The impact of correlated noise on SuperWASP detection rates for transiting exoplanets

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&

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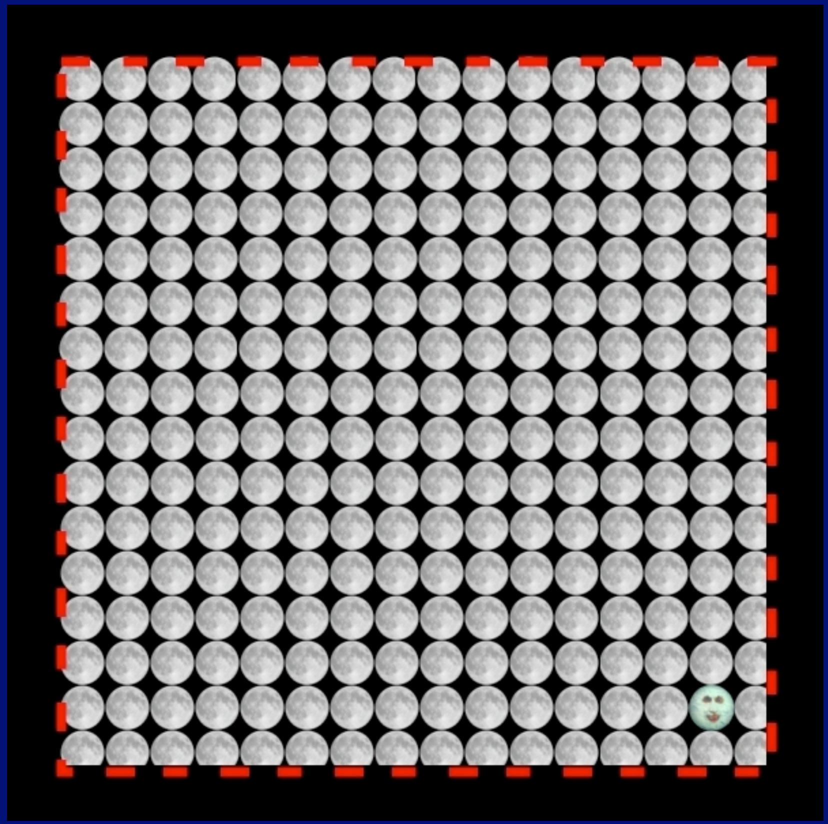
Overview

- SuperWASP-N
- **Red**, **white** and **pink** noise
- How much red noise is present in SuperWASP (SW) data?
- How does red noise affect planet hunting with SW?
- What can we do about it?
- How many planets are likely to be found in 2004 SW-N data?

(most of this work is in Smith *et al.* 2006 MNRAS **373** 1151)

SuperWASP-N

- Wide-field survey based on La Palma using 5x (in 2004) 200mm camera lenses
- Other similar transit surveys exist – e.g. HAT, TrES, XO
- Potential to find many 'Hot Jupiters' and (with RV data) characterise masses and radii



Noise

- **White**
  - Random
  - uncorrelated
- **Red**
  - Systematic
  - correlated
- **Pink**
  - mixture of red & white!

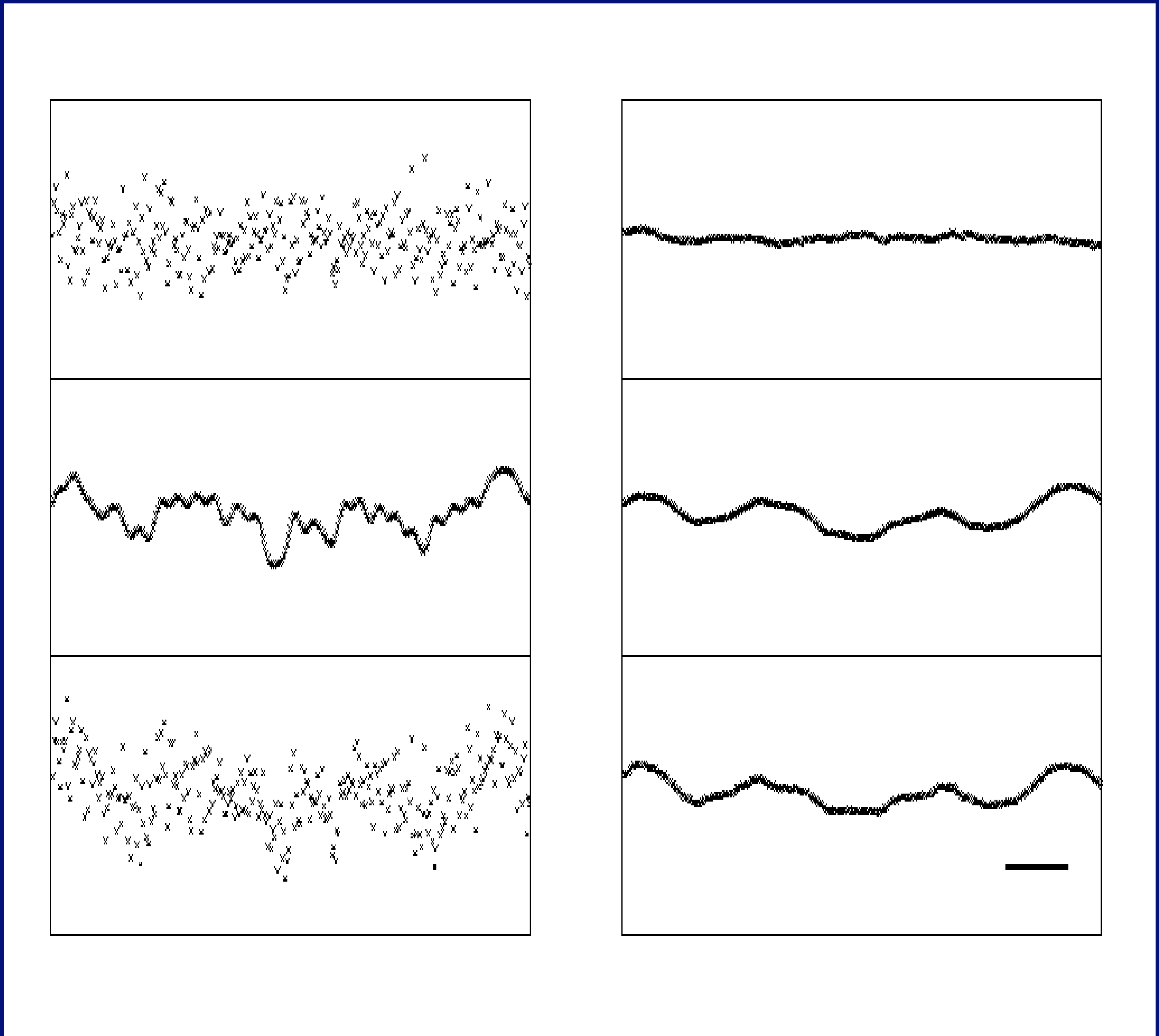


Figure from Pont (2006)

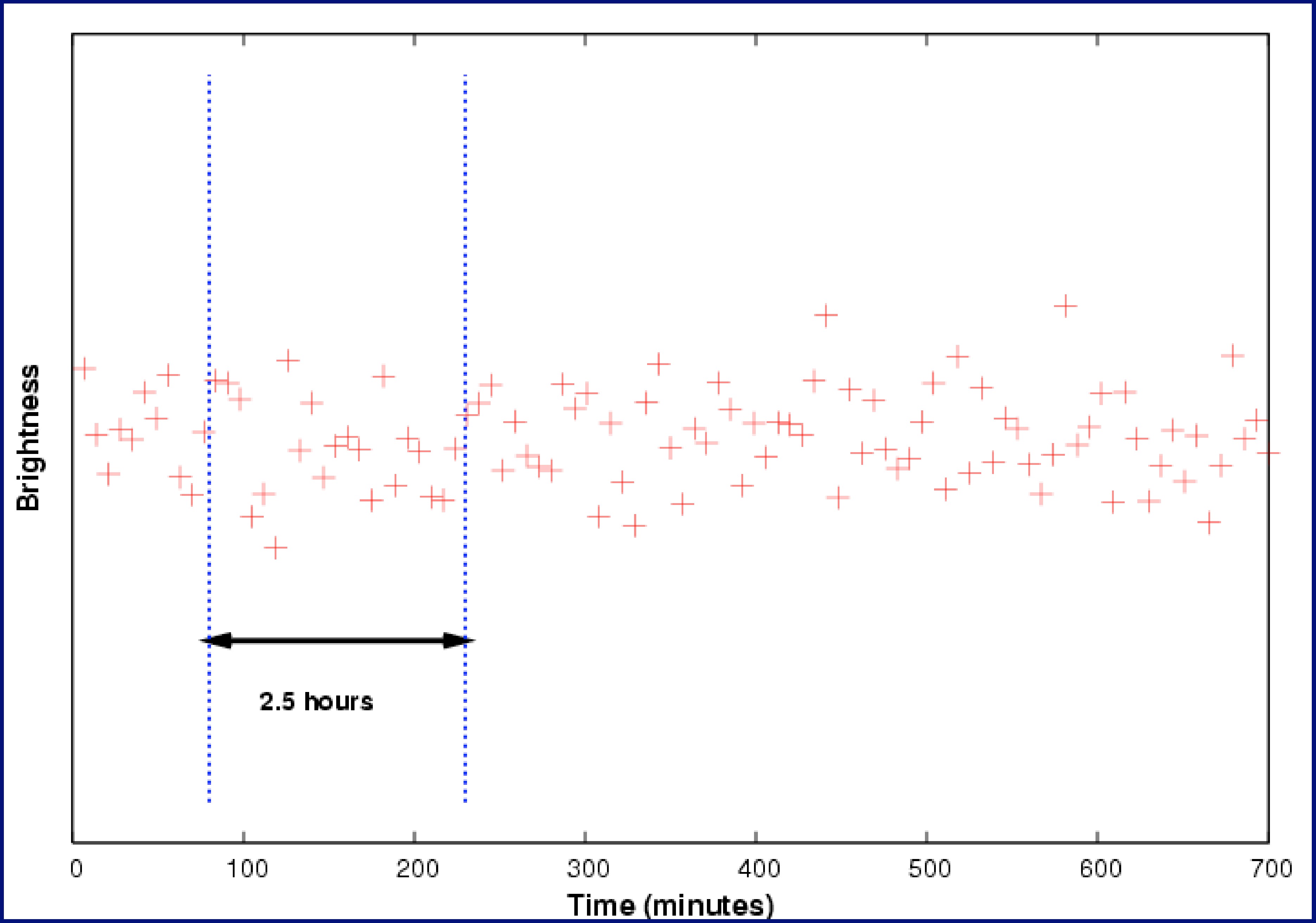
Noise

- Previously assumed that only white noise in photometric survey data – led to predictions of 15 planets / month for 5 SW cameras! (Horne 2002)
- Pont (2006) showed that red noise is generally present
- SysRem algorithm (Tamuz *et al.* 2005) applied to SuperWASP data to remove 4 components of red noise.

Red noise removed with SysRem

- Origin of 4 components not well understood, but may be functions of:
  - Residual secondary extinction
  - Temperature affecting focus
  - Sky brightness?
  - Vignetting?
- See Collier Cameron *et al.*, 2006, MNRAS **373** 799

How much red noise?

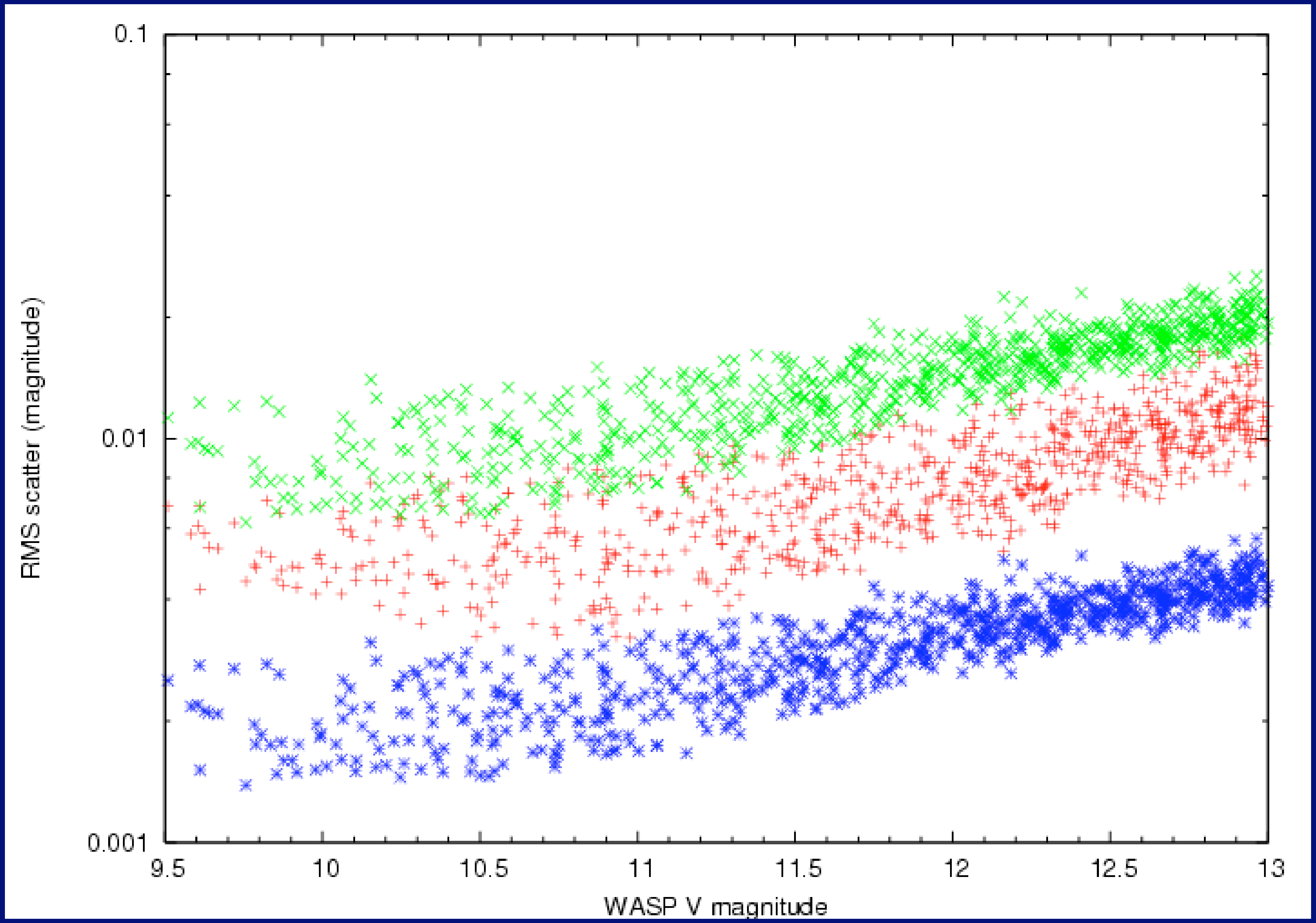


- Calculate average, x, of n points in transit duration time interval (2.5 hrs.)
- Calculate RMS, σ_r, of x over whole lightcurve

How much red noise?

- Calculate σ_r for all (non-variable) stars in 1 field
- Also have standard RMS, σ, of each lightcurve
- Define $\sigma_w = \sigma.(n)^{-½}$
- If noise is completely white, then $\sigma_r = \sigma_w$, but if $\sigma_r > \sigma_w$, red noise is present

RMS *vs.* magnitude before decorellation with SysRem

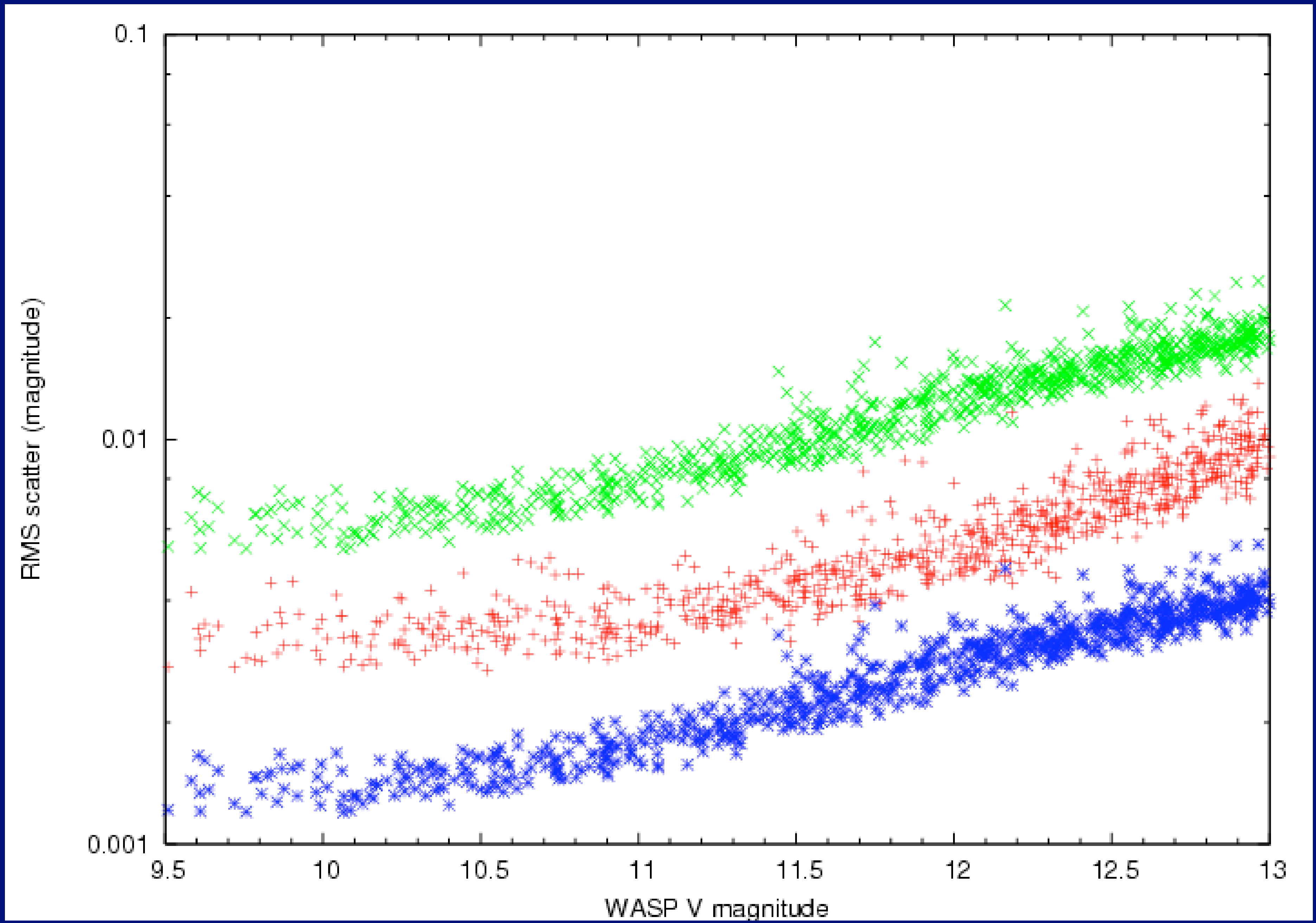


σ

σ_r

σ_w

RMS *vs.* magnitude after decorellation with SYSREM



σ

σ_r

σ_w

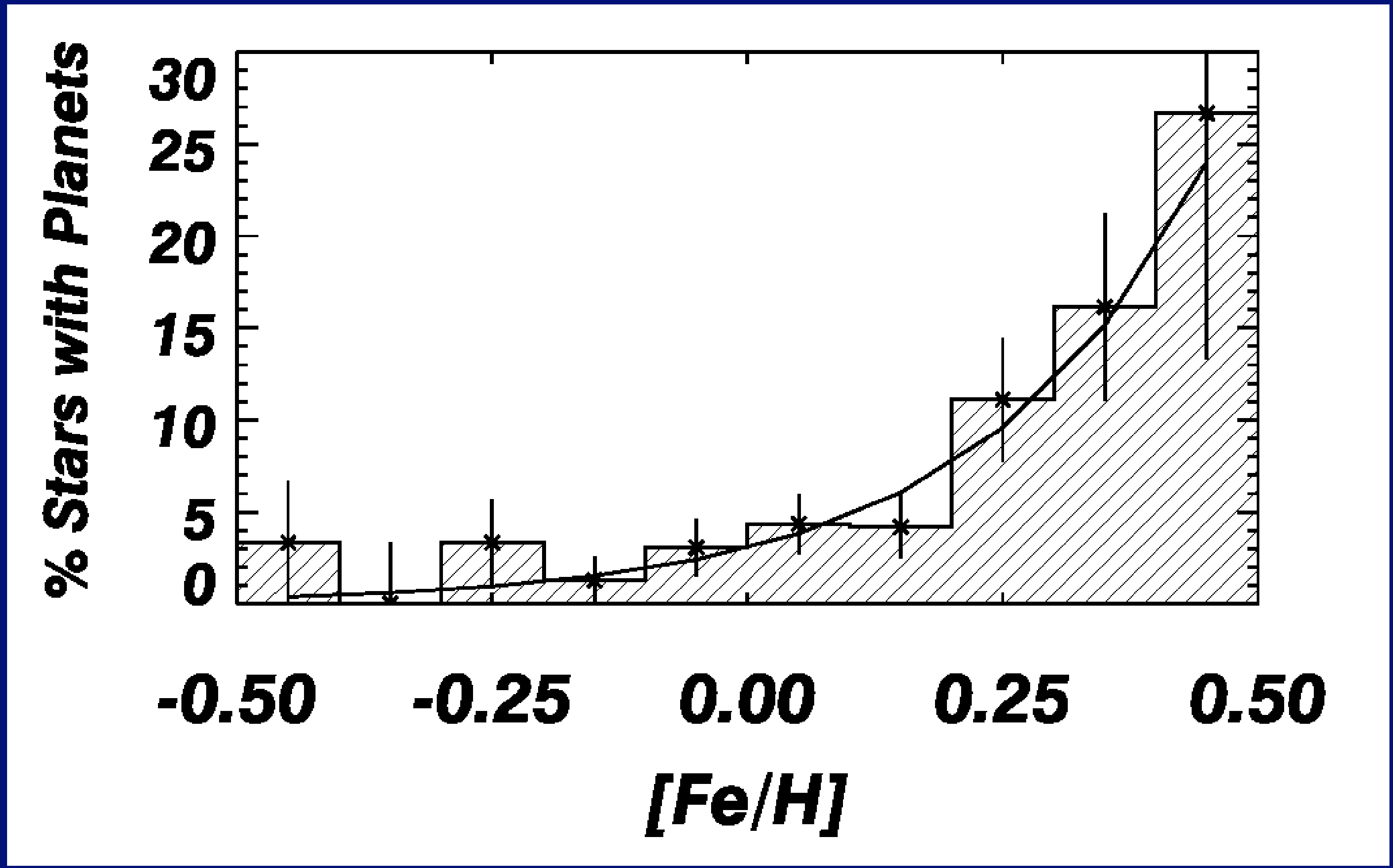
Red noise: conclusions

- SysRem algorithm does good job at removing red noise.
- However, obvious that $\sigma_r \neq \sigma_w$ (red curve doesn't lie over blue curve).
- Therefore some red noise still present.
- About 3 mmag of red noise in data on 2.5 hour time-scale

How does red noise affect planet hunting?

- Model nearby stars with Besançon galactic model (Robin *et al.* 2003)
- Semi-major axis, *a*, randomly drawn from uniform log distribution.
- Planets assigned to F,G,K IV & V stars on basis of stellar metallicity...

Probability a star hosts a planet depends on metallicity



$$\mathcal{P}(\text{planet}) = 0.03 \times 10^{2.0[\text{Fe/H}]}$$

- (Fischer & Valenti 2005)

How does red noise affect planet hunting?

$$\mathcal{P}(\text{alignment}) \approx \arctan\left(\frac{R_*}{a}\right)$$

$$\mathcal{P}(\text{transit}) = \mathcal{P}(\text{planet}) \times \mathcal{P}(\text{alignment})$$

$$\Delta m \approx 1.3\left(\frac{R_{\rm p}}{R_*}\right)^2$$

(Tingley & Sackett 2005)

The Besançon catalogue

- 154,156 stars with $9.5<V<13$ generated in 20 fields observed by 1 camera (DAS-2)
- ~47% of these are spectral types F,G or K and luminosity class IV or V.
- 151±13 (~0.1% of total) allocated *transiting* planets (all planets in model are Jupiter-sized).

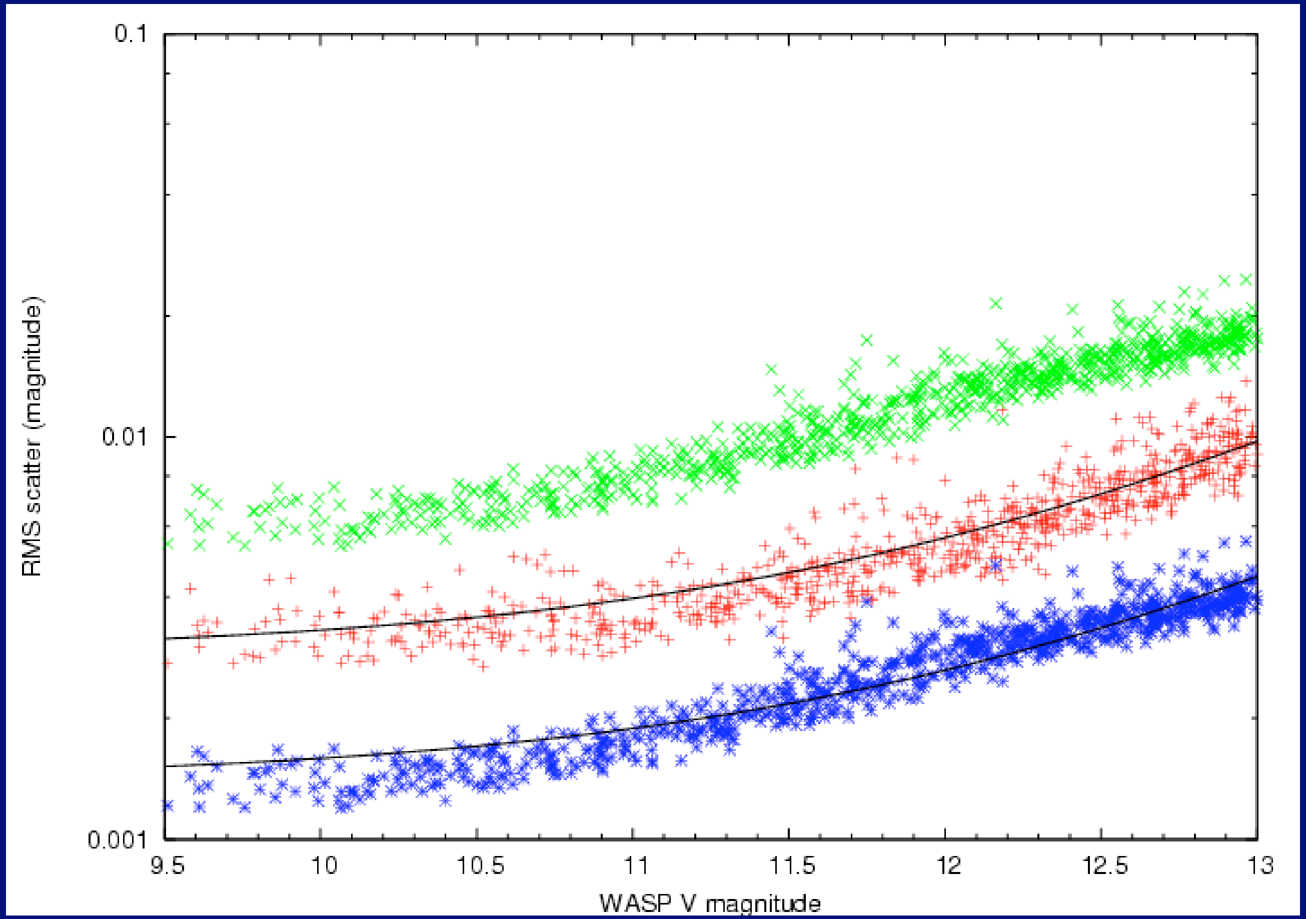
Signal-to-noise ratio, S_{red}

- SNR for red noise dominant case is given by

$$S_{\mathrm{red}} = \frac{\Delta m \sqrt{n_{\mathrm{trans}}}}{\sigma_{\mathrm{r}}(V)}$$

- Number of observed transits, n_{trans} , is simulated by assigning random epoch of transit and using real SW obs times

Determine $\sigma_r(V)$



Fit line to σ_r

$$\sigma_r(V) = c_1 + c_2 \times 10^{0.4V}$$

where

$$c_1 = 2.88 \times 10^{-3}$$

$$c_2 = 4.34 \times 10^{-8}$$

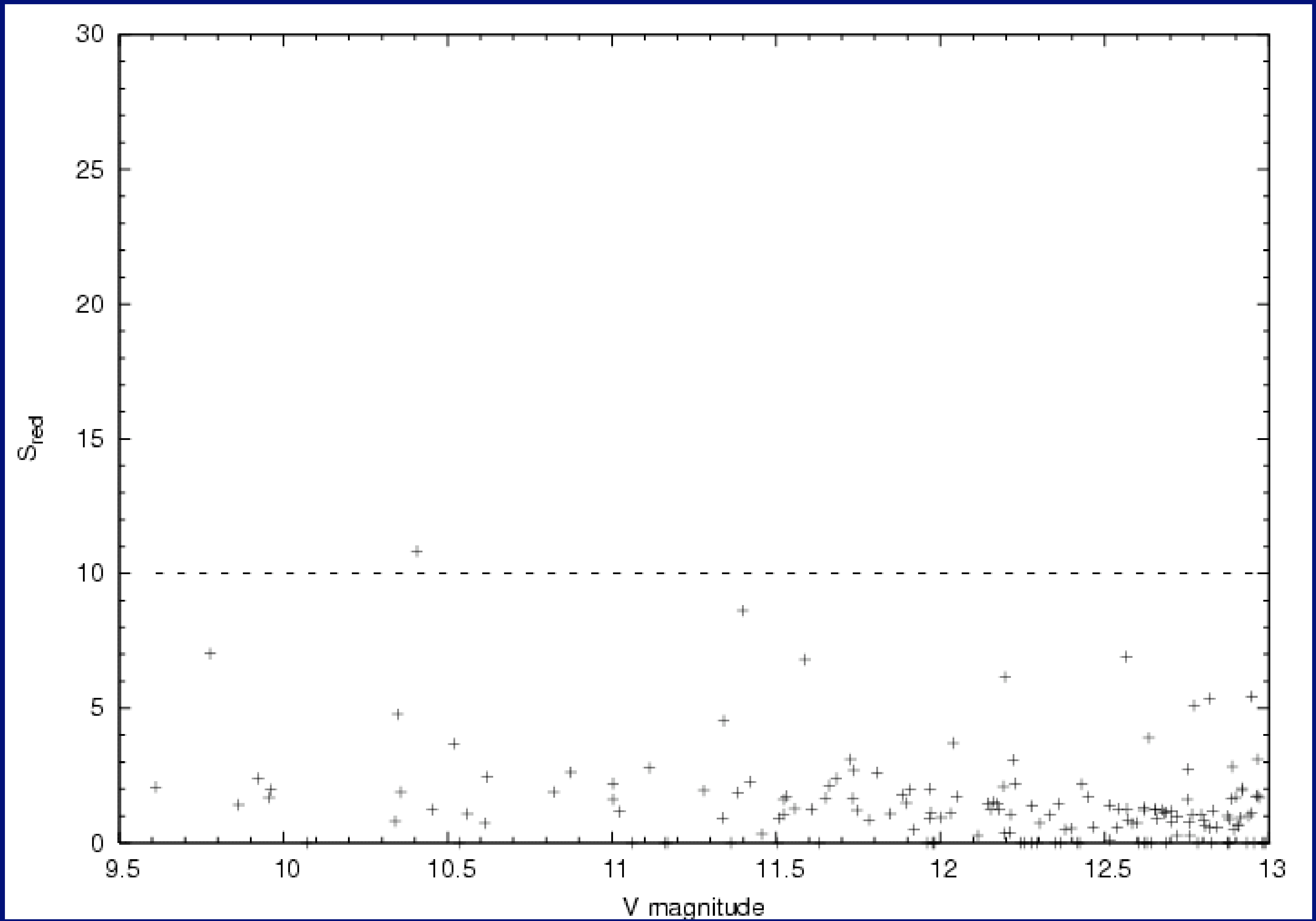
Signal-to-noise ratio, S_{red}

- Back to equation for SNR:

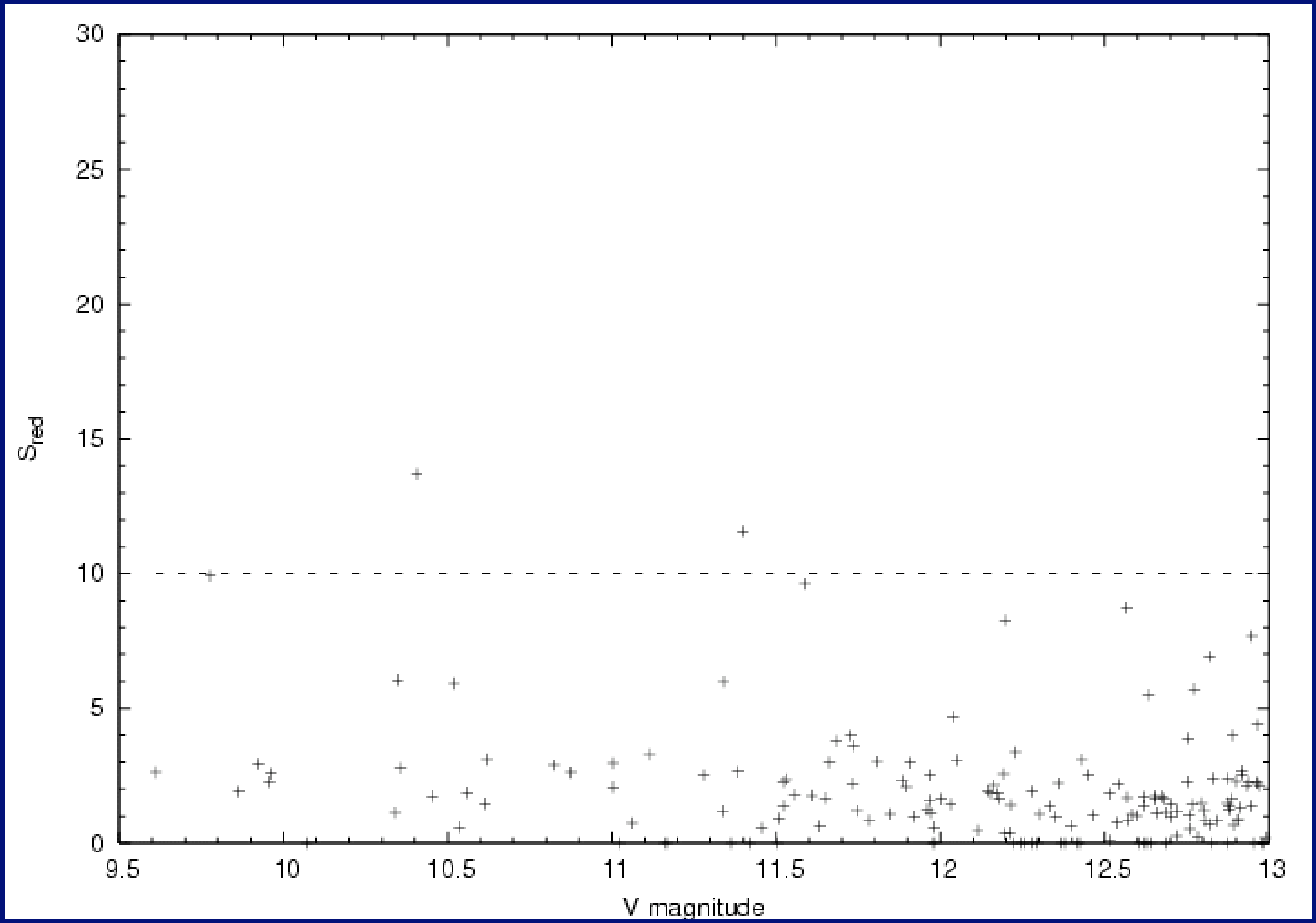
$$S_{red} = \frac{\Delta m \sqrt{n_{trans}}}{\sigma_r(V)}$$

- Δm - directly from $R_\star$ in catalogue
- n_{trans} - from simulation (real obs times)
- $\sigma_r(V)$ - fitted (previous slide)
- So we can calculate S_{red} as f^n of V

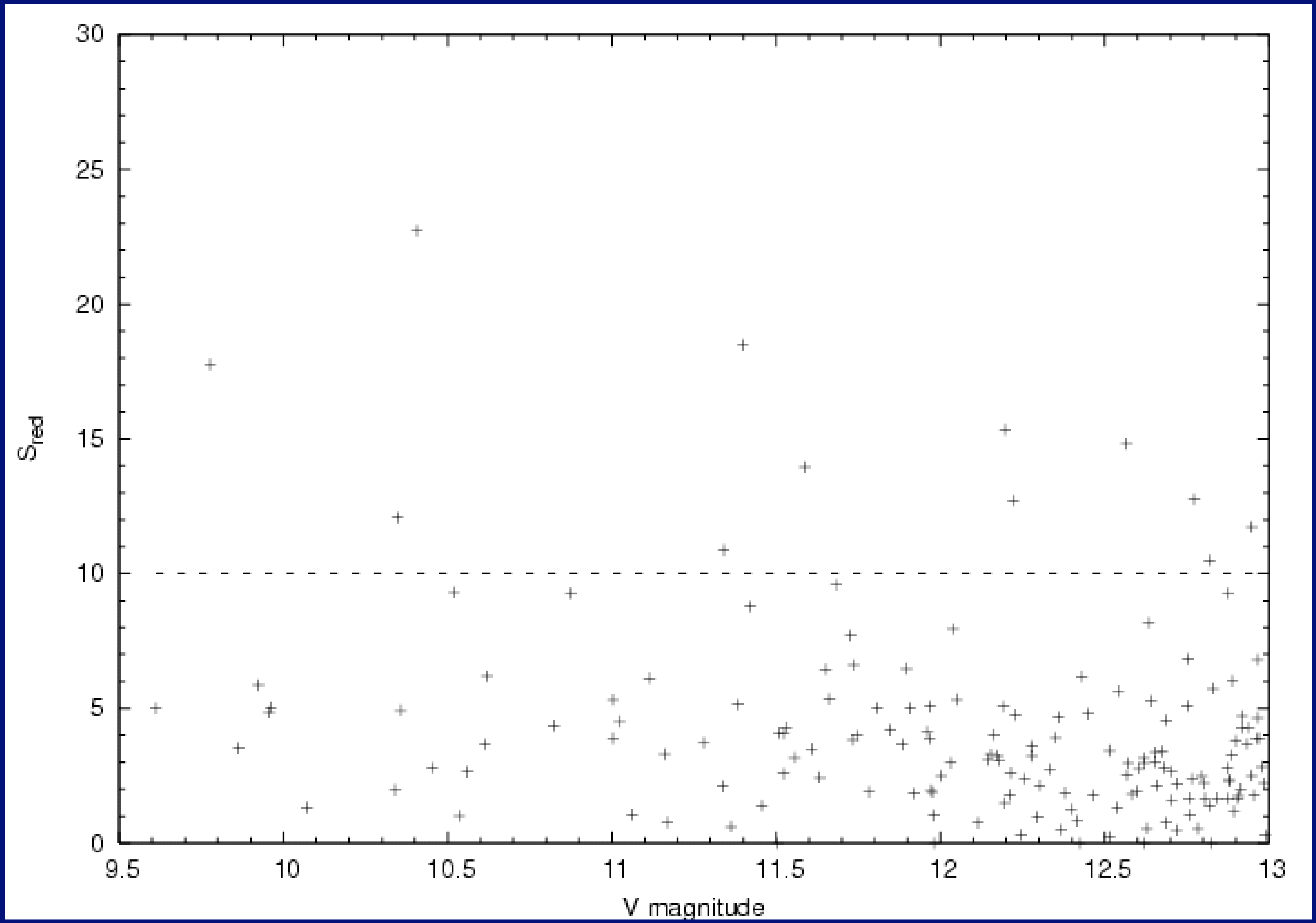
S_{red} vs. magnitude: 51 nights: 1 'detection'



S_{red} vs. magnitude: 80 nights: 2 'detections'



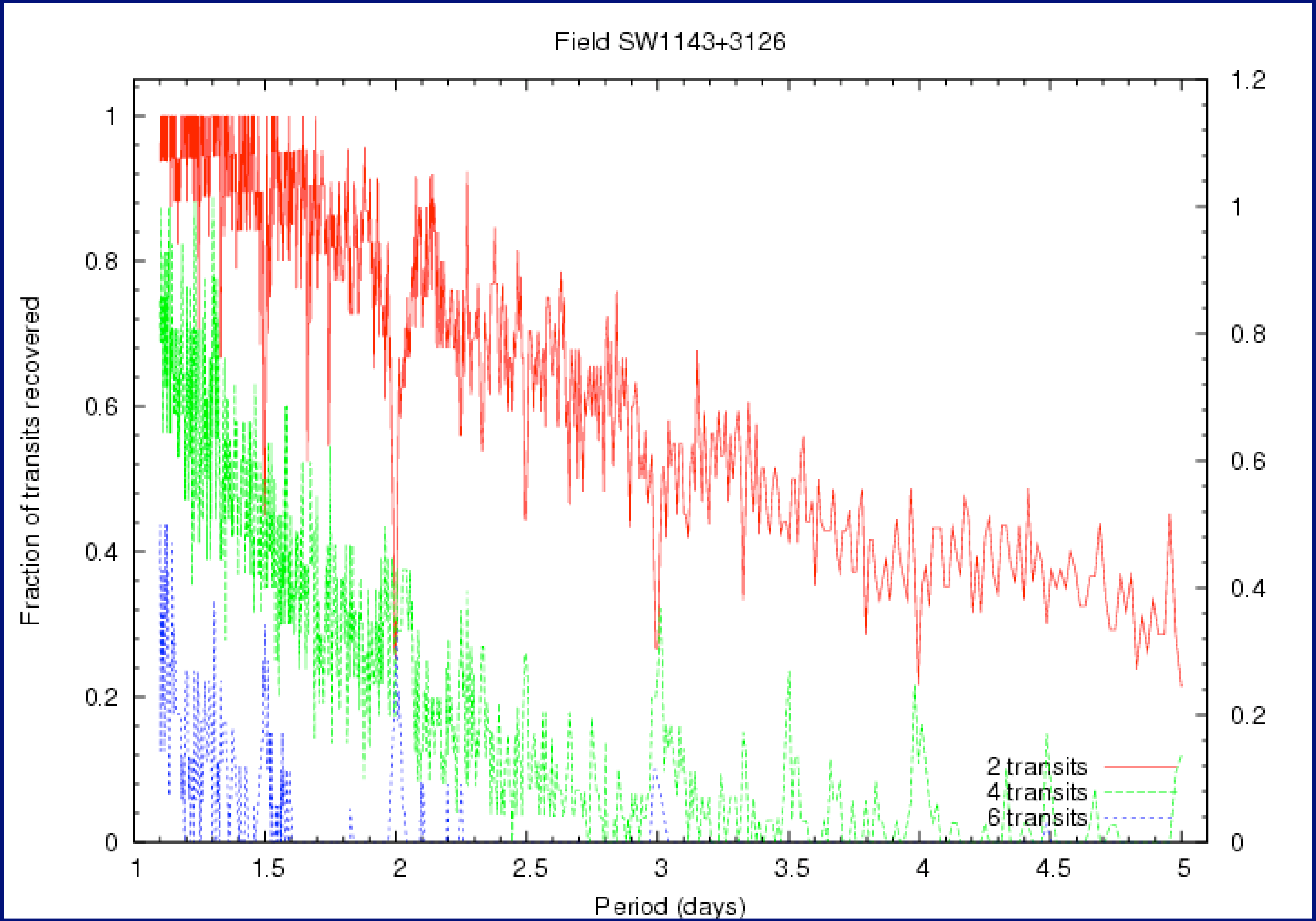
S_{red} vs. magnitude: 130 nights: 12 'detections'



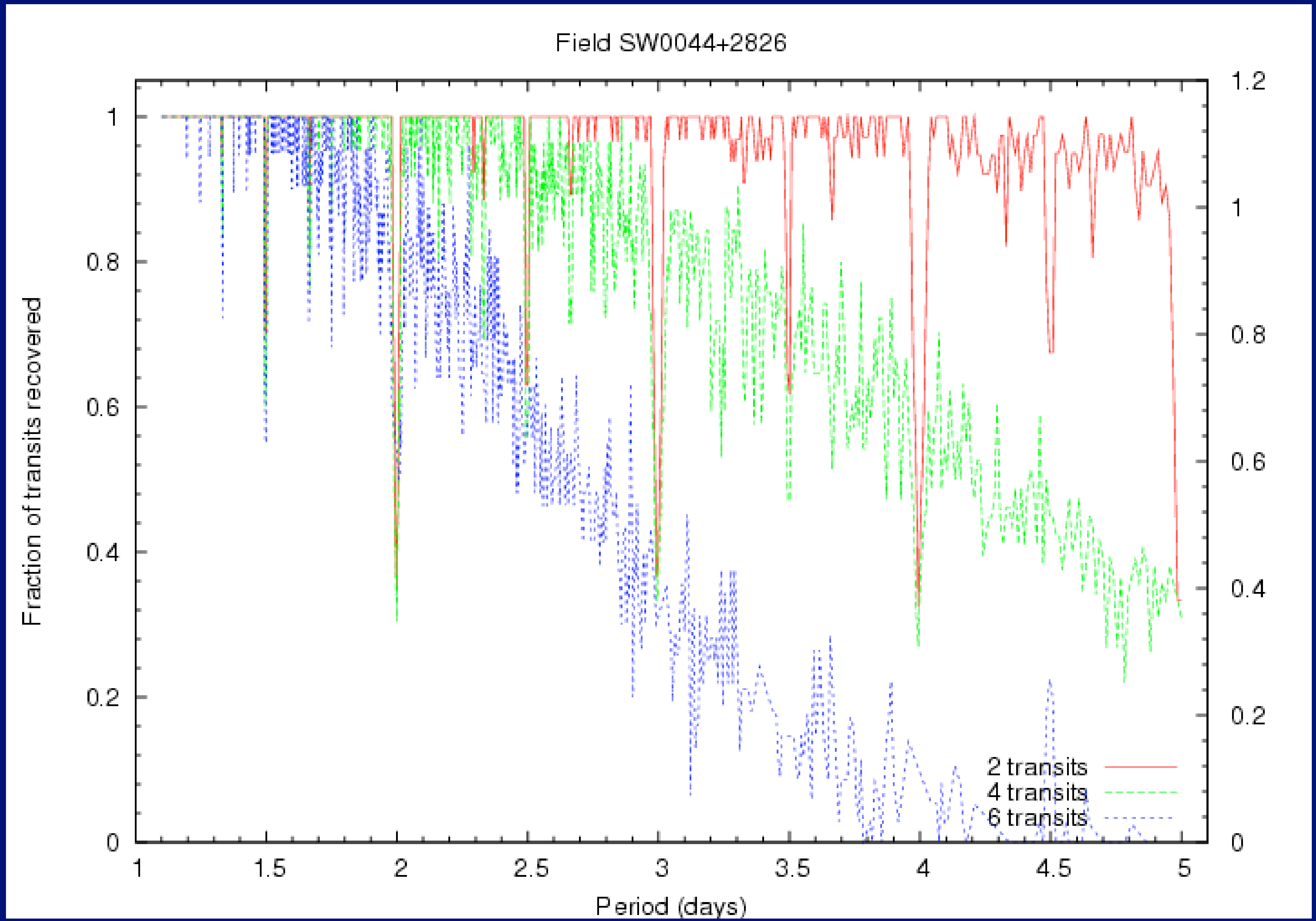
Why does increasing number of night of observations lead to more detections?

- S_{red} increases with increasing n_{trans}
- n_{trans} depends on observing baseline (see next slides)
- Hence increasing the observing baseline boosts S_{red} ...
- ...leading to more detections!

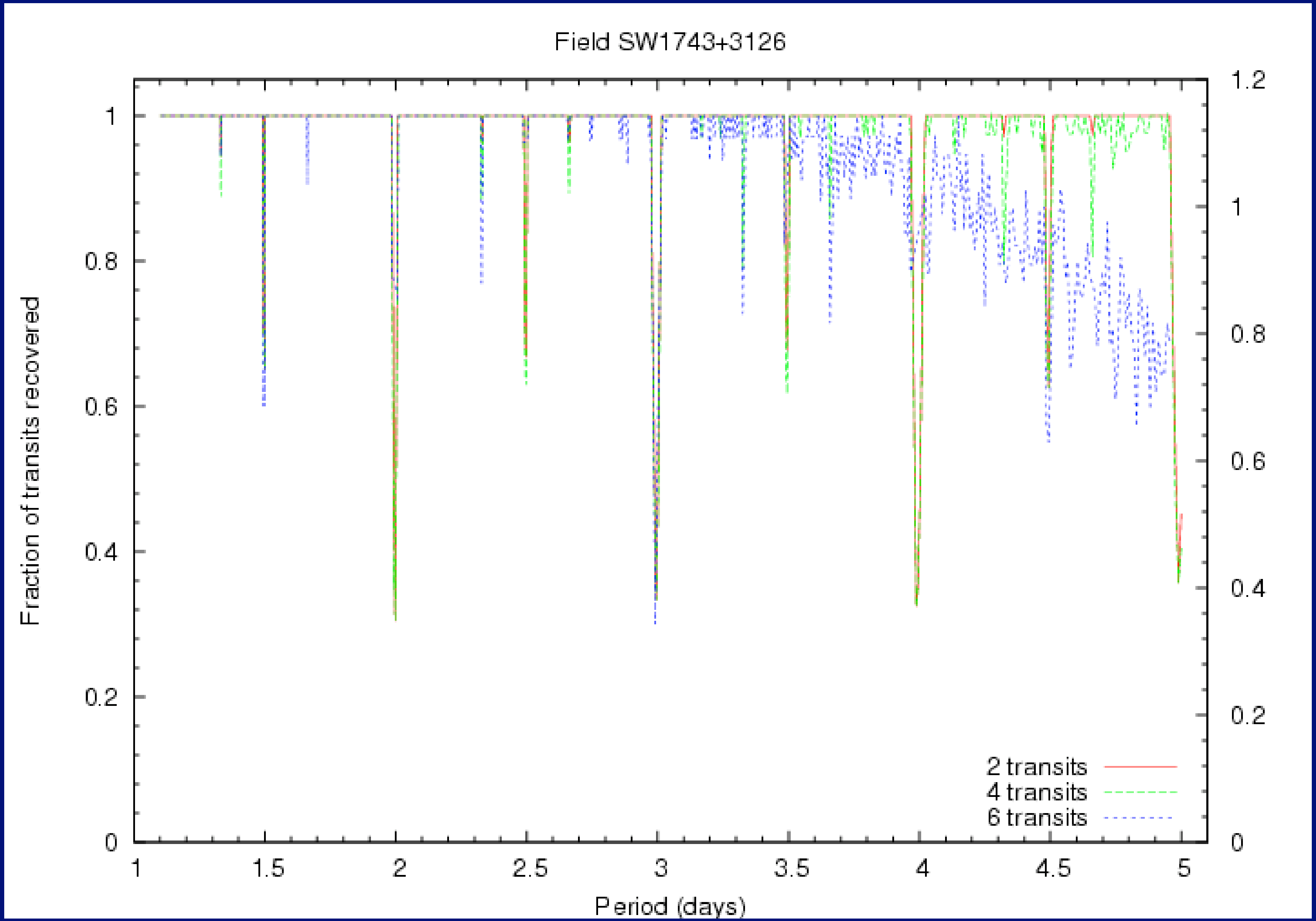
Fractional transit recovery: 51 nights of observations



Fractional transit recovery: 80 nights of observations



Fractional transit recovery: 130 nights of observations



Simulated detection rates for all 2004 SW-N DAS-2 fields

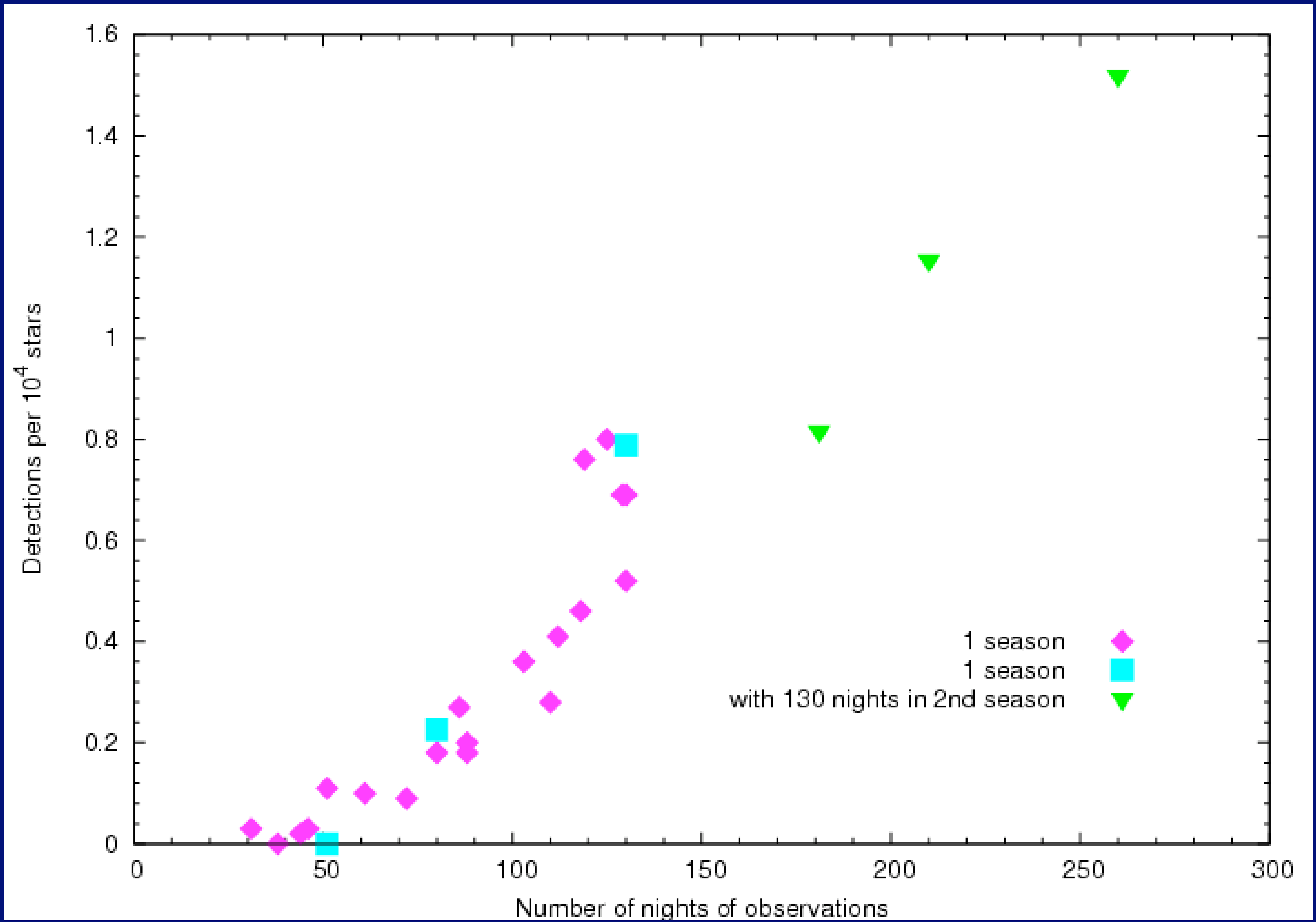
Field ID	No. of nights of observations	No. of observations	No. of stars Model	No. of stars Observed	No. of planets with $S_{red} \geq 10$ in simulation	Detections per 10^4 stars
SW0043+3126	88	2962	6150	4746	0.12 ± 0.32	0.20
SW0044+2826	80	2851	5684	7353	0.10 ± 0.30	0.18
SW0143+3126	72	2251	6354	7840	0.06 ± 0.24	0.01
SW0243+3126	61	1646	7114	8235	0.07 ± 0.26	0.10
SW0343+3126	46	1286	9630	8465	0.03 ± 0.17	0.03
SW0443+3126	44	911	16062	8314	0.04 ± 0.20	0.02
SW0543+3126	38	539	21255	15021	0.01 ± 0.10	0.00
SW1043+3126	31	473	2939	2775	0.01 ± 0.10	0.03
SW1143+3126	51	813	2628	2508	0.03 ± 0.17	0.11
SW1243+3126	86	2157	2577	2605	0.07 ± 0.35	0.27
SW1342+3824	103	2578	2482	2724	0.09 ± 0.32	0.36
SW1443+3126	125	3618	2988	3071	0.24 ± 0.51	0.80
SW1543+3126	130	4422	3899	3963	0.27 ± 0.47	0.69
SW1643+3126	129	4795	5388	6233	0.37 ± 0.59	0.69
SW1739+4723	119	4401	5361	8791	0.41 ± 0.58	0.76
SW1743+3126	130	5214	8712	11681	0.45 ± 0.65	0.52
SW1745+1727	110	3590	13700	17818	0.38 ± 0.60	0.28
SW2143+3126	88	3672	15145	24129	0.27 ± 0.53	0.18
SW2243+3126	118	4388	9175	14330	0.42 ± 0.60	0.46
SW2343+3126	112	3629	6913	9488	0.28 ± 0.53	0.41
Total			154156	170090	3.72 ± 1.60	0.24

3.72 ± 1.60 planets with $S_{red} \geq 10$

Simulated detection rates for all 2004 SW-N DAS-2 fields

- Total of 151±13 transiting planets in simulation of 20 fields with >10 nights observations
- **3.72±1.60** planets are 'detected' (i.e. have $S_{red} \geq 10$)
- Scaling up to 5 cameras on 2004 data alone – predict **18.6±8.0** planets

Detection rate vs. number of nights



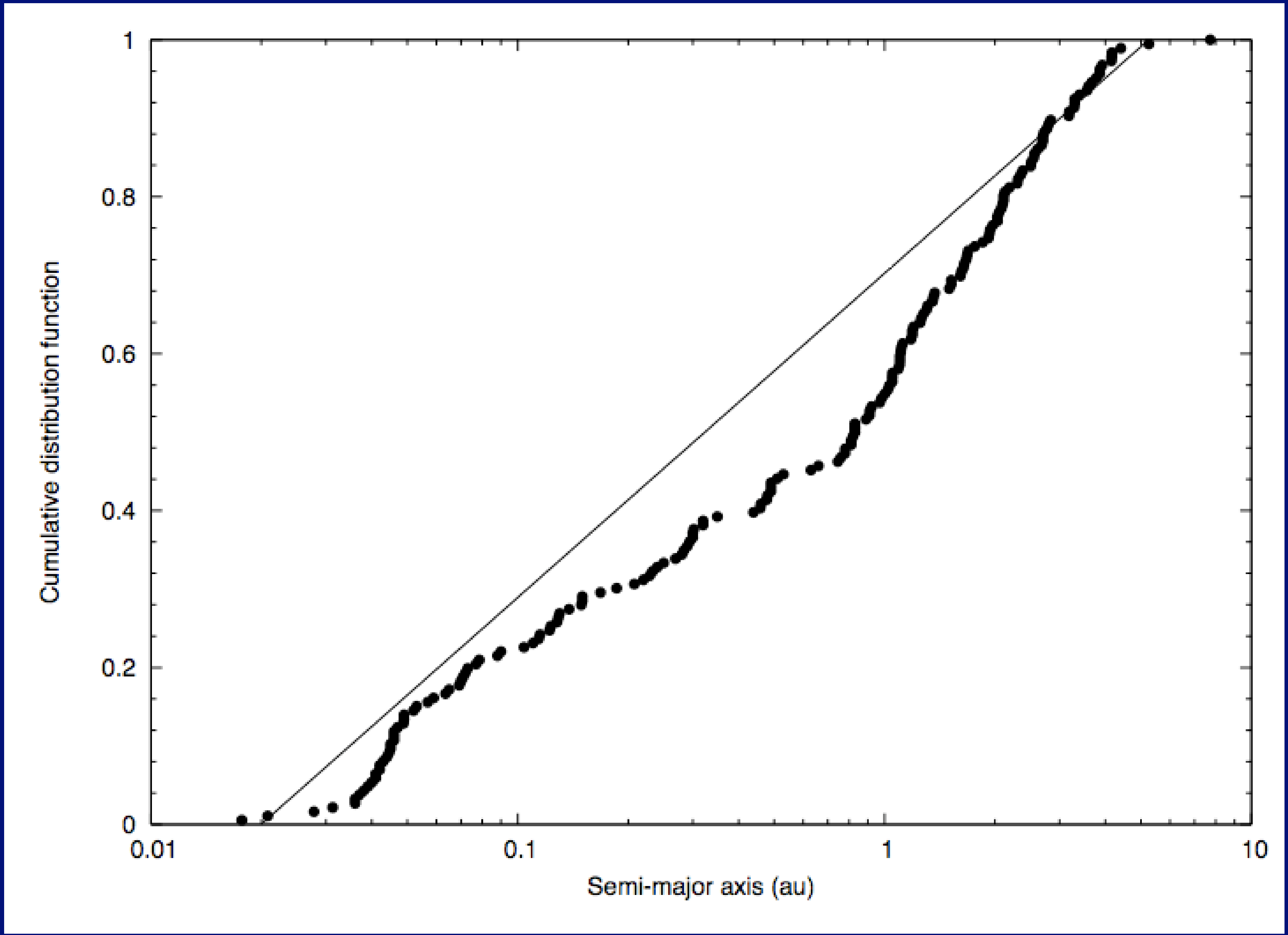
Predictions *vs*. results (so far)

- Simulations also run in 2 magnitude ranges:
  - 9.5 < V < **12** : **13.25** ± 8.0 [for 5 cameras]
  - 12 < V < **13** : **4.6** ± 4.8 [for 5 cameras]
  - because red noise greater for fainter stars
- We find 3(!) planets in 9.5 < V < **12** range.

Predictions *vs*. results (so far)

- Why only 3 planets?
  - Over-estimated no. of short *P* planets?
  - Not all candidates followed up, only the best
  - Effects of edge of CCD, etc ignored
  - Jupiter-sized planets assumed

Predictions *vs*. results (so far)



Conclusions

- SuperWASP data suffers from red noise, despite decorrelation with SysRem.
- Even 3 mmag of red noise limits ability to find planets.
- Red noise can be overcome by observing more transits – boosts SNR...
- **...Need to observe for longer to do this!**