Coma Surveys:
an Overview

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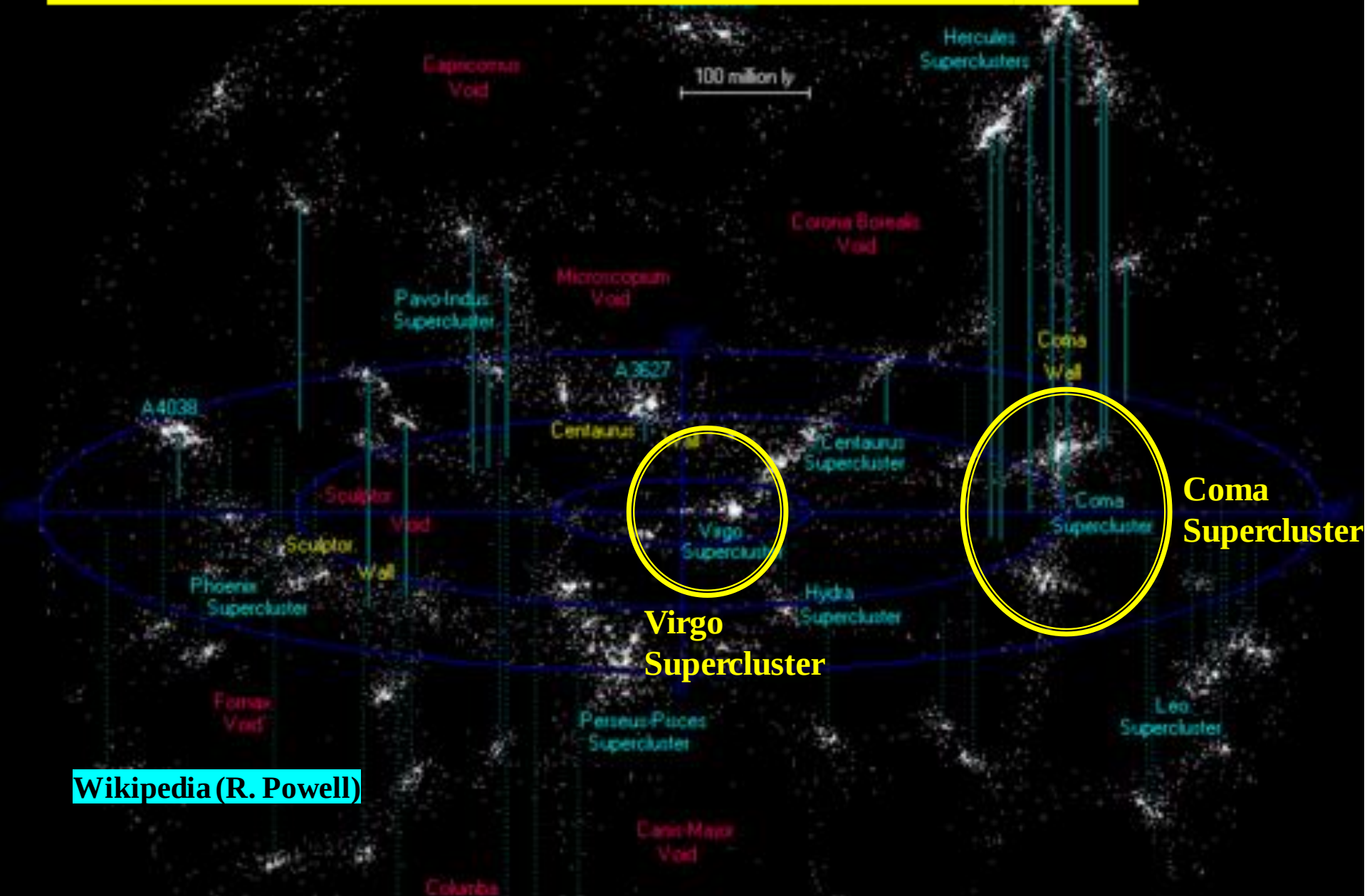
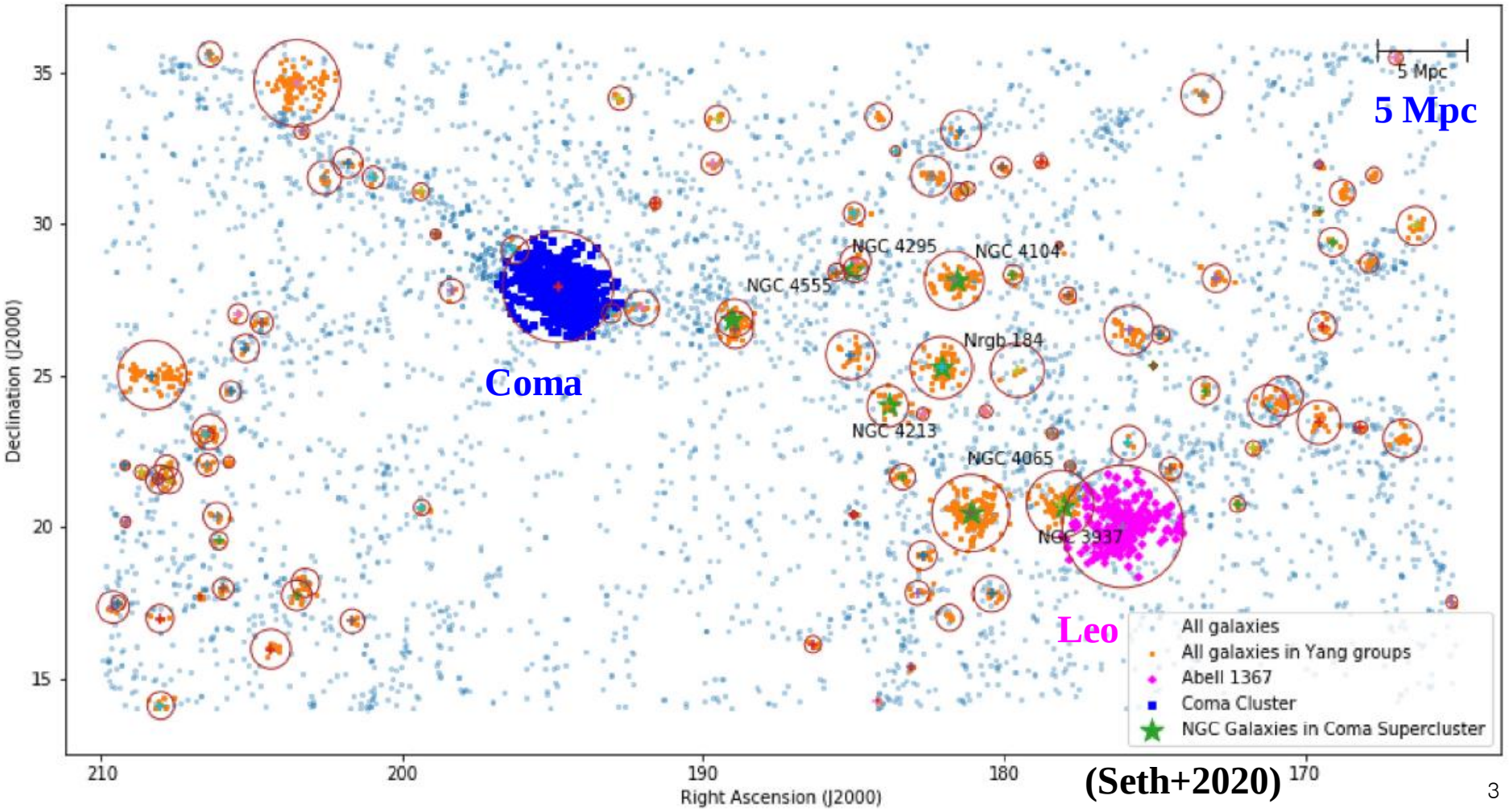
Large Scale Structures at d<150 Mpc



Wikipedia (R. Powell)

Coma supercluster (d=100 Mpc)

- Coma (A1656): a supermassive galaxy cluster dominated by ETGs!
- Leo (A1367): spiral-dominated galaxy cluster!
- Giant galaxy filaments



(Seth+2020)

Coma, Again

- A long history of Coma surveys
- Zwicky (1933) 'The redshift of extragalactic nebulae', suggested dark matter in Coma from galaxy motion

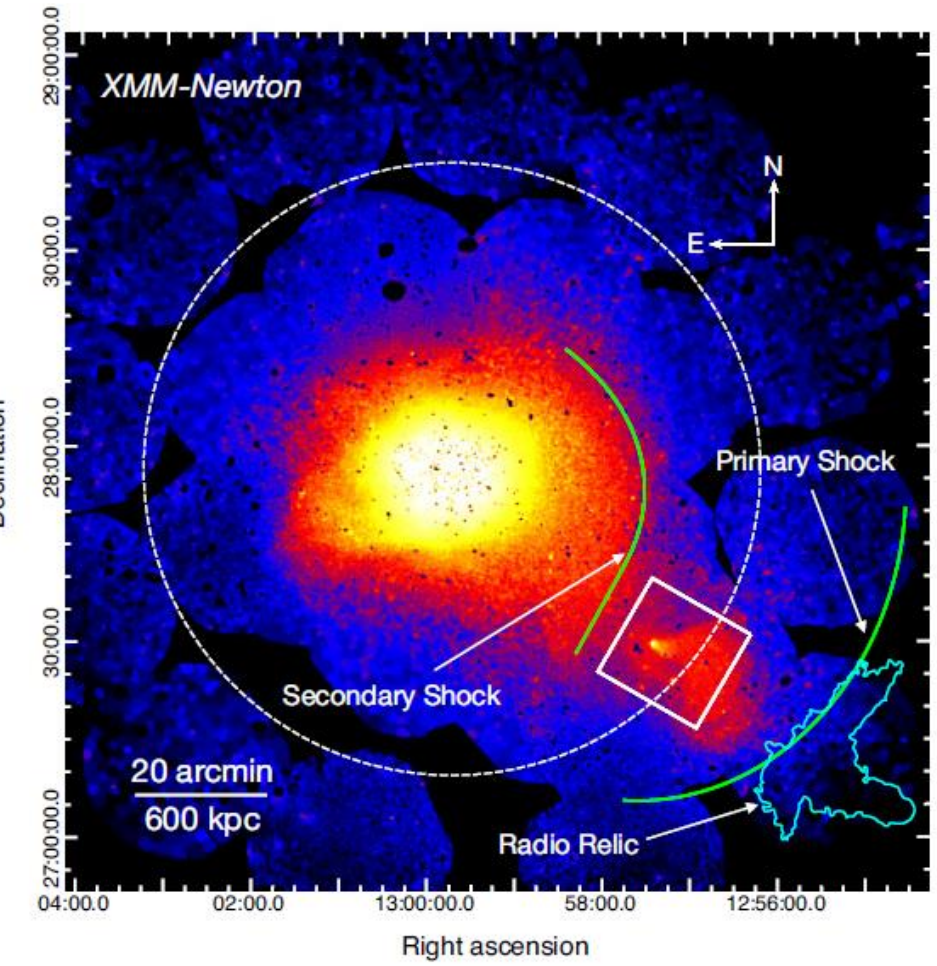


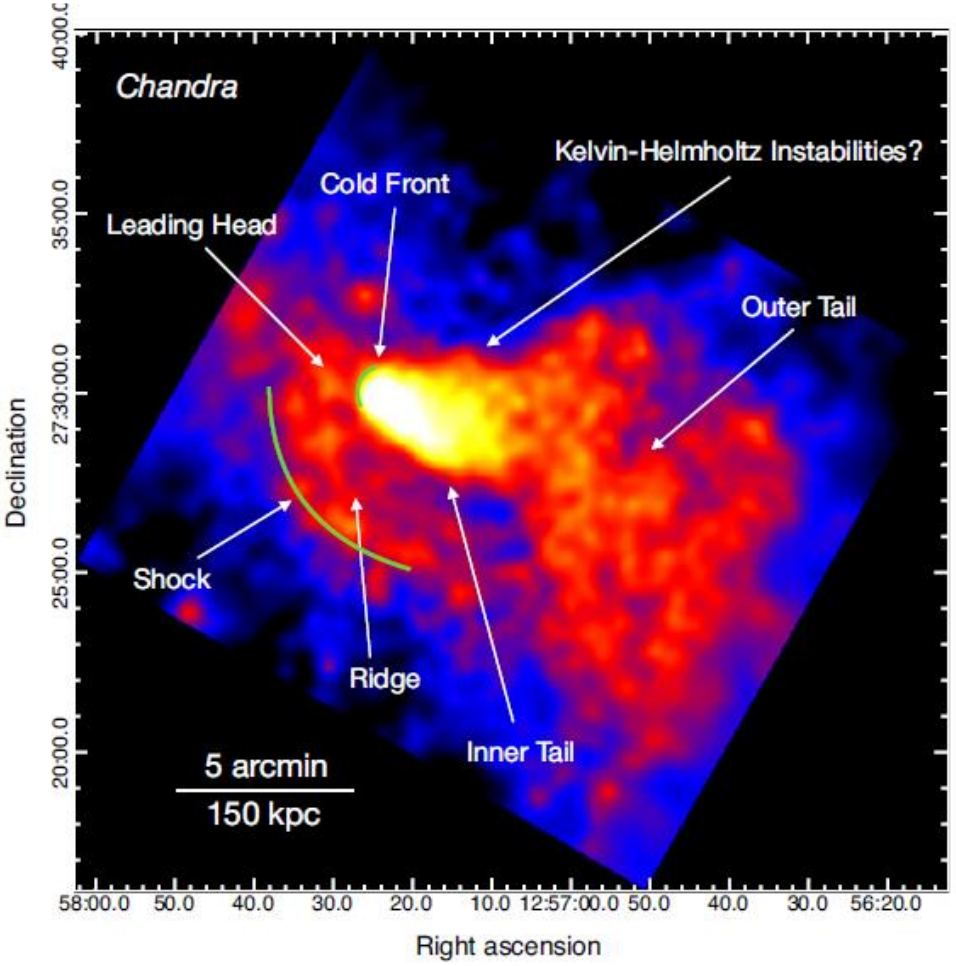
Recent Surveys of Coma: an overview

- X-ray surveys
- Radio (Continuum, HI) surveys
- Optical surveys
- Dark matter surveys with weak lensing
- SNU Coma surveys

X-ray Surveys: New Analysis of Old Data

- Mirakor+(2020,2023): XMM-Newton (Coma), main core + NGC 4839
- CXO (NGC 4839)- fine substructures in NGC 4839

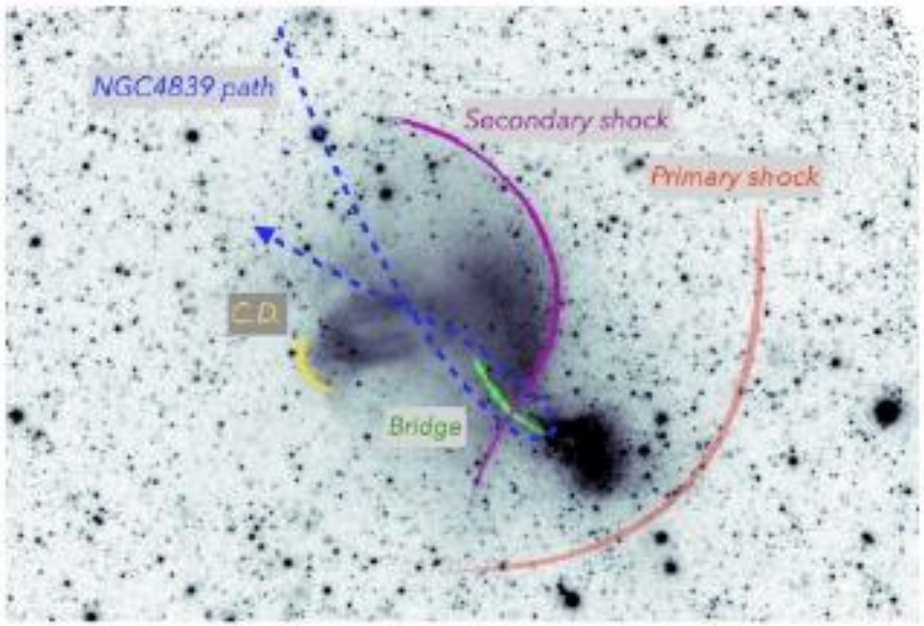




Mirakor+2023

X-ray Surveys: Recent

- Churazov+(2021,2023): eRosita/SRG
- Substructures after main core subtraction



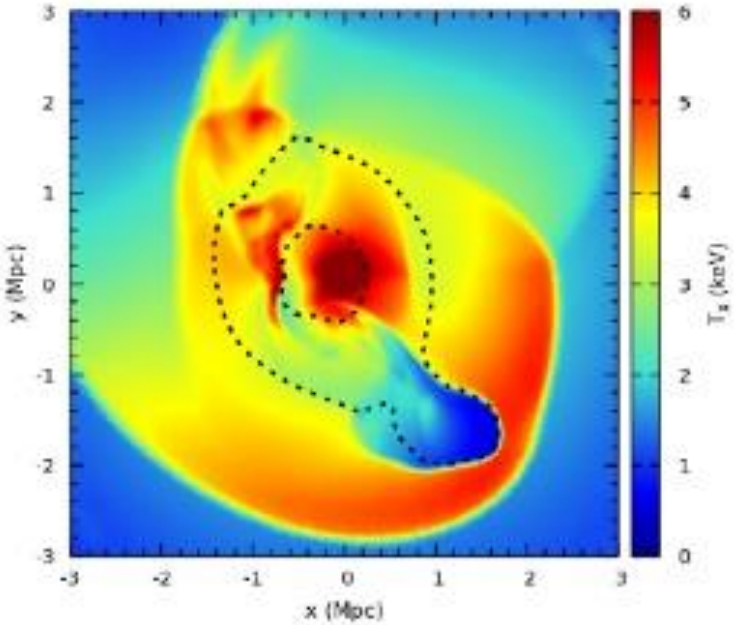


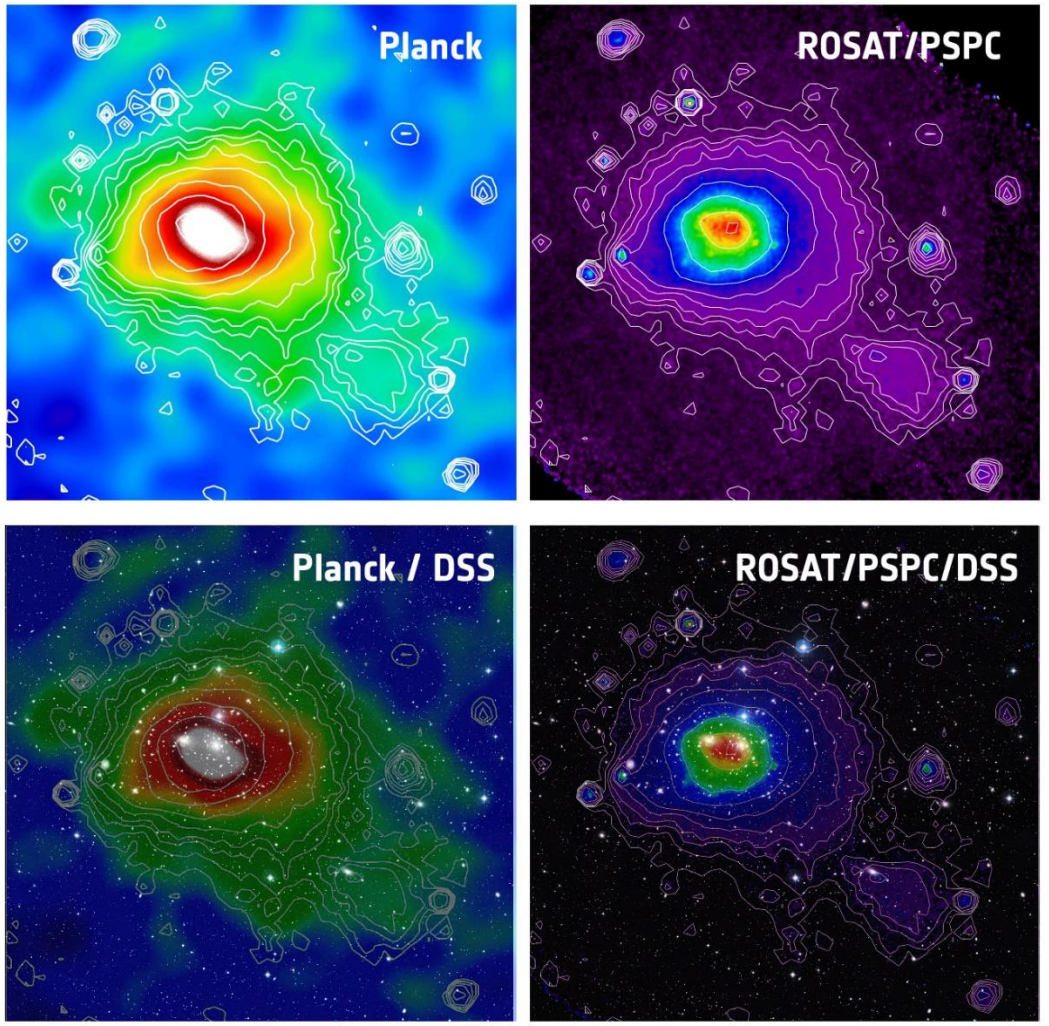
Fig. 11. Left: Flattened image of the Coma cluster field with labels schematically marking some of the features associated with the merger with the NGC4839 group. The blue dashed line is the suggested trajectory of the group (Lyskova et al. 2019; Sheardown et al. 2019; Zhang et al. 2019), which enters the Coma cluster from NE, and is currently close to the apocenter. The presumed position of the primary shock is shown with the red curve so that it goes through the radio relic SW from the NGC4839 group. The purple curve marks the secondary shock caused by settling the displaced ICM back to the hydrostatic equilibrium. This is the most salient feature directly seen in the image as the surface brightness edge. The green line shows the fain X-ray "bridge" connecting NGC4839 and the main cluster, which is a possible trace of the group through the Coma cluster. **Right:** Projected temperature map from simulations (Zhang et al. 2020b, see their fig.8 for the original version of the figure). The simulations qualitatively reproduce the morphology of the cold gas and the positions of the primary and secondary shocks. In the simulations, the inner region is a complex mixture of shocks and contact discontinuities. It is, therefore, not surprising that real observations have both types of structures.

Churazov+2021,2023

Planck/Sunyaev-Zelovich Surveys

- **Planck(2013): 100-857 GHz maps (300 GHz=1mm)**
  - Thermal SZ effect: comptonization parameter y $\propto$ P (=n_ekT) $\propto$ n_e
  - Deriving y maps with FWHM~10'
  - (XMM-Newton -> R_{500}=47'=1.3 Mpc)

$$y = \frac{\sigma_T}{m_e c^2} \int P(l) \mathrm{d}l,$$



NASA+2022

Sunyaev-Zelovich Surveys/Radio

- Planck y-map (contours)
- Radio 352 MHz (color map) (Brown+2011)

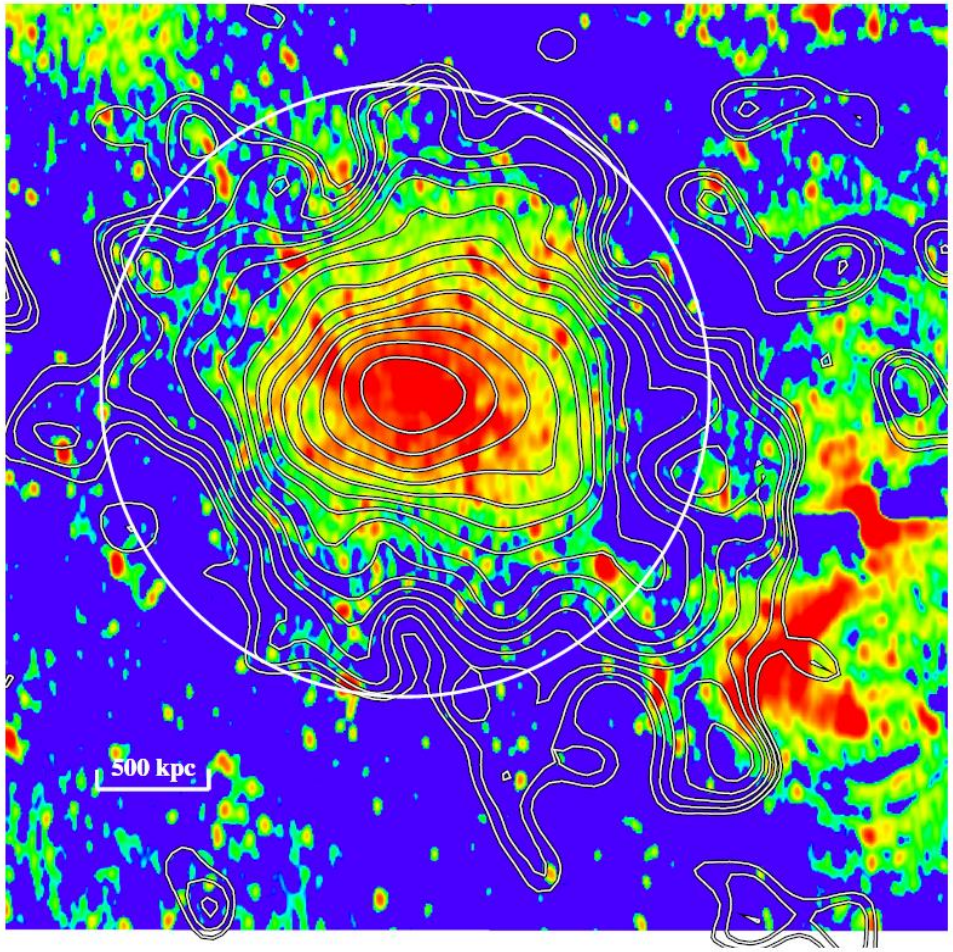
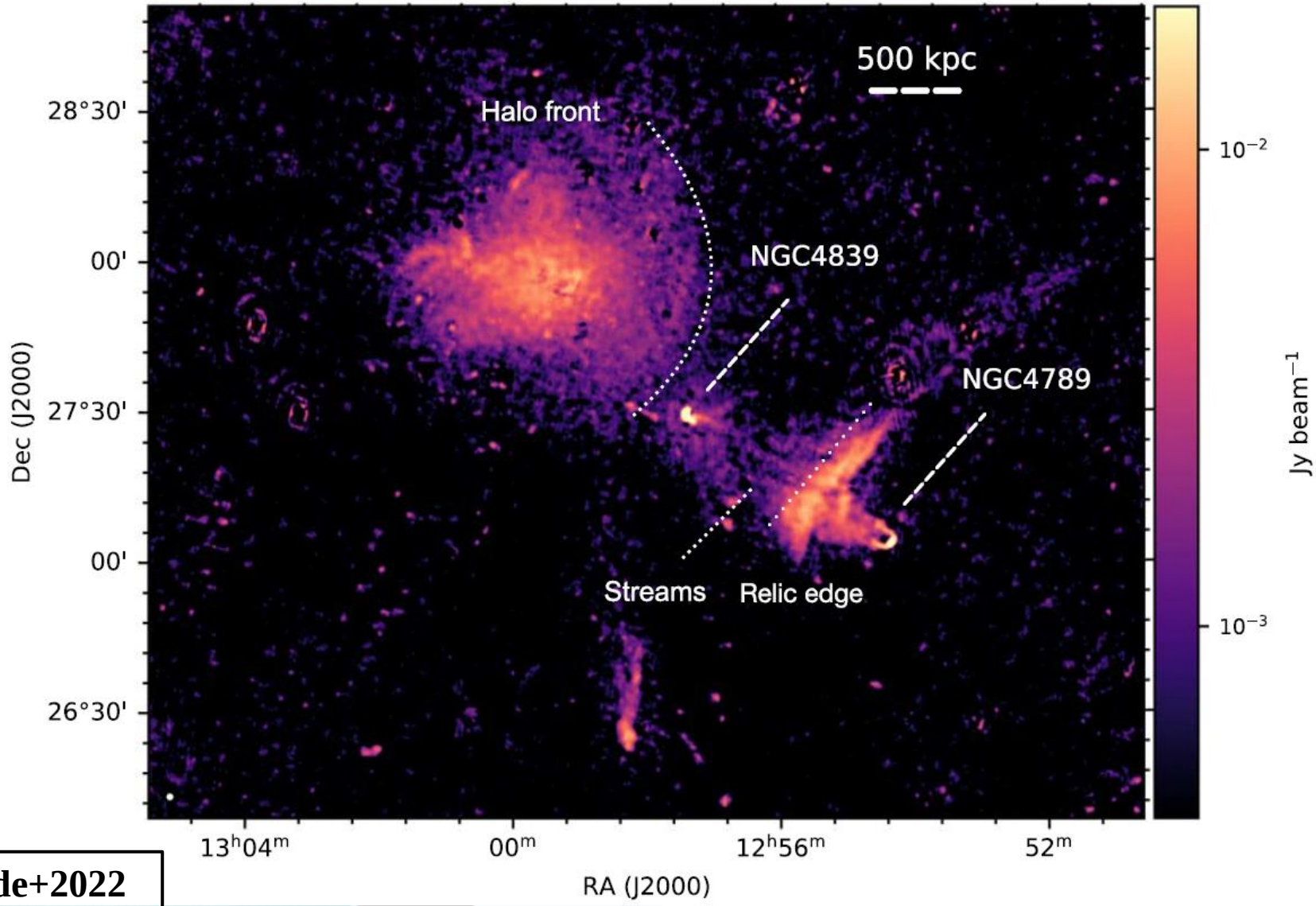


Fig. 8. Westerbork Synthesis Radio Telescope 352 MHz total intensity image of the Coma cluster from Fig. 3 of Brown & Rudnick (2011) overlaid with the y contour levels from Fig. 2. Most of the radio flux from compact sources has been subtracted; the resolution is 133 arcsec × 68 arcsec at −1.5 degrees (W of N). The white circle indicates R_{500}.

Planck (2013)

Radio Surveys

- Bonafede+(2021/2022): LOFAR 144 MHz
- Diffuse synchrotron radiation



Bonafede+2022

Radio Surveys

- **Bonafede+(2021,2022): LOFAR 144 MHz**

IR(WISE, white)-galaxies
+Radio(orange)



Figure 1. Composite IR-radio image of the Coma cluster field. In white the IR image in band 1, 2, and 3 of WISE (*Wide-field Infrared Survey Explorer*) are shown. The red-orange color scale shows the composite radio image of the diffuse emission at 1′ for the diffuse emission and of 20″ for the sources in the field.

Radio (144MHz)

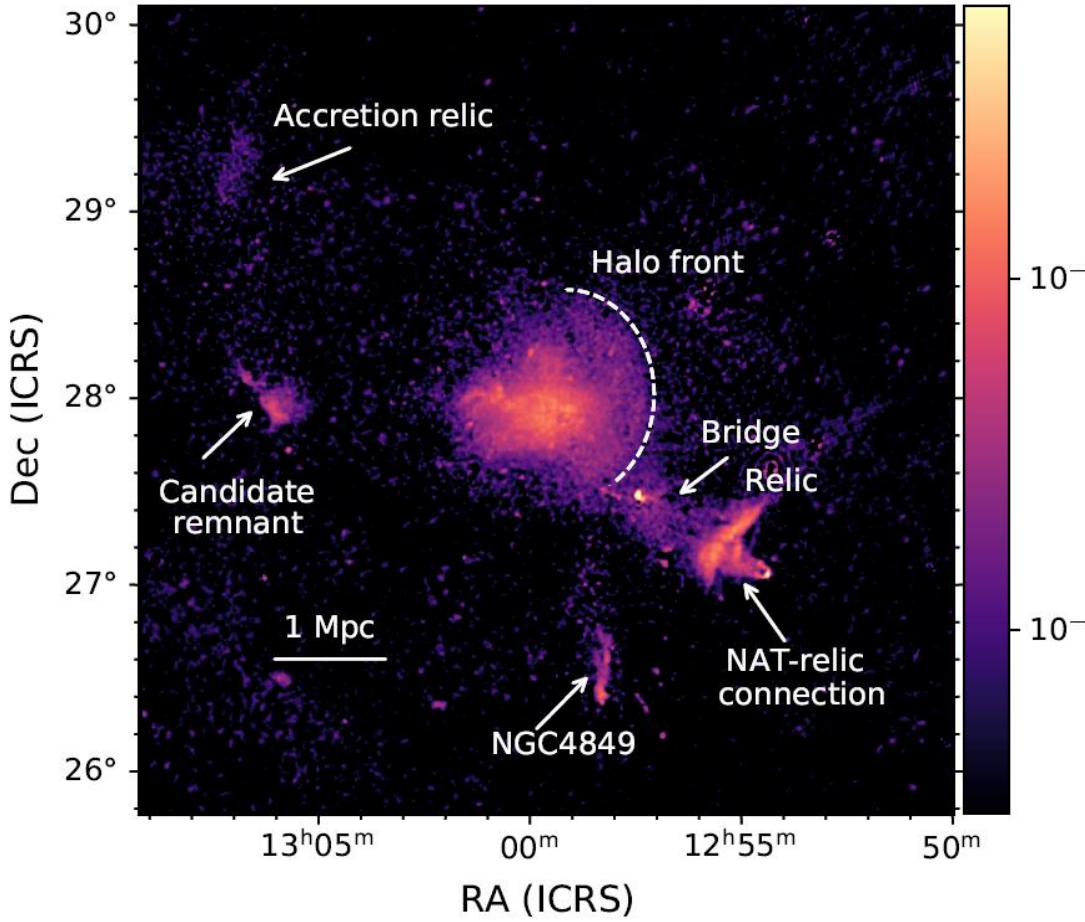
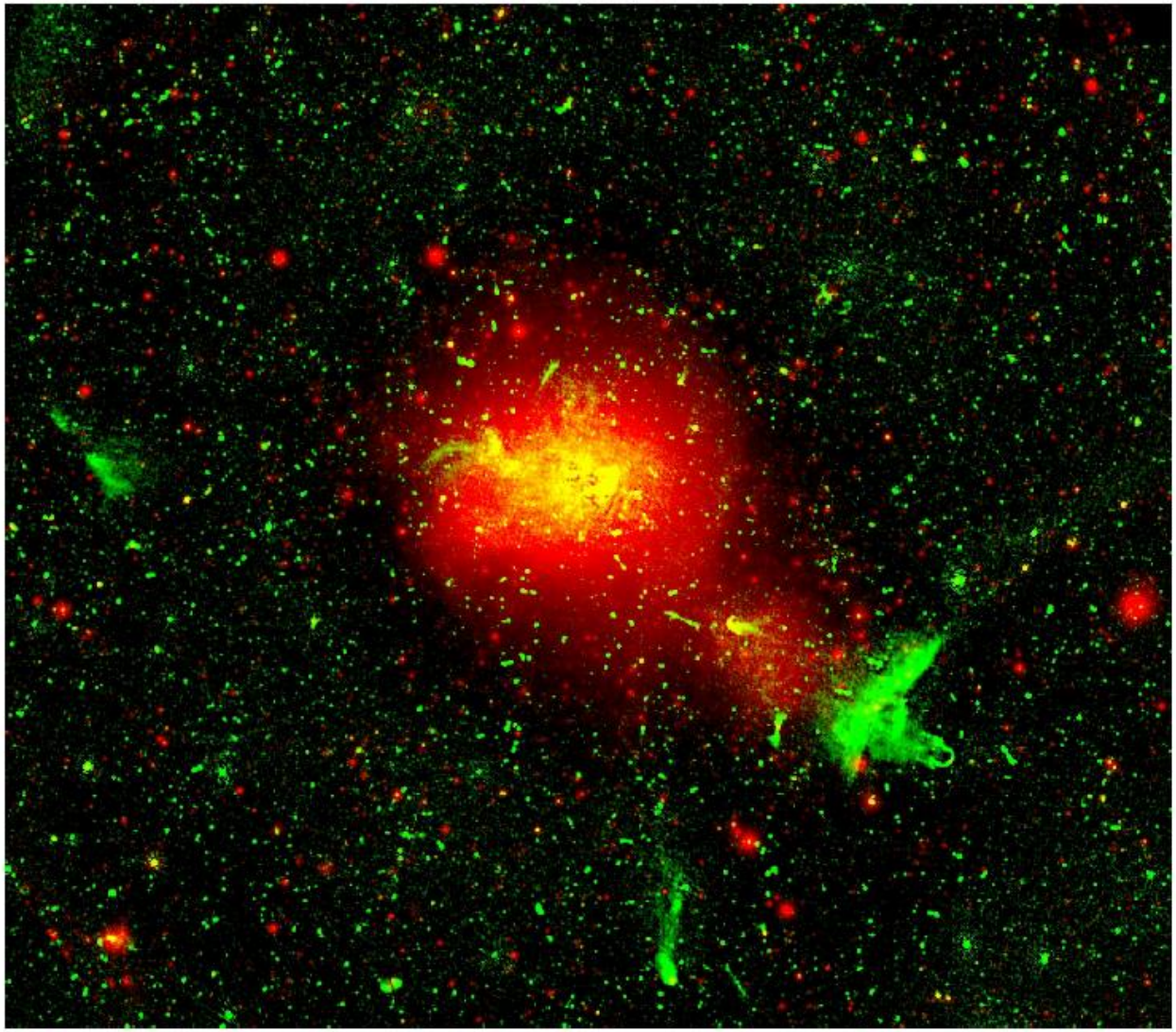


Figure 2. LOFAR emission of the Coma field at the resolution of 1 arcmin. The candidate accretion relic, halo fr
relic, and NAT-relic connection are labelled.

Bonafede+2022

Xray/Radio Surveys

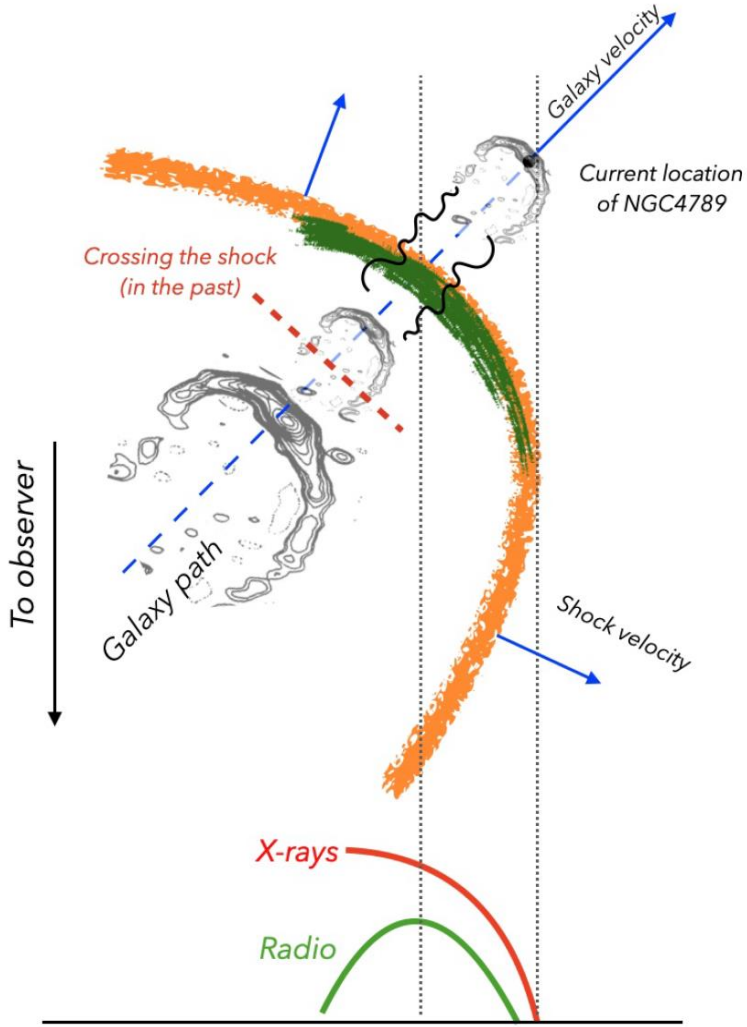
- X-ray (eRosita) and Radio (LOFAR)
- NGC 4839, NGC 4879



Churazov+2023

X-ray/Radio Surveys

- X-ray(eRosita) and Radio(LOFAR)
- NGC 4879: A pure merger shock scenario



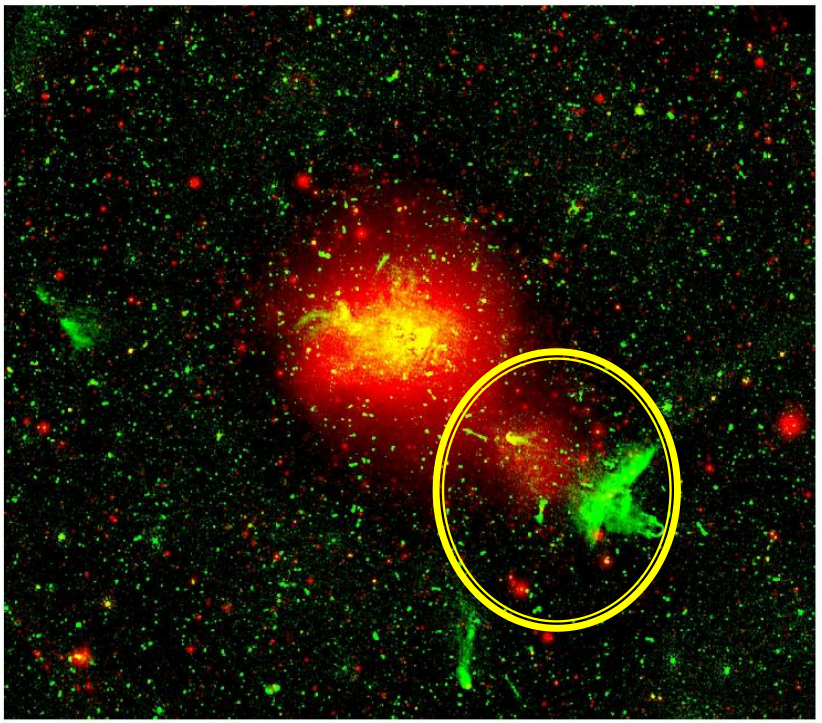


Fig. 10. NGC 4789 (sketch, top view) in a pure merger shock scenario. The geometry is reminiscent of the one in Ensslin et al. (1998, see their Fig. 2), although the origin of the sketched configuration is different. Here, NGC 4789 moves faster than the shock and eventually overtakes it. The ICM along the path of NGC 4789 can be enriched by relativistic particles. The shock crossing happened in the past. We can hope to identify some changes in radio properties (e.g., the width of the enriched region) somewhere downstream from the current position of the shock (red dashed line). The radio emission at the shock reflects a more recent history of the system. As demonstrated by the numerical simulations of Nolting et al. (2019), when the galaxy moves away from the shock, the material along bent jets moves towards the shock and can even cross it. This is depicted by the black wave curves.

Churazov+2023

Optical Surveys: ICL

- Jimenez-Teja+2019: J-PLUS
- Many since Zwicky(1957): ICL fraction of cluster light=20-50%

Jimenez-Teja+2019

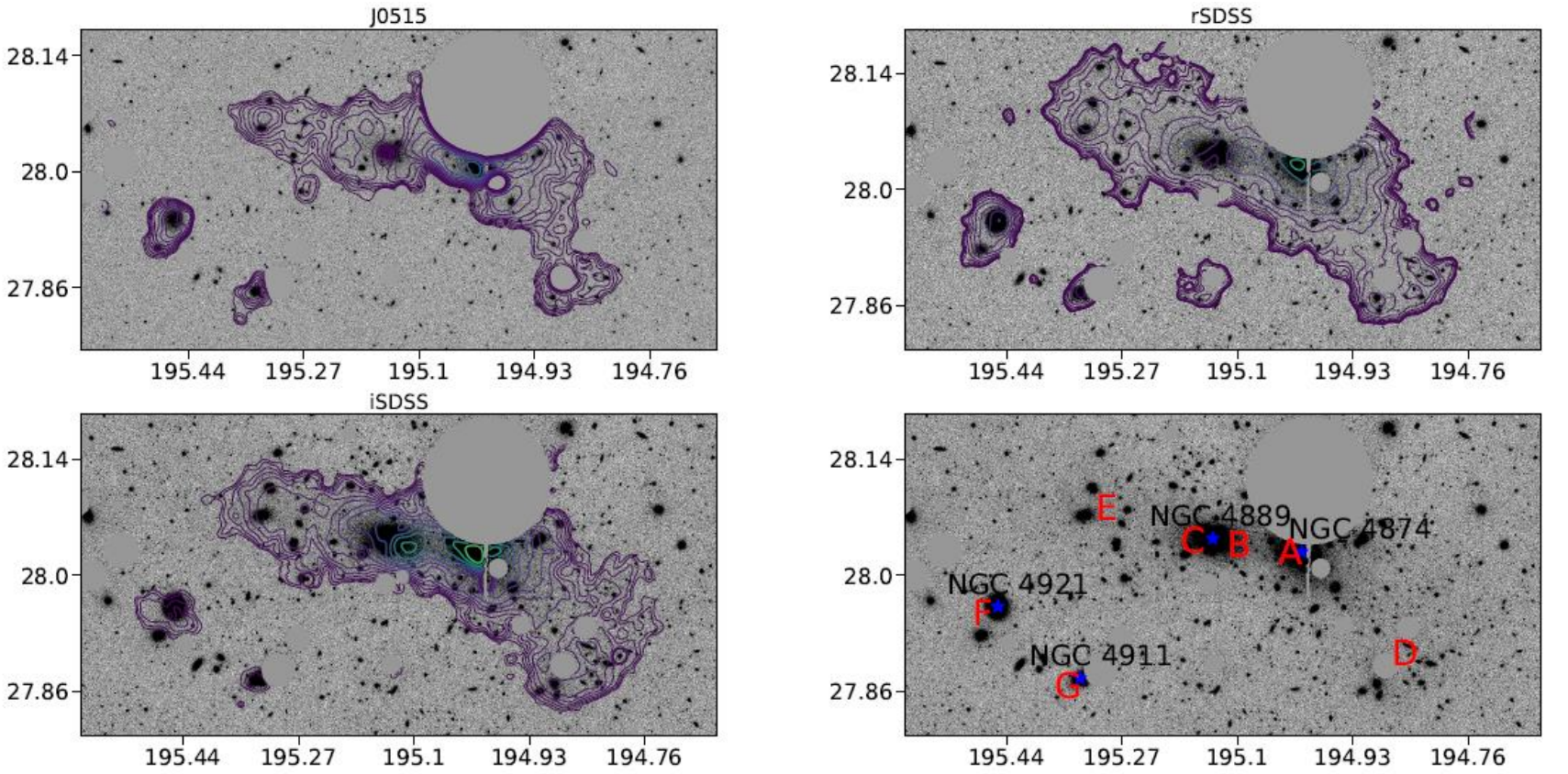
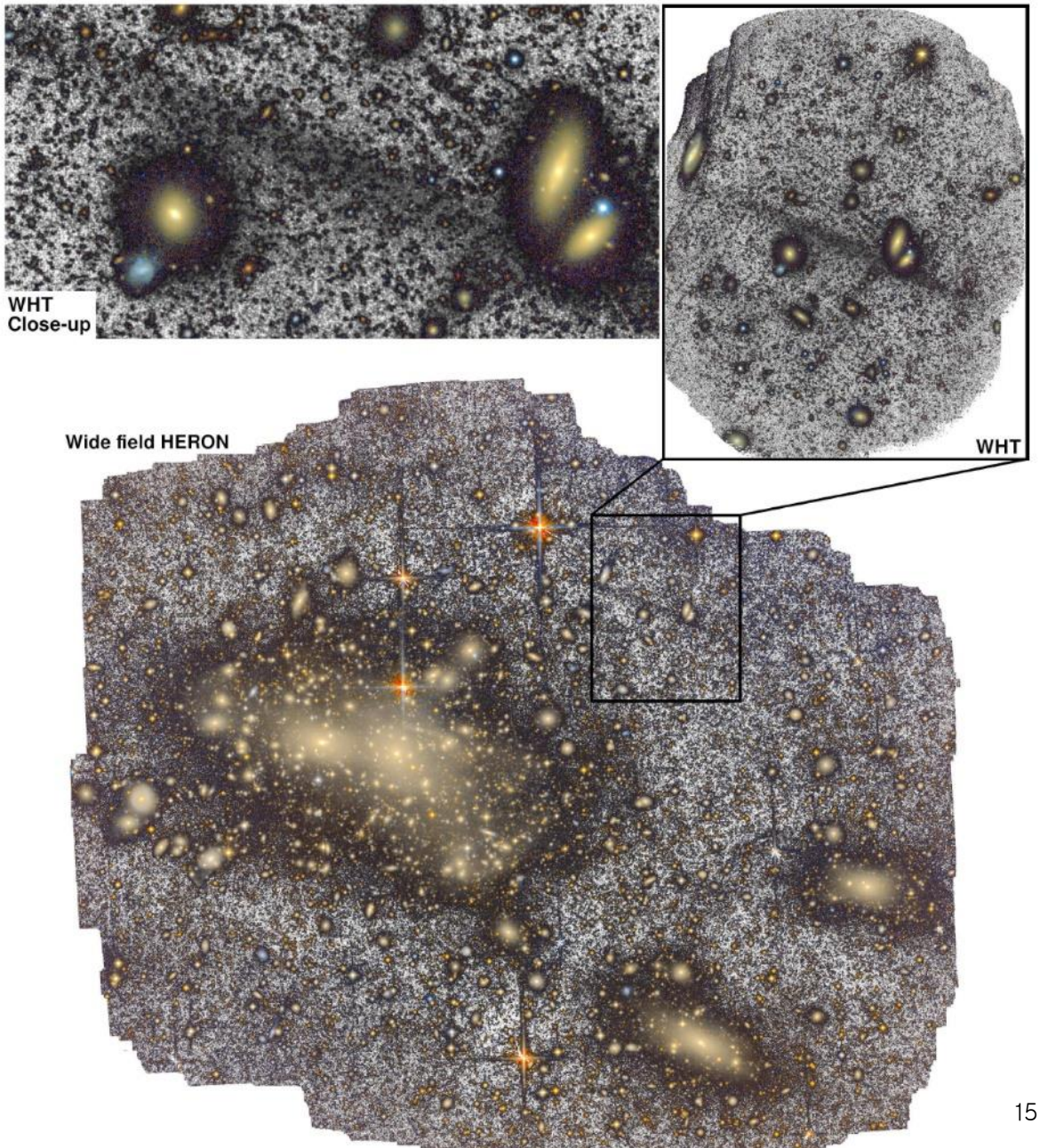


Fig. 3. Contour maps of the ICL in the central region of the Coma clusters superimposed on the original data, and guiding image to identify the ICL substructure (*bottom right panel*). Original images have the stars and spikes masked out. We have smoothed the surface distribution of the ICL with a Gaussian of 17.6 arcsec typical deviation to draw the contours. Masked-out pixels were not considered to estimate the ICL fraction or calculate the contours. The guiding image at the bottom right shows the original image in the *i* band with the main galaxies (blue stars) and ICL clumps (red letters) labeled. North is up and east is to the left.

Optical Surveys: ICL

Román, J., et al.: A&A 679, A157 (2023)

- Roman+(2023)
- HERON (with 70cm and 4.2m): A giant linear system of ICL in Coma with L~0.5Mpc



Roman+2023

Optical Surveys: ICL

- Roman+(2023)
- TNG50: a similar giant stream is produced when a dwarf (logM/Mo=8-9) fell into the massive group.

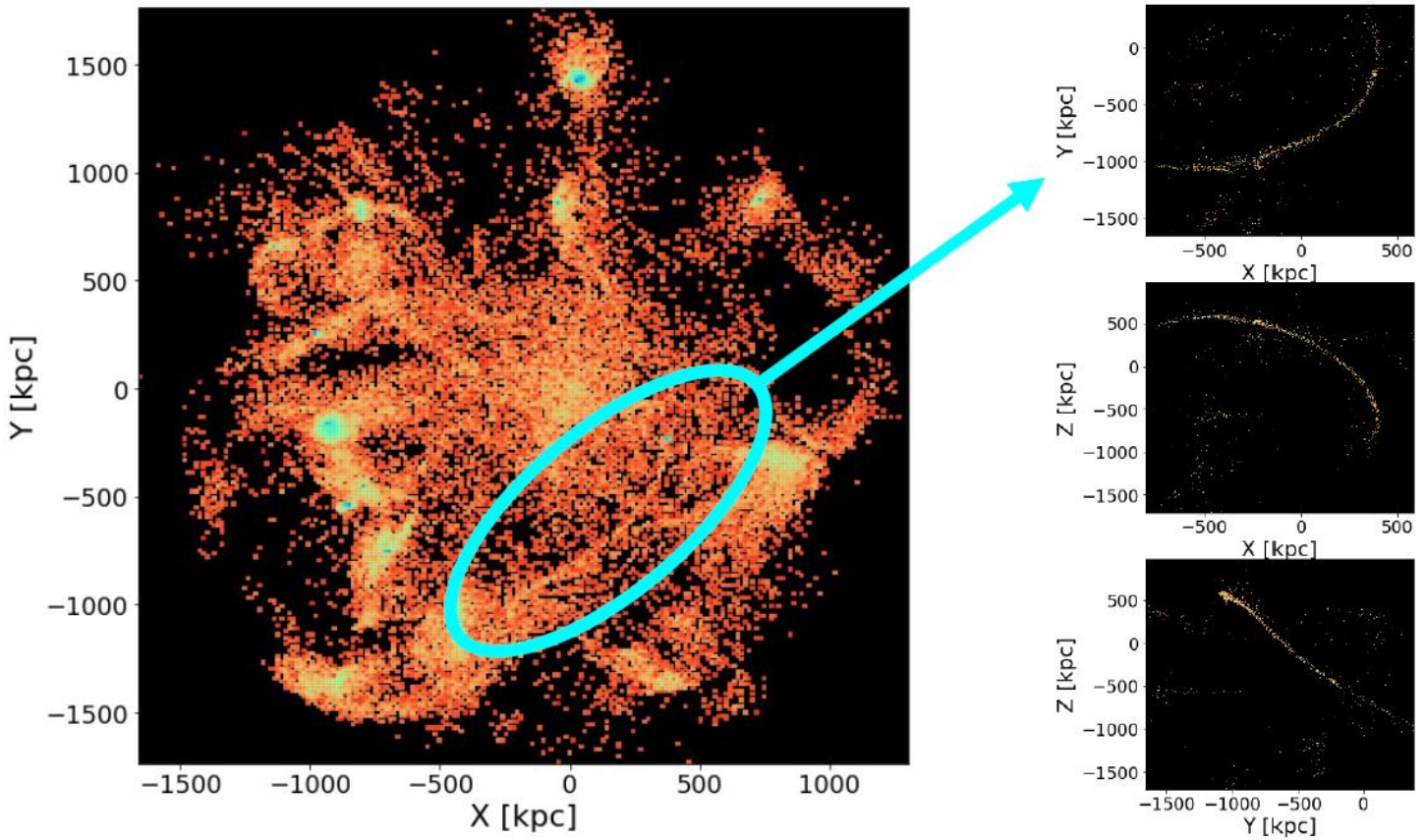


Fig. 8. Projected map of stellar remnants from the identified dwarf progenitors with $M_{\star,\mathrm{max}} = 10^{8-9}\,M_{\odot}$ that fell into the most massive group simulated by the TNG50 simulation according to our selection criteria (see text). The map is color-coded by arbitrary surface brightness units, with a resolution of 30 arcsec. The most prominent candidate for a Coma stream analog is highlighted, and the right panels show 2D projected maps of only this remnant with a resolution of 1 arcsec (comparable to observational resolution).

Roman+2023

Optical Surveys: Spectroscopy

- **Healy+2021: galaxy groups**

Healy+2021

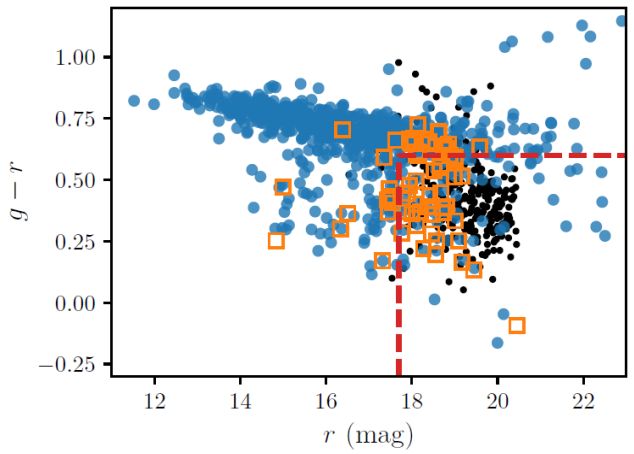


Fig. 1. Colour–magnitude diagram for the Coma cluster. The blue points represent the galaxies in the catalogue of literature redshifts. The black dots represent all galaxies targeted with Hydra, but whose redshifts place them in the foreground or background. The orange open squares represent the galaxies targeted with Hydra with redshifts that place them inside the cluster. Galaxies with $r > 17.7$ mag and $g - r < 0.6$ were prioritised as indicated by the dashed red lines.

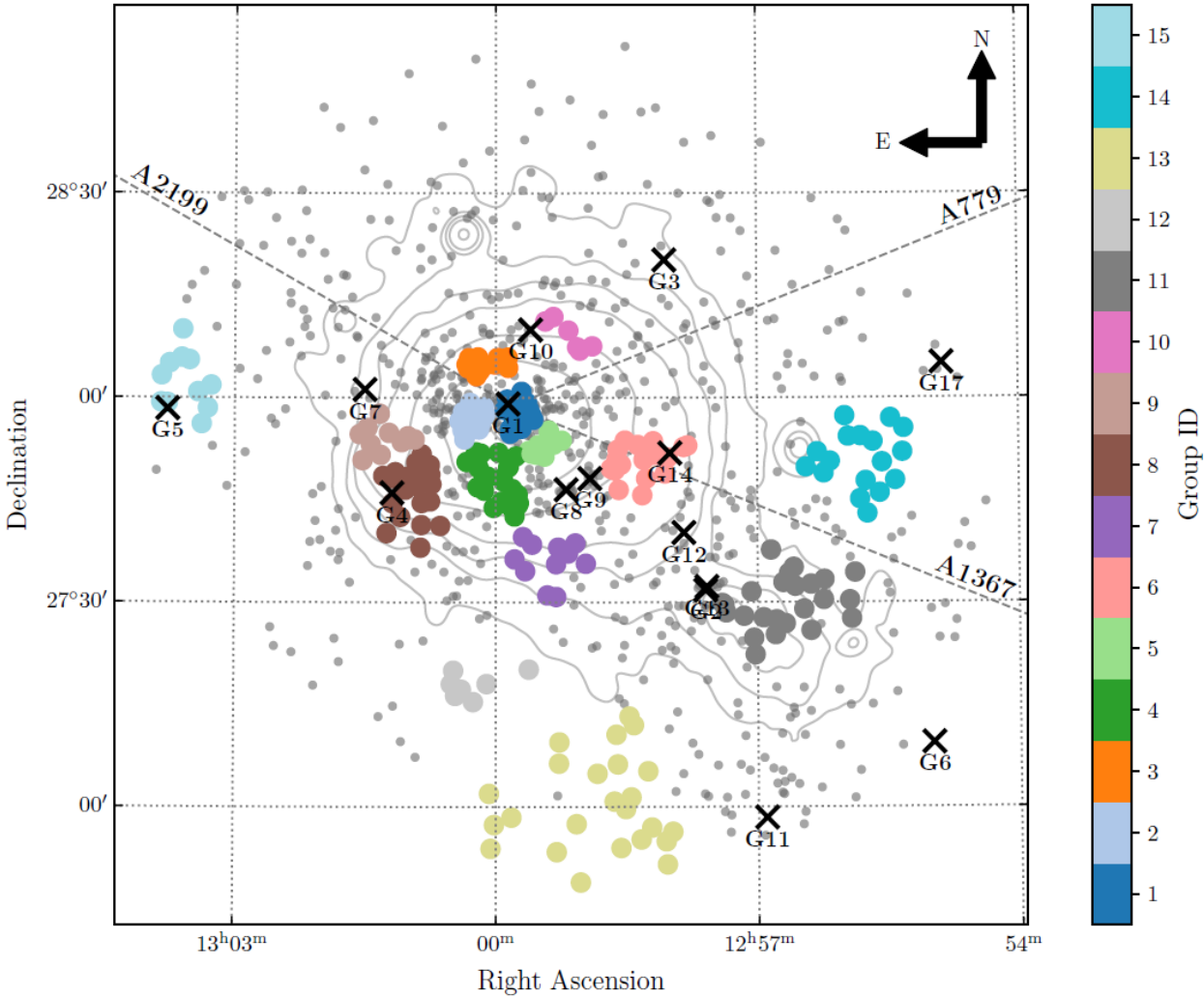
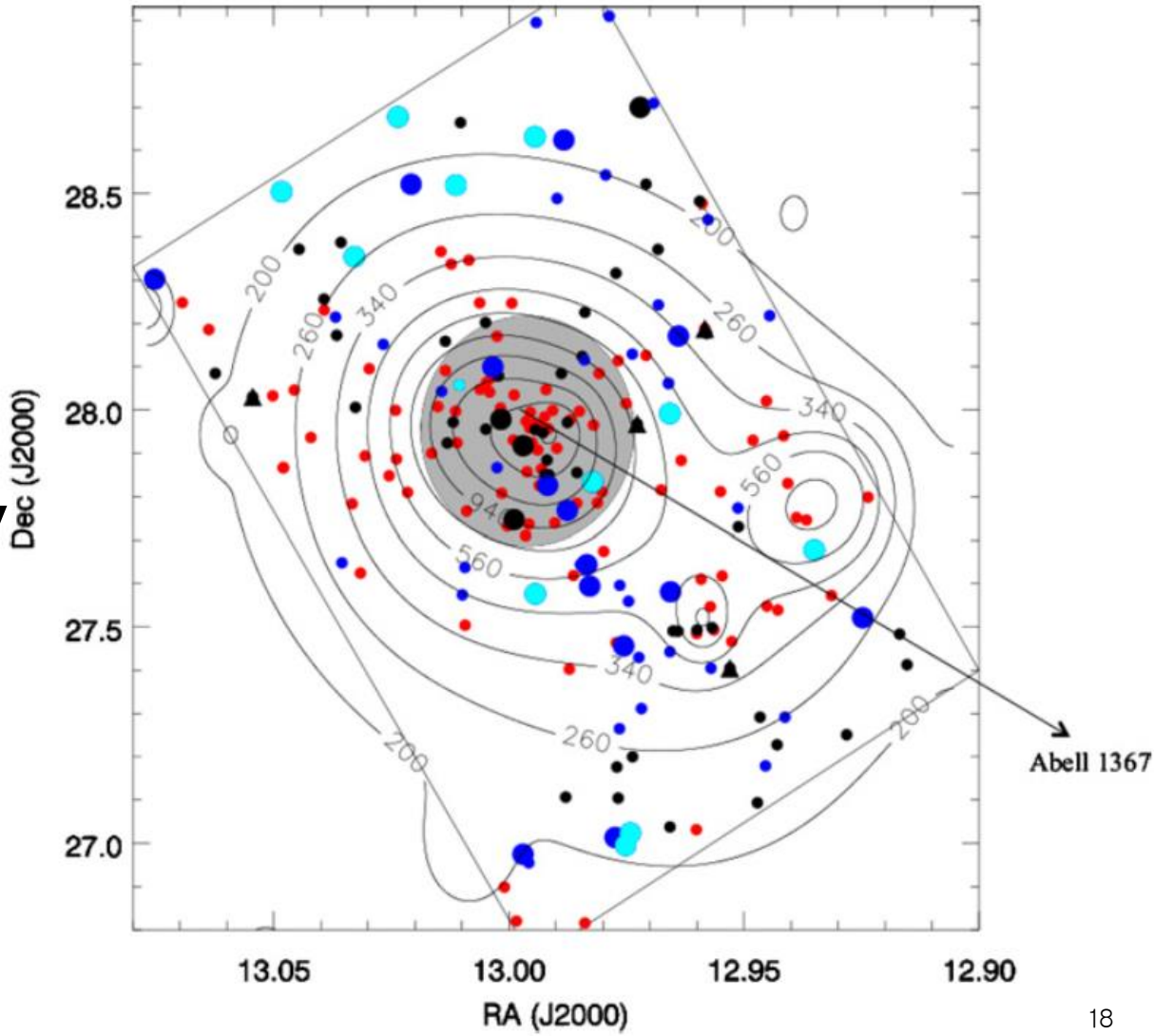


Fig. 11. Substructure in the WCS footprint. The 15 identified groups are shown in different colours. The background grey contours r
X-ray emission measured by ROSAT in 0.4–2.4 keV. The dashed grey lines indicate the direction to nearby clusters connected to
groups identified by Adami et al. (2005) are labelled and denoted by black crosses.

Optical Surveys: SFGs+ (SDSS/SST)

- Edwards+2012
- Starbursts,
- SF galaxies,
- Low SF galaxies,
- Passive galaxies
- Environmental effects on galaxy morphology!



Edwards+2012

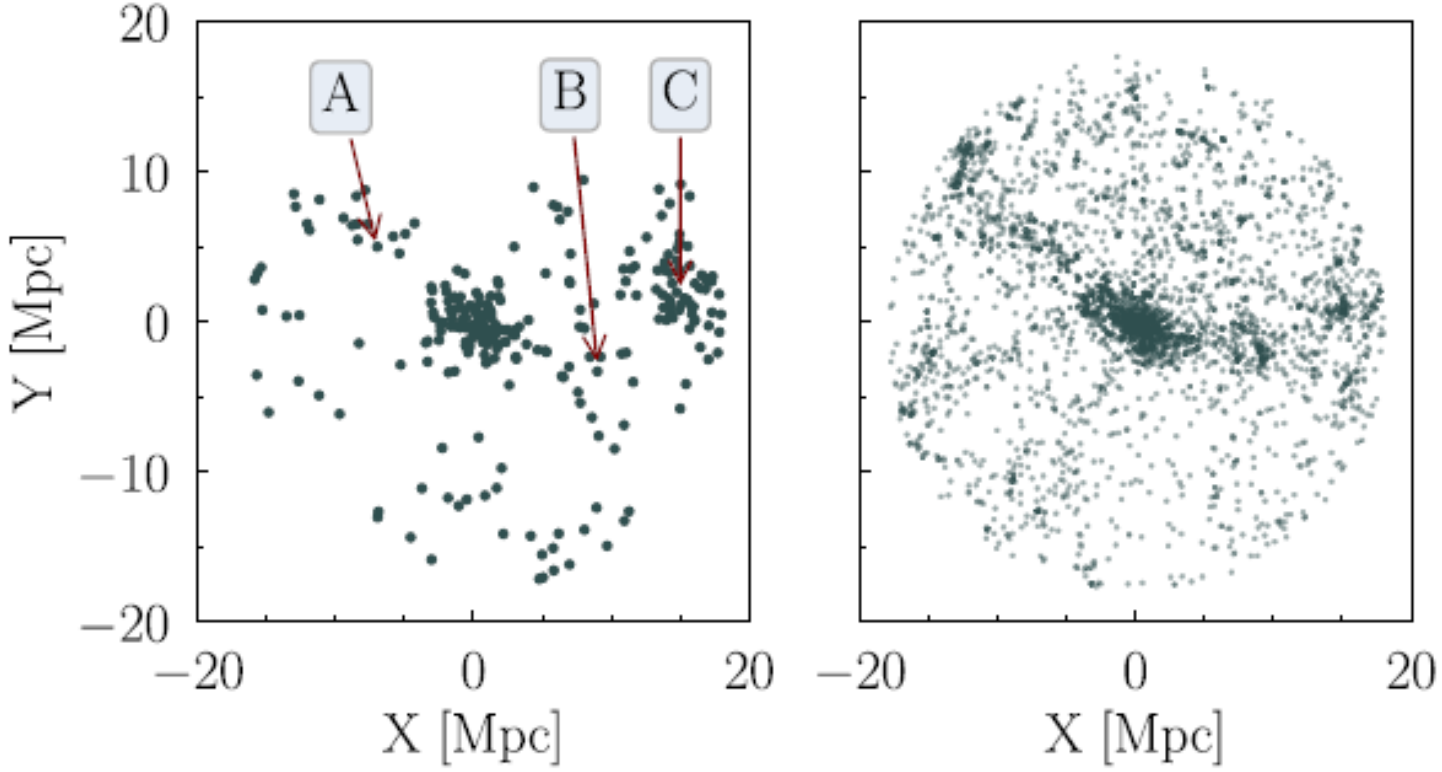
Optical Surveys: UDGs/LSBs

- Zaritsky+2021: DESI UDG + SDSS galaxies

Zaritsky+2021

DESI UDGs

SDSS galaxies



11. Projected distribution of UDGs (left panel) and SDSS galaxies (right panel) on the sky centered on the Coma Cluster. We plot in physical units assu
galaxies are at the Coma distance to provide guidance on the scale of the visible structures, which are at the distance of Coma. The UDGs represent our

Optical Surveys: UDGs/LSBs

- **Bautista+2023: Subaru/HSC gr for Coma**

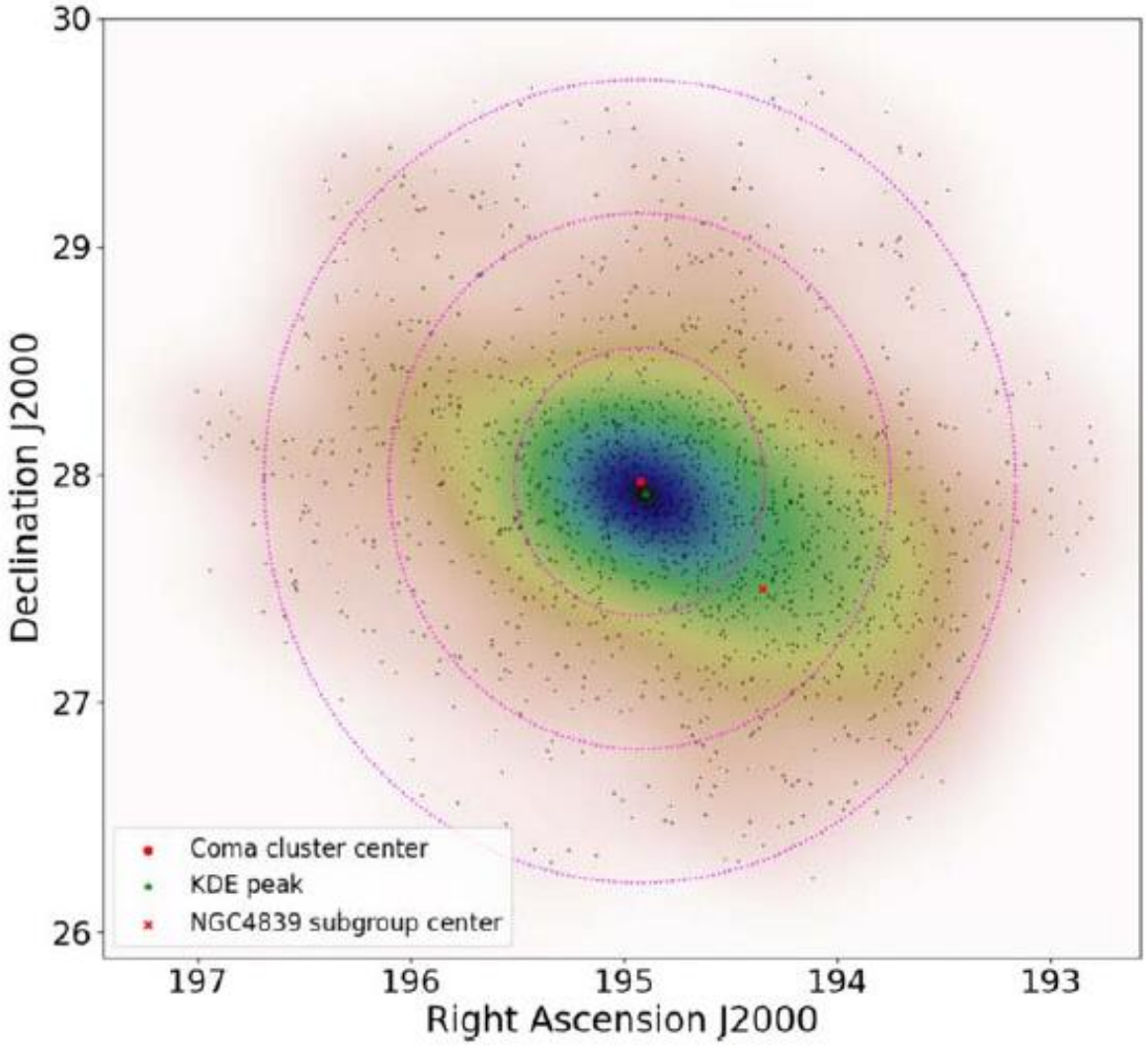


Figure 28. Kernel density estimation of UDG positions, with a Gaussian kernel. Dashed magenta lines mark increments of 1 Mpc in projected cluster radius.

Bautista+2023

Optical Surveys: Intracluster GCs

- **HST gI (Peng+2011, Madrid2018)**

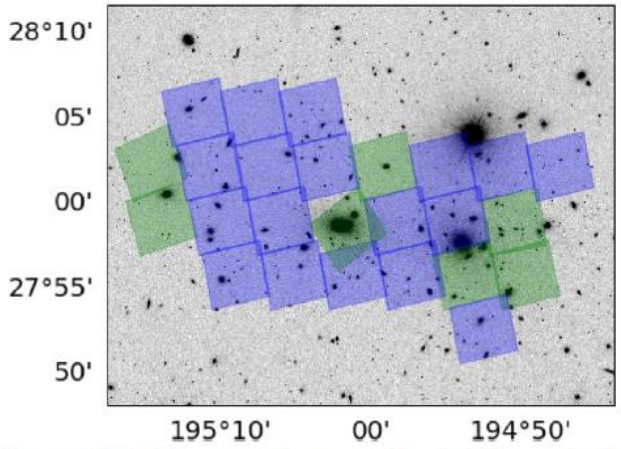


Figure 1. ACS pointings overlaid on an SDSS *g*-band image. The blue pointings were part of the study of Peng et al. (2011). For this work we include both blue and green pointings achieving a better coverage of the core of Coma. The green pointings were obtained under *HST* programs GO 11711 and GO 12918.

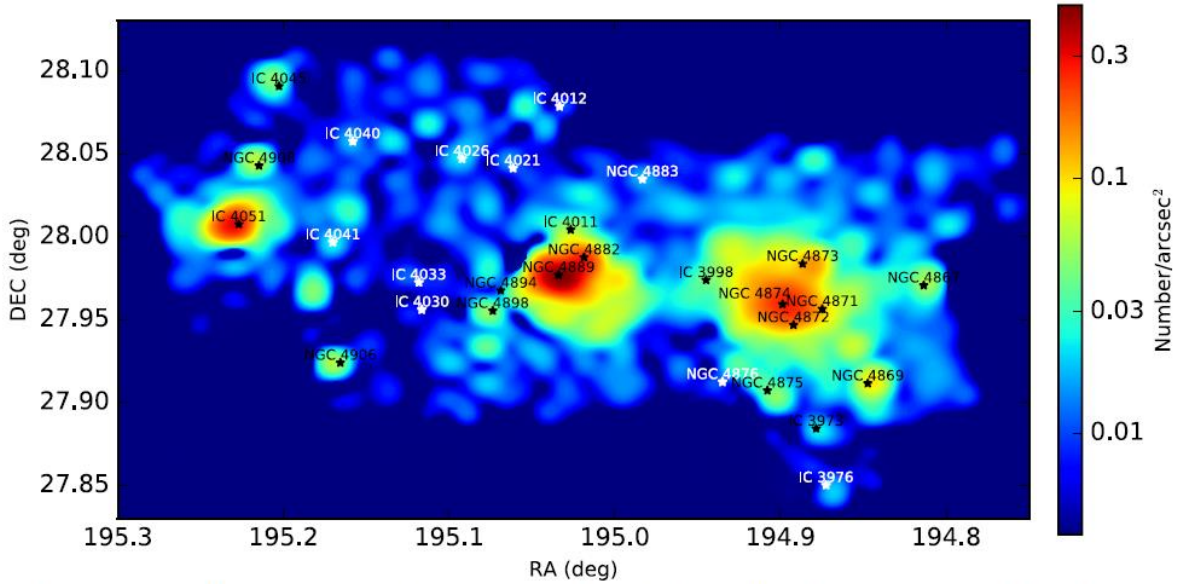


Figure 4. Surface density of globular clusters in the central regions of the Coma cluster. This heat map defines three main overdensities of globular clusters in Coma. The highest density of globular clusters in Coma is cospatial with NGC 4889. The most extended agglomeration of globular clusters can be associated with NGC 4874. A third overdensity is associated with IC 4051. North is up and east is left.

Madrid+2018

Lensing Dark Matter Surveys

- Okabe+(2014):Subaru/SCam

Contours: WL mass

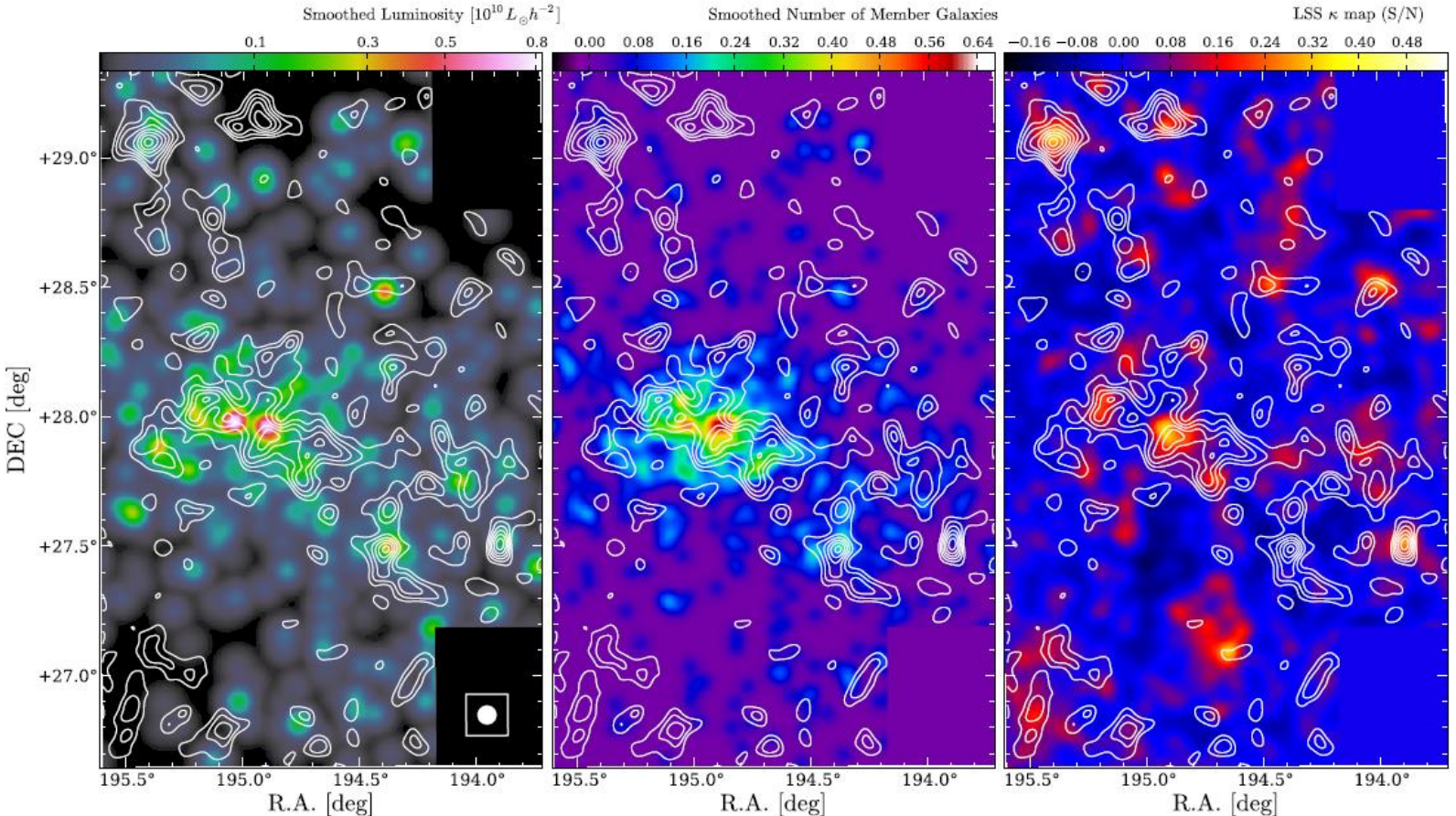
Okabe+2014

Galaxy L density

Galaxy N density

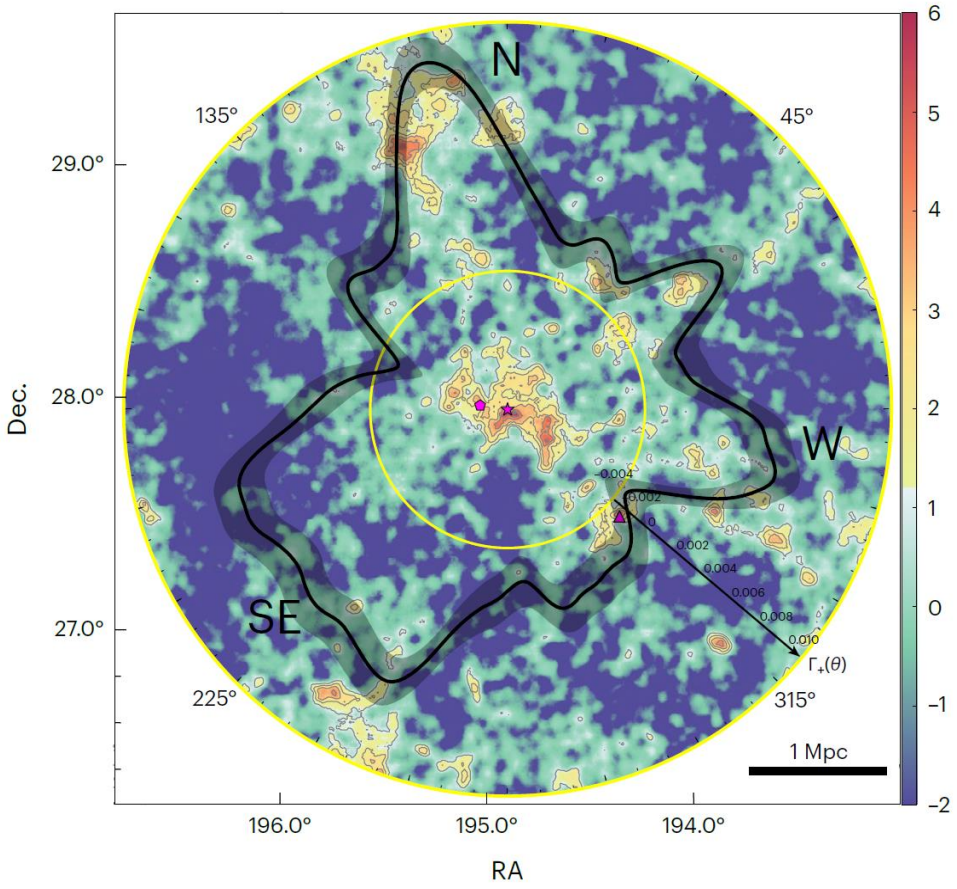
LSS Lensing DM

THE ASTROPHYSICAL JOURNAL, 784:90 (27pp), 2014 April 1



Lensing Dark Matter Surveys

- Kim+(2024): Subaru/HSC – Weak lensing analysis
- Intracluster Filaments (ICFs) from WL signals: DM filaments



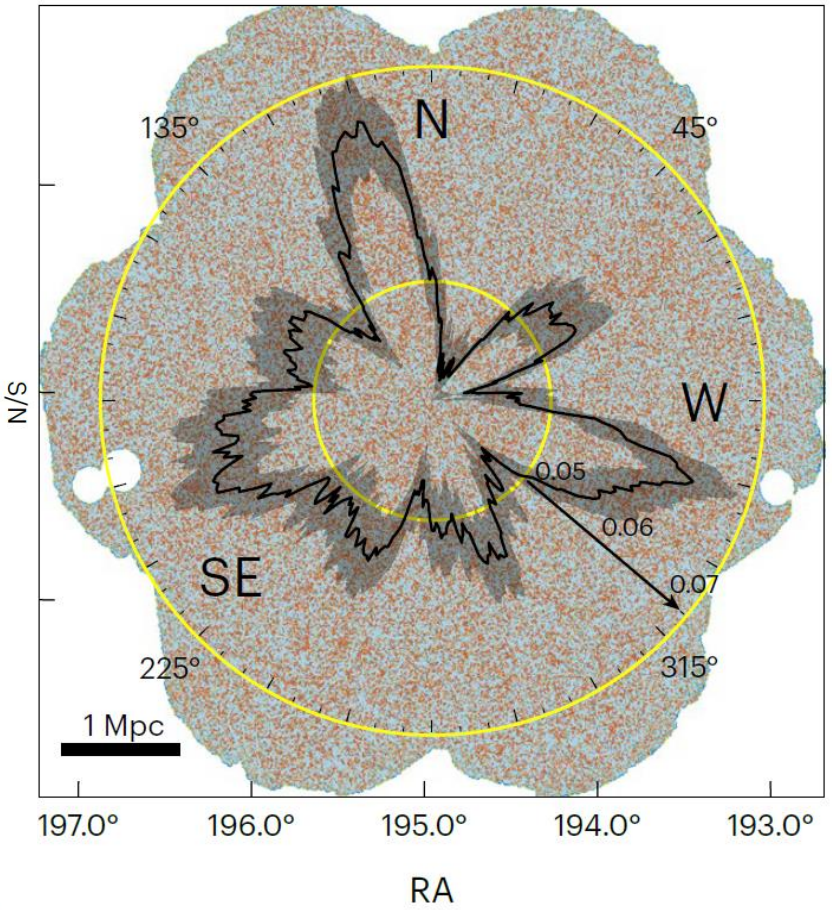


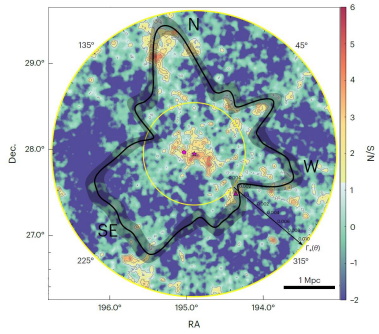
Fig. 1 | Mass reconstruction and matched-filter statistic of the Coma cluster.

Fig. 2 | Intracluster filament detection based on shear-peak statistic. Left,

Kim+2024

Lensing Dark Matter Surveys

- Kim+2024: Subaru/HSC
- ICFs (DM filaments) are aligned with SDSS galaxy filaments!



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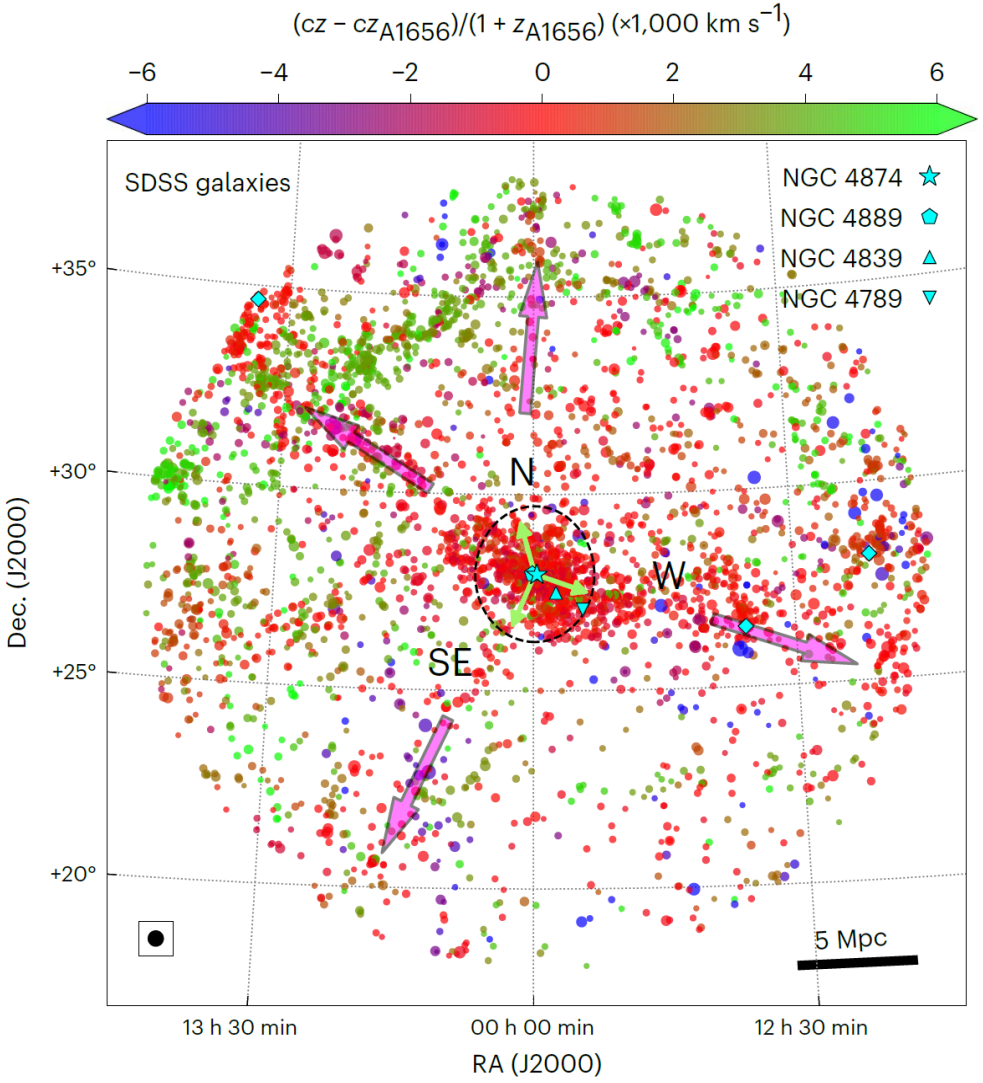


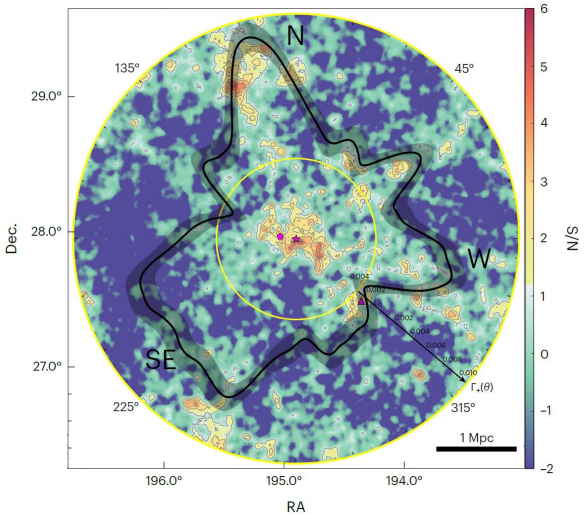
Fig. 4 | Alignment of the ICFs with the large-scale filaments. The LOS velocity

Kim+2024

SNU Coma Survey

- Lee,Cho+2024: Subaru/HSC-RS galaxies

Lee+2024



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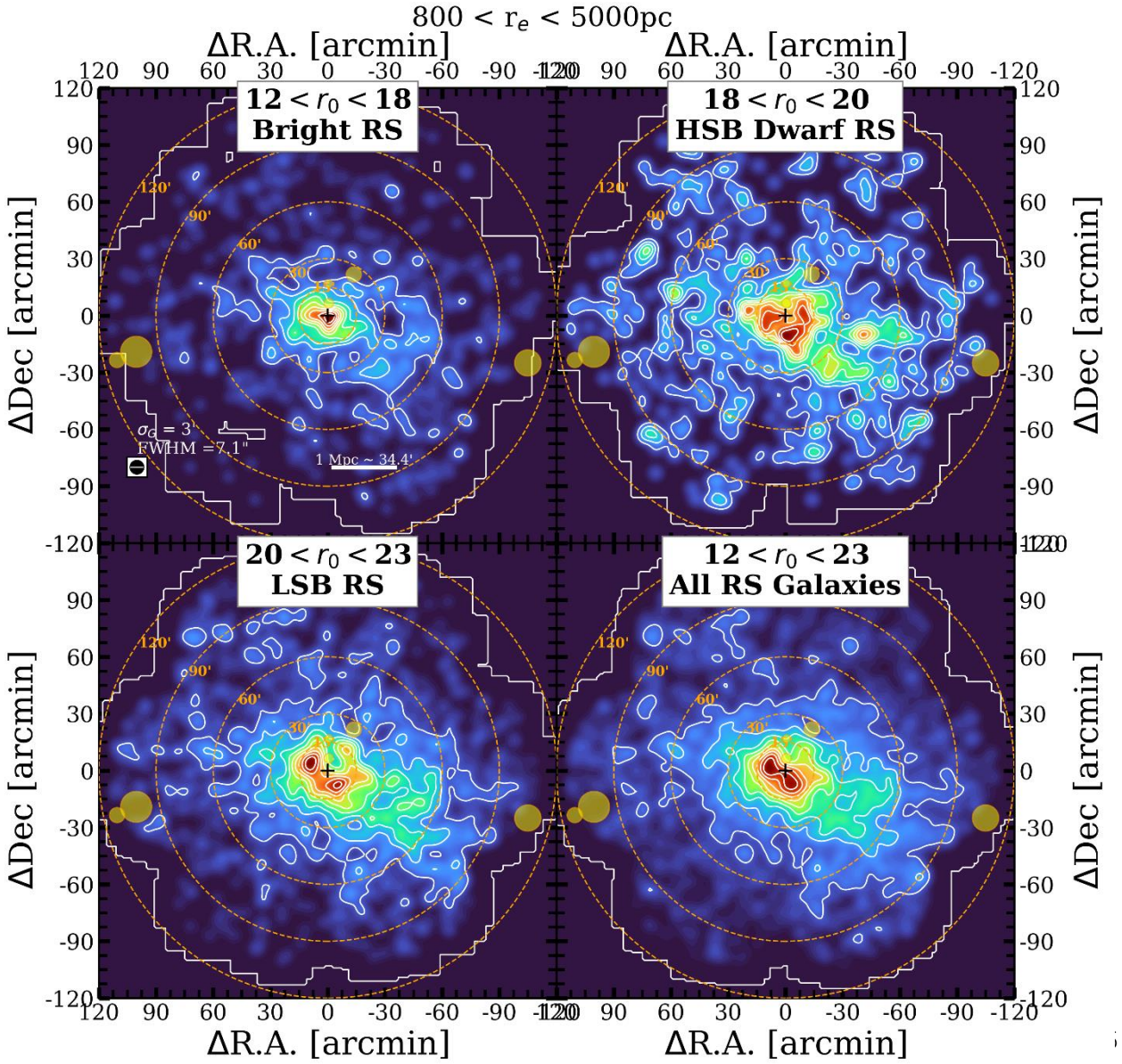

Summary and Future

- Recent wide field multiwavelength surveys provide exciting results on Coma.
- Coma is a key to understanding various aspects of massive galaxy clusters.
- Stay tuned for coming new surveys!

- Let's enjoy High 1!

Thank you!