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THE ASTRONOMY OF GUILLERMO HARO

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RESUMEN. Se presenta una visión personal de algunas de las contribuciones más importantes del Dr. Haro al desarrollo de la Astronomía.

ABSTRACT. A personal view of some of the main contributions of Professor Haro to the development of Astronomy is given.

I. INTRODUCTION

Dr. Haro has played a paramount role in the development of the mexican observatories, of mexican astronomy and of mexican science in general. I will not speak today about these aspects of his life, I will try to concentrate on his research contribution to astronomy.

The history of the Tonantzintla Schmidt and its astronomical repercusions is to a large extent the history of the enthusiasm and intuition with which Haro has carried out his research. The main areas of research that have been developed with the Tonantzintla Schmidt telescope were outlined by Haro in the late forties and in the fifties.

Haro has produced more than seventy research papers on various branches of astronomy in some cases opening new areas for astronomical research. In what follows, I will give a very brief account of these branches: a) Herbig-Haro objects, b) Flare Stars, c) Planetary Nebulae, d) Faint Blue Starlike Objects, and e) Blue Galaxies. I will leave out very important areas of his work like that on emission line stars carried out by himself and also together with E. Chavira, B. Iriarte and A. Moreno; his work on extragalactic H II regions in M31, M33, M82 and M83; and the work carried out by E. Chavira, G. González, B. Iriarte, W.W. Morgan, and L. Münch on galactic OBA high luminosity stars which to a large extent was suggested by him and to which he collaborated by obtaining a substantial amount of the observational data (see *Bol. Obs. Tonantzintla y Tacubaya*, Vol. 1 and 2, 1952-1960).

Finally I would like to mention that another facet of his passion for astronomical observations led him to discover, in the 1950-1961 period, one comet (Haro-Chavira 1954k), eleven galactic novae, one extragalactic nova and one extragalactic supernova (*Harvard Announcement Cards* 1074, 1091, 1094, 1099, 1118, 1166, 1167, 1172, 1174, 1210, 1281, 1282, 1283, 1288, 1292, 1303, 1326 and 1405; Haro, 1958; Henize and Haro 1961).

II. HERBIG-HARO OBJECTS

Herbig-Haro objects were discovered independently by Herbig (1951) and by Haro (1952*a*) (see the account of the first results on these objects given by Haro, 1976). In his search for emission line objects in the Orion Nebula, Haro (1953) found... "*7 nebulous objects characterized in the spectral red plates of Tonantzintla by a strong emission in* $H\alpha$ *and by an intense emission at* $\lambda 6300$

and λ6363, the continuous spectra on these plates not being observed". These objects have been and will be discussed at length during this meeting. One of the most interesting pieces of evidence on this topic was obtained by Haro (1952*a*) and Haro and Minkowski (1961) who based on photographic, visual and infrared plates taken with the Tonantzintla Schmidt camera, the 48" Palomar Schmidt camera, and the 200" telescope were not able to detect an embedded star in any of the seven Herbig-Haro objects first found in the Orion nebula region; the limiting magnitudes for the plates taken were: 19.5 photographic, 21 visual and 19 infrared. This key result has been very important for the development of the present theories advanced to explain the existence of Herbig-Haro objects (i.e., Cantó 1983).

III. FLARE STARS

The discovery of flare stars in the Orion nebula region by Haro and co-workers (Haro and Morgan 1953; Haro and Rivera Terrazas 1954) and later on in stellar aggregates of different ages by Haro and Chavira (Haro 1968, 1976 and references therein) has opened a new field which involves crucial aspects of pre-main sequence stellar evolution. Haro and Morgan (1953) reported that... *"three stars in the Orion Nebula have been found to undergo rapid variations in light in times varying from 20 to 60 minutes. The variations consist of sudden outbursts of 0.5 - 1.0 mag. from approximately constant minima".*

The pre-main sequence nature of T Tauri stars and Flare stars is by now well established while the evolutionary relationship proposed by Haro involving T Tauri, Flare and *UV* Ceti stars seems also well established; many papers on this second problem have been presented and representative ones are those by Haro (1962, 1968, 1976, 1983), Poveda (1964) and Gurzadyan (1982). These studies had their initial inspiration in the earlier work by Joy (1942, 1945, 1949) on T Tauri stars and by Ambartsumian (1947, 1949, 1954) on the pre-main sequence nature of T Tauri stars. This subject will be treated in this Symposium at length.

IV. PLANETARY NEBULAE

Up to 1930 there were 131 planetary nebulae known in our galaxy (Vorontsov-Veljaminov and Parenago 1931). The Henry Draper Catalogue increased the number of classified spectra from about 9000 to more than 227 000; this monumental work only added one more planetary nebula to those previously known (Curtis 1918), therefore in the thirties and early forties it was thought that most planetary nebulae in our galaxy had already been detected. Minkowski (1946, 1947, 1948) with the 10-inch telescope objective prism plates and the Palomar 18-inch Schmidt telescope carried out a search for planetary nebulae in the galactic plane; he was able to increase the number of known planetary nebulae to 342. After his search, Minkowski (1948) also concluded that with the exception of objects in obscured regions of the Milky Way most galactic planetary nebulae had already been accounted for.

The first paper published in the *Boletín de los Observatorios de Tonantzintla y Tacubaya*, was a search that Haro (1952*b*) made for emission line objects with the Tonantzintla Schmidt in a region of approximately 600 square degrees in the direction of the galactic center. Out of 437 emission line objects he found 67 new PN and 48 new probable planetary nebulae, he also detected the 121 planetary nebulae in this area previously discovered. He concluded that the total number of galactic planetary nebulae was considerably larger than the number known at that time and that the distribution of planetary nebulae indicated a considerable size for the bulge of our galaxy implying that our galaxy was of a Hubble type earlier than Sc. The number of galactic planetary nebulae known at present is of about 1400 and the estimated total number of galactic planetary nebulae is of the order of 10 000 (Alloin *et al.* 1976).

Haro proposed to several first year students of the School of Sciences of the University of Mexico to search for planetary nebulae putting at their disposal his experience and the plate collection of the Tonantzintla Schmidt, this action proved fruitful not only because two dozen new planetary nebulae were found but because some of us became interested in astronomical research (Peimbert and Bátiz 1960; Peimbert and Costero 1961).

Haro (1951) discovered H4-1 one of the only four known planetary nebulae in the galactic halo. The other three are: K648 in the globular cluster M15 (Pease 1928), DDDM-1 (Dolidze and Dzhimshelejshvili 1966), and BB-1 (Boeshaar and Bond 1977).

Halo planetary nebulae are very important for the study of the chemical composition in the early stages of the formation of the galaxy. For those elements that do not get affected by stellar evolution, like sulphur and argon, the observed abundances correspond to those of the interstellar medium at the time the stellar precursor was formed, while for those that do get affected by stellar evolution, like helium and carbon, it is necessary to consider the enrichment produced by the progenitor star to recover the original abundances. From the study of these four objects, it has been possible to determine the abundances in the halo of several elements as well as the pregalactic helium to hydrogen ratio (Barker 1980; Torres-Peimbert *et al.* 1981; Barker and Cudworth 1983; Peimbert 1983). These results are paramount for the study of chemical evolution of galaxies and for cosmology. The pregalactic helium to hydrogen ratio, derived from planetary nebulae, in the frame of the standard big-bang theory implies an open universe and at most two different types of neutrinos with masses smaller than about 1 MeV.

V. FAINT BLUE STARLIKE OBJECTS

Haro developed a photographic method at Tonantzintla Observatory for the study of T Tauri stars with strong *UV* radiation (Haro 1955, 1956; Haro and Herbig 1955). In a 103a-D plate three exposures slightly displaced from each other were taken with three different filters: ultraviolet, Corning 9863 + fused quartz; yellow, Corning 3384 + Corning 7740; and blue, Corning 5030 + Schott GG-13. The exposure times for each filter were calibrated to yield three similar images for an A0 star. In addition to objects with a *UV* excess this procedure permits to identify those objects with spectral types A0 or earlier. This method, under Haro's suggestion, was used by Iriarte and Chavira (1957) and Chavira (1958, 1959) to search in the direction of the galactic poles for blue objects similar to those discovered by Malmquist (1927,1936), Humason and Zwicky (1947), and Luyten and collaborators (1953, 1954, 1955, 1956*a*, 1956*b*).

While the original lists by Malmquist, Humason and Zwicky and Luyten and collaborators contain 18, 48 and 350 objects respectively, those by Iriarte and Chavira (1957) and Chavira (1958, 1959) contain a total of 2007 objects. The surveys of Iriarte and Chavira contained stars up to the 17th magnitude and covered 1860 square degrees in the northern polar regions and 1050 square degrees in the southern polar regions.

These previous works led to the classical paper on the field by Haro and Luyten (1962) based on the Tonantzintla three-image method. Haro and Luyten used the Palomar 48-inch Schmidt telescope with 103a-D plates and somewhat different filters than those used at Tonantzintla: ultraviolet Scott UG1; yellow Wratten No. 12; and blue Wratten No. 47. They took plates for 47 regions covering approximately 1600 degrees of southern polar regions and found 8746 starlike blue objects up to the 19th magnitude.

Based on the observed log N(m) *versus* m plot for objects in the Haro-Luyten catalogue and on the spectra of five faint blue objects that turned out to be similar to spectra of Quasi-Stellar Radio Sources Sandage (1965) concluded that about 80% of the objects fainter than mag 16 in the Haro-Luyten catalogue were Quasi-Stellar Galaxies, QSG. Sandage defined the QSG as a new major constituent of the Universe; from his very preliminary result he concluded that their surface density is of about 4 objects per square degree up to $m_{pg} = 19$ and that they were 500 times more numerous than the Quasi-Stellar Radio Sources. Later on, QSG have been known as radio quiet quasars or optically detected quasars.

Kinman (1965) and Lynds and Villere (1965) based on determinations of the density of horizontal branch stars in the halo and new estimates of the frequencey of white dwarfs found that the observed log N(m) *versus* m plot from the data by Haro and Luyten could be well represented by a combination of horizontal branch stars and white dwarfs and that most of the faint blue star-like objects are galactic stars: white dwarfs, horizontal branch stars and evolved hot subdwarfs.

By now it is generally accepted that the majority of the faint blue objects up to m = 19 are galactic stars, interesting in their own right, nevertheless most of the remaining objects correspond to the quasar family and several methods to discover them based on the lists of faint blue objects have been devised (Sandage 1965; Braccesi 1967; Braccesi *et al.* 1968; Sandage and Luyten 1969).

The catalogue by Hewitt and Burbidge (1980) includes 1491 quasars most of them found by a combination of radio and optical methods. In this catalogue 40 objects come from the list of Haro and Luyten, and are known by their PHL (Palomar Haro Luyten) numbers and 15 objects come from the three Tonantzintla lists by Iriarte and Chavira and are known by their Ton (Tonantzintla) number.

VI. BLUE GALAXIES

The same photographic material obtained with the Tonantzintla Schmidt for the identification of star-like faint blue objects at high galactic latitudes has been used by Haro to search for galaxies which show intense ultraviolet radiation. In some of these galaxies the density relation among the blue, yellow and ultraviolet images is comparable to the density relation in the three images of stars of extremely violet color, such as certain white dwarfs or the nuclei of planetary nebulae. Haro (1956) presented a preliminary list of 44 objects; for some of them he was able to obtain fairly good spectra with the Tonantzintla Schmidt plus objective prism system and found that they show very strong emission lines such as 3727 [O II], 3869 [Ne III], 4959 and 5007 [O III], and the Balmer series.

Many of the objects in the list by Haro (1956) turned out to be galaxies with strong-emission-line nuclei, some with Seyfert characteristics (see for example Dupuy 1968). Later on Markarian and collaborators (1967, 1979 and references therein) by means of the 40 inch Byurakan Schmidt together with a 1.5 degree objective prism have published several lists containing about fifteen hundred blue galaxies, some of them are Seyfert galaxies while many others show narrow strong emission lines and early-type stellar spectra.

From the three color plates obtained with the 48 inch Palomar Schmidt for the Haro-Luyten catalogue, Haro (1982) has produced a list of approximately two thousand blue galaxies which includes Seyfert galaxies, blue compact galaxies and irregular galaxies.

Finally to end these remarks I would like to add that according to me, the most important contribution of Guillermo Haro to science has been the design of general guidelines for the development of astronomical research in this country.

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DISCUSSION

Herbig: (*Comment*) I want to stress two additional aspects of Dr. Haro's contributions. First, let us not forget that a very substantial fraction of the known T Tauri stars are the result of the Tonantzintla Hα surveys carried out by Haro and his colleagues. Second, it was mentioned yesterday (by R. Schwartz) that the psychology and attitudes of astronomers in the late forties and early fifties were quite different than we know today: the leisurely development of ideas, the prosecution of very long-term programs were an accepted way of life. I can imagine that recognition of the significance of what we now call Herbig-Haro objects could well have been delayed for decades had it not been for Haro's perception and energy. He was the first to see (in 1949) the emission lines in the spectra of HH 1-2, etc. and to stress the nature of their peculiarities. We have heard yesterday, 34 years later, some of the consequences of Haro's astuteness.

Ambartsumian: (*Comment*) Dr. Peimbert has shown how many astronomical discoveries and new ideas were produced by Prof. Haro. May I add to this, that Prof. Haro has unusual ability to independent scientific thinking. Knowing very well the achievements of the past he always makes efforts to move in *new directions* and to develop new methods. Perhaps just these abilities have allowed him to reach so many brilliant results in the observational astronomy. He has shown that the observational astronomy is a field where the application of new original ideas always brings fruitful results.

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