

# Bubbles in planetary nebulae and clusters of galaxies: Jet properties<sup>★</sup>

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**Abstract.** I derive constraints on jet properties for inflating pairs of bubbles in planetary nebulae and clusters of galaxies. This work is motivated by the similarity in morphology and some non-dimensional quantities between X-ray-deficient bubbles in clusters of galaxies and the optical-deficient bubbles in planetary nebulae, which were pointed out in an earlier work. In the present Paper I find that for inflating fat bubbles, the opening angle of the jets must be large, i.e., the half opening angle measured from the symmetry axis of the jets should typically be  $\alpha \gtrsim 40^\circ$ . For such wide-opening angle jets, a collimated fast wind (CFW) is a more appropriate term. Narrow jets will form elongated lobes rather than fat bubbles. I emphasize the need to include jets with large opening angle, i.e.,  $\alpha \simeq 30\text{--}70^\circ$ , in simulating bubble inflation in both planetary nebulae and (cooling flow) clusters of galaxies.

**Key words.** galaxies: clusters: general – planetary nebulae: general – intergalactic medium – ISM: jets and outflows

## 1. Introduction

*Chandra* X-ray observations of clusters of galaxies reveal the presence of X-ray-deficient bubbles in the inner regions of many (cooling flow) clusters, e.g., Hydra A (McNamara et al. 2000), Perseus (Fabian et al. 2000, 2003), A 2597 (McNamara et al. 2001), RBS 797 (Schindler et al. 2001), Abell 4059 (Heinz et al. 2002), and Abell 2052 (Blanton et al. 2003). A nice pair of bubbles is seen in the poor cluster HCG 62 (Vrtilek et al. 2002). X-ray-deficient pairs of bubbles, although less prominent, exist also in elliptical galaxies; e.g., in M 84 (Finoguenov & Jones 2001) and NGC 4125 and NGC 4552 (White & Davis 2003). The low X-ray emissivity implies low density inside the bubbles, while the absence of evidence of strong shocks suggests that the bubbles are expanding and moving at subsonic or mildly transonic velocities (Fabian et al. 2000, 2003; McNamara et al. 2000; Blanton et al. 2001). In Paper I (Soker 2003) I pointed out an interesting and not trivial similarity in the morphology and some non-dimensional quantities between pairs of X-ray-deficient bubbles in clusters of galaxies and pairs of optical-deficient bubbles in planetary nebulae (PNs). Examples of PNs with pairs of bubbles are the Owl nebula (NGC 3587; PN G148.4+57.0: Guerrero et al. 2003), Cn 3-1 (VV 171; PN G038.2+12.0; Sahai 2000), and Hu 2-1 (PN G051.4+09.6), which possesses two prominent pairs of bubbles, one pair closer to the center and the other farther out, with inclination between the two symmetry axes

(Miranda et al. 2001). Many other PNs also possess pairs of low emissivity bubbles, although less prominent, e.g., NGC 2242 (PN G170.3+15.8: Machado et al. 1996), and a pair of bubbles within bipolar lobes in M 2-46 (PN G024.8-02.7: Machado et al. 1996). More details of the morphological similarities and the similarity in some non-dimensional variables between pairs of bubbles in these two classes of objects is given in Paper I (see Table 1 there).

The similarity in morphology and in some relevant non-dimensional variables led me to postulate in Paper I a similar formation mechanism. It is commonly accepted that bubbles in clusters are blown by AGN jets (e.g., Brighenti & Mathews 2002; Brüggén 2003; Brüggén et al. 2002; Fabian et al. 2002; Nulsen et al. 2002; Quilis et al. 2001; Reynolds et al. 2001; Soker et al. 2002). This postulate, then, was used to strengthen models for PN shaping by jets (or collimated fast winds: CFW). In particular, the presence of dense material in the equatorial plane observed in the two classes of bubbles constrains the jets and CFW activity in PNs to occur while the AGB star still blows its dense wind, or very shortly after. I argued there that only a stellar companion can account for such fast jets (or CFW). Very recent *Chandra* observations hint at more similarities between the jets in PNs and AGN jets. Kastner et al. (2003) point out that the blobby X-ray appearance of the jets in the symbiotic bipolar nebula Mz 3, probably to become a PN, is similar somewhat to the blob-like X-ray nature of some AGN jets, e.g., Centaurus A (Hardcastle et al. 2003). The similarity is not only to fat bubbles in cluster and bipolar PNs. The general X-ray image of the cooling flow cluster Cygnus A

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(Smith et al. 2002; see their Fig. 2) resembles that of the optical image of many elliptical PNs, e.g., NGC 6826 (Balick 1987; Balick et al. 1998). Cygnus A hot spots, i.e., the heads of the two jets, resemble the structure of pairs of ansae – two opposite dense blobs along the major axis of some elliptical PNs – suggesting that the ansae are formed by jets (see for example the ansae of the PN NGC 7009; Balick 1987; Balick et al. 1998; Sabbadin et al. 2003).

These similarities motivate me to consider a unified scheme for the formation of bubbles in clusters and PNs, based on the inflation of pairs of bubbles by oppositely ejected jets. Although commonly accepted by people studying clusters, the jet-inflated bubble model is still in dispute among people studying PNs. In particular, it is not widely accepted that jets that shape bipolar PNs – those with two large lobes and an equatorial waist between them – are blown by a binary companion. As argued in several papers (Paper I and references therein), more and more observations, including the similarity in morphology discussed above, point to jets blown by a binary companion in bipolar PNs (but not in all PNs).

In the present Paper I study in more detail the conditions under which more or less spherical bubbles are formed, as opposed to the case where a propagating jet inflates a long narrow region. A “fat” low-density inflated region, more or less spherical but not necessarily exactly so, is termed in the present paper a fat bubble (e.g., as in the Owl nebula), while an elongated low density inflated region is termed lobe, e.g., as in OH 231.8+4.2 (Bujarrabal et al. 2002), and He2-115 (Sahai & Trauger 1998).

## 2. Jet propagation in planetary nebulae

The flow structure is of a jet flowing into the dense circumstellar material, which is the expanding AGB wind. The speed of the material inside the jet is  $v_j$ , while the jets’ head propagates at speed  $v_h < v_j$ . The slow wind speed is  $v_s < v_h$ . The aim here is to examine the conditions for the formation of fat bubbles. The condition is that the expansion speed of the bubble surface relative to the slow wind  $v_b$  be faster than the propagation speed of the jet’s head relative to the slow wind

$$v_{hs} \equiv v_h - v_s < v_b \quad \text{for spherical bubble formation.} \quad (1)$$

If, on the other hand,  $v_{hs} > v_b$ , the expanding bubble formed by the jet lags behind the jet’s head, and an elongated lobe, rather than a fat bubble, is formed (Soker 2002; Lee & Sahai 2003). The condition in Eq. (1) implies that the jet is slow-propagating, with its velocity relative to the slow wind speed given by momentum conservation, which here reads (see Eq. (1) in Soker 2002)

$$v_{hs} \simeq \left( \frac{\dot{M}_j v_j}{\beta \dot{M}_s v_s} \right)^{1/2} v_s, \quad \text{for } \rho_s \gg \rho_j \quad (2)$$

where  $\beta$  is defined such that the jet expands into a solid angle of  $\Omega_j = 4\pi\beta$ , and  $\rho_s(r)$  and  $\rho_j(r)$  are the density of the slow wind and jet at a distance  $r$  from the center, respectively.  $\dot{M}_s$  and  $\dot{M}_j$  are the mass loss rates into the slow wind and one jet, respectively; both are constant, and defined positively.

The jet deposits kinetic energy in a power of  $\sim 0.5 \dot{M}_j v_j^2$  into the bubble. The radius of the bubble as a function of time  $t$ , can be approximated by using the results of Castor et al. (1975),

$$R_b = 0.76 \left( \frac{0.5 \dot{M}_j v_j^2}{\rho_s} \right)^{1/5} t^{3/5}, \quad (3)$$

where  $\rho_s = \dot{M}_s / (4\pi v_s r^2)$ . The expansion velocity of the bubble’s surface relative to the slow wind is

$$v_b = 0.6 R_b / t = 18 \left( \frac{v_j}{400 \text{ km s}^{-1}} \right)^{2/5} \left( \frac{\dot{M}_j}{0.01 \dot{M}_s} \right)^{1/5} \times \left( \frac{v_s}{10 \text{ km s}^{-1}} \right)^{1/5} \left( \frac{z}{10^{17} \text{ cm}} \right)^{2/5} \left( \frac{t}{1000 \text{ yr}} \right)^{-2/5} \text{ km s}^{-1}, \quad (4)$$

where the expression for  $\rho_s$  was used, and  $z$  is the coordinate along the propagation direction of the jet, with the origin at the origin of the jet. With the parameters used in the last equation, Eq. (2) gives  $v_h \sim 10[1 + 2(\beta/0.1)^{-1/2}] \text{ km s}^{-1} \sim 30 \text{ km s}^{-1}$ , where  $\beta = 0.1$  is for a jet with a half opening angle (i.e., measured from its symmetry axis) of  $\alpha = 37^\circ$ . The distance of the jet’s head from the source at time  $t$  is given by

$$z_h \sim 10^{17} \left[ \frac{1}{3} + \frac{2}{3} \left( \frac{\beta}{0.1} \right)^{-1/2} \right] \left( \frac{t}{1000 \text{ yr}} \right) \text{ cm.} \quad (5)$$

This is the reason for the scaling of  $z$  in Eq. (4). Note that what matters is the ratio  $z/t$ , which changes slowly, if at all, with time. Substituting  $v_{hs}$  from Eq. (2), and  $v_b$  from Eq. (4) in condition (1) for inflating a fat bubble, gives the condition of spherical bubble formation in the form

$$1 \lesssim \frac{v_b}{v_{hs}} = 0.9 \left( \frac{v_j}{400 \text{ km s}^{-1}} \right)^{-1/10} \left( \frac{\dot{M}_j}{0.01 \dot{M}_s} \right)^{-3/10} \times \left( \frac{\beta}{0.1} \right)^{1/2} \left( \frac{v_s}{10 \text{ km s}^{-1}} \right)^{-3/10} \times \left( \frac{z}{10^{17} \text{ cm}} \right)^{2/5} \left( \frac{t}{1000 \text{ yr}} \right)^{-2/5} \text{ km s}^{-1}. \quad (6)$$

From Eq. (5) the ratio  $z/t$  does not change much in different relevant cases. Also, the slow wind speed is  $v_s \sim 10 \text{ km s}^{-1}$  for all relevant AGB stars. The condition for fat-bubble inflation becomes mainly a condition on the jet’s properties

$$\beta \gtrsim 0.12 \left( \frac{v_j}{400 \text{ km s}^{-1}} \right)^{1/5} \left( \frac{\dot{M}_j}{0.01 \dot{M}_s} \right)^{3/5}. \quad (7)$$

Namely, more or less spherical fat bubbles will be inflated by non-well collimated jets. For these jets, a more appropriate term is CFW (collimated fast wind).

For small angles  $\beta \simeq \alpha^2/4$ , and the last condition can be written for the half opening angle of the jet

$$\alpha \gtrsim 40^\circ \left( \frac{v_j}{400 \text{ km s}^{-1}} \right)^{1/10} \left( \frac{\dot{M}_j}{0.01 \dot{M}_s} \right)^{3/10}. \quad (8)$$

The scaling of the jet (or CFW) properties used here is appropriate for a jet blown by a main sequence companion, because the jet’s speed is of the order of the escape velocity. The mass loss rate into the jets – two oppositely blown jets – is quite

high, e.g., a companion accreting a fraction of 0.2 of the AGB wind, and blows a fraction of 0.1 of the accreted mass into the two jets. In this case, the last condition implies that the jets, or more appropriately a CFW, will be non-well collimated. This is reasonable for a close main sequence companion, since the accretion disk will not be extended. The main sequence companion can reside at larger distances, but not too large  $a \lesssim 20$  AU, otherwise the jet will be weak and the bubble will not be inflated much.

At the other extreme the jets may be well collimated, and their mass deposition rate very low  $\dot{M}_j \ll 0.01 \dot{M}_s$ . For the bubbles to be fat, the jet's speed must be high. For example, for  $\dot{M}_j = 10^{-4} \dot{M}_s$  and  $v_j = 5000 \text{ km s}^{-1}$ , condition (8) reads  $\alpha \gtrsim 10^\circ$ . These parameters are appropriate for a widely separated,  $a \sim 50$  AU, white dwarf companion.

For a large pair of bubbles to be observed in PNs there are two other conditions, in addition to the condition derived here. First, the jet should be strong enough to inflate a large bubble that expands fast enough, i.e., faster than the expansion speed of the slow wind,

$$v_{\text{hs}} \gtrsim v_s. \quad (9)$$

The condition on the jet's properties implied by this inequality can be derived from Eq. (4). Second, the jet's material should not cool fast. This condition is that the bubble starts to expand close to the center,  $z \lesssim 10^{17} \text{ cm}$ . The location where the bubble starts to expand is given by Eq. (6) in Soker (2002). Basically, keeping the other parameters as used in this section, it constrains the jet's speed to

$$v_j \gtrsim 150 \text{ km s}^{-1}. \quad (10)$$

Finally, I note that the conditions on the jet's properties given in Eqs. (8) (or (6)), (9) and (10), were derived for the flow occurring before ionization and the spherical fast wind from the central post-AGB star start. These are likely to erode the bubble; in particular, after ionization the thermal pressure of the slow wind material can't be neglected any longer. Therefore, the real constraints on jets to inflate observable fat bubbles in PNs are somewhat stronger than those given by these equations.

### 3. Jet propagation in clusters

There are several significant differences between bubble inflation in PNs and clusters. (1) In clusters the thermal pressure of the ambient gas is non-negligible. (2) In clusters the ambient medium does not flow outward. (3) The inflating jets in clusters may be relativistic, and the magnetic pressure inside the bubble can be large. (4) In clusters the bubbles can be observed as they form, unlike in PNs, where they are observed long after the jets have ceased (old bubbles may be observed in clusters – termed ghost-bubbles – as in the Perseus cluster; Fabian et al. 2000). However, as argued in Paper I, these don't prevent a similar bubble-formation mechanism in PNs and clusters.

Following Soker et al. (2002) I neglect the ambient pressure and use the results of Castor et al. (1975), as in the previous section. The expansion velocity of the bubble is given by Eq. (20)

of Soker et al. (2002), which is written here as

$$v_b(\tau_I) \simeq 720 \left( \frac{\tau}{10^7 \text{ yr}} \right)^{-2/5} \left( \frac{\dot{E}_j}{10^{45} \text{ erg s}^{-1}} \right)^{1/5} \times \left( \frac{\rho_c}{10^{-25} \text{ g cm}^{-3}} \right)^{-1/5} \text{ km s}^{-1}. \quad (11)$$

For the ambient density a crude approximation for  $r > 10$  kpc in A 2052 is (Blanton et al. 2001; Soker et al. 2002, their Eq. (16))

$$\rho_c(r) \approx 10^{-25} \left( \frac{r}{10 \text{ kpc}} \right)^{-1} \text{ g cm}^{-3}. \quad (12)$$

Because of the presence of bubbles, it is impossible to know the density prior to bubble inflation in A 2052, so this approximation is more accurate for  $r > 30$  kpc and very crude for smaller radii. By neglecting the magnetic pressure inside the jet and relativistic effects, hence  $\dot{E}_j = \dot{M}_j v_j^2 / 2$ , we can take an equation similar to Eq. (2) in the previous section, and write for speed of the jet's head through the cluster medium (e.g., Krause 2003)

$$v_h \simeq \left( \frac{\dot{E}_j}{2\pi\beta z^2 v_j \rho_c} \right)^{1/2} = 1300 \left( \frac{\dot{E}_j}{10^{45} \text{ erg s}^{-1}} \right)^{1/2} \left( \frac{v_j}{10^4 \text{ km s}^{-1}} \right)^{-1/2} \times \left( \frac{\beta}{0.1} \right)^{-1/2} \left( \frac{\rho_c}{10^{-25} \text{ g cm}^{-3}} \right)^{-1/2} \left( \frac{z}{10 \text{ kpc}} \right)^{-1} \text{ km s}^{-1} \quad (13)$$

where the symbols have their meaning as in Sect. 2. For the parameters used here, at  $z \sim 10$  kpc the cluster density to jet density ratio is  $\sim 100$ . We scaled the jet velocity to the non-relativistic regime, as Omma et al. (2003) do. The velocities (which depend on the time and location)  $v_b$  and  $v_h$  given above, are mildly supersonic, or even subsonic. This means the ambient pressure cannot be neglected for late time. Still, there is justification for neglecting pressure (Soker et al. 2002), in particular in the approximate condition derived below. An accurate expression cannot be derived because of the poor knowledge of the exact density profile in the very inner regions of the cluster. For the scaling used above, the jet reaches a distance of  $r = 10$  kpc in  $\sim 1.4 \times 10^7$  yr. Therefore, the time and distance scaling used above are compatible. Inserting Eqs. (11) and (13) in the condition to inflate a fat bubble  $v_b \gtrsim v_h$  (Eq. (1)), I derive a condition on the half opening angle of the jet (similar to that used in deriving Eq. (8)),

$$\alpha \gtrsim 65^\circ \left( \frac{\dot{E}_j}{10^{45} \text{ erg s}^{-1}} \right)^{3/10} \left( \frac{v_j}{10^4 \text{ km s}^{-1}} \right)^{-1/2} \times \left( \frac{\rho_c}{10^{-25} \text{ g cm}^{-3}} \right)^{-3/10} \left( \frac{z}{10 \text{ kpc}} \right)^{-1} \left( \frac{\tau}{10^7 \text{ yr}} \right)^{2/5}. \quad (14)$$

Because several factors were neglected, as mentioned earlier, the last condition is a crude one. Still, a strong constraint can be deduced from it, namely in order to inflate a fat bubble in cooling flow clusters the CFW should be wide open. Even for  $\dot{E}_j \simeq 10^{44} \text{ erg s}^{-1}$  and  $v_j \simeq 3 \times 10^4 \text{ km s}^{-1}$ , Eq. (14)

gives  $\alpha \gtrsim 20^\circ$ . The jets which inflated the bubbles in the cluster A 2052 were probably such jets. (Weak relativistic jets can be narrow though.) This may point to a significant difference between the AGN activity in normal large elliptical galaxies, and the AGN activity of the cD galaxies in cooling flow clusters. Keeping in mind the uncertainties in the derivations of the last two sections, the conditions on the opening angle of the CFW (jets) in PNs and clusters to inflate fat bubbles are similar. This further strengthens the idea of a unified process.

#### 4. Comparison with numerical simulations

Most numerical simulations of jets aim at a specific environment. I could not find in the literature simulations of conical, rather than cylindrical, jets propagating into a denser medium in the parameter-space relevant to the present cases. This is the main motivation for the order-of-magnitude estimates presented in this paper: to encourage simulations with wide-angle jets.

The most relevant simulations in the literature are in a very recent paper by Omma et al. (2003), who conduct numerical simulations of non-relativistic jets propagating into a cooling flow cluster environment. They simulate two cases where they inject cylindrical jets, one case with a jet radius of  $r_{\text{jet}} = 2$  kpc, and the other with  $r_{\text{jet}} = 3$  kpc. Close to the source, where the distance along the jet axis is not much larger than the jet's diameter  $z \lesssim 2r_{\text{jet}}$ , they obtain an inflated fat bubble. As the cylindrical jet expands to larger distances,  $z \gtrsim 2r_{\text{jet}}$ , the bubble loses its general spherical structure, and it is detached from the center. Such simulations cannot reproduce fat bubbles as in Perseus or A 2052, unless the radius of the simulated jets at injection is very large. They do reproduce structures similar to the detached (from the center) bubbles in M 87 (Virgo A; see Fig. 15 of Omma et al. 2003) and Hydra A. The wider jet in the simulations of Omma et al. (2003) forms fatter bubbles and proceeds at a lower velocity. This implies that at a specific location in the simulated cluster environment, when the jet radius is larger than some critical radius, a bubble is formed rather than a narrow cocoon. However, eventually the jet proceeds forward faster than the bubble expands (until it slows down when injection ends). To maintain a bubble attached to the center, or close to it, the jet radius should increase, i.e., a conical jet, as was shown in the previous section of the present paper.

A more quantitative comparison is possible. The ambient density, as from David et al. (2001), is  $\rho_c \simeq 10^{-25}$  g cm $^{-3}$ , and their injection power and velocity are  $\dot{E}_j = 6 \times 10^{43}$  erg s $^{-1}$  and  $V_j = 10^4$  km s $^{-1}$ , respectively. Substituting these values in Eq. (14) gives  $\alpha \gtrsim 28^\circ$ , for the same scaling of time and distance as in Eq. (14). For the  $r_{\text{jet}} = 2$  kpc jet this implies  $z \simeq 4$  kpc, while for  $r_{\text{jet}} = 3$  kpc this implies  $z \simeq 6$  kpc. This value of  $r_{\text{jet}}/z \sim 0.5$  explains why the bubbles in Omma et al. (2003) simulations lose their ‘‘fatty’’ structure when the jet reaches a distance of about the jet diameter. Although it is hard to compare the cylindrical-jet simulations of Omma et al. (2003) with the present paper, the above discussion suggests that there is solid ground for the order of magnitude analysis conducted here.

There are less relevant simulations, which none the less shed some light on the present analysis; for these, only qualitative comparison is meaningful. Krause & Camenzind (2003b) find that as they inject the jet a spherical bubble is formed around the jet. Later the bubble becomes elongated, first to an elliptical shape, then to a narrow extension along the jet. This is compatible with the results of Omma et al. (2003) cited above. This is along the claim of the present paper that a wide-angle jet will form a long-lasting large spherical (fat) bubble. Loken et al. (1995) simulate the formation of wide-angle tailed radio sources, which are thought to form when a radio galaxy which blows two jets moves through the intracluster medium. This is quantitatively similar to precessing jets, in that the jets continuously encounters fresh ambient medium. Their three-dimensional simulations clearly show how jets are disrupted, and large bubbles are formed. These simulations support the claims that wide-angle jets or precessing jets can be disrupted more easily and form fat bubbles. Lee et al. (2001) conduct isothermal simulations of jets and winds from young stellar objects. Despite that isothermal flows are less favorable to inflate bubbles than the cases studied here where radiative cooling time is long, Lee et al. (2001) find that the overall width of the jet-driven shell is smaller than that of the wide-angle wind-driven shell. This supports the notion that wider flows form fatter bubbles (shells in their case).

Finally, it should be noted that recollimation of wide-angle jets, such that the opening angle  $\alpha$  significantly decreases, will not much change the conclusions. To recollimate a continuous jet the ambient medium must impart transverse momentum to the jet's material. For a wide-angle jet, the transverse speed is not much below the jet's speed, a factor of  $\sim \sin \alpha$ . Therefore, the ambient medium and the jet's material will go through strong shocks, heat-up, and form hot low density bubbles, as assumed in the previous sections.

#### 5. Discussion and summary

Paper I pointed out the similarities in morphology and some non-dimensional quantities between X-ray-deficient bubbles in clusters of galaxies and the optical-deficient bubbles in PNs. The comparison here, as in Paper I, is for pairs of fat, almost spherical, bubbles in these two classes of objects. The main goal of the first paper was to point out these similarities; from that I argue that pairs of fat bubbles in PNs are formed by jets, most probably blown by a companion. In the present paper the main goal is to examine some similarities between the jets in these two classes of systems, assuming indeed that jets, or CFW (for collimated fast wind) blow the fat bubbles. The main conclusion is that for such bubbles to be formed, in both classes of systems the opening angle of the jets must be large. In Eq. (8) for PNs, and Eq. (14) for clusters, the values for the half opening angle (measured from the symmetry axis) for blowing fat bubbles are given. For such wide-opening angle jets, a CFW is a more appropriate term. Narrow jets will form elongated lobes rather than fat bubbles (Krause 2003; Krause & Camenzind 2003a); some examples of these are given in Sect. 1. Presently, most simulations (e.g. Krause 2003; Krause & Camenzind 2003a, and references in these papers) simulate

narrow jets, and examine the influence of the ambient density ratio. The present study suggests that the opening angle is a crucial parameter.

Beside the similarities studied in Paper I and here, other similar processes may exist. An example is heat conduction from the hot bubbles to the cooler environment. In the past this process was studied in more detail for PNs (Soker 1994; Zhekov & Myasnikov 2000; Soker & Kastner 2003). This process, among other things, was claimed to be able to heat somewhat the cooler ( $\sim 10^4$  K) environment. The heating will not be isotropic because it is regulated by magnetic fields (Soker 1994; Zhekov & Myasnikov 2000). With the search for heating sources of the radiatively cooling ICM in cooling flow clusters, heat conduction from the hot bubble to the cooler ( $\sim 1-7 \times 10^7$  K) ICM brought this process to the attention of the cooling flow community. The hot spots found around the X-ray depression region in the cooling flow cluster in MKW3s (Mazzotta et al. 2002) may have been heated by such heat conduction, as suggested by some of these authors during the Cooling Flow meeting held in Charlottesville, Virginia, in June 2003.

I summarize by emphasizing again the need to include jets with large opening angles, i.e., half opening angles of  $\alpha \approx 30-70^\circ$ , in simulating both PNs and cooling flow clusters (and galaxies). Such jets are more appropriately called CFW.

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