STARGATEVR™ USERS MANUAL

ABSTRACT

Unlock the Universe: Explore the Stars Like Never Before with StarGateVR.

immersive SCIENCE

Contents

StarGateVR Manual

Introduction

StarGateVR represents a breakthrough in astronomical research and collaboration, offering a virtual reality application uniquely designed for the exploration of stars. This innovative tool allows users and their collaborators to immerse themselves in a shared virtual space, where the vastness of the universe is rendered in stunning three-dimensional detail. By leveraging the power of VR technology, StarGateVR provides an unparalleled platform for interactive learning, analysis, and discovery in the field of astronomy.

Purpose and Benefits of StarGateVR: Streamlining Stellar Data Analysis

StarGateVR is designed to streamline the exploration and analysis of vast stellar datasets, especially from major projects like Gaia and Chandra space telescopes. It transforms complex, multidimensional data into intuitive, three-dimensional visualizations. This innovative approach leverages the human brain's natural pattern recognition ability, significantly accelerating hypothesis generation and the discovery of unique celestial relationships. StarGateVR's detailed 3D portrayal of stars—including position, velocity, color, and metallicity—facilitates the identification of key astronomical features such as young star clusters, crucial in the search for new exoplanets. It offers an immersive platform for efficient and insightful scientific exploration. Some examples are shown in Appendix A below, and also on the StarGateVR website (immsci.com/stargate).

Star Filtering Through Gating

The cornerstone of StarGateVR's analytic capabilities lies in its Gating Tool feature, which enables filtering of star data through the selection and identification of star subsets based on their measured parameters. This process involves:

- **3D Coordinate Frame Visualization**: View star data in a chosen 3D coordinate frame, such as position, velocity, color-magnitude, or a custom mix.
- **Gate Tool**: Use this tool to highlight and filter select stars in the coordinate frame.
- **Setting Gates**: Stars within a region of interest can be selected and assigned to a 'Gate', uniquely color-coded for easy identification.
- **Exploring Different Coordinates**: Change the display coordinates (e.g., from velocity to spatial position) to see how gated stars distribute in alternate frames. This reveals new perspectives and relationships.
- **Sub-Gating and Analysis**: Further refine your focus through gating and sub-gating, zeroing in on stars of interest.
- **Saving and Exporting**: Gates can be saved, and their star data exported as a CSV for additional analysis with other astrometric tools.

Gates and Gating in StarGateVR allow for a powerful and intuitive exploration of star data, providing a dynamic way to uncover significant astrophysical relationships.

Getting Started with StarGateVR

System Requirements

StarGateVR is designed for simplicity, both in terms of download and operation, on the Meta Quest VR systems. The application is easily accessible via the in-headset Quest Library.

Get the App

Request your copy of StarGateVR and become a "Collaborator" by using the form at www.immsci.com/stargatevr. The app will then appear in your headset's Quest Library, just click to run.

Installation and Setup

Upon downloading, StarGateVR operates standalone on the headset, eliminating the need for a tethered connection to a computer. It utilizes the Quest's Wi-Fi capability for collaborative sessions, though this is not mandatory for solo use. The software includes a demo star dataset for immediate exploration, allowing users to familiarize themselves with its capabilities.

For users looking to delve deeper, StarGateVR supports the creation of custom star datasets. These can be prepared as well-structured CSV files, derived from database queries or other data sources. Details on the CSV format and sample Gaia ADQL query templates are discussed in the *Data Integration* section below.

Transferring Data to Quest

Connecting the Quest to a computer via cable, and granting the necessary permissions, allows the headset to function as an external disk drive. Users can transfer their CSV files to the StarGateVR folder on the Quest, making the data available for immersive exploration in the VR environment.

Navigating the Interface

VR-Scene Overview

Upon launching StarGateVR, you'll find yourself in a virtual environment equipped with a 3D coordinate frame for data plotting and hand controllers featuring display control panels. The coordinate axes (red, green, blue) represent an x, y, z frame, onto which you can map variables from your CSV star dataset.

Controller Functions

Right Hand Controller: Features a laser pointer for selecting objects within the VR scene. The right trigger button activates your selection. This hand also includes a gate-setting button, a

gate-editing function, and a thumb-stick that allows you to navigate (fly!) around the VR space, with motion direction set relative to the laser pointer's orientation.

Left Hand Controller: Contains buttons for managing gates (showing, hiding, deleting). The thumb-stick here navigates through the gate list displayed on the Gates Display, attached above the left controller. The Gates Panel displays currently defined gates, labels, the count of points within each gate, and the 3D coordinate frame selected during gate definition.

The Gate Tool

Central to the utility of StarGateVR is the "Gate Tool," a versatile tool in VR for delineating groups of stars. The Gate Tool is visually represented as an adjustable spheroid, manipulated via sliders on the left controller's Data Panel. The position of the Gate Tool, in the current reference frame, is display alongside the Gate Tool so it can be used as cursor to make detail measurements of selected stars.

- Using the Gate Tool:
    - Retrieve the Gate Tool by engaging the "Retrieve Gate Tool" button on the left controller.
    - Adjust the Gate Tool's dimensions using the Gate Tool Size Sliders.
    - To select stars, encompass them with the Gate Tool, then hold and move it using the left controller trigger.
    - Stars within the Gate Tool's bounds are temporarily highlighted.
    - Commit your selection by pressing the right controller's "Set Gate" button, creating a new gate displayed on the Gate Display.
- Non-Spheroid Selections:
    - Activate the selection mode by holding the left controller trigger while maneuvering the Gate Tool through the starfield.
    - Engage stars for inclusion or exclusion with a single or double click, respectively.
- Editing Gates:
    - Enter "Edit Gate" mode via the right controller to modify the constituents of an existing gate.
    - The VR environment's hue shifts to blue as a visual cue of edit mode.
    - The Gate Tool can then be used to add or remove stars from the gate.
    - Conclude editing by pressing the "Edit Gate" or "Set Gate" button, reverting to the prior visualization frame.

Quickly transitioning between visualization frames and editing gates underscores StarGateVR's capacity for efficient analysis, empowering users to refine their stellar selections with ease.

The Gates Display

Central to the functionality of StarGateVR is the Gates Display, a dedicated panel atop the left controller that monitors gates and their interrelations.

Base Gate Establishment:

- Automatically generated upon dataset loading, the Base Gate encompasses all dataset stars in white.
- Immutable, it serves as the foundation from which all subsequent gates derive.

Gate Visualization:

- Each gate is visually represented by a colored square on the display, correlating with the stars' color within that gate.
- To its right, the gate displays the star count and the axes settings active during its creation.

Focus Gate Navigation:

- One gate is highlighted as the Focus Gate for targeted manipulation.
- Navigate through gates using the left controller's thumb-stick; adjust their sequence and logical relationships.

Logical Gating:

- Sequentially, gates are combined with an OR condition.
- A rightward offset of a gate beneath another signifies an AND condition, affecting the displayed star count and visualization in the starfield.

Gate Management:

- Change starfield visibility or delete gates by interacting with the Focus Gate, using the Toggle Gate Off/On and Delete Gate buttons, respectively.
- A safety mechanism prevents accidental gate deletion, requiring a confirmation action.

Through these mechanisms, StarGateVR facilitates complex gating strategies, enabling detailed and layered analysis of stellar data.

Data Integration

Accessing Data on Quest from an External Computer (Desktop)

- Upon installing StarGateVR, a “Demo” folder is installed in the Quest headset’s “StarGateVR Directory”, which can be found at `sdcard/Android/data/com.ImmersiveScienceLLC.StarGateVR/files/demo` on your Quest headset. This directory includes a sample dataset of stars within 90 parsecs of the Earth, some sample gate files, and a Gaia Archive query template (also shown in Appendix B below).
- Connect your Quest to your computer via cable, enable remote access through the headset notifications, and then access this directory from your desktop file browser.
- In StarGateVR, use the "Load Data" and "Load Gates" buttons to display data and pre-set groups of gates for analysis.

Building Your Own Datasets

- Create a dataset by following the format of the demo CSV file, maintaining the column name capitalization up to the "one" column.
- Additional data columns can be included as needed, such as X-ray data from Chandra.
- Provide Right Ascension, Declination, and Distance for star position calculations, or include (x,y,z) directly in the file.
- Proper Motions and Radial Velocity data are used for computing star motion (u,v,w), unless directly provided.

Querying the Gaia Archive

- Visit the Gaia Archive website to perform queries for new datasets.
- Create an account to save queries and results, then navigate to the Advanced query tool.
- Paste the provided query template from `SampleGaiaArchiveQuery.txt` located in the StarGateVR directory on your Quest.
- Assign a descriptive Job Name for easy identification, submit the query, and download the CSV result.
- Transfer the downloaded CSV file to the specified directory on your Quest to access it within StarGateVR.

Collaborative Features

In-VR-Space Collaboration Experience

StarGateVR enhances scientific research through its collaborative features, offering an immersive VR space for up to six researchers to work together.

- Preparation: Prior to a collaborative session, participants share star datasets, gate files, and a designated "room name" for the meeting.
- Joining the Session: Each user loads the shared files into StarGateVR, then joins the session by entering the agreed-upon room name.
- Collaboration Environment: Participants are represented as avatars, complete with body, head, and controllers, allowing for intuitive interaction and communication. The Quest's built-in microphone and speakers facilitate full stereo audio communication.
- Synchronized Operations: All actions, such as changing display axes, setting gates, or moving stars, are synchronized among users, ensuring a cohesive and interactive experience.
- Ending the Session: The collaboration can be concluded by clicking the 'End Collaboration' button.

This feature fosters effective teamwork and joint exploration of data, embodying the spirit of collaborative scientific advancement.

Advanced Usage

Axes Selection in the Control Panels

The 3D visualization power of StarGateVR lies in its flexible axis selection, allowing users to dynamically map star parameters to the X, Y, and Z axes in the VR display. This feature is central to exploring various astrophysical phenomena:

- Parameter Assignment: Users can assign parameters from the input CSV file to each of the VR axes (capital X, Y, Z) using the Axis Parameter Selection pulldowns on the left controller's Axis and Color Panel.
- Visualization Examples:
    - Assigning x, y, z (star positions in parsecs) to X, Y, Z results in a 3D cartesian plot of star locations.
    - Selecting u, v, w (velocities) offers a view of stellar motions.
    - For specialized datasets like the M4 globular cluster, parameters like l, b, and bp_g can reveal phenomena like dust cloud-induced stellar reddening.
- Custom Parameters: StarGateVR accommodates additional star data columns in the CSV file. These user-defined column labels are integrated into the Axis Parameter Selection menus, enhancing the tool's adaptability for various research needs.

This functionality provides a robust and intuitive platform for astronomical exploration and hypothesis testing.

Point Color and Brightness

StarGateVR's default setting renders stars as uniformly bright, white points, irrespective of their actual magnitude. This representation can be customized:

- Color Customization: Activate the Point Color toggle to assign colors to stars based on specific parameters, overriding the unique colors set by Gating. This feature is accessed via a dropdown menu in the control panel.
- Brightness Control: Similarly, Point Brightness can be enabled to reflect star brightness based on chosen parameters. For instance, selecting 'abs_mag' adjusts the display to show stars in their absolute magnitude, while 'Gaia's phot_g_man_mag' reflects their apparent magnitude.

These features enhance the visual analysis, allowing for a more nuanced understanding of stellar characteristics.

Note that by having the ability to select three axes for coordinates, along with color and brightness, StarGateVR enables plotting in five dimensions (5D) simultaneously. This multidimensional plotting leverages the natural capabilities of the human visual perception system, offering an intuitive and comprehensive understanding of complex stellar data.

Coordinate Frames

The left controller control panel in StarGateVR features a row of four buttons dedicated to coordinate frame selections:

- Preset Coordinate Frames:
  - "XYZ": This button sets the axes to display star positions.
  - "UVW": Selecting this will switch the display to stellar velocity.
  - "HR": This mode presents a color-magnitude diagram, commonly used in astrophysical analysis.
- Custom Coordinate Frame:
  - To customize, set up your desired frame parameters using the Axes Selection feature, then click "Set" to save this configuration.
  - Click "Load" to retrieve your custom settings in future sessions.

Note: The custom coordinate frame settings are temporary and will not be saved once StarGateVR is closed.

Star Field Scale

Enhance your view of the cosmos by adjusting the starfield scale. Use the right controller's laser to interact with the Star Field Scale slider on the left controller. Drag it to resize the stellar panorama to your preference, making navigation and examination more intuitive.

Star Brightness Scale

This slider refines the luminosity of the stars when Point Brightness is active. It's particularly useful for highlighting fainter celestial bodies, allowing for a tailored visual experience that can reveal otherwise obscured astronomical features.

Display Info

Incorporate relevant 2D information into the VR space, such as tables or images, by placing them in the StarGateVR directory. These assets become accessible in VR, and become visible when you click the Display Info toggle, enhancing the collaborative environment with pertinent reference images.

Auto Scale

The Auto Scale toggle ensures consistent scaling across all axes, ideal when examining position or velocity data. For diverse parameter combinations, independent axis scaling is crucial to maximize the visibility and distribution of stars within the field.

Center Stars

For distant star groups, utilize the Center Stars feature to reorient their position to the central frame of reference, offering a convenient and focused analysis without the need to navigate through virtual space.

Retrieve Gate Tool

Accessibility is key when gating. If the Gate Tool is out of reach, simply activate the Retrieve Gate Tool function to bring it to your left hand, streamlining the gating process for efficient data segmentation.

Label Gate

Annotate your gates with meaningful labels, such as cluster names, to retain their context. Focus on a gate using the left controller, then engage the Label Gate function to input your annotation, preserving the information for future sessions.

Save and Restore Gates

Use the "Save and Restore Gates" button to save any gate that you have created as you likely will want to save those gates for future work, or perhaps share them with collaborators.

Reload Star Data

If necessary, you can reload all the current star data by clicking on "Reload Star Data".

Save Gated Data

If you want to do further analysis on stars you've gated, by clicking on "Save Gated Data" all gates will be written out to a .csv file in the StarGateVR directory on the Quest in the file "<stardatafilename>-LogicallyGatedData.csv". The logically gated reference is to remind you that what is saved respects the and-or relationship that you set between the gates by the order and indentation of the gates on the Gate Display. Usually this is what you want, because you have carefully subsetting the stars into a group that is your region of interest (ROI). You can copy this csv file from your Quest to your desktop computer to feed into additional astrometric tools, or e.g., Python scripts.

Star Motion Control

Some star data sources, like Gaia Archive, have star motion data along with position. StarGateVR can animate this motion. Once data is loaded, and if at least one of the axis are in the star position (xyz) reference frame, then you can use the Run, Stop, Reset, and Speed Slider to control the animation. Note that the slider is bidirectional so you can sweep the speed forward or backward. Also note that there is no dynamic computation of gravitational interaction between stars. It only projects current velocities linearly forward and backwards through time.

Hide No RV Stars

Some stars may have no measured radial velocity, so the proper motions could not be combined with RV to compute the full 3D velocity (uvw). So, these stars are remain stationary when you active star motion. If you don't want to see the stationary stars, point and click on the Hide (No RV) toggle.

Gate Tool Size Control

The Gate Tool size and shape can be controlled by using the four sliders on the left controller labeled "Gate Size Control". You can individually adjust the x, y, or z axis of the

spheroid, or you can use the “All” slide to adjust all three at once, assuring a spherical gate shape.

Interacting with the Internet while in StarGateVR

While immersed in StarGateVR, you may want to view material available on the internet, via a web browser, or possible an AI like ChatGPT. This is possible following this procedure:

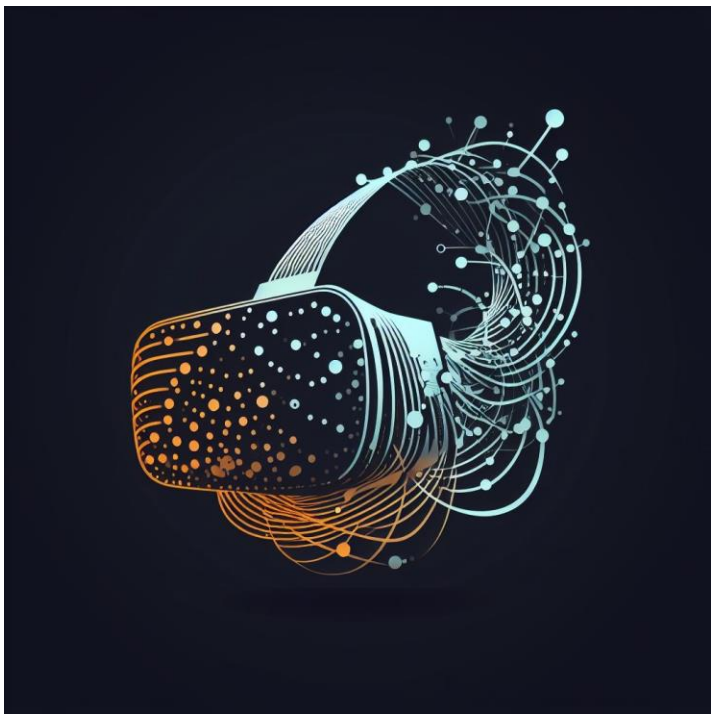
- Click the System/Quit button on the Right Controller – this brings up the standard Quest menu bar
- Click on the Browser icon – this opens a new window with a browser search bar that you can use as normal
- When done with your internet usage, click the System/Quit on the Right Controller again – this drops you back into StarGateVR where you left it
- Clicking on the System/Quit button again will conveniently return you to the Quest Browser window right where you left it, so you can quickly jump back and forth between the StarGateVR view and the Browser view.

Acknowledgements

We extend our heartfelt gratitude to several individuals whose contributions have been invaluable to the development and refinement of StarGateVR:

- **Tom Skillman:** For conception of the StarGateVR tool and the majority of the development and testing.
- **Joel Kastner**: For his insights into utilizing StarGateVR with high-dimensional Gaia Archive data.
- **Ryan Butler**: For his extensive beta testing, invaluable feedback on features, and his efforts in documenting SGVR's applications through tutorial videos and scientific posters.
- **Ben Ramsey, Ryan Wills, Sadie Coffin**: For their exploration of SGVR and feedback in the context of their Galactic Astronomy class.
- **Adin Pierce**: For implementing GPU-based acceleration in SGVR, significantly enhancing its responsiveness, even with datasets exceeding 500,000 stars.

Their dedication and expertise have been instrumental in shaping StarGateVR into a powerful tool for astronomical research.



Appendix A: Case Studies and Applications

Utilizing StarGateVR for Cluster Analysis

The scientific poster presents a study titled "Exploring NGC 2287: Insights from Gaia and TESS," authored by Benjamin Ramsey, Dr. Joel Kastner, Dr. Alex Binks, Ryan Butler, and Tom Skillman, affiliated with Rochester Institute of Technology and Immersive Sciences LLC. The study focuses on open star clusters and utilizes the Gaia mission's precise astrometry to investigate the physical properties of stars in the NGC 2287 cluster. The poster highlights the importance of studying clusters for astrophysical research and benchmarks determination of stellar initial mass function and stellar evolution.

The methods involve the use of StarGateVR for 3D visualization and sorting of the cluster's stars. The tool aids in the identification of interesting stellar groupings and allows for the export of gated sources for further study. The research incorporates Gaia's radial velocity and proper motion measurements to calculate cluster membership and investigates these clusters in both UVW and proper motion VR spaces.

Results indicate the validation of Gaia's projected rotational velocity measurements for NGC 2287's upper main sequence stars and the TESS satellite's observation of stellar rotational periods in the cluster. The study finds a significant number of new periodic variables and candidates for further investigation.

Conclusions drawn from the research demonstrate the utility of StarGateVR in cluster membership analysis and the effective combination of Gaia and TESS data for studying stellar rotation. The poster outlines future work, including a proposed observation of NGC 2287 using Chandra HRC-I to further explore X-ray activity and binary mass transfer mechanisms within the cluster.

Investigating the β Pictoris Moving Group with StarGateVR

In a separate case, StarGateVR was instrumental in analyzing the β Pictoris Moving Group (BPMG), a collection of young stars that are loosely bound and relatively close to Earth. Researchers from the Rochester Institute of Technology utilized the tool to refine data from the Gaia Data Release 3, enabling a nuanced study of stellar kinematics and membership within the group. The application facilitated a refined recovery of over 200 members and supported the age reevaluation of disk-hosting star 2MASS J15460752-6258042, thus offering new insights into the youth and dynamics of the BPMG.

This study showcases StarGateVR's capabilities in filtering and visualizing complex star data, allowing researchers to refine membership lists of stellar groups and providing fresh perspectives on the evolution of such associations.

Both poster are accessible via www.immsci.com/stargatevr.

Appendix B: Gaia Archive ADQL Query Template

```
SELECT TOP 300000

-- IMPORTANT NOTE: Parameters that are in units of Magnitude must
have an "as" name that ends in "_mag"

--Required parameters

    -- ID - force a leading hash symbol to stop Excel from reading
the ID number as a float
'#' || source_id as source_id,

    -- Measured Position
ra,
dec,
(1 / parallax)*1000 as dist,

     -- Measured Motion
pmra,
pmdec,
radial_velocity as rv,

     --Key source light params for HR diagram
phot_g_mean_mag,
bp_rp as bp_rp_mag,

     --Placeholders to be filled in by StarGateVR
0 as l,
0 as b,
0 as X,
0 as Y,
0 as Z,
0 as U,
0 as V,
0 as W,
0 as abs_mag,
0 as zero,
1 as one,

--Optional plot parameters (you can add anything you want here,
just give good unique "as" names - it will show up in the .cvs and
hence in StarGate
phot_rp_mean_mag,
phot_bp_mean_mag,
g_rp as g_rp_mag,
bp_g as bp_g_mag,
radial_velocity_error as rv_error,
parallax_error,
```

```
      -- Note: No comma after this last SELECT item

parallax_over_error

-- Use DR3
FROM gaiadr3.gaia_source

-- For any stars meeting these criteria
WHERE (parallax >= 11.11 AND parallax_over_error>=20 AND
astrometric_excess_noise<=2)
```