A Long Drive to Outer Space? Put Gravitational Waves on the Radio![1]

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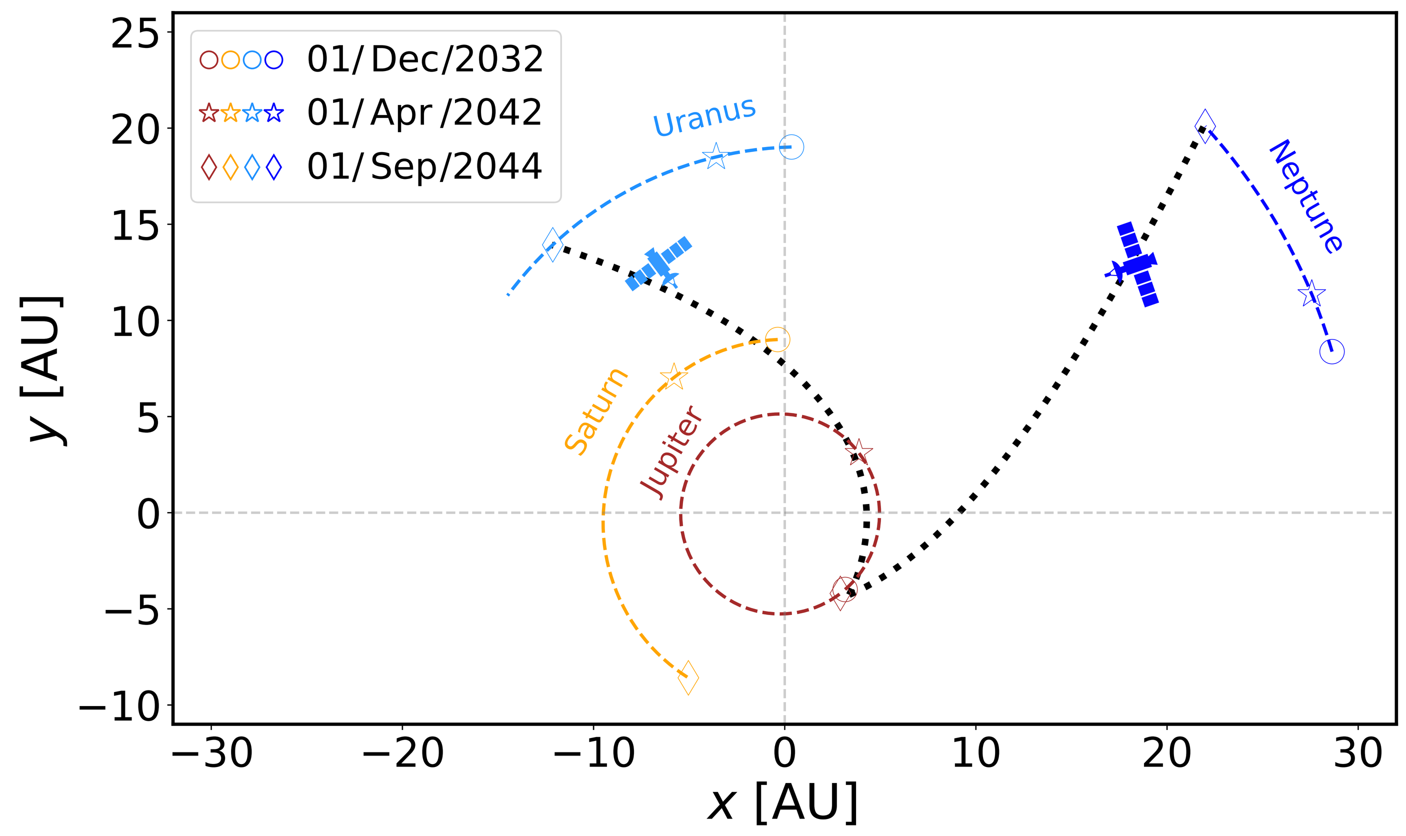
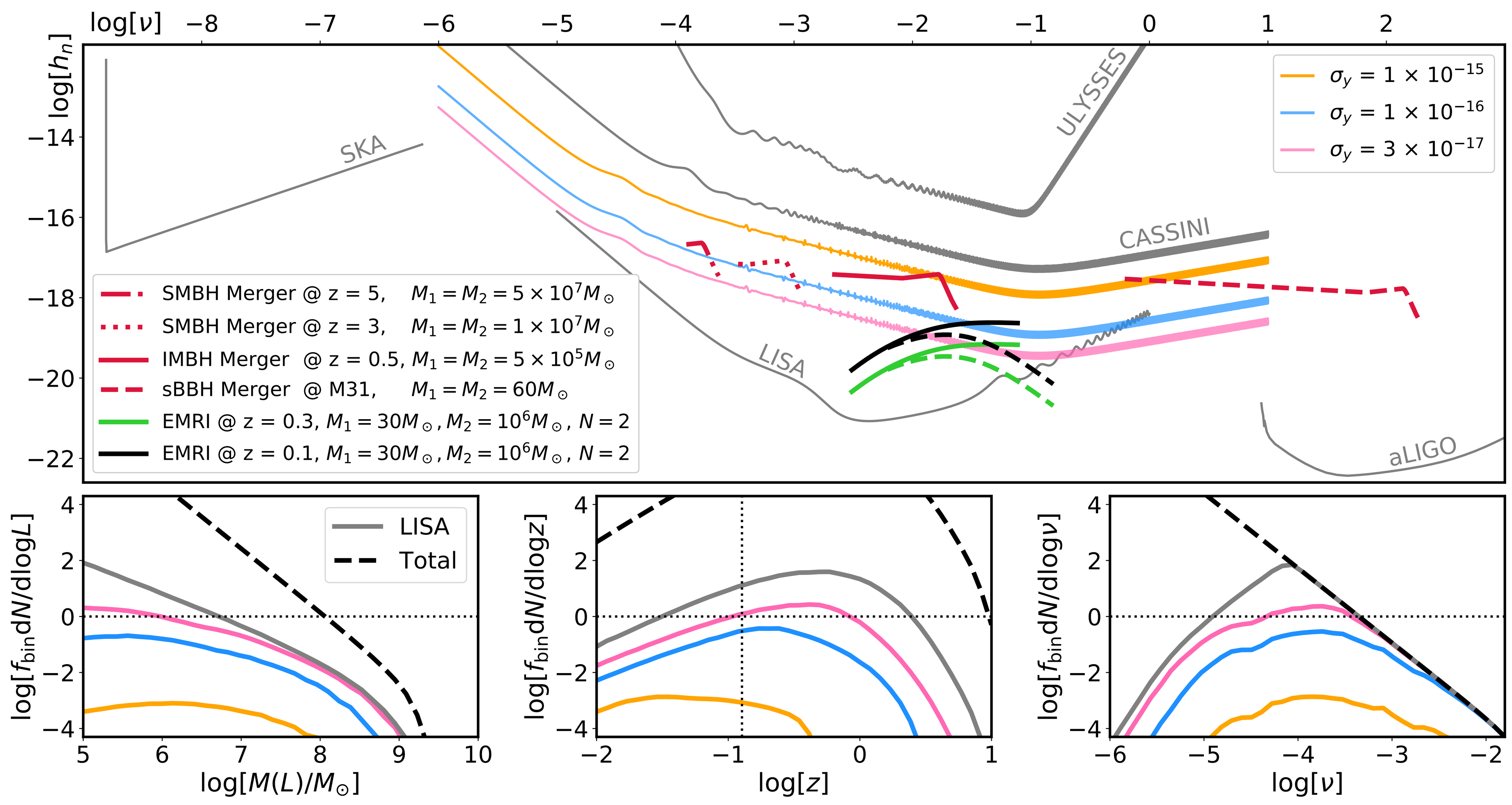
A space mission concept for 2030s

- The ice giants; **Uranus** and **Neptune**, are notoriously underexplored compared to the other Solar System giants: Jupiter and Saturn!
- Only mission to visit the ice giants was **Voyager II** in 1980s, whereas Jupiter and Saturn had many dedicated missions like the **Pioneer** and **Voyager** missions, **Ulysses**, **Galileo**, **Cassini**, **Juno** etc.
- This is unfortunate, because the ice giants have numerous unorthodox features like;[2] strong multi-polar, non-axisymmetric magnetic fields, fast atmospheric zonal winds, abundances of planetary ices, rings, and Neptune's weird moon: TRITON![3]
- There are talks of a possible **dual-mission** to ice giants in 2030s, with a cruise time of $\sim$**10 years**.
- Proposed mission plans have a Jupiter swing-by to reach Uranus and Neptune, as shown here.



*These missions can also potentially detect **Gravitational Waves** and constrain the local **Dark Matter** density!*

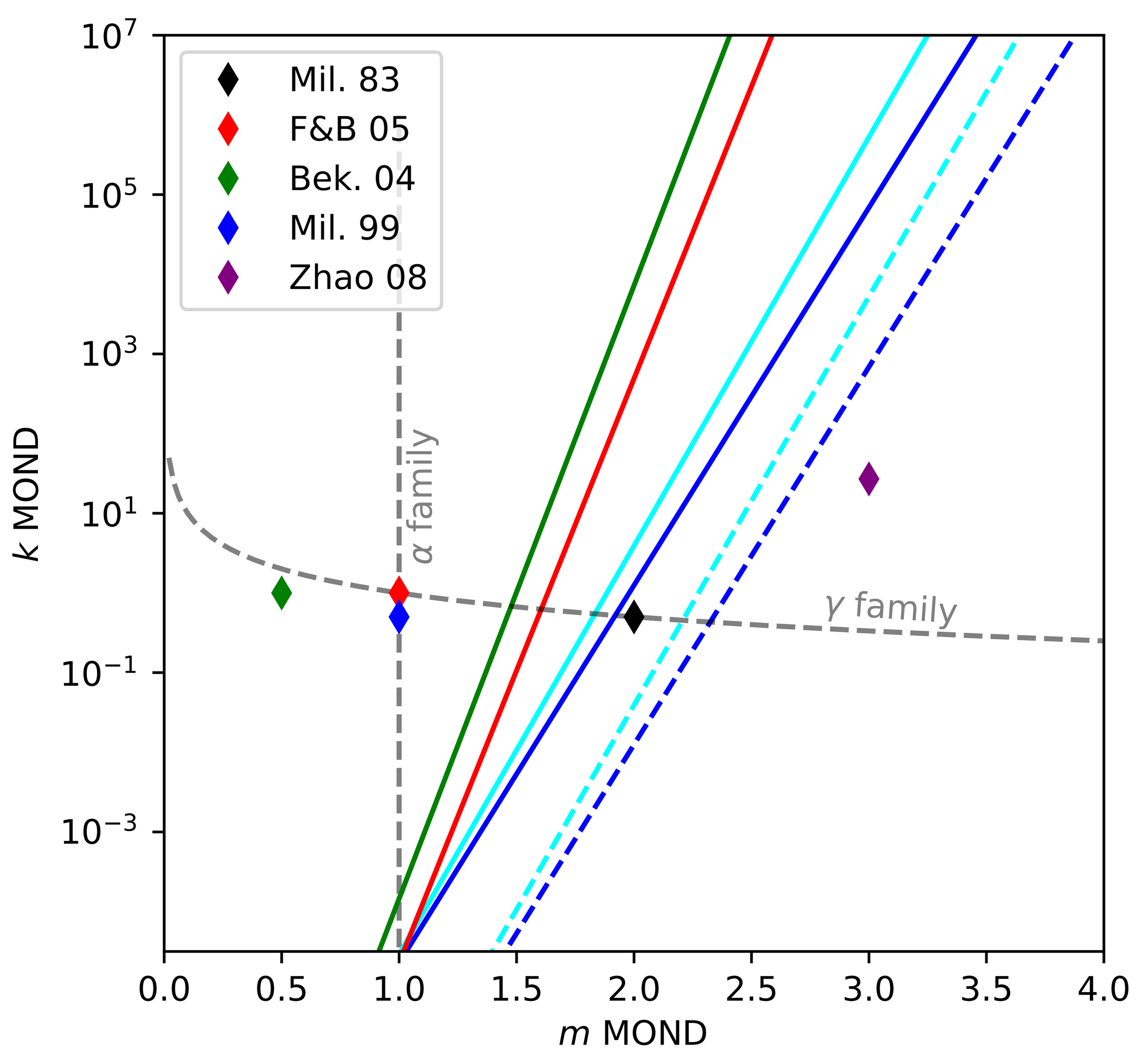
Gravitational Waves and Doppler Tracking



- The cruise time can be utilized to search for **gravitational waves** by observing the **Doppler shift** in the Earth–spacecraft radio link.[4]
- We derive a conservative estimate for the detection rate of extreme mass ratio inspirals (**EMRIs**), supermassive black hole (**SMBH**), and stellar mass binary black hole (**sBBH**) mergers.[5]
- We link the **SMBH** population to the fraction of **quasars** $f_{\rm bin}$ resulting from galaxy mergers that pair **SMBHs** to a **binary**.
- For 10, 40-day observations during the cruise of a **single** spacecraft, $\mathcal{O}(f_{\rm bin}) \approx 0.5$ detections of **SMBH** mergers are likely, if Cassini-era noise is improved by $\sim 10^2$ in the 10^{-5}–10^{-3} Hz range, as shown here.
- Furthermore, ice giant missions combined with the Laser Interferometer Space Antenna (**LISA**) would improve the localization of sources by an order of magnitude compared to LISA by itself.

The Dark Sector

- Both the presence of **dark matter** and the effects of **modified gravity** would influence the **spacecraft trajectory** and the **planetary motions** in the Solar System. A mission to **Uranus** and **Neptune** with good ranging capacity has the potential to improve current constraints on the local **dark matter** density by several orders of magnitude.
- By simulating the **spacecraft trajectory** many times from Jupiter to Uranus and Neptune, while sampling various initial conditions, we can compare the expected Doppler shift in the radio link for different dark sector scenarios.
- Furthermore, **ephemerides** measurements during the orbiting phase of the mission would improve of astrometry of **Uranus** and **Neptune**, and thus provide constraints on the **extra-precession** of ice giants due to an extra radial gravitational perturbations, like **dark matter** or **modified gravity**.[6]
- Preliminary results suggest that combining both methods could potentially match galactic estimates of the local **dark matter** density and rule out various modified gravity scenarios.
- Figure shows the **constraints on modified gravity** from **ephemerides** measurements. Points on the left side of the lines are **ruled out modified gravity theories** by this method. Red and green lines are from **Earth** and **Mars** astrometric measurements. Blue lines show **ice giant** missions with different noise improvements.



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