Hot Gaseous Halos in Early Type Galaxies

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HARVARD & SMITHSONIAN

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   - with Chandra (*a team of 14 members*)
   - with XMM-Newton (+ *Nazma Islam, Kenneth Lin*)
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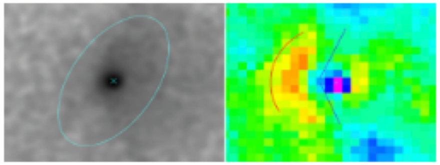
See Poster #303 by Nazma Islam

2. Hot Gas Temperature Profiles (+ *Liam Traynor*)
   - 6 types of T profiles
   - Universal (?) T profiles of hot gas
   - Hot cores

3. X-ray Scaling Relations
   - with $L_{X,GAS}$ - T_{GAS}
   - with M_{TOT}
   - with M_{GCS} as proxy of M_{TOT} (+ *Nick James*)

(CGA Home page: http://cxc.cfa.harvard.edu/GalaxyAtlas/v1/)



Chandra Early-Type Galaxy Atlas

Credits & Acknowledgments

- Acknowledgments

Chandra Galaxy Atlas products

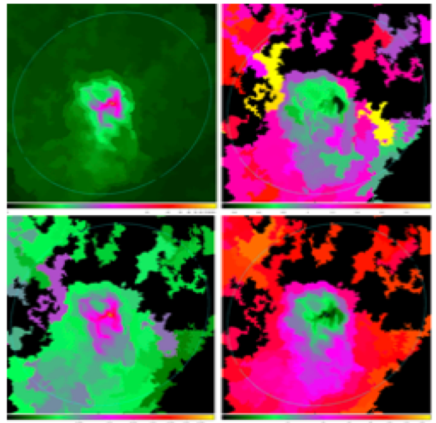
- CGA targets

Notes on Catalog

- List of data products
- Notes on individual galaxies
- Data Caveats

Links to Related Sites

- Chandra X-ray Observatory Center
- Chandra Proposal Information



Chandra Early-Type Galaxy Atlas

The hot gaseous halos in early type galaxies play a crucial role in understanding the formation and evolution of galaxies. Structural features of the hot ISM identified by Chandra (including jets, cavities, cold fronts, filaments and tails) point to key evolutionary mechanisms, e.g., AGN feedback, merging history, accretion/stripping and star formation and its quenching. In this Chandra Galaxy Atlas project, we systematically analyze the archival Chandra data of 70 ETGs to study the hot ISM. Taking full advantage of the Chandra capabilities, we derive uniform data products of spatially resolved datasets with additional spectral information. We make these products publicly available and use them for our focused science goals.

We use both ACIS-I and ACIS-S imaging observations with no grating. We limit the minimum exposure time at 10 ksec. For ACIS-I observations, we use data from the four front-illuminated chips, I0-I3 (CCDID=0-3), while for ACIS-S, we use data from the back-illuminated chip, S3 (CCDID=7) where the target lies and from the front-illuminated chip, S2 (CCDID=6) where the extended diffuse emission is often visible.

CGA

The full description of this atlas can be found in Kim et al. 2019
CGA Sample Galaxies html pdf
Individual Chandra Observations html pdf
Global Properties of Hot ISM html pdf
Total Luminosity and Temperature of Hot ISM html pdf
Overview of of the data Analysis Workflows pdf

Team

The Chanda Galaxy Atlas is maintained by the CGA team.
Dong-Woo Kim, Craig Anderson, Doug Burke, Raffaele D'Abrusco, Giuseppina Fabbiano, Antonella Fruscione, Jennifer L. Lauer, Michael McCollough, Doug Morgan, Amy Mossman, Ewan O'Sullivan, Alessandro Paggi, Ginevra Trinchieri, Saeqa Vrtilek.
Please send comments and/or questions to dkim@cfa.harvard.edu

Publications

Kim et al. 2019, ApJS, 241, 36 Chandra Early-Type Galaxy Atlas
Kim et al. 2018, ApJ, 853, 129 Disturbed Fossil Group Galaxy NGC 1132
Paggi et al. 2017, ApJ, 844, 5 Constraining the Physical State of the Hot Gas Halos in NGC 4649 and NGC 5846
Traynor et al. 2018 (AAS poster) What Can The Temperature Profiles of Hot Halos Tell Us?
Vrtilek et al. 2018 (Chandra Workship poster) Identifying the nature of point sources in external galaxies
Kim et al. 2017 (AAS HEAD poster) Chandra Early-Type Galaxy Atlas

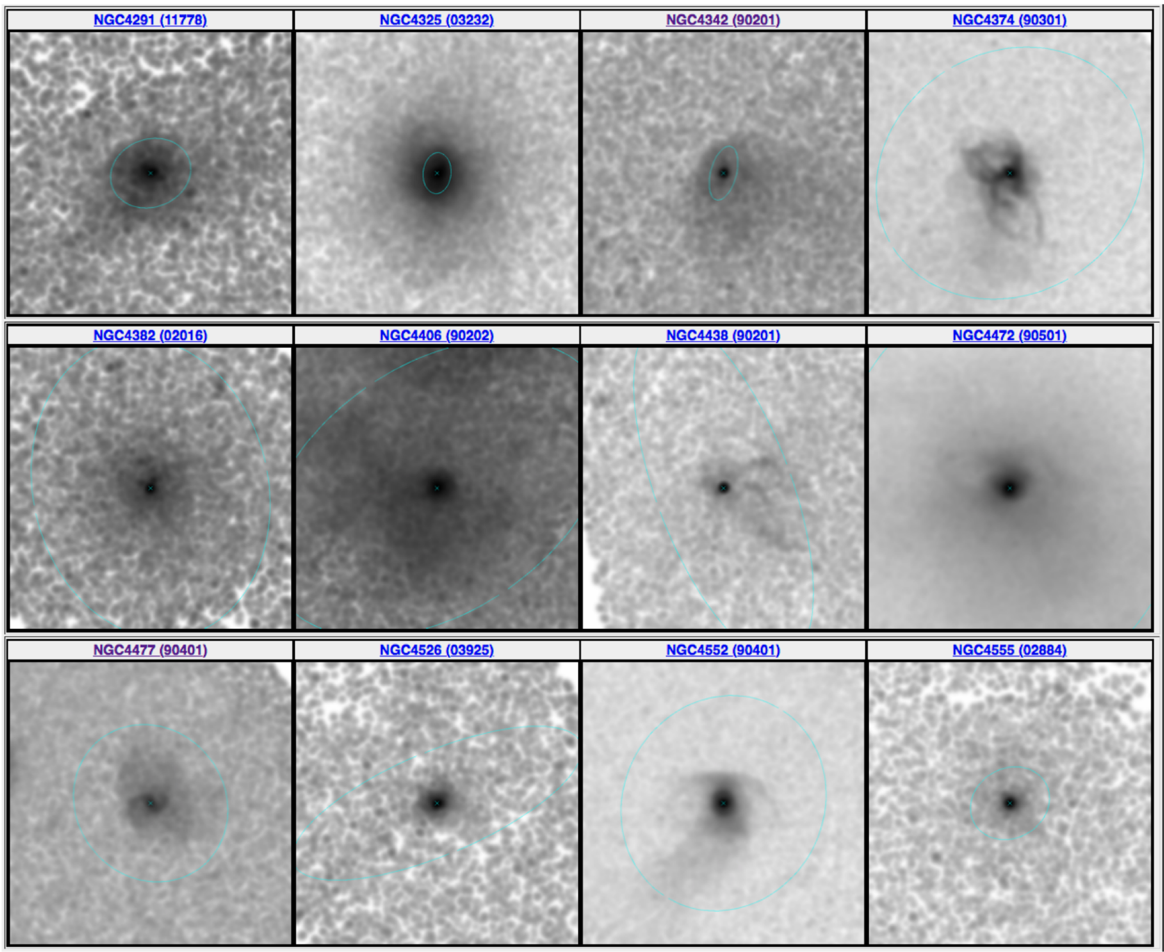
Chandra Galaxy Atlas
Main Page | CGA targets list

Chandra Galaxy Atlas

(CGA Home page: http://cxc.cfa.harvard.edu/GalaxyAtlas/v1/)

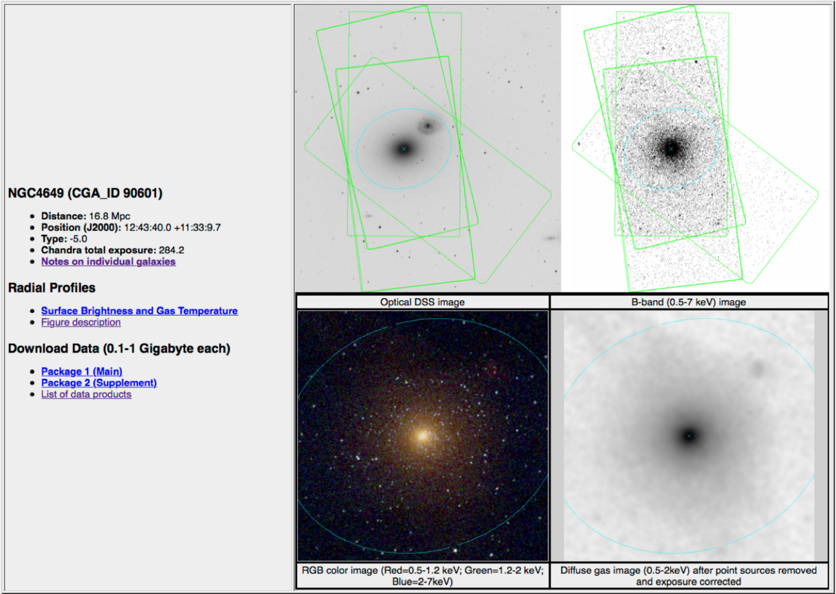
Catalog of Chandra Galaxy Atlas Targets

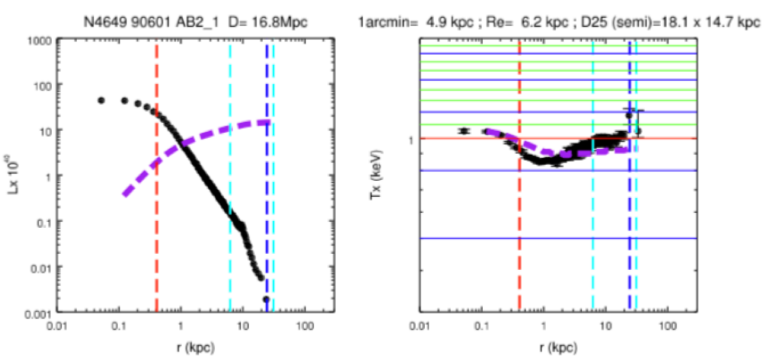
Name	Position (J2000) (R.A., Dec.)	Distance [Mpc]	ObsIDs	Exposure time [ks]	Data Products
IC1262 (90401)	17:33:2.0 +43:45:34.6	130.0	2018,6949,7321,...	138.8	Package 1 Package 2
IC1459 (02196)	22:57:10.6 -36:27:44.0	29.2	2196	52.5	Package 1 Package 2
IC1860 (10537)	02:49:33.7 -31:11:21.0	93.8	10537	36.8	Package 1 Package 2
IC4296 (03394)	13:36:39.0 -33:57:57.2	50.8	3394	24.3	Package 1 Package 2
NGC0193 (90201)	00:39:18.6 +03:19:52.0	47.0	4053,11389	106.7	Package 1 Package 2
NGC0315 (90201)	00:57:48.9 +30:21:8.8	69.8	4156,855	55.9	Package 1 Package 2
NGC0383 (02147)	01:07:24.9 +32:24:45.0	63.4	2147	42.9	Package 1 Package 2
NGC0499 (90401)	01:23:11.5 +33:27:38.0	54.5	10536,10865,10866,...	37.4	Package 1 Package 2
NGC0507 (90201)	01:23:40.0 +33:15:20.0	63.8	2882,317	60.3	Package 1 Package 2

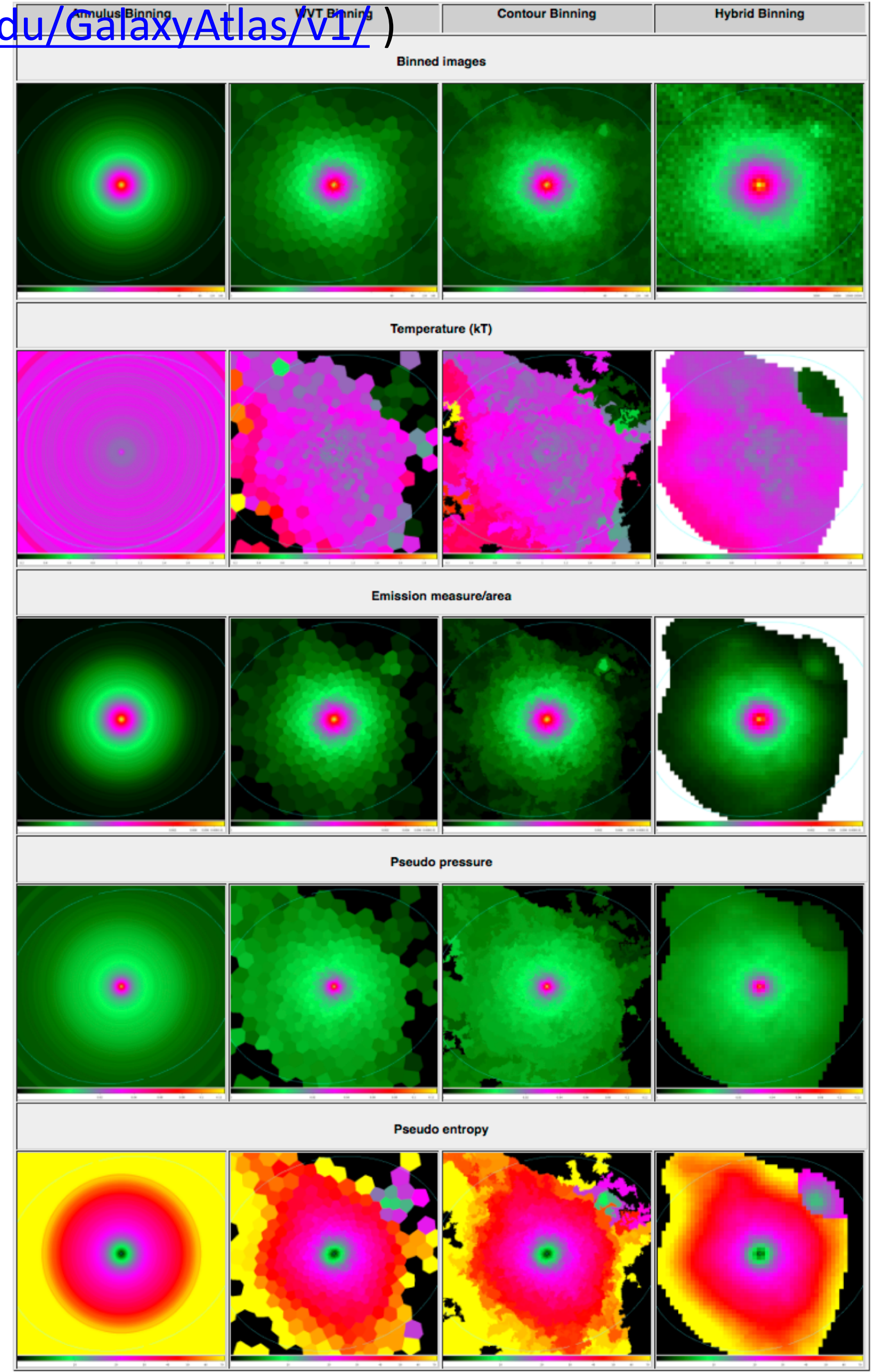


Chandra Galaxy Atlas

(CGA Home page: http://cxc.cfa.harvard.edu/GalaxyAtlas/v1/)







Chandra Galaxy Atlas

case study: NGC 1132

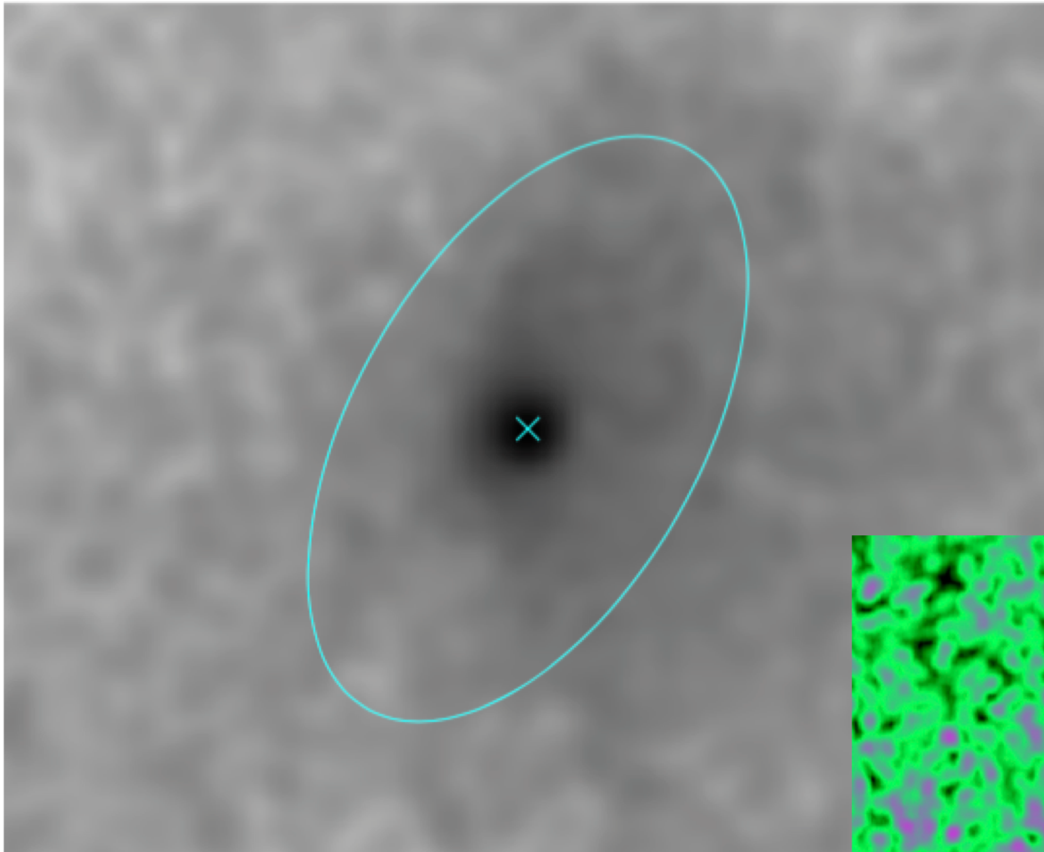
a prototype fossil group

D = 95 Mpc
L_X = several x 10^{42} erg/s
Δm_{12} = 2 mag

the end product of
assembly by mergers
➔ expected to be
➔ relaxed and undisturbed

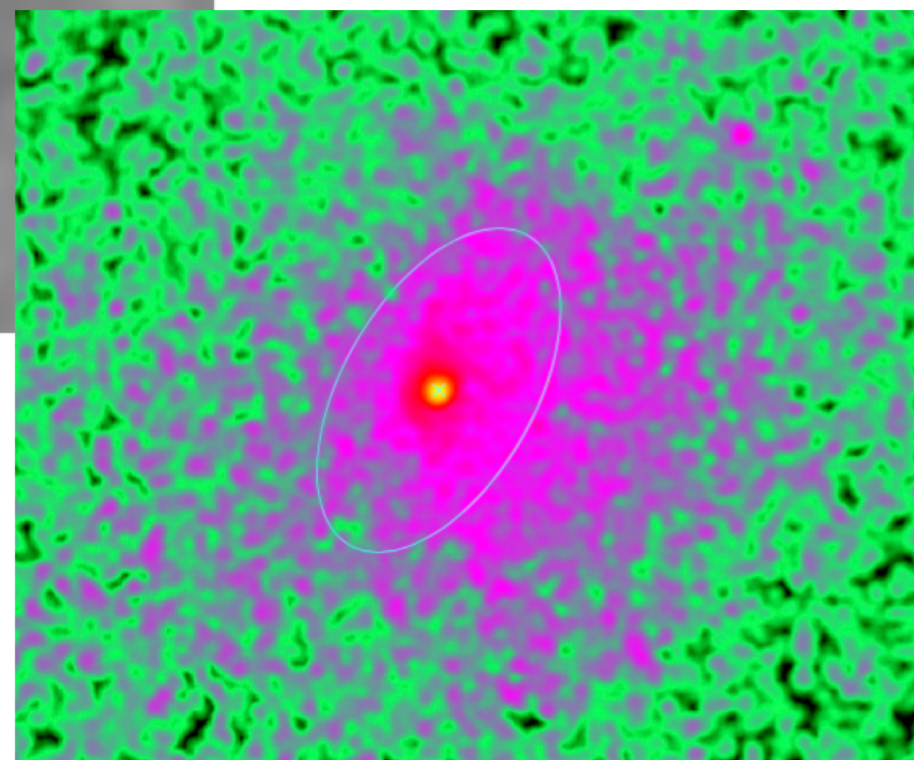
recent cosmological simulations:
rejuvenated fossil system
by renewed infall
growth of a massive galaxy may continue
(e.g., Kanagusuku et al. 2016)

Diffuse image of NGC 1132



0.5-2 keV
point source removed/filled
exposure corrected
smoothed with Gaussian σ=3.5”

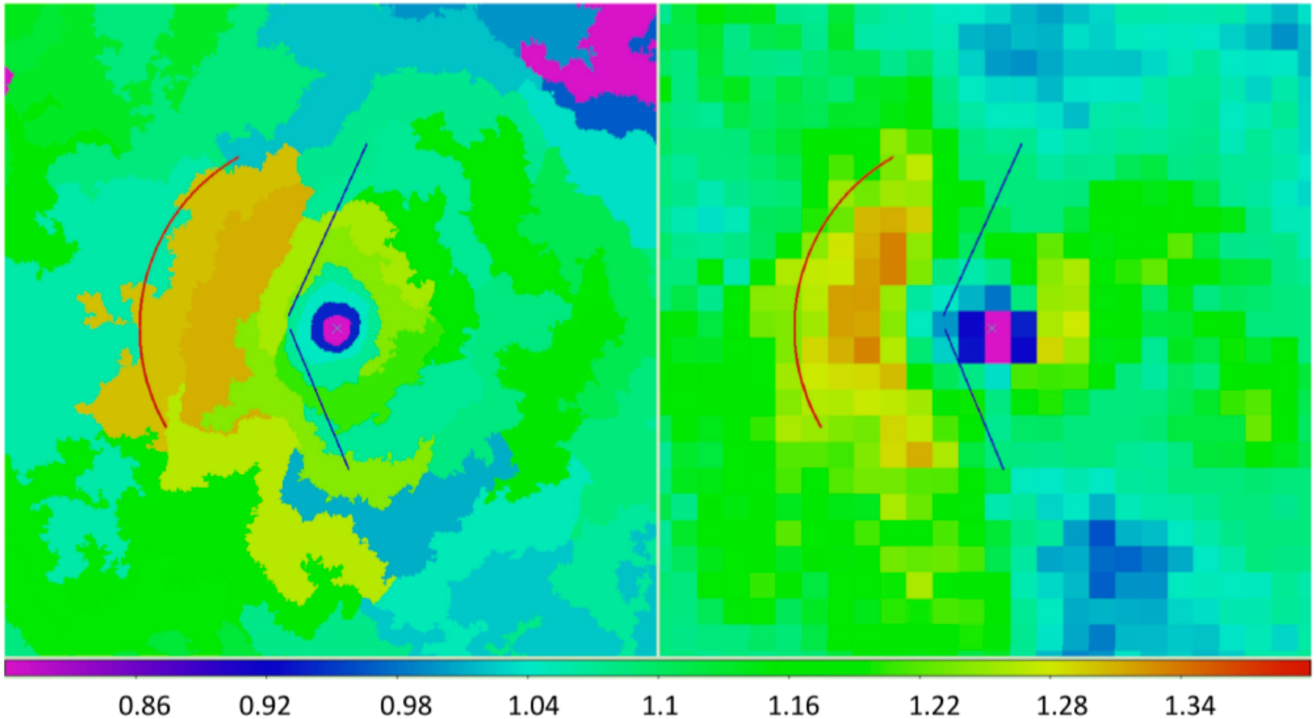
➔ edge to the East,
➔ sharp discontinuity

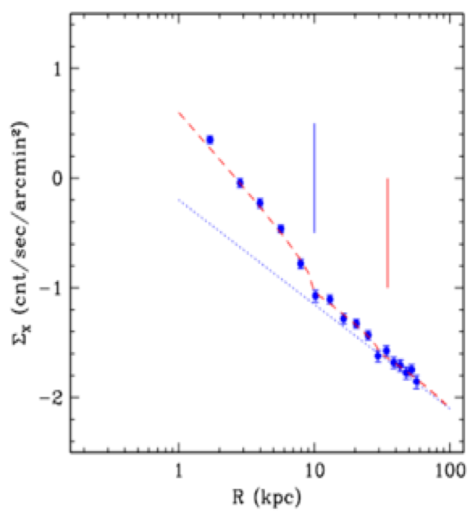


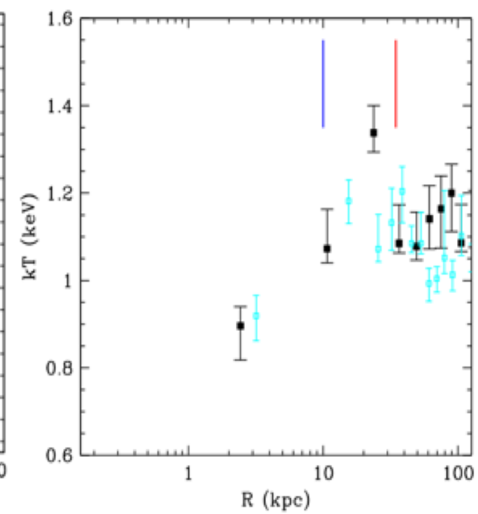
smoothed with Gaussian σ=10”

➔ asymmetric,
➔ extended toward the West

2D temperature map of NGC 1132







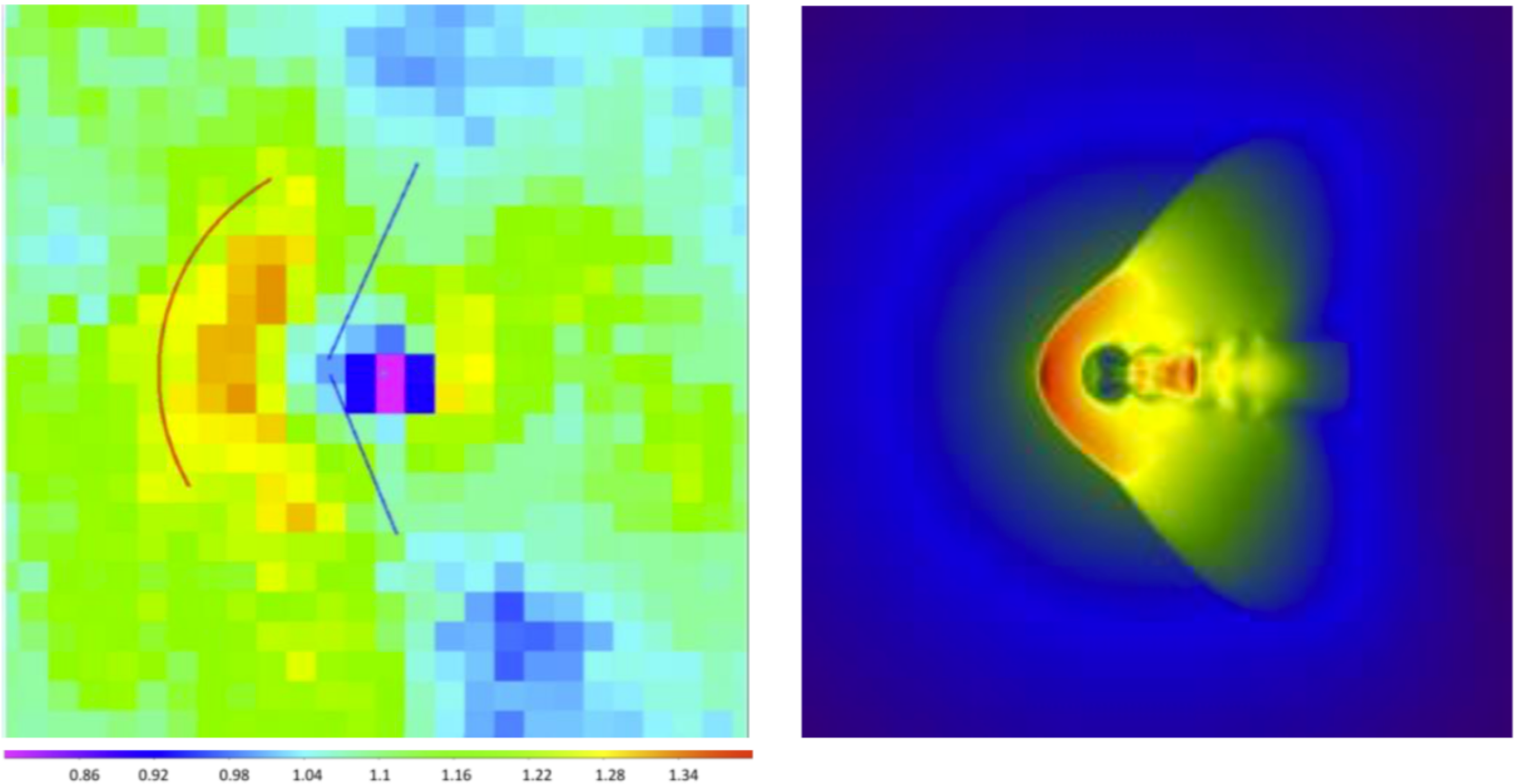


Fig 2. (left) The observed temperature map obtained with the 2D adaptive binning method (O'Sullivan et al 2014). The temperature ranges from 0.8keV to 1.4 keV. Marked are the location of the discontinuity seen in Fig.1a (in blue) and the possible shock (in red) at r~30 kpc. (right) The simulated temperature map (ZuHone and Kowalik 2016) for a head-on collision of two systems with a 1:10 ratio.

Disturbed hot halo in a fossil group ?

observed features

- cold front to the East at r ~ 10 kpc
- extended halo toward the West
- possible shock front to the East at r ~ 20 kpc

What could disturb the hot halo in a fossil group?

possible origins of the disturbed hot halo

- sloshing (needs a nearby companion)
- ram pressure (needs a bigger environment)
- nuclear outburst (predicts a temperature increasing toward the center)
- minor merger with a small impact parameter
  - consistent with cosmological simulations
  - consistent with possible optical shells (Alamo-Martinez et al. 2012)

deeper observations necessary

➔ the paradigm of the fossil system as relaxed/undisturbed needs to be revised

XMM-Newton data

larger effective area and larger field of view (compared to Chandra)

Allow to explore the diffuse ***outskirts***

Global properties from the entire system

(e.g., hot halo at the outskirts, DM profiles, M_{VIR} ...)

Allow to measure reliable abundance maps

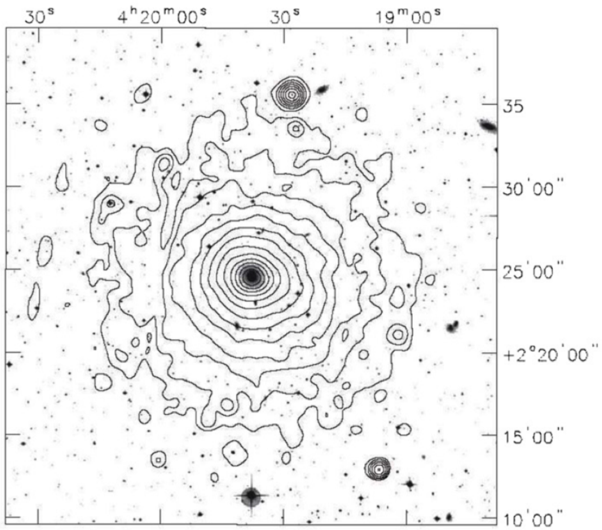
2D mapping (SB, 2D T-map, 2D ***Fe-map***)

Fe – hard to determine, but critical to many science topics

(e.g., chemical enrichment, density/entropy/mass profile ...)

(See also Poster #303 by Nazma Islam)

case study: NGC 1550

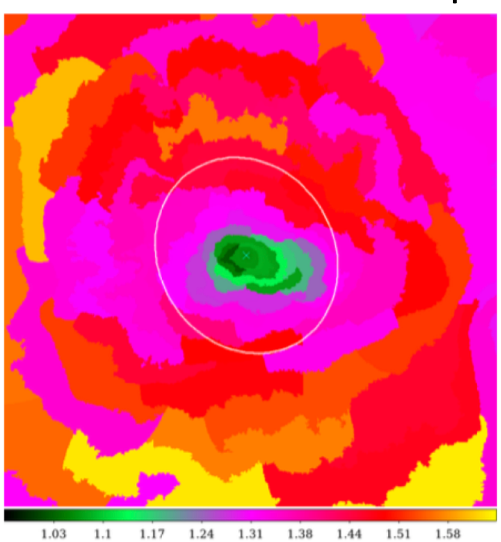


D = 51 Mpc
$L_X = 10^{43}$ erg/s
one of the most luminous local groups

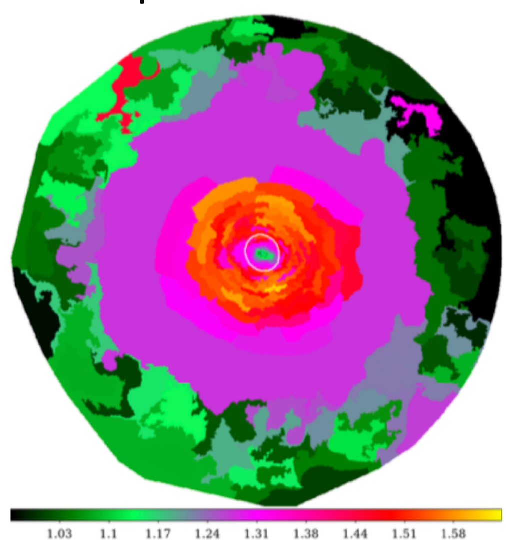
On a large scale, the hot halo is smooth and circularly symmetric

(Kawaharada et al. 2009; Sun et al. 2003)

Temperature maps

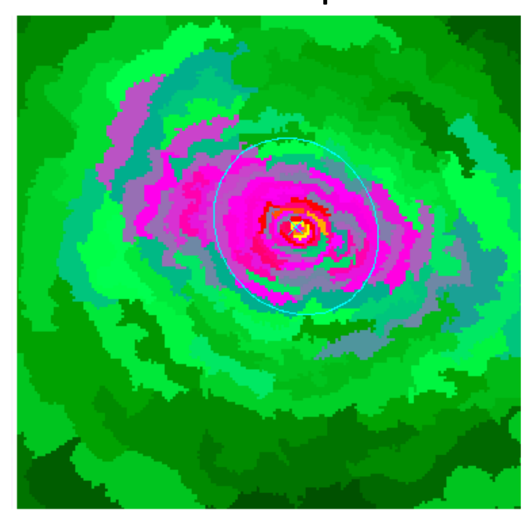


Chandra



XMM-Newton

Fe maps



<u>**Summary**</u>

- **Chandra Galaxy Atlas**

  1st version of 70 ETGs released (Kim et al. 2019)
  The data products can be viewed and downloaded from
  http://cxc.cfa.harvard.edu/GalaxyAtlas/v1/

  Will improve with feedback

- **X-ray Galaxy Atlas**

  XMM-Newton data are being analyzed in the 2nd version
  Fe map and outskirts
  Radial Profiles (All but T depend on the Fe profile)

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    - 6 types of T profiles
    - Universal (?) T profiles of hot gas
    - Hot cores

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    - with $L_{X,GAS}$ - T_{GAS}
    - with M_{TOT}
    - with M_{GCS}

The previous work by Diehl & Statler (2008)

- 4 years of Chandra data
- 54 ETGs (with 36 T-profiles)
- 4 T-profile types (hybrid-bump, positive, negative, quasi-isothermal)

This work

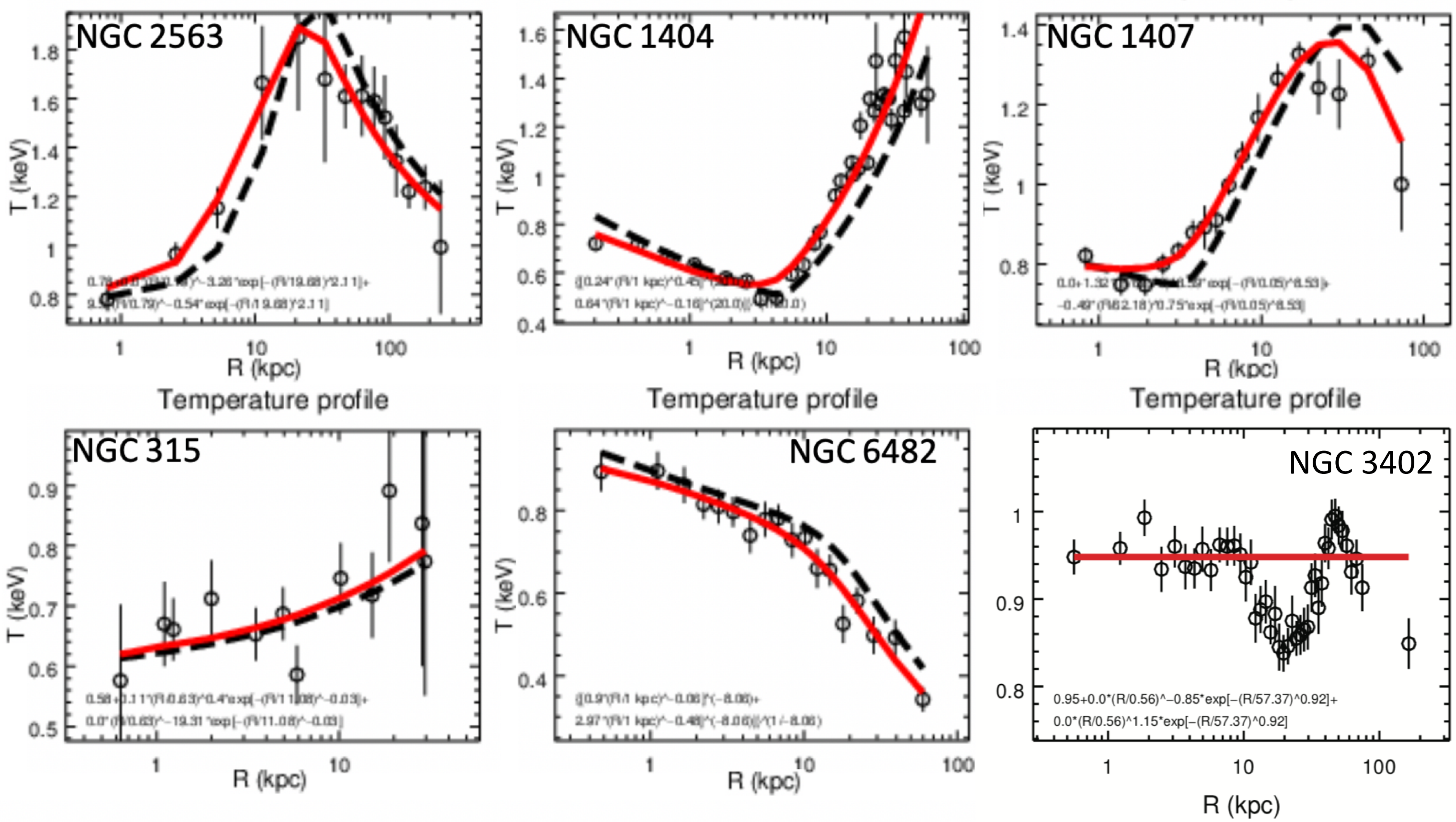
- 15 years of Chandra data
- 70 ETGs (with 60 T-profiles)
- 6 T-profile types (3 new, hybrid-dip, double-break, irregular; no isothermal)

Radial Temperature Profile

hybrid-bump
26 (43%)

hybrid-dip
14 (23%)

double-break
4 (7%)

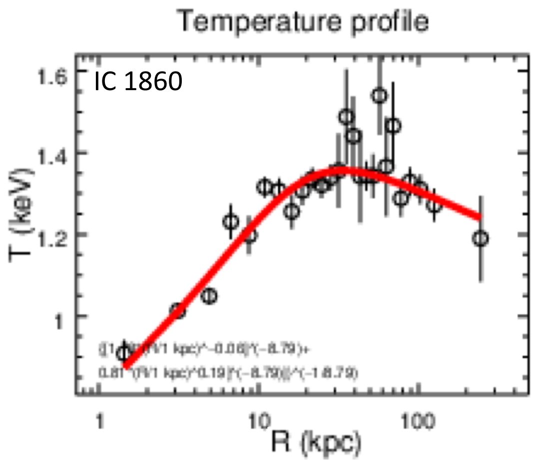


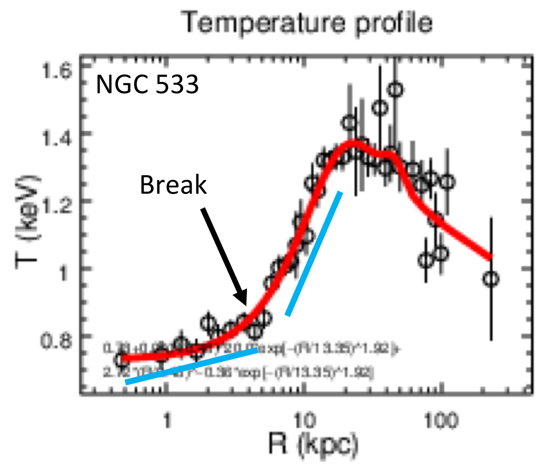
positive
5 (8%)

negative
8 (13%)

irregular
3 (5%)

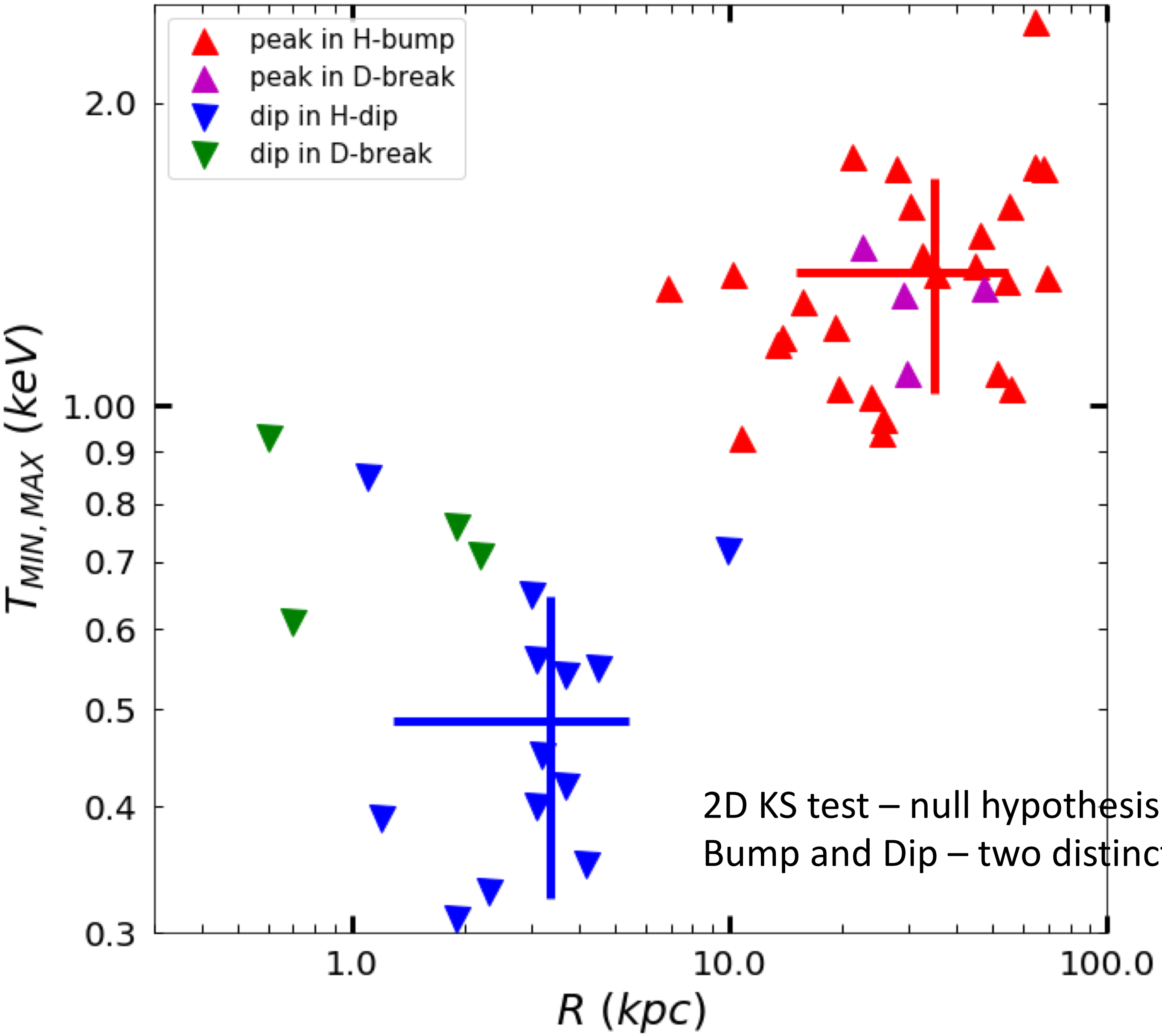
hybrid-bump





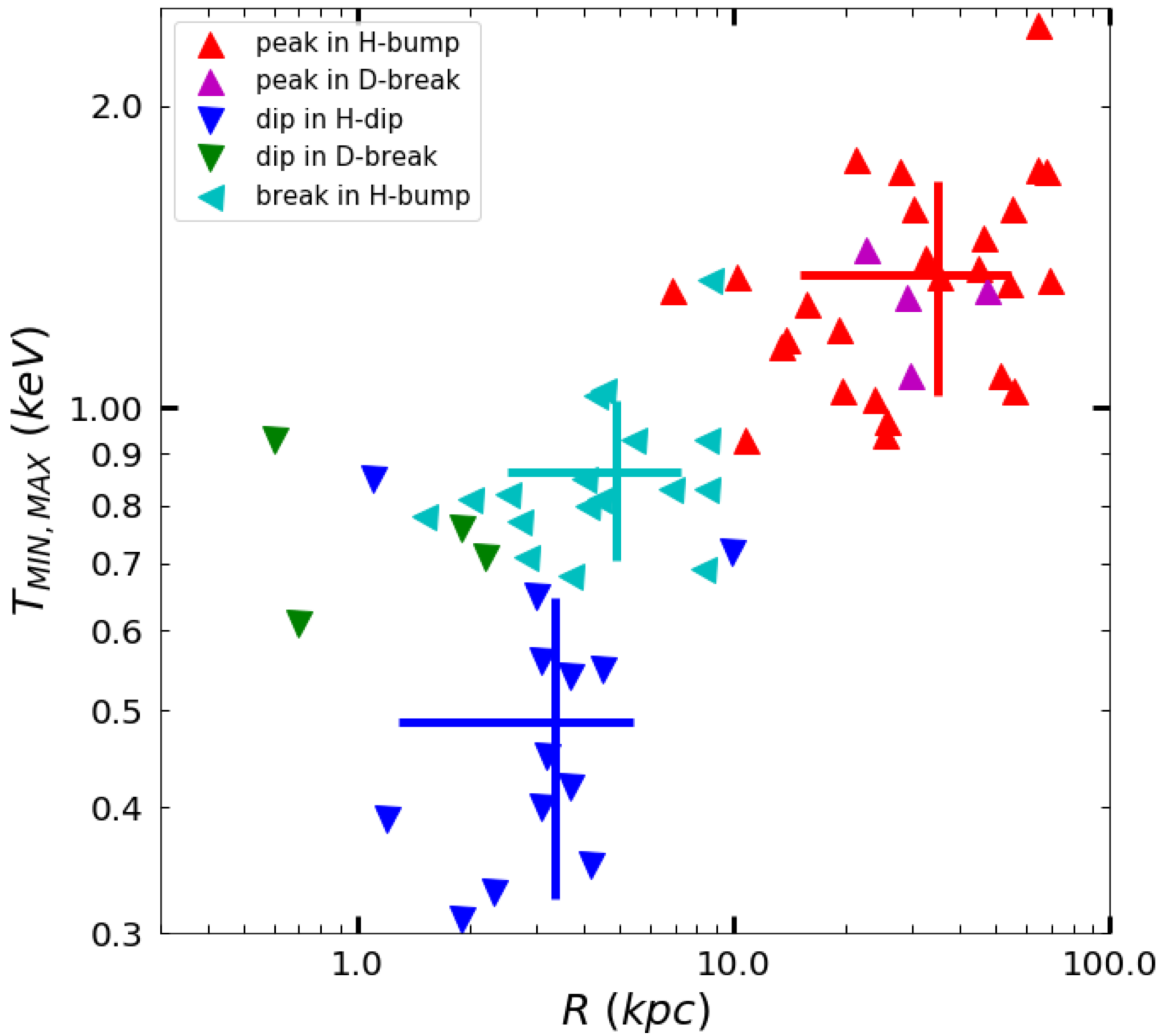
66% (17 / 26) – presence of a 2nd inner break

Compare Bumps and Dips

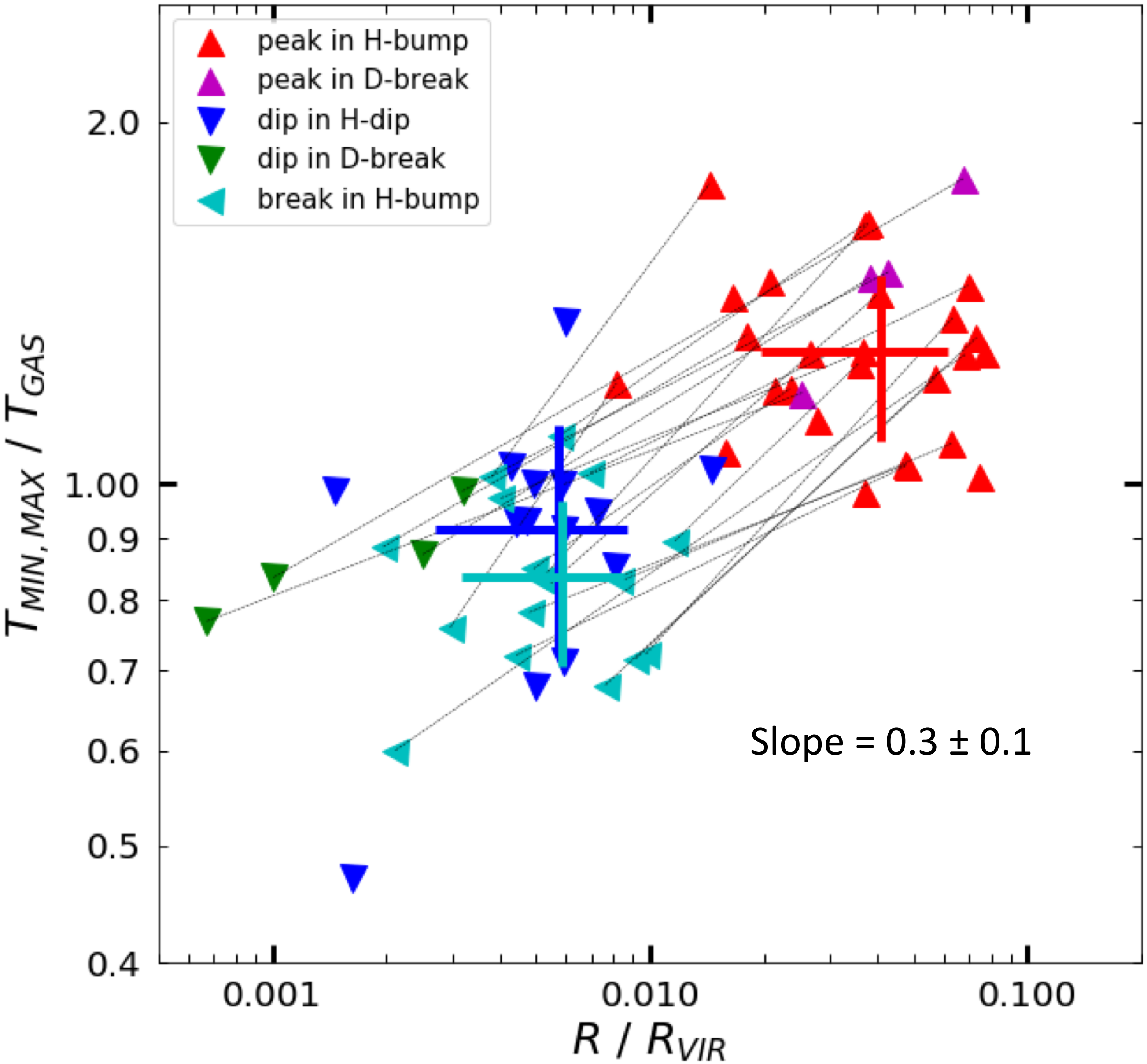


2D KS test – null hypothesis prob = 4 x 10^{-8}
Bump and Dip – two distinct features

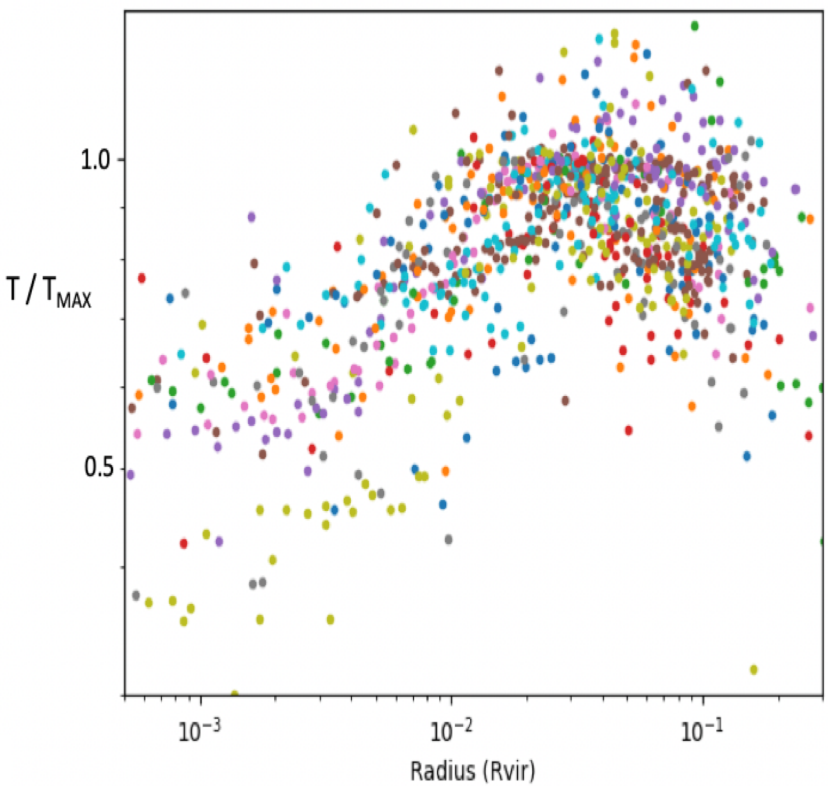
Compare Bumps and Dips

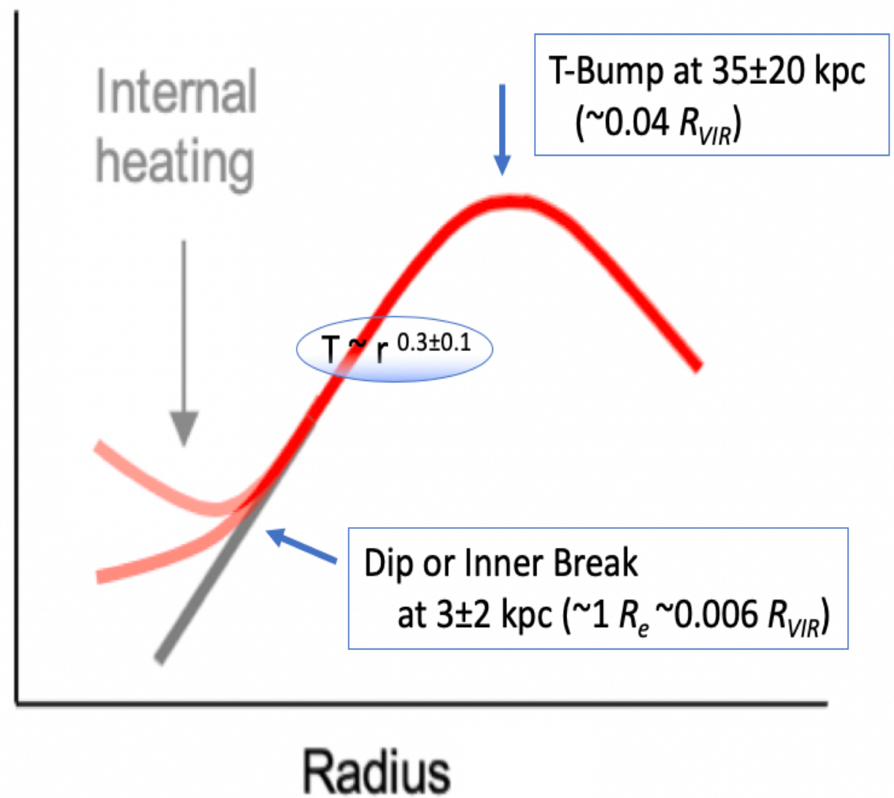


Compare Bumps and Dips

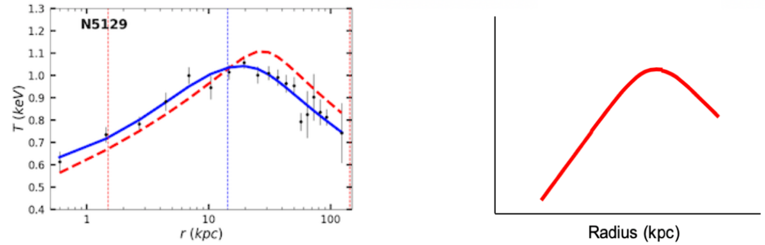


hybrid-bump + double-break : 30 (50%)

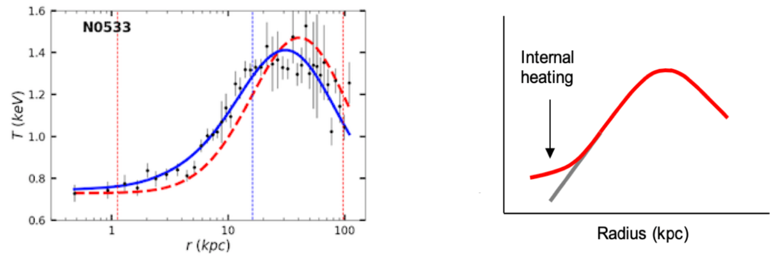




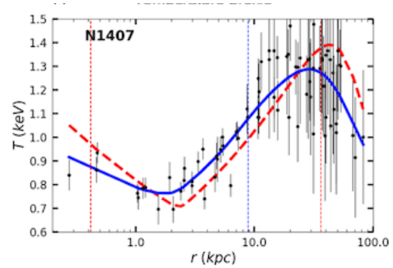
hybrid-bump



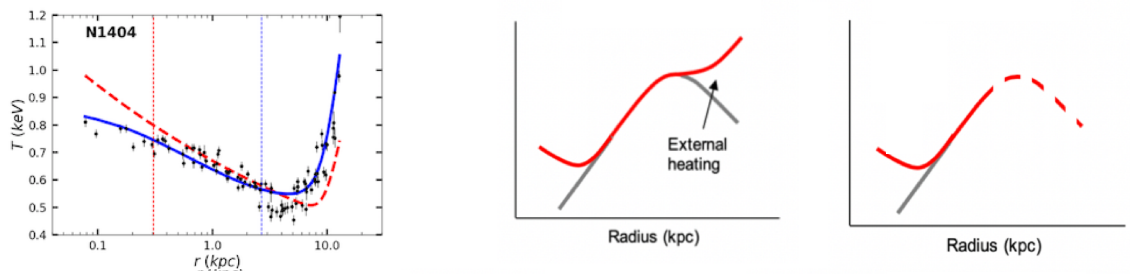
with a 2nd break



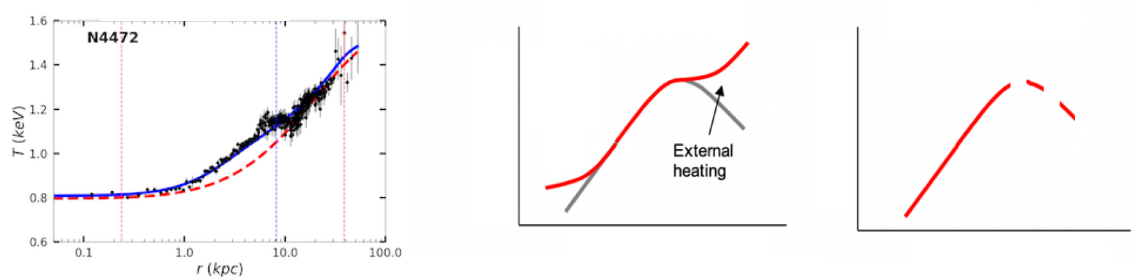
double break



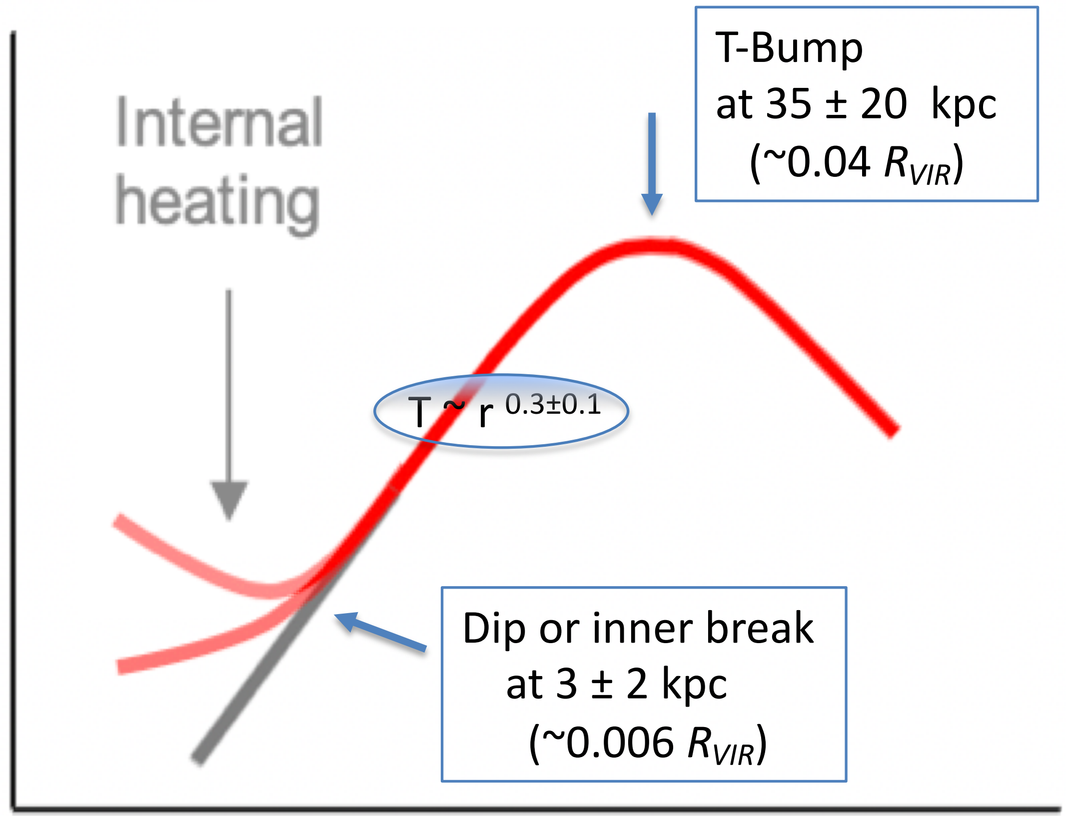
hybrid-dip



Positive



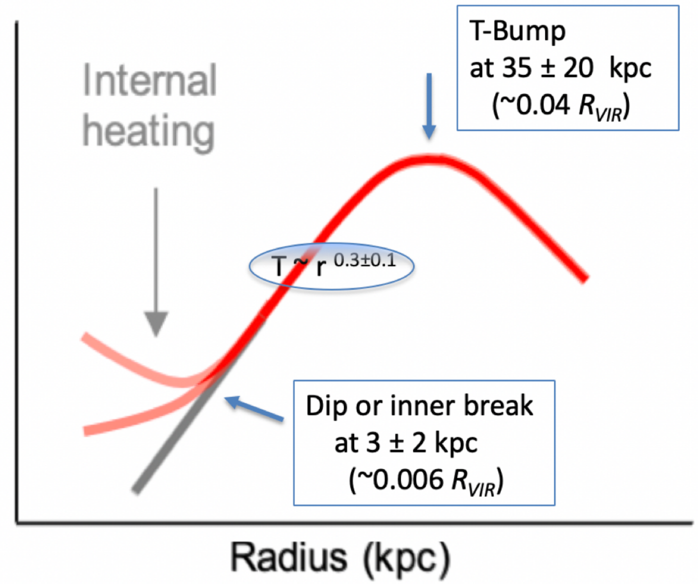
Universal T-profile ?



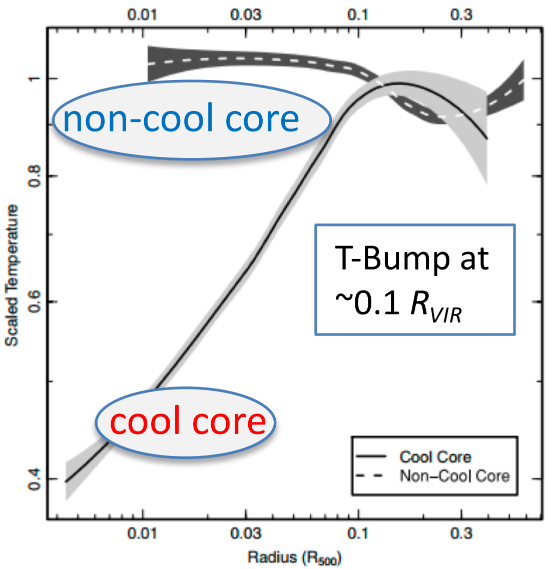
hybrid-bump + double-break : 30 (50%)
+ hybrid-dip : 44 (73%)
+ positive : 49 (82%)

exception
negative type, irregular : 11 (18%)

ETGs



Clusters



In CC – NCC dichotomy, most ETGs (82 %) belongs to CC,
with a positive T gradient (slope ~ 0.3) between ~3 kpc (dips) and ~35 kpc (peaks)

Q. Is the ***hot core*** opposite to the cool core? No. HC may or may not exist inside CC ETGs.
What makes the hot core?

Q. Is it possible that a hot core also exists in the center of CC clusters? Yes, but less likely.

Q. Are all hot halos in ETGs with positive T gradient cooling like CC?
No. Only a small fraction show signs of cooling from hot gas (e.g., CO, [CII])

Q. Are exceptional cases (negative type) more disturbed like NCC?
Not always. NGC 6482, the most clear case, is a fossil group with a relaxed hot halo.

➔ ETGs are more ***complex*** than clusters as AGN/stellar feedback effects are ***more pronounced***!

The Hot Core

Previous known cases:

NGC 4278 (Pellegrini et al. 2012)
NGC 4649 (Paggi et al. 2014)
NGC 4552 (Machacek et al. 2006),
NGC 777, NGC 5982 (O'Sullivan et al 2017)

43% (26 out of 60) host the hot core (HC) with $\nabla T_C < 0$

hybrid-dip 23% + double-break 7 % + negative 13%

R_{MIN} = 3 ± 2 kpc (~ R_e) inside R_{MAX} (x 1/10)

17 out of 26 hybrid-bump has a 2nd break at $R_{BREAK} \sim R_{MIN}$

➔ could have internal heating sources

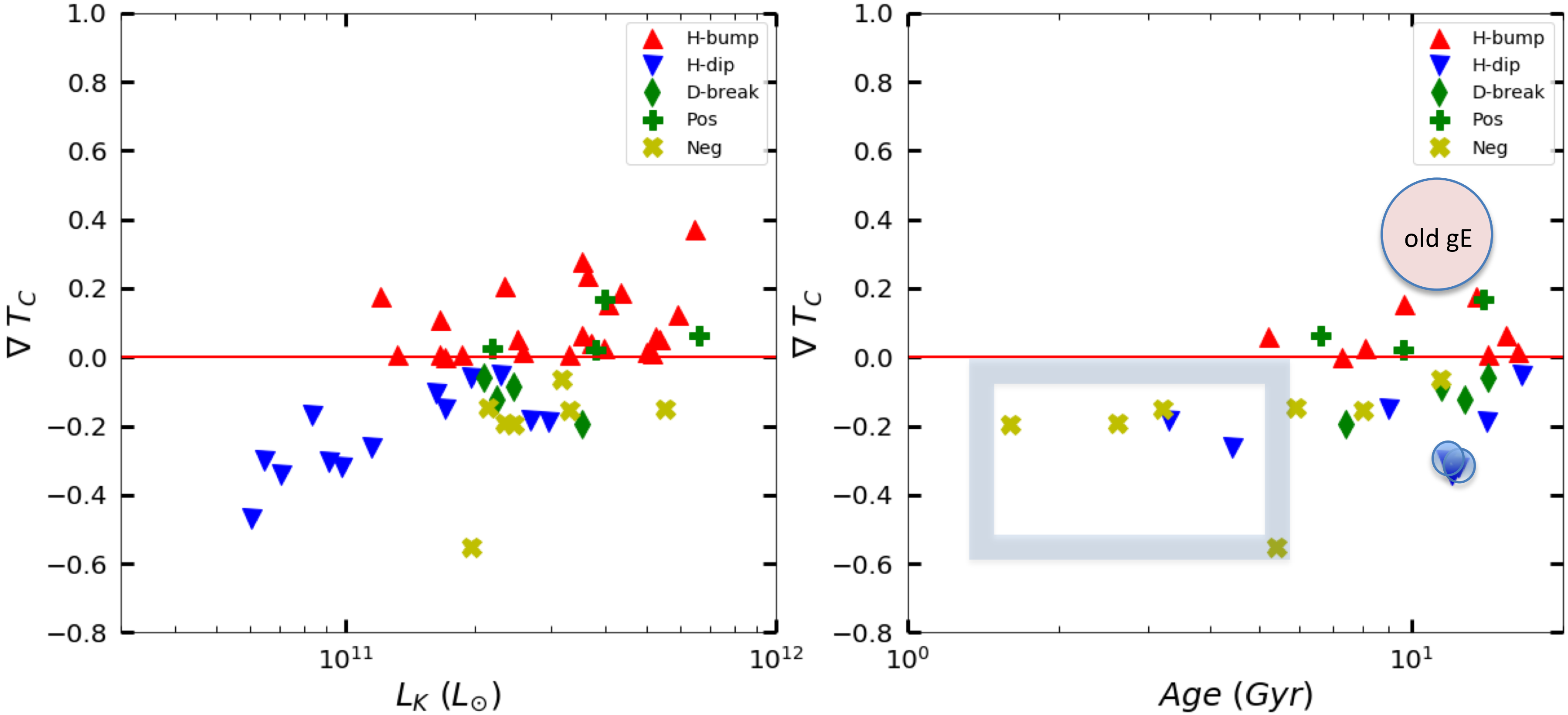
The hot cores are usually found in small systems (lower T_{GAS} and $L_{X,GAS}$)

➔ The fraction of the hot core could ***increase*** significantly in a complete sample.

What makes the hot core?

Stellar feedback
AGN feedback
Gravitational heating

Stellar feedback



What makes the hot core? possibly related to recent star formation.
could be a common features for low mass systems
where stellar feedback can be most effective and visible

The End ....