KITP BH 2013

AGN FEEDBACK IN CLUSTERS OF GALAXIES: OPEN PROBLEMS AND CHALLENGES

Ian McCarthy	(LJMU)	Richard Bower	(Durham)
Mike Balogh	(UWaterloo)	Henk Hoekstra	(Leiden)
Greg Poole	(Melbourne)	Neal Katz	(UMass)
Aida Ghazvinizadeh	(UToronto)	Joe Silk	(IAP/Oxford)
Razzi Movassaghi	(UVictoria)	Adi Nusser	(Haifa)
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Andi Mahadavi	(SFSU)	Chris Reynolds	(Maryland)
Fabrice Durier	(UVictoria)	Prateek Sharma	(IISc)

Arif Babul

University of Victoria

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IMPACT OF BLACK HOLES ON COSMIC STRUCTURE: WHAT ARE THEY REALLY GOOD FOR?

Ian McCarthy (LJMU)
Mike Balogh (UWaterloo)
Greg Poole (Melbourne)
Aida Ghazvinizadeh (UToronto)
Razzi Movassaghi (UVictoria)
Chris Bildfell (UVictoria)
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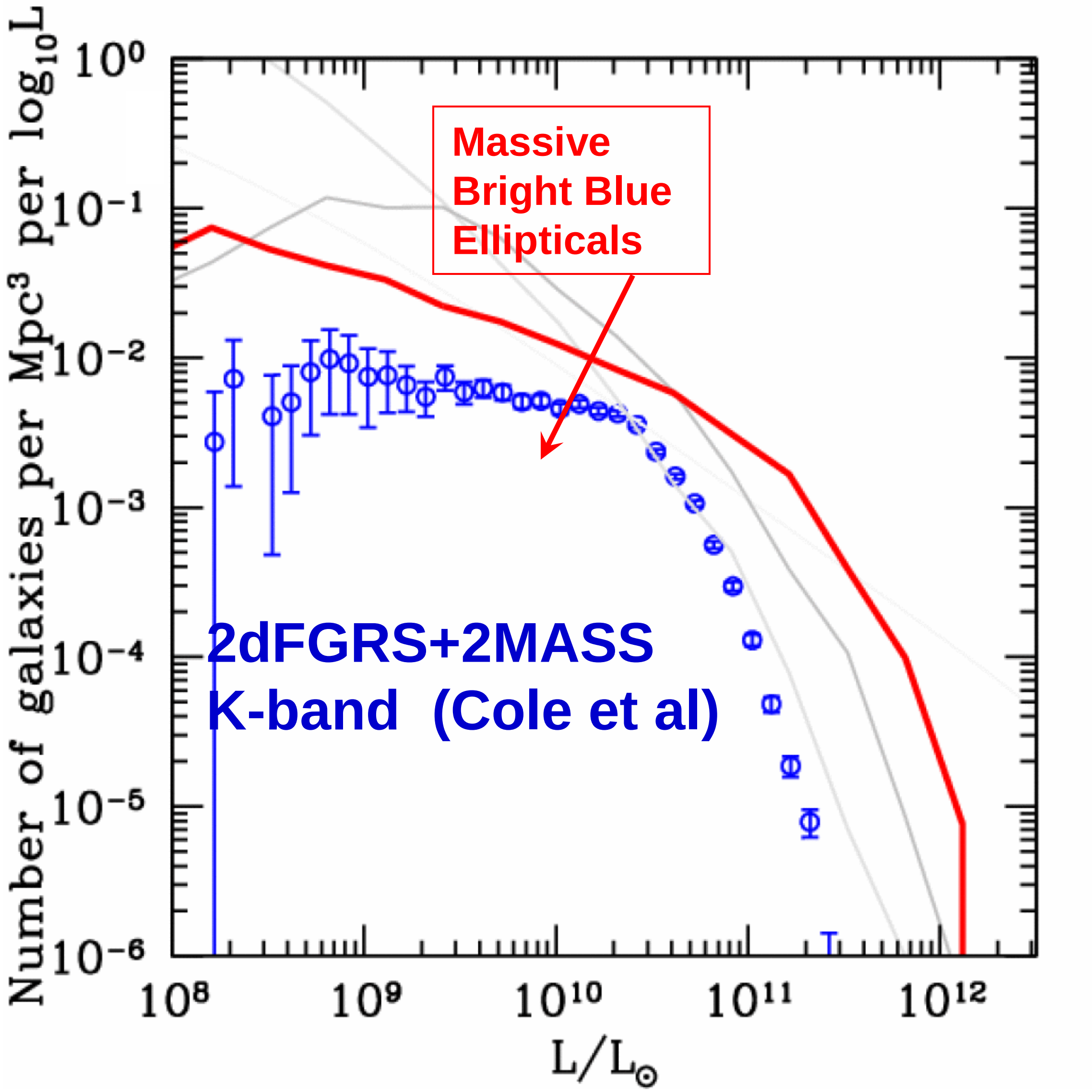
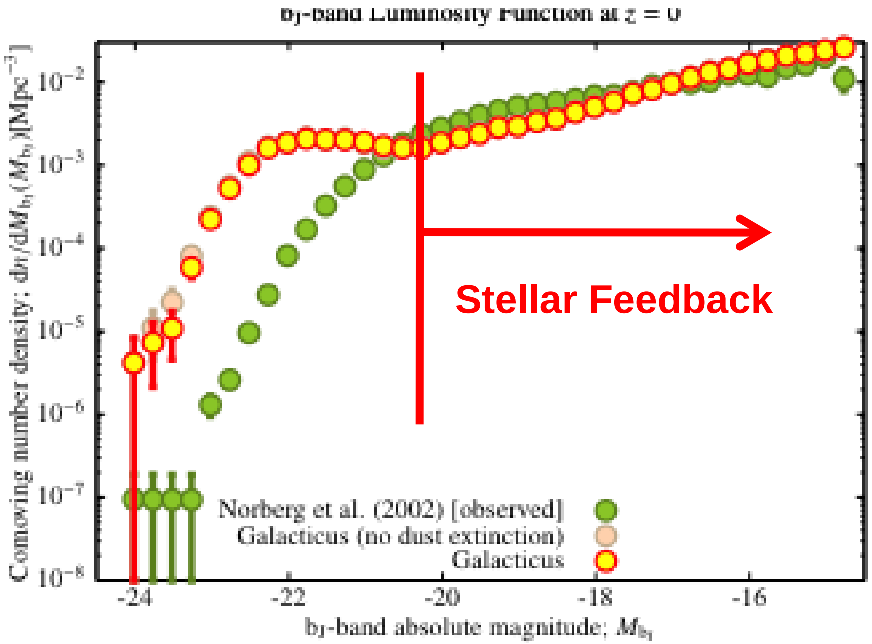
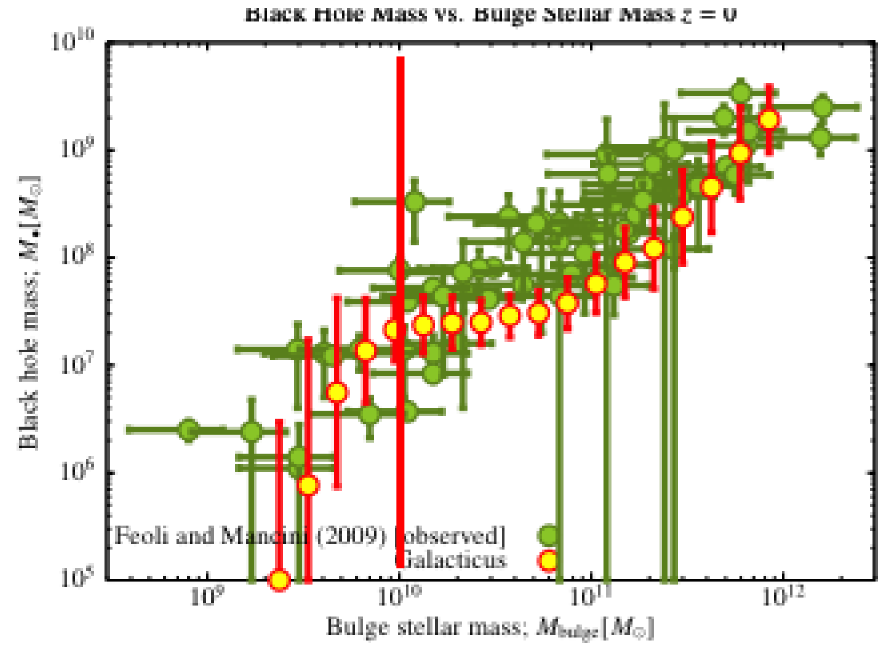
Arif Babul
University of Victoria

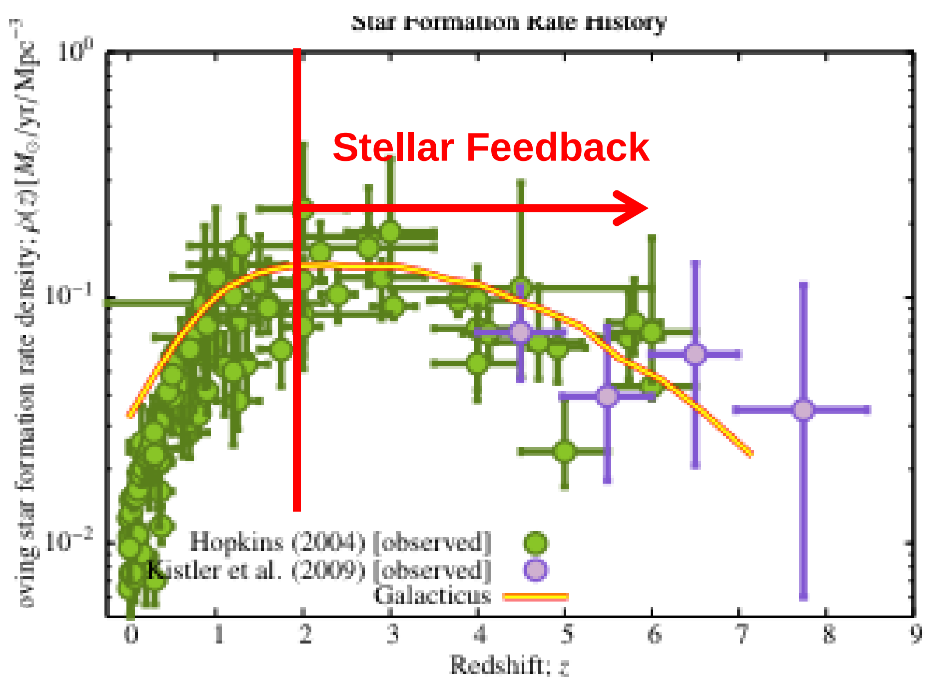
IMPACT OF AGN FEEDBACK ON GALAXIES



Credit: A. Benson



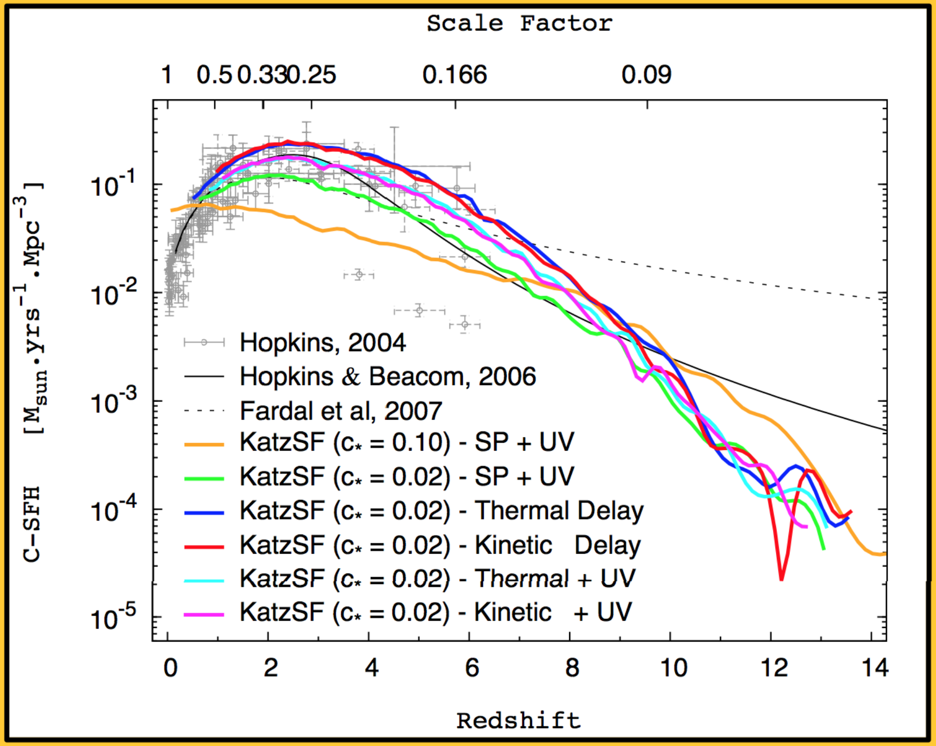




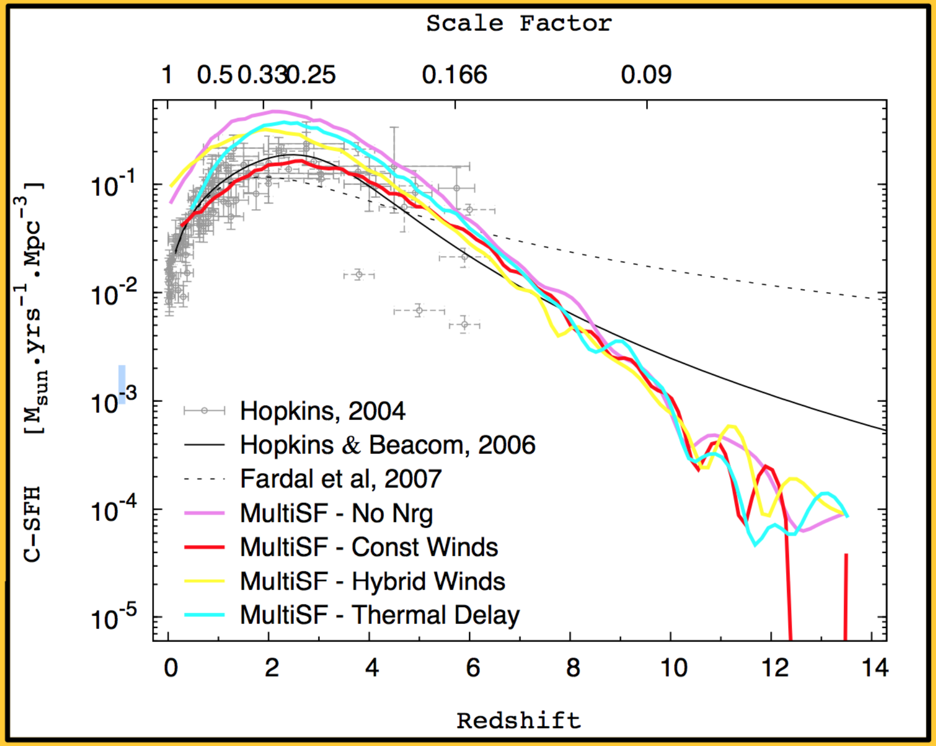
Credit: A. Benson

Cosmic Star Formation History

Katz Star Formation

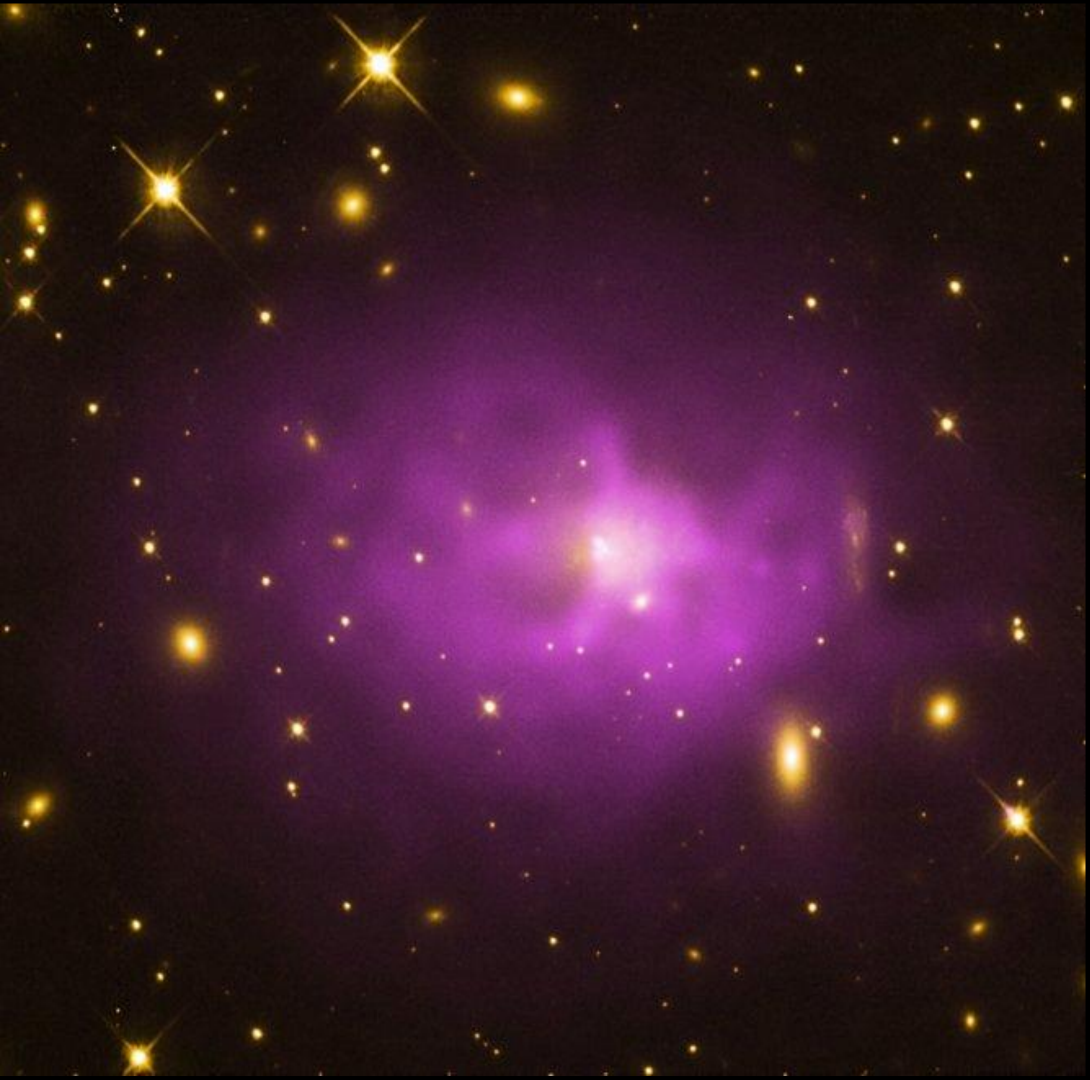


Multiphase Star Formation



Credit: F. Durier

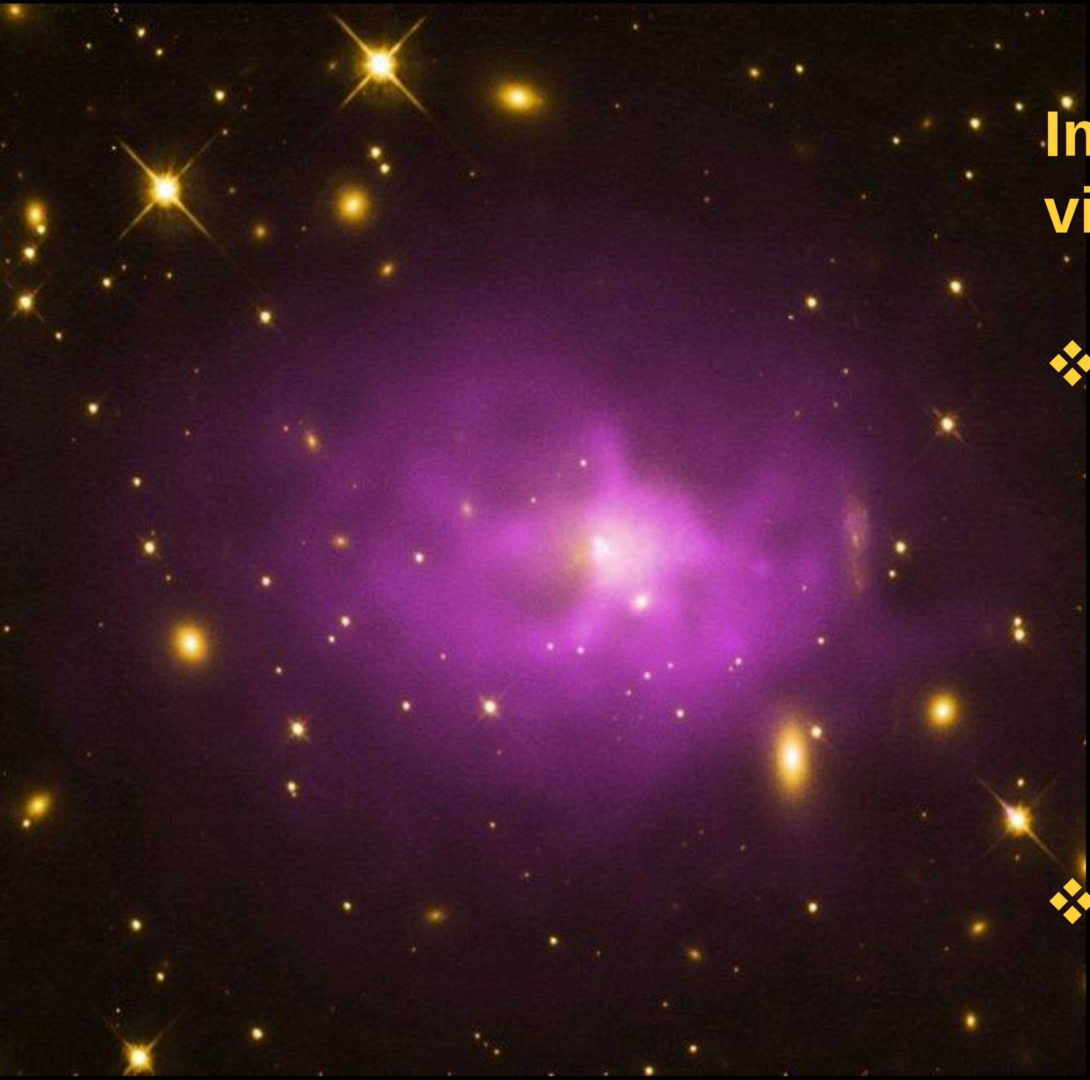
THE HOT DIFFUSE HALO GAS



- For galaxies like MW and M31, stellar feedback is sufficient to moderate SF, with feedback acting to disrupt and/or disperse the ISM

- But in progressively larger systems (massive ellipticals, groups and clusters), another baryonic component emerges and grows to play an important role…

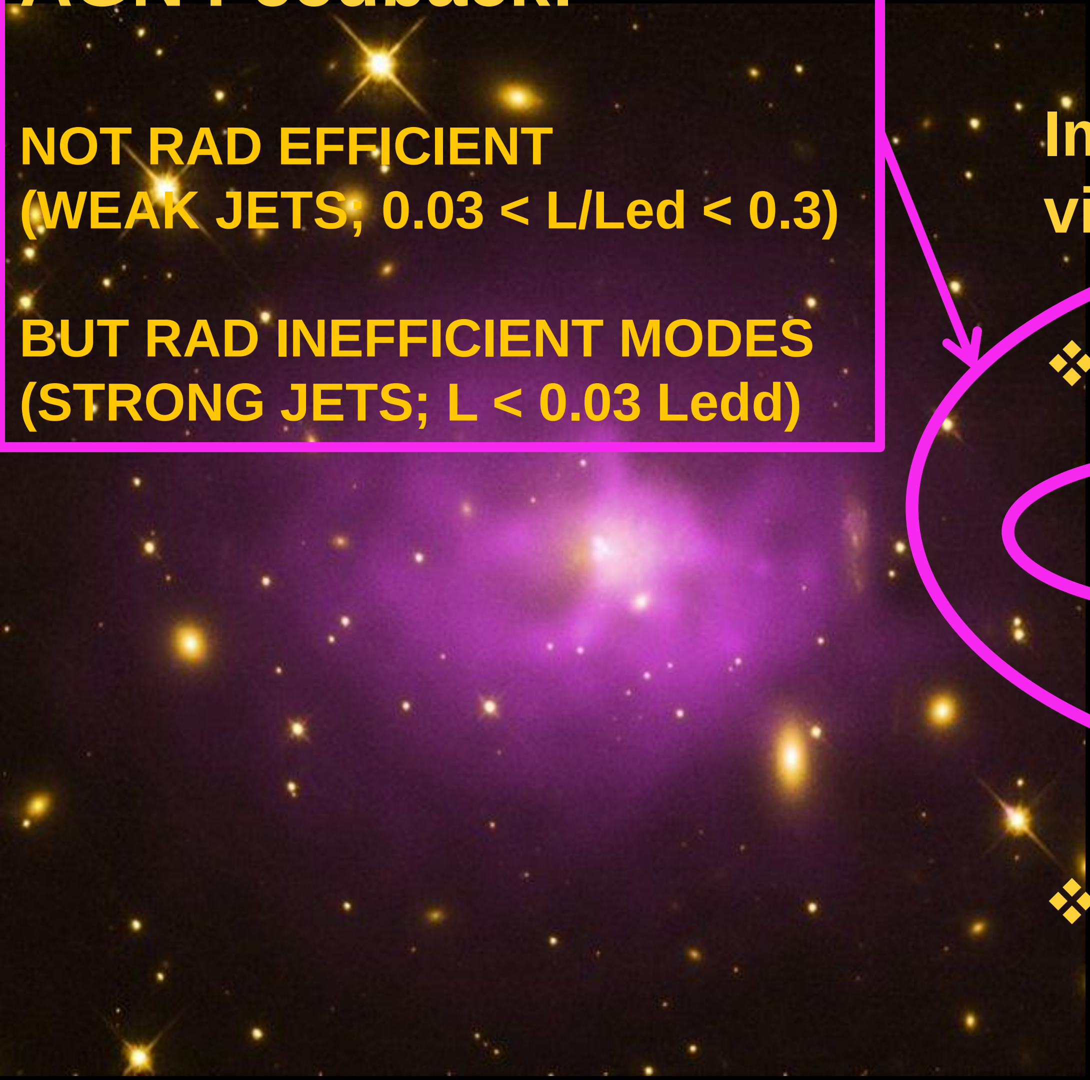
THE HOT DIFFUSE HALO GAS



Impacts Galaxy Evolution via:

- ❖Cooling and pooling of cold gas (in groups and clusters, this is especially relevant for the Central Galaxies)
- ❖Ram pressure stripping, relevant for SF and AGN activity in Satellites

THE HOT DIFFUSE HALO GAS



AGN Feedback!

NOT RAD EFFICIENT
(WEAK JETS; 0.03 < L/Led < 0.3)

BUT RAD INEFFICIENT MODES
(STRONG JETS; L < 0.03 Ledd)

Impacts Galaxy Evolution via:

- ❖ Cooling and pooling of cold gas (in groups and clusters, this is especially relevant for the Central Galaxies)
- ❖ Ram pressure stripping, relevant for SF and AGN activity in Satellites

HOT HALOS IN GALAXY CLUSTERS

OPEN QUESTIONS & CHALLENGES

- COOL CORE & NON-COOL CORE SYSTEMS
  - WHAT ROLE (IF ANY) DO AGNS PLAY IN SETTING UP THIS DICHOTOMY?
  - WHEN? HOW?
- TEMPERING COOLING FLOW IN CC SYSTEMS
  - ISOTROPY PROBLEM
- **RAD EFFICIENT VS. RAD INEFFICIENT MODES**

(WEAK JETS; L > 0.03 Ledd) (STRONG JETS; L < 0.03 Ledd)

  - DOES THE QSO MODE ACTUALLY DO ANYTHING
- **AGN ACTIVITY IN NON-CENTRAL GALAXIES**

1 Poole, G.B. et al., 2006, "The impact of mergers on relaxed X-ray clusters - I. Dynamical evolution and emergent transient structures", *MNRAS*, 373, 881.

2 McCarthy, I.G.; Babul, A.; Bower, R.G.; Balogh, M. L., 2008, "Towards a holistic view of the heating and cooling of the intracluster medium", *MNRAS*, 386, 1309.

3 Bildfell, C.; Hoekstra, H.; Babul, A.; Mahdavi, A., 2008, "Resurrecting the red from the dead: optical properties of BCGs in X-ray luminous clusters", *MNRAS*, 389, 1637.

4 Pipino, A.; Kaviraj, S.; Bildfell, C.; Babul, A.; Hoekstra, H.; Silk, J., 2009, "Evidence For Recent Star Formation In Bcgs: A Correspondence Between Blue Cores And UV Excess", MNRAS, 395, 462.

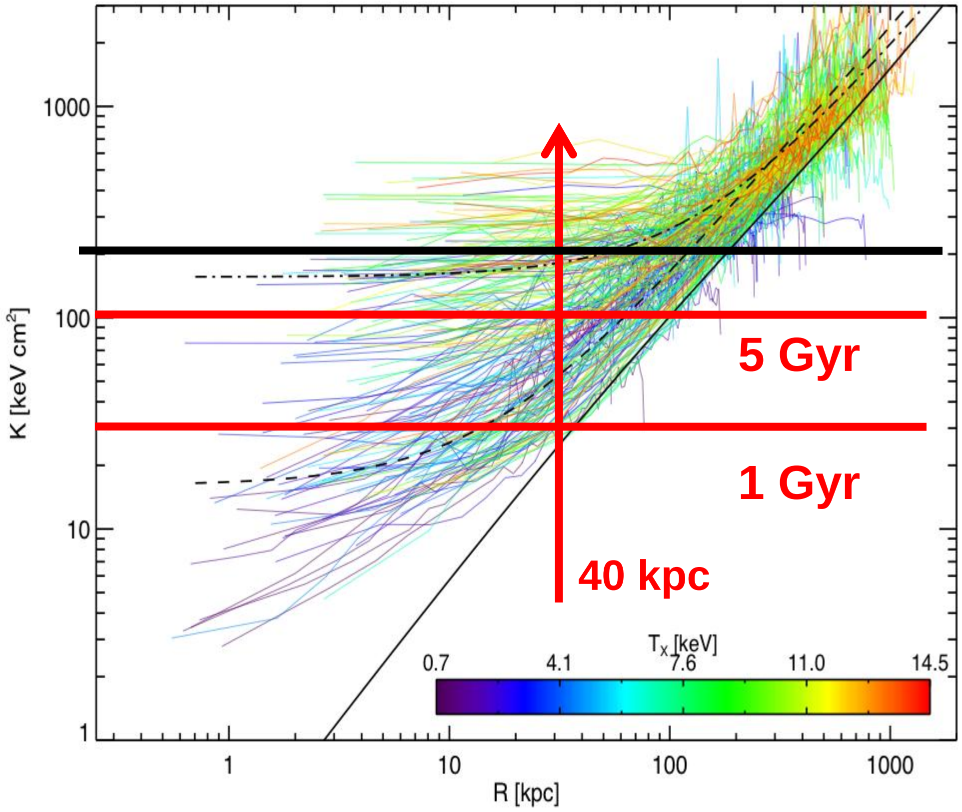
5 Benson, A.J.; Babul, A., 2009, "Maximum Spin Of Black Holes Driving Jets", MNRAS, 397, 1302.

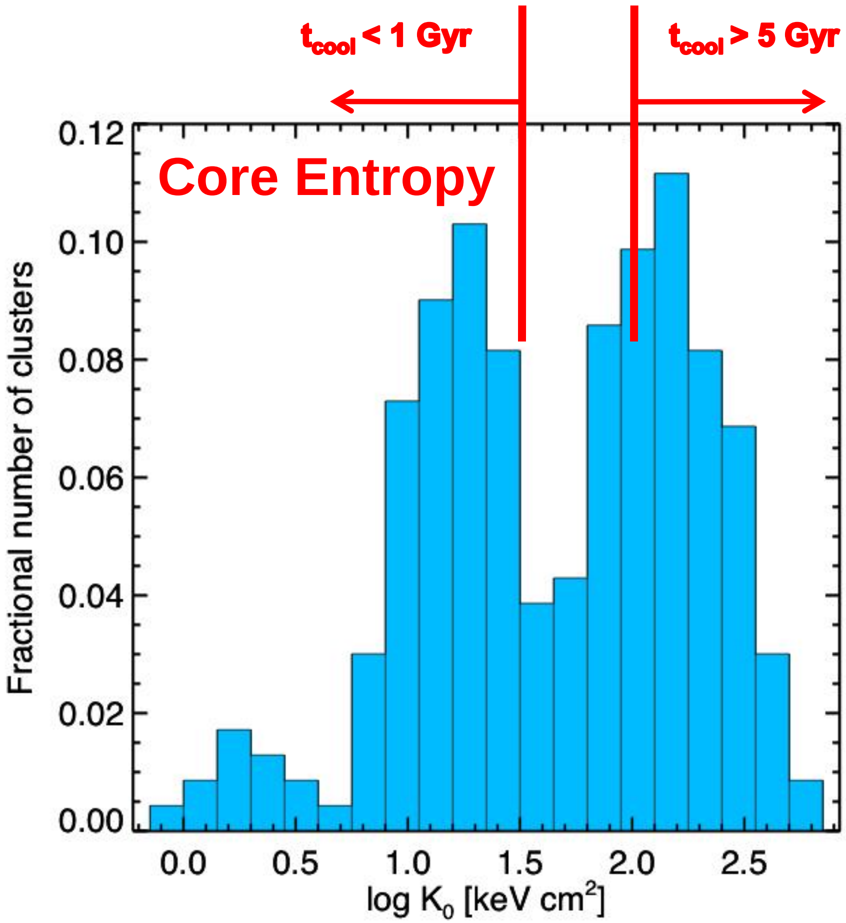
6 O'Sullivan, E. et al. 2012, " A Giant Metrewave Radio Telescope/Chandra view of IRAS 09104+4109: A type 2 QSO in a cooling flow", MNRAS, 424, 2971

7 Haines, C. P. et al., 2012, " LoCuSS: A Dynamical Analysis of X-ray AGN in Local Clusters", ApJ, 754, 97

8 Babul, A.; Sharma, P.; Reynolds, C.S., 2013, Isotropic Heating of Galaxy Cluster Cores via Rapidly Reorienting AGN Jets, ApJ, 768,11

CLUSTER ENTROPY PROFILES:





$$K \equiv \left(\frac{P}{\rho^{\gamma}} \right) \Longrightarrow \frac{kT(r)}{n_e(r)^{2/3}}$$

Cavagnolo et al 2008

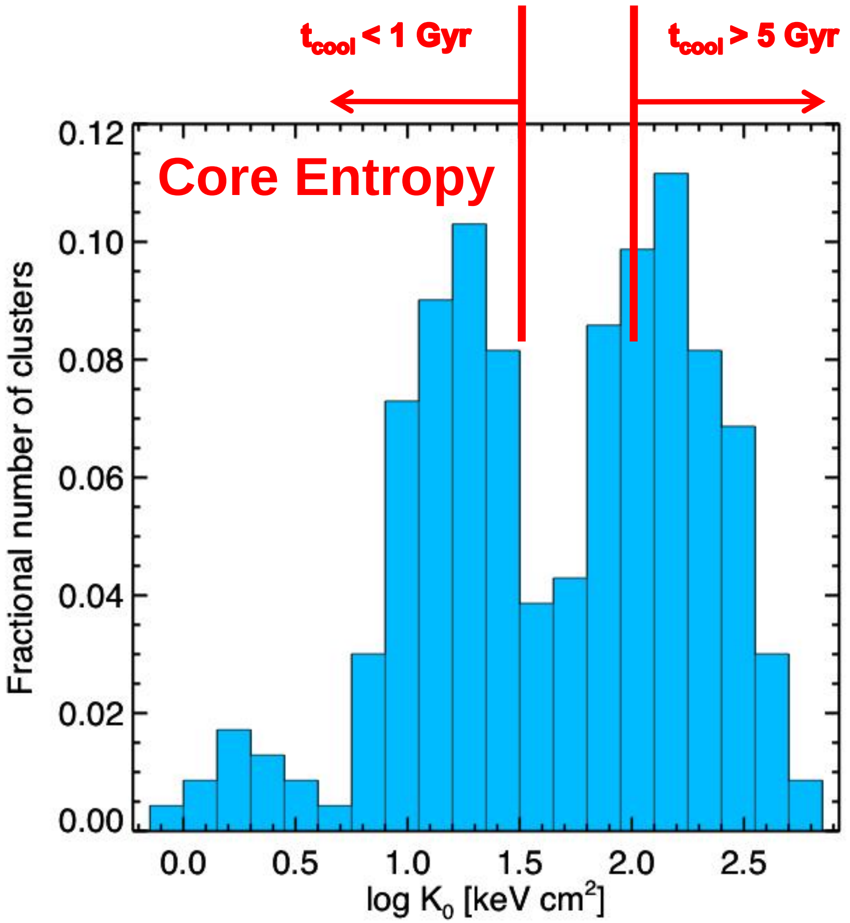
CLUSTER ENTROPY PROFILES:

Fraction of Classical Core Cores (i.e. K < 10 keV cm^2): ~10-15%

Fraction of Cool Core Clusters (i.e. K < 30; t_{cool} < 1 Gyr): ~40%

Fraction of Non-Cool Core Clusters (i.e. K > 100; t_{cool} > 5 Gyr): ~45%

NCCs typically have core entropies ~200-300 keV cm^2



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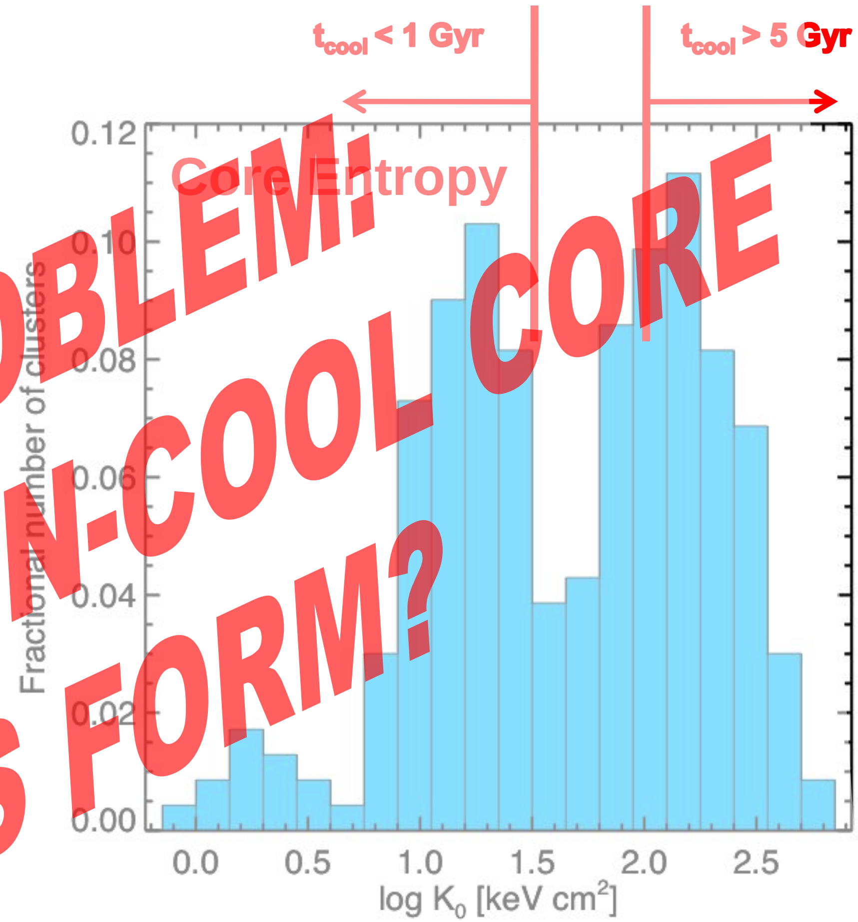


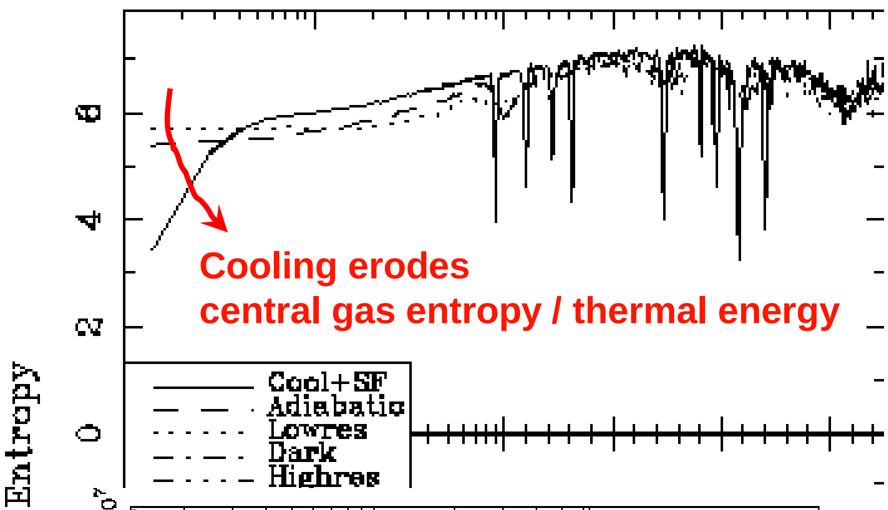
OPEN PROBLEM:
HOW DID THE NON-COOL CORE CLUSTERS FORM?

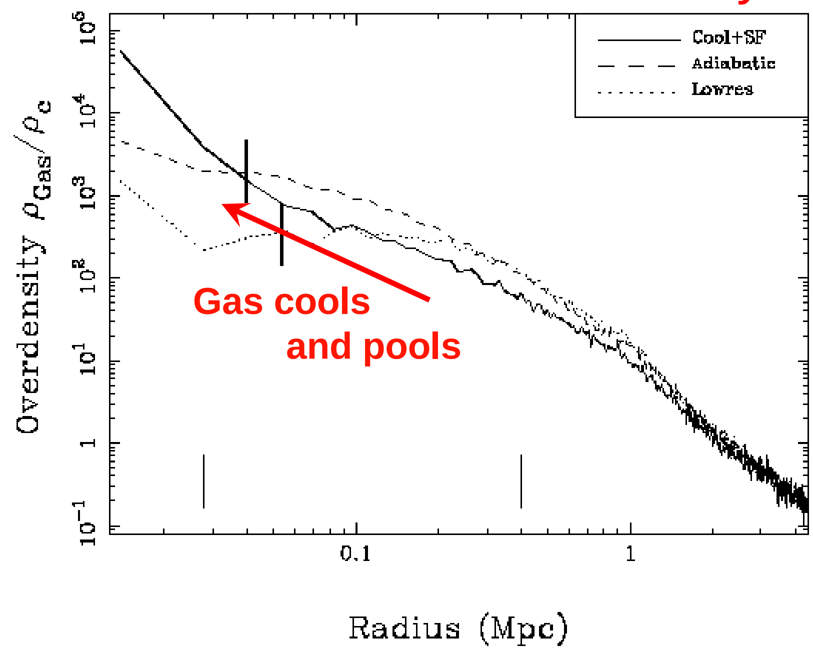
$$K \equiv \left(\frac{P}{\rho^{\gamma}}\right) \Longrightarrow \frac{kT(r)}{n_e(r)^{2/3}}$$

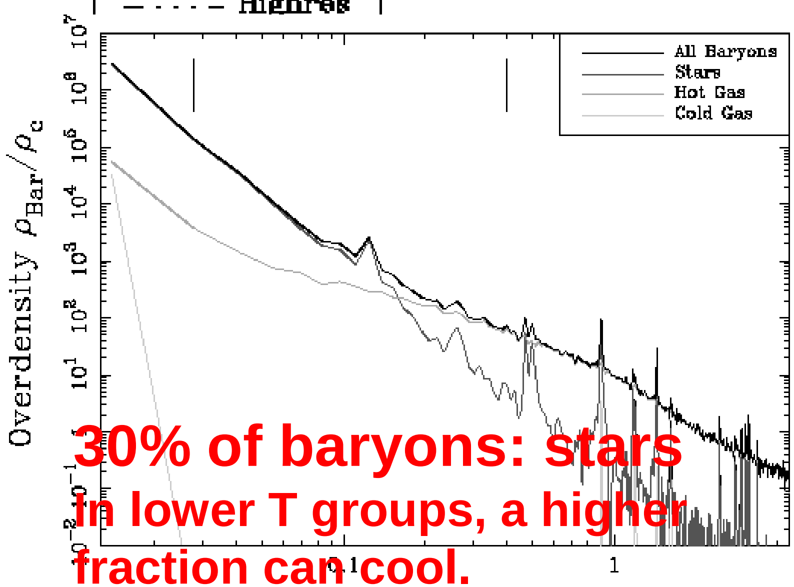
Cavagnolo et al 2008

WITH ONLY STELLAR FEEDBACK

CENTRAL GAS COOLING TIMESCALES IS VERY SHORT: < 1 Gyrs





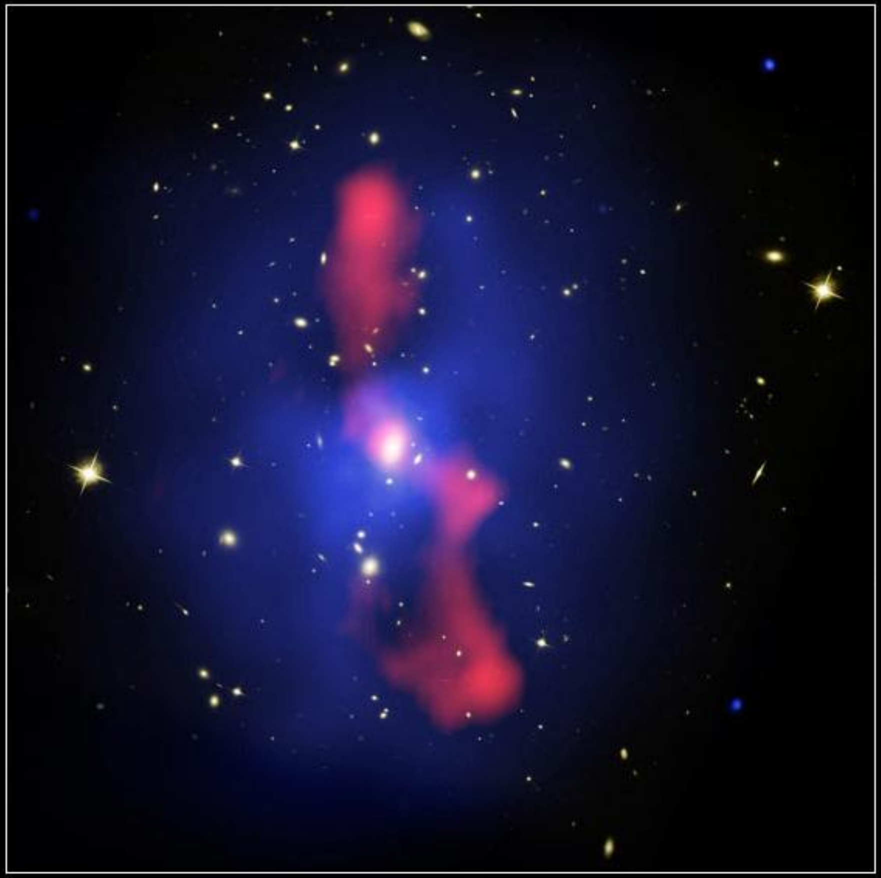


- ❖ **central entropy structure in the simulated clusters does not vary very much!**
- ❖ **Simulations incorporate merging, etc. ➔ AGNS!**

G.F. Lewis et al 2000

CAN POWERFUL AGN OUTBURTS CHANGE CCs INTO NCCs?

Galaxy Cluster MS 0735.6+7421



NASA, ESA, CXC/NRAO/STScI, B. McNamara (University of Waterloo and Ohio Un

McNamara and collaborators

UNLIKELY: McCARTHY ET AL 2008

Transforming CC systems into NCCs with Ko > 100 keV cm^2 requires > 10^{63} ergs:

P > $10^{47\text{-}48}$ ergs/s

Since $\Delta E = \eta \Delta M c^2$ where $\eta \sim 0.1$

$\Delta M > 5 \times 10^9\ \mathbf{M_\odot}$

10-100 X the "bang" of the most powerful AGN outbursts known:

Her A and MS0735

…and post-burst entropies of these clusters is not very high….

…and need to do this for ~50% of systems

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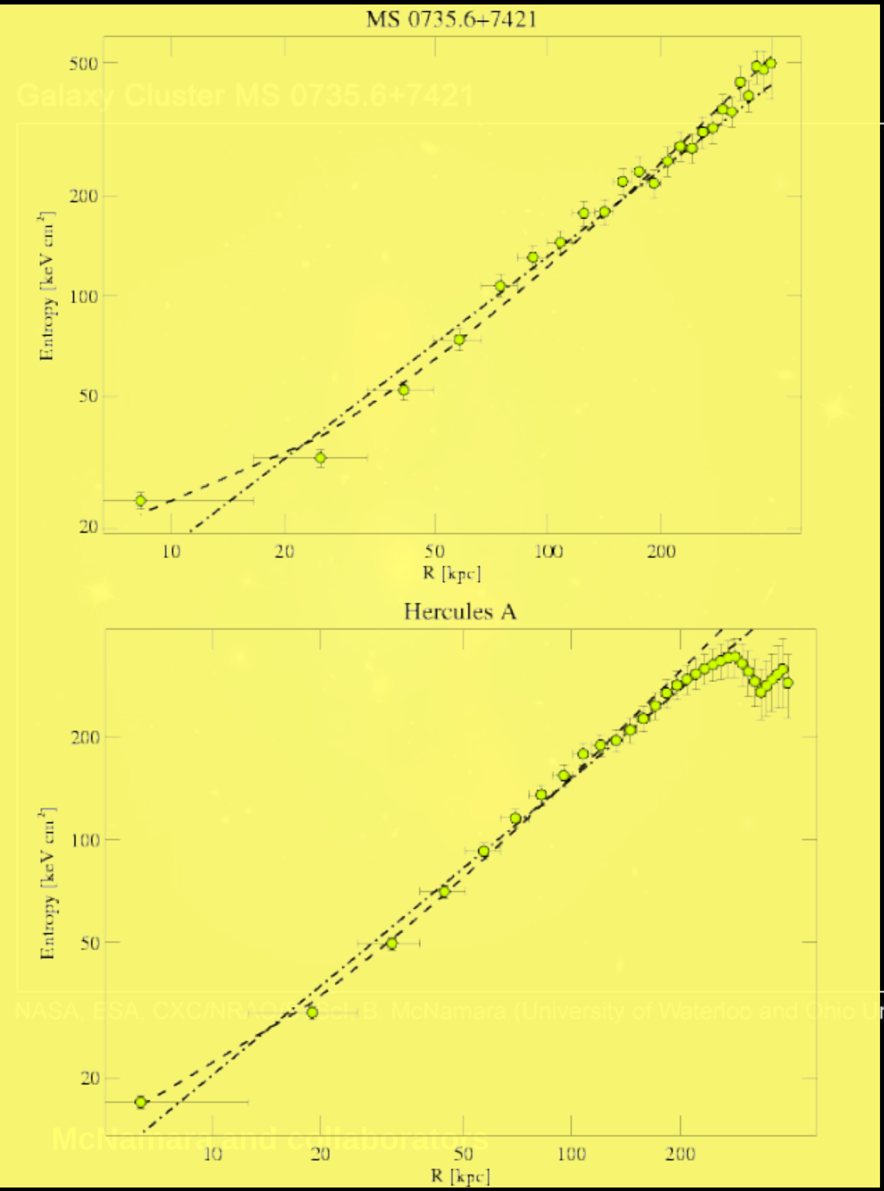

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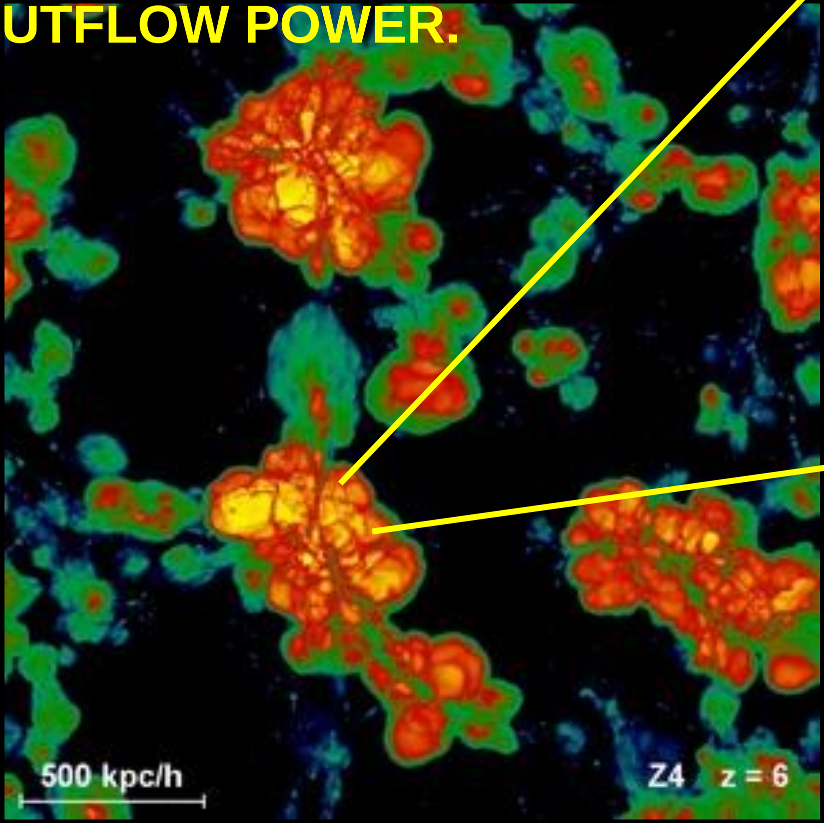
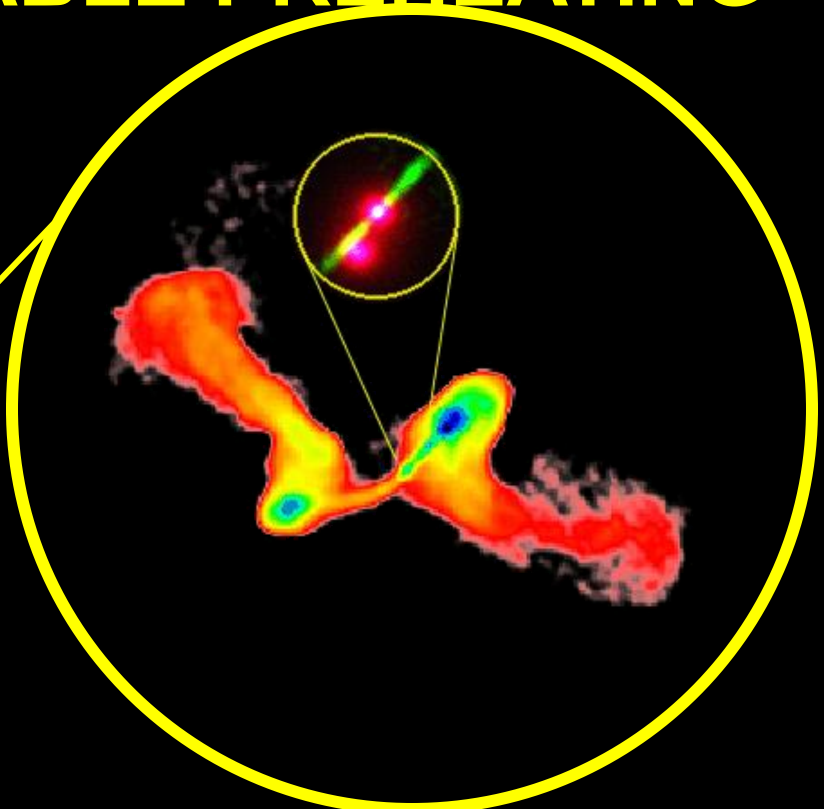
“LOCALIZED” VARIABLE PREHEATING

OUTFLOWS GENERATED DURING EPOCH OF “FIRST RADIO HEATING HEATS GAS IN VICINIT OF HALO (NOT GLOBAL!)

HEATING VARIES WITH AGN OUTFLOW POWER.





ENTROPY DEPENDS ON ENERGY AND DENSITY

AS HEATED (HIGH ENTROPY) GAS COLLECTS IN MASSIVE HALOS, IT GIVES RISE TO CENTRAL CORES

Image: T. Theuns; Balogh et al 1999; Tozzi et al. 1999; Babul et al. 2002

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OUTFLOWS GENERATED DURING EPOCH OF "FIRST RADIO HEATING HEATS GAS IN VICINIT OF HALO (NOT GLOBAL!)

HEATING VARIES WITH AGN OUTFLOW POWER.

~15 YEARS HENCE, THE ORIGIN OF THE CORE ENTROPY STRUCTURE IN CLUSTERS REMAINS UNEXPLAINED

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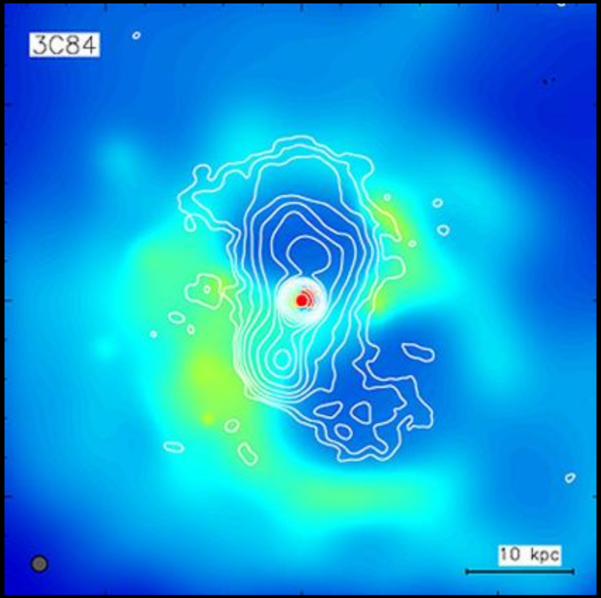
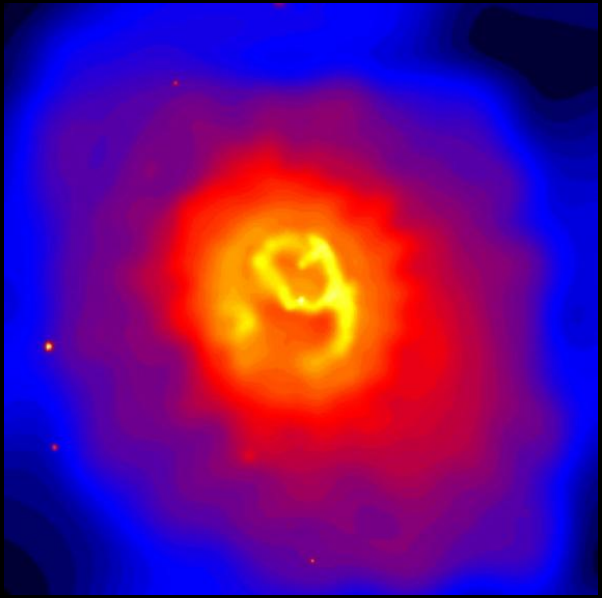
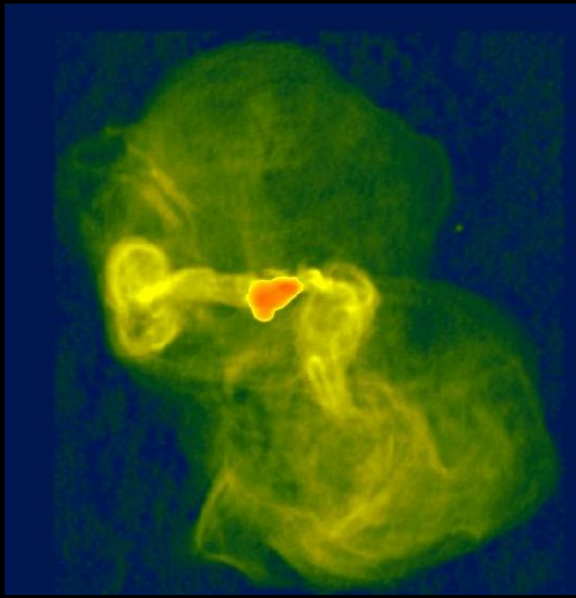
COOL CORE CLUSTERS

Gas in CCs is not cooling as efficiently as expected

- ❖ Here, we can see the reason why:
  - ❖ >80% of BCGs in CCs (Birzan et al. 2012) and >90% of X-ray bright ellipticals (Dunn/Fabian 2012) host "radio-loud" AGNs ➔ jets
  - ❖ Jets physically impact (heat) the ICM ➔updrafts, wakes, cavities and weak shocks.

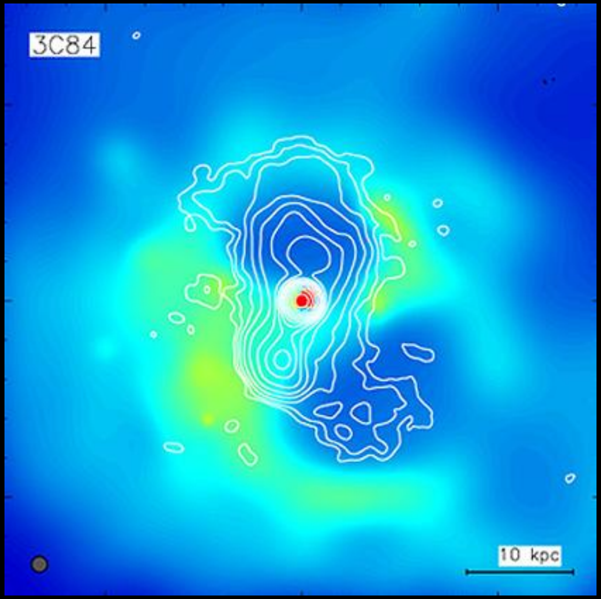


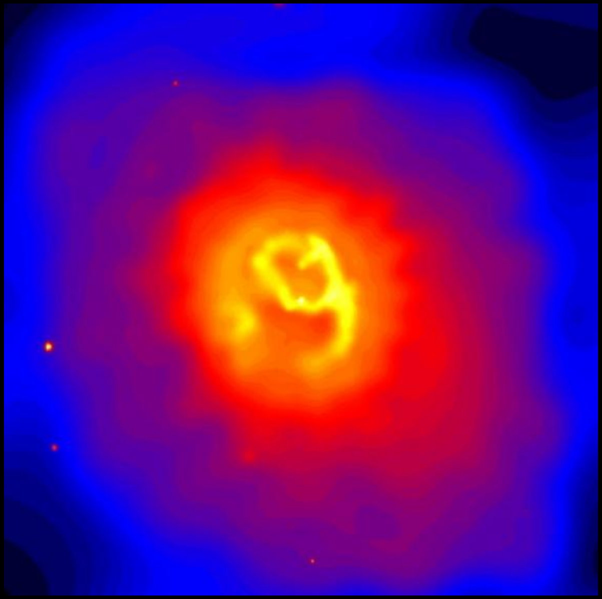
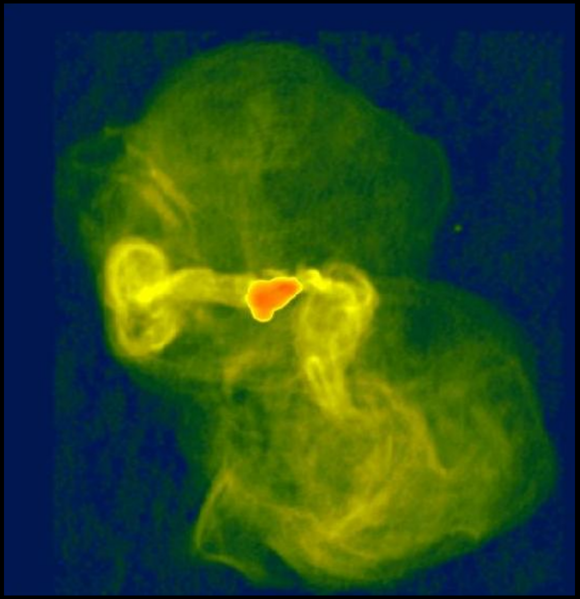



SOME CAVEATS

Cooling is NOT QUENCHED but TEMPERED

- BCGs are NOT “red & dead” but forming stars ~ 10-100 $M_{\odot}$/yr (Bildfell et al. 2008).
- SF is not episodic but continuous on ~100 Myr time.



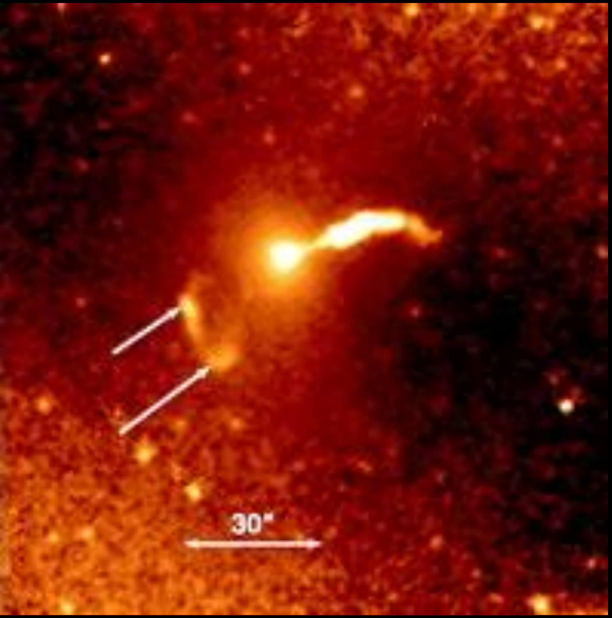



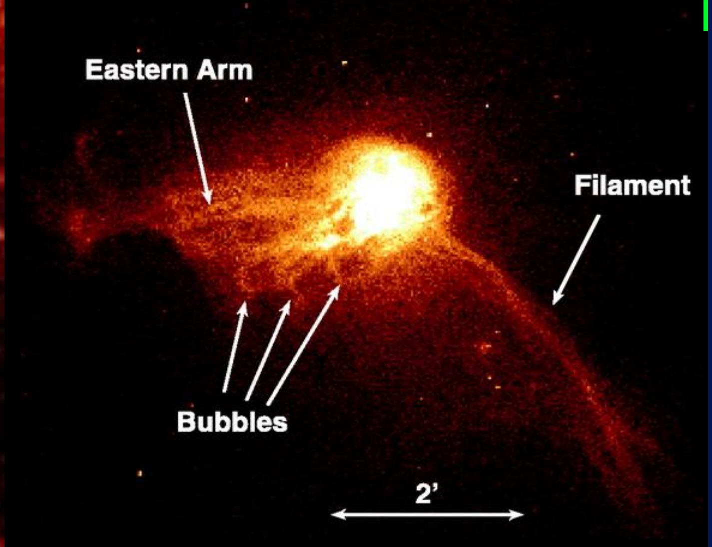
The most vexing problem is the “isotropy puzzle”.

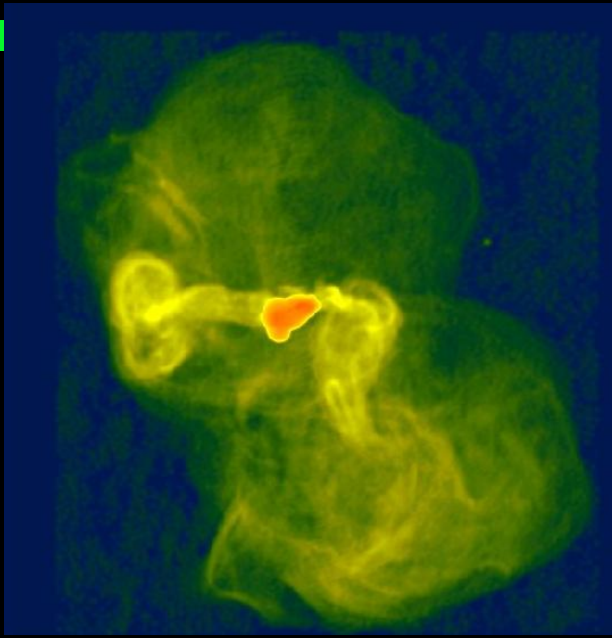
NATURE HAS (OBVIOUSLY) SOLVED THE PROBLEM

…AND OBSERVATIONS OFFER CLUES

JETS CHANGE DIRECTIONS EVERY ~20 Myrs







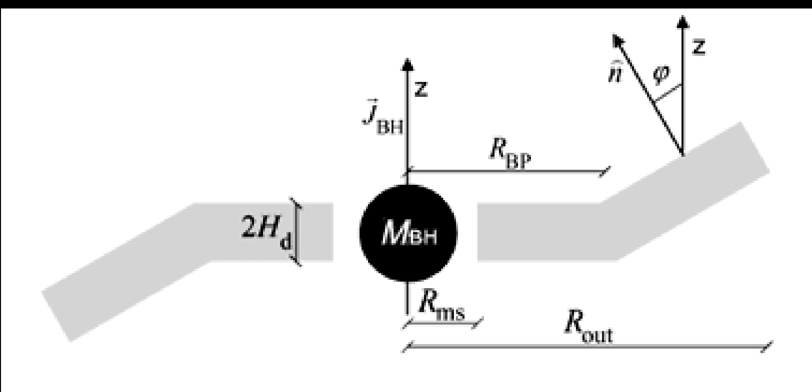
M87

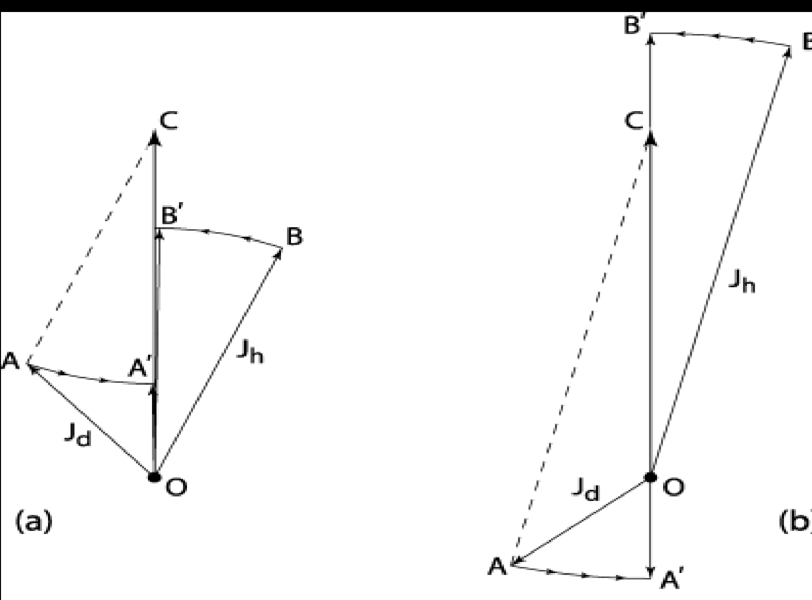
5 (8) directional changes: small-scale jet to radio bubbles .
ΔΘ between features: ~20-60^0 in plane of the sky
Δt between changes: ~20 Myrs (mean)

PERSEUS, CL0910, ETC.

…IN BABUL, SHARMA, REYNOLDS (2013), WE SUGGEST

RECURRENT (RANDOM) TILTING OF THE JET AXIS VIA OCCASIONAL MISALIGNED DISKS





- ❖ BH accretes hot gas at a low rate ($< 0.01M_{edd} = 0.2\ (M_9)\ M_{\odot}$/yr)
  → JETS
- ❖ Occasionally the accretion rate will spike due to cloud/stream of cold dense gas (Francoise Combes)
  → thin accretion disk
  → short-lived quasar
- ❖ Since gas expected to come in from any direction, accretion disks will be misaligned – with random orientation – relative to the BH spin axis.

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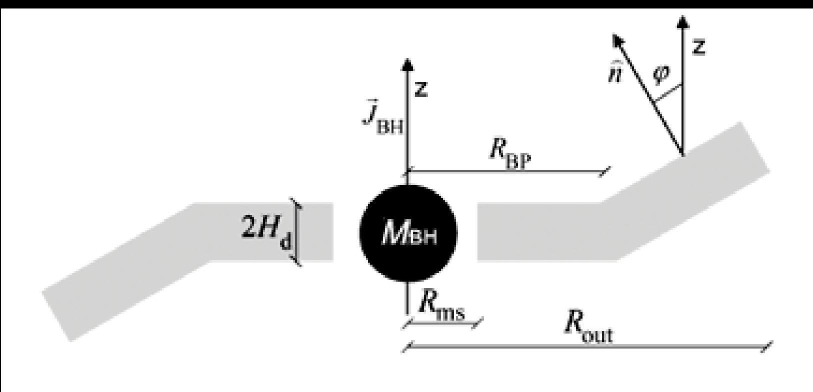
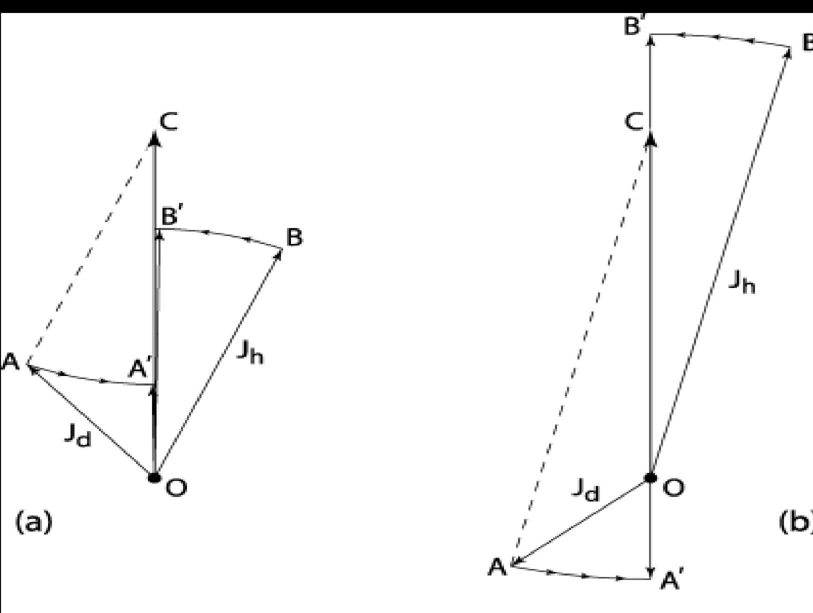




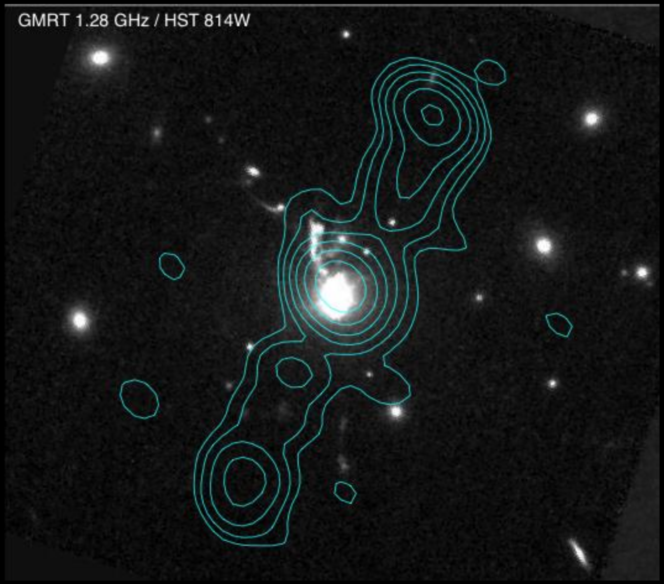
- ❖ Jets carry energy into the ICM.
- ❖ Occasional tilts allows this energy to be distributed isotropically; also explains misaligned bubbles.

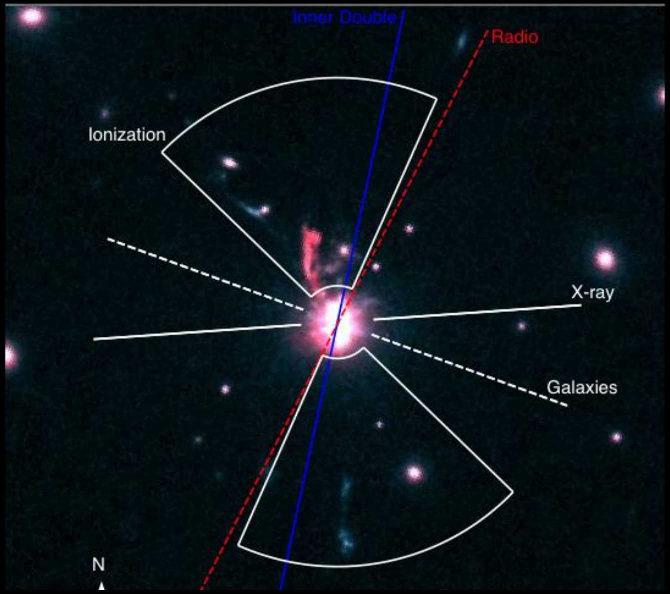
- ❖ We have started numerical experiments to explore model in detail.

IMPLICATIONS:

- ❖ BH Spin: J/J_{max} ~0.1
- ❖ ~5% duty cycle ➔ 1-2 z<0.5 CC AGNs should be quasars

QUASAR MODE VS. RIAF MODE





Popular Imaginings:

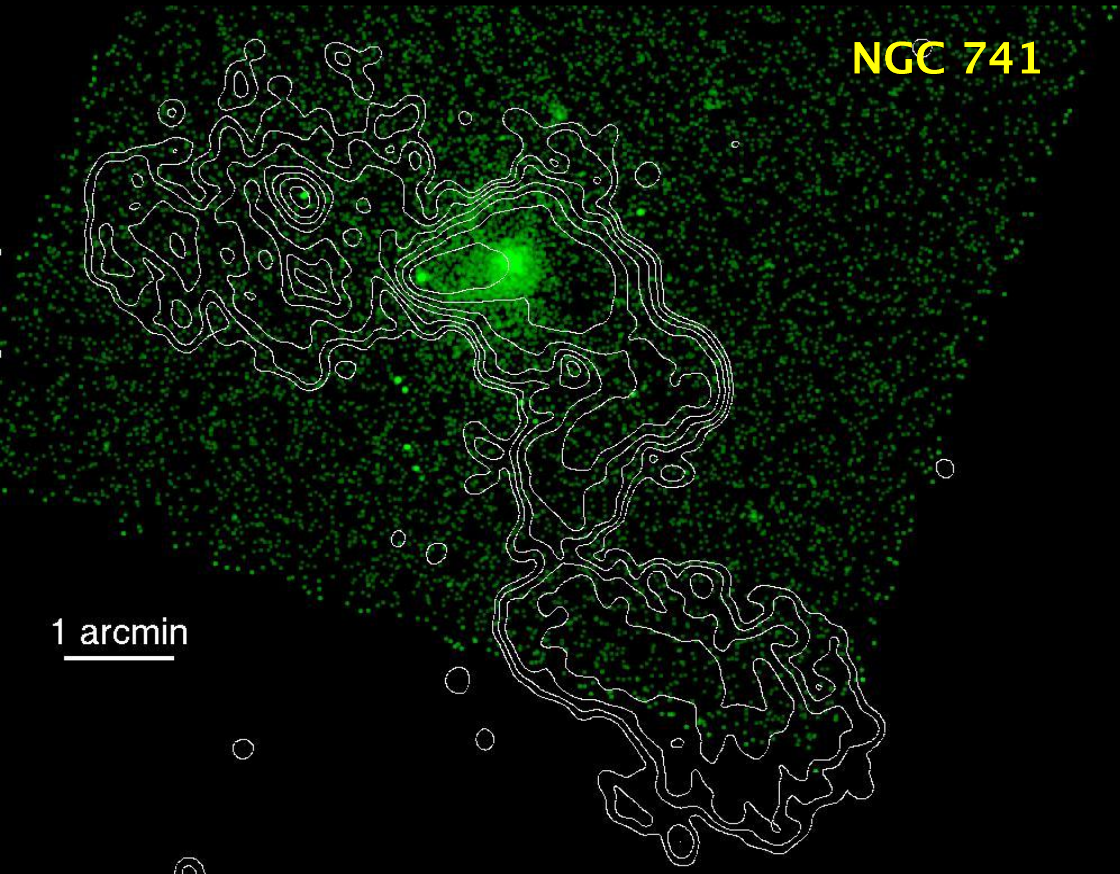
Radio Mode ➔ Maintenance
Quasar Mode ➔ Explosive
[modeled as such in sims]

IS THIS REALLY SO? DOES QUASAR-MODE LIVE UP TO ITS BILLING?

IS QUASAR MODE FEEDBACK (IN CONTEXT OF GALAXY FORMATION) ESSENTIAL OR RELEVANT?

CL0910 (IRAS 0910): O'Sulliwan et al 2012

AGN ACTIVITY IN NON-CENTRAL GALAXIES



N. Jetha, S. Raychaudhury +2008

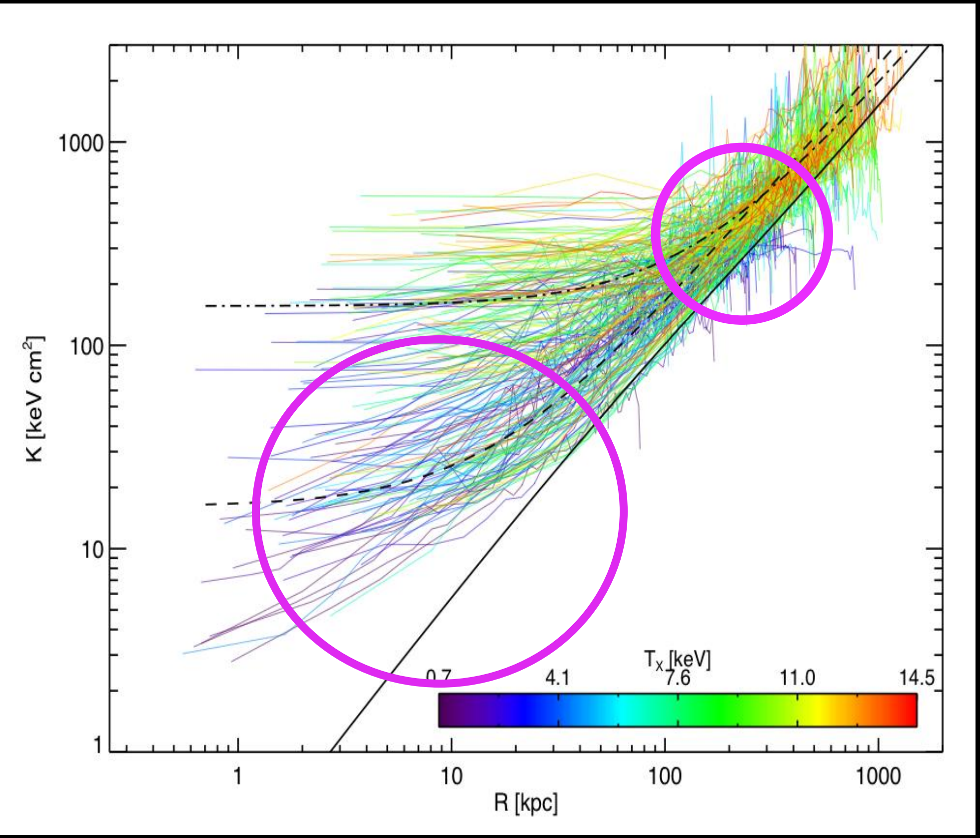
Has been observed but is relatively rare.

Example by N. Jetha (NGC 741)

X-ray AGNs by Martini+ 2006; Martini+ 2007; Haines+2013

Radio AGNs by Best +2005

DISTRIBUTED HEATING



Heating in the very center is not enough.

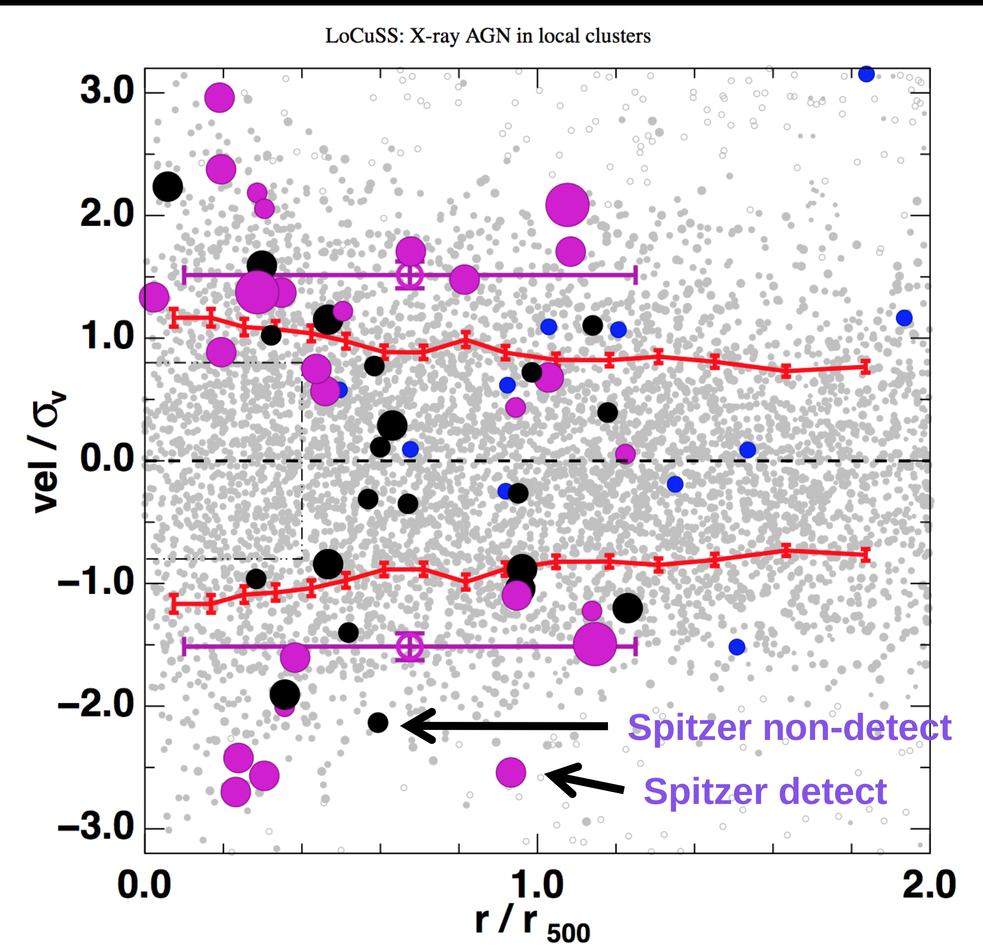
Gas at ~100-300 kpc needs to be "maintained" as well.

Nusser, Silk, Babul (2006) ➔ distributed heating by non-central AGNs.

McCarthy et al. 2008

LoCuSS AGN SURVEY

Haines et al. 2013



- 26 of 30 LoCuSS Clusters (0.15 < z< 0.3) observed in X-ray and have 200-400 spec/cluster.
- Redshift space density of X-ray AGNS is ~10x higher than field BUT increase in galaxy density is ~25x ➔ suppression.
- Trace caustic ➔ X-ray AGNs infalling (first pass through cluster)
- Low freq radio data (Raychaudhury/O'Sullivan)

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The End

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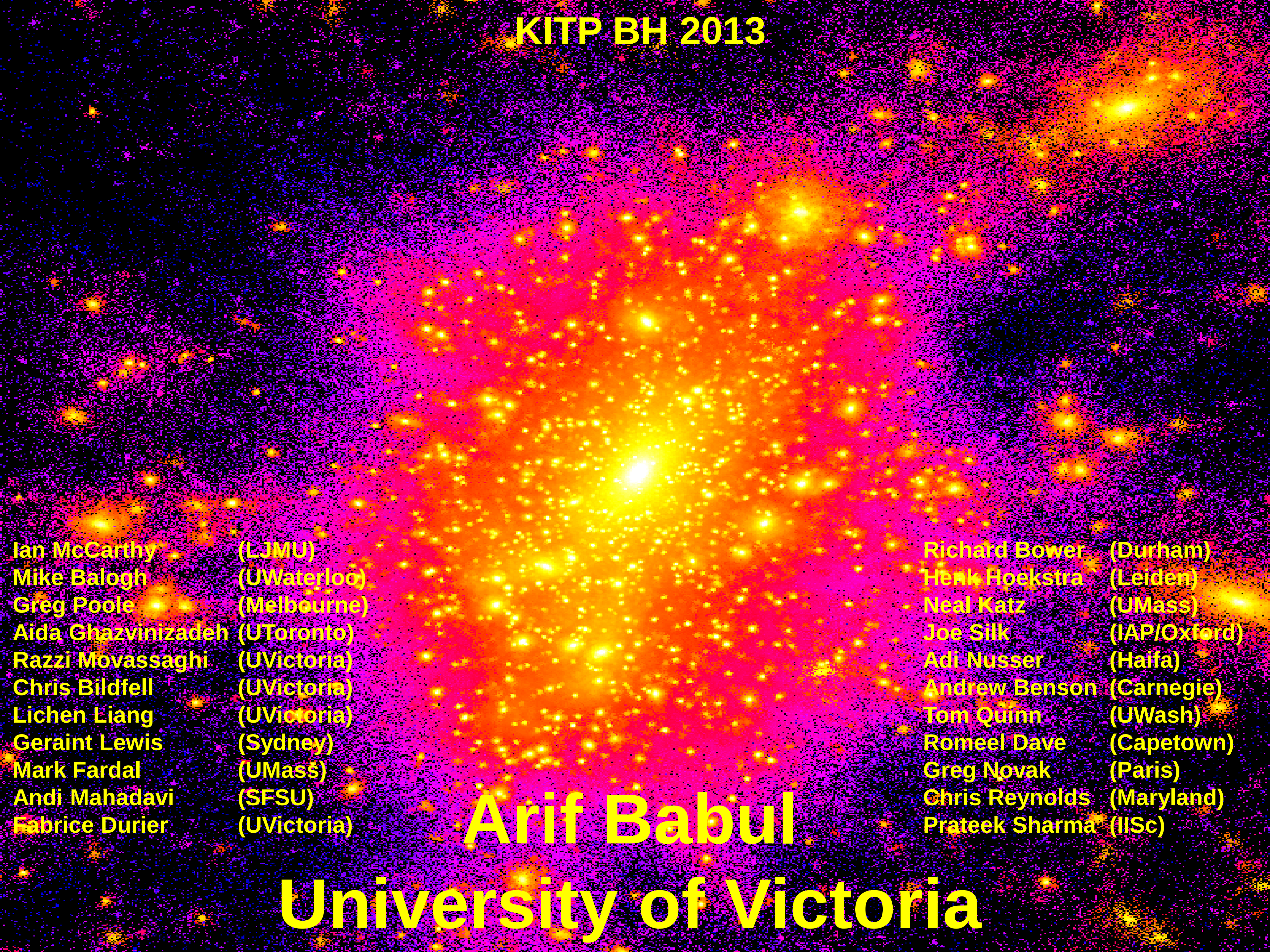

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Ian McCarthy (LJMU)
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Prateek Sharma (IISc)

Arif Babul

University of Victoria