

**Report for the event supported by RadioNet**

**TITLE** *COSMIC RAYS: THE SALT OF THE STAR FORMATION RECIPE*

**DATE:** *MAY, 2ND - 4TH, 2018*

**LOCATION:** *FLORENCE, ITALY*

**MEETING  
WEBPAGE:** *[www.arcetri.astro.it/cosmicrays](http://www.arcetri.astro.it/cosmicrays)*

**HOST INSTITUTE:** *DEPARTMENT OF PHYSICS AND ASTRONOMY, UNIVERSITY OF  
FLORENCE*

**RADIONET  
BENEFICIARY / NO:** *INAF / 4*

# 1 Scientific summary

Cosmic rays (CRs) are a key ingredient in many fields of Astrophysics and in particular in Star Formation, but despite their great relevance our understanding is still relatively incomplete. Thanks to the data delivered by the new generation of radio and (sub)millimeter telescopes (RadioNet facilities as NOEMA, IRAM 30m, APEX, Effelsberg, LOFAR, VLBI; and other such as ALMA and VLA), we have now the opportunity of reaching a comprehensive knowledge about the role of CRs in the physics and chemistry of the interstellar medium, hence about the processes leading to star and planet formation.

Given the multidisciplinary nature of the topics where CRs play an important role, our motivation to organize the event was to bring together for the first time the observational and theoretical communities working on CRs in star-forming environments to present their recent results. Indeed, the interdisciplinary environment has been particularly beneficial for students and postdocs, who might find new directions in their research by linking the different fields that coexisted in the workshop. The conference succeeded to gather international experts on astronomical observations, laboratory experiments, theory, and simulations. The CR ionisation rate ( $\zeta$ ), defined as the number of ionisation of  $H_2$  molecules per unit time, is the key-brick parameter which governs many processes of the physics and chemistry of star-forming regions. The value of  $\zeta$  strongly depends on the environment, decreasing from diffuse clouds to dense cores, to circumstellar discs. This fundamental parameter can be derived observationally using different methods which rely (all of them) on the detection of molecular ions through rotational spectroscopy in the radio and (sub)mm wavelength ranges, using radiotelescopes such as IRAM-30m, NOEMA, ALMA, APEX and Effelsberg. Moreover, CRs electrons can be also responsible for the synchrotron emission in protostellar jets. This non-thermal emission is detected with increasing accuracy with the last-generation radiotelescopes such as LOFAR, VLA, and GMRT. We briefly summarize here some of the scientific highlights of the conference:

- Impact of cosmic rays on the chemistry of the interstellar medium: CRs are the primary source of ionisation in dense molecular clouds shielded by the interstellar UV radiation field. They produce molecular ions and electrons that activate a rich chemistry in the dense cold gas, leading to the formation of molecules of increasing complexity, up to pre-biotic and possibly biotic molecules.
- Derivation of the ionisation rate from observations using IRAM 30m, NOEMA and APEX (e.g., talks by Oka, Neufeld, Fontani, Zeng, Podio).
- Synergies with laboratory experiment mimicking the irradiation with CRs or secondary UV photons produced by CRs (e.g., Palumbo, Ioppolo).
- Several talks (e.g., Jiménez-Serra, Quénard, Drozdovskaya) were focused on the role of cosmic rays in the chemical models used to interpret observations from RadioNet facilities (see Fig. 4).
- Local acceleration of CRs inside protostars can explain the synchrotron emission and the extremely high CR ionisation rate observed in protostellar jet shocks (e.g. observational results shown by Ainsworth, Fontani, Osorio, Podio and theoretical studies by Araudo, Marcowith, Rodgers-Lee, Rab).
- Role of CRs in exoplanets, planetary atmospheres, and early Earth (e.g. Helling, Struminsky, Gronoff).

RadioNet community will benefit from this workshop since the discussions arose settled the ground for a more efficient exploitation of the current facilities, especially those coordinated by RadioNet. Various groups of people attending the workshop with different background (theoretical, observational...) are already planning new proposals to exploit RadioNet telescopes. Furthermore, these new ideas will contribute to design the next challenges in the

field and to prepare future ambitious projects making use of powerful facilities available in the following years such as SKA, ALMA (bands 1-2), and the next generation VLA.

As a result of this workshop, the need of new instrumental capabilities to answer specific scientific questions emerged. As an example, the detection of the DCO+(1-0) line at 72 GHz would be extremely useful to derive accurately the CR ionisation rate in prestellar sources. However, this frequency is not observable with current facilities (it would require an extension of the frequency coverage of the new 4mm receivers installed in the IRAM-30m telescope, for instance). This workshop also provided new ideas to push for the design and implementation of new instrumentation of current RadioNet facilities.

## 2 Agenda of the event

The full scientific program can be found in Appendix to this document.

## 3 Participants

The total number participants is 63, coming from Europe, United States and Asia. The geographical distribution is the following: Italy (13 participants), UK (10), France (9), USA (7), Germany (5), Japan (4), Spain (3), Poland (3), Russia (3), and one participant from Taiwan, Czech Republic, Switzerland, Latvia, Netherlands, and South Korea; 8 students, 19 post-docs, and 36 staff with a 30% of women. We have 15 invited experts (40% of women). The conference picture with all the participants can be found at [www.arcetri.astro.it/cosmicrays](http://www.arcetri.astro.it/cosmicrays). People who requested the subscription to the RadioNet newsletter can be found in attachment.

## 4 RadioNet financial contribution

We have used the RadioNet funding of 4000 € to waive the registration fee for all the participants. We also offered the meals and coffee breaks during the event (3 meals and 5 coffee breaks). The motivation of this was to allow the participation of young researchers in the conference. Indeed, 43% of the participants were PhD student and postdocs.



## 5 Publications


We acknowledged the funding received from Radionet during the introductory and concluding talks (see photos attached to this document). We included logo from RadioNet and Europe in the conference website, and included the acknowledgment of the RadioNet support: **This event has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562 [RadioNet], and from the Italian Premiale Project iALMA.**

We will also include this acknowledgment in the case of future publications arising from the ideas and possible projects discussed during the workshop.


**List of participants, including name, affiliation and country. The signatures of the participants are in the document attached.**



## Wednesday, May 2<sup>nd</sup>

08:30-09:15	Registration	
09:15-09:30	Welcome and logistics	
<b>SESSION 1-a</b>		
<b>Role of cosmic rays in star and planet formation: Theory</b>		
Chair: Paola Caselli		
09:30-10:00	Daniele Galli (I)	Cosmic-ray ionization in clouds and disks
10:00-10:20	Tommaso Grassi (C)	The effects of cosmic rays on microphysics
10:20-10:40	Alexei Ivlev (C)	Cosmic-ray ionisation in circumstellar discs
10:40-11:00	Coffee break and Posters 	
11:00-11:30	Stefano Gabici (I)	Cosmic-ray penetration in diffuse clouds
11:30-11:50	Dmitry Chernyshov (C)	Role of self-excited turbulence in penetration of cosmic rays into molecular clouds
Chair: Alexandre Marcowith		
11:50-12:20	Philipp Girichidis (I)	Dynamical and chemical impact of cosmic rays on the ISM
12:20-12:40	Soonyoung Roh (C)	Propagation of cosmic rays in magnetized protoplanetary disks
12:40-13:00	Yuri Fujii (C)	MHD simulations of protoplanetary disks with non-equilibrium ionization chemistry
13:00-14:30	Lunch 	
14:30-14:50	James Wurster (C)	How cosmic rays shape a protostar
14:50-15:10	Thomas Bisbas (C)	Cosmic-ray induced destruction of CO in star-forming galaxies and implications for tracing H <sub>2</sub> gas
<b>SESSION 1-b</b>		
<b>Role of cosmic rays in star and planet formation: Observations</b>		
Chair: Víctor M. Rivilla		
15:10-15:40	Paola Caselli (I)	The importance of cosmic rays in star and planet formation

15:40-16:10	David Neufeld (I)	The Galactic cosmic-ray ionization rate implied by observations of atomic and molecular ions
16:10-16:30	Takeshi Oka (C)	$H_3^+$ , the ideal probe for in situ measurements of soft cosmic rays
16:30-17:00	Coffee break and Posters	
17:00-17:30	Jesús Martín-Pintado (I)	On the effects of cosmic rays on Galactic center molecular clouds
17:30-17:50	Shaoshan Zeng (C)	Chemical complexity in the Galactic centre GMCs and the imprint of cosmic rays: the nitrogen-bearing family
17:50-18:10	Farhad Yusef-Zadeh (C)	Consequences of the high rates of cosmic-ray ionization toward the Galactic center

### Thursday, May 3<sup>rd</sup>



<b>SESSION 2-a</b>		
<b>Impact of cosmic rays on the formation of interstellar molecules: Observations and Models</b>		
Chair: Ana López-Sepulcre		
09:00-09:30	Izaskun Jiménez-Serra (I)	The formation of COMs in the ISM: from cold cores to Galactic center molecular clouds
09:30-09:50	Maria Drozdovskaya (C)	The role of cosmic rays in setting the chemical content of protoplanetary disk midplanes
09:50-10:10	David Quénard (C)	Influence of the cosmic-ray ionisation rate on complex organic molecules chemistry
10:10-10:30	Will Robson Rocha (C)	Chemical evolution of PPDs employing optical constants of cosmic-ray processed ice into ProDiMo code
10:30-10:50	Coffee break and Posters	
10:50-11:10	Juris Kalvāns (C)	Cosmic-ray induced diffusion, reactions and destruction of molecules in interstellar ices
11:10-11:30	Wasim Iqbal (C)	Nautilus multi grain model: impact of cosmic-ray induced desorption in abundances of COMs in the ISM
11:30-11:50	Mélysse Bonfand (C)	The influence of cosmic rays on the chemistry in Sagittarius B2

<b>SESSION 2-b</b> <b>Impact of cosmic rays on the formation of interstellar molecules:</b> <b>Laboratory experiments</b>		
Chair: Izaskun Jiménez-Serra		
11:50-12:20	Guillermo Muñoz-Caro (I)	A comparison of UV, X-ray, and ion processing of icy dust analogs
12:20-12:40	Sergio Ioppolo (C)	Solid state chemistry driven by cosmic-ray induced secondary electrons
12:40-13:00	Gleb Fedoseev (C)	Laboratory simulations of cosmic-ray processing of N <sub>2</sub> -containing ices at dark cloud conditions
13:00-14:30	Lunch	
14:30-15:00	Maria Elisabetta Palumbo (I)	Experimental studies of the role of cosmic rays in the chemistry of interstellar icy grain mantles
15:00-15:20	Gustavo Adolfo Cruz Díaz (C)	Degradation of PAHs and radiation-induced products by cosmic-ray analogs
<b>SESSION 3</b> <b>Cosmic rays and the origin of life</b> <b>(ISM, comets, planetary atmospheres, and early Earth)</b>		
Chair: David Neufeld		
15:20-15:50	Christiane Helling (I)	The effect of cosmic rays on the ionisation and chemistry of exoplanets and brown dwarfs
15:50-16:10	John Robert Brucato (C)	Heterogeneous catalysis of organic molecules in harsh environments
16:10-16:40	Coffee break and Posters	
16:40-17:00	Alexei Struminsky (C)	Radiation conditions near exoplanets of G-M-stars
17:00-17:30	Guillaume Gronoff (I)	Chemical impact of cosmic rays: towards a new vision of planetary system evolution
17:30-17:50	Vasily Kozhevnikov (C)	The simulation of stratospheric discharges sustained by the secondary electrons from cosmic rays
18:00	<b>Promenade from Arcetri to Galileo's house</b> <b>and Social "Aperitivo"</b>	

**Friday, May 4<sup>th</sup>**

**SESSION 4**  
**Cosmic-ray factories: local acceleration in protostars**

Chair: Stefano Gabici

9:00-9:30	Elena Amato (I)	On the mechanisms of particle acceleration in astrophysical sources
9:30-9:50	Donna Rodgers-Lee (C)	The ionising effect of low energy cosmic rays from a Class II object on its protoplanetary disk
9:50-10:10	Christian Rab (C)	Modelling of high-energy ionization processes in the circumstellar environment of young solar-like stars
10:10-10:30	Coffee break and Posters	
10:30-11:00	Alexandre Marcowith (I)	In-situ cosmic-ray sources in young stellar objects
11:00-11:20	Francesco Fontani (C)	Carbon-chain growth induced by cosmic rays in the Solar-type protocluster OMC2-FIR4
11:20-11:40	Linda Podio (C)	Observational constraints on the cosmic-ray ionisation rate in the protostellar shock L1157-B1
11:40-12:00	Ignazio Pillitteri (C)	Hot and glowing: the high energy emission of the very young stellar object Elias 29
12:00-12:30	Anabella Araudo (I)	Particle acceleration, magnetic field amplification, and gamma-ray emission in protostellar jets
12:30-14:00	Lunch	

Chair: Elena Amato

14:00-14:30	Jan Forbrich (I)	New perspectives on high-energy processes from stellar radio astronomy
14:30-14:50	Rachael Ainsworth (C)	Synchrotron emission in protostellar jet shocks revealed by metre wavelength observations
14:50-15:10	Mayra Osorio (C)	Non-thermal radio emission from the jet associated with an intermediate-mass protostar
15:10-15:30	Final remarks	

# List of posters

1	Marin Chabot	PAH destruction by heavy cosmic rays and carbon chains production rates
2	Laura Colzi	Carbon isotope chemistry in intermediate- and high-mass star forming cores
3	Alicja Domaracka	Intra-cluster molecular growth processes induced by low-energy ion processing of carbonaceous system
4	Yasuo Fukui	Cosmic-ray acceleration and star formation in the gamma ray SNR RXJ1713.7-3946
5	Siddhartha Gupta	Lack of thermal energy in superbubbles: hint of cosmic rays?
6	Michał Hanasz	Synchrotron emission from cosmic-ray driven galactic winds in star-forming galaxies
7	Juris Kalvāns	Temperature spectra for interstellar grains heated by cosmic rays
8	Mateusz Ogrodnik	Piernik MHD code: modelling energy dependent transport of cosmic-ray electrons with energy spectrum
9	Bilal Ramzan	Structure of interstellar clouds with cosmic rays and waves
10	Víctor M. Rivilla	The role of cosmic rays and other energetic phenomena in the chemistry of P-bearing molecules in the Galactic Center
11	Hermann Rothard	Radiolysis and sputtering of carbon dioxide ice by swift (MeV-GeV) ions
12	Hidetoshi Sano	A star-forming dense cloud core embedded within the brightest gamma-ray SNR RX J1713.7-3946
13	Christopher Shingledecker	Cosmic ray-driven radiation chemistry in astrochemical models
14	Dominik Wóltański	Synchrotron signatures from the cosmic-ray driven dynamo
15	Yumiko Yamane	Cosmic ray acceleration and star formation in the superbubble 30 Doradus C



# Pictures of the conference



Figure 1 - Left: The organisers acknowledge the source of fundings, the Italian Premiale Project iALMA and RadioNet, during the introductory talk. Right: Víctor M. Rivilla explains the main motivation of the workshop during the introductory talk.



Figure 2 - Left: Right: Daniele Galli, from the Arcetri Observatory, gave a detailed review talk about cosmic-ray science.



Figure 3 - Left: Conference room at the Department of Physics and Astronomy of the University of Florence, and participants. Right: RadioNet posterposted at the conference room door.

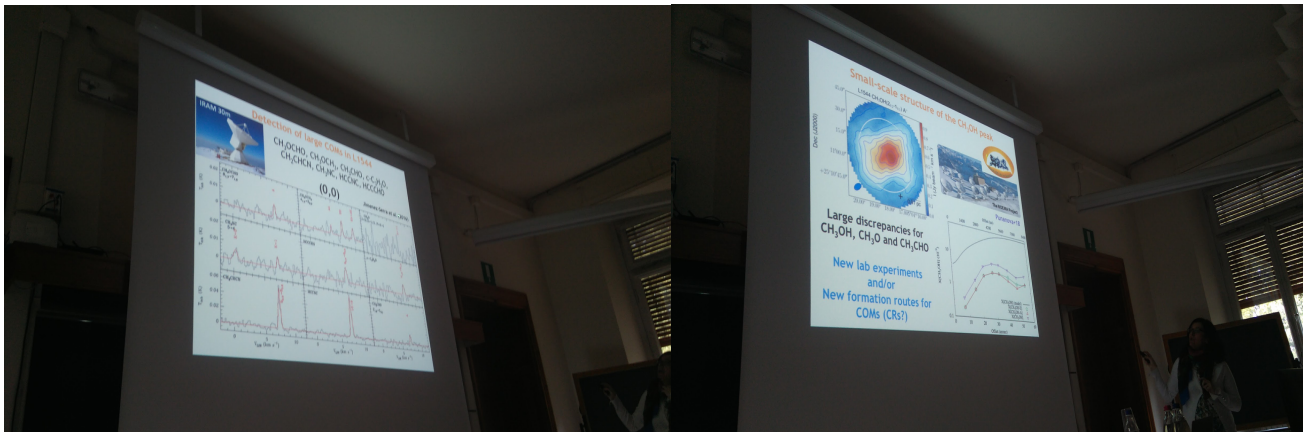


Figure 4 - Left: Results presented by Izaskun Jiménez-Serra (Queen Mary University, UK) about complex organic molecules in the prestellar core L1544, using deep IRAM 30m telescope observations. Right: Izaskun Jiménez-Serra explained that the current chemical models are not able to quantitatively explain all the molecular abundances of complex organic molecules derived from the NOEMA Large Program SOLIS data.



Figure 5 - Left: One of the invited speakers, Jesús Martín-Pintado (CAB, INTA-CSIC, Spain), showed us the APEX map of the H<sub>2</sub>CO emission in the Central Molecular Zone (CMZ) of our Galaxy, which was used to derive the temperature map. Right: Sandy Zeng (Queen Mary University, UK) presented results from a GBT and IRAM 30m survey towards the quiescent molecular Galactic Center cloud source G+0.693.

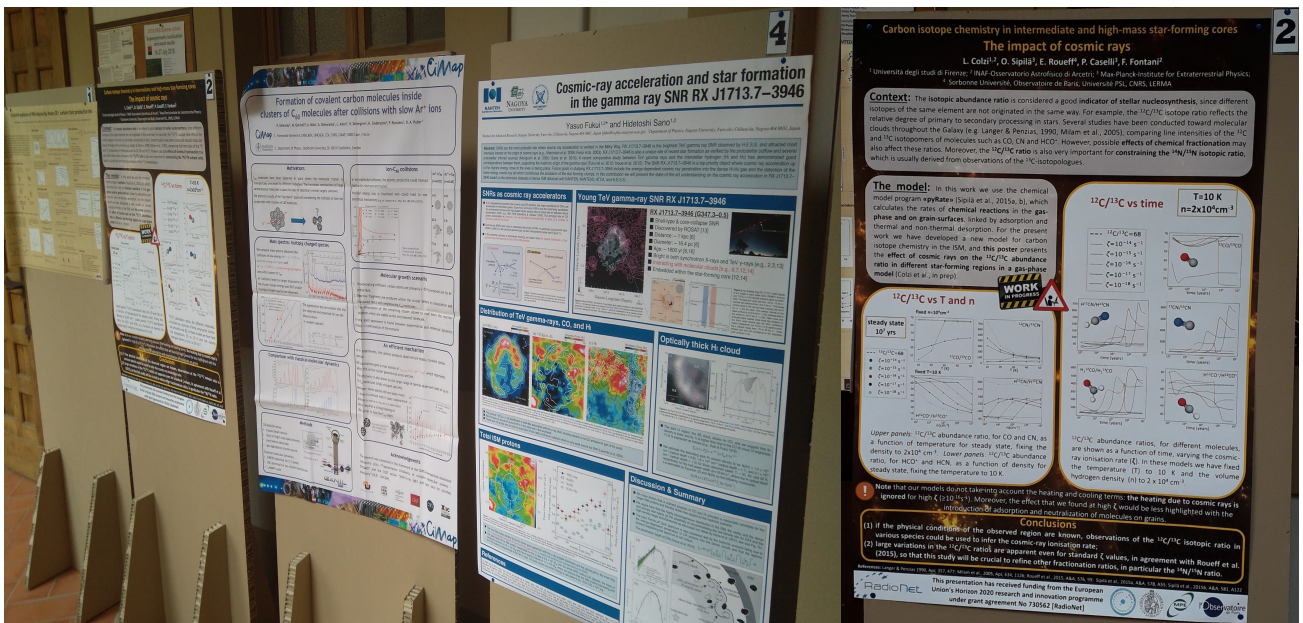


Figure 6 - Left: Some of the posters presented at the conference. Right: Laura's Colzi (INAF-Arcetri Observatory) poster about the role of cosmic rays in carbon fractionation in intermediate and high-mass star-forming cores.



Figure 7 - Participants at the venue during lunch and coffee breaks.