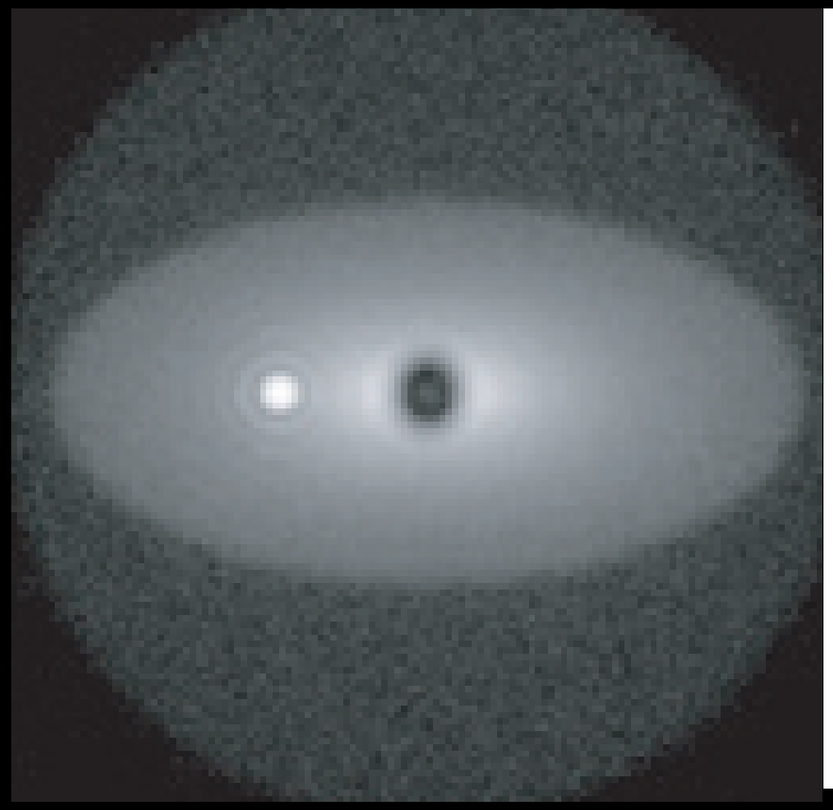
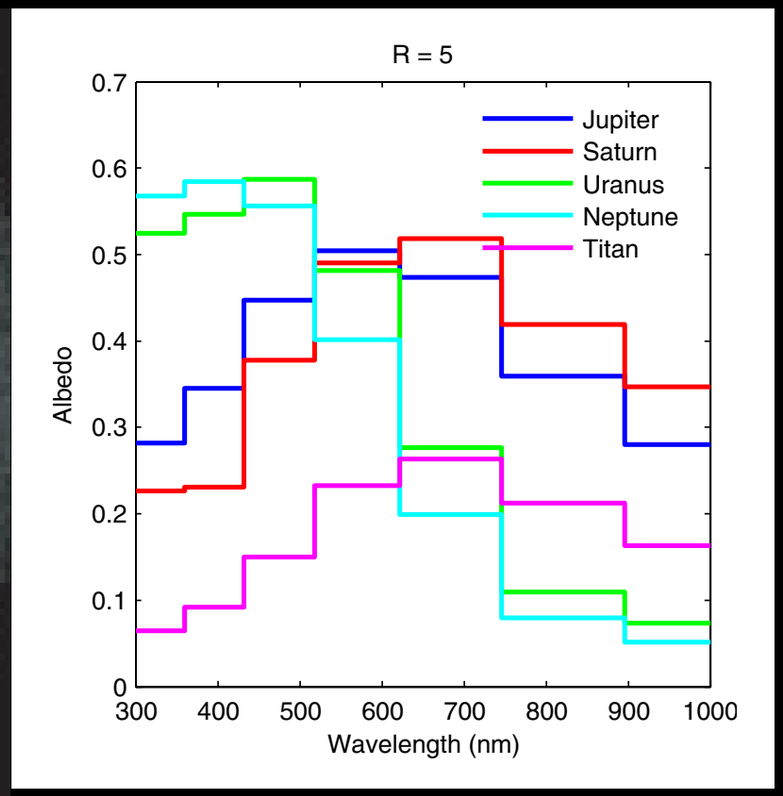
Theoretical Albedo Spectra of Exoplanet Direct Imaging Targets





From Cahoy et al. (2010)

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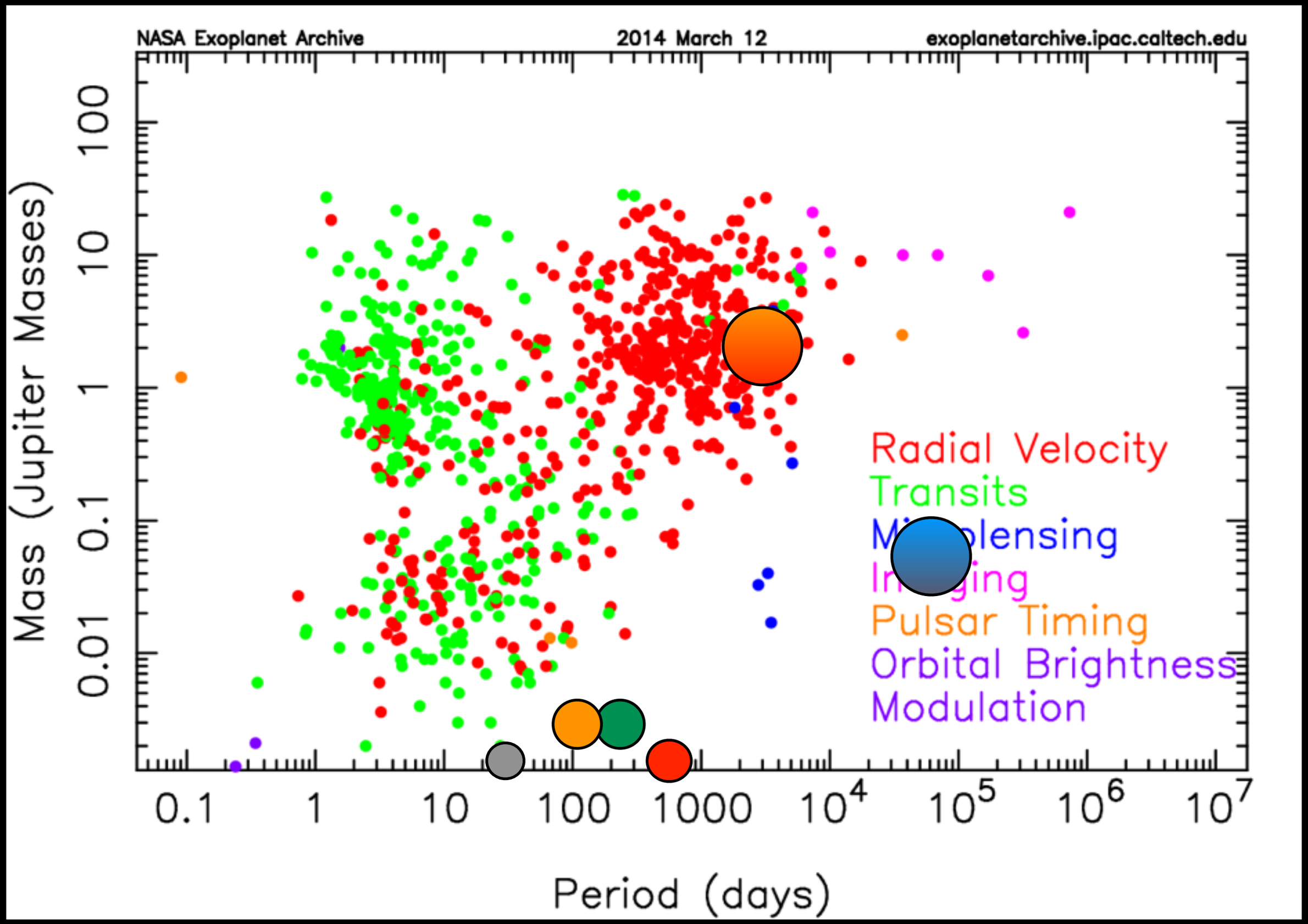
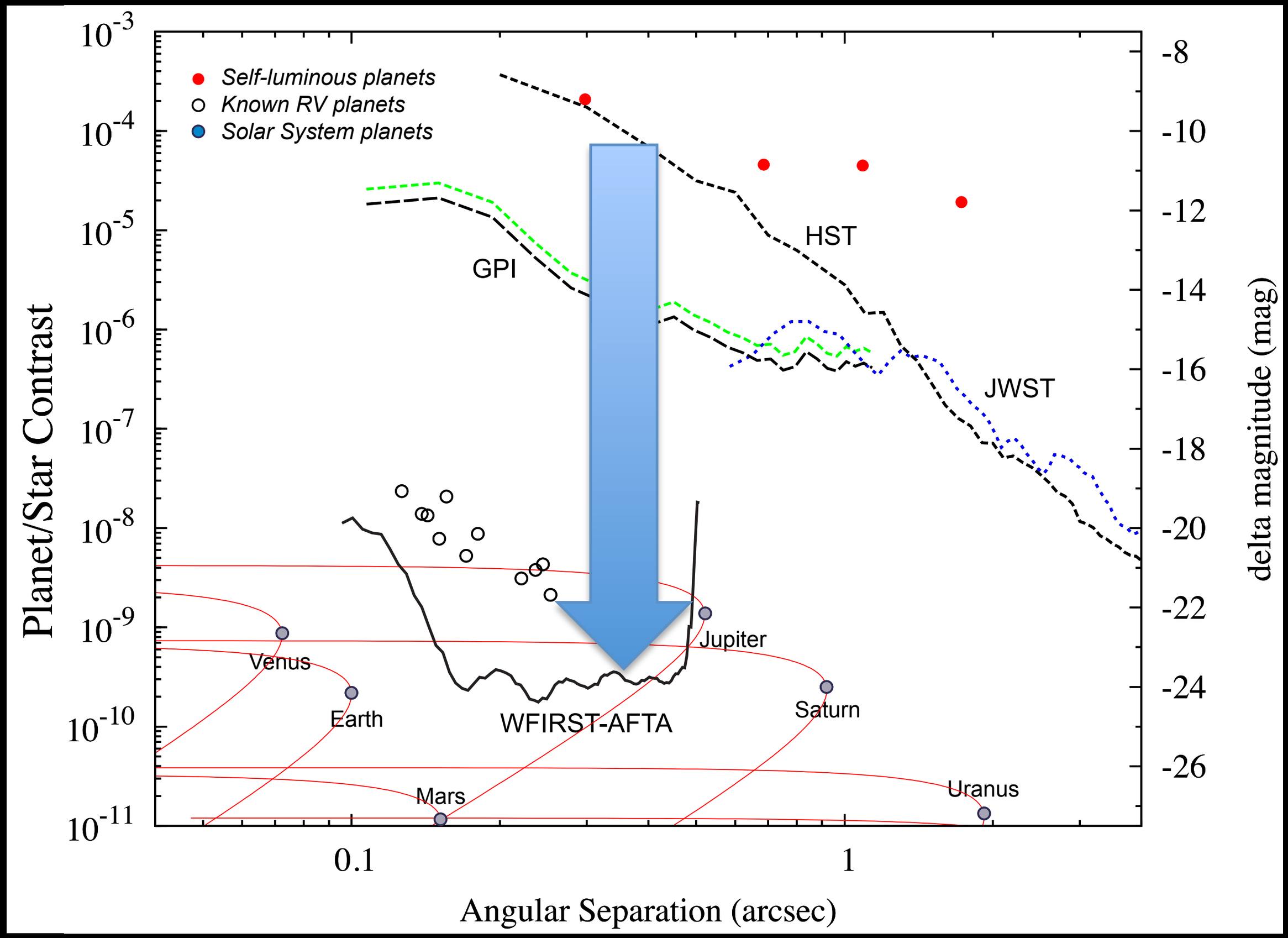
Mark Marley, NASA Ames
Jonathan Fortney, UCSC


NASA Exoplanet Archive
2014 March 12
exoplanetarchive.ipac.caltech.edu
Mass (Jupiter Masses)
100
10
1
0.1
0.01
0.1
1
10
100
1000
10^4
10^5
10^6
10^7
Period (days)
Radial Velocity
Transits
Microlensing
Imaging
Pulsar Timing
Orbital Brightness
Modulation



Credit: WFIRST-AFTA Interim Report

Key Questions

- How do clouds affect giant planet atmospheres and vary with atmospheric temperature and other planetary parameters?

- How does the composition of giant planets vary with mass, orbit, and stellar mass and metallicity?

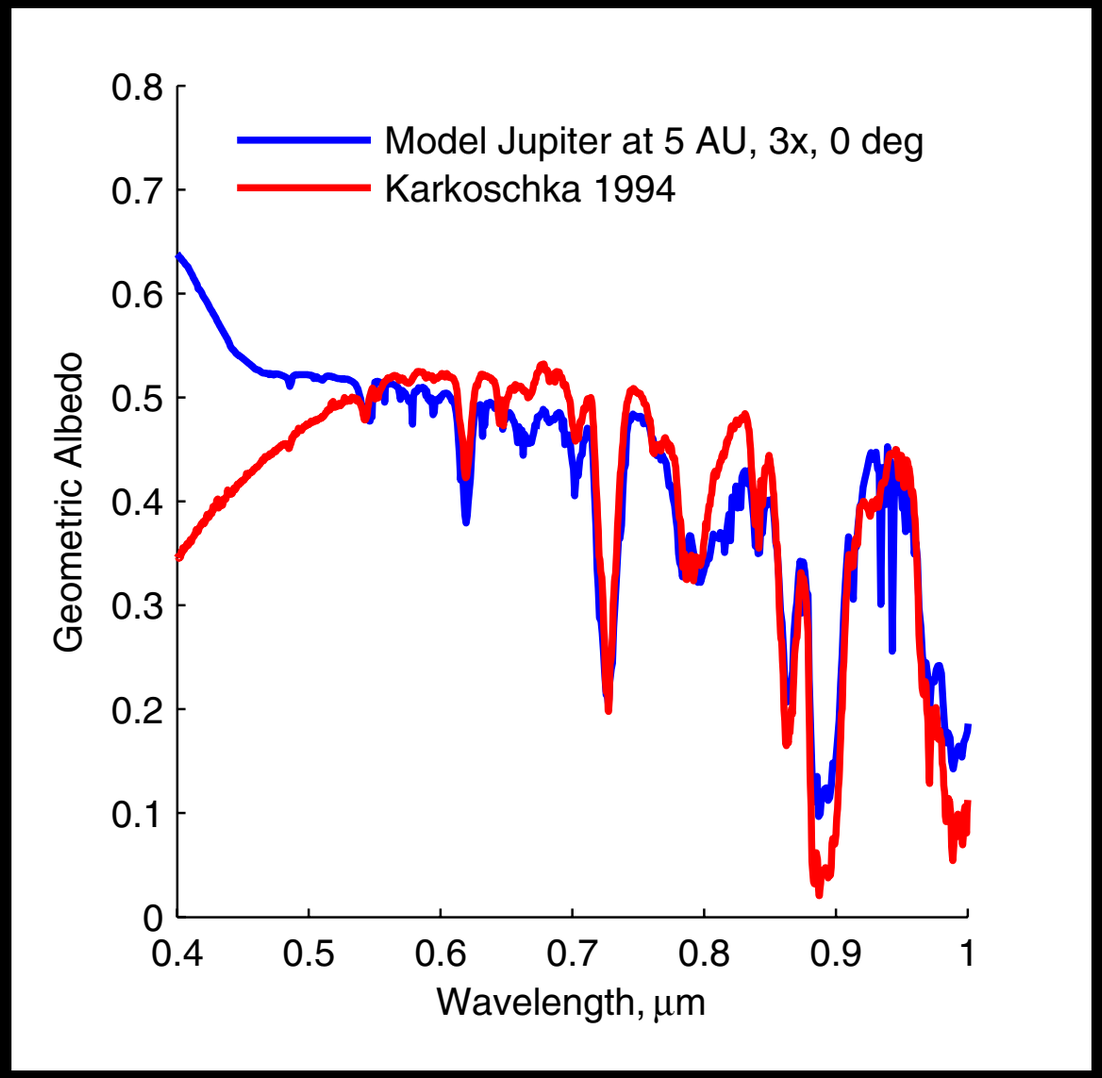
- Do planets formed inside and outside the nebular 'snow line' have different composition or C/O ratios?

Theoretical Albedo Spectra

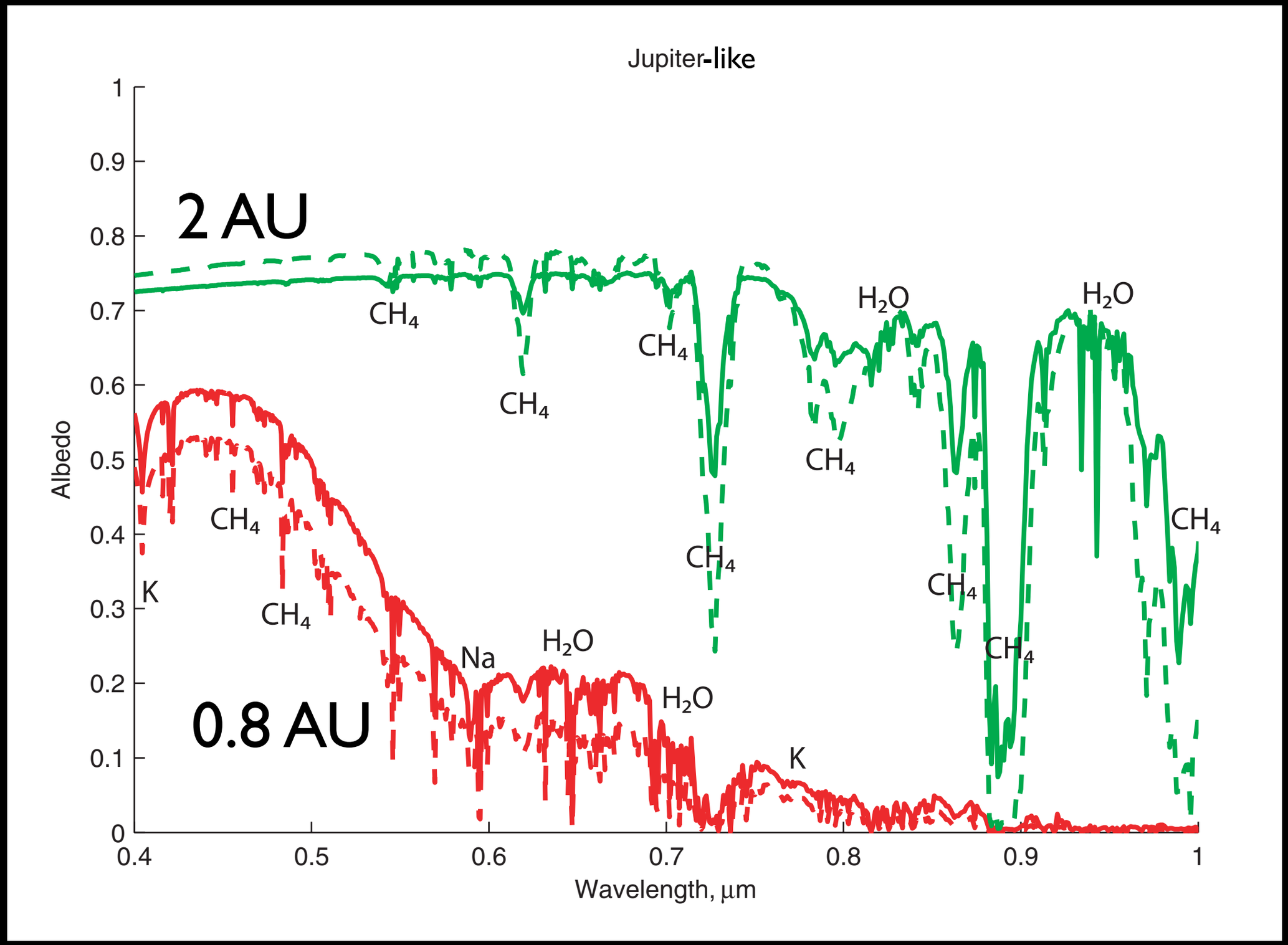
- One-dimensional Radiative-Convective Equilibrium atmospheric model

- Incorporate possibility of clouds using Ackerman & Marley (2001) formalism

- Calculate scattered radiation (Mie, Raman, Rayleigh) given atmospheric/cloud properties

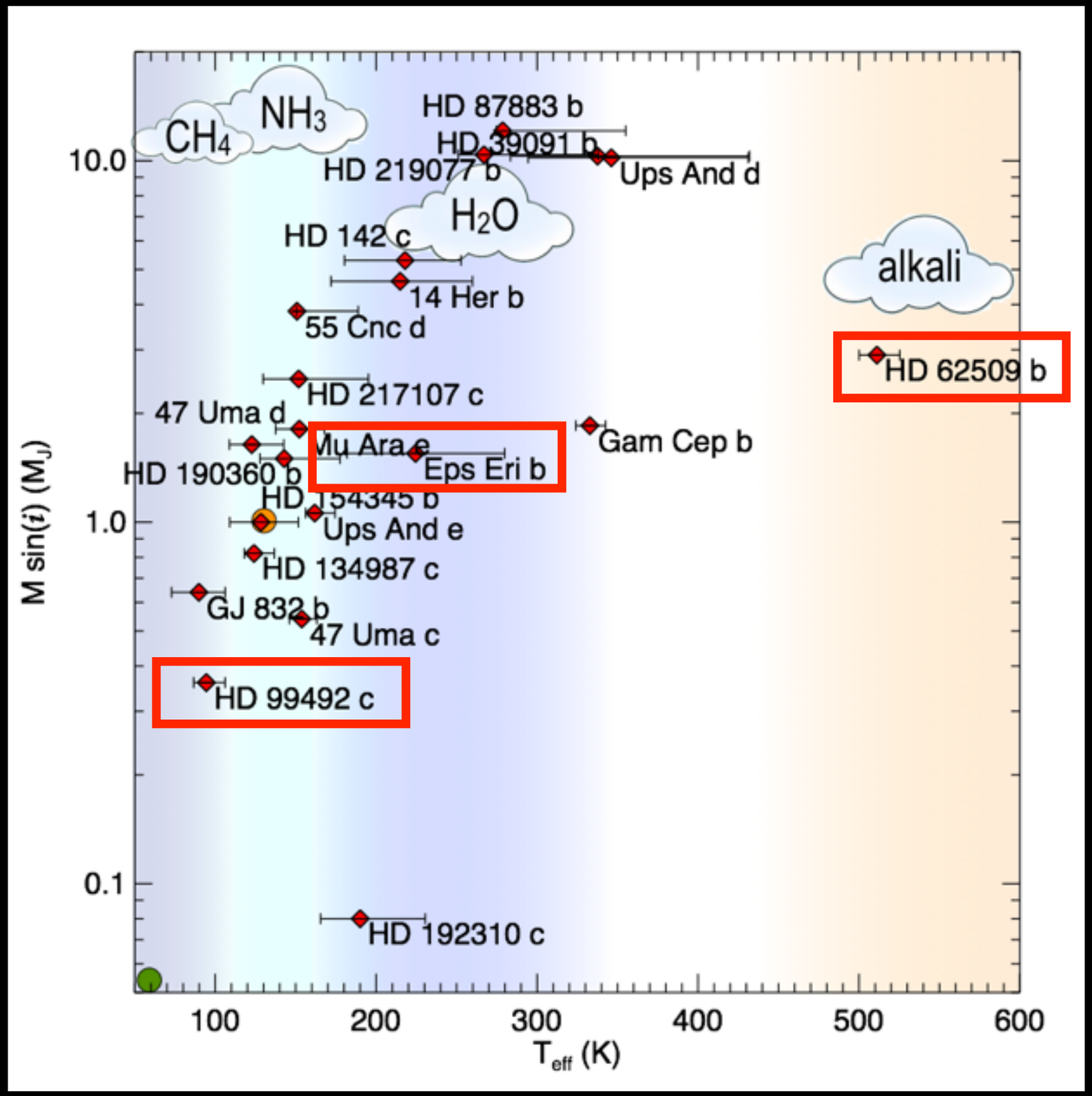


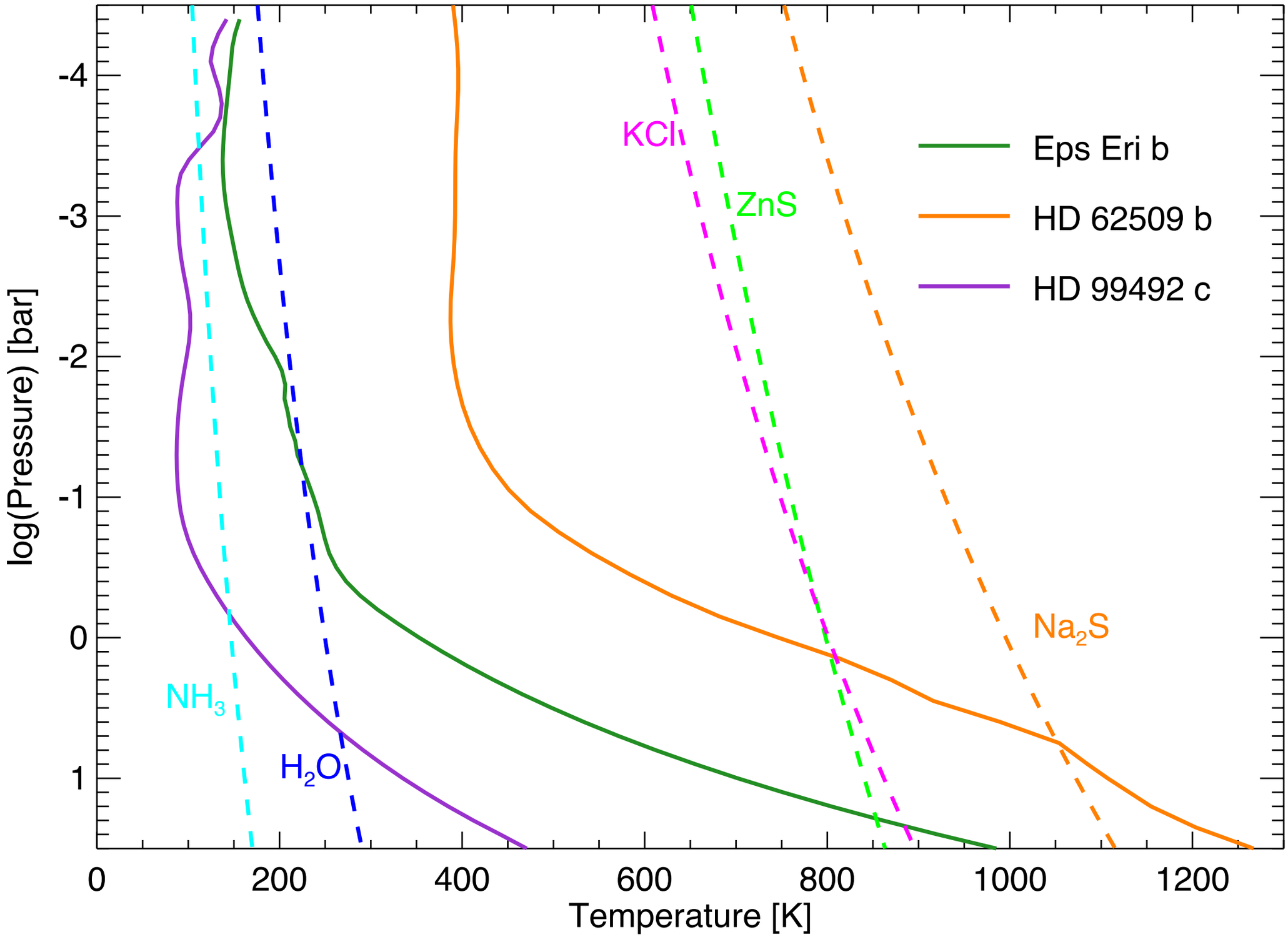
Cahoy et al. (2010)

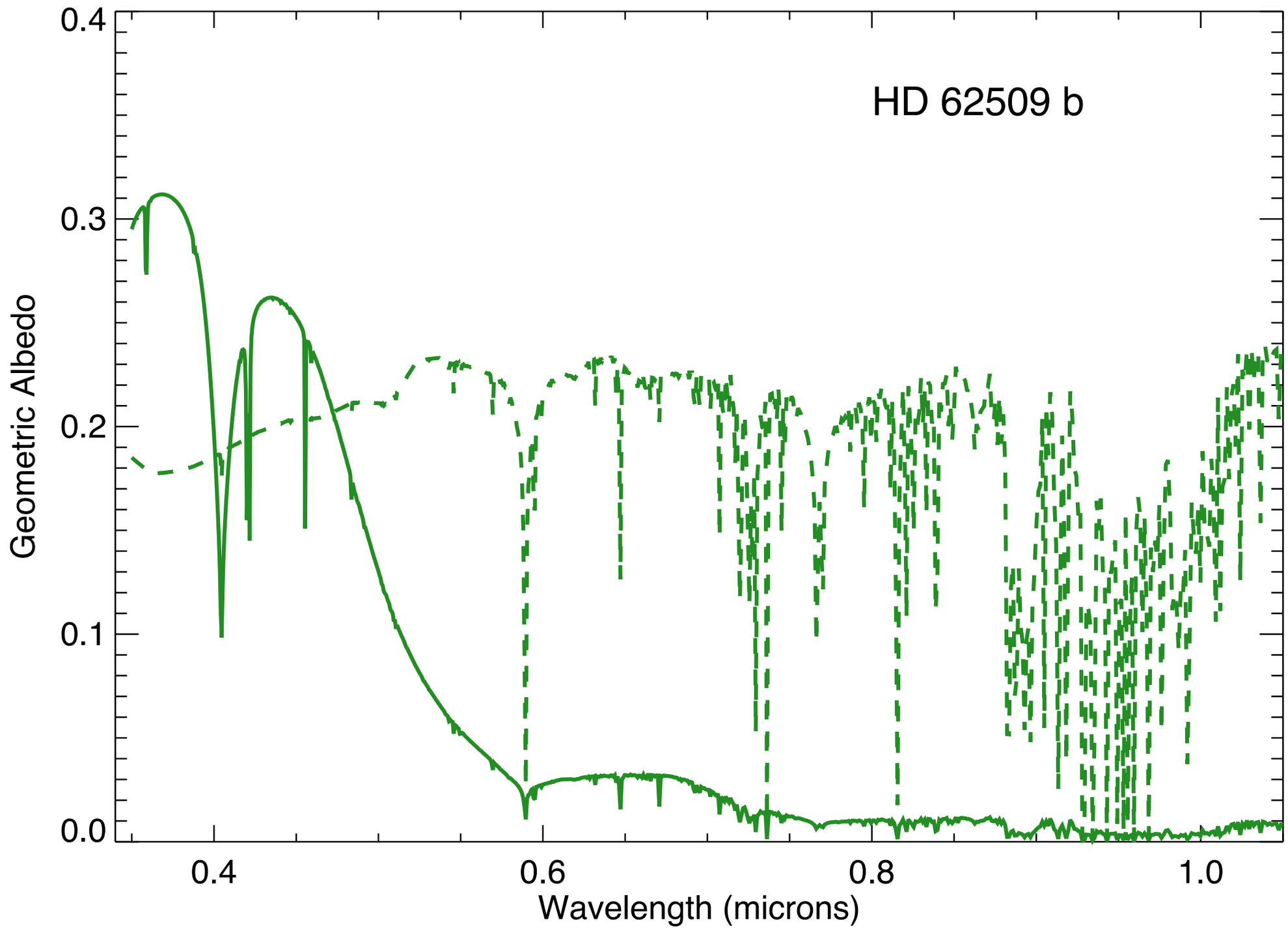


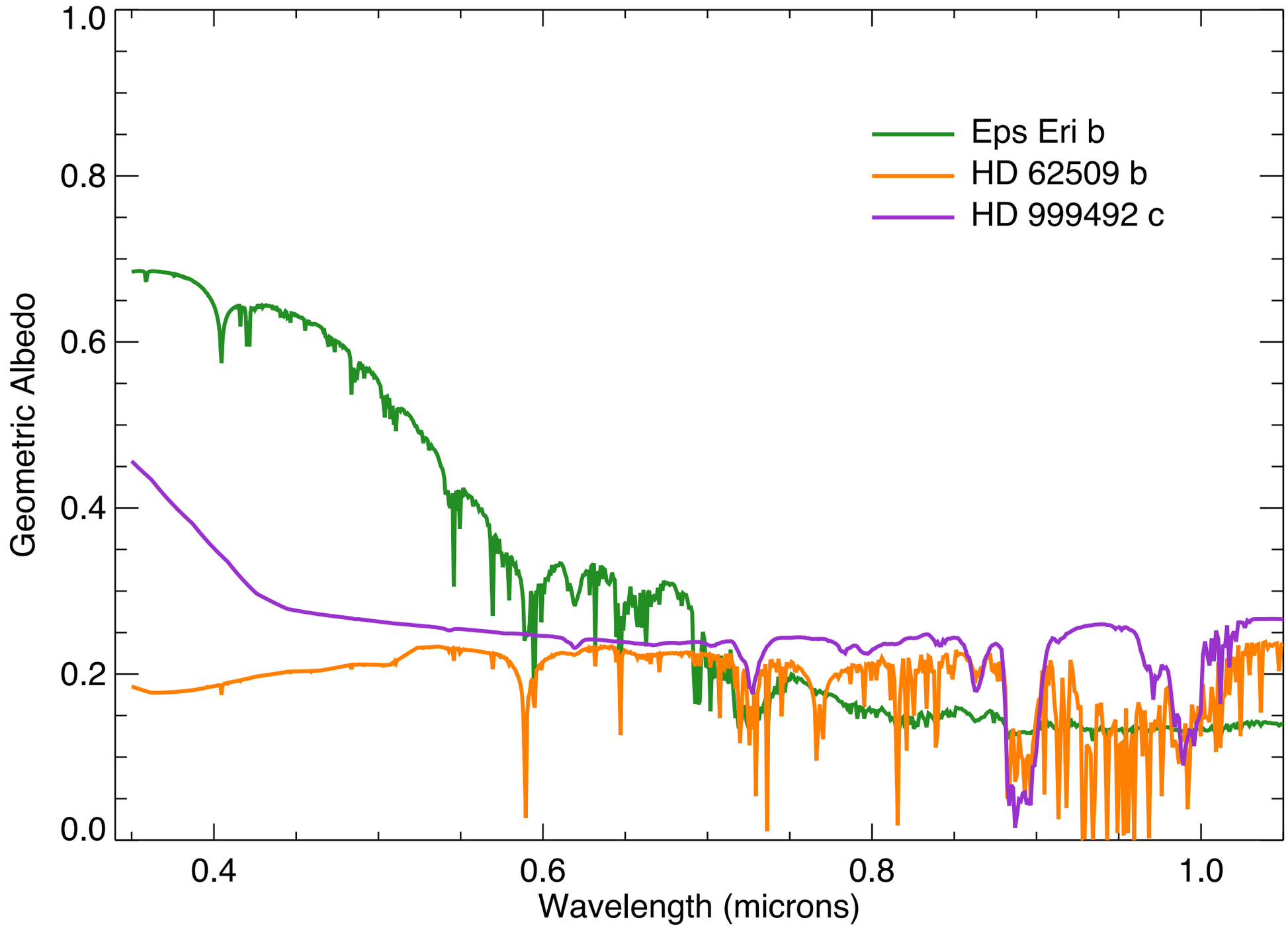
Cahoy et al. (2010)

How do clouds affect giant planet atmospheres and vary with atmospheric temperature and other planetary parameters?

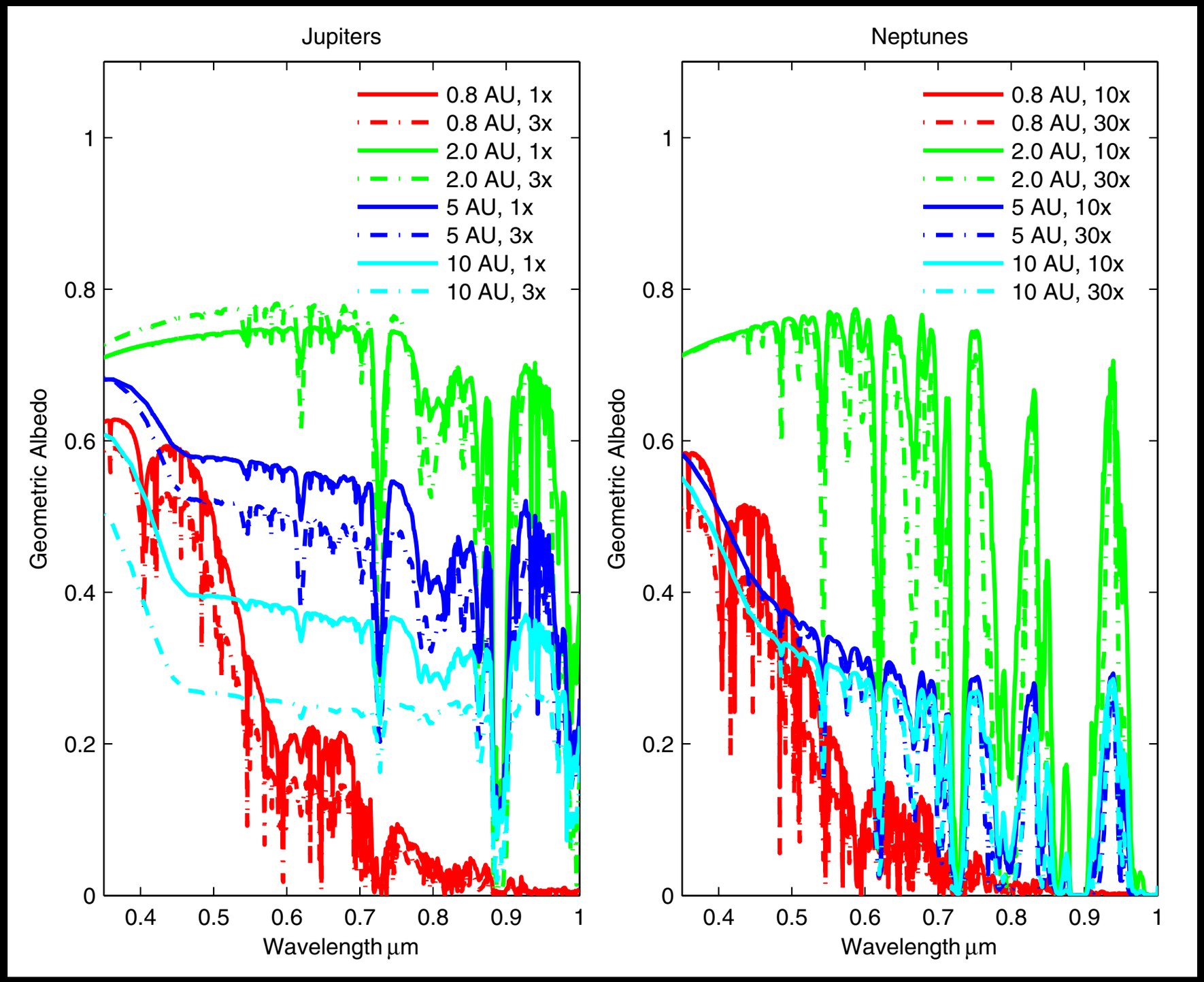



log(Pressure) [bar]
-4
-3
-2
-1
0
1
0
200
400
600
800
1000
1200
Temperature [K]
Eps Eri b
HD 62509 b
HD 99492 c
KCl
ZnS
Na$_2$S
NH$_3$
H$_2$O

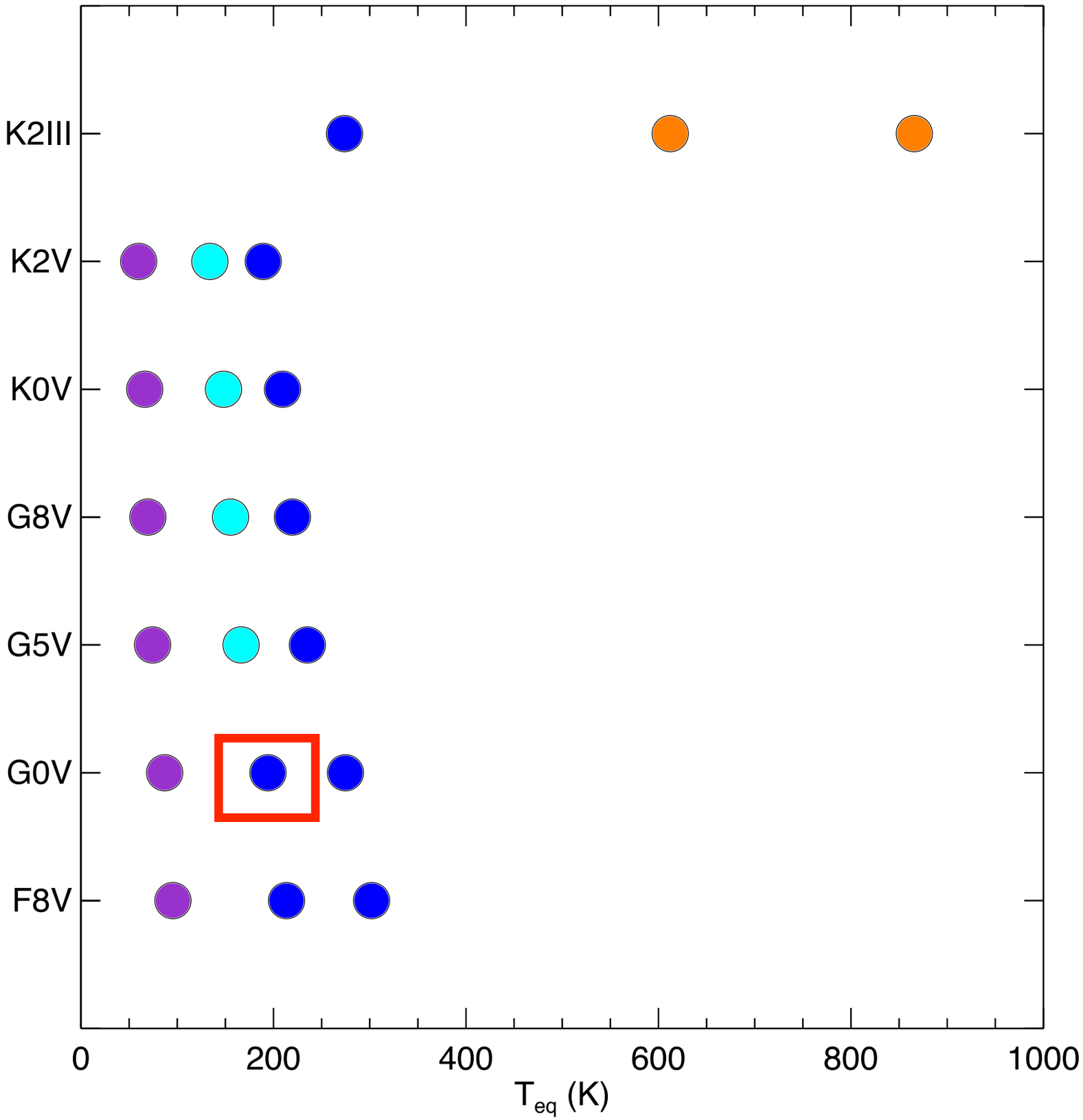

HD 62509 b
Geometric Albedo
0.0
0.1
0.2
0.3
0.4
0.4
0.6
0.8
1.0
Wavelength (microns)


Eps Eri b
HD 62509 b
HD 999492 c
Geometric Albedo
Wavelength (microns)
1.0
0.8
0.6
0.4
0.2
0.0
0.4
0.6
0.8
1.0

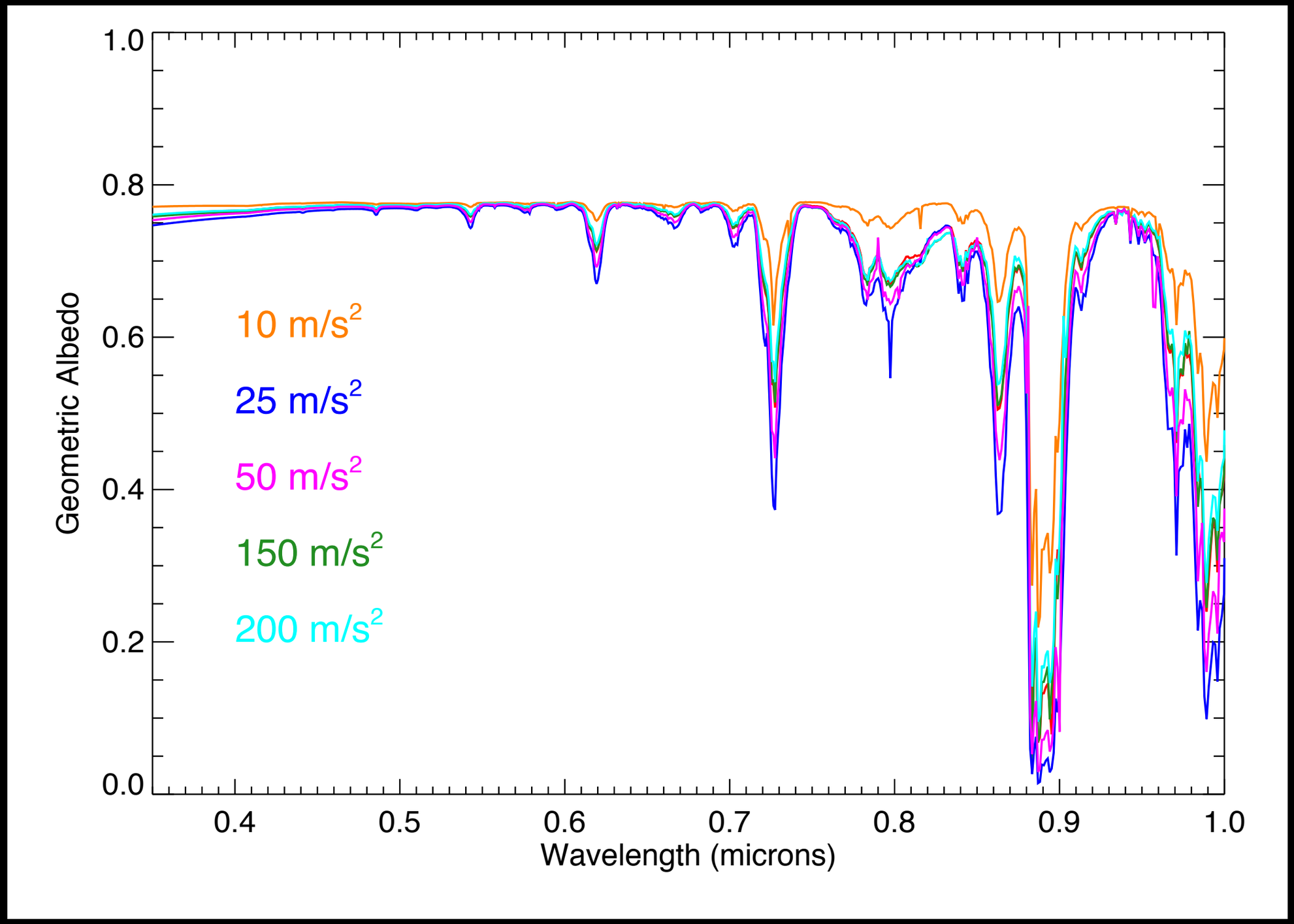
How does the composition of giant planets vary with mass, orbit, and stellar mass and metallicity?



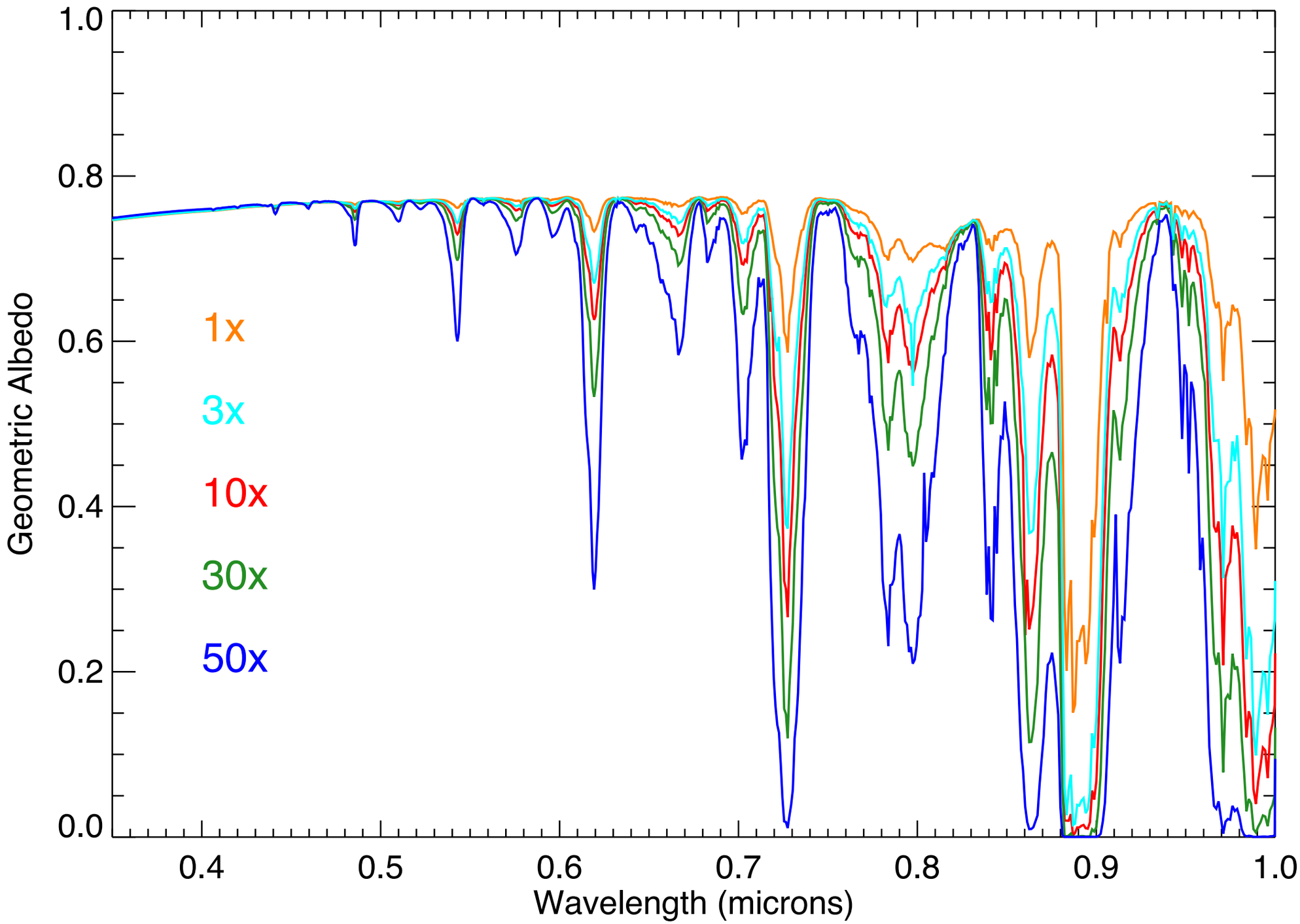
Cahoy et al. (2010)

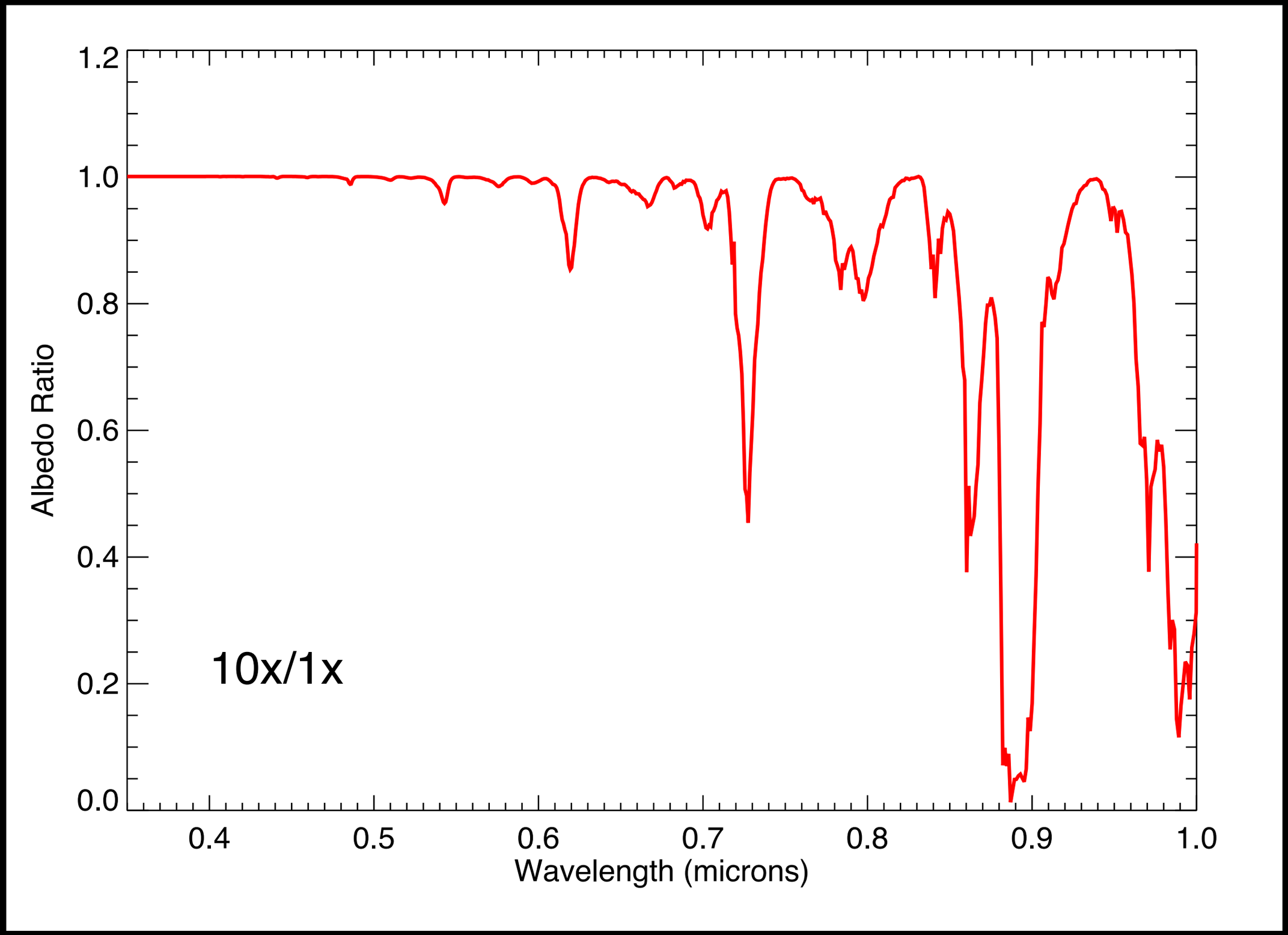

K2III
K2V
K0V
G8V
G5V
G0V
F8V
0
200
400
600
800
1000
T_{eq} (K)

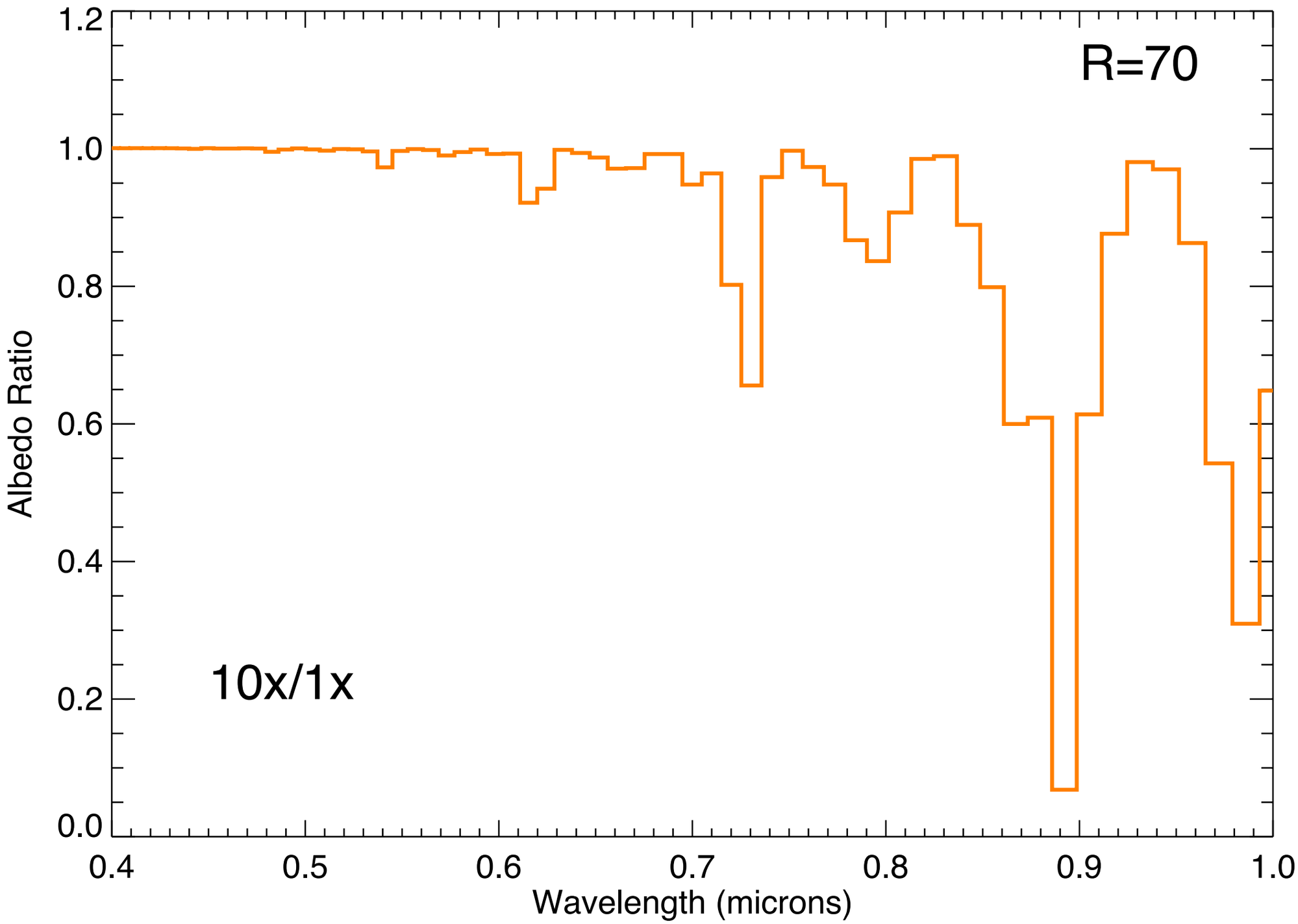
Planetary Mass Variations

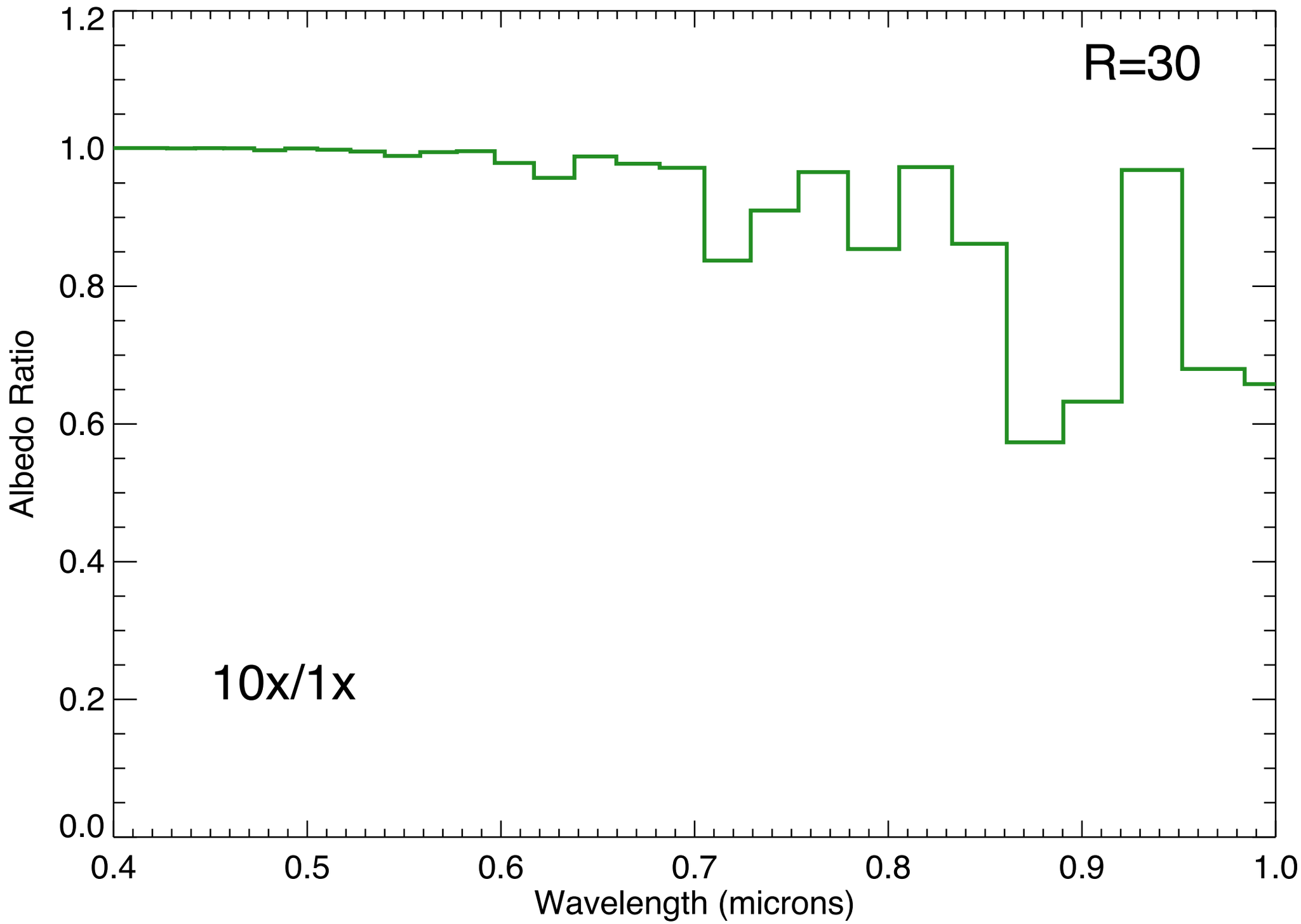


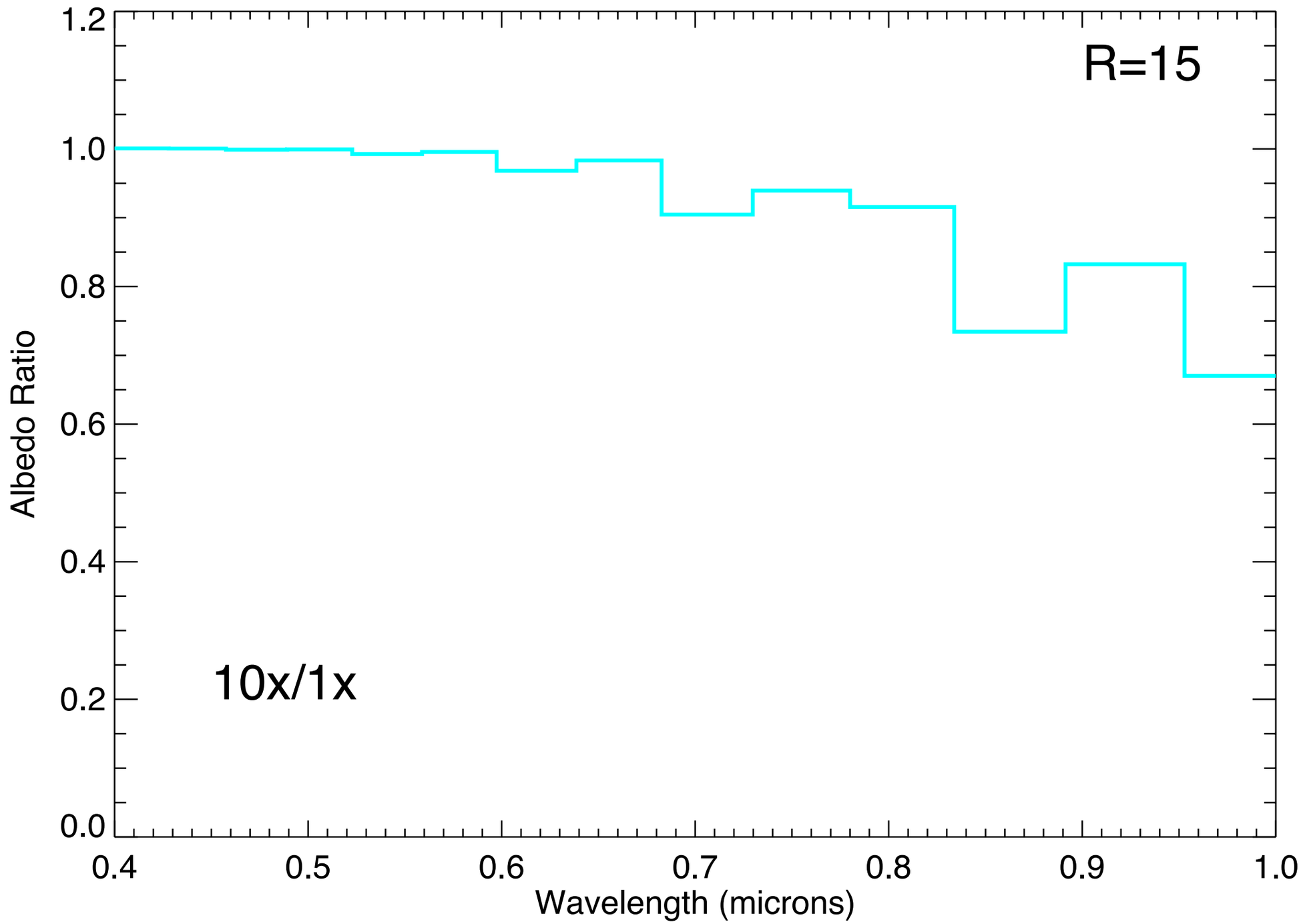
Planetary Metallicity Variations

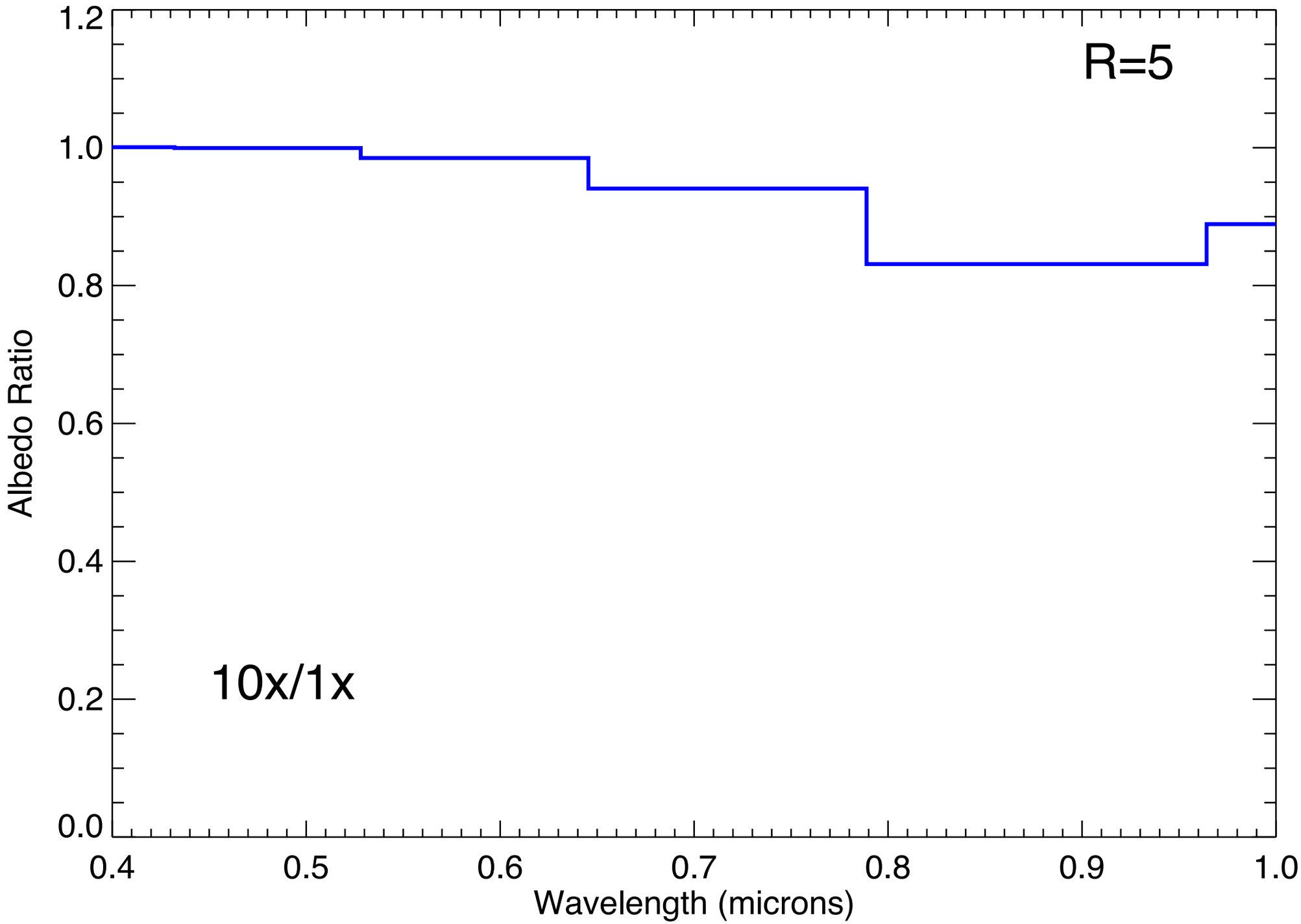



1.2
1.0
0.8
0.6
0.4
0.2
0.0
Albedo Ratio
10x/1x
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Wavelength (microns)

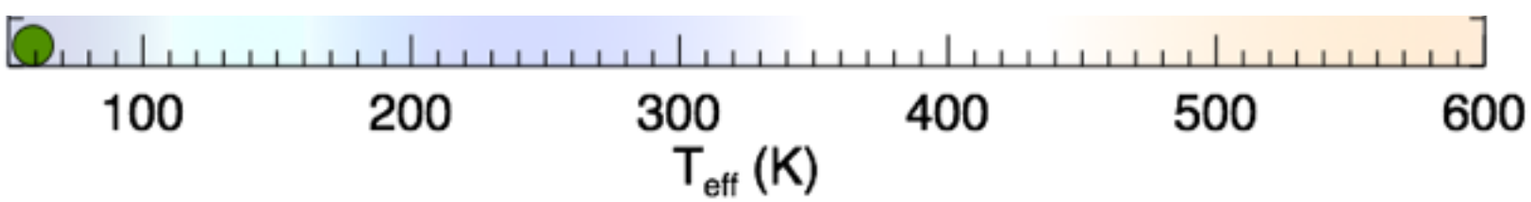

R=70
10x/1x
Albedo Ratio
Wavelength (microns)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.4
0.5
0.6
0.7
0.8
0.9
1.0


R=30
10x/1x
Albedo Ratio
Wavelength (microns)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.4
0.5
0.6
0.7
0.8
0.9
1.0

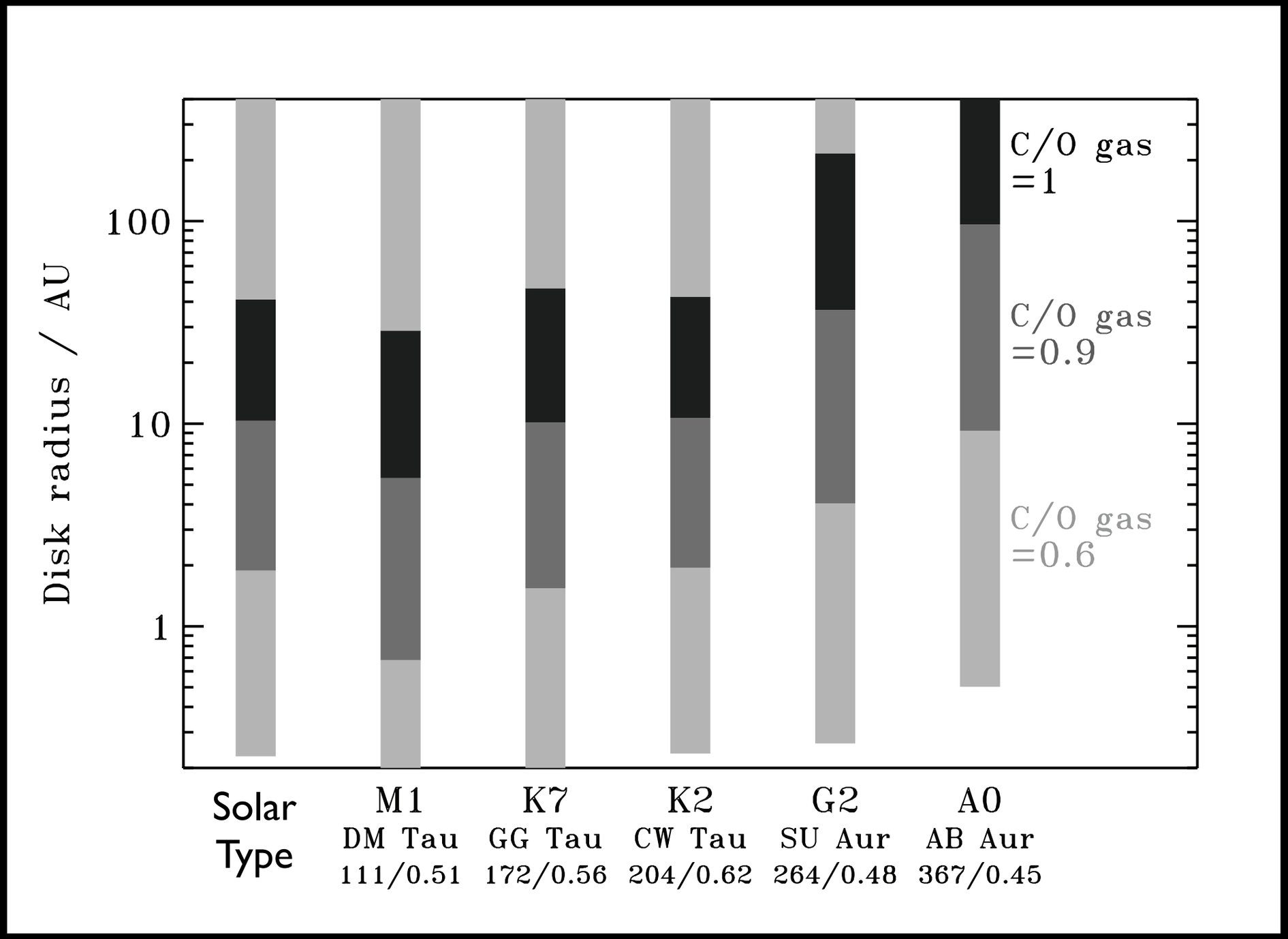

R=15
10x/1x
Albedo Ratio
Wavelength (microns)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.4
0.5
0.6
0.7
0.8
0.9
1.0


R=5
10x/1x
Albedo Ratio
Wavelength (microns)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.4
0.5
0.6
0.7
0.8
0.9
1.0

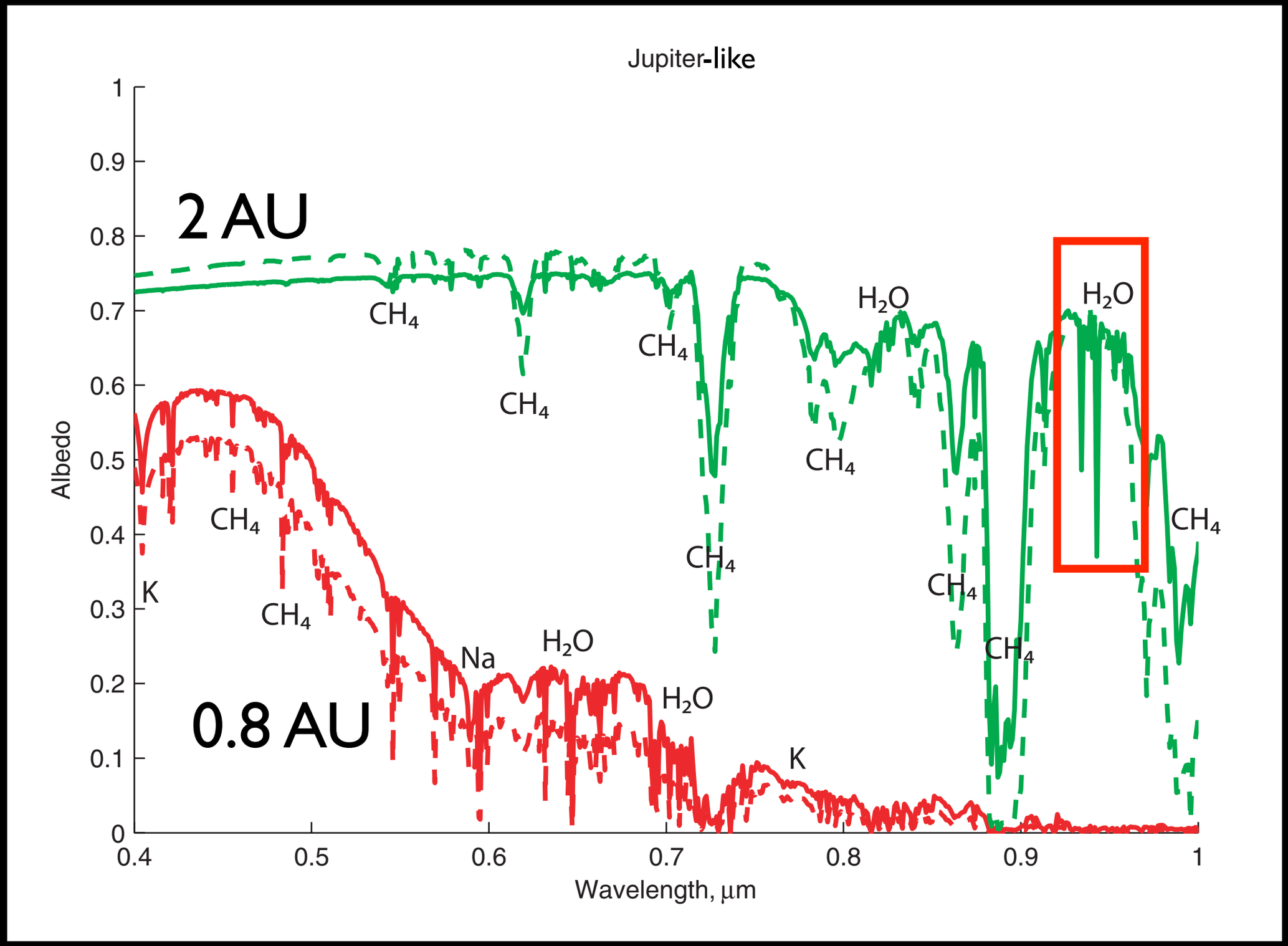
Planet	Msin(i) (M_J)	a AU	Θ ($''$)	V (mag)	SpL	Fe/H	Age (Gyr)	T_{eq} (K)	T_{int} (K)
HD 62509 b	2.900	1.69	0.16	1.15	K0IIIb	0.19	0.72	500	277
Ups And d	10.190	2.55	0.19	4.10	F8V	0.09	3.80	217	332
Ups And e	1.060	5.25	0.39	4.10	F8V	0.09	3.80	151	113
47 Uma c	0.540	3.60	0.26	5.04	G0V	0.00	7.40	152	73
47 Uma d	1.640	11.60	0.82	5.04	G0V	0.00	7.40	85	115
HD 87883 b	12.100	3.60	0.20	7.55	K0V	0.09	9.80	104	277
Mu Ara e	1.810	5.24	0.34	5.15	G3IV-V	0.28	6.41	130	126
HD 190360 b	1.500	3.92	0.25	5.71	G6IV	0.24	12.11	134	97
HD 39091 b	10.300	3.28	0.18	5.67	G1V	0.09	3.83	156	334
HD 142 c	5.300	6.80	0.26	5.70	G1V	0.04	5.93	127	211
HD 217107 c	2.490	5.27	0.26	6.18	G8IV	0.37	7.32	116	137
HD 154345 b	1.000	4.30	0.23	6.74	G8V	-0.10	4.92	110	105
14 Her b	4.640	2.77	0.16	6.67	K0V	0.43	5.10	140	205
HD 134987 c	0.820	5.80	0.22	6.46	G5V	0.25	9.70	119	77
HD 99492 c	0.360	5.40	0.30	7.53	K2V	0.36	4.00	85	72
Gam Cep b	1.850	2.05	0.14	3.22	K1III-IV	0.18	6.60	331	126
HD 192310 c	0.080	1.18	0.13	5.72	K3V	-0.04	7.81	190	42
GJ 832 b	0.640	3.40	0.69	8.67	M1.5	-0.31	5.00	52	87
Eps Eri b	1.550	3.39	1.00	3.73	K2V	-0.13	0.66	116	220
55 Cnc d	3.835	5.76	0.47	5.95	K0IV-V	0.31	10.20	93	145
HD 219077 b	10.390	6.22	0.21	6.12	G8V	-0.13	8.90	95	266



Do planets formed inside and outside the nebular 'snow line' have different composition or C/O ratios?



Oberg et al. (2011)



Cahoy et al. (2010)

Conclusions and Future Work

- Direct imaging missions such as WFIRST-AFTA will provide important probes into the formation history of giant planets around other stellar hosts.
- Understanding the formation of clouds and hazes in these planetary atmospheres will be key to the interpretation of their visible wavelength spectra.
- Even at 'sub-optimal' resolutions key spectral features allow for constraints on the composition and thermal structure of giant planets amenable to direct imaging.
- Future work with C/O ratio variations can provide key insights into the formation (and possibly migration) history of extrasolar giant planets.

References

Cahoy, K. L., M. S. Marley, and J. J. Fortney 2010. Exoplanet Albedo Spectra and Colors as a Function of Planet Phase, Separation, and Metallicity. *ApJ* 724, 189–214.

Marley, M. S., C. Gelino, D. Stephens, J. I. Lunine, and R. Freedman 1999. Reflected Spectra and Albedos of Extrasolar Giant Planets. I. Clear and Cloudy Atmospheres. *ApJ* 513, 879–893.

Fortney, J. J., M. S. Marley, D. Saumon, and K. Lodders 2008. Synthetic Spectra and Colors of Young Giant Planet Atmospheres: Effects of Initial Conditions and Atmospheric Metallicity. *ApJ* 683, 1104–1116.