

Optical monitoring of QSO in the framework of the Gaia space mission

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Abstract: This poster presents the set of optical telescopes used to observe the targets chosen for the link between the ICRF and the future GCRF. We will focus on results obtained with the TJO, Telescopi Joan Oro (Observatori Astronomic del Montsec, Spain), together with an application of the Lomb-Scargle method to the data obtained with the TAROT telescopes (OCA, France, ESO, Chile). A morphological index is defined and applied to the 5000 images obtained during a first observation campaign.

The Gaia astrometric mission of the European Space Agency has been launched the 19th December 2013. It will provide an astrometric catalogue of 500 000 extragalactic sources that could be the basis of a new optical reference frame (the **GCRF**, Gaia Celestial Reference Frame) after the Hipparcos satellite one.

On the other hand, the current International Celestial Reference Frame (**ICRF**) is based on the observations of extragalactic sources at radio wavelength.

The astrometric coordinates of sources in these two reference systems will have roughly the same uncertainty. It is then mandatory to observe a set of common targets at both optical and radio wavelength to link the ICRF with the GCRF.

This work about the link between radio and optical reference system is achieved in the frame of the ICRS Product Center. It has been shown that a clean sample of less than 10000 QSO could stabilize the axes of the future GCRF at a level of 0.5μas/year, with the assumption that the random instability of the sources is less than 20μas.

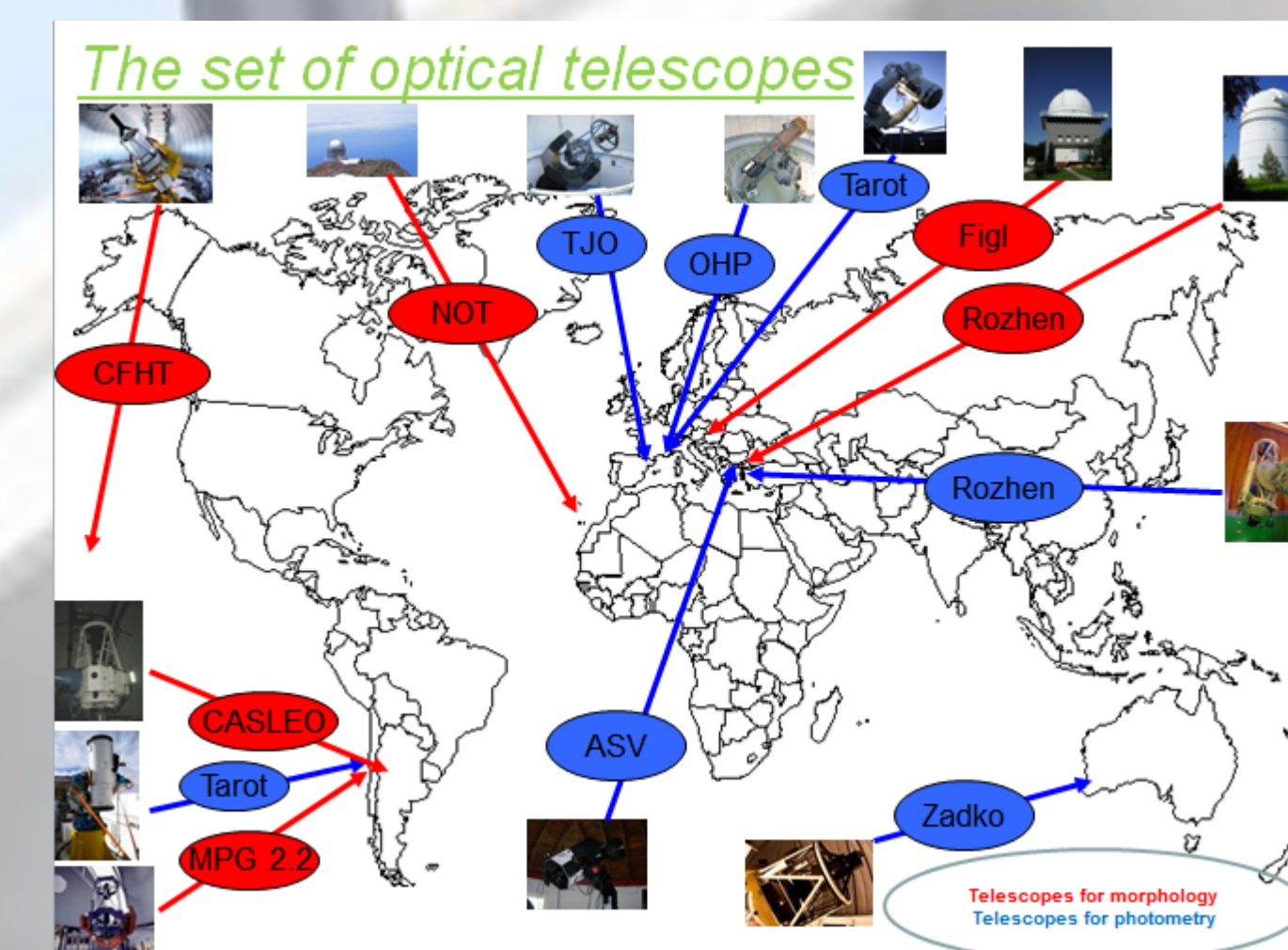
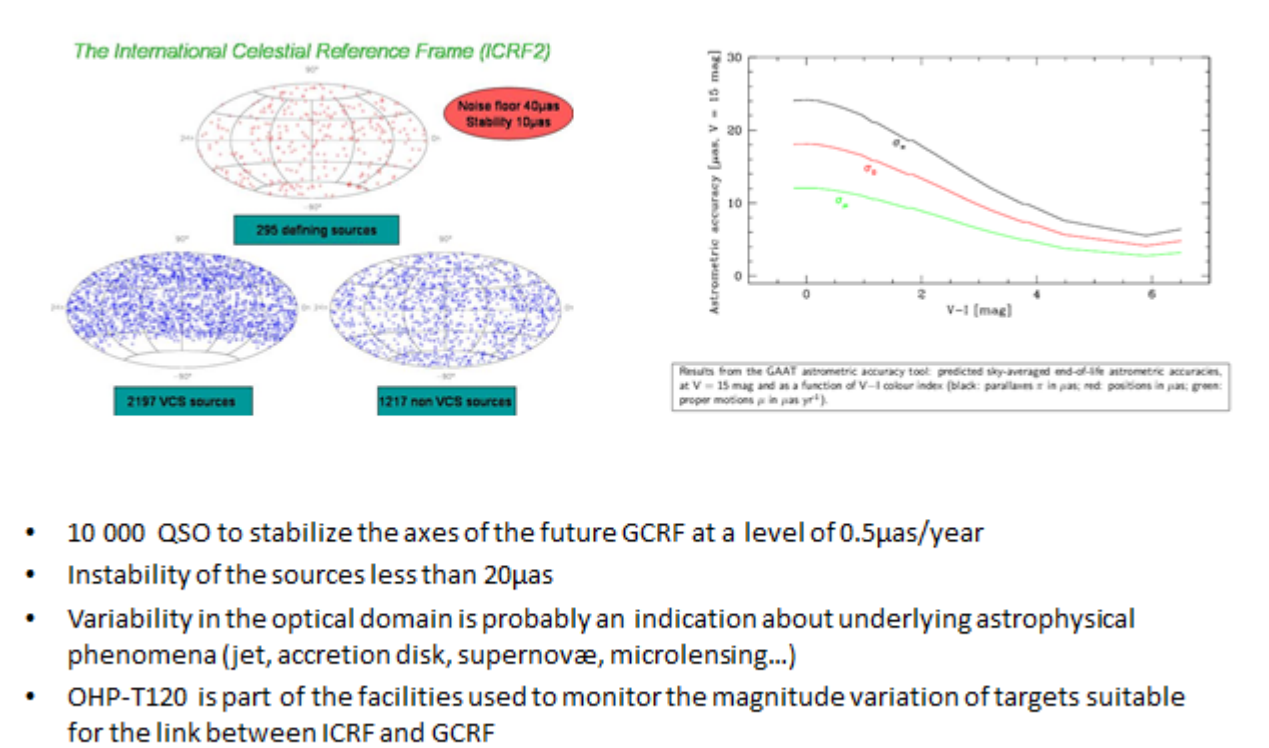
This random instability is a very stringent limit and the chosen targets must be carefully scrutinized both from the point of view of morphology and photometry. In the radio domain the morphology of an extragalactic radio source (structure with size up to the mas level) is correlated to its flux variability (jets). The effect of source structure on position as been studied and has been found as large as tens of mas. In the same way the variability in the optical domain is probably an indication about some underlying astrophysical phenomena. They could be “intrinsic” such as instabilities in the jet or in the accretion disc around the black hole, supernovae explosions, etc... or “extrinsic” such as microlensing.

A set of optical telescopes is currently used both for morphology (large facilities) and for photometry (robotic/manual and small/medium telescopes). This poster is more particularly dedicated to the photometry aspect, the morphology being currently under study and will be presented elsewhere. The photometric program (magnitude monitoring) has begun in 2010 and is currently under progress. Among all the telescopes used, three of them, **The Telescopi Joan Oró (TJO)** from the Observatori Astronòmic del Montsec (OAdM, Spain) and the two twin **TAROT telescopes** from Observatoire de la Côte d'Azur (OCA, France) and European Southern Observatory (ESO, Chile), provide **light curves** that are presented and used in the frame of this poster.

The **Lomb-Scargle periodogram** is a common tool in the frequency analysis of unequally spaced data equivalent to least-squares fitting of sine waves. This method is applied to the time series of magnitude (one obs./2nights during 4 years) to search for periodic phenomena. Results are compared with what is known in term of periodic phenomena for some well-known targets.

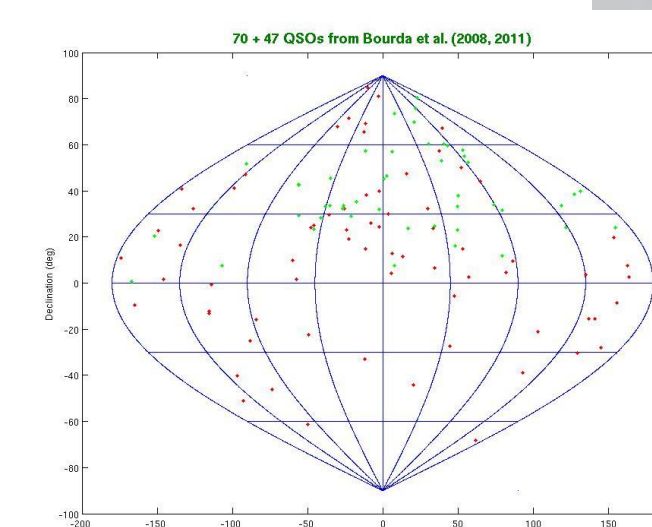
Morphological indexes have been defined in the optical domain to characterize the “pointlikeness” of a target. They are also presented here as an information coming from the Gaia Initial QSO Catalogue (GIQC).

ICRF versus GCRF

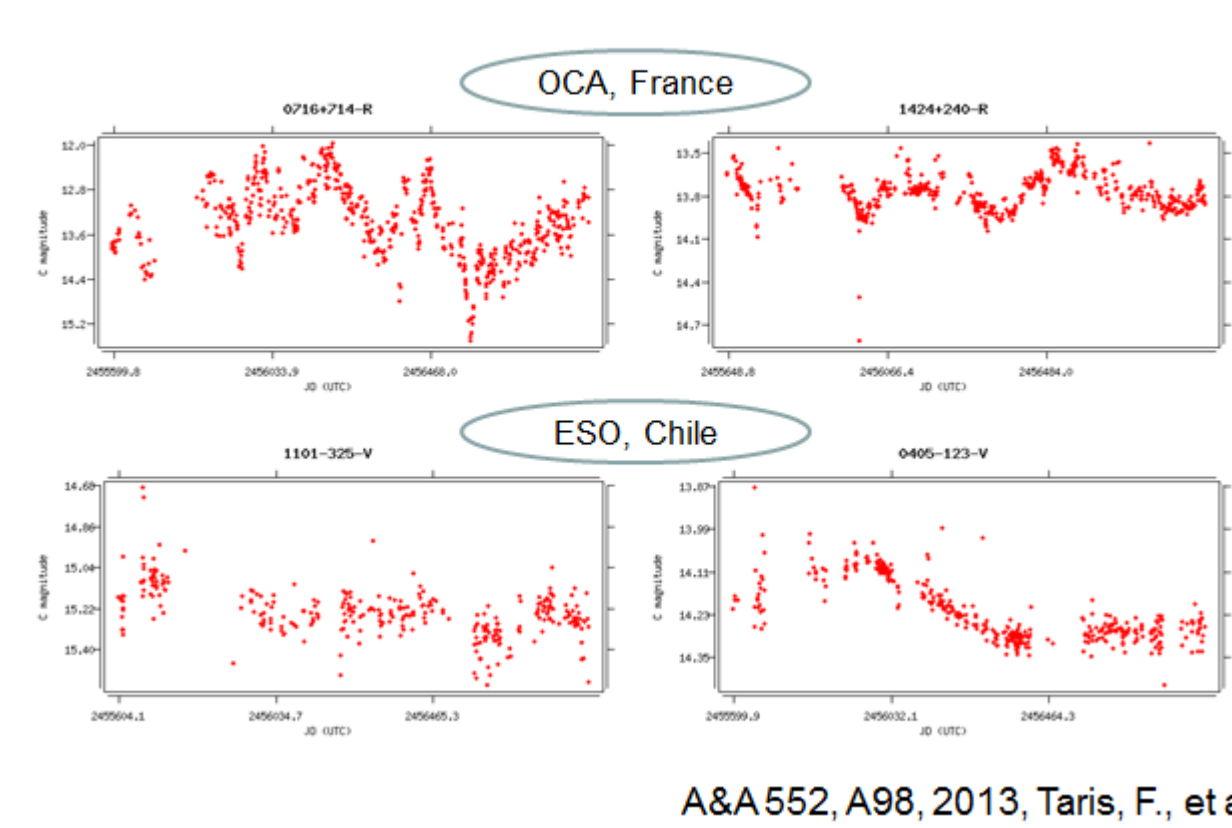


TAROT telescopes

- Twin telescopes in France (OCA) and Chile (ESO)
- Diameter 25 cm, F/D=3.4, 1.86°x1.86° FOV
- Andor CCD cameras (Marconi 4240 back illuminated) 2kx2k chip
- BVRI filters
- Detection limit is about V=17 in 1 min. exposure



TAROT light curves

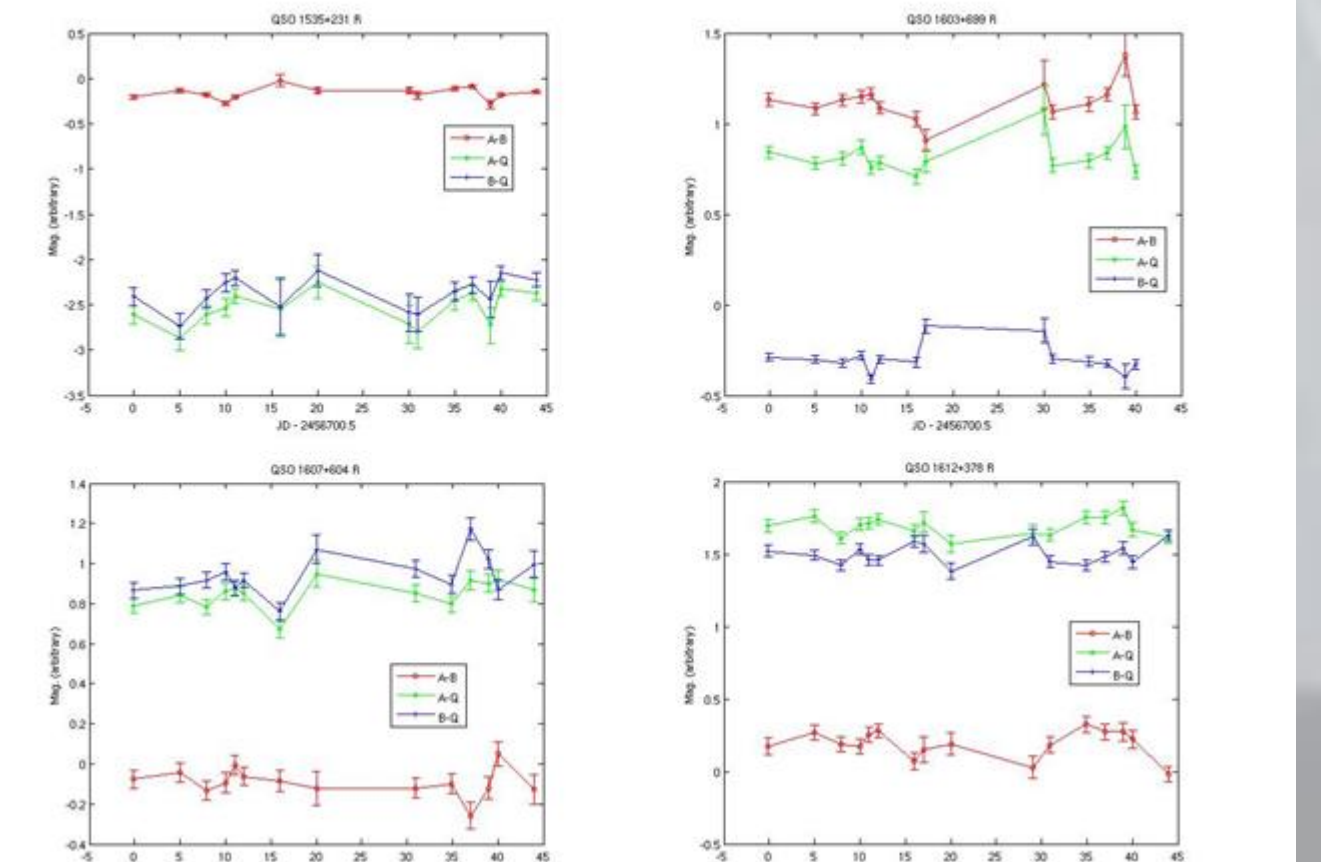


The Telescopi Joan Oró (TJO)

- Spanish robotic telescope
- Largest telescope in Catalonia (0.8-m), F/9.6 optical system in Ritchey-Chrétien configuration
- Fully automatic 6.15-m dome
- CCD camera ProLine 4240 (model PL4240-1-B), with back-illuminated 2kx2k chip
- 5 Johnson-Cousins photometric filters U, B, V, R_c, and I_c



TJO light curves



The Lomb-Scargle method

FAST ALGORITHM FOR SPECTRAL ANALYSIS OF UNEVENLY SAMPLED DATA
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Received 1989 Mar 2; accepted 1989 Aug 17

ABSTRACT
The Lomb-Scargle method performs spectral analysis on unevenly sampled data and is known to be a powerful way to find, and test the significance of, weak periodic signals. The method has previously been thought of as “slow”, requiring of order $10^4 N$ operations to analyze N data points. We show that Fast Fourier Transforms (FFT) can be used in a novel way to make the computation of order $10^2 N \log N$. Despite its use of the FFT, the algorithm is in no way equivalent to conventional FFT periodogram analysis. Subject heading: numerical methods

1. INTRODUCTION
Lomb (1976) and Scargle (1982) developed a novel type of periodogram (Fourier spectrum) analysis, quite powerful for finding, and testing the significance of, weak periodic signals in otherwise random, unevenly sampled data. Horne and Baliunas (1986) have elaborated on the method and discussed its implementation. The method is incorporated into the data analysis package “L” and is widely used in some astronomical specialties. (For a pedagogical discussion, see Press and Teukolsky 1989). Briefly, given a set of data values y_i , $i = 1, \dots, N$ at respective observation times t_i , the Lomb-Scargle periodogram is constructed as follows. First, compute the data’s mean and variance by

$$\bar{y} = \frac{1}{N} \sum_{i=1}^N y_i, \quad \sigma^2 = \frac{1}{N-1} \sum_{i=1}^N (y_i - \bar{y})^2 \quad (1)$$

Second, for each angular frequency $\omega = 2\pi f > 0$ of interest, compute a time-offset τ by

$$\tan(2\omega\tau) = \frac{\sum_{i=1}^N y_i \sin(2\omega t_i)}{\sum_{i=1}^N \cos^2(2\omega t_i - \tau)} \quad (2)$$

Third, the Lomb-Scargle normalized periodogram (spectral power as a function of ω) is defined by

$$P_{LS}(\omega) = \frac{1}{2\sigma^2} \left\{ \left[\sum_{i=1}^N (y_i - \bar{y}) \cos(2\omega t_i - \tau) \right]^2 + \left[\sum_{i=1}^N (y_i - \bar{y}) \sin(2\omega t_i - \tau) \right]^2 \right\} \quad (3)$$

The constant τ makes $P_{LS}(\omega)$ completely independent of shifting all the t_i ’s by any constant. Lomb (1976) showed that this particular choice of offset has another, deeper, effect: it makes equation (3) identical to the equation that one would obtain if one estimated the harmonic content of a data set, at a given frequency ω , by linear least-squares fitting to the model

$$M(t) = A \cos \omega t + B \sin \omega t. \quad (4)$$

CLEAN Algorithm

THE ASTRONOMICAL JOURNAL
VOLUME 91, NUMBER 4
APRIL 1997

TIME SERIES ANALYSIS WITH CLEAN. I. DERIVATION OF A SPECTRUM
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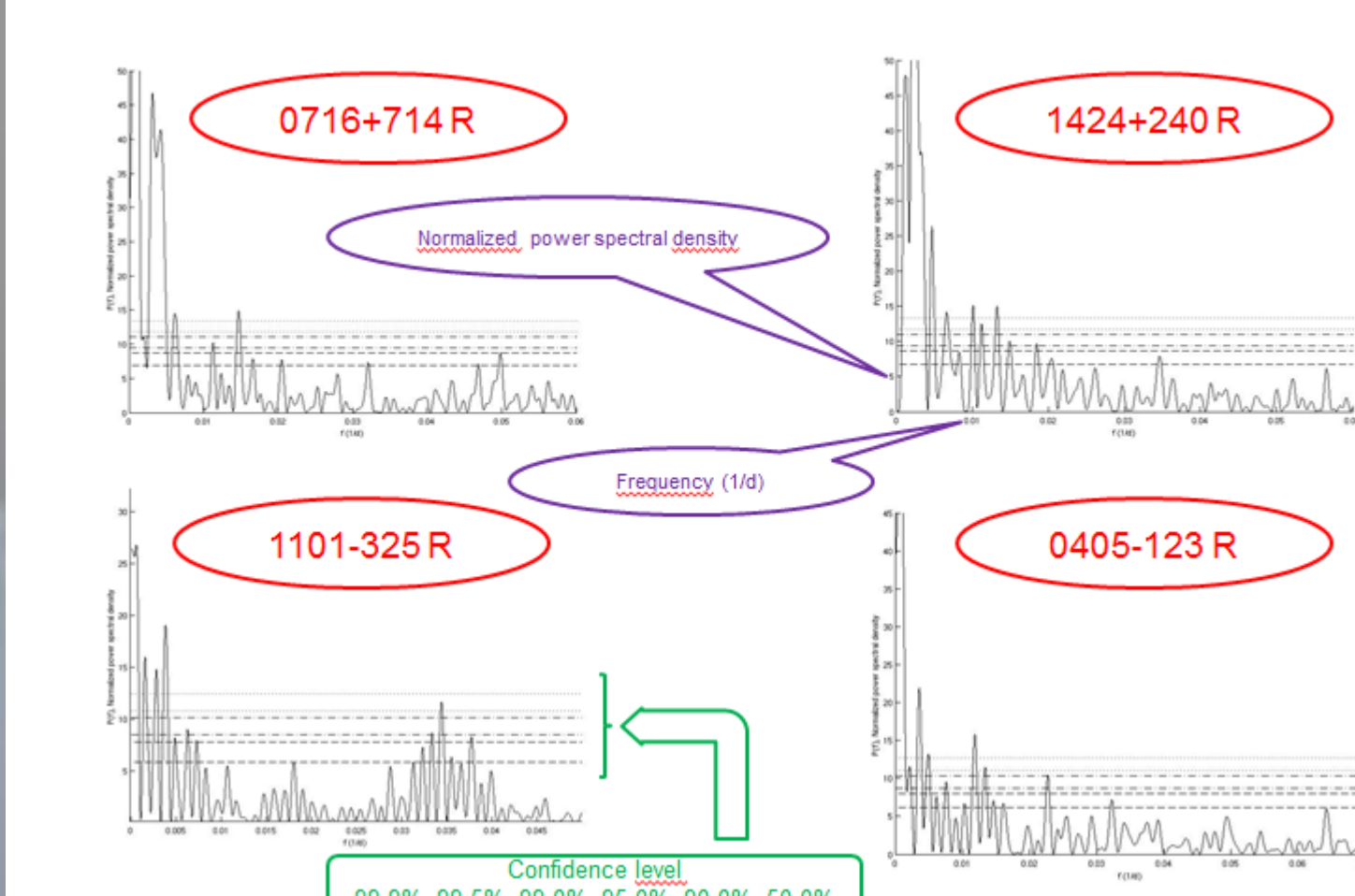
JOSEPH LEHAR AND JOHN W. DREIER
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Received 1 October 1996; revised 22 November 1996

ABSTRACT
We present a method of time-series spectral analysis which is especially useful for unequally spaced data. Based on a complex, one-dimensional version of the CLEAN deconvolution algorithm widely used in two-dimensional image reconstruction, the technique provides a simple way to understand and remove the artifacts introduced by missing data. We describe the method, give several examples, and point out various analogies with the conventional use of CLEAN.

Detected periods

| QSO | Lomb-Scargle Period (99.9% Conf. 99.9% in deg) | RMSC | Roberts et al. Period (95.0% in deg) 95.0% in deg |
|----------|--|------------------------------------|---|
| 0716+714 | 1000 | 4.48E-2 | 1000 |
| | 316 | | 310 |
| | 235 | | 215 |
| | 163 | | |
| | 68 | Astron. Astrophys. 300, 113 (1995) | 68 |
| 1424+240 | 423 | | 442 |
| | 316 | | 347 |
| | 214 | | 216 |
| | 99 | | |
| | 181 | | 159 |
| | 76 | | 76 |
| 0405-123 | 1228 | | 1169 |
| | 277 | | |
| | 84 | | 87 |
| | 201 | | |
| 1101-325 | 1759 | | 2056 |
| | 282 | | |
| | 666 | | 603 |
| | 359 | | 366 |

Lomb-Scargle periodograms



The Gaia Initial QSO Catalogue (GIQC)

