The cold feedback mechanism

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New results by Michael Refaelovich,

Avishai Gilkis, & Shlomi Hillel

Technion, Israel

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SUMMARY

Accretion cold (T<Tvirial) gas on a compact object

Jets

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

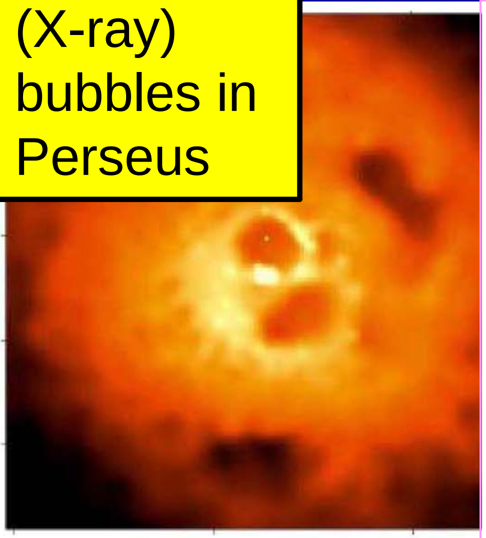
vortices

Heating the gas

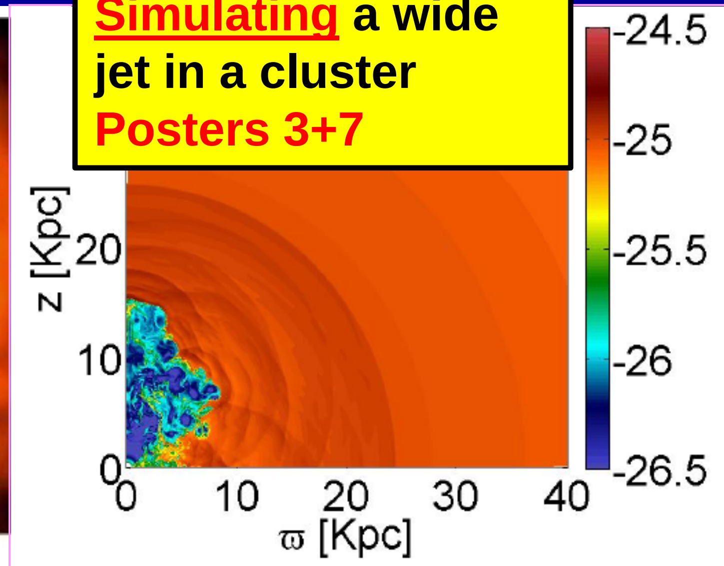
Bubbles

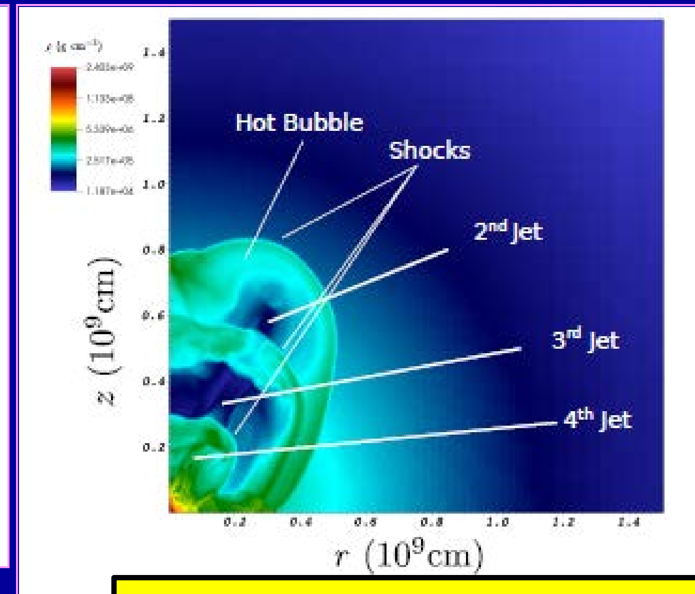
Expelling gas

Observed (X-ray) bubbles in Perseus

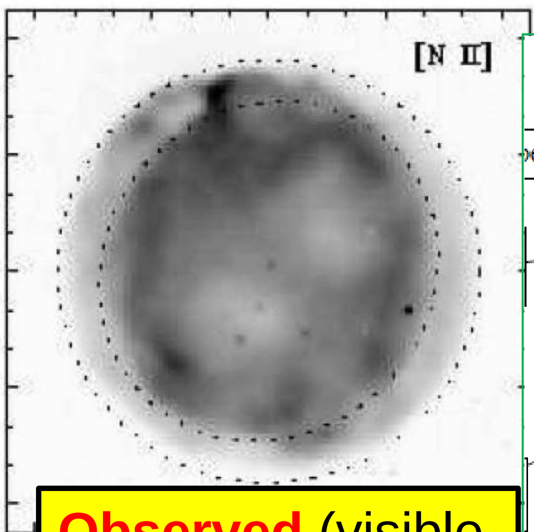


Simulating a wide jet in a cluster
Posters 3+7

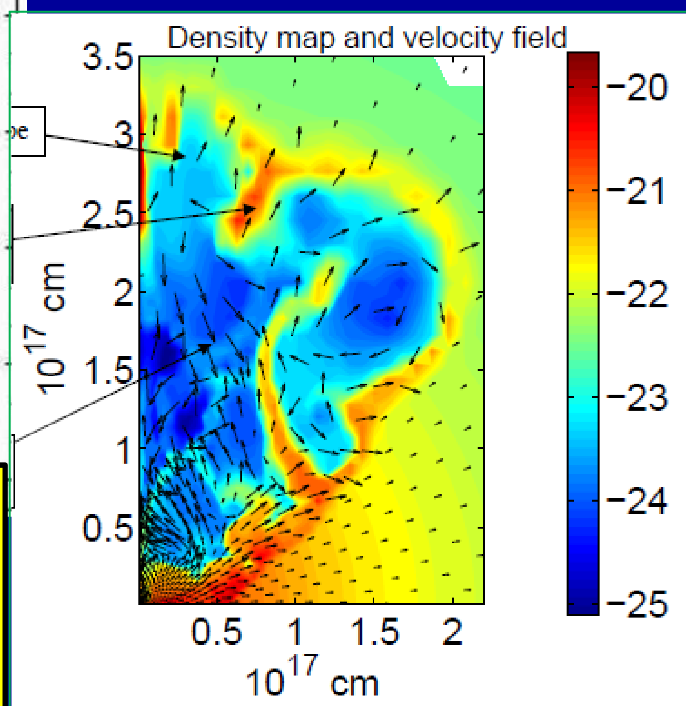




Simulating precessing jets from a new neutron star to blow a core collapse SN (Papish & Soker 2012)



Observed (visible – [N II]) bubbles in NGC 3587, a planetary nebula



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

Accreting compact object: AGN

Jets interacting with hot (virial) ICM:
Non-penetrating

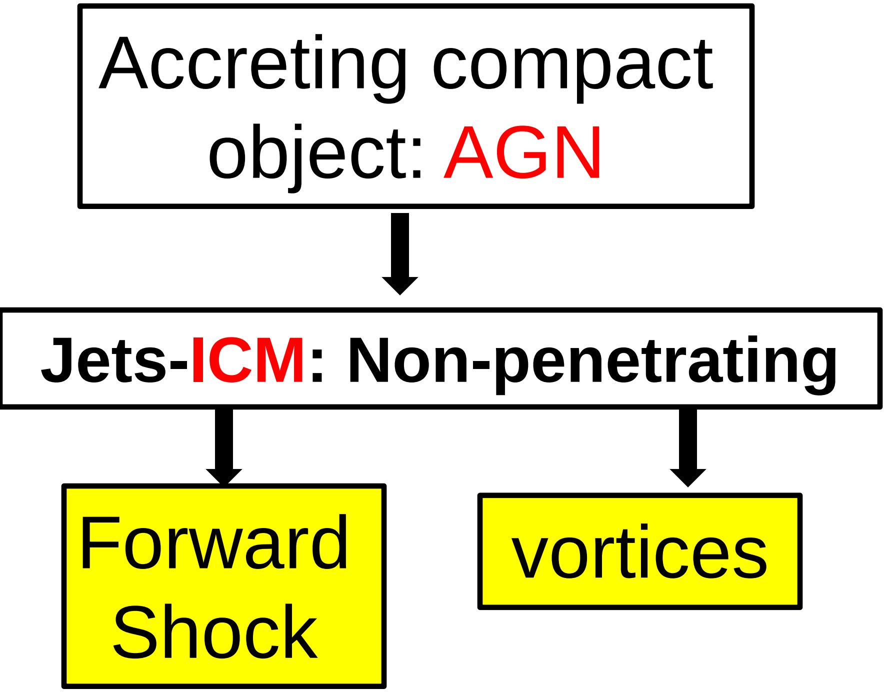
- **Wide**

or

- **Precessing**

or

- **ICM motion**

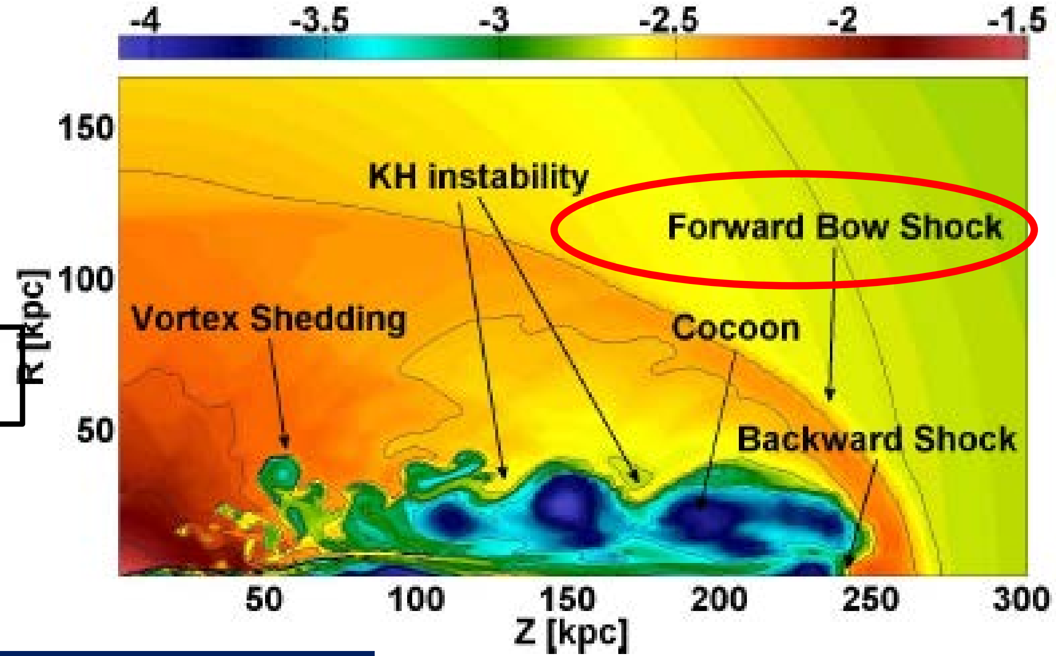

Accreting compact object: AGN
Jets-ICM: Non-penetrating
Forward Shock
vortices

Accreting compact object: AGN

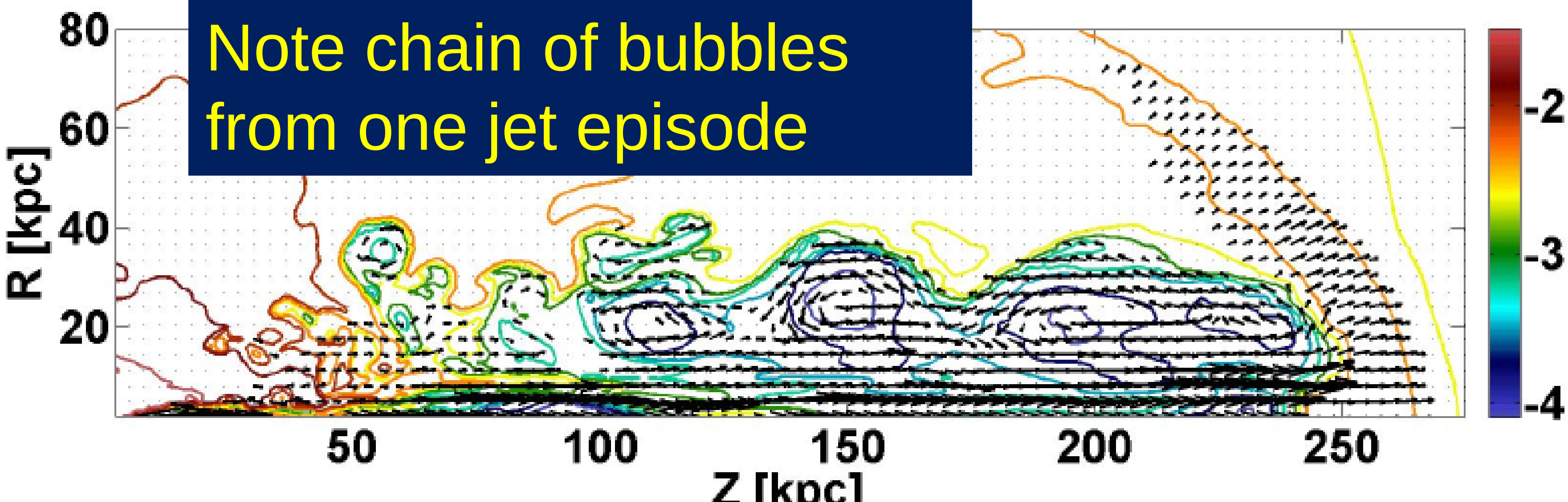
Jets-ICM: Non-penetrating

Shock

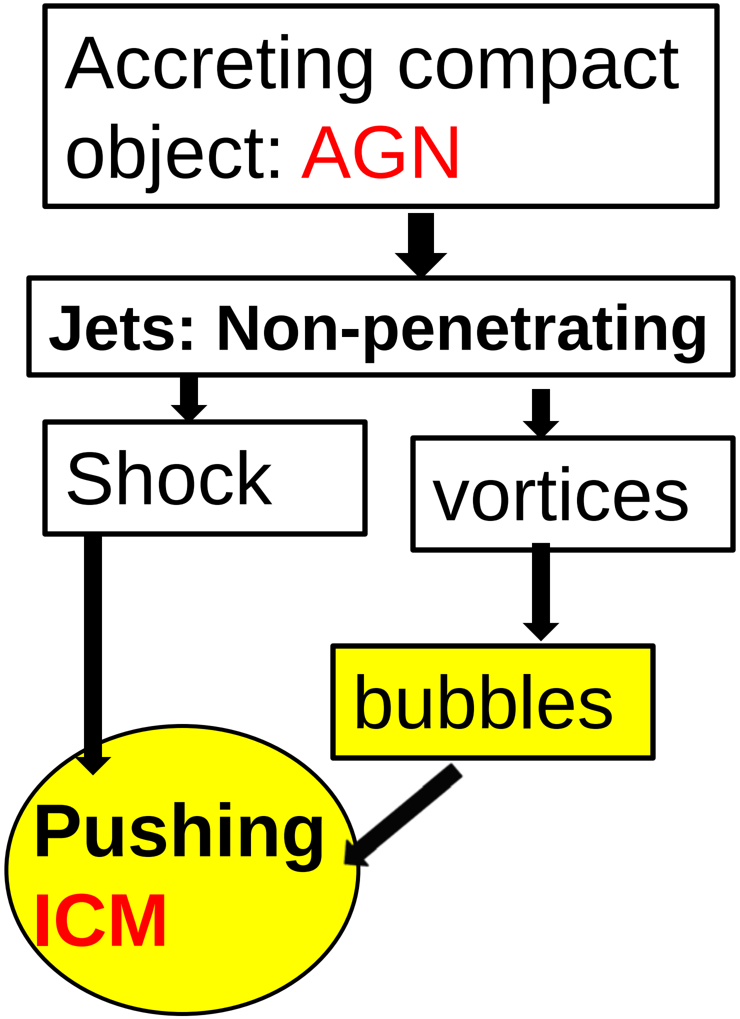
vortices

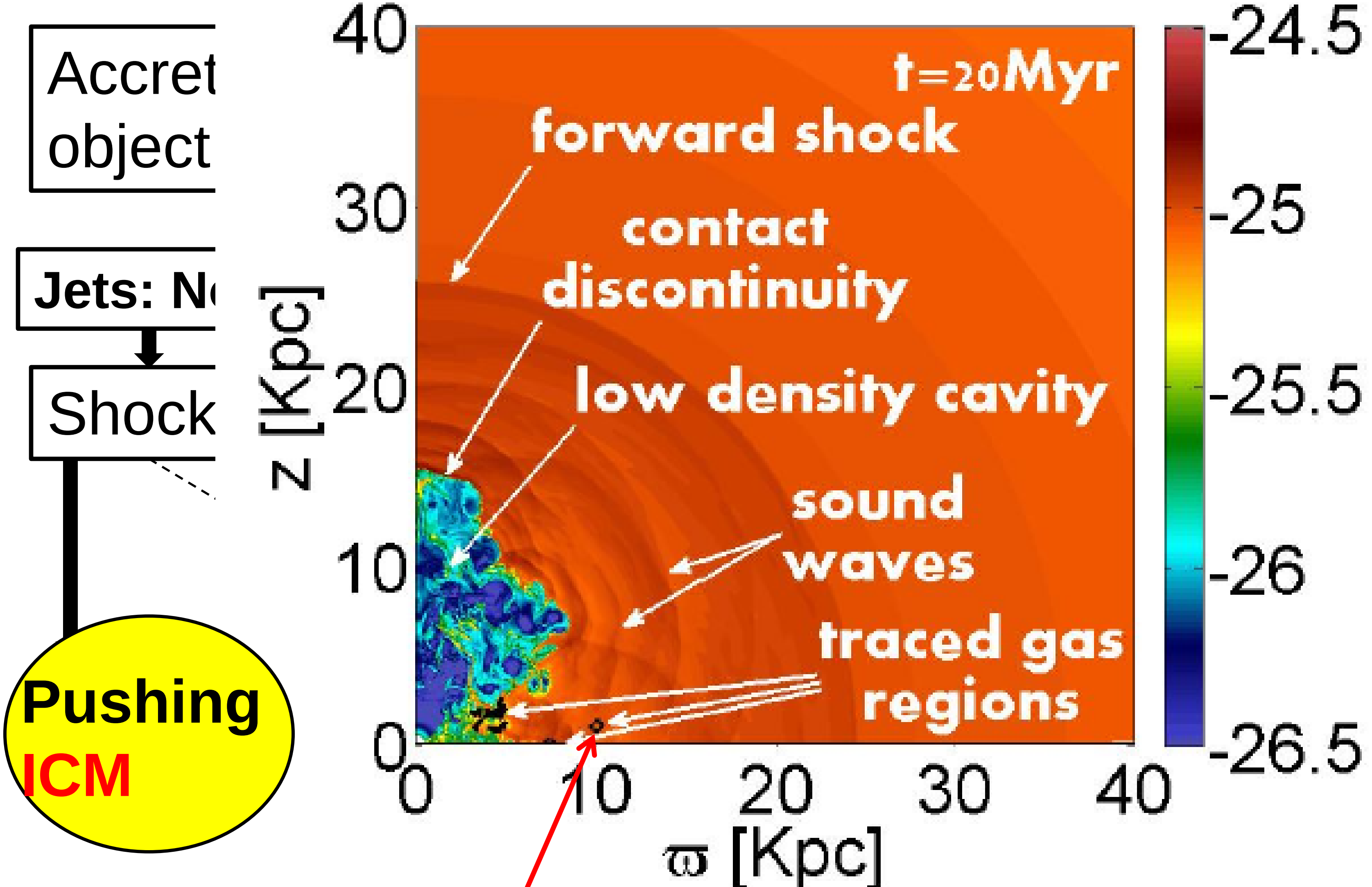


Note chain of bubbles from one jet episode



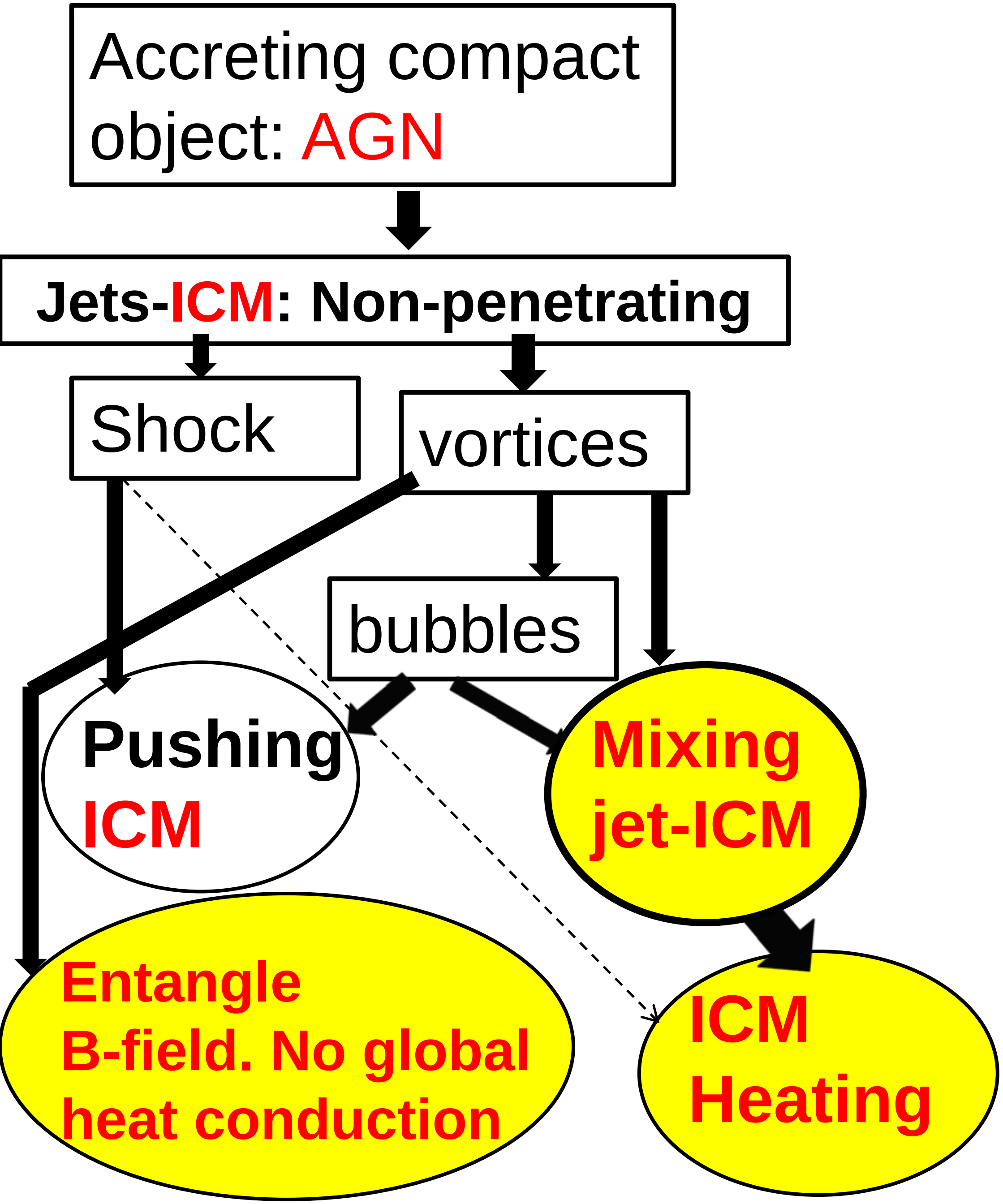
Refaelovich & Soker 2012, accepted by astro-ph
arXiv:1205.3661 (poster 7)

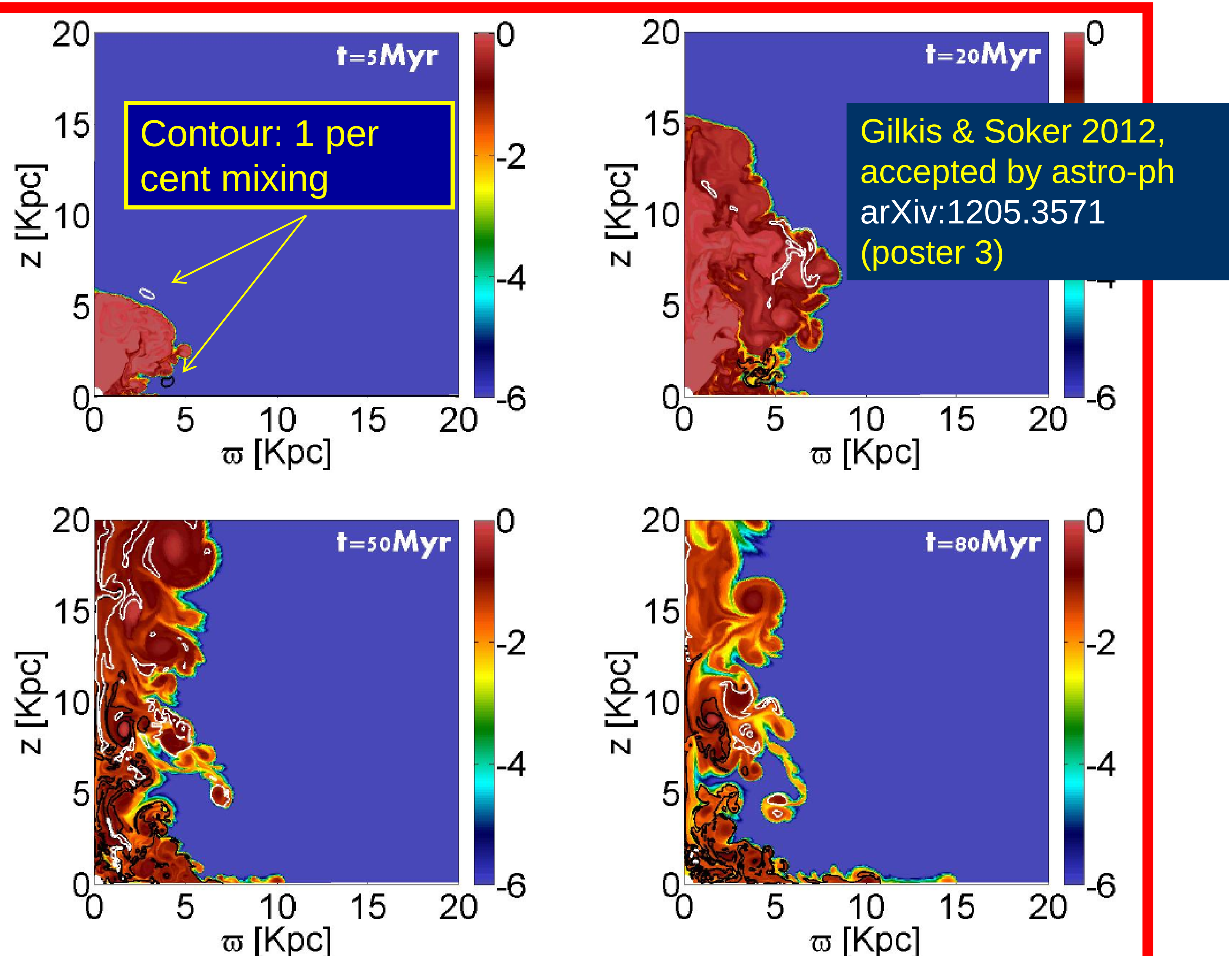

Accreting compact object: AGN
Jets: Non-penetrating
Shock
vortices
bubbles
Pushing ICM

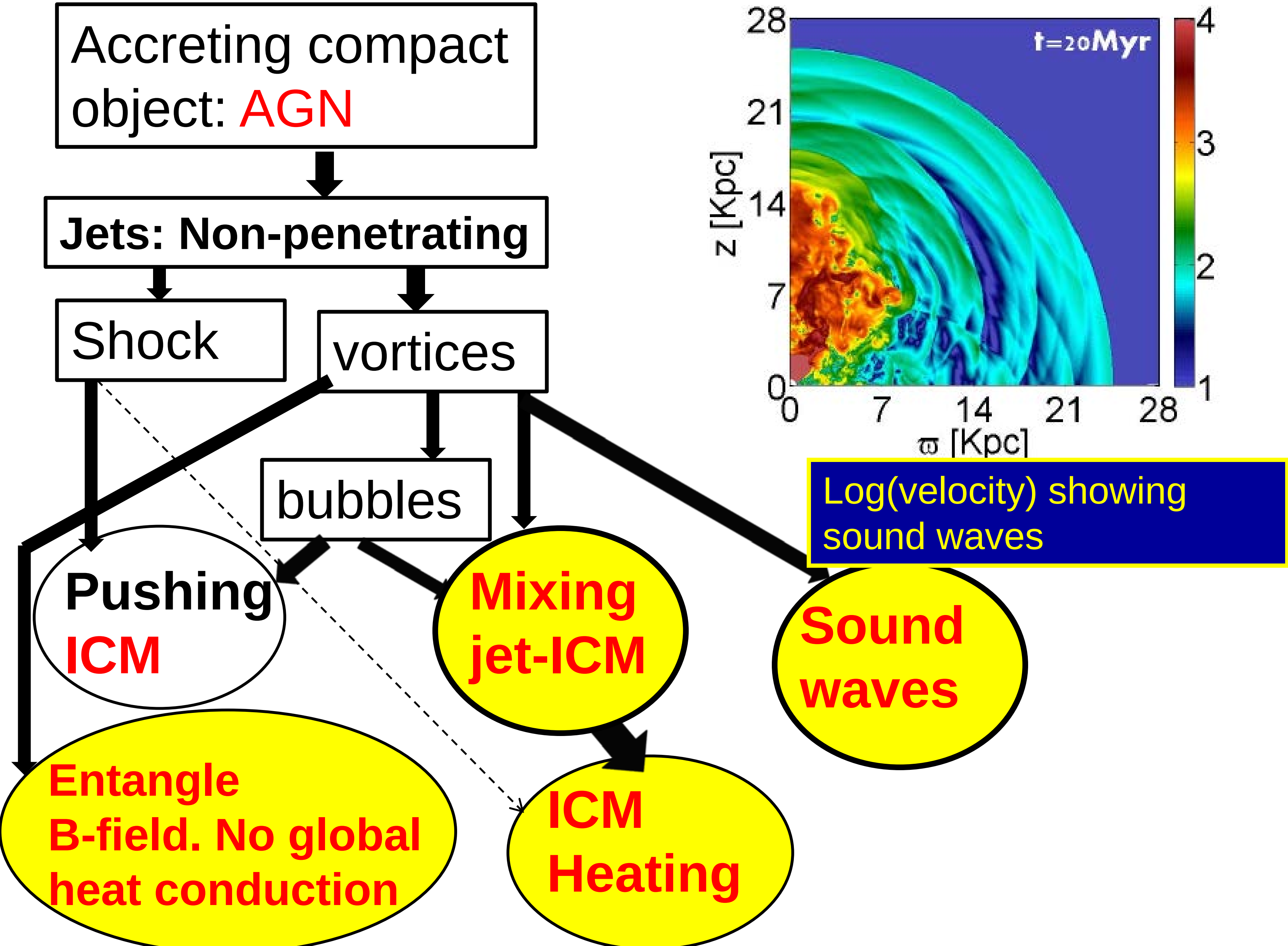


Forward shock pushed gas at (9,1)kpc to (10,1)kpc.
Velocities: 100-300 km/sec.

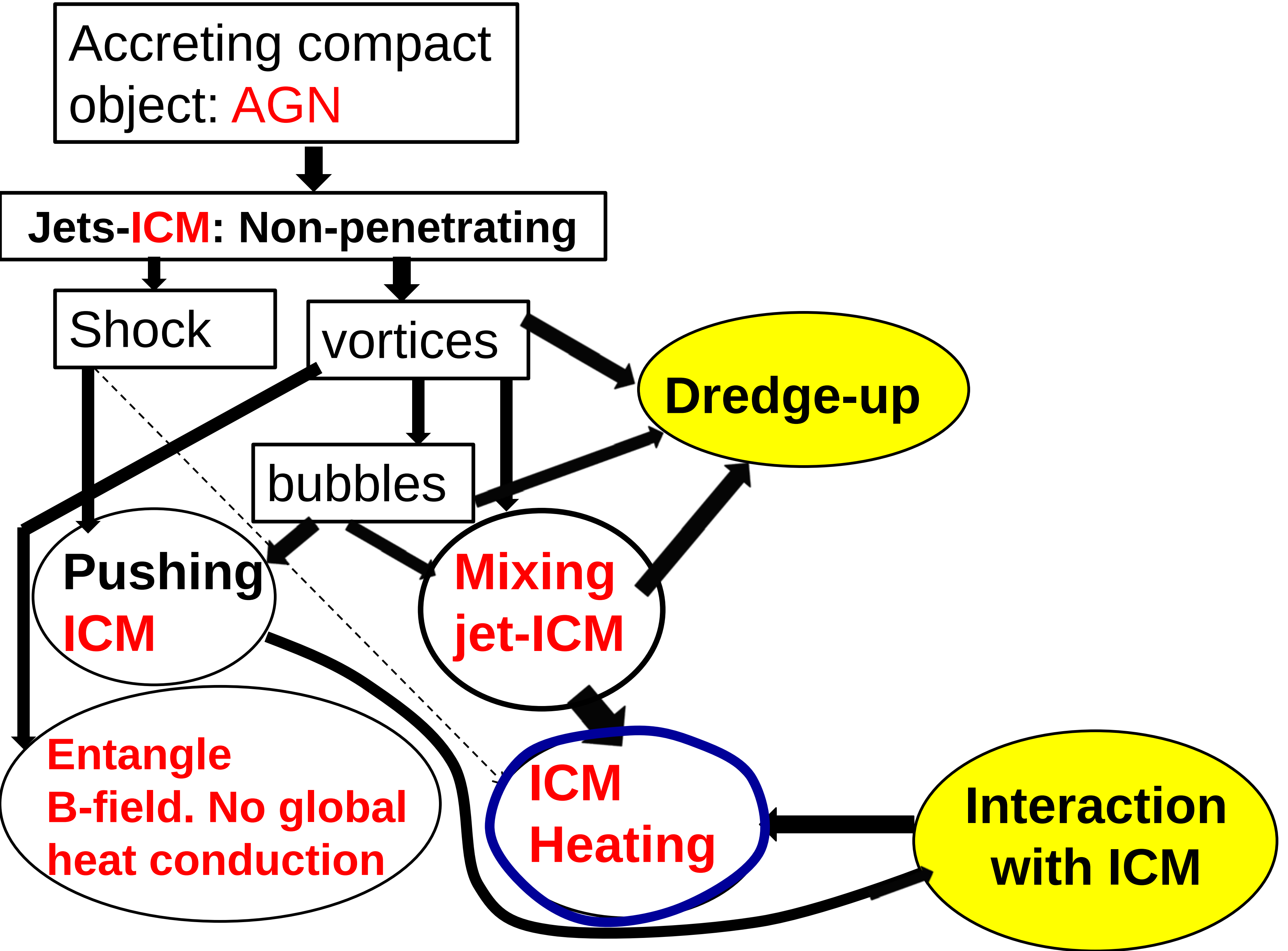
See: Gilkis & Soker 2012, accepted by astro-ph arXiv:1205.3571 (poster 3)

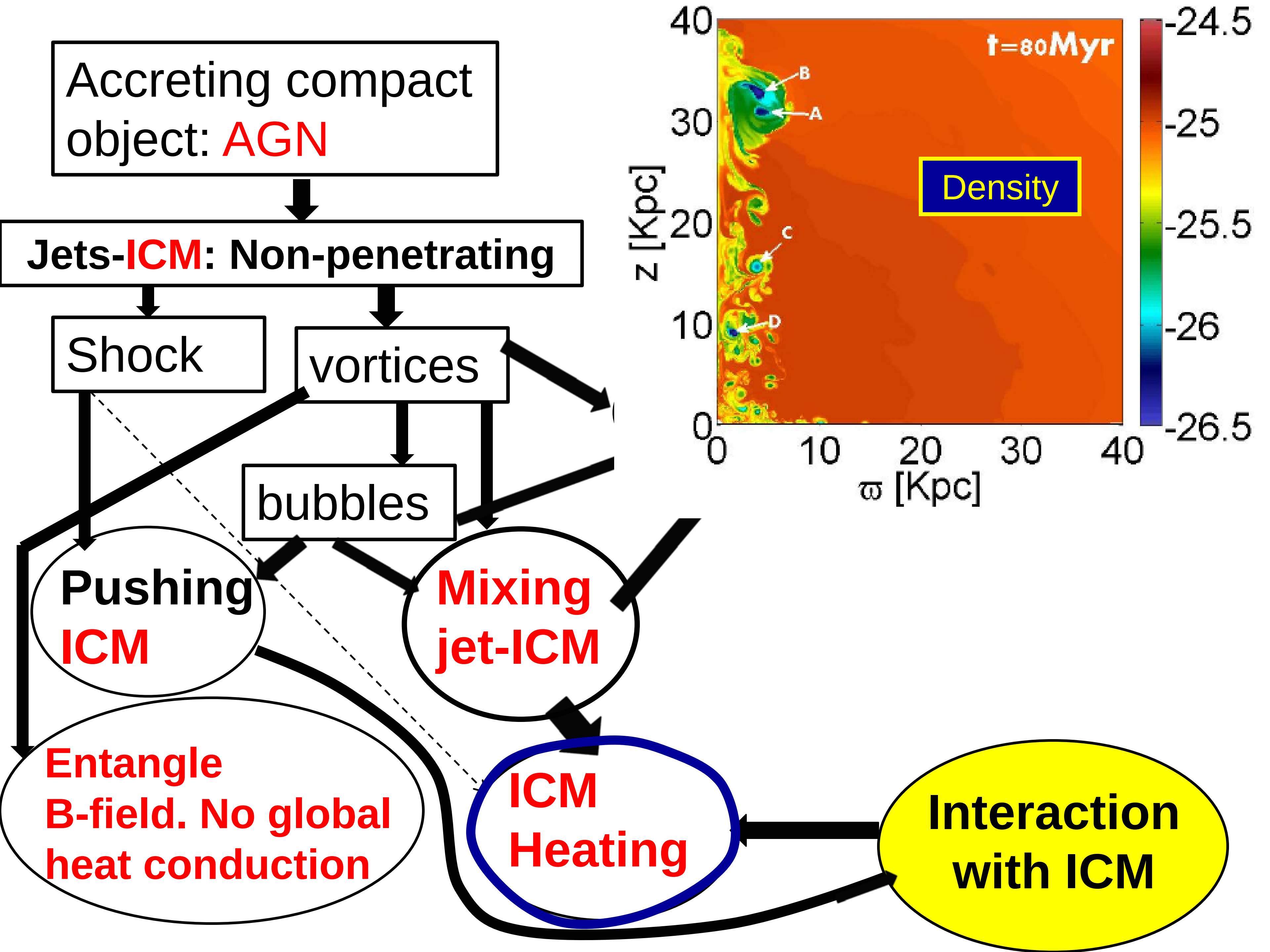

Accreting compact object: AGN
Jets-ICM: Non-penetrating
Shock
vortices
bubbles
Pushing ICM
Mixing jet-ICM
Entangle B-field. No global heat conduction
ICM Heating

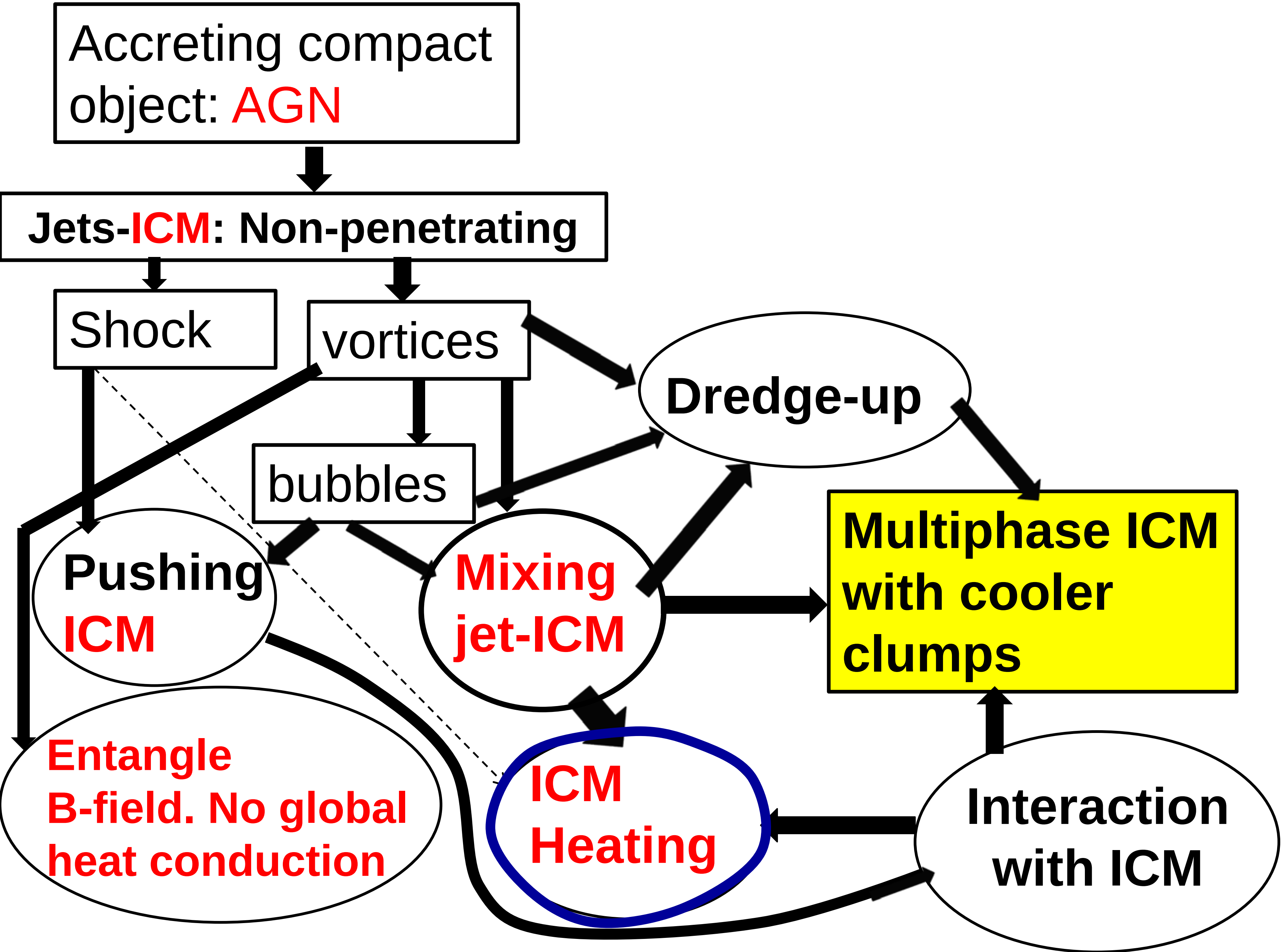

Contour: 1 per cent mixing
t=5Myr
t=20Myr
t=50Myr
t=80Myr
z [Kpc]
ϖ [Kpc]
0
-2
-4
-6
Gilkis & Soker 2012, accepted by astro-ph arXiv:1205.3571 (poster 3)



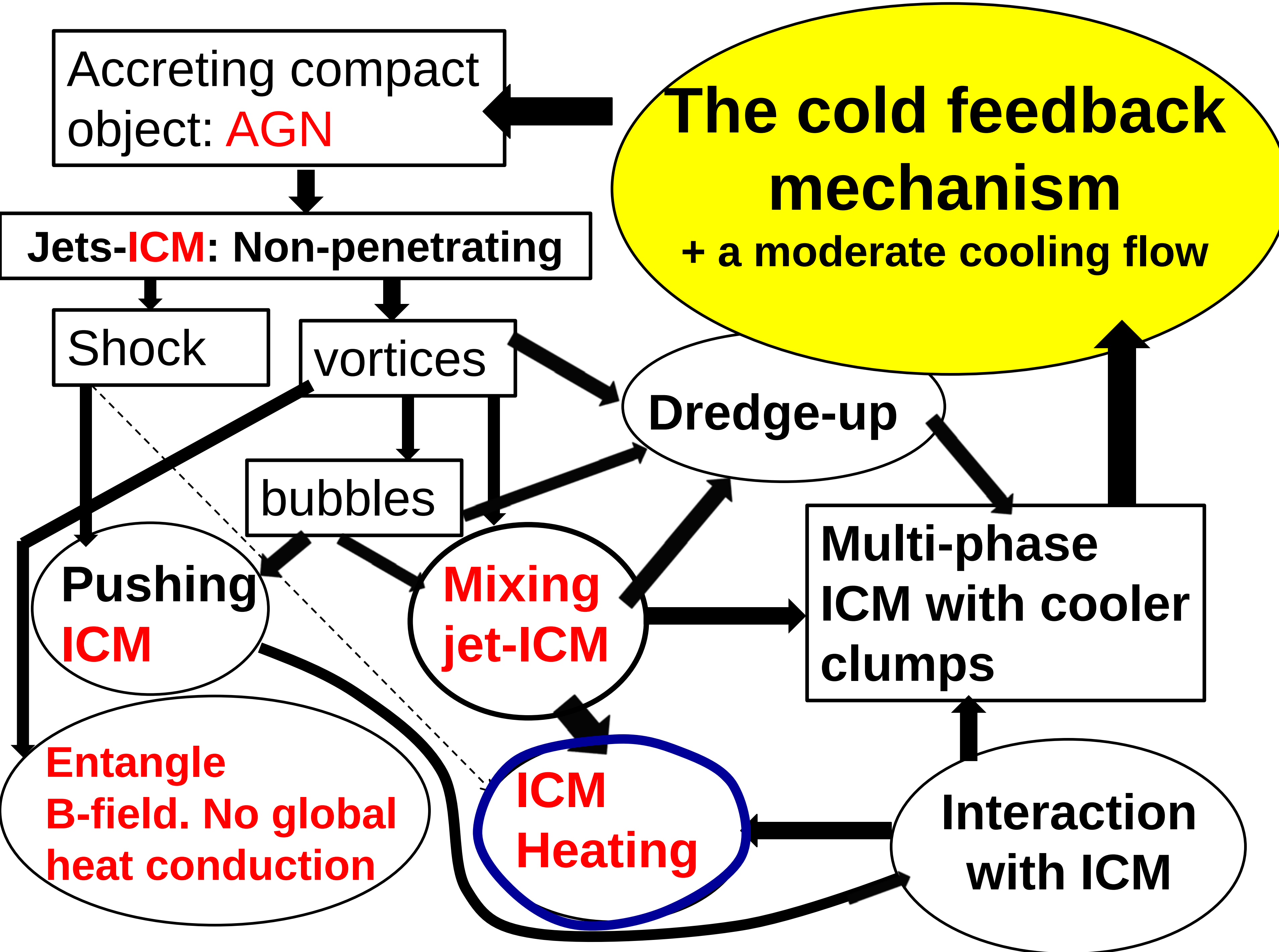
Accreting compact object: AGN
Jets: Non-penetrating
Shock
vortices
bubbles
Pushing ICM
Mixing jet-ICM
Sound waves
Entangle B-field. No global heat conduction
ICM Heating
t=20Myr
z [Kpc]
ϖ [Kpc]
0
7
14
21
28
1
2
3
4
Log(velocity) showing sound waves


Accreting compact object: AGN
Jets-ICM: Non-penetrating
Shock
vortices
Dredge-up
bubbles
Pushing ICM
Mixing jet-ICM
Entangle B-field. No global heat conduction
ICM Heating
Interaction with ICM


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
Interaction with ICM
t=80Myr
B
A
C
D
Density
z [Kpc]
ϖ [Kpc]
0
10
20
30
40
-24.5
-25
-25.5
-26
-26.5



Accreting compact object: AGN
Jets-ICM: Non-penetrating
Shock
vortices
bubbles
Dredge-up
Pushing ICM
Mixing jet-ICM
Multiphase ICM with cooler clumps
Entangle B-field. No global heat conduction
ICM Heating
Interaction with ICM

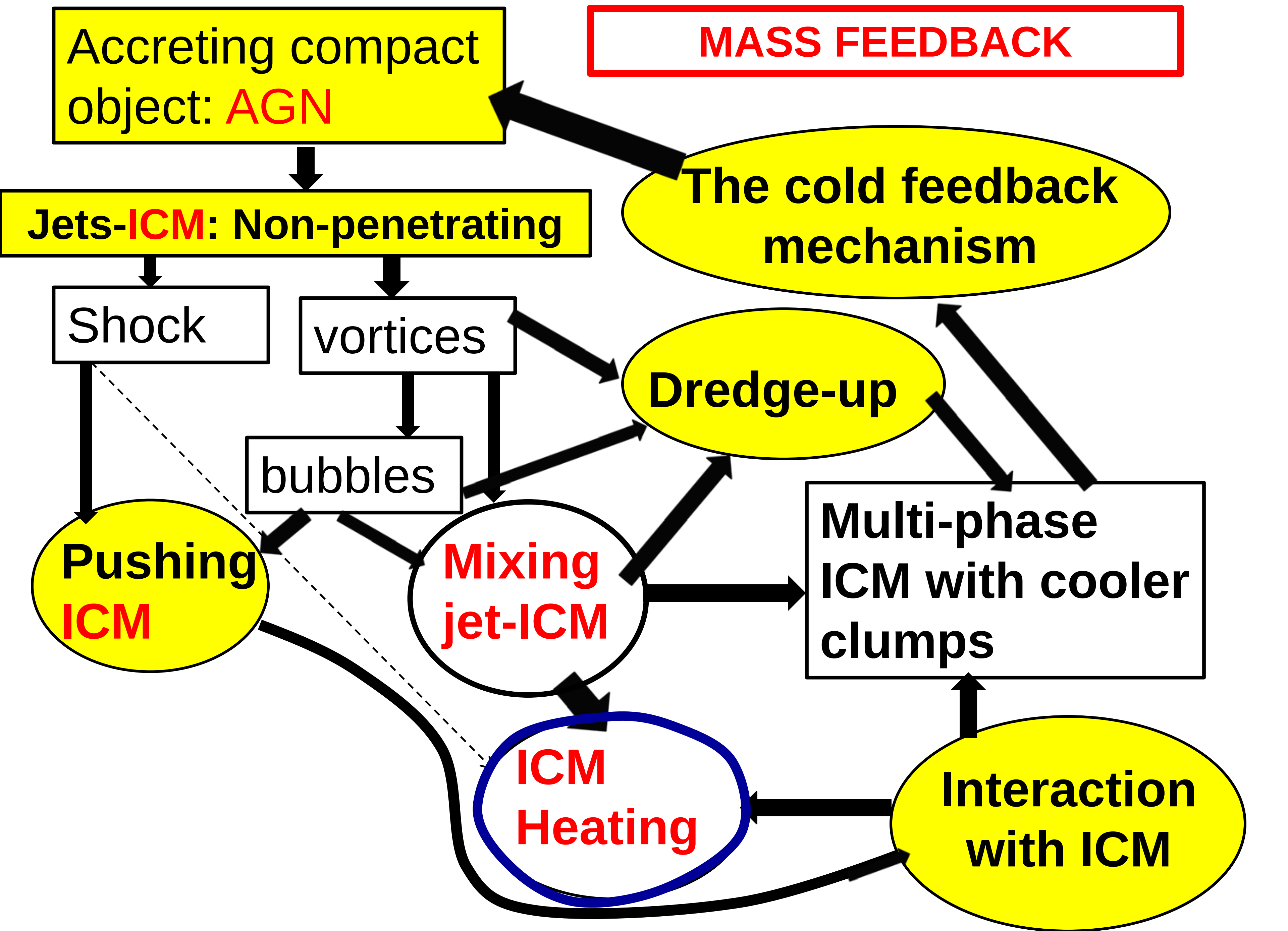

Accreting compact object: AGN
The cold feedback mechanism
+ a moderate cooling flow
Jets-ICM: Non-penetrating
Shock
vortices
Dredge-up
bubbles
Multi-phase ICM with cooler clumps
Pushing ICM
Mixing jet-ICM
Entangle B-field. No global heat conduction
ICM Heating
Interaction with ICM

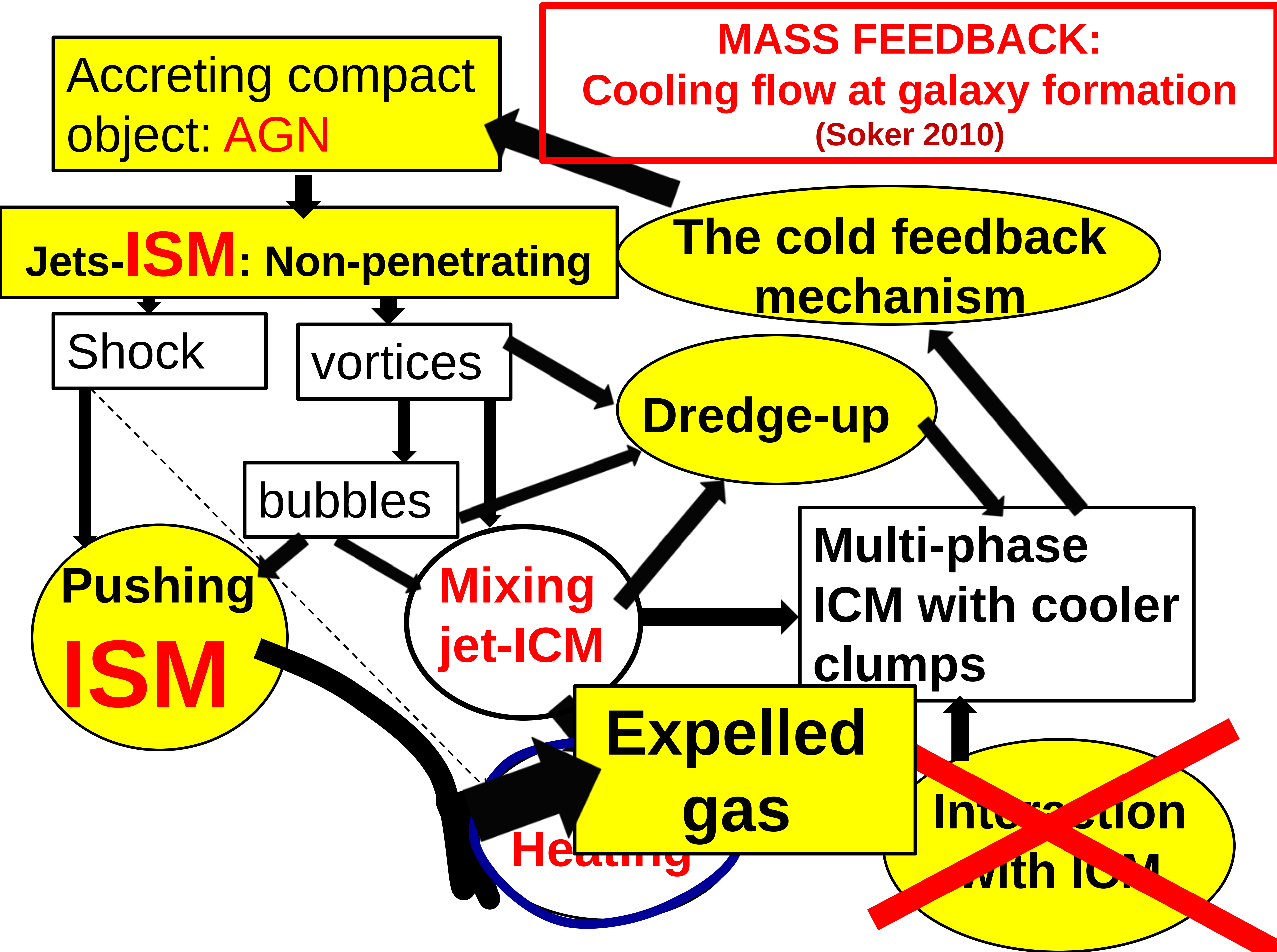
Note that Bondi accretion is a complete failure

(see poster 6)

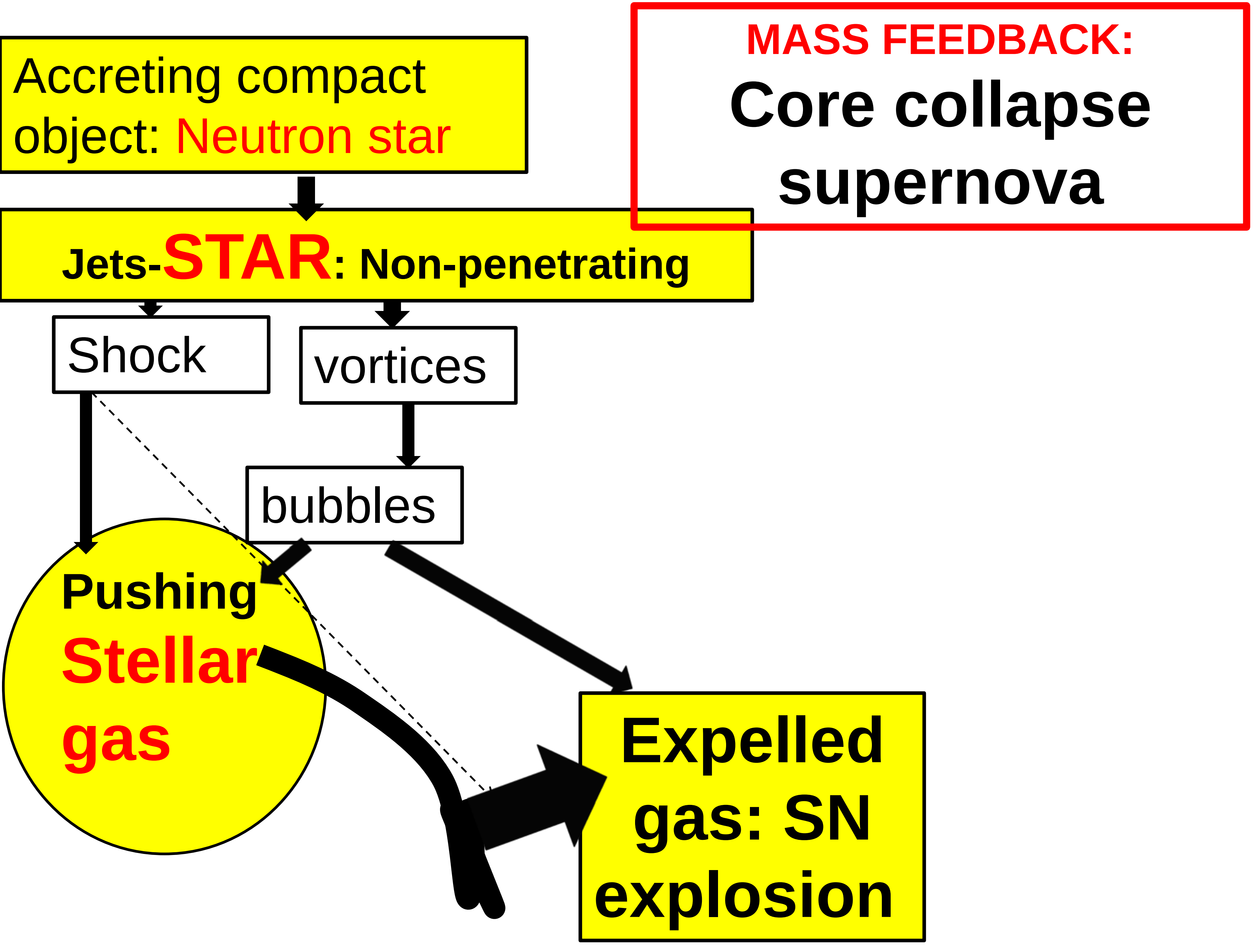
The ***cold feedback mechanism*** (Pizzolato & Soker 2005, 2010) is supported by observations of cold gas and by recent theoretical studies

(e.g., Revaz et al. 2008; Pope 2009; Wilman 2009, 2011; Nesvadba et al. 2011; Gaspari2012a ,b; McCourt et al. 2012; Sharma et al. 2012; Farage et al. 2012)


MASS FEEDBACK
Accreting compact object: AGN
Jets-ICM: Non-penetrating
The cold feedback mechanism
Shock
vortices
Dredge-up
bubbles
Pushing ICM
Mixing jet-ICM
Multi-phase ICM with cooler clumps
ICM Heating
Interaction with ICM



MASS FEEDBACK:
Cooling flow at galaxy formation
(Soker 2010)
Accreting compact object: AGN
Jets-ISM: Non-penetrating
The cold feedback mechanism
Shock
vortices
Dredge-up
bubbles
Multi-phase ICM with cooler clumps
Pushing ISM
Mixing jet-ICM
Expelled gas


MASS FEEDBACK:
Core collapse supernova
Accreting compact object: Neutron star
Jets-STAR: Non-penetrating
Shock
vortices
bubbles
Pushing Stellar gas
Expelled gas: SN explosion

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 ACCRETIO
- 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 <u>not</u> 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; Gaspari2012a ,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.

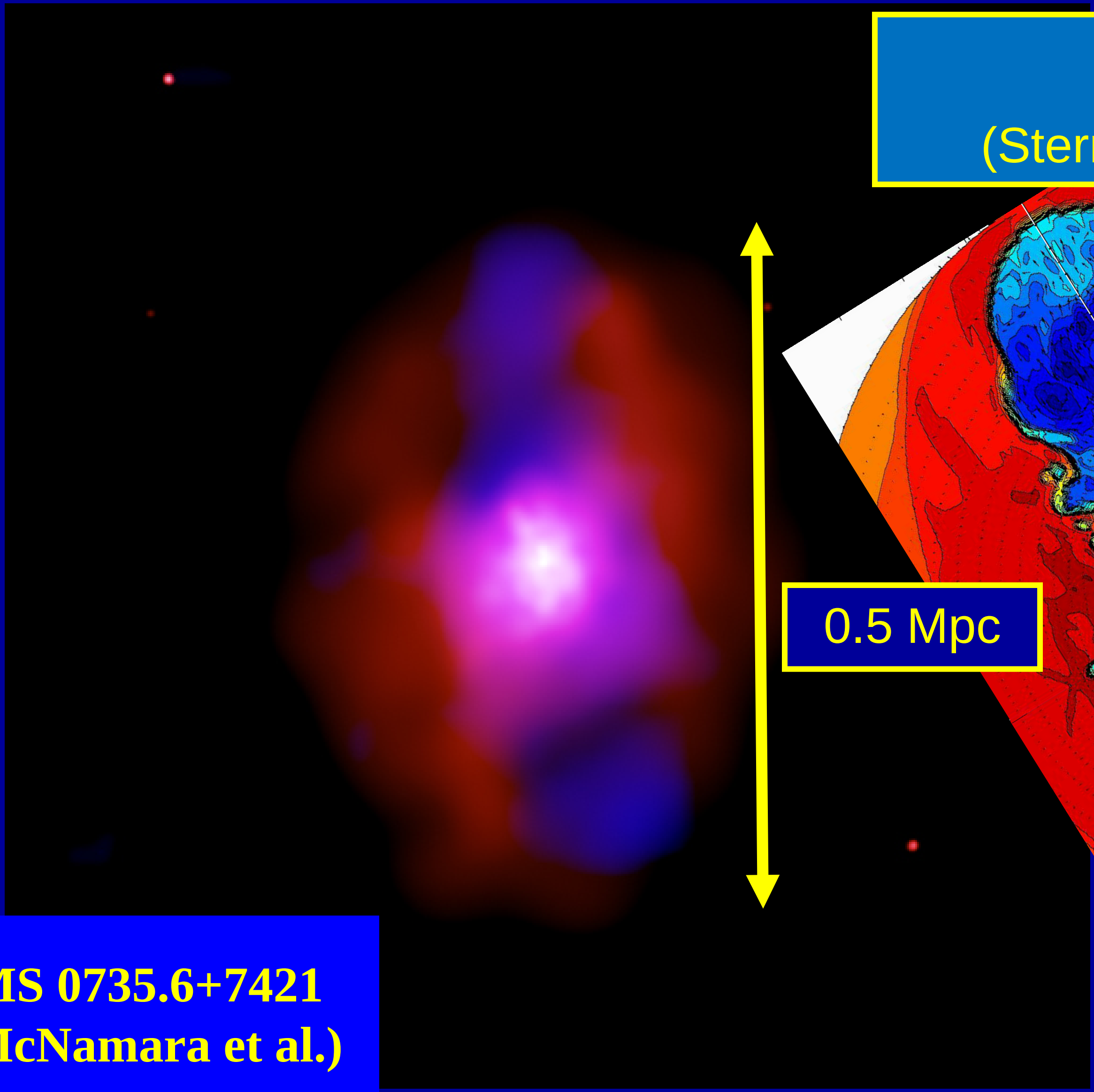
➔ Larger mass removal than star formation might occur in galaxy formation.

➔ This is the feedback mode we propose for MS 0735.6+7421 (no need for BH spin) next page

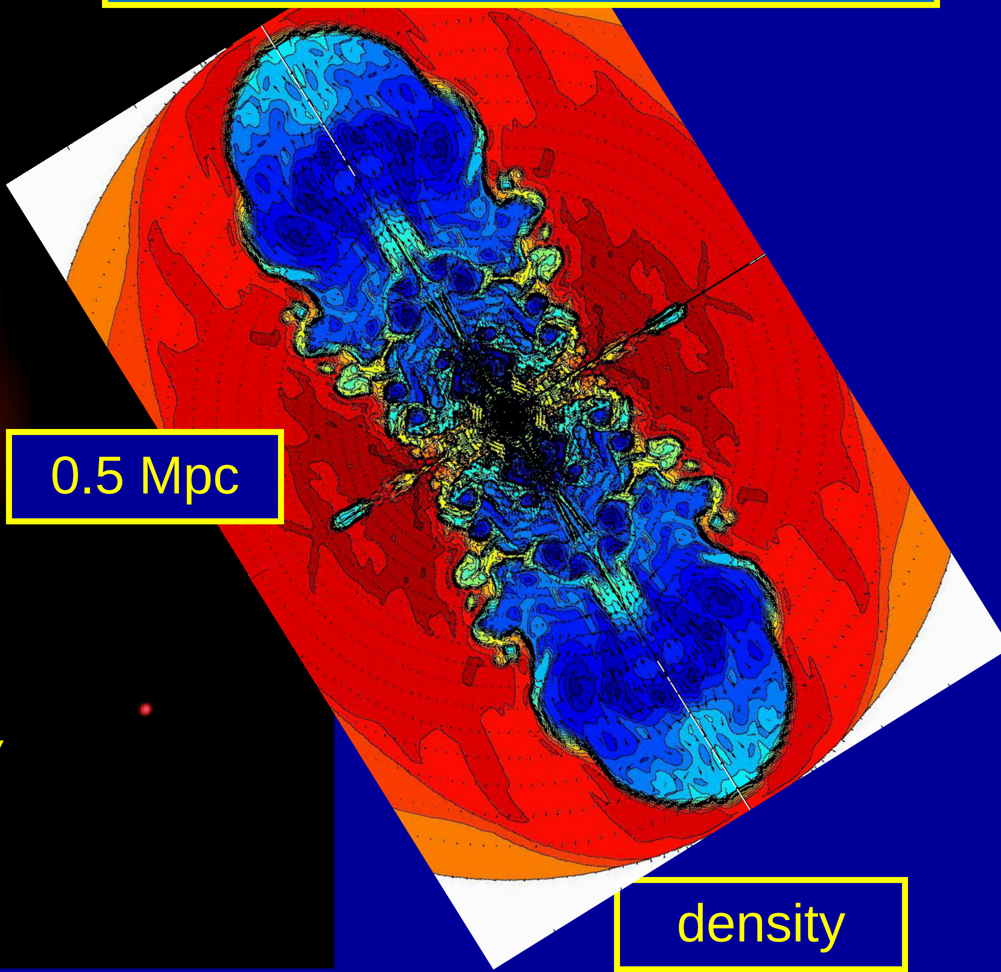
➔ MS 0735.6+7421

2.5D simulation

(Sternberg & Soker 2009)



0.5 Mpc



density

MS 0735.6+7421
(McNamara et al.)

MS 0735.6+7421

Accretion power, not spin power:

Accreted mass: $4\times10^{8}\left(\varepsilon/0.1\right)^{-1}\,\mathrm{M}_{\odot}$

Mass in jets: $8\times10^{9}\left(v/0.1c\right)^{-2}\,\mathrm{M}_{\odot}$

Allowed star formation $\sim10^{8}$ yr ago: $\sim10^{9}\mathrm{M}_{\odot}$

Star foramtion $\ll$ Expelled mass

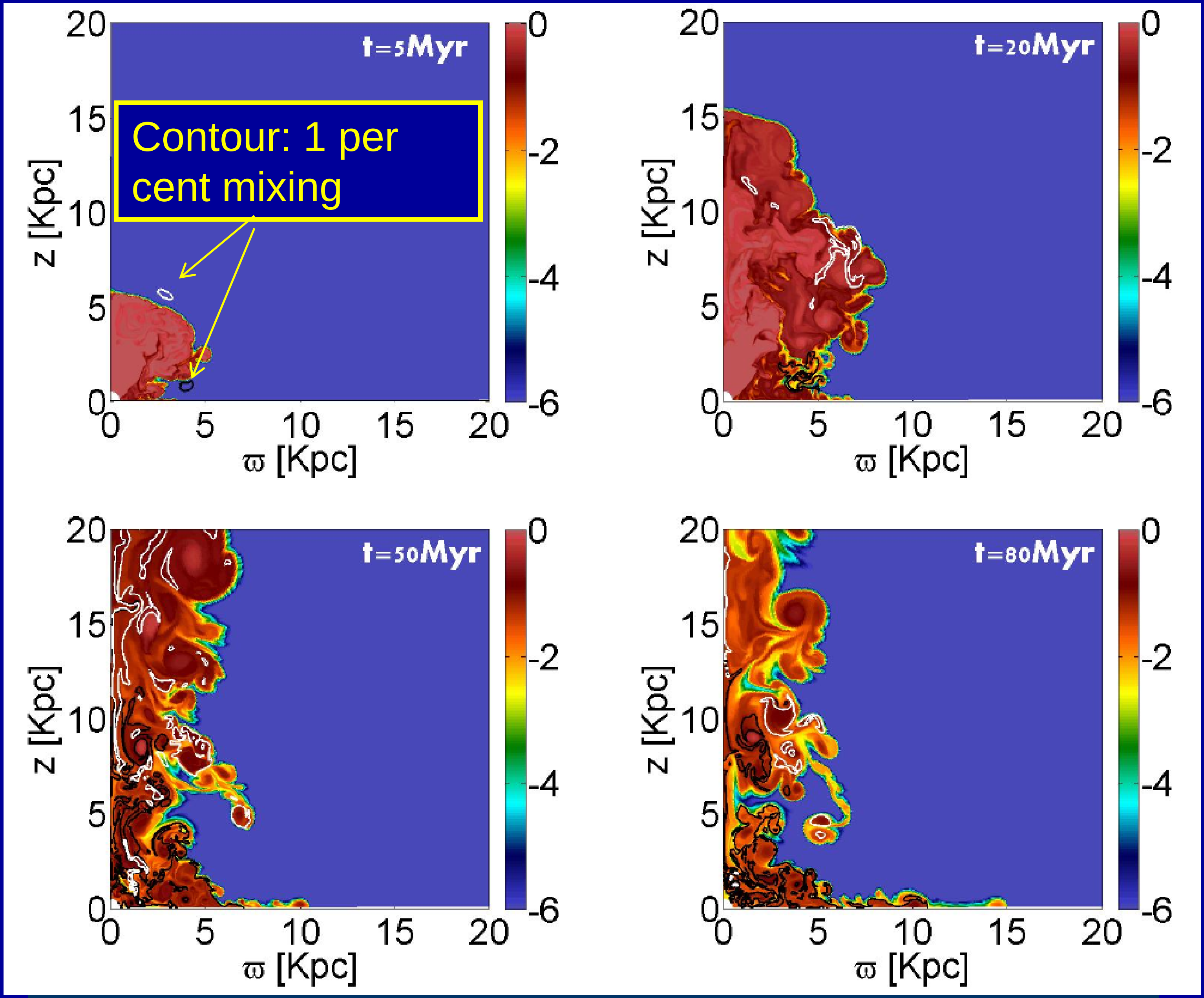
(For low star formation see also Nesvadba et al. 2011)

Heating

(1) Vortices play a key role in the jets-ICM interaction process (see posters by Gilkis and by Rafaelovich):

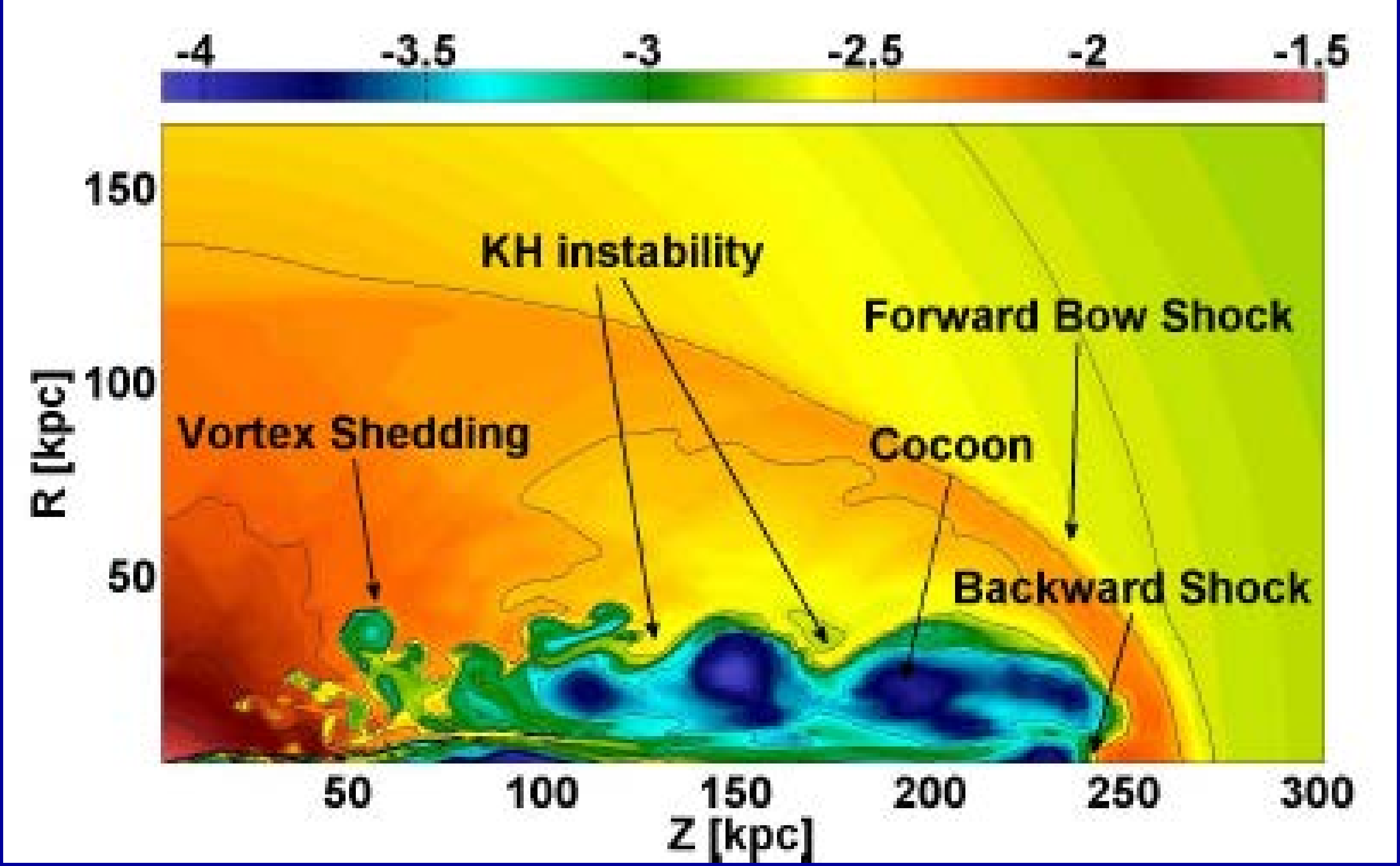
- Determine the morphology .
- Single jet-episode can excite many sound waves.
- Single jet-episode can form a chain of bubbles.
- Heating is mainly by mixing in small vortices (not by shocks!).
- Heating works perpendicular to the jets' axis.

(2) Observed morphologies require precessing, or wide jets, or ICM motion. This can remove huge amount of mass from the center.



Gilkis & Soker arXiv:1205.3571 (poster 3)

CHAIN OF X-RAY DEFICIENT BUBBLES BY A SINGLE JET ACTIVITY EPISODE



Refaelovich & Soker arXiv:1205.3661 (poster 7)

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)

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\bibitem[Mendygral et al.(2012)]{Mendygral2012} Mendygral, P., Jones, T., \& Dolag, K.\ 2012, arXiv:1203.2312

\bibitem[Nesvadba et al.(2011)]{Nesvadba2011} Nesvadba, N.~P.~H., Boulanger, F., Lehnert, M.~D., Guillard, P., \& Salome, P.\ 2011, \aap, 536, L5

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\bibitem[Revaz et al.(2008)]{Revaz2008} Revaz, Y., Combes, F., \& Salom{\'e}, P.\ 2008, \aap, 477, L33

\bibitem[Sharma et al.(2012)]{Sharma2012} Sharma, P., McCourt, M., Quataert, E., \& Parrish, I.~J.\ 2012, \mnras, 420, 3174

\bibitem[Wilman et al.(2011)]{Wilman2011} Wilman, R.~J., Edge, A.~C., McGregor, P.~J., \& McNamara, B.~R.\ 2011, \mnras, 416, 2060

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