https://www.youtube.com/watch?v=n04M39SbfW0

Python, Data Visualization, and Astronomy

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Twitter & Instagram: @VizAstro
YouTube: Visualize Astronomy

June 2022

Big thanks to Jim, Anna, Lyndele, Danielle, Will, Brenne, et al. and all the students for making this summer possible…

Overview

- History of Python
- Why use Python in Astronomy?
- Why Revision Control is important...
- Google Colab and examples
- Data Colorimetry and Presentation
- Some of my work - 3D rendering of Astronomical Data
- Resources to explore further
- Conferences (in-person and remote!)
- **Recommendations**

python

- High level programming language that is scriptable and supports many programming styles.
- Created in the late 80s/early 90s by *Guido van Rossum*, named after *Monty Python*
- The **Python Standard Library** can be used to accomplish a wide variety of tasks - always check there first!

https://ivastar.github.io/python-novice-astro/

tiobe.com - Usage of Languages 2018

Jun 2018	Jun 2017	Change	Programming Language	Ratings	Change
1	1		Java	15.368%	+0.88%
2	2		C	14.936%	+8.09%
3	3		C++	8.337%	+2.61%
4	4		Python	5.761%	+1.43%
5	5		C#	4.314%	+0.78%
6	6		Visual Basic .NET	3.762%	+0.65%
7	8	↑	PHP	2.881%	+0.11%
8	7	↓	JavaScript	2.495%	-0.53%
9	-	⇈	SQL	2.339%	+2.34%
10	14	⇈	R	1.452%	-0.70%
11	11		Ruby	1.253%	-0.97%
12	18	⇈	Objective-C	1.181%	-0.78%
13	16	↑	Visual Basic	1.154%	-0.86%
14	9	⇊	Perl	1.147%	-1.16%
15	12	↓	Swift	1.145%	-1.06%
16	10	⇊	Assembly language	0.915%	-1.34%
17	17		MATLAB	0.894%	-1.10%
18	15	↓	Go	0.879%	-1.17%
19	13	⇊	Delphi/Object Pascal	0.875%	-1.28%
20	20		PL/SQL	0.848%	-0.72%

TIOBE Index for June 2019

June Headline: Python continues to soar in the TIOBE index

This month Python has reached again an all time high in TIOBE index of 8.5%. If Python can keep this pace, it will probably replace C and Java in 3 to 4 years time, thus becoming the most popular programming language of the world. The main reason for this is that software engineering is booming. It attracts lots of newcomers to the field. Java's way of programming is too verbose for beginners. In order to fully understand and run a simple program such as "hello world" in Java you need to have knowledge of classes, static methods and packages. In C this is a bit easier, but then you will be hit in the face with explicit memory management. In Python this is just a one-liner. Enough said.

The TIOBE Programming Community index is an indicator of the popularity of programming languages. The index is updated once a month. The ratings are based on the number of skilled engineers world-wide, courses and third party vendors. Popular search engines such as Google, Bing, Yahoo!, Wikipedia, Amazon, YouTube and Baidu are used to calculate the ratings. It is important to note that the TIOBE index is not about the *best* programming language or the language in which *most lines of code* have been written.

The index can be used to check whether your programming skills are still up to date or to make a strategic decision about what programming language should be adopted when starting to build a new software system. The definition of the TIOBE index can be found here.

Jun 2019	Jun 2018	Change	Programming Language	Ratings	Change
1	1		Java	15.004%	-0.36%
2	2		C	13.300%	-1.64%
3	4	^	Python	8.530%	+2.77%
4	3	v	C++	7.384%	-0.95%
5	6	^	Visual Basic .NET	4.624%	+0.86%
6	5	v	C#	4.483%	+0.17%
7	8	^	JavaScript	2.716%	+0.22%
8	7	v	PHP	2.567%	-0.31%
9	9		SQL	2.224%	-0.12%
10	16	^^	Assembly language	1.479%	+0.56%
11	15	^^	Swift	1.419%	+0.27%
12	12		Objective-C	1.391%	+0.21%
13	11	v	Ruby	1.388%	+0.13%
14	60	^^	Groovy	1.300%	+1.11%
15	18	^	Go	1.257%	+0.38%
16	14	v	Perl	1.173%	+0.03%
17	19	^	Delphi/Object Pascal	1.129%	+0.25%
18	17	v	MATLAB	1.077%	+0.18%
19	13	vv	Visual Basic	1.069%	-0.08%
20	20		PL/SQL	0.929%	+0.08%

Jun 2020	Jun 2019	Change	Programming Language	Ratings	Change
1	2	↑	C	17.19%	+3.89%
2	1	↓	Java	16.10%	+1.10%
3	3		Python	8.36%	-0.16%
4	4		C++	5.95%	-1.43%
5	6	↑	C#	4.73%	+0.24%
6	5	↓	Visual Basic	4.69%	+0.07%
7	7		JavaScript	2.27%	-0.44%
8	8		PHP	2.26%	-0.30%
9	22	⇈	R	2.19%	+1.27%
10	9	↓	SQL	1.73%	-0.50%
11	11		Swift	1.46%	+0.04%
12	15	↑	Go	1.02%	-0.24%
13	13		Ruby	0.98%	-0.41%
14	10	⇊	Assembly language	0.97%	-0.51%
15	18	↑	MATLAB	0.90%	-0.18%
16	16		Perl	0.82%	-0.36%
17	20	↑	PL/SQL	0.74%	-0.19%
18	26	⇈	Scratch	0.73%	+0.20%
19	19		Classic Visual Basic	0.65%	-0.42%
20	38	⇈	Rust	0.64%	+0.38%

TIOBE Index for June 2021

June Headline: Python has never been so close to position #1 before

Python is about to take over the first position in the TIOBE index. The gap between the current number one, programming language C, and Python is only 0.7% now. Next month, the TIOBE index is celebrating its 20-year anniversary. Programming languages C and Java are the only 2 languages that reached a number 1 position during these 20 years. So if Python is going to take over the first position in the TIOBE index, this will certainly be a historical moment, which is worth celebrating. There appear to be hardly any interesting moves further down the chart. Possible future champions such as Dart, Kotlin, Julia, Rust, TypeScript, and Elixir didn't show any significant changes last month. -- *Paul Jansen CEO TIOBE Software*

The TIOBE Programming Community index is an indicator of the popularity of programming languages. The index is updated once a month. The ratings are based on the number of skilled engineers world-wide, courses and third party vendors. Popular search engines such as Google, Bing, Yahoo!, Wikipedia, Amazon, YouTube and Baidu are used to calculate the ratings. It is important to note that the TIOBE index is not about the *best* programming language or the language in which *most lines of code* have been written.

The index can be used to check whether your programming skills are still up to date or to make a strategic decision about what programming language should be adopted when starting to build a new software system. The definition of the TIOBE index can be found here.

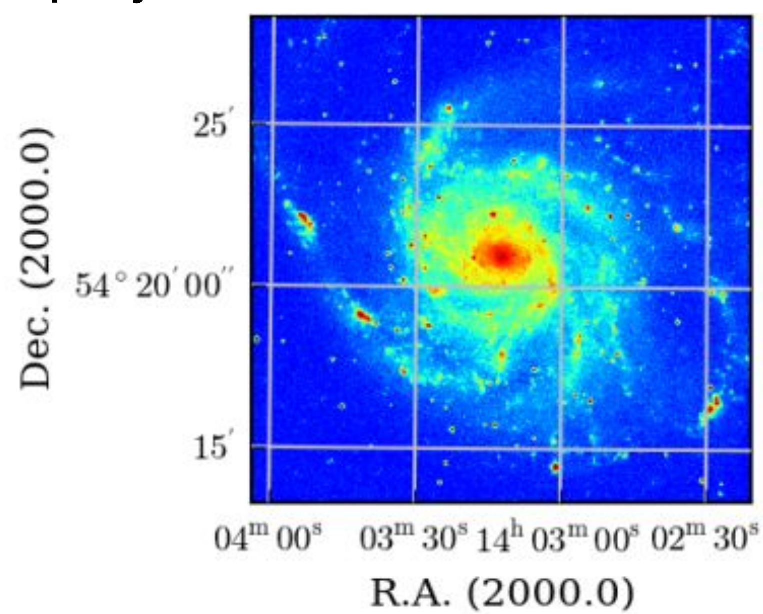
Jun 2021	Jun 2020	Change	Programming Language	Ratings	Change
1	1		C	12.54%	-4.65%
2	3		Python	11.84%	+3.48%
3	2		Java	11.54%	-4.56%
4	4		C++	7.36%	+1.41%
5	5		C#	4.33%	-0.40%
6	6		Visual Basic	4.01%	-0.68%
7	7		JavaScript	2.33%	+0.06%
8	8		PHP	2.21%	-0.05%
9	14		Assembly language	2.05%	+1.09%

Tiobe index for June 2022

Jun 2022	Jun 2021	Change	Programming Language		Ratings	Change
1	2	^		Python	12.20%	+0.35%
2	1	v		C	11.91%	-0.64%
3	3			Java	10.47%	-1.07%
4	4			C++	9.63%	+2.26%
5	5			C#	6.12%	+1.79%
6	6			Visual Basic	5.42%	+1.40%
7	7			JavaScript	2.09%	-0.24%
8	10	^		SQL	1.94%	+0.06%
9	9			Assembly language	1.85%	-0.21%
10	16	^^		Swift	1.55%	+0.44%

Python and Astronomy

- With iPython, it is used as the command line shell & interpreter for CASA
- Used for the framework for VLA/GBT imaging/ALMA pipelines
- Can interface with AIPS via Obit
- Can interface with IRAF via PyRAF
- Used in PRESTO - pulsar data reduction
- Many modules and libraries available - numpy, matplotlib, Kapteyn, astropy, AplPy, etc.
- Managed via pip or Anaconda



Popular Python Resources

iPython - more user friendly shell

Astropy - great for data import, manipulation, catalog queries

AplPy - general image/coordinate display utility

Matplotlib - general purpose plotting tool

Scipy - numpy and fitting routines (some overlap with astropy…)

Kapteyn - Good for mapping projections

AstroML - Machine Learning   http://www.astroml.org/index.html

PANDAS - Data Analysis Library http://pandas.pydata.org/

Python Data Science Handbook:

https://jakevdp.github.io/PythonDataScienceHandbook/

Recommendation: **Learn to use these inside and out!**

Where to start?

- https://safe.nrao.edu/wiki/bin/view/Main/PythonResources
- Pycon: https://us.pycon.org/2022/ (and video tutorials)

Revision Control

Revision Control for Software

Popular revision control systems (RCS) include SVN, CVS, Mercurial, and **git**.

Tracks changes made to files - good for collaboration among teams or to see when and where changes were made to your code!

Repo for this presentation:

https://github.com/brkent/SummerStudent2022

1. Plotting
2. 2D Plotting
3. Cosmology
4. Fitting Function
5. FITS images
6. VLASS and subimages

git revision control

```
mkdir sumstudent

cd sumstudent

git clone https://github.com/brkent/SummerStudent2022.git
```

This will create and link your directory to the git repository

git revision control

```
#Create a readme file
touch README.md
git add README.md
git commit -m “Initial README commit”
git push -u origin main
```

This is your modern scientific lab notebook!

Recommendation:

If you don’t already know how to use git, please take some time this summer and practice with these tutorials:

https://guides.github.com/

Google Colab

Colaboratory is a **Google** research project created to help disseminate machine learning education and research. It's a Jupyter notebook environment that requires no setup to use and runs entirely in the cloud.

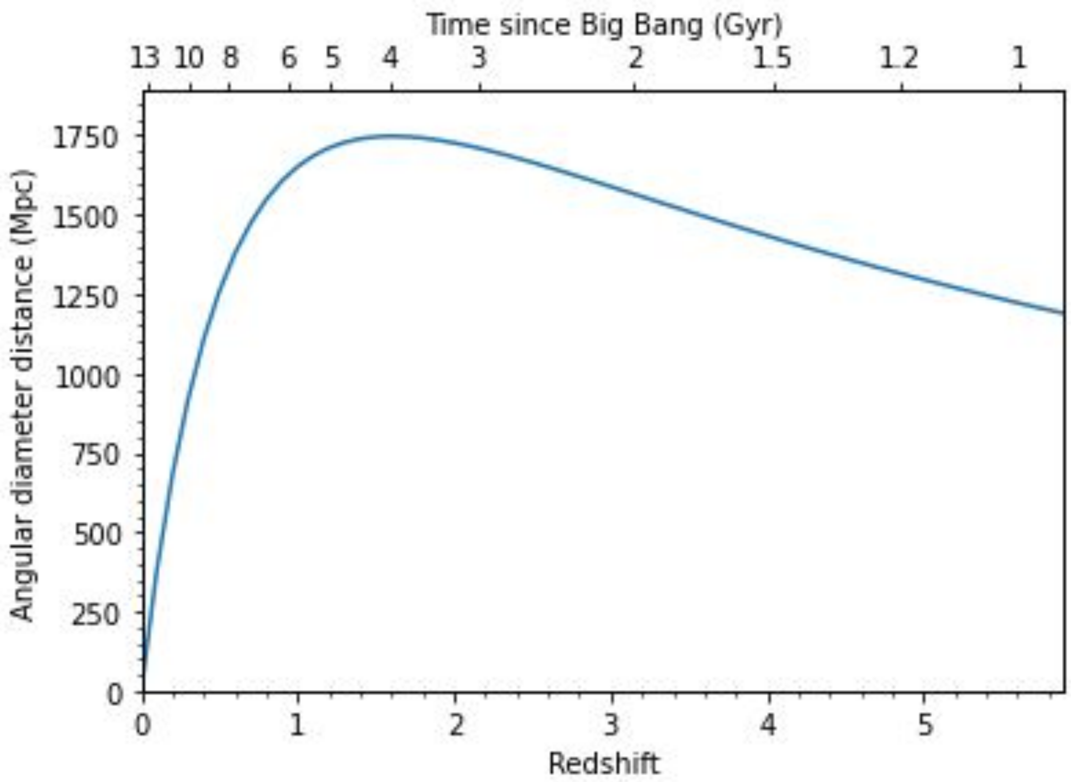
https://github.com/brkent/SummerStudent2022/blob/main/example04_gaussian_fit_seaborn.ipynb

Also works in github.dev…

Recommendation: Learn to prototype bit of code in the cloud and make clean Jupyter notebooks. Make your work portable and shareable! If you can point potential employers at york work and it is organized/documented - all the better!

Example: Astropy Cosmology Calc

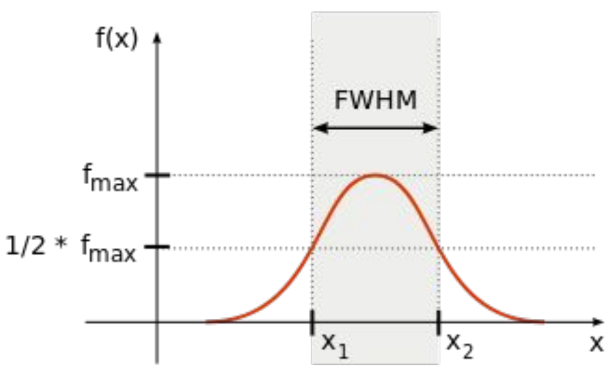
https://github.com/brkent/SummerStudent2022/blob/main/example03_cosmology.ipynb



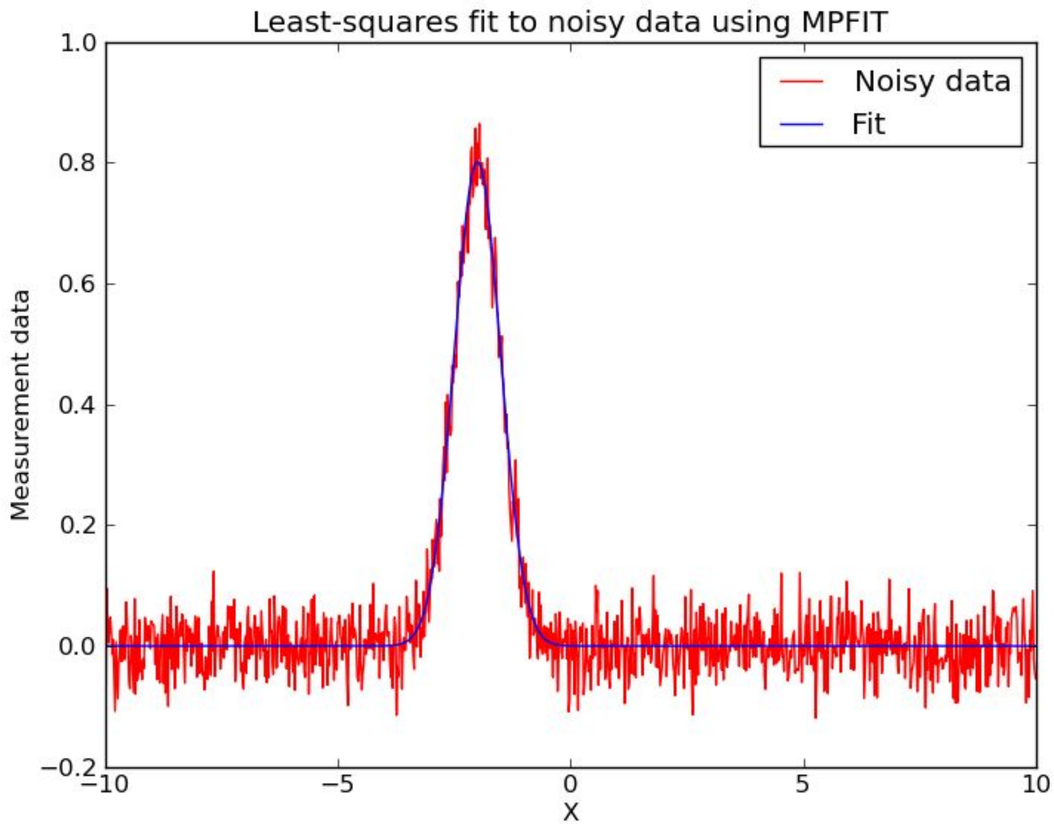
Example: Create a noisy spectrum and fit a Gaussian

https://github.com/brkent/SummerStudent2022/blob/main/example04_gaussian_fit_seaborn.ipynb

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(x-x_0)^2}{2\sigma^2}\right]$$



$$\mathrm{FWHM} = 2\sqrt{2\ln 2}\,\sigma \approx 2.355\,\sigma.$$



Another series of great fitting examples...

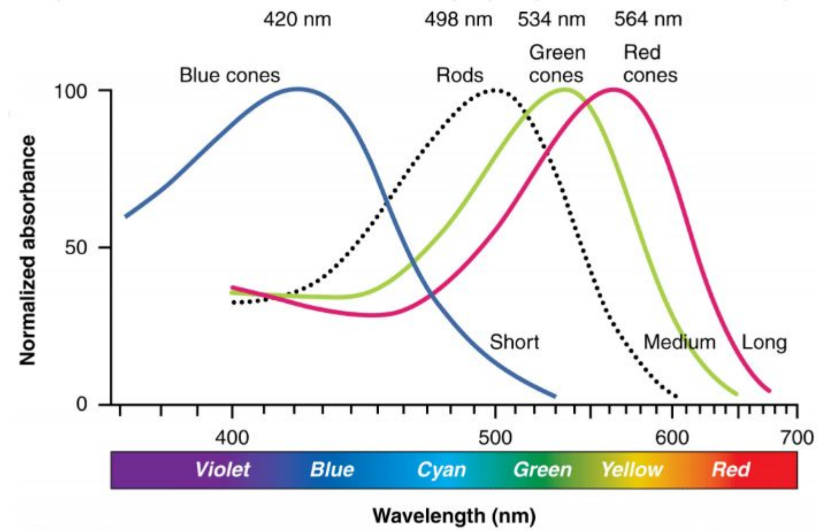
https://learn.astropy.org/tutorials/Models-Quick-Fit.html

Colorimetry for Visualization

Want your plots

to look top notch?

seaborn



https://seaborn.pydata.org/

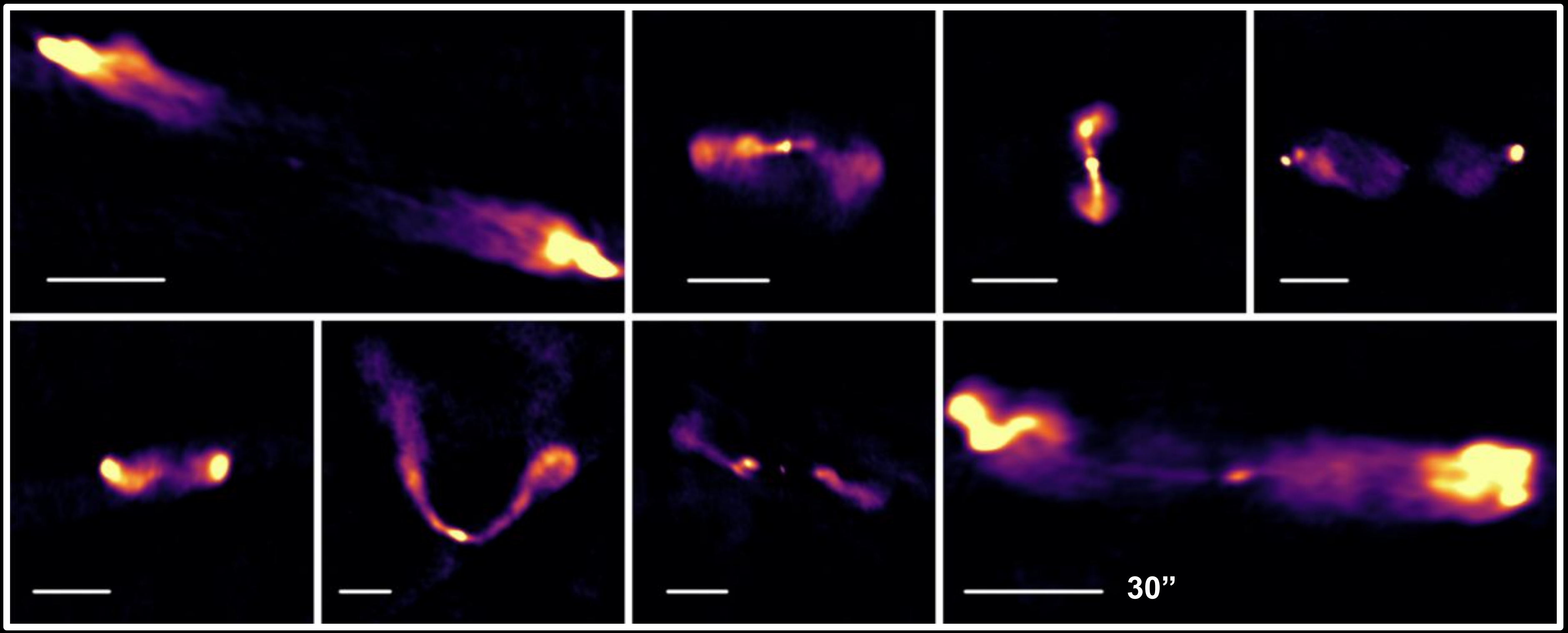
https://seaborn.pydata.org/tutorial/color_palettes.html#general-principles-for-using-color-in-plots

See references at the bottom of this page:
https://medium.com/hipster-color-science/a-beginners-guide-to-colorimetry-401f1830b65a

Talk by Dr. Michael Waters:
https://www.dropbox.com/s/7s9seplrnw3ea7p/Practical_Colorimetry_for_Scientific_Visualization_-_Michael_J_Waters_-_2021_3_14.pdf

Recommendation: Make your plots and graphics stand out for publication and presentation!

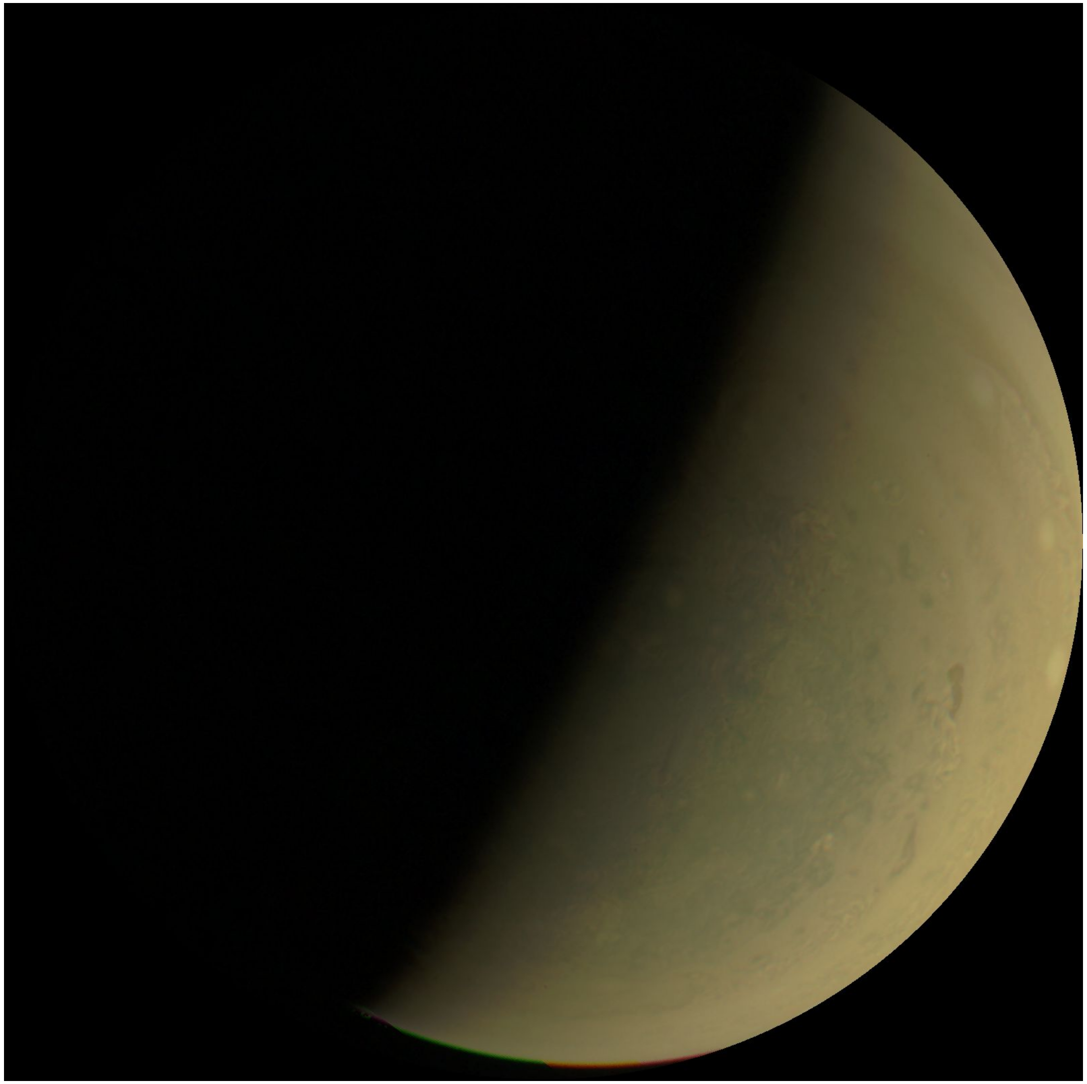
Example: VLASS



https://github.com/brkent/SummerStudent2021/blob/main/VLASS_FITS_example.ipynb
See the paper by Lacy et al. 2020 https://ui.adsabs.harvard.edu/abs/2020PASP..132c5001L/abstract

Another Example: Combine images from Juno

https://www.missionjuno.swri.edu/media-gallery/junocam



3D Graphics, Python, and Astronomy

MAYA

3DS MAX

LightWave11

CINEMA 4D

HOUDINI

PIXAR's RenderMan

I use a non-traditional package called Blender to render different forms of astronomical data - catalogs, data cubes, simulations, etc.

blender™

What is Blender?

Blender is:

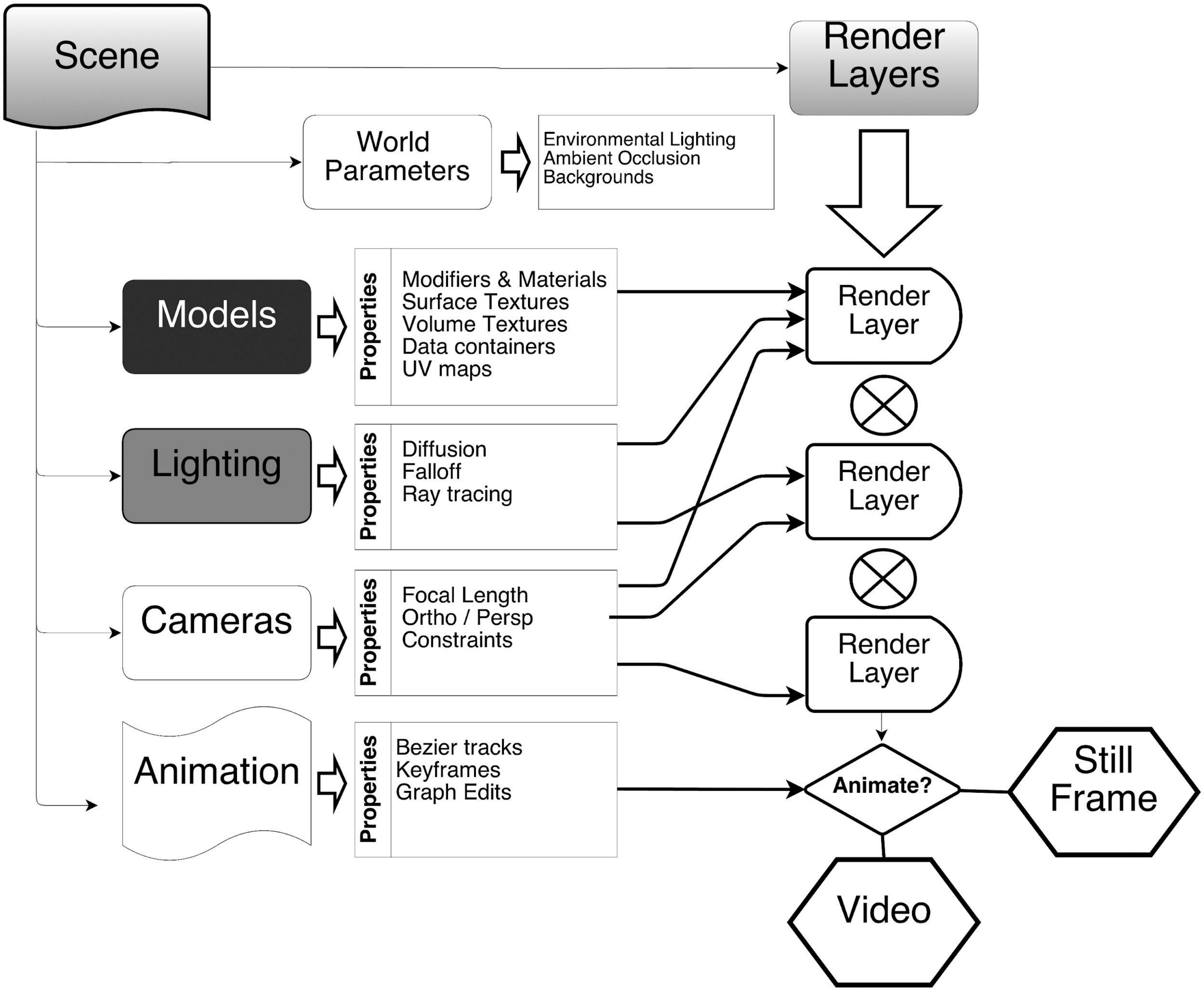
- 3D graphics software for modeling, animation, and visualization
- Open-source
- a real-time 3D viewer and GUI
- A Python scriptable interface for loading data

http://www.blender.org

Elements of 3D Graphics

We need to consider:

- Models - physical or data containers?
- Textures - 2D, 3D, and projections?
- Lighting - illumination of data - physical or artistic
- Animation - How will the model move and change?
- Camera control - lens selection, angle, image size, and movement and tracking
- Rendering - backend engine choice
- Compositing - layering final output



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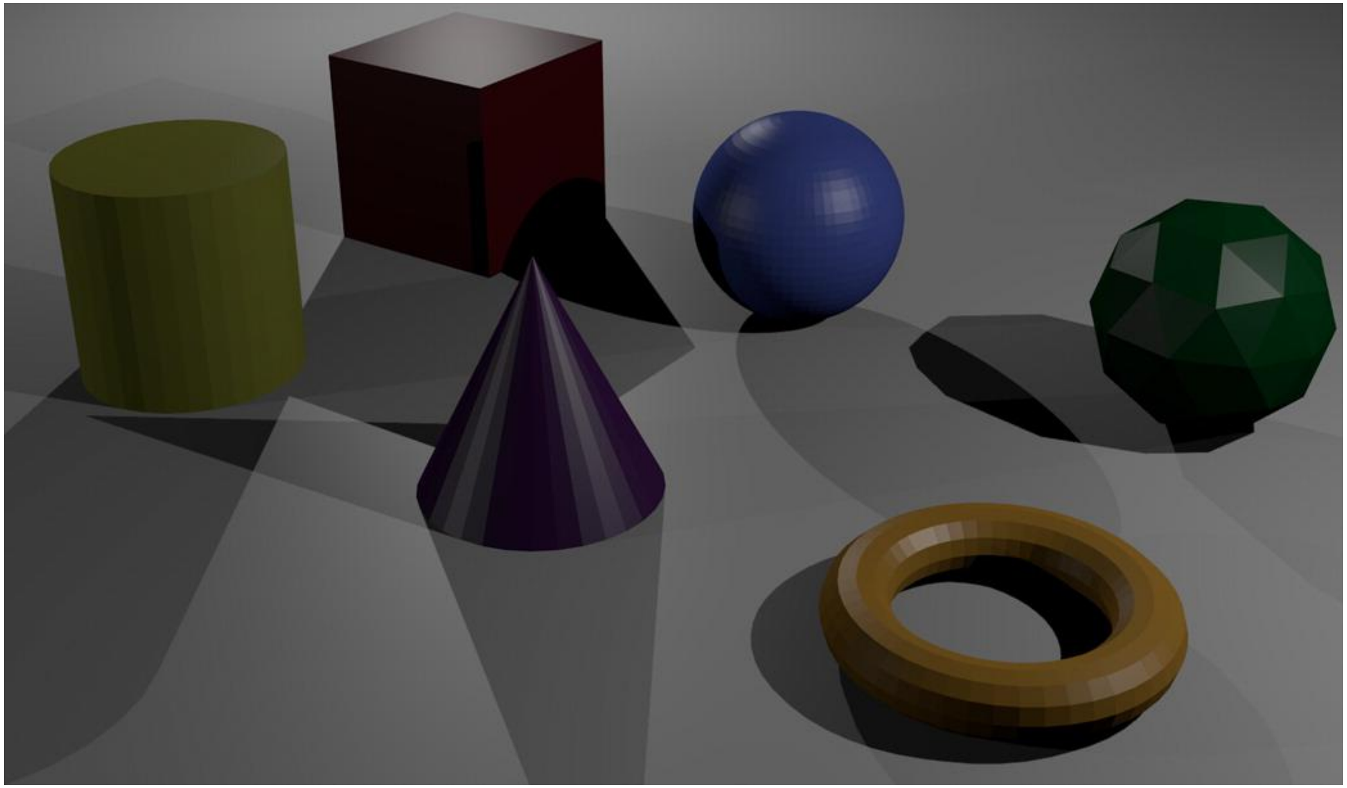
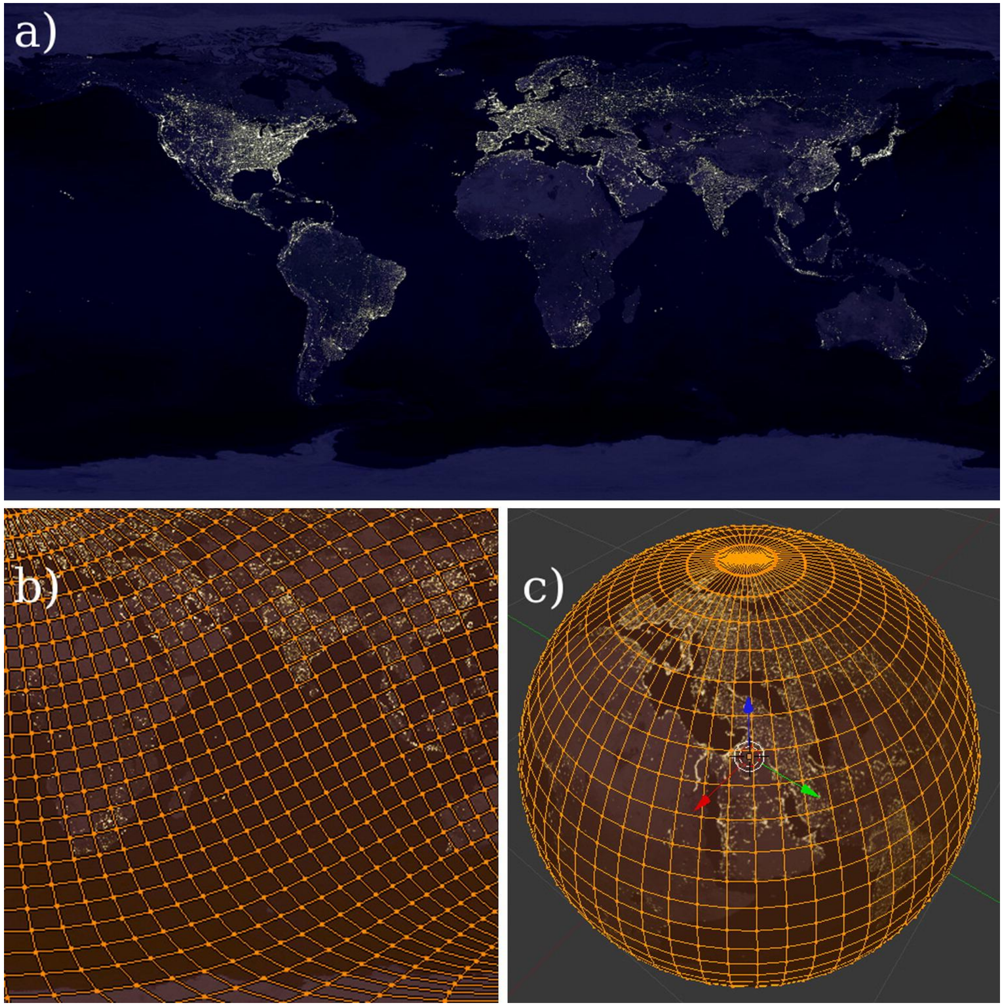
Modeling - basic shapes and containers



Texturing and Mapping



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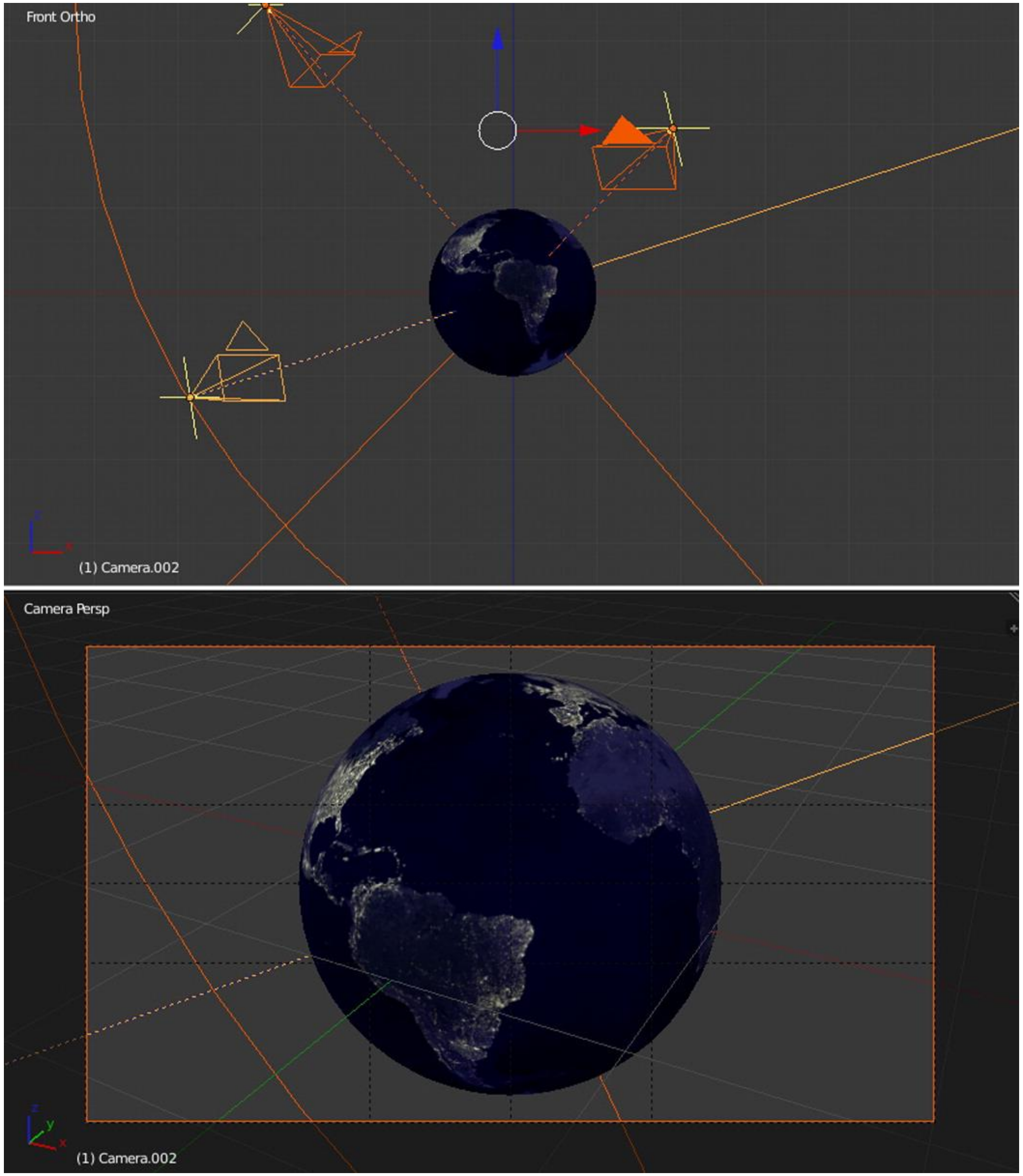
Camera Control and Movement



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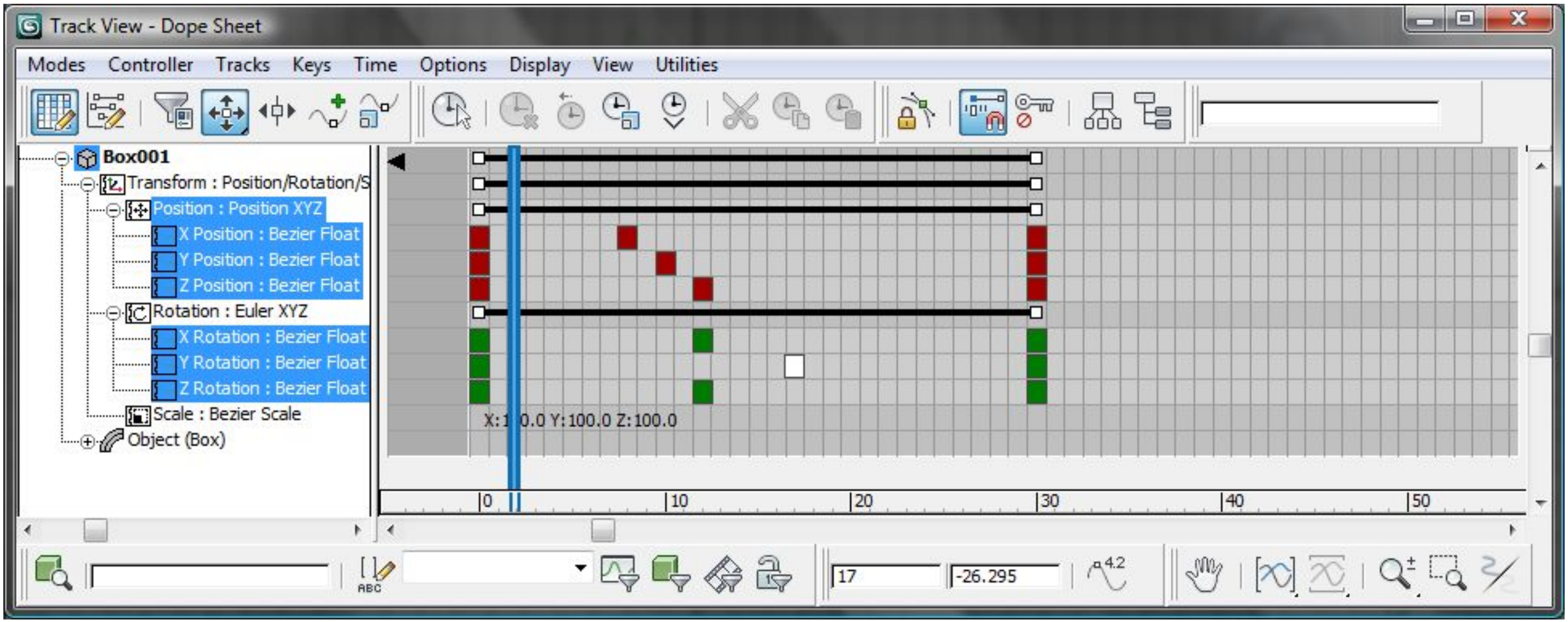
Track View - Dope Sheet
Modes
Controller
Tracks
Keys
Time
Options
Display
View
Utilities
Box001
Transform : Position/Rotation/S
Position : Position XYZ
X Position : Bezier Float
Y Position : Bezier Float
Z Position : Bezier Float
Rotation : Euler XYZ
X Rotation : Bezier Float
Y Rotation : Bezier Float
Z Rotation : Bezier Float
Scale : Bezier Scale
Object (Box)
Z:100.0
0
10
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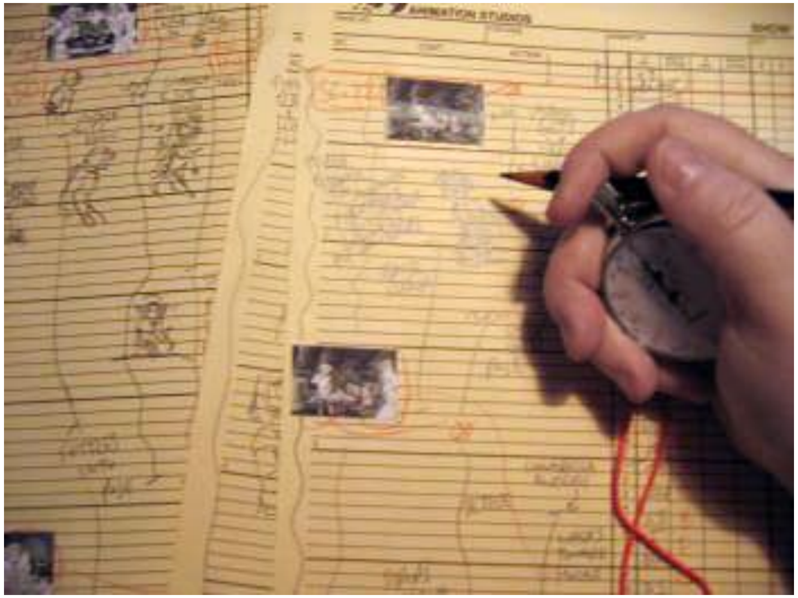
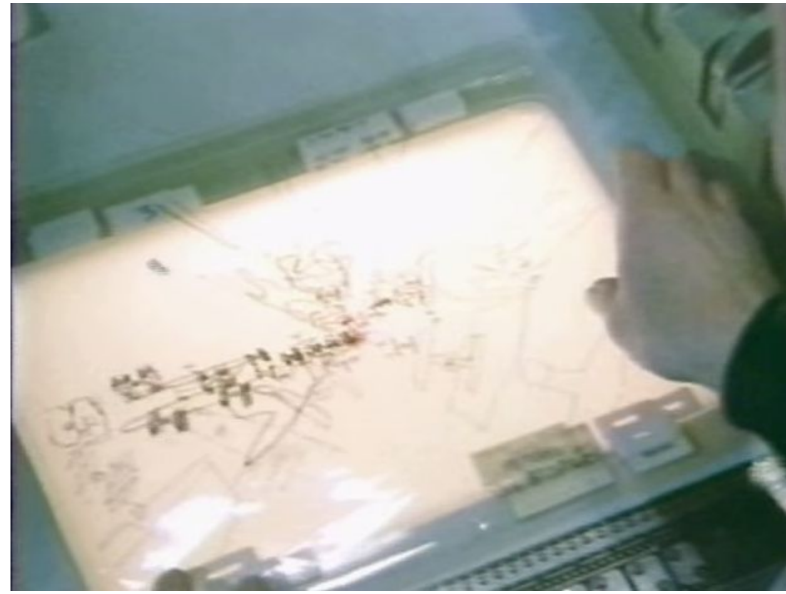
50
17
-26.295

Animation





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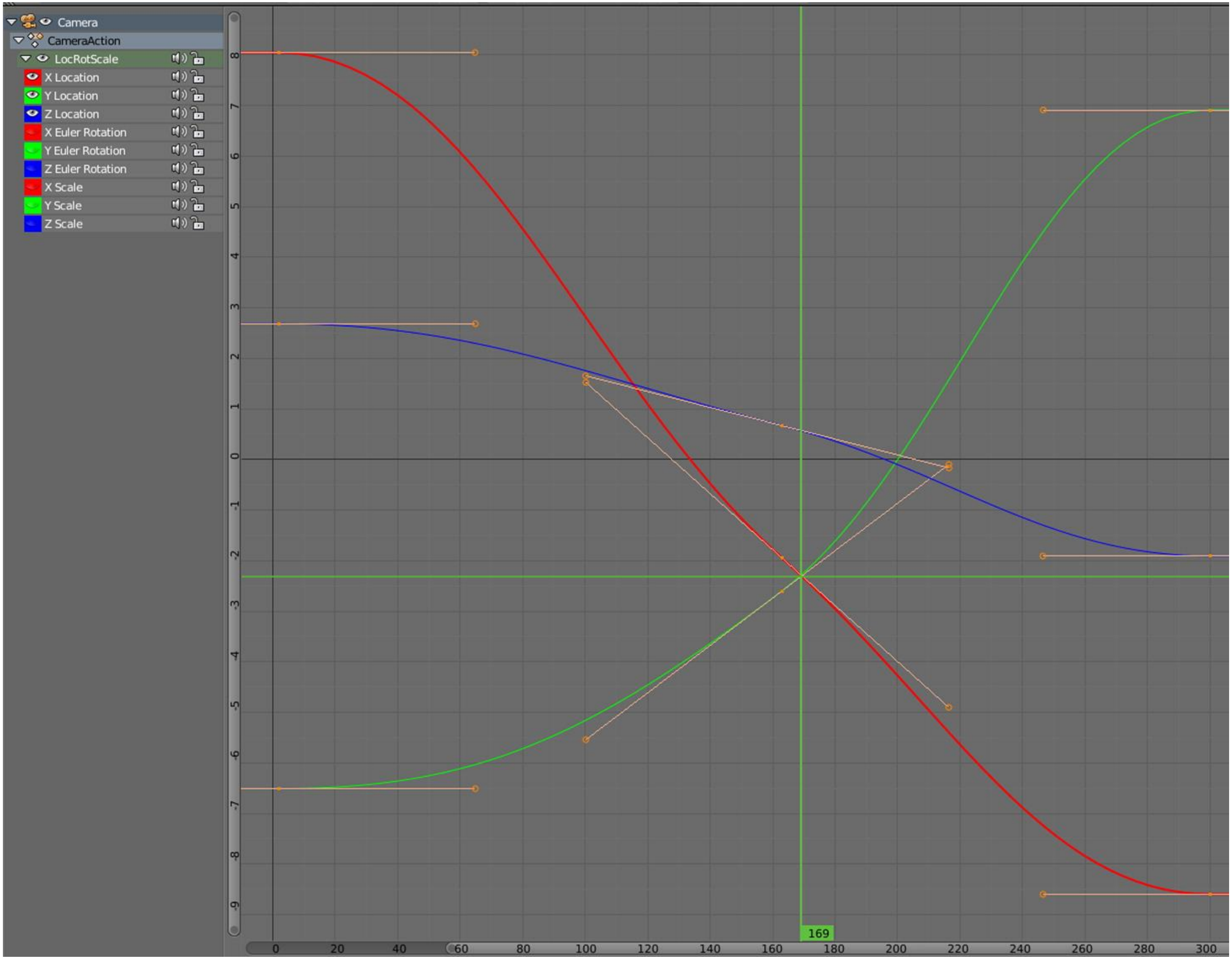
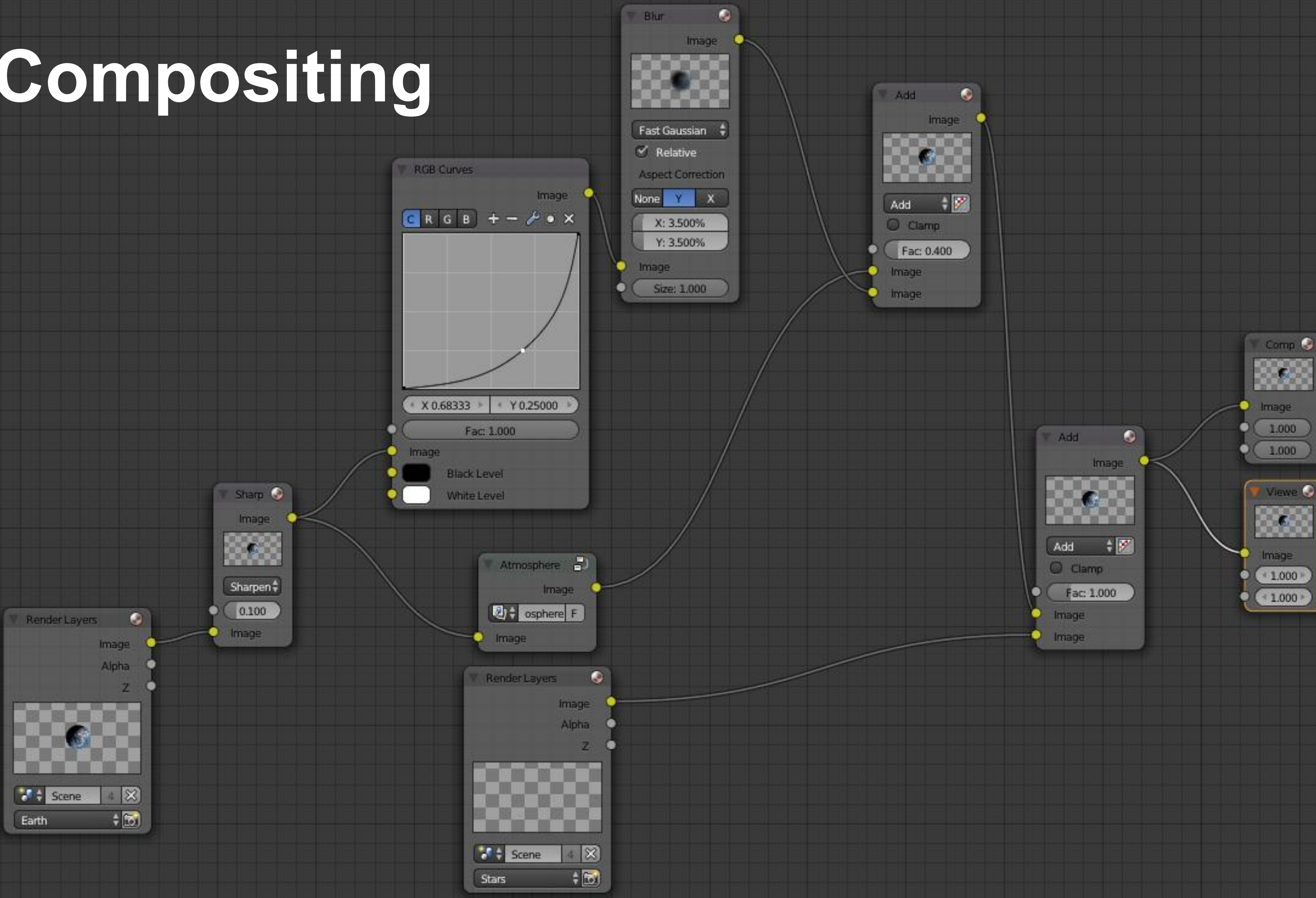


Camera
CameraAction
LocRotScale
X Location
Y Location
Z Location
X Euler Rotation
Y Euler Rotation
Z Euler Rotation
X Scale
Y Scale
Z Scale
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
169
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300

Rendering Engine

- Blender (included)
- Cycles (included)
- Yafaray (open source ray tracing engine http://www.yafaray.org/)
- Luxrender (http://www.luxrender.net/en_GB/index)
- Octane (http://render.otoy.com/)
- Renderman (http://renderman.pixar.com/view/renderman)

Compositing



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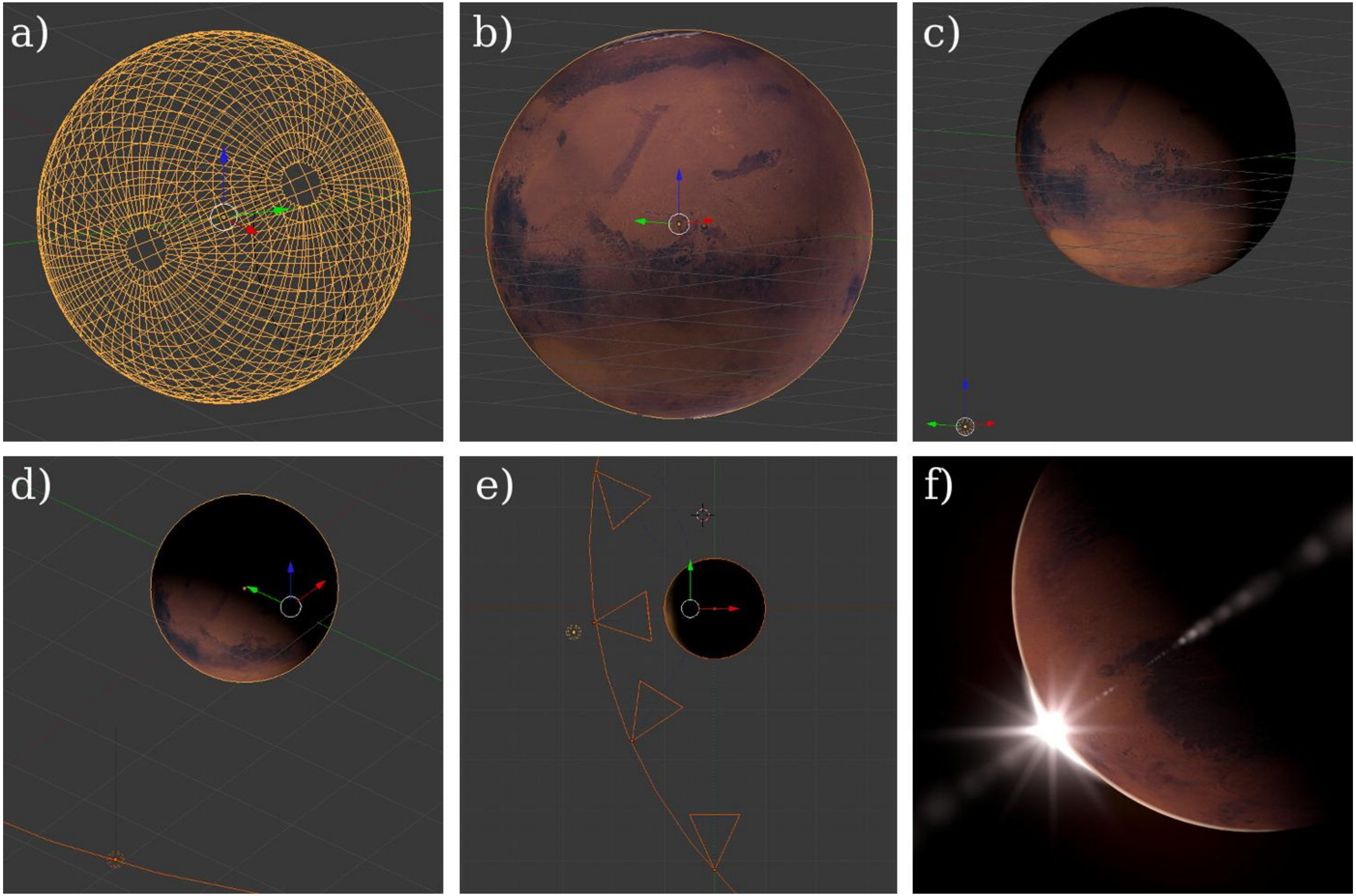
Rendering and Compositing



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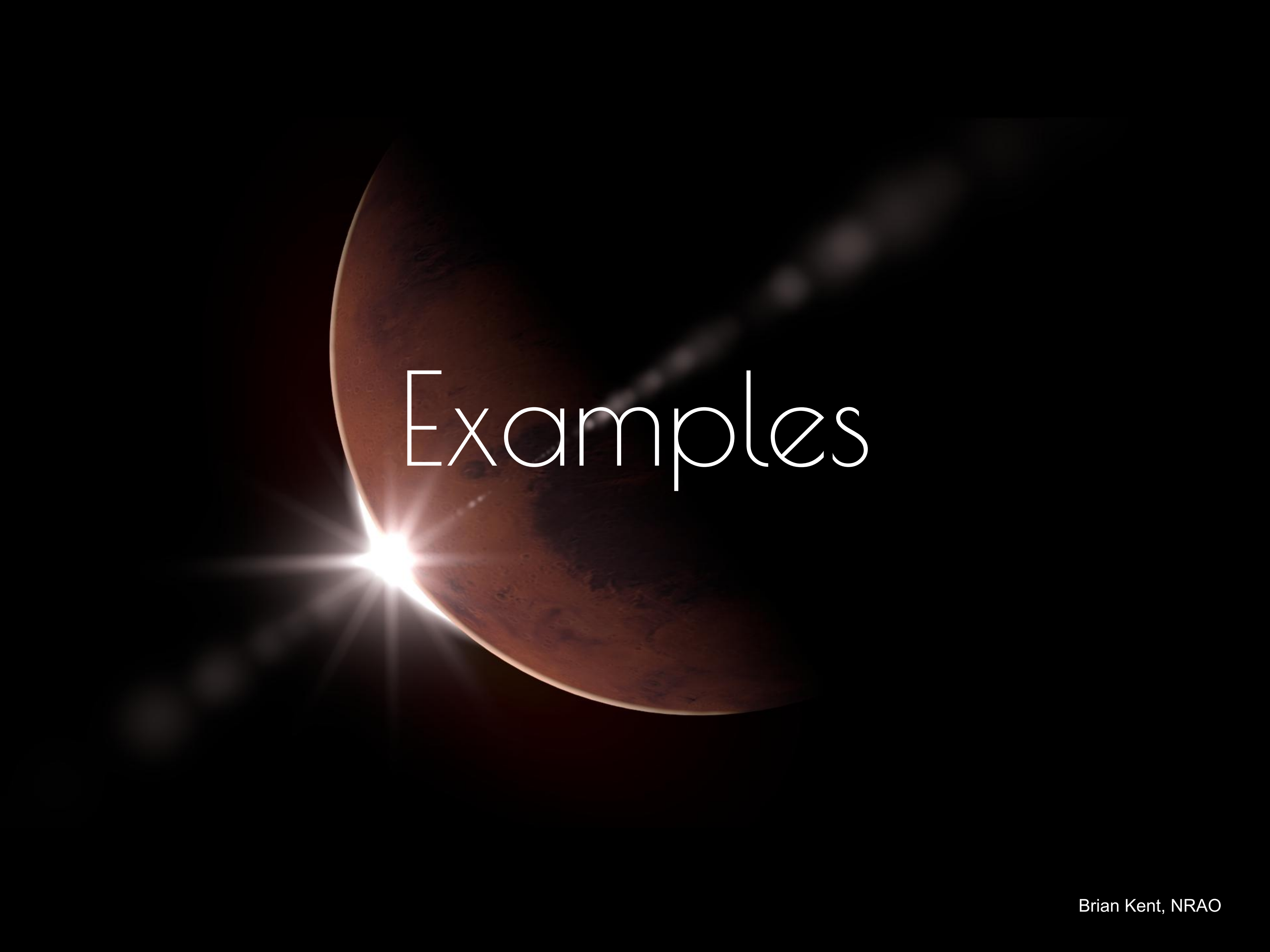
Examples
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A Tour of the Blender Interface

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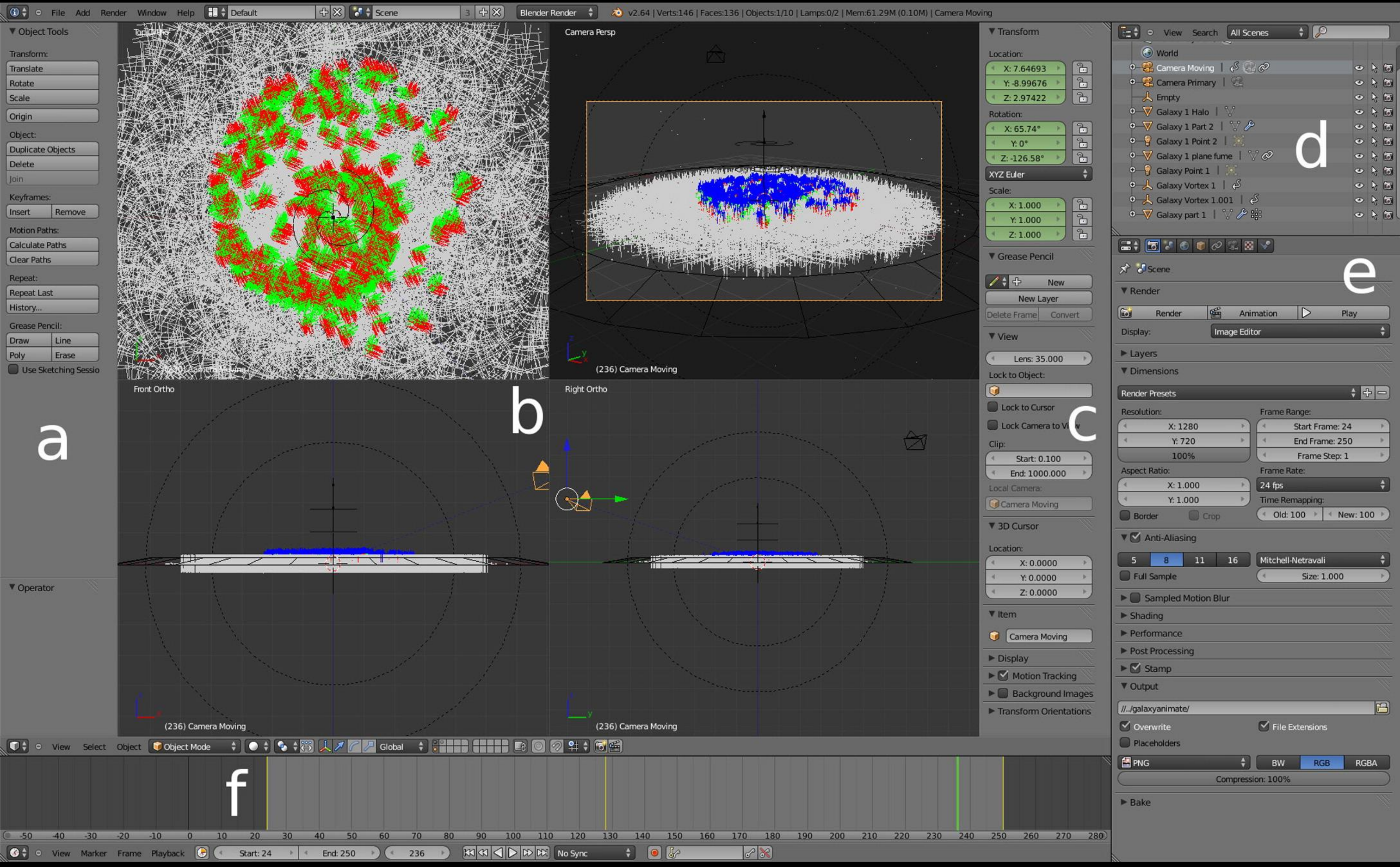

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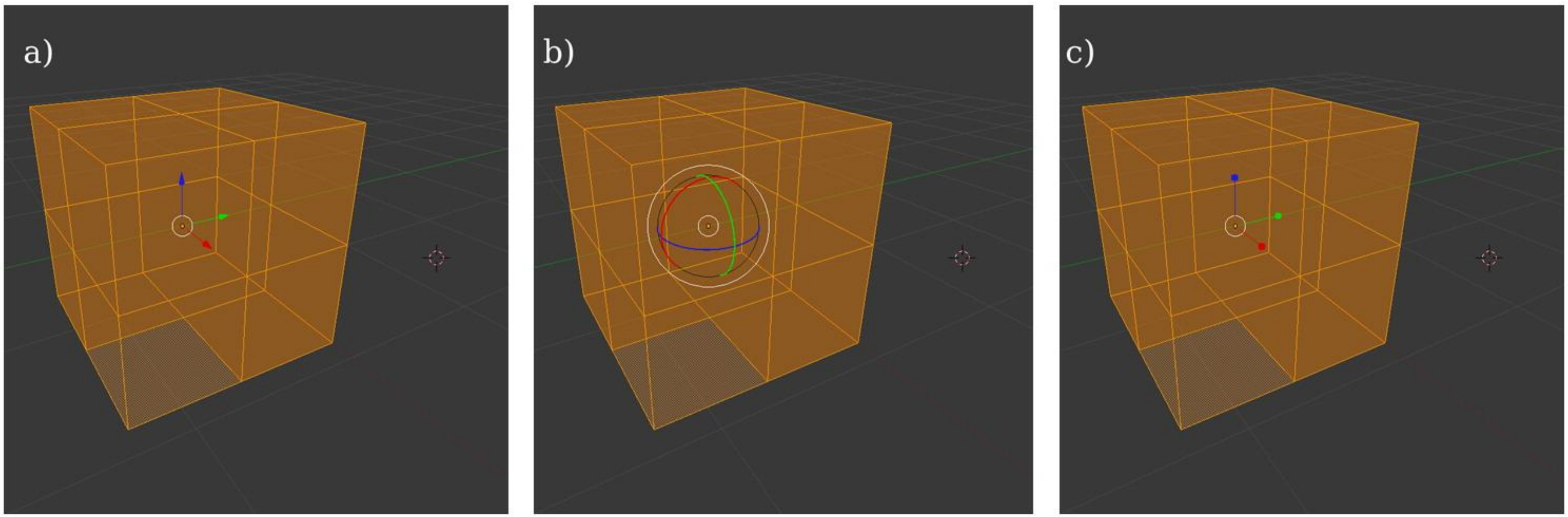
Blender interface



Translation **Rotation** **Scaling**

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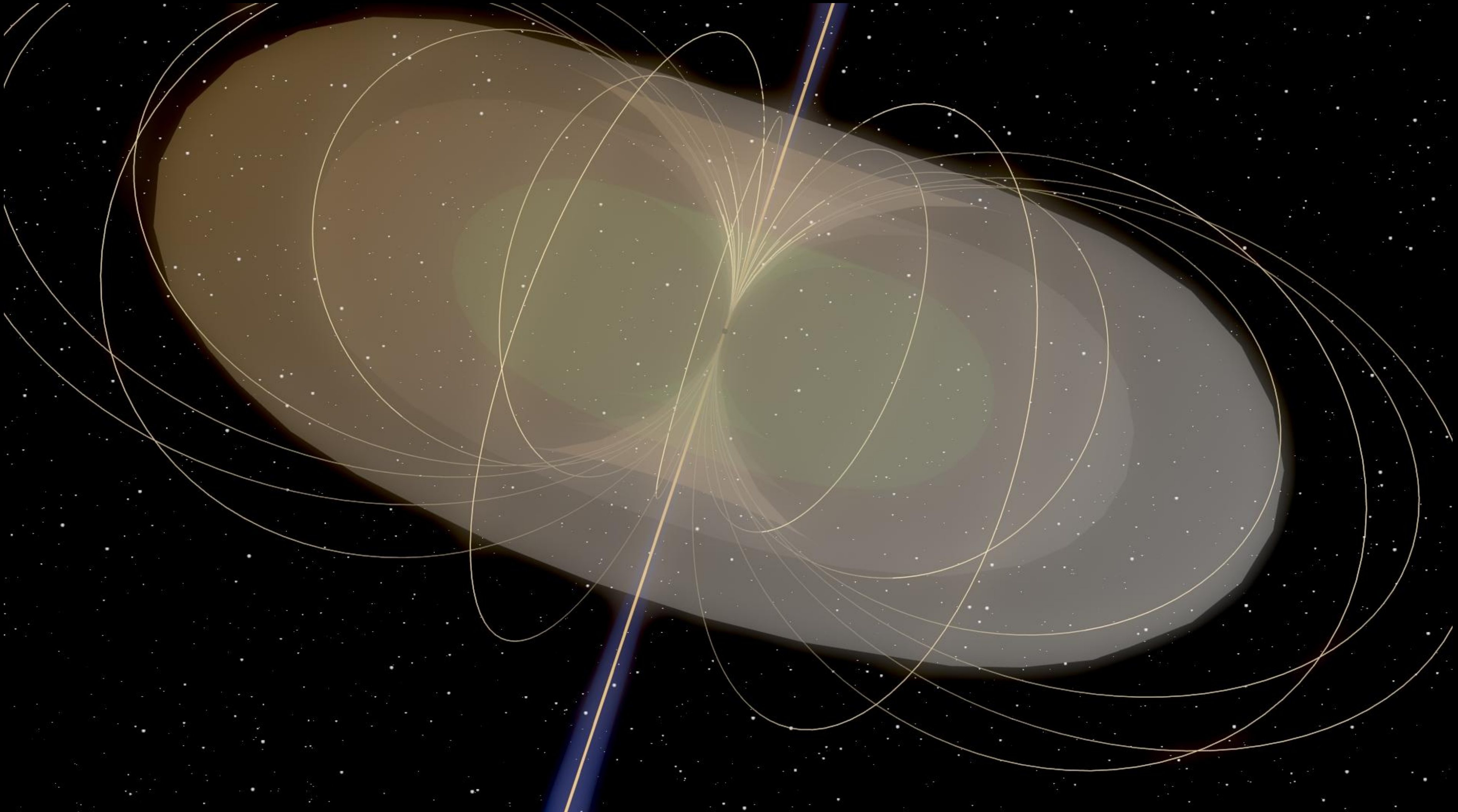

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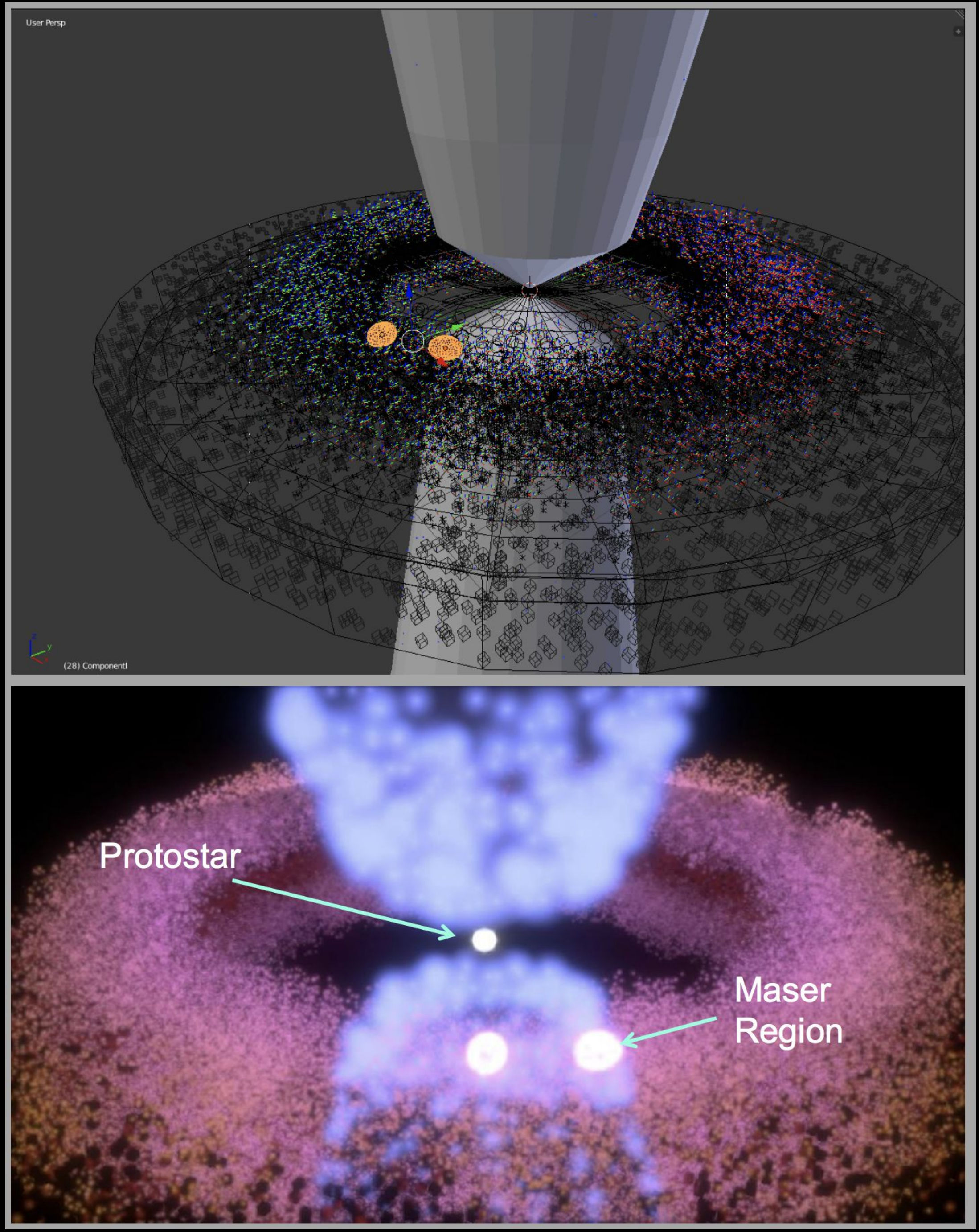


Araya et al.
Western Illinois Univ.

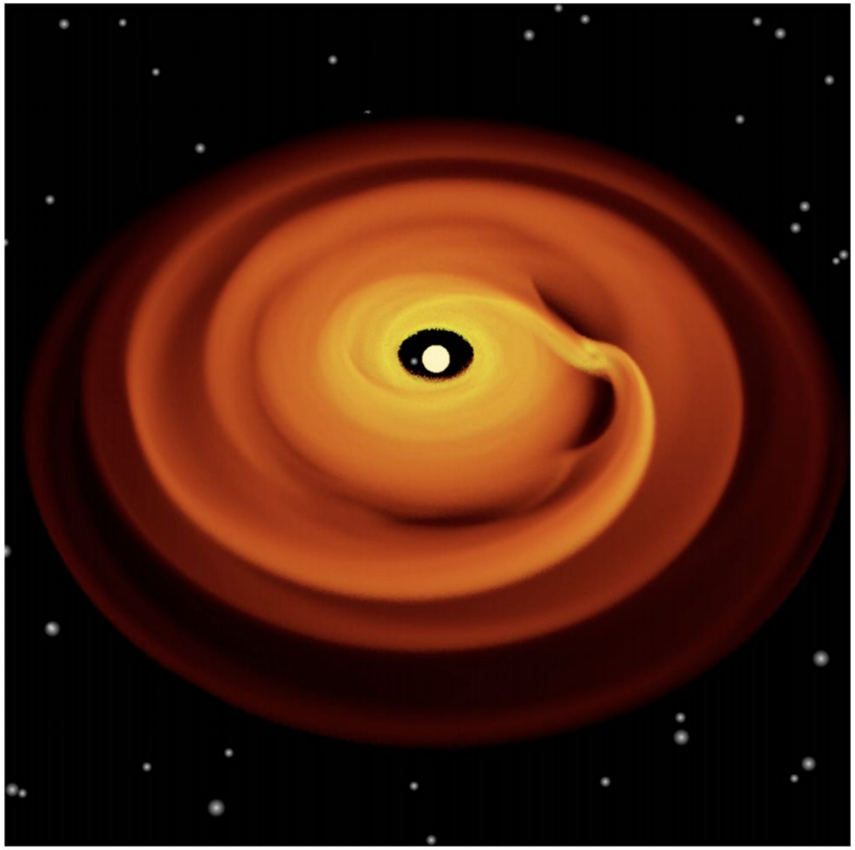


Figure 4. Protoplanetary disk with a massive planet carving a gap (S. Perez et al. 2017, in preparation). Simulation data provided by S.Perez using FARGO3D. The output was converted from an spherical grid as described in the Section 3.1. The image was post-processed to brighten the colors, and the halo points were added to emulate surrounding stars.
(A color version of this figure is available in the online journal.)

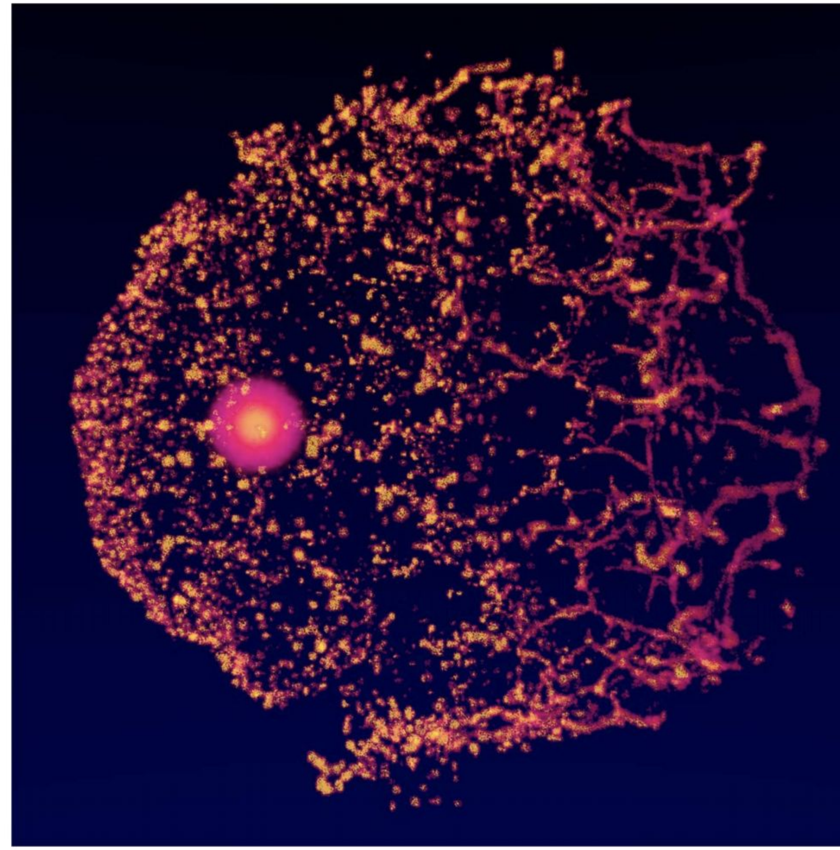
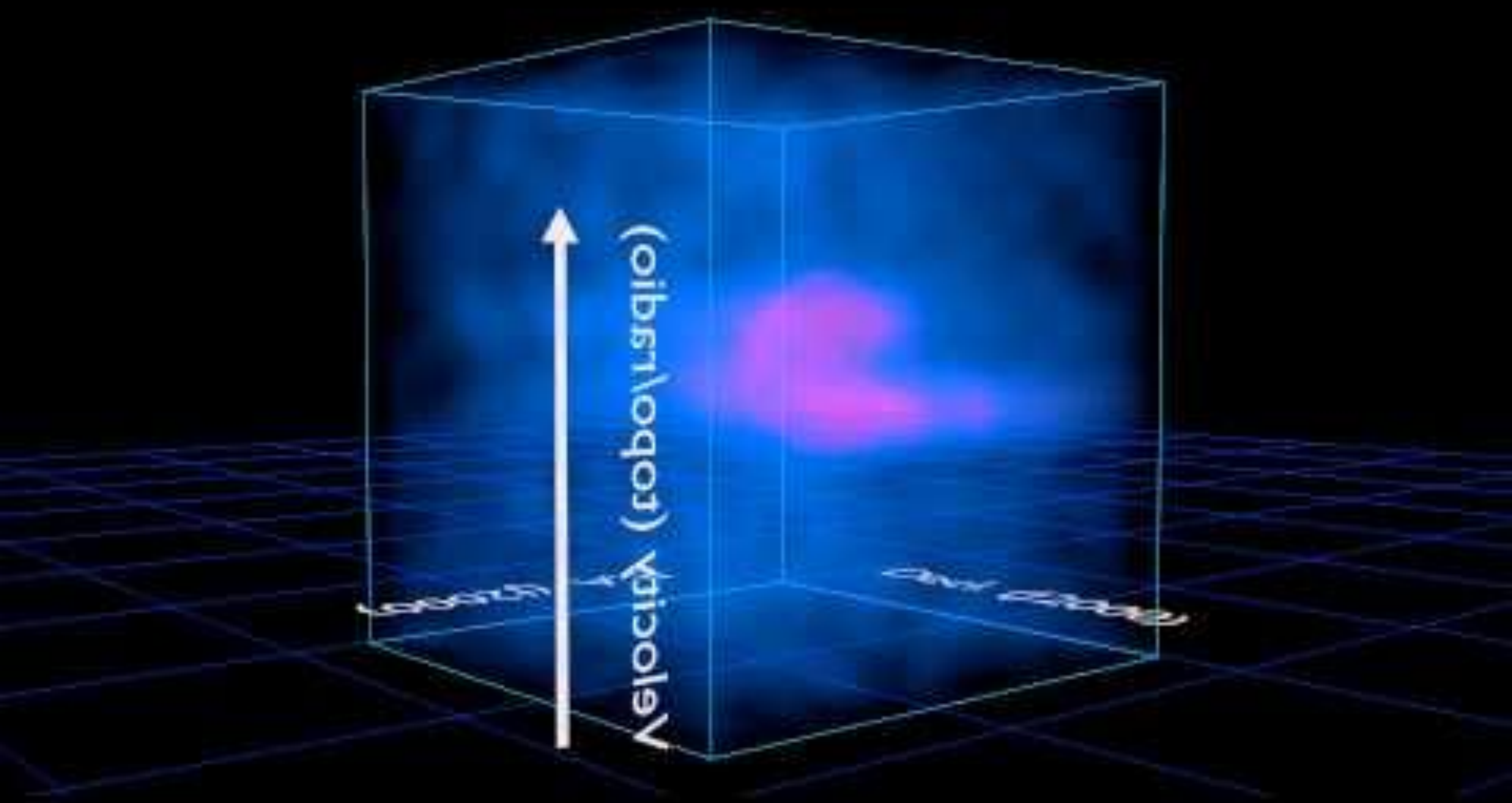


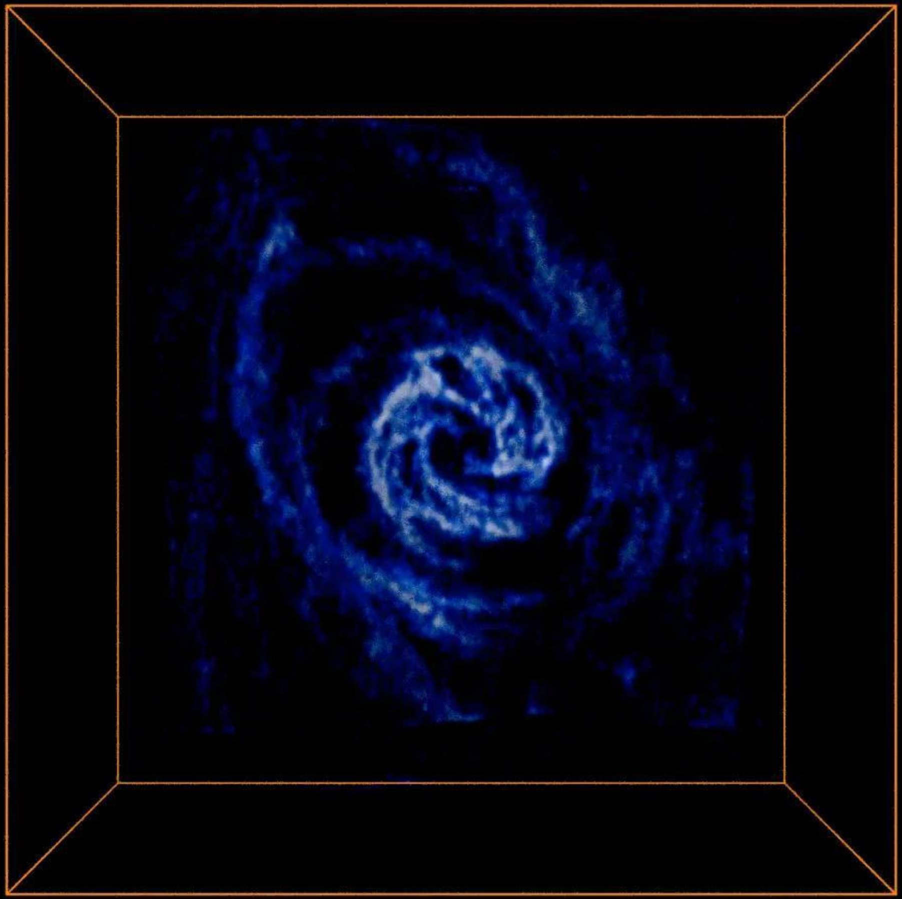
Figure 5. Stellar winds from a Wolf-Rayet star moving through the galactic center (Cuadra et al. 2008). Simulation data provided by J. Cuadra. The output was converted from an SPH simulation as described in Section 3.2. The image was post-processed to brighten the colors, and also the Blend Sky option of the World properties was used to add the background colors.
(A color version of this figure is available in the online journal.)

Data Cubes

- Gridded data can come from telescopes or simulations
- Radio telescopes produce grids that cover...
  - Two sky coordinates (RA and Decl.)
  - Frequency (Z - the doppler shifted velocity)
- These cubes can show the dynamics of galaxies, planetary disks, and large scale structure formation of clusters



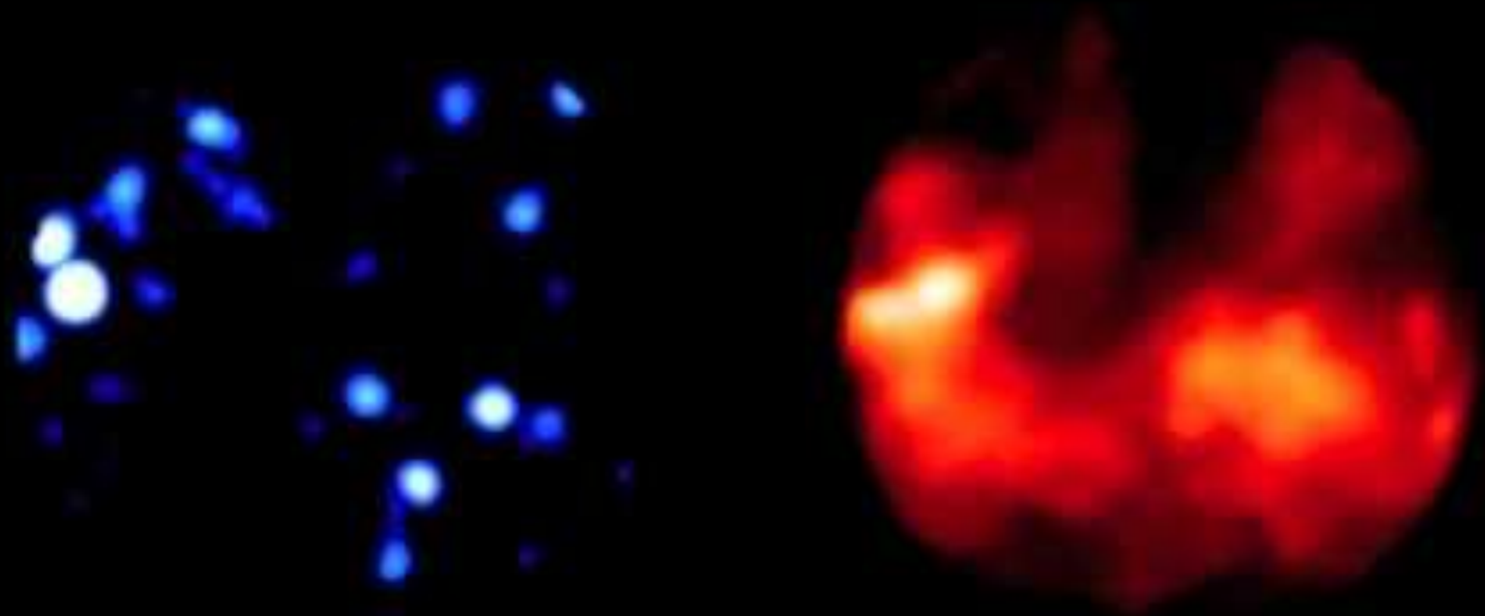
https://www.youtube.com/watch?v=RDUVZ9MlW2I



Data from Walter et al. 2008

Data Cubes

- Density maps of the nearby Universe can be created on regularly spaced grids.
- The results of these surveys allow to study not only the density of galaxies in 3D, but also the effects of gravity in the same regions of space...



https://www.youtube.com/watch?v=3cuNT8_YEF0

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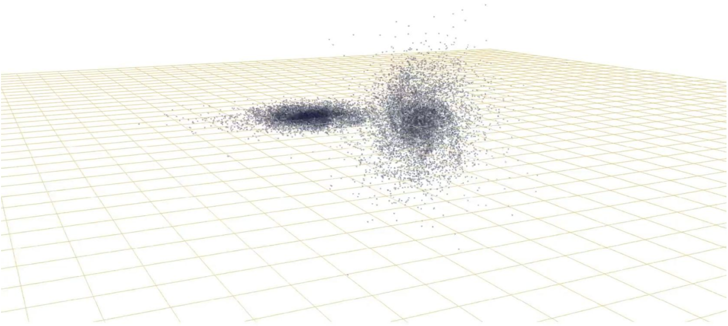
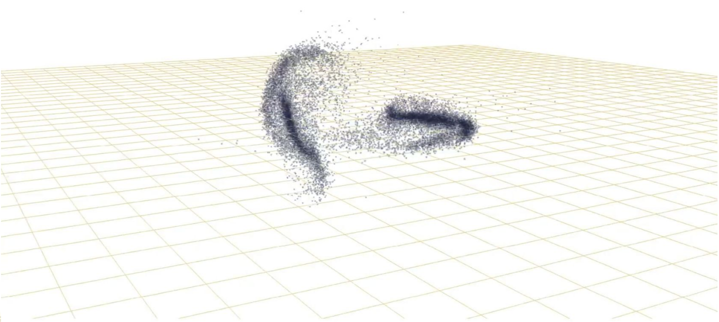
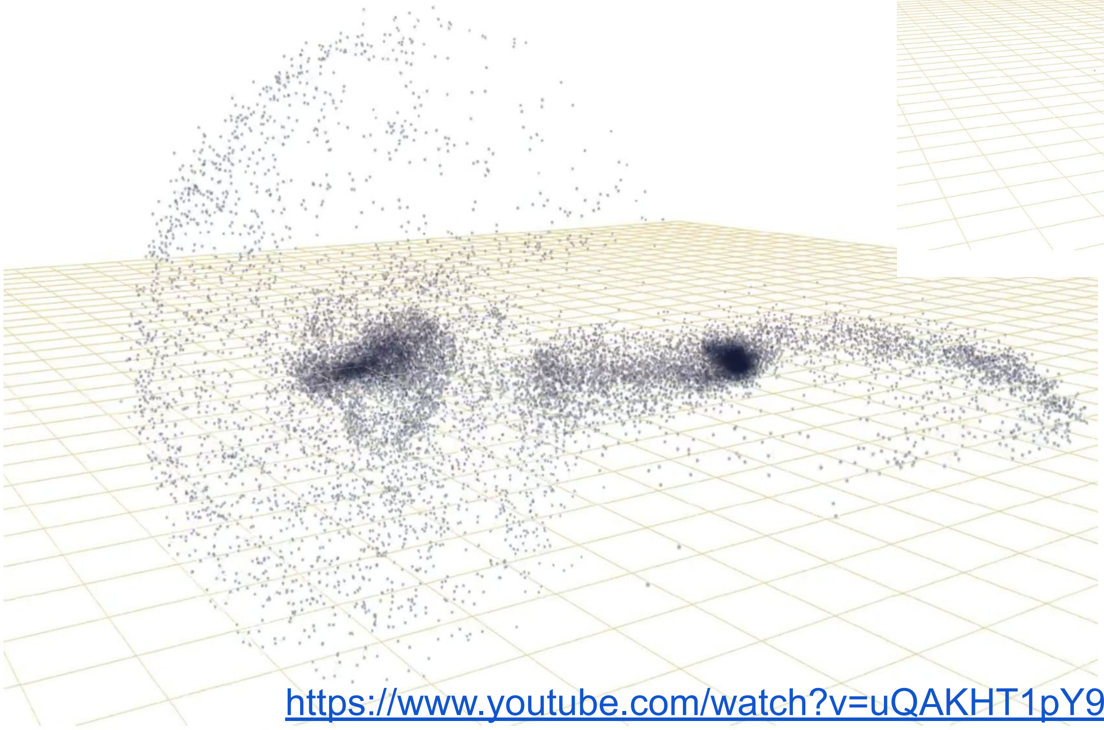
N-body Simulations

- Data generated from GADGET-2 (Galaxies and Dark Matter Interacting 2) N-body/SPH code
  - http://www.mpa-garching.mpg.de/gadget/
- 30,000 particles, 1100 snapshots run for 2 billion years
- Blender Python interface used to bring XYZ position data into the vertices of Blender objects
- Objects are “textured” with Halos.
- Each grid square is approximately 33,000 light years



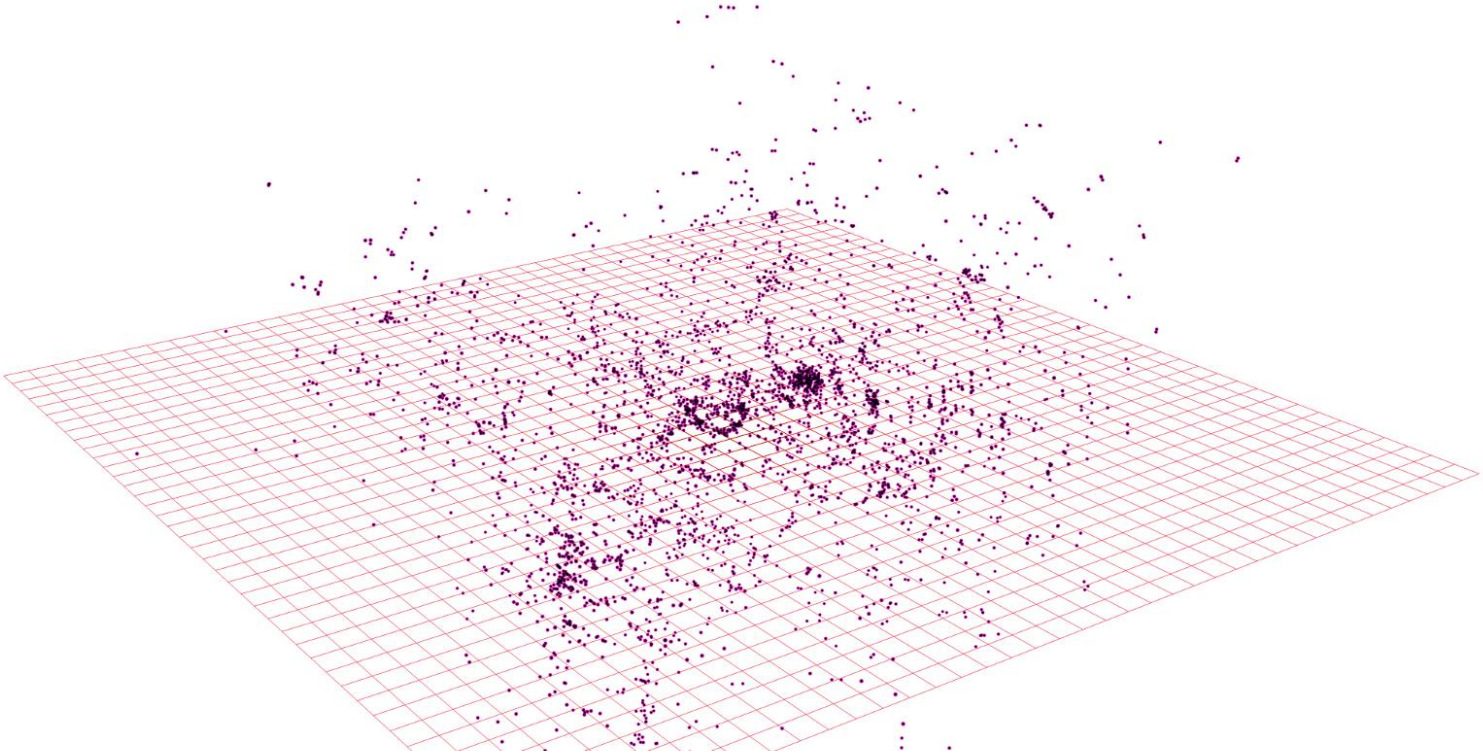




https://www.youtube.com/watch?v=uQAKHT1pY9s

Brian Kent, NRAO

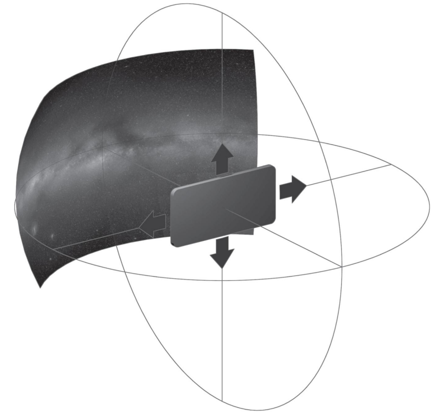
Galaxy Catalogs

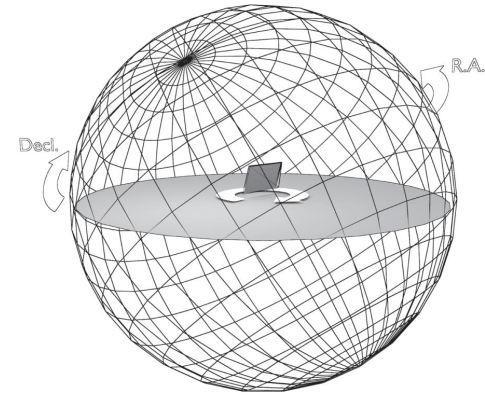


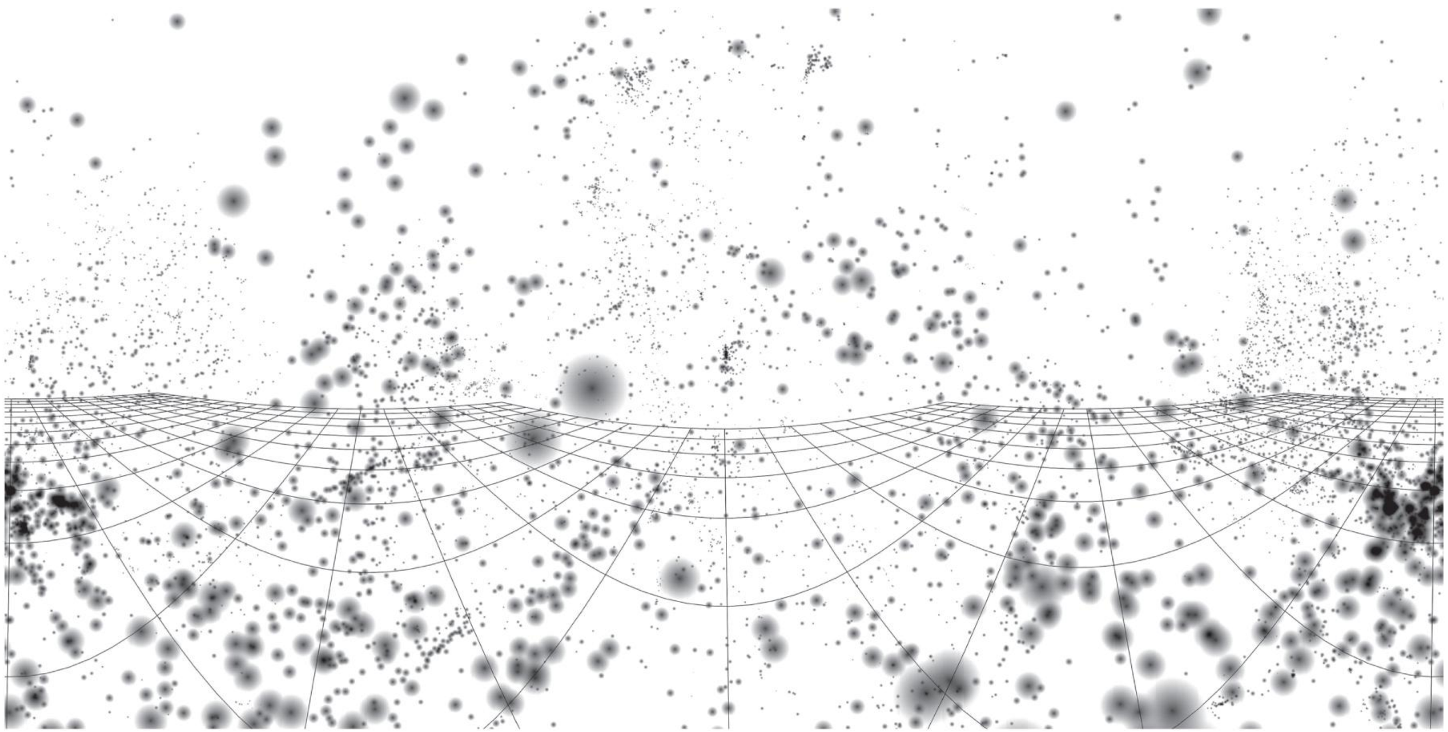
https://www.youtube.com/watch?v=eO_OKyfDAyM

Brian Kent, NRAO

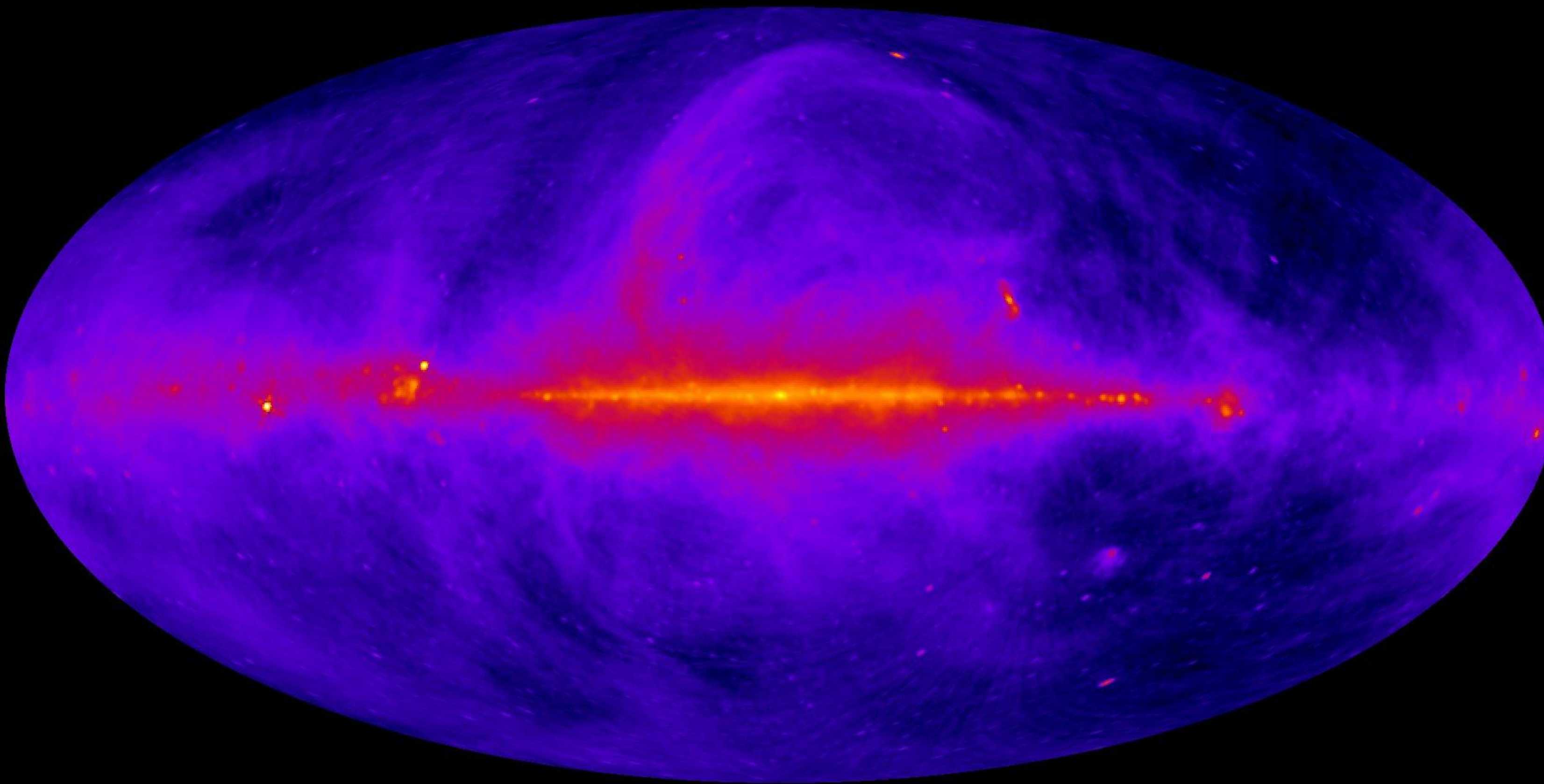
360 Panoramas







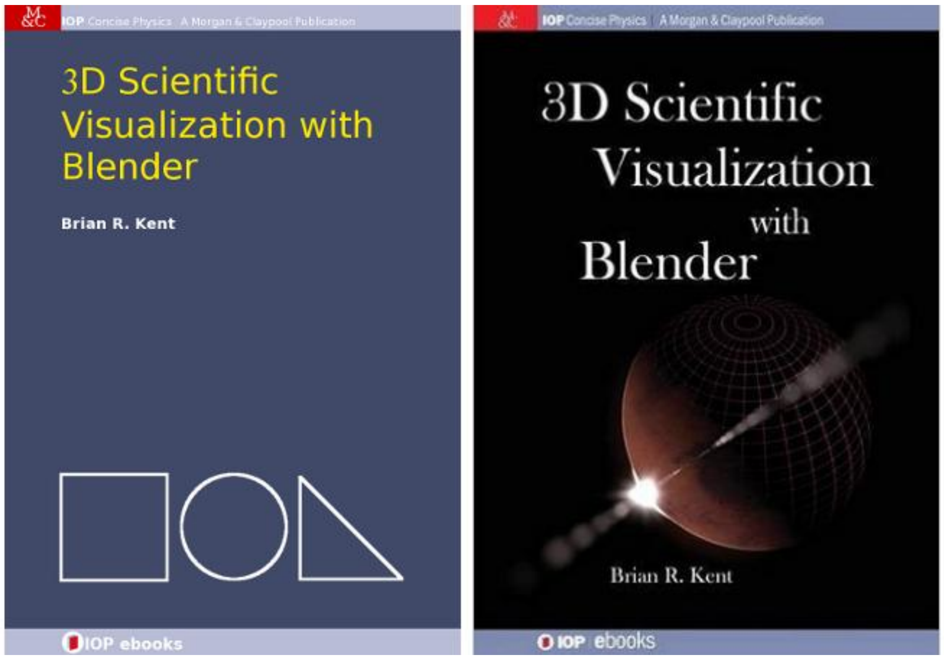
Tully et al. Cosmic Flows data



https://www.youtube.com/watch?v=YWwA49Mm1nw

408 MHz

Interesting in learning more?



Book and tutorials available at:

http://www.cv.nrao.edu/~bkent/blender/

https://www.youtube.com/VisualizeAstronomy

Resources and Opportunities

3D Graphics and Python
http://www.cv.nrao.edu/~bkent/blender/

Blender
http://www.blender.org/

General Visualization

http://www.visualizing.org/

SIGGRAPH, Pycon, SciPy

http://www.siggraph.org

https://www.youtube.com/c/PyConUS/videos - Pycon 2021

https://www.scipy2021.scipy.org/

Publications of the Astronomical Society of the Pacific

Techniques and Methods for Astrophysical Data Visualization

Brian R. Kent, *National Radio Astronomy Observatory, Charlottesville, VA, USA*

Astrophysics continues to be a leader in the data sciences, with innovative methods being developed to handle new analysis challenges. The higher rates of data acquisition in both observational and theoretical astrophysics demand innovative solutions in scientific visualization. The Publications of the Astronomical Society of the Pacific (PASP) has published a special focus issue titled **Techniques and Methods for Astrophysical Data Visualization**. Refereed submissions for this issue cover a wide variety of visualization topics, including new software packages, visualization techniques, software from other industries, and new science results. These methods and techniques can serve as a complement to data analysis software, stand on their own for data exploration, or inspire with impressive visuals for science, technology, education, mathematics (STEM) and public outreach. A number of articles from our special focus issue feature videos and tutorials as well as interactive 3D content.

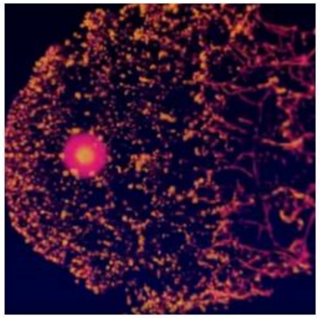


Figure. Stellar winds from a Wolf-Rayet star moving through the galactic center (Garate 2017). Simulation data provided by Cuadra et al. (2008).

"Visualization allows astronomers to break down and understand large data and explore multi-dimensional phase spaces. We encourage scientists to explore the tools and techniques presented in this issue and apply them to their own data and research."
- Brian R. Kent, Guest Editor, PASP

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Machine Learning/Deep Learning
Neural Networks/Artificial Intelligence

NVidia Deep Learning:

https://www.nvidia.com/en-us/deep-learning-ai/education/

PyTorch (Facebook):
https://pytorch.org/

Tensorflow (Google):

https://www.tensorflow.org/

Check out the NVidia GTC: https://www.nvidia.com/en-us/gtc/

Recommendation: *Please subscribe and sign up for these free tutorials and resources!*

Python, Data Visualization, and Astronomy

Dr. Brian R. Kent, Scientist
National Radio Astronomy Observatory
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June 2022