The initial stages of cluster mergers observed in radio and X-rays

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1. Introduction

Despite the observed connection between mergers and diffuse radio sources in the intra-cluster medium in the form of radio halos and relics [1, 2], little is known about the generation of synchrotron emission in the very ***early phase*** of a merger (Fig. 1). Systems in this merging phase are referred to as ***pre-merging*** clusters. From a theoretical point of view, it is still unclear if (and how) a significant fraction of the energy of gas dynamics can be channelled into non-thermal components during the pre-merger phase becoming detectable in the radio band. Radio and X-ray observations of cluster pairs can help to address this point.

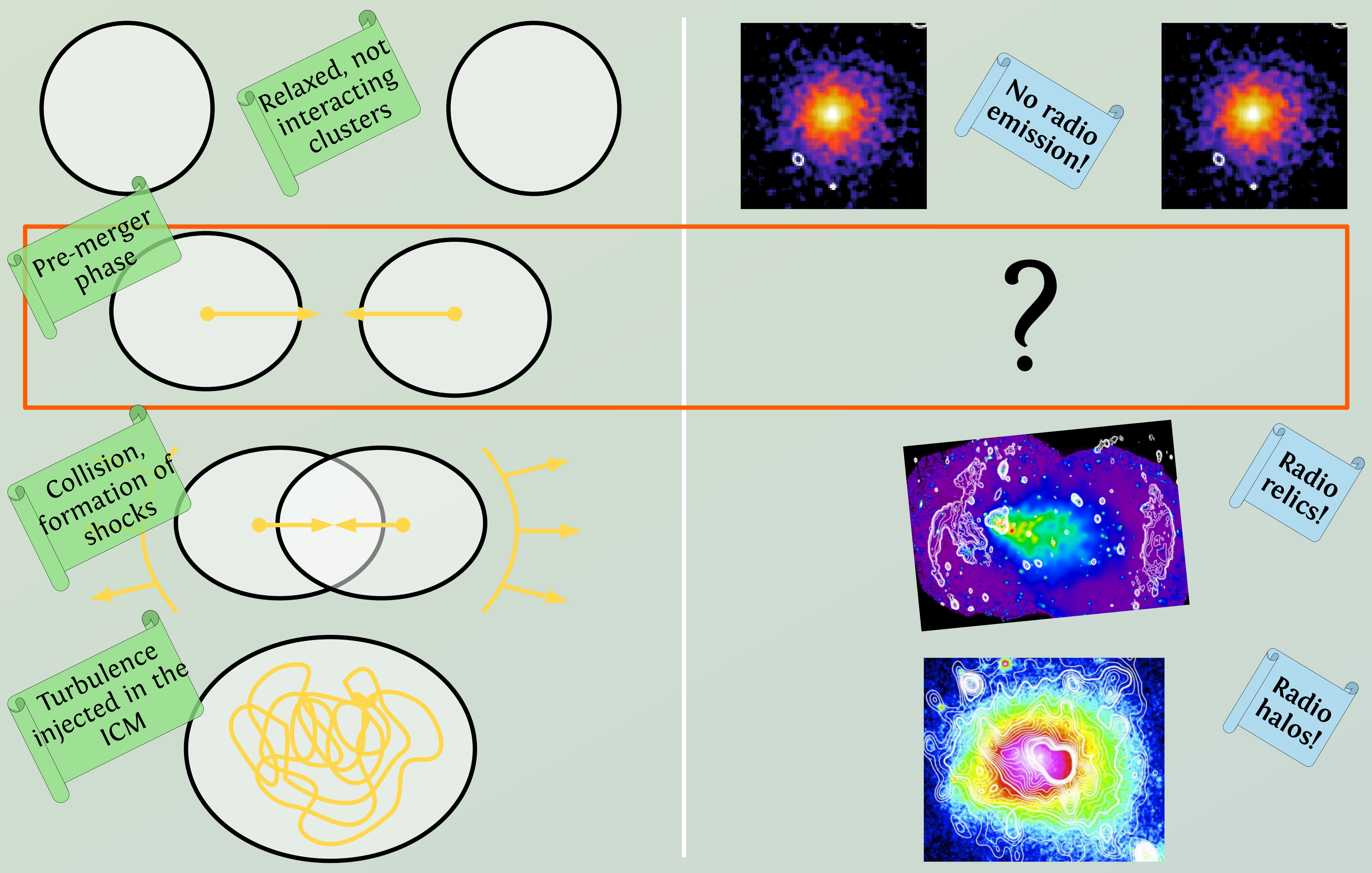

Fig. 1: Schematic view of a binary cluster merger.

2. Abell 1758 [Botteon et al. 2018, MNRAS, 478, 885-898, Botteon et al. 2020, MNRAS, 499, L11]

Abell 1758 is a massive pre-merging cluster at z=0.279 composed of two main components separated by a projected distance of ~2 Mpc (Fig. 2). We observed A1758 with LOFAR LBA (53 MHz) and HBA (144 MHz), uGMRT band 3 (383 MHz), and JVLA L-band (1.4 GHz) to investigate the presence of the radio bridge connecting the galaxy clusters suggested in our earlier work [3]. The new images are shown in Fig. 3. We confirmed the presence of a ***radio bridge*** at 144 MHz [4]. This is the second large-scale radio bridge observed to date in a cluster pair (the other is A399/A401 [5]). Only hints of radio emission are observed at 53 and 383 MHz, requiring deeper observations to provide a robust estimate of its spectral index. By comparing the X-ray and radio surface brightness of the bridge, we found that ***the two components are correlated***, suggesting that they occupy a similar volume (Fig. 4). This is in line with the expectation of recent models in which bridges may be powered by novel particle acceleration mechanisms that are activated by the ***turbulence*** that is generated in dynamically active pairs of massive systems [6].

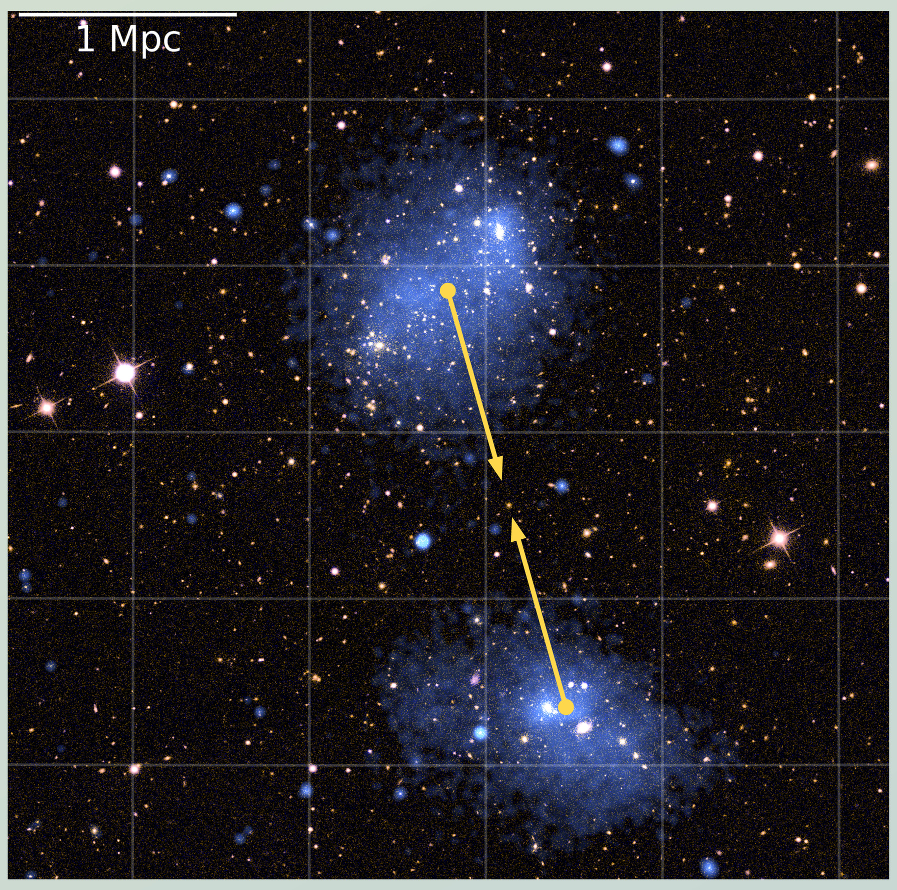

Fig. 2: Composite optical/X-ray image of Abell 1758,

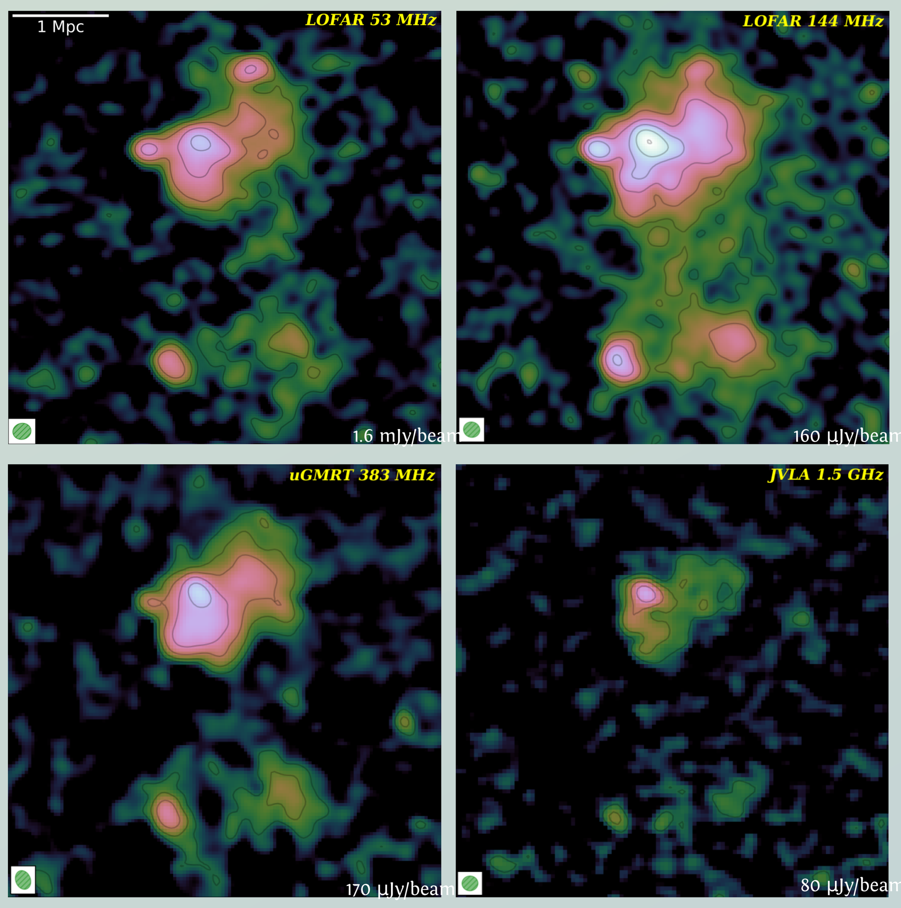

Fig. 3: Radio images of Abell 1758 from 53 MHz to 1.4 GHz.

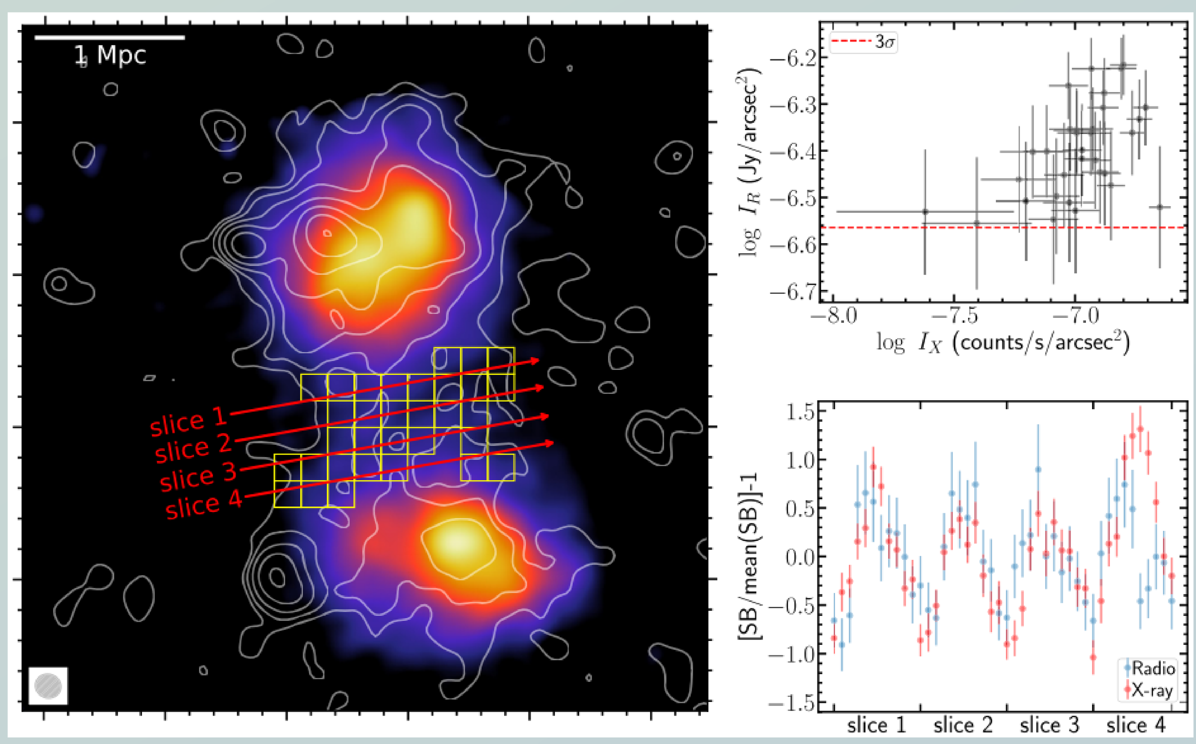

Fig. 4: Radio/X-ray correlation for the bridge in Abell 1758.

3. RXCJ1825/CIZA1824 [Botteon et al. 2019, A&A, 630, A77]

Located in the Lyra complex (z=0.07), RXCJ1825 and CIZA1824 form another pre-merging system [7, 8]. In this case, LOFAR observations at 144 MHz ***did not*** reveal a radio bridge between the two clusters, but they allowed us to discover a ***new radio halo*** (Fig. 5) [9]. This halo has a ***low-surface brightness extension*** towards the SW, leading to a maximum linear extent of the diffuse radio emission up to ~1.8 Mpc (Fig. 6). The remarkable spatial coincidence between the thermal and non-thermal emissions (Fig. 7) indicates that this feature is a consequence of the energy dissipated on small scales due to the interaction between RXCJ1825 and a galaxy group. Compared to the radio bridge pairs Abell 1758 and A399/A401, RXCJ1825/CIZA1824 is a less massive system, possibly suggesting a ***role of the mass*** in the generation of observable levels of synchrotron emission between pre-merging clusters.

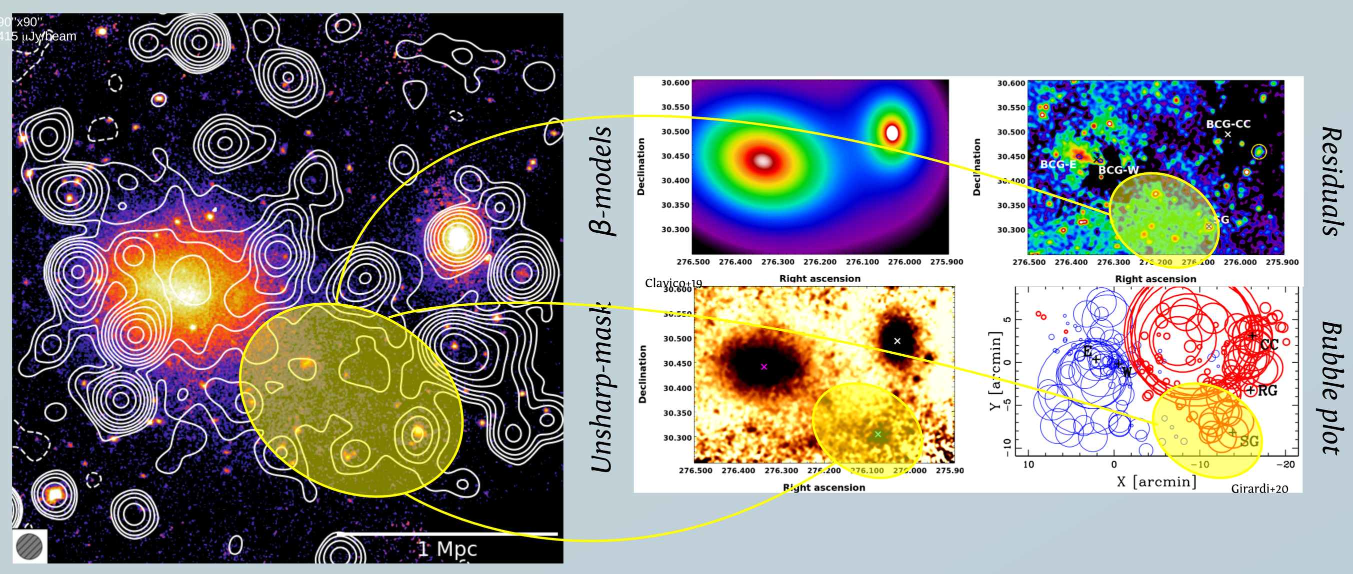

Fig. 6: The SW low-surface brightness extension of the halo in RXCJ1825.

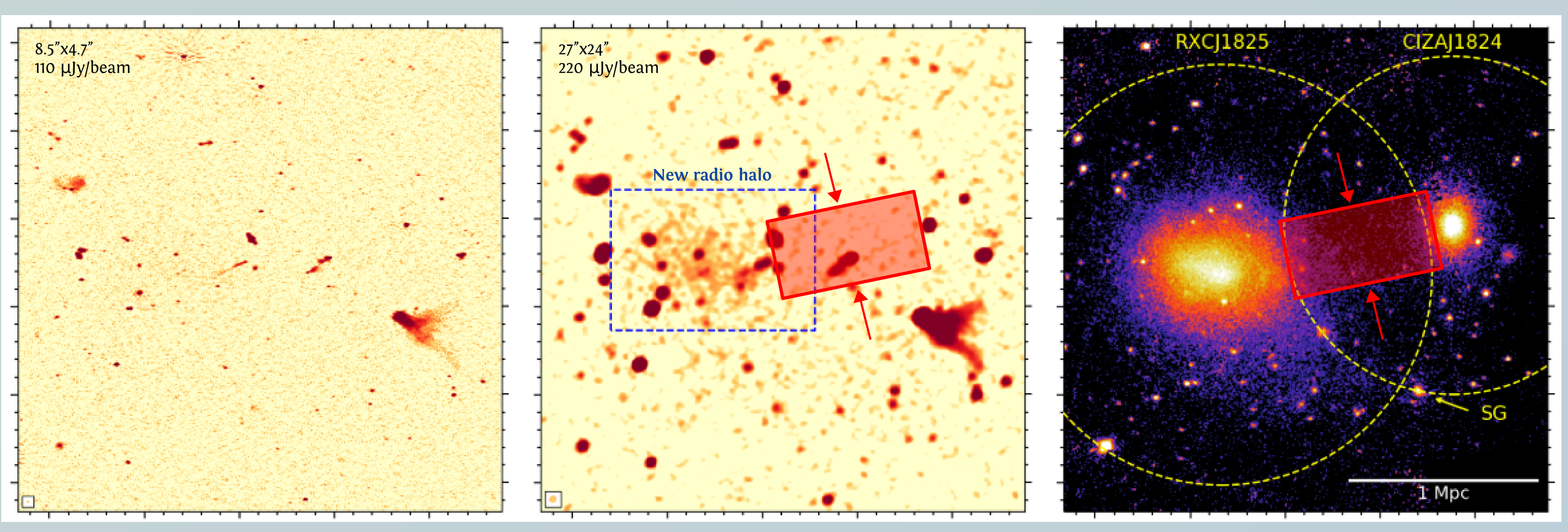

Fig. 5: LOFAR and XMM-Newton images of RXCJ1825/CIZA1824.

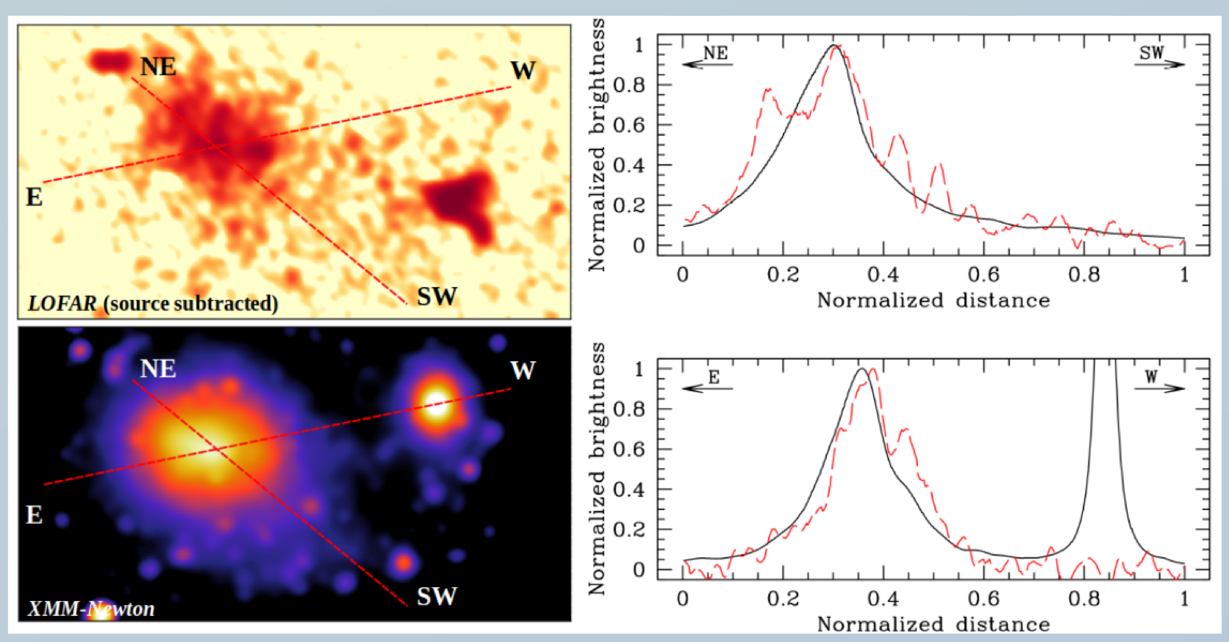

Fig. 7: 1D brightness profiles of the X-ray (black lines) and radio emission (red dashed lines) extracted across two directions.

4. Conclusion & future prospects

The detection of radio bridges and extensions of radio halos demonstrate the existence of magnetic fields and particle acceleration mechanisms at ***large distance from the cluster center***. Particularly, radio bridges probe that non-thermal phenomena can be generated ***even in the initial phase of the merger***. Future observations with LoTSS [10] and LoLSS [11] will be crucial to search for new bridges and constrain their spectral properties.

REFERENCES: [1] van Weeren et al. 2019, SSRev, 215, 16; [2] Brunetti & Jones 2014, IJMPD, 23, 30007; [3] Botteon et al. 2018, MNRAS, 478, 885-898; [4] Botteon et al. 2020, MNRAS, 499, L11; [5] Govoni et al. 2019, Science, 364, 981; [6] Brunetti & Vazza, 2020, PRL, 124, 51101; [7] Clavico et al. 2019, A&A, 632, A27; [8] Girardi et al. 2020, 633, A108; [9] Botteon et al. 2019, A&A, 630, A77; [10] Shimwell et al. 2019, A&A, 598, A104; [11] de Gasperin et al. 2021, 648, A104