CURRICULUM VITAE

Angela Ciaravella

PERSONAL INFORMATION

INAF-Osservatorio Astronomico di Palermo, P.za Parlamento 1, 90134 Palermo, Italy

POSITIONS

- 3tronomico di Palermo, ItalyDec. 2001 - until now Ricercatore Astronomo (Researcher) at INAF-Osservatorio As-

- 2011 - 2019versity, Jhongli, Taiwanabout one month per year as visiting scientist at the National Central Uni-

- 2002 - 2011Center for Astrophysics, Cambridge, USAabout three months per year as visiting scientist at the Harvard-Smithsonian

- 1995-2001USA Visiting scientist, Harvard-Smithsonian Center for Astrophysics, Cambridge,

- May.Astronomiche, Palermo, Italy1998 - 1yr Post-Doctoral Fellowship at the Dipartimento Di Scienze Fisiche ed

- Mar. 1996 - Feb. 1998 European Space Agency Post-Doctoral Fellowship at the Harvard-Smithsonian Center for Astrophysics, Cambridge, USA

- Mar. 1995 - Feb.1996 Fellowship with the Department of Astronomy and Space Science,University of Firenze, Italy

- Nov. 1995 - Apr. 1999 Visiting Scientist at the Goddard Space Flight Center, Greenbelt,USA

- Nov. 1989 - Oct. 1990 Fellowship at IAIF -National Council of Research, Palermo, Italy

EDUCATION

1994 Ph.D. in Physics - University of Palermo, Italy

1988 Master Degree in Physics - University of Palermo

PERSONAL SKILLS

- Mother tongue Italian
- Other language English (fluent both oral and written)
- Programming languages” Fortran; Data Analysis software: IDL, Origin

CURRENT SCIENTIFIC RESPONSABILITIES

- Responsible for the Light Irradiation Facility for ExochemistryCoordinator of the research team consisting of two sta↲ researcher, a TD, a PhD student, (LIFE) at INAF-OAPa. and few under graduate students.
- 2023-2025e creazione di Infrastrutture di Ricerca ”Strengthening the Italian Leadership in ELTleader of WP 4000 and coordinator of WP 4101 of the PNRR-Ra↲orzamento and SKA (STILES)” (PI A. Fontana). The WP4101 is dedicated to the design and construction of an atmospheric simulator facility at INAF-OAPa.
- 2022-2024project ”SurFace Enhanced infraRed spectroscopy for Astrochemistry (SFERA)”PI of the ”Bando Astrofisica Fondamentale - Laboratori Spaziali” with the
- Co-I of the ARIEL satellite mission, and member of chemistry related working groups.
- 2020-2023Spectroscopy of Planetary and AtmospheriC particulatE by optical TweezersResponsible of INAF Research unit and WP2 in ASI-INAF n.2018-16-HH. SPACE 0 Tweezers (PI O. Marago`)
- 2023- 2024in Interstellar Ices”, at the National Synchrotron Research Radiation Center, TaiwanCoI of the research program ”The Synthesis and Desorption of Organic Molecules

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PREVIOUS SCIENTIFIC RESPONSABILITIES

- 2021Formation of Trans-Neptunian-Objects", at the beamline 03A1 of the National Syn-CoI

  of the research program "Energetic Processing of Ices: Complex Organic Molecules chrotron

  Research Radiation Center, Taiwan

- 2020- 2022Molecules Formation of Trans-Neptunian-Objects", at the beamline 08B1 of the NationalCoI of the research program "Energetic Processing of Ices: Complex Organic

  Synchrotron Research Radiation Center, Taiwan

- 2019 - 202008B1 of the National Synchrotron Research Radiation Center, TaiwanPI of the research program "Energetic Irradiation of Ices", at the beamline

- 2018 - 2019of Radiation Flux in the Synthesis of Prebiotic Molecules; (B) the Role of Dust in thePI of the research program "Soft X-rays Irradiation of Ices: (A) the E↵ects

  Chemical Evolution of Ice", at the beamline 08B1 of the National Synchrotron Research Radiation Center, Taiwan

- 2016sistemi planetari giovani per l'insorgere della vita (P.I. C. Codella)Local coordinator of the PRIN-INAF 2016 - GENESIS-SKA: Condizioni generali in GENESIS

- 2015 - 2016of radiation flux in the synthesis of complex molecules II", at the beamline 08B1 of thePI of the research program "Soft xrays irradiation of ices: Exploring the e↵ects

  National Synchrotron Research Radiation Center, Taiwan

- 2013 - 2014e↵ects of radiation flux in the synthesis of complex molecules", at the beamline

  16A1 ofPI of the research program "Soft x-rays irradiation of ices: Exploring the the National

  Synchrotron Research Radiation Center, Taiwan

2011- PI of the research program ”Soft Xrays irradiation of ices: Role of the stellar emission in the synthesis of complex molecules”, at the beamline 16A1 of the National Synchrotron Research Radiation Center, Taiwan

- 2011-at the beamline 08B1 of the National Synchrotron Research Radiation Center, TaiwanPI of the research program ”Study of infrared spectra of soft X-rays irradiated ices”,

- PI PRIN-INAF 2006: ”Survival of prebiotic compounds in the very dense X and EUVradiation field of the young Sun”

- Co-I ESA M4 proposal 2015:Large-survey (ARIEL)” ”The Atmospheric Remote-Sensing Infrared Exoplanet

- Co-I METIS(Multi Element Telescope for Imaging and Spectroscopy)/SOLAR ORBITER,ESA M-class mission

- Co-I Progetto Premiale WOW 2014: ”A Way to Other Worlds”, responsible of WP6http://www.astropa.inaf.it/ giusi/WOW/

- Co-I ASI 2013-2016: FP7 INFRA-2012-1.1.26, grant n. 312495, ”SOLARNET - High-Resolution Solar Physics Network”

- Co-I ASI 2013-2015: ASI/INAF I/013/12/0 ”Solar Orbiter - Supporto scientifico per larealizzazione degli strumenti METIS e SWA/DPU nelle fasi B2-C1”, local responsible for INAF Osservatorio Astronomico di Palermo

- Co-I ASI 2009-2012: accordo ASI/INAF I/023/09/0 ”Attivita` Scientifica per l’Analisi DatiSole e Plasma - Fase E2/F”

- Co-I XMM AO3: ”High Energy radiation in stars hosting planets”

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- Co-I ESA M-class candidate mission 2013-2014 ”Exoplanet Characterisation Observatory(EChO) • Co-I ASI 2007-2009: I/015/07/0 ”Esplorazione Sistema Solare”

- Co-I NASA SR&T 2008: ”Post-Eruption Heating of CME Plasma”, Grant NNX09AB17G-R 3 years

- Co-I ASI 2005-2007: “Analisi dati da osservazioni del Sole da satellite”
- Co-I ASI 1995-2007: ”SOHO/UVCS”
- Co-I NASA SR&T 2005: ”UV Spectra of CMEs: Catalog and Analysis”, NASA GrantNNG06GG78G 3 yrs

- Co-I NASA SR&T 2002: ”Ultraviolet Observations of Comets”

- Co-I NASA SR&T 2002: ”Velocity Structure and Plasma Parameters of Halo CMEs”,NASA Grant NAG5-12827 3 yrs

- Co-I ASI 1998-2001: ” Osservazioni solari con Yohkoh, SOHO e TRACE”
- Co-I NASA SOHO (AO-1) 1997: ”Diagnostics of Heating Episodes in Active Regions”
- Co-I NASA SOHO (AO-1) 1997: ”Coronal Loops and EUV Cool Loops Rooted in Sunspots”

- Co-I NASA SOHO 1996: ”UVCS observations of the polar high speed solar wind gener-ation region and CDS, EIT, and SUMER ancillary observations of the related chromospheric and coronal regions.”

TESTING & CALIBRATION CAMPAIGNS

- Dec 95 – Mar 99 UVCS/SOHO Mission Operations at NASA Goddard Space Flight Center, Greenbelt, USA
- Dec 95 – Mar 99 Data acquisition and on flight calibration of UVCS spectrometer, Goddard Space Flight Center, Greenbelt and Harvard-Smithsonian Center for Astrophysics, Cambridge, USA

- June – July 1995 UVCS/SOHO end-to-end test, Functional and optical testings and Calibrations of UVCS/SOHO, Harvard-Smithsonian Center for Astrophysics, Cambridge, USA

SCIENTIFIC ACHIEVEMENTS

General description The main topics of my current research activity are: astrochemistry, either experimental and theoretical, esoplanetary atmospheres, models and laboratory, experimantal astrobiology, and solar and stellar coronae.

I have pioneered the use of soft X-rays, analogue of young stellar emission, as a driving agent for the synthesis of organic matter in space;

I am responsible for the Light Irradiation Facility for Exochemistry (LIFE) laboratory at INAF-OAPa;

I am involved in exoplanetary reasearch activity, including numerical modeling and experimental simulations of exoplanetary atmospheres. A prototype of an atmospheric chamber to study the evolution of a gas mixture simulating alien atmospheres has been developed at INAF-OAPa;

I am responsible of the design and construction of a laboratory facility to study the chemical evolution of simulated exoatmospheres processed by high energy radiation and lightning at INAF-OAPa, in the framework of the italian INAF-led EU Recovery Fund project "STILES" (IR0000034) "Strengthening the Italian Leadership in ELT and SKA";

I have been leading studies on the e↵ects of UV and X-ray radiation on organic molecules and on the role of clays in protecting organic molecules against primordial solar X-ray emission;

I have been leading, in collaboration with J. Raymond, the ultraviolet spectroscopy of Coronal Mass Ejection events detected by UVCS/SoHO coronagraph spectrometer;

I was part (1995-1998) of the team for the mission operations of UVCS/SoHO at NASA Goddard Space Flight Center (Greenbelt, USA);

I was part of the team for the functional tests, calibration at the Harvard Smithsonian Center for Astrophysics (Cambridge,USA);

I have performed modeling of solar and stellar coronae, studies of the heat conduction in the outer regions of the solar and stellar atmospheres, and spectroscopic diagnostics of the solar corona in EUV and X-rays.

Publications

Author of 140 scientific publications (based on ADS), first author in 39, within the first three authors in 18, corresponding authors in many of them, 4453 citation, H-index 32; • Author of 1 paper to Nature Astronomy, 1 to PNAS, and 9 letters to ApJ

Rsearch Activity and Main Results

Astrochemistry I am leading experiments using soft X-rays in the irradiation of ice analogs obtaning new results in the chemical evolution of ice samples (Ciaravella et al. 2013, 2015),

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photo induced desorption of complex molecules (Jim´enez-Escobar et al. 2018, Ciaravella et al. 2019), di↵usion induced by X-rays (Ciaravella et al. 2020, Jim´enezEscobar et al. 2022), and the evolution of silicates as analog of astrophysical dust grains (Ciaravella et al. 2018, 2016).

Numerical simulations of dust grain–grain collisions driven by turbulence in interstellar or circumstellar regions as a route for the synthesis of prebiotically relevant species (Cassone et al. 2018); I am also part of a collaboration aimed at a sistematic analysis of the freeenergy landscapes of interstellar chemical reactions using metadynamics (Cassone et al. 2021).

I designed and constructed an ultra high vacuum chamber for experimental astrochemistry, the Light Irradiation Facility for Exochemistry (LIFE).

Optical Tweezers for Astrochemistry I am leading the WP2 in the ”Space Tweezers” project (ASI-INAF n.2018-16-HH.0) aimed at: applying optical tweezers at the analysis of solid particles of astrophysical interest; providing diagnostics of small solid particles, such as refractory residues obtained in typical irradiation experiments of ice analogues.

Nano Antennas for Astrochemistry I am leading an interdisciplinary project aimed at making a step forward in infrared spectroscopy of ices by using for the first time metal nanoantennas substrates in laboratory astrochemistry. As demonstrated in other fields (nanophotonics, plasmonics), such devices produce on very small scales, highly intense electromagnetic fields enhancing by several orders of magnitude the intensity of IR spectra of molecules located within these fields (Surface-Enhanced IR Absorption, SEIRA). This activity is developed in collaboration with Dr. L. Petti (IASIS/CNR, Pozzuoli).

Exoplanetary Atmospheres I am involved in modeling the e↵ects of X-rays and EUV radiation, both quiescent and transient, from early solar-type stars on planetary atmospheres.
I am leading the design and construction of an atmosphere simulator facility to explore the chemical/physical evolution of gas mixtures, the ”atmosphere”, under high-energy irradiation (EUV and X-rays), and high-current discharge simulating lightning events. The laboratory simulations will supply experimental spectroscopic data that are imperative to fully exploit the data from present and future space telescopes. This project has been financed in the framework of the of the italian INAF-led EU Recovery Fund project “STILES” (IR0000034) “Strengthening the Italian Leadership in ELT and SKA”.

Astrobiology E↵ects of UV and X-ray radiation on organic molecules (DNA and amino acids). I have demonstrated that free and clay adsorbed DNA are di↵erently a↵ected by X-rays (Ciaravella et al., 2004), suggesting that clays could have protected the building blocks of life on the primordial Earth when the solar X-ray emission was much stronger than today. On the olther hand, my experiments on amino acids have shown that X-rays irradiation can also facilitate the chemical evolution, leading in the increase of structural complexity (Ciaravella et al. 2010).
Currently, I am collaborating with geeologists of the Universit`a degli Studi di Ferrara (Prof. C. Bonadiman) to study the chemistry of complex organics (e.g., formamide) mixed

with meteorite powders. A further collaboration with Prof. M.G. Parisi of the Universita` di Palermo (Dipartimento di Zoologia e Immunologia) has been initiated to investigate the survival and the adaptation of animal cells in alien environments.

Solar Physics Physics of the Solar Corona. Spectroscopic diagnostics of the solar corona in EUV and X-rays. Ultraviolet spectroscopy of Coronal Mass Ejection events. Characterisation of the solar wind and its interaction with interplanetary space, coronal abundances.
I have been leading in collaboration with J. Raymond the ultraviolet spectroscopy of Coronal Mass Ejection events detected by UVCS/SoHO coronagraph spectrometer. These studies have provide unprecedented results on CMEs 3D structure and the evolution (Ciaravella et al. 2000), their collisionless shock fronts (Raymond et al. 2000; Ciaravella et al. 2005, 2006), the thermal structure and post-ejection heating of the CME plasma (Akmal et al. 2001; Ciaravella et al. 2001), density diagnostics from lines excited by resonant scattering (Raymond and Ciaravella 2004).
I studied the characterization of solar wind using the ultraviolet spectra (Kohl et al. 1999)

Comets The interaction of the solar wind with Sun-grazing comets allows to derive the velocity and the temperature of the wind protons very far from the Sun (Ciaravella et al. 2010; Raymond et al. 1998).

Space Physics Optical and functional tests and calibration at system level of the coronagraph spectrometer UVCS/SOHO. Grating mechanisms, wavelength and radiometric calibration of the UVCS ultraviolet channels (Gardner et al 2002). Participation to SOHO mission operations at NASA Goddard Space Flight Center.
Partecipation to the first campaign of thermo-vacuum tests of the filters for the X-IFU Instrument on Athena using LIFE laboratory (Barbera et al. 2016, 2018)

Science Keywords

Interstellar medium; Planetary systems sciences; Solar and interplanetary physics; Astrochemistry; Photochemistry; Astrobiology; Stars and stellar systems; Spectroscopic and spectrometric techniques;

NATIONAL AND INTERNATIONAL COLLABORATIONS

- Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra, University of Messina - Italy
- Dipartimento di Scienze Molecolari e Biomolecolari dell'Universita` di Palermo, Italy
- Dipartimento di Fisica e Scienze della Terra, University of Ferrara, Ferrara, Italy INAF-Osservatorio Astrofisico di Torino, Torino, Italy
- INAF-Osservatorio Astronomico di Cagliari, Cagliari, Italy
- Istituto per i Materiali Nanostrutturati ISMN/CNR, Palermo, Italy
- Istituto per i Processi Chimico Fisici IPCF/CNR, Messina, Italy

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- Centro de Astrobiolog´ıa (INTA-CSIC), Madrid, Spain
- Harvard-Smithsonian Center for Astrophysics, Cambridge, USA
- Naval Research Laboratory, Washington, DC, USA
- Low Temperature Science, Hokkaido University, Sapporo, Japan
- National Central University, Jhongli, Taiwan
- National Synchrotron Research Radiation Center, Hsinchu, Taiwan
- University College London, UK

AWARDS

- 1995 Goddard Space Flight Center for the end-to-end testings and Calibrations of UVCS/SOHO.
- 1997activity.European Space Agency for the contribution to UVCS/SOHO mission operations

TEACHING ACTIVITIES

- 2020Appunti di Fisica '20 & Dottorato di Ricerca in Fisica, University of Messina andLecture on ”Organic Chemistry in Space: a path towards prebiotic chemistry”,

  IPCF/CNR, Messina

- 2017University of PalermoLecture on Laboratory Studies of Organic Chemistry in Space”, Physics department,
- 2016versity, Jhongli City, TaiwanLecture on ”Organic Molecules in Proto-Planetary Disks” at National Central Uni-
- 2014University of Palermo, Program ”Messaggeri della Conoscenza” - Exoplanets, Palermo,Lecture on ”Laboratory Studies of Organic Chemistry in Space”, Degree in Physics,

  Italy

- 2012dinia Summer School of Astrophysics 30 Sept- 6 Oct, 2012.”Tutorial and beginning of hands-on activities on Laboratory Astrochemistry”, Sar-

- 2005 - 2006servazione e Restauro dei Beni Culturali”, Univ. of Palermo, ItalyTeaching Professor of ”Fisica applicata ai beni culturali” , Degree in ”Con-

- 2004 - 2005servazione e Restauro dei Beni Culturali”, Univ. of Palermo, ItalyTeaching Professor of ”Fisica applicata ai beni culturali” , Degree in ”Con-

- Sept. 1 -6, 2003 ”Ultraviolet Observations of Coronal Mass Ejection”, International, ”New Prospects for Space Observtaions of the Dynamics of the Sun”, School of Space

  Science L’Aquila, Italy

- Sept. 1, 2000 - Jan 2001 Teaching Fellow for Astronomy 14, Harvard University, Cam-bridge, USA

Thesis and Internship

2020 - laurea Magistrale in Chimica, University of Messina, L. Inferrera

2020 - laurea Magistrale in fisica, University of Messina, S. Marrara

2019 - PhD Thesis, National Central University (Zohngli, TW) , Chao-Hui Huang

2018 - laurea triennale in Chimica, University of Palermo, T. Germano

2015 - laurea Magistrale in Fisica, University of Palermo, G. Cosentino

2013 - laurea triennale in Fisica, University of Palermo, G. Cosentino

2006 - laurea triennale in Biologia, University of Palermo, O. Siniscalchi

2023 - Tirocino Chimica, University of Palermo, L.R. Consentino

2023 - Tirocino Fisica, University of Palermo, L. Bilardello

2023 - Tirocino Chimica, University of Palermo, F. Piazzese

2022 - Tirocino Geologia, University of Ferrara, G. Permunian

2020 - Tirocino Fisica, University of Palermo, A. Romancino

2020 - Tirocino Fisica, University of Palermo, G. Sacco 2020 -

Tirocino Fisica, University of Palermo, F. Greco

2016 - Tirocino Fisica, University of Palermo, O. Milazzo

2003 - Tirocino Fisica, University of Palermo, C. Cocorullo

2003 - Tirocino Fisica, University of Palermo, S. Terzo

2002 - Tirocino Fisica, University of Palermo, D. Scelfo

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OTHER ACTIVITIES

- Member of the panel review NASA/EXPLORER 2011
- Referee for major international astrophysical journals
- 2020 - 2022 member of INAF/RSN3 committee
- 2020 - 2022 member of the ”Consiglio di Struttura” at INAF-OAPa
- 2017 - Member of the evaluation VQR 2011-2014 ”Programma per Giovani Ricercatori”

CONFERENCES

1989 - 2023 oral and poster contributions and invited talks to many international conferences.

2021 - Ciaravella A., ”Soft X-Ray Irradiation of Ice Analogues: a Realistic Ice mantle”, ECLA2020, Linking Dust, Ice and Gas in Space, 26 Sept.- 1 Oct 2021, Anacapri (Italy), Contributed talk

2021 - Ciaravella A., ”Soft X-ray irradiation of bilayer ice mantle analogs: photo-desorption and di↵usion”, Laboratory Astrophysics Workshop, 22-24 Nov. 2021, Jena (germany). Invited talk

2018 - Ciaravella A., ”X-ray Photo-desorption of Circumstellar N-bearing ice analogs”, ILST Symposium, 14-16 Nov 2018, Sapporo (Japan). Contributed talk

2017 - Ciaravella A., ”X-rays Induced Dust Surface Chemistry at the Down of the Solar System”, COST Action CM1401 11-13 Dec 2017 Ciudad Real- (Spain), Invited Talk

2015 - Ciaravella, A., Cecchi Pestellini, C., Jim´enez Escobar, A., Chen, Y.-J.,Mun˜oz Caro, G.M: ”Soft X-ray Irradiation of CO Ice: E↵ects of the Photon Energy and Flux”, Icy Grain Chemistry for Formation of Complex Organic Molecules: From Molecular Clouds to Protoplanetary Disks, Comets and Meteorites, 5-7 March 2015, ELSI Building 407, Tokyo Institute of Technology, Japan, contributed talk

2010 - Ciaravella A., ” E↵ects of Soft X-ray Radiation on a Methanol Ice”, 2010, Western Pacific Geophysical Meeting, Taipei, Invited Talk

2006 - Ciaravella A., Studying Halo and partial Halo Coronal Mass Ejections through UV Spectra, SoHo 17 7-12 May 2006, Giardini Naxos, Sicily, Contributed talk

2005 - Ciaravella A., Spectroscopic Properties of Halo CMEs IUGG General Assembly, Toulouse July 18-29, 2005. Invited Talk

2004 - Ciaravella A., Role of Clay on adsorbed DNA against X-ray radiation: Possible implications for the origin of life, ”Bioastronomy 2004 - Habitable Worlds”, Eigth International Conference on Bioastronomy, Reykjavik, Iceland July 12-16 2004., Contributed Talk

OUTREACH

I am partecipating to public events (e.g., ”INAF, Light in Astronomy”, ”La notte dei ricercatori”, and ”La settimana della Scienza”).

2018 - ”L’universo in una Scatola”, Pint of Science 2018, Palermo

2018 - Astrochemistry at LIFE laboratory-experiments

2015 - ”Pianeti Extrasolari e Vita nello Spazio”, Public conference in Sambuca di Sicilia (AG)

2014 - Chapter 15 ”Forse anche noi siamo un po’ Extraterrestri”, in the book ”Astrokids: Avventure e Scoperte nello Spazio”, eds Scienza Express, ISBN-10: 8896973260, p.114

2013 - ”Anche noi siamo un po’ extraterrestri......”, AstroKids conference, Feltrinelli, Palermo

2011 - ”Astrobiologia Scienza Applicata alla Ricerca della Vita nell’Universo”, Conference at Liceo Scientifico Cannizzaro, Palermo

2008 - ”Da dove veniamo? Chi siamo? E dove andiamo?”, Public conference in Sambuca di Sicilia (AG)

2020 - ”Chimica prebiotica fra i ghiacci protoplanetari”, Media INAF article by M. Guarcello citing the results of the PNAS paper (Ciaravella et al. 2020)

2019 - ”Le molecole di Angela, da Taiwan alle stelle”, Media INAF article by M. Guarcello citing the results of the ApJ paper (Ciaravella et al 2019)

2018 - ”Raggi X, raggi di vita”, Media INAF article by M. Guarcello citing the results of the ApJ paper (Jim´enez-Escobar et al 2018)

Le informazioni contenute nel presente ”curriculum vitae et studiorum” sono rese sotto la personale responsabilita` della sottoscritta, ai sensi degli articoli 46 e 47 del Decreto del Presidente della Repubblica 28 dicembre 2000, numero 445, e successive modifiche ed integrazioni, consapevole della responsabilit`a penale prevista dall’articolo 76 del medesimo Decreto per le ipotesi di falsita` in atti e dichiarazioni mendaci

RESEARCH ACTIVITY Angela Ciaravella

Summary

My scientific activity started in the framework of the physics of solar and stellar atmospheres, and later evolved towards the e↵ects of the high energy stellar emission on the synthesis and evolution of complex organic molecules (COMs) in space, and search for the origin of life. Here are briefly summarized the major topics of my research activity and the main results.

Experimental Astrochemistry

The interstellar medium mainly composed of gas (99%) and dust (1%) is a lively rich environment, where organic chemistry can reach a high level of complexity (Herbst and van Dishoeck, 2009, ARA&A 47 427), and where molecules are synthesized either in the gas- and solid-statephases. More than 250 molecules have been observed in interstellar and circumstellar regions. Some of them are found in external galaxies (McGuire, 2022, ApJS 259 30). The inventory of molecular species in space is dominated by organic molecules including those with cyanide (-CN) group such as cyano methane CH_3CN, glycolonitrile $HOCH_2CN_6$ and acetonitrile NH_2CH_2CN, a species close to the simplest amino acid glycine. Most of the molecules are detected in the gas phase. However, even in dense clouds, gas-phase chemistry can only partially explain the observed species. Highly saturated molecules such as ethanol, acetic acid, and glycolaldehyde cannot be formed in gas phase, and they originate in icy mantles coating dust particles, where chemical routes otherwise inhibited in the gas-phase are activated. Chemical reactions in ices are induced by non-energetic (e.g., hydrogenation) and energetic (e.g., radiation and particles) sources. The molecules formed into icy mantles can then be released by photo and/or thermal desorption to the gas-phase, where they can be detected in the infrared and radio domains. In this context, laboratory studies of interstellar ice analogs are of invaluable relevance for the interpretation of the data including analytic chemical analyses of planetary surfaces, sample returns and remote observations. Experimental studies on the chemical evolution of ice analogs began around the end of 1970s (e.g., D'Hendecourt et al. 1982, A&A 109 L12) and they were generally performed using UV radiation and energetic particles.

Since 2010 I pioneered the use of soft X-rays, simulating the emission of young stars, as driving agent for the synthesis of organics in ices. The rationale for introducing this new type of experiments is based on observational evidence that X-rays emission is a common characteristic of stars with a wide range of luminosity (Vaiana et al 1981, ApJ 245 163). In particular, young solar type stars emit X-rays at a level 3 4 orders of magnitude higher than the present-day Sun, both during the pre-main sequence phase when the emission is dominated by intense flares (Favata et al., 2005, ApJS 160 469), and during the first phases of the main sequence. A 100 Myr old star has an X-ray (0.1 10 nm) flux larger than the extreme ultraviolet (10 90 nm) (Ribas et al. 2005, ApJ 622 680), and it remains within a factor of two for stars as old as 1 Gyr; the today Sun ratio is about 0.25 [40]. During the phase in which the cloud core collapses and the star is still deeply embedded, the UV radiation density in the gas is drastically reduced (e.g., Sta¨uber et al. 2004, A&A 425 577), and the dominant ionizing source are X-rays. Because of

their high energy, X-ray photons produce phenomena that cannot be attributed to radiation in any other of the lower energy bands, regardless of their flux. Stellar high energy emission is now recognized as a crucial factor in the formation and evolution of stars and planetary systems, as well as in the life origin and evolution. The higher penetrability of X-rays into the hydrogen rich interstellar gas [22] suggests that their role in inducing chemical evolution both on ices [37], and in the gas phase needs to be taken into account in the interpretation of observational data (e.g., Walsh et al. 2015, ApJS 582 88).

My activity in experimental astrochemistry is articulated in di↵erent branches connected by the tread of high energy emission from stars, and its e↵ects on the surrounding environment. I have been in charge of the design and construction of the Light Irradiation Facility for Exochemistry (LIFE at INAF/OAPa), laboratory for which I am the leading person. In those years it started my collaboration with the Centro de Astrobiolog´ıa (CAB, CSIC-INTA, Spain), in the person of Dr. Guillermo Mun˜oz-Caro [37], and the National Central University (NCU) and the National Synchrotron Radiation Research Center (NSRRC) in Taiwan, with Prof. Y.J. Chen [29]. Such cooperation has been providing guaranteed time, on yearly basis, for the use of beamlines at NSRRC, in particular EUV and X-rays. It is still on going, and it has been extremely fruitful, as testified by the publication list. Recently, I have initiated to use fast electrons to stimulate organic chemistry in dirty water ices, simulating the surface of icy bodies. Icy moons orbiting gas giants provide an intriguing alternative to Earth-like planets for the search of life in the Universe. The relevant number of Jupiter-sized exoplanets discovered so far, and the ubiquity of water in space make these environments an exciting case to study.

Realistic Ice Mantles and Ice Mixing Induced by X-rays - Ice mantles covering submicron dust grains in interstellar and protoplanetary environments are mainly composed of simple species in a water-dominated ice. Hydrogenation of O, C, and N on the grain surface produces a first layer of water (H_2O), methane (CH_4), ammonia (NH_3), and other reduced species. On top of this, there is a second layer of more volatile species that are formed in the gas phase, with carbon monoxide (CO) being the most abundant component. Such CO envelope provides the feedstock for methanol formation through hydrogenation. These two layers are thought to be physically segregated, unless an increase in temperature favors mobility and reactivity within the ice. No experiments using such layered structure were attempted before our successful study in 2019.

Main Results In two recent papers I and my group reported the simulation of a realistic stratified ice mantle by making a double layer ice in which a mixture of H_2O:CH_4:NH_3 was covered by a second mixture of CO:CH_3OH. The ice was irradiated with a soft X-rays spectrum (250 1250 eV). X-ray processing of such realistic ice mantles can explain the gas abundances in protoplanetary disks [12], and also provide robust evidence of X-ray-induced molecular di↵usion at 10 K [3]. The results have two main implications. First, molecular mixing enhances chemical reactions from which COMs, including many of prebiotic interest, are formed. Second, di↵usion drives the desorption of species that would otherwise remain buried near the surface of dust, thus enhancing their abundances in the gas-phase. Such a scenario has implications for the chemical history of ices in protoplanetary disks, in particular in the early stages of their life. We keep pioneering new realistic descriptions of ice evolution in space. We are currently simulating the dynamics of the ice deposition with and without irradiation, monitoring the synthesis of organic species and the e↵ects on the residue composition.

Electron irradiation Electron irradiation produces chemical reactions within the ice and at its surface, and release of species to the gas-phase. We explored the modifications undergone by icy mixtures irradiated by electrons in the energy range from 0.2 to 1 keV. Such subkeV electrons are particularly interesting as their energies are close to the energies of primary electrons produced by cosmic-ray and X-ray impacts within dense molecular gas.
Main Results We derive the chemistry and determine cross-sections for relevant processes as functions of the energy of the impacting electrons. We quantify the electron-stimulated desorption of significant species in terms of their desorption yields, and relate these quantities to the electron penetration depth and the desorption-relevant length [1,13]. This research has benefited from a PhD student of the NCU (Taiwan), that spent 6 months under my supervision at the INAF-OAPa.

SurFace Enhanced infraRed spectroscopy for Astrochemistry is a multi-disciplinary on-going project, developed by the LIFE laboratory in collaboration with CNR-IASIS (Pozzuoli, Dr. L. Petti), CNR-IPCF (Messina, Dr. O. Marago`), and the University of Cantabria (Spain, Dr. P. Albella). Mid-IR spectroscopy widely used in astrochemistry is a powerful tool to study the chemical evolution of ice analogues under irradiation. Its main limitation is the molecular low vibrational absorption cross-sections requiring large abundances to be detected. Objective of the project is to design and construct devices based on resonant metal nanoantenna techniques – never employed in astrochemistry but successfully applied in other fields – to enhance spectroscopic diagnostics, opening the way to more realistic astrophysical conditions. We already explored some configuration of nanoantennas and we are now fabricating new arrays that, based on theoretical predictions, should enhance the fingerprints of many organic molecules in the 4 10 μm region. The mehodology that we are developing for laboratory astrochemistry will be also of importance for e.g., planetary exploration in-situ analyses, and sample returns.

Optical Tweezers are powerful tools based on focused laser beams able to trap, manipulate, and investigate microscopic and nanoscopic particles in liquids, air, and vacuum. In collaboration with the group of CNR-IPCF (Messina) we are applying such tecniques for the manipulation of solid matter such as circumsolar grains and refractory residues obtained in a typical irradiation experiments of ice analogues [7,9]. This on-going project has been financed by ASI-INAF no. 2018-16HH0 (Space Tweezers).

Astrobiology

The widely accepted scenario that the delivery of extraterrestrial organic molecules to Earth by meteorites and dust aggregates may have been important for the origin of life, requires that biological compounds present in the planetary system survived the harsh environment. Life on the Earth appeared earlier about 4 billion years ago when the Sun was much more active than today, with an X-ray flux more than three orders of magnitude higher (Micela 2002, ASP Conf. Proc. 269, 107). Such an intense solar activity, either impulsive and secular, a↵ected planetary atmospheric chemistry through ionization and heating, and biological activity through direct mutational enhancement or sterilization. Synthesis and evolution of COMs must thus have proceeded under conditions that are quite di↵erent from today.
Main Results Free and clay adsorbed DNA are di↵erently a↵ected by X-rays. The former is damaged and the level of damage depends on the energy dose rather than the hardness of the

radiation. Our experiments proved that clay materials may have protected the building blocks of life on the primordial Earth [50]. On the other hand, the e↵ect of X-rays induce conditions through which complexity can increases. X-rays irradiation of tryptophan molecules in water solutions lead to both fragmentation of the tryptophan molecules and to the formation of species of increasing complexity [36]. Currently, I am collaborating with geeologists of the Universita` degli Studi di Ferrara (Prof. C. Bonadiman) to study the chemistry of COMs mixed with meteorite powders. A further collaboration with Prof. M.G. Parisi of the Universita` di Palermo (Dipartimento di Zoologia e Immunologia) has been initiated to investigate the survival and the adaptation of animal cells in alien environments.

Exo-planetary Atmospheres

A field of great interest in modern astronomy is the search for exoplanets, in particular habitable planets. Observations of exoplanetary atmospheres open a window on the indicators of habitability and life. Direct spectroscopic detection of atmospheric composition is one of the major tasks in present (JWST) and future (ARIEL) space missions. While the chemical composition is at the equilibrium in deep atmospheric layers, kinetic processes dominated by photochemical reactions drive drastic departures in the upper regions of an atmosphere, and may also involve the escape of its constituents to space. Thus, to study the e↵ects of the stellar radiation field on the chemical structure of the atmospheres is mandatory to understand the possible ranges of their characteristics, in order to predict and interpret future observations. My activity in this area is related to the e↵ects of high-energy radiation on the distribution of the chemical abundaces within an atmosphere, and to use such results in the design of laboratory simulations reproducing such chemical disequilibrium. I am Co-I of the ARIEL satellite mission, and member of chemistry related working groups.

Main Results I contributed to develop a model of the interaction of EUV and X-ray stellar radiation with a gas of solar composition. The model simulates solar-like atmospheres. The theoretical analysis is relevant for the identification of spectroscopic features in the planet's emission spectrum distinguishable from the stellar spectrum [44,40,22,4]. I am also involved in the experimental simulations of exo-planetary atmospheres. A prototype of atmospheric chamber in which we have ran preliminary studies on the evolution of a gas mixture resembling an atmosphere has been developed at OAPa. In the framework of the italian INAF-led EU Recovery Fund project "STILES" (IR0000034) "Strengthening the Italian Leadership in ELT and SKA (STILES)" (P.I. A. Fontana, pnrr.inaf.it/progetto-stiles), I am the leading person in the design and construction of an atmospheric simulator facility at INAF-OAPa. High-resolution spectroscopy is the ultimate technique for investigating astrophysical environments. Of particular interest are the simulation of haze and particulate formation. Their strong interactions with visible and UV radiation, cool the planet climate, eventually contributing to make it habitable.

Solar Physics

Coronal Mass Ejections (CMEs) As distinct from the the solar wind, an almost continuous flow of matter coming mainly from the polar regions during solar minimum, the CMEs originate by occasional violent explosions of magnetically confined structures. The plasma is ejected through the corona into the interplanetary space at speeds up to several thousand km/sec, with frequency of one event every two days at solar minimum up to three events per day during solar maximum. Interest in CMEs goes beyond astrophysics and aims also to the possibility of predicting their occurrence to limit the e↵ects on the Earth (e.g., damage of satellites). CMEs are also relevant for understanding explosive phenomena in other astrophysical environments. The launch of SoHO satellite marked a turning point in the study of CMEs. Along with the traditional visible light images UV spectra from UVCS coronagraph spectrometer have become available.

Main Results I have been leading with Dr J. Raymond the study of CMEs through the UV spectra provided by the UVCS. We studied the 3D structure and the evolution of helical CMEs [61,70], the collisionless shock fronts [43,48,60], and the thermal structure and post-ejection heating of the CME plasma [58,59]. UV spectra of the current sheets connecting the CME to post-flare loop showing a localized emission in many highly ionized lines implies temperature above $10^{6.6}$ K [30,39,41,46,55]. We derive temperature, density, and gas velocity in the front, cavity and core of a ”flux-rope CME” [34], morphological reference for CME models. We derived line-of-sight speeds, that combined with speeds in visible ligth provided the true speed event [35]. Halo CMEs are generally very well correlated with the geomagnetic activity. Their UVCS spectra revealed the nature of their associated shock fronts [48,43,42]. Another relevant result is the diagnostics of the density from UV spectra lines excited by resonant scattering in the velocity range 1000 2000 km/sec [49]. We build a catalog of all the UV spectral observation of CMEs [31] and included it in the SoHO CME catalog (CME list). New insights on CMEs arise from visisble light and UV HI-Ly observations of METIS coronagraph on board Solar
Orbiter[2,5].

Solar Wind UVCS provided spectroscopic diagnostics such as UV lines pumped in corona by resonant scattering of the chromospheric radiation. I studied the characterization of solar wind using the ultraviolet spectra [20, 22].

Comets The interaction of the solar wind with Sun-grazing comets allows to derive the velocity and the temperature of the wind protons very far from the Sun [67, 38].

Technical Activities I was part of the team performing the functional tests and calibration of the SoHO/UVCS spectrometer at the Harvard-Smithsonian Center for Astrophysics. After the launch of the satellite, I was part of the team responsible for the mission operations of UVCS at NASA/GSFC. I was involved in the activity of in flight calibrations of the grating mechanism, the study of the instrumental profile (spatial resolution), and the radiometric calibration performed using the observations of stellar spectra [29]. As usual, such technical activities are documented in internal reports.

Solar and Solar Type Stellar Coronae X-ray images of the solar corona show that archlike structures of plasma magnetically confined are responsible for its quiescent and dynamical X-ray emission. Stationary loop models describe well structures that persist unchanged over timescales much longer than the time of radiative and conductive losses. Given the strong temperature gradients and the low densities, the electrons mean free paths become comparable to the length of the loop in which the plasma is confined. Thus, the energy balance is no longer local, the classical Spitzer formulation of thermal conduction is not applicable. A thermal conduction that takes into account the non-locality of the heat flow is needed. I incorporated in hydrostatic loop model the description of the non-local heat flux, and explored its e↵ects. In long, low density loop structures, electrons with large mean free paths from the loop apex deposit their energy in the lower regions of the loops smoothing of the local temperature gradient [82,81,80]. The work was extended to stellar coronae [81,79,74]. I contributed to the development of a software package ASAP for spectral analysis [77,78].

Refereed Publications

1. Huang, C.-H., Cecchi-Pestellini, C., **Ciaravella, A.**, Jim´enez-Escobar, A., Hsiao, L. -C., Sie, N. -E., Chen, Y. -J., *Chemical and physical processes caused by electrons impacting on H_2O-CO mixed ices*, 2022, MNRAS, 517, 3078. doi:10.1093/mnras/stac2855 https://ui.adsabs.harvard.edu/abs/2022MNRAS.517.3078H/abstract

2. Telloni, D., et al., *Linking Small-scale Solar Wind Properties with Large-scale Coronal Source Regions through Joint Parker Solar Probe-Metis/Solar Orbiter Observations*, 2022, ApJ, Volume 935, 112.
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3. Jim´enez-Escobar, A., **Ciaravella**, A., Cecchi-Pestellini, C., Mun˜oz Caro, G. M. , Huang, C.-H., Sie, N.-E., Chen, Y.-J., *X-Ray-induced Di�usion and Mixing in Layered Astrophysical Ices*, 2022, ApJ, 926, 176. doi:10.3847/1538-4357/ac4810 https://ui.adsabs.harvard.edu/abs/2022ApJ...926..176J/abstract

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