RadioNet support for Short Term Missions (staff exchange)

Application form

STM Information	
Applicant 's Name	Víctor Manuel Rivilla Rodríguez
Applicant's Affiliation	Istituto Nazionale di Astrofisica - Osservatorio Astrofisico di Arcetri Post-Doc
Host Institute	Max-Planck-Institüt für extraterrestrische Physik, Giessenbachstrasse 1, D-85748, Garching bei München, Germany Contact Person: Prof. Dr. Paola Caselli, e-mail: caselli@mpe.mpg.de, Phone: +49-89-30000-3400 In attachment, there is a copy of the invitation letter.
Date of the STM	16/10/2017 - 27/10/2017 (2 weeks)
Total Cost of STM	1500 EUR
Other sources of funding	None

Request

Topic	Phosphorus (P) is a crucial element for the development of **prebiotic** chemical processes and for the **development of life** in the Universe. It is one of the key components of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), phospholipids (the structural components of all celullar membranes) and the adenosine triphosphate (ATP) molecule, from which all forms of life assume energy (Pasek & Lauretta 2005). Despite this great relevance for astrobiology there are only a handful number of detections of P-bearing species towards star-forming regions. Consequently, **little is known about the chemistry of P in the interstellar medium**. While the chemistry of the other chemical elements relevant for Life (C, O, N, S) are relatively well understood, this is not the case for P. Different theoretical pathways have been proposed to explain the abundance of gas-phase P-bearing molecules: thermal desorption and shock-induced desorption from grain mantles. The very few detections prevent to discriminate between them. Given the astrobiological importance of phosphorus, it is mandatory its **study in star-forming regions**, where stars, planets (and eventually life) are expected to arise. With the aim of investigating the chemistry of P in star-forming regions, **our group in the Arcetri Observatory** (Florence, Italy) started a project to study P-bearing species in star-forming regions. We have recently carried out several observational campaigns using different facilities such as ALMA and VLA, and including also Radionet telescopes (IRAM 30m and APEX). We also have an accepted Effelsberg proposal. All these observations are allowing us to build-up an unbiased and representative sample of star-forming regions where P-bearing molecules are detected. We have already published two papers with the first results, Fontani et al. (2016a) and Rivilla et al. (2016), presenting PN and PO detections (the last for the first time in star-forming regions) obtained with the IRAM 30m telescope. To discriminate between the competing scenarios for the formation of interstellar phosphorus we need to compare the observational results with: i) **chemical models where P-chemistry is properly implemented**. ii) **new laboratory experiments** dedicated to the study of interstellar dust grain analogs and gas phase chemistry containing phosphorus (see for instance the recent work by Turner et al. 2016). A close and continuous collaboration between observations, chemical models and laboratory is required to significantly improve our understanding about the chemistry of interstellar phosphorus.

RadioNet has received funding from the EU's Horizon 2020 research and innovation programme under grant agreement No 730562

Proposed work	I propose to visit the CAS-MPE group to directly work with: i) The **chemical model** team: Anton Vasyunin and Johanna Chantzos. ii) **Laboratory** team: Barbara Michela Giuliano and Luca Bizzochi. Both teams are coordinated and supervised by the Head of the group and director of the institute Prof. Dr. **Paola Caselli**. The host institution is the perfect environment to carry out this work because it includes in the same group experts in observations, chemical modelling and laboratory. Regarding the chemical model team, the short stay will serve to reinforce the collaboration we have already started (see e.g. Rivilla et al. 2016). The MPE chemical model team is currently **improving the P chemical network**, with the inclusion of new chemical reactions and more P-bearing species. The predictions of the updated chemical model will tell us what are the most abundant molecules in the interstellar medium, and thus what are the most promising candidates to search for with new observations. Moreover, we will use the results of current observations (PN and PO) to fine-tune the models (reaction rates, initial amount of phosphorus, chemical pathways…). Regarding the laboratory, the visit will be used to concrete preliminary ideas we already have about the design of **new laboratory experiments dedicated to phosphorus**. We plan to include P in interstellar ice analogs and to follow its evolution to the gas phase, with the aim of studying both surface and gas-phase chemistries. The results of the experiments will be used to improve the chemical model, and to possibly **guide new observations**.
Cross-disciplinary	The study of Astrochemistry, and in a more general context, Astrobiology, is a **multidisciplinary task** that require the expertise of scientists of many different fields. In particular, to understand how the chemical building blocks of life are formed in space, a close collaboration between astronomers, chemists and laboratory physicists is needed. This is especially true in the case of Phosphorus, whose chemistry is still in the dark, and then requires joint efforts. Our group in Arcetri has a deep expertise on the observation of star-forming regions, but we lack experience (and equipment) of chemical modelling and laboratory experiments. To properly analyse our data we need to interact with experts on these fields. Our previous experience collaborating with them has told us that a short visit (2 weeks) is the most efficient way to develop the collaboration. In a more general context, this work perfectly fits the “Origin of Life initiative”, a network to explore the origins of evolution of Life, which involves several Munich research groups of different fields (astronomy, chemistry, physics, biology and geology). The study of the P chemistry in star-forming regions would contribute to the reconstruction of the very first steps of the chemical complexity that will form living organisms.
Impact	The study of P in the interstellar medium requires the observation of rotational transitions of P-bearing molecular species in the (sub)millimeter. Our previous and current observational projects make use of Radionet facilities such as the IRAM 30m telescope, APEX and Effelberg. Since this topic is a new brach of astrochemistry and hence it is still poorly unknown, follow-up observations using these facilities are needed. Therefore, this project will make extensive use of Radionet telescopes in the following years. Despite the key relevance of P for prebiotic and biotic processes (and eventually to Life), the amount of P in the interstellar medium is very low. This is because it is created in the interior of very massive stars (m > 25 M_{sun}), which are rare. Therefore, the cosmic abundance of P is relatively low. As a consequence, P-bearing molecules are not very abundant, and then the molecular lines are intrinsically weak. Then, **to detect P-bearing molecules, high sensitivity instrument are needed**. In fact our single-dish observations using IRAM 30m and APEX show that the PN detections are limited to the brightest sources due to sensitivity. However, these sources are not representative of the star formation in the galaxy. Therefore, to detect P in a broader and more representative context we will need a new generation of instruments with higher sensitivity. Therefore, the development of the study of interstellar P will be a strong scientific case to **push for the design of new instrumentation**, which will attain the interest of the industry.
Curriculum Vitae	The CV of the applicant, Dr, Victor M. Rivilla, is attached.

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RESEARCHER CV

Víctor Manuel Rivilla Rodríguez

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Spanish

21/09/1985

Research interests

Star formation, astrochemistry, molecular astrophysics, complex organic molecules, fractionation, astrobiology, molecular hot cores, molecular outflows, turbulence in star-forming regions, fragmentation in molecular clouds, variability of young stars.

Current position

January 8 2015 - today : iALMA Fellowship (postdoctoral researcher in Astrophysics)
Osservatorio Astrofisico di Arcetri, INAF-OAA
Largo Enrico Fermi 5, I-50125 Firenze, Italy

Previous positions

- July 25 2014 - January 7 2015: Post-doctoral researcher in Astrophysics
  Spanish Council for Scientific Research (CSIC-CAB/INTA), Torrejón de Ardóz (Madrid), Spain
- 2010 - 2014: JAE Studentship: PhD student in Astrophysics
  Spanish Council for Scientific Research (CSIC-CAB/INTA), Torrejón de Ardóz (Madrid), Spain

Summary of scientific production

- 15 refereed papers published (8 as first author), 114 citations in the last 4 years
- H index = 7
- 14 oral contributions and 11 poster contributions to national and international conferences.

Awards

- 2017: *'Marie Sklodowska-Curie Actions Seal of Excellence',* quality label awarded by the European Commission.
- March 2017: Best Poster contribution in **IAUS 332: Astrochemistry VII – Through the Cosmos from Galaxies to Planets** (Puerto Varas, Chile): *The first detections of the key prebiotic molecule PO in star-forming regions.*
- 2014: Finalist of the *"Best Spanish doctoral thesis in Astrophysics Prize"*, awarded by the Spanish Astronomical Society (SEA).

Academic achievements

- 2010-2014: PhD in Astrophysics, Thesis title: ***'The role of low-mass star clusters in the formation of massive stars'***, supervised by Prof. Jesús Martín-Pintado.

http://www.arcetri.astro.it/~rivilla/Tesis/

Grade: “Sobresaliente” cum laude (maximum)

Institution: Center of Astrobiology, Spanish Council for Scientific Research (CSIC-CAB/INTA), Torrejón de Ardoz, Madrid, Spain / University Autónoma of Madrid, Spain

• 2008-2010: Postgraduate Master's Degree in Astrophysics

Institution: University Complutense of Madrid (UCM) and University Autónoma of Madrid (UAM), Spain.

Grade: 8.89 (10.0 max)

• 2003-2008: Degree in Physics Science

Institution: University Autónoma of Madrid (UAM), Spain

Grade: 8.86 (10.0 max)

• 2001-2003: High School in Scientific Subjects

Institution: Jorge Manrique High School, Tres Cantos, Madrid, Spain

Grade: 9.9 (10.0 max).

Academic Grants Awarded

• 2008-2010: JAE Studentship for the completion of the postgraduate Master's degree in Astrophysics, awarded by the Spanish Council for Scientific Research (CSIC).

• 2007-2008: Collaboration Grant, awarded by the Spanish Ministry of Education and Science.

• 2007: Grant of Introduction to Research for students at penultimate degree course, awarded by the Spanish Council for Scientific Research (CSIC).

• 2005-2006: Grant of Excellence, awarded by the Region of Madrid (CAM).

• 2004-2005: Grant of Excellence, awarded by the Region of Madrid (CAM).

• 2003-2004: Grant of Excellence, awarded by the Region of Madrid (CAM).

Research Funds Awarded

• 2015-today: iALMA Project Fellowship (Post-doc position at Arcetri Astrophysical Observatory, Florence)

• 2014-2015: Researcher contract (Post-doc position at the Center of Astrobiology, Spanish Council for Scientific Research, CSIC, Madrid)

• 2010-2012: Contract for the completion of the PhD doctoral thesis (PhD position at the Center of Astrobiology, Spanish Council for Scientific Research, CSIC, Madrid)

Participation in Funded Scientific Projects

• 2015-today: iALMA Italian Premiale Project, Italian National Institute of Astrophysics (INAF).

Participation: Post-doc

• 2011-2015: Spanish contribution to SAFARI/SPICA (Phase B) and HERSCHEL (Phase D). Scientific exploitation of observations in the mid- and far-IR with satellites (AYA2010-21697-C05-01), Spanish Council for Scientific Research, CSIC, Madrid.

Participation: PhD student

• 2008-2010: HERSCHEL: Contribution to the Control Center of the HIFI instrument and to the Scientific Program (ESP2007-65812-C02-01), Spanish Council for Scientific Research, CSIC, Madrid.

Participation: PhD student and Post-doc

Participation in Scientific Events

• 5 - 9 June 2017: **Francesco´s Legacy: Star formation in space and time**, Florence, Italy
Participation: Talk - *The formation of prebiotic molecules in star-forming regions*
http://www.arcetri.astro.it/~sfst2017/

• 20 - 24 March 2017: **IAUS 332: Astrochemistry VII – Through the Cosmos from Galaxies to Planets**, Puerto Varas, Chile
Participation: Poster - *The first detections of the key prebiotic molecule PO in star-forming regions* (awarded with the prize of best poster of the conference)
https://iaus332.physics.unsw.edu.au

• 13 - 17 March 2017: **Astrowin 2017**, University of Florida, Gainesville, USA
Participation: Talk 1 - *The formation of prebiotic molecules in star-forming regions: Phosphorus and COMs*
Talk 2 - *The low D/H ratio in the Galactic Center quiescent gas*
http://www.astro.ufl.edu/~jt/astrowin/

• 21 - 25 November 2016: **European Conference on Laboratory Astrophysics** - ECLA 2016 – Gas on the Rocks
Participation: Poster - *The first detections of the key prebiotic molecule PO in star-forming regions*
http://www.ecla2016.com

• 10 - 13 October 2016: **Fractionation of isotopes in space: from the solar system to galaxies,** Florence, Italy
Participation: Poster - *Low D/H ratio in the Galactic Center Quiescent Gas*
https://www.arcetri.astro.it/~fraction/index.html

• 2 -20 May 2016: Programme **Origins of habitable Planets**, Gothenburg Centre for Advanced Studies in Science and Technology, Chalmers University, Gothenburg, Sweden
Participation - Talk 1 - *Update on radio/X-ray input from YSOs*
Talk 2 - *The path to pre-biotic molecules*
https://www.chalmers.se/en/centres/GoCAS/Events/Origins-of-Habitable-Planets/Pages/default.aspx

• 10 - 11 March 2016: **1st Italian Workshop on Astrochemistry: Astronomical Complex Organic Molecules in different environments**, Florence, Italy
Participation: Talk - *Understanding the formation of astrobiological molecules in star-forming regions*
https://www.arcetri.astro.it/astrochem/

• 4 - 8 October 2015: Conference **From Clouds to protoplanetary disks: the chemical link**, Hans Harnack Haus, Berlin,
https://cas-events.mpe.mpg.de/indico/event/0/
Participation: Talk - *Understanding the formation of astrobiological molecules in star-forming regions.*

• 15 - 17 September 2015: **5th Workshop of the Italian Astrobiology Society: Life in a Cosmic context**, International School for Advanced Studies (SISSA), Trieste,
https://www.ict.inaf.it/indico/event/106/
Participation: Talk - *Understanding the formation of astrobiological molecules in star-forming region.s*

• July 1-8 2015: **Orion (un)plugged conference**, University of Vienna, Austria
Participation: Talk - *The role of low-mass stars in the formation of massive stars in Orion,*
https://www.univie.ac.at/alveslab/orion_unplugged/assets/online_program.pdf
Participation: Poster – *Constraining the non-thermal emission from young stars in Orion*

• 22-26 June 2015: **European Week of Astronomy and Space Science (EWASS 2015)**, Universidad de la Laguna, Tenerife, Spain,
http://eas.unige.ch/EWASS2015/
Participation: invited by the Spanish Astronomical Society (SEA).

• 9-10 April 2015: **ALMA proposal preparation day 2015**, Italian ARC, Istituto di Radioastronomia di Bologna, Italy
http://www.alma.inaf.it/index.php/ALMA_proposal_preparation_day_2015

• 15-20 March 2015: Conference **The Soul of massive star formation**, Puerto Varas, Chile,
http://www.das.uchile.cl/star-formation/
Participation: Poster - *The role of low-mass star clusters in the formation of massive stars*
http://www.arcetri.astro.it/~rivilla/Posters/Poster-cile.pdf.

• 19-20 February 2015: **iALMA Project Workshop**, CNR Research Area, Bologna, Italy
http://ialma.alma.inaf.it/index.php/19-20_Febuary_2015_-_Face2face_meeting
Participation: Talk - *HCO as precursor of glycolaldehyde*

• 22-23 January 2015: **Workshop on mm-VLBI with ALMA**, CNR Research Area, Bologna, Italy
http://www.alma.inaf.it/index.php/Workshop_on_mm-VLBI_with_ALMA
Participation: Poster – *Constraining the non-thermal emission from young stars in Orion*,
http://www.alma.inaf.it/images/Rivilla.pdf.

• 20-21 January 2015: **Third workshop on Millimeter Astronomy in Italy**, CNR Research Area, Bologna, Italy
http://www.alma.inaf.it/index.php/Terzo_Workshop_sull%27Astronomia_Millimetrica_in_Italia
Participation: Talk – *Radio flares from Orion young stars*
http://www.alma.inaf.it/images/Rivilla_mm15.pdf.

• 8-12 September 2014:: **44st Young European Radio Astronomers Conference** (YERAC), Toruń Centre for Astronomy at the Nicolaus Copernicus University, Poland,
http://yerac2014.astro.uni.torun.pl
Participation: Poster and talk – *Short- and long-term radio variability of young stars in the Orion Nebula Cluster and Orion Molecular Cloud*
http://yerac2014.astro.uni.torun.pl/wp-content/uploads/yerac-2014-rivilla.pdf.

• 10-14 June 2013: **Conference Massive Stars: From α to Ω**, Rodes, Greece
http://a2omega-conference.net/Default.aspx

Participation: Poster – *The role of low mass star clusters in massive star formation. The Orion case*, http://www.arcetri.astro.it/~rivilla/Posters/Poster-Rodas-SessionI_17_Rivilla.pdf.

• 9-13 July 2012: **X Astronomical Spanish Society Meeting**, Valencia
http://www.sea-astronomia.es/drupal/SEA2012
Participation: Poster – *The kinematics of the hottest gas in massive star-forming regions*
http://www.arcetri.astro.it/~rivilla/Posters/Poster-X-SEA-VMRivilla.pdf.

• 18-20 July 2011: **41st Young European Radio Astronomers Conference** (YERAC), University of Manchester - Jodrell Bank Observatory, UK,
http://www.jb.man.ac.uk/meetings/YERAC2011/
Participation: Poster and talk – *The overall systematic trends in the kinematics of the hottest gas in massive star-forming regions*
http://www.jodrellbank.manchester.ac.uk/meetings/YERAC2011/downloads.html#Presentations

• 30 May - 3 June 2011: **The Molecular Universe (IAU Symposium 280)**, Toledo, Spain 2011 http://www.iau.org/science/meetings/past/symposia/993/
Participation: Poster – *The overall systematic trends in the kinematics of the hottest gas in massive star forming regions*
http://adsabs.harvard.edu/abs/2011IAUS..280P.316R
http://www.arcetri.astro.it/~rivilla/Posters/poster_toledo_victor.pdf.

• 18 October 2010: **1st Center of Astrobiology Astrophysics Department Workshop**, Torrejón de Ardoz, Madrid, Spain
Participation: Talk – *On the role of low mass stars in the formation of massive stars. The Orion Case*.

• 28 November - 1 December 2010: **ALMA Early Science,** IRAM, Grenoble, France
http://www.iram-institute.org/EN/content-page-183-7-67-183-0-0.html

Invited Scientific Seminars

• December 14 2017 (*planned date*), Center for Space and Habitability (CSH), Bern, Switzerland
• November 14 2016: *Understanding the formation of prebiotic molecules in star-forming regions*, Istituto di Radioastronomia (IRA), Bologna, Italy
• May 24 2015: *Understanding the formation of astrobiological molecules in star-forming regions*, General Seminar, Arcetri Astrophysical Observatory, Florence, Italy, http://www.arcetri.astro.it/~rivilla/Talks/ rivilla-seminar-arcetri6.pdf
• December 19 2014: *The role of low-mass star clusters in the formation of massive stars*, University of Alicante, Alicante, Spain
• August 29 2014: *The role of low-mass star clusters in the formation of massive stars*, Smithsonian Astrophysical Observatory, Harvard-Smithsonian Center for Astrophysics (CfA), Cambridge, MA, USA
• April 7 2014: *The role of low-mass star clusters in the formation of massive stars*, University of Vienna, Austria

Short research stays

• 8 -12 May 2017, Munich, **Center of Astrochemical Studies (CAS), Max Planck Institute for Extraterrestrial Physics (MPE)**, Munich, Germany

Collaborator: Prof. Dr. Paola Caselli and Dr. Anton Vasyunin
Work: Comparison between observations and chemical models of phosphorus chemistry.

• September 22 2014 - October 11 2014: **National Radio Astronomy Observatory** (NRAO, Socorro, New Mexico, USA).
Collaborators: Dr. Claire Chandler and Dr. Jan Forbrich
Work: Extensive calibration, imaging and preliminary analysis of VLA data.

• February 19 - May 23 2011: **Smithsonian Astrophysical Observatory, Harvard-Smithsonian Center for Astrophysics** (CfA), Cambridge, MA, USA
Collaborators: Dr. Qizhou Zhang and Dr. Izaskun Jiménez-Serra
Work: Reduction and study of SMA interferometric observations of the dense gas of massive star forming regions.

• 21 October - December 20 2010: **Arcetri Astrophysical Observatory**, INAF, Florence, Italy.
Collaborator: Dr. Riccardo Cesaroni
Work: Analysis of VLA interferometric observations of massive star-forming regions.

• February 15-19 2010: **University College of London** (UCL), England.
Collaborator: Dr. Jeremy Yates
Work: Use of the radiative transfer code SMMOL to model molecular lines from vibrationally excited states.

• July 31- September 30 2009: **National Radio Astronomy Observatory** (NRAO), Socorro, New Mexico, USA.
Collaborator: Dr. Claire J. Chandler
Work: Reduction of high frequency VLA observations of regions of massive star formation, both galactic and extragalactic.

Participation in schools

• 19-21 September 2016: **KROME Computational School**, Florence, Italy, http://kromepackage.org/bootcamp/index.php
• September 2011: **6th IRAM 30m Summer School**, Institute de Radio Astronomie Millimetrique (IRAM), Granada, Spain, http://iram-institute.org/EN/content-page-202-7-67-202-0-0.html
• June 2010: **12th Synthesis Imaging Workshop**, National Radio Astronomy Observatory, Socorro, New Mexico, USA, http://www.aoc.nrao.edu/events/synthesis/2010/

Teaching activities

• June 2017: 1 hr lesson to high-school students: "Astrochemistry", Arcetri Astrophysical Observatory, Florence, Italy
• June 2016: 1 hr lesson to high-school students: "Star Formation: physics and chemistry", Arcetri Astrophysical Observatory, Florence, Italy
• May 25-29 2015: School of Astrophysics "Francesco Lucchin"
Tutorial: "*Using the ALMA Science Archive*"
http://www.arcetri.astro.it/~lt/scuola2015/

Experience organising scientific events

• Local Organising Committee (LOC) member of the conference *"Fractionation of isotopes in space: from the solar system to galaxies"* (Florence, Italy, 10-13 October 2016), https://www.arcetri.astro.it/~fraction/

Experience refereeing scientific papers

• Referee of 1 article published in Astronomy and Astrophysics.
• Referee of 1 article published in Astrophysical Journal.

Astrophysical Facilities used

• Atacama Large Millimeter Array (ALMA): Principal investigator [PI] in 3 projects.
• Very Large Array (VLA): Principal investigator [PI] in 5 projects.
• IRAM NOEMA interferometer: PI in 1 project.
• Sub-millimeter Array (SMA): PI in 2 projects.
• Green Bank Telescope (GBT): PI in 2 projects.
• Effelsberg Telescope: PI in 1 project.
• APEX Telescope: co-PI in 1 project.
• IRAM 30 meter telescope: PI in 4 projects, including a Director's Discretionary Time (DDT) project.
• Deep Space Network (DSN) 34 meter telescope: PI in 1 project.
• I have also used multi-wavelength archival data from multiple others facilities: Chandra Space Telescope, Hubble Space Telescope (HST), Spitzer Space Telescope, James Clerk Maxwell Telescope (JCMT), Herschel Space Telescope, United Kingdom IR Telescope (UKIRT), or Sloan Digital Sky Survey (SDSS).

Software Skills

• *Development and testing of astronomical software:* Madrid Data Cube Analysis on ImageJ (MADCUBA), software package to visualize and analyze datacubes and spectra.
• *Astrophysical data calibration and analysis:* CASA, AIPS, GILDAS, MADCUBA, MIRIAD, GBT-IDL, ds9, Aladdin Sky Atlas, SIMBAD, NED.
• *Programming:* Fortran, Python (basic).

Science outreach activities

• June 2017: Interview for MEDIA-INAF TV to explain the detection of CH_3NCO in solar-type protostars, http://www.media.inaf.it/2017/06/08/isocianato-di-metile-attorno-a-baby-stelle/
• May 2017: "*Bambineide 2017: Arcetri e le sette terre - Giochiamo con la Scienza!*", Open Day for the public (kids and parents) at the Arcetri Astrophysical Observatory, Firenze, Italy.
• March 2016: *"What are those tiny dots in the sky?"*, talk at Europa International School, Sevilla, Spain.
• May 2015: "*Bambineide 2015: I segreti della luce*", Open Day for the public (kids and parents) at the Arcetri Astrophysical Observatory, Firenze, Italy.
• June 2012: "*Astrophysics for kids*", talk at Antonio Osuna School, Tres Cantos, Madrid, Spain.
• June 2012: "*Astrophysics for kids*", talk at Jorge Manrique High School, Tres Cantos, Madrid, Spain.
• April 2010: "*Radio-interferometry: Revealing the details of the unvisible universe*", talk at Jorge Manrique High School, Tres Cantos, Madrid, Spain.

List of publications

As first author:

• R. Martín-Domenech (co-led), **V. M. Rivilla** (co-led)**,** I. Jiménez-Serra, D. Quénard, L. Testi, J. Martín-Pintado, '*Detection of methyl isocyanate (CH_3NCO) in a solar-type protostar*', MNRAS, 469, 2230, arXiv:1701.04376, https://arxiv.org/abs/1701.04376

• **V. M. Rivilla**, M. T. Beltrán, J. Martín-Pintado, F. Fontani, P. Caselli, R. Cesaroni, *'On the chemical ladder of esters. Detection and formation of ethyl formate in the W51 e2 hot molecular core',* A&A, 599, 26, arXiv:1611.00719, https://arxiv.org/abs/1611.00719

• **V. M. Rivilla**, M. T. Beltrán, R. Cesaroni, F. Fontani, C. Codella, Q. Zhang, '*Formation of ethylene glycol and other complex organic molecules in star-forming regions',* A&A, 598, 59, arXiv:1608.07491, https://arxiv.org/abs/1608.07491

• **V. M. Rivilla**, F. Fontani, M. T. Beltrán, A. Vasyunin, P. Caselli, J. Martín-Pintado, R. Cesaroni, *`The first detections of the key prebiotic molecule PO towards star-forming regions`*, ApJ, 826, 161, arXiv:1605.06109, http://arxiv.org/abs/1605.06109

• **V. M. Rivilla**, C. J. Chandler, J. Sanz-Forcada, I. Jiménez-Serra, J. Martín-Pintado, and J. Forbrich, '*Short- and long-term radio variability of young stars in the Orion Nebula Cluster and Molecular Cloud*', ApJ, 808, 146, August 2015, doi:10.1088/0004-637X/808/2/146, arXiv: 1504.0089, http://arxiv.org/abs/1504.00849

• **V. M. Rivilla**, I. Jiménez-Serra, J. Martín-Pintado, J. Sanz-Forcada', '*The role of low-mass star clusters in forming the massive stars in DR 21'*, MNRAS, 437:1561-1575, January 2014, doi: 10.1093/mnras/stt1989; arXiv:1307.528, http://arxiv.org/abs/1310.4049

• **V. M. Rivilla**, J. Martín-Pintado, J. Sanz-Forcada, I. Jiménez-Serra, A. Rodríguez-Franco, '*X-ray embedded stars as driving sources of outflow-driven turbulence in OMC1-S*', MNRAS, 434:2313-2328, September 2013, doi: 10.1093/mnras/stt1173; arXiv:1307.5283, http://arxiv.org/abs/1307.5283

• **V. M. Rivilla**, J. Martín-Pintado, I. Jiménez-Serra, A. Rodríguez-Franco, '*The role of low mass star clusters in massive star formation. The Orion case*', A&A, 554: A48, June 2013, doi: 10.1051/0004-6361/201117487; arXiv:1302.2763, http://arxiv.org/abs/1302.2763

As coauthor:

• R. Cesaroni, A. Sánchez-Monge, M. T. Beltrán, K. G. Johnston, L. T. Maud, L. Moscadelli, J. C. Mottram, A. Ahmadi, V. Allen, H. Beuther, T. Csengeri, S. Etoka, G. A. Fuller, R. Galván-Madrid, C. Goddi, T. Henning, M. G. Hoare, P. D. Klaassen, R. Kuiper, M. S. N. Kumar, S. Lumsden, T. Peters, **V. M. Rivilla**, P. Shilke, L. Testi, F. van der Tak, S. Vig., C.M. Walmsley, H. Zinnecker, *'Chasing discs around O-type (proto)stars: Evidence from ALMA observations'*, A&A, 59 602

• J. Forbrich, M. Reid, K. M. Menten, **V. M. Rivilla**, S. Wolk, U. Rau, C. J. Chandler, *'Extreme radio flares and associated X-ray variability from young stellar objects in the Orion Nebula Cluster'*, ApJ, in press, arXiv: 1706.05562, https://arxiv.org/abs/1706.05562

• F. Fontani, **V. M. Rivilla**, P. Caselli, A. Palau, *`Phosphorus-bearing molecules in massive dense cores`*, ApJ, 822, 30, 2016, arXiv:1604.02565, http://arxiv.org/abs/1604.02565

• J. Forbrich, **V. M. Rivilla**, K. M. Menten, M. Reid, C. J. Chandler, U. Rau, S. Bhatnagar, S. J. Wolk, S. Meingast, *`The population of Compact Radio sources in the Orion Nebula Cluster´*, ApJ, 822, 93, 2016, arXiv:1603.05666, http://arxiv.org/abs/1603.05666

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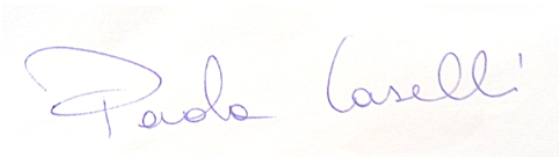
1 July 2017

Dear Dr. Rivilla,

It is a pleasure to invite you to spend one month at the Center for Astrochemical Studies at the Max-Planck Institute for Extraterrestrial Physics to carry out the project within the context of RadioNet. During your stay, we will work together on Phosforous chemistry and compare your observational results with our astrochemical model predictions. This will improve our understanding of P-chemistry toward regions of high-mass star formation and the first steps toward the production of pre-biotic molecules.

With kind regards



Prof. Dr. Paola Caselli
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