The Journey of the Sun - A Virtual Reality Simulation

Final Report for NASA Grant NAG 5-8163

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Contents

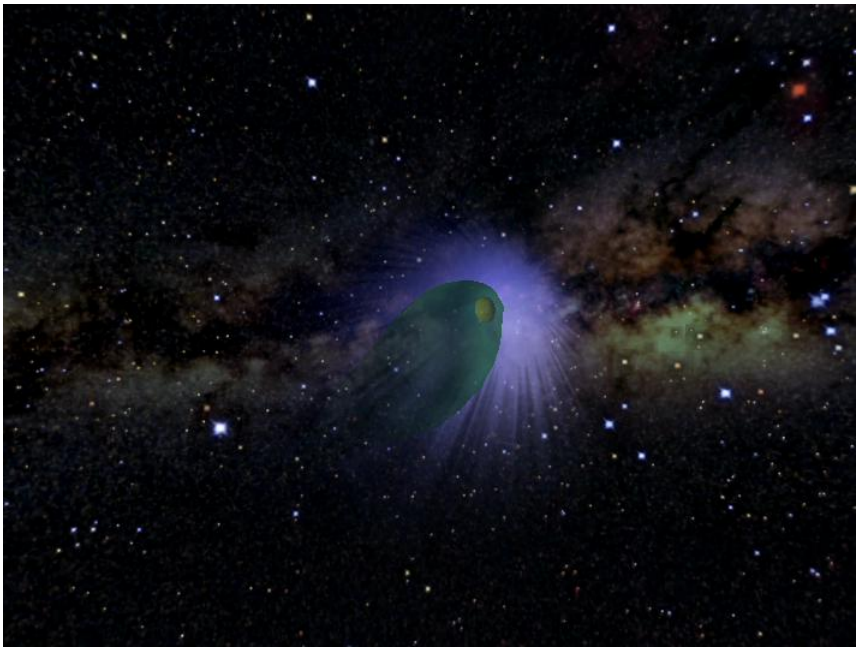

Figure 1: *The Galactic Environment of the Sun – Upstream viewpoint:* Visualization of MHD heliosphere simulation, showing the heliosphere moving through our galactic neighborhood (model by Linde et al. 1998). Stars from the Hipparcos Catalog and the Mellinger Milky Way composite image are shown. The Mach $\sim$1 bow shock around the heliosphere is apparent, as is the termination shock of the solar wind (the smaller rounded surface inside of the heliopause where the solar wind transitions to subsonic). This figure is excerpted from a movie showing a 3D visualization of the heliosphere and the Milky Way Galaxy, which can be viewed at `http://www.cs.indiana.edu/~soljourn`.

1 Project Summary

This research has focused on three underlying efforts:

1. Develop new tools and software for scientific data visualization.
2. Produce products that exploit the scientific data visualization tools for sharing the results of scientific research with the public.
3. Assemble astronomical data sets that provide the basis for the data visualization, and analyze graphics representation issues that must be addressed to effectively exploit these data sets.

2 Software and Data Visualization Tools

2.0.1 Completed Software Projects

The following software and data visualization tools have been developed over the course of this grant:

1. **Distance Editing Tool:** This program is designed to support astronomers using domain expertise to interactively determine estimates of gas cloud boundaries starting information in the Hipparcos data set, as well as other custom-selected datasets. Built directly in OpenGL with the universal GLUI user interface, this system is usable on any Unix or Linux workstation or Window PC. The DistEdTool will accept a wide variety of selection criteria describing the stars and features of the sky to be studied. It will then construct an hypothesized gas cloud surface using column densities estimated from standard principles. The user can load any of a large set of spectral images as background information to display behind an editable graphics image of the selected stars, their distances, column densities, and the conjectured cloud boundary surfaces lying between the Sun and the stars.
2. **Local Galactic Environment Data Set and Viewing Tool:** Several alternative versions of 3D models of the local environment have been constructed. These systems were assembled to support the 3D depiction and browsing of a wide collection of objects available in data sets describing the local galactic environment, including the Sun and planets, heliopause, bow shock, Loops (from supernova remnants), CO clouds, nebulae, high-latitude gas clouds, and stars in standard constellations. The user can navigate through this environment with several selected travel methods, and special viewpoints can be selected to provide context for the astronomer.
3. **Constrained Navigation Systems:** Previous work on individual and collaborative constrained navigation has been incorporated into our CAVE$^{\mathrm{TM}}$ virtual reality display systems for local galactic data and galaxy data to aid the users' perception and experience of context.
4. **Power10Time Virtual Reality System:** A multiscale spatial and temporal virtual reality system was built using entirely new concepts (published as noted below) for handling large scale ranges in real time in the CAVE immersive virtual reality environment at Indiana University. Incorporating data from the Earth scale out to the COBE scale, temporal animation, and constrained navigation, this system permits the viewer to absorb the context of spatial and temporal evolution of the entire cosmos while personally controlling all the interactive parameters. The system includes, for the first time ever attempted in such an environment, the ability to select between comoving and physical cosmological coordinates, using the most recent cosmological models provided by University of Chicago cosmologist Sean Carroll.

5. **Movie Animation Utilities:** A comprehensive library of movie generation tools were developed to provide the transition between the interactive visualization systems and virtually any desired film script scenario. Two movies have been produced with these tools, and more are planned.

3 Scientific publications and talks related to this project

3.1 Prof. Hanson and students

3.1.1 Computer Science Dissertation

This project provided support for Indiana University Computer Science PhD candidates Philip Chi-Wing Fu, Hui Zhang, and Yinggang Li. Dr. Fu defended his dissertation, entitled "A Visualization Framework for Large-Scale Virtual Astronomy," in December, 2003, and is now employed in the development of a state-of-the-art digital planetarium facility to be installed for the City of Beijing, China. Hui Zhang and Yinggang Li continue Dr. Fu's work, and are actively engaged in maintaining and improving the software, as well as in the development of animations and digital planetarium tools and content; these efforts will continue to benefit both professional scientists and the general public through our outreach distribution efforts.

3.1.2 Scientific Publications

1. Andrew J. Hanson, Chi-Wing Fu, and Eric A. Wernert, "Very Large Scale Visualization Methods for Astrophysical Data," in Data Visualization 2000, Proceedings of the Joint EUROGRAPHICS and IEEE TCVG Symposium on Visualization, May 29–31, 2000, Amsterdam, the Netherlands, pp. 115–124, Springer-Verlag, 2000.

2. E.A. Wernert and A.J. Hanson, "Tethering and reattachment in collaborative virtual environments," in Proceedings of Virtual Reality 2000, p. 292, IEEE Computer Society Press, 2000.

3. Siggraph 2000 Electronic Theater: Andrew J. Hanson and Chi-Wing Fu, "Cosmic clock." Siggraph Video Review, vol. 134, scene 5, 2000. 3:35 minute refereed video animation: Observing the Universe from the Earth and the local Galactic environment out to Quasar scales using the finite speed of light to place measured objects in their correct spatiotemporal context.

4. Andrew J. Hanson and Chi-Wing Fu, "Approaches to Interactive Visualization of Large-scale Dynamic Astrophysical Environments," paper based on invited talk submitted to Proceedings of NSF/DOE Lake Tahoe Workshop on Hierarchical Approximation and Geometrical Methods for Scientific Visualization, 15–17 October 2000, Tahoe City, CA. in Gerald Farin, Bernd Hamann, and Hans Hagen (editors), *Proceedings of NSF/DoE Lake Tahoe Workshop on Hierarchical Approximation and Geometrical Methods for Scientific Visualization*, October 2000, Tahoe City, CA, pp. 119–142, Springer-Verlag, Berlin, 2003.

5. Andrew J. Hanson, Chi-Wing Fu, and Eric A. Wernert, "Visualizing Cosmological Time," Dagstuhl Scientific Visualization Seminar, 21–26 May 2000, Schloss Dagstuhl, Germany. In F.H. Post, G.P. Bonneau, and G.M. Nielson (editors), *Data visualization : the State of the Art*, pp. 423–438, Kluwer Academic Publishers, 2003. (Kluwer international series in engineering and computer science : 713)

6. "Constraint-Based Astronometric Modeling Tools," for book entitled *Geometric Modelling for Scientific Visualization,* Andrew J. Hanson, Chi-Wing Fu, and Priscilla C. Frisch, edited by Guido Brunnett, Bernd Hamann, and Heinrich Mueller. pp. 437–452, Springer-Verlag, 2003.

3.1.3 Invited Talks

1. 21–26 May 2000, Dagstuhl Scientific Visualization Seminar, Schloss Dagstuhl, Germany. Title: "Visualizing Cosmological Time." (Published paper in Proceedings noted above.)

2. 29–31 May 2000, Visualization Symposium 2000, Amsterdam, The Netherlands. Title: "Very Large Scale Visualization Methods for Astrophysical Data." (Published paper in Proceedings noted above.)

3. 6 June 2000, EPFL, Lausanne, Switzerland. Title: "Very Large Scale Space and Time Visualization Methods in Astrophysics."

4. 13 June 2000, EPFL, Lausanne, Switzerland. Title: "Visualizing Quaternion Fields."

5. 20–22 September 2000, NASA AISRP (Applied Information Systems Research Program) Principal Investigators' meeting, Boulder, CO. Gave presentation and demonstration of progress on NASA "The Journey of the Sun" project.

6. 6 October 2000, Indiana University Computer Science Colloquium. Title: "Interactive Visualization of Large Scale Dynamic Astrophysical Environments."

7. 15–17 October 2000, One of four Invited Speakers at NSF/DoE Lake Tahoe Workshop on Hierarchical Approximation and Geometrical Methods for Scientific Visualization, Tahoe City, CA. Title: "Approaches to Interactive Visualization of Large-scale Dynamic Astrophysical Environments." (Published paper in Proceedings noted above.)

8. *Lecture* "Virtual Astronomy," Chinese University of Hong Kong, June, 2002.

9. *Lecture* "Virtual Astronomy," EPFL, Lausanne, Switzerland, November, 2002.

10. *Lecture* "Virtual Astronomy," INRIA, Montbonnot, France, November, 2002.

3.1.4 Miscellaneous

1. *Conference Course:* Refereed conference course presented at ACM Siggraph 2000, 23–28 July 2000, New Orleans, LA: A.J. Hanson, "Visualizing Quaternions," with published notes.

2. *Conference Course:* Refereed conference course presented at Siggraph 2001, Los Angeles: A.J. Hanson and D. Weiskopf, "Visualizing Relativity," with published notes.

3. Invited to provide graphics for book cover: Callendar and Huggett: Physics Meets Philosophy at the Planck Scale

4. Scientific Adviser for the Chicago, IL, Adler Planetarium "Sun-Earth Connection" show.

5. Invited to have "Cosmic Clock" animation included in the NHK (the Japanese TV network) special program "Digital Stadium Special - Siggraph 2000" in August, 2000, and rebroadcast January 5th, 2001.

3.2 Dr. Frisch

The topology and physical properties of nearby interstellar matter must be understood prior to effective visualization. The following scientific publications are preparatory to fully understanding the properties of the galactic environment of the Sun. While much of Frisch's research support is from other NASA grants, the results from that research directly affect the Solar Neighborhood model being created as part of this project. The following scientific publications are related to this project, and have been partially supported by NAG 5-8163. Frisch has shown, at numerous conferences, the heliosphere visualization placing the Sun and heliosphere set in their galactic environments. This visualization is highly successful, and scenes from the visualization have been borrowed by many scientists for use in scientific presentations and outreach efforts.

3.2.1 Scientific Publications

During 1999–2003, Frisch is author or co-author of many refereed papers and conference publications that directly probe the topology and physical properties of the galactic environment of the Sun and interstellar clouds, including:

1. "Galactic Environment of the Sun and Stars: Interstellar and Interplanetary Material", In *Astrophysics of Life*, in press, Eds: M. Livio, I. N. Reid & W. B. Sparks, Cambridge: Cambridge University Press, 2003. (With H. R. Mueller, G. P. Zank, and C. Lopate.)

2. "Constraining the Heliosphere: The Need for High-Resolution Observations of Nearby Interstellar Matter", in press, "ASP Conf. Ser.: Hubble's Science Legacy: Future Optical-Ultraviolet Astronomy from Space", 2002.

3. "The Velocity Distribution of the Nearest Interstellar Gas", ApJ, v574, pp834–846, 2002 (With L. Grodnicki & D. E. Welty).

4. "Chemical Composition and Gas-to-Dust Mass Ratio of the Nearest Interstellar Matter", ApJ, 594, 844–858 (With J. D. Slavin)

5. "The Ionization of Nearby Interstellar Gas", ApJ, v565, pp364–379, 2002. (With J. D. Slavin)

6. "Why Study Interstellar Matter very Close to the Sun?" 2002 COSPAR 2002–Houston, Submitted to Adv. Space Res., 2002. Eds: Klaus Scherer, Iver Cairns, Giancarlo Genta.

7. "The galactic environments of nearby cool stars" pages 206–210, 2001. *In Book: Proceedings of NStars Workshop*, Ed. D. Backman, Eds: D. Backman, S. Burg, T. Henry, Pub: Ames Research Center.

8. "The Galactic Environments of Cool Stars - part I: Modeling Interstellar Dust around the Sun and Nearby Cool Stars ", pages 211–216, 2001. *In Book: Proceedings of NStars Workshop*, Eds: D. Backman, S. Burg, T. Henry, Pub: Ames Research Center. (With Markus Landgraf)

9. "The Galactic Environment of the Sun.' JGR, v105, pp10279–10290, 2000.

10. "The Galactic Environment of the Sun", *American Scientist*, 88, 52–59, 2000.

11. "Foreword to Interstellar Dust and the Heliosphere" special issue of JGR (JGR, v105, 10237–10238, 2000),

3.2.2 Scientific Talks

During 1999-2003, Frisch was coauthor on a number of papers presented at scientific meetings that utilized the heliosphere visualizations developed during this research (e.g. American Astronomical Society, American Geophysical Union), including:

1. The results of this project were presented at: "The Solar Journey: Modeling Features of the Local Bubble and Galactic Environment of the Sun," P.C. Frisch and A.J. Hanson Poster 11.04, 199th meeting of the American Astronomical Society (AAS), Washington DC, January 2002.
2. "Modeling the Boundary Conditions of the Heliosphere", (Featured Presentation) AGU, Spring Meeting 2002, abstract #SH22C-02, 2002.
3. COSPAR–2002, Houston Texas, "Why Study Interstellar Matter very Close to the Sun?"
4. "Galactic Environment of the Sun and Stars: Interstellar and Interplanetary Material", *Astrophysics of Life Symposium*, Space Telescope Science Institute, Fall 2002.
5. "Constraining the Heliosphere: The Need for High-Resolution Observations of Nearby Interstellar Matter", At *Hubble's Science Legacy: Future Optical-Ultraviolet Astronomy from Space*, 2002.
6. "Nearby Interstellar Matter", Space Telescope Science Institute, At *Treasury Workshop*, Fall 2002.

4 Education and Public Outreach activities

The results of the software development described below have been shared with the public by providing visualizations to various astronomy outreach programs. These outreach efforts include:

- Film: "Solar Journey." Creates an animated film emphasizing the scientific features of the local galactic environment. This was be similar in character to the existing "Cosmic Clock" film, but with more broad-ranging scientific content.
- Adler Planetarium Sun/Earth Connection show: Both the PI's and graduate students associated with this project have spent a considerable amount of time assisting and advising the Adler Planetarium staff on this project.
- Astronomy Picture of the Day used a visualization of the heliosphere on website: `http://antwrp.gsfc.nasa.gov/apod/image/0206/heliosphere_pc_big.jpg`.
- The *Journey of the Sun* video is being displayed for public viewing in an Elumens kiosk workstation in the new NASA gallery at the Adler Planetarium.

In addition, our heliosphere visualizations are now used throughout the space physics and astronomical communities to illustrate the heliosphere in its setting in the Milky Way Galaxy. For instance, Ed Stone, former director of the Jet Propulsion Lab in California, requested permission to include our heliosphere visualizations in a JPL outreach webcast, at `http://www.jpl.nasa.gov/events/lectures/sep02a.html`. The heliosphere visualizations are also available through our web sites.

5 Addendum: Submission of Report (March 30, 2004)

This report is submitted to: Dr. Joseph Bredekamp, Senior Program Executive, NASA Office of Space Science. Postal Address: Code SS, NASA Headquarters, 300 E Street SW, Washington DC 20024-3210; Phone: 202/358-2348; Fax: 202/358-3987; Email: joe.bredekamp@hq.nasa.gov. A copy will also be sent to: Dr. Susan Hoban, Applied Information Systems Research Program, UMBC Goddard Earth Science & Technology Center. Postal Address: Mail Code 900.1, NASA Goddard Space Flight Center, Building 28, Room W270 Greenbelt, MD 20771.