

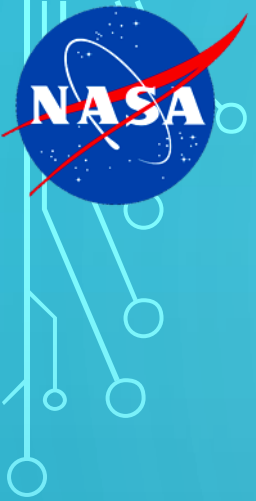
APPLIED XR FOR NASA SCIENCE AND ENGINEERING

THOMAS G. GRUBB

GODDARD SPACE FLIGHT CENTER AR/VR PRODUCT
DEVELOPMENT LEAD

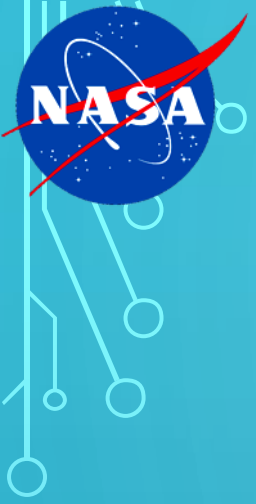
IEEE SPACE COMPUTING CONFERENCE, JULY 18





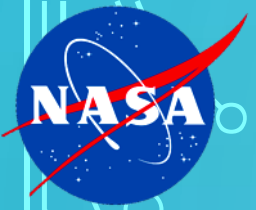
AGENDA

- Background
- Astrophysics Use Case: Moving Star Groups
- Engineering Use Case: Hardware Integration & Test
- Earth Science Use Case: Climate Data
- Conclusion

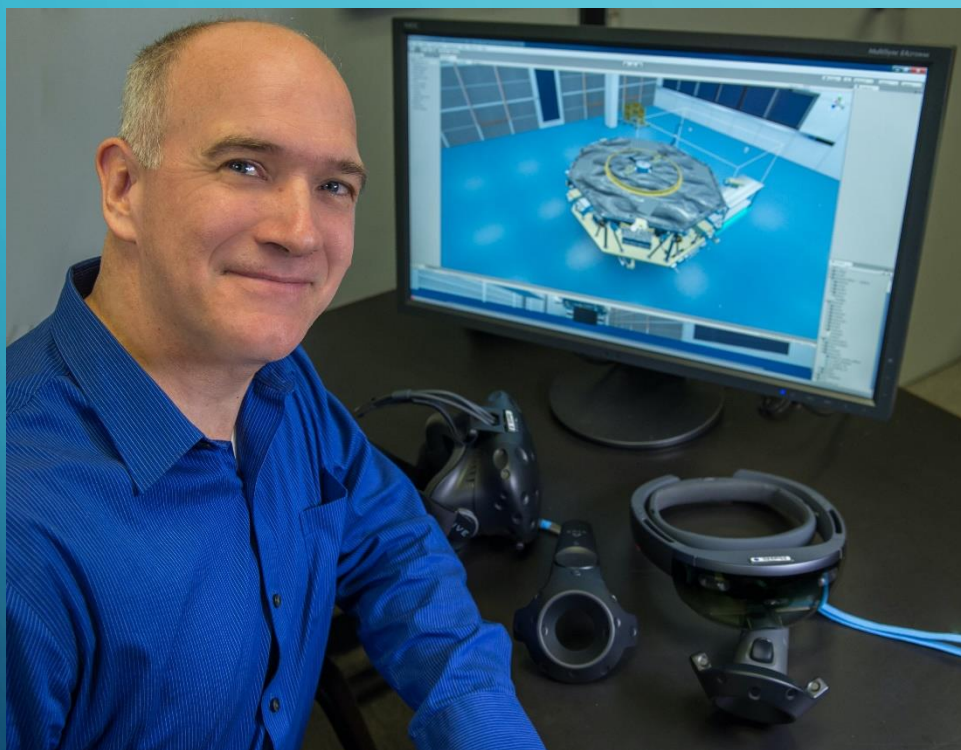


BACKGROUND

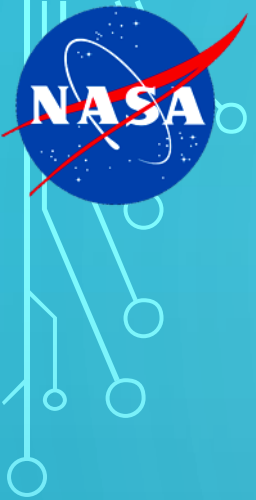




ABOUT ME



- Thomas G. Grubb
- 36 year NASA Employee
- GMSEC Developer 2006-2008, Acting Technical Lead in 2008
- Earth Science Technology Office (ESTO) Advanced Information Systems Technology (AIST) Goddard Associate 2008-2015
- AR/VR Development Lead at GSFC since 2016 (and PDL since 2018)



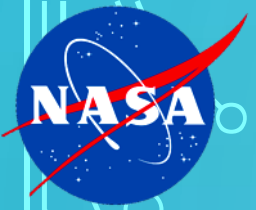
GSFC AR/VR RESEARCH & DEVELOPMENT LAB

THOMAS G. GRUBB, AR/VR PRODUCT DEVELOPMENT LEAD



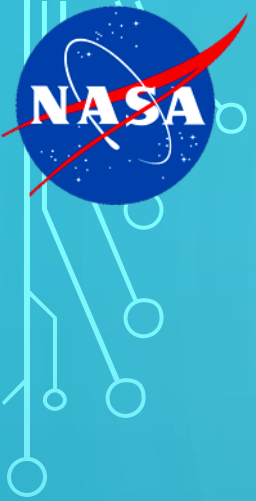
The Mission Beyond Reality

- Started in 2016 using combination of Goddard Research, HQ Research, and organizational funds
- Collaboration
 - GSFC Center Organizations (SED, ExIS, GMSEC)
 - Missions (OSAM-1, CCRS, Roman Space Telescope)
 - Scientists & Engineers
 - Universities (UMBC, UMD, UNT, JHU/APL)
 - Other NASA Centers



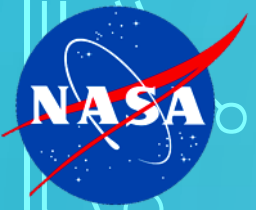
ADVANTAGES OF XR

- XR provides several advantages
 - Improved Visualizations
 - Quicker and more intuitive understanding of complex, spatially related, problems and situations
 - Improved retention and recall
 - Improved Interactions
 - Improved Collaboration
 - “Killer App” of XR
 - Reduced time and **money**
- How can we get maximum Return on Investment?
 - Reduce Costs
 - Reduce Time
 - Reduce Risk
 - Increase Understanding

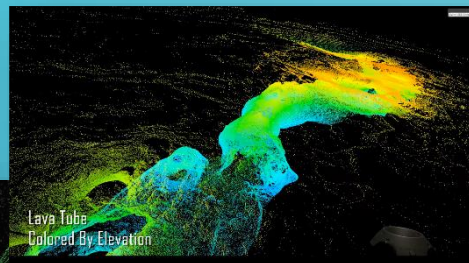


MANDATE

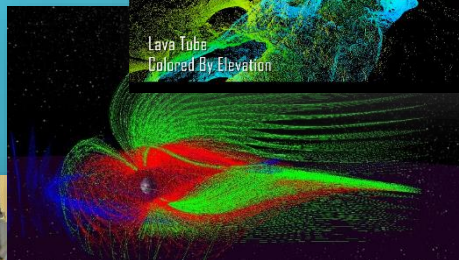
- Survey scientists and engineers at Goddard Space Flight Center to figure out ways that XR can benefit them
 - NASA is different than industry (lots of one-offs)
 - GSFC is different than other centers (scientist oriented, not manned spaceflight oriented)
 - Risk Adverse Culture
- Applied XR
 - Outreach is a natural benefit



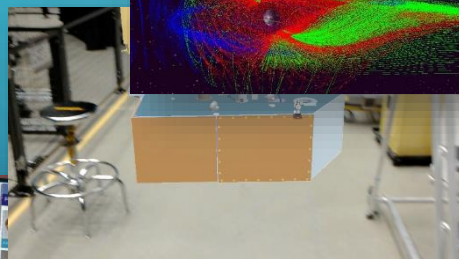
FROM 5 CONCEPTS TO ONE APPLICATION



Virtual Landscapes



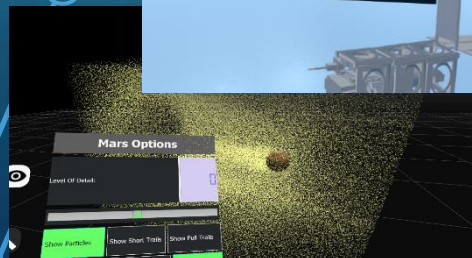
Space Weather VR



Robot Control AR



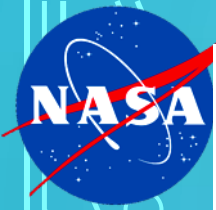
Assembly VR



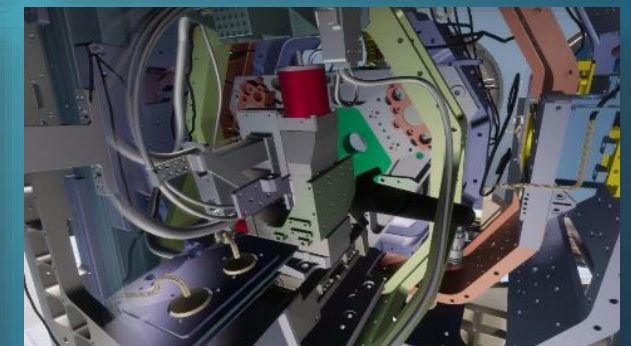
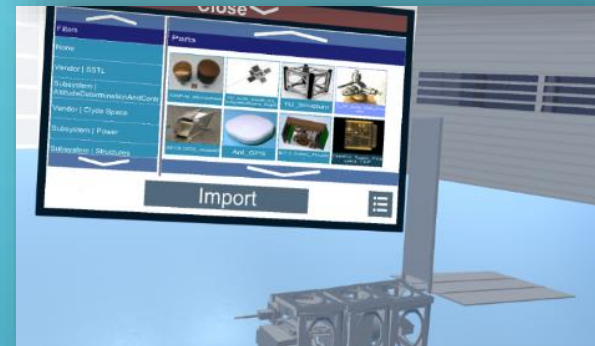
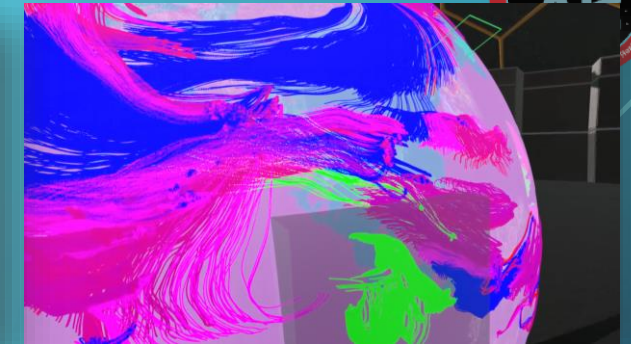
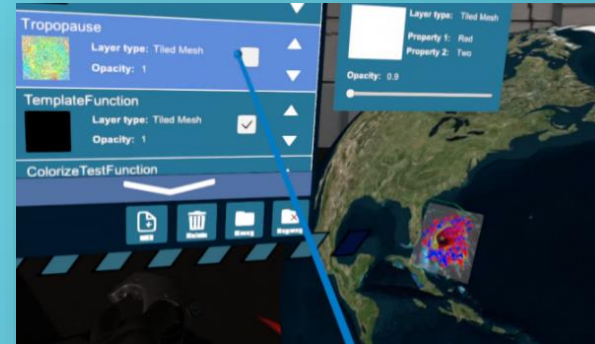
PointClouds VR



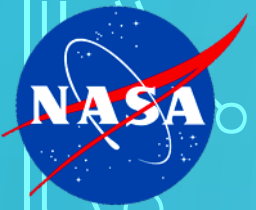
MIXED REALITY EXPLORATION TOOLKIT



- Cross-domain, mission lifecycle support tool in Science and Engineering for rapidly building XR environments for NASA domain problems, e.g., pulling in CAD models of thermal vac chamber and Roman Space Telescope to do fit checks
 - NASA Open Source
 - Integration with NASA data
 - Secure Collaboration
- VR/Desktop/AR (Hololens 2)
- Developed in Unity/C#



MRET is NASA Open Source and available at
<https://github.com/nasa/Mixed-Reality-Exploration-Toolkit>



MRET HIGHLIGHTS



COMBINE 3D MODELS,
POINT CLOUDS, AND
TERRAINS



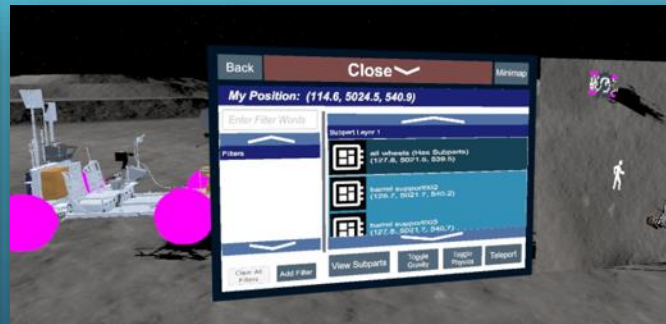
FOR VR AND PC DESKTOP
(LIMITED AR)



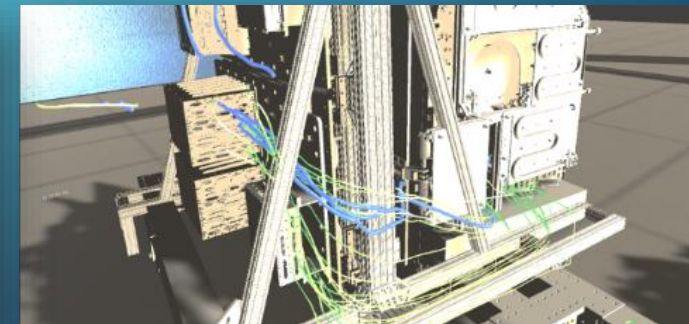
COLLABORATE ON SECURE
NETWORKS AND OVER VPN



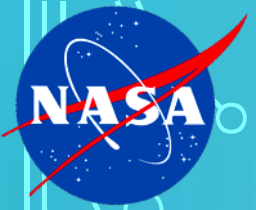
DRIVE MODELS FROM REAL-
TIME TELEMETRY. INTEGRATES
WITH GMSEC, ROS, NASA
IOT, MATLAB, SPICE, AND 42



PROJECT BASED TOOL FOR
RAPIDLY BUILDING XR
ENVIRONMENTS FOR NASA
DOMAIN PROBLEMS



COMMON TOOLSET, E.G.,
MOVE, MEASURE, DRAW,
VOICE, NOTES, ANIMATION...



INTEGRATION WITH NASA SOFTWARE AND DATA SOURCES IS CRUCIAL



GMSEC

Integration with the General Mission Services Evolution Center (GMSEC) to get spacecraft/instrument telemetry and secure XR collaboration



ROS

Integration with the Robot Operating System to get robotic telemetry



NASA IOT PLATFORM

Integration with NASA Internet of Things (IoT) Platform to get industry standard telemetry and control/interact with systems

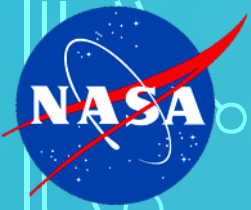


RAPID MODEL IMPORT TOOL

Integration with NASA Open Source tool to convert on-demand CAD models to GLTF (XR Ready file format)

*Other Toolkits

- MATLAB
- SPICE
- Virtual Data Explorer (VDE)

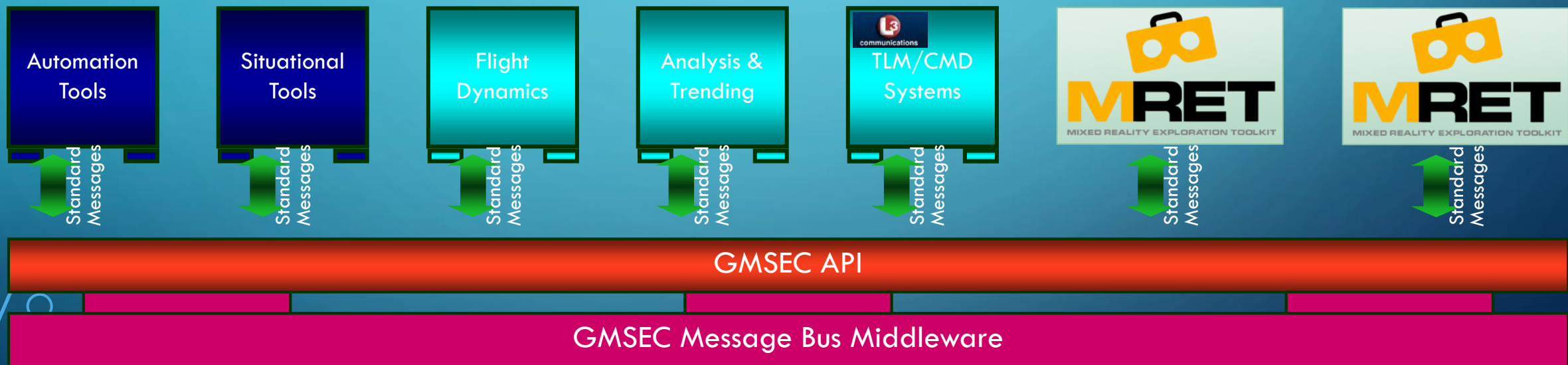


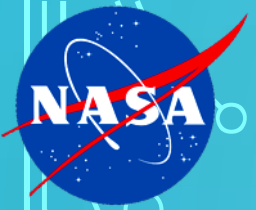
GMSEC AND MRET

MRET is GMSEC-Compliant

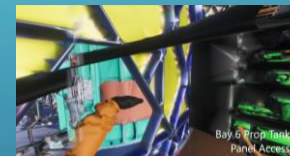
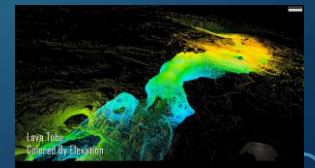
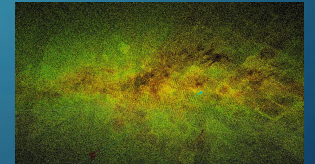
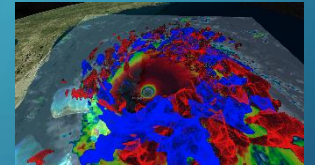
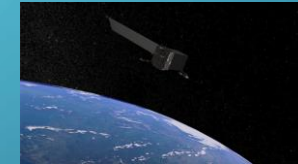
- Other GMSEC Components can drive XR, e.g., provide situational awareness by subscribing to real-time telemetry messages to drive 3D models of spacecraft
- MRET can use GMSEC for collaboration, allowing collaborative sessions on secure networks, even over VPN

(Situational Awareness, Automation)





XR THROUGHOUT THE NASA MISSION LIFECYCLE



Pre-Phase A
Conceptual Studies

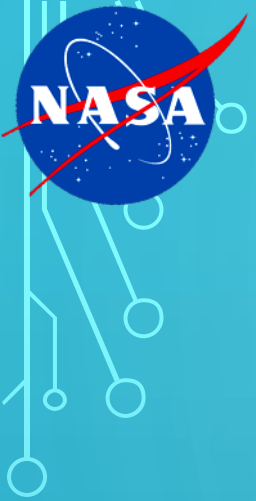
Phase A
Preliminary
Analysis

Phase B
Definition

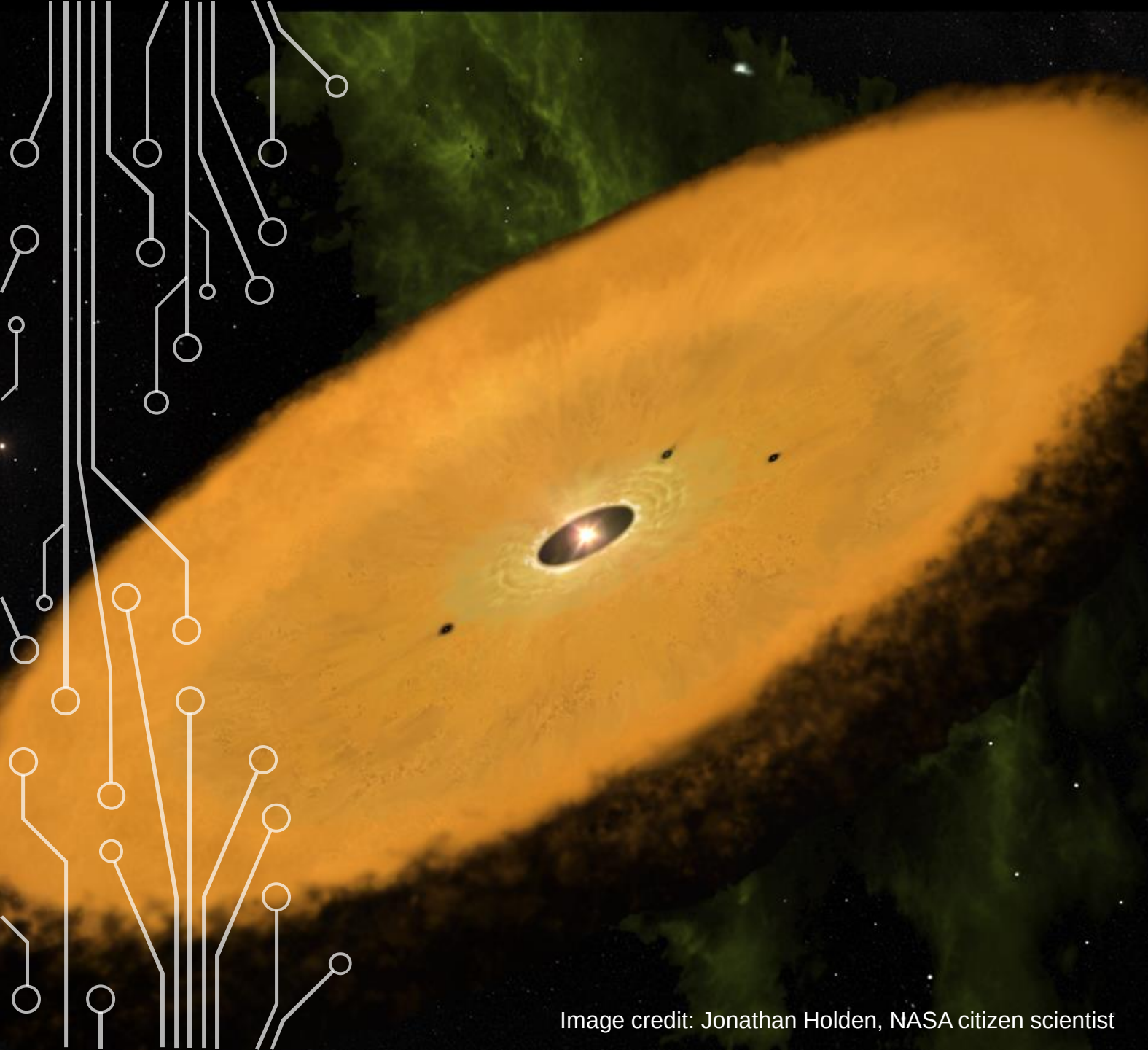
Phase C/D
Design &
Development

Operations
Phase
Mission Ops &
Data Analysis

Science



ASTROPHYSICS USE CASE: MOVING STAR GROUPS

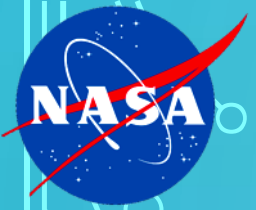


SCIENCE BACKGROUND

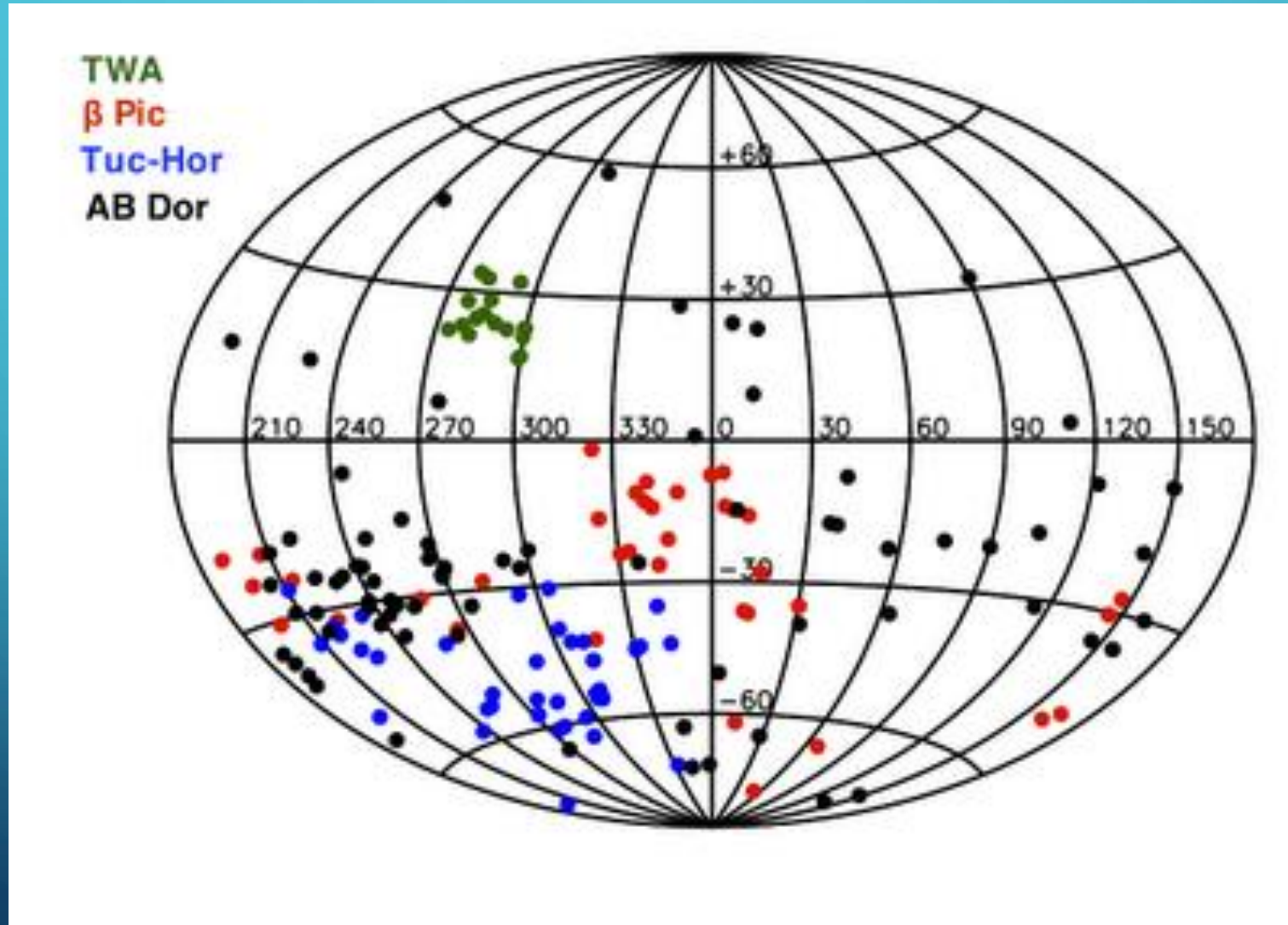
- Planets form in disks of dust, rocks, and sometimes gas around nearby stars
- Scientists need a sample of nearby disks at different ages to study how they evolve
- Volunteers working on the Disk Detective Citizen Science Project found more than 40,000 of them!

But how **old** are these disks?

Image credit: Jonathan Holden, NASA citizen scientist



GROUPS OF STARS CALLED “MOVING GROUPS” OR “YOUNG STELLAR ASSOCIATIONS” THAT ORBIT AROUND THE GALAXY TOGETHER CAN TELL US.

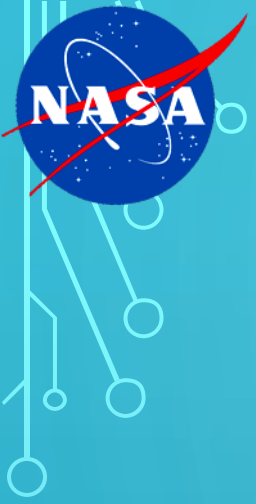




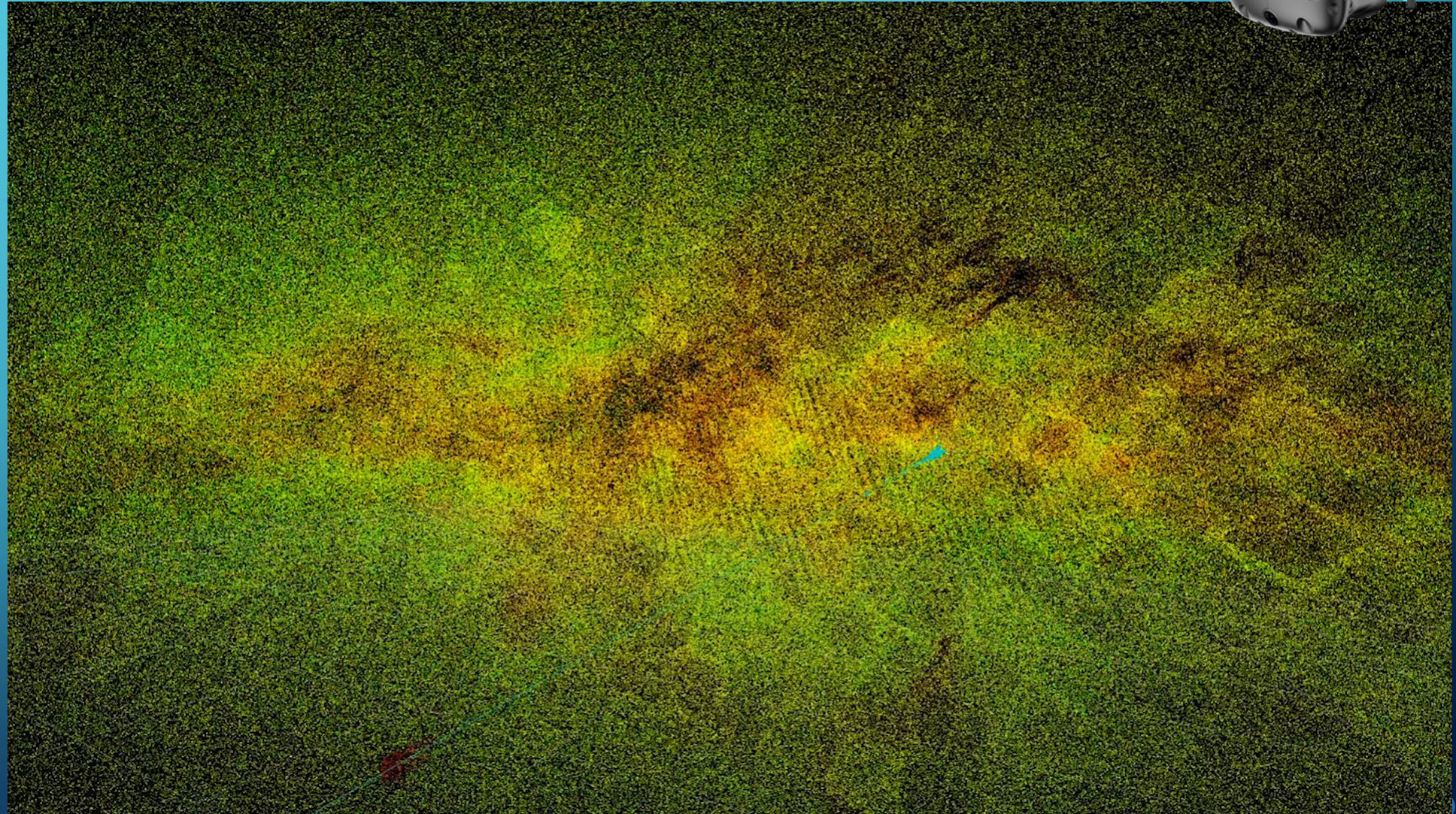
FINDING MOVING STAR GROUPS USING VR

- Import European Space Agency GAIA Data
- Animate Stars over Millions of Years
- Leverage ability to see complex spatial relationships in VR
- Pre-MRET Application - most functionality replicated in MRET

PointClouds VR is NASA Open Source and available at
<https://github.com/nasa/PointCloudsVR>

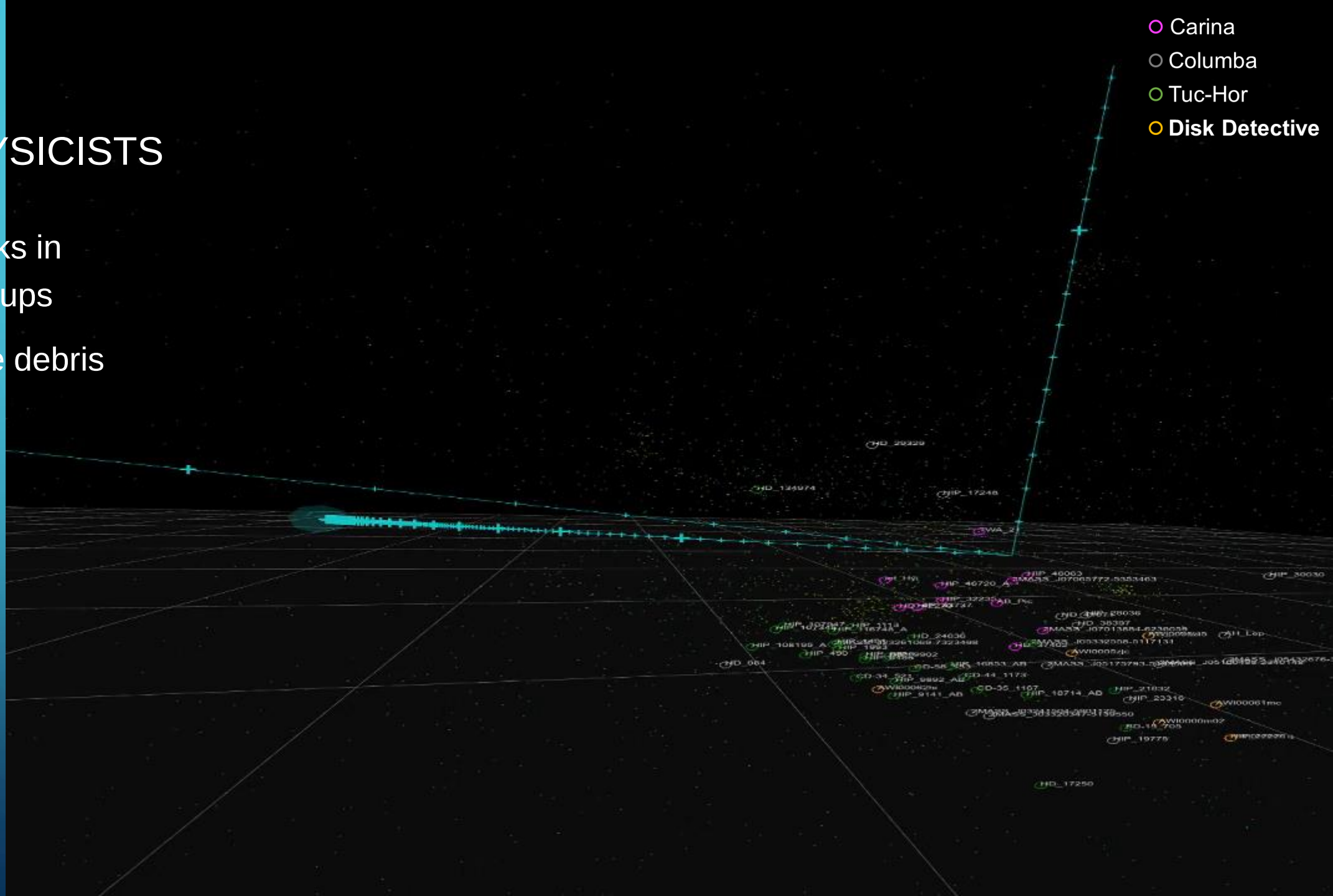


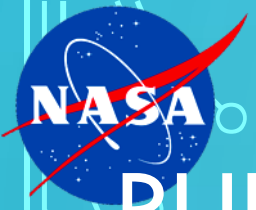
POINT CLOUDS VR AND GAIA CITIZEN SCIENCE





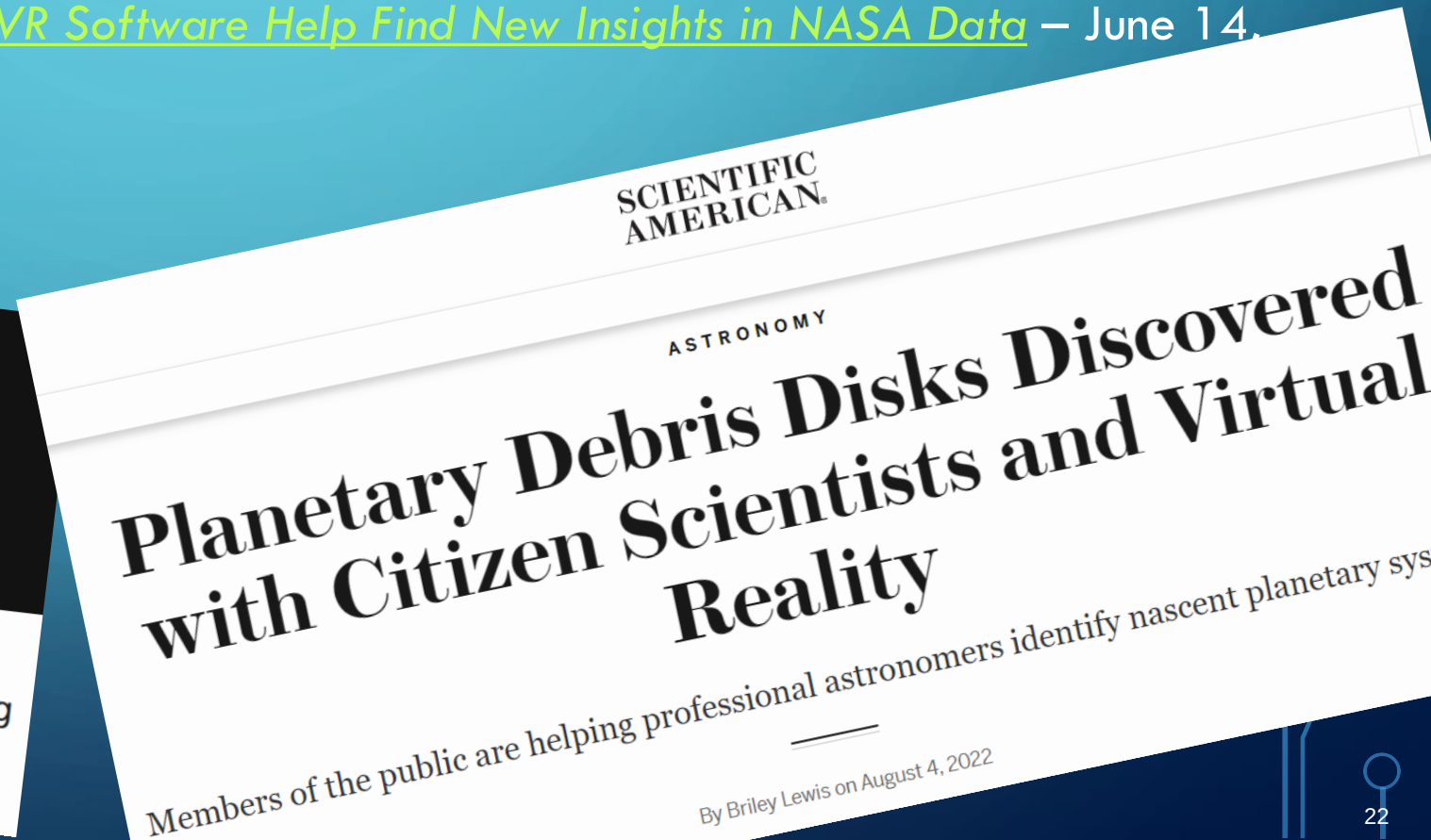
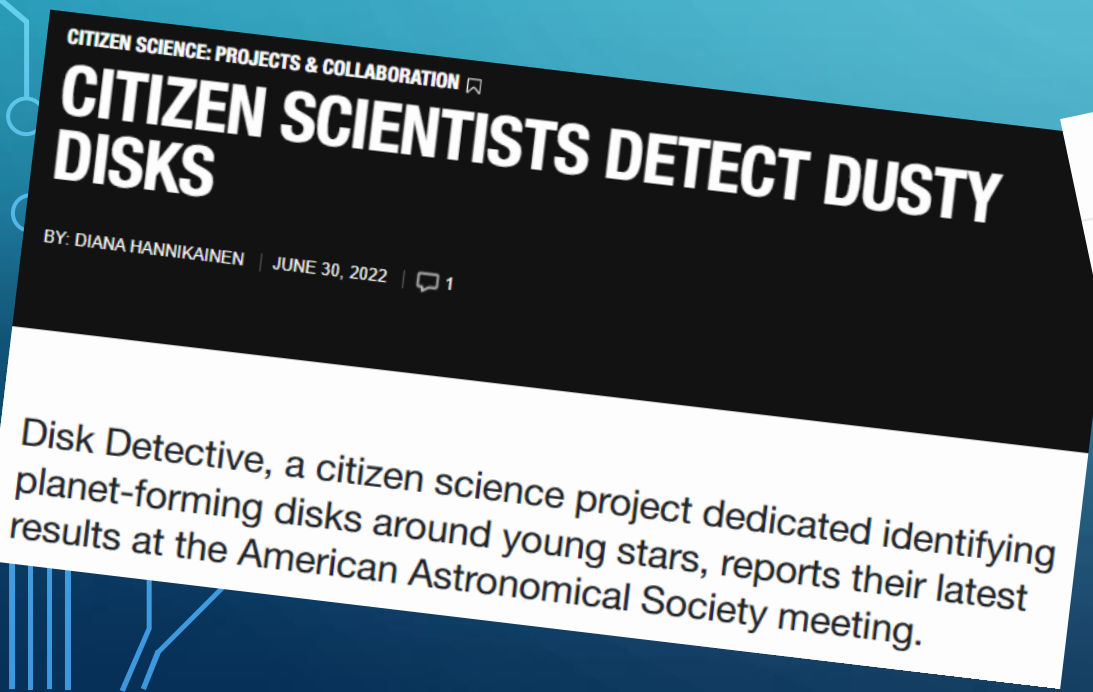
- 10 new disks in moving groups
- An extreme debris disk

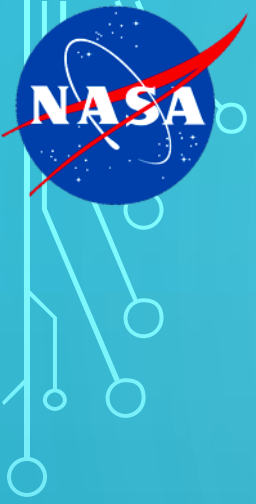




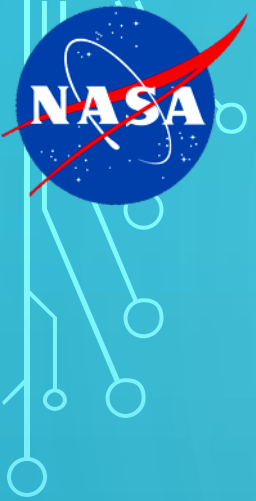
PUBLISHED RESULTS

- NASA Astrophysicist Dr. Marc Kuchner and Researcher Susan Higashio have been published
- *Disks in Nearby Young Stellar Associations Found Via Virtual Reality* has been published in The Astrophysical Journal <https://iopscience.iop.org/article/10.3847/1538-4357/ac649f>
- NASA feature [Citizen Scientists and VR Software Help Find New Insights in NASA Data](#) — June 14, 2022



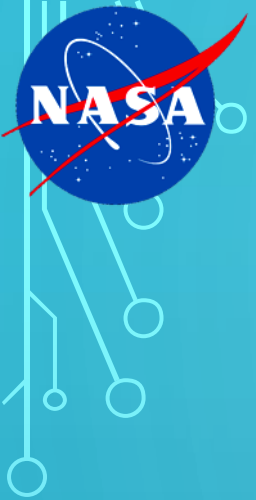


ENGINEERING USE CASE: HARDWARE INTEGRATION & TEST



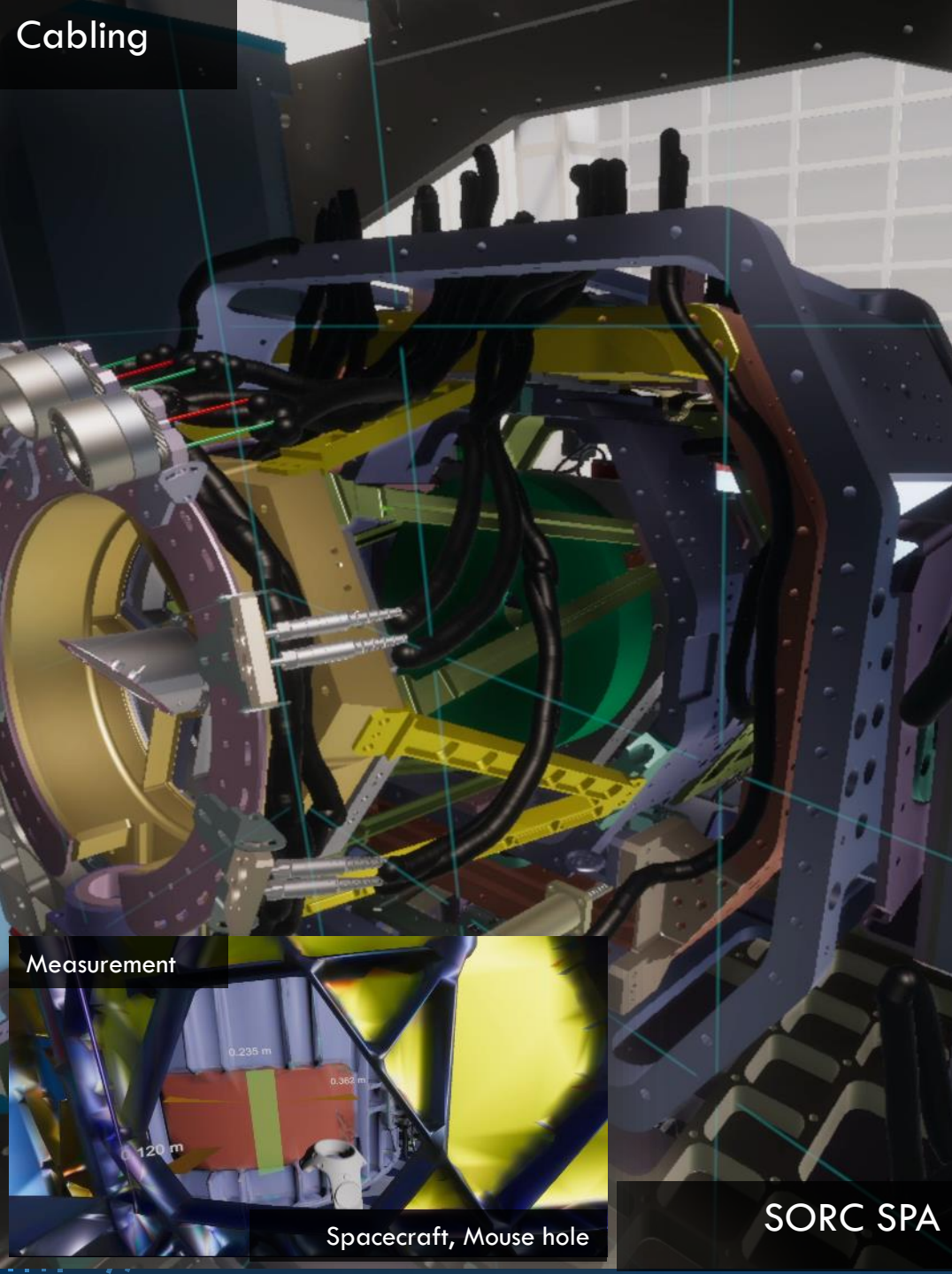
HARDWARE I&T – MANY APPLICATIONS FOR XR

- “Low hanging fruit” for XR at NASA
- Except for large, expensive missions, expending lots of cost and effort for a one-off solution is not an option
- Need to target specialized, customized domains too small for industry solutions
- What can we do cheaply?
- What saves time?
- What reduces risk?
- What increases understanding of issues?



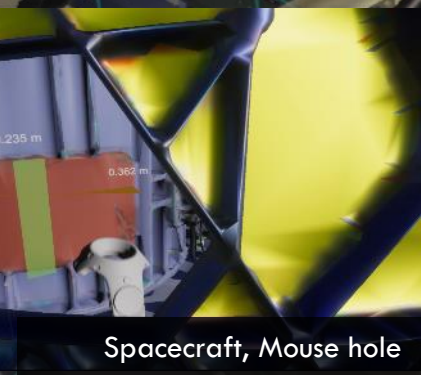
HARDWARE I&T – MANY APPLICATIONS FOR XR

- Fit Checks
- Reach and Access
- Cable Routing
- I&T Planning
- Lab Configuration
- Work Order Authorization Integration
- Remote Quality Assurance



Cabling

Measurement



Spacecraft, Mouse hole

SORC SPA

HARDWARE INTEGRATION & TEST



Reach & Access



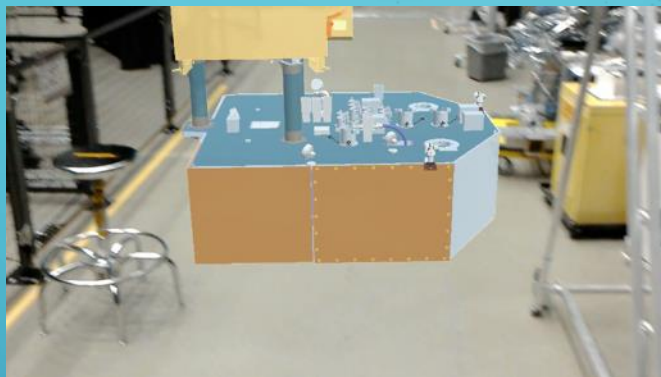
HARDWARE INTEGRATION & TEST

Physical World



- I&T
- Live Telemetry Display
- Documentation
- QA Oversight

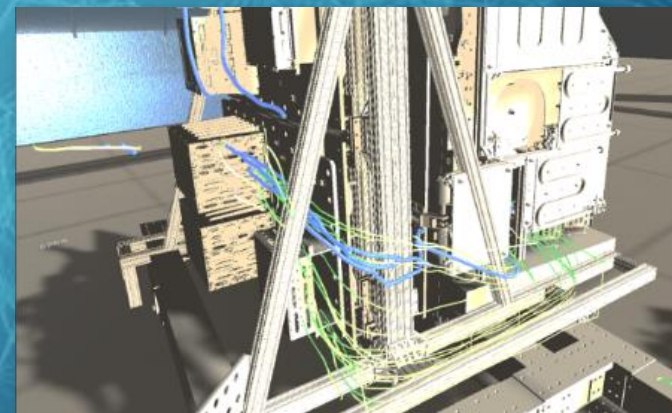
Augmented Reality



- Planning
- Fit Checks
- Reach & Access
- Harness Routing
- Training
- Walk-throughs

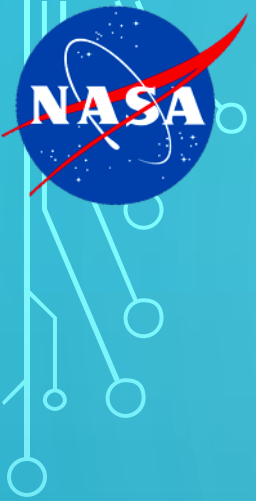


Virtual Reality

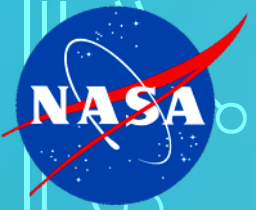


- Planning
- Fit Checks
- Reach & Access
- Harness Routing
- Training
- Walk-throughs
- Pre-Viz

FY25



EARTH SCIENCE USE CASE: CLIMATE DATA



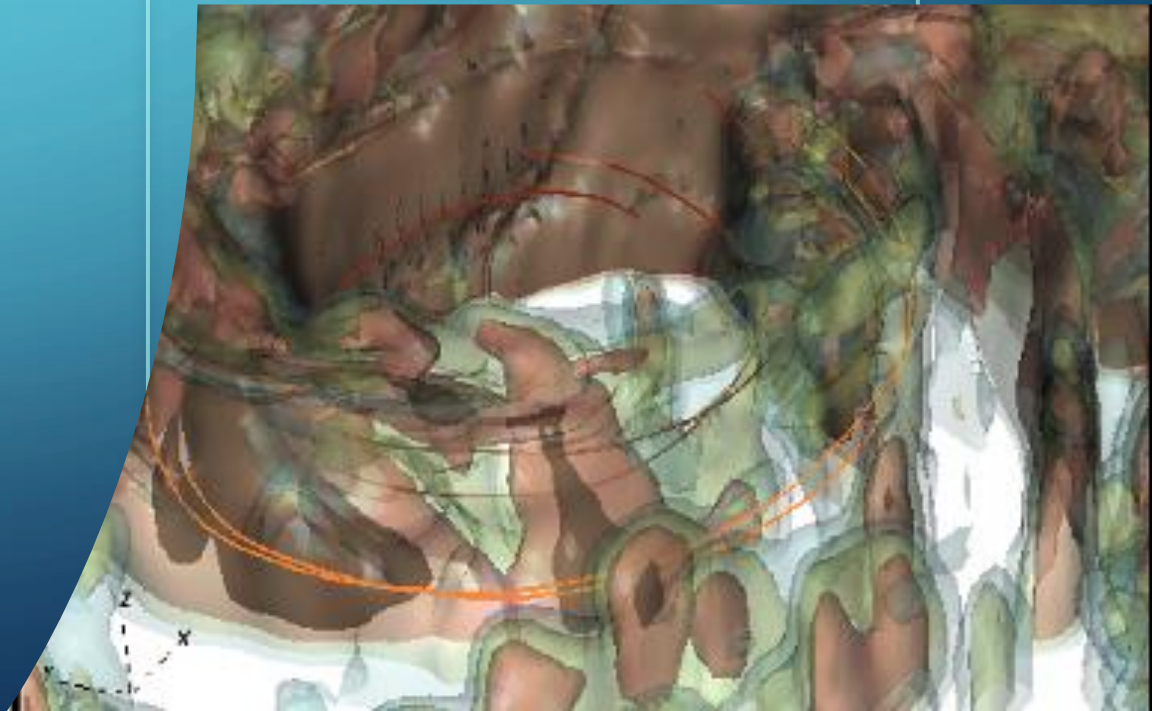
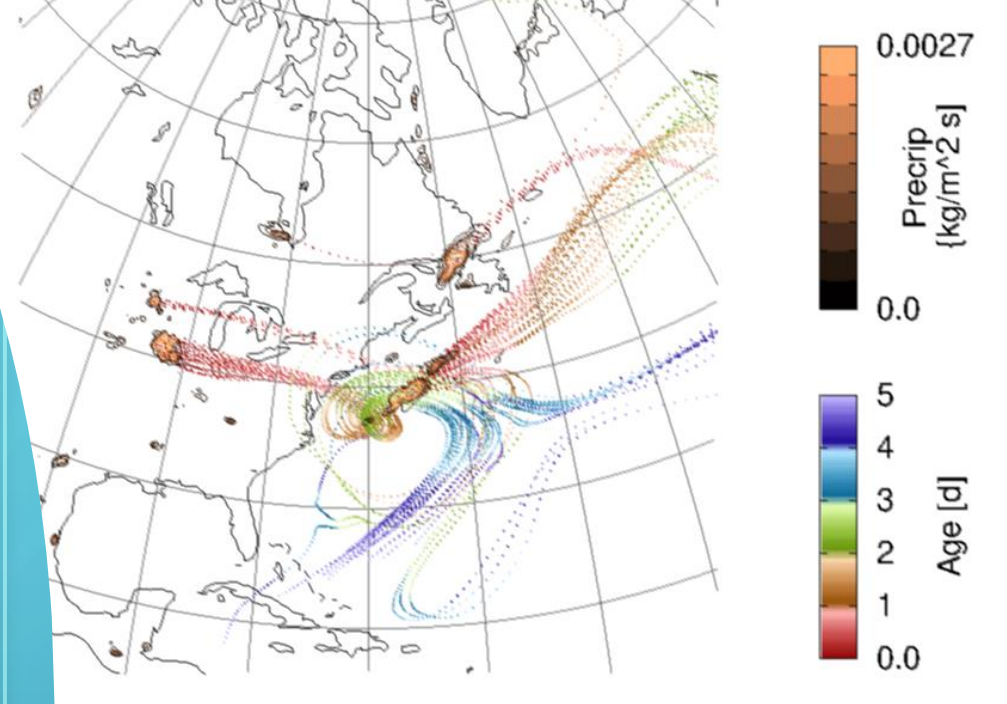
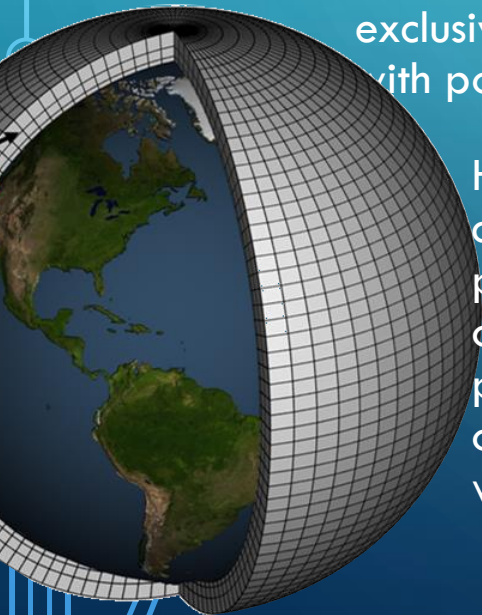
NUMERICAL CLIMATE MODELS

Traditionally, earth scientists view and analyze the result of calculated or measured observables with static 1-D, 2-D or 3-D plots.

Difficult to identify, track and understand the evolution of key features due to poor viewing angles and the nature of flat computer screens.

Numerical models, such as the NASA **Goddard Earth Observing System (GEOS)** climate model, are almost exclusively formulated and analyzed on Eulerian grids with points fixed in space and time.

However, atmospheric phenomena such as convective clouds, hurricanes and wildfire smoke plumes move with the 3-D flow field, and it is often difficult and unnatural to understand these phenomena in an Eulerian reference frame as opposed to the Lagrangian reference frame in which nature operates.



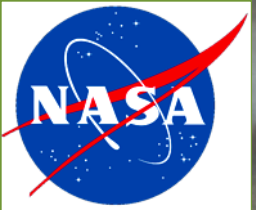
GEOS VISUALIZATION AND LAGRANGIAN DYNAMICS IMMERSIVE EXTENDED REALITY TOOL (VALIXR) FOR SCIENTIFIC DISCOVERY

Godard Earth Observing System (GEOS)

- Integrate trajectory model into GEOS numerical weather model to calculate Lagrangian trajectories of specific Earth Science phenomena
- Create an open-source point cloud component for visualizing and animating a set of point clouds netCDF files
- Enhance MRET with Lagrangian Dynamics (LD) tools for the initialization, finalization and visualization of trajectories with associated dynamic budget terms, and to output a parameter package for use in GEOS model runs
 - Working closely with two universities to infuse improved human factors paradigms into the visualizations and interactions in XR

ESTO AIST 2021 2 Year Project
ending this calendar year

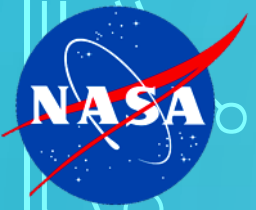




WHAT IS GEOS

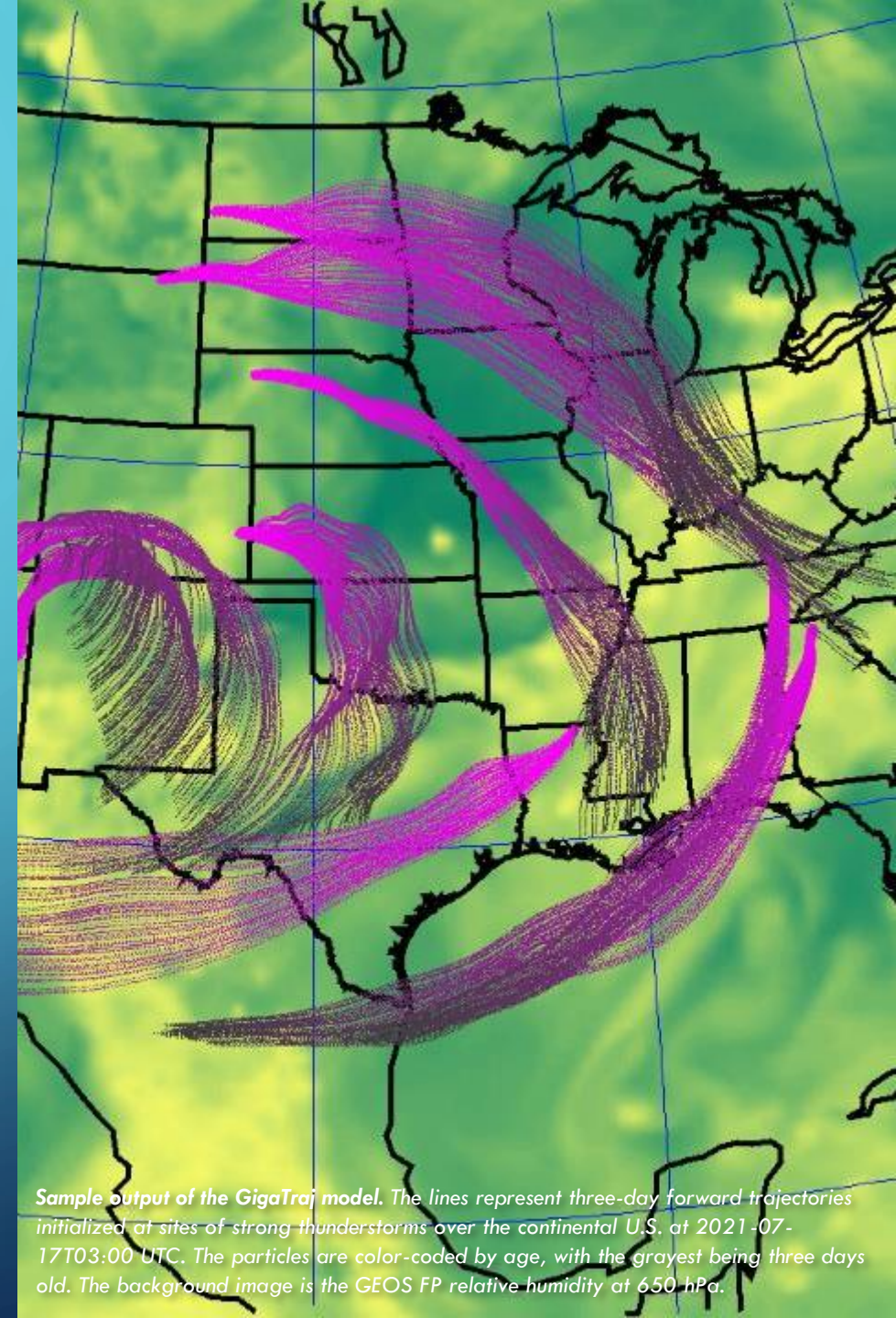


- GEOS is a highly modular Earth modeling system based upon the Earth System Modeling Framework (ESTO funded)
 - Data assimilation
 - Weather forecasting
 - Chemistry transport, etc.
- Additional modules that model physical processes can be readily incorporated with a thin component wrapper that conforms to GEOS conventions.

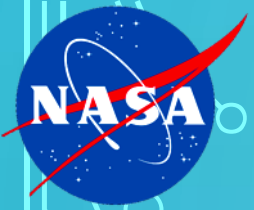


GIGATRAJ

- Lagrangian trajectory model previously developed at Goddard Space Flight Center for use in atmospheric research
- Traces particle motions as they are carried by the wind fields obtained from any of several meteorological sources (selectable at run-time) and in any of several coordinate systems, reflecting different physical approximations. For example, particles may be traced
 - Kinematically (i.e., using vertical wind fields)
 - Isentropically (along surfaces of potential temperature)
 - Diabatically (approximately along isentropic surfaces, while using diabatic heating fields to move the particles vertically)
- GigaTraj has been wrapped as an Earth System Modeling Framework (ESMF) component in GEOS

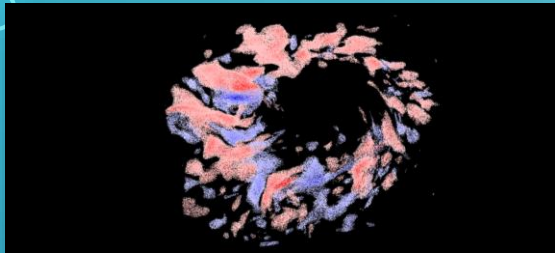


Sample output of the GigaTraj model. The lines represent three-day forward trajectories initialized at sites of strong thunderstorms over the continental U.S. at 2021-07-17T03:00 UTC. The particles are color-coded by age, with the grayest being three days old. The background image is the GEOS FP relative humidity at 650 hPa.



POINT CLOUDS DEVELOPMENT

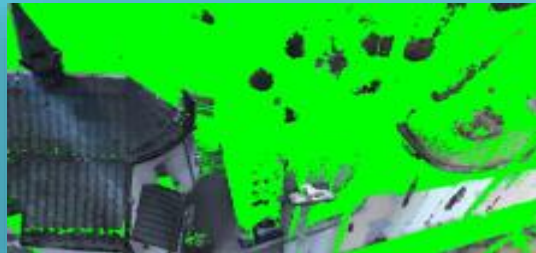
Point Clouds Implementation has been a major effort. VALIXR point cloud requirements (animatable, selectable) versus more general point cloud requirements have required pursuing multiple solutions



ComputeRasterizer

Porting ComputeRasterizer (open source c++ GLSL implementation) components and logic to Unity

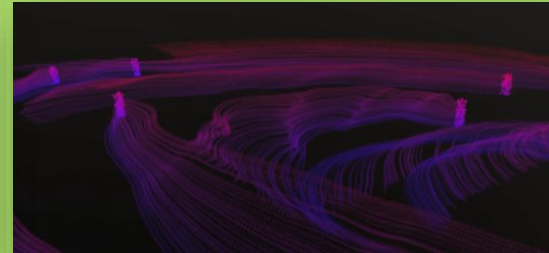
- BILLIONS of points
- Animatable with minor modifications
- Integration of ComputeRasterizer as DLL failed (UMBC)
- Unity Shader Language (HLSL) limited compared to GLSL
- Two previous attempts to translate GLSL to HLSL have failed (UMD and UCLA)
- Third attempt on-going



Remote Rendering

Render PC frames on remote computer and transfer to VALIXR computer (UMCP)

- BILLIONS of points
- Animatable with minor modifications
- Too slow (1 frame/second)
- Distorted graphics



Unity VFX

Native Unity solution that relies on Unity VFX Graph for visualizing point clouds

- Limited by GPU (10M-40M points)
- Animatable
- Selectable



Potree

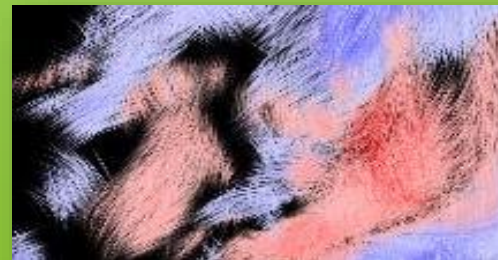
Integration of open source point cloud solution for visualizing point clouds

- BILLIONS of points
- Requires preprocessing
- Static (not animatable)
- No transparency

Neural Net

Using NN to enhance point cloud visualization with FX (UMCP)

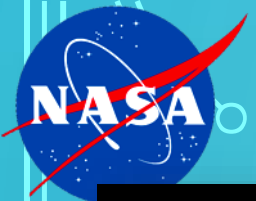
- Mitigates issues with visualizing limited size point clouds
- Post processing step in pipeline
- Limitations:
 - Approximation
 - Needs training for domain
 - Not interactable
 - Does not optimize the point cloud
- Still to be integrated



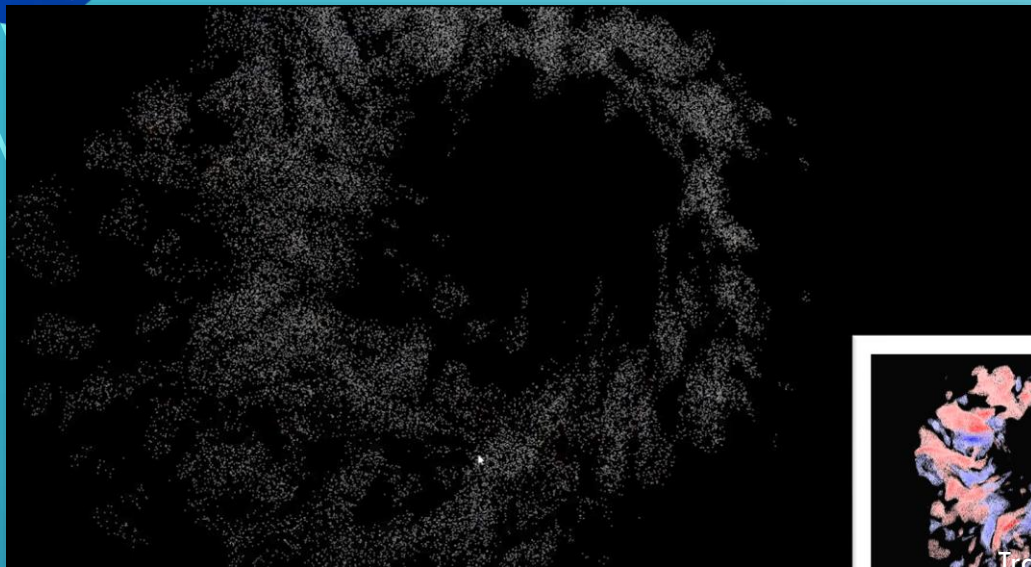
VALIXR

UMBC upgraded the Potree Unity implementation to support Potree v2:

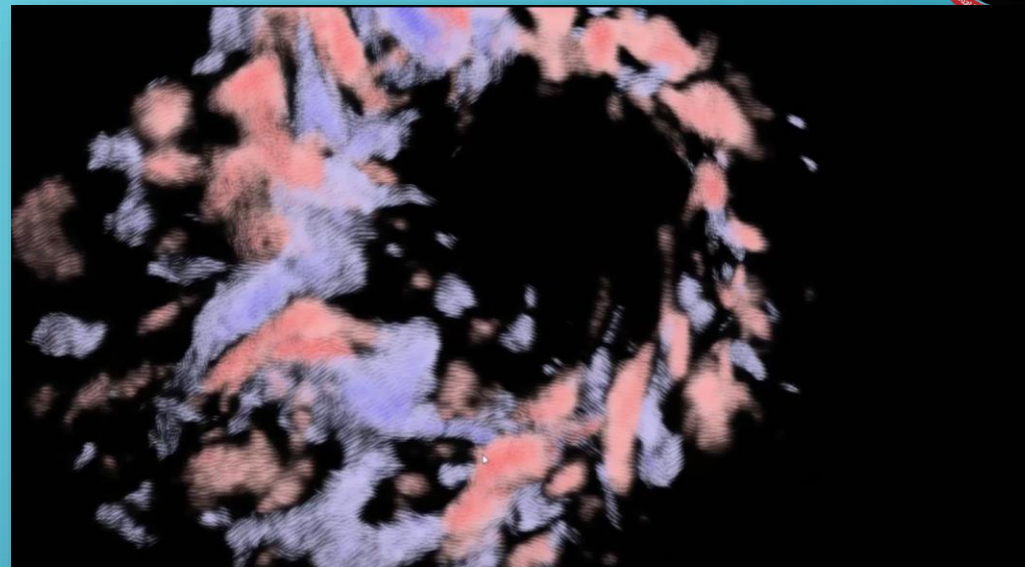
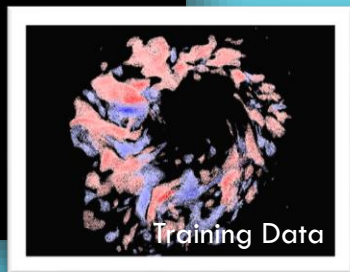
https://github.com/SFraissTU/BA_PointCloud/commit/674a172c1f7ff88ba0ca19a330fbb4470e9fcdff



NEURAL NETWORK SUPER-RESOLUTION



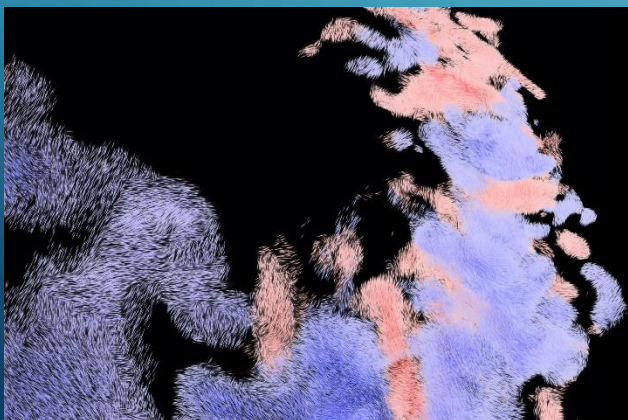
Sparse Point Cloud 2D Image



Neural Super-resolution of same image

Rendering Performance

(on GeForce RTX 2080Ti GPU at 2000 × 1328)



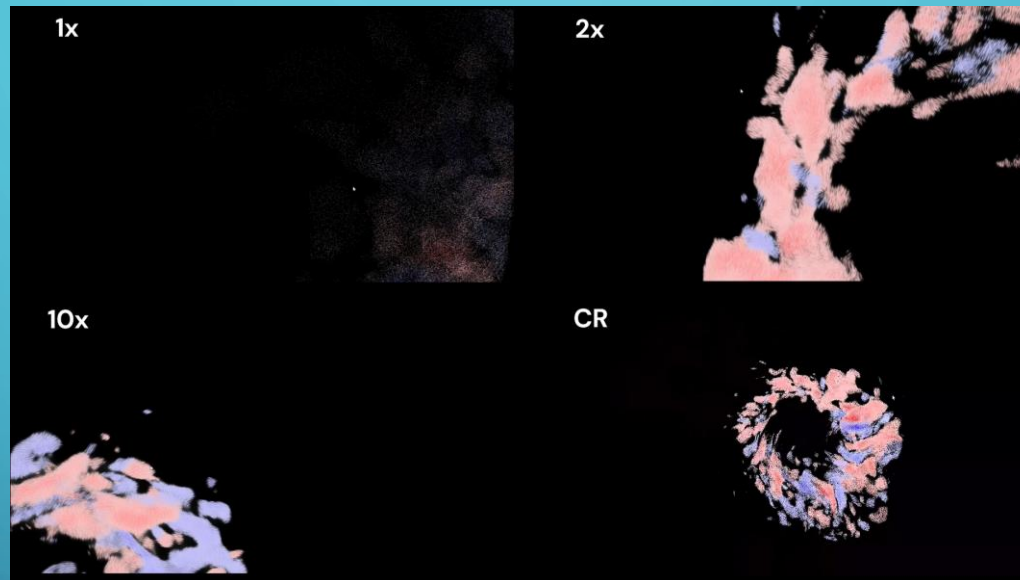
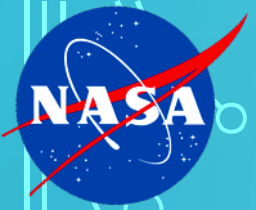
Hurricane (400K pts) 145 fps

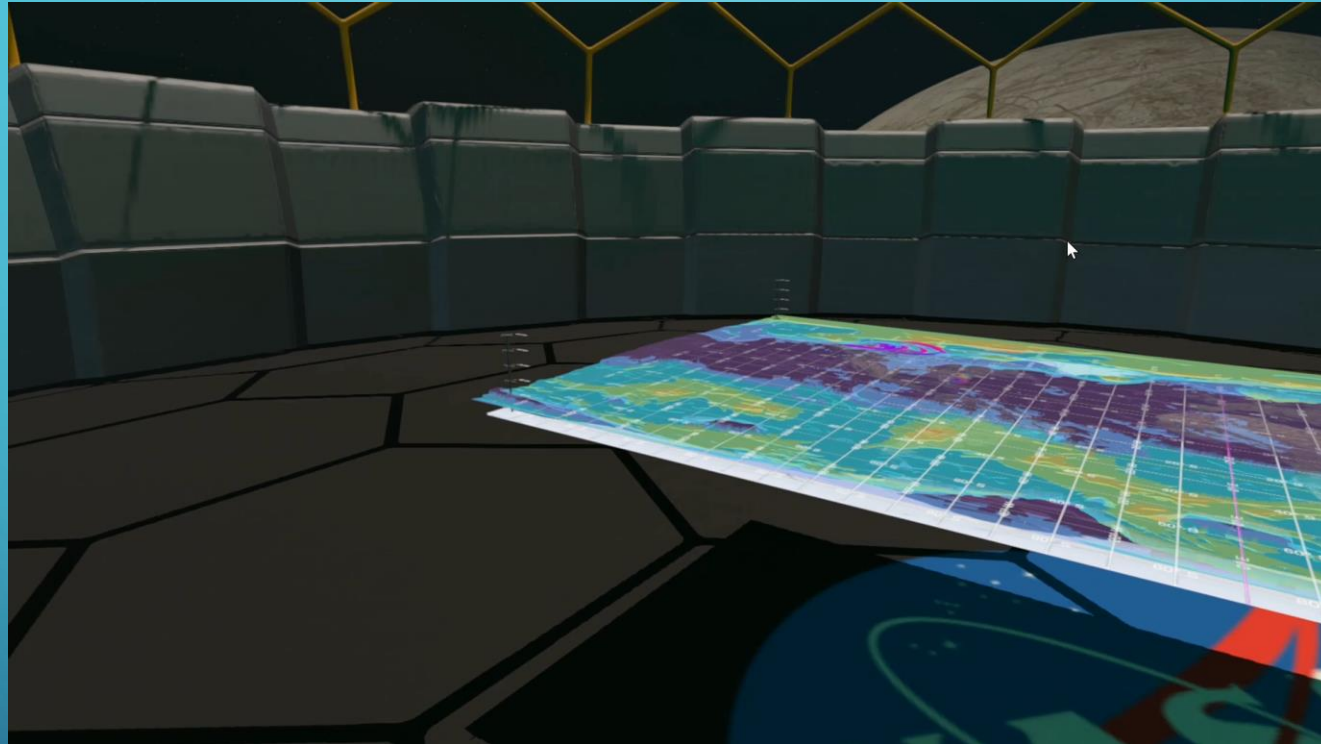
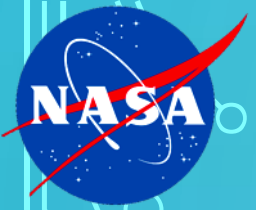


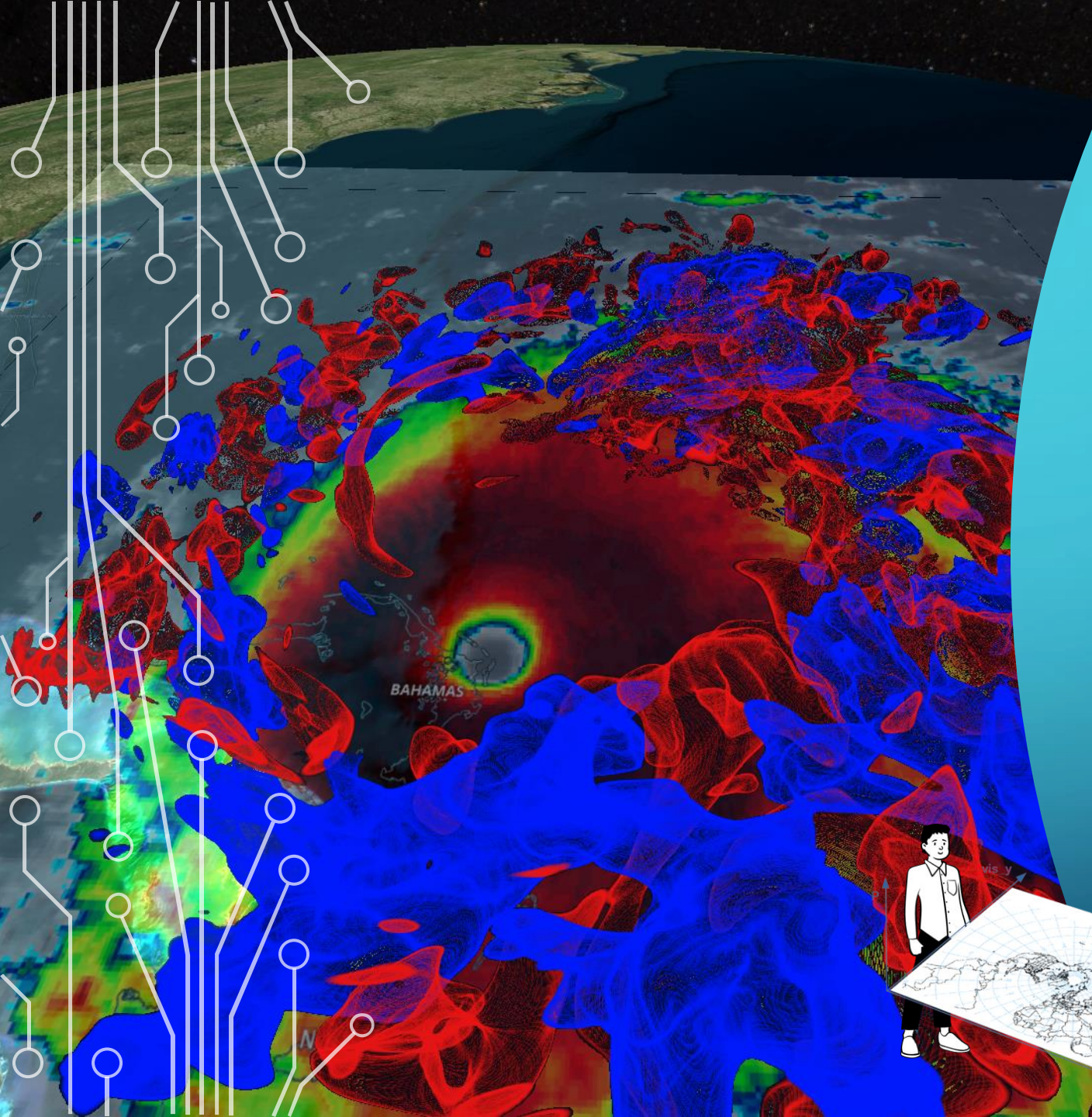
Storms (45M pts) 147 fps



Morro Bay Terrain (350M pts) 139 fps



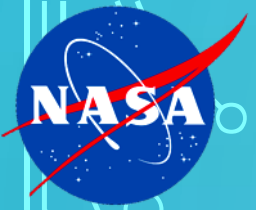




VALIXR “HOLOGRAPHIC TABLE”

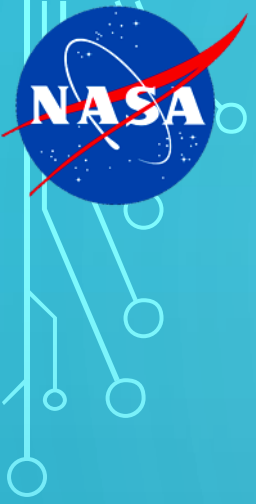
- “Layering” of 2D and 3D data with on-demand tiling
 - Elevation Data
 - Geographical/Political Maps
 - GOES Cloud Maps
 - NEXRAD Data
 - Image overlay layers
- 3D “Layers” using Animated Point Clouds, Volumetric Rendering, Isosurfaces, and Procedural Mesh (Tropopause)
- Supports Open Geospatial Consortium (OGC) standard services* (i.e., WMS, WFS, WCS, etc.), NOAA Open Data Dissemination (NODD) Program, and Grid Analysis and Display System (GrADS) Data Server (OPeNDAP protocol)

* Support is limited to the data needed right now, but will expand in the future



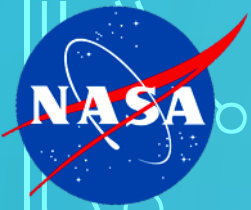
CONCLUSION

- XR can be a highly rewarding, useful tool for NASA scientists and engineers
 - NASA-wide Enabling Technology and is part of a larger Digital Engineering effort to help realize NASA 2040 and Goddard 2040 goals
- XR for NASA engineering has challenges
 - Except for large, expensive missions, expending lots of cost and effort for a one-off solution is not an option
 - Off the shelf solutions often provide most functionality – opportunity for customized, specific solutions
 - Reducing barrier of entry is required for adoption
- XR for NASA science provides an **immersive, intuitive environment for visualizing and interacting with science, though it requires a highly iterative, hopefully human factors approach to become a true tool for scientists**
 - More than likely, the XR tool won't have all the features the scientists need
 - XR is an adjunct tool to help the scientists understand the data first and then use traditional tools later for deeper understanding and publication
- **Leveraging the NASA open source MRET software** and pursuing a multi-stakeholder approach has been successful at GSFC



BACKUP SLIDES



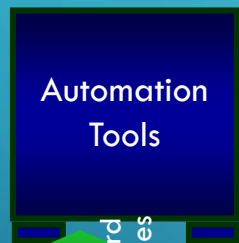
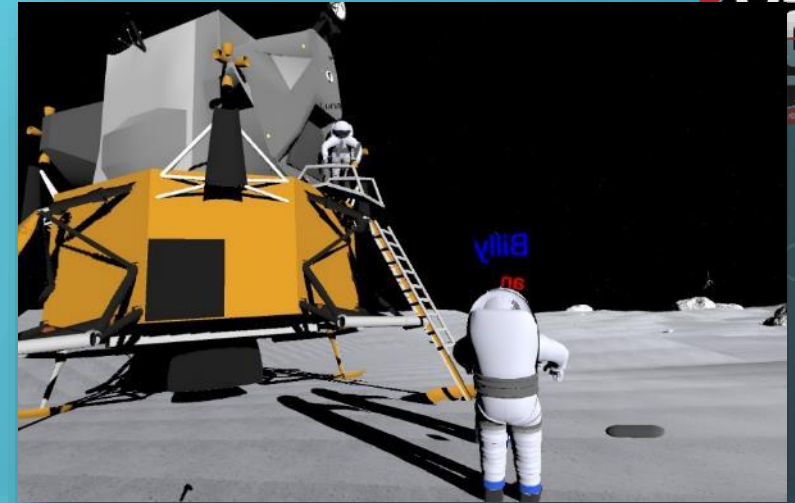


GMSEC AND MRET

MRET is GMSEC-Compliant

- Other GMSEC Components can drive XR, e.g., provide situational awareness by subscribing to real-time telemetry messages to drive 3D models of spacecraft
- MRET can use GMSEC for collaboration, allowing collaborative sessions on secure networks, even over VPN

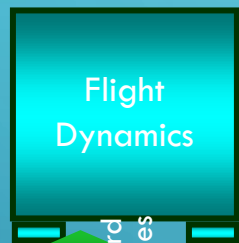
(Situational Awareness, Automation)



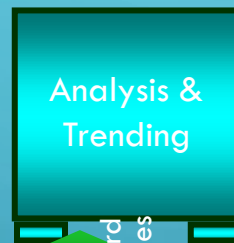
Standard Messages



Standard Messages



Standard Messages



Standard Messages



Standard Messages



Standard Messages



Standard Messages

GMSEC API

GMSEC Message Bus Middleware

AAS	American Astronomical Society
ACM	Association for Computing Machinery
ADAPT	Advanced Data Analytics Platform
AGCM	Atmospheric General Circulation Model
AIAA	American Institute of Aeronautics and Astronautics
AIST	Advanced Information Systems Technology
API	Application Programming Interface
AR	Augmented Reality
CAD	Computer-Aided Design
CCRS	Capture, Containment and Retrieval System
CIF	Center Innovation Fund
COTS	Commercial Off-the-shelf
CTA	Cognitive Task Analysis
DCOTSS	Dynamics and Chemistry Of The Summer Stratosphere
DEM	Digital Elevation Map
ESMF	Earth System Modeling Framework
ESTO	Earth Science Technology Office
ESTO	Earth Science Technology Office
ExIS	Exploration & In-space Services
GEOS	Goddard Earth Observing System
GeoTIFF	Georeferenced Tag Image File Format
GIS	Geographic Information System
GMAO	Global Modeling and Assimilation Office
GMAT	General Mission Analysis Tool
GMSEC	Goddard Mission Services Evolution Center
GSFC	Goddard Space Flight Center
GUI	Graphical User Interface
HUD	Heads Up Display
I/O	Input/Output
IEEE	Institute of Electrical and Electronics Engineers
IRAD	Internal Research & Development
IS&T	Information Science and Technology

JPEG	Joint Photographic Experts Group
JPL	Jet Propulsion Laboratory
LD	Lagrangian Dynamics
LIDAR	Light Detection and Ranging
MRET	Mixed Reality Exploration Toolkit
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCCS	NASA Center for Climate Simulation
netCDF	network Common Data Form
NSPIRES	NASA Solicitation and Proposal Integrated Review and Evaluation System
OSAM-1	On-orbit Servicing, Assembly, and Manufacturing 1
PCD	Point Cloud Data
PDL	Product Development Lead
PNG	Portable Network Graphic
PY	Program Year
ROSES	Research Opportunities in Space and Earth Sciences
RMIT	Rapid Model Import Tool
SED	Software Engineering Division
TRL	Technology Readiness Level
UMBC	University of Maryland Baltimore County
UMD	University of Maryland (College Park)
UMIACS	University of Maryland Institute for Advanced Computer Studies
UNT	University of North Texas
VALIXR	Visualization And Lagrangian dynamics Immersive eXtended Reality Tool (VALIXR)
VR	Virtual Reality
XR	Extended Reality (AR/VR/MR)