Limitation of the TTV technique for the detection of non-transiting planets

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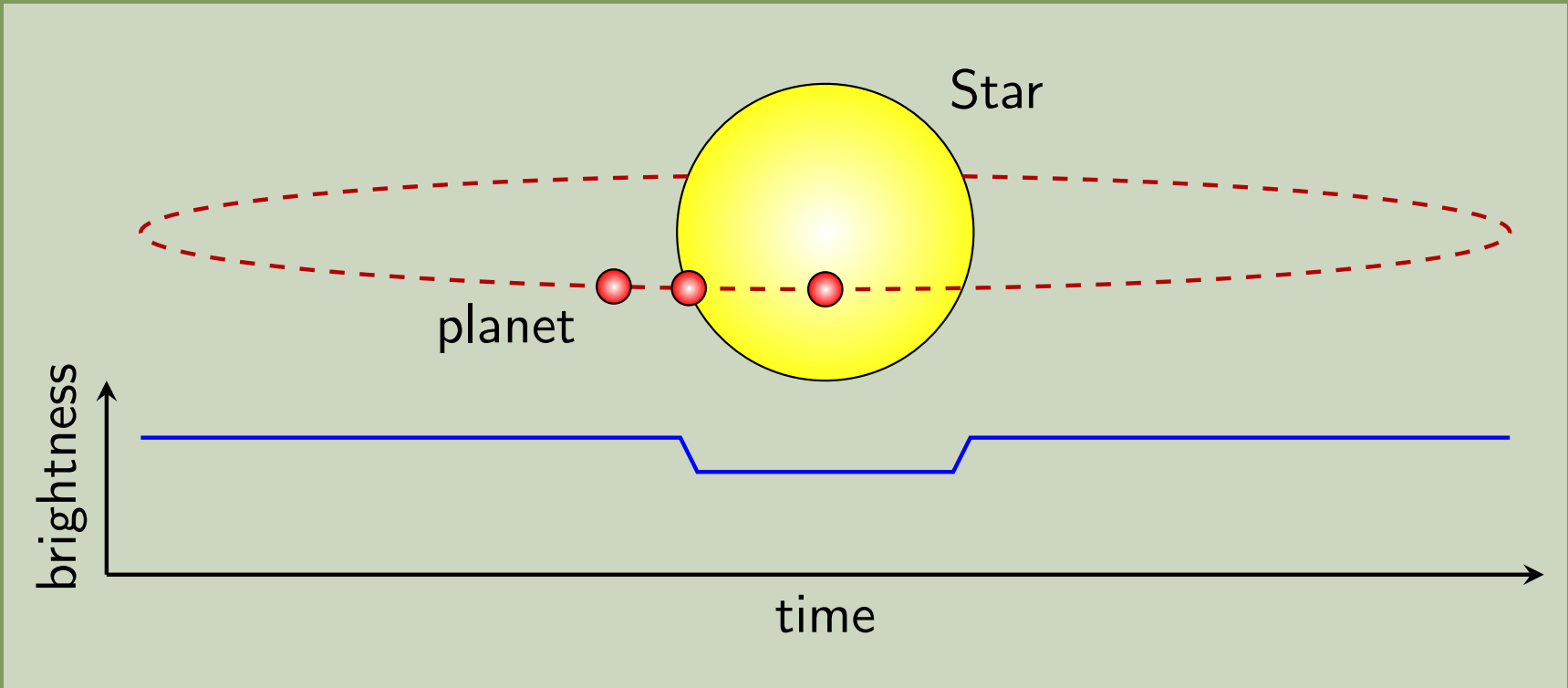
TTV (Transit Timing Variation)



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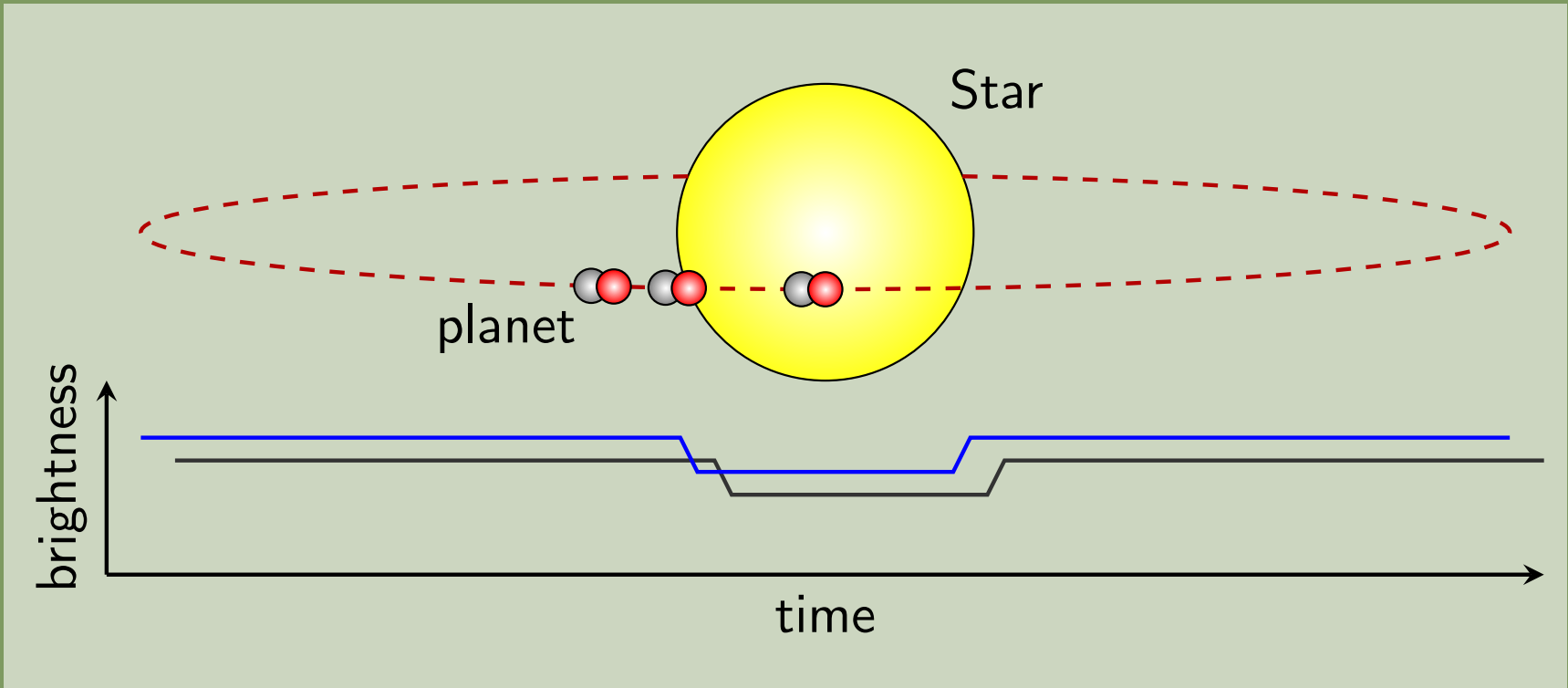

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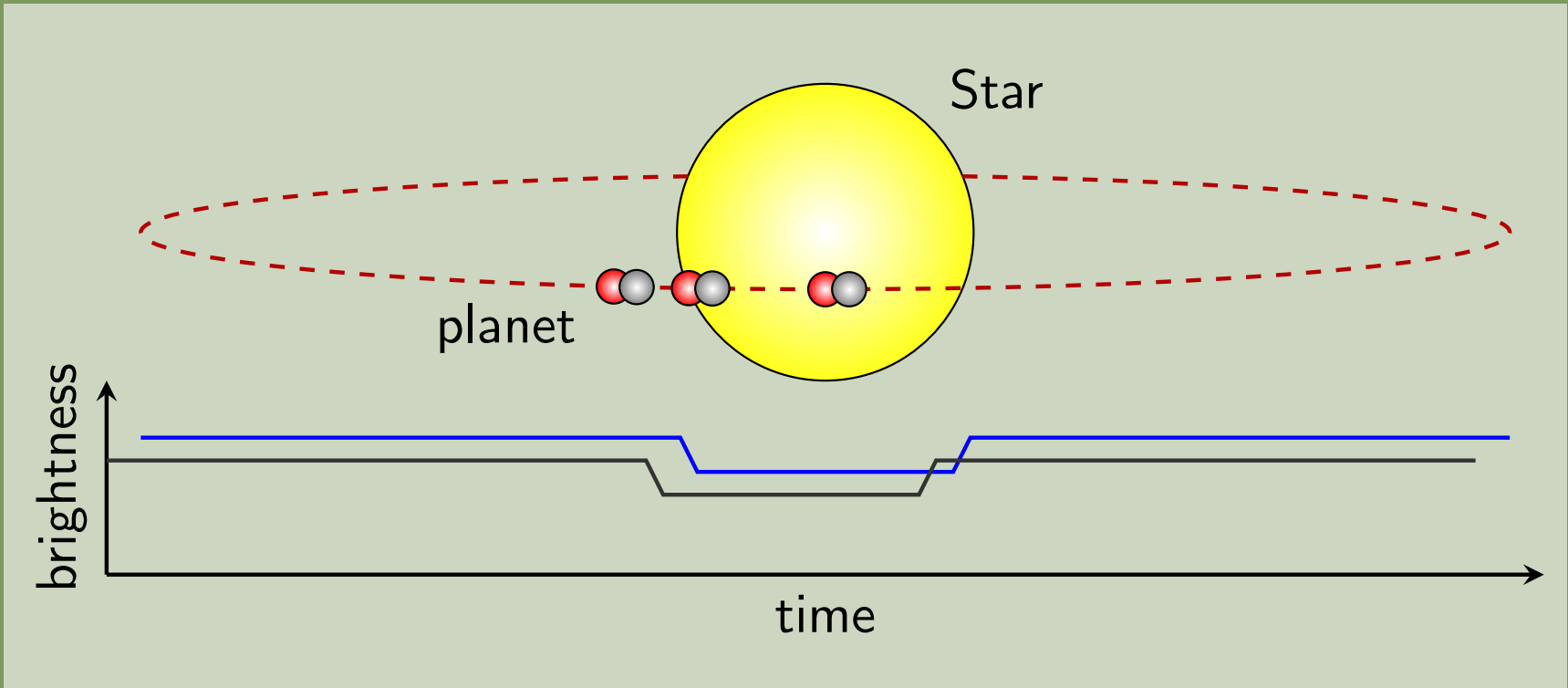

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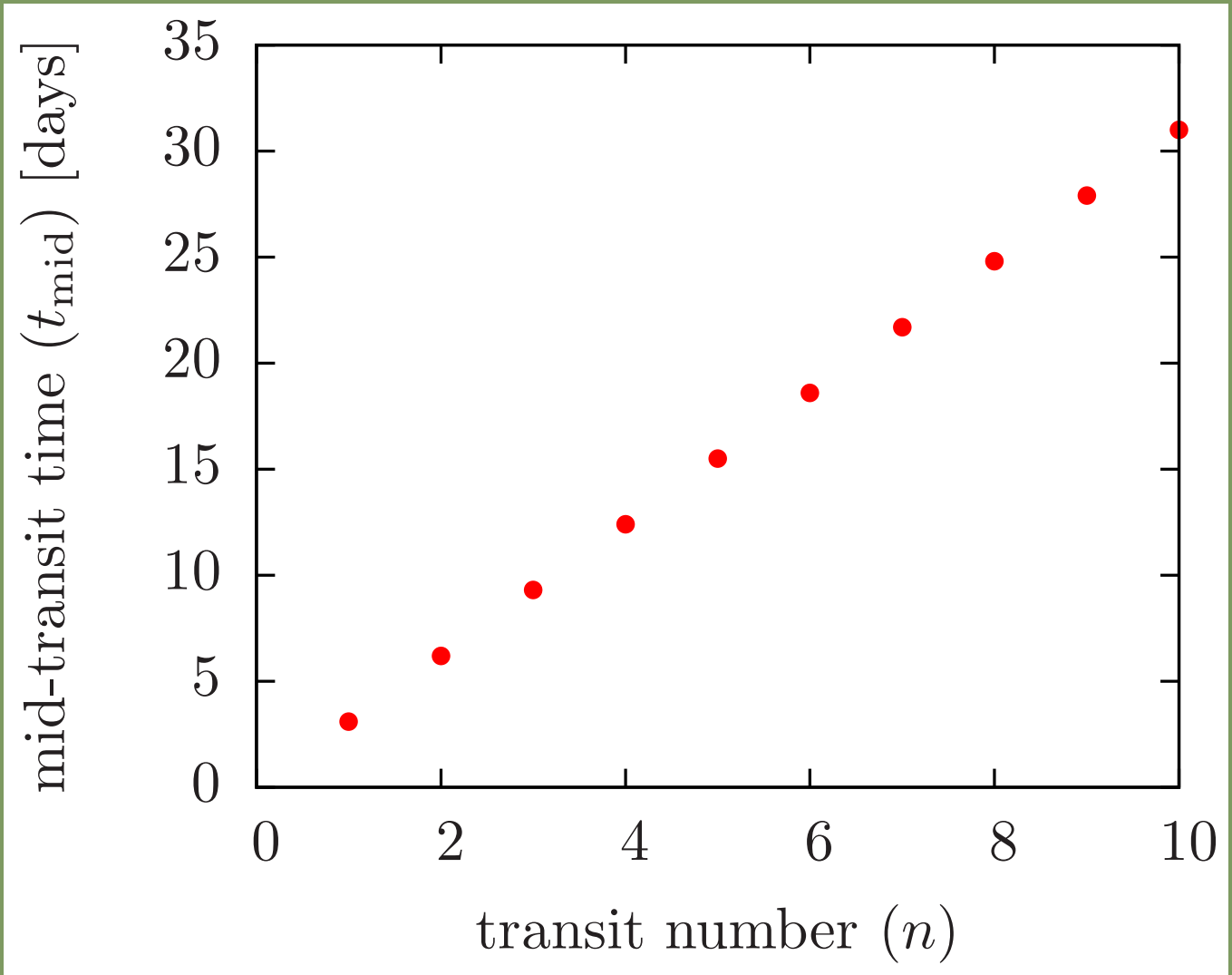

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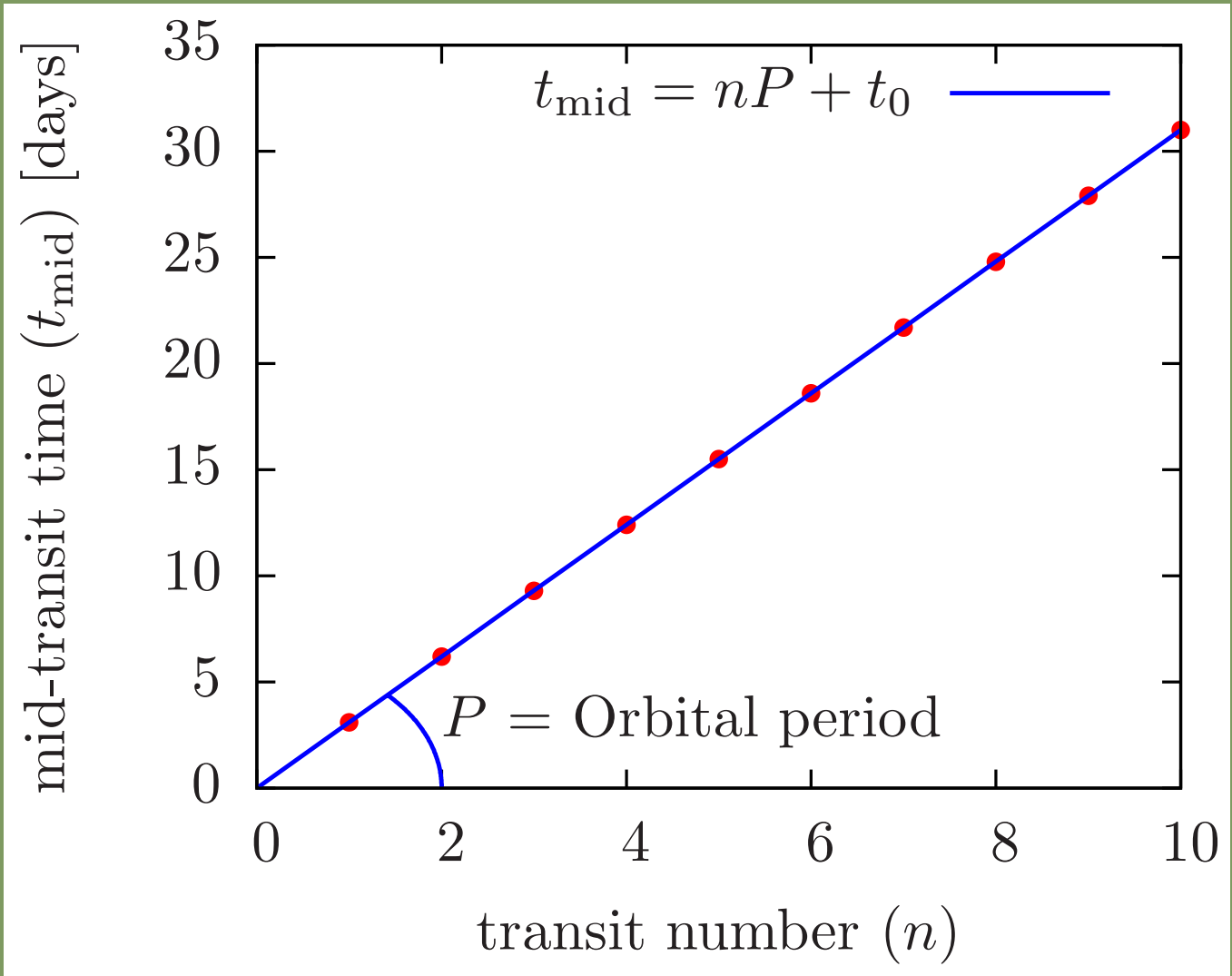
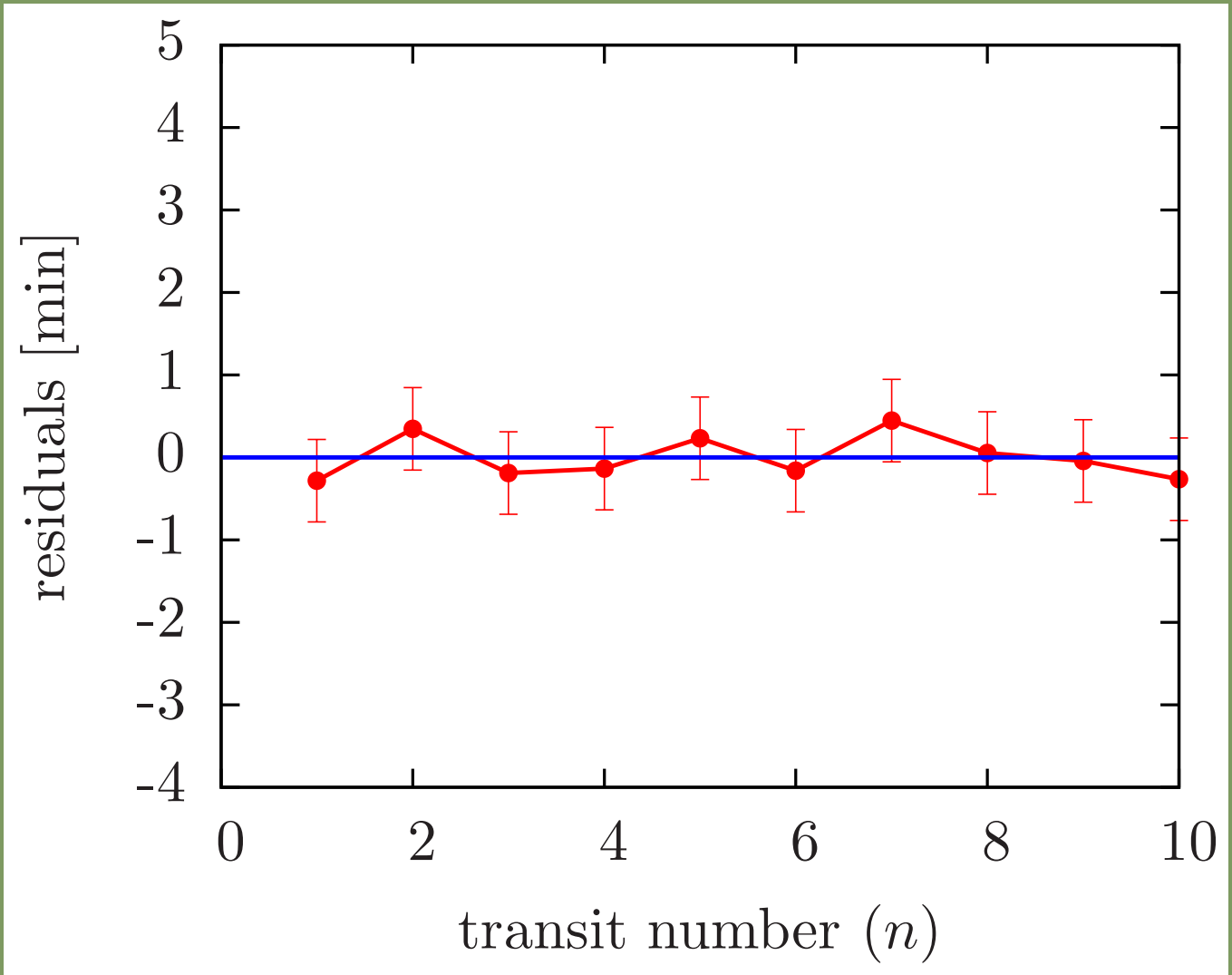
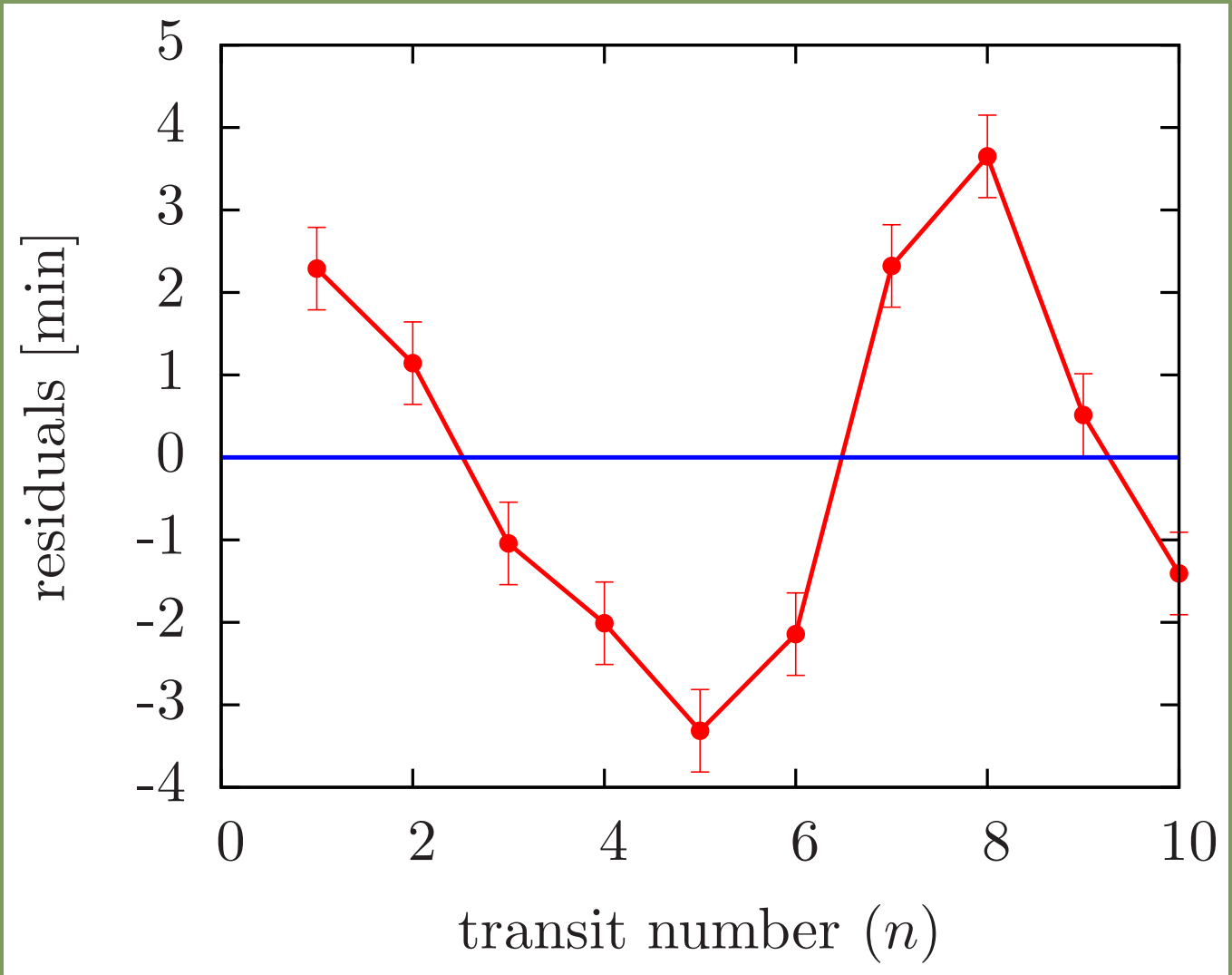


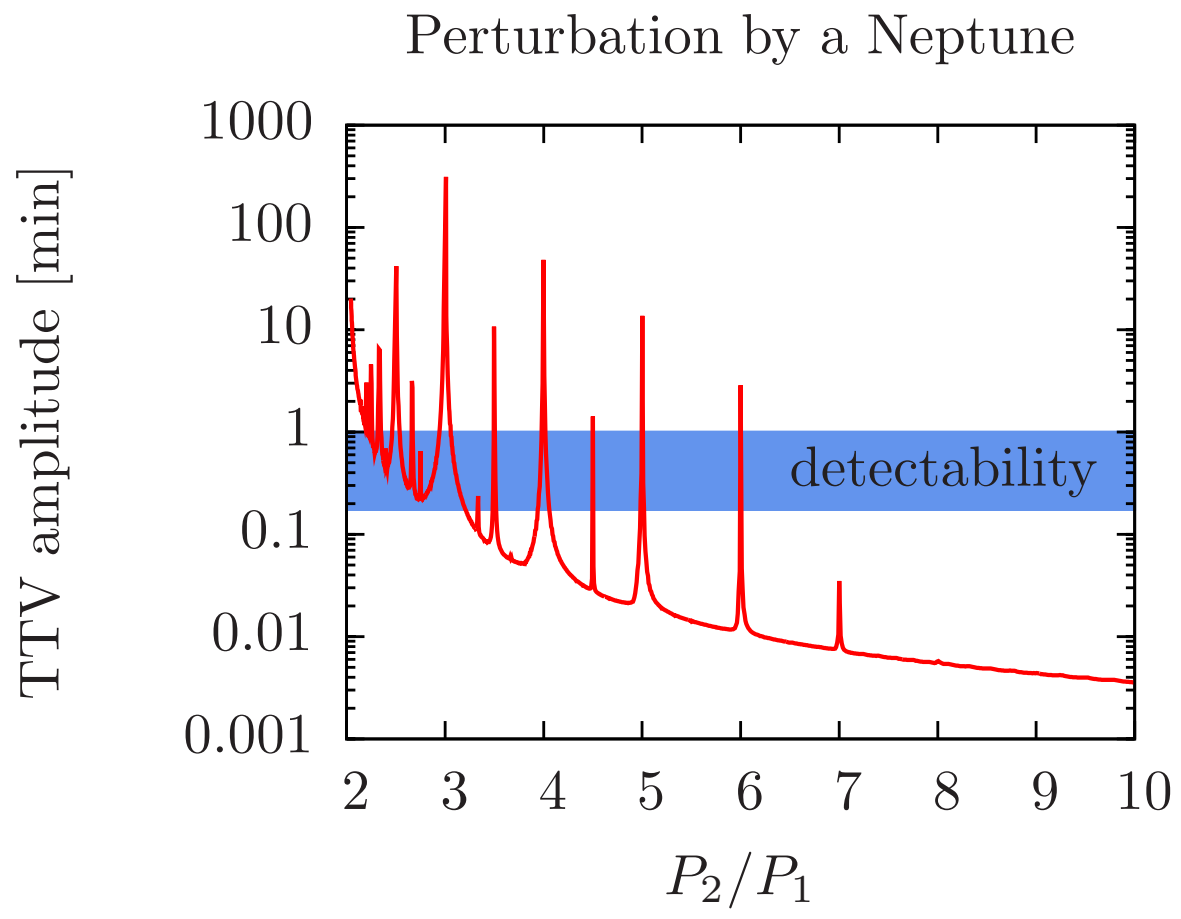
TTV (Transit Timing Variation) (unperturbed)



TTV (Transit Timing Variation) (perturbed)



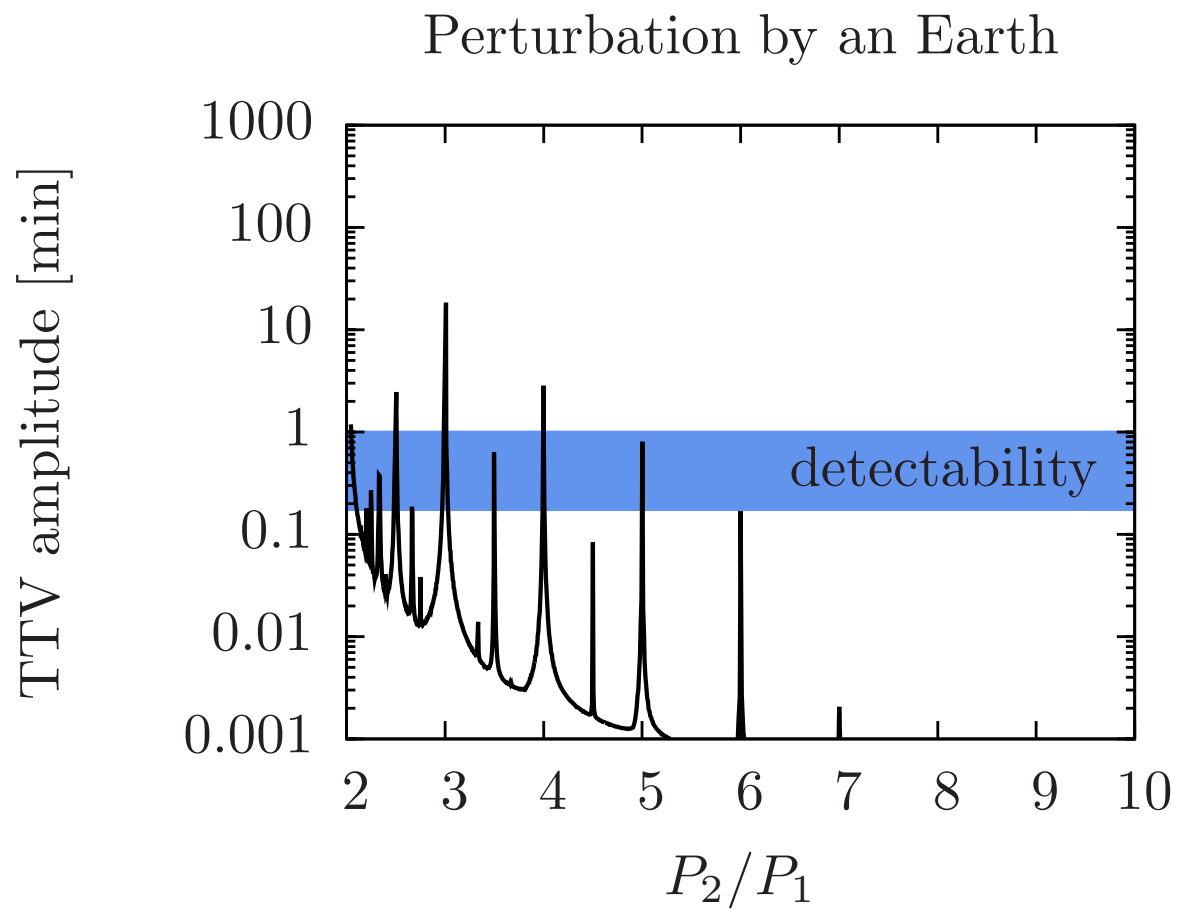
Amplitude of TTV



	trans.	pert.
m	$M_{\rm Jup}$	$M_{\rm Nep}$
P [d]	3	6 – 30
e	0	0.1

Mass of the star: 1 $M_\odot$.

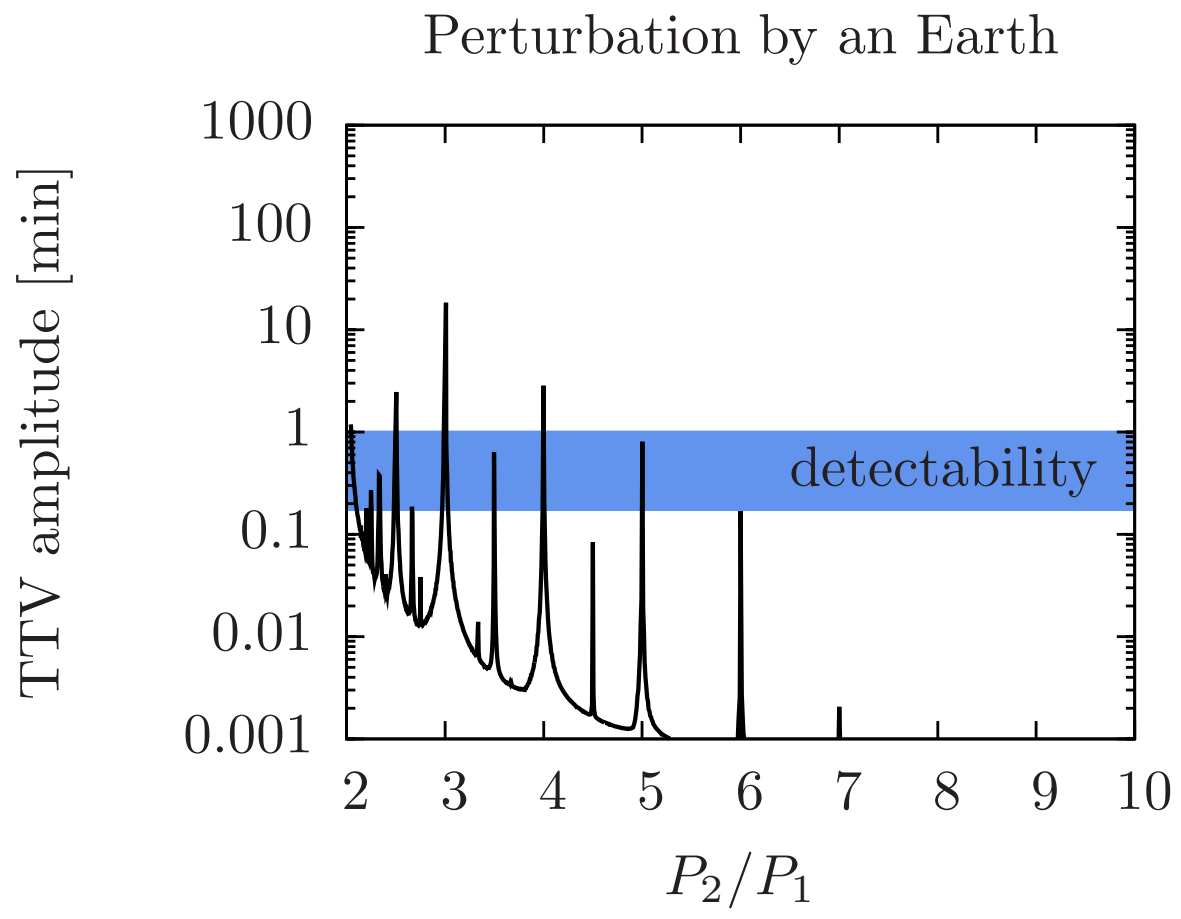
Amplitude of TTV



	trans.	pert.
m	$M_{\rm Jup}$	$M_{\rm Ear}$
P [d]	3	6 – 30
e	0	0.1

Mass of the star: 1 $M_\odot$.

Amplitude of TTV

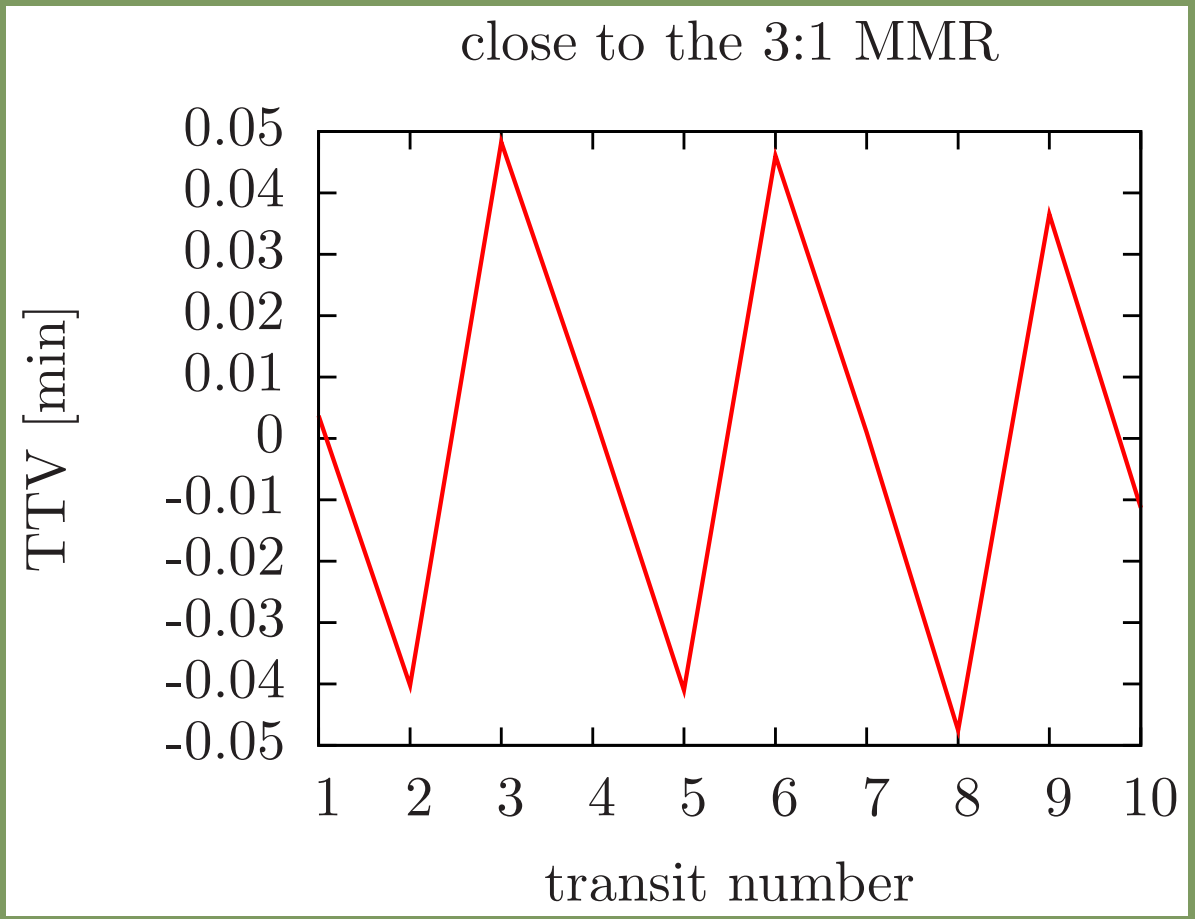


	trans.	pert.
m	$M_{\rm Jup}$	$M_{\rm Ear}$
P [d]	3	6 – 30
e	0	0.1

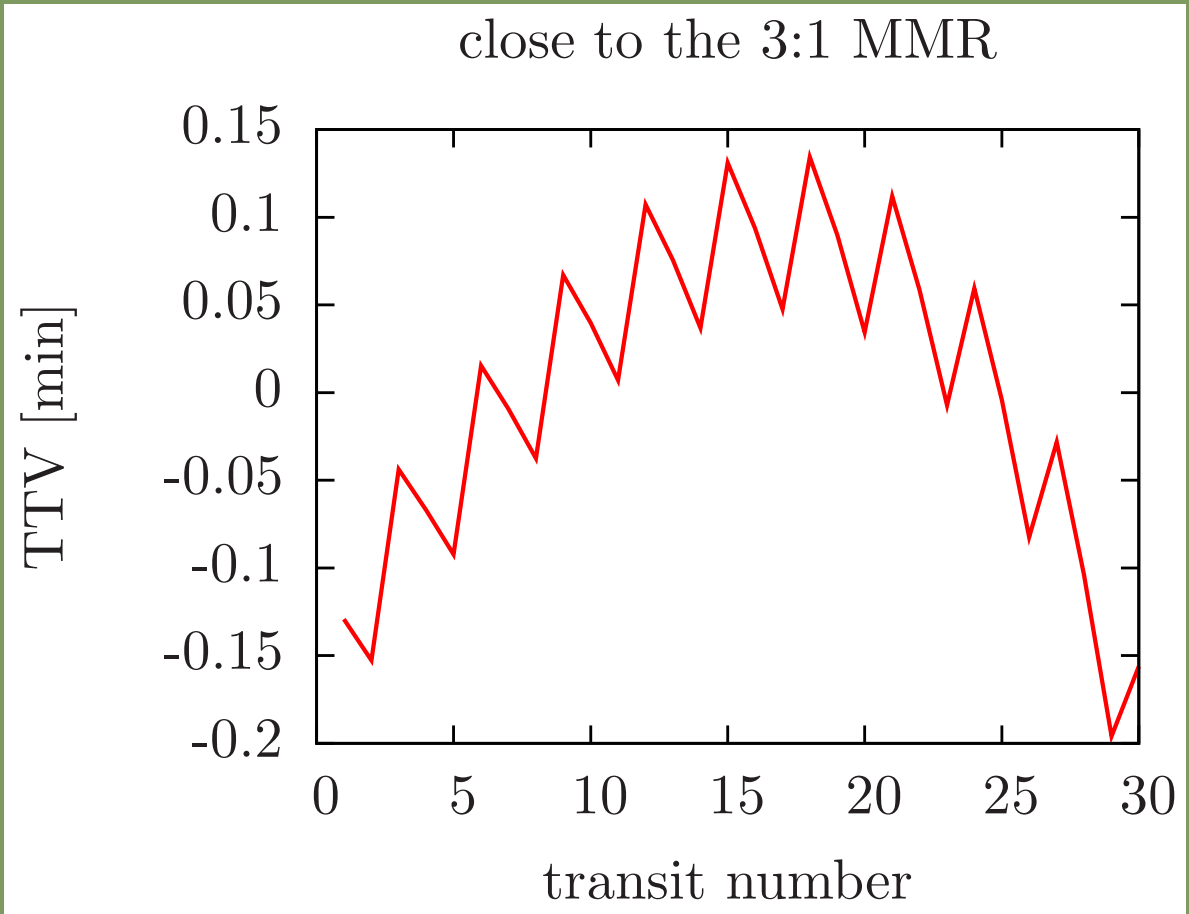
Mass of the star: 1 $M_\odot$.

**** Possible detection at MMR (e.g. Agol et al., 2005) ****

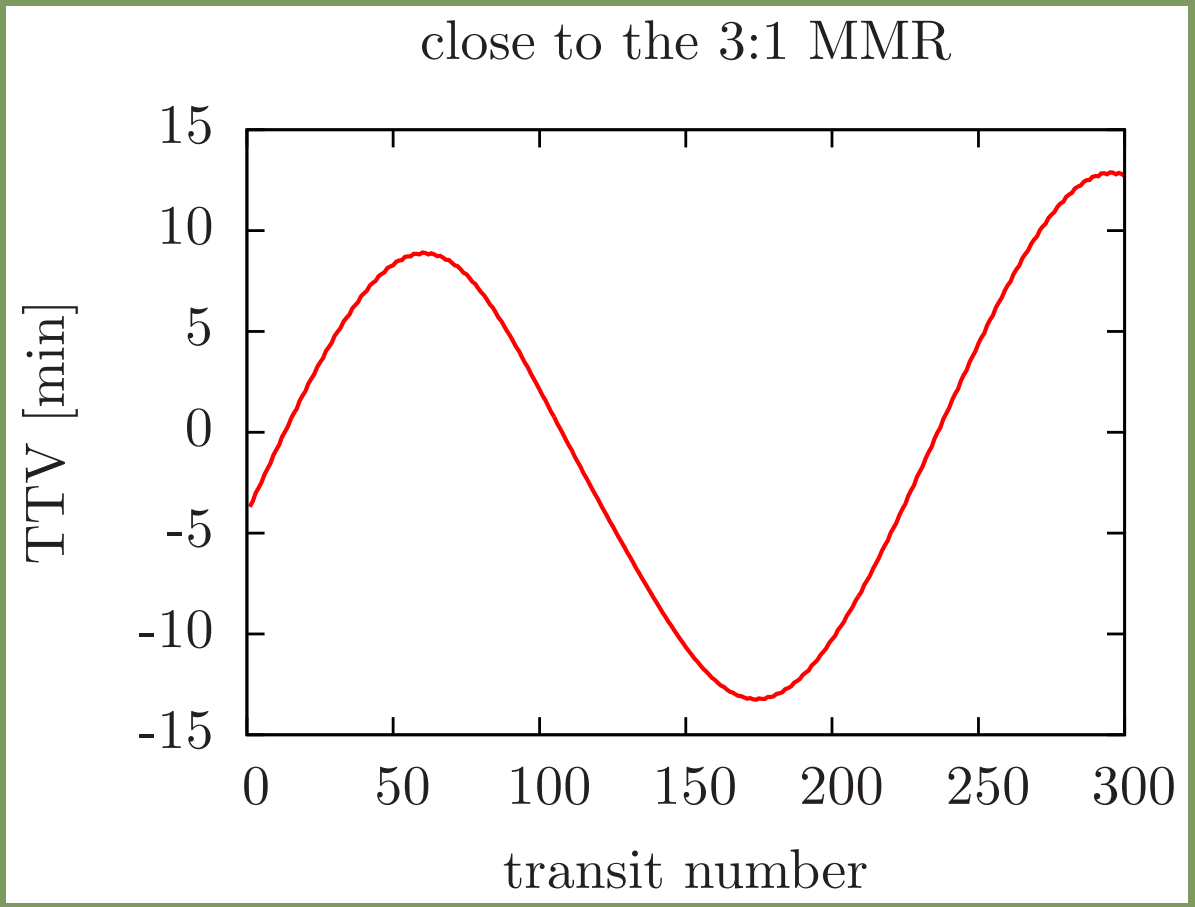
Amplitude versus observation length



Amplitude versus observation length



Amplitude versus observation length



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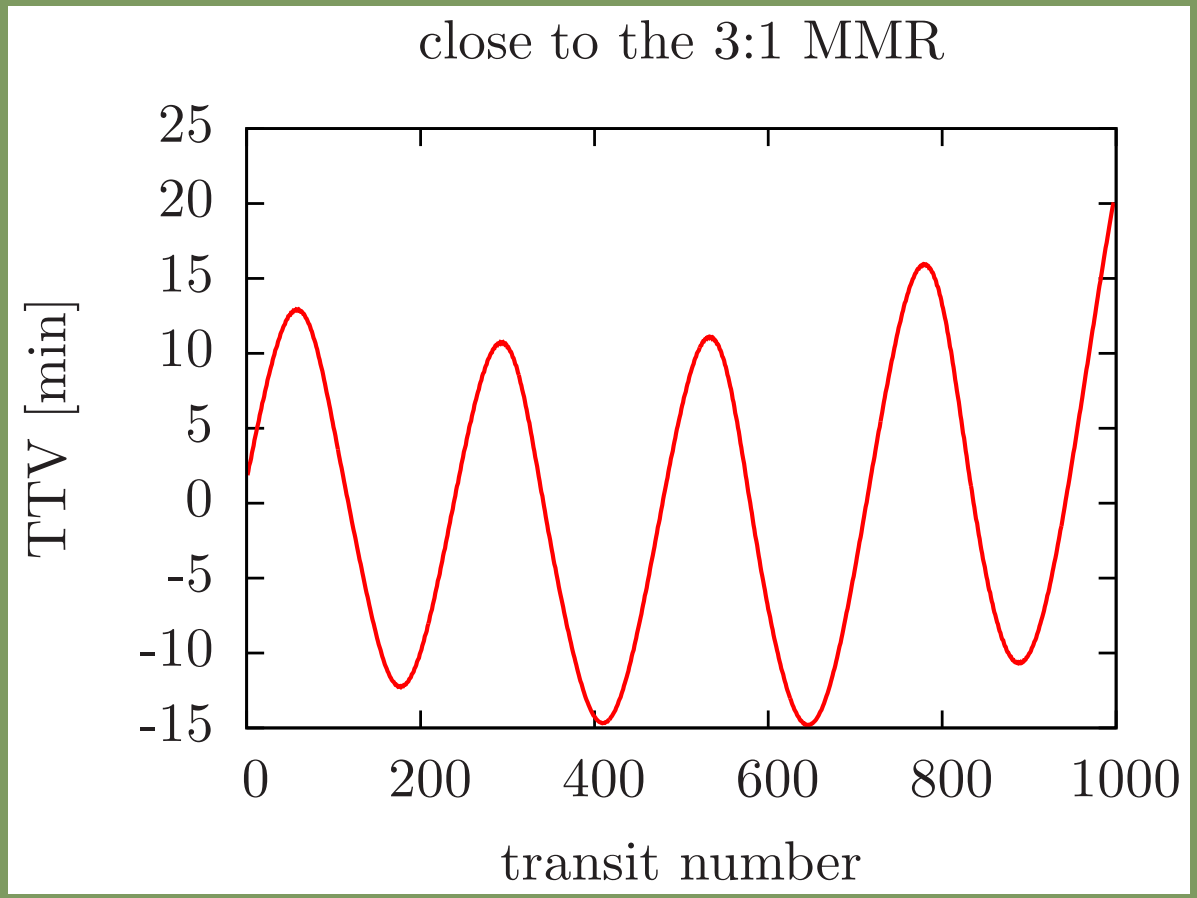


main frequency

MMR $p : p + q$

param $\epsilon = \left| 1 - \frac{p+q}{p} \frac{n_2}{n_1} \right|$

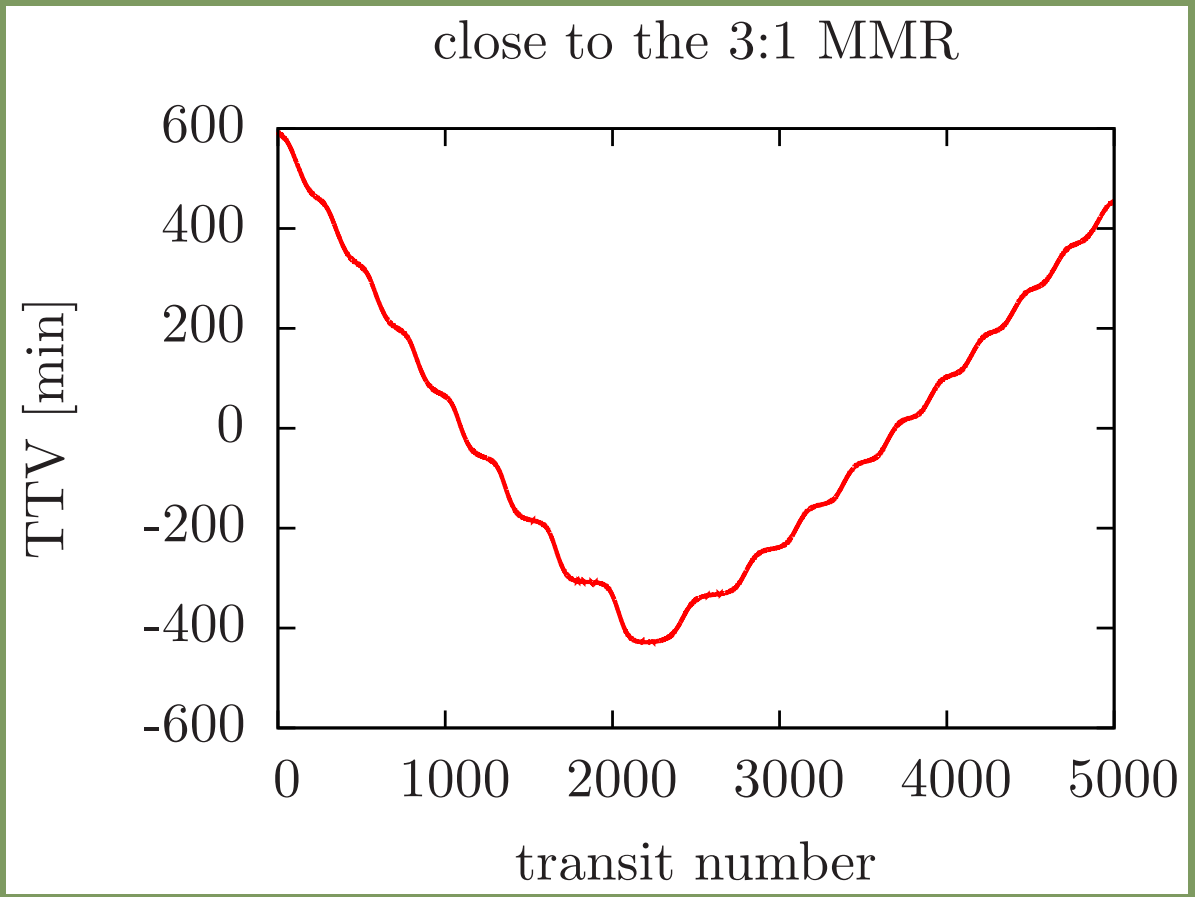
freq $pn_1 - (p+q)n_2$

period $\frac{1}{p\epsilon} P_1$

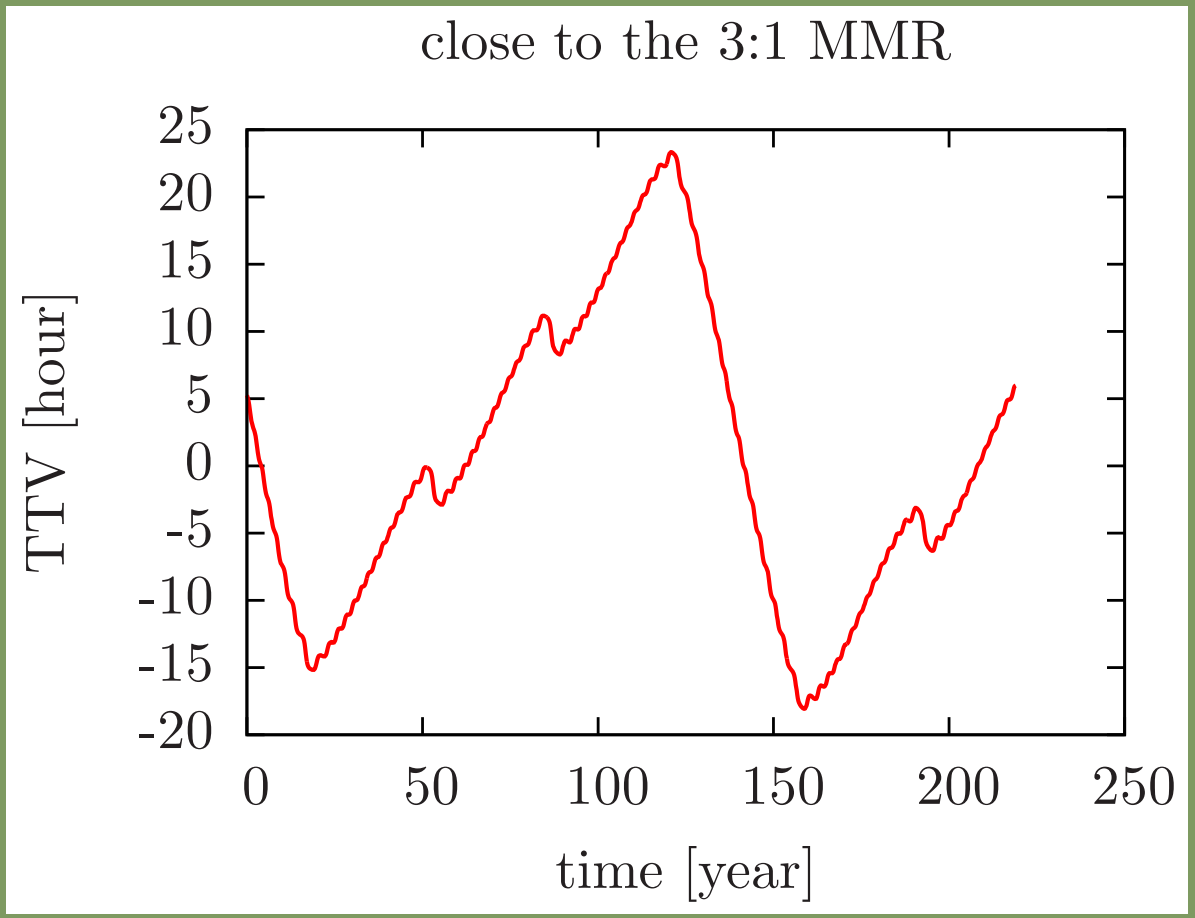
ampl $\propto \frac{m_2}{\epsilon^2}$

(Agol et al. 2005)

Amplitude versus observation length



Amplitude versus observation length

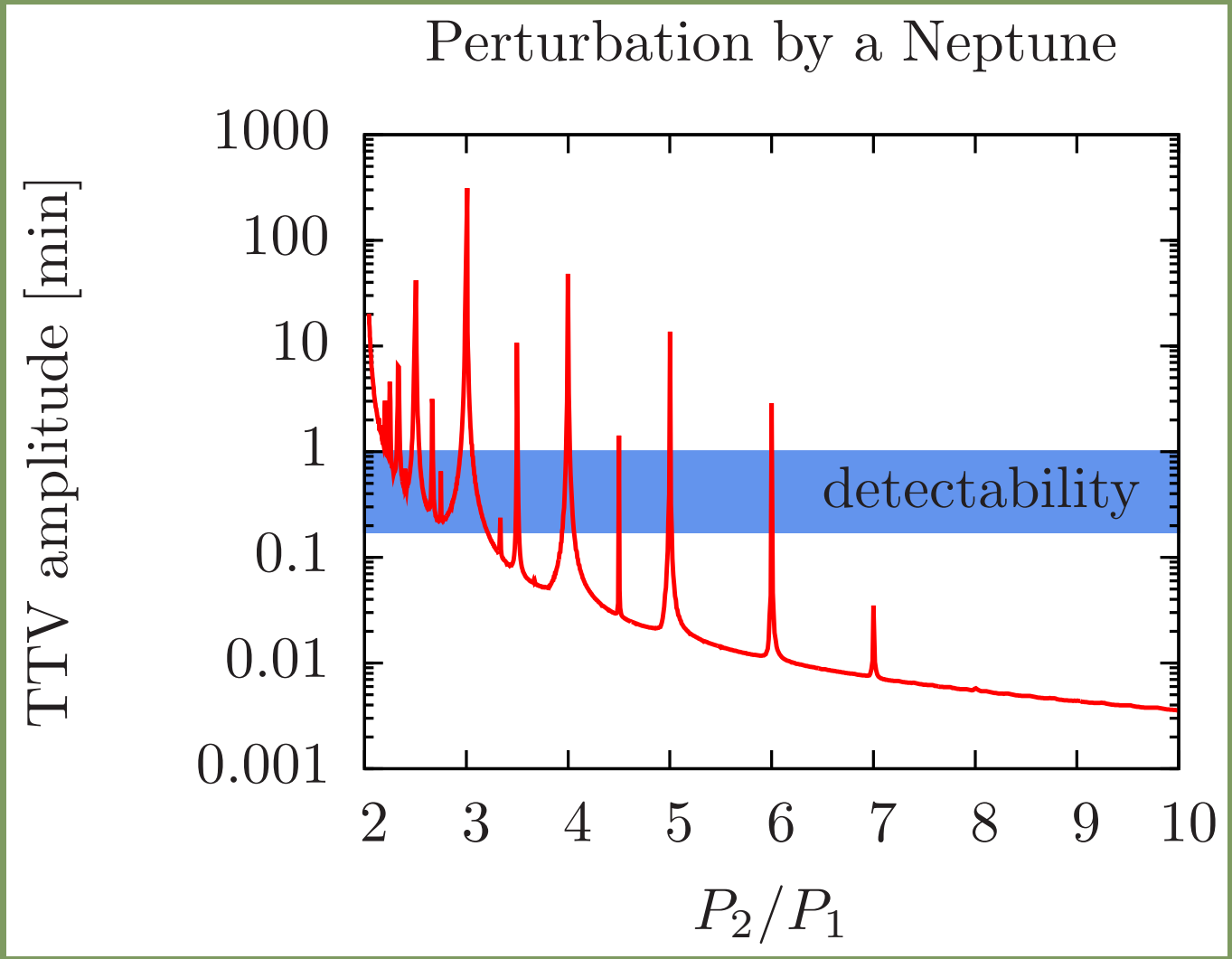


Conclusion

one needs long term observations $\gtrsim$ 3 years to detect planets with period of $\sim$10 days

(e.g. Veras et al. 2011)

Amplitude versus observation length



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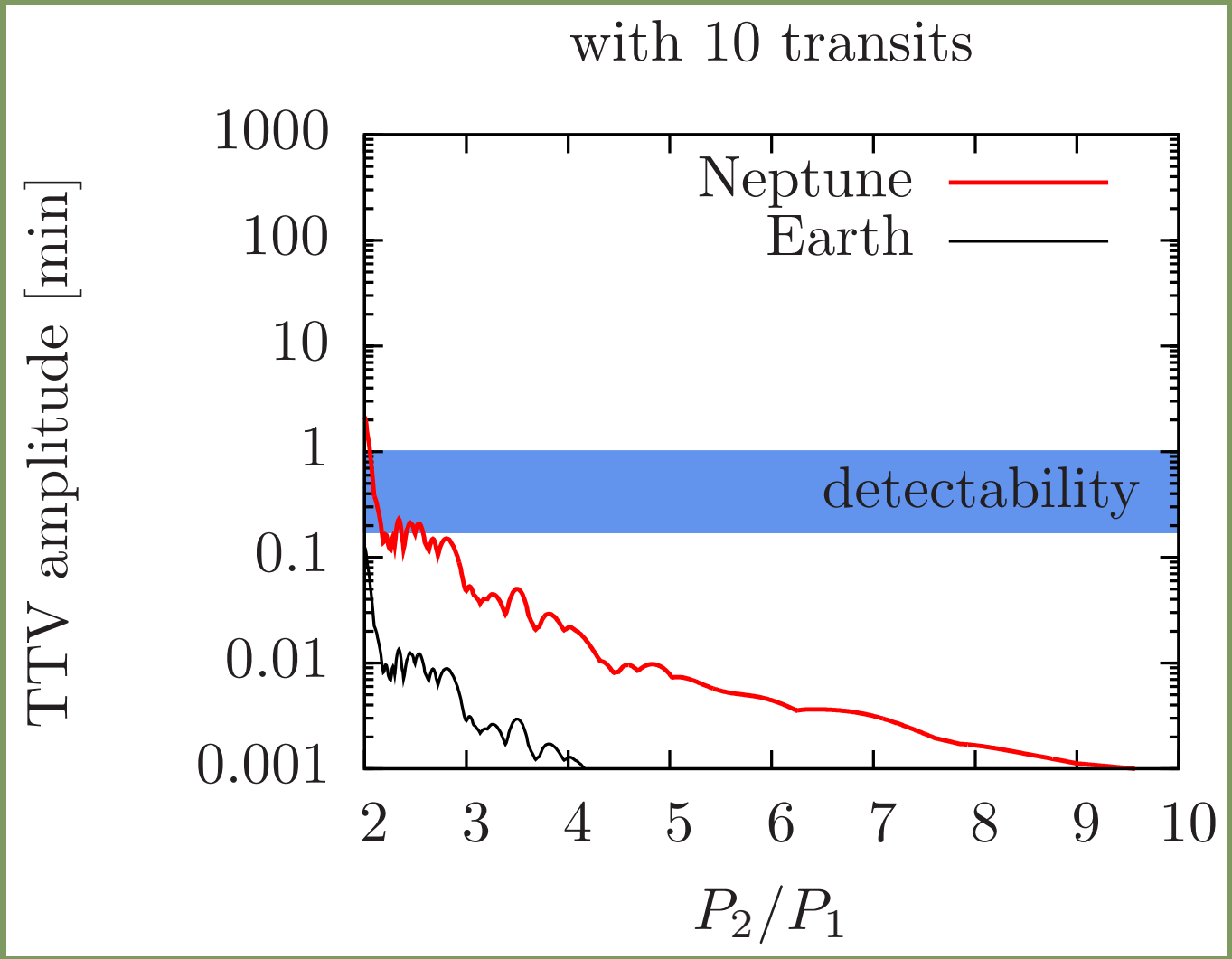

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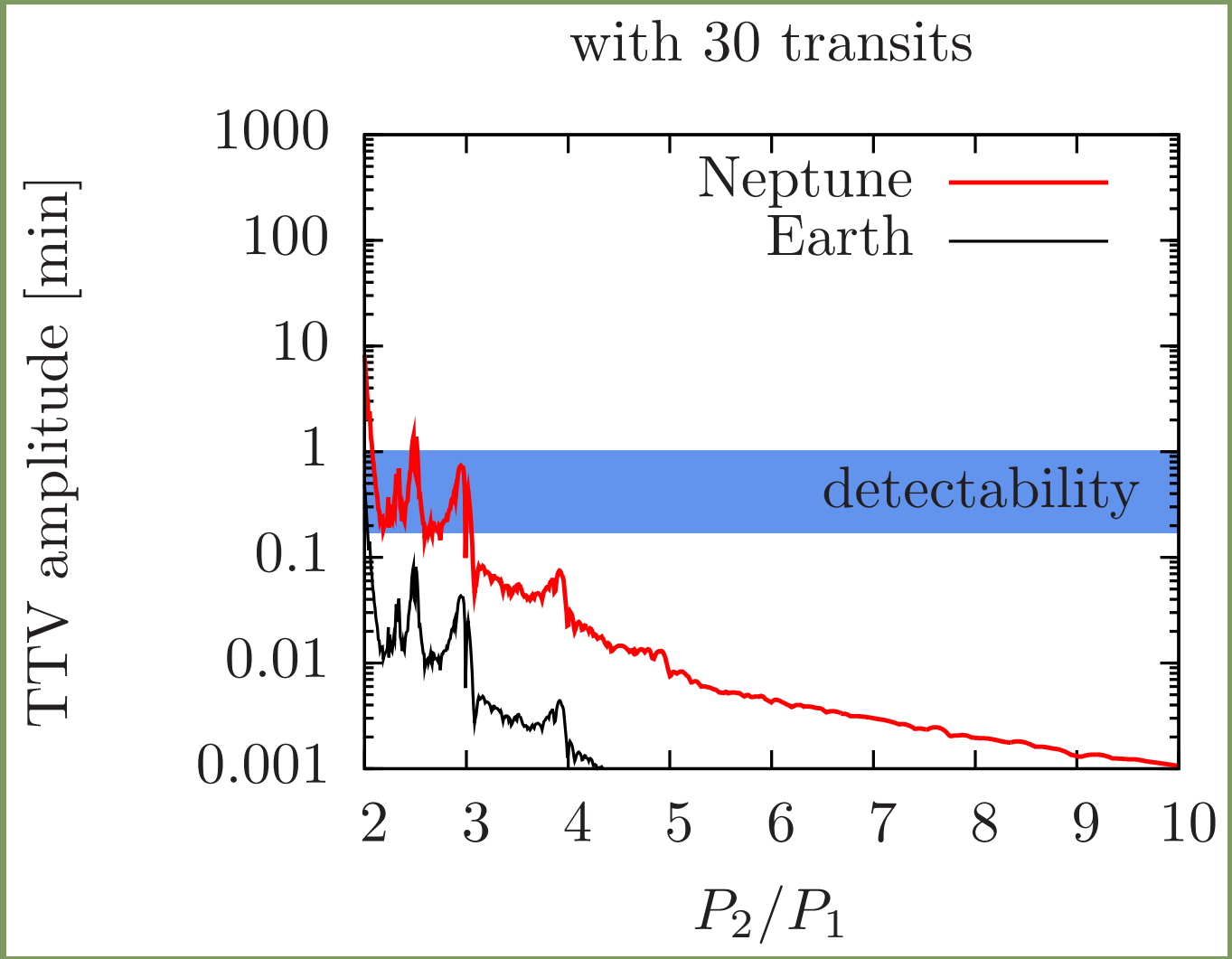

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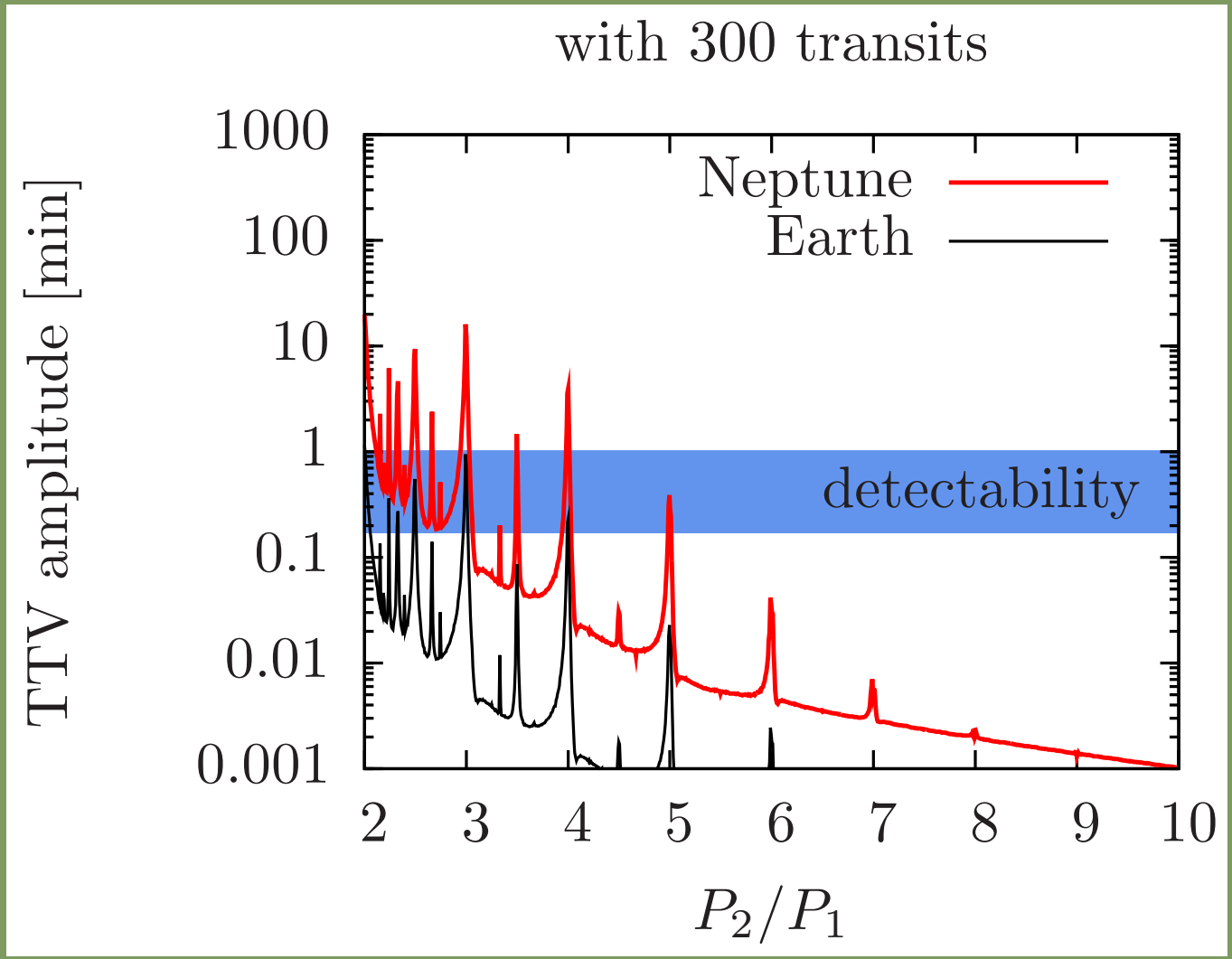

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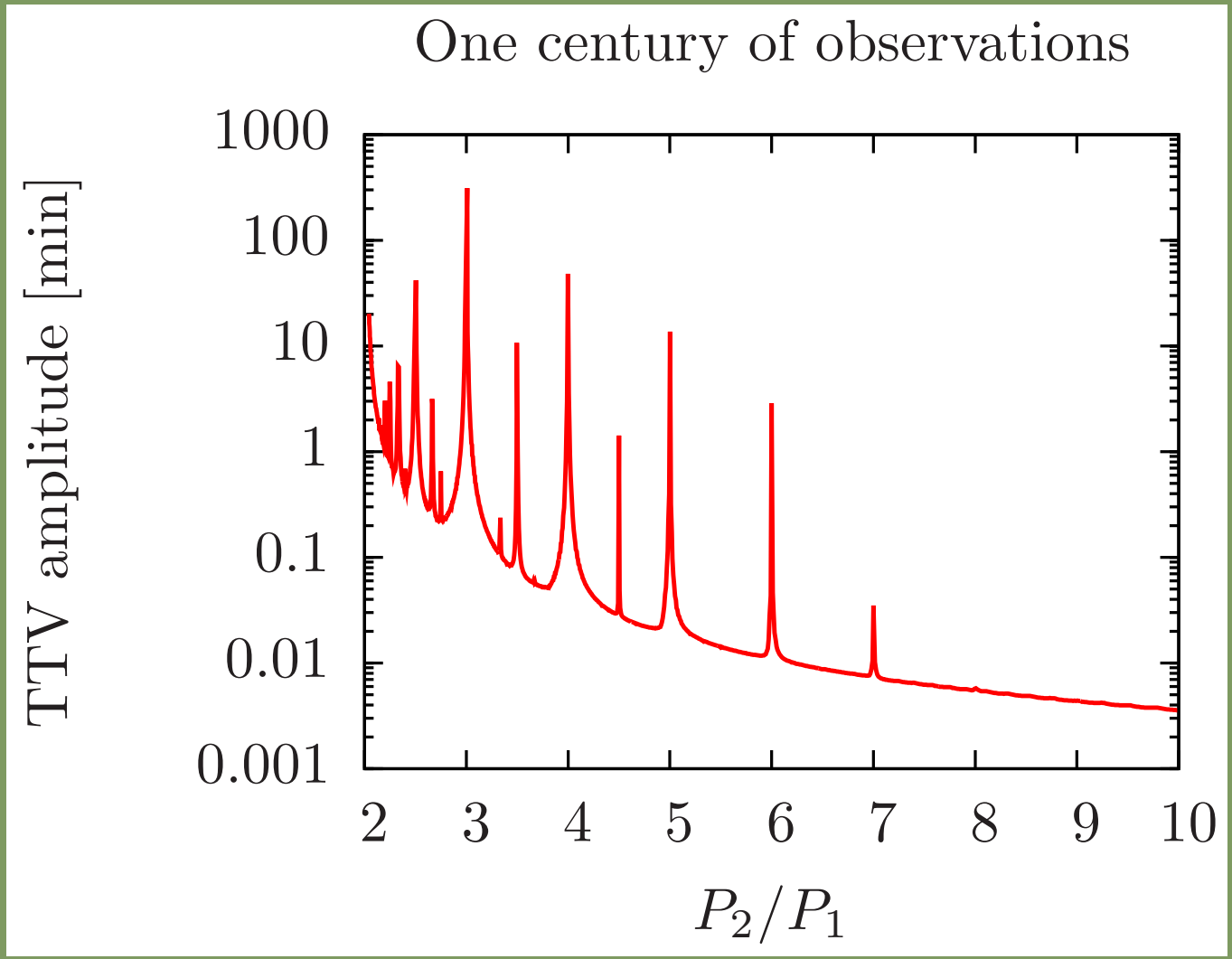
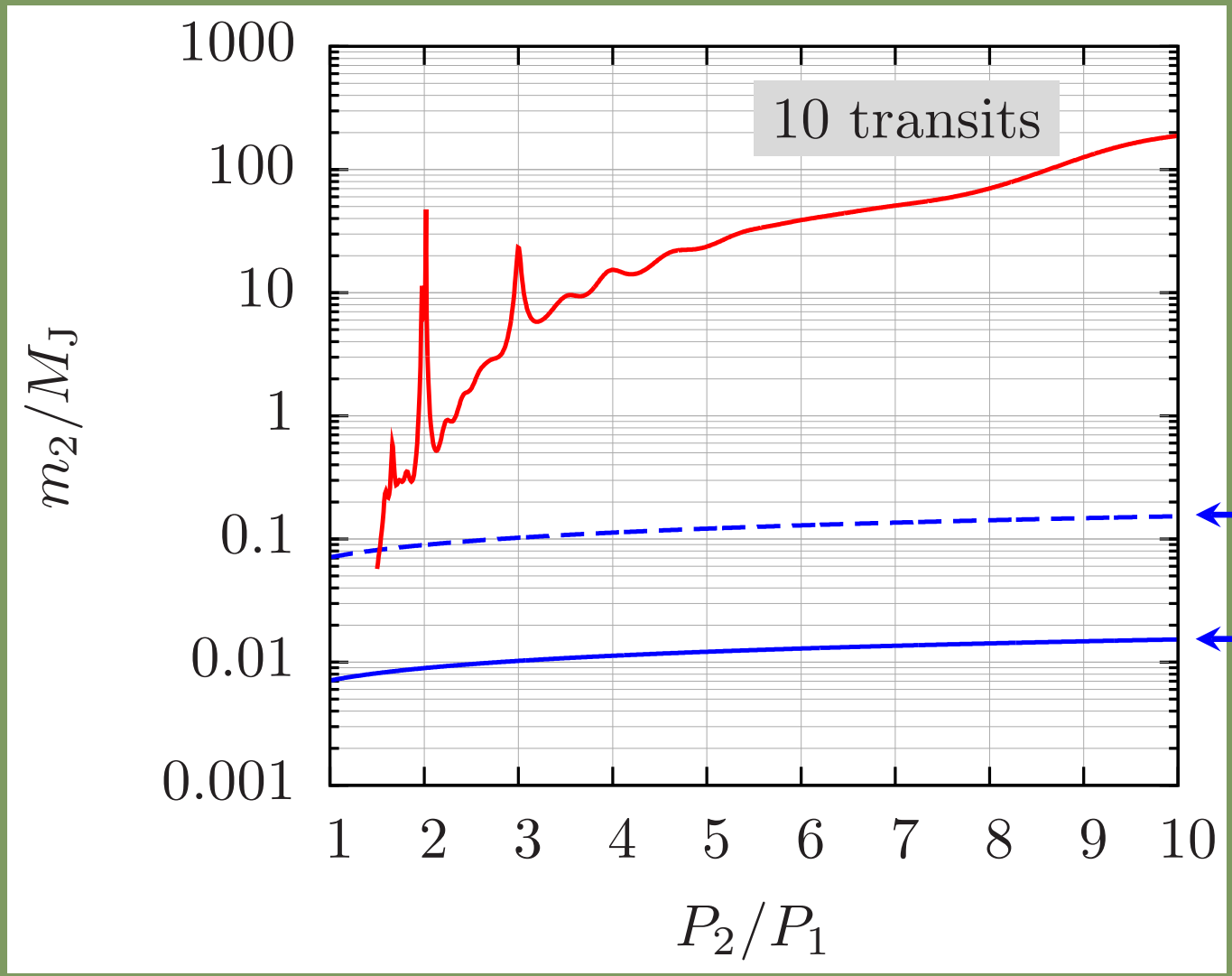


Detection limit versus observation length ($e_2 = 0$)



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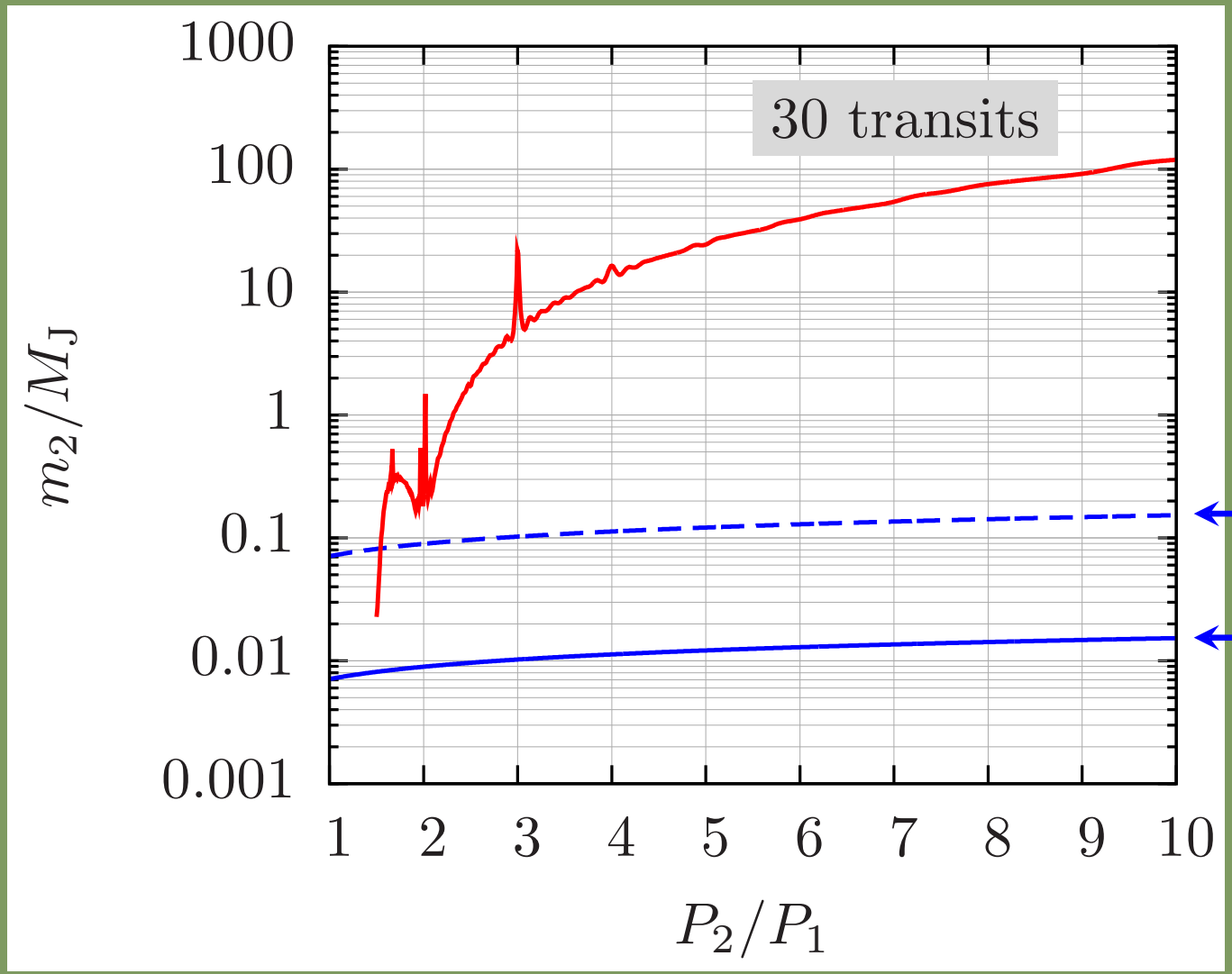

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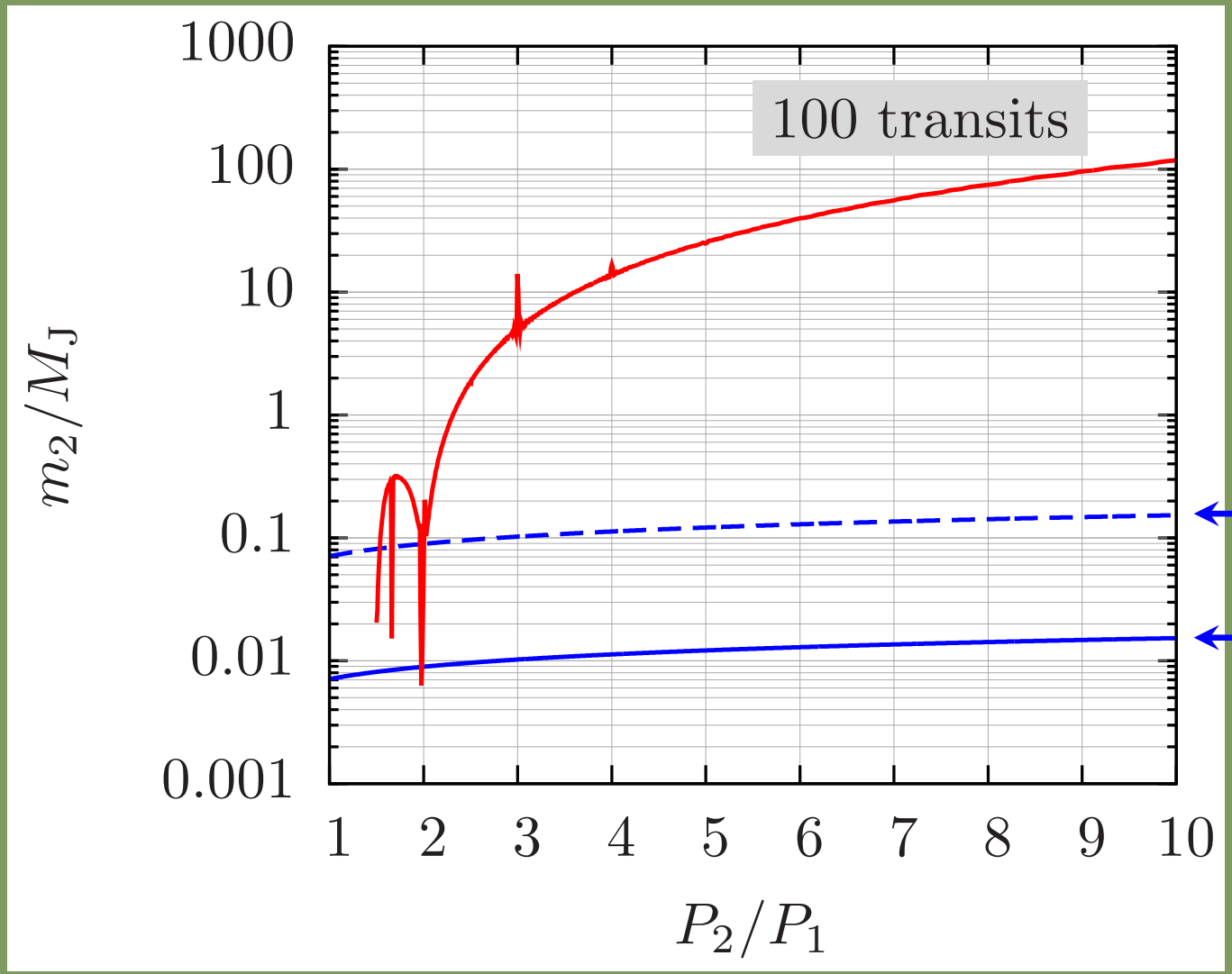

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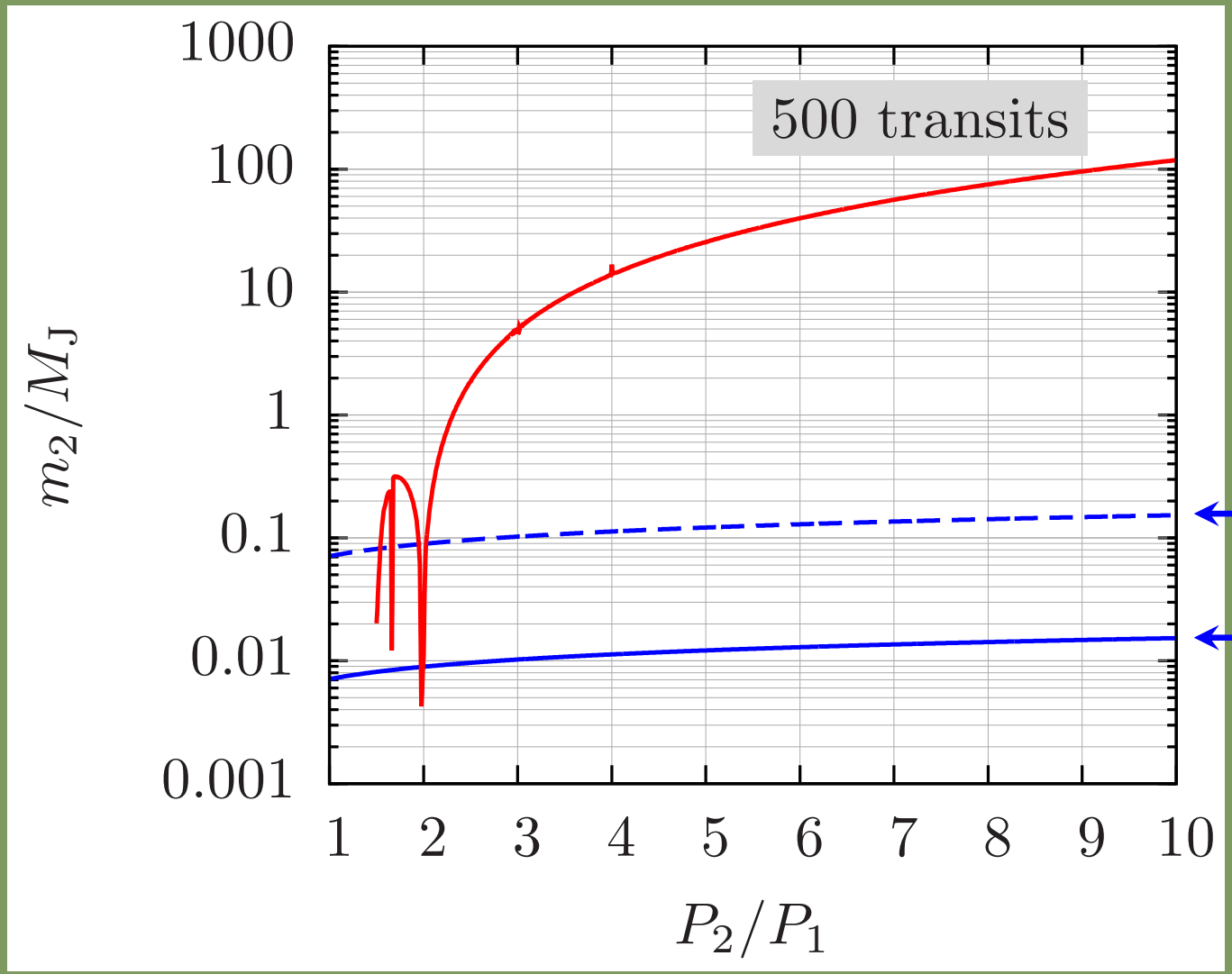

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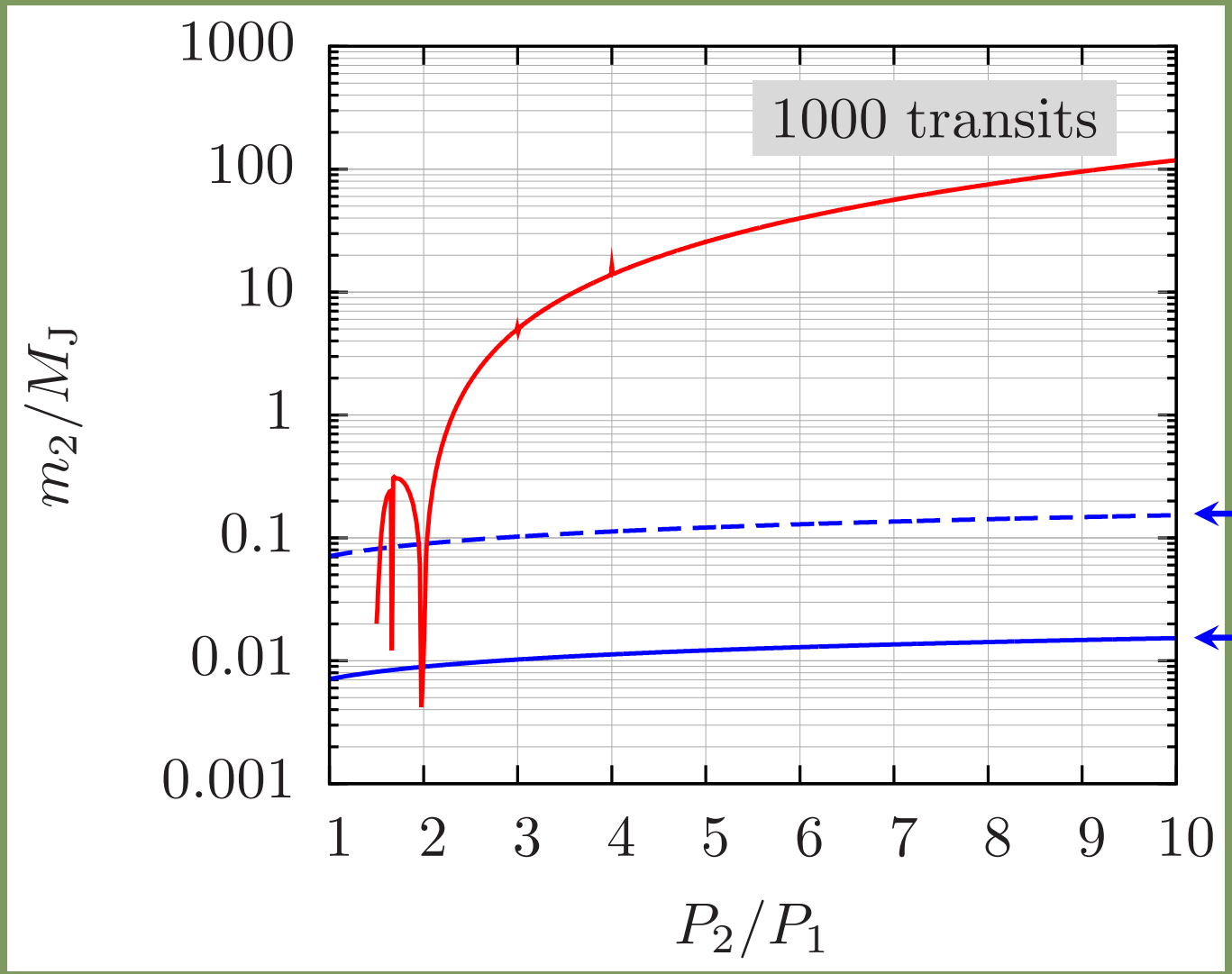
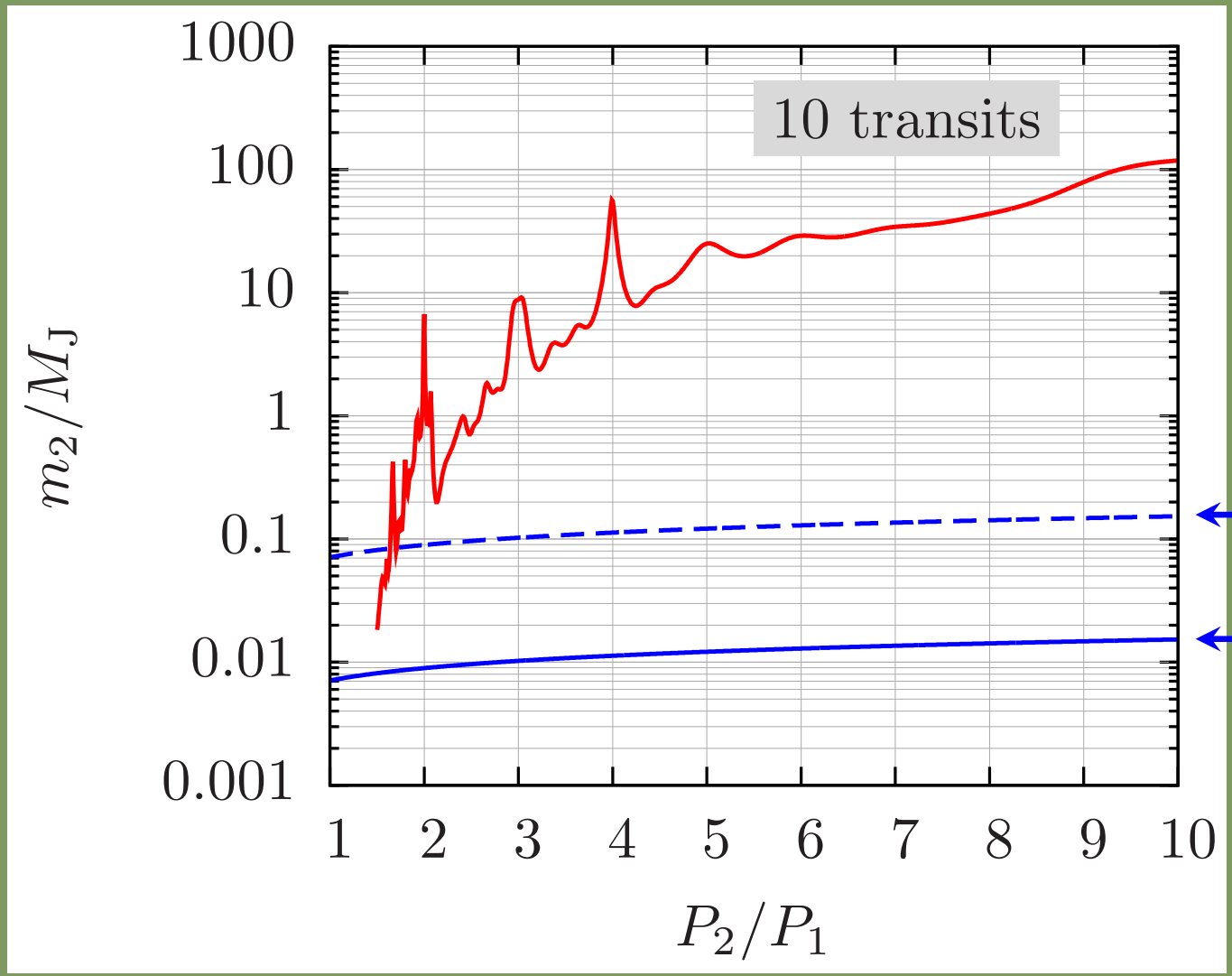
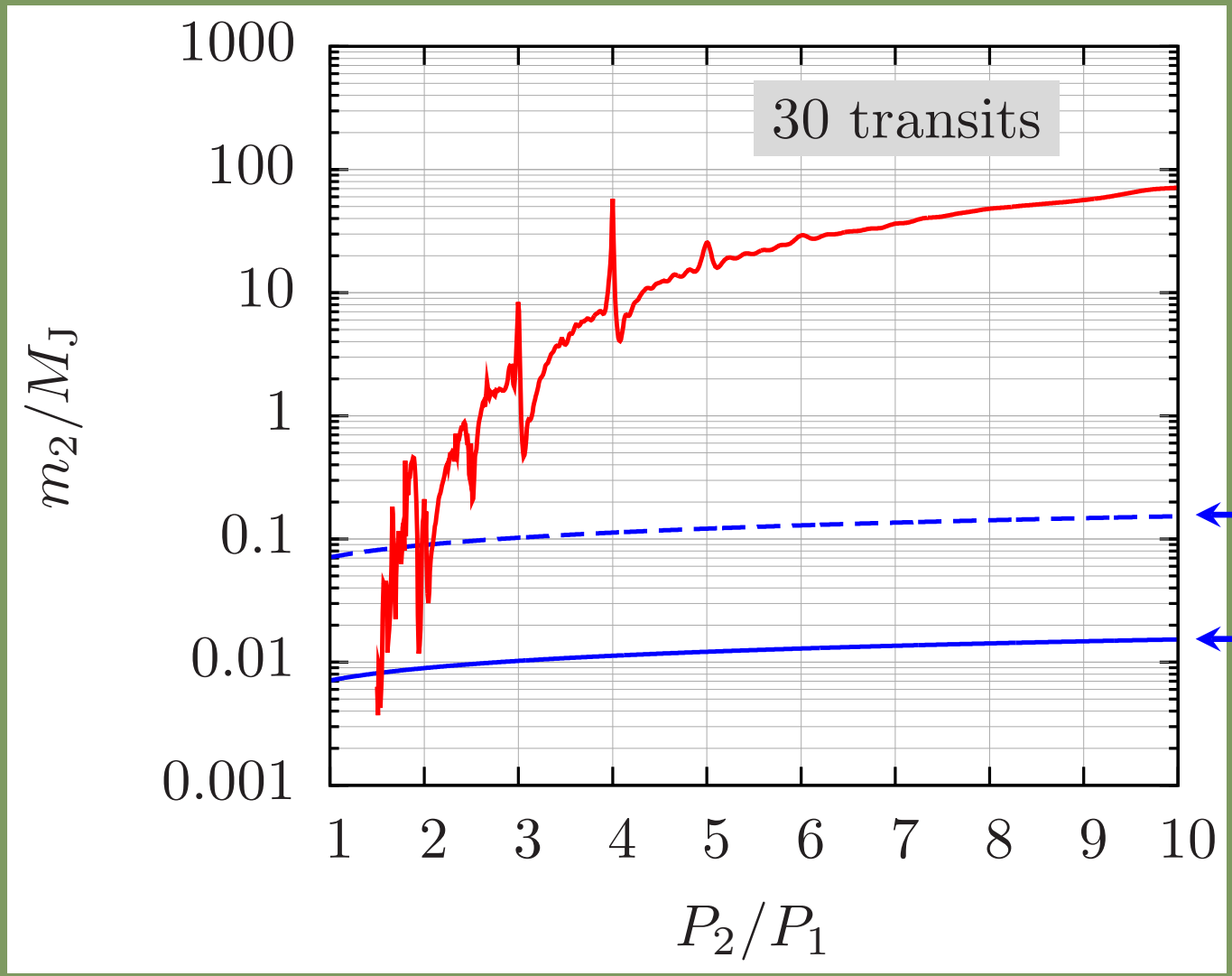


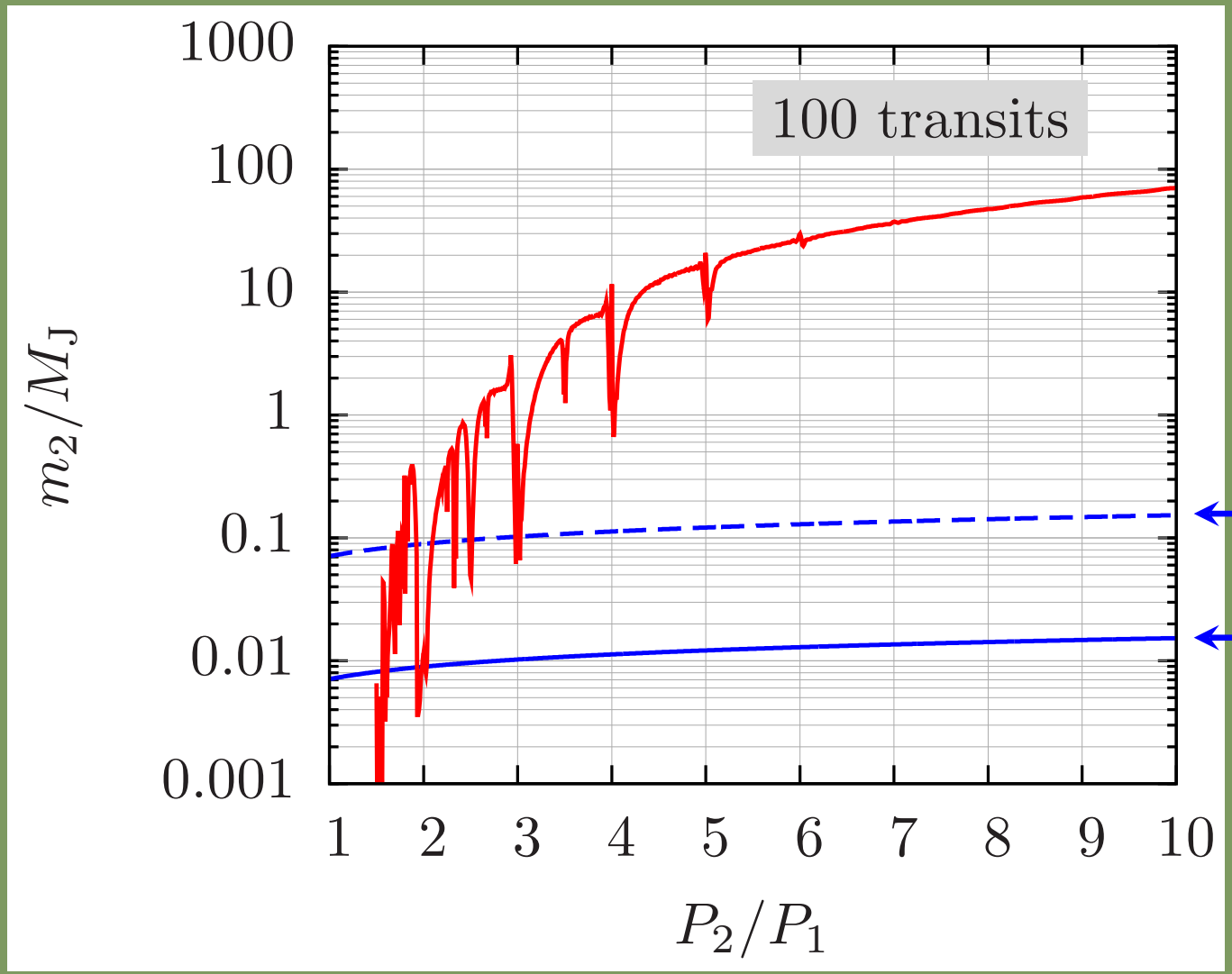
Detection limit versus observation length ($e_2 = 0.1$)



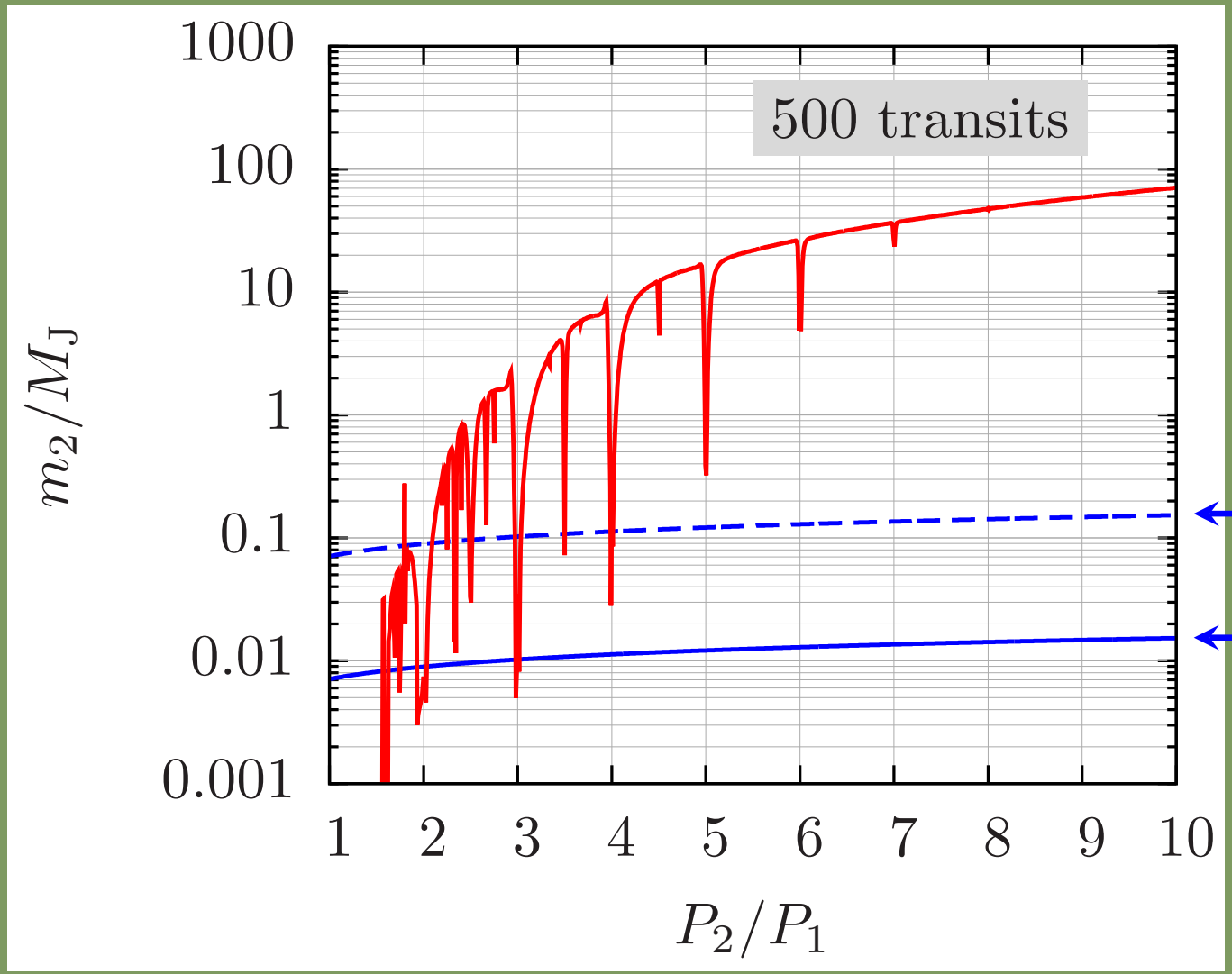
Detection limit versus observation length ($e_2 = 0.1$)



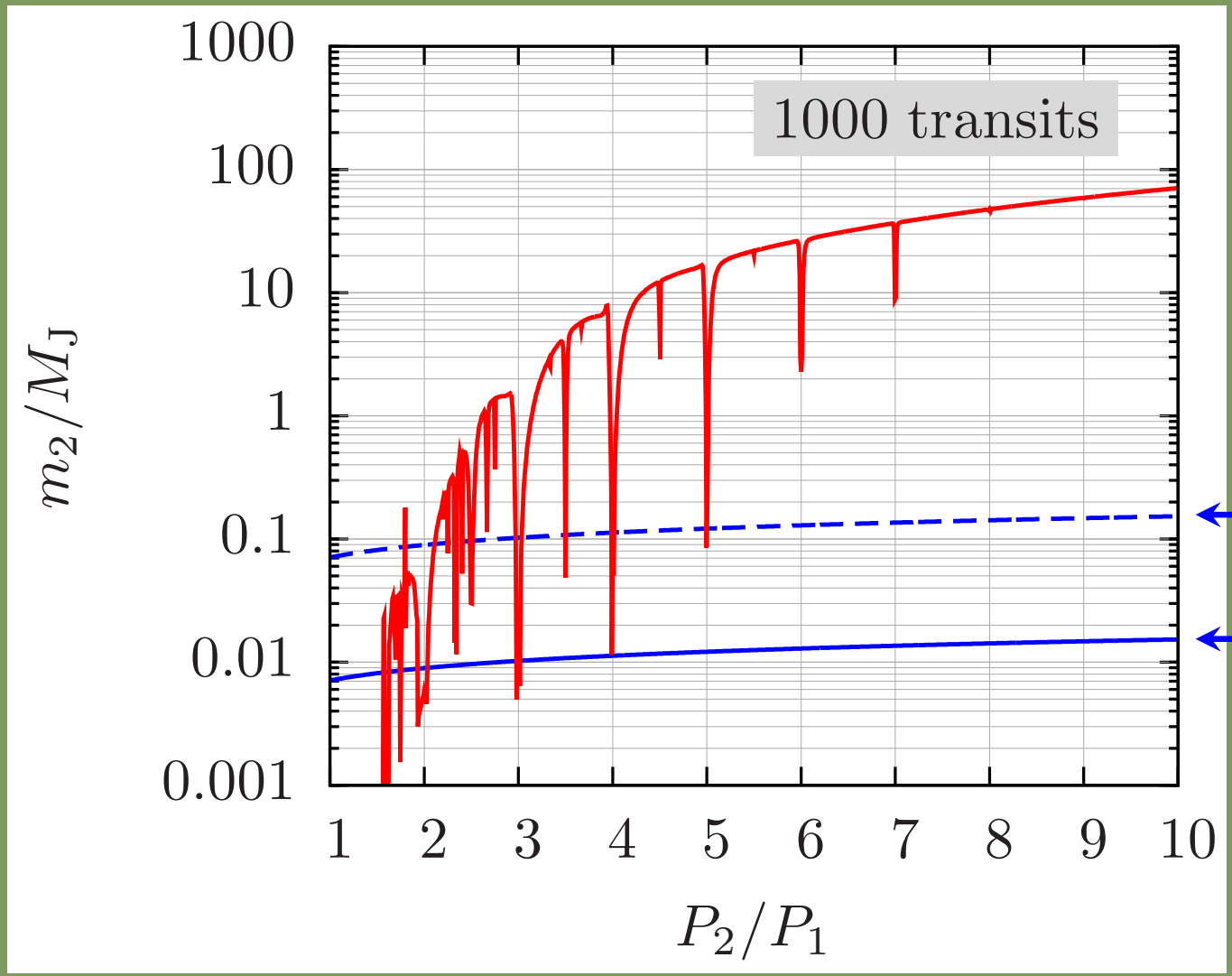
Detection limit versus observation length ($e_2 = 0.1$)



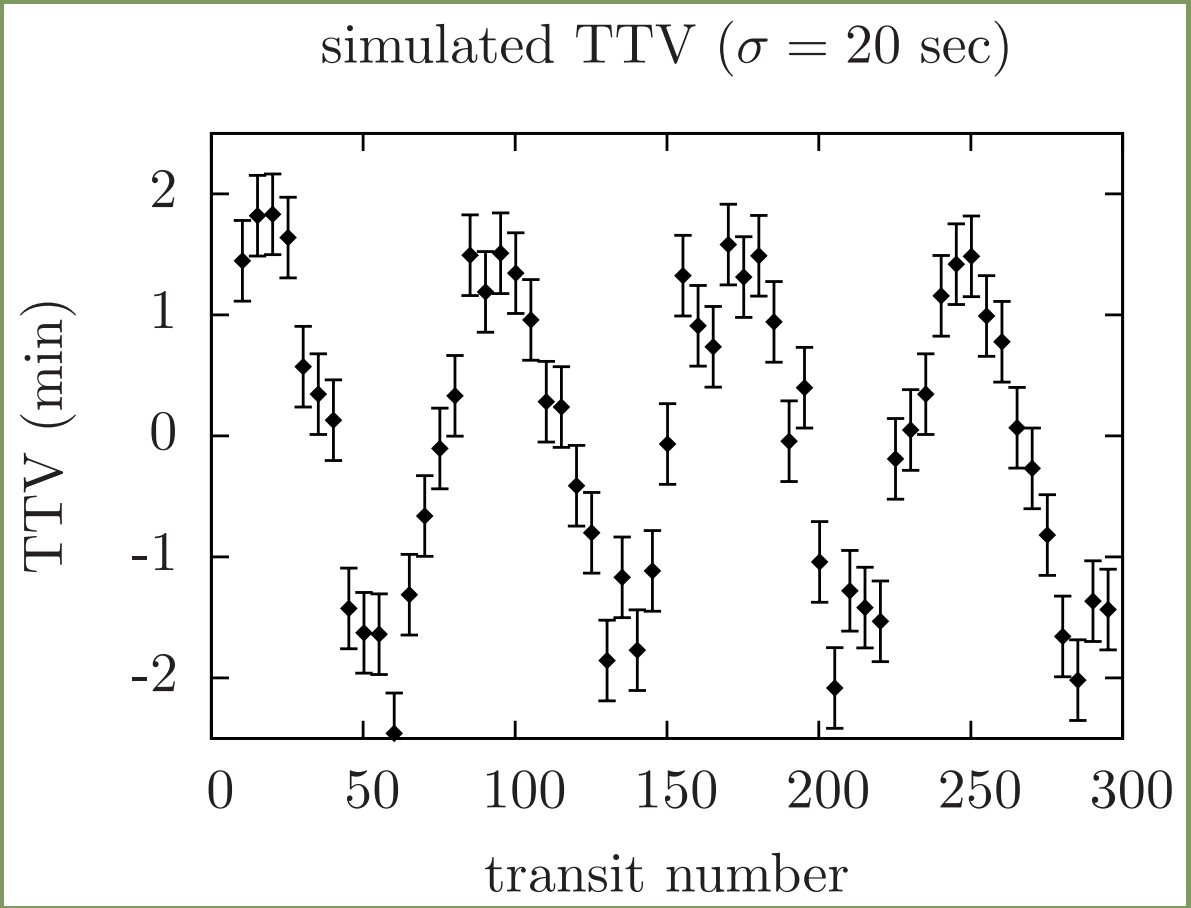
Detection limit versus observation length ($e_2 = 0.1$)



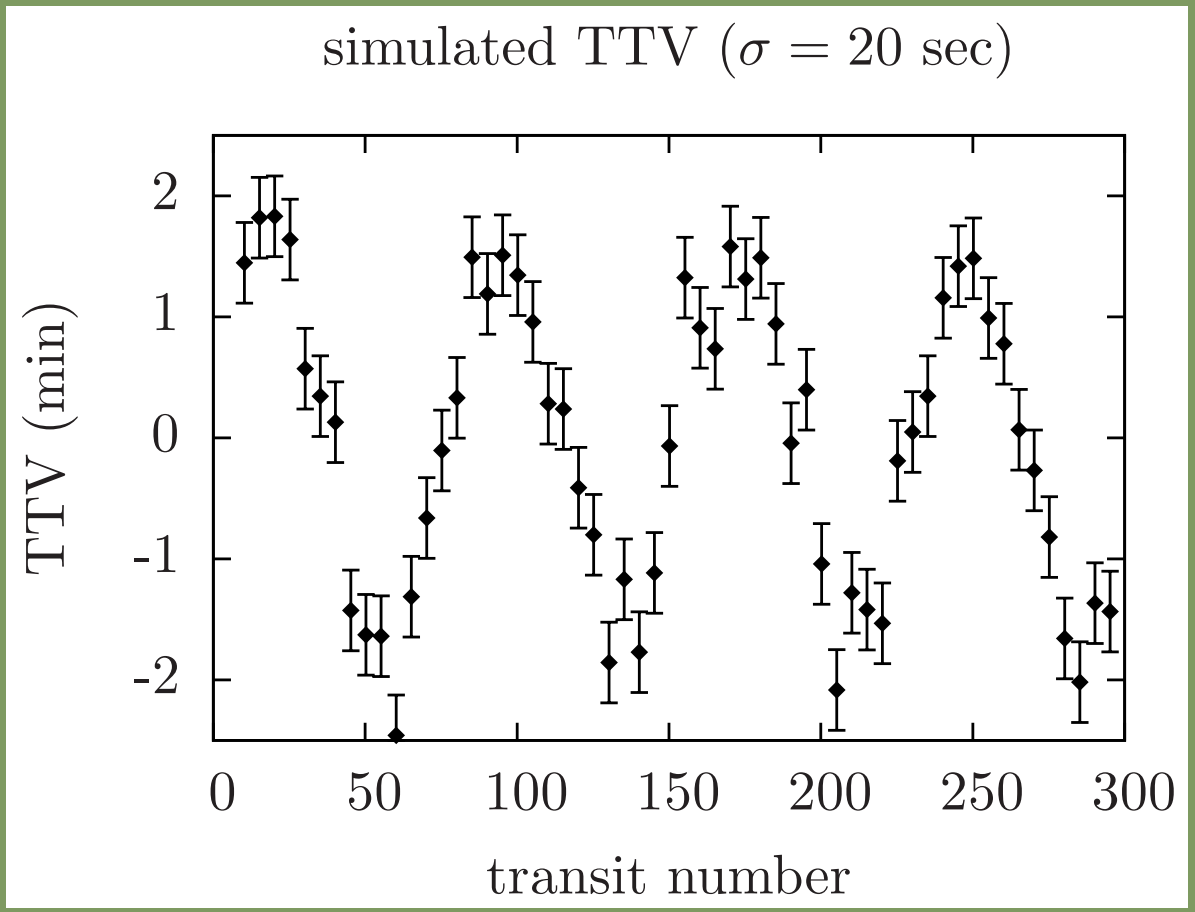
Detection limit versus observation length ($e_2 = 0.1$)



Degeneracy $(\sqrt{\chi^2_r} = 3.6)$



Degeneracy $(\sqrt{\chi^2_r} = 3.6)$



main frequency

MMR $p : p + q$

param $\epsilon = \left| 1 - \frac{p+q}{p} \frac{n_2}{n_1} \right|$

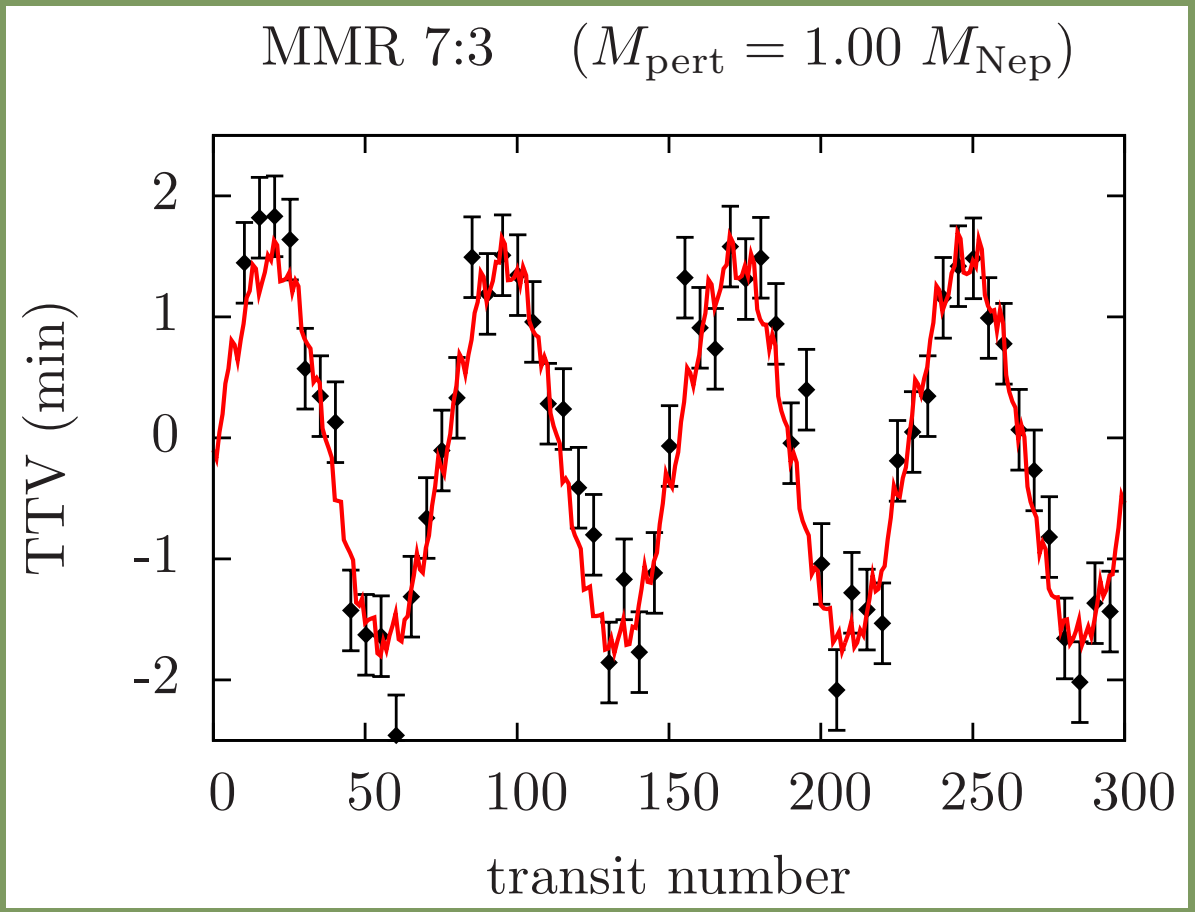
freq $pn_1 - (p+q)n_2$

period $\frac{1}{p\epsilon} P_1$

ampl $\propto \frac{m_2}{\epsilon^2}$

(Agol et al. 2005)

Degeneracy $(\sqrt{\chi^2_r} = 1.19)$



main frequency

MMR $p : p + q$

param $\epsilon = \left|1 - \frac{p+q}{p}\frac{n_2}{n_1}\right|$

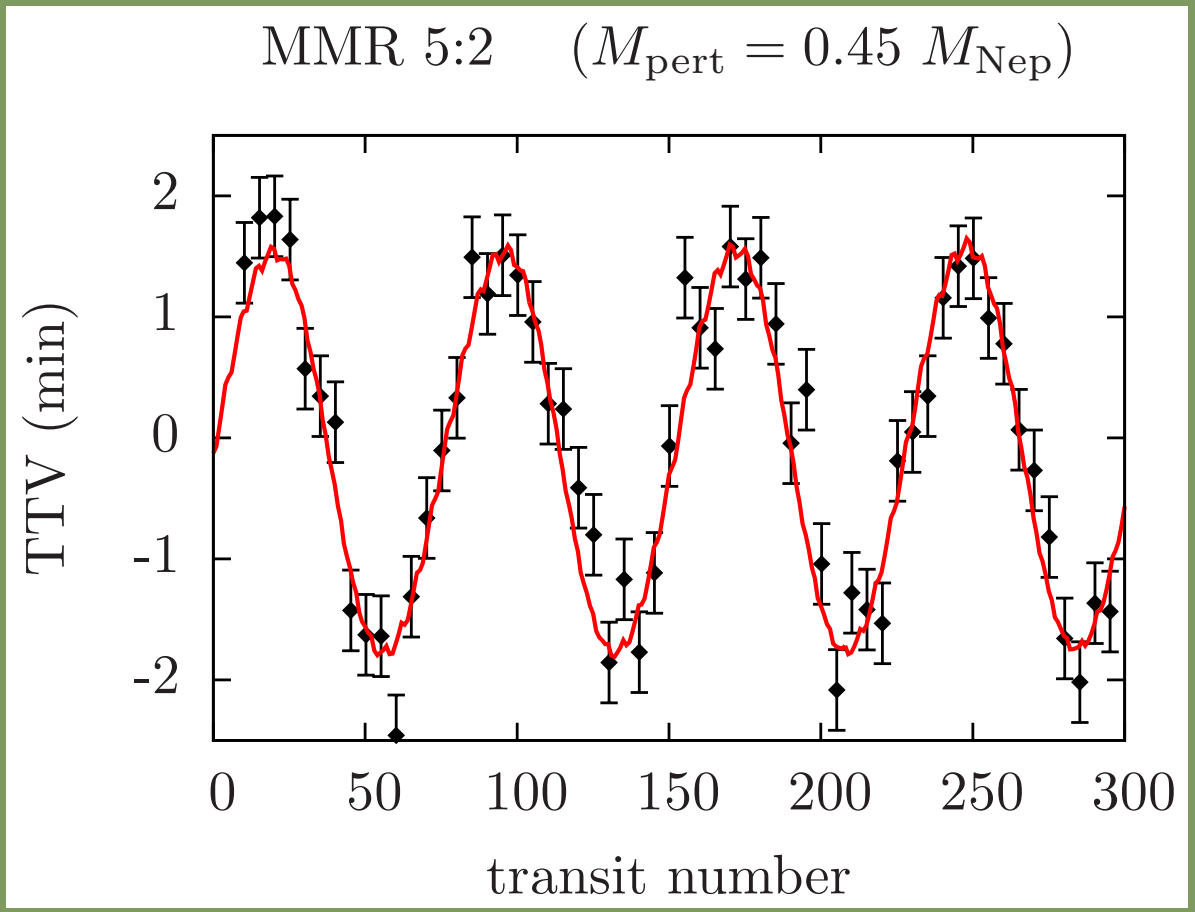
freq $pn_1 - (p+q)n_2$

period $\frac{1}{p\epsilon}P_1$

ampl $\propto \frac{m_2}{\epsilon^2}$

(Agol et al. 2005)

Degeneracy $(\sqrt{\chi^2_r} = 1.16)$



main frequency

MMR $p : p + q$

param $\epsilon = \left|1 - \frac{p+q}{p}\frac{n_2}{n_1}\right|$

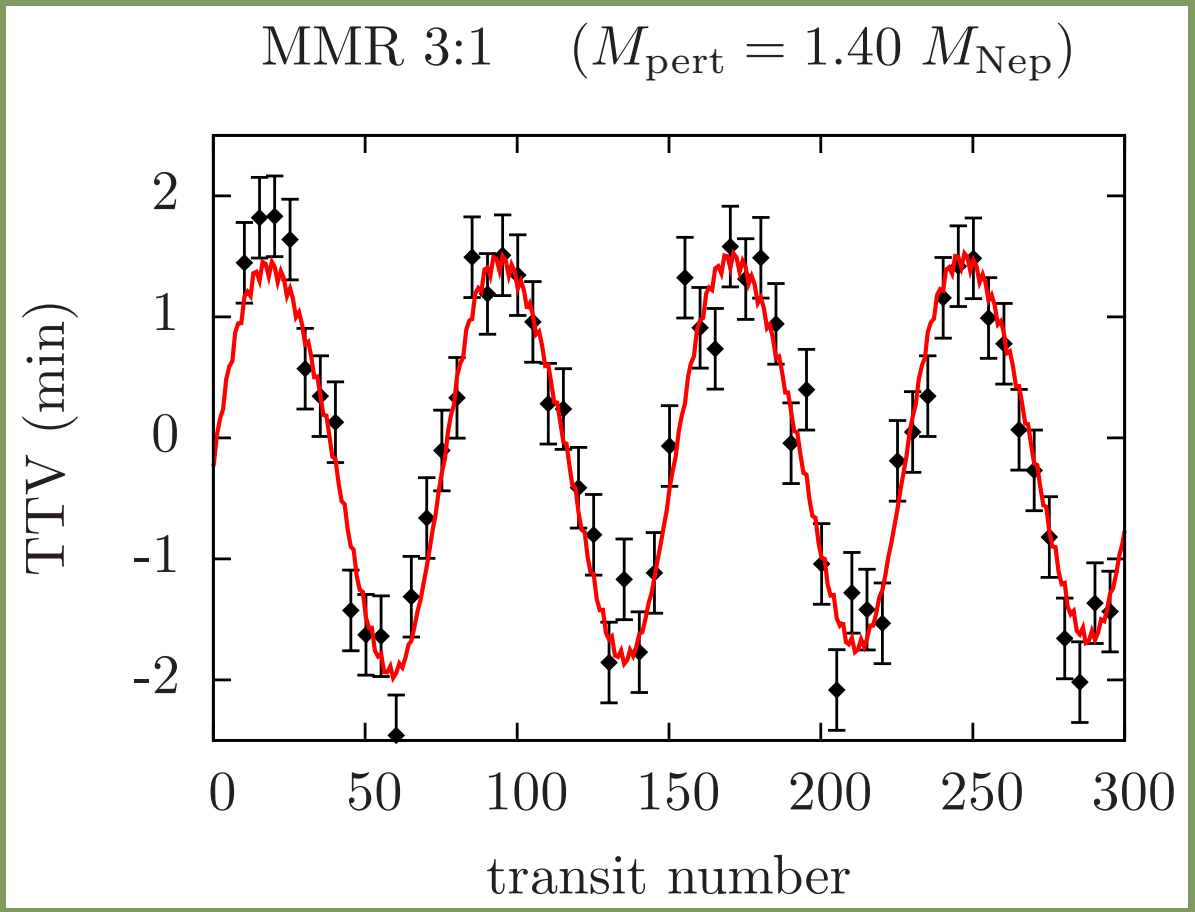
freq $pn_1 - (p+q)n_2$

period $\frac{1}{p\epsilon}P_1$

ampl $\propto \frac{m_2}{\epsilon^2}$

(Agol et al. 2005)

Degeneracy $(\sqrt{\chi^2_r} = 1.07)$



main frequency

MMR $p : p + q$

param $\epsilon = \left|1 - \frac{p+q}{p}\frac{n_2}{n_1}\right|$

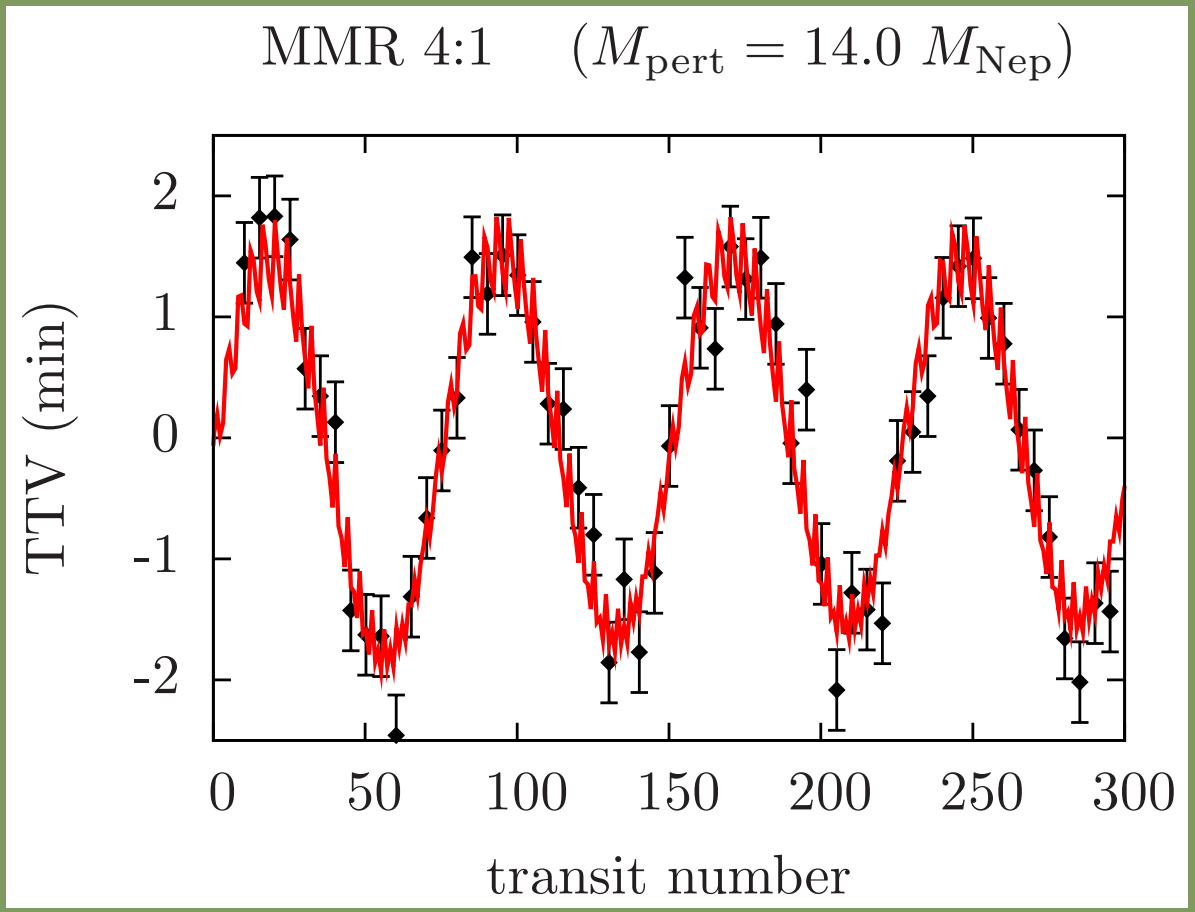
freq $pn_1 - (p+q)n_2$

period $\frac{1}{p\epsilon}P_1$

ampl $\propto \frac{m_2}{\epsilon^2}$

(Agol et al. 2005)

Degeneracy $(\sqrt{\chi^2_r} = 1.22)$



main frequency

MMR $p : p + q$

param $\epsilon = \left|1 - \frac{p+q}{p}\frac{n_2}{n_1}\right|$

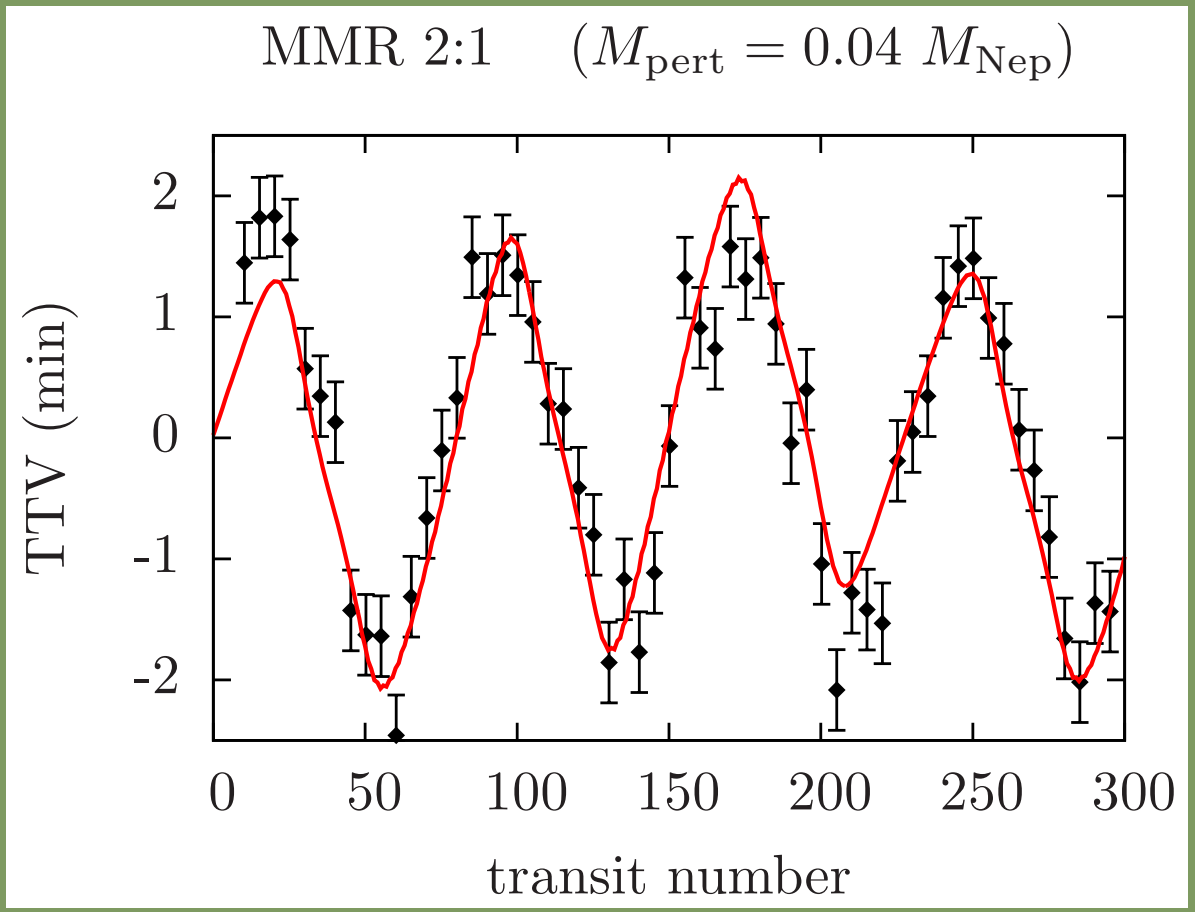
freq $pn_1 - (p+q)n_2$

period $\frac{1}{p\epsilon}P_1$

ampl $\propto \frac{m_2}{\epsilon^2}$

(Agol et al. 2005)

Degeneracy $(\sqrt{\chi^2_r} = 1.39)$



main frequency

MMR $p : p + q$

param $\epsilon = \left|1 - \frac{p+q}{p}\frac{n_2}{n_1}\right|$

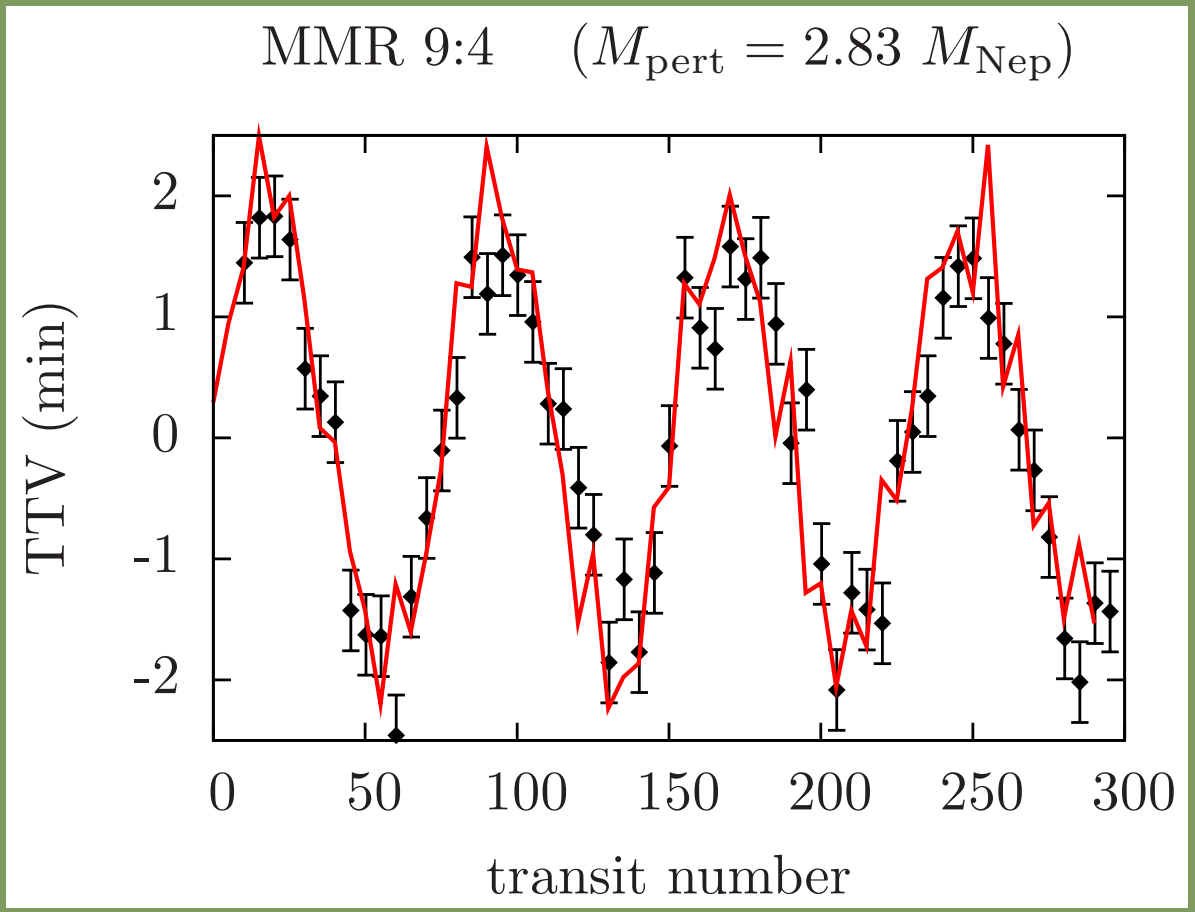
freq $pn_1 - (p+q)n_2$

period $\frac{1}{p\epsilon}P_1$

ampl $\propto \frac{m_2}{\epsilon^2}$

(Agol et al. 2005)

Degeneracy $(\sqrt{\chi^2_r} = 1.83)$



main frequency

MMR $p : p + q$

param $\epsilon = \left| 1 - \frac{p+q}{p} \frac{n_2}{n_1} \right|$

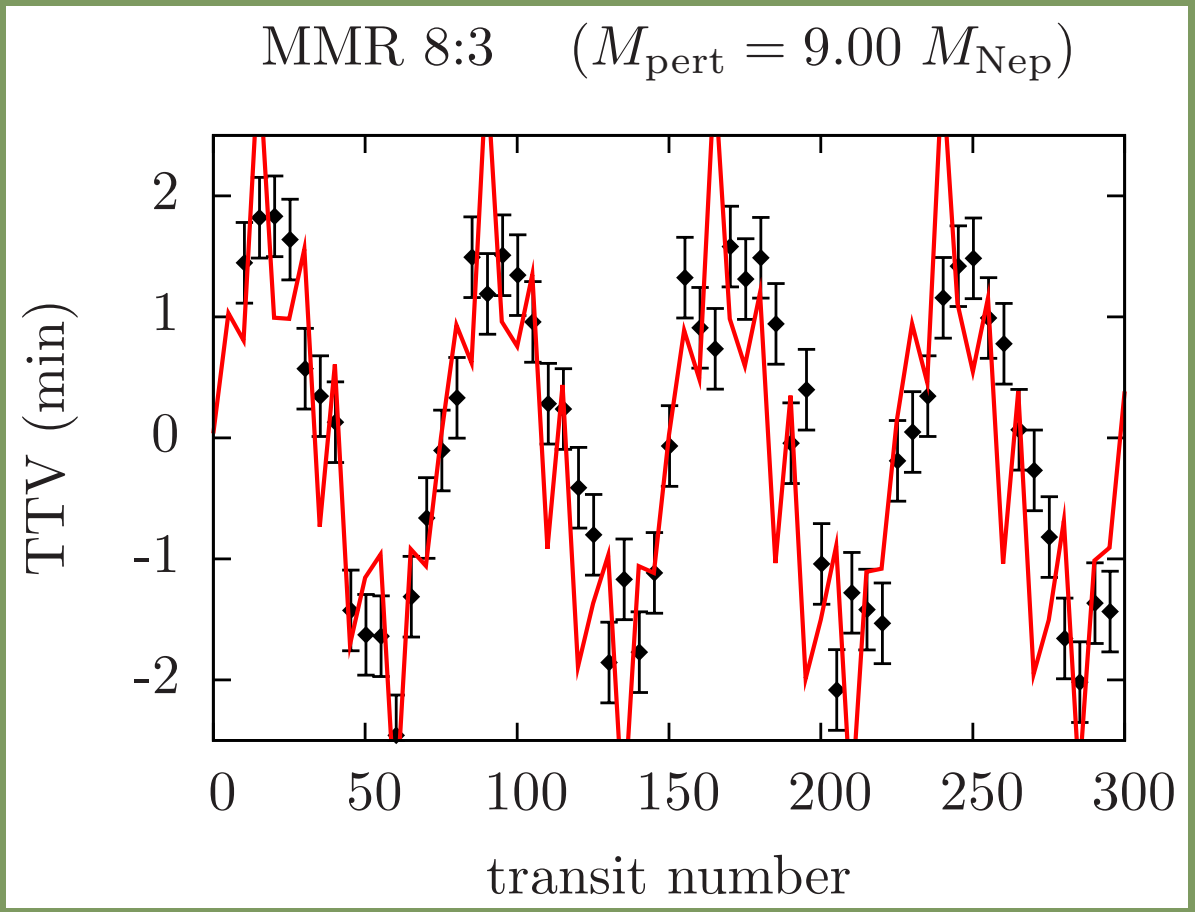
freq $p n_1 - (p+q) n_2$

period $\frac{1}{p\epsilon} P_1$

ampl $\propto \frac{m_2}{\epsilon^2}$

(Agol et al. 2005)

Degeneracy $(\sqrt{\chi^2_r} = 2.90)$



main frequency

MMR $p : p + q$

param $\epsilon = \left|1 - \frac{p+q}{p}\frac{n_2}{n_1}\right|$

freq $pn_1 - (p+q)n_2$

period $\frac{1}{p\epsilon}P_1$

ampl $\propto \frac{m_2}{\epsilon^2}$

(Agol et al. 2005)

Masses vs resonance for the degenerate fit

resonance	$M_{\rm pert}/M_{\rm Nep}$	$\sqrt{\chi^2_r}$
2:1	0.04	1.39
9:4	2.83	1.83
7:3	1.00	1.19
5:2	0.45	1.16
8:3	9.00	2.90
3:1	1.40	1.07
4:1	14.00	1.22

Problem raised by

Nesvorný & Morbidelli 2008
Meshiari & Laughlin 2010
Veras et al. 2011

Conclusion

TTV properties

- low mass planets produce detectable signal at MMR

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Problem

- long period $\rightarrow$ long term observation
- degeneracy mass - MMR

Conclusion

TTV properties

- low mass planets produce detectable signal at MMR

Problem

- long period $\rightarrow$ long term observation
- degeneracy mass - MMR

Conclusion

- TTV needs radial velocity measurements to characterize non-transiting planets