

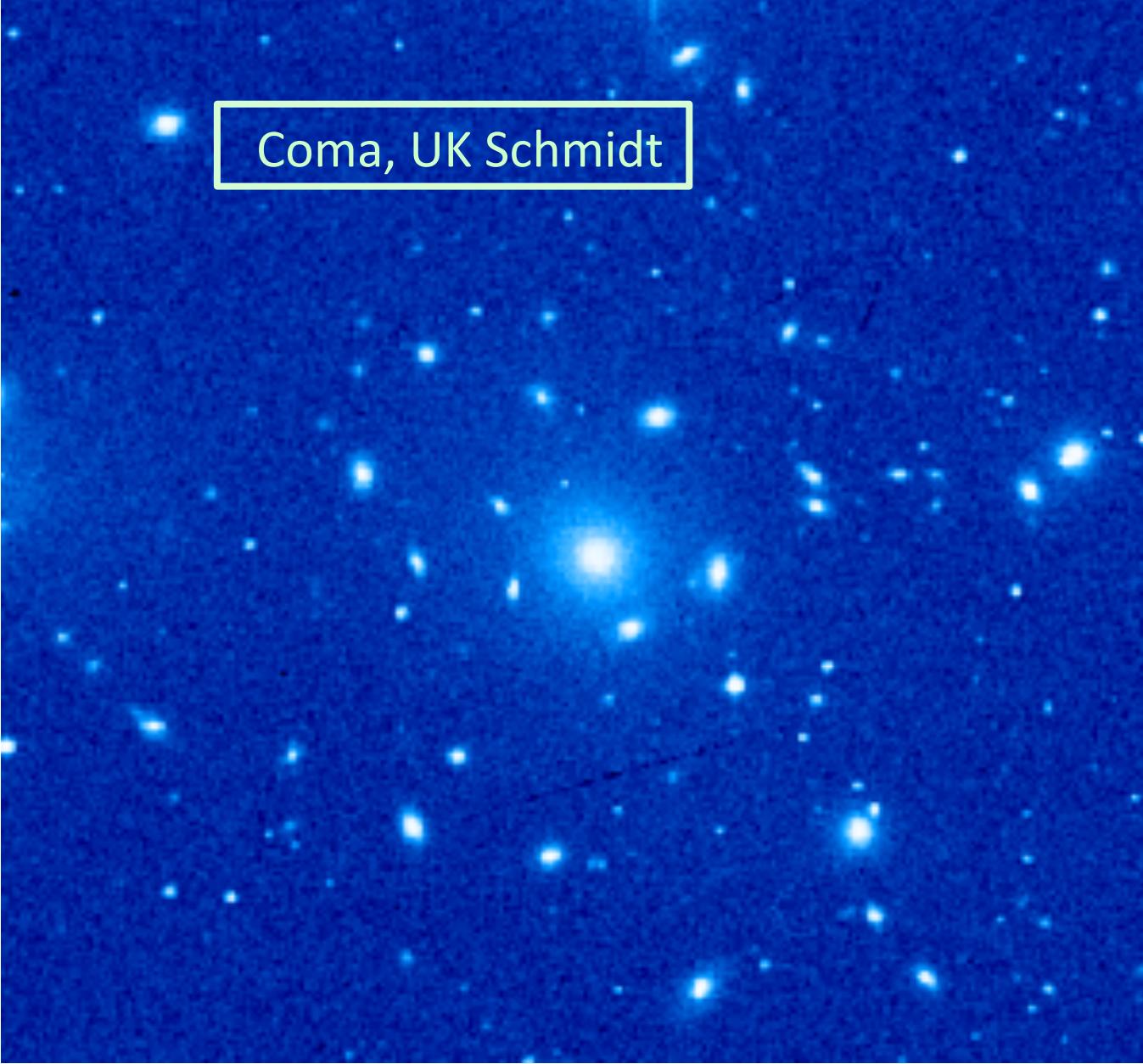


Galaxy Clusters, Garching, July 2010

If ever a competition were held for the most unrecognized genius of twentieth century astronomy, the winner surely would be Fritz Zwicky (1898–1974). A bold and visionary scientist, Zwicky was far ahead of his time in conceiving of supernovas, neutron stars, dark matter, and gravitational lenses. ”

AMNH Web page

And they forgot to mention CLUSTERS OF GALAXIES!

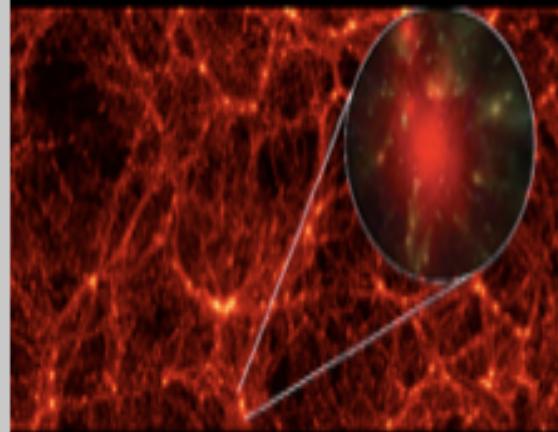


Coma, UK Schmidt

- a) He recognized the existence of clusters of galaxies and published the first catalogs the 1960s.
- b) He recognized that these were the most massive self-gravitating systems in the universe.
- c) He recognized that they were in equilibrium and was the first to use the Virial Theorem to compute total mass.
- d) He recognized that $M_{\text{tot}} \gg M_*$ and postulated “dark matter” (in fact “CDM”) as the binding ingredient.
- e) He recognized that the common SNI could be used to determine their distance (and in fact the extra-galactic distance scale) getting masses in solar units.

His reward was that he was thought a lunatic professor!

Galaxy clusters: observations, physics and cosmology



Clusters of Galaxies Conference

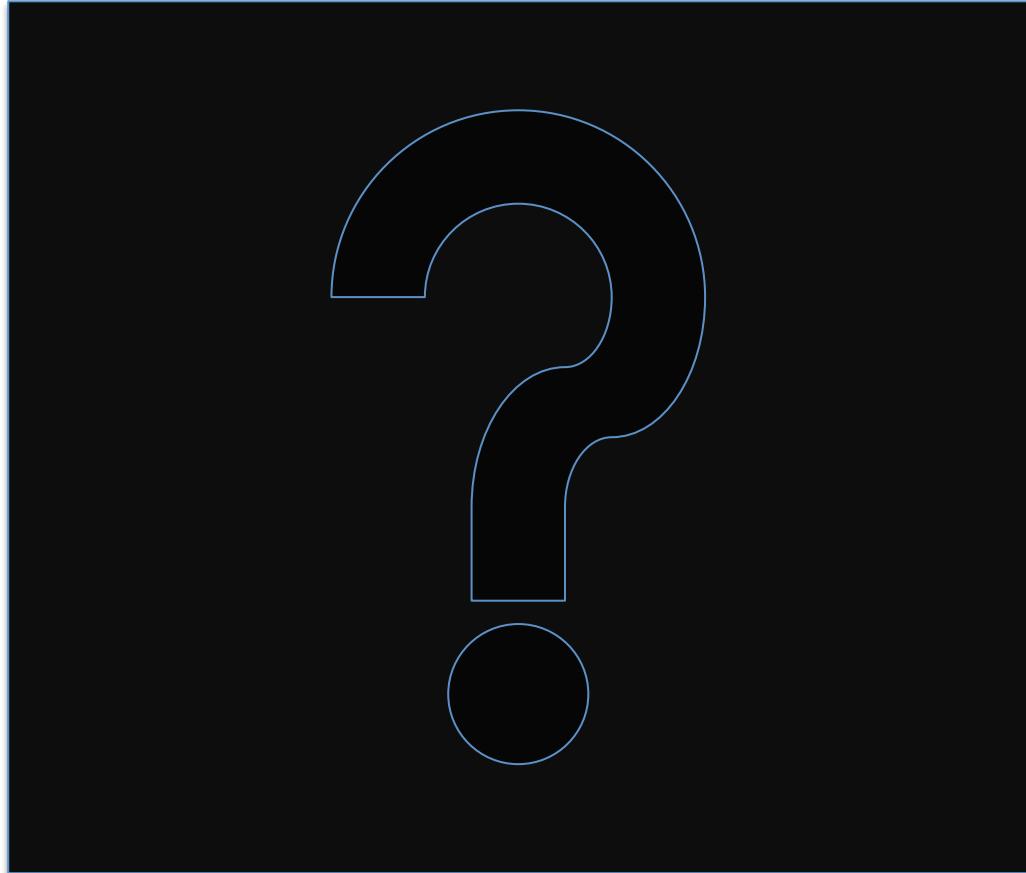
- First: heartfelt thanks to the scientific organizers and the staff: *REALLY!*
 - Tradition of well picked, meaty subjects
 - Well picked, well qualified reviewers
 - Convivial atmosphere and organization: wine & beer

=⇒ Very successful conference!!



Planck

Spectacular stuff but what ??

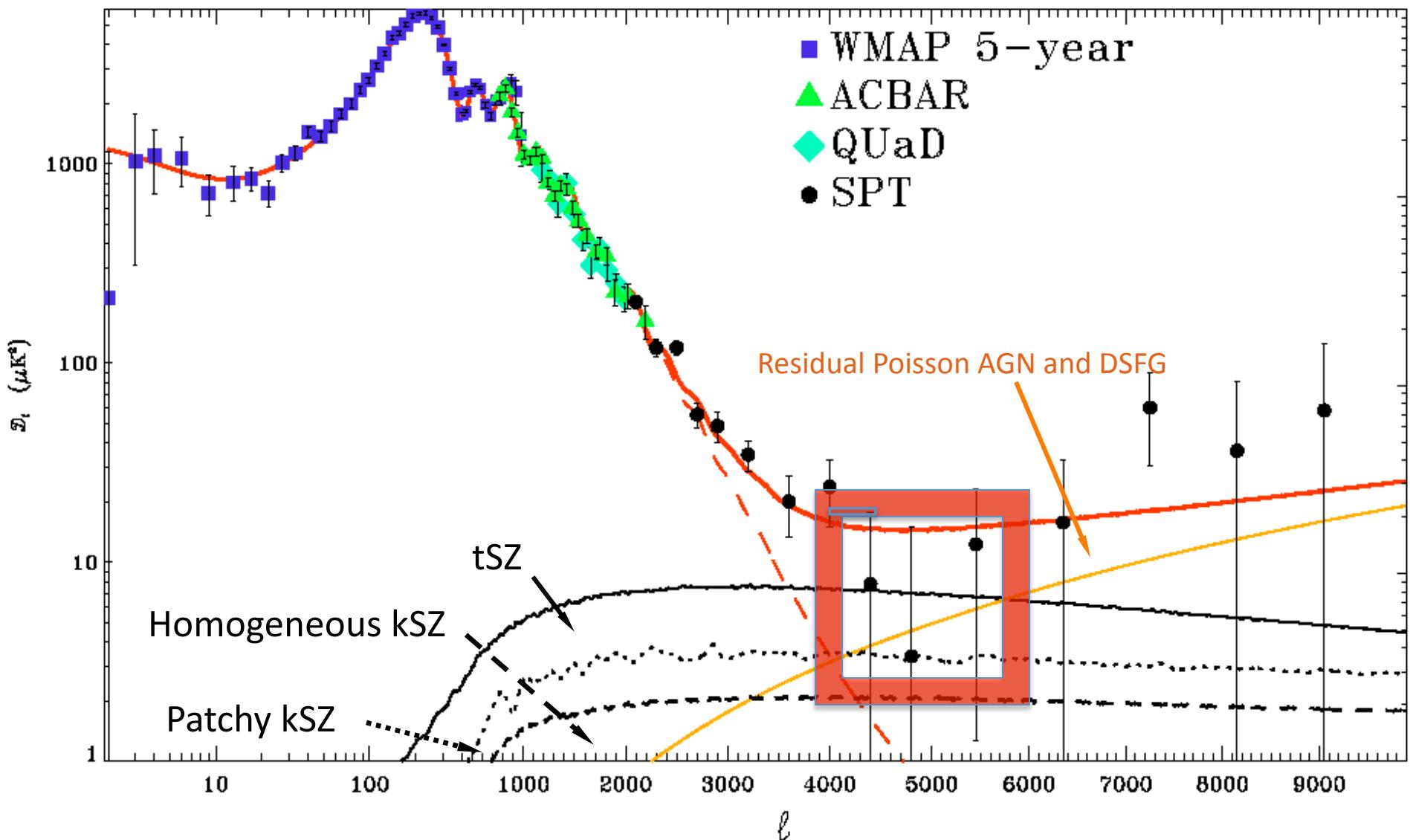


My Approach

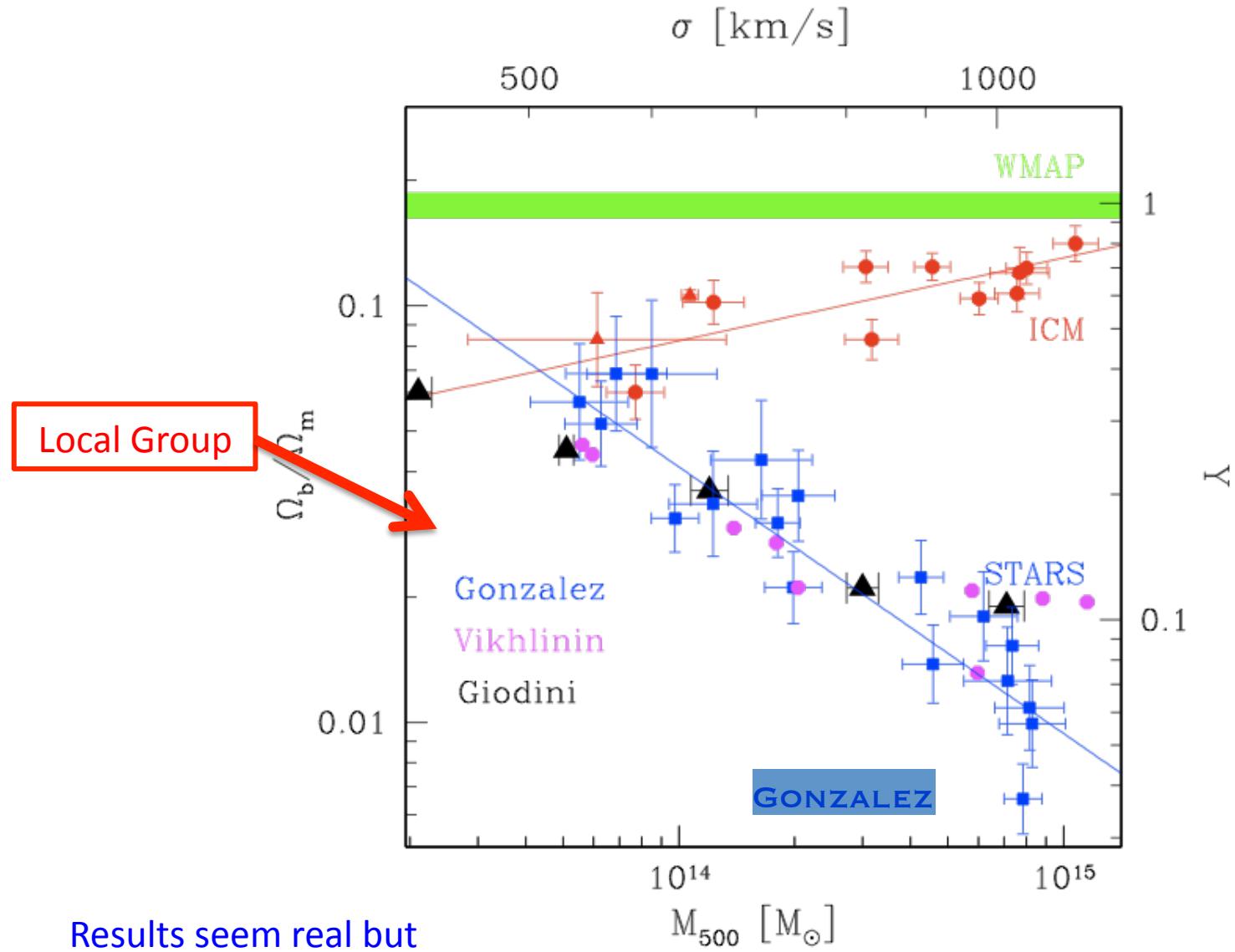
- Could ask and try to answer
 - what did we learn? No, too much to cover and
 - I would get it wrong in places and
 - to boring to do it that way!
- Instead will ask
 - what were the questions?
 - Where was our understanding of either nature or each other not clear???

First detection of SZ Power Spectrum

$$t\text{SZ} + 0.46 * k\text{SZ} = 4.2 +/- 1.5 \mu\text{K}^2$$



Lueker et al. 2009 (ApJ in press) arXiv:0912.4317

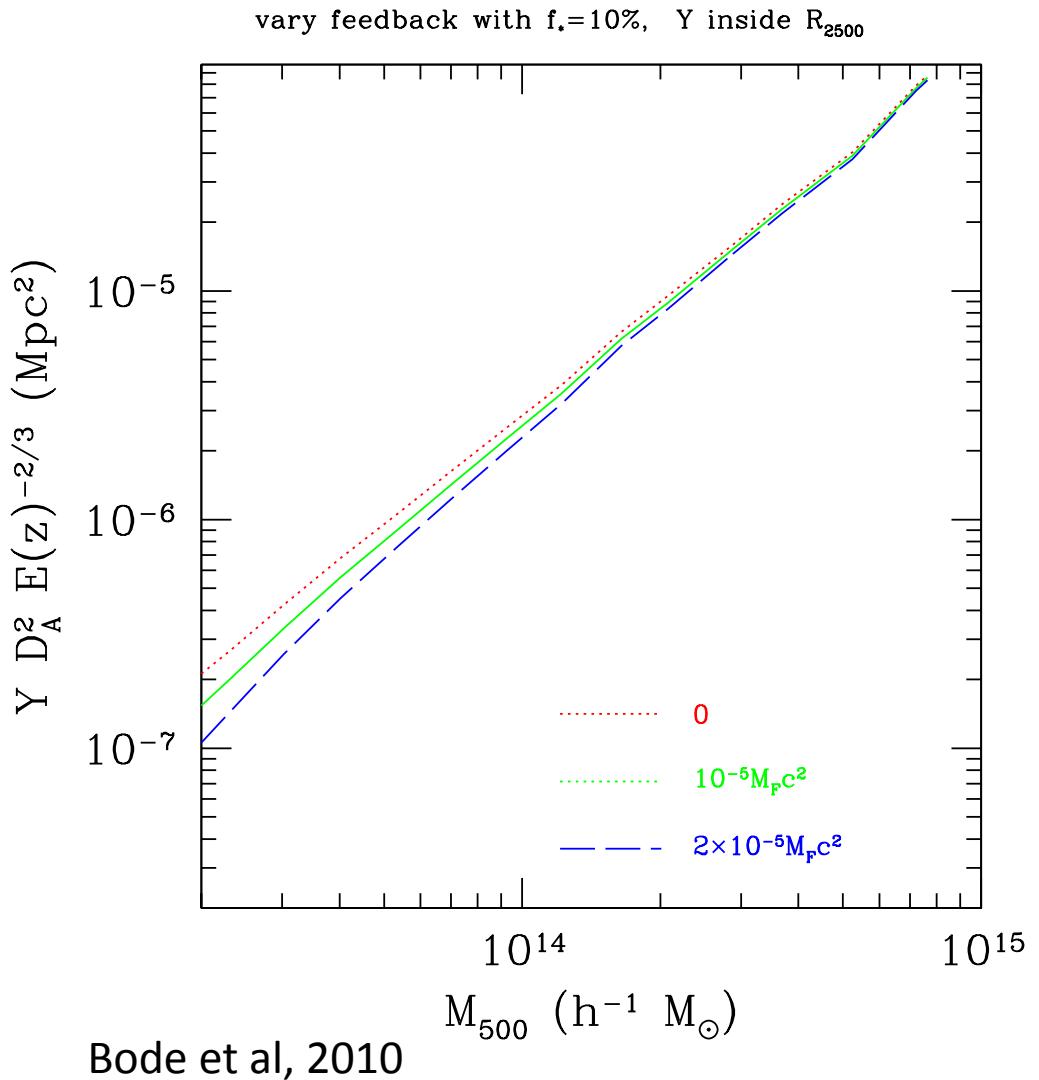


Results seem real but
are high compared to
prior expectations.

A. Gonzalez, 2010

Day One

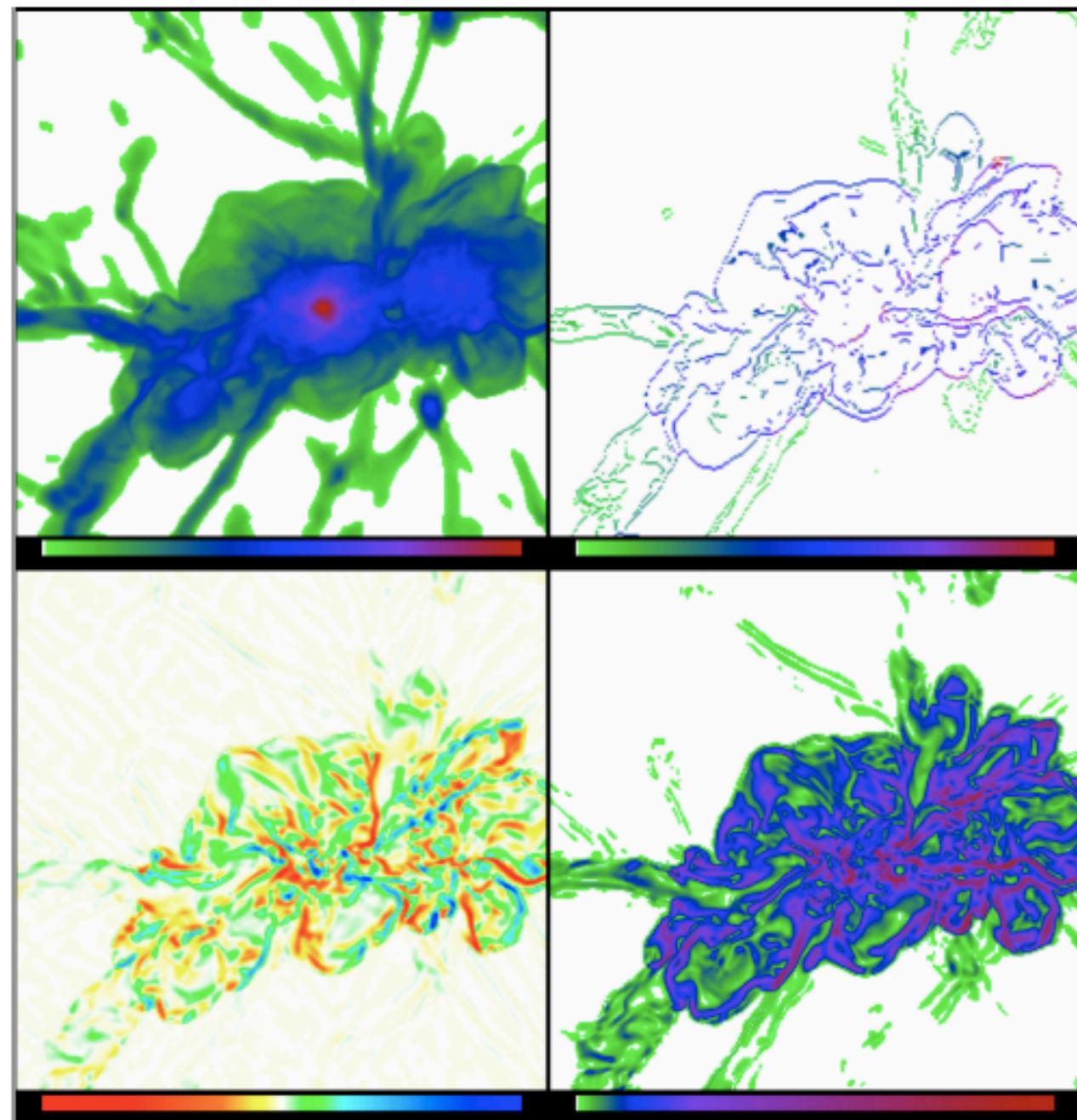
- Are high mass and low mass clusters self-similar?
 - Yes(Arnould, Bartlett); No(Page, Vikhlinin)
- How does the fraction $f_* = M_*/(\Omega_b * M_{\text{tot}})$ vary with M_{halo}
 - Much? Little? Max value?
- Is “feedback” needed for cluster properties to be understood?
 - Yes, significant shifts; No, gastrophysics calibratable
- Why is SZ overpredicted (Holzapfel)?
 - Outer parts of smaller clusters done wrong?



Day Two

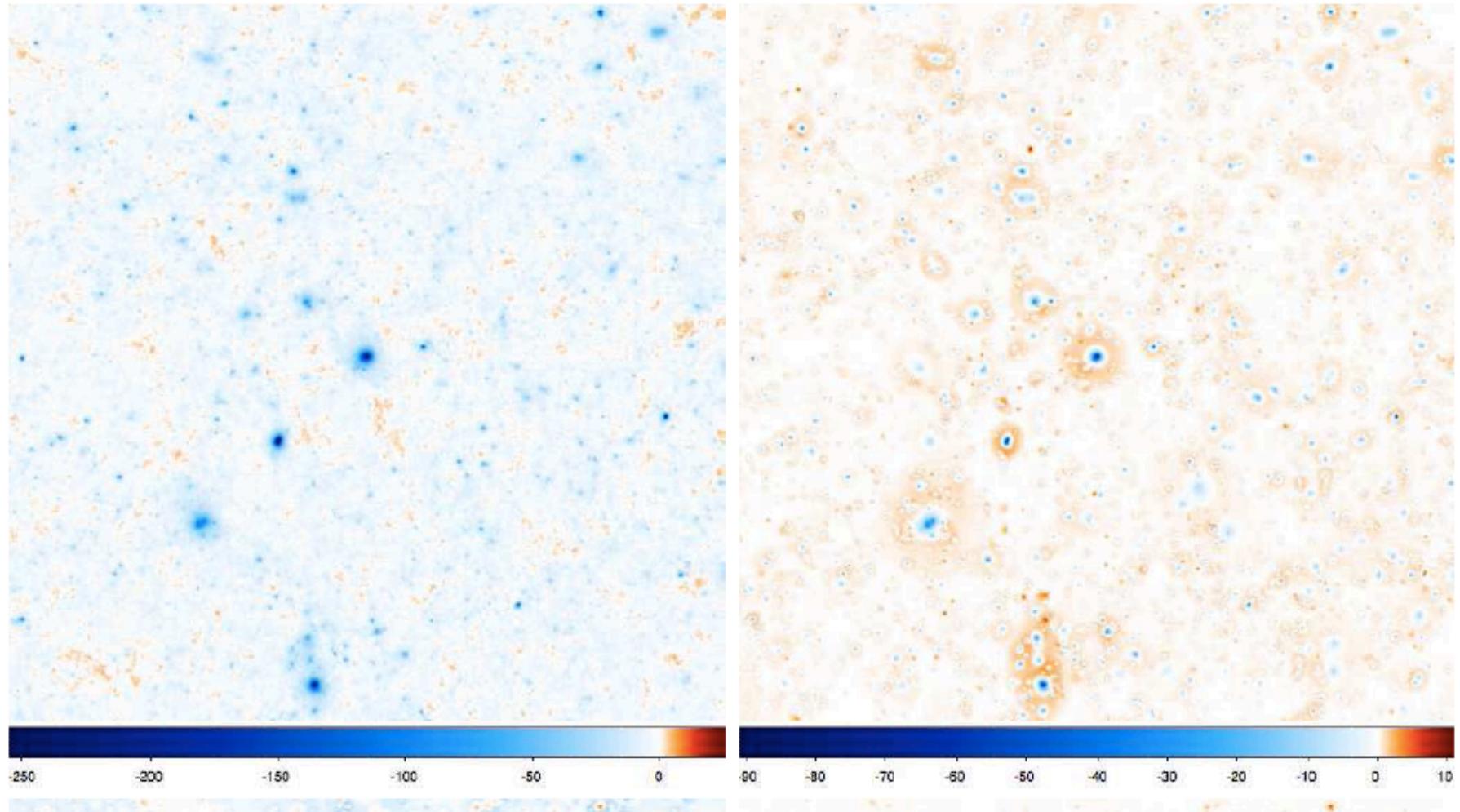
- Is $T_e < T_i$??
 - Yes?(Sunyaev, Basu); No(Markevitch, Vikhlinin)
- Is $P_{th} < P_{tot}$??
 - By how much? Where?
- Is “AGN feedback” for galaxies
 - First order effect?; A correction?
- Is “AGN feedback” for clusters
 - First order effect(Bond,Finoguerov)?; A correction (prior work)?
- Is scatter in Y-M relation and Y-L relation
 - Real?, Errors in obs measures?
- Is abundance pattern Fe/O vs radius in clusters
 - Declining, constant (Bohringer, Matsushita)

Fig. 1 Two-dimensional images showing X-ray emissivity (*top left*), locations of shocks with color-coded shock speed V_s (*top right*), perpendicular component of vorticity (*bottom left*), and magnitude of vorticity (*bottom right*) in the region of $(25 h^{-1} \text{ Mpc})^2$ around a galaxy cluster at present ($z = 0$). Color codes V_s from 15 (green) to $1,800 \text{ km s}^{-1}$ (red)



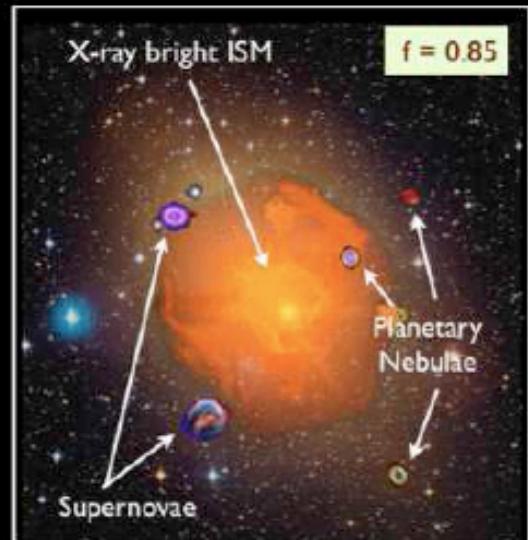
Day Three

- Why does no one try Sunyaev's 1982 suggestion for using strongly polarized radio rad for rad clusters to get mass of electrons?
- Can cluster fields be measured, understood?
 - Seed field? Dissipation? (Balbus, Dolag..)
- Turbulence, how important"
 - Origin, support, $\langle P_{\text{turb}} / P_{\text{tot}} \rangle$, radial dependence?
- Transport processes?
 - Conduction = 1/3 Spitzer or Zero?
 - Viscosity is dominant, negligible ? Interaction w turbulence (and what about code viscosity etc)?
- Instabilities, thermal, HBI, MTI, conductive
 - Critical? Ignorable? How to be handled?
- Is abundance pattern Fe/O vs radius in clusters
 - Declining, constant ?? (Bohringer, Matsushita)

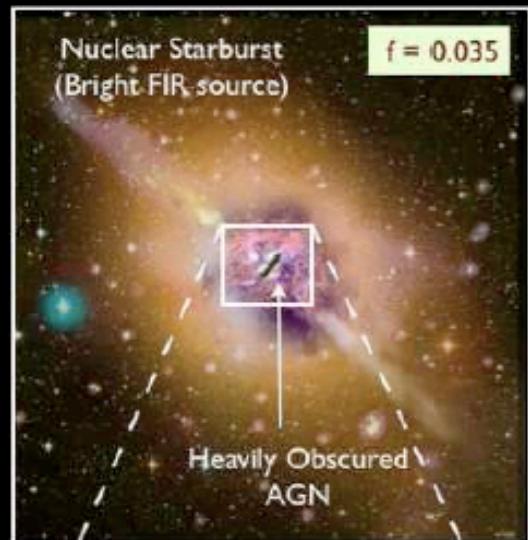


Day Three Continued

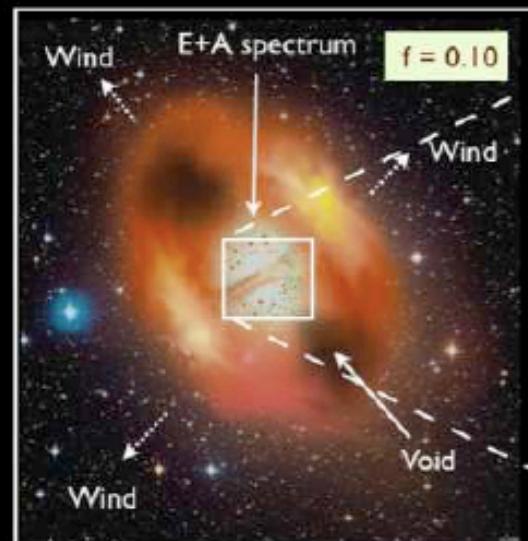
- Feedback from AGN – direct mode?
 - Radio jet, BAL wind, Photons
- Feedback from AGN – direct output?
 - Momentum, mass, energy
- Feedback from AGN – direct amount?
 - .1, .01,.001,.0001.....
- Feedback from AGN – secondary components?
 - weak & strong shocks, CR, turbulence...



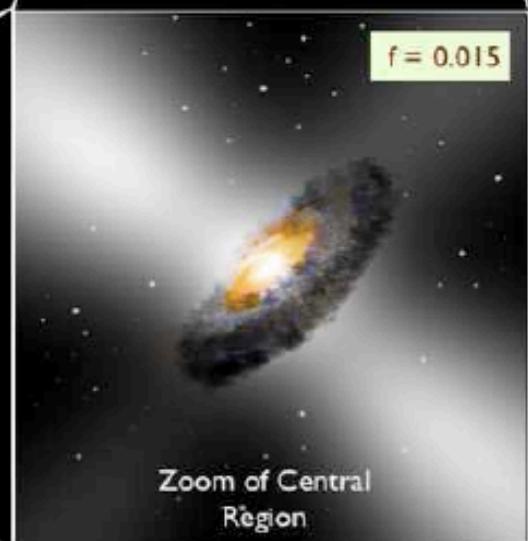
Incipient Cooling Flow Phase



Starbursting Phase



Pre-cooling Hot Core Phase



QSO Outburst Phase

Thermal Gas Cooling

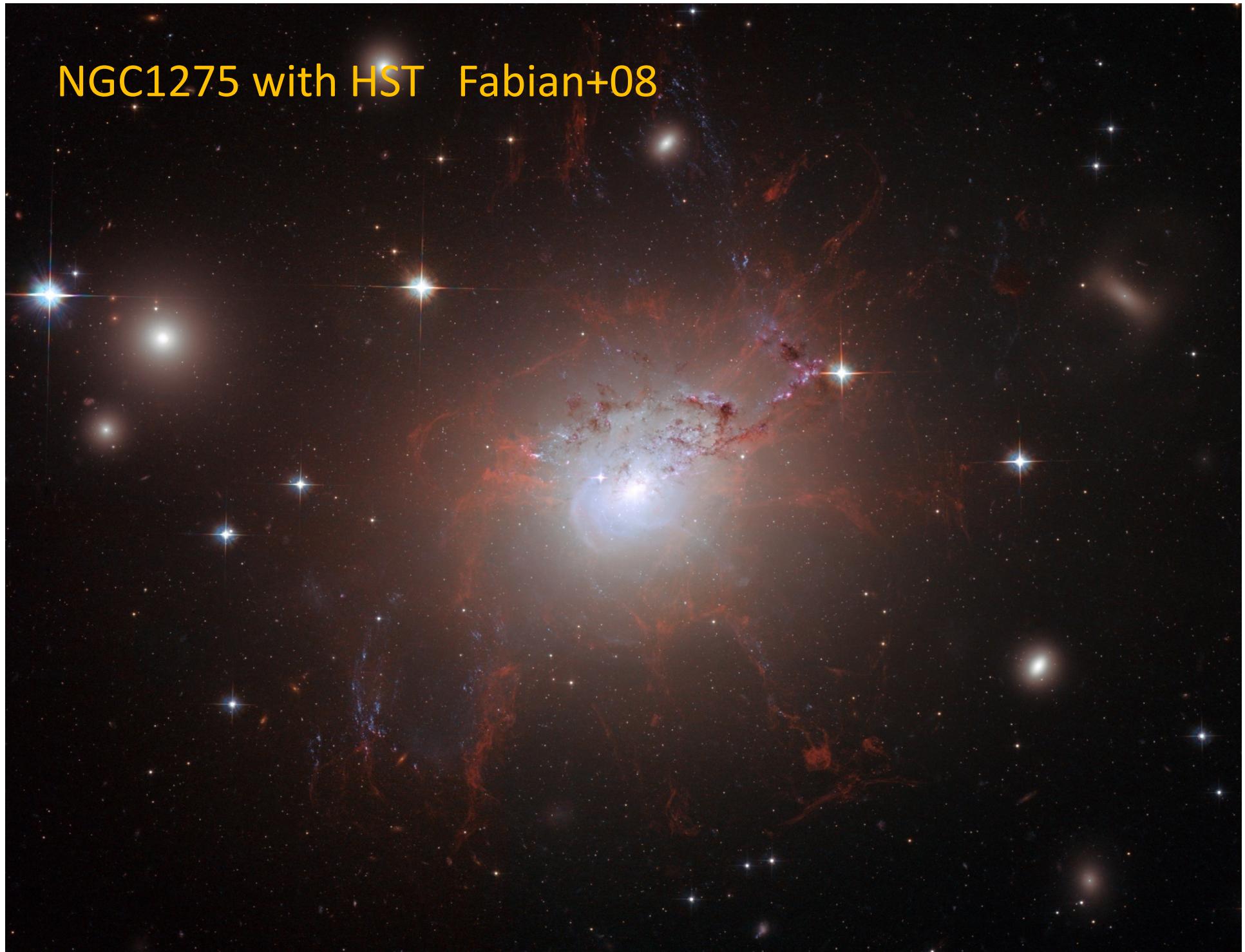
↑

↓

Gas Outflow

←

NGC1275 with HST Fabian+08



Day Four

- Cooling flows – detected at last!
 - The amount? Average star formation level in CC and NCC systems? Consistent w other observations?
- Cooling flows, trigger for AGN feedback?
 - Outskirts vs inner, stellar evolution trigger is triggered?
- Cluster properties, masses and star formation
 - Too much for LCDM, understandable as life in a universe with higher Omega?
- Early galaxies now observed?
 - big or small, two phase?

Day Five

- Instrumentation – surveys:
 - “holy grail” vs “discovery space”
 - NoName vs WFXT, Hypersuprimcam, Panstars
 - X-ray output from $\sim < L_{\ast}$ galaxies; obs and theory pbs?
 - X-rays from stars, SN(I&II), AGN heated gas, cooling flow?
 - *Style of science; enormous progress as we move to industrial mode. Fantastic instruments, fantastic results. But almost all the ideas in fundamental physics are from nearly a century ago and the cosmological ideas from nearly a half century ago.....*
- to be discarded as the musings of a grumpy old man!