

Ph.D. Report

(XXXIV Cycle - III year)

PROJECT TITLE: “*The J1030 Field: a new window on SMBH formation and evolution within early large scale structures*”

CANDIDATE: QUIRINO D’AMATO

SUPERVISOR: *Dr Isabella Prandoni*

UNIVERSITY REFERENCE: *Prof. Cristian Vignali*

CO-SUPERVISORS: *Dr Roberto Gilli, Dr Marcella Massardi*

Research project

Context: The $z=6.31$ SDSS J1030+0524 QSO field ($\sim 30'' \times 30''$) is a very promising candidate for investigating the link between early SMBH formation and large scale structures in the high-redshift Universe ($z > 2-3$) (Balmaverde+17). As such, has been targeted by numerous campaigns that led to an unprecedented radio-to-X-ray multi-band coverage. Recently, the presence of a galaxy overdensity at $z \sim 6.3$, around the QSO, has been spectroscopically confirmed (Mignoli+20). Moreover, a protocluster has been recently discovered at $z=1.7$ around a powerful FR II in the center of the field (Gilli+19). Eight SFGs have been discovered at the spectroscopic $\Delta z=1.687-1.699$, close (< 1 Mpc) to the FR II. Furthermore, a significant X-ray diffuse emission overlapping the region covered by the overdensity has been detected. Remarkably, four of the protocluster members lie in an arc-like shape around the main component of the X-ray extended emission. We propose that such emission originates from an expanding bubble of gas shock heated by the FR II jet, that is promoting the star formation on nearby galaxies by compression of their ISM. If confirmed, this would be the first evidence of positive AGN feedback on multiple galaxies on hundreds-kpc scales. As part of the observing program of our field we obtained new ALMA CO(2-1) (PI: R. Gilli) of the region around the FR II and new JVLA deep continuum (1.4 GHz) observations (PI: I. Prandoni) of the entire field. The analysis of these datasets is the main focus of my PhD project.

Results: *ALMA data:* We targeted the CO(2-1) line emission in order to trace the gas content of the protocluster, possibly detecting new gas-rich members. I developed a new code that performs automatic line detection on the basis of spectral, spatial and reliability criteria, thanks to which we discovered three new gas-rich ($M_{H_2} \sim 1.5 - 4.8 \times 10^{10} M_{\odot}$) galaxies. This leads to a total of 11 confirmed overdensity members, within a projected distance of 1.15 Mpc from the FR II and in a redshift range of $\Delta z=0.012$. Under simple assumptions, we estimated that the system has a total mass of $\gtrsim 3 - 6 \times 10^{13} M_{\odot}$, and showed that it will likely evolve into a $\gtrsim 10^{14} M_{\odot}$ cluster at $z=0$. Furthermore, we unveiled the presence of a large molecular gas reservoir ($M_{H_2} \sim 2 \times 10^{11} M_{\odot}$) distributed in a region of $\sim 27 \times 17$ kpc² around the FR II host galaxy. The FR II is located at the center of the projected spatial distribution of the structure members; this, coupled with the large amount of gas around the FR II, its stellar mass of $\sim 3 \times 10^{11} M_{\odot}$, SFR of $\sim 200 - 600 M_{\odot}/\text{yr}$, and powerful radio-to-X-ray emission, suggests that this source is the likely progenitor of the future BCG. These results have been published in D’Amato+20b. *JVLA data:* During the first and second year of PhD I performed the reduction, calibration, self-calibration and imaging of the dataset, which was found to be strongly affected by RFI contamination, determining the failure of the automatic VLA pipeline. The final image reaches a rms of $\sim 2.5 \mu\text{Jy}/\text{b}$, making our field one of the deepest extra-galactic radio surveys to date. In the last year of my PhD I extracted a catalogue of ~ 1300 radio-sources and performed completeness and reliability analysis; we derived the source counts and compared them with the literature, finding a good agreement down to few tens of μJy . Thanks to the wide-band coverage of this field, we investigated the relation between the radio-sources and their X-ray counterparts up to $z \sim 3$, finding that the faint radio-source population is powered by both AGN- and SFR-driven radio emission, and that in these sources the SMBH is likely accreted through an inefficient accretion mechanism. As for the $z=1.7$ protocluster, we unveiled the presence of a diffuse radio emission around the lobes of the FR II, more extended than that previously known from shallower observations (Gilli+19), that is co-spatial with the X-ray diffuse emission that surrounds the FR II, supporting the positive AGN feedback scenario. In addition, one of the gas-rich sources detected by ALMA is detected in the JVLA image as well, and we showed that this is likely a second AGN in the structure, located closely (projected distance < 80 kpc) to the FR II. Finally, we detected for the first time at 1.4 GHz the QSO at the center of the overdensity at $z=6.3$, showing that is the most radio-quiet found to date at $z > 6$. These results will be published in D’Amato+, Subm.(a). Despite the lack of polarization calibrator in the JVLA observations, I developing ad-hoc methods to perform peculiar calibration of the radio polarized emission of the FR II; we showed an enhancement of the fractional polarization in the regions where the total intensity shows a bending morphology, as a likely signature of interaction with the ICM. These results, along with the analysis of the ALMA continuum and Optical/IR SED-fitting of the FR II host, that show how it is caught in its brief starburst assembling phase, will be published in D’Amato+, Subm.(b).

Note: The activities related to the third year of PhD are reported in red.

Workshops, conferences and meetings

- 4 - 8 OCTOBER 2021, Online
Workshop: *"Third National SKA Workshop"*
Contributed talk: *"Galaxy formation, ICM heating and AGN feedback: the turbulent youth of a proto-cluster at $z=1.7$ "*
- 24 - 27 AUGUST 2021, Online
Workshop: *"YERAC 2021"*
Contributed talk: *"Galaxy formation, ICM heating and AGN feedback: the turbulent youth of a proto-cluster at $z=1.7$ "*
- 14 - 18 JUNE 2021, Online
Workshop: *"Galaxy Cluster Formation II"*
Contributed talk: *"Galaxy formation, ICM heating and AGN feedback: the turbulent youth of a proto-cluster at $z=1.7$ "*
- 8 - 11 MARCH 2021, Online
Workshop: *"A new window on the radio emission from galaxies, clusters and cosmic web"*
Contributed talk: *"Galaxy formation, ICM heating and AGN feedback: the turbulent youth of a proto-cluster at $z=1.7$ revealed by mm and radio interferometers"*
- 31 AUGUST - 4 SEPTEMBER 2020, Online
Workshop: *"Protoclusters: Galaxies in Confinement"*
e-Poster: *"Discovery of molecular gas fueling galaxy growth in a protocluster at $z = 1.7$ "*
- 15-16 JULY 2020, Online
Conference: *"Technological Advances in X-ray Astronomy: Strategizing the Path Forward"*
- 18-19 DECEMBER 2019, Bologna, Italy
Conference: *"J1030 team meeting"*
Contributed talk: *"JVLA data reduction and analysis: status and first results"; "ALMA observations of the $z=1.7$ protocluster"*
- 18-22 NOVEMBER 2019, Milano, Italy
Conference: *"The art of measuring galaxy physical properties"*
Contributed talk: *"On the dust and gas component of high- z obscured QSO in the CDFS"*
- 30 SEPTEMBER - 2 OCTOBER 2019, Bologna, Italy
Workshop: *"SKA data challenges workshop" (Valid as Ph.D. school)*
Contributed talk: *"Handling large data-sets: a JVLA study case"*
- 8-13 SEPTEMBER 2019, Bologna, Italy
Conference: *"X-ray 2019"*
LOC member
- 2-6 SEPTEMBER 2019, Bologna, Italy
Conference: *"Views on the Interstellar Medium in galaxies in the ALMA era"*
Contributed talk: *"On the dust and gas component of high- z obscured QSO in the CDFS"*
LOC member
- 3-7 JUNE 2019, Viana do Castelo, Portugal
Conference: *"Uncovering early galaxy evolution in the ALMA and JWST era"*
Poster: *"The molecular gas content in a protocluster at $z=1.7$: star formation and AGN feedback"*
- 25-27 FEBRUARY 2019, Bologna, Italy
Workshop: *"ALMA Science and Proposals Workshop" (Valid as Ph.D. school)*
Contributed talk: *"On the dust and gas component of high- z obscured QSO in the CDFS"*

Ph.D. Schools

- 30 NOVEMBER - 2 DECEMBER 2020, Online (Organizer: IRA-ARC, OAS, Unibo)
Title: *"The Interstellar Medium"*
- 17-22 SEPTEMBER 2020, Online (Organizer: University of Bologna, Bologna, Italy)
Title: *"GAIA: Great Advances In Astrophysics"*
- 27 MAY - 22 JULY 2020, Online (Organizer: University of Munich, Munich, Germany)
Title: *"Neutrinos and Dark Matter in Astro- and Particle Physics"*

- 7-18 OCTOBER 2019, Socorro, New Mexico (USA)
Title: *"7th VLA Data Reduction Workshop"*
- 11-14 JUNE 2019, Bologna, Italy
Title: *"The first Italian LOFAR School 2019"*

Courses and Lectures

- 5 -14 MAY 2021, Bologna, Italy
Title: *"Writing, talking and presenting Science"*
Lecture by: *Dr. Roberto Decarli, OAS, Bologna, Italy*
- 17-18 DECEMBER 2019, Bologna, Italy
Title: *"Active Galactic Nuclei: what's in a name?"*
Lecture by: *Dr. Paolo Padovani, ESO, Garching, Germany*
- 17-25 JUNE 2019, Bologna, Italy
Title: *"Statistics for Astrophysics"*
Lecture by: *Dr. Robert Metcalf, University of Bologna, Bologna, Italy*

ISA Lectures

- 13 MAY 2021, Bologna, Italy
Title: *"Vaccini e sviluppo del farmaco tra Verità, Miti e Falsità"*
Lecture by: *Silvia Camporesi, King's College London, England*
- 28 SEPTEMBER 2021, Bologna, Italy
Title: *"How the Brain Controls Pain"*
Lecture by: *Mary Heinricher, Oregon Health and Science University, USA*
- 19 NOVEMBER 2019, Bologna, Italy
Title: *"Rigour and aesthetics: Japanese traditional mathematics"*
Lecture by: *Emanuele Delucchi, University of Fribourg, Fribourg, Switzerland*
- 12 NOVEMBER 2019, Bologna, Italy
Title: *"This turbulent turbulent world"*
Lecture by: *Alexandre Lazarian, University of Wisconsin, Madison, WI-USA*
- 12 FEBRUARY 2019, Bologna, Italy
Title: *"Dante and the Foundations of Argentine National Identity: Literature, Politics, and the Dream of a New Nation"*
Lecture by: *Mariano Pérez Carrasco, CONICET - University of Buenos Aires, Buenos Aires, Argentina*
- 13 NOVEMBER 2018, Bologna, Italy
Title: *"A heart attack: can we re-wire the heart?"*
Lecture by: *Damia Mawad, University of New South Wales, Sidney, Australia*

Invited speaker Seminars

- 8 JUNE 2021, Scuola Internazionale Superiore di Studi Avanzati (SISSA), Bologna, Italy
Title: *"Galaxy formation, ICM heating and AGN feedback: the turbulent youth of a proto-cluster at $z=1.7$ "*
- 29 NOVEMBER 2019, Istituto di Radioastronomia, Bologna, Italy
Title: *"SDSS J1030+0524 Field: a new window on SMBH formation and evolution within early large structures"*

Referee experience

- Distributed peer reviewing of ALMA Cycle 8 proposals.

PI of Accepted Proposals

- **ALMA** - *"Forging the core of a galaxy cluster: molecular gas properties and AGN feedback of a proto-BCG at $z=1.7$ "*; Scheduled for Cycle 8

PRIN (Progetti di Rilevante Interesse Nazionale) memberships

- “The environment of first quasars: shedding light on the large scale structures around the most distant cosmological beacons” (PI: R. Decarli)
- “FORECaST” (PI: I. Prandoni)
- “BLACKOUT” (PI: R. Fiore)

Publications

As first author:

- D’AMATO Q., PRANDONI I., BRIENZA M., GILLI R., VIGNALI C., PALADINO R., LOI F., MASSARDI M., MIGNOLI M., MARCHESI M., JAGANNATHAN P. - “Multi-wavelength study of a proto-BCG at $z=1.7$ ”; Submitted to *Galaxies*. (http://j1030-field.oas.inaf.it/QD_FRII.pdf)
- D’AMATO Q., PRANDONI I., GILLI R., VIGNALI C., BRIENZA M., MASSARDI M., MIGNOLI M., LIUZZO E., PECA A., MARCHESI S., AND NORMAN C. - “Deep 1.4 GHz catalogue of the J1030 equatorial field: a new window on the early stages of the Universe”; Submitted to *A&A*. (http://j1030-field.oas.inaf.it/QD_JVLA.pdf)
- D’AMATO Q., GILLI R., PRANDONI I., VIGNALI C., MASSARDI M., MIGNOLI M., CUCCIATI O., MORISHITA T., DECARLI R., BRUSA M., CALURA F., BALMAVERDE B., CHIABERGE M., LIUZZO E., NANNI R., PECA A., PENSABENE A., TOZZI P. AND NORMAN C. - “Discovery of molecular gas fueling galaxy growth in a protocluster at $z = 1.7$ ”; 2020, *A&A Letter*, 641, L6
- D’AMATO Q., GILLI R., PRANDONI I., VIGNALI C., MASSARDI M., POZZI F., ZAMORANI G., CIRCOSTA C., VITO F., FRITZ J., CRESCI G., CASASOLA V., CALURA F., FELTRE A., MANIERI V., RIGOPOULOU D., TOZZI P. AND NORMAN C. - “On the dust and gas content of high-redshift galaxies hosting obscured AGN in the CDF-S”; 2020, *A&A*, 636, A37
- D’AMATO Q., PRANDONI I., GILLI R., MASSARDI M., LIUZZO E., MIGNOLI M., VIGNALI C., PECA A. AND NANNI R. - “The molecular gas content in a protocluster at $z = 1.7$: Star formation and AGN feedback”; 2020, *Uncovering Early Galaxy Evolution in the ALMA and JWST Era. Proceedings of the International Astronomical Union*, 352, 168-170

As co-author:

- GIULIETTI M., MASSARDI M., LAPI A., BONATO M., ENIA A., NEGRELLO M., D’AMATO Q., BEHIRI M., AND DE ZOTTI G. - “The far-infrared/radio correlation for a sample of strongly lensed dusty star-forming galaxies detected by *Herschel*”; Submitted to *MNRAS*. **Contribution:** Observations with ATCA and paper revision
- MARCHESI S., MIGNOLI M., GILLI R., PECA A., BOLZONELLA M., NANNI R., ANNUNZIATELLA M., BALMAVERDE B., BRUSA M., CALURA F., CASSARA L., CHIABERGE M., COMASTRI A., CUSANO F., D’AMATO Q., IWASAWA K., LANZUISI G., MARCHESINI D., MORISHITA T., PRANDONI I., ROSSI A., TOZZI P., VIGNALI C., VITO F., ZAMORANI G., AND NORMAN C. - “Redshift identification of X-ray selected active galactic nuclei in the J1030 field: searching for large-scale structures and high-redshift sources.”; 2021, Accepted from *A&A* (arXiv:2109.08162). **Contribution:** Cross-check of multi-band catalogues and paper revision.
- PANTONI L., MASSARDI M., LAPI A., DONEVSKI D., D’AMATO Q., GIULIETTI M., POZZI F., TALIA M., VIGNALI C., CIMATTI A., SILVA L., BRESSAN A., AND RONCONI T. - “An ALMA view of 11 dusty star-forming galaxies at the peak of cosmic star formation history.”; 2021, *MNRAS*, 507, 3998. **Contribution:** Measurement of the gas size and 2-D image fitting of the sources. Paper revision.
- MORISHITA T., D’AMATO Q., ABRAMSON L., ABDURRO’UF E., STIAVELLI M., AND LUCAS R.A. - “Extremely Low Molecular Gas Content in the Vicinity of a Red Nugget Galaxy at $z = 1.91$ ”; 2021, *ApJ*, 908, 163. **Contribution:** Cross-check of the non-detection of sources using the blind searching tool that I developed for ALMA data-cubes.
- CALURA F., VANZELLA E., CARNIANI S., GILLI R., ROSATI P., MENEGHETTI M., PALADINO R., DECARLI R., BRUSA M., LUPI A., D’AMATO Q., BERGAMINI P., AND CAMINHA G. - “Constraints on the [C II] luminosity of a proto-globular cluster at $z \sim 6$ obtained with ALMA.”; 2021, *MNRAS*, 500, 3083. **Contribution:** cross-check of the detected sources using the blind searching tool that I developed for ALMA data-cubes and line analysis.

- GILLI R., MIGNOLI M., PECA A., NANNI R., PRANDONI I., LIUZZO E., D'AMATO Q., BRUSA M., CALURA F., CAMINHA G. B., CHIABERGE M., COMASTRI A., CUCCIATI O., CUSANO F., GRANDI P., DECARLI E., LANZUISI G., MANNUCCI F., PINNA E., TOZZI P., VANZELLA E., VIGNALI C., VITO F., BALMAVERDE B., CITRO A., CAPPELLUTI N., ZAMORANI G., NORMAN C. - *“Discovery of a galaxy overdensity around a powerful, heavily obscured FR II radio galaxy at $z=1.7$: star formation promoted by large-scale AGN feedback?”*; 2019, A&A, 632, A26. **Contribution:** measurements of the radio-emission of the FR II at the center of the overdensity, derivation of physical quantities and interpretation.
- PERNA M., SARGENT M. T., BRUSA M., DADDI E., FERUGLIO C., CRESCI G., LANZUISI G., LUSSO E., COMASTRI A., COOGAN R. T., D'AMATO Q., GILLI R., PICONCELLI E., VIGNALI C. - *“Molecular gas content in obscured AGN at $z > 1$ ”*; 2018, A&A, 619, A90. **Contribution:** visibility fitting of ALMA data and measurement of the gas sizes.
- BURKUTEAN S., GIANNETTI A., LIUZZO E., MASSARDI M., RYGL K., BRAND J., BEDOSTI F., BONATO M., D'AMATO Q., GALLUZZI V., MANCUSO C., STOEHR F., KNAPIC C., SMAREGLIA R. - *“KAFE: the Key-analysis Automated FITS-images Explorer”*; 2018, JATIS, 4, 028001. **Contribution:** testing the tool on archival ALMA data.
- CAMPANA R., MASSARO E., BERNIERI E., D'AMATO Q. - *“Application of the MST clustering to the high energy γ -ray sky. I – New possible detection of high-energy γ -ray emission associated with BL Lac objects”*; 2015, ASS, 360, 19. **Contribution:** I performed likelihood analysis in order to confirm the γ -ray detection obtained with the MST tool.

References

Balmaverde et al. (2017), A&A, 606, A23
 D'Amato et al. (2020a), A&A, 636, A37
 D'Amato et al. (2020b), A&A, 641, L6
 D'Amato et al., subm. (a) to A&A ([PDF](#))
 D'Amato et al., subm. (b) to Galaxies ([PDF](#))
 Gilli et al. (2019), A&A, 632, A26
 Mignoli et al. 2020, A&A, 642, L1