

# Rodrigo Carvajal

Final-year PhD student in Astronomy and Astrophysics at the Instituto de Astrofísica e Ciências do Espaço (IA), in the Faculty of Sciences of the University of Lisbon (FCUL). Working on identification and characterisation of radio-detected active galactic nuclei and implementation of machine learning tools to detect and study them in large-area radio surveys.

## Education

### Instruction

- 2019 – 2024 **PhD in Astronomy and Astrophysics**, *Faculdade de Ciências, Universidade de Lisboa*, Lisbon, Portugal  
Project: The First Radio Galaxies in the Universe. Supvs.: J. Afonso, I. Matute, H. Messias.
- 2016 – 2019 **MSc in Astrophysics (Maximum distinction)**, *Pontificia Universidad Católica de Chile*, Santiago, Chile  
Thesis: Stacking UV-selected Lyman-Break Galaxies in the ALMA Frontier Fields<sup>1</sup>. Supv.: F. E. Bauer.
- 2007 – 2014 **Licenciado en Ciencias (BSc equivalent. Distinction)**, *Universidad de Chile*, Santiago, Chile, *Astronomy (no thesis required)*

### Prizes and Awards

- 2019 – 2024 **PhD::SPACE Fellowship**, *Instituto de Astrofísica e Ciências do Espaço*, Lisbon, Portugal
- 2017 **Teaching Assistant Scholarship**, *Pontificia Universidad Católica de Chile*, Santiago, Chile
- 2007 – 2010 **Beca Universidad de Chile**, *Universidad de Chile*, Santiago, Chile

## Publications

Nine refereed publications in total. Three of them as first author with 18 citations. Six publications as co-author, with 116 citations. Additionally, one publication in a conference proceedings book and one press release with impact on mass media. Citation values from NASA ADS as of December, 2023<sup>2</sup>.

### Refereed Articles

- Carvajal, R., Matute, I., Afonso, J., Norris, R. P., Luken, K. J., Sánchez-Sáez, P., Cunha, P. A. C., Humphrey, A., Messias, H., Amarantidis, S., Barbosa, D., Cruz, H. A., Miranda, H., Paulino-Afonso, A. and Pappalardo, C. 'Selection of powerful radio galaxies with machine learning'. In: *A&A* 679, A101 (Nov. 2023), A101. doi: 10.1051/0004-6361/202245770.
- Humphrey, A., Cunha, P. A. C., Paulino-Afonso, A., Amarantidis, S., Carvajal, R., Gomes, J. M., Matute, I. and Papaderos, P. 'Improving machine learning-derived photometric redshifts and physical property estimates using unlabelled observations'. In: *MNRAS* 520.1 (Mar. 2023), pp. 305–313. doi: 10.1093/mnras/stac3596.
- Miranda, H., Pappalardo, C., Papaderos, P., Afonso, J., Matute, I., Lobo, C., Paulino-Afonso, A., Carvajal, R., Lorenzoni, S. and Santos, D. 'An investigation of the star-forming main sequence considering the nebular continuum emission at low-z'. In: *A&A* 669, A16 (Jan. 2023), A16. doi: 10.1051/0004-6361/202244390.
- Carvajal, R., Matute, I., Afonso, J., Amarantidis, S., Barbosa, D., Cunha, P. and Humphrey, A. 'Exploring New Redshift Indicators for Radio-Powerful AGN'. In: *Galaxies* 9.4 (Oct. 2021), p. 86. doi: 10.3390/galaxies9040086.
- Pappalardo, C., Cardoso, L. S. M., M. Gomes, J., Papaderos, P., Afonso, J., Breda, I., Humphrey, A., Scott, T., Amarantidis, S., Matute, I., Carvajal, R., Lorenzoni, S., Lagos, P., Paulino-Afonso, A. and Miranda, H. 'Self-consistent population spectral synthesis with FADO. II. Star formation history of galaxies in spectral synthesis methods'. In: *A&A* 651, A99 (July 2021), A99. doi: 10.1051/0004-6361/202039792.
- Carvajal, R., Bauer, F. E., Bouwens, R. J., Oesch, P. A., González-López, J., Anguita, T., Aravena, M., Demarco, R., Guaita, L., Infante, L., Kim, S., Kneissl, R., Koekemoer, A. M., Messias, H. et al. 'The ALMA Frontier Fields Survey. V. ALMA Stacking of Lyman-Break Galaxies in Abell 2744, Abell 370, Abell S1063, MACSJ0416.1-2403 and MACSJ1149.5+2223'. In: *A&A* 633, A160 (Jan. 2020), A160. doi: 10.1051/0004-6361/201936260.
- González-López, J., Bauer, F. E., Aravena, M., Laporte, N., Bradley, L., Carrasco, M., Carvajal, R., Demarco, R., Infante, L., Kneissl, R., Koekemoer, A. M., Muñoz Arancibia, A. M., Troncoso, P., Villard, E. and Zitrin, A. 'The ALMA Frontier Fields Survey. III. 1.1 mm emission line identifications in Abell 2744, MACSJ

<sup>1</sup>Thesis text available at <https://repositorio.uc.cl/handle/11534/22335>

<sup>2</sup>ADS Public Library: <https://ui.adsabs.harvard.edu/public-libraries/prom6U0VR26WDYTftnpfYw>

**0416.1-2403, MACSJ 1149.5+2223, Abell 370, and Abell S1063**. In: *A&A* 608, A138 (Dec. 2017), A138. doi: 10.1051/0004-6361/201730961.

Laporte, N., Bauer, F. E., Troncoso-Iribarren, P., Huang, X., González-López, J., Kim, S., Anguita, T., Aravena, M., Barrientos, L. F., Bouwens, R., Bradley, L., Brammer, G., Carrasco, M., **Carvajal, R.** et al. **The ALMA Frontier Fields Survey. II. Multiwavelength Photometric analysis of 1.1 mm continuum sources in Abell 2744, MACSJ0416.1-2403 and MACSJ1149.5+2223**. In: *A&A* 604, A132 (Aug. 2017), A132. doi: 10.1051/0004-6361/201730628.

González-López, J., Bauer, F. E., Romero-Cañizales, C., Kneissl, R., Villard, E., **Carvajal, R.**, Kim, S., Laporte, N., Anguita, T., Aravena, M., Bouwens, R. J., Bradley, L., Carrasco, M., Demarco, R. et al. **The ALMA Frontier Fields Survey. I. 1.1 mm continuum detections in Abell 2744, MACS J0416.1-2403 and MACS J1149.5+2223**. In: *A&A* 597, A41 (Jan. 2017), A41. doi: 10.1051/0004-6361/201628806.

### Conference Proceedings

**Carvajal, R.**, Matute, I., Afonso, J., Amarantidis, S. and Barbosa, D. **Radio Galaxy Detection Prediction with Ensemble Machine Learning**. In: *Machine Learning for Astrophysics*. Ed. by F. Bufano, S. Riggi, E. Sciacca and F. Schilliro. Cham: Springer International Publishing, 2023, pp. 25–29. ISBN: 978-3-031-34167-0.

### Press Releases

Dec 2023 **Black holes are missing in the early Universe, and computers are after them**, *Institute of Astrophysics and Space Sciences, Faculty of Sciences, University of Lisbon*

## Research Experience

- Nov 2019 – **PhD Researcher**, *Institute of Astrophysics and Space Sciences, Faculty of Sciences, University of Lisbon*, Lisbon, Portugal, Research as a PhD student. Project 'The first Radio Galaxies in the Universe'.
- Mar 2024
- Jan 2019 – **Research Assistant**, *Institute of Astrophysics, Pontificia Universidad Católica de Chile*, Santiago, Chile
- Oct 2019 Imaged and analysed ALMA data for project 'Hunting for redshifts of faint DSFGs in A2744'.
- Mar 2016 – **MSc Researcher**, *Institute of Astrophysics, Pontificia Universidad Católica de Chile*, Santiago, Chile
- Jan 2019 Research as MSc student. Project 'Lyman-Break Galaxies in the ALMA Frontier Fields'.
- Aug 2015 – **Research Assistant**, *Institute of Astrophysics, Pontificia Universidad Católica de Chile*, Santiago, Chile
- Mar 2016 Used image enhancement techniques to improve quality of ALMA observations and study objects with low signal-to-noise ratio. Supervised by Prof. Franz Bauer and Dr Jorge González.
- Jan 2014 – **Research Assistant**, *Joint ALMA Observatory (JAO)*, Santiago, Chile
- Mar 2015 Studied Mars' atmosphere and produce profiles for temperature, and wind speed using ALMA observations. Supervised by Dr Rüdiger Kneissl and Dr David Rabanus, from JAO.
- Aug 2013 – **Research Assistant**, *Departament of Astronomy, Universidad de Chile*, Santiago, Chile
- Oct 2013 Studied differences from outer structures of lensing galaxies through absorbed light of far quasars. Supervised by Prof. Sebastián López.
- Mar 2013 – **Research Assistant**, *Departament of Astronomy, Universidad de Chile*, Santiago, Chile
- May 2013 Searched quasars pairs at small distances over catalogue of more than 100 000 objects (SDSS-DR9 Quasar Catalog. Pâris et al. 2012). Supervised by Dr Isabelle Pâris.
- Mar 2012 – **Research Assistant**, *Departament of Astronomy, Universidad de Chile*, Santiago, Chile
- Jul 2012 Confirmed influence of thermal-broadening Doppler parameter in turbulent broadening in Intergalactic Medium. Supervised by Prof. Sebastián López.
- May 2012 – **Research Assistant**, *Departament of Astronomy, Universidad de Chile*, Santiago, Chile
- Jul 2012 Measured correlation for results of Voigt curve-fitting procedures in metallic species absorption lines from far quasar emission. Supervised by Prof. Sebastián López.
- Aug 2011 – **Research Assistant**, *Departament of Astronomy, Universidad de Chile*, Santiago, Chile
- Dec 2011 Determined influence of thermal-broadening Doppler parameter in turbulent broadening in Intergalactic Medium. Supervised by Prof. Sebastián López.
- Jan 2011 **Research Assistant**, *Departament of Astronomy, Universidad de Chile*, Santiago, Chile
- Worked in project "A study of the Molecular Properties of the Vela Molecular Ridge (Coud C)" searching possible clumps using data from Mopra Radio Telescope. Supervised by Dr Nadia Lo.

## Participation in Conferences and Seminars

### Contributed Talks

- Nov 2023 **Extracting physical rules from ensemble machine learning for the selection of radio AGN**, *Debating the potential of Machine Learning in astronomical surveys # 2*, IAP, Paris/Flatiron institute, New York
- Sep 2023 **Ensemble Machine Learning for the selection of radio AGN in multi-survey data**, *XXXIII Encontro Nacional de Astronomia e Astrofísica (ENAA)*, University of Coimbra, Coimbra, Portugal

- Nov 2022 **Ensemble Machine Learning for Radio Galaxy detections**, *SPARCS XI. 2022 meeting of the SKA Pathfinders Radio Continuum Surveys (SPARCS)*, IDIA, South Africa
- Sep 2022 **Ensemble Machine Learning for the Extraction of High-Redshift Radio Galaxies**, *XXXII Encontro Nacional de Astronomia e Astrofísica (ENAA)*, University of Lisbon, Lisbon, Portugal
- Jul 2022 **Searching for High-z Radio Galaxy Detections with Ensemble Machine Learning**, *EMU International Virtual Meeting*, Evolutionary Map of the Universe
- Feb 2022 **Prediction of distant Radio Galaxies candidates with Machine Learning**, *Jornadas Doutorais (Doctoral Day) from the Department of Physics*, Faculty of Sciences - University of Lisbon, Lisbon, Portugal
- Feb 2022 **High-redshift Radio Galaxies candidates prediction with ensemble Machine Learning.**, *SAZERAC SIPS: Learning the high-redshift Universe*
- Jan 2022 **Prediction of high-redshift Radio Galaxy candidates with ensemble Machine Learning.**, *XVII SOCHIAS Meeting. 2022 meeting of the Chilean Society of Astronomy*, Chile
- Nov 2021 **Using ensemble Machine Learning to predict high-redshift Radio Galaxy detections.**, *SPARCS X 2021. 2021 meeting of the SKA Pathfinders Radio Continuum Surveys (SPARCS)*, IDIA, South Africa
- Nov 2021 **Obtaining High-redshift Radio Galaxy candidates with Machine Learning**, *Internal Workshop of the Institute of Astrophysics and Space Sciences (IA-ON8)*, IA - University of Coimbra, Portugal
- Oct 2021 **Using a series of Machine Learning Models for the detection of high-redshift Radio Galaxy candidates**, *Debating the potential of Machine Learning in astronomical surveys*, IAP Colloquium, Institut d'Astrophysique de Paris, France
- Aug 2021 **Using Machine Learning to identify high-redshift Radio Galaxy candidates**, *50th Young European Radio Astronomers Conference*, online event, IRAM
- Mar 2021 **Exploring new redshift indicators for radio-powerful AGNs**, *RGCW: A new window on the radio emission from galaxies, clusters and cosmic web*, Italy
- Oct 2020 **Searching for the earliest AGN in the radio sky**, *Internal Workshop of the Institute of Astrophysics and Space Sciences (IA-ON7)*, Porto, Portugal
- Mar 2020 **The first Radio Galaxies in the Universe**, *Jornadas Doutorais (Doctoral Day) from the Department of Physics*, Faculty of Sciences - University of Lisbon, Lisbon, Portugal
- Dec 2017 **Stacking in the ALMA Frontier Fields**, *Distant Galaxies from the Far South*, Bariloche, Argentina

### Invited Talks or Seminars

- Nov 2023 **Selection of radio-detected AGN with ensemble machine learning**, *Machine Learning in Australian Astronomy*, Australia
- Jun 2021 **Developing a ML pipeline to detect high-redshift Radio Galaxy candidates**, *Machine Learning in Astronomy Group – SPARCS*, Western Sydney University. Sydney, Australia
- May 2021 **Explaining Machine Learning Models: SHAP**, *IA - Galaxies Machine Learning Club*, Porto, Portugal
- Jul 2020 **Stacking UV-selected Lyman-Break Galaxies in the ALMA Frontier Fields**, *Instituto de Astrofísica e Ciências do Espaço*, Lisbon, Portugal
- Jun 2019 **Stacking UV-selected Lyman-Break Galaxies in the ALMA Frontier Fields**, *ESO*, Santiago, Chile

### Contributed Posters

- Jul 2023 **Ensemble Machine Learning for the prediction of Radio AGN in multi-survey data**, *Encontro Ciência '23: Encontro com a Ciência e Tecnologia em Portugal*, Aveiro, Portugal
- Feb 2023 **Radio Galaxy prediction with multi-survey data and ensemble Machine Learning**, *Coordinated Surveys of the Southern Sky*, ESO, Garching, Germany
- Sep 2022 **Searching for Radio Galaxy detections with ensemble Machine Learning**, *VLA Sky Survey in the Multiwavelength Spotlight*, NRAO, Socorro, NM. U.S.A.
- May 2022 **Radio Galaxy detection prediction with ensemble Machine Learning**, *International Conference on Machine Learning for Astrophysics – ML4Astro*, Catania, Italy
- May 2022 **Finding high-redshift Radio Galaxies with Machine Learning**, *Encontro Ciência '22: Encontro com a Ciência e Tecnologia em Portugal*, Lisbon, Portugal
- Sep 2021 **Detection of high-redshift Radio Galaxies using Machine Learning models**, *Encontro Nacional de Astronomia e Astrofísica*, Portugal
- Jun 2021 **Using Machine Learning to look for high-redshift Radio Galaxies**, *Encontro Ciência '21: Encontro com a Ciência e Tecnologia em Portugal*, Lisbon, Portugal
- Mar 2021 **Exploring new redshift indicators for radio-powerful AGNs**, *A precursor view of the SKA Sky*, online event, The SKA Observatory

- Nov 2020 **Mining the radio sky toward the earliest AGN**, *Encontro Ciência '20: Encontro com a Ciência e Tecnologia em Portugal*, Lisbon, Portugal
- Sep 2020 **Mining the radio sky toward the earliest AGN**, *Encontro Nacional de Astronomia e Astrofísica*, Portugal
- Mar 2015 **Mapping the winds on Mars. Test study (master project) for planetary atmospheric monitoring with ALMA**, *Ground and space observatories: a joint venture to planetary science*, Santiago, Chile

### Other Meetings

- Nov 2023 **Artificial intelligence and the uncertainty challenge in fundamental physics**, SCAI, Paris and Institut Pascal Paris-Saclay, France
- Nov 2023 **Machine Learning meets galaxy classification: addressing paradigms of galaxy evolution and their environment**, ESAC, Villafranca del Castillo, Spain
- Dec 2021 **Cosmology in the Radio Sky: Prospects and Challenges in the Square Kilometre Array Observatory era**, *Workshop*, Instituto de Astrofísica e Ciências do Espaço
- Dec 2020 **Machine Learning in Science & Engineering**, Columbia University - Data Science Institute
- Dec 2020 **SOCHIAS (Chilean Society of Astronomy) annual meeting**, Pucón, Chile
- Nov 2020 **Exploiting Archives for Radio Astronomy in the SKA-era**, Lisbon, Portugal
- Jun 2020 **European Astronomical Society Annual Meeting**, Leiden, Netherlands
- Jan 2011 **SOCHIAS (Chilean Society of Astronomy) annual meeting**, Santiago, Chile

## Observation Experience

- Nov 2022 **NIKA2 and EMIR instruments**, *30m Pico Veleta Radio Telescope*, IRAM, Spain, One-week observation run under pooled observations scheme.
- Feb 2013 **MagE instrument**, *6.5m Magellan-Clay Telescope*, LCO, Chile, One-night observation run under the supervision of Dr. Isabelle Pâris.

## Teaching Experience

- Mar 2013 – Jul 2013 **Universidad de Chile**, *Teaching Assistant FI1001. Introduction to Newtonian Physics*, Department of Physics, Santiago, Chile. Professor: Sebastián López
- Mar 2013 – Jul 2013 **Universidad de Chile**, *Teaching Assistant EI2001. Project Workshop*, School of Engineering, Santiago, Chile. Professor: S. López. Taught students how to characterise a CCD at the University Observatory.
- Mar 2012 – Jul 2012 **Universidad de Chile**, *Teaching Assistant AS3004–AS758. Intergalactic Medium*, Department of Astronomy, Santiago, Chile. Professor: S. López

## Student Supervision

- Jul 2023 **Instituto de Astrofísica e Ciências do Espaço**, *Co-supervised Summer Internships*, With supervisors (B. Arsoli, I. Matute) guided L. Rodrigues, G. Monteiro, A. Correia, D. Barreta, and T. Melo on project 'Multifrequency Analysis and Machine Learning for the most powerful quasars in the Universe'.
- Sep 2022 – Feb 2023 **Universidade de Lisboa**, *Co-supervised BSc student*, With supervisor (I. Matute) guided J. Bagagem on project 'Connecting galaxies photometry with Super-Massive Black Hole (SMBH) properties: A machine learning approach'.
- Sep 2021 – Feb 2022 **Universidade de Lisboa**, *Co-supervised BSc student*, With supervisor (I. Matute) guided J. Lopes on project 'Modelling Active Galactic Nuclei with Machine Learning'.
- Sep 2021 – Jan 2022 **Universidade de Lisboa**, *Co-supervised BSc student*, With supervisor (I. Matute) guided B. Resendes on project 'Identifying and characterising AGN in next-generation radio surveys with machine learning'.
- Jul 2021 **Instituto de Astrofísica e Ciências do Espaço**, *Co-supervised Summer Internships' students*, With supervisor (I. Matute) guided J. Sandrin, P. Ferreira, P. Rodrigues, and A. Monteiro on project 'Identifying and characterising AGN in next-generation radio surveys using machine and deep learning'.
- Jul 2021 **Instituto de Astrofísica e Ciências do Espaço**, *Co-supervised Summer Internships' students*, With supervisor (J. Afonso) guided A. Labib, M. E. Pimentel, L. Barroso, and J. Rato on project 'The 200: exploring the most active supermassive black holes in the first Gyr of the Universe'.
- Sep 2020 – Feb 2021 **Universidade de Lisboa**, *Co-supervised BSc student*, With supervisor (I. Matute) guided I. Tiago on project 'Understanding triggering Radio emission from AGNs'.
- Jul 2020 **Universidade de Lisboa**, *Co-supervised BSc student*, With supervisor (J. Afonso) guided L. Piscarreta on studying radio and X-ray emission of high-*z* AGN.

## Outreach

- Aug 2023 **IX Escuela Ecuatoriana de Astronomía y Astrofísica**, (*IX Ecuadorian School of Astronomy and Astrophysics*), Quito, Ecuador, Lecture: 'Looking for galaxies in a Universe of data'.
- Jul 2022 **Ser Cientista**, *Co-supervision of high schoolers*, Faculdade de Ciências, University of Lisbon, Portugal Helped main supervisor (C. Pappalardo) guiding students on project 'O FADO das Galáxias'.
- Oct 2021 **Festival Internacional de Ciência (FICA)**, Oeiras, Lisbon, Portugal Answer questions about observatories in the stand of the Instituto de Astrofísica e Ciências do Espaço.

## Working Experience

- 2013 – 2019 **Tourist guide**, *Observatorio Astronómico Andino (OAA)*, Santiago, Chile, Showed tourists main features of night sky and answering questions on Astronomy and Astrophysics in both Spanish and English.

## Training

- May 2022 **18th Synthesis Imaging Workshop**, National Radio Astronomy Observatory. Socorro, NM. U.S.A.
- Apr – May 2022 **SKilled, Innovative & Entrepreneurial Scientists**, Instituto de Astrofísica e Ciências do Espaço. Coimbra, Portugal
- Feb 2022 **SKA regional centre training event. Hands-on Containerization**, Science User Engagement (SUE) group of the SKA Regional Centre Steering Committee
- Mar 2019 **ALMA Community Day (Cycle 7 Proposing Workshop)**, *Joint ALMA Observatory (JAO)*, Santiago, Chile

## Participation in Projects

- Jan 2022 – Dec 2023 **Finding Lyman-alpha emitters through machine learning (Encontrando emissores de Lyman-alpha através de aprendizagem máquina)**, *PTCRIS: EXPL/FIS-AST/1085/2021*, Funding: Fundação para a Ciência e a Tecnologia, Portugal, P.I. A. Paulino-Afonso

## Memberships

Evolutionary Map of the Universe (EMU)  
 Square Kilometre Array Observatory (SKAO), *Extragalactic Continuum Science Working Group*  
 SKA Pathfinders Radio Continuum Surveys Working Group (SPARCS)  
 Multi-Object Optical and Near-infrared Spectrograph (MOONS)

## Service

- 2023 **Member of data validation team**, Evolutionary Map of the Universe
- Jul 2022 **Chair of KS8 session**, *EMU International Virtual Meeting*, Evolutionary Map of the Universe
- Sep 2022 – Jul 2023 **Co-organiser Journal Club**, *Galaxies Research Group*, Instituto de Astrofísica e Ciências do Espaço, Weekly meetings to discuss relevant articles and topics.
- 2019 – 2020 **PACE Analyst**, *Portuguese ALMA Centre of Expertise (PACE)*, Instituto de Astrofísica e Ciências do Espaço

## Languages

- Spanish – Native speaker
- Portuguese – Basic knowledge
- English – IELTS Academic 7.5/9.0

## Coding Skills

- Python – Intermediate level
- C – Intermediate level
- Java – Intermediate level.
- Matlab – Intermediate level
- $\text{\LaTeX}$  – Intermediate level
- Mathematica – Basic level
- Bash – Basic level
- git – Elementary user

## Software Skills

- Common Astronomy Software Application (CASA)
- Image Reduction and Analysis Facility (IRAF)
- Tool for operations on catalogues and tables (TOPCAT)
- The Atmospheric Radiative Transfer Simulator (ARTS)
- Gnuplot
- SAOImage DS9

- ESO-MIDAS

- EsoRex

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## References

- **Dr José Afonso**

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- **Dr Hugo Messias**

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