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Students Discovered the Curvature of Space: They Photographed a Gravitational Lens and Explained it

Hans-Otto Carmesin[1,2,3]

[1] *Gymnasium Athenaeum Stade, Harsefelder Str. 40, 21680 Stade*
[2] *Studienseminar Stade, Bahnhofstr. 5, 21682 Stade*
[3] *University Bremen, 28334 Bremen*

The *goal* of this project was that students of an astronomy club discover the curvature of space on the basis of their own photo. These students ranging from class 5 to 12 used the school observatory. The equipment includes the 11 inch telescope Celestron type C11 and the camera SBIG type ST-402. Since the telescope is relatively small, a rather bright object with obvious curvature was photographed, namely the twin quasar 0957+561.

The photo shows two seperate pictures of the same galaxy and the corresponding *explanation* was established at four levels. At the basic level, the students performed a computer simulation with a given computer program. With this tool, they discovered the curvature of the path of the light. On this basis, they explained the emergence of multiple pictures of the galaxy. At a second level, the students developed the computer program using the corresponding equations of motion. At a third level, the students derived the Schwarzschild metric in a simple and exact manner[1]. Moreover, they discovered the equations of motion for the propagation of light in curved space using Huygens' principle in a new way. At a fourth level, the students derived formulae for the deflection angle in order to analyze the multiplicity of the pictures.

In summary the students discovered the curvature of space on their own on four levels progressively. I report about the concept and experiences with teaching it.

[1] Carmesin, H.-O. (2012): Schüler entdecken die Einstein-Geometrie mit dem Beschleunigungssensor. PhyDid B, 2012, ISSN 2191-379-DD15p06.