Local Constraints on the Dark Sector

by Future Missions to Uranus and Neptune

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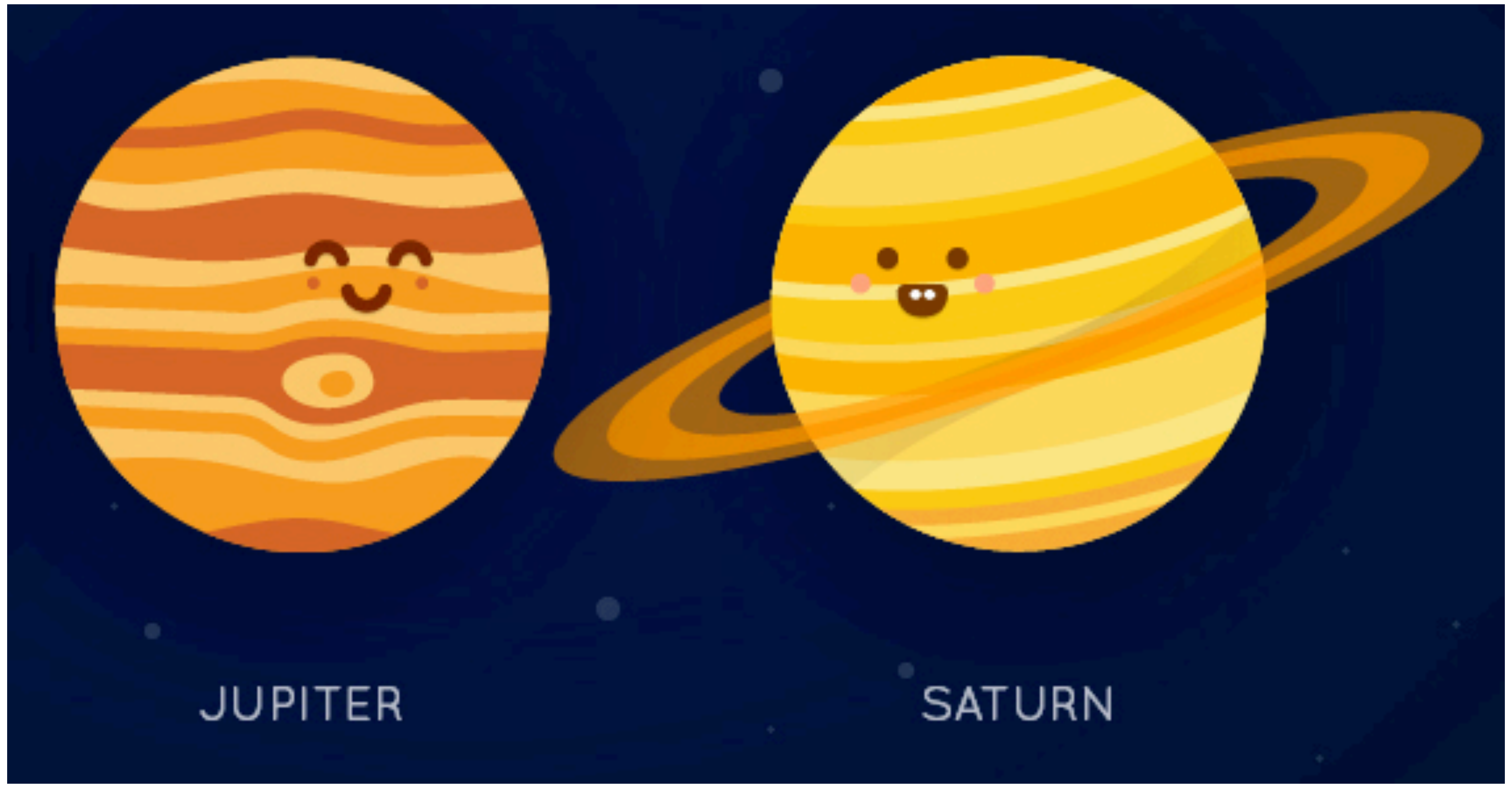
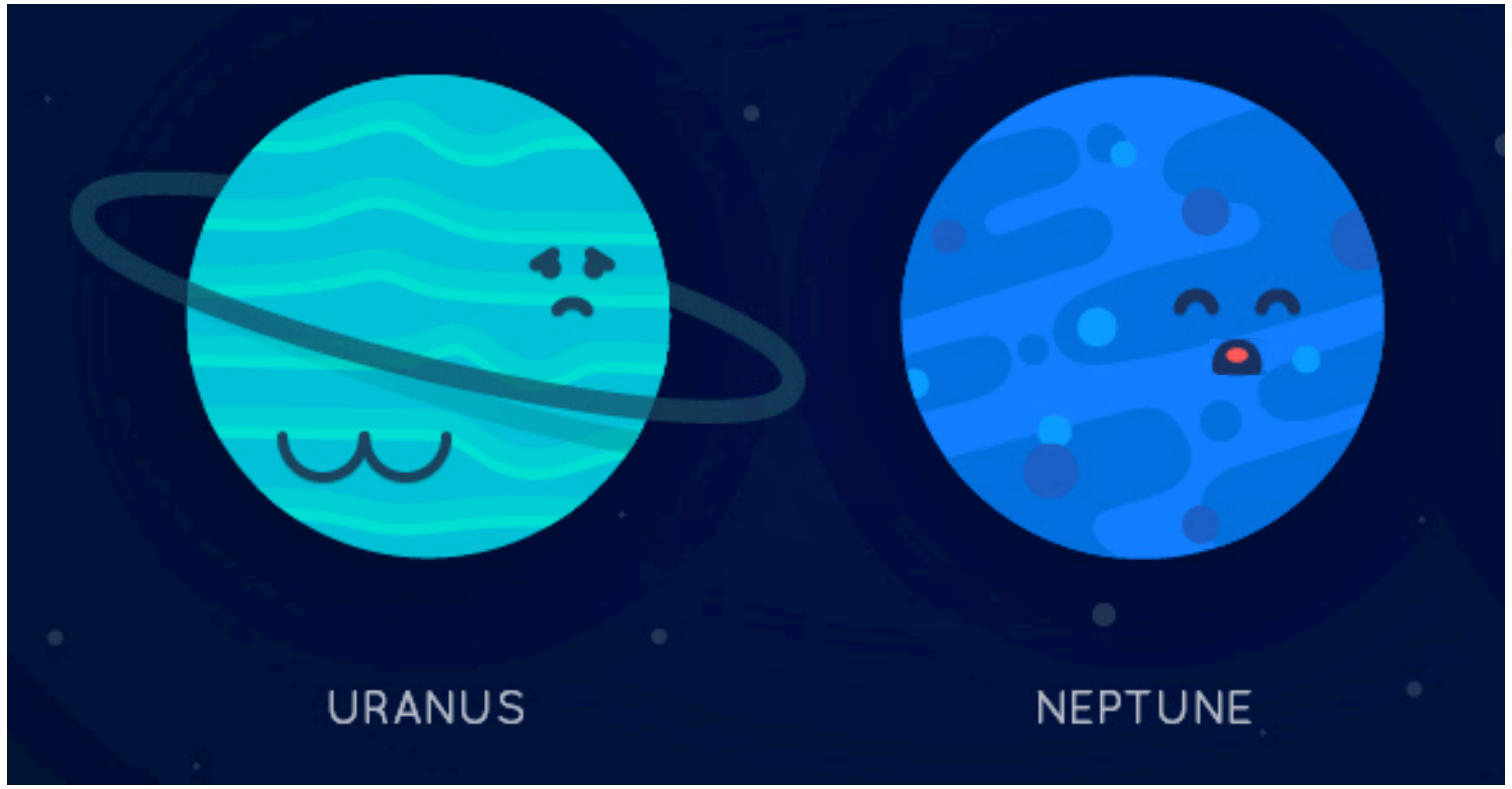




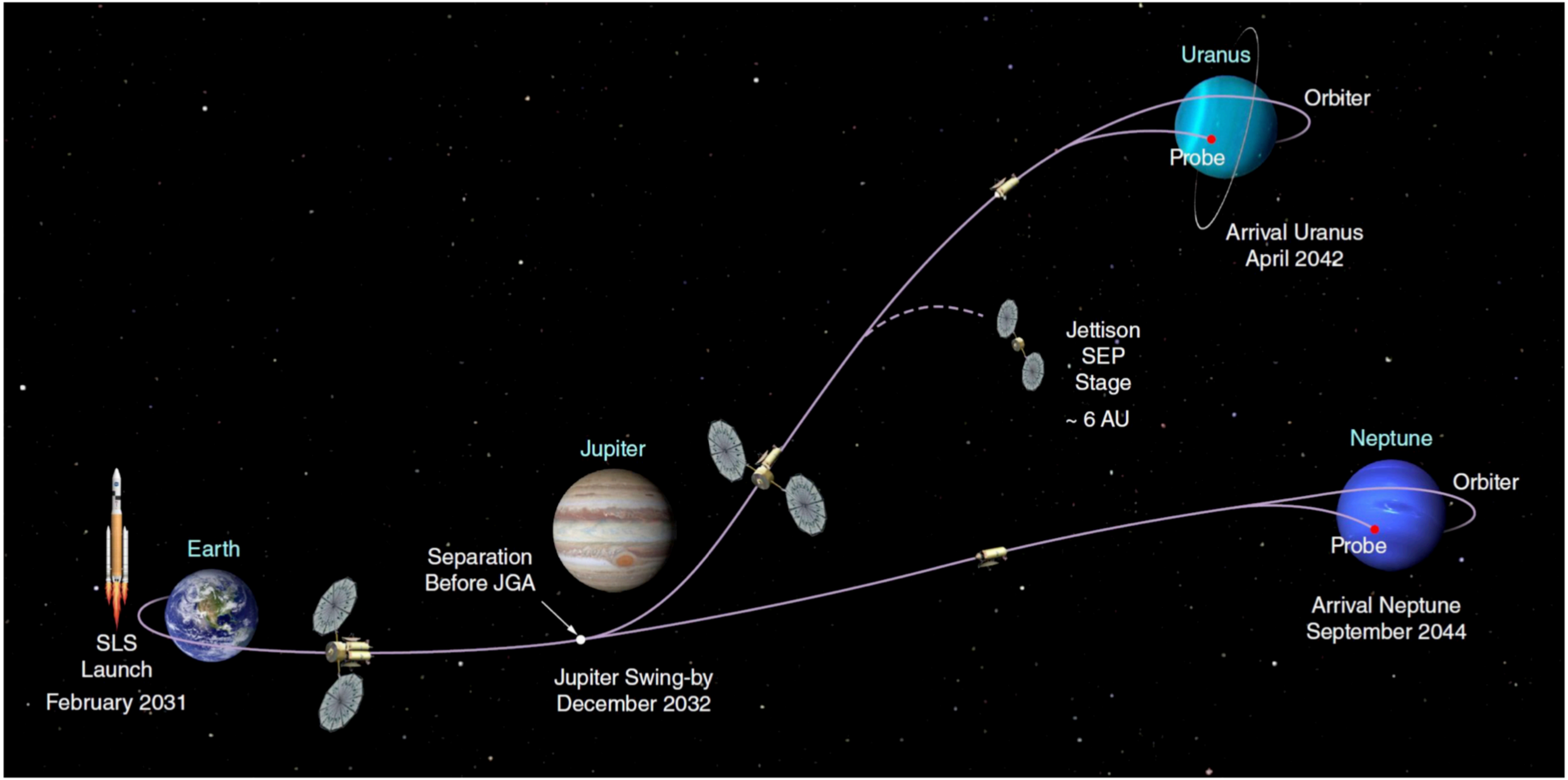
Missions that have visited Jupiter and Saturn:

- Pioneer 10
- Pioneer 11
- Voyager 1
- Voyager 2
- Ulysees
- Galileo
- Cassini
- New Horizons
- Juno
- JUICE (2022)

Missions that have visited Uranus and Neptune:

- Voyager 2

Two Planet-Two Spacecraft Mission Concept



Credit: John O. Elliott, *Ice Giant Systems 2020*

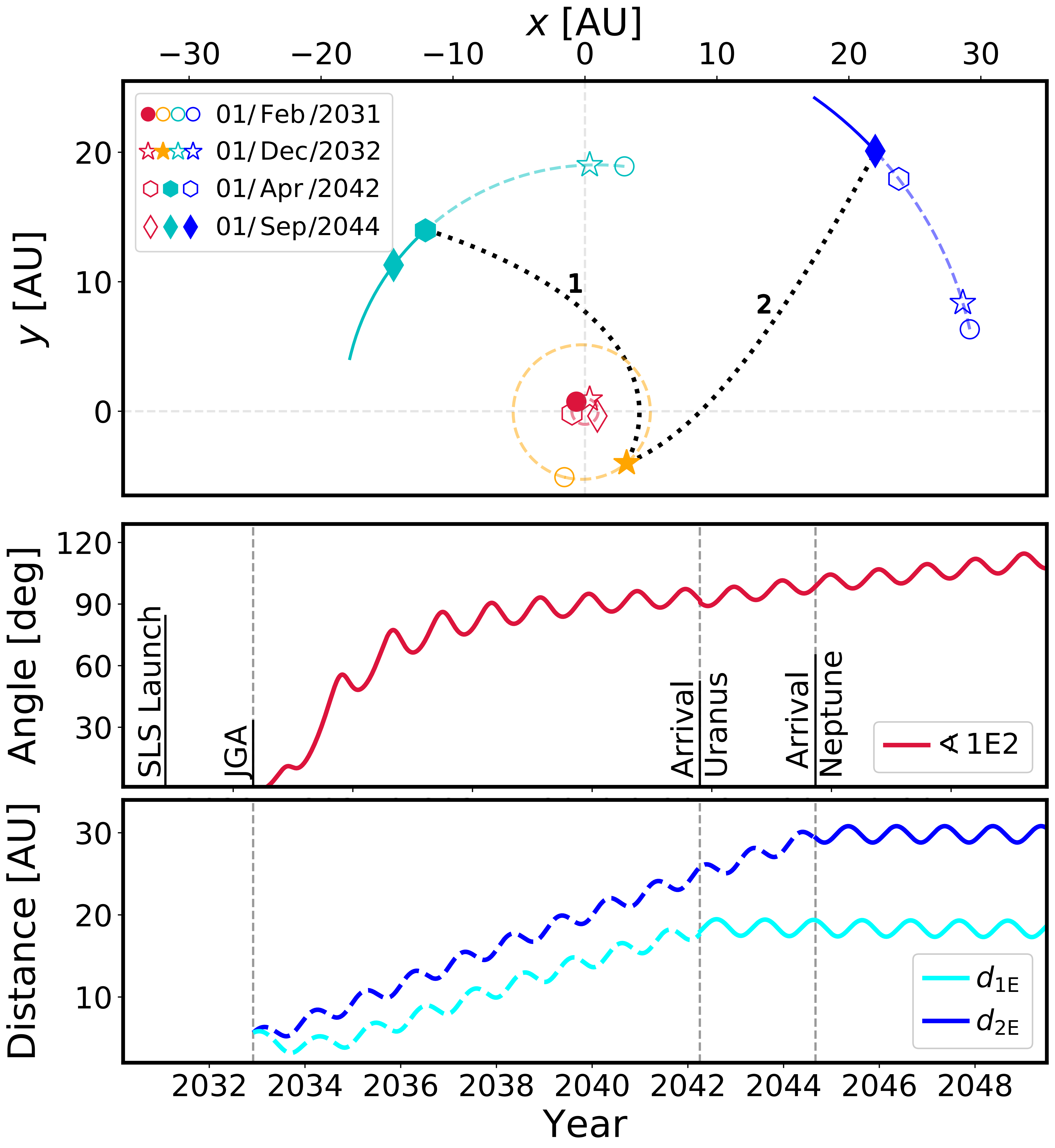
Here is how the mission would look like

2031 February:
Space Launch System departure from Earth.

2032 December:
Separation of the spacecraft and subsequent JGA.

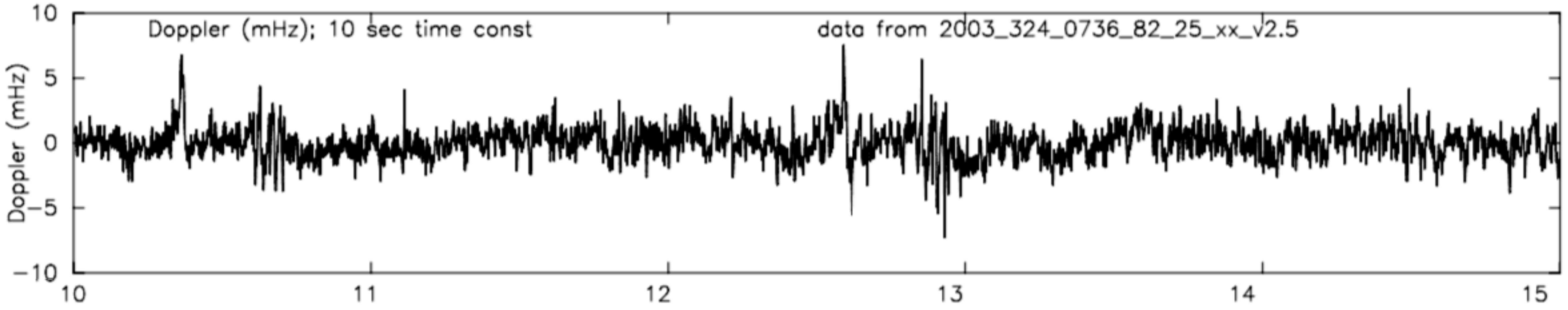
2042 April:
Arrival of the first spacecraft at Uranus.

2044 September:
Arrival of the second spacecraft at Neptune.

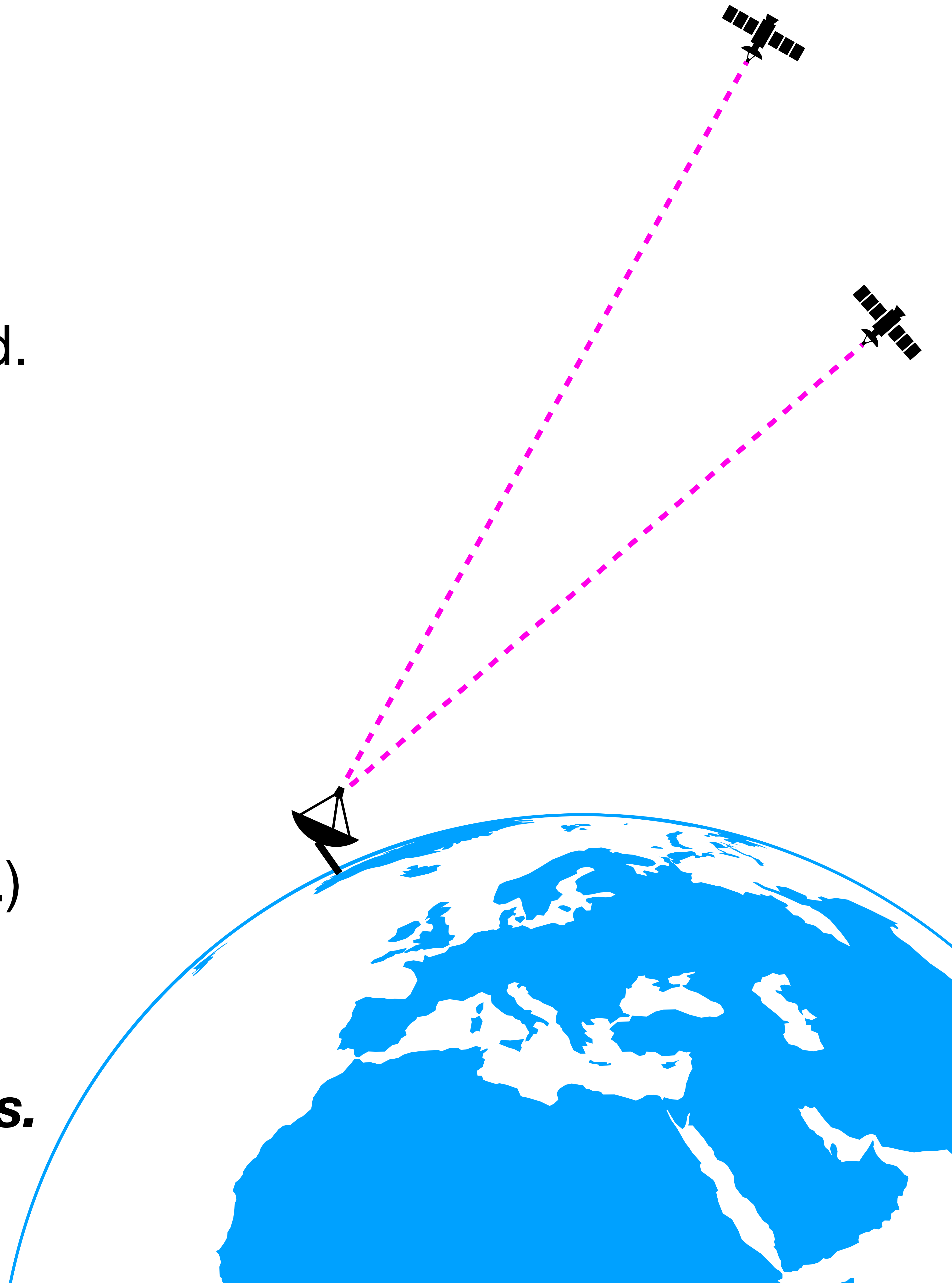


Searching for Gravitational Waves

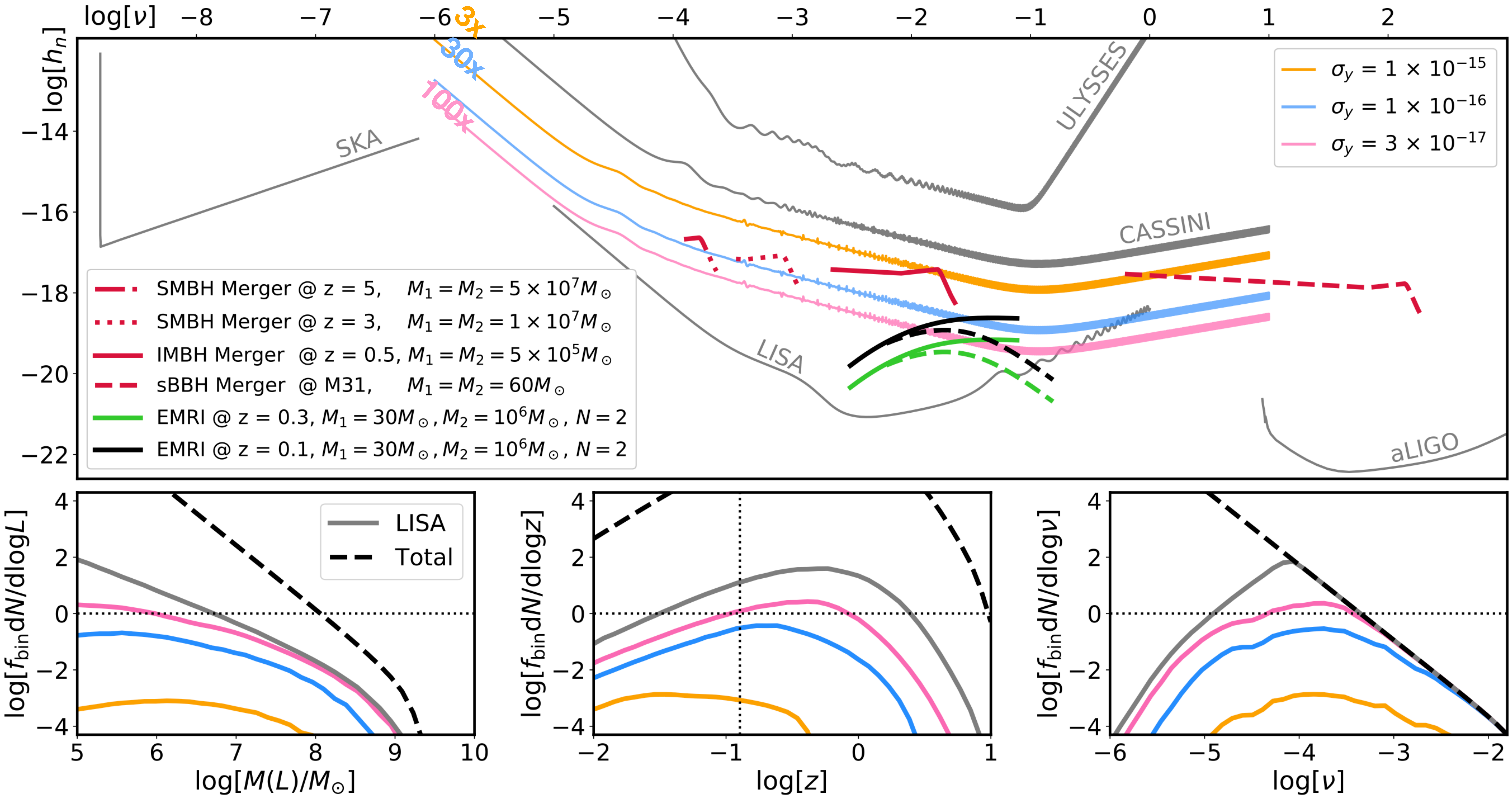
- Cruise time is around **10 years** to the ice giants.
- Constant communication through the radio link.
- Fluctuations in the radio carrier frequency are recorded.



- **GW**s passing through the system cause fluctuations.
- Has been tried before (*Pioneer 11, Ulysses, Cassini* etc.)
- Until now: Low SNR → No detection
- *Revisit the topic* ***24 years after Cassini*** *for* ***IG missions.***



Sensitivity Curve of an Ice Giant mission to Gravitational Waves

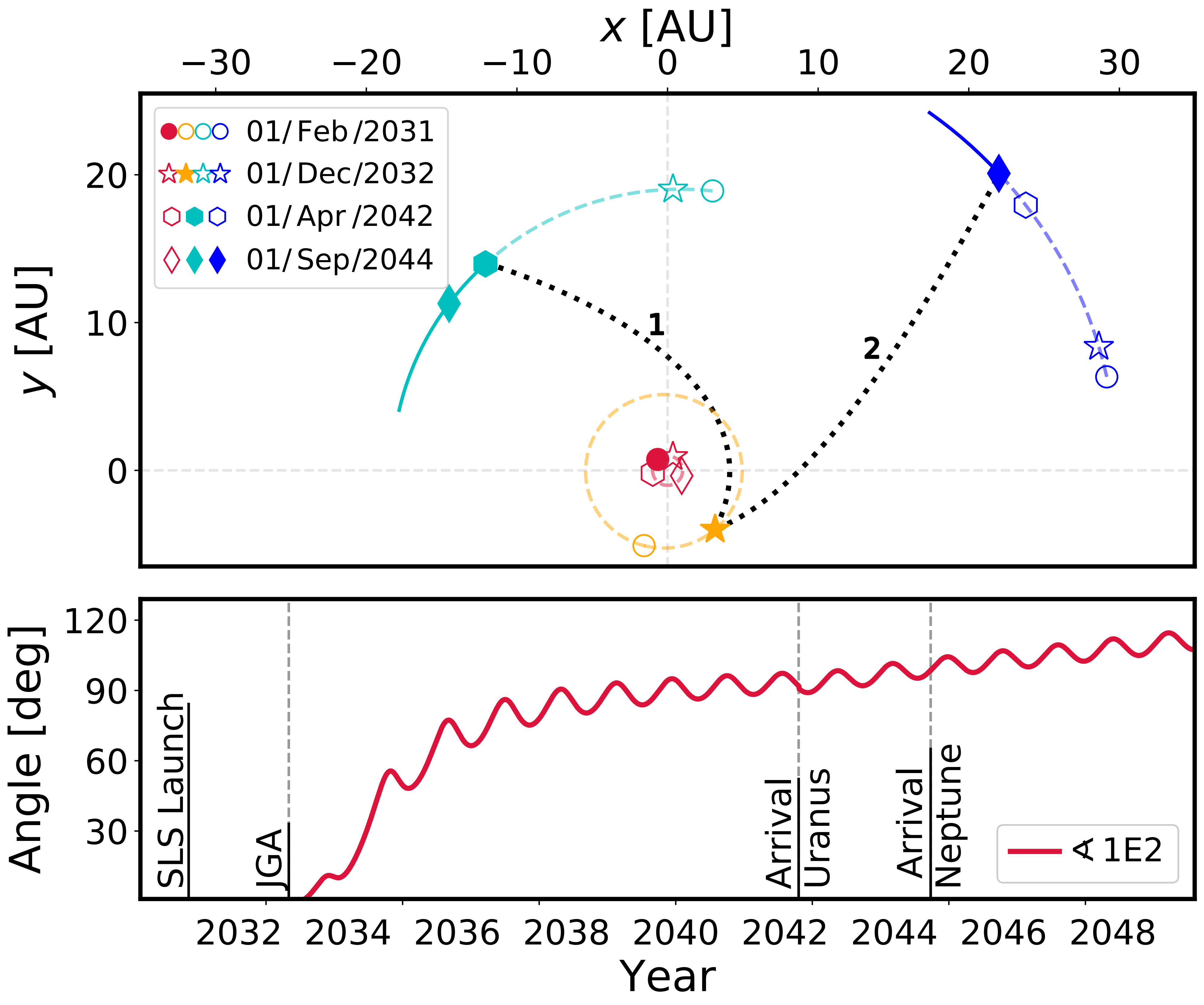


Credit: Soyuer et al. 2021, *Searching for Gravitational Waves via Doppler Tracking by Future Missions to Uranus and Neptune*

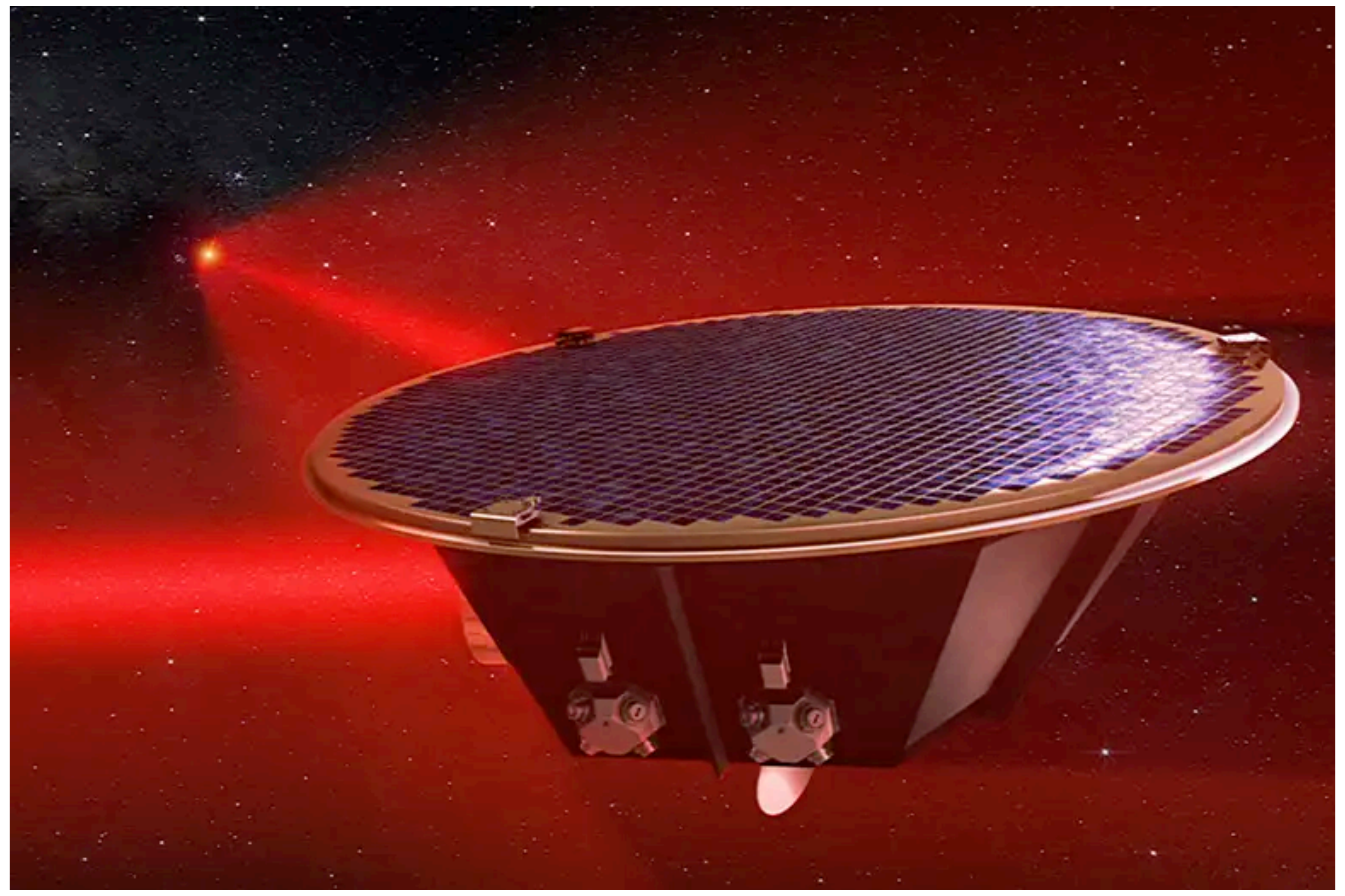
Ice Giants + LISA

- **Remember that the IG missions and LISA form a ~90° triangle.**

- Improved sky localization would enable optical follow-up with wide-field telescopes.



- $2 \times 10^6 M_\odot$ SBHB at $z = 1$:
  - **LISA alone:** ~10 deg^2
  - **LISA with some Doppler help:** ~1 deg^2



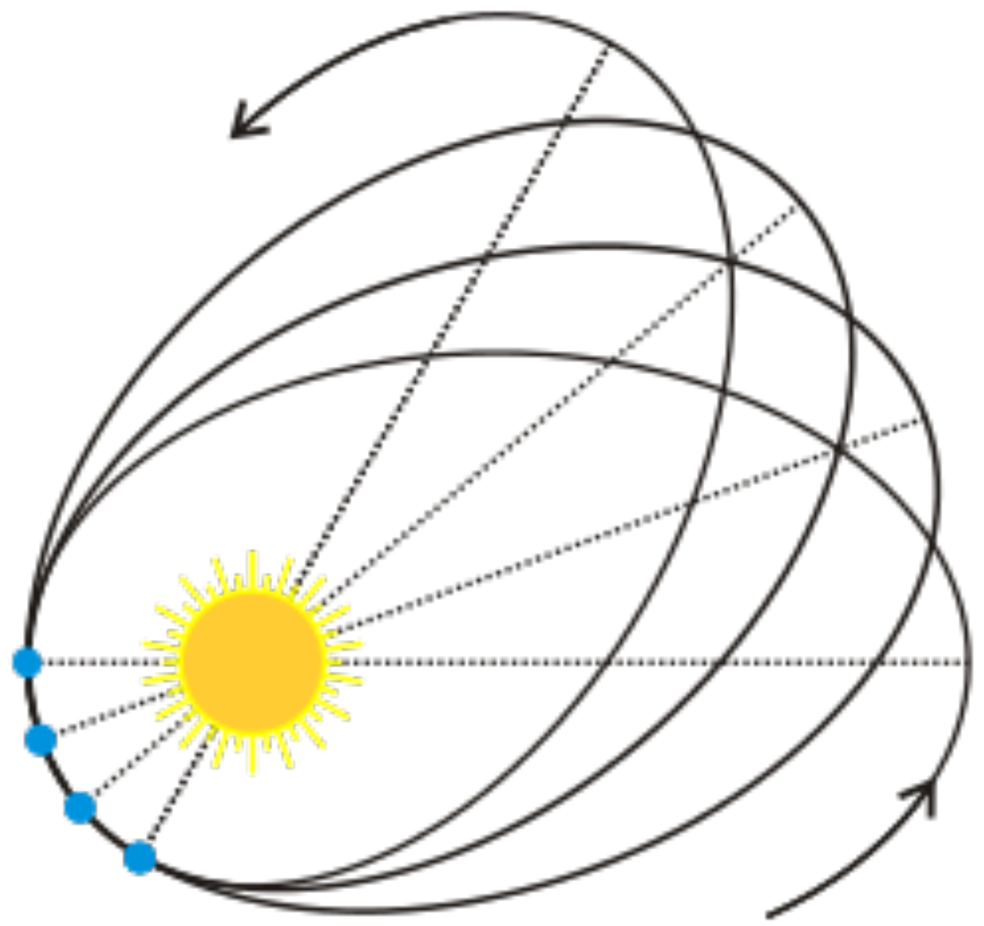
Credit: *AEI/Milde Marketing/Exozet*

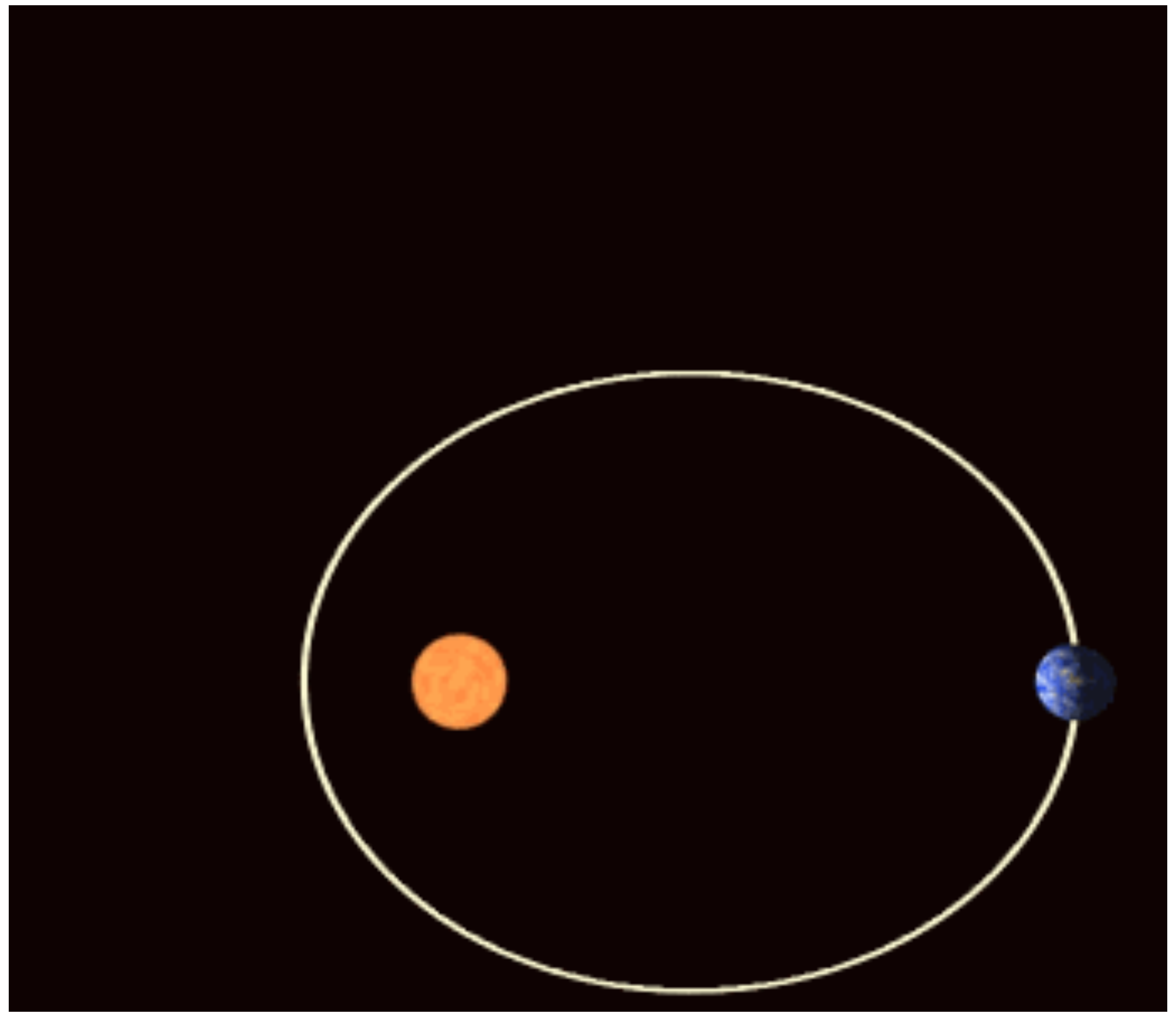
Perihelion Precession of Planets

- The elliptical orbits of planets rotate depending on the **distance to the Sun** and the **enclosed mass.**
- **Radial perturbations** δA_R to the central potential changes this precession rate.
- Compare **expected** precession to **observation** to infer the nature of perturbations.

$$\langle \dot{\omega}_p \rangle = \frac{\sqrt{1 - e^2}}{na} \delta A_R$$

$$n = \sqrt{GM/a^3}$$



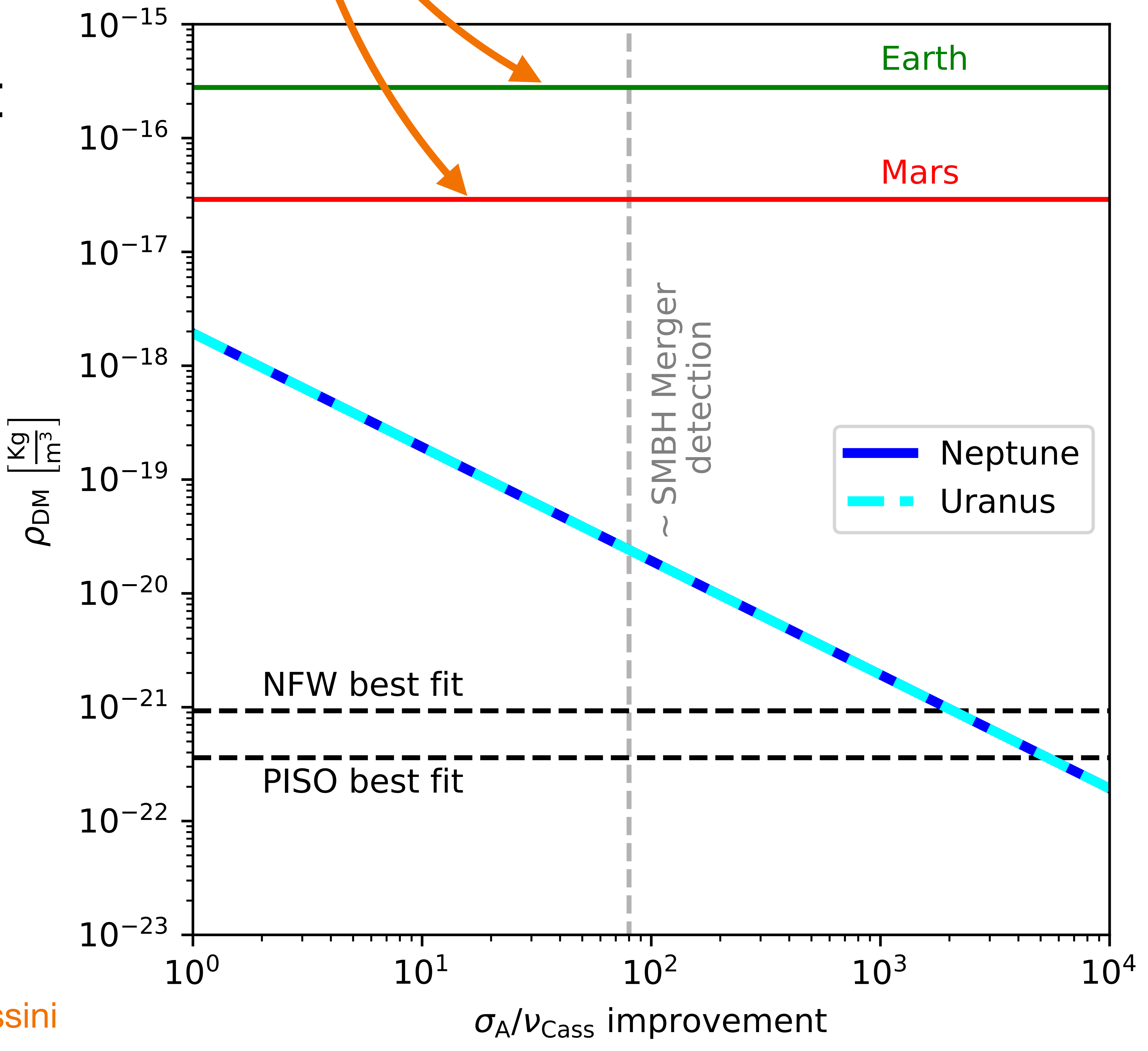


Dark Matter

- Modififications to the precession due to constant density local dark matter would look like:

$$\langle \dot{\omega}_p \rangle = -\frac{\sqrt{1-e^2}}{n} 2\pi G \rho_{\mathrm{DM}}$$

Current bounds from Earth and Mars

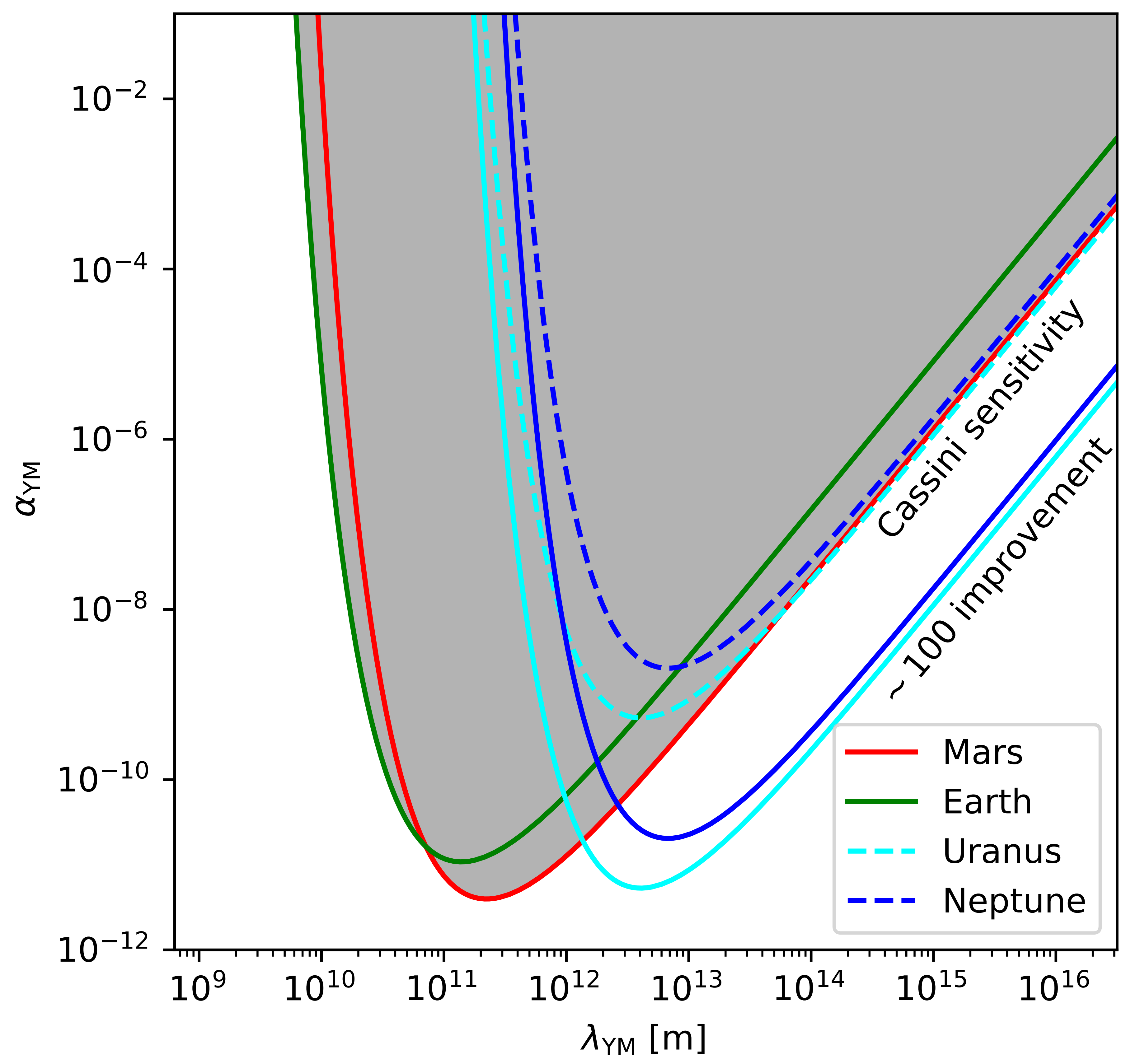


Noise improvement relative to Cassini

Yukawa-like Potential

$$\phi = -\frac{G_\infty M}{r}\left[1 + \alpha_Y \exp\left\{-\frac{r}{\lambda_Y}\right\}\right]$$

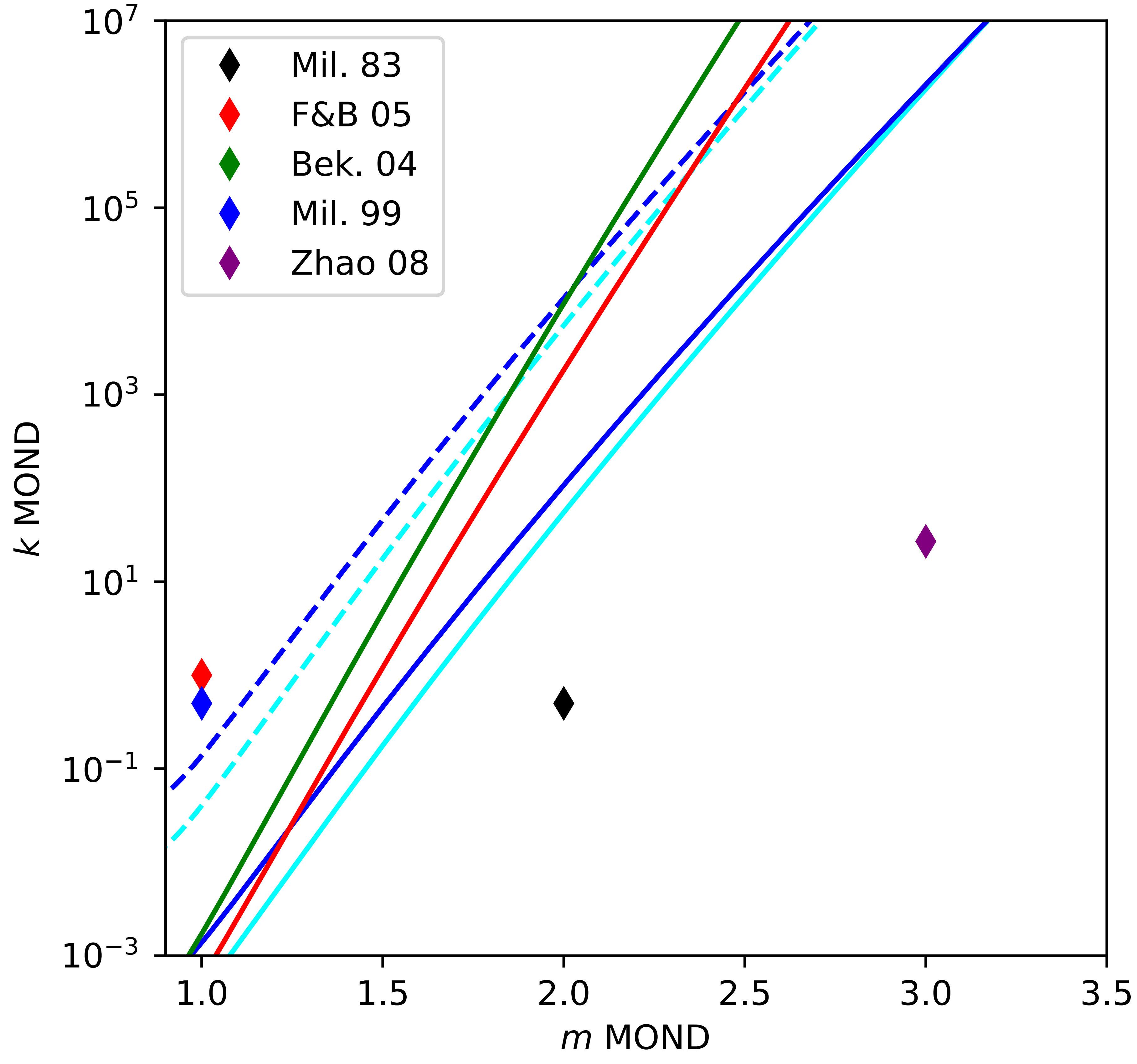
$$\langle\dot{\omega}_{\rm p}\rangle = \alpha_{\rm Y}\left(\frac{a}{\lambda_{\rm Y}}\right)^2 \exp\left\{-\frac{a}{\lambda_{\rm Y}}\right\}\frac{n}{2}\times\left\{1-\frac{1}{8}\left[4-\left(\frac{a}{\lambda}\right)^2\right]e^2+\mathcal{O}\left(e^4\right)\right\}$$



Modified Gravity Models

$$\boldsymbol{g} \simeq \boldsymbol{g}_{\rm N}\left[1 + k_0\left(a_0/\left|\boldsymbol{g}_{\rm N}\right|\right)^m\right]$$

$$\langle\dot{\omega}_{\rm p}\rangle = -k_0 n\left(\frac{a}{r_{\rm M}}\right)^{2m} m\left\{1+e^2[1-m(5-2m)]/4+\mathcal{O}\left(e^4\right)\right\}$$



Conclusions and Summary

- Doppler tracking experiments are a ***cheap*** and ***easy*** way to search for **GW**s from **SBHB**s.
  - Chance of detecting a SBHB merger for the price of LISA's windshield washer fluid.

- Doppler tracking experiments are a ***cheap*** and ***easy*** way to complement **LISA** science.
  - ~10x better source localization compared to LISA alone.

- Doppler tracking experiments are a ***cheap*** and ***easy*** way to **constrain** the local dark sector.