The cold feedback mechanism

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New results by Michael Refaelovich, Avishai Gilkis, & Shlomi Hillel

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SUMMARY

Accretion cold (T<T\text{virial}) gas on a compact object

Jets

Jets’ non-penetrating interaction with the hot (virial) gas

vortices

Heating the gas

Bubbles

Expelling gas
Simulating a wide jet in a cluster
Posters 3+7

Simulating precessing jets from a new neutron star to blow a core collapse SN (Papish & Soker 2012)

Observed (X-ray) bubbles in Perseus

Simulating bubble formation in planetary nebulae (Akashi & Soker 2012)

Observed (visible – [N II]) bubbles in NGC 3587, a planetary nebula
Accreting compact object: AGN

Jets interacting with hot (virial) ICM: Non-penetrating
- Wide
or
- Precessing
or
- ICM motion
Accreting compact object: AGN

Jets-ICM: Non-penetrating

Forward Shock

vortices
Accreting compact object: AGN

Jets-ICM: Non-penetrating

Shock  vortices

Note chain of bubbles from one jet episode

Refaelovich & Soker 2012, accepted by astro-ph
arXiv:1205.3661 (poster 7)
Accreting compact object: AGN

Jets: Non-penetrating vortices

Shock ICM Heating bubbles

Forward shock pushed gas at (9,1)kpc to (10,1)kpc. Velocities: 100-300 km/sec.

Accreting compact object: AGN

Jets-ICM: Non-penetrating

Shock

vortices

bubbles

Pushing ICM

Mixing jet-ICM

Entangle B-field. No global heat conduction

ICM Heating
Accreting compact object: AGN

Jets:
- Non-penetrating vortices
- Shock

ICM Heating Pushing ICM bubbles

Entangles B-field. No global heat conduction.

Accreting compact object: AGN

Jets: Non-penetrating

Shock

vortices

bubbles

Pushing ICM

Mixing jet-ICM

Entangle B-field. No global heat conduction

ICM Heating

Sound waves

Log(velocity) showing sound waves
Accreting compact object: AGN

Jets-ICM: Non-penetrating

Shock → vortices → bubbles

Pushing ICM

Mixing jet-ICM

ICM Heating

Dredge-up

Interaction with ICM

Entangle B-field. No global heat conduction
Accreting compact object: AGN

Jets-ICM: Non-penetrating

Shock
vortices
bubbles

Pushing ICM

Entangle B-field. No global heat conduction

Mixing jet-ICM

ICM Heating

Interaction with ICM
Accreting compact object: AGN

Jets-ICM: Non-penetrating

Shock

vortices

bubbles

Pushing ICM

Entangle B-field. No global heat conduction

Mixing jet-ICM

ICM Heating

Dredge-up

Multiphase ICM with cooler clumps

Interaction with ICM
Accreting compact object: AGN

Jets-ICM: Non-penetrating

Shock

Vortices

Bubbles

Pushing ICM

Mixing jet-ICM

ICM Heating

Interaction with ICM

Dredge-up

Multi-phase ICM with cooler clumps

The cold feedback mechanism + a moderate cooling flow

Entangle B-field. No global heat conduction

Jets-ICM: Non-penetrating
Note that Bondi accretion is a complete failure (see poster 6)

The *cold feedback mechanism* (Pizzolato & Soker 2005, 2010) is supported by observations of cold gas and by recent theoretical studies (e.g., Revaz et al. 2008; Pope 2009; Wilman 2009, 2011; Nesvadba et al. 2011; Gaspari 2012a, b; McCourt et al. 2012; Sharma et al. 2012; Farage et al. 2012)
Accreting compact object: AGN

Jets-ICM: Non-penetrating

Shock

vortices

bubbles

Pushing ICM

Mixing jet-ICM

ICM Heating

Interaction with ICM

Dredge-up

Multi-phase ICM with cooler clumps

The cold feedback mechanism

MASS FEEDBACK

The cold feedback mechanism

Jets-ICM: Non-penetrating

Shock

vortices

bubbles

Pushing ICM

Mixing jet-ICM

ICM Heating

Interaction with ICM

Dredge-up

Multi-phase ICM with cooler clumps

The cold feedback mechanism

MASS FEEDBACK

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MASS FEEDBACK

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The cold feedback mechanism

MASS FEEDBACK
Accreting compact object: AGN

Jets-ISM: Non-penetrating

Shock

vortices

bubbles

Mixing jet-ICM

Expelled gas

Multi-phase ICM with cooler clumps

Dredge-up

Interaction with ICM

Heating

The cold feedback mechanism

Expelled gas

MASS FEEDBACK: Cooling flow at galaxy formation (Soker 2010)
Cooling Flow clusters

• Cooling flow does exist, but at a moderate mass cooling rate. *(The moderate cooling flow model; Soker, White, David, & McNamara 2001).*

• Mass accreted by the central BH originates in non-linear over-dense blobs of gas residing in an extended region: ~1-30 kpc. *The cold feedback cycle* (Pizzolato & Soker) NOT BONDI ACCRETION

• Part of the cold gas is ejected back to the ICM, at velocities of ~0.01-0.1c, making mass an ingredient in the feedback cycle (in addition to energy) (Pizzolato & Soker).

• The ejected mass, a slow massive wide (or precessing) jets, inflate `fat’ bubbles (Sternberg & Soker; Gilkis & Soker – Poster 3; Rafaelovich & Soker – Poster 7)

• The same mechanism that forms slow massive wide jets can expel mass in galaxy formation, and explain the BH-bulge mass correlation (Soker 2010, 2011).
It is well established now that Bondi accretion does not work

(1) No time for feedback because Bondi radius (<<1kpc) is much smaller than cooling region (~10 kpc).

(2) Accretion rate is much too low in clusters (in some simulations an accretion rate of 100 Bondi is used, and it is still called “Bondi accretion”).

(3) NEW In places where the predicted Bondi accretion rate is low, ram pressure by stellar winds near the central BH might further reduce the accretion rate (see poster 6 by Shlomi Hillel).
The **cold feedback mechanism** (Pizzolato & Soker 2005, 2010) is supported by observations of cold gas and by recent theoretical studies (e.g., Revaz et al. 2008; Pope 2009; Wilman 2009, 2011; Nesvadba et al. 2011; Gaspari 2012a, b; McCourt et al. 2012; Sharma et al. 2012; Farage et al. 2012)

- It allows a fast communication between the surrounding gas (ICM) and the SMBH.

- In some cases the AGN feedback in clusters proceeds faster than star formation does. **Consequences:**
  - SMBH that are above the BH-bulge mass relation (e.g., McConnell et al. 2011), might be formed in such energetic feedback modes.
  - Such an energetic outburst might remove a cooling flow.
  - Larger mass removal than star formation might occur in galaxy formation.
  - This is the feedback mode we propose for MS 0735.6+7421 (no need for BH spin) next page
MS 0735.6+7421
(McNamara et al.)

2.5D simulation
(Sternberg & Soker 2009)

0.5 Mpc

density
Accretion power, not spin power:

Accreted mass: $4 \times 10^8 \left( \varepsilon / 0.1 \right)^{-1} M_\odot$

Mass in jets: $8 \times 10^9 \left( v / 0.1c \right)^{-2} M_\odot$

Allowed star formation $\sim 10^8$ yr ago: $\sim 10^9 M_\odot$

Star formation $\ll$ Expelled mass

(For low star formation see also Nesvadba et al. 2011)
(1) Vortices play a key role in the jets-ICM interaction process (see posters by Gilkis and by Rafaelovich):

- Determine the morphology.
- Single jet-episode can excite many sound waves.
- Single jet-episode can form a chain of bubbles.
- Heating is mainly by mixing in small vortices (not by shocks!).
- Heating works perpendicular to the jets’ axis.

(2) Observed morphologies require precessing, or wide jets, or ICM motion. This can remove huge amount of mass from the center.
Contour: 1 per cent mixing
Implications to galaxy formation

(1) Cooling flow existed during galaxy formation:
To efficiently remove the ISM, the gas needs to occupy a large volume. This implies hot gas, hence the presence of cooling flow during galaxy formation (Soker 2010).

(2) AGN feedback as in clusters can remove dark matter from the center at galaxy formation:
The AGN heating by wide or precessing jets via vortices removes large quantities of gas from the center in a short time. Such a process during galaxy formation can remove a substantial fraction of the mass from the center in a short time. This influences the orbits of stars as well as of dark matter particles. Namely, AGN activity with a mass feedback as in cooling flow clusters can remove dark matter from the center of galaxies during their formation. (see Governato et al. 2012 for mass removal with Sne)
REFERENCES


Governato, F., Zolotov, A., Pontzen, A. et al. MNRAS,


