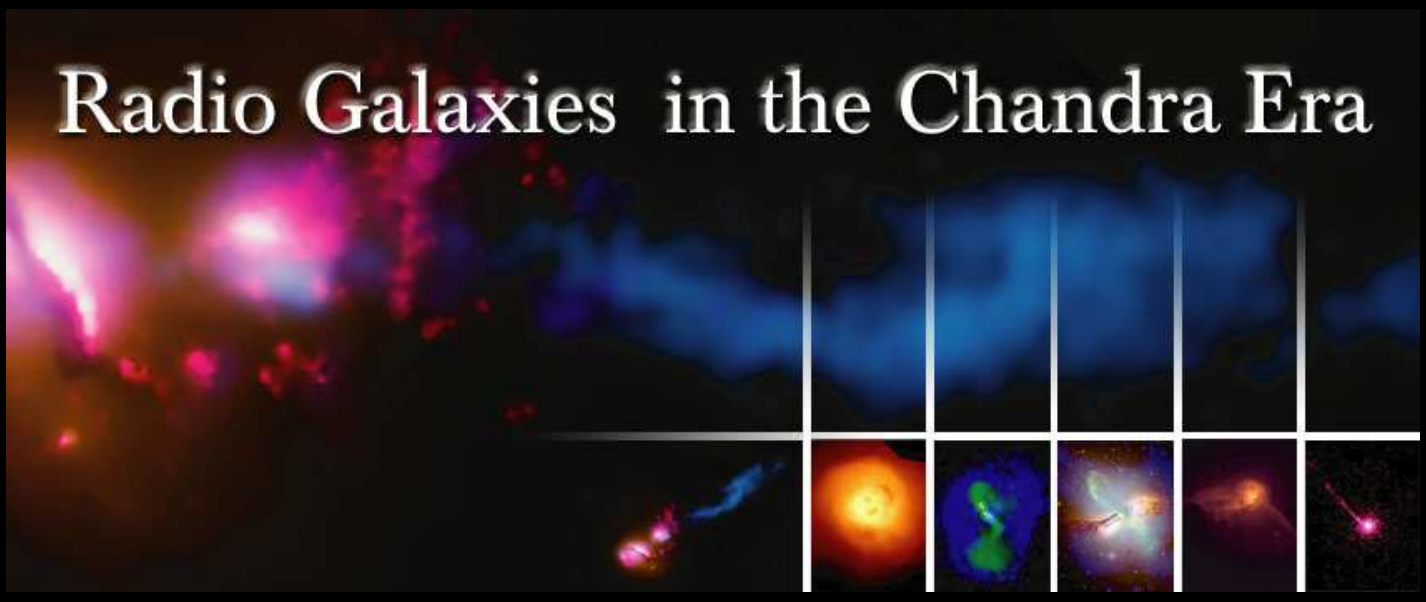
# Radio Galaxies in the Chandra Era



**July 8-11, 2008**
**Cambridge, Massachusetts**

**at the**
**Harvard Student Organization Center at Hilles**

**Hosted by the Chandra X-Ray Center**

Chandra X-Ray Center

Smithsonian Astrophysical Observatory

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This Chandra science workshop is sponsored by the Chandra Director's Office (CDO) at the Chandra X-ray Center (CXC), part of the Smithsonian Astrophysical Observatory in Cambridge, MA.

# RADIO GALAXIES IN THE CHANDRA ERA
July 8-11, 2008
PROGRAM

## TUESDAY JULY 8

9:00-9:15 Opening Remarks - Ralph Kraft and Harvey Tananbaum

9:15-9:50 **Invited Talk: Dave De Young**
***Radio Galaxies in X-ray Light: Problems and Processes***

SESSION I - RADIO GALAXIES IN THE LOCAL UNIVERSE
CHAIR: DAN SCHWARTZ

9:50-10:25 **Invited Talk: Mark Birkinshaw**
***AGN Jet Flows***

10:25-10:40 Talk I-1 : D. Harris
*Impulsive Brightening and Variability Timescales in the M87 Jet*

10:40-11:10 Coffee

11:10-11:25 Talk I-2 : R. Daly
*The Properties of the Most Powerful FRII Radio Galaxies*

11:25-11:40 Talk I-3 : C. Jones
*Centaurus A*

11:40-11:55 Talk I-4 : R. Laing
*Precision Jet Physics: low-power radio galaxies and their environments*

11:55-12:10 Talk I-5 : I. Fernini
*Radio Hot Spots in FR II Radio Galaxies and Quasars*

12:20-1:00 Poster Haiku Session 1

1:00-2:30 LUNCH

SESSION II - RADIO GALAXIES AT HIGH REDSHIFT
CHAIR: ANETA SIEMIGINOWSKA

2:30-3:05 **Invited Talk: Teddy Cheung**
***High Redshift Relativistic Jets***

3:05-3:20 Talk II-1 : P. Hardee
*Helically Twisted Shocks in the M87 Jet*

3:20-3:35 Talk II-2 : F. Massaro
*X-ray and optical detections of the bent radio jet in 3C 17*

3:35-3:50 Talk II-3 : J. Goodger
*A Radio and X-ray Study of Particle Acceleration in the Centaurus A Jet*

3:50-4:05 Talk II-4 : S. Jorstad
*Connection between X-ray and Polarized Radio Emission in the Quasar Jets*

4:05-4:20 Talk II-5 : H. Marshall
*Two Components of the X-ray Emission from the 3C 273 Jet*

4:30-5:00 Coffee

SESSION III - RADIO LOBES
CHAIR: RALPH KRAFT

5:00-5:35 **Invited Talk: Judith Croston**
***The physics of radio lobes: insights from Chandra and XMM***

5:35-5:50 Talk III-1 : N. Isobe
*X-ray study of lobes of radio galaxy Fornax A*

5:50-6:05 Talk III-2 : L. Godfrey
*VLBI Imaging of a High Luminosity X-ray Hotspot*

6:05-6:20 Talk III-3 : E. Hallman
*The Properties of Radio Relics from Cosmological Simulations of Galaxy Clusters*

6:20-6:35 Talk III-4 : L. Birzan

*Radiative Efficiency and Content of Extragalactic Radio Sources*

6:35-7:20 **Tutorial I : Mitch Begelman**

***The Role of Special Relativity in Modifying the Spectral, Temporal, and Morphological Features of Extragalactic Jets***

## WEDNESDAY JULY 9

SESSION IV - THEORY AND SIMULATIONS ON THE INTERACTION OF JETS WITH THE AMBIENT MEDIUM
CHAIR: PAUL NULSEN

9:00-9:35 **Invited Talk: Tom Jones**

***Stirring and Heating the ICM with AGN Outflows: What Are Simulations Telling Us?***

9:35-9:50 Talk IV-1 : B. McNamara

*How are Cluster-scale AGN Outbursts Powered?*

9:50-10:05 Talk IV-2 : N. Soker

*Inflating Fat Bubbles in Clusters of Galaxies by Slow Wide Jets*

10:05-10:20 Talk IV-3 : M. Perucho Pla

*Numerical Simulations of the evolution of FRI jets*

10:30-11:00 Coffee

SESSION V - RADIO LOBE/ICM INTERACTIONS AND FEEDBACK
CHAIR: SEBASTIAN HEINZ

11:00-11:35 **Invited Talk: Marcus Brueggen**

***The physics of AGN feedback in clusters of galaxies***

11:35-11:50 Talk V-1 : N. Jetha

*Shock heating in the group atmosphere of the radio galaxy B2 0838+32A*

11:50-12:30 Poster Haiku Session 2

## 12:30-2:00 PM Lunch

2:00-2:15 Talk V-2 : D. Rafferty
*The Regulation of Cooling and Star Formation by AGN Feedback*

2:15-2:30 Talk V-3 : P. Nulsen
*Radio Mode Feedback in Giant Elliptical Galaxies*

2:30-2:45 Talk V-4 : R. Mittal
*Role of central AGN in cooling-core galaxy clusters*

2:45-3:00 Talk V-5 : H. Li
*Cosmological MHD Simulations of Jets and Lobes in Galaxy Clusters*

3:10-4:30 Dedicated poster session and coffee

4:30-5:15 **Tutorial 2 : Lukasz Stawarz**
***A Role and a Structure of the Magnetic Field in Jets, Hotspots and Lobes of Radio Galaxies***

5:15-6:00 **Tutorial 3 : Mark Birkinshaw**
***Jets: particle acceleration and entrainment***

## Thursday July 10

### Session VI - Radio-Loud Seyferts and Low Power Radio Galaxies
### Chair: Dan Harris

9:00-9:35 **Invited Talk: Matteo Guainazzi**
***Did I say "radio-quiet"? Radio-loudness in (almost) radio-quiet AGN***

9:35-9:50 Talk VI-1 : A. Tilak
*Chandra Observations of AGN in Low Luminosity Radio Galaxies*

9:50-10:05 Talk VI-2 : D. Evans
*High-Resolution Chandra, HST, and VLA Observations of Radio-Loud Seyferts*

10:05-10:20 Talk VI-3 : S. Raychaudhury
*The role of feedback in galaxy groups*

10:20-10:35 Talk VI-4 : P. Ogle

*Impact of Jet Feedback on Molecular Gas and Star Formation in Radio Galaxies*

10:45-11:15 Coffee

SESSION VII - THE LINK BETWEEN RADIO GALAXIES AND STELLAR BINARIES
CHAIR: ELIZABETH BLANTON

11:15-11:50 **Invited Talk: Sera Markoff**

***Exploring the Relationship between (Radio Loud) Quasars and Microquasars***

11:50-12:05 Talk VII-1 : K. Blundell

*The evolution of classical double radio galaxies: enhanced with X-ray vision*

12:05-12:20 Talk VII-2 : M. Sobolewska

*What can we learn about AGN from $\alpha_{ox}$ measurements in GBHs?*

12:30-2:00 PM LUNCH

SESSION VIII - ACCRETION AND THE CENTRAL ENGINE IN RADIO GALAXIES
CHAIR: DAN EVANS

2:00-2:35 **Invited Talk: Rita Sambruna**

***The disk-jet connection in radio-loud AGN: The X-ray perspective***

2:35-2:50 Talk VIII-1 : M. Hardcastle

*Accretion modes and feedback in radio-loud AGN*

2:50-3:05 Talk VIII-2 : R. Hickox

*Host galaxies, clustering, and evolution of radio, X-ray, and IR AGN at $z< 1$*

3:05-3:20 Talk VIII-3 : S. Wilner

*High redshift 3CR sources: Mid-infrared spectral energy distributions*

3:20-3:35 Talk VIII-4 : R. Antonucci

*Which radio galaxies have hidden quasars: results from a large Spitzer survey*

3:35-3:50 Talk VIII-5 : H. Rottgering
*Two distinct accretion processes in radio galaxies*

4:00-4:30 Coffee

SESSION IX - LIFECYCLES AND EVOLUTION OF RADIO GALAXIES
CHAIR: HERMAN MARSHALL

4:30-5:05 **Invited Talk: Stefi Baum**
***There and Back Again: Cycles of Activity in Radio Galaxies***

5:05-5:20 Talk IX-1 : Q. Hart
*X-ray and Radio AGN in Coma Cluster Progenitors*

5:20-5:35 Talk IX-2 : Y.-T. Lin
*Statistical Properties of Radio Galaxies in the Local Universe*

5:35-5:50 Talk IX-3 : S. Giacintucci
*Low frequency radio observations of galaxy group*

# FRIDAY JULY 11

## SESSION X - BL LACS AND BLAZARS
## CHAIR: MARTIN HARDCASTLE

8:30-9:05 **Invited Talk: Greg Madejski**
***Structure of jet cores in blazars: Gamma-ray observations in multi-wavelength perspective***

9:05-9:20 Talk X-1 : P. Kharb
Pc-scale rotation measures across radio galaxy jets

9:20-9:35 Talk X-2 : A. Marscher
*The Long, Bright Extended X-ray Jet of OJ287*

9:35-9:50 Talk X-3 : R. Mukherjee
*Observations of VHE gamma-rays from M87 by VERITAS*

9:50-10:05 Talk X-4 : R. Chatterjee
*X-ray Dips and Superluminal Ejections in the Radio Galaxy 3C 120*

10:05-10:35 Coffee

## FUTURE MISSIONS
## CHAIR: CHRISTINE JONES

10:35-11:00 **Invited Talk: Tracy Clarke**
***The Promise of Future Radio Telescope Facilities***

11:00-11:15 Sebastian Heinz
*Radio galaxies in the Constellation X era*

11:15-12:30 Conference Finale - Mitch Begelman: Where do we go from here?

12:30-12:45 Closing Remarks - Aneta Siemiginowska

## POSTER HAIKU SESSION 1
## TUESDAY, JULY 8, 12:20

- Keiichi Asada - SMA and IRAM/PdBI observations of the jet in quasar 3C 273
- Lucia Ballo - The XMM and Chandra view of the misaligned blazar PKS 0521-365
- Elizabeth Blanton - Deep Chandra Observations of the Cool Core Clusters A2052 and A262
- William Cotton - 3 mm Observations of Radio Galaxies with the Green Bank Telescope
- Walter Del Pozzo - The black hole mass function in groups and clusters of galaxies
- Edmund Douglass - The Cluster Environment of Wide Angle Tail Radio Sources
- Justin Finke - Inverse Compton Scattering of Cosmic Microwave Background Photons in Blazars
- Daria Guidetti - The intracluster magnetic field power spectrum in Abell 2382
- Brandon Hogan - X-ray Jets in Superluminal Blazars
- Minsun Kim - Chandra Archival Survey of Galaxy Clusters: X-ray Point Sources and Radio Galaxies
- Magdalena Kunert-Bajraszewska - X-ray properties of compact CSS quasar with BALs - 1045+352
- Dharam Vir Lal - Spectral structure of X-shaped radio sources - A statistical view
- Francesco Massaro - The Chandra 3C Snapshot Survey for Sources with z<0.3
- Matthew Merlo - Mid-infrared observations of nearby radio galaxies Pictor A and 3C84.
- Brendan Miller - Chandra observations of hybrid morphology radio sources
- Ewan O'Sullivan - A combined X-ray/low-frequency radio survey of AGN feedback in galaxy groups
- John Wardle - The radio structures of very high redshift quasars
- Anna Wolter - The TeV BL Lac 1ES 1426+428: spectrum and variability
- Nadia Zakamska - Hot self-similar relativistic MHD flows

## POSTER HAIKU SESSION 2
## WEDNESDAY, JULY 9, 11:50

- Alessandro Baldi - The unusual X-ray morphology of NGC 4636 revealed by Chandra
- Jonathan Bird - The Lifetime of FRIIs in the MaxBCG Cluster Environment
- Teddy Cheung - XJET: an On-Line Inventory of Extragalactic X-ray Jets
- Francesca D'Arcangelo - Rapid Multiwavelength Polarization Correlation in OJ 287 and Other Blazars
- Steven Diehl - Constraining the Nature of X-ray Cavities in Clusters
- Eli Dwek - The AGN Contribution to the Cosmic Radio Background
- Percy Gomez - What Bends Wide-Angle Tailed Radio Sources? A New Vision Based on Chandra Data
- Frank Heymann - Cluster assembly around the z=1.53 quasar 3C270.1
- Manasvita Joshi - Time-dependent Radiation Transfer in the Internal Shock Model for Blazars Jets
- Ralph Kraft - An XMM-Newton Study of the Cen A Northern Middle Lobe
- Christian Leipski - High redshift 3CR sources: Spitzer mid-infrared spectra
- Peter Mendygral - Synthetic X-ray and Radio Observations of 3D MHD Jets in Clusters
- Giulia Migliori - The broadband Spectral Energy Distribution of the CSS quasar 3C 186
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- Belinda Wilkes - High Redshift 3CR Sources: Chandra Observations
- Joshua Wing - Distant Galaxy Clusters Associated with Radio Sources
- Hao Xu - Formation of X-ray Cavities by Magnetically Dominated Jet in Galaxy Clusters

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## POSTERS

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## WHICH RADIO GALAXIES HAVE HIDDEN QUASARS: RESULTS FROM A LARGE SPITZER SURVEY

ROBERT ANTONUCCI
UC Santa Barbara

We find that roughly half of the 3C FR II radio galaxies have mid-IR dust reprocessing of radiation from a hidden quasar at the level predicted by the Unified Model. That is, after selection by radio lobe emission, and matching for redshift, only half the radio galaxies show mid-IR emission at a level similar to those of the matched quasars - the prediction of the Unified Model. The others presumably have qualitatively different central engine, and differences are being sought in the vlbi properties of the two different engine types. For FR Is from the 3C, most have undetectable hot dust emission, so that luminous obscured nuclei are not present. This was inferred on other grounds by other investigators, but this method of "calorimetry" seems particularly robust. Importantly, a small minority of FR I's show strong evidence (hot dust, broad lines in total optical flux or polarized flux) for hidden broad-line agn. For the most favorable case, M87, the upper limit on dust reradiation implies that the kinetic power of the jet is at least several orders of magnitude greater than the radiated power. Our survey has also show strong H2 rotational lines, directly indicating masses of up to a billion solar masses of molecules at temperatures of hundreds of degrees. These "Molecular Hydrogen Emitting Galaxies (MOHEGs)" are almost all merging systems.

## SMA AND IRAM/PDBI OBSERVATIONS OF THE JET IN QUASAR 3C 273

KEIICHI ASADA
ISAS/JAXA

We present the result of SMA and IRAM/PdBI observations at 230 GHz of the jet in quasar 3C 273 with the resolution of sub-arcsecond. Most recently, deep Spitzer, HST, and Chandra imaging of the jet in 3C 273, one of the nearest (z=0.158) and brightest quasars known, has revealed the SEDs of the jet emission with unprecedented levels (Uchiyama et al.). The newly constructed SEDs can be explained by either (1) a "double-synchrotron" model, or (2) a "synchrotron+inverse-Compton(IC)" model. In order to discuss the origin of the SED, we performed the SMA and IRAM/PdBI observations at 230 GHz. We detected the several knots at 230 GHz for the first time, and would discuss the origin of it.

# THE UNUSUAL X-RAY MORPHOLOGY OF NGC 4636 REVEALED BY CHANDRA

ALESSANDRO BALDI
Harvard-Smithsonian Center for Astrophysics

We present Chandra observations (~200ks) of the X-ray luminous elliptical galaxy NGC 4636. A 0.5-2 keV image shows a bright core in the center surrounded by an extended X-ray halo and two outstanding quasi-symmetric, 8 kpc long, arm-like features, associated with ellipsoidal bubbles. We present surface brightness and temperature profiles along the bubbles, showing that their edges are sharp and presents temperature jumps of about 20-25%. Through a comparison of the observed profiles with theoretical shock models, we demonstrate that a scenario where the bubbles were produced by shocks, driven by AGN outbursts (as suggested by the weak central radio-source), is the most viable explanation to the X-ray morphology observed in NGC 4636.

# THE XMM AND CHANDRA VIEW OF THE MISALIGNED BLAZAR PKS 0521-365

LUCIA BALLO
ESAC-ESA

Due to its misaligned jet, the blazar PKS0521-365 is an ideal source to study the circumnuclear regions of blazars, and possibly to test the unified scheme of radioloud AGN. With this aim, we are studying its emission, both nuclear and due to the environment, to determine its physical properties. Here we present the preliminary results of our analysis of the XMM data of PKS0521-365, comparing what we found with the results from Chandra data. The EPIC spectra show the presence of a thermal component in addition to the non-thermal nuclear emission, with a temperature lower than the value obtained for the halo emission observed in the Chandra circumnuclear data alone. If the low temperature component is associated to the accretion disc, the parameters obtained require an unconventional disc

## THERE AND BACK AGAIN - CYCLES OF ACTIVITY IN RADIO GALAXIES

STEFI BAUM
Rochester Institute of Technology

In this talk we will review the current radio source paradigm with an emphasis on the time scales of activity. The talk will discuss fuelling of FRI and FRII radio sources and estimates of total lifetimes based on statistical and spectral aging estimates. The talk will further review evidence that compact radio sources (GPS, and CSO) are young radio sources and will present results on proper motions and dynamical ages. Dynamical models for radio galaxy evolution and current observational constraints will be presented. Finally, evidence that radio activity can be repetitive and/or long-lived will be discussed.

## THE LIFETIME OF FRIIS IN THE MAXBCG CLUSTER ENVIRONMENT

JONATHAN BIRD
The Ohio State University

We cross-correlate the Koester maxBCG catalog with the VLA first survey to determine the maximum lifetime of the FRII radio sources associated with the BCG. We create mock catalogs of FRII sources, recording several source properties such as size and luminosity, via the self-similar growth model of Kaiser. Through various cuts on these mock catalogs, we imitate the selection criteria of FIRST and the redshift distribution of the maxBCG sample. Ultimately, we compare the projected length distribution of the observed sample and the mock catalogs to determine the maximum lifetime of the FRII radio sources. The results suggest a fiducial time frame for energy injection from AGN in the cluster environment and can be employed to test AGN feedback scenarios.

# AGN JET FLOWS

MARK BIRKINSHAW
University of Bristol

In this talk I will summarize some aspects of jet structures as seen in the radio, IR, optical, and X-ray, including features that appear in surface brightness, polarization, spectrum, and variability. I will outline the inferences on the properties of the underlying plasma flows that are drawn from these data and highlight the uncertainties that remain and the observations that might be made to resolve these issues.

# JETS: PARTICLE ACCELERATION AND ENTRAINMENT

MARK BIRKINSHAW
University of Bristol

Since jets flow through some medium with which they are in intimate contact, momentum sharing and mass pick-up by the jet flow should cause deceleration. This process should also lead to heating in both the jet and external medium. Heating will appear as an increase in the mean thermal energy content of the flows, irregular flow structures, and the acceleration of particles to high Lorentz factors. This tutorial will consider jet flows as free shear layers, describe their transport properties, the steady entrainment that might be implied, and then look at flow instabilities, turbulence, intermittency, and the likelihood of episodic entrainment, with some suggestions about how different flow regimes might lead to variations in particle acceleration that may lead to observable effects.

# RADIATIVE EFFICIENCY AND CONTENT OF EXTRAGALACTIC RADIO SOURCES

LAURA BIRZAN
Penn State University

We present an analysis of the energetics and particle content of the lobes of 24 radio galaxies at the cores of cooling clusters. Using the X-ray cavities created by the lobes, we examine the ratio between radio power and total jet power and find that jet (cavity) power increases with radio synchrotron power approximately as $P_{\rm jet} \sim L_{\rm radio}^{0.35-0.70}$, depending on the bandpass of measurement and state of the source. Accounting for the effect of variations in age on this ratio, we find the scatter is reduced by $\sim$ 50%, yielding the most accurate scaling relation available between lobe radio power and mechanical jet power. Furthermore, using a variety of X-ray constraints, we place limits on the particle content of the lobes that suggest heavy jets and entrainment.

# DEEP CHANDRA OBSERVATIONS OF THE COOL CORE CLUSTERS A2052 AND A262

ELIZABETH BLANTON
Boston University

We present results from long Chandra observations of Abell 2052 (162 ksec total) and Abell 262 (141 ksec total). The clusters are bright and nearby with cooling cores, and at redshifts of z=0.035 and z=0.016 for A2052 and A262, respectively. For A2052, ripple-like surface brightness discontinuities are revealed in the cluster center, and these features are consistent with shocks driven by the AGN. The southern cavity in A2052 now appears to be split into two cavities with the southernmost cavity likely representing a ghost bubble from earlier radio activity. There also appears to be a ghost bubble present to the NW of the cluster center. Bright emission in the X-ray corresponds very well with optical line emission, and the correlated X-ray emission is seen to continue from the N bubble edge closer to the AGN in this longer exposure, tracking the H-alpha emission. The energy deposited by the radio source, as determined by measuring the pressure in the bright, X-ray shells, averaged over the repetition rate of the radio source (determined from either the shock features distances from the AGN or the ghost cavity distances) can easily offset the cooling in the core of the cluster. In A262, there is a clear bubble to the E of the cluster center as well as a tunnel to the W. There is evidence for at least one ghost bubble to the E of the AGN. Multi-frequency radio observations match very well with features in the X-ray and may point to locations where we would expect to find future ghost bubbles. Using the repetition rate of the radio source determined from the ghost bubble distances and the energy deposited in the inner bubble and tunnel, the radio source comes much closer to balancing the cooling than was found with an earlier study (Blanton et al. 2004).

## THE EVOLUTION OF CLASSICAL DOUBLE RADIO GALAXIES: ENHANCED WITH X-RAY VISION

KATHERINE BLUNDELL
Oxford University

I will present comparisons of low-frequency radio images and Chandra and XMM-Newton images of some prototypical classical double radio galaxies, together with recent Gemini near-IR data. I will show how – using these data in combination – meaningful determinations of the low-energy turnover in the synchrotron spectra of jets, lobes and hotspots are obtained. From low- and high-frequency radio synchrotron emisson, together with inverse Compton scattered CMB emission, I will present evidence for previous episodes of jet activity in some of these objects, and signatures of precession in their jet axes between successive jet ejections, in a manner analogous to the behaviour observed in the Galactic microquasar Cygnus X-3.

## SIMULATION OF THE AGN-ICM INTERACTION

MARCUS BRÜGGEN

Feedback by hot, underdense bubbles powered by AGN play a key role in structure formation. The simulation of this interaction is not trivial. While pure-hydro simulations indicate that AGN bubbles are disrupted into resolution-dependent pockets of underdense gas, proper modeling of subgrid turbulence indicates that this a poor approximation to a turbulent cascade that continues far beyond the resolution limit. Capturing the evolution of such bubbles has important implications for many ICM properties. In particular, it significantly changes the impact of AGN-driven clouds on the mixing of metals into the ICM as well as in determining the entropy profiles in cool-core clusters. We review the current state of simulations and present recent progress in simulating hydrodyn. instabilities.

# X-RAY DIPS AND SUPERLUMINAL EJECTIONS IN THE RADIO GALAXY 3C 120

RITABAN CHATTERJEE
Boston University

Marscher et al. (2002, Nature, 417, 625) have previously reported four dips in the X-ray flux from the central engine of 3C 120 from 1997 to 1999, each followed by the appearance of a bright superluminal radio knot. In order to confirm and expand on this finding, we monitored the radio galaxy intensely with the VLBA and RXTE from March 2002 to May 2007. The X-ray PSD is consistent with a broken power law with break time scale of ~10 days. Radio and X-ray fluxes are anti-correlated with a time delay of order 60 days (X-ray leading), as expected if new superluminal knots cause radio flares and are associated with X-ray dips. We also employ correlation studies to determine whether there is a connection between the 'equivalent' width or depth of the dips and the flux or speed of the knots. This paper is based on work supported by NSF grant AST-0406865 and several NASA grants.

# HIGH REDSHIFT RELATIVISTIC JETS

TEDDY CHEUNG
NASA GSFC

High-redshift radio galaxies and quasars have long been heralded as unique probes of jet physics and galactic environments in the early universe. This is because the pronounced increase in the IGM gas density and strong dependence of the CMB energy density with redshift should manifest in observable differences in the radio and X-ray properties of high-z sources versus their lower-z counterparts. Current radio and X-ray studies of such systems have focused on systems at z~2.5 and less, with only a handful studied at higher redshifts (up to z~5). We will summarize results from these studies in the context of the aforementioned expectations and will discuss prospects for expanding such studies with Chandra and the improved radio facilities that will become available in the coming years.

# XJET: AN ON-LINE INVENTORY OF EXTRAGALACTIC X-RAY JETS

TEDDY CHEUNG
NASA GSFC

XJET (http://hea-www.harvard.edu/XJET/) is an on-line catalogue of extragalactic radio sources with published X-ray detections of jet knots and hotspots. We describe the information and data we provide through the website, and give a brief summary of the currently known sources. Additions and modifications to the website will benefit from comments and suggestions from the community.

# THE PROMISE OF FUTURE RADIO TELESCOPE FACILITIES

TRACY CLARKE
Naval Research Laboratory

In this talk I will review some significant, exciting advances that are currently underway for radio telescope facilities and highlight new capabilities that will help advance our understanding of radio galaxy physics. In the case of the cm regime of the Expanded Very Large Array (EVLA), opportunities begin now with some of the new capabilities that are already starting to come on-line. The first science with the unprecedented mm/sub-mm capabilities of the Atacama Large Millimeter/submillimeter Array (ALMA) will begin in 2010. At the other end of the radio spectrum, m/dkm instruments such as the Low Frequency Array (LOFAR) and the Long Wavelength Array (LWA) will push to arcsecond resolution and mJy sensitivity by 2012.

# 3 mm Observations of Radio Galaxies with the Green Bank Telescope

William Cotton
National Radio Astronomy Observatory

One of the outstanding problems in the radio jets from AGNs is the question of particle acceleration. X-ray observations of extended jets clearly show that the relativistic particle acceleration occurs over an extended region. The balance between particle acceleration and energy losses are shown in the SED with a break in the radio/mm region frequently indicating the maximum energy of the surviving particles. The recently commissioned MUSTANG 3 mm bolometer camera on the GBT allows sensitive measurements of the extended regions of radio galaxies with enough resolution (8") to detect variations in the spectral break. Recent results on M87 and Hydra A will be presented.

# The Physics of Radio Lobes: Insights from Chandra and XMM-Newton

Judith Croston
University of Hertfordshire

X-ray observations offer a number of methods for constraining the physical conditions in radio-galaxy lobes. X-ray inverse-Compton emission from scattering of the CMB is now routinely detected from the lobes of powerful (FRII) radio galaxies and radio-loud quasars, providing direct information about electron energy density, and when combined with radio observations, about magnetic field strengths and the total energy budget of radio lobes. For the low-power (FRI) radio-galaxy population, inverse-Compton limits do not yet provide useful constraints, but X-ray measurements of the external pressure distribution in the surrounding ICM are helping to resolve long-standing questions about FRI particle and field content. In this talk I will review recent progress in using X-ray observations to constrain radio-lobe physics, highlighting important differences in the physical properties of FRI and FRII radio lobes.

# THE PROPERTIES OF THE MOST POWERFUL FRII RADIO GALAXIES

RUTH DALY
Penn State University

Results obtained using a sample of 31 very powerful FRII radio galaxies with redshifts between zero and 1.79 and sizes of 30 to 400 kpc will be discussed. The radio source structures are analyzed to obtain source widths, internal pressures, and rates of growth, and these are combined to study beam powers, total lifetimes, and total energies of large-scale outflows. Source properties are used to determine whether the outflows are Eddington limited; the sources follow relationships that are significantly different from those predicted for an Eddington limited system. An interesting relationship between braking magnetic field strength and black hole properties is indicated by the study. The use of the sources for cosmological studies will also be discussed.

# RAPID MULTIWAVELENGTH POLARIZATION CORRELATION IN OJ 287 AND OTHER BLAZARS

FRANCESCA D'ARCANGELO
Boston University

We compare rapidly-varying polarization properties at 43 GHz and IR/optical bands to establish the location of unresolved emission in the parsec-scale jet. We compare variations in degree of polarization, electric vector position angle (EVPA), and total flux density during two 10-night campaigns to resolved images of the 43 GHz jet taken at 3 epochs per campaign with the VLBA. We find a clear correlation between behavior of the optical EVPA and the compact core of the 43 GHz jet for 15 of our 19 objects. With correction for Faraday rotation, 13 of these objects have comparable optical and radio core EVPA values. We conclude that the optical emission in the majority of blazars originates in the 43 GHz core. Future work will extend this conclusion to locate of higher-energy emission.

# RADIO GALAXIES IN X-RAY LIGHT: PROCESSES AND PROBLEMS

DAVID DE YOUNG
National Optical Astronomy Observatory

The Chandra Observatory has provided a vast body of new knowledge about extragalactic radio sources, and an overview of the state of our understanding of these objects is given in light of these x-ray data. However, many important questions about radio galaxies and their bipolar outflows remain unsolved, and these issues are reviewed, togther with the role that multiwavelength observations and theoretical simulations may have in their resolution. In particular, the critical role that the interaction between collimated outflows and their environment may play in revealing key physical processes on scales from parsecs to megaparsecs is discussed. The implications of these interactions for models of galaxy formation and Lambda-CDM cosmologies are also outlined.

# THE BLACK HOLE MASS FUNCTION IN GROUPS AND CLUSTERS OF GALAXIES

WALTER DEL POZZO
School of Physics & Astronomy, Birmingham Univ.

The composite black hole mass function(BHMF) is constructed for a sample of rich clusters and groups of galaxies in the local universe using three different methods. 1-The BHMF is obtained by selecting early-type galaxies, from SDSS photometry, using a colour criterion, and applying the $L_{bulge} - M_{BH}$ relation. 2-The method is applied to all galaxies, but the BH masses are scaled with the mass of the bulge, using SDSS photometric model fits. 3-The width of the $H_\alpha$ line from optical spectra is used to identify AGN and thus find their mass function. We compile mass functions and compare with the distribution of observed radiogalaxies. This is the initial stage of a study of the effect of multiple AGNs in groups and clusters on the X-ray emitting hot intergalactic medium.

# CONSTRAINING THE NATURE OF X-RAY CAVITIES IN CLUSTERS

STEVEN DIEHL
Los Alamos National Laboratory

We present results from a survey of 64 cavities in the X-ray halos of clusters, groups and normal elliptical galaxies. We show that the evolution of the size of the cavities as they rise in the X-ray atmosphere is inconsistent with the standard model of pure adiabatic expansion of purely hydrodynamic models. We also note that the majority of the observed bubbles should have already been shredded apart by instabilities if they were of purely hydrodynamic nature. Instead we find that the data agrees much better with a model where the cavities are magnetically dominated and inflated by a current-dominated magneto-hydrodynamic jet model. Our results have considerable impact on the energy budget associated with active galactic nucleus feedback.

# THE CLUSTER ENVIRONMENT OF WIDE ANGLE TAIL RADIO SOURCES

EDMUND DOUGLASS
Boston University

Wide angle tail radio sources (WATs) are intermediate power, double-lobed radio sources, typically associated with cluster dominant galaxies. Their lobes are often bent as a result of their interaction with the intracluster medium in which they are embedded. We present detailed analyses of Chandra observations of the WAT clusters Abell 562 and Abell 1446. Both clusters exhibit evidence of merger events which may be causing their bent WAT morphologies. Additionally, we present a preview of a Chandra archival study implemented to investigate the connection between WAT sources and the cluster environment.

## THE AGN CONTRIBUTION TO THE COSMIC RADIO BACKGROUND

ELI DWEK
NASA Goddard Space Flight Center

Using the radio-IR correlation fro star forming galaxies and recent measurements of the extragalactic radio background I will present an estimate of the contribution of AGNs to the intensity of cosmic radio background. This contribution provides an integral constraint on the evolution of the radio luminosity function of AGN as a function of redshift.

## HIGH-RESOLUTION CHANDRA, HST, AND VLA OBSERVATIONS OF RADIO-LOUD SEYFERTS

DANIEL EVANS
Harvard University

High-resolution Chandra imaging and gratings spectroscopy, combined with with HST and VLA observations, are powerful tools for probing the nuclei and ionized kpc-scale NLRs in Seyfert galaxies. By observing the subclass of "radio-loud Seyferts", we can study the energetics and relationships between the AGN, outflows, and gas, and test models that link outflows with feedback between gas accretion and black-hole growth. Here, we present multiwavelength observations of the nearby Seyfert 2 galaxies NGC 2110 and IC 5063. We discuss the morphological interdependencies of the warm [OIII] gas, hot X-ray gas, and radio outflows, and argue that both collisional ionization and AGN photoionization play important roles in governing the extended circumnuclear environments in these sources.

# RADIO HOT SPOTS IN FR II RADIO GALAXIES AND QUASARS

ILIAS FERNINI
UAE University

Two samples of 13 FR II radio galaxies and 13 FR II quasars have been observed with the VLA at high resolution at 3.6 cm to cleanly identify the location and size of the radio hot spots. In terms of location, our preliminary results show that these sources have more edged than recessed hot spots. A trend seems to appear in which the jetted sources have more recessed hot spots than the unjetted sources. This is an important point since most of the jetted sources are quasars. In terms of size, the quasars hot spots are slightly more compact than the radio galaxies hot spots. We will present our hot spots results and discuss their importance in terms of their implications for models of radio sources.

# INVERSE COMPTON SCATTERING OF COSMIC MICROWAVE BACKGROUND PHOTONS IN BLAZARS

JUSTIN FINKE
US Naval Research Laboratory

Recent observations of VHE gamma-rays from blazars (e.g., 1101-232 or 0229+200), when corrected for absorption by the extragalactic background light (EBL) are quite hard ($\Gamma < 2$) and difficult to explain with the convential synchrotron self-Compton model. We explore the possibility instead that the hard VHE gamma-ray spectra are produced by Compton scattering of CMB photons by shock-accelerated electrons in a relativistically moving extended jet. Furthermore, Compton scattering of CMB photons in (non-relativistically moving) radio lobes in blazars may be a source of GeV photons that could be detectable with the Gamma-ray Large Area Space Telescope (GLAST). Detection of these photons can help put constraints on the magnetic field in radio lobes.

# LOW FREQUENCY RADIO OBSERVATIONS OF GALAXY GROUPS

SIMONA GIACINTUCCI
CfA, Cambridge, USA

WAGN feedback in currently considered to be the most promising mechanism by which excessive cooling is prevented in the central region of galaxy clusters and groups. Indeed, radio and X-ray images provide direct evidence of the widespread existence of AGN-driven phenomena in an increasing number of cool core clusters and groups. Evidence of strong interactions between the radio and thermal plasma can be found in the detection of X-ray disturbances in the hot gas, such as cavities, edges, and filaments, which appear correlated with the structure of the central radio galaxy. However, the mechanism of the energy transfer from the radio source to the surrounding medium is still unclear, as is the mechanism of the distribution of energy throughout the cooling region. The combination of high quality X-ray imaging and high sensitivity observations is a powerful tool to investigate the ICM/AGN connection in clusters and groups. In particular, the examination of radio images at multiple frequencies (especially at frequencies < 1 GHz) is important to study the cycle of the radio activity and elucidate the timescales and physical mechanisms of the energy injection. With this aim we have started a low frequency radio survey of a sample of 18 galaxy groups using the Giant Metrewave Radio Telescope at 610 MHz, 327 MHz and 235 MHz. The surveys aims to study the morphological and spectral properties of the central radio galaxy, correlate the radio data with extant X-ray data, and investigate the AGN effects at various phases of its activity. I will present the preliminary results of the survey and focus on the analysis of few objects of the sample which represents the prototype of the study we have in mind.

# VLBI IMAGING OF A HIGH LUMINOSITY X-RAY HOTSPOT

LEITH GODFREY
Australian National University

VLBI imaging of the z=0.662 broad line radio galaxy PKS1421-490 reveals a compact hotspot with peak radio surface brightness $\sim 400$ times greater than the hotspots of Cygnus A. The hotspot X-ray luminosity is more than an order of magnitude greater than any other hotspot observed with Chandra. We successfully model the radio to X-ray spectral energy distribution using a one-zone synchrotron self Compton model with a near equipartition magnetic field strength of 3 mG, confirming the special status of equipartition field strengths in high luminosity hotspots. The hotspot radio spectrum flattens significantly at low frequencies (spectral index $\alpha < 0.2$ at frequencies $\nu < 5$ GHz). We successfully model the flattening by incorporating a cut-off in the electron energy distribution at $\gamma_{\rm min} \sim 650$.

## WHAT BENDS WIDE-ANGLE TAILED RADIO SOURCES? A NEW VISION BASED ON CHANDRA DATA

PERCY GOMEZ
Gemini Observatory

We analyzed archival and new Chandra and optical data of Wide-Angle Tailed Radio Sources(WATs) clusters in order to determine the physical mechanism responsible for their shape. Several models have been proposed for their formation but the leading model proposes that the jets are bent by ram pressure. The relative velocity needed between the jets and the gas is estimated to be in the 200 km/s and 1500km/s interval (depending on the physical characteristics of the jets). The source of the ram pressure is still in debate. It has been proposed that a merger scenario can provide a natural way to create a large organized bulk flow motion of gas that can bend the jets. This is consistent with the view that most WATs are located at rest within a cluster. In this poster, we report a new analysis of new and archival Chandra and optical data that supports the fact that most WAT cluster have undergone a recent cluster merger event.

## A RADIO AND X-RAY STUDY OF PARTICLE ACCELERATION IN THE CENTAURUS A JET

JOANNA GOODGER
University of Hertfordshire

Centaurus A is the nearest radio galaxy and nearest massive elliptical to the Milky Way. I will be presenting new results from a Chandra Very Large Project ( 700ks of data), and of a long-term multifrequency radio monitoring program at the VLA, giving us unrivalled insights into the dynamics and energetics of Centaurus A's kpc-scale jets. From our investigation into the spectra, variability and proper motions of the jet knots, we detect significant motions of the jet and counterjet knots, with some remaining stationary while others migrate along the jet, as well as real variability at a low level in both radio and X-ray jet features. I will discuss the implications for models of particle acceleration in the jets of low-power radio galaxies.

## DID I SAY RADIO-QUIET? RADIO-LOUDNESS IN RADIO-QUIET AGN

MATTEO GUAINAZZI
European Space Astronomy Centre - ESA

Standard structure models for radio-quiet AGN do not explicitly include at first order the role of a radio plasma. Nonetheless, radio survey have demonstrated that a large fraction of Seyfert galaxies are radio emitters. The correlation (or lack thereof) between radio and X-ray flux/luminosity may provide hints on the origin of radio emission in low-luminosity AGN. On the pc to kpc-scale, there is often morphological coincidence between linear and/or diffuse radio emission in Seyferts and extended soft X-ray emission. I will discuss the implication of these results for the physical processes ultimately energizing Broad- and Narrow-Line Regions. Finally, I will review what we can learn about the X-ray emission of radio-galaxies from our understanding of X-ray emission in Seyferts.

## THE INTRACLUSTER MAGNETIC FIELD POWER SPECTRUM IN ABELL 2382

DARIA GUIDETTI
Istituto di Radioastronomia-INAF Bologna

The strongest evidence for the presence of magnetic fields (MF) in galaxy cluster comes from radio studies in conjunction with X-ray observations of the hot ICM. We present a detailed study of the Rotation Measure (RM) of two polarized radio sources in A2382, observed by VLA at 20 and 6cm. We derived the radial profile of electron gas density $n_e$ from the X-ray emission of A2382 observed by ROSAT. We simulated random 3D MF models with different power spectra and, using the derived $n_e$ profile, we produced synthetic RM images. By comparing simulations with the observed polarization properties of the radio sources, we derived that: the intracluster MF, which better reproduces the observations, has a strength of 3 $\mu$Gauss at the cluster centre, decreasing outward as the square root of $n_e$.

## THE PROPERTIES OF RADIO RELICS FROM COSMOLOGICAL SIMULATIONS OF GALAXY CLUSTERS

ERIC HALLMAN
University of Colorado

Results from numerical hydro/N-body cosmological simulations of galaxy clusters will be presented. We have studied the properties of merger shocks within a large cosmological volume. These merger shocks are morphologically similar to observed radio relics, which are presumed to result from diffusive shock acceleration of high energy cosmic rays at shocks. Our simulations include additional non-gravitational physics such as radiative cooling, star formation, and thermal feedback from supernovae. We characterize the properties and likely radio structure of these relics as a function of redshift and merger stage. We also estimate the number of these sources at are expected from future low frequency radio observations.

## ACCRETION MODES AND FEEDBACK IN RADIO-LOUD AGN

MARTIN HARDCASTLE
The University of Hertfordshire

Radio-loud AGN show a dichotomy in their nuclear X-ray spectra: while some are dominated (in luminosity terms) by a component originating near the traditional accretion disk, others show only emission that can be attributed to the base of a jet, and appear to be accreting in a genuinely radiatively inefficient manner. We have argued that this difference in accretion properties may reflect a genuine difference in the nature of the accreting material, which, if true, has very important implications for models of 'feedback' mediated by radio-loud AGN. I will present the latest results from our ongoing X-ray and infrared studies of the nuclei of samples of radio galaxies, and discuss the implications for their environmental impact.

## HELICALLY TWISTED SHOCKS IN THE M87 JET

PHILIP HARDEE
The University of Alabama

Double Gaussian fits to the optical and radio images of the M87 Jet between HST-1 and Knot A reveal the presence of dual twisted filaments with increasing filament twist wavelength. We have combined this result with proper motion information and theoretically predicted normal mode behavior along an assumed kinetically dominated relativistic jet. The resulting energy flux conserving models require jet deceleration and heating, and the presence of an accelerating and heating sheath with the jet becoming transonic at Knot A. Line of sight Doppler boosted intensity images including all appropriate time delays imply jet viewing angles on the order of 30 degrees or larger. Jet deceleration and sheath acceleration are the result of the jet surface velocity discontinuity driven twisted shocks indicated by the filaments and shock strength declines along the jet. The shocks provide acceleration sites for X-ray emitting particles between the prominent knots.

## IMPULSIVE BRIGHTENING AND VARIABILITY TIMESCALES IN THE M87 JET

D. E. HARRIS
SAO

We investigate the variability timescales in the jet of M87 with two goals. The first is to search for evidence of differences in the X-ray timescales of the unresolved nuclear region (diameter $< 0.6''$, and of the first jet knot clearly resolved by Chandra, HST-1. These features, separated by more than 60pc, are the two chief contenders for the origin of the TeV variable emissions observed by HESS in 2005. The second goal is to use the rise times and decay times in the radio, optical and X-ray lightcurves of HST-1 to constrain the source size and the energy loss mechanisms affecting the relativistic electron distributions. The X-ray light curve of HST-1 displays a quasi-periodic brightening, most obvious in 2003 and 2004 prior to the major flare. The work at SAO was supported by NASA grants NAS GO6-7112X and GO7-8119X. RG08handbook4.pdf

## X-RAY AND RADIO AGN IN COMA CLUSTER PROGENITORS

QUYEN HART
CASA, University of Colorado at Boulder

Comparisons of galaxy clusters at different redshifts can potentially obscure any true evolution, particularly in galaxies hosting AGN. Guided by cosmological simulations we select a sample of clusters at various epochs that are predicted to end with X-ray properties of the present day Coma Cluster. In this first investigation, we use this "Road to Coma" sample to consistently study the evolution of cluster AGN. Using a low-z sample of 100 AGN, we find that most cluster X-ray AGN and radio galaxies are hosted by passive galaxies. With more than 50% located within 0.5 Mpc projected radius, we surprisingly find little overlap between these two classes of cluster AGN. I will discuss cluster AGN properties as well as the importance of distributed AGN in heating cluster gas. Studies concentrating in only one wavelength are underestimating the AGN fraction in galaxy clusters.

## RADIO GALAXIES IN THE CONSTELLATION X ERA

SEBASTIAN HEINZ
University of Wisconsin-Madison

We will present simulated Chandra and Constellation X observations of radio galaxy dynamics to highlight the capabilities of Chandra and the power of Constellation X to map the dynamics of cluster gas under the influence of powerful radio glaxies like Cygnus A, Perseus A, and M87. This presentation will serve as a forum to advertise a set of computational tools to easily convert the output of numerical simulations into Chandra and Constellation X spectro-images. We plan to release those tools to the community of numerical simulators in the coming months.

## HIGH REDSHIFT 3CR SOURCES: CLUSTER SIGNATURES AROUND THE Z=1.5 QUASAR 3C270.1

FRANK HEYMANN
ESO

We are studying the environment of the complete sample of 60 high-z 3CR sources between 3.6 and 24 microns with the Spitzer Space Telescope. Here we present first cluster signatures obtained for the z=1.5 quasar 3C270.1, when combining the Spitzer maps with ground-based optical/near-infrared images from the 6.5-m MMT and with the Chandra map. Properties of the high-z cluster galaxy candidates and implications for the cluster formation are discussed.

## HOST GALAXIES, CLUSTERING, AND EVOLUTION OF RADIO, X-RAY, AND IR AGN AT Z<1

RYAN HICKOX
Harvard-Smithsonian Center for Astrophysics

We present studies of active galactic nuclei and their host galaxies at $z < 1$ using data from the 9 deg$^2$ multiwavelength Boötes survey, with redshifts from MMT/AGES. AGN selected in different wavebands (radio, X-ray, infrared) have distinctly different host galaxy and clustering properties, and likely represent different modes of supermassive black hole accretion. Radio and X-ray modes may be responsible for feedback that influences the star formation history of their host galaxies. We discuss the various AGN modes in the context of the cosmological evolution of galaxies and their central black holes.

## X-RAY JETS IN SUPERLUMINAL BLAZARS

BRANDON HOGAN
Purdue University

We are currently investigating a sample of 32 sources selected from the MOJAVE sample of highly relativistically beamed jets to examine the correlations between X-ray and radio emission. The sample consists of all MOJAVE quasars which have over 100 mJy of extended radio emission at 1.4 GHz and a radio structure of at least 3 in size. Previous Chandra observations have detected X-ray jets in 12 of 18 members of the sample, and we are carrying out cycle-9 observations of the remaining sources. Of the new sources, so far we have found 4 of 6 to have X-ray jets. We discuss the correlations between X-ray and radio knots, the relation between apparent bends and sudden decreases in the X-ray/radio ratio along the jets, and the resulting implications for current X-ray emission models.

## X-RAY STUDY OF LOBES OF RADIO GALAXY FORNAX A

NAOKI ISOBE
RIKEN

In 1990's, with ASCA, we started to explore the diffuse inverse-Compton (IC) X-ray emission from lobes of radio galaxies, and have made a pioneering detection from Fornax A. This result motivated many authors to reveal IC X-ray emissions from numbers of radio galaxies with new X-ray telescopes including Chandra, and to evaluate the electron and magnetic field energy densities there. We summarize the X-ray studies of the lobes of the prototypical radio galaxy Fornax A with ASCA, Newton and Suzaku. We put a particular emphasis on the detection of the hard IC X-rays up to 20 keV from its west lobe, with the hard X-ray detector (HXD) onboard Suzaku. The measured X-ray flux density is $98 \pm 4$ nJy at 1 keV, which derived a magnetic field of $1.2 \pm 0.4 \mu$Gauss. The Suzaku result on the host galaxy will also be presented.

## SHOCK HEATING IN THE GROUP ATMOSPHERE OF THE RADIO GALAXY B2 0838+32A

NAZIRAH JETHA
IRFU, CEA-Saclay

We present Chandra and VLA observations of the restarting radio galaxy B2 0838+32A and its environment and argue that the currently activelobes are expanding supersonically, driving a shock with Mach number 2.4 into the inter-stellar medium (ISM), in a similar way to Cen A and NGC 3801. However there is no evidence here for a recent merger or a reservoir of cold gas feeding the central black hole. Rather, the AGN spectrum indicates a radiatively inefficient accretion flow controlled by AGN heating and cooling of the X-ray gas. We also find that the large scale radio lobes could counteract radiative losses, demonstrating for the first time that feedback regulated radio galaxies can not only regulate catastrophic cooling in galaxy groups/clusters but also increase the entropy of the ISM.

## CENTAURUS A

CHRISTINE JONES
CfA

Deep Chandra and XMM-Newton observations of Centaurus A reveal of wealth of phenomena related to outbursts from the central black hole which include a jet with a complex X-ray morphology of bright knots and diffuse emission, overpressured extended regions in the northern middle lobe which are likely "fed" by the jet, as well as a supersonically expanding southern lobe, whose sharp edge shows that there is no mixing of the expanding lobe with the hot interstellar medium. In addition to describing these and other features found in the X-ray images, we will compare the recurrent outbursts in Cen A with those found in other elliptical galaxies, including NGC5813 and NGC4472.

## STIRRING AND HEATING THE ICM WITH AGN OUTFLOWS: WHAT ARE SIMULATIONS TELLING US

THOMAS JONES
University of Minnesota

Fully 3D HD and MHD jet simulations are well established tools. The sophistication of the simulations and observations across the spectrum now provide basic model tests of the nature of the jets and the jet-ambient medium interactions. It is possible to simulate self-consistent thermal and nonthermal synthetic observations of the jets including unsteady or terminated jets, and their environments that can be compared in some detail with real observations, such as those provided by Chandra. I will review briefly the state of the simulation art in this area and touch on some of the lessons it is teaching us about the interactions between AGNs and their environments. This work is supported by the NSF and by the University of Minnesota Supercomputing Institute.

## CONNECTION BETWEEN X-RAY AND POLARIZED RADIO EMISSION IN THE QUASAR JETS

SVETLANA JORSTAD
IAR, Boston University

We present total and polarized intensity images obtained with the VLA at 5 and 15 GHz of three quasars, 1222+216, 1317+520, and 2209+080 that we observed with the Chandra ACIS-S3 camera. All of the quasars show prominent kiloparsec-scale radio jets extended up to 10-15 arcsec from the core and X-ray knots coincident with some radio features. We analyze the polarization properties along and across the radio jet and compare the polarization parameters of knots detected at high energies with those that are not seen in X-rays. The radio knots with X-ray emission are more highly polarized, with direction of polarization distinct from that of the features not detected at high energies. We discuss the polarization properties of radio jets in the light of existing models for X-ray production on kiloparsec scales. This research was supported in part by National Science Foundation grant AST04-06865 and Chandra Guest Observer grant GO2-3137X.

## TIME-DEPENDENT RADIATION TRANSFER IN THE INTERNAL SHOCK MODEL FOR BLAZARS JETS

MANASVITA JOSHI
Ohio University

This work presents the use of the internal shock model to explore the acceleration of particles and the subsequent production of radiation via synchrotron and synchrotron self Compton (SSC) processes at sub-pc scales inside a relativistic jet. A single inelastic collision is assumed to take place between an inner fast shell and an outer slow shell. We consider the instantaneous acceleration of relativistic particles at the forward and reverse shocks, and the subsequent, self-consistent production of synchrotron and Compton radiation and radiative cooling. We treat the self-consistent radiation transfer by taking into account the inhomogeneity in the photon density throughout the emission region as well as all the light-travel time effects. Here, we present our first results obtained from carrying out this analysis on the BL Lac object 3C 66A.

## PC-SCALE ROTATION MEASURES ACROSS RADIO GALAXY JETS

PREETI KHARB
Purdue University

Pc-scale rotation measures have been obtained with the Very Long Baseline Array for a number of radio bright, beamed AGNs, but the plane-of-sky radio galaxies have typically remained undetected in polarized light. We present the results of our VLBA polarization experiment at three frequencies for the FRI radio galaxies 3C66B, 3C78 and 3C264, including pc-scale rotation measures for 3C78 and 3C264. A clear gradient in the Faraday rotation measure is detected across the jet of 3C78, suggesting the presence of a helical magnetic field associated with this jet. The similarity in the pc-scale rotation measures of the few FRI and FRII jets studied so far, could be reflective of a common origin. We discuss our results in the wider context of the nature of FRI and FRII jets.

## CHANDRA ARCHIVAL SURVEY OF GALAXY CLUSTERS: X-RAY POINT SOURCES AND RADIO GALAXIES

MINSUN KIM
Korea Astronomy and Space Science Institute

We study the physical properties of X-ray point sources in galaxy clusters based on Chandra archival data. We detect 46,000 X-ray point sources in 600 Chandra ACIS observations of 300 galaxy clusters, covering 32 deg2 in the sky. Using this catalog, we investigate the radial distribution of the X-ray point sources in galaxy clusters. In addition, we cross-correlate the X-ray point sources of galaxy clusters with extragalactic radio sources in FIRST radio survey. We discuss the characteristics of X-ray sources with/without their radio counterparts. We also compare the physical properties of X-ray point sources with radio counterparts in galaxy clusters to those found in the non-cluster fields.

## AN XMM-NEWTON STUDY OF THE CEN A NORTHERN MIDDLE LOBE

RALPH KRAFT
SAO

We present results from a 40 ks XMM-Newton observation of the X-ray filament associated with the Centaurus A Northern Middle Radio Lobe (NML). This filament is $\sim$20 kpc in length, centered $\sim$25kpc from the nucleus, and lies along the southeastern boundary of the NML. We find that it is composed of five bright, spatially resolved knots with lower surface brightness emission connecting them. The emission from all the knots is thermal. Each knot is roughly 1 kpc in diameter, and the elemental abundance of the knots is low (less than 30% of the Solar value). Interestingly, the knots are overpressurized relative to the ambient medium. The most likely explanation for these features is a direct interaction of the jet with cold gas clouds.

## X-RAY PROPERTIES OF COMPACT CSS QUASAR WITH BALS - 1045+352

MAGDALENA KUNERT-BAJRASZEWSKA
Torun Centre for Astronomy, Poland

We present Chandra ACIS-S observation of the high ionization broad absorption line (HiBAL) compact steep spectrum (CSS) radio-loud quasar 1045+352. The X-rays are critical to studies of the environment of BALQSO and properties of their outflow. The radio-loud BALs have additional information about their orientation, however they are quite rare. 1045+352 HiBAL quasar has a very complex radio morphology indicating a possible re-start of the activity or a precession of the radio jet. Our X-ray observation of this source gave the most extreme suppression factor known for all radio-loud BAL quasars with the X-ray detections. This suggests the source must be shielded by a dense medium which is consistent with its complex radio structure and the fact that 1045+352 is a very young AGN.

## PRECISION JET PHYSICS: LOW-POWER RADIO GALAXIES AND THEIR ENVIRONMENTS

ROBERT LAING
ESO

By modelling deep radio observations of the jets in low-power radio galaxies as symmetrical, relativistic flows, we can derive three-dimensional models of their velocities, magnetic fields and emissivities. We have recently found evidence for mildly relativistic backflow around some jets. In combination with X-ray imaging of the radio-galaxy environments with Chandra and XMM-Newton, our models can be used to measure the jet energy and mass fluxes. We can then quantify the process of mass entrainment and jet deceleration. Precise measurements of radio and X-ray spectra constrain particle-acceleration mechanisms and imaging of Faraday rotation, (again in combination with X-ray observations) can be used to derive the magnetic-field structure in the surrounding medium.

## SPECTRAL STRUCTURE OF X-SHAPED RADIO SOURCES - A STATISTICAL VIEW

DHARAM VIR LAL
Max-Planck-Institut fuer Radioastronomie

X-shaped or winged radio galaxies are those having a pair of low-surface-brightness lobes oriented at an angle to the high-surface-brightness radio lobes. Their nature is a matter of considerable debate; these are considered to be binary supermassive black hole candidates; also, it has even been proposed that they provide evidence for black-hole-mergers/spin-reorientation, and hence constrain the rate of strong gravitational wave events. Recent GMRT results at 240 and 610 MHz suggest an evidence that low-surface-brightness features for several X-shaped sources show a flatter spectral index than the high-surface-brightness features, which also suggests that the simple picture of electron spectral ageing needs revision. We shall present new preliminary results obtained using GMRT.

## HIGH REDSHIFT 3CR SOURCES: SPITZER MID-INFRARED SPECTRA

CHRISTIAN LEIPSKI
University of California, Santa Barbara

We are obtaining 19-38 micron spectra of the complete 1<z<1.4 3CRR sample with the Spitzer Space Telescope. This sample is nearly unbiased by orientation. Results of 10 sources observed so far will be presented and implications for the Unified Scheme discussed.

# COSMOLOGICAL MHD SIMULATIONS OF JETS AND LOBES IN GALAXY CLUSTERS

HUI LI
Los Alamos National Laboratory

We will present cosmological MHD simulations of jets and lobes in galaxy clusters, using the recently developed ENZO+MHD code. The global simulations of the injection, propagation, and termination of the magnetically dominated jets will be compared in detail with observations of the lobe morphologies, energy contents, size distributions, and their correlations with the background ICM. These cosmological simulations evolve the dark matter, baryon and magnetic fields self-consistently. Since the jet/lobe is evolving in an ICM while the cluster is still forming, the dynamic interaction between the ICM and jet/lobe system naturally distorts the morphology of the jet/lobe. Heating of the ICM by such jet/lobe systems will also be discussed.

# STATISTICAL PROPERTIES OF RADIO GALAXIES IN THE LOCAL UNIVERSE

YEN-TING LIN
Princeton University Observatory

Combining rich datasets from SDSS, NVSS, and FIRST, we have constructed the largest sample of radio galaxies (RGs) in the local Universe (z<0.3) to date, consisting of 10,500 objects. Utilizing the statistical power of this sample, we characterize several fundamental properties of the RGs, including the radio-optical bi-variate luminosity function and the two-point correlation function, to unprecedented accuracy. We show that the RGs cluster more strongly than the radio-quiet galaxies, a conclusion that remains true even when the galaxies are further divided into various optical color and luminosity subsamples. Incorporating the Halo Occupation Distribution formalism into our analysis, we suggest that RGs most likely reside in massive halos ($> 10^{13} M_{\odot}$), and discuss possible triggering mechanisms for the radio-loud AGN phenomenon.

## JET CORES IN BLAZARS: GAMMA-RAY OBSERVATIONS IN MULT-BAND PERSPECTIVE

GREG MADEJSKI
KIPAC / SLAC, Stanford

In many cases, the overall energy output of cores of quasars and BL Lac objects is dominated by their gamma-ray emission. Those objects are often strongly variable in all spectral bands, and their variability places additional constraints on their structure and emission processes. This presentation covers the current results and future opportunities regarding multiband observations of blazars with the emphasis on the synergy between the X-ray and gamma-ray bands. In particular, it highlights recent results from observations with the Asca, RXTE, XMM, and Suzaku satellites, and discusses the potential for studies of variability from broad-band studies in the GLAST era. It also discusses the future missions - such as NuSTAR, NeXT, and MAXI - that are likely to provide new insight on blazar structure, especially via the new data resulting from sensitive time-resolved observations in the hard X-ray band.

## X-RAY AND OPTICAL DETECTIONS OF THE BENT RADIO JET IN 3C 17

FRANCESCO MASSARO
Harvard, Smithsonian Astrophysical Observatory

3C 17, a BLRG at z=0.2, was observed with Chandra during the 3CR snapshot program, which aims completing the X-ray observations of 3CR radio galaxies at redshift z<0.3. From our 8ks observation, we detect two knots in the curving radio jet. Both X-ray detected knots are also seen in HST archival images. We present the SED of the jet components and the source parameters obtained for different X-ray emission models. The basic models to explain the emission of the extended X-ray jets and knots is believed to be non-thermal, involving synchrotron or inverse Compton radiation. We provide evidence favoring synchrotron emission as the cause of the observed X-rays in 3C 17. Finally, we will discuss another interesting feature which is unique to this jet.

## THE CHANDRA 3C SNAPSHOT SURVEY FOR SOURCES WITH z<0.3

FRANCESCO MASSARO
Harvard, Smithsonian Astrophysical Observatory

We report on our Chandra Cycle 9 program to observe half of the 60 as yet unobserved 3C radio sources at z<0.3 for 8 ksec each. We have proposed for the remainder in cycle 10. Here we report on the preliminary analyses of all of these first 30 AO-9 sources which have recently been observed. We show the first results about the diffuse emission around their active nuclei. We also compare these observation with VLA radio maps and HST data to search for extended emission corresponding to jets and hotsposts. Finally, a comparison within X-rays flux maps in different energy range is presented. This allow us to study the absorption of nuclear regions and, when possible, to investigate the emission of their extended regions. The work at SAO is supported by NASA grant GO8-9114A.

## EXPLORING THE RELATIONSHIP BETWEEN (RADIO LOUD) QUASARS AND MICROQUASARS

SERA MARKOFF
API, University of Amsterdam

A lot is being made lately about the possible connections between the little black holes in stellar binaries, and their supermassive brethren in galactic nuclei. While general relativity does predict that the effect of black holes on spacetime scales nicely with mass, it is not so clear that accretion and its various outcomes will. At the very least, black holes in the centers of galaxies accrete off of many sources, not just the winds of a single star. Thus we expect that the time-dependence of the accretion rates at these two scales is likely not a function of simple mass scalings. On the other hand, once "activated" perhaps the physics of the accretion process is comparable — X-ray binaries have certainly earned the monicker "microquasar" based on their morphologically similar jets. After briefly reviewing some microquasar phenomenology, I will present an overview of the latest developments in the search for self-similar physics between XRBs and AGN. In particular I will describe the various difficulties in associating radio loud AGN with a particular XRB accretion state. I will also highlight the areas where such mappings do seem justified, and emphasize *Chandra's* unique role in helping us make comparisons between accreting black holes across the mass scale.

## THE LONG, BRIGHT EXTENDED X-RAY JET OF OJ287

ALAN MARSCHER
Boston University

The radio jet of the BL Lac object OJ287, as seen on a 1.4 GHz VLA image by Perlman and Stocke extends 10 arcsec to the west with some hints of patchy continuation to the northwest for another 20 arcsec. In late 2007, we observed OJ287 with Chandra (50 ks exposure), Spitzer, and HST in an attempt to detect the extended jet at higher frequencies. Contrary to the prejudices of many, this FR 1 source emits X-rays along its full length. The author will compare the X-ray emission profile with that at lower frequencies and will discuss the implication of the results in terms of jet deceleration and spine-sheath structure. This work is supported in part by the following guest observer grants: Chandra GO8-9097X, HST-GO-11344.01-A, and Spitzer 1326216.

## TWO COMPONENTS OF THE X-RAY EMISSION FROM THE 3C 273 JET

HERMAN MARSHALL
MIT Kavli Institute

By combination of spectroscopy and image analysis, we show that there are at least two distinct structures in the 3C 273 jet. The jet is resolved in the cross-flow direction into a broad "channel" in which unresolved knots are embedded.

## How are Cluster-scale AGN Outbursts Powered?

Brian McNamara
University of Waterloo

Cluster-scale AGN outbursts with energies approaching $10^{62}$ erg are thought to be powered by the accretion of more than 10E8 solar masses of matter onto a preexisting supermassive black (SMBH). The accreted mass is comparable to that of the preexisting SMBH itself. The cluster-scale outburst in MS0735.6+7421 implies that nearly half of the cold gas within 5 kpc of the central galaxy's nucleus was consumed by the SMBH in a period of only 100 Myr, and it did so without triggering star formation. We show that the accretion efficiencies in this and other cluster-scale outbursts are remarkably large and are inconsistent with galaxy and SMBH growth along the Magorrian relation. We discuss implications for feedback models and potential fueling mechanisms.

## Synthetic X-ray and Radio Observations of 3D MHD Jets in Clusters

Peter Mendygral
University of Minnesota

We present synthetic X-ray and radio observations of 3D magnetohydrodynamic (MHD) simulations of jets in a galaxy cluster environment. X-ray emission is modeled by thermal Bremsstrahlung, and radio emission is modeled by synchrotron emission from relativistic electrons accelerated at shocks. Two different jet models are compared; a relic jet shut off after 26 Myr and an intermittent jet switched on and off every 13 Myr. X-ray cavities, easily seen after a simple isothermal β-model brightness profile subtraction, are filled with radio emission. We compare the morphologies of the X-ray and radio structures between the two models and discuss the observational implications. This work is supported by the NSF and by the University of Minnesota Supercomputing Institute.

## MID-INFRARED OBSERVATIONS OF NEARBY RADIO GALAXIES PICTOR A AND 3C84.

MATTHEW MERLO
Florida Tech

The mid-IR emissions of radio galaxies are important because they give a picture of the environment surrounding the central black hole, since the dust and gas predicted in theoretical models of radio galaxies would radiate in the mid-IR. In this poster, we will present our observations of Pic A and 3C84. Initial observations of these galaxies showed an unresolved nucleus plus some type of extended structure. We will present these initial findings plus results from deeper follow-up observations of Pic A. We will characterize the extended structure and compare it to structures seen at other wavelengths and investigate the broad-band spectra. Finally, we will compare these observations to observations of other radio galaxies to build a picture of radio galaxies in the mid-IR.

## THE BROADBAND SPECTRAL ENERGY DISTRIBUTION OF THE CSS QUASAR 3C 186

GIULIA MIGLIORI
SISSA/ISAS

We present our study on the Spectral Energy Distribution (SED) of the Compact Steep Spectrum (CSS) quasar 3C 186. We analyze the peculiarly high radio loudness and disentangle the contributions in the radio band from the nuclear and extended (i.e. jet, hot spots, lobes) components. Then we discuss the emission processes which could explain the spatially unresolved X-ray luminosity, considering all the components of the quasar as well as the effect of its expansion into the surrounding intergalactic medium.

## CHANDRA OBSERVATIONS OF HYBRID MORPHOLOGY RADIO SOURCES

BRENDAN MILLER
Pennsylvania State University

A small number of radio sources possess both an FRI jet and an FRII lobe on opposite sides of the core; the structure of such hybrid morphology radio sources may arise from propagation of twin jets into an asymmetric medium (Gopal-Krishna & Wiita 2000). Our Chandra observation of PG 1004+130 revealed an X-ray jet slightly upstream of the FRI jet but with multiwavelength and X-ray spectral properties similar to those of other FRII jets, supporting the hypothesis that the FRI structure results from an intrinsically powerful jet encountering a relatively dense environment. We present results from recent 40 ks Chandra observations of the hybrid sources 3C 433 and 4C 65.15; both objects display X-ray emission aligned with the FRI radio jet and nuclear properties consistent with FRII sources.

## ROLE OF CENTRAL AGN IN COOLING-CORE GALAXY CLUSTERS

RUPAL MITTAL
Argelander-Institute for Astronomy

In recent years, heating by AGN through outflows has gained fundamental importance in regulating cooling flows in galaxy clusters. Intermittent phases of powerful AGN activity may likely be responsible for quenching condensation of the hot ICM onto cluster dominant galaxies. The AGN-regulated feedback in clusters is tested using a statistically-complete and homogeneous sample comprising the 64 brightest X-ray galaxy clusters, HIFLUGCS. Global cluster properties derived from Chandra observations are correlated with the total synchrotron power of the centrally located radio galaxies to segregate strong cooling core clusters with cooling times shorter than a gigayear from weak and non-cooling core clusters. In this talk, I present these correlations as a way of understanding the underlying mechanisms that link the AGN and cooling activity in clusters.

# OBSERVATIONS OF VHE GAMMA-RAYS FROM M87 BY VERITAS

RESHMI MUKHERJEE
Barnard College, Columbia University

The giant radio galaxy M87 is the only extragalactic non-blazar object which has been detected as a source of very high energy gamma-rays. The proximity of M87 makes it an attractive target for studying the phenomena of gamma-ray emission from a nearby AGN. In this talk we report results from the observations of M87 taken with the imaging atmospheric Cherenkov telescope array VERITAS in the 2007 and 2008 observing seasons. In 2008, a long-term monitoring study of M87 was coordinated between VERTAS, MAGIC, and HESS, along with X-ray observations by Chandra and Swift XRT. In February 2008, VERITAS observed M87 more intensively following a trigger alert issued by MAGIC. Here we present a preliminary analysis of the VERITAS observations including a comparison with Chandra observation of the core and HST-1 knot.

# GALEX ULTRAVIOLET IMAGING OF THE CEN-A JET

SUSAN NEFF
NASA Goddard Space Flight Center

We present GALEX ultraviolet (125-300nm) images of Centaurus A over a 1.1 degree field. We detect UV emisison from young stars and shocks at the interface between the outer jet and an HI cloud, at locations where the inner jet bends or is disrupted, and in the central disk. Although some of these star-forming regions were previously imaged with HST, not all have been. We also detect faint, diffuse UV emission from several regions where young stars are not obviously present. New radio images of the Northern Middle Lobe of Cen A may also be presented, depending on the progress of data reduction.

# RADIO MODE FEEDBACK IN GIANT ELLIPTICAL GALAXIES

PAUL NULSEN
Harvard-Smithsonian Center for Astrophysics

We examine the significance of energy due to radio outbursts on the atmospheres of a sample of nearby elliptical galaxies. Evidence of outbursts is detected in about 1/4 of the galaxies with substantial hot atmospheres. The power of the outburst is sufficient to offset radiative coolings in nearly every case where an outburst is present. Averaged over the whole sample, AGN power is sufficient to make up for radiative losses. Thus heating by intermittent outbursts is capable of preventing cooling and star formation in these galaxies over a wide range of luminosity. This coincidence provides a strong argument that AGN outbursts and cooling are coupled, so that the radio mode of AGN feedback is primarily responsible for limiting star formation in nearby elliptical galaxies with hot atmospheres.

# IMPACT OF JET FEEDBACK ON MOLECULAR GAS AND STAR FORMATION IN RADIO GALAXIES

PATRICK OGLE
Caltech Spitzer Science Center

Radio jet feedback on hot gas in radio galaxies has been well established by Chandra, but it is unclear what effect it has on other phases of the ISM. Spitzer has revealed a new class of radio galaxies with extremely large $H_2$/IR dust emission ratios, with up to $10^{10}$ solar masses of $H_2$ heated to 100-1500 K. Tidal interactions or cooling flows may deliver the molecular gas to the galaxy centers, where it is disrupted and shock-heated by the radio jet. The specific star formation rate is clearly suppressed in some $H_2$-emitting radio galaxies, and may remain so over time scales much greater than the radio source lifetime. This process may limit the growth of massive elliptical galaxies and supermassive black holes.

## A COMBINED X-RAY/LOW-FREQUENCY RADIO SURVEY OF AGN FEEDBACK IN GALAXY GROUPS

EWAN O'SULLIVAN
SAO

Recent studies of galaxy clusters suggest that the powerful radio sources hosted by the massive ellipticals which dominate the cluster cores are the main source of feedback regulating cooling in the hot gas halo. To extend these studies to lower mass scales, we have begun a program of multi-band, low-frequency GMRT radio observations of 18 galaxy groups with archival Chandra and/or XMM data. We present early results from several of the groups which reveal complex, extended, correlated radio and X-ray structures. The combined survey provides a powerful diagnostic tool, allowing us to determine the properties of the radio sources and the effects of their interaction with X-ray gas in detail, and to examine the geometry, timescale and physical mechanisms of energy injection.

## NUMERICAL SIMULATIONS OF THE EVOLUTION OF FRI JETS

MANUEL PERUCHO PLA
Max-Planck-Institut fuer Radioastronomie

We present results from numerical simulations of FRI jets that test the evolution paradigm. We use realistic parameters for the jet and atmosphere, and an equation of state for a two-component relativistic gas (including baryonic and leptonic matter). Our results show that the bow shock evolves self-similarly at a quasi-constant speed, up to the simulated 10% of a typical source age. The jet expands until it becomes underpressured with respect to the ambient medium, and then recollimates. The generation of standing shocks leads to the mass loading and disruption of the jet flow. We report that the results for the temperatures and densities in the shocked region are in agreement with those given by X-ray observations. Finally we present the last advances in our work.

# THE REGULATION OF COOLING AND STAR FORMATION BY AGN FEEDBACK

DAVID RAFFERTY
Penn State University

We use broadband optical imaging and Chandra X-ray data for a sample of 46 cluster central galaxies to investigate the connection between star formation, the intracluster medium, and the central active galactic nucleus (AGN). By comparing the optical and X-ray-derived properties on similar spatial scales, we find that the central galaxy is likely to experience significant star formation when: 1) the X-ray and galaxy centroids are within $\sim 20$ kpc of each other, 2) the central cooling time of the hot atmosphere is much less than $\sim 8 \times 10^8$ yr, and 3) the ratio of cavity power to X-ray cooling luminosity is approximately less than unity. These conditions are consistent with the idea that cooling and star formation at the centers of cooling flows are regulated by AGN feedback.

# THE ROLE OF FEEDBACK IN GALAXY GROUPS

SOMAK RAYCHAUDHURY
University of Birmingham, UK

The lack of very cool gas at the centers of groups and clusters of galaxies, even where the cooling time is significantly shorter than the Hubble time, has been interpreted in terms of various mechanisms that might re-heat the IGM. Gravitational heating, mergers and conduction are among the candidates, but most studies of rich clusters adopt AGN heating to be predominant. Here we assess the roles of various sources of feedback in groups of galaxies, comparing them to their relative roles in clusters. With the help of specific examples of groups, we show how Chandra X-ray observations, used in tandem with low-frequency GMRT radio observations, presents evidence of multiple AGN outbursts in groups, and helps to address the nature of the energy transfer between the AGN and the intergalactic gas.

## TWO DISTINCT ACCRETION PROCESSES IN RADIO GALAXIES

HUUB ROTTGERING
Leiden Observatory

There is increasing evidence that many physical relations between AGN, galaxies and the large scale structures have to be taken into account if their formation and evolution is to be understood. We have studied aspects of these relations on the basis of XMM-Newton, CFHTLS, Spitzer and radio surveys in the XMM-LSS field. The radio surveys we have carried out with the Very Large Array at 74 and 325 MHz, and with the Giant Meterwave Radio Telescope (GMRT) at 230 and 610 MHz. The results clearly show that there are two groups of radio galaxies. The first group resides in massive galaxies, do not show signs of infrared excess due to a torus and are preferentially found in cluster environments. The second goup consists of radio galaxies with less massive hosts, that show infrared torus emission, and are located in large scale underdensities, Finally, X-ray selected AGN show infrared torus emission and are preferentially found in environments underdense on large scales. These results are interpreted due to AGN being fed through two different types of accretion: the Radio mode or Hot mode versus the Quasar mode or Cold mode. In this picture, the quasar mode is radiatively efficient, and is caused by accretion of cold gas onto the supermassive black hole, while the radio mode is radiatively inefficient and results from the accretion of hot gas.

## THE DISK-JET CONNECTION IN RADIO-LOUD AGN: THE X-RAY PERSPECTIVE

RITA SAMBRUNA
NASA/GSFC

Unification schemes assume that radio-loud AGN contain an accretion disk and a relativistic jet perpendicular to the disk, and an obscuring molecular torus. The jet dominance decreases with larger viewing angles from blazars to Broad-Line and Narrow-Line Radio Galaxies. A fundamental question is how accretion and ejecta are related. The X-rays provide a convenient window to study these issues, as they originate in the innermost nuclear regions and penetrate large obscuring columns. I review the data, using observations by Chandra but also from other currently operating high-energy experiments. Synergy with the upcoming GLAST mission will also be highlighted.

# WHAT CAN WE LEARN ABOUT AGN FROM $\alpha_{ox}$ MEASUREMENTS IN GBHS?

MALGOSIA SOBOLEWSKA
FORTH/IESL, Crete, Greece

We parametrize spectra of a number of Galactic Black Hole X-ray binaries (GBHs) with an $\alpha_{GBH}$ parameter defined as a slope of a nominal power law function between 3 and 20 keV. This parameter corresponds to the X-ray loudness, $\alpha_{ox}$, in AGN. Comparing the GBH and AGN data we are able to conclude that majority of the observed Type 1 radio quiet AGN may be in a very high/intermediate spectral state. We also study variations of the spectral slopes ($\alpha_{GBH}$, $\alpha_{ox}$, and the X-ray photon index, $\Gamma$) as a function of disc and Comptonization fluxes in both GBHs and AGN. Finally, we simulate AGN spectra based on a GBH outburst and check if the mass distribution in AGN can account for the observed correlations between the AGN spectral parameters.

# INFLATING FAT BUBBLES IN CLUSTERS OF GALAXIES BY SLOW WIDE JETS

NOAM SOKER
Dept. of Physics, Technion, Israel

I will present our recent results of inflating pairs of large bubbles attached to the center of the cluster. We show that slow (highly non relativistic) wide jets can inflate such bubbles. Precessing, instead of wide, jets can also inflate such bubbles. The slow and high power jets imply that their mass outflow rate is large, 1-50 solar masses per years. Such jets not only explain the presence of large bubbles attached to the center of the cluster, but also have implications to the feedback heating of the intracluster medium.

# A Role and a Structure of the Magnetic Field in Jets, Hotspots and Lobes of RGs

Lukasz Stawarz
KIPAC, Stanford University, USA

In this talk we will review theoretical predictions, observational constraints, as well as the most recent results of the numerical simulations regarding a role and a structure of the magnetic field in extragalactic jets. This role manifests in (i) launching of the jet from a spinning black hole surrounded by an accretion disk, (ii) providing collimation, confinement and stability of the outflow as it propagates up to Mpc distances from the central engine, and (iii) producing very high energy ultrarelativistic particles responsible for the observed broad-band (radio-to-gamma-ray) non-thermal jet emission. Different arguments for and against a dynamical domination of the magnetic field in extragalactic jets at different scales will be summarized, and prospects for better understanding of the jet magnetic field structure with the forthcoming new observational data and numerical experiments will be discussed.

# Chandra Observations of AGN in Low Luminosity Radio Galaxies

Avanti Tilak
Smithsonian Astrophysical Observatory

I present archival Chandra observations of 12 nearby low luminosity radio galaxies, part of a larger sample of 21 AGN. The nuclear X-ray flux densities are well correlated with radio and optical emission, in line with earlier results. There is evidence that the broad-band nuclear emission, from radio to X-ray bands, may be dominated by synchrotron emission.

## THE RADIO STRUCTURES OF VERY HIGH REDSHIFT QUASARS

JOHN WARDLE
Brandeis University

We are making VLA observations of all 154 known radio-loud quasars with z > 2.5 in the area common to both FIRST and the SDSS, and with radio fluxes > 70 mJy at either 1.4 or 5.0 GHz. The sample contains 154 objects ranging in redshift up to z = 5.5. When combined with previous lower redshift samples we have a unique dataset for studying the evolution of radio loud AGN and their environment back to the earliest epochs. We will present VLA images showing the variety of extended structures exhibited by the highest redshift sources, and also give some preliminary results concerning the density and clumpiness of the intergalactic medium at these early epochs. A parallel goal of these observations is to find new high redshift jets for observing with Chandra.

## HIGH REDSHIFT 3CR SOURCES: CHANDRA OBSERVATIONS

BELINDA WILKES
SAO

We report preliminary results from new Chandra, snap-shot observations of 24 sources from a complete subset of 38 radio-lobe-selected, 3CRR, massive radio galaxies with 1<z<2. These data allow us to measure the strength of the nuclear activity and study the relation of X-ray flux and spectral hardness to orientation, estimated from the radio core-dominance. In combination with the rich, multi-wavelenth dataset for this inclination unbiased sample (including Spitzer 3.6-70$\mu$m photometry), we will test AGN Unification at these redshifts. SED fitting will further constrain models for the obscuring material, the relative number of obscured and unobscured AGN and X-ray selection effects. Preliminary results include detection of extended X-ray emission, sometimes associated with radio emission.

## HIGH REDSHIFT 3CR SOURCES: MID-INFRARED SPECTRAL ENERGY DISTRIBUTIONS

STEVEN WILLNER
Harvard-Smithsonian Center for Astrophysics

We are observing the complete z>1 3CR sample at 3.6 to 24 microns with the Spitzer Space Telescope. This sample is nearly unbiased by orientation. Results of 60 sources will be presented and implications for the Unified Scheme discussed.

## DISTANT GALAXY CLUSTERS ASSOCIATED WITH RADIO SOURCES

JOSHUA WING
Boston University

We have cross-correlated the SDSS with samples of radio sources selected from the VLA FIRST catalog and measured the richness of the environments surrounding the sources. We find that bent double-lobed radio sources have a 75% success rate of locating clusters of galaxies, while straight double-lobed and compact radio sources are less often in clusters. The bent double-lobed cluster sources are most often associated with bright E galaxies at the cluster centers. This cross-correlation has led to the discovery and classification of a large number of clusters out to a redshift of z 0.6-0.8; those sources without i.d.'s in the SDSS are potentially located in even more distant clusters. We have also correlated the radio sources with X-ray catalogs.

## THE TEV BL LAC 1ES 1426+428: SPECTRUM AND VARIABILITY

ANNA WOLTER
INAF-OABrera

The BL Lac 1ES 1426+428 is an extreme object, with the hard synchrotron component peaking at energies at or above 100 keV, resembling the hard states of Mkn 501 and 1ES 2344+514. We have observed it with INTEGRAL: the detection confirms the earlier interpretation of the BeppoSAX observation. Here we collect all the available X-ray observations of this object, from the historical ones, to the one obtained with the current satellites: Chandra, XMM-Newton, SWIFT, RXTE, to determine if the variability pattern of this source is similar to other high peaked objects.

## FORMATION OF X-RAY CAVITIES BY MAGNETICALLY DOMINATED JET IN GALAXY CLUSTERS

HAO XU
UCSD/LANL

High resolution X-ray images of galaxy clusters by the Chandra X-ray telescope have revealed giant cavities in the hot cluster gas, apparently produced by the energy ejected from supermassive black holes (SMBHs) as massive as a billion solar masses residing in the centers of active galaxies. Here we report results from self-consistent AMR cosmological magentohydrodynamic simulations, showing the formation of cavities and shock front as the evolutionary outcome of the magnetic energy injection by a SMBH. We find that the cavities are magnetically dominated and their morpologies are determined jointedly by the magnetic fields and the background cluster pressure profile. We will discuss the details of the injected magnetic energy going into the hot cluster medium, heating and lifting it in the cluster potential by bubbles and weak shock.

# HOT SELF-SIMILAR RELATIVISTIC MHD FLOWS

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Institute for Advanced Study

We consider self-similar axisymmetric relativistic jets with a toroidal magnetic field and an ultrarelativistic equation of state, to study the lateral structure of jets whose pressure is matched to the pressure of the surrounding medium. As the jet material expands due to internal pressure gradients, it runs into the ambient medium resulting in a pile-up of material along the jet boundary, while the magnetic field acts to produce a magnetic pinch along the axis of the jet. We construct maps of optically thin synchrotron emission and polarization from our models. Effects due to geometric orientation and emissivity significantly complicate the interpretation of the polarization data in terms of the intrinsic magnetic field.

# NOTES