Prospecting for Transits in 2MASS and Other Surveys

Peter Plavchan
(IPAC/JPL)

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Collaborators

- UCLA
  - Mike Jura, Sarah Gallagher, Liz Jensen, Patricia Wells
- IPAC/ Caltech
  - Roc Cutri, Davy Kirkpatrick, David Ciardi, Mike Werner, Alan Gee

Overview

- Practical Considerations
- Science Motivation
- 2MASS
- Other Surveys

Stereotypes

Transit Search

- Exquisite photometric precision
- N_{obs}>>1
- Large spatial coverage / sample size
- Single, visible wavelength
  - Contaminants
- Solar-type stars

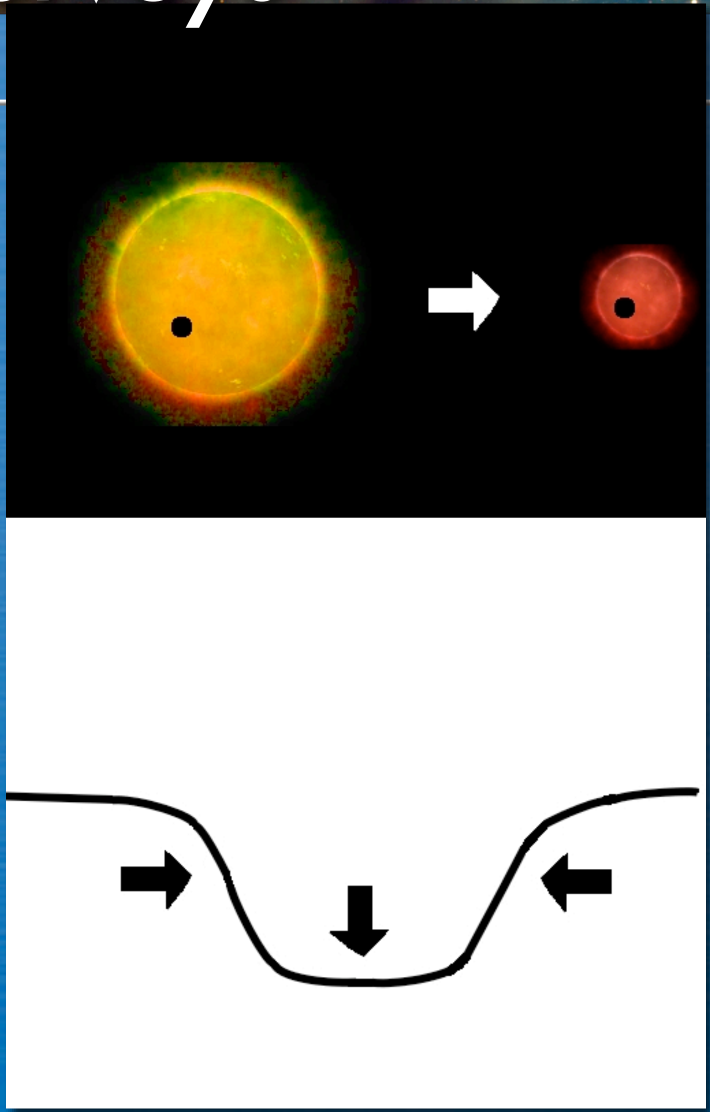
Generic Sky Survey

- Photometric precision ~1-2%
- N_{obs}=1
- Large spatial coverage / sample size

Are general sky surveys and transit searches mutually exclusive?

Finding Transits in Surveys

- Photometric precision ~1-2%?
  - M dwarfs
- Any wavelength?
  - Longer wavelengths preferred
    - (B-K=5 for M0)
- Single epoch?
  - Calibration observations or overlapping regions
    - Regular cadence
    - N_{obs}>>1
- Still need:
  - Spatial coverage / sample size
  - Multi-band / followup



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Why Look for Planets Transiting M Dwarfs?

Primary:

- M dwarfs are numerous
- Wide range of stellar mass and radii
- Few known M dwarfs with planets
  - GJ 876, GJ 849, GJ 674, GJ 581, HD 41004B b, & GJ 317 RV; GJ 436 transiting; two microlensing
- Jovian companion frequency poorly constrained
  - Endl et al. 2006
- Test planet formation theories, Jovian migration mechanisms

Why Look for Planets Transiting M Dwarfs?

Secondary:

- Few known detached M dwarf eclipsing binaries (~10)
  - Mass-radius relation poorly constrained (Lopez-Morales et al. 2007)
- Variability of sky at near- and mid-IR largely an unknown
  - YSOs, CVs, AGN
  - Plavchan et al. (2007), Carpenter et al. (2001,2002), Barsony et al. (1997)

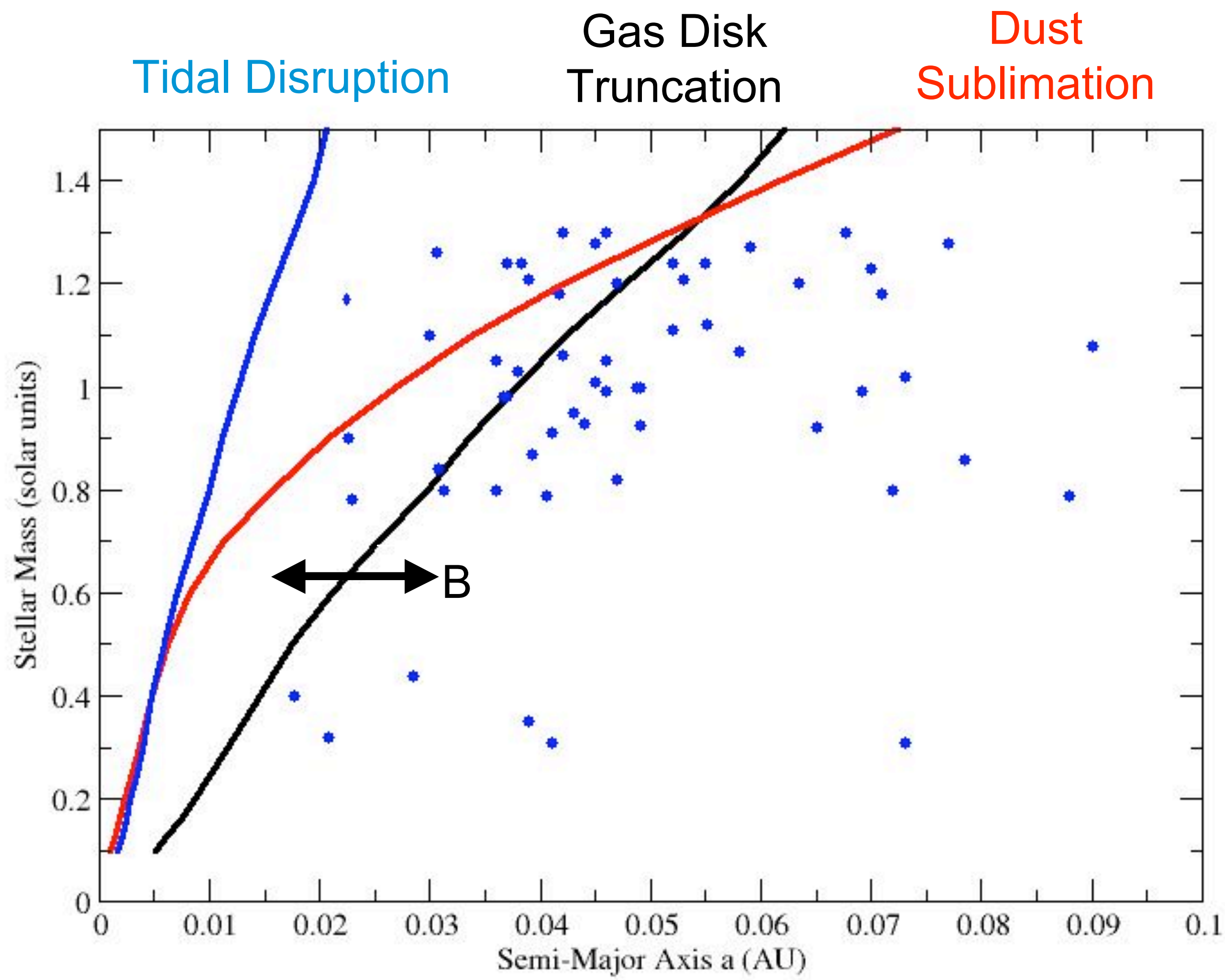
Testing Planet Formation Theory with M Dwarfs

Frequency of M dwarfs with planets and mass distribution of planets relative to G stars

==> formation mechanism (GI vs. core accretion)

How can M dwarfs can test migration halting mechanism?

- For M dwarfs, dust sublimation radius, $R_{subl} < R_{tidal}$!
- Gas disk truncation from magnetospheric accretion scales as the stellar radius (at fixed B)


Tidal Disruption
Gas Disk Truncation
Dust Sublimation
B
Stellar Mass (solar units)
Semi-Major Axis a (AU)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1

The Transit Search, Sky Survey Hybrid Summary

- Stick to M dwarfs
  - Precision of ~1% sufficient
  - Interesting extra-solar planet science
  - The "false-positives" (eclipsing systems) still useful
- Use calibration observations or overlapping regions
  - $N_{obs}>>1$
- Longer wavelengths
  - Near-IR
- Still need:
  - Spatial coverage / sample size
  - Multi-band / follow-up

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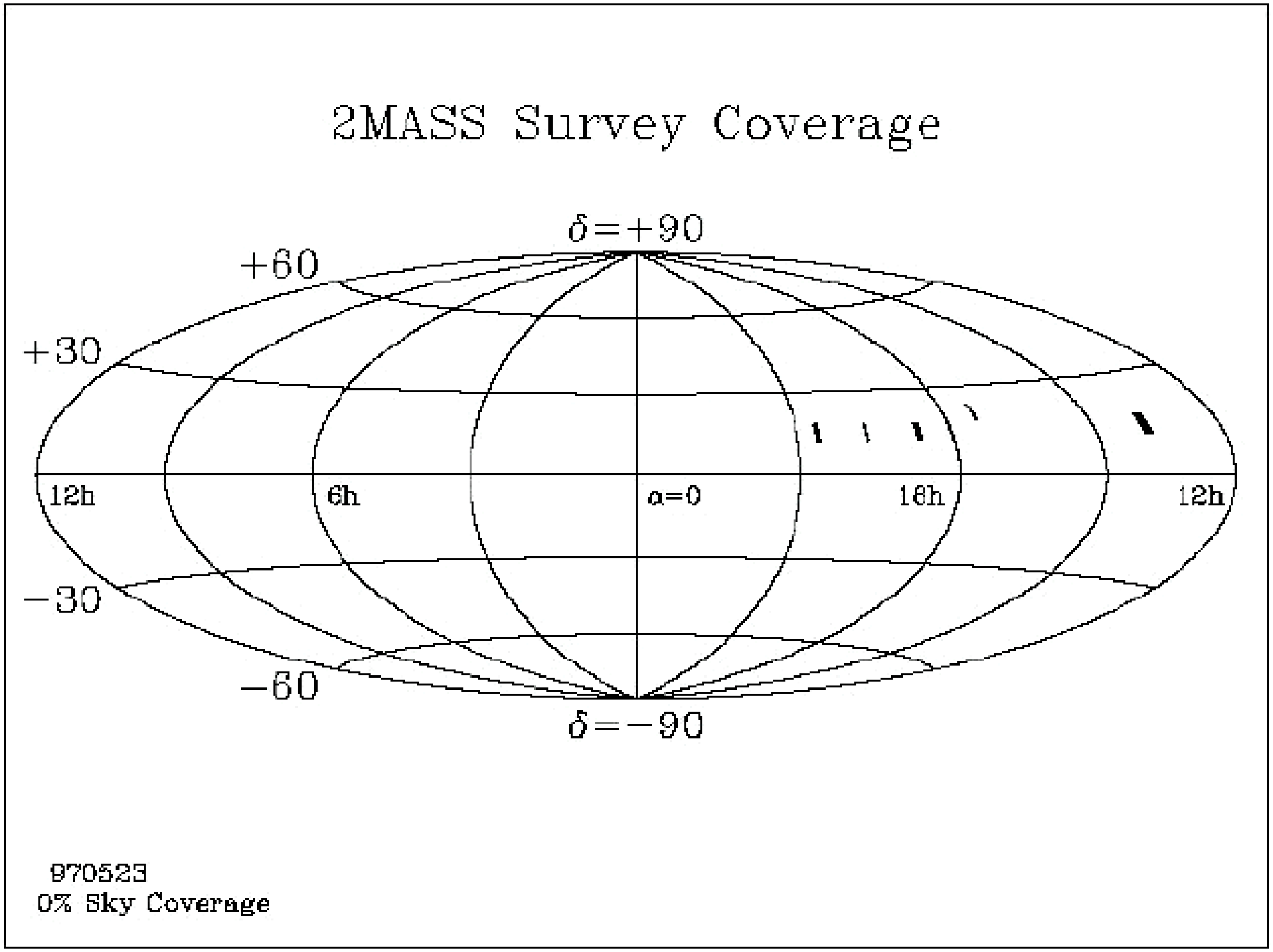
The 2MASS Survey - All Sky, J,H, K_s



Source: 2MASS Explanatory Supplement (Sec. 3.2.b)

The 2MASS Calibration Fields

- 35 separate 8.5'x1° fields
  - 26 with |b|>20
  - ~4 square degrees on the sky
- Multi-band: J,H, & K_s
  - Same observing strategy as the 2MASS Survey
- Multi-epoch: ~500-3500 repeated observations
  - Groups of 6 observations taken in ~10 minutes of real time
  - One field visited every hour
  - Each field typically visited once per day, ~3 months per year
- Data now public! (http://www.ipac.caltech.edu/2mass/)

M Dwarf Sample

Selection Criteria:

- Repeatability
- $H\text{-}K_s > 0.2$ in 2MASS PSC
- |b|>20

Sample Contaminants:

- Galaxies
- Giants & evolved stars
- Earlier type stars

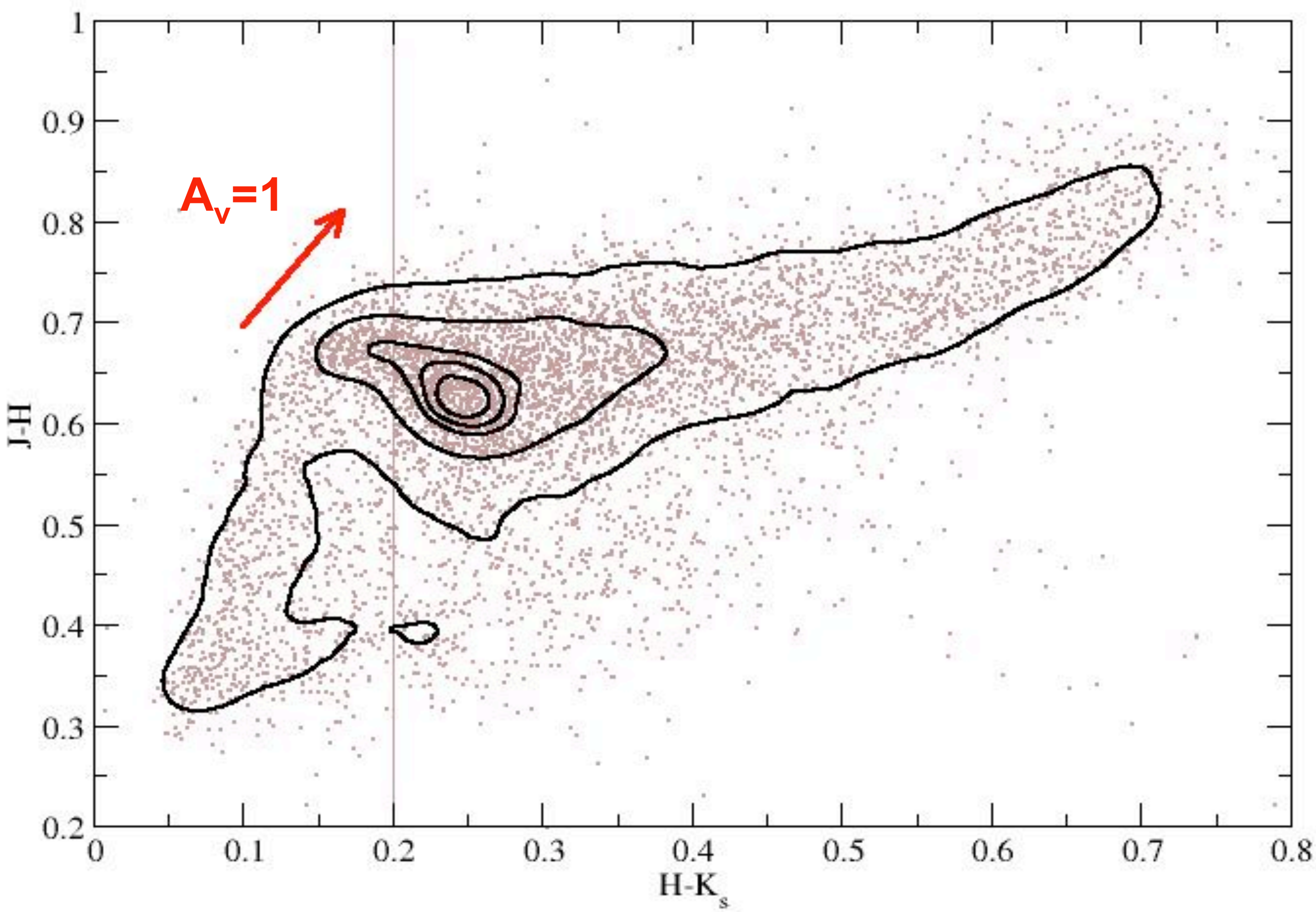
Initial Sample:

- 5631 sources

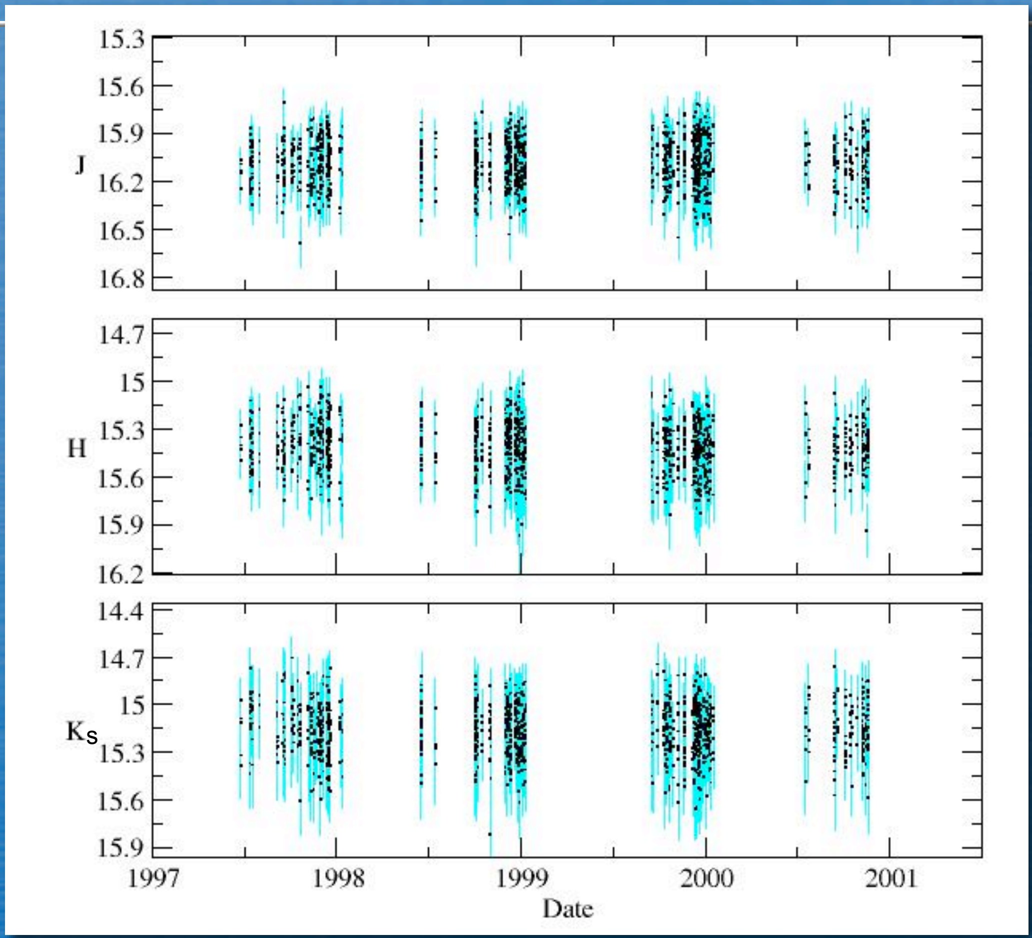
M Dwarfs:

~1600

|b|>20 Sample



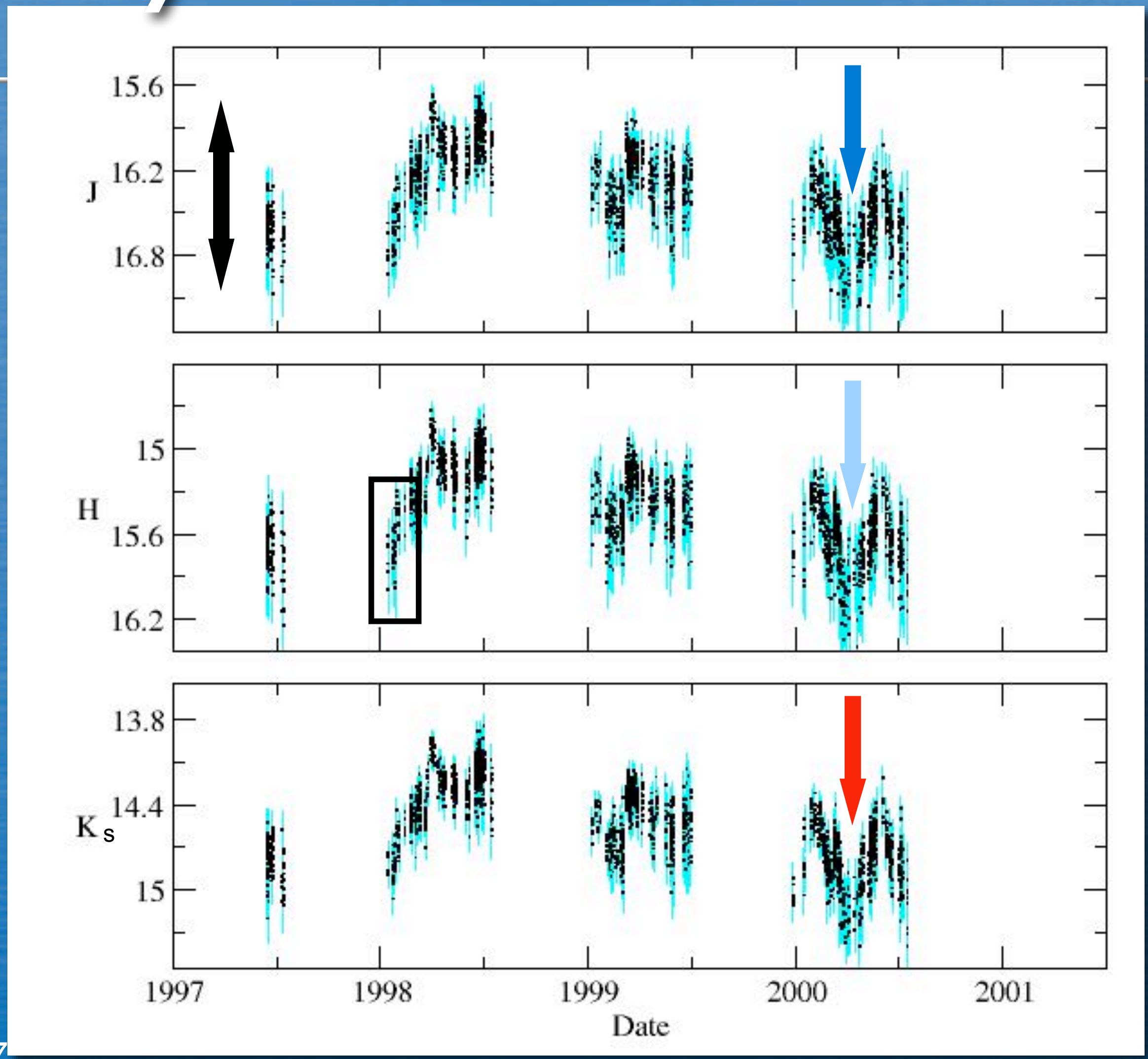
Sample Light Curve



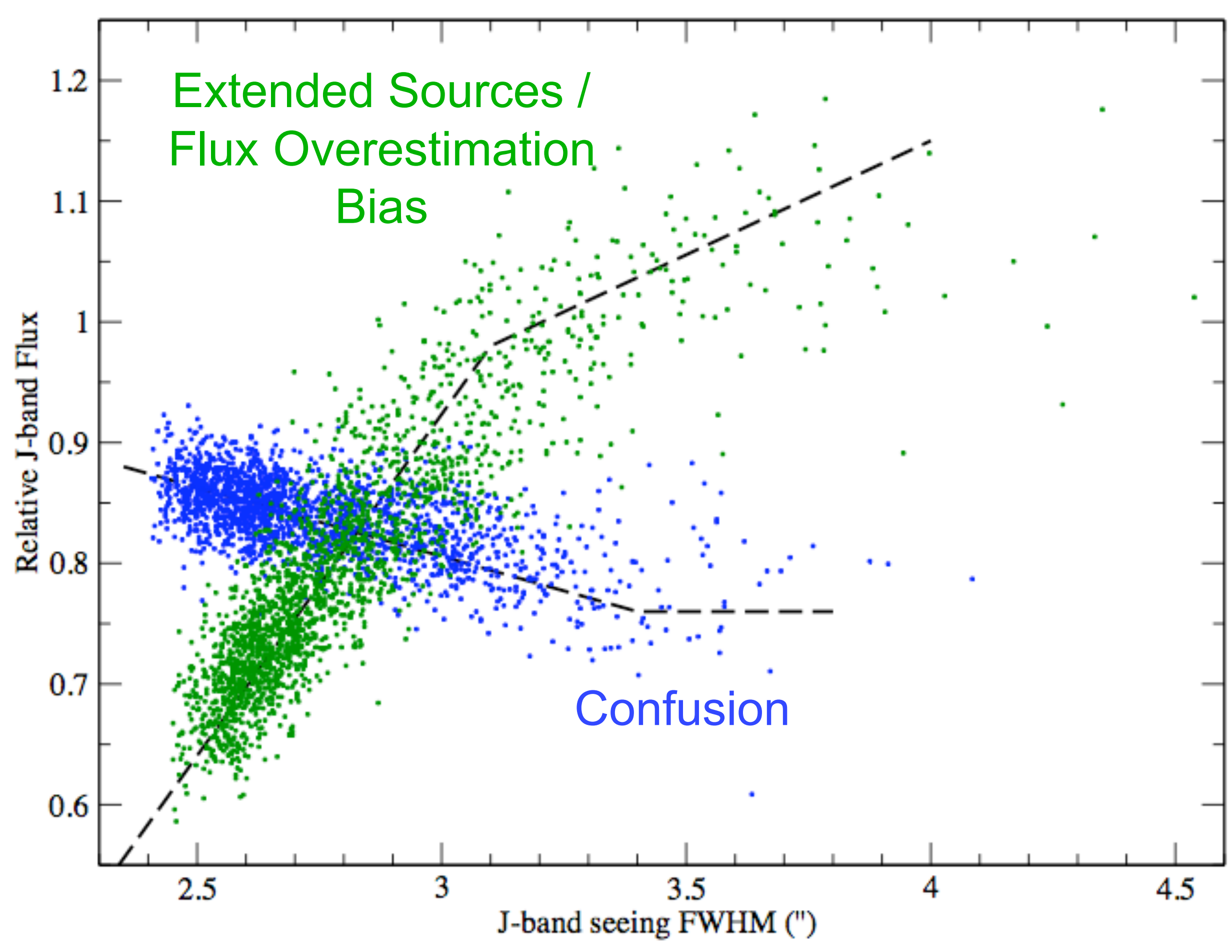
Legend:
Black: Data
Teal: 1-σ Error Bars

Photometric scatter approximately Gaussian

Variability



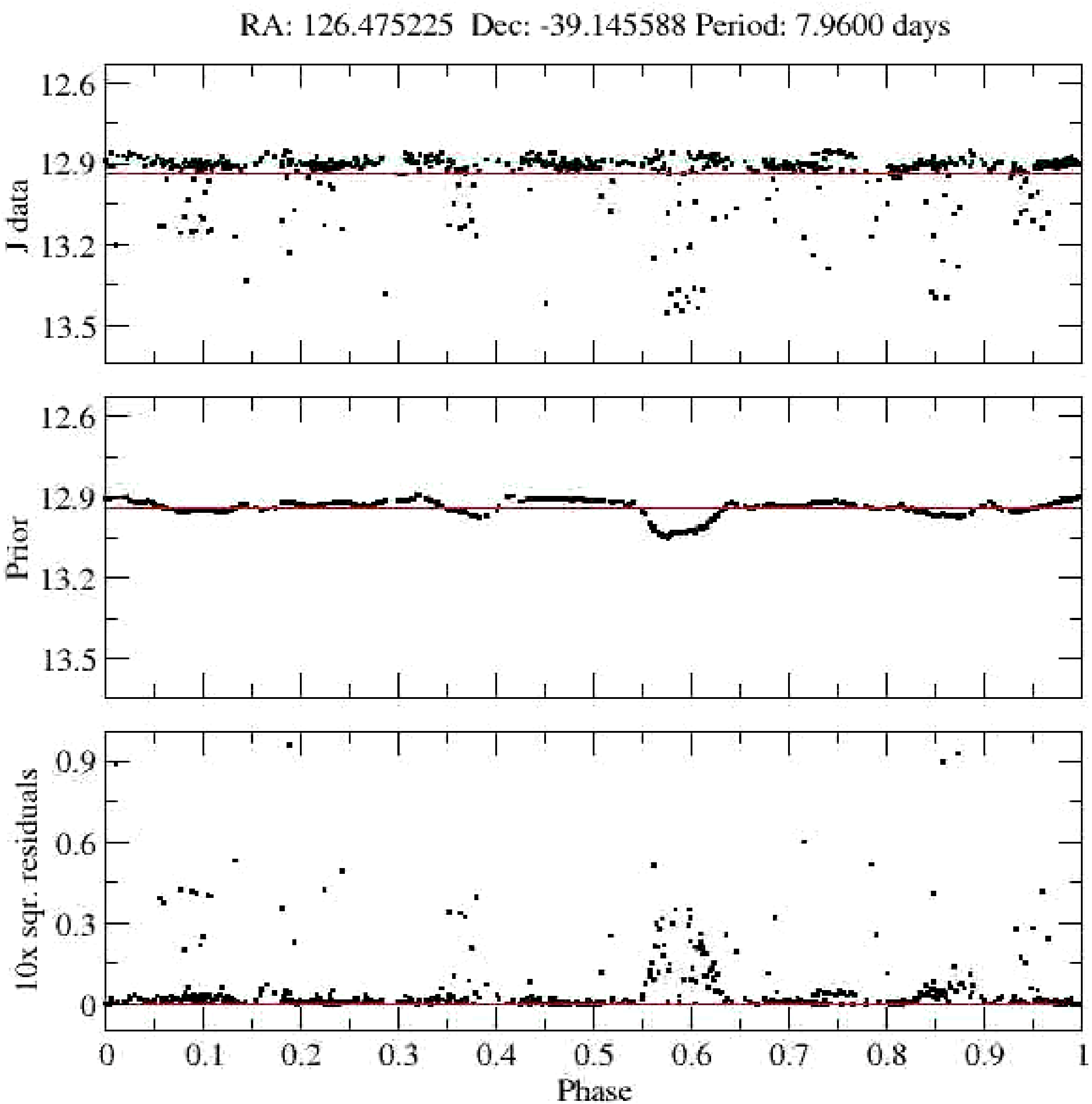
Pitfalls: Seeing



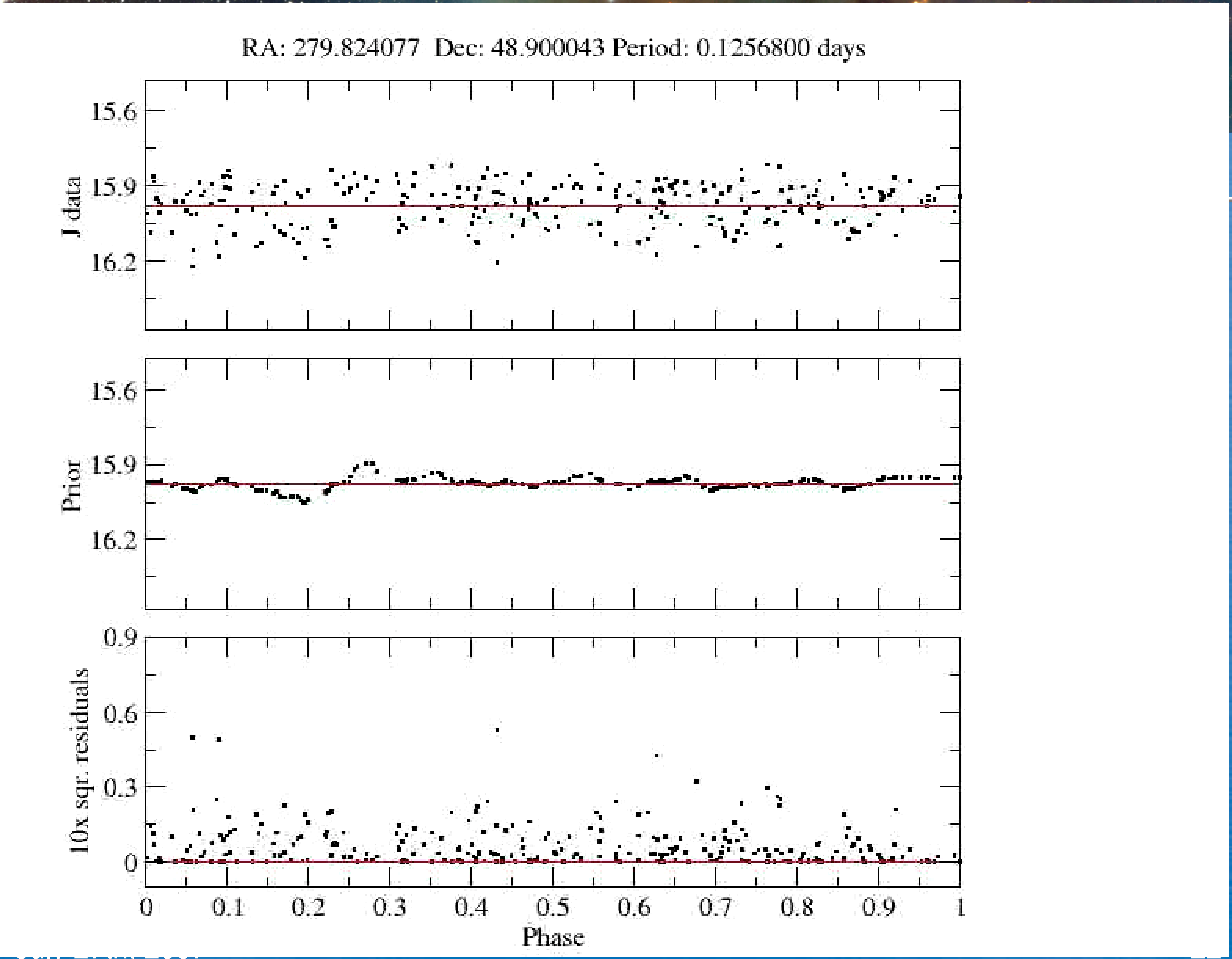
Period-Finding

Novel implementation of "Phase dispersion minimization"

- Don't know what you're going to find
- Brute force
  - ~15,000 periods, 0.1 to 50 days
  - Data "folded" to each test period
- A "smooth prior" is generated
  - Data are compared to prior
  - No binning!



RA: 126.475225 Dec: -39.145588 Period: 7.9600 days
J data
12.6
12.9
13.2
13.5
Prior
12.6
12.9
13.2
13.5
10x sqr. residuals
0.9
0.6
0.3
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Phase

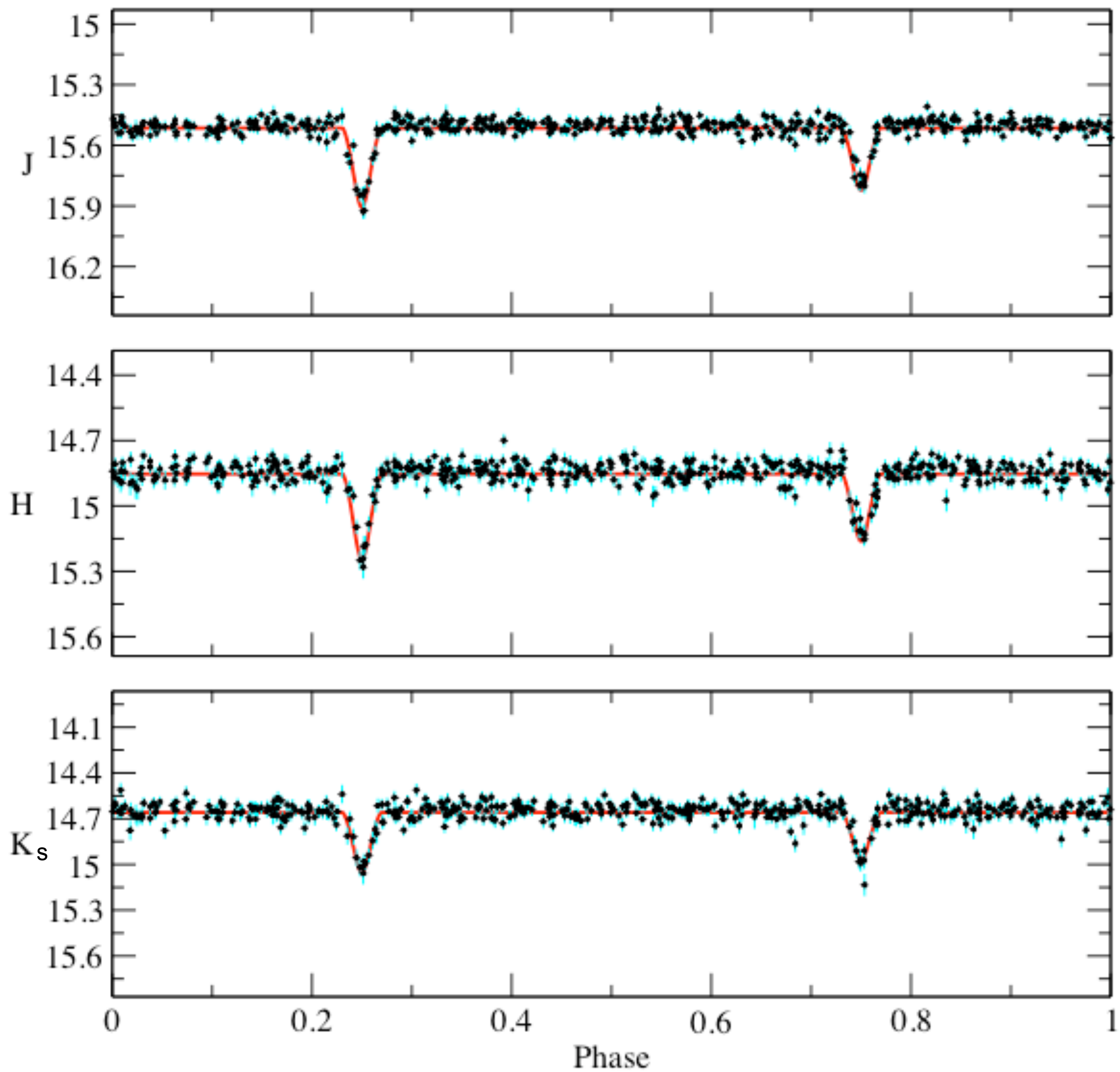


RA: 279.824077 Dec: 48.900043 Period: 0.1256800 days
J data
Prior
10x sqr. residuals
15.6
15.9
16.2
0.9
0.6
0.3
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Phase

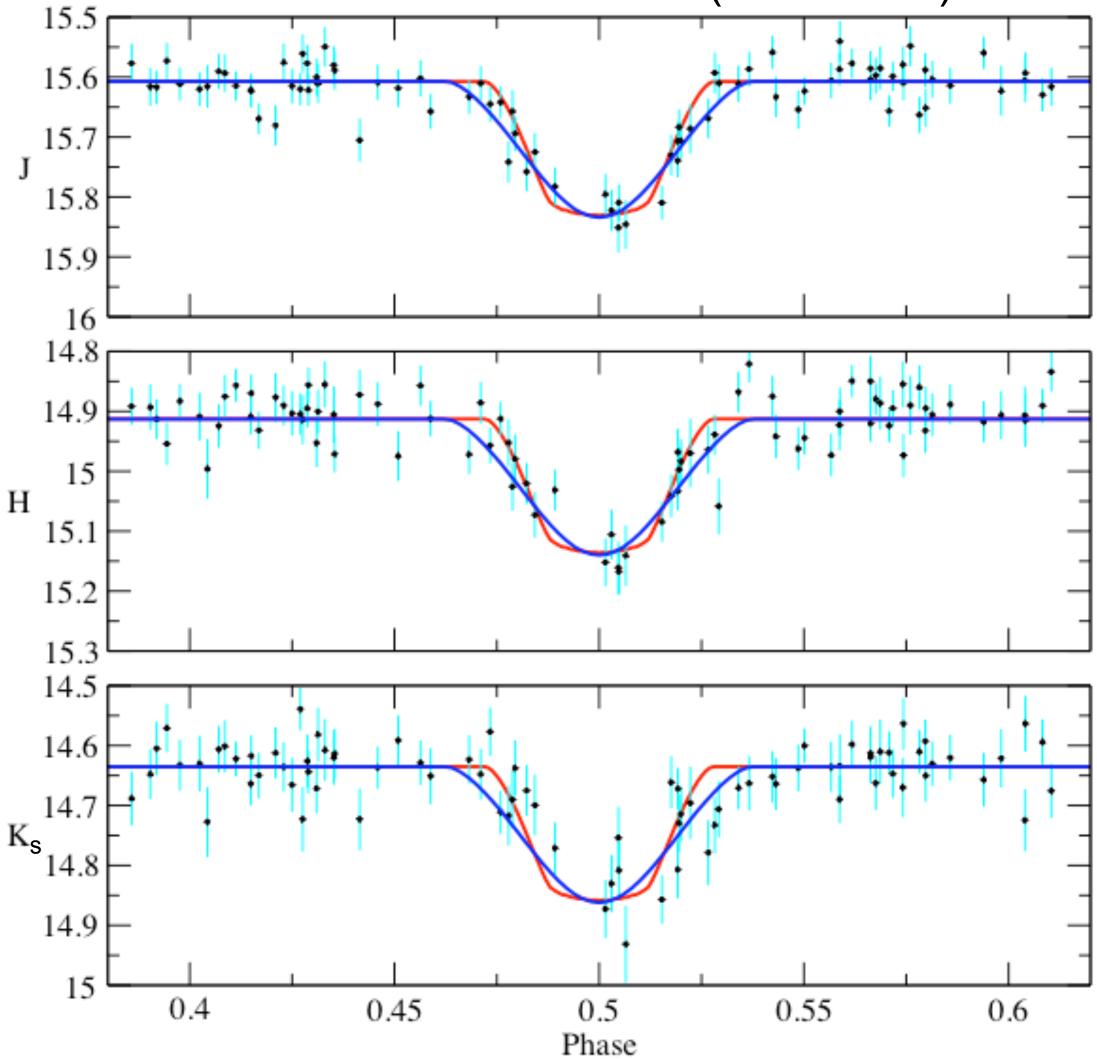
Results:

- 173 variables with $|b|>20$ (73 with $|b|<20$)
- 23 periodic variables
- 10 eclipsing binaries, of which
- 3 are M dwarf eclipsing binaries (2 with spectroscopically confirmed primary spectral types), of which
- 2 the data are consistent with a transiting Jovian companion
- 25 additional candidate M type eclipsing systems
  - 1 or 2 events 0.07-0.22mag detected in one or more bands at 5-σ (and 3-σ in at least one other band)

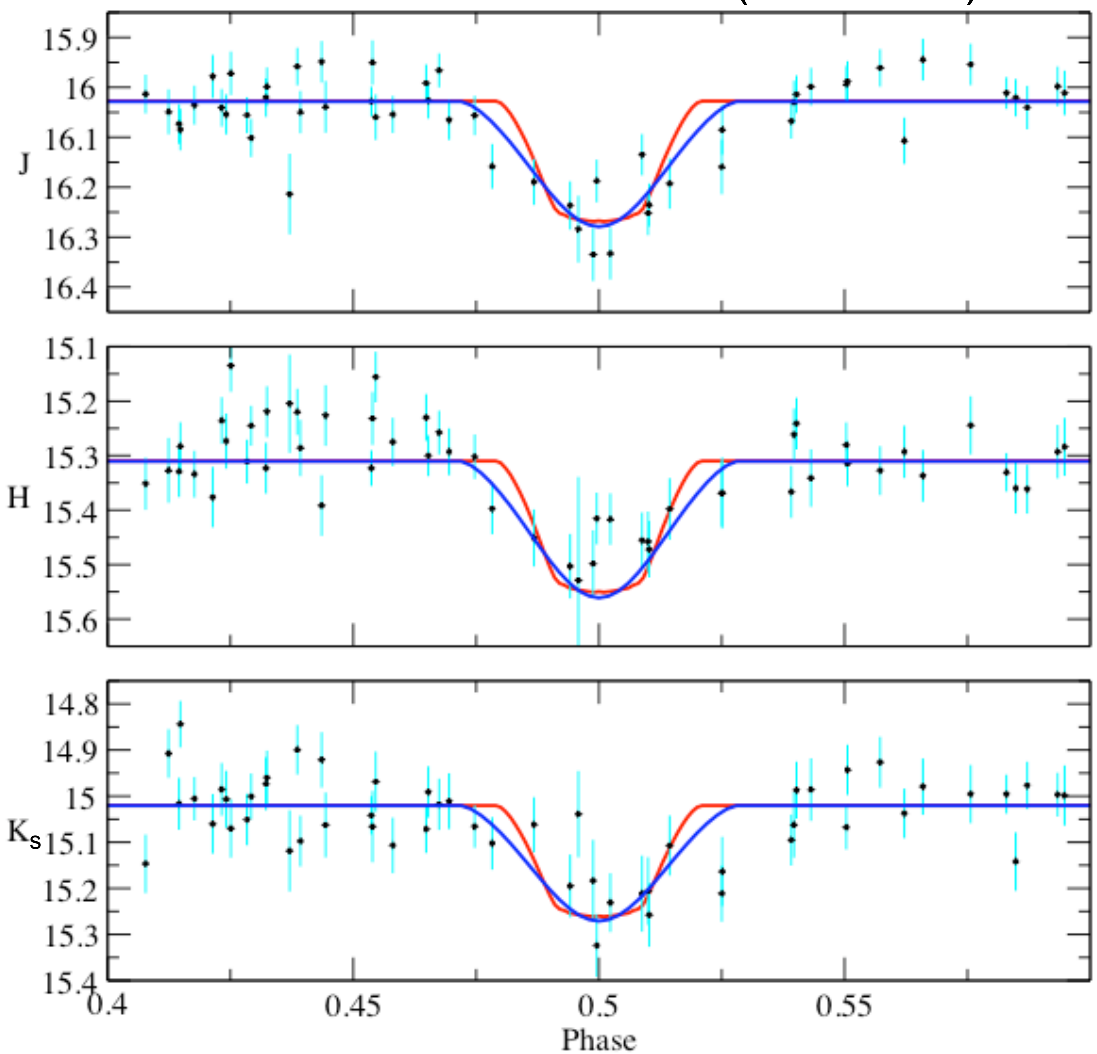
Partially Eclipsing ~M0 binary (2.639 days)



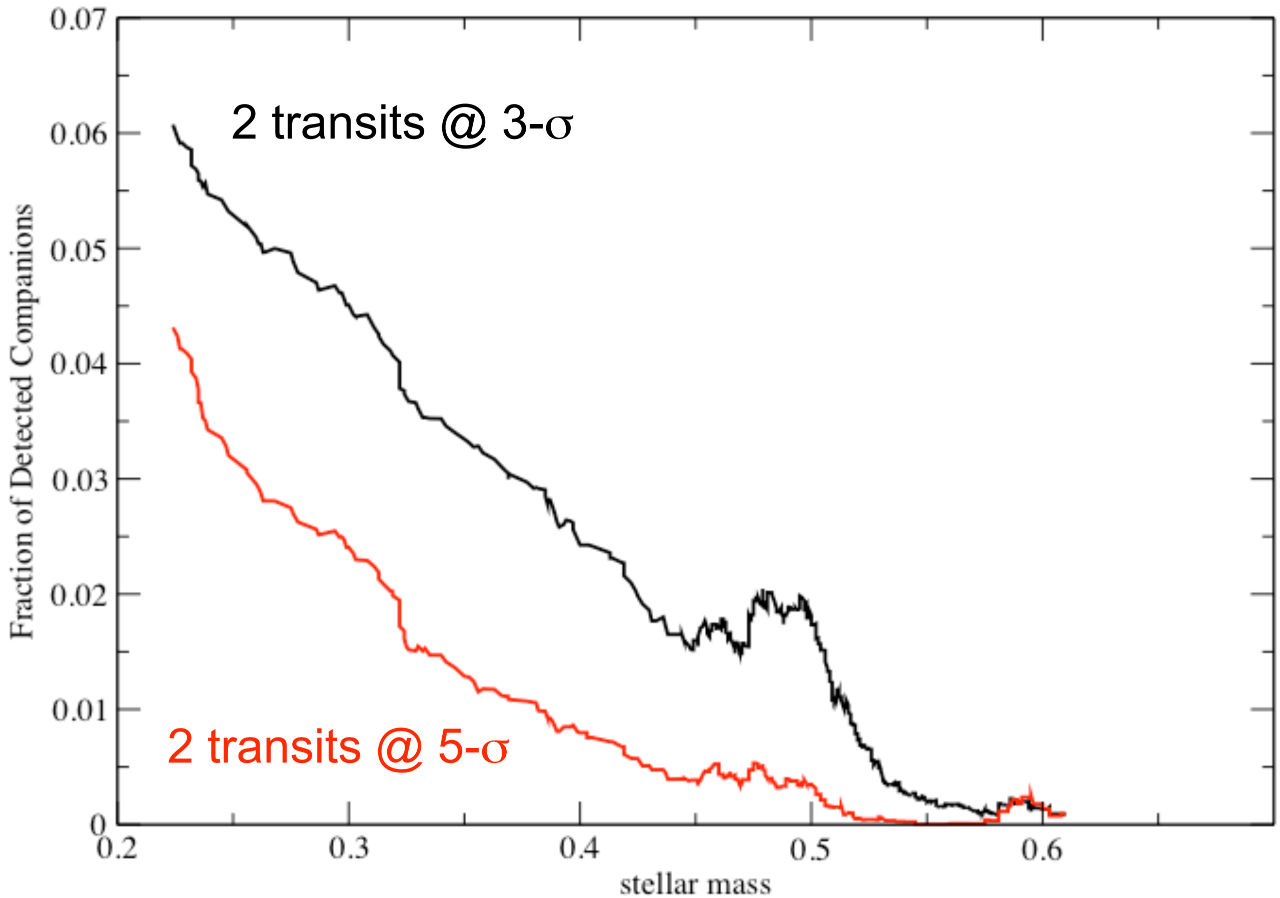
~M4 transit candidate (~22 hours)



~M4.5 transit candidate (~25 hours)



Monte Carlo Analysis - Companion Frequency



2MASS Transit Search Summary (1/2)

What is the frequency of planetary systems around M Dwarfs, and how does that compare to solar-type stars?

- < 6.5% at 67% significance for $a=9.25R_*$
- <1.3% for $a=3R_*$
- Preliminary!

==> Frequency of M Dwarfs with Jovian planets not likely to be significantly greater than the frequency for solar-type stars (1.2%). Consistent with RV results of Endl et al.(2006)

==> Doesn't really tell us much yet about formation and migration processes, except that M dwarf planets aren't piling up at the tidal disruption radius

2MASS Transit Search Summary (2/2)

- 2MASS Calibration Database
  - Near-IR variability observed from a wide variety of astrophysical phenomena

- Two Transit Candidates
  - Need radial velocity follow-up*

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Other Missions / Surveys

Surveys directly designed for transits

From yesterday's talks:

- MOST
- Corot
- Kepler

+ many others

Other Missions / Surveys

Exploring the time domain for any astrophysical variability with transits in mind

- SDSS-II (S. Gaudi's talk)
- Pan-Starrs (C. Alfonso's talk)
- LSST (S. Gaudi's talk)
- TransVar (K. von Braun)
  - Archiving transit search survey light curves for all field stars
  - Jovian planets transiting M dwarfs could be previously overlooked in such data sets

Other Missions / Surveys

<u>Transit searches as secondary science</u>

Ongoing/Past:

- 2MASS
- OGLE
- MACHO
- ROTSE
- Spitzer IRAC

Future:

- Spitzer Warm Mission
- WISE
- GAIA
- OBSS
- EPOXI/EPOCh

OGLE III (2001)

- Microlensing search for dark matter MACHOs in bulge, SMC and LMC
  - 2 microlensing planets
  - 37’x37’ f.o.v.
- Precision photometry and cadence suitable for detecting transits

==> 5 transiting planets confirmed

MACHO

- Like OGLE
- 180,000 stars in ~7 square degrees

==> Drake & Cook (2004):

- 9 transit candidates in galactic bulge

BUT Huegelmeyer et al. (2007):

- From RV, 5 consistent with grazing eclipsing systems

ROTSE-III (~2004)

- GRB monitoring and optical transients
- 4 telescopes around globe for continuous coverage
- 1.85^ox1.85^o f.o.v.
- ~2% precision at ~12th magnitude
  - M0 at ~ 40pc

Spitzer IRAC

- The IRAC Dark Field (J. Surace)
  - ~15' f.o.v., m(L)~22 at 5-σ
  - ~20,000 objects; mostly extragalactic
  - Observed every 2-4 weeks
  - Relative limiting precision of ~1-2%
  - Number of M dwarfs unknown (field selected against the presence of foreground stars), but being looked at…

==> Probably not enough f.o.v./ sample size given the cadence; systematic uncertainties an issue

Spitzer Warm Mission (2009)

- Targeted follow-up of known transits (D. Deming's talk)
- Blind field transit searches not feasible
  - IRAC f.o.v. 5'x5'
  - ~1-2 transits / week of Spitzer time
- However, several large sky, deep imaging campaigns are being proposed
  - Variety of science objectives
    - YSO variability, galactic structure, AGN, high-z galaxies, brown dwarfs
  - Time domain considered

  ==> Piggyback transit science

WISE (late 2009)

- All Sky
- 3.3 & 4.6 microns
- ~100 square degrees with N_{obs}>100
- Limiting magnitude with S/N>100:
  - ~8-10 (M0 at ~40-100pc)

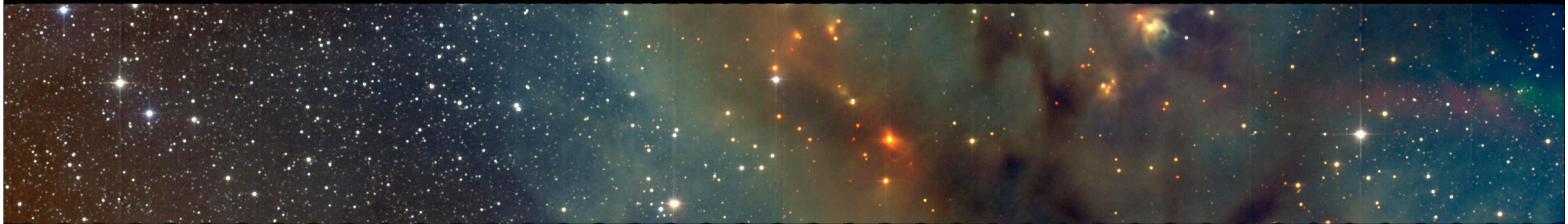
==> May not have sufficient S/N and hence sufficient sample size for transits; M dwarf eclipsing binaries still discoverable

GAIA (2011), OBSS

- Astrometry + RV for 1 billion stars
- Magnitude limit of ~14-16 for detecting Jovian transits around solar-type stars (~millimagnitude precision)
- Similar to the Origins Billion Star Survey (OBSS), currently under feasibility study

Conclusions

- Carefully designed calibration observations and overlapping regions for general sky surveys lend themselves nicely to M dwarf transit searches
  - “Free” and important science
- Same limitations to dedicated transit searches apply



The End