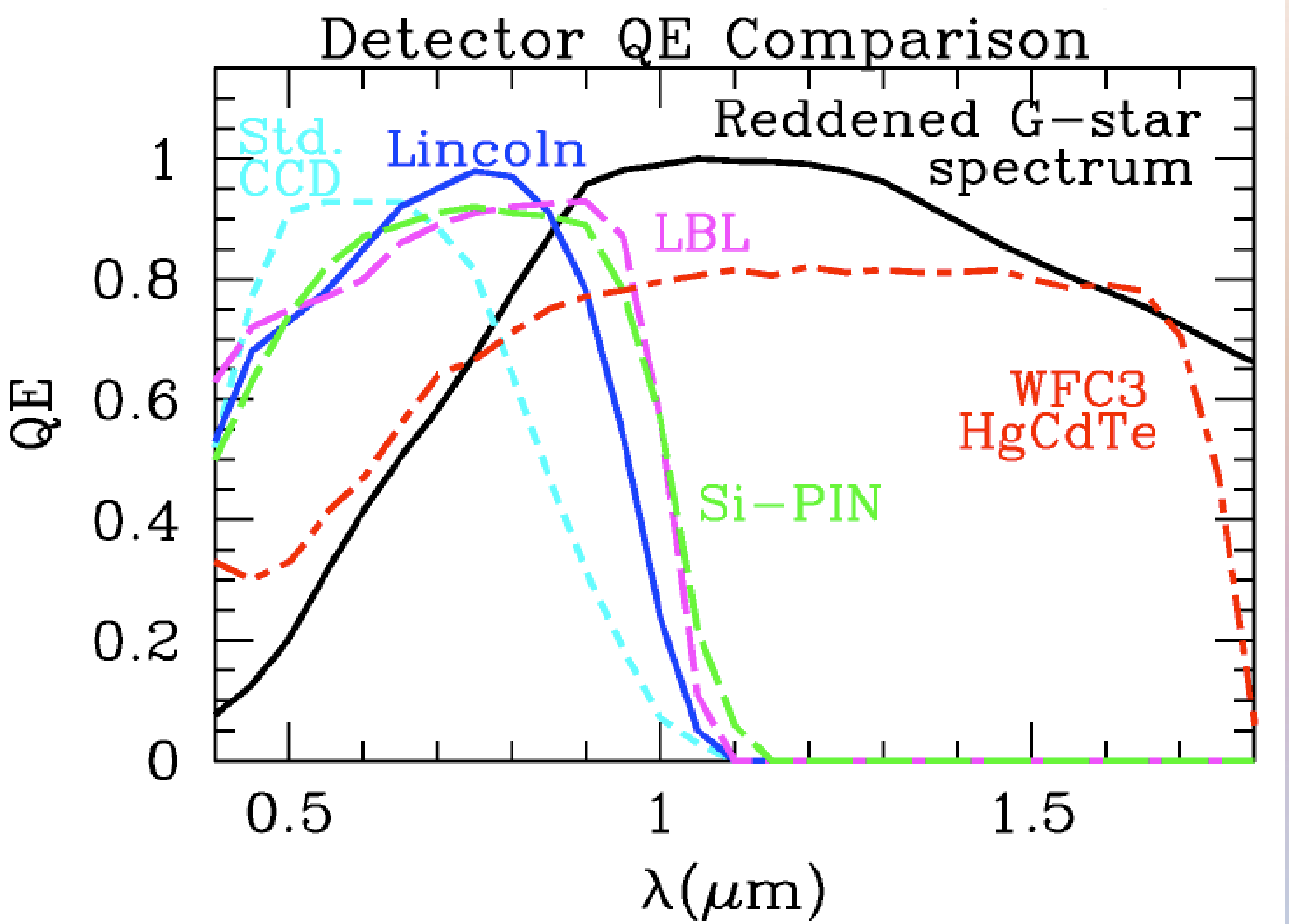
Need for reconnaissance IR microlensing survey

NIR Microlensing Optical Depth Survey with DECam

Technical requirements:

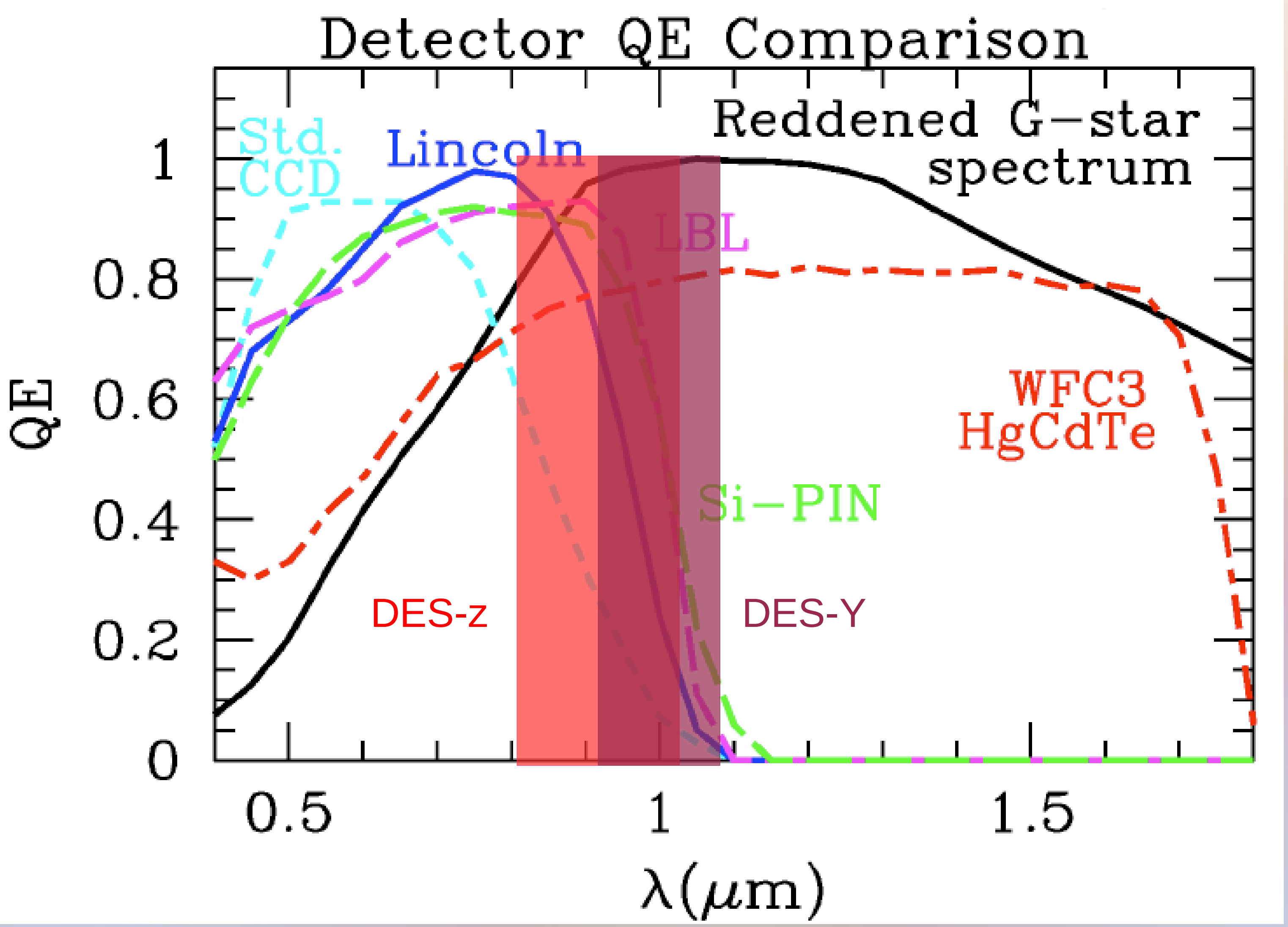
- Pixel scale ≤ 0.3 arcsec/pixel
- NIR sensitivity
- Ultra-wide (multi-degree) field of view
- 2m or larger aperture ground-based telescope

Microlensing - future



Courtesy: David Bennett

Microlensing - future



Courtesy: David Bennett

NIR Microlensing Optical Depth Survey with DECam

Survey requirements:
• Low cadence but regular monitoring - just want the event rate, not to detect planets.
• Staggered exposure times for stars i~16-20 mag: 30s, 60 in z and Y.
→Exposure+readout per pointing ~8.5 mins.

OGLE-IV covers 81.2 sq deg (~50% of Bulge)
≈ 37 DECam pointings
Whole Bulge region ≈ 74 pointings.

• Observe Bulge between March and October,
~8hrs/night ≈ 56 pointings/night

→ *Survey entire Bulge with ~2day cadence*

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- Anticipate ~2000 events per year based on current survey yields

- Additional science:

  Planets: Follow-up of anomalous events via LCOGT (complementary filterset)

  Catalog of variable sources, which need to be excluded from space missions

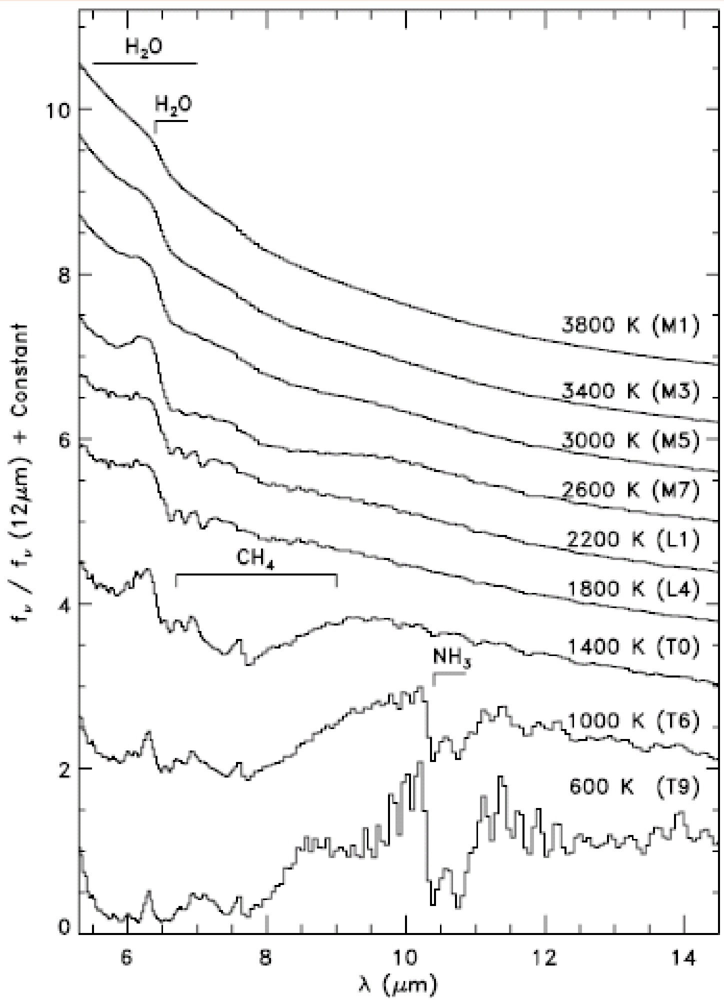
Low-Mass Stellar Objects

Low-mass end of the Main Sequence

- Flux distribution peaks in the IR
  - Abs Y~18 mag, depending on age/Teff
- Spectra heavily dominated by molecular lines
- Predicted to form clouds in some Teff ranges
- Current catalog of L, T dwarfs: 804 [DwarfArchives.org]

Mostly from cluster surveys of young (hotter) objects, older field objects cooler but fainter, harder to find

Need to survey solar neighborhood

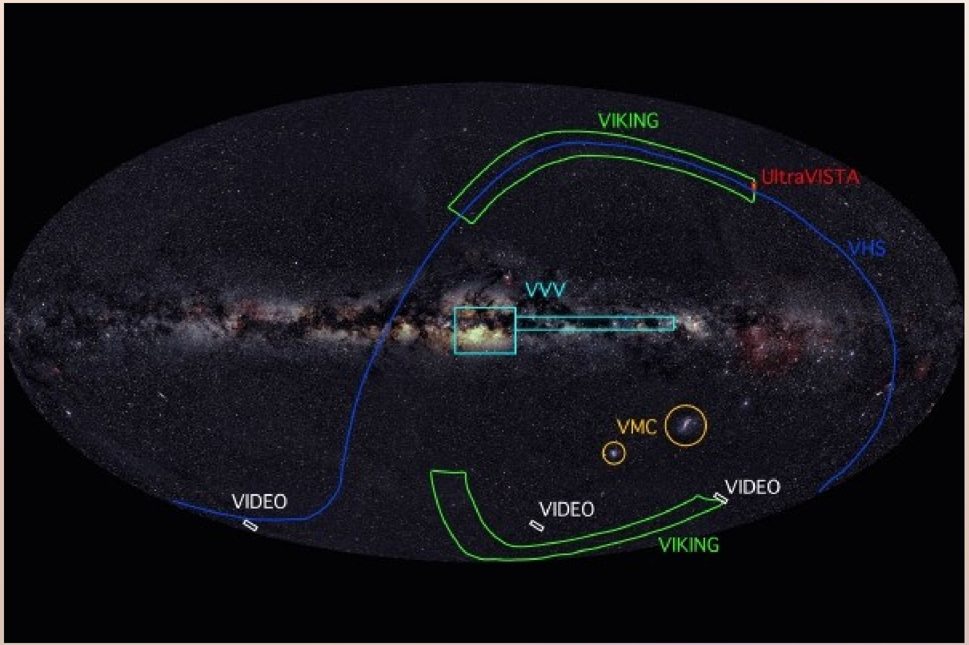


Model spectral of M1 - T9 dwarfs from Cushing et al 2009

Low-Mass Stellar Objects

• Existing surveys

2MASS: whole sky
    J limit ~15.8 mag resolution 2"/pix
SDSS: northern sky
    SDSS-i limit ~22.0 mag
WISE 0.4m telescope
    Whole sky at (3.4,4.6,12 &22μm)
    Finding local (<75ly) brown dwarfs
    ..but resolution 6.1-12"/pixel
Palomar Transient Factory
    1.2m telescope
    northern sky R~20 mag
Pan-Starrs northern sky
    Down to r~21-22mag, pixel scale 0.26"/pix
UKIDSS Large Area Survey Y,J,H,K down to K~18.4, 4000 sq. deg. northern sky



VISTA 4m IR telescope multiple surveys, smaller sky coverage

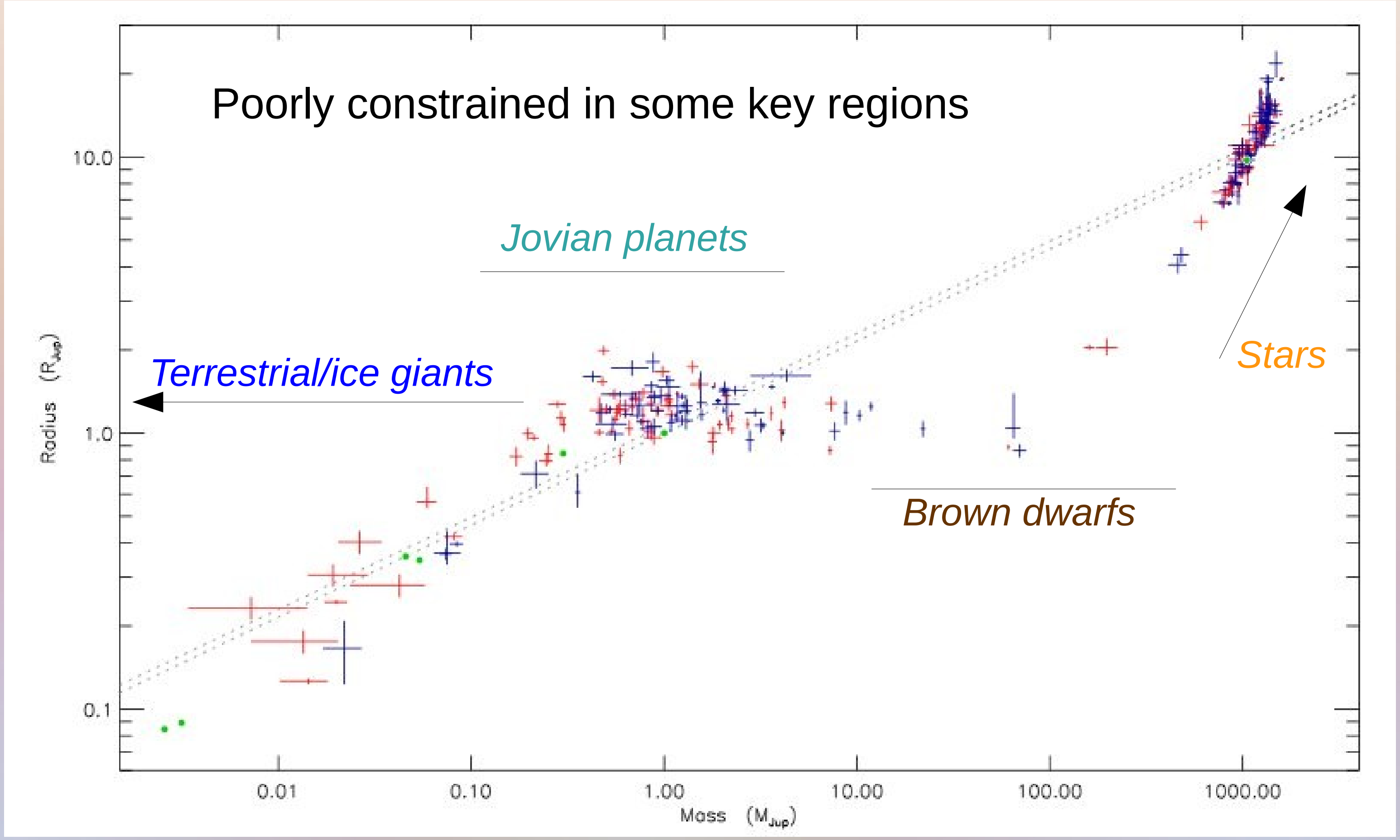
SkyMapper 1.35m whole southern sky down to z~20mag resolution~1.5" - underway

• Cadence generally not good enough to detect binaries

Low-Mass Stellar Objects

Mass, radius, luminosity relations at lowest end of Main Sequence

→ More complex functions of age/Teff and metallicity



Most accurate way to measure this is to identify a significant sample of eclipsing binaries

From Southworth, 2011, arXiv: 1107.1235

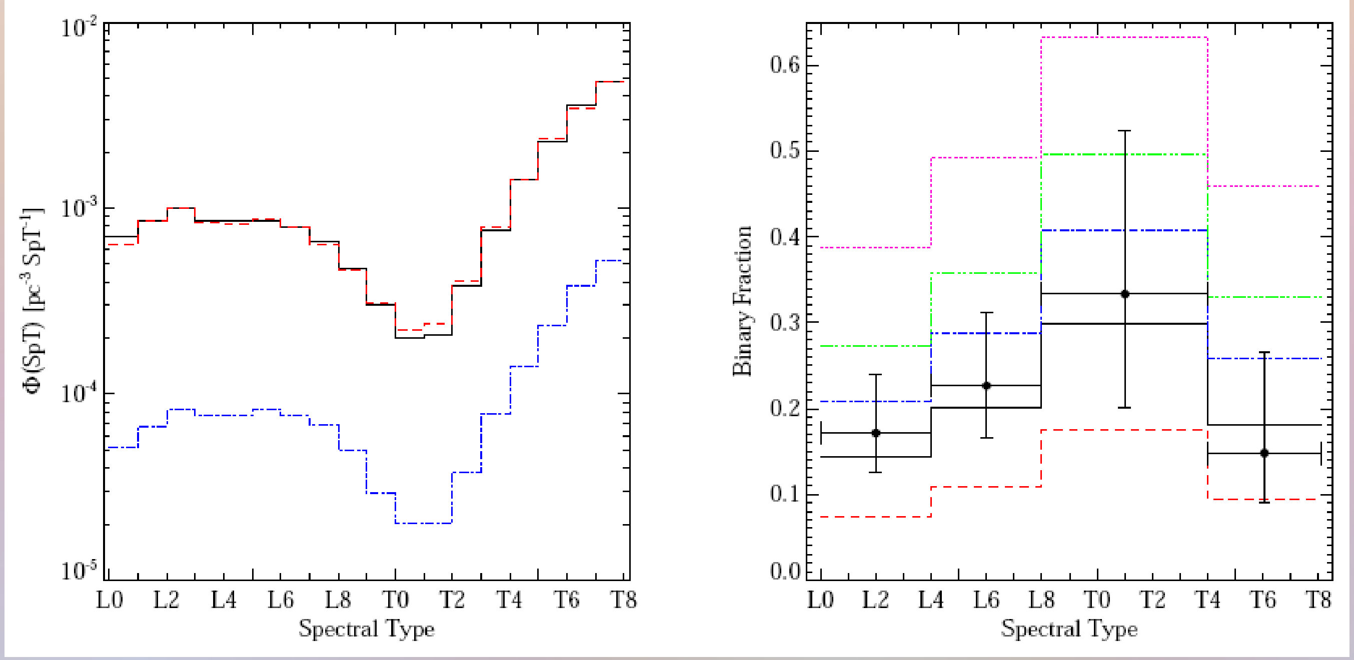
Low-Mass Stellar Objects

- Binary fraction/exoplanets?

Some late-M stars with known exoplanets:

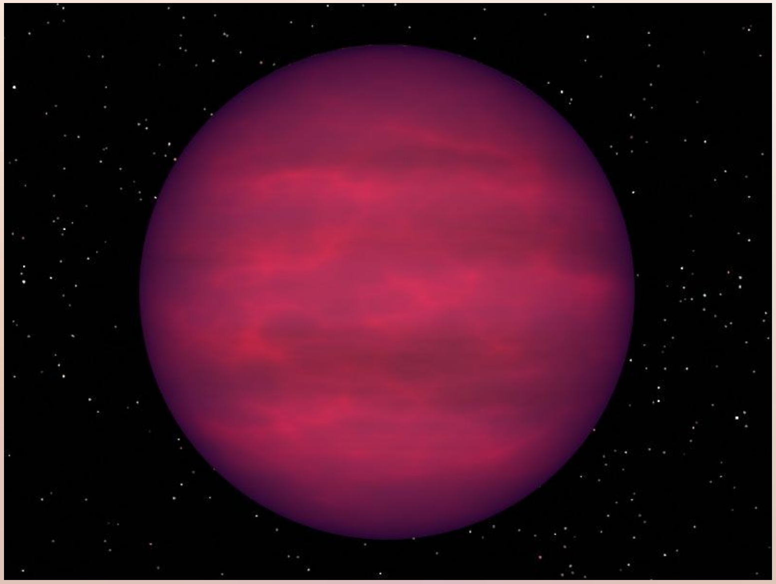
- Both close in, e.g. GJ 1214 *[Charbonneau et al. (2009), Nature, 462, 891]*
  (SuperEarth orbiting an M-type host star in 1.6d orbit)

- and at wide separations, e.g. 2M1207 *[Chauvin et al. (2004), A&A, 425, L29]*
  (4MJ gas giant planet with projected separation 46 AU)



From Burgasser 2008 - simulation predicting space density (left) and binary fraction (right) of brown dwarfs.

Low-Mass Stellar Objects



NASA artist's impression

- Do they have weather?

Marley et al 2010 predicts that clouds should form as BD cool over time, possibly causing a brightening in J band flux as cloud opacity is lost with lower Teff.

Artigau et al. 2009 found 50mmag variability on brown dwarf
→would expect flux variability on rotation period as clouds rotate in and out of view

Young BD may exhibit pulsations during periods of deuterium burning (Cody, Palla & Baraffe 2005)

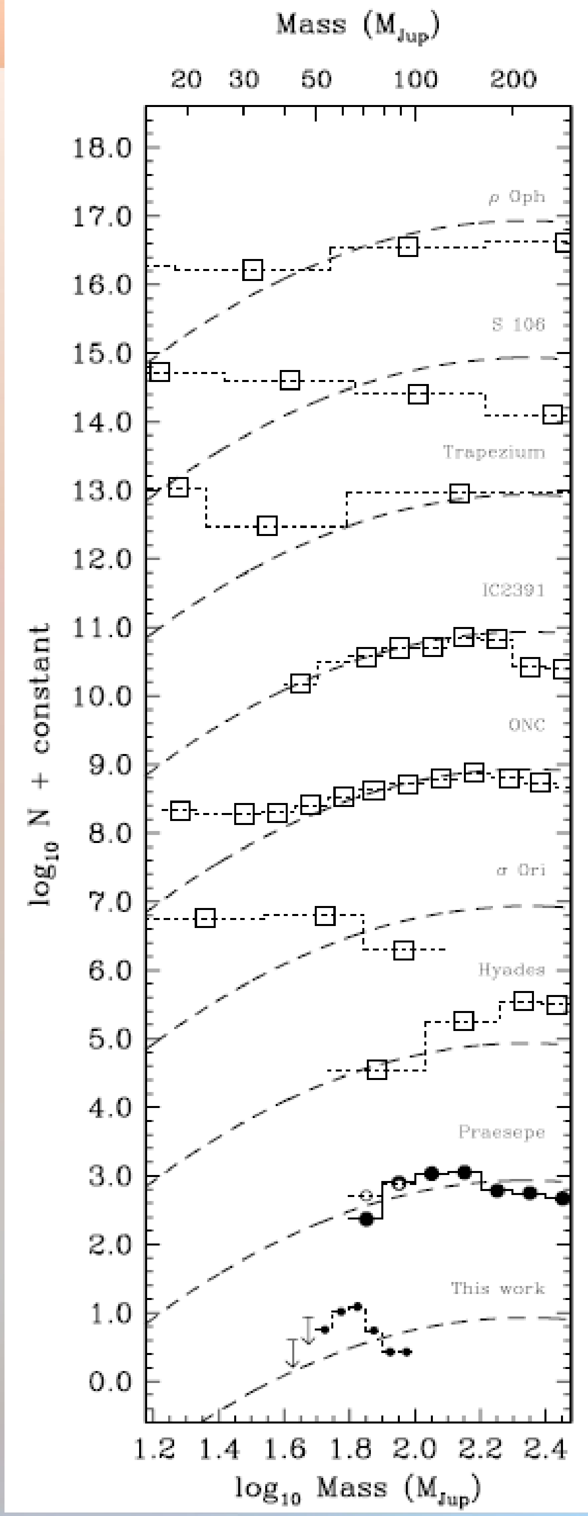
Cody & Hillenbrand (2011) found 1 out of 14 sig Orionis cluster members to be variable up to 0.1mag amplitude, which may be due to dust obscuration

To date, there have been a few surveys, with inconclusive results

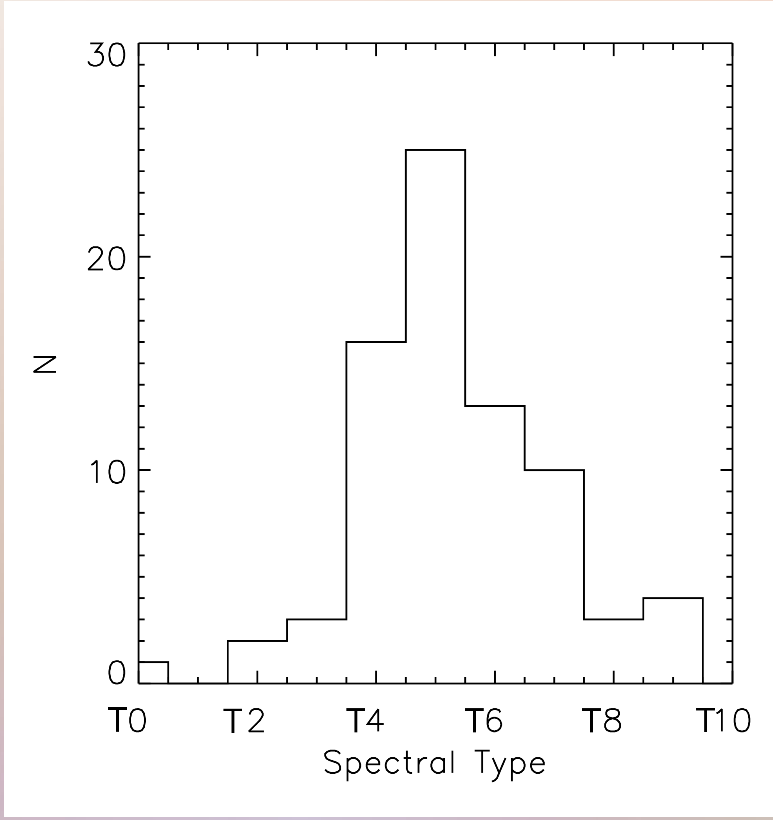
Low-Mass Stellar Objects

From Wang
et al 2011

BD histograms by mass from a number of open clusters summarizing their distributions at a range of young ages/temperatures



Low-Mass Stellar Objects



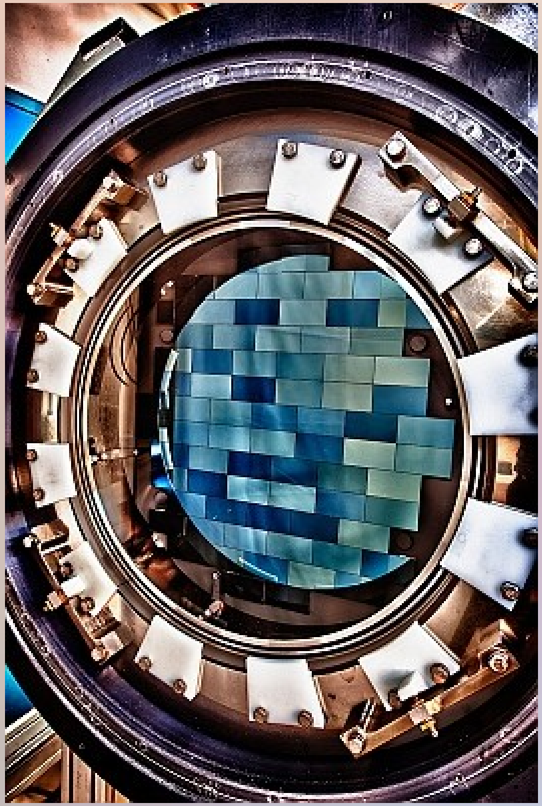
From UKIDSS Large Area Survey
(talk by Burningham, 2009)

Field IMF different from clusters?
Missing T dwarf population?

Low-Mass Stellar Objects with DECam

- DES will take a census of solar neighborhood low-mass population
- Cadence is generally not high enough to find eclipsing objects
- SN field survey may be high enough to identify them

  Suggest targeting restricted area at higher cadence?



Multi-color, high-res data will help to eliminate blends, identify very low mass companions even in the Galactic Plane

Complement current northern surveys