2nd Visualizing Offline and Live Data with AI (VOLDA) Workshop

Application of XR and Cinematic-Quality Rendering in Magnetic Confinement Fusion Visualization

SciVisual 可视科学

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Madrid, Spain

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Zixi Liu

Prof. of USTC
Doctoral Supervisor
CN member of ITPA-PEP

Plasma physics
I-mode physics in MCF
BOUT++ 2-Fluid simulation
Applications of AI and SV

$$\frac{\partial \varpi}{\partial t} = -\frac{1}{B_0}\hat{b}\times\nabla_\perp\phi\cdot\nabla\varpi + B_0^2\nabla_\parallel\left(\frac{J_\parallel}{B_0}\right) + 2\hat{b}\times\hat{\kappa}\cdot\nabla P_i$$
$$-\frac{1}{2\Omega_i}\left[\frac{1}{B_0}\hat{b}\times\nabla P_i\cdot\nabla(\nabla_\perp^2\phi) - Z_i e B_0\hat{b}\times\nabla n_i\cdot\nabla\left(\frac{\nabla_\perp\phi}{B_0}\right)^2\right]$$
$$+\frac{1}{2\Omega}\left[\frac{1}{B_0}\hat{b}\times\nabla\phi\cdot\nabla(\nabla_\perp^2 P_i) - \nabla_\perp^2\left(\frac{1}{B_0}\hat{b}\times\nabla\phi\cdot P_i\right)\right] + \mu_{\parallel i}\nabla^2_{\parallel 0}\varpi$$

$$\frac{\partial u_{\parallel i}}{\partial t} = -\frac{1}{B_0}\hat{b}\times\nabla_\perp\phi\cdot\nabla u_{\parallel i} - \frac{1}{m_i n_{i0}}\hat{b}\cdot\nabla P$$

$$\frac{\partial n_i}{\partial t} = -\frac{1}{B_0}\hat{b}\times\nabla_\perp\phi\cdot\nabla n_i - \frac{2n_i}{B_0}\hat{b}\times\hat{\kappa}\cdot\nabla\phi - \frac{2}{Z_i e B_0}\hat{b}\times\hat{\kappa}\cdot\nabla P_i - n_i B_0\nabla_\parallel\left(\frac{u_{\parallel i}}{B_0}\right)$$

$$\frac{\partial A_\parallel}{\partial t} = -\nabla_\parallel\phi + \frac{\eta}{\mu_0}\nabla_\perp^2 A_\parallel + \frac{1}{e n_{e0} B_0}\nabla_\parallel P_e + \frac{0.71 k_B}{e B_0}\nabla_\parallel T_e - \frac{\eta_H}{\mu_0}\nabla_\perp^4 A_\parallel$$

$$\frac{\partial T_i}{\partial t} = -\frac{1}{B_0}\hat{b}\times\nabla_\perp\phi\cdot\nabla T_i - \frac{2}{3}T_i\left[\left(\frac{2}{B_0}\hat{b}\times\hat{\kappa}\right)\cdot\left(\nabla\phi + \frac{1}{Z_i e n_{i0}}\nabla P_i\right.\right.$$
$$\left.\left.+\frac{2}{5}\frac{k_B}{Z_i e}\nabla T_i\right) + B_0\nabla_\parallel\left(\frac{u_\parallel}{B_0}\right)\right] + \frac{2}{3 n_{i0} k_B}\nabla_{\parallel 0}(k_{\parallel i}\nabla_{\parallel 0} T_i)$$
$$+\frac{2}{3 n_{i0} k_B}\nabla_\perp\cdot(\kappa_{\perp i}\nabla_\perp T_i) + \frac{2m_e}{m_i}\frac{Z_i}{\tau_e}(T_e - T_i)$$

$$\frac{\partial T_e}{\partial t} = -\frac{1}{B_0}\hat{b}\times\nabla_\perp\phi\cdot\nabla T_e - \frac{2}{3}T_e\left[\left(\frac{2}{B_0}\hat{b}\times\hat{\kappa}\right)\cdot\left(\nabla\phi - \frac{1}{e n_{e0}}\nabla P_e - \frac{5}{2}\frac{k_B}{e}\nabla T_e\right)\right.$$
$$\left.+B_0\nabla_\parallel\left(\frac{u_{\parallel e}}{B_0}\right)\right] + 0.71\frac{2T_e}{3 e n_{e0}}B_0\nabla_\parallel\left(\frac{J_\parallel}{B_0}\right) + \frac{2}{3 n_{e0} k_B}\nabla_{\parallel 0}(\kappa_{\parallel e}\nabla_{\parallel 0} T_e)$$
$$+\frac{2}{3 n_{e0} k_B}\nabla_\perp\cdot(\kappa_{\perp e}\nabla_\perp T_e) - \frac{2m_e}{m_i}\frac{1}{\tau_e}(T_e - T_i) + \frac{2}{3 n_{e0} k_B}\eta_\parallel J_\parallel^2$$

MR (Mixed reality) technologies first show

MR (Mixed reality) technologies has been shown in 6th IAEA Technical Meeting on Fusion Data Processing, Validation and Analysis

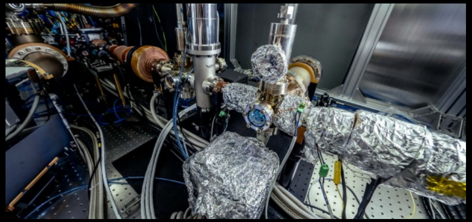
Reported by China Central Television (CCTV)

In a 2025 National Day special program, CCTV News Channel aired a seven-minute feature report titled “Making China‘s Core Science Visible,” which demonstrated to the public the use of these vivid and authentic new methods, including XR, to present scientific research achievements.

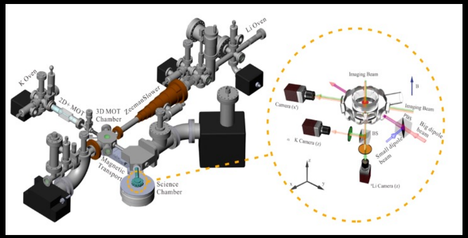
DEMO

The Visualization Technologies

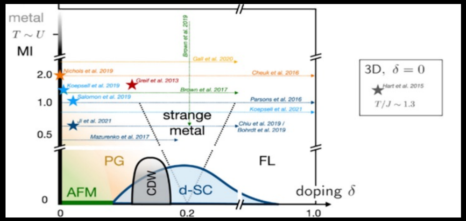
Journal Article



Equipment



Exp. Procedure

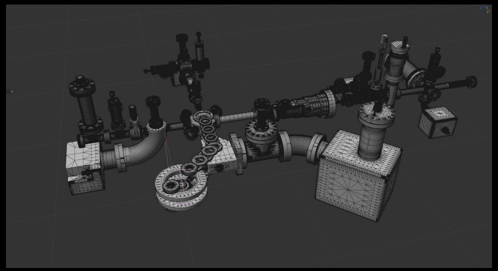


Exp. / Sim. Data

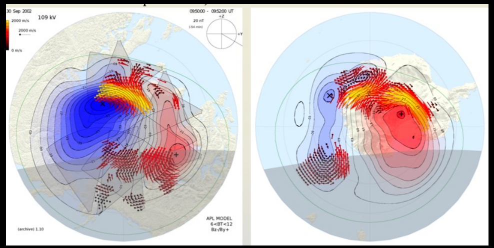
Decomposing

Modeling

Reduced Models



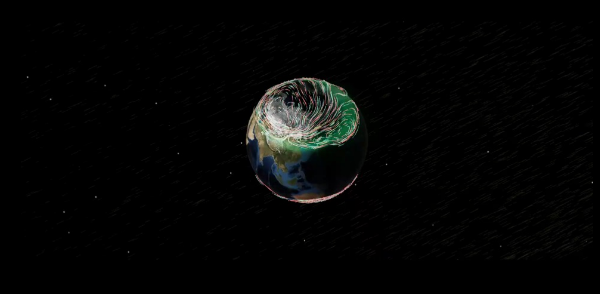
Reduced Data



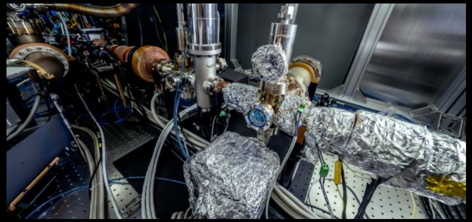
Digital models

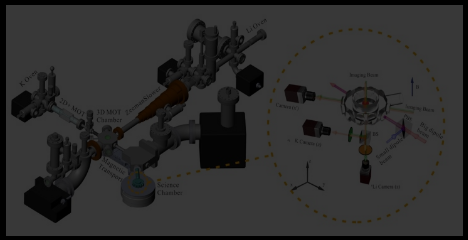
Model Visualization

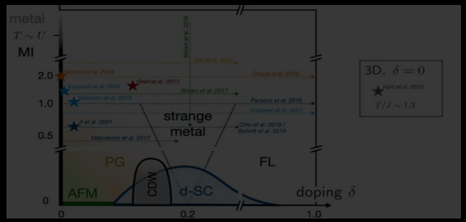
Data Visualization



Equipment Visualization Technologies







Journal article

Equipment

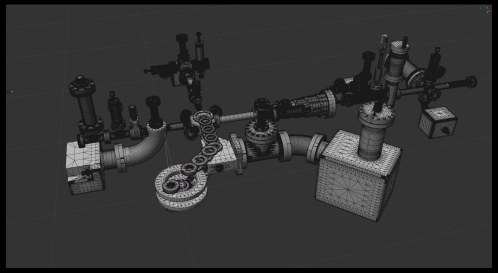
Exp. Procedure

Exp. / Sim. Data

Decomposing

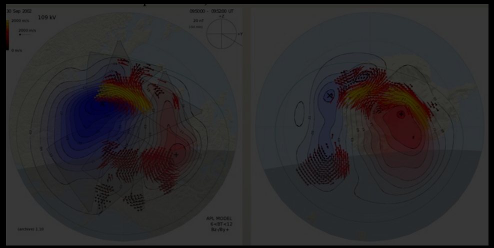
Modeling

Reduced Models



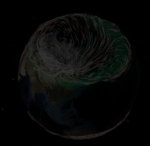
Digital models

Reduced Data

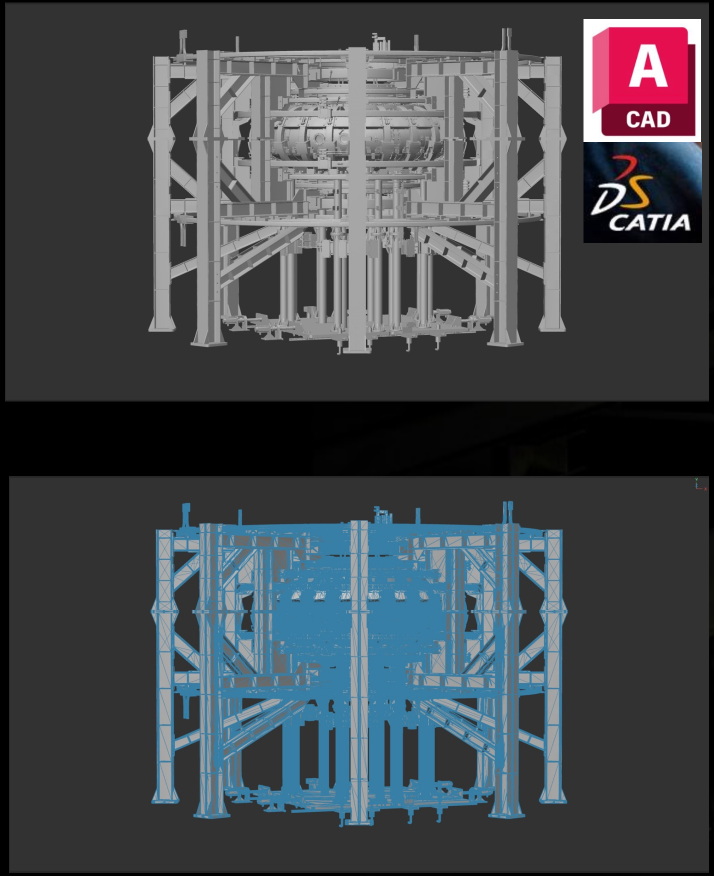


Model Visualization

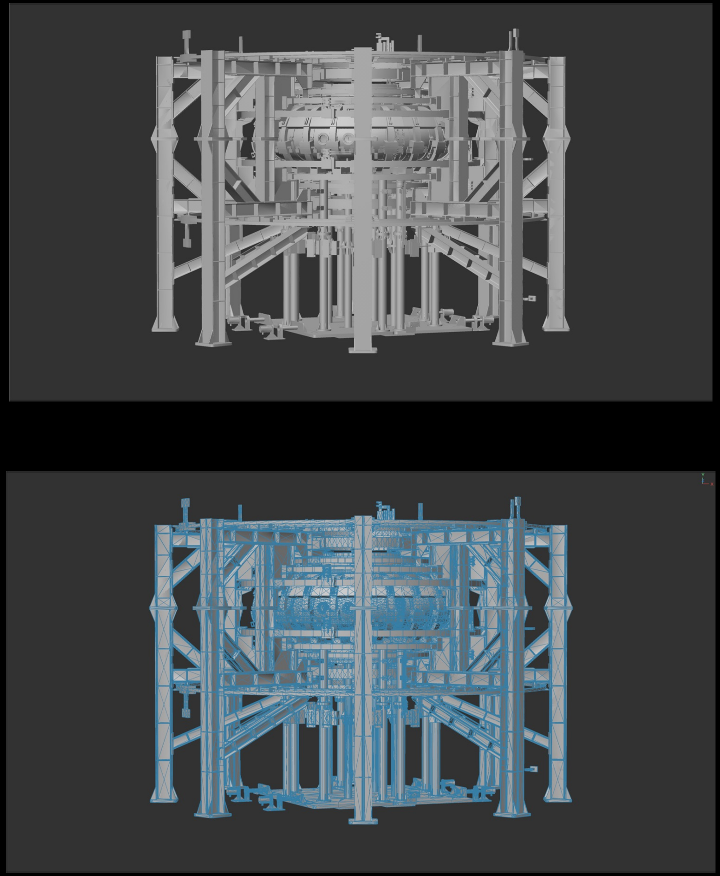
Data Visualization



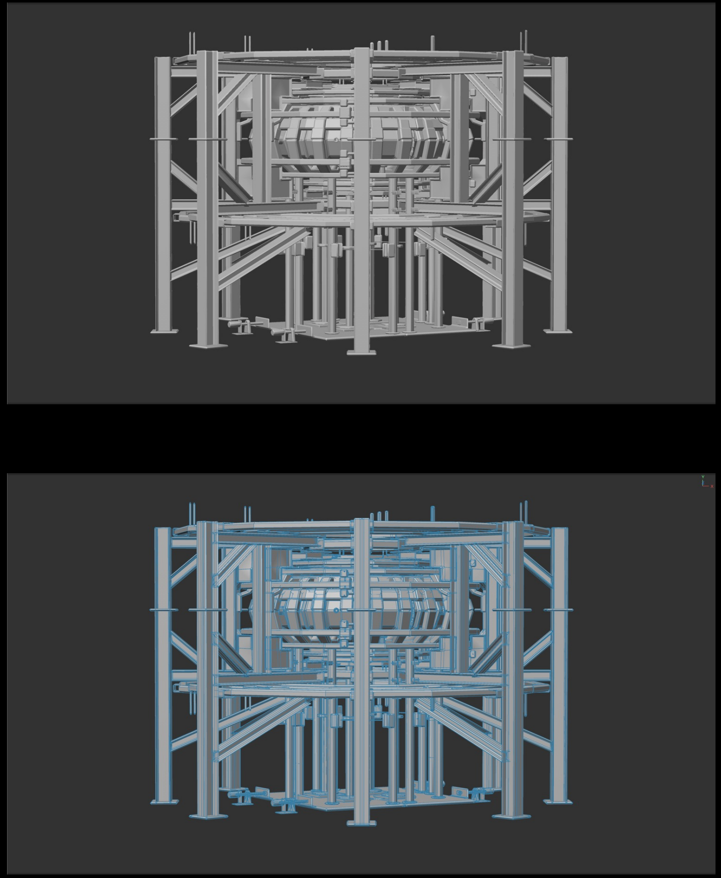
Retaining original features, the number of polygons could be reduced to ~0.4%



polygons (Original)
165,909,086

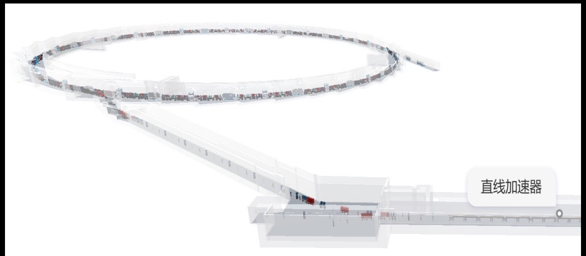


polygons (for Vision Pro)
287,033



polygons (for Web)
58,070

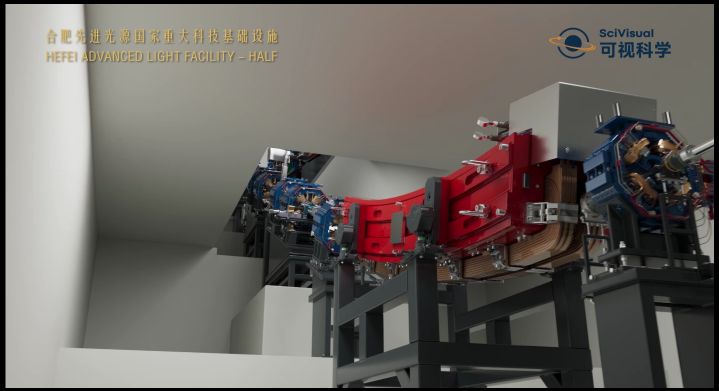
Choosing Edge Collapse has accelerated the reduction process

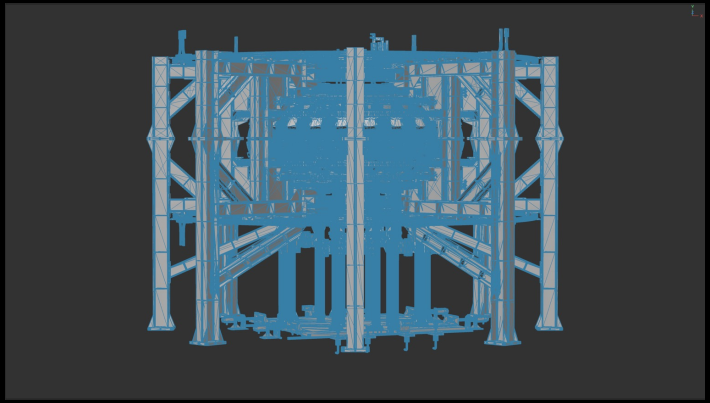


polygons (Original)
~1,000,000,000

Quadric Error Metrics、
Vertex Clustering、
Progressive Meshes、
Edge Collapse…AI

~0.7 million polygons/h





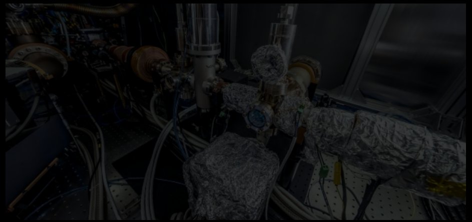
polygons (Original)
165,909,086

Edge Collapse

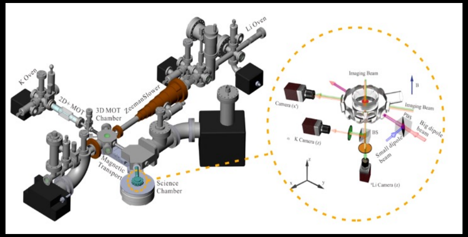
~2 million polygons/h

Experimental Procedure Visualization process

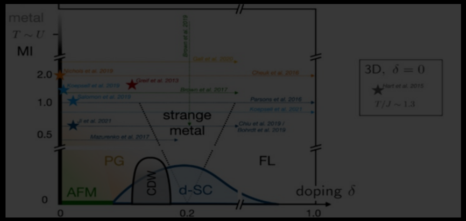
Journal article



Equipment



Exp. Procedure

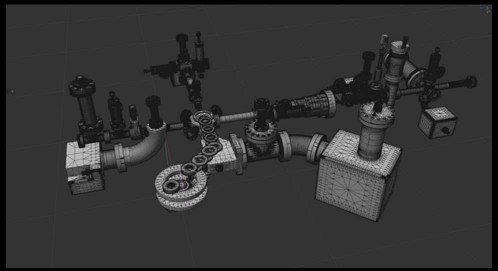


Exp. / Sim. Data

Decomposing

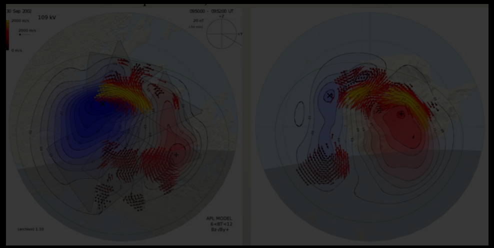
Modeling

Reduced Models



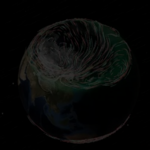
Digital models

Reduced Data

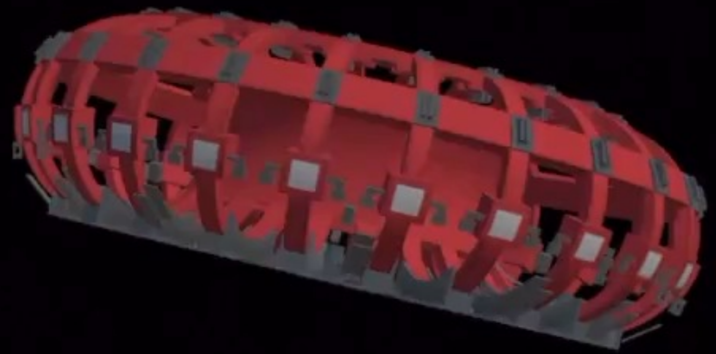


Model Visualization

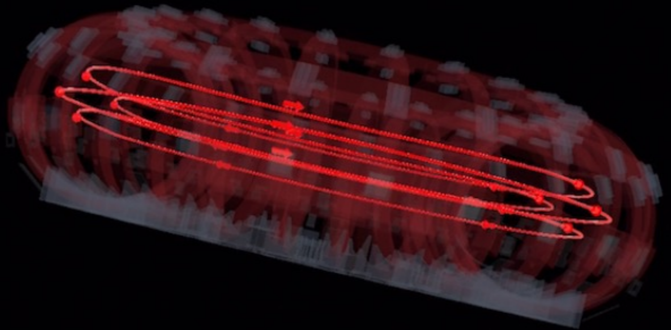
Data Visualization

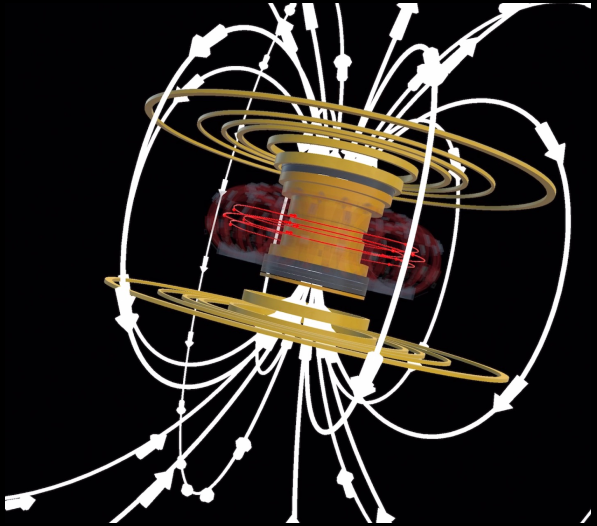


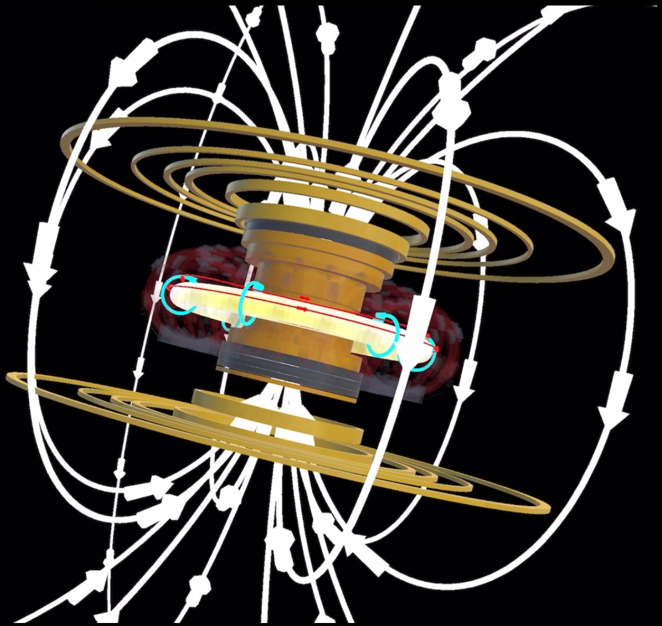
How does magnetic confinement fusion confine the plasma（‘sun’）?

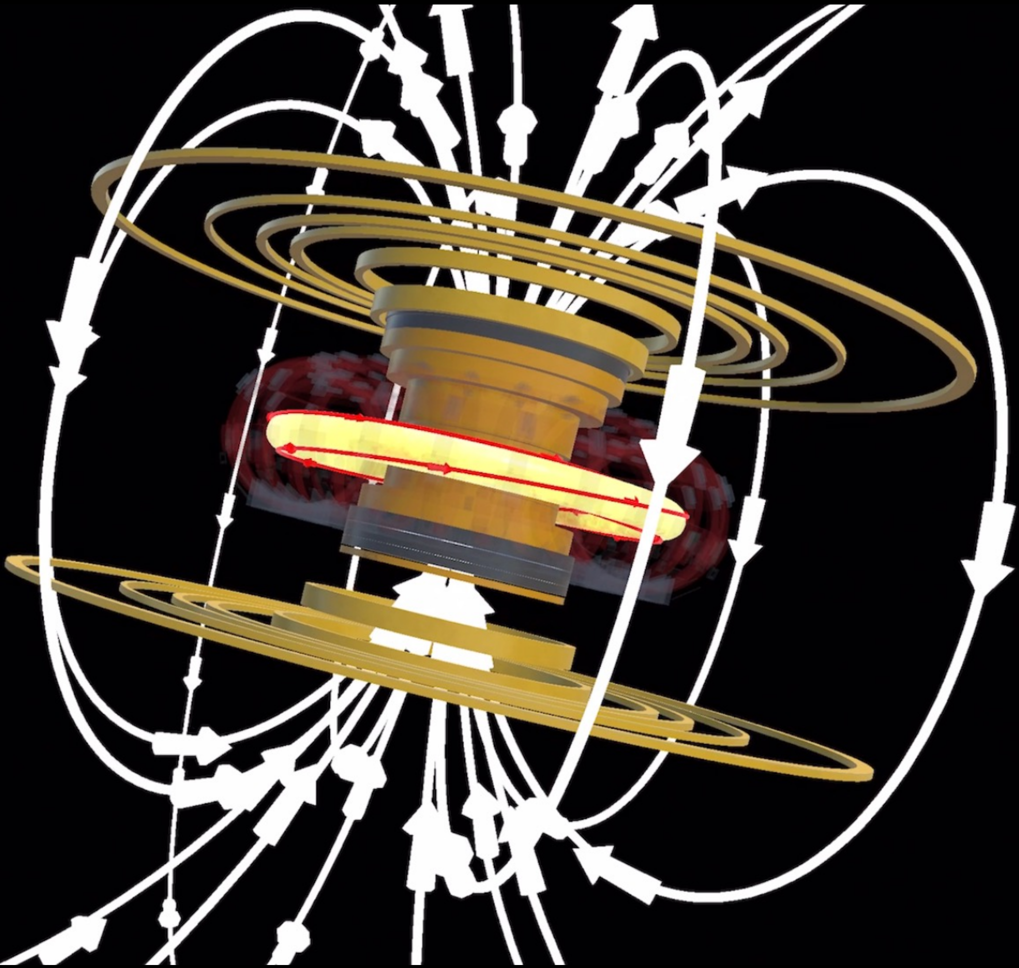


How does magnetic confinement fusion confine the plasma（‘sun’）?





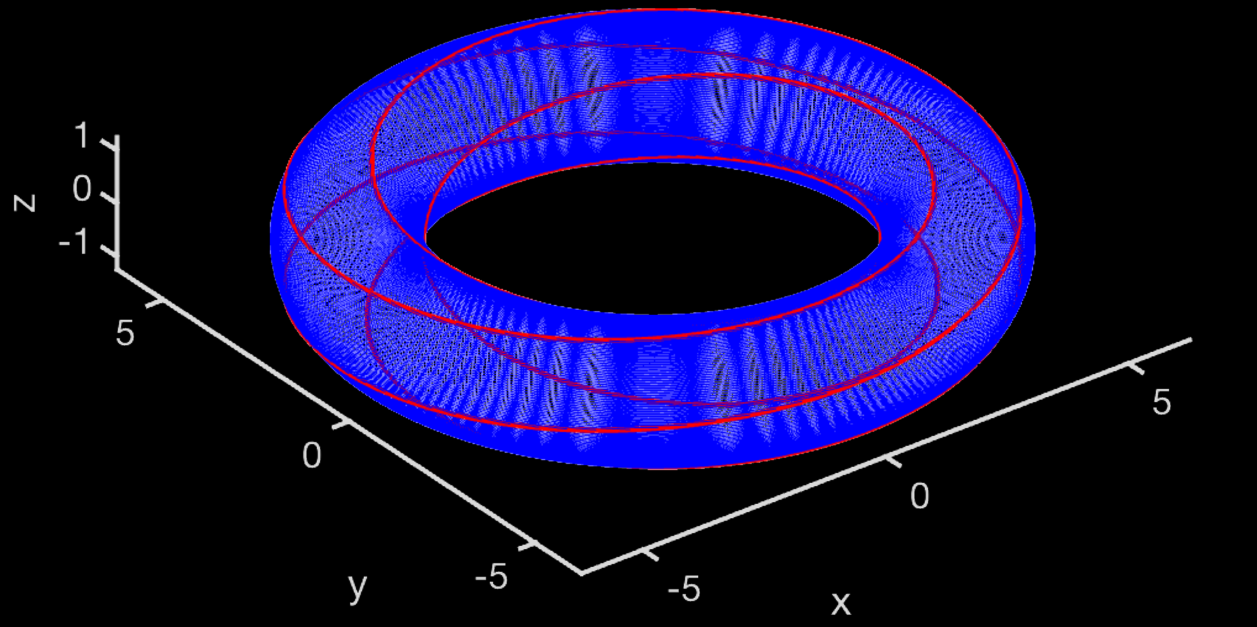




Using the same function to get the B field line

```
R=5.0;r=1.25;n=2;m=5;
q=m/n;
theta=0:pi/10000:m*n*2*pi;phi1=q.*theta;
phi=phi1+4*i;
x=(R+r.*cos(theta)).*cos(phi);
y=(R+r.*cos(theta)).*sin(phi);
z=r.*sin(theta);
```

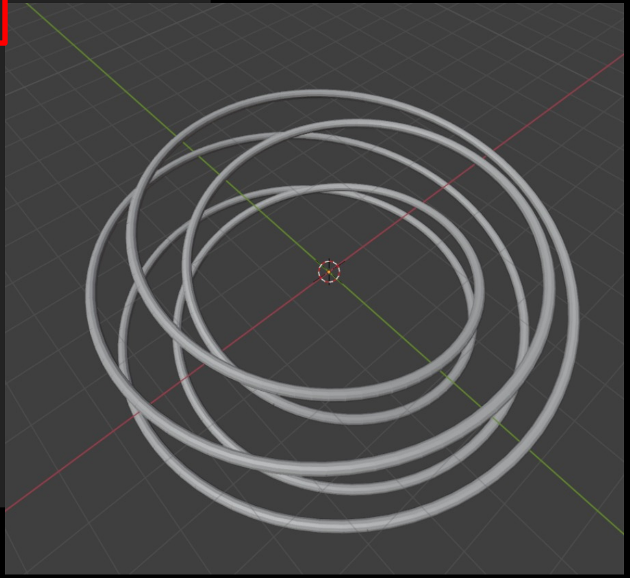
MATLAB




```
phi = q * theta + math.pi/2
x = (RR + rr * math.cos(theta)) * math.cos(phi) * factor[0]
y = (RR + rr * math.cos(theta)) * math.sin(phi) * factor[1]
z = rr * math.sin(theta) * factor[2]
targetPos.append([x,y,z])
```

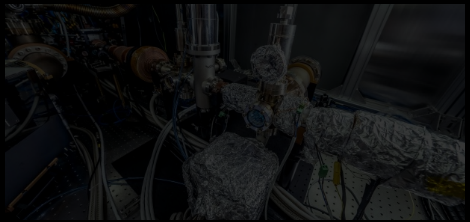
```
imp
imp
imp
imp

mes
obj
bpy

#相关参数
RR = 5
rr = 1.25
m = 5
n = 2
factor = [0.75,0.75,1.2]
q = m/n
total = m*n*2*math.pi
step = total/200/m/n
targetPos = []
for theta in np.arange(0, total, step):
    phi = q * theta + math.pi/2
    x = (RR + rr * math.cos(theta)) * math.cos(phi) * factor[0]
    y = (RR + rr * math.cos(theta)) * math.sin(phi) * factor[1]
    z = rr * math.sin(theta) * factor[2]
    targetPos.append([x,y,z])

points = np.array(targetPos)
mesh.vertices.add(len(points))
mesh.vertices.foreach_set("co", points.ravel())
edges = []
for i in range(len(points)):
    if i == 0:
        print("A")
    elif i == len(points) - 1:
        print("A")
    else:
        edges.append((i, i-1))
        edges.append((i, i+1))

mesh.edges.add(len(edges))
mesh.edges.foreach_set("vertices", np.array(edges).ravel())
mesh.update()
obj.select_set(True)
bpy.context.view_layer.objects.active = obj
bpy.ops.object.convert(target='CURVE')

#设置线粗
bpy.context.object.data.bevel_depth = 0.1
bpy.ops.object.convert(target='MESH')
```

Blender

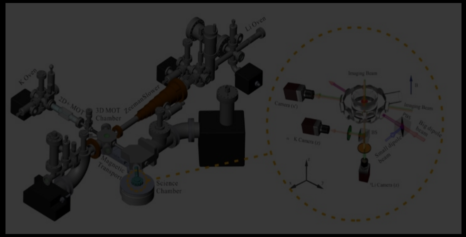


Science data Visualization Technologies

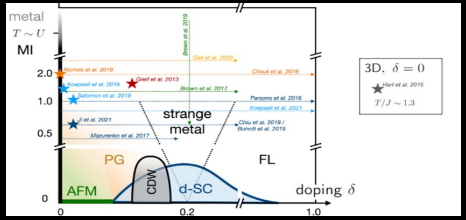
Journal article



Equipment



Exp. Procedure

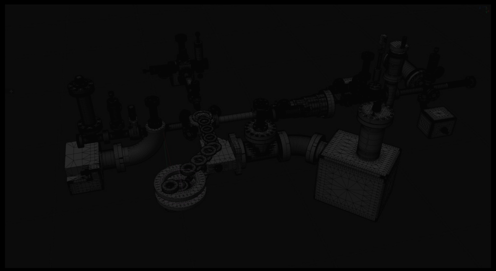


Exp. / Sim. Data

Decomposing

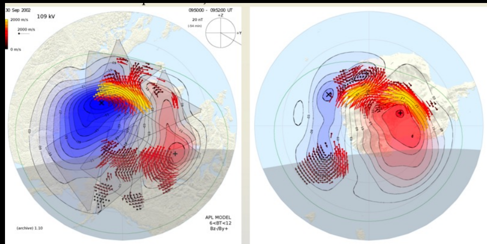
Modeling

Reduced Models

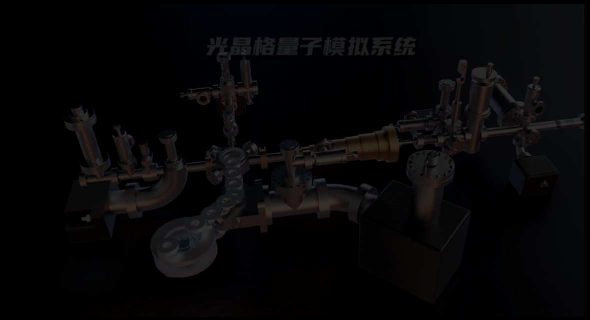


Digital models

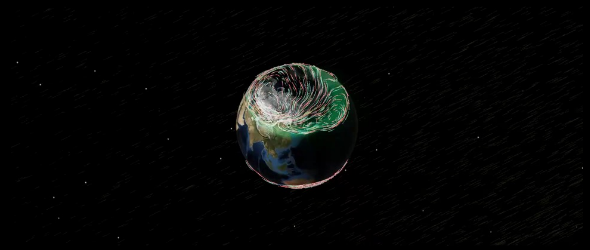
Reduced Data



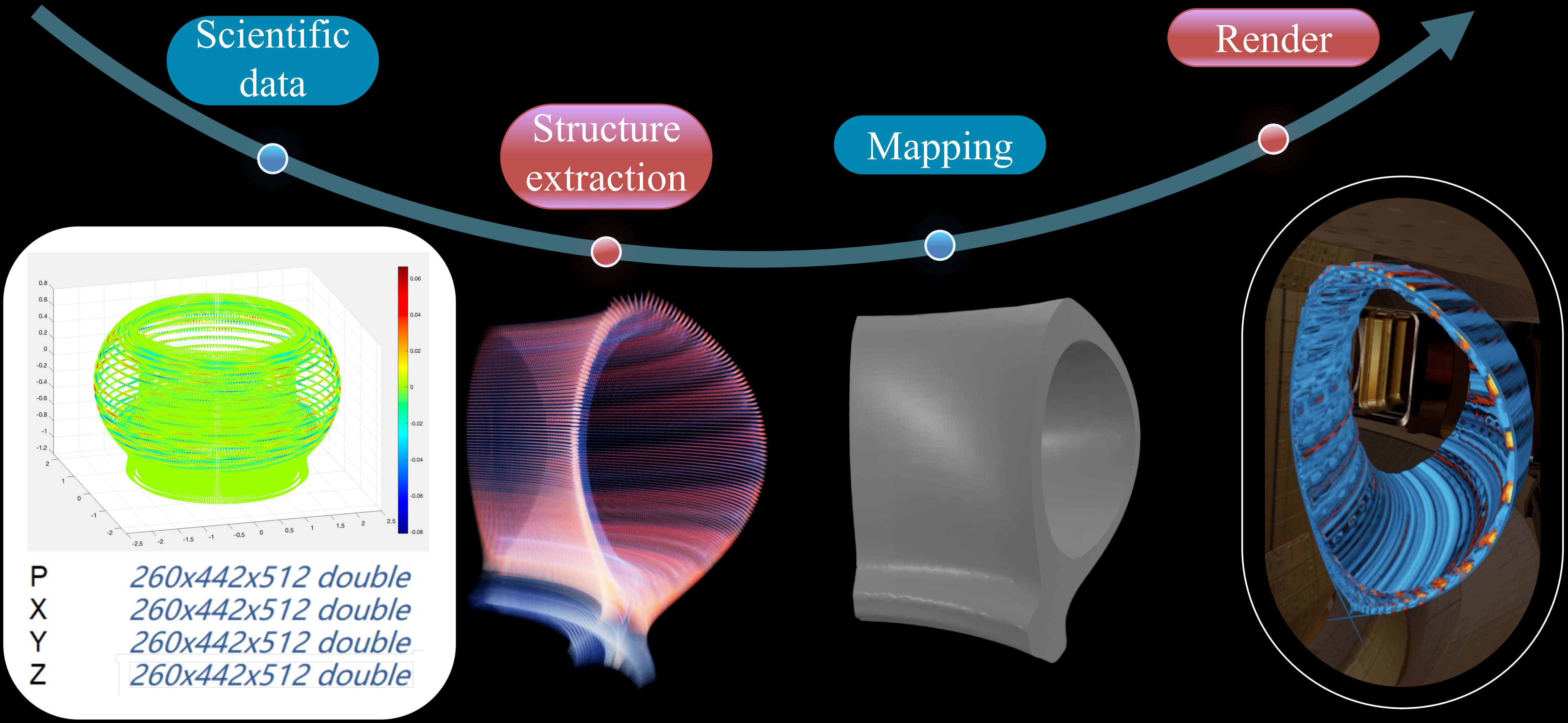
Model Visualization



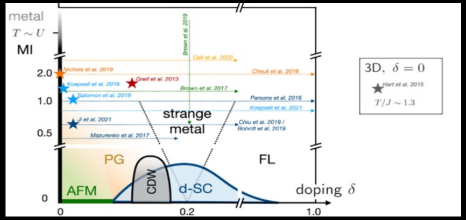
Data Visualization



Science data Visualization Technologies



Mapping from Scientific Visualization to Film-Quality Visualization



Exp. / Sim. Data

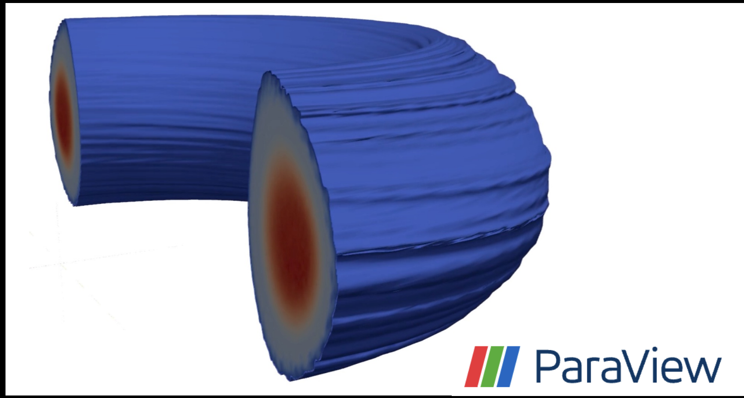
Scientific Visualization

ParaView · yt · MegaMol · VTK · Inviwo

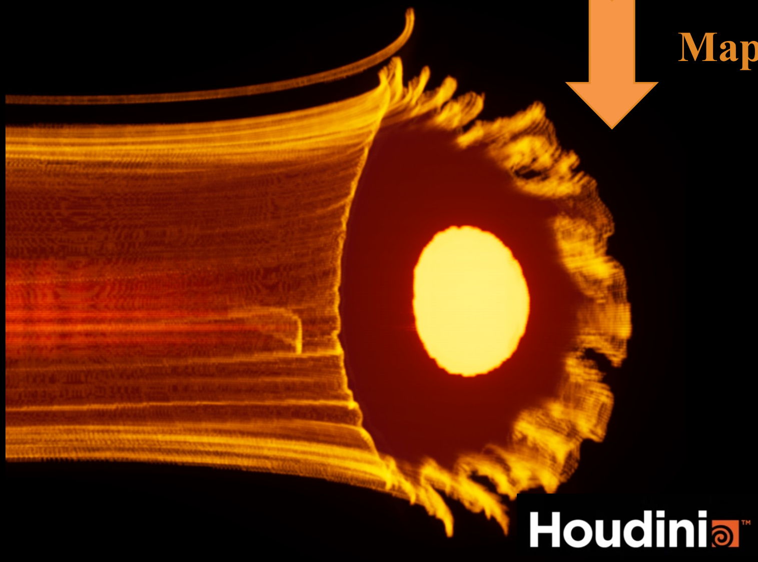
Mapping

Film-Quality Visualization

Ae · blender · Redshift · CINEMA 4D · Houdini · NVIDIA OMNIVERSE ENTERPRISE



Mapping



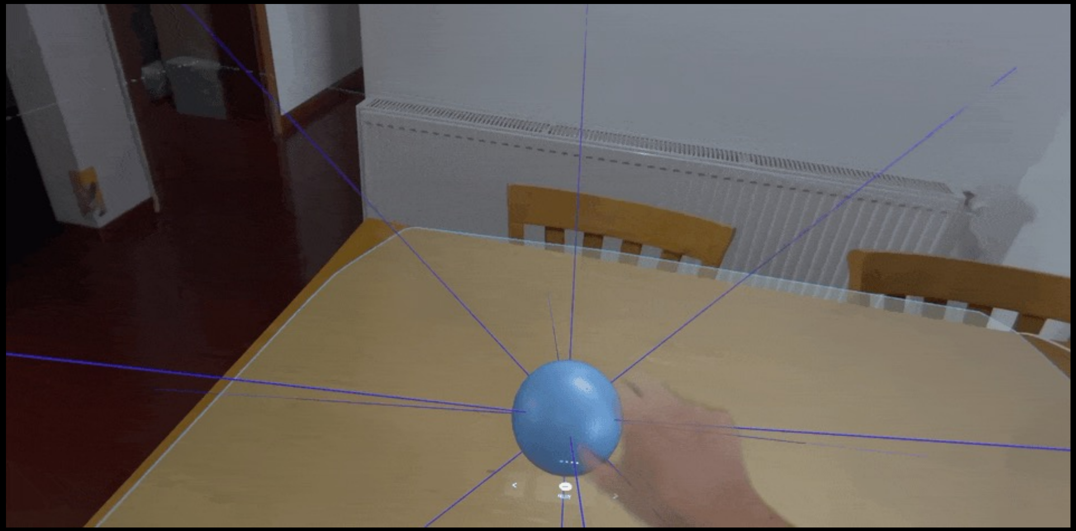
Mapping from Scientific Visualization to Film-Quality Visualization

WCM

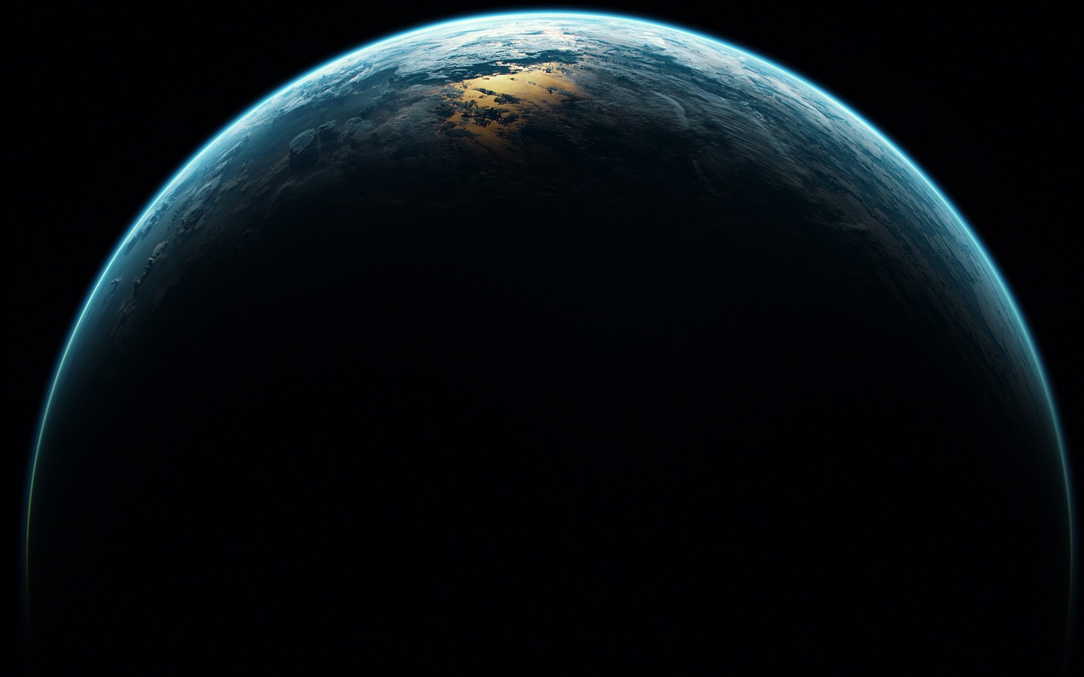
ELM

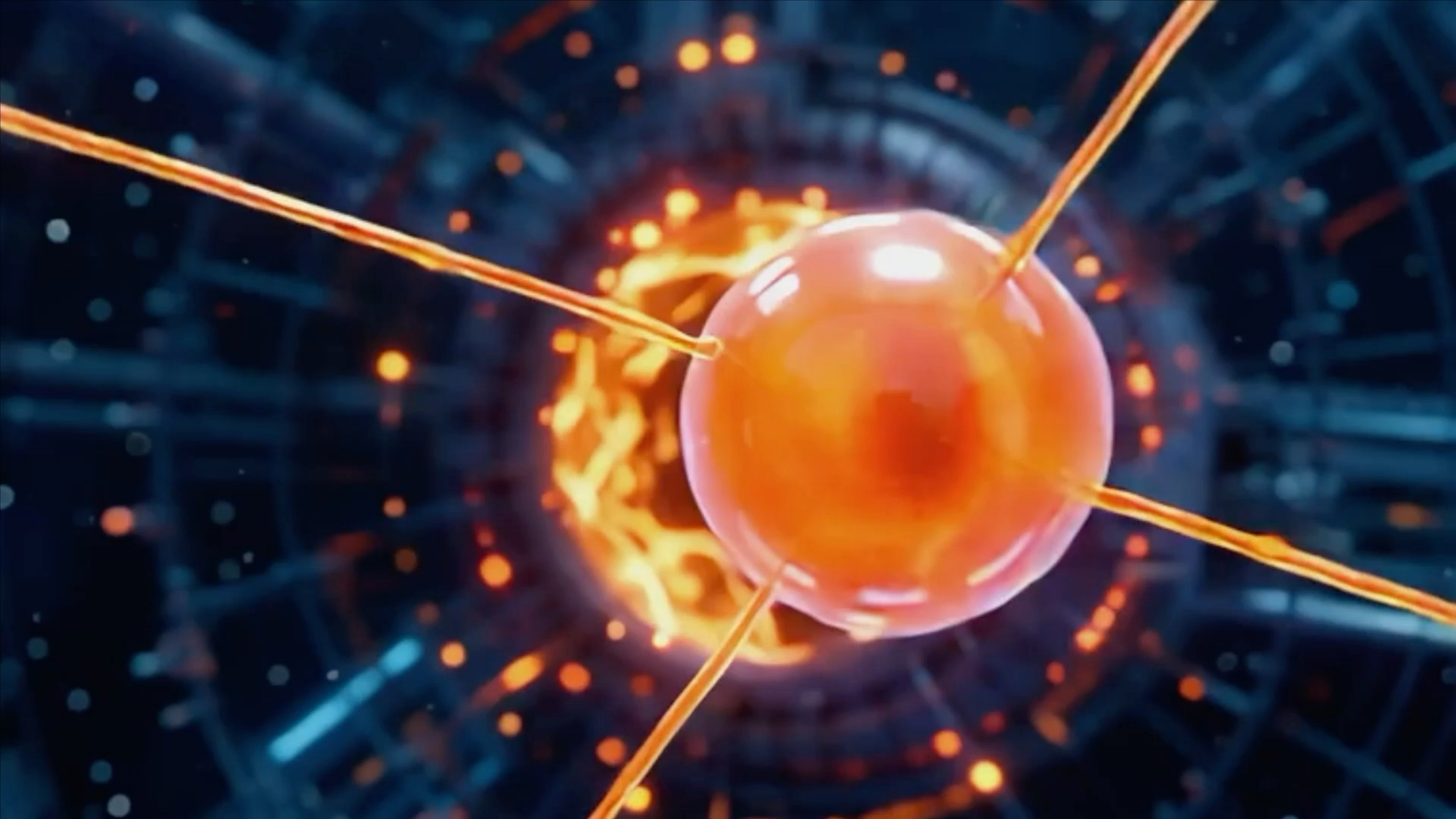
Immersive Exploration （3D GS）

Virtual Teaching



Make Science Visible





Chinese version

https://testflight.apple.com/join/EUAjVmB9

CN/EN version

https://testflight.apple.com/join/R4ns4rhX

Software for iphone or ipad is now on the TestFlight.

Android version will come soon.

If you want to try, contact me. zxliu316@ustc.edu.cn