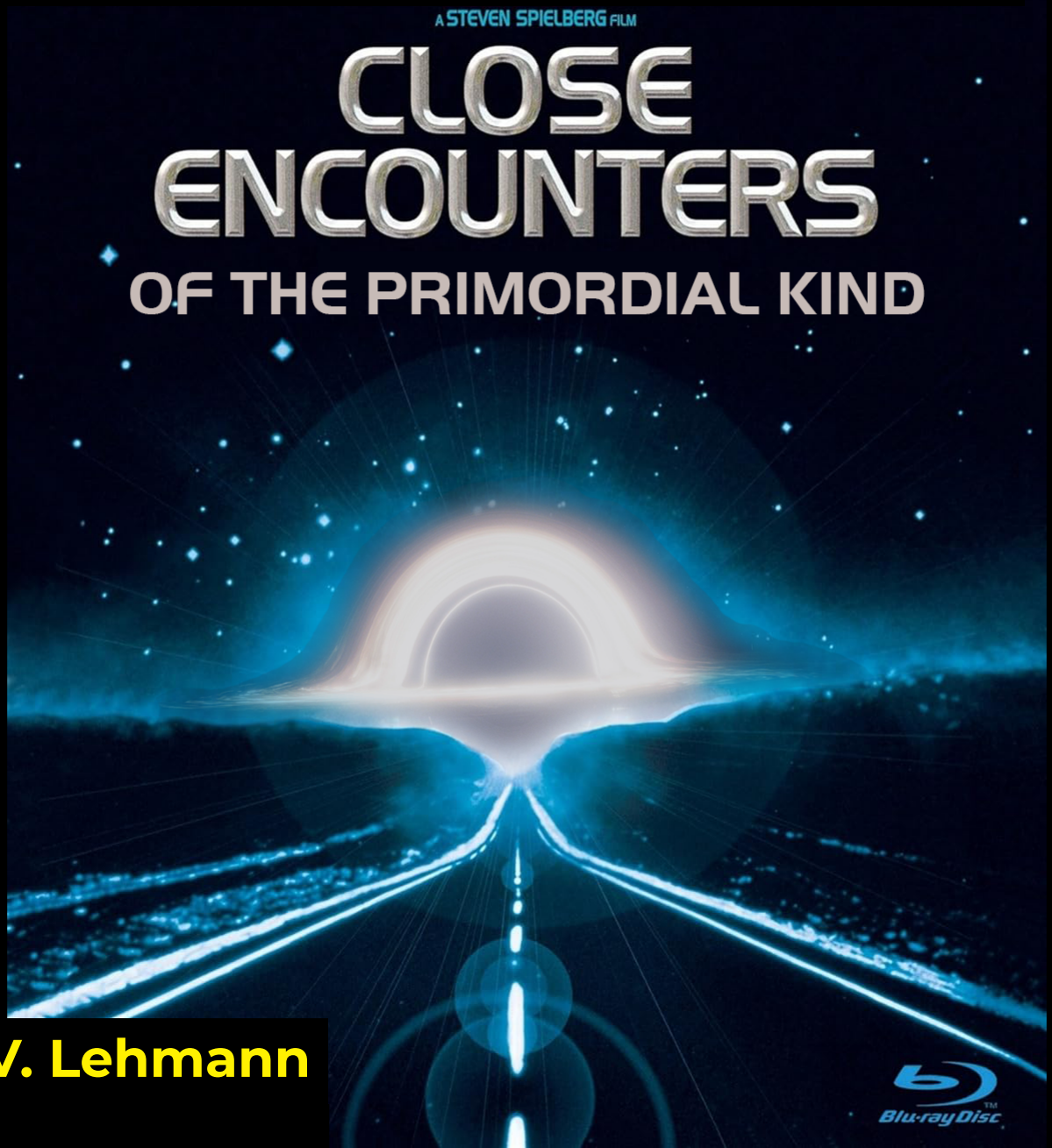
Massachusetts
Institute of
Technology

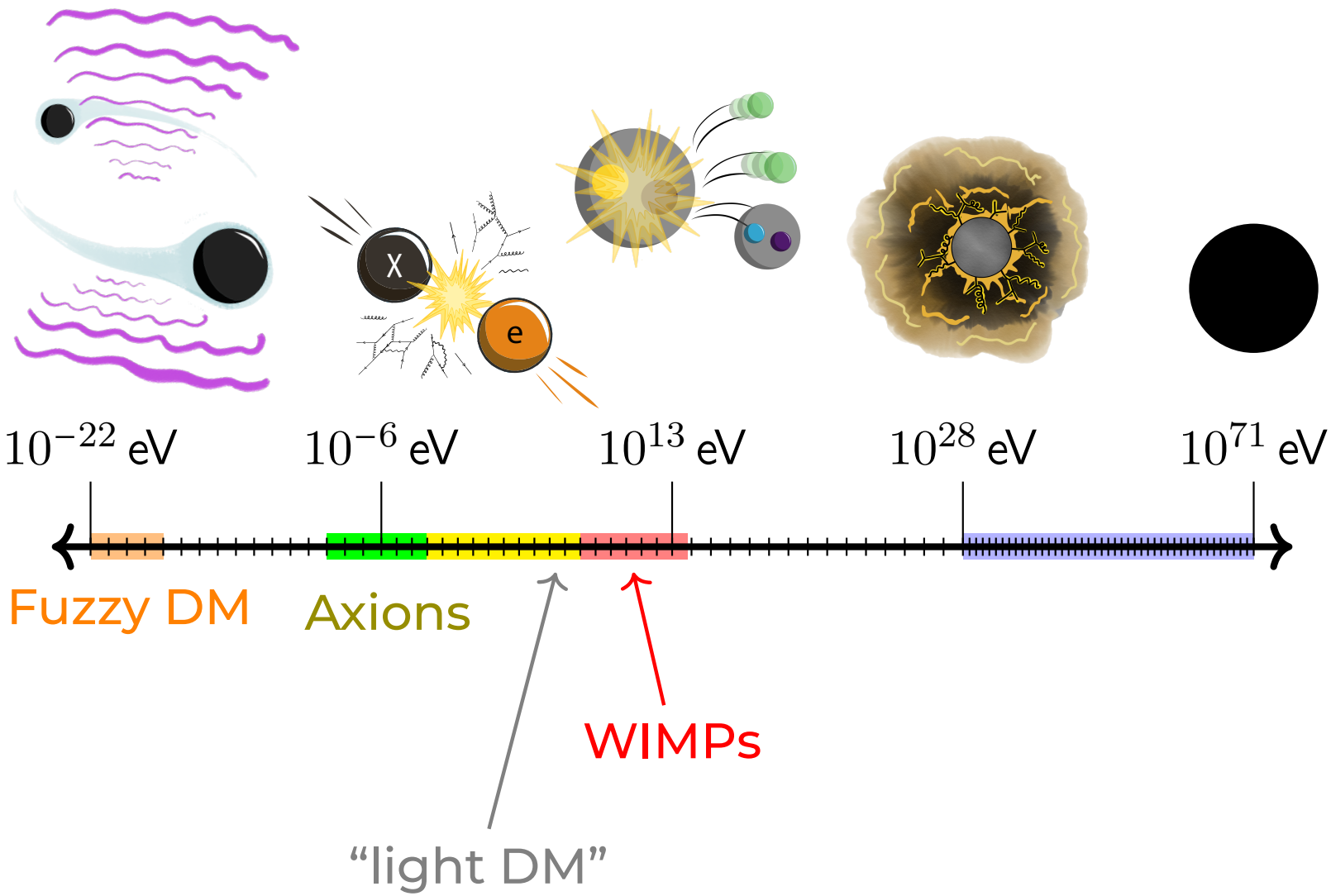
+Tung X. Tran
+Sarah R. Geller
+David I. Kaiser



2312.17217

Benjamin V. Lehmann

The dark matter parameter space



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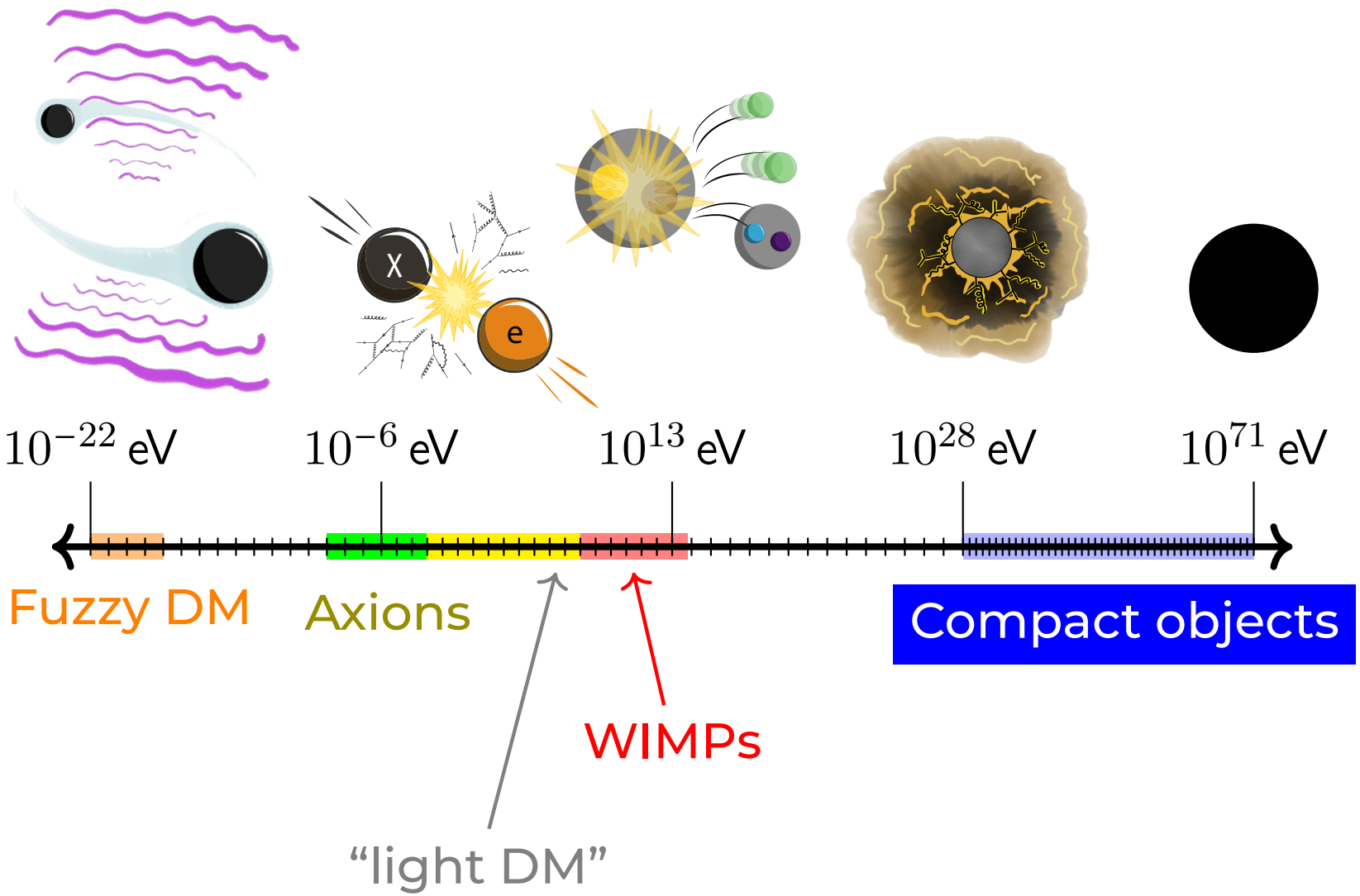
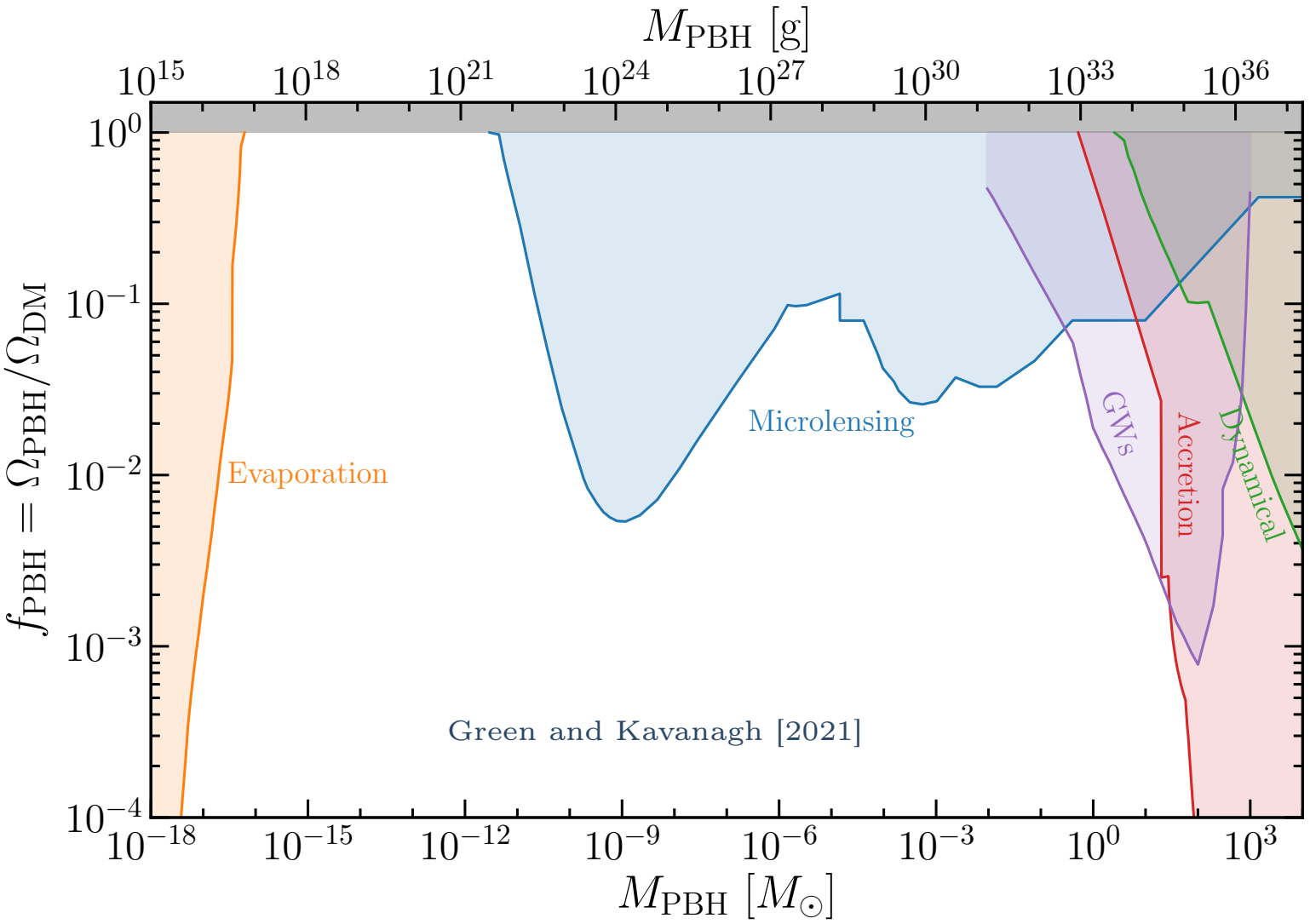


Primordial black holes as DM



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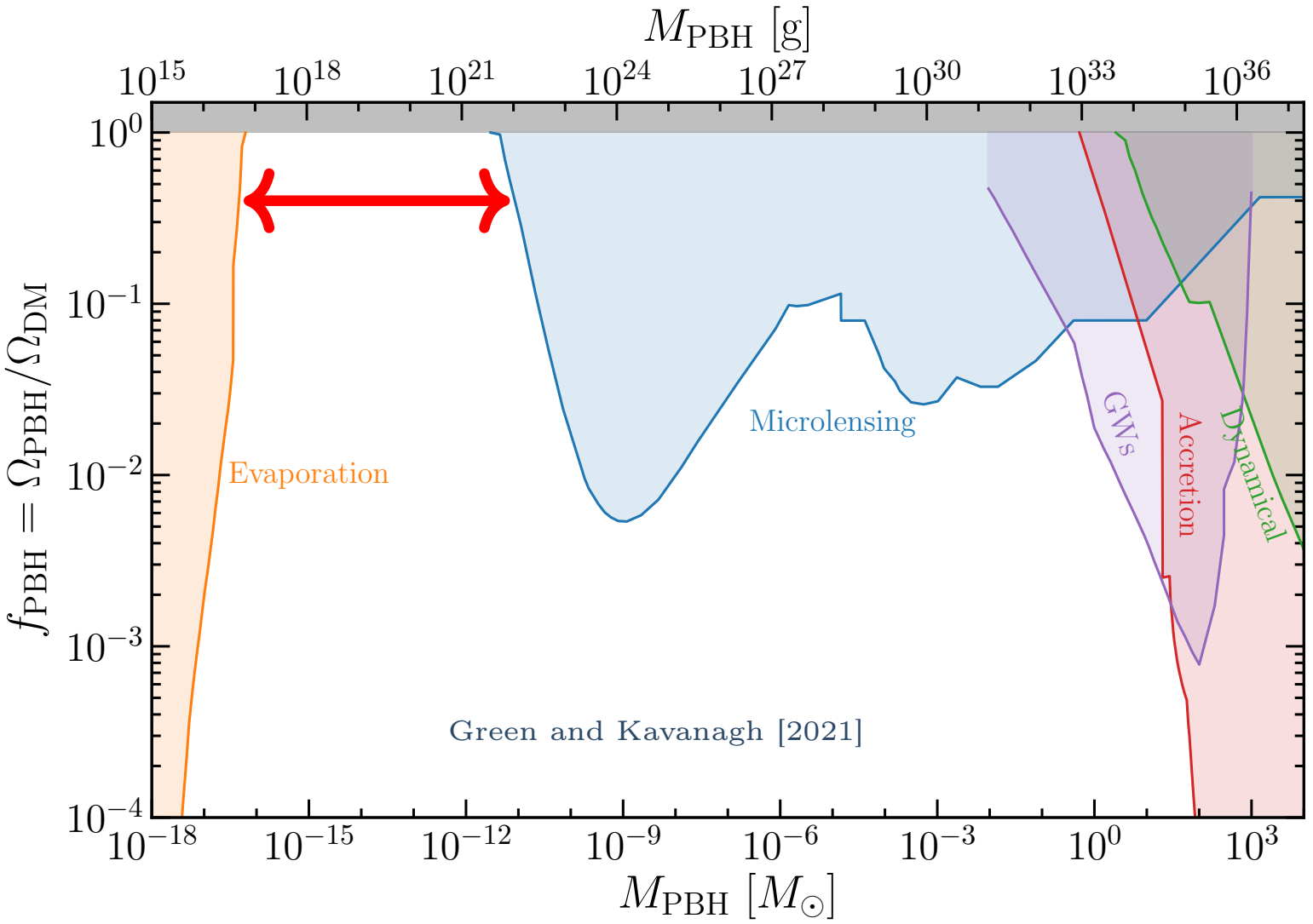
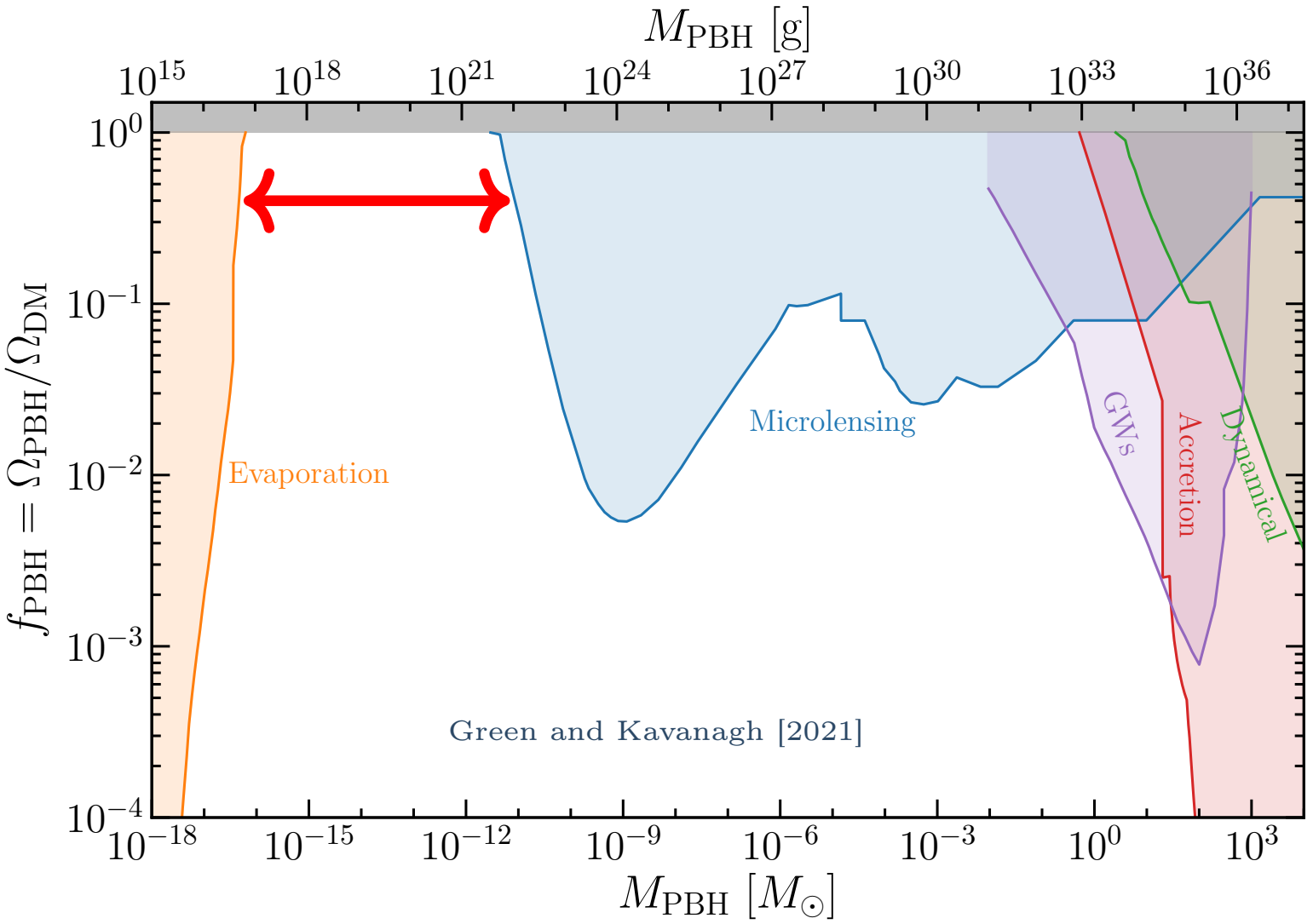
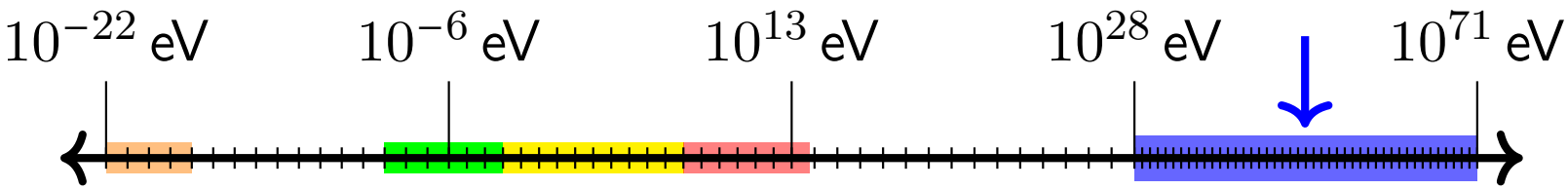


Primordial black holes as DM

only in “asteroid mass” range



This talk in one slide



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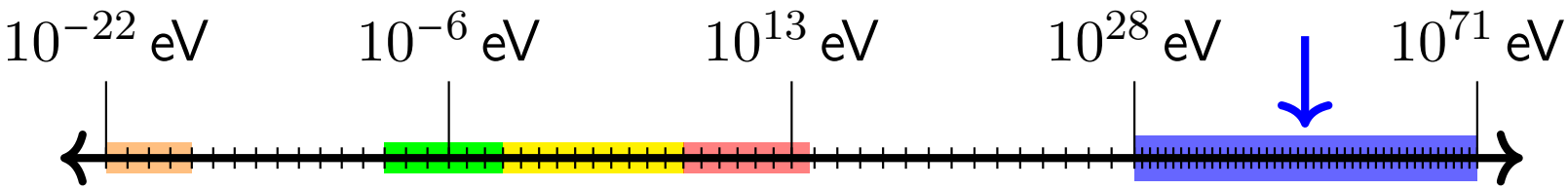

1. The Solar System can detect PBH encounters

Precision measurements are sensitive to small deflections

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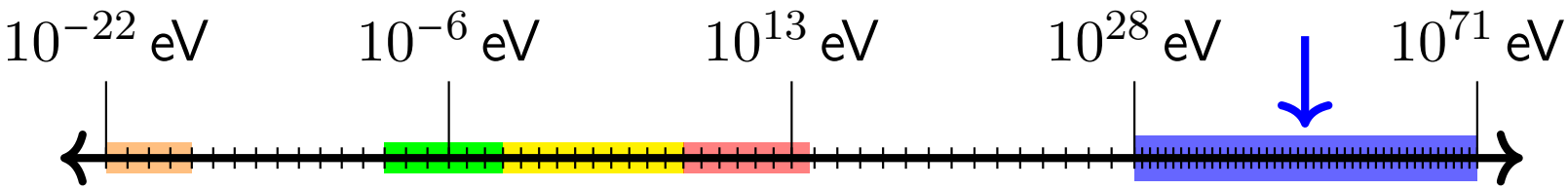

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2. Possible sensitivity to asteroid-mass range

Simple proof-of-principle calculation on a laptop

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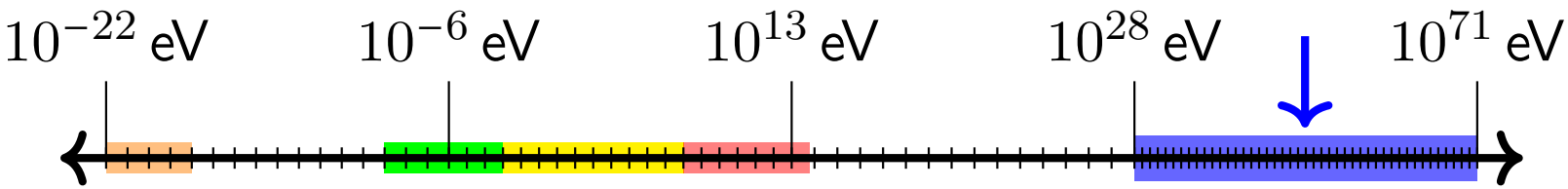

1. The Solar System can detect PBH encounters

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Simple proof-of-principle calculation on a laptop

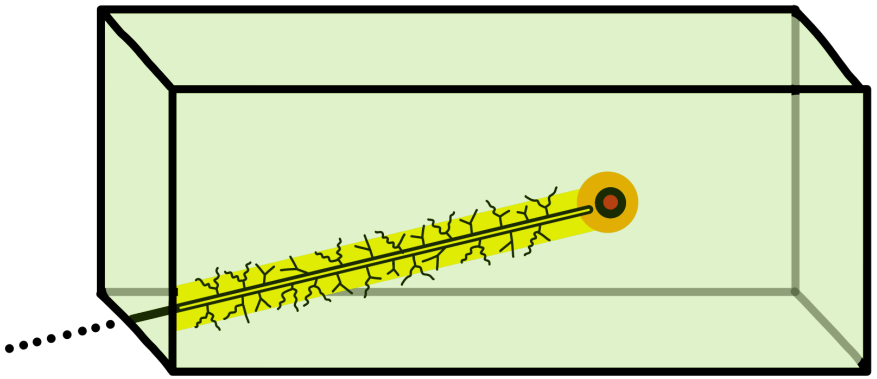
3. Precision analysis starting now

Collaboration with Paris Observatory simulation group

Black hole direct detection

Black hole direct detection

Search for individual scatters with a target system



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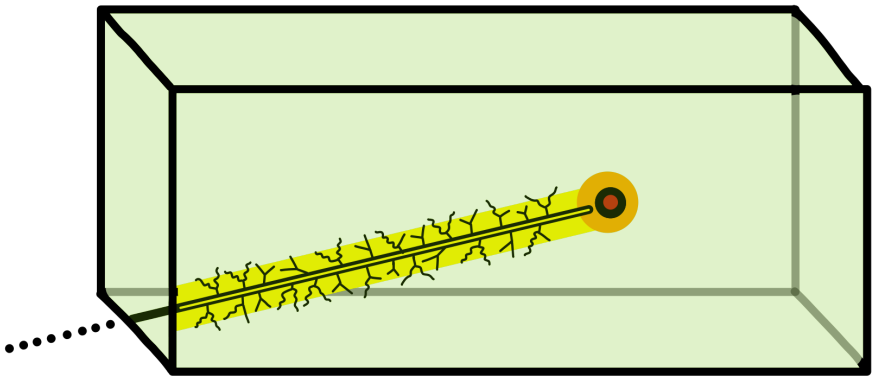

Flux-limited

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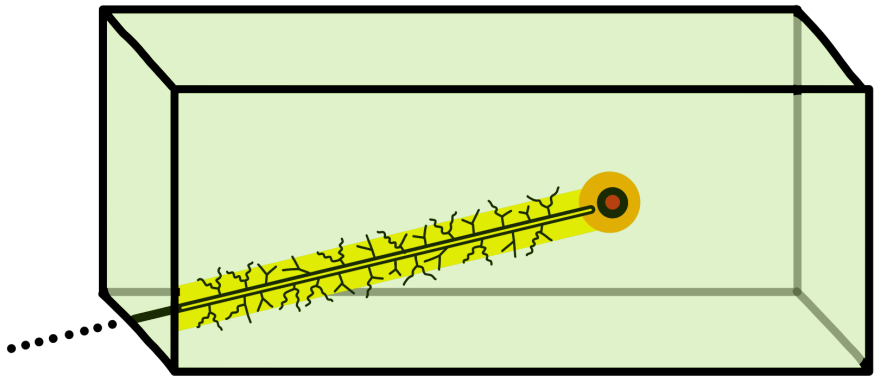

Flux-limited

$M_{\mathrm{PBH}} \simeq 10^{-5}\,\mathrm{g}$

Planck-scale PBHs

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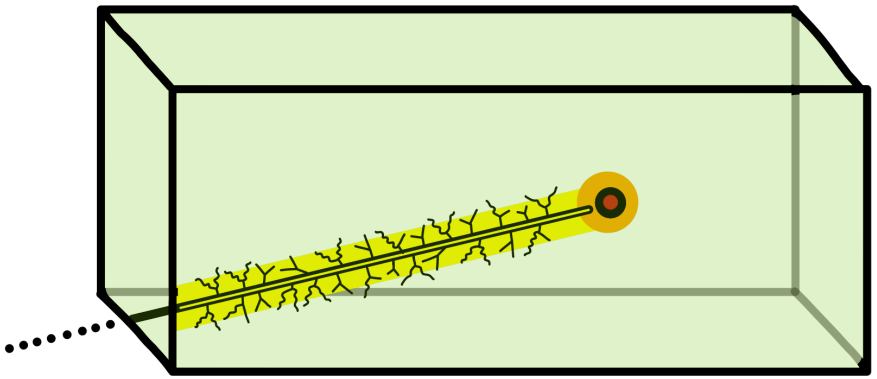

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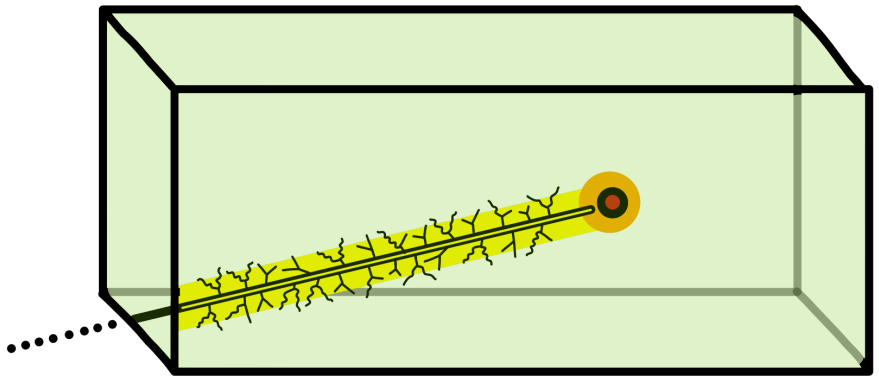

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Laboratory-scale
(e.g. WINDCHIME)

Black hole direct detection

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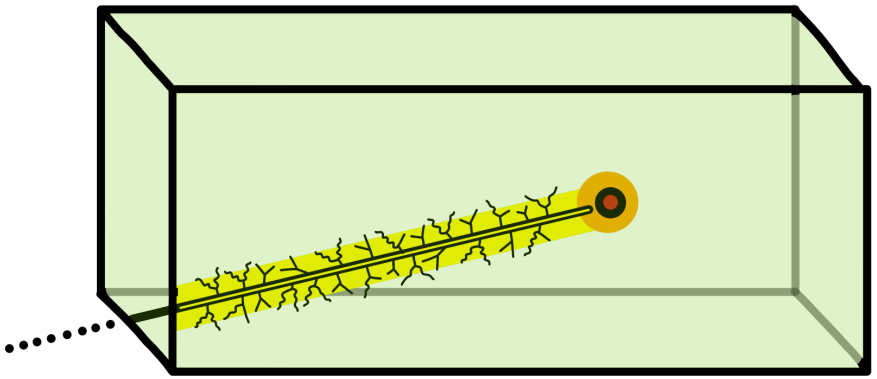

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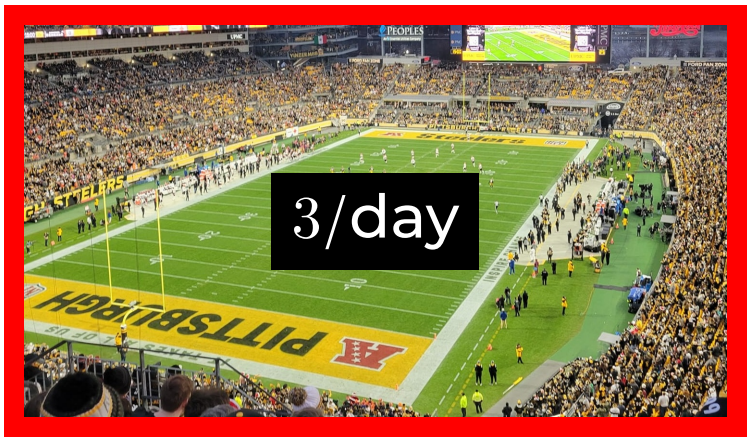

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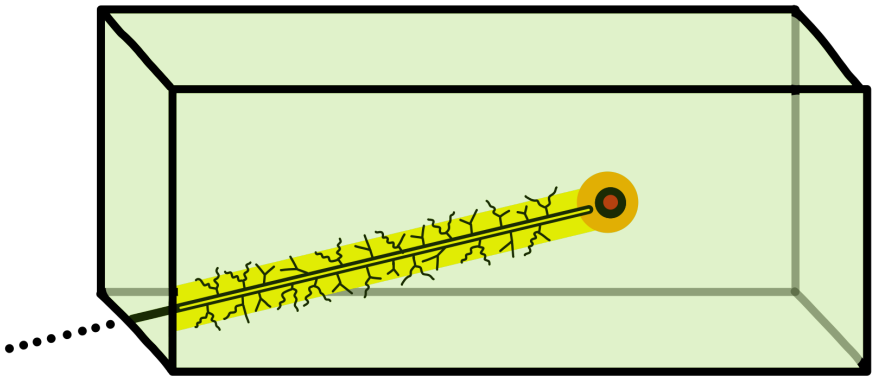

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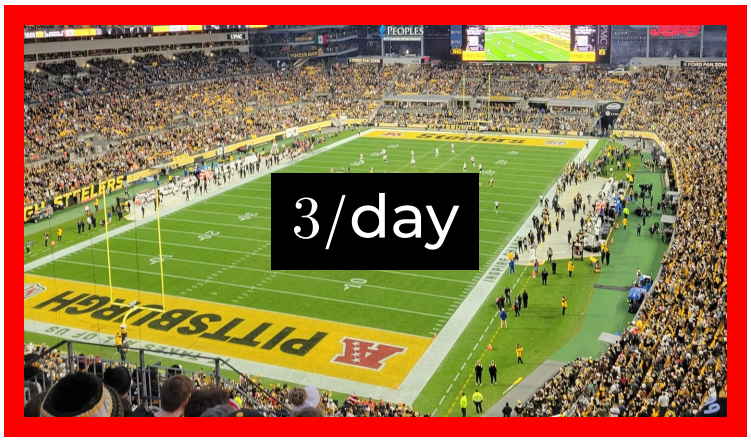

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Asteroid-mass PBHs

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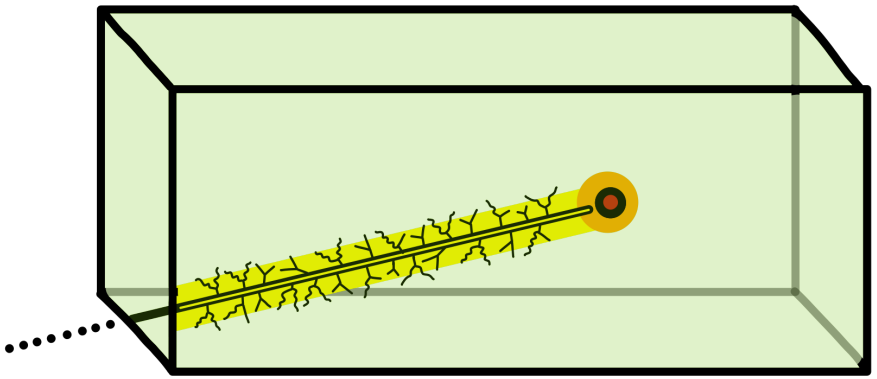

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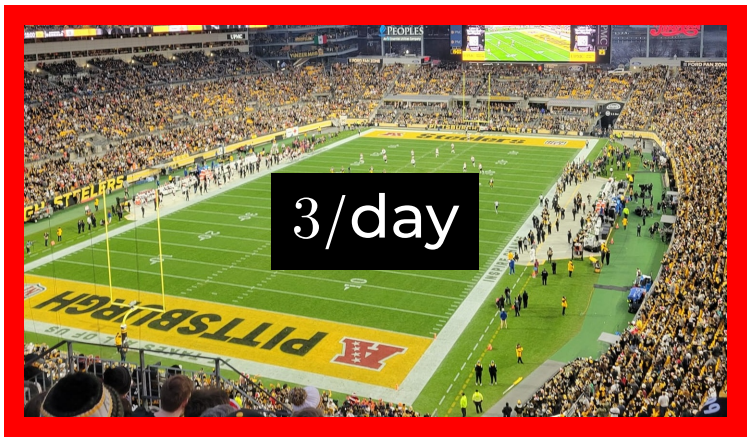

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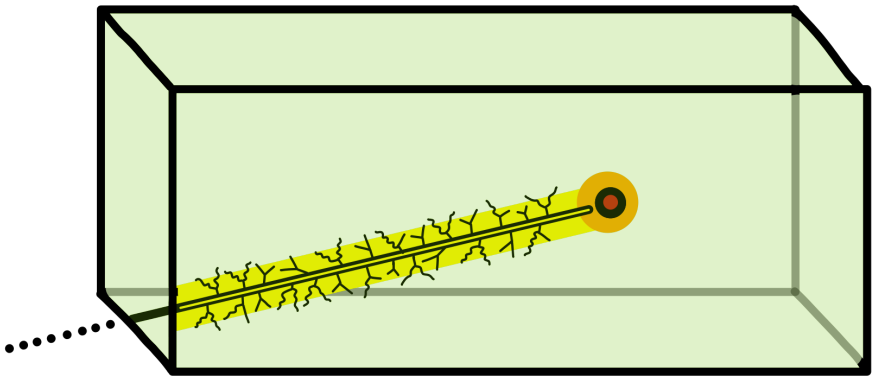

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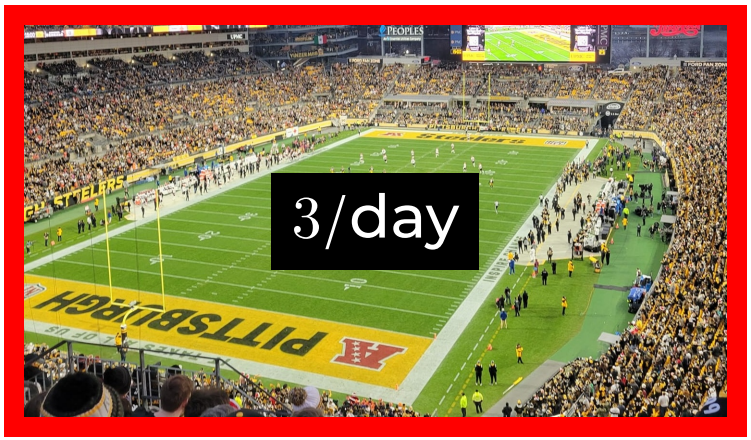

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Asteroid-mass PBHs

Our hero: Ephemerides

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Could ephemerides record a PBH encounter?

Precision measurements in the Solar System

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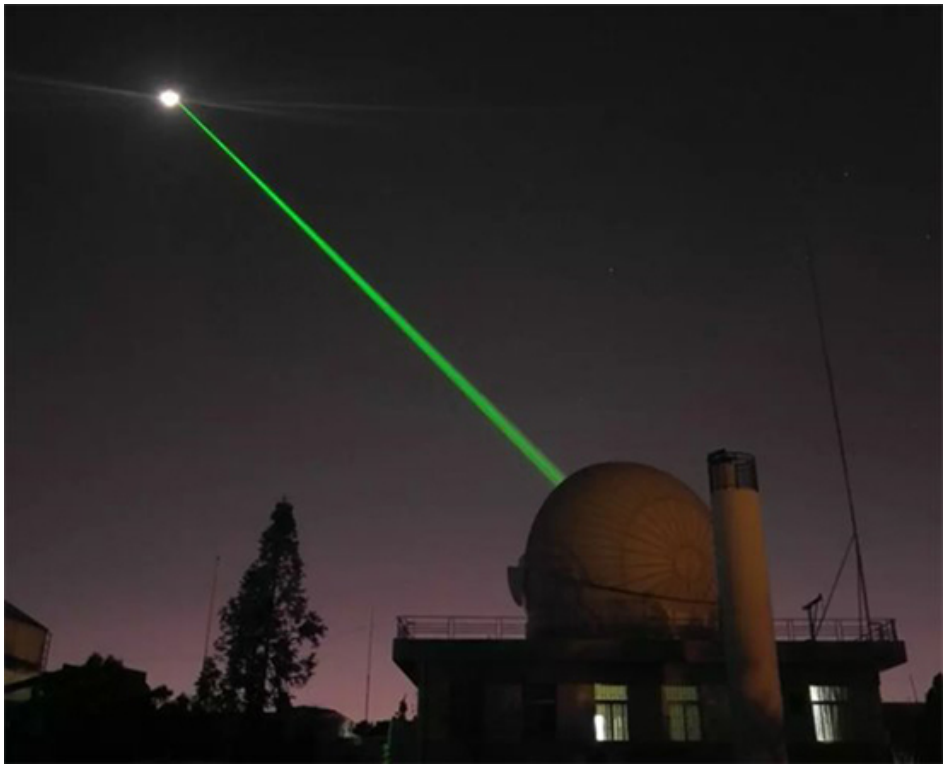

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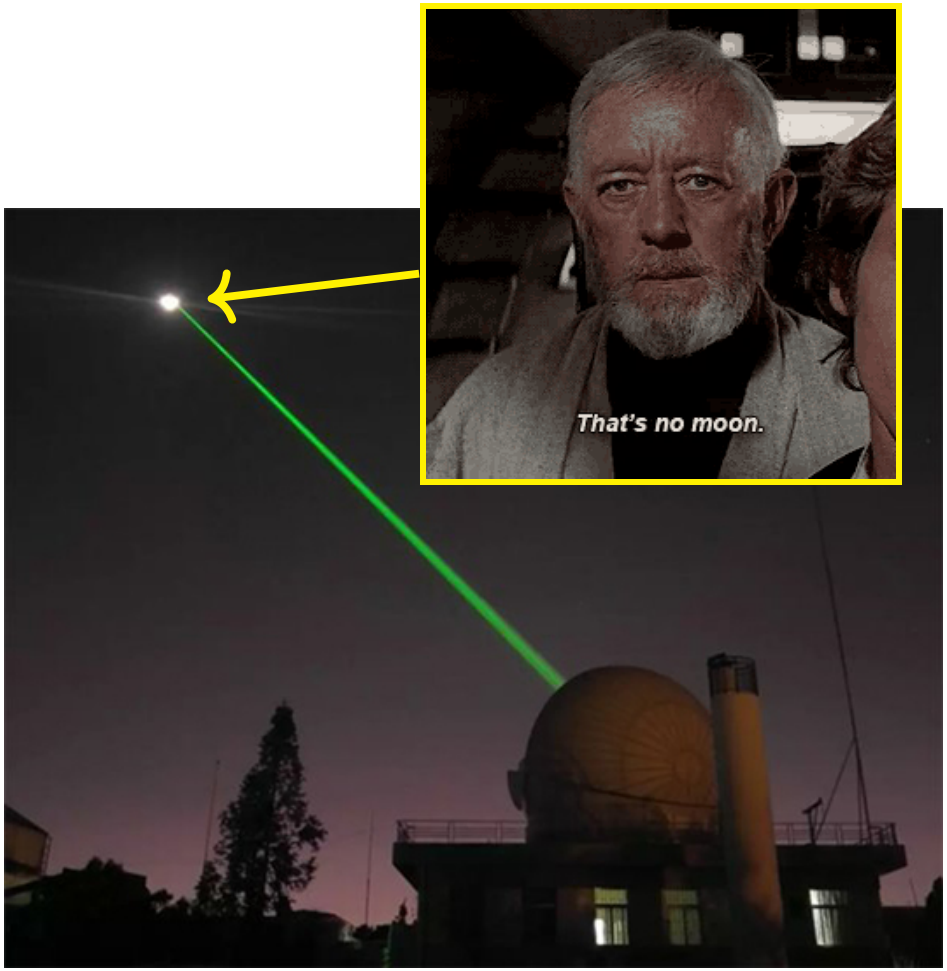

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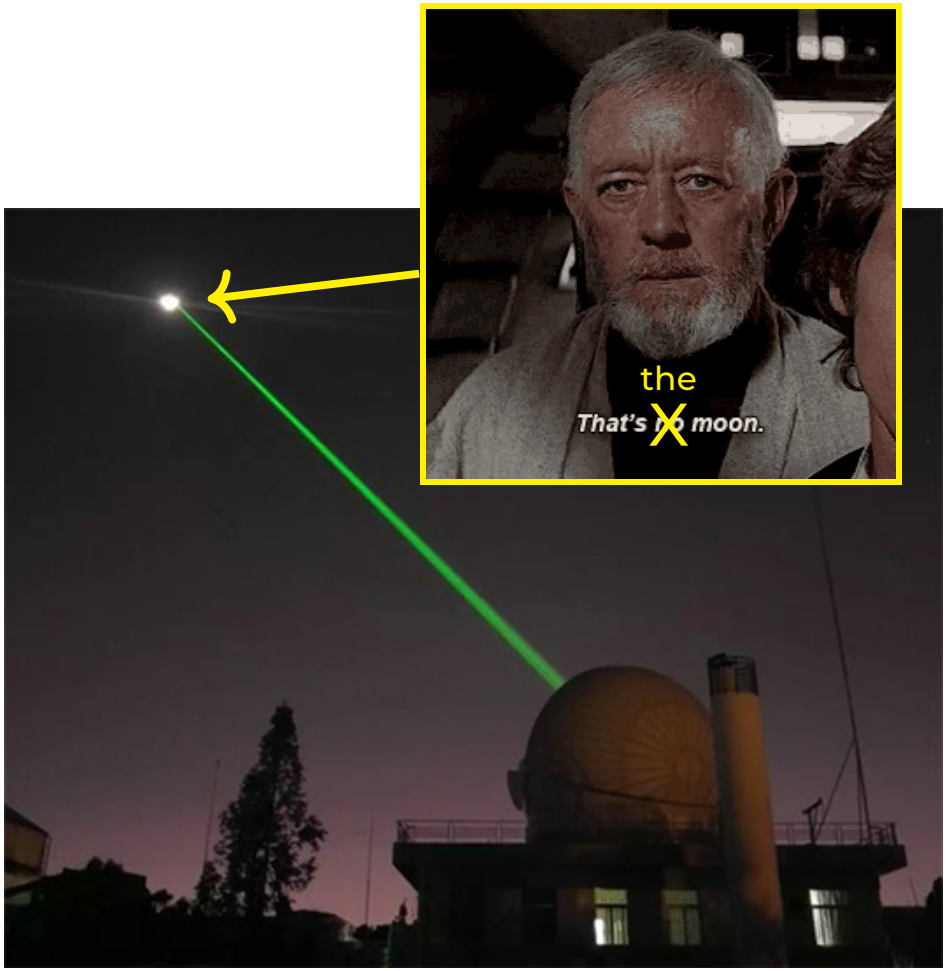

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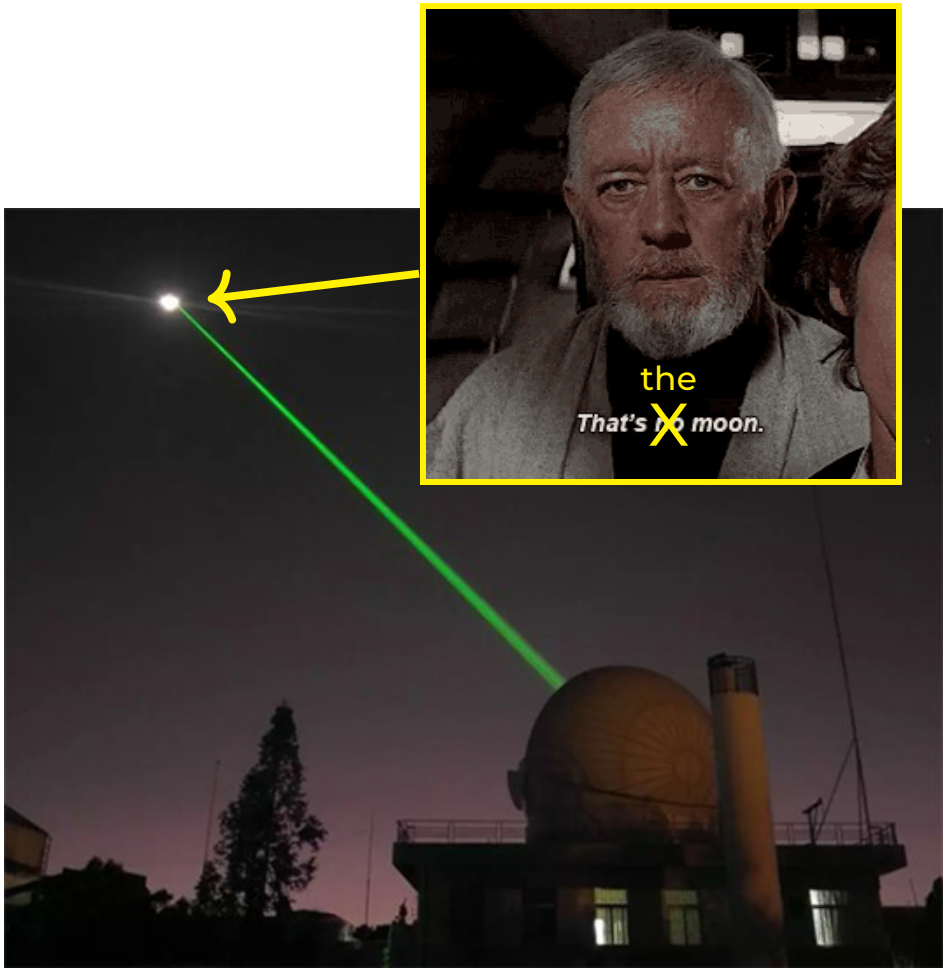

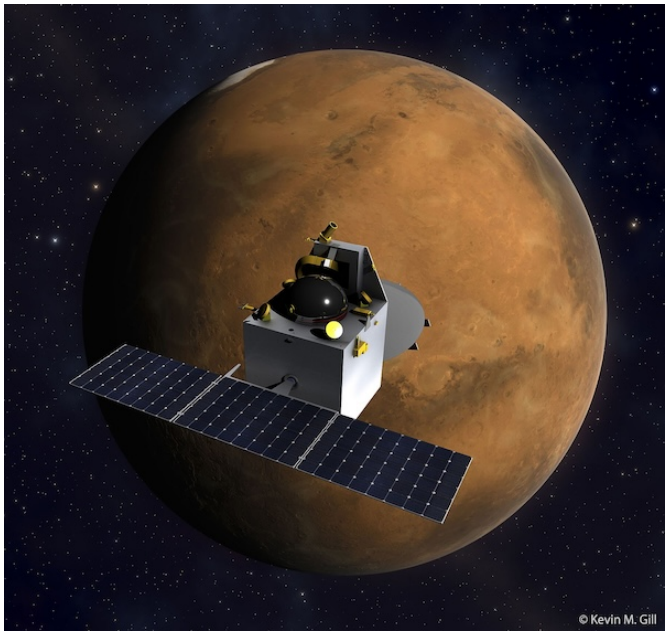

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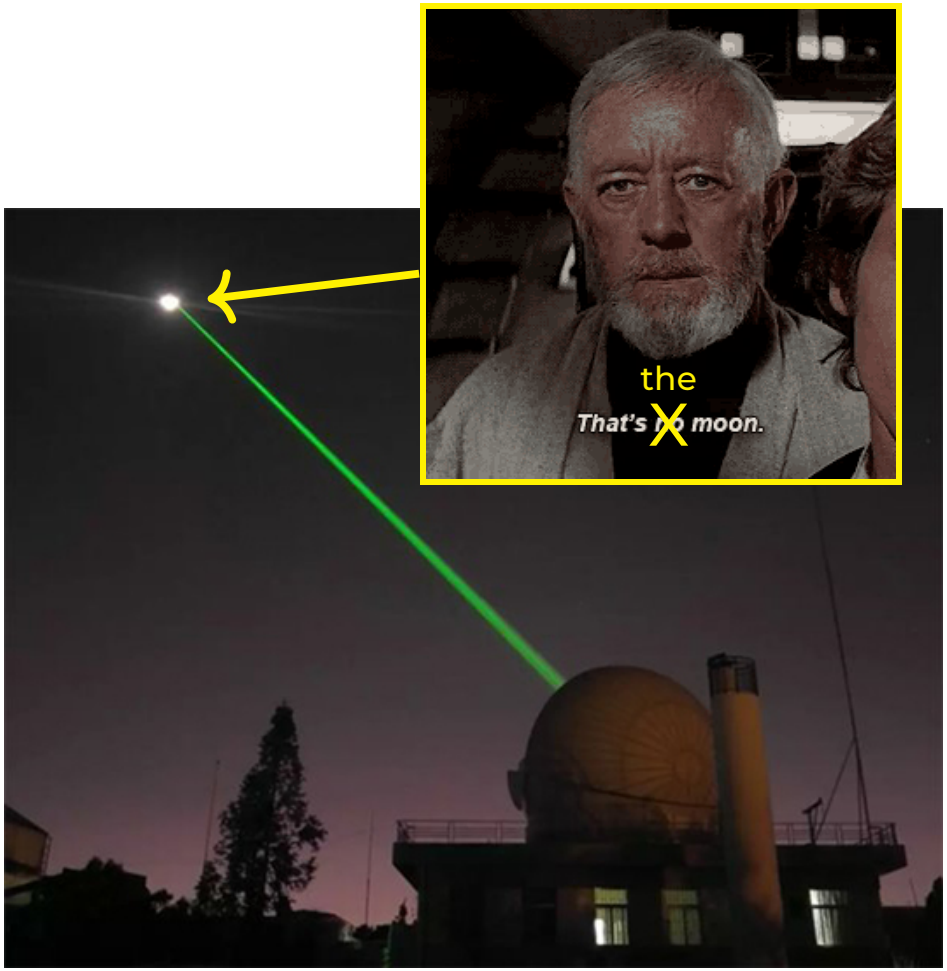

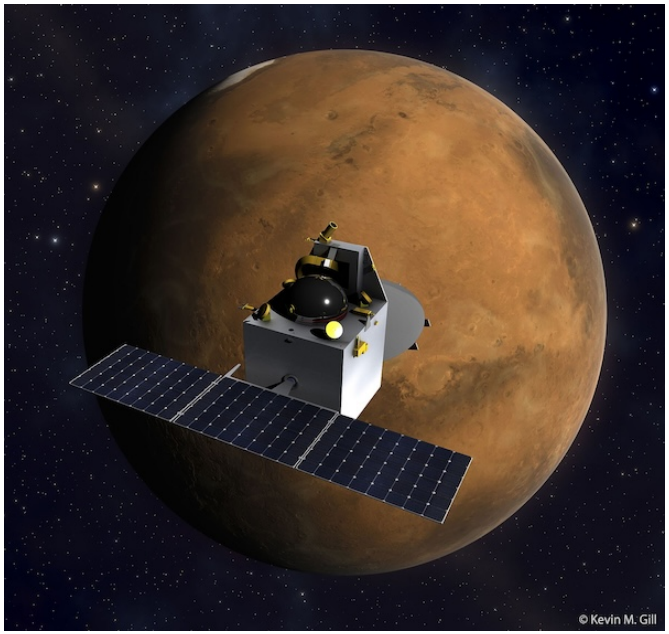

Mars orbiters have had $\mathcal{O}(10\,\mathrm{cm})$ precision for $\mathcal{O}(20\,\mathrm{yr})$!

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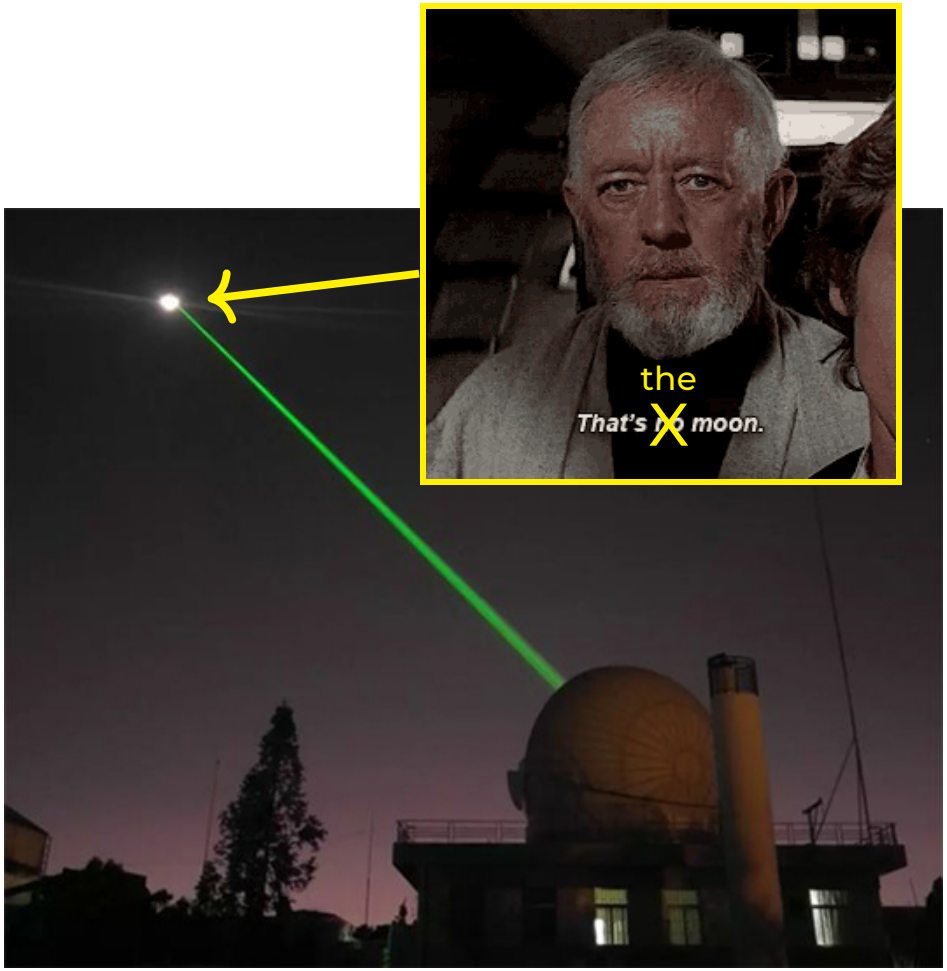
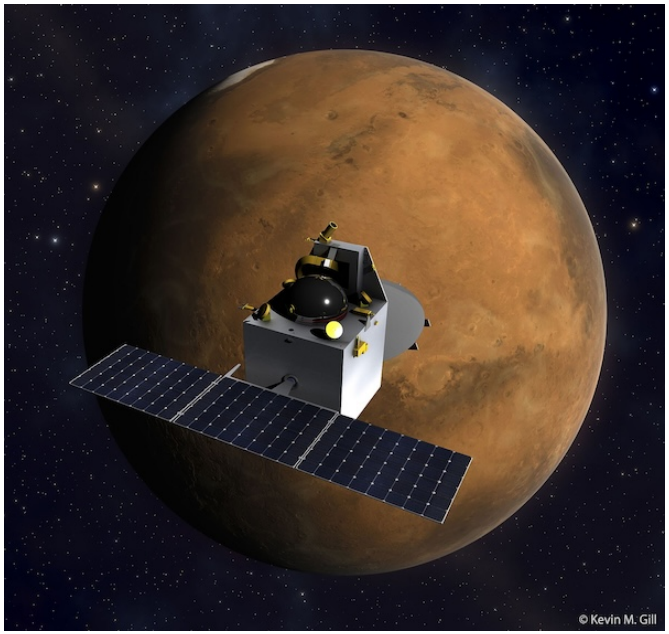
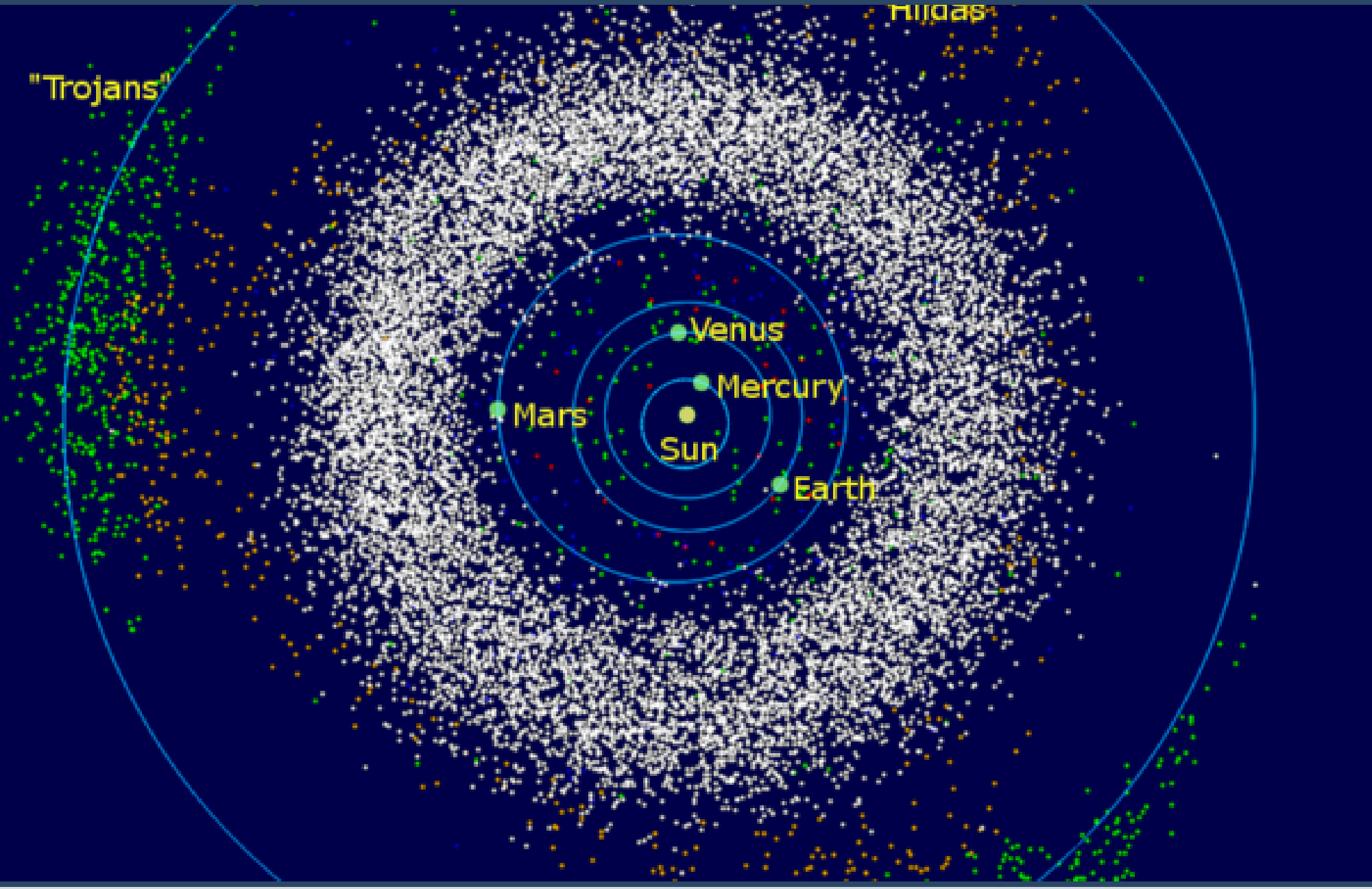




Mars orbiters have had $\mathcal{O}(10\,\mathrm{cm})$ precision for $\mathcal{O}(20\,\mathrm{yr})$!
Let's model the impact of a PBH flyby on r(Earth–Mars).

Precision Solar System modeling



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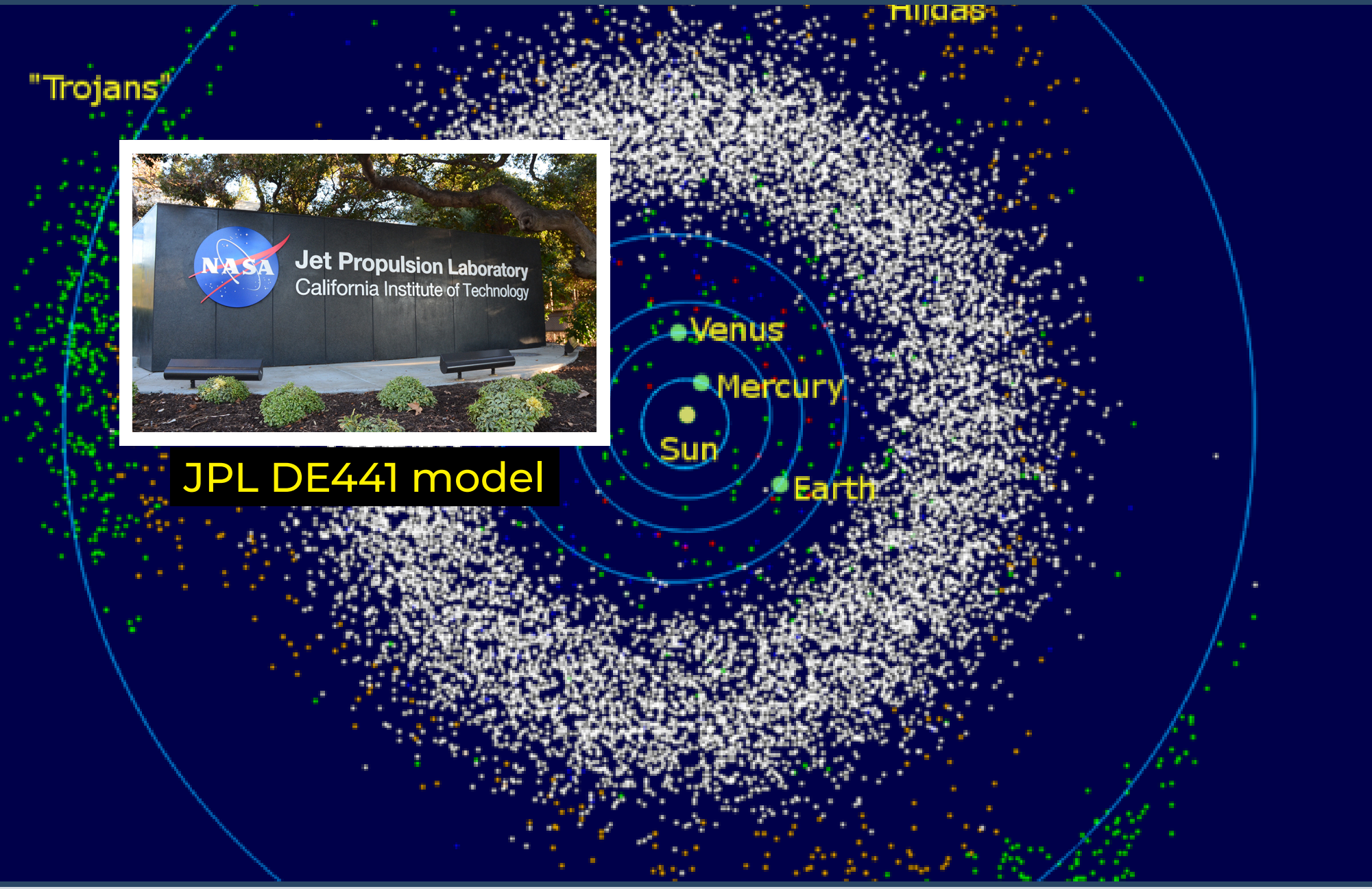

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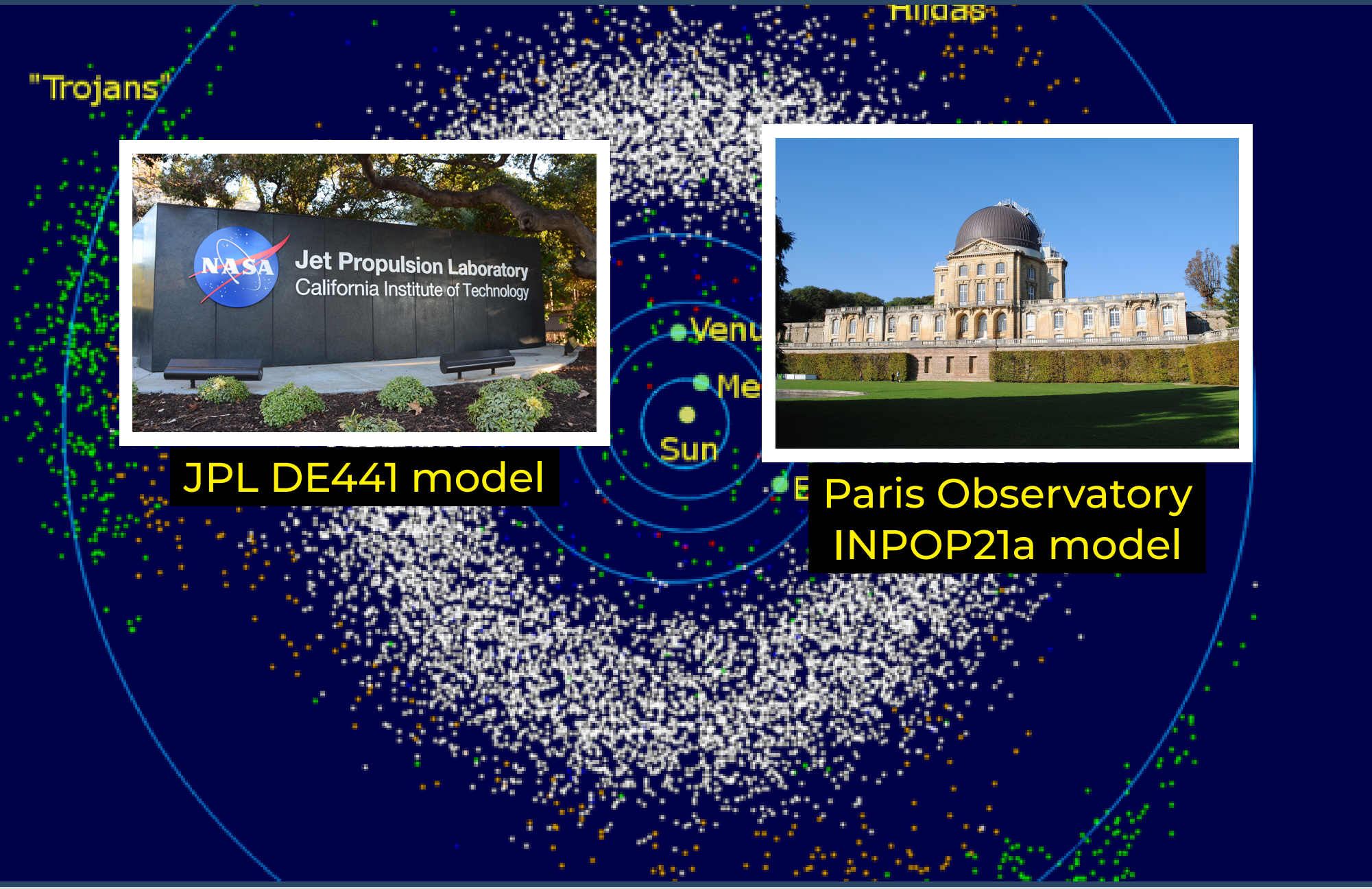
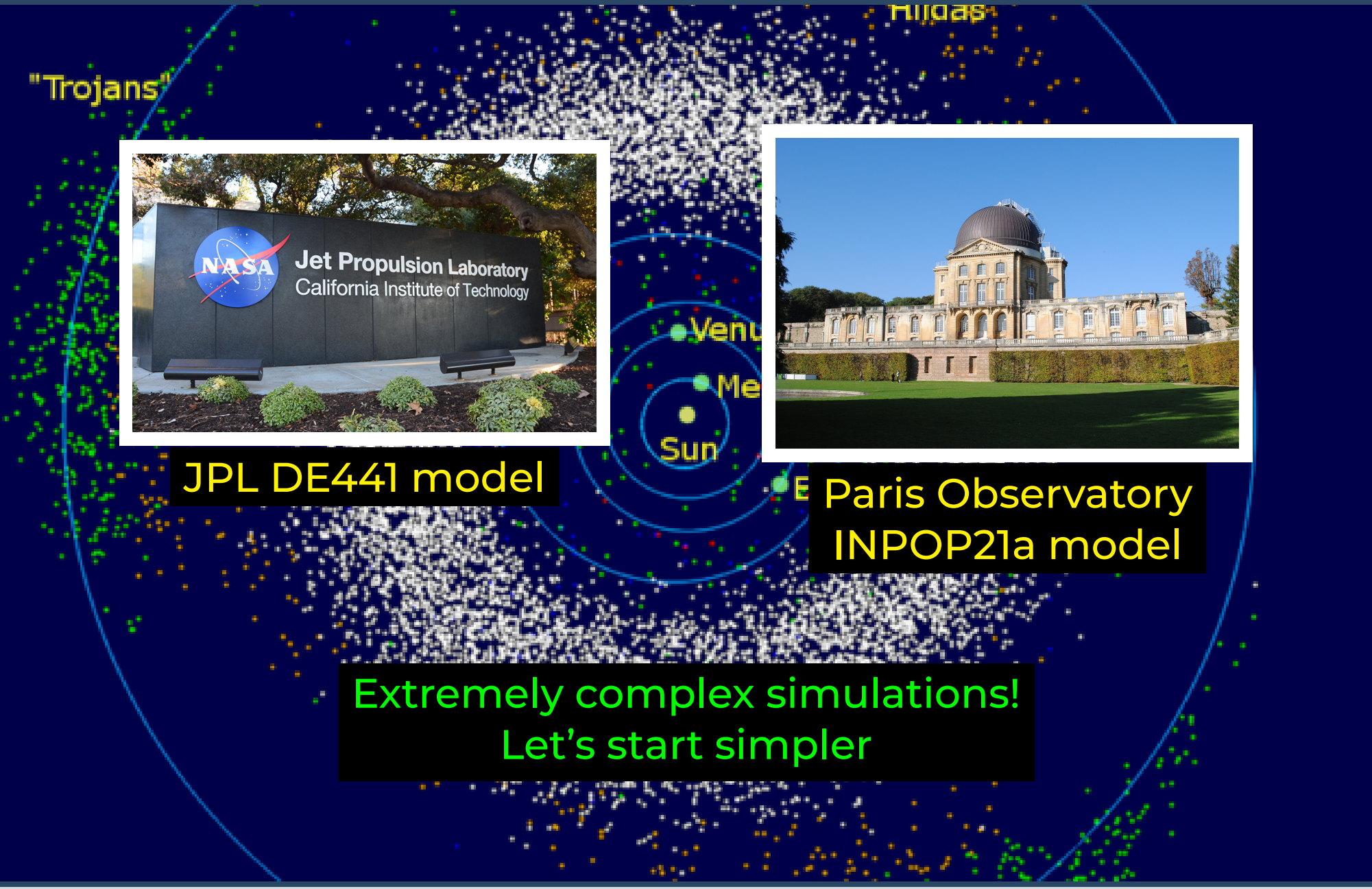


JPL DE441 model

Paris Observatory
INPOP21a model

Precision Solar System modeling



JPL DE441 model

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Extremely complex simulations!
Let's start simpler

Quantitative approach

Precise Solar System modeling is a specialized task

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Let’s estimate **differences** induced by a PBH flyby

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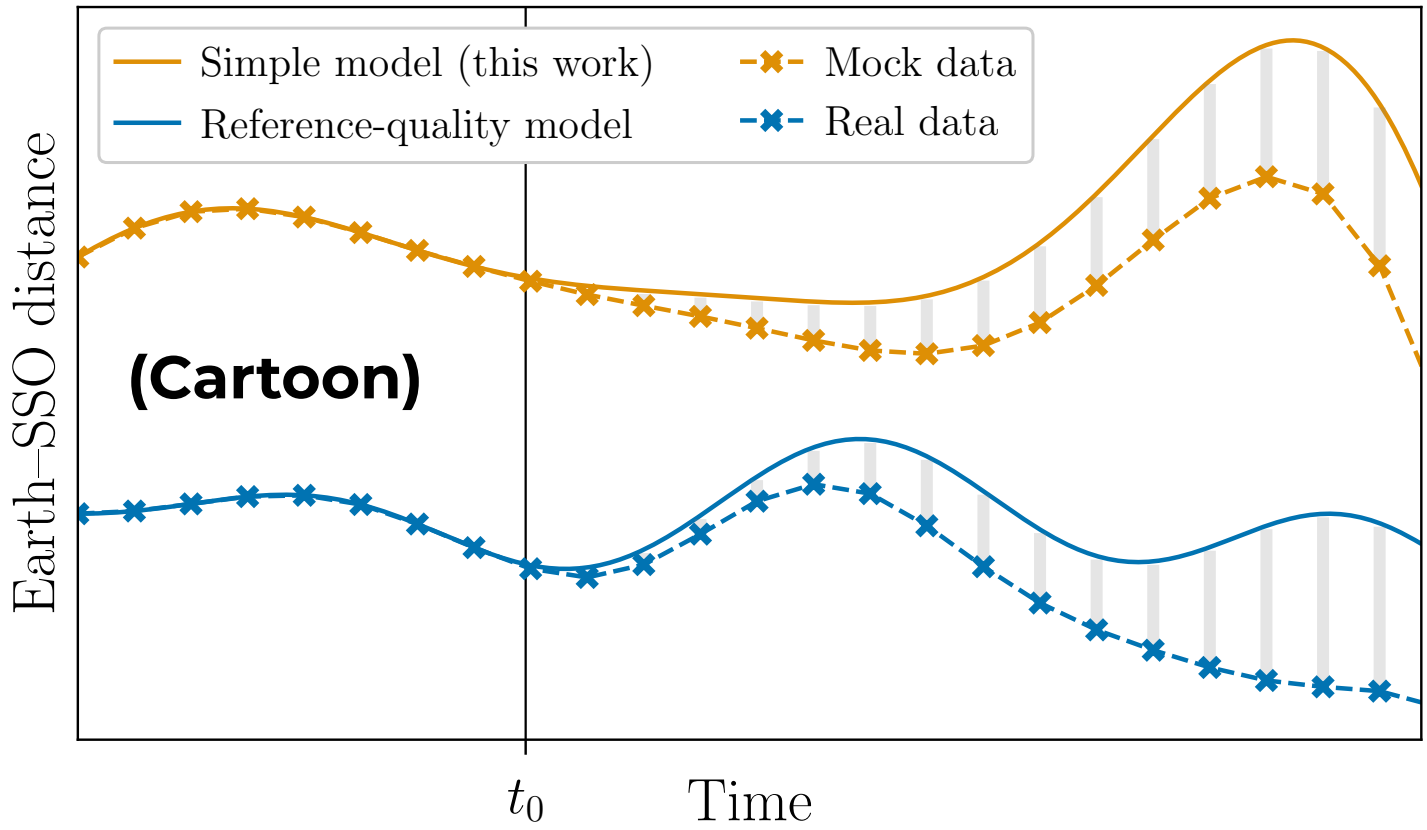

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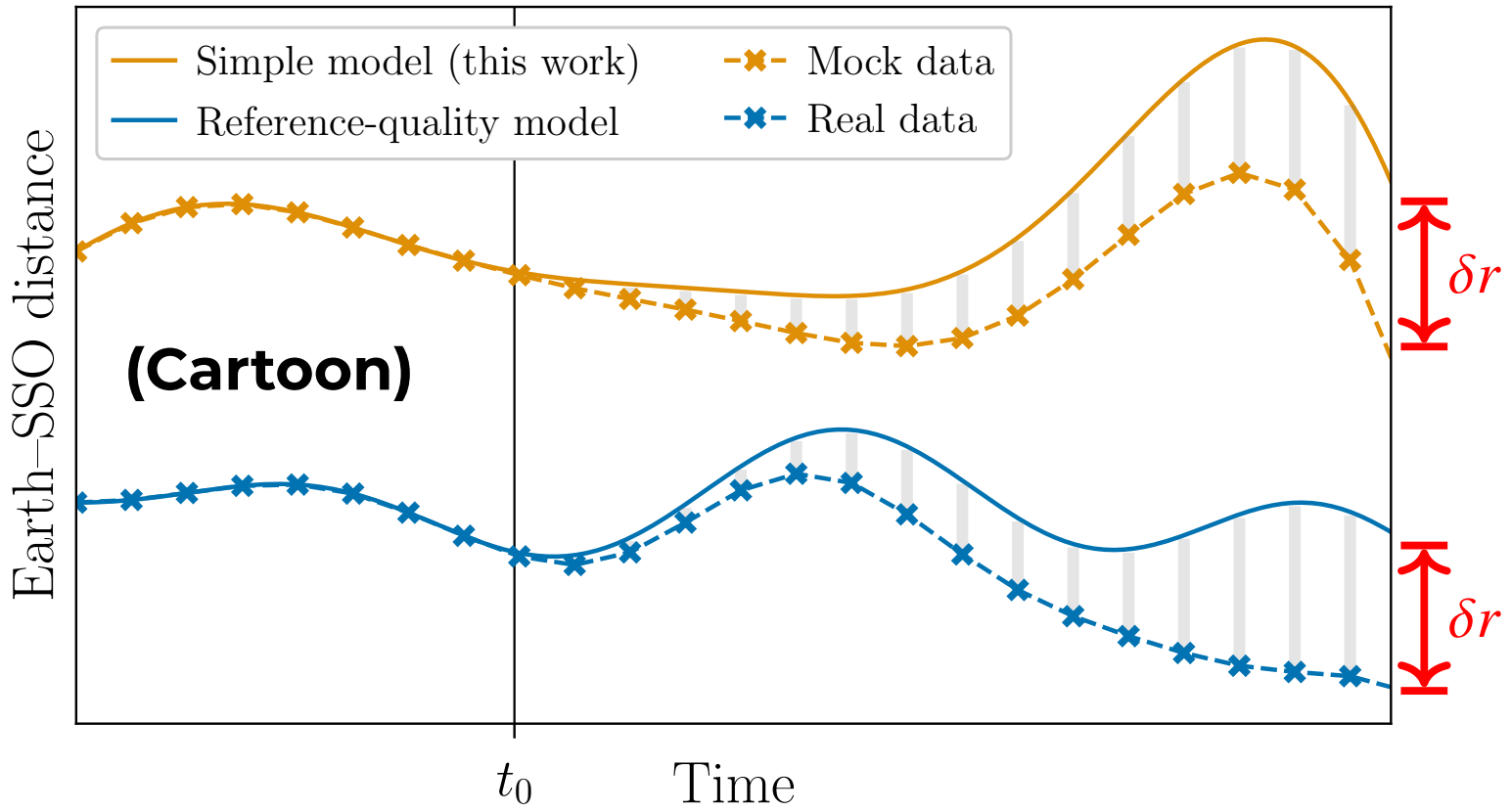

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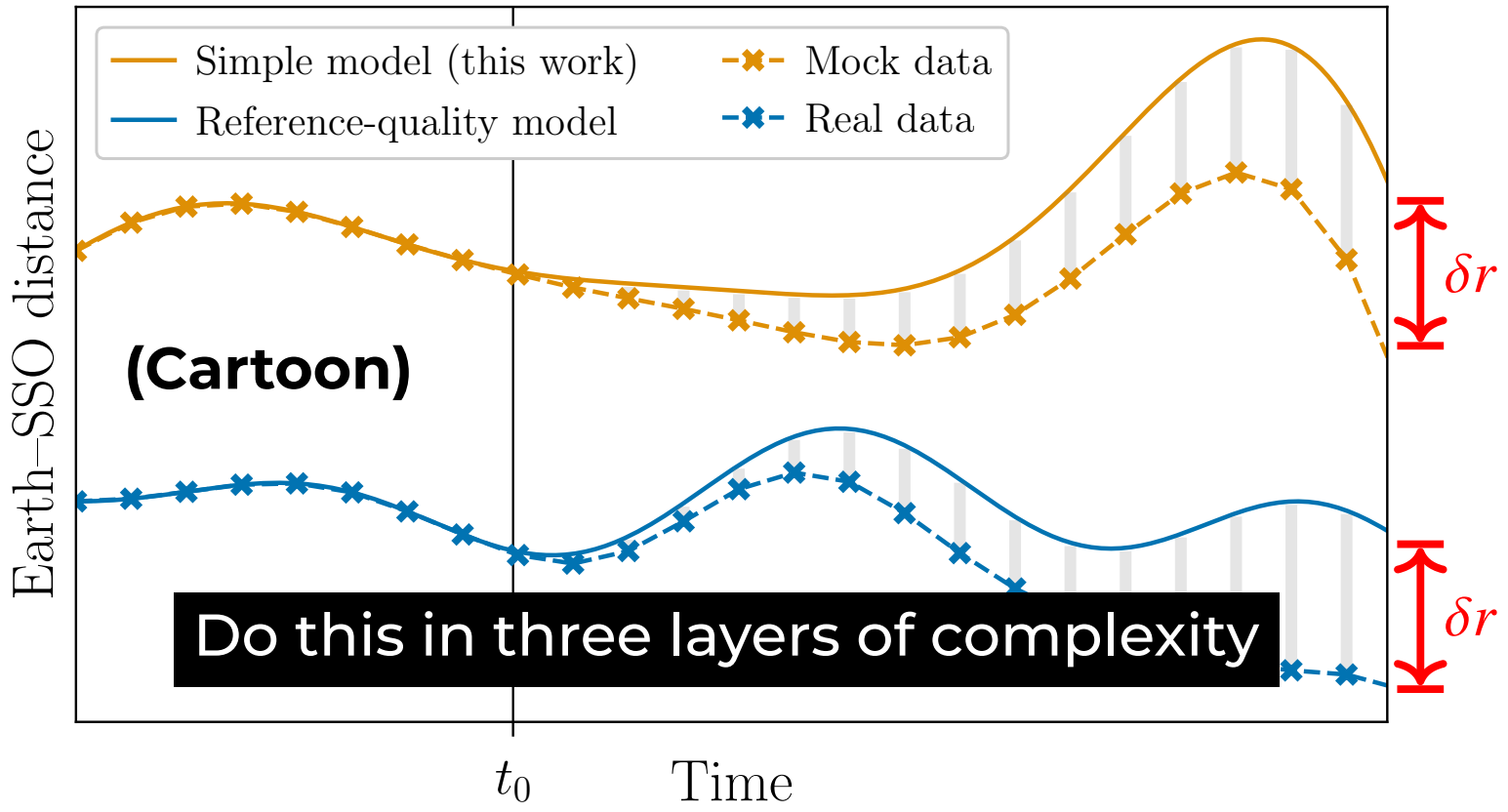
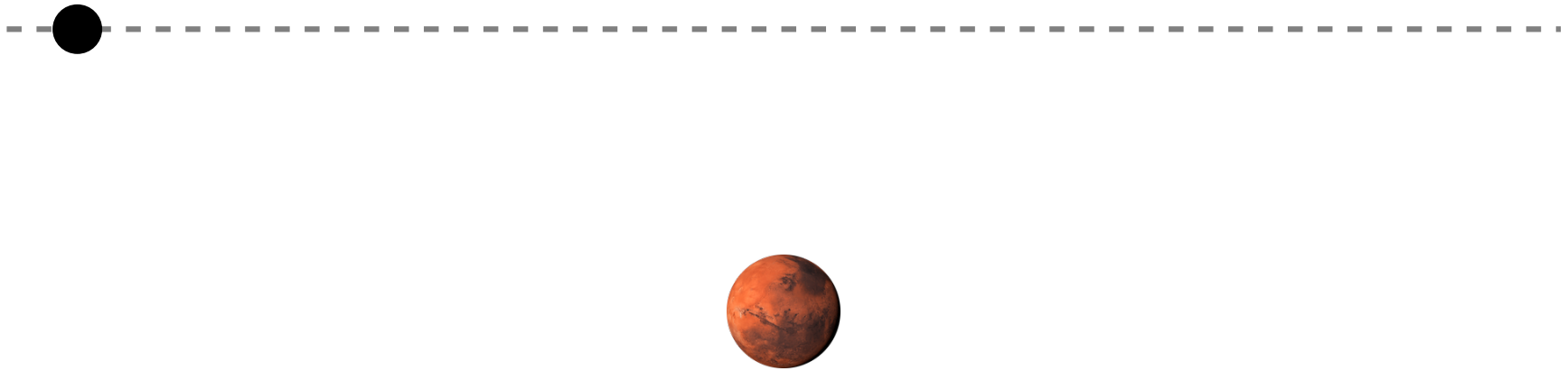


Layer 1: The impulse approximation



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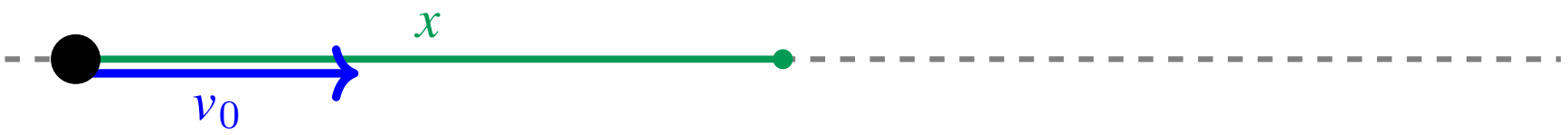

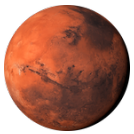

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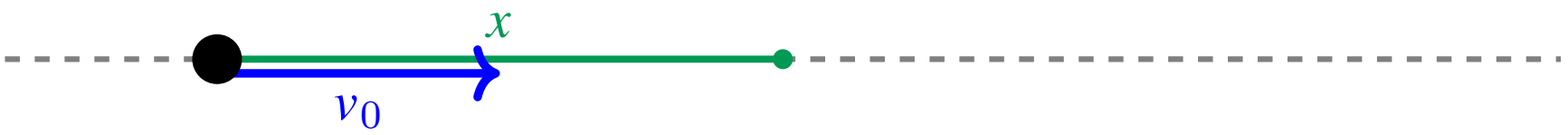

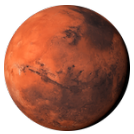

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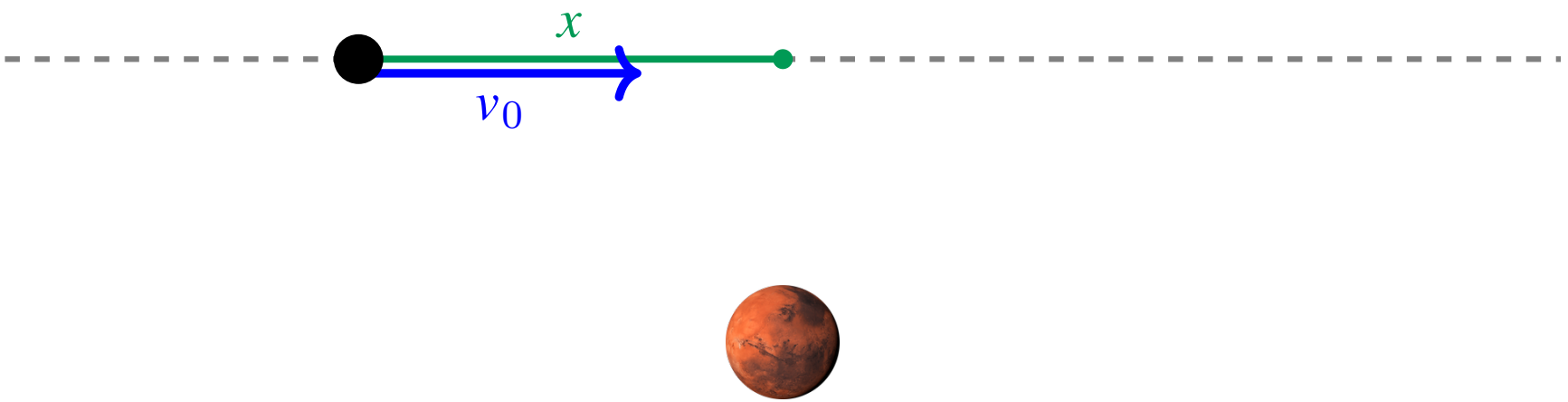

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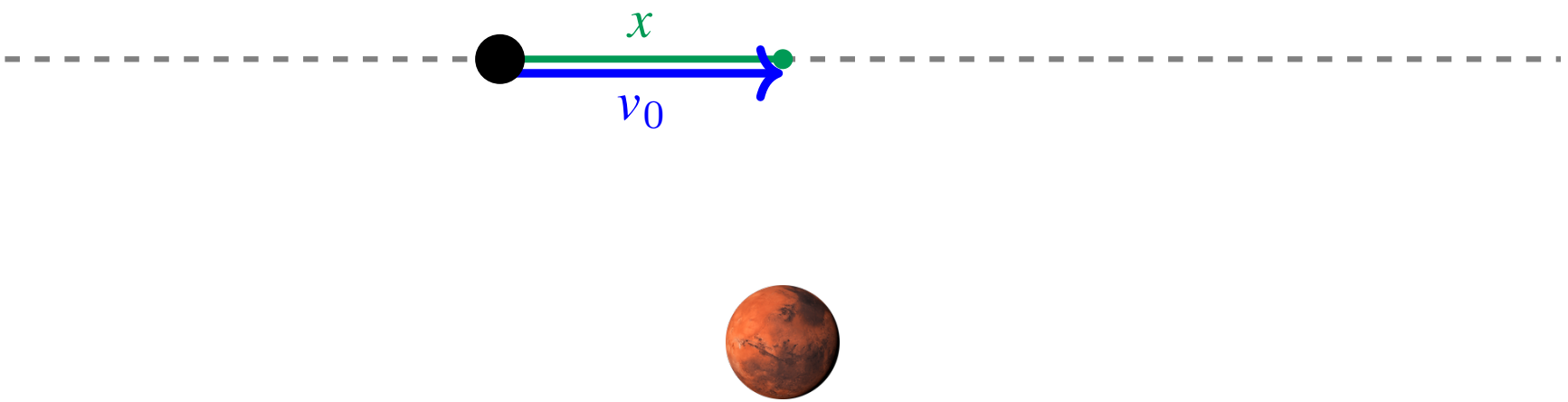

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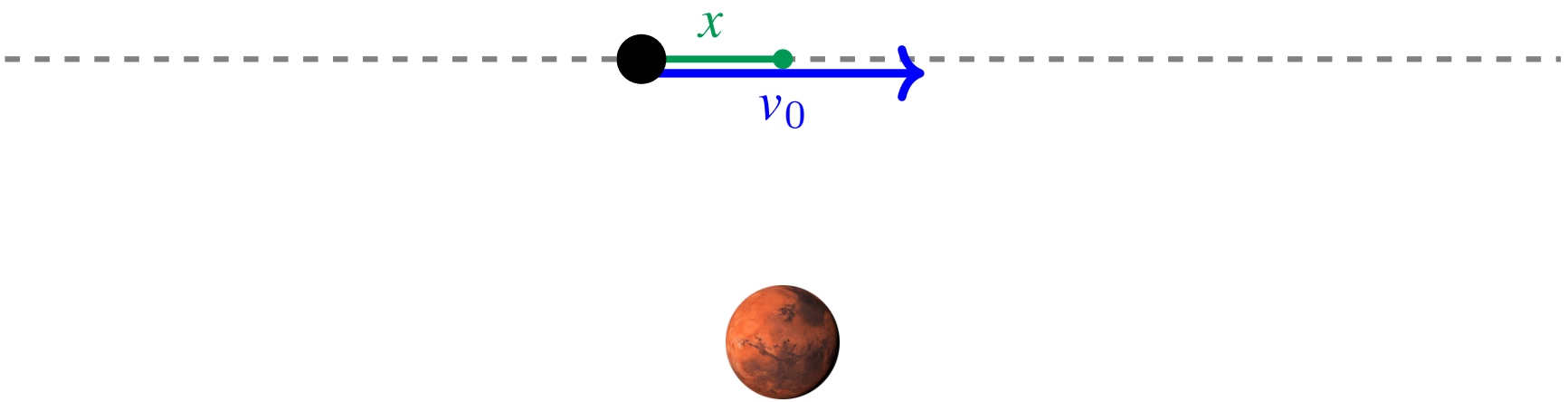

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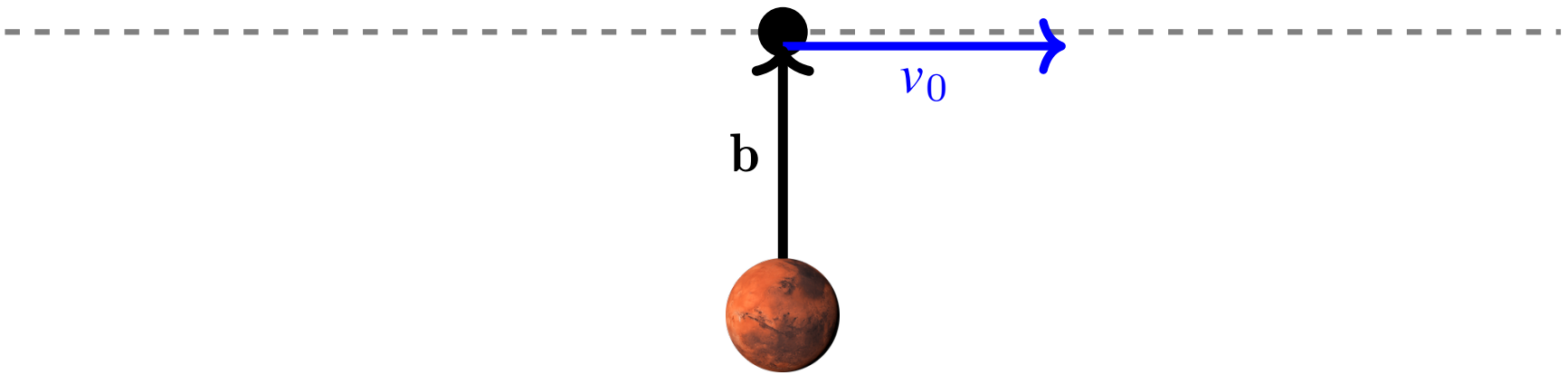

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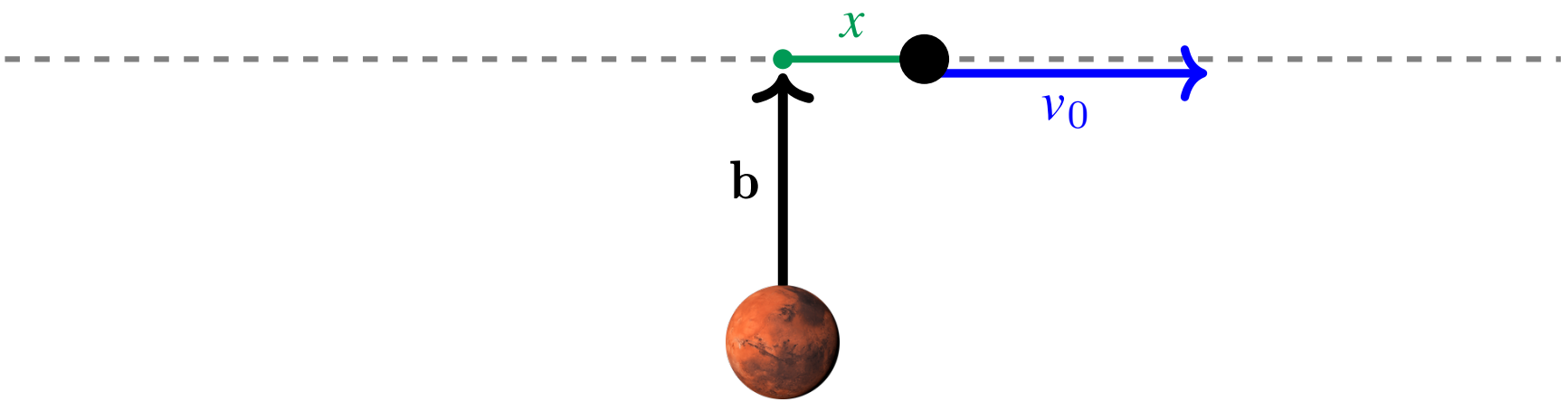

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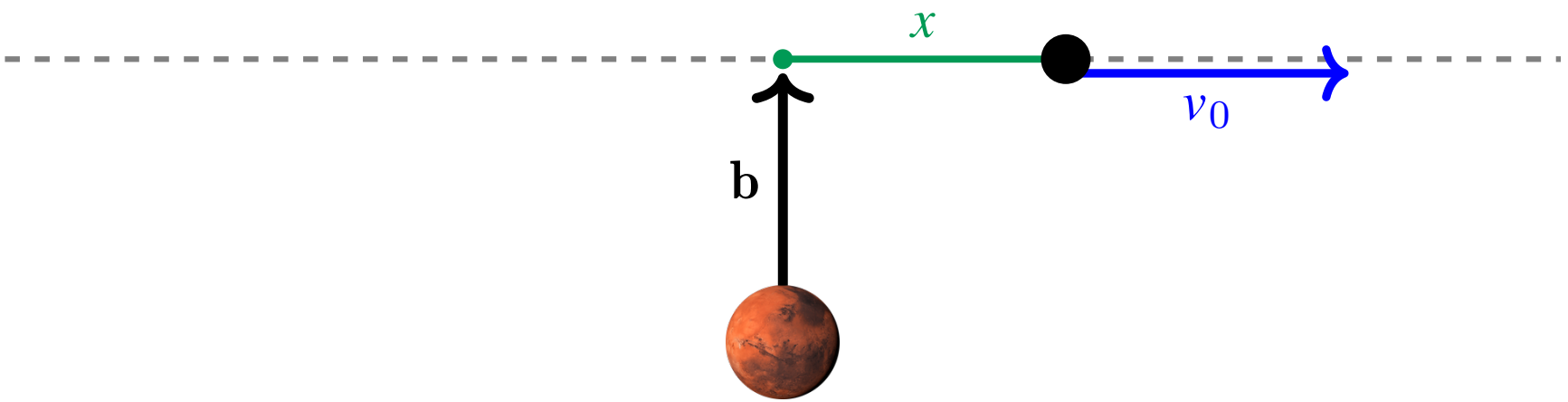

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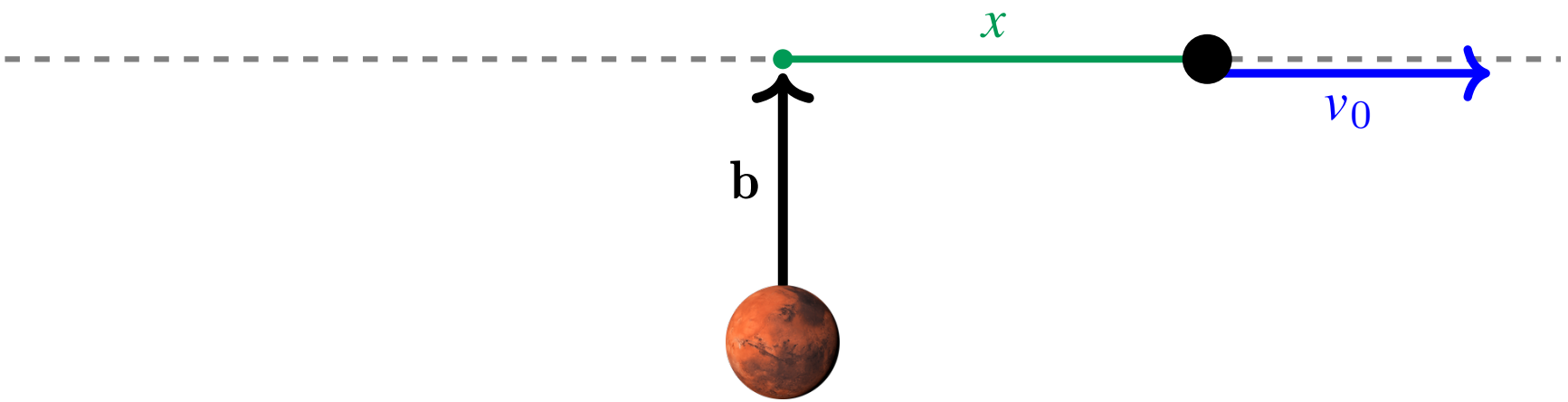

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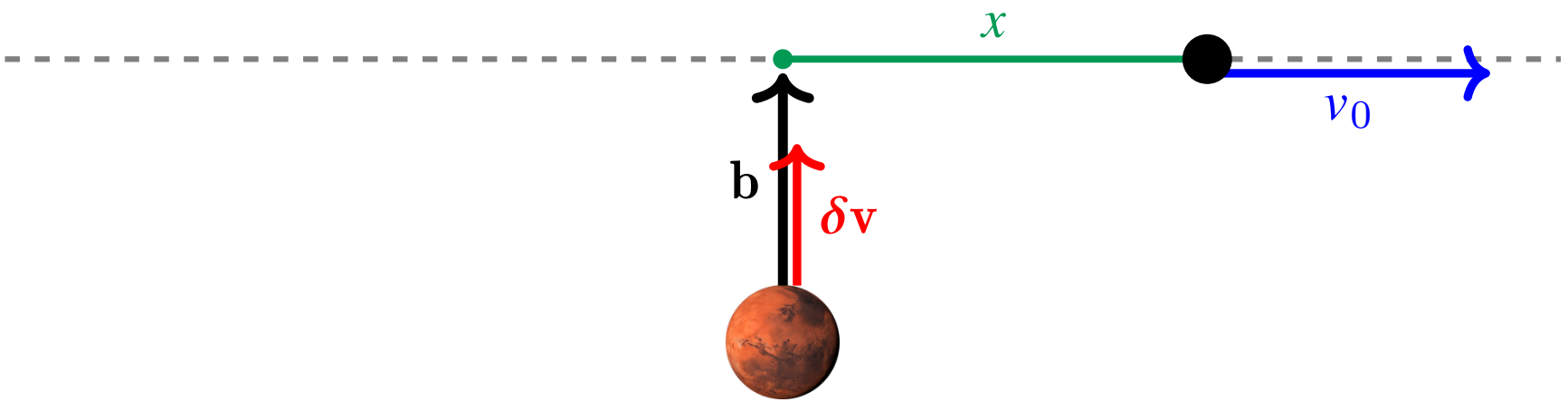
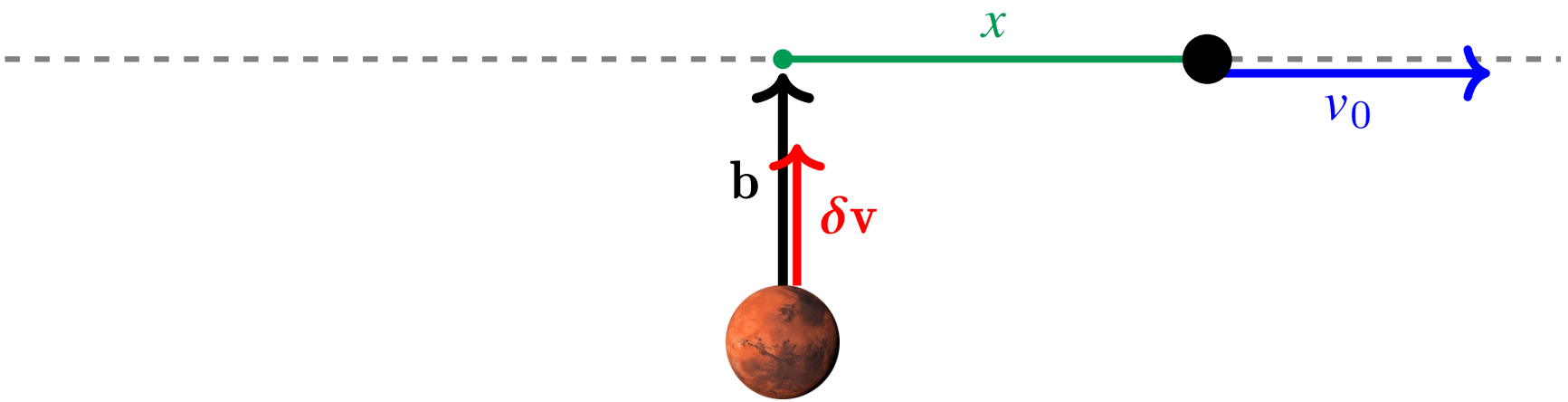


$$\delta\mathbf{v} \simeq \int \frac{\mathrm{d}x}{v_0} \frac{GM_{\mathrm{PBH}}\mathbf{b}}{(\mathbf{b}^2 + x^2)^{3/2}} = \frac{2GM_{\mathrm{PBH}}}{v_0 b^2}\,\mathbf{b}$$

Layer 1: The impulse approximation



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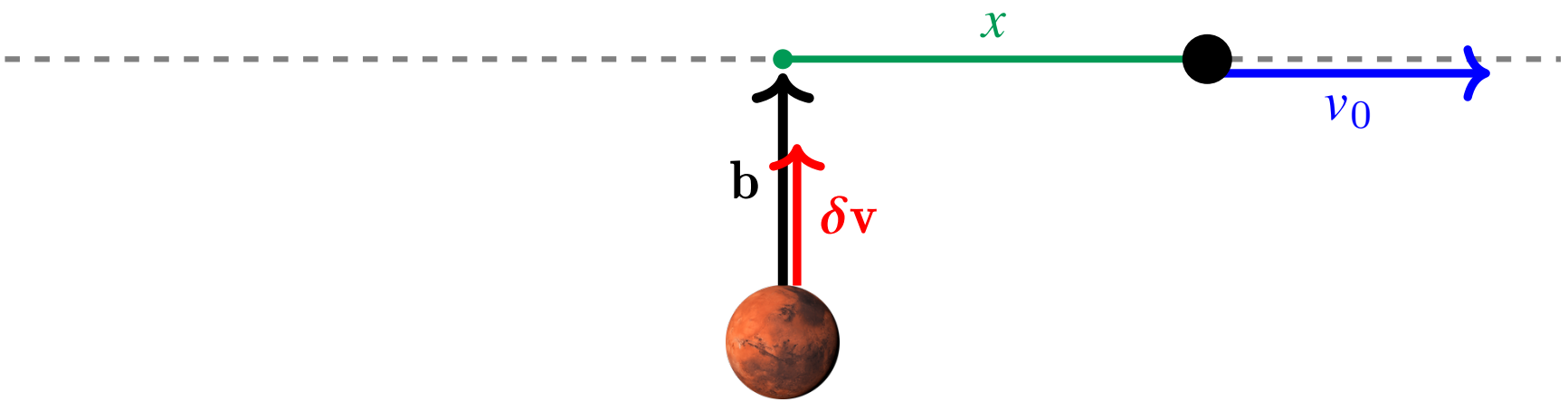

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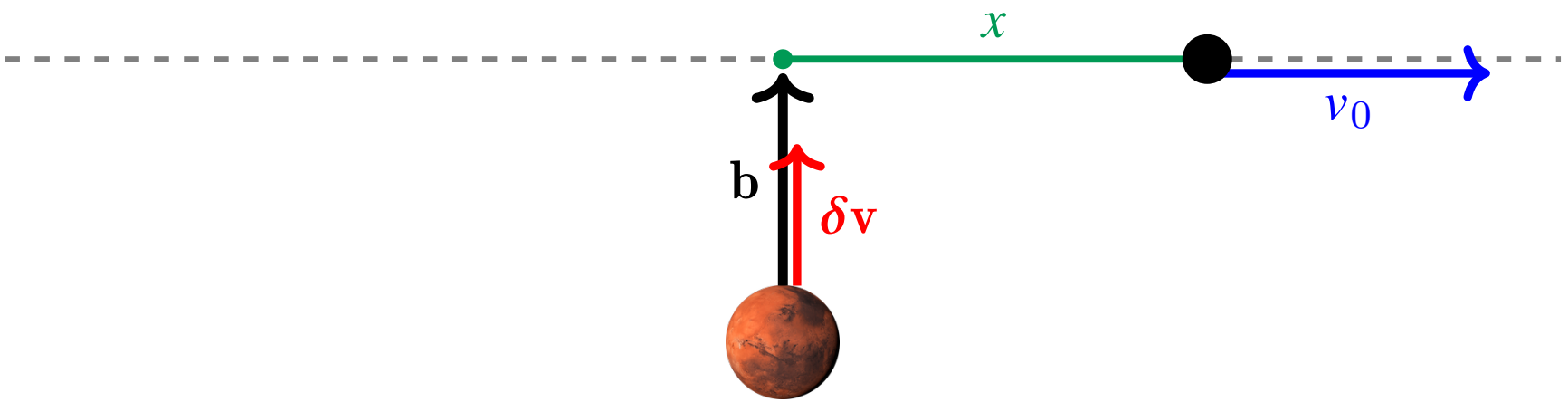

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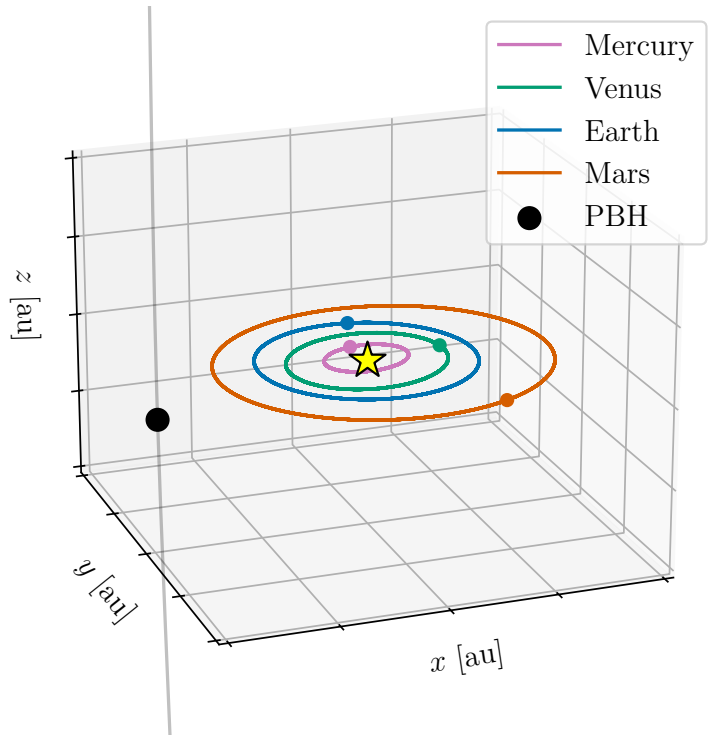
~ 1 detectable per $\Delta t_{\min} \approx 26\,\mathrm{yr} \left(\frac{M_{\mathrm{PBH}}}{10^{20}\,\mathrm{g}}\right)^{-1/3} \left(\frac{\sigma_r}{0.1\,\mathrm{m}}\right)^{2/3}$

Layer 2: Simple N-body simulations



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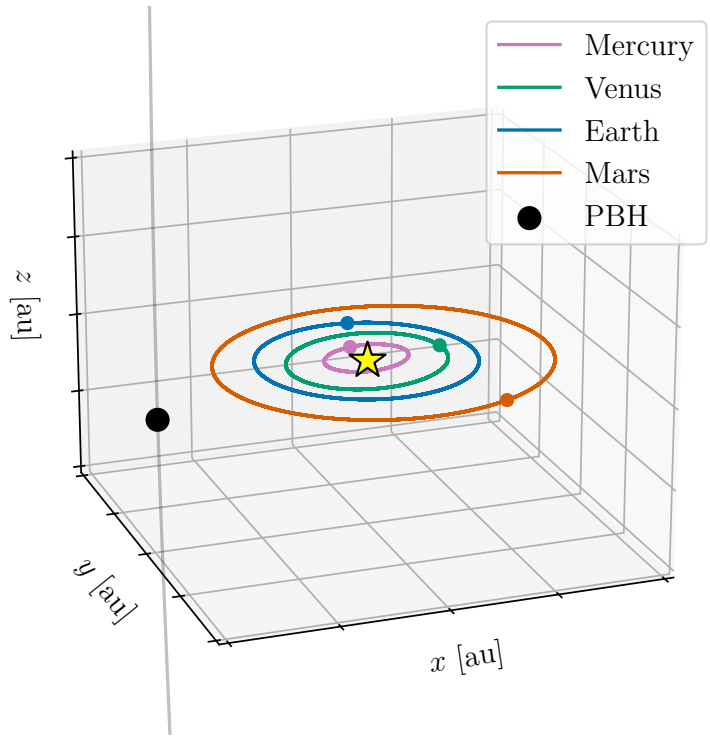

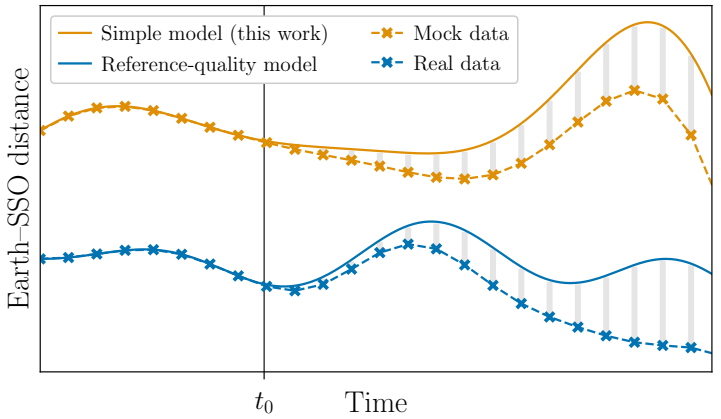

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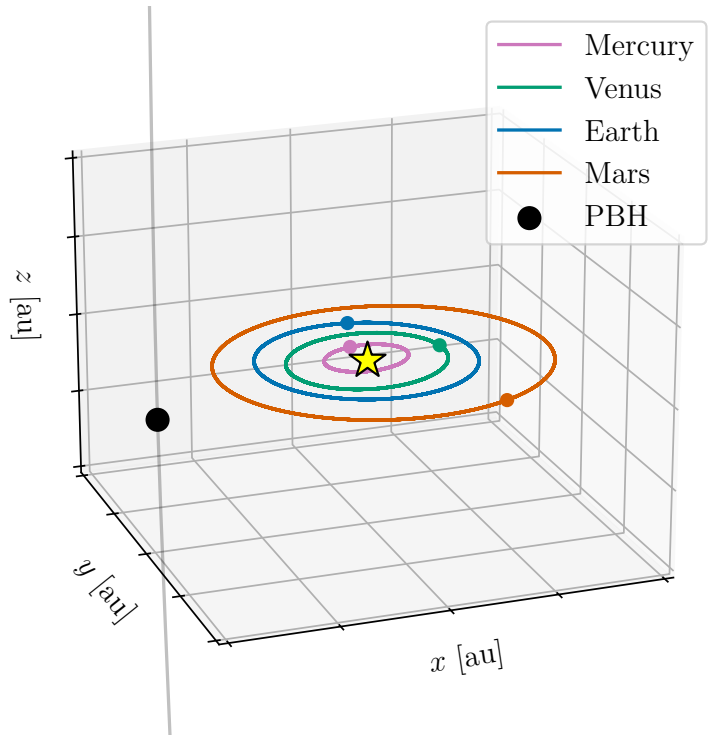

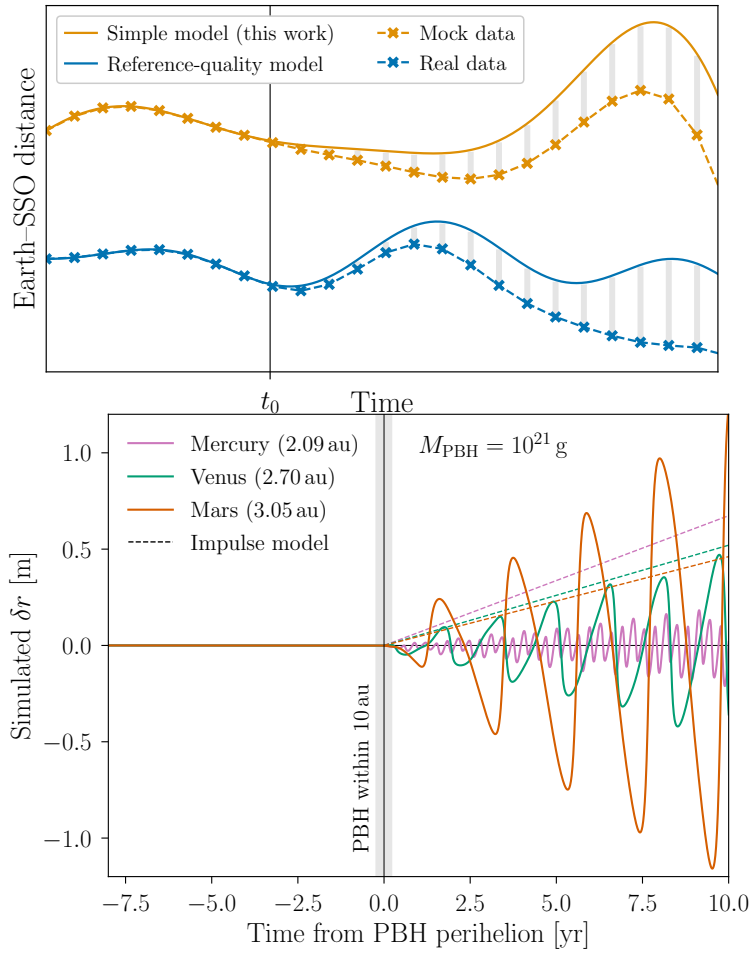

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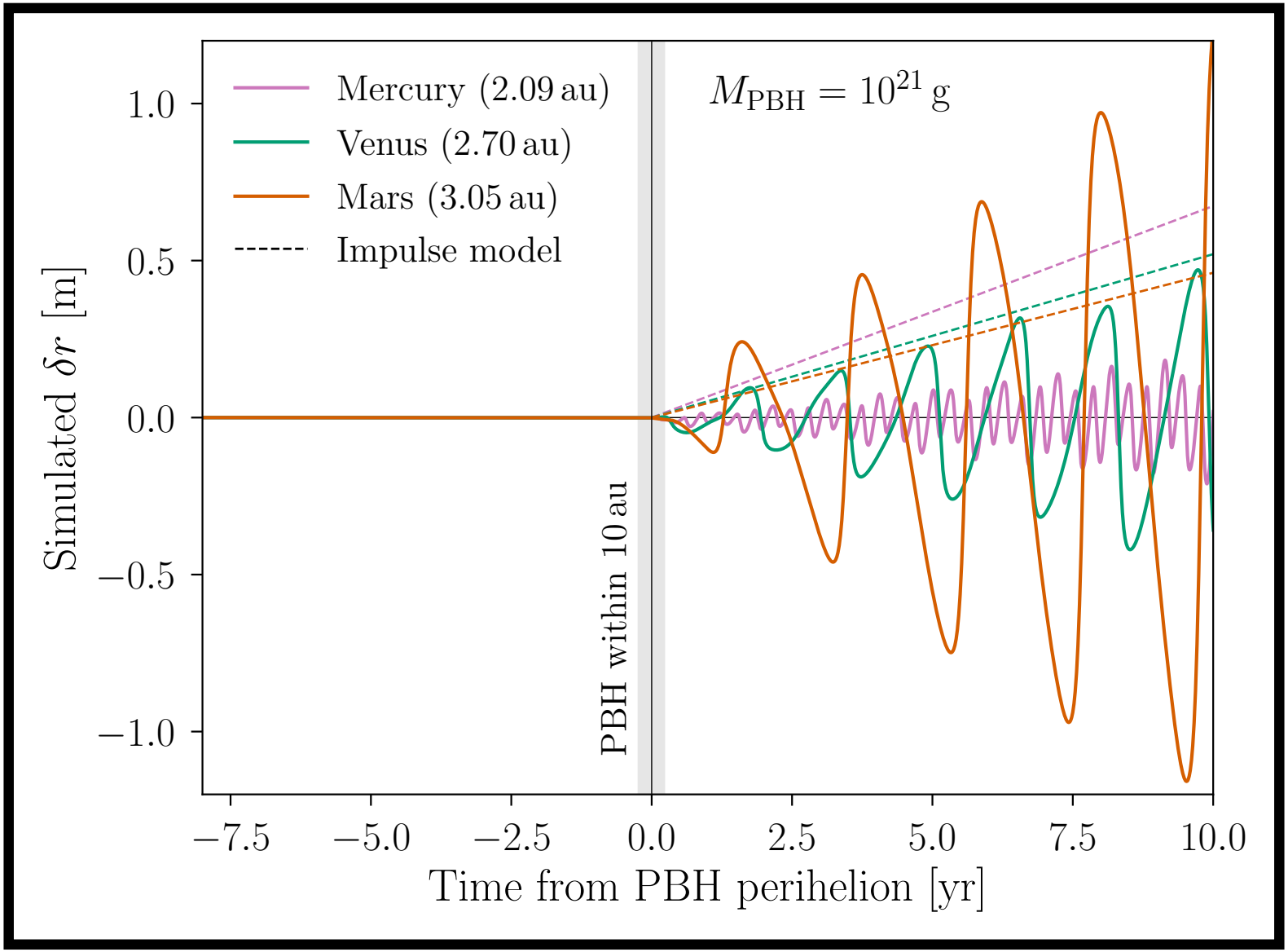

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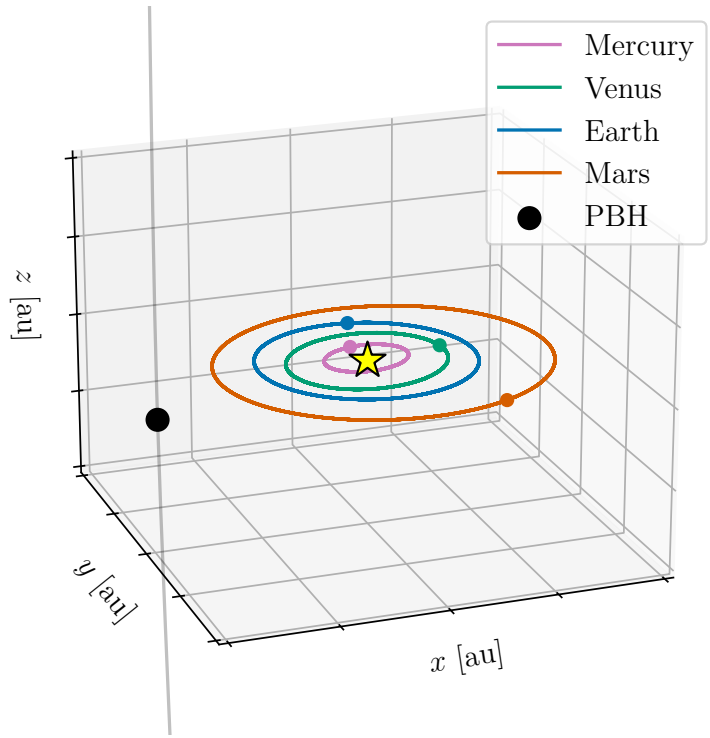

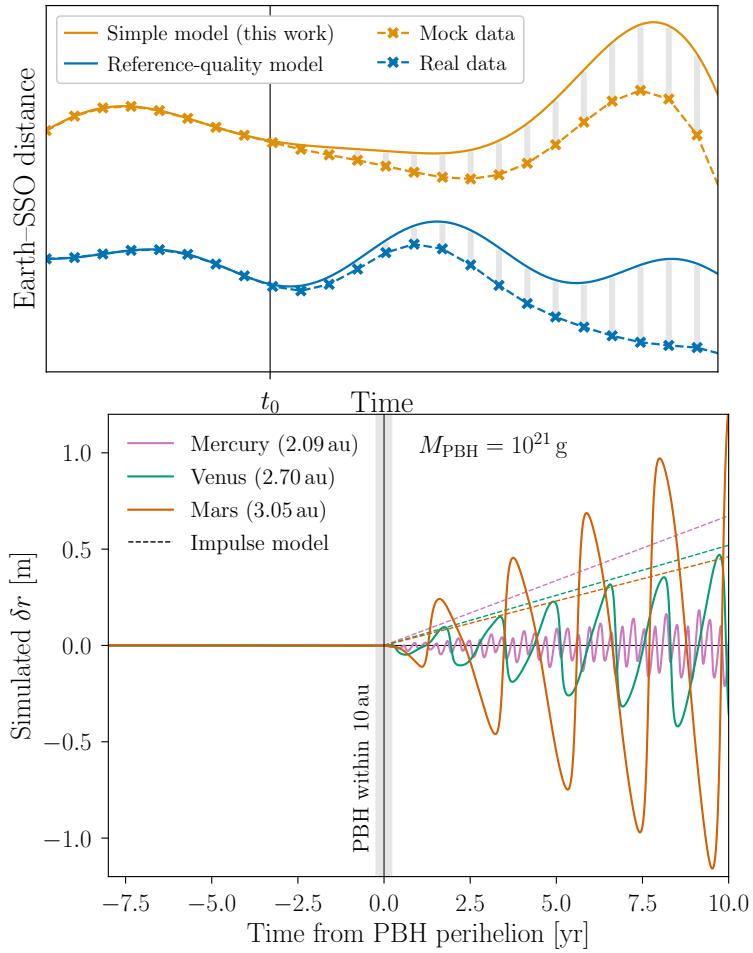

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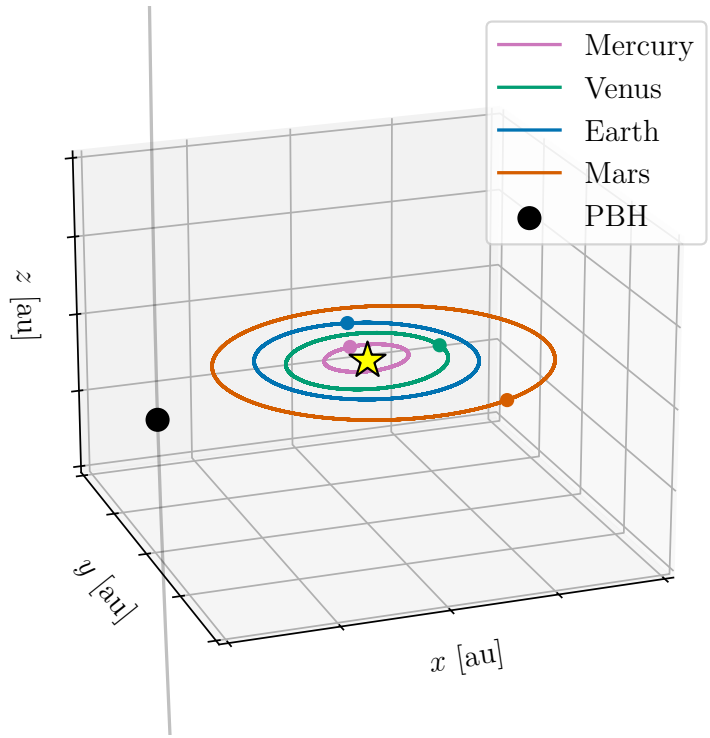
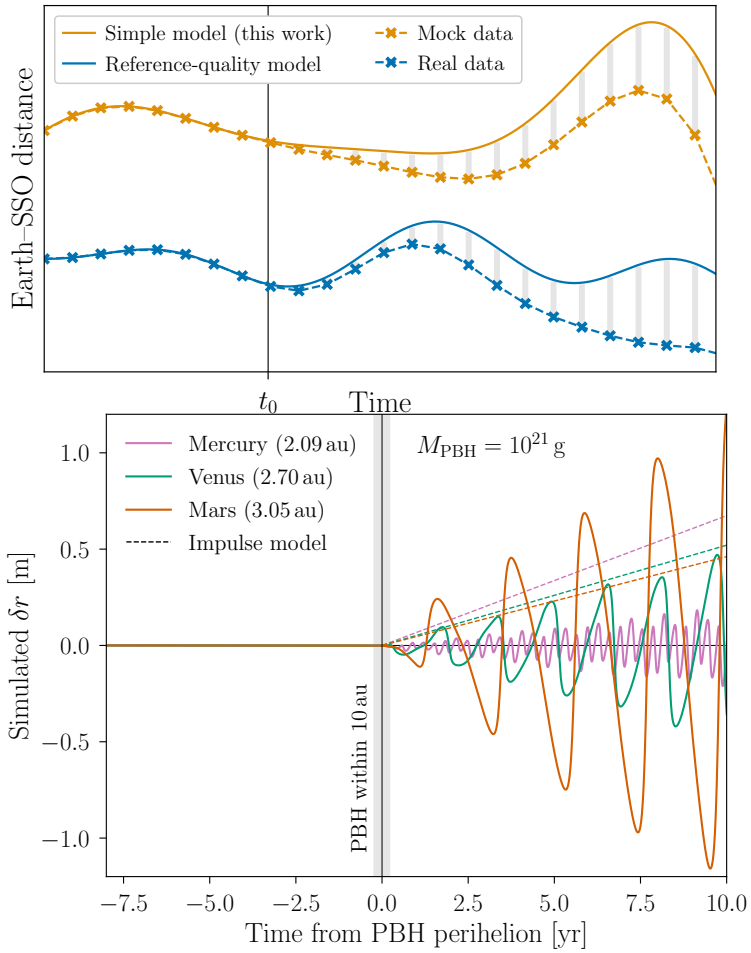
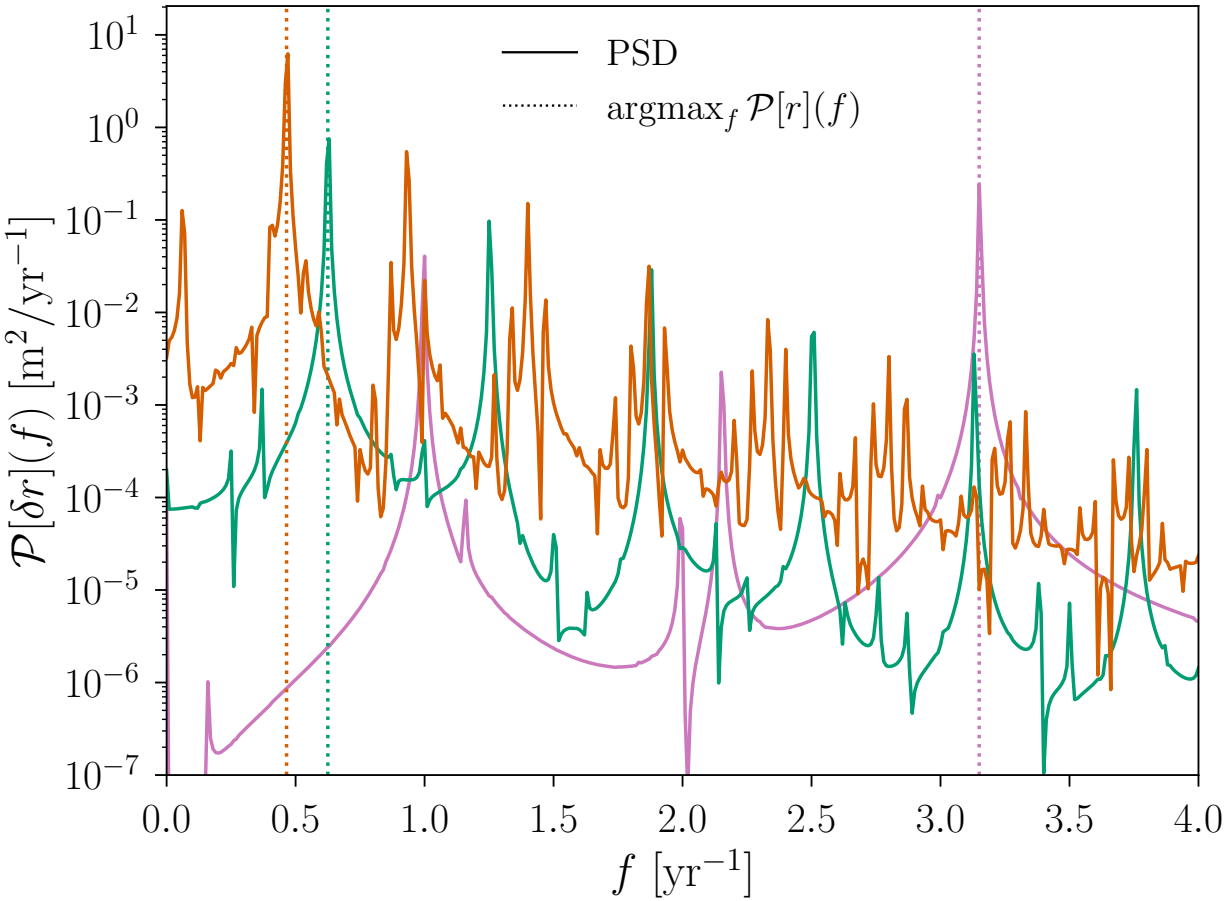




Consistent so far!

Layer 2: Frequency-space structure



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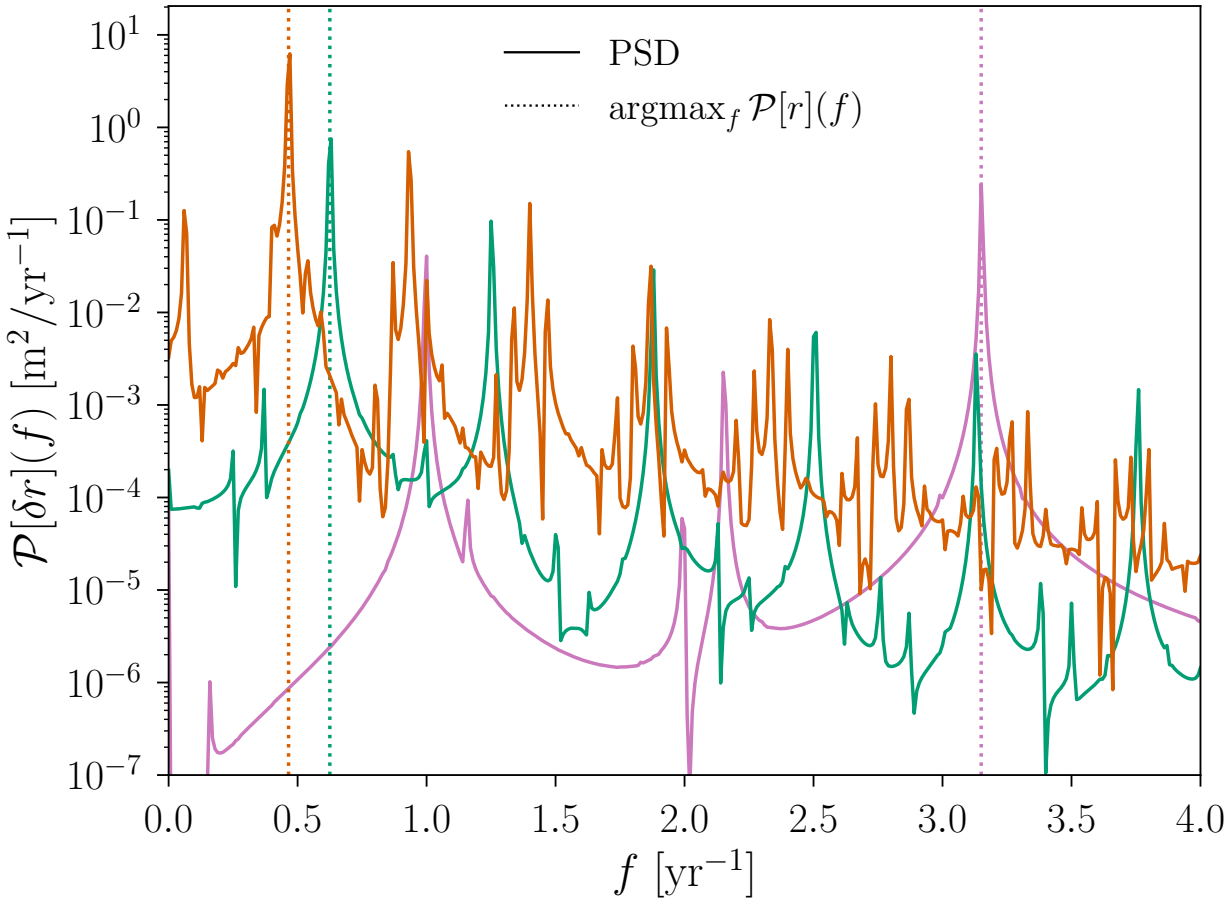
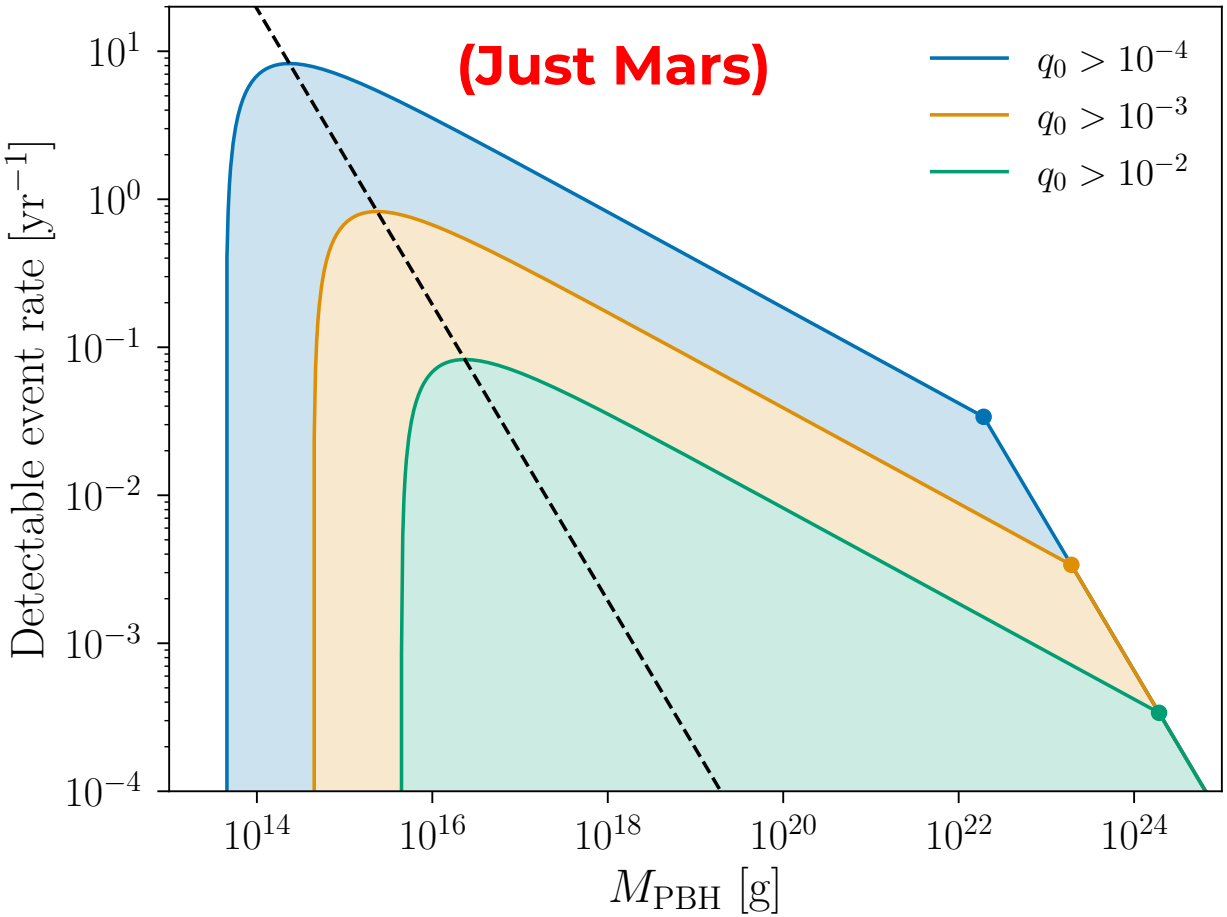


Improve signal-to-noise over many cycles

Layer 2: Rates and constraints



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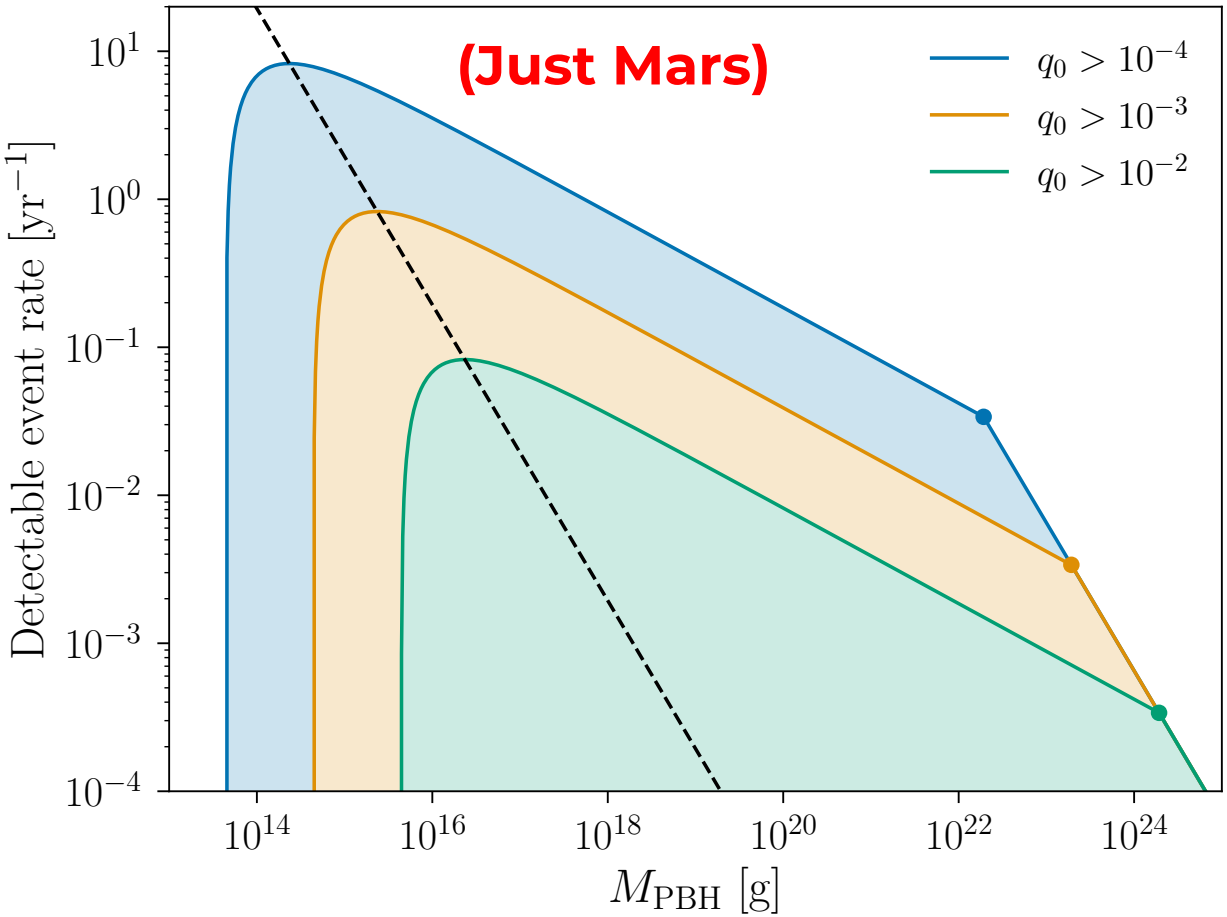

Constraints are possible with full simulation precision
(and careful statistical analysis)

Layer 3: Full physics

all bodies — dissipation — SR/GR — spin-orbit coupling — …

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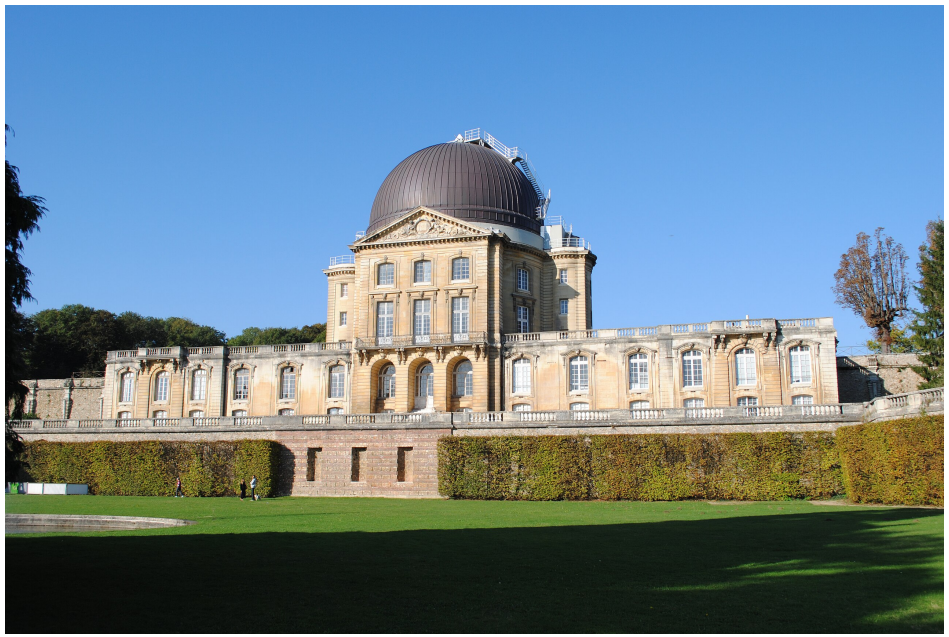
Starting now: study of PBH flybys in INPOP21a



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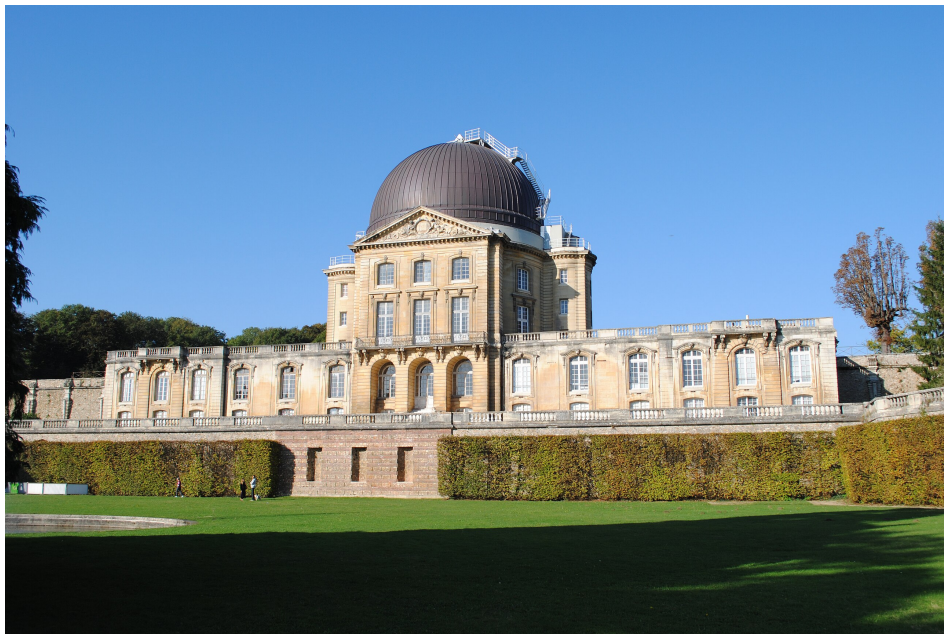
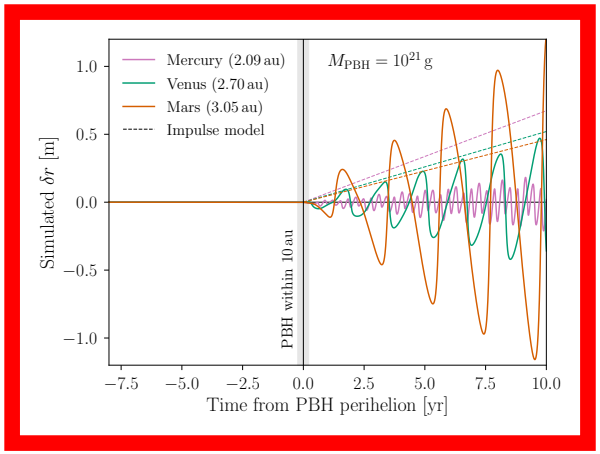


Potential for constraint (or discovery) from existing data

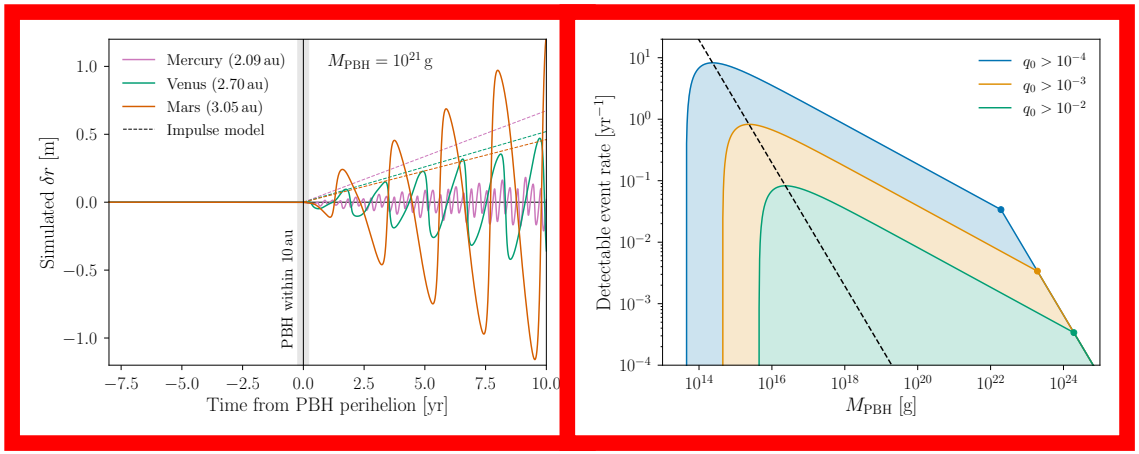
Conclusions

Conclusions



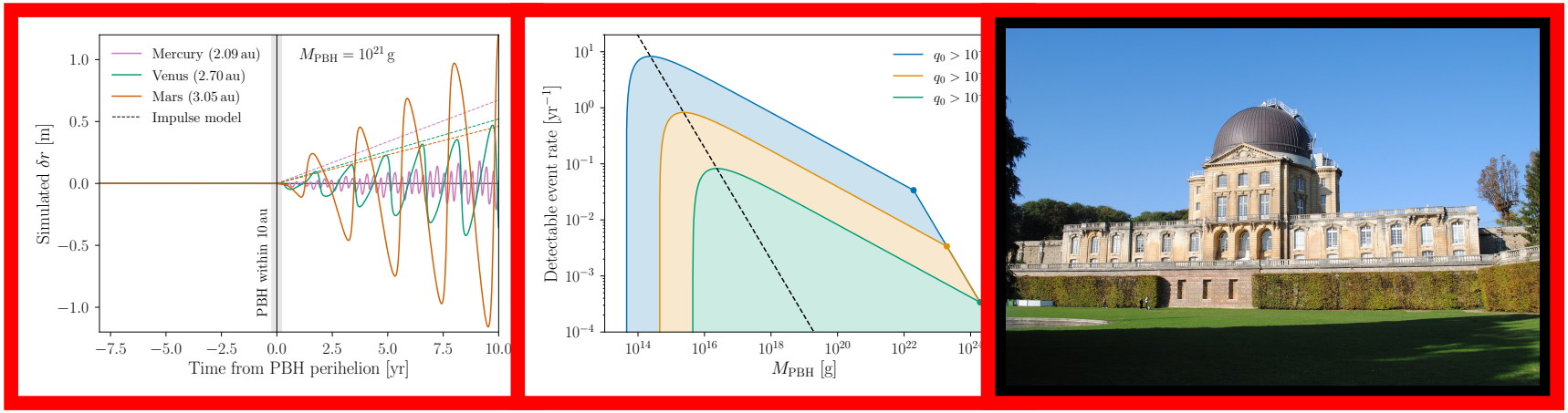
1. The Solar System is a PBH detector

Conclusions



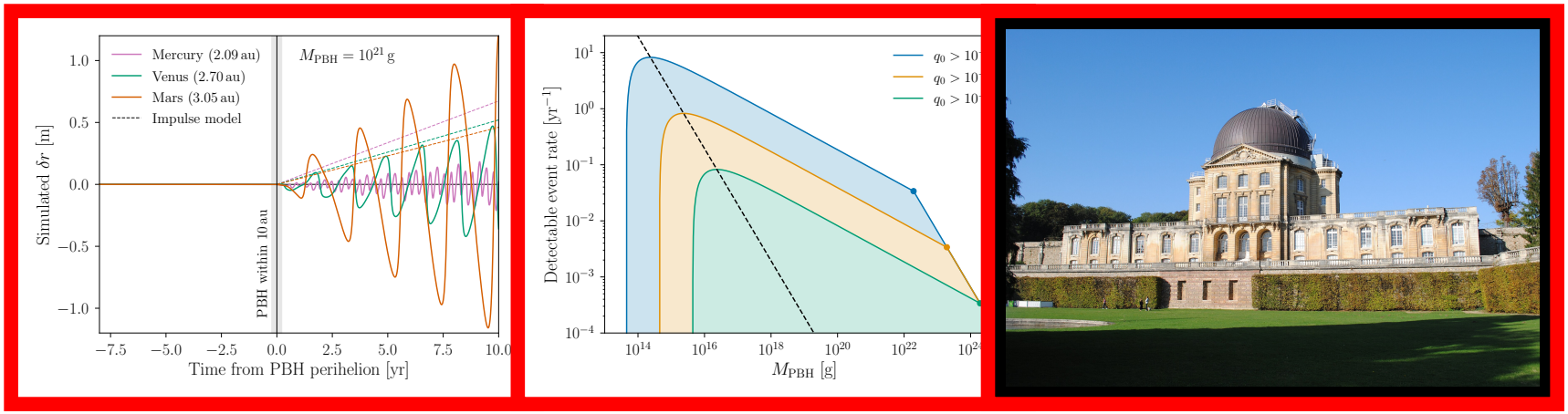
1. **The Solar System is a PBH detector**
2. **Best sensitivity in asteroid-mass range**

Conclusions



1. **The Solar System is a PBH detector**
2. **Best sensitivity in asteroid-mass range**
3. **Constraint or discovery possible soon**

Conclusions



1. **The Solar System is a PBH detector**
2. **Best sensitivity in asteroid-mass range**
3. **Constraint or discovery possible soon**

Not a boring answer after all!

References I

A. M. Green and B. J. Kavanagh. Primordial Black Holes as a dark matter candidate. *J. Phys. G*, 48(4):043001, 2021. doi: 10.1088/1361-6471/abc534.