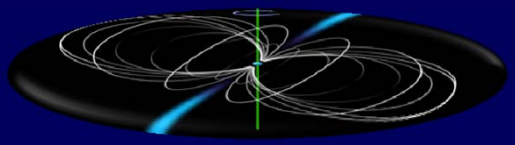

XNAV – Deep Space Navigation with X-ray Pulsars

Towards autonomous on-board spacecraft navigation using X-ray pulsar timing

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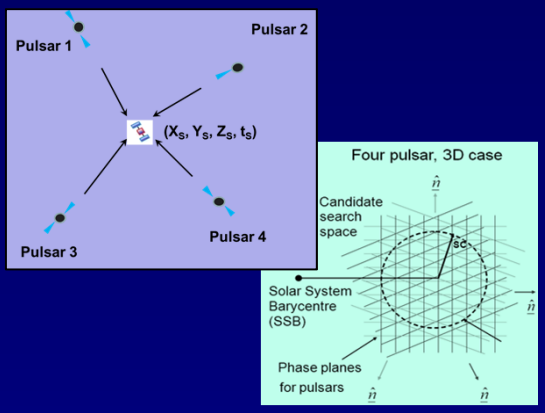
Introduction:
We have recently completed a study contract for the **European Space Agency**, to establish the feasibility of the XNAV technique, considering all primary aspects of the 'system', i.e.: suitable pulsars & their sky distribution; available & future instrumentation; navigation strategies & algorithms; overall performance (e.g. position accuracy).

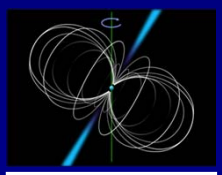
Advantages:
Compared with navigation using e.g. the Deep Space Network (DSN), XNAV can offer:
- Autonomous or semi-autonomous navigation on-board the spacecraft
- 3D position solutions (or 1D/2D solutions to complement DSN)
- Improved deep-space accuracy

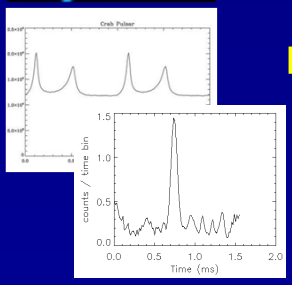


Requirements:
- 3–4 pulsars for full 3D solution
- Low-mass, low-volume, low-power X-ray instrument
- Timing/navigation algorithms
- High-accuracy pulse timing

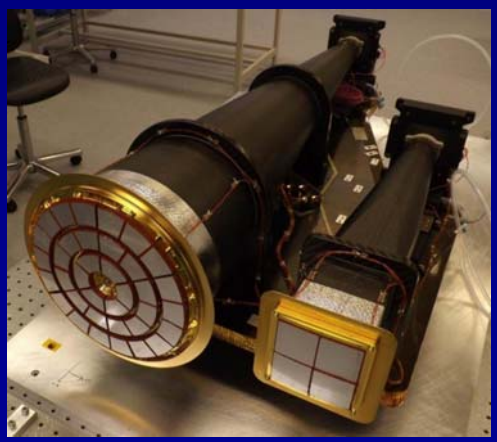
Performance [1D]:
- Simulation results (for PSR B1937+21): ~3 km, T_{int}~1 hr
- Position error reduces as 1/√[integration time, T_{int}]
- Demonstrated ~50 km position error with real data (Crab, see below), short integration times, T_{int}~3 s

XNAV is analogous to GPS: uses pulsars as precise clocks – 'cosmic lighthouses' – to yield spacecraft position & velocity





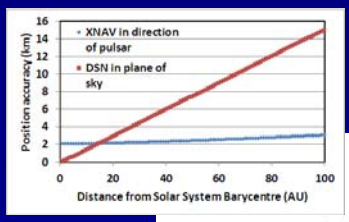
Pulsars, ~10 known, suitable for high-accuracy pulse timing with feasible instrumentation.

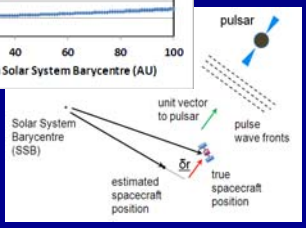


X-ray telescope with low-mass Micro-Channel Plate (MCP) optics: being developed at U.Leicester (PI: G.Fraser) for first use in space on ESA/JAXA BepiColombo mission to Mercury (MIXS – Mercury Imaging X-ray Spectrometer).

Flight model now under construction, delivery to ESA end-2014.

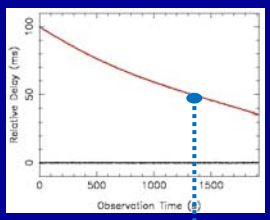
Total instrument mass ~10 kg, focal length 1 m.



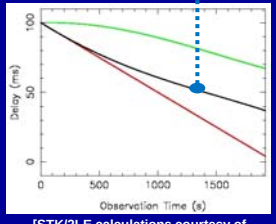


Simulated Errors: Shown for single pulsar 1D case using PSR B1937+21.

Navigation algorithm: principle demonstrated using real data from an X-ray astronomy mission – RXTE Crab-pulsar: pulse Time of Arrival (TOA).



Comparison of barycentric-corrected (BC) (black) & non-BC (red) TOA measurements .



Position of RXTE relative to SSB as projected onto direction of Crab pulsar, in terms of light-travel delay. Motion of spacecraft (black) is due to orbit of RXTE around Earth (green) + orbit of Earth around Sun (red).

[STK/2LE calculations courtesy of N.Bannister/U.Leicester]

For the future - summary:
- Raise TRL
- Develop simplified, lower-cost optic
- Develop navigation algorithms
- Investigate suitable, flight-qualifiable, on-board atomic clock
- Investigate suitable pointing systems/methods (to track pulsars)

Dedicated to the memory of George W. Fraser 1955 - 2014

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