Millisecond Pulsars as Standards: Timing, Positioning and Communication

Clément Vidal[1]

[1]Vrije Universiteit Brussel

November 24, 2022

Abstract

Millisecond Pulsars (MSPs) are likely to be or to become a timing, navigation, and metadata communication standard across the galaxy. Regarding timing, they provide a parallel clock to terrestrial ones, are based on macroscopic neutron stars behavior instead of quantum processes, and they will remain ticking longer than any clock we can construct on Earth. Regarding navigation, X-ray MSPs provide all the necessary ingredients for a Pulsar Positioning System that has many similarities with GPS. In astronautics, X-ray pulsar-based navigation (XNAV) uses a time-of-arrival navigation method comparable to GPS, accurate down to about 100 meters. Regarding metadata communication, MSPs would be a natural metadata coding choice for any galactic communication effort. On Earth, any letter or email contains metadata information about where it comes from, where it goes, and when it was written. We can expect that similar conventions exist for any potential galactic communication. Most messages are likely to be galacto-tagged and pulsar-time-stamped by reference to MSPs. This simple remark opens a simplified SETI search. Given any suspicious message we want to decode, the first step becomes to attempt to decode not the message itself, but its metadata (Vidal 2017). GPS is a technological breakthrough that enables many others: one needs only to think about all the location-based services (LBS) that it has unlocked in our modern societies. The realm of potential galactic LBS is an area totally unexplored, and may well be a key to find technosignatures of many kinds. Is GPS a technology? The answer is an obvious yes. Now imagine that we would find around an exoplanet's orbit well-distributed timekeeping devices with an accuracy comparable with atomic clocks, beaming timing information that can be used as a positioning system, just like GPS. Would not we be compelled to check if it is a technosignature? This is exactly the current situation with MSPs, but on a galactic scale. This is why I have proposed ways to test whether the pulsar positioning system is actually an instance of galactic engineering (Vidal 2019). Seeking such a galactic technosignature proof is actually searching for a distributed signal, instead of searching for a localized signal around one particular star or planet. If the search program succeeds, it would lead to the discovery of extraterrestrial intelligence, through their engineered timing and navigation system. References: Vidal, C. 2017. "Millisecond Pulsars as Standards: Timing, Positioning and Communication." Proceedings of the International Astronomical Union 13 (S337): 418–19. doi:10.1017/S1743921317008596. https://arxiv.org/abs/1711.06036. (where this poster was first presented) Vidal, C. 2019. "Pulsar Positioning System: A Quest for Evidence of Extraterrestrial Engineering." International Journal of Astrobiology 18 (3): 213–34. doi:10.1017/S147355041700043X. https://arxiv.org/abs/1704.03316.

MILLISECOND PULSARS AS STANDARDS:

TIMING, POSITIONING AND COMMUNICATION

Dr Clément Vidal
Center Leo Apostel, Free University of Brussels (VUB)

1. TIMING - *Why use MSPs as clocks?*

Millisecond pulsars (MSPs) are promising as a **galactic timing standard** as they:

- provide a **parallel clock** to terrestrial ones,
- are based on macroscopic **neutron stars** instead of quantum processes
- they will **tick longer** than any Earth clock (Hobbs 2012).

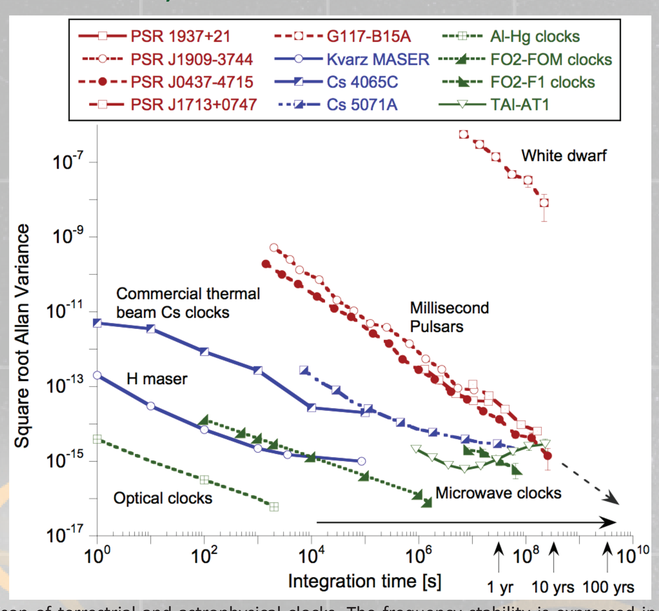


Figure 1 - Comparison of terrestrial and astrophysical clocks. The frequency stability is expressed in terms of square root Allan variance (y-axis), and the x-axis represents the integration time. Optical clocks are currently the best ones, but the long-term trend of the best millisecond pulsar (dashed arrow) shows that MSPs may compete if we allow a long integration time. See (Hartnett and Luiten 2011) for details.

2. POSITIONING - *Why and how to navigate with MSPs?*

MSPs can be used as a **pulsar positioning system** for solar system missions, and arguably for the galaxy. This is known as **X-ray pulsar NAVigation**, or **XNAV** (see e.g. Sheikh et al. 2006; Becker, Bernhardt, and Jessner 2013).

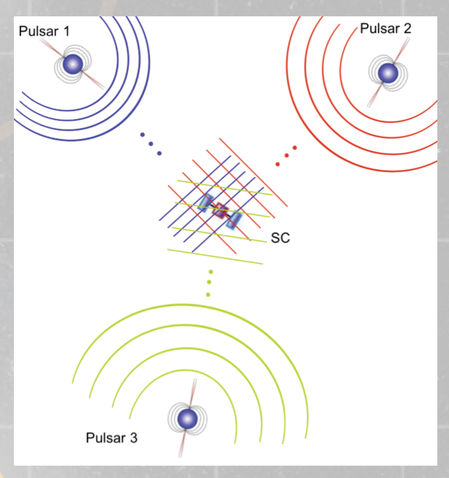


Figure 2 - A three dimensional position fix can be obtained by observing at least three pulsars. Given three well chosen pulsars, there is only one unique set of pulses that solves the location of the spacecraft (SC). Figure adapted from (Sheikh 2005, 200).

Why X-ray MSPs?

Intense - X-rays have short wavelengths, so small detectors can be embarked.

ISM-proof: X-rays can go through the interstellar medium (ISM).

Periodic - the behavior is highly predictable, allowing a low computational load on the spacecraft

Sharp pulse profiles - quick to identify

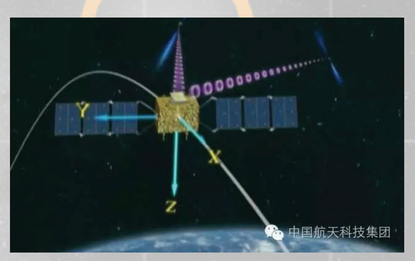
Unique signature - the average pulse profile is unique, this avoids confusion with other sources

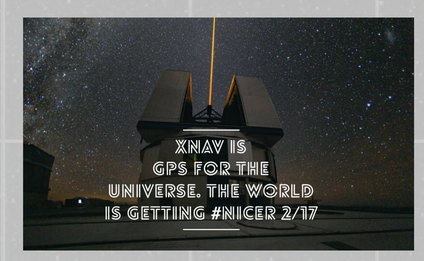
Stable - position, velocity and attitude can be determined with high accuracy

(Sheikh 2005, 34)

Property	GPS	XNAV
Accuracy	~ 3 ns (1 m)	**~ 100 ns (30 m)**
Navigation method	Time-of-Arrival-based	Time-of-Arrival-based
Regular signal for beacon identification	Coarse/Acquisition-code	Stable pulse profile
Passive navigation	Yes	Yes
Absolute navigation	Yes	Yes

Satellite and pulsar navigation are similar in many respects (Buist et al. 2011; Vidal 2017)





China and **USA** are **testing XNAV**
with the XPNAV1 satellite and within NASA's NICER mission.

3. COMMUNICATION - *Why use pulsars for metadata?*

Astrophysical coding suggests to encode interstellar messages according to a shared astrophysical context, such as pulsars. (Cordes and Sullivan 1995, Sullivan and Cordes 1995).

Subject: 50 Years of Pulsars - IAUS 337 - Final Announcement

From: Benjamin Stappers <Ben.Stappers@manchester.ac.uk>

To: Clément Vidal <contact@clemvidal.com>

Mon, 14 Aug 2017 08:15:47 -0700 (PDT)

Content-Type: text/plain; charset="utf-8"

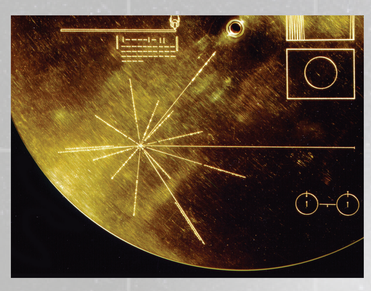
Content-Transfer-Encoding: base64

RGVhciBQYXJ0aWNpcGFudCwNCg0KSXQgaXMgZ
VudGlsIHdlIGNlbGVicmF0ZSA1MCB5ZWFycyBvZiBwdWxzYXJzIQ0KDQpQbGVhc
[...]

Most messages contain metadata such as their origin and destination, and are time-stamped according to a timing standard.

It's much easier to decode metadata information than encoded information.

Humans have already used pulsars to locate the Earth, in the Voyager golden record.



The same localisation method was used back in 1972 in the Pioneer plate (Sagan, Sagan and Drake 1972).

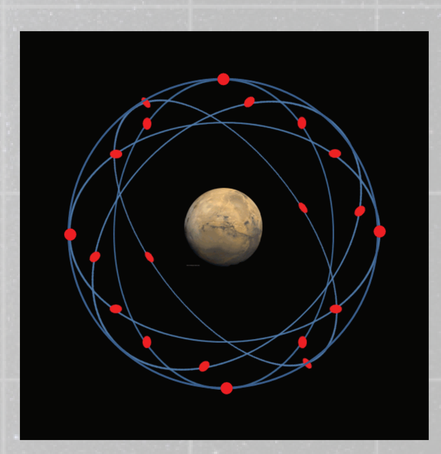
Most messages are likely to be galacto-tagged and pulsar-time-stamped by reference to MSPs (Vidal 2017).

Given any suspicious message we want to decode, the first step becomes to attempt to decode not the message itself, but its metadata.

4. LITTLE GREEN MEN AFTER ALL?

Do MSPs have a distribution that is suitable for galactic navigation, significantly more than a random distribution?

Could extraterrrestrials modulate pulsar signals (Chennamangalam et al. 2015) to engineer a pulsar positioning system? (Vidal 2017)



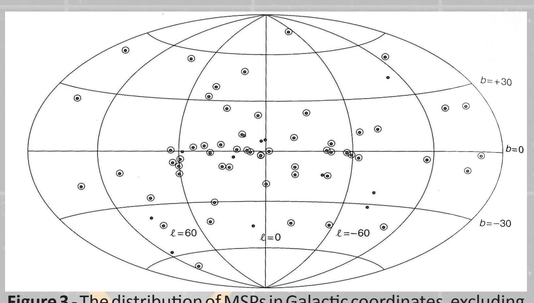


Figure 3 - The distribution of MSPs in Galactic coordinates, excluding those in globular clusters. Binary MSPs are shown by open circles. Figure from (Lyne and Graham-Smith 2012, 116).

Imagine that we would find around Mars' orbit -or an exoplanet- well-distributed timekeeping devices with an accuracy comparable to atomic clocks, beaming timing information that can be used as a **"Mars Positioning System"**, just like GPS.

Wouldn't we be compelled to explore the hypothesis that extraterrestrial intelligence is at play? This is exactly the current situation with millisecond pulsars, but on a galactic scale. For details on how to test this idea, see (Vidal 2017).

5. SUMMARY

Millisecond pulsars hold great promises for the future of humanity, to set **timing**, **positioning** and **communication** standards.

Timing: Astrophysicists already use the timing properties of pulsars (e.g. International Pulsar Timing Array)

Positioning: Astronautics engineers are testing XNAV now.

Communication: We have already used pulsar metadata to message to potential extraterrestrials (golden plate).

There is still a wide array of applications to be explored, as GPS has many applications beyond navigation, e.g. to map the galaxy.

6. REFERENCES

Becker, Werner, Mike G. Bernhardt, and Axel Jessner. 2013. "Autonomous Spacecraft Navigation With Pulsars." *Acta Futura* 7: 11–28. doi:10.2420/AF07.2013.11. http://arxiv.org/abs/1305.4842.

Buist, Peter J., Steven Engelen, Arash Noroozi, Prem Sundaramoorthy, Sandra Verhagen, and Chris Verhoeven. 2011. "Overview of Pulsar Navigation: Past, Present and Future Trends." *Navigation* 58. doi:10.1002/j.2161-4296.2011.tb01798.x.

Chennamangalam, J., A. Siemion, D. R. Lorimer, and D. Werthimer. 2015. "Jumping the Energetics Queue: Modulation of Pulsar Signals by Extraterrestrial Civilizations." *New Astronomy* 34: 245–249. http://arxiv.org/abs/1311.4608.

Cordes, J. M., and W. T. III Sullivan. 1995. "Astrophysical Coding: A New Approach to SETI Signals. I. Signal Design and Wave Propagation." In *Progress in the Search for Extraterrestrial Life*, 74:325–34. ASP Conference Series. http://adsabs.harvard.edu/abs/1995ASPC...74..325C.

Hartnett, John G., and Andre N. Luiten. 2011. "Comparison of Astrophysical and Terrestrial Frequency Standards." *Reviews of Modern Physics* 83 (1): 1–9. doi:10.1103/RevModPhys.83.1. https://arxiv.org/abs/1004.0115.

Hobbs, G., W. Coles, R. N. Manchester, M. J. Keith, R. M. Shannon, D. Chen, M. Bailes, et al. 2012. "Development of a Pulsar-Based Time-Scale." *Monthly Notices of the Royal Astronomical Society* 427 (4): 2780–87. doi:10.1111/j.1365-2966.2012.21946.x.

Lyne, A. G., and F. Graham-Smith. 2012. Pulsar Astronomy. 4th ed. Cambridge Astrophysics Series. Cambridge ; New York: Cambridge University Press.

Sagan, Carl, Linda Salzman Sagan, and Frank Drake. 1972. "A Message from Earth." *Science* 175 (4024): 881–84. doi:10.1126/science.175.4024.881.

Sheikh, Suneel I. 2005. "The Use of Variable Celestial X-Ray Sources for Spacecraft Navigation." PhD Dissertation http://drum.lib.umd.edu/handle/1903/2856.

Sheikh, Suneel I., Darryll J. Pines, Paul S. Ray, Kent S. Wood, Michael N. Lovellette, and Michael T. Wolff. 2006. "Spacecraft Navigation Using X-Ray Pulsars." *Journal of Guidance, Control, and Dynamics* 29 (1): 49–63. doi:10.2514/1.13331. http://www.asterlabs.com/publications/2006/Sheikh_et_al,_AIAA_JGCD_Jan_Feb_2006.pdf.

Sullivan, W. T. III, and J. M. Cordes. 1995. "Astrophysical Coding: A New Approach to SETI Signals. II. Information About the Sender's Environment." In *Progress in the Search for Extraterrestrial Life*, 74:337–42. ASP Conference Series. http://adsabs.harvard.edu/abs/1995ASPC...74..337S.

Vidal, C. 2017. "Pulsar Positioning System: A Quest for Evidence of Extraterrestrial Engineering." *International Journal of Astrobiology*, In press. https://arxiv.org/abs/1704.03316.