MODERN ASTRONOMY: FROM THE EARLY UNIVERSE TO EXOPLANETS AND BLACK HOLES

Length of day multifractal dynamics

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Abstract. In this work, the power spectral densities (PSD) of several combined and instrumental length of day (LOD) multifractal time series are computed. As a result, a stable power spectrum, practically independent of the type of time series, of multifractal structure is obtained. The power spectrum of the duration of the day can be divided into three frequency bands. For periods of less than three months, the LOD behaves like a power noise with a score close to −1.5. Over periods of three months to three years, LOD behaves almost like white noise. Finally, over periods of more than three years, the LOD also exhibits power noise behavior with a score of about −1.5. It turns out that the revealed structure practically does not depend on the type of time series (combined or instrumental), its length, and the parameters of the method for assessing PSD.

Keywords: Earth: rotation; length of day; fractals

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1 Introduction

As a measure of the speed of the Earth's rotational motion, the duration of the day or length of day (LOD) is traditionally used, that is, the deviation of the instantaneous duration of the average solar day from 86 400 atomic seconds. It is also known, that the LOD time series exhibit a complex structure in which small, but regular, tidal and seasonal fluctuations are superimposed on powerful irregular fluctuations of unknown nature with a characteristic time scale from units to tens of years.

Regular tidal LOD variations are basically due to deformations of the solid Earth under the action of zonal tides. They are well described by simple linear theory of tidal deformation with the use of Love numbers. Typical amplitude of tidal variations are of the order of fractions of millisecond. Regular seasonal LOD fluctuations are due to atmospheric circulation, namely, the motion term of the atsmospheric angular mometum, which is due to variations of zonal atmospheric winds.

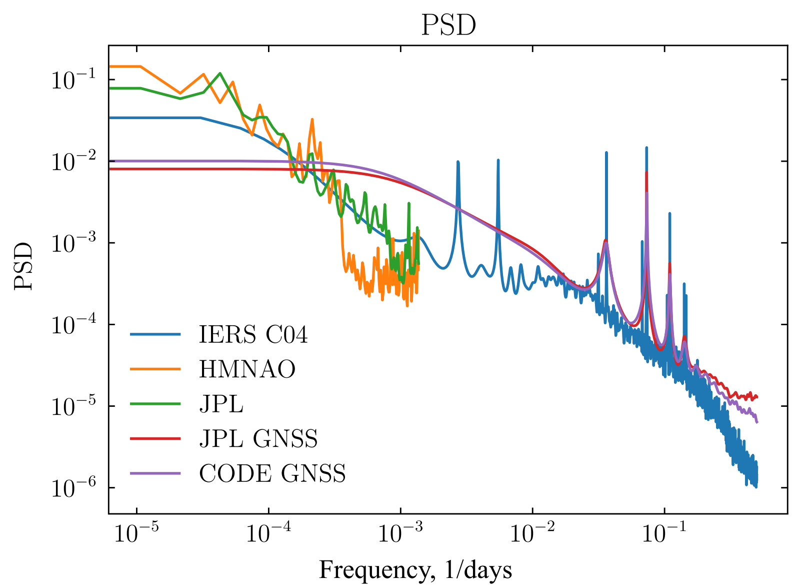

Fig. 1. Power spectrum density for different series.

On the other hand, on the regular tidal and seasonal LOD variations, huge irregular or chaotic variations of decadal timesacle are superimposed. Their nature is still unknown and is probably conditioned by currents in the Earth's liquid core, or variations of the Solar wind, or both of these effects together.

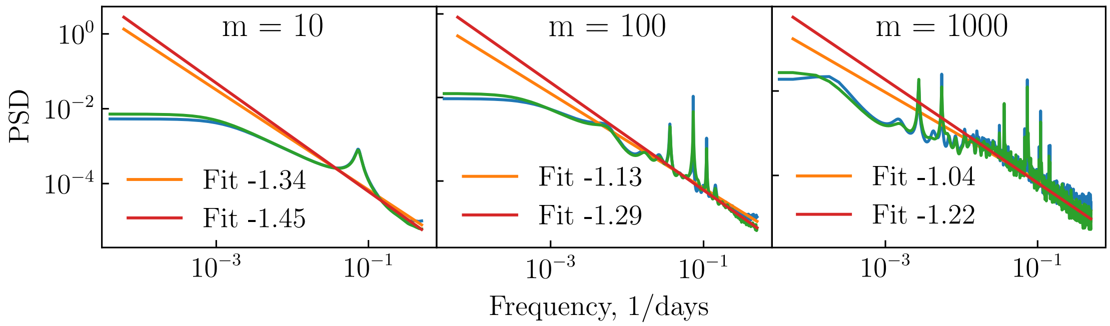

Fig. 2. Linear fit of PSD for different filter length for Burg metod, JPL (blue) and CODE (green).

Putting aside the physical nature of decadal LOD fluctuations, in this work, we concentrate on phenomenological analysis of the LOD time series. Since the appearance of the decadal LOD fluctuations is nonlinear, then it is natural to expect that this phenomenon may exhibit a fractal structure, that is already shown by e.g. Frede & Mazzega (1999a,b). These authors have shown that long term structure of the LOD time series is chaotic and fractal. In this study, we concentrate on multifractal structure of the LOD time series with the use of their spectral analysis.

2 Observational data

We selected five different LOD time series: estimates from the combined Jet Propulsion Laboratory (JPL) Earth orientation series LUNAR97[1], Her Majesty's Nautical Almanac Office (HMNAO) measurement of the Earth's rotation from 720 BC to AD 2015 (Morrison et al. 2021), International Earth Rotation and Reference Systems Service (IERS) combined Earth rotation parameter solution C04, and Center for Orbit Determination in Europe (CODE) operational series[2]. Of all these data, HMNAO and JPL that have been going on since the 17th century are the longest ones. The combined IERS C04 series that have been going on since the 19th century are shorter. Finally, JPL Global Navigation Satellite Systems (GNSS) and CODE GNSS are the instrumental series based on GNSS data alone. They are the shortest ones and started only about 25 years ago.

[1] Gross R.S., Marcus S.L., Dickey J.O., 1993, Determination of the Excess Length-of-Day Since 1630, JPL Open Repository https://hdl.handle.net/2014/35000

[2] Dach R., Schaer S., Daniel A., et al., 2024, CODE final product series for the IGS, Published by Astronomical Institute, University of Bern https://boris.unibe.ch/197025/

It is also important to note that accuracy of these series varies significantly not only from series to series but also may differ for various time periods. Also, the longest series are combined from different observations from old and imprecise Lunar occultations to modern and most precise GNSS and very-long-baseline interferometry (VLBI) data.

3 Spectral analysis of LOD series

The well known Burg or Maximum entropy spectral estimation method is used in this study. The only variation of the standard method implemented here is that we do not limit the filter length, but instead allow it to be as big as as necessary to obtain a decent spectral resolution.

In Fig. 1, the power spectral densities for different LOD time series is shown in logarithmic scale on both axes. It can be seen from the figure that different LOD time series reveal similar power spectra. Differences in spectra may be due to different observational data that was used and degree of smoothing in the series.

In Fig. 2, power spectra for GNSS series are shown for different values of filter length in Burg method. It can be seen that values of the fitted exponents converge well with the increase of filter length. However, JPL and CODE series give slightly different fitted exponents. This effect should be the subject of further analysis.

4 Summary

A stable multifractal structure, practically independent of the type of time series, was revealed in the resulting power spectrum. The power spectrum of the duration of the day can be divided into three frequency ranges. For periods of less than three months and more than three years, LOD behaves like a power noise with a score close to -1.5. For periods from three months to three years, LOD behaves almost like white noise. It turns out that the revealed structure practically does not depend on the type of time series (combined or instrumental), its length, and the parameters of the spectral power estimation method.

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