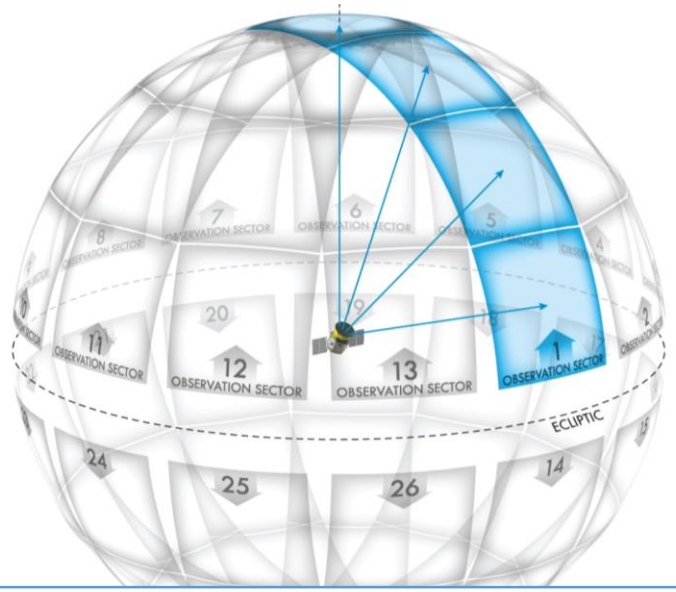
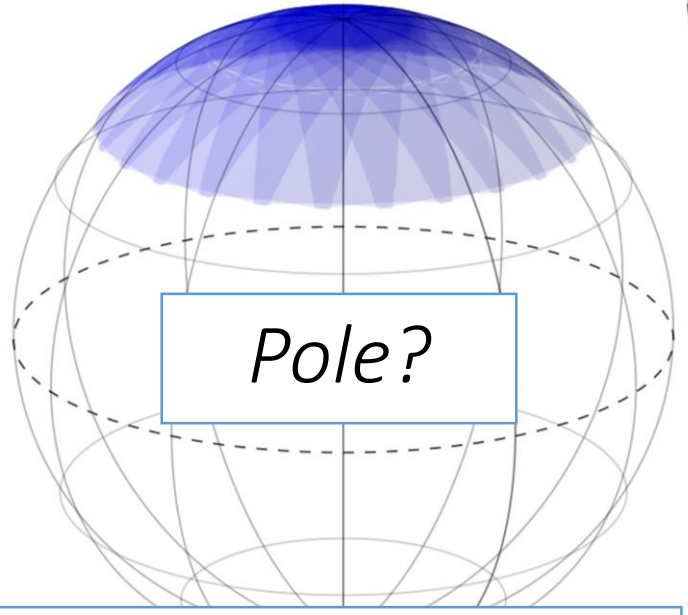
We've begun quantifying extended mission scenarios to inform our long-term observing strategy (>2019).

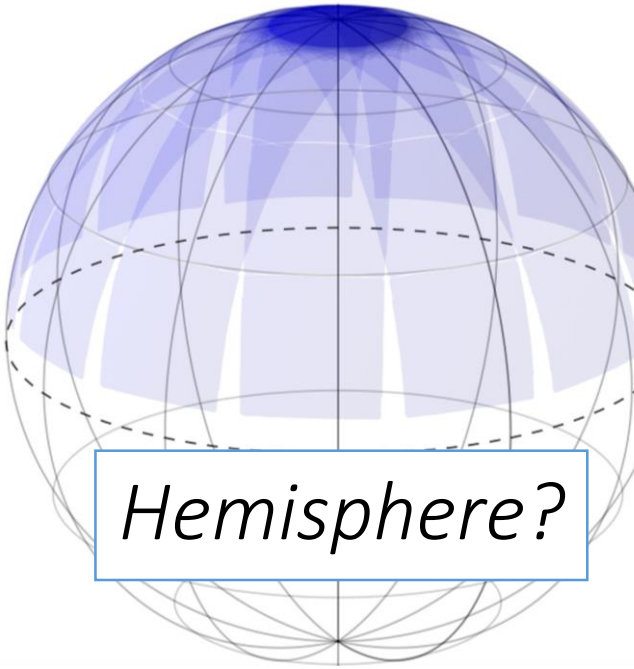


Primary mission

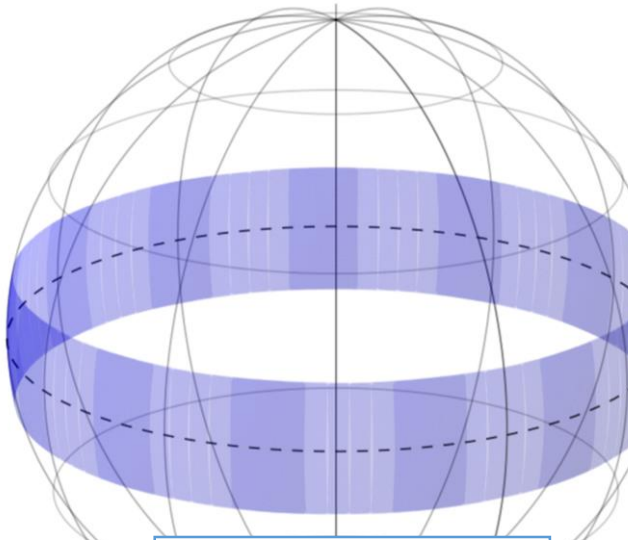


Pole?

Extended mission



Hemisphere?



Ecliptic?

Luke Bouma & Josh Winn

TESS Science Team Meeting, May 19, 2016

Our approach is to simulate TESS's planet detections.

See Sullivan, Winn, Berta-Thompson+ 2015

Luke Bouma | lgbouma@mit.edu

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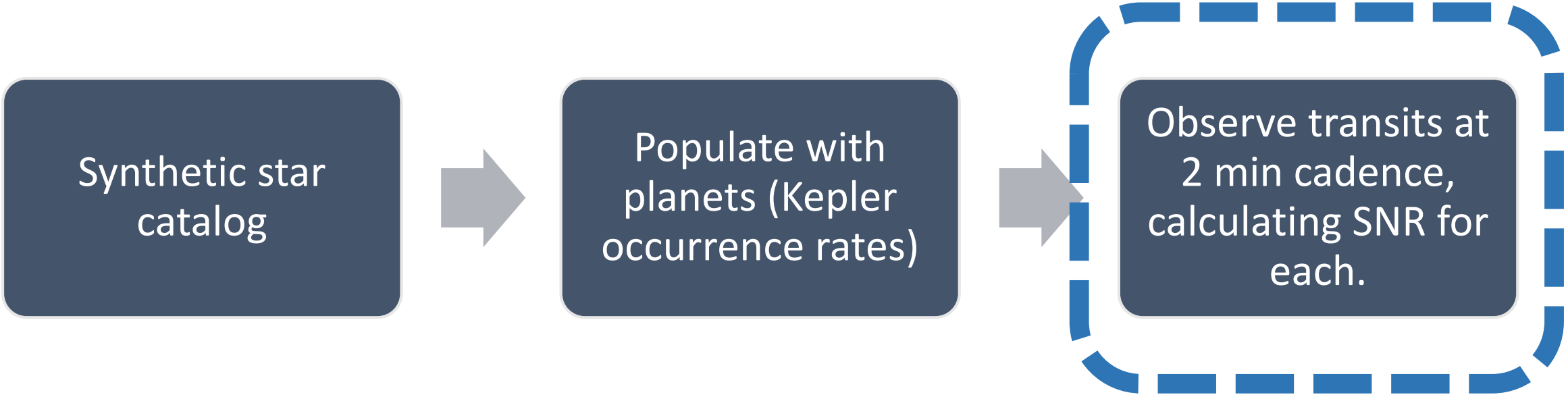

How do we select target stars?

See Sullivan, Winn, Berta-Thompson+ 2015

Luke Bouma | lgbouma@mit.edu

Our target selection favors small, bright stars that are observed more often.

$$\textsc{Merit} = \frac{(1/R_\star^2)}{(\sigma_{1\mathrm{hr}}(I_c)/\sqrt{N_{\mathrm{obs}}})}$$

Luke Bouma | lgbouma@mit.edu

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Exposure time

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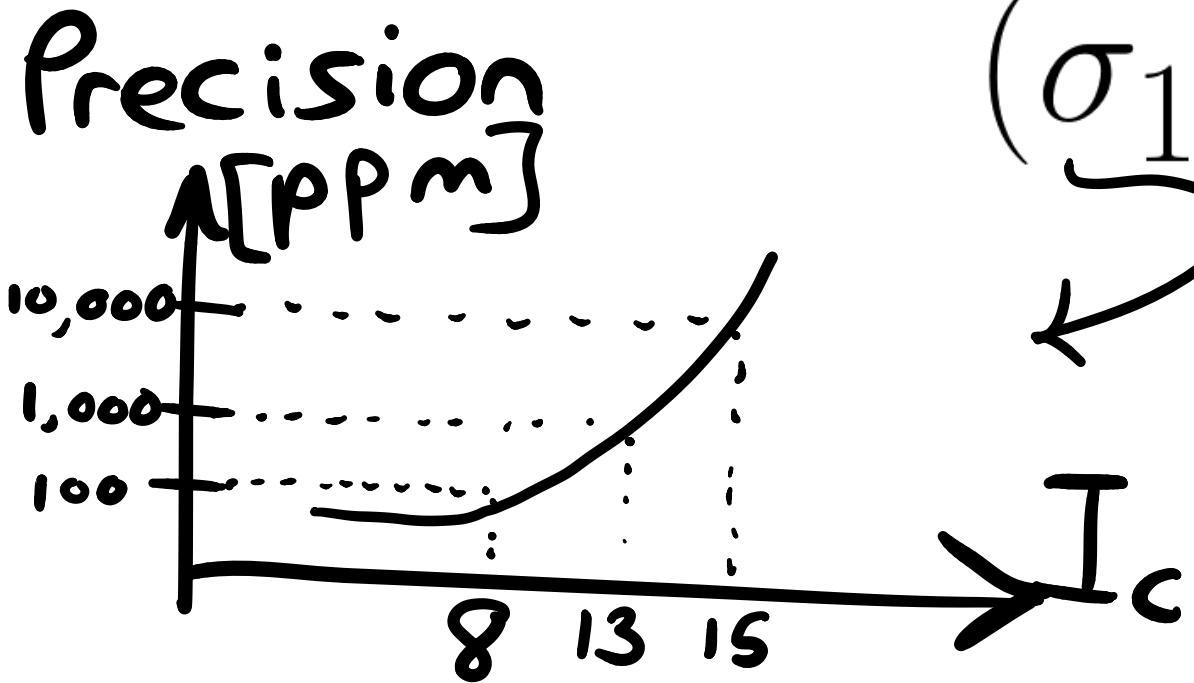
δ

Exposure time



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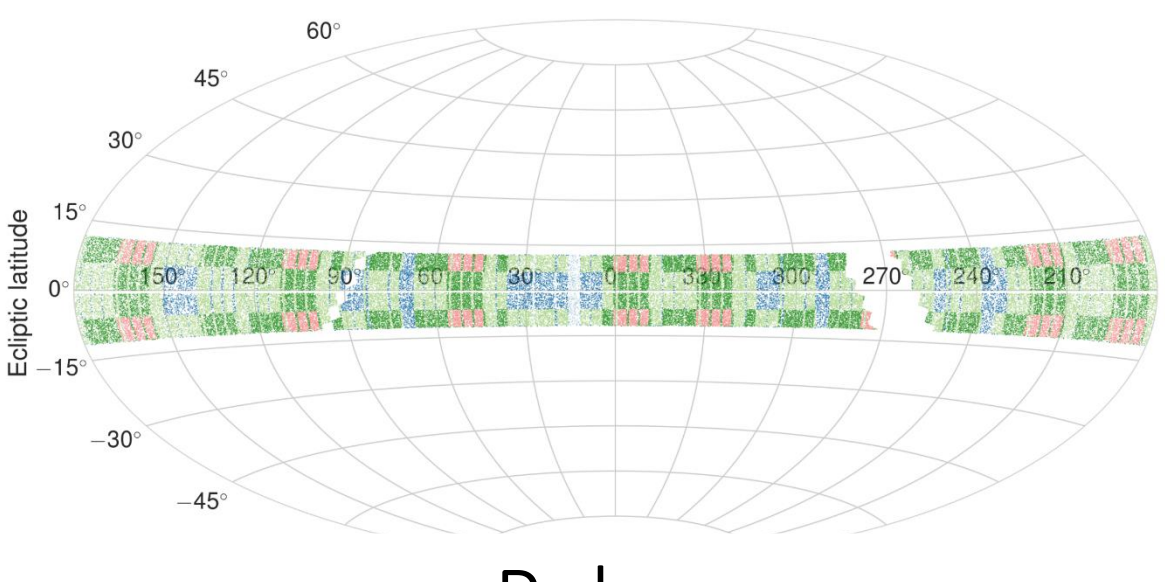
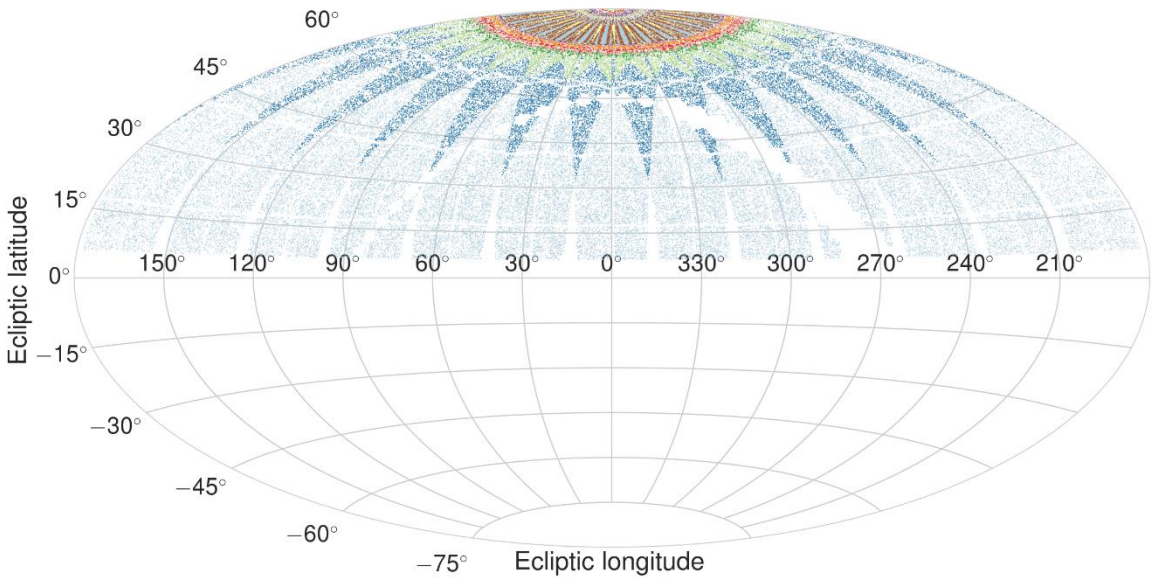
Compute MERIT for every star in our catalog; observe the “best” 100,000 stars per extended mission year.

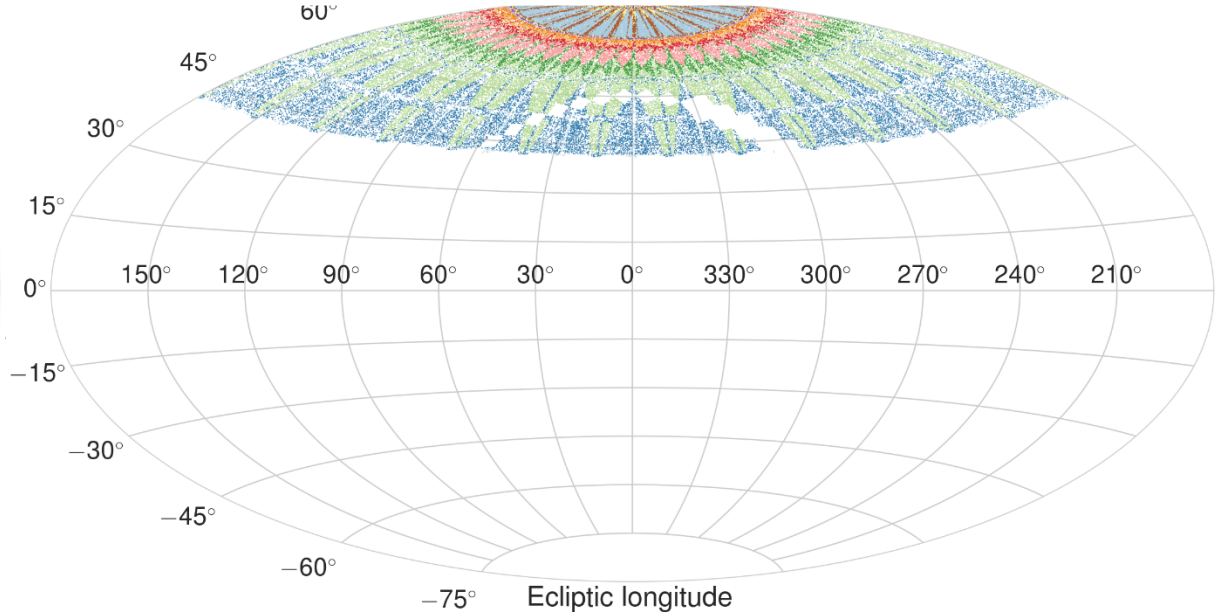
Ecliptic



Hemisphere



Pole



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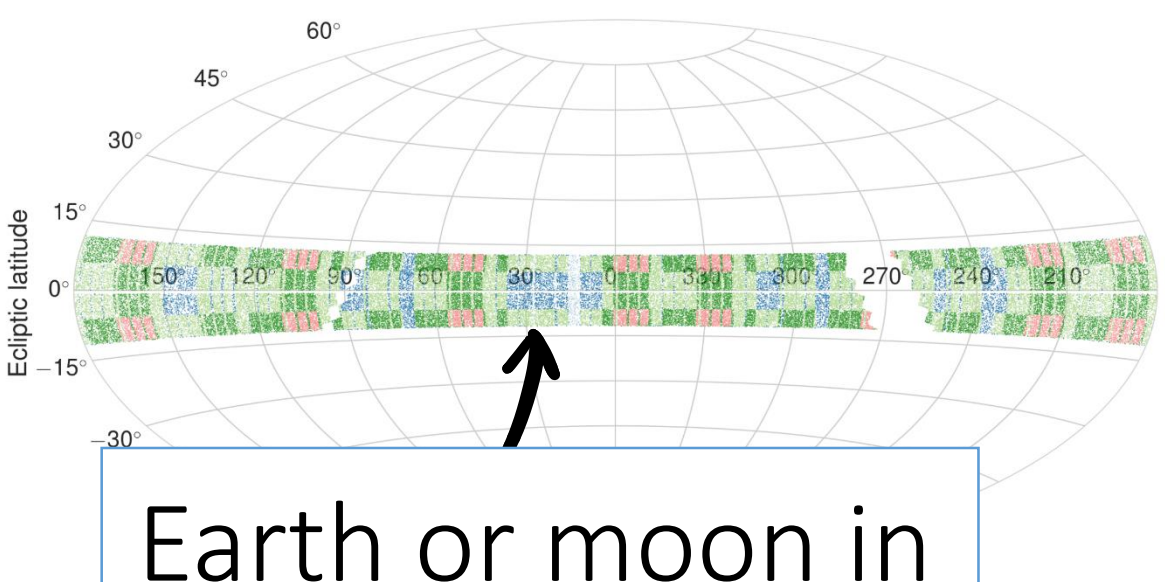
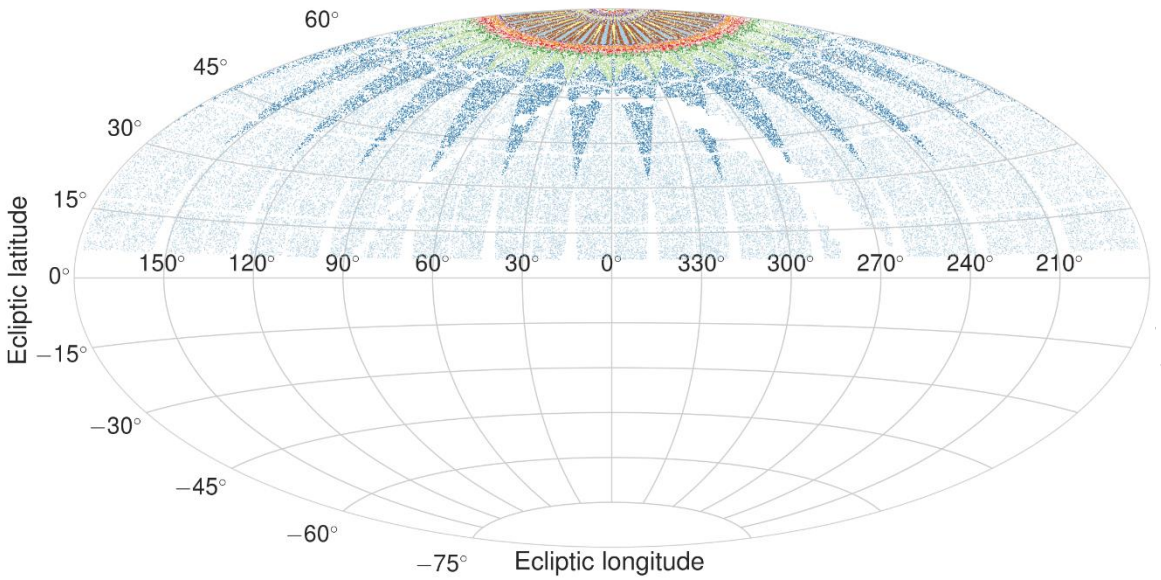
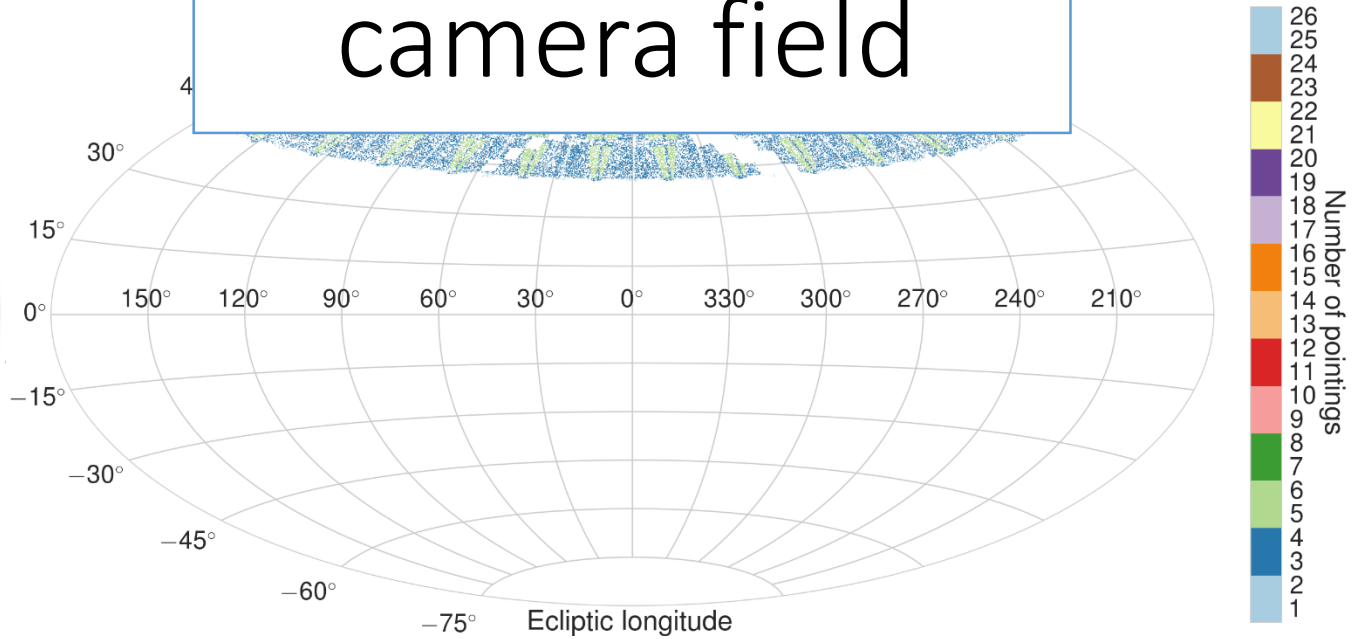


Earth or moon in camera field

Hemisphere





Observe transits, calculate SNR for each.

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Year 3 Scenario
Planets detected over all 3 years
New planets
New P>20d planets
New 0.2<$S/S_{\oplus}$<2 planets
Systems with extra planets detected
New planets amenable to atmospheric study (R<4$R_{\oplus}$)

Numbers rounded to nearest “10”.

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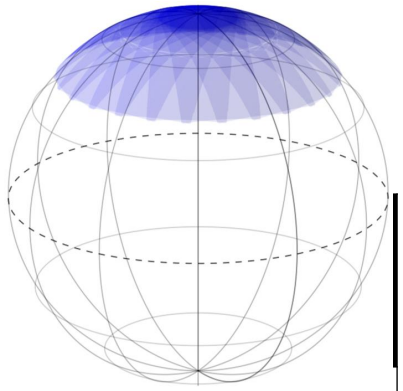

Year 3 Scenario	
Planets detected over all 3 years	2280
New planets	730
New P>20d planets	200
New 0.2<$S/S_{\oplus}$<2 planets	130
Systems with extra planets detected	60
New planets amenable to atmospheric study (R<4$R_{\oplus}$)	80

Numbers rounded to nearest “10”.

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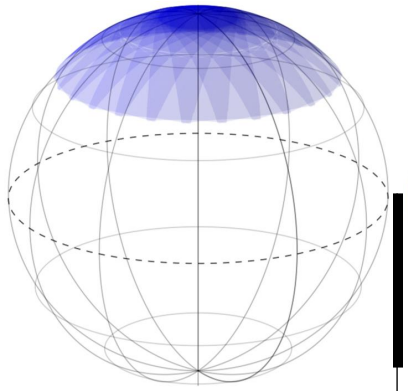
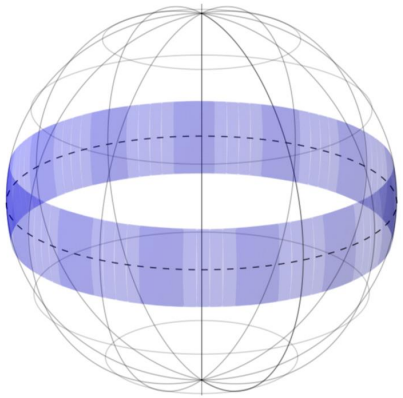
Year 3 Scenario		
Planets detected over all 3 years	2280	2300
New planets	730	720
New *P*>20d planets	200	160
New 0.2<$S/S_\oplus$<2 planets	130	110
Systems with extra planets detected	60	10
New planets amenable to atmospheric study (R<$4R_\oplus$)	80	170

Numbers rounded to nearest “10”.

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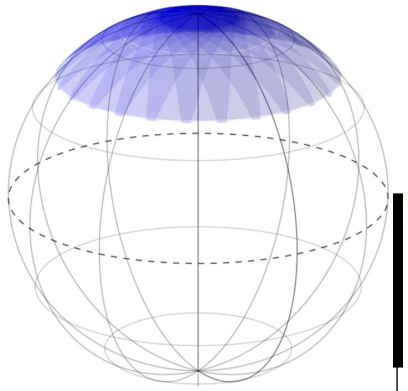
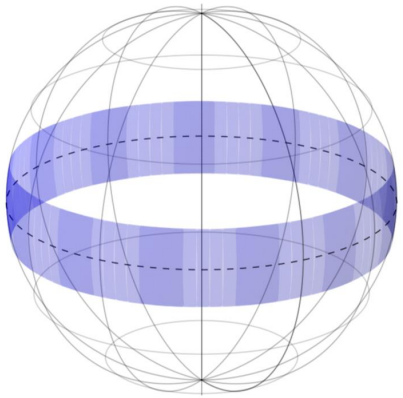
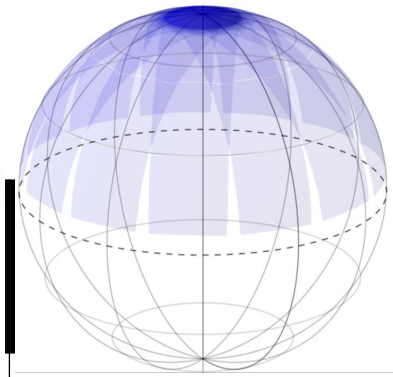
Year 3 Scenario			
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Numbers rounded to nearest “10”.

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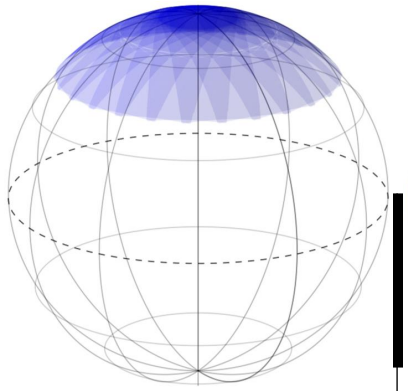
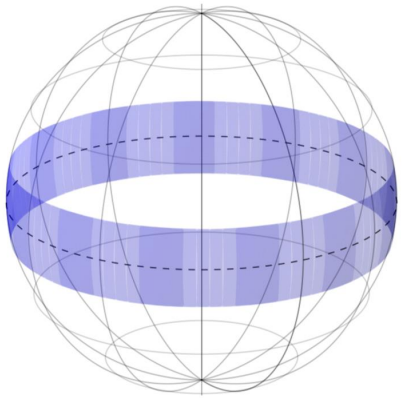
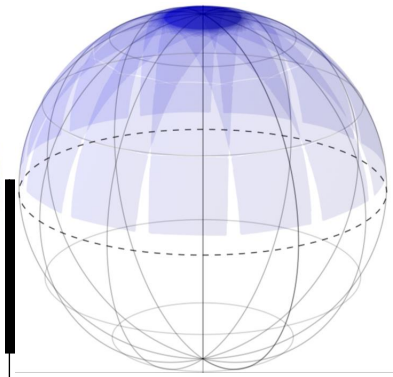
Year 3 Scenario			
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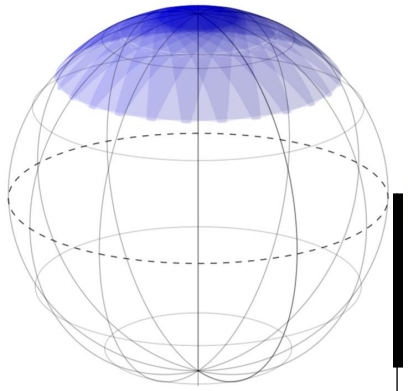
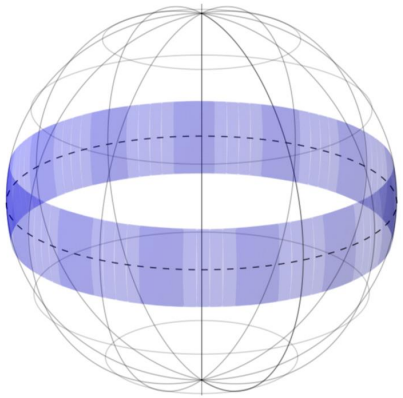
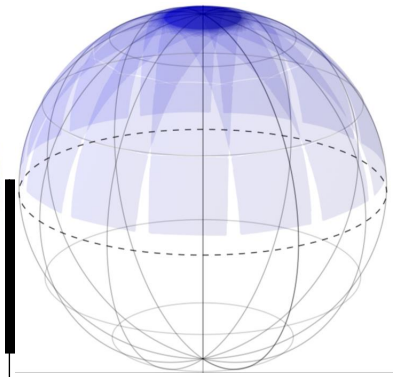
Year 3 Scenario			
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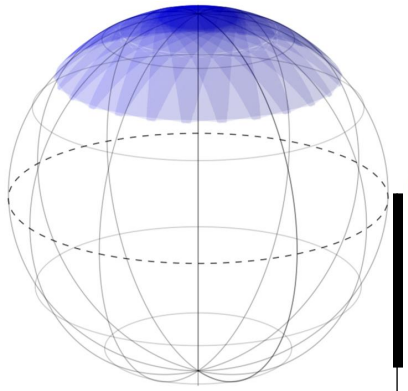
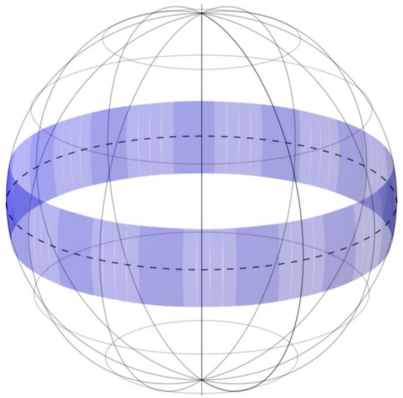
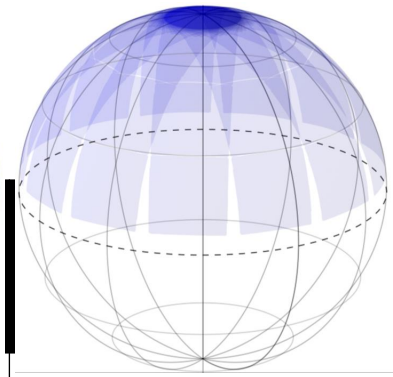
Year 3 Scenario			
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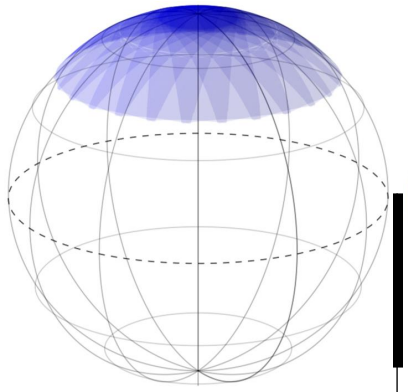
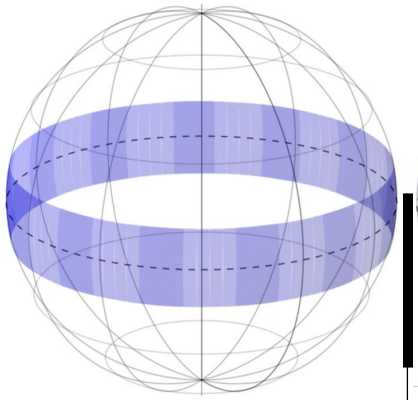
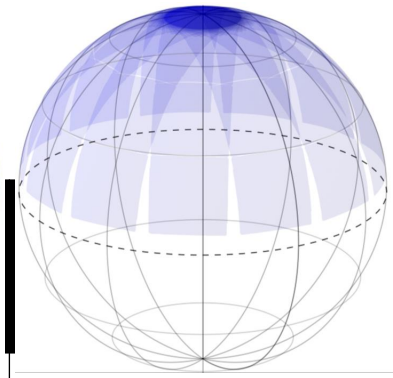
Year 3 Scenario			
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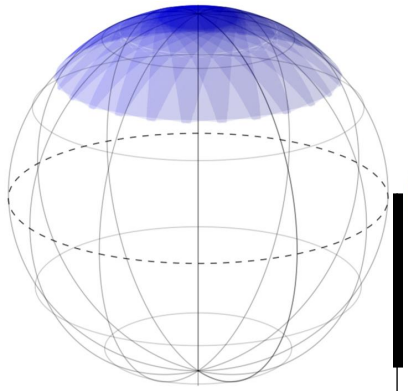
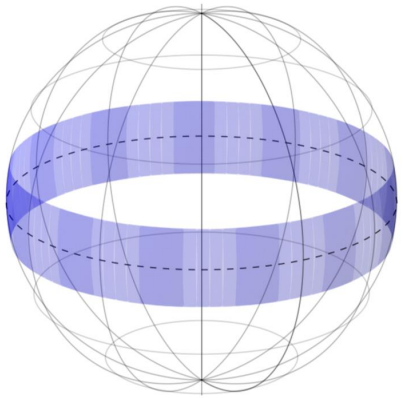
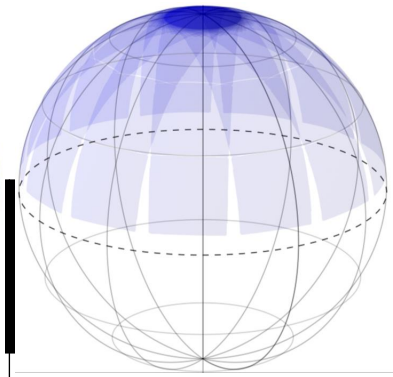
Year 3 Scenario			
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Systems with extra planets detected	60	10	60
New planets amenable to atmospheric study ($R<4R_{\oplus}$)*	80	170	60

Reference: primary mission finds 355±15

Numbers rounded to nearest “10”.

*** Atmospheric SNR at least (that of GJ1214b)/4.**

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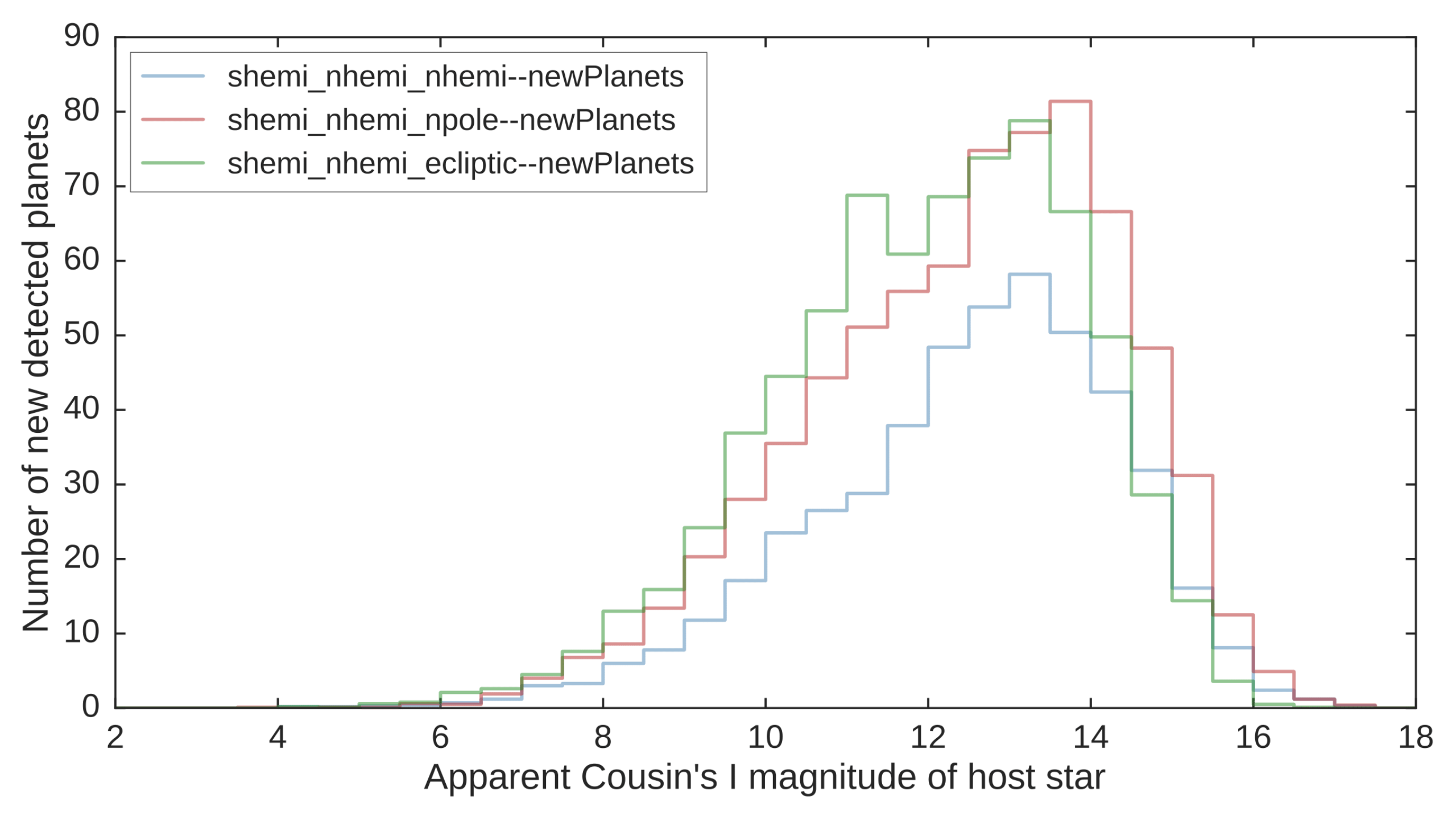
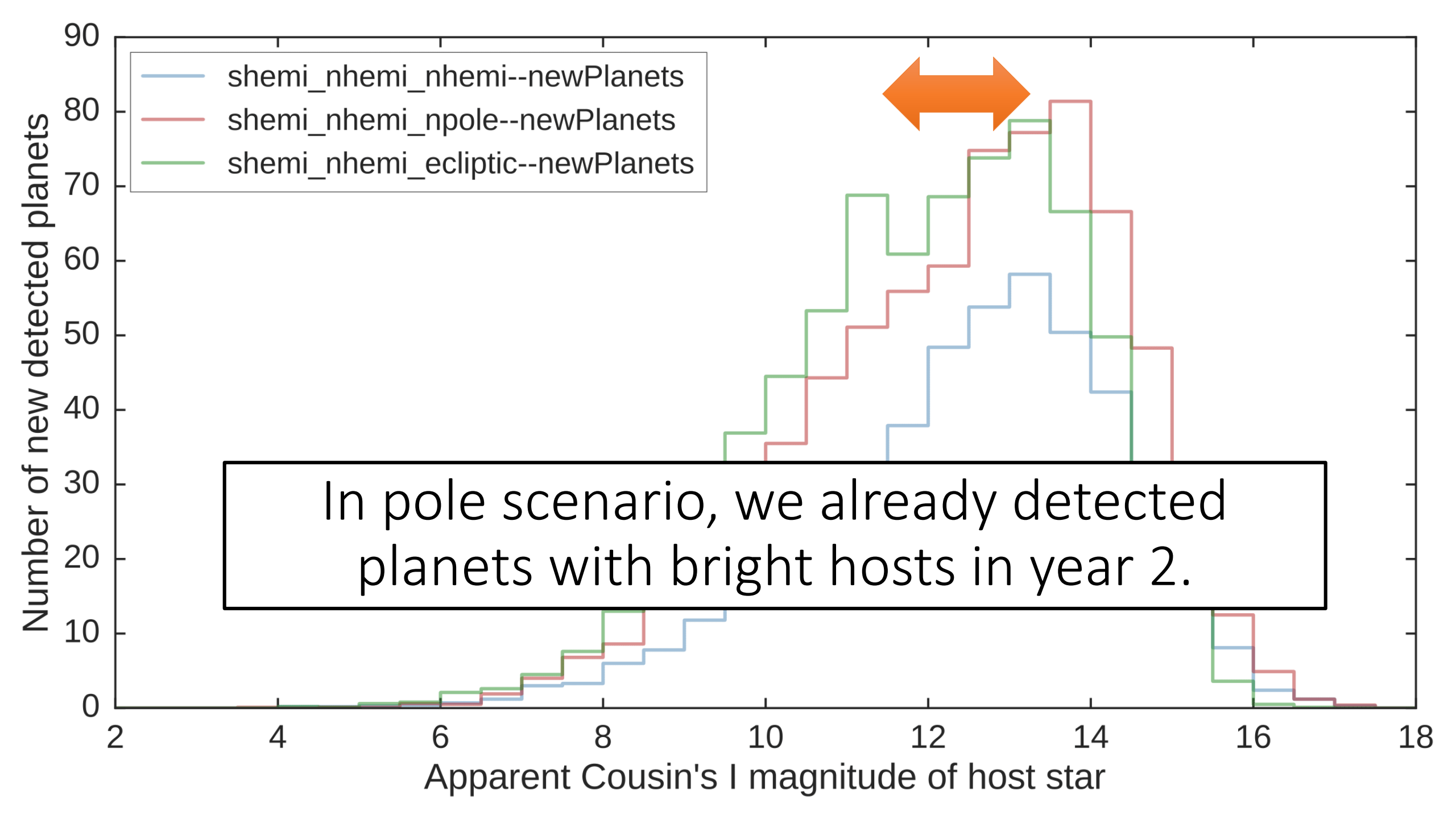

shemi_nhemi_nhemi--newPlanets
shemi_nhemi_npole--newPlanets
shemi_nhemi_ecliptic--newPlanets
Number of new detected planets
Apparent Cousin's I magnitude of host star
0
10
20
30
40
50
60
70
80
90
2
4
6
8
10
12
14
16
18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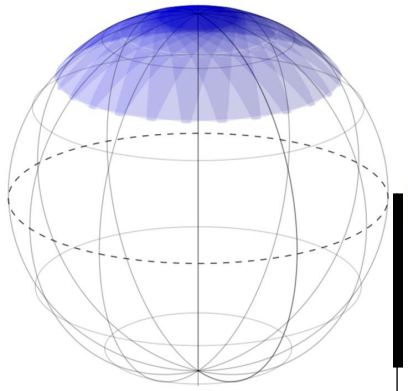
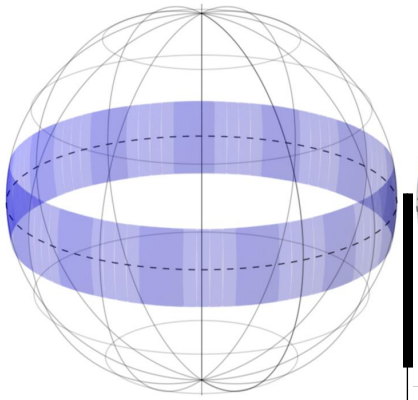
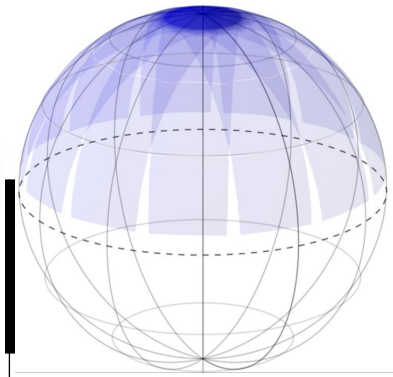
80
90
2
4
6
8
10
12
14
16
18
In pole scenario, we already detected planets with bright hosts in year 2.

Year 3 Scenario			
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New $0.2<S/S_{\oplus}<2$ planets	130	110	120
Systems with extra planets detected	60	10	60
New planets amenable to atmospheric study ($R<4R_{\oplus}$)	80	170	60

The ecliptic pointing yields twice as many new planets with easily-characterizable atmospheres.

TODO:

1. Full frame images (30 minute cadence)
2. Uncertainty in ephemeris times

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- Simulating 2-min postage stamps with a simple selection procedure we find:
  - Ecliptic pole maximizes the number of newly detected planets at *P*>20days (also most HZ planets; most multis).
  - Ecliptic plane detects a comparable number of new planets. Their host stars are the brightest, making their atmospheres easiest to characterize.
- Two-year simulations look like linear combinations of one-year runs

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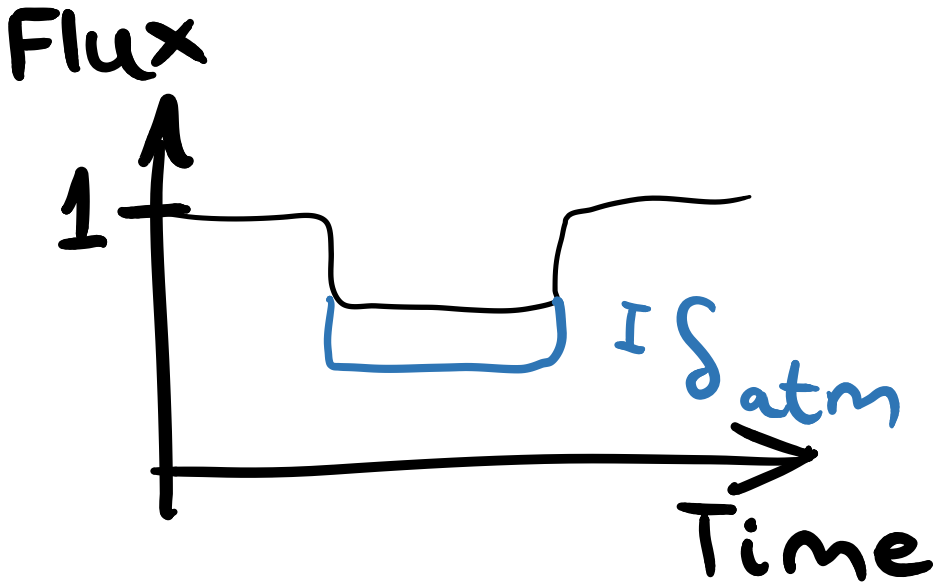
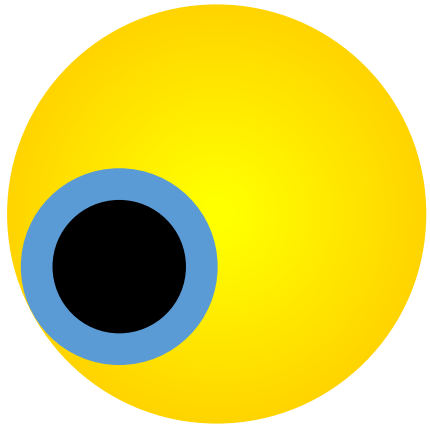
Reminder of what I mean by atmospheric SNR





$$\text{Signal} = \delta_{\text{atm}} = \frac{2\pi R_p H}{\pi R_\star^2}$$

$$\text{Noise} \approx \frac{\sigma_{\text{1-hr}}(I_c)}{\sqrt{T_{\text{dur,hr}}}}$$

	shemi-nhemi-npole	shemi-nhemi-ecliptic	shemi-nhemi-nhemi
Planets detected over all 3 years	2280	2300	2010
New planets from extended mission	730	720	480
New P>20d planets from extended mission	200	160	150
New 0.2<$S/S_{\oplus}$<2 planets from extended mission	130	110	120
Multiple-planet systems detected over 3 years	210	190	200
New planets from extended mission amenable to atmospheric study (R<4$R_{\oplus}$)	80	170	60

Numbers rounded to nearest “10”.

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The ecliptic pointing yields twice as many new planets with easily-characterizable atmospheres.

	Number of new planets comparable to GJ1214b	Number of unique planets from entire mission comparable to GJ1214b
shemi_nhemi_nhemi	62	406
shemi_nhemi_ecliptic	172	544
shemi_nhemi_npole	84	436

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Ecliptic pole maximizes the number of newly detected…

…planets with “long” orbital periods

~200 vs ~160

…habitable zone planets

~130 vs ~110

…multiple-planet systems.

~190 vs ~175
2-planet systems

Ecliptic plane detects…

… the same number of new planets,

~700

orbiting brighter host stars,

1.5 mag median shift

making them more amenable to atmospheric study.

Twice as many with atmospheric SNR comparable to GJ1214b

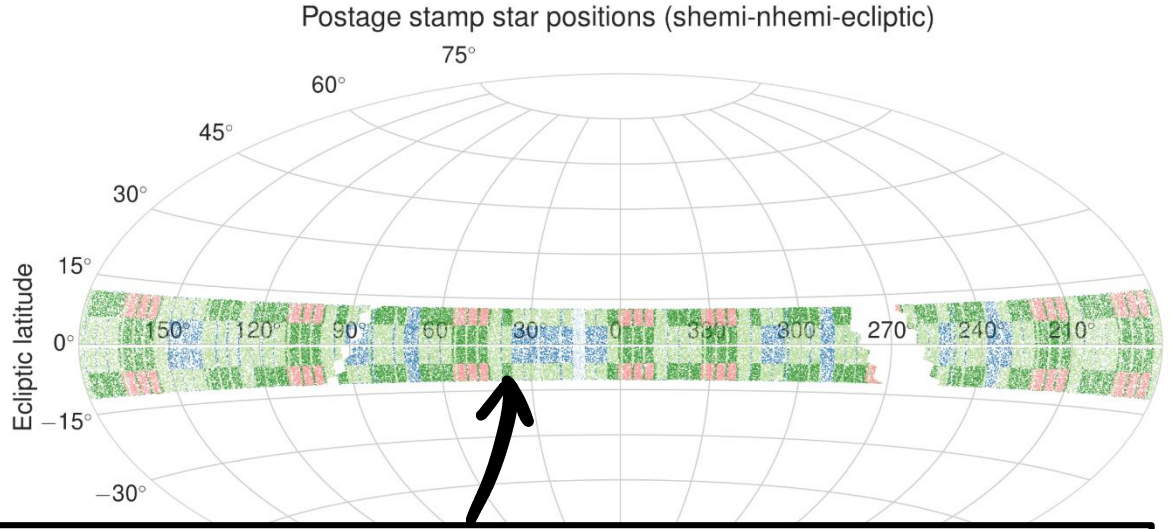
Assumptions

- Postage stamp only (no FFI)
- Target selection: pick 200,000 best targets for detecting small planets transiting bright stars. We sort by

$$\mathrm{Stat} = \frac{\delta}{\sigma_{1\text{-hr}}(I_c)}\sqrt{N_{\mathrm{ph}}} \propto \frac{(1/R_\star^2)}{\sigma_{1\text{-hr}}(I_c)}\sqrt{N_{\mathrm{pntg}}}$$

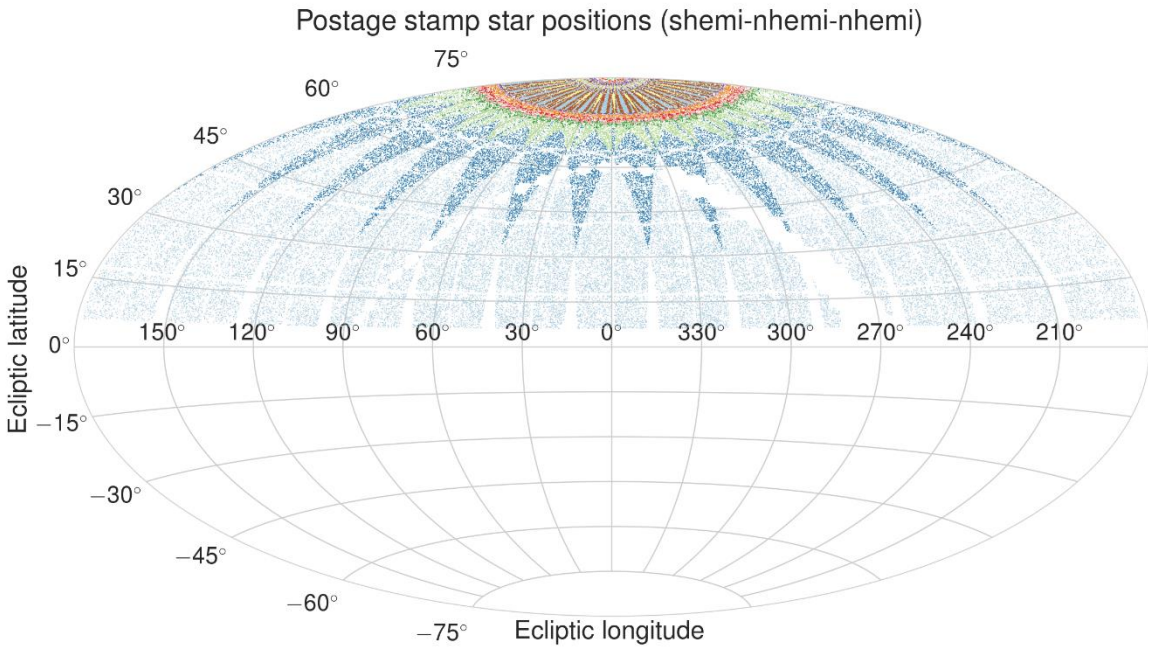
- For extended missions means: same sky gets ~same stars selected. For 1yr extended missions, pick 100,000 best.
- Earth/Moon crossings for ecliptic pointings: throw out ~12.5% of camera fields
- Noise model; ideal stellar radii; *Kepler* planet distributions, …

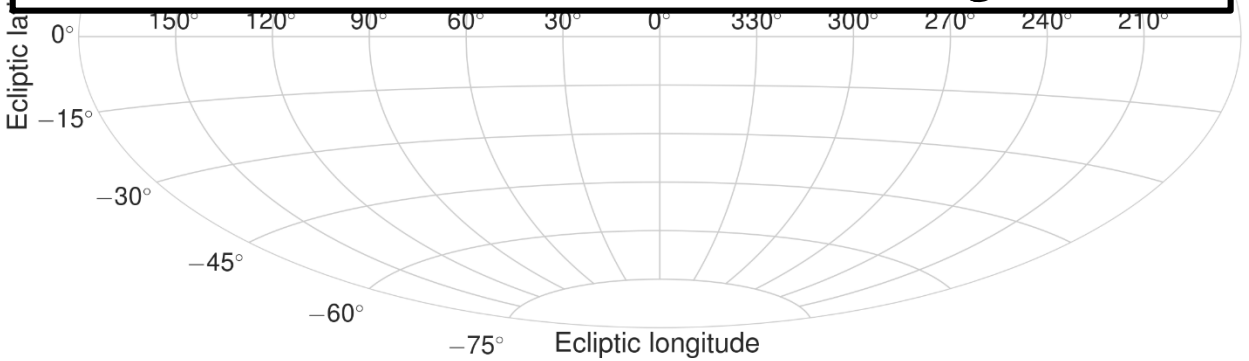
Compute STAT for every star in our catalog, then observe the "best" 100,000 stars per extended mission year.



$$\text{Prob}(\oplus \text{ or moon in field}) \approx \frac{24^\circ}{360^\circ} \times 2 = 13\,\%$$

↑either object

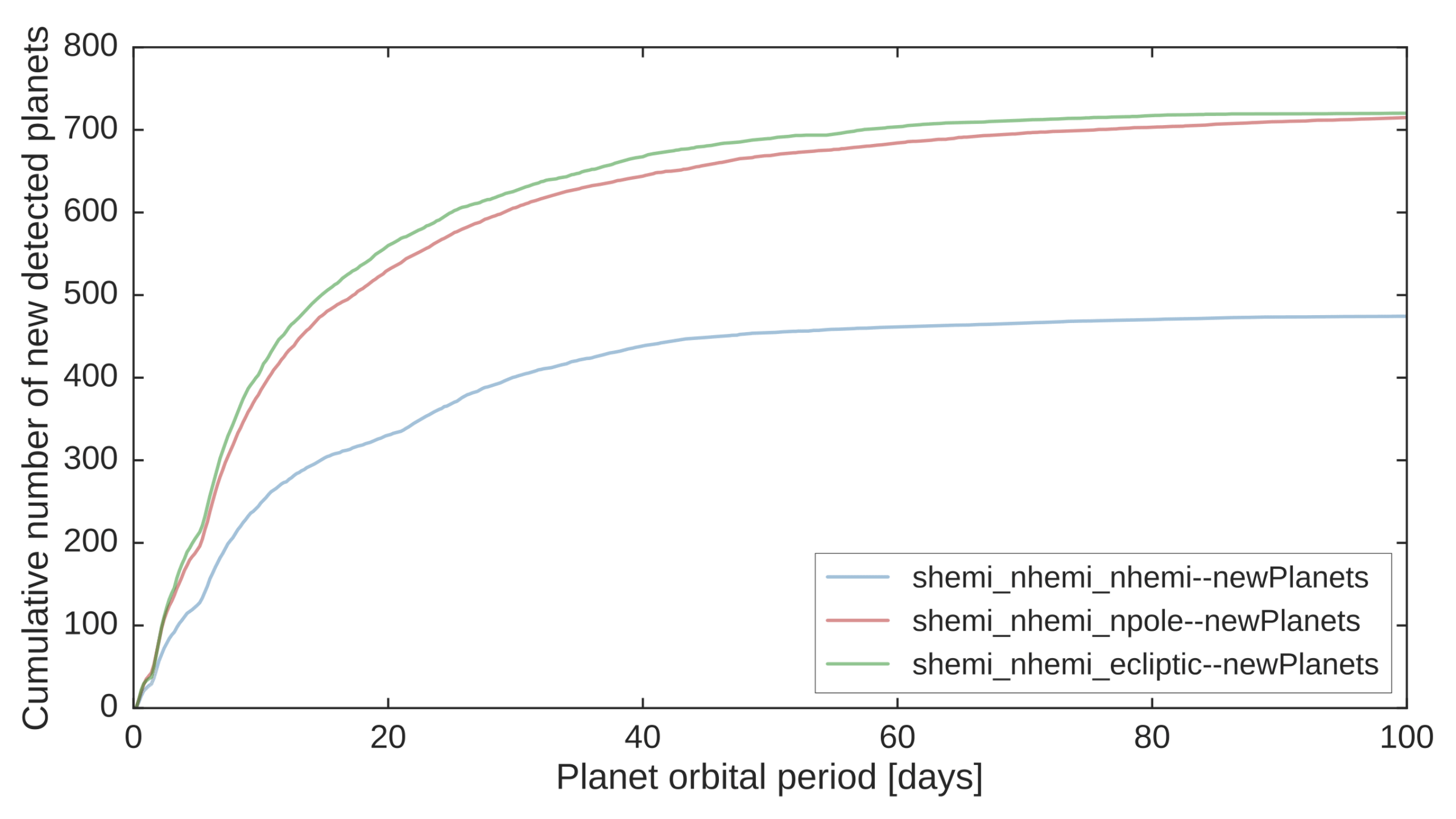


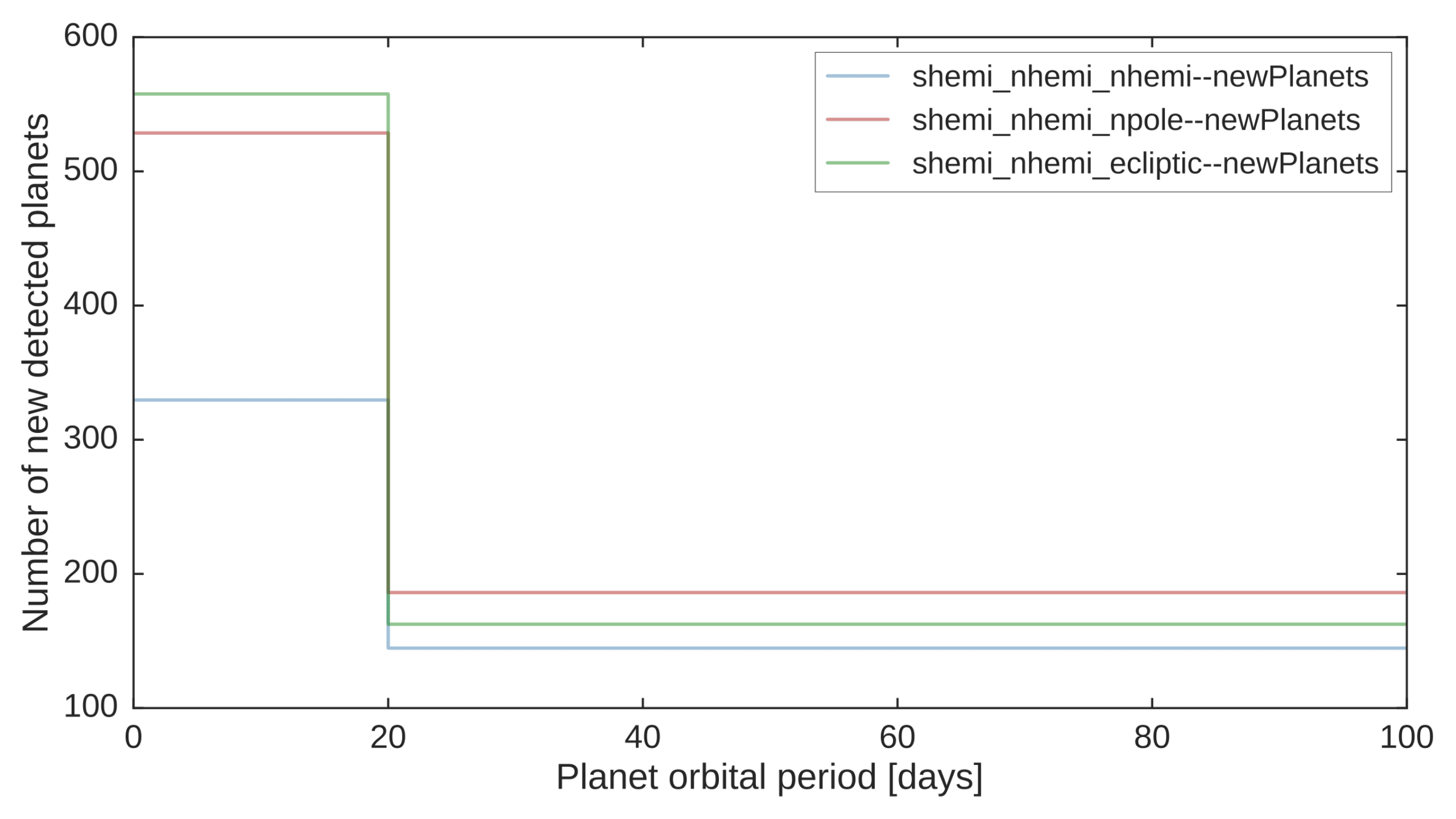


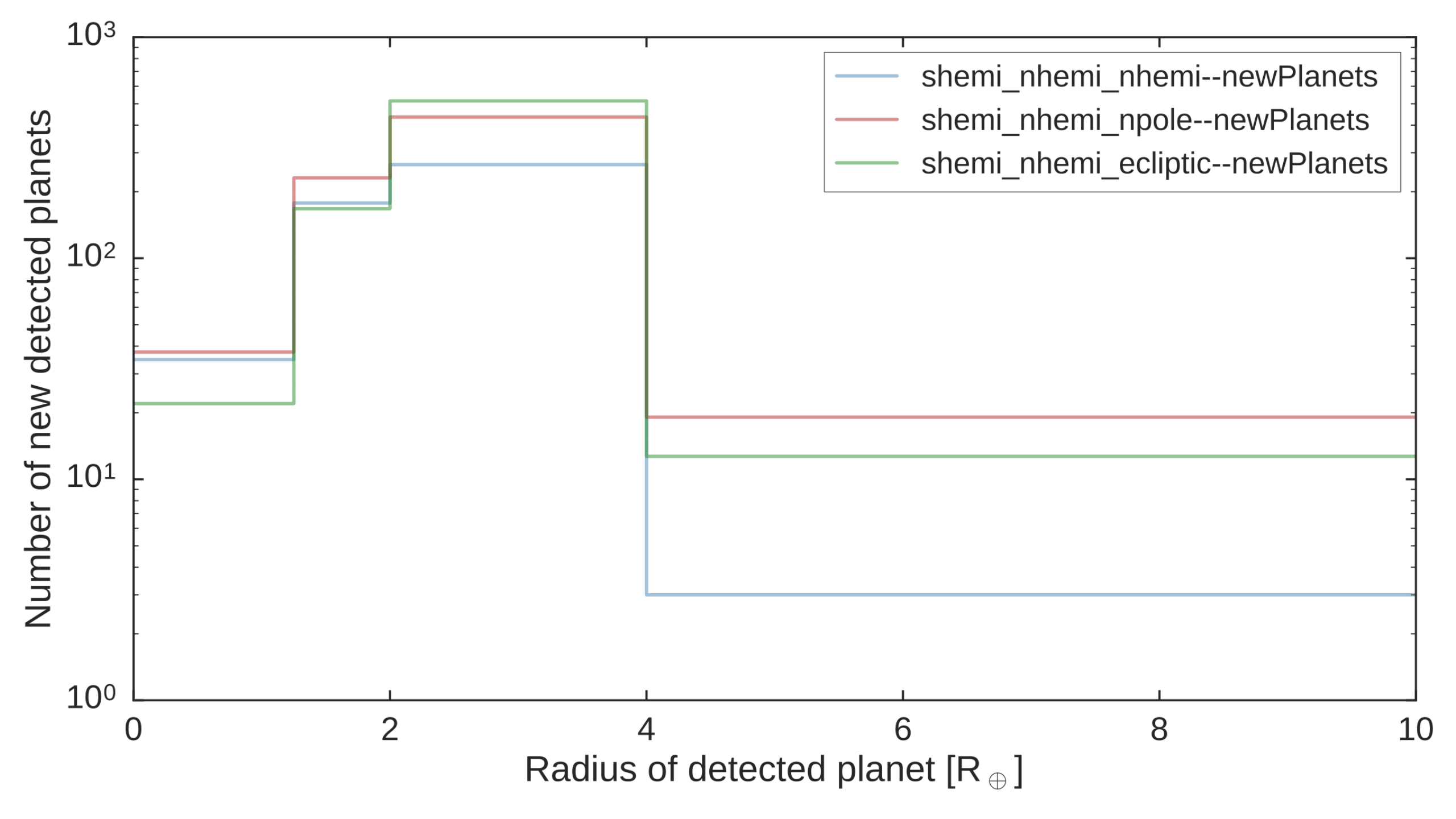
	N uniq planets total	N planets detected in ext	N new planets from ext
shemi_nhemi_nhemi-	2007.0	1220.6	481.9
shemi_nhemi_npole-	2276.5	1297.3	729.0
shemi_nhemi_ecliptic-	2302.7	793.5	720.8

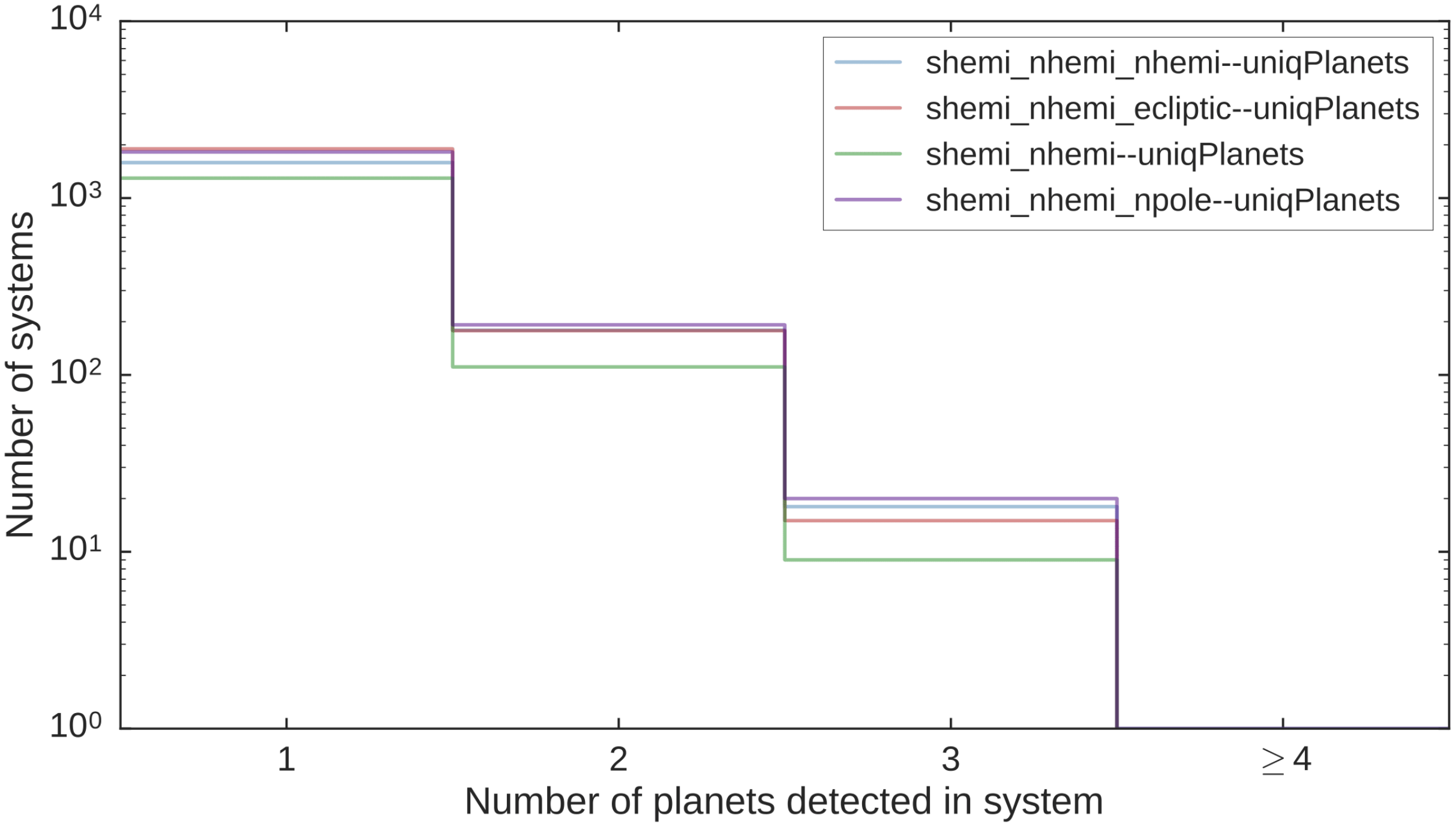
	N new planets from new star	N new planets from SNR boost	N new planets with P>20d
shemi_nhemi_nhemi-	15.5	466.4	152.3
shemi_nhemi_npole-	296.9	432.1	200.4
shemi_nhemi_ecliptic-	593.0	127.8	163.1

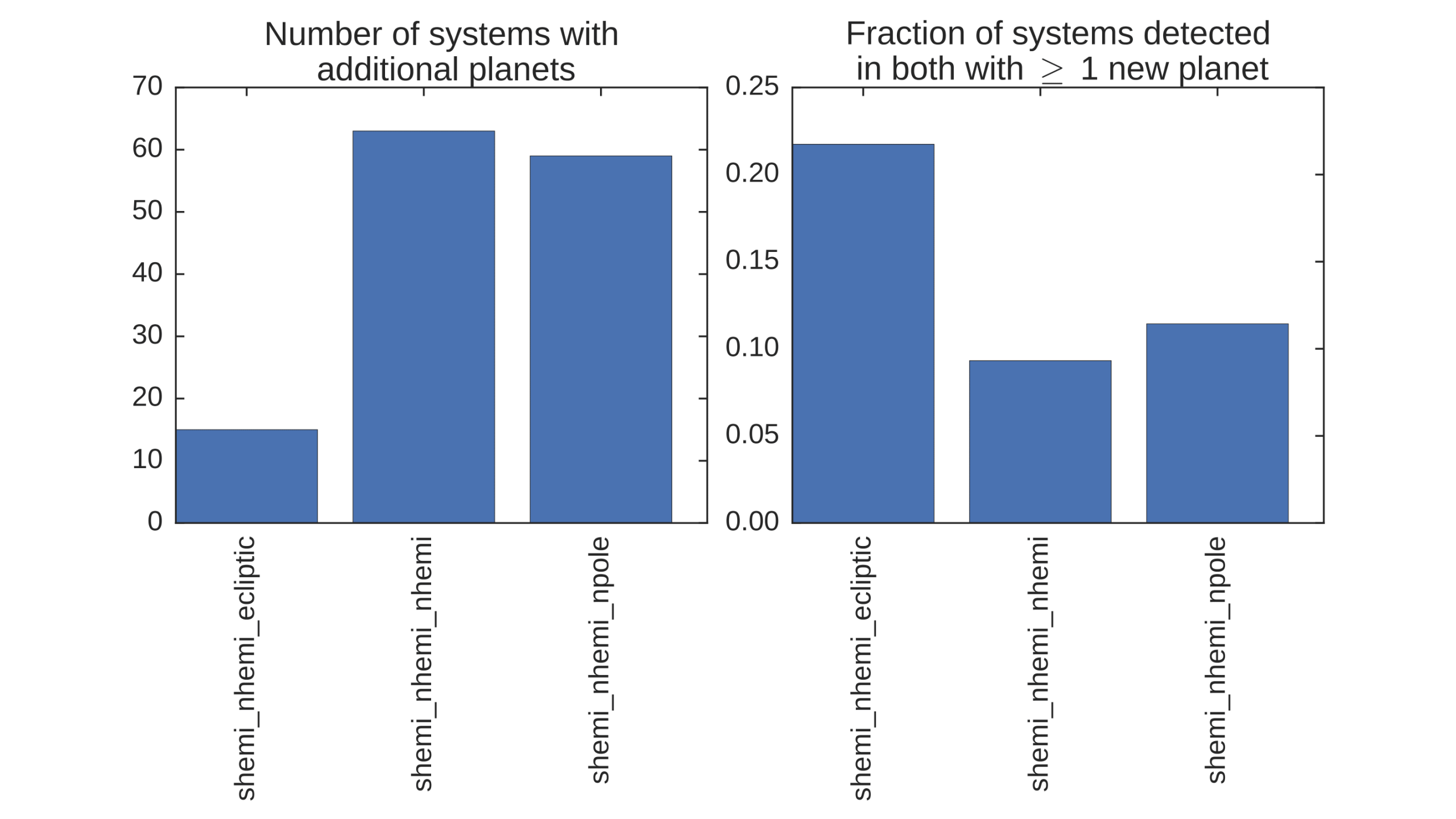
	N new planets with 0.2<S/S_earth<2	3|4yr N pntgs of stars obsd in ext	3|4yr N photons from stars obsd in ext
shemi_nhemi_nhemi-	118.8	8.00e+05	2.13e+16
shemi_nhemi_npole-	128.1	1.08e+06	2.51e+16
shemi_nhemi_ecliptic-	110.0	3.54e+05	1.02e+16


Cumulative number of new detected planets
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
Planet orbital period [days]
shemi_nhemi_nhemi--newPlanets
shemi_nhemi_npole--newPlanets
shemi_nhemi_ecliptic--newPlanets


shemi_nhemi_nhemi--newPlanets
shemi_nhemi_npole--newPlanets
shemi_nhemi_ecliptic--newPlanets
Number of new detected planets
Planet orbital period [days]
600
500
400
300
200
100
0
20
40
60
80
100


shemi_nhemi_nhemi--newPlanets
shemi_nhemi_npole--newPlanets
shemi_nhemi_ecliptic--newPlanets
Number of new detected planets
10^3
10^2
10^1
10^0
0
2
4
6
8
10
Radius of detected planet [$R_\oplus$]


shemi_nhemi_nhemi--uniqPlanets
shemi_nhemi_ecliptic--uniqPlanets
shemi_nhemi--uniqPlanets
shemi_nhemi_npole--uniqPlanets
Number of systems
10^4
10^3
10^2
10^1
10^0
1
2
3
≥ 4
Number of planets detected in system


Number of systems with additional planets
70
60
50
40
30
20
10
0
shemi_nhemi_ecliptic
shemi_nhemi_nhemi
shemi_nhemi_npole
Fraction of systems detected in both with ≥ 1 new planet
0.25
0.20
0.15
0.10
0.05
0.00
shemi_nhemi_ecliptic
shemi_nhemi_nhemi
shemi_nhemi_npole