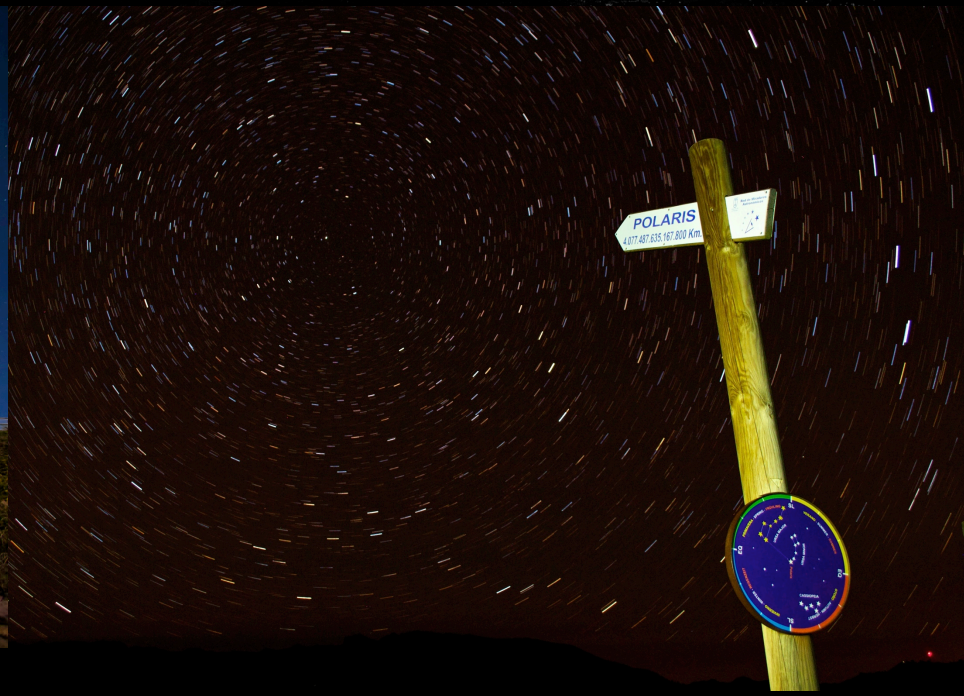
POLARIS
4.077.487.635.167.800 Km.

What have I been doing on La Palma the past ~4 years?

1. NGTS prototyping work
2. NITES exoplanet survey of M71
3. Developing DONUTS a/g algorithm

+ going to the beach, starting a family, running in the mountains etc …

1. NGTS

The Next Generation Transit Survey

James McCormac

www.ngtransits.org

Overview

- Motivation for NGTS
- What is NGTS?
- Prototype telescope - NGTS-P on La Palma
- Results of NGTS-P & improvements for NGTS
- NGTS facility design
- Early results from NGTS-1 (Geneva)
- Summary

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Motivation

Discover Neptune/super-Earth sized planets around bright stars in order to:

- Characterise them (using VLT, E-ELT & JWST) to understand bulk and atmospheric compositions
- Understand planetary formation, evolution and migration processes
- Kepler has shown an abundance of Neptune-sized planets in their field

Also, provide to the ESO community sub-millimag photometry of many stars for non-exoplanet science.

www.ngtransits.org

Correlated vs Uncorrelated Noise

Uncorrelated (white):

- Random in nature
- Gaussian distribution

e.g. Read noise from CCD

Data may be binned to reduce the RMS

Correlated (systematic or red):

- Noise correlates with part of the observational process
- non-Gaussian distribution

Correlations may occur with:

- Time, temperature, position on CCD, focus etc.

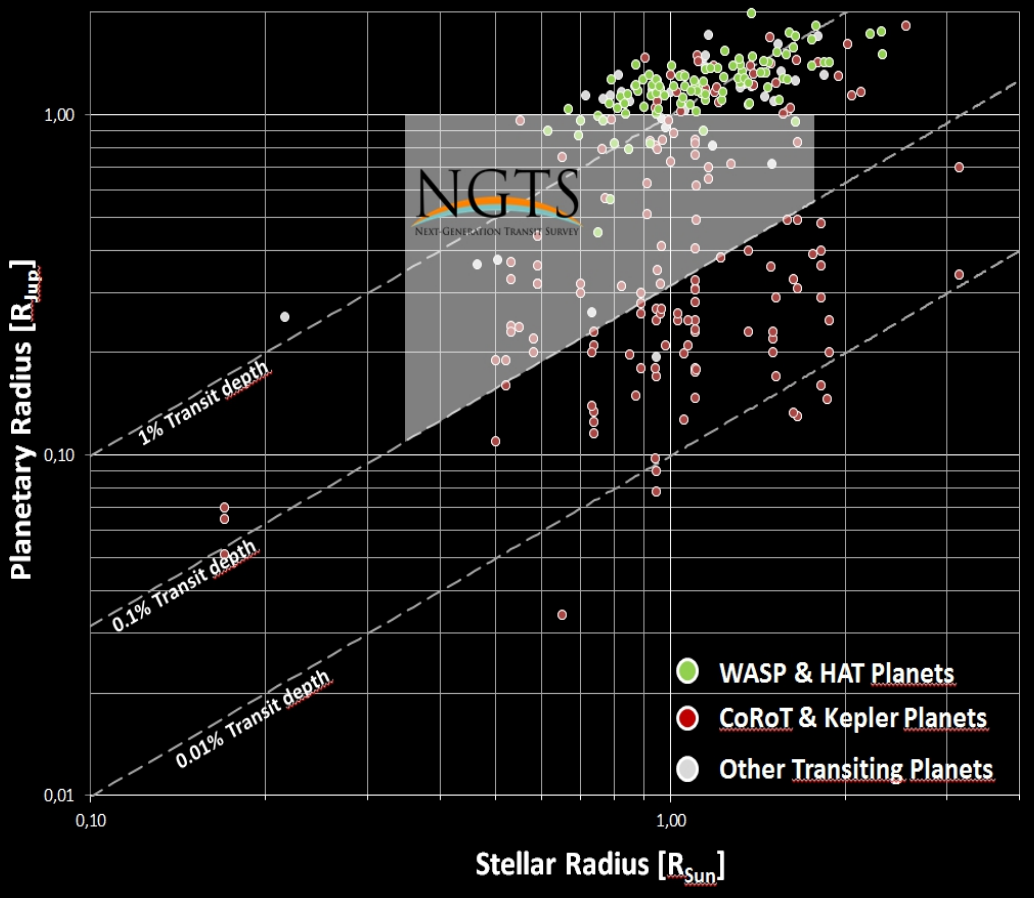
Binning of data may NOT reduce RMS

Proposed Solution:

- Simple experiment, keep as many parameters constant!
- E.g. polar mounted telescope, no derotator or filter wheel
- Fix stars in place on CCD, autoguding.
- Fix focus etc

What is NGTS?

- Robotic wide-field photometric survey
- Targets K and early M-type stars (V<13)
- Neptune-sized or smaller transiting planets
- Emphasis on bright targets for easier spectroscopic follow-up
- Builds on experience from SuperWASP



Credit Philipp Eigmueller

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NGTS Prototype – La Palma

Goals:

- Determine the noise characteristics of an NGTS-like system
- Prove the technical feasibility of NGTS
- Perform mmag photometry on transit time scales

- 18cm f/2.8 telescopes
- Deep depleted CCDs
- Separate autoguider
- Paramount ME (GEM)
- Remotely operated
- Sept 09 – Sept 10

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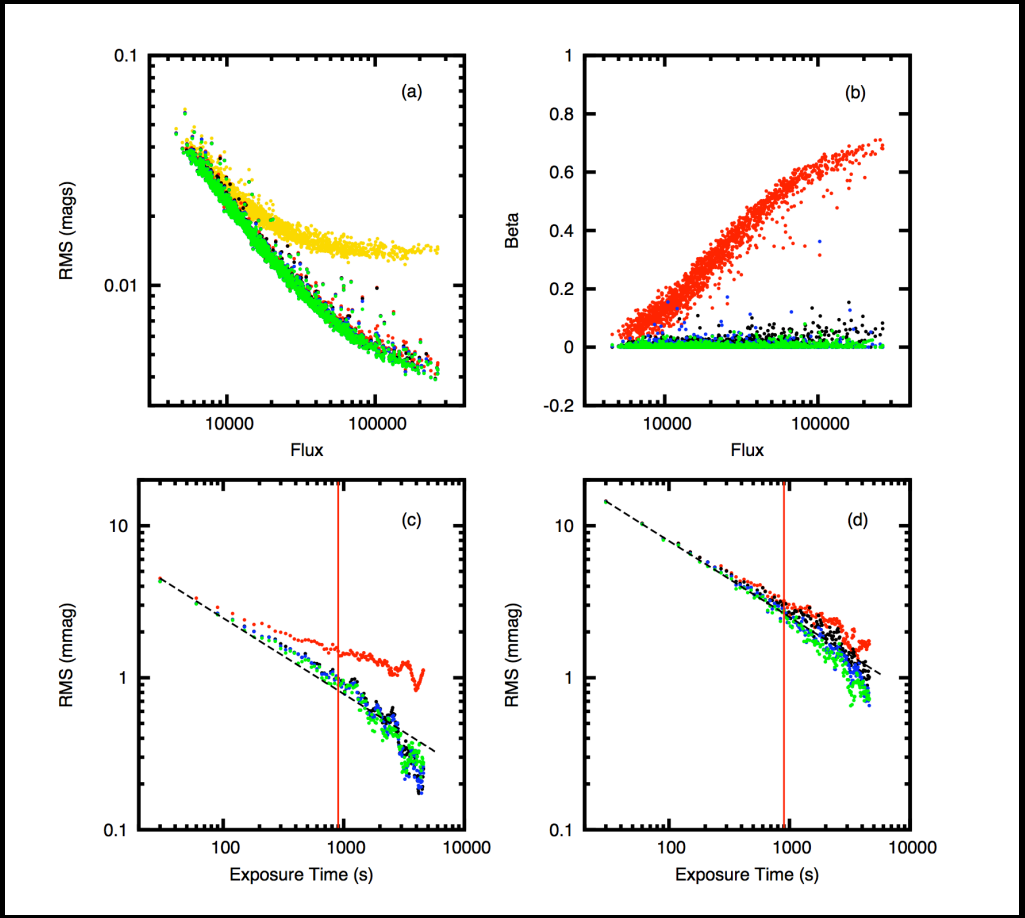
NGTS-P Results

Systematic noise analysis using SysRem (Tamuz et al. 2005)

Relatively free from systematic noise

≤ 1mmag RMS on transit timescale with room for improvement



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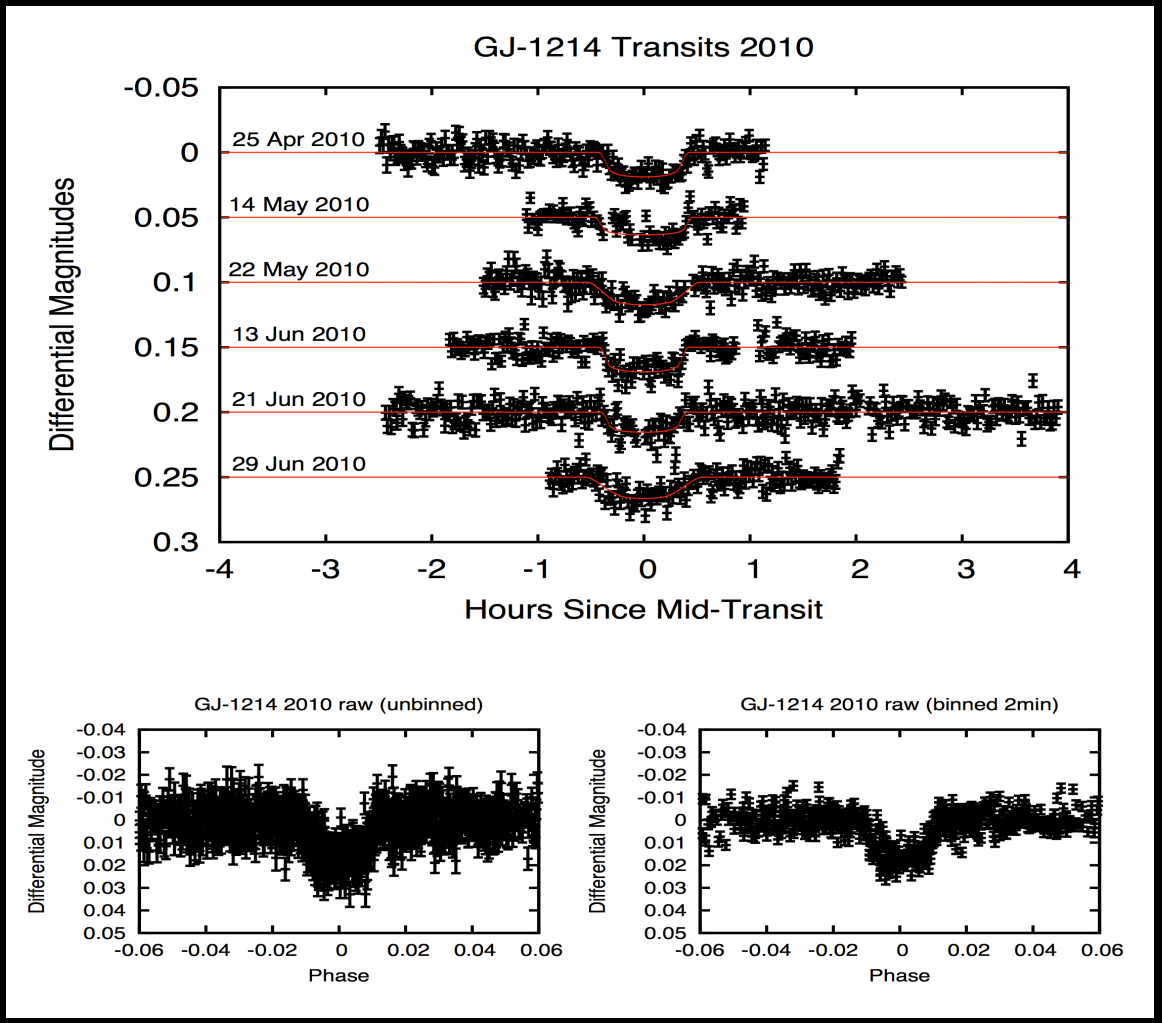
NGTS-P Results

Faint super-Earth detection

GJ 1214:
M star
V=14.71
d=13 pc

GJ 1214b:
P = 1.58 d
$R_p = 2.79\ R_{Earth}$
Depth = 16.7 mmag



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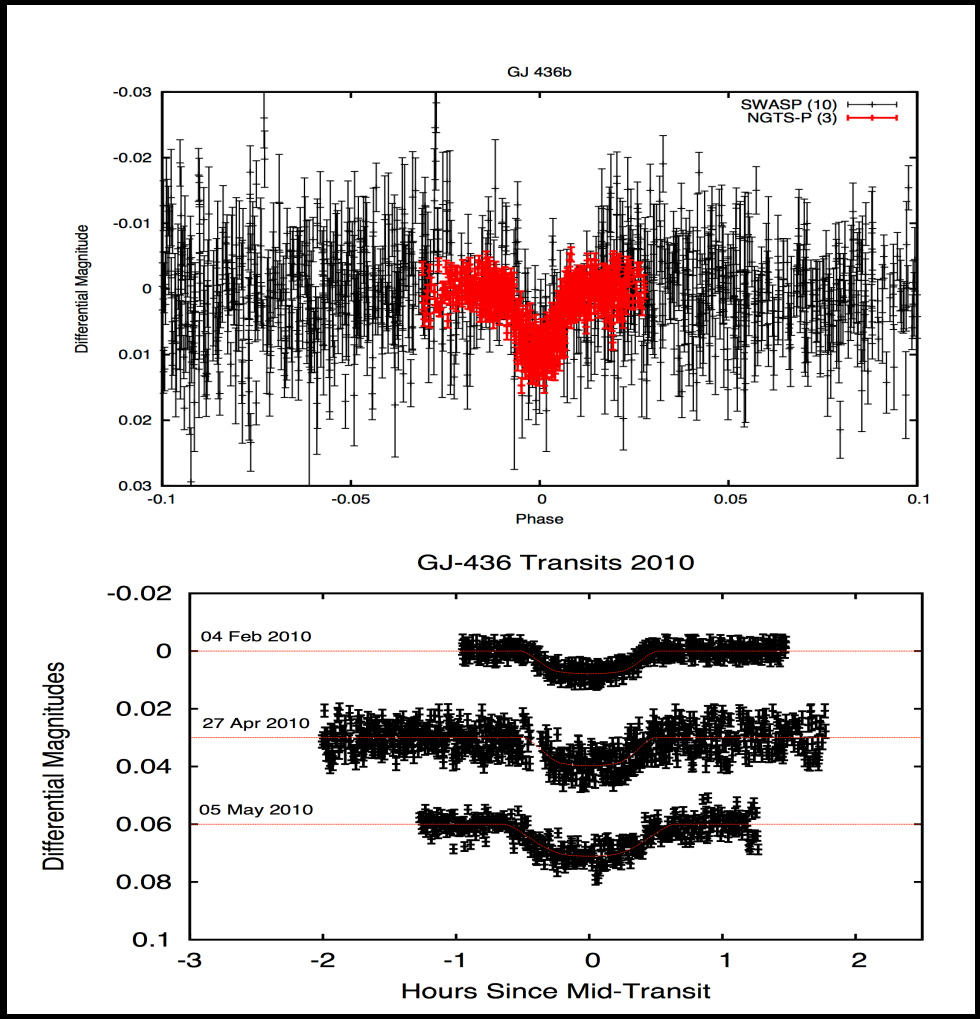
NGTS-P vs SuperWASP

GJ 436:
M2.5, V=10.68, d=10.2 pc

GJ 436b:
P=2.64 d, R =1.41 $R_{Neptune}$,
Depth=9 mmag

NGTS-P stare mode clearly better. SuperWASP now operates in stare mode.

Staring = Increased no. of points per transit = Confidence in single transit detections = Earlier RV follow-up



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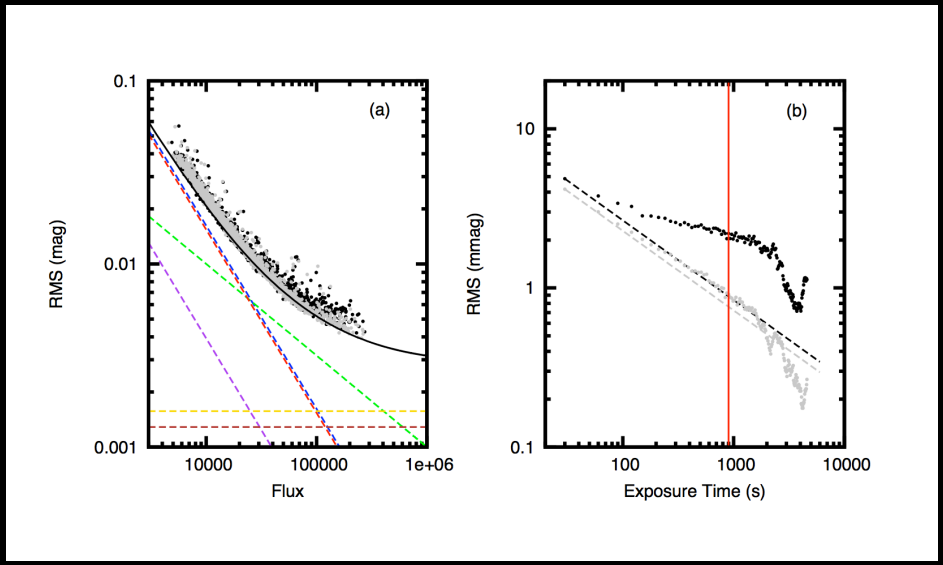
Lessons learnt from NGTS-P

- Precise polar alignment – no field rotation
- Guide using science images – no mechanical flexure or drifting
- Baffling – reduce scattered light during flats and full moon



Effects of scattered light during flat fields.
Black points = with flat fielding
Grey points = without flat fielding

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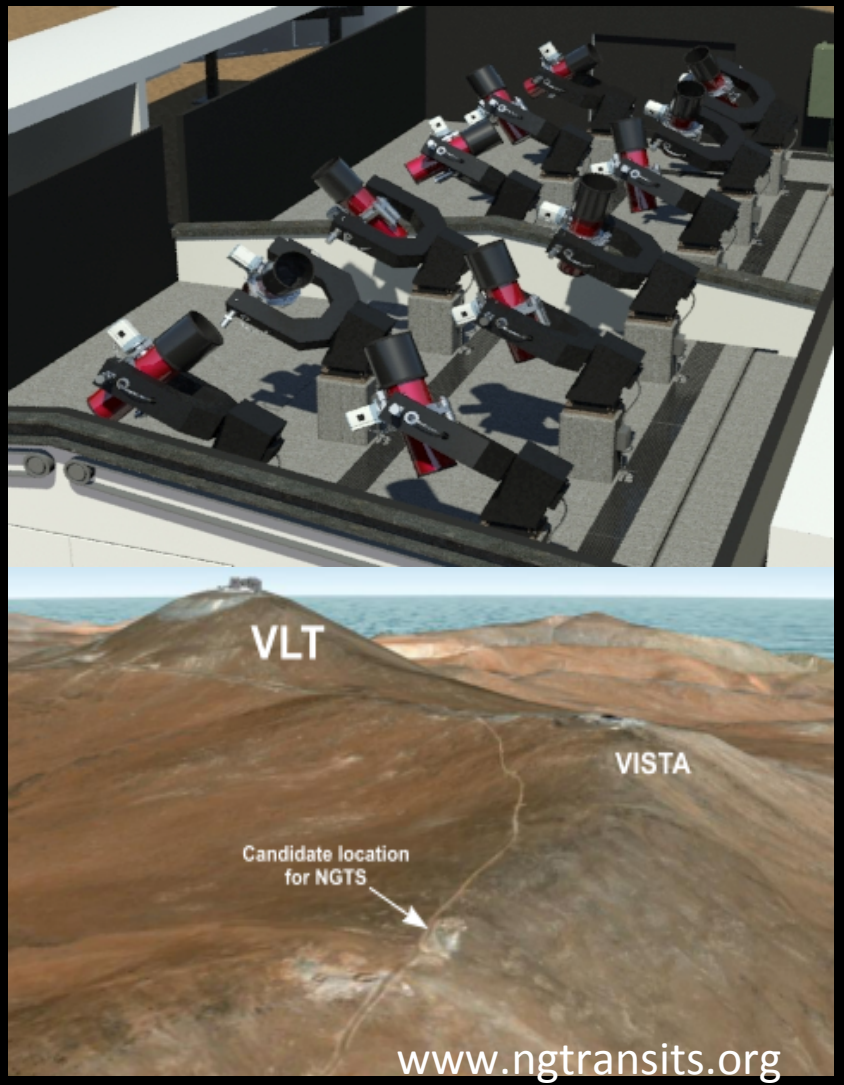
NGTS Facility Design

- 12 x 20cm f/2.8 Newtonian + baffle
- Red sensitive CCDs
- 8 deg^2 x 12 (4.96’’/pix)
- 12 x OMI Equatorial Forks
- 600-900nm filter
- Autoguiding with DONUTS (McCormac et al. 2013)
- Located at ESO Paranal



Tests of NGTS-1 Geneva 2012/13

- First system installed at Geneva Observatory
- Tested during late 2012 and 2013
- Custom firmware for autoguiding
- Tracking, guiding and focus tests
- Early photometric results are promising - even from Geneva ;)

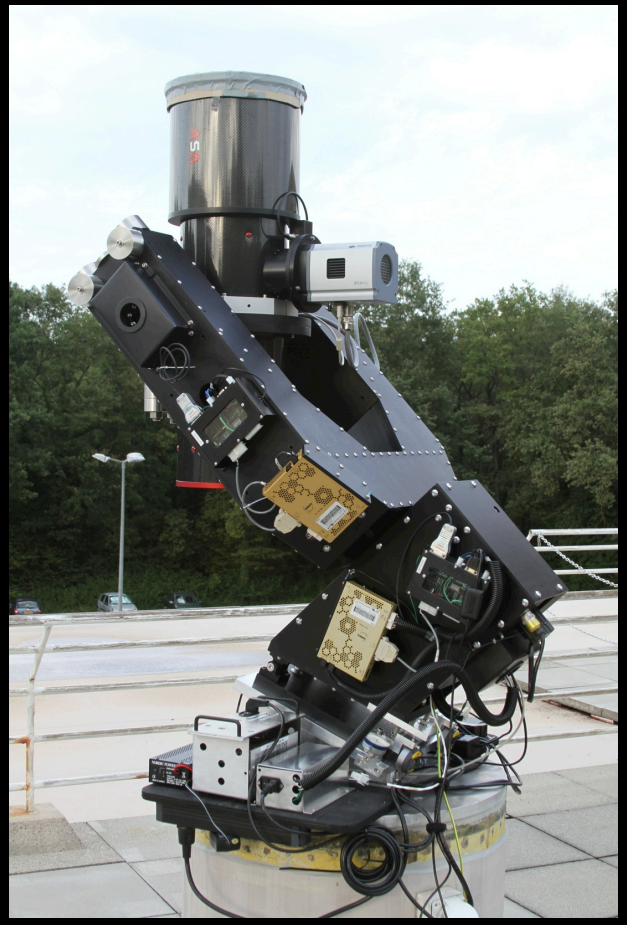
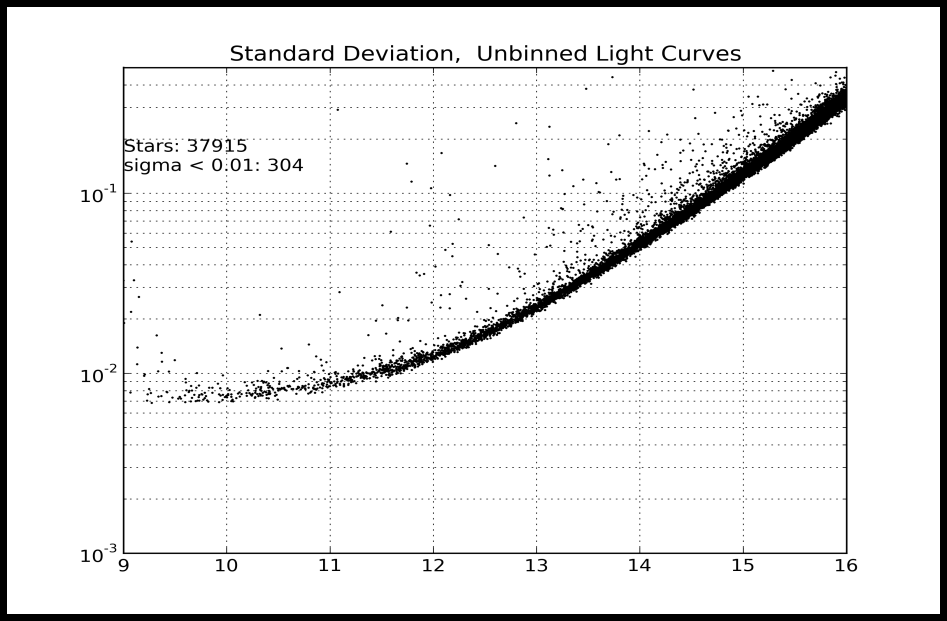
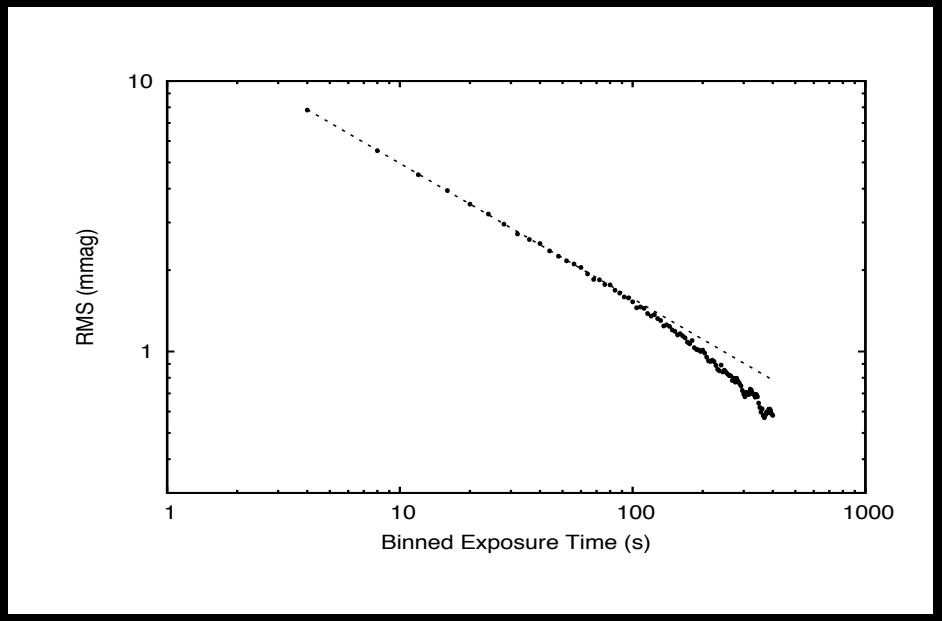
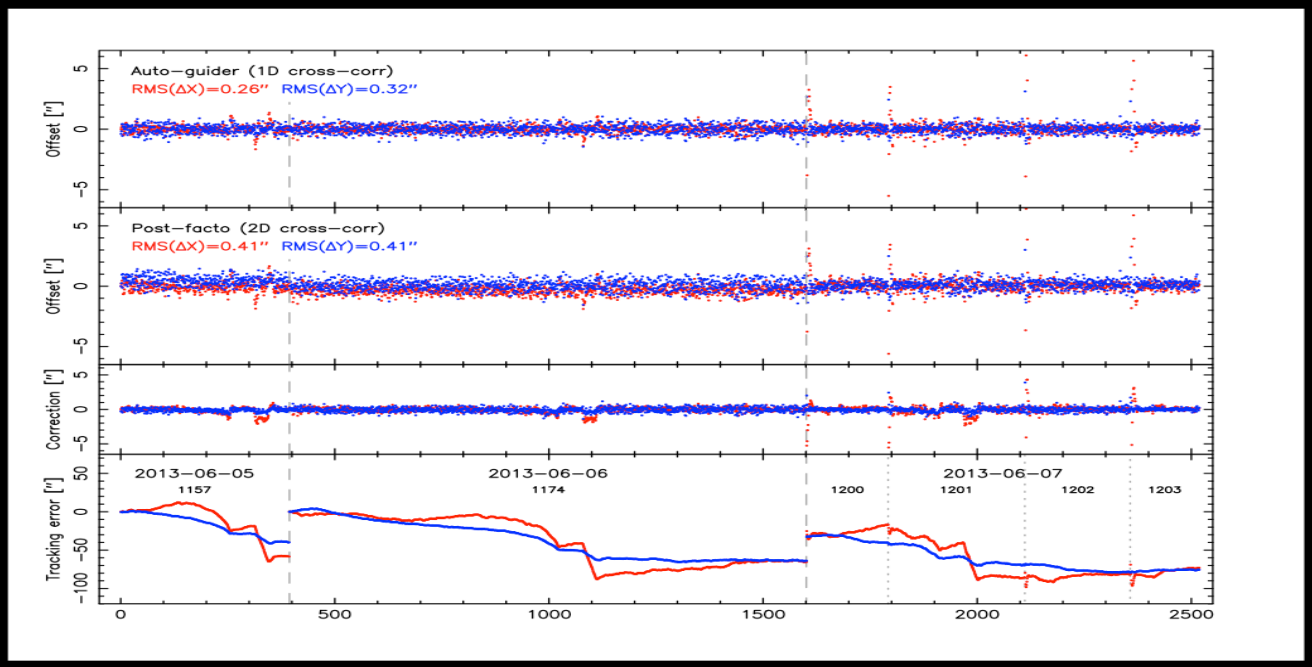


Photo: Richard West

www.ngtransits.org







Credit: Simon Walker & Richard West

www.ngtransits.org

Summary

- NGTS new wide field transiting exoplanet survey
- Targets bright stars V<13 for easier follow-up
- Project is technically feasible
- Promising results from NGTS-P and NGTS-1
- All hardware purchased and undergoing tests
- Site preparation at Paranal underway
- First light at Paranal expected in 2014
- Phased commissioning of groups of telescopes

www.ngtransits.org

2. NITES + M71

Overview

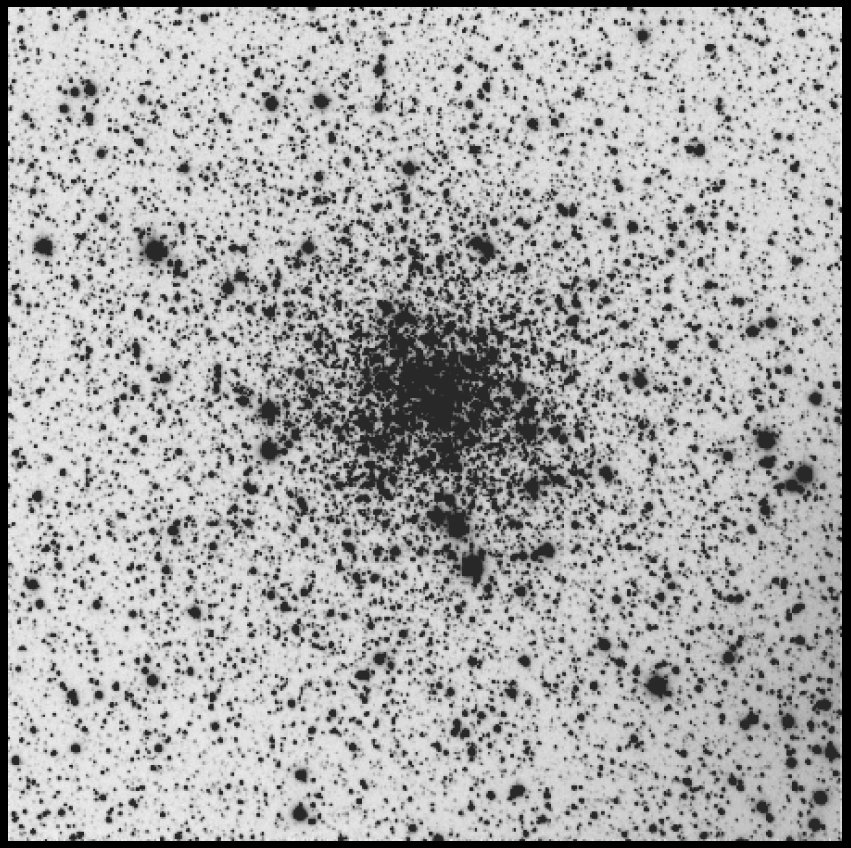
- The NITES telescope
- M71 – target for exoplanet survey
- Survey outline + data reduction
- Planet detection simulations + results
- Variable stars in M71
- Future work in M71
- Future of NITES telescope

Near Infra-red Transiting ExoplanetS (NITES) Telescope

- 16’’ Meade LX200-GPS
- FLI Proline 1k x 1k DD-CCD camera
- 11’x11’ FOV, 0.66’’/pix
- No filter (UBVRI + Ha planned upgrade)
- Science frame autoguiding
- Remotely operated
- Located beside SuperWASP

M71 (NGC 6838)

- 19:53:46 +18:46:45 (l=57, b=-5)
- Metal-rich (Fe/H= -0.7), low stellar density globular cluster
- Disk-like orbit in the Milky Way
- Tidal radius = 9 arcmin
- Several photometric surveys in 1990s and early 2000s.
- No transiting planets found from many cluster surveys at time of study
- 23 variable stars known beforehand



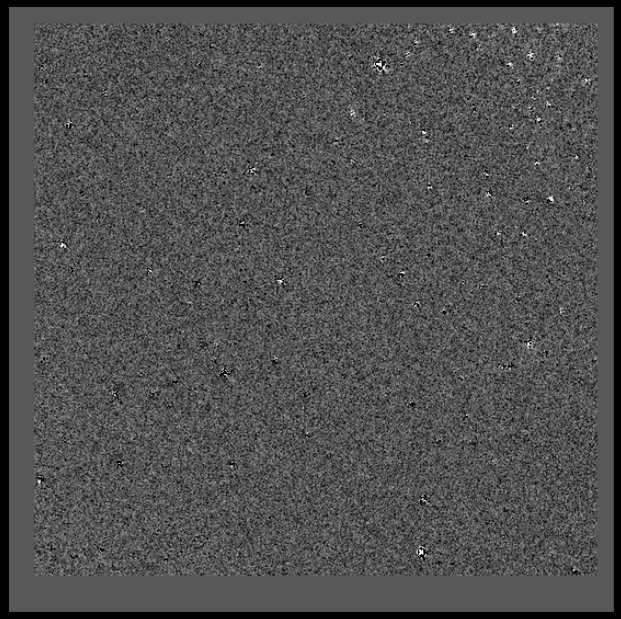
Approx. 4000 stars surveyed with NITES

Survey Outline

- June 17 to Aug 27 2011
- 74 d baseline, 47 nights on target
- 228 hrs = 28,340 images (30s typical exptime)
- All observations done remotely from sea level
- One 11'x11' field centered on M71

Data Reduction

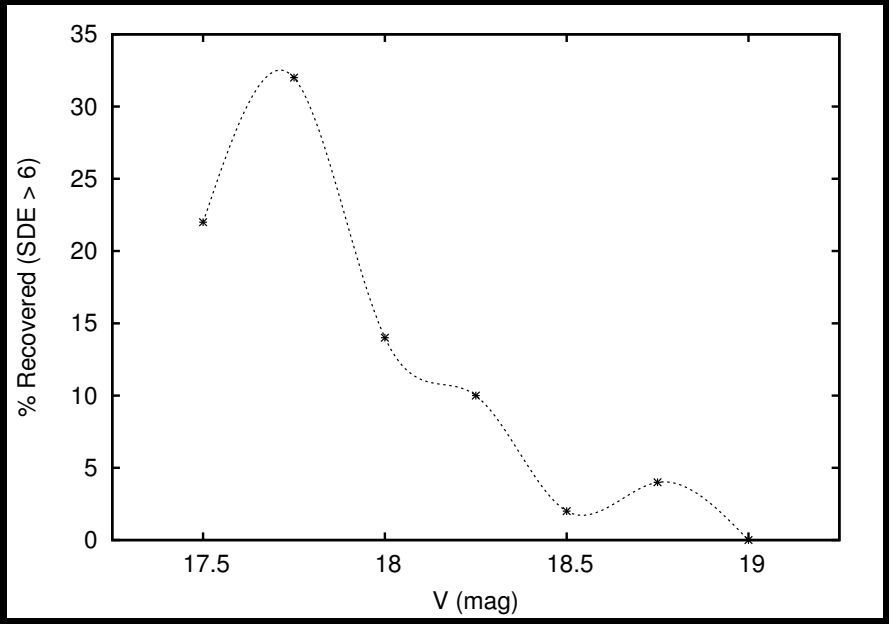
- Data reduced using standard IRAF routines
- Light curves extracted using difference imaging with DIAPL2*
- 1 week on cluster at QUB
- DIAPL2 is based on the Optimal Image Subtraction (Alard & Lupton 1998)
- Top-right shows 1 quadrant of M71 from NITES image
- Bottom-right shows the same quadrant after subtraction with DIAPL2



*Wojtek Pych 2011 Private Communication

Planet Simulations & Results

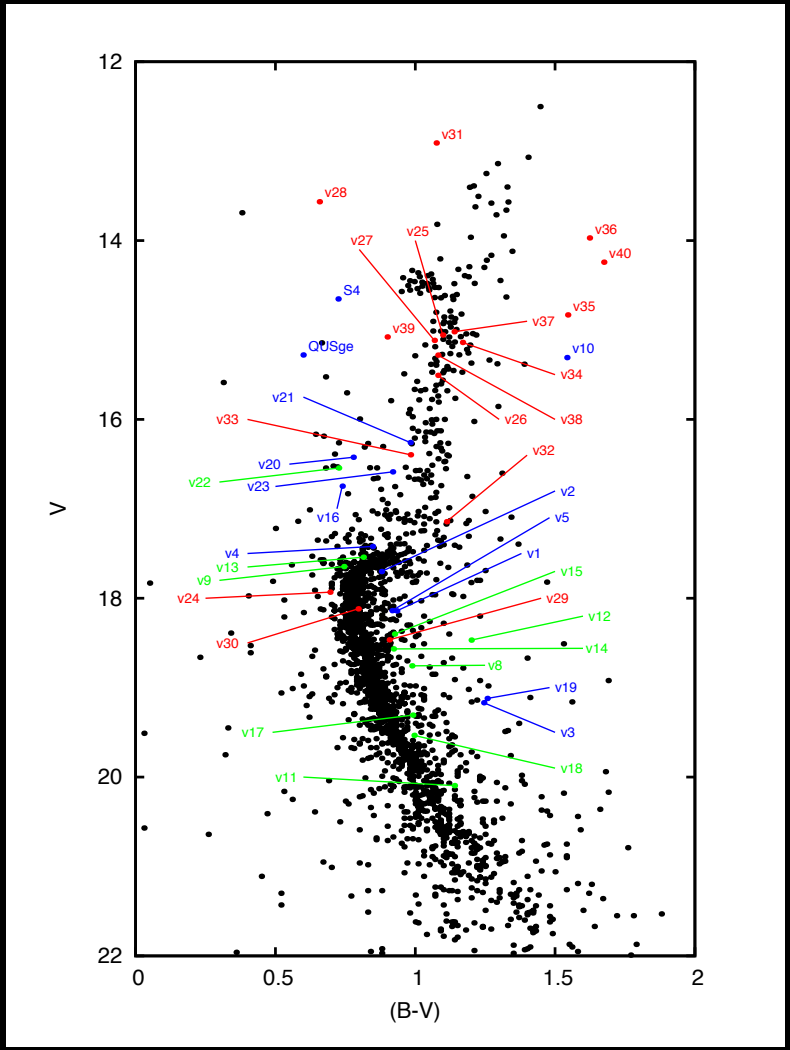
- Simulated 3500 light curves of transiting planets with real noise profiles from NITES data
- Approx. 10 % chance of detecting 1 planet on MS (MSTO V=17.5) of M71
- None were found



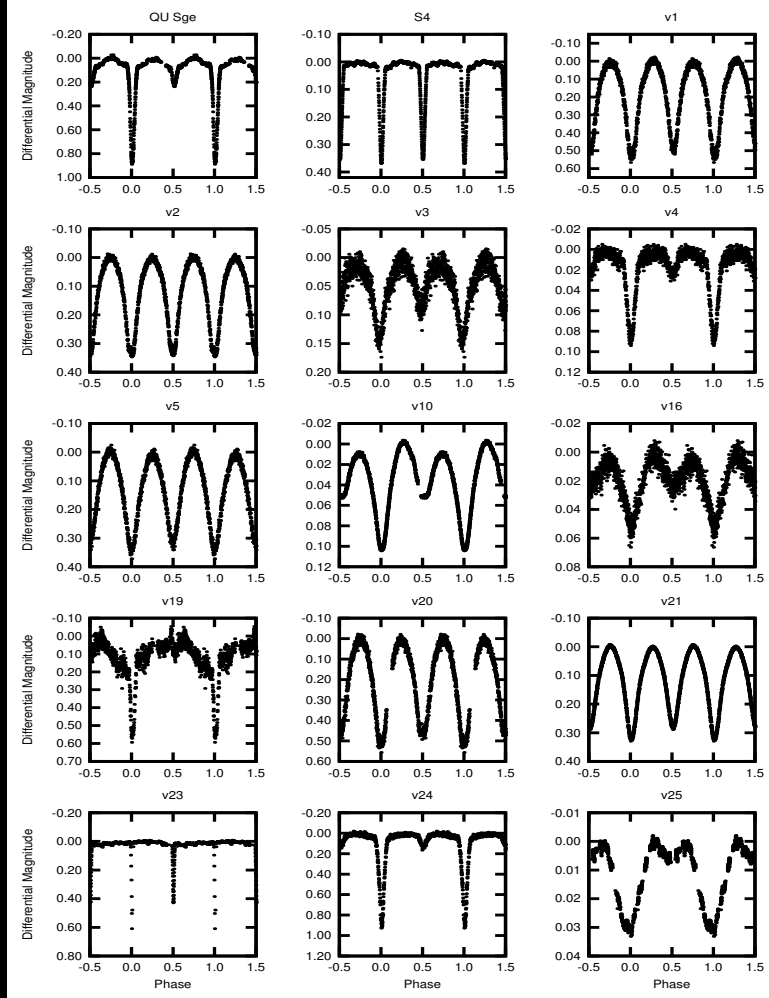
On the limit of detectability for the MS of M71.
Meibom et al 2013 recently found the first 2 transiting planets in a cluster (NGC 6811 - Kepler 66b & 67b)

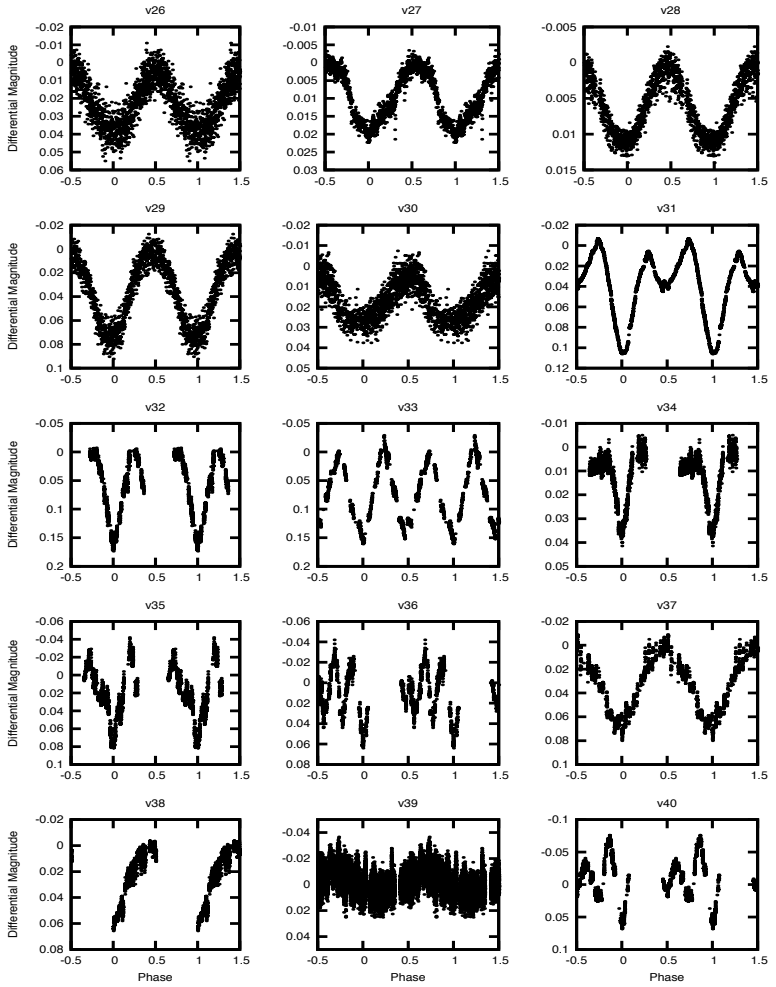
Variable stars

- Discovered 17 new variable stars
  - 2 Eclipsing binaries
  - 9 Long period (P > 10d)
  - 11 Low amplitude (ΔM < 0.1 mag)
  - 4 Multi-frequency
- Confirm variability of 13 previously known objects
  - Refine/determine periods for 7
- Confirm M71 is devoid of RR Lyrae stars
- Estimated spectral types from BV WFC data

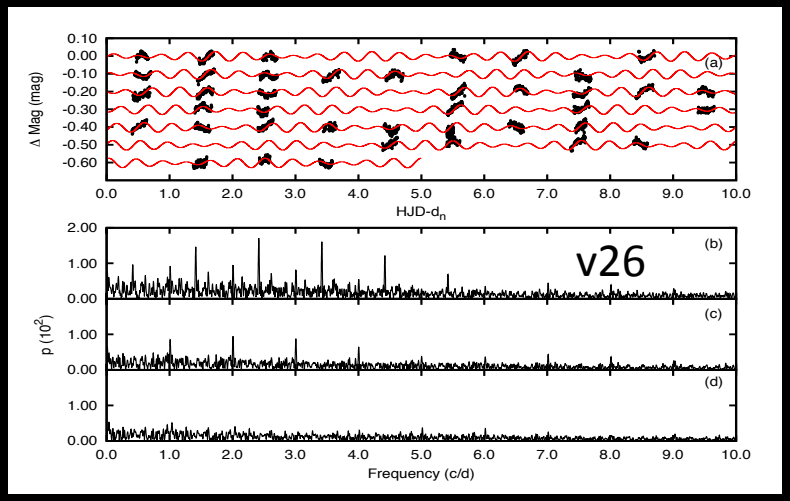


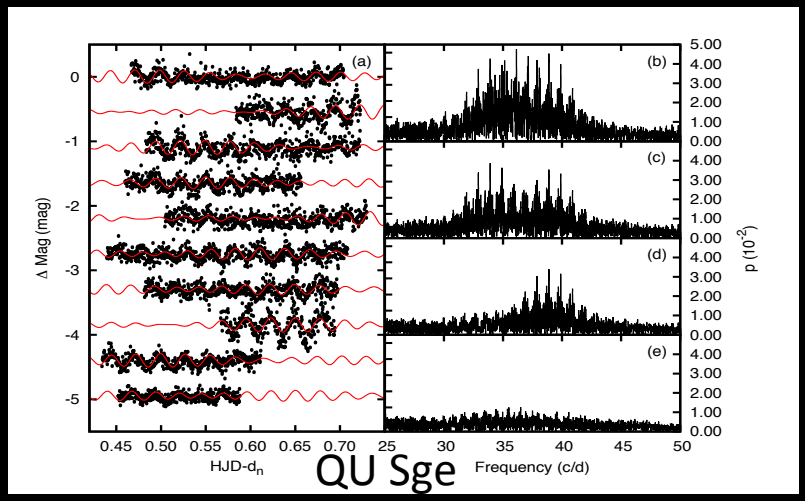
Variable stars

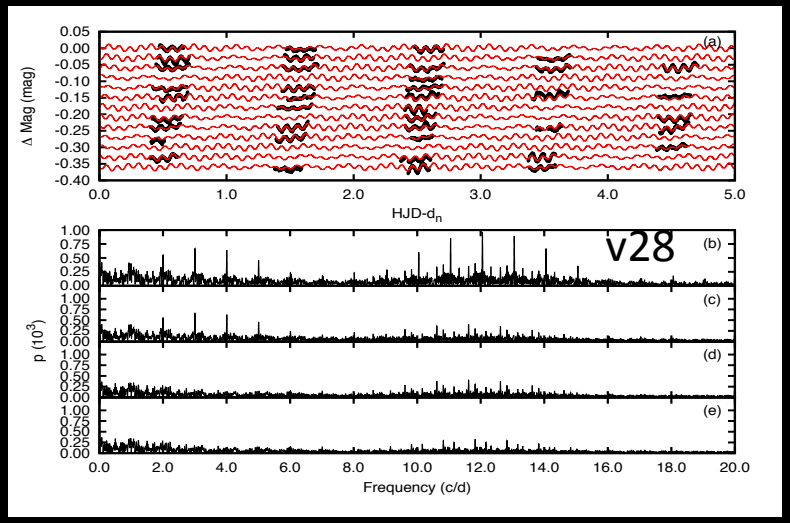


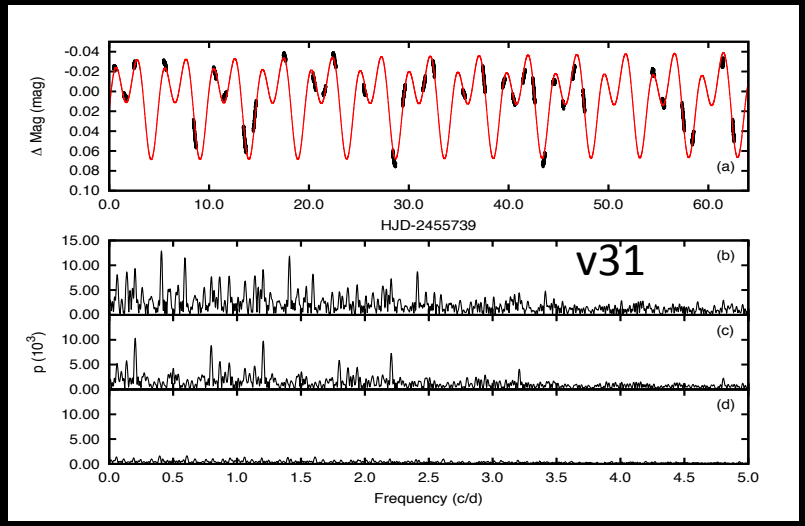


Some Interesting Objects









Future Work on M71

- Spectroscopic characterisation of variable stars (ongoing with IDS)
- Recently acquired UBVRI data with WFC. Cluster characterisation analysis also ongoing, with ING summer student Patrick Sandquist

Future of NITES telescope

- Telescope will be moved to SQT platform
- Plan to add colour filter wheel
- Exoplanet follow-up alongside SQT
- Possible student projects

3. DONUTS

DONUTS: A science frame autoguiding algorithm with sub-pixel precision, capable of guiding on defocused stars.

(McCormac J., Pollacco D., Skillen I., Faedi F., Todd I., Watson C. A. 2013, PASP, 125, 548)

Overview

- Thoughts that led up to DONUTS
- How it works
- PSFs tested
- Off sky results
- On sky results
- Facilities deployed

Thoughts behind DONUTS

Motivation: Reduce systematic noise in high-cadence time-series photometry (e.g. exoplanet transits)

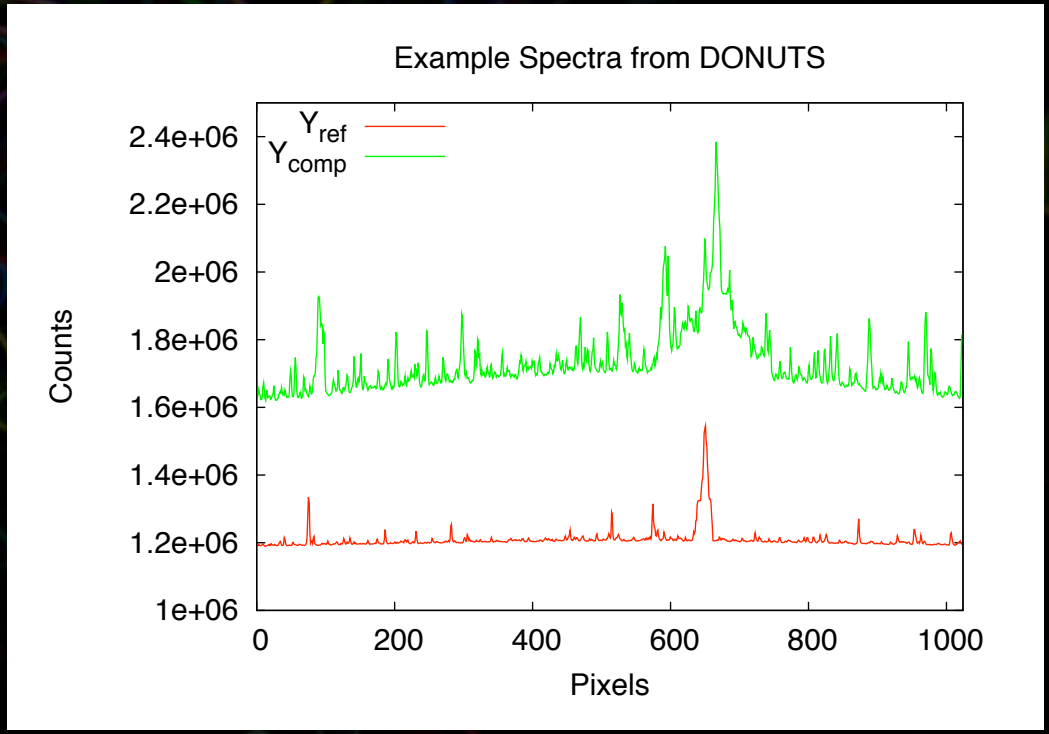
Method: Fix stars in place on CCD over long periods of time (nightly & night-to-night)

Requirements: Eliminate mechanical flexure, guide on variety of PSFs, fast calculations.

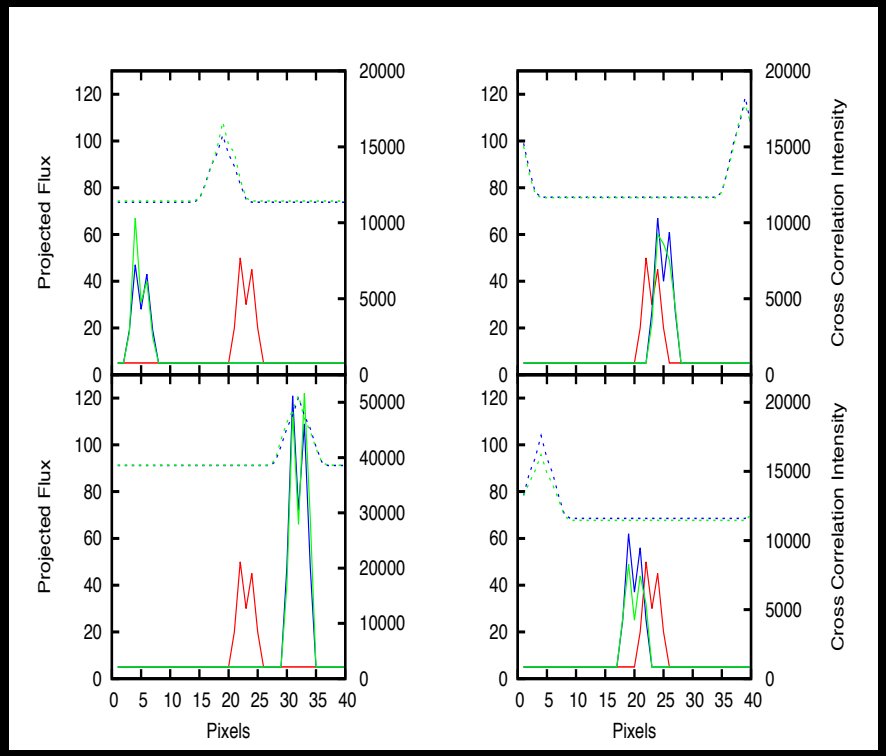
Result: Science frame guiding (on donuts if needed)

How it works

- Collapse 2D images into 1D projections (X & Y)
- Using master image projections, cross correlate subsequent 1D image projections to determine guide corrections (X & Y)
- Apply shifts to telescope & repeat
- Uses all stars in FOV



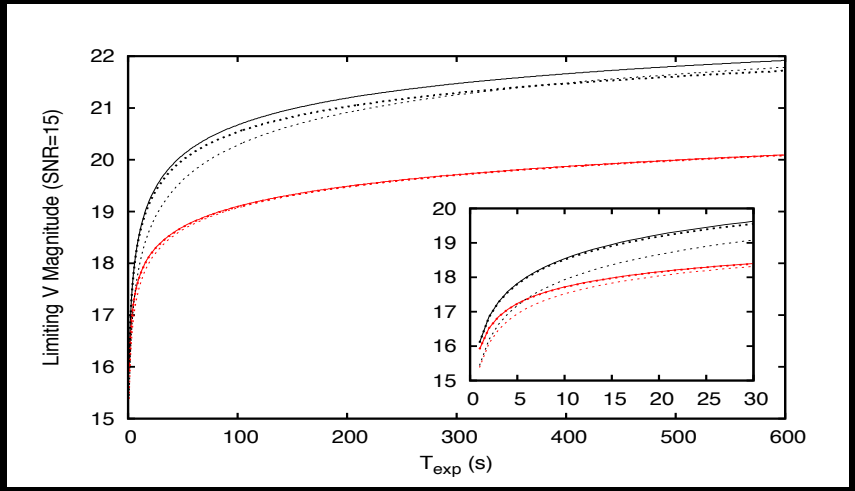
Off Sky Results



- Simulated 10,000 defocused projections
- Only 7 predicted shift incorrect by 1 pixel

- Manually applied shifts to hundreds of images with 4 different PSFs
- Shifts recovered using DONUTS
- Average residual errors < 0.3 pixels regardless of PSF

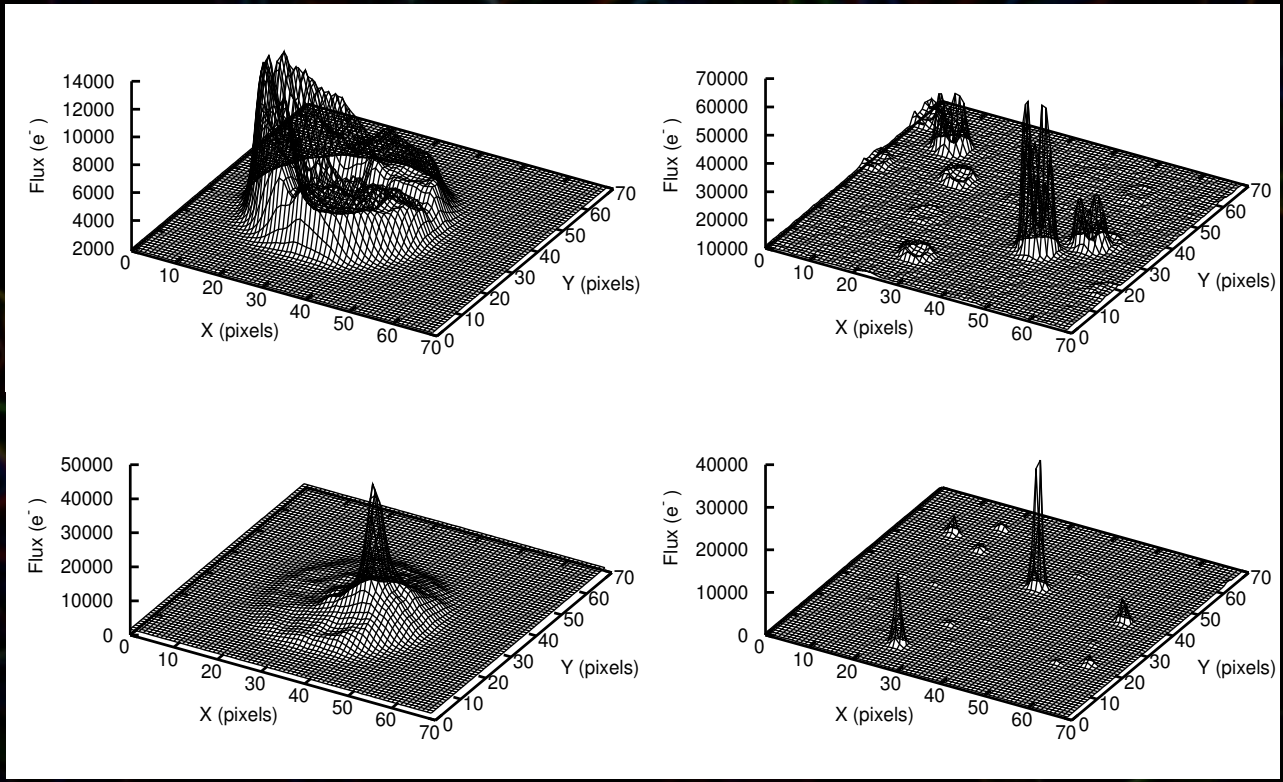
- Tested limiting case of single low SNR guide star
- Find limiting SNR = 9
- Quote conservative limit of SNR = 15



PSFs Tested

Heavily defocused
INT – WFC

Defocused
NGTS-P

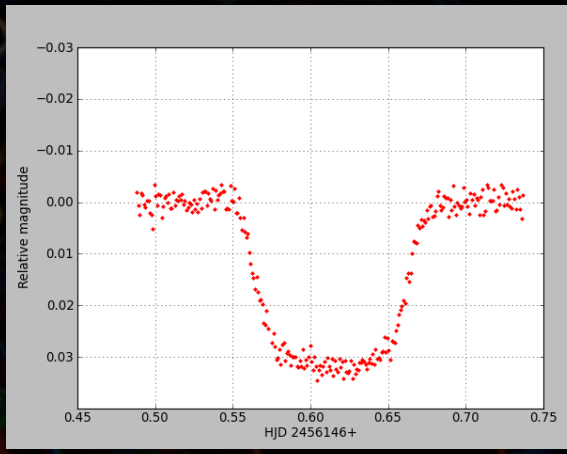


Asymmetrical PSF
WHT – AG2

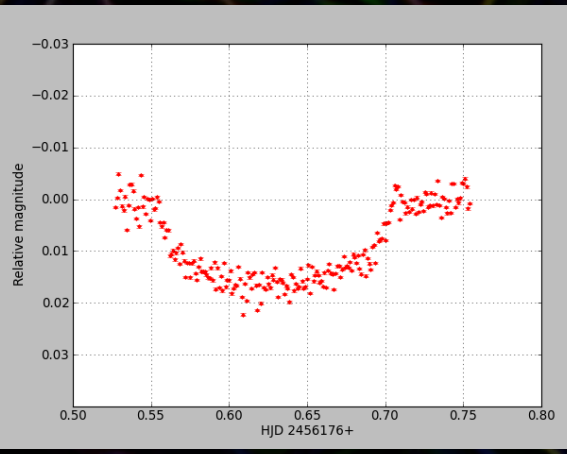
Under-sampled
NGTS-1

On Sky Results

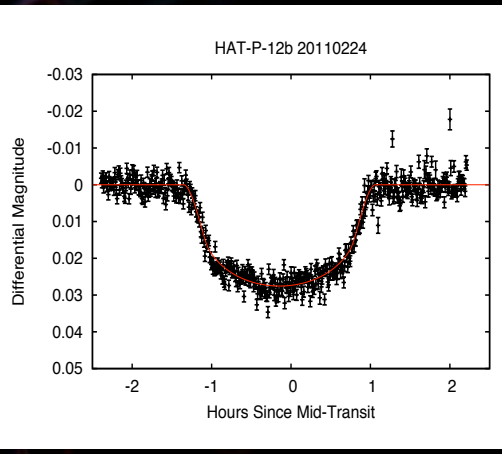
SWASP EBLM (NITES)



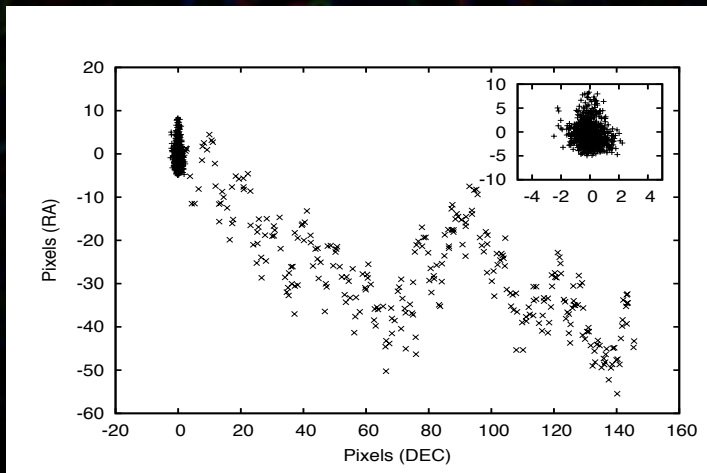
WASP 76b (NITES)



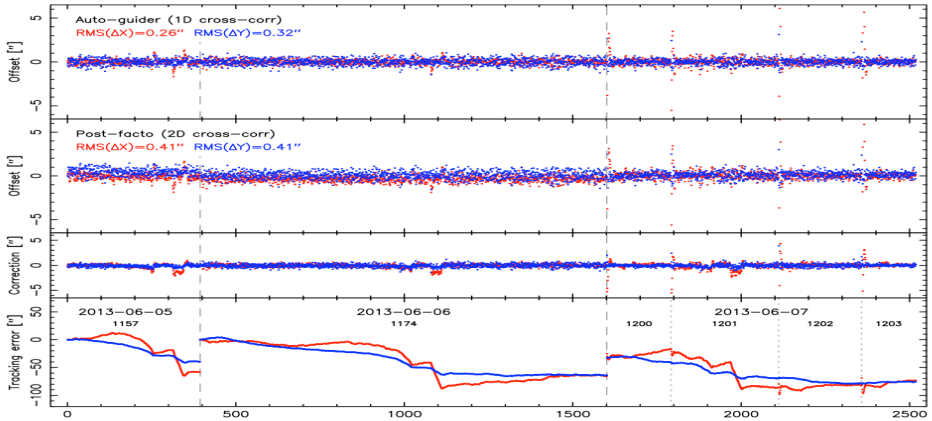
HAT-P-12b (NITES)



DONUTS On/Off (NITES)



DONUTS On/Off multi-night (NGTS-1)



Facilities Deployed

DONUTS was designed for our own needs at:

- NGTS
- SQT
- NITES

Although it can be used in any application of high-cadence time-series photometry where flexure and/or inability to defocus are a problem.

Finally…Other Activities

- INT studentship programme
- SQT 1m telescope
- SuperWASP
- Collaborating on various science projects with Warwick University

Thank you!