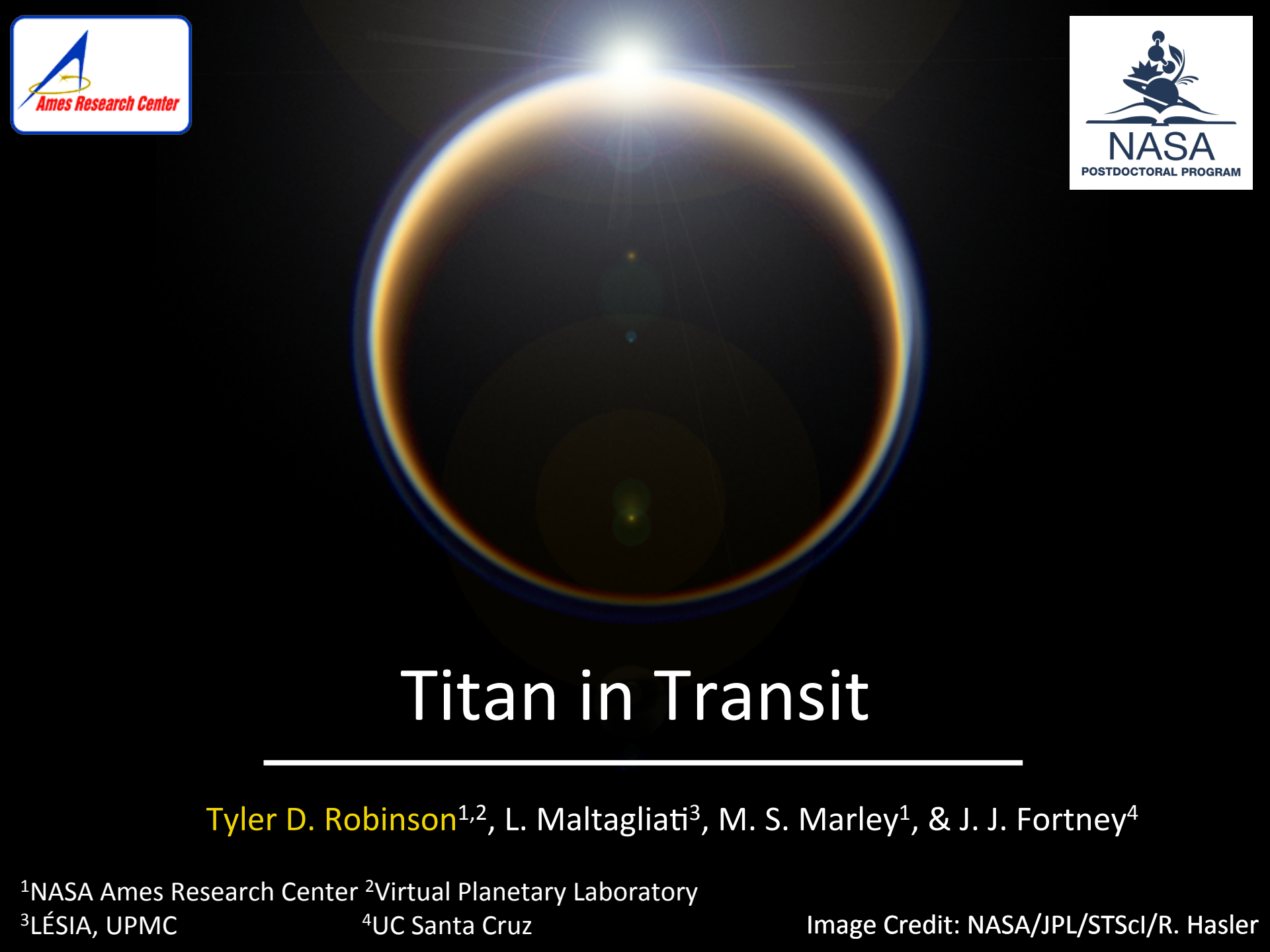
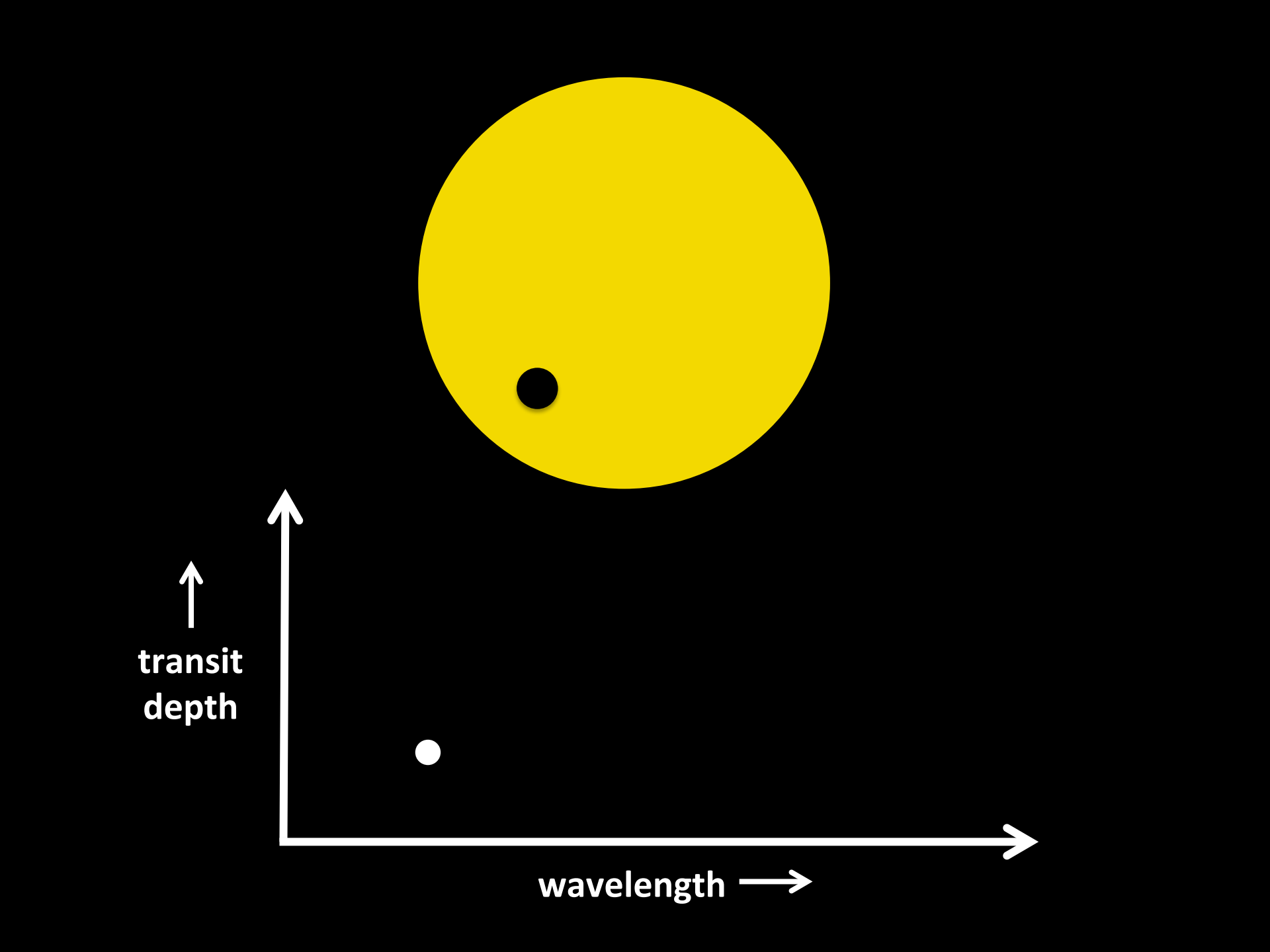


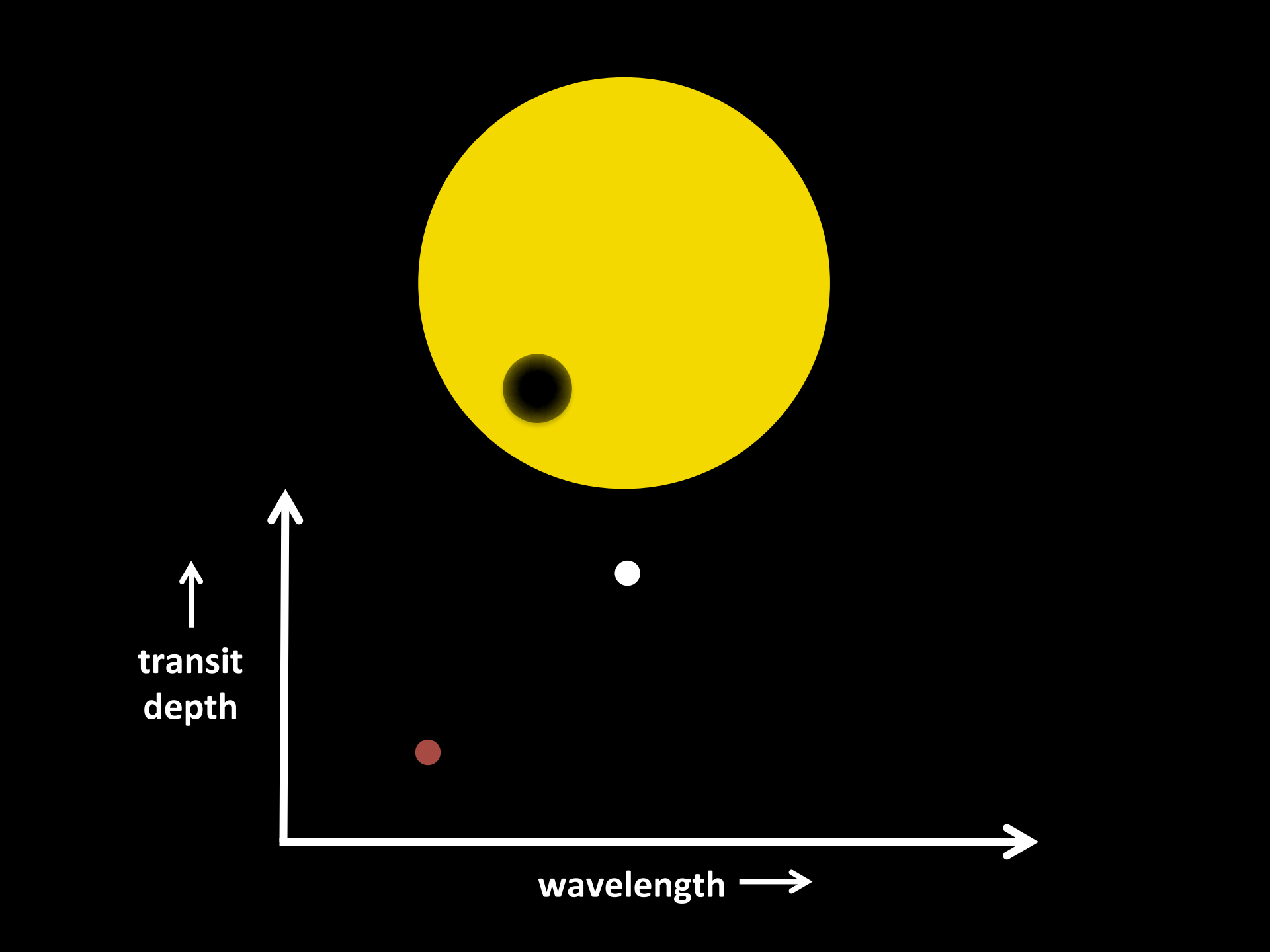
Titan in Transit

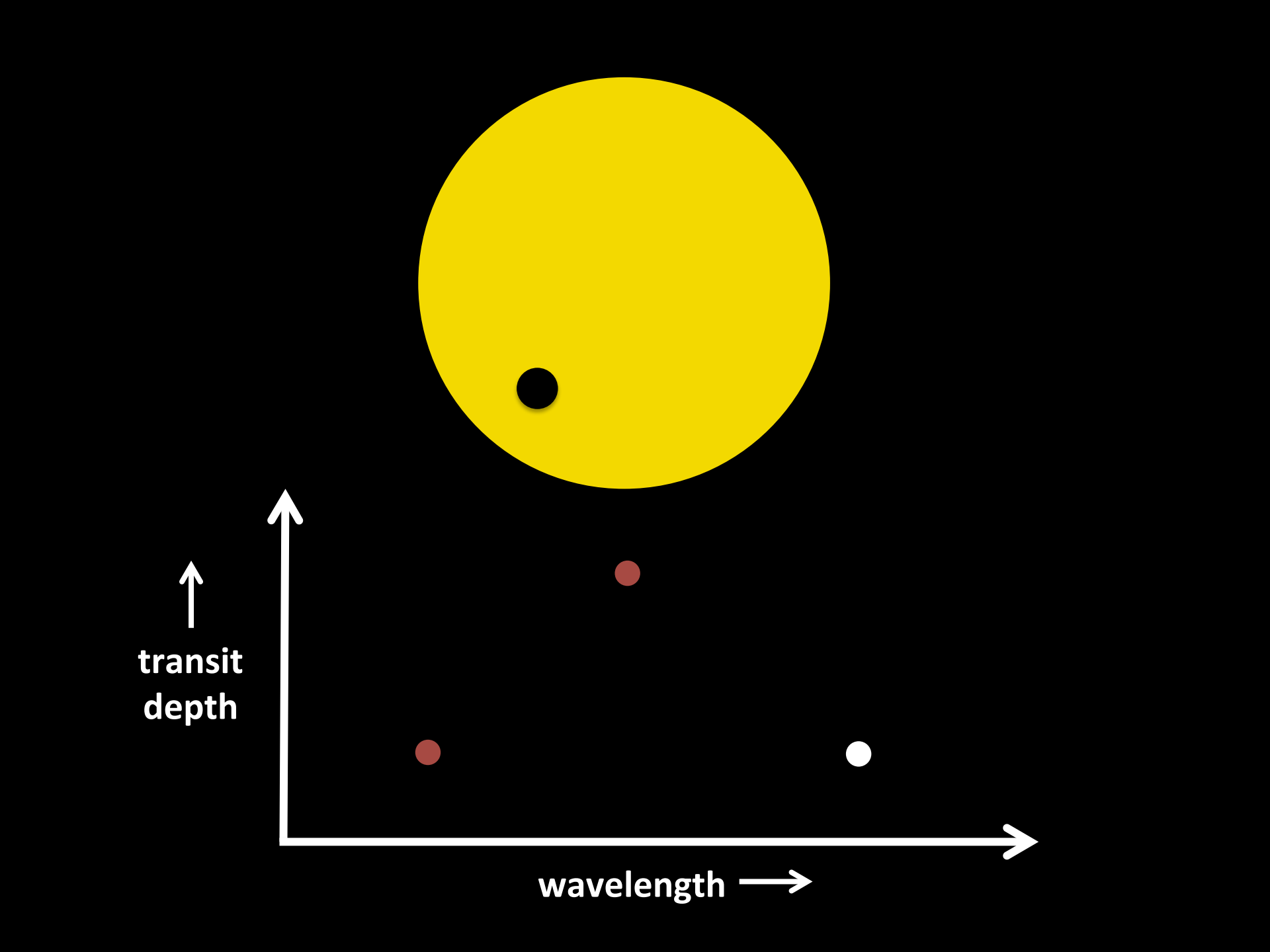
Tyler D. Robinson[1,2], L. Maltagliati[3], M. S. Marley[1], & J. J. Fortney[4]

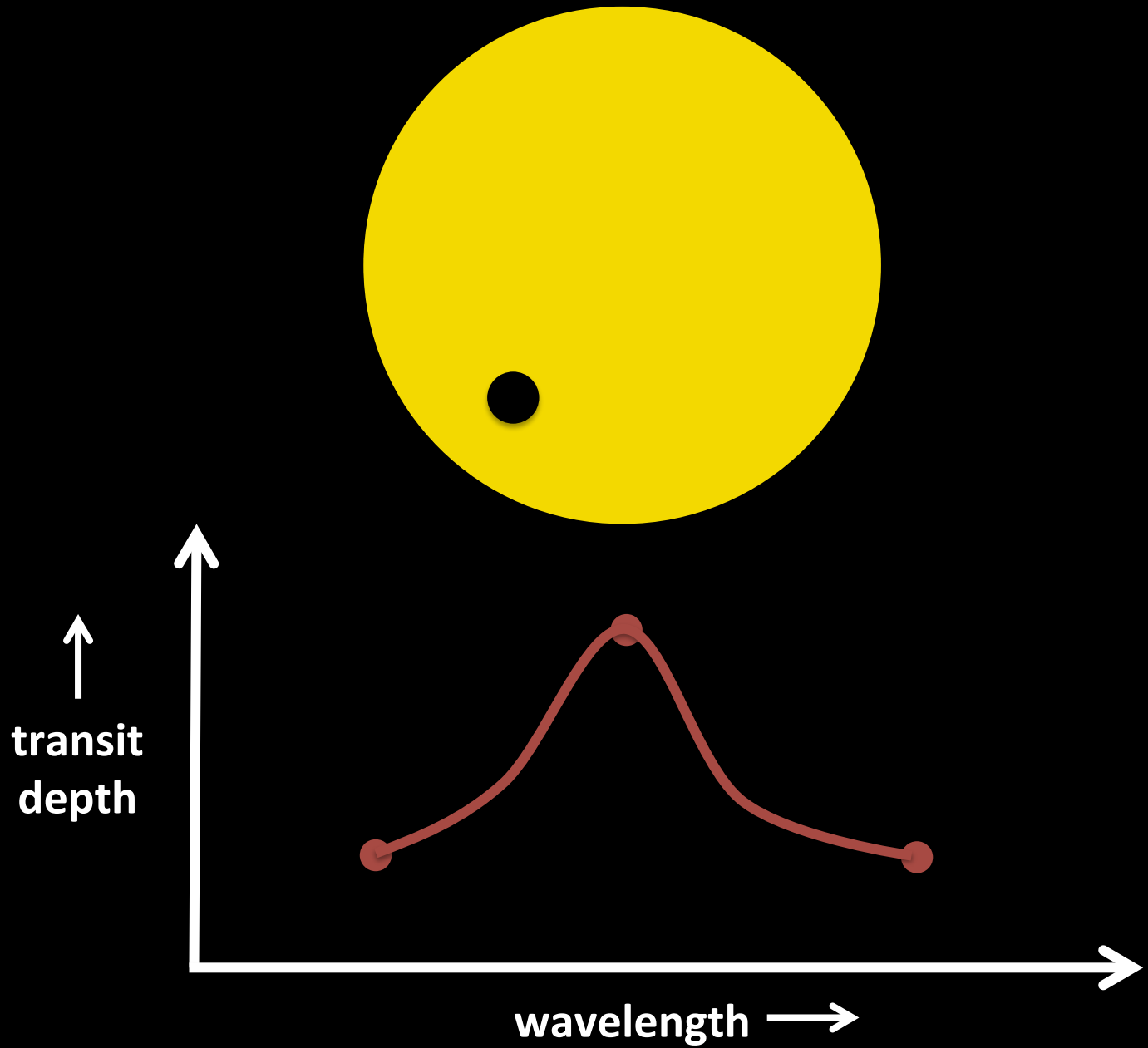
[1]NASA Ames Research Center [2]Virtual Planetary Laboratory
[3]LÉSIA, UPMC [4]UC Santa Cruz

Image Credit: NASA/JPL/STScI/R. Hasler


transit
depth
wavelength


transit
depth
wavelength

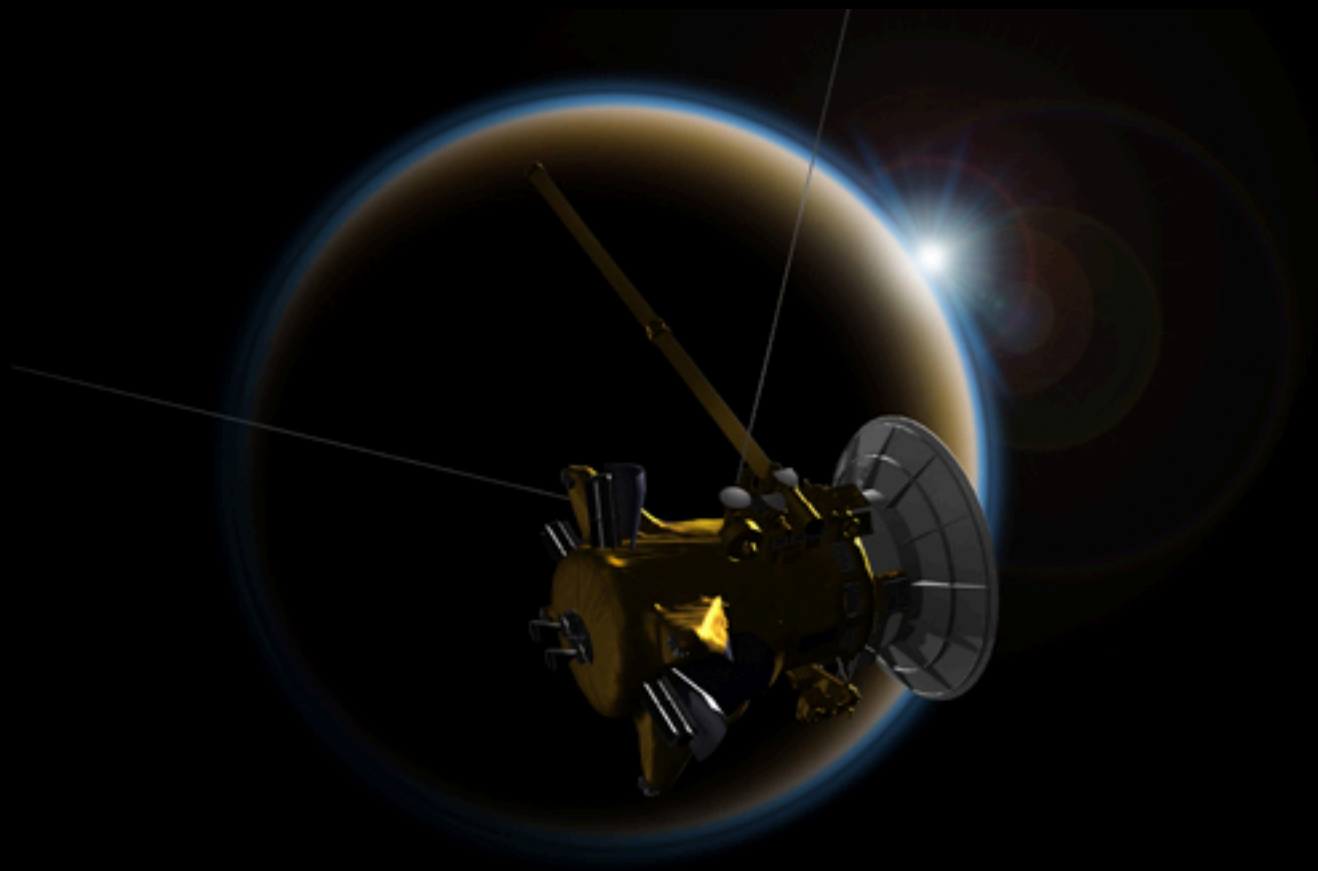

transit
depth
wavelength


transit
depth
wavelength

GJ 1214b

HST/WFC3

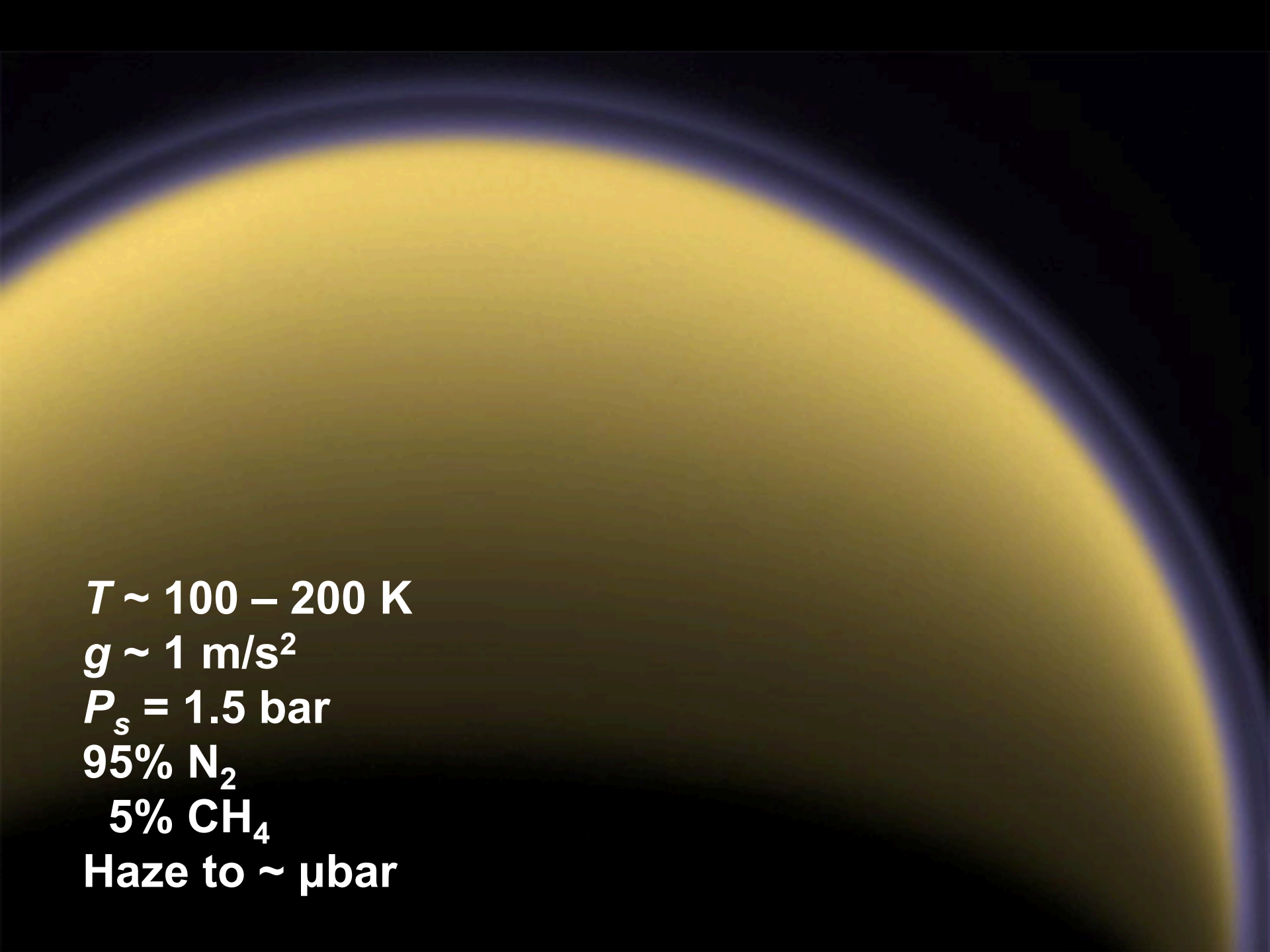
Kreidberg et al. (2014)

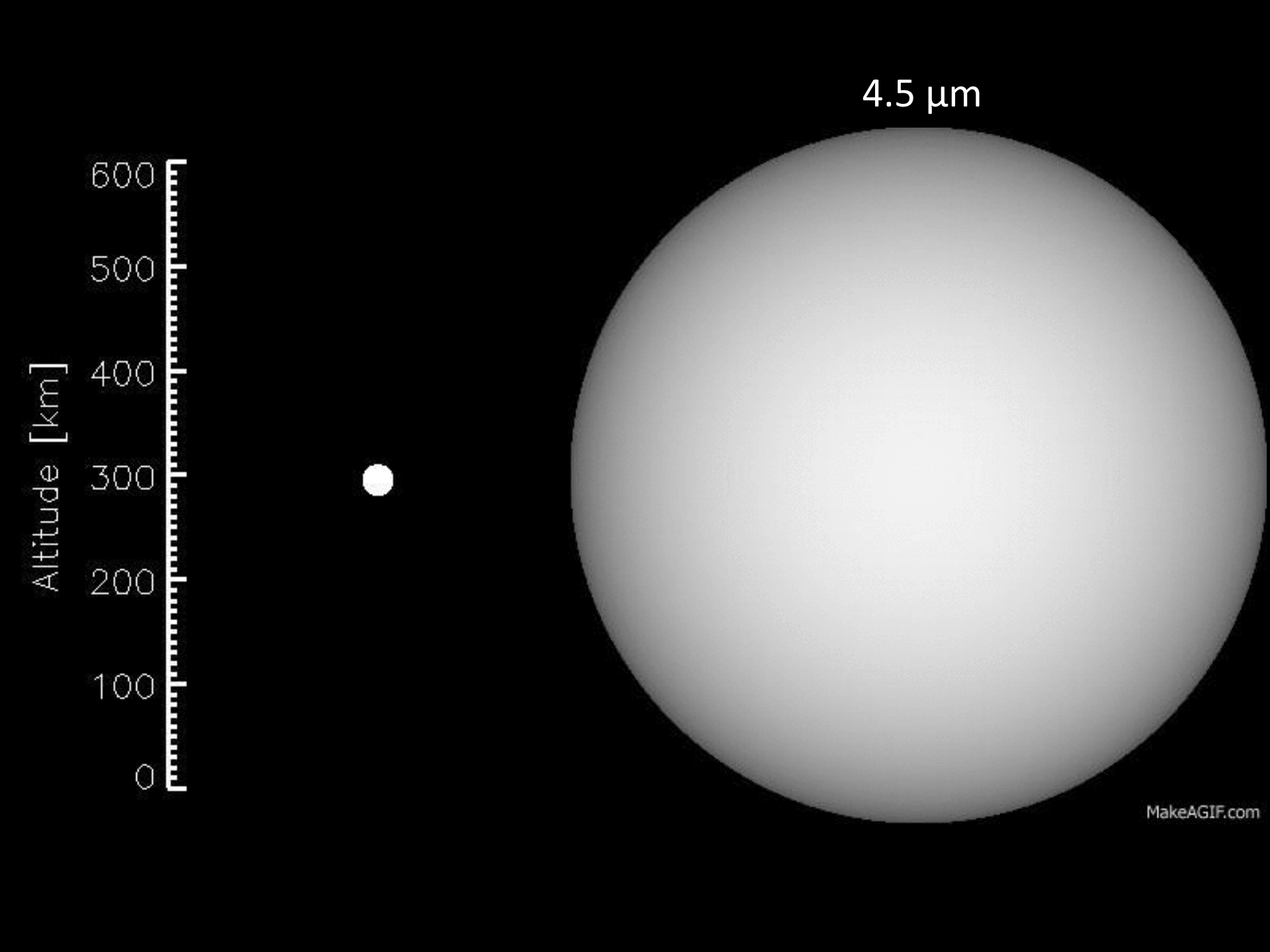


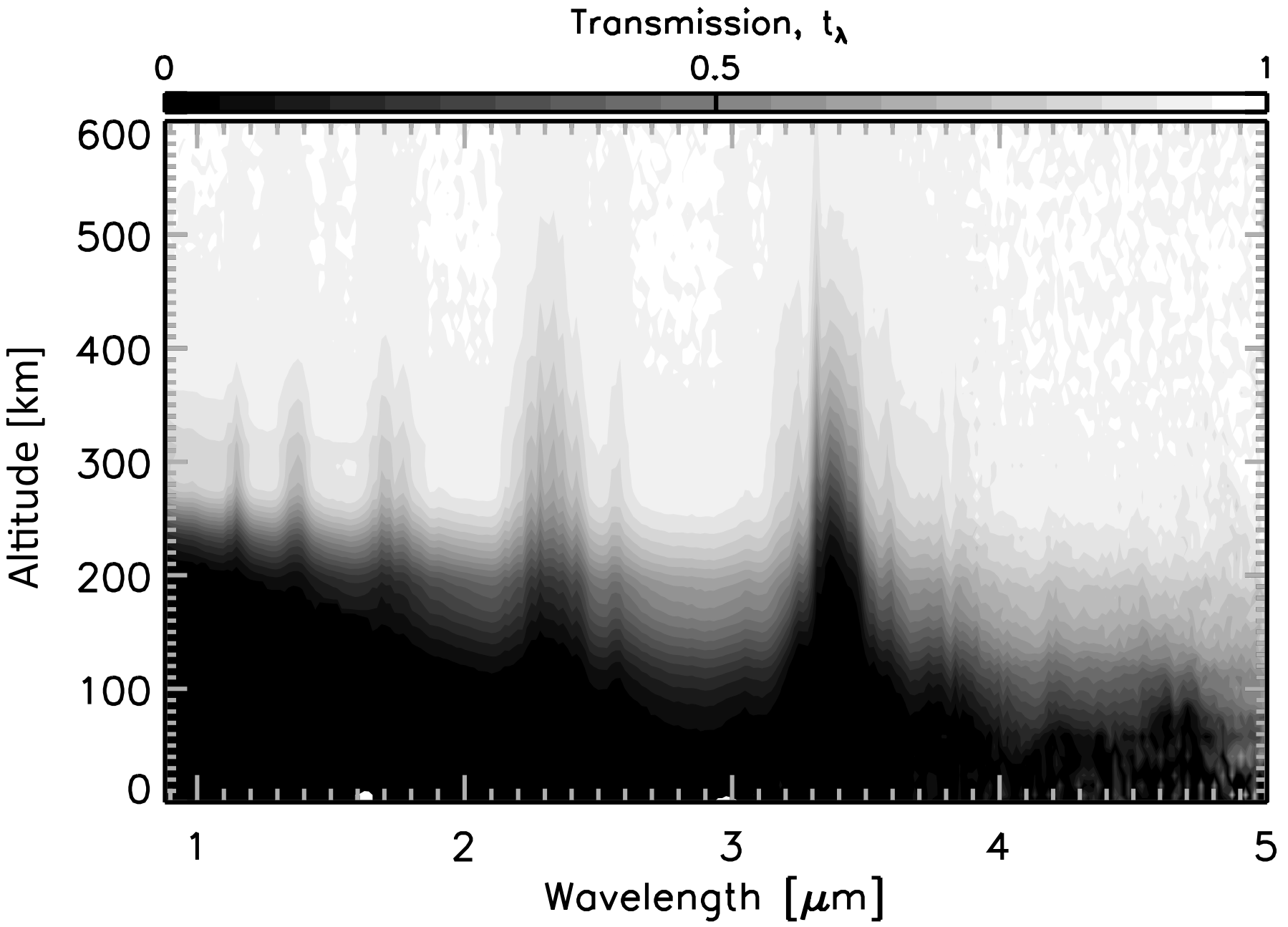
Reference:

Maltagliati, L., et al. 2015. Titan's atmosphere as observed by *Cassini*/VIMS solar occultations: CH_4, CO, and evidence for C_2H_6 absorption. *Icarus*, 248, 1

Image Credit: NASA/JPL/STScI

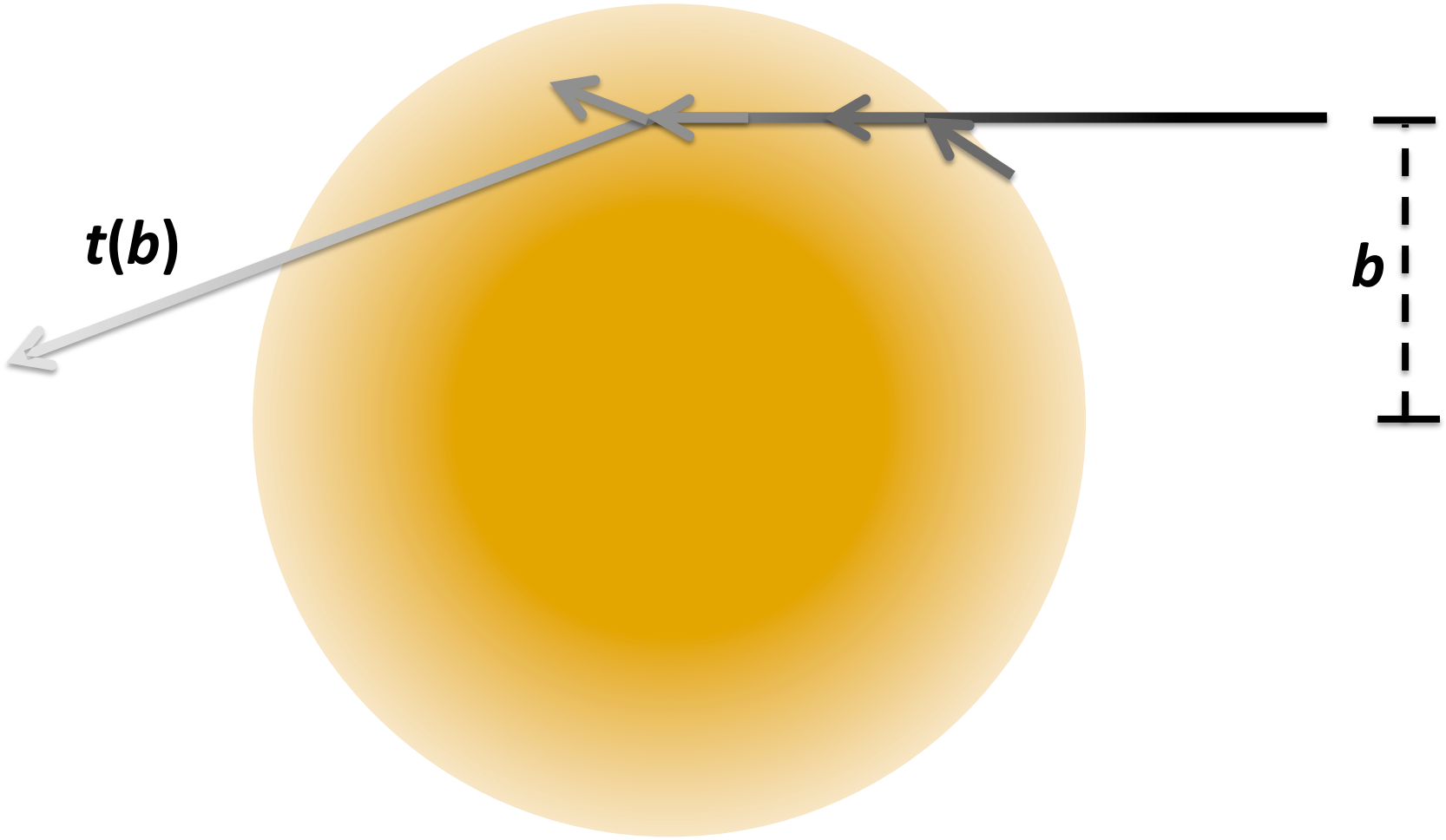

T ~ 100 – 200 K
g ~ 1 m/s^2
P_s = 1.5 bar
95% N_2
5% CH_4
Haze to ~ μbar


4.5 µm
Altitude [km]
600
500
400
300
200
100
0
MakeAGIF.com

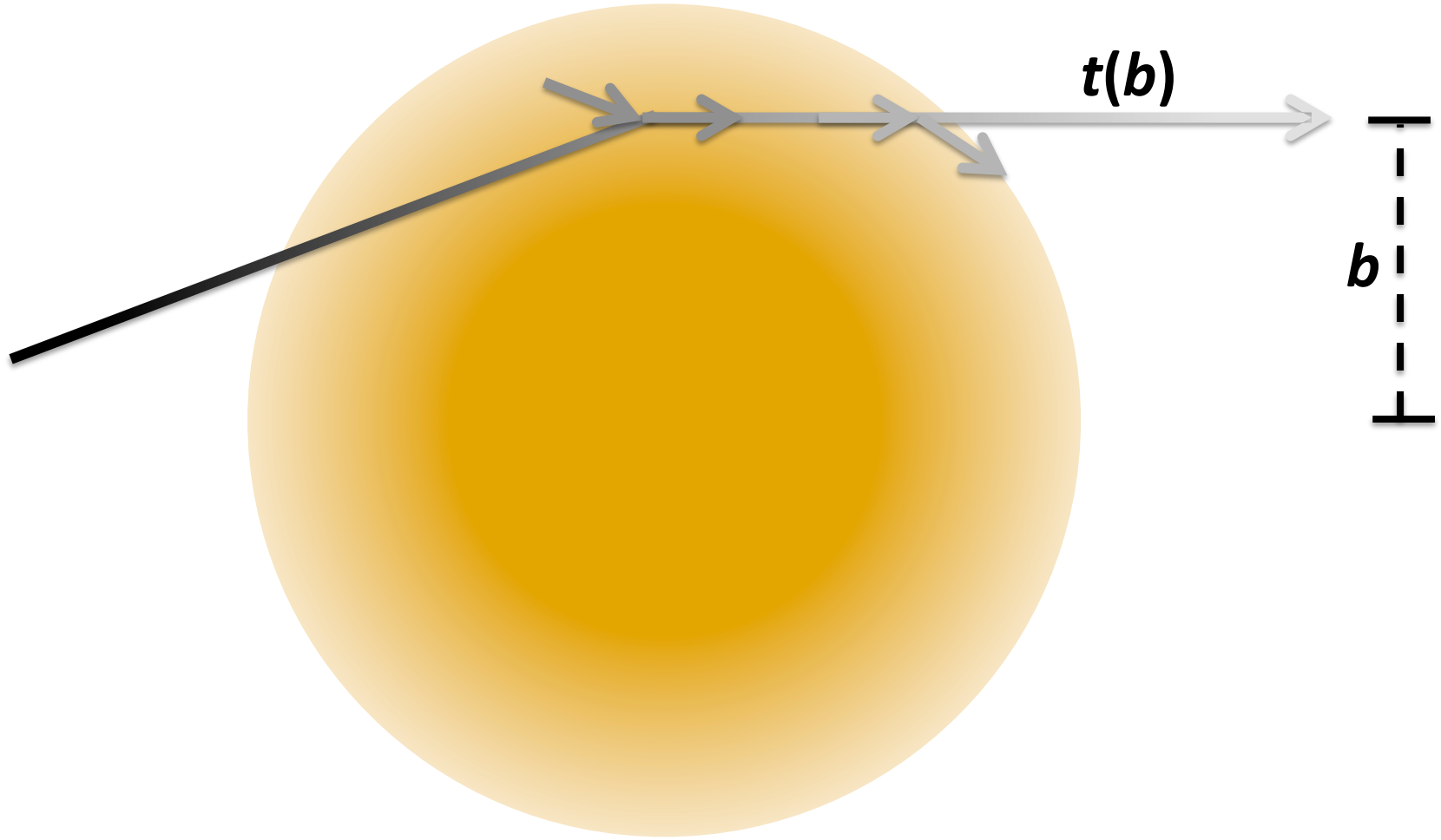


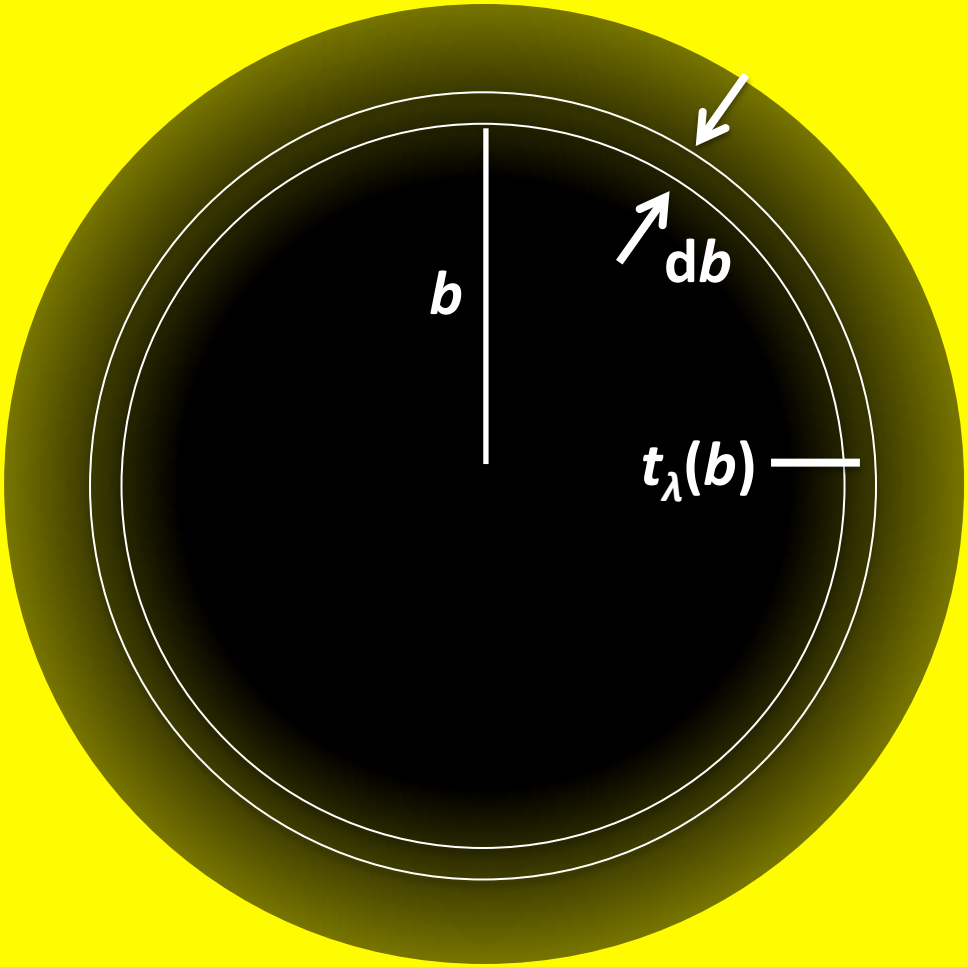
Robinson et al. (2014); Maltagliati et al. (2015)

Occultation:

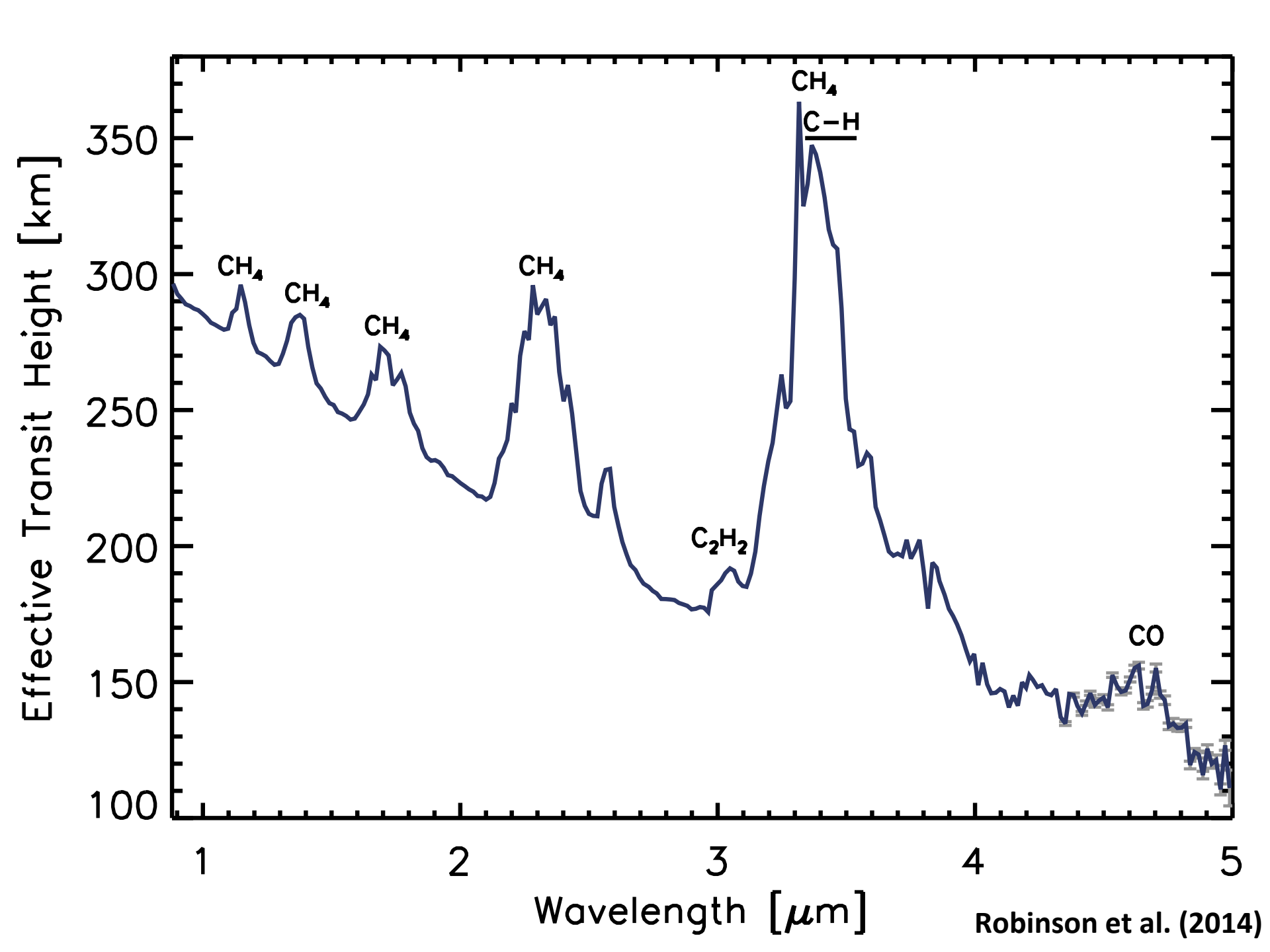


Transit:

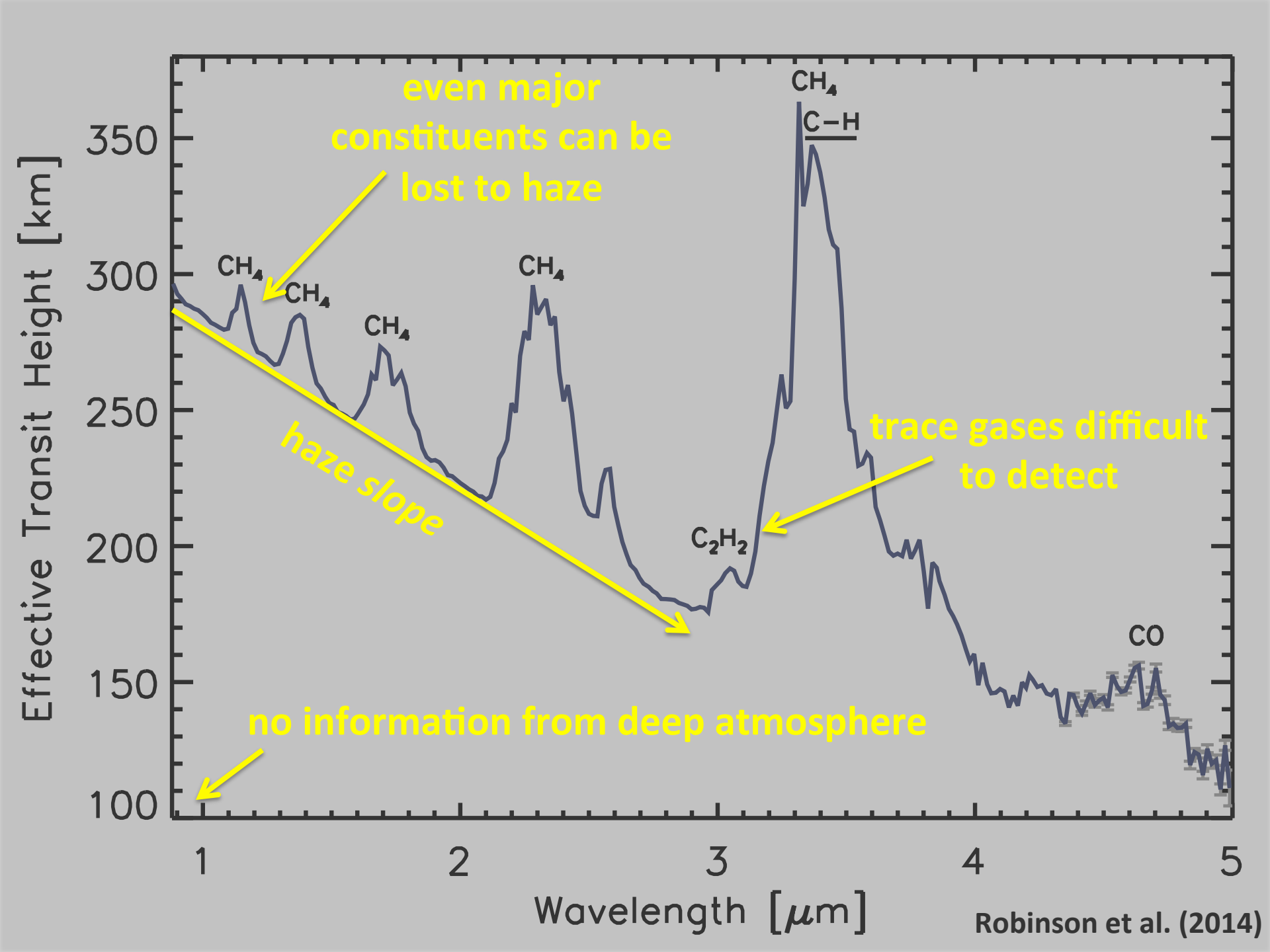


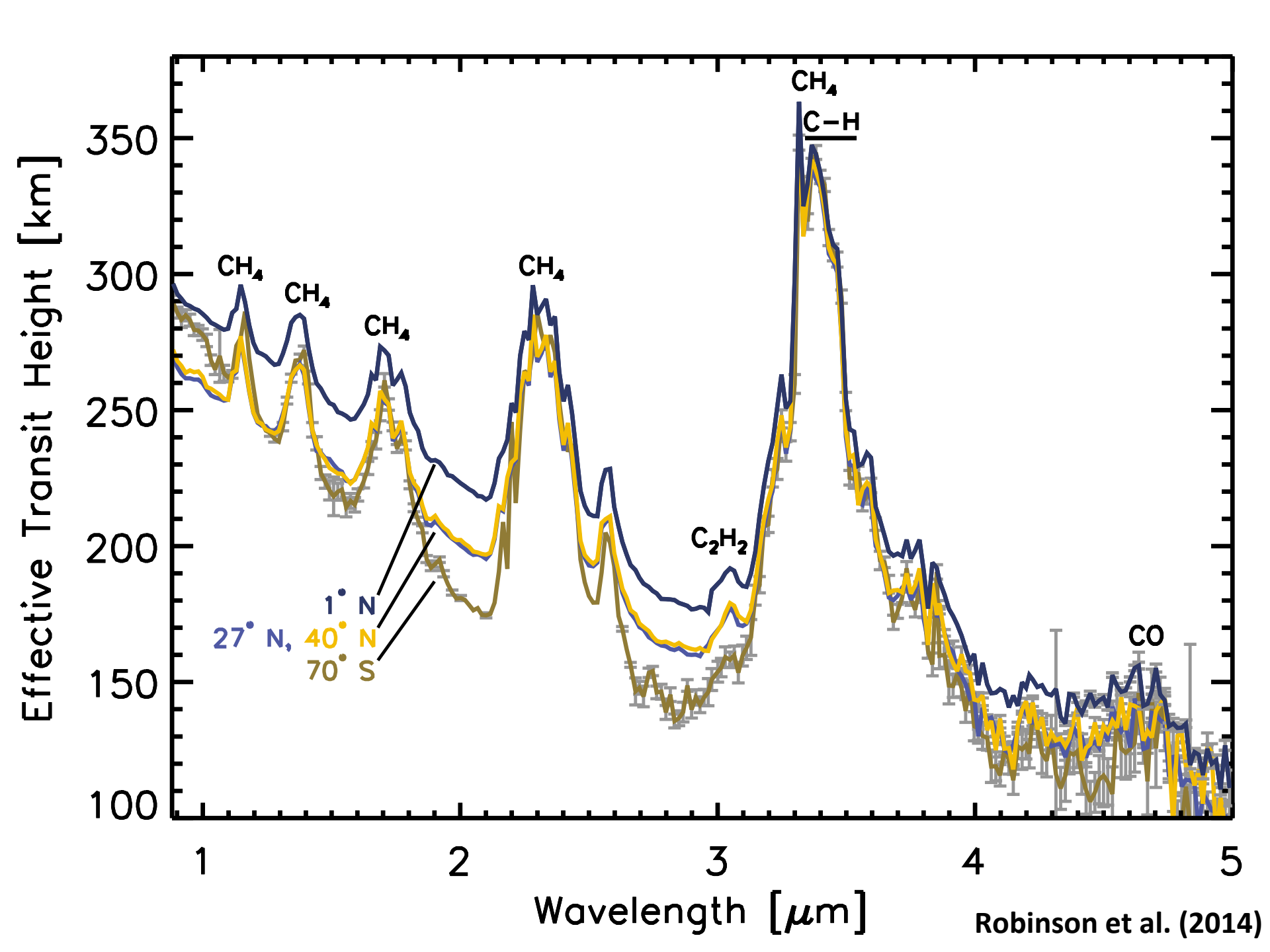


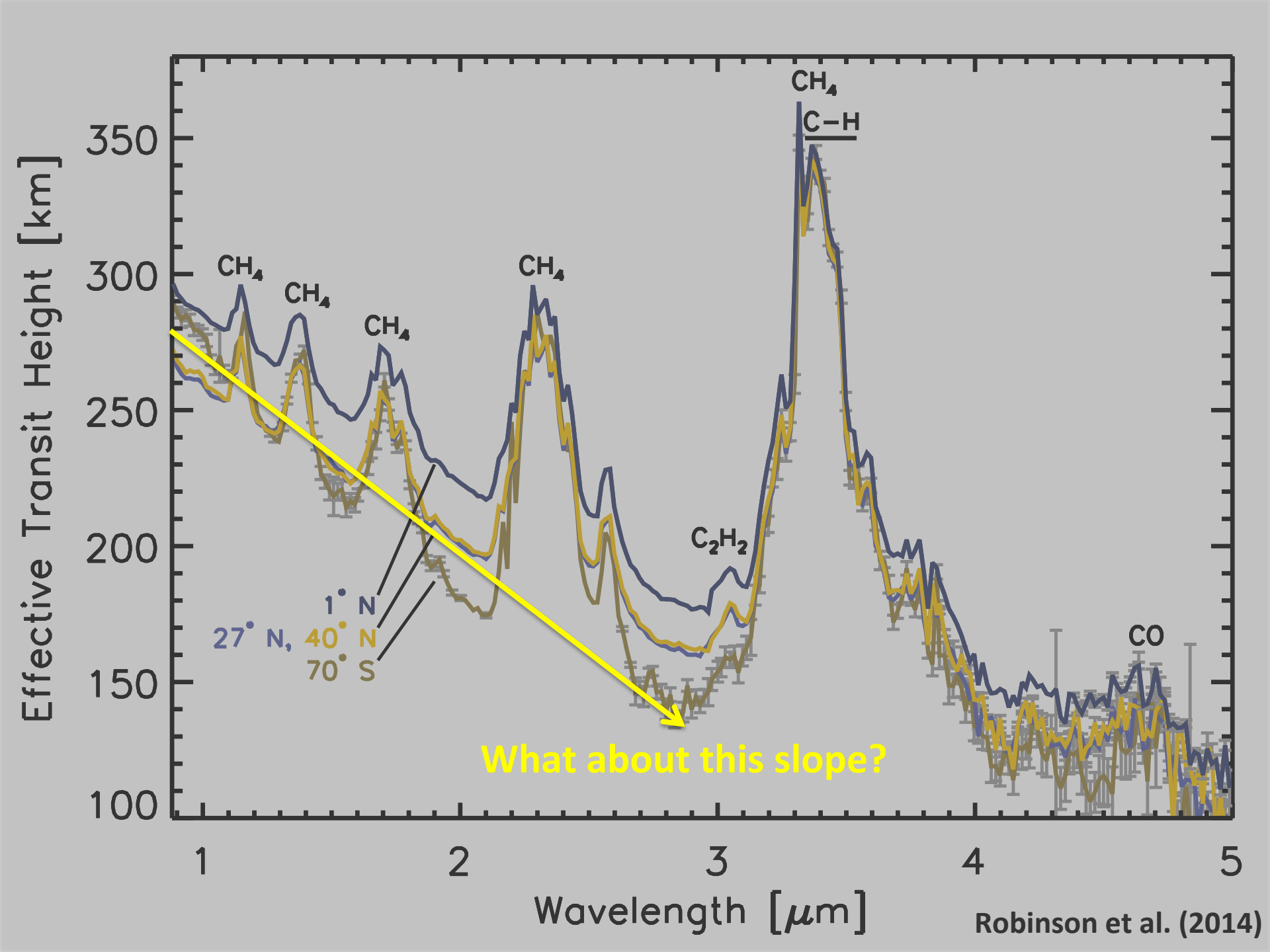
$$\left(\frac{R_p + z_\lambda}{R_s}\right)^2 = \left(\frac{R_{p,\lambda}}{R_s}\right)^2 = \frac{1}{\pi R_s^2}\int_0^\infty [1 - t_\lambda(b)]\, 2\pi b\, db$$



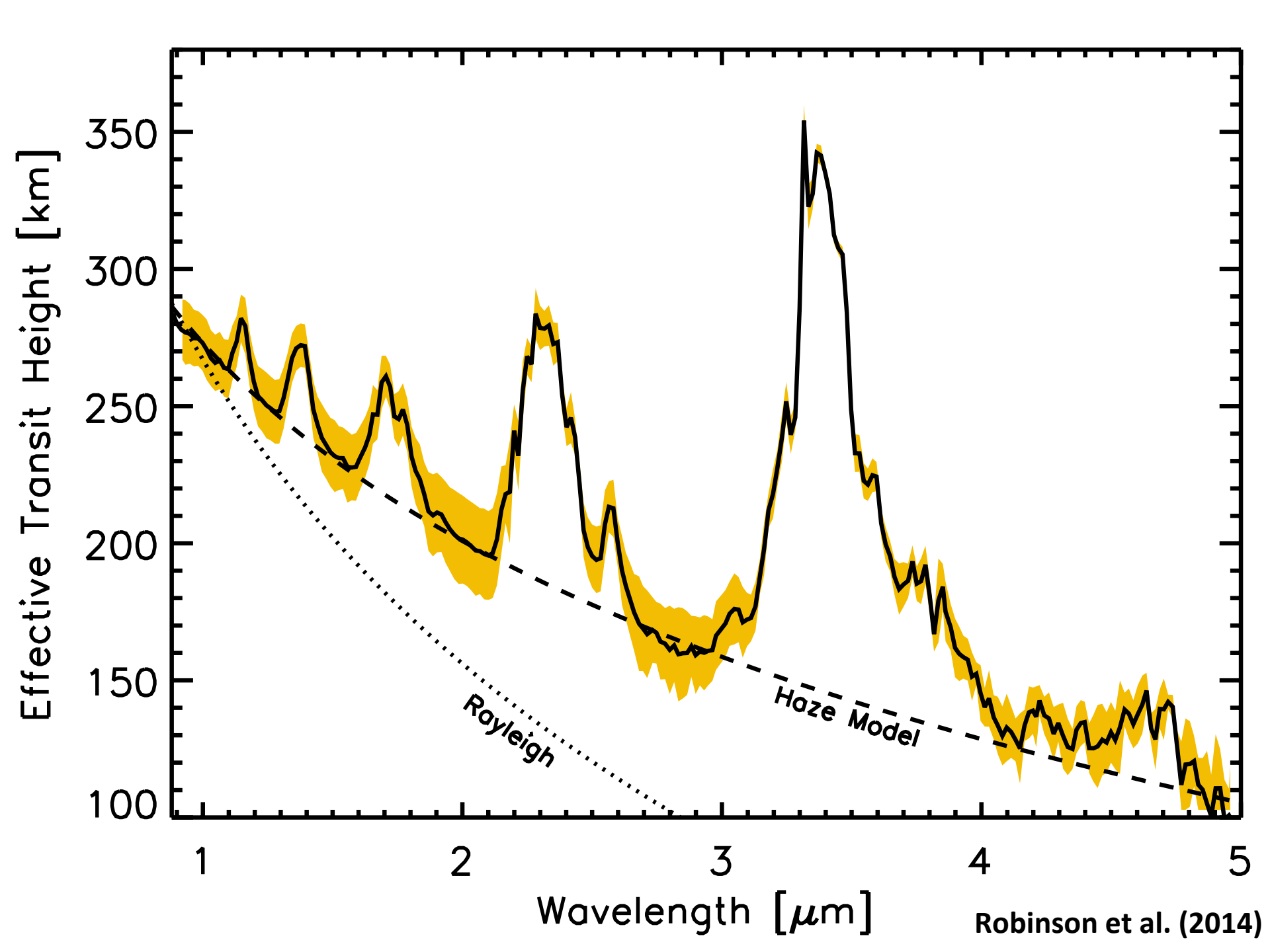
Robinson et al. (2014)


even major
constituents can be
lost to haze
haze slope
trace gases difficult
to detect
no information from deep atmosphere
CH4
CH4
CH4
CH4
CH4
C–H
C2H2
CO
Effective Transit Height [km]
350
300
250
200
150
100
1
2
3
4
5
Wavelength [μm]
Robinson et al. (2014)


Effective Transit Height [km]
350
300
250
200
150
100
1
2
3
4
5
Wavelength [μm]
CH4
CH4
CH4
CH4
CH4
C–H
C2H2
CO
1° N
27° N, 40° N
70° S
Robinson et al. (2014)



Robinson et al. (2014)


Effective Transit Height [km]
350
300
250
200
150
100
1
2
3
4
5
Wavelength [μm]
Rayleigh
Haze Model
Robinson et al. (2014)

$$\tau_{\text{vert}}(z) = \tau_0 e^{-(z-z_0)/H_h}$$

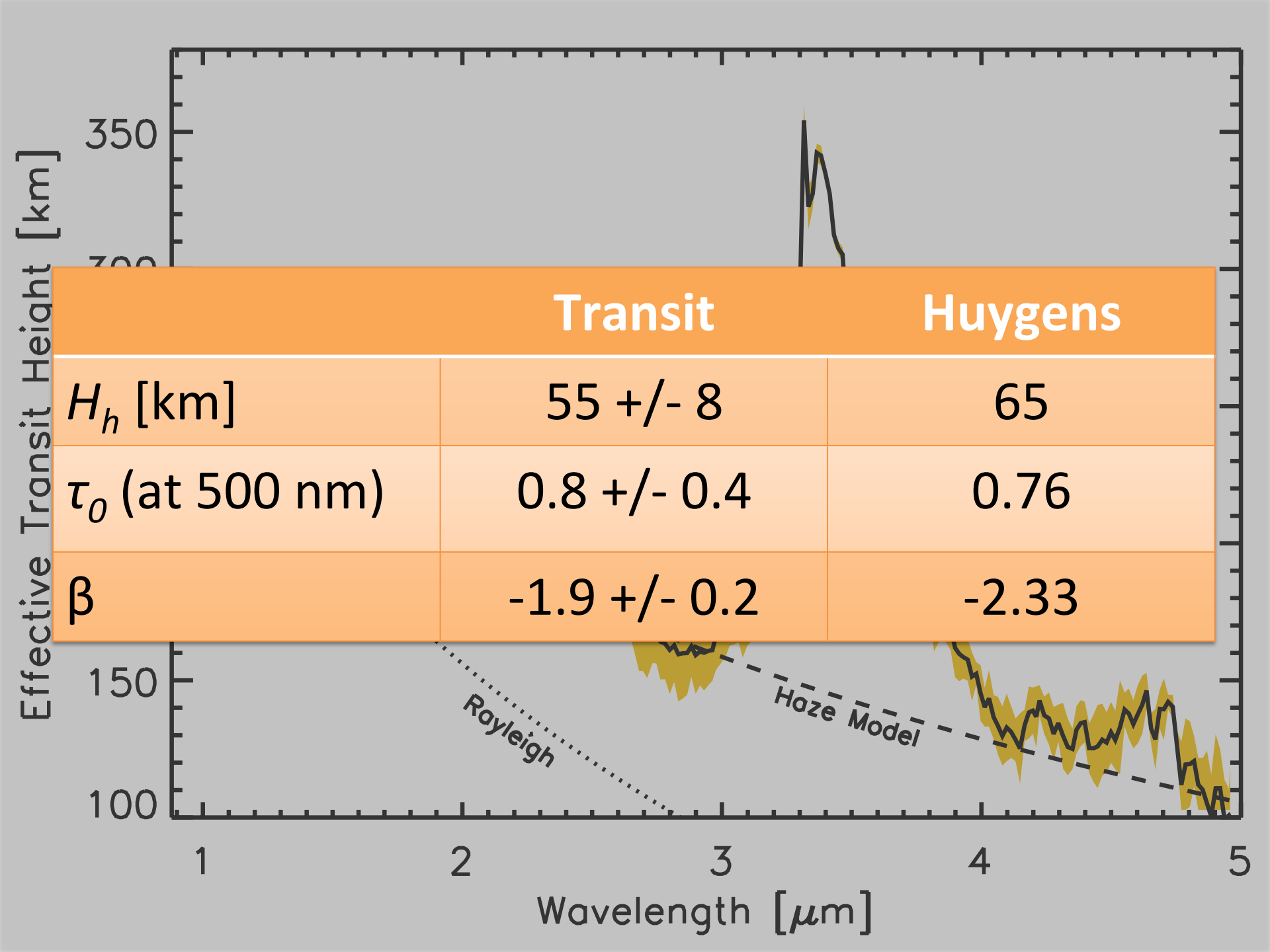
Robinson et al. (2014)

$$\sigma(\lambda) = \sigma_0 \left(\frac{\lambda}{\lambda_0} \right)^{\beta}$$

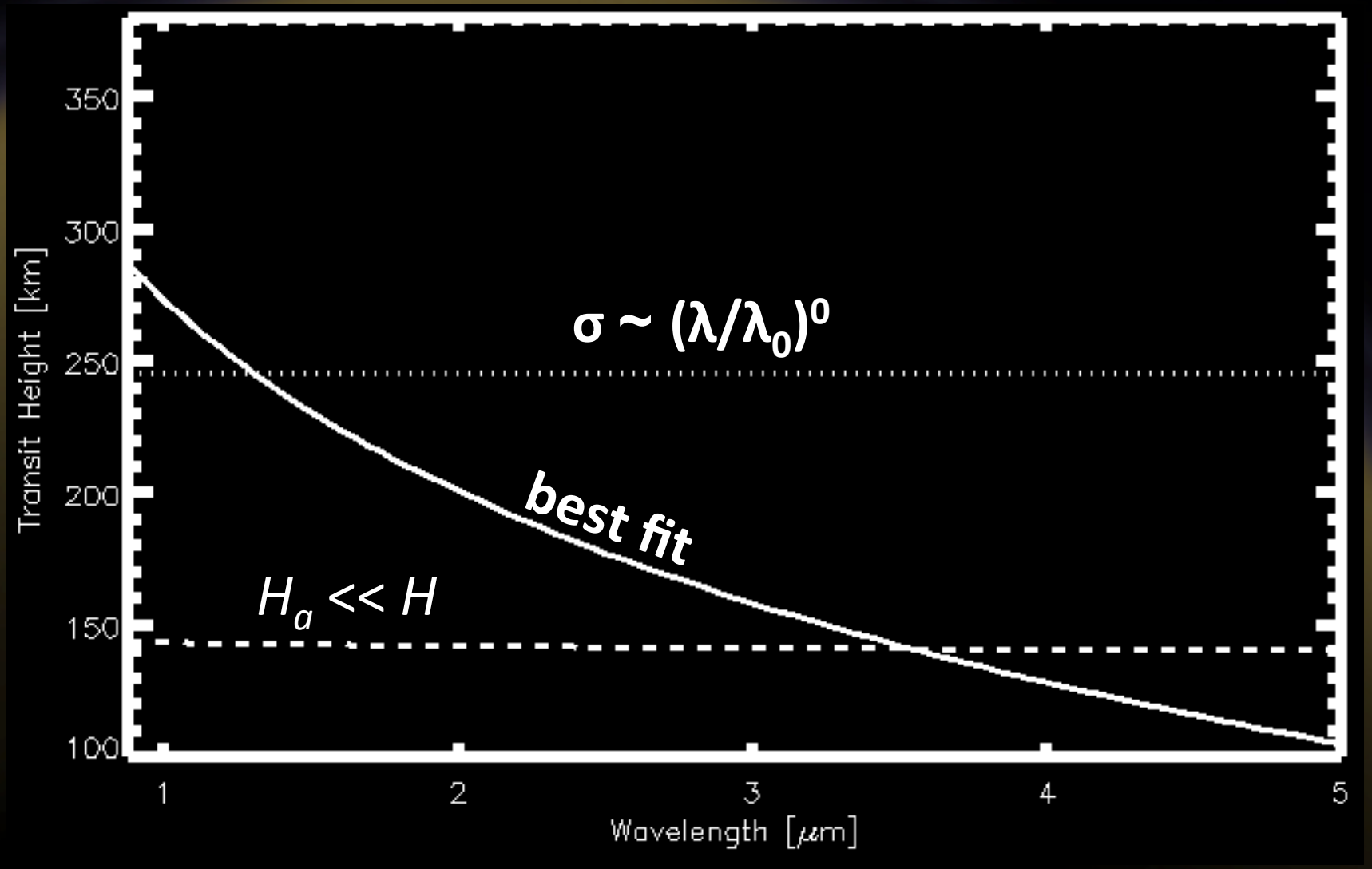
Robinson et al. (2014)

$$\tau_\lambda(b) = 2\tau_0 \left(\frac{\lambda}{\lambda_0} \right)^\beta \frac{b}{H_h} K_1 \left(\frac{b}{H_h} \right) e^{\left(R_p + z_0\right)/H_h}$$

Robinson et al. (2014)



	Transit	Huygens
H_h [km]	55 +/- 8	65
τ_0 (at 500 nm)	0.8 +/- 0.4	0.76
β	-1.9 +/- 0.2	-2.33


Transit Height [km]
350
300
250
200
150
100
1
2
3
4
5
Wavelength [μm]
σ ~ (λ/λ0)0
best fit
Ha << H

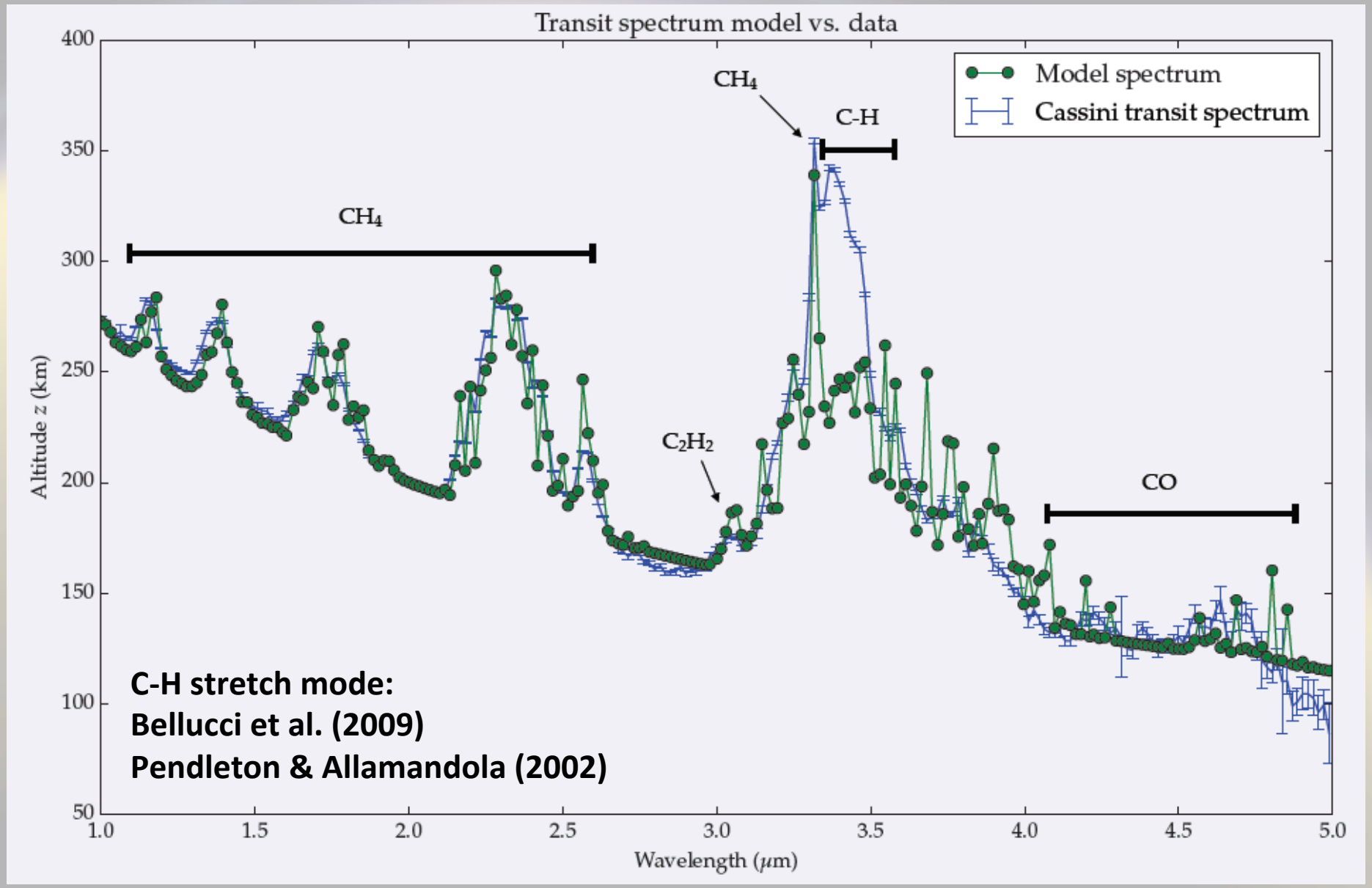


figure from Teal, Line, et al. (2015)

Implications & Conclusions

1. Hazes and clouds need not imply a flat transit spectrum.

2. Gas absorption can still be detected despite a high-altitude haze.

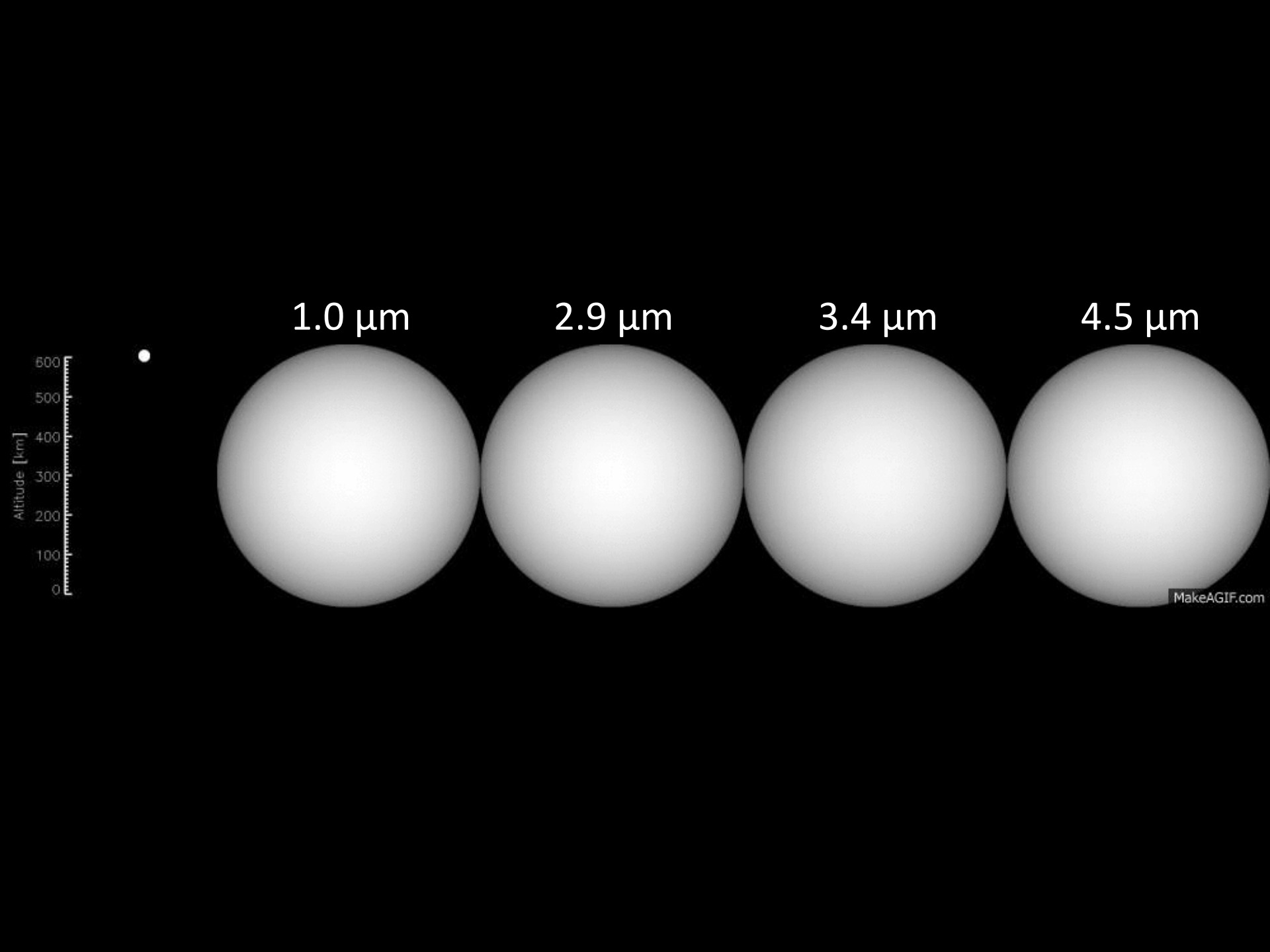
3. Depending on wavelength, hazes can obscure gaseous absorption, especially for trace species.

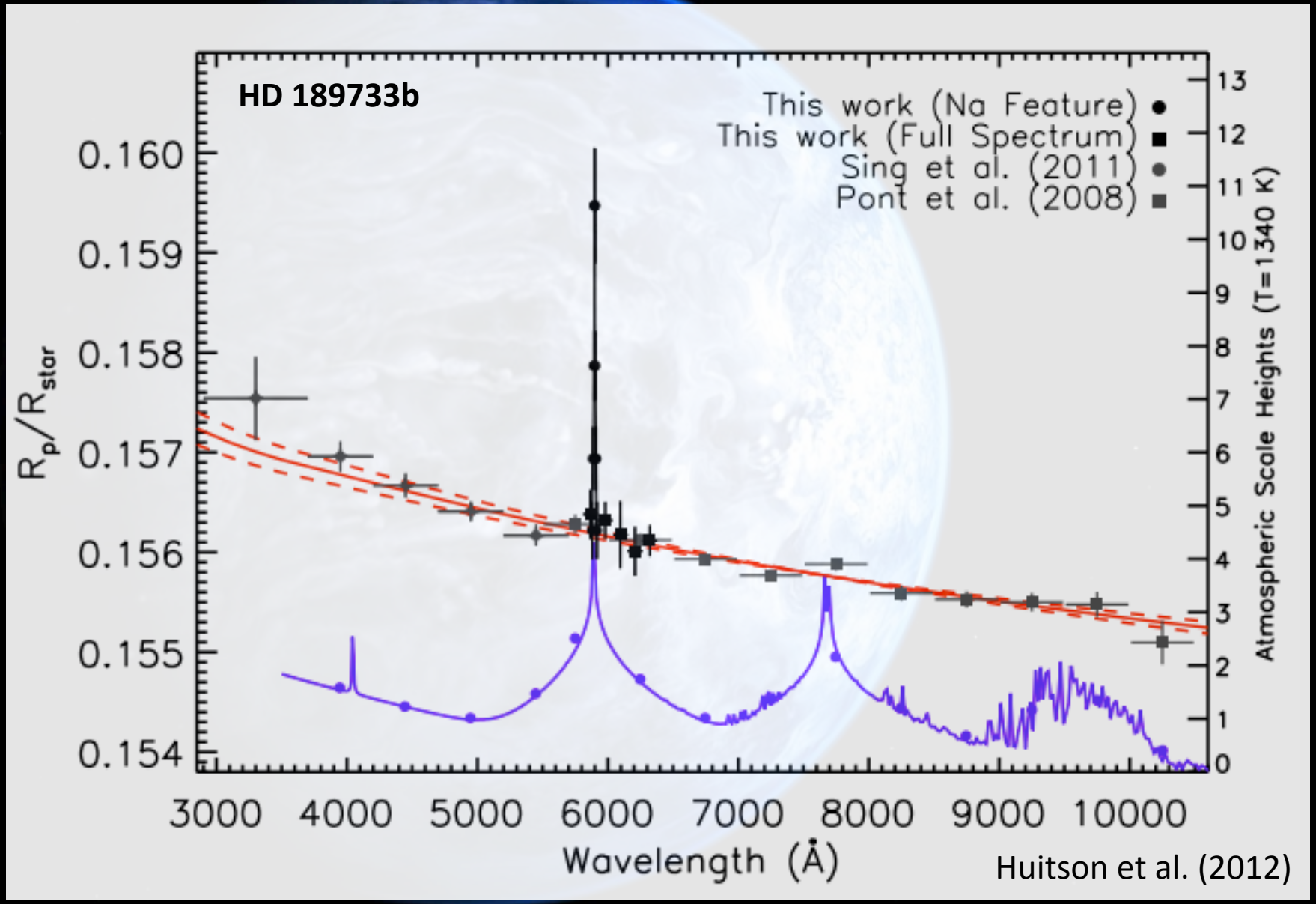
4. Surprising features may exist in exoplanet spectra, and these may bias retrieval algorithms.

Questions?

VLT/SPHERE (1.59 μm)

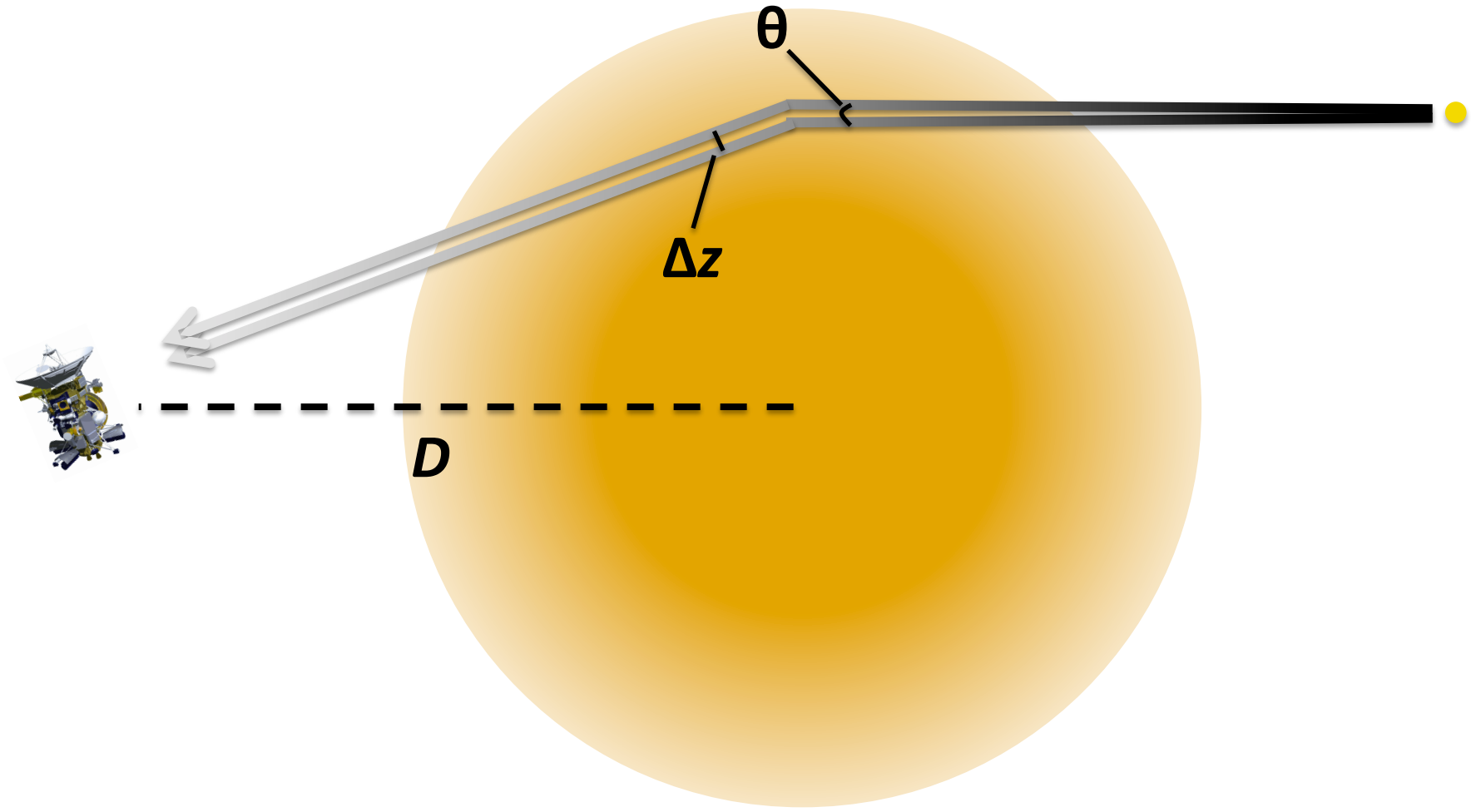
Reference:
Robinson, T.D, Maltagliati, L., Marley, M.S., and Fortney, J.F. (2014) Titan solar occultation observations reveal transit spectra of a hazy world. *PNAS*, 111:9042


1.0 µm
2.9 µm
3.4 µm
4.5 µm
Altitude [km]
600
500
400
300
200
100
0
MakeAGIF.com

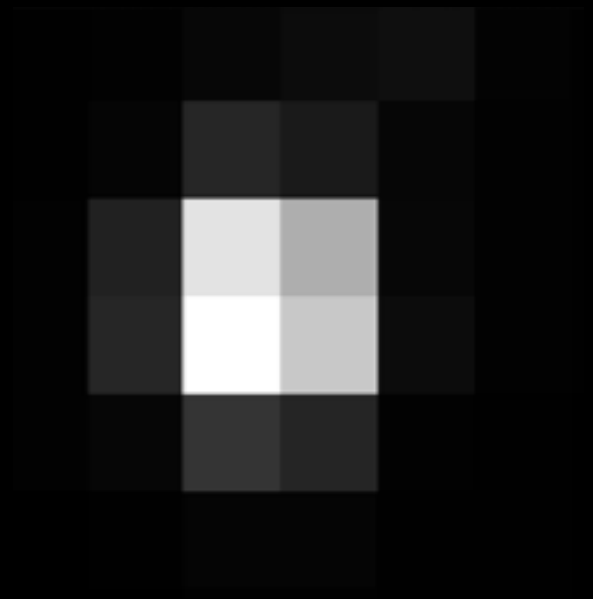


Huitson et al. (2012)

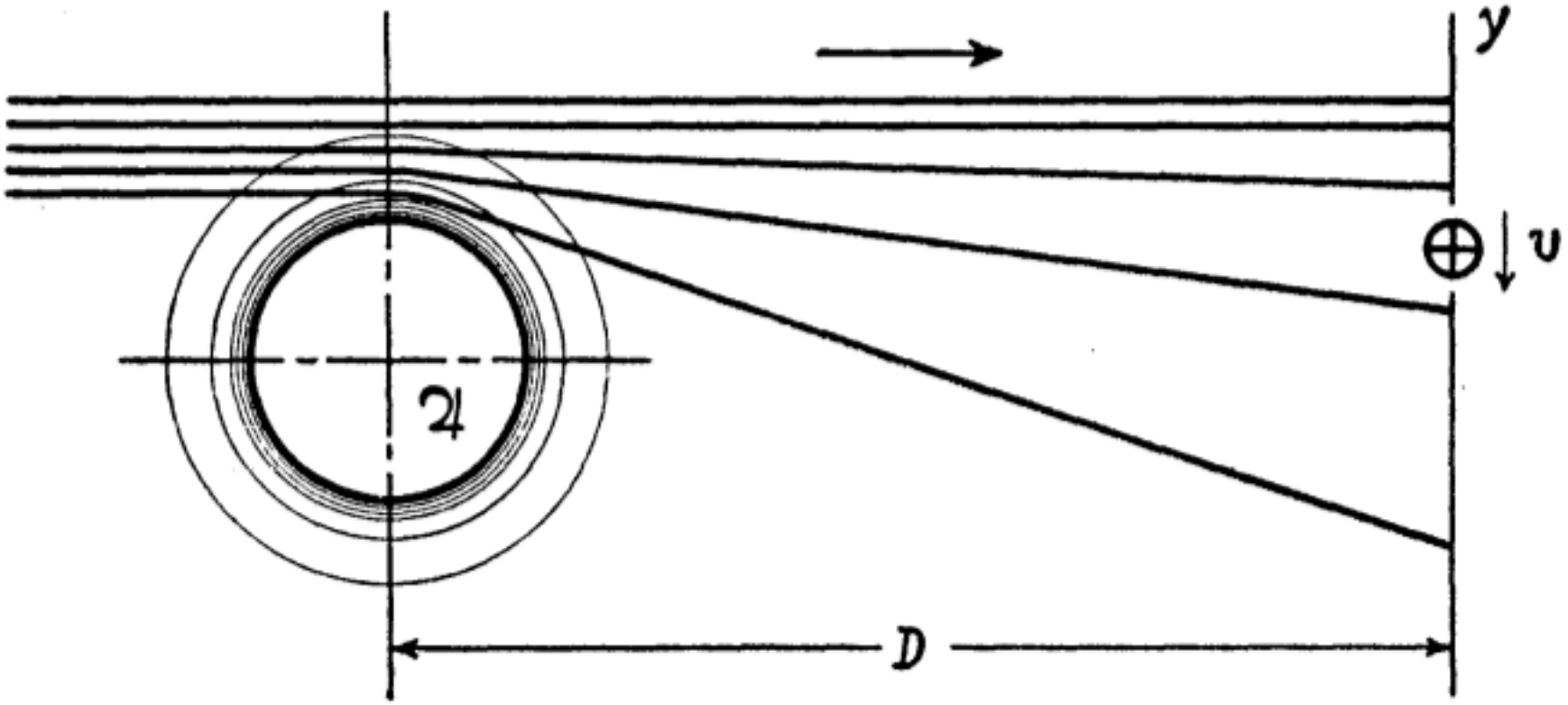
Image credit: NASA/ESA/M. Kornmesser



$$\Delta z = D\theta$$

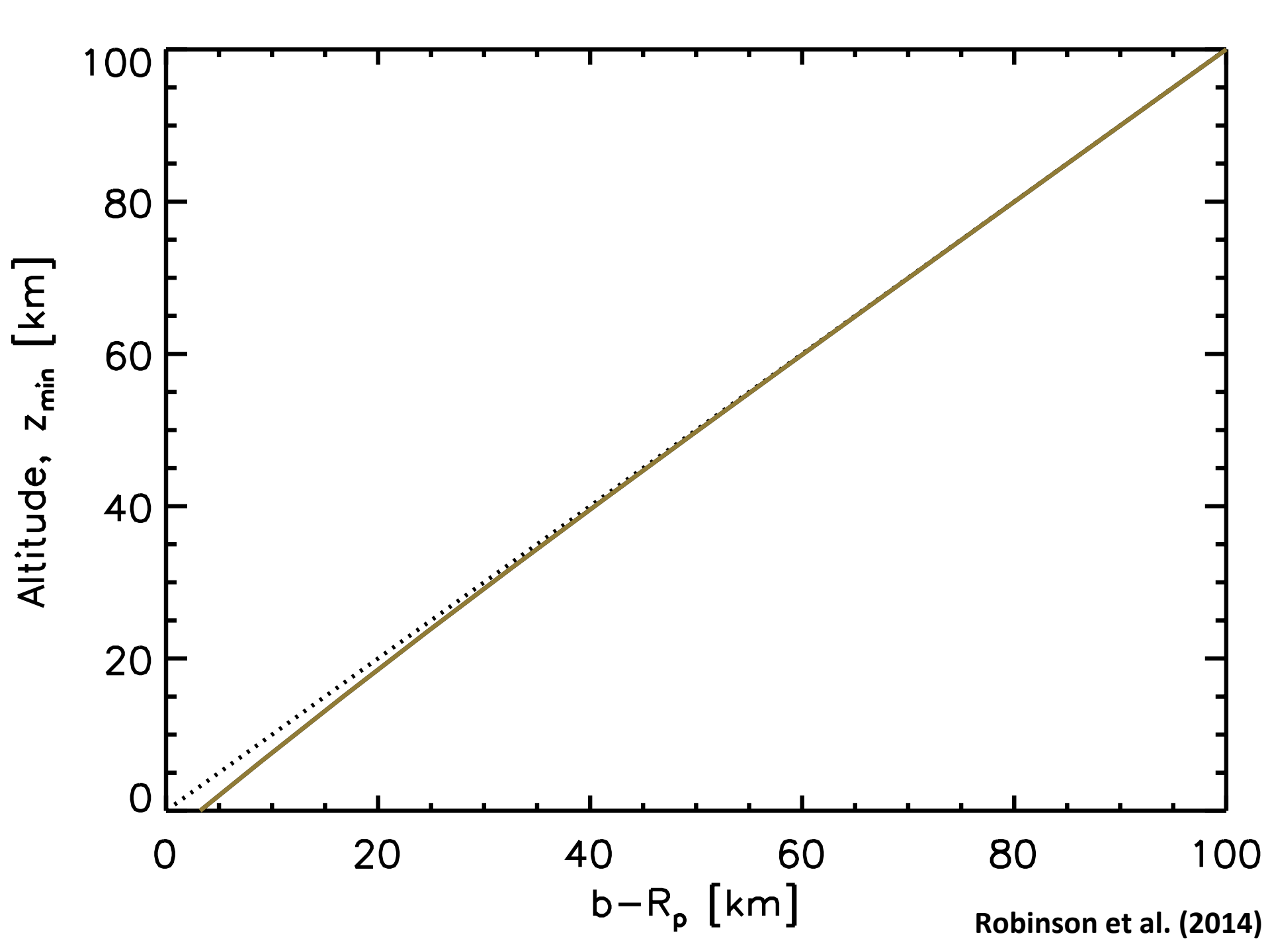


$\theta = 1$ mrad $\longrightarrow$ $\Delta z \sim 10$ km

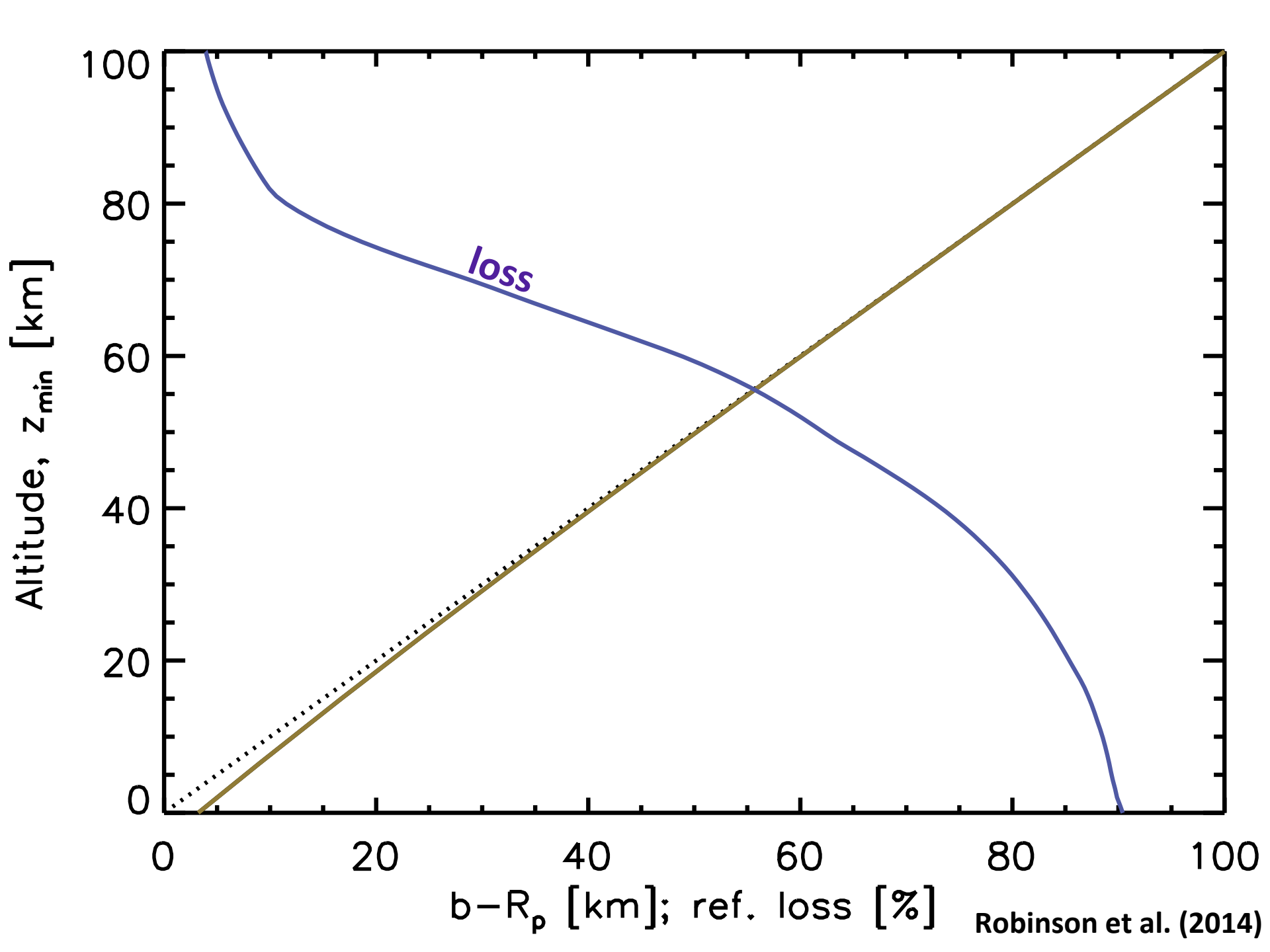


Baum & Code (1953)

Credit: ISS



Robinson et al. (2014)


100
80
60
40
20
0
Altitude, z_{min} [km]
loss
0
20
40
60
80
100
b−R_p [km]; ref. loss [%]
Robinson et al. (2014)

Date	*Cassini* flyby	Season	Latitude	D [km]	Resolution [km]
Jan. 2006	T10	N winter	70° S	8300	15
Apr. 2009	T53	equinox	1° N	6300	7
Sep. 2011	T78	N spring	40° N	9700	10
Sep. 2011	T78	N spring	27° N	8400	10