X-ray Iron Line Profiles From Warped Accretion Discs

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Introduction

The observations of broad iron lines (K-alpha) in the X-ray spectrum of many active galactic nuclei (AGN) and, in particular, Seyfert 1 galaxies, stimulated modeling of line profiles from accretion discs around black holes. Indeed such lines are thought to originate in the innermost regions of the accretion ow, carrying information about geometry and dynamics of the gas within few gravitational radii and of the space-time geometry around the black hole [2].

In fitting the observed K-alpha line profiles, the standard assumption is that the accretion disc is geometrically thin and at. However there are several reasons to consider different disc geometries, in particular warped accretion discs: 1) in some cases, the inclination of the disc inferred from the K-alpha line differs from the one inferred from other observations like radio jets, broad line optical lines etc; 2) the multiwavelength spectrum of some sources e.g. RE J1034+396 cannot be explained by a standard disc and aring or warping of the disc is invoked [4]; 3) the Lense-Thirring effect causes important changes in the geometry of an accretion disc around a rotating black hole.

We here present a method for calculating the relativistic iron line profile from warped accretion discs (twist-free and twisted), implementing and extending previous studies [3] to various emissivity laws and to rotating black holes.

We also discuss the consequences of modeling lines from warped discs using a priori a at accretion disc geometry.

From the disc to the line profile

Some results are presented in this figure for discs around a non-rotating (Schwarzschild) black hole. We consider twist-free discs (whose shape depends on two parameters that fix the magnitude of the warp and the curvature of the disc, and on the azimuthal angle Ω of the observer) and twisted discs (whose shape depends on one parameter that fixes the magnitude of the warp and on the azimuthal angle of the observer). All general relativistic and shadowing effects are taken into account. The following parameters are fixed: inner radius of the disc $R_{in} = 6\ R_g$, outer radius $R_{out} = 50\ R_g$; inclination angle of the disc $i = 30^o$.

Row 1: a standard thin at accretion disc, for comparison.

Rows 2,3,4,5: twist-free accretion discs for various values of the parameters.

Rows 6,7,8,9: twisted accretion discs for various values of the parameters.

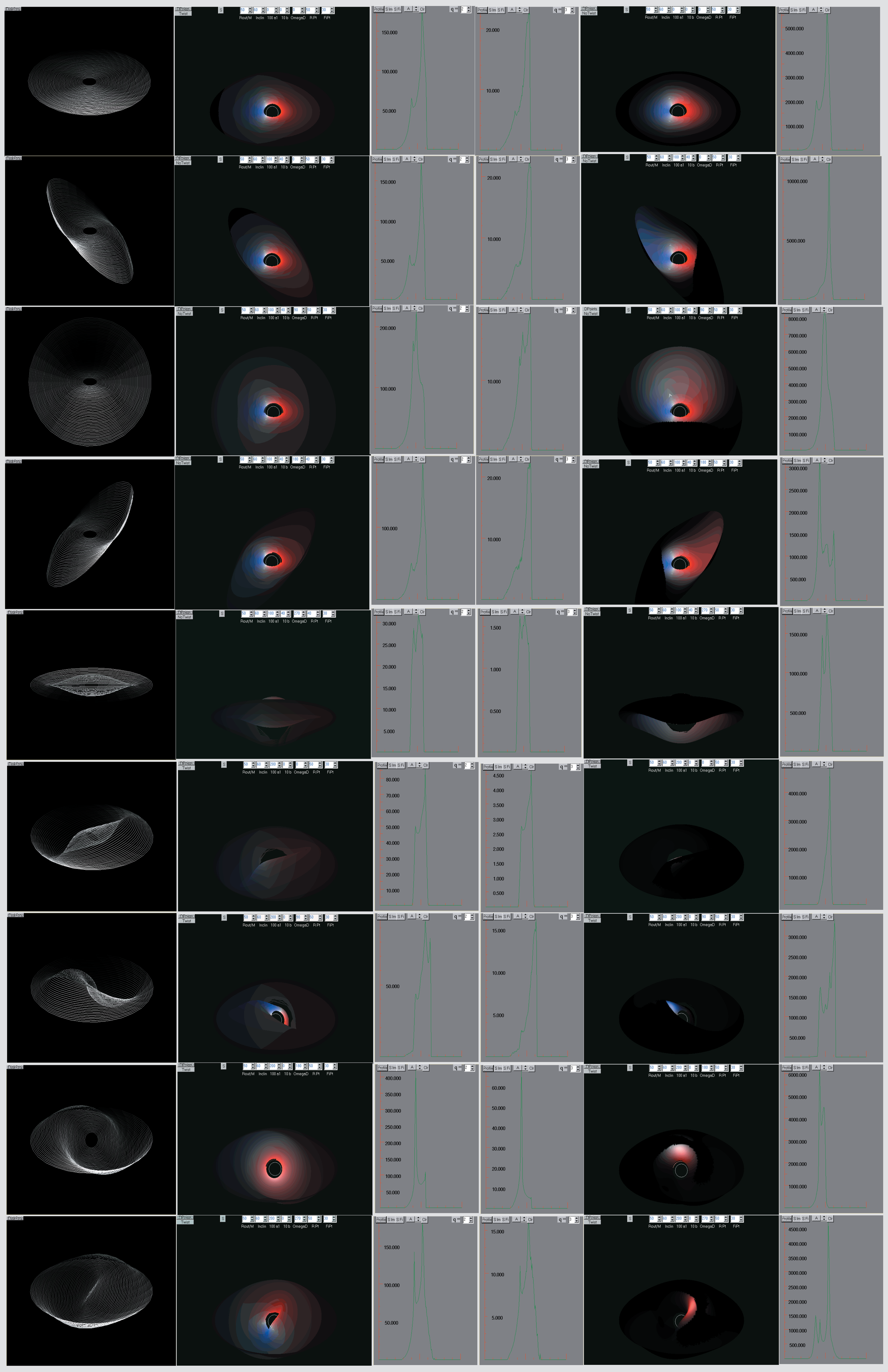
Column A: "classical" view of the disc

Column B: general relativistic view of the disc. The different colors refer to blue or red-frequency shift, white is the zero-shift region.

Column C: resulting line profile for emissivity law $\varepsilon(r) \sim r^{-2}$.

Column D: resulting line profile for emissivity law $\varepsilon(r) \sim r^{-3}$.

Columns E,F: we consider now a hard X-ray point source at a height $H = 20\ R_g$ above and below the black hole. Shadowing effects by the disc of the source and by the disc of the disc toward the observer are considered. Resulting view of the disc and line profile are shown.



1 2 3 4 5 6 7 8 9

A B C D E F

It is evident, even from the few examples presented here, that taking into account possible warping of the accretion disc produces a large variety of line profiles. The most important results to point out are:

1) the possibility of having lines with several narrow peaks;
2) there are profiles that are red-dominated or blue-dominated, depending on the azimuthal angle of the observer;
3) profiles can extend more to the blue and/or less to the red compared to a at disc. Recalling that for at discs the blue extent of the line depends mostly on the disc inclination while the red extent strongly depends on the radius of the innermost emitting region (and therefore also on the rotation of the black hole) it is obvious that assuming a priori a at disc may lead to wrong conclusions in fitting observed K-alpha lines.

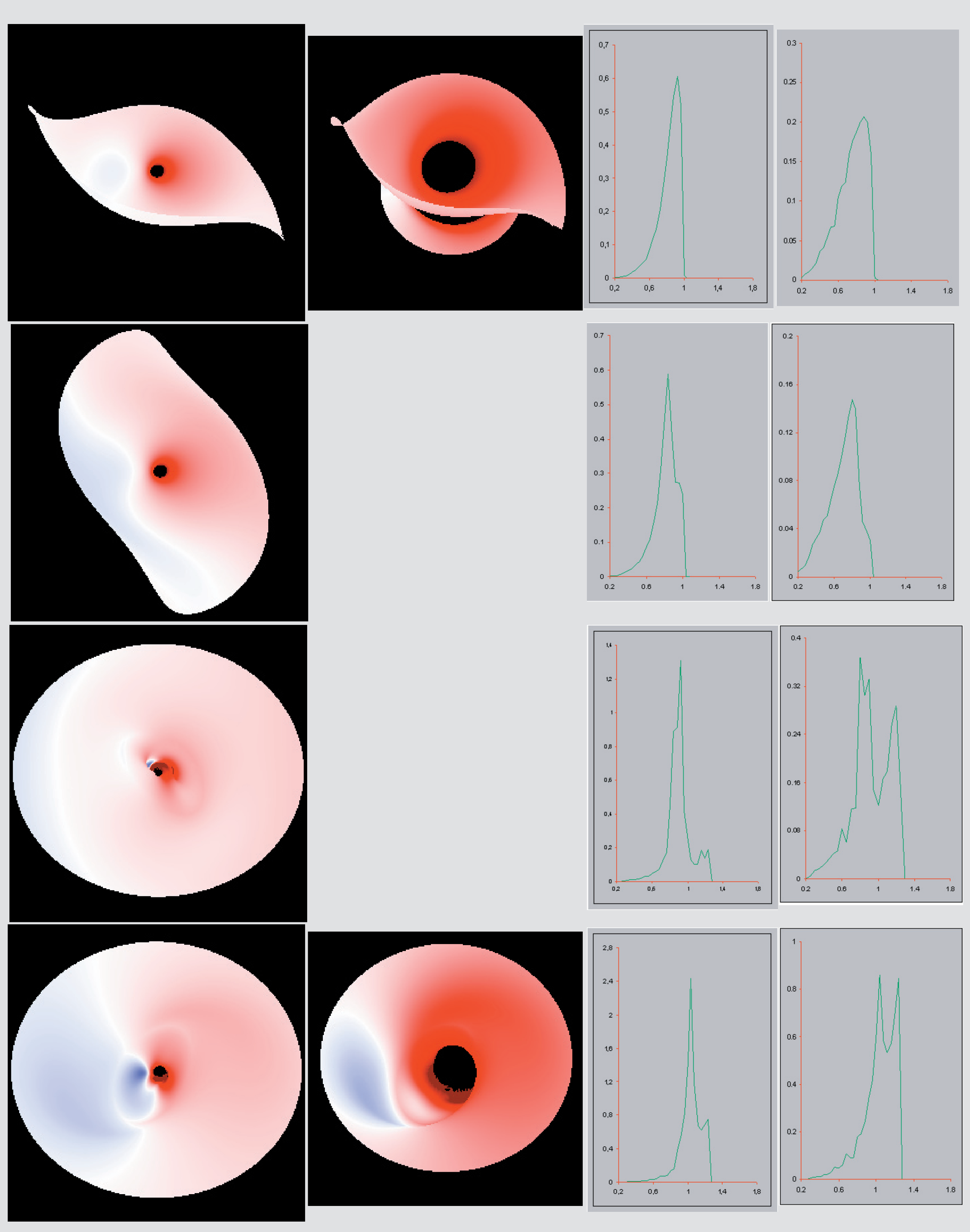
From the line profile to the disc

We here apply the method that we developed in [1] to invert the line profile and to obtain the best fitting inclination angle of the disc and the emissivity law (we restrict ourselves here to non-rotating black holes).
We first construct artificial line profiles from warped discs, then we try to fit them assuming a priori that the disc is at.
As expected, the best fitting values that we derive are in general not consistent with the original ones.

What if the black hole is rotating?

Deriving line profiles from warped discs in the case of an accretion disc around a rotating (Kerr) black hole is really a hard task. Indeed, apart from the complications of the space-time geometry and the loss of symmetry, the photon trajectories are now non-planar. We here present some preliminary results.
Of course the introduction of another parameter - the angular momentum *a* of the black hole - gives rise to an even wider variety of line profiles.
The following images refer to a Kerr black hole with a=0.9998M and a disc with $R_{in} = 1.24\ R_g$, $R_{out} = 50\ R_g$.

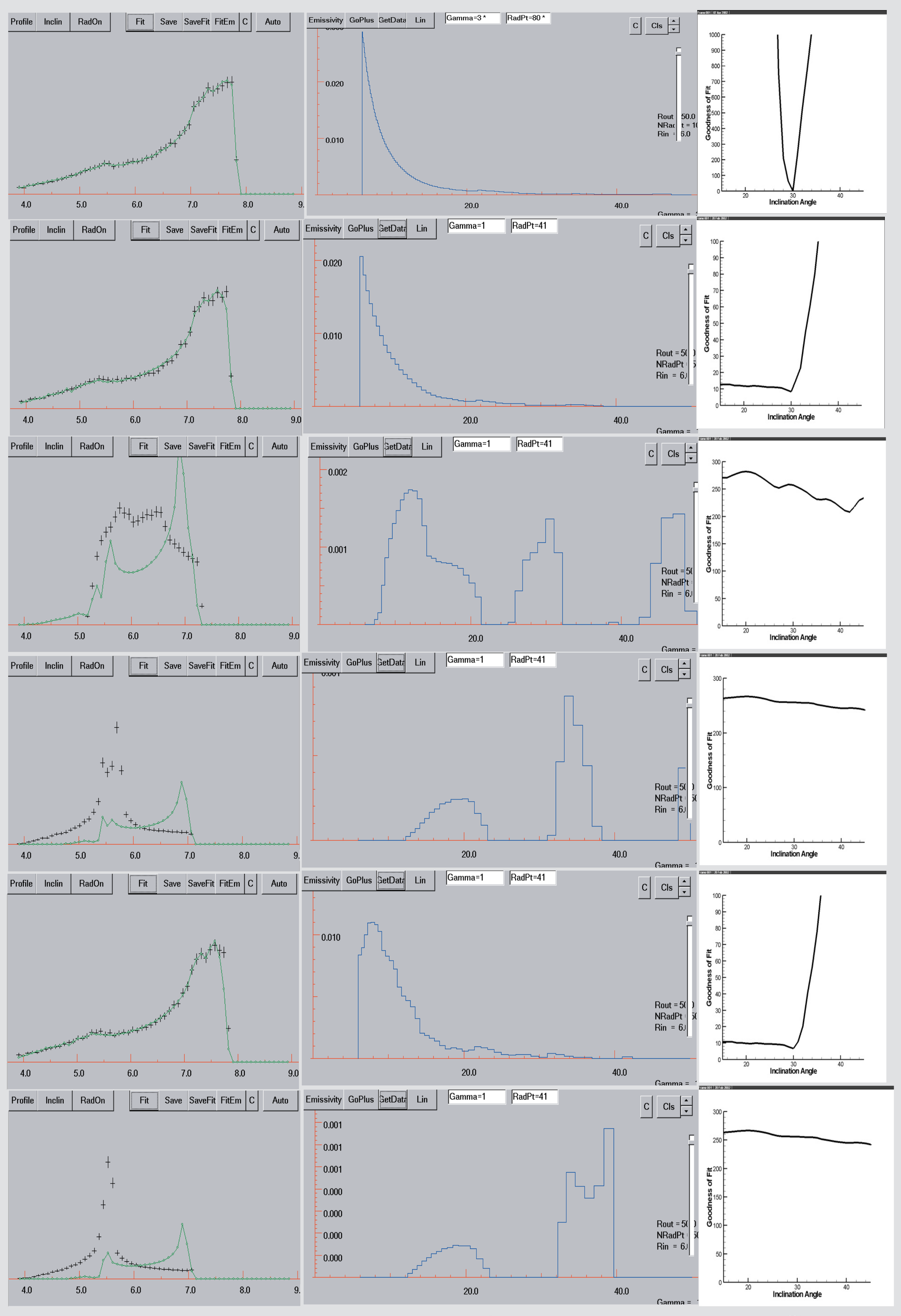
Row 1: twist-free disc, Ω=30°.
Row 2: twist-free disc, Ω=90°.
Row 3: twisted disc, Ω=30°.
Row 4: twisted disc, Ω=150°.
Column 1: general relativistic view of the disc.
Column 2: blowup of the inner disc region, $R_{out} = 10\ R_g$.
Column 3: resulting line profile for emissivity law $\varepsilon(r) \sim r^{-2}$.
Column 4: resulting line profile for emissivity law $\varepsilon(r) \sim r^{-3}$.



1 2 3 4

A B C D

The figure shows:
Raw 1: the at disc case for comparison. Note that the fit to the initial data is very sharp;
Raws 2,3,4,5,6: some examples of twisted disc line profiles;
Column A: the "twisted disc" line profile and its best fitting " at disc" line profile (in green);
Column B: the derived emissivity law. Note that the original one is a power law $\varepsilon(r) \sim r^{-3}$;
Column C: the best fitting inclination angle for the at disc. The y-axis is the value of χ^2 in arbitrary units. Note that the original angle is i=30°.



1 2 3 4 5 6

A B C

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