

## Interstellar spaceship simulator for astronomical education and communications

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An interstellar spaceship simulator, “HippLiner” is introduced. “HippLiner” has been developed for visualization of interstellar traveling and drawing constellations. Because “HippLiner” contains several catalogues of stars, galaxies and open clusters, operators can enjoy simulated relativistic/superluminal interstellar traveling, proper motions of stars, and deformation of constellations as they move from one star to another star. For astronomical education and communications, “HippLiner” is performed in Science Live Show “UNIVERSE” for five years.

### 1. Introduction

3D visualizations of celestial bodies are powerful methods for astronomical education because they exist three dimensionally and quite sparsely in the space. Three dimensional positions of more than hundred thousands of stars are available since *the Hipparcos and Tycho catalogues* [1] were published in 1997. Astronomical catalogues with three dimensional positions and sizes of open clusters and galaxies are also available. Several 3D visualization programs have been developed using data of *the Hipparcos catalogue* and the other catalogues. The author has been developed an astronomical simulator named *HippLiner*. In this paper, the author first introduces *HippLiner*. Implementation of relativistic interstellar traveling is then briefly reviewed, and finally, actual usage of *HippLiner* in *Science Live Show UNIVERSE* (Hereafter abbreviated as *UNIVERSE live-show*) performed in the Science Museum, Tokyo is described.

### 2. *HippLiner*: Interstellar spaceship simulator

*HippLiner* was originally developed for drawing constellation lines displayed in *Solar System Simulator* [2] in 2001. However, it is now an interstellar spaceship simulator that enables superluminal and relativistic interstellar journey to a hundred thousands of stars around the sun. It is also a tool for browsing information of stars in the Hipparcos catalogues and other celestial bodies.

*HippLiner* contains three dimensional positions of stars, open clusters, and galaxies. For

fundamental information of stars around the sun, *the Hipparcos catalogue* [1] is used. There are 117954 stars with right ascension, declination and magnitude in *the Hipparcos catalogue*. For radial velocity of stars, *the Hipparcos input catalogue* [3] is also used. Simulation of three dimensional proper motions of stars are possible as linear motion approximation using proper motions and radial velocity for 15672 stars. For positions and sizes of 601 open clusters, *New Catalog of Optically Visible Open Clusters and Candidates* [4] is used. *Nearby Galaxies Catalogue* [5] is also used for positions and diameters of 2365 galaxies.

The primary function of *HippLiner* is interstellar spaceship simulation and constellation line drawing. As an interstellar spaceship simulator, operation of *HippLiner* is quite simple. Operators just need to double click the target star and press “move” button in a panel displayed below the simulation. The scenery displayed after arrival is the night sky of

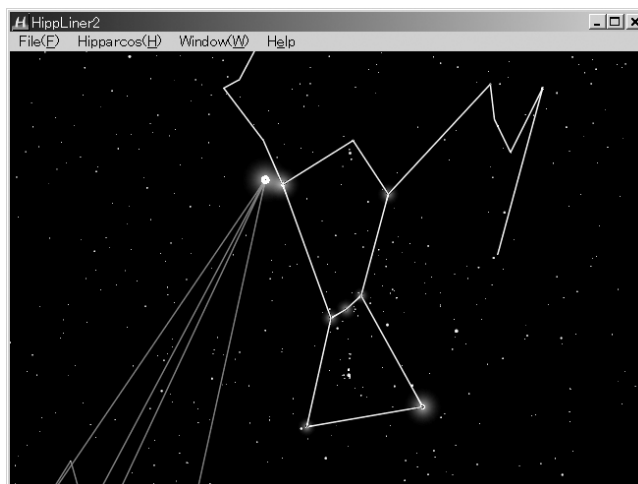


Fig.1. A scenery observed from alpha Centaur simulated by *HippLiner*. Shape of Orion is not much changed while Sirius comes very close to Betelgeuse.

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the target star (Fig.1.). In the superluminal mode of *HippLiner*, operators can adjust speed of the spaceship with a unit of light year per second. Drawing of constellations is also simple. After entering the constellation drawing mode, operators just need to double click the stars to connect stars with lines. At the end of the lines, operators need to click separator button, or space key. To finish drawing a constellation, operators need to click the end button or return key. In addition to operation using menus and panels, operation using shortcut keys are also possible. Several functions are assigned to each keys, and operators need not access panel windows. This function enables smooth operation of the simulator during live-shows or presentations. *HippLiner* is used in *UNIVERSE live-show* for 5 years with 3D stereoscopic projection.

### 3. Relativistic mode of *HippLiner*

Quite recently, the author added a relativistic mode of interstellar spaceship simulation. Previously, *HippLiner* supported only superluminal spaceship simulation which allows exceeding light speed such as several light years per second. However, in the principle of physics, it is impossible to exceed light speed. Hence, more realistic interstellar spaceship simulation requires relativistic theory. According to the relativistic theory, we need to simulate aberration, Doppler effect and proper time. First, apparent positions of stars change to the direction of motion as speed of spaceship becomes close to light speed. Doppler effect results in changes of colors and magnitudes of the stars to blue-shifted or red-shifted with brightening or darkening dependent on spaceship speed. Approximation of proper time is also necessary because progression of time in the spaceship becomes slower as spaceship becomes faster. As a result, all the sky view is converged to the direction of motion, and the brightness of stars also becomes brighter.

The above relativistic effects are implemented in *HippLiner*. Positions of stars observed in simulator become different as the spaceship becomes faster (Fig.2a,b). Colors of stars are also changed to bluish or reddish dependent on the speed of spaceship. For simulation of colors of stars, black body radiation

was assumed as a point light source.

Change of apparent star positions by aberration is expressed as

$$\cos \theta' = (\cos \theta + \beta) / (1 + \beta \cos \theta) ,$$

where  $\beta = v/c$  is relative speed of spaceship to light speed [6].  $\theta$  and  $\theta'$  are colatitude angle from the line of motion of the spaceship observed from rest frame of stars and spaceship frame respectively (Fig.2c,d).

The energy distribution of black body radiation observed in rest frame is expressed as

$$S(\lambda, T) = A \lambda^{-5} [\exp(hc/\lambda k_B T) - 1]^{-1} ,$$

where  $T$  is temperature of stars,  $A$  is amplitude of radiation for obtaining corresponding apparent magnitude for each star. The distribution of light intensity is changed to

$$S'(\lambda', T) = AD^{-2} \lambda'^{-5} [\exp(hc/\lambda' k_B DT) - 1]^{-1} ,$$

by angle-dependent Doppler effect [6] where

$$D = (1 + \beta \cos \theta) / \sqrt{1 - \beta^2} , \lambda \text{ and } \lambda' \text{ are wavelength}$$

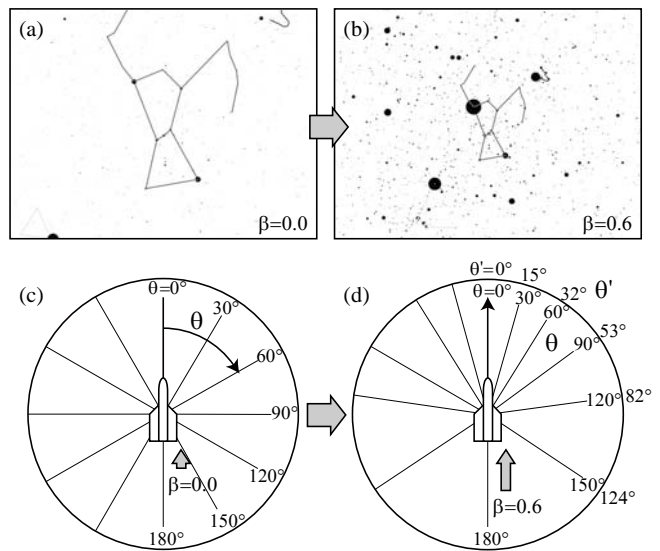


Fig.2. Examples of relativistic effects simulated by *HippLiner*. (a) Original night sky on the earth with 0 % of light speed ( $\beta=0.0$ ). (b) The same direction observed from the position of the earth with 60 % of light speed ( $\beta=0.6$ ). Shapes of constellations and magnitudes of stars are changed. (c), (d) Changes of apparent position on the sky by aberration dependent on the relative speed of the spaceship. Lines in (c) are original angle of the stars in rest frame while lines in (b) are aberrated angle of the stars in starship frame.

of radiation observed in rest frame of stars and spaceship frame respectively. The relationship of  $\lambda$  and  $\lambda'$  is  $\lambda' = \lambda/D$ . Apparent magnitude is calculated from above distribution. RGB values of standard RGB (sRGB) color space [7] are also transformed via CIE (1931) XYZ color space [8]. The resulting color still corresponds to that of black body radiation with temperature  $DT$  in starship frame. Dark stars below an adjustable threshold can be drawn in grayscale to simulate scotopic vision.

*HippLiner* adopted uniform motion for each step of drawing frame during flight from one star to another star. The distance from the starting position in rest frame becomes summation of length of progression at each drawing frame as

$$distance = \sum_{step} \beta_{step} \Delta t' / \sqrt{1 - \beta_{step}^2},$$

where  $\beta_{step}$  is relative speed to light speed for each frame of 3D rendering, and  $\Delta t'$  is fixed interval of 3D renderings in proper time of starship frame. After starting journey to the stars,  $\beta_{step}$  gradually increases to the maximum speed and it decreases to zero before arrival. The total time becomes at least several years if we apply maximum  $\beta < 0.9$ . For example, even if we apply uniform motion to alpha Centaur at 99.9999% of light speed, it takes 40 hours to arrive that is not preferable for lives-show and users. It is also not preferable to accelerate speed to much faster because the simulation itself becomes incorrect. This is because the most dominant celestial bodies observed by human's eyes become those with strong infrared irradiation when we apply faster speed, whereas *the Hipparcos catalogue* does not contain those objects. On this account, a parameter: time acceleration ratio between starship time and operator's time was introduced to make the journey within minutes. As a result, actual time of the journey for operator is adjustable as total time. Thus, *HippLiner* enables the relativistic journey of spaceship in limited time of live show.

#### 4. Usage of *HippLiner* in a liveshow

*UNIVERSE live-show* is a popular attraction of the Science Museum, Tokyo which started in 1996 [9-10]. Since 2002, *HippLiner* is used in a part of *UNIVERSE live-show* that is about the interstellar

space and interstellar journey. Using stereoscopic 3D projection of *HippLiner*, interstellar travel and the distribution of stars near the sun are shown in *UNIVERSE live-show*. Usually, the host speaker first explains about that the stars in the sky is not attached to the sphere above us, and exist at different position with different distances. In the 3D stereoscopic theater, alpha Centaur can be seen as popped out when the spaceship is on the sun because it is the nearest star from the sun. The spaceship with audience is then moved to alpha Centaur in several seconds. The scenery of the celestial sphere is not much changed because of close distance from the sun. However, there are also some differences in alpha Centaur. When we see Orion, bright star is shining at very close to Betelgeuse. The host speaker asks the audiences like "Where is the bright star from?", and then the simulator comes back to the sun. The bright star moves to downward to Orion's hound during travel, and finally we know that the bright star near Betelgeuse was Sirius. Alnilam ( $\epsilon$  Ori) also often becomes the target star to go because it is the farthest star in Orion. Hyades or Pleiades are also major showplaces to go. After showing shapes of constellations changing by observer's position, one of the volunteer audiences can choose the star where he/she wants to go. The scenery viewed from the star chosen is printed out and given to the audience as a souvenir.

Because the sceneries from the other stars were not possible to simulate before *the Hipparcos catalogue*, showplaces where are worth going are totally unexplored yet. Double stars or stars which have exoplanets are possible showplaces of the interstellar journey. For visualization of the showplaces more impressive, an extension program of *HippLiner* is developed by Kuniaki Koike. The extension program, named "*Wakusei-guruguru*" is an exoplanet simulator [11]. Effective representation and usages of simulation of interstellar space is still under investigation. The author is welcome to hear about impressive usages or requests of new functions.

#### 5. Conclusion

*HippLiner* is a free superluminal/relativistic interstellar spaceship simulator with more than

hundred thousands of celestial bodies. It has been performed in a part of *UNIVERSE live-show* for five years, and is freely downloadable from the following URL.

<http://T.NOMOTO.org/HippLiner/index-e.html>

By using *HippLiner*, users can access many visualization parameters manually for adding flexibility to live-shows or finding ideas for astronomical studies or writing science fictions. The author is pleased when users can improve their inspirations or ideas by using *HippLiner*.

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## References

- [1] ESA, 1997, "The Hipparcos and Tycho Catalogues", ESA SP-1200.
- [2] Solar System Simulator Project, 1997, Solar System Simulator series (<http://www.sssim.com/>).
- [3] Turon C., *et al.*, 1992, "The Hipparcos Input Catalogue", ESA SP-1136.
- [4] Dias W. S., *et al.*, 2002, "New Catalog of Optically Visible Open Clusters and Candidates", A&A 389, 871.
- [5] Tully R. B., 1988, "Nearby Galaxies Catalogue", Cambridge, Cambridge University Press.
- [6] McKinkey J. M. & Doherty P., 1979, "In search of the "starbow": The appearance of the starfield from a relativistic spaceship", Am. J. Phys. 47, 309.
- [7] Stokes M., *et al.*, 1996, "A Standard Default Color Space for the Internet - sRGB" (<http://www.w3.org/Graphics/Color/sRGB>).
- [8] Commission Internationale de l'Eclairage, 1932, "CIE Proceedings 1931", Cambridge University Press.
- [9] Nomoto T., *et al.*, 1998, "Scientific Live Show in Computerized Theater: Universe", Frontiers Science Series No. 27, Proc. of the Misato International Symposium 1998 on Astronomical Education with the Internet, pp.117 - 123.
- [10] Handa T., 2007, "A science liveshow UNIVERSE, which will go beyond the horizon", Proc. of the GHOU 2007 in Tokyo.
- [11] Koike K. & Handa T., 2007, "Softwares to expand "UNIVERSE Liveshow" Raytrace simulation & Wakusei-guruguru (exoplanet simulator)", Proc. of the GHOU 2007 in Tokyo.