Deceleration of SS 433 radio jets

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Abstract

The mildly relativistic jets of SS 433 are believed to inflate the surrounding supernova remnant W 50 depositing in its expansion possibly more than 99% of their kinetic energy (Dubner et al. 1998). Where and how this transformation of energy is curried out, it is not yet known. What can we learn from it that the jets decelerate and the deceleration is non-dissipative, i.e. radiatively dark. In this paper we unclose the observed deviations of the precessing radio jets of SS 433, within a few arcseconds from a jets source, from the ballistic track, described by the kinematic model, as a signature of the deceleration which, on other hand, issues from the jets colliding with ambient medium. For that we model kinematics of these colliding jets. The ram pressure on the jets is estimated from the observed profile of brightness of synchrotron radiation along the radio jets. We have found that to fit observed locus the radio jets should be decelerated and twisted, additionally to the precession twist, mostly within the first one-fifth of precession period, and further they extend imitating ballistic jets. The fitted physical parameters of the jet model turned out to be physically reliable and characteristic for SS 433 jets that unlikely to be occasional. This model explains naturally, and meets approval by a) the observed shock-pressed morphology of the radio jets and their brightness, b) the observed ~ 10% deflections from the standard kinematic model — just a magnitude of the jet speed decrement in the model, c) regularly observed for the radio jets the precession phase deviation from the standard kinematic model prediction, d) dichotomy of distance to the object, 4.8 kpc vs. 5.5 kpc, determined on the basis of the radio jets kinematics on scales of a sub-arcsecond and several arcseconds. The latter fact once again convinces that the kinematic distance to SS 433 could not be correct without accounting for the jets deceleration.

The model proposed here several reveals evolution of SS 433 radio jets with distance.

1 Introduction

Jets of SS 433 are the brilliant representative of star relativistic jets (see review of Fabrika 2004). In radio wavelengths the jets are viewed from some milliarcseconds to some arcseconds as a corkscrew — a signature of jets precession. Kinematics of the radio jets as well as the shifts of spectral lines of the X-ray (at the distances from a jets source \( z \sim 10^{11} \text{ cm} \)) and optical (at the distances \( z \sim 10^{15} \text{ cm} \)) jets fulfill the same (standard) kinematic model, according to which each element of the jets moves freely (so-called ballistic movement) along the jets axis, which precesses and nutates (Abell & Margon 1979; Hjellming & Johnston 1981; Newsom & Collins 1981). Though the radio jets in the beginning are intimately connected with the optical jets, which are believed to be ballistic (Kopylov et al. 1987), its behaviour some differs: the radio jets departure from kinematics of the optical jets by as much as 10% (e.g. Blundell & Bowler 2004; Schillemat et al. 2004; Roberts et al. 2008); the radio clouds could be found far out of jet axis (e.g. Spencer 1984; Romney et al. 1987); the radio jets appear more continuous vs. the bullet-like optical jets (Borisov & Fabrika 1987); the radio jets are outstanding for the zones of a qualitative change in jet flow at distances of \( 0.050 - 0.100 \) (the radio brightening zone, Vermeulen et al. 1987) and \( \sim 1.5 \) (the reheating zone, observed in X-ray, Migliari et al. 2002). These peculiarities could
be due to the dynamics of the jets. In the environments of SS 433, with the powerful wind of a mass flow rate \( \sim 10^{-4} \, \text{M}_\odot/\text{yr} \) and a velocity \( v_w \sim 1500 \, \text{km/s} \) from supercritical accretion disk, the wind-jet ram pressure might radically influence behaviour of the precessing jets if there was not anisotropy of the wind nor evacuation of gas from the jets channel by previous precession runs of the jets.

Nevertheless the jets should decelerate somewhere on a way to the shell of supernova remnant W50 encircling SS 433: the flight time of the jets with the velocity \( v_j \approx 0.26 \, c \) of the optical jets, where \( c \) is the speed of light, over W50 radius \( R_{W50}/v_j \approx 80 \, \text{pc}/0.26 \, c \sim 1000 \) years is much smaller than the age \( \sim 10^4 \) years of W50. Moreover, on the basis of the X-ray data the jets lose their helical appearance and are decelerated already in interiority of W50 (Brinkmann et al. 2007). And at the same time the jets are dark: only less than 1% of the huge kinetic luminosity \( L_k \sim 10^{39} \, \text{erg/s} \) of the jets goes into jet radiation and heating of W50 and the rest likely goes into mechanical energy of W50, with an unbelievable effectiveness of \( \sim 99\% \) (Dubner et al. 1998; Brinkmann et al. 2007).

Other indications of the deceleration may be the followings:

1. The difference of jet speed in X-ray, at distance \( z \sim 10^{11} \, \text{cm} \), and optical, at \( z \sim 10^{15} \, \text{cm} \), spectral domains — \( 0.2699 \pm 0.0007 \, c \) (Marshall et al. 2002) vs. \( 0.2581 \pm 0.0008 \, c \) (Davydov et al. 2008). This corresponds to the rate of loss of jet kinetic energy \( \dot{W}_k/L_k \approx 26 v_j = 9\% \), if the jet mass flow rate \( \dot{M}_j \) is constant.

2. As Kundt (1987) has already remarked the kinematic distance to the object determined by kinematics of the extended jets (on a scale of several arcseconds), is more than the distance determined by kinematics of the inner jets (on a scale of sub-arcsecond): \( 5.5 \pm 0.2 \, \text{kpc} \) (Hjellming & Johnston 1981; Blundell & Bowler 2004) from unresolved in time images of the extended jets vs. the estimations from inner jets \( 4.9 \pm 0.2 \, \text{kpc} \) (Spencer 1984), \( 4.85 \pm 0.2 \, \text{kpc} \) (Vermeulen et al. 1993) and \( 4.61 \pm 0.35 \, \text{kpc} \) (Stirling et al. 2002) from proper motion of radio knots, and \( 5.0 \pm 0.3 \, \text{kpc} \) (Fejes 1986) and \( 5.0 \pm 0.5 \, \text{kpc} \) (Romney et al. 1987) from unresolved in time images. This dichotomy could be explained by the fact that a priori assumption of the constancy of the speed \( v_j \) in kinematic simulation of really decelerated extended jets leads to an overestimation of the distance \( D \) to SS 433 to meet the observed angular size, which in the first approximation is proportional to the ratio \( v_j/D \). So Roberts et al. (2008) note that if to accept for the extended jets the kinematics with the set \( v_j/D = 0.2647 \, c/5.5 \, \text{kpc} \), the kinematics of the inner jets agrees better with the set \( 0.2647 \, c/5.0 \, \text{kpc} \) or with the velocity greater than that of the optical jets while holding the distance, \( 0.29 \, c/5.5 \, \text{km/kk} \). In this regard, they suggest the variations of the radio jet velocity \( \pm 10\% \).

3. The velocity profile along the radio jets received by Blundell & Bowler (2004, Fig.4), shows variations of \( v_j \) with distance along the jets. Scope of these variations corresponds to the rate of jet speed change \( \leq 0.018 \, c/P_0 \), where \( P_0 \) is the precession period.

Stirling et al. (2004) found that jet model fit to the inner and extended radio jets on the same image is much better when the jet kinematic model with the distance \( D = 4.8 \, \text{kpc} \) enables the deceleration \( 0.02 \, c/P_0 \). What Bell et al. (2011) noticed that a satisfactory fit can be obtained with a constant speed, if to use a larger distance, \( D = 5.5 \, \text{km/kk} \), that supports estimations of the same distance in Blundell & Bowler (2004; Lockman et al. 2008). However, the choice of constant \( v_j \) and \( D = 5.5 \, \text{kpc} \) does not eliminate the above distance dichotomy, resulting from many observations.

Recently was received the brightness profile of synchrotron radio emission along the jets of SS 433 up to a distance of 800 days of flight (Roberts et al. 2010; Bell et al. 2011). Emitting relativistic electrons there are probably accelerated in shock waves resulted from the colliding of the jets with environments (Heavens et al. 1990; Paragi et al. 2002). This profile allows to evaluate the dynamic pressure of the medium on the jets and, as a result, their deceleration. In our work we use this profile for research of the model of the radio jets that satisfies the observed kinematics both internal and external jets at the same distance to an observer.
2 Dynamics of SS 433 jets

The morphology of the radio jets on the maps of Roberts et al. (2008) gives a clear indication of a significant role in its formation of dynamic pressure of the environments. We propose a model in which the jet is quasi continuous and clumped, and the gas from environment swept by jet provides dynamic pressure on the jet surface, resulting in deviation of the jet from ballistic kinematics. The shock waves arising on the surface and spreading inside the jet can cause strong turbulence at density inhomogeneities in the jet and, as a result, strengthen the magnetic field, and very effectively accelerate the relativistic particles, as it is in supernova remnants (Inoue et al. 2012). In contrast to the model of Hjellming & Johnston (1988) in our model the synchrotron radiation of the radio jets occurs not on the surface of homogeneous jets, but at the vicinity of the dense clouds, and adiabatic jets are not expected: the radio jets heat up to temperature $T > 10^7$ K (Migliari et al. 2002).

According to this model, the average internal jet pressure $p_m$, equal to the sum of the pressures of magnetic field $p_b$, relativistic particles $p_e$ and gas $p_g$, should be approximately equal to the dynamic pressure $p_{\text{dyn}}$ on the surface of the jet, neglecting the magnetic field and gas pressure of the environment — we believe their equality:

$$ p_{\text{dyn}} = p_m \equiv p_m(1 + \frac{1}{3\beta_H} + \beta_g), \quad (1) $$

where $\beta_H = \epsilon_H/\epsilon_e$ is the ratio of energies of the magnetic field $\epsilon_H$ and of the relativistic particles $\epsilon_e$, $\beta_g = p_g/p_m$. Profile of the magnetic pressure of $p_m$ along the jet is evaluated using the spectral density of observed synchrotron radiation flux $S_\nu$ (hereinafter brightness) in jet comoving frame of reference, in the assumption of power-law energy spectrum of electrons (e.g. Ginzburg 1979):

$$ p_m \equiv H^2/8\pi = (k_\nu \beta_H \beta_e D^2 S_\nu / V)^{4/7}, \quad (2) $$

where $\beta_c = \epsilon_r/\epsilon_e$ is the ratio of the energy of relativistic particles to the energy of relativistic electrons $\epsilon_e$, $H$ the magnetic field strength, $V$ the volume of the radiating gas within a beam of telescope. In the case of SS 433 coefficient $k_\nu$ equals to $5.47 \cdot 10^7$ for a synchrotron spectral index $\alpha = 0.74$ ($S_\nu \propto \nu^{-\alpha}$), the radiation frequency $\nu = 4.86$ GHz, at which Bell et al. (2011) defined the brightness $S_\nu(t)$ as a function of flight time $t$, and for the frequency range $4.86 \div \infty$ GHz accepted as a whole power-law radiation spectrum of the relativistic electrons. The pressure $p_m$ may be underestimated maximum 2 $+$ 3 times due to uncertainties in the lower border of the synchrotron spectrum.

In our model, the magnetic field inside the jets and, therefore, the region of synchrotron radiation is localized at the vicinity of dense clouds, in the shell of the thickness $l_{\text{sh}}$ approximately equal to the size of clouds $l_{\text{cl}}$, as Inoue et al. (2012) demonstrated in the case of clouds in supernova remnants. For a jet segment of unit length equation (2) is transformed to

$$ p_m = (k_\nu (1 + \frac{1}{3\beta_H} + \beta_g) \beta_H \beta_e \mu m_p \lambda_j D^2 S_\nu/k_\nu k_B T_{\text{cl}})^{4/3} \quad (3) $$

after substituting in equation (2) the volume of the clouds shell

$$ V = \frac{k_\nu M_j}{\rho_{\text{cl}} \lambda_j} = \frac{k_\nu k_B T_{\text{cl}}}{\mu m_p (1 + \frac{1}{3\beta_H} + \beta_g) p_m \lambda_j}, \quad (4) $$

and resolving obtained expression with respect to $p_m$. Here $S_\nu = dS_\nu/dl$ is the differential spectral density of the synchrotron radiation flux, or brightness per a jet unit length, $l$ the jet length, $k_\nu$ the ratio of the volumes of cloud shell and cloud itself, $k_\nu = (2l_{\text{sh}}/l_{\text{cl}} + 1)^3 - 1$ in the case of a spherical cloud, $\rho_{\text{cl}}$ and $T_{\text{cl}}$ the mass density and temperature of the cloud, which gas pressure $p_{\text{cl}} = \rho_{\text{cl}} k_B T_{\text{cl}}/\mu m_p$ is assumed dominant and equal to the pressure $p_m$ of intercloud medium, $M_j$ the rate of jet mass flux contained in the clouds, $\lambda_j$ the jet length per unit of the flight time, otherwise the jet speed in the frame of reference...
corotating with jet, $\mu$ the average relative molar mass of clouds ($\approx 0.6$ for solar abundances), $m_p$ the proton mass, $k_B$ the Boltzmann constant.

Temperature of the clouds presumably increases with the distance $z$ from a jets source, in line with the observed X-ray brightening of the jets [Migliari et al. 2002]. In our model the power-law profile $T_{cl}(z) = T_0 z^n$ was adopted. The following hence model of clouds evolution, given the profiles of pressure and temperature, is limited by a condition on volume filling of the jets by the clouds:

$$f(z) = \frac{M_j}{\rho_c \pi (z \theta_{jr}/2)^2 v_j} = \frac{k_B T_{cl} M_j}{\mu m_p (1 + \frac{1}{3 \mu}) + \beta_n} \frac{1}{\pi (z \theta_{jr}/2)^2 v_j} < 1.$$  \hspace{1cm} (5)

Here it is assumed a conical geometry of the radio jets, with the opening $\theta_{jr}$, and the volume of a jet segment is approximated by the cylinder volume $\pi (z \theta_{jr}/2)^2 v_j$ since the expansion of the jets is negligible: $v_j/z \ll 1$.

The extended radio jets are not showing the nutation pattern, although there are the signs of nutation of the inner radio jets within the zone of brightening [Vermeulen et al. 1993, Mioduszewski & Rupen 2007]. This allows to suggest that the nutation structure is blurring in the radio jets, and they acquire an opening $20^0-28^0$ the nutation cone semi-opening of the optical jets [Borisov & Fabrika 1987]. In this case the angular velocity of the radio jets is the precession one, and the length $\lambda_j$ equals $|v_j(z) - \vec{v}_{\perp}^2(z)|$, where $v_{\phi} = \omega z \sin(\theta_0)$ is the azimuthal velocity of the jets obeying to the precession rotation with the angular velocity $\omega = 2\pi/P_0$ at the inclination $\theta_0$ to rotation axis at the distance $z$ from the source and with the precession period $P_0$. In general, while the distance $z$ increases the vector of jet velocity $v_j(z)$ more and more deviates from the initial velocity vector — hereinafter $Z$-axis of the frame of reference, which co-rotate with the jet, with $Y$-axis directed oppositely to the precession movement, i.e. to vector $\vec{v}_{\perp}^2(z)$.

The brightness profile of the radio jets is approximated as

$$S_\nu(z) = S_0 \exp(-z/\tau)$$  \hspace{1cm} (6)

with the brightness $S_0 = 32.7$ mJy per a beam of telescope of a size $\phi_b = 0^\prime.32$ at $\nu = 4.86$ GHz and at a distance $z = 50^d \times v_j^*$. [Roberts et al. 2010; Bell et al. 2011], the decrement $\tau = 55^{d,9} \times v_j^*$ at flight times $t = 50 \div 250^d$ and $\tau = 115^{d,4} \times v_j^*$ at flight times $t > 250^d$, where $v_j^* = 0.2647 c$ is the fiducial speed. Given the expression [8] for the brightness the differential brightness will be the function $s_\nu(z) = s_0 \exp(-z/\tau)$, with the normalization factor $s_0 = S_0/2 \pi \sinh(l_b/2\tau)$, where $l_b = \phi_b D$ is the linear size of the telescope beam. The differential brightness in dependency on jet length is obtained as $s_\nu(l) = s_\nu(z) v_j(z)/\lambda_j(z)$, where $v_{\perp z}(z)$ is the $z$-component of jet velocity.

At flight times $t < 50^d$ the profile $S_\nu(z)$ is undetermined because of contamination by the radio core. However, the exponential run of the brightness persists down to a flight time of $\sim 10^d$ accordingly to the observations of higher resolution of [Roberts et al. 2008]. Transverse size of the jets at the plane of the sky is smaller than size of the beam, hence the above definition of the differential brightness $s_\nu(z)$ of the jet remains legal at flight times $< \phi_b D/\theta_{jr} v_j \approx 290^d$. Extrapolation of $s_\nu(z)$ in the zone of radio brightening ($5^d,4$) and estimation by formulae [2, 3] gives a magnetic field $0.50$ G, whose difference with the result of [Vermeulen et al. 1987], $0.08$ G, is explained by accounting for the clumping of the jets.

The dynamic pressure [1] on the surface of the quasi-continuous radio jets causes their acceleration. Now we have all constituents to write the equation of dynamics

$$\frac{d^2}{dt^2} = -\eta \frac{p_n(1 + \frac{1}{3 \mu} + \beta_{th}) \lambda_{jr} z \theta_{jr}}{M_j} v_n$$  \hspace{1cm} (7)

of a jet segment, which is considered to be independent on other segments, of the length $\lambda_j$, of the transverse size $z \theta_{jr}$, of the mass $M_j$, within the geometrical factor $\eta \sim 1$, depending on transverse profile
of the jet. Here $\vec{n}$ is the unit normal vector to jet axis directed oppositely to movement of the jet pattern. We believe that equation (7), in a fact an equation for the material point, correctly describes the behavior of the precessing jet, which is really a quasi-continuous flow, while the displacements of the jet from the ballistic position is relatively small.

At angular distances beyond $\sim 4''$, or $t \sim 430^d$, the SS433 radio jets look fragmentary (e.g. Roberts et al. 2010, Fig. 2) — likely the jets there are not constitute a continuous flow and the model is not true there. Another characteristic distance corresponds to $t = 250^d$, where the slope of the brightness profile becomes flatter (Roberts et al. 2010) and, on other hand, the angle of the impingement of swept gas and the jets becomes almost constant, namely normal to the jets.

3 Simulation of dynamical jets of SS 433

The acceleration (7) was used to find locus of the SS433 radio jets. The initial conditions of this kinematic problem are defined by the standard kinematic model, whose parameters, most accurate to now, are collected in Table 1. The simulated 3D locus was projected onto the plane of the sky accounting for the time delay of arrival of photons to an observer (the effect of light propagation), which differs for different points of the jet trajectory resulting in distortion of jets image.

| Parameter                                      | Value               | ref.|
|-----------------------------------------------|---------------------|-----|
| jet velocity                                  | $v_j = 0.2581 \, c$ | [1] |
| inclination of precession axis to the line    | $i = 78^\circ 81'$ | [1] |
| of the sight                                  |                     |     |
| precession cone half-angle                    | $\theta_0 = 19^\circ 75'$ | [1] |
| precession period                             | $P_0 = 162.250^d$  | [1] |
| initial precession phase epoch$^2$            | $t_0 = JD 2 443 508.41$ | [1] |
| position angle of jet precession axis         | $\chi = 98^\circ 2$ | [2] |

1 [1] — Davydov et al. (2008), [2] — Stirling et al. (2002)

2 of the minimal inclination of the east jet to the line of the sight

The model jets are shown in Fig. 1 where they are superimposed on the image of radio jets of SS433 on July 11, 2003 taken from (Roberts et al. 2010). This image is extremely deep and the jets are seen up to 800 days of a flight. It is seen that the dynamic jets, simulated in our model with the settings $v_j/D = 0.2581 \, c/4.8 \, \text{kpc}$ for the initial speed and distance, and the ballistic jets obtained by Roberts et al. (2010) with the settings $v_j/D = 0.2647 \, c/5.5 \, \text{kpc}$, visually are almost indistinguishable in both inner and external jets: the difference between the model jets is less than the accuracy of determination of jet axis at the image. For other settings for the dynamic model of jets we chose following characteristic values: a geometry factor $\eta = 1$; a ratio of thickness of the radio bright shell around a jet cloud to size of the cloud $l_h/l_c = 0.5$, the finding of Inoue et al. (2012) for supernova remnants; a pressure ratio of thermal gas and magnetic field $\beta_g = 1$, that is expected at the vicinity of jets clouds where the magnetic field is amplified (Jones et al. 1996; Inoue et al. 2012); a ratio of energy densities of the magnetic field and relativistic particles $\beta_{H} = 3/4$, that corresponds to minimal total energy of the field and particles (Ginzburg 1979); an initial flux of kinetic energy in the jet contained in the clouds $L_j = 10^{39} \, \text{erg/s}$ and a temperature of the jet clouds $T_j = 2 \cdot 10^4 \, \text{K}$ at a distance of $10^{15} \, \text{cm}$, these are approximately determined by observations of the optical jet. The rate of jet mass flux $\dot{M}_j$ was supposed to be constant through jet length. Only two
parameters were fitted: an exponent of the clouds temperature profile \( n = 1.50_{-0.07}^{+0.07} \), that influences on synchronism of the fits to inner and extended jets; and a ratio of energies of all relativistic particles and relativistic electrons \( \beta_e = 2.7 \pm 0.4 \), although it is not an independent fitting parameter. The accuracies of the fitted parameters correspond to a deviation of the dynamical model jet from the ballistic model jet of a half of an image resolution \( 0''47 \) at a distance of \( 6'' \), on which the position of precession spiral of eastern jet is still clearly discernible. The dynamics of the radio jets was taken into account only in the region from the zone radio brightening to a distance \( t_1 = 215d \) of a flight, where the filling factor \( f \) is close to 1 and the model becomes invalid.

Deceleration and deviation of kinematics of the dynamic jets, with the parameters given above, from the ballistic ones is shown in Fig. 2. The profile of the deceleration \( a(t) \), that is module of the tangential component of the jet acceleration vector relative to the jet velocity vector, shows that the deceleration occurs mainly in the inner jets and peaks at \( 0.082c/P_0 \) in the zone of radio brightening, as Stirling et al. (2004) have guessed. An average deceleration in the first precession cycle is \( 0.0191c/P_0 \). A relative jet speed decrement is \( \delta v_j = 7.5\% \), a half of it is accumulated before a distance of \( t_{1/2} = 32d \), i.e. for one-fifth of the precession period. Approximately the same distance limits the zone of significant slowdown of the jets: the deceleration beyond this distance leads to a shift of the precession spiral by a half of the image resolution \( \phi_b/2 \) at a distance of approx \( 6'' \). Thus, the external jet, at \( t > P_0 \), should be like ballistic. During a flight time \( P_0 \), or in bounds of \( 1''386 \), the precession cone semi-opening increases by \( \Delta \theta_0 = 270 \), the azimuth relative to the axis of precession increases (or the precession phase decreases) by \( \Delta \psi = 3757 \), or the jet offsets along the azimuth by \( \Delta y = 323 \) milliarcsec (mas) in the direction opposite to the precession rotation direction, which is approximately 4 times more than the radial offset \( |\Delta z| = 85 \) mas against Z-axis — the precession helix becomes more compressed and twisted. These should show up as slowing down and precession lag of the jets relatively to the standard kinematic model. An average visual
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slowdown — along Z-axis, which is observable as compression of the helix — is 0.0423 c/P₀ in the first precession cycle and 0.0230 c/P₀ during a flight time of 350d. The latter is close to 0.02 c/P₀, the value found by Stirling et al. (2004) approximately at the same length of a flight. They also pay attention to the delay of the jets in precession phase. The fact of a significant offset Δy of the model dynamic jets allows to explain the appearance of individual clouds outside the SS433 jets track as a result of uneven dynamic pressure of inhomogeneous wind on the fragmented radio jets.

Figure 2: Kinematics deviations of the dynamical jet from the ballistic jet in dependency on flight time. Along left axis: tangential deceleration, \( \dot{v}_j \), in units of c/P₀ — solid red line; relative decrement of velocity, \( 1 - v_j(t)/v_j(0) \) — dashed blue line. Along right axis: longitudinal, \( -\Delta z \), and transverse, \( \Delta y \), deviations of the jet locus in the comoving frame of reference, in units of mas — dotted black lines with plus and circle symbols, respectively; increment of azimuth of precession rotation, \( \Delta \psi \), in units of degree/10 — dotted blue line; increment of precession cone semi-opening, \( \Delta \theta_0 \), in units of degree/100 — dash-dotted red line.

4 Discussion

We found that the SS433 jets should be noticeably decelerating to satisfy to observed radio synchrotron brightness, if the radiating relativistic electrons are steadily injected by shocks in the jets. In the colliding with ambient medium the jet acquires the additional momentum which lies in the tangential plane to the precession cone and makes the jet to decelerate along Z-axis and shift along Y-axis, in the reverse direction to the precession. The acquired shift must be observed as an increase of torsion of the precession helix, or a decrease of the precession phase. Note that the known azimuthal asymmetry of radiation of the optical jets points on a similar character of the interaction (Panferov et al. 1997). In the case of only head collision of clouds of a jet with impinging gas would be observed only deceleration of the jet.

The dynamical model of the jets does good fit to observed jets of SS433 at a distance of 4.8 kpc. The deceleration has maximum in the zone of radio brightening and decreases further. So the maximum of radio jets radiation associates with the maximum of the jets kinetic energy dissipation. The zone of deceleration, i.e. where the deceleration is essential for the jets, spans flight time of only one-fifth of the
precession period. Beyond the zone of deceleration the dynamical jets imitate ballistic ones with an initial velocity $0.2647 \, c$ and at a higher distance to the object $5.5 \, kpc$. There are contradictory estimations of the distance, including those obtained by the kinematic method on the basis of observations of the inner and extended radio jets. The dynamical model soothes the dichotomy of the kinematic distance. Blundell & Bowler (2004) have fitted by the kinematic model, allowing the jets speed to variate stochastically, on the scales where the jets are already ballistic in our dynamical model. So, jets deceleration does not influence on their conclusions. A speed variations amplitude they found is of $0.032(4.8 \, kpc/5.5 \, kpc) = 0.028 \, c$, or $12\%$ of the jets speed, within parameters of our model, that is comparable with a speed relative decrement $\delta v_j = 7.5\%$ originated from the jets deceleration. These speed variations may be due partly to the uneven process of jets slowing. The results of Blundell & Bowler (2004) do not exclude the dynamic model, which shows the extended jets deceleration. These speed variations may be due partly to the uneven process of jets slowing. The results of Blundell & Bowler (2004) do not exclude the dynamic model, which shows the extended jets are ballistic ones, with parameters $v_j = 0.2386 \, c$ and $D = 4.8 \, kpc$, being an intermediate to the two options they considered.

It is quite possible the blurring of the nutation structure of the jets within the zone of deceleration, because the ram pressure on the jets would be strongly modulated with nutation phase. Besides, the blurring could be initiated by abrupt heat and expansion of the jet clouds and decollimation of the jets in the zone of radio brightening, where pressure in the clouds should fall (Vermeulen et al. 1993; Panferov 1999).

Found above physical parameters of the dynamical model are not independent of each other. They allow variations which leave the acceleration to be invariant:

$$a(z) = k_a(z) \left(1 + \frac{1}{M_j \bar{l}_0} + \frac{\beta_k}{\bar{M}_j}\right)^{7/3} \left(\frac{\beta_H \beta_k}{k VT_0}\right)^{4/3},$$

as obtained from (3) and (7), where $k_a(z) = \eta z^{1-4n/3} \beta_{\lambda}^7 \lambda_{j}^{7/3}(k \nu \mu m_p D^2 s_t / k_B)^{4/3}$. Nevertheless, the found magnitudes of $l_{sh}/l_{cl}$, $\beta_H$, $\beta_e$, $\beta_k$, $M_j$ and $T_0$ are observationally and theoretically justified with an accuracy of a some.

A power of loss of the radio jet kinetic energy $\dot{W}_k \approx 2 \delta v_j L_j = 1.50 \cdot 10^{38} \, \text{erg/s}$ is huge and unobserved radiatively. Possible, this power is drained into momentum of the wind colliding with the jets and transformed eventually into momentum of W 50 (Dubner et al. 1998). A high efficiency of the mechanical energy transfer from jets to atomic and molecular outflows in the surroundings is observed also in AGNs (Morganti et al. 2013).

The dynamical model of the jets satisfying the jets kinematics has implications on physics of the jets. The filling of the clumped jets increase with distance due to clouds heating and expansion, while clouds pressure is determined by the ram pressure on the jets. The clouds temperature rises from $1.4 \cdot 10^5 \, K$ in the brightening zone to $3 \cdot 10^5 \, K$ at flight times $\sim t_1 = 215^d$ where the filling $f \rightarrow 1$ and the model becomes invalid. Really, the model jets kinematics in not sensitive to departures of jets physics from the dynamical model beyond the deceleration zone. Possibly, the clouds reheating is non-monotonic. Given the temperature increment $\Delta T_{cl}$ a power of jet heating is $Q = k_B \Delta T_{cl}(3M_j/2\mu m_p) = 2.1 \cdot 10^{35} \, \text{erg/s}$, that is far more than an observed jet X-ray luminosity of $\sim 10^{33} \, \text{erg/s}$ and surprisingly close to the radio jet synchrotron luminosity.

Our work shows that there is a small deceleration of the radio jets and, on arcsecond-scales, they can be imitated by ballistic jets choosing inappropriate distance to the object. Explicit detection of the deceleration is a problem for further observations of the inner radio jets.

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