

Analisi e visualizzazione di fenomeni astrofisici con HPC e VR

S. Orlando
INAF – Osservatorio Astronomico di Palermo

NELL'AMBITO DELLA
XXII SCUOLA
DI COMPUTER GRAFICA E AI
PER I BENI CULTURALI E LA SCIENZA

Codici Numerici

Fenomeni astrofisici



Supernovae
e resti di supernova



Buchi neri
e dischi di accrescimento



Venti stellari
e stelle massicce



Galassie
e mezzi interstellari

...

Equazioni MHD 3D

La dinamica dei plasmi astrofisici è descritta da un sistema di equazioni accoppiate:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \qquad \text{(continuità)}$$

$$\frac{\partial (\rho \mathbf{v})}{\partial t} + \nabla \cdot \left(\rho \mathbf{v}\mathbf{v} + p\mathbf{I} - \frac{\mathbf{B}\mathbf{B}}{4\pi} \right) = \rho \mathbf{g} \qquad \text{(momento)}$$

$$\frac{\partial E}{\partial t} + \nabla \cdot \left[(E + p)\mathbf{v} - \frac{(\mathbf{B} \cdot \mathbf{v})\mathbf{B}}{4\pi} \right] = \rho \mathbf{v} \cdot \mathbf{g} + \nabla \cdot (\kappa \nabla T) + Q \qquad \text{(energia)}$$

$$\frac{\partial \mathbf{B}}{\partial t} - \nabla \times (\mathbf{v} \times \mathbf{B}) = 0 \qquad \text{(induzione magnetica)}$$

$$\nabla \cdot \mathbf{B} = 0 \qquad \text{(divergenza zero)}$$

dove $\rho, \mathbf{v}, p, \mathbf{B}, E, T,$ sono le grandezze fisiche del plasma.

Non si possono risolvere analiticamente

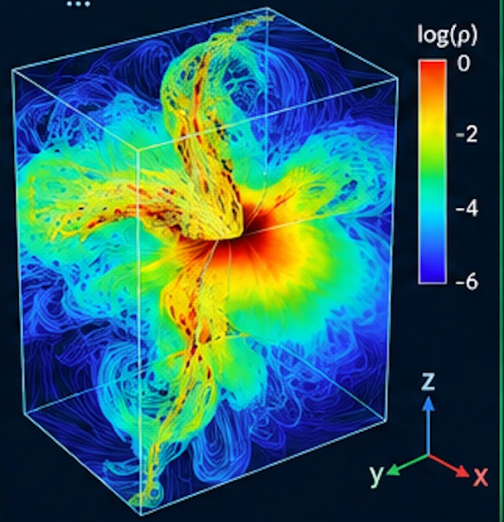
- ✗ Geometrie complesse (3D)
- ✗ Condizioni al contorno realistiche
- ✗ Grandi scale spaziali e temporali
- ✗ Non linearità e forti accoppiamenti fisici

→ Le soluzioni analitiche **esistono** solo in casi molto semplici e idealizzati.

Codici numerici per plasmi astrofisici

Si ricorre a codici di simulazione che risolvono il sistema MHD 3D con metodi numerici avanzati.

PLUTO
FLASH
PROMETHEUS-HOT
KEPLER
MESA
...



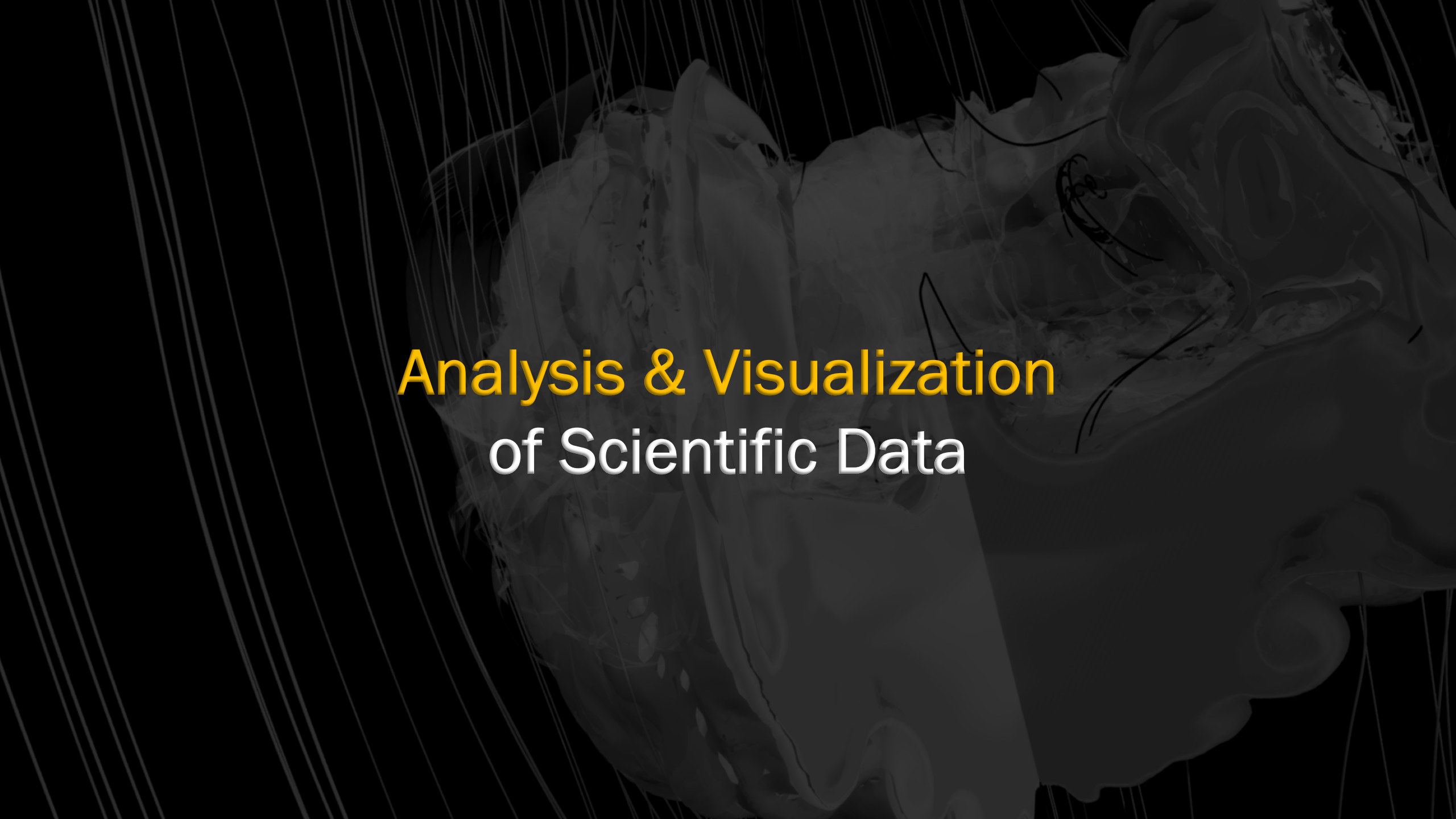
Hydro/MHD Numerical Codes in Astrophysics

Selected *Publicly Available* Codes

- **PLUTO** Modular finite-volume code for HD/MHD & relativistic flows (jets, shocks)
- **FLASH / FLASH-X** AMR multi-physics framework (HD/MHD, gravity, radiation, supernovae)
- **RAMSES** AMR code for self-gravitating HD/MHD (galaxies, star formation)
- **MPI-AMRVAC** Flexible AMR toolkit for HD/MHD, scalable to large 3D simulations
- **Athena / Athena++** High-order Godunov MHD code (turbulence, ISM, disks)
- **Phantom** SPH/MHD code (disks, star formation, dust–gas physics)
- **Pencil Code** High-order finite-difference code (turbulence, dynamos)
- **Enzo** AMR cosmology code (structure formation, galaxy evolution)
- **GADGET** N-body + SPH code (cosmology, galaxy mergers)
- **AREPO** Moving-mesh code combining Lagrangian & grid methods
- **VH-1** PPM-based hydro code for strong shocks
- **NIRVANA** Finite-volume HD/MHD code (jets, accretion flows)

High Performance Computing



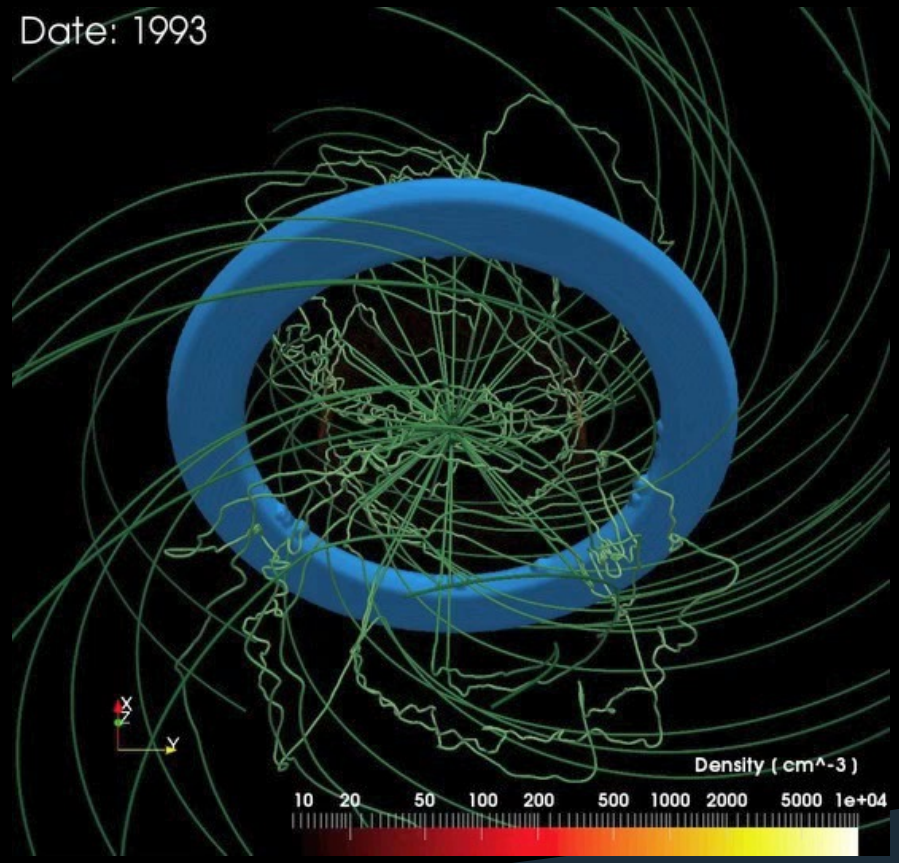

Analysis & Visualization
of Scientific Data

The Visualization Pipeline

The Formal Definition

Scientific visualization is the process of mapping data attributes to visual attribute.
This follows a specific linear flow:

1. **Data Acquisition**: Simulations (HPC output) or models
2. **Filtering/Pre-processing**: Data reduction, denoising, or selecting a region of interest
3. **Mapping**: Converting values (e.g.,density, temperature, velocity) into geometric primitives (points, lines) and optical properties (color, opacity).
4. **Rendering**: The GPU process of converting 3D scenes into 2D pixel arrays for the screen.



From simulations to datasets

What do we actually have?

- 3D distributions: density, temperature, velocity, magnetic field, abundances…
- Tracers and passive scalars
- Time evolution / snapshots
- Synthetic observables
- Huge multidimensional datasets

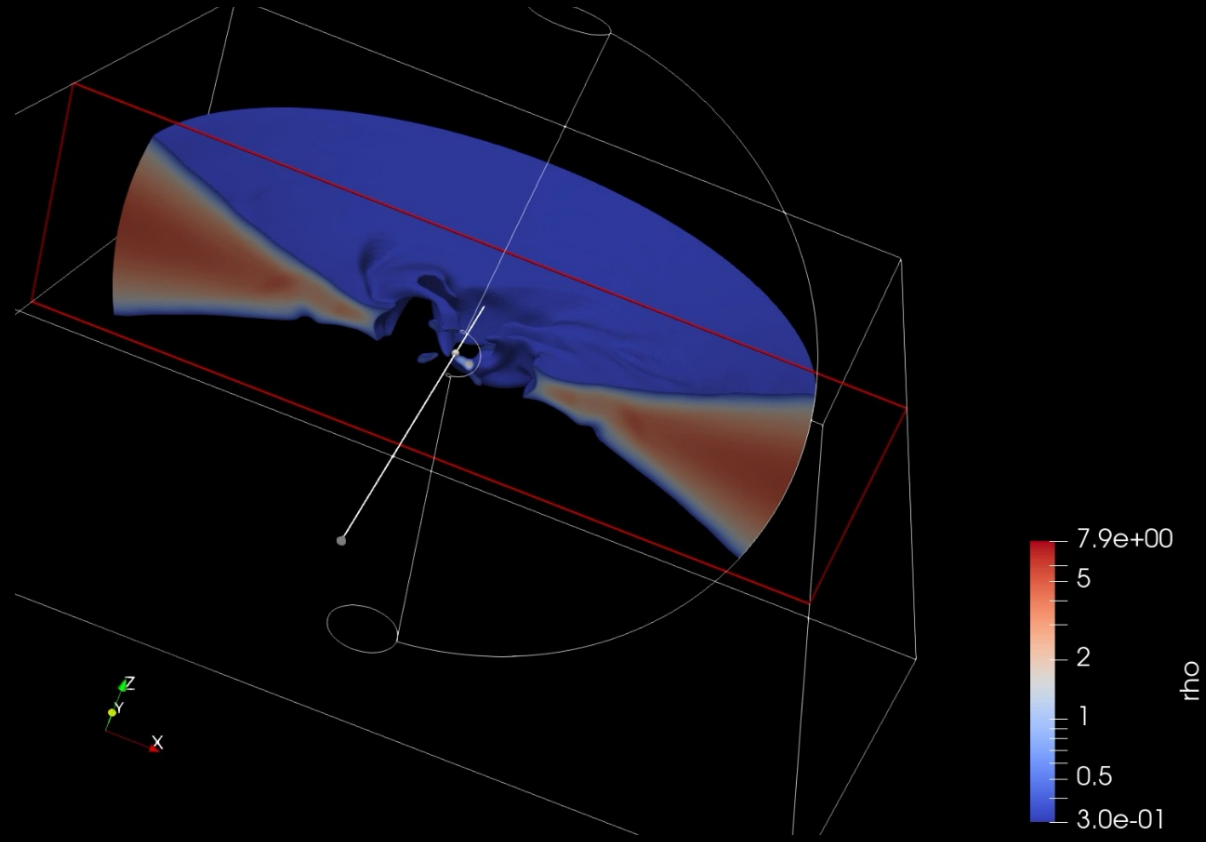
→ **The simulation produces data,** ***not yet understanding***



Exploring the simulation

How do we explore the data?

- Select regions, times, and physical components
- Slice, filter, and extract sub-volumes
- Follow tracers and structures
- Track shocks, clumps, filaments, instabilities…
- Compare different simulations / physical models (exploration of parameter space)



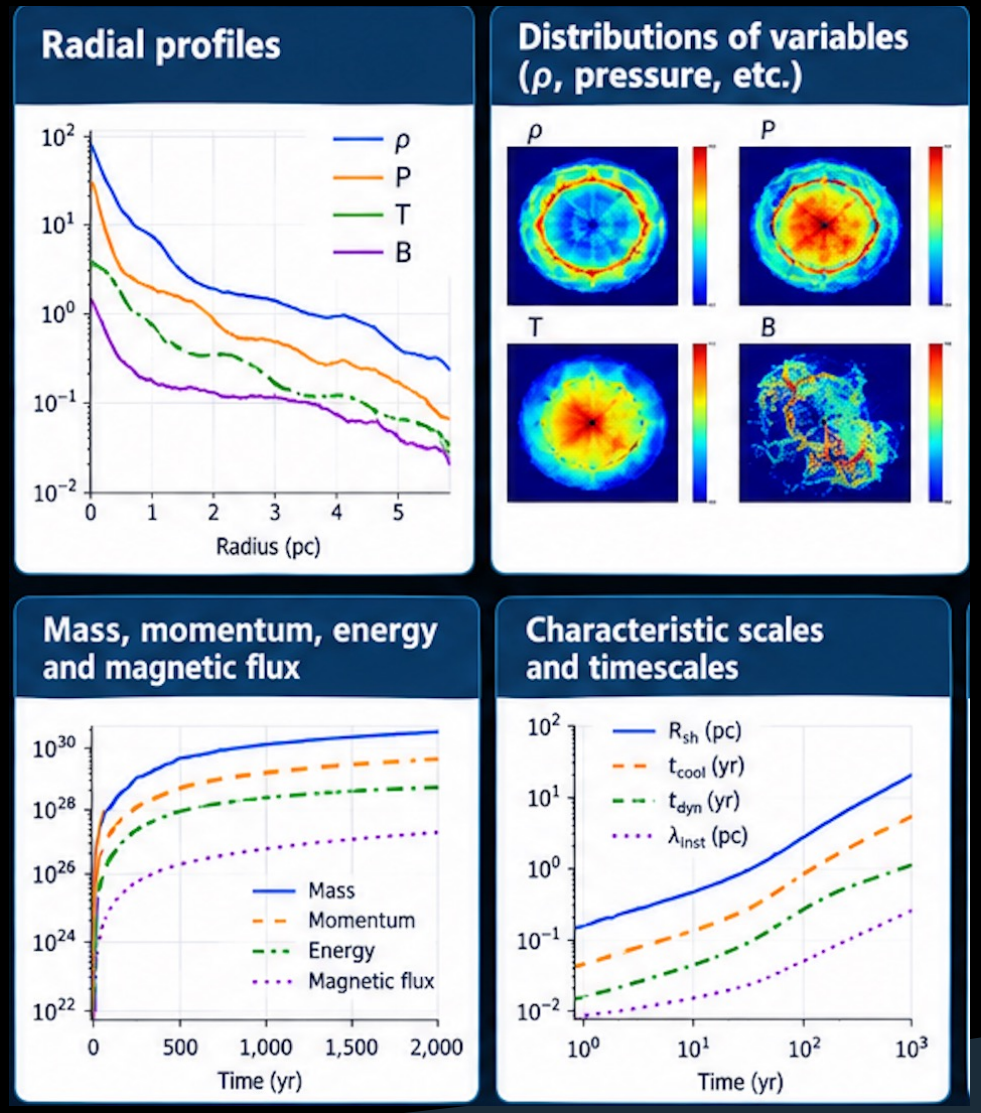
Quantifying the physics

From visual inspection to measurements

- Radial profiles
- Distributions of variables (rho, pressure, etc.)
- Energy budgets
- Shock velocities and Mach numbers
- Mass, momentum, energy and magnetic flux
- Characteristic scales and timescales
- Correlations between physical quantities

Explore ≠ Visualize

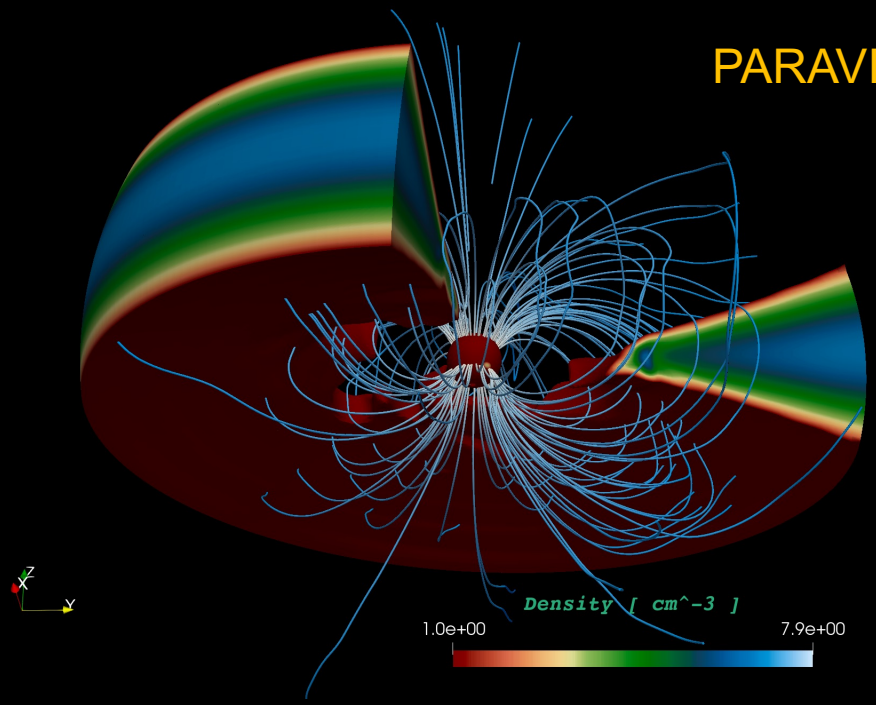
identify where, when and why something happens




EXPLORATION
Data analysis and extraction of information

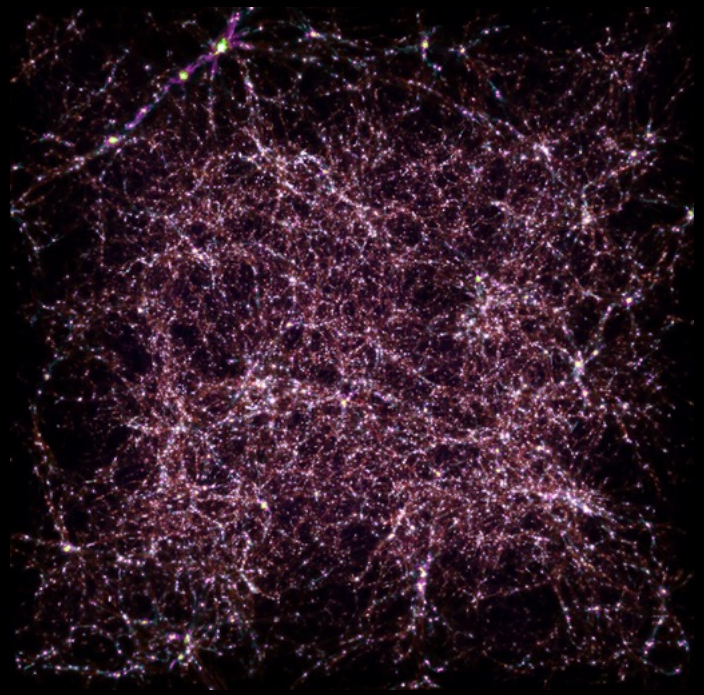
Grid-based vs Particle-based Models

Grid-Based Models (Eulerian)
- PLUTO
- FLASH



PARAVIEW

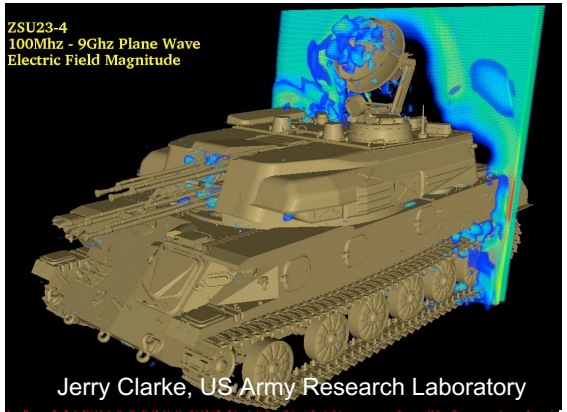
Particle-Based Models (Lagrangian)
- GADGET
- PHANTOM



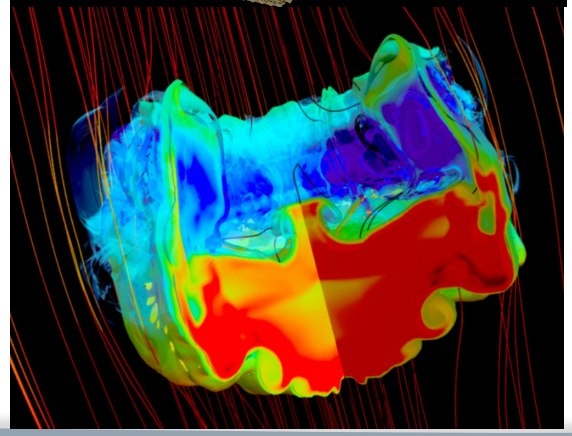
SPLOTCH

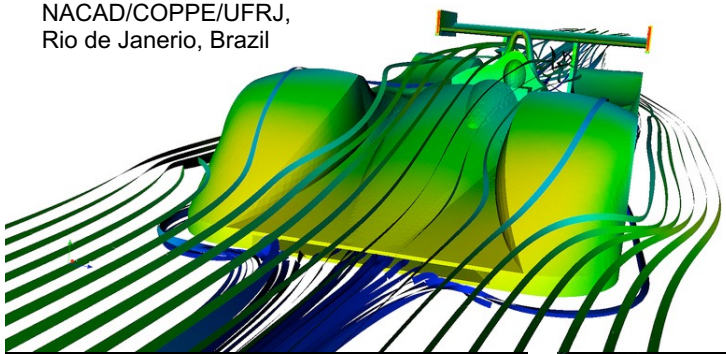
ParaView

- An open-source, scalable, multi-platform visualization application
- Support for distributed computation models to process large data sets
- An open, flexible, and intuitive user interface
- An extensible, modular architecture based on open standards

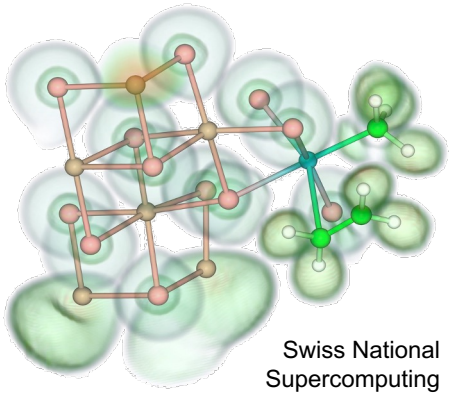


Jerry Clarke, US Army Research Laboratory

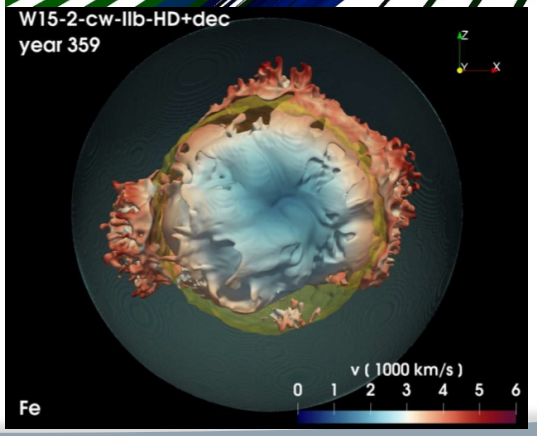


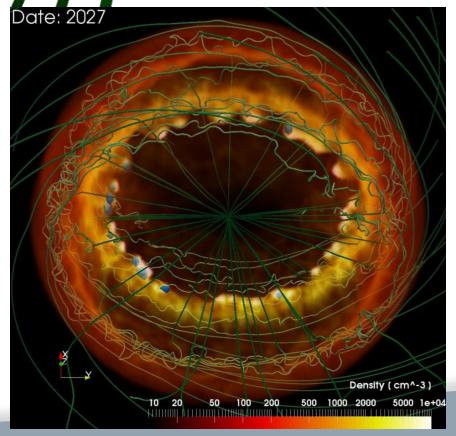


Renato N. Elias,
NACAD/COPPE/UFRJ,
Rio de Janerio, Brazil



Swiss National
Supercomputing
Centre





S. Orlando
INAF - OAPa

ParaView

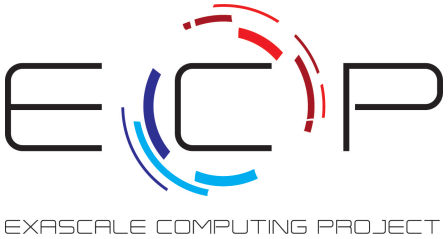




- Started in 2000 as collaborative effort between Los Alamos National Laboratories and Kitware Inc. Sandia has been a major contributor since 2005
- Used by academic, government, and commercial institutions worldwide
- Downloaded ~200K times per year
- Current funding



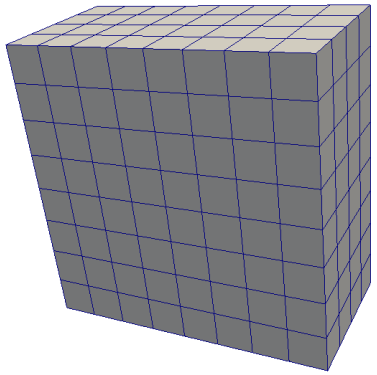




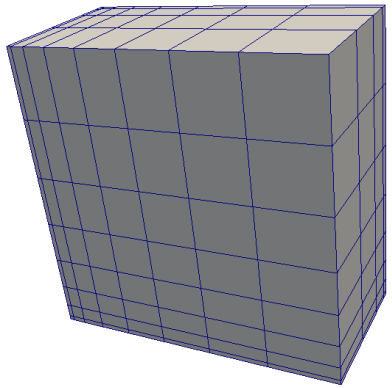


This research was supported by the Exascale Computing Project (17-SC-20-SC), a collaborative effort of the U.S. Department of Energy Office of Science and the National Nuclear Security Administration.

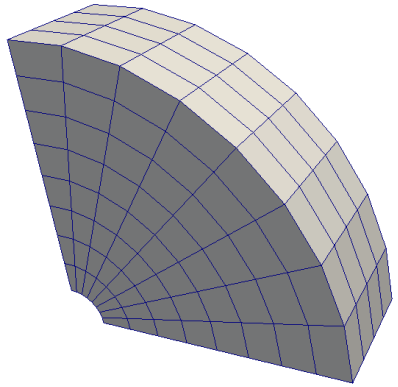
Data Types



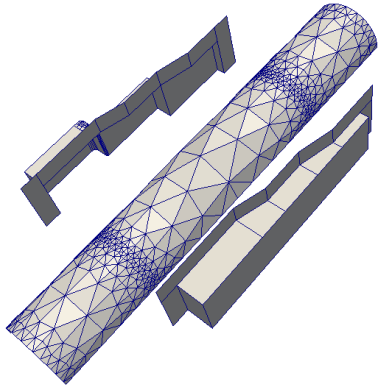
Uniform Rectilinear
(vtkImageData)



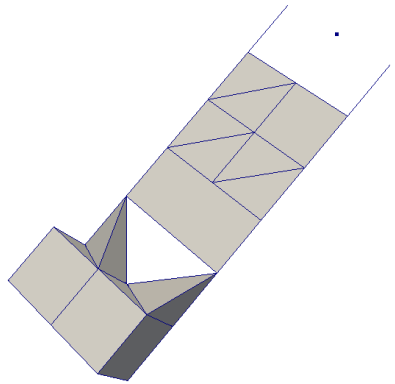
Non-Uniform Rectilinear
(vtkRectilinearData)



Curvilinear
(vtkStructuredData)



Polygonal
(vtkPolyData)



Unstructured Grid
(vtkUnstructuredGrid)

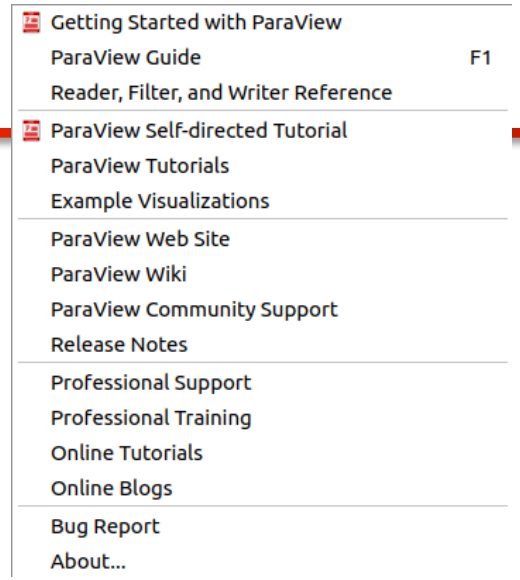
Multi-block

Hierarchical Adaptive Mesh Refinement (AMR)

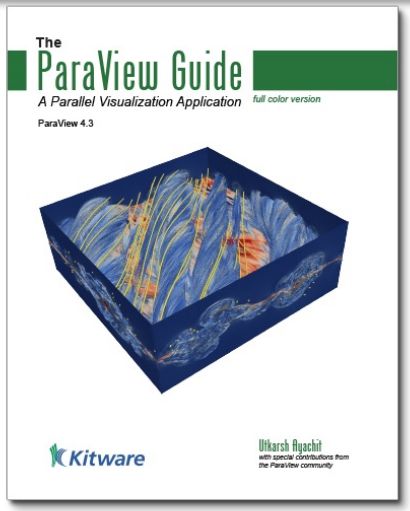
Hierarchical Uniform AMR

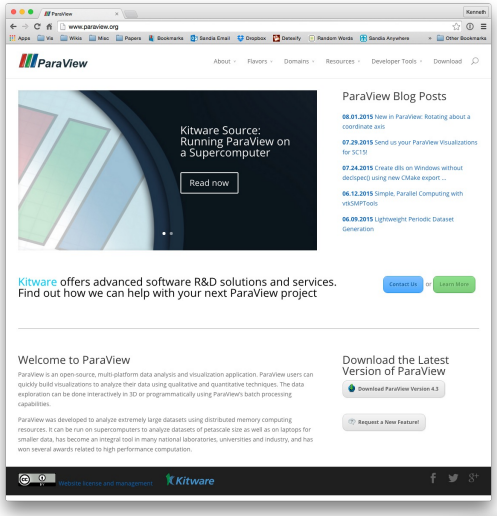
Octree

More Information



- The ParaView web page
  - www.paraview.org
- Help Menu
- *The ParaView User's Guide*
  - https://docs.paraview.org/en/v5.12.0/UsersGuide/index.html
- Tutorials
  - https://docs.paraview.org/en/v5.12.0/Tutorials/index.html
- ParaView community support
  - https://discourse.paraview.org/c/paraview-support/7





User Interface

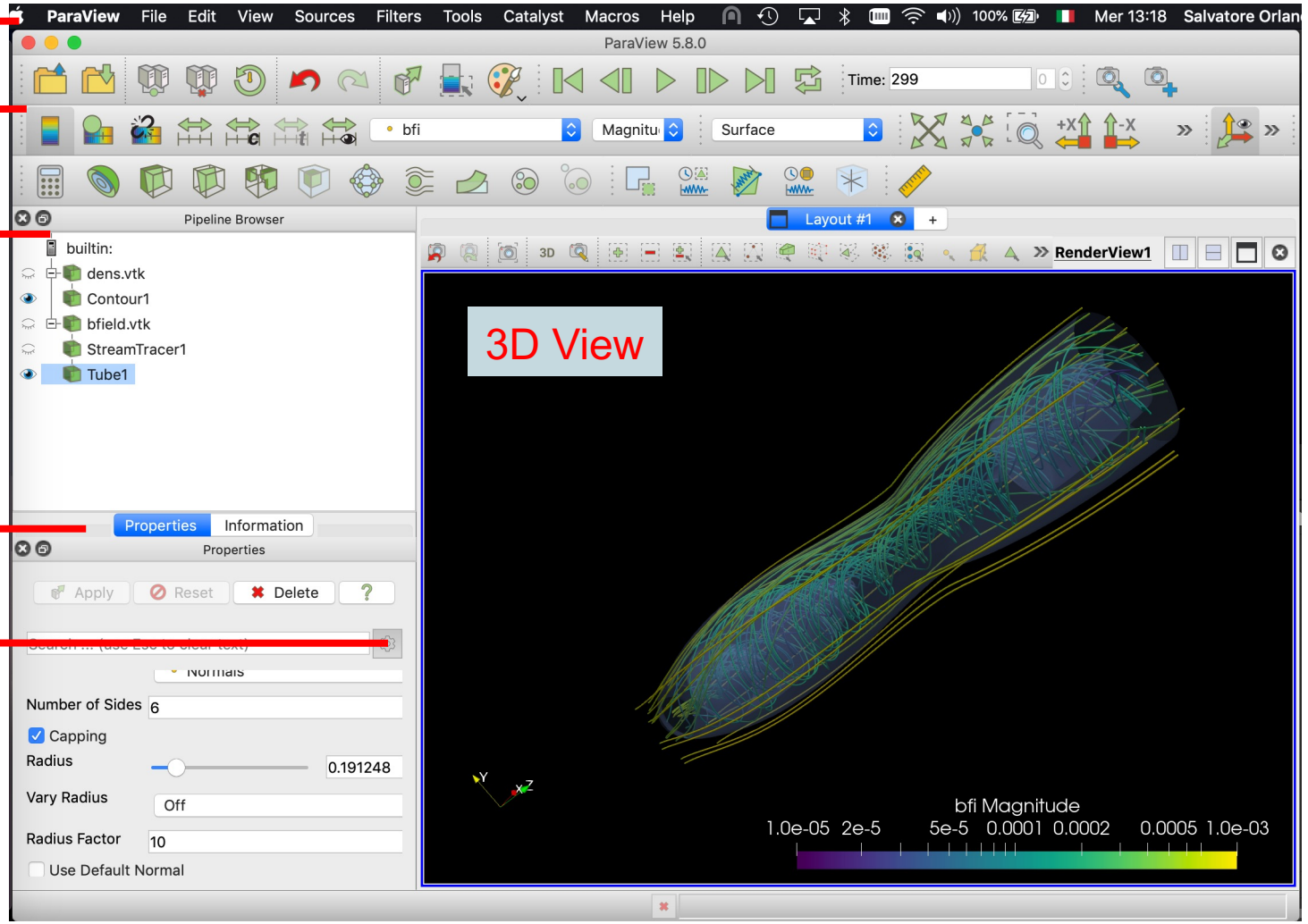
Menu Bar

Toolbars

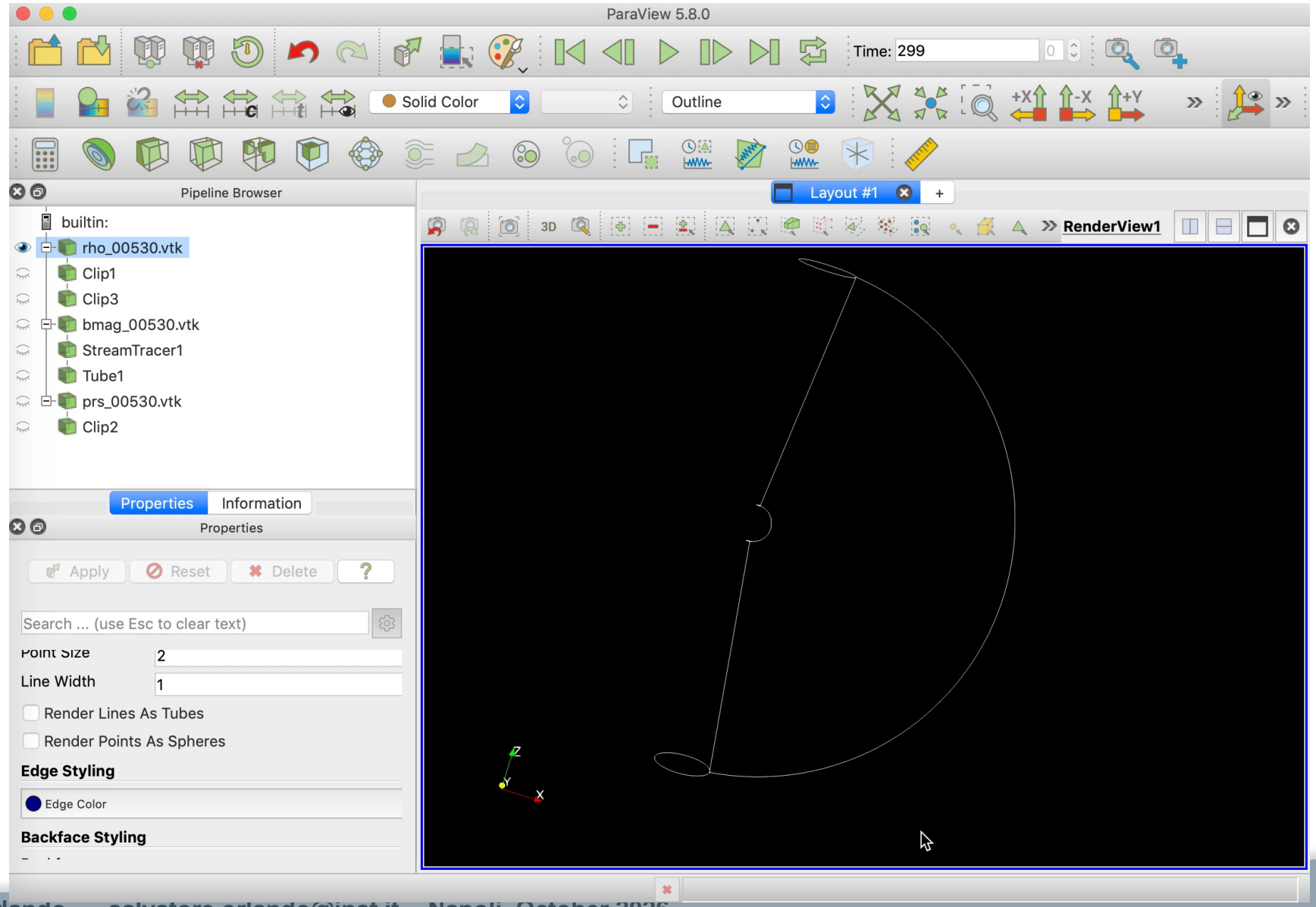
Pipeline Browser

Properties Panel

Advanced Toggle



Analysis of simulation data

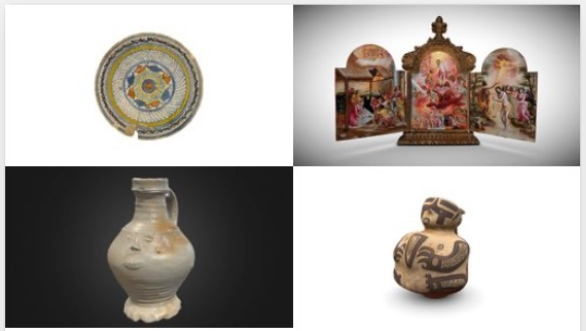



VISUALIZATION / DISSEMINATION
Production of engaging images,
movie, VR scenes





Cultural Heritage Hi... 47 8



Cultural Heritage an... 10 2



The Sketchfab Store ... 13 1



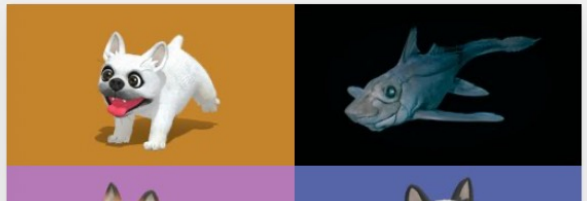
Animals 118 26



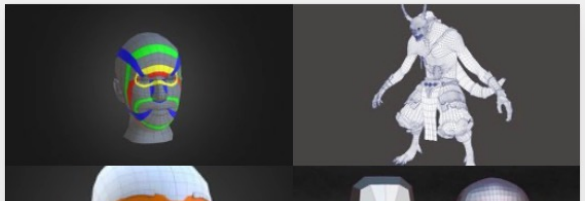
Useful for Projects 351 54



Sea Animals and ... 93 126









Tutorials

https://sketchfab.com/blogs/community/category/tutorial/

General

- Getting Started with Sketchfab
- Learning 3D - Part I: Simple geometry
- Learning 3D - Part II: Adding color, texture & light
- Learning 3D - Part III: Create your own models
- Using Projects in Sketchfab for Teams
- Camera Limits and Annotations

See all 10 articles

Software

- 3D-Coat
- 3ds Max
- 3ds Max - Animation
- Agisoft Metashape (Photoscan)
- Blender
- Blender - Animation

See all 33 articles

Getting Started with Sketchfab

1. Prepare your 3D Files
2. Upload
3. Check the appearance and modify the model
4. Publish
5. Share!

Prepare your 3D Files

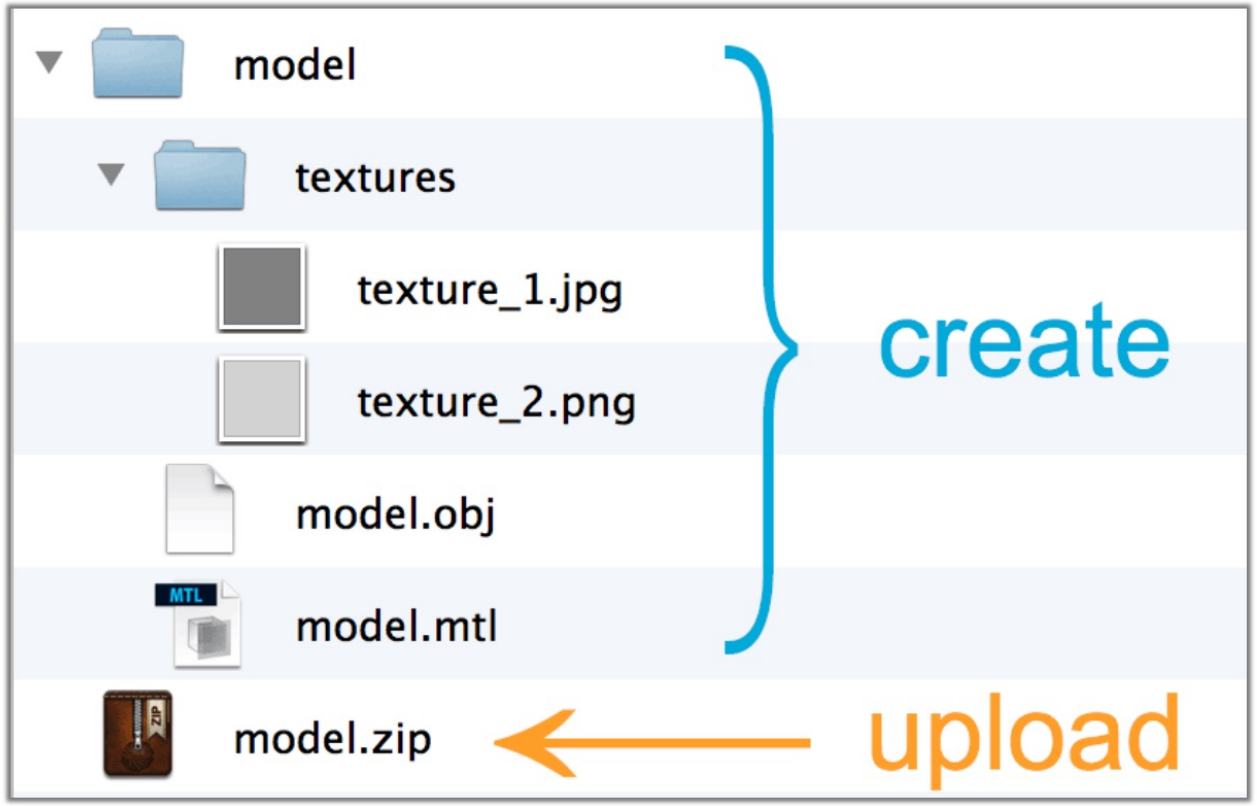
Recommended file formats

File format/type	File name
.obj*	Alias Wavefront
.blend	Blender
.fbx	Autodesk Filmbox, FBX
.gltf (+.bin), .glb	GL Transmission Format



OBJ files should almost always come with an MTL material library file. Both should be uploaded together, along with any textures

Prepare your 3D Files



prepare your models by combining all your files into a ZIP file

SAVE VIEW

GENERAL

Straighten model

X | Y | Z

Show advanced rotation

Renderer

PBR | Matcap

Shading

Lit

CAMERA

Field Of View

45°

LIMIT ORBIT CAMERA OFF

Limit Pan

Limit Zoom

Limit vertical rotation (pitch)

Limit horizontal rotation (yaw)

PREVIEW CAMERA LIMITS

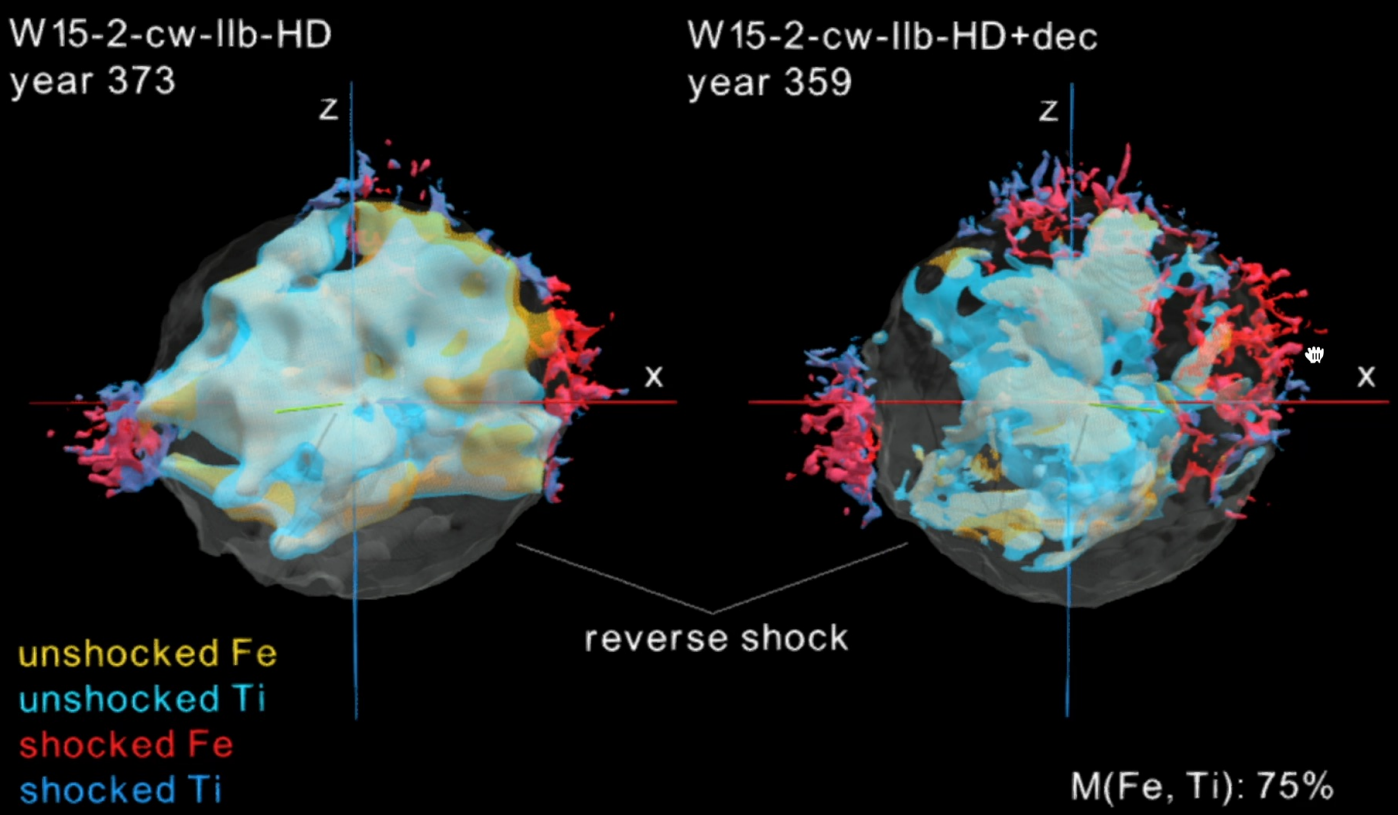
Show advanced camera settings

WIREFRAME OFF

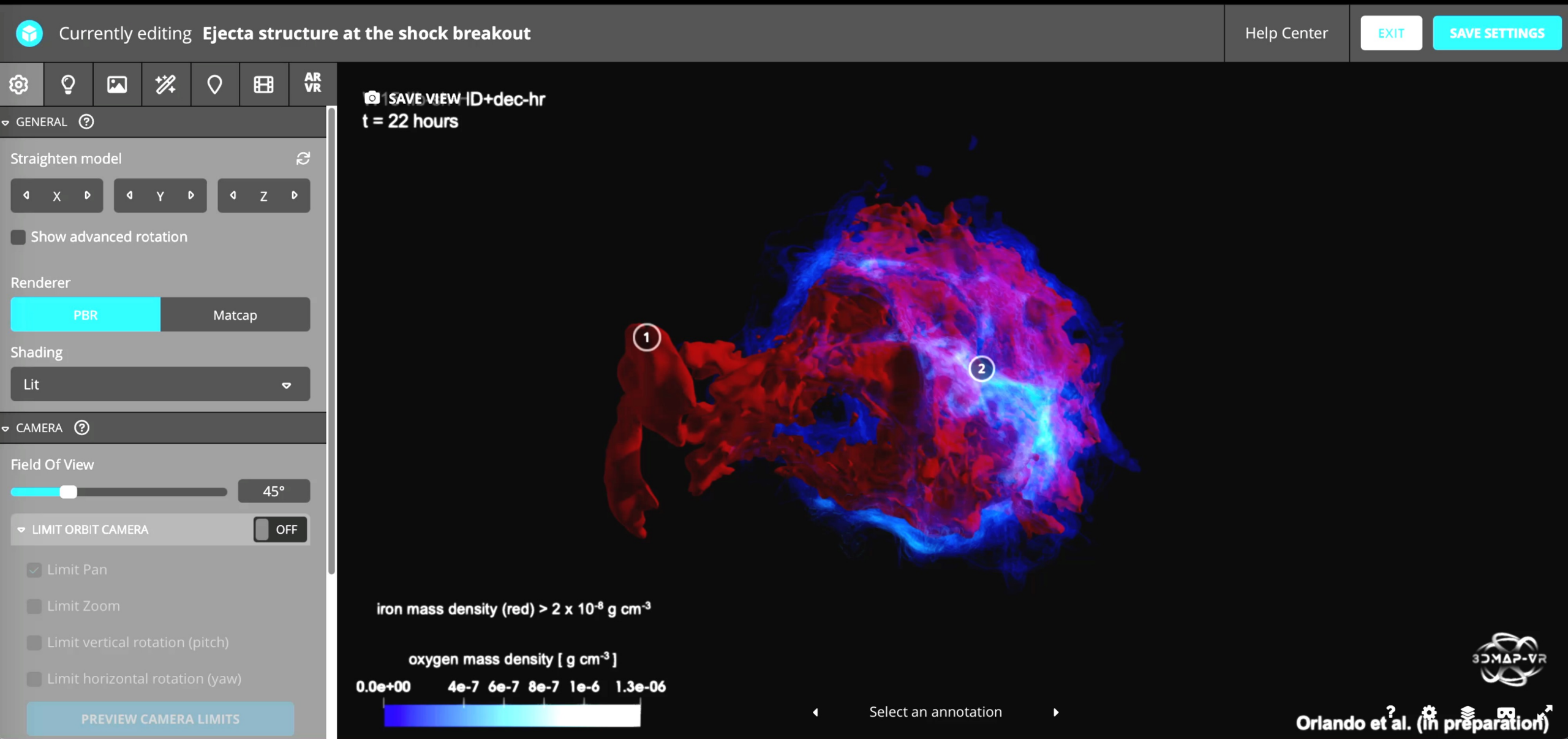
BACKGROUND ON

DEVELOPER

Display logs

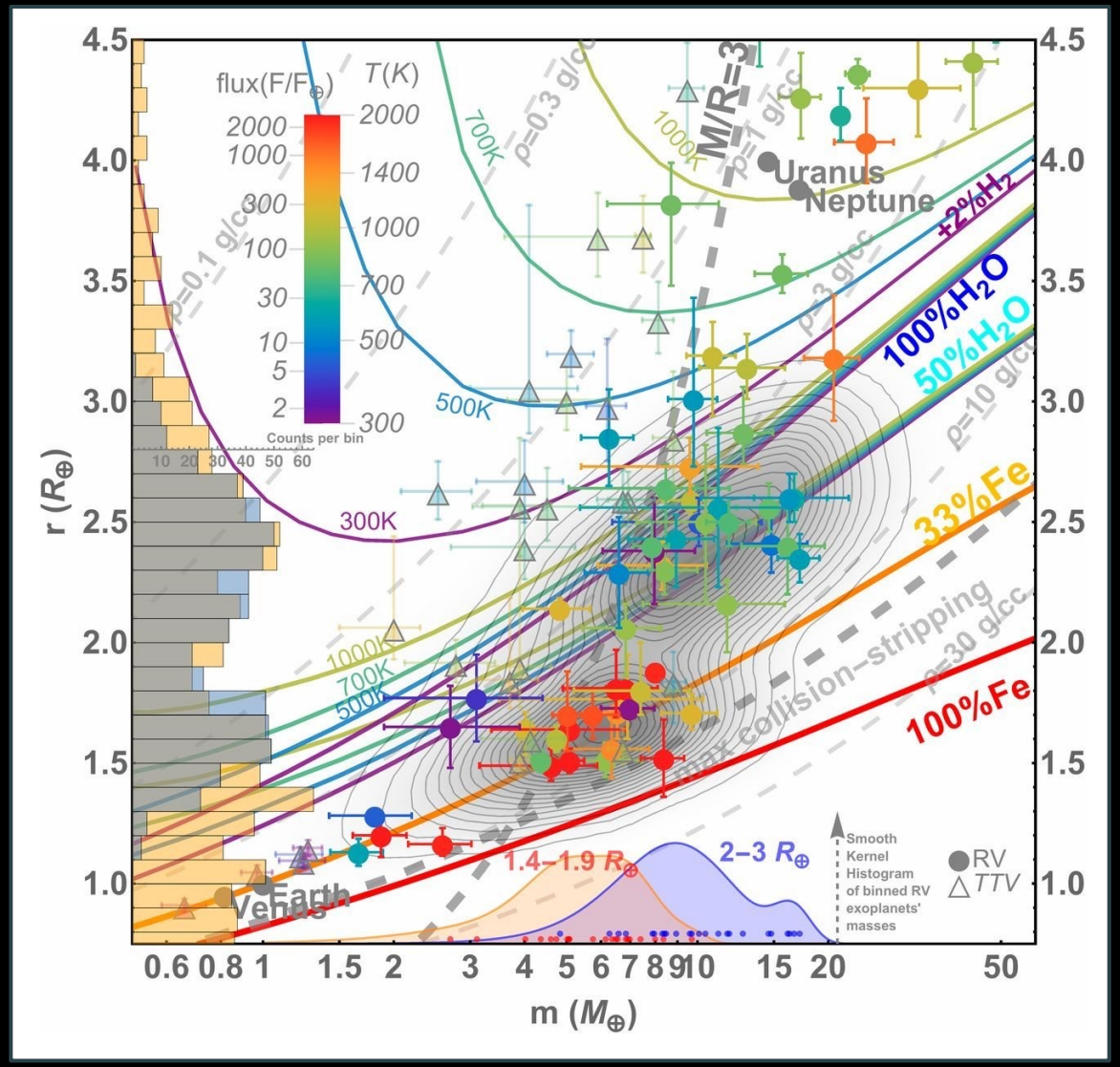


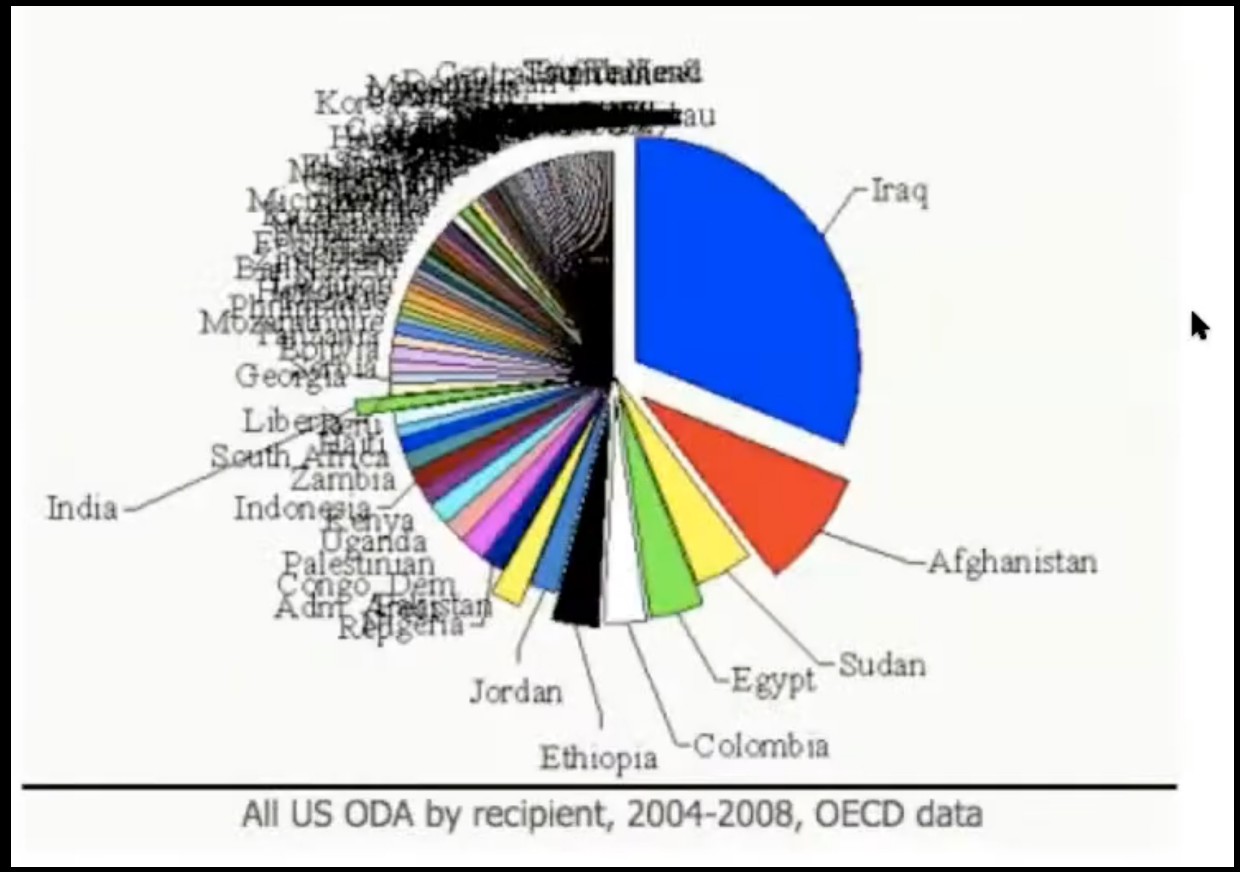
Virtual and Augmented Reality




How to Design an
Effective Visualization

What is an Effective Visualization?

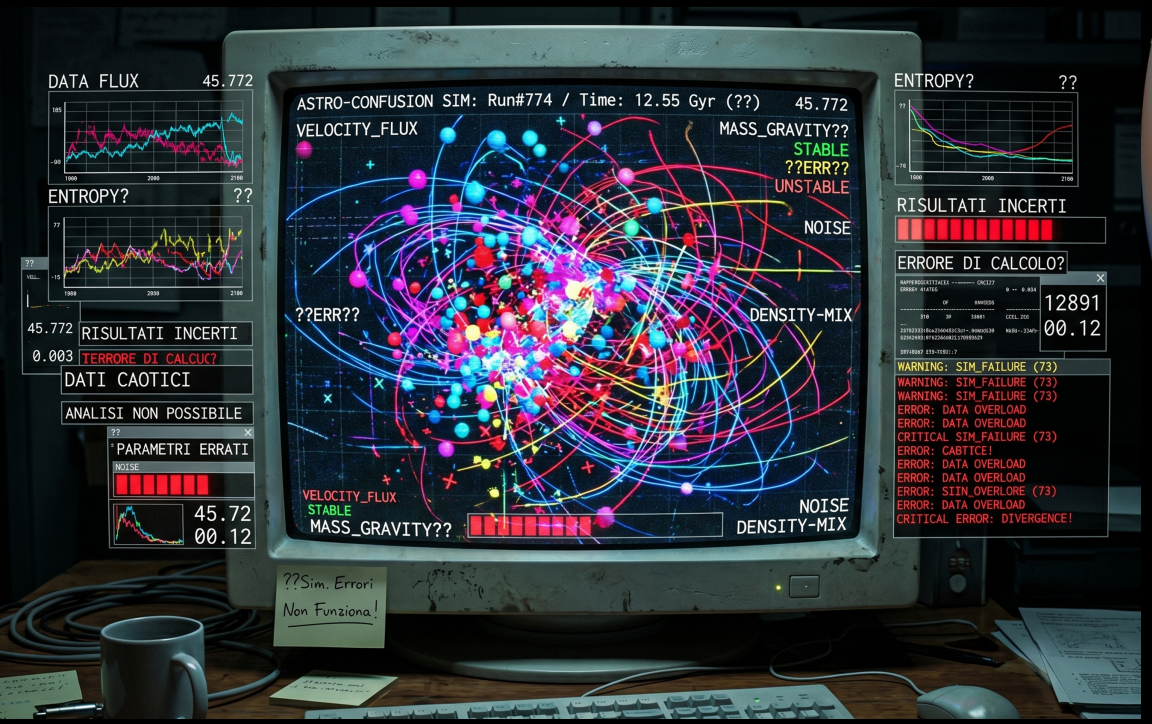


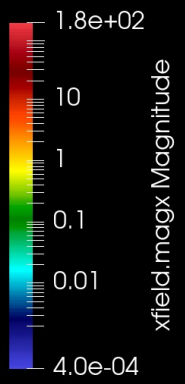


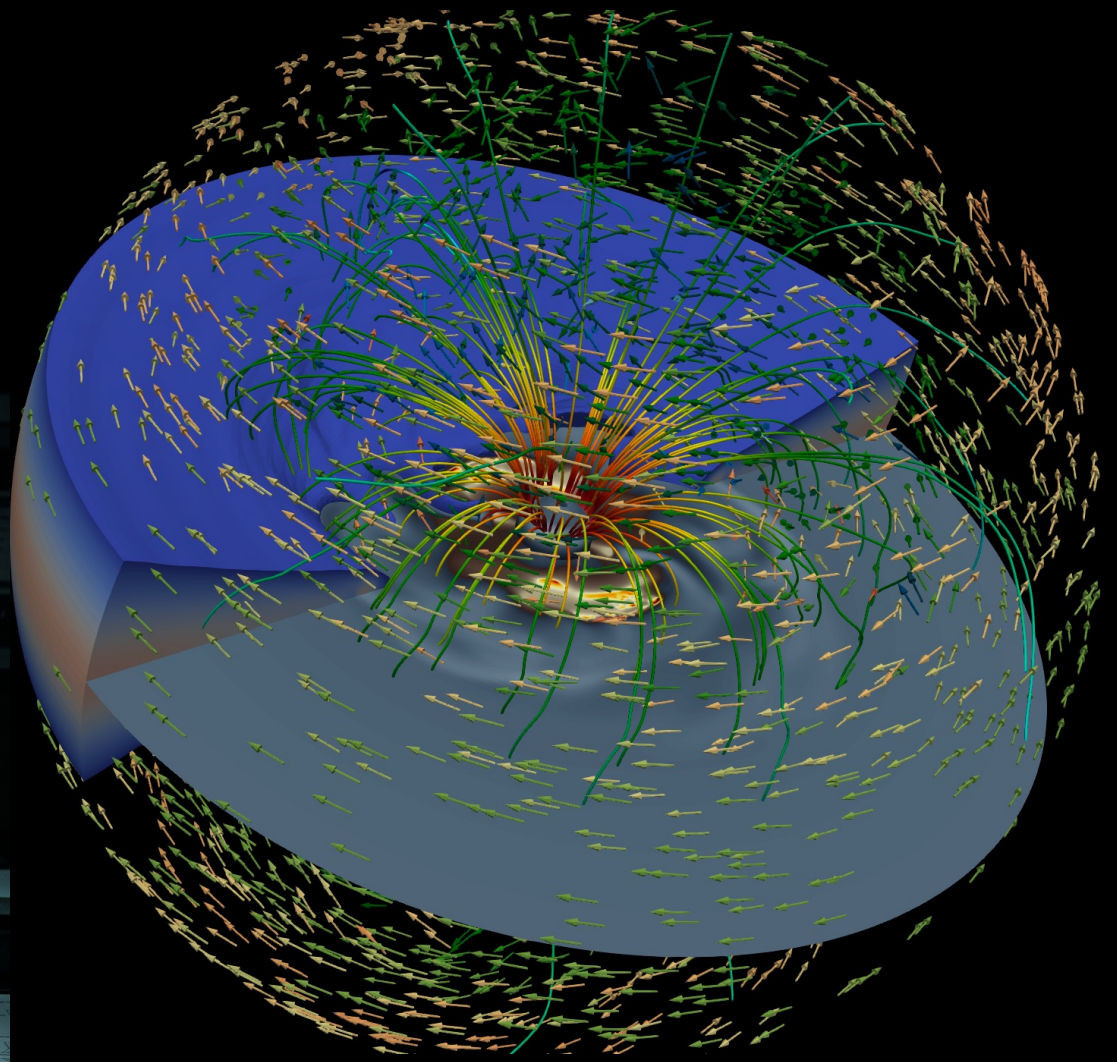
NOT **Effective**

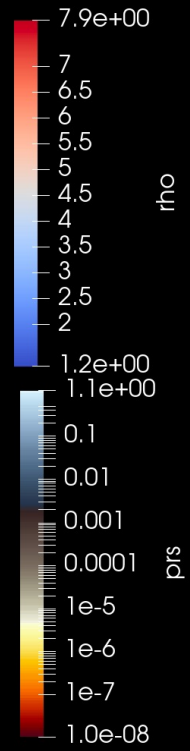
What is an Effective Visualization?

NOT Effective







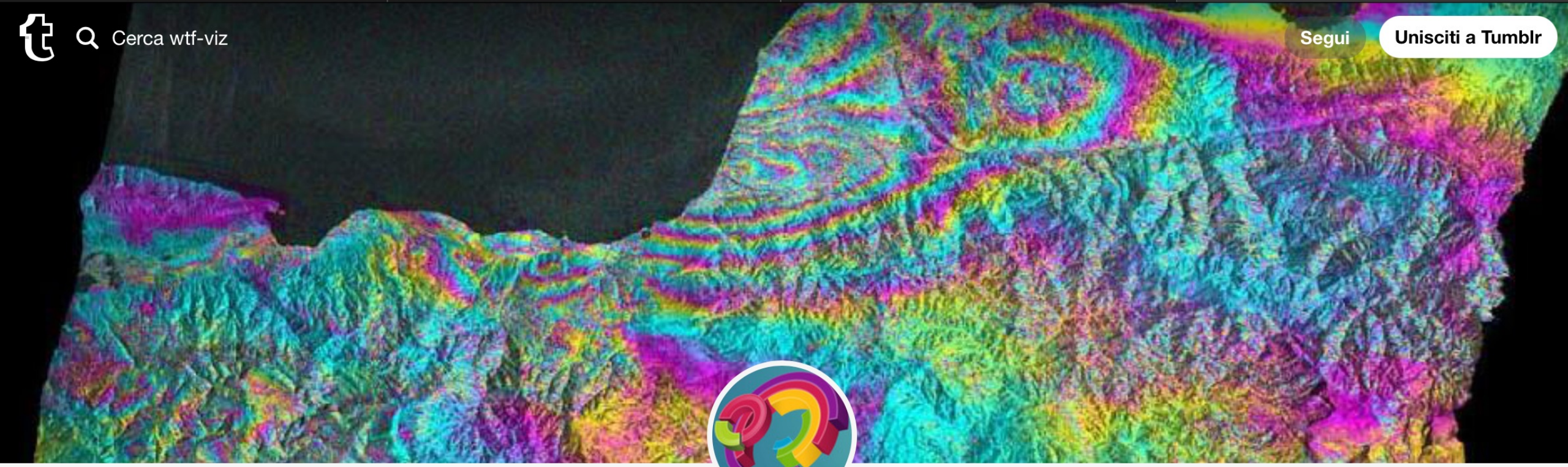


"... a wealth of information creates a poverty of attention"

– Herbert A. Simon

influenced the fields of computer science, economics, and cognitive psychology





WTF Visualizations

Visualizations that make no sense.
For a discussion of what is wrong with a particular visualization, tweet at us @WTFViz.
Submit a WTFViz you found.

https://viz.wtf

PUBBLICARE UN POST ARCHIVIO

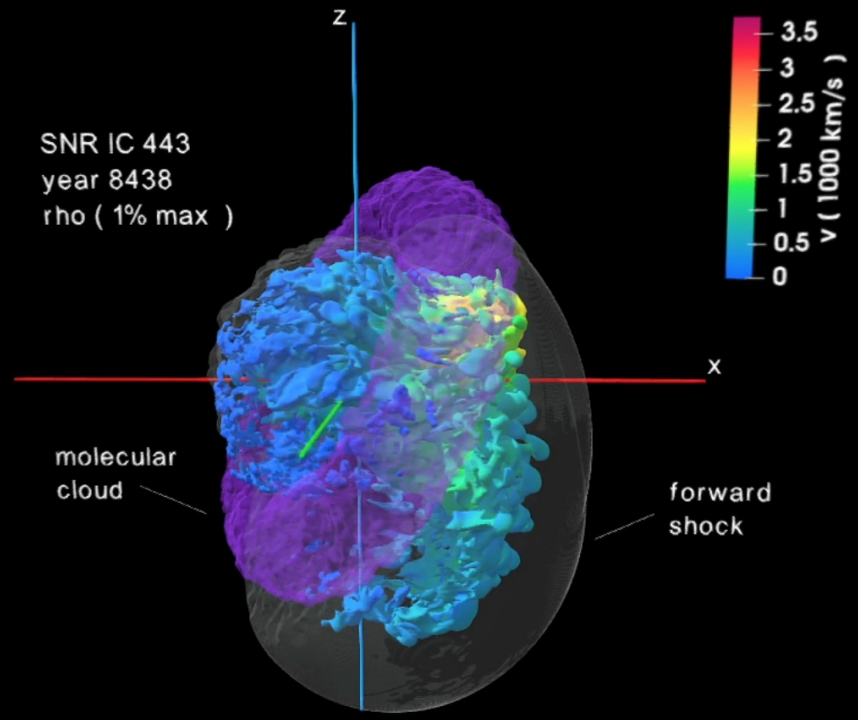


Human Perception and Cognition

understand the "human hardware" (the eye and brain)

Initial Processing

- **Spatial Position**
  The most powerful channel for quantitative data
- **Color/Intensity**
  Highly effective for categorical and ordinal data
- **Shape/Size**
  Good for differentiating multi-component structures (e.g., CSM/ISM, stellar debris)



The Power of Perception

JXNEFHMBCBZCNKJFLVEFKDJLIJKKEFKBGKDSJHKD
EICHFERJDERIARIVLKDSJBCRTHBKJLIFNXZALKSEF
NBVZEGYTWEZNMSUJRHXRZQWOUDHWVEMCOIBL
RDXGUWKJCOEUHZLMXNCWIEUYVZTXTPEPOKHMH

The Power of Perception

JXNEFHMBCBZCNKJFLVEFKDJLIJKKEFKBGKDSJHKD
EICHFERJDERIARIVLKDSJBCRTHBKJLIFNXZALKSEF
NBVZEGYTWEZNMSUJRHXRZQWOUDHWVEMCOIBL
RDXGUWKJCOEUHZLMXNCWIEUYVZTXTPEPOKHMH

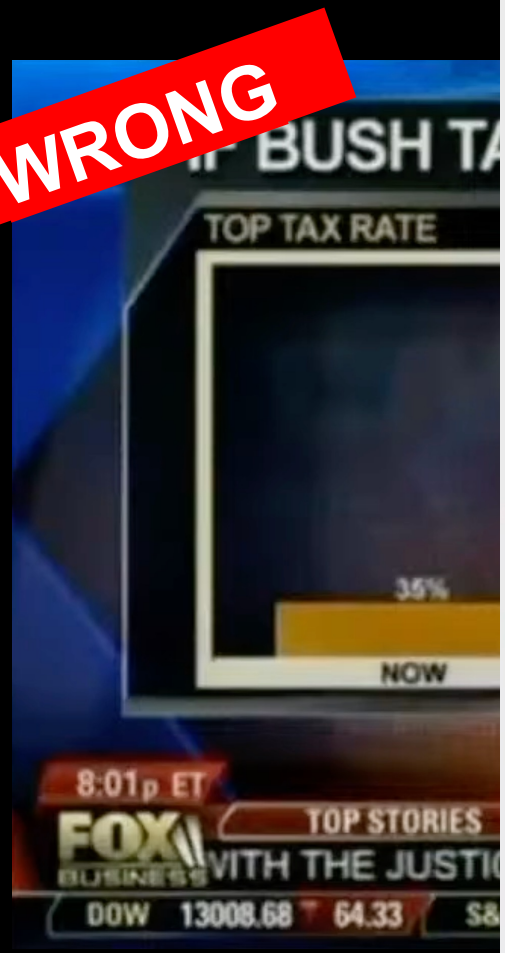
The Power of Perception

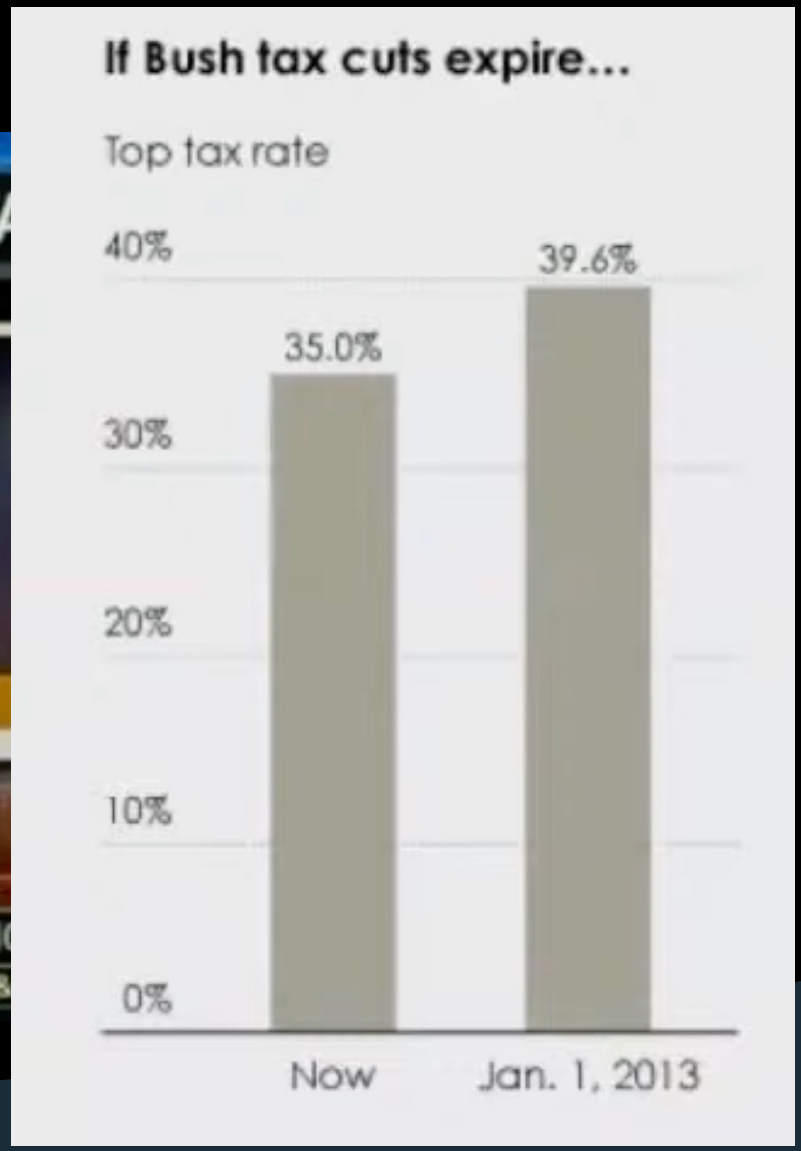
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What is an Effective Visualization?

Effective visualizations use the power of perception to offload cognition

- Have graphical integrity

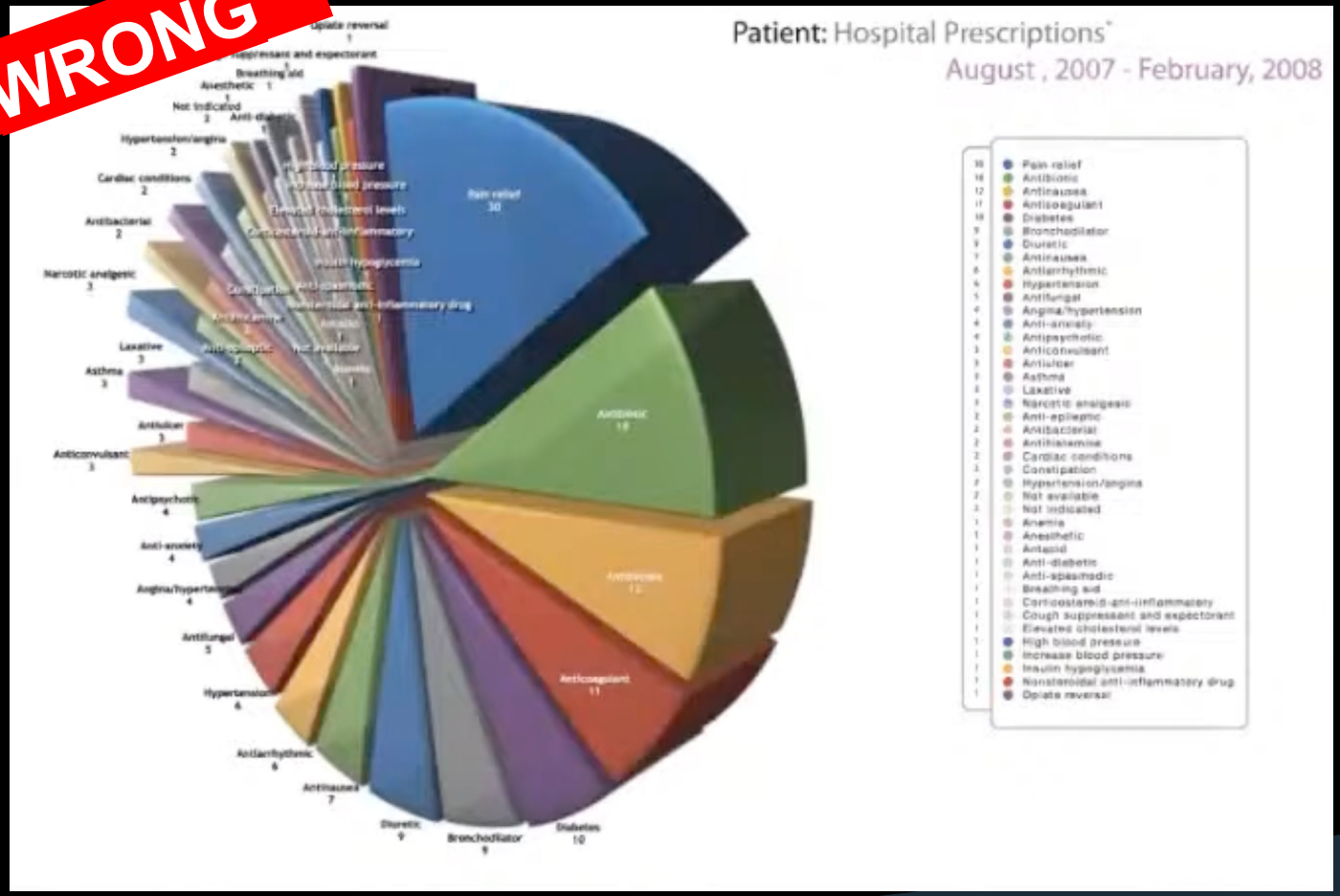




What is an Effective Visualization?

Effective visualizations use the power of perception to offload cognition

- Have graphical integrity
- Keep it simple



What is an Effective Visualization?

Effective visualizations use the power of perception to offload cognition

- **Have graphical integrity**
- **Keep it simple**

"... a wealth of information creates a poverty of attention"

- Herbert A. Simon

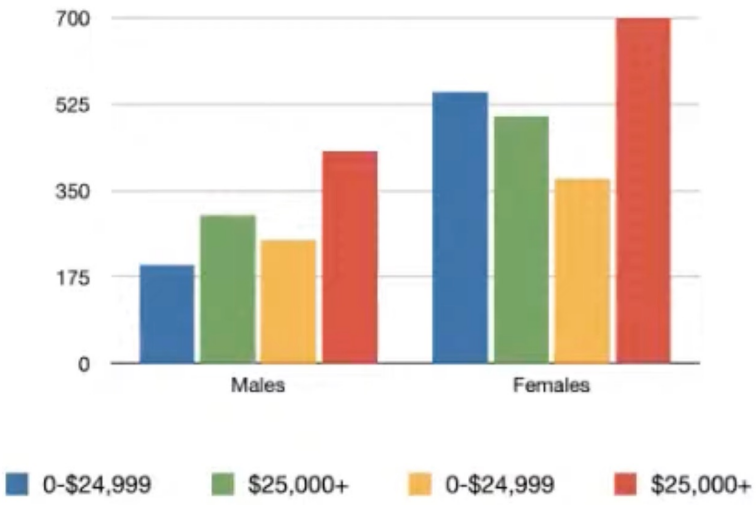


What is an Effective Visualization?

Effective visualizations use the power of perception to offload cognition

- **Have graphical integrity**
- **Keep it simple**
- **Use the right display**

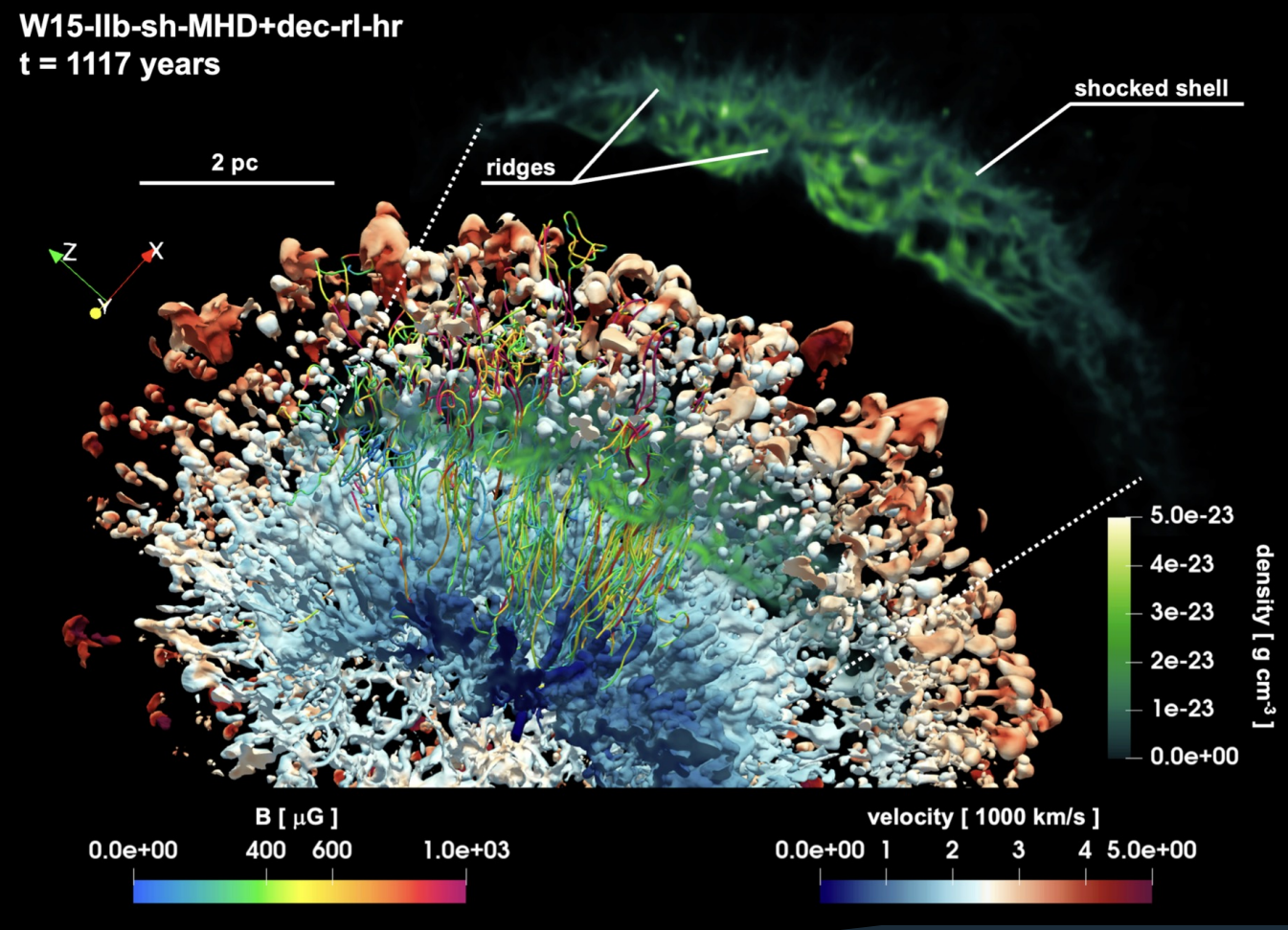
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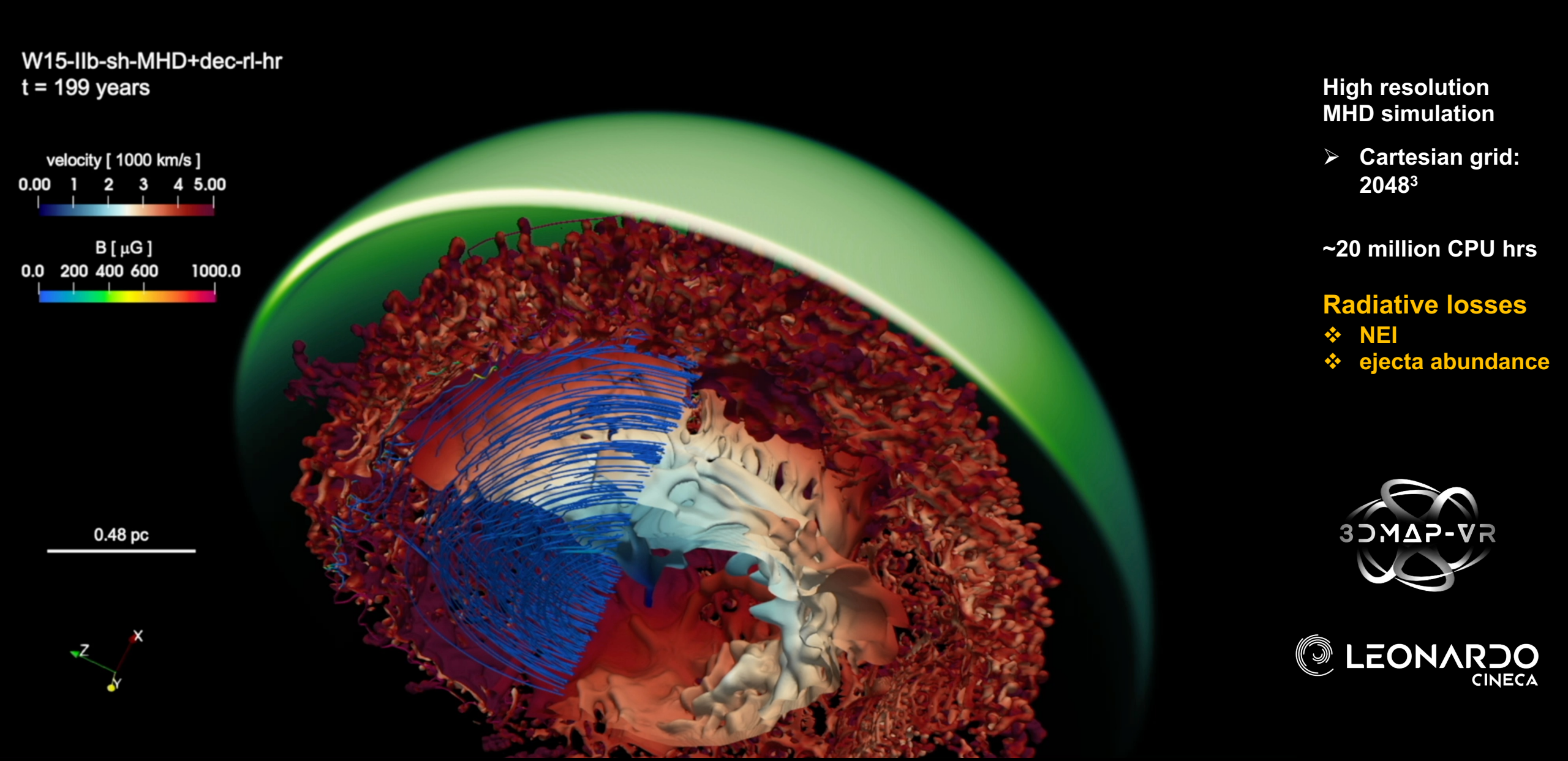


What is an Effective Visualization?

Effective visualizations use the power of perception to offload cognition

- Have graphical integrity
- Keep it simple
- Use the right display
- Use colors strategically





High resolution MHD simulation

- **Cartesian grid: 2048^3**

~20 million CPU hrs

Radiative losses

- **NEI**
- **ejecta abundance**

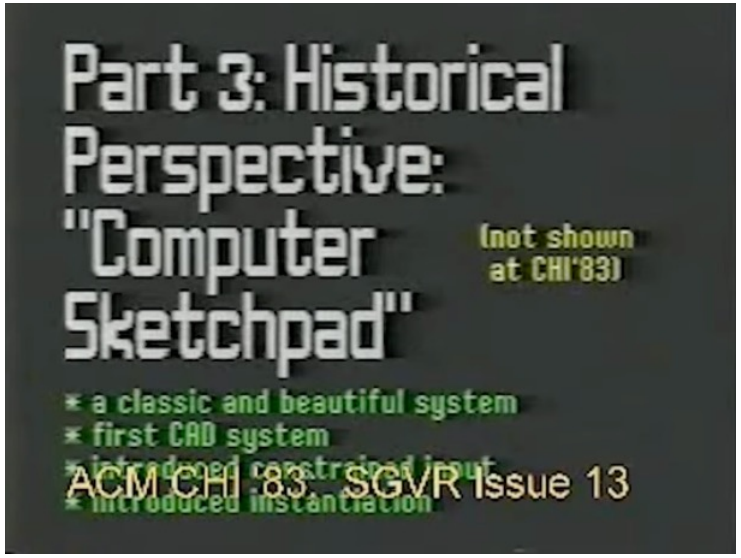
3DMAP-VR

LEONARDO CINECA

(Orlando et al. 2025)


Immersive Horizons
A Semi-Serious Guide to Finding Your Way in Virtual Data Space

What is Virtual Reality



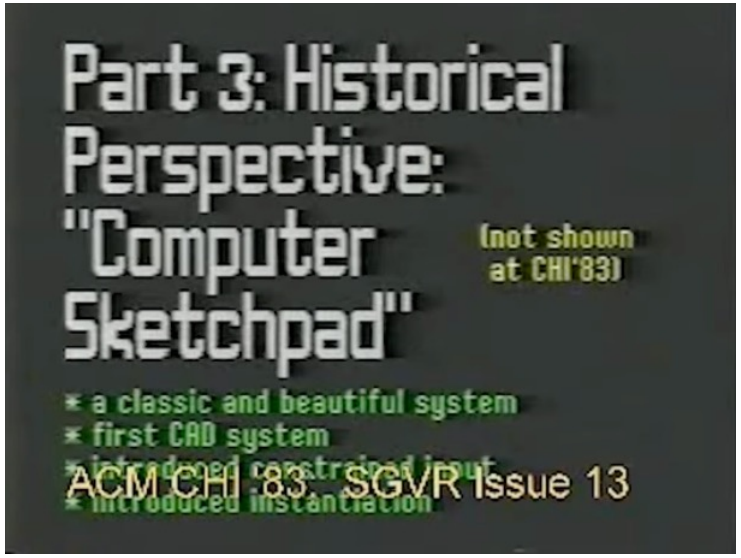


Ivan Sutherland is considered by many to be the creator of Computer Graphics and an Internet pioneer. Starting with his Ph.D. thesis, named *Sketchpad*, which is one of the most influential computer programs ever written by an individual, Sutherland has contributed numerous ideas to the study of Computer Graphics and Computer Interaction. He introduced concepts such as 3-D computer modeling, visual simulations, computer aided design (CAD), virtual reality, etc.

Ivan Sutherland Sketchpad Demo

https://www.youtube.com/watch?v=icDz35zYFwM

What is Virtual Reality





The Ultimate Display

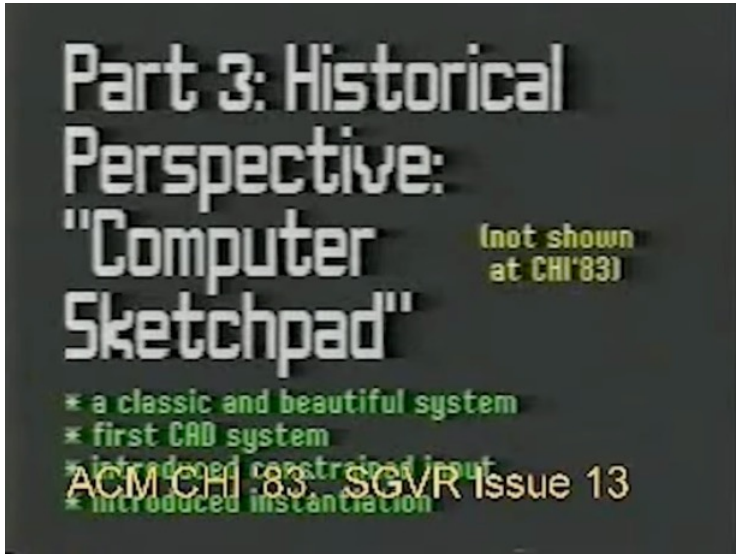
"The ultimate display would, of course, be a room within which the computer can control the existence of matter.

Ivan Sutherland, 1965

Ivan Sutherland Sketchpad Demo

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What is Virtual Reality





The Ultimate Display

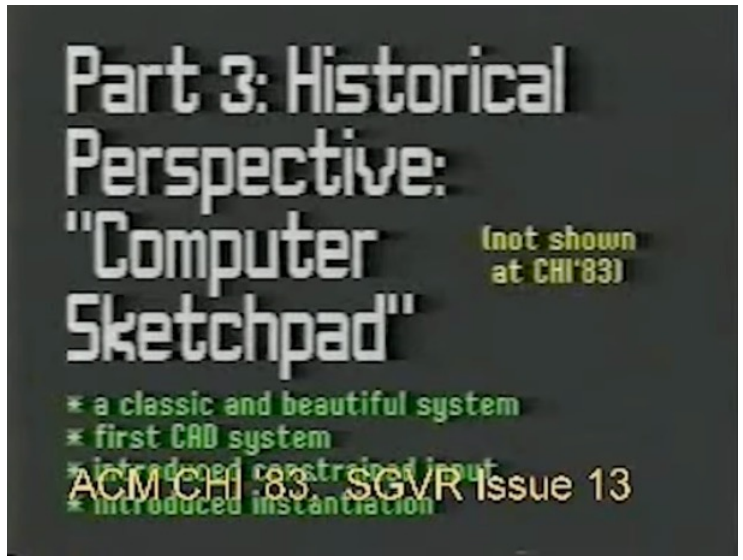
"The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in.

Ivan Sutherland, 1965

Ivan Sutherland Sketchpad Demo

https://www.youtube.com/watch?v=icDz35zYFwM

What is Virtual Reality





The Ultimate Display

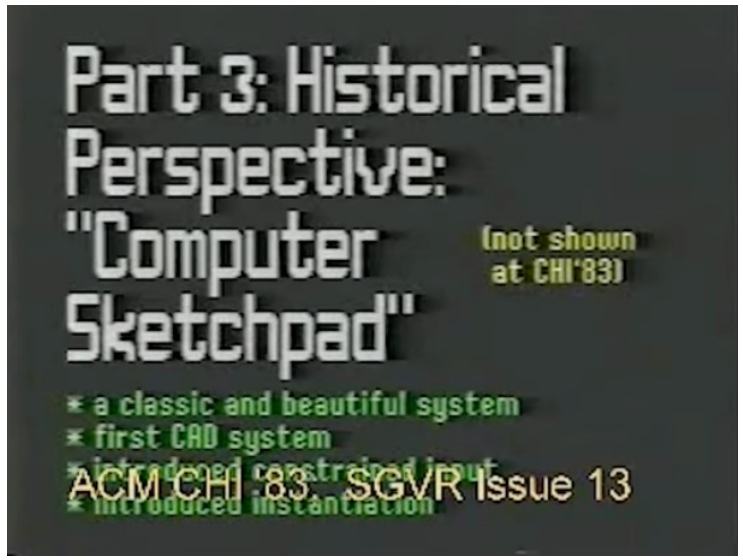
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What is Virtual Reality





The Ultimate Display

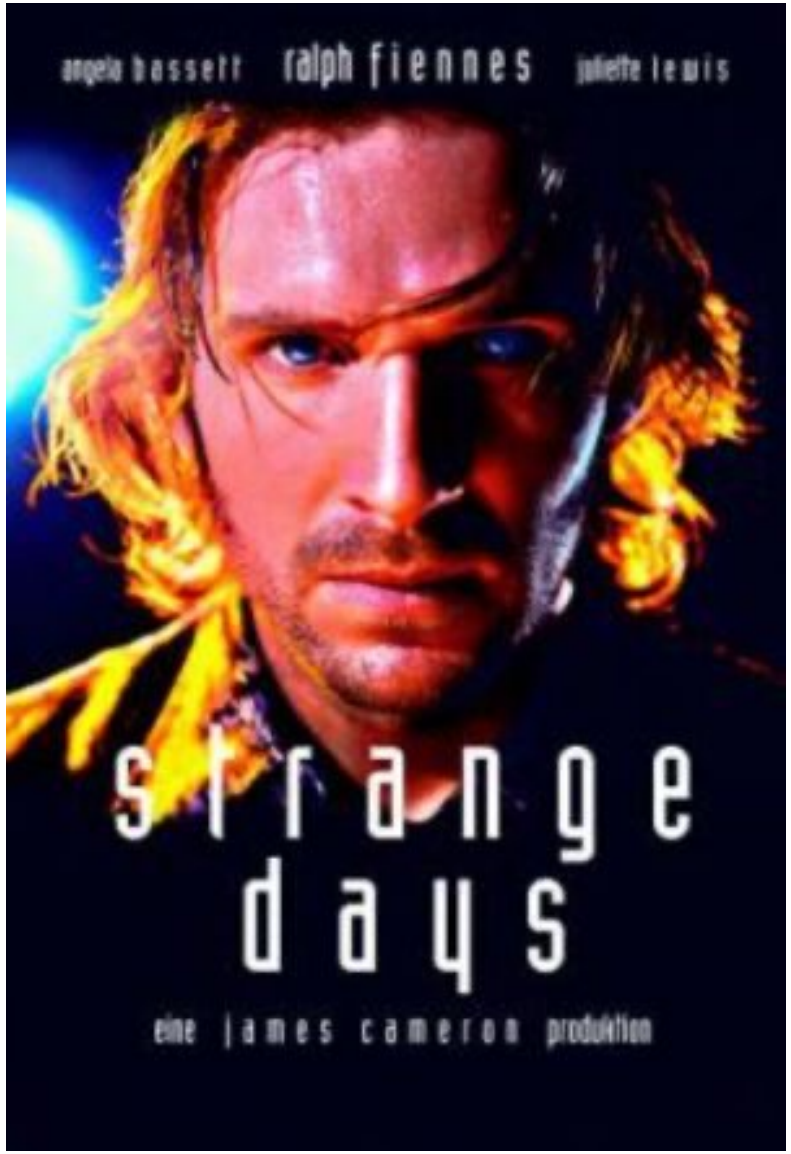
"The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal".

Ivan Sutherland, 1965

Ivan Sutherland Sketchpad Demo

https://www.youtube.com/watch?v=icDz35zYFwM

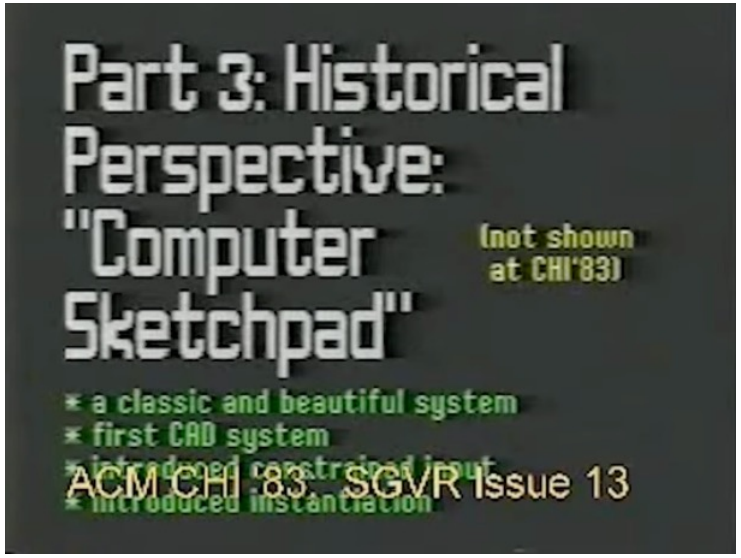
What is Virtual Reality







What is Virtual Reality





Merriam-Webster Dictionary Thesaurus virtual reality

Est. 1828

virtual reality noun

: an artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided by a computer and in which one's actions partially determine what happens in the environment

also : the technology used to create or access a virtual reality

Ivan Sutherland Sketchpad Demo

https://www.youtube.com/watch?v=icDz35zYFwM

VR Head-Mounted Displays (HMDs)

Oculus Quest



Sony



HTC Vive





Flow

Google Daydream



Cardboard

Also Valve Index, HP Reverb, etc...

Applications



Military

Healthcare





Education



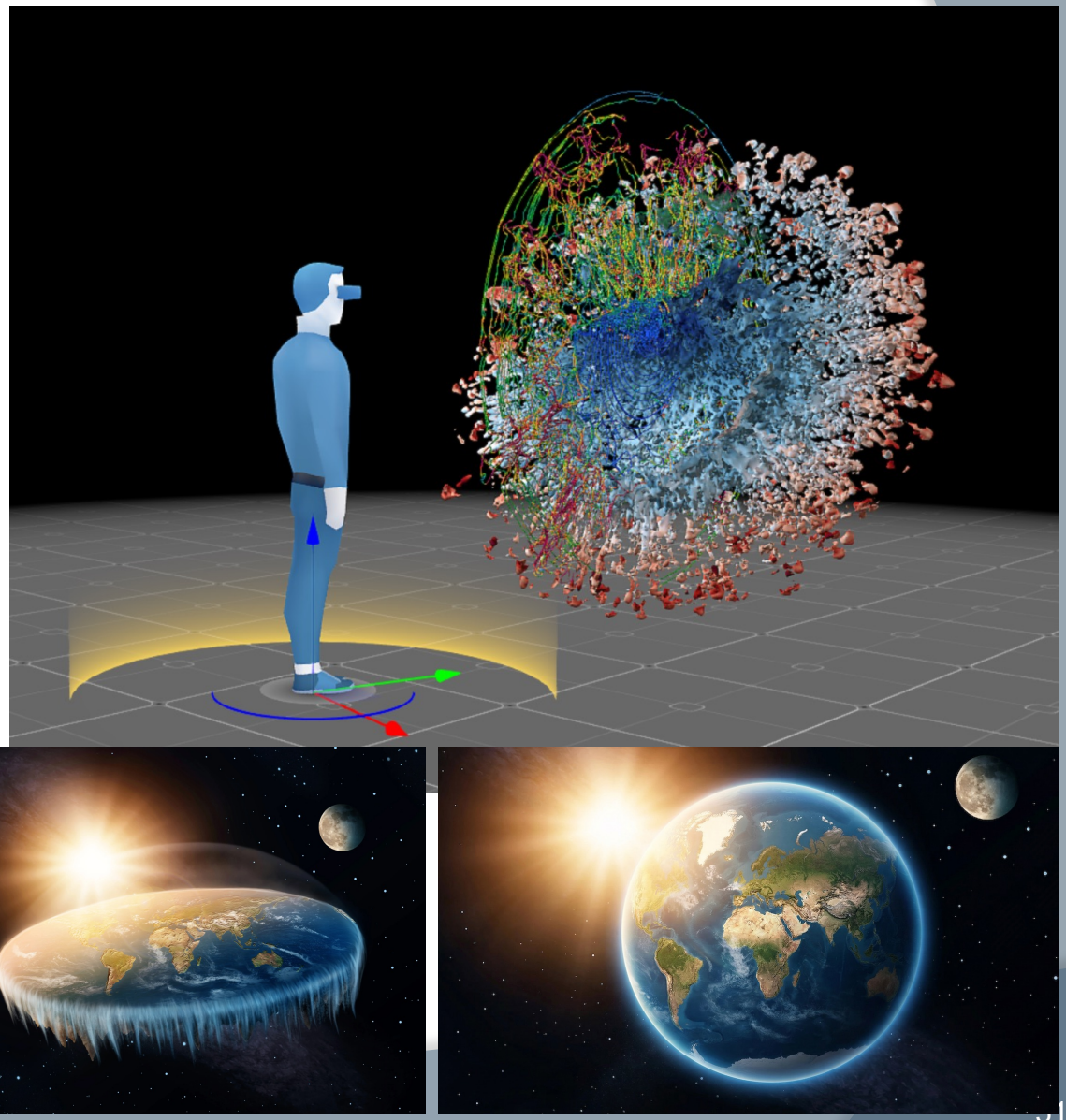
Scientific Visualization

Entertainment



Beyond the "Flatland" of Screens

- **The 2D Bottleneck:** Modern simulations are 3D (or 4D with time), but we analyze them through 2D glass (screen, figures, movies)
- **The Immersive Shift:**
  Moving from *looking at* data to *being inside* data
- **Key Definitions:**
  - **Virtual Reality (VR):** Full occlusion; total immersion in a synthetic data world.
  - **Augmented/Mixed Reality (AR/MR):** Overlaying complex models (e.g., a galactic merger) onto your physical desk.
  - **Immersive Analytics:** The science of using these tools for actual discovery, not just demonstration.



Virtual Reality (VR) vs Augmented Reality (AR)

VR = virtual reality

- User is completely immersed in virtual world - sees only light emitted by display (e.g., ready player one)



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VR = virtual reality

- User is completely immersed in virtual world - sees only light emitted by display (e.g., ready player one)

AR = augmented reality

- Display is an overlay that augments user's normal view of the real world (e.g., Terminator)



Virtual Reality (VR) vs Augmented Reality (AR)

VR = virtual reality

- User is completely immersed in virtual world (sees only light emitted by display)

AR = augmented reality

- Display is an overlay that augments user's normal view of the real world (e.g., Terminator)



Spatial Understanding & The "Depth" Advantage

- Our brain uses the distance between our eyes to perceive depth. In VR, this is restored, making complex 3D structures (like ejecta distributions in SNRs) instantly legible

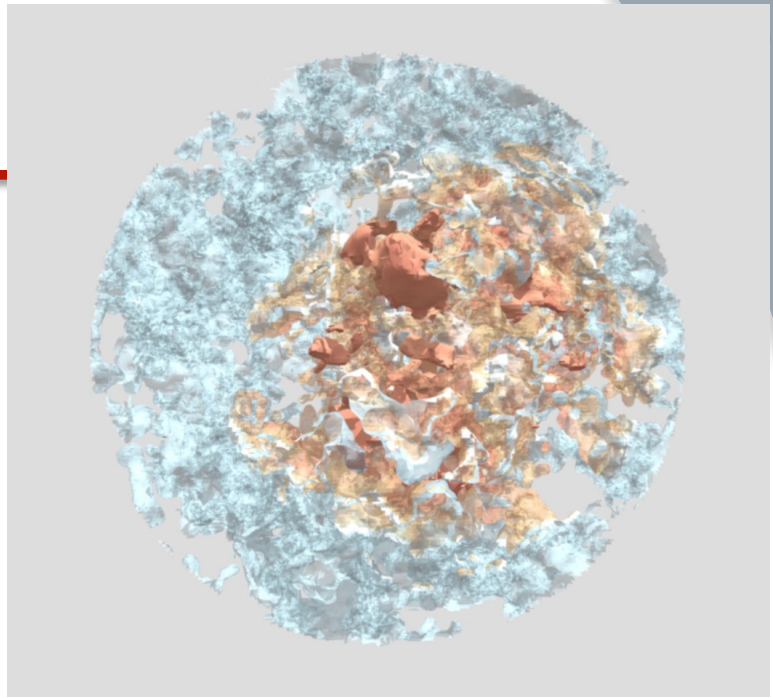
- In VR, moving your head changes the perspective. This "motion parallax" is the most powerful cue for understanding 3D shape

- We perceive the relative sizes of features much more accurately *even if they are not presented at a 1:1 human scale*

Star Blast: a VR tour of the outcome of stellar explosions



Principles Grounded in Reality



Immersion ≠ Magic:
The principles in designing graphics still apply!

- **Color *Ethics*:** Poor colormaps are even more confusing in 3D

- **Data Reduction:** You cannot render 1 billion points in a VR headset at 90fps. Decimation and Isosurfacing are *more* critical here



- **Occlusion:** In VR, you can "walk through" an occluding layer, solving one of the biggest problems of 3D desktop visualization

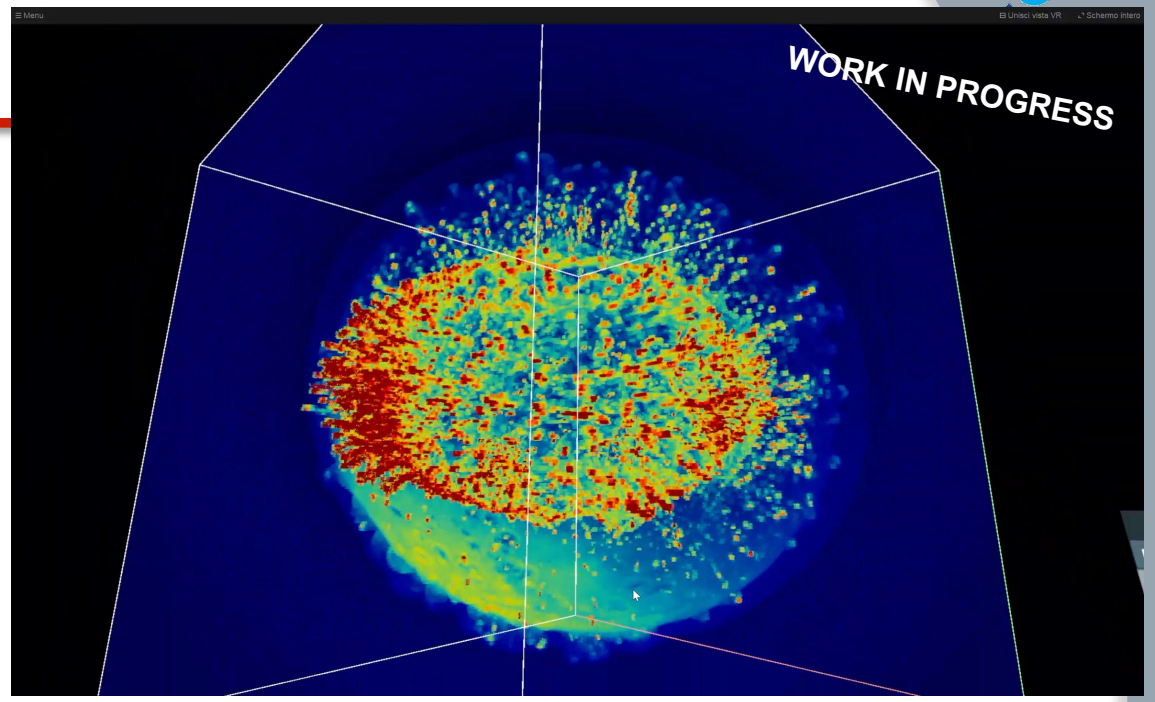
Exploratory Analysis vs. Presentation

Exploration

"Walking" through a simulation to find unexpected topological features

- Grabbing and rotating a model with your hands to inspect a specific structure

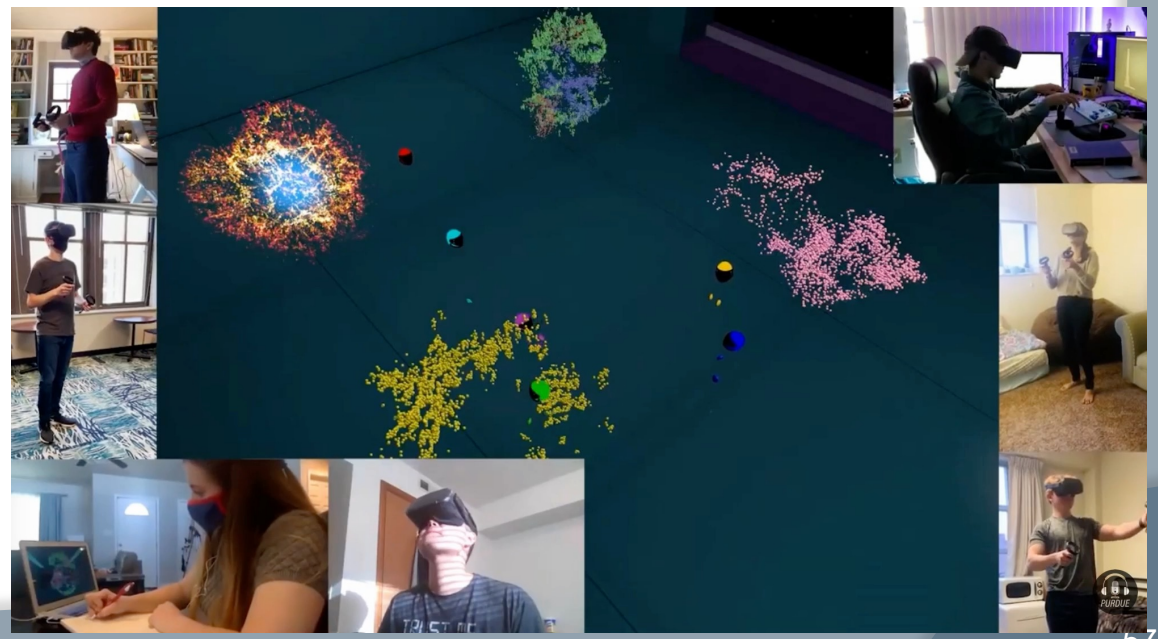
INAF, Italy
Fabio Vitello



Communication

- **Public Outreach:** Allowing the general public to "fly" through a nebula.
- **Collaborative VR:** Two scientists in different cities meeting *inside* the same dataset to discuss a specific feature.

Purdue University, USA
Danny Milisavljevic

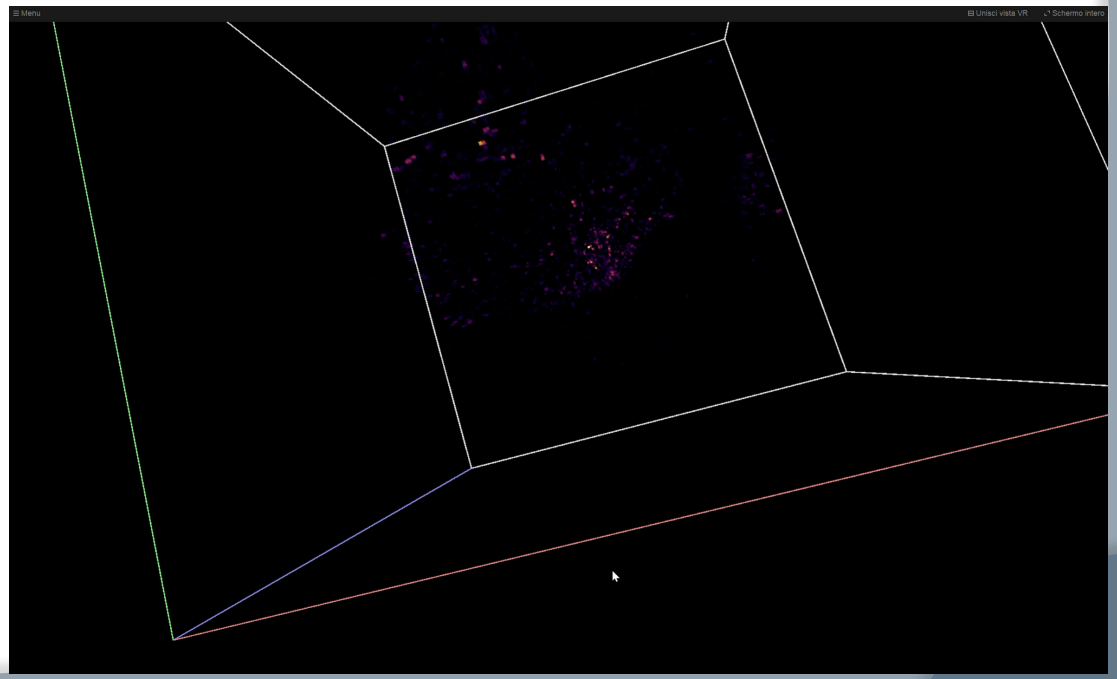


The "Cost" of Immersion (Constraints)



- **Simulator Sickness**
  Frame rate must be high (>90 FPS). If the visualization lags, the user gets nauseous

- **UI/UX Challenges**
  You can't use a standard keyboard and mouse in VR. We need "Spatial UI" (floating menus)



- **Information Overload**
  Being immersed in data can be overwhelming
  Keeping things simple remains the golden rule

Closing Remarks – The Responsibility of the Visualizer

Clarity as a Scientific Duty

- **Visualization is an Act of Translation**
  You are translating mathematical abstractions (e.g., MHD equations) into a visual language; if the translation is obscure, the science *is lost*

- **Complexity is not a Virtue**
  A "busy" or "complex-looking" plot does not prove the complexity of your model; it often only proves a lack of editorial focus

- **The Cognitive Load**
  Every unnecessary color, label, or 3D artifact competes for the viewer's limited attention; your job is to maximize the signal-to-noise ratio

Closing Remarks – The Responsibility of the Visualizer

Know Your Audience, Define Your Goal

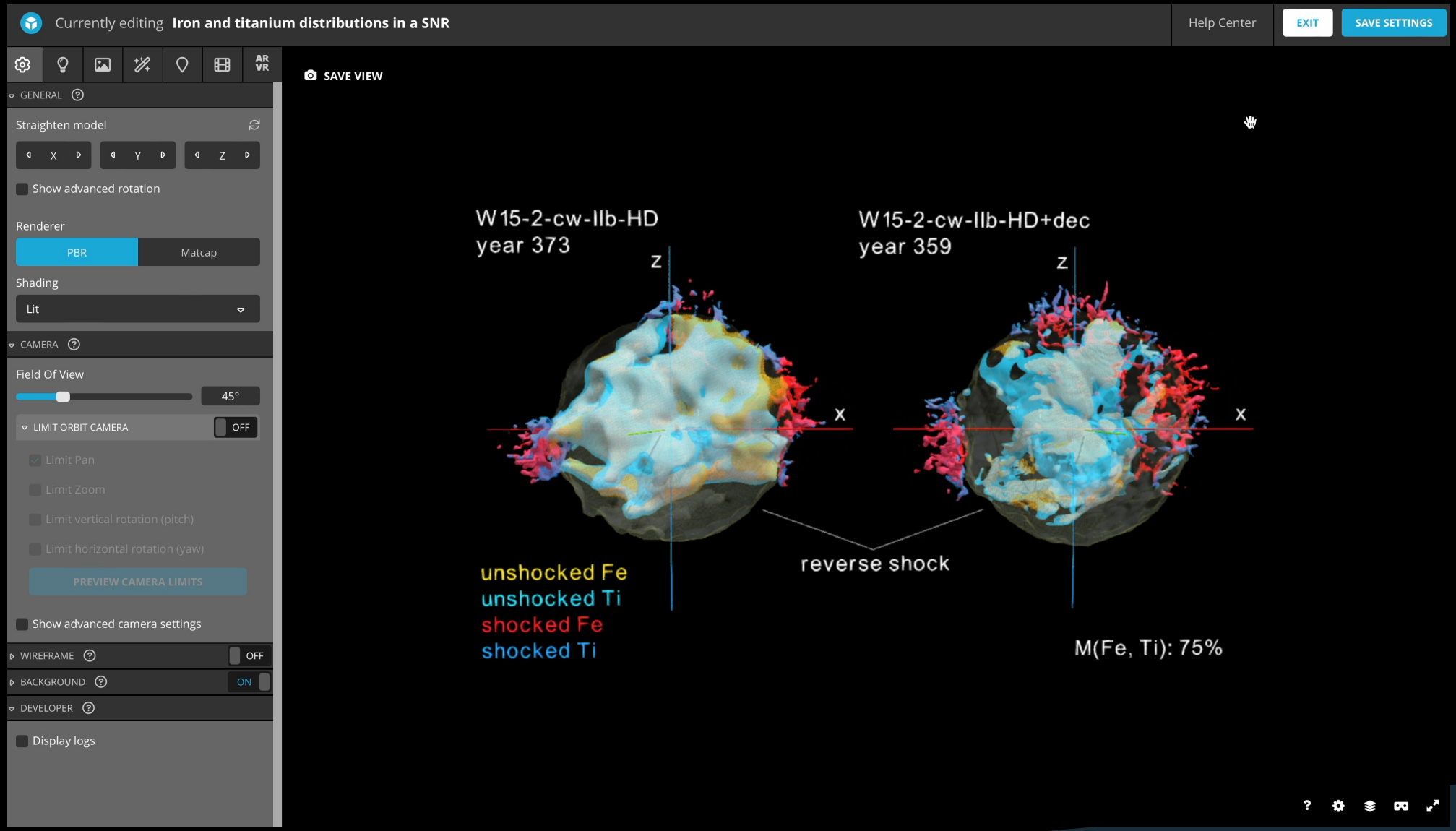
The "best" visualization does not exist. It is defined by who is looking at it

Target Audience	Primary Goal	Strategy
Peer Researchers	**Validation & Discovery**	Technical accuracy, raw data context, high-density information, standard colormaps
Students / Education	**Conceptual Linking**	Highlight physical mechanisms, use analogies, simplify specialized jargon
Public Outreach	**Impact & Engagement**	*Wow* effect, emotional resonance, extreme simplification, focus on the "Why" over the "How"



Possible Applications

Data Analysis



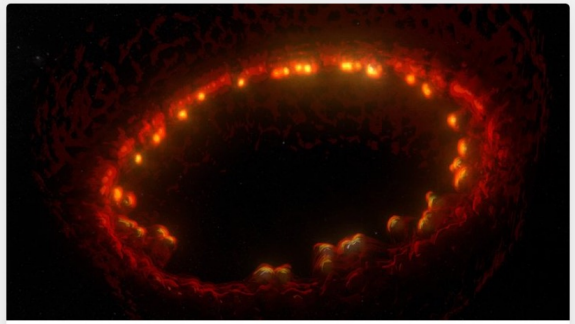
Dissemination of Scientific Results

References

- Orlando, Miceli, Pumo, et al., 2015, ApJ 810, 168
- Orlando, Miceli, Ono, et al., 2019, A&A 622, A73
- Ono, Nagataki, Ferrand, et al., 2020, ApJ 888, 111
- Orlando, Ono, Nagataki, et al., 2020, A&A 636, A22
- Orlando, Miceli, Ono, et al., 2025, A&A 699, A305

References:

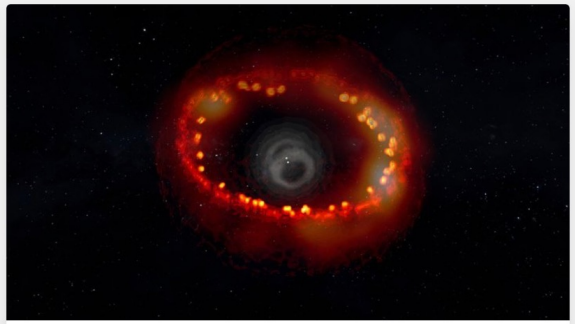
- Orlando, Wongwathar
- Orlando, Wongwathar



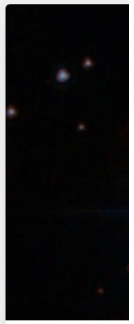
X-ray emission from supernova 1... 2.1k 0 36



Evidence



A pulsar beats in the heart of SN ... 1.4k 2 29



The remr

Orlando, S., et al.: A&A, 696, A188 (2025)

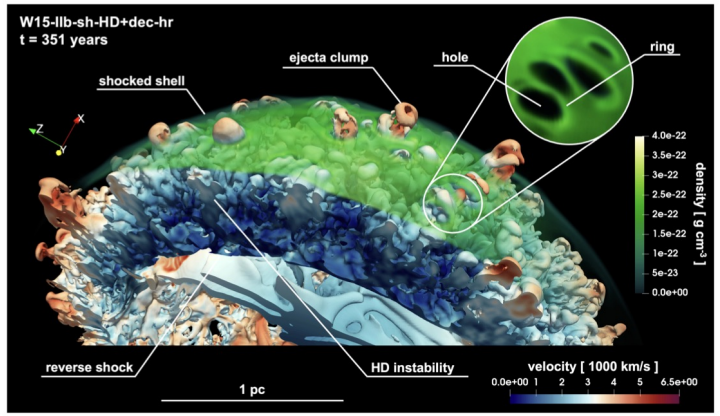


Fig. 1. 3D visualization of ejecta-shell interaction in Cas A from model W15-IIb-sh-HD+dec-hr (see Table 1). The irregular isosurface describes ejecta with mass density $>10^{-23}$ g cm^{-3}; the colors represent the radial velocity in units of 1000 km s^{-1} (the color coding is defined in the bottom right corner of the figure). The green volume rendering describes the mass density of the shocked shell material (color bar on the right of the figure). The upper right inset highlights the shell structure characterized by holes and rings, resulting from interaction with the ejecta.

measurements (e.g., Reed et al. 1995; DeLaney et al. 2010; Milisavljevic & Fesen 2013). In particular, the latter was crucial in determining that the shell is located on the near side of the remnant. In fact, this Doppler velocity asymmetry can be explained as the effect of a denser shell on the blueshifted near side that limits the forward expansion of the ejecta toward the observer.

As a result, our preferred model (run W15-IIb-sh-HD-1eta-az in Orlando et al. 2022) assumes the shell is rotated by 50° about the z-axis, counterclockwise from the $[x, z]$ plane, placing its densest portion on the blueshifted near side to the northwest. This configuration successfully reproduces the apparent redshift of the center of expansion, with a velocity consistent with observational estimates (Milisavljevic & Fesen 2013), as well as the properties of the reverse shock (Vink et al. 2022). These findings suggest that the GM, the peculiar behavior of the reverse shock in the western hemisphere, and the redshifted center of expansion in Cas A can all be interpreted as manifestations of the remnant's interaction with an asymmetric circumstellar shell. Another sign of this interaction is the presence of circumstellar dense clumps with negligible velocity often referred to as quasi-stationary flocculi (QSFs; e.g., Reed et al. 1995; Koo et al. 2018).

The overall interaction of the remnant with the shell is described in Orlando et al. (2022) and is reproduced, at higher resolution, in Fig. 1. More specifically, the figure provides a detailed visualization of the ejecta structures and their interactions with the shell at Cas A's current evolutionary stage, derived from model W15-IIb-sh-HD+dec-hr (see Table 1). The forward shock encountered the circumstellar shell approximately 200 years after the SN event, causing a significant deceleration as it passed through the dense material. At around 250 years post-explosion, ejecta fingers and clumps driven by HD instabilities and emerging from the contact discontinuity began penetrating the shocked shell material. This mechanism led to distinctive morphological features characterized by holes generated by the ejecta within the shell structure (see also De Looze et al. 2024). Figure 1 illustrates the basic mechanism underlying hole formation and the complex interplay between ejecta dynamics and shell structure. As the ejecta structures propagated through the shell, they displaced the surrounding shell material, which subsequently accumulated along the peripheries of these penetration sites. This process produced dense, ring-like structures encircling the newly formed holes. The progressive evolution of these interactions resulted in a characteristic pockmarked pattern analogous to that observed in Cas A today.

Although the general morphology of holes and rings is very similar to that observed in Cas A, we found that most of the simulated features have diameters in the range of ≈5″−20″ (corresponding to ∼0.07−0.3 pc). As noted by De Looze et al. (2024), these dimensions are significantly larger than those observed in the GM, which range from ≈1″−3″. This discrepancy raises some questions on the interpretation of the GM's structure based on the mechanism described above. The same authors suggested that the size difference may arise from the limited spatial resolution of the simulations considered, which hinders an accurate representation of the small-scale structure of the ejecta. However, as shown in Fig. 1 for run W15-IIb-sh-HD+dec-hr (see Table 1), our analysis revealed that the diameters of the holes and rings do not change significantly compared to earlier, lower-resolution simulations (presented in

Orlando, S., et al.: A&A, 699, A305 (2025)

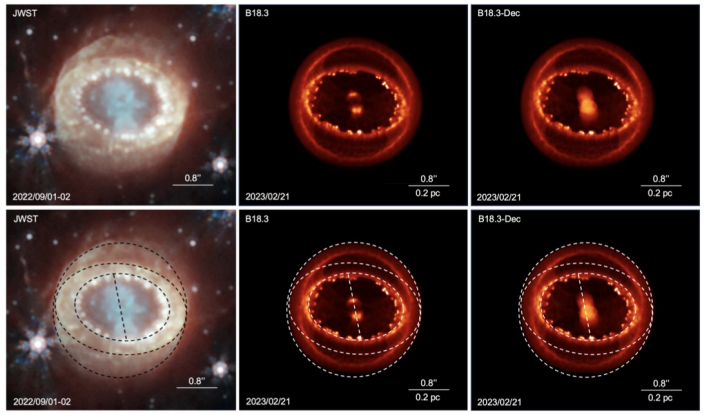


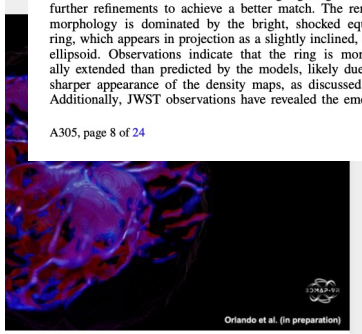
Fig. 3. Upper panels: Comparison between JWST observations of SN 1987A from September 1–2, 2022 (left column), and the density distribution of the remnant–including both shocked plasma and unshocked Fe-rich ejecta–predicted by models B18.3 (Paper I; center column) and B18.3-Dec (right column) as of February 2023. Lower panels: Same as the upper panels but with identical ellipsoids overlaid on all images as a reference for comparing the large-scale morphology of the remnant across observations and models. The dashed line at the remnant's center marks the approximate orientation of the homunculus' major axis. While the model-generated images reproduce the general structure of the remnant, they are not intended to exactly match the observed appearance. The original JWST image was created by Alyssa Pagan (STScI), and the image credits belong to NASA, ESA, CSA, Mikako Matsuura (Cardiff University), Richard Arendt (NASA-GSFC, UMBC), Claes Fransson (Stockholm University), and Josefin Larsson (KTH).

It is important to note that while the model-derived images combine the distributions of shocked plasma and unshocked Fe-rich ejecta to create an analog of the JWST observations (left panels of Fig. 3), they are not intended to precisely replicate the observational data. Instead, these images illustrate the remnant's structure and emphasize key morphological features. A direct match between model-derived images and observations would require detailed emission modeling in the specific bands observed by JWST. For example, the infrared image exhibits a "halo" around the brightest structures due to radiative ionization from photons, an effect not accounted for in the sharp density maps. Incorporating such a halo around density structures could make the model images appear more extended and better resemble the observations. Despite this limitation, the strong similarity between the model-derived images and JWST observations underscores the model's ability to reproduce the global structure and dimensions of the remnant, capturing many of the key features observed in SN 1987A.

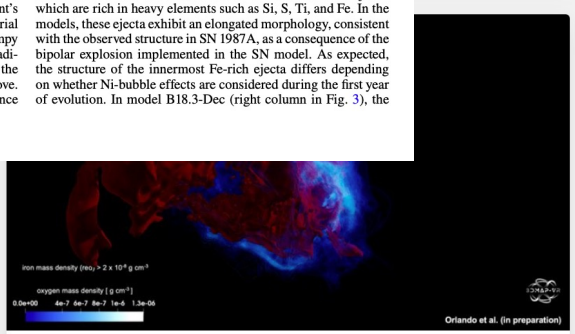
However, as discussed below, some discrepancies remain between the models and observations, highlighting the need for further refinements to achieve a better match. The remnant's morphology is dominated by the bright, shocked equatorial ring, which appears in projection as a slightly inclined, clumpy ellipsoid. Observations indicate that the ring is more radially extended than predicted by the models, likely due to the sharper appearance of the density maps, as discussed above. Additionally, JWST observations have revealed the emergence of new bright knots (e.g., Matsuura et al. 2024) that are not present in the models. These structures likely form as the blast wave propagates through the CSM, unveiling previously undetectable inhomogeneities (and, therefore, not included in the model developed before these observations). Their appearance suggests that the CSM is more complex than currently modeled, possibly containing finer-scale density variations or unresolved clumps that can influence the remnant's evolution and emission properties.

The models successfully reproduce the diffuse emission observed beyond the equatorial ring, as indicated by the largest ellipsoid in Fig. 3. This emission appears more elongated in the north-south direction, consistent with the blast wave propagating through the hourglass-shaped cavity carved by the fast wind from the BSG progenitor. However, differences in the fine structure and distribution of the shocked material suggest that additional physical processes, such as small-scale instabilities or variations in the CSM, may play a role in shaping the observed remnant.

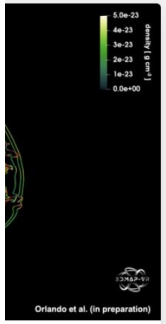
The most striking discrepancies between the models and observations arise in the distribution of the innermost ejecta, which are rich in heavy elements such as Si, S, Ti, and Fe. In the models, these ejecta exhibit an elongated morphology, consistent with the observed structure in SN 1987A, as a consequence of the bipolar explosion implemented in the SN model. As expected, the structure of the innermost Fe-rich ejecta differs depending on whether Ni-bubble effects are considered during the first year of evolution. In model B18.3-Dec (right column in Fig. 3), the



ilaments in C... 261 0 6



Ejecta structure at the shock bre... 394 0 17

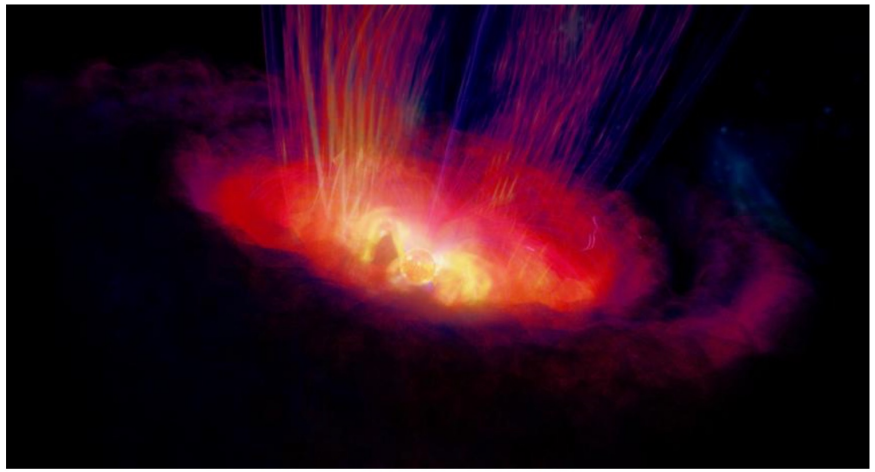


3 4 12

Dissemination of Scientific Results

Royal Astronomical Society

First observational evidence of gamma-ray emission in young Sun-like stars



Artist's impression of a T Tauri star: system formed by a central star and a circumstellar disk. This is what our Solar System looked like 4.5 bill years ago. The gamma-ray emission would be produced in the star's most violent and energetic flares.
Credit: INAF-OAPa/S. Orlando
Licence type: Attribution (CC BY 4.0) (/licence/attribution-cc-40)

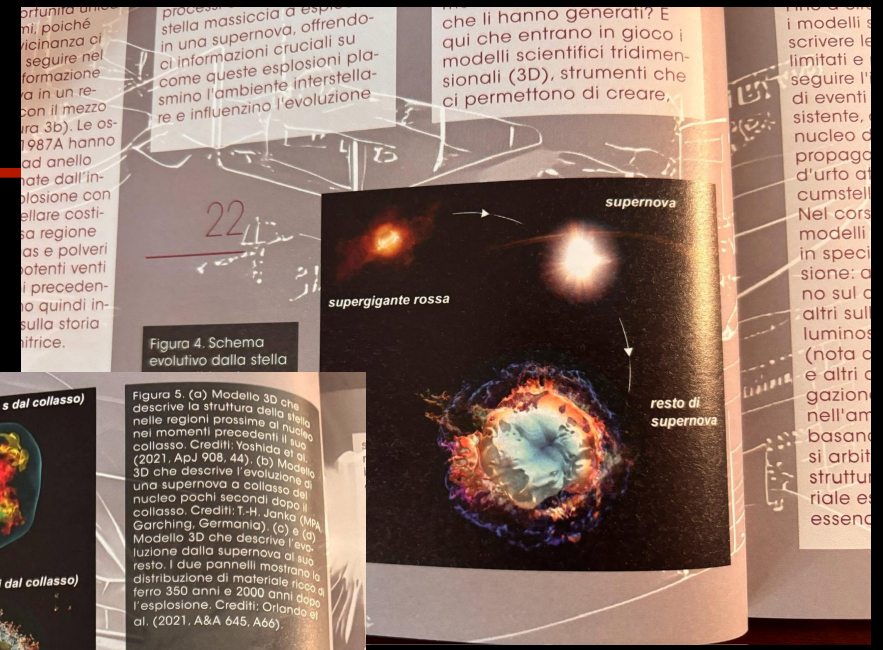


Figura 4. Schema evolutivo dalla stella

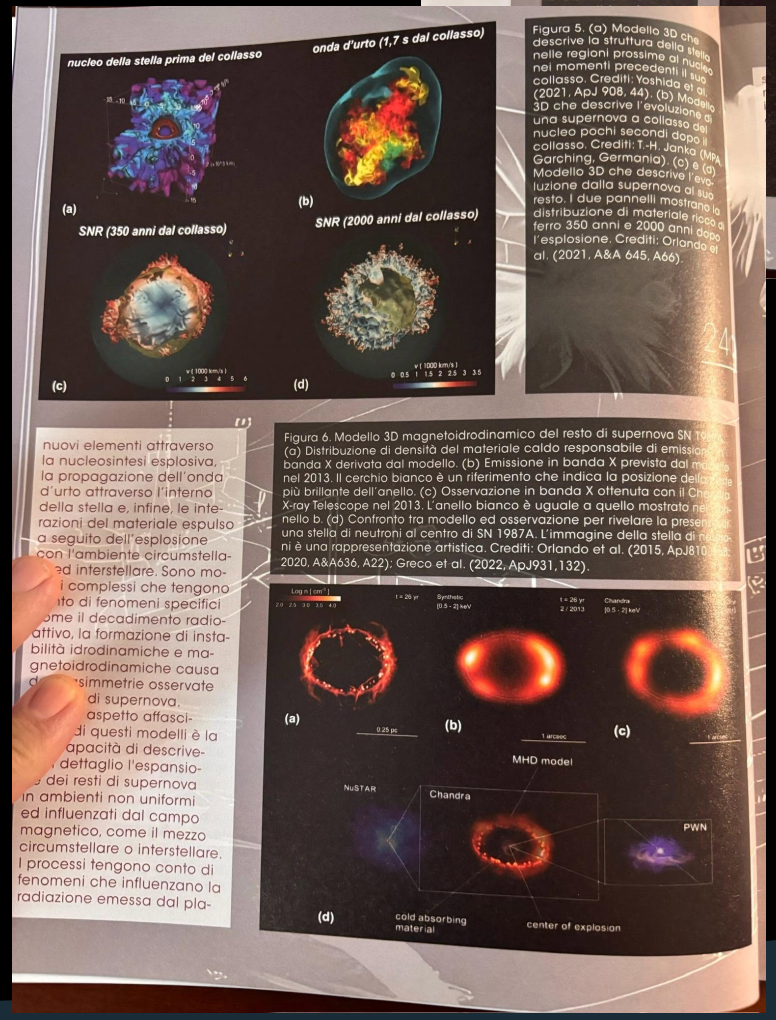


Figura 5. (a) Modello 3D che descrive la struttura della stella nelle regioni prossime al nucleo nei momenti precedenti il suo collasso. Crediti: Yoshida et al. (2021, ApJ 908, 44). (b) Modello 3D che descrive l'evoluzione di una supernova a collasso del nucleo pochi secondi dopo il collasso. Crediti: T.-H. Janka (MPA Garching, Germania). (c) e (d) Modello 3D che descrive l'evoluzione dalla supernova al suo resto. I due pannelli mostrano la distribuzione di materiale ricco di ferro 350 anni e 2000 anni dopo l'esplosione. Crediti: Orlando et al. (2021, A&A 645, A66).

Figura 6. Modello 3D magnetoidrodinamico del resto di supernova SN 1987A. (a) Distribuzione di densità del materiale caldo responsabile di emissione in banda X derivata dal modello. (b) Emissione in banda X prevista dal modello nel 2013. Il cerchio bianco è un riferimento che indica la posizione della parte più brillante dell'anello. (c) Osservazione in banda X ottenuta con il Chandra X-ray Telescope nel 2013. L'anello bianco è uguale a quello mostrato nel pannello b. (d) Confronto tra modello ed osservazione per rivelare la presenza di una stella di neutroni al centro di SN 1987A. L'immagine della stella di neutroni è una rappresentazione artistica. Crediti: Orlando et al. (2015, ApJ810, 168; 2020, A&A636, A22); Greco et al. (2022, ApJ931,132).

nuovi elementi attraverso la nucleosintesi esplosiva, la propagazione dell'onda d'urto attraverso l'interno della stella e, infine, le interazioni del materiale espulso a seguito dell'esplosione con l'ambiente circumstellare ed interstellare. Sono molti complessi che tengono conto di fenomeni specifici come il decadimento radioattivo, la formazione di instabilità idrodinamiche e magnetoidrodinamiche causa delle asimmetrie osservate nei resti di supernova, l'aspetto affascinante di questi modelli è la capacità di descrivere in dettaglio l'espansione dei resti di supernova in ambienti non uniformi ed influenzati dal campo magnetico, come il mezzo circumstellare o interstellare. I processi tengono conto di fenomeni che influenzano la radiazione emessa dal pla-

che li hanno generati? E qui che entrano in gioco i modelli scientifici tridimensionali (3D), strumenti che ci permettono di creare,

Cover of books

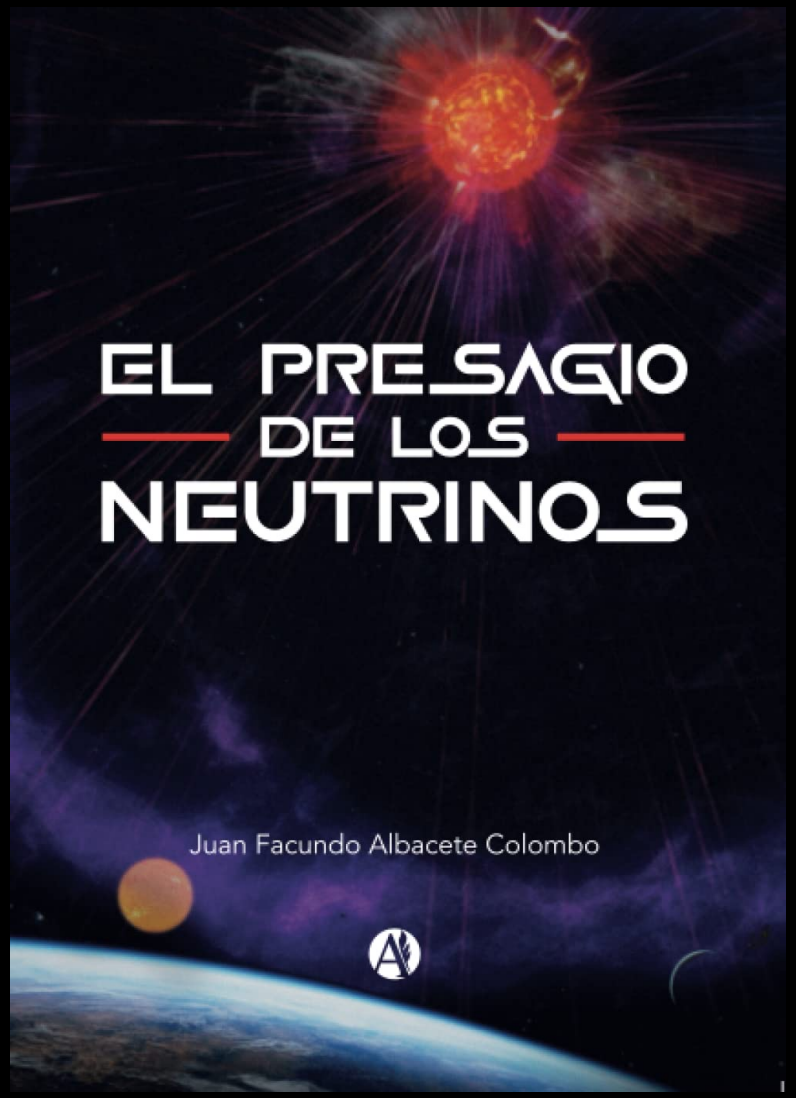


Una novela para los que buscan respuestas mirando al cielo.

Sinopsis
La explosión de una estrella liberó partículas que viajaron durante siglos por el Universo. Su destino: la Tierra. Y con ellas, el presagio de una amenaza.

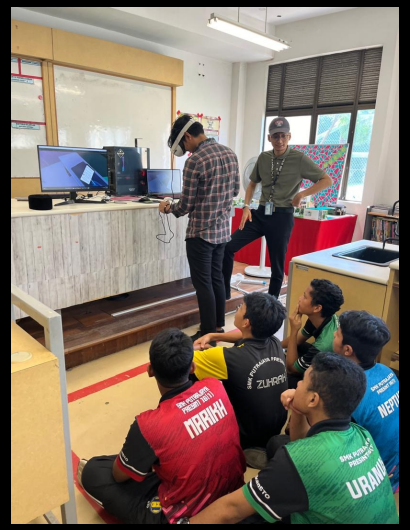
CULTURA RN

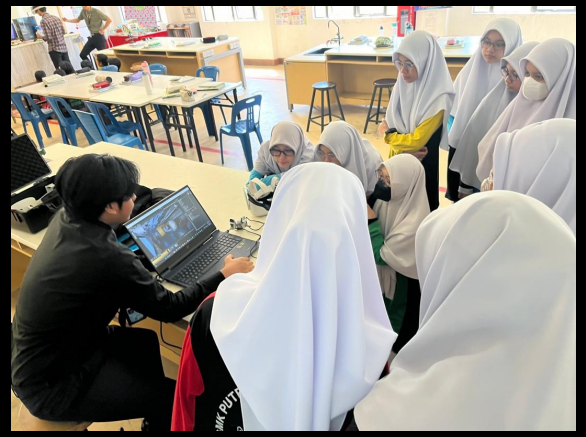
Gobierno Río Negro



Education



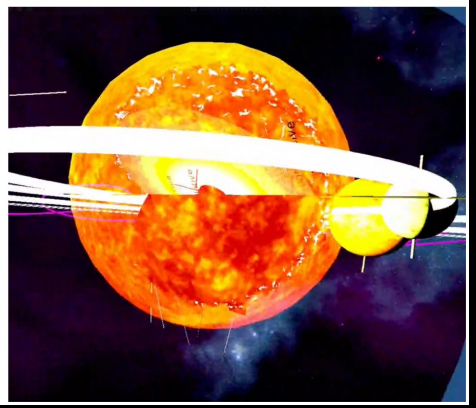




Malaysia: Using Virtual Reality for Astronomy Education in Secondary School







India: Project “Being Aarvam” promoted by the Payir Foundation

Public Outreach: Model Galleries

Sketchfab EXPLORE BUY 3D MODELS FOR BUSINESS Search 3D models UPLOAD

The remnant of a neutrino-driven supernova 3D Models

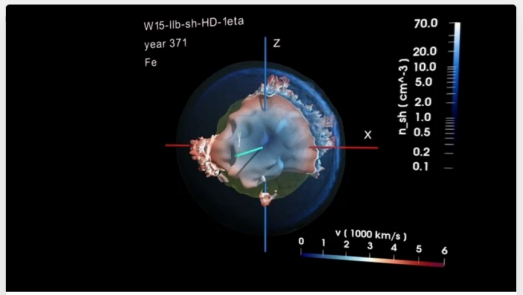
6 models - 5 subscribers

The models presented here aim at exploring to which extent the remnants of supernova explosions keep memory of the asymmetries that develop stochastically in the neutrino-heating layer due to hydrodynamic instabilities (e.g., convective overturn and the standing accretion shock instability) during the first second after core bounce.

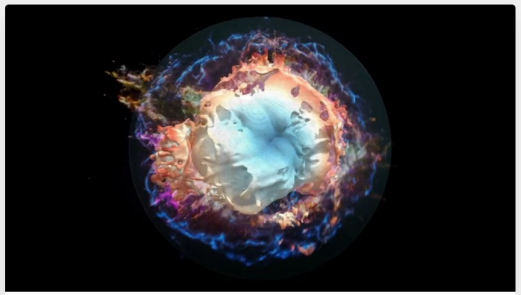
EMBED SHARE SETTINGS

The models include all physical processes relevant to describe the complexities in the SN evolution and the subsequent interaction of the stellar debris with the wind of the progenitor star. The 3D graphics show the distribution of ejecta at the age of the SNR Cassiopeia A and demonstrate that the chemical and physical properties of its ejecta can be explained in terms of asymmetries that developed from stochastic processes that originate during the first seconds of the SN blast.

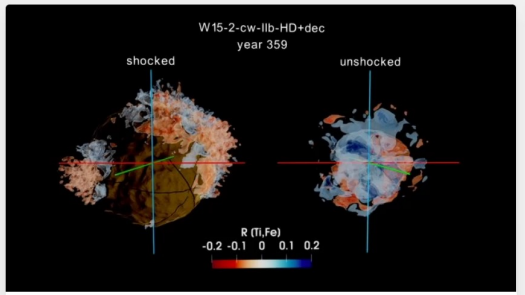
Reference: S. Orlando, A. Wongwathanarat, H.-T. Janka, M. Miceli, M. Ono, S. Nagataki, F. Bocchino, and G. Peres 2021, A&A 645, A66



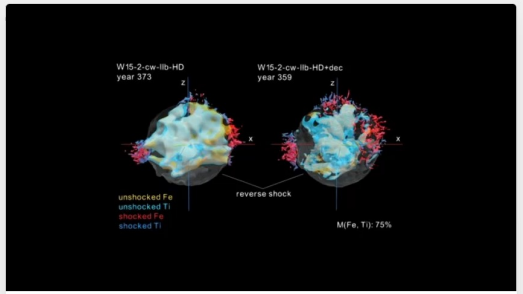
Cassiopeia A: Interaction with a dens... 430 0 14



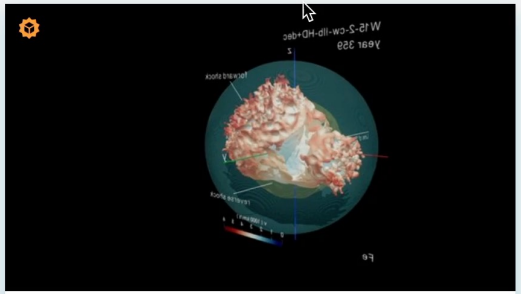
Iron distribution in the SNR Cassiop... 1.1k 3 23



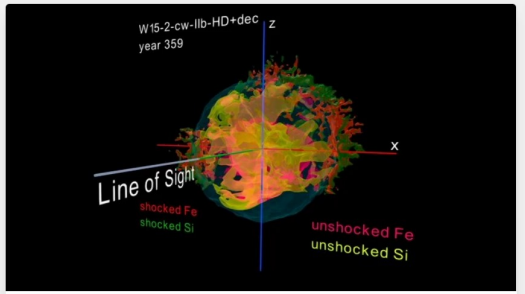
Abundance of Fe and Ti in a SNR 71 0 9



Iron and titanium distributions in a SNR 93 0 9

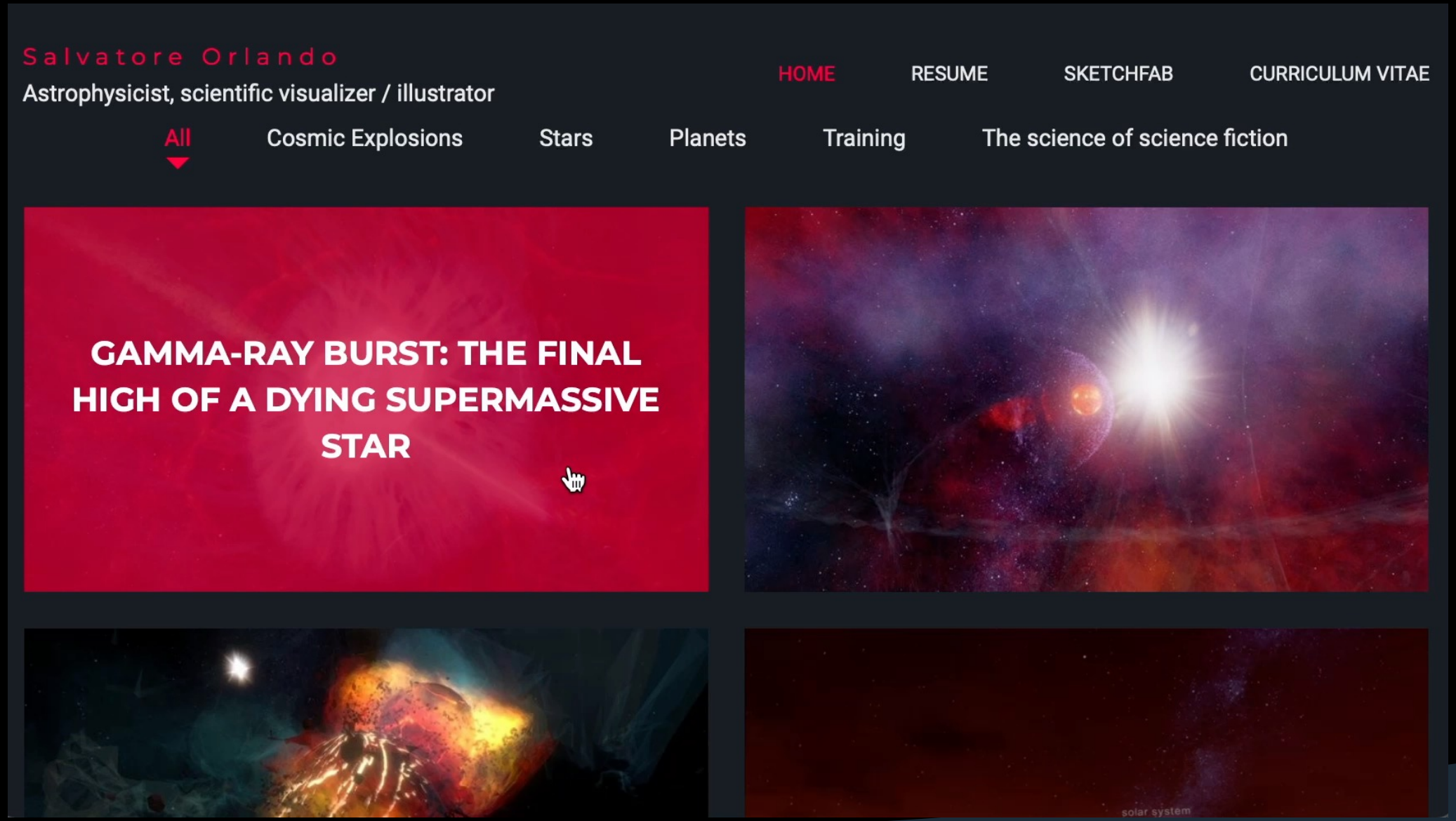


Iron distribution in a Supernova Re... 1.2k 10 42

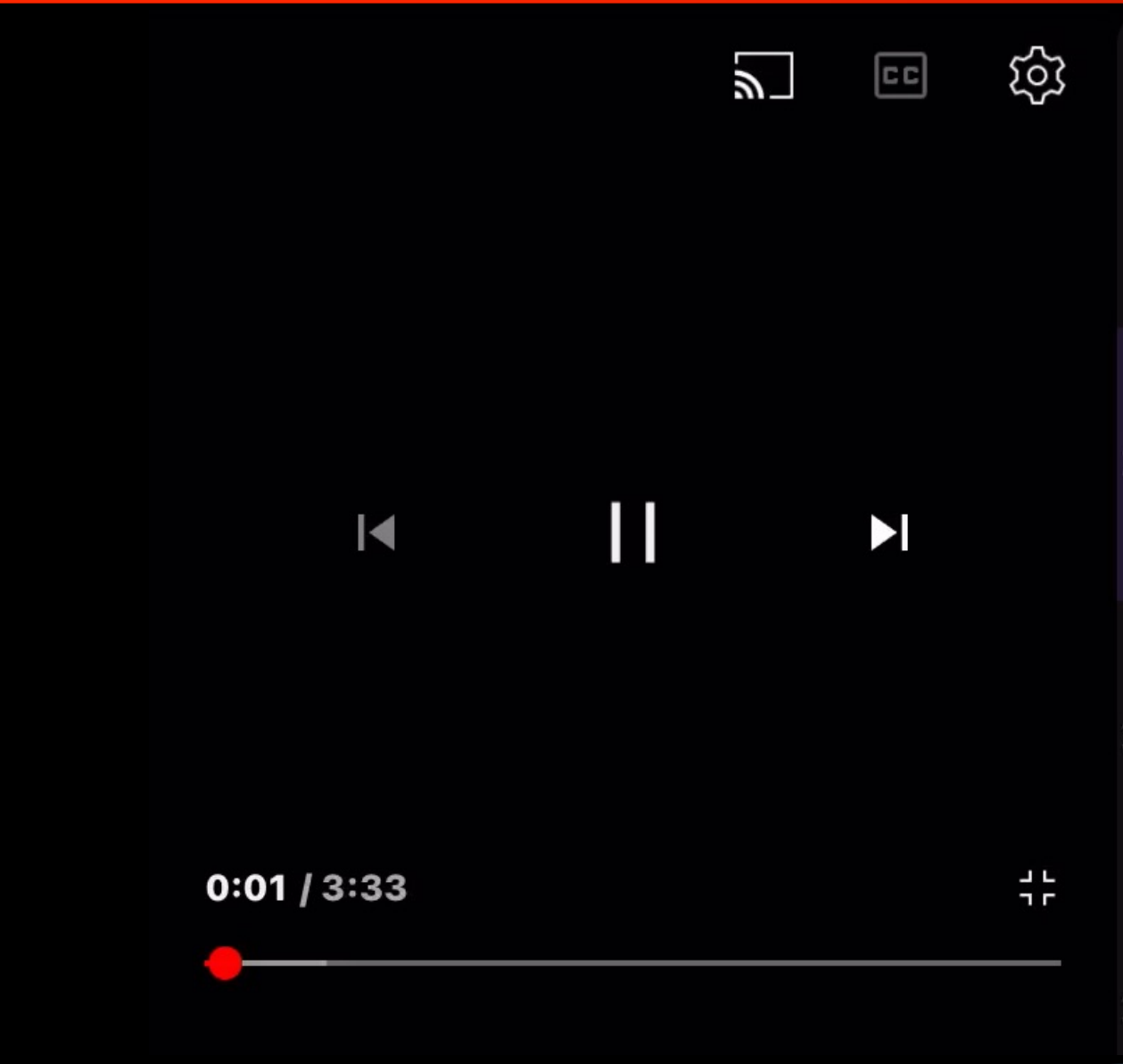


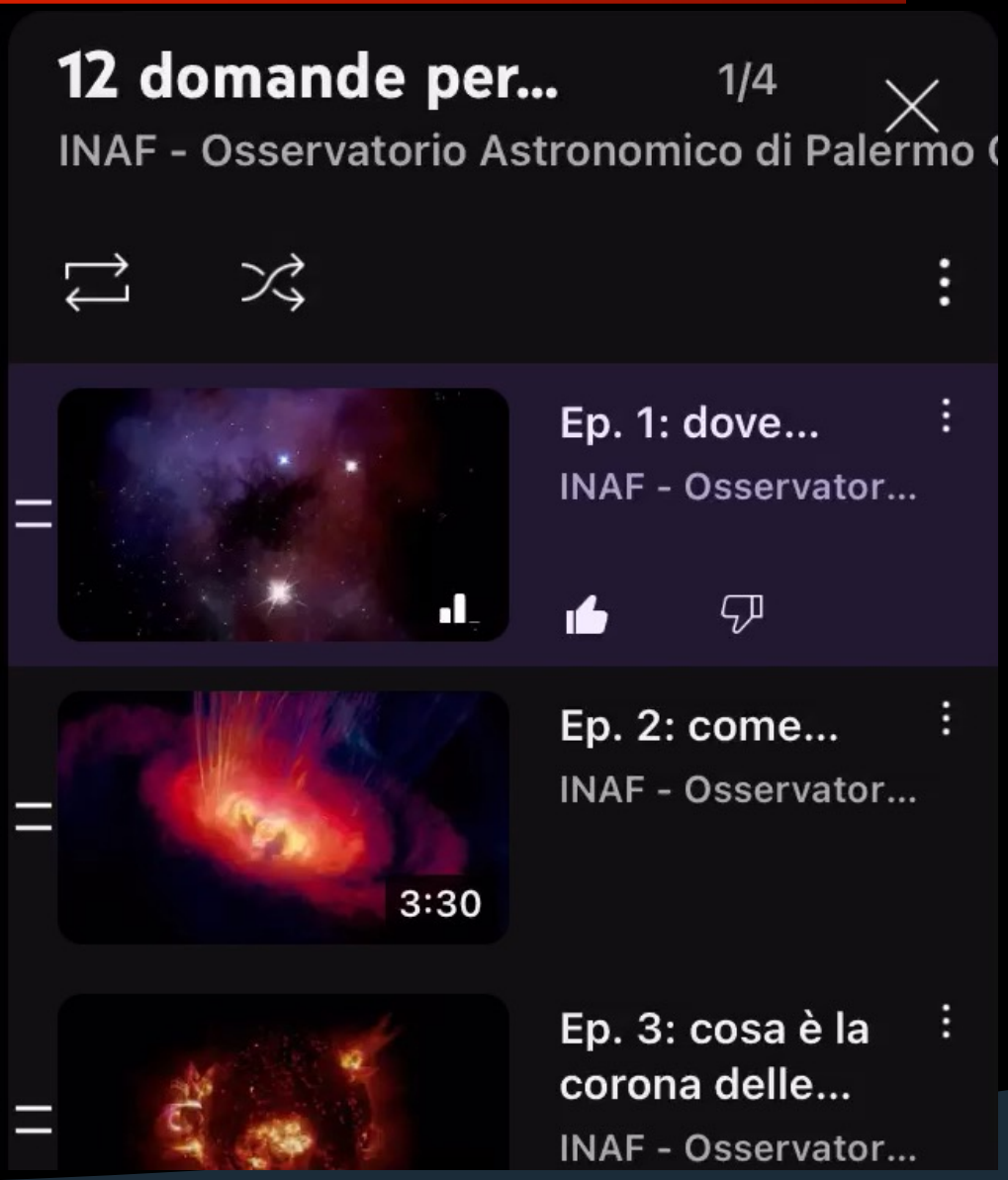
Ejecta structure of a Supernova Rem... 139 0 13

Public Outreach: Model Galleries

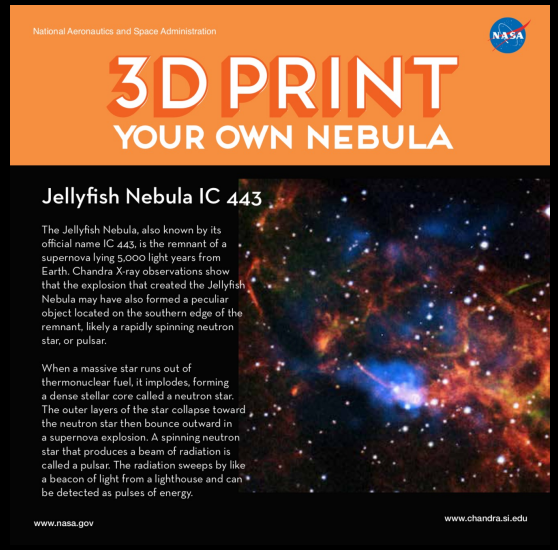


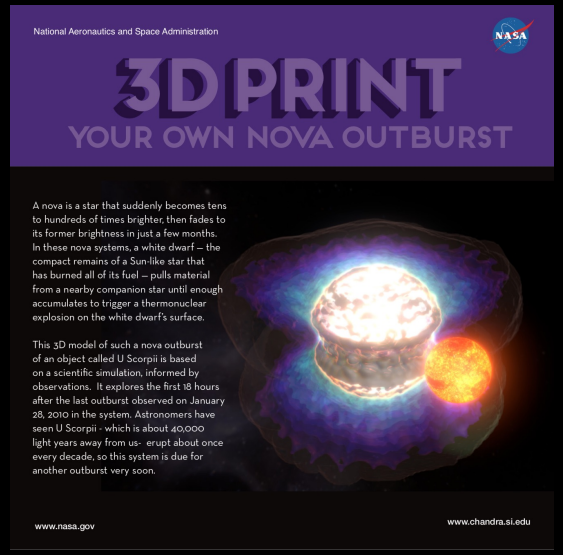
Public Outreach: Videos

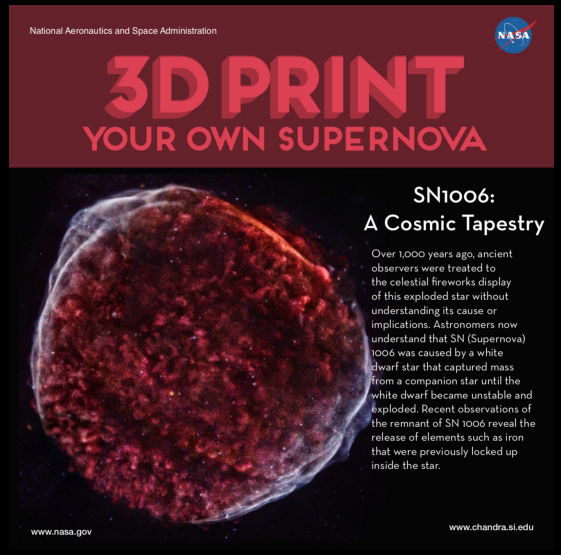


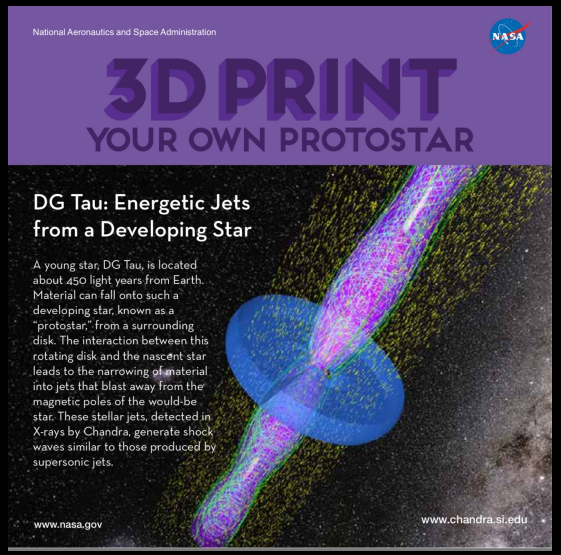


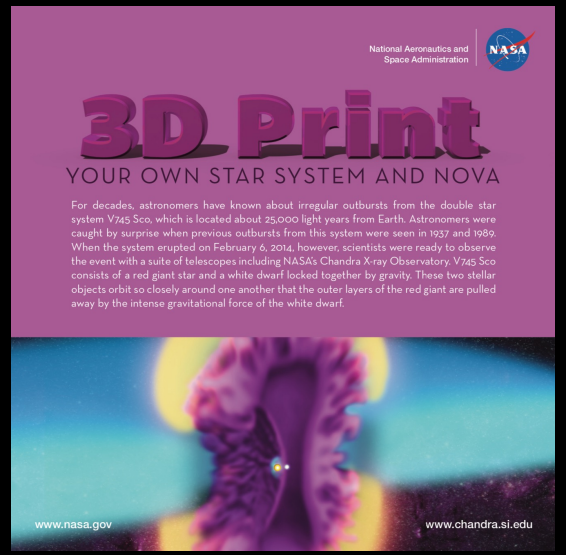
Public Outreach: 3D Prints

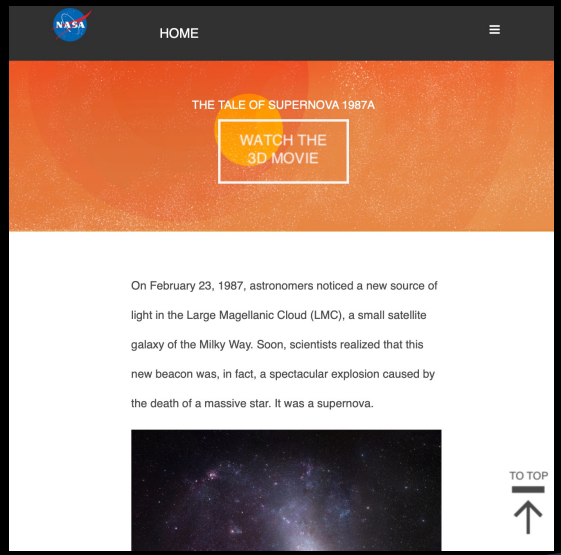






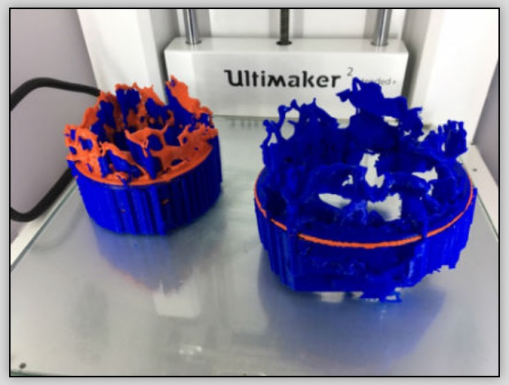






Public Outreach: 3D Prints

SN1987A



Description

Author/Origin: Salvatore Orlando (INAF-Osservatorio Astronomico di Palermo) & NASA/CXC/SAO/A.Jubett et al.

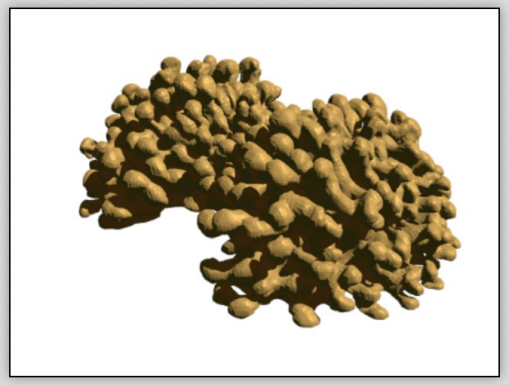
Relevant Mission: Chandra X-ray Observatory

Date Added: April 3, 2017

Keywords: Chandra, Supernova

GitHub Repository: SN1987A

V745 Sco



Description

Author/Origin: Salvatore Orlando (INAF-Osservatorio Astronomico di Palermo) & NASA/CXC/SAO/A.Jubett et al.

Relevant Mission: Chandra X-ray Observatory

Date Added: October 10, 2017

Keywords: Chandra, Supernova

GitHub Repository: SN87a

U Scorpii



Description

Author/Origin: INAF-Osservatorio Astronomico di Palermo/ Salvatore Orlando

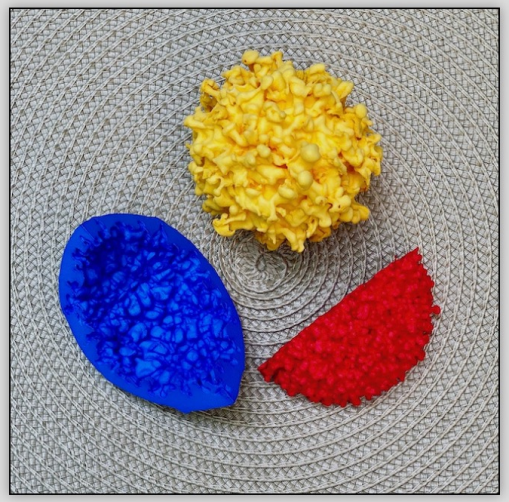
Relevant Mission: Harvard-Smithsonian Center for Astrophisics

Date Added: July 27, 2021

Keywords: Supernova

GitHub Repository: U Scorpii

SN 1006



Description

Author/Origin: INAF-Osservatorio Astronomico di Palermo/ Salvatore Orlando

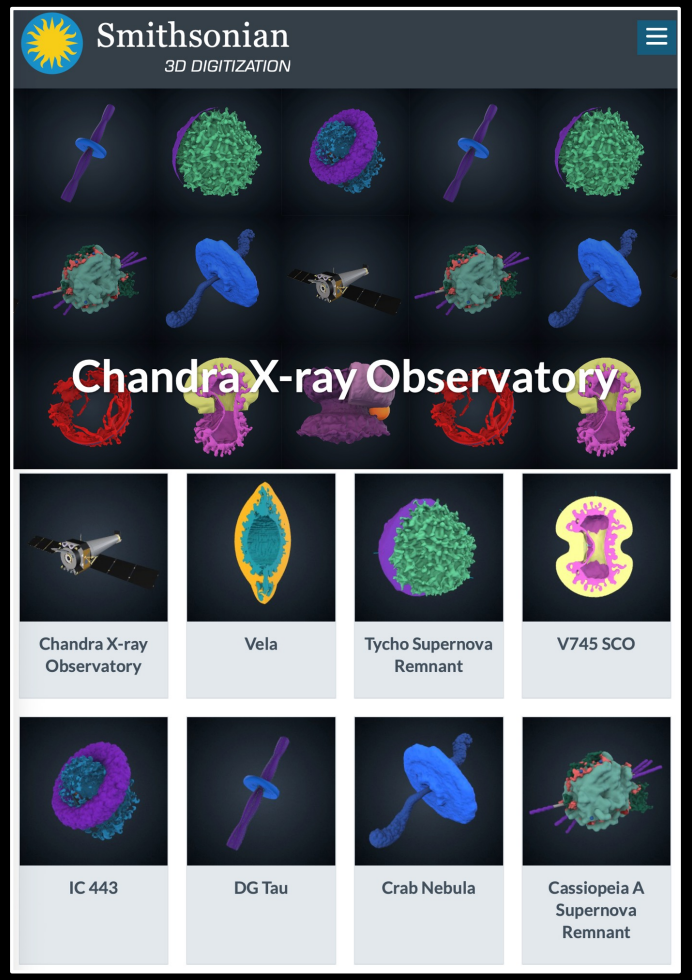
Relevant Mission: Harvard-Smithsonian Center for Astrophisics

Date Added: July 22, 2021

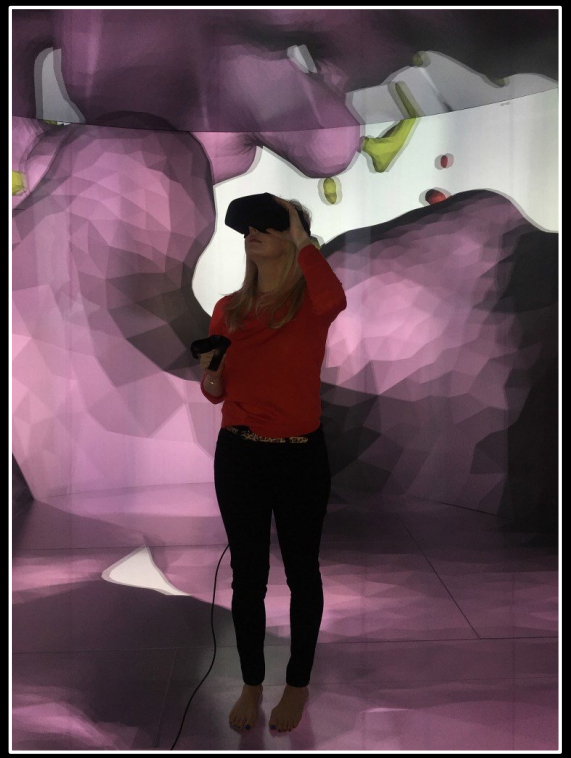
GitHub Repository: SN 1006

Public Outreach: International Institutions

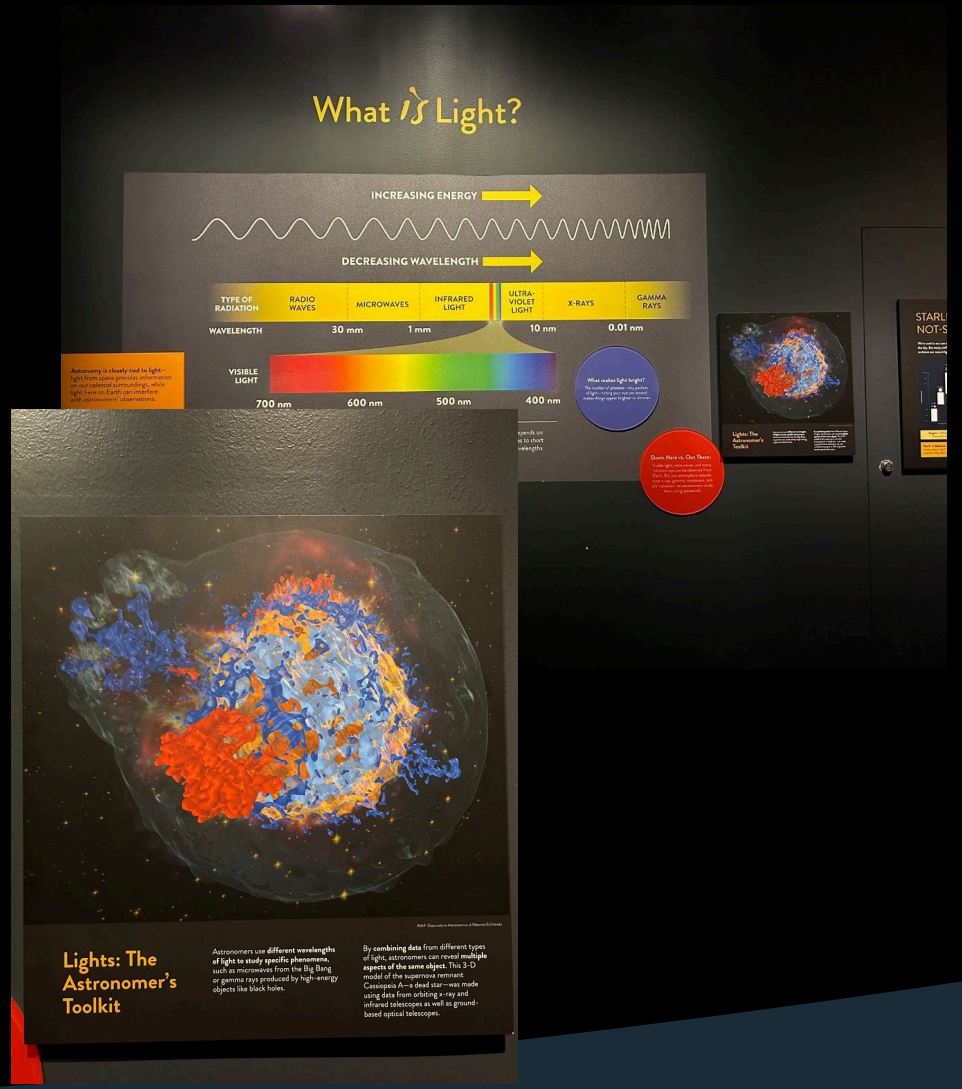
Smithsonian Astrophysical Observatory



NASA



Natural history museum of Washington



Public Outreach: VR applications

PHAROS
THE MULTI-MESSENGER PHYSICS AND ASTROPHYSICS OF NEUTRON STARS

HOME

HOME > STAR BLAST: A VR TOUR OF THE OUTCOME OF STELLAR EXPLOSIONS

Star Blast: a VR tour of the outcome of stellar explosions





Public Outreach: Support to Documentaries

(Orlando et al. 2021, 2022)



Public Outreach: Support to Documentaries



Jeroen Lapré is an Industrial Light & Magic veteran who worked on a range of films, including *The Perfect Storm*, the original *Iron Man*, and *Star Wars I* and *II*.

Jeroen led the research into, and adoption of, Houdini as a core tool for the Visualization Studio. On *Expedition Reef*, Jeroen worked on the powers-of-ten dive into a coral—showing the community of polyps at the microscopic level, the coral bleaching, and coral spawning sequences. He also used Houdini to create the aquarium rippling water surface, boat wake, and falling tetrapod simulations. Jeroen took the lead on the visual development of *Living Worlds*, and he developed an extended sequence in the show that takes audiences underneath the icy crust of Saturn's moon Enceladus to view hypothetical thermal vents and to visit a proposed mission to explore the moon.



Iron Man
★ 7,9 — 2008
digital artist: ILM



Pirati dei Caraibi - Ai confini del mondo
★ 7,2 — 2007
digital artist: ILM



Eragon
★ 5,1 — 2006
digital artist: ILM



Pirati dei Caraibi - La maledizione del forziere fantasma
★ 7,4 — 2006
digital artist: ILM



Poseidon
★ 5,7 — 2006
digital artist: ILM



Harry Potter e il calice di fuoco
★ 7,7 — 2005
digital artist: ILM (as Jeroen Lapré)



Star Wars: Episodio III - La vendetta dei Sith
★ 7,7 — 2005
digital effects artist



Star Wars: Episodio II - L'attacco dei cloni
★ 6,6 — 2002
digital effects artist: ILM



The Time Machine
★ 6,0 — 2002
digital artist: ILM



A.I. - Intelligenza artificiale
★ 7,2 — 2001
digital artist: ILM



Star Wars: Episodio I - La minaccia fantasma
★ 6,5 — 1999
digital effects artist: ILM



Starship Troopers - Fanteria dello spazio
★ 7,3 — 1997
digital effects artist: ILM



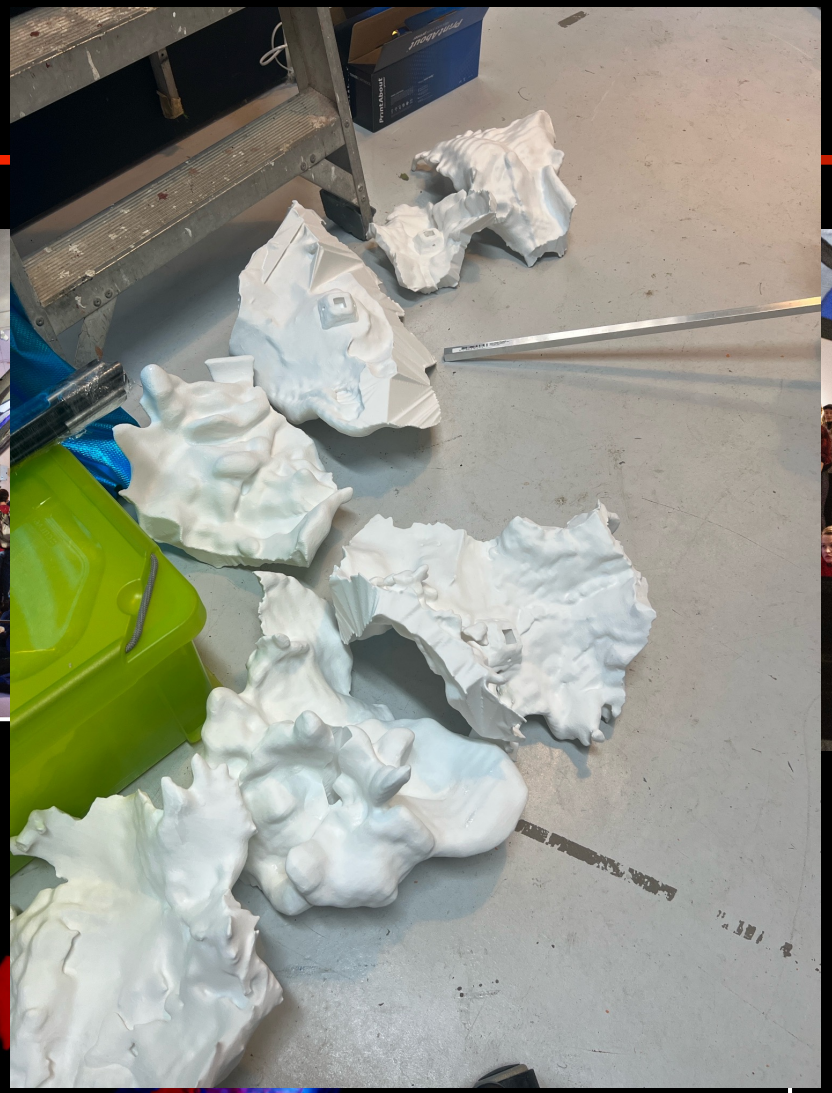
E.T. - L'extra-terrestre
★ 7,9 — 1982
development CG artist: ILM (2002 special edition)

Science & Art

Anna Hoetjes









Further reading

Visualization is not about making 'pretty' pictures. It is about maximizing the bandwidth between the data and the researcher's brain while minimizing the noise introduced by the software

Recommended Reading

- *Tufte, E. R. (2001). The Visual Display of Quantitative Information*
- *Cole Nussbaumer Knaflic (2015). Storytelling With Data: A Data Visualization Guide for Business Professionals*

