

Are the Publications of Mexican Astronomers in Line with World Trends?

María Magdalena Sierra Flores^{1,*}, Alejandro Cristian Raga², Juan Claudio Toledo Roy²

¹Instituto de Ciencias Nucleares, UNAM, MEXICO.

²Instituto de Ciencias Nucleares UNAM, MEXICO.

ABSTRACT

We present an evaluation of the 2010-2019 production of refereed papers by Mexican astronomers. We show that the yearly number of papers grows by a factor of ~ 2 (over this period), and that this growth appears to be due to the combination of a decrease in the average fraction of Mexican co-authors and an increase in the number of Mexican researchers active in astronomy. We also show the behaviour of a set of chosen astronomical fields, and an evaluation of Mexican institutions with active astronomers. We find that the growth of Mexican astronomical publications in the 2010-2019 period can be explained as a combination of the growth in the number of researchers (as found in studies of the dominant countries in astronomical research) and also of a growing "import industry" of research papers. This latter mechanism is due to a trend of growing participation of small numbers of Mexican astronomers in large collaborations with foreign researchers. Finally, a comparison of these results with astronomical publications of countries with large numbers of researchers is made.

Keywords: Bibliometric indicators, Research evaluation, Astronomy, Publication rates, Mexico, Productivity, Bibliometric analysis.

Correspondence

María Magdalena Sierra Flores

Instituto de Ciencias

Nucleares, UNAM, MEXICO.

Email id: sierra.magdalena@gmail.com

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INTRODUCTION

Several studies of the astronomical publications of different countries have been done in the past. For example, Liu and Shu^[1] study the 1986-1990 Chinese astronomical publications. The 1980-2010 Turkish production was described by Bilir *et al.*^[2] (Uzun and Ozel^[3] study the shorter 1985-1994 period). The evolution of astronomical publications in general, and of the publications of French astronomers in the 1986-1987 period was described by Davoust and Schmadel.^[4] Also, Abt^[5] presented a comparison of the evolution of USA astronomical publications (in the 1970-1975 period) with other fields (mostly within the exact sciences).

In this paper, we present an evaluation of the publication of mainstream astronomical refereed papers by astronomers from Mexican institutions in the 2010-2019 decade. This study is based on data from the Clarivate Analytics' Web of Science (WoS) database, limited to a chosen set of mainstream astronomical journals (in which Mexican astronomers publish actively) and to papers having at least one Mexican co-author.

We then compare the trends in the publications of Mexican astronomers with the ones of other countries. This comparison

allows us to evaluate the different mechanisms for publication rate growth available to countries with small and large contributions to the total publications in a given research field.

In the field of astronomy, the large increase in numbers of authors per paper brought on by the appearance of "large collaborations" (involving ~ 1000 researchers, all of them co-authors of the resulting papers) has not had such a large impact as in the field of particle physics. However, some "large collaboration papers" in subjects like cosmic rays appear in astronomical journals. Though the number of these papers is not large, their effect on the calculation of the average number of authors per paper can be significant (due to the huge number of authors involved in these papers). In order to evaluate this effect, we study both the number of papers as well as the number of papers normalized by the number of co-authors in each paper. Discussions of the growth of large collaborations in particle physics and in astronomy have been presented, e.g., by Zhang, Vogeley and Chen^[6] and by Irvine and Martin.^[7]

The paper is organized as follows. In section 2 we discuss the generation of the 2010-2019 Mexican astronomical publication database, the identification of individual authors and institutions, and the division of the papers into a set of chosen astronomical subjects. Finally, the rationale for a specific selection of journals is given, and their relative use by Mexican authors is presented. Section 3 discusses the calculation of normalized paper counts and their use in determining the

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average number of authors per paper. In section 4, we discuss the time-evolution of the publications, normalized publications (both in “observational” and “theoretical” topics) and the number of Mexican authors over the 2010–2019 time period. In section 5, we discuss the author number distributions of the “observational” and “theoretical” papers, for the 2010–2019 sample as a whole. Section 6 presents an analysis of the time-evolution of the chosen “astronomical fields”. In section 7, we present a list of Mexican institutions with substantial astronomical publications in the 2010–2019 period, giving estimates of their number of associated researchers and publication rates. Finally, in section 8 we summarize our results, and discuss some interesting issues that may have general implications for the evaluation of publications of researchers in countries with small numbers of researchers.

The database of 2010-2019 Mexican astronomical papers

We first restrict ourselves to the group of journals listed in Table 1. These journals contain almost all of the publications of Mexican astronomers during the 2010–2019 period. A similar approach of using a limited number of journals for a study of the publications in physics (of Indian institutions) has been used by Mondal.^[8]

We have not included journals dedicated exclusively to solar and interplanetary physics (e.g., the Solar Physics journal), since many of the papers in this area are published in physics or geophysics journals, and it is hard to separate them from papers in other areas (the separation done in databases such as the “Web of Science” being unreliable). We have left out journals that cover some areas in the edge between astrophysics and theoretical physics (such as Classical and Quantum Gravity, Physical Review D and Cosmology and Astroparticle Physics), which mostly have papers that would not be publishable in a mainstream astronomical journal because of their mostly tenuous links to astronomical reality, or papers in high energy and particle physics. We have also left out the journal Icarus (of solar system studies) and Astrobiology (of the search for extraterrestrial life). Finally, we have not included the Astrophysics and Space Science and Astronomische Nachrichten journals because many of their issues actually correspond to conference proceedings.

Even though in the chosen sample of journals we have not included the journals dedicated to solar/interplanetary physics and to exobiology, our study includes some of the papers in these areas, namely, the ones that appear in the mainstream astronomical journals. However, it is clear that the study presented in this paper seriously undercounts the papers published in these areas.

The journals listed in Table 1 include most of the papers published by Mexican astronomers in the 2010–2019 period. This table gives the name of the journal, their impact factor

(two values are given, the value for 2019 and in parentheses the average value over the 2014–2019 period), and the quartile (of impact factors) to which they belong, obtained from the Journal Citation Reports (of Clarivate Analytics). The last column of Table 1 gives the percentage f_{pap} of the papers of our database that has been published in each journal.

We have included the Mexican regional journal (next to last entry of Table 1) which has 7% of the publications of Mexican astronomers. Interestingly, this journal falls at the edge between the Q1 and Q2 quartiles, and is the highest impact parameter mainstream astronomical free-access journal. We have not included other regional publications (e.g., the Acta Astronomica journal from Poland or the Publications of the Astronomical Society of Japan) because they have a vanishingly small number of papers from Mexican astronomers.

We have downloaded the information of all of the 2010–2019 refereed papers with at least one co-author from a Mexican institution from the “astrophysics and space science” area of the WoS database. This gives 5050 papers, 2536 of which are in the mainstream astronomy journals listed in Table 1. Therefore, our analysis is based on a database of 2536 papers.

In this database, we have normalized the names of the Mexican authors, as well as the identifications of the institutions of the Mexican authors with at least five publications in 2010–2019. We have also inspected all of the individual papers in order to divide them into “observational” or “theoretical” papers. In many cases, the papers can be clearly identified in one of these two categories. However, some papers present both observational and theoretical contributions, and a qualitative judgement of what is the main contribution of the papers has been made. A small number of papers on instrumental development have been grouped together with the observational papers. Finally, papers describing data reduction techniques (without application to specific observations) have been grouped together with the theoretical papers.

We have also classified the papers into seven different subjects:

- ISM: the interstellar medium in our Galaxy,
- Stars: studies of stars in our Galaxy,
- Compact objects: neutron stars and black holes in our Galaxy,
- Galaxies: external galaxies, including their stellar content, interstellar medium and massive central black holes,
- Cosmology: studies of the early universe, gravitation, dynamics of galaxies and gravitational lenses,
- Planets: studies of our planetary system and exoplanets,
- Solar: solar and interplanetary physics.

Table 1: Astronomical journals.

Journal	IF2019	Q	fpap
Nature astronomy	11.5 (11.7)	Q1	0.2
Astrophysical Journal Letters	8.2 (6.3)	Q1	5.3
Astrophysical Journal Supplement Series	8.0 (6.3)	Q1	1.6
Astronomical Journal	5.8 (5.1)	Q1	4.0
Astrophysical Journal	5.7 (5.5)	Q1	30.7
Astronomy and Astrophysics	5.6 (5.4)	Q1	18.4
Monthly Notices of the Royal Astron. Soc.	5.4 (5.0)	Q1	30.6
Publications of the Astron. Soc. of the Pacific	4.0 (4.2)	Q2	1.1
Revista Mexicana de Astronom. y astrofísica	2.7 (2.4)	Q2	7.0
New Astronomy	1.1 (0.9)	Q4	0.7

Other topics are represented at a combined level of less than 5 % of the papers in our sample, and are not described in our paper.

This division into subjects is similar to the one chosen by Liu and Shu^[1] for their study of Chinese astronomical publications. We have carried out a division into these fields by (“visually”) evaluating the titles, keywords, abstracts and (when necessary) the texts of the individual papers. This is of course not a possible strategy for databases much larger than ours!

Boyack^[9] presents a division of the astronomical literature into subjects (considering ~ 10⁵ entries!) using different algorithms. A comparison with the subjects listed in Table 2 of Boyack^[9] shows that our chosen fields lie within their five subjects with larger numbers of papers. For example, our “stars” and “compact object” fields are grouped into Boyack’s first subject, “galaxies” is in his second subject, and “interstellar medium” (though not explicitly named) is probably split within these two subjects. Luckily, the relatively small size of our database allows us not to address the difficult problem of algorithmic detections of coherent fields within sets of publications.

Paper numbers and normalized paper numbers

For an individual researcher we compute:

- the total number of papers N_p with the researcher as a co-author,
- the normalized number of papers n_p , where

$$n_p = \sum_{i=1}^{N_p} \frac{1}{N_{a,i}} \quad (1)$$

have very small weights, therefore \rightarrow where $N_{a,i}$ is the total number of authors of paper i . This normalized number of papers is the sum of all of the papers of an individual researcher but giving each paper a weight of one over total author number. For example, single author papers are counted as “full papers”, with weight 1, and two-author papers are counted as “half papers”,

with a weight of $\frac{1}{2}$. Papers from “large collaborations” have very small weights, therefore do not contribute a lot to the normalized number of papers (see equation 1).

One can calculate a (non-linear) average number of co-authors as:

$$\frac{\text{authors}}{\text{paper}} = \frac{n_p}{N_p} \quad (2)$$

In order to illustrate the behaviour of this non-linear average, let us consider the following simple case. Let us assume that we have a sample of papers with:

- a total number of papers N_p ,
- a number N_s of papers with a narrow distribution of co-author numbers centered in a number N_{as} of co-authors,
- a number $N_l = N_p - N_s$ of “large collaboration” papers with a number of co-authors $N_{al} \gg N_{as}$.

If we compute the author/paper ratio for a single researcher (i.e., using equations 1 and 2) we obtain:

$$\text{Authors/paper} = \frac{(N_s + N_l)}{(N_s/N_{as} + N_l/N_{al})} \approx \frac{N_{as}}{1 + N_l/N_s} \quad (3)$$

Where for the second equality we have neglected the second term in the denominator of the first equality. Therefore, for our chosen distribution of author numbers (i.e., a “small author number” and a “large collaboration” component with N_{as} , N_{al} respective author numbers and N_s , N_l paper numbers), the non-linear average is $\approx N_{as}$ for a small relative number of large collaboration papers (i.e, for $N_l/N_s < 1$) and is $\approx N_{as} N_l/N_s$ for $N_l/N_s > 1$. Eventually, for groups of papers that are completely dominated by large collaborations (i.e., with $N_l > (N_{al}/N_{as})N_s$), the average authors/paper given by equation (3) approaches N_{al} (i.e., the number of authors of the large collaborations).

Therefore, provided that the proportion of large collaboration papers is small, the nonlinear average given by equation (2) gives us the authors/paper of the “small collaboration papers”, without an appreciable interference from the large collaborations. For individuals or groups with a large proportion of large collaboration papers, equation (2) gives authors that grows proportionally to the N_l/N_s “large to small collaboration” paper ratio. The estimate given by equation (2) for the average number of authors per paper is used in the following sections.

Also, in sections 4 and 7 we have computed paper and author numbers including and excluding papers of “large collaborations”. For this, we have arbitrarily chosen a limit of more than 100 co-authors for defining the “large collaboration” category.

The Mexican astronomical community as a whole

The top frame of Figure 1 shows the number of theoretical and observational papers and the total paper number in each year of our 2010–2019 time period. The number of observational papers appears to show a minor decrease from 2010 to 2012, followed by an increase from 2012 to 2019. The number of theoretical papers is systematically lower (by a factor of ~ 3) than the number of observational papers, and shows a sustained growth from 2010 to 2019. Both the number of theoretical and observational papers shows a growth by a factor of ≈ 1.8 over the whole of the 2010–2019 period.

We have also calculated a “normalized number” of papers, by assigning a fractional value of $N_{a,mex}/N_{a,tot}$ (where $N_{a,mex}$ is the number of Mexican co-authors and $N_{a,tot}$ the total number of authors) to each paper. The normalized number of yearly observational and theoretical papers is shown in the second (from top) panel of Figure 1. While the normalized paper numbers show a behaviour that is qualitatively similar to the one of the total paper numbers, it is clear that their general increase over the 2010–2019 period is of only a factor of ≈ 1.5 for the total, theoretical+observational papers. The normalized observational and theoretical papers show similar numbers over the 2010–2019 period, with a faster growth (by a factor of ≈ 2) for the theoretical papers, and with a slower growth (by a factor of ≈ 1.3) for the observational papers.

In the third (from top) panel we show the “mexican fraction of authors” of the papers, averaged over all papers in each of the years of our sample. We find that the $\langle N_{a,mex}/N_{a,tot} \rangle$ average of all of the papers decreases by a factor $\approx 1/1.2$ over the 2010–2019 period. The observational papers have a decrease in $\langle N_{a,mex}/N_{a,tot} \rangle$ by a factor $\approx 1/1.3$, and the theoretical papers show an oscillation over the 2010–2019 period, but ending at approximately the same value it began. This decrease in the average fraction of Mexican authors approximately accounts for the difference in the growth of the total (top panel of Figure 1) and the normalized paper counts (second from top panel) over the 2010–2019 period.

In the bottom panel of Figure 1, we show the number of Mexican authors present in each year of our sample. We show the total number (upper thick line) and the number excluding the authors who only appear in “large collaboration papers (upper thin line of the bottom panel of Figure 1). We have also calculated these numbers considering only authors who have at least 5 papers in the 2010–2019 period (lower thick and thin lines in the bottom frame of Figure 1).

Therefore, we obtain growths in the total and normalized paper numbers that differ from each other because of a decreasing fraction of Mexican co-authors in the author lists over the 2010–2019 period. We have not answered the

obvious question of why do we have a growth in the normalized publications over this time-period?

In order to explore the obvious possibility that this growth is a result of a growing population of Mexican researchers, we look at the total number $N_{t,mex}$ of Mexican authors who have published at least 1 paper in a given year, and the corresponding number $N_{t,mex}^5$ of authors who have at least 5 papers in 2010–2019, and have published at least 1 paper in a given year. From the bottom panel of Figure 1, we see that the $N_{t,mex}^5/N_{t,mex}$ ratio has a relatively stable value of ≈ 1.5 . This ratio indicates that approximately 2 out of 3 Mexican authors have a publication rate of at least 0.5 papers/year in astronomical topics over the 2010–2019 period.

We also see (bottom panel of Figure 1) that with and without large collaborations both the $N_{t,mex}$ and $N_{t,mex}^5$ author numbers grow by a factor of ≈ 1.5 during 2010–2019. This factor coincides with the growth of the normalized paper numbers shown in the second (from top) panel of Figure 1.

Let us summarize these results:

- the total number of astronomical papers with at least 1 Mexican co-author have grown from ≈ 200 to ≈ 400 papers per year in the 2010–2019 period,
- the number of normalized papers has grown (over 2010–2019) by only a factor of ≈ 1.5 ,
- the average “Mexican/total author fraction” of the papers has fallen by a factor of $1/1.2$ (in 2010–2019). This fall in the relative Mexican contribution to the author lists approximately coincides with the difference in the growths of the total and normalized paper numbers,
- the number of Mexican authors has also grown by a factor of ≈ 1.5 in 2010–2019, which coincides with the growth of the normalized paper counts.

From this, we conclude that the growth in the paper counts over 2010–2019 is due to a combination of two effects:

1. a decrease in the fraction of Mexican co-authors by a factor of ≈ 1.2
2. an increase in the number of active Mexican astronomers by a factor of ≈ 1.5 .

The average level of activity of individual Mexican astronomers (measured by the normalized paper production to the number of researchers) has remained approximately constant in 2010–2019.

A final point is that the paper and author numbers and fractions of Mexican co-authors have been calculated for:

- all of the papers in our sample,

- all of the papers with at most 100 co-authors (i.e., excluding the “large collaborations”, see section 3),

Which are shown with two histograms with identical line-types in each of the four frames of Figure 1. A significant difference between these two cases is only seen in the total yearly number of Mexican authors (bottom frame of Figure 1).

The number of authors in observational and theoretical papers

We now consider the papers in all of the 2010–2019 period, and calculate the distribution function of the number of co-authors of the individual papers. The distribution functions

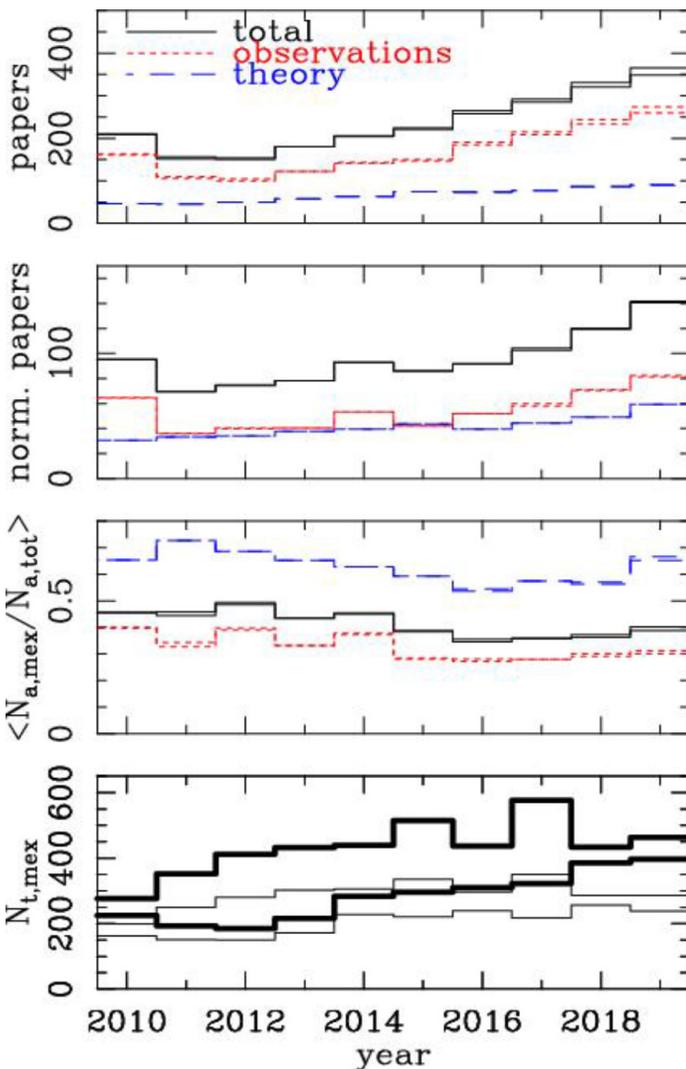


Figure 1: Top panel: total papers (solid line), observational papers (short dashes) and theoretical papers (long dashes) with at least 1 Mexican co-author. Second panel from top: number of total, observational and theoretical papers normalized by the number of co-authors of the individual papers. Third panel from top: average Mexican-to-total author number. Bottom panel: total number of Mexican researchers (thick line) and “active” researchers (thin line). The two histograms with the same type of line correspond to all papers (upper line) and to the papers excluding the “large collaborations”.

of the observational and theoretical papers are presented in the top panel of Figure 2.

We see that the observational papers have a distribution that grows to a peak in 10 coauthors, and then has an extended, low paper number wing to up to ~ 1000 co-authors. The author number distribution of the theoretical papers has a peak at 3 co-authors, followed by a decrease to low values at ≈ 50 co-authors, and by a very low wing to higher numbers of co-authors. It is clear that the observational papers have consistently larger numbers of co-authors than the theoretical papers.

In the central panel we plot the number of Mexican co-authors as a function of the total number of co-authors of the individual papers. We find that the number of Mexican co-authors initially grows (which is inevitable), and for papers with total author numbers between 3 and 100 remains approximately constant at a value of $\approx 3 \rightarrow 4$ Mexican co-authors (for both

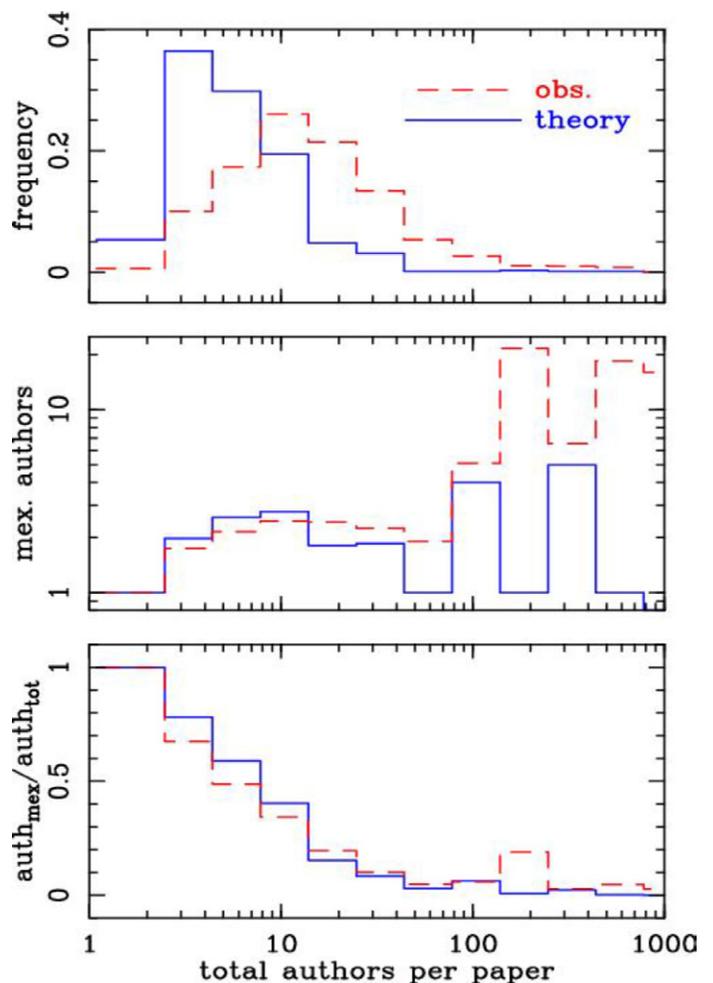


Figure 2: Top: normalized distribution of the number of co-authors per paper in the theoretical (solid line) and observational (dashed line) papers. Center: number of Mexican co-authors in theoretical and observational papers. Bottom: mexican/total co-author ratio as a function of total number of co-authors.

theoretical and observational papers). For papers with 100 → 1000 authors, the number of Mexican authors grows to values of $\sim 5 \rightarrow 10$.

In the bottom panel of Figure 2 we show the ratio of co-authors from Mexican institutions to the total number of co-authors. We find that this ratio (as inevitable) starts at 1 for a total author number of 1, and then decreases with increasing total author numbers.

The evolution of different astronomical topics

The top frame of Figure 3 shows the yearly numbers of papers in the seven dominant astronomical fields of publications with Mexican co-authors, and the bottom frame shows the numbers of papers normalized by their “mexican/total author number” ratio. It is clear that the two dominant fields are the study of external galaxies (labeled “galaxies” in Figure 3) and of the interstellar medium (labeled “ISM”). The studies of individual stars (labeled “stars”), of black holes and neutron stars (labeled “comp. obj.”) and of cosmological topics (labeled “cosmol.”) show substantial growths in the 2010–2019 period.

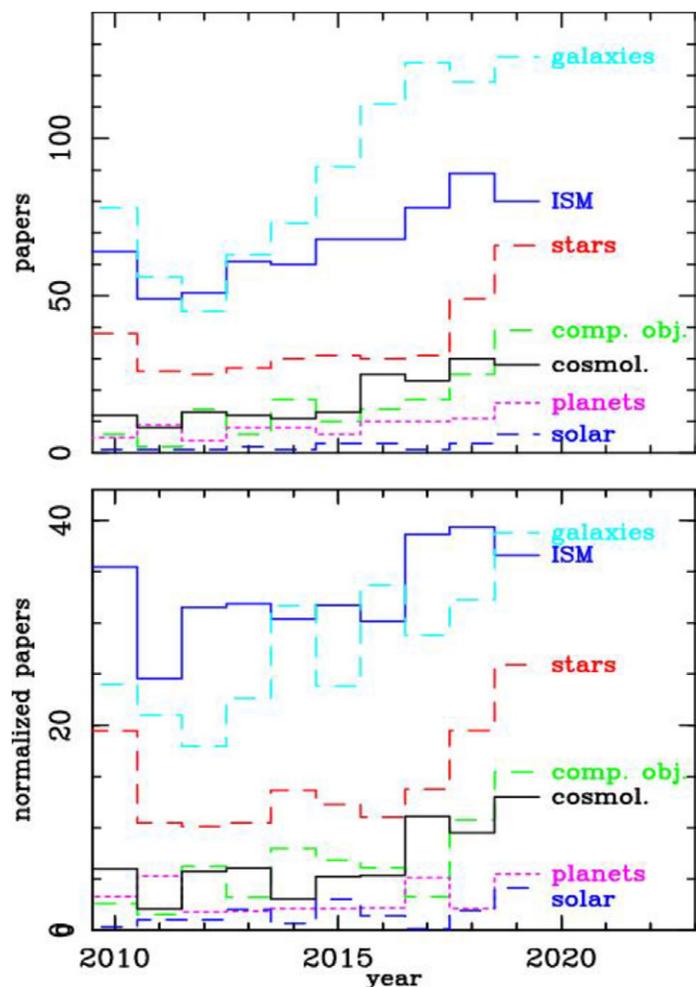


Figure 3: Time-evolution of the total (top) and normalized (bottom) paper numbers for the chosen set of astronomical topics.

The field of “galaxies” shows a quite dramatic increase (by a factor of ≈ 2) in number of papers and a growth of a factor of ≈ 1.5 in normalized paper number. Therefore, the papers in this field have had a substantial increase in the number of co-authors over the 2010–2019 period. Similar but less pronounced increases in numbers of co-authors are present in the other fields.

Finally, we should note that the low numbers of papers in the fields of planets/exoplanets (labeled “planets” in Figure 3) and solar physics (labeled “solar”) are partially a result of the fact that some of the main journals of these fields have not been included in our database (see the discussion in Section 2). The publication numbers given here are most probably a substantial underestimate of the correct paper numbers in these fields.

Astronomers in different Mexican institutions

In our database, we have normalized the names of Mexican institutions with at least one researcher with 5 or more publications in the 2010–2019 period. The institutions that satisfy this condition are listed in Table 3. Of a total of 32 research institutes/departments, the first 9 belong to the National Autonomous University of Mexico (UNAM), which is the dominant research university in Mexico. Also, the two groups labeled “CINVESTAV” and “IPN” belong to the National Polytechnic Institute (IPN). The rest of the entries group together researchers in independent institutes or universities. All of the entries in Table 3 are public institutions, because no private institutions had at least one researcher with 5 or more publications in 2010–2019.

In Table 2 we give an evaluation of the 2010–2019 astronomical production of these institutions. The columns of this table give:

1. the identifier of the institution (see the first column of Table 3),
2. the total number N_{aut} of institutional members with at least 5 papers in 2010–2019,
3. the sum N_{pap} of the total number of papers of the institutional members (this number counts repeats of papers with more than one local co-author),
4. the sum n_{pap} of the number of papers normalized by the total author number of each paper,
5. the total number of papers per institutional member $N_{\text{pap}}/N_{\text{aut}}$,
6. the total number of normalized papers per institutional member $n_{\text{pap}}/N_{\text{aut}}$,
7. the $N_{\text{pap}}/n_{\text{pap}}$ ratio, which corresponds to a (non-linear) average number of total authors per paper for each institution (see section 3).

All of these quantities have been calculated for all of the papers in our sample (first number in each column) and for all

Table 2: 2010-2019 production of Mexican institutions.

Institution	Naut	Npap	npap	Npap/Naut	npap/Naut	Npap/npap
IAUNAM	200(190)	1526(1375)	226.1(225.3)	7.6(7.2)	1.13(1.19)	6.7(6.1)
IRYA-UNAM	100(99)	978(955)	152.4(152.3)	9.8(9.6)	1.52(1.54)	6.4(6.5)
IAEUNAM	99(99)	652(616)	94.2(94.1)	6.6(6.2)	0.95(0.95)	6.9(6.1)
ICNUNAM	36(29)	368(293)	66(54)	10.2(10.1)	1.82(2.26)	5.6(4.5)
IFUNAM	25(18)	178(60)	3.8(3.2)	7.1(3.3)	0.15(0.18)	46.5(18.8)
IGUNAM	21(18)	71(42)	9.1(9.0)	3.4(2.3)	0.43(0.50)	7.8(4.7)
CFAPUNAM	2(2)	7(7)	1.1(1.1)	3.5(3.5)	0.57(0.57)	6.2(6.2)
FCUNAM	1(1)	5(5)	2.5(2.5)	5.0(5.0)	2.50(2.50)	2.0(2.0)
DGTICUNAM	1(1)	5(5)	1.7(1.7)	5.0(5.0)	1.73(1.73)	2.9(2.9)
INAOE	125(117)	984(848)	97.0(96.3)	7.9(7.2)	0.78(0.82)	10.1(8.8)
UGUAN	39(39)	179(168)	36.9(36.9)	4.6(4.3)	0.95(0.94)	4.9(4.6)
UPUEBLA	26(20)	234(77)	8.9(8.3)	9.0(3.9)	0.34(0.41)	26.2(9.3)
UGUADAL	16(16)	123(93)	16.4(16.2)	7.7(5.8)	1.03(1.02)	7.5(5.7)
IPN	15(15)	97(64)	10.5(10.4)	6.5(4.3)	0.70(0.69)	9.2(6.2)
CINVESTAV	12(11)	80(22)	4.8(4.4)	6.7(2.0)	0.40(0.40)	16.8(5.0)
UMICHOACAN	10(5)	92(32)	7.1(6.8)	9.2(6.4)	0.71(1.36)	13.0(4.7)
UPACHUCA	7(4)	57(12)	0.5(0.1)	8.1(3.0)	0.07(0.04)	57.0(12.0)
ININ	5(5)	23(23)	5.5(5.5)	4.6(4.6)	1.1(1.1)	4.2(4.2)
USONORA	5(5)	17(17)	4.8(4.8)	3.4(3.4)	0.96(0.96)	3.5(3.5)
UCHIAPAS	4(3)	63(15)	0.58(0.31)	15.8(5.0)	0.10(0.10)	63.0(15.0)
USLP	4(4)	10(10)	3.3(3.3)	12.5(2.5)	0.83(0.83)	3.0(3.0)
CMETRO	4(4)	6(6)	2.5(2.5)	1.5(1.5)	0.63(0.63)	2.4(2.4)
UHIDALGO	3(3)	40(14)	1.3(1.1)	13.3(4.7)	0.44(0.38)	30.5(12.3)
UAEH	3(3)	11(11)	2.3(2.3)	3.7(3.7)	0.76(0.76)	4.8(4.8)
UBAJAC	3(3)	10(9)	1.2(1.2)	3.3(3.0)	0.39(0.38)	8.6(7.8)
UMONTERREY	3(3)	9(9)	1.0(1.0)	3.0(3.0)	0.35(0.35)	8.6(8.6)
UNLEON	2(2)	6(6)	1.5(1.5)	3.0(3.0)	0.73(0.73)	4.1(4.1)
USINALOA	2(2)	7(7)	0.9(0.8)	3.5(3.5)	0.45(0.45)	7.0(7.0)
ITECENS	2(2)	5(5)	0.7(0.7)	2.5(2.5)	0.33(0.33)	5.0(5.0)
UAM	2(2)	5(5)	0.94(0.94)	2.5(2.5)	0.47(0.47)	5.0(5.0)
UQUER	1(1)	9(1)	0.1(0.01)	9.0(1.0)	0.07(0.01)	9.0(1.0)
CEMAFIT	1(1)	17(3)	0.1(0.01)	17.0(1.0)	0.15(0.01)	17.0(1.0)

of the papers with at most 100 co-authors (second number, in parentheses).

From Table 2 we see that the five institutes with more than 100 researchers are the first two entries (corresponding to groups at the UNAM) and the INAOE. These institutes have total paper numbers ~ 1000 , normalized paper numbers ~ 150 and numbers of authors per paper $N_{pap}/n_{pap} \sim 6 - 10$.

Interestingly, 23 of the institutions have average authors per paper numbers $N_{pap}/n_{pap} \sim 2 - 10$, and the remaining ones have considerably greater numbers, ranging from ~ 15 to above ~ 70 . The production of the institutions with large N_{pap}/n_{pap}

ratios is dominated by the participations of their researchers in papers of large collaborations, and has a near absence of local, small author number papers. These “large collaboration” dominated groups can be easily identified by comparing the total paper numbers calculated for all of the sample (first number of the N_{pap} column of Table 1) and the paper numbers excluding large collaborations (second number, in parentheses).

DISCUSSION AND CONCLUSION

We have presented an analysis of the production of refereed astronomical papers with Mexican co-authors in the 2010-

Table 3: Mexican institutions with astronomers.

Identifier	Institute
IAUNAM	Inst. de Astronomía, UNAM, CDMX
IRYA-UNAM	Inst. de Radioastronomía y Astrofísica, UNAM, Michoacán
IAEUNAM	Inst. de Astronomía, UNAM, Baja California Norte
ICNUNAM	Inst. de Ciencias Nucleares, UNAM, CDMX
IFUNAM	Inst. de Física, UNAM, CDMX
IGUNAM	Inst. de Geofísica, UNAM, CDMX
CFAPUNAM	Centro de Física Aplicada, UNAM, Querétaro
FCUNAM	Fac. de Ciencias, UNAM, CDUNAM
DGTICUNAM	Dir. General de Cómputo, UNAM, CDMX
INAOE	Inst. Nac. de Astronomía, Óptica y Electrónica, Puebla
UGUAN	Univ. de Guanajuato
UPUEBLA	Univ. de Puebla
UGUADAL	Univ. de Guadalajara, Jalisco
IPN	Inst. Politécnico Nacional, CDMX
CINVESTAV	Centro de Inv. Avanzada, Inst. Politécnico Nac., CDMX
UMICHOACAN	Univ. de Michoacán
UPACHUCA	Univ. Politécnica de Pachuca, Hidalgo
ININ	Instituto Nac. de Investigaciones Nucleares, Edo. de México
USONORA	Univ. de Sonora
UCHIAPAS	Univ. de Chiapas
USLP	Univ. de San Luis Potosí
CMETRO	Centro Interdisc. de Estudios Metropolitanos, CDMX
UHIDALGO	Univ. de Hidalgo
UAEH	Univ. Autónoma del Estado de Hidalgo
UBAJAC	Univ. de Baja California
UMONTERREY	Universidad de Monterrey
UNLEON	Univ. de Nuevo León
USINALOA	Univ. de Sinaloa
ITECENS	Instituto Tecnológico de Ensenada, Baja California
UAM	Univ. Autónoma Metropolitana, CDMX
UQUER	Univ. de Querétaro
CEMAFIT	Centro Mesoamericano de Física Teórica, UNACH, Chiapas

2019 period. The database that we have used has been obtained from the Clarivate Analytics' WoS database, and contains all of the papers in this period with at least one Mexican co-author, and in a chosen set of astronomical journals (given in Table 1). We find that $\approx 80\%$ of the papers were published in three journals (ApJ, MNRAS and A&A) belonging to the first quartile (of impact factors). Through an inspection of the titles, keywords and abstracts we have classified these papers into either "observational" or "theoretical", and also into a group of 7 different astronomical fields.

We first analyze the publications of the Mexican astronomers as a whole. We find that the yearly numbers of total, theoretical and observational papers have grown by a factor $f_p \approx 1.8$ over 2010–2019 (Figure 1 and section 4). During this period, the number of papers normalized to the number of co-authors (of each paper) has grown by a factor $f_{np} \approx 1.5$. The difference in the growths of total and normalized paper counts is consistent with the fact that the average fraction of Mexican co-authors (in the author lists of the papers) has decreased by a factor of $1/1.2$ over 2010–2019 (Figure 1).

We also find that the total number of Mexican authors has grown by a factor of $f_a \approx 1.5$ over this time period (see the bottom frame of Figure 1). This growth coincides with the growth in normalized paper counts. We can compare this growth of a factor of 1.5 in Mexican authors with the work of Jasheck,^[10] who estimated a factor of ~ 2 growth in the world wide number of astronomers in the 1980–1990 period. It would clearly be interesting to extend the work of Jasheck^[10] to more recent times.

These results can be compared with the results of Abt,^[5] who found that in astronomy and in other research fields (mostly within the exact sciences) the number of published papers (with USA authors) appears to scale with the number of researchers in the respective fields (as measured by the number of members of the respective scientific societies). Davoust and Schmadel^[11] also concluded that the growth in a 17 year period in astronomical publications approximately follows the growth in the number of astronomers.

We find that the observed increase in Mexican publications reflects both an increase in the number of researchers (as seen by Abt^[5] for USA astronomy) and a decrease in the average "Mexican to total author" fraction. This second mechanism of publication growth by "importing" papers (by collaborating with larger groups of foreigners) is not available for countries with large numbers of researchers (as they contribute a majority of the authors in larger research groups).

Davoust and Schmadel^[4] argue that the productivity of individual French astronomers clearly grew over the 1969–1987 period. This result is consistent with the qualitative assessment of French astronomers that they "started to work seriously" during this period. Our study of the 2010–2019 growth of the Mexican production does not support a similar growth of the productivity of the individual astronomers, and instead shows that the growth in published papers is a combination of a decreasing "Mexican to total co-author fraction" and an increasing number of local researchers. This result is again consistent with the qualitative assessment of Mexican astronomers, who present a clear lack of enthusiasm as a result of decreasing levels of funding over this period.

We then calculate the frequency of observational and theoretical papers as a function of number of co-authors (section 5 and Figure 2). We find a clear difference between theoretical papers (with a peak at 3 co-authors and a wing extending out to ~ 30 co-authors) and observational papers (with a peak at 10 co-authors). A low paper number wing extending out to ~ 1000 co-authors (corresponding to “large collaborations”, see, e.g. Zhang, Vogeley and Chen)^[6] is seen more strongly in the observational papers.

We also find that the fraction of Mexican co-authors monotonically drops as a function of increasing author numbers (bottom frame of Figure 2). An unexpected result is that the number of Mexican co-authors per paper remains approximately constant at a value of $2 \rightarrow 3$ for papers with total numbers of co-authors ranging from 3 to 70 (and then growing to ~ 10 Mexican co-authors for papers of up to 1000 total co-authors).

We can only speculate as to what is the reason for this unexpected result. It is probably an expected sociological effect that small collaborations (i.e., with 2-3 co-authors) are likely to be within a local group of “friends” with similar interests and abilities. We personally find that when we participate in larger research groups, we are aiming at projects which involve a larger range of expertise and/or access to large international facilities (e.g., large Earth or space-based telescopes), both of which are many times not available within our small Mexican astronomical community. Therefore, these larger research groups are likely to have a larger “foreign astronomer” fraction. It would be interesting to see if other countries with small scientific communities have similar behaviour of a constant number of local co-authors as a function of total author number. We expect that countries with large scientific communities will not show such an effect.

This is illustrated by the study of Abt^[12] who divided papers in USA journals into “purely USA”, “USA/foreign” (with leading USA authors and at least 1/8 of the authors being non-USA astronomers), “foreign/USA” (with leading foreign authors) and “purely foreign”. Abt finds that in 1989 the publications in the *Astrophysical Journal* were $\sim 61\%$ “purely USA”, $\sim 12\%$ “USA/foreign” and $\sim 9\%$ “foreign/USA” collaborations (with a remainder of $\sim 18\%$ “purely foreign” papers). Therefore, adding the first two categories, we have the result that USA astronomers had a dominant contribution in $\sim 73\%$ of the published papers.

The results of Abt^[12] for the USA are in quite strong contrast to the results which we find for Mexican astronomy, in which the fractional contribution of local astronomers to the authors lists of the published papers tend to be much smaller. While in the “theoretical” category, Mexican astronomers have average contributions of above 60% to the lists of coauthors of individual papers, in the “observational” category they have contributions of only $\sim 30\%$ (the 3rd panel of Figure 1). These

results indicate that while Mexican astronomers have been able to develop relatively independent local theoretical collaborations, they have not been as successful in doing this for observational projects. This is not surprising given the fact that the large funds necessary for developing and maintaining modern astronomical instruments are mostly not available within the Mexican research funding.

We then present the time-evolution of the paper numbers and normalized paper numbers of the different astronomical research fields which we have chosen (section 6 and Figure 3). We find that the Mexican production is dominated by the “galaxies”, “interstellar medium” and “stars” fields. The “cosmology” and “compact objects” fields are smaller, but show a large growth over the 2010-2019 period.

Finally, we have identified the Mexican institutions which have at least one researcher who has published at least five papers in 2010-2019 (see section 7). We identify 32 institutions (Table 3), with 9 corresponding to different research institutes of the UNAM (the dominant Mexican research university). An evaluation of the productivity of these institutions (Table 2) shows that the leading astronomical research institutes are the Astronomy (IAUNAM and IAEUNAM in Tables 3 and 2) and Radioastronomy (IRYA-UNAM) institutes of the UNAM, and the INAOE (the national astronomy institute of the Mexican research foundation CONACyT).

It is interesting to compare the number of Mexican astronomical publications of the 2010-2019 period with the numbers reported by Rodríguez and Canto^[13] for an earlier period. These authors report that in the 1970-1980 period, the Instituto de Astronomía (UNAM), then the only group of astronomers in Mexico, published between 20 and 30 papers per year, half of these in the leading, first quartile astronomical journals and half in the “Boletín de los observatorios de Tonantzintla and Tacubaya” (which later became the “Revista Mexicana de Astronomía y Astrofísica”). Clearly, Mexican astronomy has evolved quite considerably since 1980, as our 2010-2019 bibliographical study gives $150 \rightarrow 350$ yearly paper numbers (basically, a factor of ~ 10 increase since 1980).

Also, White^[14] finds that publications from Mexican astronomers in the *Astrophysical Journal* and the *Astronomical Journal* rose from a number of 6 in 1960-1969 to 35 in 1970-1979 and 61 in 1980-1989. For 2010-2019, we find a total number of 830 papers in these two journals, which appears to indicate that a growth by a factor of ~ 10 (in the number of publications in these two journals) has occurred from 1990 to 2020. This result is qualitatively consistent with the large growth in paper numbers deduced from comparisons with the work of Rodríguez and Canto^[13] (see above).

In a future paper we will present a comparison between the Mexican astronomical production (of refereed papers) and the

corresponding productions of other Latin American countries. This is a necessary step towards evaluating the evolution of the contributions from Latin American and other developing countries to the astronomical literature (work in this direction has been made, e.g., by Russell).^[15]

Missing from our present paper is a study of the citations to the papers of our sample (see, e.g., the work of van der Kruit^[16] regarding astronomical citations). This is because we chose the recent 2010–2019 period in order to evaluate the more recent evolution of Mexican astronomical publications. For studying citations, we should be choosing a less recent set of papers (e.g., a period ending at the latest in ~2015), so that the papers have had time to accumulate citations. A study of citations to Mexican astronomical publications (limited to a specific research field) was presented by Sierra-Flores *et al.*^[17] but more work clearly needs to be done. Also, a more detailed evaluation of the contribution (in our case in astronomy) of the work of researchers from a given country should involve a study of the role of the individual researchers in the international collaborations in which they participate (for an astronomical example of this, see Chang and Huang).^[18] Clearly, many different things still remain to be done.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

- Liu J, Shu S. Statistical analysis of astronomical papers of China during 1986–1990. *Scientometrics*. 1995;32(3):237–45. DOI: 10.1007/bf02017643
- Bilir S, Gogus E, Onal O, Ozturkmen ND, Yontan T. Research performance of Turkish astronomers in the period of 1980–2010. *Scientometrics*. 2010;97(2):477–89. DOI: 10.1007/s11192-012-0922-3
- Uzun A, Ozel ME. Publication patterns of Turkish astronomers. *Scientometrics*. 1996;37(1):159–69. DOI: 10.1007/bf02093492
- Davoust E, Schmadel LD. A study of the publishing activity of astronomers since 1969. *Scientometrics*. 1991;22(1):9–39. DOI: 10.1007/bf02019273
- Abt H. The publication rate of scientific papers depends only on the number of scientists. *Scientometrics*. 2007;73(3):281–8. DOI: 10.1007/s11192-007-1807-8
- Zhang J, Vogeley MS, Chen C. Scientometrics of big science: A case study of research in the Sloan Digital Sky Survey. *Scientometrics*. 2011;86(1):1–14. DOI: 10.1007/s11192-010-0318-1
- Irvine J, Martin BR. Evaluating big science: CERN's past performance and future prospects. *Scientometrics*. 1985;7(3-6):281–308. DOI: 10.1007/BF02017150
- Mondal D. Scientometric assessment of Indian scientists' contribution to selected physical review journals during 2004–2008. *Journal of Scientometric Research*. 2020;9(2):146–53. DOI:10.5530/jscires.9.2.18
- Boyack KW. Investigating the effect of global data on topic detection. *Scientometrics*. 2017;111(2):999–1015. DOI: 10.1007/s11192-017-2297-y
- Jasheck C. The size of the astronomical community. *Scientometrics*. 1991;22(2):265–82. DOI: 10.1007/BF02020001
- Davoust E, Schmadel LD. A study of the publishing activity of astronomers since 1969. *Publications of the Astronomical Society of the Pacific*. 1987;99:700–10. DOI: 10.1086/132035
- Abt HA. Trends toward internationalization in astronomical literature. *Publications of the Astronomical Society of the Pacific*. 1990;102(649):368–72. DOI: 10.1086/132642
- Rodríguez LF, Cantó J. Una evaluación cuantitativa de la importancia internacional de la astronomía mexicana, in "Historia de la Astronomía en México. Ciudad de México: Fondo de Cultura Económica. 1995.
- White JC. Publication rates and trends in international collaborations for astronomers in developing countries, Eastern European countries, and the former Soviet Union. *Publications of the Astronomical Society of the Pacific*. 1992;104(676):472. DOI: 10.1086/133019
- Russell JM. Publishing patterns of Mexican scientists: Differences between national and international papers. *Scientometrics*. 1998;41(1-2):113–24. DOI: 10.1007/BF02457972
- Van Der Kruit PC. Comparison of astronomy in fifteen member countries of the Organization for Economic Co-operation and Development. *Scientometrics*. 1994;31(2):155–72. DOI: 10.1007/BF02018558
- Sierra-Flores MM, Guzmán MV, Raga AC, Pérez I. The productivity of Mexican astronomers in the field of outflows from young stars. *Scientometrics*. 2009;81(3):765–77. DOI: 10.1007/s11192-008-2264-8
- Chang HW, Heang MH. Cohesive subgroups in the international collaboration network in astronomy and astrophysics. *Scientometrics*. 2014;101(3):1587–607. DOI: 10.1007/s11192-014-1312-9