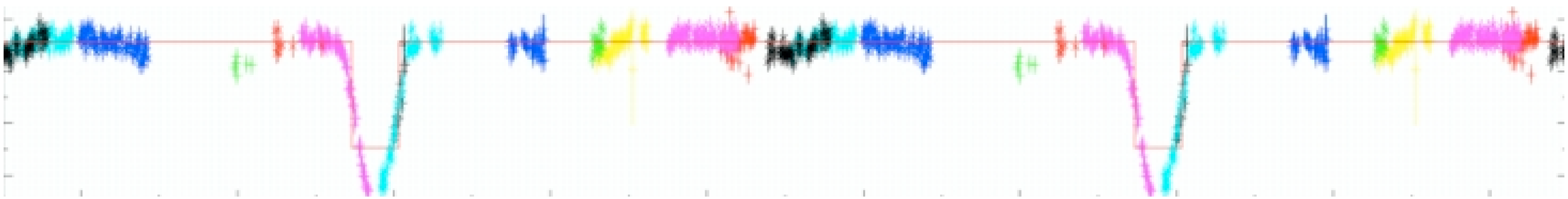
The Monitor project

Transits, eclipses & rotation in young open clusters



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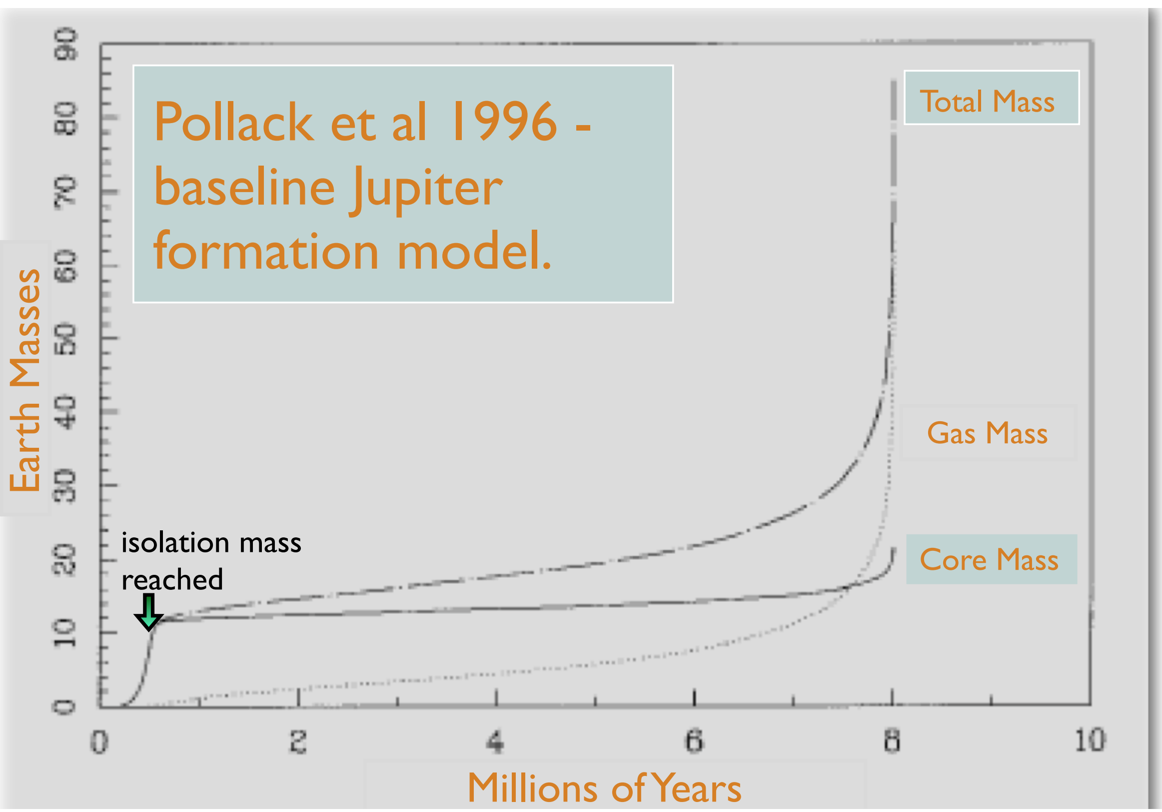
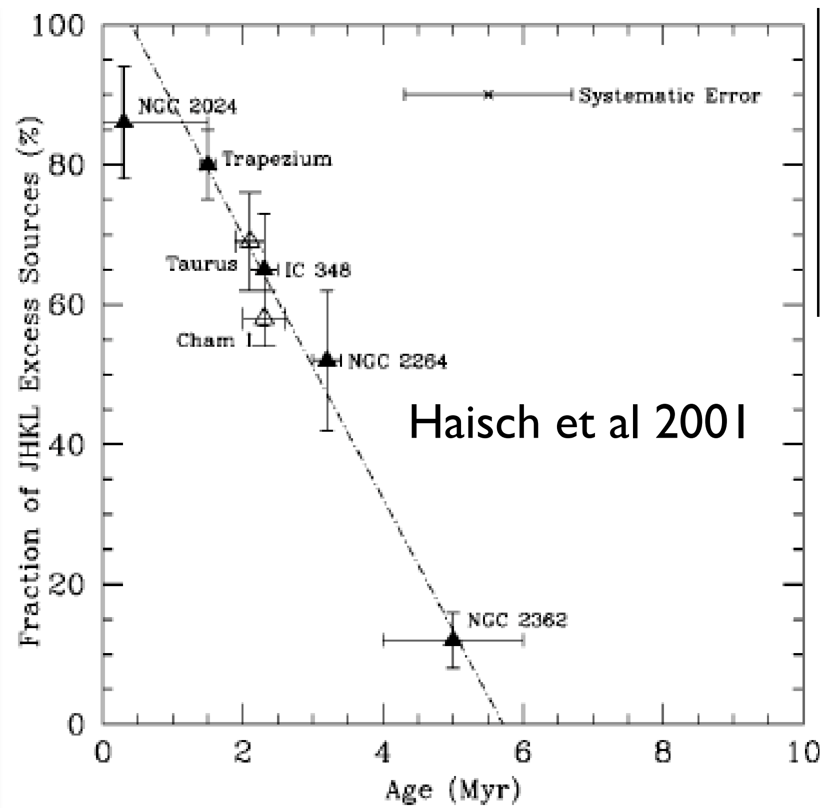
What is Monitor?

- Photometric monitoring survey of young (1-200 Myr), rich, compact and nearby open clusters
- 2-4 m telescopes, 0.25-1 sq.deg. FOV, mainly I-band
- ~100 hours / cluster either in nights or in hourly blocks, 3-15 min sampling
- Goal I: detection of transits by planets, brown dwarfs and very low-mass stars in the light curves of low-mass cluster members
- Goal II: detection of rotation periods
- Additional science: flaring, accretion, pulsation, eclipses / transits in background stars

Motivation - eclipses

Can planets form as fast as disks evaporate?



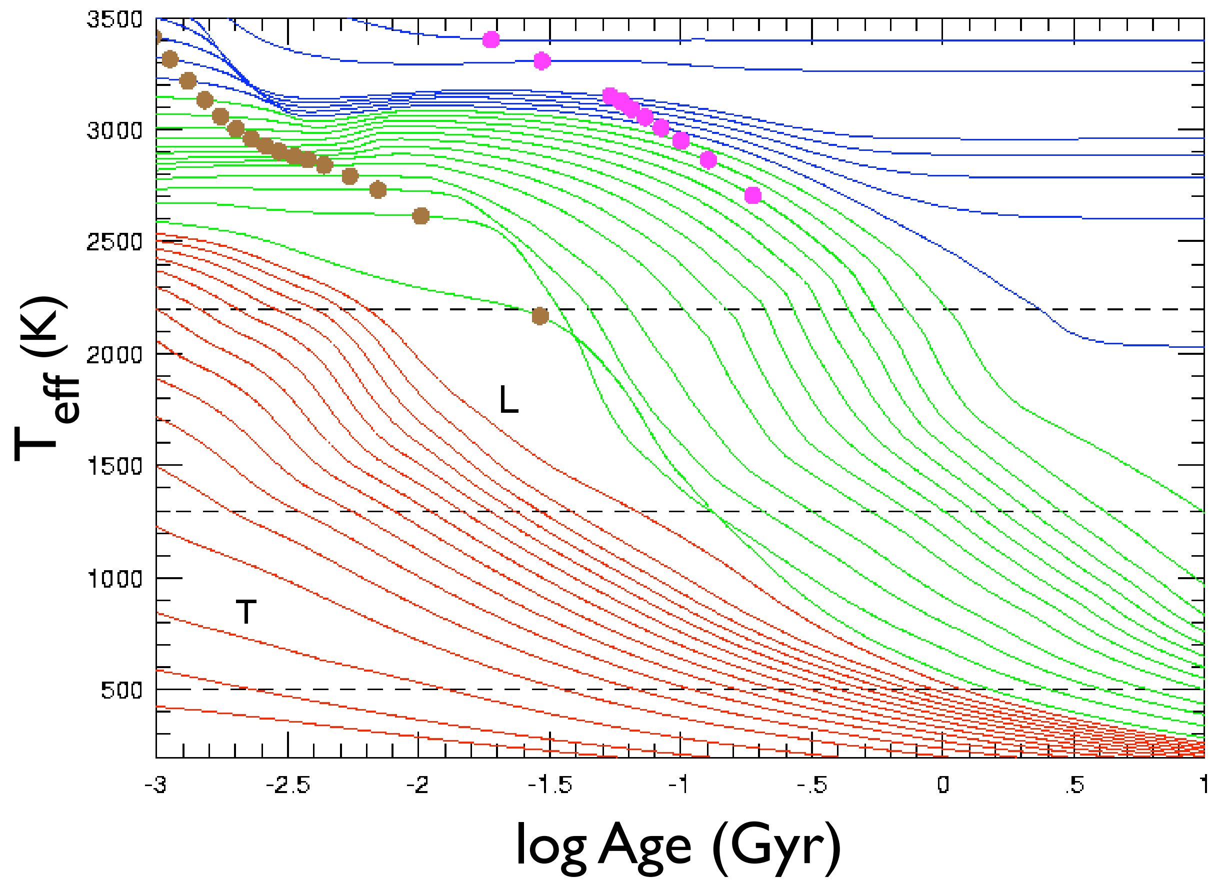


slides from G. Laughlin (2005)

Motivation - eclipses

Can planets form as fast as disks evaporate?

How bright & large are young brown dwarfs and planets?



Burrows et al. 1997

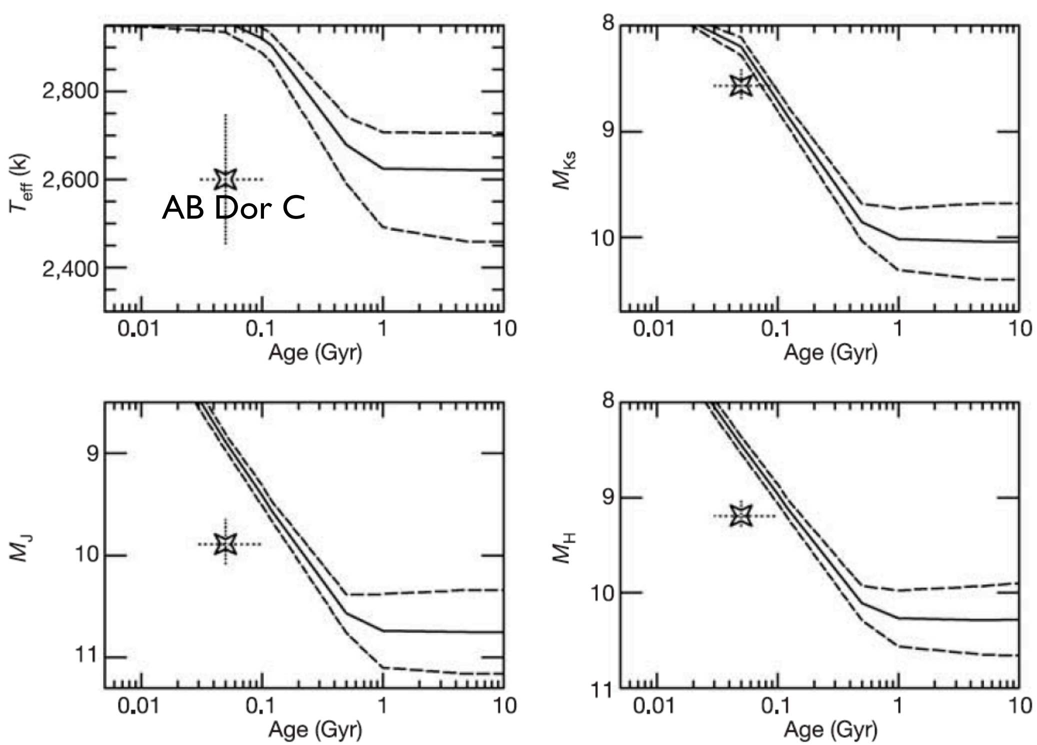
Motivation - eclipses

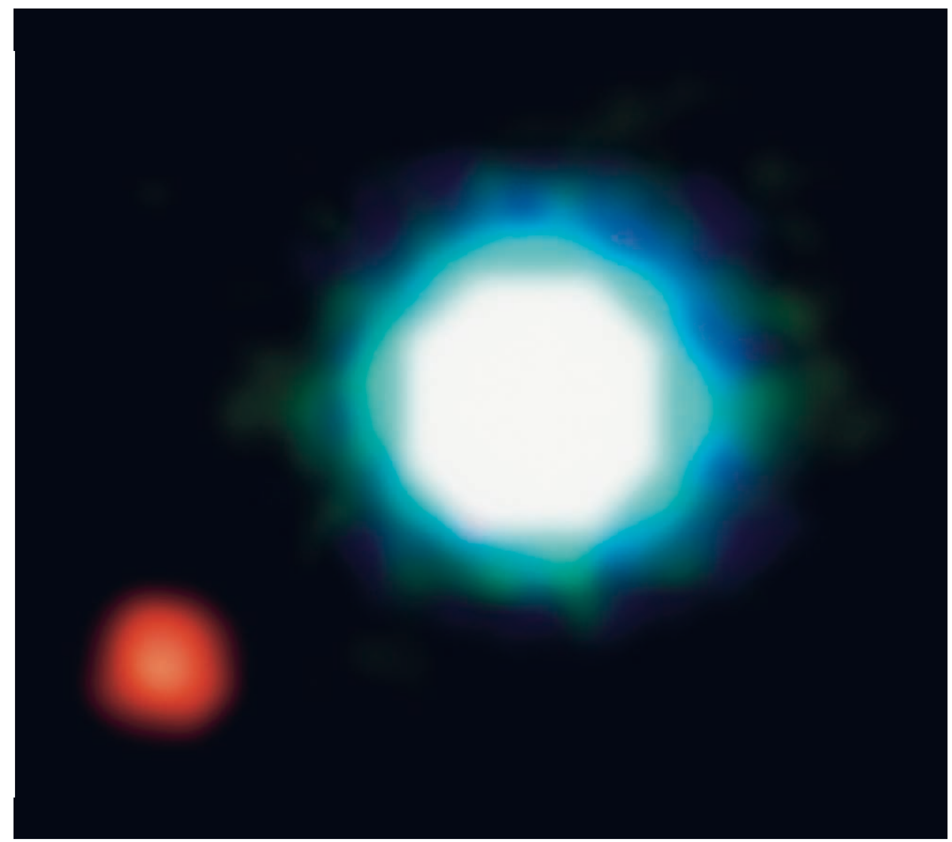
Can planets form as fast as disks evaporate?

How bright & large are young brown dwarfs and planets?

Chauvin et al. 2005a,b

Close et al. 2005





Motivation - eclipses

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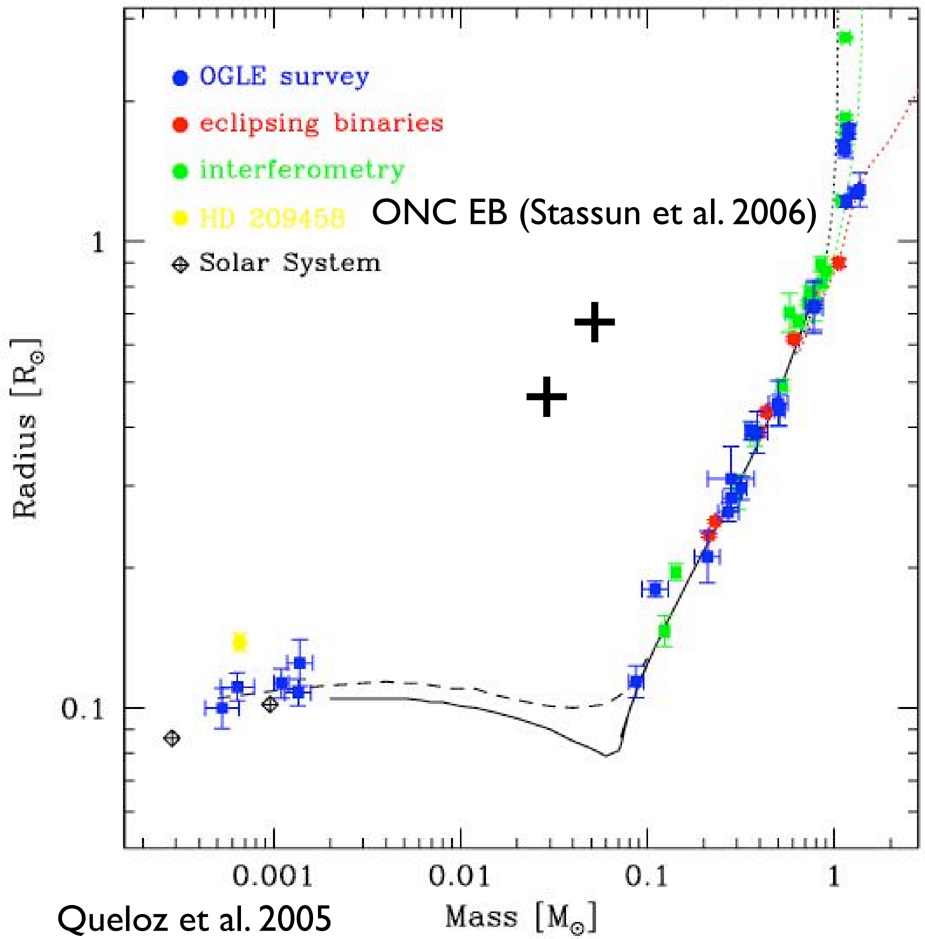

Queloz et al. 2005

Motivation - eclipses

Can planets form as fast as disks evaporate?
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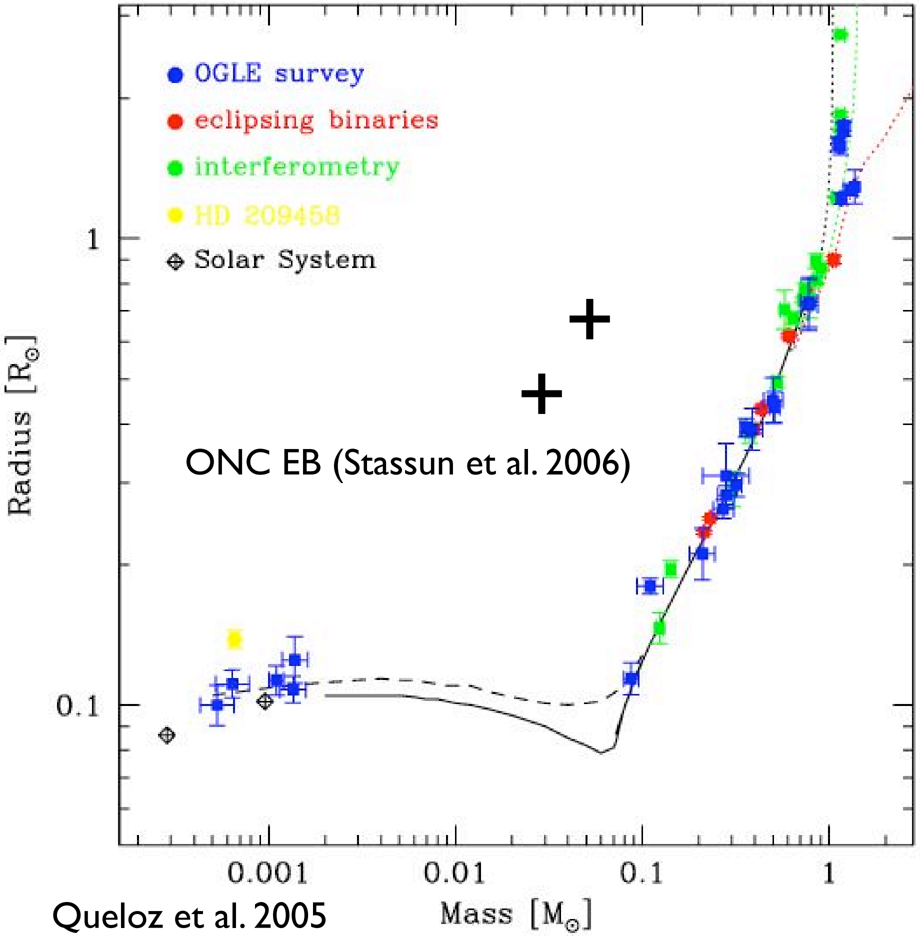


Queloz et al. 2005

Motivation - eclipses

Can planets form as fast as disks evaporate?
How bright & large are young brown dwarfs and planets?
A crucial and unchartered area of parameter space

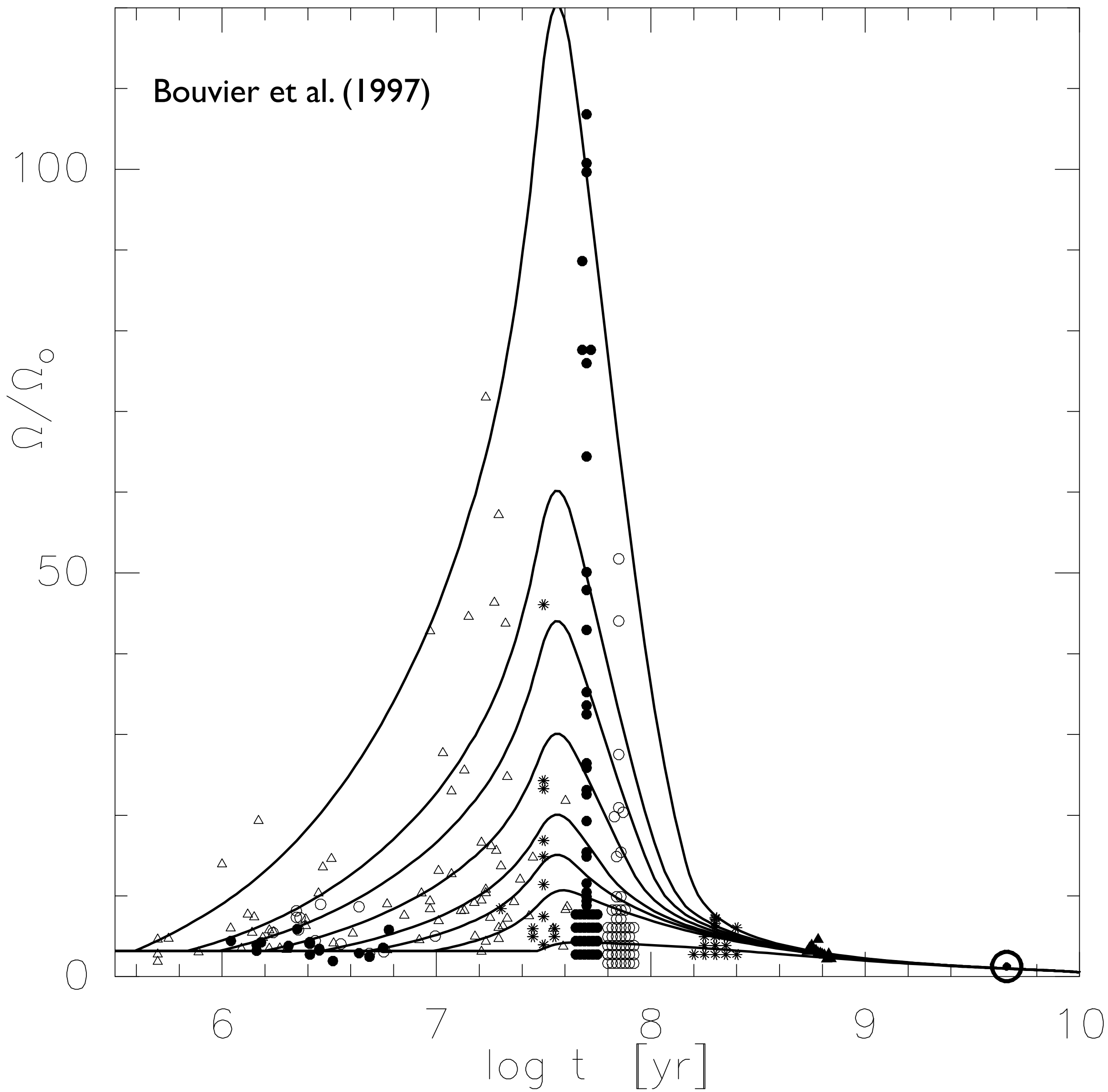
- ~ 170 known exoplanets, mostly from RV surveys, 9 that transit
- Few K & M eclipsing binaries
- 1 eclipsing brown dwarf: OGLE-TR-122 (Pont et al. 2005)
- But all orbit main sequence stars with ill-known ages
- 1 M-type EB in M35 (Hebb et al. 2004)
- 1 brown dwarf EB in ONC (Stassun et al. 2006)
- Monitor should detect significant numbers of EBs and several transiting planets

Detection rate estimates

(Aigrain et al. 2006, in prep.)

- Adapted approach of Gaudi et al. 2005 (for surveys of field stars such as OGLE) to young open clusters (see also Pepper et al. 2005, for older clusters).
- Ingredients include
  - cluster mass function, age, distance, extinction
  - mass-radius and mass-radii relations from Baraffe et al. 1998 (stars / BDs) and Burrows et al. 1997 (planets)
  - companion incidence and period / mass distribution from literature
  - real (observed) time distribution of observations and noise properties
- Predicts ~80 EBs and ~8 transiting planets over the Whole of Monitor
- Several refinements need to be made, including accounting for systematics and magnitude limits for RV follow-up

Motivation - rotation



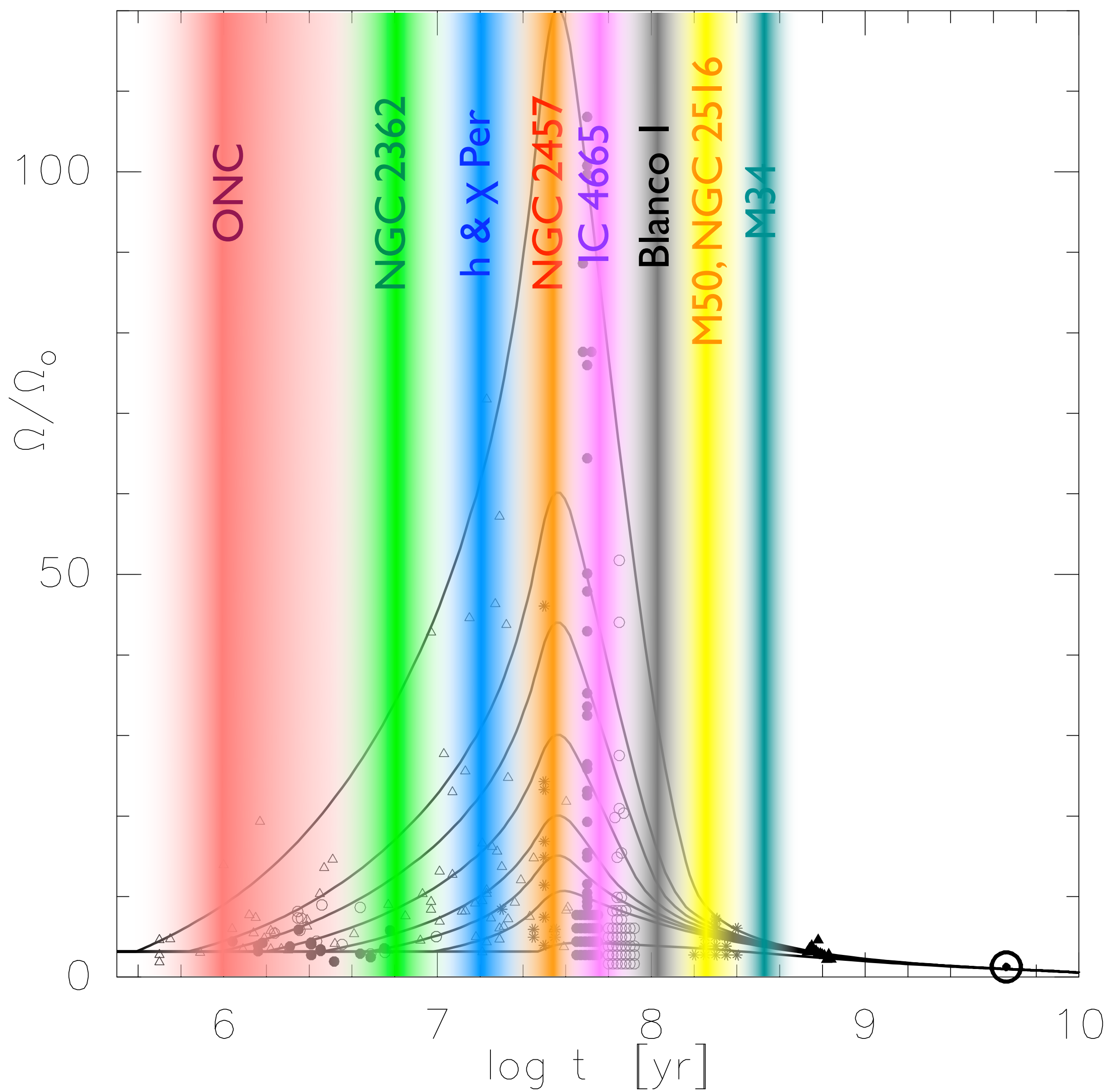
Disk-locking stage: rotation rate essentially constant

Once disk connection is broken, contraction leads to fast spin-up

Maximum rotation is reached at ZAMS

Angular momentum loss driven by magnetized wind then leads to slow spin-down

Motivation - rotation



Monitor target clusters cover the entire evolutionary sequence up to the early MS

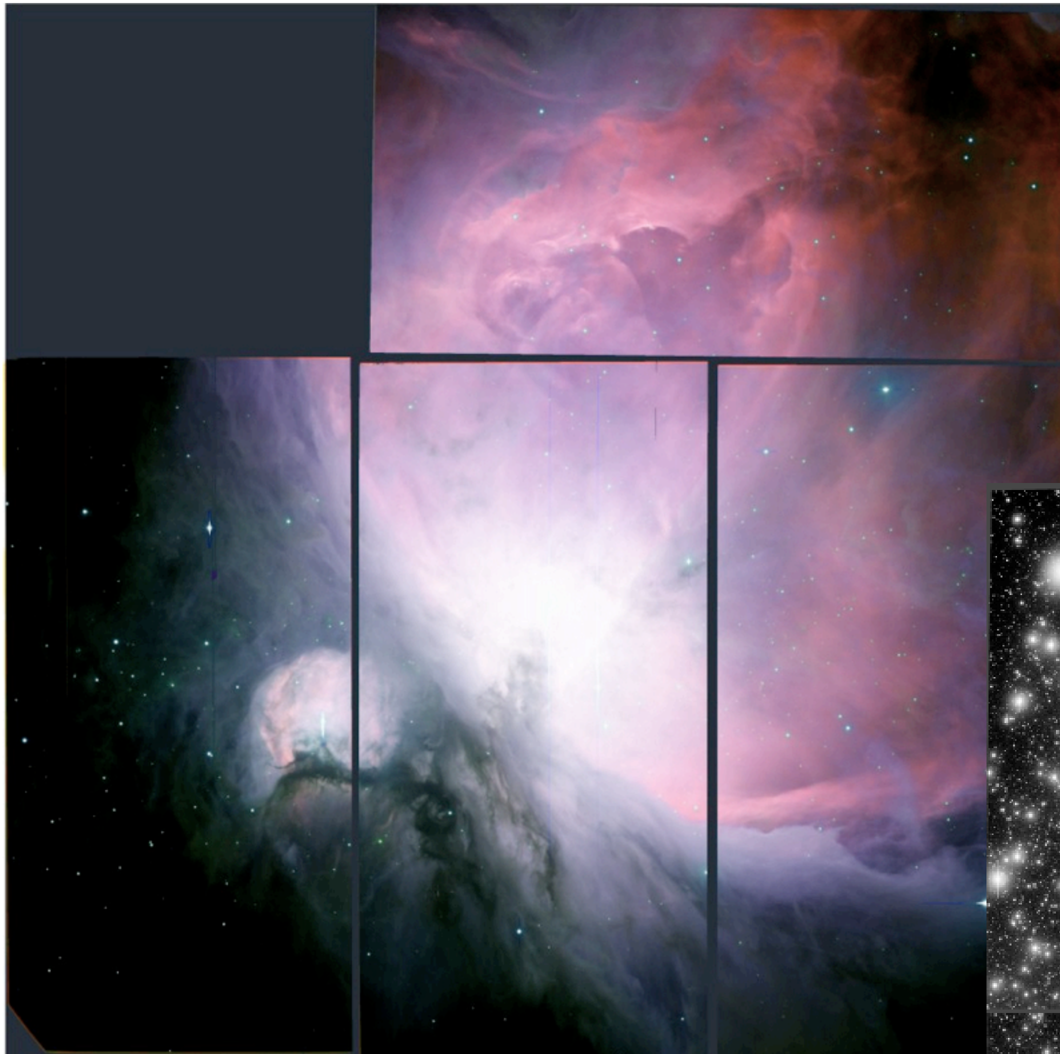
In the TTauri phase, examine link between rotation and presence of disks

Will also reach down to the BD regime, where the star-disk connection may be altered

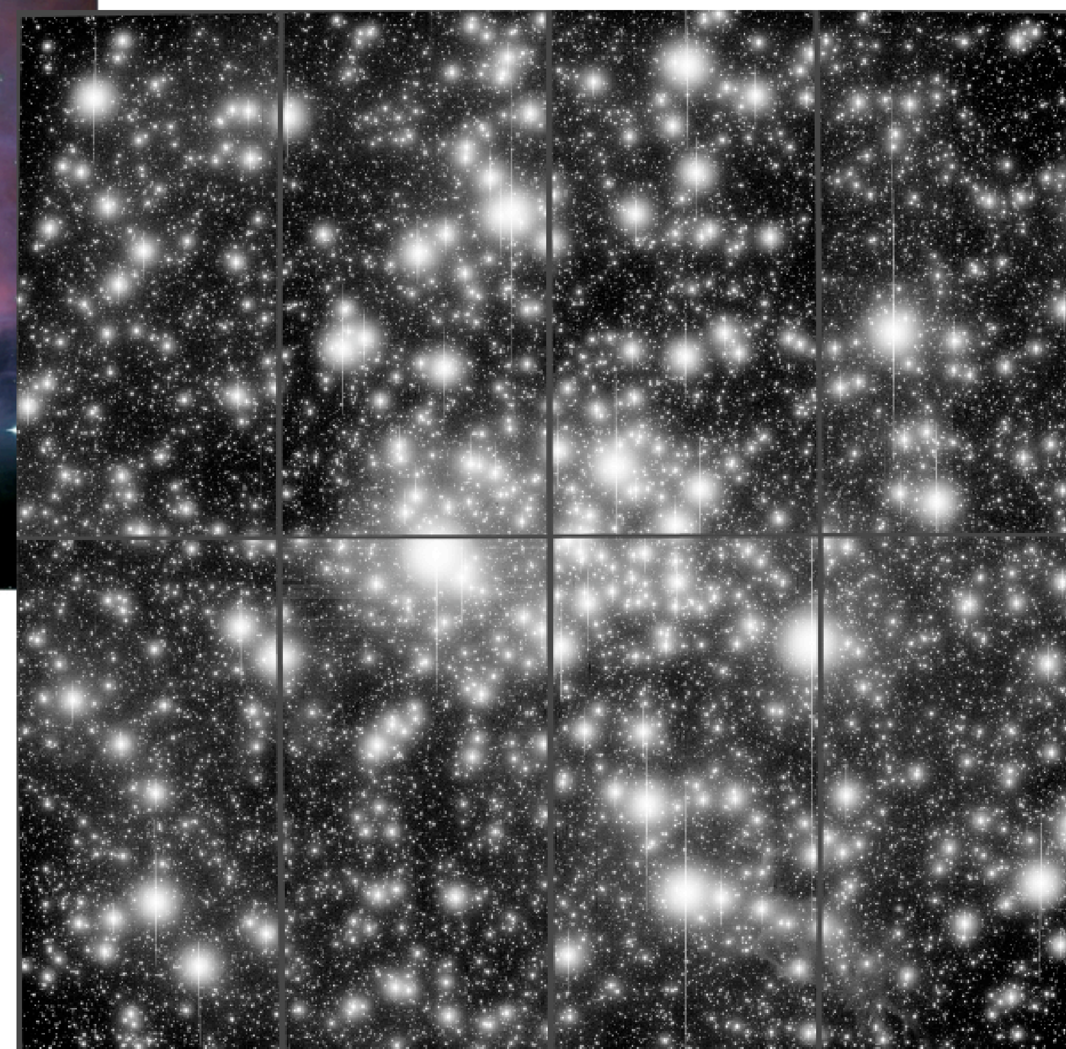
Will cover in detail the ZAMS phase, which is crucial for constraining spin-down models

Observations

semester	telescope	instrument	time awarded	targets	strategy	status
2004B	INT 2.5m	WFC	20 nights	ONC M34	nights	analysed
2005A	CTIO 4m	Mosaic II	6 nights	NGC 2632 M50	nights	analysed
	CFHT 3.6m	MegaCAM	40 hours	IC4665	blocks	under analysis
	ESO 2.2m	WFI	50 hours	Blanco 1	blocks	being reduced
2005B	ESO 2.2m	WFI	150 hours	Blanco1 NGC 2457	blocks	awaiting data
	CFHT 3.6m	MegaCAM	40 hours	M34 h & X Per	blocks	awaiting data
		WIRCAM (IR)	40 hours	ONC	blocks	no data
	INT 2.5m	WFC	10 nights	ONC	nights	no data
	CTIO 4m	Mosaic II	8 nights	NGC 2362 M50	nights	being reduced
2006A	CTIO 4m	Mosaic II	8 nights	NGC 2516	nights	



ONC (1 Myr)
fake colour V, Hα, i image
INT + WFC (33’x33’)
~ 2000 sources (almost all likely members)



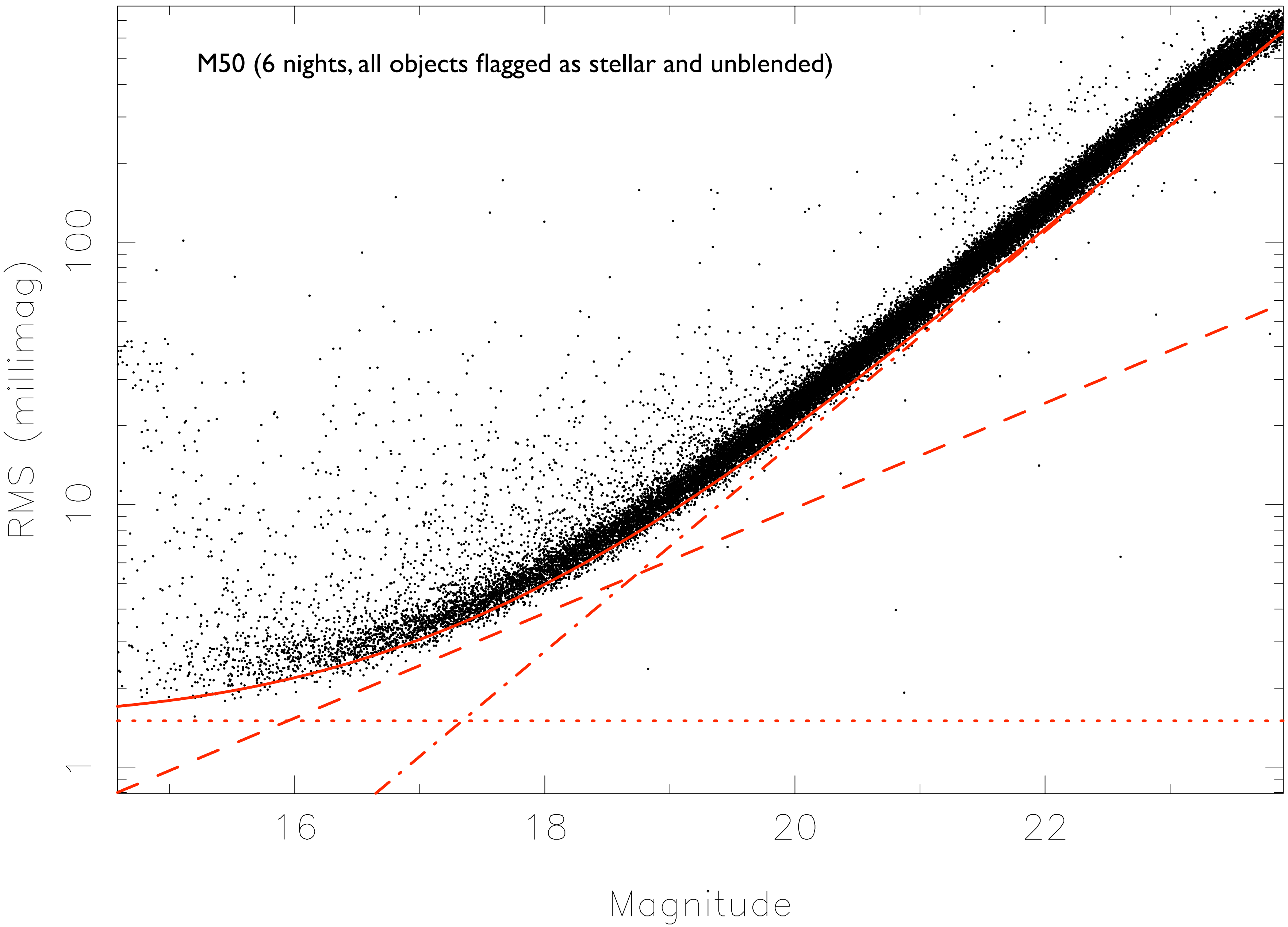
M50 (130 Myr)
greyscale i-band image
CTIO 4m + Mosaic (40’x40’)
~ 80000 sources (~8000 likely members)

Data reduction & light curves

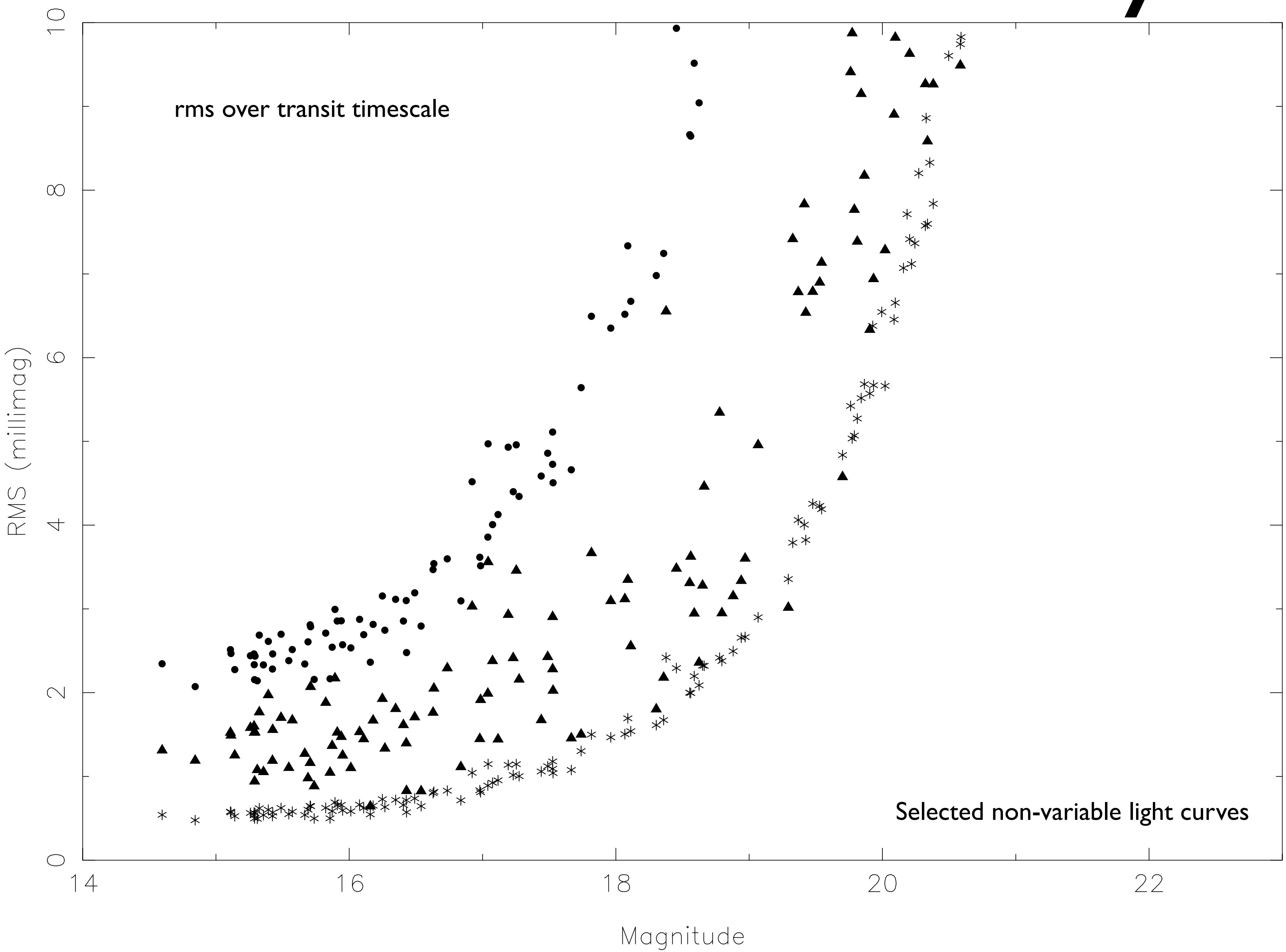
(J. Irwin et al. 2006a, in prep.)

- All basic reduction and calibration steps carried out using standard INT Wide Field Survey (WFS) pipeline developed by the Cambridge Astronomy Survey Unit (Irwin & Lewis 2001)
- Co-located aperture photometry:
  - Refine astrometric solution to 0.1" accuracy
  - Generate master catalogue 'noise free' stacked master frame, flagging likely blends and non-stellar objects
  - Perform aperture photometry at master catalogue position on each frame, choosing from a range of aperture sizes to maximise SNR in aperture
  - Background estimated by interpolating across grid of 64x64 pixel bins
- Fit 2-D polynomial surface to map of light curve residuals versus x-y position to remove systematics that vary temporally as a function of position

Photometric accuracy



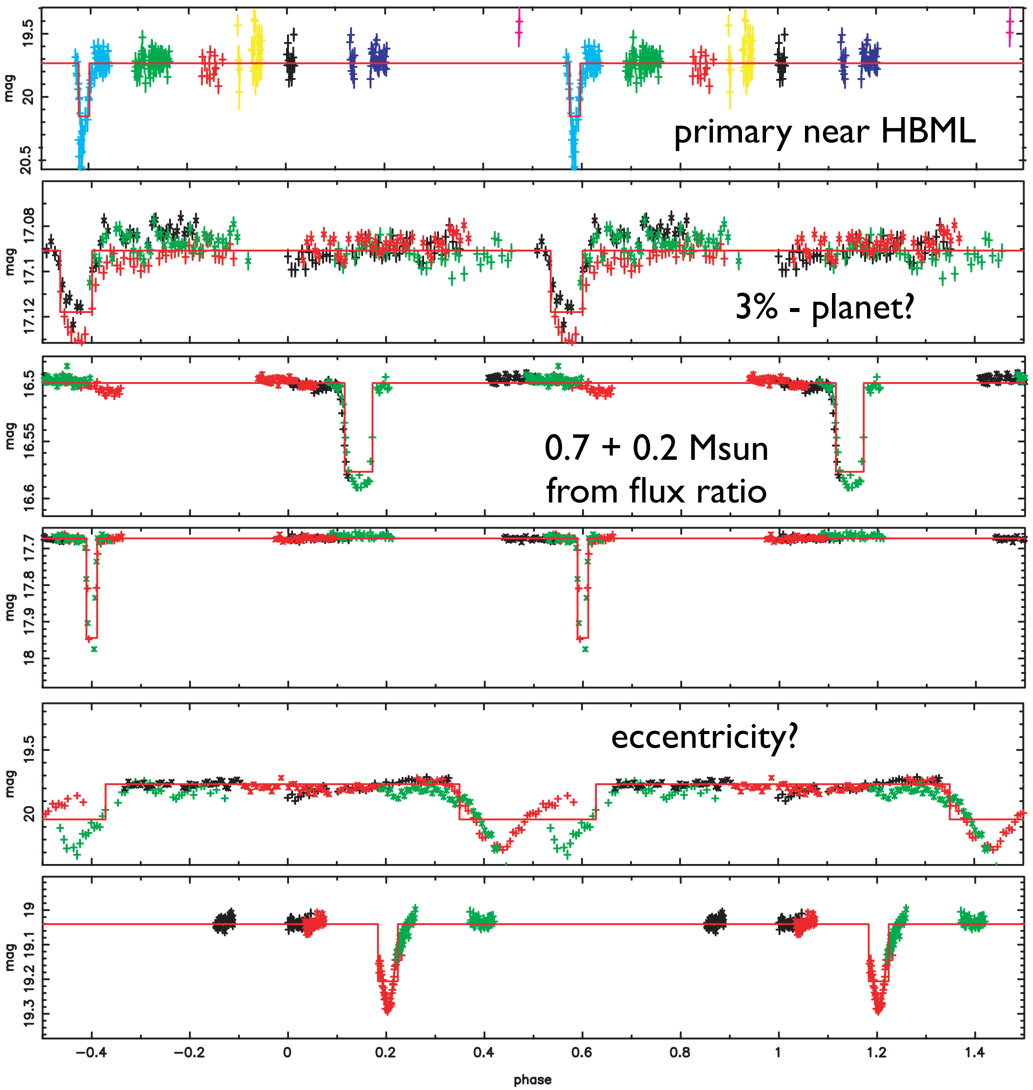
Photometric accuracy



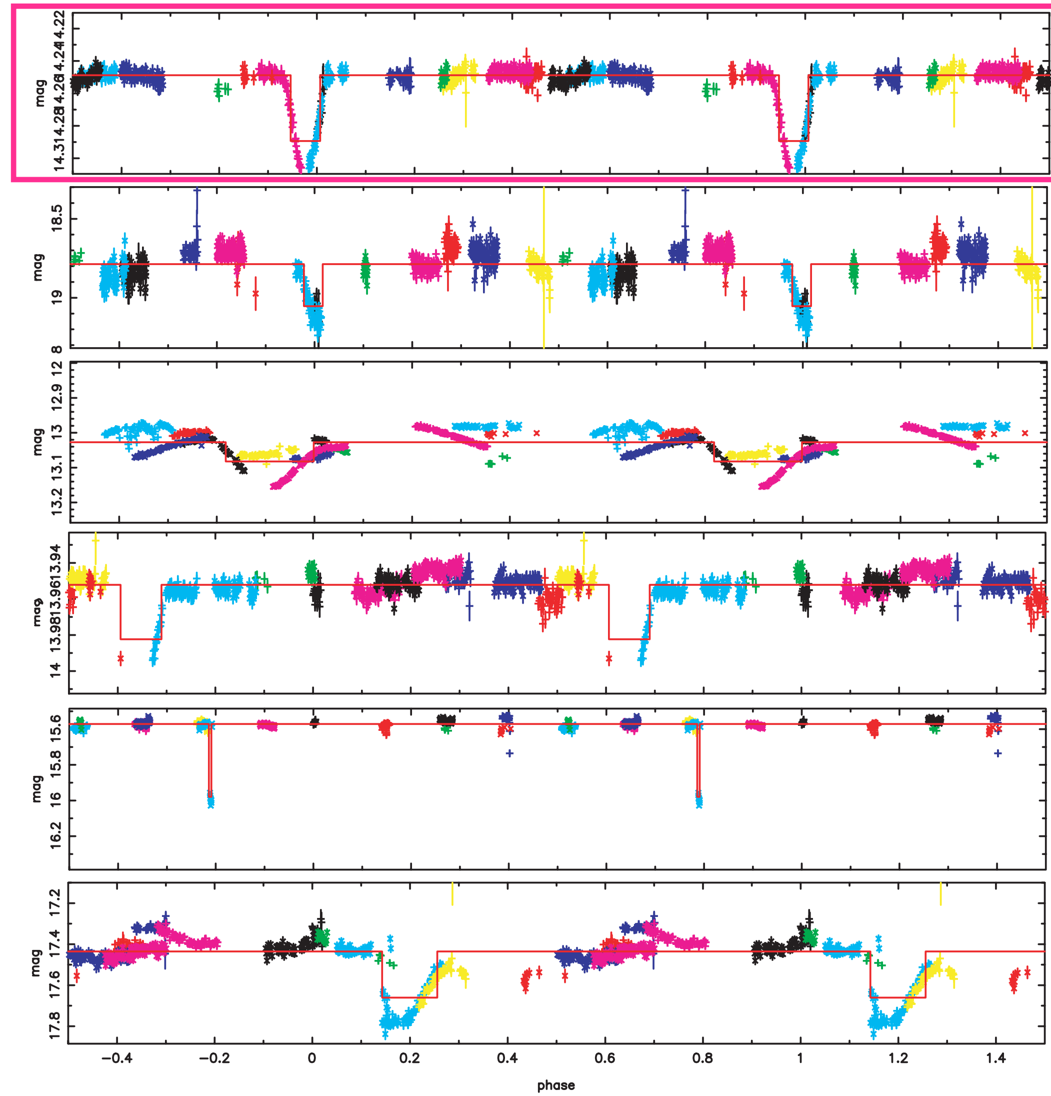
Transit / eclipse detection strategy

- Systematics removal (PCA-like algorithm of Tamuz et al. 2005)
- Membership selection from V, V-I CMD using empirical sequence
- In young clusters with active stars, high pass filter or sine fit to remove rotational modulation
- Transit search algorithm (Aigrain & Irwin 2005) for box-shaped transits (good enough approximation for most eclipses)
- Currently, correlated noise implies we have to set relatively high detection threshold - all our candidates were independently identified by eye
- Modification of algorithm to account for correlated noise under implementation

Eclipse candidates from 2004-2005

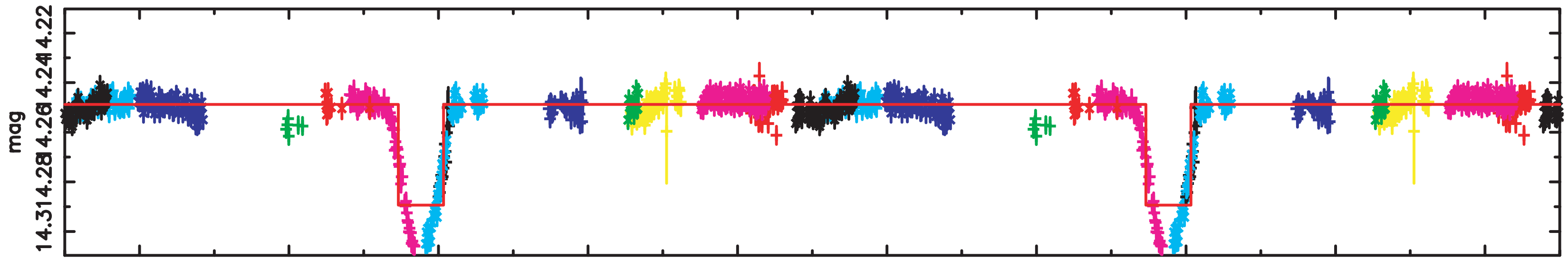


M34, M50, NGC 2362



ONC

ONC-1-290

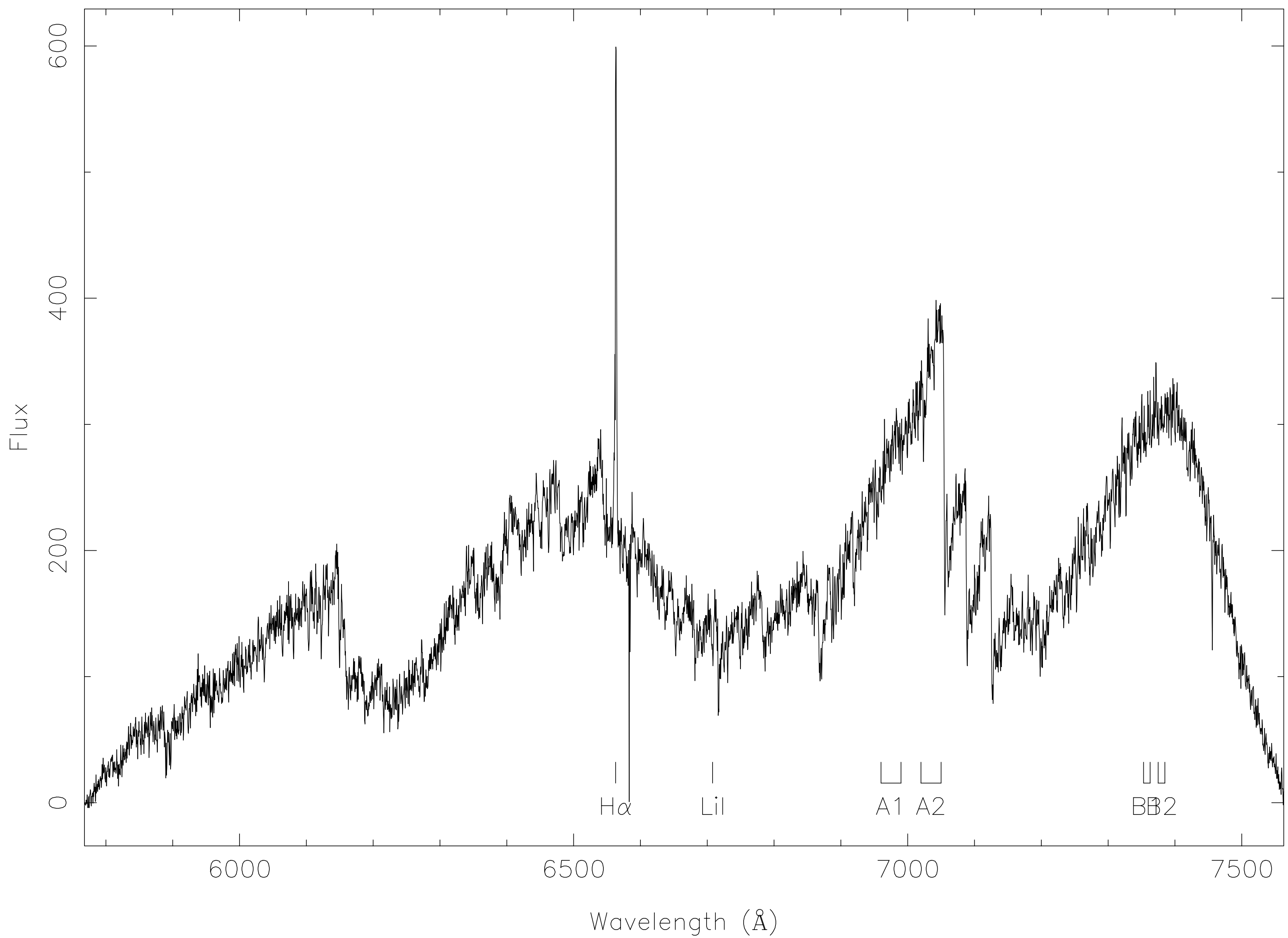


- $I = 13.82$, $V = 16.92$, $P = 2.65$ days, $d = 0.2$ days, $\Delta F/F = 0.06$
- Grazing?; Hillenbrand (1997) membership probability 99%
- $M_1 \sim 0.50\ \mathrm{M}_\odot$, $R_1 \sim 2.08\ \mathrm{R}_\odot$ (1 Myr NextGen models)
- R_1, $\Delta F/F \Rightarrow R_2 > 0.51\ \mathrm{R}_\odot$
- $M_2 \sim M_{\rm Jup} \rightarrow K \sim 0.4\ \mathrm{km\ s^{-1}}$, $M_2 \sim 0.1\ \mathrm{M}_\odot \rightarrow K \sim 42\ \mathrm{km\ s^{-1}}$

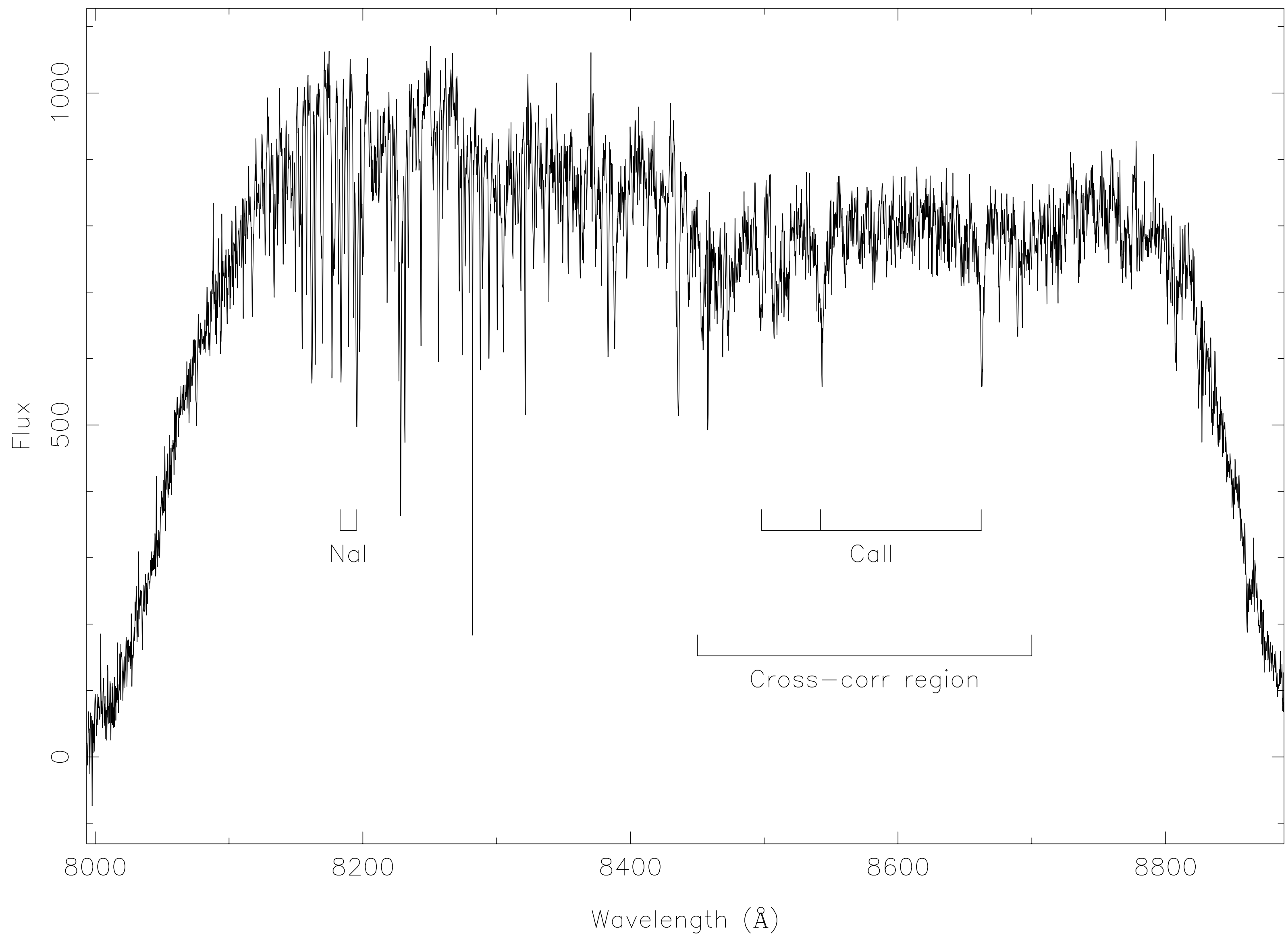
Spectroscopy to date

- Spectroscopy is needed to confirm cluster membership and measure companion mass
- Membership: youth indicators (Lithium, Halpha emission), gravity sensitive lines
- Spectral type: e.g. using Kirkpatrick (1991) relative flux indices
- Companion mass: radial velocities, e.g. using cross-corrleation with standards over CaII infrared triplet region at 8500 A
- Not much luck with 2006A proposal round
- WHT/ISIS
- Red arm 8085-8075 A, R~5000, get RV accuracy ~ 4 km/s for SNR~10
- Blue arm 5950-7350 A, R~2000
- 1 night in Dec 2005, few hours in Feb 2006, poor seeing in both... 2 epochs of two objects, 1 of a few others

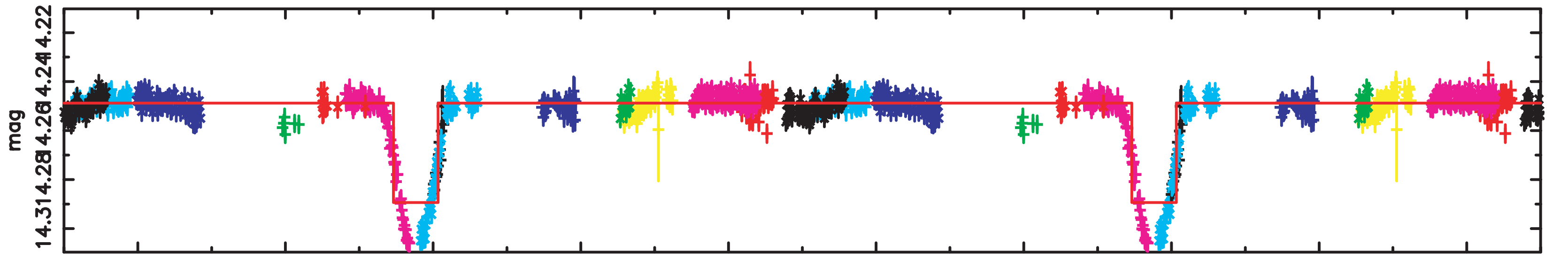
ISIS blue arm



ISIS red arm


1000
500
0
Flux
NaI
CaII
Cross−corr region
8000
8200
8400
8600
8800
Wavelength (Å)

ONC-1-290



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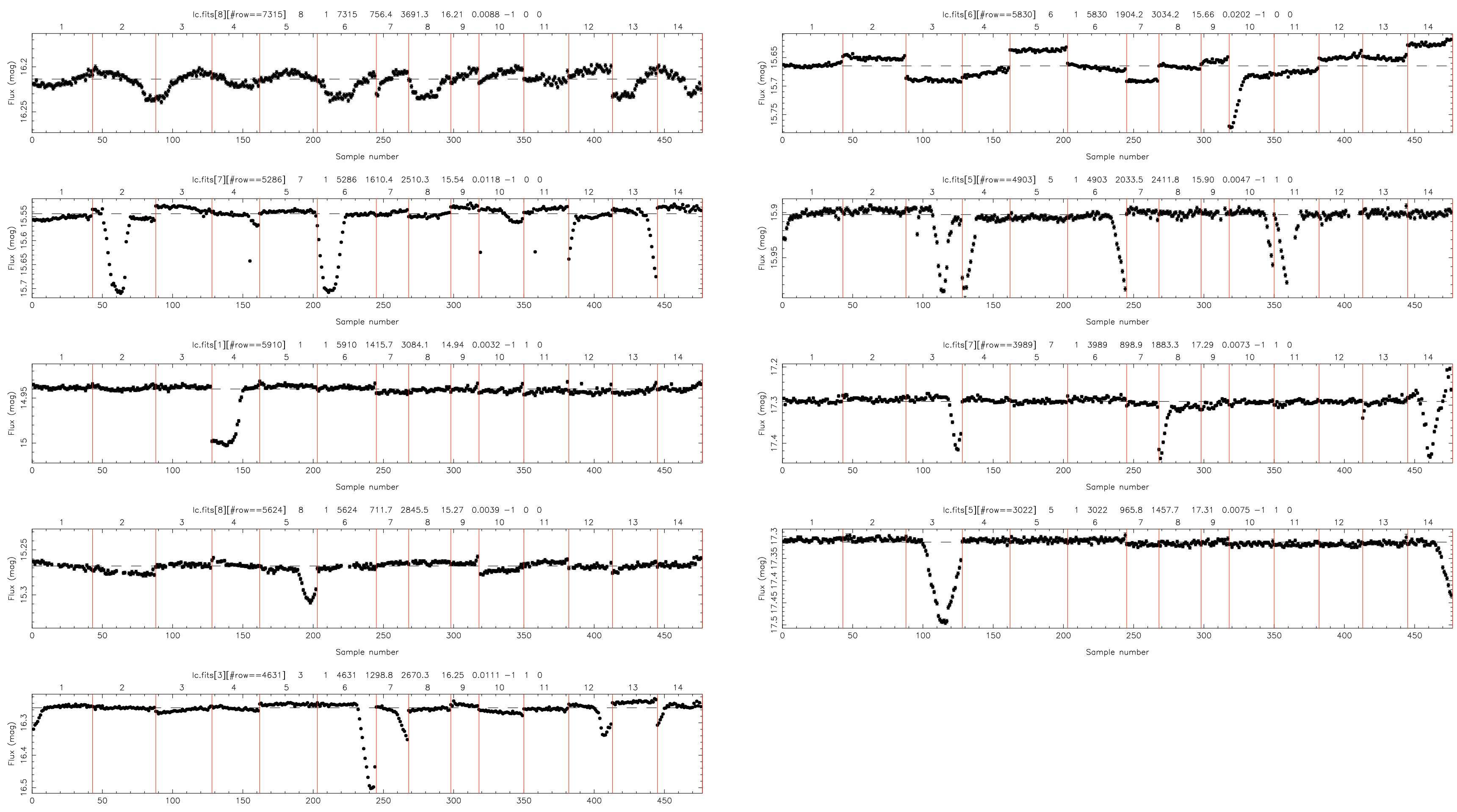
- 2 spectra with ISIS
  - RV measurements 17.1 ± 6.3, $21.1 \pm 12.4\ \mathrm{km\ s}^{-1} \rightarrow$ inconclusive
  - Preliminary Feb 2006 RV $27.2 \pm 4.2\ \mathrm{km\ s}^{-1}$
  - Broad lines in ISIS spectrum, maybe double-lined in Keck spectrum
  - LiI 6708 Å in absorption, SpT M4-M5V

Some new candidates in M50

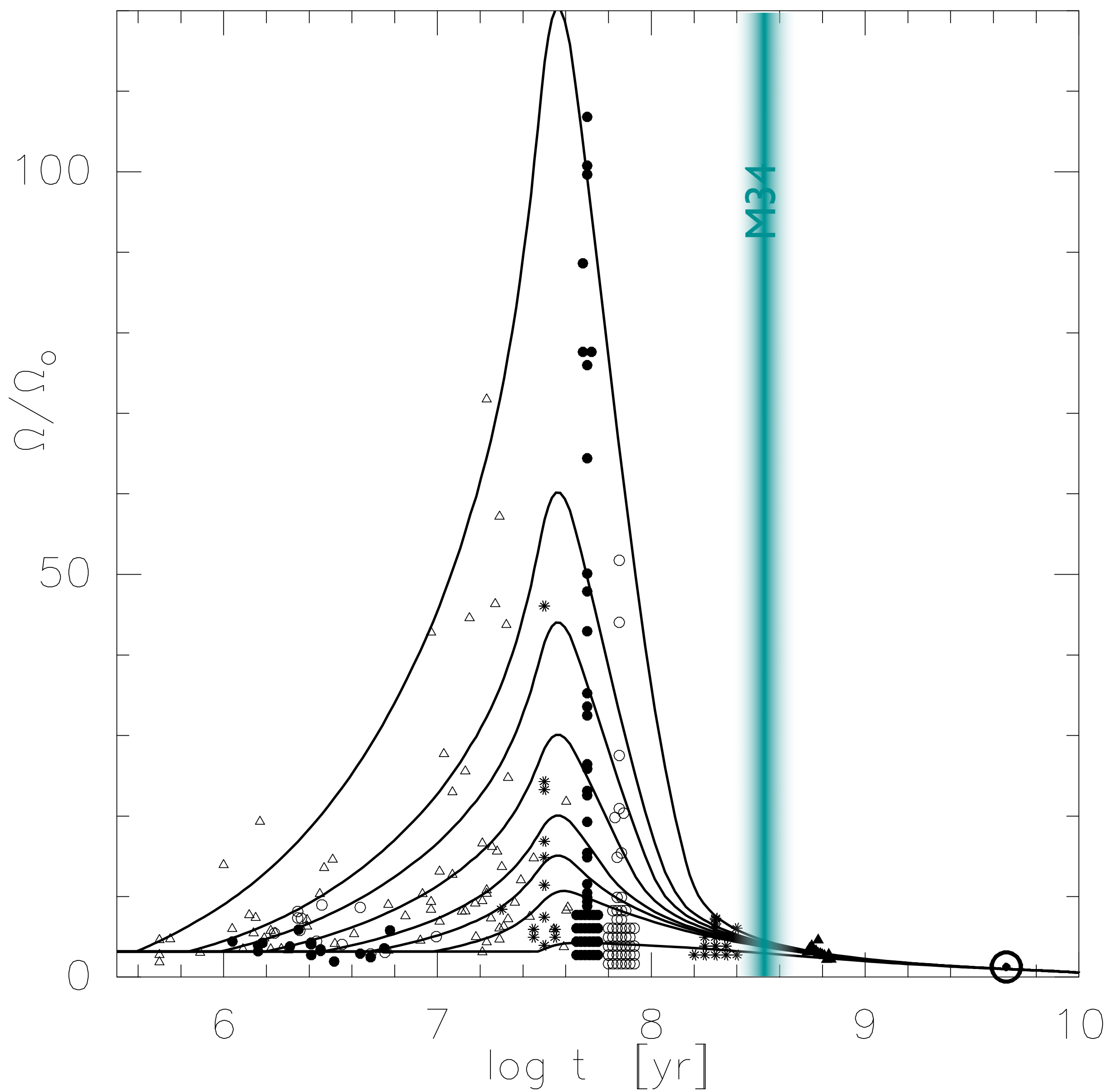


Rotation periods

- sine-fitting $m(t) = m_{\rm dc}(t) + a \sin(2\pi t/P + \phi)$
- goodness of fit estimated by by subtracting smoothed phase-folded light curve at best period $\Delta\chi^2 = \chi^2_{\rm red}({\rm after}) - \chi^2_{\rm red}({\rm before}) \geq 0.4$
- no a priori variability test to ensure sensitive to low-amplitudes
- check quality of detection and of period determination by eye (process can be fully automated, but at the cost of loss of sensitivity at faint / long period end)
- combine multiple filters when available, forcing period and phase to be the same but allowing for different amplitudes (use multiple bandpasses to minimise alias pollution)
- insert fake signals into non-variable light curves to test completeness and contamination as a function of magnitude, period and amplitude

Rotation in M34

(J. Irwin et al. 2006b, in prep.)



Monitor's age makes it ideal to constrain ZAMS spin-down relative to alpha Per and Pleiades

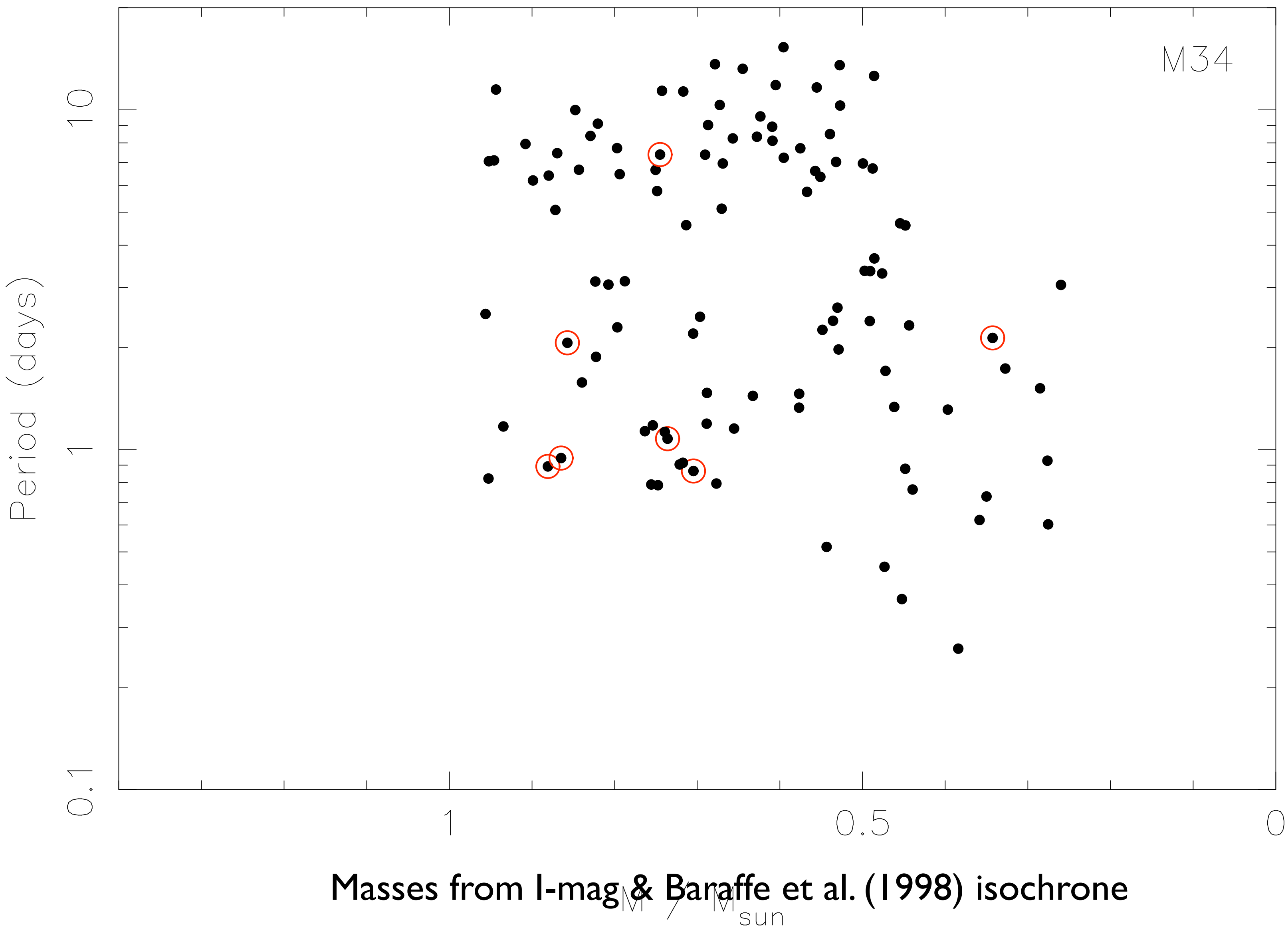
Rotation (both v sin i and periods) has only been explored down to mid-K (Soderblom et al. 2001, Barnes 2003)

107 periods identified

Simultaneous V- and i-band monitoring allows us to explore spot properties

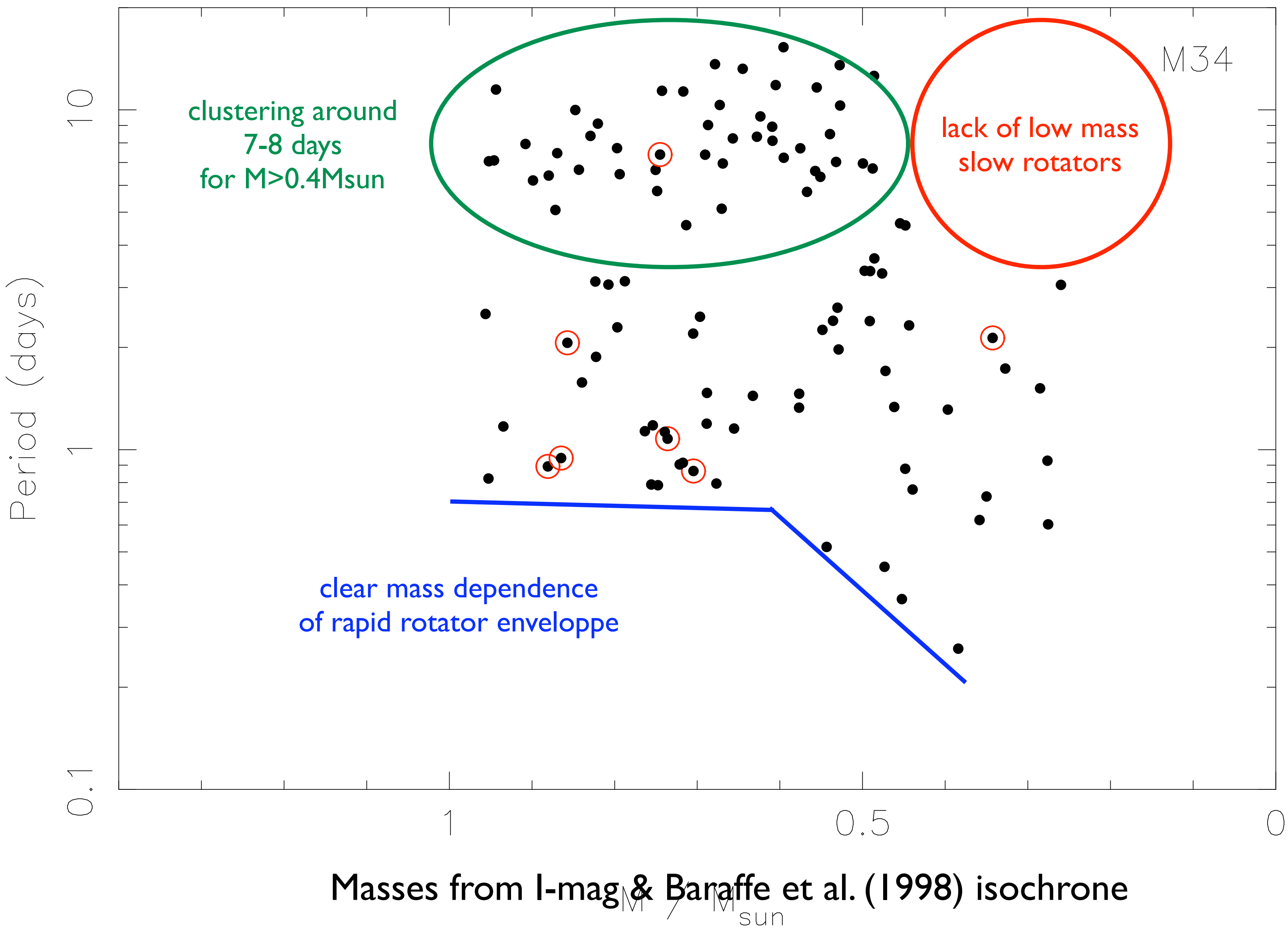

INT-M34-1-304 P=6.201 A=0.023
INT-M34-1-459 P=1.461 A=0.015
INT-M34-1-654 P=9.115 A=0.011
INT-M34-1-1015 P=10.304 A=0.019
INT-M34-1-1017 P=3.655 A=0.027
INT-M34-1-1054 P=13.538 A=0.028
INT-M34-1-1178 P=1.078 A=0.029
INT-M34-1-1493 P=15.300 A=0.012
INT-M34-1-1540 P=7.064 A=0.013
INT-M34-1-1711 P=12.590 A=0.012
INT-M34-1-1719 P=0.879 A=0.021
INT-M34-1-1850 P=13.216 A=0.020
INT-M34-1-1906 P=2.394 A=0.020
INT-M34-1-1918 P=11.333 A=0.007
INT-M34-1-1977 P=1.705 A=0.019
INT-M34-1-2060 P=7.711 A=0.012
INT-M34-1-2324 P=0.621 A=0.022
INT-M34-1-2370 P=0.603 A=0.020
INT-M34-1-2402 P=0.260 A=0.022
INT-M34-1-2414 P=0.866 A=0.011
INT-M34-1-2436 P=6.954 A=0.013
INT-M34-1-2476 P=5.121 A=0.033
INT-M34-1-2483 P=1.877 A=0.007
INT-M34-1-2573 P=4.582 A=0.011
INT-M34-1-2628 P=7.381 A=0.006
INT-M34-1-2679 P=7.234 A=0.026
INT-M34-1-2694 P=2.291 A=0.006
INT-M34-1-2813 P=0.928 A=0.044
INT-M34-1-2901 P=5.741 A=0.012
INT-M34-1-2944 P=2.509 A=0.006
INT-M34-1-2953 P=0.893 A=0.038
INT-M34-1-3164 P=6.668 A=0.006
INT-M34-1-3185 P=2.616 A=0.016
INT-M34-1-3330 P=7.719 A=0.008
INT-M34-1-3362 P=6.725 A=0.017
INT-M34-2-230 P=11.486 A=0.004

Mass dependence



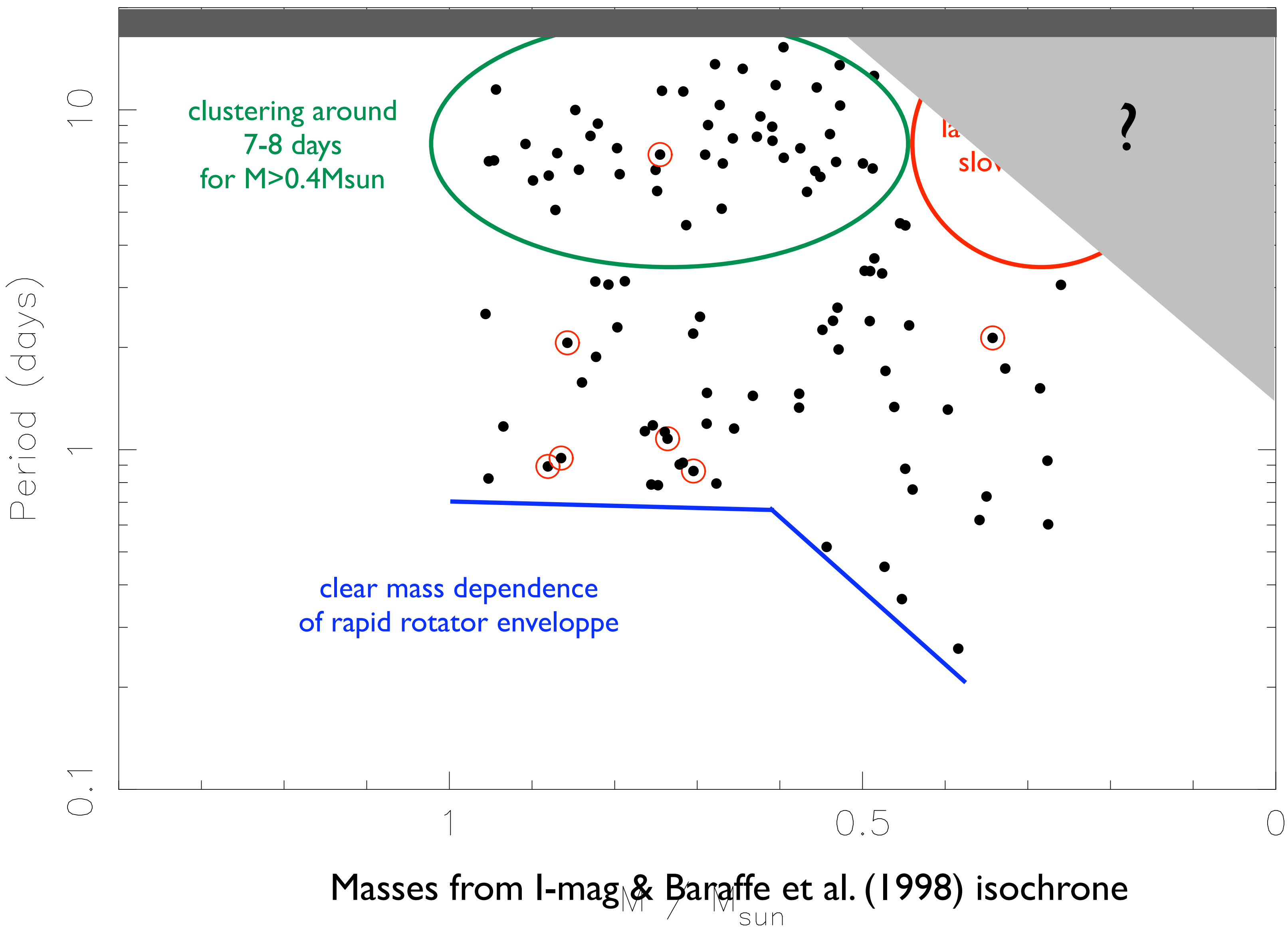
Masses from I-mag & Baraffe et al. (1998) isochrone

Mass dependence



Masses from I-mag & Baraffe et al. (1998) isochrone

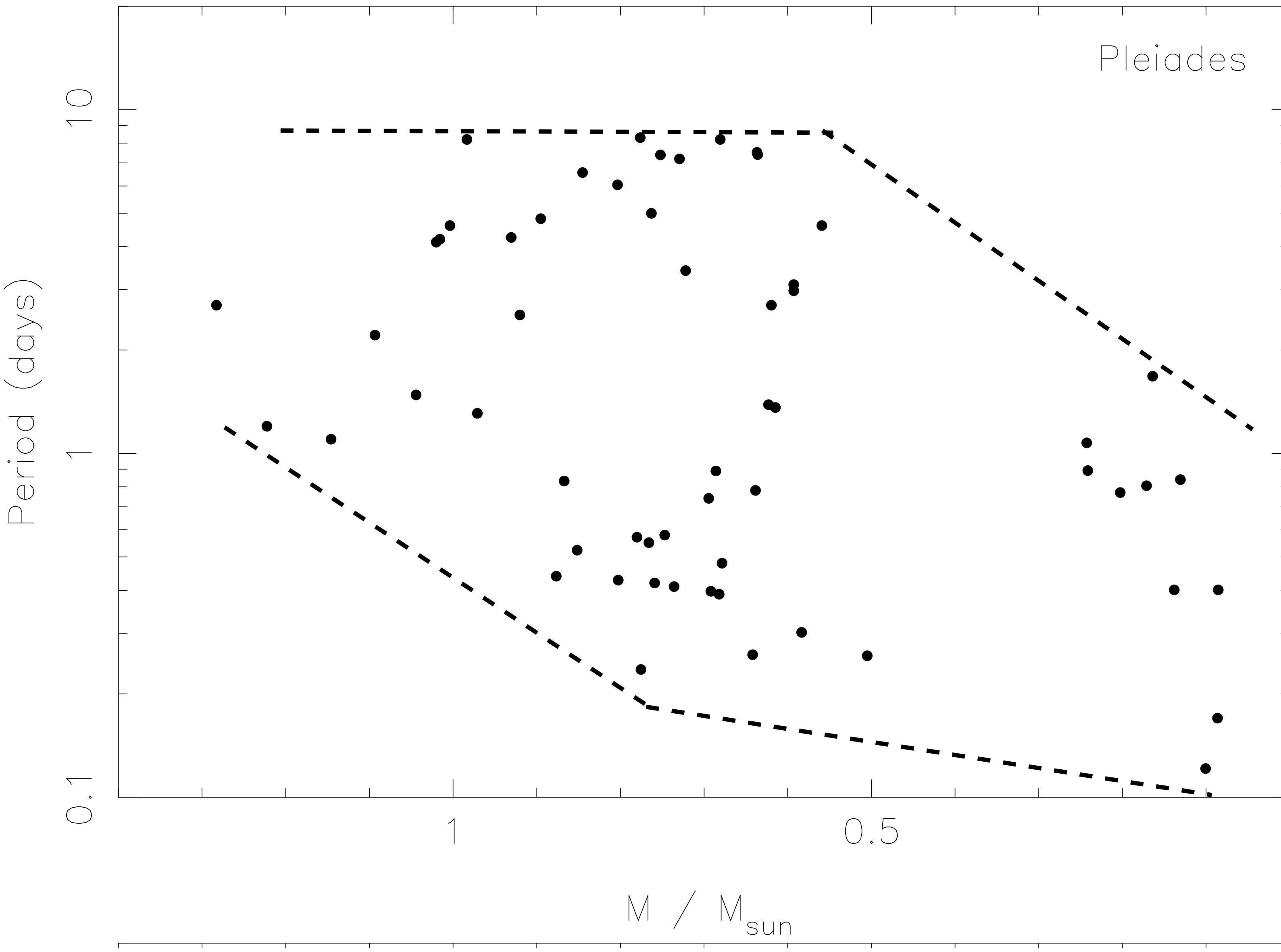
Sentivity limits



Masses from I-mag & Baraffe et al. (1998) isochrone

Comparison to Pleiades

Periods from Van Leeuwen, Alphenaar & Meys (1987), Stauffer al. (1987), Magnitskii (1987), Prosser et al (1993a), Prosser et al. (1993b), Prosser et al. (1995), Krishnamurthi et al. (1998), Terndrup et al. (1999) and Scholz & Eisloeffel (2004)



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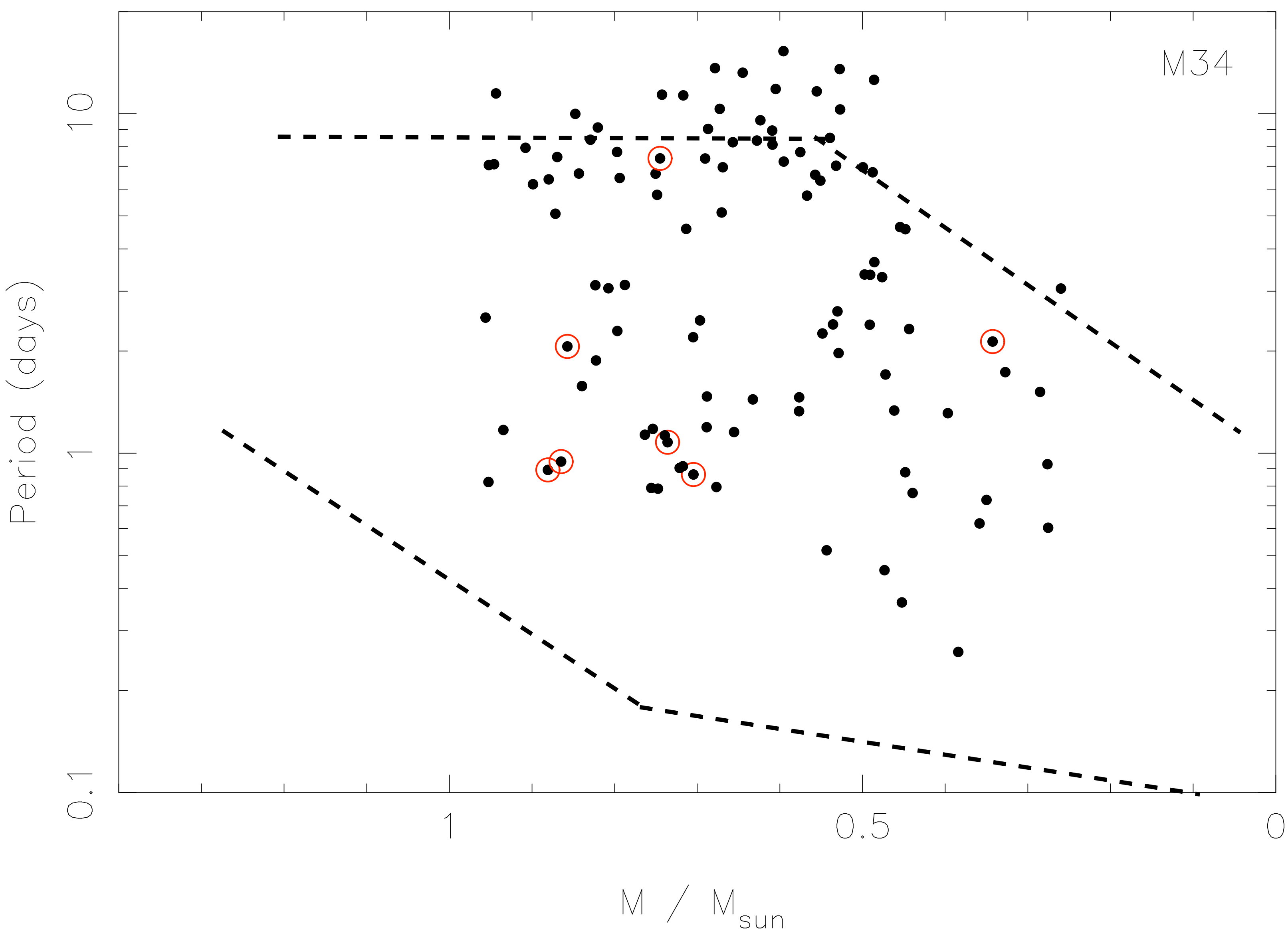

Summary

- About 1/3 of the Monitor photometric observations are complete and reduced
- We have 25 eclipse candidates so far. Based on current trends, should rise to ~40 from completing the first pass analysis on the currently available data.
- Taking estimated contamination into account, the current candidate set is already expected to represent an increase of several 100% on the currently known set of PMS eclipsing binaries
- Rotation period analysis in M34 already is showing interesting trends:
  - Above 0.5 Msun, cluster of slow rotators superimposed on uniform background of faster rotators, indicative of different disk-locking timescales
  - Below 0.5 Msun, tentative evidence for faster fast rotators, and lack of slow rotators (TBC), indicative of less efficient / less long-lasting disk locking
- Comparison to published periods in other clusters is hampered by (ill-known) sensitivity limits of previous surveys. The complete, uniformly analysed Monitor sample should help circumvent this problem.