The Long Arc of Science

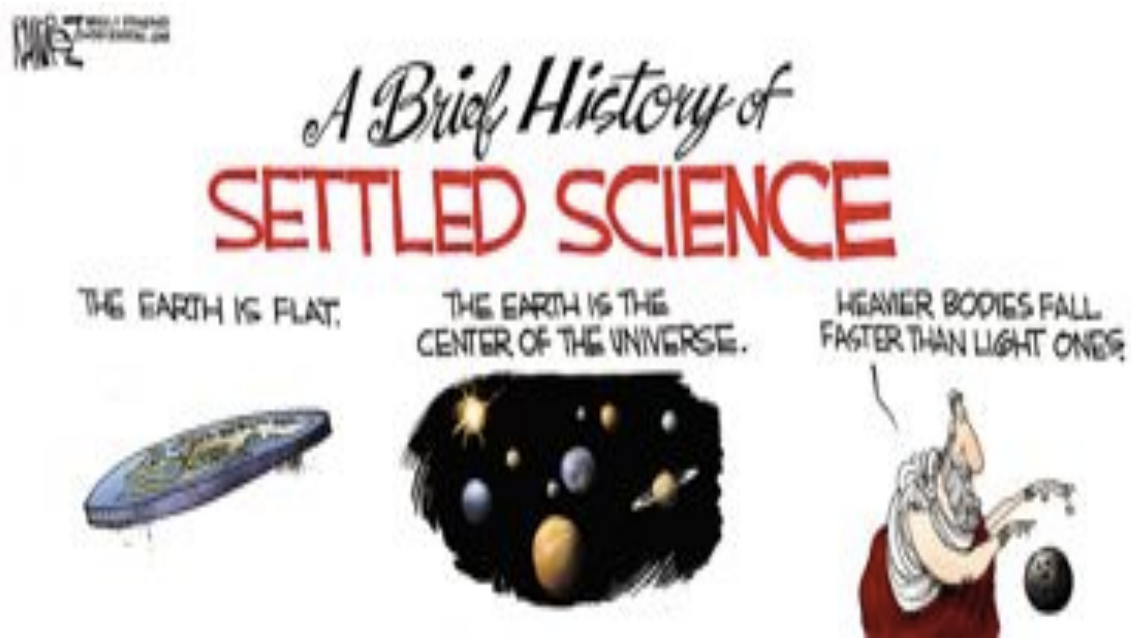
STEFI BAUM, DEAN FACULTY OF SCIENCE UNIVERSITY OF MANITOBA

PROFESSOR, DEPARTMENT OF PHYSICS AND ASTRONOMY

The Long Windy Road of Scientific Truth

- "I do not pretend to understand the moral universe; the arc is a long one, my eye reaches but little ways; I cannot calculate the curve and complete the figure by the experience of sight; I can divine it by conscience. And from what I see I am sure it bends towards justice."[59]
  George Parker on the abolitionist cause
- Or as paraphrased by Martin Luther King a century later,
  - "The arc of the moral universe is long, but it bends toward justice".[60]

"The truth may be puzzling. It may take some work to grapple with. It may be counterintuitive. it may contradict deeply held prejudices. It may not be consonant with what we desperately want to be true. But our preferences do not determine what's true." — Carl Sagan

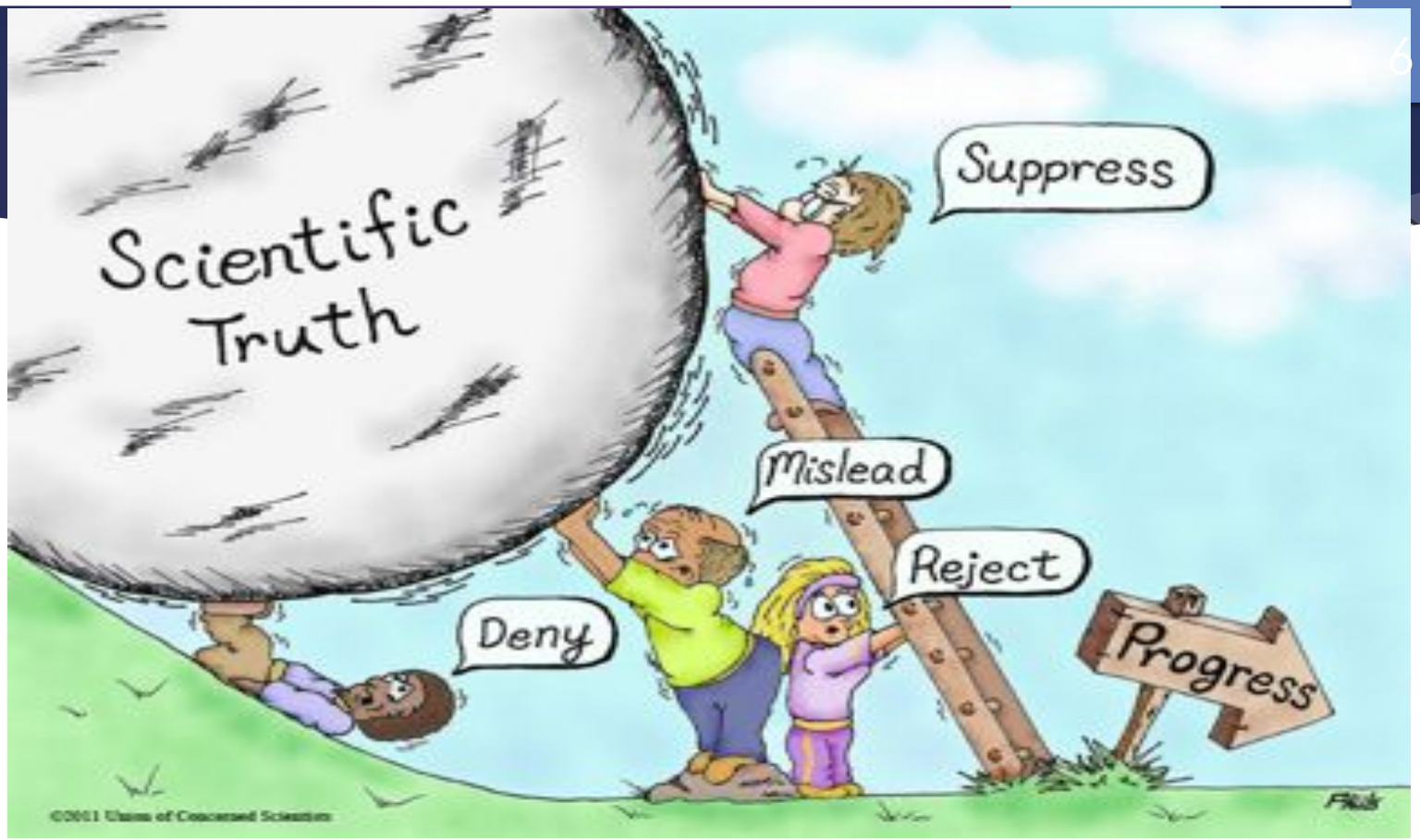


Even Newton had trouble with gravity…

- **"That gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance, through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man who has in philosophical matters a competent faculty of thinking, can ever fall into it. "**

Thomas Kuhn's – The Structure of Scientific Revolutions, 1962

- https://www.youtube.com/watch?v=3cp6pEzx3uw


Scientific Truth
Suppress
Mislead
Reject
Deny
Progress
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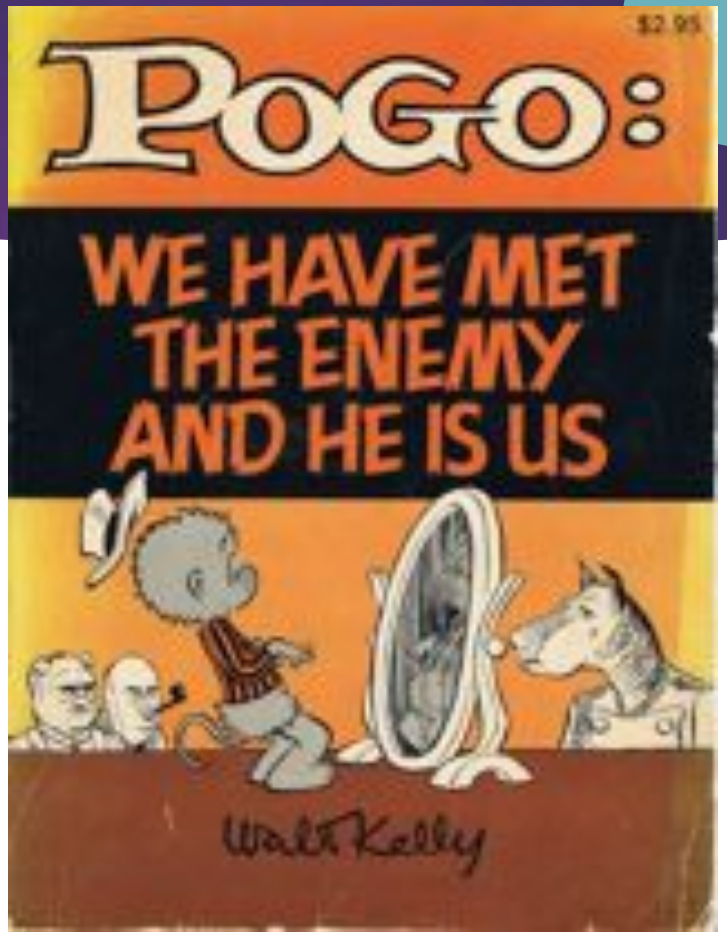
What If…



What Do These Scientists Have in Common?

http://www.megafoundation.org/Genius/GeniusHall.html
http://amasci.com/weird/vindac.html

Tip of the Iceberg…

1961

Resistance by Scientists to Scientific Discovery

This source of resistance has yet to be given the scrutiny accorded religious and ideological sources.

Bernard Barber

- Substantive Conceptions (cultural resistance, traditional patterns of thought, established theories)
- Methodological Conceptions (preference for current techniques, resistance to mathematics, does not fit model, way of doing science etc.)
- "Religious" Ideas (acceptability, patterns of social interaction)
- Professional Standing (and specifically individuals of standing impeding)
- Professional Specialization (Hemholz (Medicine) -> physics, Pasteur (Chemist-> Medicine)
- Societies, Schools and Seniority (i.e, camps, Established scientists, risks)

Linus Pauling "There is no such thing as quasicrystals, only quasi-scientists." about Dan Shectman Nobel 2011

Archway from the Darb-i Imam shrine, Isfahan, Iran (1453 C.E.) with two overlapping girih patterns. Image courtesy of K. Dudley and M. Elliff

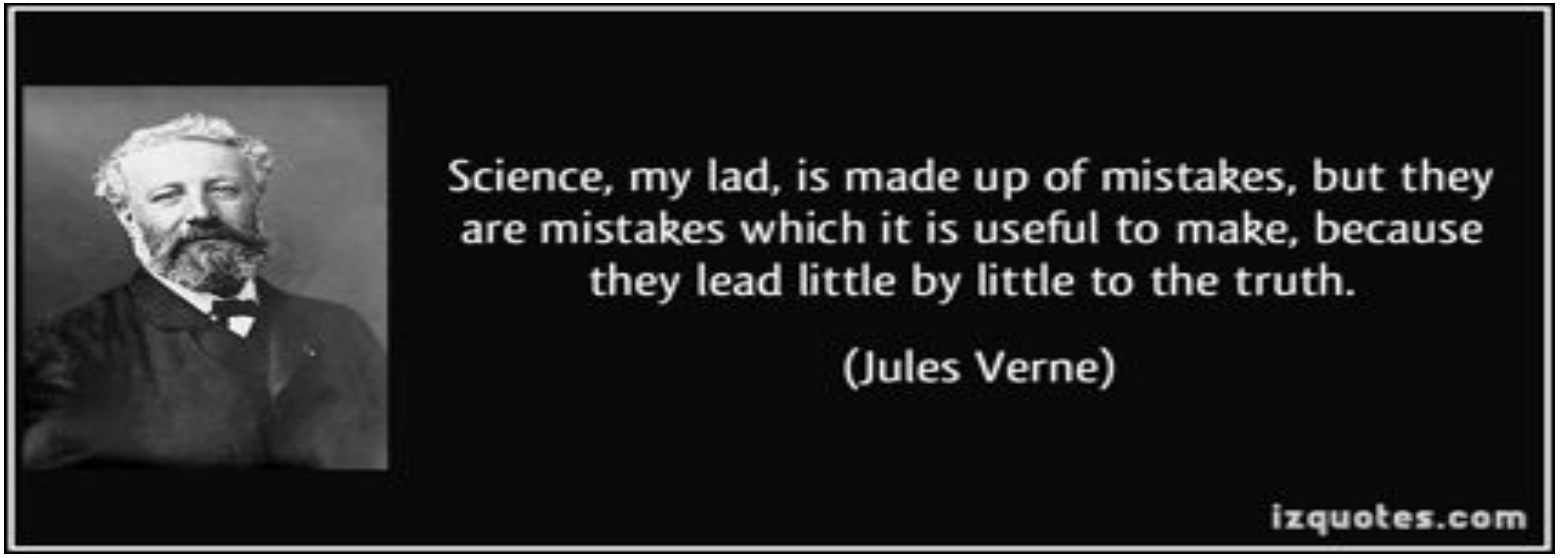
Professor Dan Shechtman, who discovered quasicrystals, displays a model at his lab in Haifa, Israel. Photograph: David Blumenfeld

https://www.youtube.com/watch?v=FOozoDTHO7w

Safe..Science.

- "*Concepts which have proved useful for ordering things easily assume so great an authority over us, that we forget their terrestrial origin and accept them as unalterable facts. They then become labeled as 'conceptual necessities,' etc. The road of scientific progress is frequently blocked for long periods by such errors.*" – Einstein

Unfortunately – Risk doesn't lead to security



papers PhD/graduation jobs grants Observing time

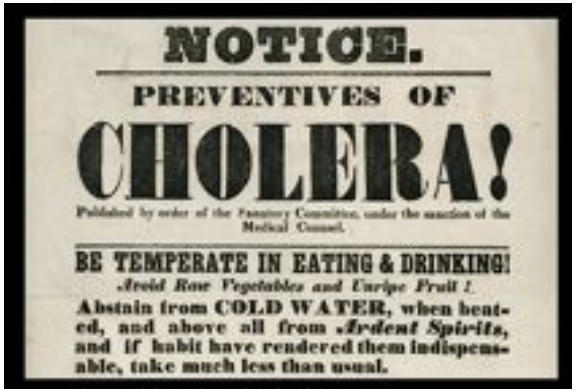
Some thoughts…

- **Science seeks Truth, but the road to scientific truth is long, and nature, thus far, infinitely complex.**
- **The relationship between Scientific Consensus and Scientific Truth is sketchy, historically, at best.**
- **Scientists need to be aware of the powerful force of scientific consensus impacting grants, telescope time, promotion, acceptance.**
- **Developments in Technology expertly used are powerful tools for changing the consensus, but even then they operate slowly.**

When It Matters

- **Miasma London –tens of thousands died of cholera from dumping of sewage into the Thames, the public water supply. Authorities actively worked to increase dumping into the Thames, believing the stink of miasma of piled up sewage was causing the disease, denying water born theory (Snow 1849). The completion of the water works in 1875 and the ceasing to dump sewage in the Thames in 1887 saved England from the epidemic of 1892**

This cartoon shows a cloaked skeleton eerily rowing through the Thames, dead creatures float pass him as he makes his way. St Paul's Cathedral is silhouetted in the distance.


NOTICE.

PREVENTIVES OF

CHOLERA!

Published by order of the Sanitary Committee, under the sanction of the Medical Council.

BE TEMPERATE IN EATING & DRINKING!

Avoid Raw Vegetables and Unripe Fruit.

Abstain from COLD WATER, when heated, and above all from *Ardent Spirits*, and if habit have rendered them indispensable, take much less than usual.

Bad Advice from NY Public Health1832

When it Matters…

2016. A 15-year study involving more than 3,000 adults found full-fat dairy can reduce your risk of developing diabetes by 46 per cent on average (Circulation). Full-fat dairy products have also been found to lower women's risk of being overweight or obese by eight per cent, (The American Journal of Clinical Nutrition.

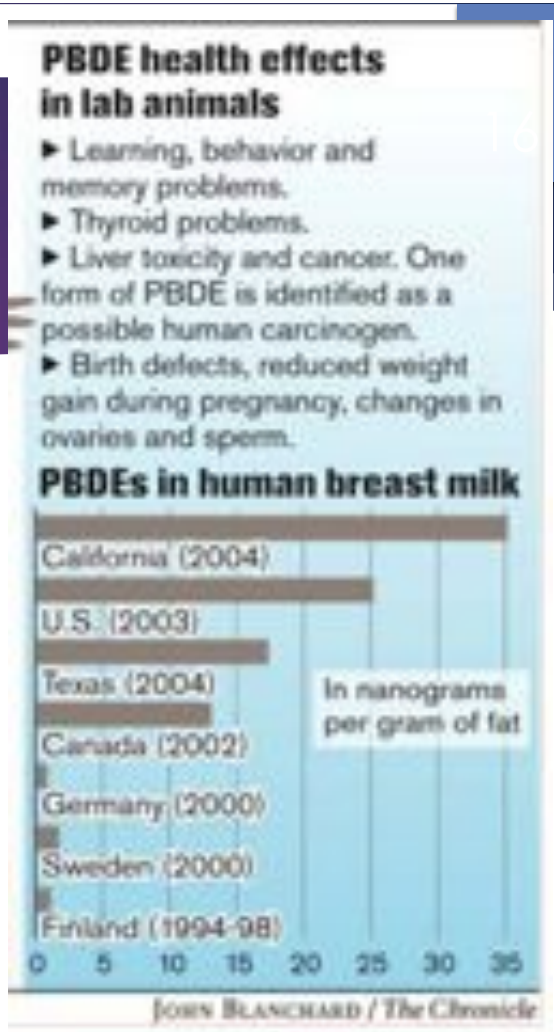
.

When It Matters

Living room: Emily May/Flickr; Poison sign: Robert Leonardo/The Noun Project

"The average American baby is born with 10 fingers, 10 toes and the highest recorded levels of flame retardants among infants in the world. "

1975, California Technical Bulletin 117 (TB117) was passed, including requirements for children 9 months to 14 years, cribs etc.. Updated 2013



Science is Seldom Certain -

Precautionary Principle

"The **precautionary principle** or precautionary approach states that if an action or policy has a suspected risk of causing harm to the public or to the environment, in the absence of scientific consensus that the action or policy is harmful, the burden of proof **that it is *not* harmful falls on those taking an action.**"

http://en.wikipedia.org/wiki/Precautionary_principle

More Thoughts…

- The number of world altering discoveries made against the consensus of their time is impressive to say the least, as is the descriptions of what the scientists who made those discoveries went through, from their fellow scientists!
- Not too surprising because it is in the things that don't fit that the remarkable discoveries lie.
- Science is filled with uncertainty and refinement. As scientists we need to be cognizant of the limits of our knowledge, at any one time, when judging each other and when talking to policy makers.
- Such opportunities will arise in your own research – don't back away.

New Results + Personal Retrospectives on the Study of Radio Galaxies

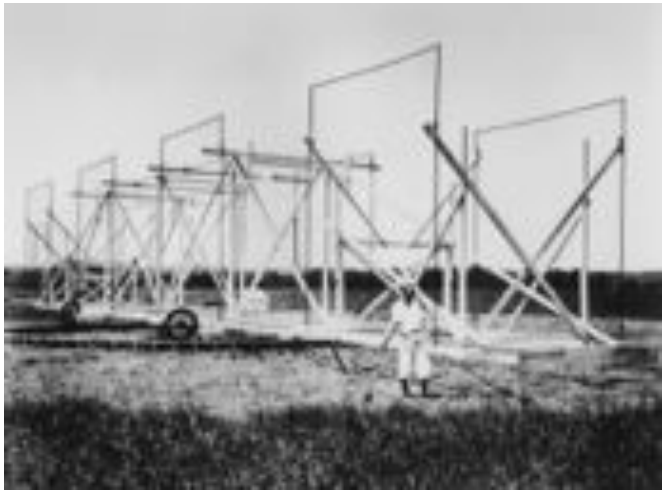
- **From an Exciting new Discovery to Inconsequential Butterflies to THE determinants of galaxy and cluster evolution all in Twenty Years!**
  - **From Janksy to KPNO 4M (1973) Einstein (1978) to the VLA (1980) and VLBI (1980) to HST (1990) to Chandra (1999) to Gemini (2000) Spitzer (2003) to ALMA (2011)**
- **And then there was me, BS Physics (1980), Data Aide Einstein (1980-1983), Graduate School (PhD 1983 - 1987), getting old…2016…**

Jansky (1935) found radio emission at 14.6 m associated with the Milky Way galaxy.

Radar/Radio technology advanced greatly during WWII.

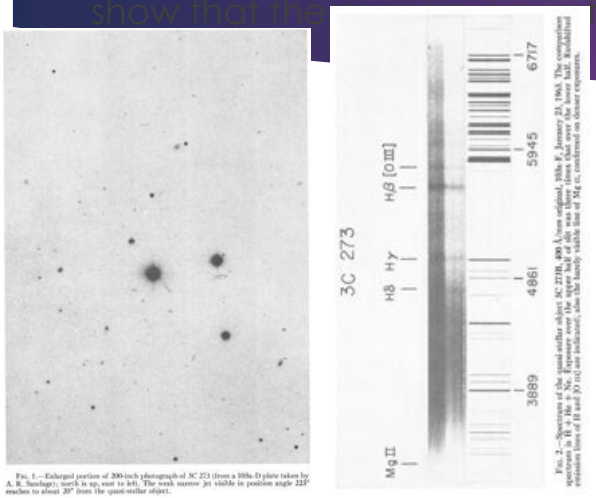
After WWII radio sources identified with galaxies (e.g., Bolton 1948, Bolton, Stanley & Slee 1949).

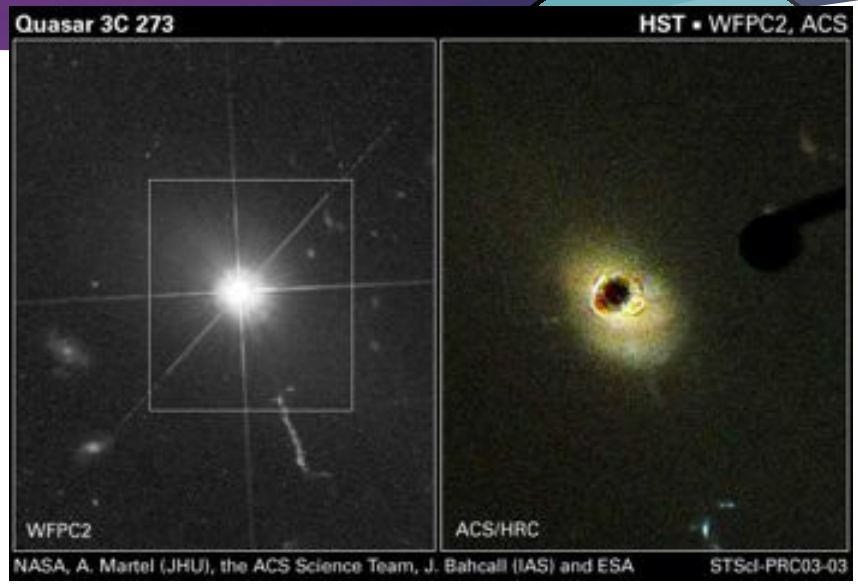
The synchrotron mechanism (high energy electrons in magnetic fields) (Kiepenheuer 1950, Ginzburg 1951).



Quasar 3C273 Outshines its Host Galaxy

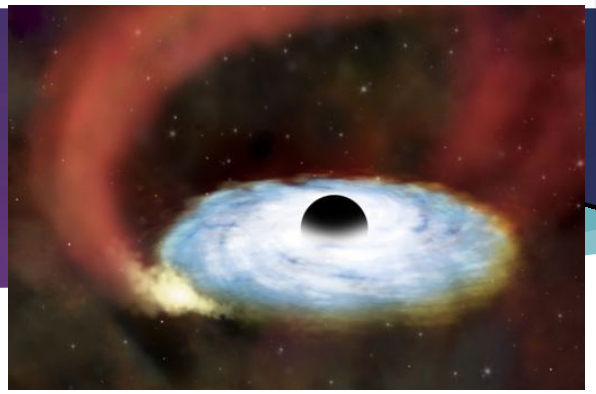
- The quasars looked stellar because there was a very small accretion disk around the central black hole which was outshining the entire galaxy. Modern observations clearly show that there is the nuclei of galaxies.





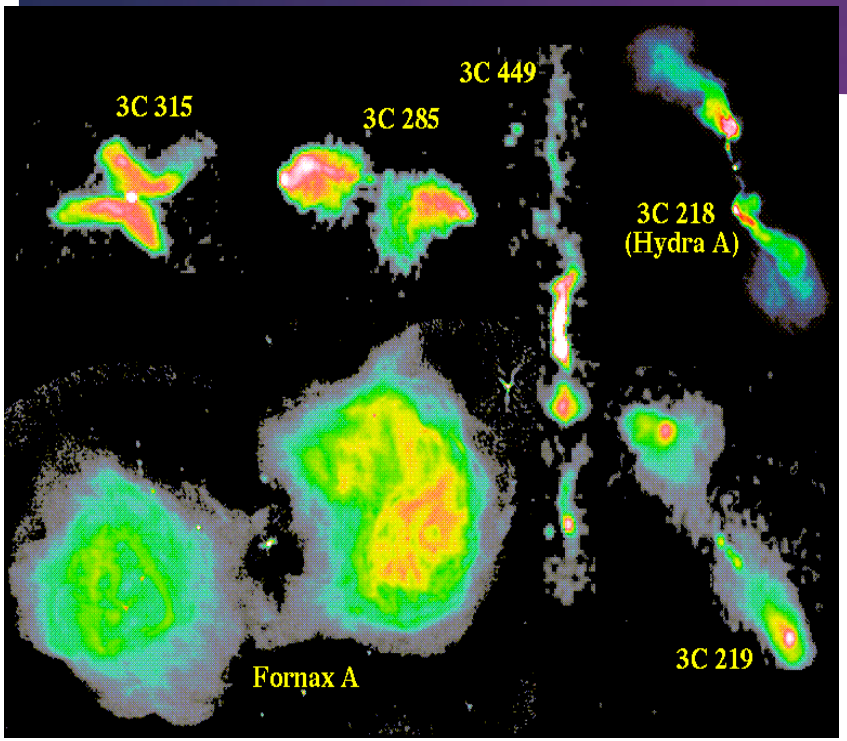
3C273 (Left) photo showing stellar object with jet. (Right) spectrum showing a redshift of z = 0.16. (Greenstein & Schmidt 1964)

Fascinating Objects!



- Baade & Minkowski (1954) - radio galaxies distant and very luminous.
- Burbidge (1959) energies enormous ~ 10^{60} ergs, equivalent to the luminosity of one billion suns radiating for 10 billion years.
- Salpeter (1964) and Zeldovich (1964) proposed energy production from accretion onto a supermassive black hole.
- Rees 1966 predicted apparent superluminal motion of relativistically expanding sources seen in 1971 in VLBI observations of 3C273 and 3C279 (Knight et al. 1971, Whitney et al. 1971, Cohen et al. 1971).

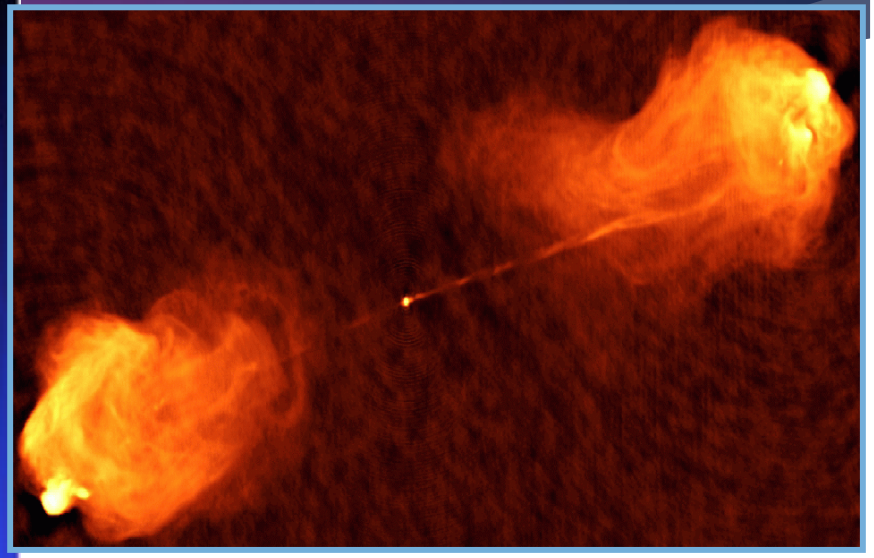
Structure



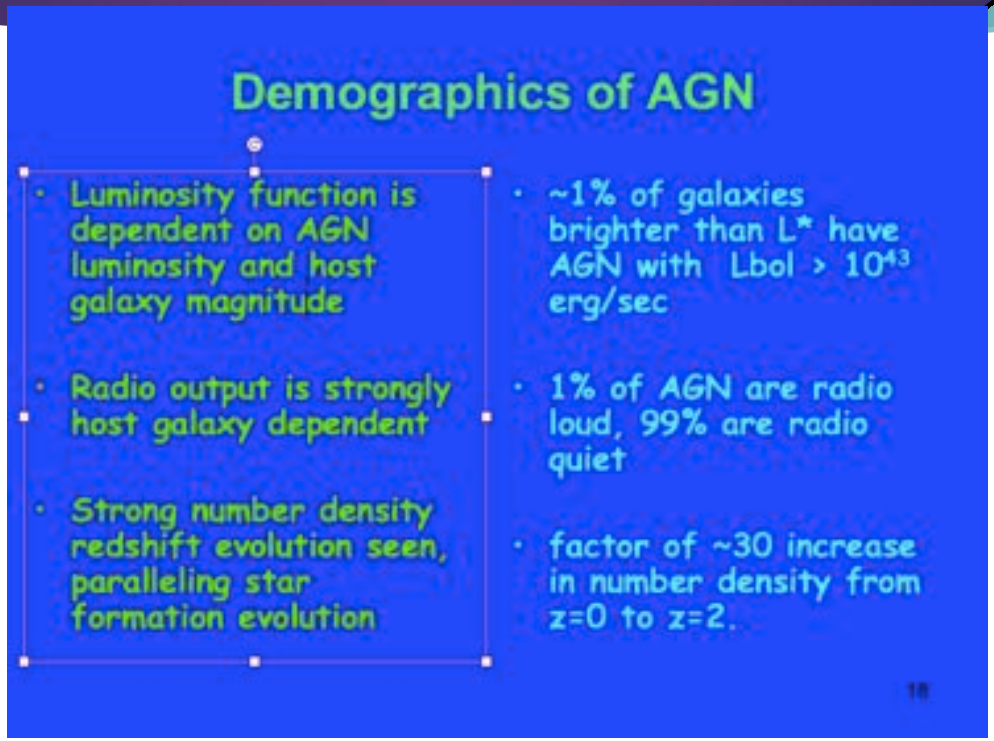
- Two components straddling the optical galaxy (Jennison and Das Gupta (1952)
- Early interferometers (Cambridge, WSRT) started imaging radio galaxies in the 70's.
- The first realistic model for radio sources was the "twin-jet" model (Scheuer 1974, Blandford & Rees 1974).
- .
- The quality of images greatly improved when the Very Large Array (VLA) came on line ~1980

Butterfly Collecting

Hercules A, VLA and HST. O'Dea + 2013, Rotated for PR image.



RARE:
Less than 0.1% of galaxies have powerful AGN



But do they matter?

- Lots of energy, but contained in radio source (no evidence of impact, no theory for how energy exchange could occur)
- Rare, and only in ellipticals
- Mass infall rates to fuel "insignificant"
  - A radio power of 10^{25} W/Hz corresponds to a Luminosity of 10^{34} W. Assuming a 1% efficiency of conversion of jet power to radio power and 10% conversion of rest mass energy to jet power gives a **mass accretion rate of ~ 10^{-4} solar masses per year which is small compared to star formation rates.**

The Decline of Radio Galaxies

The VLA radio studies led to some improvements in our understanding of the propagation of jets.

But there were no major "breakthroughs" and continued study of radio sources was considered "butterfly collecting" by some.

Powerful radio galaxies are rare. It was thought that they did not play a significant role in the universe.

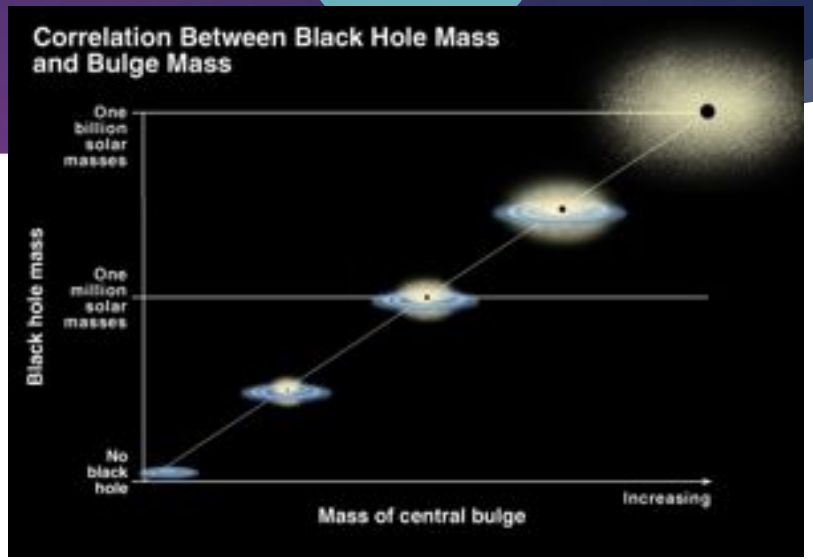
The "Rebirth" of Radio Galaxies

By the mid 2000's three major developments resulted in the idea that radio galaxies have a critical role to play in providing energy to their environments.

1. **There is a relation between black hole mass and galaxy mass (all galaxies have central BHs)**
2. **The galaxy luminosity function cuts off at high mass, contrary to models.**
3. **The gas in clusters of galaxies is too hot.**

Black Hole & Host Galaxy Mass are Correlated

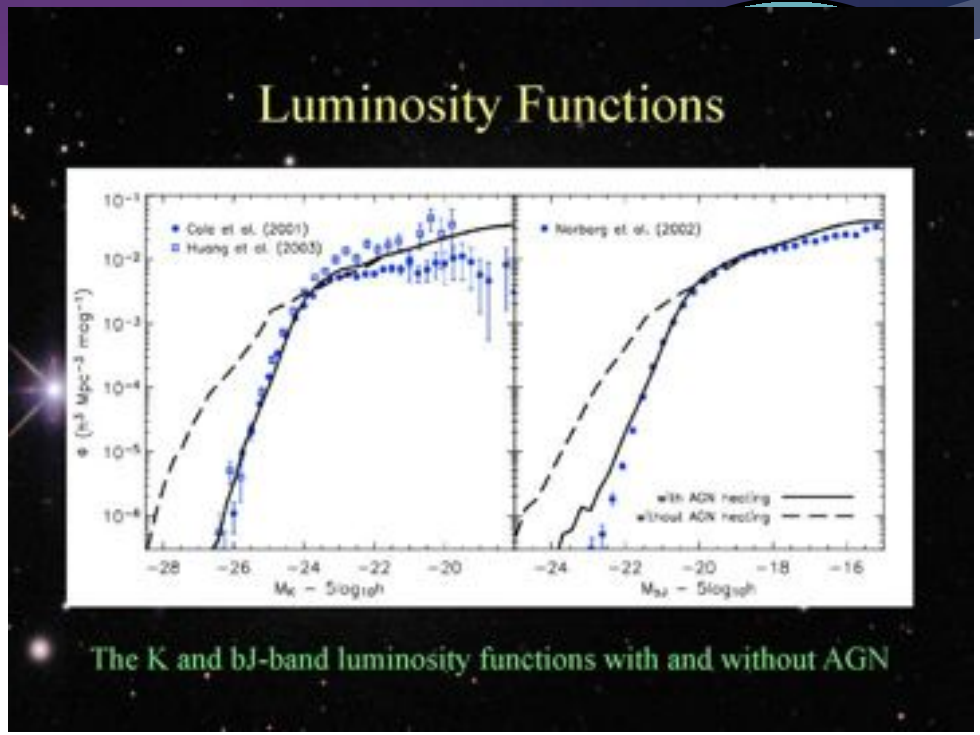
The relation between BH and galaxy bulge mass suggests that their growth is related, perhaps by a feedback mechanism between star formation and BH growth. BH growth will correspond to periods of BH activity.



- Black Hole mass and Galaxy bulge mass are correlated. Elliptical galaxies may have more massive black holes than Spiral galaxies.

Galaxy Modelers Predict Many More Massive Galaxies than we Observe

Models for galaxy formation make too many massive galaxies unless they include some form of feedback from an AGN. The feedback is larger as BHs get more massive and this shuts off star formation in the most massive galaxies.



The Gas in Clusters is Too Hot

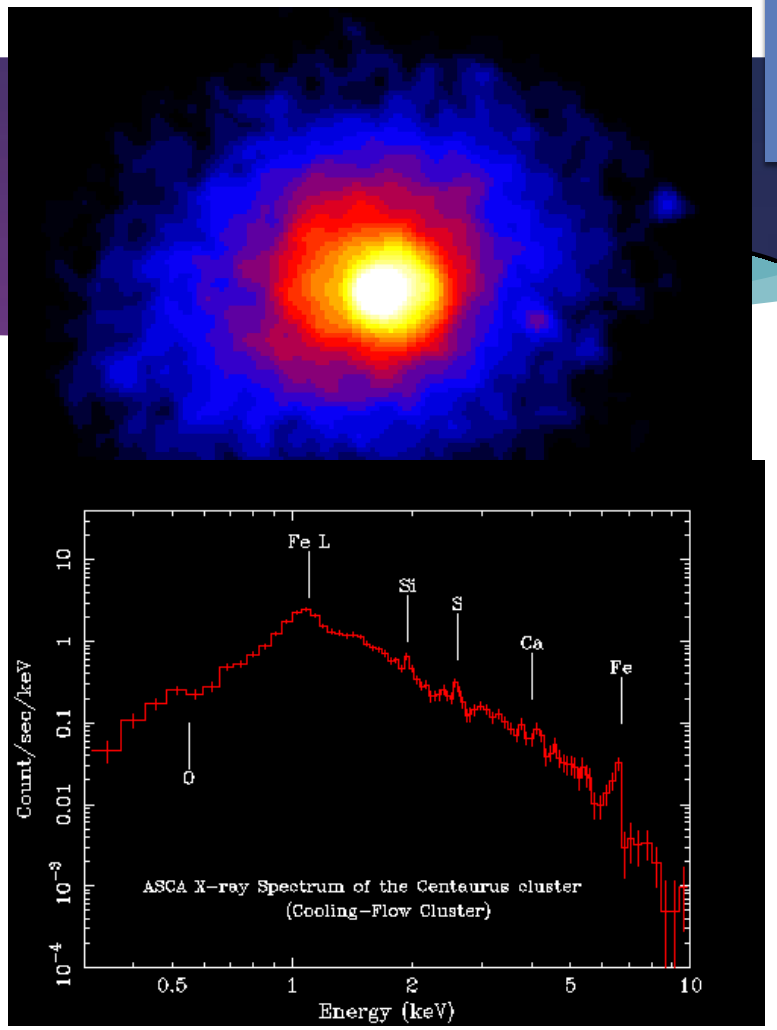
Left: Deep Chandra x-ray image of the Perseus cluster. Right: Matched optical image of Perseus cluster showing the extensive system of line-emitting filaments around NGC 1275. The images are 11.8 arcmin from N to S. Figures taken from Fabian et al 2011, via McNamara & Nulsen 2012.

Cooling Flows
X-rays in the Centaurus Cluster

The X-ray emission carries away the thermal energy of the hot gas.

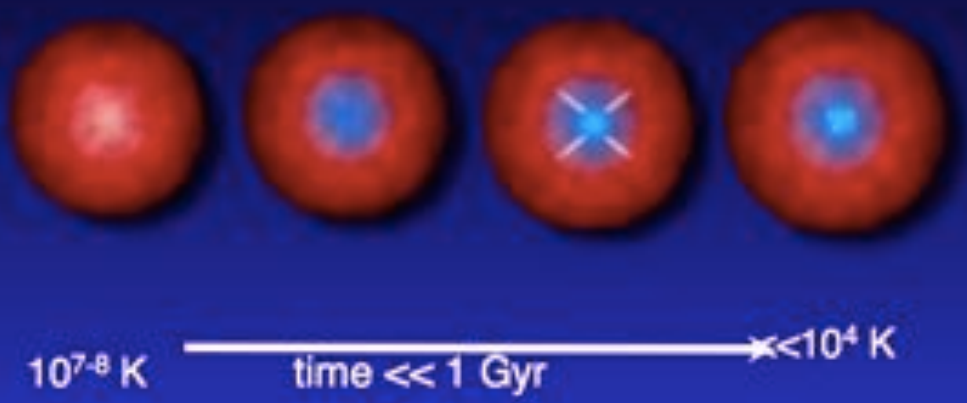
The gas will continue to radiate and lose energy and cool unless there is energy input.

We should see gas at a range of temperatures.



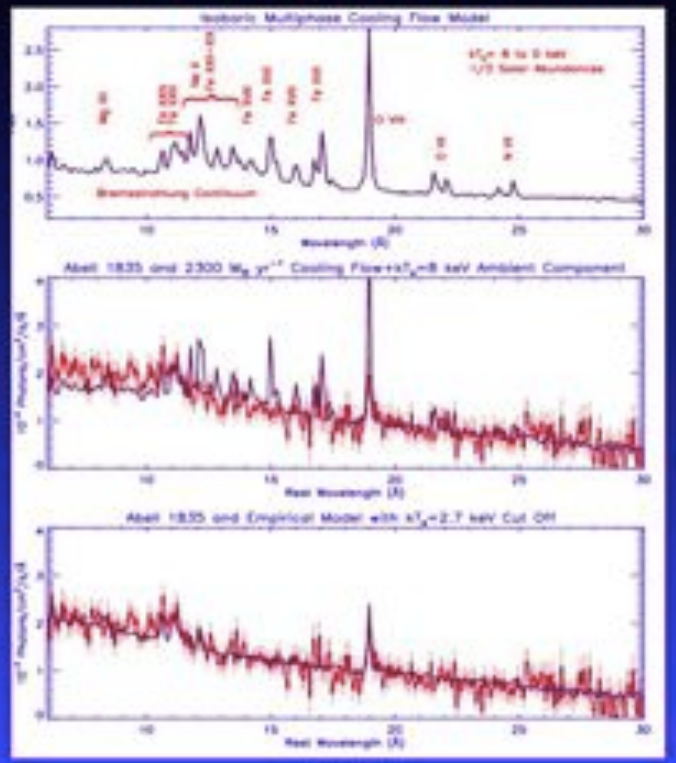
ROSAT image and ASCA spectrum of the Centaurus Cluster of galaxies. (U Cambridge X-ray Astronomy Group).

If relaxed enough, this megaparsec-scale ball of gas should cool very rapidly in its center.



Catastrophic entropy loss in cool cores should drive extreme star formation in the central galaxy (BCG)

The Expected Cooler Gas is Missing



The X-ray spectroscopy was the final nail in the coffin for the cooling flow model. At this point the field was ready to consider mechanisms that would re-heat the gas. The most logical candidate was radio galaxies (as suggested by Baum & O'Dea 1991).

8 keV → 3 keV → ?

Peterson et al. 2003, ApJ, 590, 207

Searching for Cluster Cold Gas – Impossible!

THE ASTRONOMICAL JOURNAL VOLUME 94, NUMBER 6 DECEMBER 1987

A SEARCH FOR OH ABSORPTION IN NGC 1275

CHRISTOPHER P. O'DEA[a)]
National Radio Astronomy Observatory,[b)] Edgemont Road, Charlottesville, Virginia 22903

STEFI A. BAUM[a)]
Astronomy Program, University of Maryland, College Park, Maryland 20742
and
National Radio Astronomy Observatory, Edgemont Road, Charlottesville, Virginia 22903

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CONSTRAINTS ON MOLECULAR GAS IN COOLING FLOWS AND POWERFUL RADIO GALAXIES

CHRISTOPHER P. O'DEA,[1] STEFI A. BAUM,[1] PHILIP R. MALONEY,[2]
LINDA J. TACCONI,[3] AND WILLIAM B. SPARKS[1]

Received 1993 April 5; accepted 1993 August 24

THE ASTRONOMICAL JOURNAL VOLUME 109, NUMBER 1 JANUARY 1995

A HIGH SPECTRAL RESOLUTION VLA SEARCH FOR H I ABSORPTION TOWARDS A496, A1795, AND A2584

CHRISTOPHER P. O'DEA, JACK F. GALLIMORE,[1] AND STEFI A. BAUM
Space Telescope Science Institute[2] 3700 San Martin Dr., Baltimore, Maryland 21218
Electronic mail: odea@stsci.edu, gallim@stsci.edu, sbaum@stsci.edu

Received 1994 June 10; revised 1994 September 8

Interesting constraints … Advice – "you will never get tenure if you keep publishing Non detections!"

Problems with the "cooling flow" model

The picture of uninhibited cooling suggested that there should be lots of cold gas and star formation. However, the actual amounts of gas and star formation detected were much smaller (by about a factor of 10) then expected.

The central galaxies in cooling flow clusters are almost always radio galaxies. The enormous energies in the radio sources were generally ignored.

Some of us still thought they did…

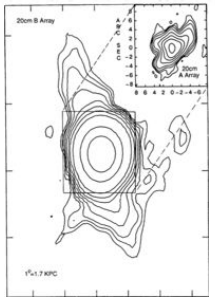
Signs that something special was happening – my thesis..

- 0745, 3C274, 3C317

New class of amorphous radio galaxies, found in clusters, anonymously high radio and emission line power

Multifrequency VLA observations of PKS 0745 − 191: the archetypal 'cooling flow' radio source?

S. A. Baum★ † and C. P. O'Dea‡
Netherlands Foundation for Research in Astronomy Postbus 2, 7990 AA Dwingeloo, The Netherlands



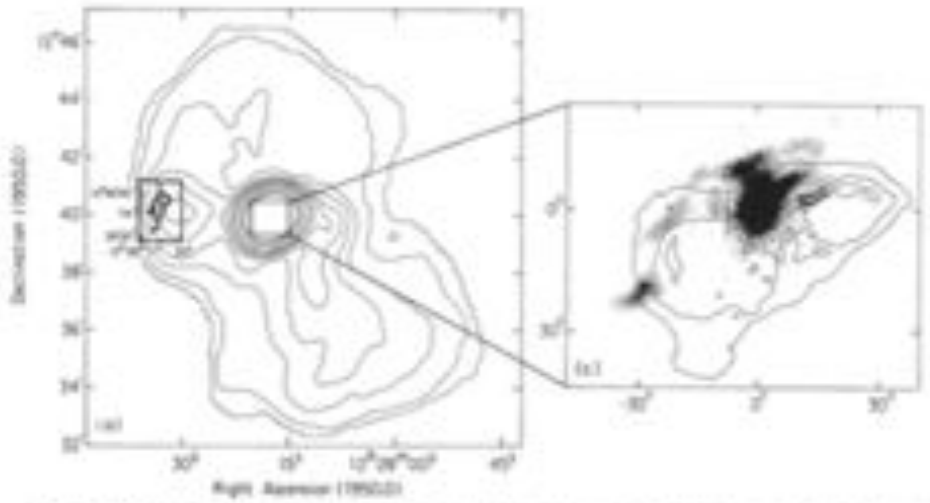
Accepted 1991 January 29. Received 1991 January 28; in original form 1990 August 16

We show that, while the radio source is energetically unimportant for the cluster as a whole, it is certainly important on the scale of the cooling flow. The radio source should be an important source of local heating, in the form of kinetic energy, cosmic rays, and enhancement of thermal conductivity. The mere existence of cosmic rays and magnetic fields within a substantial fraction of the volume inside the cooling radius has important consequences for cooling-flow models. Since the radio data imply that large amounts of energy are being deposited in the cluster core, we suggest that non-steady state models for the cooling flow in PKS 0745 − 191 should be considered.

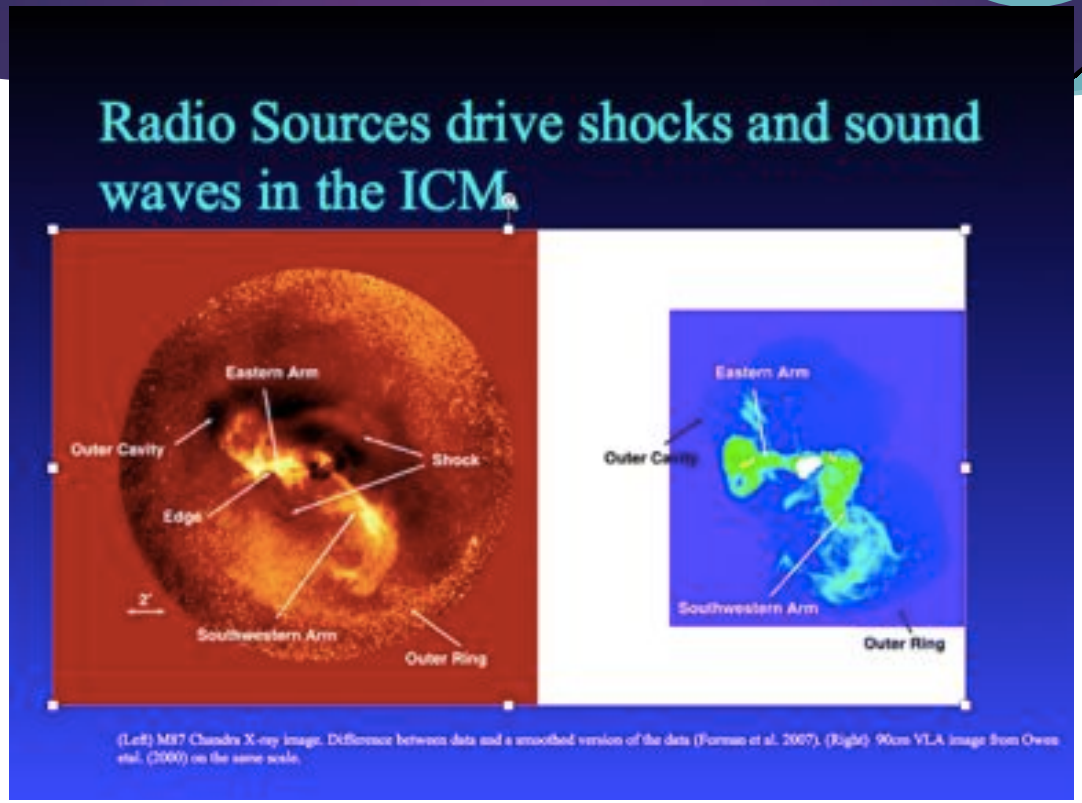
e.g., Tucker & Rosner 1983; Pedlar et al. 1990; Baum & O'Dea 1991; Binney & Tabor 1995; Sarazin, Baum, O'Dea 1995; Tucker & David 1997)

Signs that something special was happening – my thesis..

1989



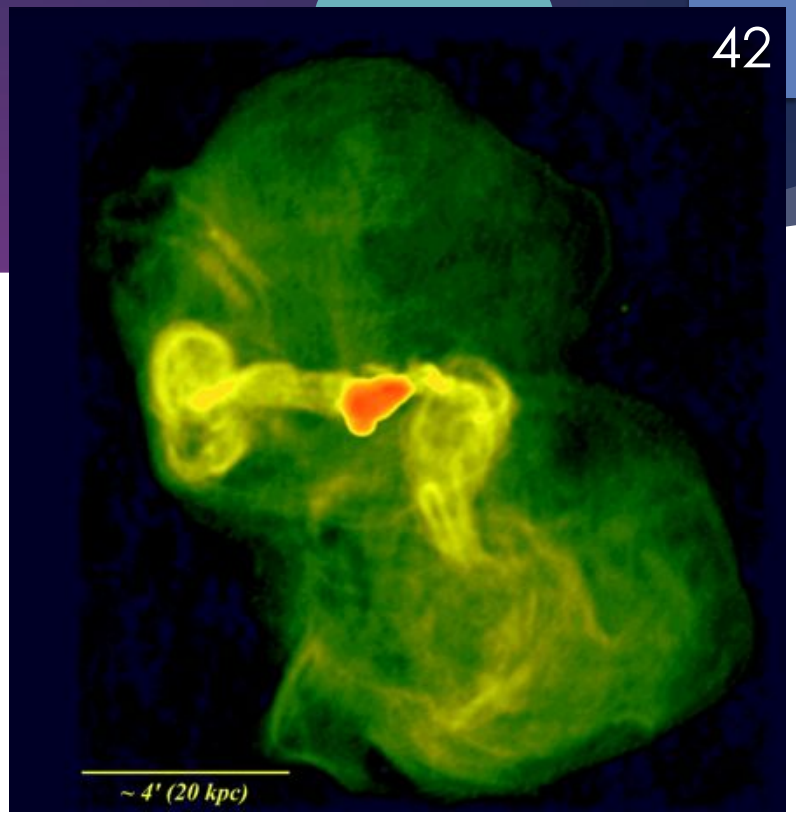
Oh Wow it is happening!



2007

Radio Sources dissipate energy on large scales in the ICM.

- Triggering star formation
- Snow plowing the ambient gas – creating arcs and large scale bubbles
- Dissipating energy on large scales in the ICM.

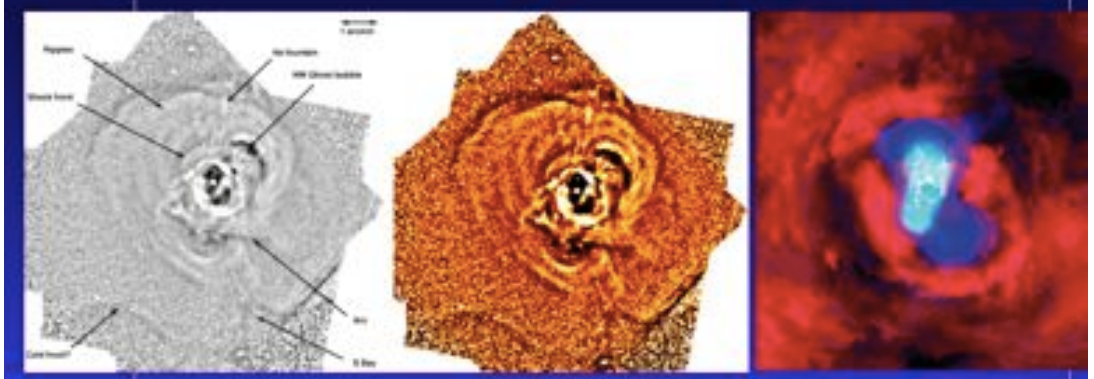


90 cm image of M87. The central region containing the jet and inner radio lobes is in the red-orange region near the image center. The convolving beam for this maximum entropy image is 7.8" 6.2" at P.A. = 86°;. One arcsecond corresponds to 85 pc at our assumed distance of 17 Mpc. Owen, Eilek & Kassim (2000)

OMG…

New Paradigm The Cyclical AGN Feedback Model

Cavities, Shocks, and Sound Waves in deep *Chandra* observations of Perseus

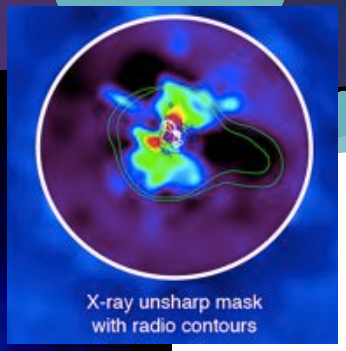


(Left Panel) Unsharp mask image from Chandra Image. Features are labelled in the lower contrast image on the left. (Right Panel) Radio image in blue superimposed on pressure difference map in red (Fabian+ 2006)

A Recent Story - The cool core cluster Abell 2597 (z=0.08)

Radio and X-ray observations show that the radio source is interacting strongly with the hot X-ray emitting gas confirming Baum & O'Dea (1991).

But how does the radio source couple with the cold molecular gas which is forming stars?



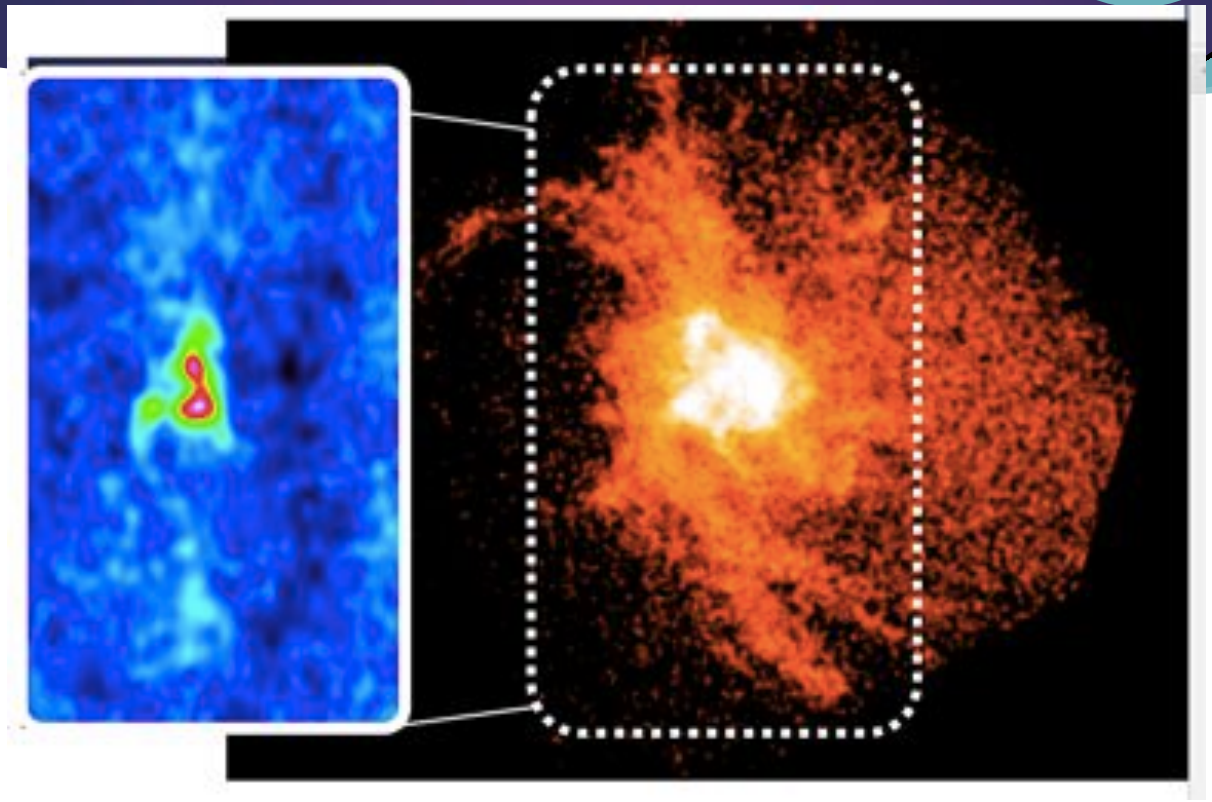
Chandra 120 ksec

Tremblay+12a,b

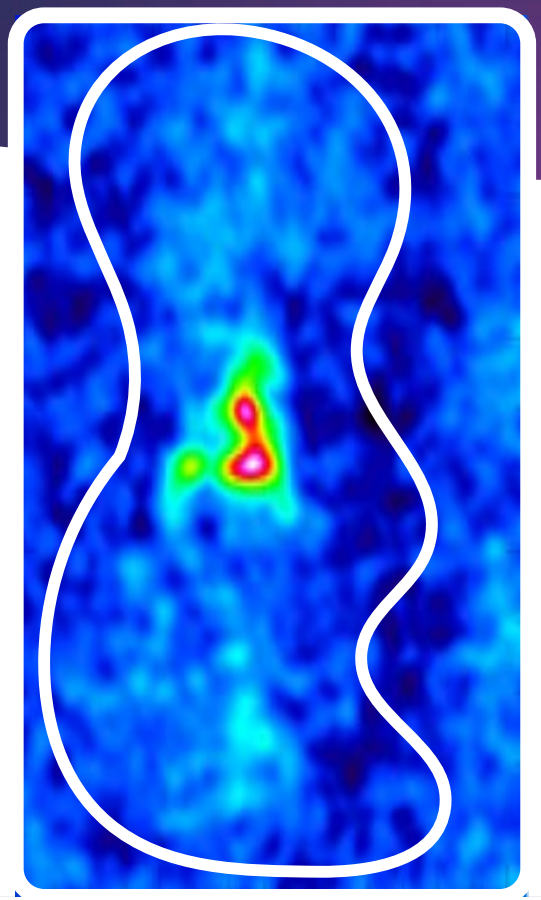
Oh ALMA! – Coming to Nature

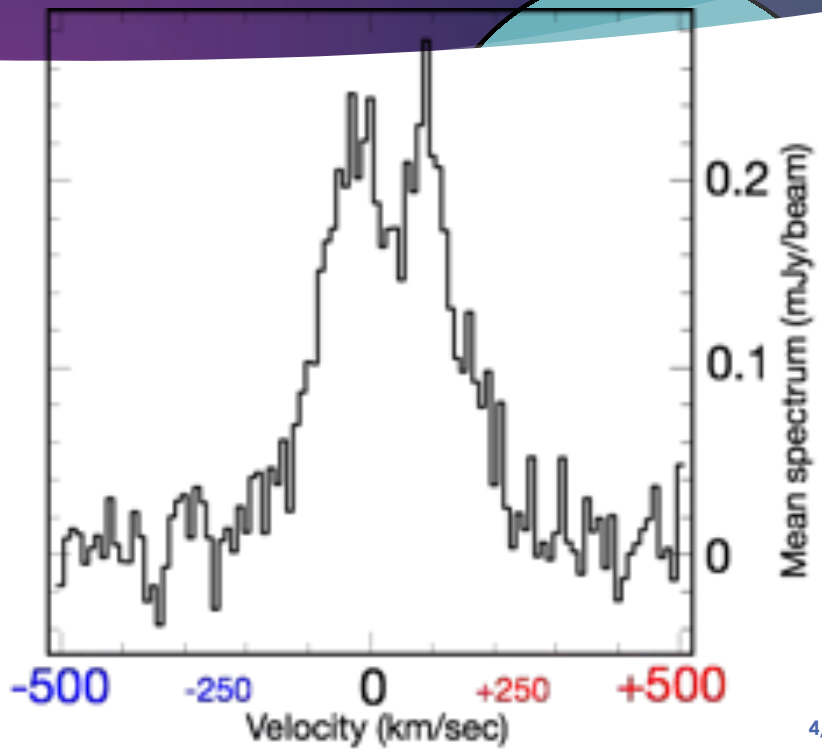
Atacama Large Millimeter/Submillimeter Array (ALMA)

ALMA CO(2-1) 212 GHz left, Lyman alpha right

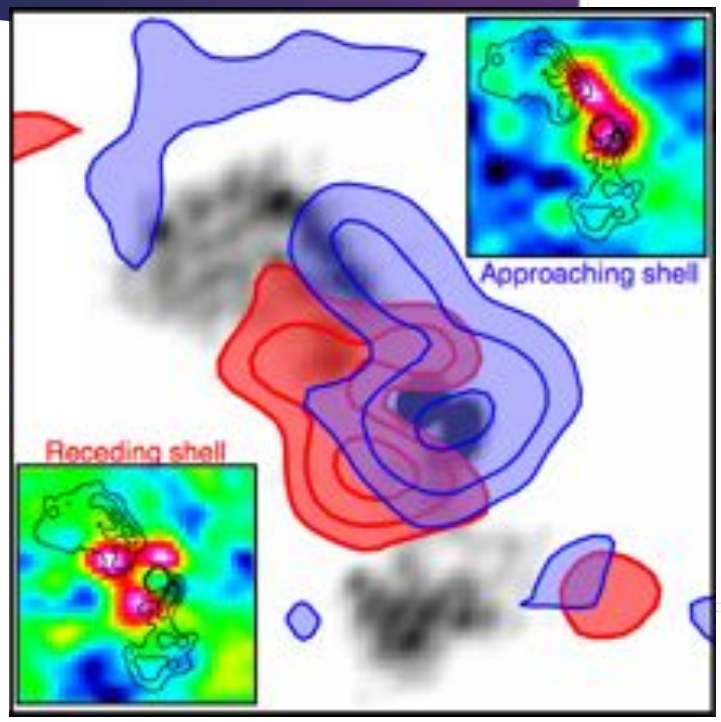


ALMA CO(2-1)



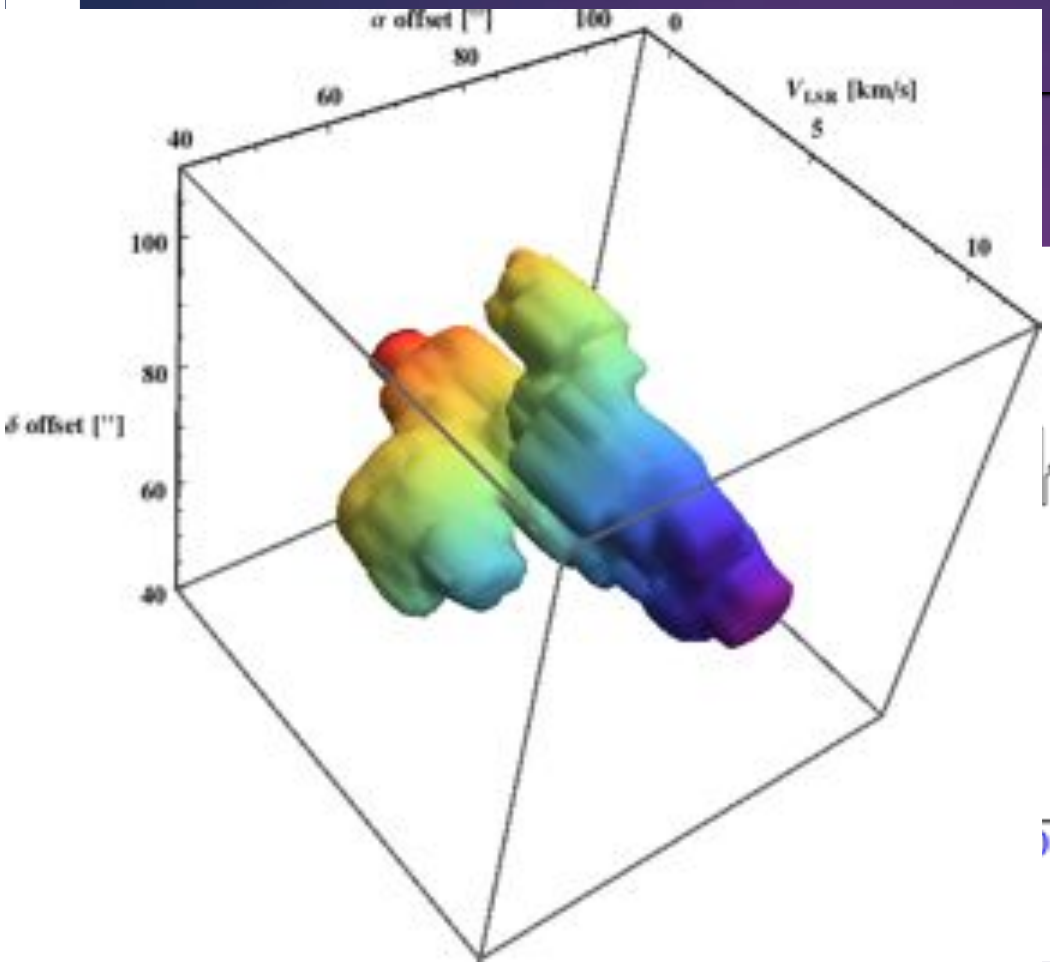

0.2
0.1
0
Mean spectrum (mJy/beam)
-500
-250
0
+250
+500
Velocity (km/sec)

Approaching and receding sides of the outflow



~900 million $M_\odot$ of molecular gas entrained in jet-driven outflow.

Cold outflow kinetic luminosity ~10^{43} erg/s, which is roughly the X-ray cavity power


α offset ["]
100
80
60
40
V_{LSR} [km/s]
5
10
δ offset ["]
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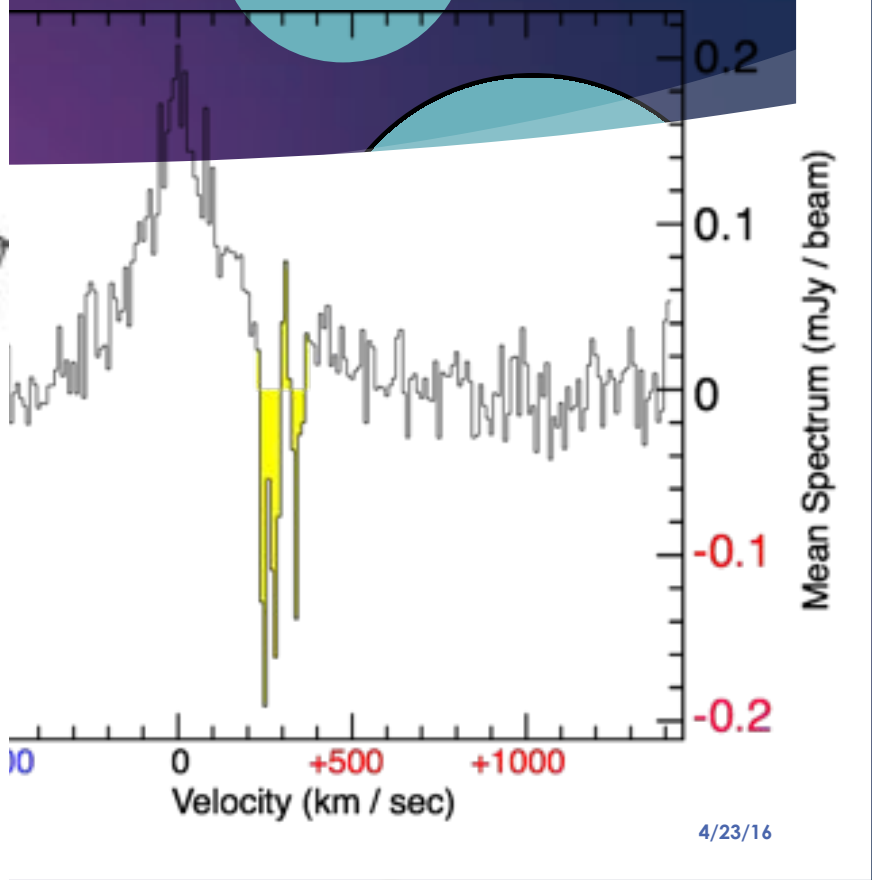
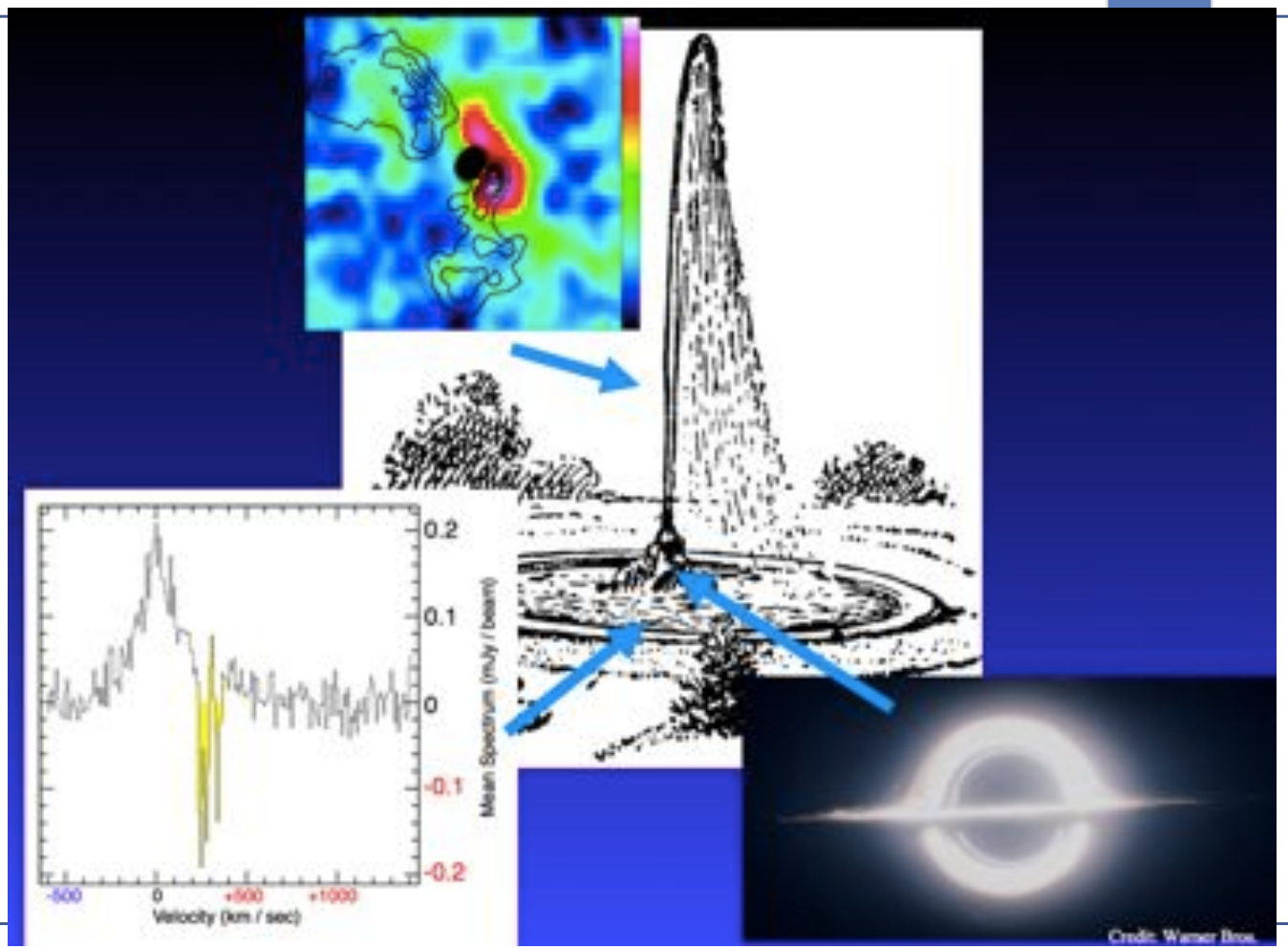
60
40


0.2
0.1
0
-0.1
-0.2
Mean Spectrum (mJy / beam)
0
+500
+1000
Velocity (km / sec)

When all the cold gas Is gone, Star formation Ceases, the engine shuts off and time must pass to build up the reservoir again



Alma + Take Aways…

- **Supermassive BH+disks affect their environments.**
- **May explain the BH-galaxy mass relation, the luminosity function of galaxies, and properties of the Intracluster Medium.**
- **Clues to how BHs interact, driving a fountain, infueling and outflow in one system, and a potential shut off mechanism tied to the outflow.**
- **Our vision of the Universe is forever changing**
- **Sometimes ideas come back around!**

Aristotle's Universe

"The besetting danger is not so much of embracing falsehood for truth, as of mistaking a part of the truth for the whole. " John Stuart Mill"

"No, I do not think 'The truth, the whole truth, and nothing but the truth' is overkill."