Local galaxy groups in the X-ray band

a few selected example

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Why do we study groups?

- ✓ most of the matter in the Universe is in small aggregates
- ✓ groups are excellent tracers of LSS of the universe
- ✓ environmental dependence of galaxy properties
- ✓ interactions between galaxies and hot/cold gas

..... but

they are fainter smaller and more complex than clusters of galaxies

Why study **local** groups?

✓obtain details!!! extremely important to understand / properly assess "cosmological" objects

Why in X rays?

Probe specific constituents :

- ✓ **gas [ISM/IGM]**
- ✓ **[stars/] galaxies [AGN]**
- ✓ **forces (gravity! kinetic)**
- ✓ **[dark matter]**

BUT **-- group components ARE ALL sources of X-ray emission → complex to study.**

plus they are faint and require area+resolution!!

X-ray observations of groups

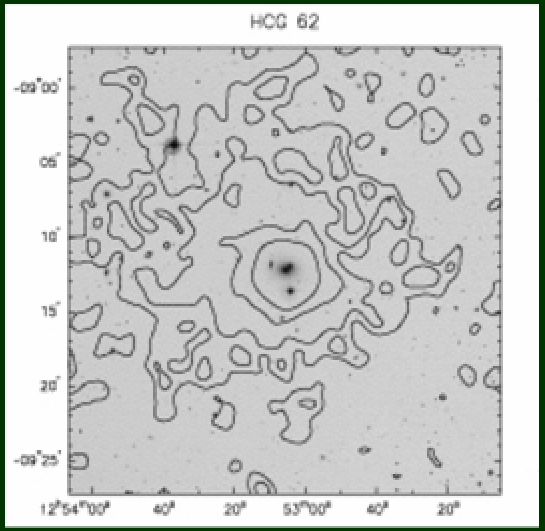
Do X-rays define an evolutionary sequence? ROSAT (Mulchaey et al 2003)
Correlation between stage and morphology/galaxy content

- round, symmetrical morphologies → EVOLVED
  virialized [a la cluster]
  - ➔ mostly **early-type** gal
  - ✓ bimodal X-ray distributions → second X peak also on luminous E
  - ✓ Fossil groups → isolated luminous E
- irregular, clumpy morphologies → INTERMEDIATE
  not centered on any galaxy
- no hot IGM → YOUNG
  spiral-only groups
  temp. or density too low??

3 examples from the Mulchaey et al. catalogue
(COMPACT Groups/ROSAT PSPC DATA)

YOUNG INTERMEDIATE EVOLVED

- round, symmetrical morphologies
  virialized [a la cluster]
  centered on the main galaxy
  → composed of mostly **early-type** gal



Best studied, many examples in literature for compact, poor, loose, rich …

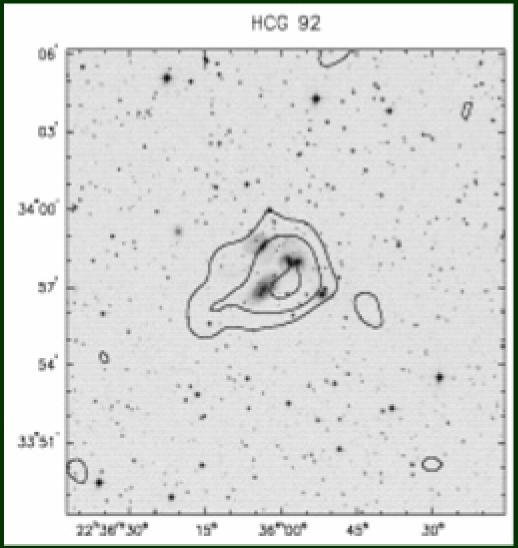
$kT \sim 1\text{-}3$ keV; < solar abundances

$L_x \sim 10^{42}\text{-}10^{43}$ erg/s

$M_{gas} > 10^{11} M_{\odot}$

3 examples from the Mulchaey et al. catalogue
(COMPACT Groups/ROSAT PSPC DATA)

YOUNG INTERMEDIATE EVOLVED



- irregular [clumpy] morphologies

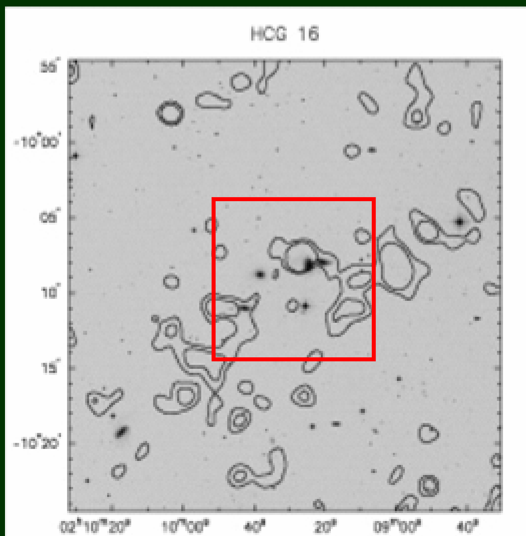
not centered on any galaxy

mixed morphologies

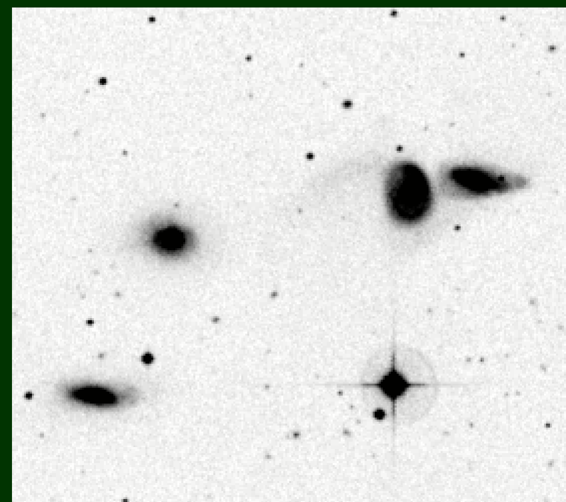
very few examples in the literature

3 examples from the Mulchaey et al. catalogue
(COMPACT Groups/ROSAT PSPC DATA)

YOUNG INTERMEDIATE EVOLVED



XMM-Newton finds extended emission!



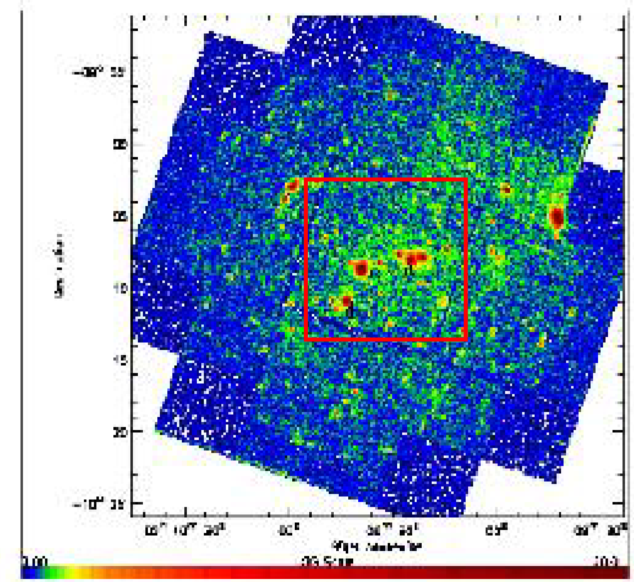


Fig 1. HCG 16 EMOS 1+EMOS 2 image in the energy band 0.2-7.0 keV. The 4 main galaxies are labelled as in Hickson (1982).

Belsole et al 2003

- no hot IGM -- only galaxies detected

spiral-only groups

No gas or gas temperature or density too low??

still fewer examples in the literature

HGC 16 (Belsole et al 2003): diffuse X-ray emission with XMM-Newton

- ✓elliptical morphology, radius of 135 kpc from the group centre.
- ✓Thermal plasma spectrum with 0.49+/-0.17 keV
- ✓ bolometric X-ray luminosity of ~ 10^{41} erg/s
- ✓ M_{gas} 3 10^9 $M_\odot$

Young Spiral -only low mass groups

no longer without gas!

other examples – still very few:

+ HCG 57 (ASCA: Fukazawa et al. 2002)
detection L_x~1x10^{41} [but: how much is "pure" IGM?]

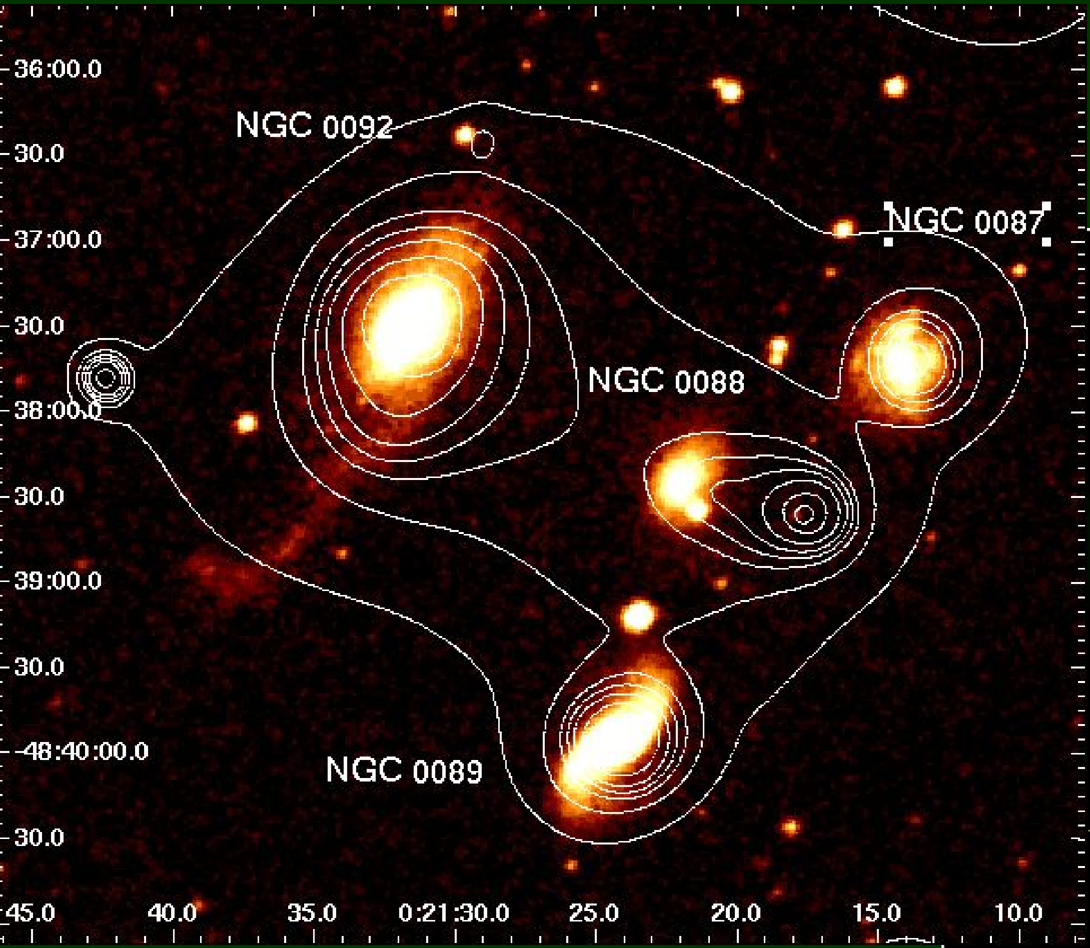
+ NGC 4410 (Chandra: Smith et al. 2003)
detection L_x~1x10^{41}

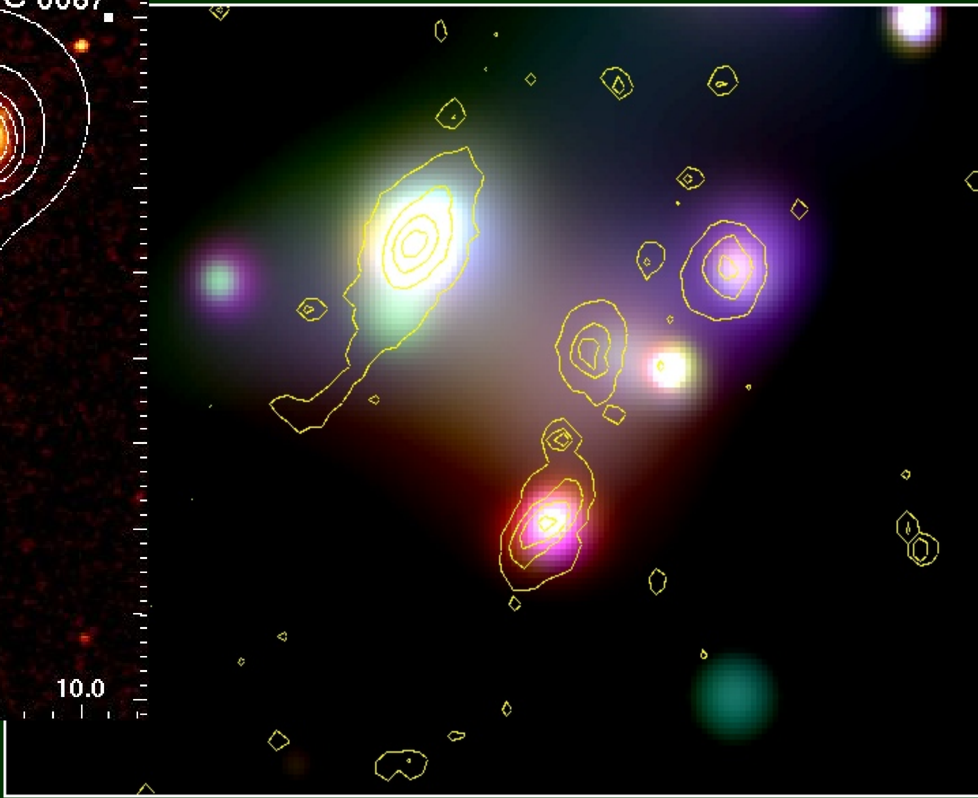
- HCG 80 (Chandra: Ota et al. 2004)
no detection L_x<6x10^{40}

SCG0018-4854: a dynamically young spiral dominated compact group in the South (Iovino et al. 2003, AJ 125, 1660)

- velocity dispersion of 67 km/sec
- high fraction of active galaxies :
  3 Liners, 1 star-forming galaxy
- evidence of no HI deficiency from radio data
- evidence for interaction [tidal tail in NGC0092, Hα, HI, star formation]

SCG 0018-4854 with XMM-Newton





X-ray contours and true X-ray color image with optical contours (Trinchieri, Iovino et al. in prep)

➔ **All galaxies detected**

each object detected with luminosities/spectra in line with other late type, mildly active galaxies:

NGC 87 and 88 ➔ $L_x \sim 10^{39}$ erg/s (0.5-2.0 keV) (+ bkg source to the W of N88)

NGC 89 ➔ $L_x \sim 6\ 10^{39}$ erg/s (0.5-2.0 keV)

NGC 92 ➔ Mildly absorbed nucleus, $L_x\ 10^{41}$ erg/s (0.5-10 keV)

plasma, kT~0.6 keV, $L_x \sim 10^{40}$ erg/s (0.5-2.0 keV)

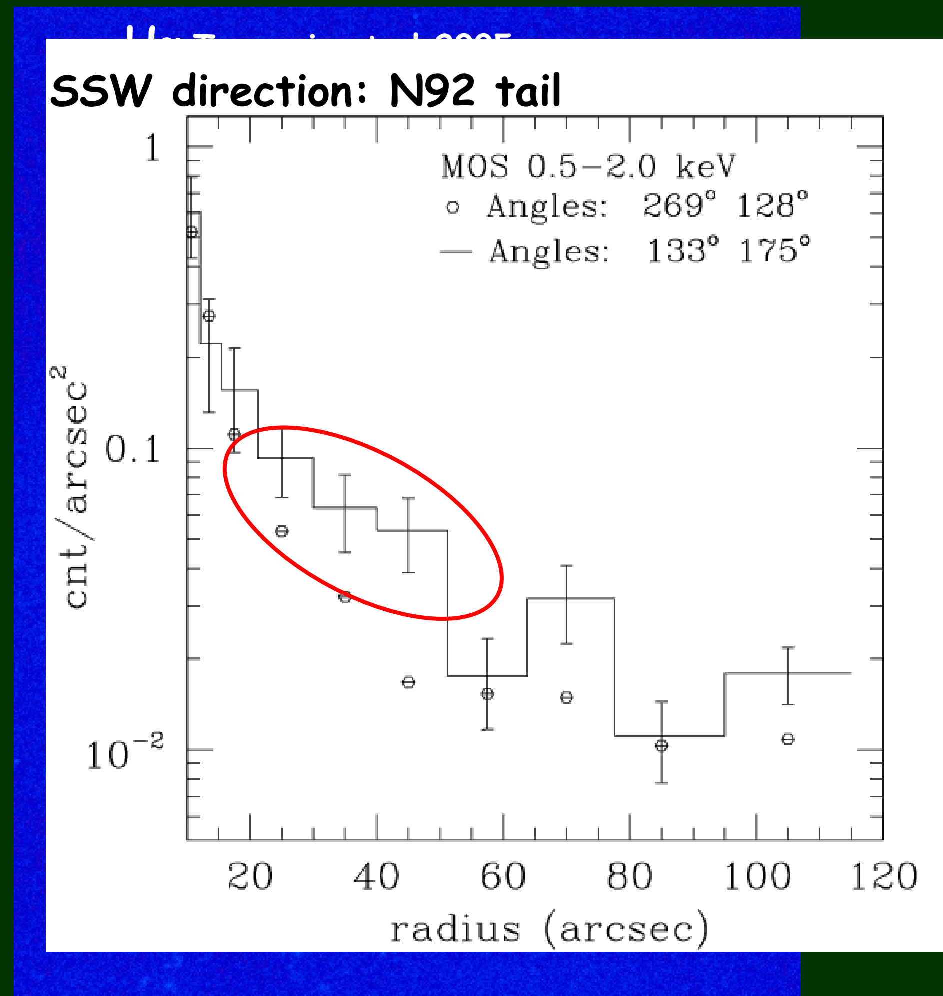
➔ **Detection of the "TAIL" in NGC 0092**

➔ **Detection of EXTENDED emission between galaxies**

➔ evidence for a tail in NGC 0092 in X rays coincident with Hα, HI

L_x ~6 10^{38} erg/s assuming plasma spectrum

True color map + optical contours

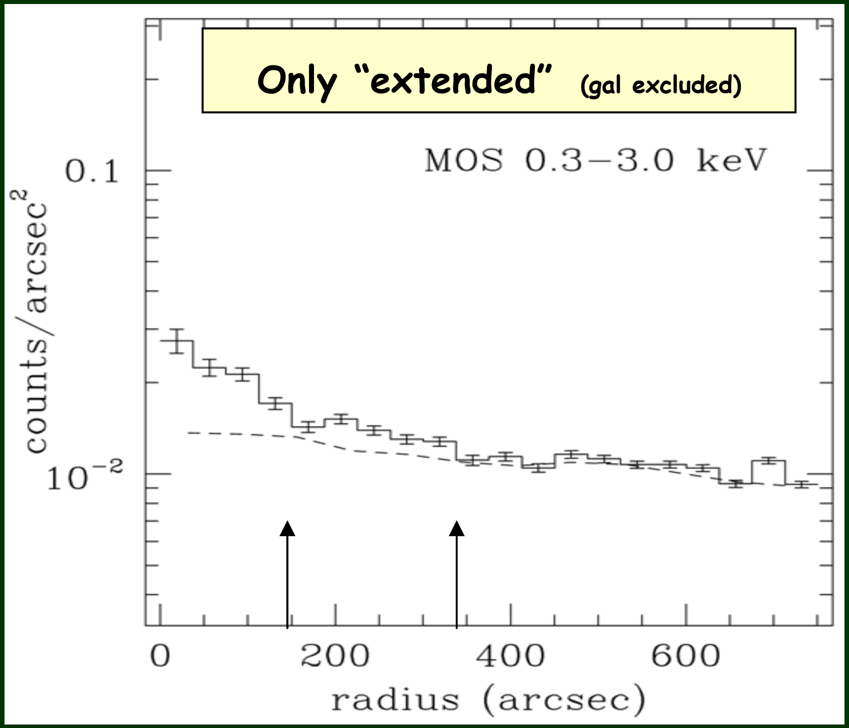


Intergalactic medium is detected although at low Lx and low kT

- L_x ~ $10^{40}h^{-2}$ erg/s [0.5-2.0] in ~3′ radius (50 kpc) – could extend to 6′
- kT~0.25 keV

➔ M_{gas} 3 10^9 $M_\odot$

n_e ~3×10^{-4} cm^{-3}



BASED on 2-3 examples ...

L_x 10^{40}- 10^{41} erg/s [compare at > 10^{42}]

kT 0.25-0.5 keV [compare at > 1]

M_{gas} 10^{9}-10^{10} $M_{\odot}$ [compare at > 10^{11-12}]

➔Is this typical of dynamically young systems?

Need more examples at the relevant sensitivity ....

BUT we can see IGM building/shaping/enrichment at a very early stage ....

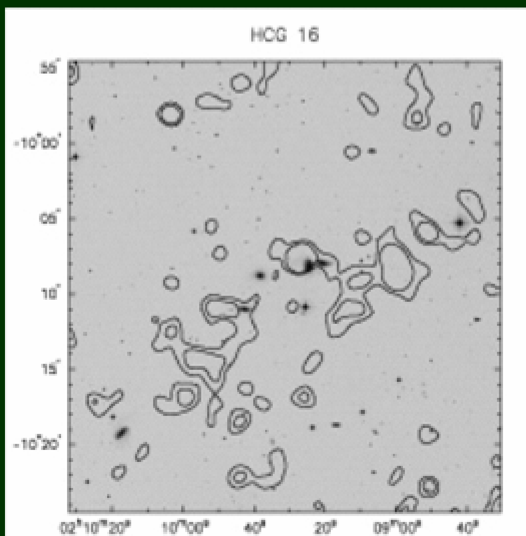
What is the relevance of gas in "young" systems?

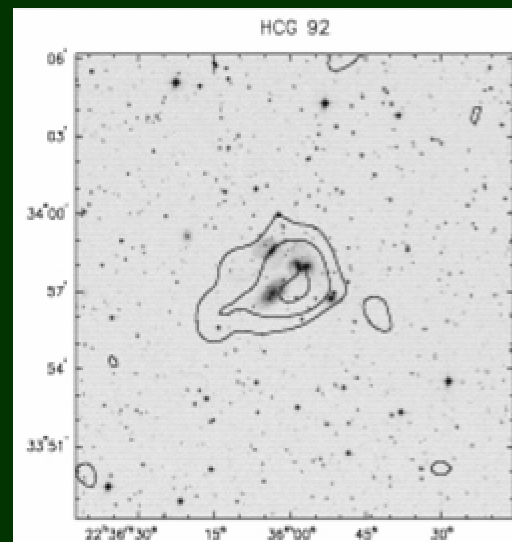
✓Confirms the existence of a common potential, therefore of the "group", as in more evolved groups
✓Could supply additional causes for distortions / stripping thus modifying the "natural" evolution of S galaxies
✓As a natural reservoir for the material expelled from galaxies, probes the history of the galaxy evolution (enrichment – heating) at an earlier stage

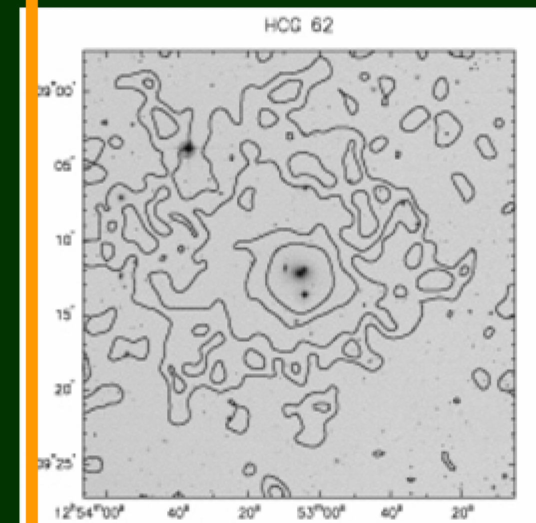
There should be more dynamically young systems at high z – so a more complete knowledge of all their constituents is going to help us better understand them and their evolution
+ ALL COMPONENTS MUST BE TAKEN INTO ACCOUNT

3 examples from the Mulchaey et al. catalogue (COMPACT Groups/ROSAT DATA)

YOUNG | INTERMEDIATE | OLD







irregular [clumpy] morphologies
not centered on any galaxy
mixed galaxy morphologies

Why Stephan's Quintet?

- ✓Multiwavelength data – A LOT!!
  - ✓Radio continuum, HI line, multiband optical continuum (ground, HST), Hα (many vel), ISO, SPITZER, GALEX, X-ray

- ✓Somewhat UNIQUE (mostly because better studied??):
- ✓Evidence for complex dynamics
- ✓Site of a lot of action

strong evidence of multiple episodes of past and recent (current) interactions from new members/ passage of intruders

Excellent test case for a number of phenomena

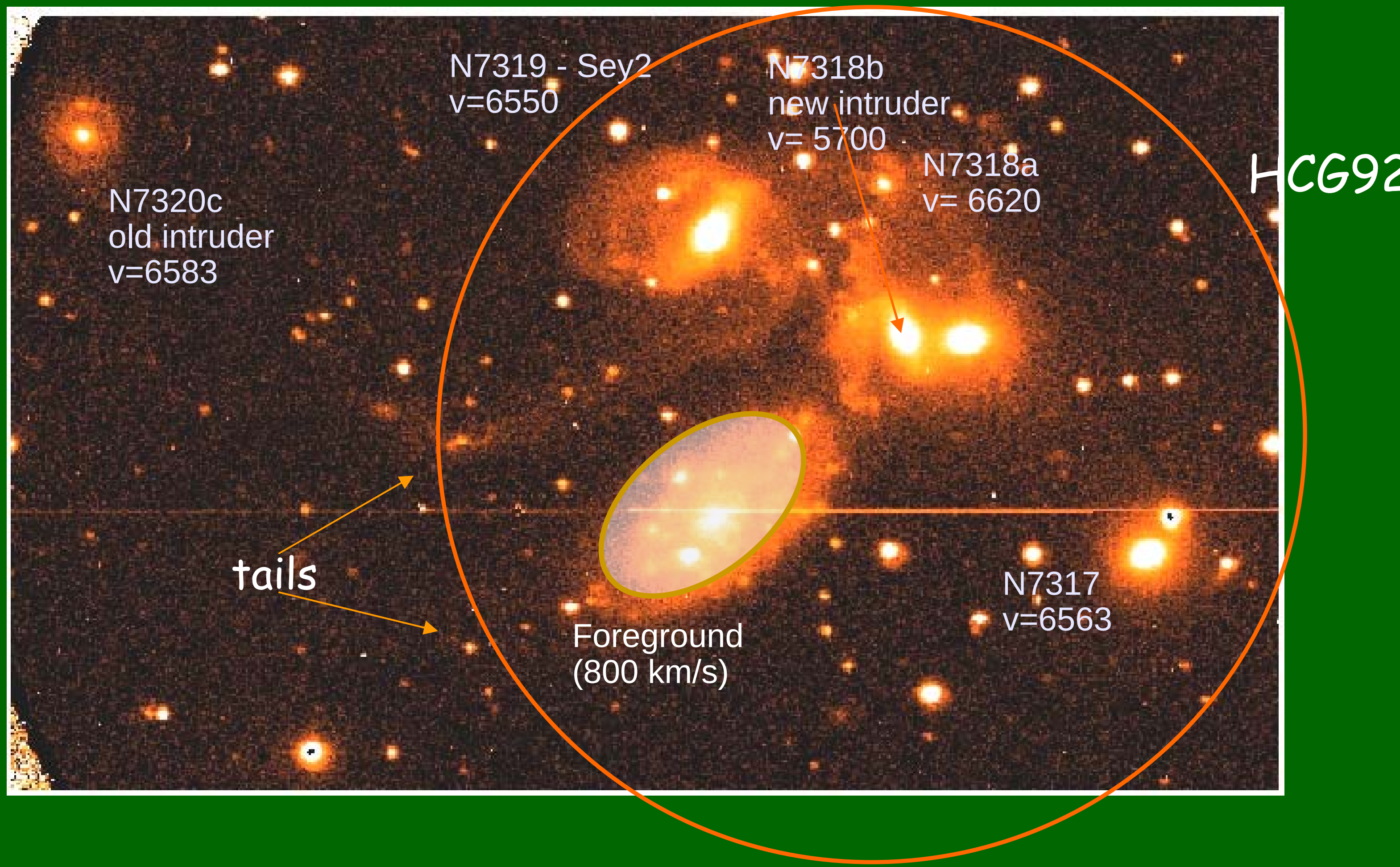
What can we learn from Stephan's Quintet in the X-ray band

- Einstein: only a detection (Harris et al 1979)
- PSPC/ASCA: a group like many others ... diffuse hot gas in the potential, kT=1 keV, a hard tail from the Seyfert (Pietsch et al. Awaki et al.)
- HRI: a NS structure, the Sey2 is well separated and some individual sources (Pietsch et al Sulentic et al.)
- Chandra/XMM-Newton: (Trinchieri et al 2003/2005)

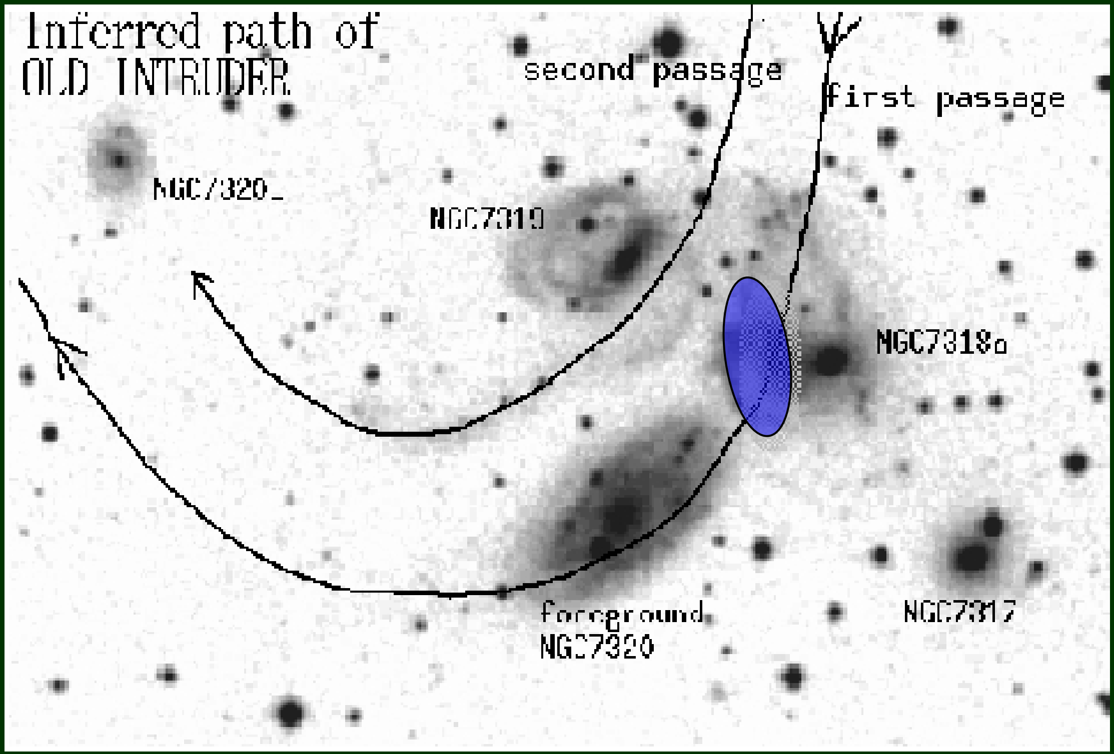
Active collaboration with: Jack Sulentic @ Alabama U., Dieter Breitschwerdt @ Wien U. , Wolfgang Pietsch @ MPE Garching

Credits are also due to several people who gave us inputs and free use of their data: **C. Gutierrez, L. Verdes-Montenegro**, **C. Xu** and more

Stephan's Quintet: The system



One possible scenario to explain the observed lack of HI in galaxies, the optical tails and the general evidence of interactions and activities



later [now] the other galaxy arrives at 1000 km/s!

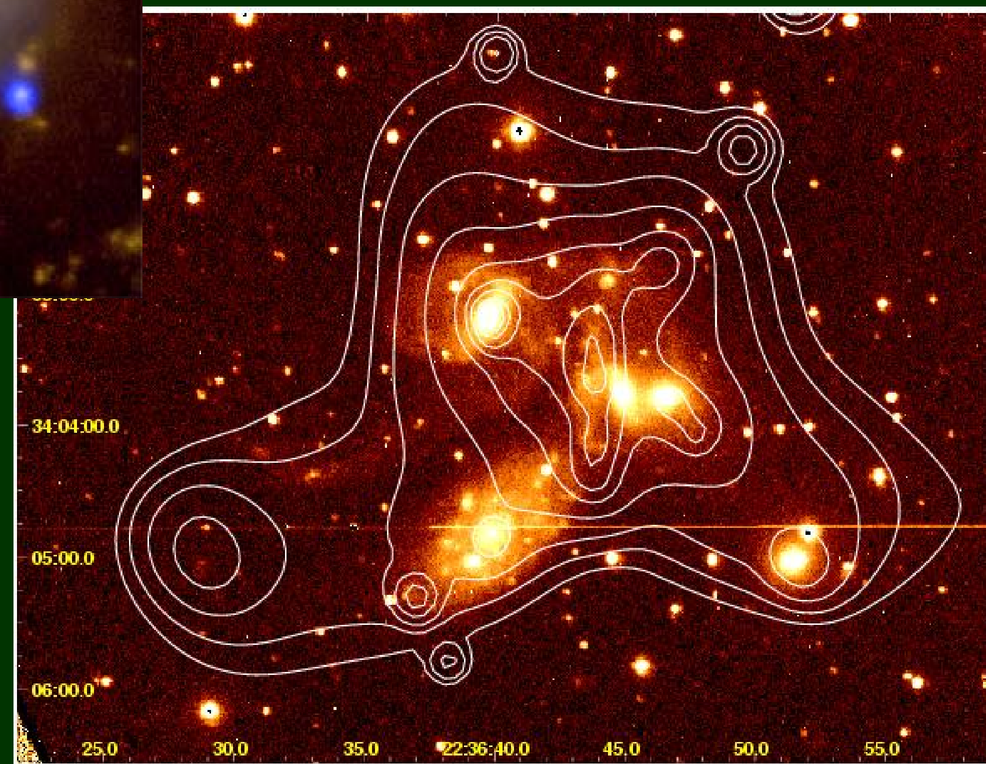
<u>However:</u> Xu et al 2005 propose NGC7318a through NGC7319 for second tail, based on time-scale of the encounter vs age of tail ➔ just to show how complex the system is .....

Blue: X-rays (Chandra ACIS-S, 0.3-3.0 keV)

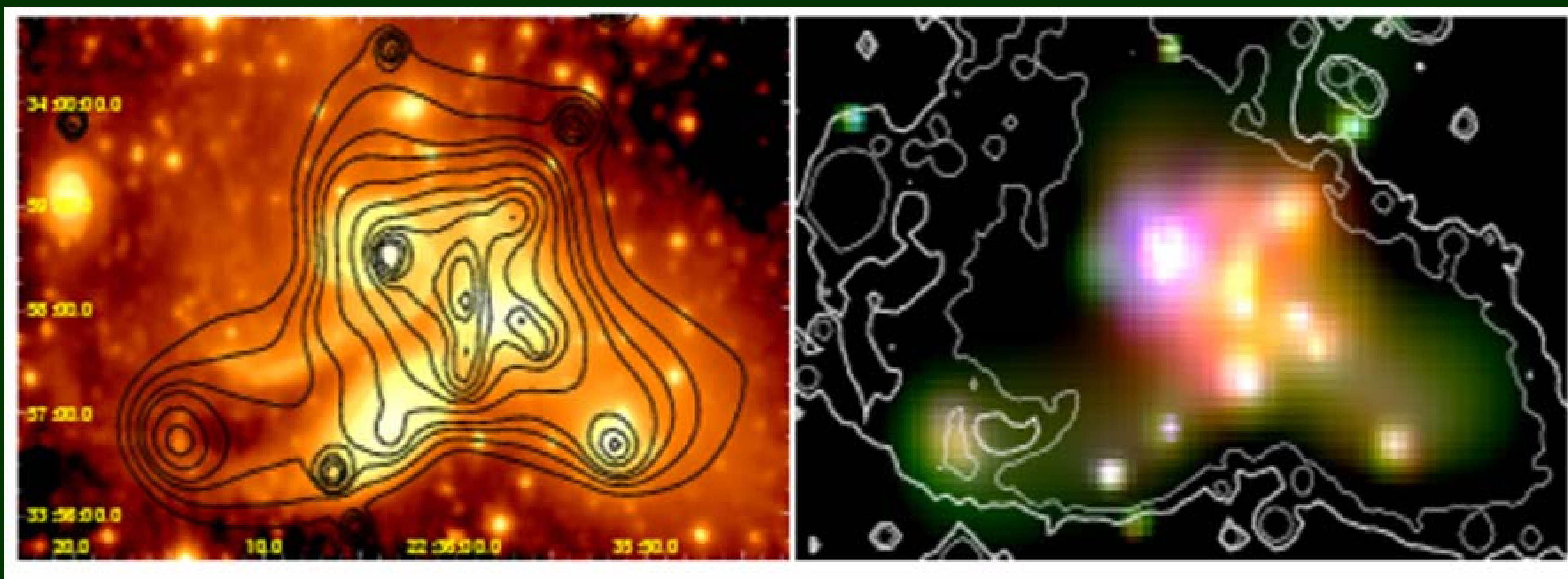
DSS

Credit: X-ray: NASA/CXC/INAF-Brera/G.Trinchieri et al.; Optical: Pal.Obs. DSS)

Optical [[NII] plus continuum]
X-ray contours (XMM-Newton MOS adaptive smoothing, 0.3-3.0 keV)



Building the IGM !!



Red continuum (Gutierrez et al 2003) **and X-ray contours**

X-ray colors and red contours

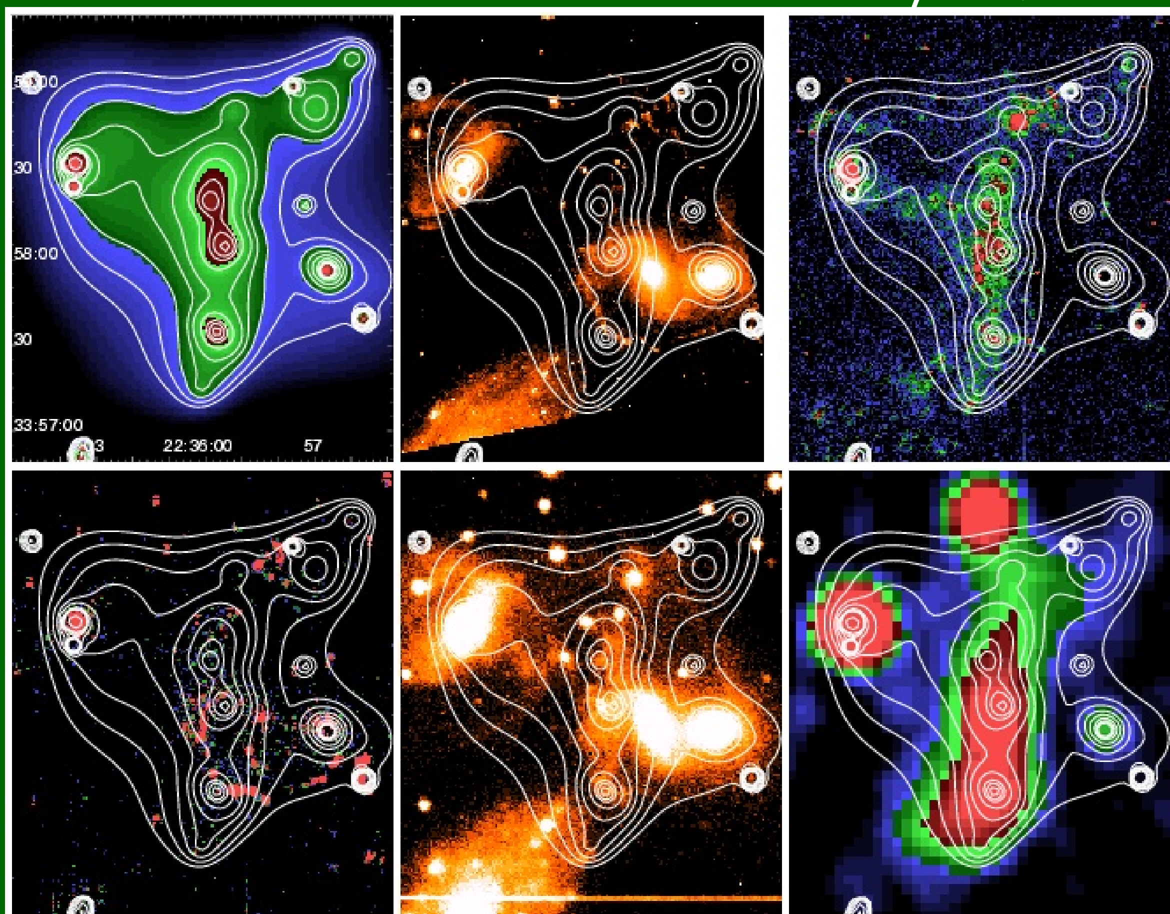
Remarkable similarities in the low surface brightness emissions
Extensions to both SW (NGC 7317) and SE (old and new tails)

SHOCK

X -ray
Chandra 0.5- 2 keV

Blue HST

Hα @ 6500 km/s
=system velocity



Hα @ 5700 km/s
=intruder velocity

N[II] + cont.

Radio cont.

✓Correspondence with Radio, Hα6500 (SQ vel) and N[II]

✓No correspondence with optical or Hα5700 (intruder vel) [1 region only]

Hα + HI distributions @ SQ velocity

(Williams et al 2002)

Hα + X- ray distributions

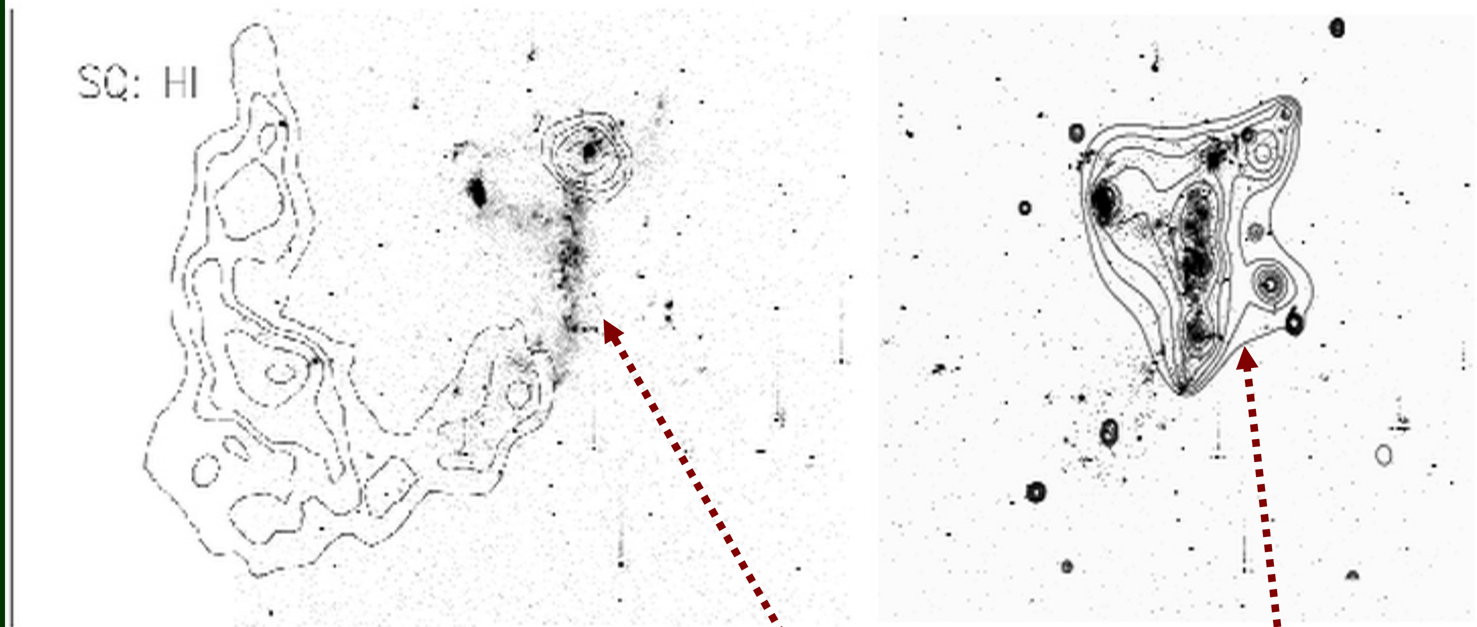
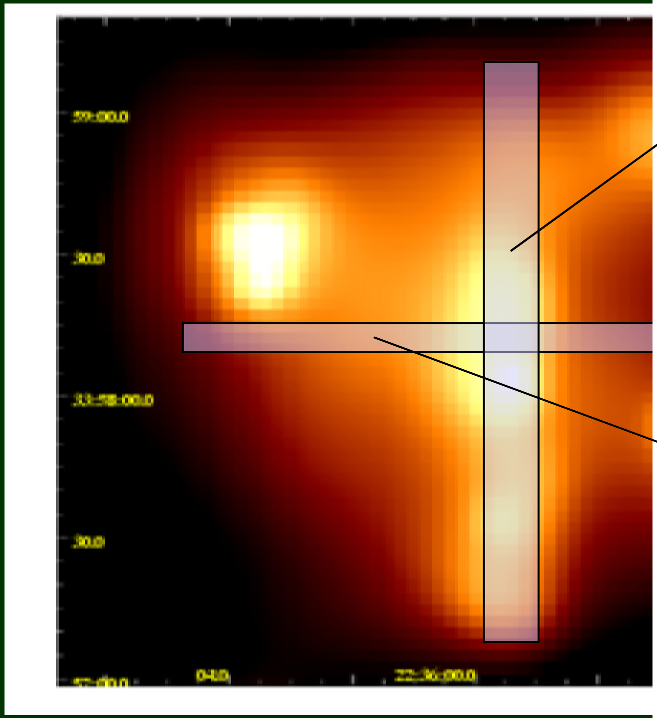
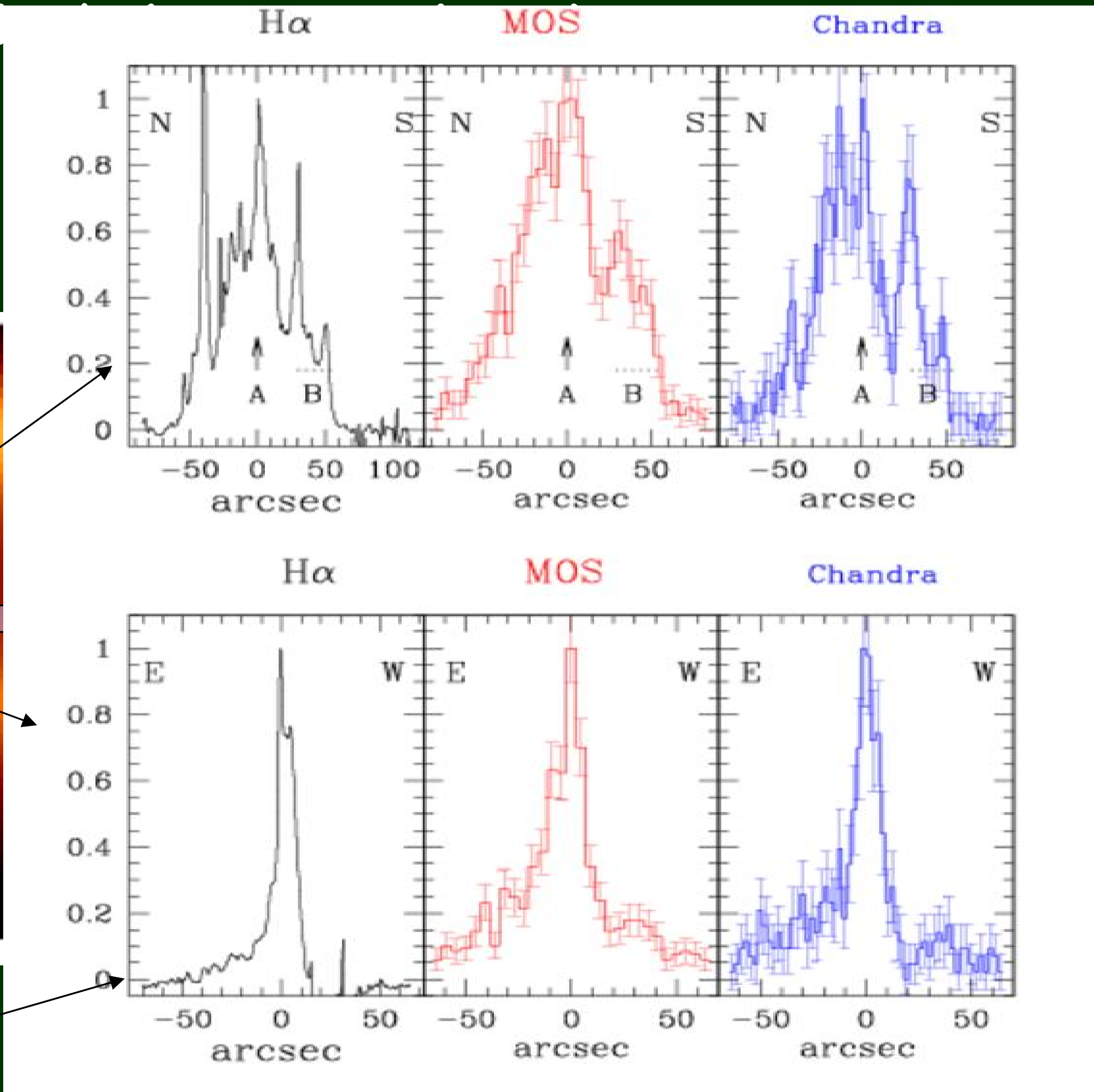


Fig. 13. Comparison of the spatial distribution of the HI (left; from Fig. 5 in S01) and X rays relative to Hα at the SQ velocity.

Anti- correlated distributions: No HI where X- rays (and Hα) are

X-ray and Ha @6700

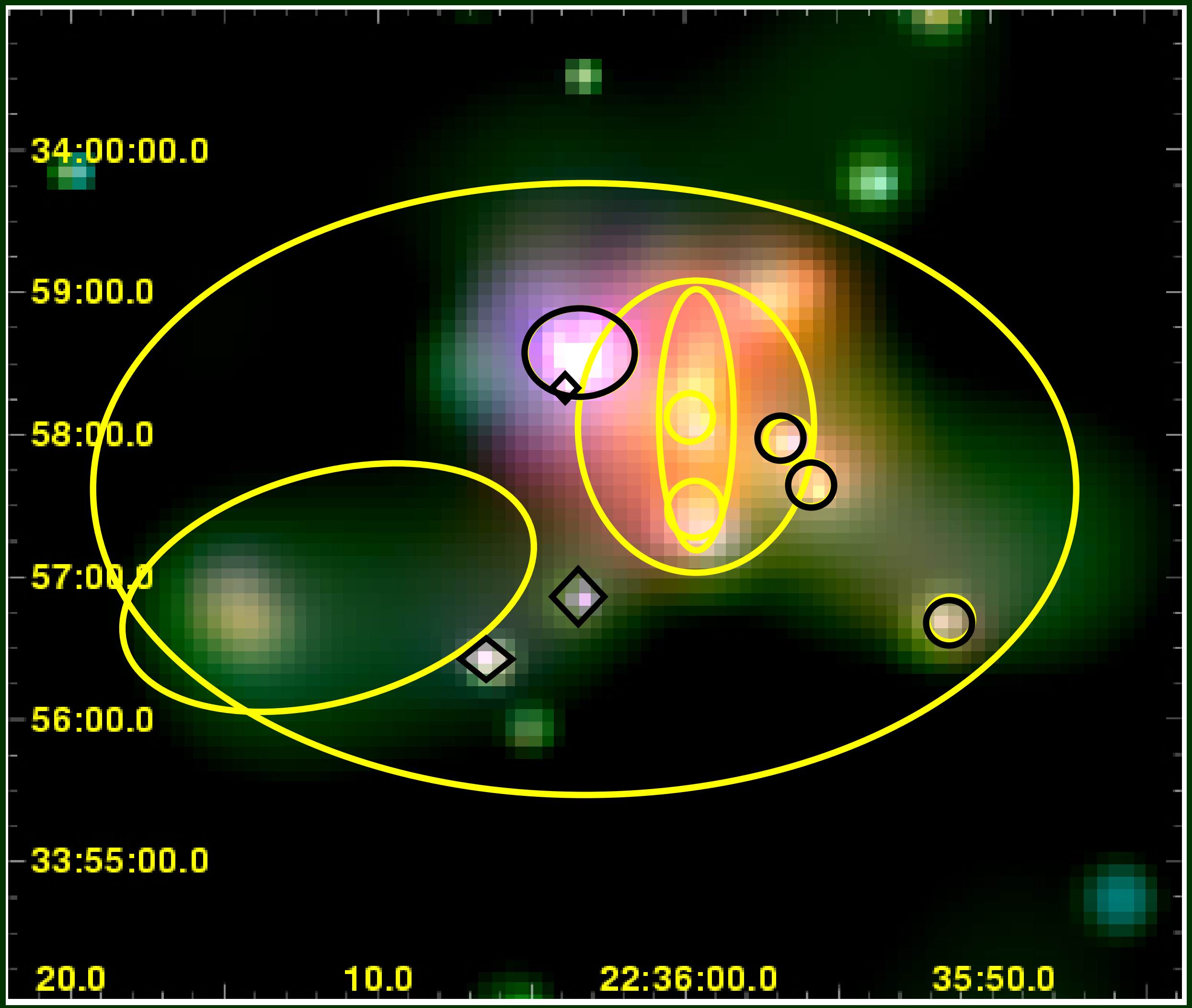




Disk of N7318b?

Spectroscopy confirms shock excitation (Xu et al. 03)

X-ray colors: 0.5-1.5; 1.5-2.5; 2.5-7.0 kev



Z~2
Galianni et al
2005

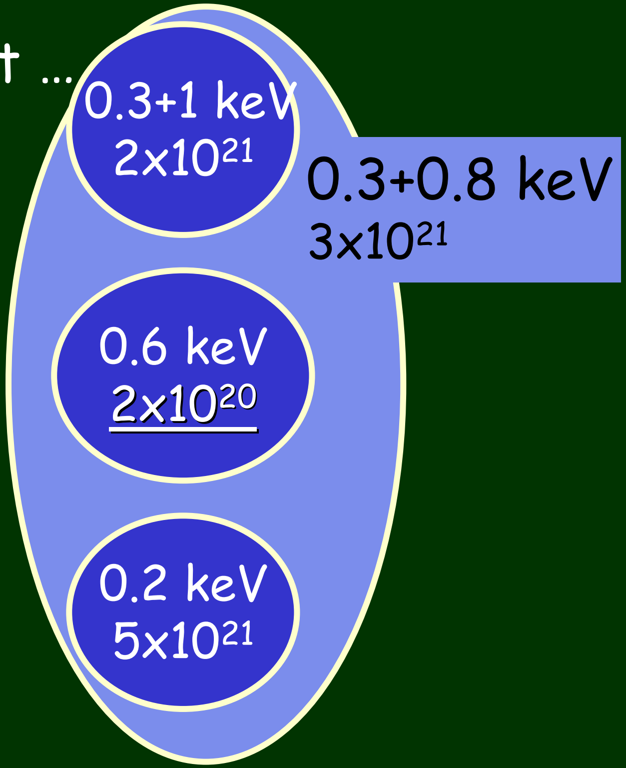
In NGC7320
foreground

SHOCK REGION The spectral fits are hard to interpret

Multi temperature in the shock !

Which abundance ratio? Used 0.3x but …

Different absorbing N_h



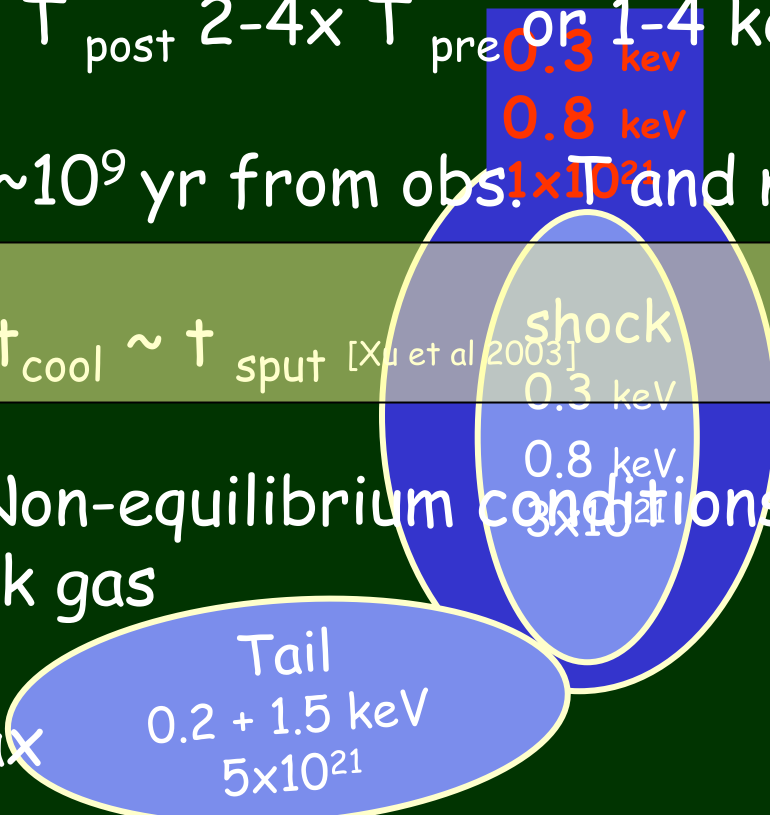
✓ Non equilibrium spectrum!

✓ Geometric effects!

More problems with shock:

Shock temperature ~ pre-shock temperature

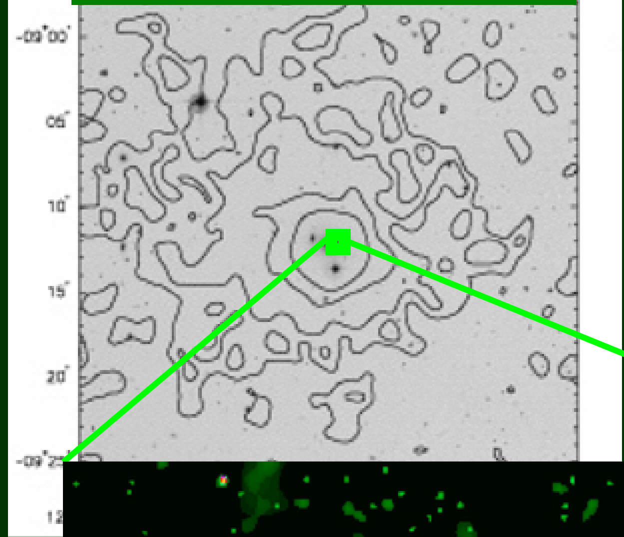
- ✓ IGM already hot? ➡ Mach number is lower but with observed vel. T_{post} 2-4x T_{pre} or 1-4 keV
- ✓ Cooling already? ➡ t~10^9 yr from obs. T and n_e
- ☺ ✓ Cooling from dust? ➡ $t_{cool} \sim t_{sput}$ [Xu et al 2003]
- ✓ Just shocked? ➡ Non-equilibrium conditions, spectra mimic pre-shock gas
- ✓ Oblique shock? 30^0 max



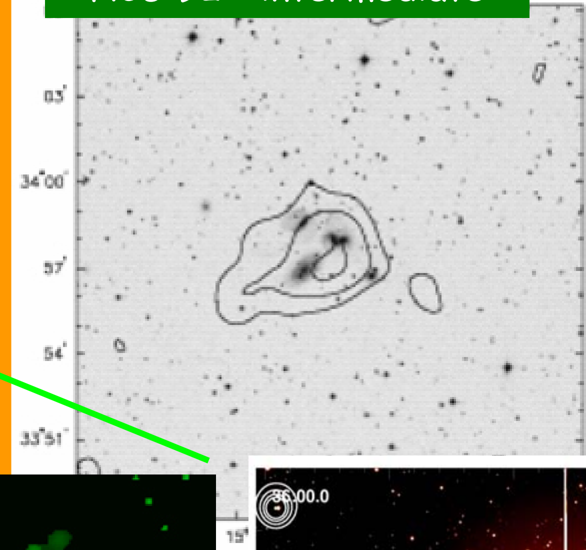
Summary for SQ and implications …

- Complex multiphase medium:
  - morphological similarities are with
    - the ionized gas, the radio continuum in the shock region
    - the red continuum in the "halo"
  - anticoincidence with the HI distribution
  - suppressed emission from the most active starforming region (SB-A)
  - ⇨ THERE MUST BE A LINK with the ionizing agent
  - ⇨ WITHNESSING the accretion/enrichment of the IGM
- Spectral characteristics are quite complex
  - multi-temperature
  - non-equilibrium conditions
  - cooling from dust
  - ⇨ SHOCKS are important for the heating IGM
  - ⇨ need to be recognized/separated from the "rest" of the emission
- X-ray emission from individual galaxies is not remarkable
  - not high (no hot halos) – maybe enhanced in new intruder (shock)
  - ⇨ NEED to separate them from the IGM (Sey nucleus !)

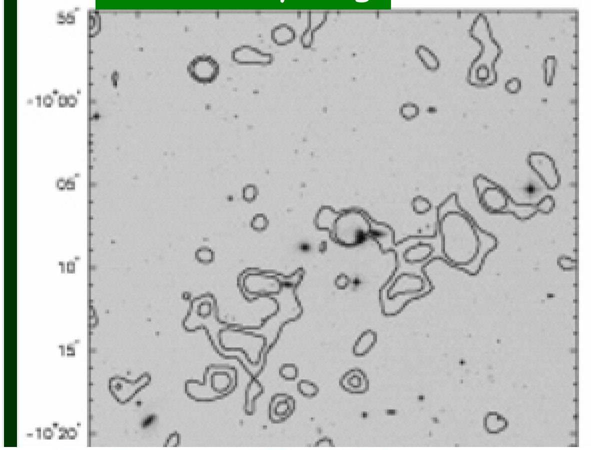
HCG 62 - evolved

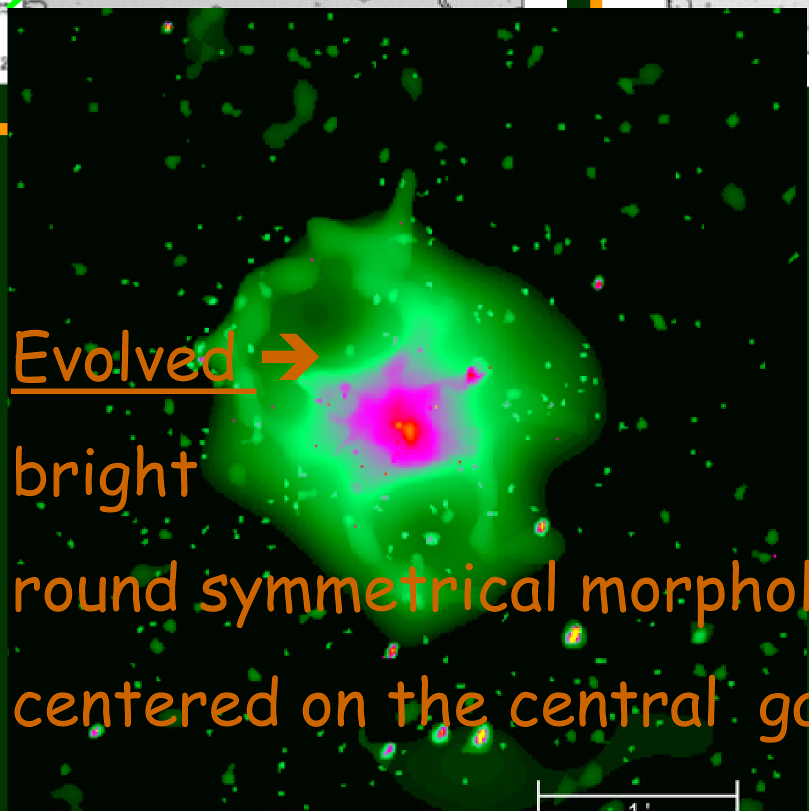


HCG 92 - intermediate



HCG 16 - young





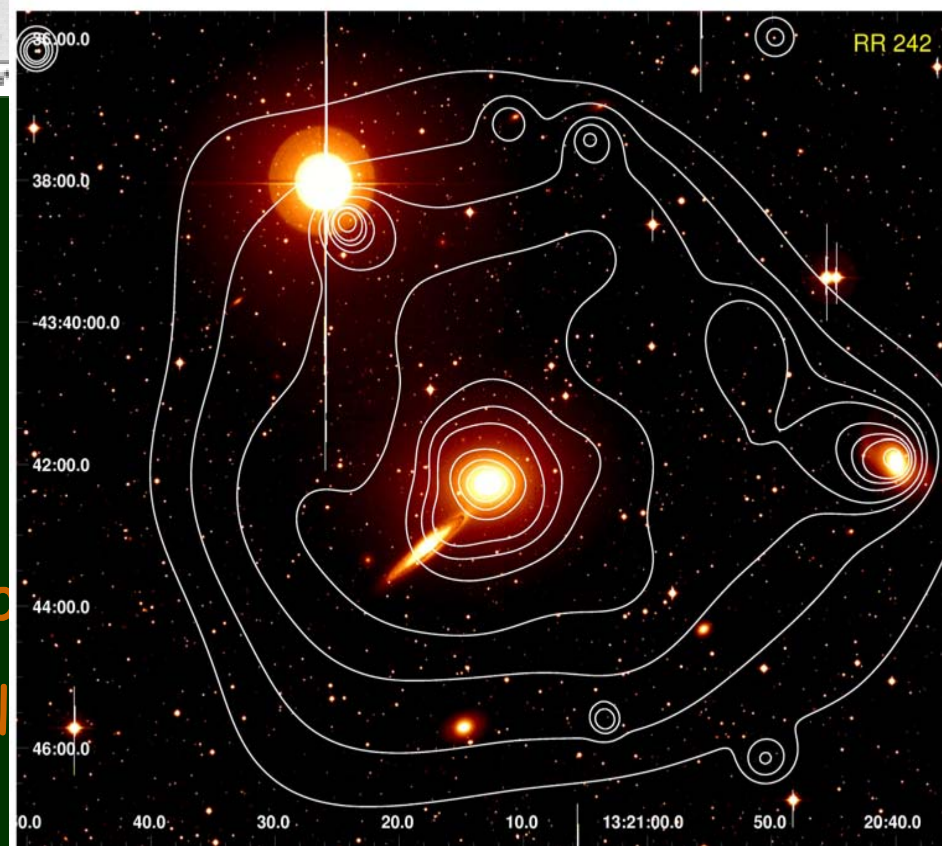
Evolved →

bright

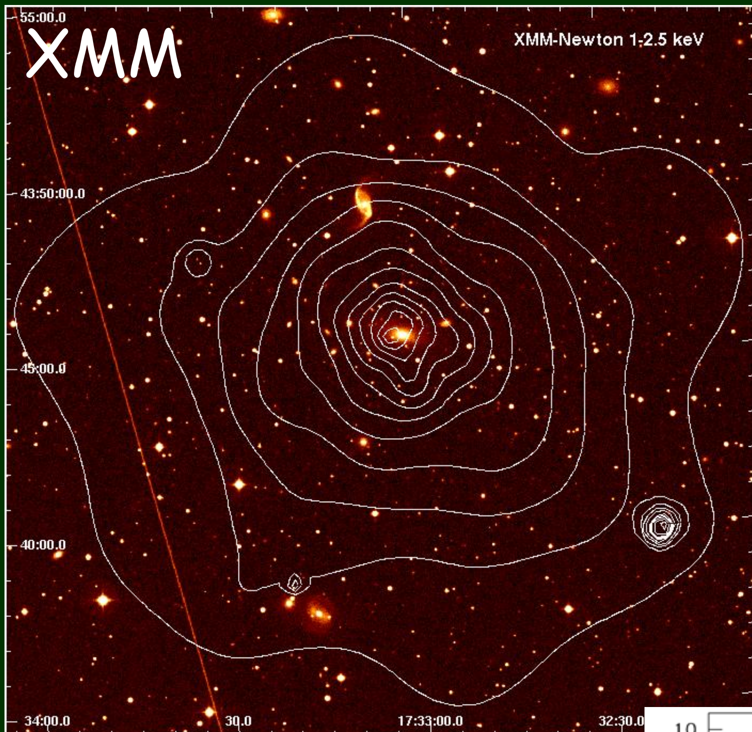
round symmetrical morpholo

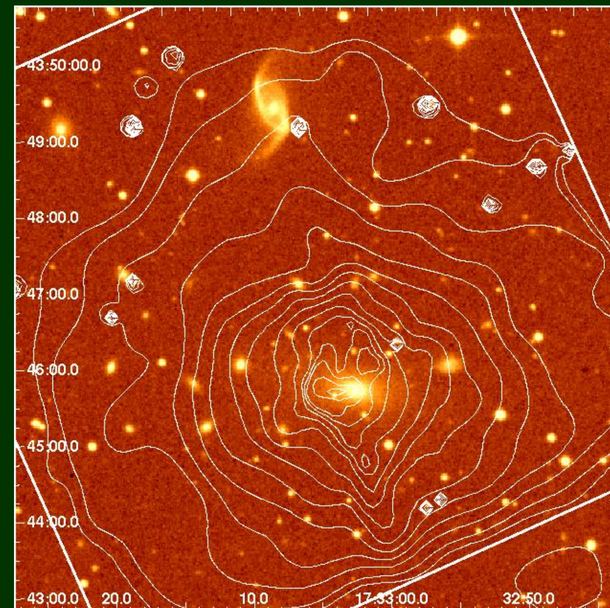
centered on the central gal

NASA/CfA/J. Vrtilek et al.



Another interesting odd case! [with W. Pietsch, J. Sulentic, D. Breitschwerdt, A. Wolter, work in progress]





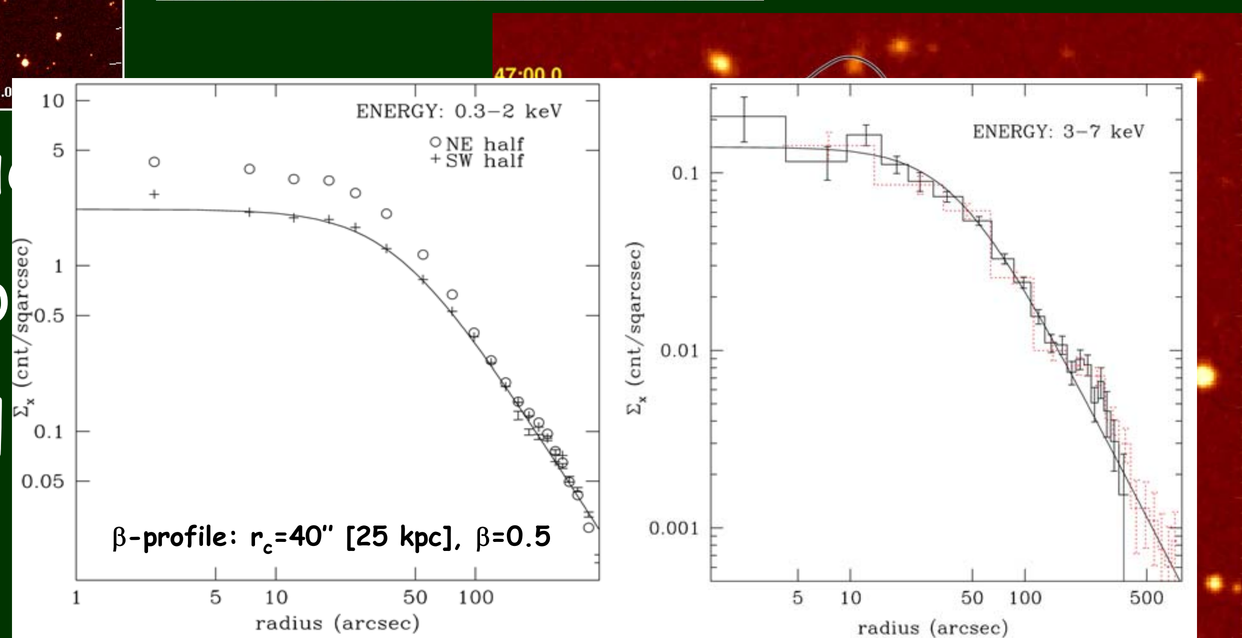
IC1262: central galaxy in a small group with no signs of interaction or merging events

$L_x > 10^{43}$ erg/s

Extent > 350 kpc

Chandra

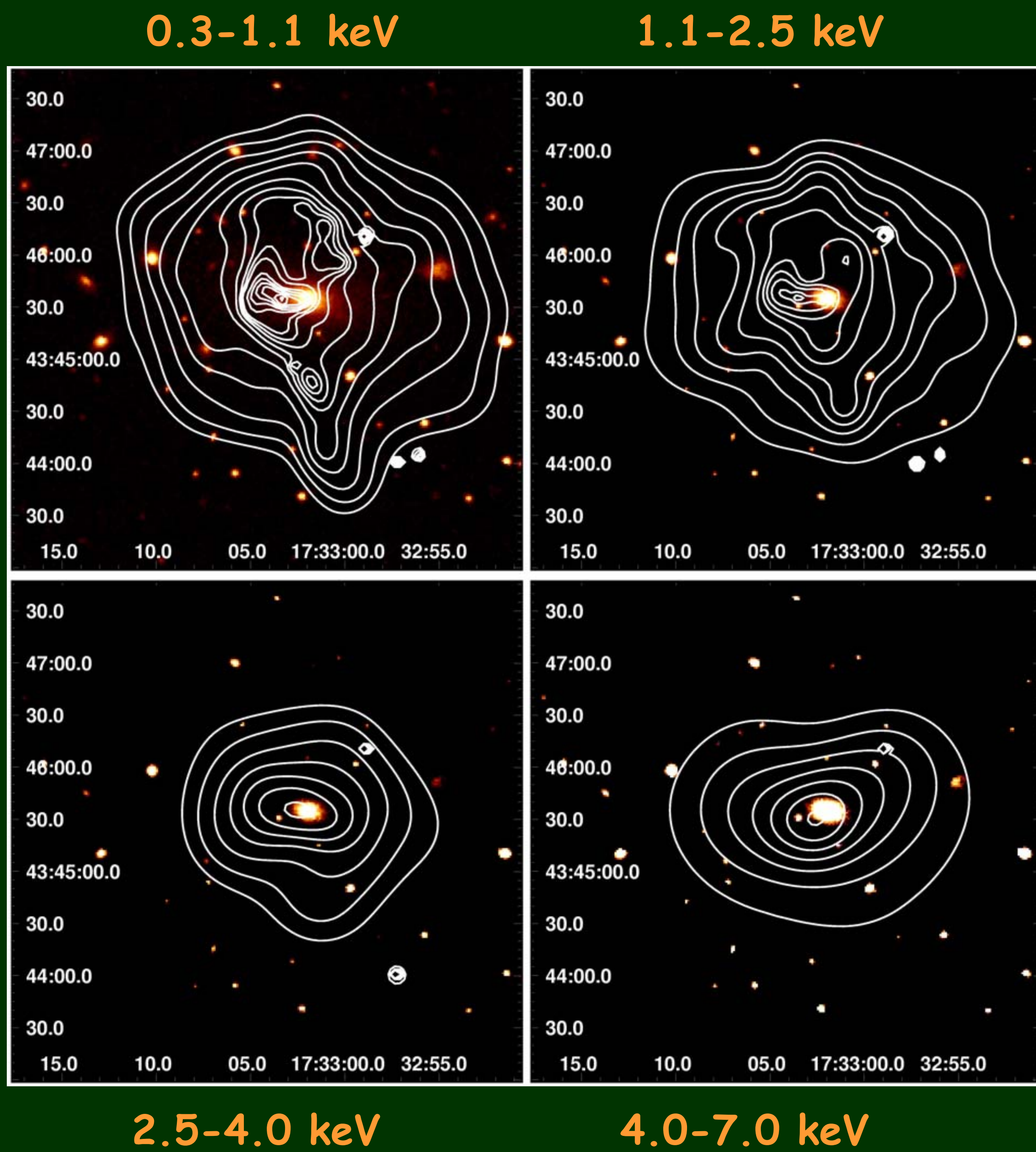
- Large scale stru
- Intermediate: so
- Small: very pecul



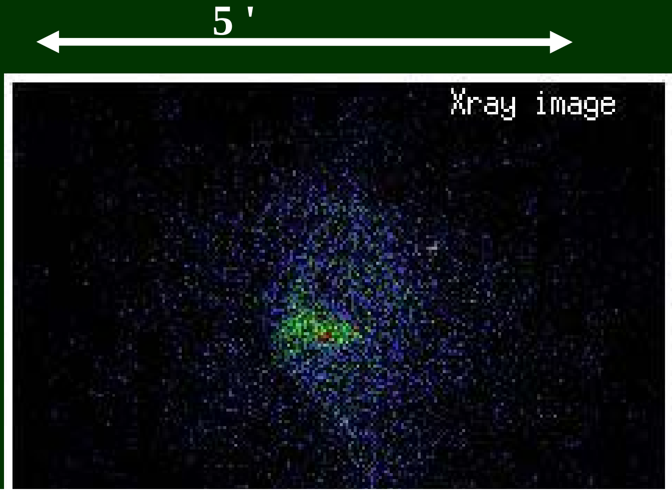
structure is
most pronounced
in the softer bands

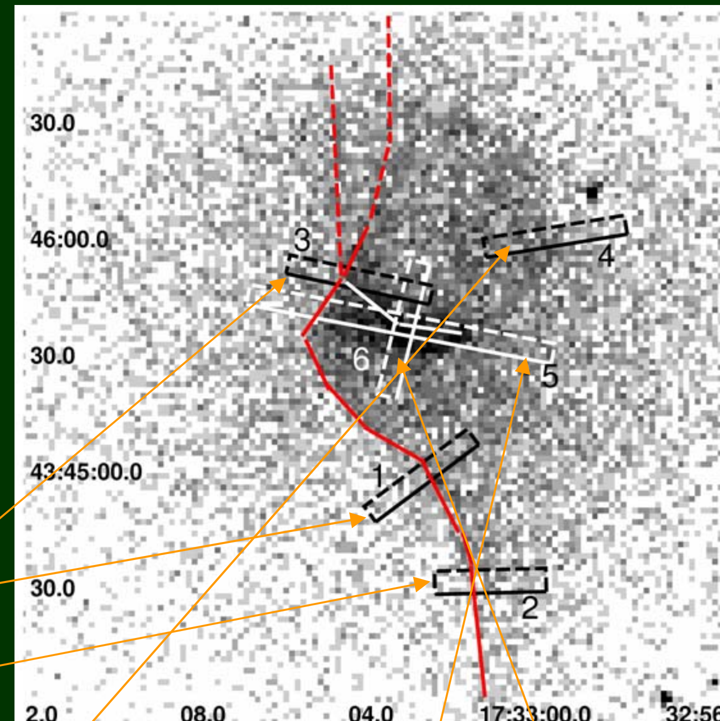
harder emission
centred on galaxy

softer emission
displaced to the E

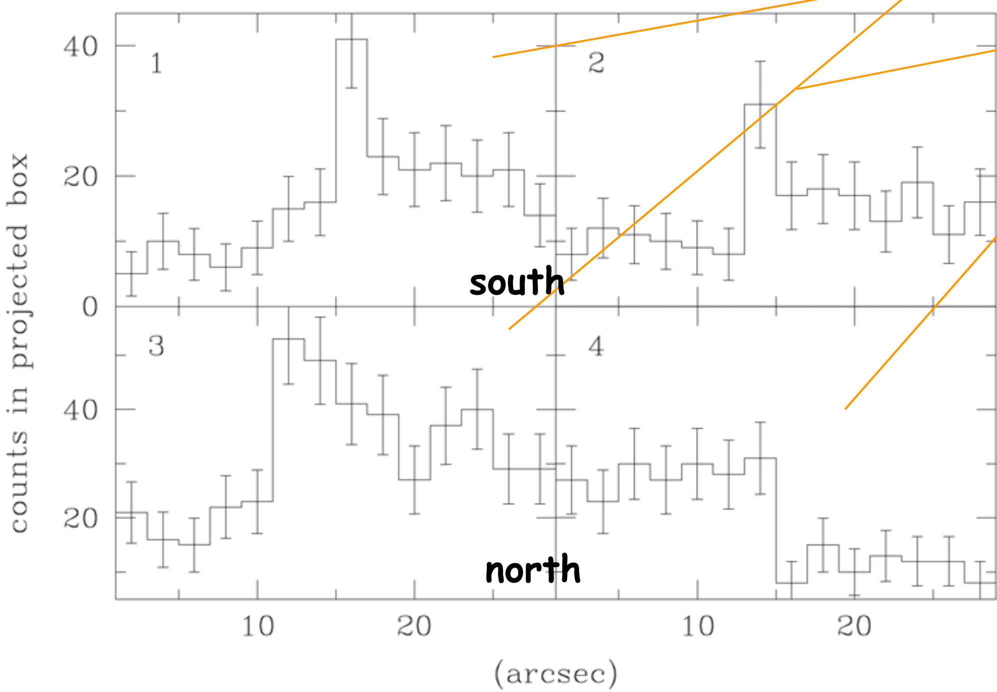


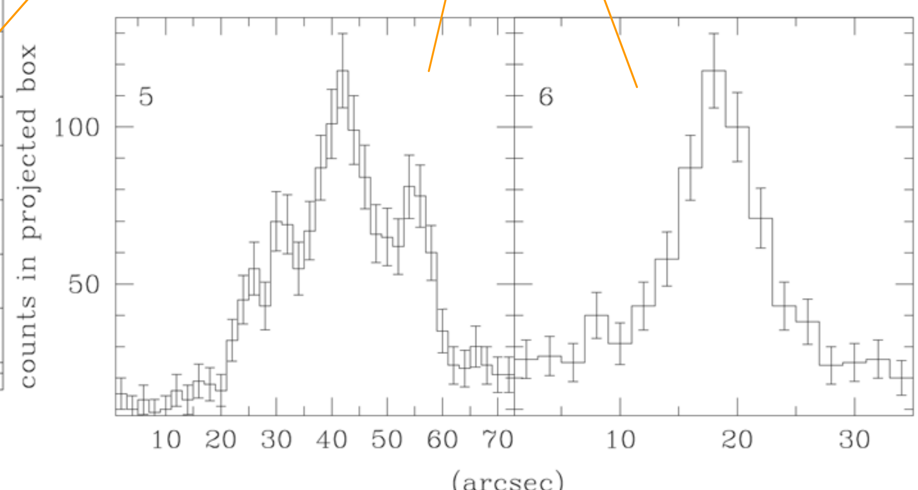
Feature is extremely sharp and narrow even in the raw data and > 100 kpc long





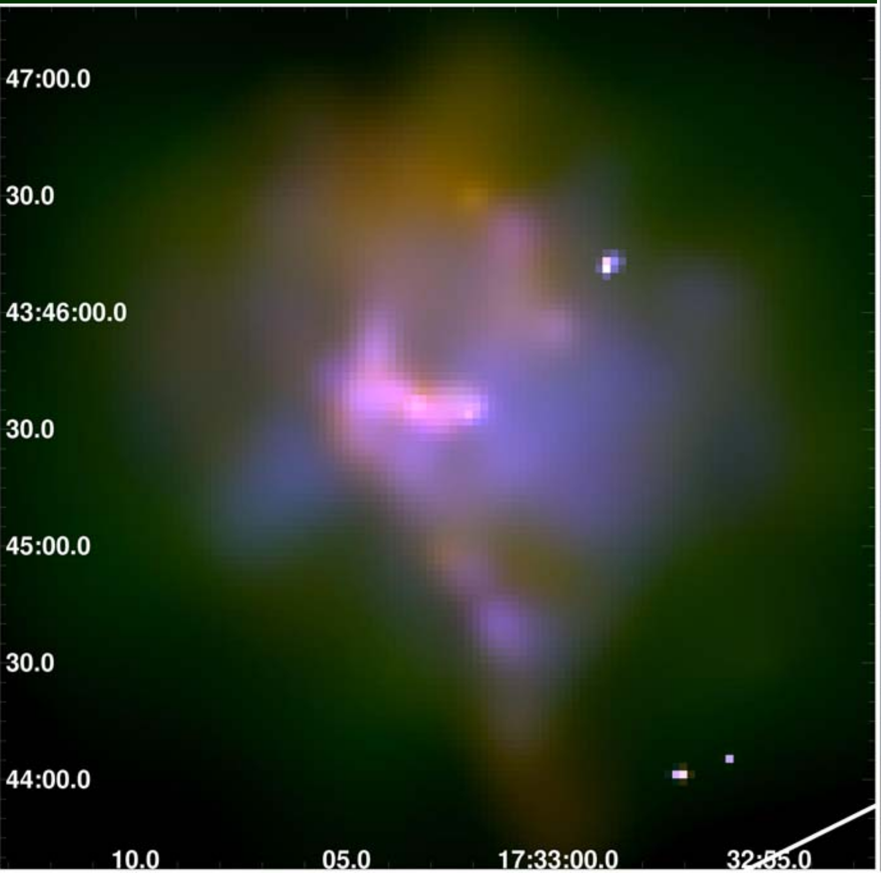
Jumps of >2x in <2", ~2" wide, plateau behind the jump



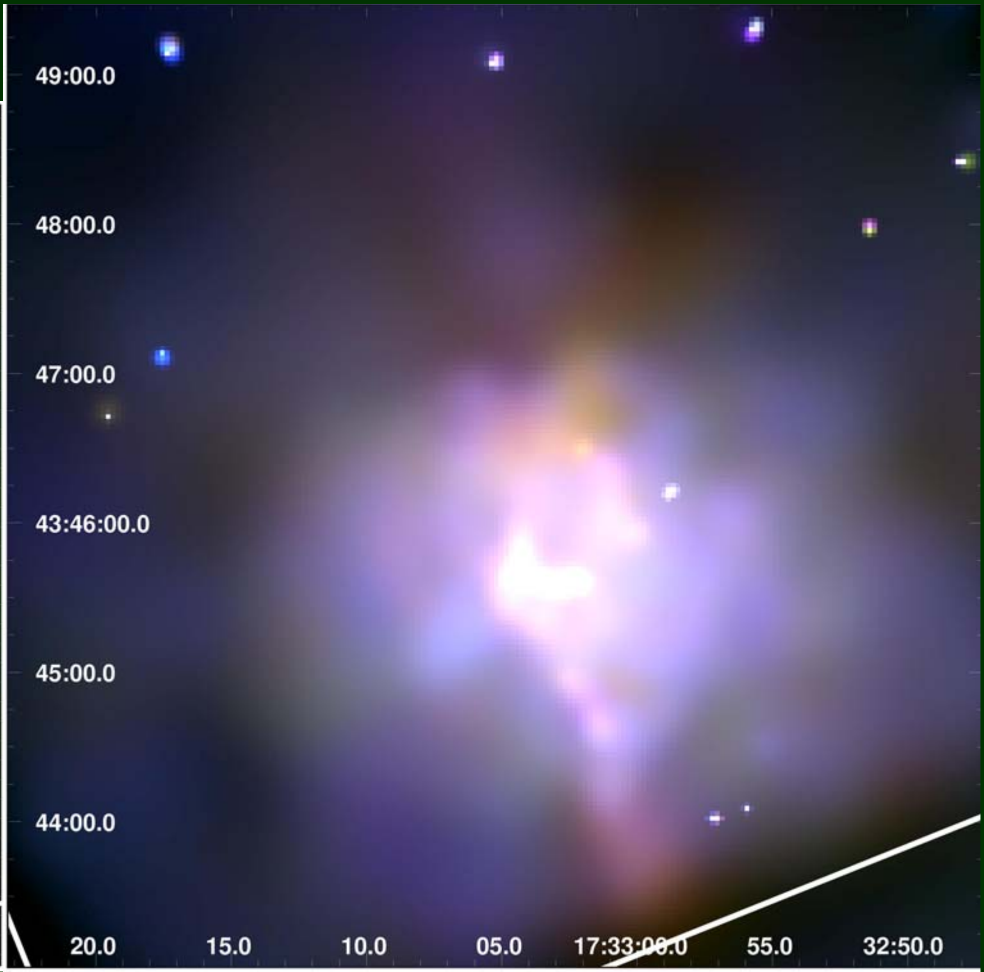


Once again: it's a mess!

red: 0.3-1.1, green: 1.1-2.5, blue: 2.5-5.0

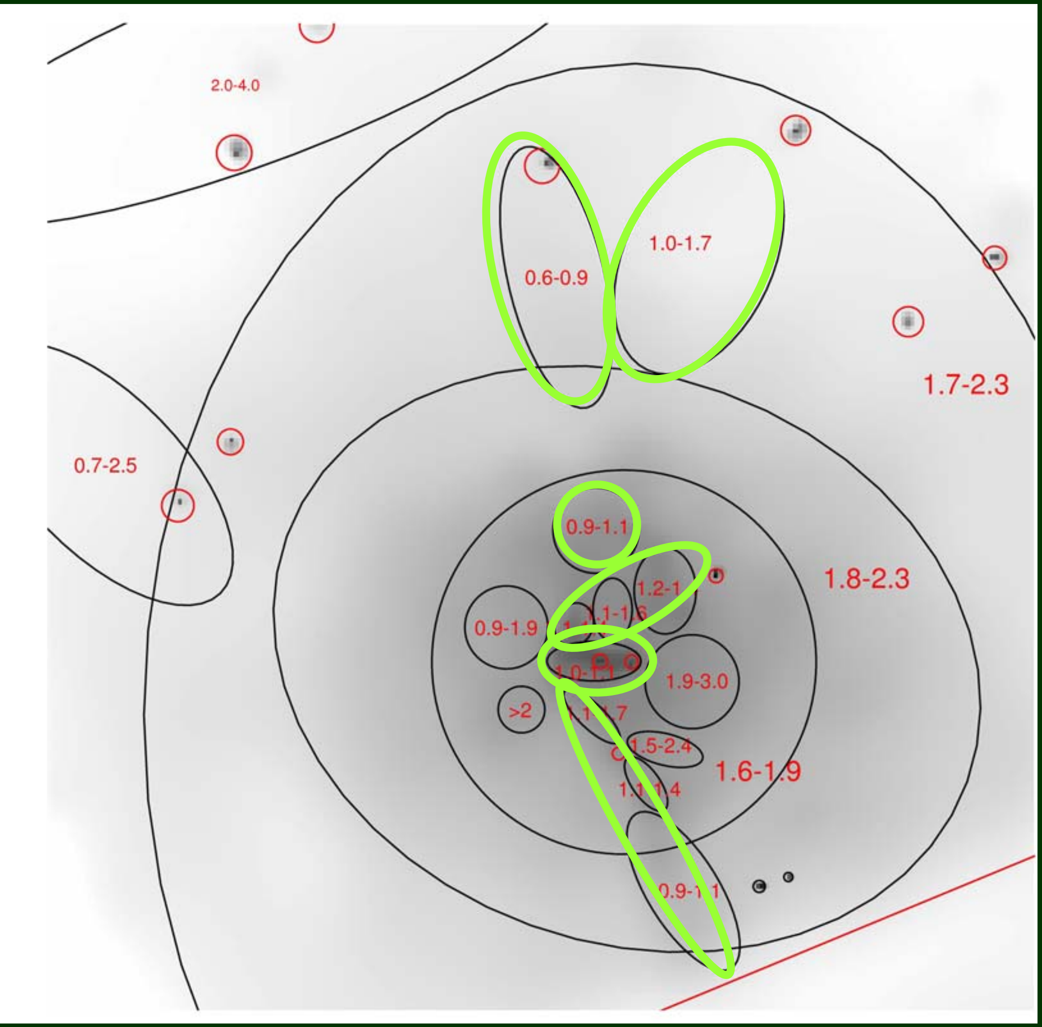


True color picture
Inner region



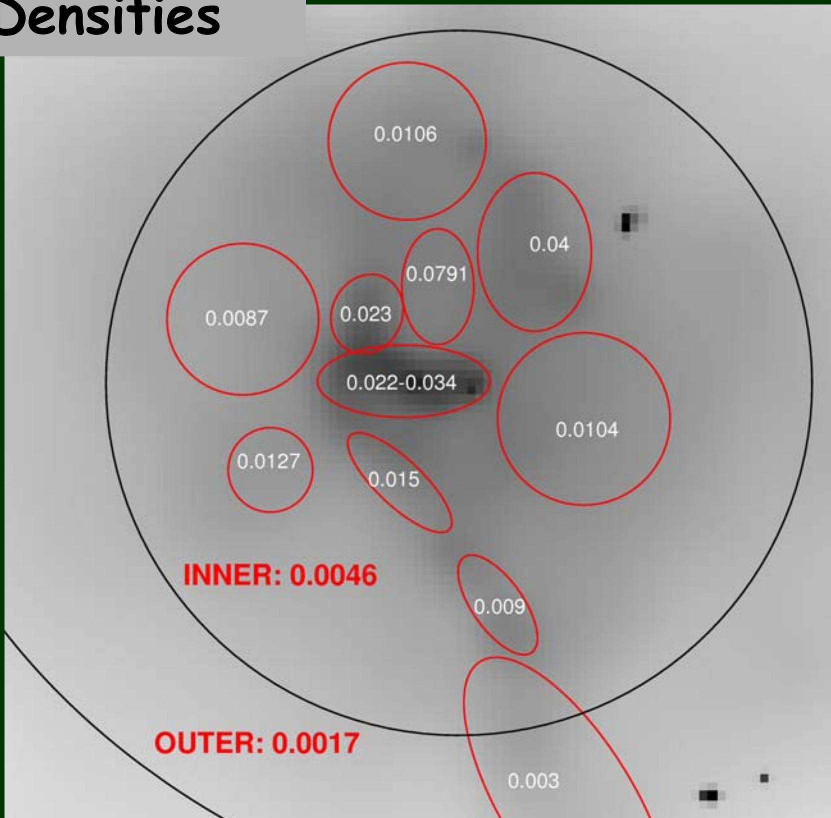
Outer region

Temperatures in different regions



cooler, @~1 keV
outside >1.5 keV
possible T increase with r

Densities



What is the origin of the narrow, sharp, cool, long, coherent feature at the center?

Analogy with clusters:

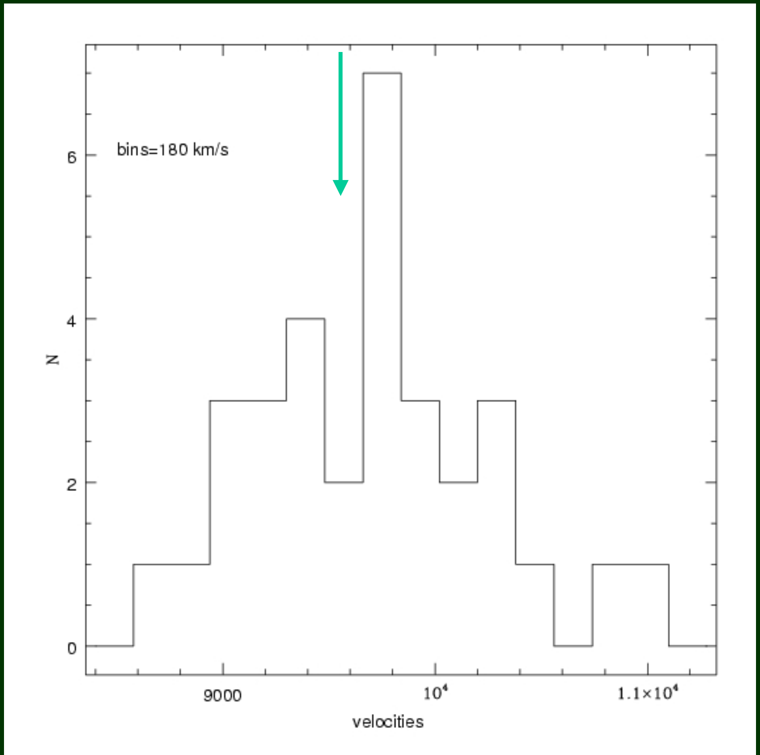
- **shocks [eg. SQ]**
  - ✗ Temperature is lower than outside
  - ✗ no peculiar motions regular velocity distribution [~500 km/s]
  - ✗ no obvious intruder – different morphology/size
- **Cold fronts/filaments** [eg. A3667, Perseus, ESO137-001 in A1795]
  - ✗ Morphology is different
  - ✗ again no evidence of infall/merger
  - ✗ No association with "other" filamentary structures [Hα, HI …] –
  - ✗ not a tail of a S galaxy [ESO137-001]

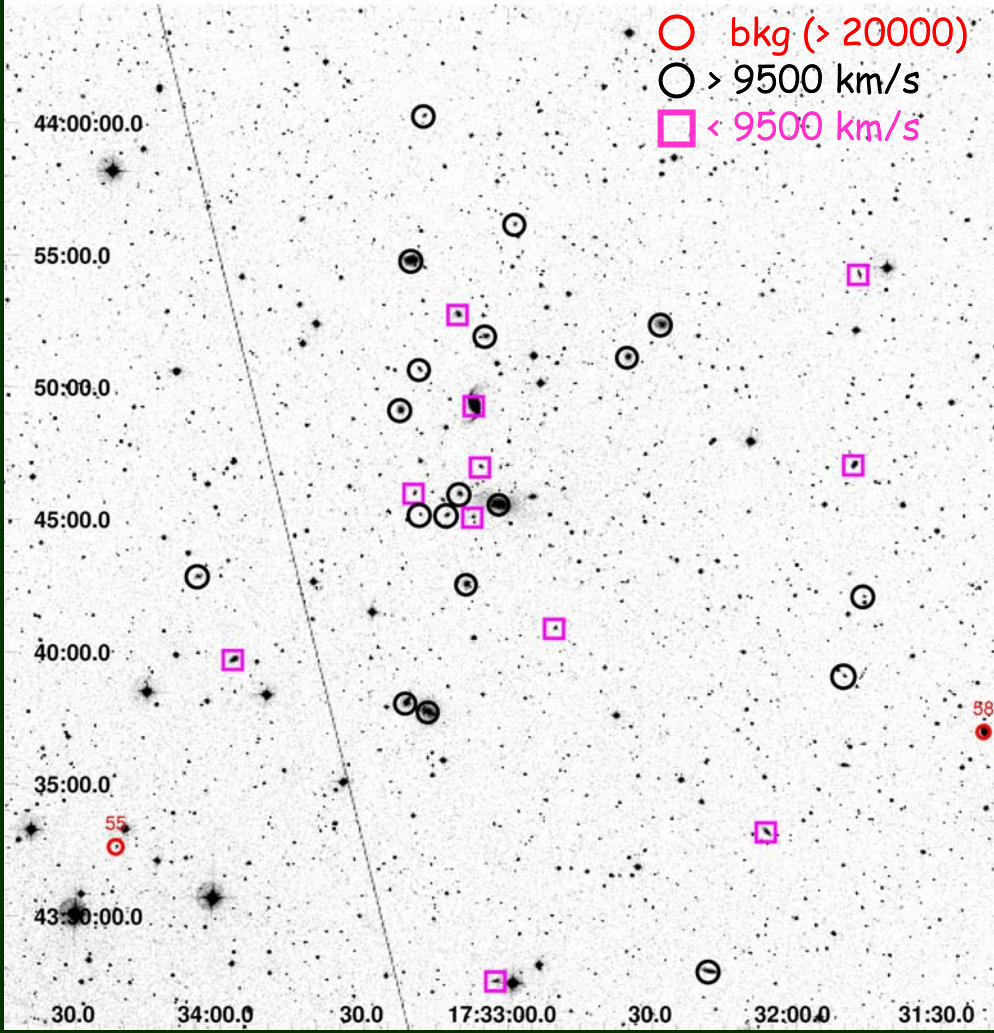
but also lack of data …

IC1262: central galaxy in a small group with no signs of interaction/merging events

Regular velocity distribution: ~30 members (E-type)

(data from Smith et al. 2005)





origin of the narrow, sharp, cool, long, coherent feature

- **Radio cavities** [eg. Perseus, Hydra-A] **or Ghost radio cavities** [eg. A2597, A4059, NGC 4636]
  - ✗ Morphology is different – not really cavities
  - ✗ much bigger structure than other cases
  - ✗ very weak radio source, no evidence of AGN …
    radio [AGN] could have been stronger in the past but ..

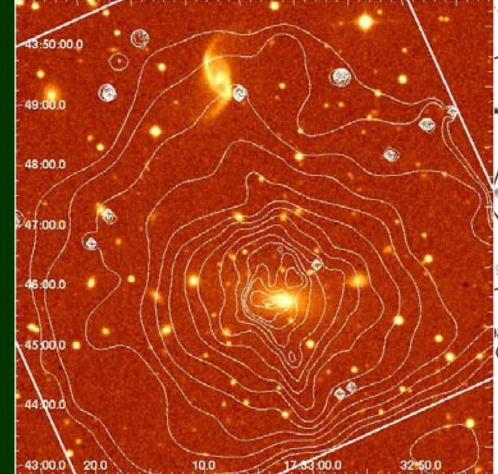
✓ **Trail behind IC1263**

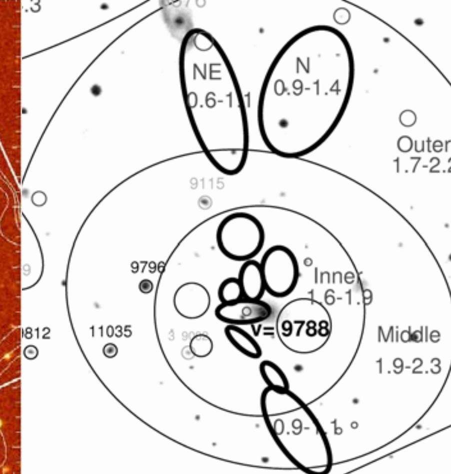
Nearby S (4' north), disturbed morphology, $\Delta v \sim 1000$ km/s wrt IC1262

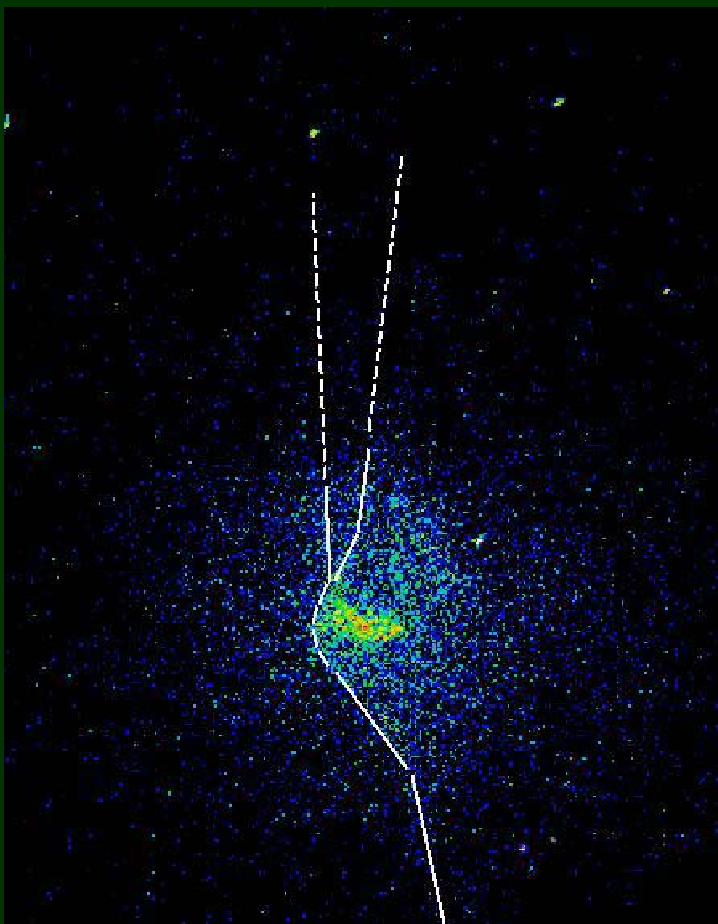
feasible

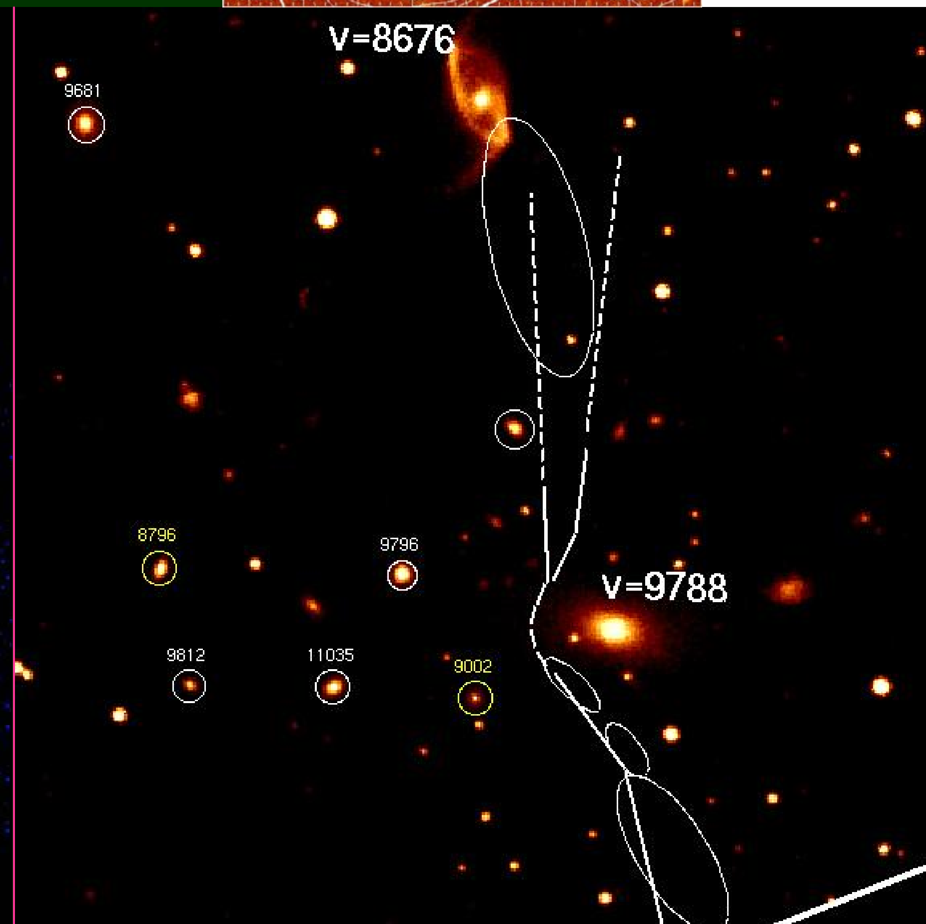
If we draw the edges of the feature on the optical

are we observing yet another IGM enrichment process?









Trail behind IC1263

✓ **Total mass ~** M_{gas} 6 10^9 M – available in a normal S like IC1263 [but no HI obs. to confirm ....]

✓ Cooling time > 10^9 yr – travelled distance ~1 Mpc longer than feature

✓ velocity/density allow "stripping" of the ISM in IC1263

is this the correct explanation? – does not explain all features [plateau, extension to the N, large central "banana-shape"] – needs more work!

To summarize:

IGM is a property of all groups, regardless of their evolutionary stage

Properties of IGM [T, Lx] might depend on the evolutionary stage – still a lot of work needed on cool/young systems (also faint!), but we should not take the hotter one for granted

Building/enrichment of IGM can be "seen" directly in the X-ray images and it can happen at any evolutionary stage

➔ <u>needs to be taken into account</u>

Many phenomena are at play at the same time in groups today

➔ <u>what about in the past?</u>