Galaxy Evolution in Cluster Cores and Outskirts

Activity at the cluster core
Enhanced Activity in Outskirt/Filament Galaxies
Going after the density of the intra-filament medium

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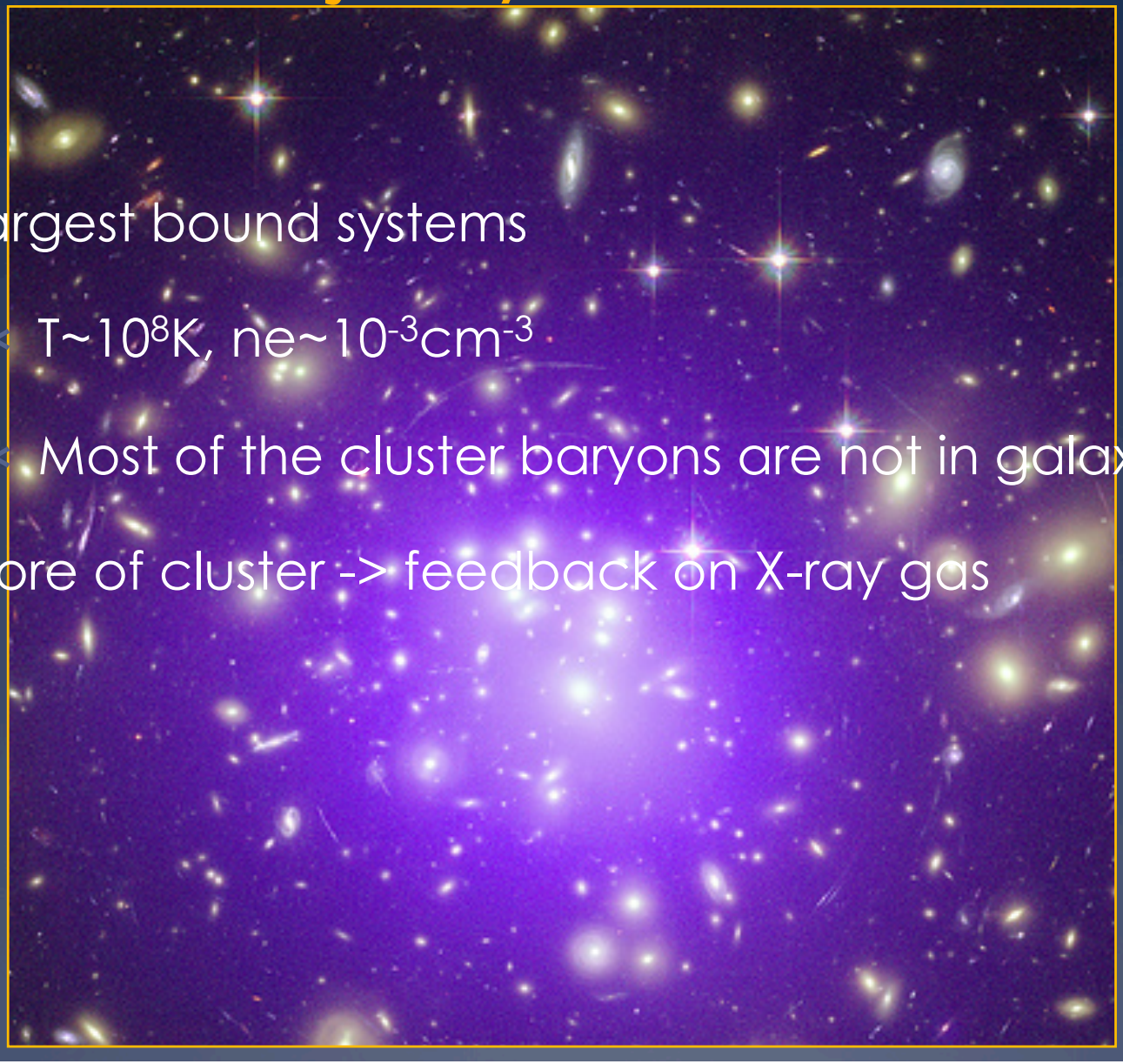
The Majesty of Clusters



- Largest bound systems
  - $T \sim 10^8 K$, $ne \sim 10^{-3} cm^{-3}$
  - Most of the cluster baryons are not in galaxies
- Core of cluster -> feedback on X-ray gas

Cluster galaxies are not all 'old red and dead'

- The brightest cluster galaxy
  - At cluster core, cD
  - Related to the cooling flow
  - BCG emission lines
- At outskirts
  - Multi-wavelength observations
  - Abell 1763-Abell 1770
  - Starbursts and AGN

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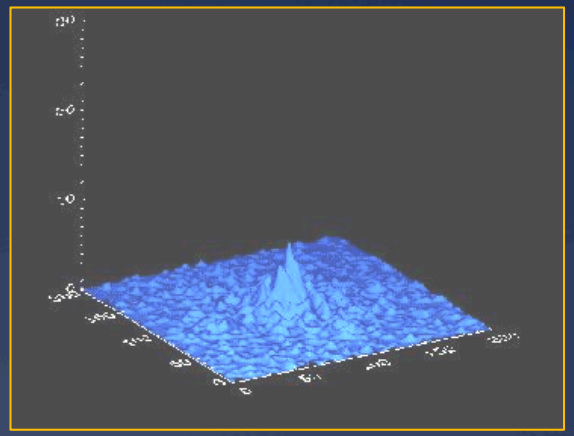
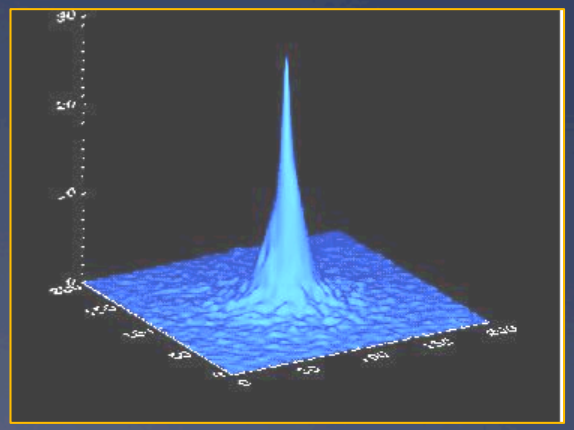
Cluster cores Bright in X-ray

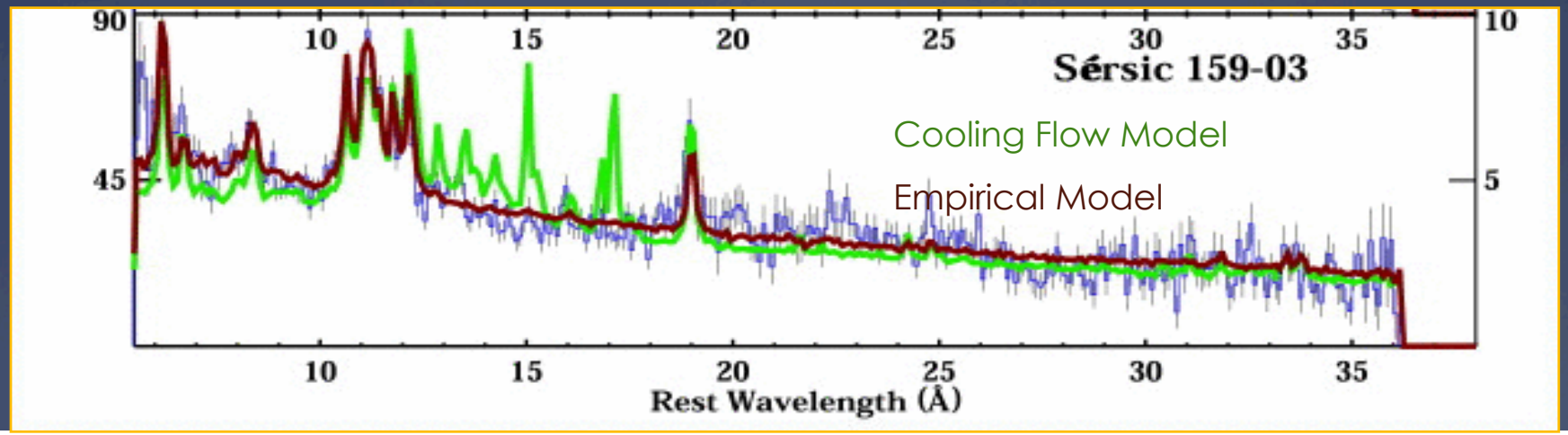
- Classic Cooling Flow
  - Observational signature is peak in X-ray surface brightness
  - thermal X-ray emission – gas radiates -> entropy decreases -> gas compresses and flows inwards
- Classical Cooling flow problem:
  - 100Msun/yr cooling
  - 10Msun/yr measured





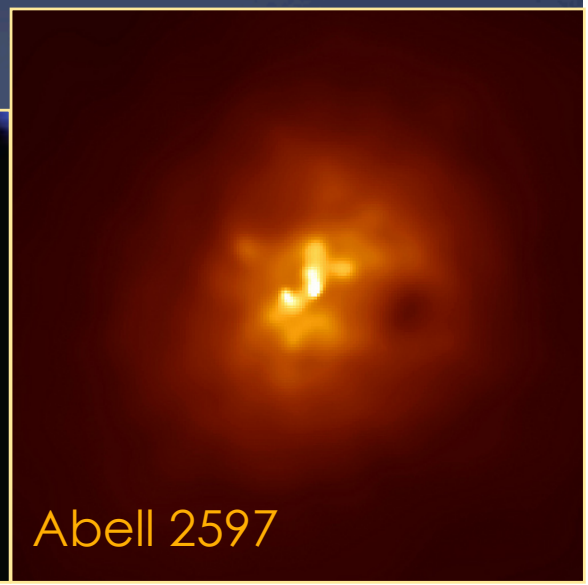
Cluster cores Bright in X-ray

- The New View of Cooling Flows:
  - XMM RGS – resolves FeL spectrum for extended object
  - Observed lack of FeXVII Lines, diagnostic of T distribution
  - Continuous distribution of T's required but little cooling < 2keV



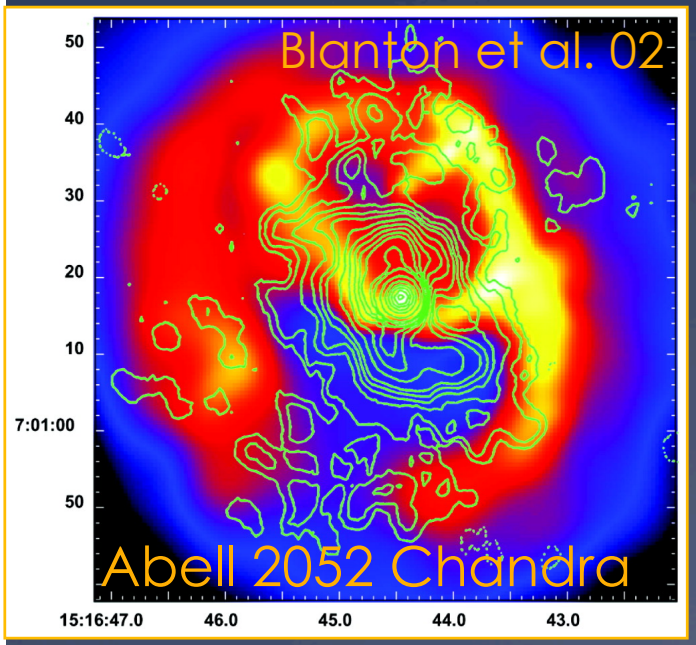
Cluster cores Bright in X-ray

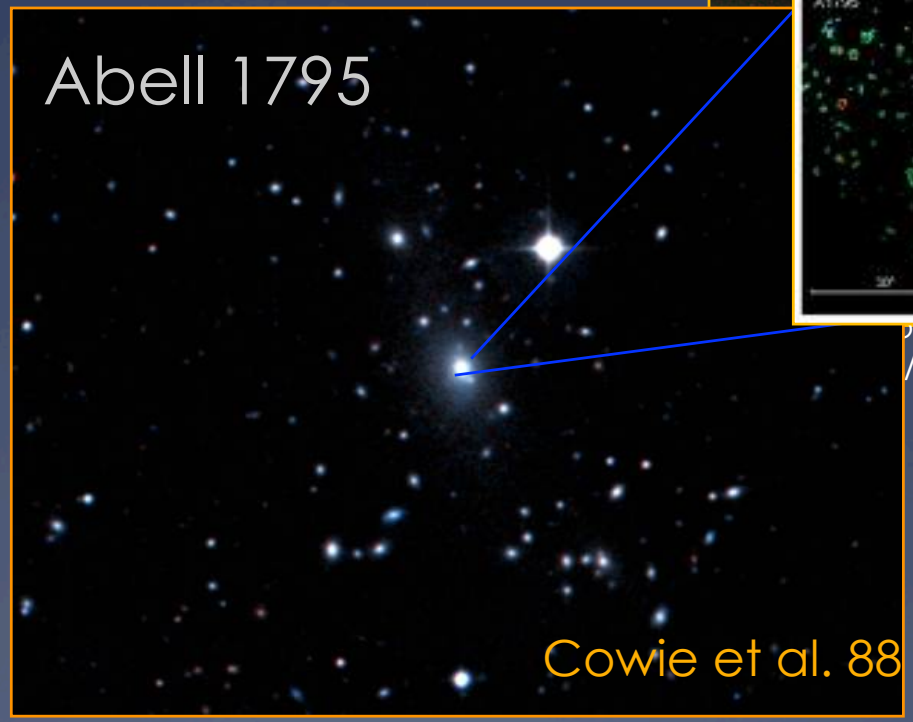
- The New View of Cooling Flows:
  - High resolution images show emission is not homogeneously spread throughout r_{Cool}
  - localized - very central – regions,
  - this is the gas that is cooling and MDR should naturally be lower than classical values

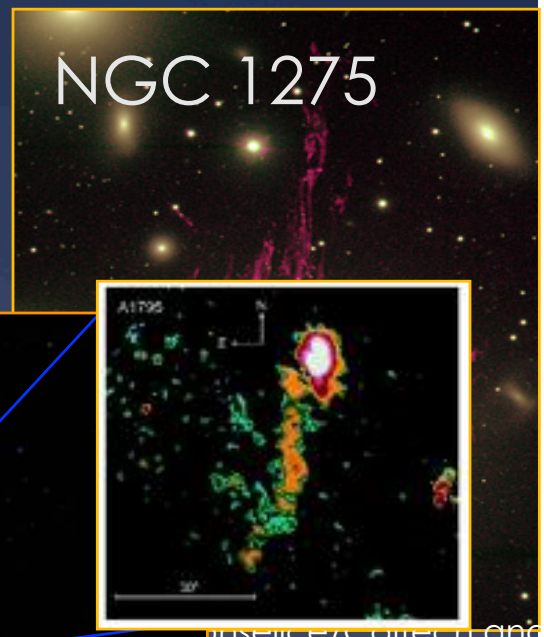


Cluster cores are Bright in Radio and Optical Emission Lines

- AGN (SMBH) is a major potential source of heating: Lobes, jets
- Cooling FLOW has a new meaning







/NOAO/AURA/NSF

Activity at cluster core

How often to BCGs so signs of activity?

What are physical properties of the line emitting gas?

Line Emission in BCGs

* Only in BCGs?
* Only in CF BCGs?
* Can type and source of activity be characterized?

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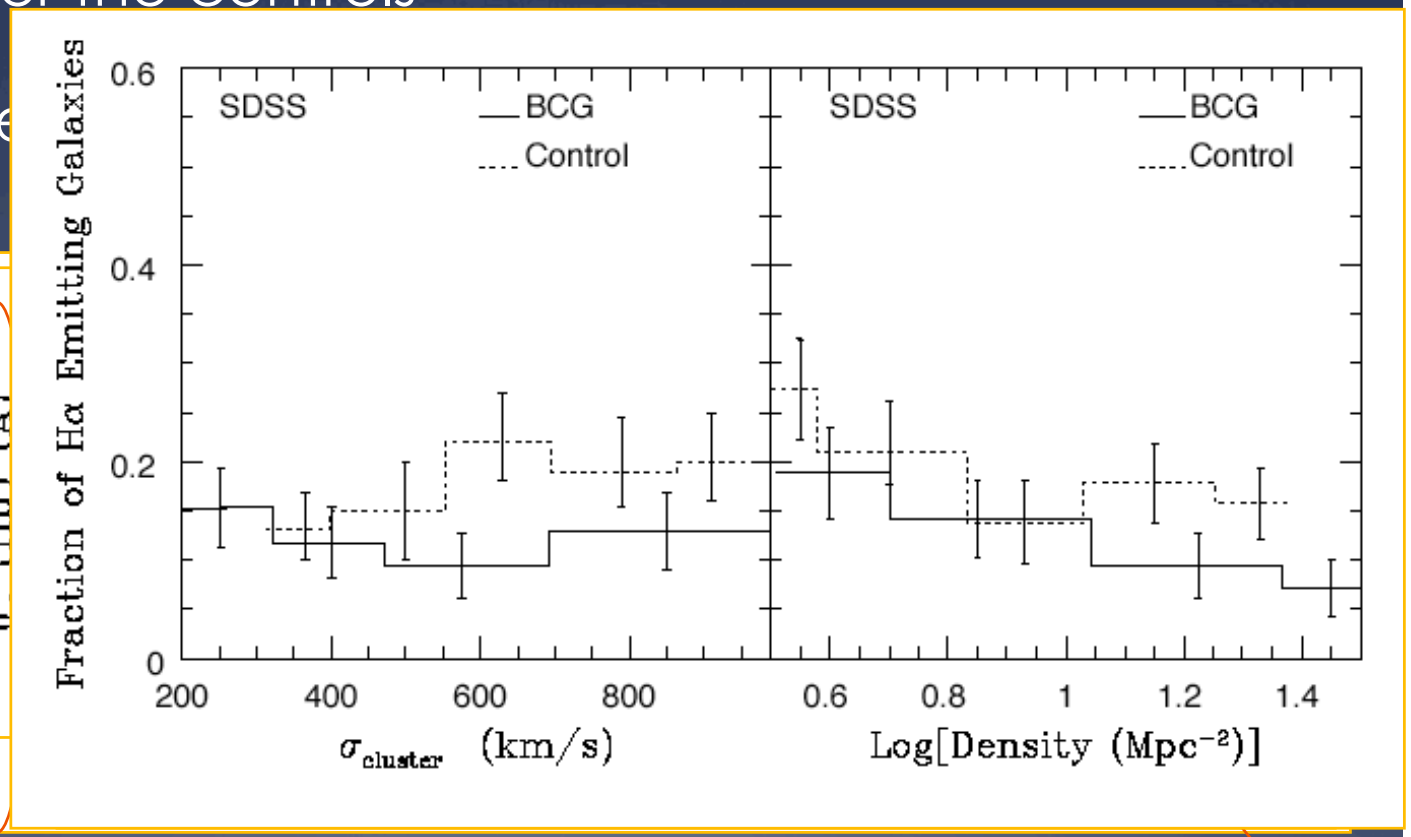
* NFPS – 60 BCGs + 159 Controls
  * Massive X-ray clusters, Hbeta
* SDSS – 338 BCGs + 526 Controls
  * Cluters and Groups, Halpha, NII

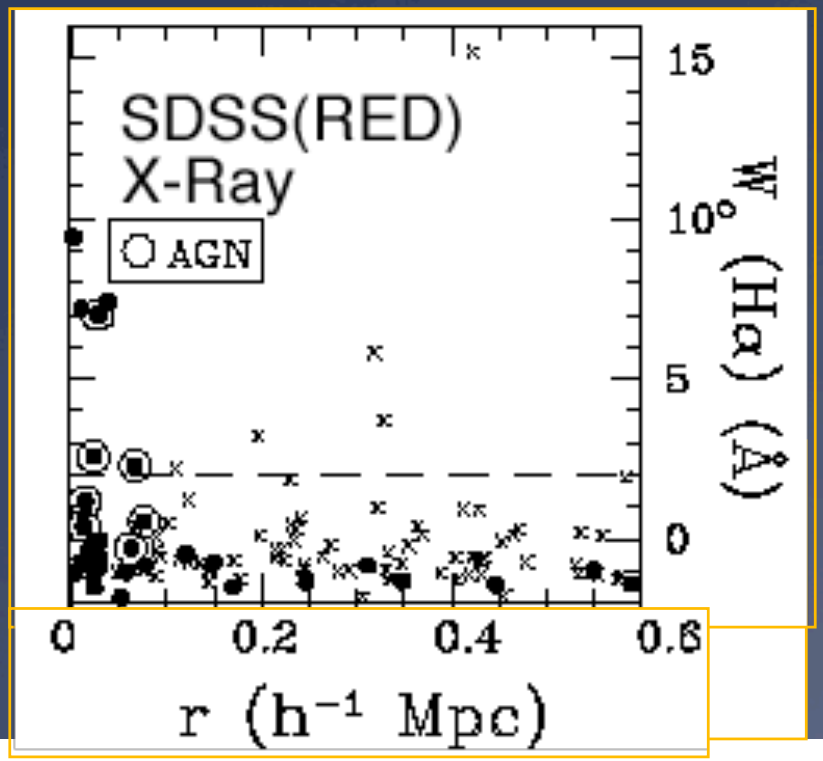
BCG Location

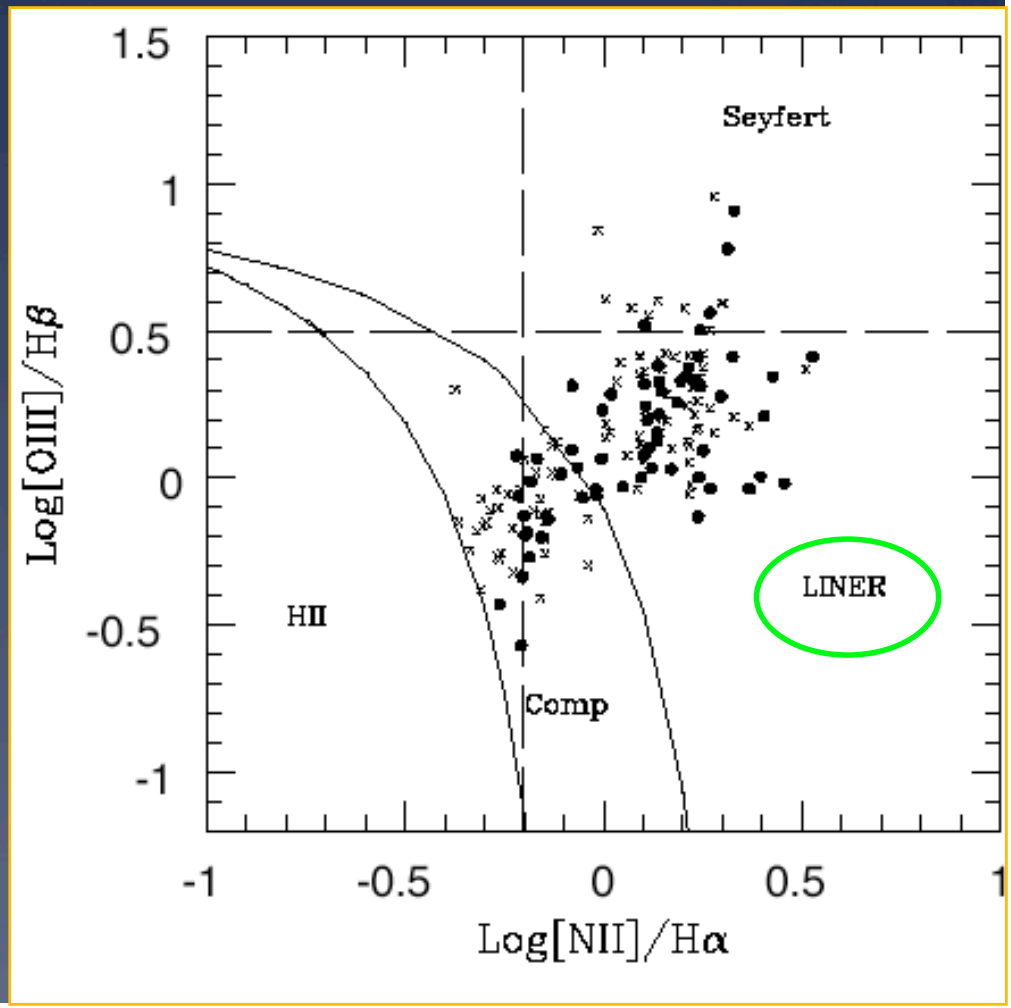
- The line emitting galaxies are near to center, CF
- Not true for the controls
- Difference



Properties of the Galaxy

* Half are AGN





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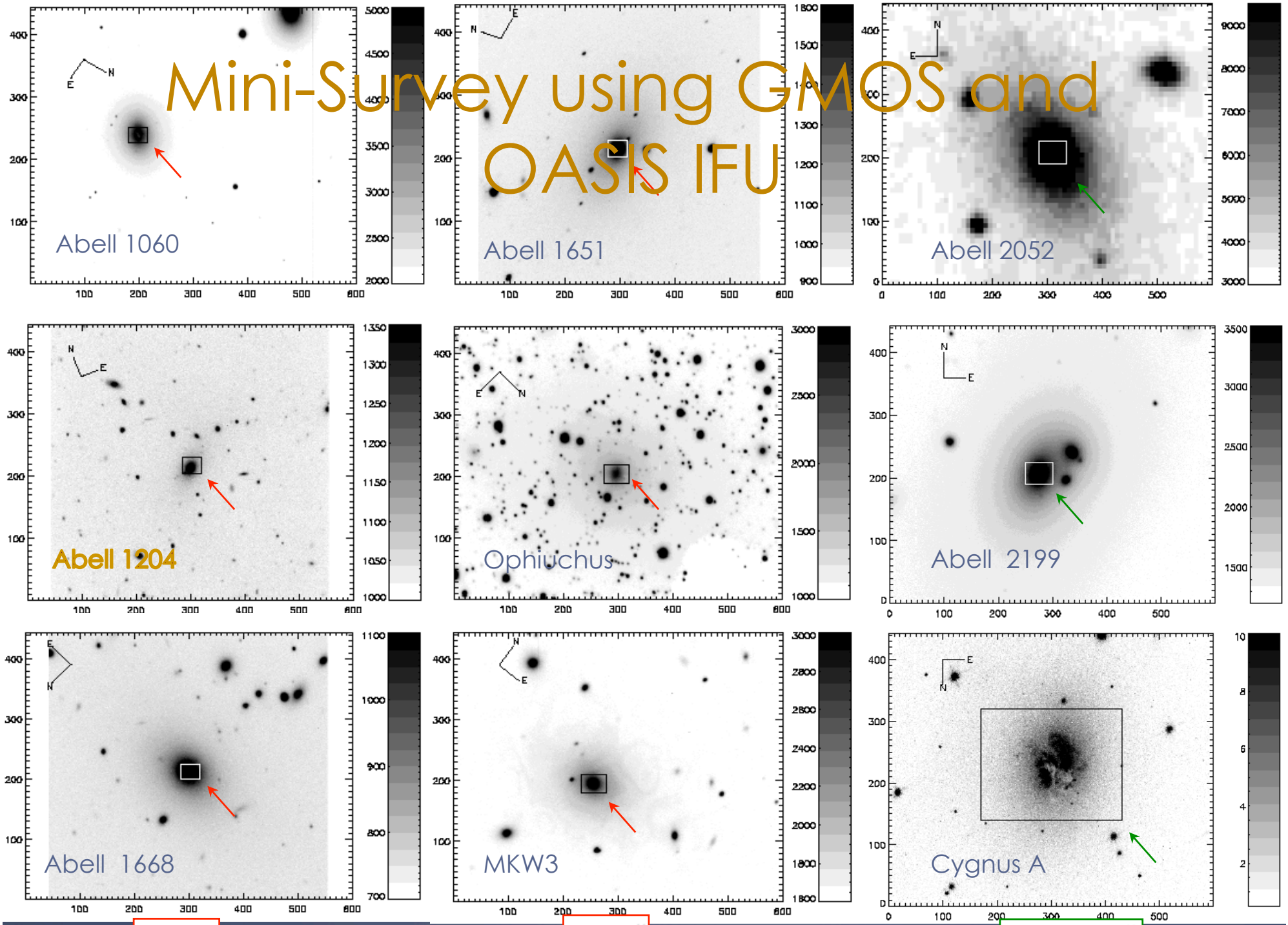
Explore Optical Emission Lines

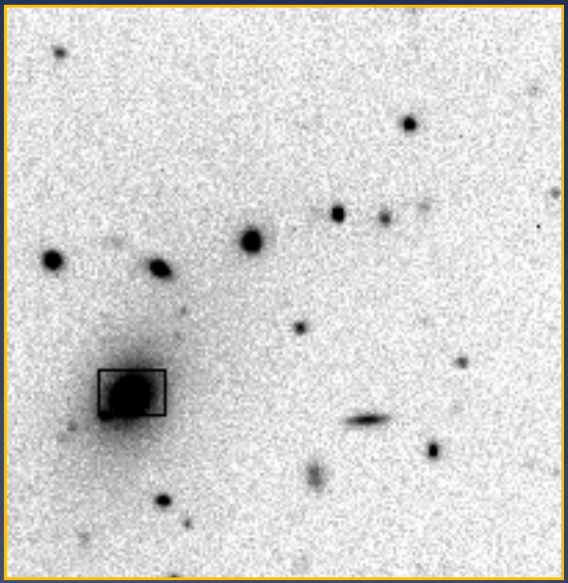
Common in BCGs in Cooling Flows

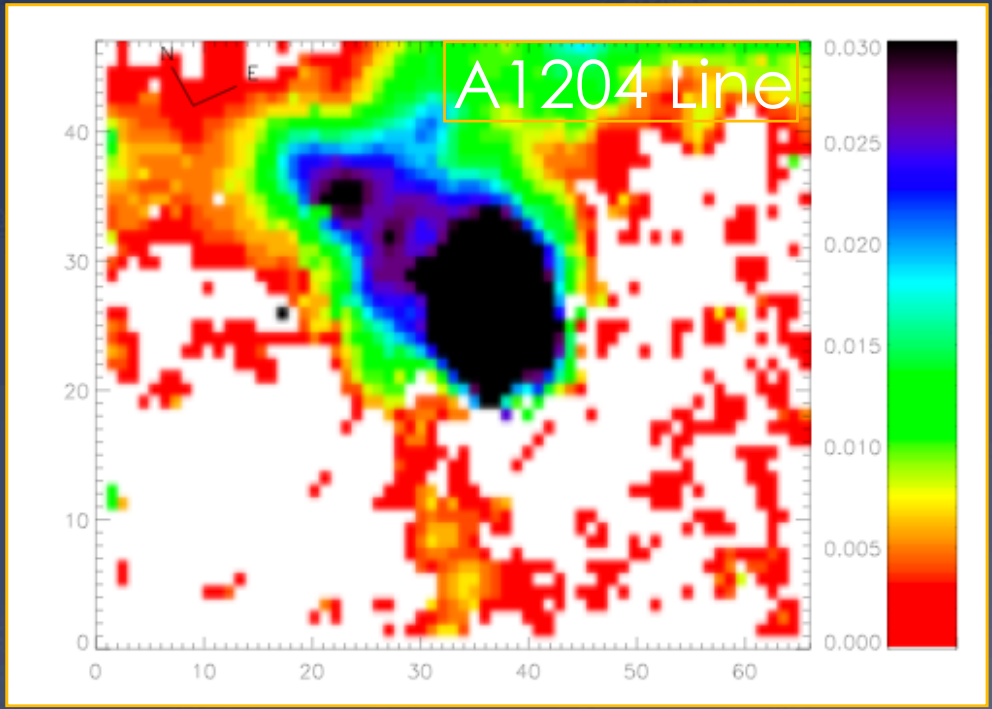
What are physical and properties of the line emitting gas?

Mini-Survey using GMOS and OASIS IFU



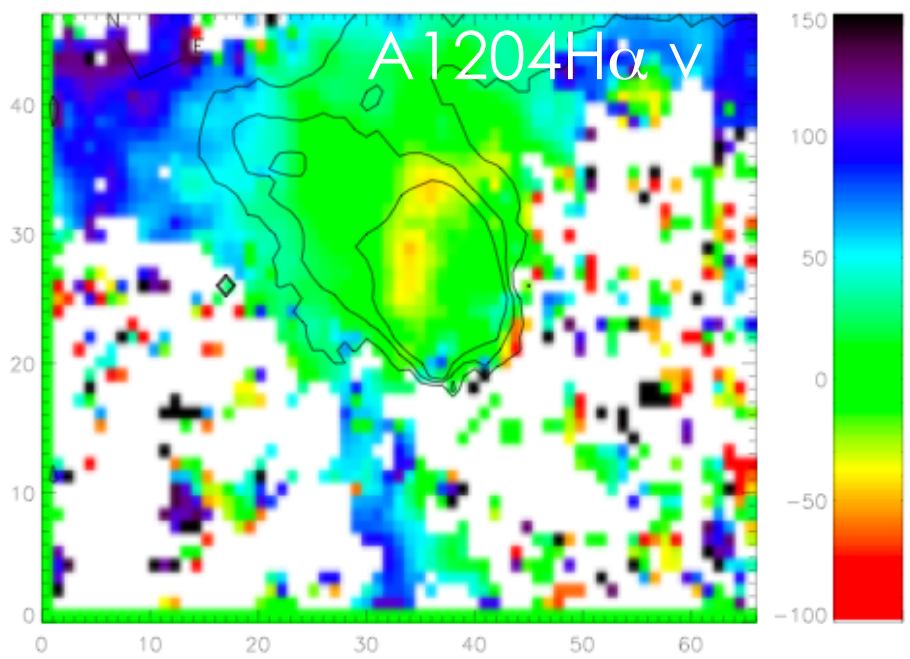
Morphology, Kinematics, Emission Mechanism

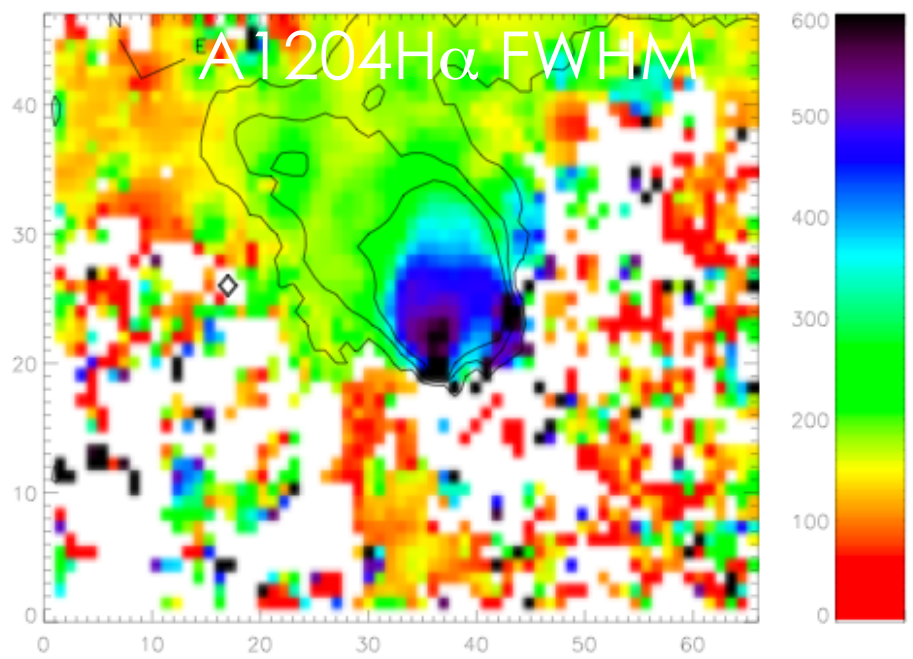




Morphology, Kinematics, Emission Mechanism

- Rotation and bulk flows of ~100km/s
- Increased FWHM near AGN





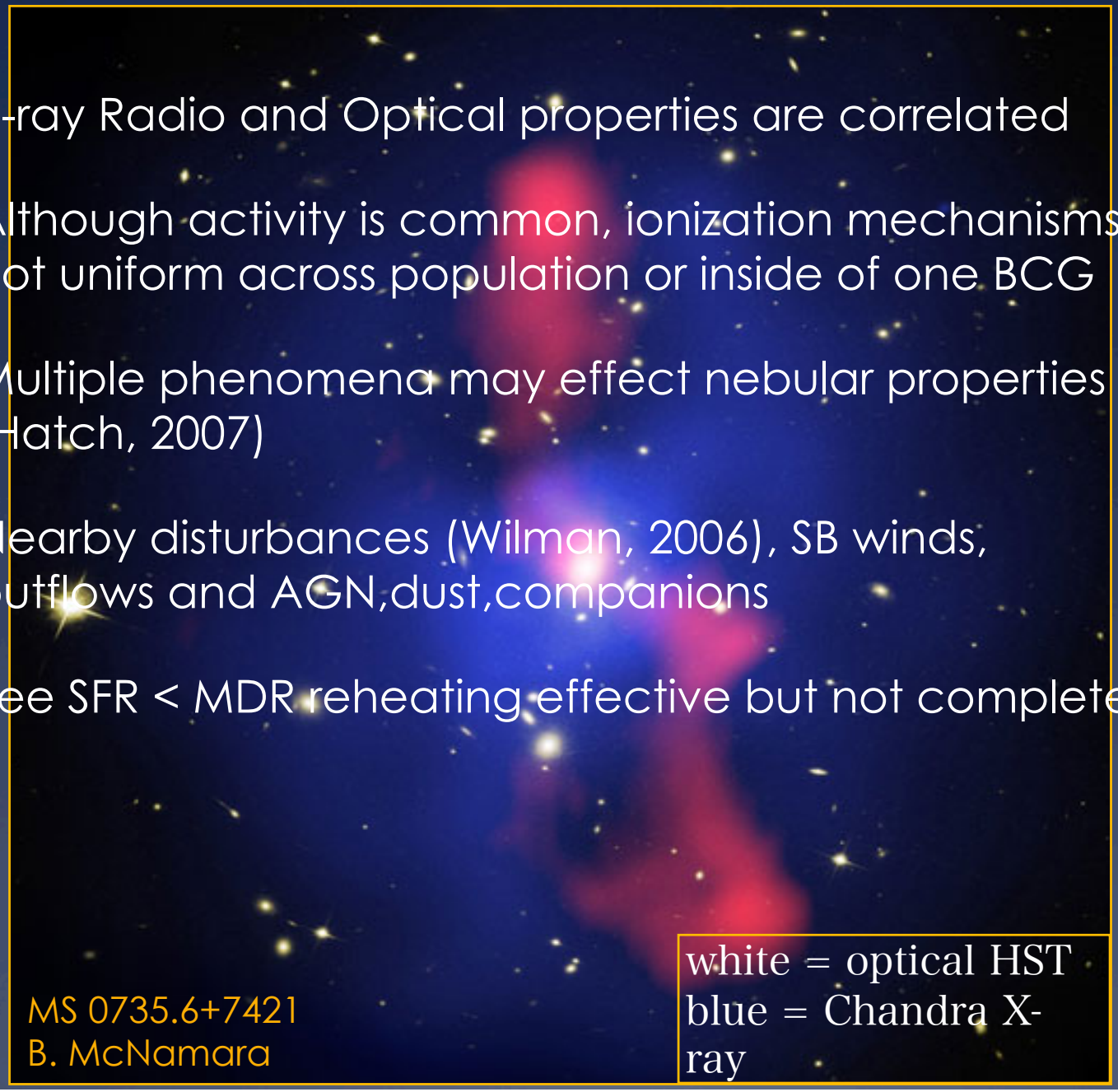
Morphology, Kinematics, Emission Mechanism

* Possibilities for emission mechanism
* Shocks, Conduction, CR heating, AGN, SF…
* Some can be discerned by their flux ratios
* Only 2 cases where SF is plausible

With SB99,
A1060: 0.02 Msun/yr
A1204: 7 Msun/yr

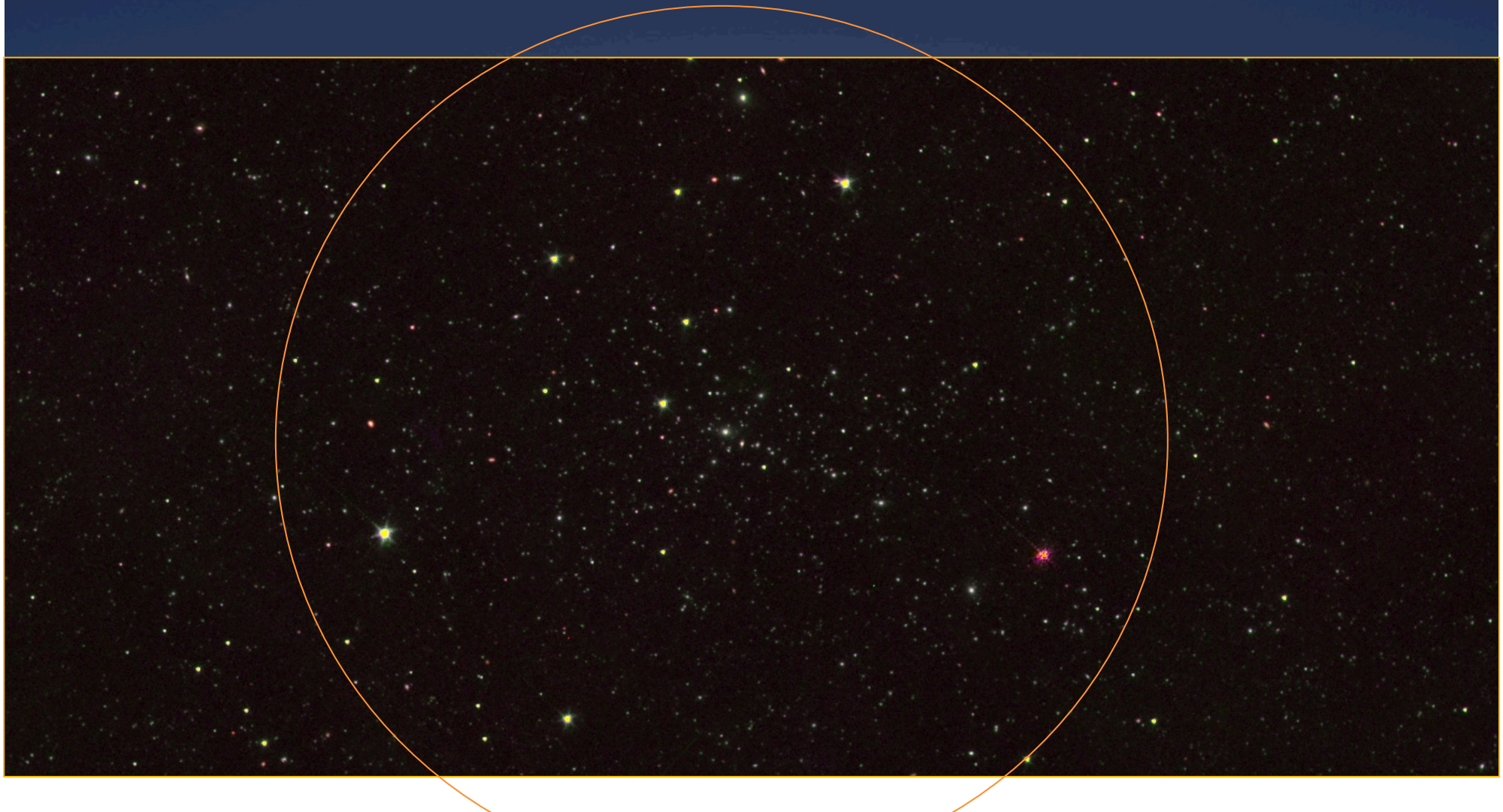
Summary

* X-ray Radio and Optical properties are correlated
* Although activity is common, ionization mechanisms not uniform across population or inside of one BCG
* Multiple phenomena may effect nebular properties (Hatch, 2007)
* Nearby disturbances (Wilman, 2006), SB winds, outflows and AGN,dust,companions
* See SFR < MDR reheating effective but not complete



The BCG is active

* But just one galaxy in the center…



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Galaxy Evolution in Cluster Cores and Outskirts

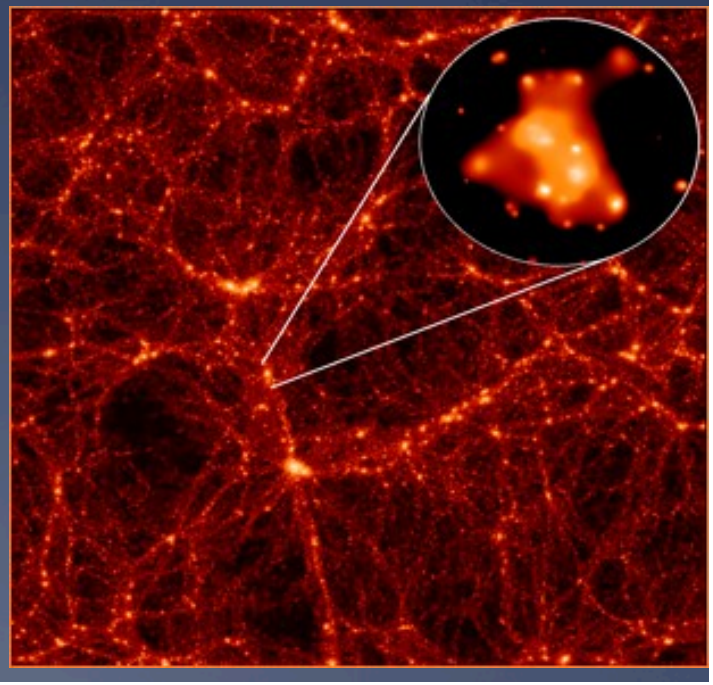
Galaxies at massive X-ray cluster cores are active

Activity in Outskirt/Filament Galaxies

Going after the density of the intra-filament medium

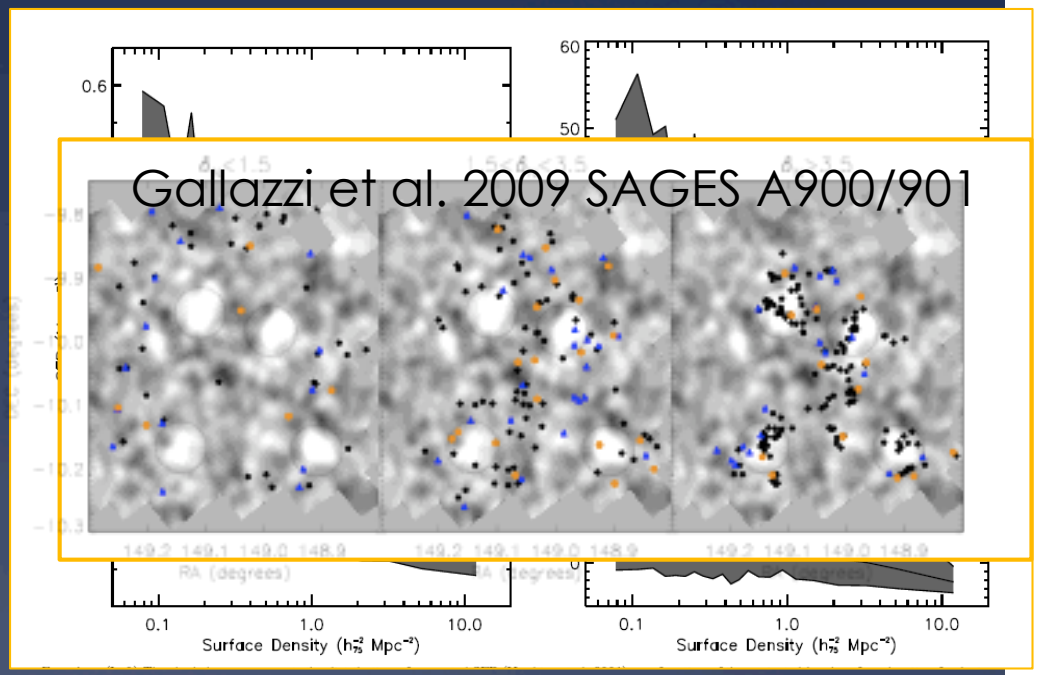
A Tour through the LSS

- Connected by filaments and separated by voids
- Constantly accreting matter in small galaxy groups through the filaments (Benson 2005, Virgo Consortium (MPA),…)



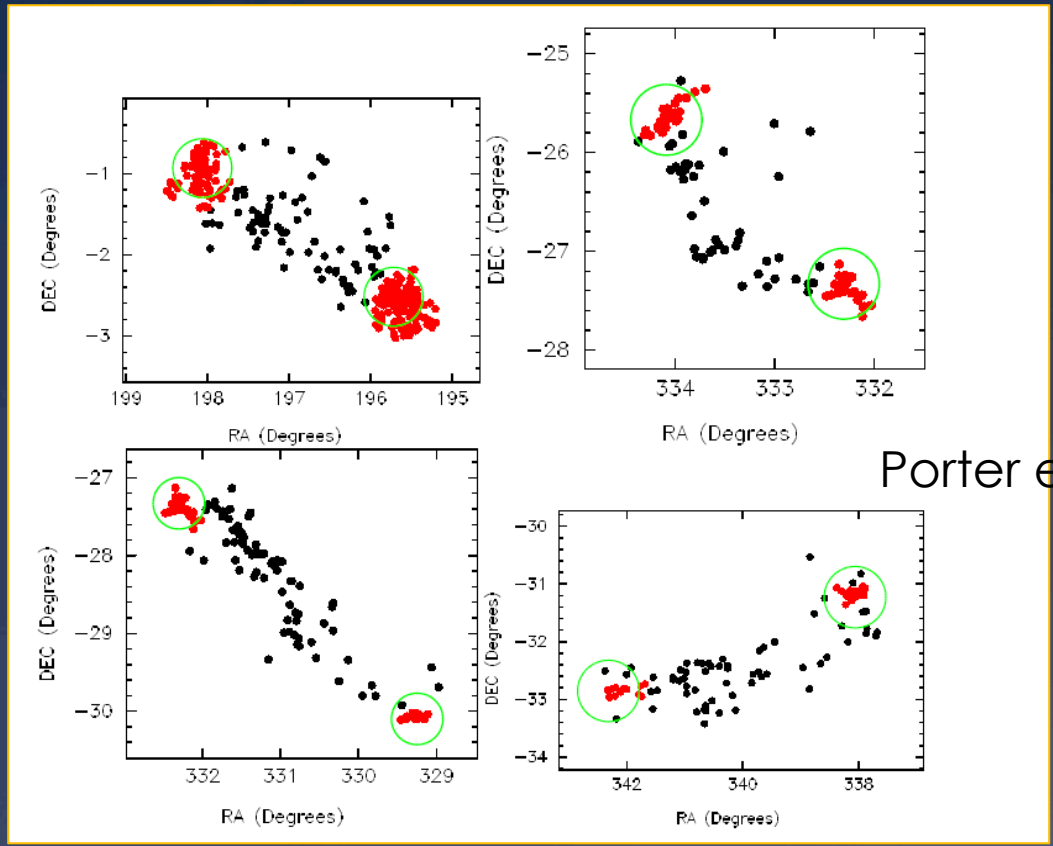
Outskirts

- Star formation is depressed as local galaxy density increases
  - Ram-pressure (cold)
  - Strangulation (hot)
  - Harassment
  - Galaxy-galaxy interactions (or lack there of)
- Star forming galaxies found at cluster edges, and between clusters, in regions of intermediate galaxy density

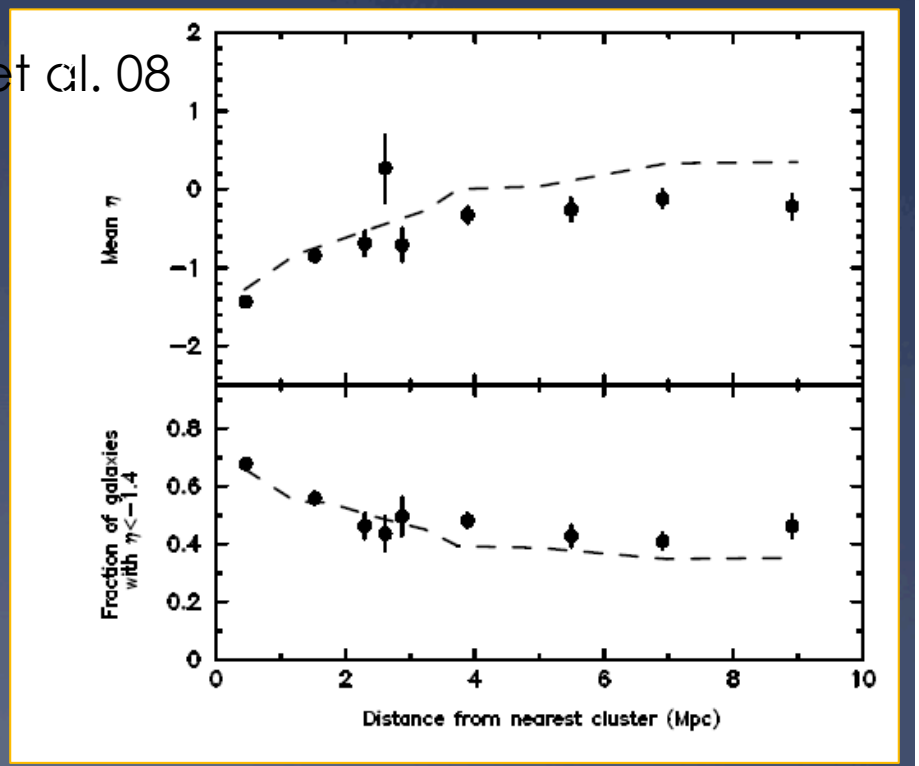


Gomez et al. 2003 SDSS Local Galaxies

Cluster Filament Galaxies are active in Optical, IR

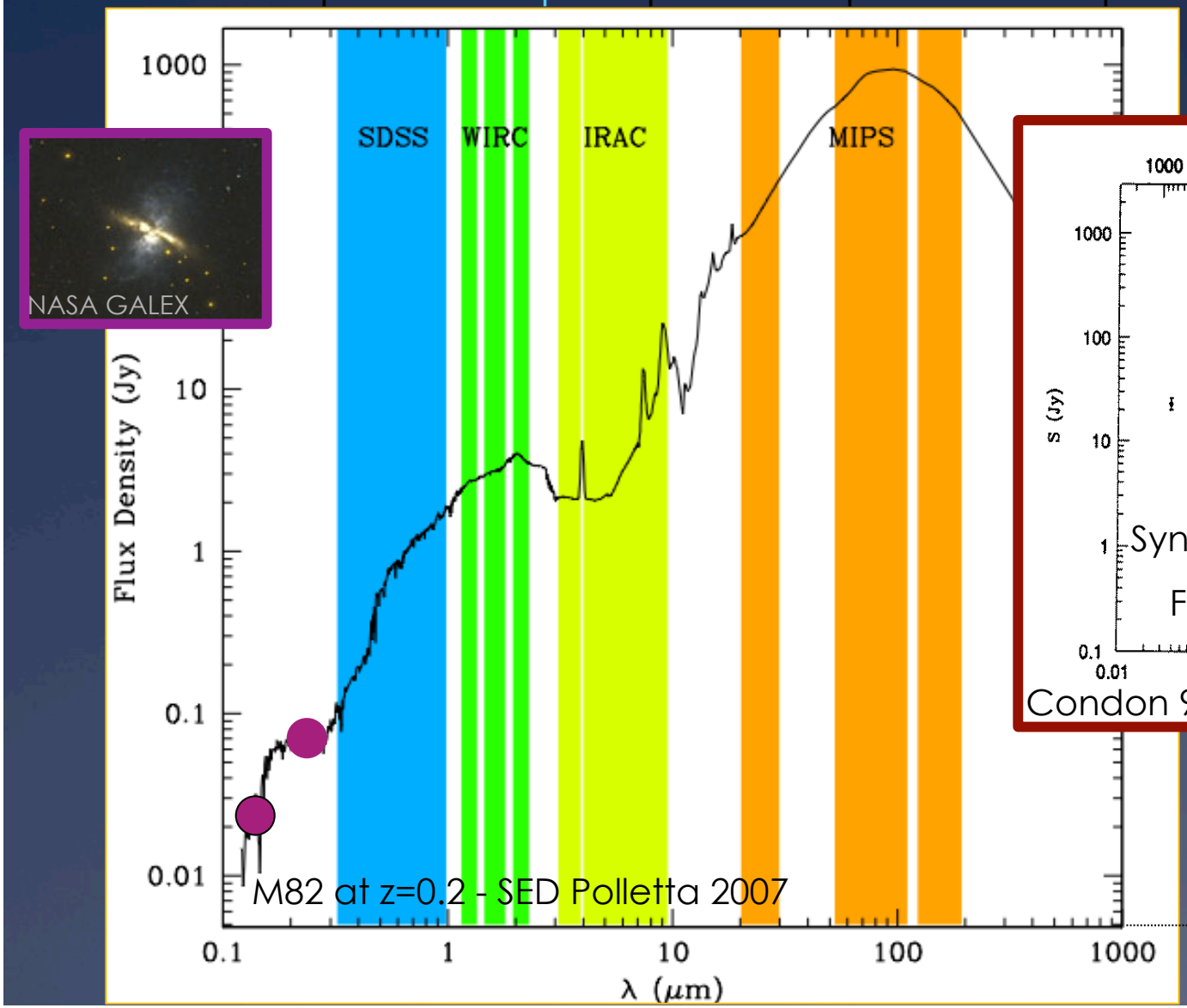


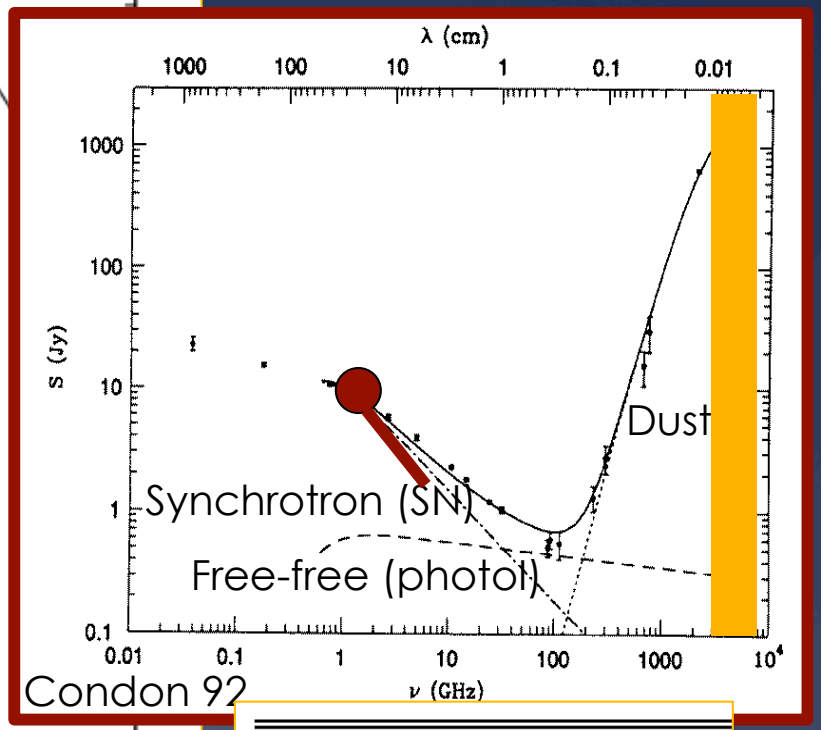
Porter et al. 08



Multi-wavelength Observations

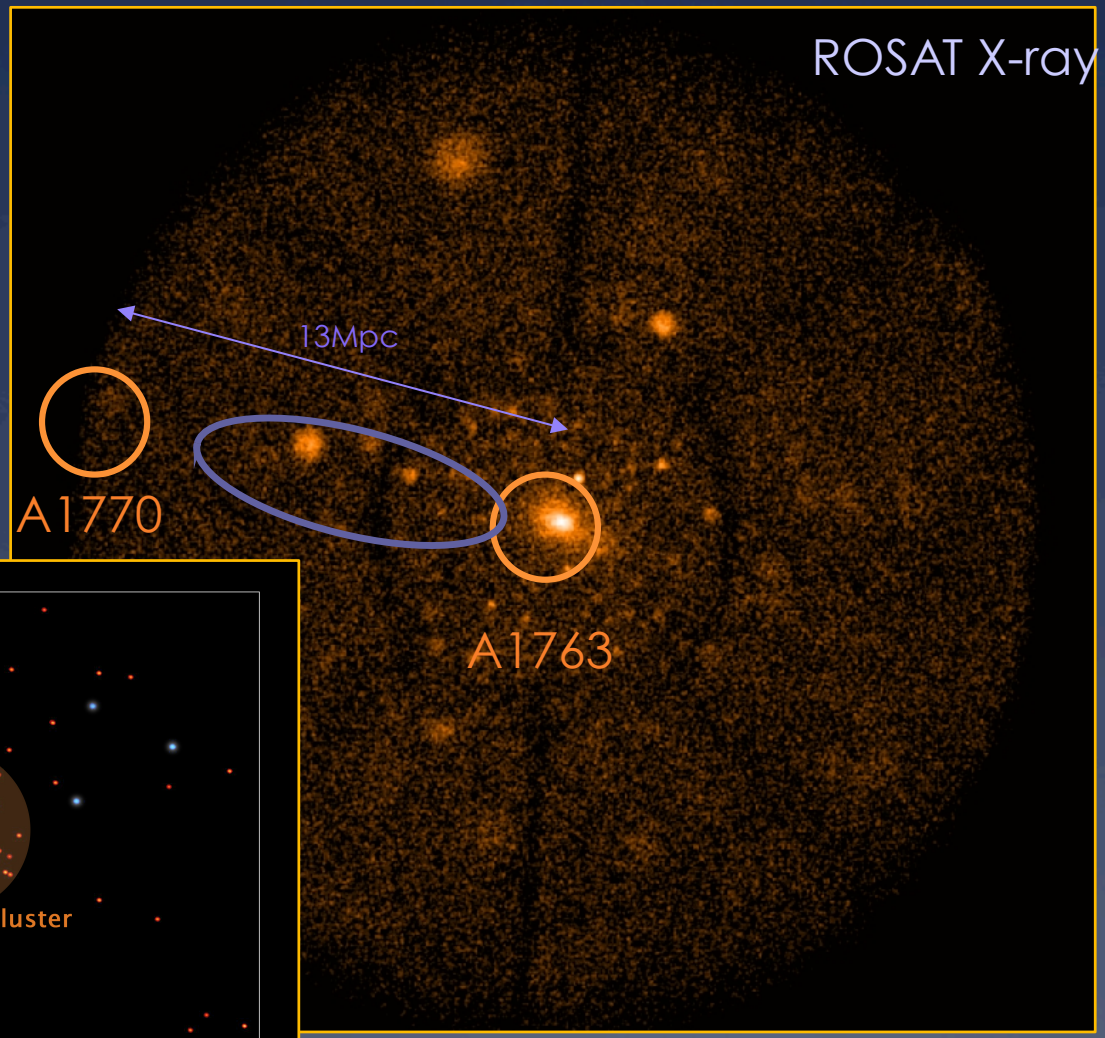
UV ext corr SF | colours+spec | masses | Hidden SF | total SF

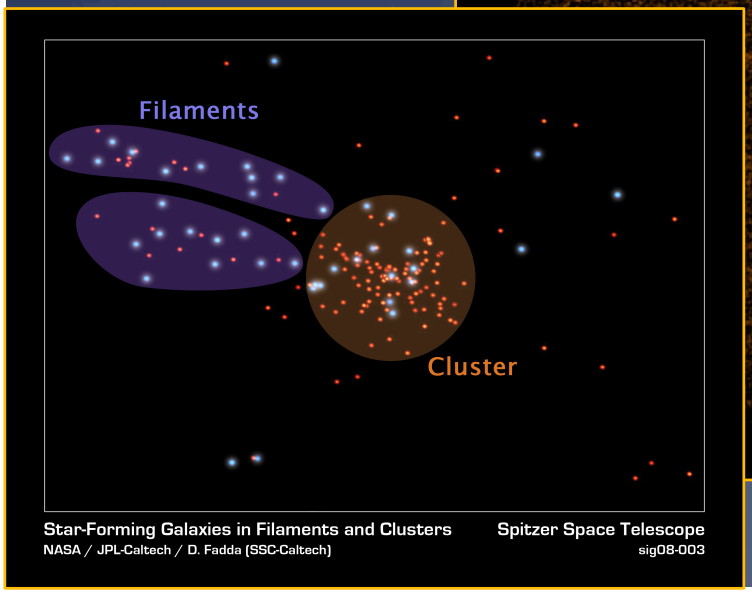




Survey	N_z Total	N_z Cluster	N_z Cluster & 24μm
WIYN	573	174	83
TNG	297	35	8
SDSS	139	104	16
Total	988	294	93

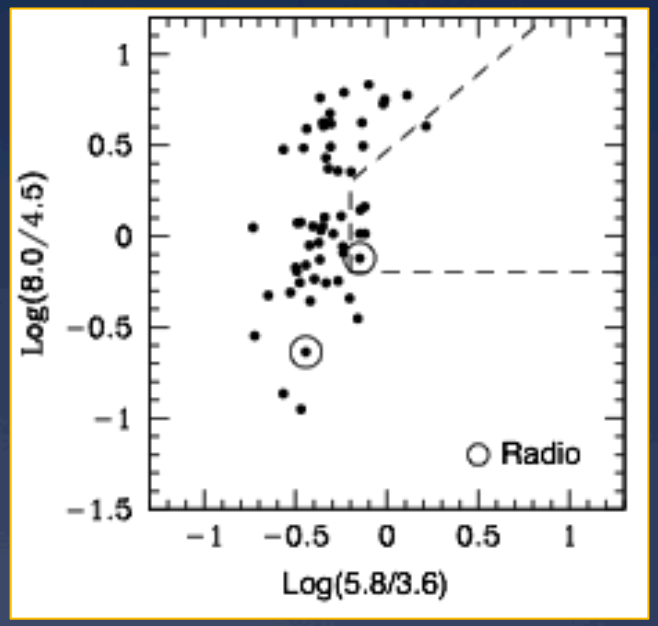
The Abell 1763 - Abell 1770 Superstructure





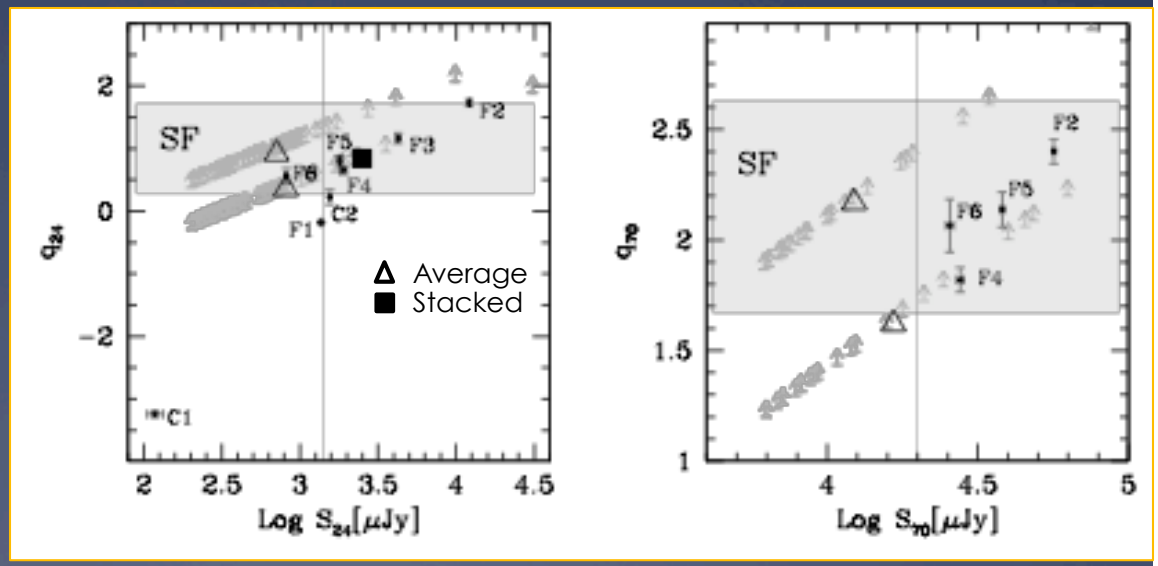
Characterizing AGN and Starburst

- Convinced radio AGN contamination is low
  - Use FIR-Radio correlation (Appleton et al. 2004)
  - IRAC colors (Lacy et al. 2004)
  - BPT, Check quasar catalogs, Stacking

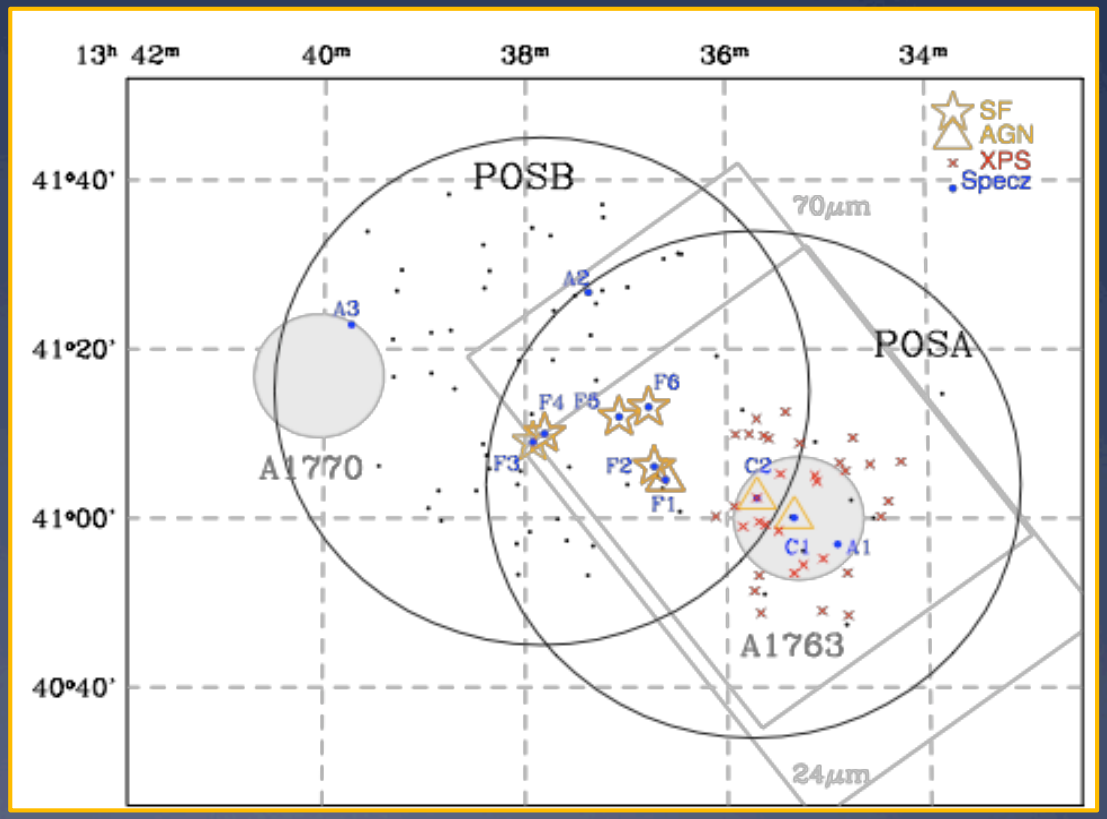


For the rest, measure SFRs
L_{IR} --> SFR (Kennicutt 98)
L_K --> M_* (Lin et al. 2003)
~10-100Msun/yr

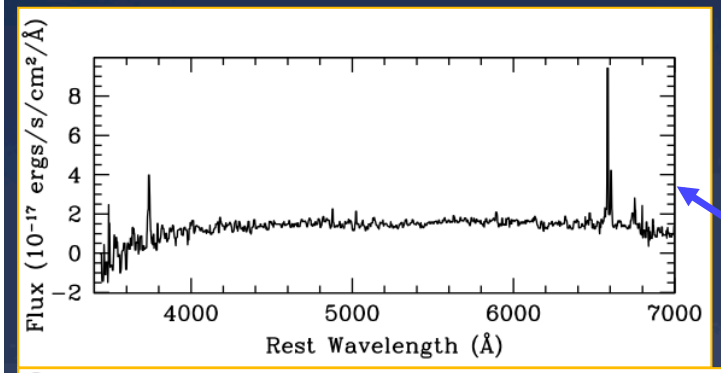
TEMPLATES: GRASIL
(Silva et al. 1998)
Also E, Sp, SB, pSB (Polletta 2007)

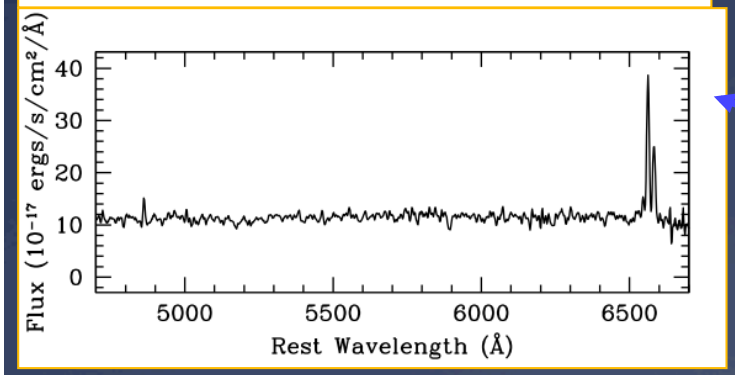


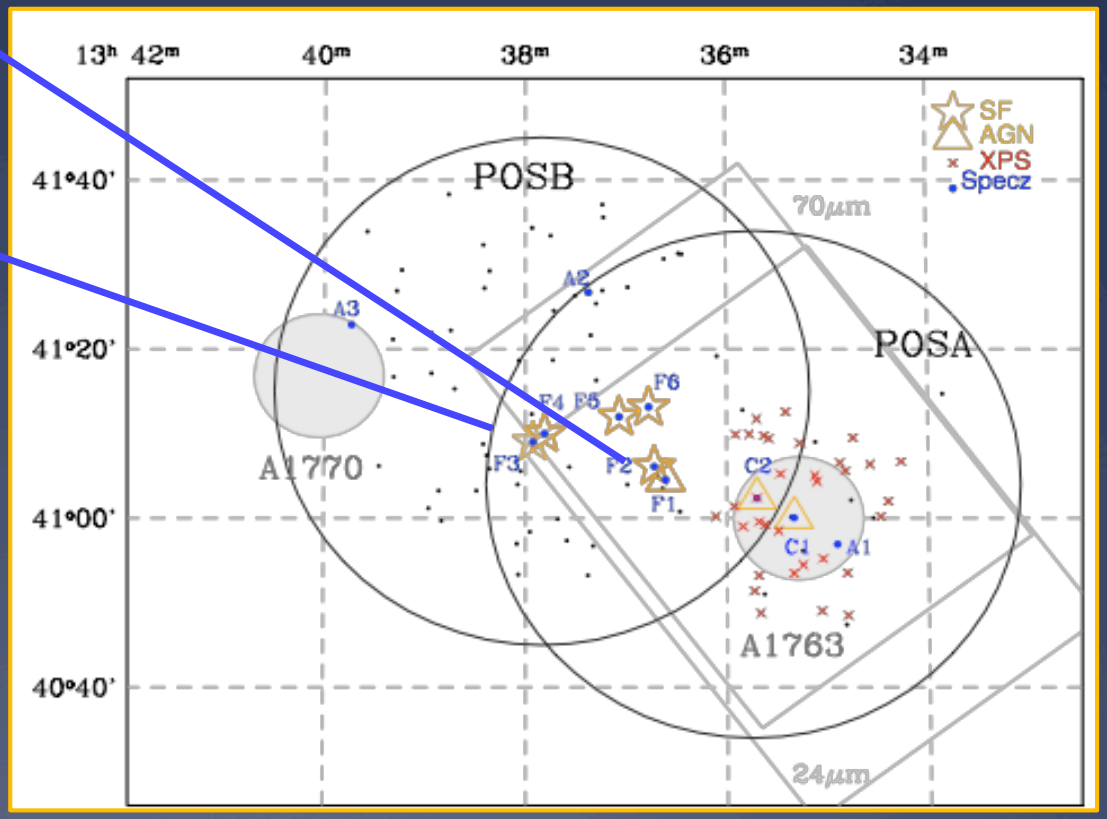
Environmental dependence



Type of Activity in Filament







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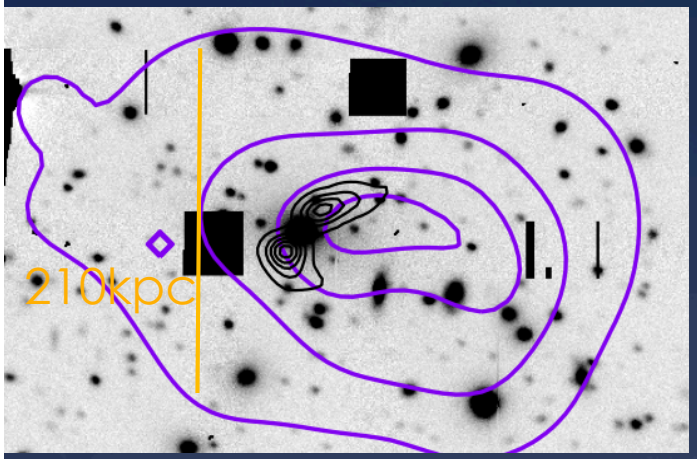

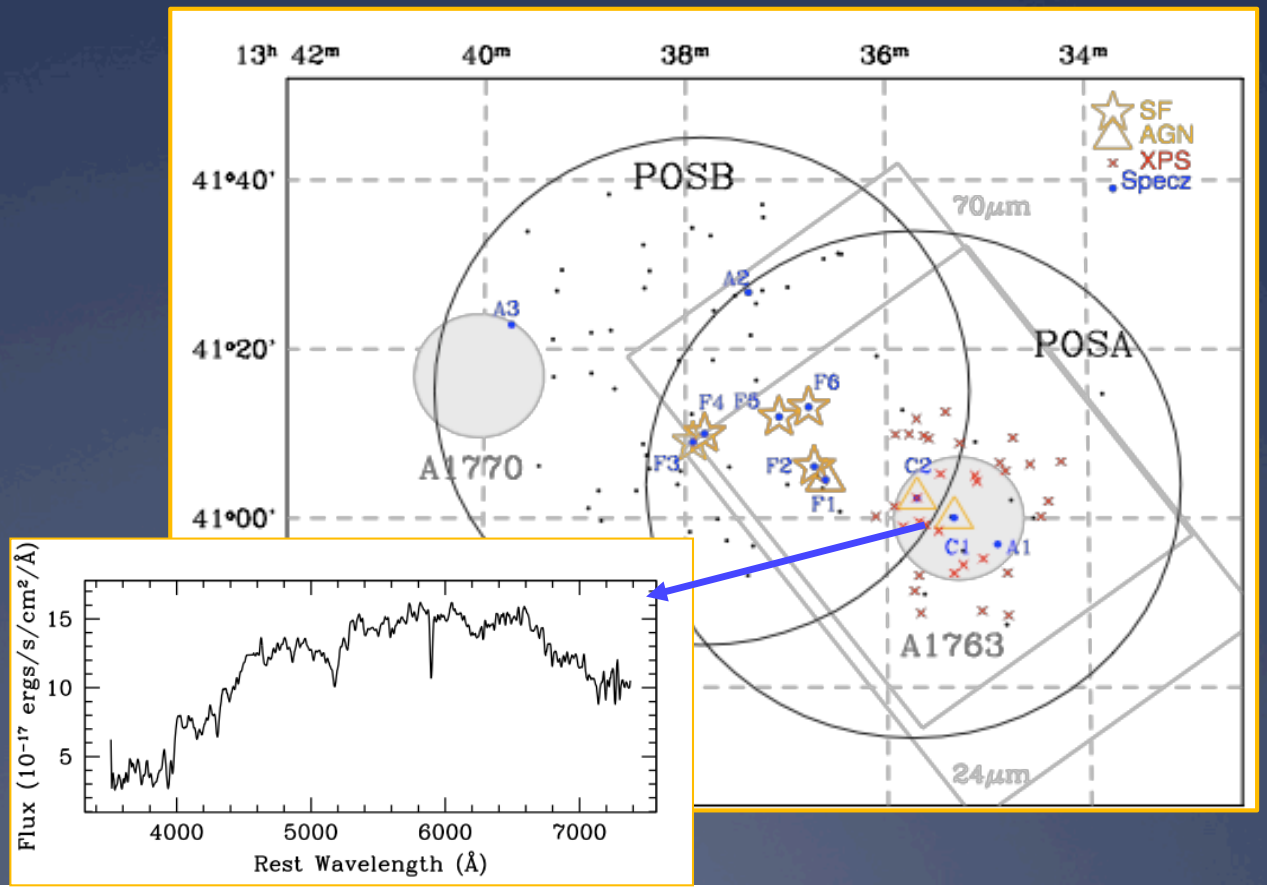

Summary

* Most IR or radio galaxies are Mstar SFing galaxies
* Higher frequency of sf and SFR than core or rest of outskirts
* Of 8 galaxies with bright IR and Radio, ~50% AGN
* Confirmed Radio+IR members are all projected along the filament
* WAT morphology, direction, and BCG displacement support streaming motions in cluster
* A second WAT ~3Mpc from cluster core…

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Galaxy Evolution in Cluster Cores and Outskirts

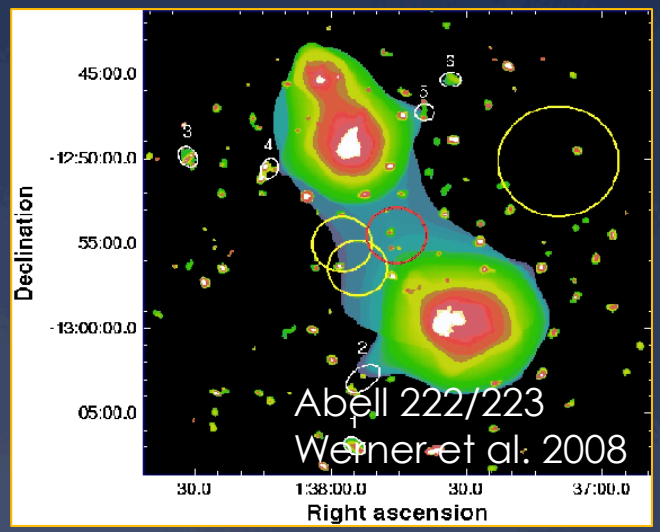
Galaxies at massive X-ray cluster cores are active

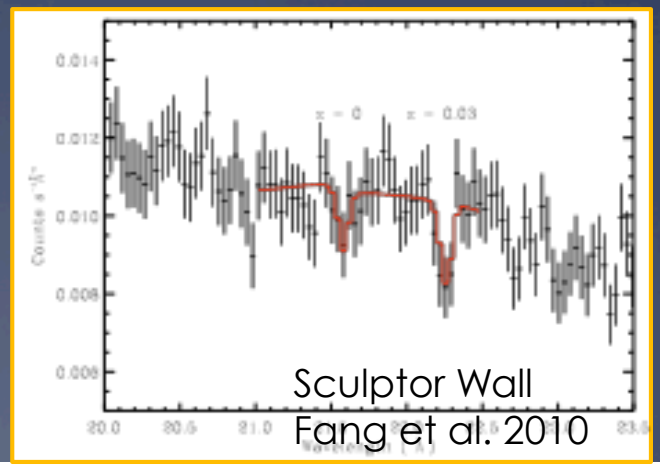
Filament gals are the most, and most often starbursting

Going after the density of the intra-filament medium

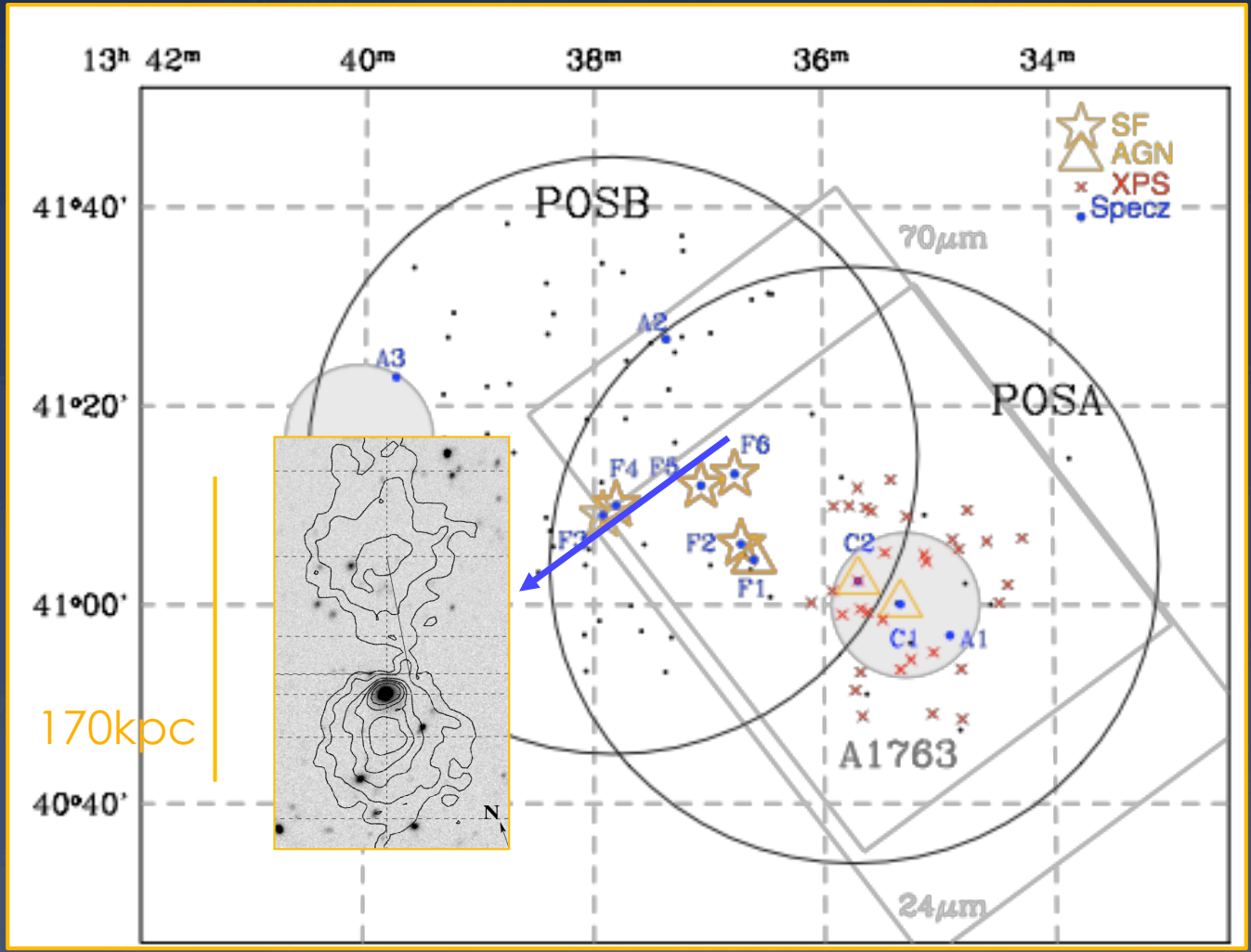
The Warm Hot Intergalactic Medium

- Half of baryons in Universe are invisible
  - In X-ray gas between clusters (filaments)
- Limitied observations conducted this far
  - Absorption of background quasor (Fang et al 2010, Zappacosta et al. 2010)
  - One direct observation (Werner et al. 2008)
- Freeland 2008 and others have postulated the existance of bend double lobe radio sources in filaments
- We announce the first discovery of a bent DLRS in a known filament
  - Use to measure the WHIM in this filament





The First Bent Double-Lobe Radio Source in a known filament



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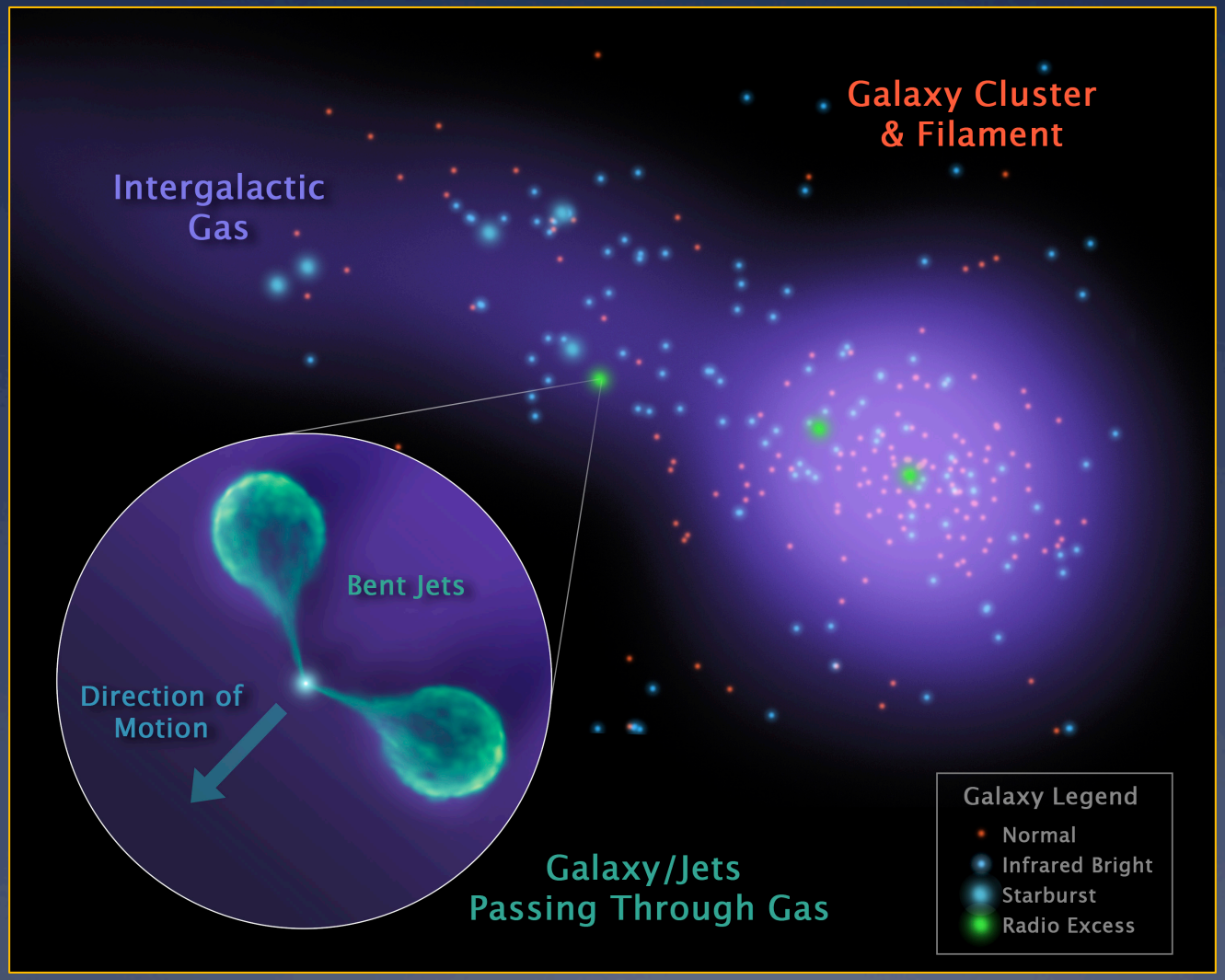
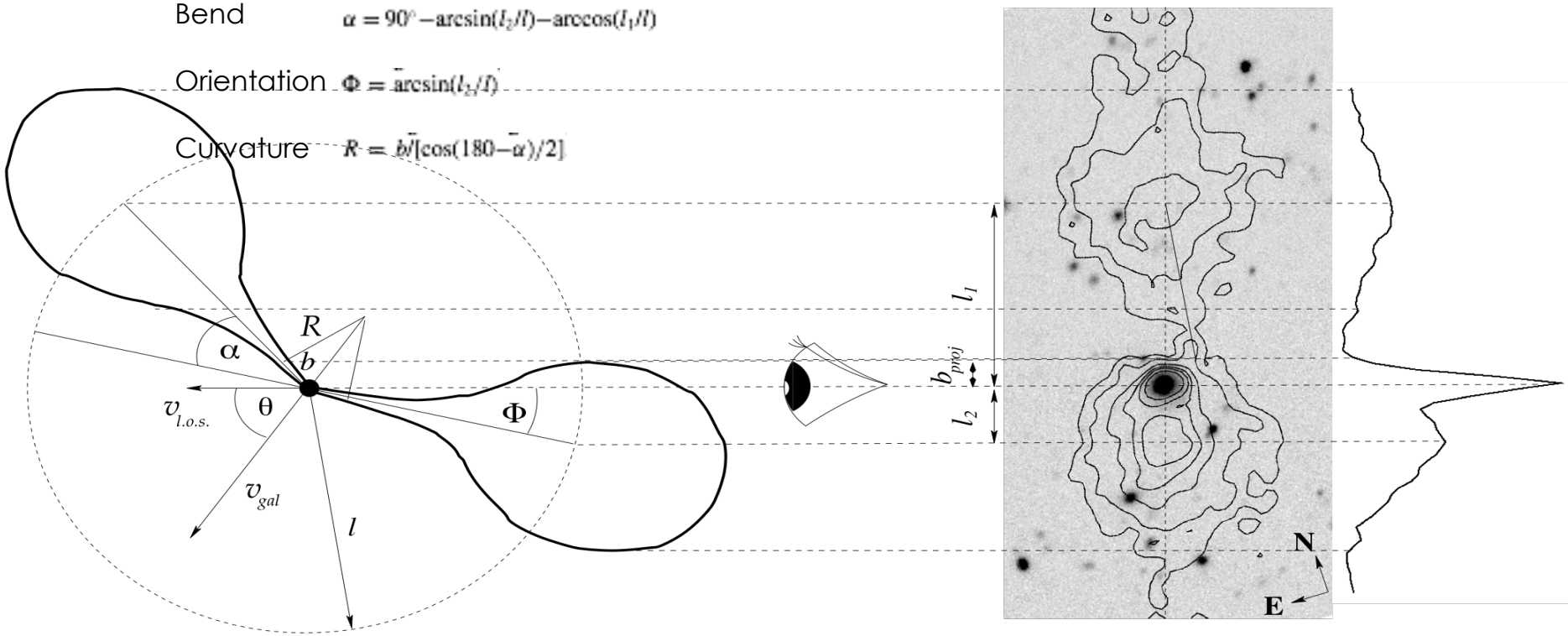


Geometry of the Jets

Bend $\alpha = 90^\circ - \arcsin(l_2/l) - \arccos(l_1/l)$

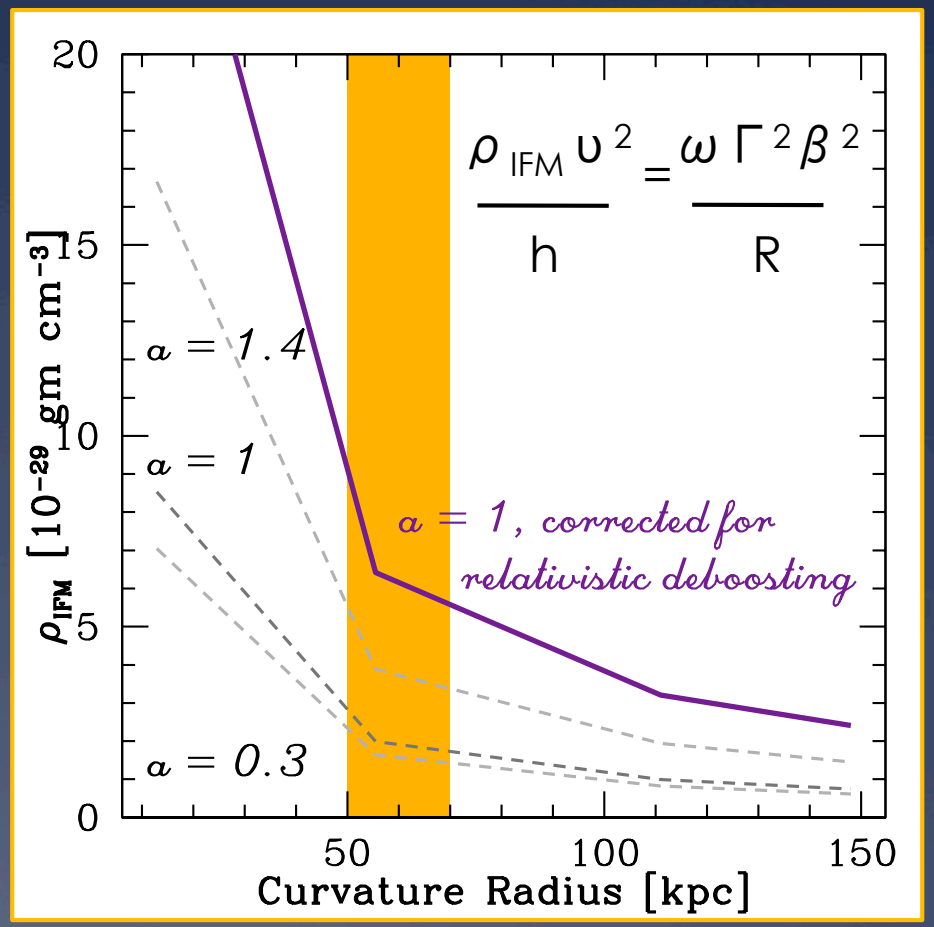
Orientation $\Phi = \arcsin(l_2/l)$

Curvature $R = b/[\cos(180-\alpha)/2]$



Constraining the Intra-Filament Medium

- Spectral index ~ 1
- Relativistic deboosting
- Curvature Radius
- $6^{+14}_{-5} \times 10^{-29}$ gm/cm^3
- ~6×10^{-5} cm^{-3}

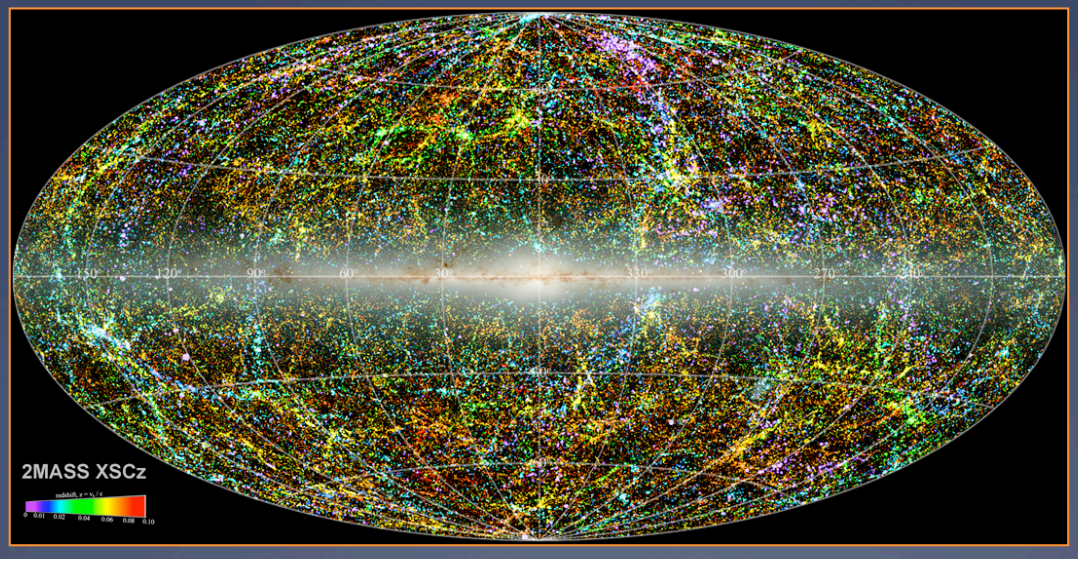


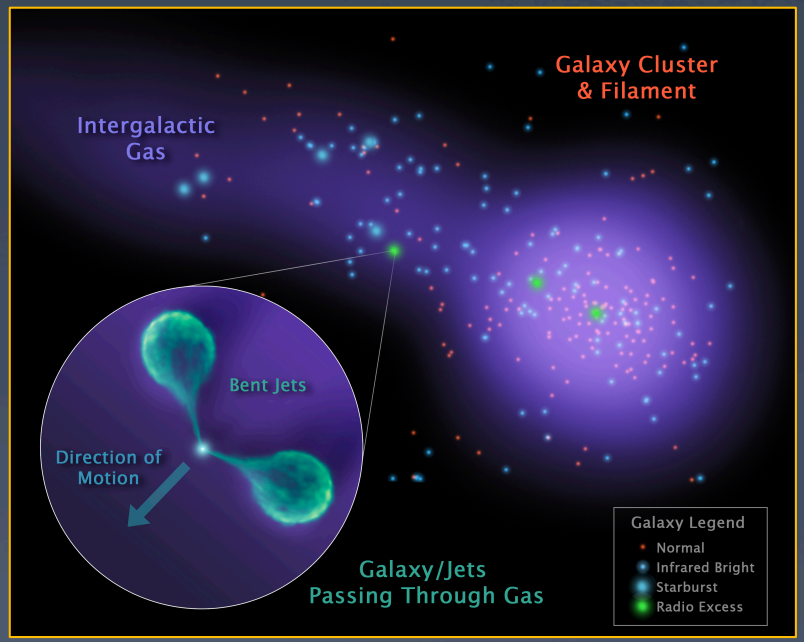
Results consistent with previous WHIM values

- From Simulations
  - Davé et al. 2001 WHIM $4x10^{-6}$ to $1x10^{-4}$ cm^{-3}
  - Dolag et al. 2006 filament ~10-100 mean density
- From one direct filament X-ray observation
  - $3x10^{-5}$ cm^{-3}
- From sculptor wall WHIM measurement
  - 30 times mean density
- Cluster feeding filaments not just made of a significant medium
- IFM can bend jets
- Does it also pre-process galaxies on their way to clusters?

One step closer to a statistical understanding

- The Filament is full of active galaxies, but just one filament across one supercluster…
- Follow up all known filaments in Radio
- Mine DLRS catalogs and search for filaments around -> deeper radio observations if far from a cD





Galaxy Clusters are Hotbeds of Galaxy Activity

Galaxies at massive X-ray cluster cores are active

Filament gals are the most, and most often starbursting

IFM is ~100 times < dense than ICM ~100 times > dense than ρ_{mean}