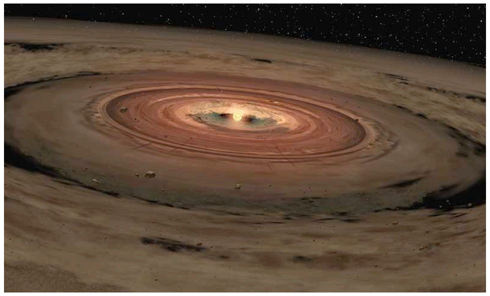
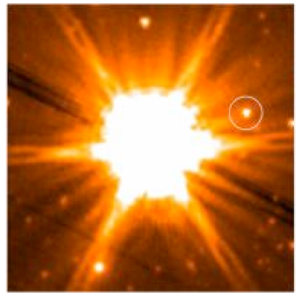
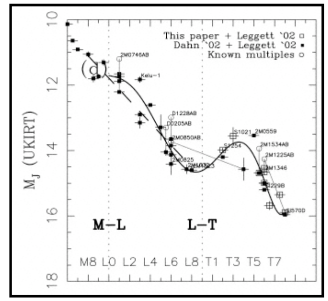
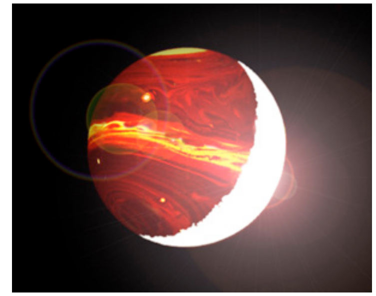
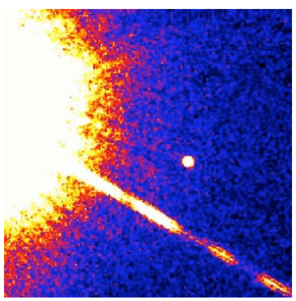


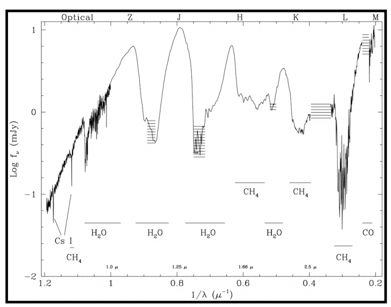


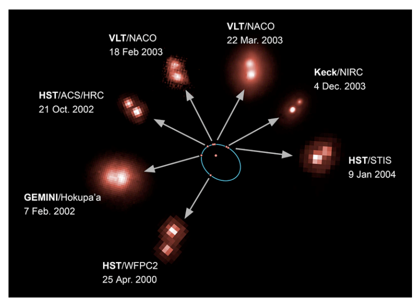


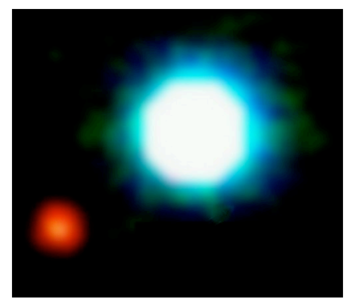


Lecture 2:
Brown Dwarf Detection



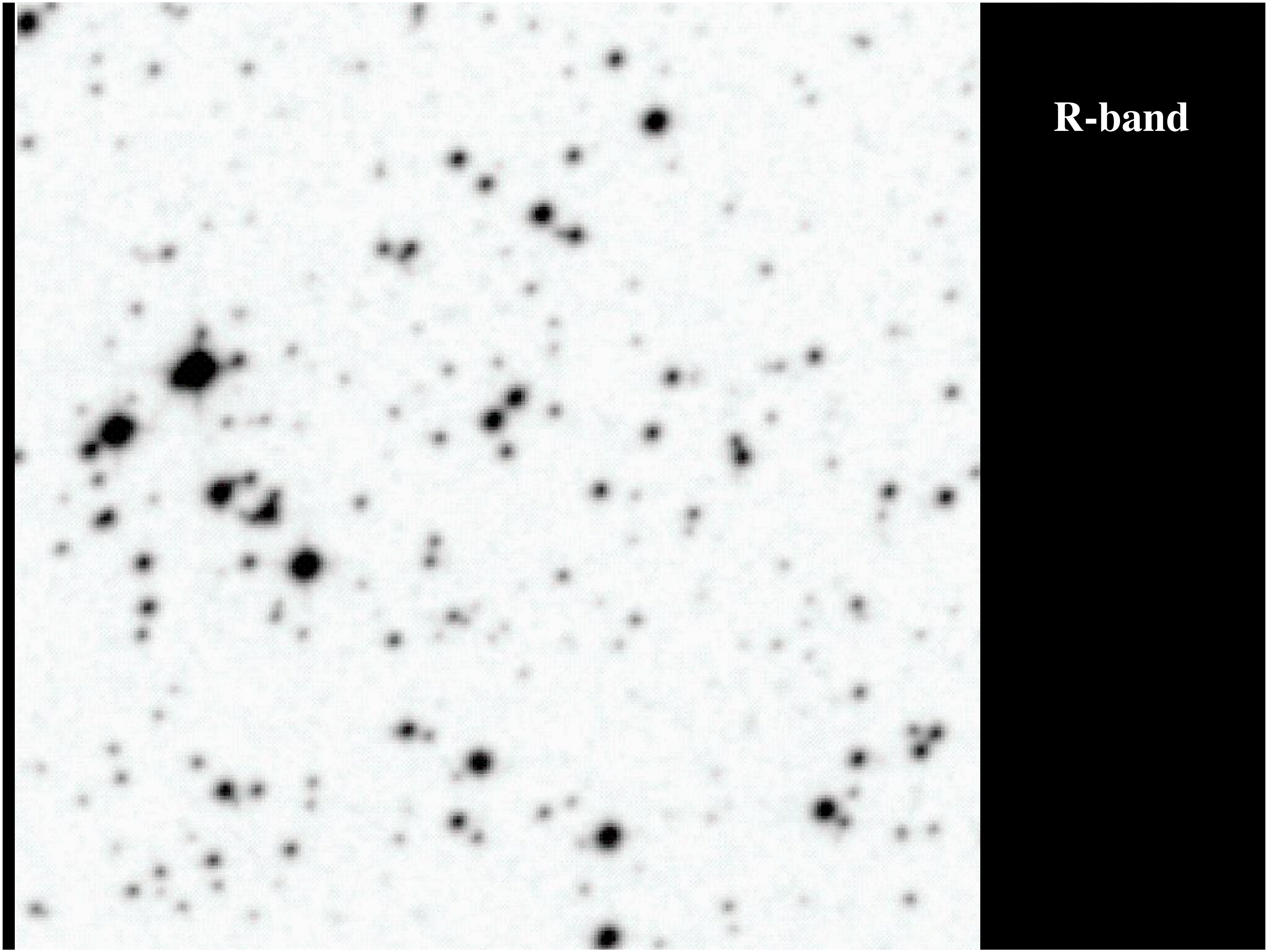


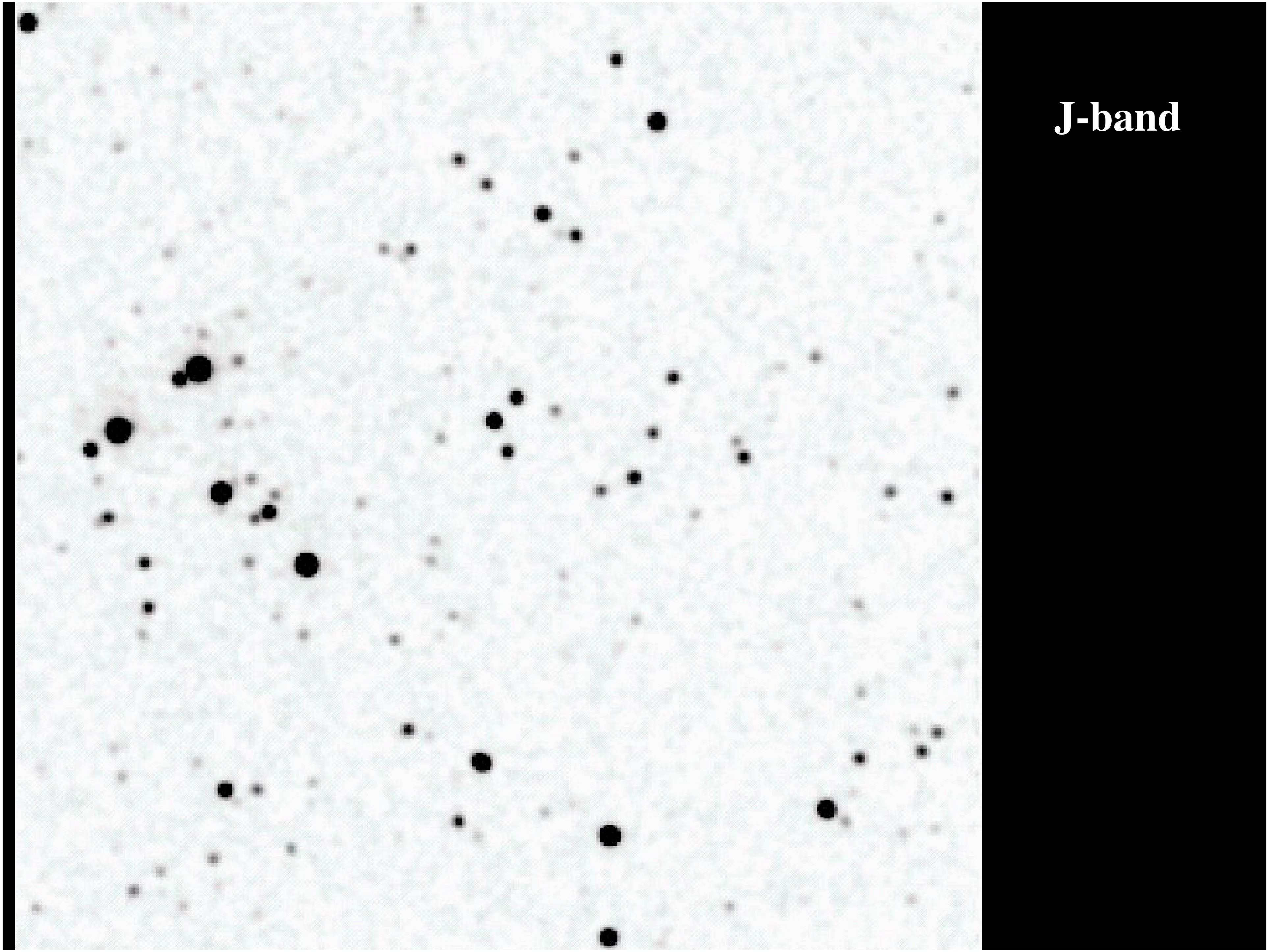


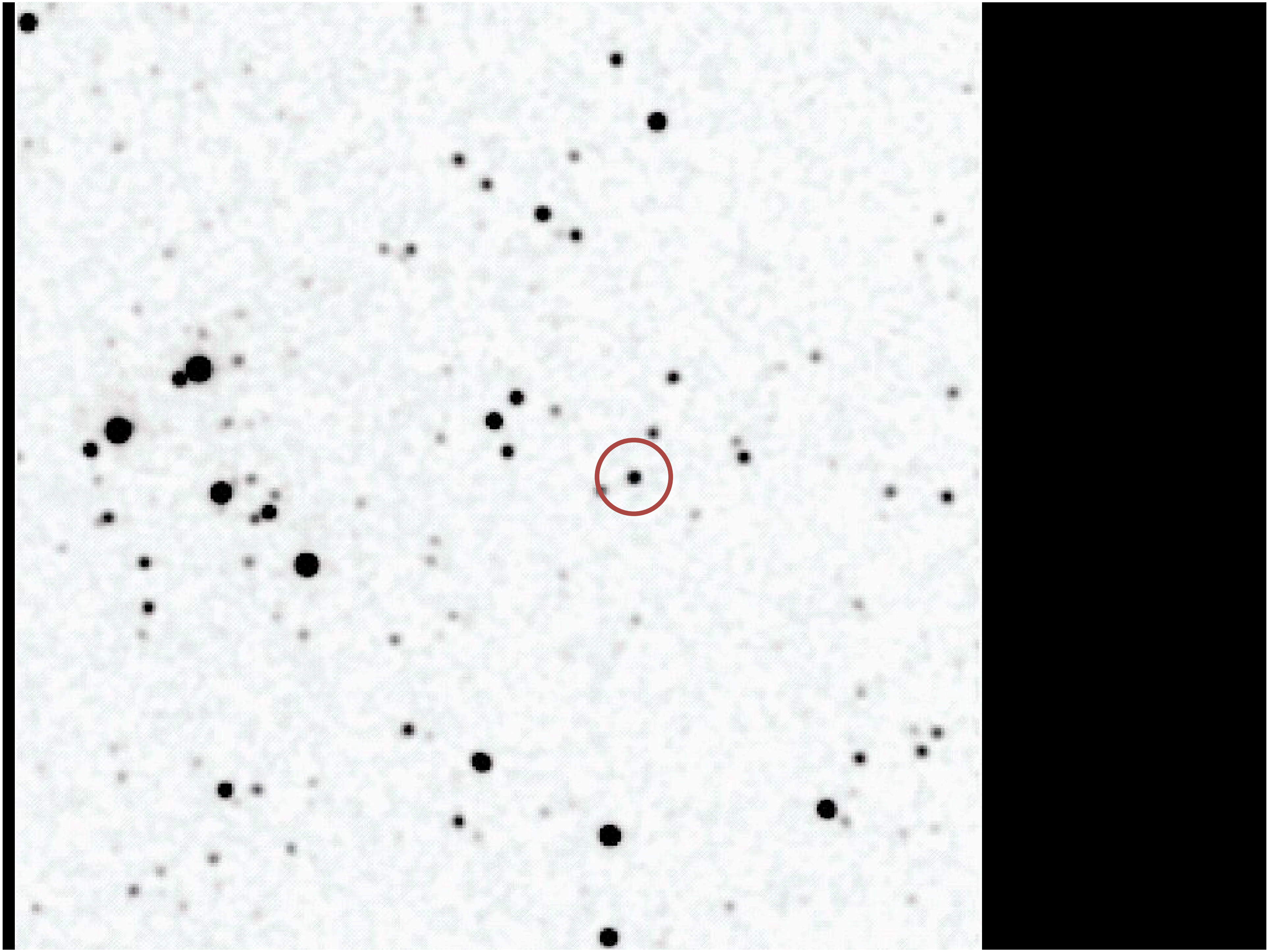


How to find a brown dwarf

- Look in the near-infrared
- Look for objects with weird (red) colors
- Look for high proper motion objects
- Look in young star forming regions
- Look around nearby stars

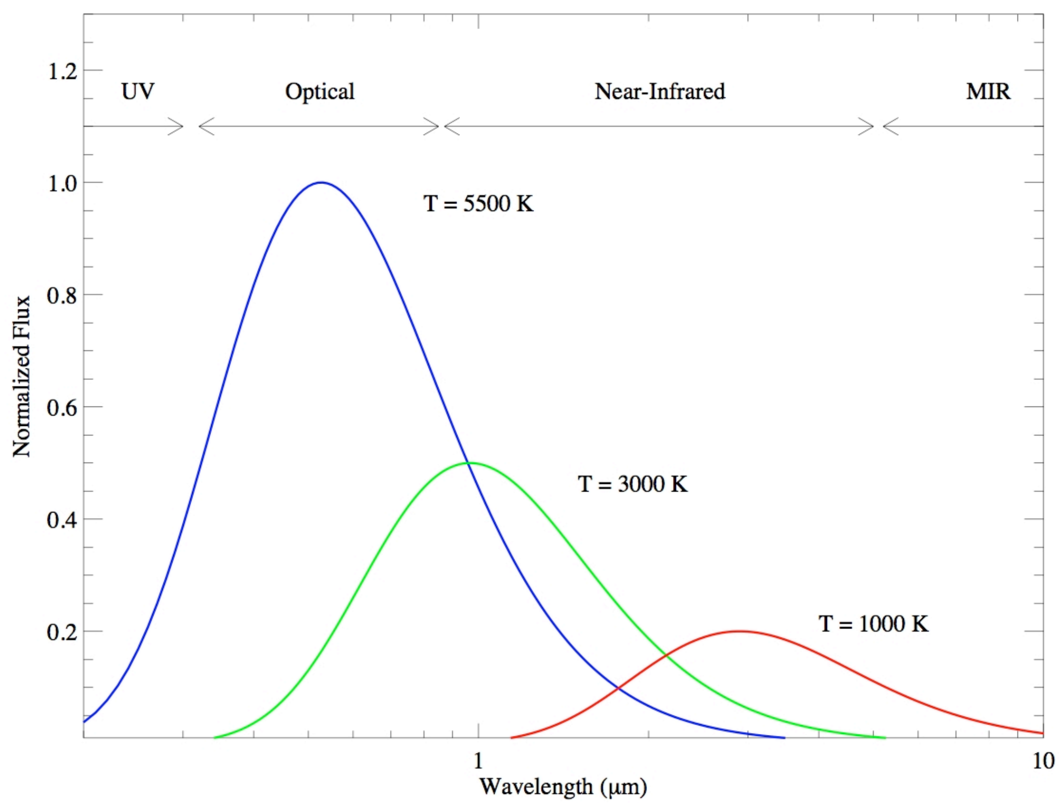

R-band


J-band



Cool stars are (near-infra)red stars

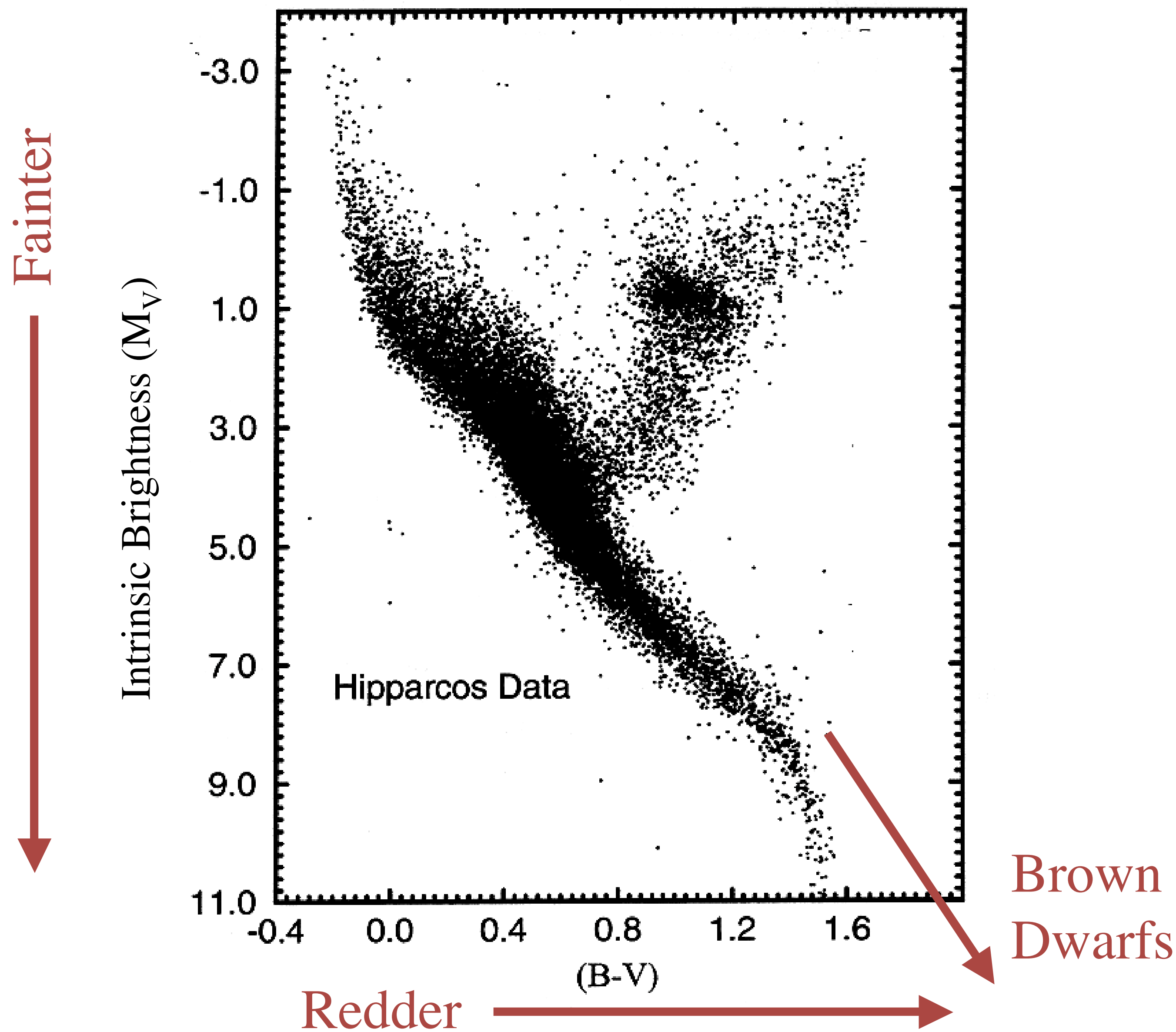
Blackbody flux distribution: $I_0(\lambda) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k T_{eff}}} - 1}$



Low temperature stars emit more flux at longer wavelengths: **Wien's Displacement Law:**

$$\boxed{\lambda_{pk} T \approx 3000 \text{ K-}\mu\text{m}}$$

Easier to see cool BDs at longer wavelengths.


Fainter
Intrinsic Brightness (M_V)
-3.0
-1.0
1.0
3.0
5.0
7.0
9.0
11.0
Hipparcos Data
-0.4
0.0
0.4
0.8
1.2
1.6
(B-V)
Redder
Brown Dwarfs

Big Near-infrared Surveys

DENIS (1996-2001)
- I (0.8 μm), J (1.25 μm) & K (2.16 μm)
- Southern sky (16,700 deg^2)
- 355,000,000 point sources (DR3)

2MASS (1997-2001)
- 3 NIR bands J (1.25 μm), H (1.6 μm), K_s (2.1 μm)
- Whole sky (40,000 deg^2)
- 471,000,000 point sources (ADR)

SDSS (1998-present)
- u, g, r, i, z (0.35-0.90 μm) + optical spectroscopy
- Northern sky and Galactic Plane (8,000 deg^2)
- 215,000,000 point sources (DR5)


Galactic Center (2MASS)

Magnitudes and Colors

A common system for measuring the brightness of star in a given band is to use "Vega magnitudes":

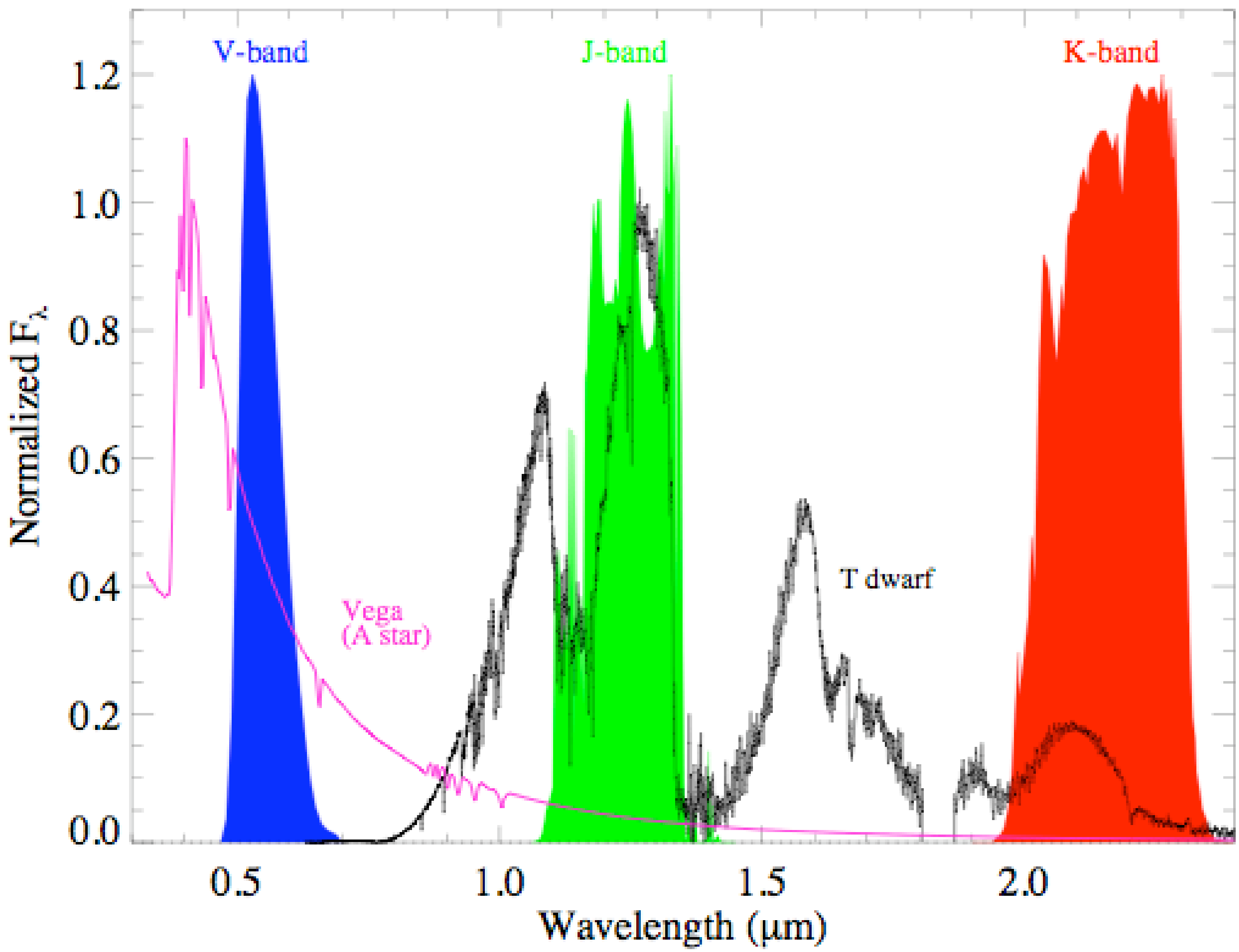
$$m_b = -2.5 \log \frac{f_b}{f_b^V}$$

where $$f_b = \int_{\lambda_1}^{\lambda_2} f(\lambda) T_b(\lambda) d\lambda$$

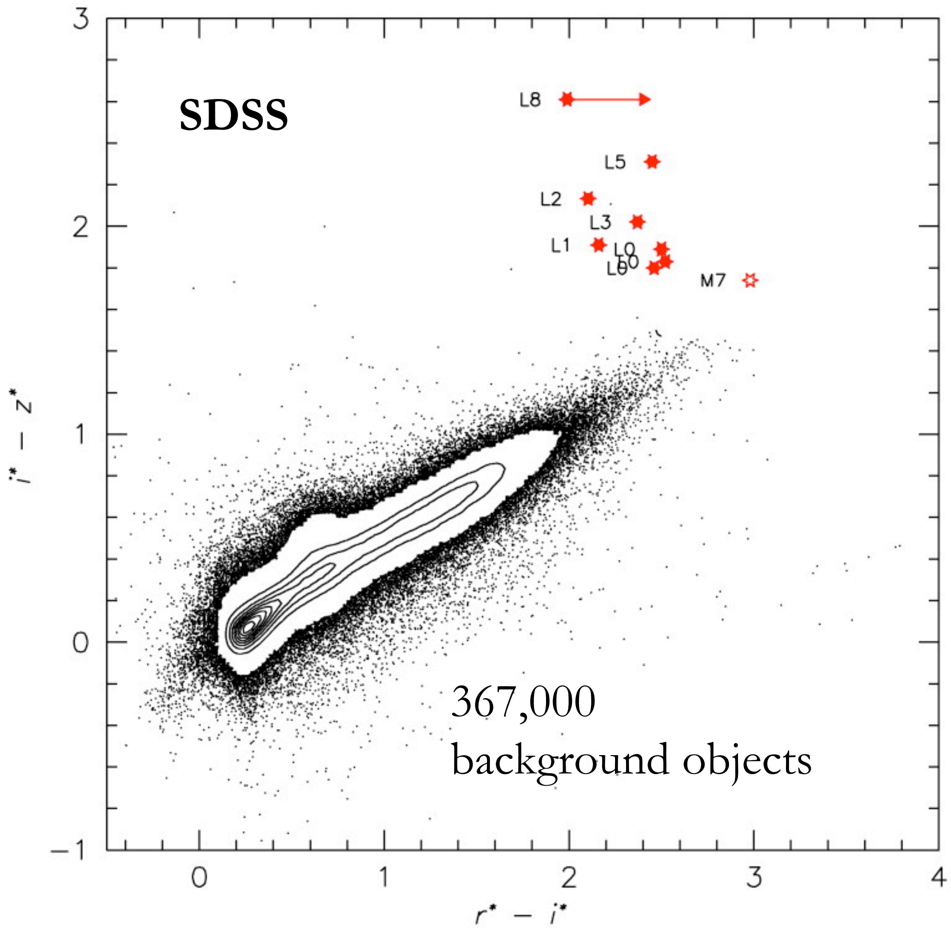
is the net flux emitted within the filter passband $T_b(\lambda)$ and f_b^V is the equivalent calculation for the star Vega.

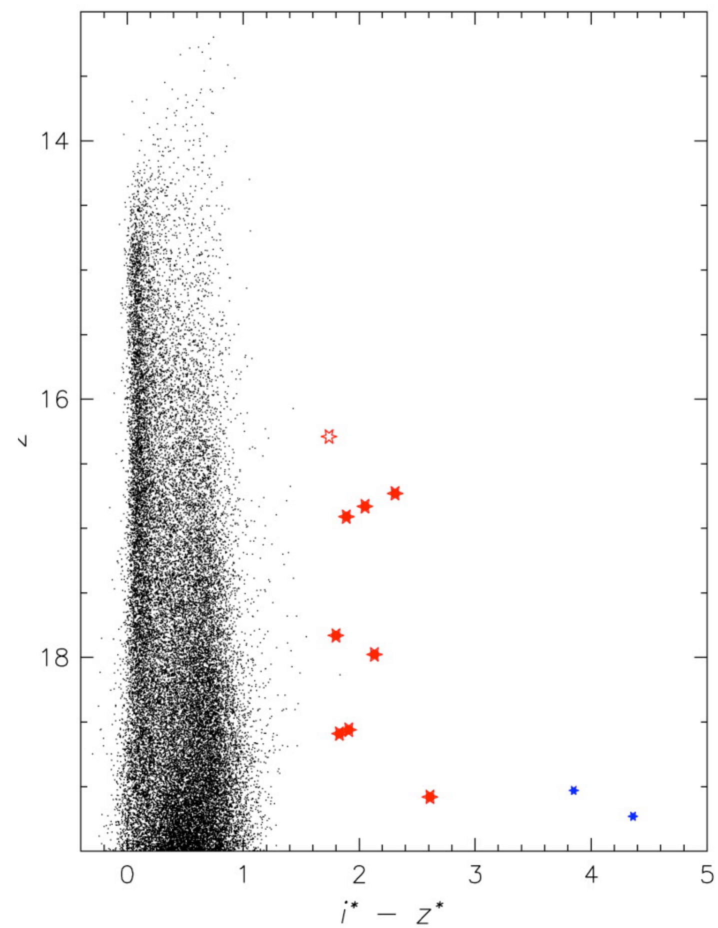
A color is then: $$\boxed{m_{b1} - m_{b2} = -2.5 \log \frac{f_{b1}}{f_{b2}} \frac{f_{b2}^V}{f_{b1}^V}}$$

Choosing the right filters



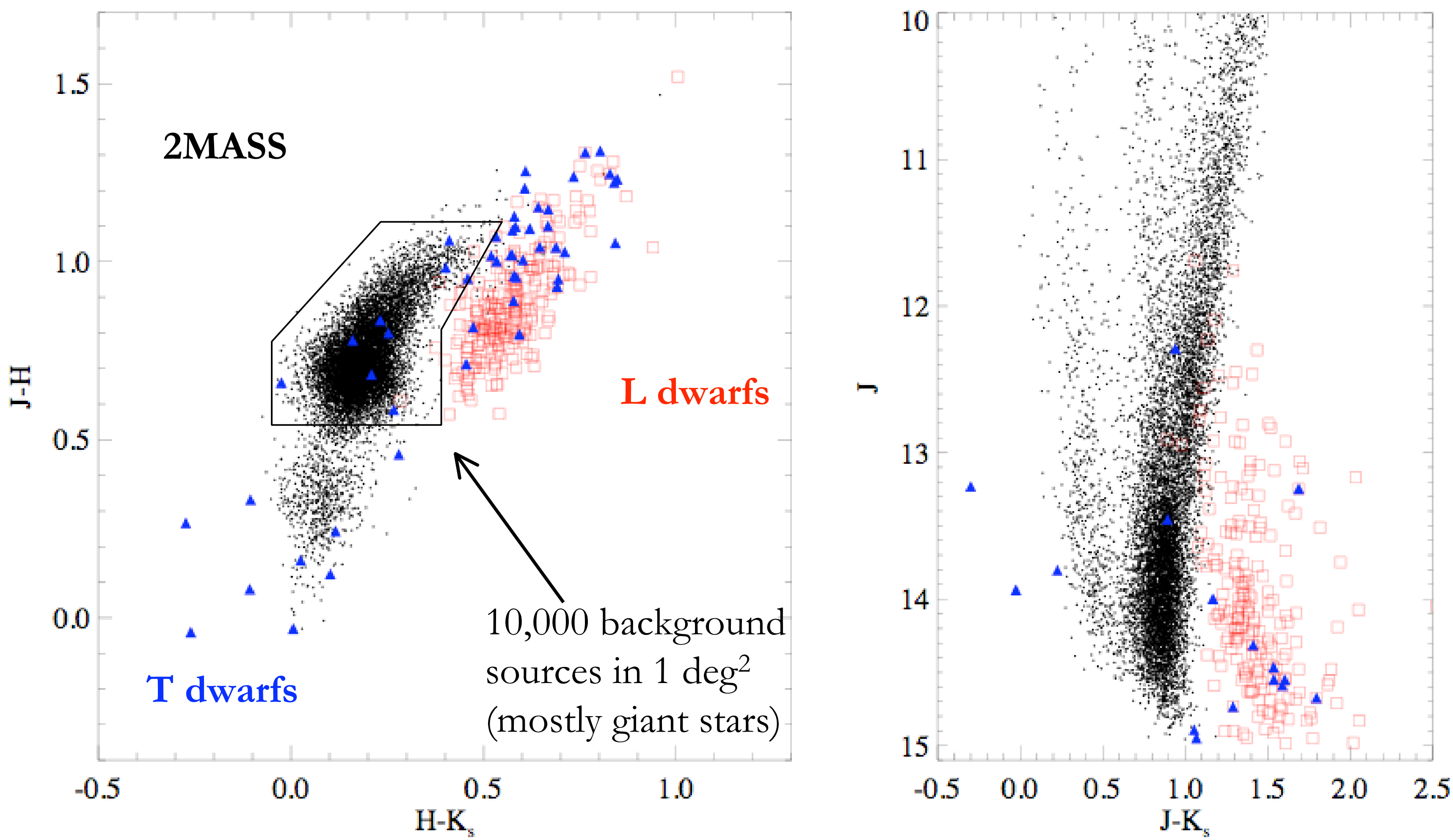
Sometimes easy…

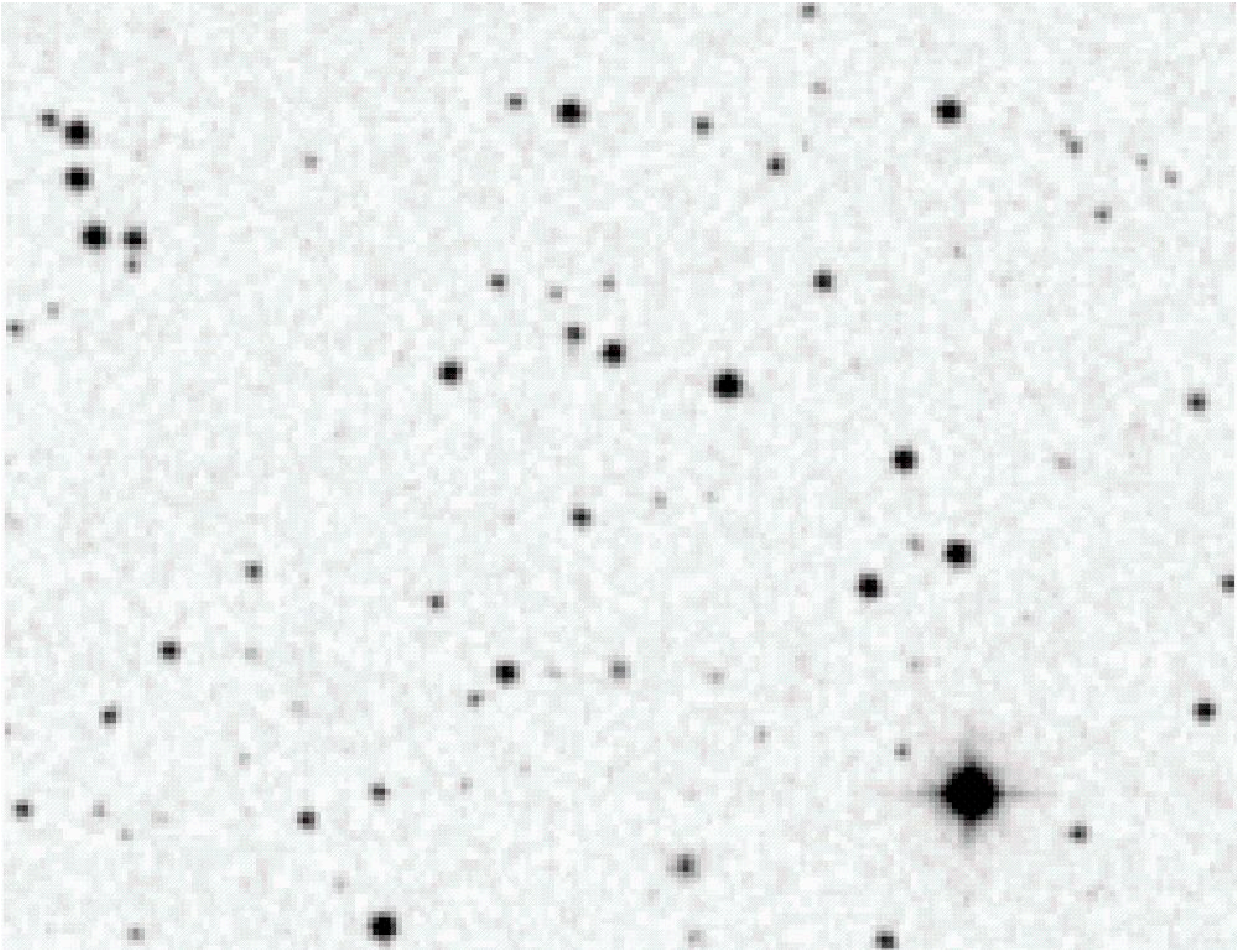


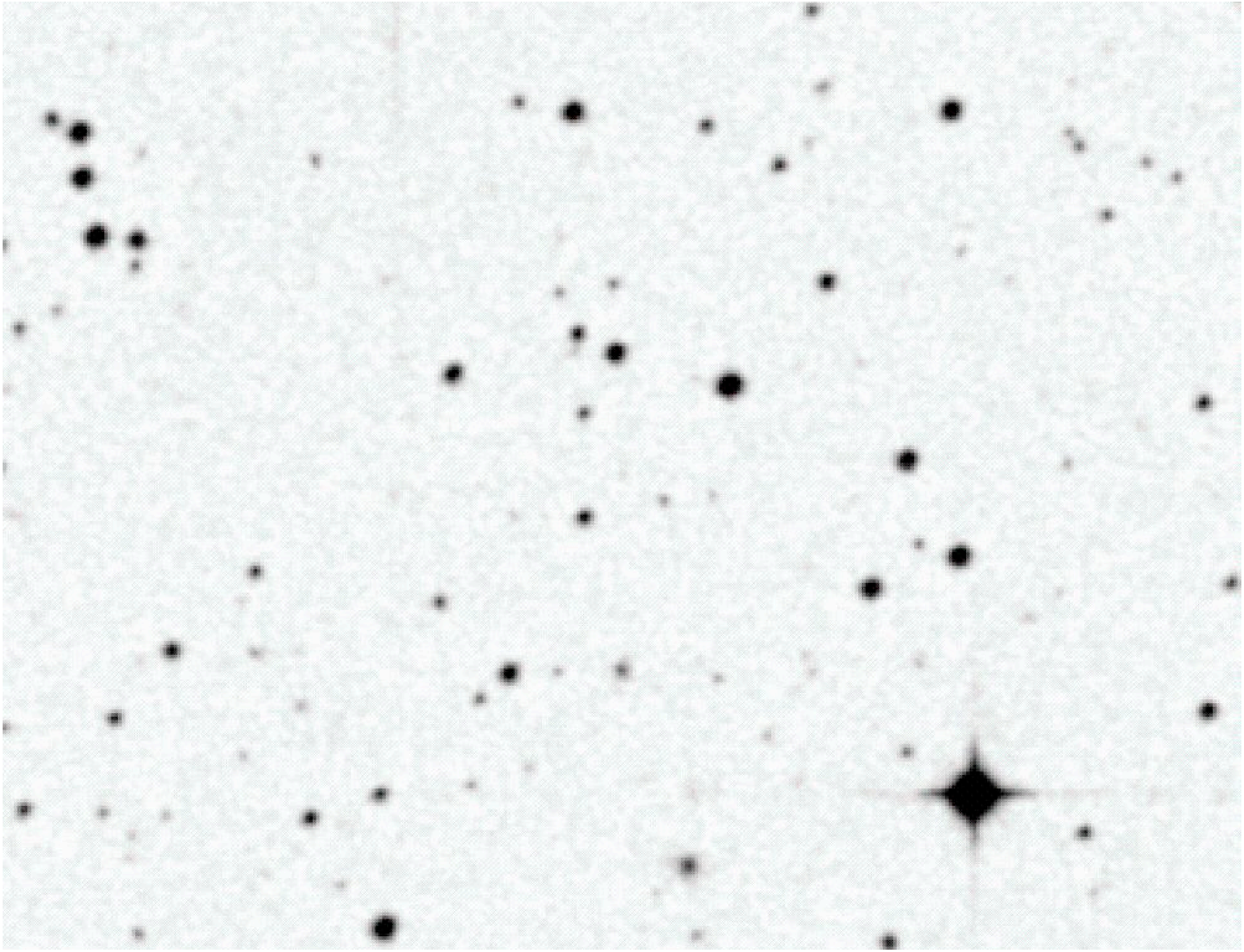


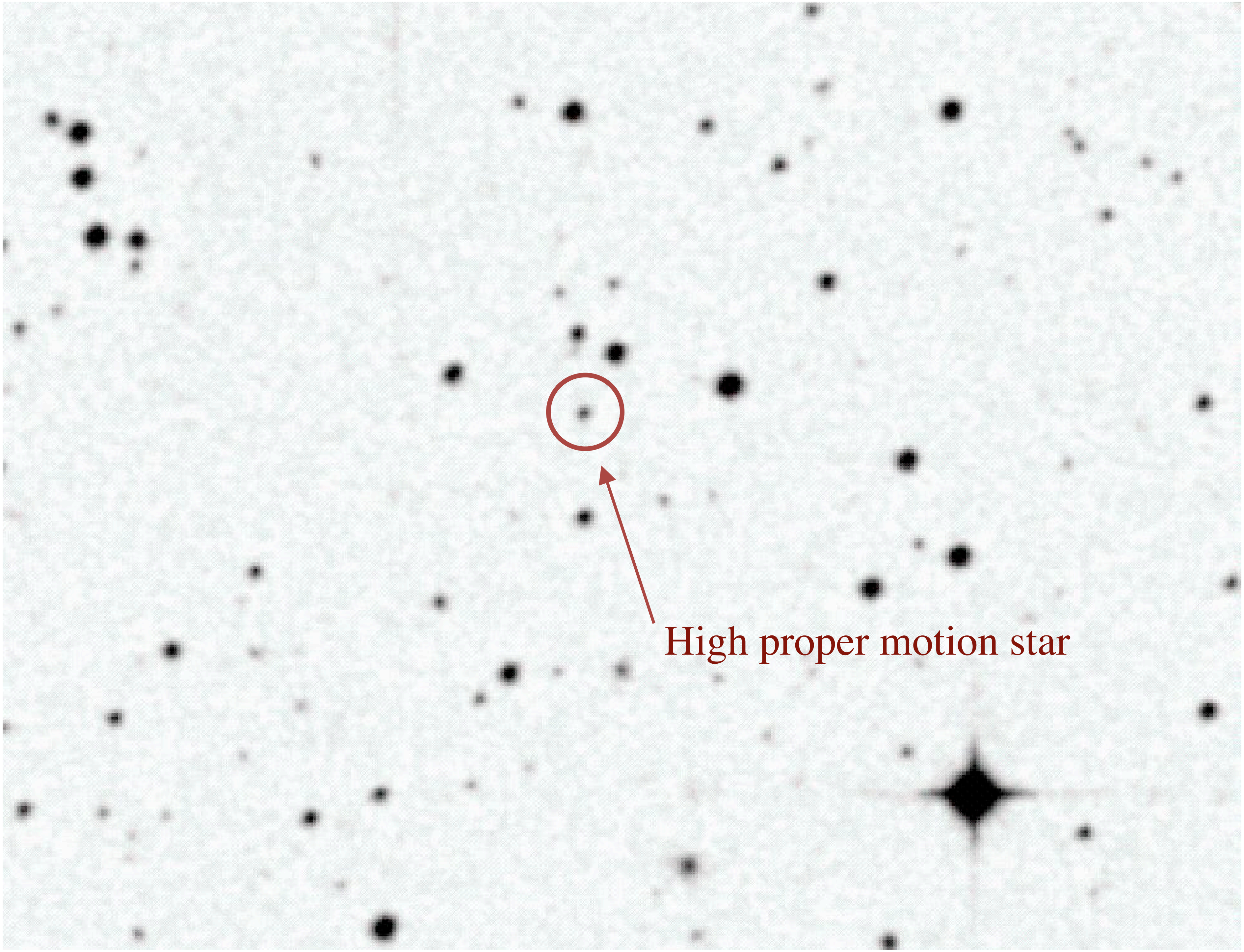
Fan et al. (2000)

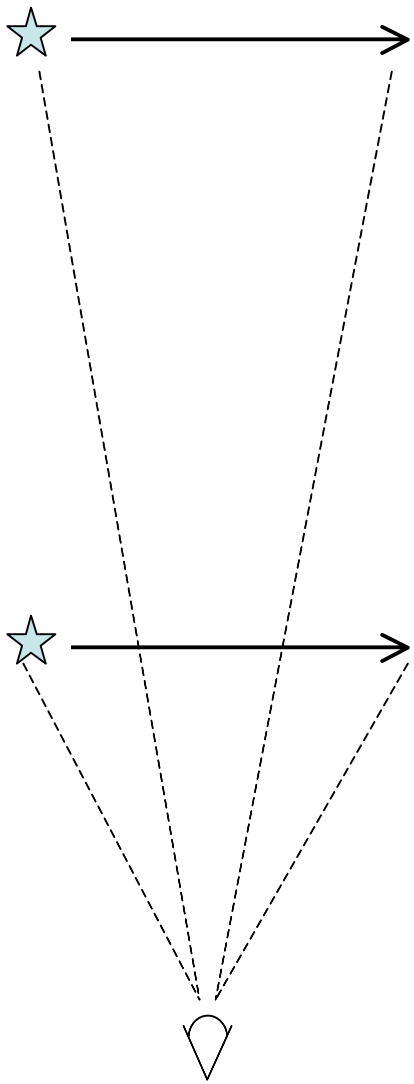
Sometimes not…








High proper motion star



Using motion

Nearby stars and brown dwarfs tend to have higher **proper motions** than more distant sources - a projection effect:

$$\mu(''/yr) = 4.74 \times d(pc) \times V_{tan}(km/s)$$

A faint near-infrared source with a high proper motion is an excellent brown dwarf candidate

Motion can be used in addition to color criteria

Reduced proper motion

A useful statistic is the reduced proper motion:

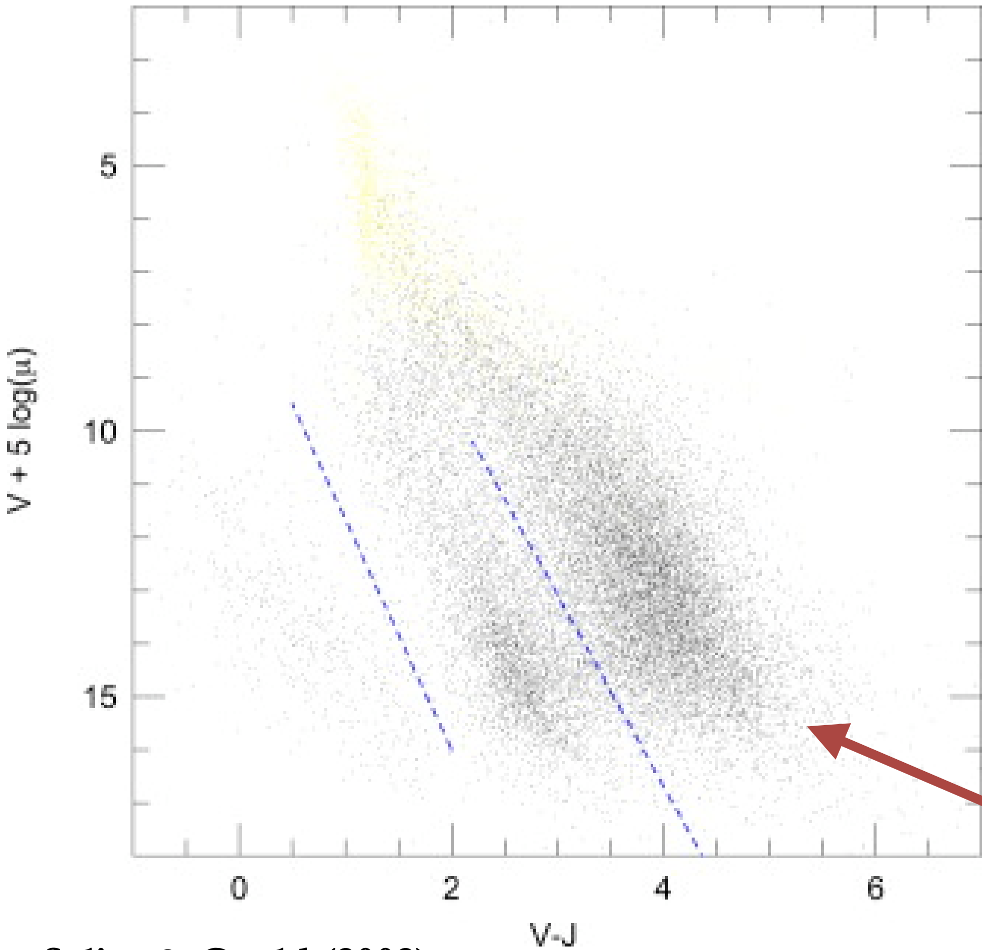
$$H_b \equiv m_b + 5 \log \mu + 5$$

which is equivalent to

$$H_b = M_b + 5 \log V_{tan} + 3.38$$

where M_b is the absolute magnitude of a source and V_{tan} is its tangential velocity (motion in the plane of the sky)

Brown dwarfs will have large values of H_b because M_b is large.



Salim & Gould (2002)

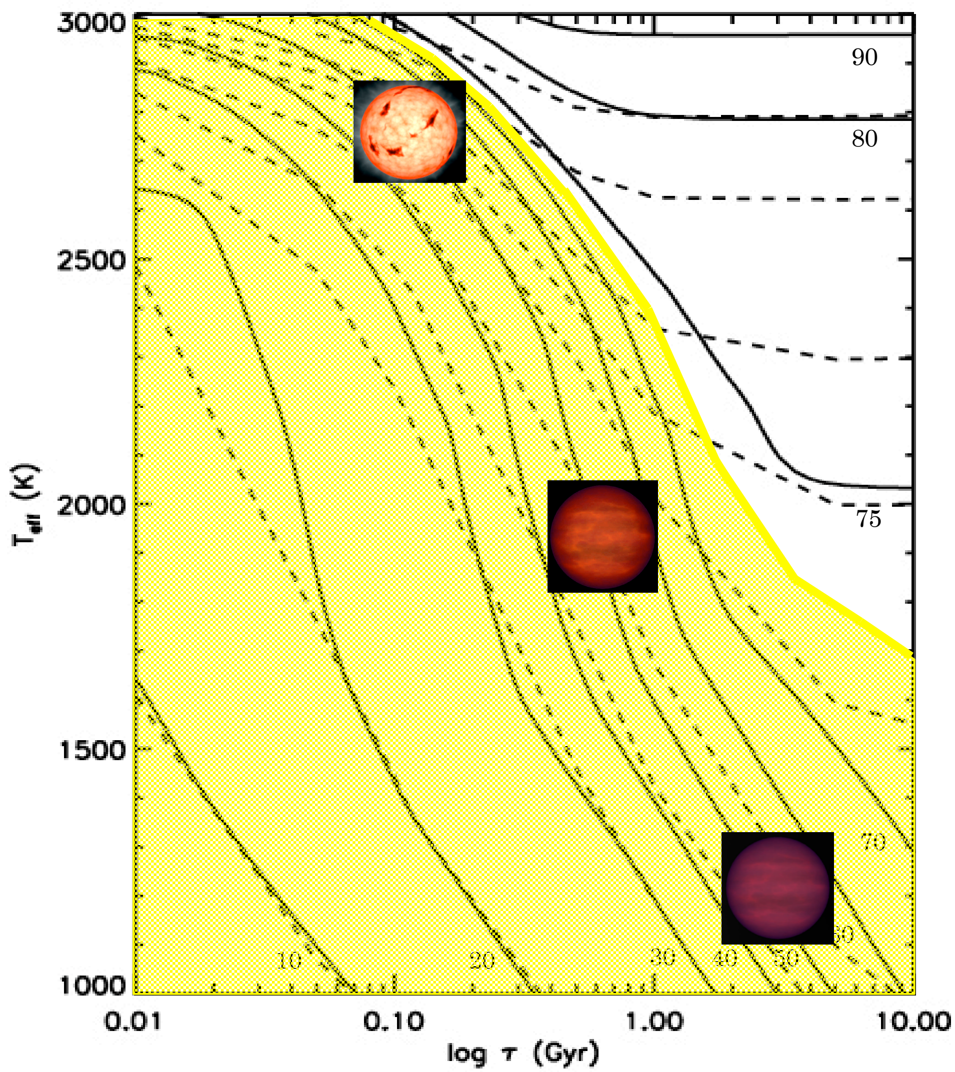
Both color and reduced proper motion can be used to make a “pseudo” color-magnitude diagram.

NB: Requires a proper motion survey - several now underway!

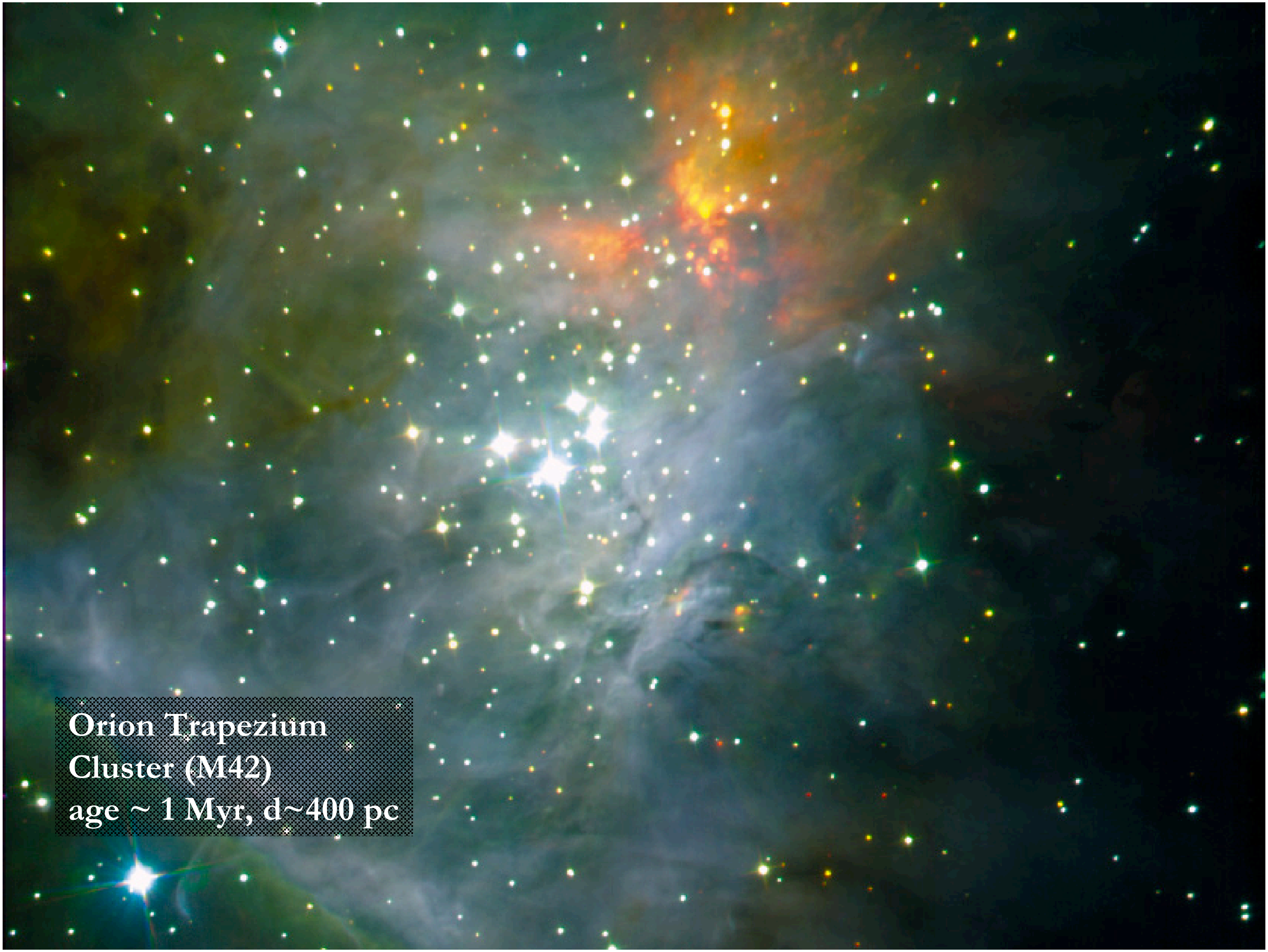
Brown Dwarfs

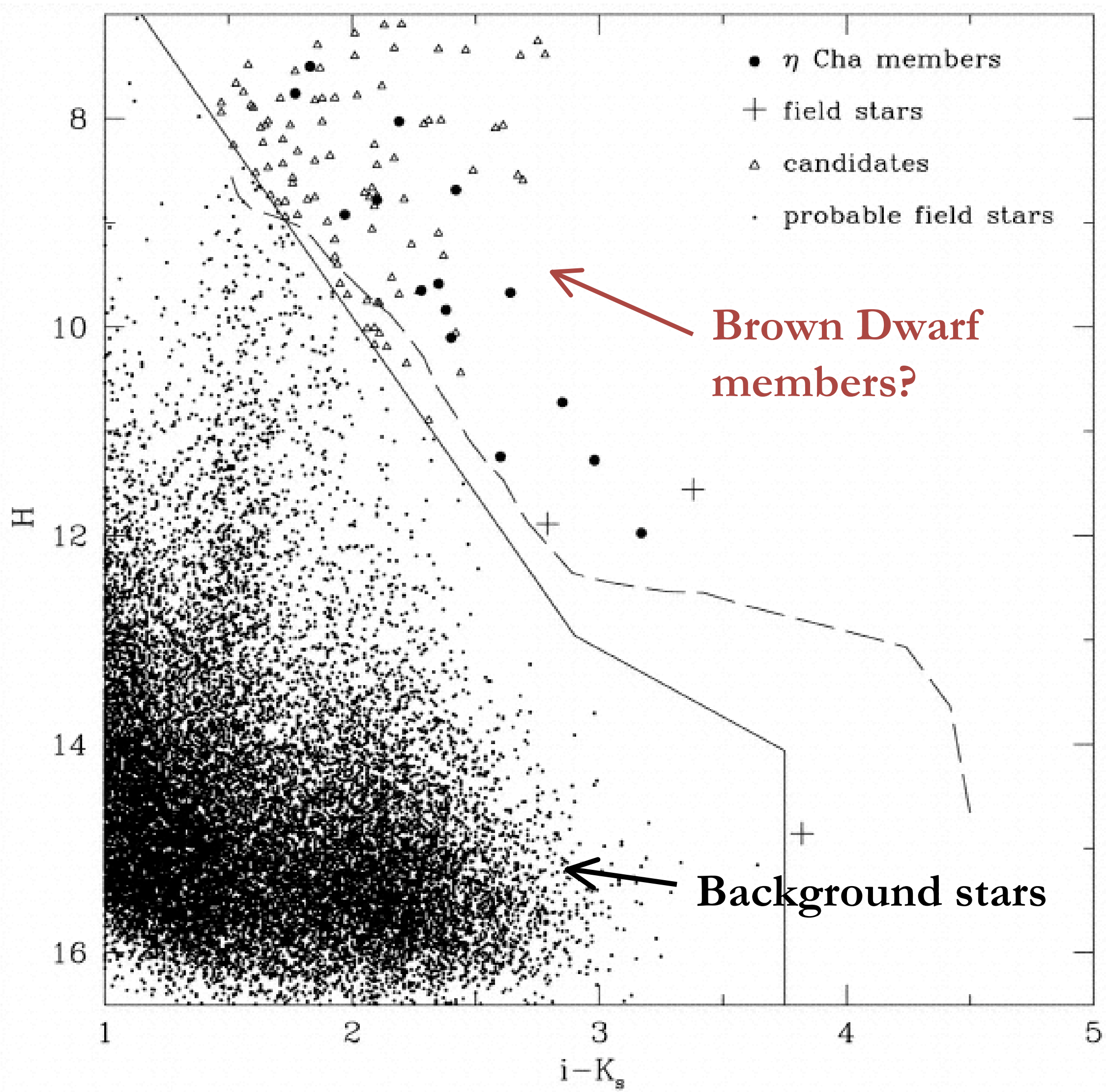
Searching for field brown dwarfs

- Pros:
  - Nearest brown dwarfs to the Sun, more easily studied, can find faintest/coldest brown dwarfs
  - Can use existing wide field near infrared and proper motion surveys
- Cons:
  - Very faint, so very rare
  - Can't constrain individual properties well - unknown distance, age, mass, etc.
  - Selection can be difficult, biases may be present



Brown dwarfs are brighter when they are young, so one strategy is to look in young star forming regions.

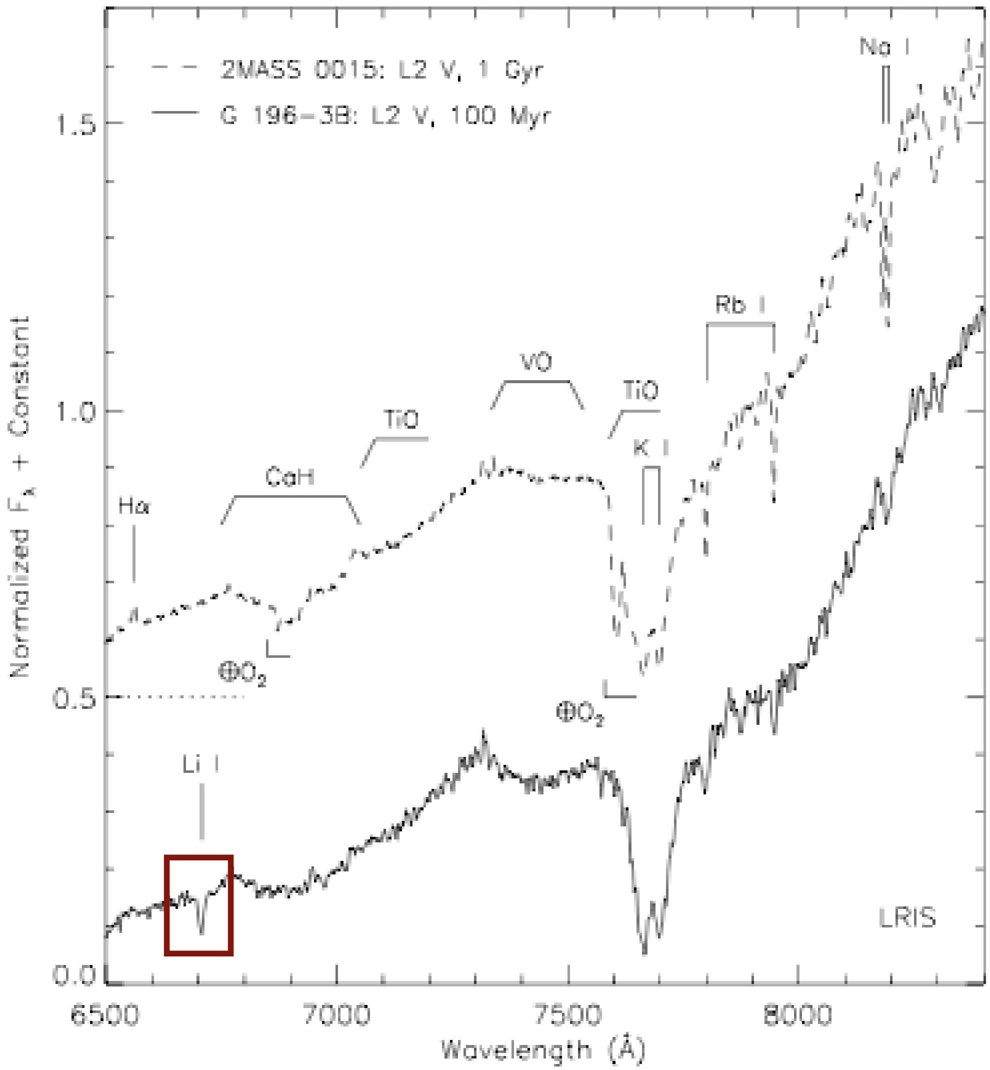

Orion Trapezium
Cluster (M42)
age ~ 1 Myr, d~400 pc



Luhman (2004)

Cluster members can be segregated in a color-magnitude diagram.

Problem: young brown dwarfs are M dwarfs, most common field stars/contaminants!



The Lithium Test

Li I is destroyed by nuclear reactions in the cores of stars/BDs more massive than 0.065 $M_\odot$ (e.g., Rebolo et al. 1992)

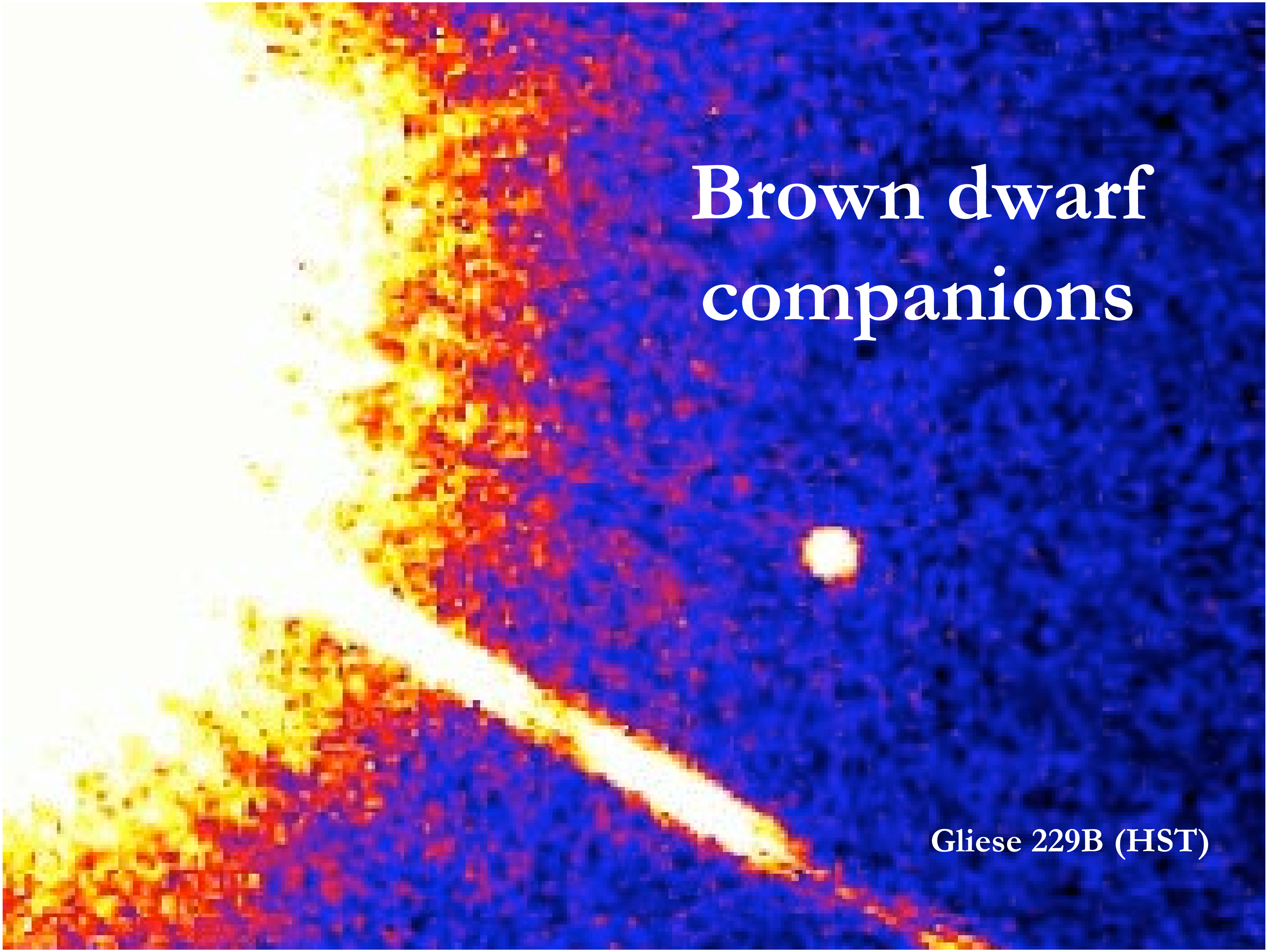
Fully convective interiors means <u>all</u> Li is destroyed, including photospheric Li

Detection of Li I in the spectrum of an M/L dwarf implies that it is a young brown dwarf

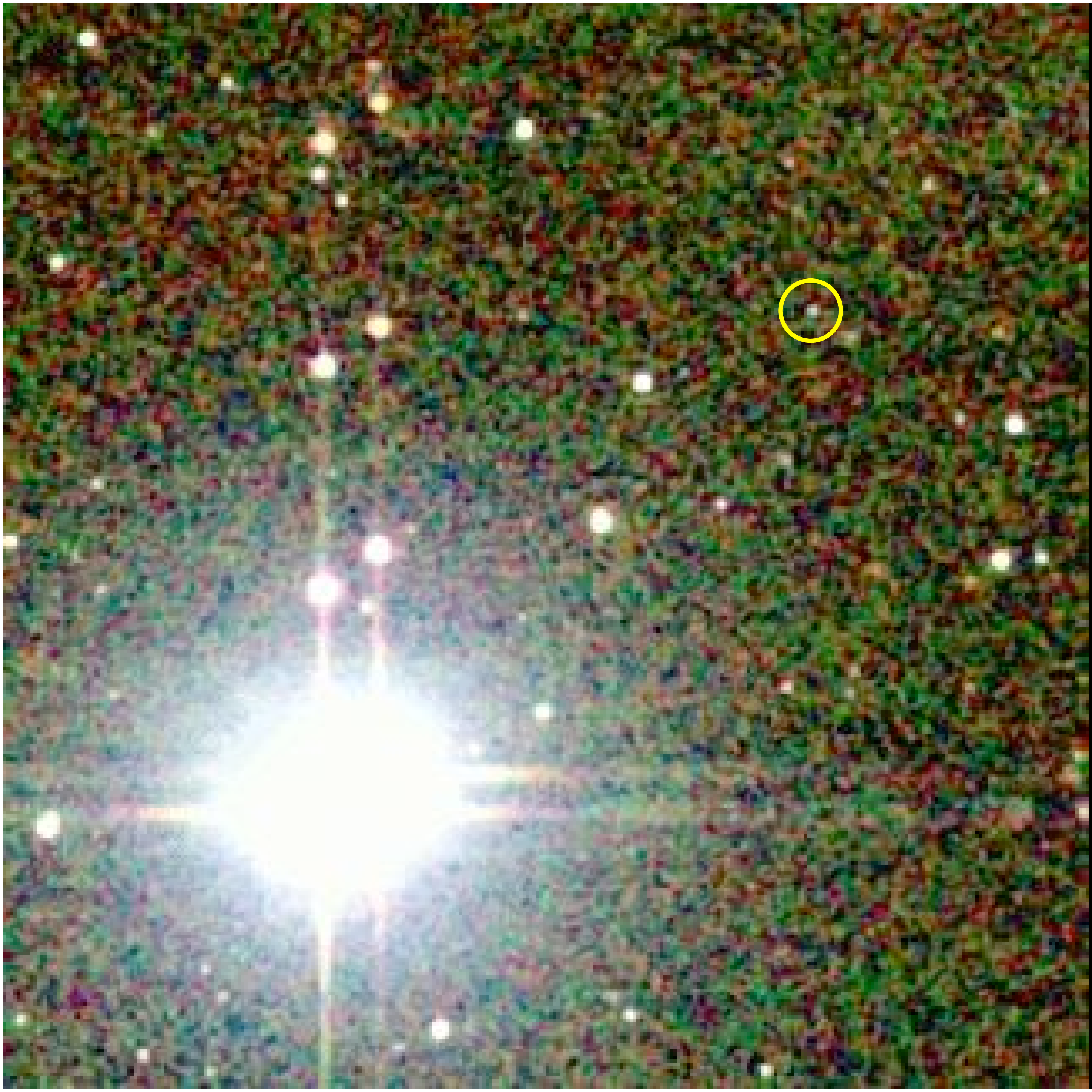
Searching for young brown dwarfs

- Pros:
  - Intrinsically brighter, so can find very low mass brown dwarfs when they are still hot
  - Ages are generally well constrained
- Cons:
  - Star forming regions are generally distant (> 100 pc)
  - Reddening effects may reduce brightness gains
  - Source confusion is a problem, follow-up required

Brown dwarf companions



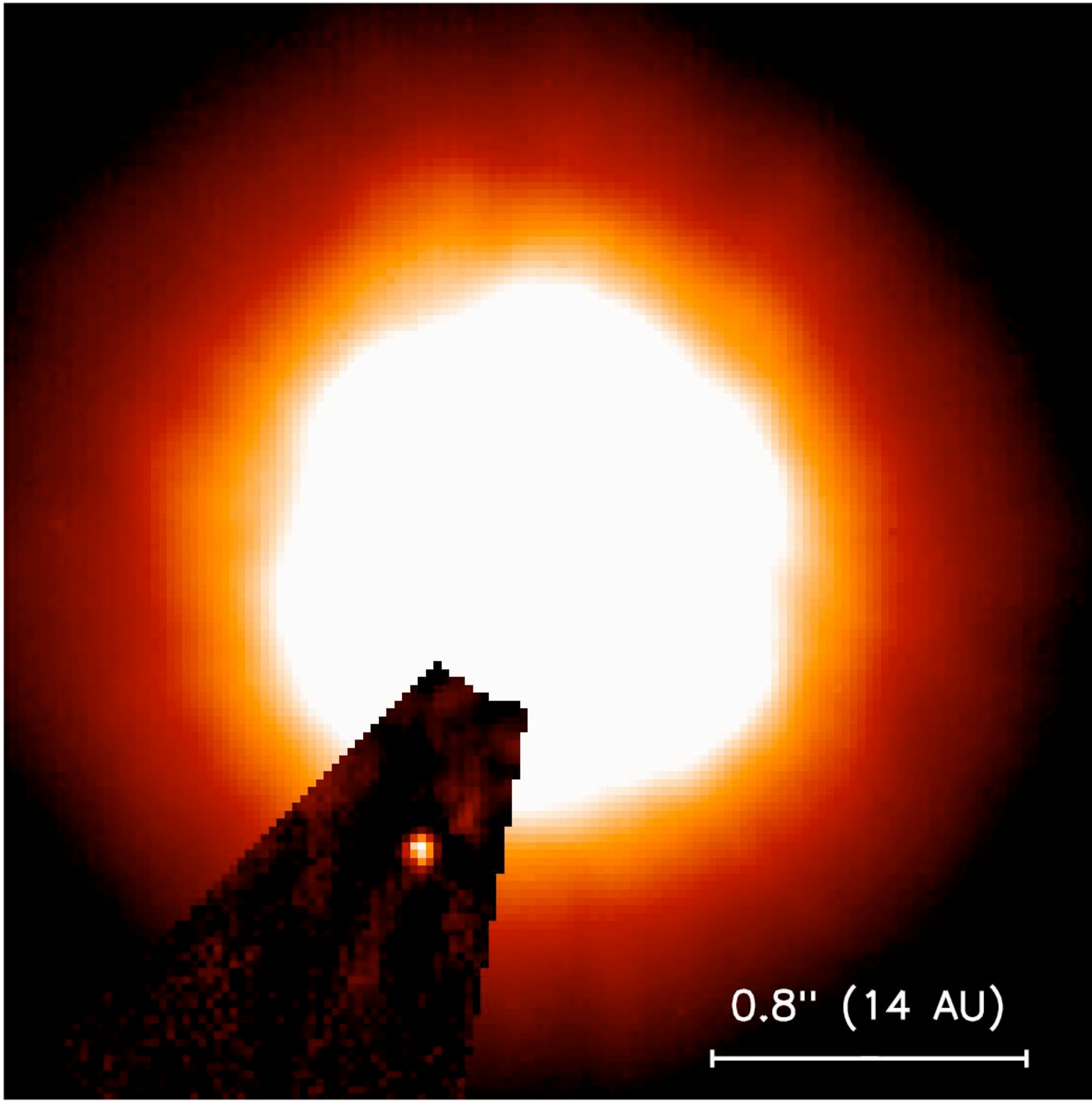
Gliese 229B (HST)



An easy case: Gliese 570D

(Burgasser et al. 2000)

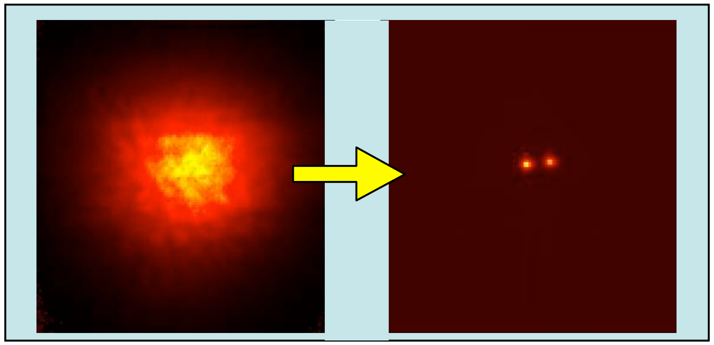
2MASS JHK_s

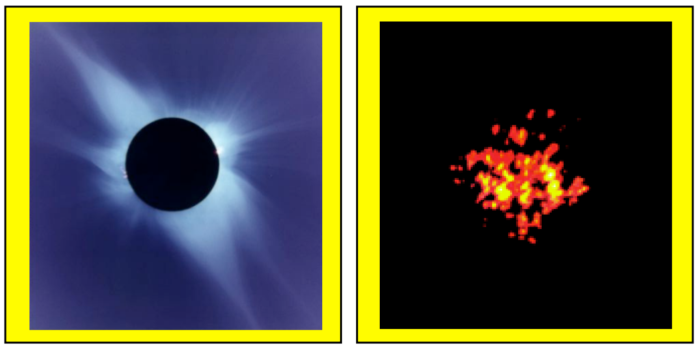


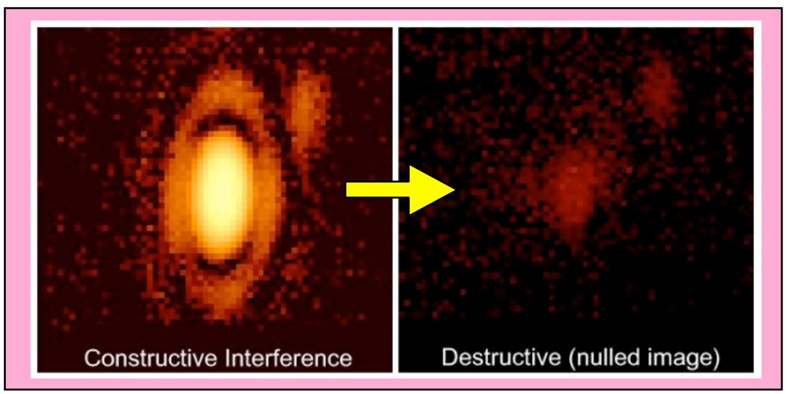
A hard case: HR 7672B

(Liu et al. 2002)

Gemini AO







Techniques for finding BD companions

- Direct imaging (wide companions)
- Radial Velocity (rare!)
- Speckle Interferometry
- Adaptive Optics
- Coronography
- Spectral Difference Imaging
- Interferometric nulling
- Combinations of the above!*

Correct for atmospheric blurring

*See next Thursday's Astrophysics Colloquium by Ben Oppenheimer

Searching for BD companions

- Pros:
  - Can target nearby stars to find faintest companions
  - Distance, composition and age constraints from primary
  - Only need to search a limited area
- Cons:
  - Close in companions hard to see in glare of star
  - Brown dwarf companions to stars are rare (~5%)
  - Must confirm companionship (e.g., common proper motion)

How to find a brown dwarf

- Look in the near-infrared
- Look for objects with weird (red) colors
- Look for high proper motion objects
- Look in young star forming regions
- Look around nearby stars