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## **Deep Space Navigation - Leveraging Experience from Radio Astronomy**

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There is no GPS available when spacecraft venture beyond Earth orbit. Many Earthlings today have forgotten that there are other ways to find their place and direction. Indeed, some of the most venerable of these methods use observations of the Sun by day and stars by night to guide us.

For more than fifty years, we have navigated our deep space missions using a suite of techniques that mostly derive from those used in astronomy—and mainly radio astronomy. The reason that radio astronomy is so important is that our spacecraft carry radio transmitters that are used for returning science data to Earth. In effect, our spacecraft are artificial celestial radio sources.

Some of our navigation tools measure spacecraft position by observing the position of these artificial radio sources relative to well-known natural astronomical sources, via the group delay of the observed signal. Others take advantage of the cooperative nature of the spacecraft, measuring round-trip delays in the communication signals as well as Doppler signatures caused by the relative motion of the spacecraft and Earth—somewhat akin to radar techniques.

Indeed, the evolution of these navigational measurements has developed in parallel with improvements in radio astronomy techniques. In return, the Deep Space Network tracking antennas have become some of the most precise radio astronomy instruments – particularly in the Southern hemisphere.

Our presentation will tell this story and also discuss some future exciting developments in deep space navigation.