Transits by planets and brown dwarfs and rotation in young open clusters

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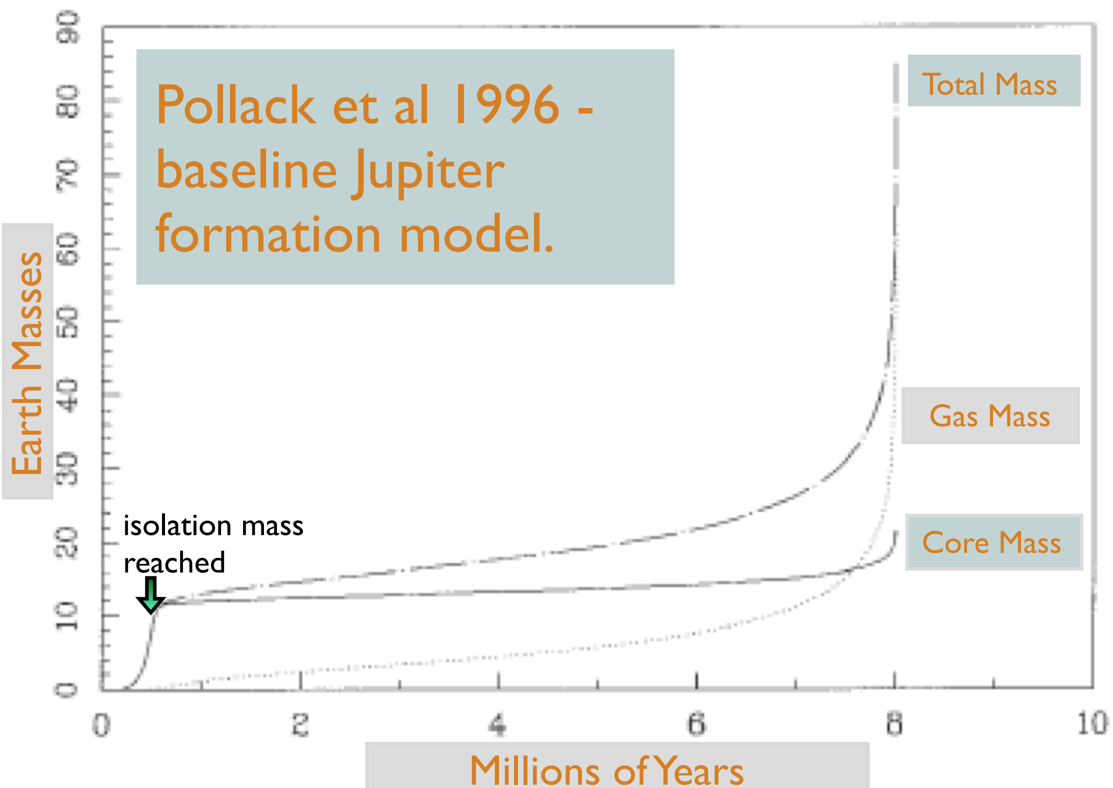
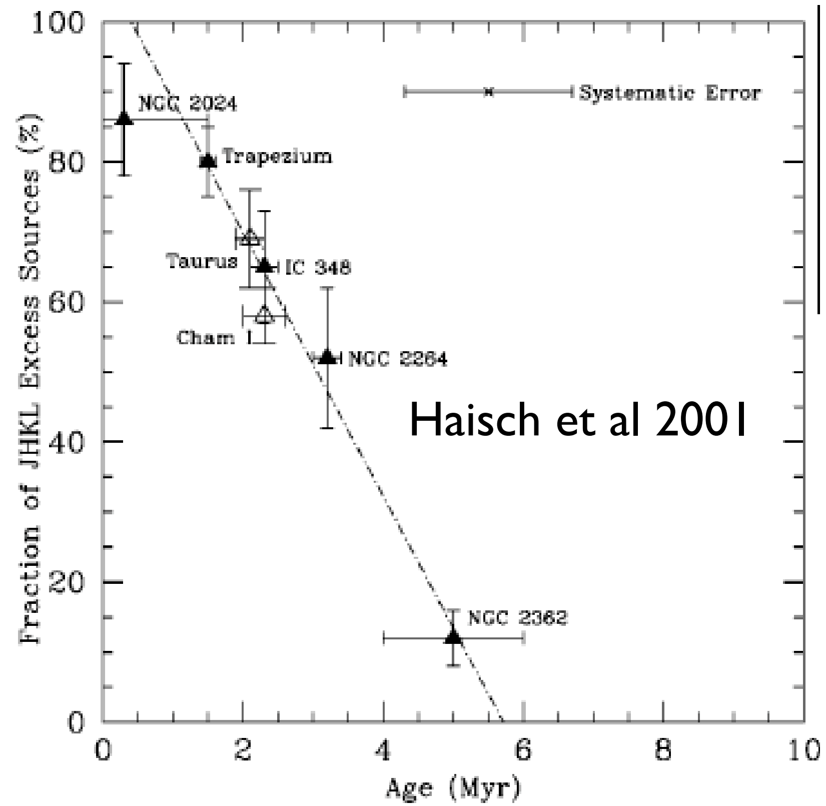
Outline

- Motivation & background
- Targets, observing strategy & expected yield
- Data reduction & light curve production
- Early results:
    - Rotation in M34 & ONC
    - Eclipse and transit candidates

Motivation - I

Can planets form as fast as disks evaporate?

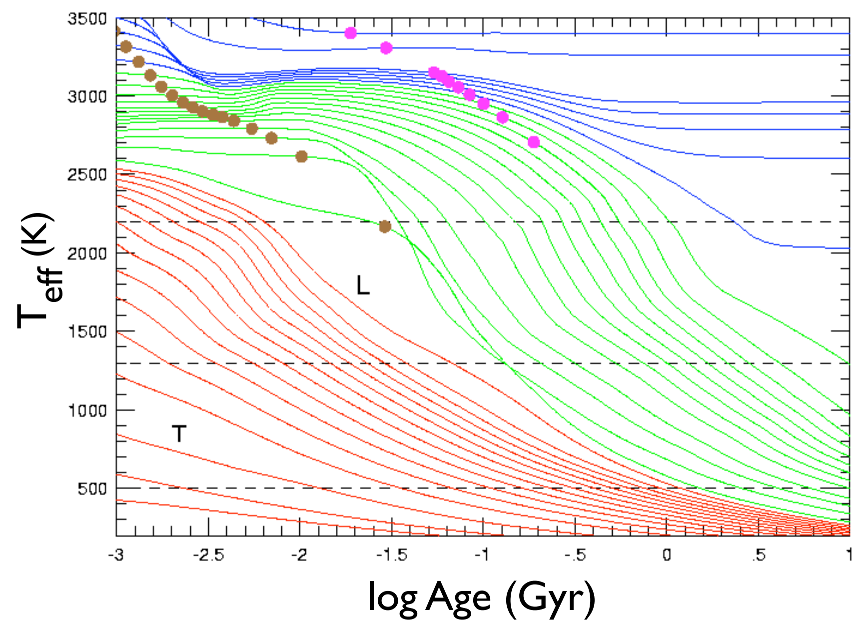




Motivation - 2

How bright & large are young brown dwarfs and planets?

- Evolutionary models
  - Baraffe et al. 98
  - Chabrier et al. 00
  - Burrows et al. 97



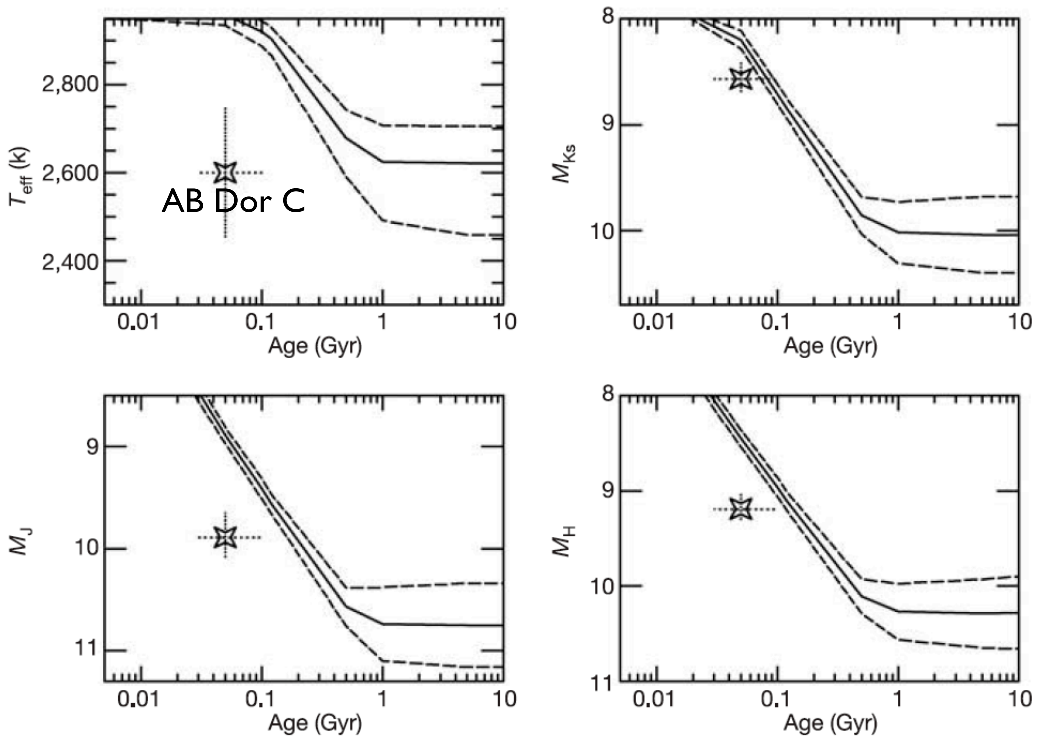
Burrows et al. 1997

- Initial conditions?
- High uncertainties at early ages (Baraffe et al. 2003, Marley et al 2005)

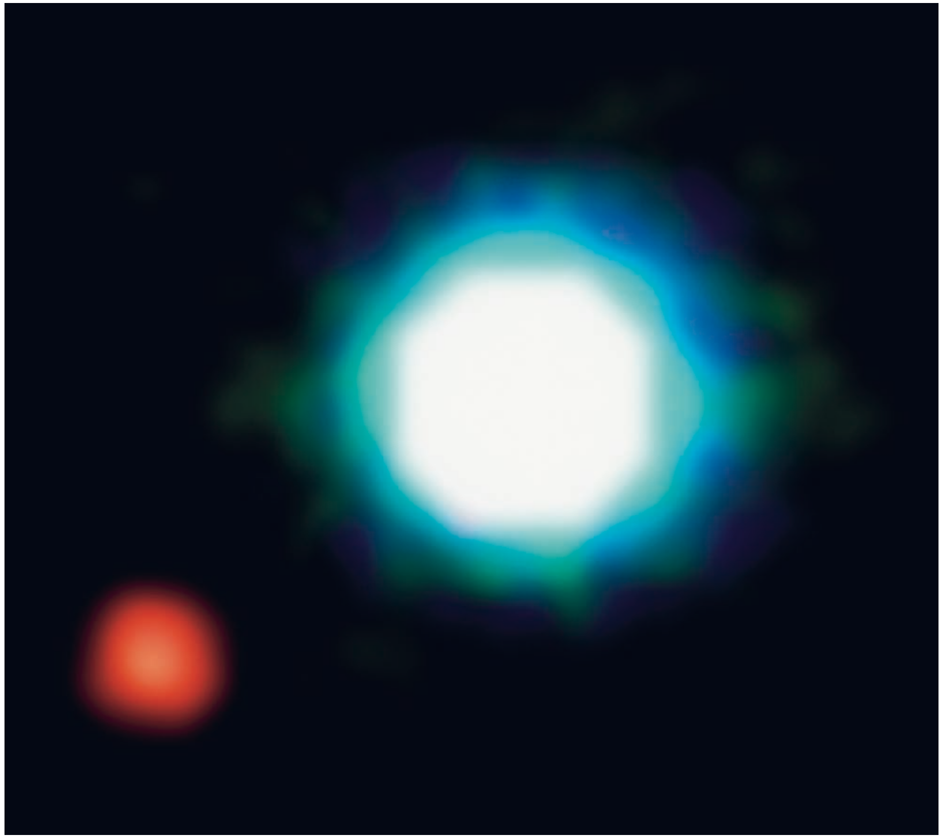
Motivation - 2

How bright & large are young brown dwarfs and planets?

Close et al. 2005

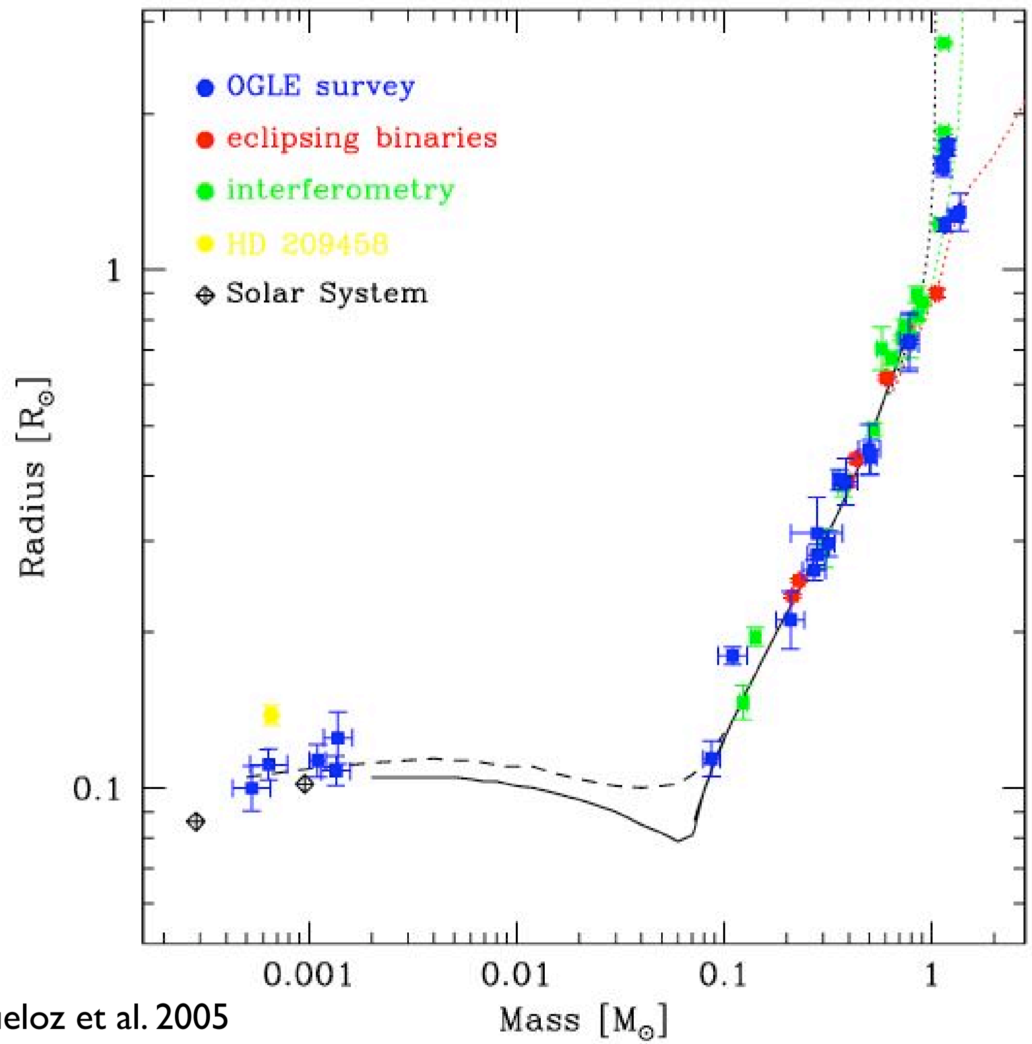


Chauvin et al. 2005a,b



Motivation - 2

How bright & large are young brown dwarfs and planets?



Queloz et al. 2005

Motivation - 3

A crucial and unchartered area of parameter space

- ~ 154 known exoplanets, mostly from RV surveys, 9 that transit:
    - HD 209458b, 189733b, 149026b,
    - OGLE-TR-10, 56, 111, 113, 132, TrES-1
- Few K & M eclipsing binaries
- 1 eclipsing brown dwarf: OGLE-TR-122
- But all orbit main sequence stars with ill-known ages

Transits...

- Simultaneously survey 1000's of stars
- With RV follow-up, constrain companion radius & mass
  - In EB case, contrain T_{eff} & luminosity to few %
- Potential for follow-up:
  - Transit spectroscopy
  - Secondary eclipse searches

...in young open clusters

- Known ages (& metallicities)
- Increased alignment probabilities (bloated primaries)
- Luminous BDs & planets - enhanced follow-up potential
- Observations tailored for low and very low mass primaries
  - Unchartered region of parameter space
  - Deeper transits
  - Larger RV amplitude: easier confirmation

but...

- Strong bias towards short periods (Queloz et al. 2005, Gaudi et al 2005)
- Need many observations per field (Pepper & Gaudi 2005, Pont et al. 2006)
  - partly mitigated by our observing strategy: more later

- Activity and accretion related variability may impede transit detection
  - variability filters
  - simultaneous V & i monitoring for the youngest targets

- Faint targets + activity induced jitter may impede RV follow-up?
  - expect jitter ~ 60 m/s at 3 Myr
  - $0.03M_{\odot}$ BD in 3d orbit around $1M_{\odot}$ star: RV amplitude 3 km/s
  - 1 M_{Jup} planet in 3 d orbit around $1M_{\odot}$ star: RV amplitude 140 m/s

Related studies

- EXPLORE-OC (von Braun et al. 2004)
- St Andrews Open Cluster Planet Search (Street et al. 2003, Bramich et al. 2005)
- PISCES (Mochejska et al 2002, 2004, 2005)
- Older open clusters (1 to a few Gyr)
- No detections so far (some viable candidates)
- Early detection rate estimates were over-optimistic: more careful estimates (Pepper et al 2005) show absence of detections consistent with results of RV searches

Related studies

- Survey of middle aged open clusters to search for VLM EBs (Hebb et al. 2004)
-
-
-
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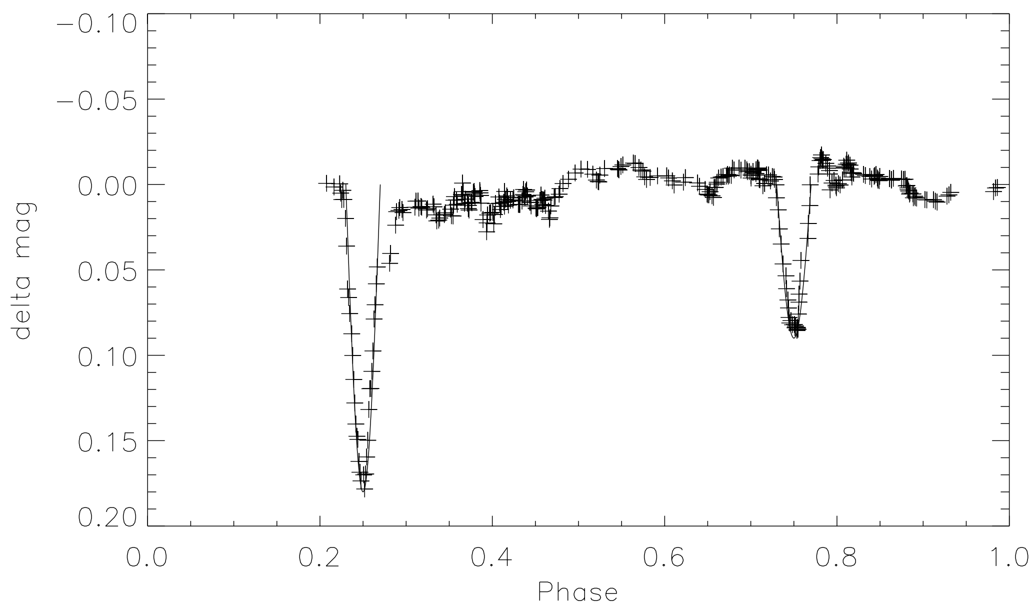
-
- Candidate in M35



  - Secondary eclipse detected during main survey from INT & KPNO
  - Primary eclipse detected during a Monitor INT run in Jan 2005

Targets

aim to cover all sufficiently rich, compact and nearby OCs with age 1-200 Myr

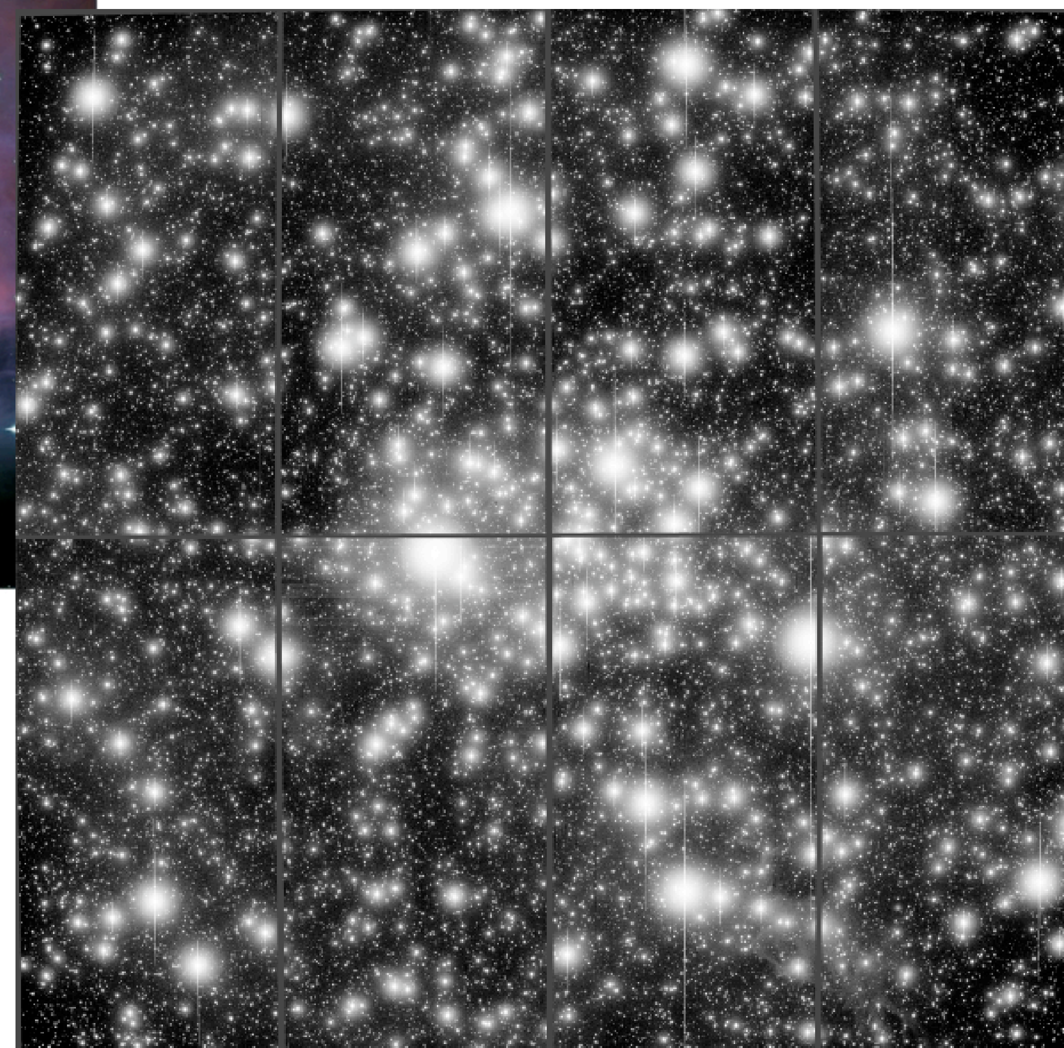
Name	RA (hh~mm)	Dec (dd~mm)	Age (Myr)	(M-m)_0 (mag)	E(B-V) (mag)	I(HBL) (mag,a)	M(I=20) (M_Sun,b)	N (c)	Area (°,d)
Blanco~1	00 04	-29 56	100	7.1	0.01	19.2	0.06	300 (0.03,0.6)	2.3
h/χ~Per	02 20	+57 08	12.8	11.85	0.56	22.0	0.22	230 (4,10)	1.0
M34	02 42	+42 47	180	8.7	0.07	21.7	0.11	89 (0.9,2.5)	0.55
IC~348	03 44	+32 17	~3	8.0	??	16.9	0.02	150 (0.08,1.25)	0.35 (g)
ONC	05 35	-05 23	~1	8.16	0.05	16.6	0.02	500 (0.02,0.5)	0.07
M50	07 02	-08 23	130	10.5	??	22.6	0.25	1100 (0.15,0.55)	0.35
NGC~2362	07 19	-24 57	7	11.0	??	20.5	0.09	500 (0.11,0.65)	0.11
NGC~2516	07 58	-60 52	150	7.7	??	20.0	0.08	1200 (0.02,0.2)	2.0
NGC~2547	08 10	-49 10	30	8.4	??	19.2	0.05	500 (0.035,0.9)	0.855
IC~4665	17 46	+05 43	50	8.3	??	19.6	0.06	150 (0.02,0.2)	4.0

many already have deep CMDs (from e.g. CFHT key project)

Observations

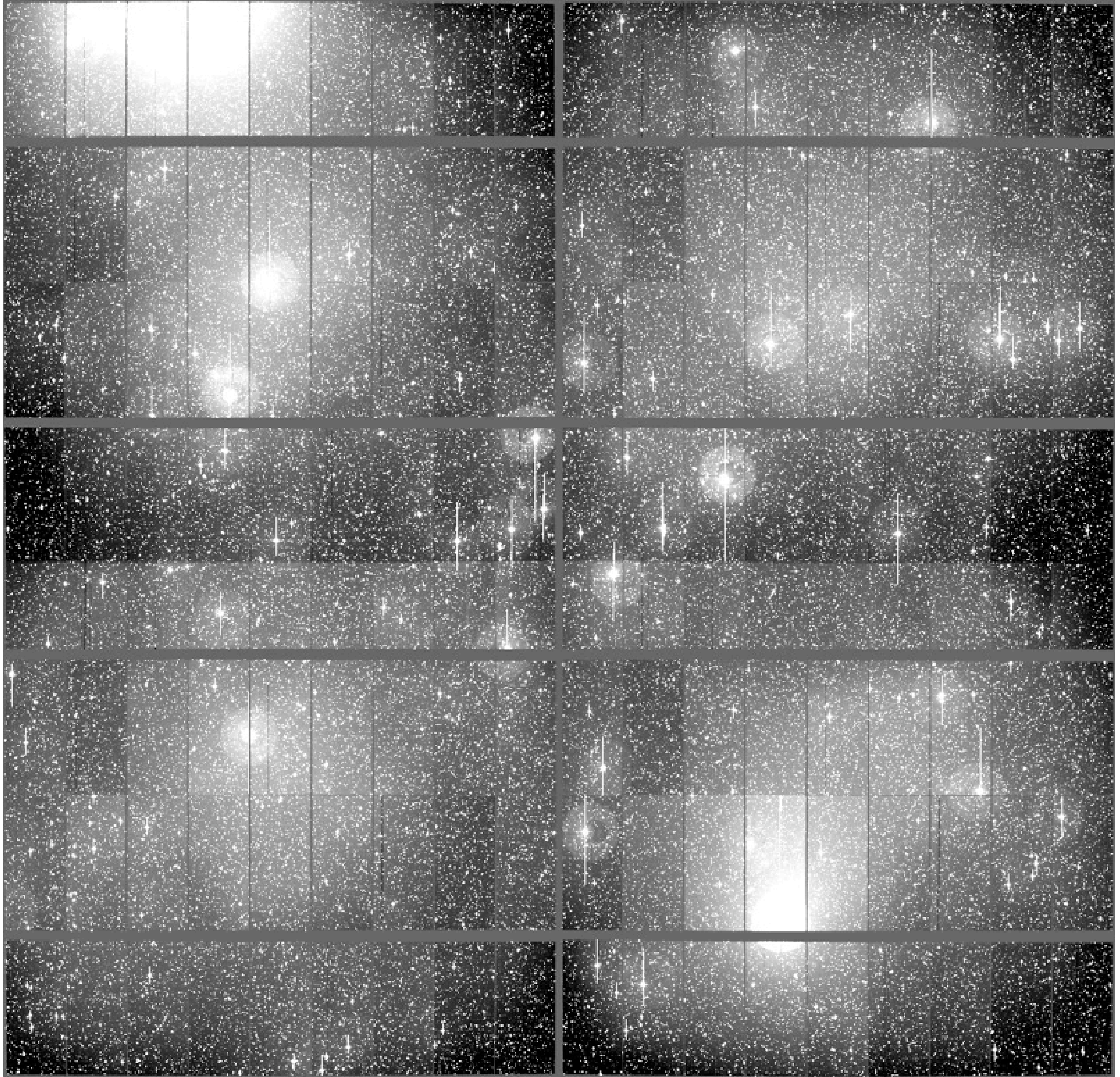
semester	telescope	instrument	time awarded	targets	strategy	status
2004B	INT 2.5m	WFC	20 nights	ONC M34	nights	analysed
2005A	CTIO 4m	Mosaic II	6 nights	NGC 2632 M50	nights	analysed
	CFHT 3.6m	MegaCAM	40 hours	IC4665	blocks	under analysis
	ESO 2.2m	WFI	50 hours	Blanco 1	blocks	being reduced
2005B	ESO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

IC4665 (50 Myr)
greyscale I image
(not corrected for zero-point differences between detectors)
CFHT + MegaCAM
(60’x60’)



Observing strategy

- 2 distinct requirements:
  (a) need to monitor enough targets with sufficient photometric precision to have a good chance of detecting transits / eclipses
  (b) need to characterise eclipse shape well enough to fit the parameters of the system

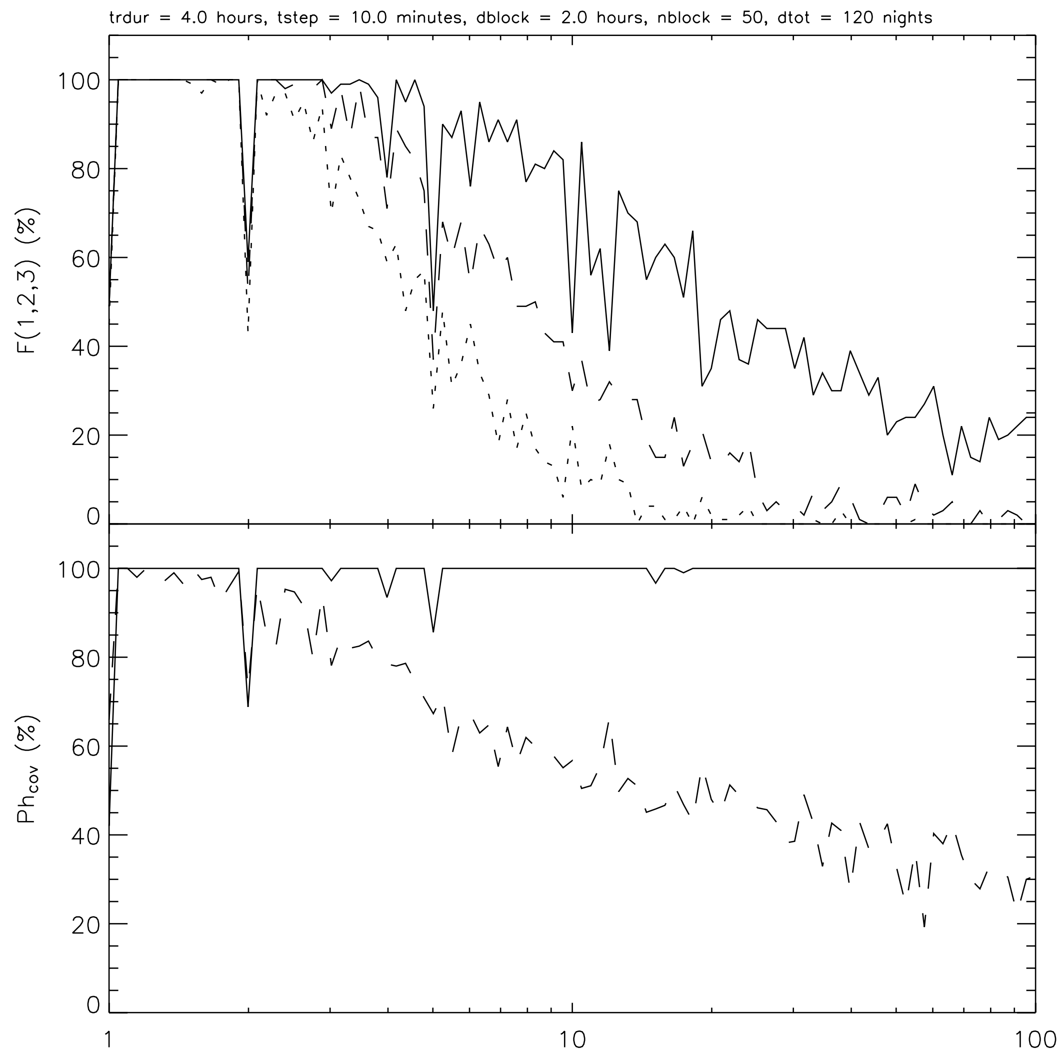
(b) implies sampling time shorter than ingress / egress and blocks of observations longer than 2/3 of a typical eclipse

- typical BD eclipse: duration (P = 2d): 1.5h, ingress / egress 30 min
- need 1-2 hour blocks with 1 point every 15 min

(a) implies many observations over time scale >> periods of interest

- when possible, request service mode, blocks of ~ 2 hours scheduled randomly throughout observability window
- lax observing conditions requirements - ease of scheduling

Observing strategy



Detection rate estimates

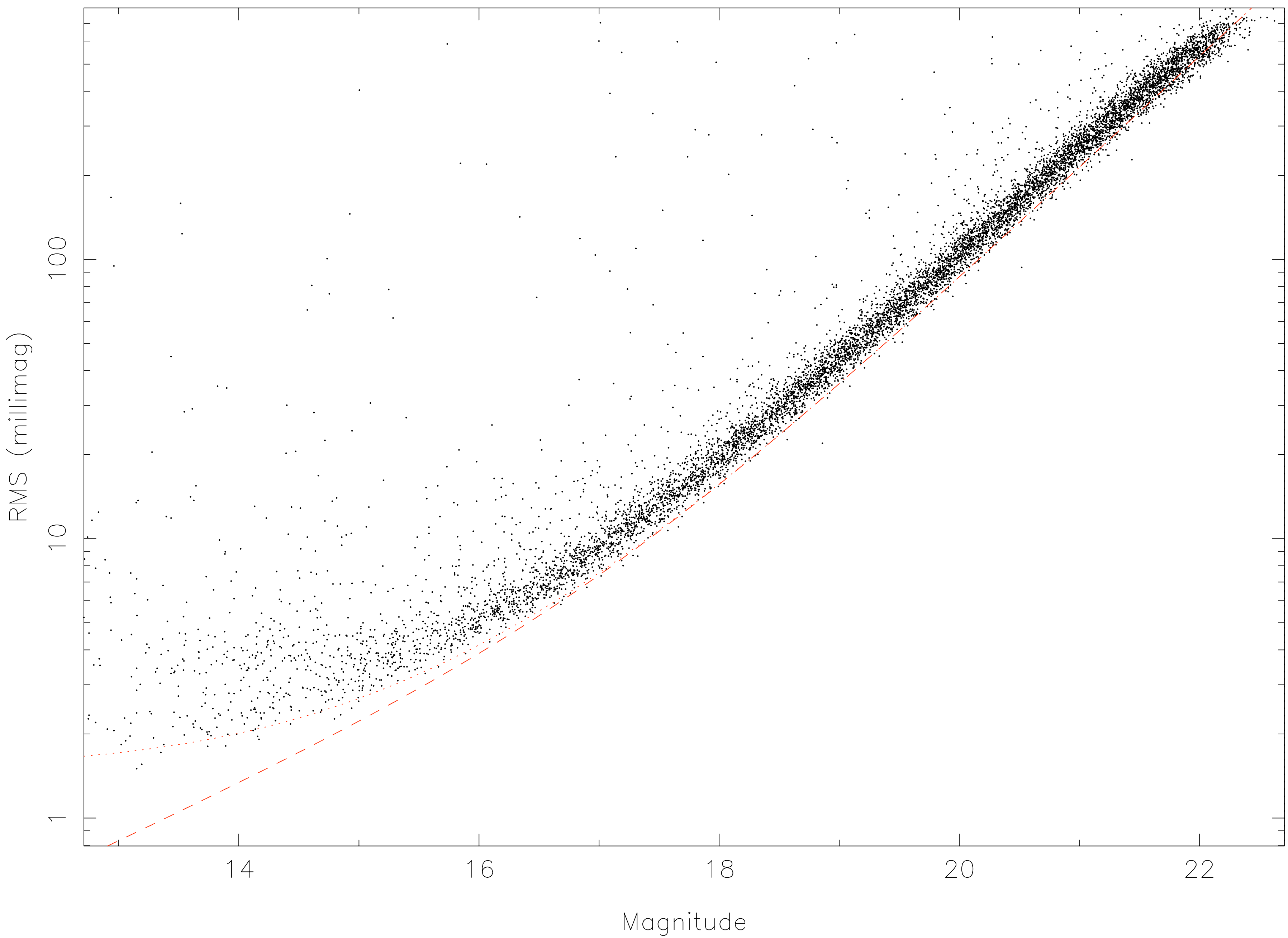
- Adapted approach of Gaudi et al. 2005 (for surveys of field stars such as OGLE) to young open clusters (see also Pepper et al. 2005, for older clusters).
- Ingredients include
  - cluster mass function, age, distance, extinction
  - mass-radius and mass-radii relations from Baraffe et al. 1998 (stars / 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

The motivation, survey design and detection estimates will be described in a forthcoming paper (Aigrain et al. in prep.)

Data reduction & photometry

- 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)
- Collocated 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

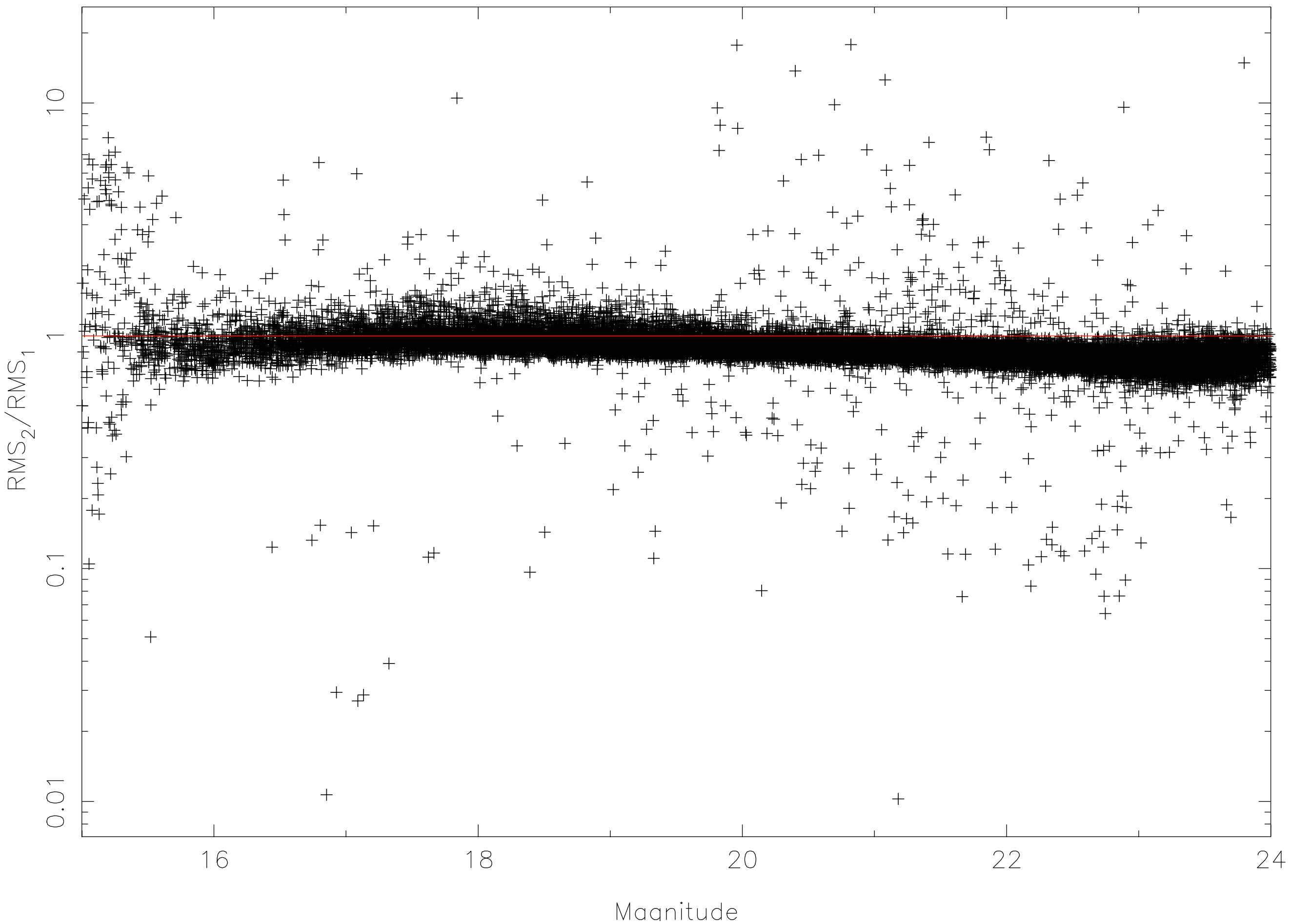
M50 (6 nights, all objects flagged as stellar and unblended)



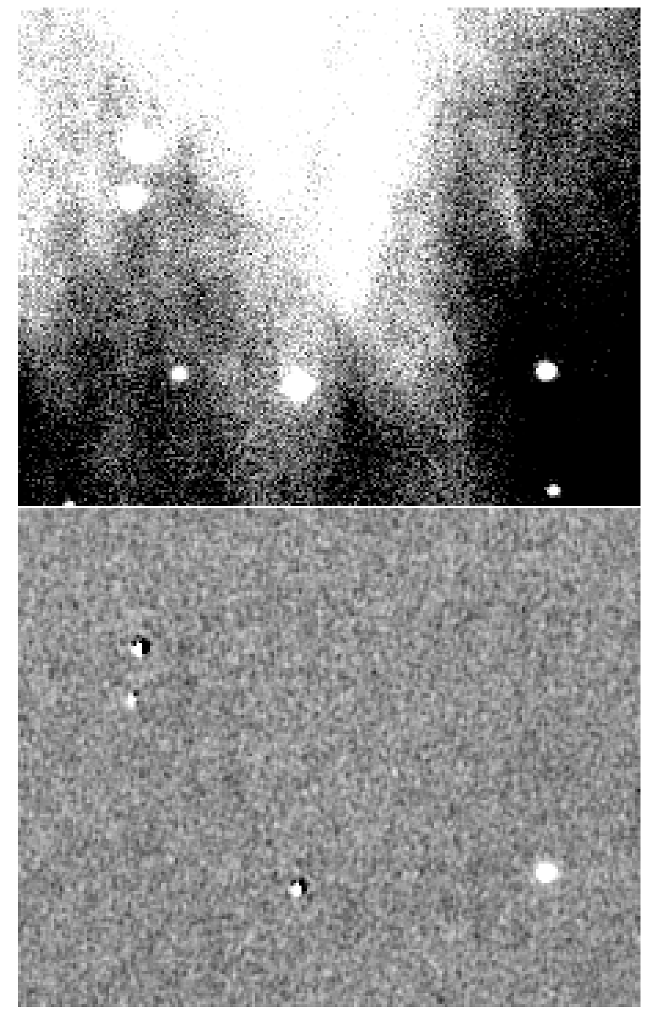
Why not do DIA?

- Difference image analysis should give better results than aperture photometry
- Particularly interesting to cope with spatially varying nebulosity in ONC
- Implemented our own version, including background subtraction prior to differencing, followed by collocated aperture photometry on difference images
- For data taken in good conditions (stable seeing <0.8” in i), marginal improvement over aperture photometry (specially for faint stars)
- For INT (ONC) data, elliptical images (due to auto-guider problems) induce ringing in the difference images, which introduces scatter in the light curves
- Fix is non trivial as fitting of elliptical kernels non-linear - slow and unstable
- Opted to stick with aperture photometry for all datasets (for consistency), but will keep investigating fixes to ellipticity problem

M50 (CTIO)



ONC (INT)



Systematics

- 2-D polynomial procedure does not remove effects that do not smoothly depend on position, e.g. varying contamination from neighbours as seeing varies.
- These can induce transit-like features in the light curves, so we investigated 2 recently published systematics removal techniques.
- Kovacs et al. 2005 - linear decomposition onto a set of template light curves that do not contain real variability. Potentially very powerful, but depends on template selection. Our implementation was not generally successful.
- Tamuz et al. 2005 - generalisation of PCA, iterative correction across all frames and all stars. Can repeat process to remove further 'components', the optimal number of which is a compromise between decreased detection rate (as one starts to remove transits), and reduced false alarm rate.
- Systematics removal distorts variability other than transits, and so it was used only prior to transit searching.

The data reduction, light curve production and tests of systematics removal and other filters will be described in a forthcoming paper (Irwin et al. in prep.)

early results - 1

Membership & rotation in M34

(J. Irwin et al. in prep)

red - i’
blue - V
green - (i’+V)/2

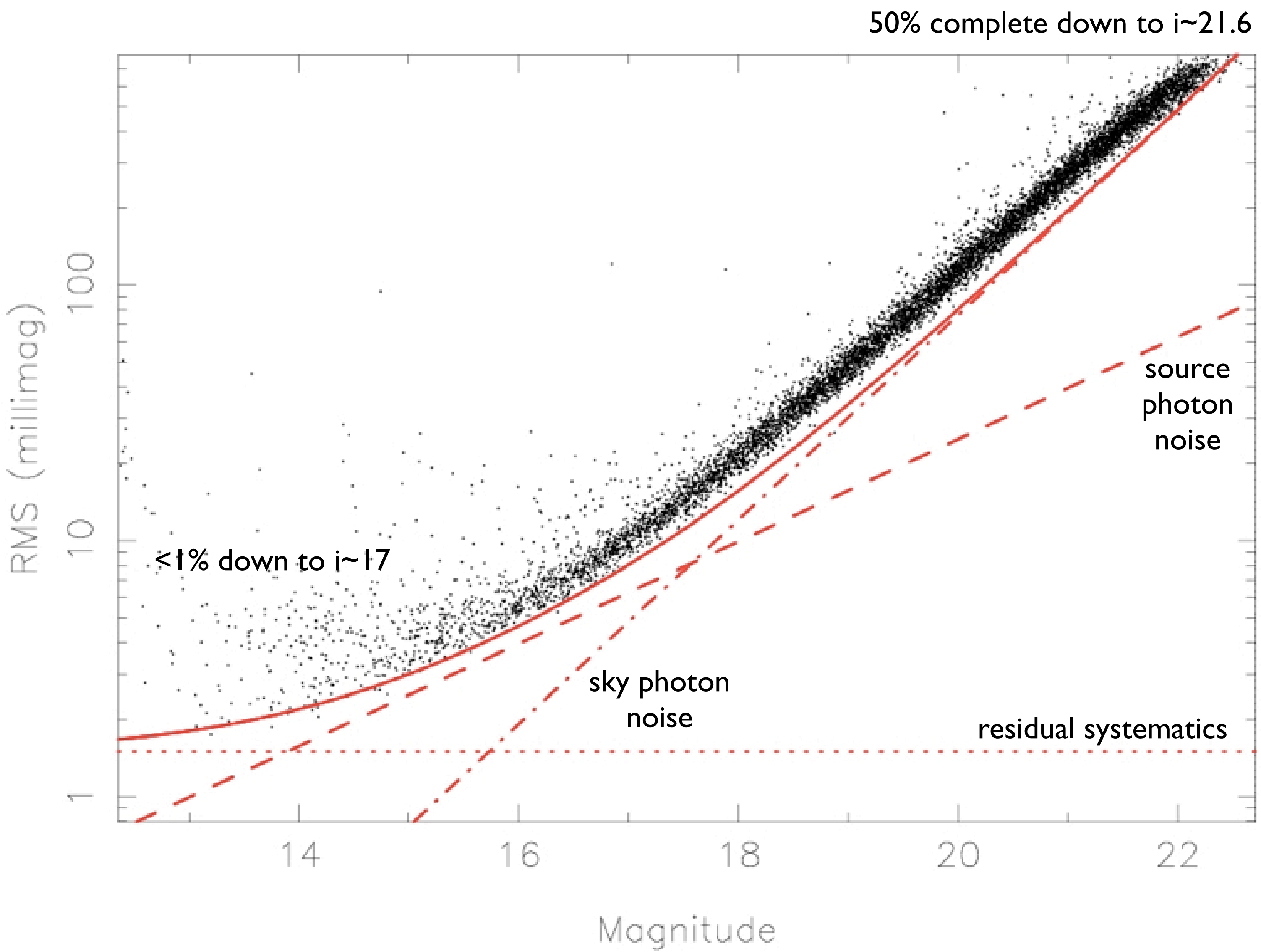
The cluster

- ~200 Myr, 470 pc (Jones & Prosser 1996)
    - critical age range for angular momentum evolution (transition from PMS to ZAMS for K & M stars, intermediate between Pleiades and Hyades)
- Previous studies concentrated on types K & earlier
    - Mean proper motion 20 mas/yr based on photographic plates (Ianna & Schlemner 1993, Jones & Prosser 1996) down to 0.7 $M_{\odot}$
    - Mean spectroscopic abundance $[Fe/H] = 0.07 \pm 0.04$(Shculer et al. 2003)
    - Spectroscopic (Soderblom et al. 2001) & photometric (Barnes et al. 2003) rotation studies down to G spectral types
    - 32 ROSAT sources (Simon et al. 2000)

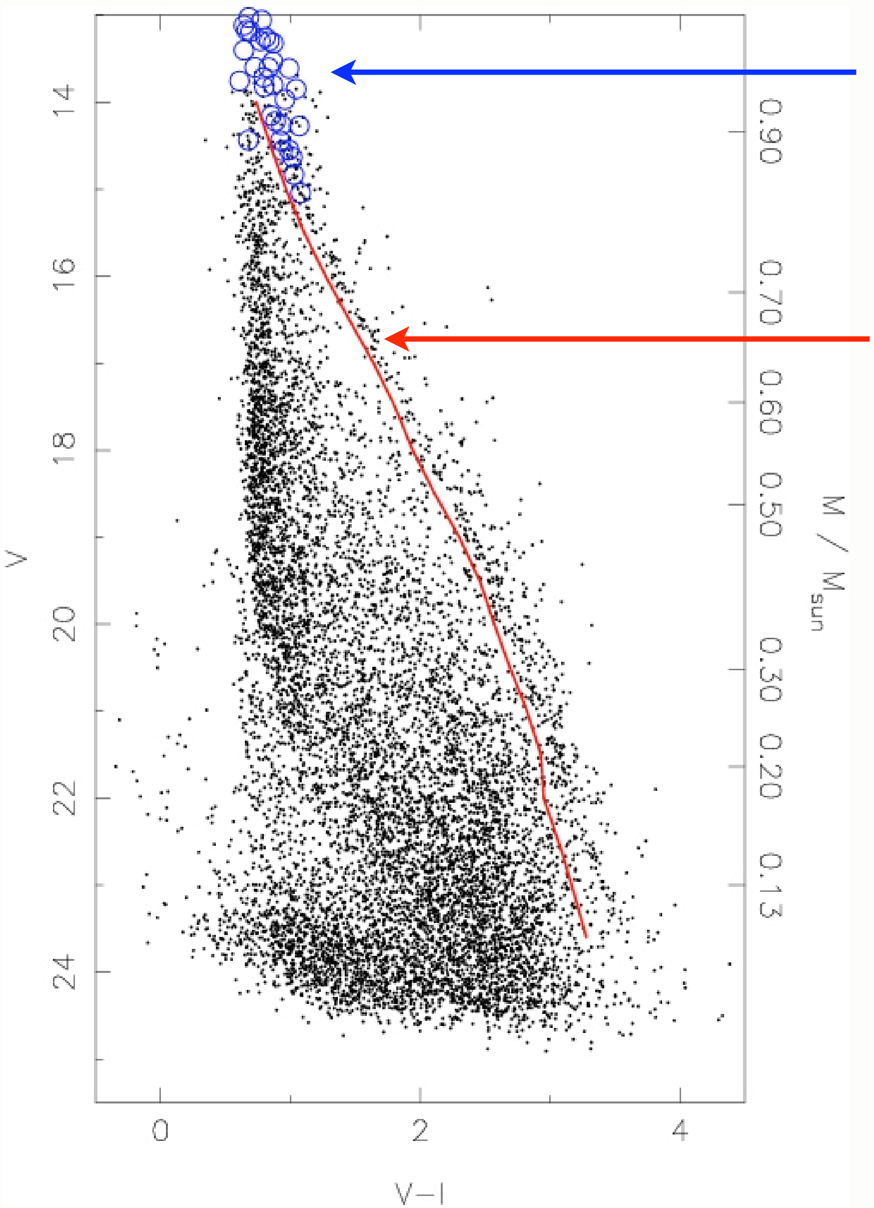
The survey

- 10 nights in Nov. 2004 with INT+WFC
  - 5 clear + 3 partial
  - M34 observed for 1st half of night
- alternate exposures of 30s in i’ & 60s in V
  - cycle time 3.5 min
  - 280 frames total
- mag range $12.8 < i' < 21.5$
  - mass range $1.05 < M/M_{\odot} < 0.06$
- Deeper survey with longer timebase and sparser sampling underway on CFHT + MegaCAM

Photometric accuracy



Membership selection



candidate members from Jones & Prosser 1996

empirical main sequence definition (initial guess then iterative k-σ clipping) down to I=20

cutoff based on shifting empirical main sequence to the faint blue end by 0.1±2σ(V-I)

714 candidates to the right and up of cutoff

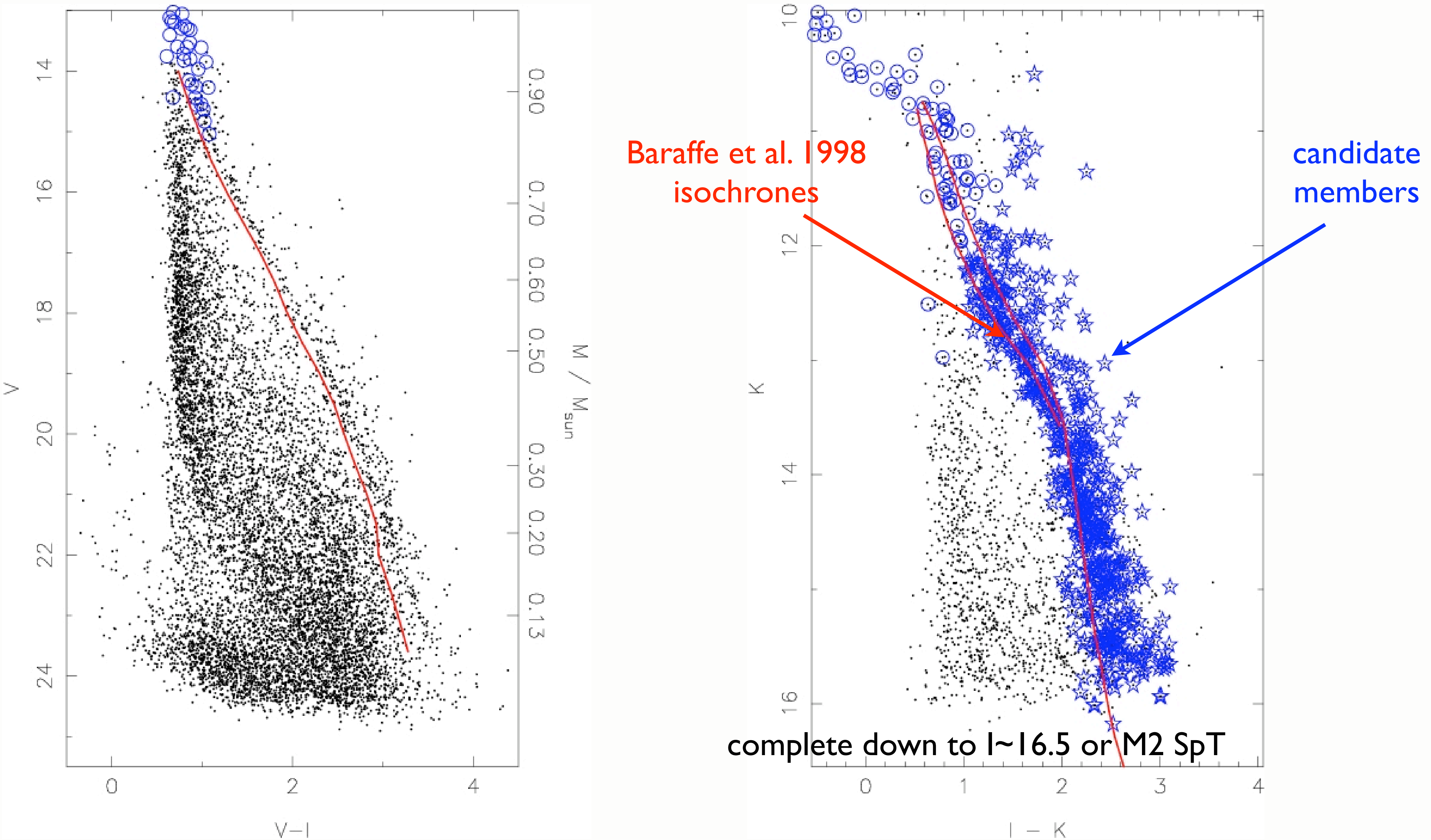
contamination estimated from Besancon model at 39% (including source completeness)

also examined possibility of using CC diagrams (no significant improvement) and PM based on Palomar (dispersion too large) or 2MASS (baseline too small)

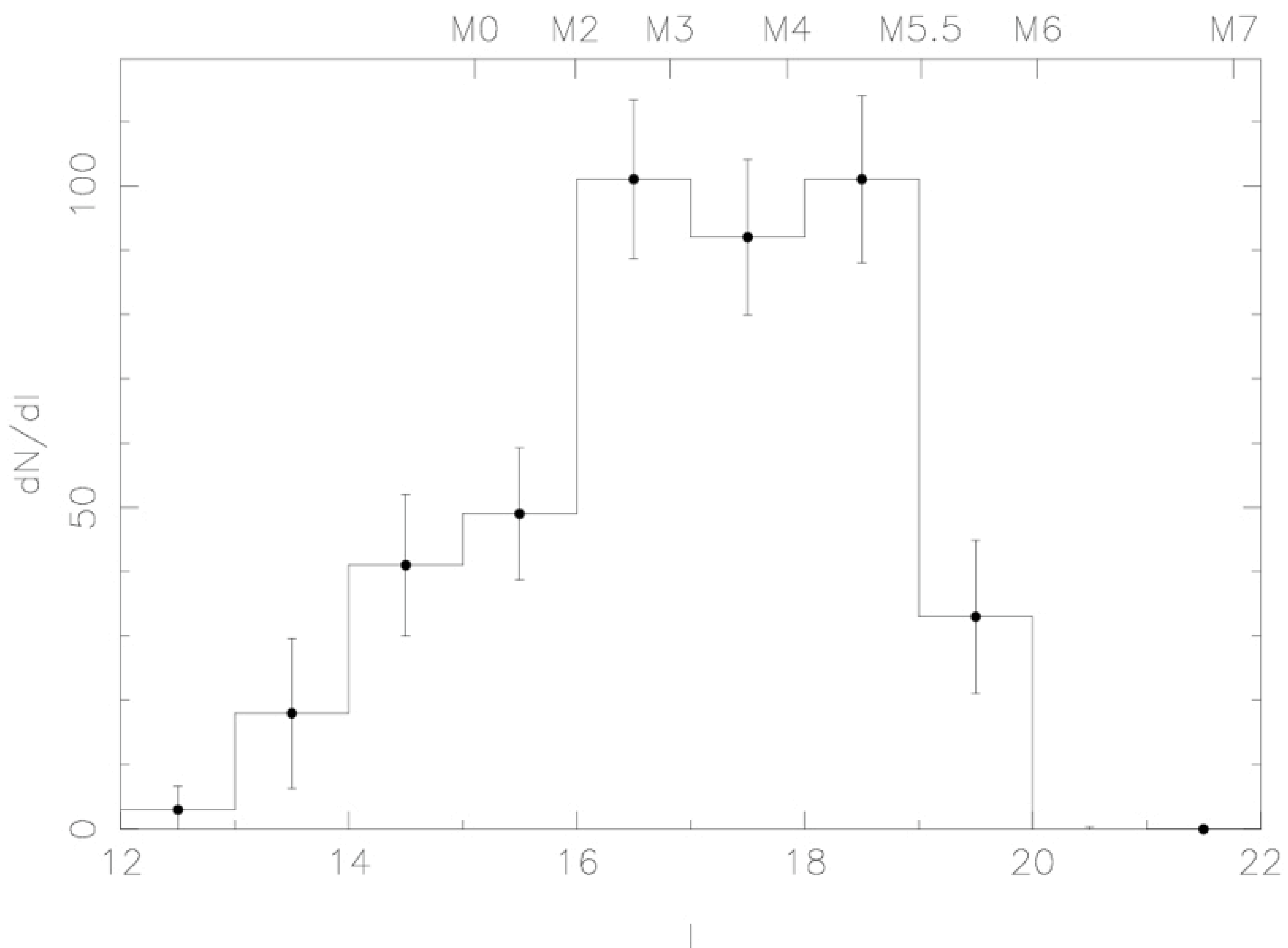
PM survey feasible in ~15 yrs wrt 2MASS

ideal target for multi-object RV survey from 4-8 telescopes

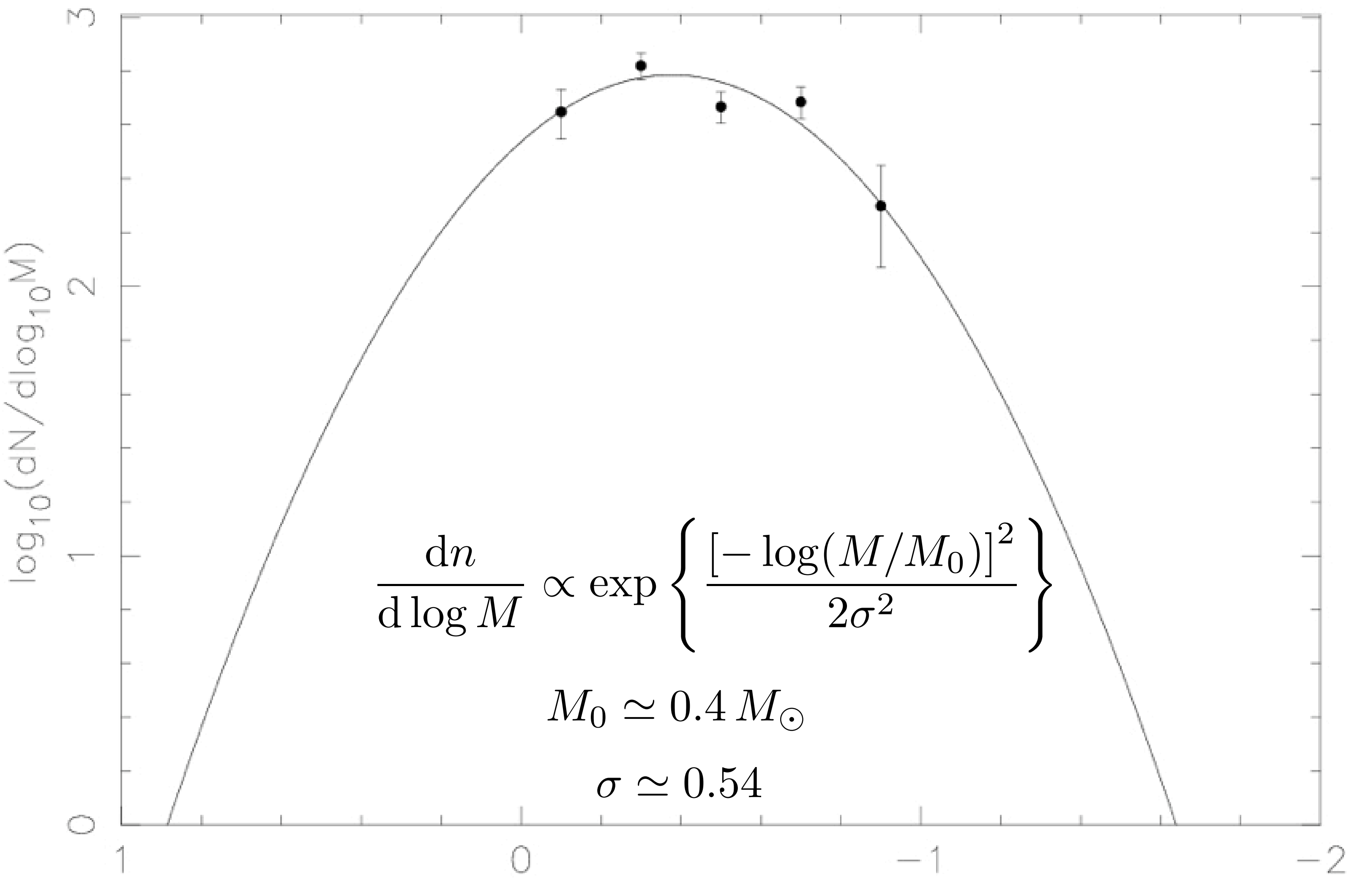
Membership selection



Luminosity function



Mass function



$$\frac{\mathrm{d}n}{\mathrm{d}\log M} \propto \exp\left\{\frac{[-\log(M/M_0)]^2}{2\sigma^2}\right\}$$

$$M_0 \simeq 0.4\,M_\odot$$

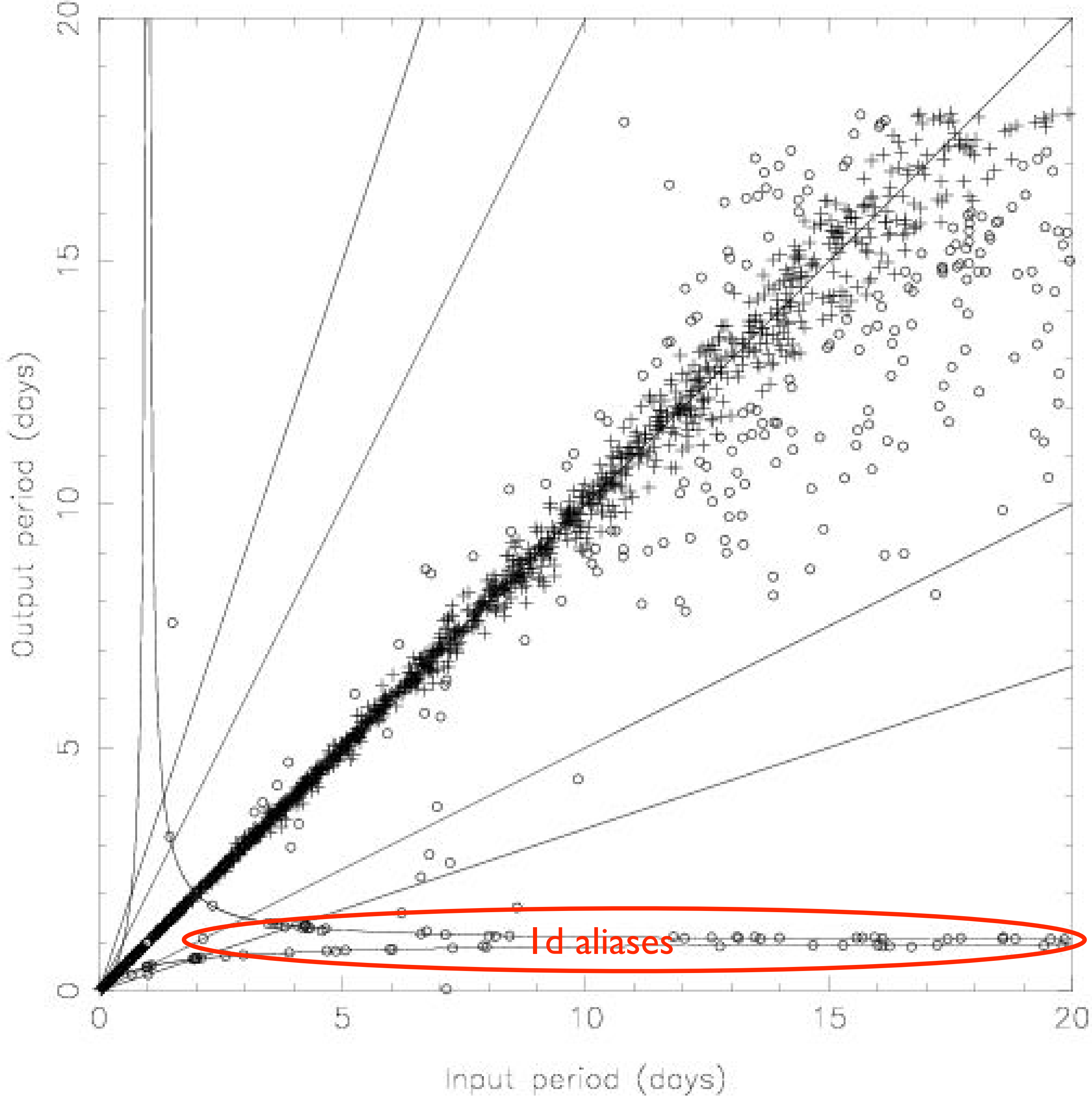
$$\sigma \simeq 0.54$$

consistent with other MF fits in PMS clusters (e.g. Bouvier et al. 2003) - but beware of small mass range

Rotation periods

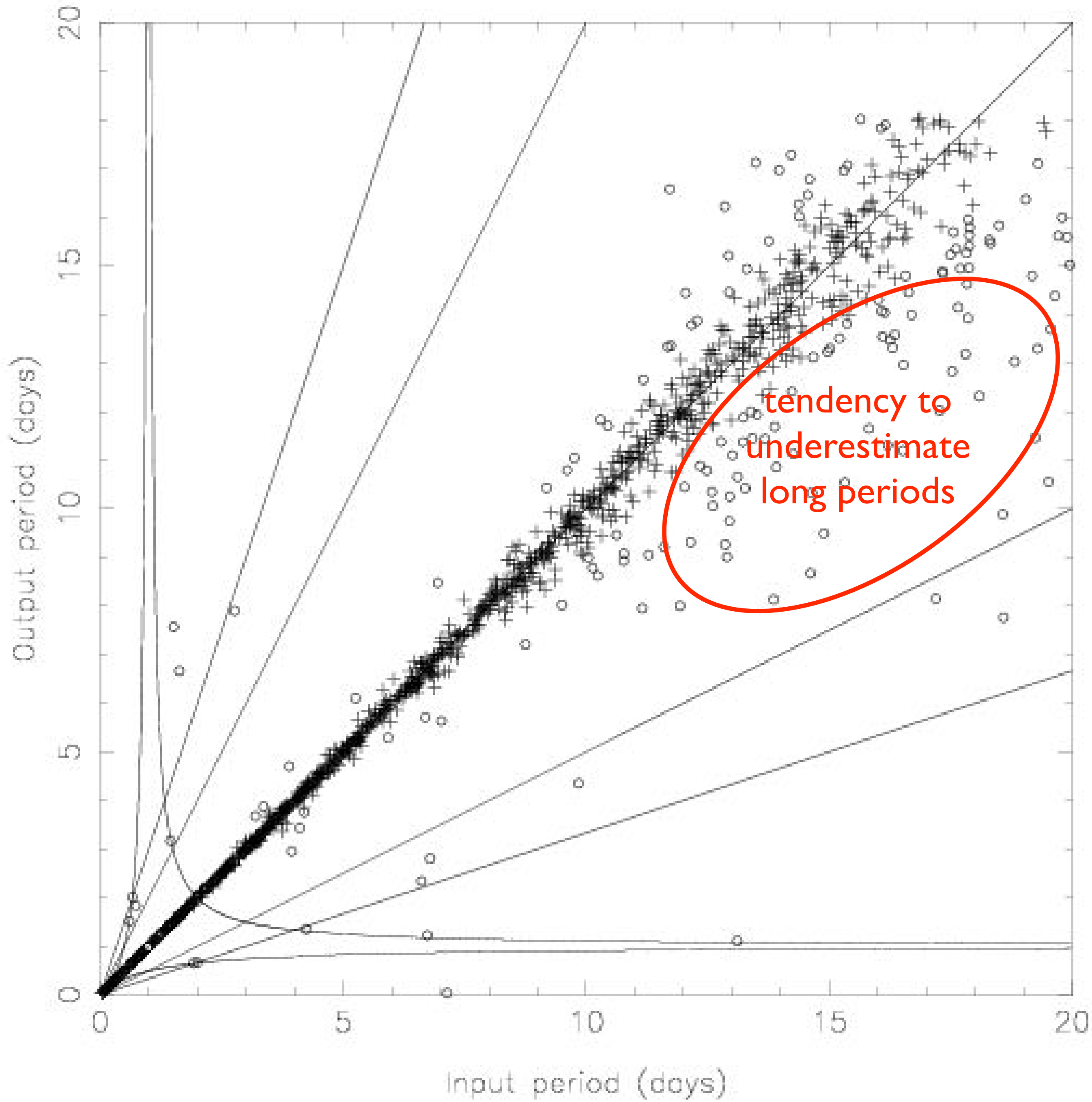
- sine-fitting $m(t) = m_{\rm dc}(t) + a\sin(2\pi t/P + \phi)$
- goodness of fit estimated by by subtracting smoothed phase-folded light curve at best period
- $$f = \frac{\chi^2_{\rm red} - \chi^2_{{\rm red},P,{\rm smooth}}}{\chi^2_{\rm red}} \geq 0.5$$
- searched all i-band LCs of stellar, unblended objects → 118 detections
- require independent detection in V → 86 detections
- when i-band period consistent with 1-d alias, use V-band period
- simulations to estimate reliability and completeness
  - inject sinusoids into non variable light curves $\chi^2_{\rm red} < \langle\chi^2_{\rm red}\rangle + 3\sigma(\chi^2_{\rm red})$
  - 0 < P < 20 d, 0 < α < 0.1 mag, uniform distributions

i-band only



+ - "correct" detection: pass threshold and output period within 10% of input

o - "incorrect" detection: pass threshold but output period not within 10% of input i + V

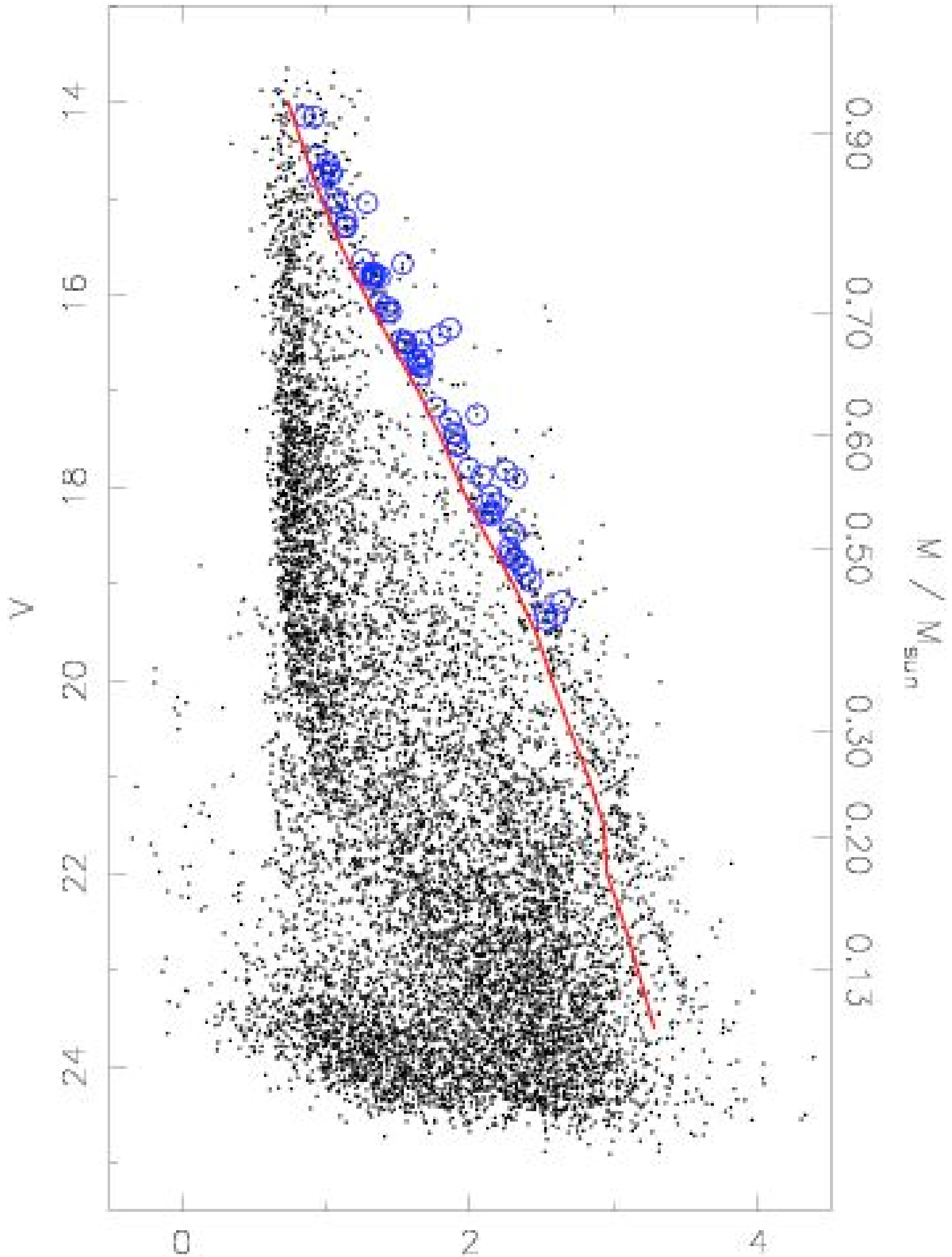


+ - “correct” detection: pass threshold and output period within 10% of input
o - “incorrect” detection: pass threshold but output period not within 10% of input

Completeness & reliability

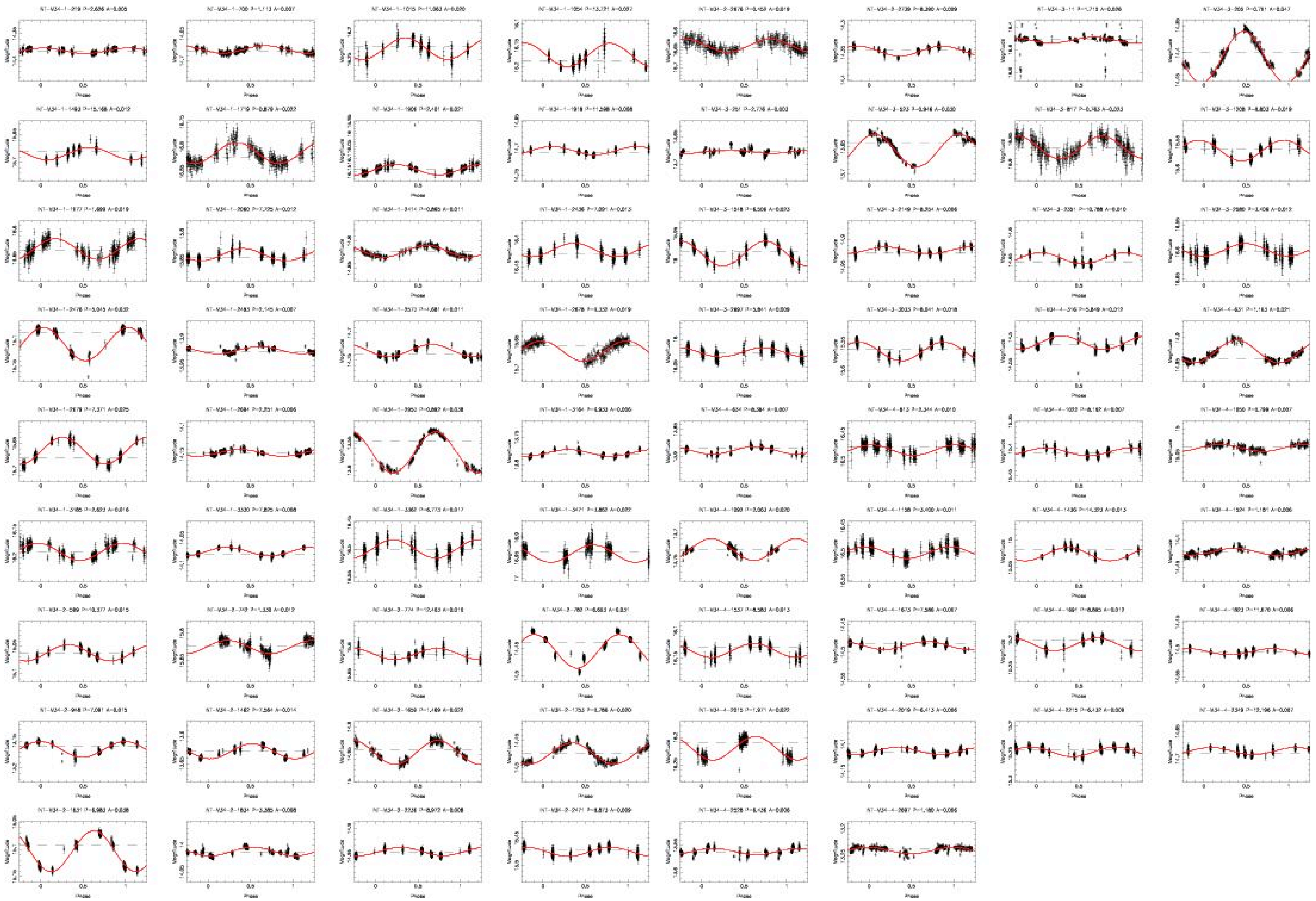
- Completeness = fraction of the simulations where the modulation is detected and the output period is within 10% of the input period
(for otherwise favourable conditions: P = 0.386 d, amplitude 0.1 mag, i < 16)
    - > 90% complete down to amplitudes of 0.02 mag
    - > 90% complete down toi~18 (50% complete at i~19)
    - > 80% complete down to P ~ 15 d
- Reliability = fraction of the detections where the detected period within 10% of the input period as a function of input period (for all amplitudes and magnitudes)
    - for P_in ≤ 10 d, reliability > 95%
- Contamination = fraction of the detections where the detected period is not within 10% of the input period as a function of output period (for all amplitudes and magnitudes)
    - for P_out ≤ 8 d, contamination< 5%
    - for P_out ≤ 14 d, contamination < 25%

Rotation in members

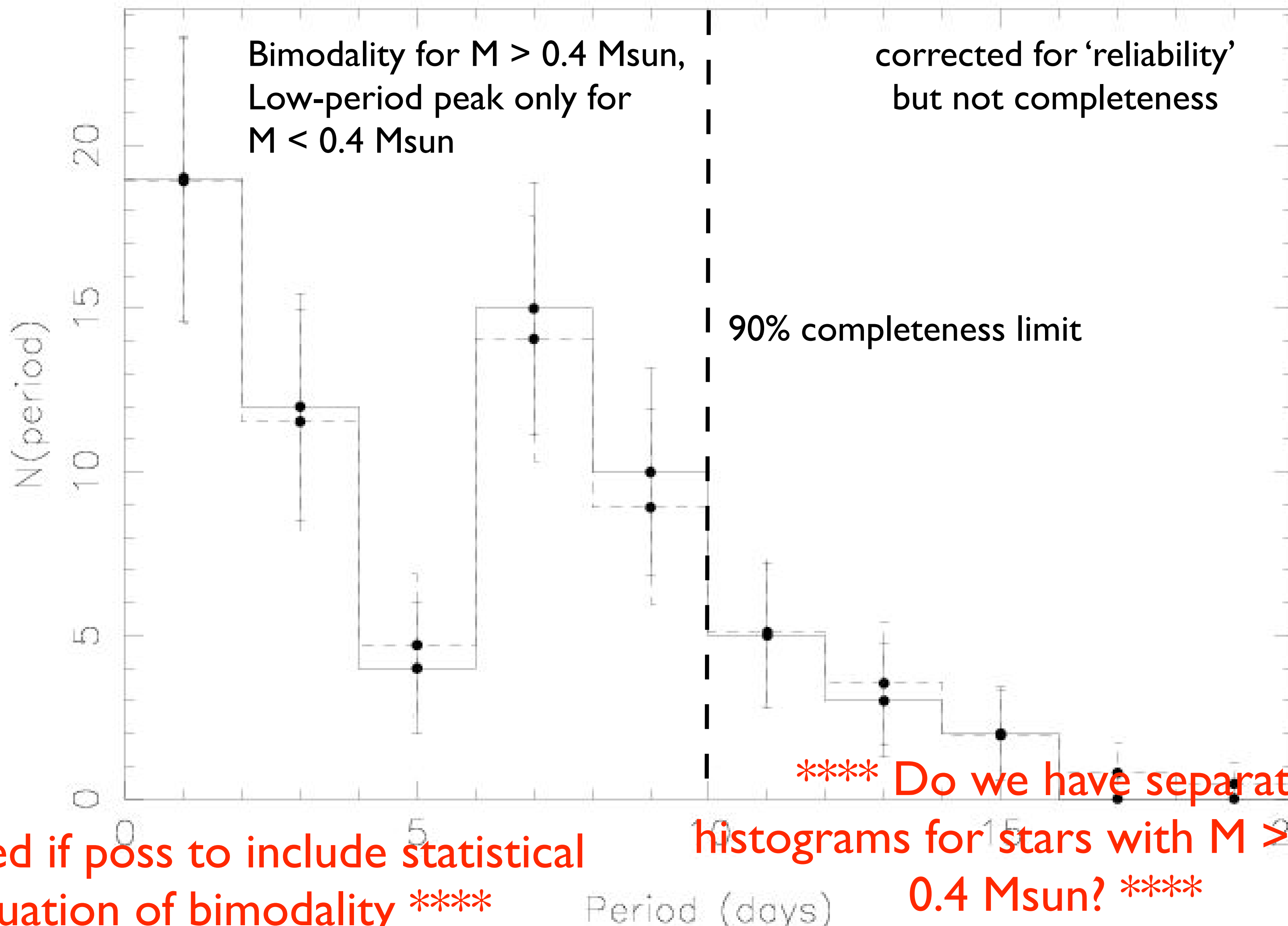


- Periodic modulation detected in 86 light curves
- 70 were candidate M34 members, i.e. ~10% of total membership
- Completeness correction:
  - Multiply luminosity function by completeness as a function of magnitude to get number of candidate members where we could have detected a modulation = 562
  - Calculate, given number of candidate members where we did detect a modulation, the expected number of candidate members where we should have missed it because amplitude too low or period too long = 174
- Completeness-corrected fraction of candidate members with rotational modulation is thus ~30%
- In magnitude range where complete, the fraction of members with detected periods increases with decreasing mass

Candidate members with rotation periods



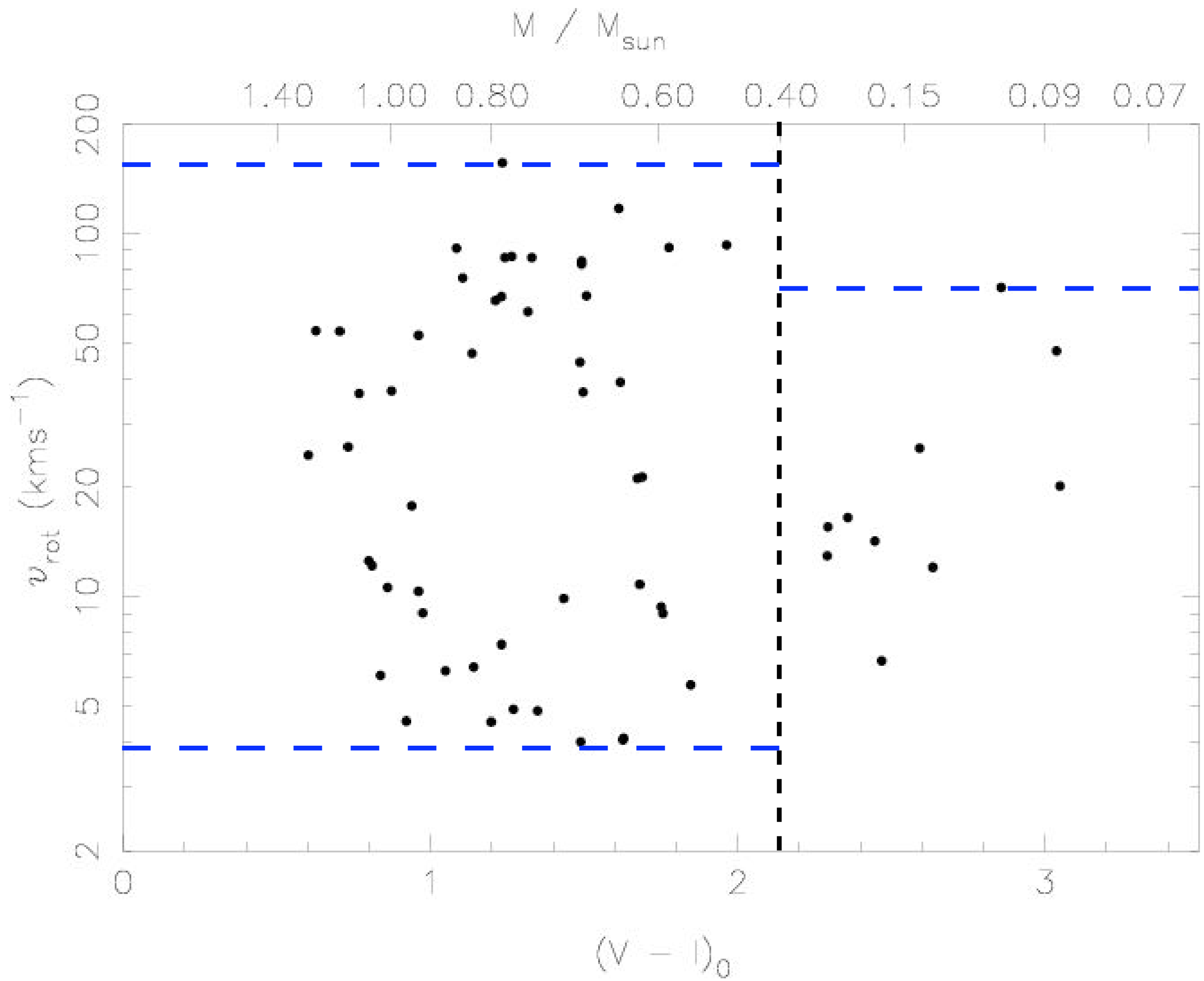
Period distribution



**** Need if poss to include statistical evaluation of bimodality ****

**** Do we have separate histograms for stars with M > and < 0.4 Msun? ****

Angular momentum evolution



Pleiades, 125 Myr

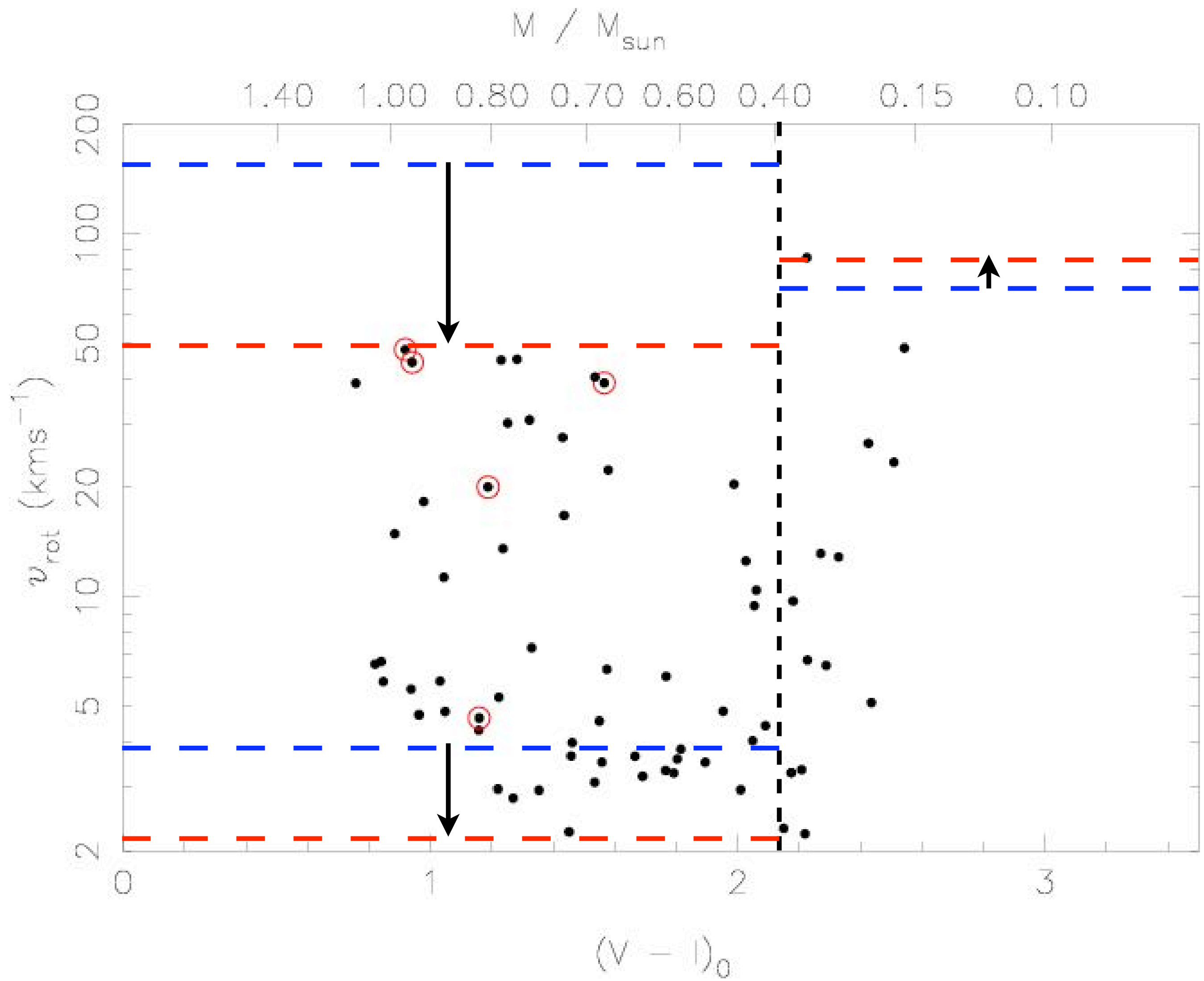
(Prosser & Stauffer Open Cluster Database, Terndrup et al. 1999, Stauffer & Eislöeffel 2004)

All v sin i's are derived from photometric period & radius from Barraffe et al. (1998)

Angular momentum evolution

M34, 200 Myr
(This work)

All v sin i's are derived from photometric period & radius from Barraffe et al. (1998)

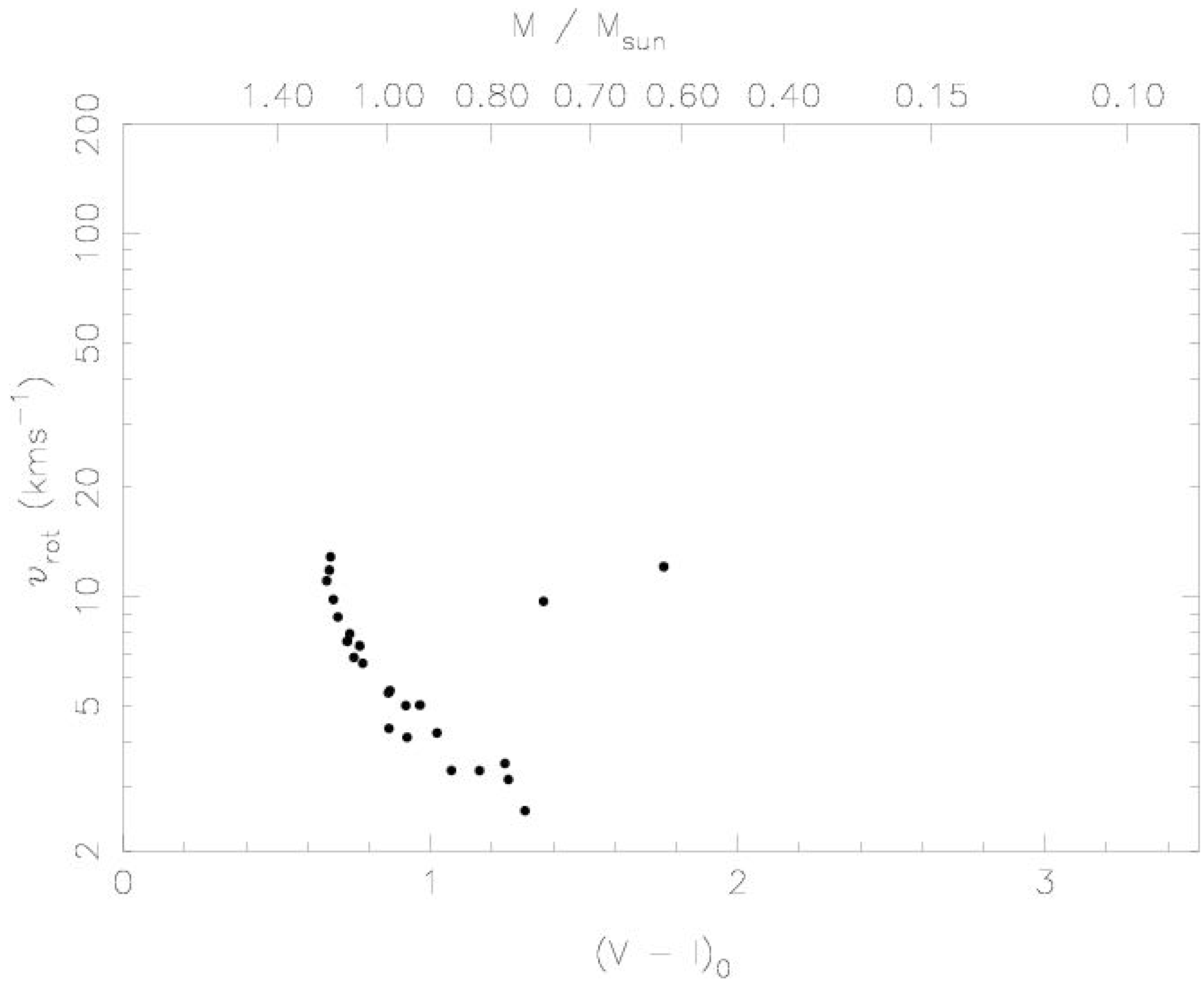


Angular momentum evolution

Hyades, 625 Myr

(Prosser & Stauffer Open Cluster Database)

All v sin i's are derived from photometric period & radius from Barraffe et al. (1998)



Spot coverage and temperature

Simple model:

$$T_{\rm eff}, \Delta T, f$$

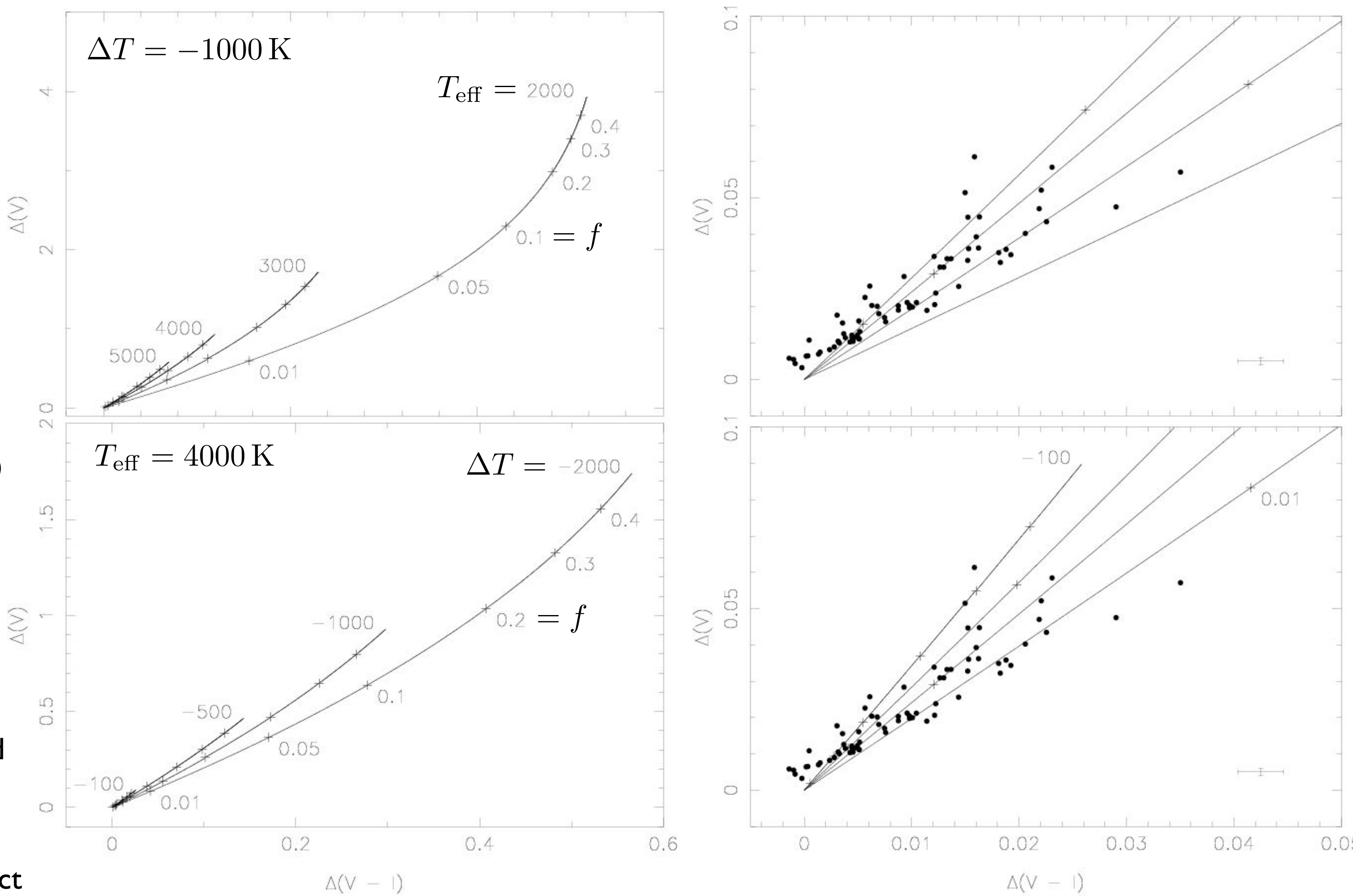
→ too much scatter to constrain ΔT & f

Our model implies $f \leq 0.6$ for $\Delta T < -100\,K$

while spectroscopy of field dwarfs (O'Neal et al. 2004) shows $\Delta T \sim -1000\,K$ and $f \sim 0.3$

→ single spot model inadequate: distribution of spots gives smaller amplitude for same temperature difference and covering factor

→ blackbody spectra also inaccurate, but smaller effect



M34 - conclusions

- 714 candidate members identified from CMD with $0.9 > M/M_\odot > 0.01$, and estimated ~40% contamination
- Log-normal MF with $M0 = 0.4\ M_\odot$ and $\sigma = 0.54$, comparable with other clusters of similar age
- Rotation periods detected in 70 candidate members, i.e. a completeness corrected fraction of ~30% of total members
- Rotation fraction increases towards lower masses
- For $M > 0.4\ M_\odot$, bimodal period distribution with peaks at 1-2 and 8 d
- For $M < 0.4\ M_\odot$, unimodal distribution with peak at 1-2 d
- M34 intermediate between Pleiades and Hyades in evolutionary sequence
- Angular momentum loss between Pleiades and M34 age is more efficient for stars with $M > 0.4\ M_\odot$

Future prospects

- ONC (1 Myr)
  - Stassun et al. 1999: 254 periods down to ~ 0.2 Msun
  - Herbst et al. 2002: 369 periods down to ~ 0.1 Msun
  - We have detected 900 periods, into the BD regime
  - under analysis, hoping to combine datasets with the Herbst & Stassun
- Other clusters with ages 3, 7, 30, 50, 100, 130, 150 Myr: complete PMS sequence

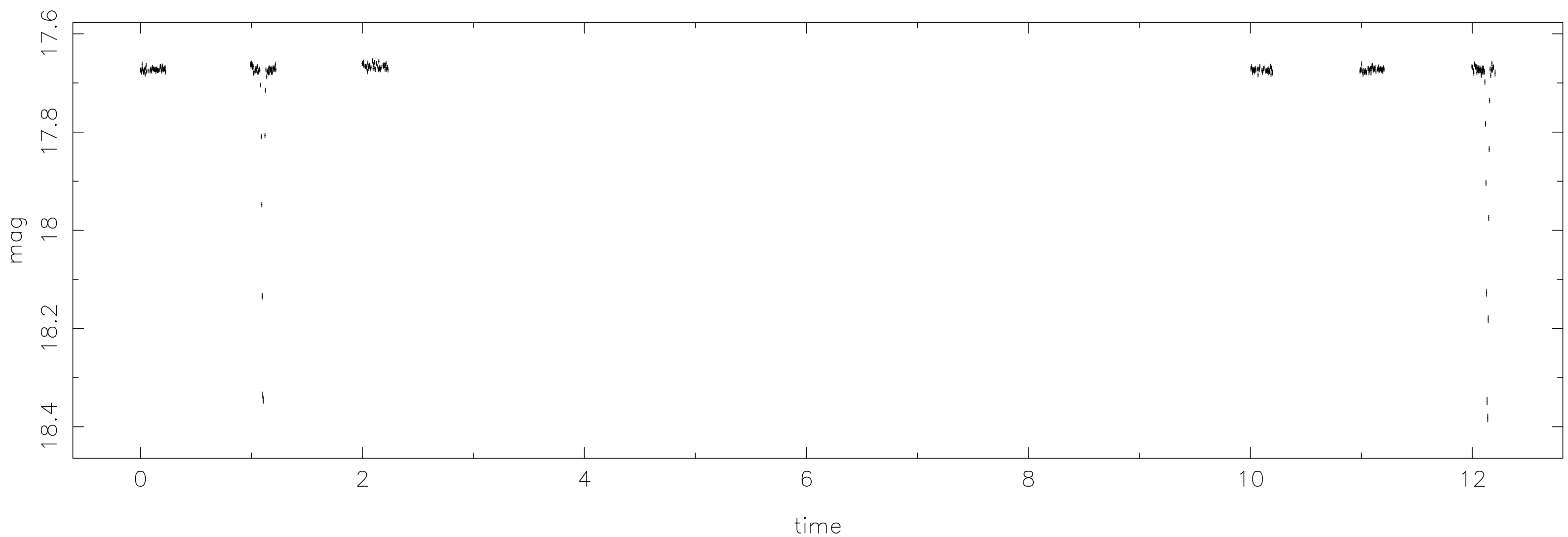
early results - II

Eclipse candidates
in M34, ONC, M50 & NGC 2362

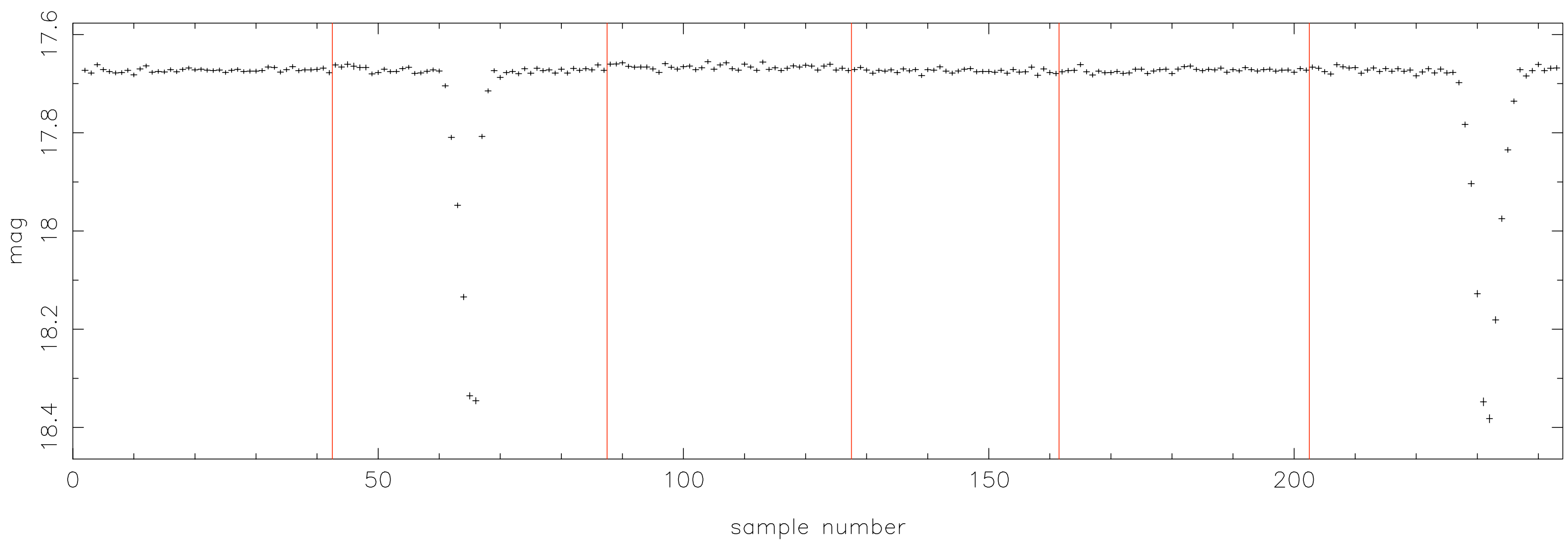
Eclipse candidate selection

- Light curves of unblended stars falling near cluster sequence searched by eye (ONC) or using the transit search algorithm of Aigrain & Irwin (2005) (other clusters)

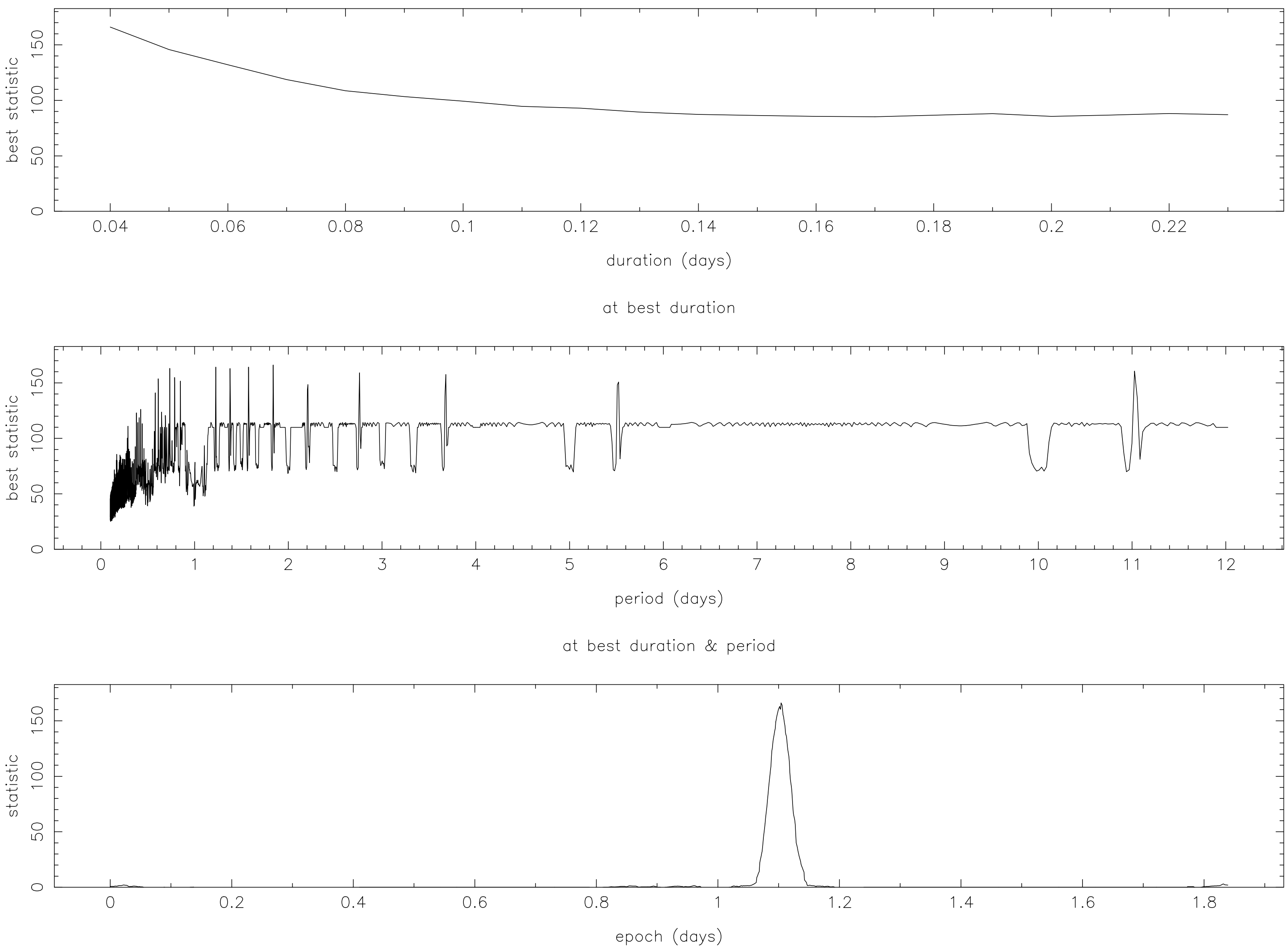
Transit search - 1



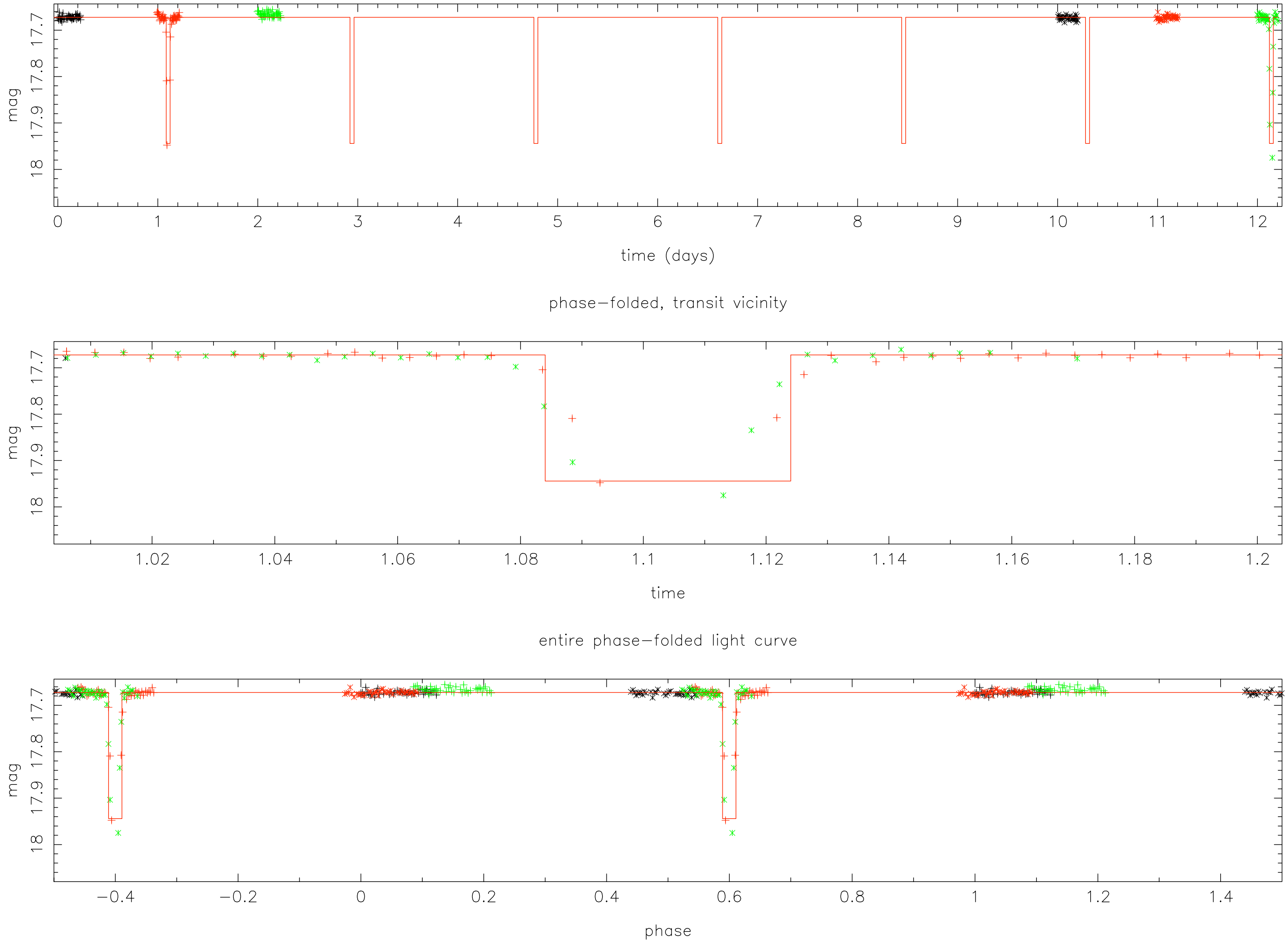
M50 object, I=17.4, 6 nights on CTIO 4m + Mosaic in February 2005



Transit search - 2



Transit search - 3

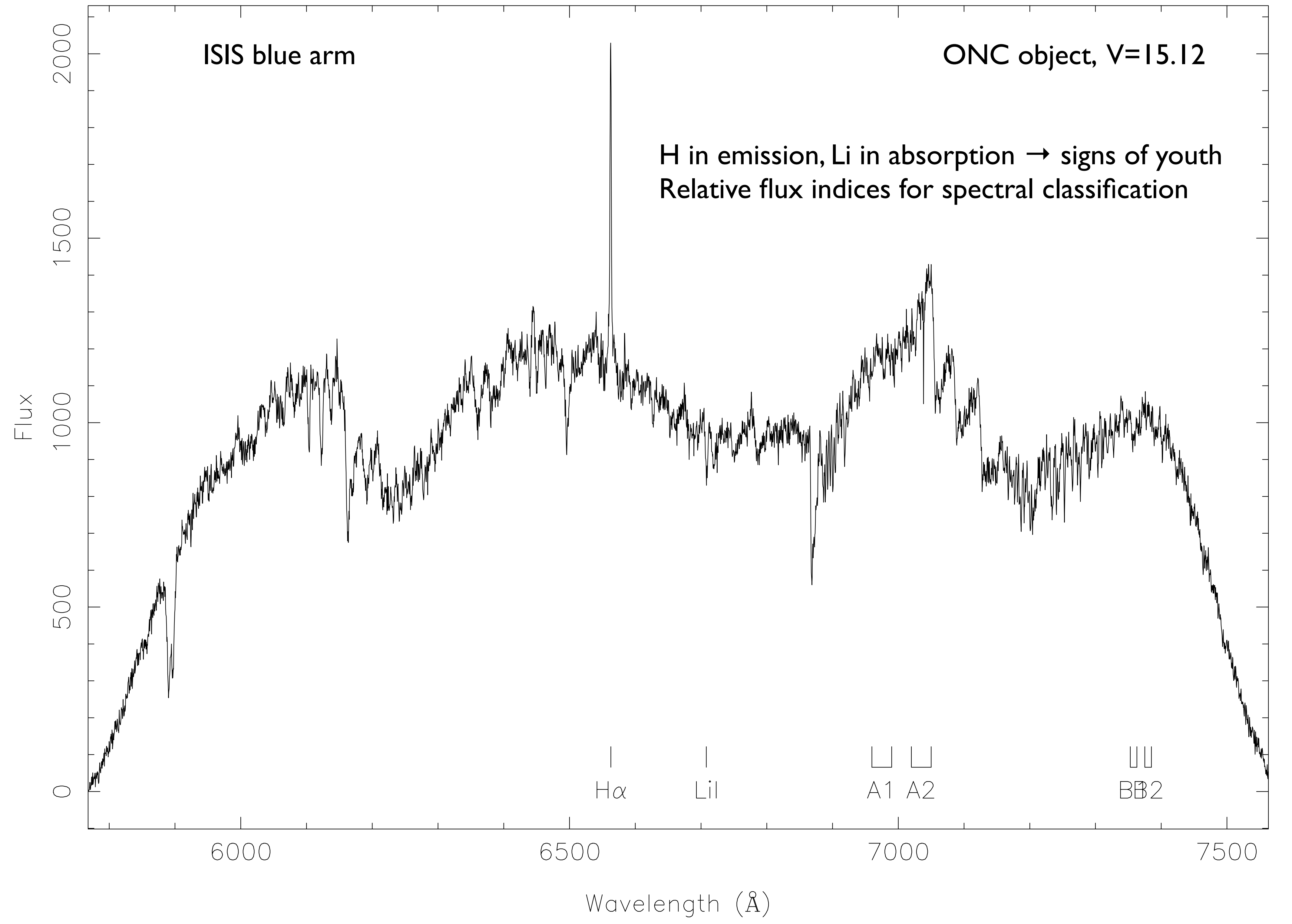


Eclipse candidate selection

- Light curves of unblended stars falling near cluster sequence searched by eye (ONC) or using the transit search algorithm of Aigrain & Irwin (2005) (other clusters)
- When applicable, remove rotational modulation by fitting sine curve to eclipse-free nights before estimating eclipse parameters
- Check if duty cycle consistent with eclipse (rather than, say, spots)
- Approximate primary masses and radii deduced from optical + IR (2MASS) colours
- Minimum secondary radii deduced from eclipse depth
- Minimum secondary mass derived, when possible, from eclipse duration
- 12 high quality candidates, 4 with lower quality light curves

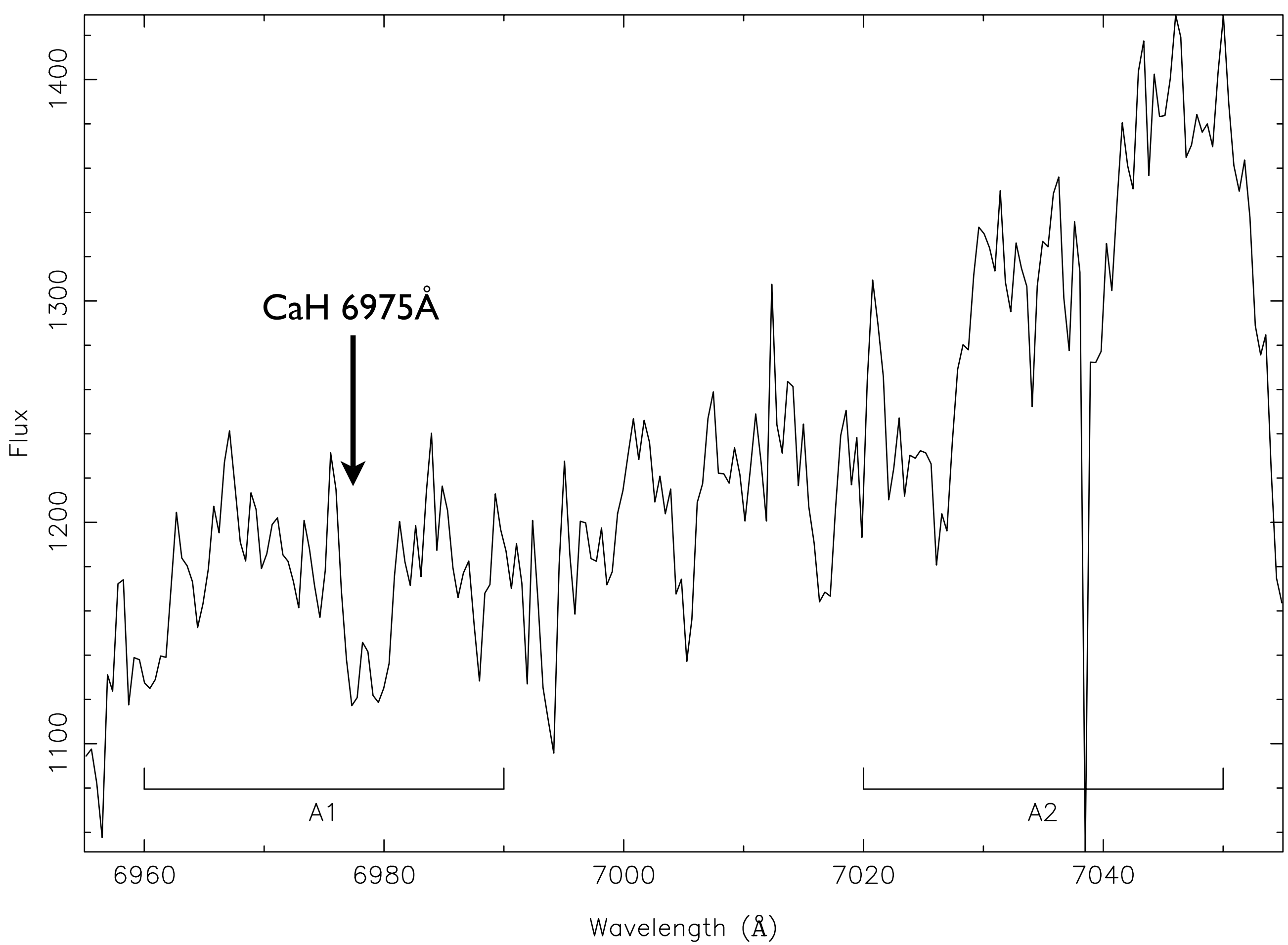
Spectroscopic follow up

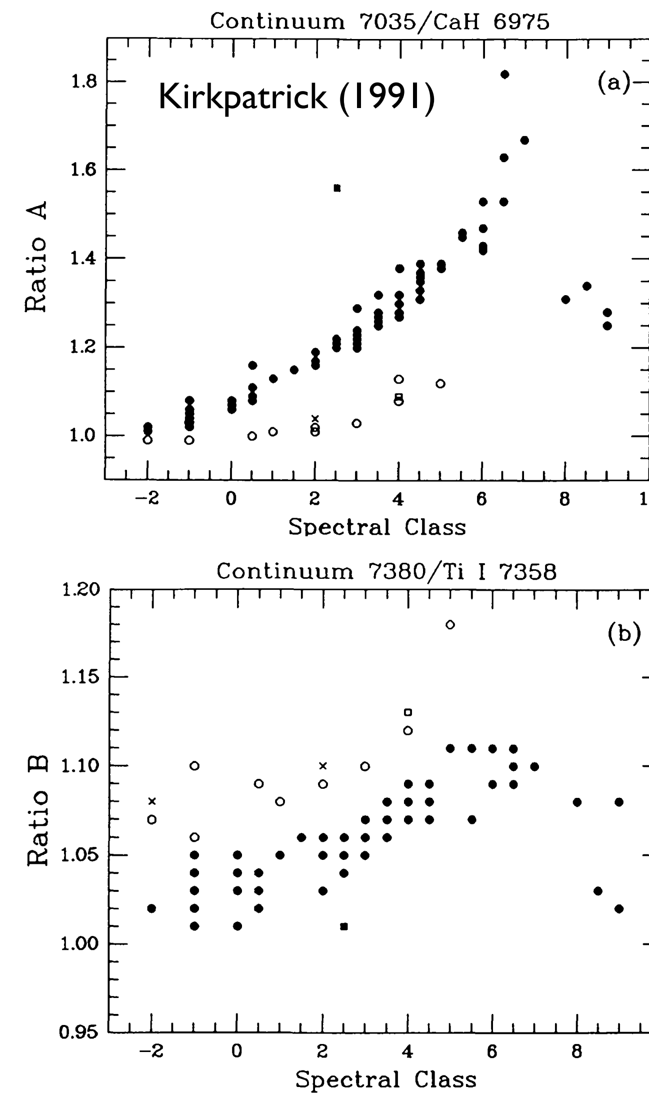
- Goal:
  - Establish membership and spectral type of primary
  - Constrain companion masses from multi-epoch RV measurements
- 3 1/2 nights on APO3.5m - mostly lost to bad weather and technical problems
- 2 night on WHT / ISIS - 1 cloudy, 1 with 2-3” seeing
  - red arm: R1200R grating, 8085 - 8715 Å, R ~ 9500
  - blue arm: R600B grating, 5950 - 7350 Å, R ~ 3300
  - flats and arcs after each target to minimise effect of flexure
  - only 1 or 2 epochs (separated by few h)

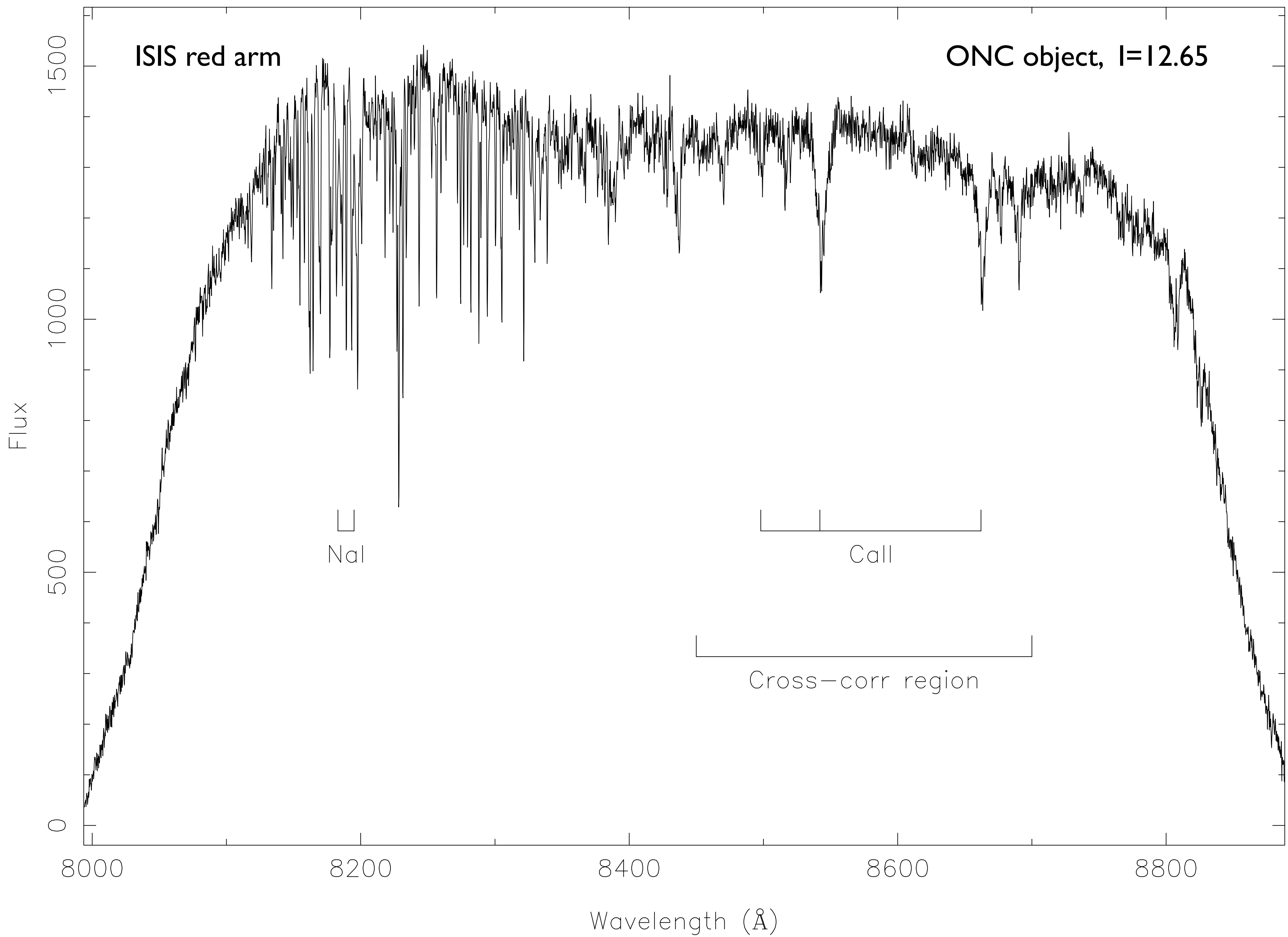

ISIS blue arm
ONC object, V=15.12
H in emission, Li in absorption → signs of youth
Relative flux indices for spectral classification
Flux
Wavelength (Å)
Hα
LiI
A1
A2
B1
B2
0
500
1000
1500
2000
6000
6500
7000
7500

Spectral classification

Used the Kirkpatrick A/B indices, each if which measures the ratio of flux in a specific line or band to the nearby continuum. A is sensitive to both temperature and luminosity class. and was used in preference to B which offers less clear discrimination

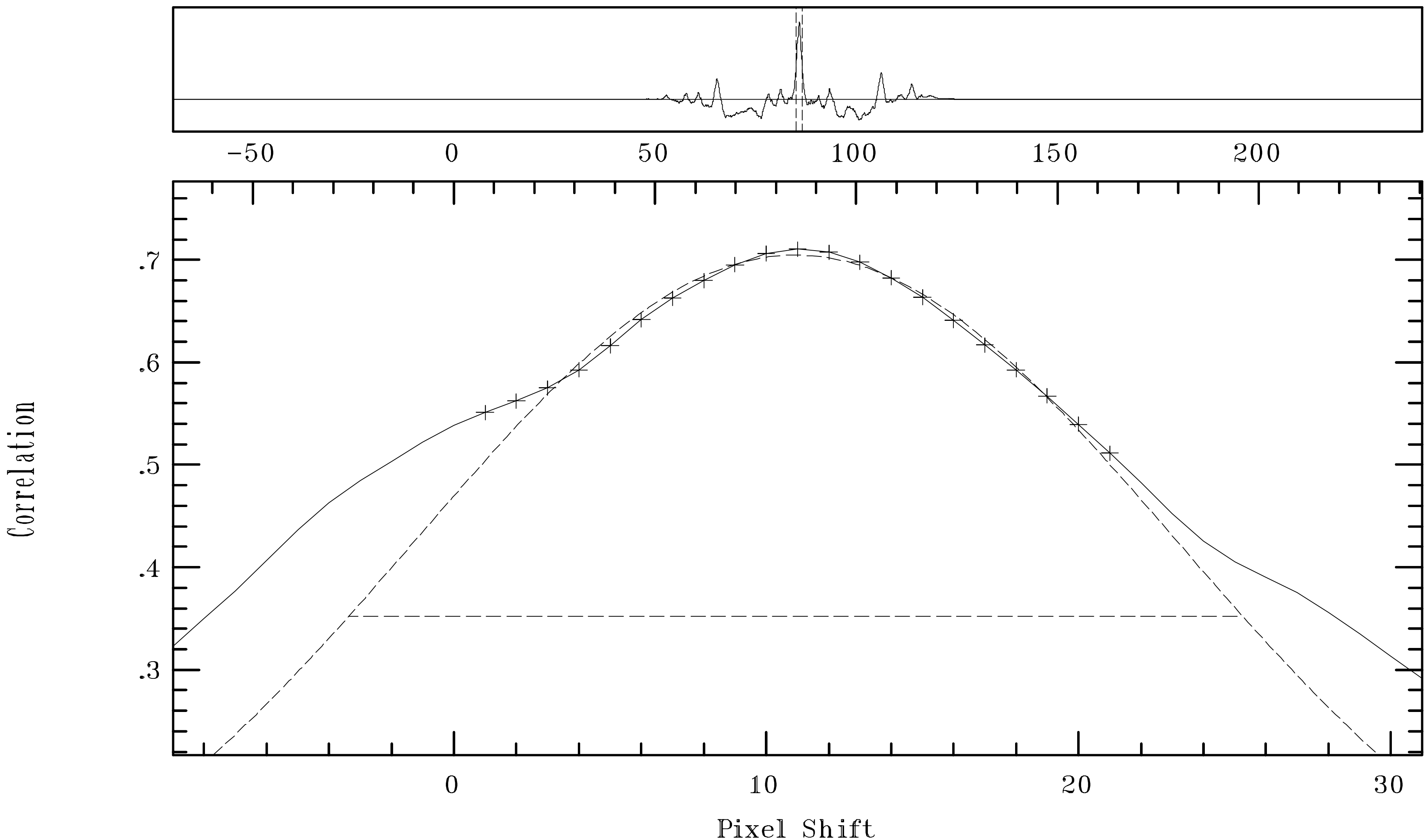




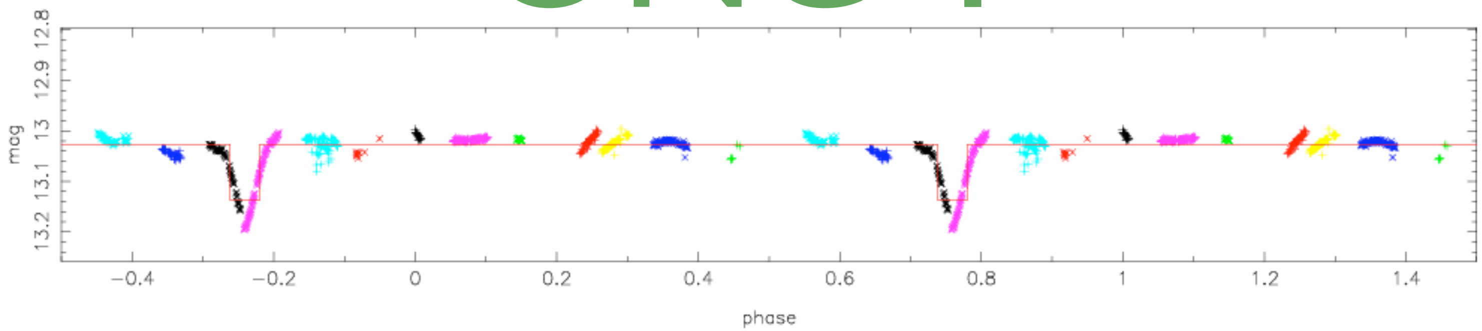

ISIS red arm
ONC object, I=12.65
Flux
Wavelength (Å)
NaI
CaII
Cross-corr region
0
500
1000
1500
8000
8200
8400
8600
8800

Cross-correlation

Each object spectrum is cross-correlated with spectra of HD1326A (M1V) and GJ908 (M1.5V), and average of the two measurements is used.

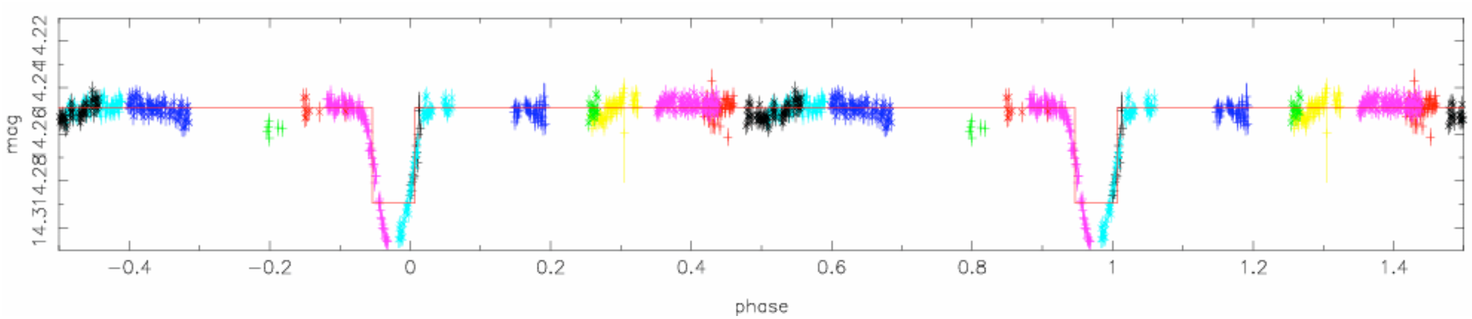


ONC-1



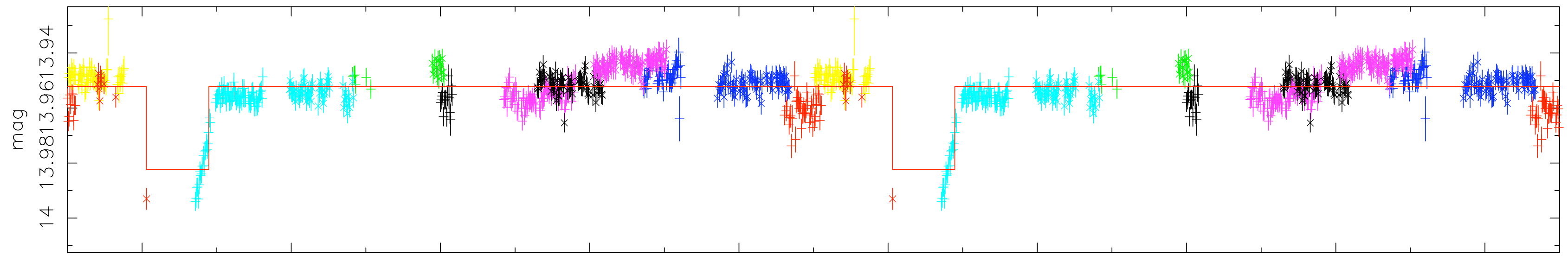
- I = 12.65, V = 15.12, P = 2.56 d , d = 0.3 d, dF/F = 0.10, grazing
- Hillenbrand(1997): memb. prob. 98%, M2V, M1 = 0.2 Msun, R1 = 3.13 Rsun
- (V,I,J,H,K, age 1 Myr) → M1 ~ 0.92 Msun, R1 ~ 2.64 Rsun
- (R1, dF/F) → R2 > 0.83/0.98 Rsun
- If M1 = 0.3 Msun & M2 ~ 0.1 Msun → K ~ 29 km/s
- 2 spectra with WHT+ISIS
  - RV = 47.1 ± 3.1; 38.6 ± 4.4 km/s (Sicilia Aguilar 2005 gives -31 ± 2 km/s) → evidence of large variation, K > 39 km/s
  - Li 6708 in absorption, SpT M0-M1V (Hillenbrand 1997 gives M2V)
- Applied for additional time on WHT+ISIS

ONC-2



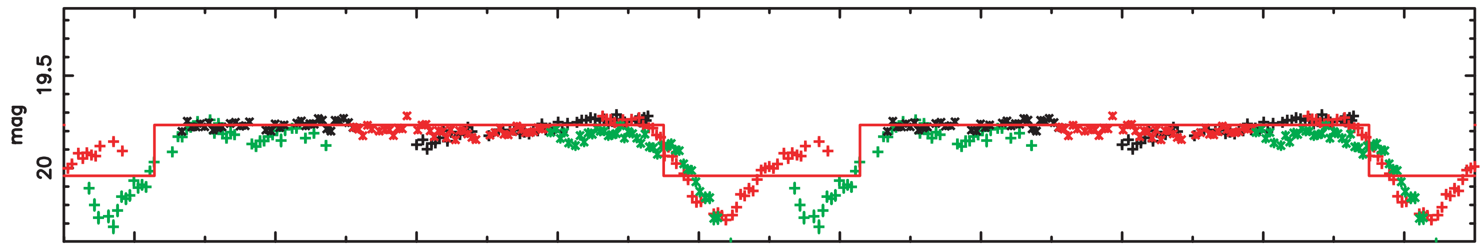
- I = 13.82, V = 16.92, P = 2.65 d , d = 0.2 d, dF/F = 0.06, could be grazing
- Hillenbrand(1997): memb. prob. 99%
- (V,I,J,H,K, age 1 Myr) → M1 ~ 0.50 Msun, R1 ~ 2.08 Rsun
- (R1, dF/F) → R2 > 0.24 Rsun, which at that age can be anything from VLM star to planet
- If M2 ~ 1 Mjup, → K ~ 3 km/s; if M2 ~ 0.1 Msun → K ~ 29 km/s
- 2 spectra with WHT+ISIS
  - RV = 17.1 ± 6.3; 21.1 ± 12.4 km/s (broad lines), → inconclusive wrt variation
  - Li 6708 in absorption, SpT M4-M5V
- Applied for additional time on WHT+ISIS

ONC-3



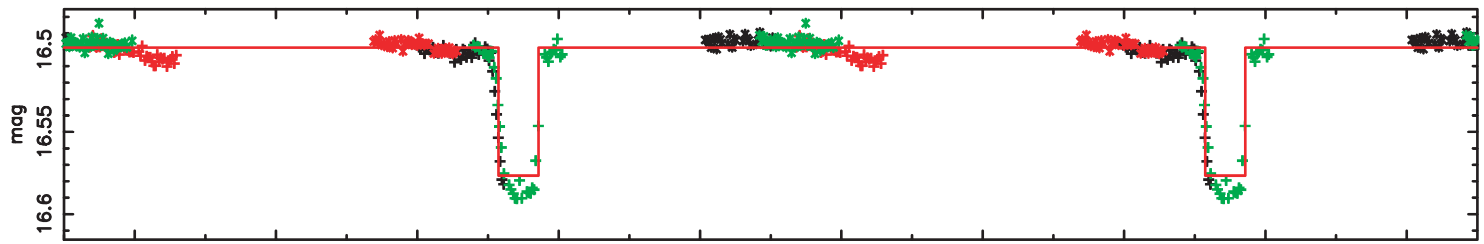
- I = 13.67, V = 16.10, P = 2.39 d , d = 0.2 d, dF/F > 0.03, partial
- Hillenbrand(1997): memb. prob. 2%, late G to early K
- (V,I,J,H,K, age 1 Myr) → M1 ~ 0.55 Msun, R1 ~ 2.15 Rsun
- (R1, dF/F) → R2 > 0.37 Rsun
- If M2 ~ 0.07 Msun → K ~ 16 km/s
- 2 spectra with WHT+ISIS
  - RV = 18.9 ± 2.4; 16.6 ± 2.8 km/s (Sicilia Aguilar 2005 gives -46 ± 8 km/s)
  - Halpha in absorption, SpT K5-K7V
- No sign of youth - rejected as background non-member

NGC 2362-1



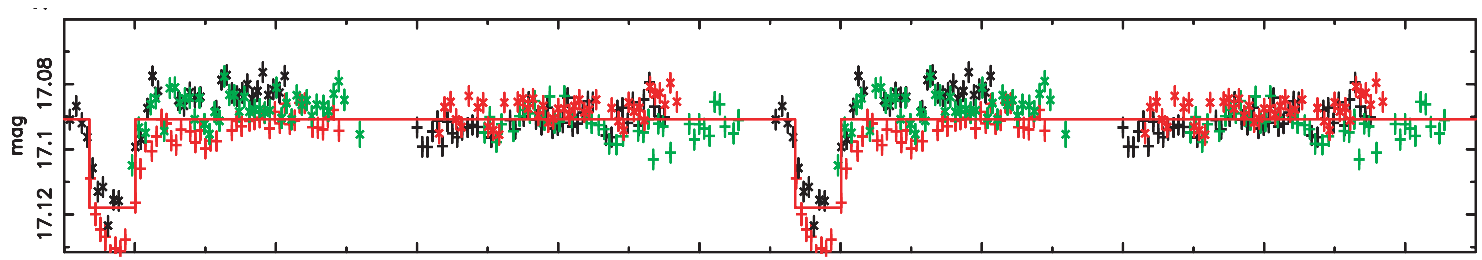
- I = 19.51, R = 21.32, P = 1.58 d , d = 0.1 d, dF/F = 0.41, grazing
- Possible eccentricity at double detected period? (constraint on circularisation!)
- (R,I, age 7 myr) → M1 = 0.41 Msun, R1 = 0.37 Rsun
- (R1, dF/F) → R2 >~ 0.24 Rsun → anything from VLM star to planet
- R2 = 1 Mjup would give K ~ 3 km/s, R2 = 0.1 Msun would give K ~ 29 km/s
- Interesting object, but really faint for RV follow-up!
- Just reobserved in photometry from CTIO 4m.

M50-1



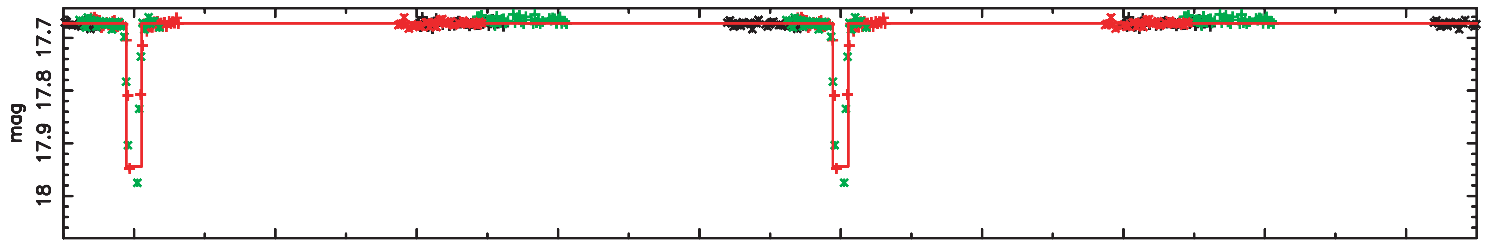
- I = 16.44, R = 17.02, P = 1.85 d , d = 0.1 d, dF/F = 0.09
- (R,I,J,H,K, age 130 Myr) → M1 ~ 0.67 Msun, R1 ~ 0.62 Rsun
- (R1, dF/F) → R2 ~ 0.20 Rsun
- (R,I, primary & secondary depth) → M1 ~ 0.7 Msun, M2 ~ 0.2 Msun → K ~ 37 km/s
- One spectrum in Dec 05 with WHT+ISIS: early-K5V, RV = +60 +/- 5 km/s
- Consistent with cluster membership if EB hypothesis is correct (system RV +6 km/s)
- Need more RV measurements to check for variations and determine mass
- Just reobserved in photometry from CTIO 4m, and will observe again with WHT/ISIS next month

M50-2



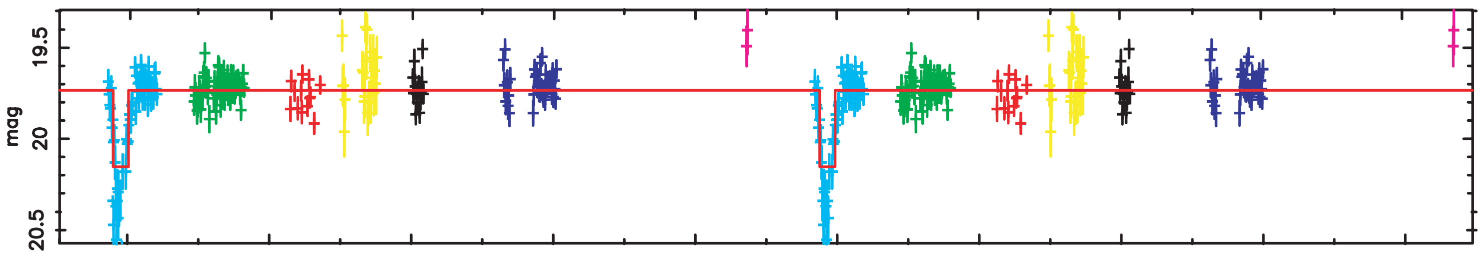
- I = 17.00, R = 17.67, P = 0.65 d , d = 0.04 d, dF/F = 0.04
- (R,I,J,H,K, age 130 Myr) → M1 ~ 0.67 Msun, R1 ~ 0.62 Rsun
- (R1, dF/F) → R2 ~ 0.12 Rsun
- If M2 = 1 Mjup → K~ 3 km/s; if M2 = 0.1 Msun → K ~ 23 km/s
- One spectrum in Dec 05 with WHT+ISIS → SpT = K5-K7V, vrad = 0+/- 7 km/s (system RV +6 km/s)
- Membership looks likely, but need multiple RV measurements to determine mass
- Just re-observed in photometry from CTIO 4m, and will observe again with WHT/ISIS next month

M50-3



- I = 17.40, R = 19.09, P = 1.84 d , d = 0.04 d, dF/F = 0.31, grazing
- (R,I,J,H,K, age 130 Myr) → M1 = 0.74 Msun, R1 = 0.67 Rsun
- (R1, dF/F) → R2 >~ 0.37 Rsun → M2 >~ 0.4 Msun → K >~ 60 km/s
- One spectrum in Dec 05 with WHT+ISIS: early-K5V, RV = -40 +/- 10 km/s
- Consistent with cluster membership if EB hypothesis is correct (system RV +6 km/s)
- Need more RV measurements to check for variations and determine mass
- Just reobserved in photometry from CTIO 4m, and will observe again with WHT/ISIS next month

M34-1



- I = 19.56, V = 22.48, Pmin = 1.373 d , d = 0.05 d, dF/F = 0.33
- (V, I, age 130 Myr) → M1 ~ 0.13 Msun, R1 ~ 0.17 Rsun
- (R1, dF/F) → R2 ~ 0.1 Rsun
- If M2 = 1 Mjup → Kmax ~ 7 km/s
- Attempted to observe in Dec 05 with WHT+ISIS but seeing was too poor for such a faint object
- Should get better light curve from CFHT data imminently

Conclusions - outlook

- Identified 16 candidates in 4 clusters from semester 04B
- 1 or 2 spectra obtained for 9 of these in 1 night in Dec 05
- Need more spectra!
- Repeat photometry in 05B: improved periods + additional candidates in NGC2362/M50/M34 (ONC run cloudy)
- New photometric surveys in 05B/06A: h & X per, Blanco1, NGC2457, NGC2516
- IR extension for ONC...