False alarms versus planets
observational solutions

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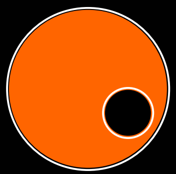
- Configurations that cause transit-like events
- Overview of methods of false alarm rejection
- Examples from STARE
- What works when?

Astron. Sources of false alarms

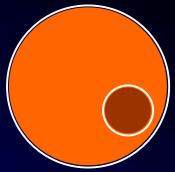
We look for:

Planetary transits
MPU (MainSeqSt. - Planet -Undiluted)



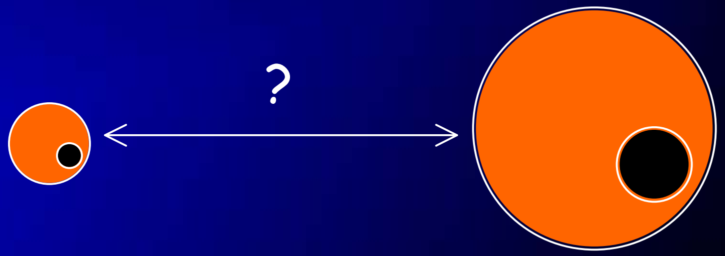
Interesting are also:

Brown Dwarf transits
MBU (MainSeqSt. - BD -Undiluted)



If we may have found a terrestrial planet we should ascertain:

terrestrial planet across solar-like star



Giant planet or BD crossing giant star

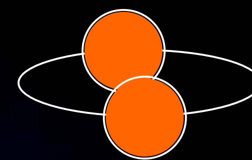
(adapted fromBrown 2003)

Astron. Sources of false alarms

Confusion from:

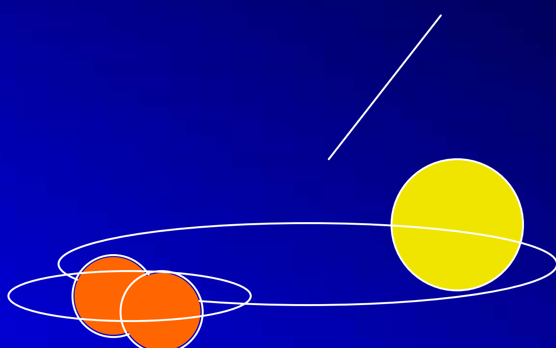
- Grazing Eclipsing Binaries

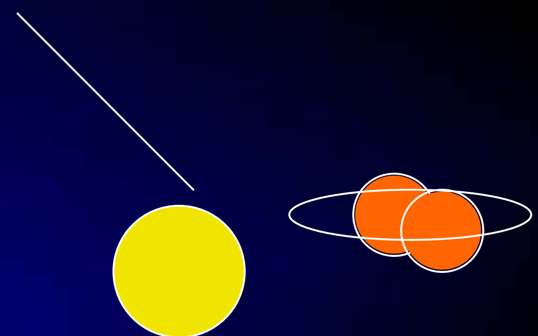
MSU (MainSeqSt.- Star -Undiluted)



- Diluted Eclising Binaries

EB with deep eclipses + light by bright 3rd star -> shallow eclipses





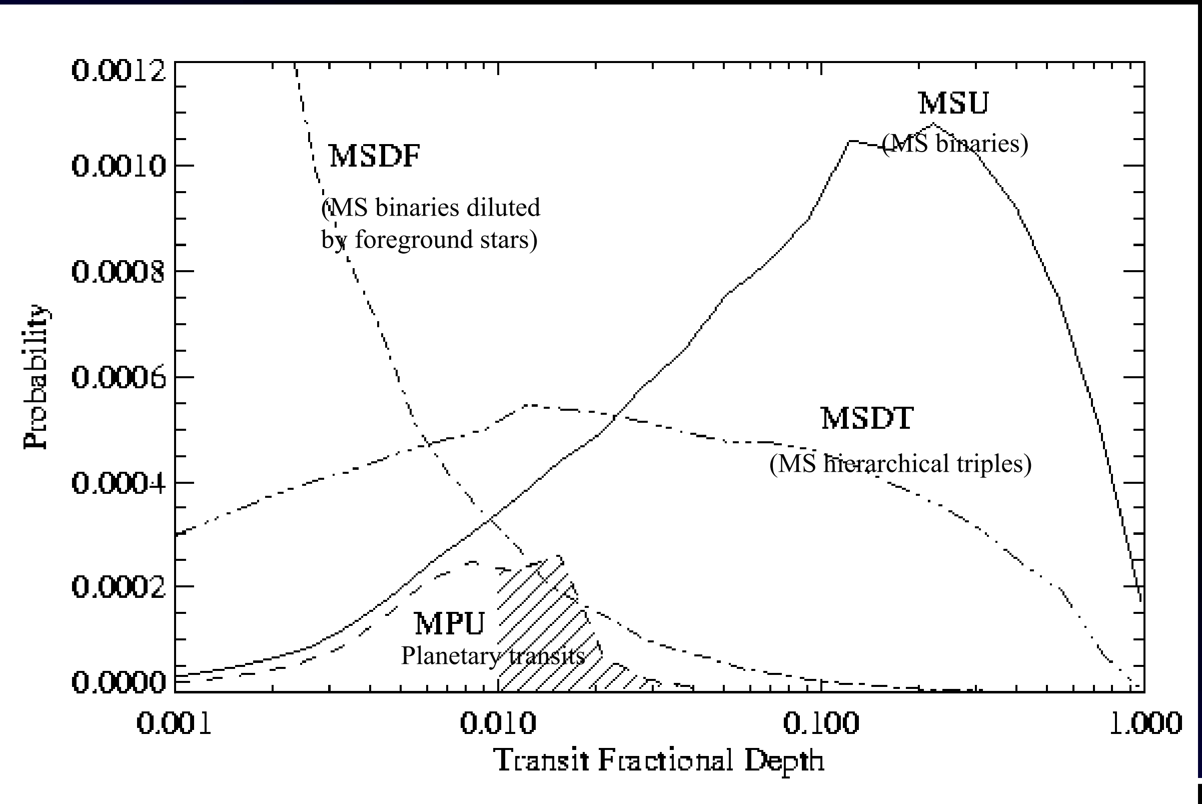
EB in triple sys

MSDT (MainSeqSt.- Star -Diluted -Triple)

EB + unrelated (fg/bg) star within psf

MSDF (MainSeqSt.- Star -Diluted -Fg/Bg)

What do we expect?



- mag R < 12
- 1d < period < 30d
- 0.01 < dF/F < 0.05
- 0.06d < tr. dur. < 0.25d

Brown 2003

Expected detection and false alarms per 10000 stars, total and in STARE run (45d obsv, requring 2 or 3 transits)

Category	Total	n ≥ 2	n ≥ 3	
MPU	1.43	0.74	0.39	Planets
MSU	4.56	2.82	2.27	Ecl. Binary
MSDF	1.90	1.52	1.26	Ecl. Binary + *
MSDT	1.64	1.20	0.98	Ecl. Binary + *

Verification of transit candidates 1

first step:

Careful interpretation of the transit in COROT lightcurve,

- are primary/secondary eclipses distinguishable?
- is there a non-transit-like shape?
- off-transit features?
- how is the color signature?

combined with
knowledge about the star (spectral, luminosity class, from prep. obsv),
verify compatiblity with planet - star system (Seager & Mallén-Ornelas, 2003)

- transit depth,
- transit duration, period & 'duty-cycle'
- duration of ingress/egress

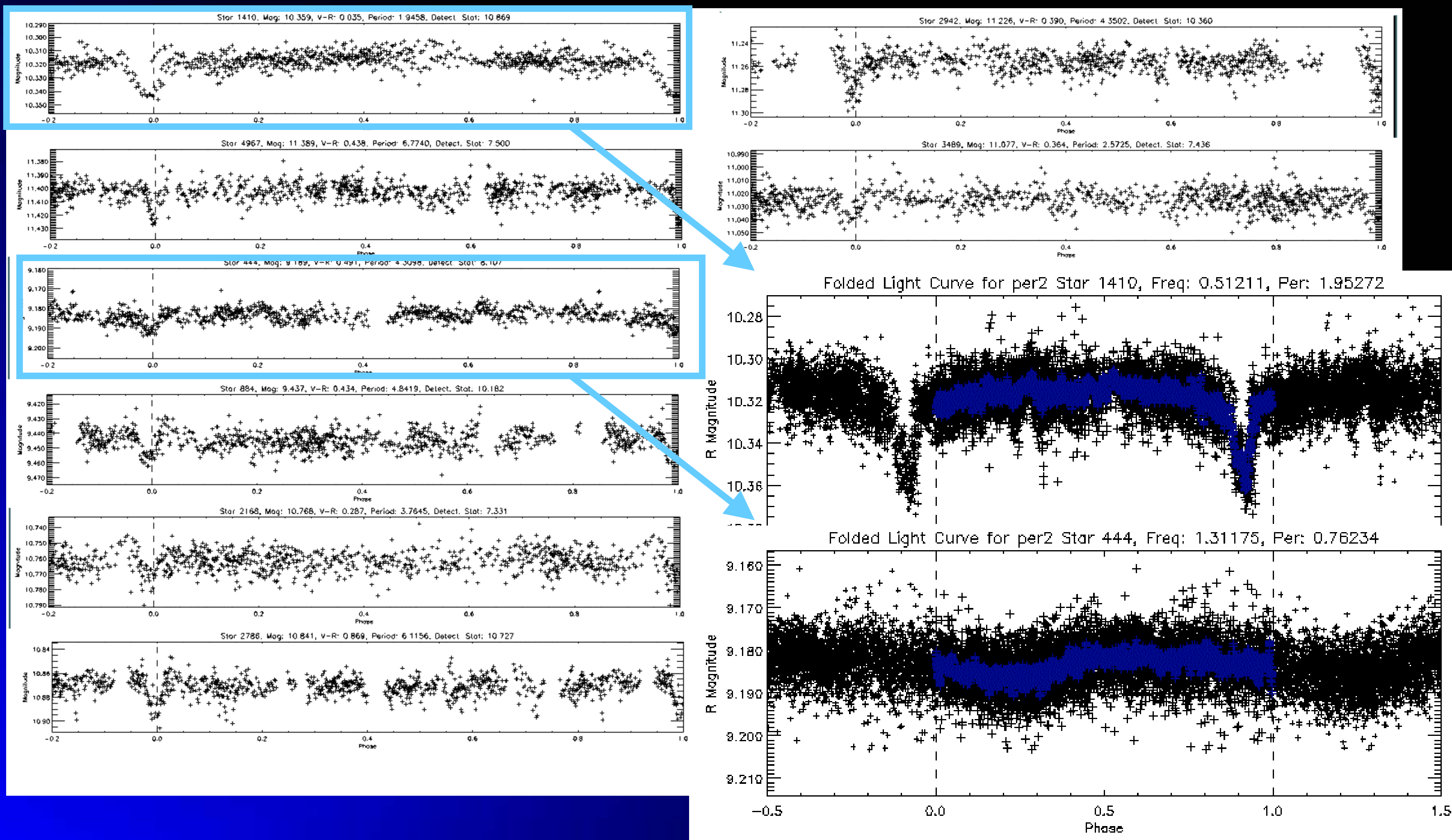
Verification of transit candidates 2

second step: observational tests
from simple (light-weight) to sophisticated (resource-intensive) ones:

- High res imaging (from INT/WFC obs) or very high res (adapt. optics) Imaging
  - indicates if there are bright enough nearby stars = potentially Ecl. Binaries
- Time-series (transit on-off) photometry with higher spatial resolution
  - detects very most background Ecl. binaries.
- Low-mid res spectroscopy (if not done as preparatory obs.)
  - detects many cases of Ecl. binaries
  - clarification of stellar class
- High res spectroscopy (radial velocities)
  - independent verification of planet

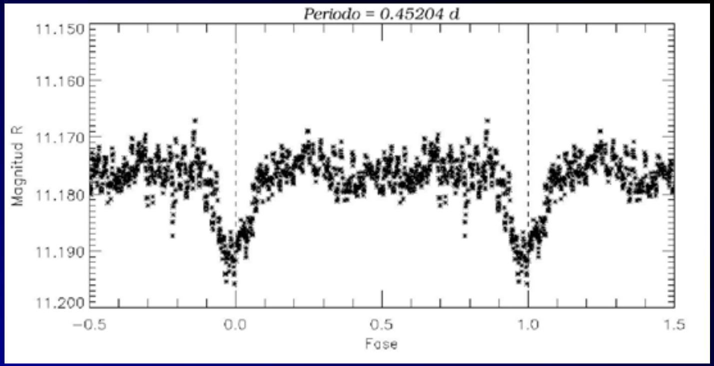
Some examples from STARE

Interpretation of the lightcurve

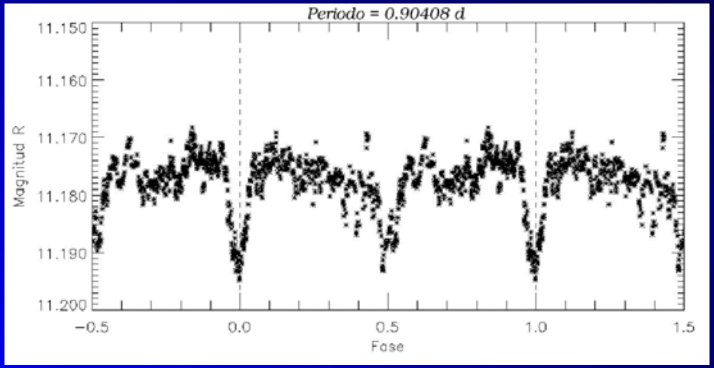


Are there secondary eclipses?

Nominal period



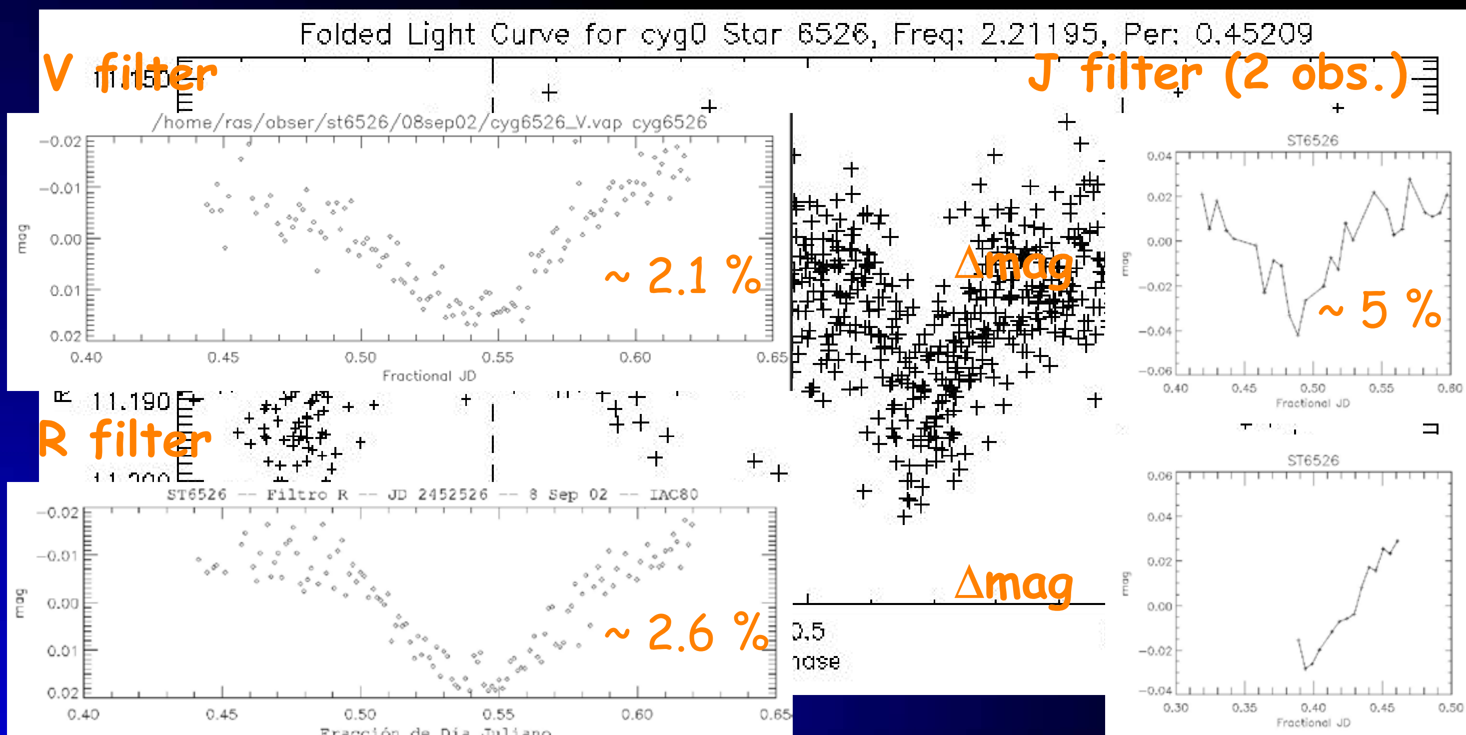
Double period



-> probably an eclipsing binary

Multi-color timeseries photometry

Vulcan 3433 = ST 6526 transit candidate with dF/F ~1.5% (0.015mag)

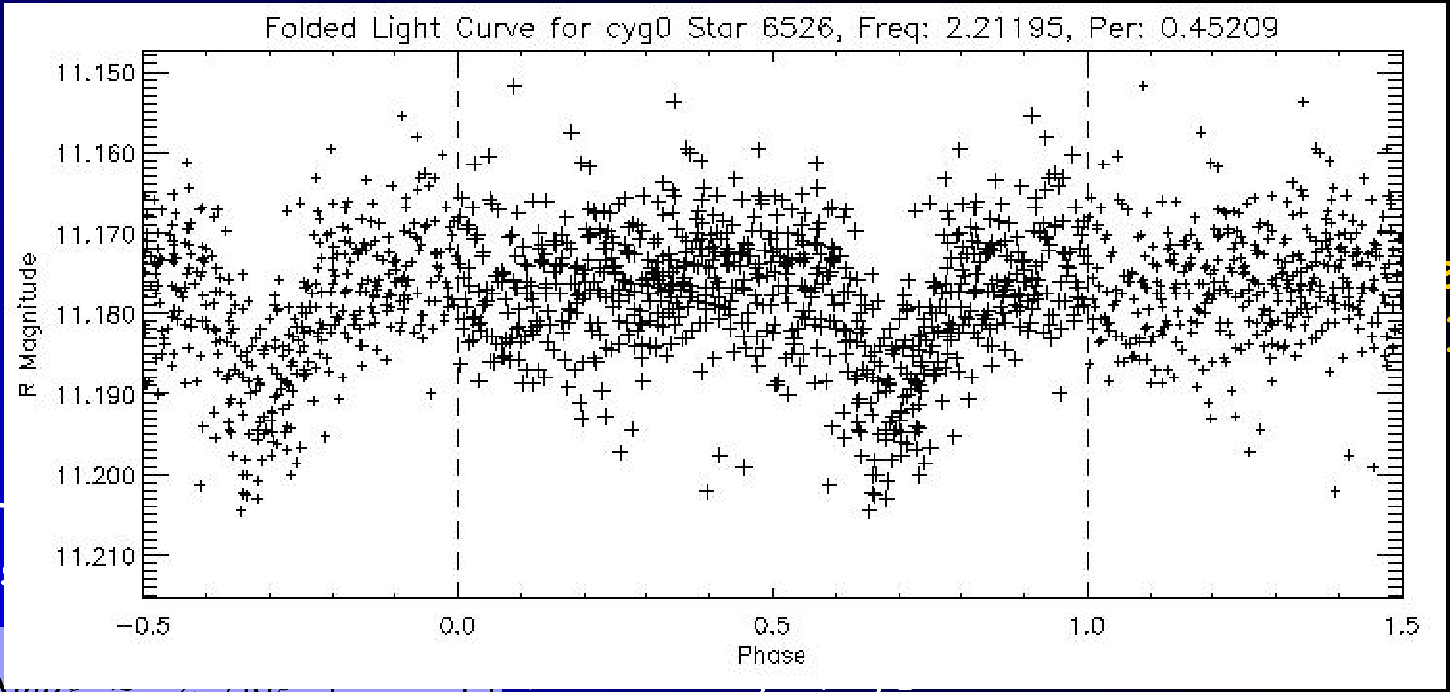


Unlikely for a planet: Vshaped eclipse, depth difference in J

Higher resolution imaging

Vulcan 3433 = ST 6526 transit candidate with dF/F ~1.5% (0.015mag)

STARE: pixel-size: 11". Re-observation with IAC 80cm telescope (1,2"psf):



...explain ...1.5%.

T... i...

Δmag ... $2.5 \log_{10} \left(\frac{\ldots}{2\delta} \ldots \right)$

For δ = 0.001, Δmag ≤ 6.7

Higher resolution imaging 2

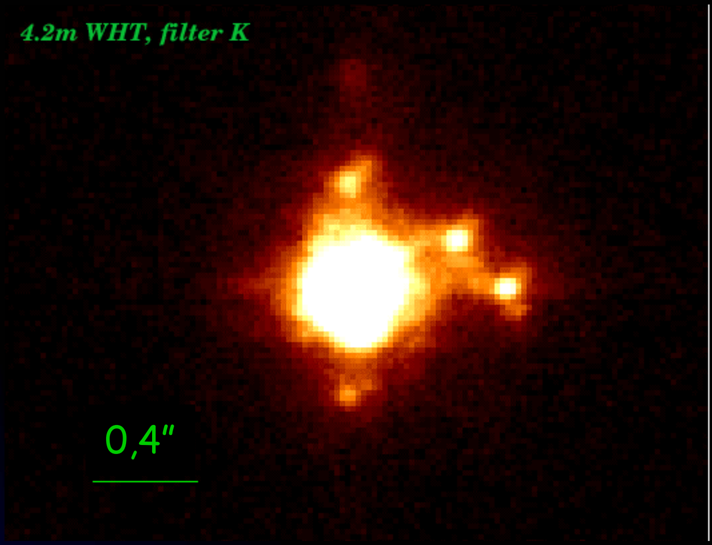
The probability to resolve with higher resolution (d_{newpsf}) two unrelated stars that are currently (with d_{oldpsf}) unresolved is:

$$P = 1 - \left(\frac{d_{newpsf}}{d_{oldpsf}} \right)^2$$

For COROT data against WHT's NAOMI Imager this is:

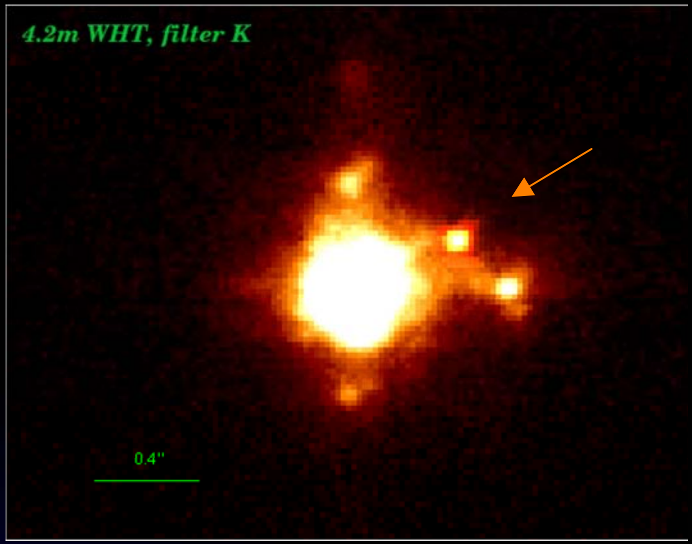
$d_{COROT} = 20''$

$d_{NAOMI} = 0.2''$ P = 0.9999 = 99.99 %



e.g. **if** there is an EB in background of a star (case MSDF), probability is very high to separate it with high-res imaging

Transit-on/off photometry with high spatial resolution

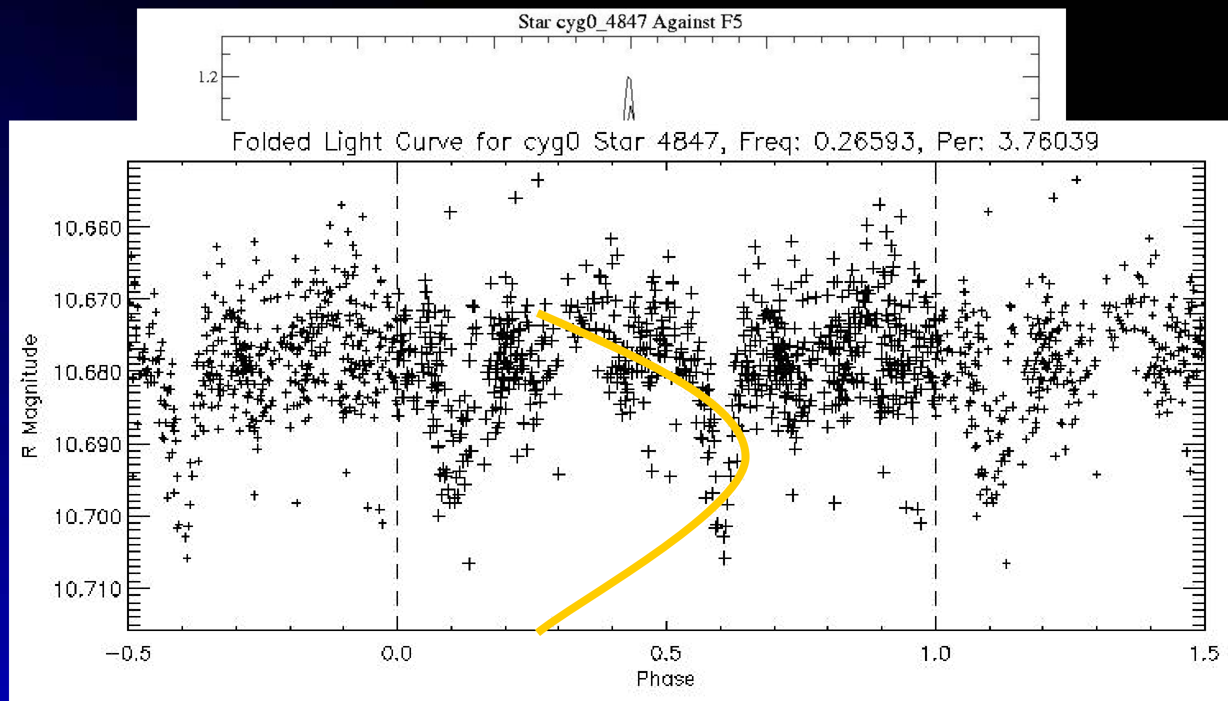


Transit on-off imaging/photometry:
Shows which of the faint nearby stars may be generating an EB-like eclipse
(most cases should be resolvable with conventional telescope, few need Adapt. Opt.)

Especially useful in the verification process of earth-like transits
(*difficult* targets for radial velocity follow-up)

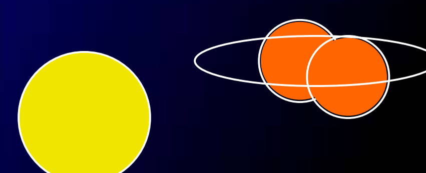
Radial velocity follow-up

Candidate in cygnus
ST 4847

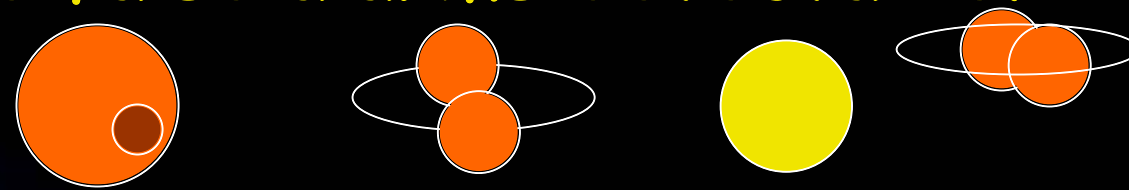


radial velocity

-> a diluted
eclipsing binary

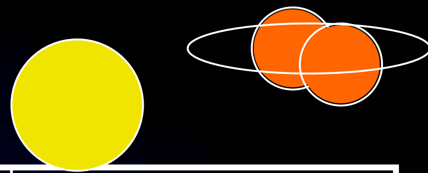


Are false alarms detectable?



	MBU	MSU	MSD[T/F]
Lc analysis monocolor	no	Many: prim <> sec transit, trans. duty cycle, in/egress dur.	Some: prim <> sec transit, trans. duty cycle, in/egress dur.
Lc analysis multicolor	no	yes, if T_1 <<>> T_2	yes, if T_{EB} <<>> T_3
Hi-res imaging	no	no	gives indication
Hi-res transit on-off photom.	no	no	yes, if α (EB,s_3) > res.
low-res RV spectrosc.	maybe	yes	yes, if F_{EB} not << F_3
hi-red RV spectrosc.	yes	yes	yes, if F_{EB} not << F_3

Are all false alarms detectable?



	MSD[T/F]
Lc analysis monocolor	Some: prim <> sec transit, trans. duty cycle, in/egress dur.
Lc analysis multicolor	yes, if T_{EB} <<>> T_3
Hi-res imaging	gives indication
Hi-res transit on-off photom.	yes, if α (EB,s_3) > res.
low-res RV spectrosc.	yes, if F_{EB} not << F_3
hi-red RV spectrosc.	yes, if F_{EB} not << F_3

Problematic case to detect false alarm:

EB in background of star if

- EB components temp. $T_1 \approx T_2$
- spat. distance α(EB,s_3) very small
- star temp $T_3 \approx T_{EB}$
- EB very faint

  (EB may be up to 7mag fainter)

How likely is this??

if no false alarm cause can be found:

high res RV spectr. may give positive verification (depends on brightness, planet-mass)

else:

uncertain detection, upper planet mass limit

Conclusions

Most false alarms should be found from light curve analysis with knowledge of star:

importance of previous knowledge

photometry, spectra as far as possible

sequence of follow-up observations shall find vast(?) majority of false alarms

importance of being prepared for them,

'decision algorithm' for most economic sequence to follow

positive planet verification from RV highly desirable