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Tracing large-scale gas outflows from spiral galaxies in clusters with radio-continuum observations

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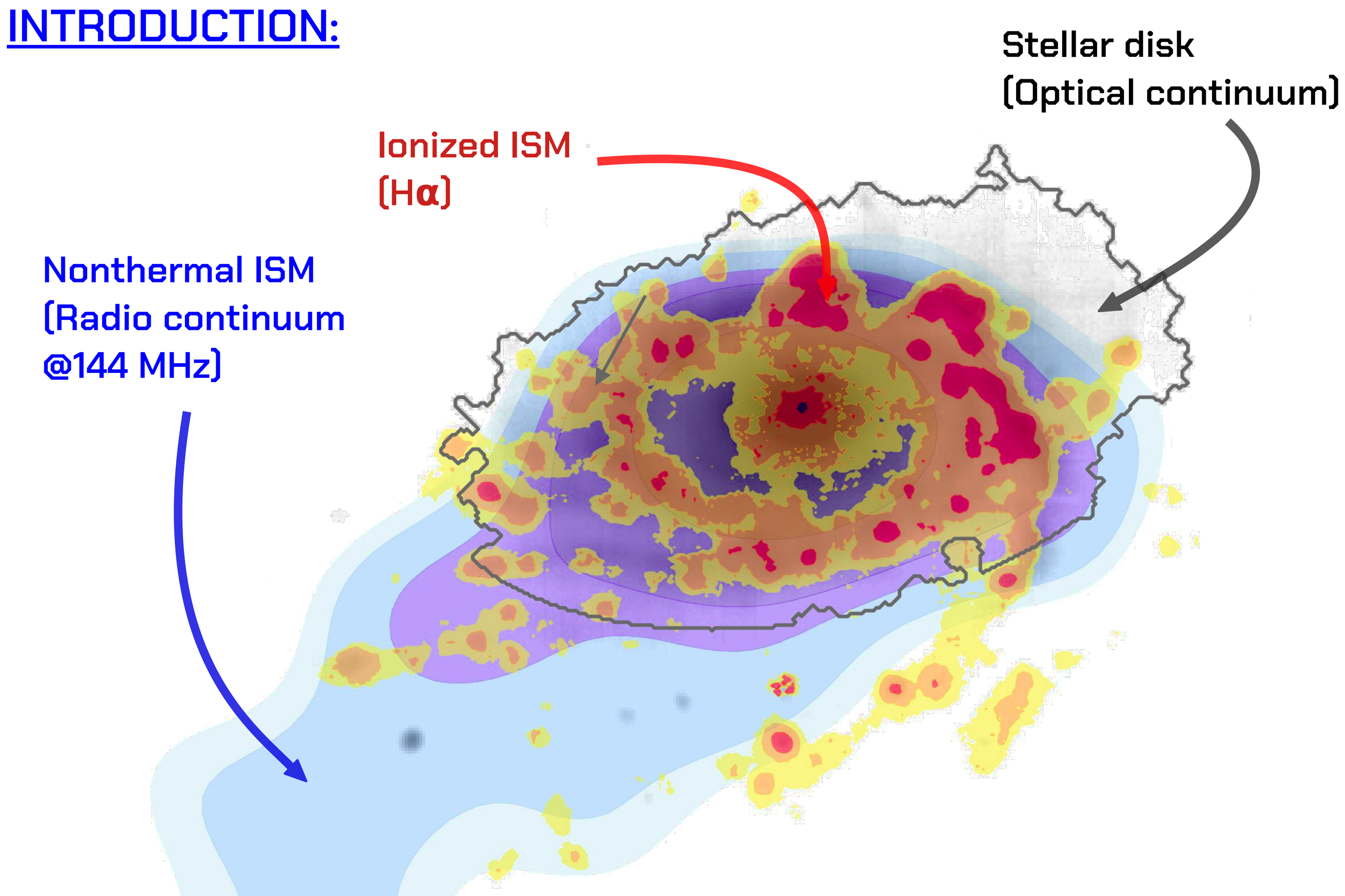
INTRODUCTION:

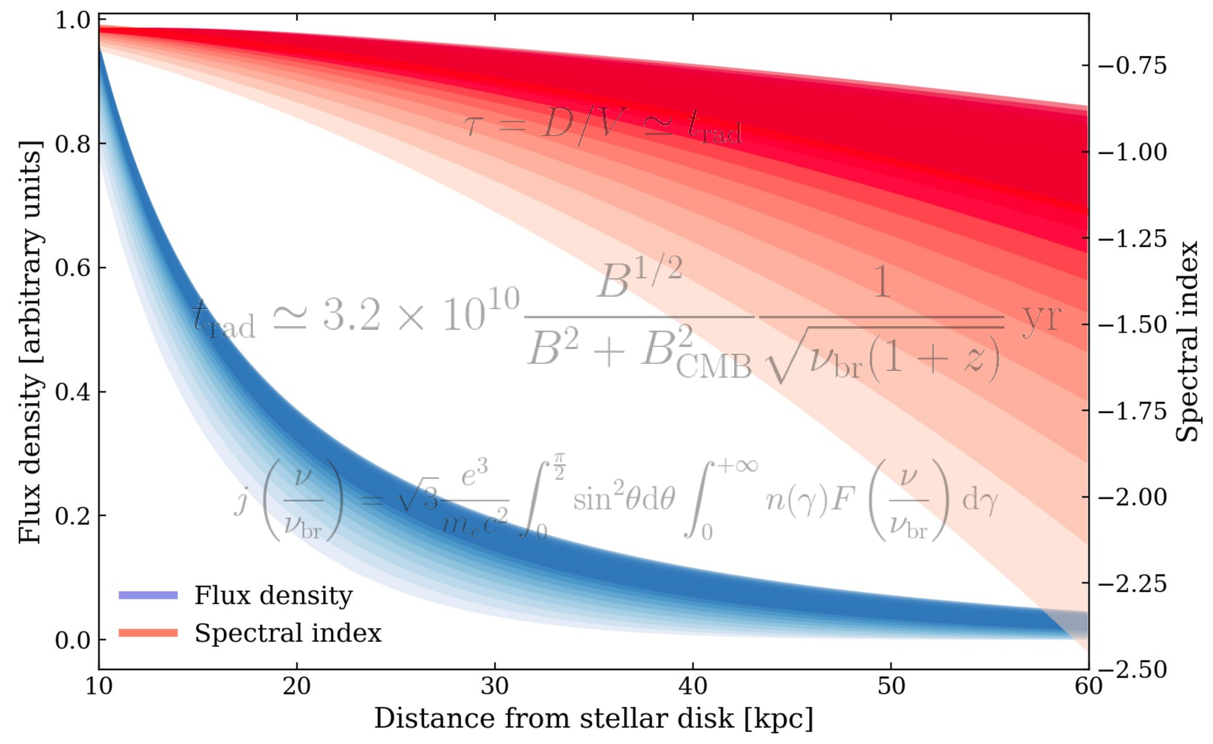


Composite MUSE+LOFAR image of spiral galaxy JW36 (Ignesti+2022)

Ram pressure stripping is the main driver of star formation quenching in clusters. The large-scale interstellar medium (ISM) outflows induced by ram pressure also contain relativistic electrons and magnetic field, producing radio continuum tails extending tens of kpc beyond the disk. These radio tails are now routinely observed with LOFAR. We propose to use the flux density gradient along these tails to constrain the outflow velocity.

METHOD:

We develop a semi-empirical model was based on the pure synchrotron cooling of a radio plasma moving along the stripping direction with a uniform velocity **V**.



Different profiles for flux density (blue) and spectral index (red) for increasing values of V (light to dark)

This model predicts:
- Monotonic decline of flux density and spectral index with the distance from the stellar disk
- Decline rate depends on the outflow velocity **V**
- Tail length decreases with the observed frequency ν as: $\frac{D_1}{D_2} = \sqrt{\frac{\nu_2}{\nu_1}}$

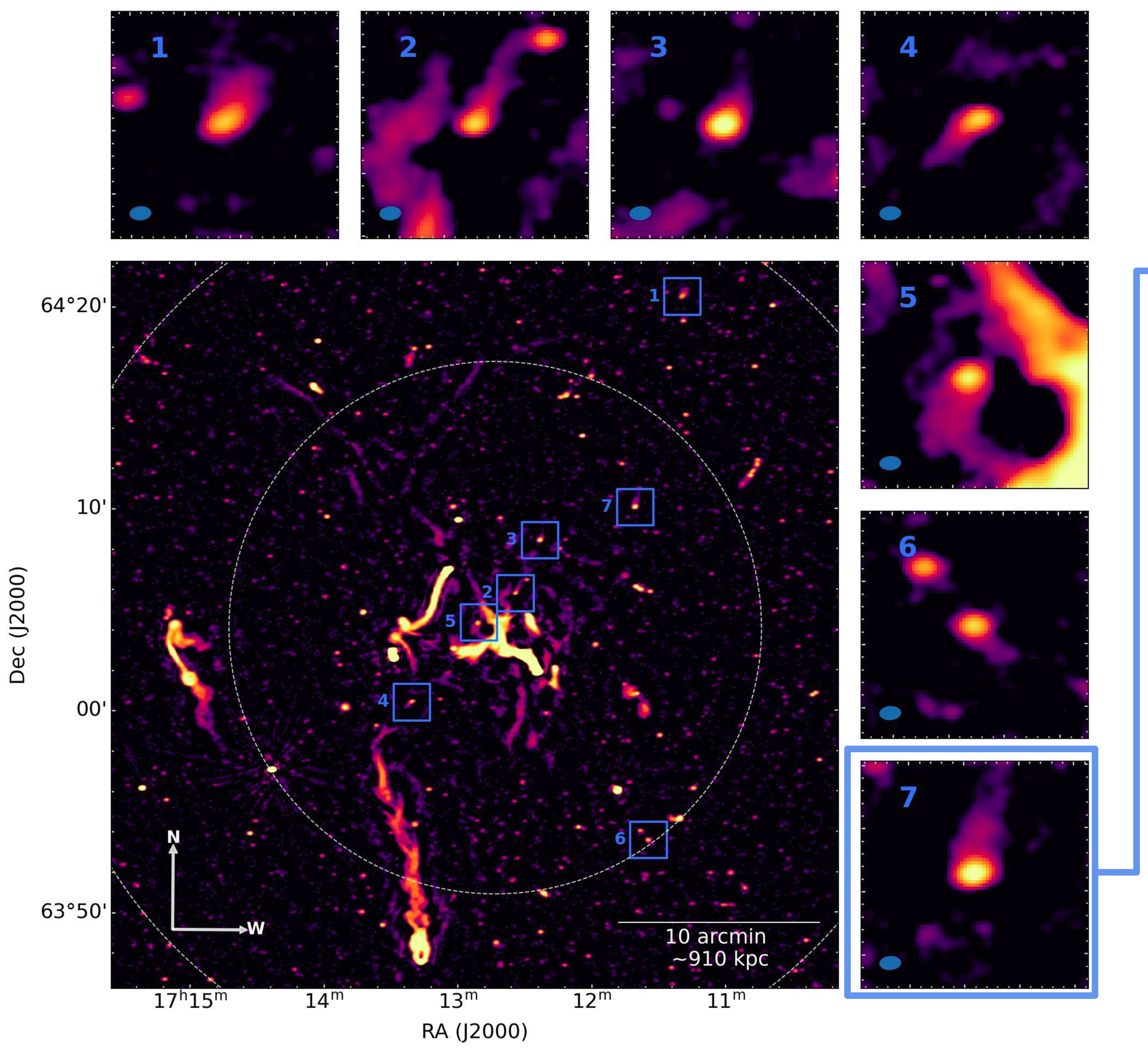
Main assumptions:
- Uniform magnetic field
- No injection/reacceleration of radio plasma outside of the disk

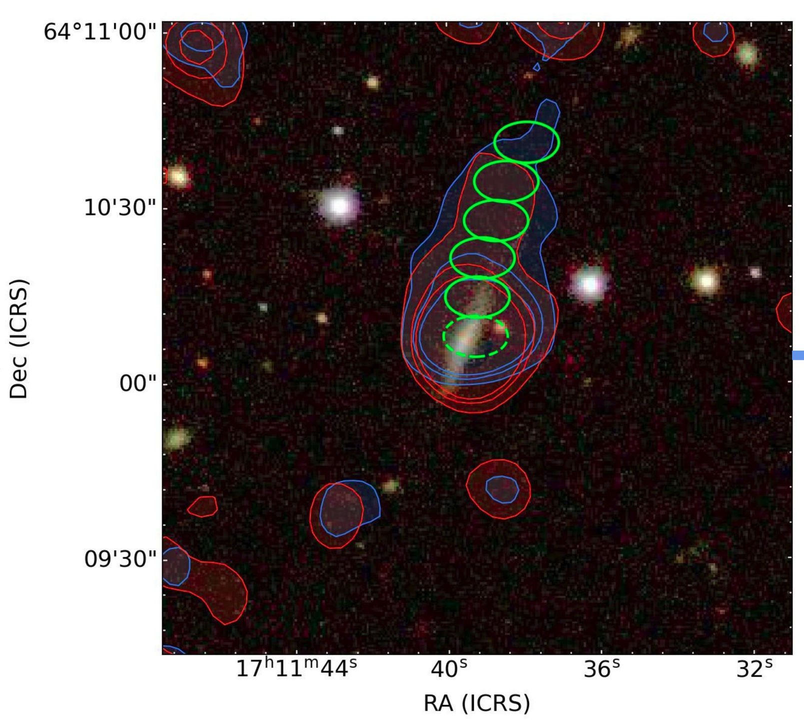
About the author:

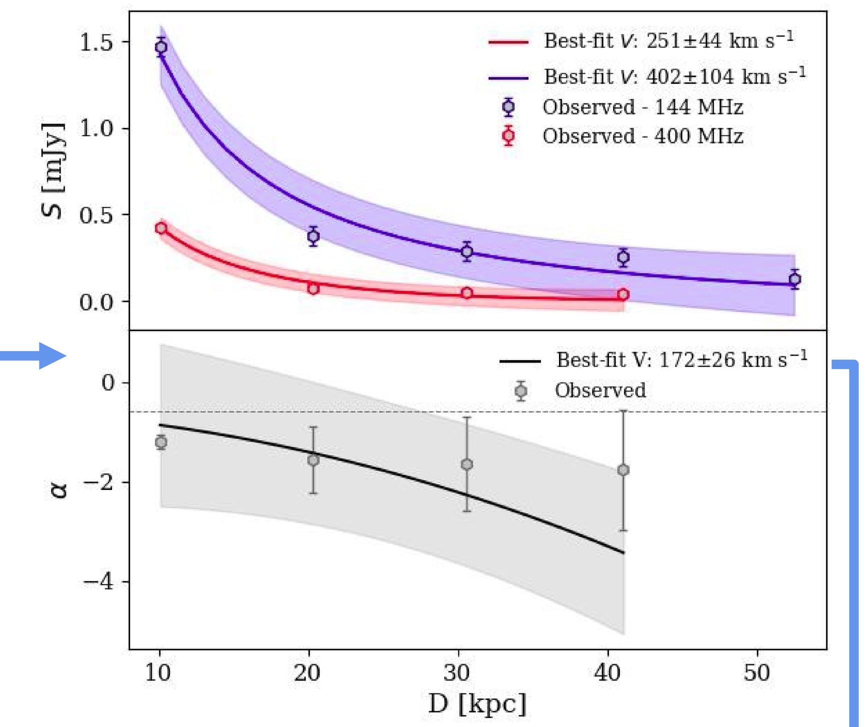
About this work:

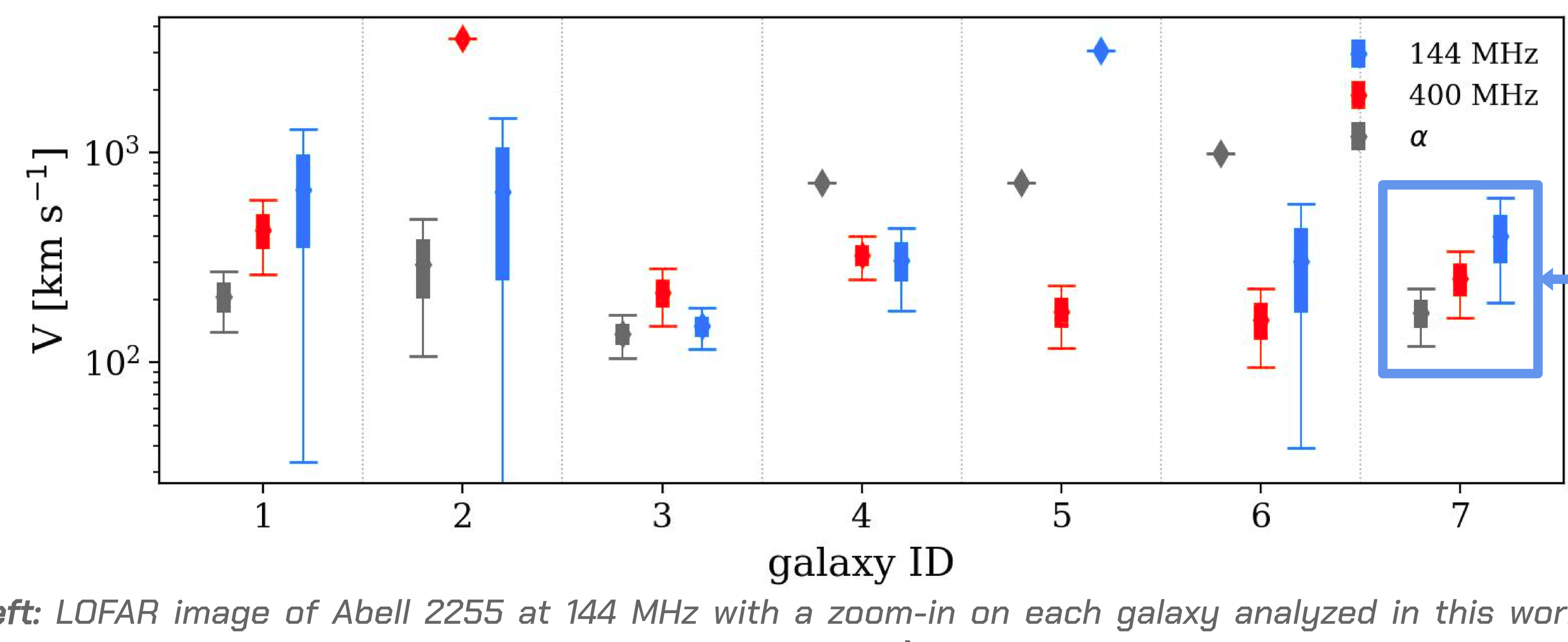
RESULTS:

We test the model by fitting the radio continuum tails of a sample of cluster spiral galaxies. We locate seven suitable candidates in the galaxy cluster Abell 2255, for which deep LOFAR and uGMRT observations at 144 and 400 MHz provided us unprecedented sensitivity to detect the faint, extraplanar emission. These galaxies show nonthermal radio tails which extends for 30-60 kpc from the stellar disk. For each galaxy, we fit the profiles of flux density, at 144 and 400 MHz, and spectral index to constrain the outflow velocity **V**.









Left: *LOFAR image of Abell 2255 at 144 MHz with a zoom-in on each galaxy analyzed in this work (see Botteon+2020 for details about the LOFAR data analysis);* ***Top-right:*** *SDSS image of galaxy #7 with the contours of the 144 (blue) and 400 MHz (red) emission, and the resulting observed (point) and best fitting profiles (line);* ***Bottom-right:*** *best-fitting outflow velocity for each galaxy (from Ignesti+2023a)*

DISCUSSION:

The observed radio-continuum tails constrian the outflow velocity in the range **V=160-600 km s^{-1}**. We can use this new piece of information to explore the ISM outflow properties and the physics of ram pressure stripping:

ISM outflow velocity [V=160-600 km s^{-1}]
- Stripped ISM clouds survival time-scale [$\tau > t_{rad,144} \sim (1\text{-}3) \times 10^8$ yr]
  - Magnetic field constraint [$t_{rad,144} < t_{adb}$ for B~4-7 μG]
  - Time-scales constraint
    - Turbulence development
    - Cloud crushing
- Proxy for plane-of-sky galactic velocity $V_{\parallel}$
  - 3D galactic velocity [$V_{3D} = (V_{\perp}^2 + V_{\parallel}^2)^{1/2}$=330-1029 km s^{-1}]
    - Exact ICM ram pressure [$P = \rho_{ICM} V_{3D}^2$ =(0.14-2.91)x 10^{-11} erg cm^{-3}]
  - Disk-wind angle $\Theta = \arccos(\hat{v} \cdot \hat{n})$

CONCLUSIONS:

LOFAR routinely observes spiral galaxies in clusters with radio continuum tails, which indicate that ram pressure is stripping the ISM from these galaxies, thereby quenching their star formation. We develop a semi-empirical model to constrain the velocity of the ISM outflows from the galaxies by studying the decrease in flux density with distance from the disk. For seven galaxies in Abell 2255 we measure **V=160-600 km s^{-1}** and similar results have been obtained for galaxies in the Coma cluster (Roberts+2024). The measurement of the outflow velocity can be used to further explore the physics of the ram pressure stripping.

Bibliography
- *Ignesti et al, 2020, The Astrophysical Journal, Volume 937, Issue 2, id.58, 16 pp.*
- *Ignesti et al., 2022, Astronomy & Astrophysics, Volume 675, id.A118, 14 pp*
- *Roberts et al., 2024, Astronomy & Astrophysics, Volume 683, id.A11, 58 pp.*
- *Botteon et al., 2020, The Astrophysical Journal, Volume 897, Issue 1, id.93*

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