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DIFFUSION COEFFICIENTS OF A NON-LINEAR ASTROPHYSICAL PROCESS: LUIS CARRASCO'S SCIENTIFIC (AND OTHER) CONTRIBUTIONS

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RESUMEN

El fenómeno "Luis Carrasco" en la Astrofísica es un evento que aparece en muchas áreas de la Astronomía, tanto teórica como observacional, así como en la instrumentación astronómica. Es un efecto no-lineal de múltiples constantes de acoplamiento. Para entenderlo, es necesario imbuirnos, no sólo en muchas áreas de la Astronomía, sino en aspectos de la cultura humana y del conocimiento en general. Algunos autores creen que es sólo a través de la interpretación de "muchos mundos" de la Mecánica Cuántica que este fenómeno puede ser entendido. En el trabajo presente, demostraremos su naturaleza fractal, presentaremos una visión panorámica de este efecto global, y estimaremos sus coeficientes de difusión en los regímenes regular e irregular. También mostraremos algunas conexiones con áreas fuera de la Astronomía.

ABSTRACT

The Luis Carrasco phenomenon in Astrophysics is a widespread event that has appeared in many branches of theoretical and observational Astronomy, as well as in astronomical instrumentation. It is an ubiquitous and highly non-linear effect with multiple coupling constants. To understand it, it is necessary to dwell, not only into many areas of Astronomy, but of human culture and knowledge in general. Some authors believe that it is only through the "many-worlds" interpretation of Quantum Mechanics, that this effect can be understood. In this work, we will demonstrate its fractal nature, present a panoramic view of this global effect, and estimate its diffusion coefficients in the regular and irregular regimes. Connections with areas outside Astronomy will be shown.

Key Words: BL Lacertae objects: general — Galaxy: structure — instrumentation: miscellaneous — ISM: dust, extinction — quasars: general — stars: formation

1. ORIGINS

Luis Carrasco has deep roots in México. His family on his paternal side comes from Oaxaca, a place rich in culture and traditions that go back to precolumbian times. On his maternal side, it comes from Sinaloa, which represents the Spanish, forward-looking northern part of México. His father, Lorenzo Carrasco, was a famous architect, his mother, Norma Bazúa, is a poet.

Luis attended school from elementary to high school in Mexico City. He got his B. Sc. studying Physics at the School of Sciences in the Universidad Nacional Autónoma de México (UNAM). The School of Sciences at UNAM was the pioneering school in Physics and Mathematics in México. A prestigious place in which most of the Mexican pioneers in these sciences studied. He then moved to "El Norte" to do his graduate studies at the University of California at Berkeley, where he got his Ph. D. in Astronomy.

From Berkeley, Luis moved to the observatory of Kitt Peak in Arizona, where he worked with Steve Strom, who was to make a lasting impression in the young astronomer apprentice. In 1973 Luis returned to México, to work at the Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE), where Guillermo Haro, of Herbig-Haro objects fame, invited him to help establish a young research group.

In 1974 he moved to the Instituto de Astronomía at UNAM, then the most prestigious and largest group dedicated to astronomical research in México. He worked up his way on the academic echelons, becoming "Investigador titular C", the top most rank, in 1982. From 1987 to 1991, he moved to Ensenada, Baja California, home of the Observatorio Astronómico Nacional at San Pedro Mártir, the foremost observatory in México, where he served as its director.

In 1993 he went back to INAOE, where he played an instrumental part in getting the Large Millimeter Telescope (LMT) started. He was principal scientist for this project, on the Mexican side, from 1992 to

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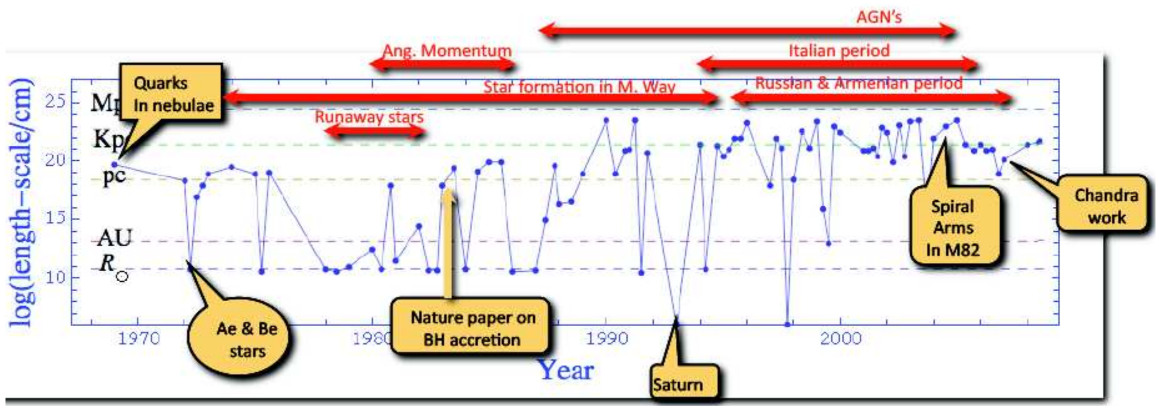

Fig. 1. The published work of Luis Carrasco as a function of time and of length scale of the phenomena studied. Some key publications are indicated, as well as some particular periods which are discussed in the text.

2005. To this day he works at INAOE, where besides research and the time devoted to the LMT, he has had a vigorous teaching program, forming many young researchers, some of whom work at INAOE.

2. RESEARCH

Luis Carrasco's published work consists of over 90 articles spanning 40 years. He started his scientific career off the trodden path: his first paper proposed a method to detect free quarks in diffuse nebulae (Carrasco & Méndez 1969), it is clear that at this early time, the concept of quark confinement had not been well established.

After his swift mingling with quarks, Luis started a very fruitful collaboration with Steve and Karen Strom. In 1973 came out a study of the growth of interstellar dust grains and the anomalous extinction law in the ρ-Ophiuchi cloud (Carrasco, Strom, & Strom 1973). This work became a classic in the field. Another much cited work comes from this early epoch, a work with the Stroms and a good old buddy of Luis, Gary Grasdalen, where they posited that Ae and Be stars are very young (Strom et al. 1972).

My worldline crossed that of Luis in the late 70's, when I worked on my B. Sc. thesis under his supervision. In 1982 we published an article on the rotation of O-type stars, adding support to Luis's idea that runaway O stars are different than run-of-the-mill main sequence stars (Carrasco, Aguilar, & Recillas-Cruz 1982).

Luis has always been very keen on exploring diverse fields and his published work shows it: he has done research on planets, on stars and star formation, on dust and diffuse nebulae, on galaxies and clusters of galaxies. He has even made a quick foray on blazar territory (Carrasco et al. 1985). He has also worked in instrumentation (e.g. Roth et al. 1980) and novel statistical techniques (Mercado & Carrasco 2005). He managed to discover that the good old, edge-on galaxy, M82, has spiral arms (Mayya et al. 2005) and even got time to talk a bit about Astrobiology (Irvine et al. 2002)!

It is interesting to display the published work of Luis as a function of time, and as a function of scale length involved, as it is shown in Figure 1. Here we can see how Luis's interests range from the planetary scale (Hubbard, et al. 1993, 1997) all the way up to the realm of clusters of galaxies at the megaparsec scale (e.g. Cortese et al. 2004).

Like Rufino Tamayo, the famous painter from his home state, Luis's work can also be split in various periods. While Tamayo went from French Modernism, to Expressionism, to Fauvism, to Cubism and then to Figurative abstraction, Luis had his star formation period (mid 70's to mid 90's), his runaway stars period (late 70's to mid 80's), his stellar angular momentum period (late 70's to mid 80's), his AGN period (mid 80's to middle of this decade). He has also had his "Italian period", where Peppo Gavazzi was the inspiration (mid 90's to date) and most recently, his "Russian and Armenian period", where among others, Tovmassian the elder was involved (late 90's to date). Figure 1 has these periods and some landmarks indicated.

2.1. *Diffusion coefficient*

In order to quantify the spread in the scale length of phenomena studied by Luis, we can define a "dispersal velocity" as the time derivative of the data in the previous plot:

$$v_{\rm disp}(t) = \frac{d}{dt}\log(\text{spatial length} - \text{scale})\,. \qquad (1)$$

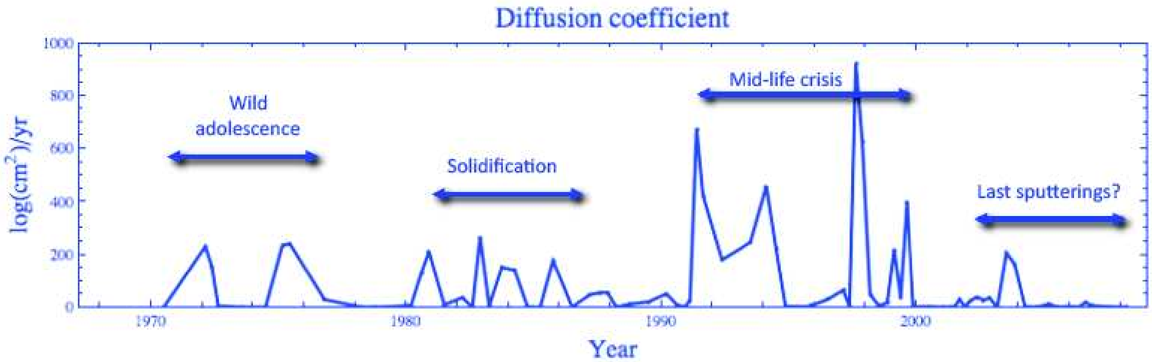

Fig. 2. Diffusion coefficient as a function of time for Luis published work. Several notable periods in this plot are indicated and described in the text.

We can also take the difference between the spatial scale length between successive publications, as the path length of jump from study to study (λ).

From the previous two quantities, we can determine the diffusion coefficient D (Fick 1855), for the spread of Luis among the various spatial scales he has studied along time:

$$D(t) = v_{\rm disp}\lambda\,. \tag{2}$$

Figure 2 presents the resulting diffusion coefficient as a function of time. We can identify several stages in this plot. The curve begins in the decade of the 70's with a couple of large and broad peaks that signal Luis's emergence in science. Let's call this the *Wild adolescence period.* In the 80's a different pace is apparent, Luis's work has settled in a steady pattern of successive narrow peaks. We will call this the *solidification period.* In the 90's, yet a different pattern appears: now we have a broad double peak and several wild peaks with no apparent pattern. We will call this the *Mid-life crisis period.* Finally, during the last decade, we see a tapering off that we will call the *Last sputterings period.* The power of the diffusion coefficient formalism is apparent in this plot, where we can clearly identify the various periods we have shown here, and which would be difficult to spot from the original data in Figure 1.

2.2. *Regular and irregular regimes*

In Galactic Dynamics, a field close to my heart, we recognize two qualitatively different types of motion: regular and irregular orbits (Binney & Tremaine 2008). The former is structured in torii in phase space, the latter lack any such ordered structure (Lichtenberg & Lieberman 1983). A simple way to tell them apart is in Fourier space, since regular orbits have a line spectra which consists of linear combinations of at most three basic frequencies. Irregular orbits spectra are not reducible in this sense (Carpintero & Aguilar 1998). Figure 3 shows the power spectrum of the spatial scale length of Luis's topics of study, as a function of time. It is clear that this is not the simple spectra of integrable systems. In fact, a whole continuum of frequencies, the landmark of chaotic motion, is apparent.

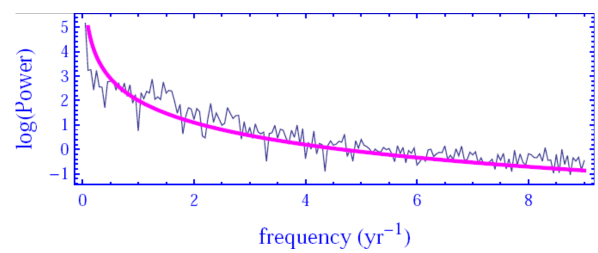

Fig. 3. Power spectrum of the spatial length scale of Figure 1. The thick line is a $(1/f)$ fit.

The thick line in Figure 3 represents a $(1/f)$, "pink noise", or fractal (Mandelbrot & Van Ness 1968) fit, which has equal power per octave. This kind of time behavior that varies of order unity at multiple timescales, is interesting on its own and it may be tempting to seek a deep meaning to it in Luis's psyque (see for instance, Natarajan 2004). Unfortunately for Luis, however, Press (1978) has made a convincing case that its appearance in astronomical phenomena is most likely devoid of a meaningful signal.

2.3. *Fields of interest and coupling constants*

As has been made apparent in the previous section, Luis's work spans many different spatial scale lengths, this implies a multiplicity of fields of interest. Figure 4 presents the number of published works as a function of the spatial scale length. As we can

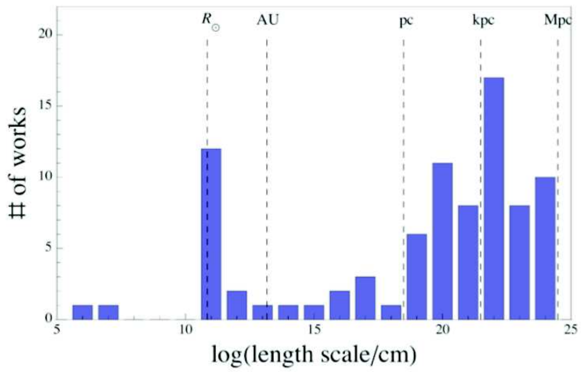

Fig. 4. Number of publications as a function of spatial scale of the studied phenomenon. Although broad, this distribution is skewed toward galactic and extragalactic scales.

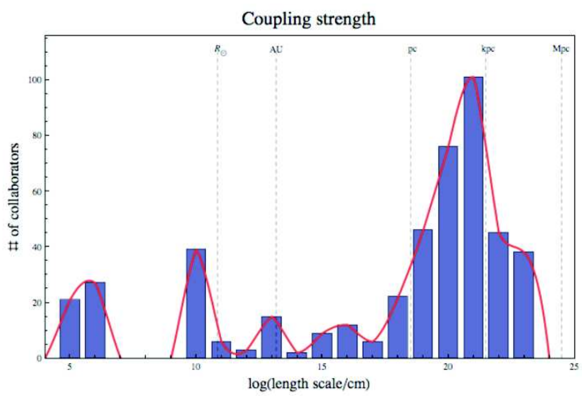

Fig. 5. Number of collaborators as a function of spatial scale of the studied phenomenon. This represents Luis's "coupling" to a given area of astronomical study.

see in this figure, although Luis's interest covers a wide range, his heart is in the galactic and extragalactic realms.

We can gauge the "coupling" of Luis to the various fields of study he has worked in, by counting the number of collaborators he has worked with as a function of spatial scale. This is shown in Figure 5, where the red line shows a low bandpass filtering of the histogram. It is apparent that Luis's coupling is non-negligible over many different scales, but it peaks at the galactic scale. This confirms that Luis has a preference for large-scale phenomena ("bigger is better").

2.4. *Luis across the electromagnetic spectrum*

To end our analysis of the Luis Carrasco phenomenon in Astronomy, we now study its presence across the electromagnetic spectrum. Figure 6 shows the part of the electromagnetic spectrum covered by each published work, as a function of the publication year. The vertical bars represent the frequency range while the black dots are the median values.

What is remarkable in this plot is, again, the vast tracks of covered range, from radio waves, all the way up to the X-ray region. There is, however, a marked preference for the near IR and optical regions. This ubiquity of the Luis Carrasco phenomenon is reminiscent of dim, red dwarf, flare stars, whose EM emissions range from radio to X-rays, but whose steady radiation is emitted mostly in the visible and near IR wavelengths. Maybe Luis is such a star, after all, Guillermo Haro was fond of flaring stars (Haro et al. 1960).

2.5. *Other endeavors*

The Luis Carrasco phenomenon is not confined to the realms of pure research in Astronomy. It has also been sighted in technological activities, like development of astronomical instrumentation, in applied math, like the introduction of novel statistical techniques, and even managerial activities, like big project oversight and direction of an observatory.

Almost 30 years ago, Luis got involved in the construction of a photometer for IR astronomy (Roth et al. 1980). More recently, Luis directed the development of a near-IR camera (CANICA) for the 2.1 m telescope at the *Guillermo Haro* INAOE astrophysical observatory in northern México. His restlessness took him also into studying near IR extinction coefficients and setting reliable standard stars for JHK photometry at the National Astronomy Observatory of México in San Pedro Mártir (Carrasco et al. 1991).

3. NON-ASTRONOMICAL ACTIVITIES

Luis has had an interesting life (Carrasco 2008, private communication). He witnessed the student revolts that swept México in the 60's and participated in some of them. In the early 70's, as a fresh arrival in Berkeley, he landed in the middle of the free speech movement and the Vietnam era demonstrations. He claims to have met a young singer of later fame on those days (Joan Baez). He also claims to have met Marilyn Monroe during her visit to México City in 1962. He has been present at some crucial events, like at Mauna Kea, when in 1996 fire broke out at the Subaru telescope.

He has some extracurricular activities that I'm sure are quite offbeat for an astronomer nowadays: He has a ranch in Juchitán, Oaxaca, where he grows sorghum. This ranch is one of the largest sorghum

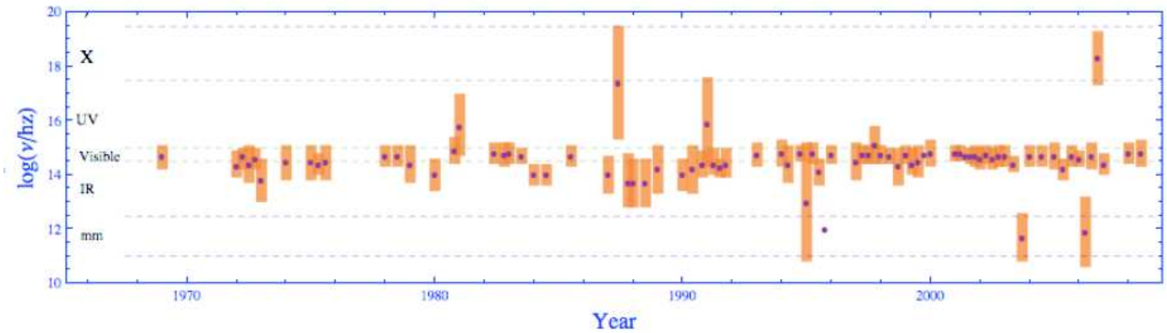

Fig. 6. Spread of the Luis Carrasco phenomenon across the electromagnetic spectrum as a function of time. Each bar represents the swath of EM spectrum covered in each publication. The black dot within each represent the median value.

Fig. 7. Luis Carrasco in the mid 70's.

producers in the Tehuantepec Isthmus. You may say that he is continuing the tradition of genteel, land owner astronomers, that goes back to William Parsons, 3rd. Earl of Rosse in XIX century England. He also tried to learn to fly and get a pilot's license, unfortunately, a weak heart prevented him from accomplishing this.

In fact, he has met so many famous and important people, he has been at so many interesting places, present at so many crucial events, and done so many strange activities, that the only similar character I can think of, is a mythical figure portrayed by the actor Tom Hanks in a 1994 movie. We can say that Luis Carrasco is the "Forrest Gump" of Mexican Astronomy. Congratulations Luis on this happy occasion!

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