### SWG membership

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<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Research Focus</th>
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<tr>
<td>Megan Donahue</td>
<td>MSU</td>
<td>Cluster-scale feedback</td>
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<tr>
<td>Chris Reynolds</td>
<td>UMd</td>
<td>ICM-Jet interaction / AGN winds</td>
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<td>Nahum Arav</td>
<td>VT</td>
<td>AGN winds / BALQSOs</td>
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<td>Elizabeth Blanton</td>
<td>Boston U</td>
<td>Cluster Feedback</td>
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<tr>
<td>Laura Brenneman</td>
<td>CfA</td>
<td>Accretion and BH spin</td>
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<td>Askbiz Danehkar</td>
<td>CfA</td>
<td>Planetary Nebulae</td>
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<td>Larry David</td>
<td>CfA</td>
<td>Cluster feedback</td>
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<tr>
<td>Oleg Gnedin</td>
<td>U.Mich</td>
<td>Cosmological Simulations / Feedback</td>
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<tr>
<td>Sebastian Heinz</td>
<td>U.Wisc</td>
<td>Cluster and micro-quasar feedback</td>
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<td>Julie Hlavacek-Larrondo</td>
<td>Montreal</td>
<td>Cluster scale feedback over cosmic time</td>
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<tr>
<td>Edmund Hodges-Kluck</td>
<td>U.Mich</td>
<td>CGM, ICM and radio-galaxies</td>
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<td>Christine Jones</td>
<td>CfA</td>
<td>Elliptical galaxy and cluster feedback</td>
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<td>Peter Maksym</td>
<td>CfA</td>
<td>Tidal disruption events</td>
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<td>Alex Markowitz</td>
<td>UCSD</td>
<td>AGN winds</td>
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<tr>
<td>Herman Marshall</td>
<td>MIT</td>
<td>High-resolution spectroscopy</td>
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<td>Brian McNamara</td>
<td>Waterloo</td>
<td>Cluster feedback</td>
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<tr>
<td>Jon Miller</td>
<td>U.Mich</td>
<td>Disk winds across BH mass scale</td>
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<tr>
<td>Brian Monsony</td>
<td>UMd</td>
<td>Cluster feedback and GRBs</td>
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11/16/16

X-ray Surveyor STDT

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### SWG membership (cont)

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<td>AGN and GBHB winds/jets</td>
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<td>Scott Randall</td>
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<td>Mateusz Ruszkowski</td>
<td>U.Michigan</td>
<td>Galaxy and cluster AGN feedback</td>
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<td>Eric Schlegel</td>
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<td>Norbert Schulz</td>
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<td>Micro-quasars</td>
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<td>Dan Schwarz</td>
<td>CfA</td>
<td>AGN Jets</td>
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<td>Paul Sell</td>
<td>U.Crete</td>
<td>Micro-quasar feedback</td>
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<td>Aneta Siemiginowska</td>
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<td>Jet-ISM interactions</td>
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<td>Gregory Sivakoff</td>
<td>Alberta</td>
<td>Accretion-jet connection in XRBs</td>
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<tr>
<td>Makoto Tashiro</td>
<td>Saiama Univ</td>
<td>GRB and high-z enrichment</td>
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<tr>
<td>Francesco Tombesi</td>
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<tr>
<td>Grant Tremblay</td>
<td>Yale</td>
<td>Galactic-scale feedback/multiwaveband</td>
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<td>Norbert Werner</td>
<td>Stanford</td>
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<td>Dan Wilkins</td>
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<td>Mihoko Yukita</td>
<td>JHU</td>
<td>Stellar feedback</td>
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<tr>
<td>Shuo Zhang</td>
<td>MKI</td>
<td>BH jets and Sgr A*</td>
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<tr>
<td>Irene Zhuravleva</td>
<td>Stanford</td>
<td>Cluster feedback</td>
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</table>
How is the evolution of structure regulated by stellar processes and supermassive black hole accretion?
Subgroups

- AGN feedback in clusters (S.Randall / J.Hlavecek-Larrondo)
  - Co-chairs responsible for low-z and high-z cluster physics
- AGN feedback on group/galaxy scales (EHodges-Kluck)
  - Co-chair interfaced with Baryon-Cycling SWG
- AGN winds and quasar feedback (A.Markowitz / F.Tombesi)
  - Co-chairs interfaced with Extreme Physics SWG
- Jet physics and related feedback physics (A.Siemiginowska)
- Stellar feedback (M.Yukita)
Top level questions

• How does AGN feedback evolve as a function of cosmic time, system mass, and AGN power?
• How does stellar feedback evolve as a function of cosmic time, system mass, and star formation rate?
• What are the physical processes by which the AGN influences the ICM/ISM?
• How, and when, do SMBH accretion disks produce winds and/or jets capable of exercising feedback?
• How is AGN fueling related to, and regulated by, the environment?
• What is the role of AGN/stellar feedback processes in dispersing metals into the CGM/ICM/IGM?
Key observations

• High-spatial and high-spectral resolution maps of temperature, density, metallicity, dynamics of...
  – ICM in galaxy clusters (low-z and high-z)
  – Hot ISM of elliptical galaxies and massive spirals
  – CGM of isolated galaxies across the mass scale (low-z and high-z)
  – Internal structure of hot ISM across the mass scale (low-z and high-z)
• High-resolution spectroscopy of AGN outflows
• High-resolution, high-dynamic range imaging of core regions of luminous AGN.
• High-spatial resolution maps of AGN jets

• Exploit synergies with JWST, WFIRST, LSST, ALMA, ELTs
• Most of these key observation types have bearings on multiple science questions!
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Feedback in clusters of galaxies
2 arcsec
0.7 kpc
\sim 1 \text{ mpf}
Simulated XMIS spectra of 2x2 arcsec$^2$ region of Perseus (500ks)

Assume
150km/s turbulence
150km/s bulk velocity offset
(formally reconstruct these velocities to ±20km/s)
Measuring gas fluctuations on small scales: XRS vs Athena

window for probing microphysics, including shocks, turbulence, transport processes, which are important for understanding, e.g., gas heating mechanisms

contact: Irina Zhuravleva [zhur@stanford.edu]

• simulations: #0148, $z=0.05$ (50ks observation)
• inner 2’=120 kpc
• use soft–band images: 0.5–3.5 keV
Residual images and power spectra

$P_{2D}$: initial spectra of SB fluctuations

Poisson noise

$P_{2D}$-Poisson noise

Irina Zhuravleva
Conclusions:

- Limited resolution of simulations produces high-k tail in case of XRS (the peak is at ~ pixel size, the peak distorts spectrum down to smaller k - this is artifact of the Mexican-hat filter used for calculations of the power spectrum). 
- Resolution effect is less prominent in the case of Athena, since Athena resolution partially smears grid effects.
- Athena PSF affects scales ~ 10 kpc (comparable or even larger than the width of ripples in the Perseus cluster). With 50 ks exposure scales > 5 kpc are dominated by Poisson noise.
- XRS can in principle measure fluctuations ~ 1 kpc size, but it is difficult to show with current situations. With 50 ks exposure scales > 2 kpc are dominated by noise.
- XRS will probe microphysics on scales that Athena cannot reach (or even current numerical simulations).
Feedback in groups and elliptical galaxies
Feedback Energy Partitioning

- Why don’t AGN overheat groups/galaxies?
- The dominant heating mechanism or duty cycle may be different than in clusters.
- Required measurements:
  - Active outbursts: shock strength, thermal/nonthermal content of bubbles, cavity enthalpy
  - Relic outbursts: frequency, structure, surrounding kT differential
- Lower surface brightness, X-ray binaries, and other atmospheric disturbances require XRS.
At the group and galaxy scale, the cavity power usually exceeds the cooling rate.

Edmund Hodges-Kluck

Fabian 2012
Observational Goal: We need Virgo or Perseus-like maps within r<10 kpc to isolate different AGN components from other disturbances. This problem is compounded by XRBs.

Edmund Hodges-Kluck
There are \( \sim 100 \) galaxies within 100 Mpc with \( \sigma > 150 \) km/s. Observations of nearby, low-mass halos show what to expect for more distant systems.

Resolving different AGN heating mechanisms requires: high S/N, resolution of a few hundred pc or better for imaging and the calorimeter IFU (\( \leq 1 \) arcsec).
Cavity size increases with radius, but within 10 kpc Athena will be unable to reliably measure shock strengths, bubble volume, etc., even locally.
XRBs also limit the value of deeper Athena observations. XRS can remove them even with a steep luminosity function.

Edmund Hodges-Kluck
XRB contamination is a serious obstacle for detecting relic lobes, and especially for measuring their structure (which tells us how they fall apart and mix).
Exposure Times

• Active outbursts:
  – *Chandra* found cavities; XRS (+LOFAR/SKA/ALMA/optical IFUs) will show how they distribute energy.
  – A deep, high-resolution survey of 10-20 galaxies/groups (not cDs) within 100 Mpc where temperature, metallicity, and line centroids can be measured to accuracies of better than 10% across a few hundred pc (a few arcsec).
  – Exposure time per system: **100-300 ks per group, 50-300 ks per galaxy** (depends strongly on distance). *Chandra* has put ~13 Ms total into these systems (>5 Ms is dedicated to bright cluster galaxies). A transformative view of a **representative sample with XRS would require about 10 Ms** (overlapping with other major scientific goals).

• Relic radio lobes:
  – Hard X-rays trace relic lobes. The combination of hard X-rays and low-frequency radio provides the B-field, and the structure shows how the bubbles break up.
  – A deep search in tens of galaxies and groups (with and without active cavities) is necessary. For approximate equipartition between the cavity enthalpy and nonthermal radio population, 100-300 ks per target is necessary to identify and measure relic lobes through hard X-rays. Targets can be selected from LOFAR or SKA catalogs. **This involves ~10-15 Ms total, but piggy-backs on any deep observation.**

Edmund Hodges-Kluck
Physics of AGN winds and jets
NGC 4051, 100 ks
Calorimeter
CAT Gratings
APM 08279+5255 (z=3.9) 100ks CAL (black) CAT (red)
FOM Line Det.: $\sqrt{\frac{A}{1 + \Delta E/W}}$: $W=10$ eV

- XRS CAT
- XRS Calor. 6x20 (solid)
- XRS Calor. 3x10 (dash)
- XRS HDXI
- ATH. XIFU
- LEG (+1)
- HEG (+1)
- MEG (+1)
- XMM RGS1 (+1)
- XMM RGS2 (+1)

Observed Energy (keV) vs. FOM ($\text{cm}^{0.5}$)
FOM Veloc: \((E/\Delta E)^{*}\sqrt{A / (1 + \Delta E/W)}\): \(W=10\) eV

![Graph showing FOM vs. observed energy (keV) with various curves for different observations and instruments.](image-url)
Sub-arcsec Angular Resolution

Required to resolve jet structure

3C273 jet from Jester et al (2006)
Broad-band combined image:
Blue: X-rays, Green: Optical, Red: Radio

Complex emission on sub-arcsec scales:
Sub-arcsec Angular Resolution

Quasar Jets and Radio galaxies at High Redshift:
Detecting faint emission close to a bright point source; a ‘peaky’ narrow PSF for high dynamic range observations at high-z.

Example: The most distant quasar jet detected in X-rays at z=4.72. The jet knot located at 3.6 arcsec from the core.

Figure 1. Chandra 0.3–7 keV (color) and VLA 1.4 GHz (contours) images of GB 1428+4217 showing the bright core and faint ~3'6 distant jet knot at P.A. ~ 295°. Coordinates are in J2000.0 equinox. The X-ray data are binned by 1/2 of the native 0'0.492 pixels and Gaussian smoothed with kernel radius of 3 pixels. The 10 radio contours start at 0.17 mJy bm^{-1} (four times the off-source rms) increasing by factors of two up to 87 mJy bm^{-1} (peak is 155.4 mJy bm^{-1}) with circular beam size = 1''5.

(A color version of this figure is available in the online journal.)

Aneta Siemiginowska
High-z Quasars

- The number of radio-loud quasars at z>3 is smaller than expected from the number of blazars.
- This could result from a difference in jets, higher density surroundings, or CMB “quenching” \( u_{\text{rad}} = u_{z=0} (1+z)^4 \). The former two could transform our understanding of feedback at high z (both in the galaxy and IGM).
- CMB quenching turns radio emission into X-ray emission. Counting jetted quasars at z>3 requires ~1 arcsec resolution and 10-50 ks per field.
- SDSS quasar density for \( z_{\text{spec}} > 3 \) (4) is 1.2 (0.07) deg\(^{-2}\). 500 HDXI pointings are needed to rule out CMB quenching in a blind survey (5-7 Ms). This can piggy-back on other surveys.
- If X-ray lobes are detected in a targeted search, the project is cheaper: deep observations of these sources can rule out CMB quenching (~1-1.5 Ms assuming a \( 10^{45} \) erg/s quasar).
At $z=3$, a lobe with an extent of 10 kpc is indistinguishable from a point source in Athena but is clearly elongated in XRS HDXI.

For a typical quasar luminosity of $10^{45}$ erg/s and a typical radio loudness, 10-50 ks is needed to find “quenched” quasars through elongated X-ray morphology.
Stellar-driven feedback
Stellar Feedback: XRS Spectra

M82:
Resolving a starburst driven Superwind

KT ~0.4 keV
V ~ 500 km/s

KT ~3 keV
V >1000 km/s
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Mission drivers

• Critical :
  – Calorimeter pixels ≤1 arcsec
    • (detailed studies of galactic nuclei / ISM)

• Desirable :
  – Calorimeter resolution ≤ 3eV
    • (detectability and characterization of abs lines)
  – Simultaneous Calorimeter and grating ability
    • (characterization of variable multi-zone winds)
Backup slides
Fueling and Feedback in the Inner kpc

• How do “maintenance-mode” AGN regulate their fuel supply?
• Episodic vs. continuous feeding
• Required measurements:
  – 2D Temperature, entropy, density, and bulk velocity maps within 1 kpc at comparable resolution (50-100 pc) to state-of-the-art IFU and ALMA/SKA.
• The kinematic measurements require the IFU calorimeter to have pixels of ≤1 arcsec.
• Athena measurements provide an important pathfinder, but are not a substitute.
Even nearly-quiescent BHs often have central dust or CO disks. Is this disk built up from condensation? Or, is the hot gas outflowing?
Exposure Times

• Targets:
  – Lower activity levels preferred (no bright central AGN), and a range of atmosphere brightnesses
  – Several large central galaxies within 50-100 Mpc (deep existing Chandra, XMM-Newton data)

• Ultra-deep study with HDXI+MIS
  – Determine inflow/outflow rates, kinetic energy carried, etc. down to near the Bondi radius
  – ~500 ks – 1 Ms per target (several targets=4-6 Ms)
  – Spectroscopic simulations pending...
Fraction of radio-loud quasars expected from blazar counts for a minimal (green) and maximal (red) model of blazar evolution. The observed fraction is shown as blue points. This model assumes quasars accrete at the Eddington ratio and that jets have a Doppler factor $\Gamma=15$. 

Volonteri et al. (2011)
**Precipitation-Limited Luminosity**

Voit+ 16, in preparation

\[ \frac{t_{\text{cool}}}{t_{\text{ff}}} \gtrsim 10 \]

\[ n_e \lesssim \frac{3kT}{10 t_{\text{ff}} \Lambda(T)} \]

\[ L_X(<R) \lesssim \int_0^R 4\pi r^2 \Lambda \left( \frac{3kT}{10t_{\text{ff}} \Lambda} \right)^2 dr \]

\[ L_X(<R) \lesssim \frac{9\pi}{25} (kT)^2 \Lambda^{-1} \sigma_v^2 R \]
Precipitation-Limited Luminosity

Voit+ 16, in preparation

\[ L_{\text{X}}(\leq R) \propto \left( \frac{kT}{\Lambda} \right)^2 \frac{1}{\sigma_v^2} R \]

- Multiphase Werner Ellipticals
- Single Phase Werner Ellipticals
- NGC 4261
- Milky Way
How efficient is galaxy formation?

$M_{\text{baryons}} = 0.16 \ M_{\text{total}}$

$M_\ast$: Disks

$M_\ast$: Spheroids

$M_\ast$: BCGs

$M_{\ast}/M_\odot$

$f_\ast = 0.16$

$M_{\text{total}}$

Courtesy of Mark Voit