Présentation de l'article

NANOGrav 12.5 years Data Set

Search for an Isotropic Stochastic Gravitational Wave Background

D. Verkindt
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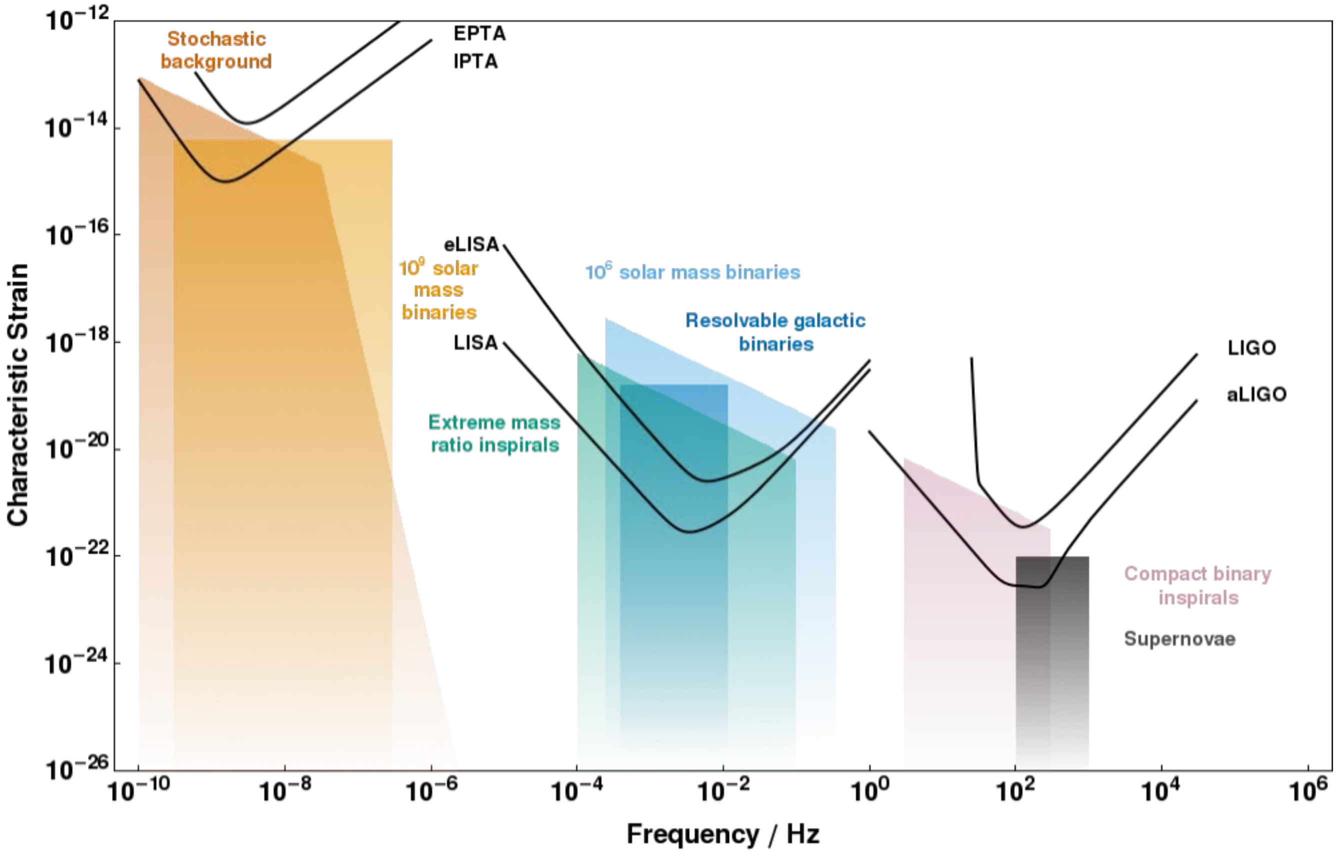
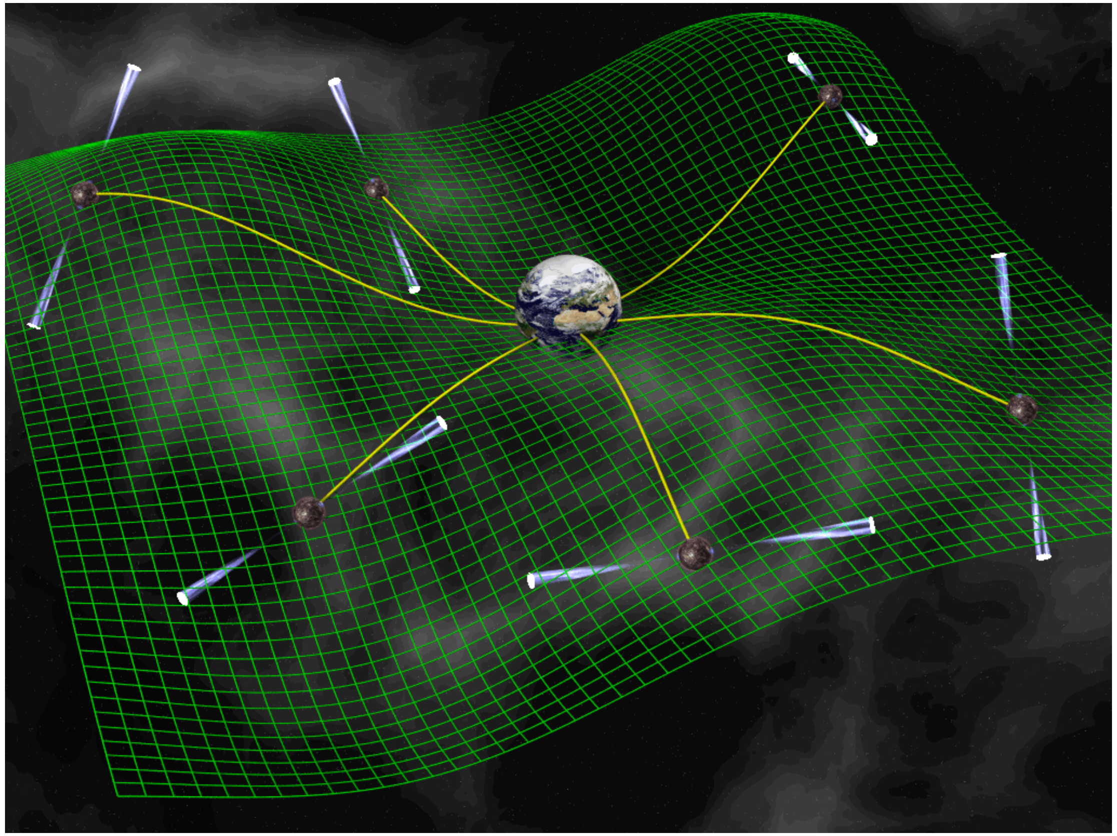
La collaboration NANOGrav





La collaboration NANOGrav utilise les données d'un PTA (Pulsar Timing Array) pour y détecter les effets d'une onde gravitationnelle très basse fréquence sur des signaux de pulsars.

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The NANOGrav 12.5-year Data Set: Search For An Isotropic Stochastic Gravitational-Wave Background

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The NANOGrav Collaboration

https://arxiv.org/pdf/2009.04496.pdf

ABSTRACT

We search for an isotropic stochastic gravitational-wave background (GWB) in the 12:5-year pulsar timing data set collected by the North American Nanohertz Observatory for Gravitational Waves.
Our analysis finds strong evidence of a stochastic process, modeled as a power-law, with common amplitude and spectral slope across pulsars.
Under our fiducial model, the Bayesian posterior of the amplitude for an $f^{-2/3}$ power-law spectrum, expressed as the characteristic GW strain, has median $1.92\ 10^{-15}$
and 5%-95% quantiles of $1.37\text{-}2.67\ 10^{-15}$ at a reference frequency of $f_{yr} = 1\ yr^{-1}$;
the Bayes factor in favor of the common-spectrum process versus independent red-noise processes in each pulsar exceeds 10000.
However, we find no statistically significant evidence that this process has quadrupolar spatial correlations, which we would consider necessary to claim a GWB detection consistent with general relativity.
We find that the process has neither monopolar nor dipolar correlations, which may arise from, for example, reference clock or solar system ephemeris systematics, respectively. The amplitude posterior has significant support above previously reported upper limits; we explain this in terms of the Bayesian priors assumed for intrinsic pulsar red noise. We examine potential implications for the supermassive black hole binary population under the hypothesis that the signal is indeed astrophysical in nature.

2.1. Observations

We used the 305-m Arecibo Observatory (Arecibo or AO) and the 100-m Green Bank Telescope (GBT) to observe the pulsars.
Arecibo observed all sources that lie within its declination range (0 < < +39),
while GBT observed those sources that lie outside of Arecibo's declination range, plus PSRs J1713+0747 and B1937+21.
Most sources were observed approximately once per month.
Six pulsars were observed weekly as part of a high-cadence observing campaign, which began at the GBT in 2013 and at AO in 2015 with the goal of improving our sensitivity to individual GW sources (Burt et al. 2011; Christy et al. 2014):
J0030+0451, J1640+2224, J1713+0747, J1909 3744, J2043+1711, and J2317+1439.

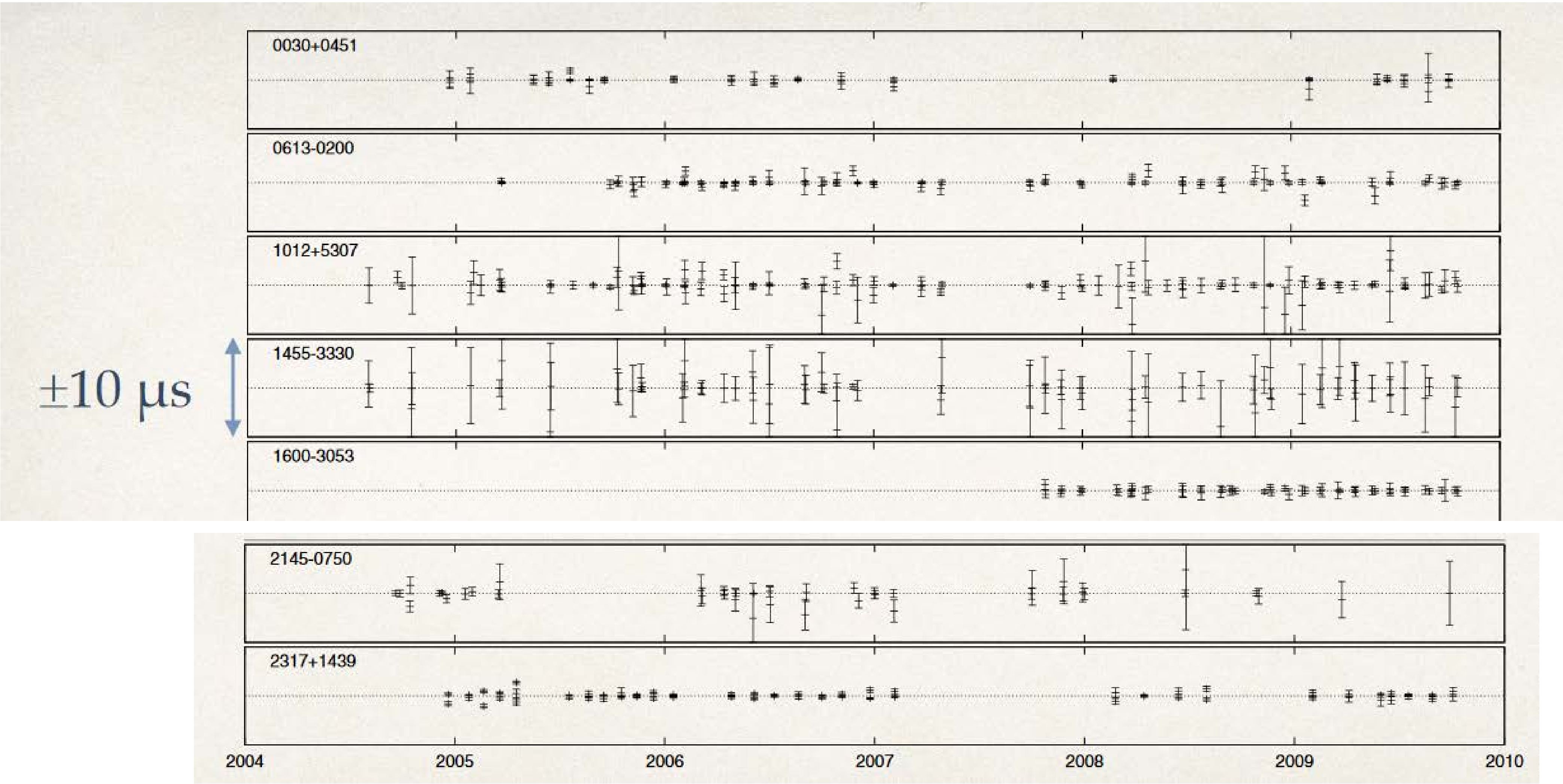
Principe de la détection

Mesurer les variations de la période des signaux des pulsars.

Signal à détecter:
une modification commune des signaux des pulsars

Principaux « faux signaux » (bruit de fond):
Bruit intrinsèque de chaque pulsar
Influence du système solaire (notamment Jupiter)

Principe de la détection



From https://arxiv.org/abs/1201.6641

4. GRAVITATIONAL WAVE BACKGROUND ESTIMATES

Our Bayesian analysis of the 12.5-year data set shows definitive evidence for the presence of a time-correlated stochastic process with a common amplitude A_{CP} and a common spectral index γ_{CP} across all pulsars.
Given this finding, we do not quote an upper limit on a GWB amplitude as in NG9gwb and NG11gwb, but rather report the median value and 90% credible interval of A_{CP}, as well as the $\log_{10}$ Bayes factor for a common-spectrum process vs. pulsar-intrinsic red noise only…
In addition, we characterize the evidence for HD correlations, which we take as the crucial marker of GWB detection, by obtaining the Bayes factors between the models of Table 1.

Evidence d'une variation commune a tous les pulsars d'origine externe

Recherche de corrélations HD caractéristiques d'un bruit de fond d'onde gravitationnelle

A_{CP} : amplitude of common-spectrum process
γ_{CP} : common spectral index

Principaux résultats de l'analyse bayésienne

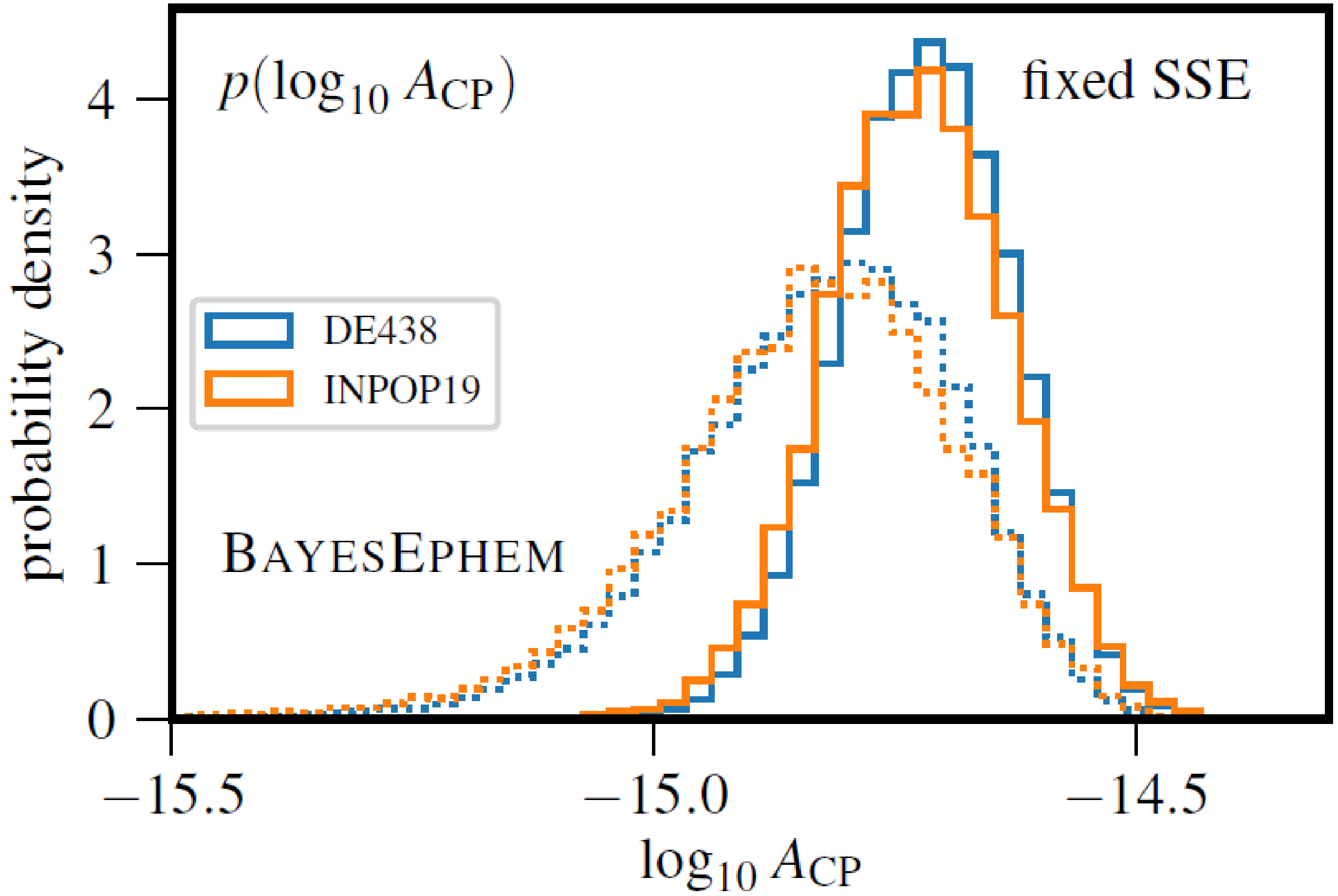
Modification commune 10000 fois plus probable que bruit intrinsèque des pulsars

We find the $\log_{10}$ Bayes factor for a spatially uncorrelated common-spectrum process versus independent red-noise processes in each pulsar to range from 2.7 to 4.5, depending on which solar system ephemeris (SSE) modeling scheme we employ.

Modification commune modélisée comme un bruit en $f^{-2/3}$ a une amplitude de 1.9 10^{-15} à la fréquence 1/31400000 Hz

The posterior on the amplitude of the common spectrum process, A_{CP}, modeled with an $f^{-2/3}$ power law spectrum, has a median of 1.9 10^{-15} with 5%-95% quantiles of 1.4-2.7 10^{-15} at a reference frequency of $f_{yr} = 1\ yr^{-1}$, based on a log-uniform prior and using the latest JPL SSE (DE438, Folkner & Park 2018), which we take as our fiducial model in this paper.

Principaux résultats de l'analyse bayésienne

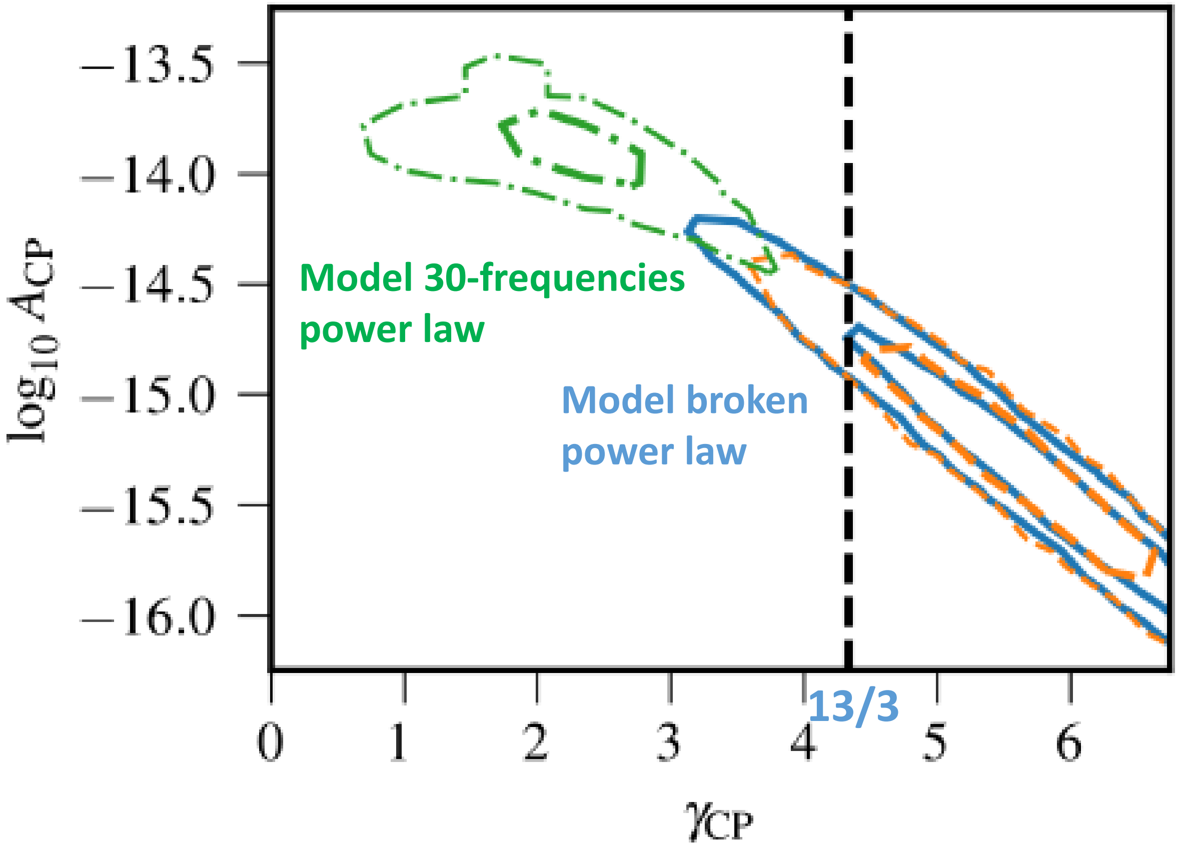


SSE : Solar System Ephemeris
DE438 : latest JPL SSE model
INPOP19: other SSE model with Jupiter

BAYESEPHEM: Bayesian model used

ACP: amplitude of the common spectrum process

Principaux résultats de l'analyse bayésienne



3.1. *Models of time-correlated processes*

The principal results of this paper are referred to a fiducial power-law spectrum of the characteristic GW strain:

$$h_c(f) = A_{\rm GWB} \left(\frac{f}{f_{\rm yr}} \right)^{\alpha}, \quad (1)$$

with $\alpha = -2/3$ for a population of inspiraling SMBHBs in circular orbits whose evolution is dominated by GW emission (Phinney 2001). We performed our analysis in terms of the timing-residual cross-power spectral density

$$S_{ab}(f) = \Gamma_{ab} \frac{A_{\rm GWB}{}^2}{12\pi^2} \left(\frac{f}{f_{\rm yr}} \right)^{-\gamma} f_{\rm yr}^{-3}. \quad (2)$$

where $\gamma = 3 - 2\alpha$ (so the fiducial SMBHB $\alpha = -2/3$ corresponds to $\gamma = 13/3$), and where Γ_{ab} is the overlap reduction function (ORF), which describes average correlations between pulsars a and b in the array as a function of the angle between them. For an isotropic GWB, the ORF is given by Hellings & Downs (1983) and we refer to it casually as "quadrupolar" or "HD" correlations.

6.2. Astrophysical Implications

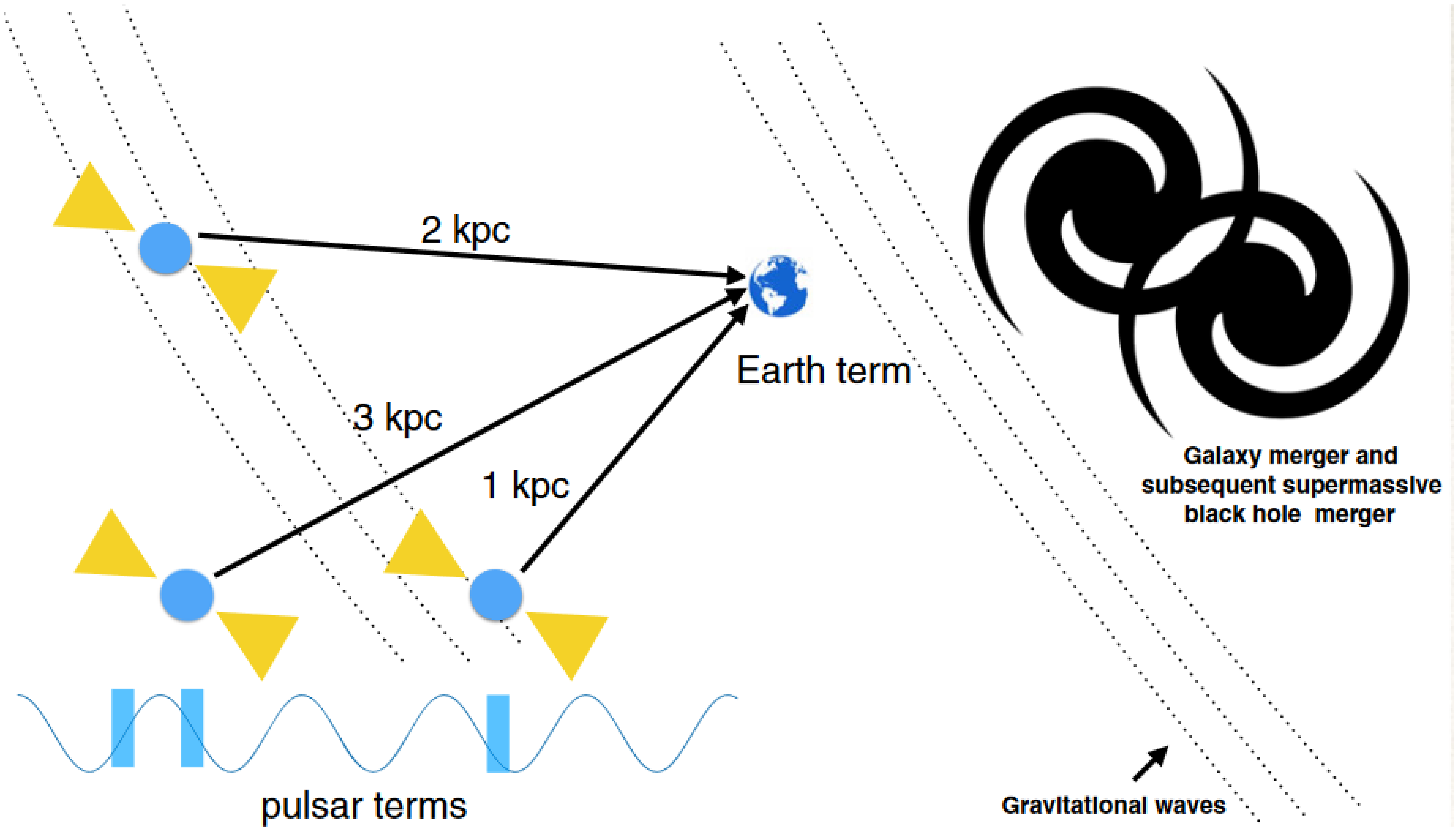
The first hint of a signal from our analysis of NG12 is indeed tantalizing. However, without definite evidence for HD correlations in the recovered common-spectrum process, there is little we can say about the physical origin of this signal.
Models have been proposed which give rise to a GWB in the nanohertz frequency range (1-100 nHz) through either
primordial GWs from inflation (Grishchuk 1975; Lasky et al. 2016),
bursts from networks of cosmic strings (Siemens et al. 2007; Blanco-Pillado et al. 2018),
or the mergers of SMBHBs (Rajagopal & Romani 1995; Phinney 2001; Jae & Backer 2003; Wyithe & Loeb 2003).
Black hole mergers are likely the most studied source, though what fraction (if any) of galaxy mergers are able to produce coalescing SMBHBs is virtually unconstrained.

If the common spectrum process is due to SMBHBs, it would be the first definitive demonstration that SMBHBs are able to form, reach sub-parsec separations, and eventually coalesce due to GW emission.

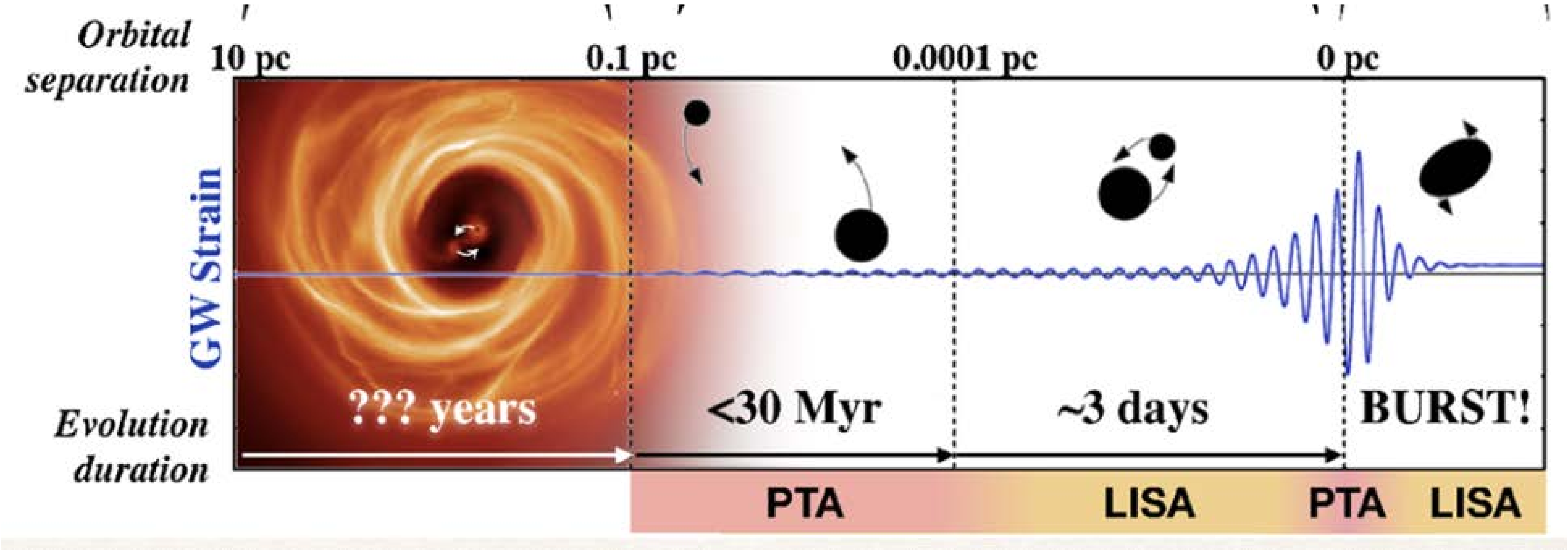
Pas de conclusion hâtive sur l'origine astrophysique du signal

Mais scenario préféré: SuperMassive Black Holes Mergers

SMBH : source astrophysique préférée



SMBH : source astrophysique préférée



PTA: Pulsar Timing Array
LISA: Détecteur d'ondes gravitationnelles dans l'espace, vers 2030-2035
1 pc = 1 parsec = 3.26 années-lumière

6.3. Expectations for the Future

The analysis of NANOGrav pulsar timing data presented in this paper is the first PTA search to show definite evidence for a common-spectrum stochastic signal across an array of pulsars.
However, evidence for the tell-tale quadrupolar HD-correlations is currently lacking, and there are other potential contributors to a common-spectrum process.

A majority of the pulsars with long observational baselines show the strongest evidence for a common-spectrum process; this subset of pulsars could be starting to show similar spin noise with a consistent spectral index.
However, it is unlikely that strong spin noise would appear at a similar amplitude in all millisecond pulsars (Lam et al. 2017). Additionally, the per-pulsar evidence is significantly reduced when we apply BayesEphem, as expected;
there remain other solar system effects for which we do not directly account, such as planetary Shapiro delay (Hobbs & Edwards 2012), that could contribute to the common spectrum process.

Pour plus d'informations:

Article de NANOGrav:
https://arxiv.org/pdf/2009.04496.pdf

Résumé sur les PTA par Réza Ansari lors d'un séminaire à l'Irfu (CEA Octobre 2020)
http://irfu.cea.fr/Phocea/Vie_des_labos/Seminaires/index.php?id=4592

Astrophysics of NanoHertz GW
https://arxiv.org/abs/1811.08826