TRACING THE INCEPTION OF THE GALAXY CLUSTER ERA

DETECTION OF FORMING INTRACLUSTER GAS IN A GALAXY PROTOCLUSTER AT Z~2.16

LUCA DI MASCOLO

FIFTH WORKSHOP ON MILLIMETRE ASTRONOMY IN ITALY

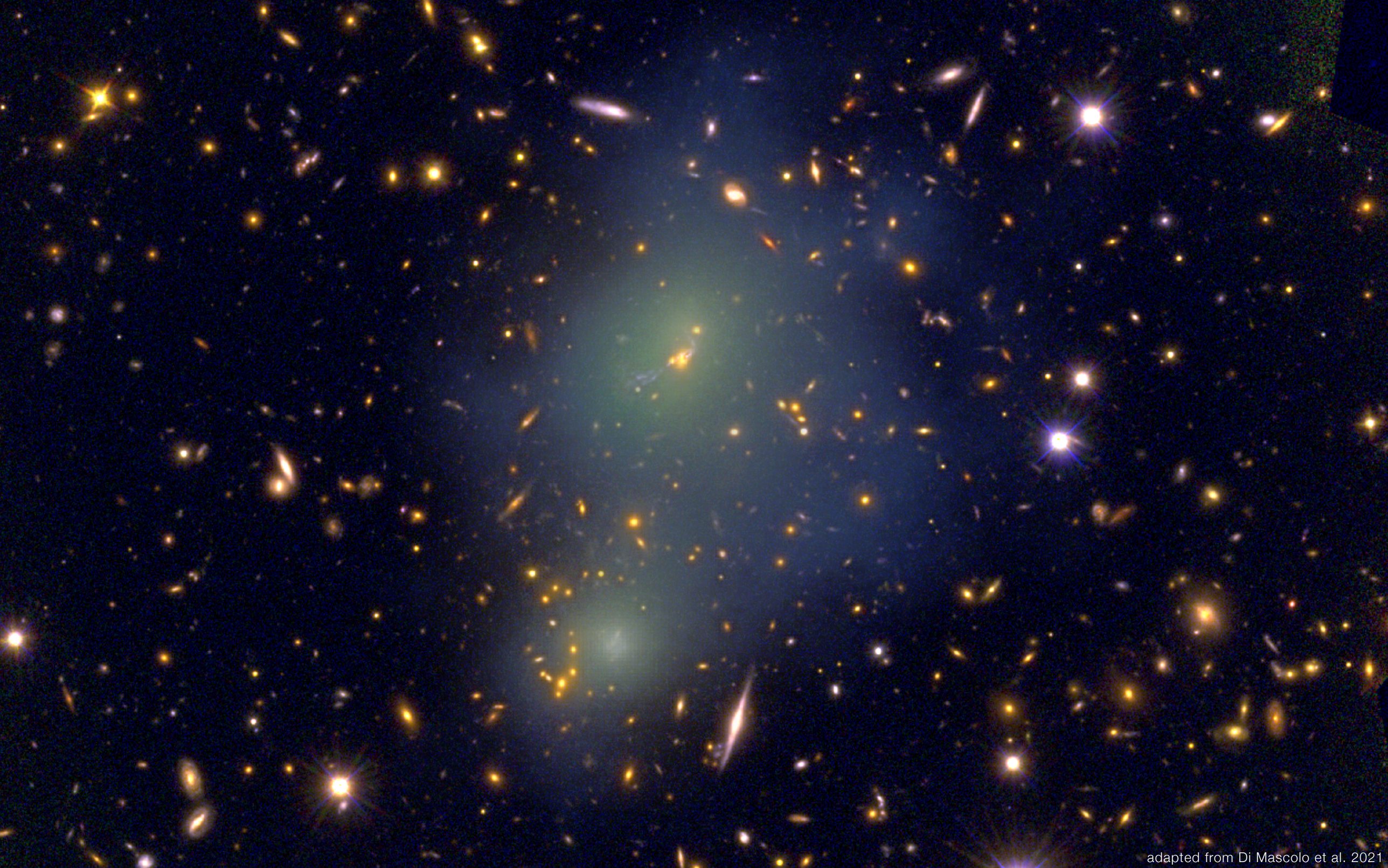
14-06-2023

UNIVERSITÀ DEGLI STUDI DI TRIESTE

INAF ISTITUTO NAZIONALE DI ASTROFISICA

ifpU

adapted from Di Mascolo et al. 2021



adapted from Di Mascolo et al. 2021

ENVIRONMENT FOR GALAXY EVOLUTION

impact galaxy morphology,
star formation, AGN activity, …

LARGEST STRUCTURES IN THE UNIVERSE

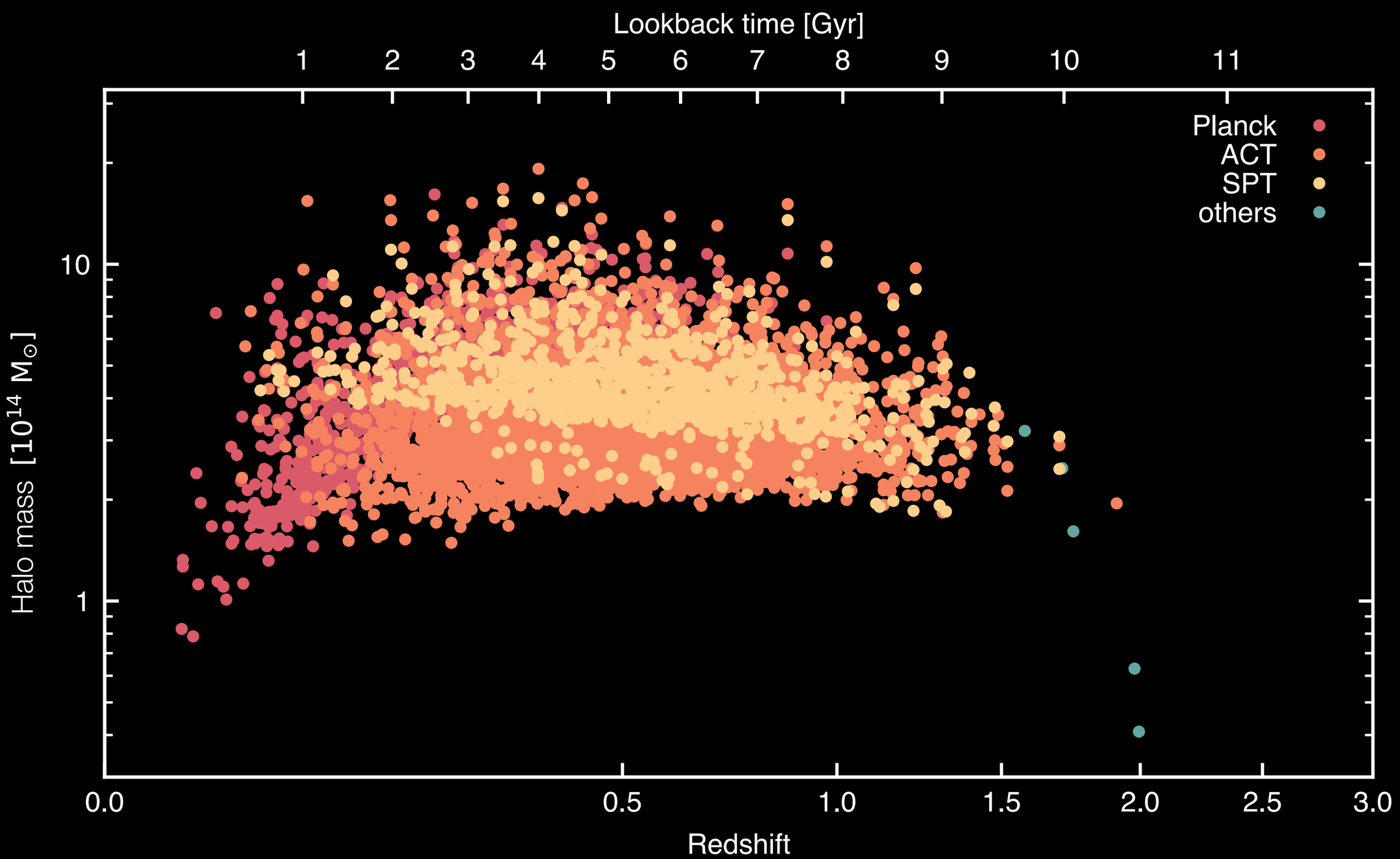
tracers of large-scale structure formation
and mass content of the Universe
window on dark matter properties

LARGE RESERVOIRS OF PLASMA

host most energetic events in the universe
unique laboratories for plasma physics

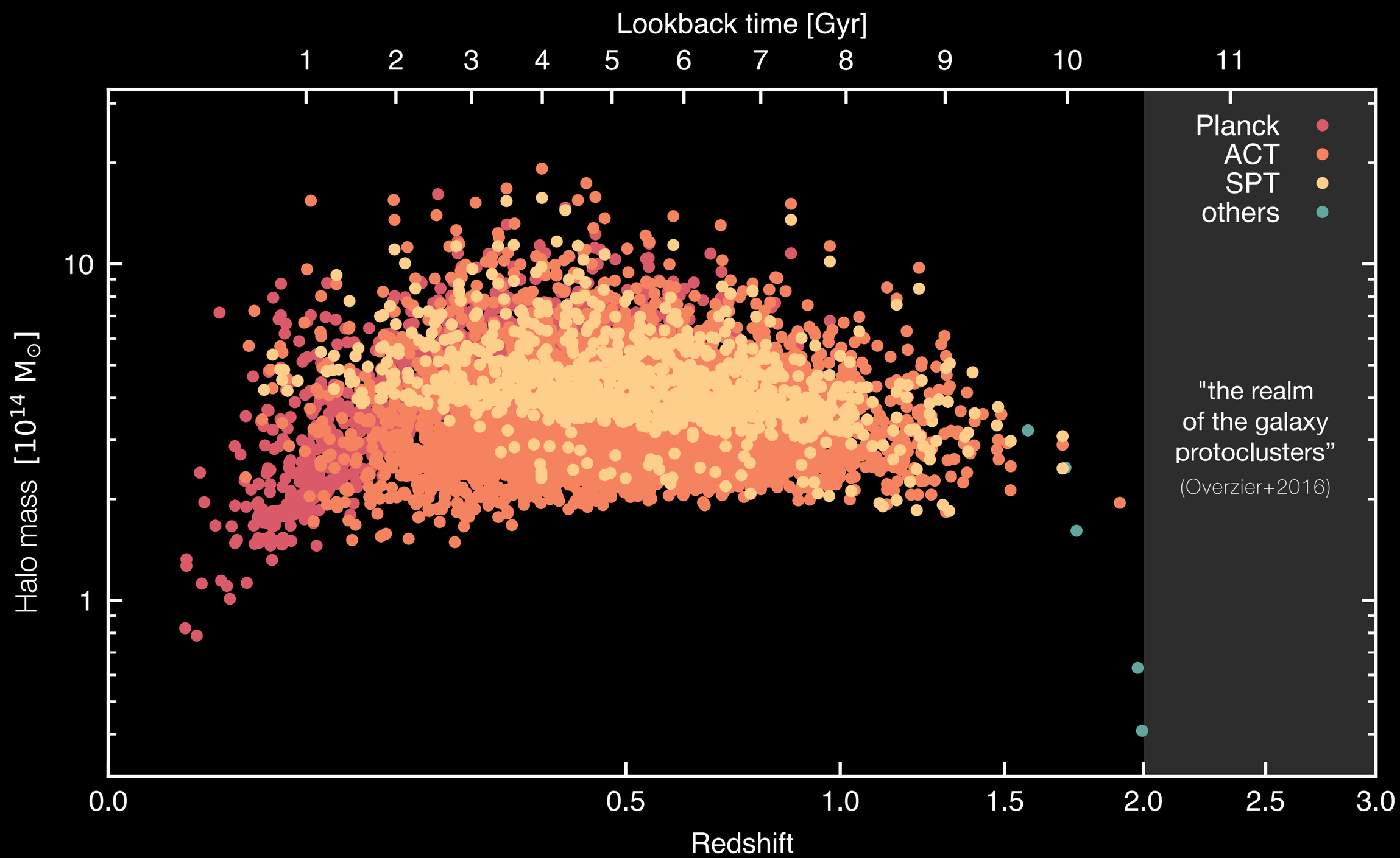
adapted from Di Mascolo+2021

clusters across cosmic time



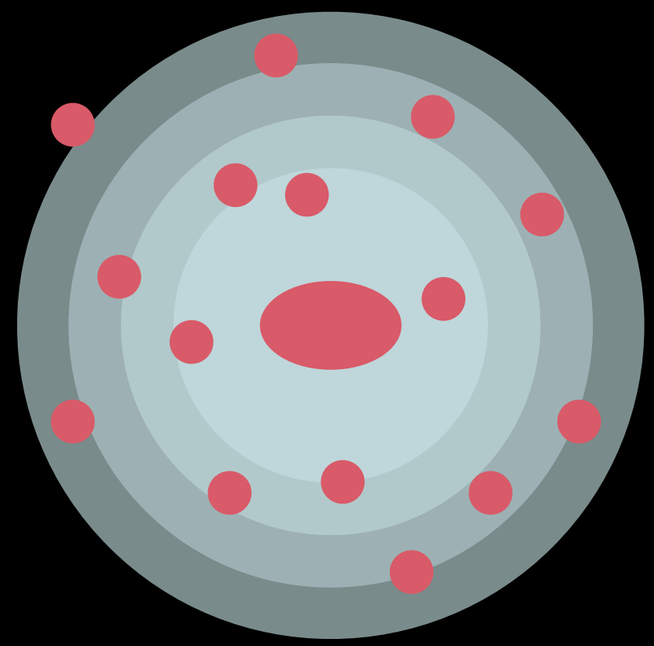
PlanckXXVII 2016, Hilton+2021, Bocquet+2019, Huang+2020, Bleem+2020

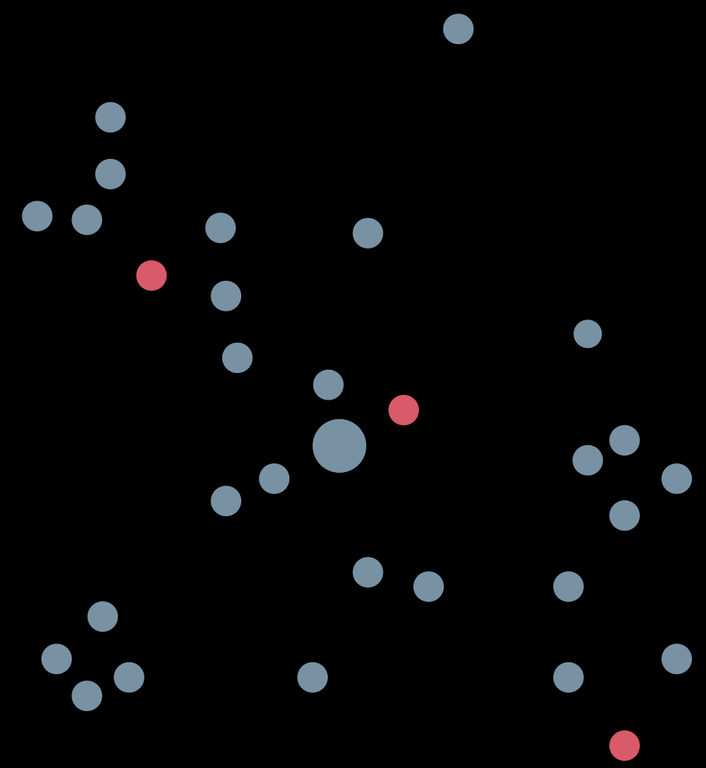
clusters across cosmic time



PlanckXXVII 2016, Hilton+2021, Bocquet+2019, Huang+2020, Bleem+2020

a turning point in cosmic history





mature clusters

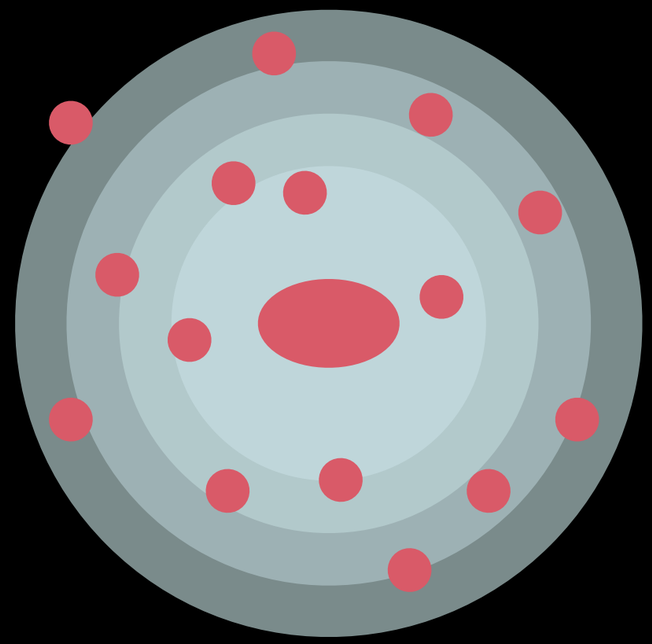
environmental quenching
extended, thermalised haloes
of intracluster medium

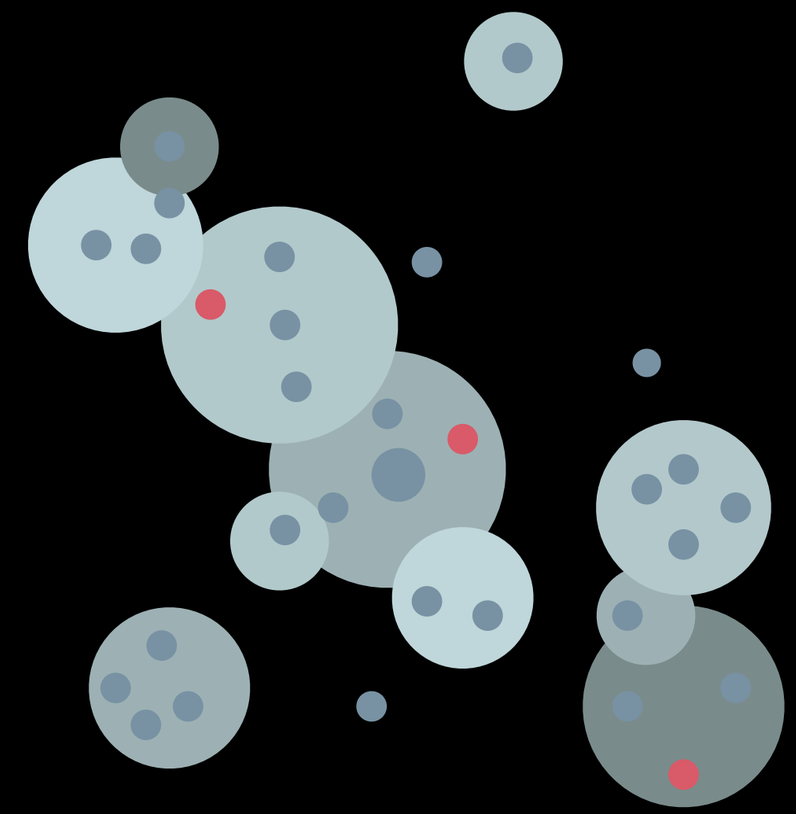
protocluster overdensities

energetic AGN feedback
sustained star formation

adapted from Chiang+2017 & Shimakawa+2018

a turning point in cosmic history





mature clusters

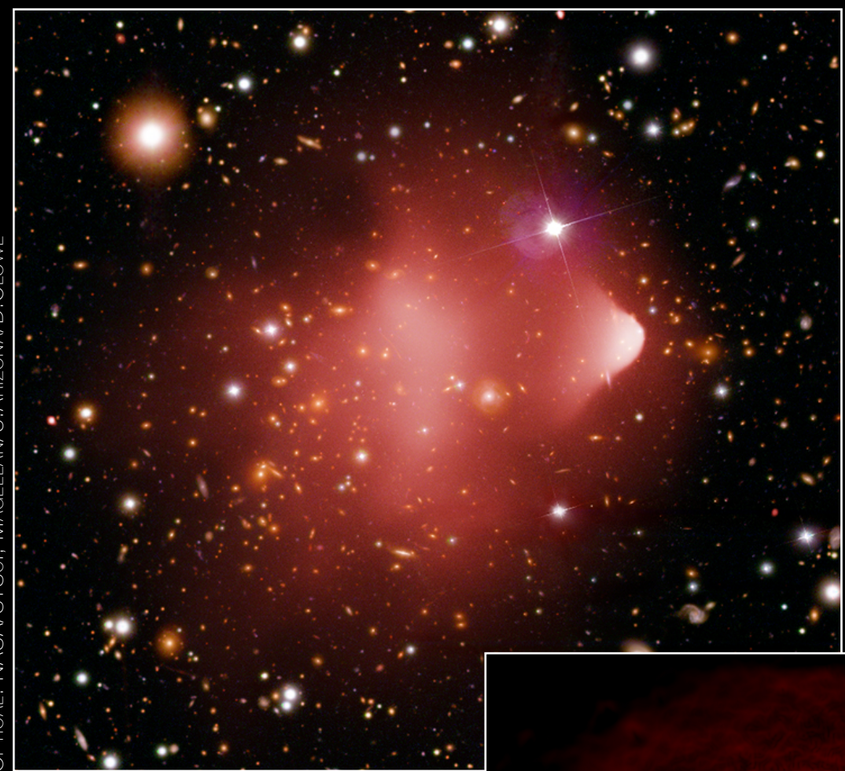
environmental quenching
extended, thermalised haloes
of intracluster medium

protocluster overdensities

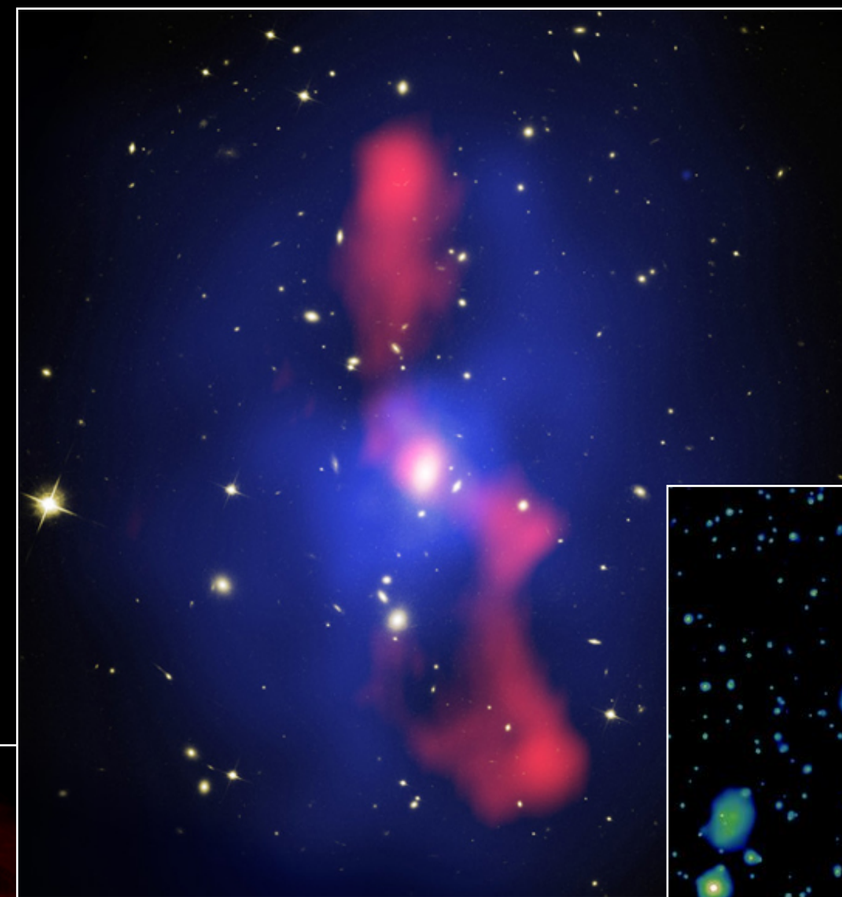
energetic AGN feedback
sustained star formation
pre-heated cores
(Saro+2009,Remus+2023)

adapted from Chiang+2017 & Shimakawa+2018

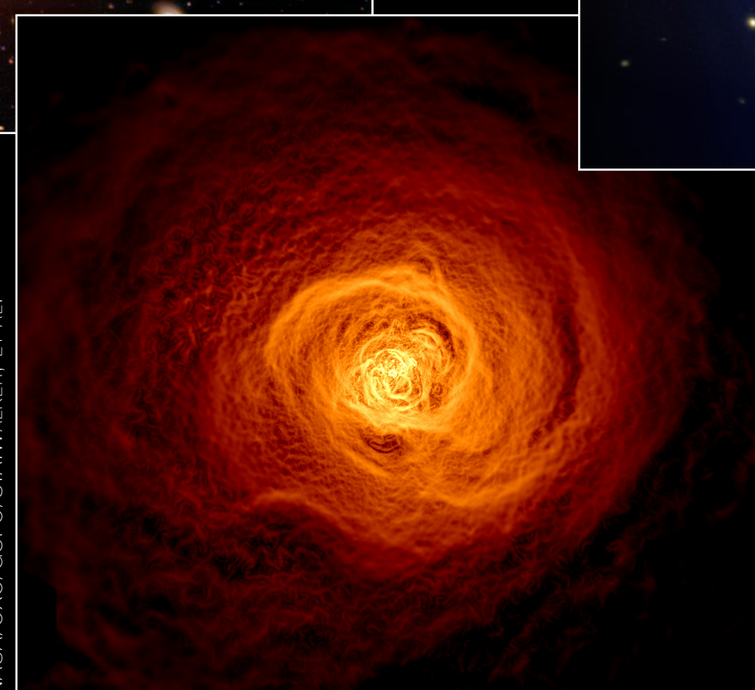
X-ray measurements as key drivers of ICM studies



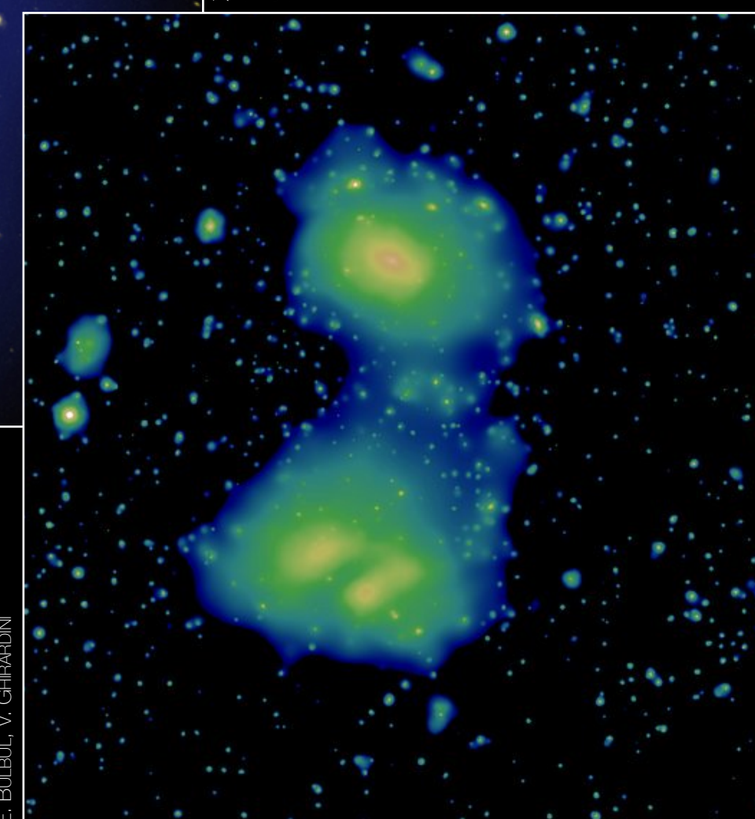
X-ray: NASA/CXC/CfA/M.Markevitch,
Optical: NASA/STScI, Magellan/U.Arizona/D.Clowe



X-ray: NASA/CXC/Univ. Waterloo/
B.McNamara; Optical: NASA/ESA/STScI/
Univ. Waterloo/B.McNamara; Radio:
NRAO/Ohio Univ./L.Birzan et al.

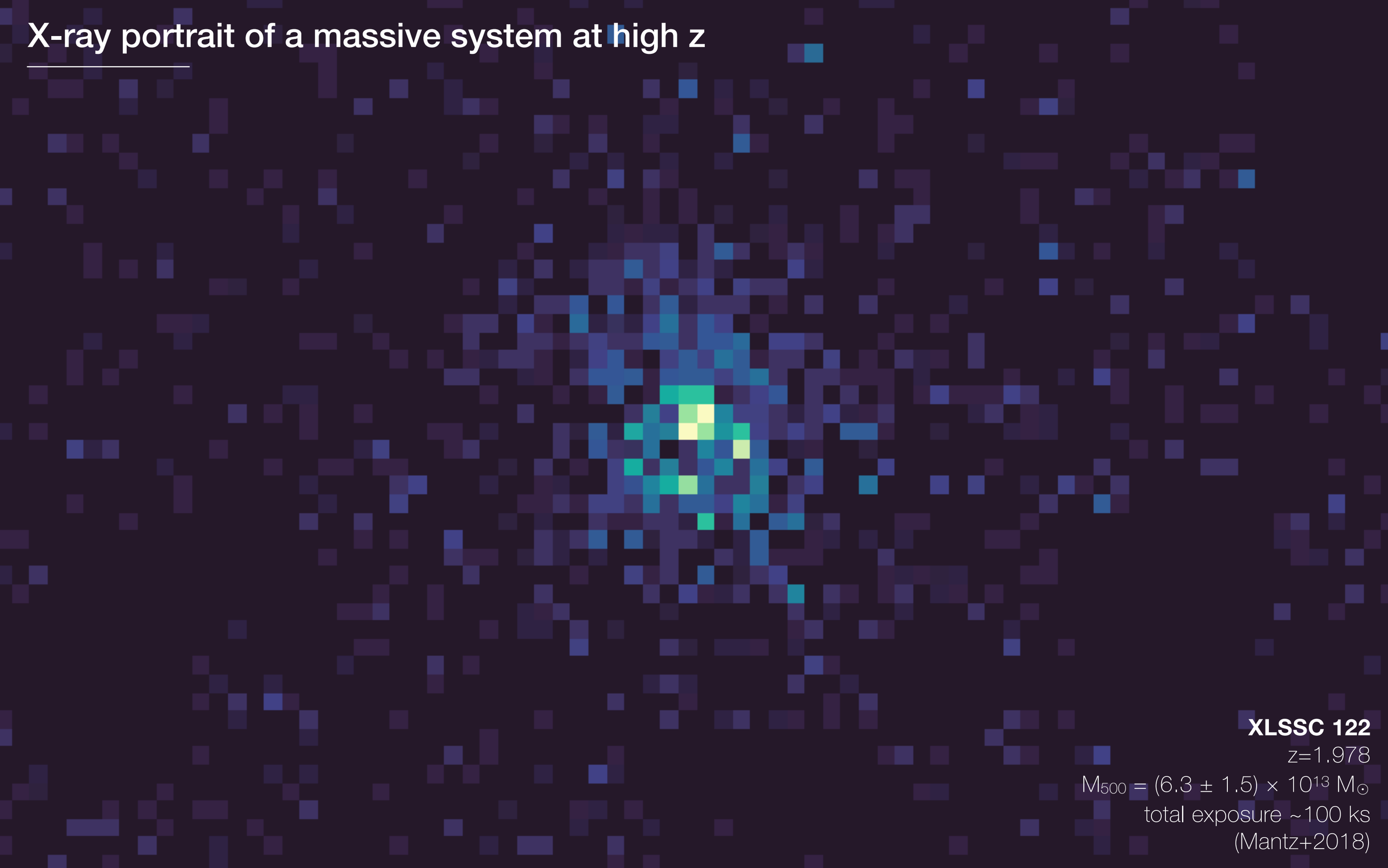


NASA/CXC/GSFC/S.A.Walker, et al.

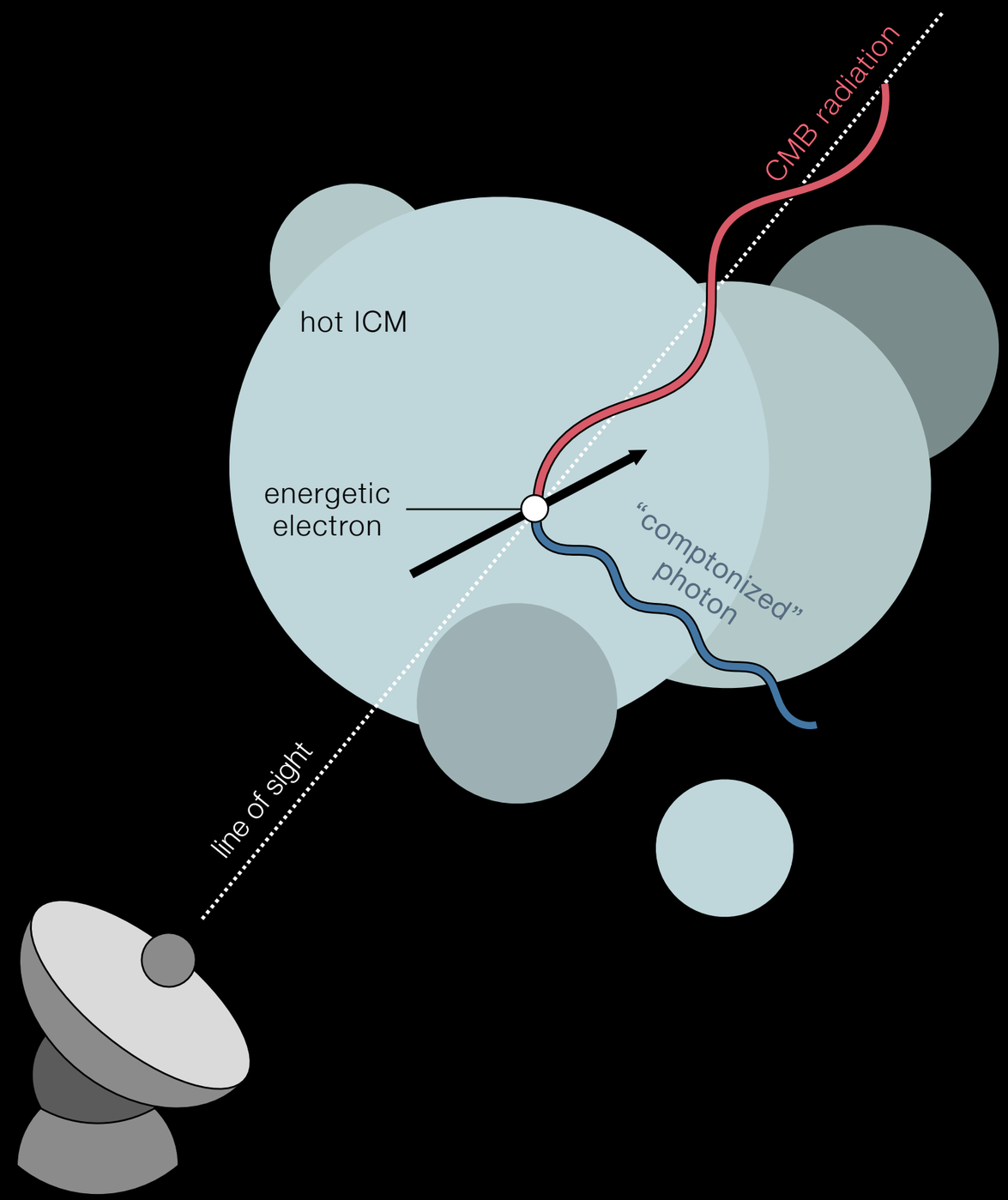


Univ. Bonn/T. Reiprich, F. Pacaud
Univ. Geneva/D. Eckert
MPE/M. Ramos-Ceja, J. Sanders,
E. Bulbul, V. Ghirardini

X-ray portrait of a massive system at high z



SZ effect, a review



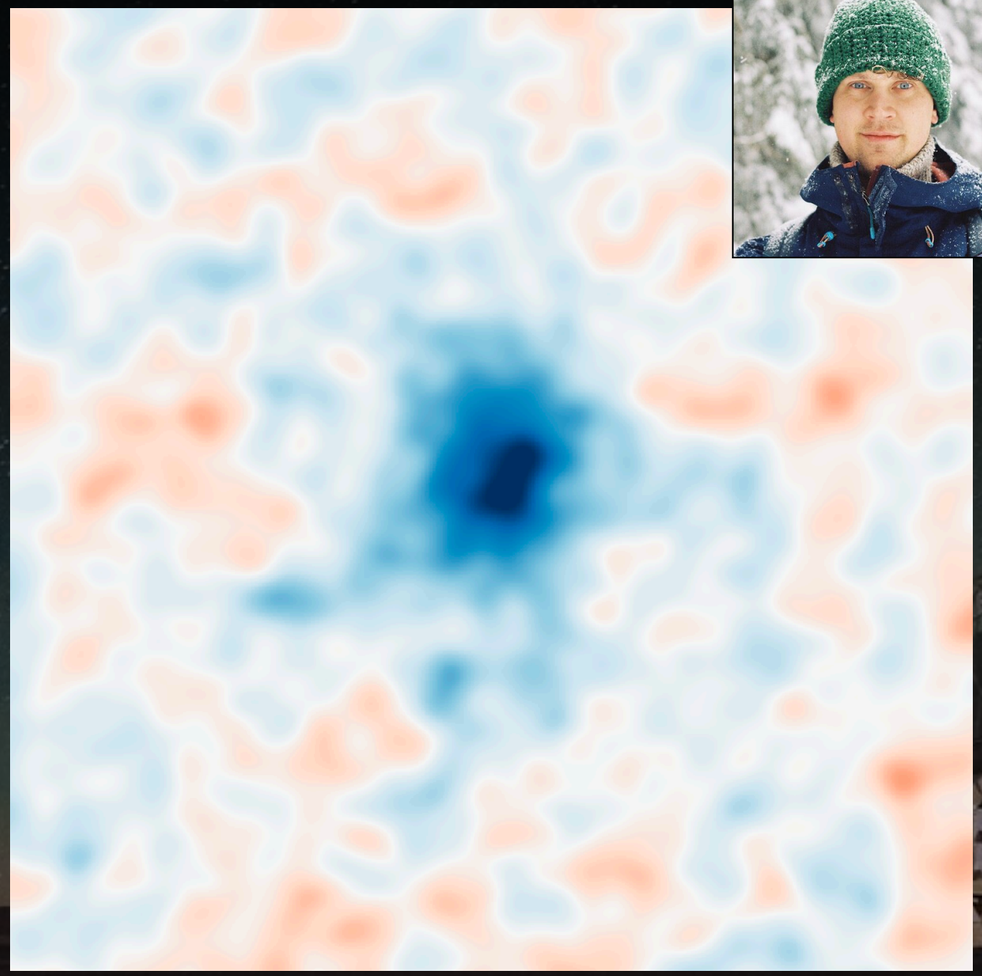
inverse Compton scattering
of CMB photons off ICM electrons

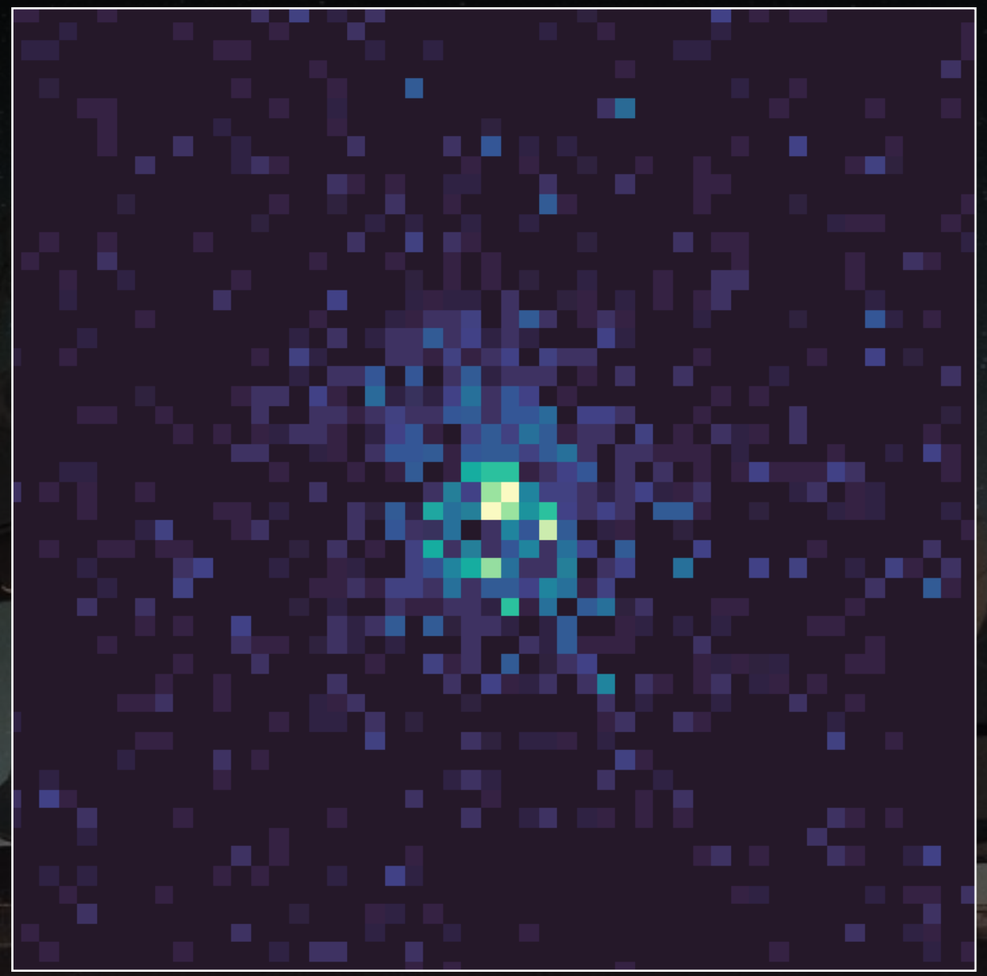
peculiar spectral distortion

redshift-independent
surface brightness

tracing thermalised
intracluster electrons


ALMA





(van Marrewijk+ in prep)

galaxy evolution studies

Spiderweb galaxy

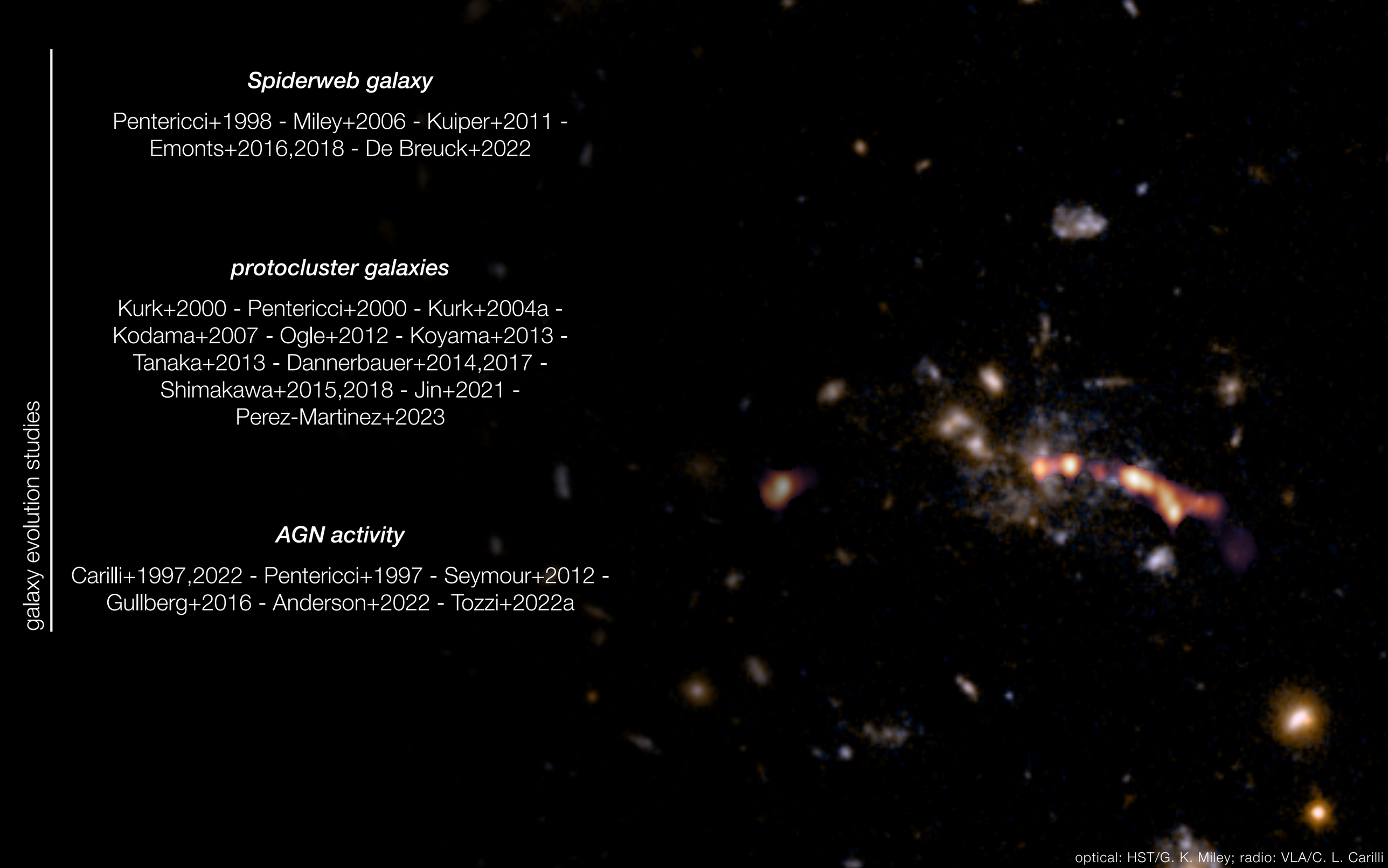
Pentericci+1998 - Miley+2006 - Kuiper+2011 - Emonts+2016,2018 - De Breuck+2022

protocluster galaxies

Kurk+2000 - Pentericci+2000 - Kurk+2004a - Kodama+2007 - Ogle+2012 - Koyama+2013 - Tanaka+2013 - Dannerbauer+2014,2017 - Shimakawa+2015,2018 - Jin+2021 - Perez-Martinez+2023

AGN activity

Carilli+1997,2022 - Pentericci+1997 - Seymour+2012 - Gullberg+2016 - Anderson+2022 - Tozzi+2022a



optical: HST/G. K. Miley; radio: VLA/C. L. Carilli

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environment

proto-ICM

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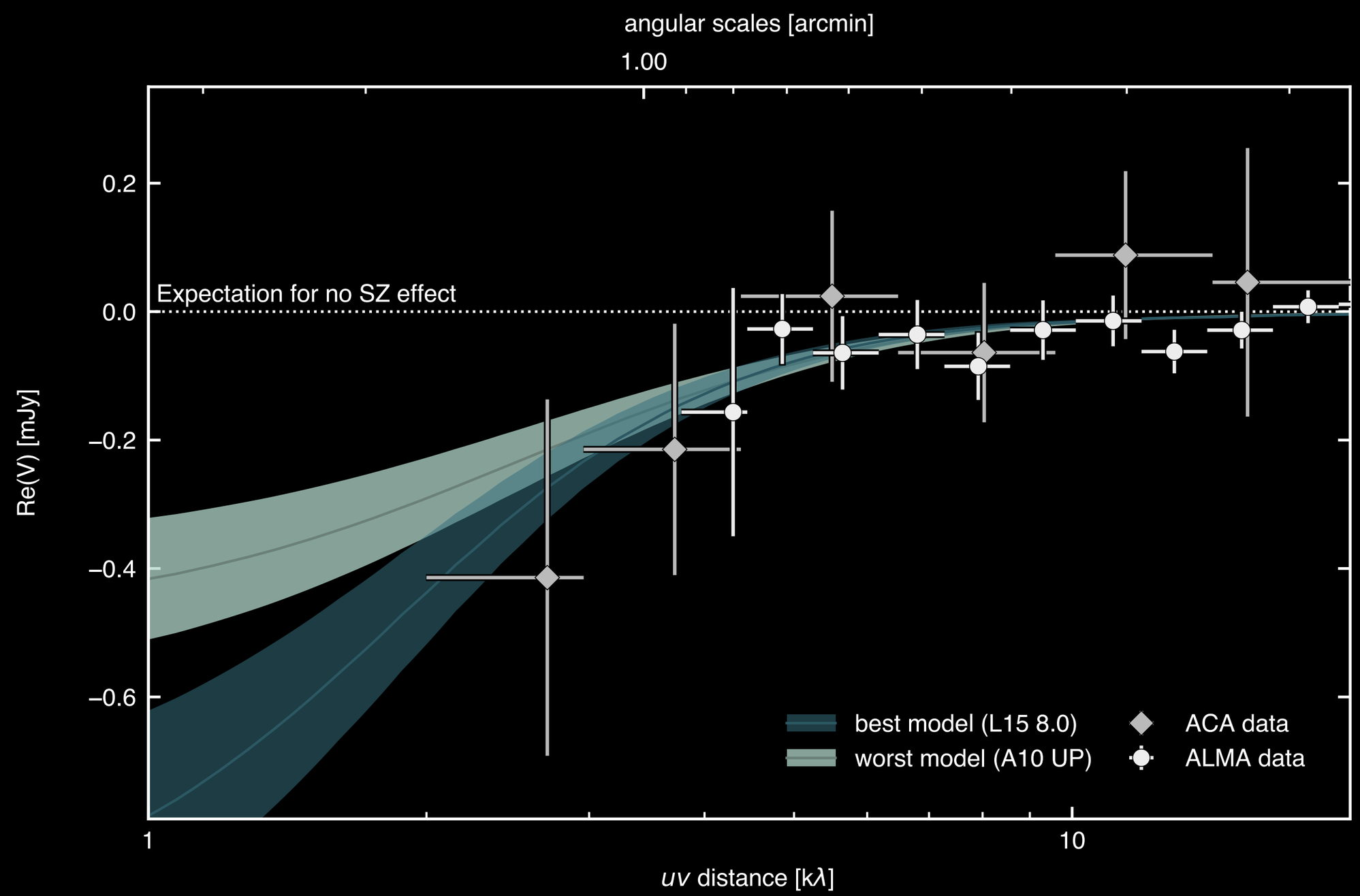
optical: HST/G. K. Miley; radio: VLA/C. L. Carilli

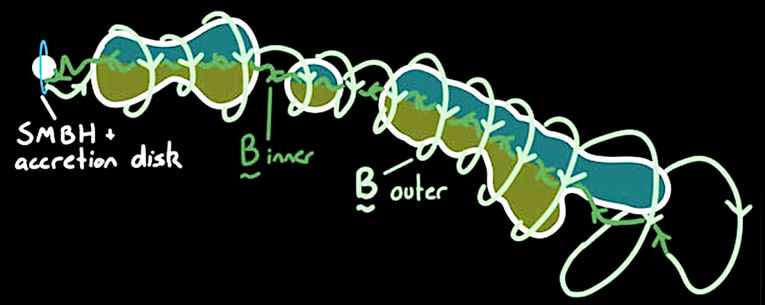
let's put our Fourier glasses on



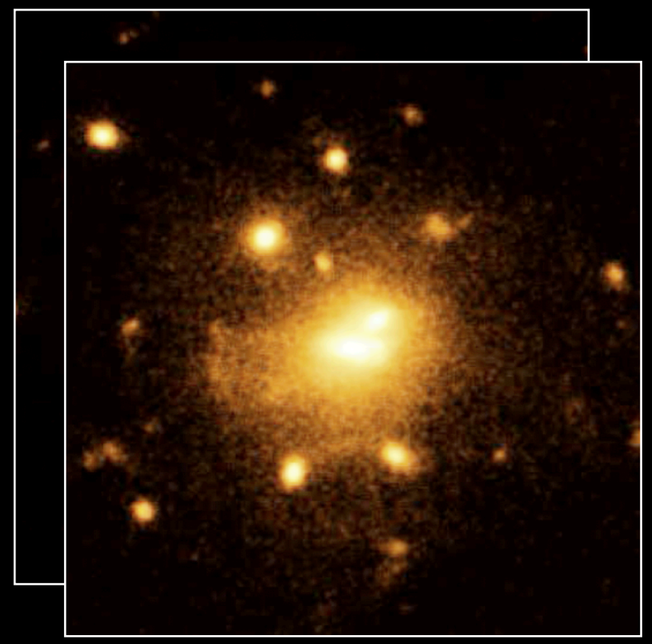
adapted from Di Mascolo+, *Nature*, 2023

confirmation of long-standing predictions

Pentericci+1997, Hatch+2009
Star-bursting proto-BCG fed by "cooling flow"-like precipitation (but not the only scenario)

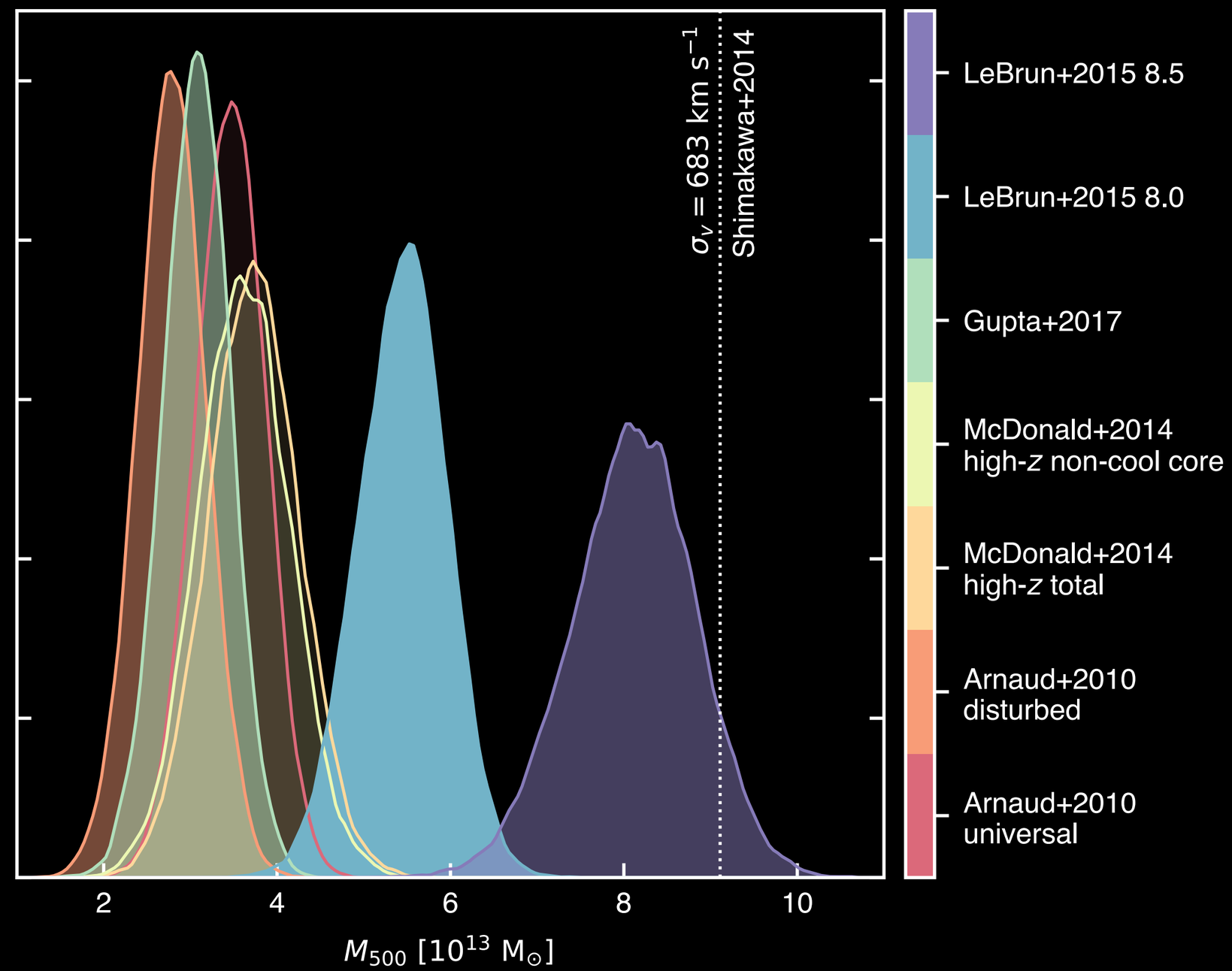


Carilli+1997, Anderson+2022
RMs generate in thin sheath of hot gas around the radio jet



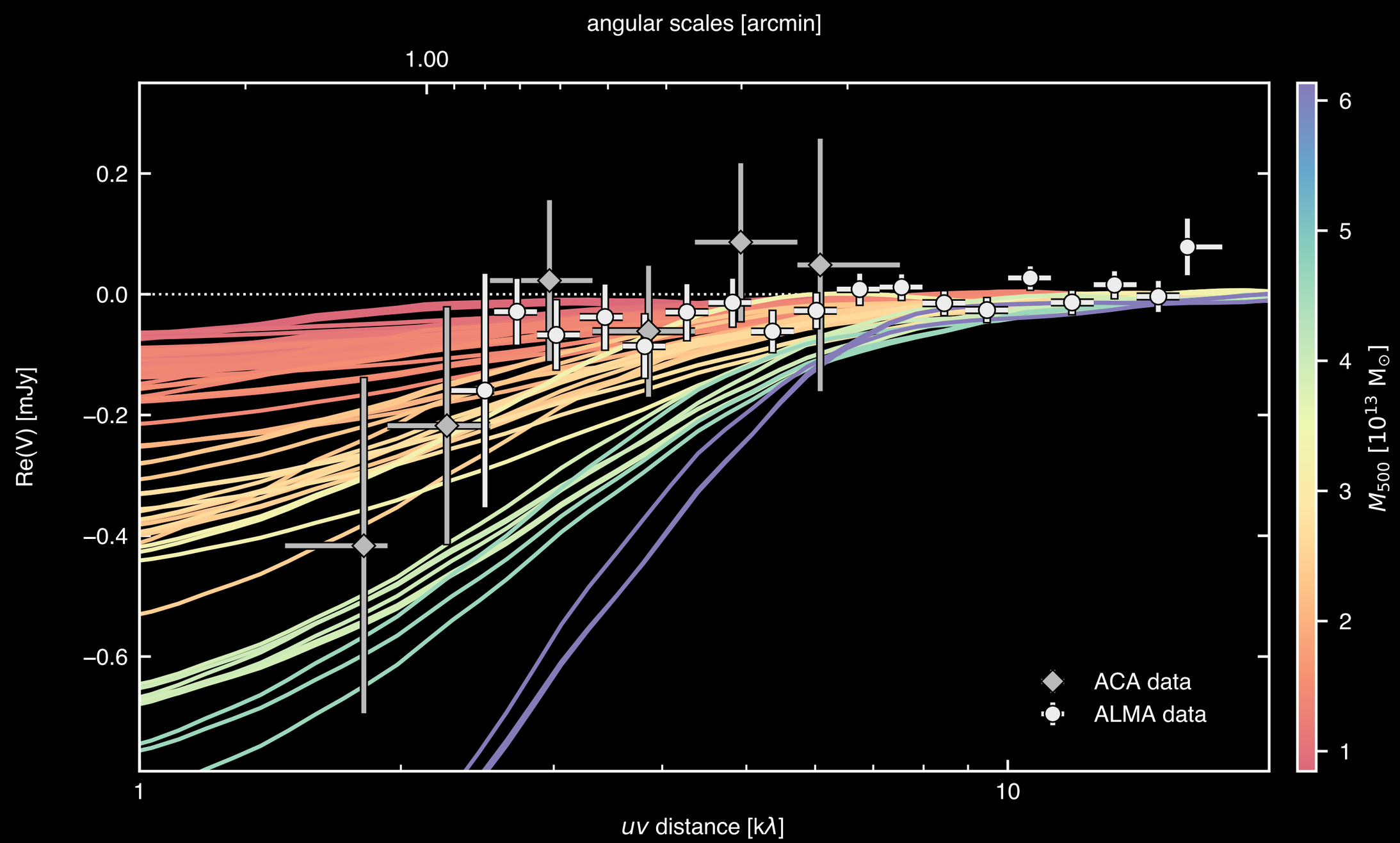
Saro+2009
simulated protoclusters with gravitational potential permeated by ICM at 2-5 keV

small masses

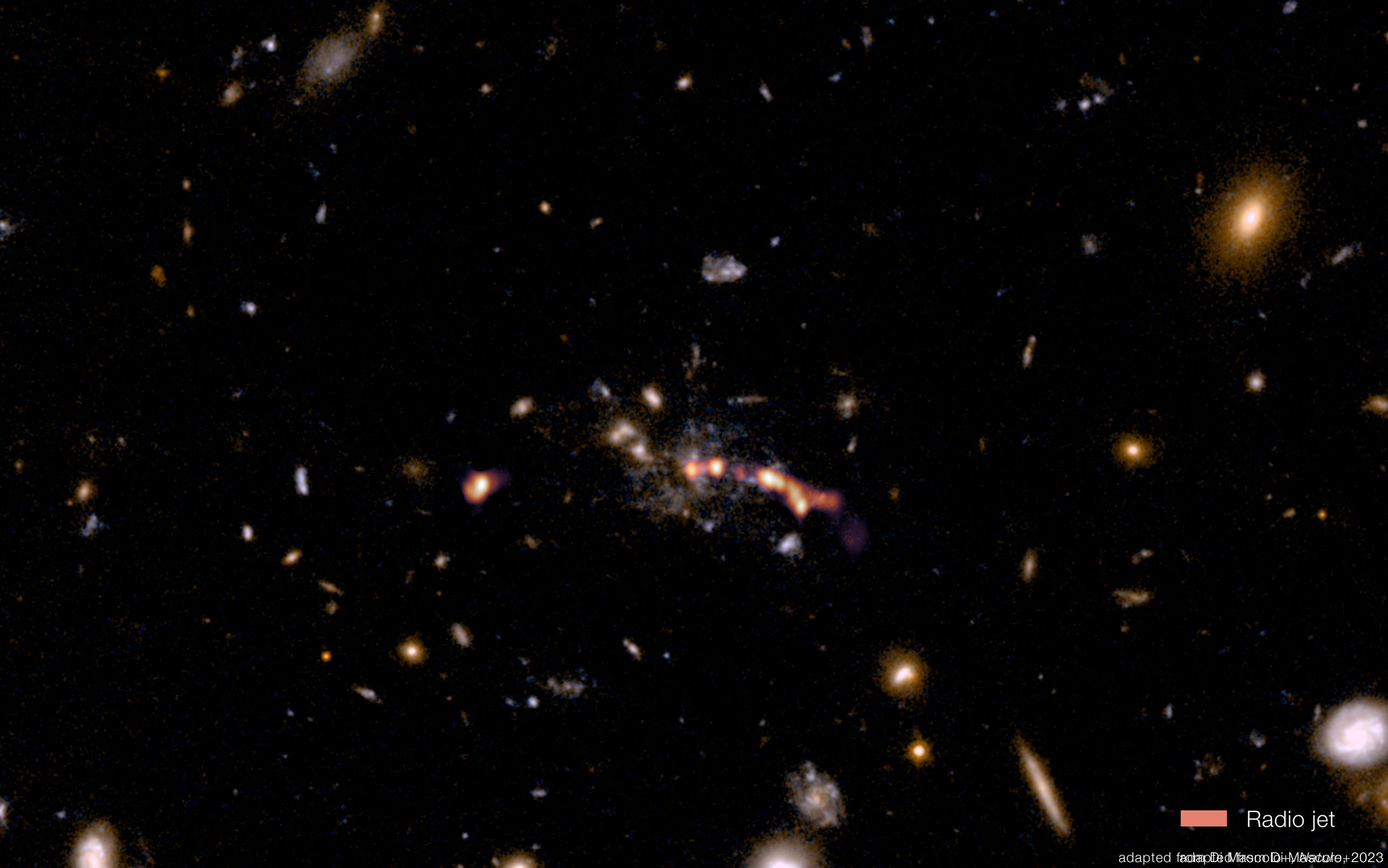


adapted from Di Mascolo+, *Nature*, 2023

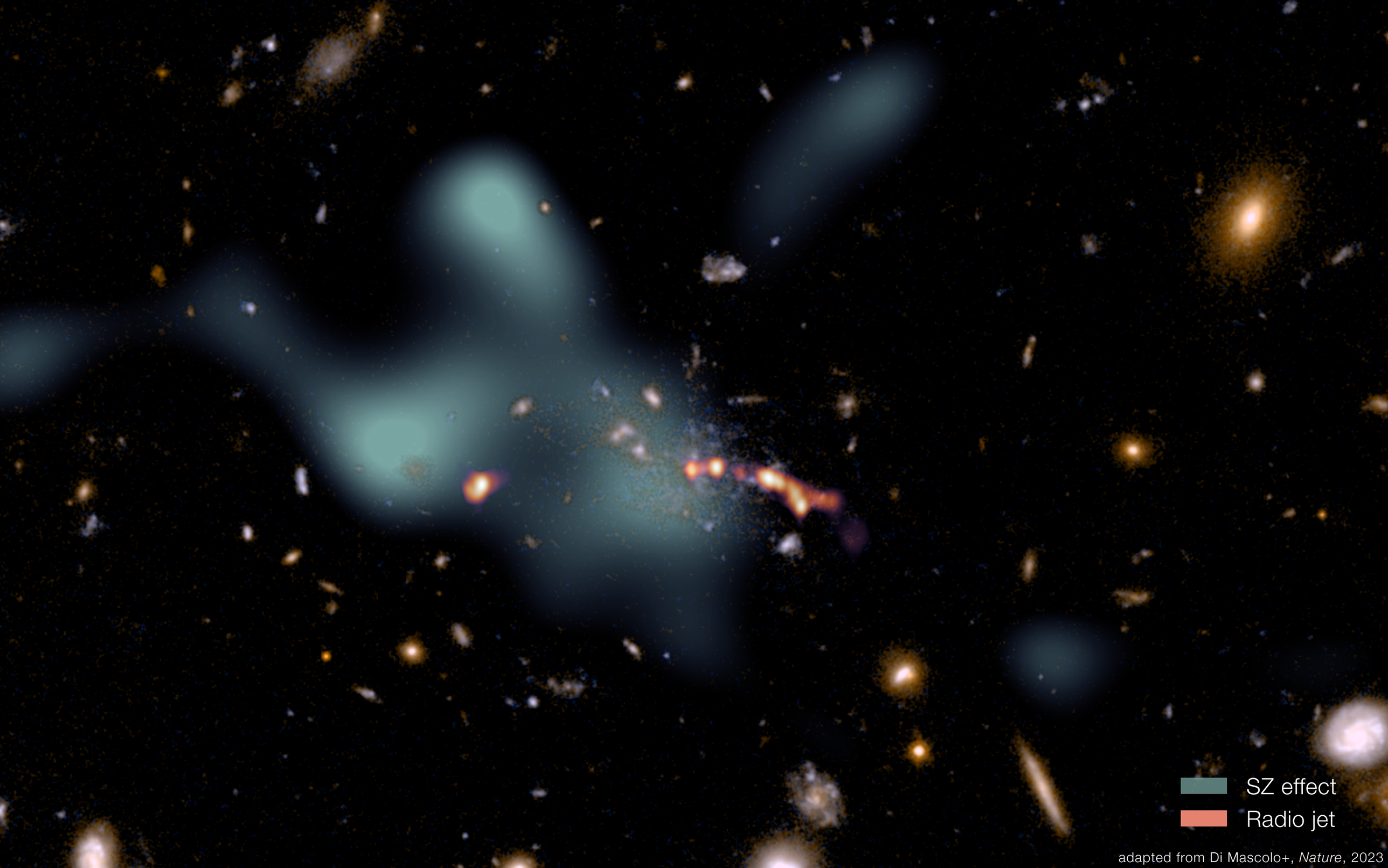
consistent results from cosmo hydrosims



adapted from Di Mascolo+, *Nature*, 2023



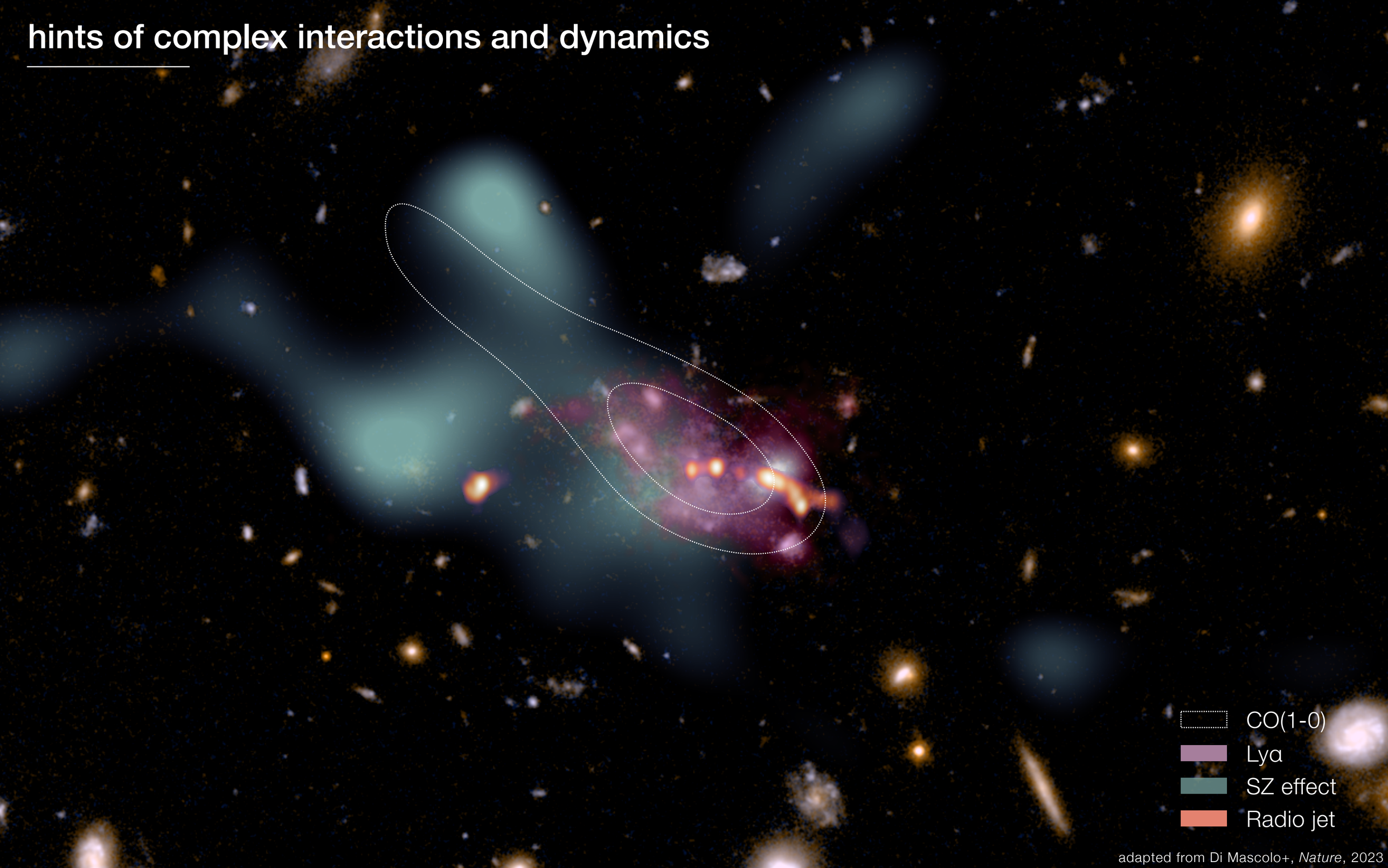
adapted from Di Mascolo, Valore, +2023



adapted from Di Mascolo+, *Nature*, 2023

adapted from Di Mascolo+, *Nature*, 2023

hints of complex interactions and dynamics



adapted from Di Mascolo+, *Nature*, 2023

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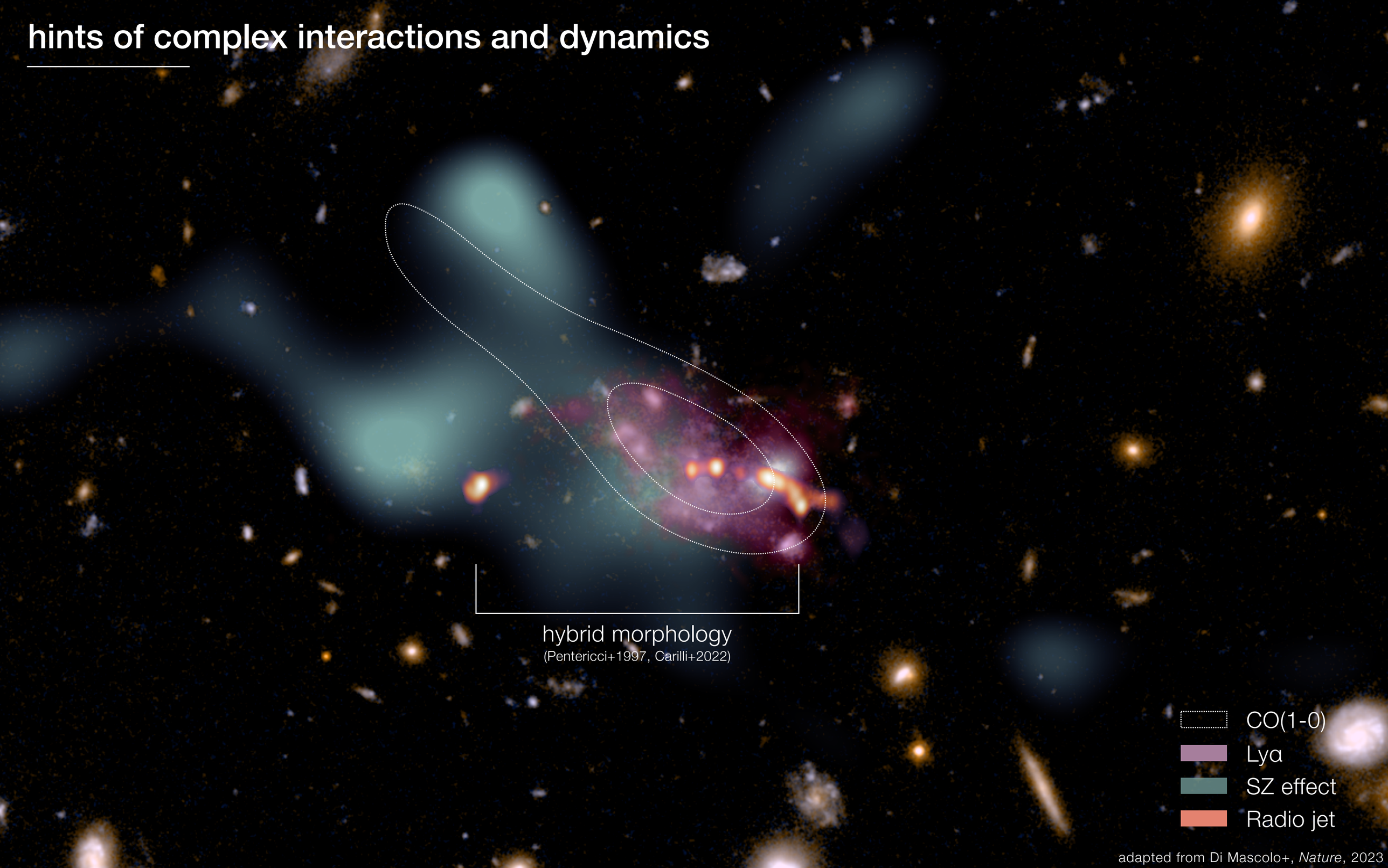

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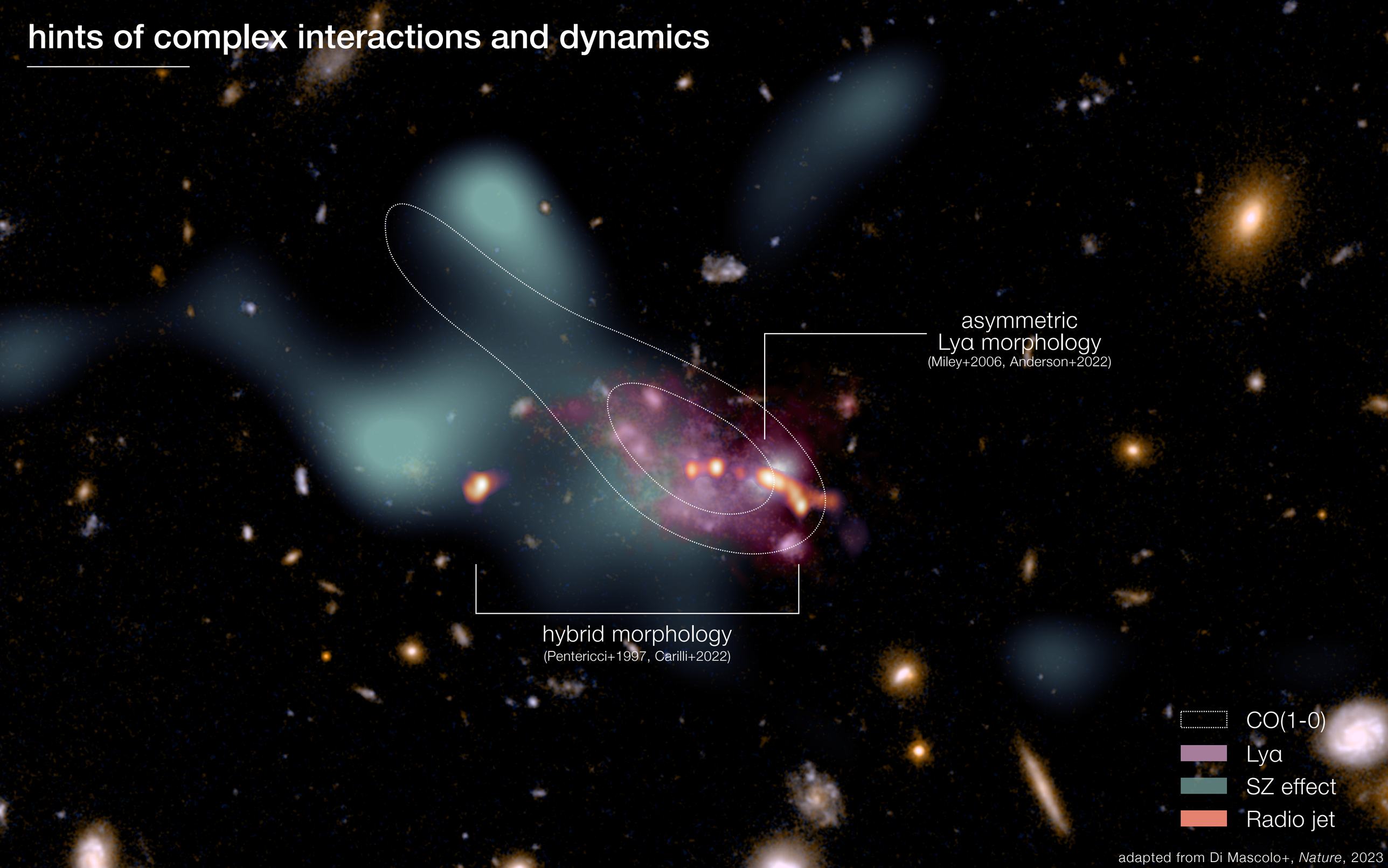
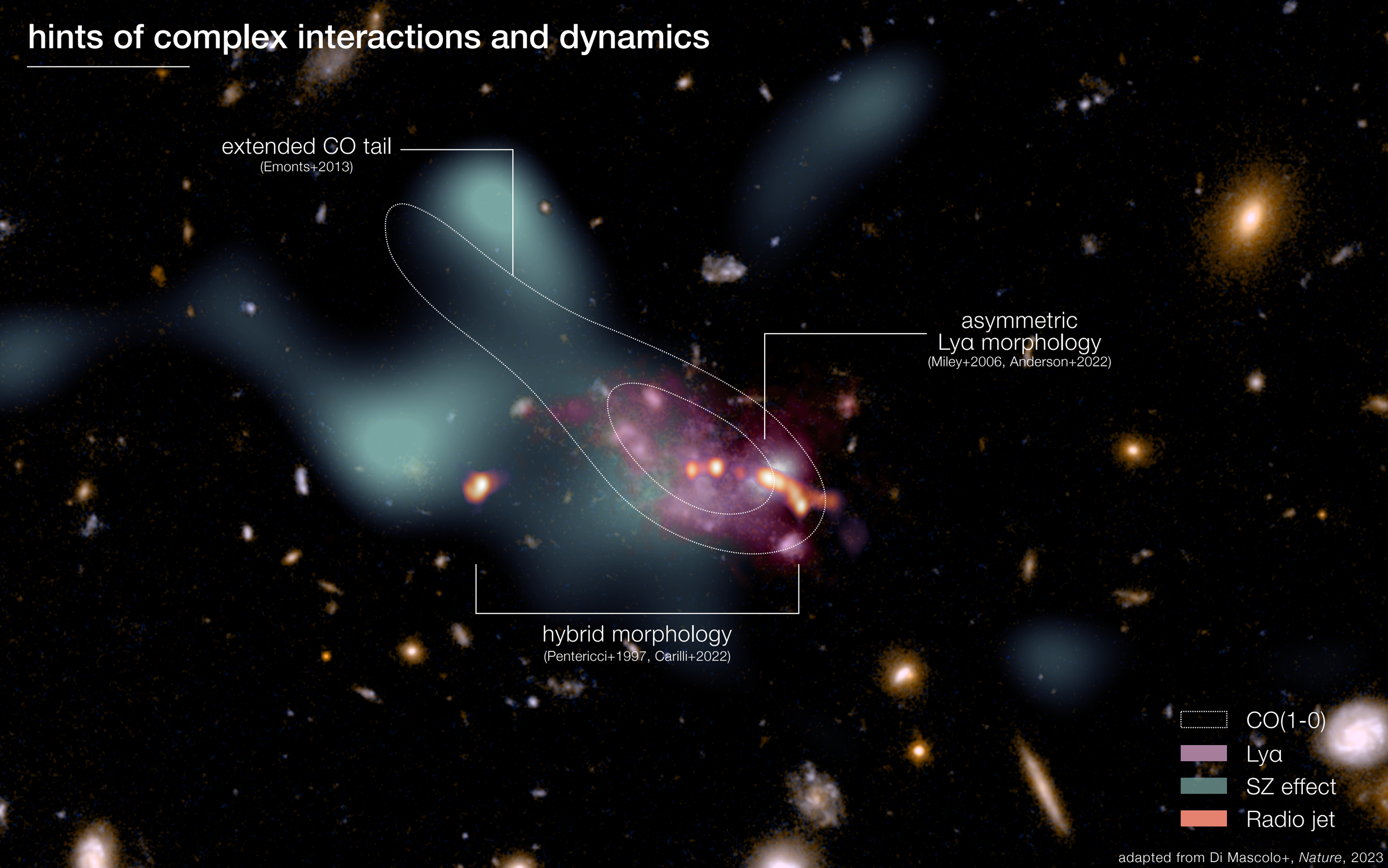
hints of complex interactions and dynamics



adapted from Di Mascolo+, *Nature*, 2023

hints of complex interactions and dynamics



adapted from Di Mascolo+, *Nature*, 2023

conclusions

For the first time, ALMA is allowing us to witness the emergence of proto-ICM in a protocluster complex

The SZ effect provides a reliable observational probe for detecting hot (thermalised) gas with virtually no limit in redshift

A multiwavelength characterisation highlights an extreme dynamical state, with complex interplay between multiple gas phases

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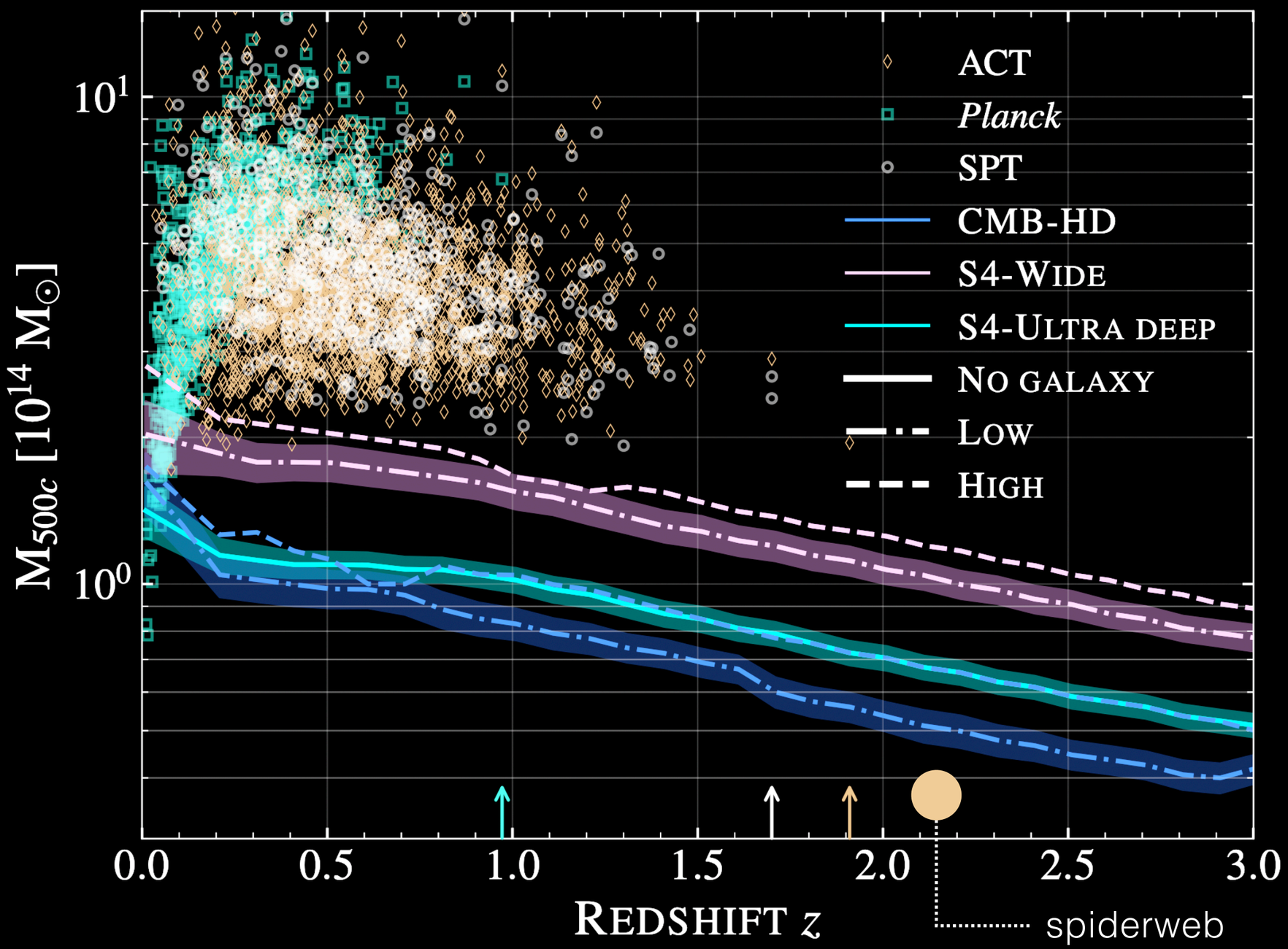
how and when the multi-phase protocluster gas turn into extended ICM?

how different mechanisms contribute to heating the proto-ICM?

adapted from Di Mascolo+, *Nature*, 2023

looking forward, at last



adapted from Mroczkowski+2023, Raghunathan+2022a,b

Atacama Large Aperture Submillimeter Telescope

5000m site on the Chajnantor Plateau near APEX, maximising **synergy** with observatories on the Plateau

an international partnership **open to collaborations** (e.g. Japanese LST) where Europe has a central role

powered by solar energy and equipped with hybrid storage solutions, enabling **~100% green operations**

multiple (6) instruments with large FoV:
4 with D_{FoV} = **1 deg**
2 with D_{FoV} = **2 deg**

50-m diameter
2.6” res @ 600 μm (500 GHz)
mapping speed **~10^3** better than ALMA

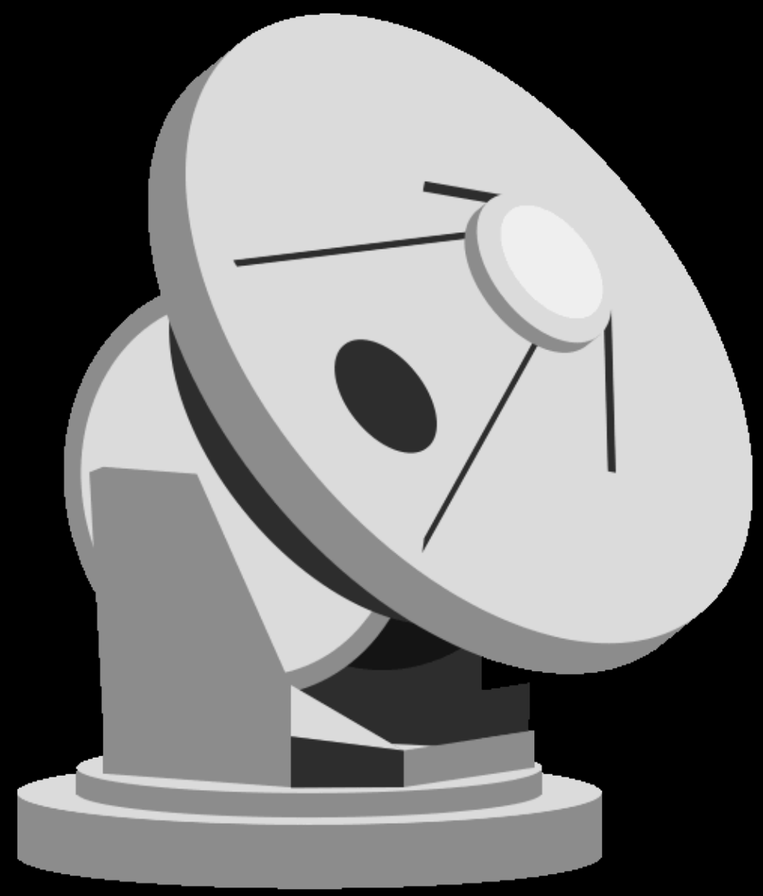
a flexible and efficient facility serving a **broad community**, performing PI observations and ambitious surveys

a new telescope whose design is driven by **transformational** and **unique** science goals

new types of survey science (ultradeep, sub-mm SDSS), re-thinking galaxy evolution and baryon cycling, detect and resolve the SZ effect from filaments connecting large scale structures, down to individual galaxies, …

looking forward, at last

looking forward, ~~at last~~ AtLAST



50-m diameter single dish,
with a high throughput and **~2 deg^2** FoV

mapping speed **~10^3** better than ALMA

broadband, multichroic imaging will allow for
enhanced SZ science

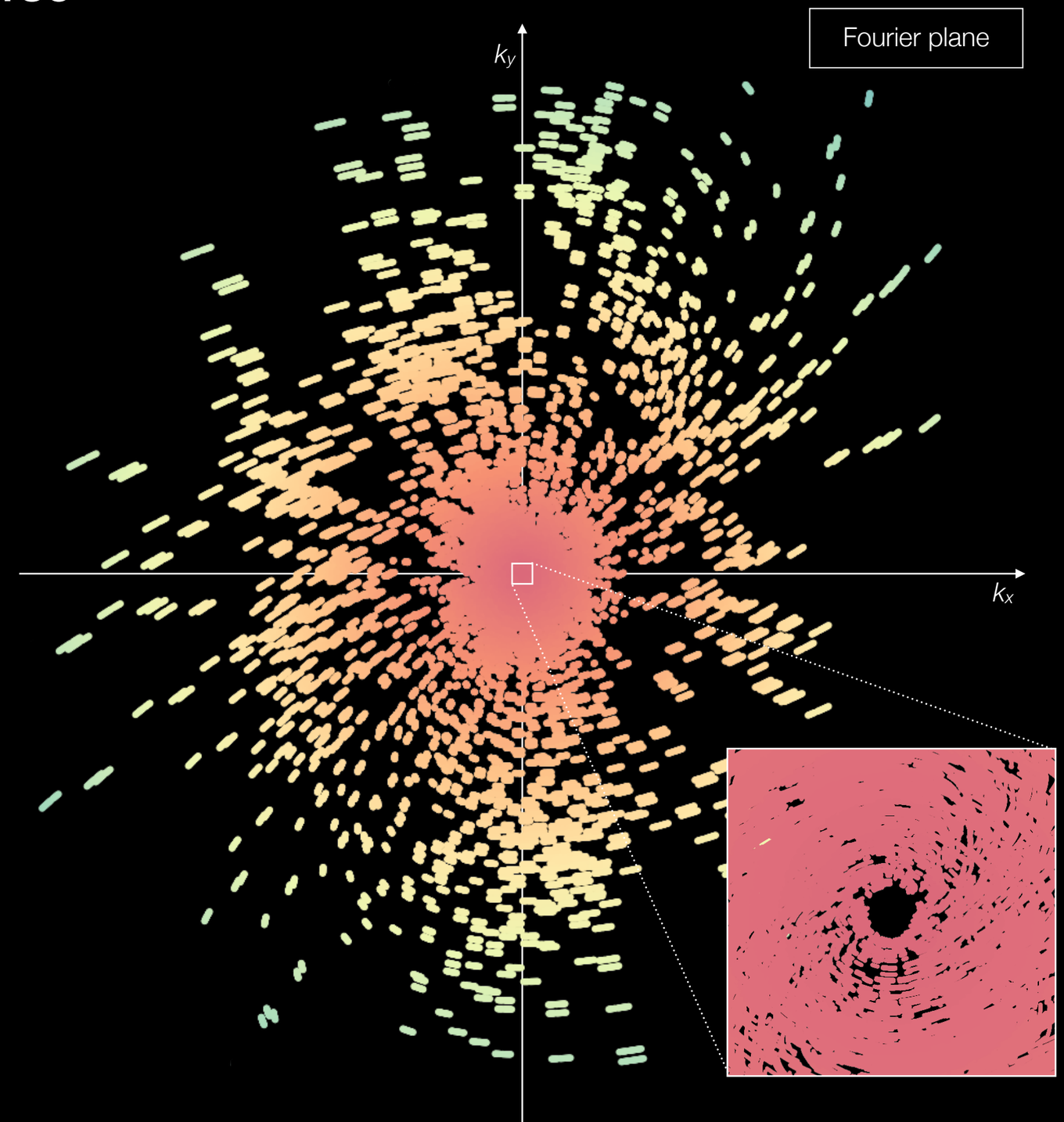
Stay tuned for some neat forecasts!

a high-pass filtered view of the Universe

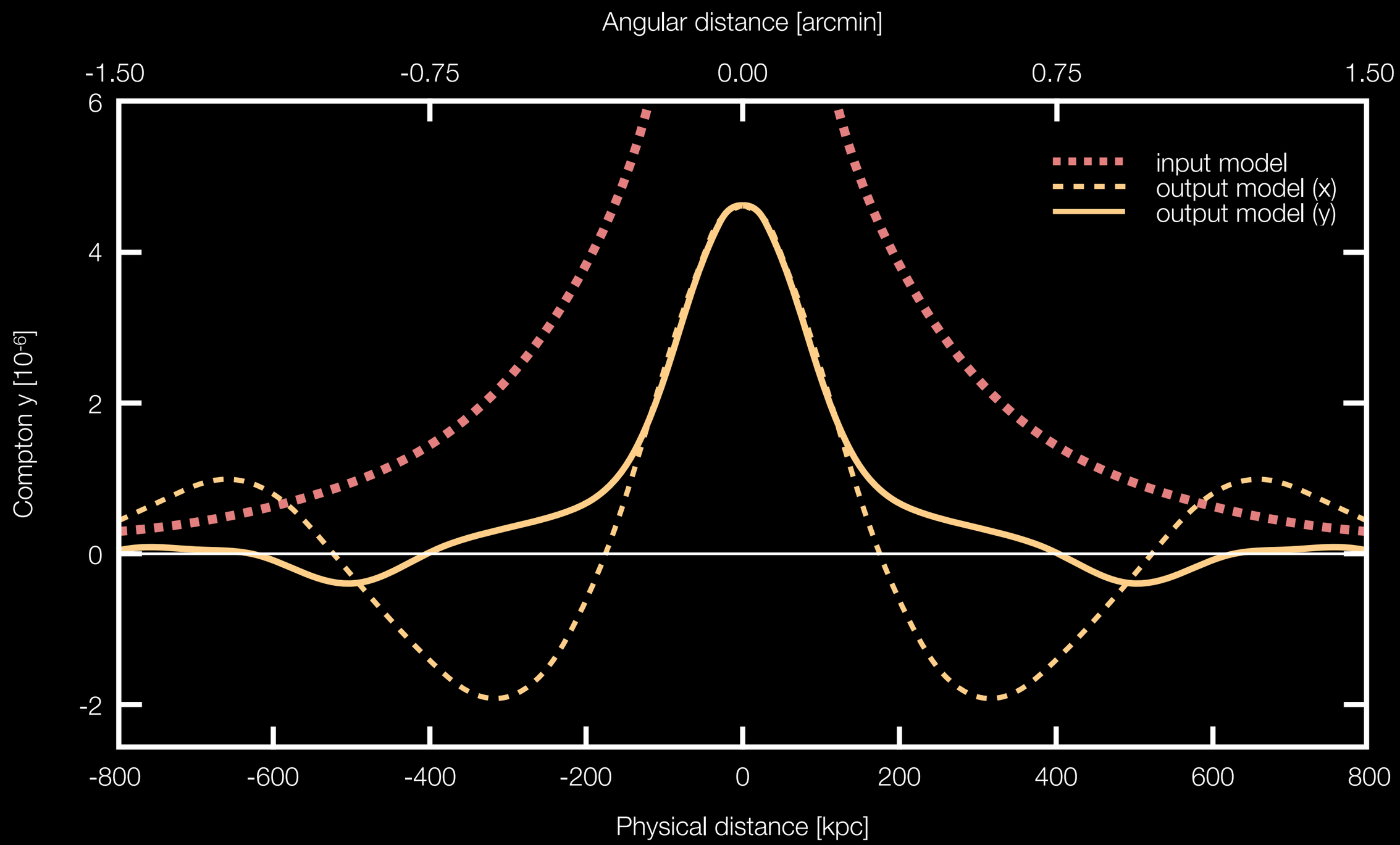
large-scale Fourier modes not observed,
resulting in dramatic information loss

existing imaging tools not optimised
for reconstruction of large-scale/SZ signal

modelling techniques limited by
lack of adequate descriptions

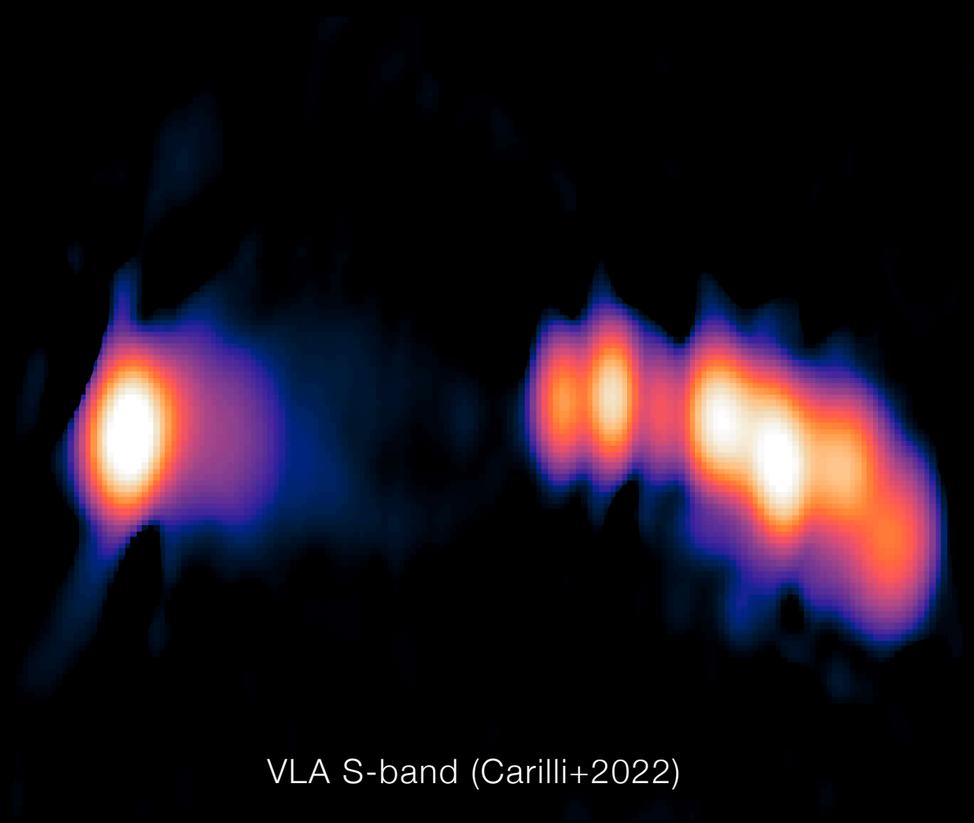


a high-pass filtered view of the Universe

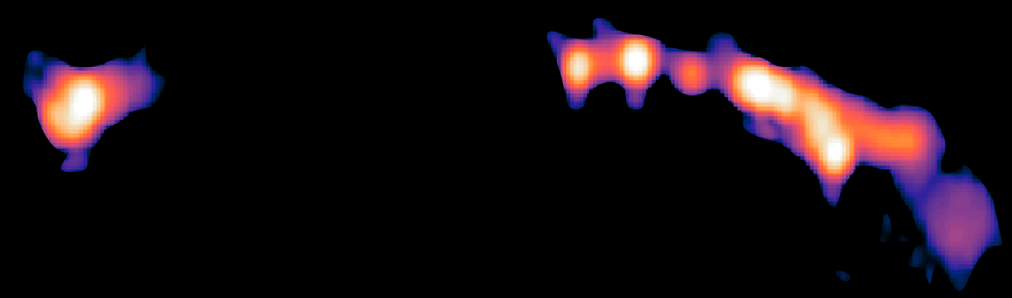


adapted from Di Mascolo+2020

morphologically complex “contamination”



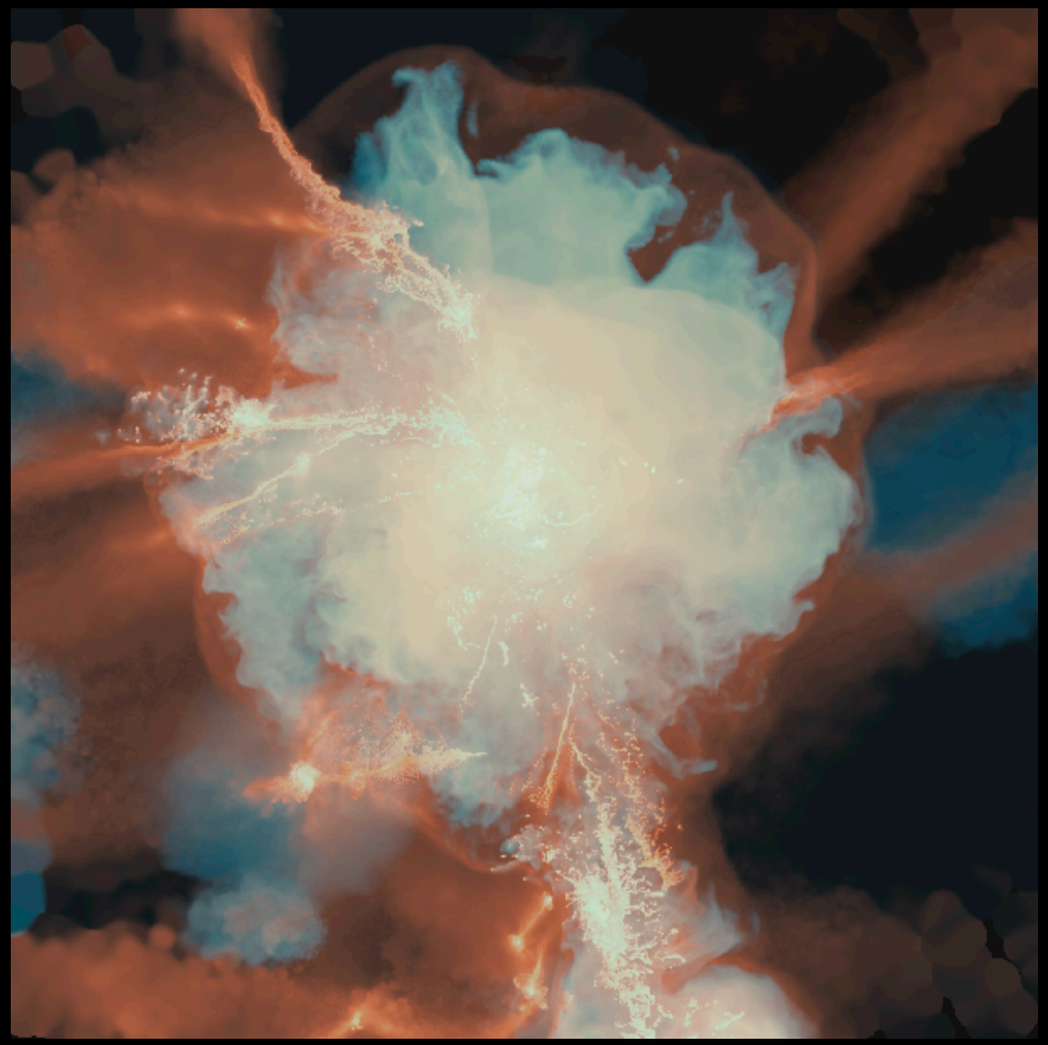
VLA S-band (Carilli+2022)

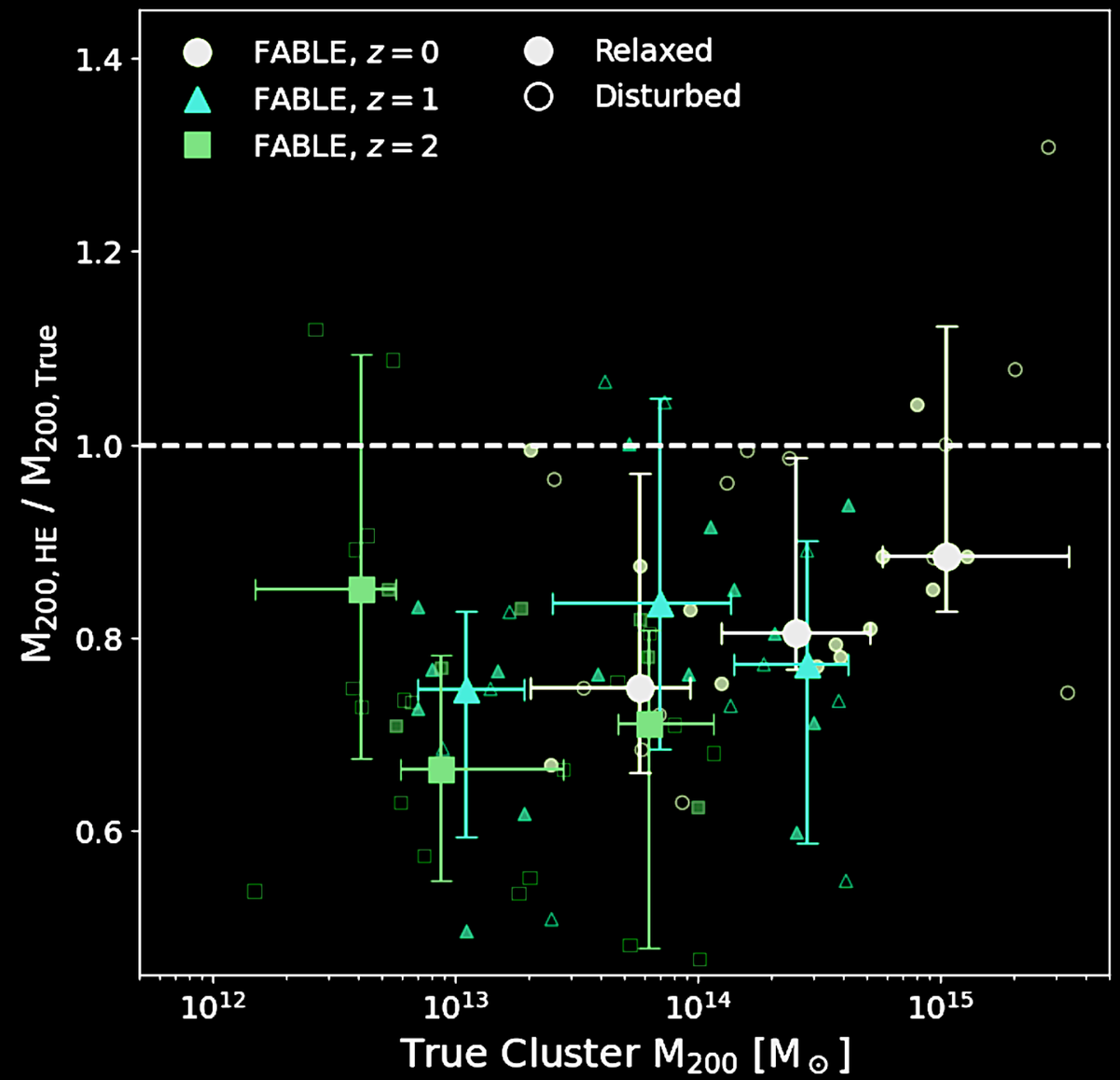


VLA X-band (Carilli+2022, Anderson+2022)

small masses…or systematics?

1. non-thermal pressure support

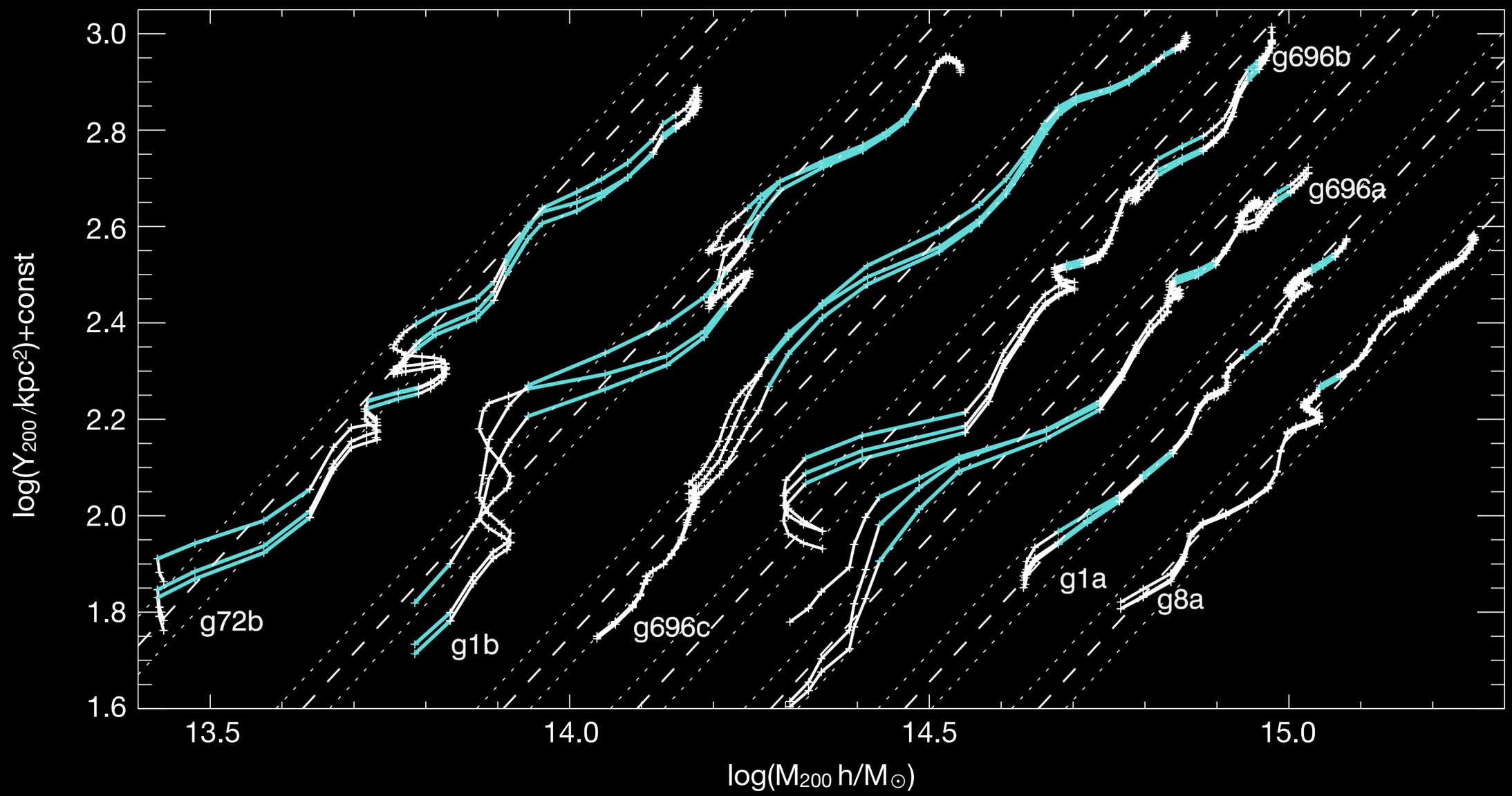




adapted from Bennet+2022

small masses…or systematics?

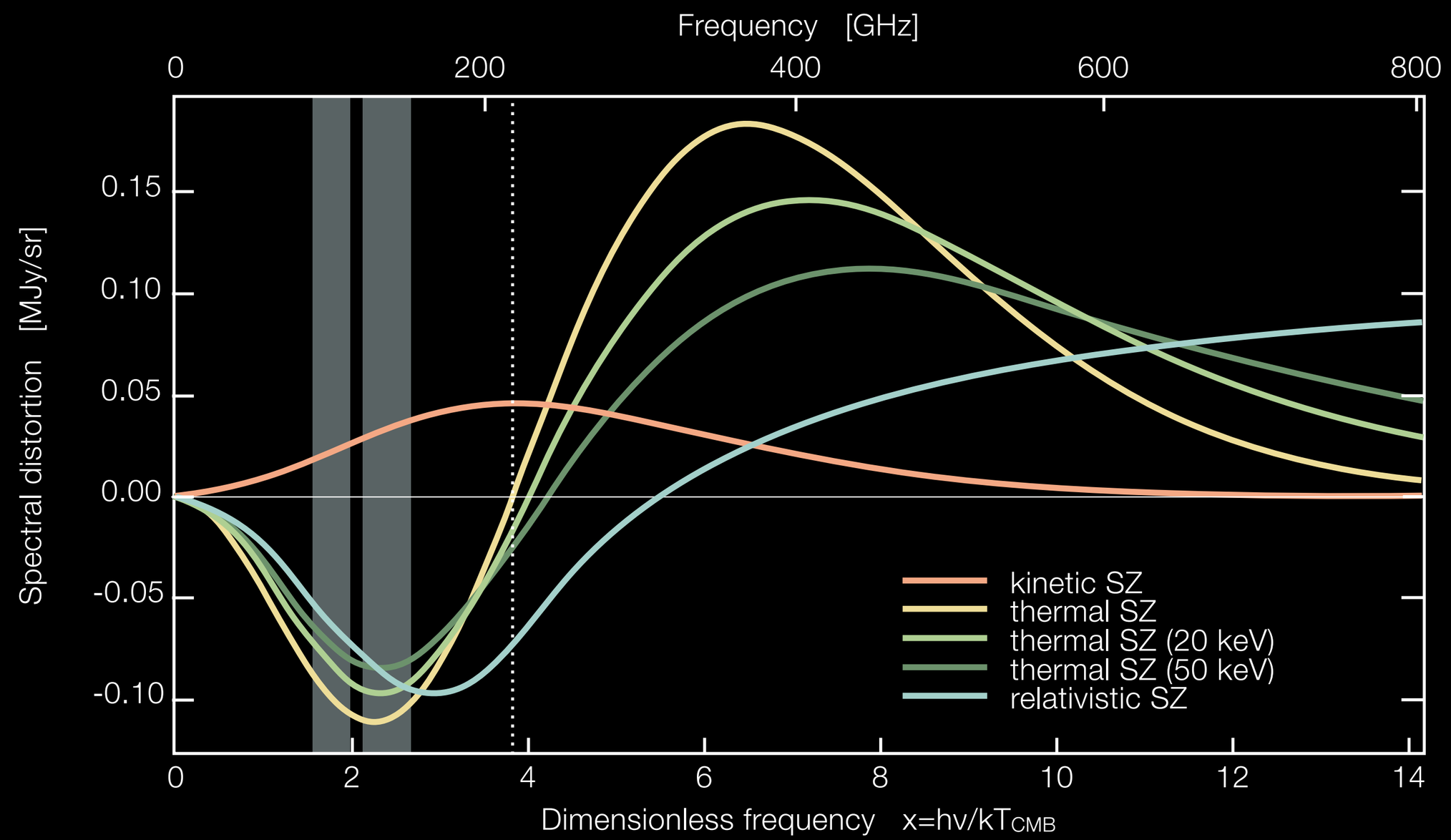
1. non-thermal pressure support
2. dynamical effects



adapted from Krause+2012

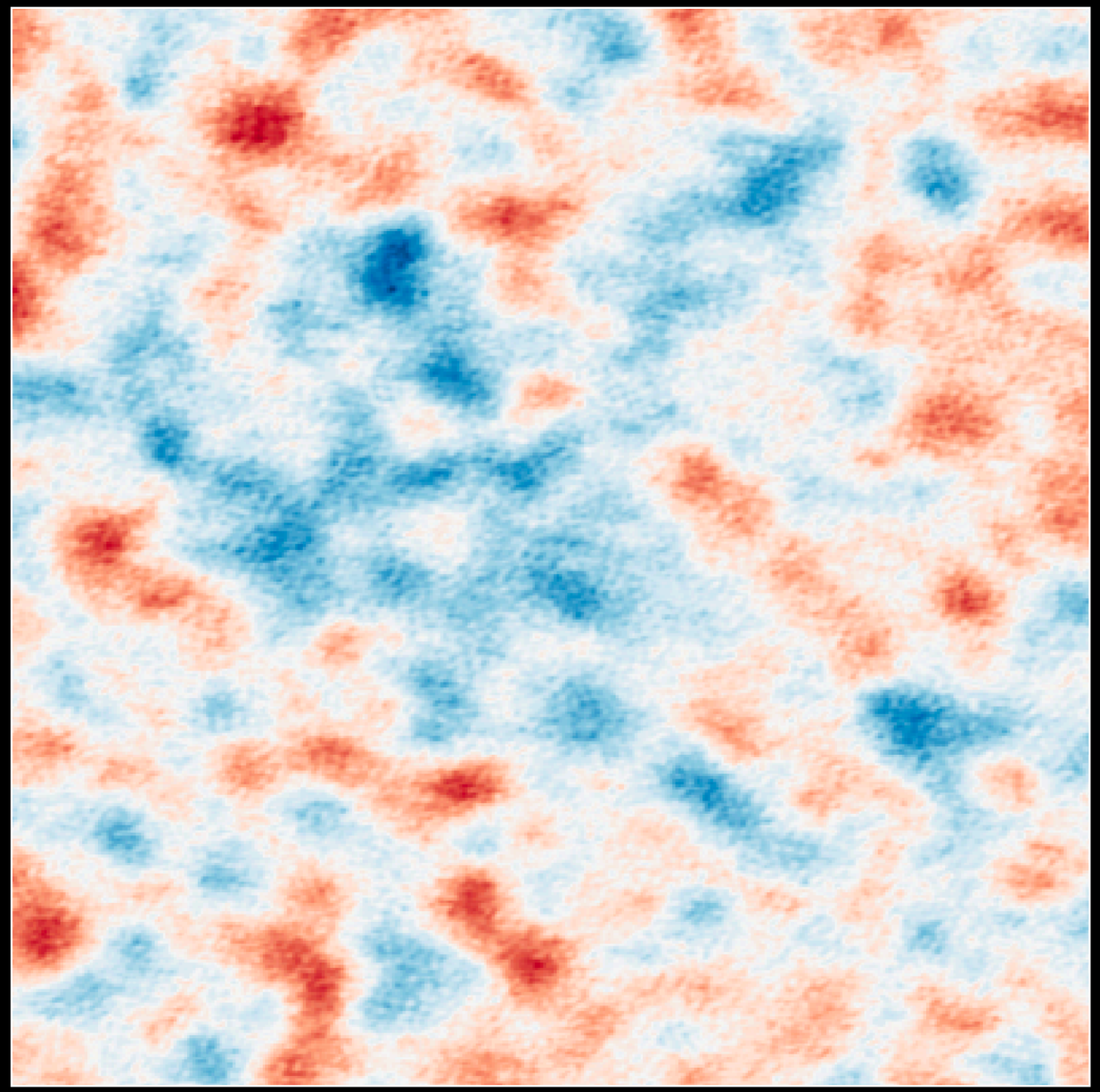
small masses…or systematics?

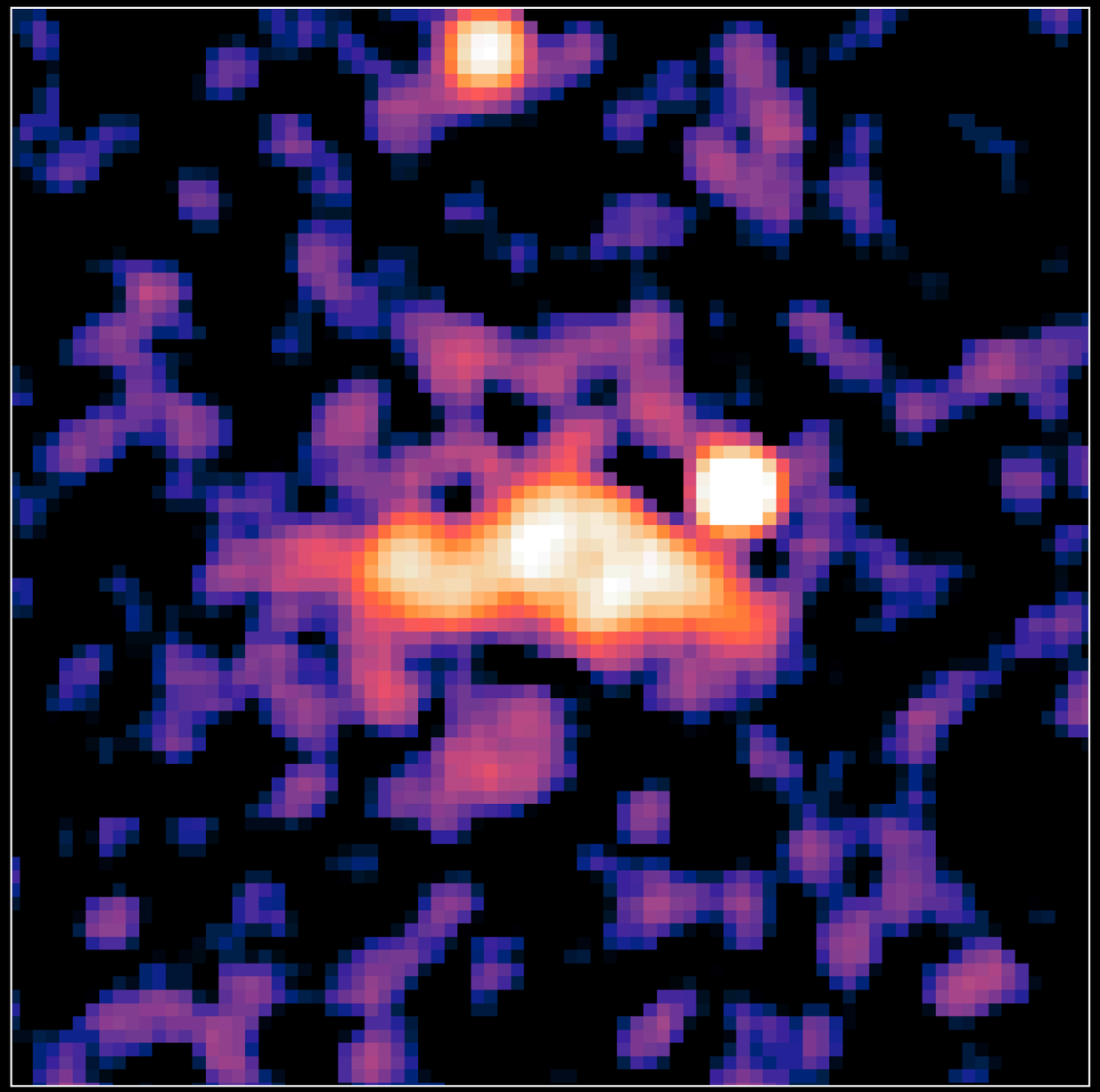
1. non-thermal pressure support
2. dynamical effects
3. many SZ flavours



adapted from Di Mascolo+2023

multiwavelength support





adapted from Di Mascolo+2023