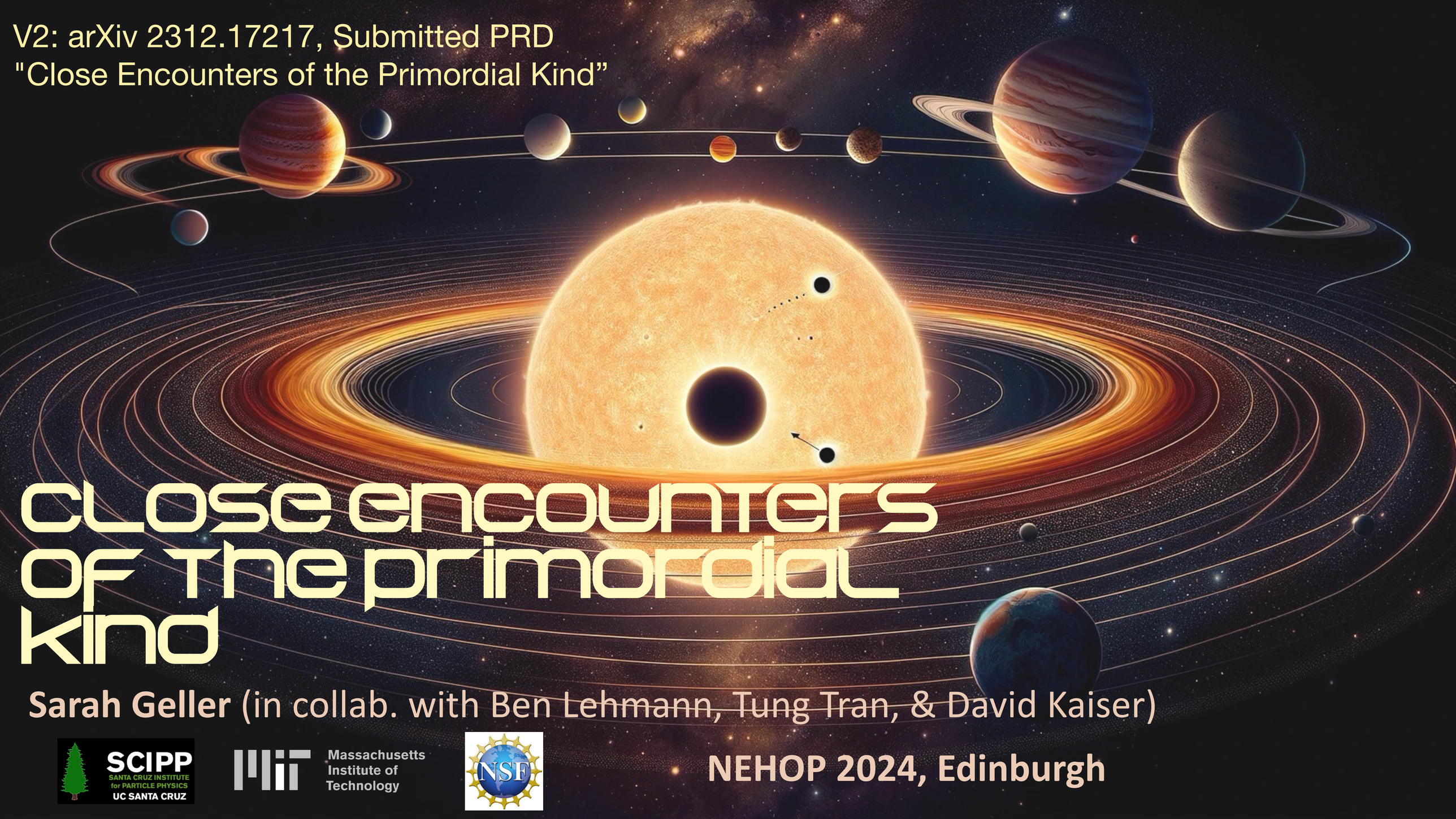
V2: arXiv 2312.17217, Submitted PRD
"Close Encounters of the Primordial Kind”



close encounters of the primordial kind

Sarah Geller (in collab. with Ben Lehmann, Tung Tran, & David Kaiser)

SCIPP SANTA CRUZ INSTITUTE for PARTICLE PHYSICS UC SANTA CRUZ

Massachusetts Institute of Technology

NSF

NEHOP 2024, Edinburgh

COLLABORATORS:

Tung Tran (Graduate Student)

Benjamin Lehmann
MIT Pappalardo Fellow

Professor David Kaiser

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The problem: There could be enough PBHs in the asteroid mass range ($\sim 10^{17} - 10^{22}$ grams) to constitute as much as $\mathcal{O}(1)$ fraction of the dark matter… none have been detected.

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Claim: Close encounters of PBHs with our solar system can produce detectable perturbations in the orbital trajectories of solar system objects.— **Proposed observable is Earth-Mars distance. Can potentially detect a PBH and/or derive constraints from absence of an encounter**

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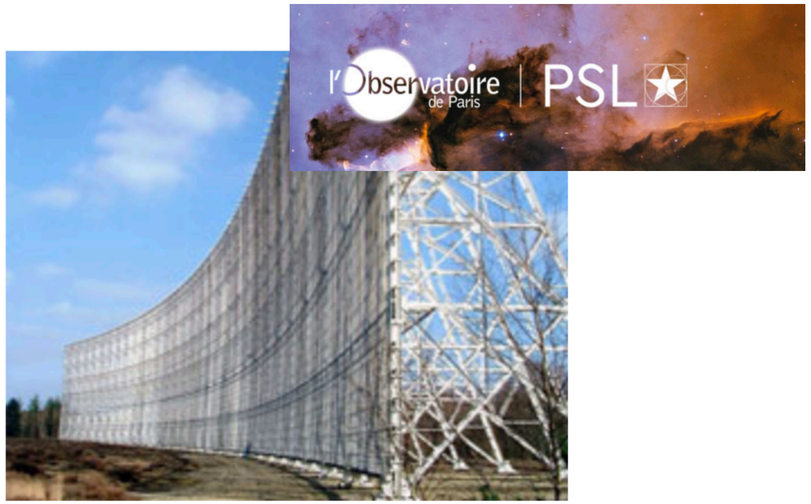

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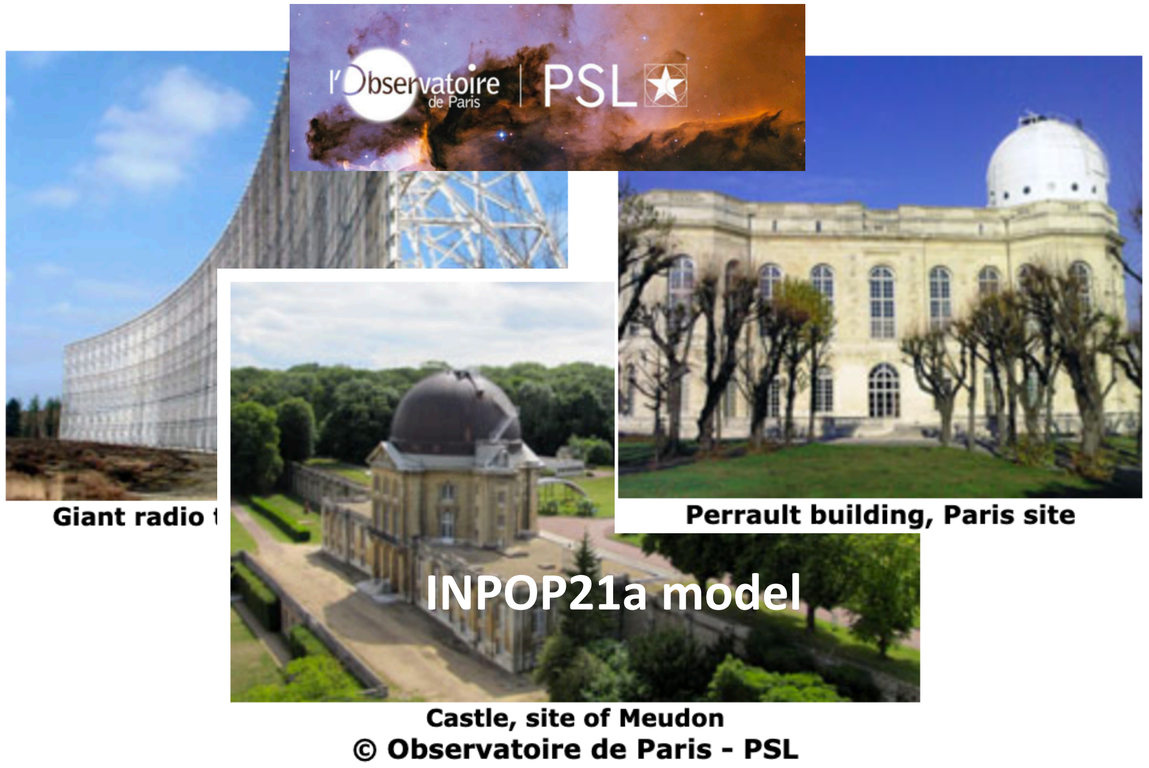

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All have small effect on residual:

$$\sum_n \frac{\delta r_n}{\delta r_0} << 1$$

PBH flyby perturbs the orbit of a SSO*, changes distance r between Earth and SSO by *residual*

$$\delta r = \delta r_0 + \sum_n \delta r_n(\delta r_{n-1})$$

δr_0: **initial pert.**

*SSO ≡ solar system object

A proposed observable of PBH dark matter

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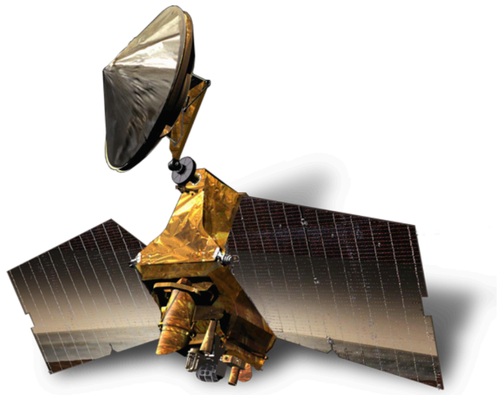

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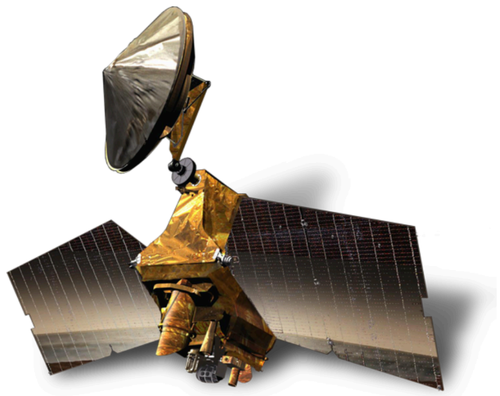

Radio tracking (Doppler)

Very Long Baseline Interferometry (VLBI)

Use orbiters like
* Mars Odessy
* Mars Express
* MAVEN
* Mars Rovers

It's a beautiful PBH in the neighborhood!

Similar to dark matter density calculation

If $f_{\mathrm{PBH}} \sim 1, \rho_{\mathrm{PBH}} \simeq .4$ GeV/cm^3

Rate of detectable flybys: an analytic estimate vs (simplified) numerical simulation

Similar to dark matter density calculation

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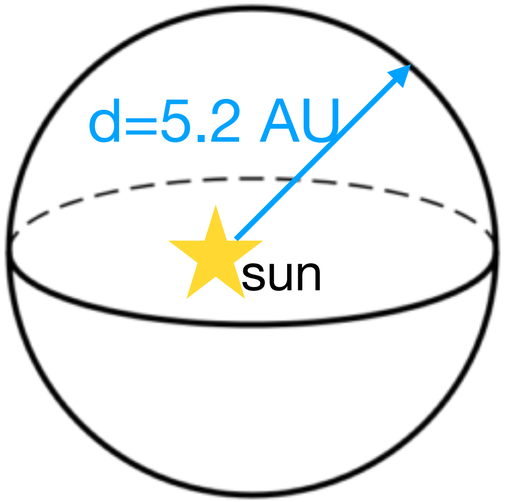

Expectation for flybys: $N_{\rm PBH} \sim 1.4 \left(\frac{M_{\rm PBH}}{10^{18}{\rm gm}} \right)^{-1}$ with $\langle v_{PBH} \rangle \sim 220$ km/s

Simplification: assume monochromatic mass spectrum

Comparing flyby time to orbital time $\Longrightarrow$ Impulse model

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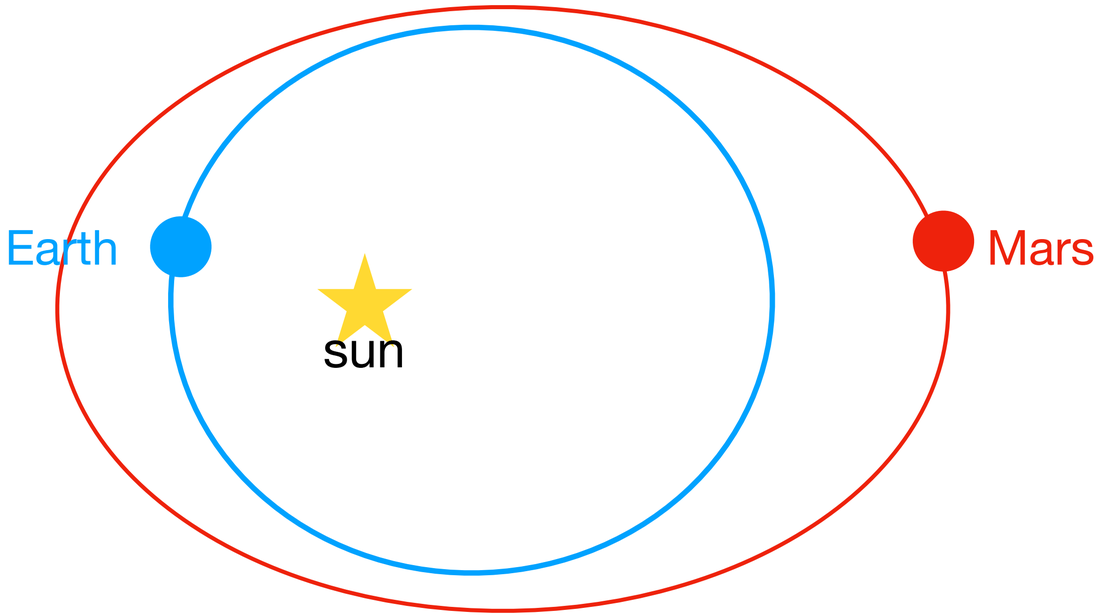

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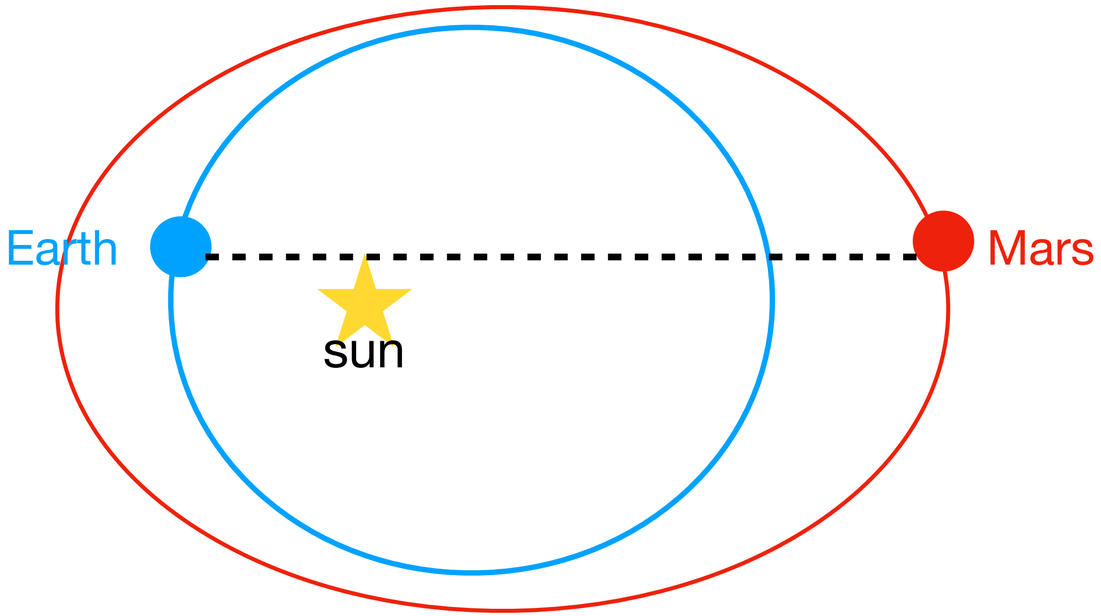

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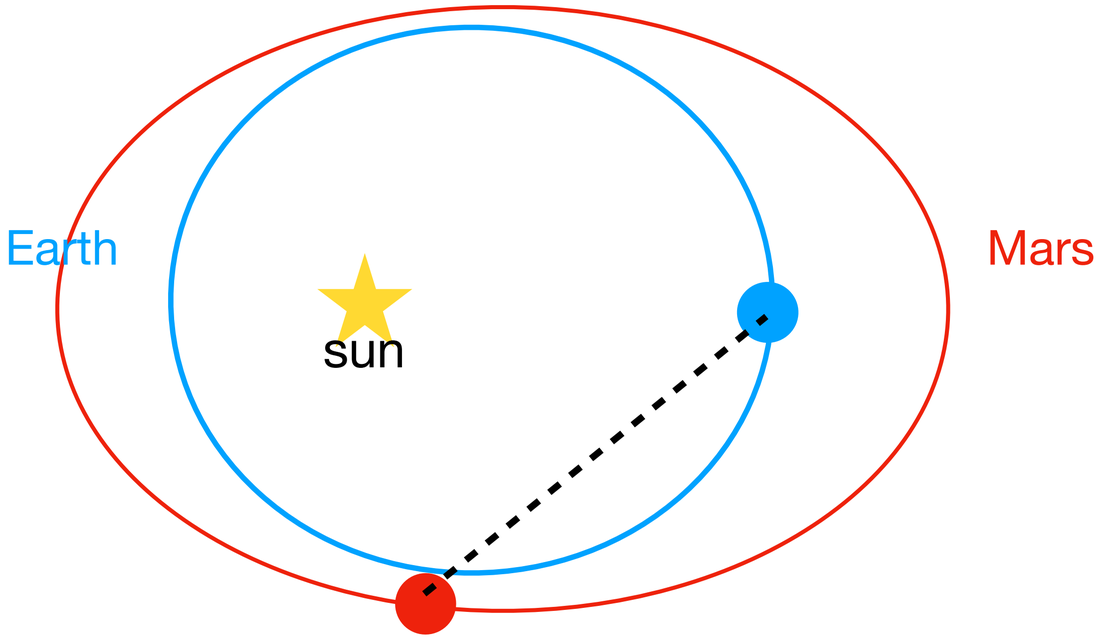

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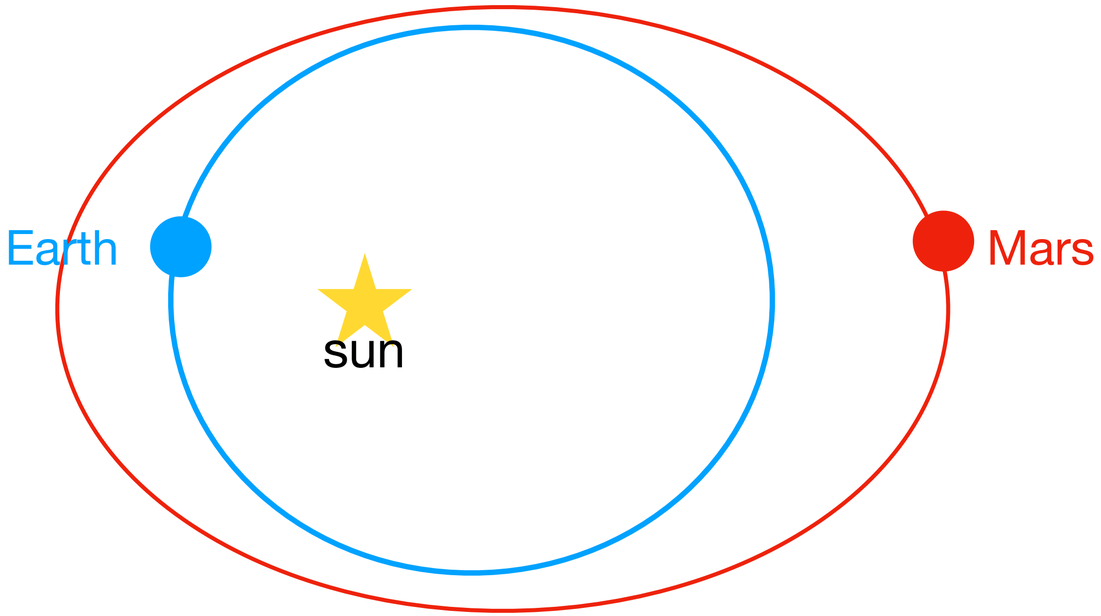

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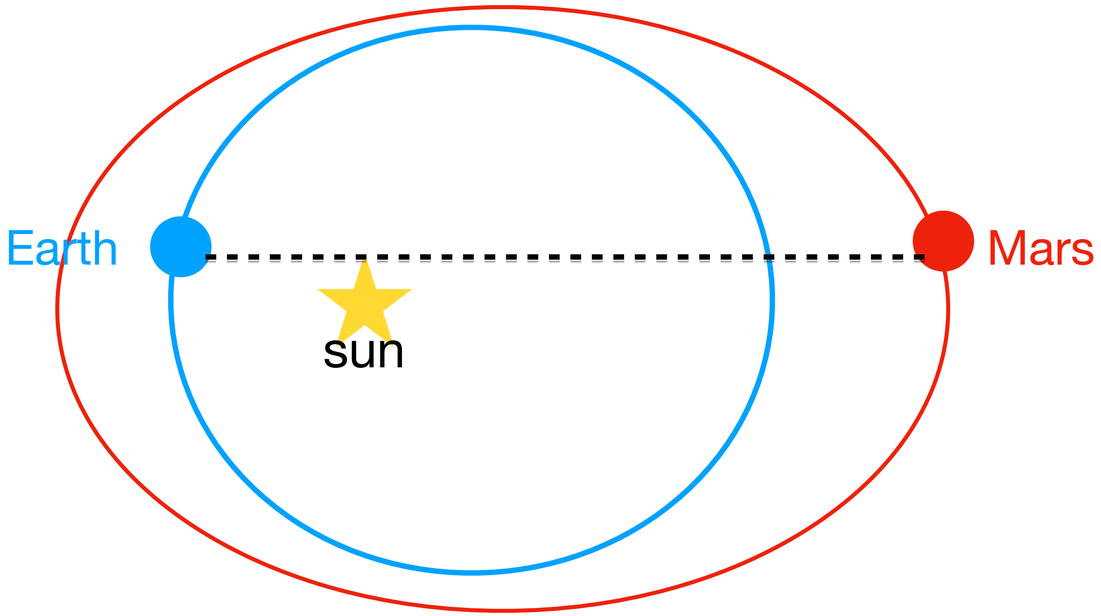

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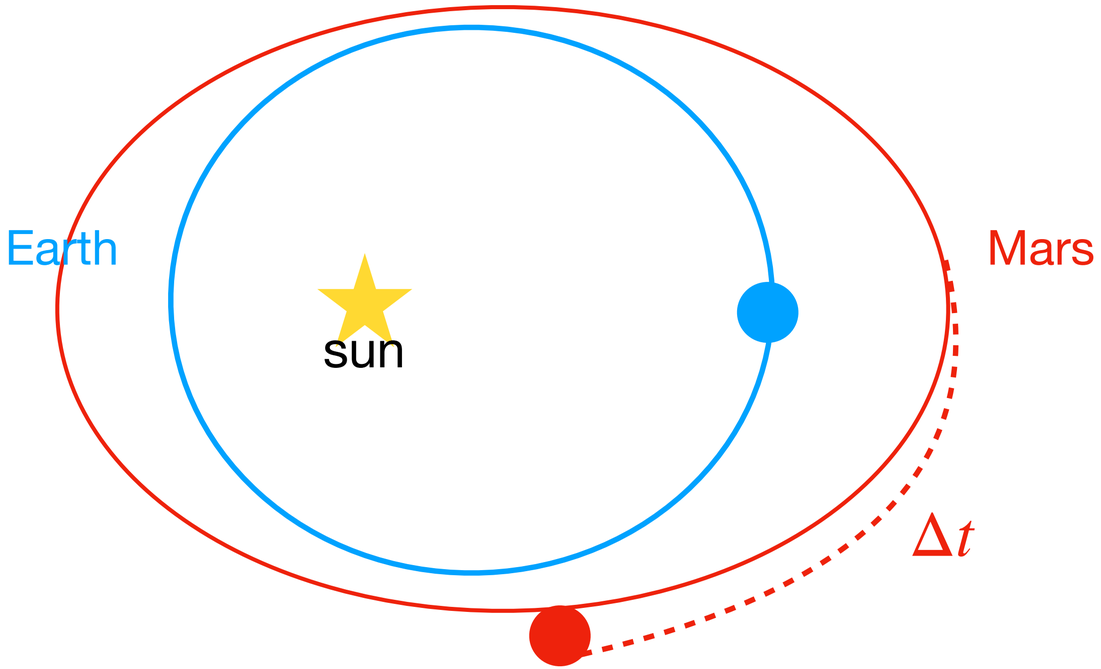

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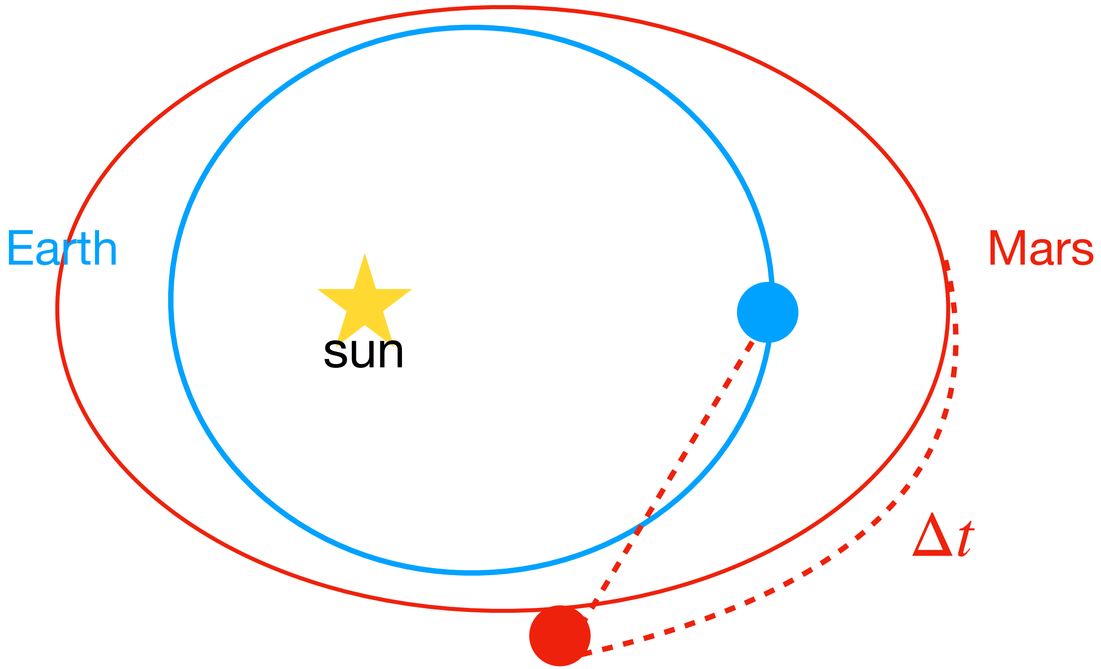

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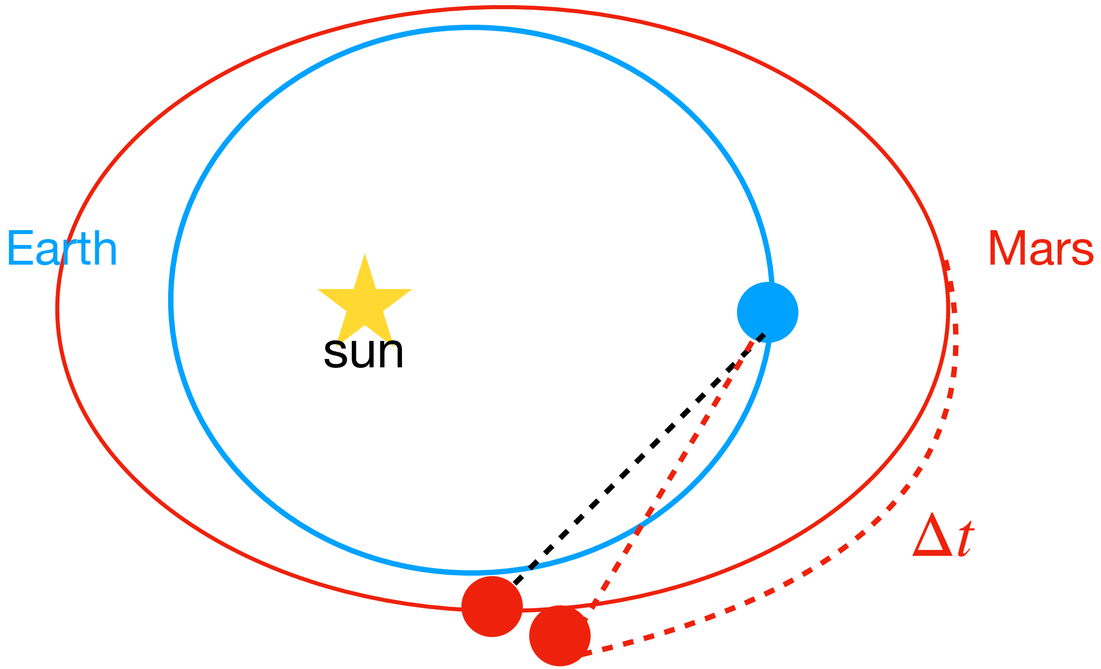

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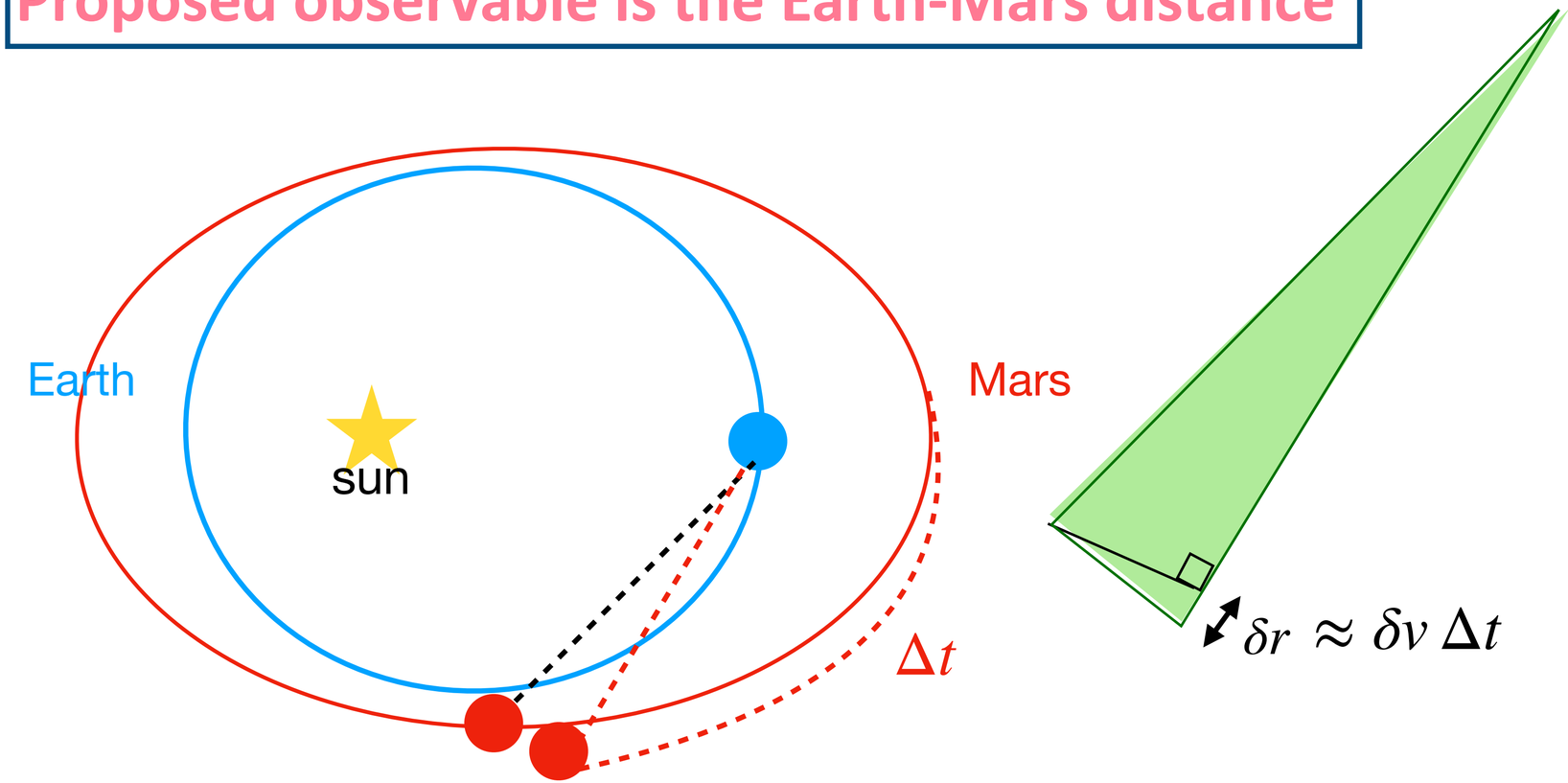

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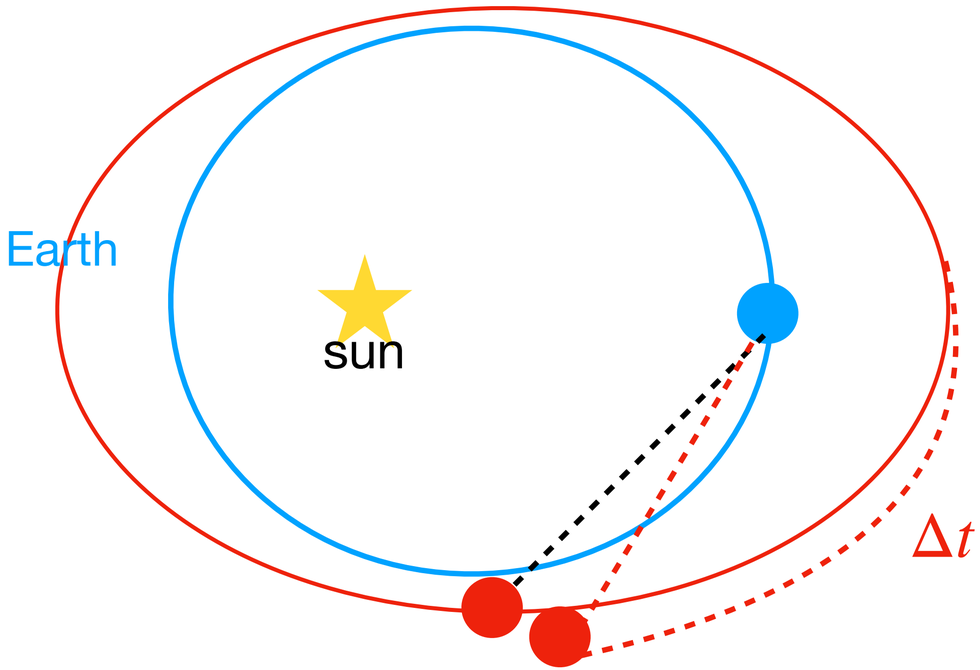

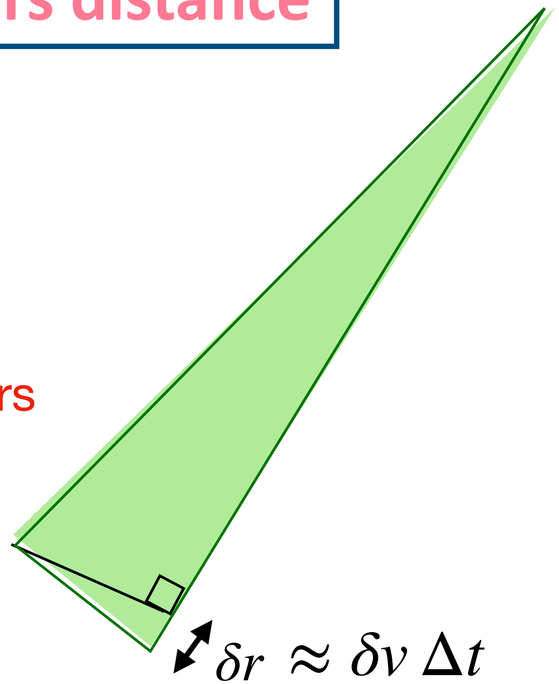

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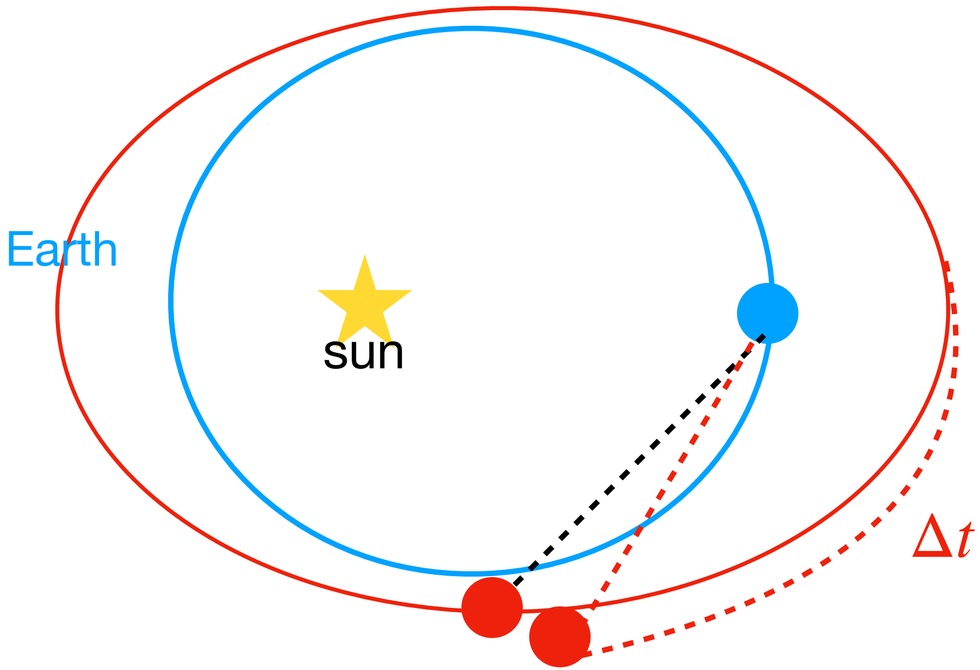

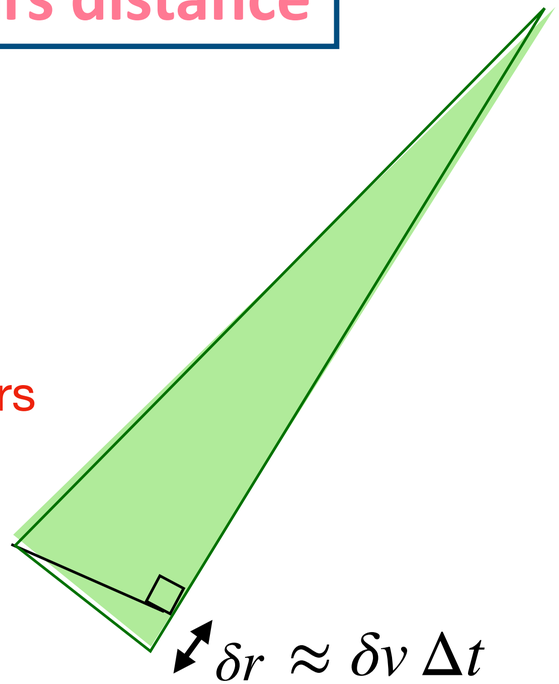

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net impulse velocity imparted to SSO

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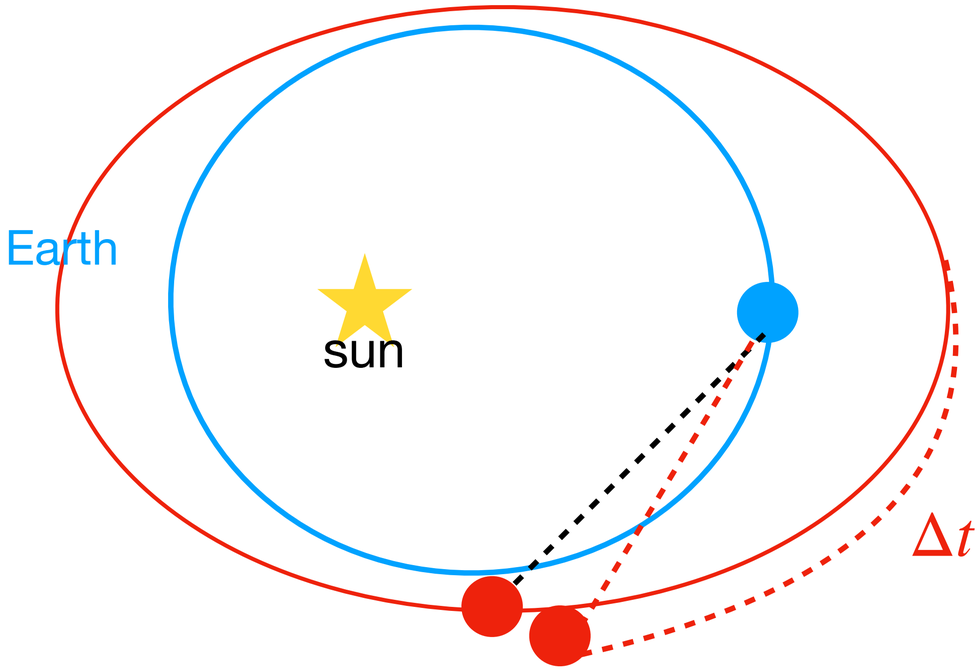

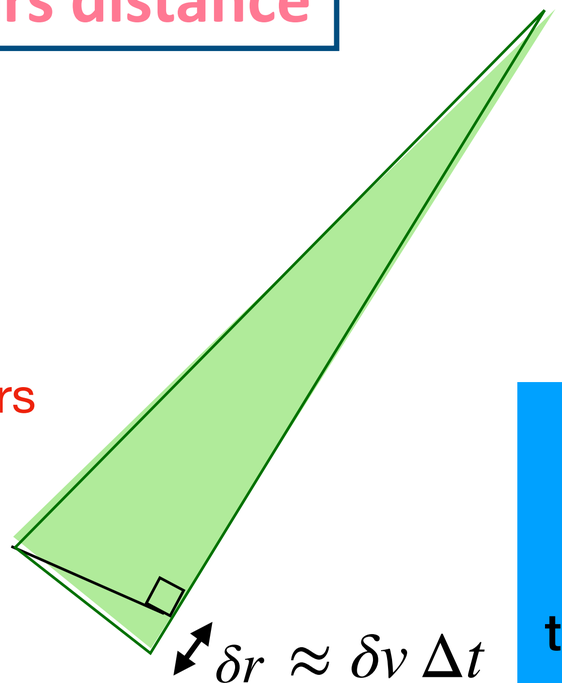

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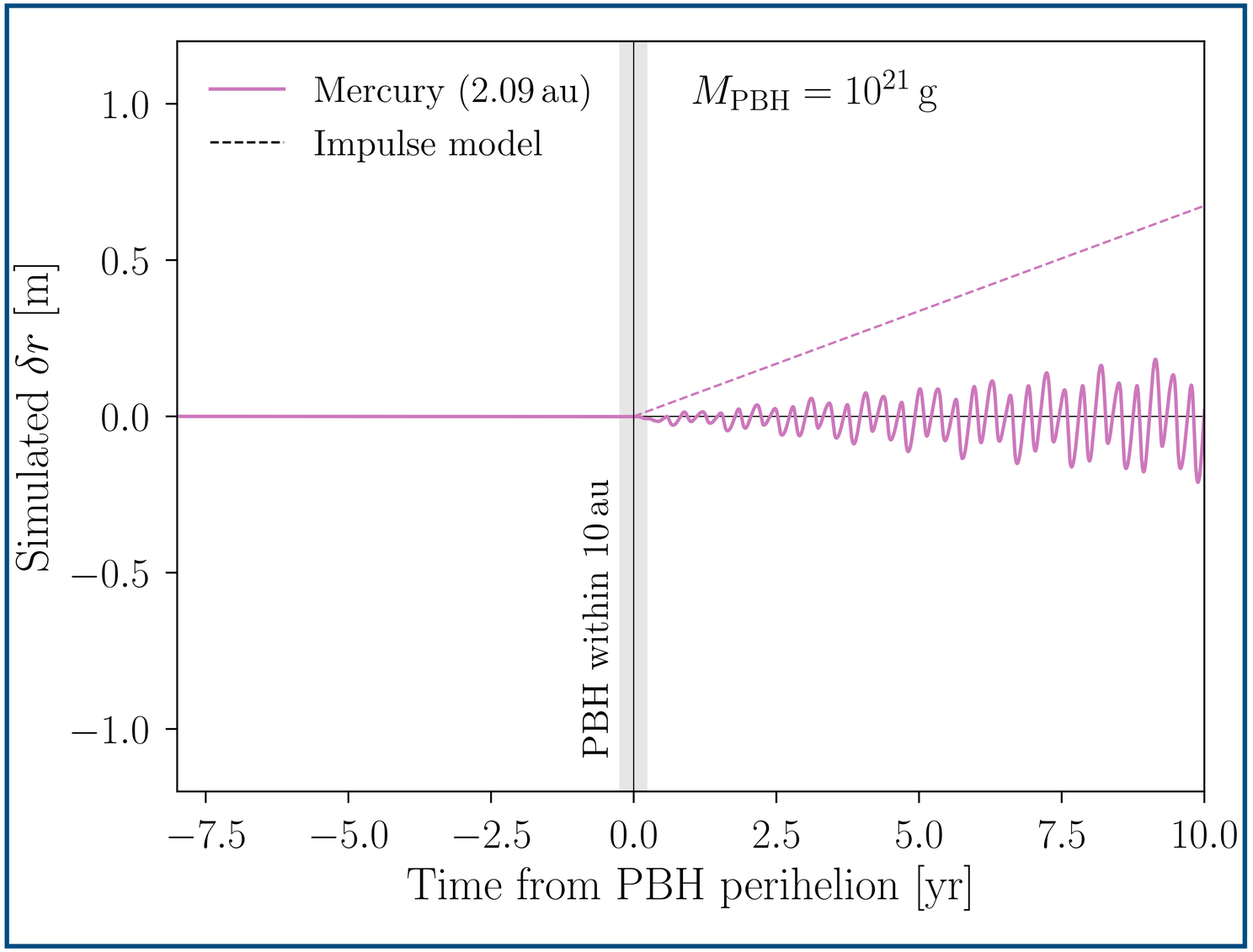
Condition for detectability:

$\delta r \gtrsim \sigma_r$ **implies for** $\Delta t \simeq 26$ **years,**

there will be $\mathcal{O}(1)$ **detectable events**

within impact parameter $b \simeq 3.3$ **Au!!!**

The Solar System itself as a new PBH telescope:



Object	Mass [g]	Horizons ID
Sun	2.0×10^{33}	10
Mercury	3.3×10^{26}	199
Venus	4.9×10^{27}	299
Earth	6.0×10^{27}	399
Moon / (Earth)	7.3×10^{25}	301
Mars	6.4×10^{26}	499
Phobos	1.1×10^{19}	401
Deimos	1.8×10^{18}	402
Jupiter	1.9×10^{30}	599
Io	8.9×10^{25}	501
Europa	4.8×10^{25}	502
Ganymede	1.5×10^{26}	503
Callisto	1.1×10^{26}	504
Saturn	5.7×10^{29}	699
Titan	1.3×10^{26}	606
Uranus	8.7×10^{28}	799
Neptune	1.0×10^{29}	899
Pluto	1.5×10^{25}	999
Ceres	9.4×10^{23}	2000001
Vesta	2.6×10^{23}	2000004

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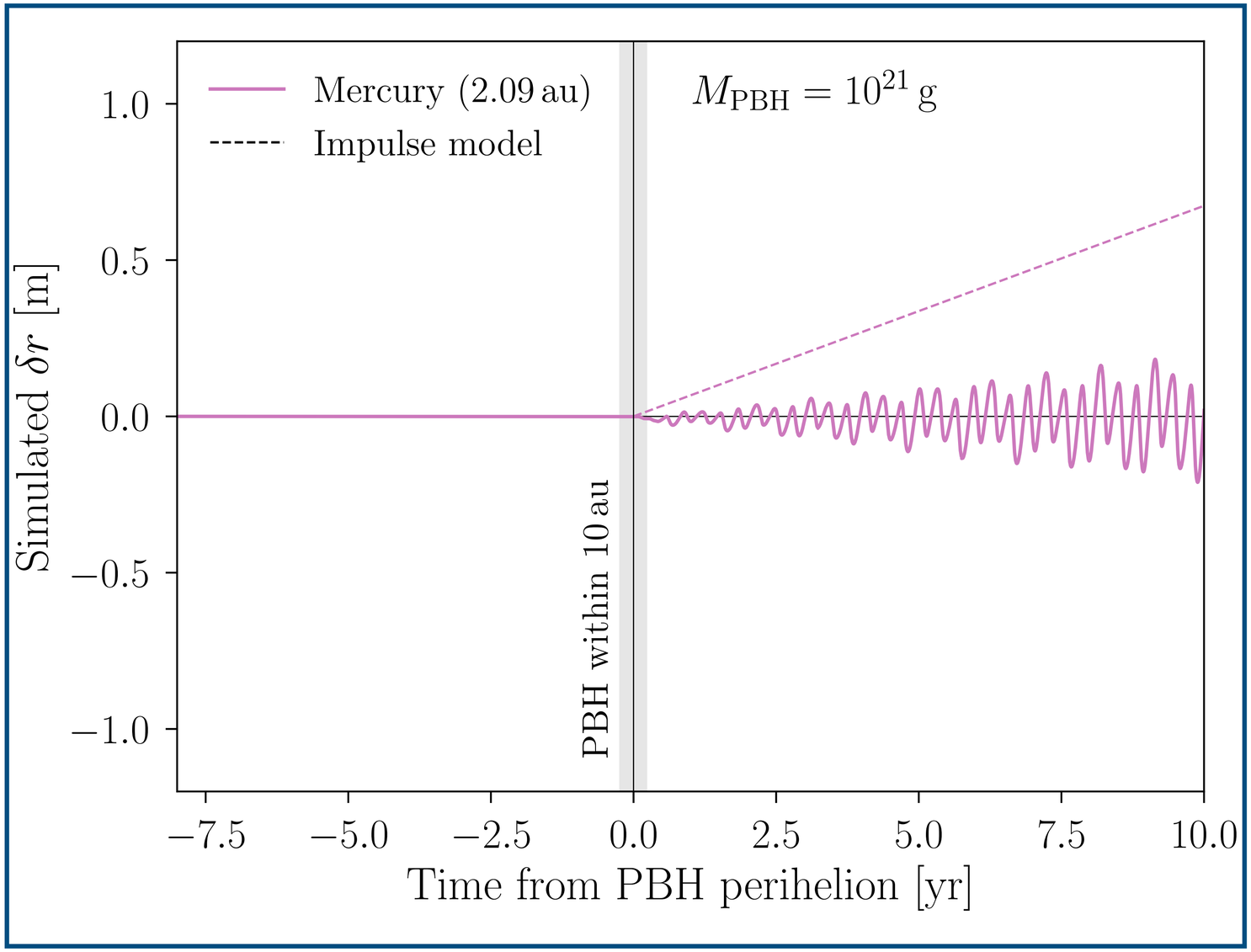

On a timescale of ~ 10 yr from PBH closest approach

Impulse model: linear growth of distance

Envelope tracks impulse model + many other bodies- grows linearly

On much longer timescales (>10 yr, < instability timescale of solar sys.) slope of impulse model switches sign.

Acts as a guide: where do we look? Is δr viable observable?

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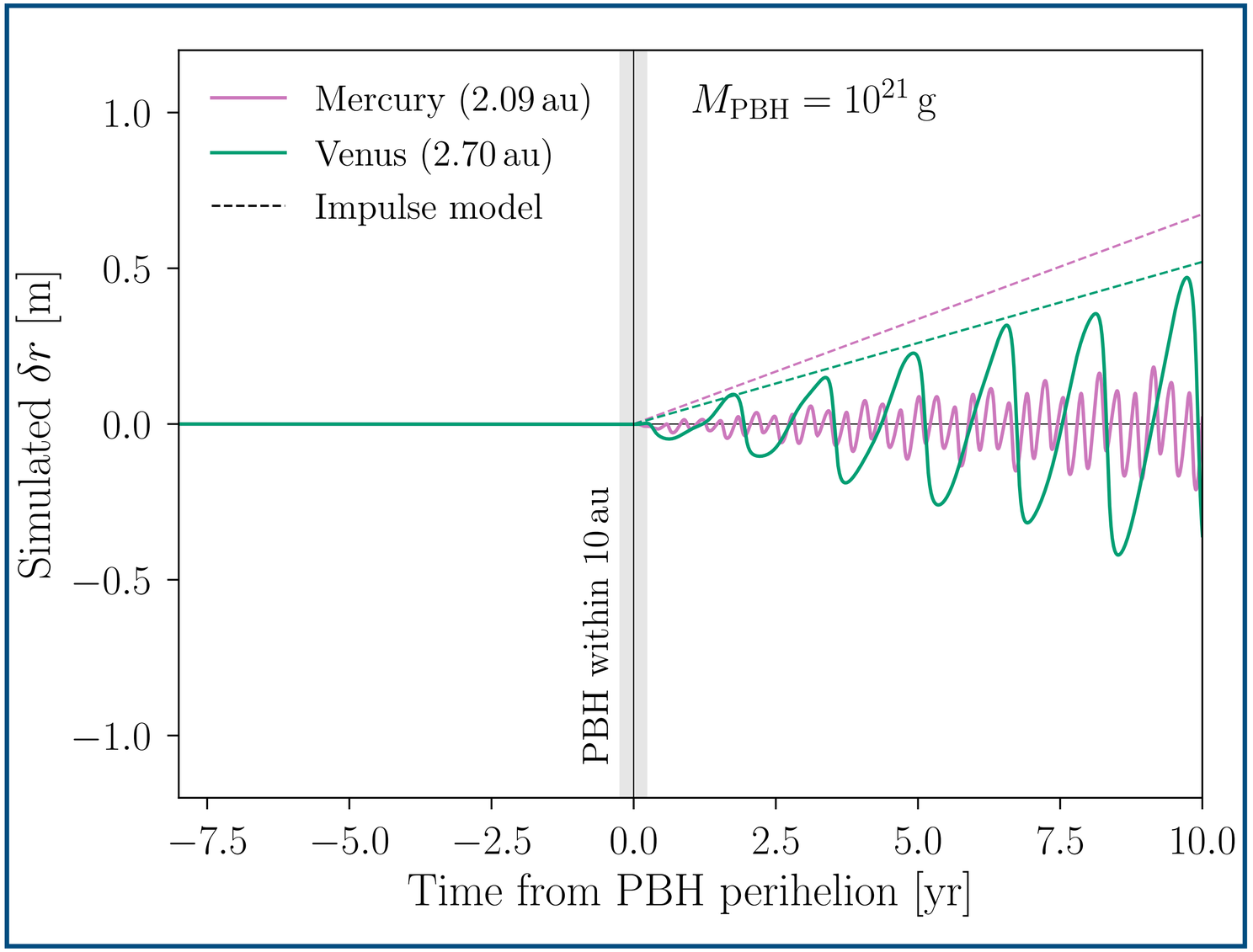

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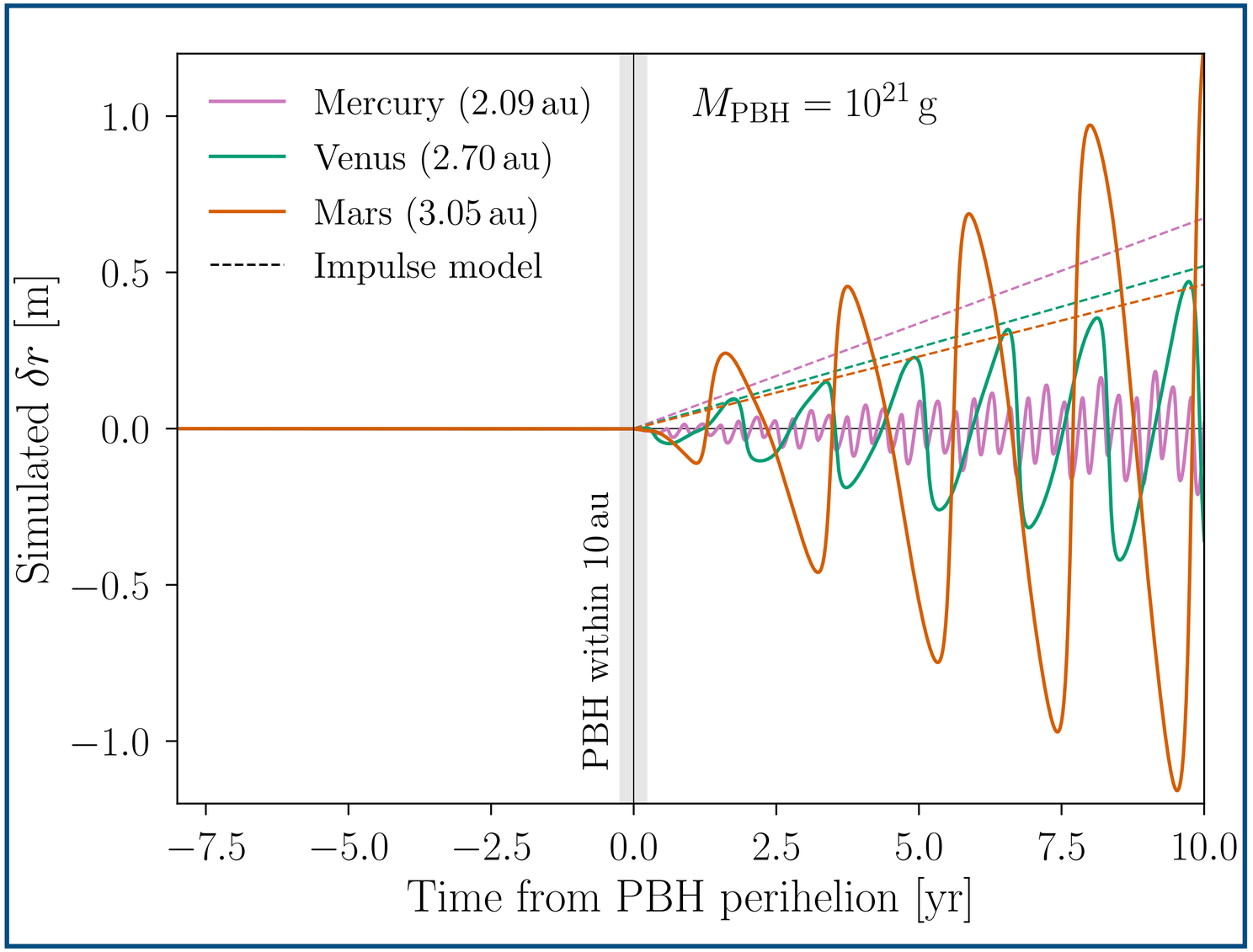
The Solar System itself as a new PBH telescope:



On a timescale of ~ 10 yr from PBH closest approach

Impulse model: linear growth of distance

Envelope tracks impulse model + many other bodies- grows linearly

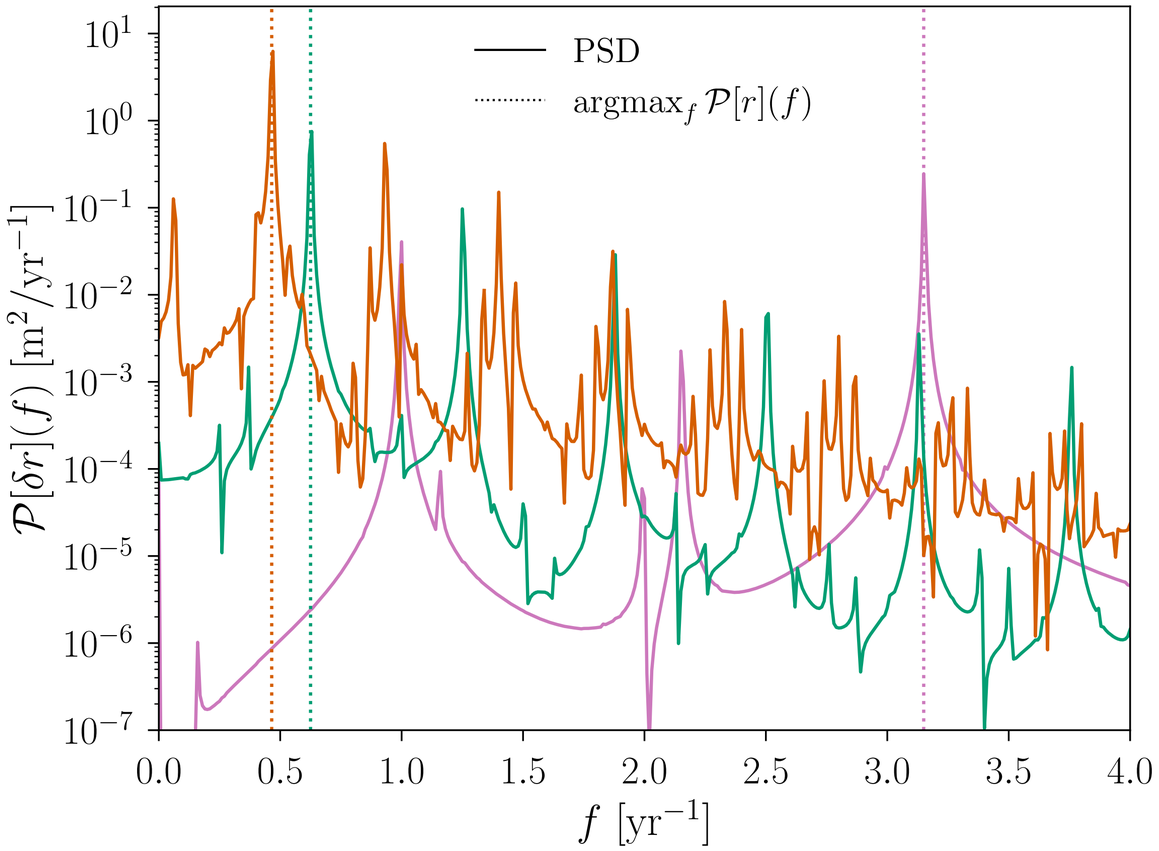
On much longer timescales (>10 yr, < instability timescale of solar sys.) slope of impulse model switches sign.

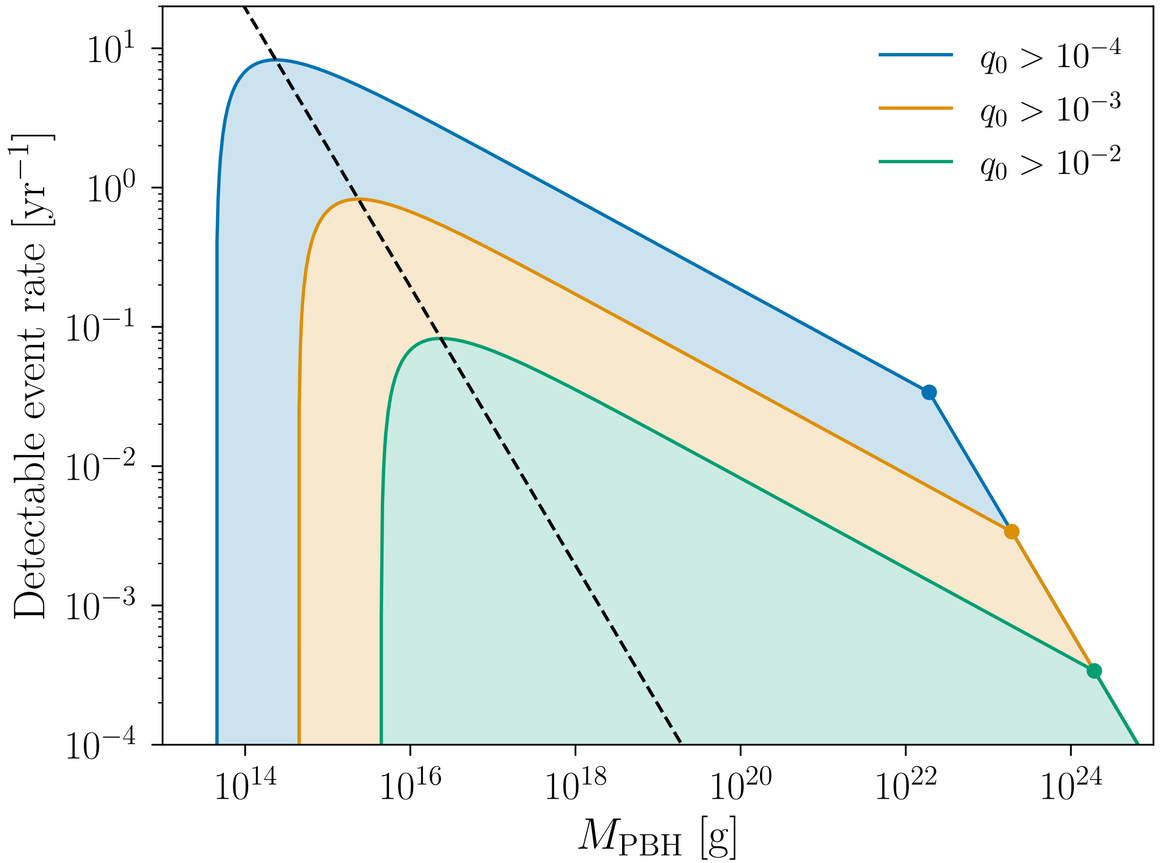
Acts as a guide: where do we look? Is δr viable observable?

Correlations amongst gravitational orbital perturbations!

Because of the distinct temporal pattern, one could exploit *matched filter analysis* to boost SNR! (LIGO achieves $q_0 \sim 10^{-4}$)

We get ~1 event at $q_0 \sim 10^{-2}$





COMPETING BACKGROUNDS

If future observations ***do*** find $\delta r_{\rm Mars} > \sigma_r$, could we ***distinguish*** a PBH from other possible sources of such perturbations?

Trajectory characteristics: $v_{\rm pbh} \sim 200$ km/s, whereas $v_{\rm sso} \sim O(10)$ km/s.

CNEOS database: 17,828 NEOs since 1900. $v_{\rm avg} = 10.29 \pm 5.17$ km/s; $v_{\rm max} = 42.92$ km/s.
The ***interstellar object*** 'Oumuamua has $v_{\rm asymptotic} = 26.4$ km/s and $v_{\rm perihelion} = 87.7$ km/s.

In addition, SSOs are ***co-planar***, whereas PBHs are likely to come from throughout a ***spherical region*** centered on the Milky Way galactic core.

credit: D.I.Kaiser

COMPETING BACKGROUNDS

And….

(Lack of a) visual component: NASA, ESA, and other agencies continually monitor for small NEOs.

The interstellar object 'Oumuamua has $M = 10^{12}$ g, with dimensions ~ 100 m x 30 m x 10 m, and it was ***nonetheless detected*** by multiple Earthbound telescopes (first identified at $r = 0.22$ AU). Of course, abense of evidence is not evidence of absence.... but it could lend additional support.

credit: D.I.Kaiser

To do:
- Lensing?
- Upcoming LNPOP collaboration
- Triggering of event capture/monitoring?