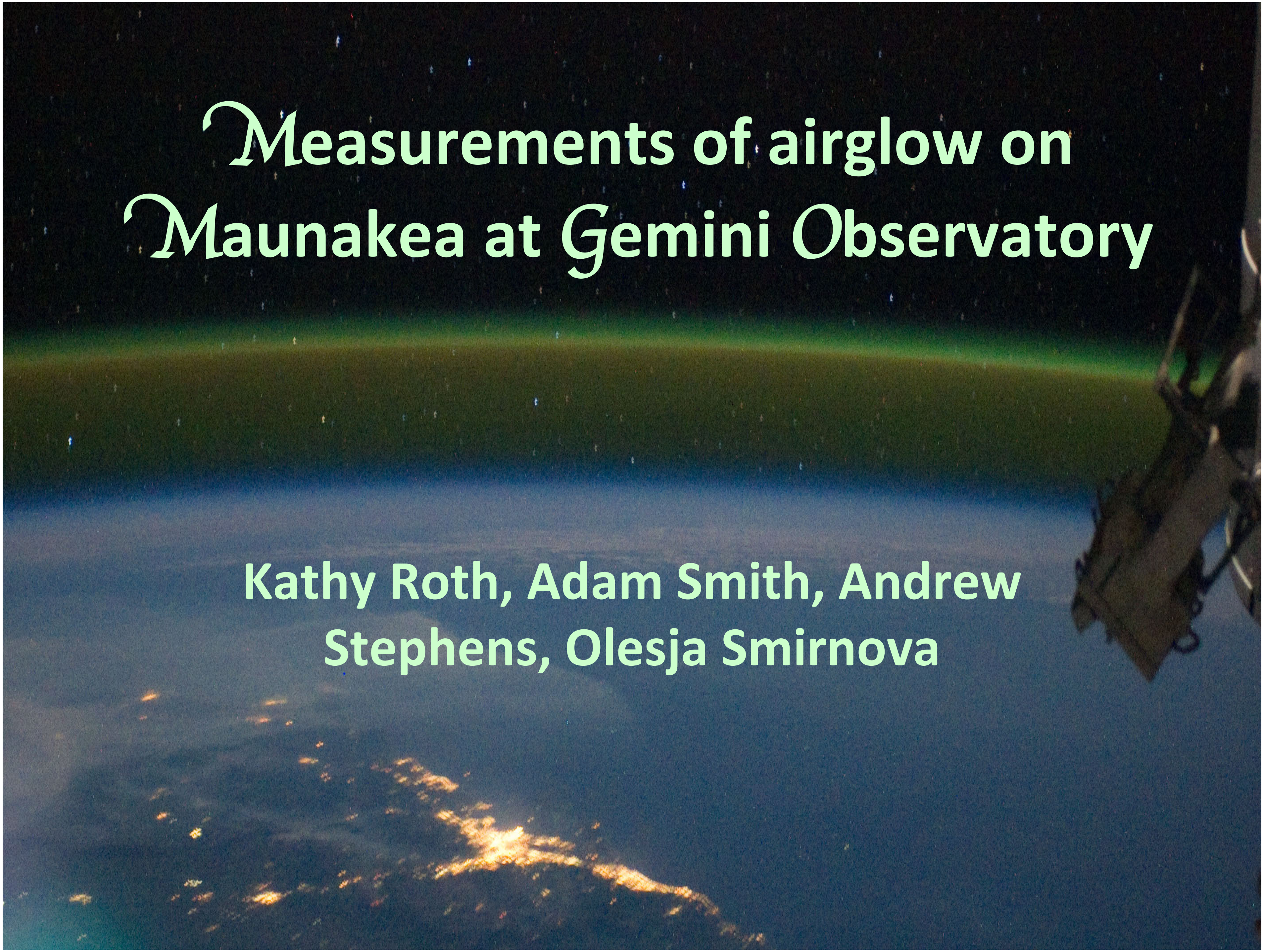


Measurements of airglow on Maunakea at Gemini Observatory

Kathy Roth, Adam Smith, Andrew Stephens, Olesja Smirnova

Airglow captured over the Atacama Desert (December 2015)

Gemini cloud camera (North)

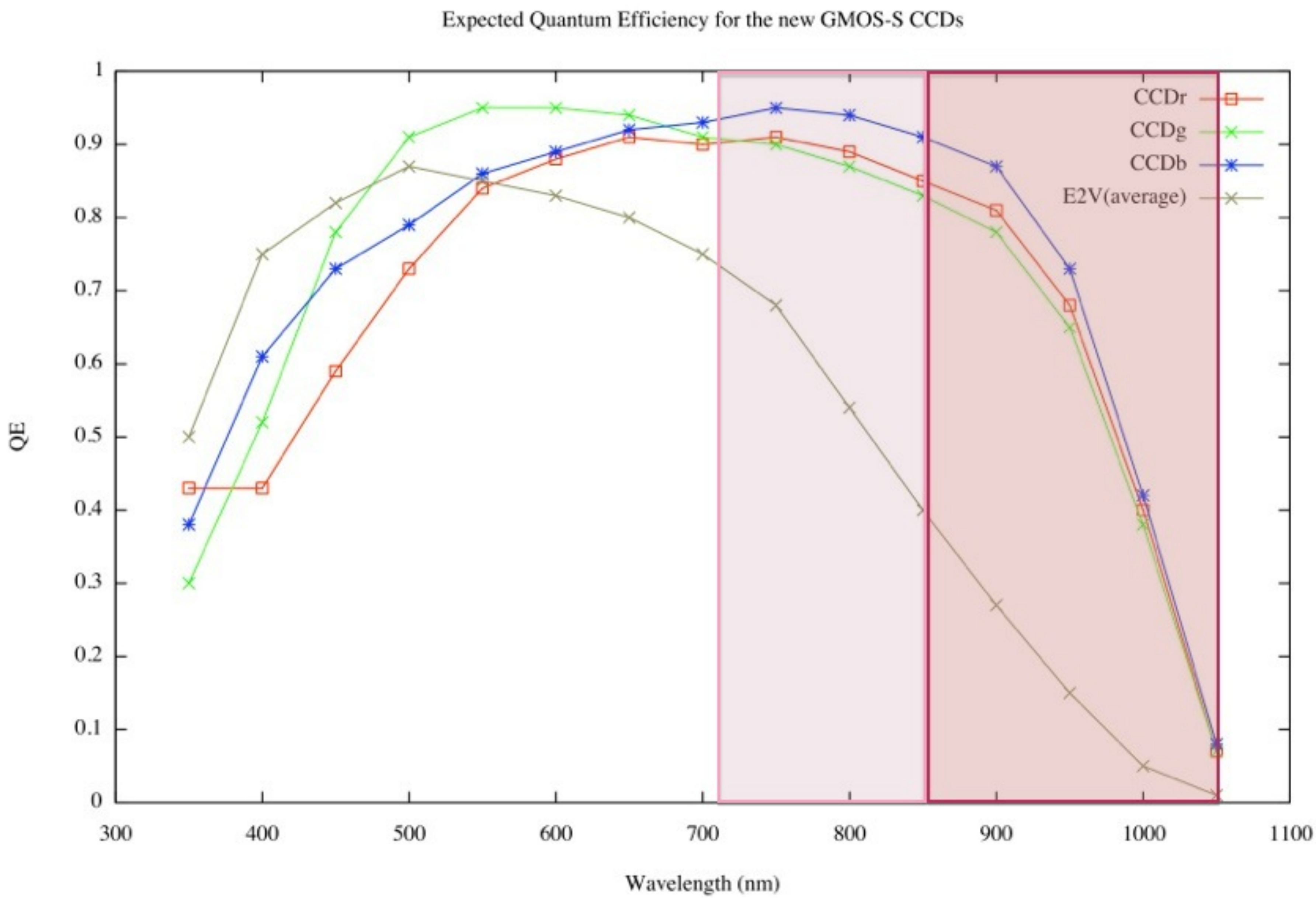
Gemini cloud camera (North)

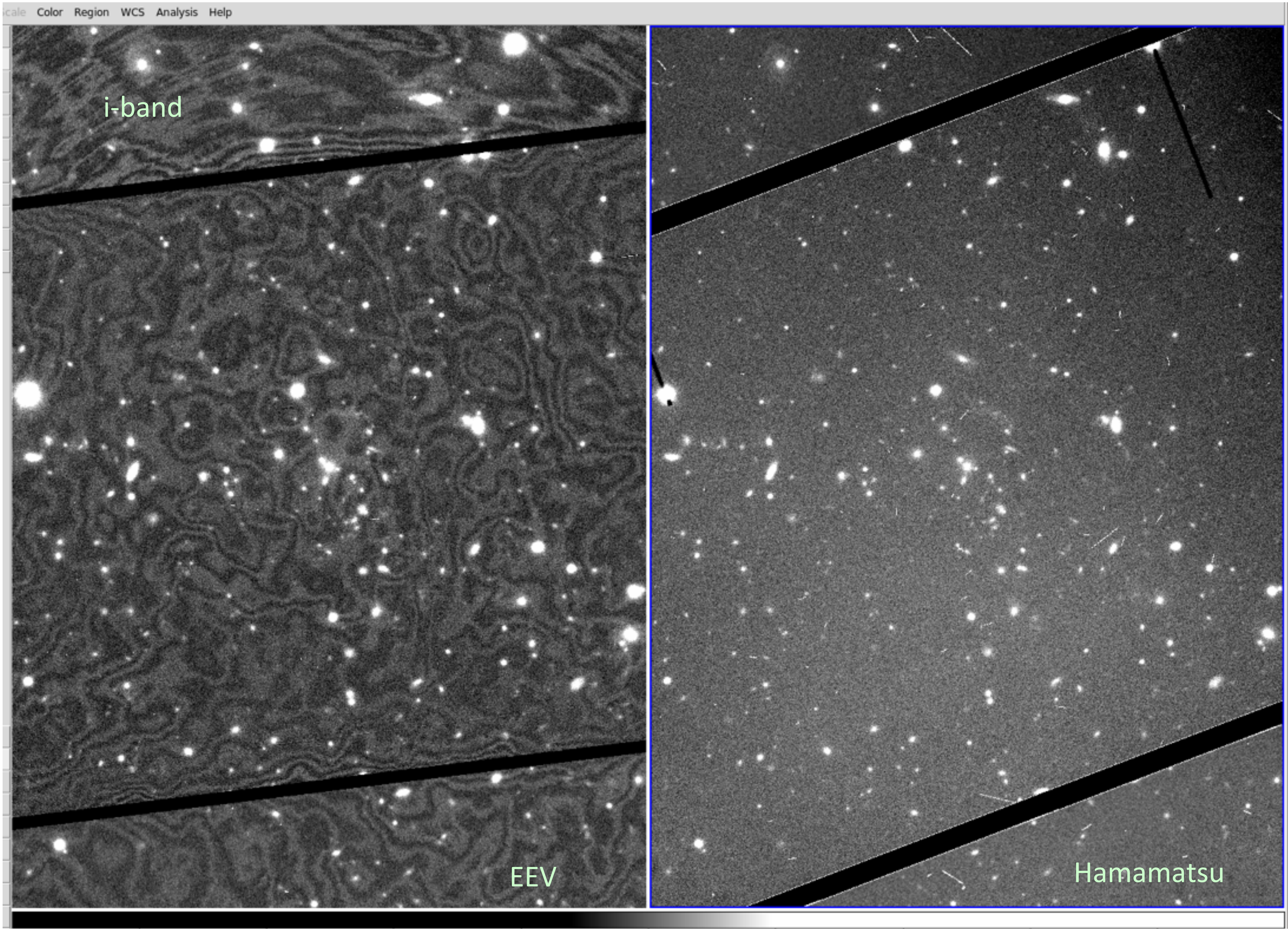

Gemini cloud camera (South)
21:08:34

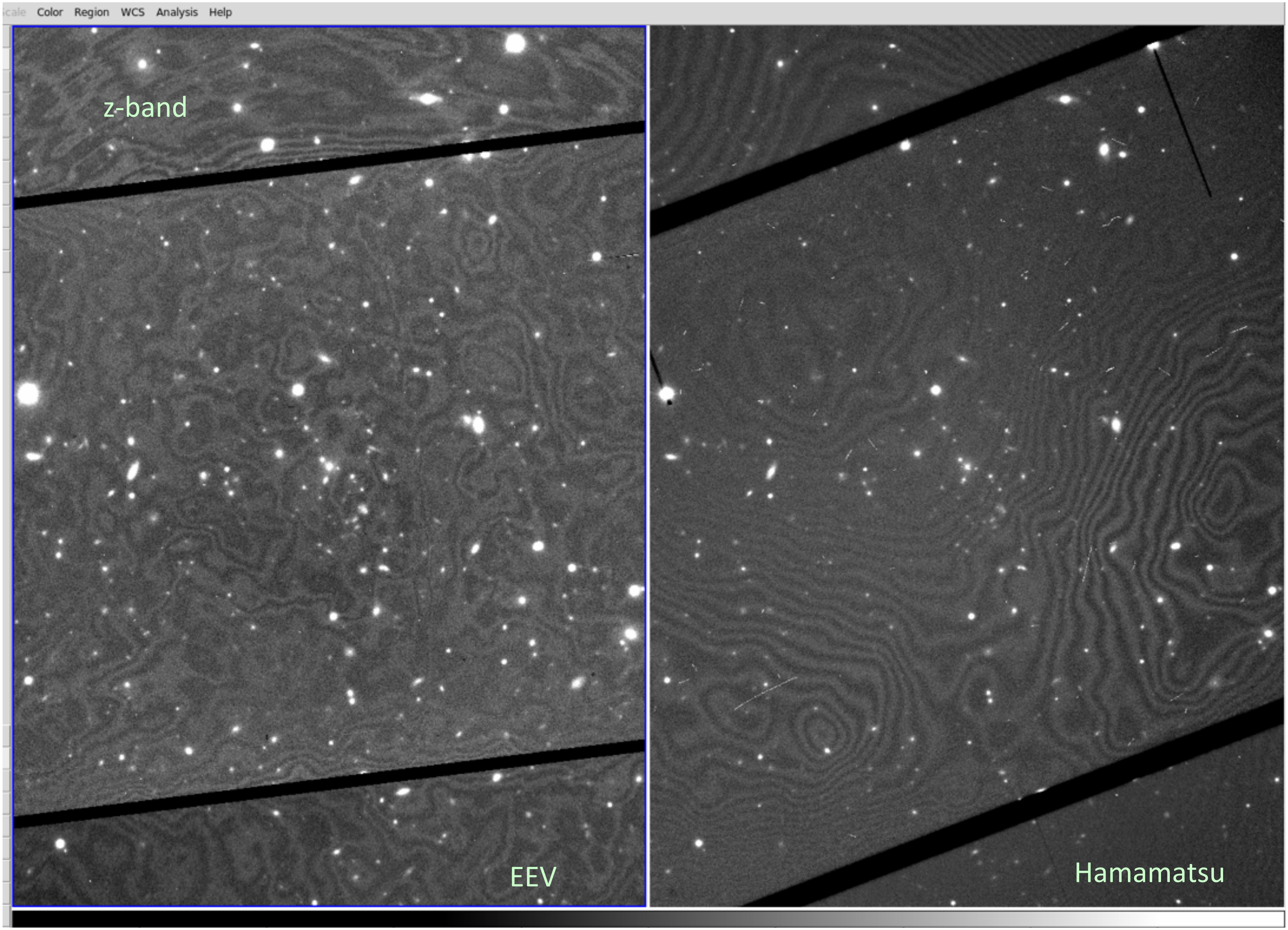
Gemini cloud camera (South)

GMOS-S Hamamatsu CCD Commissioning

- PR imaging of science field previously imaged in excellent seeing in i,z-band with the original EEV detectors.


Expected Quantum Efficiency for the new GMOS-S CCDs
QE
Wavelength (nm)
CCDr
CCDg
CCDb
E2V(average)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
300
400
500
600
700
800
900
1000
1100


Color Region WCS Analysis Help
i-band
EEV
Hamamatsu


Scale Color Region WCS Analysis Help
z-band
EEV
Hamamatsu

GMOS-S Hamamatsu CCD Commissioning

- Measured background with EEV ~ 4200e^-
- Measured background with Hamamatsu ~ 38000e^-
  → no gain in sensitivity
- EEV image taken at 2am with no moon, Hamamatsu image taken just after evening twilight in full moon.
  - Does the moon impact i-band imaging? Not at that level
  - Did proximity to Twilight impact the background? No, subsequent images had same levels
  - Must be airglow

Measuring sky background with QAP (Quality assurance pipeline)

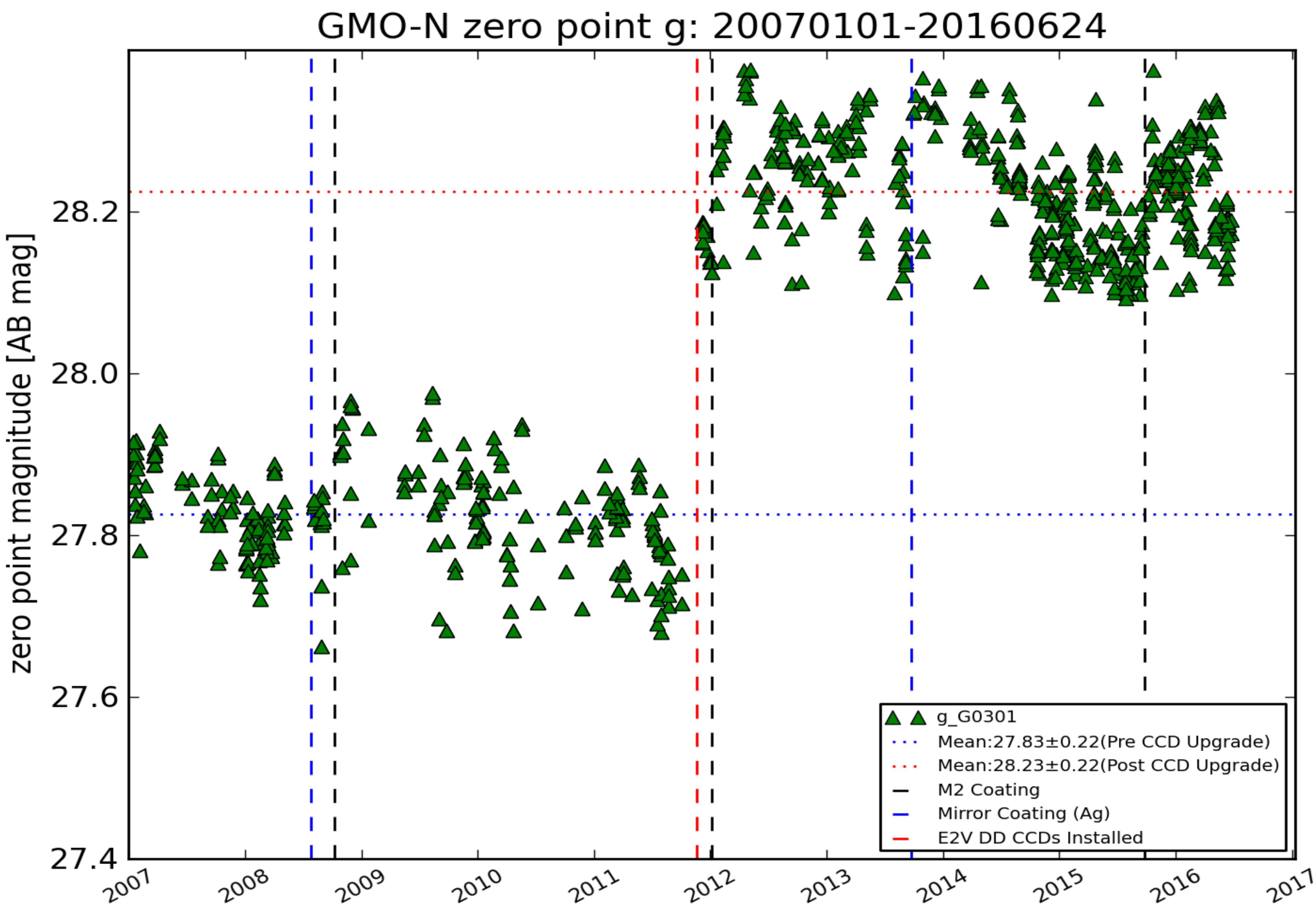
- QAP uses instrument/filter zero-points to calculate the measured sky background in imaging data
- QAP not intended to produce scientific quality images or measurements
- Use QAP automatic sky background values measured in 13 years of GMOS and NIRI imaging data to verify
  - How well are we doing - are we delivering data with the expected sensitivity?
  - What could we do better - anyway to improve the scheduling?

Preliminary Investigation

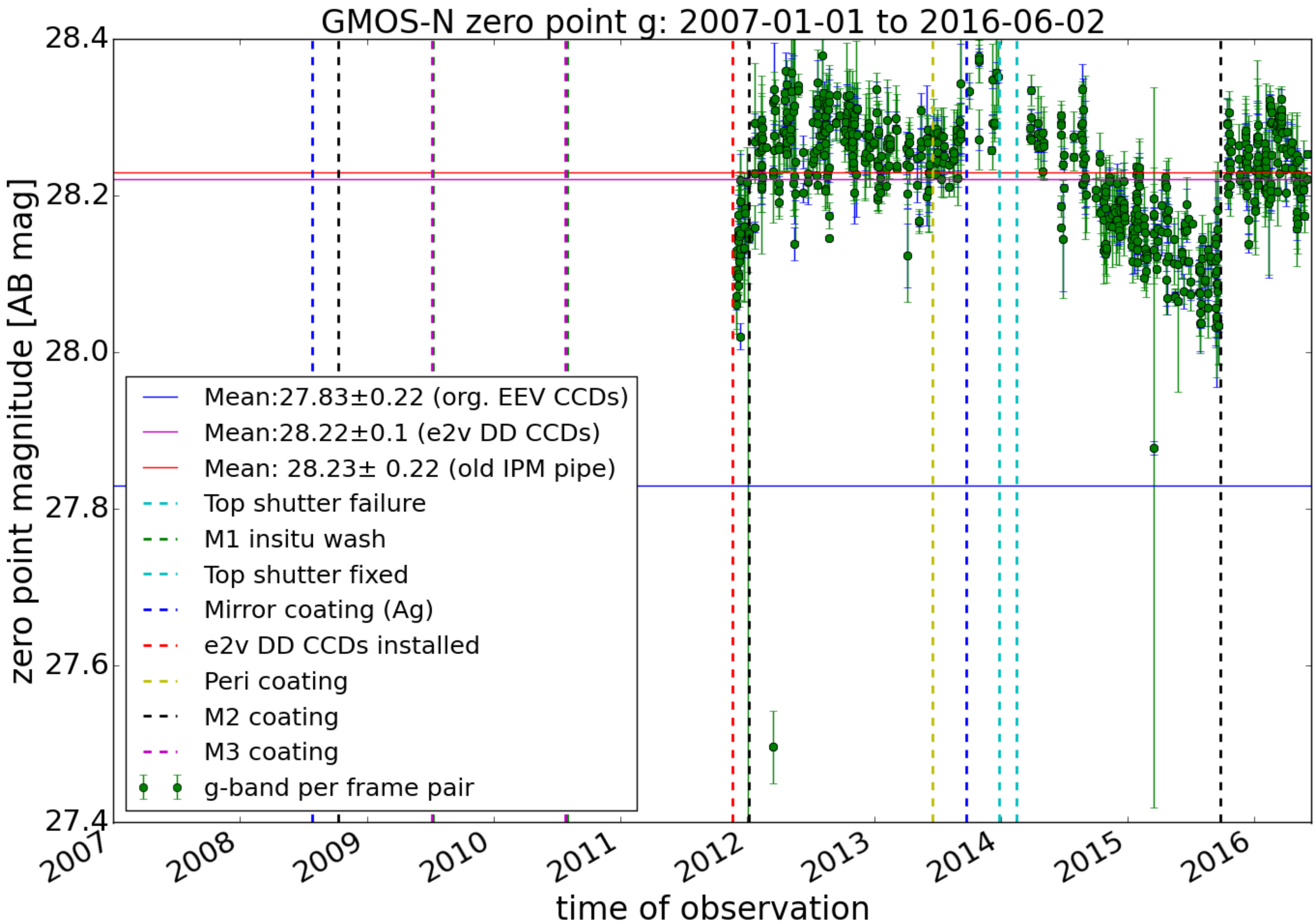
- Currently have run QAP on Gemini North imaging data back through mid 2010
- Correct QAP background values for changes in instrument/filter zero-points
- Empirically determine airmass correction to QAP background measurements
- Look for trends in background values with various parameters (moon phase, time of night, solar cycle, time of year, etc)
- A purely empirical approach

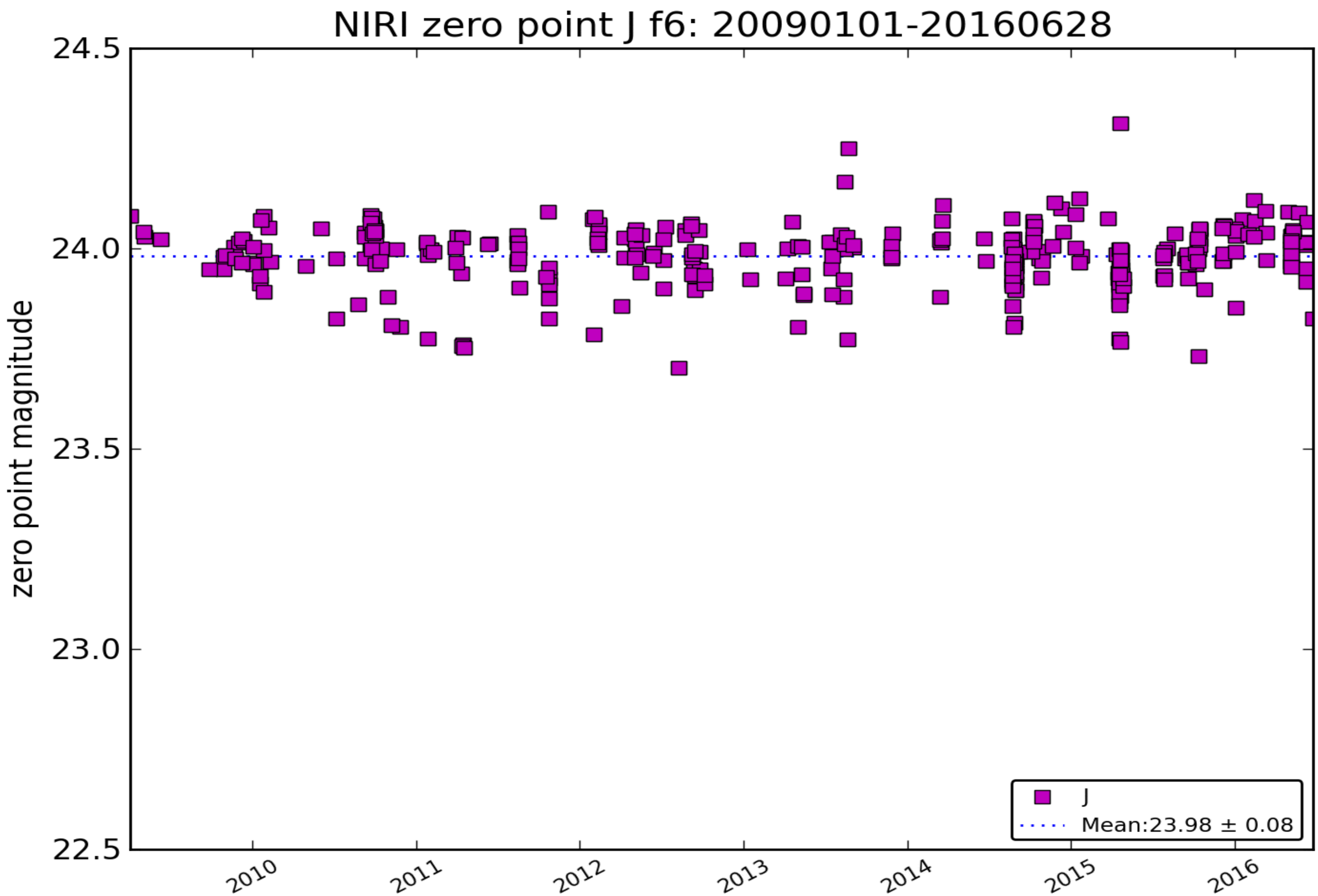
Performance Monitoring: Instrument zero points

- Photometric standards are taken whenever imaging data are taken on photometric nights for both NIRI and GMOS.
- Dedicated “performance monitoring” data are taken in all filters / modes ideally at least once per month
- Zero points are automatically derived from scripts running in background and results are posted on the web
- Recent investigations into GMOS zero points have reduced errors and reveal trends with zero point related to various mirror reflectivities



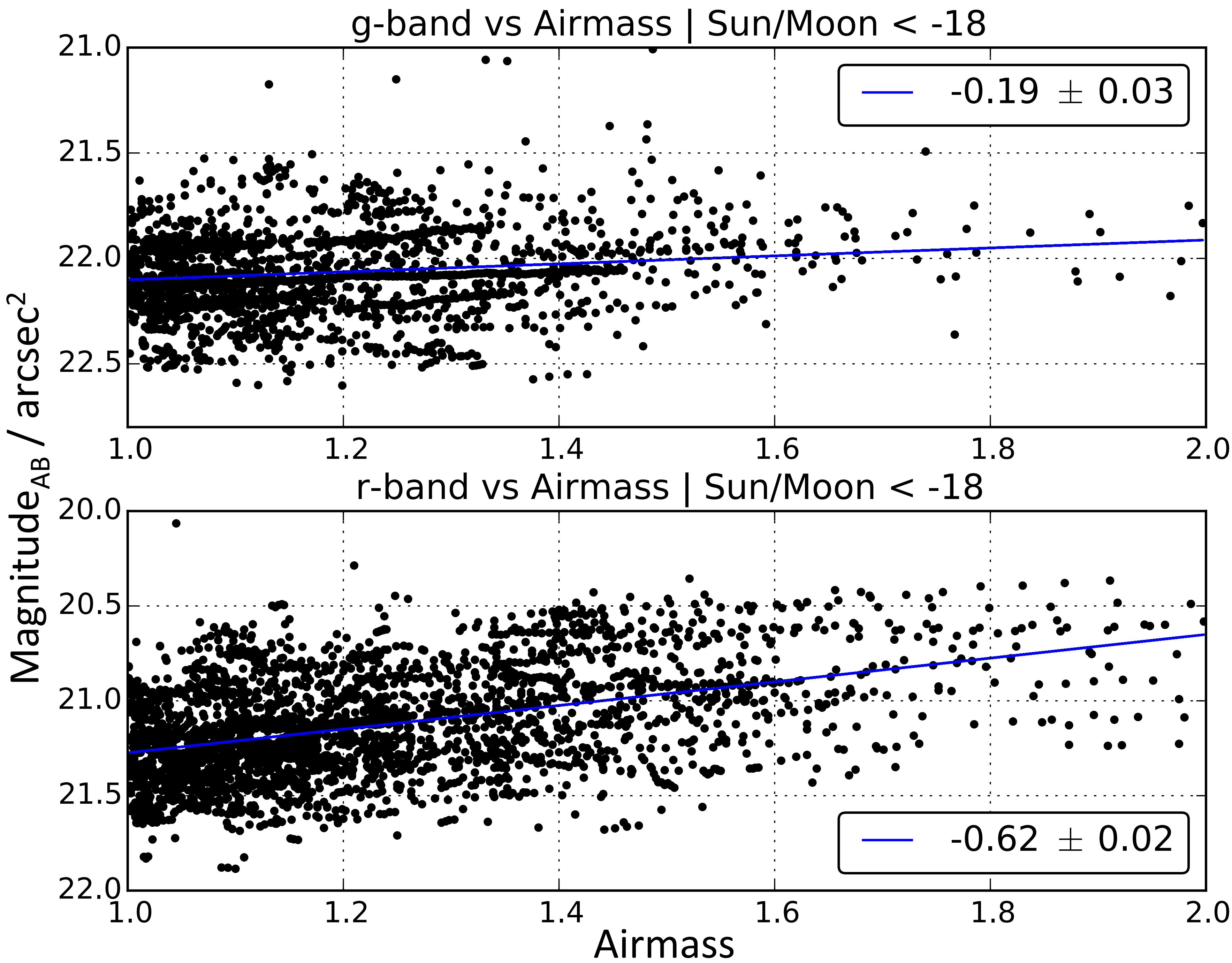
GMO-N zero point g: 20070101-20160624
zero point magnitude [AB mag]
27.4
27.6
27.8
28.0
28.2
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
g_G0301
Mean:27.83±0.22(Pre CCD Upgrade)
Mean:28.23±0.22(Post CCD Upgrade)
M2 Coating
Mirror Coating (Ag)
E2V DD CCDs Installed


GMOS-N zero point g: 2007-01-01 to 2016-06-02
zero point magnitude [AB mag]
time of observation
28.4
28.2
28.0
27.8
27.6
27.4
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Mean:27.83±0.22 (org. EEV CCDs)
Mean:28.22±0.1 (e2v DD CCDs)
Mean: 28.23± 0.22 (old IPM pipe)
Top shutter failure
M1 insitu wash
Top shutter fixed
Mirror coating (Ag)
e2v DD CCDs installed
Peri coating
M2 coating
M3 coating
g-band per frame pair

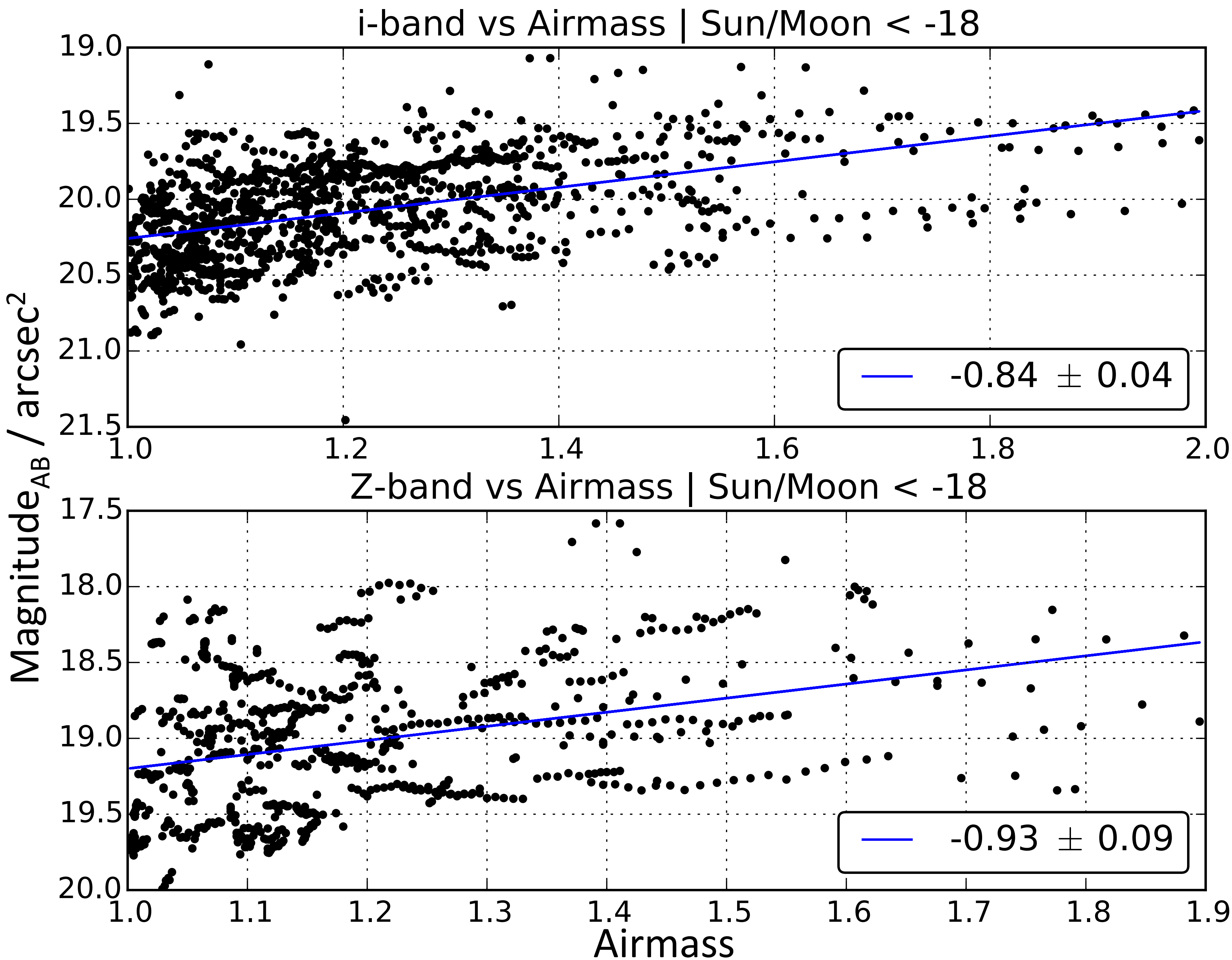

NIRI zero point J f6: 20090101-20160628
zero point magnitude
24.5
24.0
23.5
23.0
22.5
2010
2011
2012
2013
2014
2015
2016
J
Mean:23.98 ± 0.08

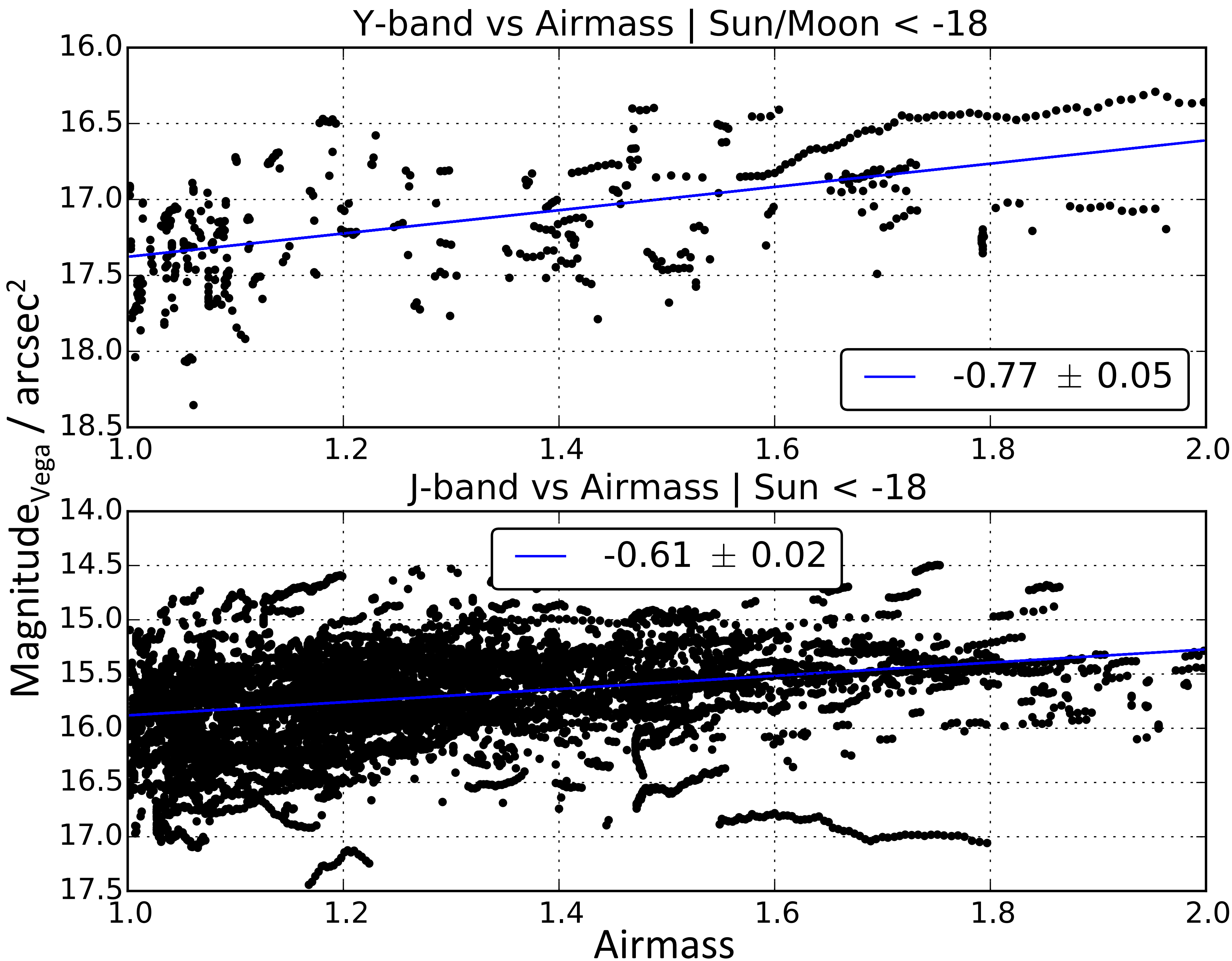
Airmass Dependence

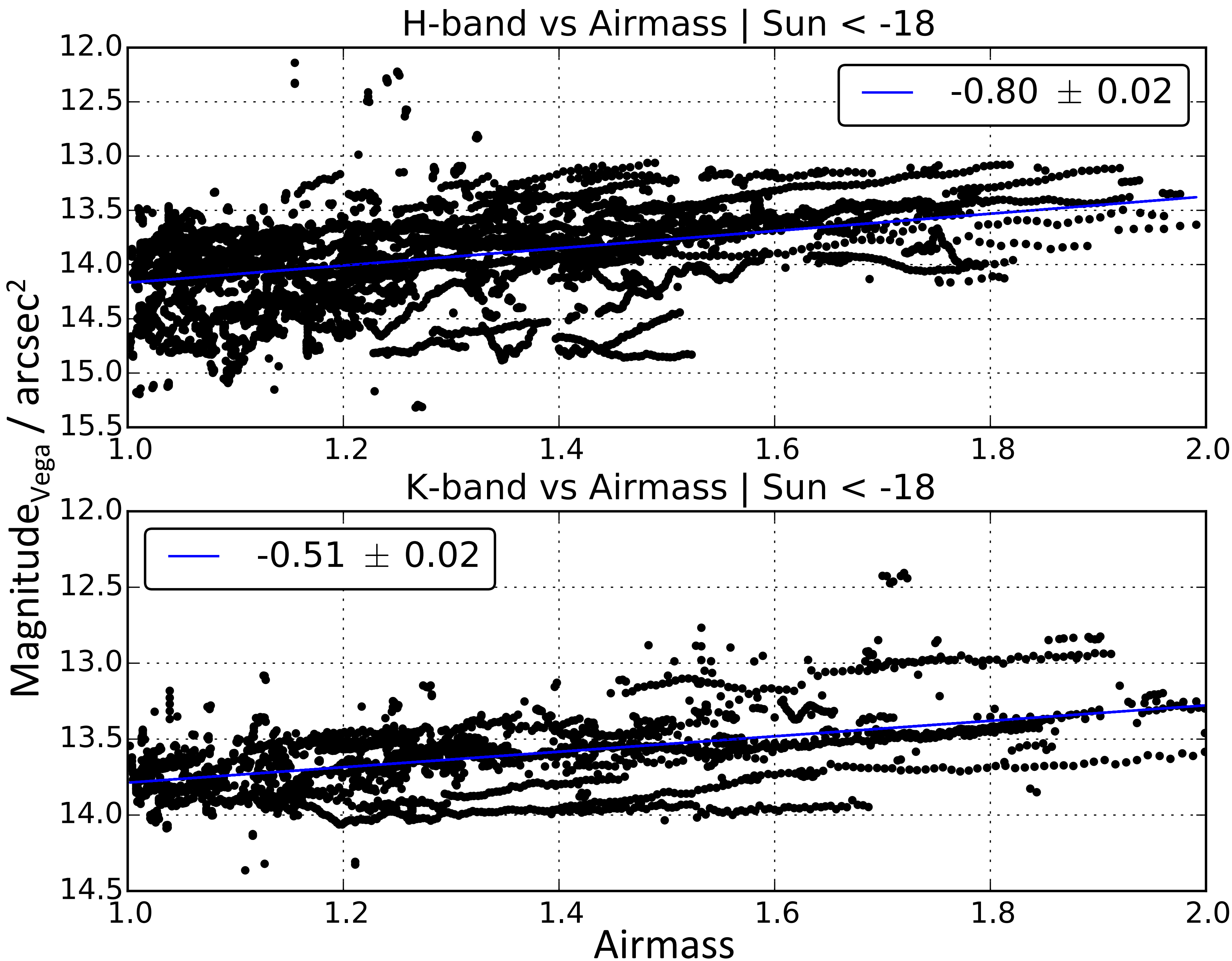
- Linear fits to QAP background brightness values as a function of airmass.
- In the optical only data with sun and moon below -18 deg elevation considered
- In the infrared no moon restriction is considered, only sun below -18 deg



g-band vs Airmass | Sun/Moon < -18
-0.19 ± 0.03
r-band vs Airmass | Sun/Moon < -18
-0.62 ± 0.02
Magnitude$_{AB}$ / arcsec^2
Airmass
21.0
21.5
22.0
22.5
20.0
20.5
1.0
1.2
1.4
1.6
1.8
2.0


i-band vs Airmass | Sun/Moon < -18
-0.84 ± 0.04
Z-band vs Airmass | Sun/Moon < -18
-0.93 ± 0.09
Magnitude$_{AB}$ / arcsec^2
Airmass
19.0
19.5
20.0
20.5
21.0
21.5
1.0
1.2
1.4
1.6
1.8
2.0
17.5
18.0
18.5
19.0
19.5
20.0
1.1
1.3
1.5
1.7
1.9

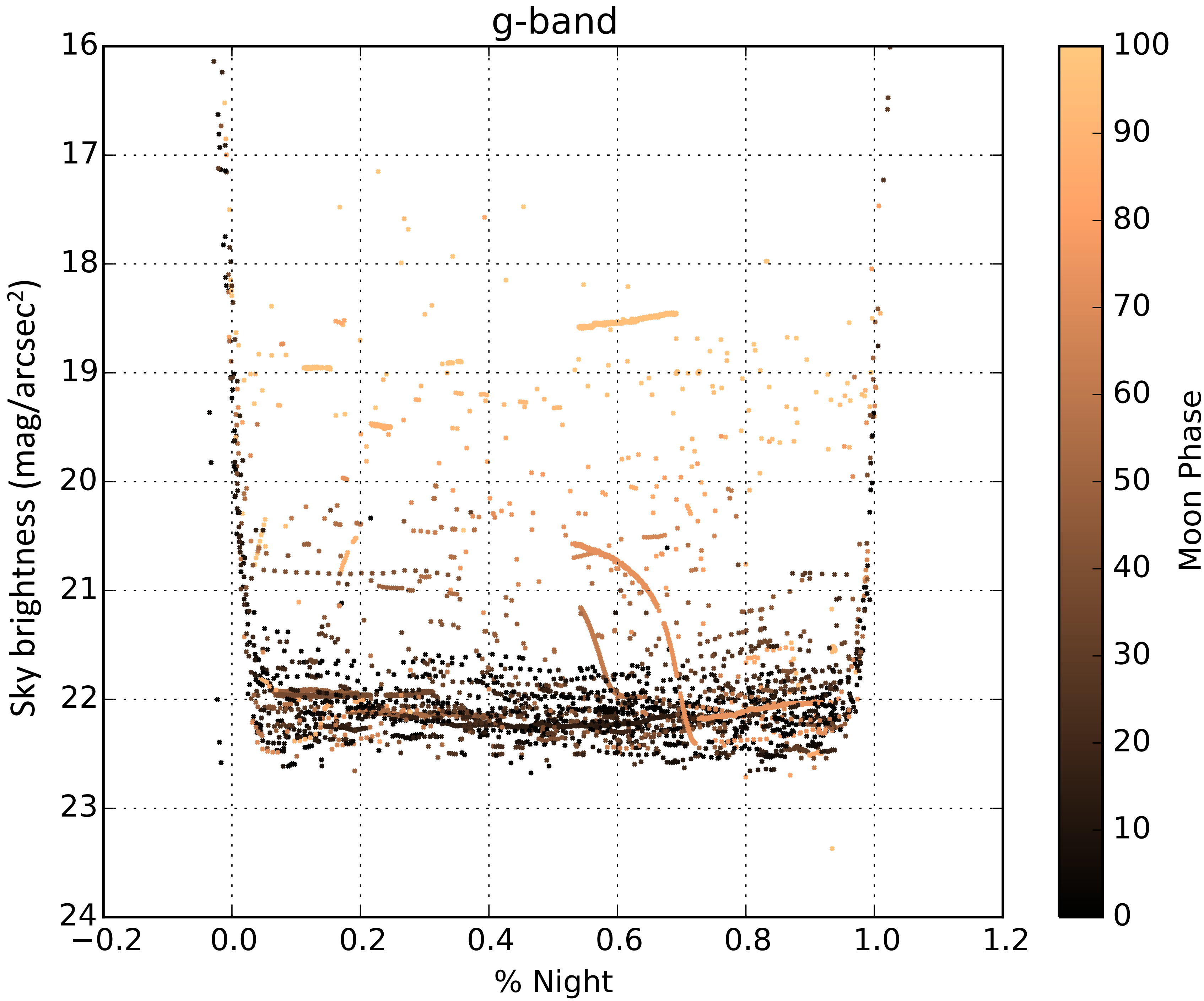

Y-band vs Airmass | Sun/Moon < -18
16.0
16.5
17.0
17.5
18.0
18.5
1.0
1.2
1.4
1.6
1.8
2.0
-0.77 ± 0.05
J-band vs Airmass | Sun < -18
14.0
14.5
15.0
15.5
16.0
16.5
17.0
17.5
-0.61 ± 0.02
Magnitude$_{Vega}$ / arcsec^2
Airmass

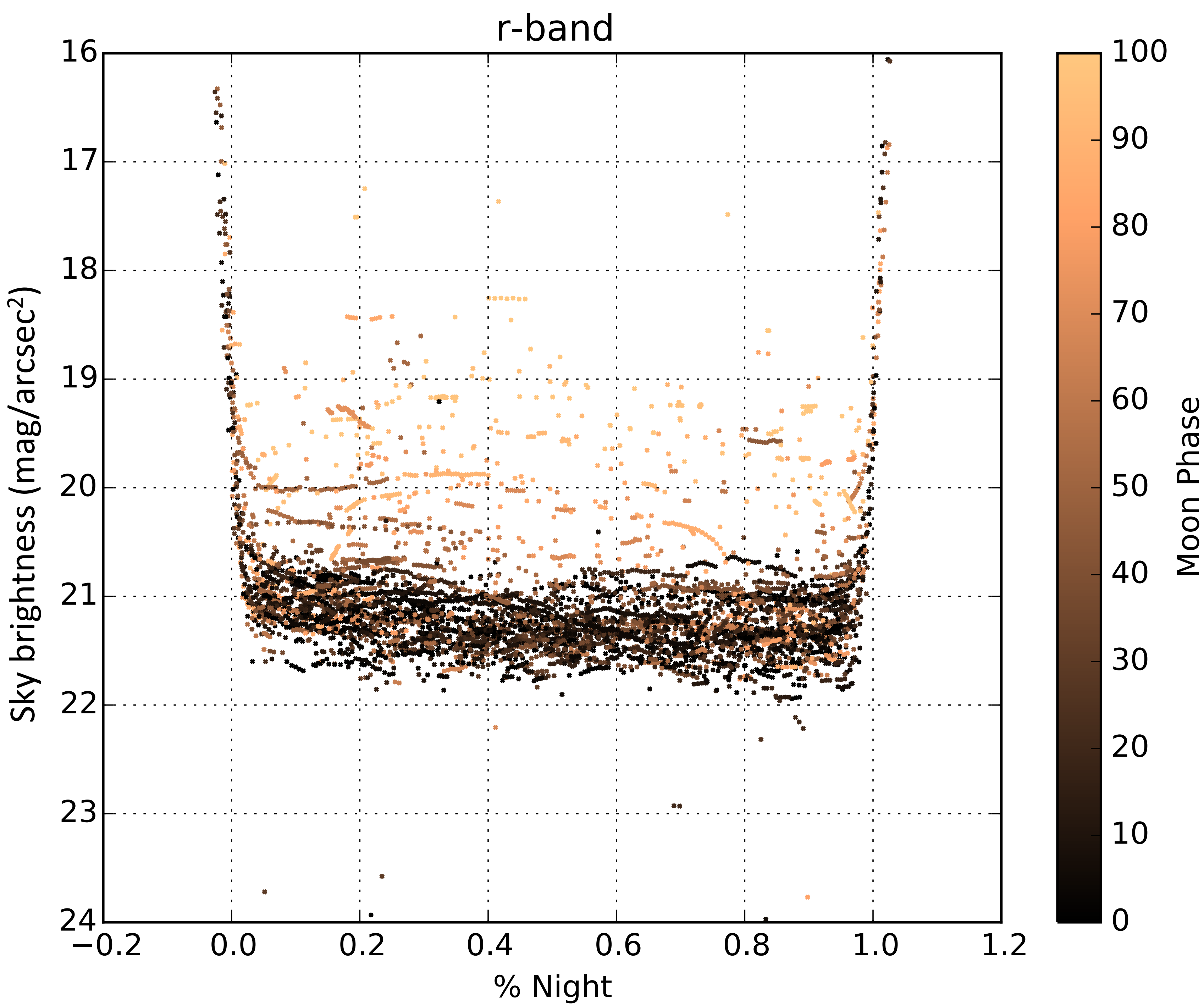


H-band vs Airmass | Sun < -18
-0.80 ± 0.02
K-band vs Airmass | Sun < -18
-0.51 ± 0.02
Magnitude$_{\mathrm{Vega}}$ / arcsec^2
Airmass
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
1.0
1.2
1.4
1.6
1.8
2.0

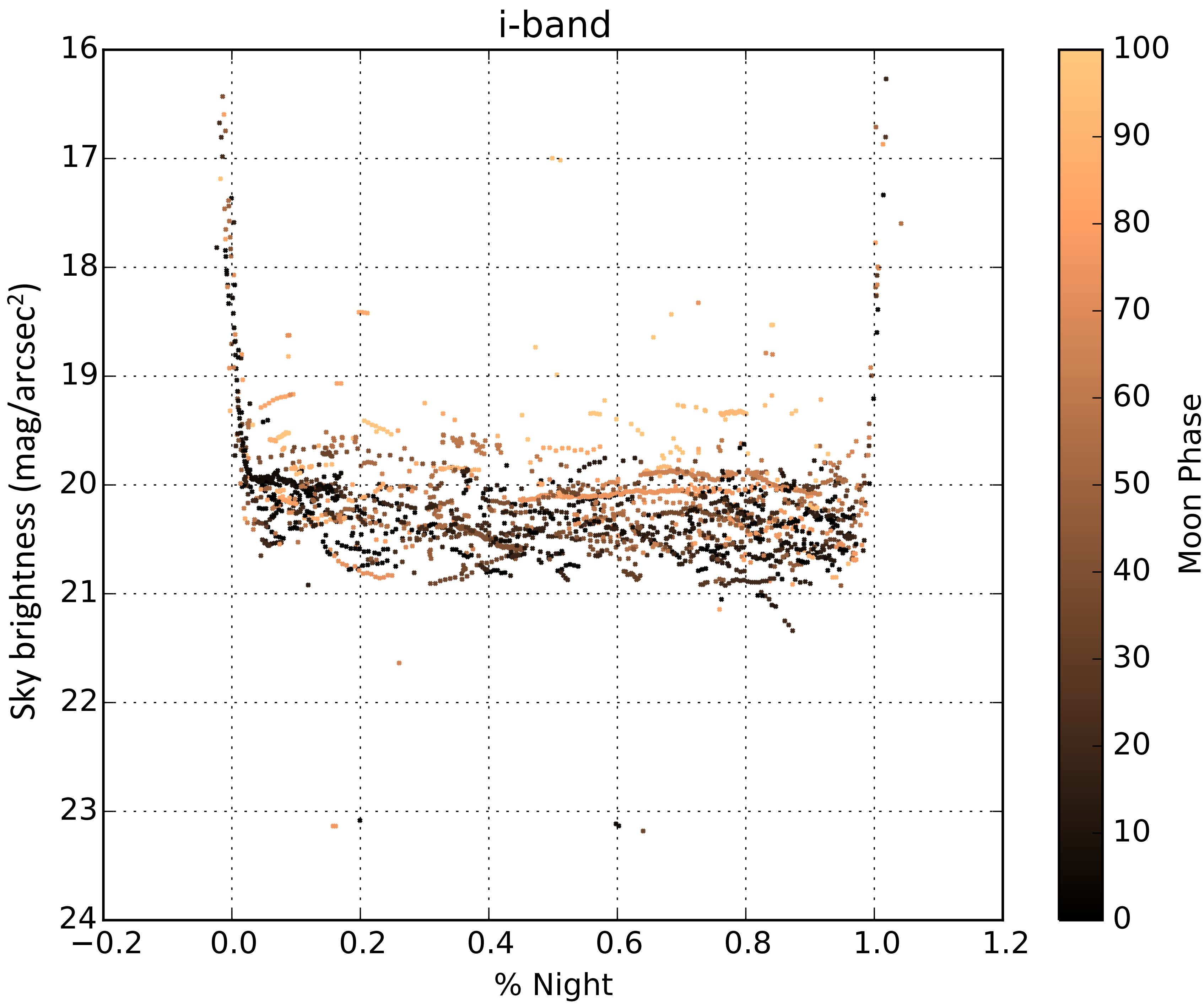
Time Of Night

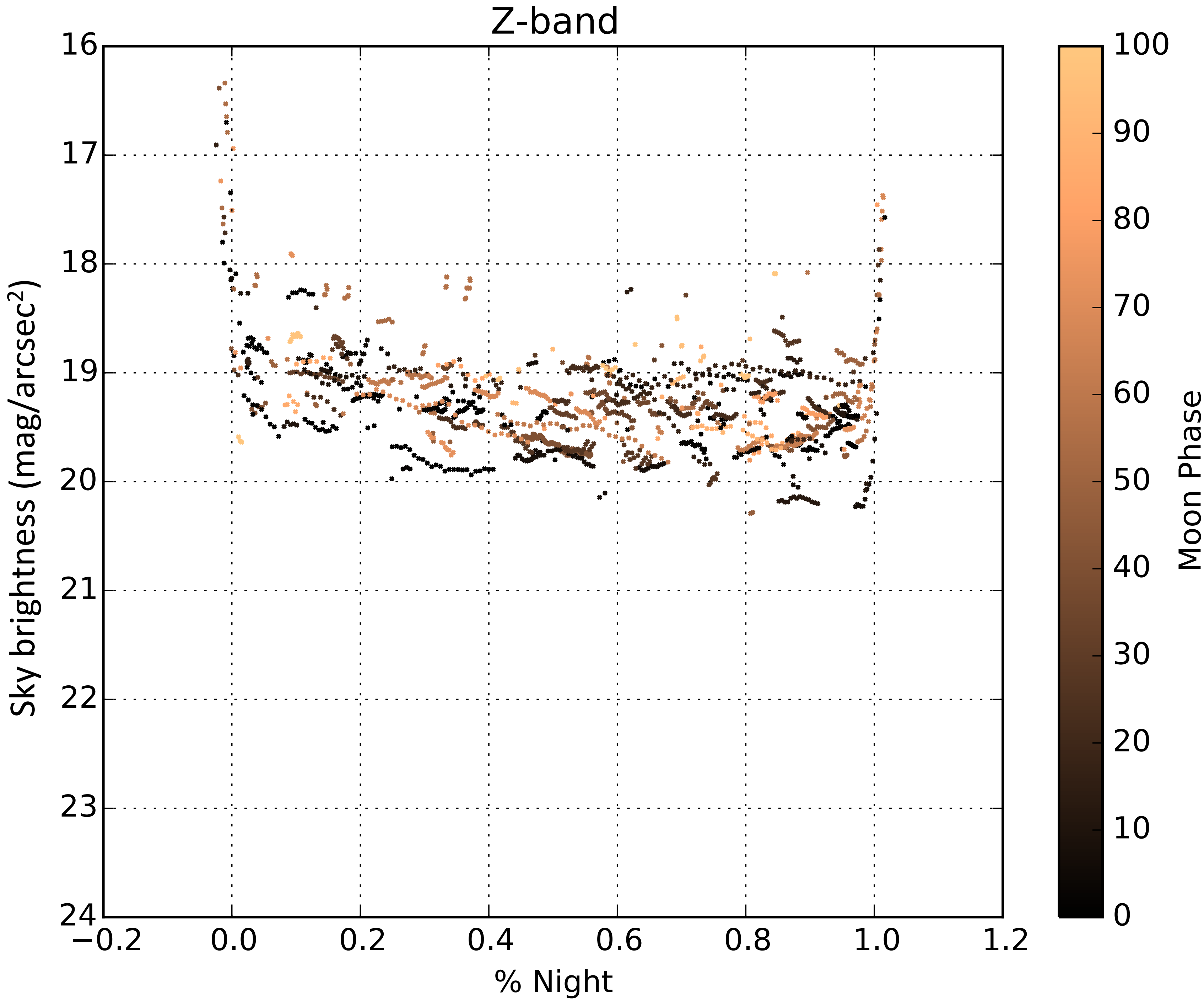
- Corrected sky brightness values plotted against percent of night, where evening 12-deg twilight is 0% and morning 12-deg twilight is 100% of night completed.
- Hawaii nights are 8.9 hours long in the summer and 11.4 hours long in the winter
- Some expected results: optical bands see the moon and Twilight
- Unexpected result: all bands except g and K take 20-30% of the night to reach darkest values


g-band
Sky brightness (mag/arcsec^2)
% Night
Moon Phase
16
17
18
19
20
21
22
23
24
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
100
90
80
70
60
50
40
30
20
10
0

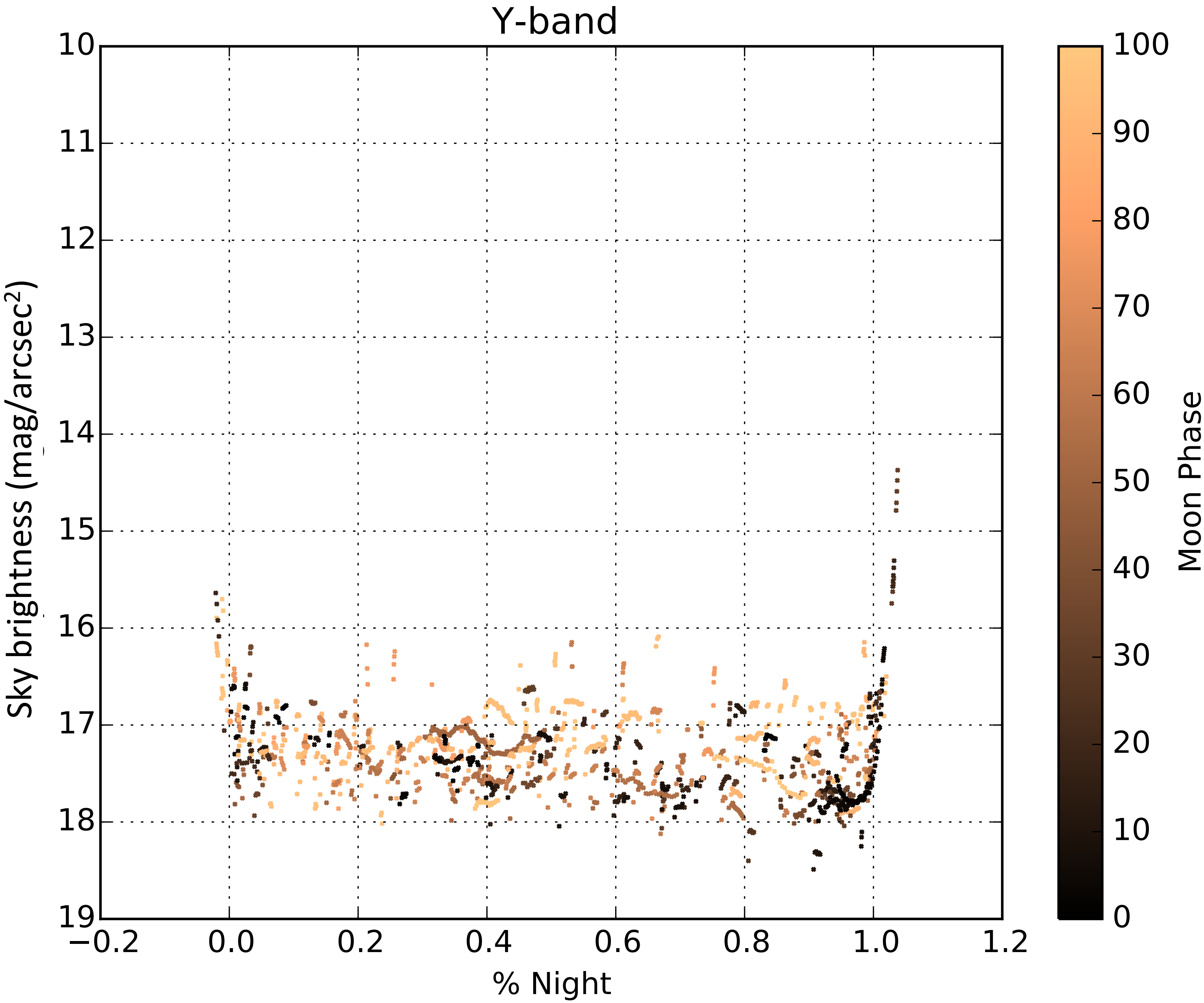


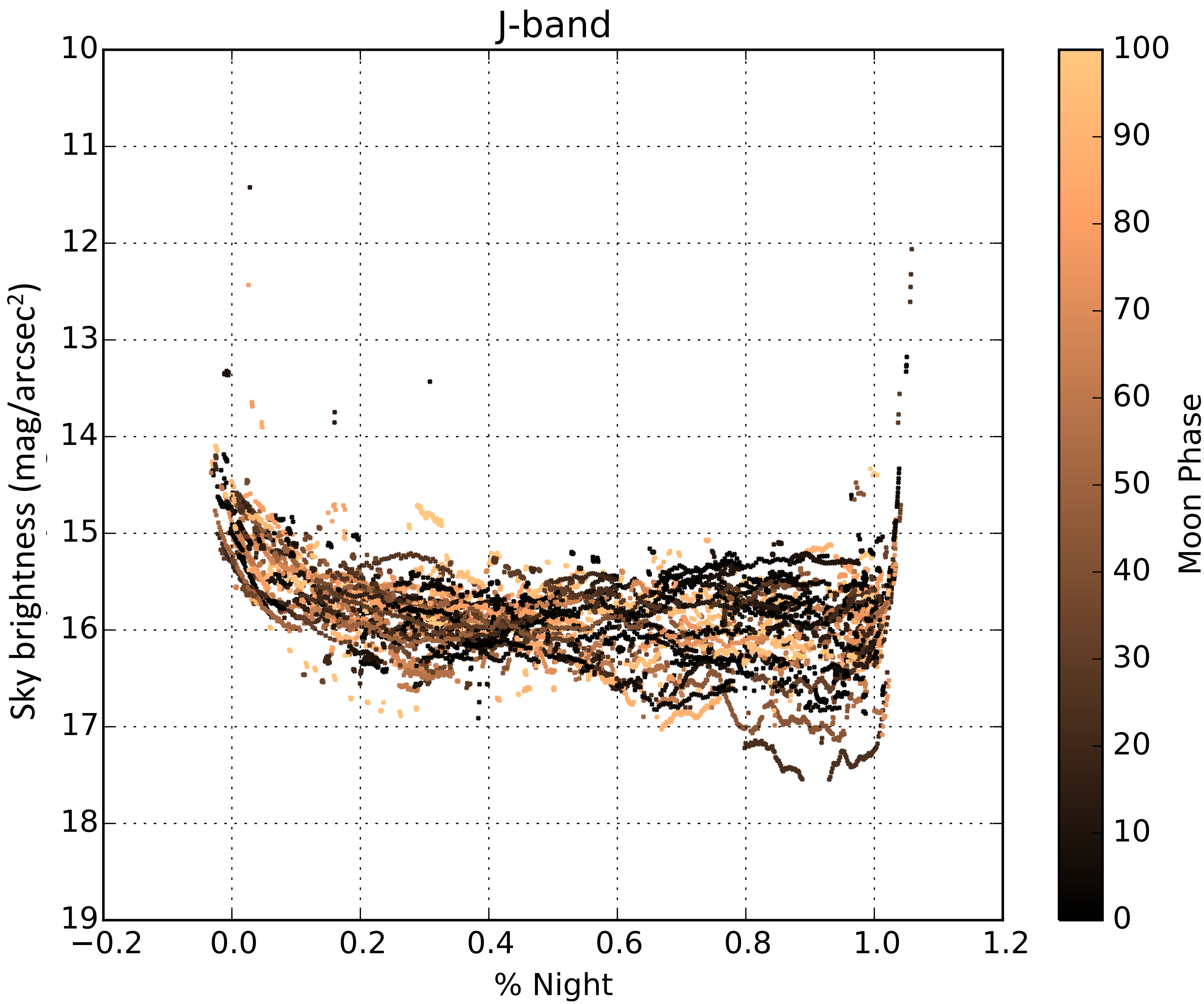
r-band
16
17
18
19
20
21
22
23
24
Sky brightness (mag/arcsec^2)
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
% Night
100
90
80
70
60
50
40
30
20
10
0
Moon Phase


i-band
Sky brightness (mag/arcsec^2)
% Night
Moon Phase
16
17
18
19
20
21
22
23
24
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
100
90
80
70
60
50
40
30
20
10
0

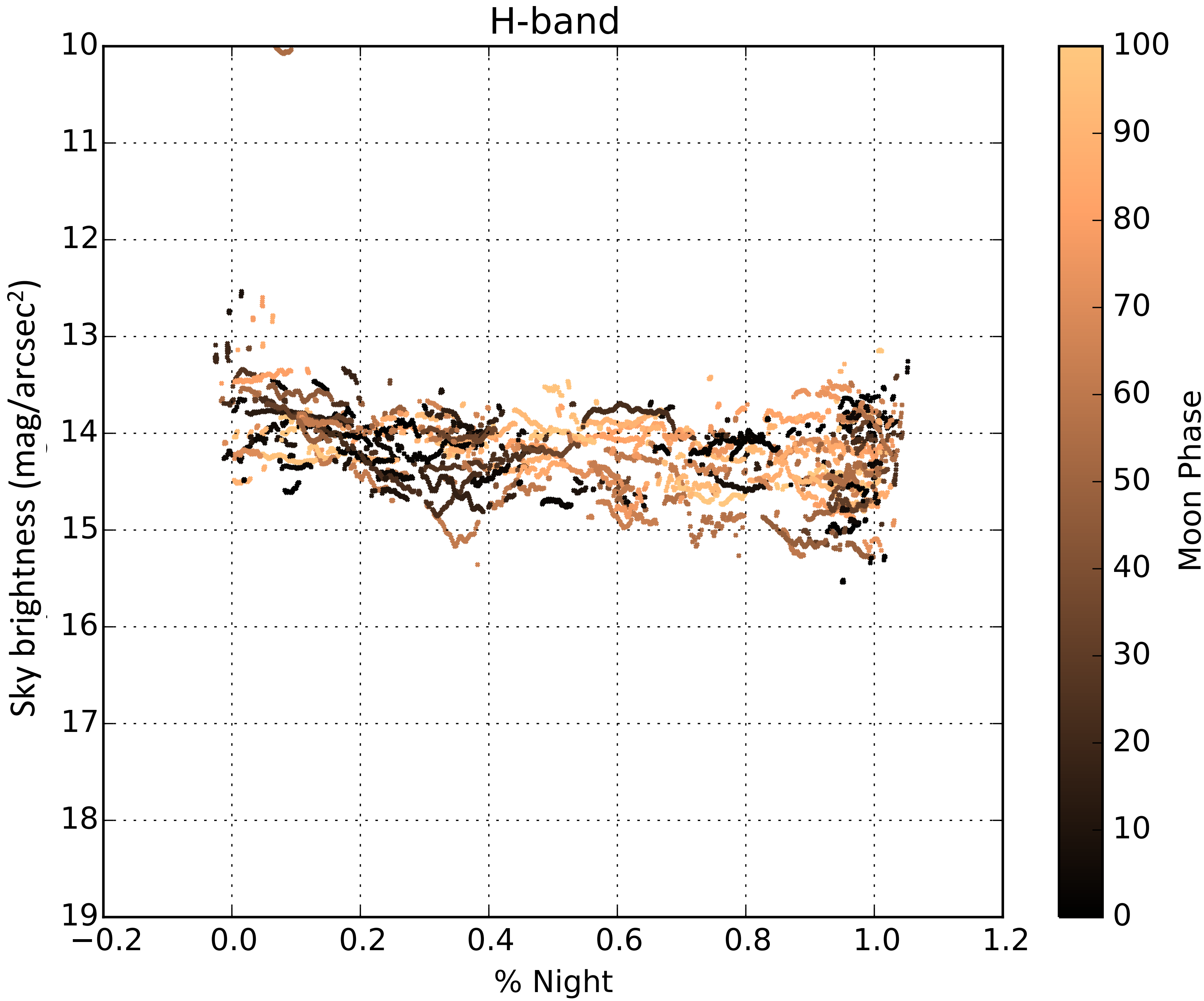


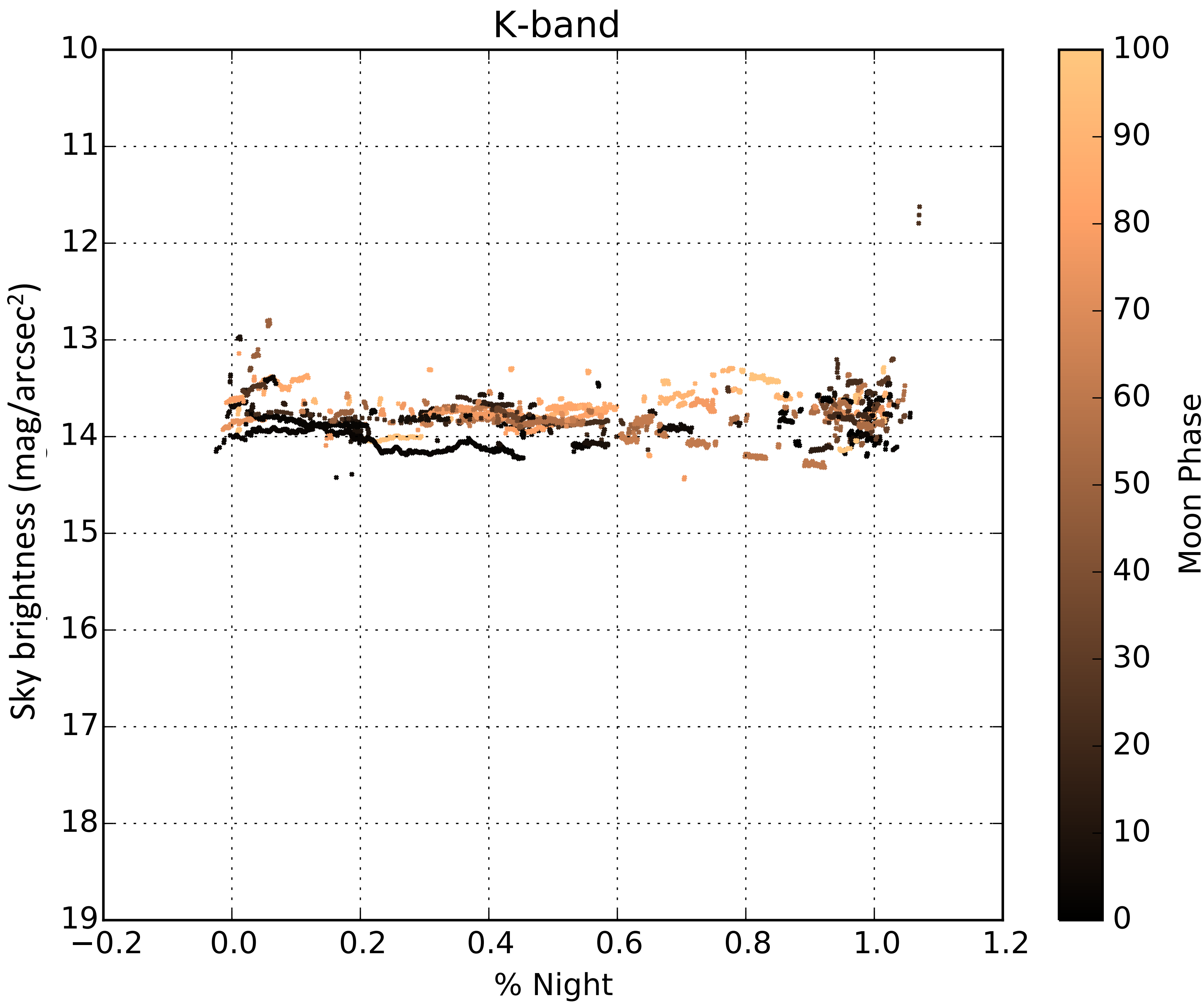
Z-band
Sky brightness (mag/arcsec^2)
% Night
Moon Phase
16
17
18
19
20
21
22
23
24
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
100
90
80
70
60
50
40
30
20
10
0


Y-band
Sky brightness (mag/arcsec^2)
% Night
Moon Phase
10
11
12
13
14
15
16
17
18
19
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
100
90
80
70
60
50
40
30
20
10
0



J-band
Sky brightness (mag/arcsec^2)
% Night
Moon Phase
10
11
12
13
14
15
16
17
18
19
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
100
90
80
70
60
50
40
30
20
10
0

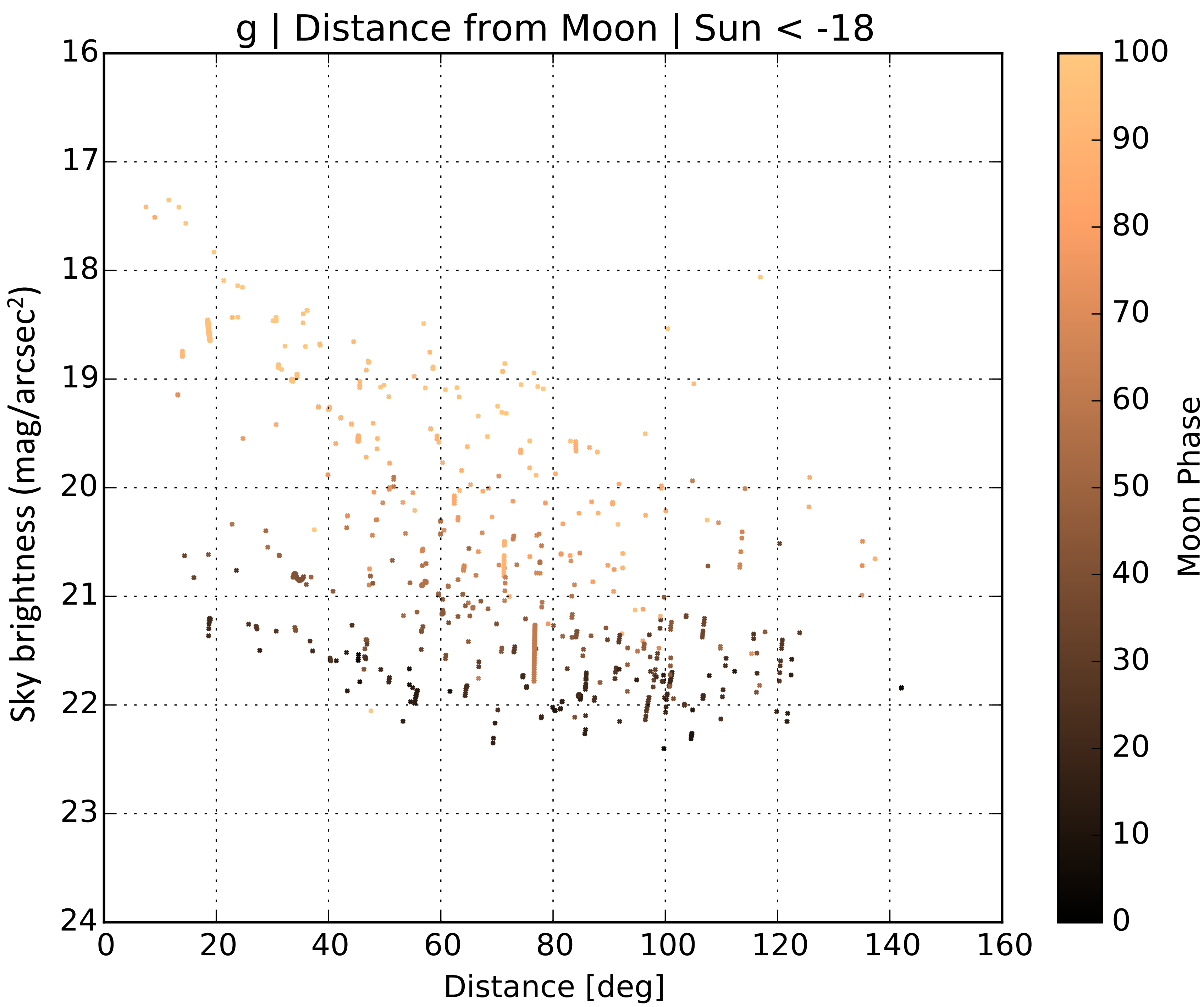

H-band
Sky brightness (mag/arcsec^2)
% Night
Moon Phase
10
11
12
13
14
15
16
17
18
19
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
100
90
80
70
60
50
40
30
20
10
0



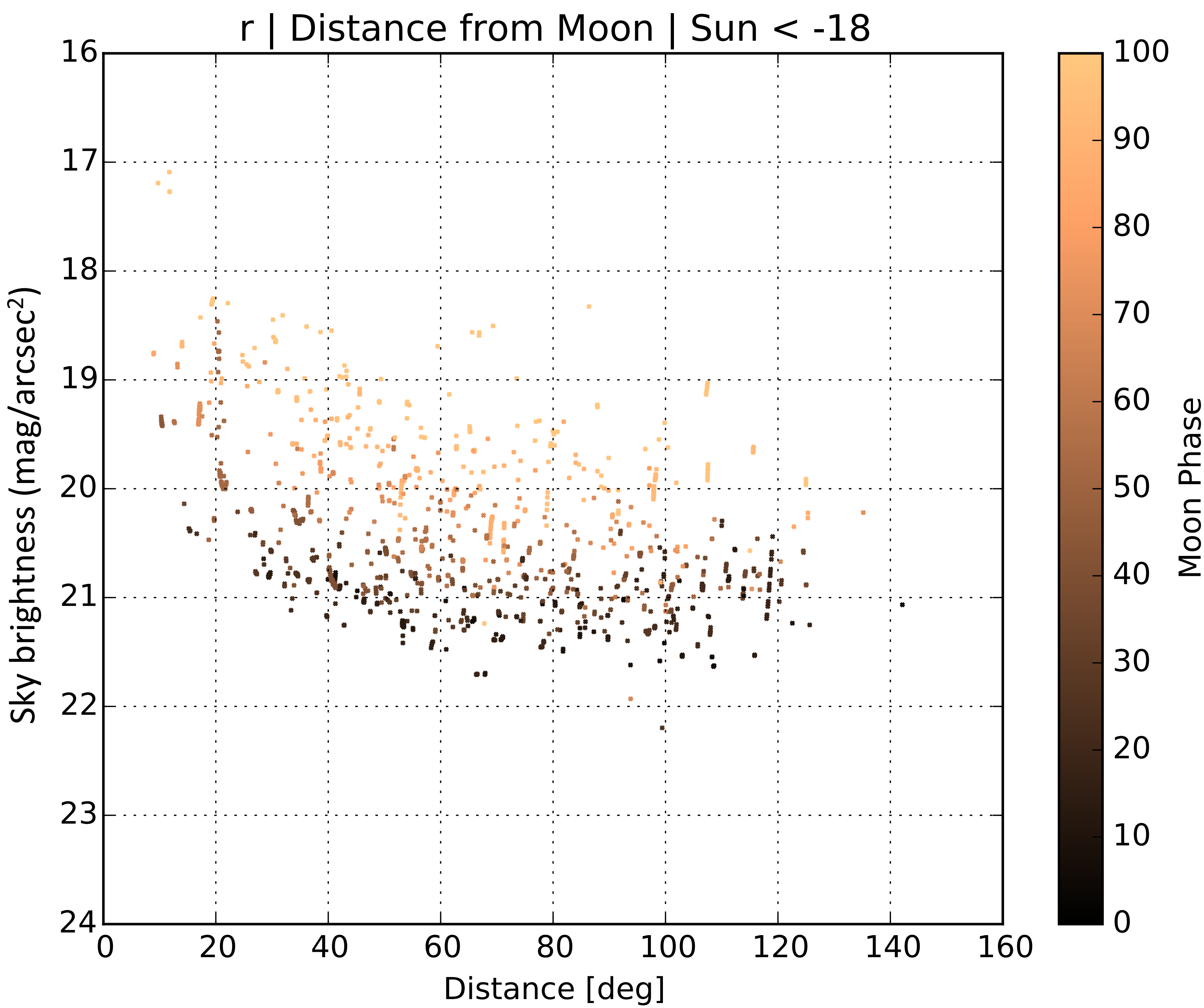
K-band
Sky brightness (mag/arcsec^2)
% Night
Moon Phase
10
11
12
13
14
15
16
17
18
19
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
100
90
80
70
60
50
40
30
20
10
0

Target – Moon distance

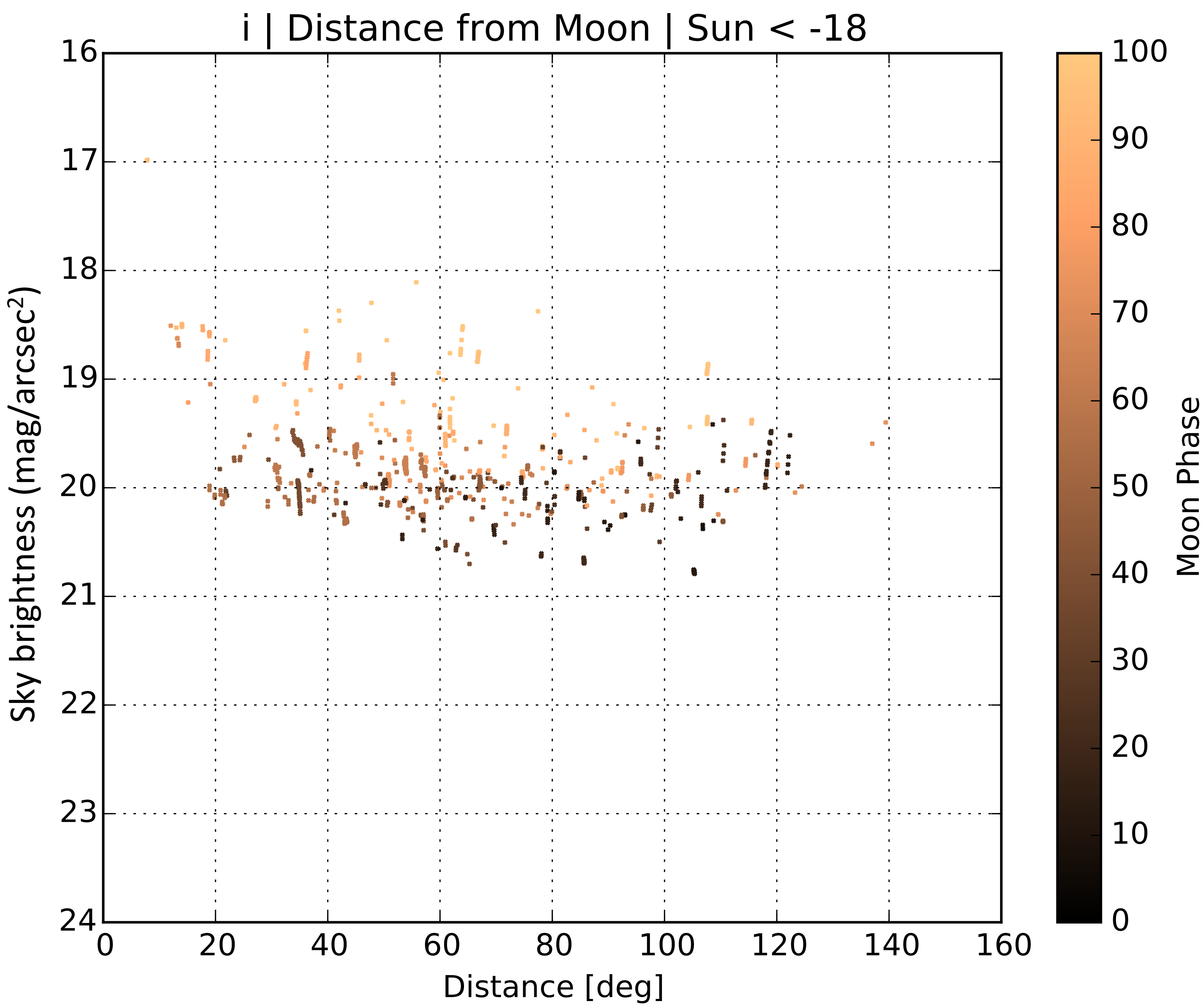
- Sky brightness plotted as a function of distance from the moon, sun below -18 and moon above horizon
- Only optical data show a dependence on the moon phase and distance from the moon.
- Strongest correlation in g-band
- z,Y show no correlation unless very close to the bright moon
- J, H, K do not see the moon



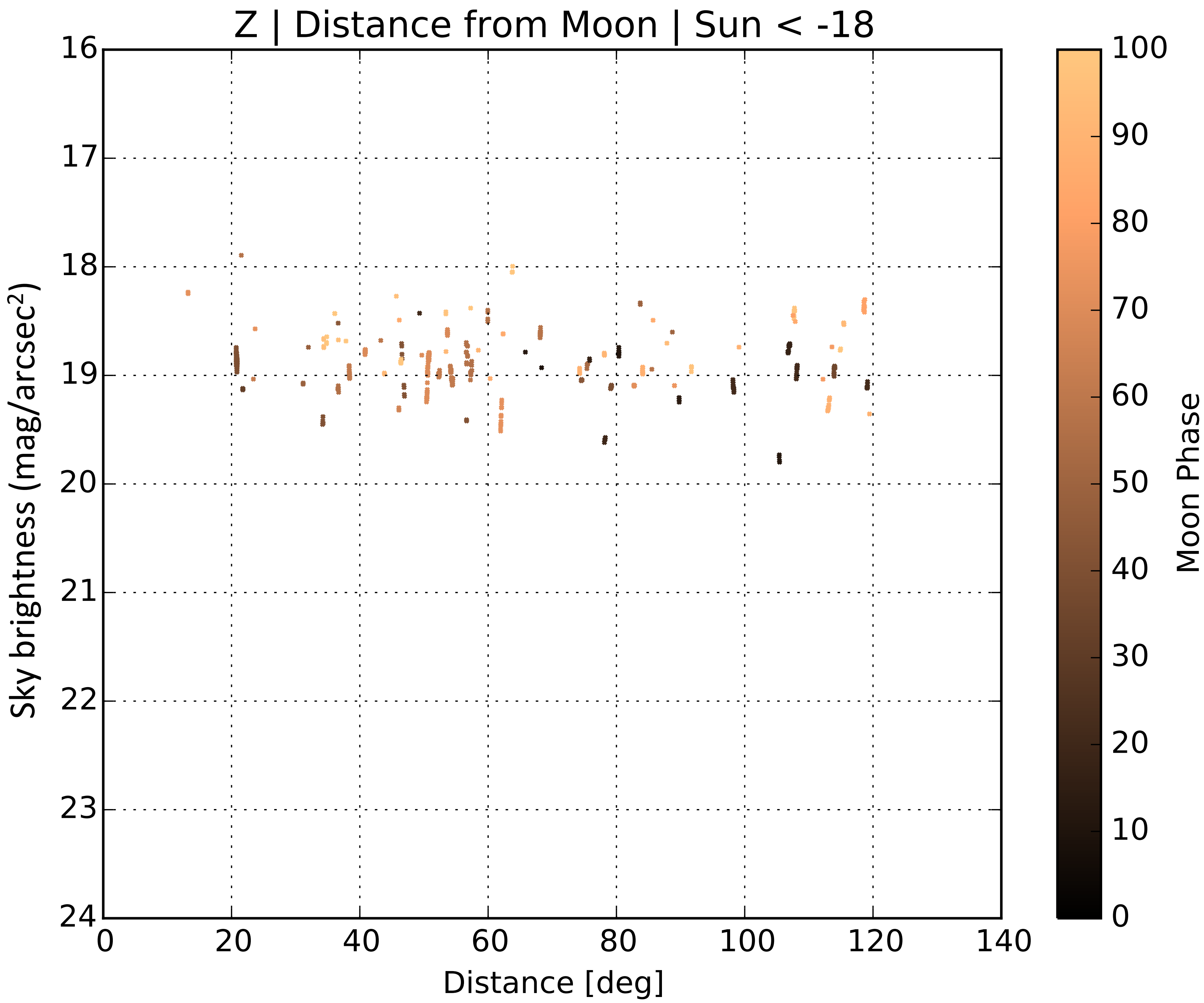
g | Distance from Moon | Sun < -18
Sky brightness (mag/arcsec^2)
16
17
18
19
20
21
22
23
24
0
20
40
60
80
100
120
140
160
Distance [deg]
Moon Phase
100
90
80
70
60
50
40
30
20
10
0

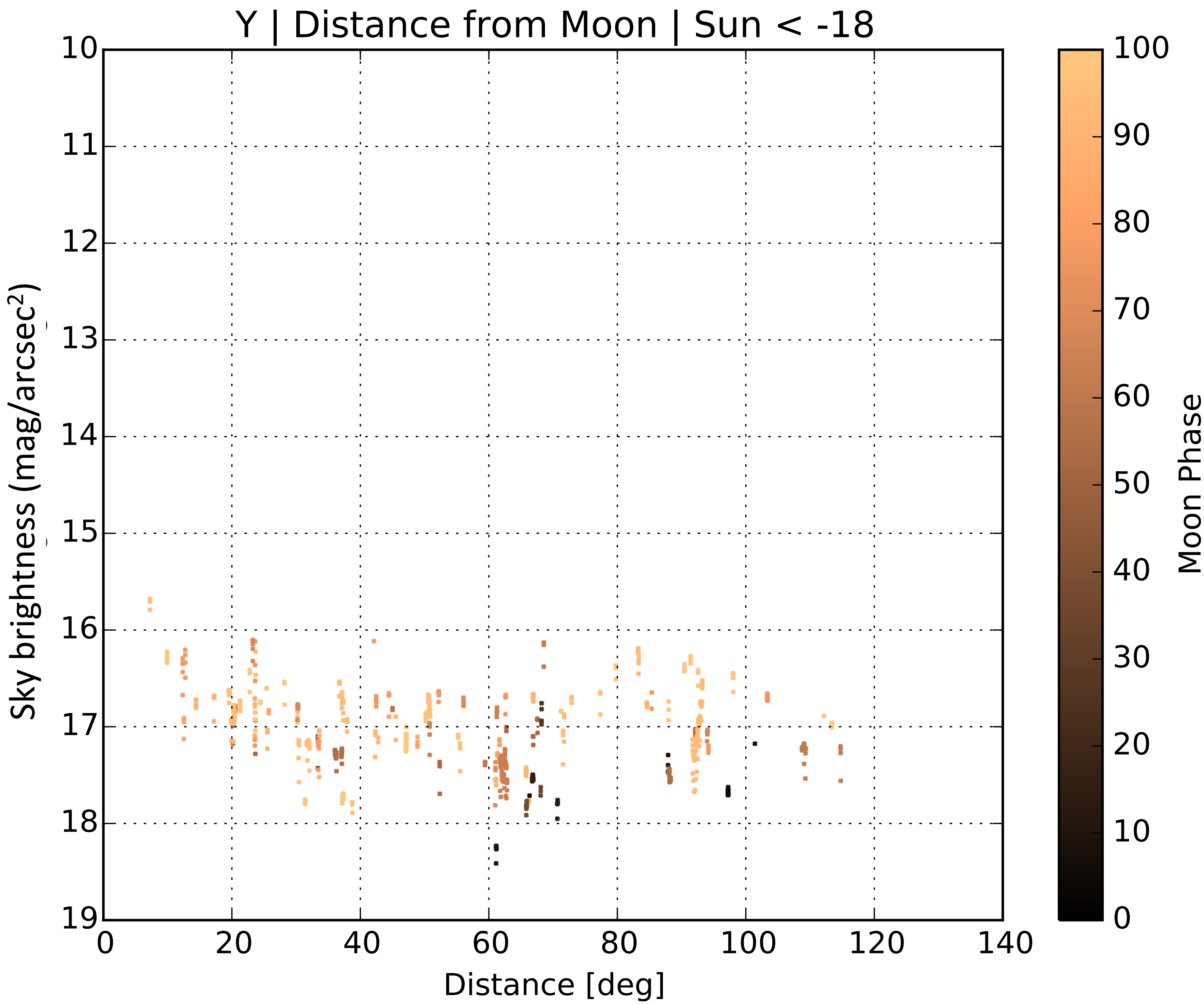


r | Distance from Moon | Sun < -18
Sky brightness (mag/arcsec^2)
Distance [deg]
Moon Phase
16
17
18
19
20
21
22
23
24
0
20
40
60
80
100
120
140
160
100
90
80
70
60
50
40
30
20
10
0

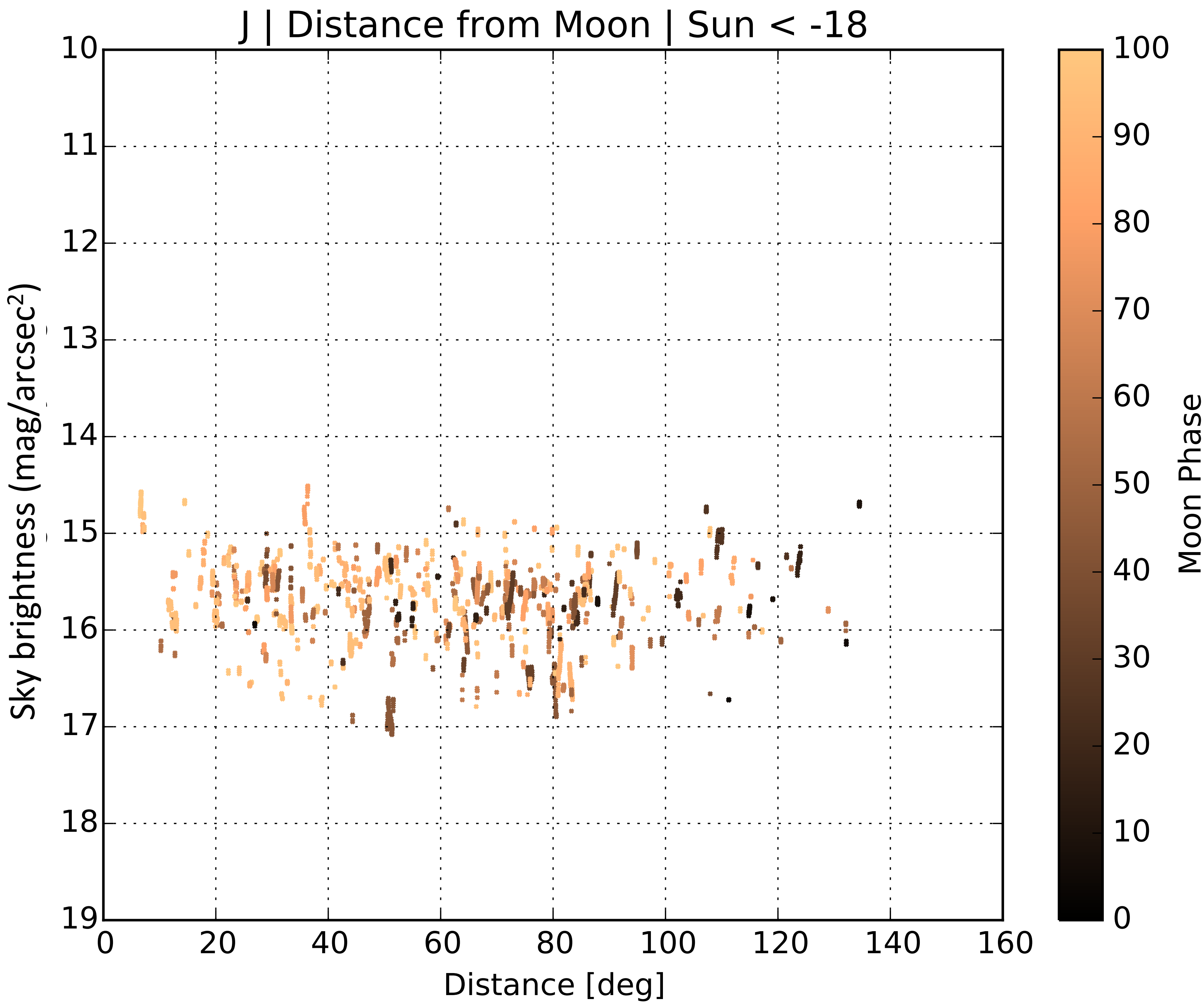


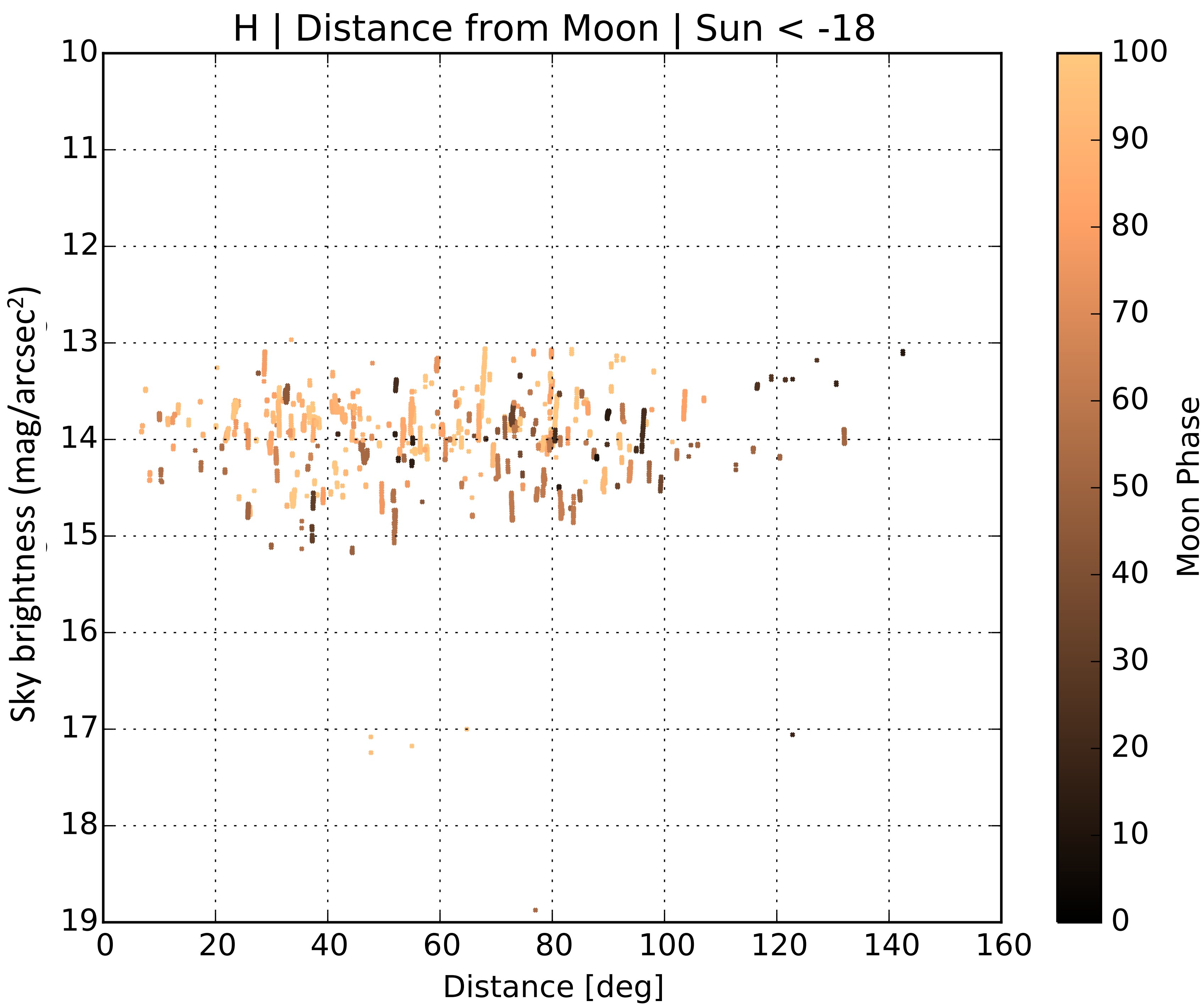
i | Distance from Moon | Sun < -18
Sky brightness (mag/arcsec^2)
16
17
18
19
20
21
22
23
24
0
20
40
60
80
100
120
140
160
Distance [deg]
Moon Phase
100
90
80
70
60
50
40
30
20
10
0

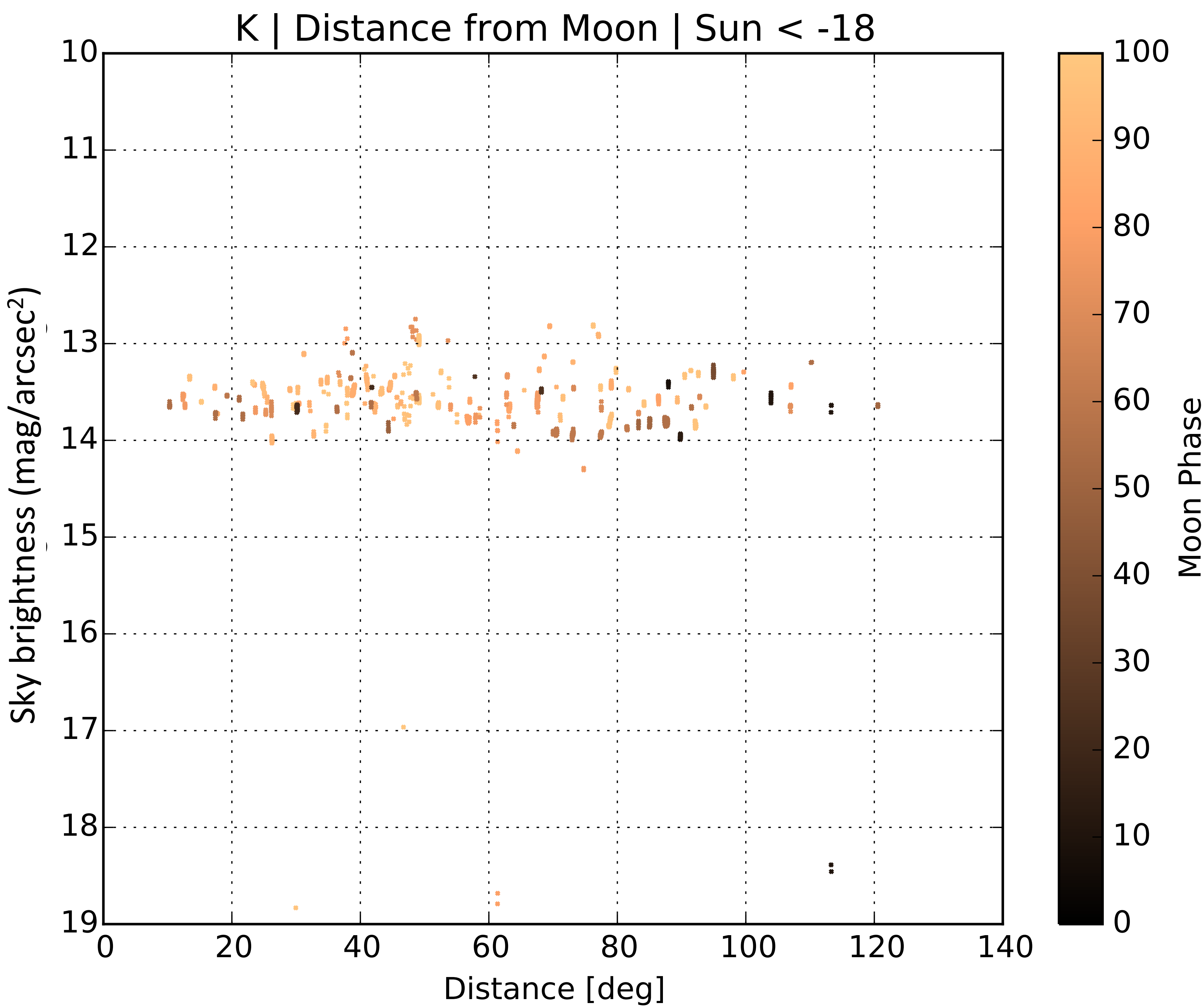

Z | Distance from Moon | Sun < -18
Sky brightness (mag/arcsec^2)
Distance [deg]
Moon Phase
16
17
18
19
20
21
22
23
24
0
20
40
60
80
100
120
140
0
10
20
30
40
50
60
70
80
90
100



Y | Distance from Moon | Sun < -18
Sky brightness (mag/arcsec^2)
Distance [deg]
Moon Phase
10
11
12
13
14
15
16
17
18
19
0
20
40
60
80
100
120
140
0
10
20
30
40
50
60
70
80
90
100


J | Distance from Moon | Sun < -18
Sky brightness (mag/arcsec^2)
10
11
12
13
14
15
16
17
18
19
0
20
40
60
80
100
120
140
160
Distance [deg]
Moon Phase
100
90
80
70
60
50
40
30
20
10
0

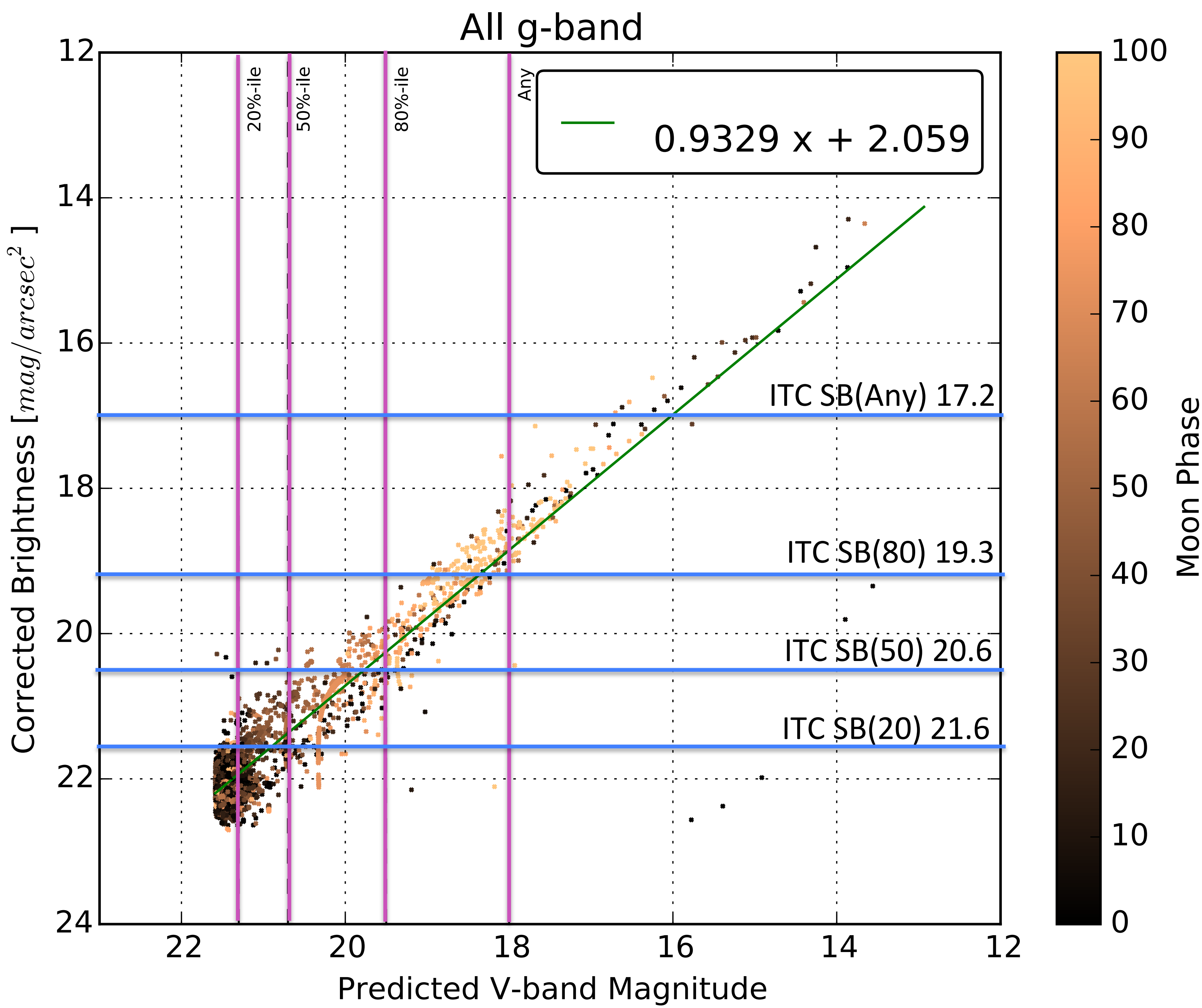

H | Distance from Moon | Sun < -18
Sky brightness (mag/arcsec^2)
Distance [deg]
Moon Phase
10
11
12
13
14
15
16
17
18
19
0
20
40
60
80
100
120
140
160
0
10
20
30
40
50
60
70
80
90
100



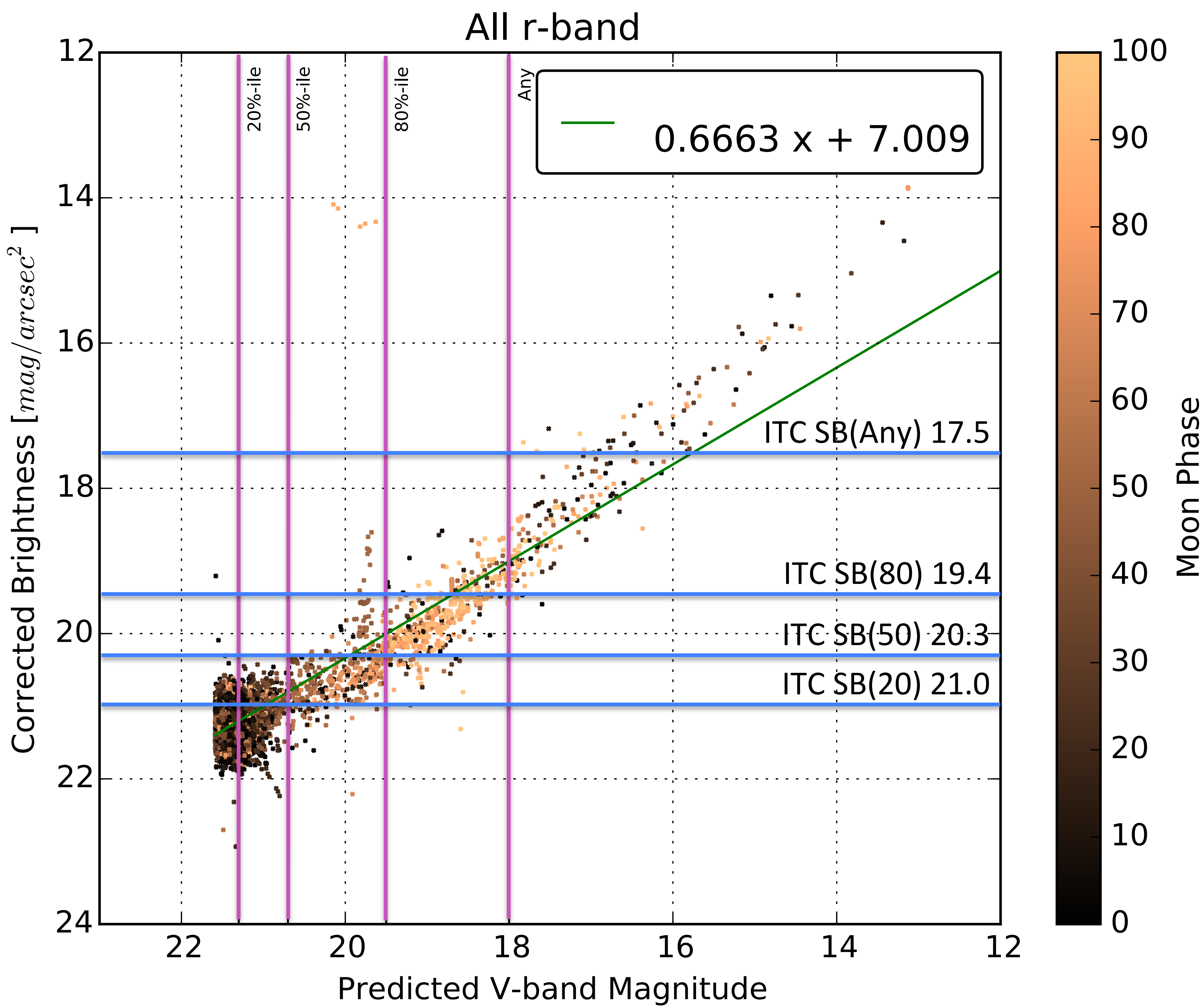
K | Distance from Moon | Sun < -18
Sky brightness (mag/arcsec^2)
Distance [deg]
Moon Phase
10
11
12
13
14
15
16
17
18
19
0
20
40
60
80
100
120
140
100
90
80
70
60
50
40
30
20
10
0

Gemini Sky Background Observing Condition

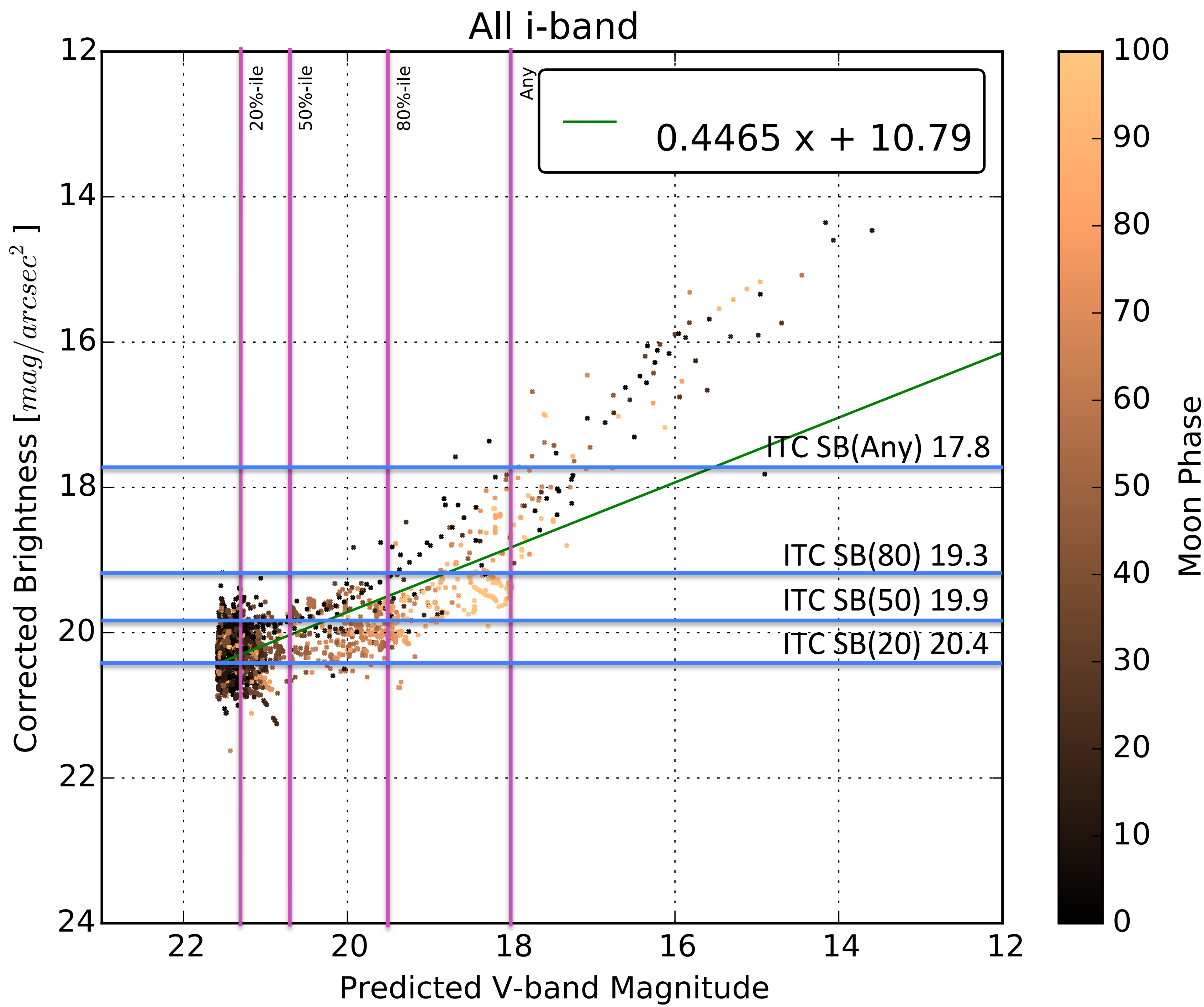
- Sky background combination of Sun and moon position, moon phase, zodiacal light based on visible observations and scattering models
- Gemini PIs use ITC to derive expected sensitivity of their imaging data for a given sky background (20,50,80,Any) between Nautical Twilights
- Gemini queue coordinators use QPT to schedule observations in conditions that do not violate the observing conditions awarded
- In the infrared, QPT and ITC do not attempt to model the sky background

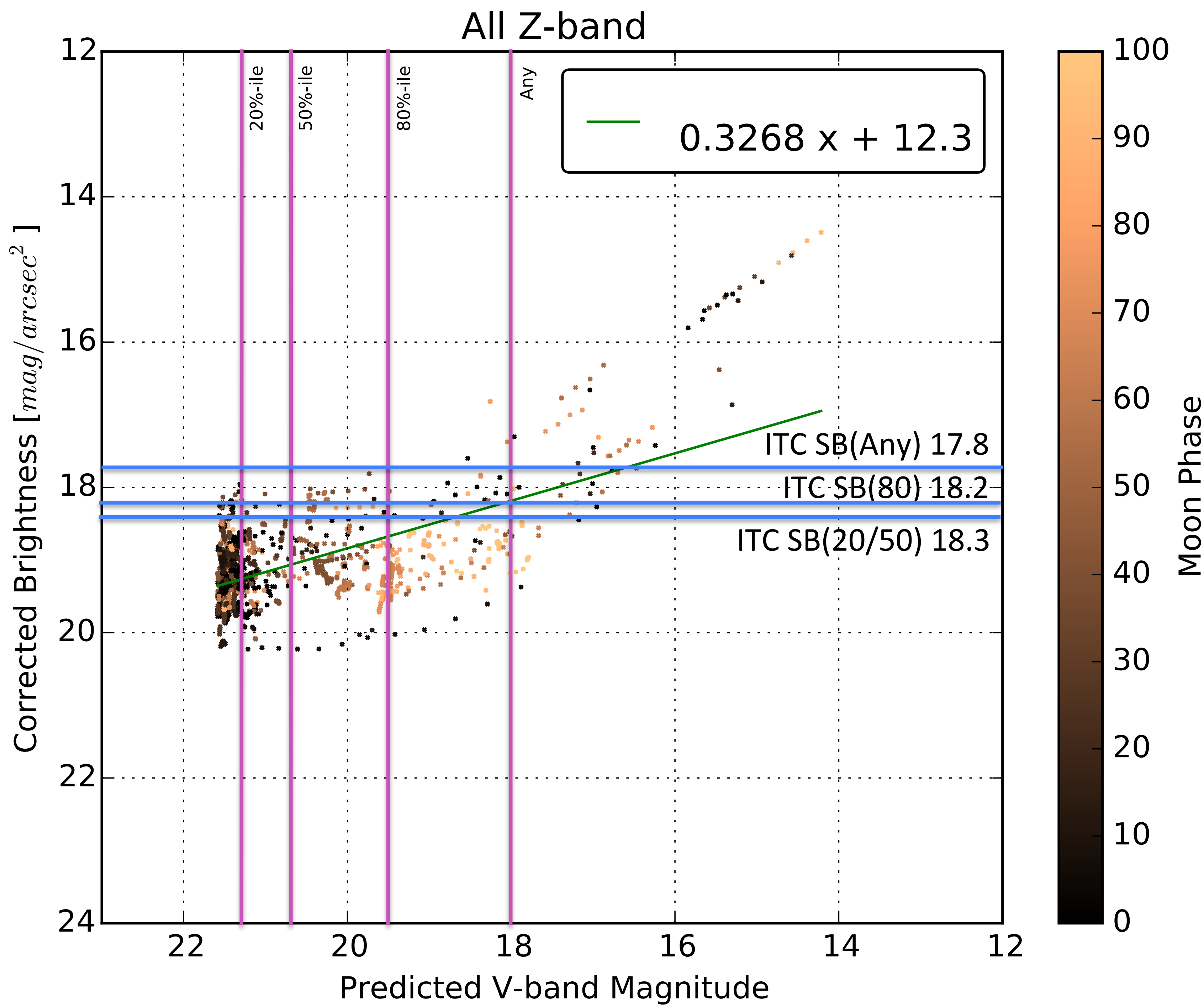


All g-band
20%-ile
50%-ile
80%-ile
Any
0.9329 x + 2.059
ITC SB(Any) 17.2
ITC SB(80) 19.3
ITC SB(50) 20.6
ITC SB(20) 21.6
Corrected Brightness [$mag/arcsec^2$]
Predicted V-band Magnitude
Moon Phase
12
14
16
18
20
22
24
22
20
18
16
14
12
100
90
80
70
60
50
40
30
20
10
0

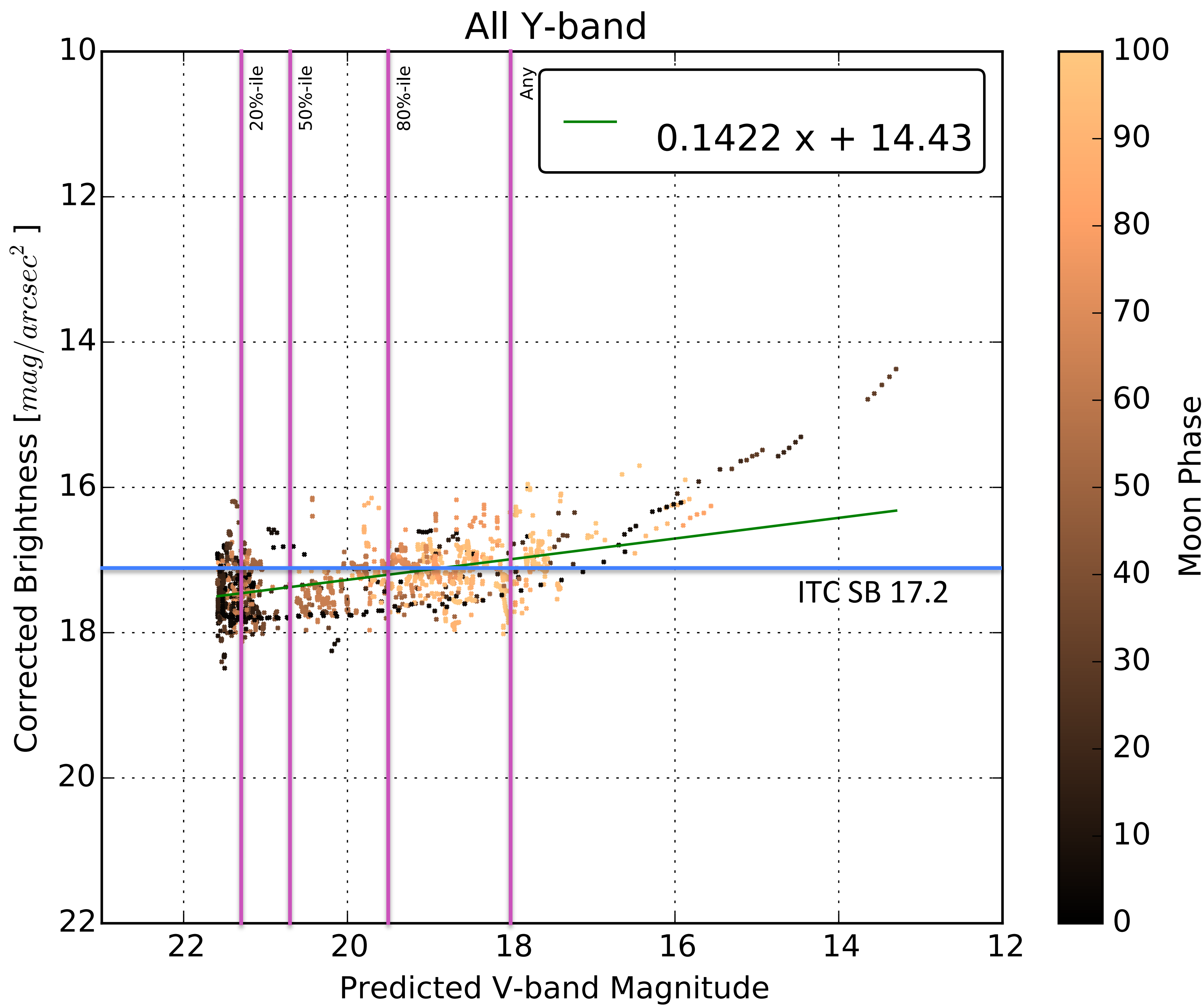


All r-band
0.6663 x + 7.009
20%-ile
50%-ile
80%-ile
Any
ITC SB(Any) 17.5
ITC SB(80) 19.4
ITC SB(50) 20.3
ITC SB(20) 21.0
Corrected Brightness [$mag/arcsec^2$]
Predicted V-band Magnitude
Moon Phase
12
14
16
18
20
22
24
22
20
18
16
14
12
0
10
20
30
40
50
60
70
80
90
100

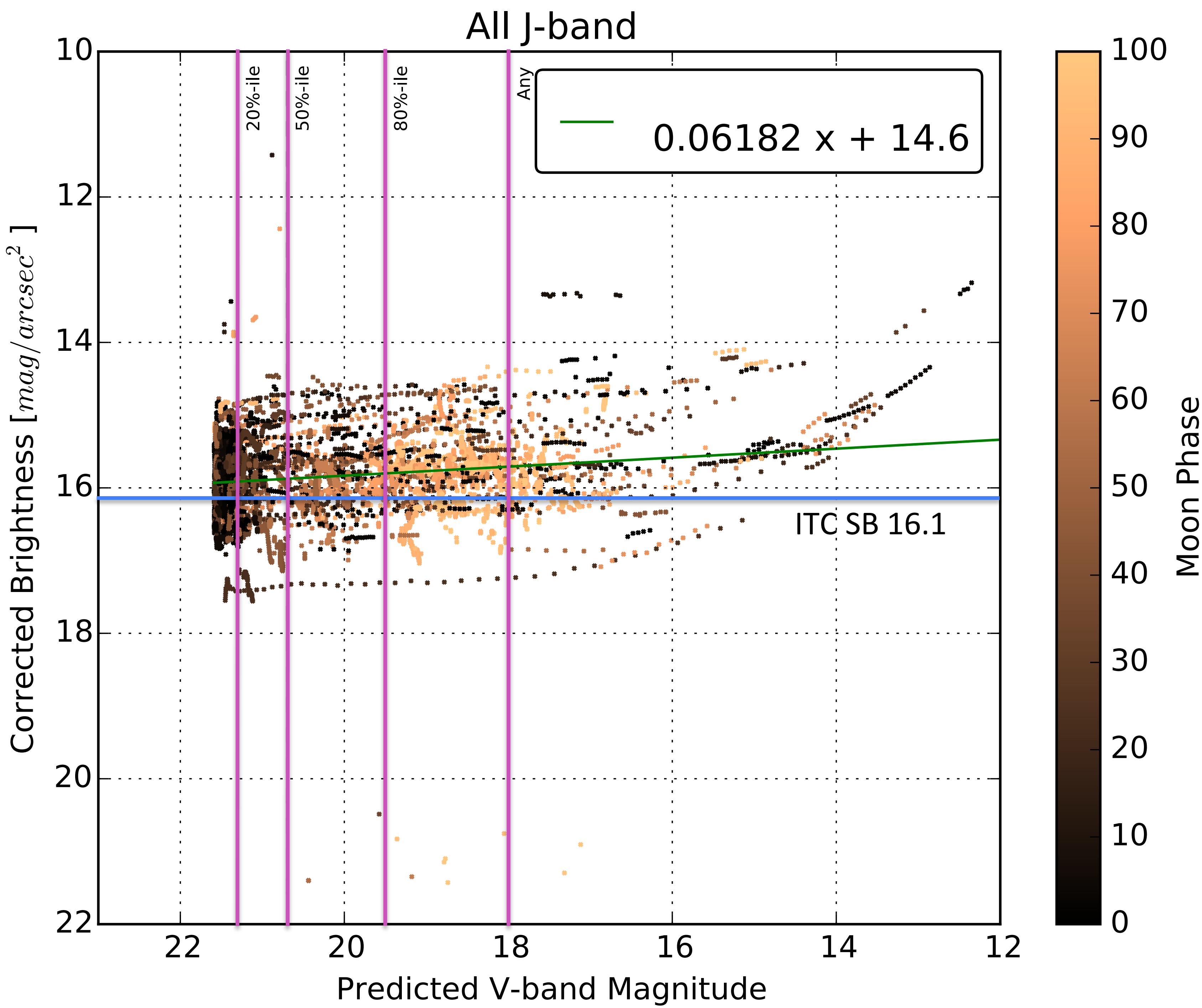

All i-band
0.4465 x + 10.79
20%-ile
50%-ile
80%-ile
Any
ITC SB(Any) 17.8
ITC SB(80) 19.3
ITC SB(50) 19.9
ITC SB(20) 20.4
Corrected Brightness [$mag/arcsec^2$]
Predicted V-band Magnitude
Moon Phase
12
14
16
18
20
22
24
22
20
18
16
14
12
100
90
80
70
60
50
40
30
20
10
0

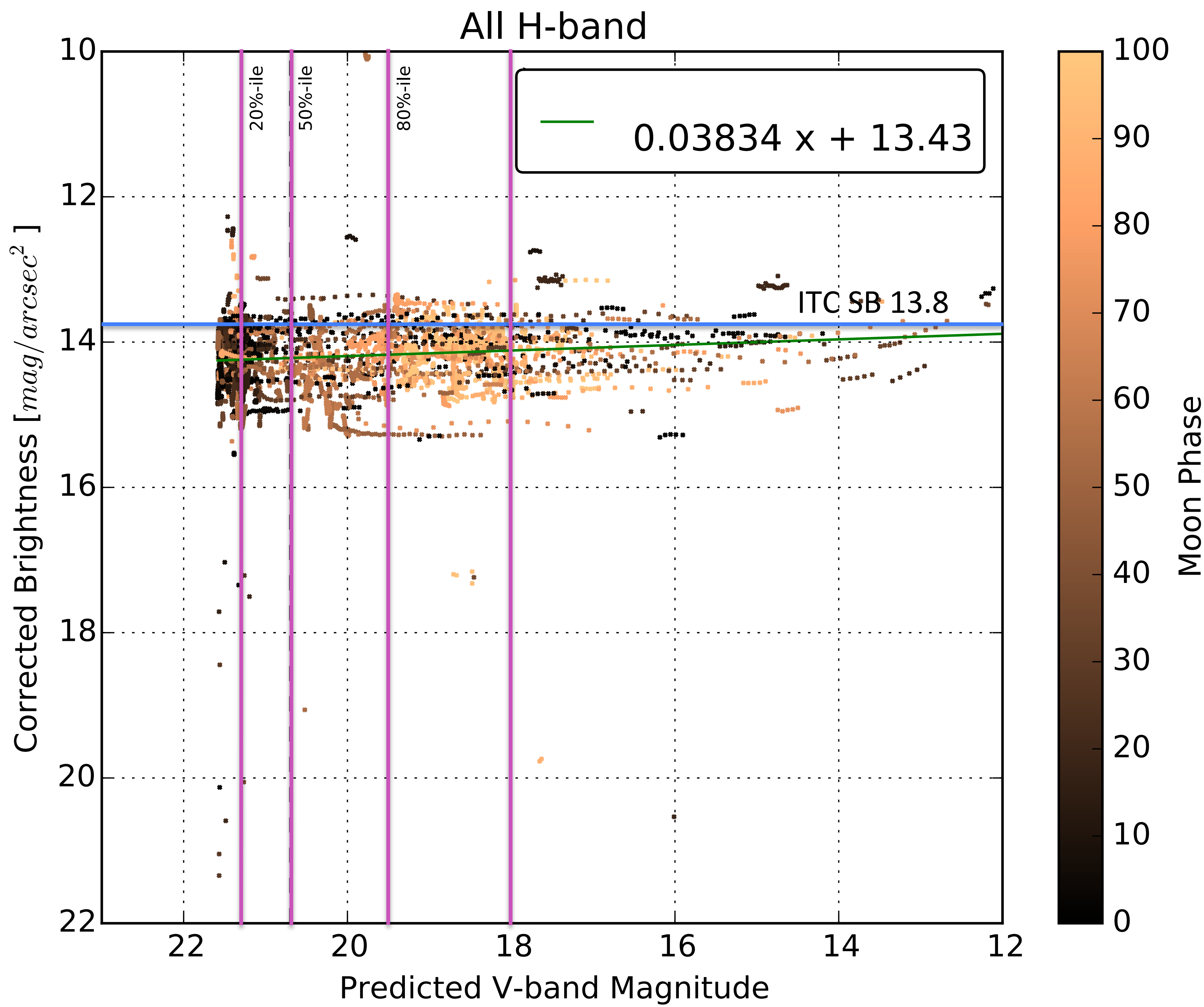


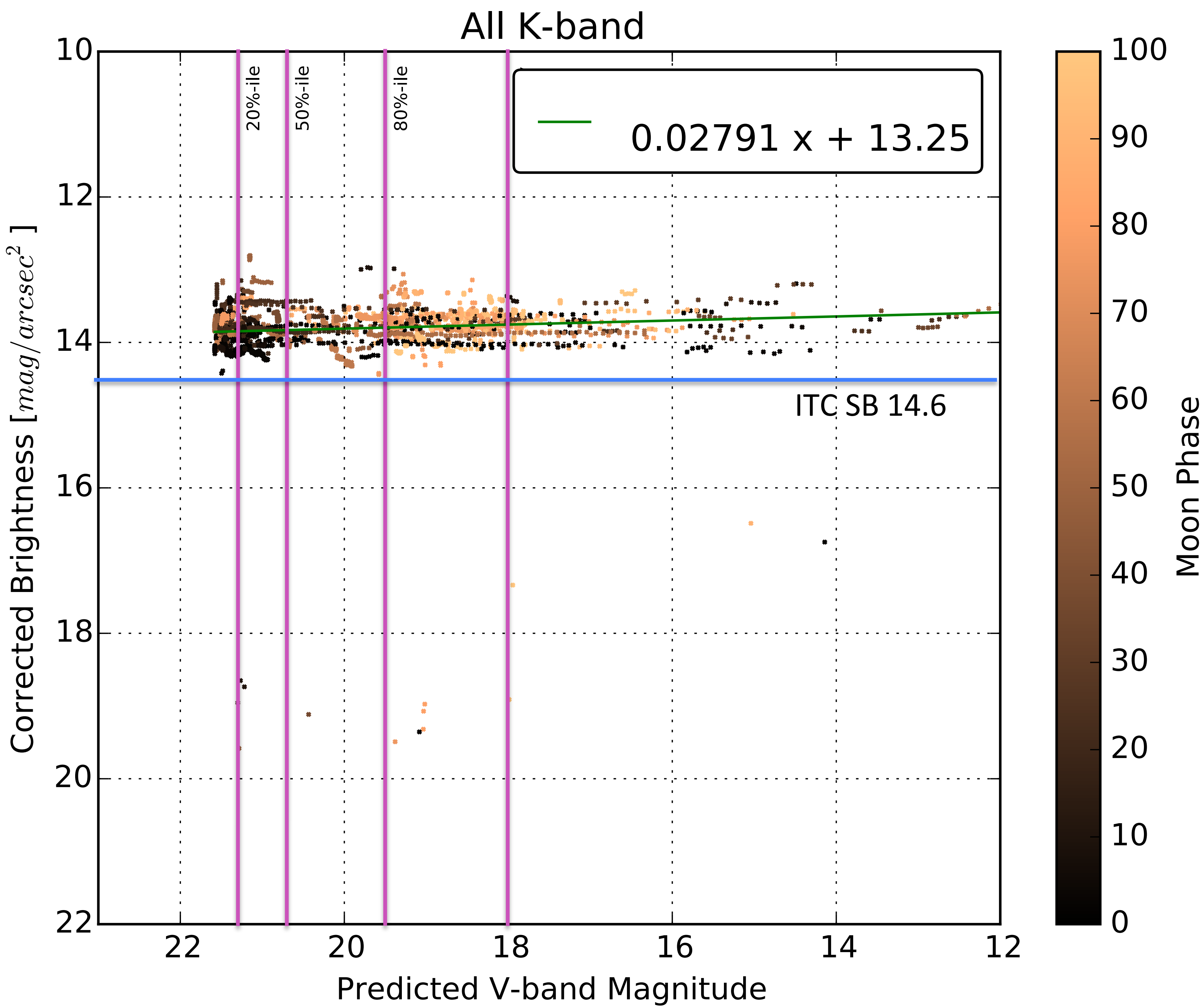
All Z-band
0.3268 x + 12.3
20%-ile
50%-ile
80%-ile
Any
ITC SB(Any) 17.8
ITC SB(80) 18.2
ITC SB(20/50) 18.3
Corrected Brightness [$mag/arcsec^2$]
Predicted V-band Magnitude
Moon Phase



All Y-band
0.1422 x + 14.43
20%-ile
50%-ile
80%-ile
Any
ITC SB 17.2
Corrected Brightness [$mag/arcsec^2$]
Predicted V-band Magnitude
Moon Phase
10
12
14
16
18
20
22
22
20
18
16
14
12
0
10
20
30
40
50
60
70
80
90
100


All J-band
20%-ile
50%-ile
80%-ile
Any
0.06182 x + 14.6
ITC SB 16.1
Corrected Brightness [$mag/arcsec^2$]
Predicted V-band Magnitude
Moon Phase
10
12
14
16
18
20
22
22
20
18
16
14
12
0
10
20
30
40
50
60
70
80
90
100

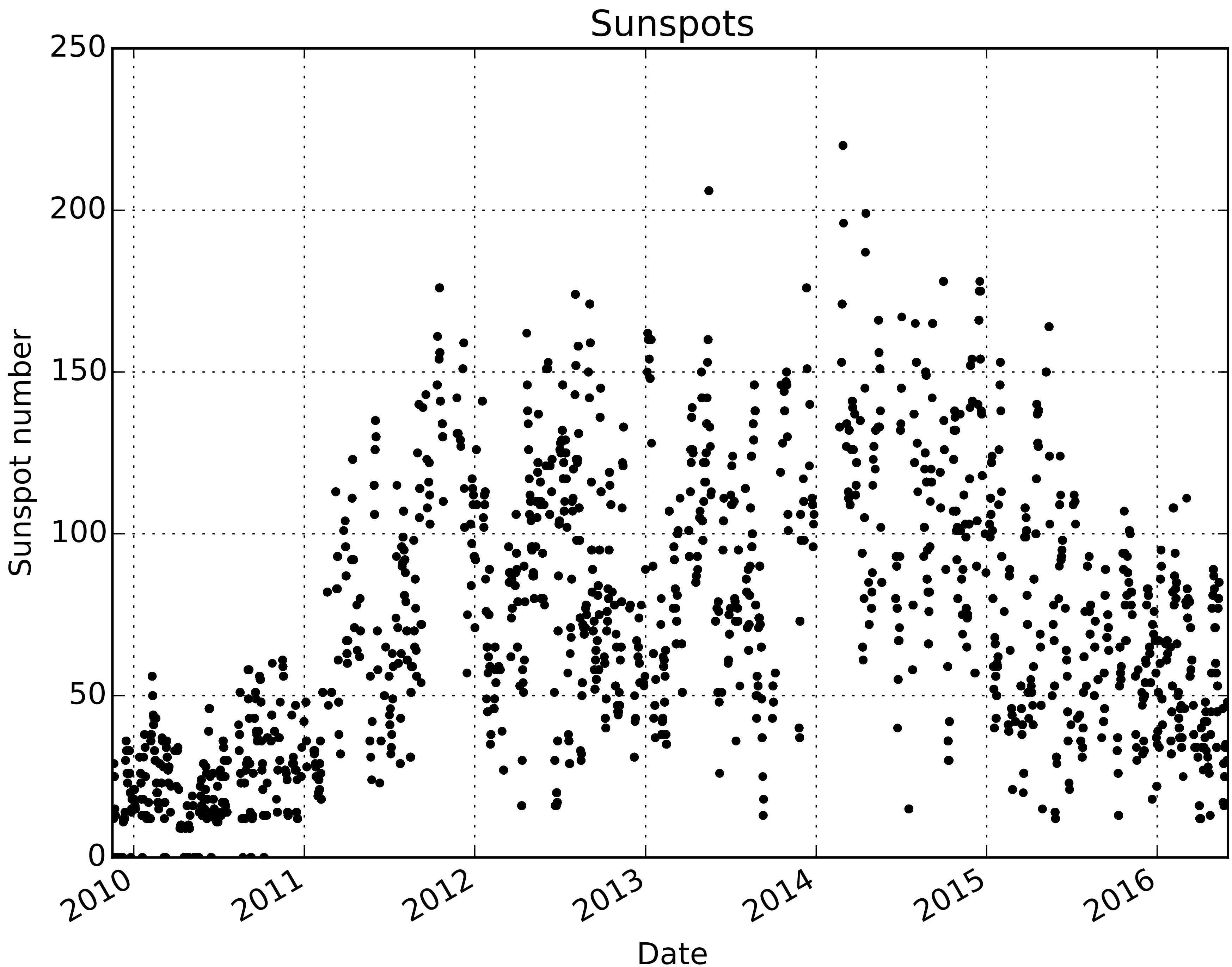

All H-band
0.03834 x + 13.43
20%-ile
50%-ile
80%-ile
ITC SB 13.8
Corrected Brightness [$mag/arcsec^2$]
Predicted V-band Magnitude
Moon Phase
10
12
14
16
18
20
22
22
20
18
16
14
12
100
90
80
70
60
50
40
30
20
10
0



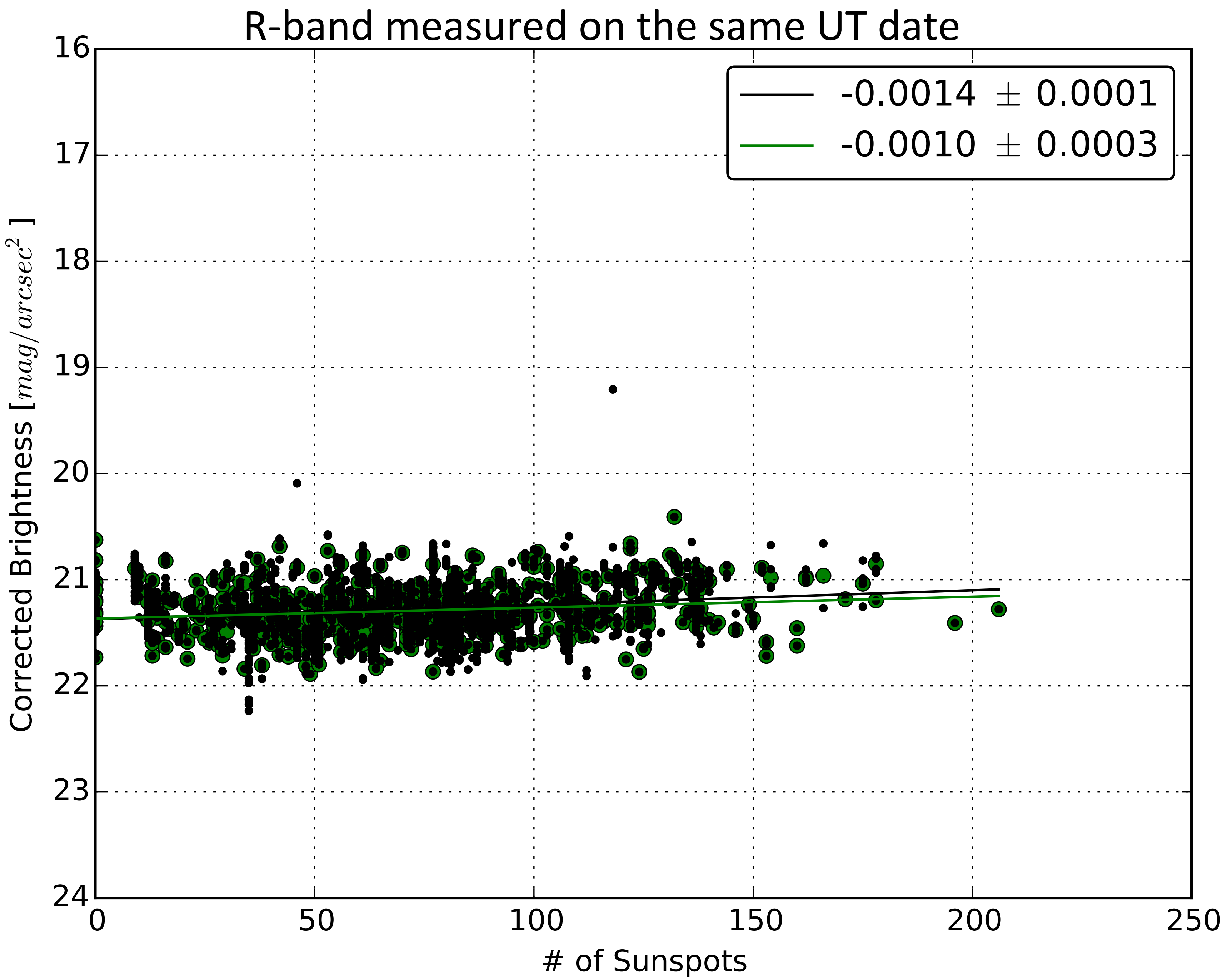
All K-band
0.02791 x + 13.25
20%-ile
50%-ile
80%-ile
ITC SB 14.6
Corrected Brightness [$mag/arcsec^2$]
Predicted V-band Magnitude
Moon Phase
10
12
14
16
18
20
22
22
20
18
16
14
12
100
90
80
70
60
50
40
30
20
10
0

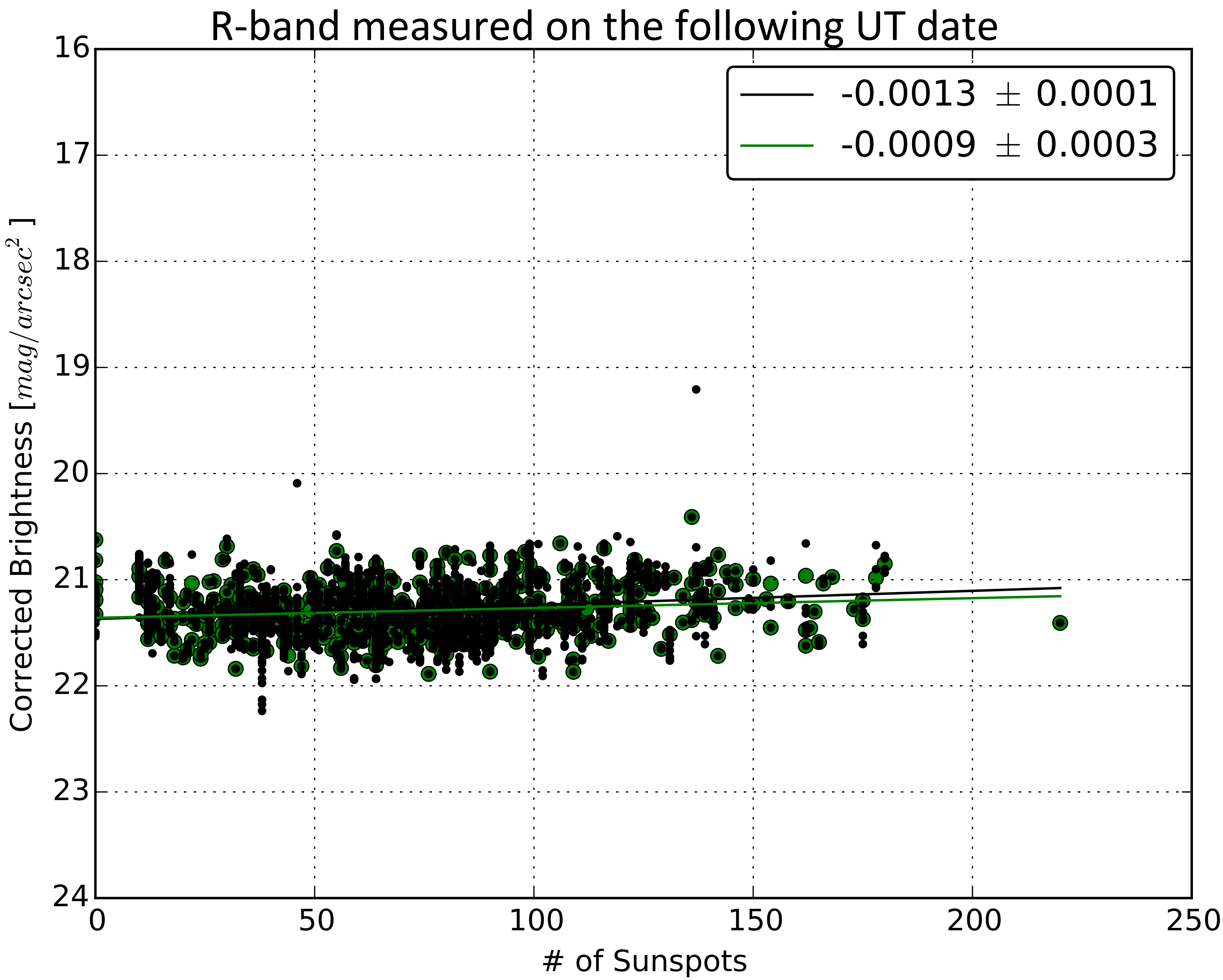
Other Fun Stuff

- Explore seasonal signature
- Looking for correlations with sun spots
- K-band thermal component correlation with ambient temperature
- Zodiacal Light

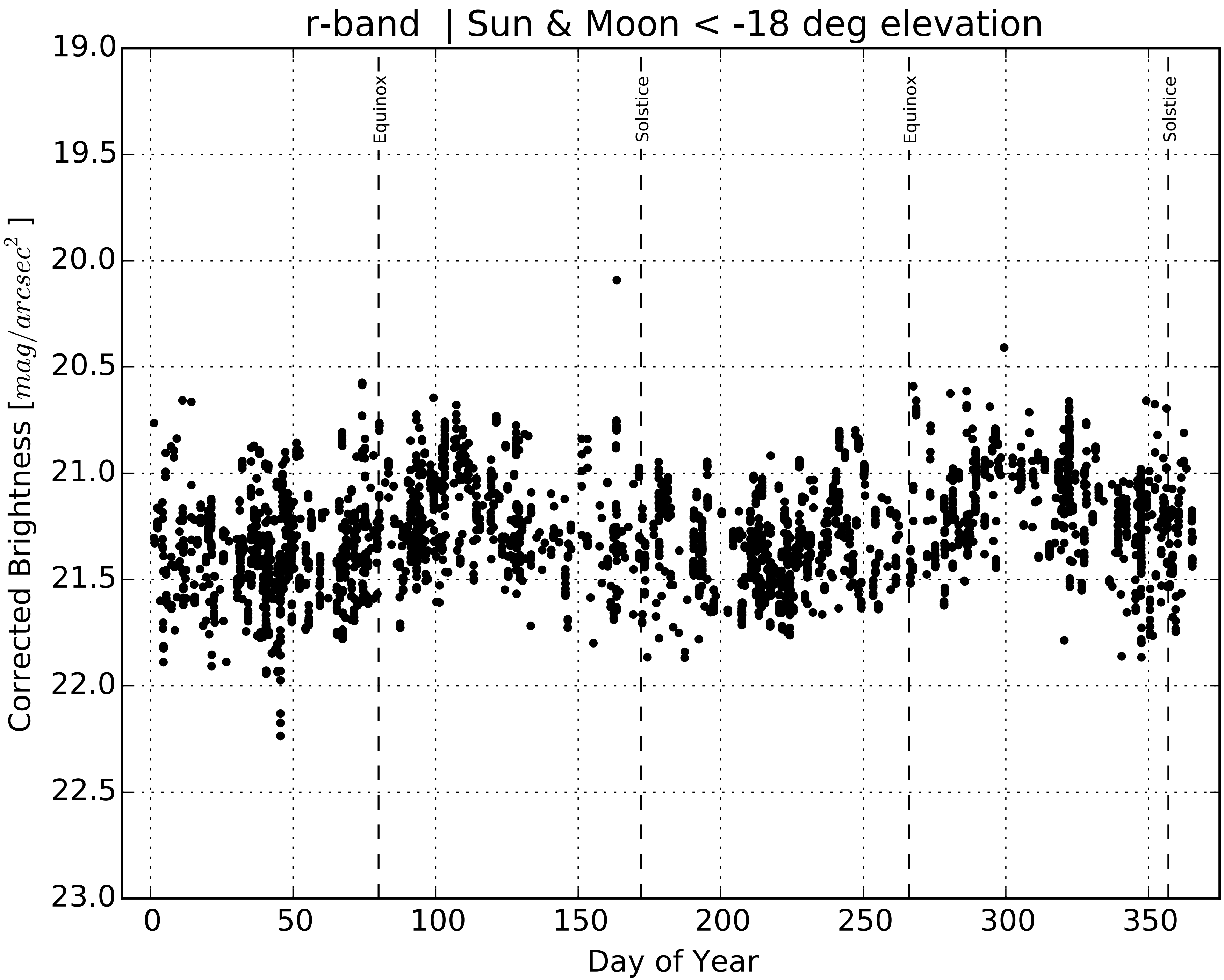


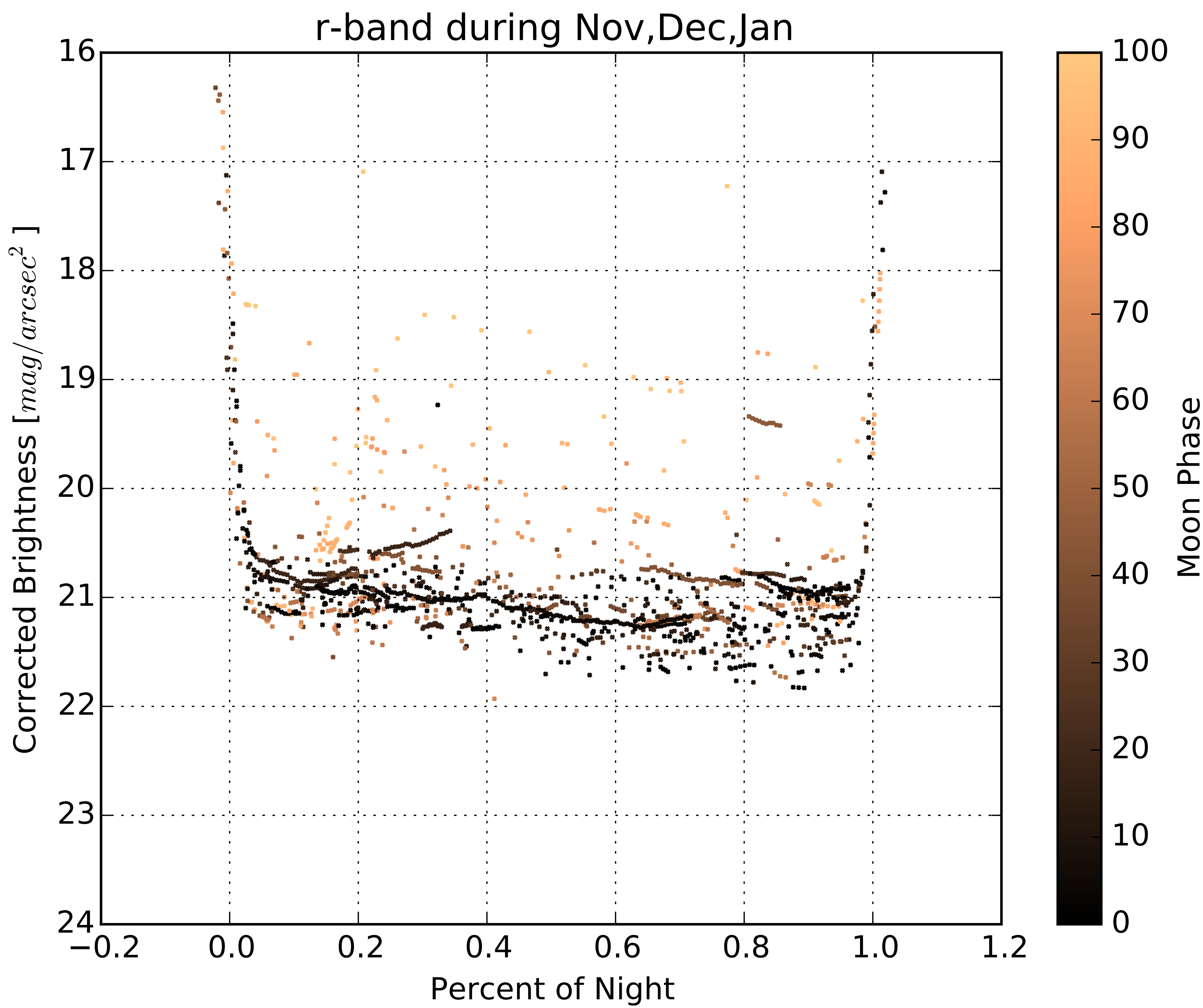
Sunspots
Sunspot number
Date
0
50
100
150
200
250
2010
2011
2012
2013
2014
2015
2016


R-band measured on the same UT date
-0.0014 ± 0.0001
-0.0010 ± 0.0003
Corrected Brightness [$mag/arcsec^2$]
# of Sunspots
16
17
18
19
20
21
22
23
24
0
50
100
150
200
250

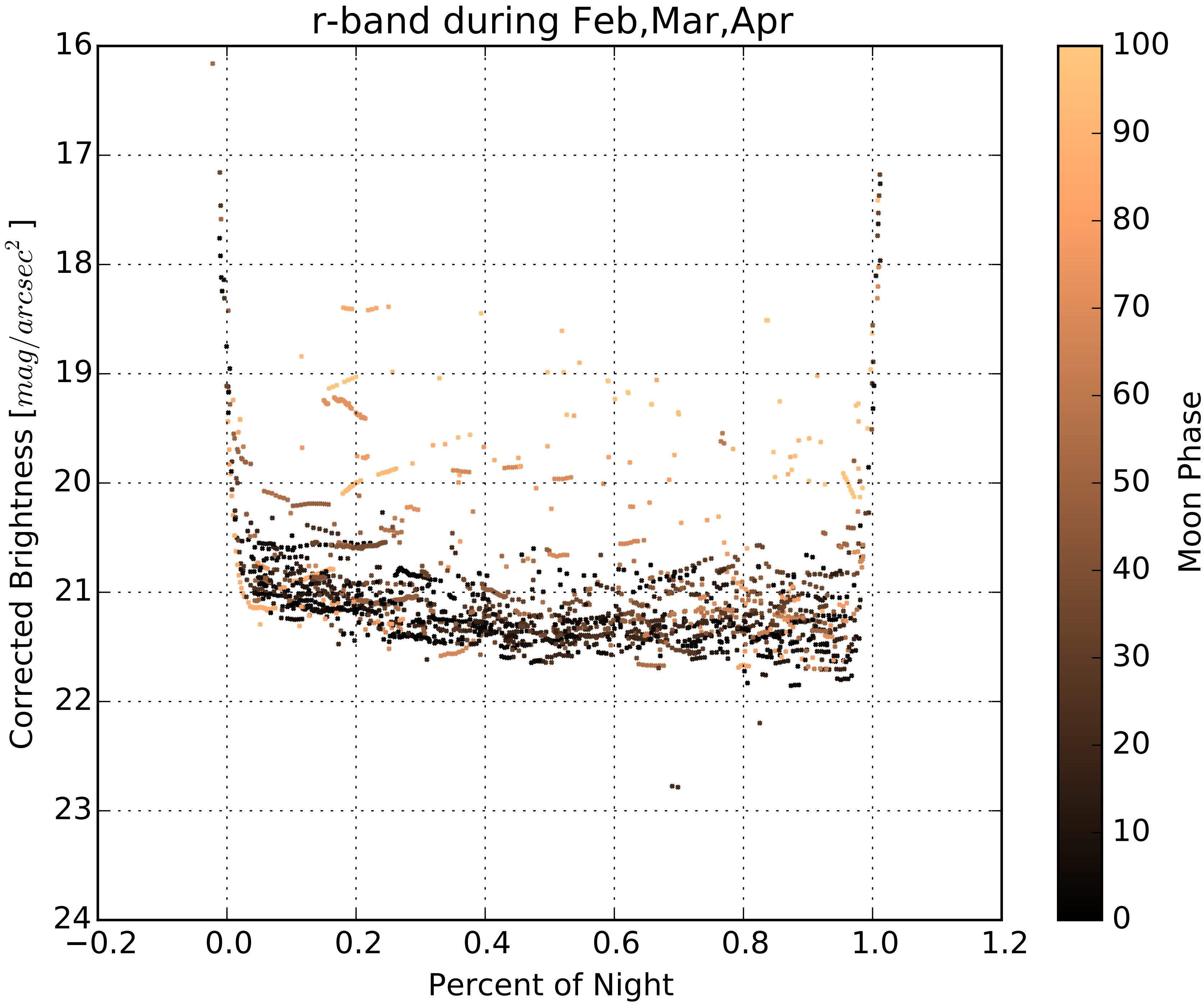


R-band measured on the following UT date
-0.0013 ± 0.0001
-0.0009 ± 0.0003
Corrected Brightness [$mag/arcsec^2$]
# of Sunspots
16
17
18
19
20
21
22
23
24
0
50
100
150
200
250

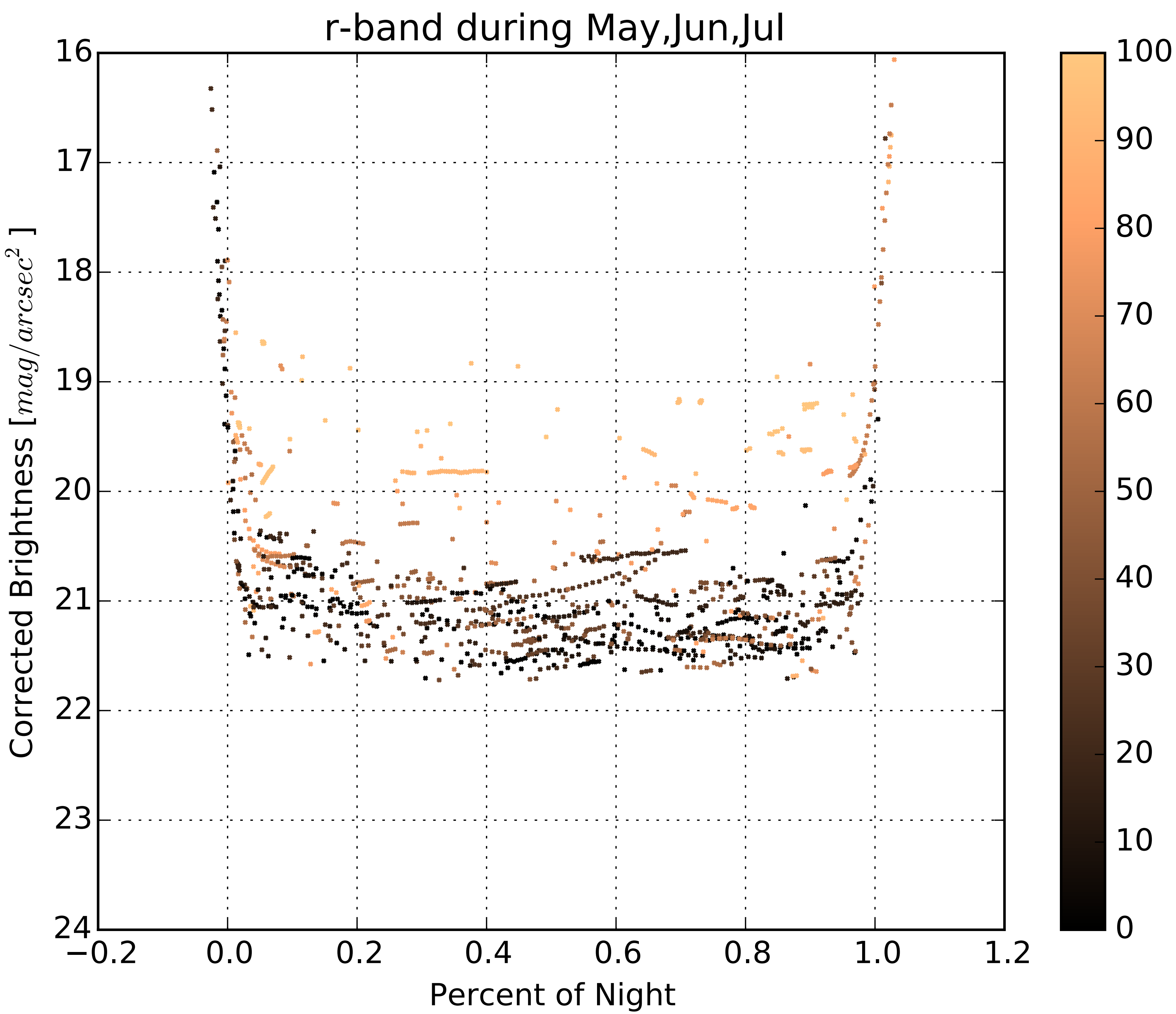

r-band | Sun & Moon < -18 deg elevation
Corrected Brightness [$mag/arcsec^2$]
Day of Year
Equinox
Solstice
Equinox
Solstice
19.0
19.5
20.0
20.5
21.0
21.5
22.0
22.5
23.0
0
50
100
150
200
250
300
350

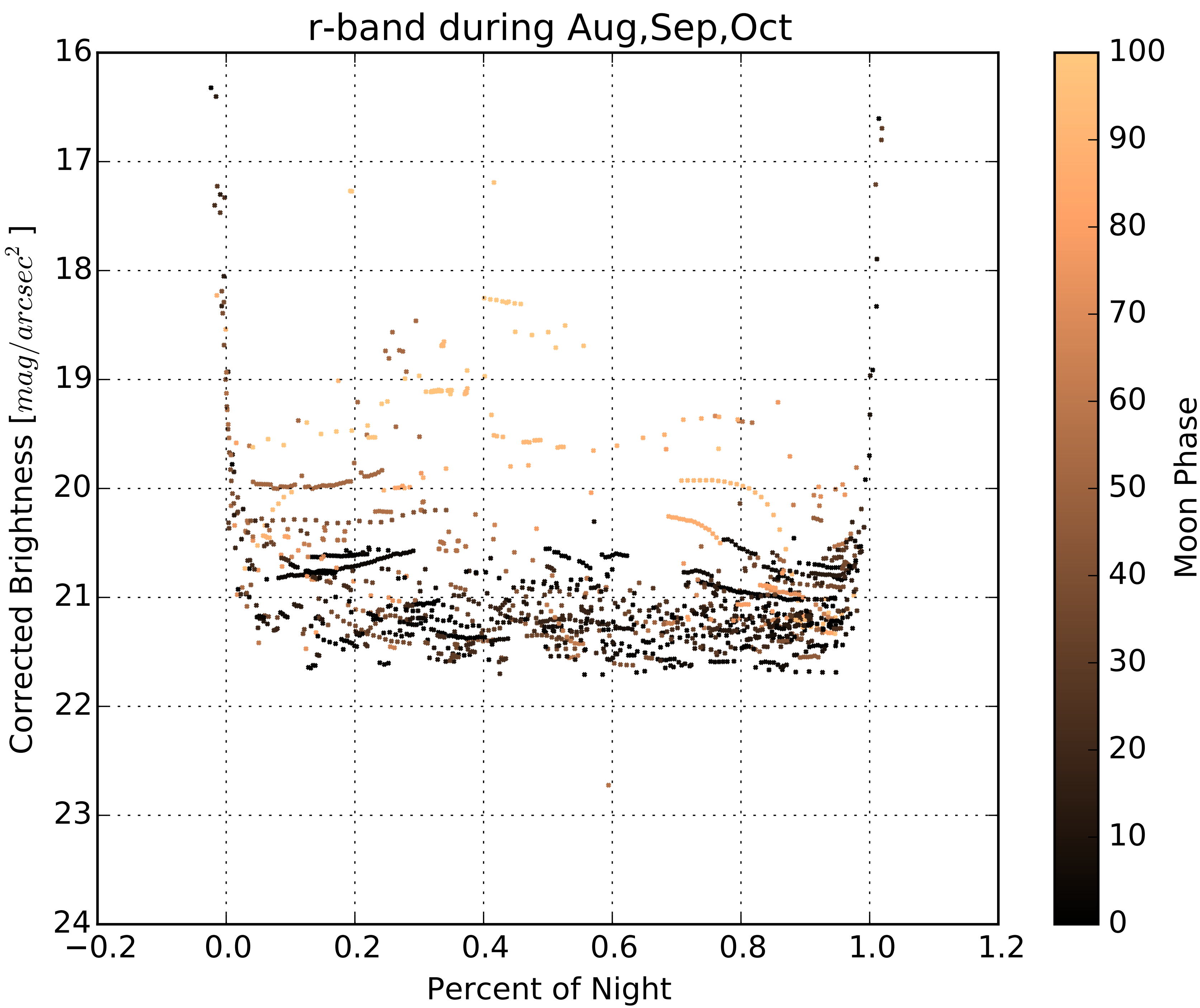


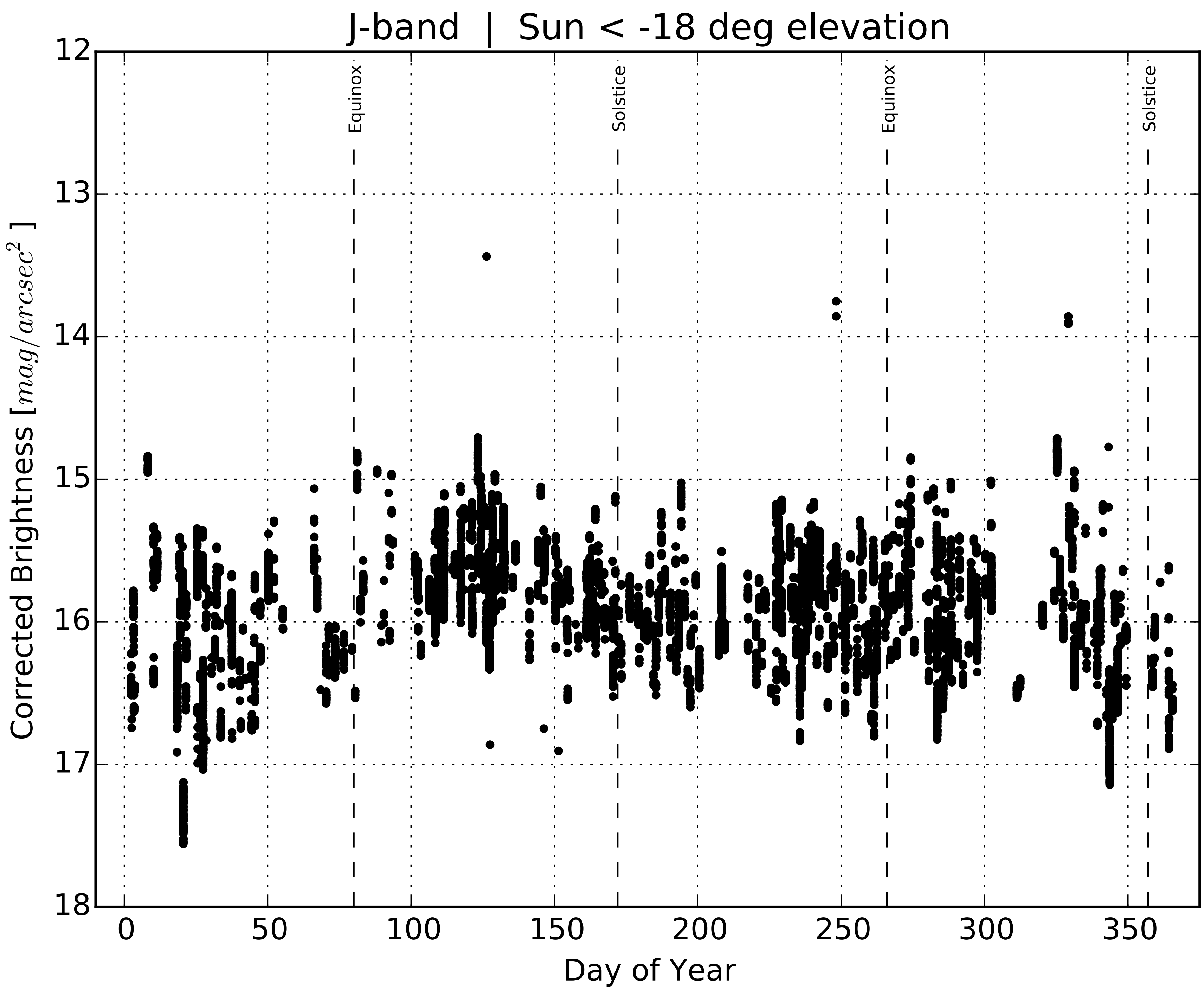
r-band during Nov,Dec,Jan
Corrected Brightness [$mag/arcsec^2$]
Percent of Night
Moon Phase
16
17
18
19
20
21
22
23
24
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
10
20
30
40
50
60
70
80
90
100



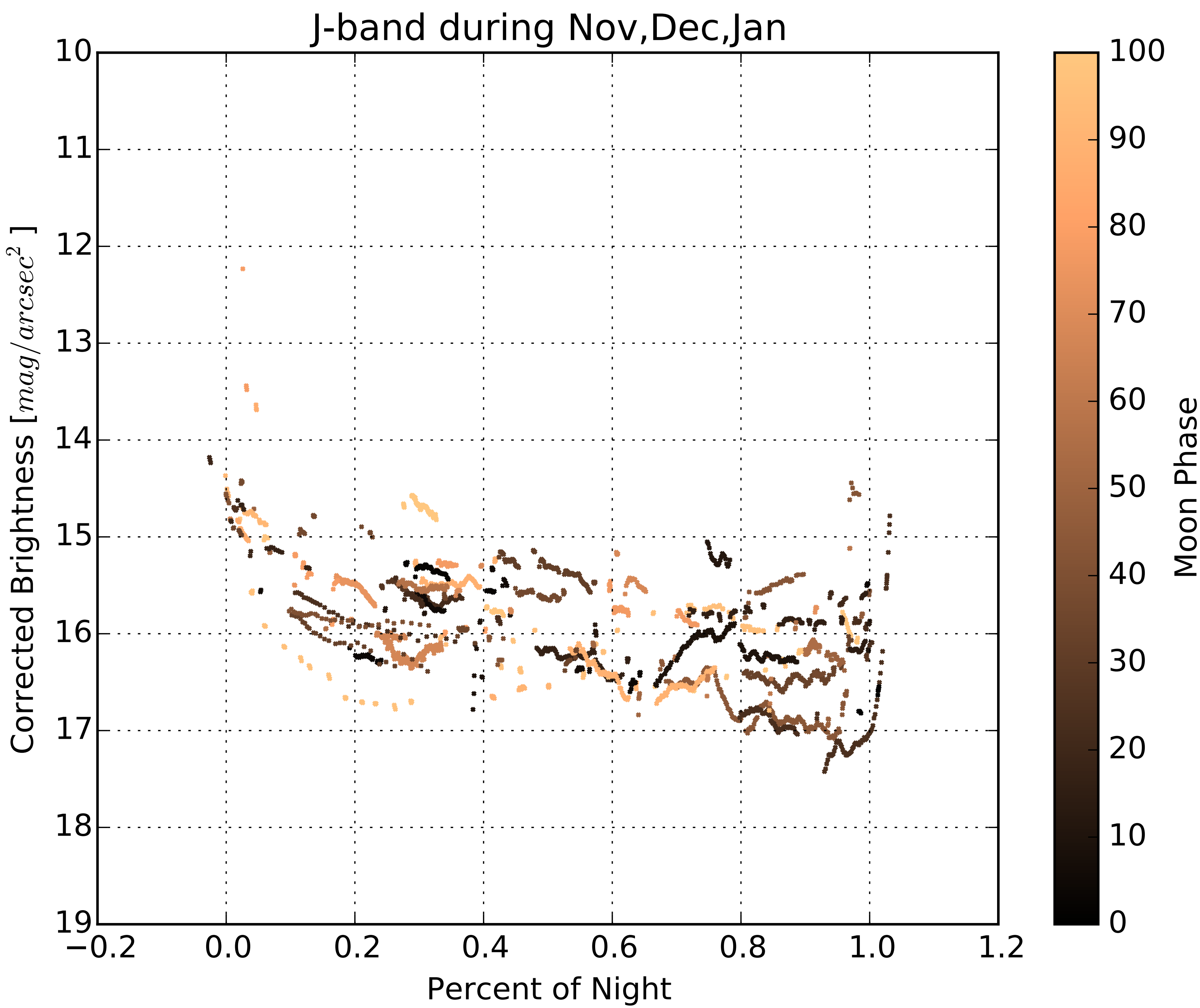
r-band during Feb,Mar,Apr
Corrected Brightness [$mag/arcsec^2$]
Percent of Night
Moon Phase
16
17
18
19
20
21
22
23
24
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
10
20
30
40
50
60
70
80
90
100

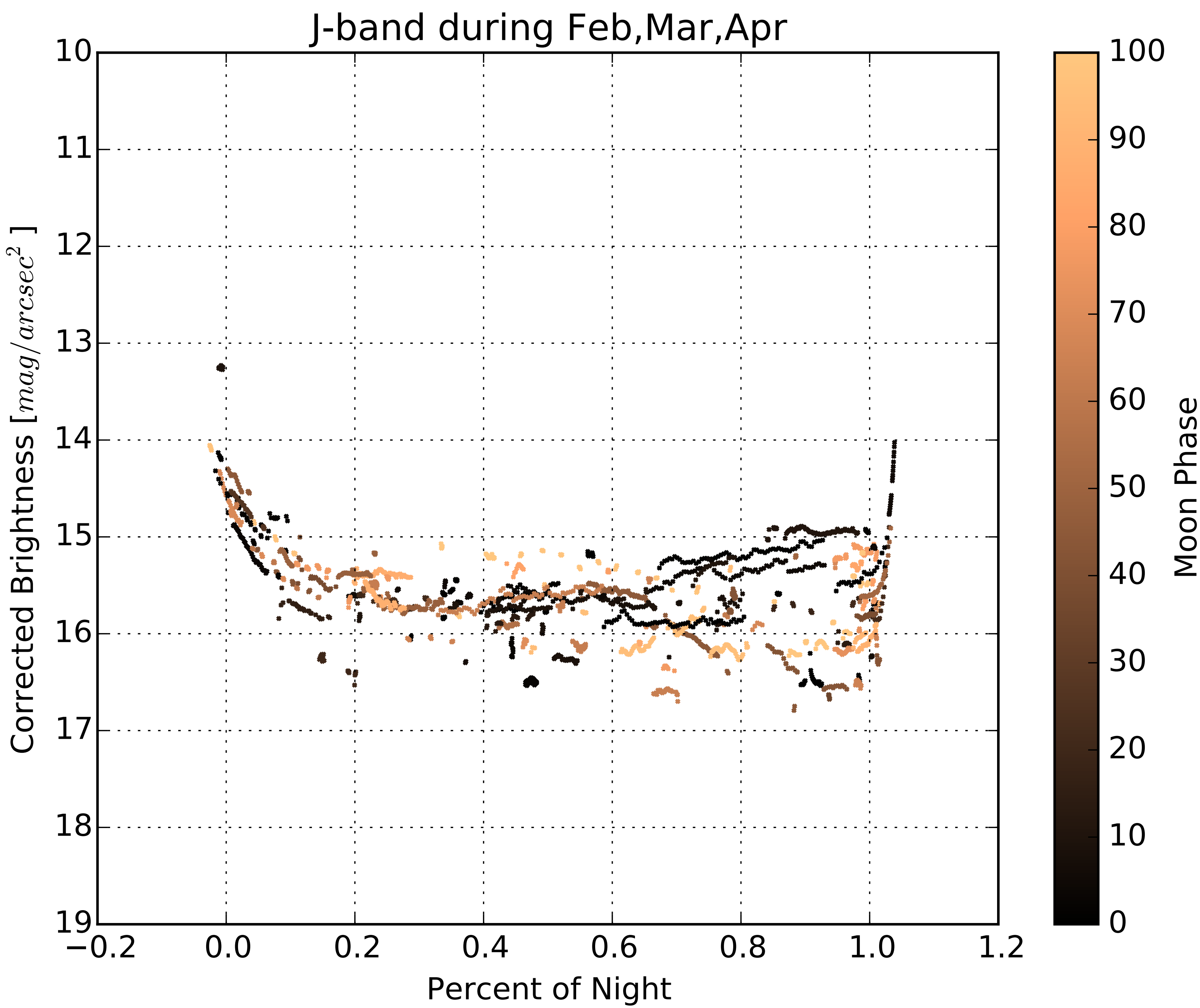

r-band during May,Jun,Jul
Corrected Brightness [$mag/arcsec^2$]
Percent of Night
Moon Phase
16
17
18
19
20
21
22
23
24
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
10
20
30
40
50
60
70
80
90
100

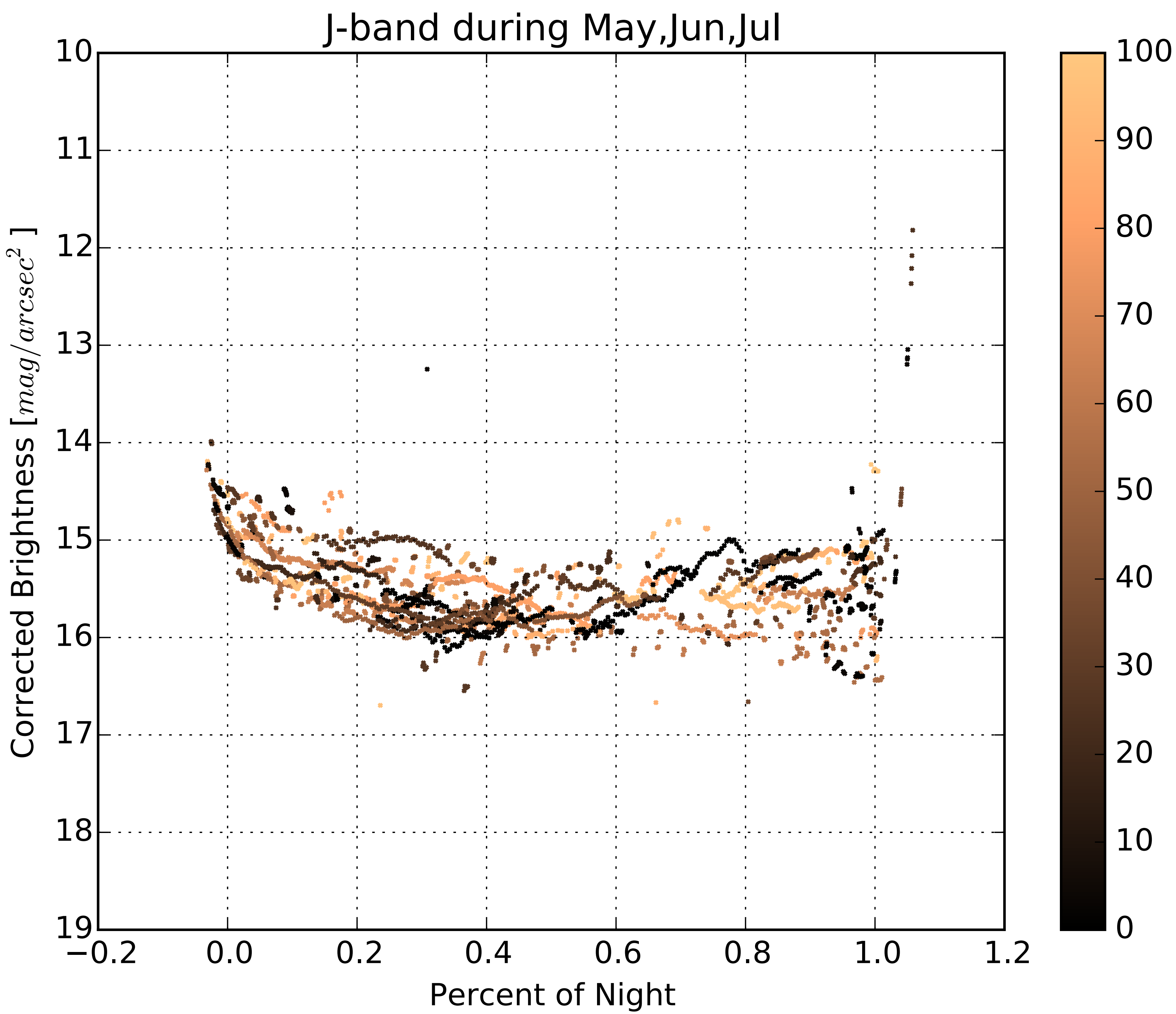

r-band during Aug,Sep,Oct
Corrected Brightness [$mag/arcsec^2$]
Percent of Night
Moon Phase
16
17
18
19
20
21
22
23
24
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
10
20
30
40
50
60
70
80
90
100



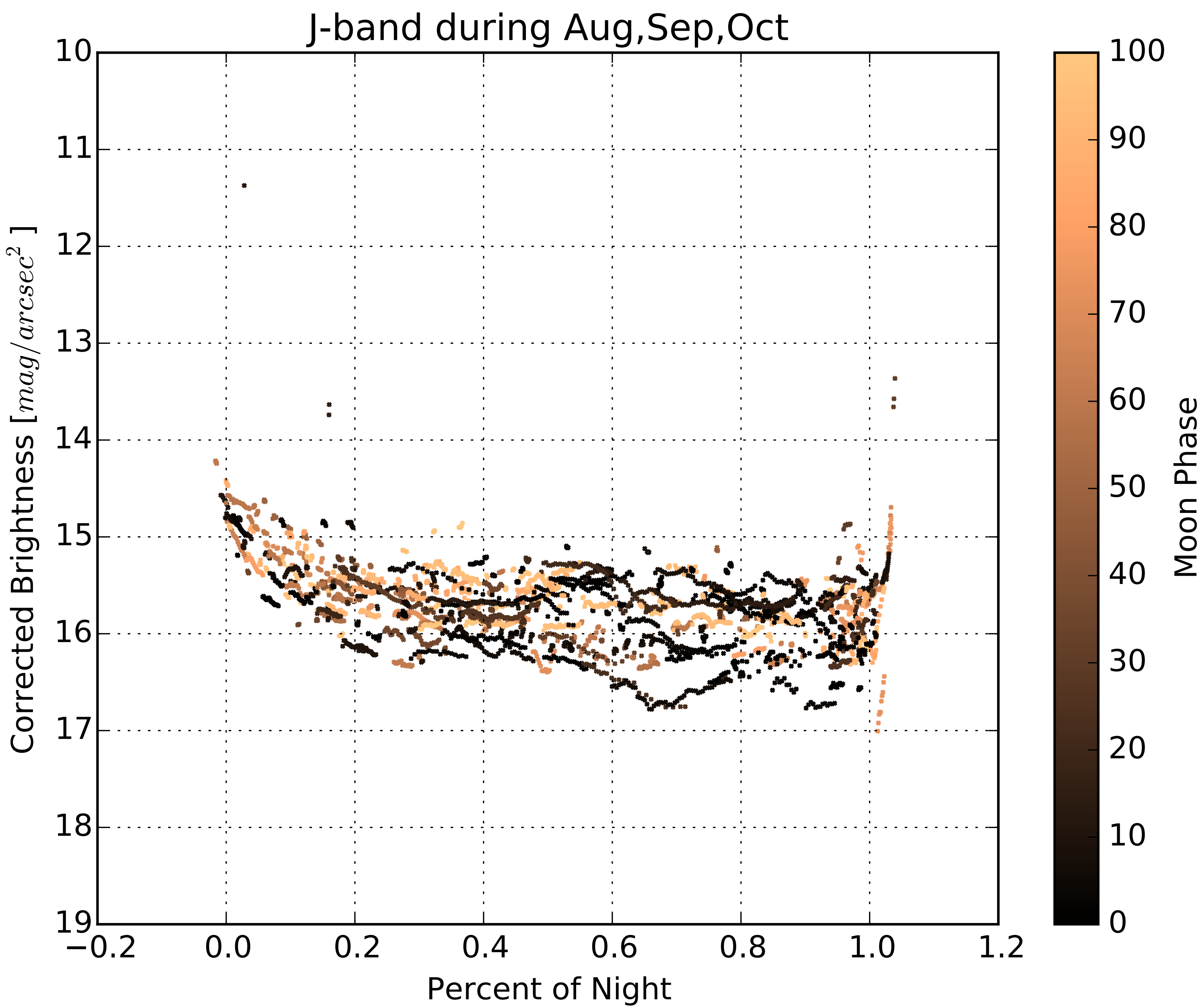
J-band | Sun < -18 deg elevation
Corrected Brightness [$mag/arcsec^2$]
Day of Year
Equinox
Solstice
Equinox
Solstice
12
13
14
15
16
17
18
0
50
100
150
200
250
300
350

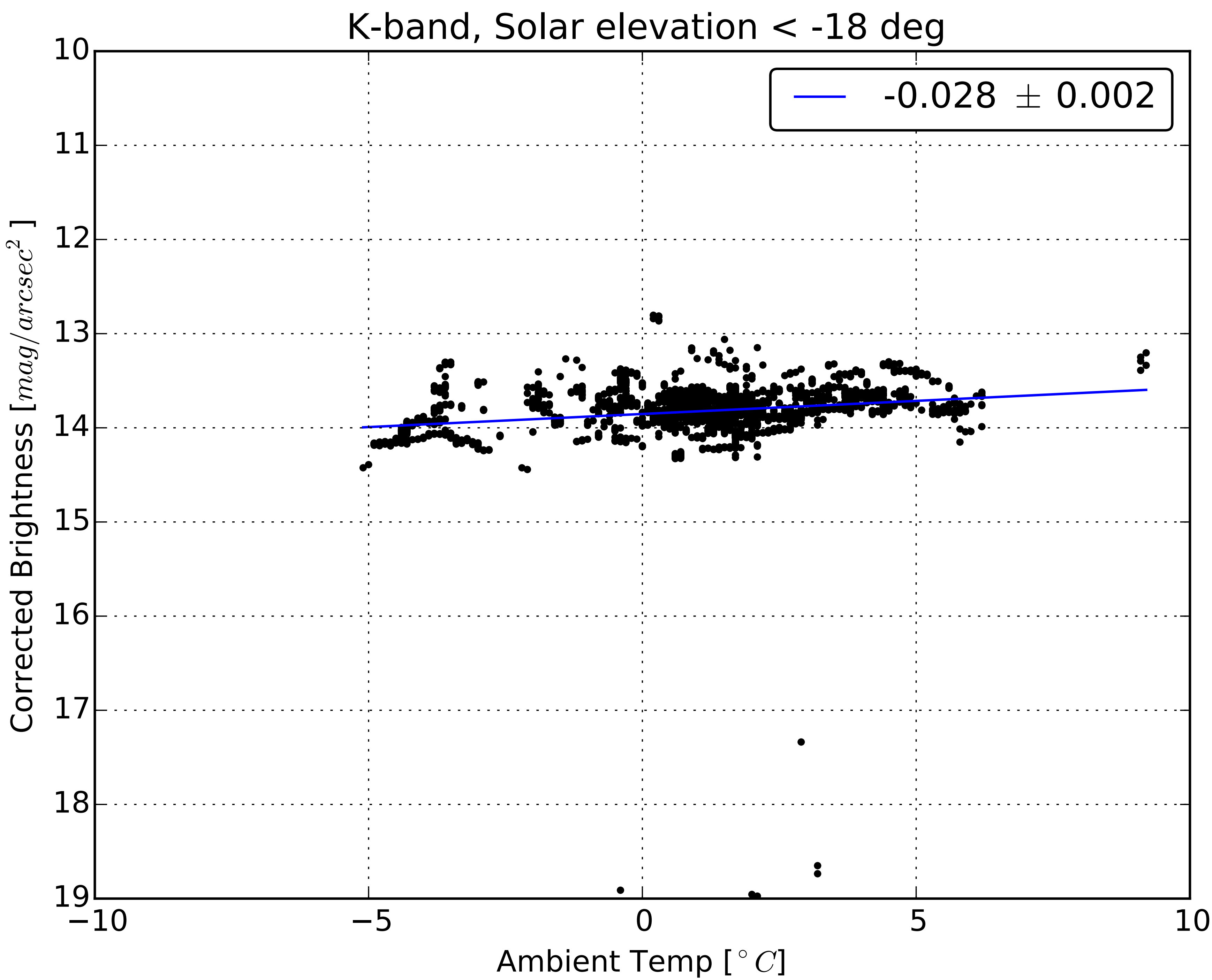

J-band during Nov,Dec,Jan
Corrected Brightness [$mag/arcsec^2$]
Percent of Night
Moon Phase
10
11
12
13
14
15
16
17
18
19
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
10
20
30
40
50
60
70
80
90
100


J-band during Feb,Mar,Apr
Corrected Brightness [$mag/arcsec^2$]
Percent of Night
Moon Phase
10
11
12
13
14
15
16
17
18
19
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
10
20
30
40
50
60
70
80
90
100

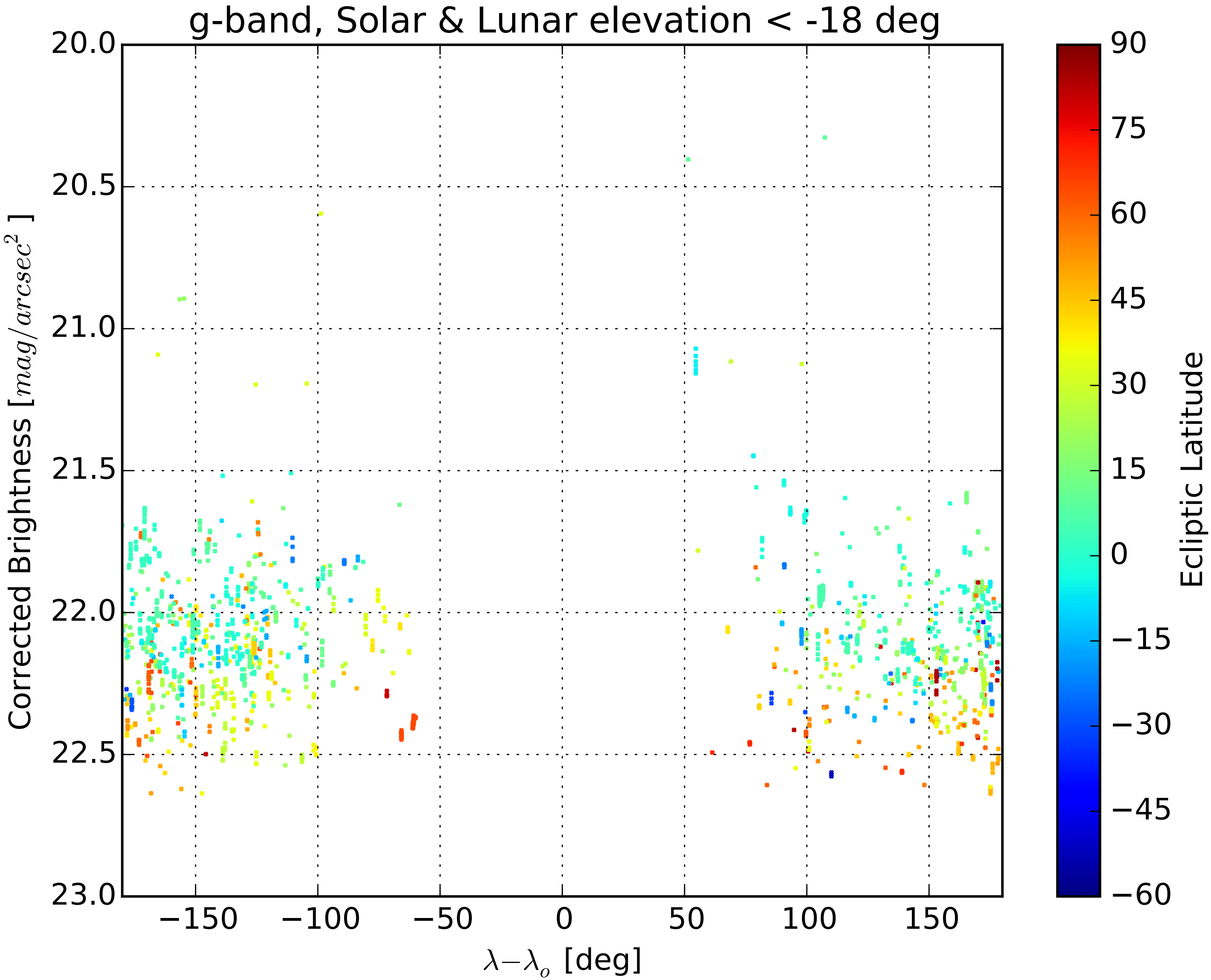


J-band during May,Jun,Jul
Corrected Brightness [$mag/arcsec^2$]
10
11
12
13
14
15
16
17
18
19
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Percent of Night
Moon Phase
0
10
20
30
40
50
60
70
80
90
100

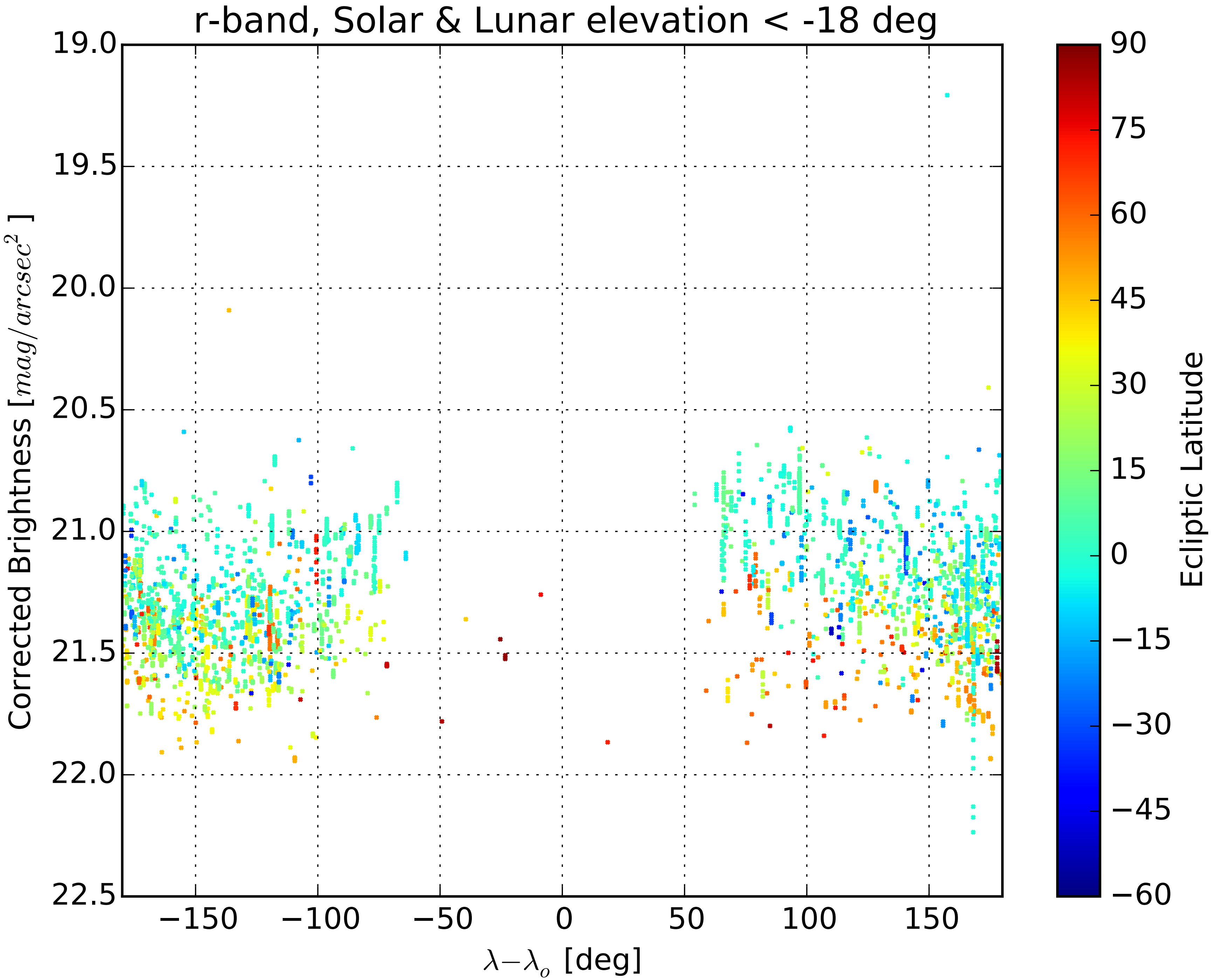

J-band during Aug,Sep,Oct
Corrected Brightness [$mag/arcsec^2$]
Percent of Night
Moon Phase
10
11
12
13
14
15
16
17
18
19
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
10
20
30
40
50
60
70
80
90
100



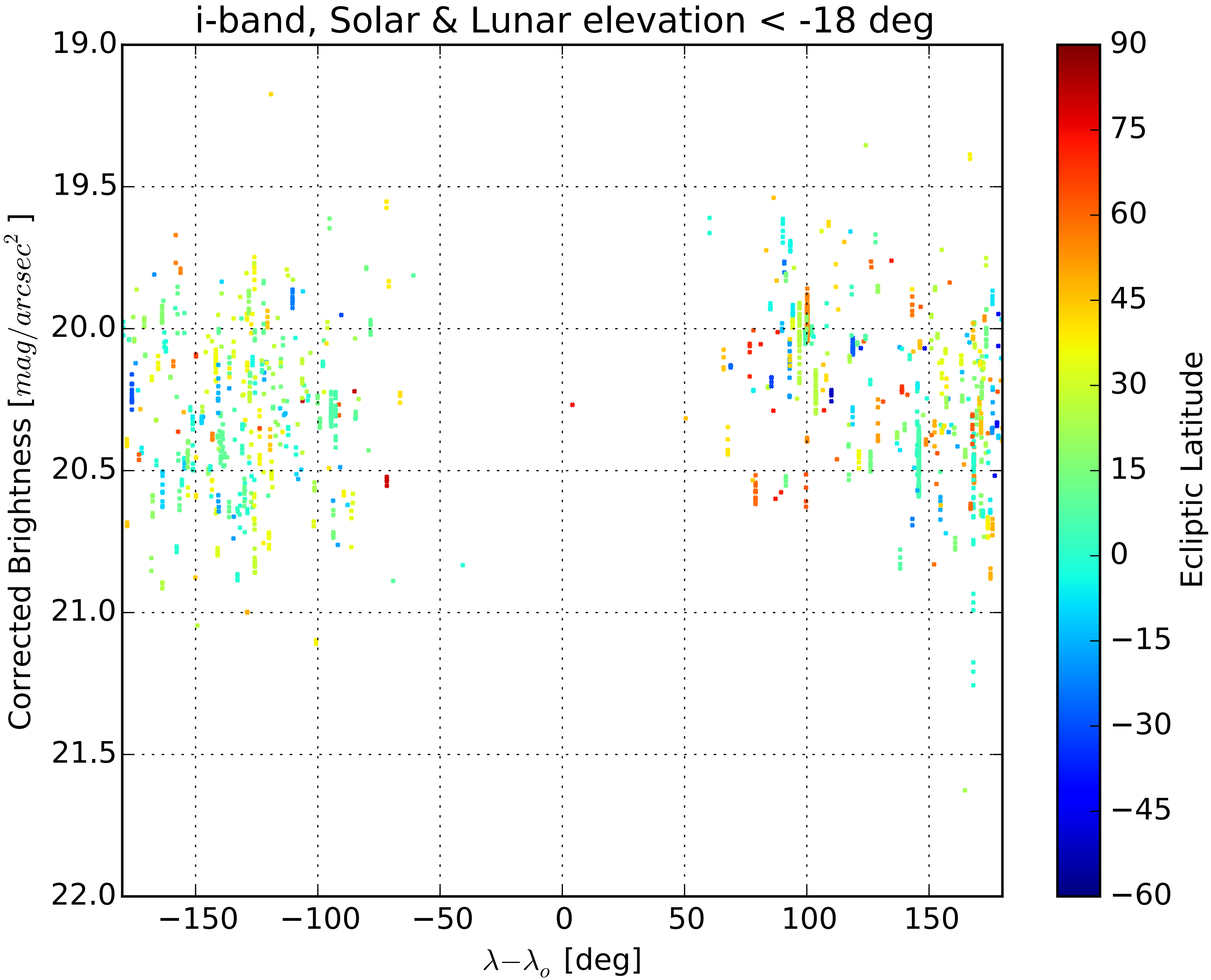
K-band, Solar elevation < -18 deg
-0.028 ± 0.002
Corrected Brightness [$mag/arcsec^2$]
Ambient Temp [$^\circ C$]
10
11
12
13
14
15
16
17
18
19
−10
−5
0
5
10



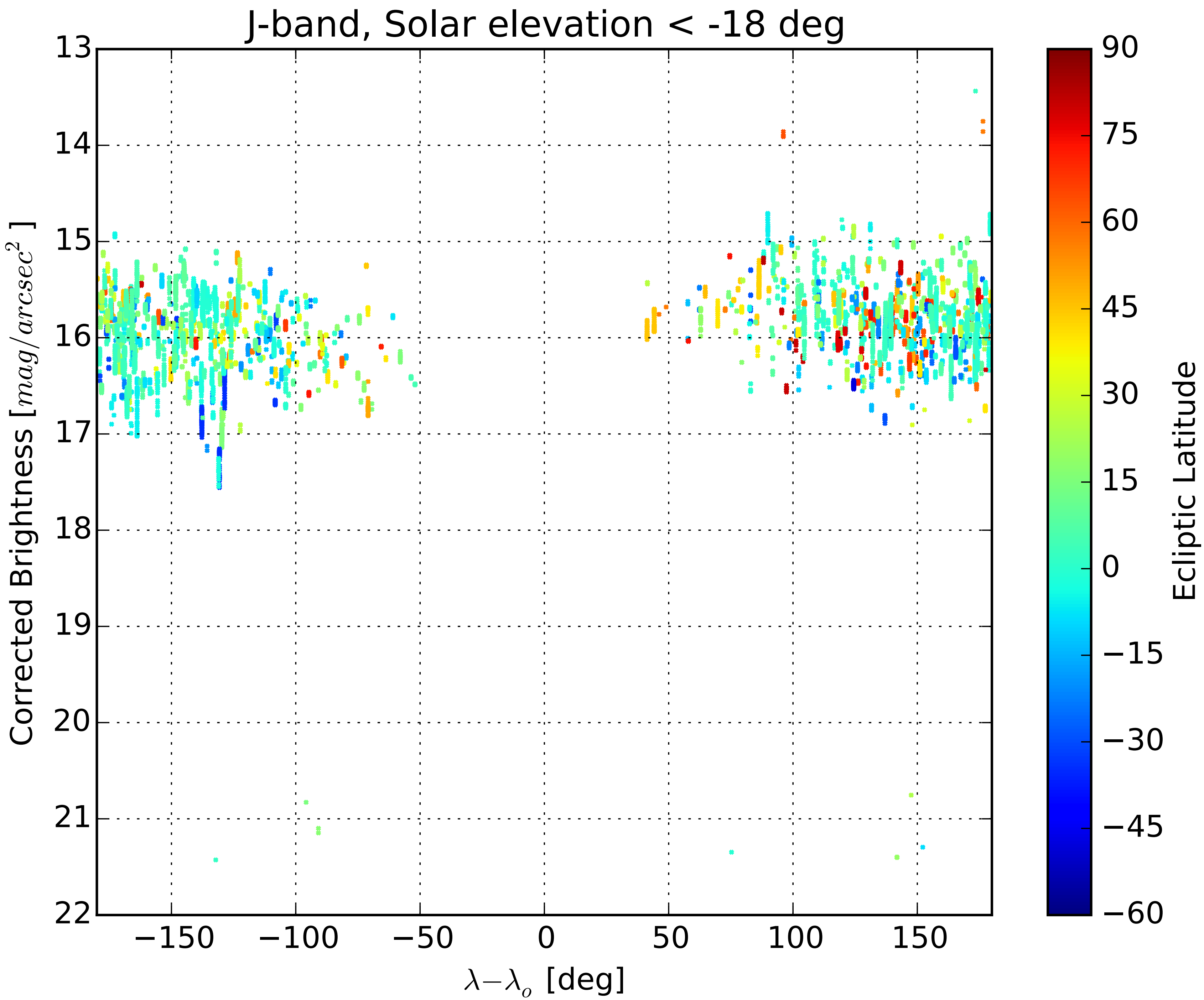
g-band, Solar & Lunar elevation < -18 deg
Corrected Brightness [$mag/arcsec^2$]
20.0
20.5
21.0
21.5
22.0
22.5
23.0
−150
−100
−50
0
50
100
150
$\lambda - \lambda_o$ [deg]
Ecliptic Latitude
90
75
60
45
30
15
0
−15
−30
−45
−60



r-band, Solar & Lunar elevation < -18 deg
Corrected Brightness [$mag/arcsec^2$]
19.0
19.5
20.0
20.5
21.0
21.5
22.0
22.5
−150
−100
−50
0
50
100
150
$\lambda - \lambda_o$ [deg]
Ecliptic Latitude
90
75
60
45
30
15
0
−15
−30
−45
−60



i-band, Solar & Lunar elevation < -18 deg
Corrected Brightness [$mag/arcsec^2$]
19.0
19.5
20.0
20.5
21.0
21.5
22.0
−150
−100
−50
0
50
100
150
$\lambda - \lambda_o$ [deg]
Ecliptic Latitude
90
75
60
45
30
15
0
−15
−30
−45
−60



J-band, Solar elevation < -18 deg
Corrected Brightness [$mag/arcsec^2$]
13
14
15
16
17
18
19
20
21
22
−150
−100
−50
0
50
100
150
$\lambda - \lambda_o$ [deg]
Ecliptic Latitude
90
75
60
45
30
15
0
−15
−30
−45
−60

Preliminary Conclusions

- r, i, z, J, H and maybe Y band sky background values decrease during the first several hours of the night before reaching their darkest values
- There may be a seasonal dependence on this decay especially in the optical – under investigation
- The observing constraints and ITC under-estimate the background level in J and K

Possible scheduling Improvements

- Revise Observatory Constraints and ITC values to match sky background values actually measured.
- Avoid scheduling imaging in the first 2-3 hours of the night for science requiring the darkest background
- More advanced / challenging improvements
  - Revise QPT scheduling software to match optical sky background values actually measured
  - Implement sky background constraints in the infrared, cannot easily be predicted but would require on-sky measurements (similar to water vapor scheduling constraint)