Transit Survey Design Considerations

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NASA Ames
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Transit Survey Design Considerations

<u>Outline:</u>

- Numbers / Quantities
- Principal Goals and Inherent Challenges of Transit Surveys
- Target Selection
- Observing Strategy

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Planet Transits – Numbers

Close-in Extrasolar Giant Planets / Hot Jupiters:

- period: ~ few days ; orbital radius ~ 0.05 AU
- transit duration: ~ few hours (duty cycle: few %)
- chance of favorable system inclination: ~10%
- transit depth: ~1% to few %
- Solar neighborhood: 1 star in 150 with close-in extrasolar giant planet (Butler et al. 2000, Marcy et al. 2004)
- assume binary fraction is ~50%
- assume transit detection only possible around single stars

transiting planet should be observable around 1 star in 3000!

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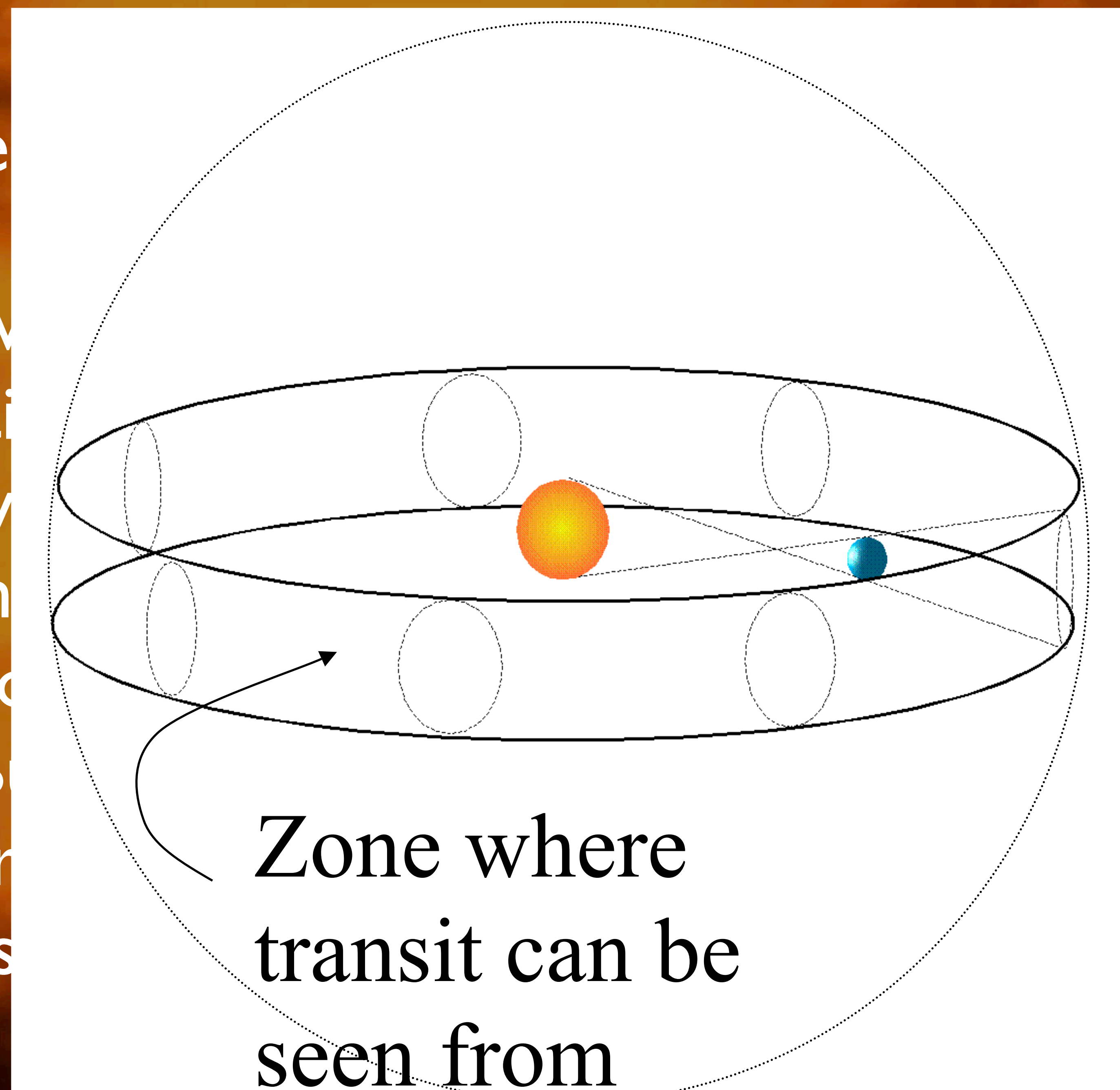

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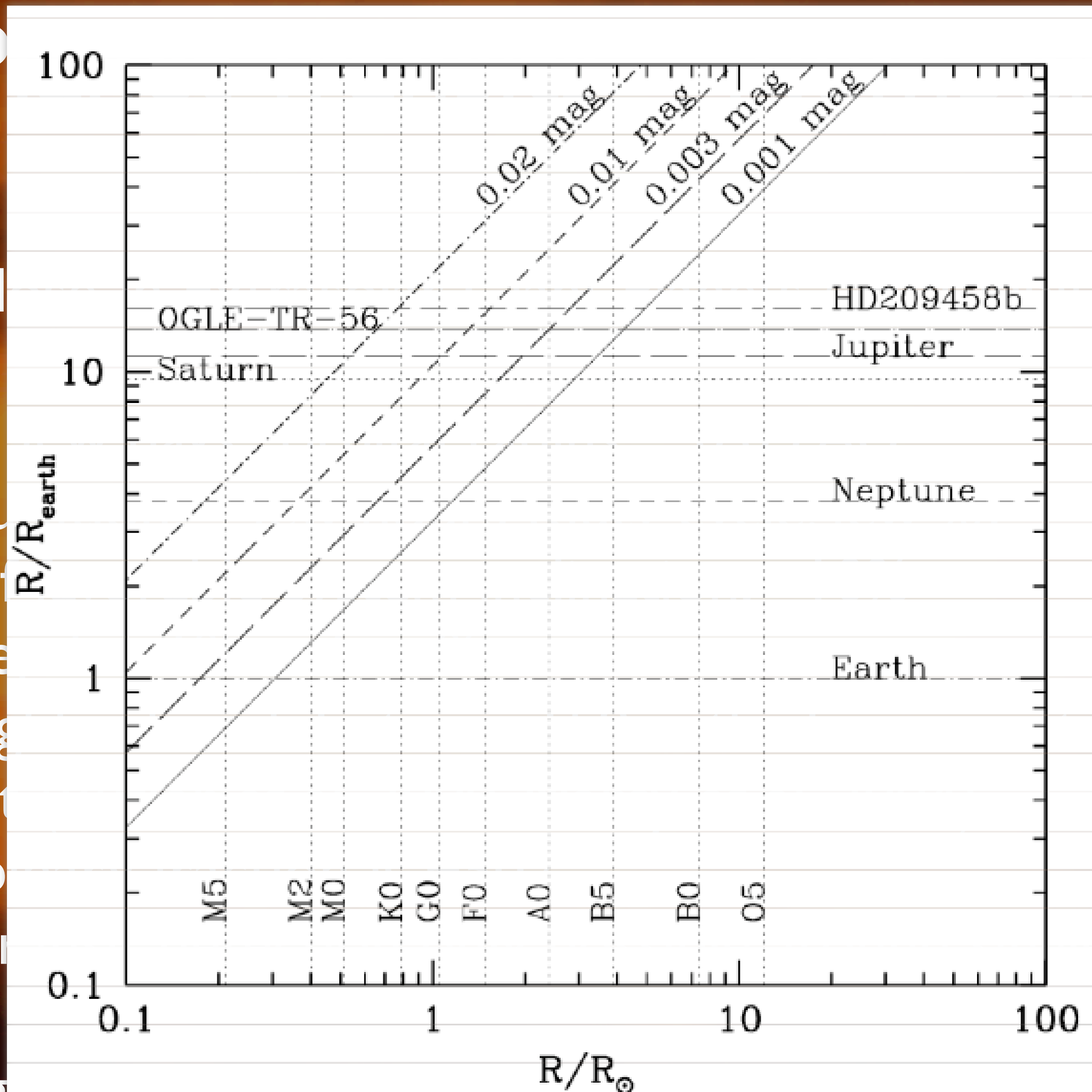

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Status up to 2005

K. Horne (2005)
http://star-www.st-and.ac.uk/%7Ekdh1/transits/table.html

Transit Search Programmes

Programme	D (cm)	focal ratio	$W^{0.5}$ (deg)	N_x (kpix)	N_y (kpix)	no. of CCDs	pixel (arcsec)	sky mag	star mag	d (pc)	stars ($x10^3$)	planets /month
1 PASS	2.5	2.0	127.25	2.0	2.0	15	57.75	6.8	9.4	83	18	6.3
2 WASP0	6.4	2.8	8.84	2.0	2.0	1	15.54	9.6	11.8	246	2	0.8
3 ASAS-3	7.1	2.8	11.21	2.0	2.0	2	13.93	9.9	12.0	272	5	1.7
4 RAPTOR	7.0	1.2	55.32	2.0	2.0	8	34.38	7.9	11.1	179	33	11.7
5 TrES	10.0	2.9	10.51	2.0	2.0	3	10.67	10.5	12.7	362	10	3.5
6 XO	11.0	1.8	10.06	1.0	1.0	2	25.00	8.6	11.9	258	3	1.2
7 HATnet	11.1	1.8	19.42	2.0	2.0	6	13.94	9.9	12.5	338	28	9.7
8 SWASP	11.1	1.8	31.71	2.0	2.0	16	13.94	9.9	12.5	338	74	26.0
9 Vulcan	12.0	2.5	7.04	4.0	4.0	1	6.19	11.6	13.4	497	12	4.1
10 RAPTOR-F	14.0	2.8	5.93	2.0	2.0	2	7.37	11.3	13.4	498	8	2.9
11 BEST	19.5	2.7	3.01	2.0	2.0	1	5.29	12.0	14.2	668	5	1.8
12 Vulcan-S	20.3	1.5	6.94	4.0	4.0	1	6.10	11.7	14.1	642	24	8.5
13 SSO/APT	50.0	1.0	5.05	2.9	3.1	2	4.20	12.5	15.5	1103	65	22.8
14 RATS	67.0	3.0	1.31	2.0	2.0	1	2.30	13.8	16.4	1548	12	4.2
15 TeMPEST	76.0	3.0	0.77	2.0	2.0	1	1.35	15.0	17.1	1944	8	2.9
16 EXPLORE-OC	101.6	7.0	0.32	2.0	3.3	1	0.44	17.1	18.4	2881	5	1.6
17 PISCES	120.0	7.7	0.38	2.0	2.0	4	0.33	17.1	18.6	3045	8	2.7
18 ASP	130.0	13.5	0.17	2.0	2.0	1	0.30	17.1	18.7	3125	2	0.6
19 OGLE-III	130.0	9.2	0.59	2.0	4.0	8	0.26	17.1	18.7	3125	20	7.1
20 STEPSS	240.0	0.0	0.41	4.0	2.0	8	0.18	17.1	19.5	3757	17	5.9
21 INT	250.0	3.0	0.60	2.0	4.0	4	0.37	17.1	19.5	3800	37	13.1
22 ONC	254.0	3.3	0.53	2.0	4.0	4	0.33	17.1	19.5	3817	30	10.5
23 EXPLORE-N	360.0	4.2	0.57	2.0	4.0	12	0.21	17.1	19.9	4196	46	16.2
24 EXPLORE-S	400.0	2.9	0.61	2.0	4.0	8	0.27	17.1	20.0	4313	58	20.1
Total number of planets/month:												**186**

$W^{0.5}$ degrees is the square root of the field of view. Not all fields are square.
d parsecs is the distance at which a transit with $R = R_{Jup}$ and P = 4 days across a G2V star will be detected with a S/N of 10.
star mag is the limiting magnitude for this event.

Vital statistics questionnaire

Keith's June 2002 Washington Conference preprint (.ps)

Updated: 2005.05.18

Open Cluster Transit Searches

small nearby bright → big distant faint

low spatial res. → high spatial res.

long observ. runs → “short” observ. runs

not listed: space-based surveys (HST, MOST, COROT)

Transit Survey Design Considerations

Purpose and Outline:

- Numbers / Quantities
- Principal Goals and Inherent Challenges of Transit Surveys
- Target Selection
- Observing Strategy

Transit Surveys:
Principal Goals & Inherent Challenges

- Detect and characterize planetary systems.
- Provide statistics concerning planetary frequency / characteristics as function of astrophysical properties of surveyed sample / environment.

- Maximize number of stars monitored at sufficiently high relative photometric precision.
- Maximize probability of detecting observable transits.
- Eliminate false positives.
- Understand the sample.

Transit Survey Design Considerations

Outline:

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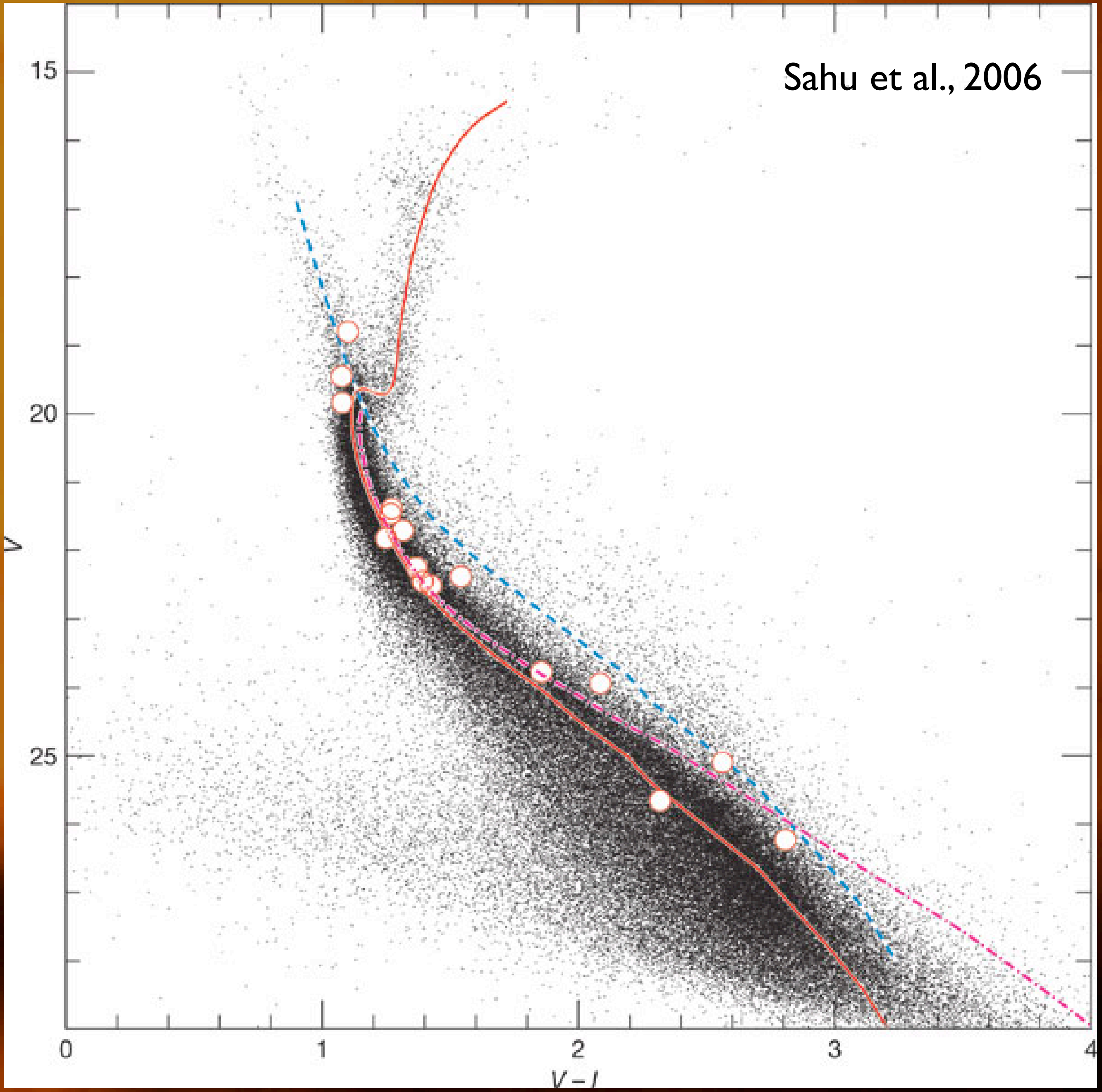
Transit Surveys -- Target Selection

<u>based on:</u>

- richness of observed target
- observability (hours per night, number of nights, cadence)
  - window functions (later in this talk)
- crowding (function of pix size)
  - Tim Brown's talk
- range in astrophysical properties (age, metallicity, environment...)
- distance / brightness versus cadence
- contamination / number of "good" stars

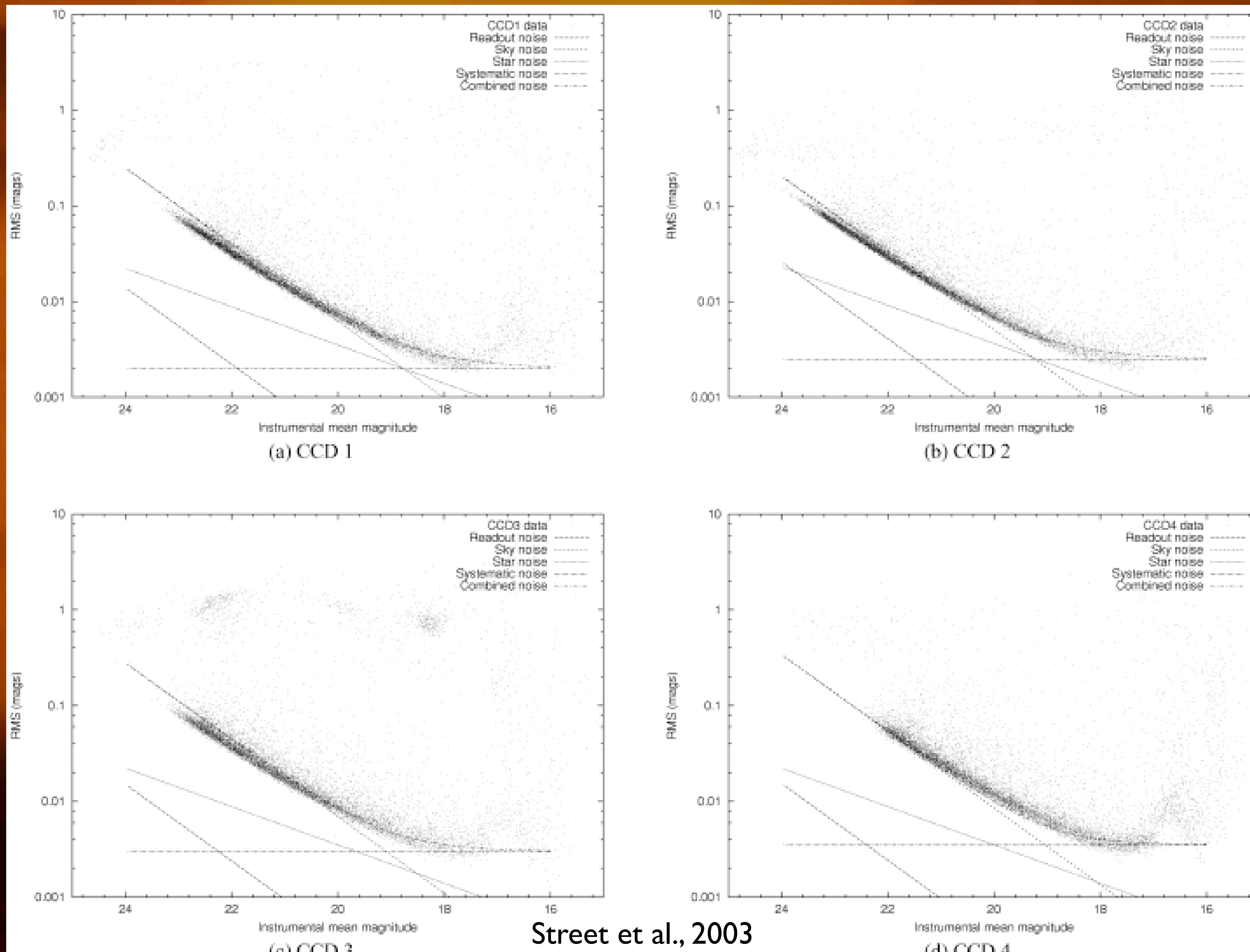
Transit Surveys -- Target Selection
range in astrophysical properties

- clusters: need to target several clusters (EXPLORE/OC, UStAPS, PISCES, STEPSS, 47 Tuc studies, MONITOR, etc)
- field: get them automatically, but need auxiliary data (spectra)



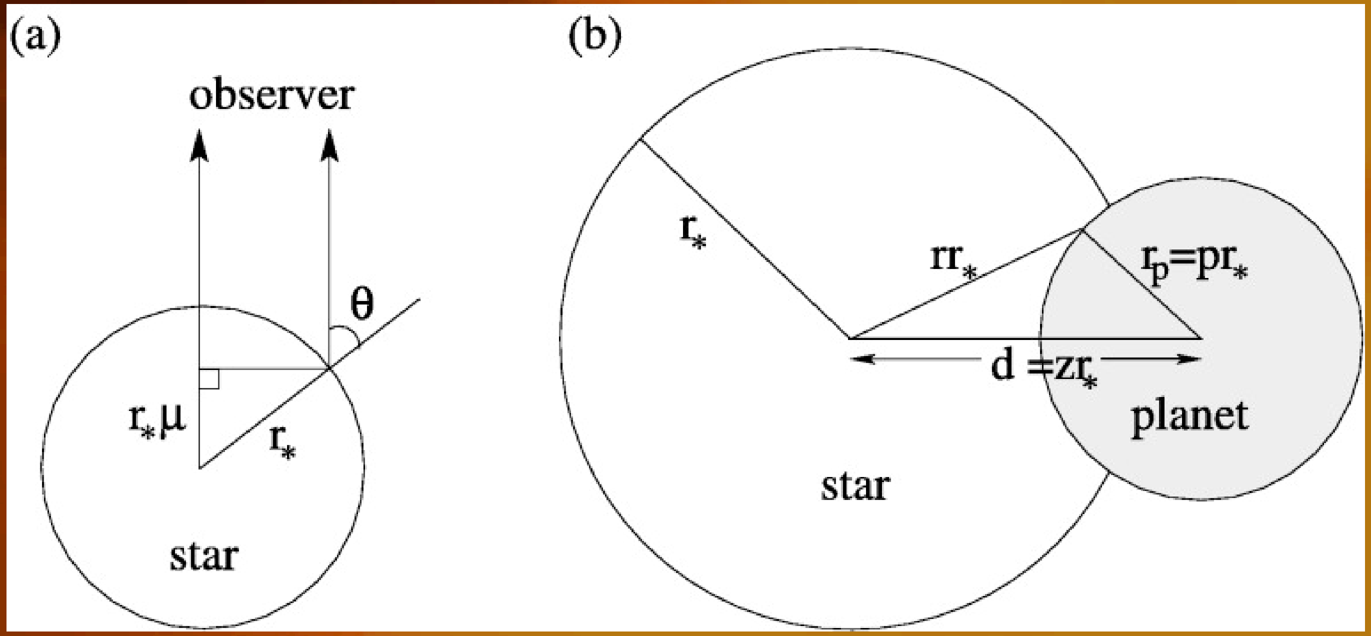
Transit Surveys -- Target Selection

distance / brightness versus cadence

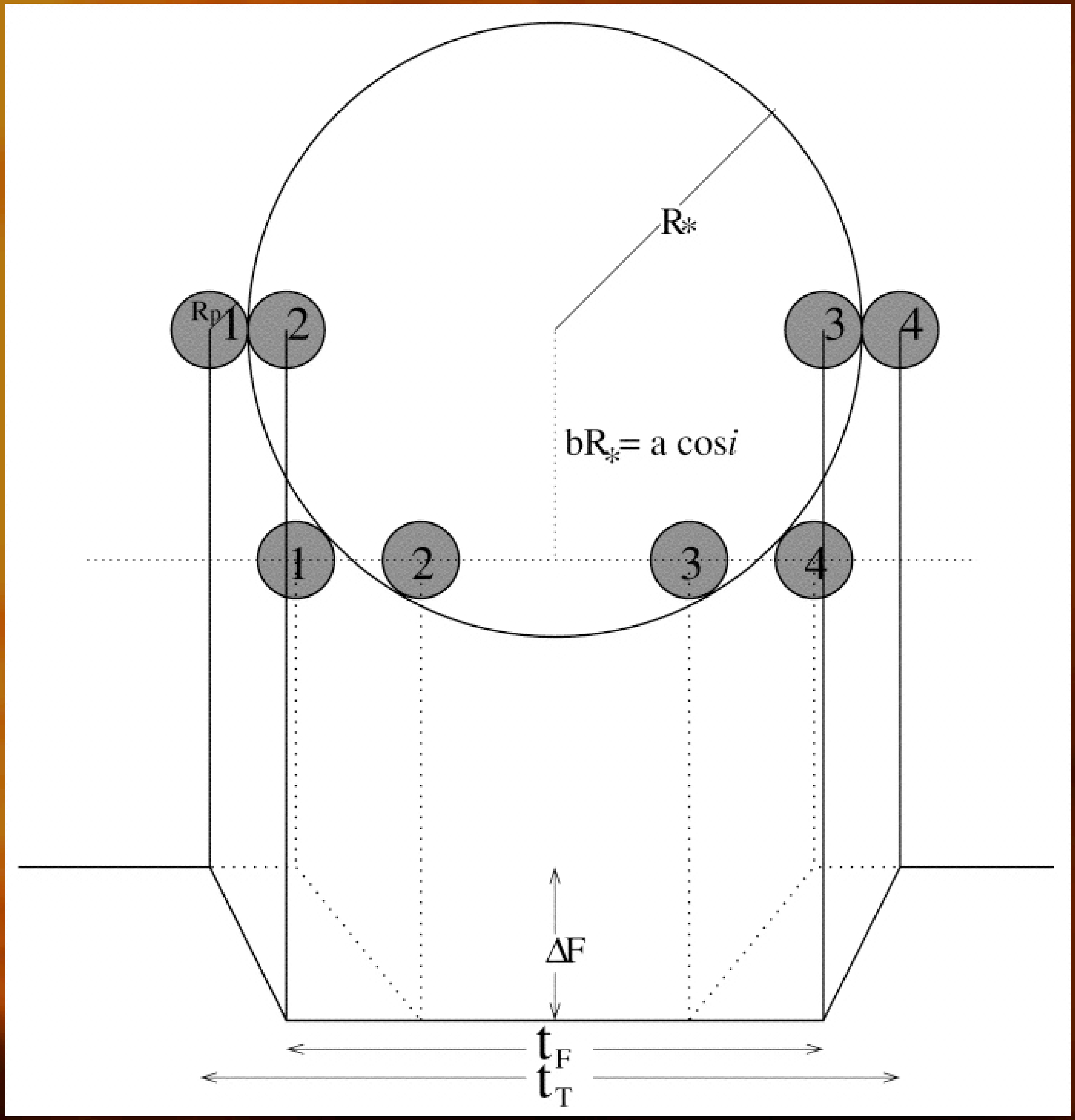


Street et al., 2003

Transit Surveys -- Target Selection
distance / brightness versus cadence

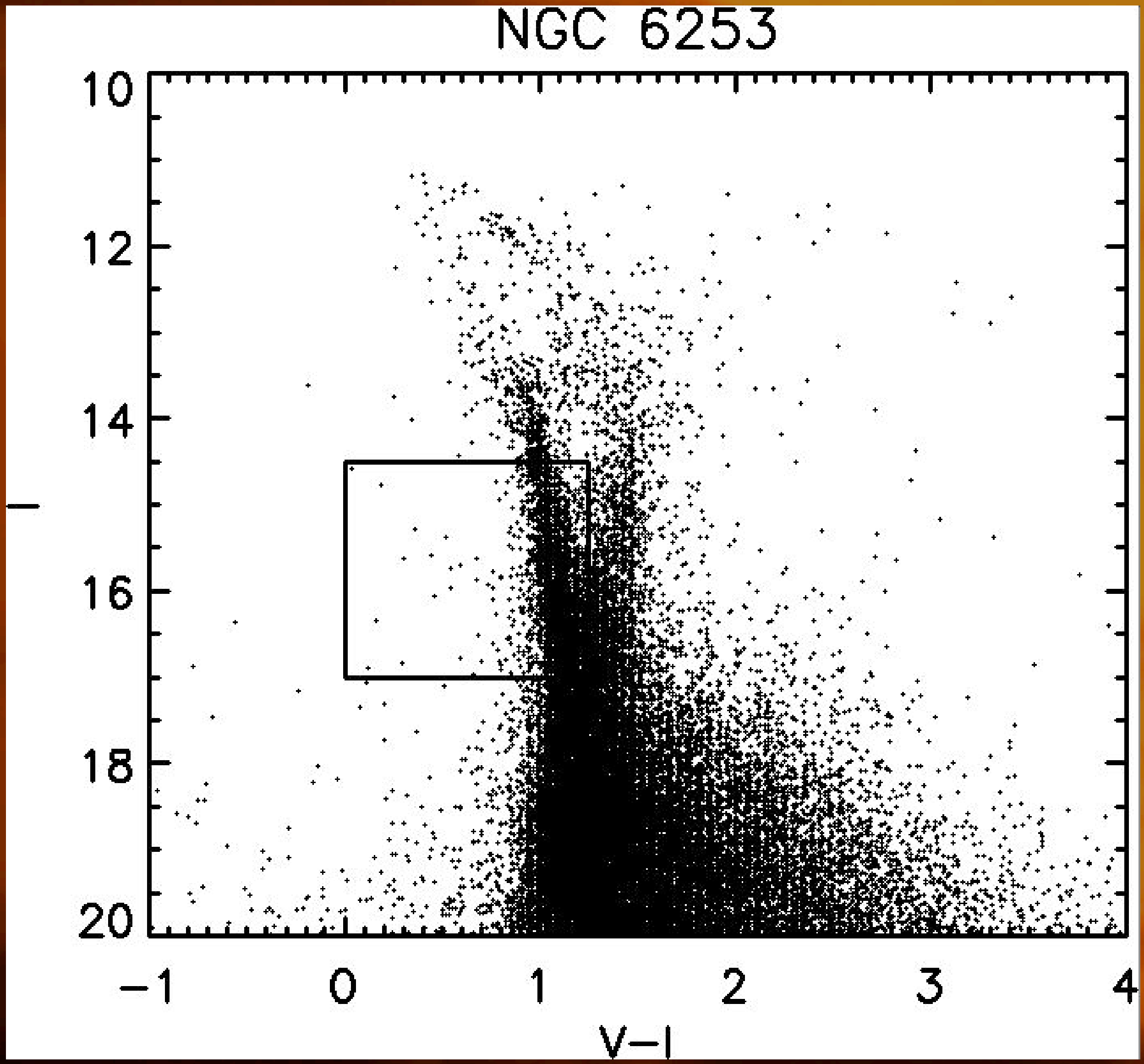


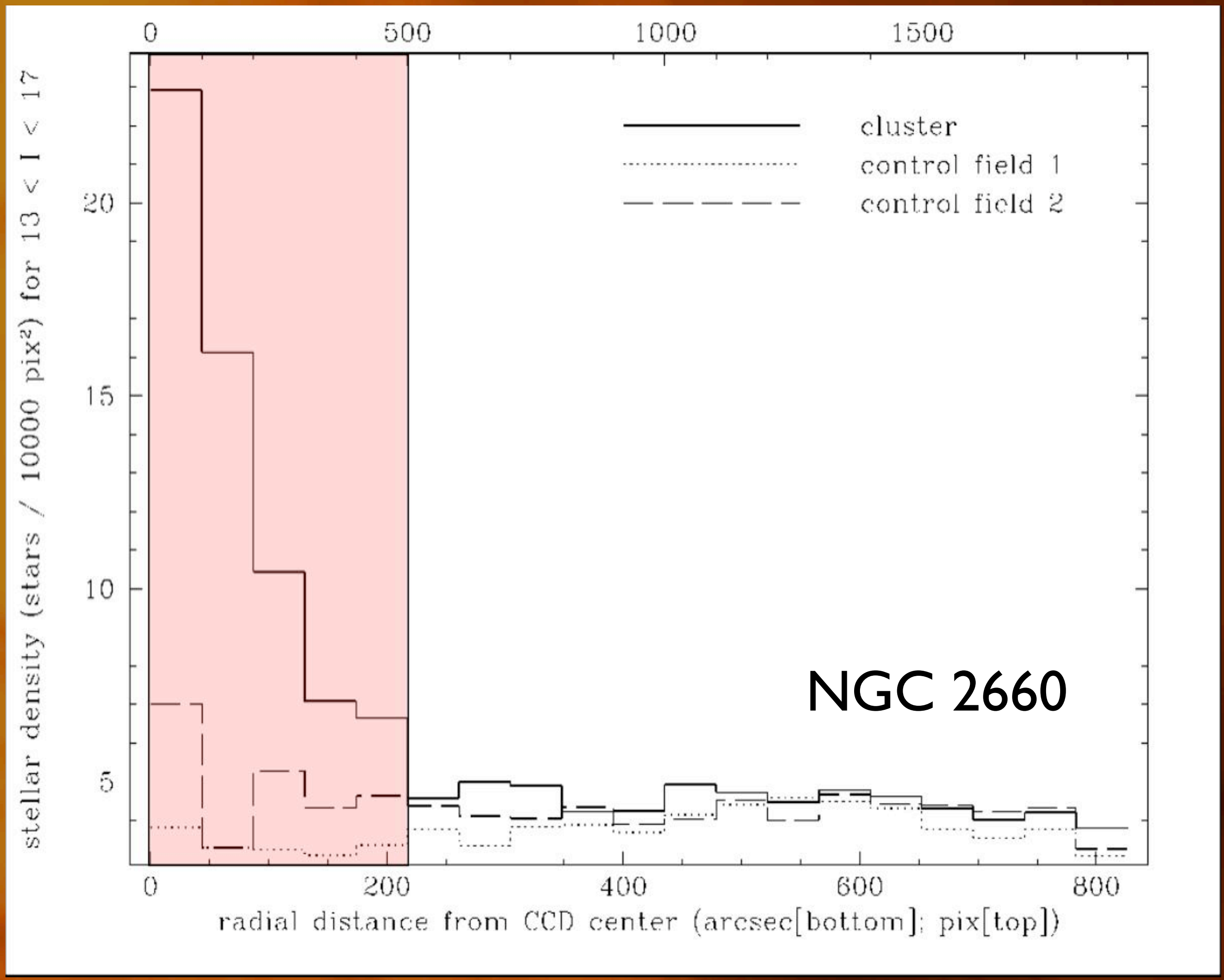
- Mandel & Agol 2002



- Seager & Mallén-Ornelas 2003

Transit Surveys -- Target Selection
number of "good" stars / contamination





- von Braun et al. 2005

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Transit Surveys -- Observing Strategy

Principal Challenges:

- false positives.
- noise sources.
- sampling.

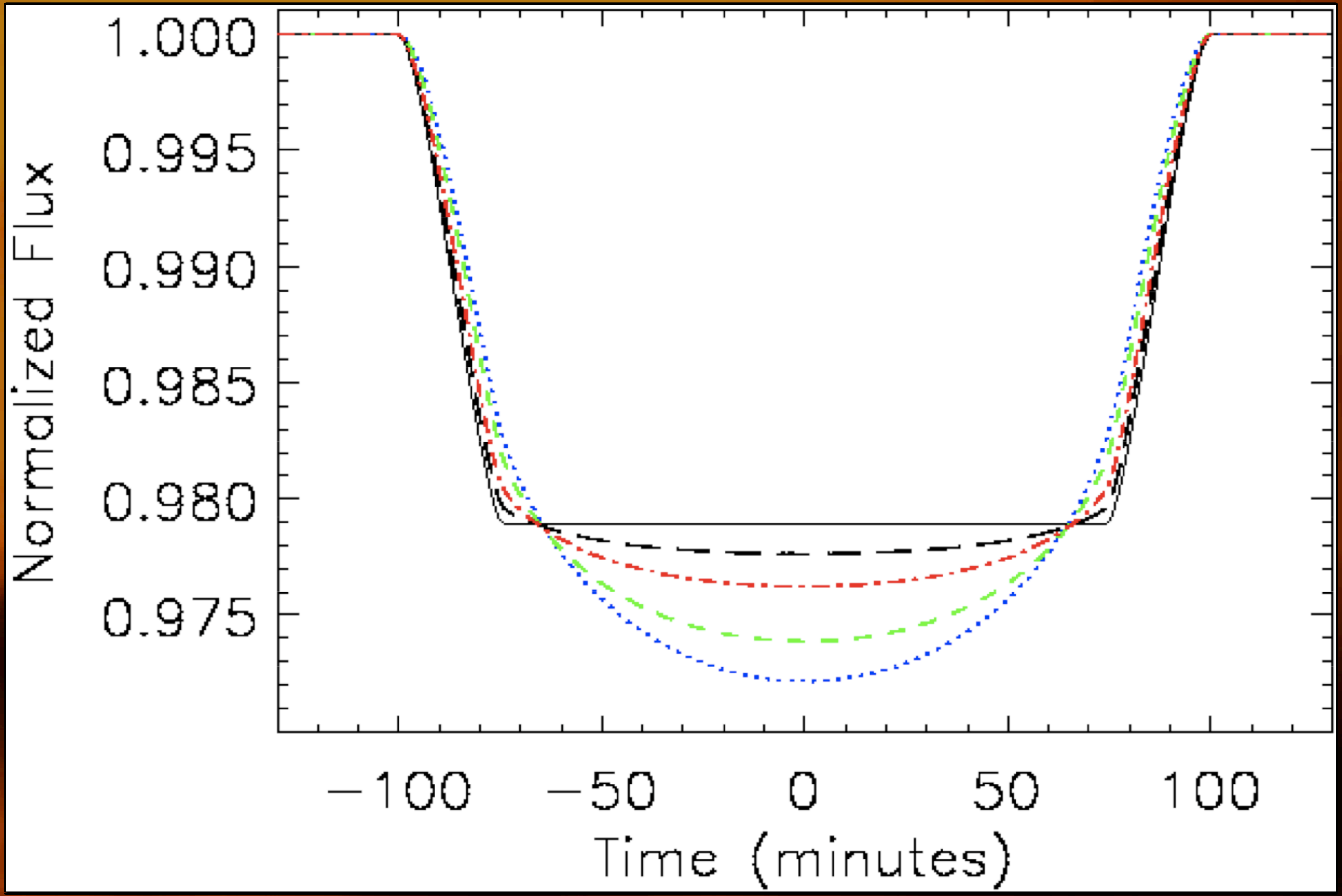
Strategy:

- optimize cadence (eliminate false positives).
- red (RI) band (eliminate false positives).
- minimize noise.
  - pix-to-pix variation effects.
  - avoid saturation (of even a few pixels).
  - photon noise: spectrally or spatially broaden PSF.
  - avoid undersampling (for PSF fitting).
- optimize window function.

Transit Surveys -- Observing Strategy

- red (RI) band (eliminate false positives)
  - sensitive to redder (smaller) stars
  - dust extinction smaller
  - limb darkening considerations: eliminate false positives

Limb darkening at 3, 0.8, 0.55, 0.45 microns



Mallén-Ornelas et al. 2003

Transit Surveys -- Observing Strategy

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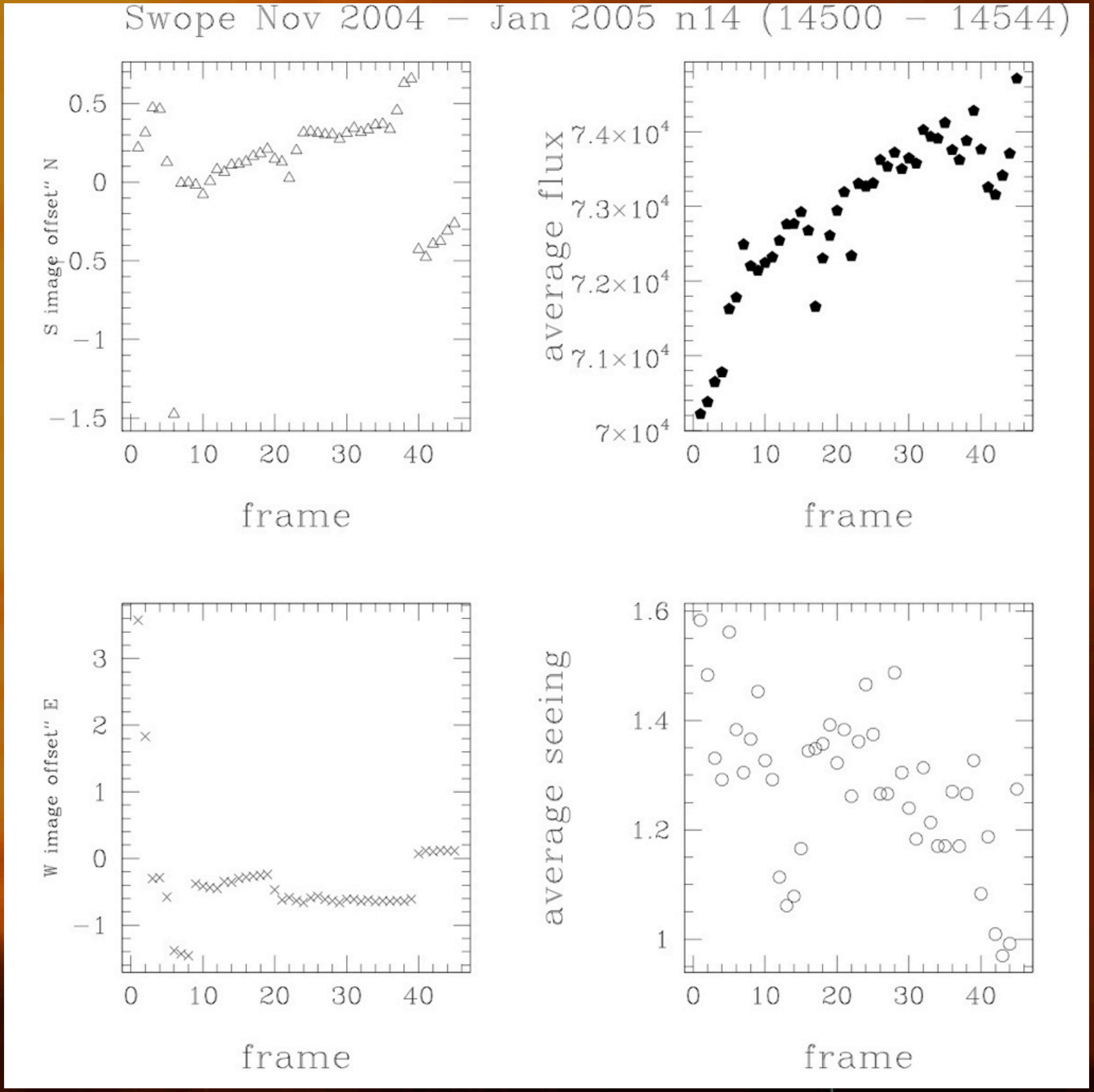

EXPLORE/OC nightly monitoring

Transit Surveys -- Observing Strategy

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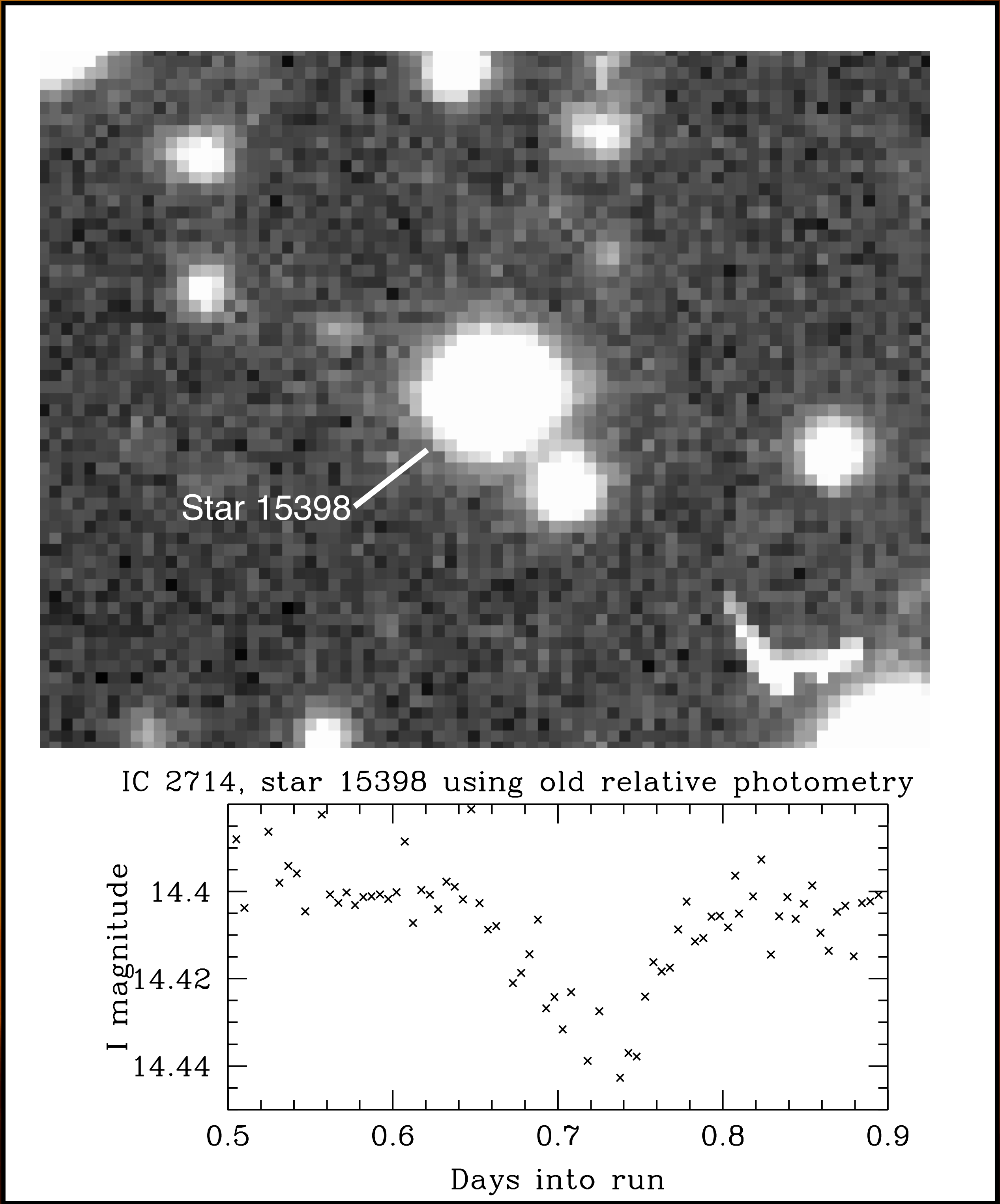

B. L. Lee's Dissertation (2007)

Transit Surveys -- Observing Strategy

- minimize noise
  - pix-to-pix variation effects
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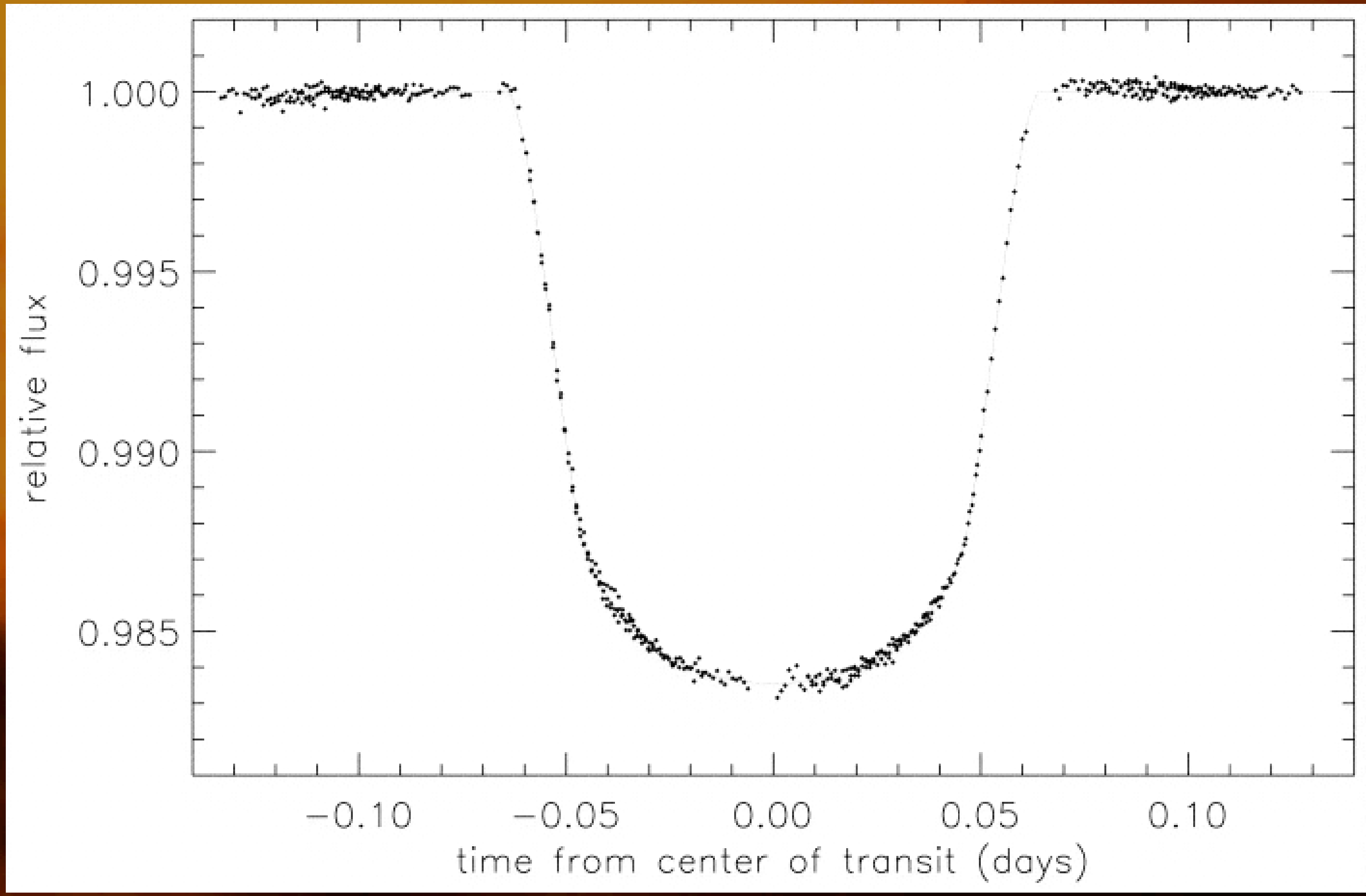
HST/STIS light curve of HD209458b



Brown et al. 2001

Transit Surveys -- Observing Strategy

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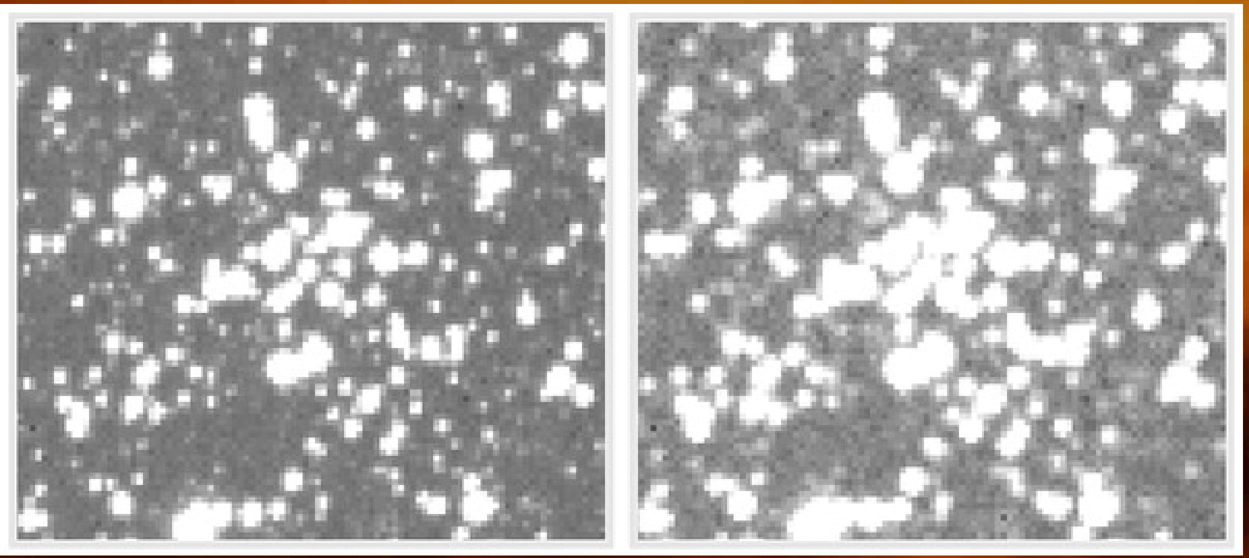
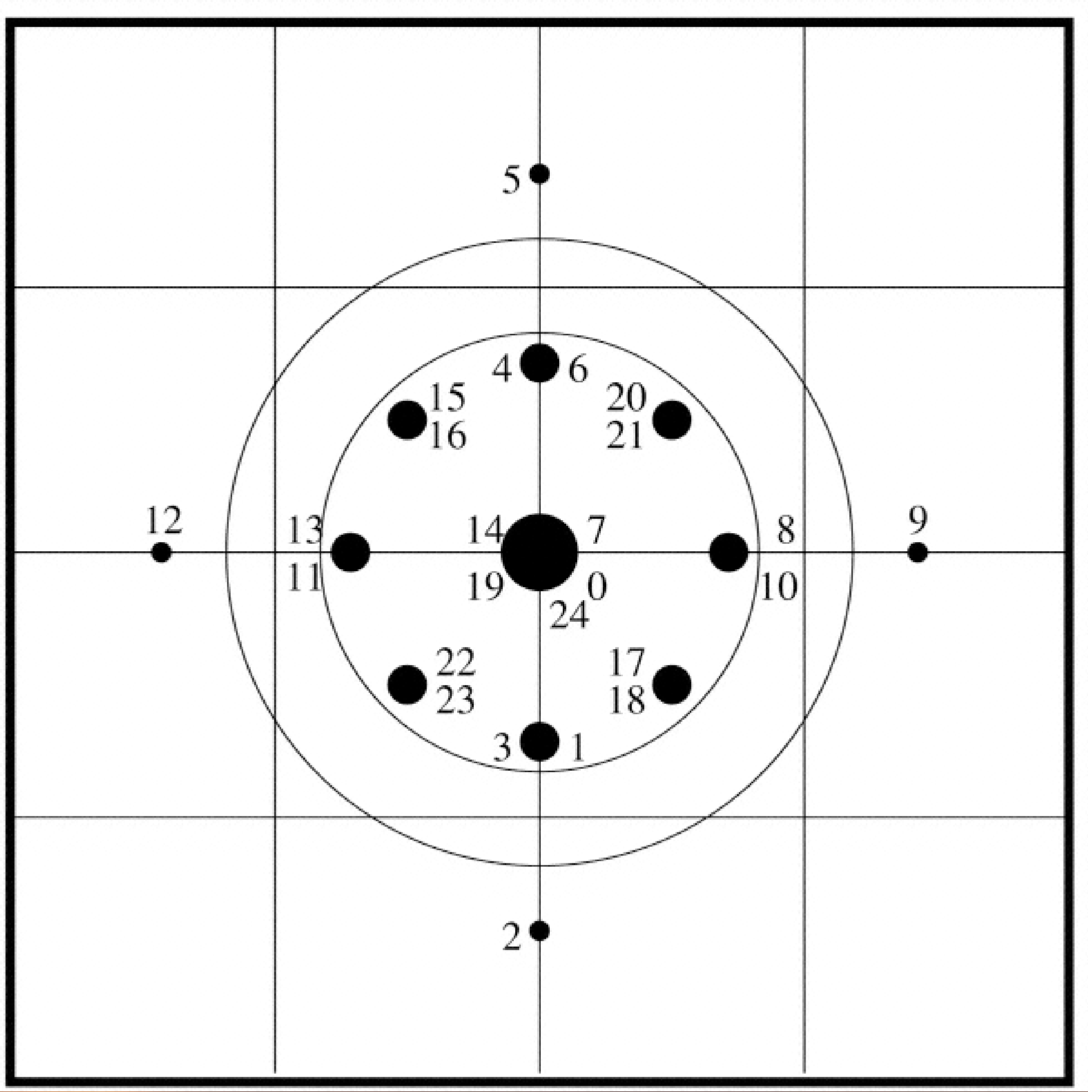


HAT Survey PSF-Broadening Method



Bakos et al. 2004

Transit Surveys -- Observing Strategy

optimize window function

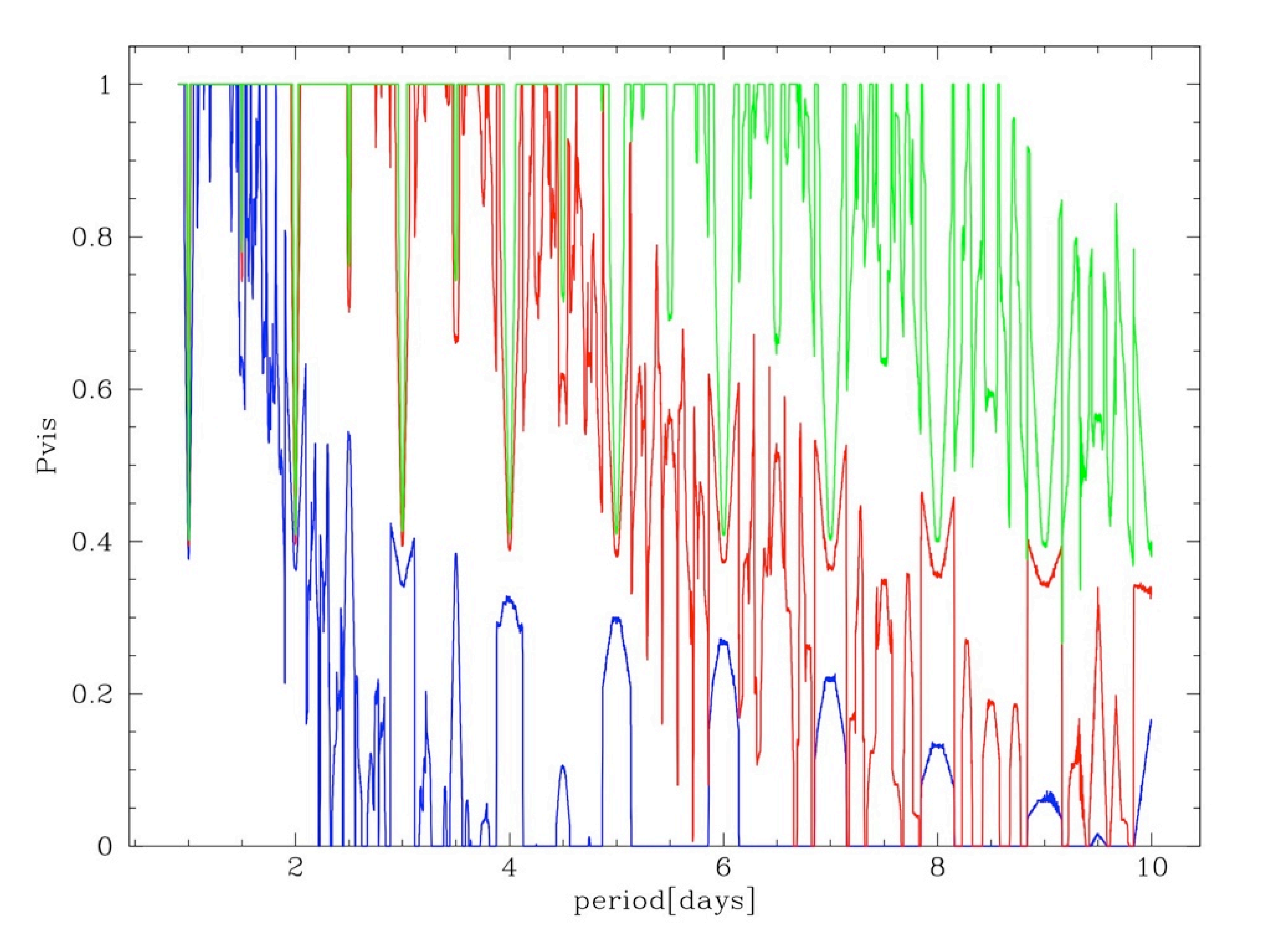
- window function calculated very differently in literature, hard to compare.
- SNR (transit) = sqrt(N) * depth/rms
  - N: number of data points observed during transit
  - depth: depth of transit = f(R_{star}, R_{planet}, *i*)
  - rms = f(survey, brightness)
  - N = f(run length, cadence, transit duration, period)
- assume:
  - SNR >= 10.0
  - rms = 0.01 mag
  - R_{star} = 1.0 R_{sun}, R_{planet} = 0.1 R_{sun} (depth = 0.01; *i* = 90 deg)
  - N = 100

Transit Surveys -- Observing Strategy

window function -- length of observing run

- P = 1 - 10 days
- duty cycle 9% - 2%
- night length = 8h
- cadence = 5 min

20 consecutive nights
40 consecutive nights
60 consecutive nights



Transit Surveys -- Observing Strategy

window function -- cadence

- P = 1 - 10 days
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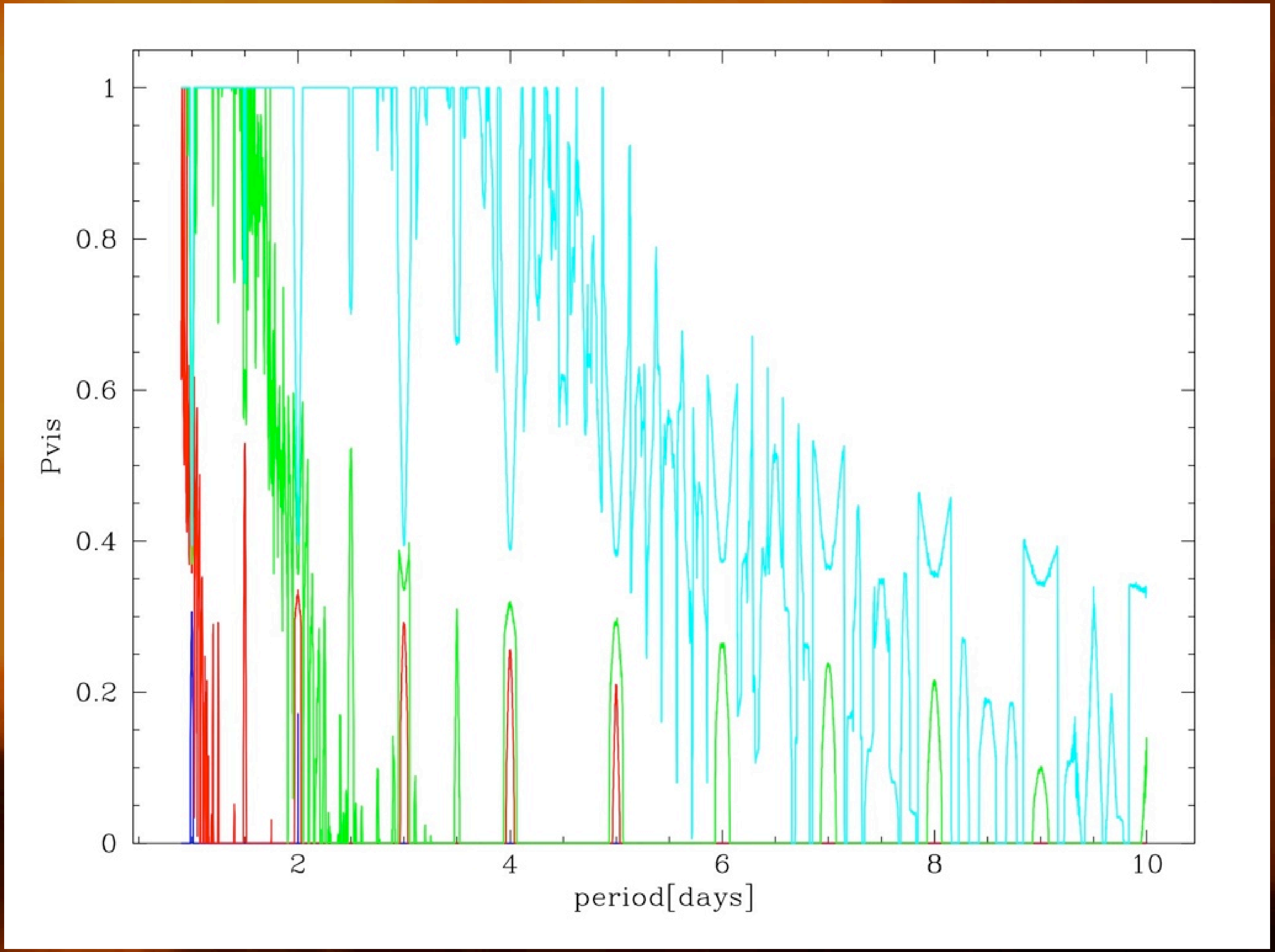
30 minutes
15 minutes
10 minutes
5 minutes



Transit Surveys -- Observing Strategy

window function -- night length

- P = 1 - 10 days
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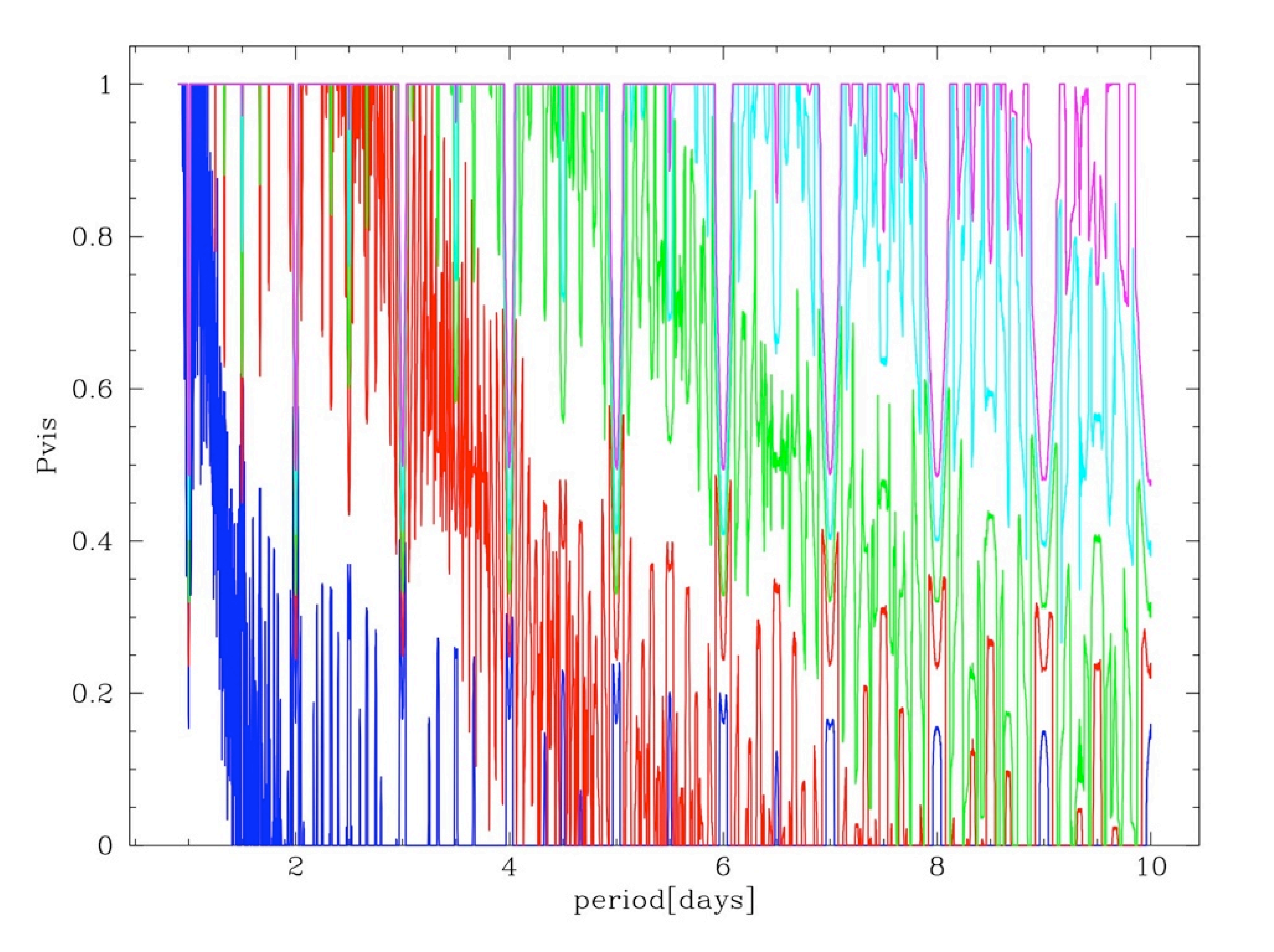
2 hours
4 hours
6 hours
8 hours
10 hours

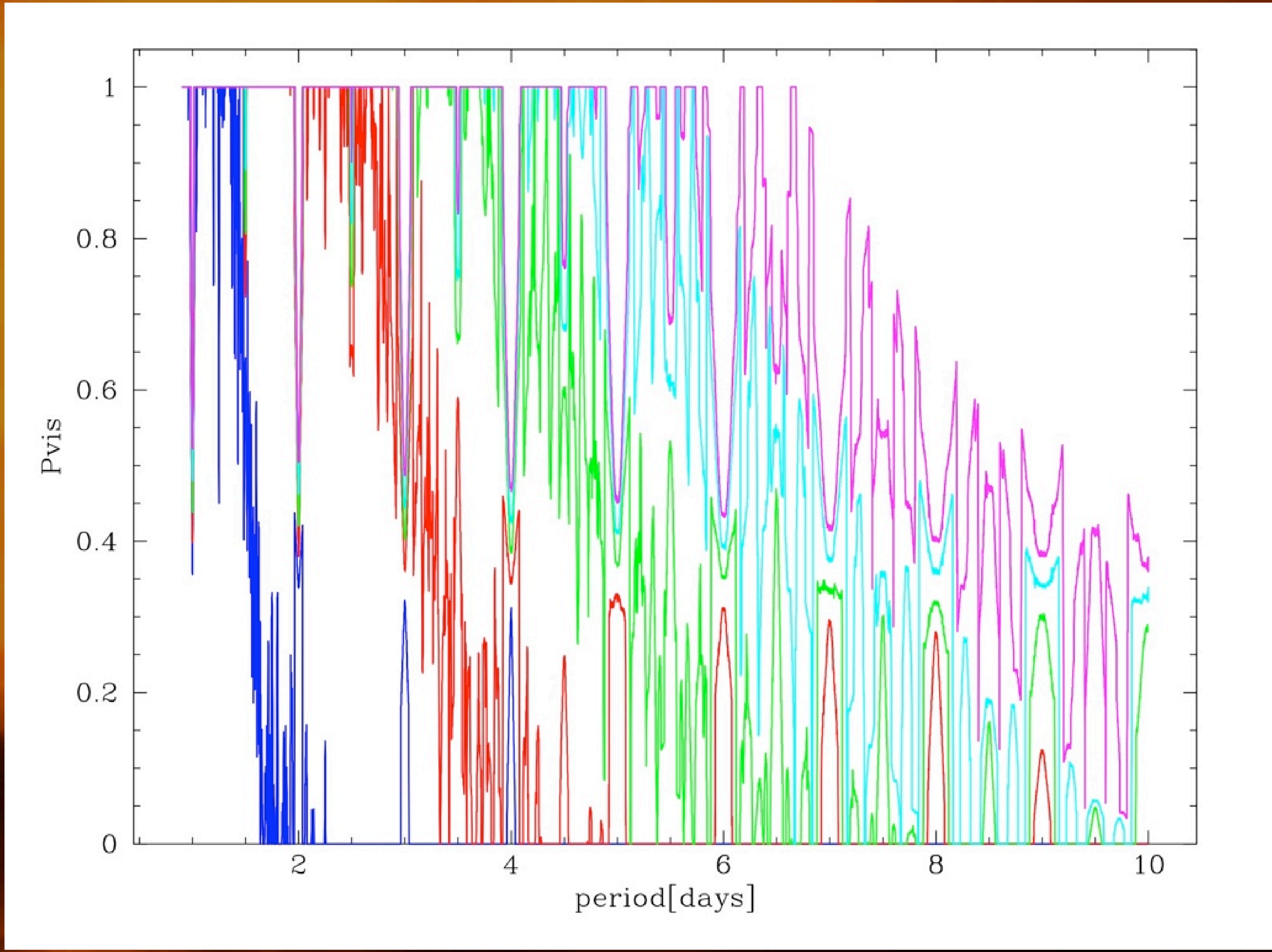


Transit Surveys -- Observing Strategy

window function -- transit duration

- P = 1 - 10 days
- cadence: 5 min
- 40 consec. nights
- 8 hours / night

1 hour
2 hours
3 hours
4 hours
5 hours

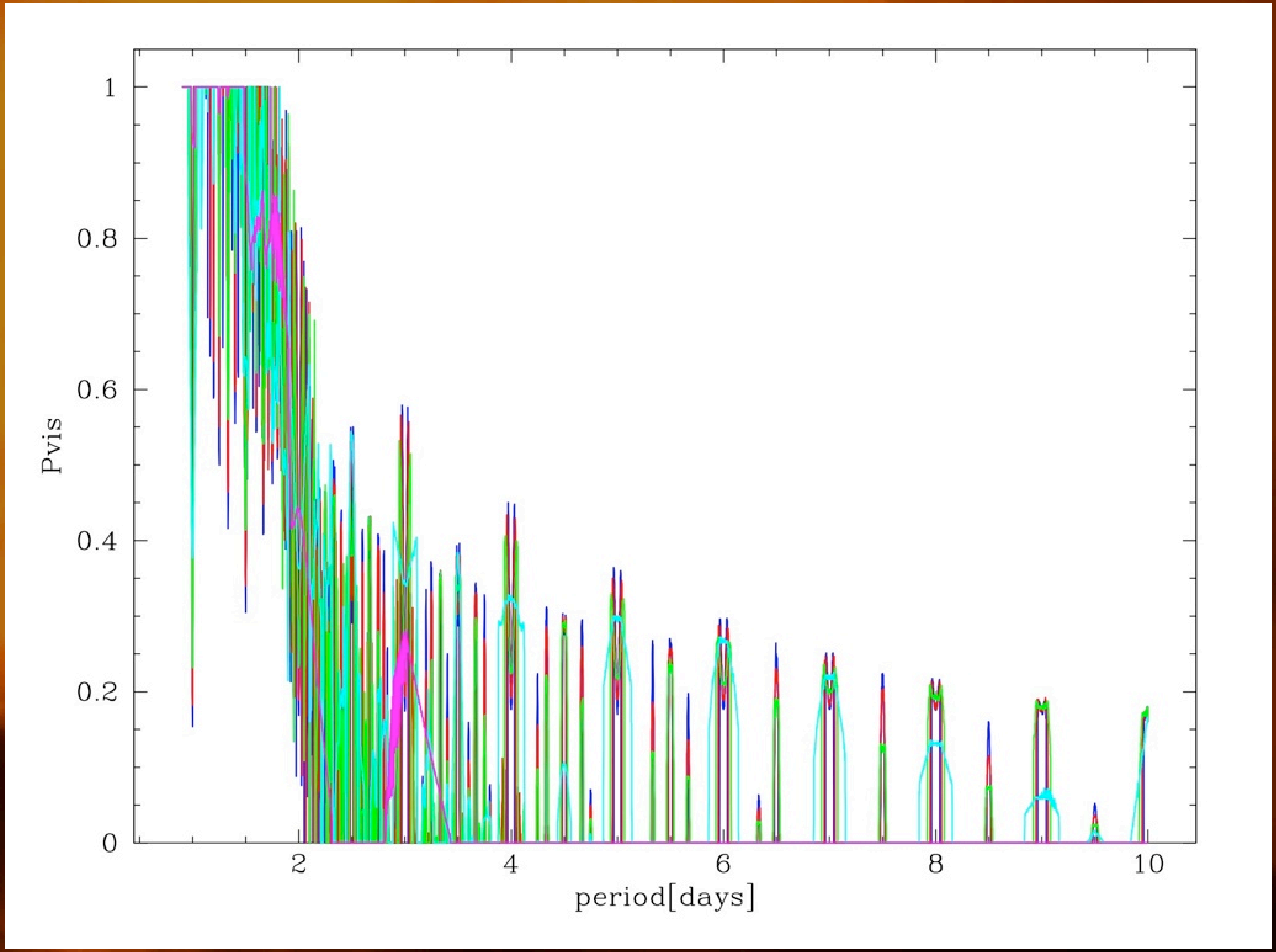


Transit Surveys -- Observing Strategy

window function -- total number of hours (160)

- P = 1 - 10 days
- duty cycle 9% - 2%
- cadence: 5 min

80 nights; 2h / night
60 nights; 2.7h / night
40 nights; 4h / night
20 nights; 8h / night
7 “nights”; 23h / night



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