Mem. S.A.It. Vol. 82, 161

Memorie della

A wide-angle tail galaxy at z = 0.53 in the COSMOS field

A. Oklopčić[1,2], V. Smolčić[2,3,4], S. Giodini[5], G. Zamorani[6], L. Bîrzan[7], E. Schinnerer[8], C. L. Carilli[9], A. Finoguenov[5], S. Lilly[10], A. Koekemoer[11], and N. Z. Scoville[2]

[1] University of Zagreb, Bijenička cesta 32, 10002 Zagreb, Croatia
[2] California Institute of Technology, MC 105-24, 1200 East California Boulevard, Pasadena, CA 91125, e-mail: oklopcic@caltech.edu
[3] ESO ALMA COFUND Fellow, European Southern Observatory, Karl-Schwarzschild-Strasse 2, 85748 Garching b. Muenchen, Germany
[4] Argelander Institut for Astronomy, Auf dem Hügel 71, Bonn, 53121, Germany
[5] Max Planck Institut für Extraterrestrische Physik, Giessenbachstrasse, Garching bei München, D-85478, Germany
[6] INAF - Osservatorio Astronomico di Bologna, via Ranzani 1, 40127, Bologna, Italy
[7] Leiden Observatory, Leiden University, Oort Gebouw, P. O. Box 9513, 2300 RA Leiden, The Netherlands
[8] Max Planck Institut für Astronomie, Königstuhl 17, Heidelberg, D-69117, Germany
[9] National Radio Astronomy Observatory, P.O. Box 0, Socorro, NM 87801-0387
[10] Eidgenössische Technische Hochschule - Zürich, CH - 8093 Zürich, Switzerland
[11] Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218

Abstract. Wide-angle tail (WAT) galaxies are radio galaxies whose jets are bent forming a wide C shape. The bending of the jets is a result of ram pressure, due to the relative motion of the host galaxy and the intra-cluster medium. We present an analysis of a WAT galaxy located in a galaxy group in the COSMOS field at the redshift of z = 0.53 (CWAT-02). An in-depth study of CWAT-02 and its surroundings reveals many indications that this system in the process of an ongoing group merger. We analyze the radio jets of CWAT-02 and present an estimate of discrepancy between the observed and the intrinsic luminosity, due to Doppler beaming of the relativistic jets. We finally discuss the impact of radio-AGN heating from CWAT-02 into its environment.

Key words. galaxies: fundamental parameters – galaxies: active, evolution – cosmology: observations – radio continuum: galaxies

1. Introduction

Wide-angle tail (WAT) radio galaxies are characterized by jets bent in a wide C shape. WATs are usually found in dense environments, like galaxy clusters and groups. Their characteristic morphology is thought to originate from ram pressure exerted on the radio jets, due to the relative motion between the host galaxy and the intra-cluster medium (ICM; e.g. Begelman et al. 1979).

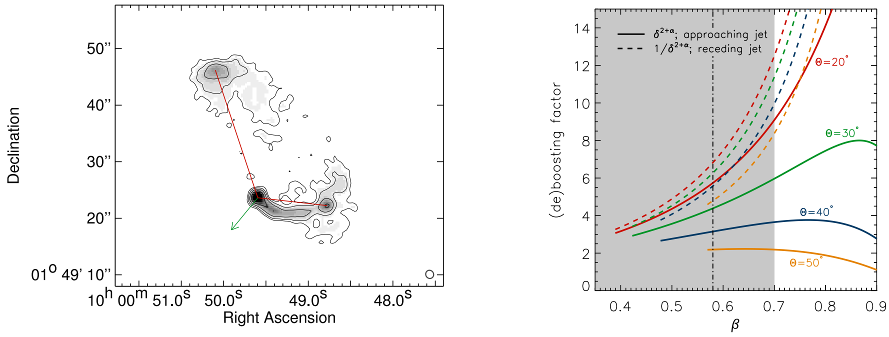

Fig. 1. Left panel: 1.4 GHz radio image of CWAT-02. The arrow indicates the direction of the movement of CWAT-02 (relative to the ICM), in the plane of the sky. Right panel: The Doppler boosting factor of the approaching jet (solid lines) and the deboosting factor of the receding jet (dashed lines) as function of the bulk jet speed $\beta = v/c$ and the jet orientation angle to the line of sight θ for a range of jet–to–counter-jet ratios $\geq$ 10. The sound speed sets a lower limit to the CWAT-02 jet velocity (see text for details; see also Oklopčić et al. 2010).

WATs are generally associated with brightest cluster galaxies (Owen & Rudnick 1976) and are found to move with peculiar velocities of a few hundreds km s^{-1} relative to the cluster center. Furthermore, a number of observations report the presence of WAT galaxies in connection with other indicators of a recent cluster merger, such as X–ray substructure (Burns et al. 1994), the elongation of the X–ray emission region along the line that bisects the WAT (Gomez et al. 1997), and a significant offset ($\sim$ 100 kpc) of the WAT from the X-ray centroid (Sakelliou & Merrifield 2000).

In general, the interest in radio galaxies has recently been renewed because they have been proposed to solve the missing baryon problem in galaxy groups through the process of mechanical heating of gas by radio outflows of the central AGN, resulting in the removal of gas from within the group (Bower et al. 2008). Only recently, this idea has been observationally supported by Giodini et al. (2010).

We performed a multi-wavelength study of a wide-angle tail galaxy at $z = 0.53$ in the COSMOS field (CWAT-02 hereafter) and its environment (Oklopčić et al. 2010). The data used for this analysis have been obtained from the panchromatic (X-ray to radio) COSMOS 2□° survey (Scoville et al. 2007), including HST imaging of the entire field (Koekemoer et al. 2007). We make use of the galaxy cluster catalog described in detail in Finoguenov et al. (2007).

2. Doppler boosting and the jet luminosity

The radio morphology of CWAT-02, taken from the 20 cm VLA-COSMOS image (Schinnerer et al. 2007) and shown in Fig. 1, is highly asymmetric. A plausible explanation provides Doppler boosting causing the luminosity of the jet moving towards the observer to be amplified and the luminosity of the jet moving away to be suppressed, if the bulk velocity of the jet is relativistic.

Assuming equal intrinsic luminosities of the jets and constraining the effect of Doppler boosting from observation and the results of Jetha et al. (2006) (see Fig. 1, right panel), we find that the observed total jet flux is approximately a factor of 5 higher than the intrinsic one. However, since the observed jet flux accounts for only a minor part (12%) of the total observed flux of CWAT-02, the observed value of the luminosity is a good estimate of the total intrinsic luminosity. For more details see Oklopčić et al. (2010).

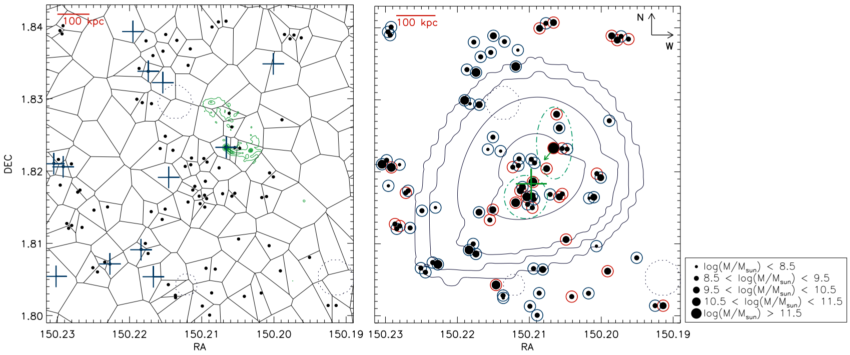

Fig. 2. Left panel: Voronoi tessellation of the area around CWAT-02 overlaid with radio contours. Filled dots represent "high density" galaxies and crosses indicate the position of the galaxies for which a spectroscopic redshift is available. The right panel shows the same area as in the left panel, but overlaid with X-ray contours. The galaxies are represented by encircled dots, where the size of each dot is related to the stellar mass of the corresponding galaxy. The arrow indicates the velocity direction of CWAT-02. The cross marks the center of mass of the system and dash-dotted lines indicate the two assumed merging galaxy subgroups.

3. WATs as tracers of dynamically young clusters

To identify the galaxy overdensity associated with CWAT-02, we use the Voronoi tessellation approach (see Smolčić et al. 2007 for more details). The existence of CWAT-02's host galaxy group at $z = 0.53$ has been independently determined in three different wavelength windows (radio, optical, and X-ray). We find that, although it is the brightest and most massive galaxy in the analyzed region, CWAT-02 is not, as one would expect in a relaxed system, at the center of its host group. This is an indication for a disturbed system, probably undergoing a process of group or sub-group merger.

To test this idea we put constraints on the velocity of CWAT-02's host galaxy, relative to the ICM, needed to explain the observed bending of the radio jets. Using the model developed by Begelman et al. (1979) we obtain a velocity of $v_{gal/ICM} \sim 900$ km s^{-1}.

Based on our spectroscopic data we can further put limits on the peculiar line-of-sight velocity of CWAT-02's host galaxy. The obtained biweight velocity dispersion is 437 km s^{-1}. Note that based on the X-ray luminosity of the group, a velocity dispersion of 300 − 500 km s^{-1} is expected (Mulchaey 2000).

The velocity difference between CWAT-02's host galaxy and the biweight mean velocity of group galaxies is 244 km s^{-1}. This is higher than the expected line-of-sight peculiar velocities of brightest group galaxies located in relaxed systems (Beers et al. 1995; see also Oegerle & Hill 2001), which are found to be $\lesssim 150$ km s^{-1}. Thus it independently suggests a disturbed state of the system.

4. Can radio-AGN heating expel baryons from CWAT-02's host group?

Recent cosmological models assume that radio-AGN heating is powerful enough to expel a fraction of baryons from the cluster/group potential well (Bower et al. 2008). Such a process provides a satisfactory solution for the missing baryon problem on galaxy group scales, i.e. it can potentially reconcile the observed discrepancy between the baryon to dark matter mass ratio in galaxy groups and the WMAP-CMB value (see Giodini et al. 2009). The first observational support for this scenario has been presented by Giodini et al. (2010). They performed an analysis of 16 COSMOS galaxy groups, including CWAT-02's host group, and find that the radio-AGN heating provided by CWAT-02 is powerful enough to expel gas from its host group.

Our Doppler boosting analysis shows that the relativistic boosting does not significantly alter the total intrinsic radio luminosity of CWAT-02, which was used to compute the output energy by Giodini et al. (2010).

It is possible that some of the most prominent galaxies in the merging system were once the central galaxies in the merging constituents. Re-occurring radio outflows are expected in these galaxies. While no significant change in radio power is expected for such massive galaxies over cosmic time (see Smolčić et al. 2009), the binding energy of the merging constituents could have been substantially lower (compared to the merged system), thus facilitating the removal of gas. Therefore, our finding of the unrelaxed state of the analyzed system strengthens the result of Giodini et al. (2010).

5. Summary

We have presented an analysis of a wide-angle tail galaxy in the COSMOS field (CWAT-02) and its host galaxy group at $z = 0.53$, presented by Oklopčić et al. (2010). The in-depth study of the galaxy's environment, morphology and velocity suggests an unrelaxed state of the host group, possibly caused by a galaxy group merger. This is consistent with the idea that WAT galaxies can be used as good tracers of dynamically young, unrelaxed systems. Furthermore, we discuss the energetics of the radio outflows from CWAT-02, in the context of the missing baryon problem on galaxy group scales.

Acknowledgements. AO thanks California Institute of Technology for generous support through NASA grants 1292462 and 1344606. VS acknowledges support from the Owens Valley Radio Observatory, which is supported by the National Science Foundation through grant AST-0838260. The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n No 229517. VS & AO thank Unity through Knowledge Fund (www.ukf.hr) for collaboration support through the 'Homeland Visit' grant. SG acknowledges support by the DFG Cluster of Excellence "Origin and Structure of the Universe" (www.universe-cluster.de). CC acknowledges support from the Max-Planck Society and the Alexander von Humboldt Foundation through the Max-Planck-Forschungspreis 2005. GZ acknowledges support from an INAF contract PRIN-2007/1.06.10.08 and an ASI grant ASI/COFIS/WP3110 I/026/07/0.

References

Beers, T.C., et al., 1995, AJ 109, 874
Begelman, M.C., et al. 1979, Nature 279, 770
Bower, R.G., et al. 2008, MNRAS 390, I399
Burns, J.O., et al., 1994, ApJ 423, 94
Finoguenov, A., et al. 2007, ApJS, 172, 182
Giodini, S., et al., 2010, ApJ, 714, 218
Giodini, S., et al., 2009, ApJ, 703, 982
Gomez, P.L., et al., 1997, AJ 114, 1711
Jetha, N.N., et al., 2006, 368, 609
Koekemoer, A. M., et al. 2007, ApJS 172, 196
Mulchaey, J. S., 2000, ARA&A, 38, 289
Oegerle, W.R. & Hill, J.M. 2001, AJ 122, 2858
Oklopčić, A., et al., 2010, ApJ, 713, 484
Owen, F. N., Rudnick, L. 1976, ApJ 205, L1
Sakelliou, I. & Merrifield, M.R., 2000, MNRAS 311, 649
Schinnerer, E., et al. 2007, ApJS 172, 46
Scoville, N., et al. 2007, ApJS 172, 150
Smolčić, V., et al. 2007, ApJS 172, 295
Smolčić, V., et al. 2009, ApJS 690, 610