Eclipsing binaries in young star clusters

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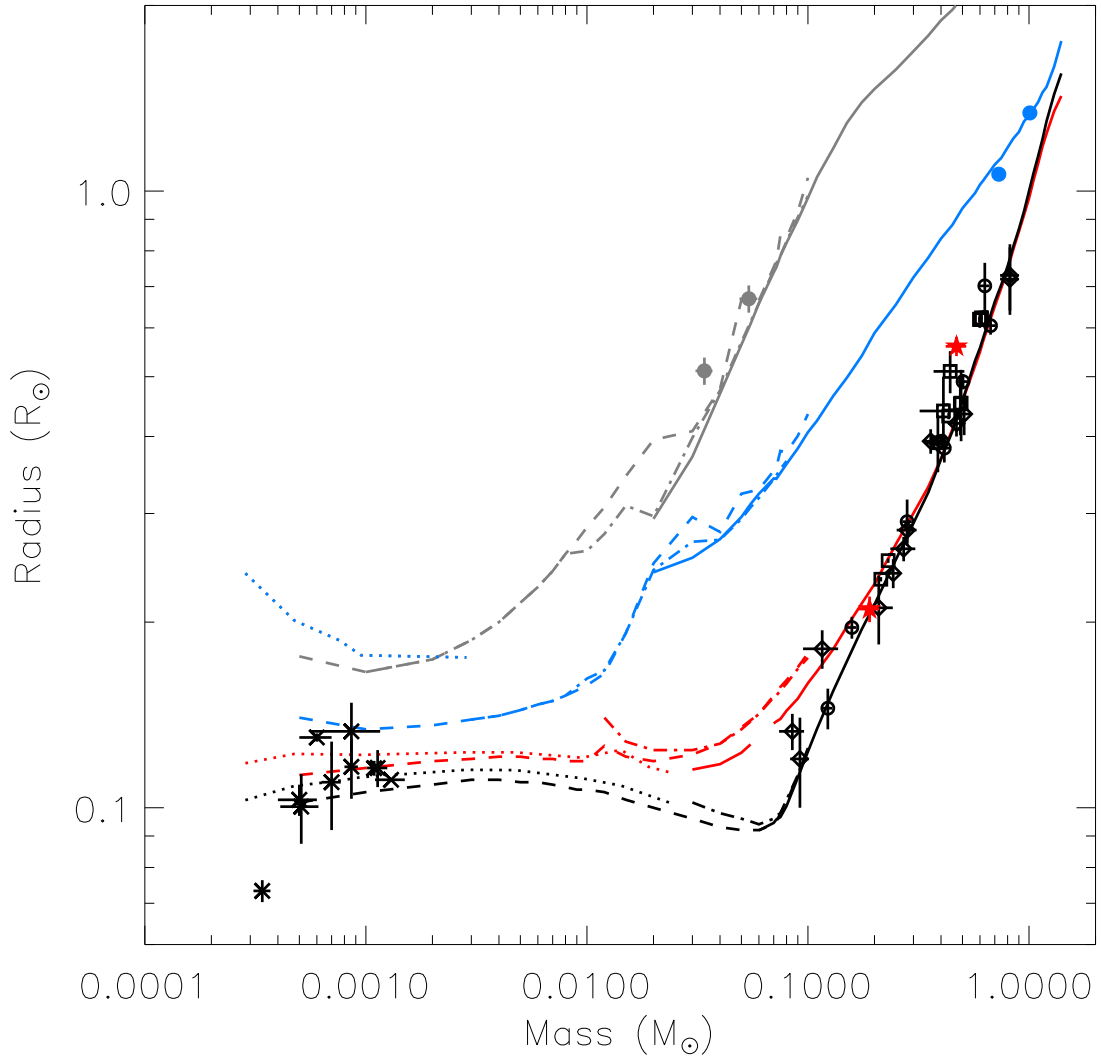
Motivation: Mass-radius relation

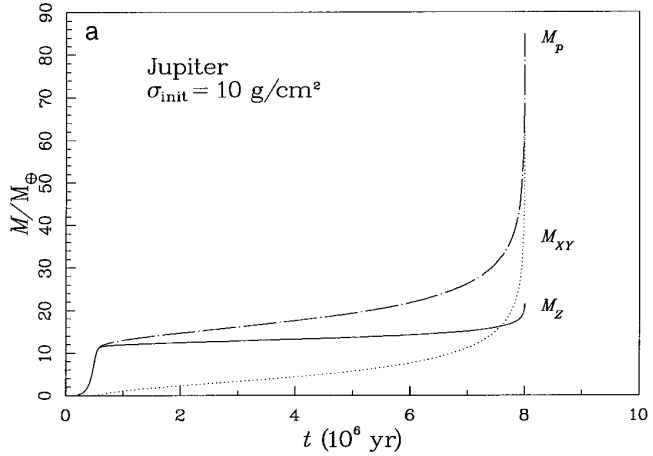


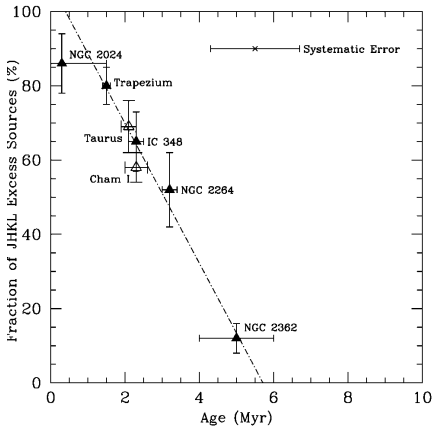
- Few young M-dwarf binaries
- BD desert - only one BD (Stassun et al. 2006)
- No young planets

Lines: NextGen (solid), DUSTY (dashed), COND (dotted), at 1, 10, 100, 1000 Myr

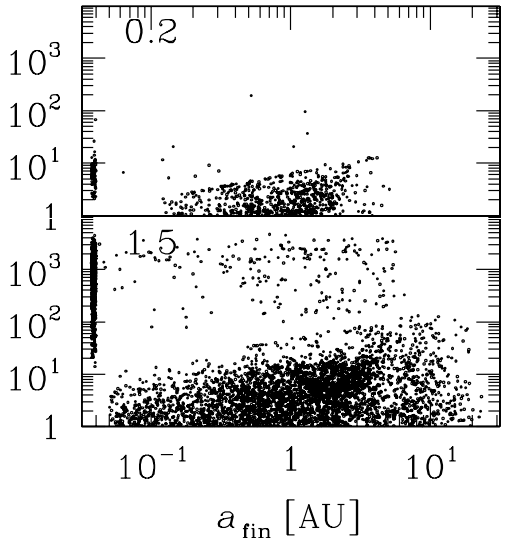
Motivation: Planet formation

- Core accretion timescale problem:





- Dependence on host mass:

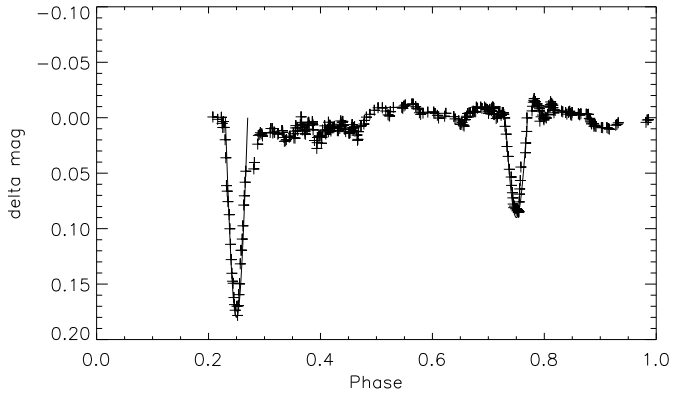


From Ida & Lin (2005)

- Rocky planets common around all spectral types
- Gas giants form in large numbers only around solar-mass stars

Related work

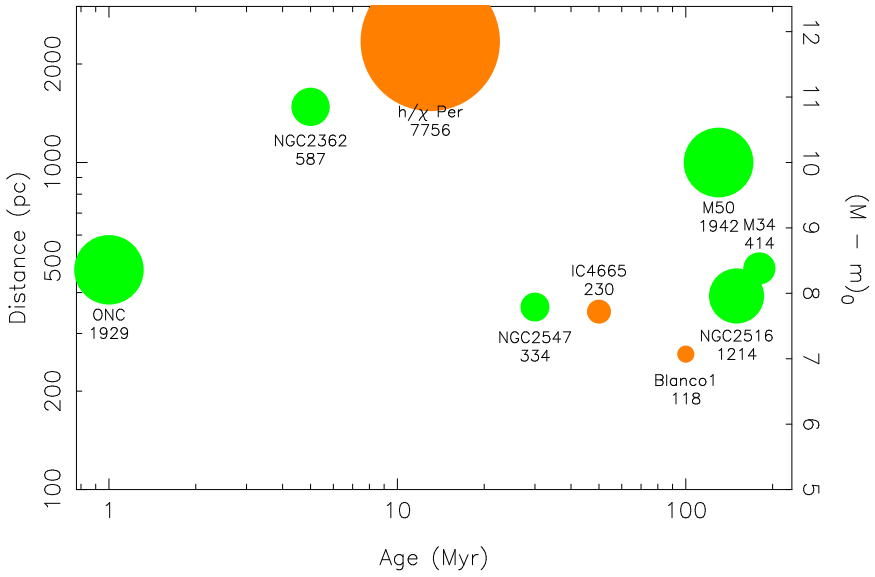
- Including:
  - EXPLORE-OC (von Braun et al. 2004)
  - UStAPS (Street et al. 2003, Bramich et al. 2005, Hood et al. 2005)
  - PISCES (Mochejska et al. 2002, 2004, 2005)
  - See Aigrain & Pont (MNRAS, in press) for a general discussion
- Hebb et al. (2004, 2006)



  - Survey of mid-age open clusters ($150\ \mathrm{Myr} - 1\ \mathrm{Gyr}$)
  - M-dwarf EB candidate in M35
  - Confirmed $0.47, 0.19\ \mathrm{M}_\odot$ EB in NGC 1647 ($150\ \mathrm{Myr}$)
- Stassun et al. (2004, 2006)
  - $1.0, 0.7\ \mathrm{M}_\odot$ and $0.054, 0.034\ \mathrm{M}_\odot$ EBs in Orion
  - Some uncertainty in age, but $\sim 1 - 10\ \mathrm{Myr}$

The Monitor project

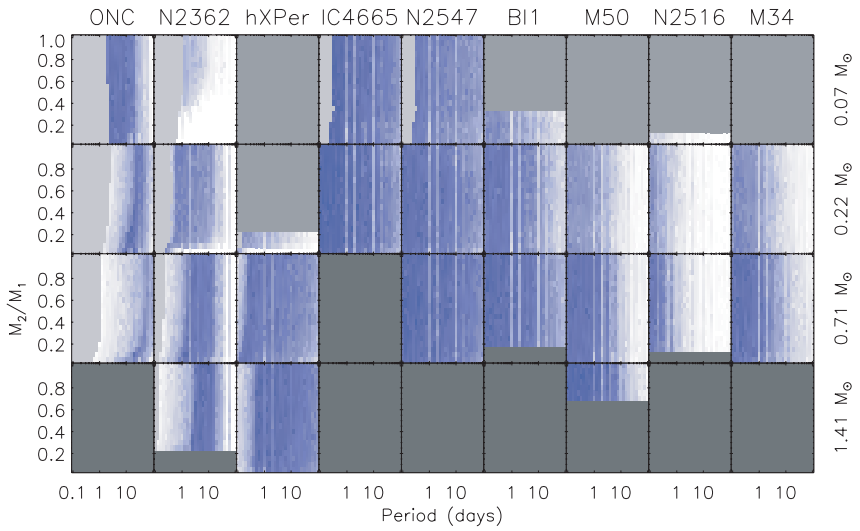
Cluster	Age/Myr	$M_{\rm sat}$	$M_{5\%}$	N_*
ONC	1 ± 1	0.75	0.04	1929
NGC 2362	5	1.14	0.07	587
h & χ Per	13	1.49	0.33	7756
NGC 2547	38.5	0.56	0.06	334
IC 4665	50	0.45	0.04	216
Blanco 1	90	0.80	0.06	148
M50	130	0.88	0.18	1942
NGC 2516	150	0.56	0.08	1214
M34	200	0.99	0.16	414
Total:				14540



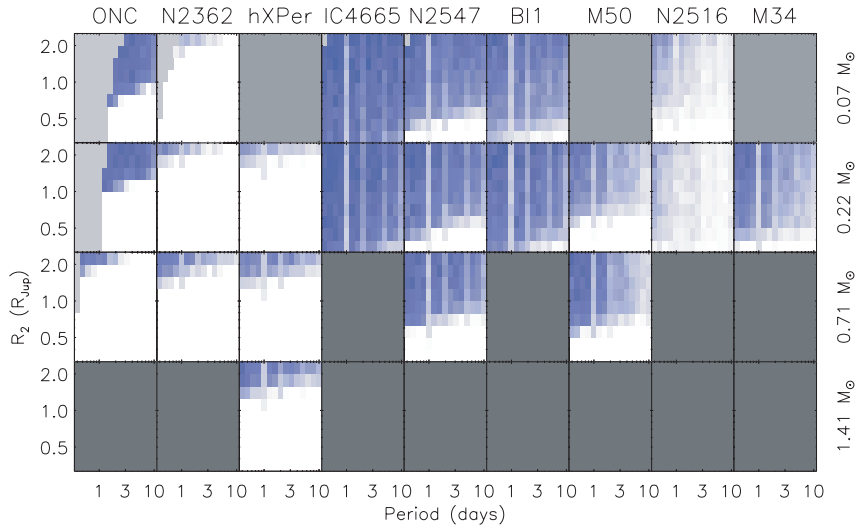
- Transit survey in young open clusters and SFRs
  - Known age, metallicity, ...
  - Bloated primaries
- Concentrating on low- and very low-mass primaries
  - Deeper transits
  - Larger RV amplitudes
- Targets
  - Ages up to ~ 200 Myr
  - Need to be relatively rich and compact
  - Small distance modulus to reach low-mass

Sensitivity estimates

- Method:
  - Based on Pepper & Gaudi (2005) semi-analytic method
  - Method extended to handle binaries as well as planets
  - Used real (observed) noise properties and sampling where possible
  - See Aigrain et al. (2007) for much more detail



EBs



Planets

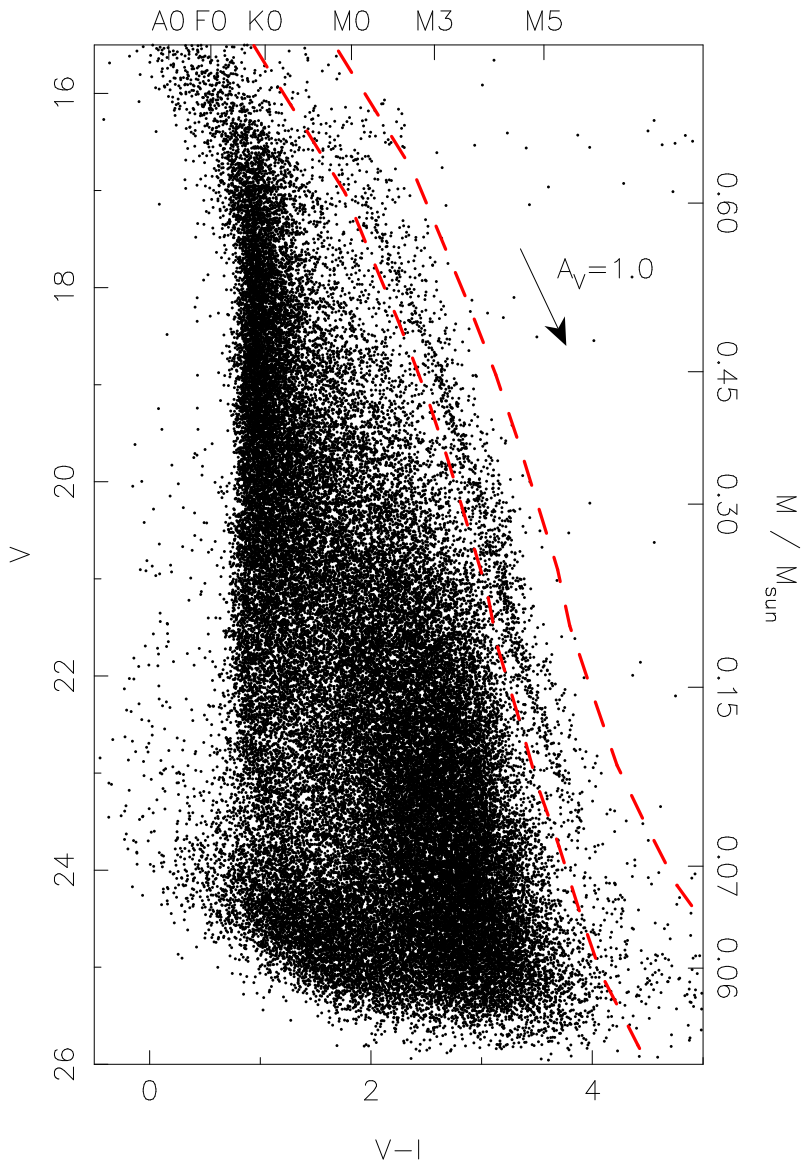
Sensitivity estimates - II

- Eclipse/transit detectability:

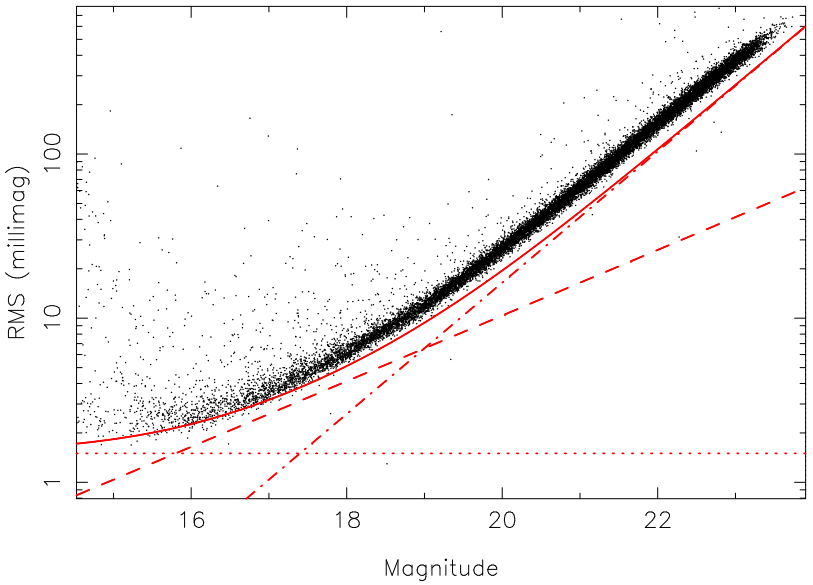
	Binaries			Planets		
Name	$N_{\rm c}$	$N_{\rm o}$	$N_{\rm d}$	$N_{\rm c}$	$N_{\rm o}$	$N_{\rm d}$
ONC	167.3	57.3	27.8	135.0	47.8	2.3
NGC 2362	45.6	11.0	4.7	37.1	11.3	0.0
$h\&\chi$ Per	648.9	106.0	67.0	631.9	118.1	1.2
IC 4665	21.5	5.8	4.6	14.3	4.3	3.1
NGC 2547	30.4	5.1	3.9	20.7	3.9	0.9
Blanco 1	10.3	0.9	0.6	8.0	1.0	0.5
M50	160.0	12.7	5.4	127.0	13.4	0.8
NGC 2516	103.0	8.4	1.5	76.9	8.4	0.7
M34	45.1	3.4	1.4	34.1	3.5	0.8
Total	1230.7	207.3	114.0	1084.4	209.4	8.6

- RV followup:
  - 100% of EBs with detectable eclipses produce RV modulations detectable with VLT/FLAMES
  - 25% can be detected on a 4m
  - Only 29% of the planets in the ONC, and 10% of those in NGC2547, produce a detectable RV signal
- See Aigrain et al. (2007)

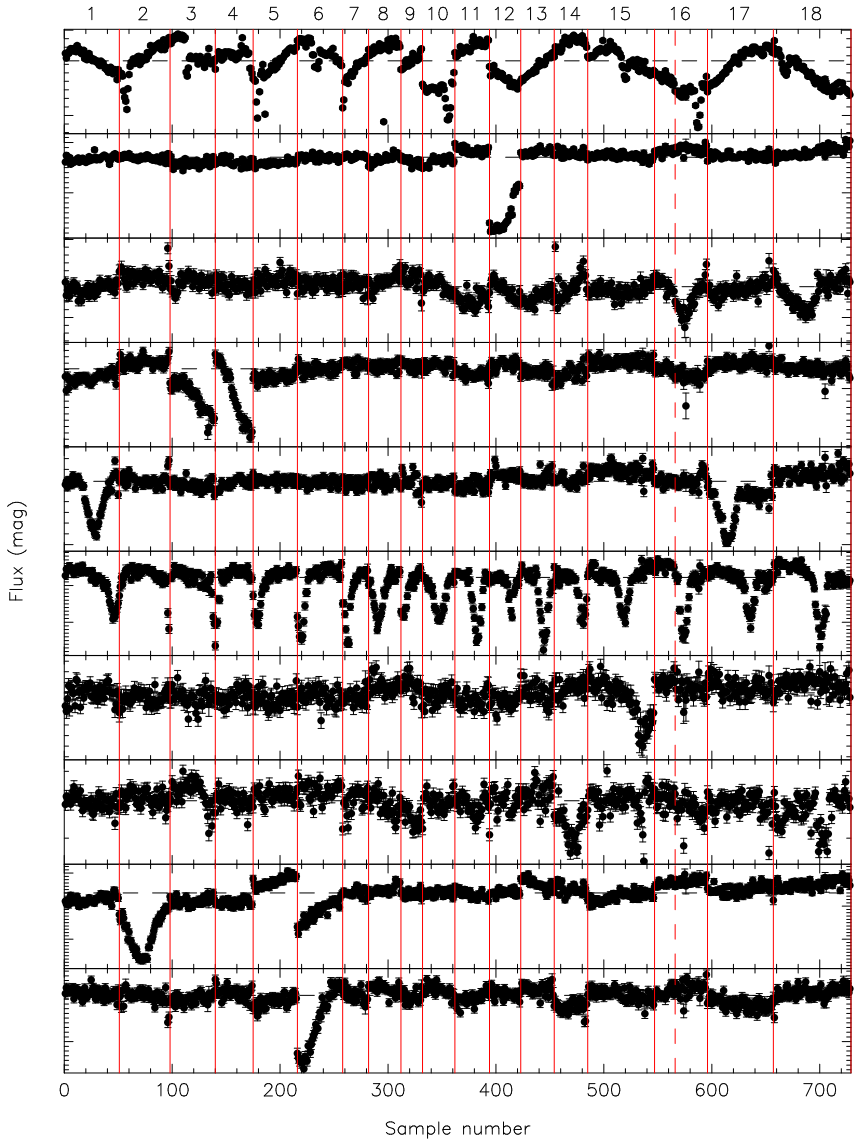
Photometry



- Candidate cluster members selected in V, $V-I$ CMDs
- High-cadence (< 15 min) aiming for 100 hours per cluster in i-band
- Better than 1% to $i \sim 19$ (CTIO), $i \sim 17$ (INT)



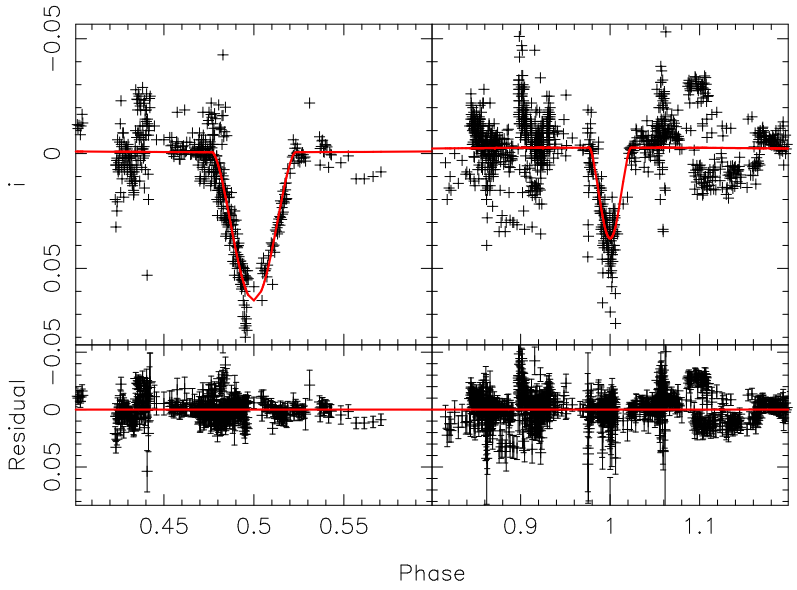
Candidates

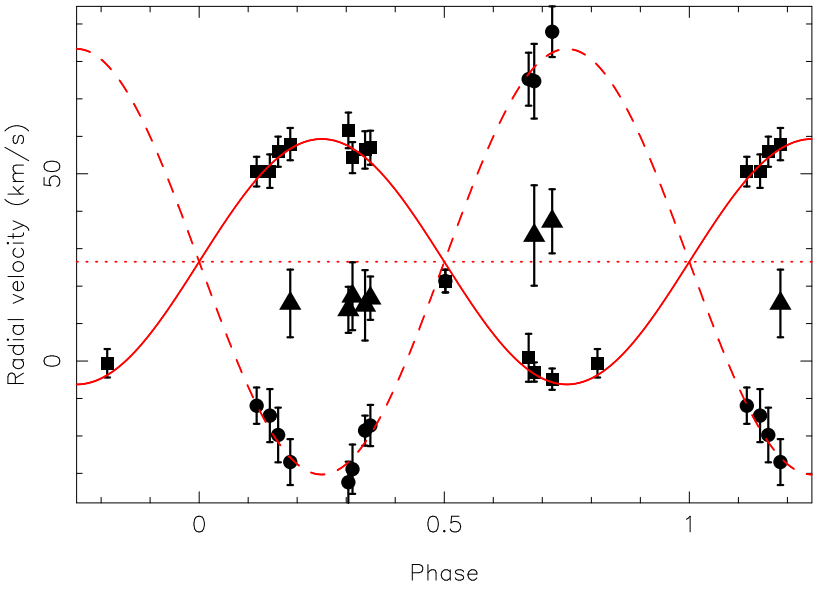


NGC 2362

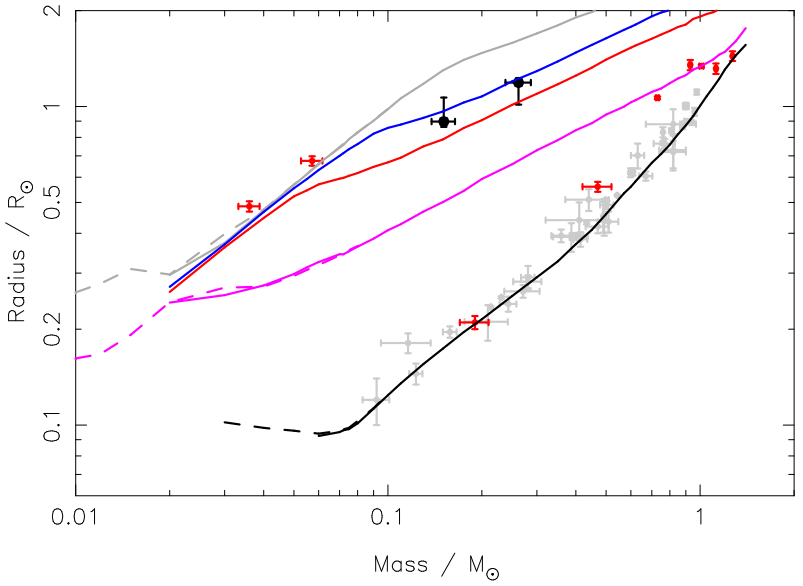
- Combination of visual and automatic techniques
- ~ 35 high-quality candidates, in 5 clusters ($\sim 1 - 200$ Myr)
- 4 partially solved
  - 2 appear to be genuine ONC EBs
  - 2 in the field towards NGC 2362, NGC 2547
- 7 need more data to say
- Most followup done on brightest objects (higher field contamination)

A new ONC PMS EB





- Membership probability 99% (Jones & Walker 1988)
- Lithium detected (next slide)
- Components 0.26, 0.15 $\mathrm{M}_{\odot}$
- Third light ($\sim 20\%$ of L)

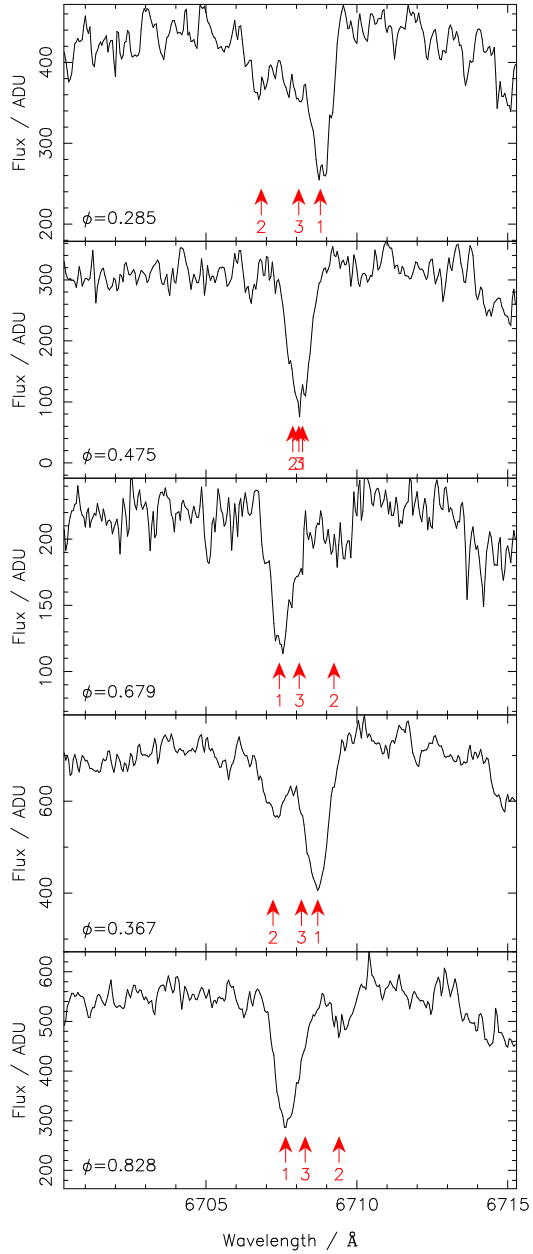


ONC PMS EB: LiI 6708 Å

- EWs smaller than expected:

Primary	0.35 ± 0.05 Å
Secondary	0.18 ± 0.04 Å
Tertiary	0.12 ± 0.05 Å

- May indicate depleted Li?
- Tertiary close to ONC systemic velocity $\Rightarrow$ ONC member, probably physical triple
- High-res imaging observations to attempt to resolve it?
- Still need $T_{\rm eff}$ measurements to put on H-R diagram
- See Irwin et al. (MNRAS, submitted)



Future work

- Observations: radial velocities (NTT, VLT), h/χ Per photometry (CFHT)
- Search for shallower eclipses / in highly variable objects
- Secondary science:
  - Continuation of rotation work – esp. membership confirmation
  - Flares in ONC (and possibly others)
  - X-ray – optical connection in ONC with COUP

Summary

- We have a huge time-series database in ~ 6 young clusters
- 1 confirmed EB with masses and radii (Irwin et al., submitted)
- Many more candidates awaiting spectroscopic follow-up
- Rotation results (see Irwin et al. 2006, 2007, in prep)
- Host of other science (data waiting to be exploited)
- Thanks due to:
  - Maria Rosa Zapatero Osorio – LAEFF/INTA
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  - Jon Holtzman and Thierry Morel – NMSU 1m and Mercator
  - Richard Alexander and Patricia Verrier – Observing

`http://www.ast.cam.ac.uk/research/monitor`