数值模拟中的大规模粒子与流场可视化

单桂华
中国科学院计算机网络信息中心
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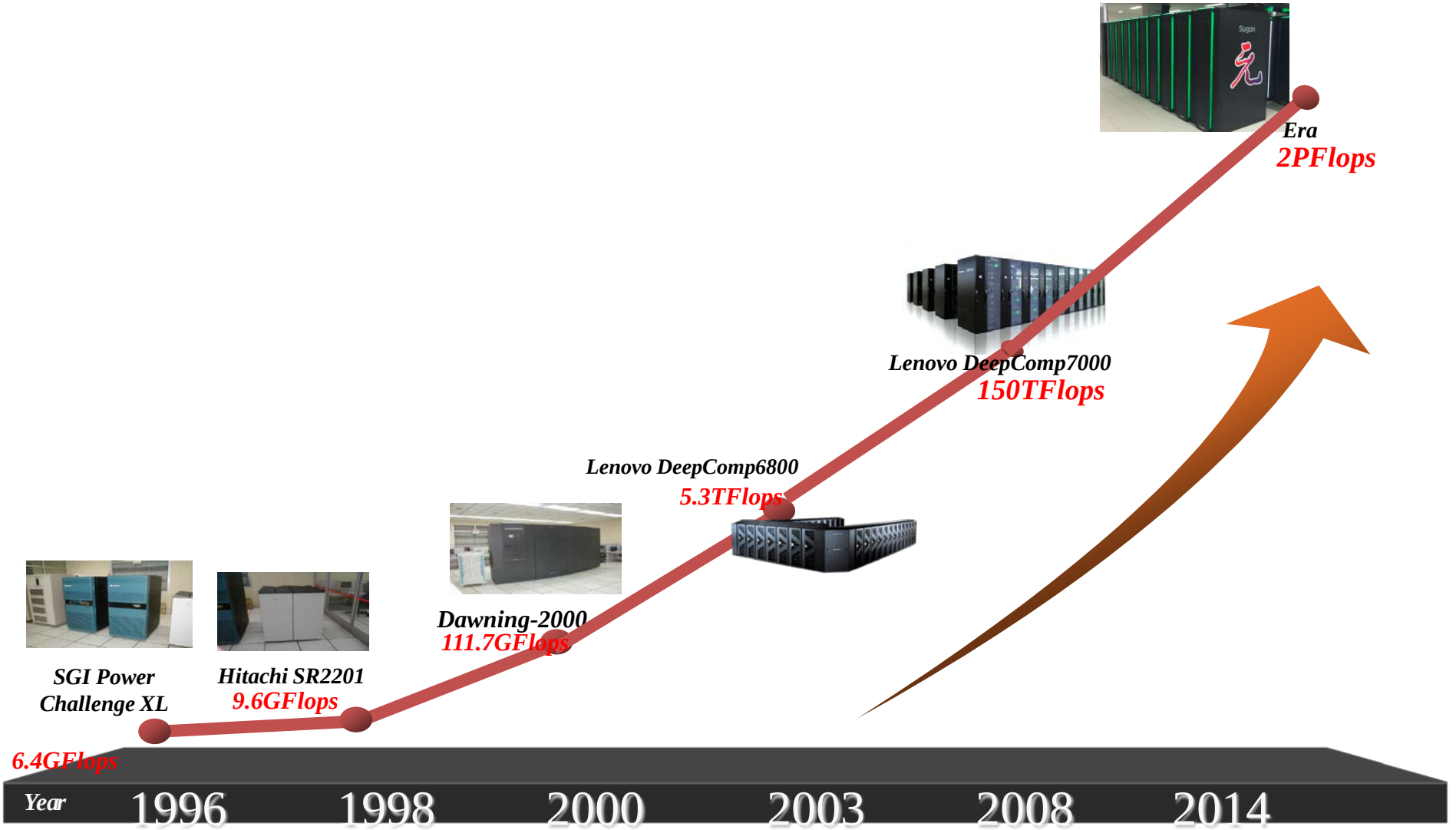
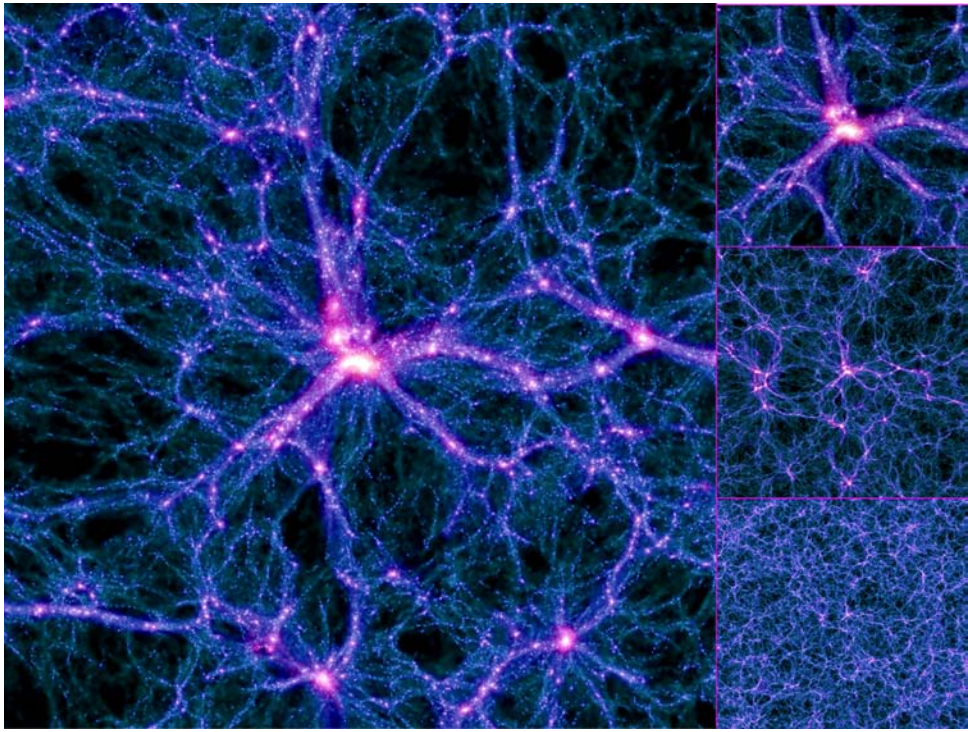
中国科学院
计算机网络信息中心
Computer Network Information Center,
Chinese Academy of Sciences

中科院超级计算环境


Era
2PFlops
Lenovo DeepComp7000
150TFlops
Lenovo DeepComp6800
5.3TFlops
Dawning-2000
111.7GFlops
Hitachi SR2201
9.6GFlops
SGI Power
Challenge XL
6.4GFlops
Year
1996
1998
2000
2003
2008
2014

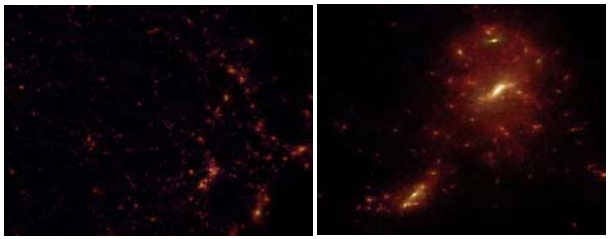
宇宙结构模拟数据的时序可视化

- **数值模拟**
  - 300亿粒子(3072^3)
  - 边长45亿光年
  - 再现宇宙140亿年的演化
  - 2048核×13天
- **输出数据**
  - 300亿粒子->每时刻**1.4TB**
  - 64个时刻，共**90TB**
  - 131,072文件
  - 7个变量

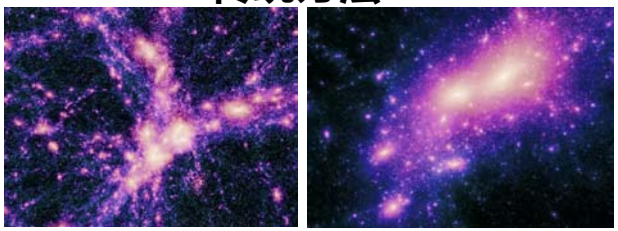


大规模数据绘制与加速算法

- **时序高动态范围的色调映射算法**
  - **前提**：由于显示设备限制，需要将变量高动态范围的值域映射到0-255区间。
  - **困难**：天文数据存在值域跨度大（相差10^9）、分布极不均匀、多时刻的特点
  - **解决**：基于统计直方图的时序色调映射

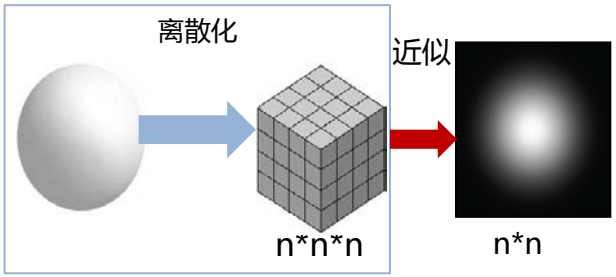


传统方法



新方法

- **数据精简与加速渲染算法**
  - 数据压缩、层次细节、视窗剪裁、粒子合并
  - 基于点精灵技术的GPU加速实现

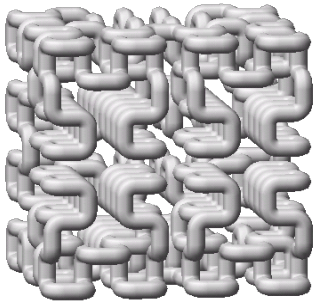


宇宙结构模拟数据的时序可视化

- **时序问题**
  - 64个时刻
  - 理想状态是64+630时刻
    - 62PB
    - 元 2PB，天河1号1PB，天河2号12PB, 太湖之光10PB

时序动画

- **基于可见性裁剪的时序实时插值计算**
  - 利用视锥裁剪来减少需要插值计算和绘制的粒子数
    - 两相邻时刻可见粒子并集，ID配对
    - 希尔伯特哈希元胞加速剪裁



  - 插值计算
    - 根据速度计算粒子位置

$$P_{t_i}^j = P_{t_i} + \vec{V}_{t_i} \cdot t_i^j + 0.5c \cdot t_i^{j^2} + f_{ij} \cdot t_i^{j^3}$$

其中

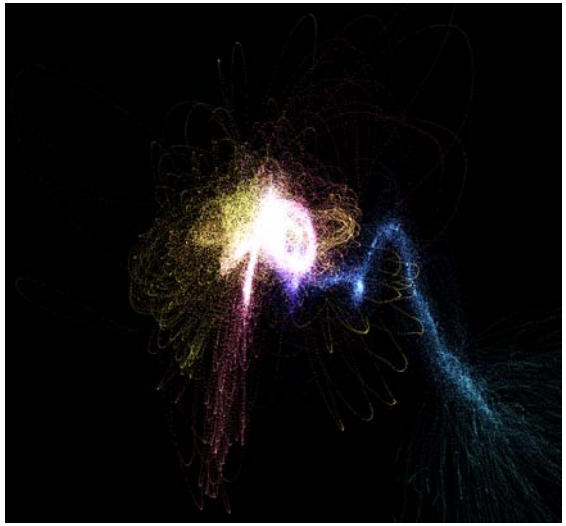
$$c = (3(P_{t_{i+1}} - P_{t_i}) - (3\vec{V}_{t_i} + \Delta\vec{V}) * \Delta t) * 2 * \Delta t$$

$$f_i = (\Delta\vec{V} - \Delta t \cdot c)/(3\Delta t^2)$$

$$\vec{V}_i = \Gamma_i * V_i \quad , \Delta t = \log\ (t_{i+1} - t_i)$$

$$\Gamma_i = \frac{\sqrt{t}}{H \cdot \sqrt{\Omega_{\gamma_i} + \Omega_\lambda}}$$

(H哈勃常数， Ω， Ω_λ为宇宙轴长比)



    - 半径、密度、弥散、质量

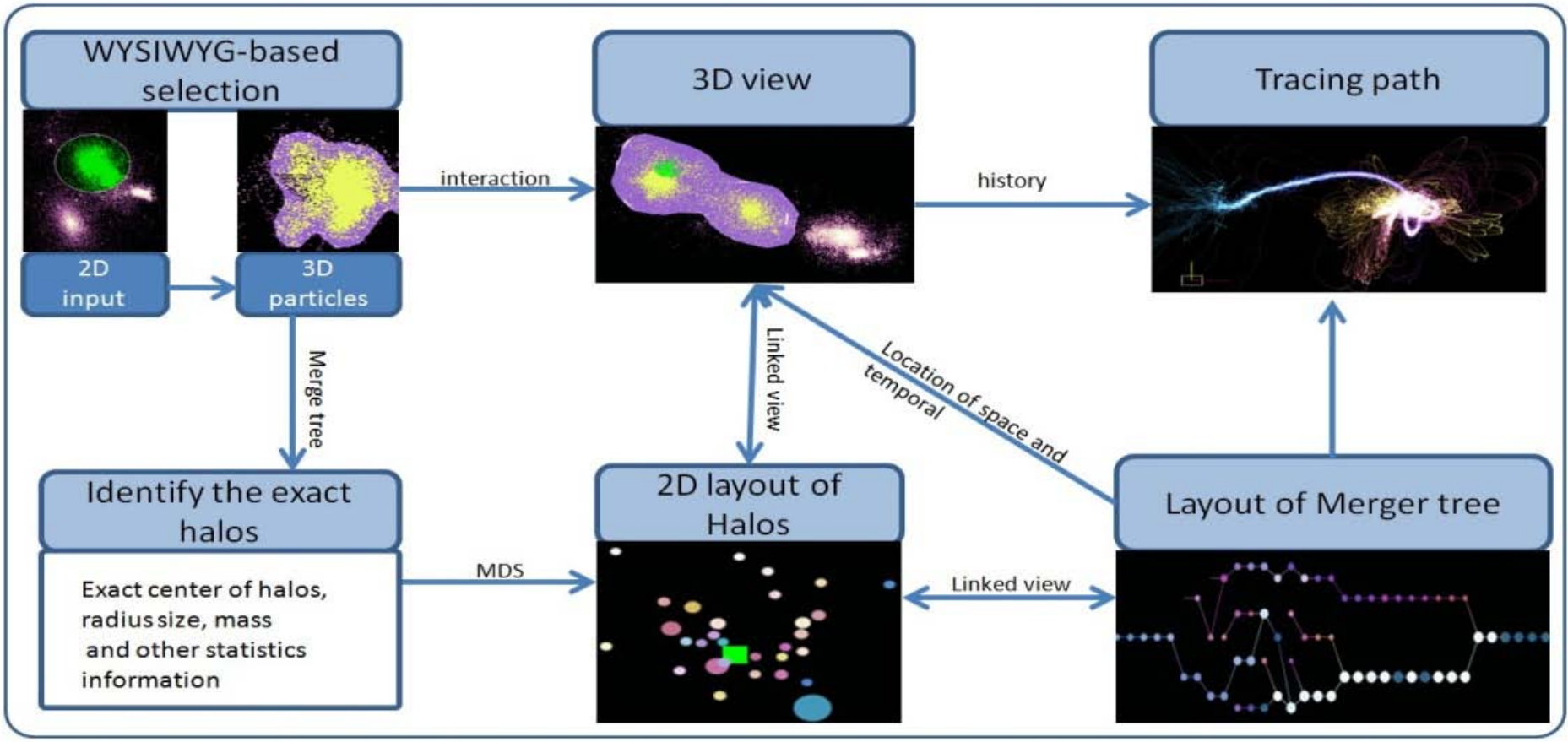
$$r = e^{(\log r_i + \log(r_{i+1}/r_i)) \cdot t/\nabla t}$$

$$\rho = e^{(\log \rho_i + \log(\rho_{i+1}/\rho_i)) \cdot t/\nabla t}$$

$$\sigma = e^{(\log \sigma_i + \log(\sigma_{i+1}/\sigma_i)) \cdot t/\nabla t}$$

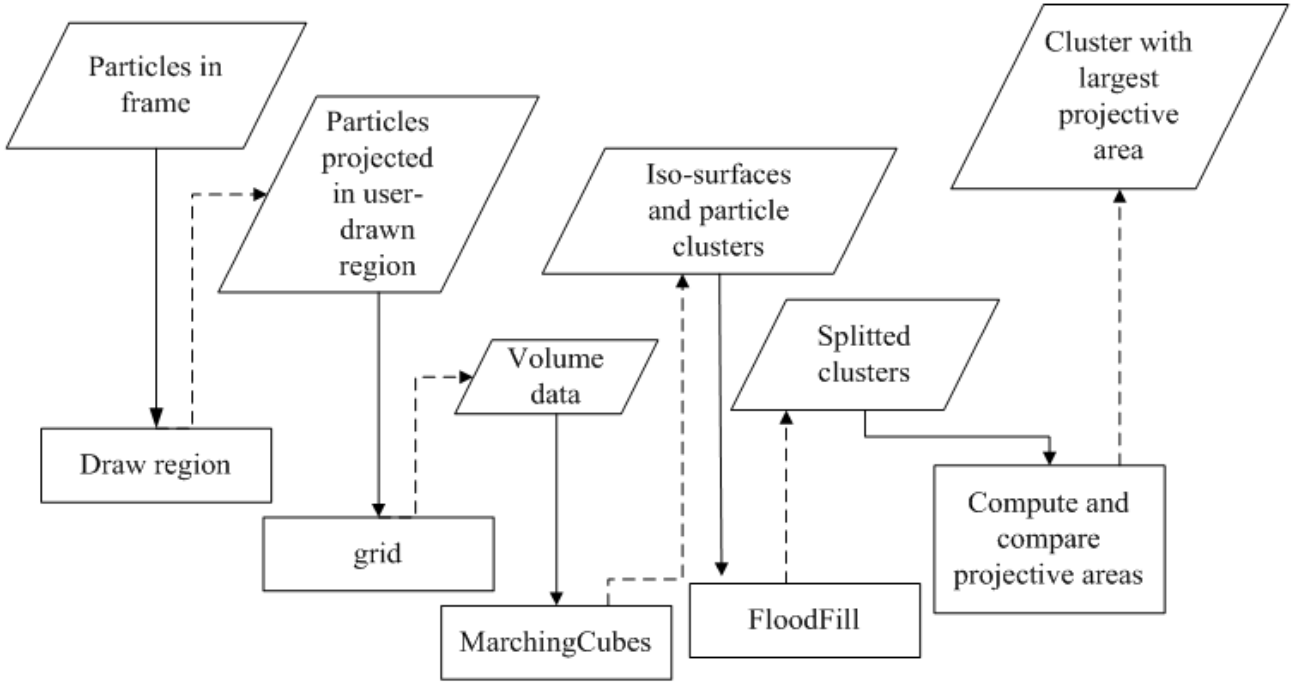
$$m = e^{(\log m_i + \log(m_{i+1}/m_i)) \cdot t/\nabla t}$$

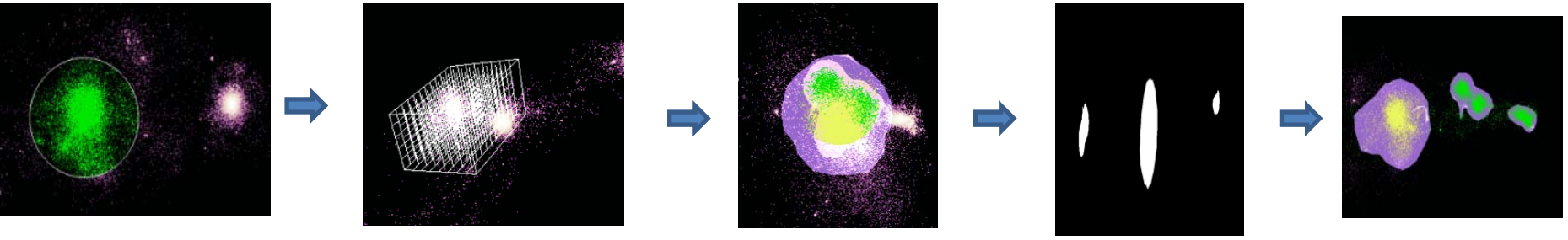
交互式的时序分析

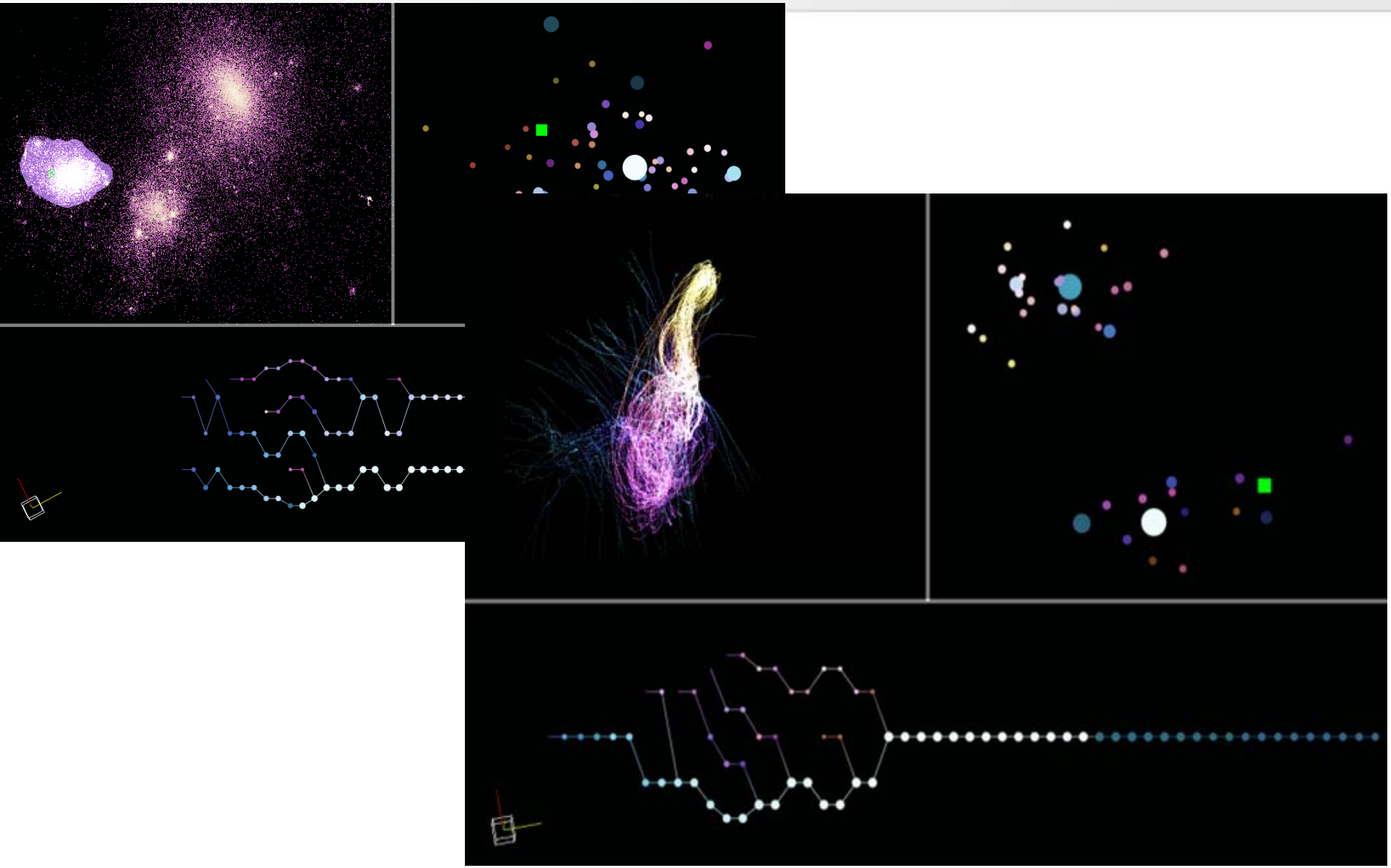

WYSIWYG-based selection
2D input
3D particles
interaction
3D view
history
Tracing path
Merge tree
Linked view
Location of space and temporal
Identify the exact halos
Exact center of halos, radius size, mass and other statistics information
MDS
2D layout of Halos
Linked view
Layout of Merger tree

所见即所的选取

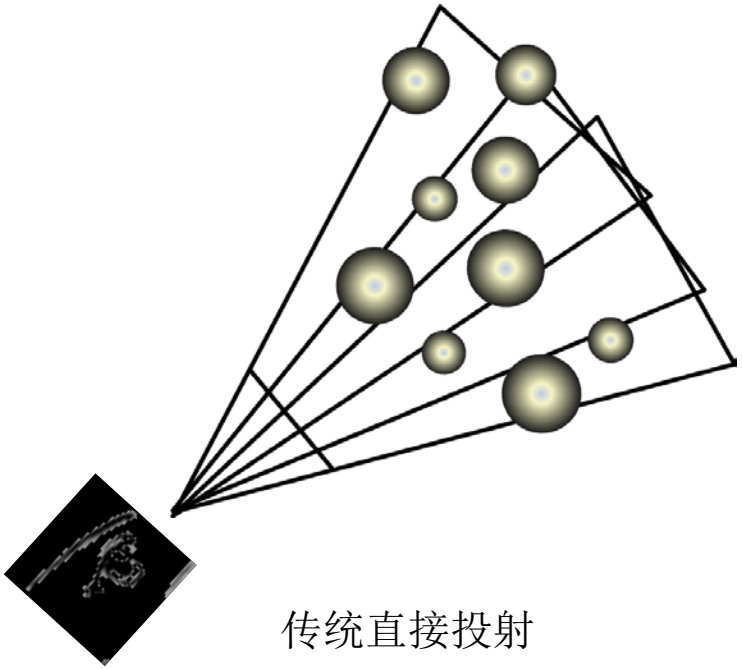
- 二维->三维



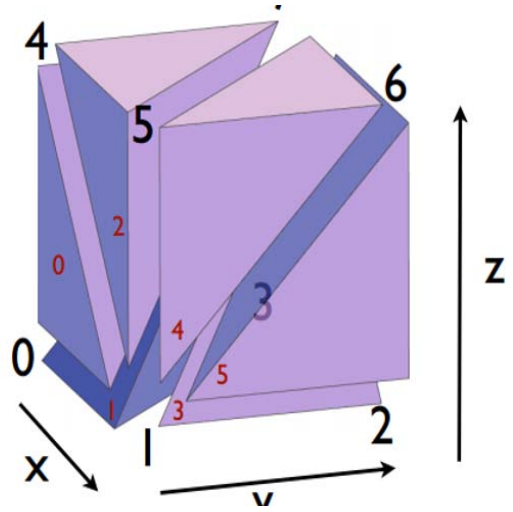




特征可视化优化方法比较

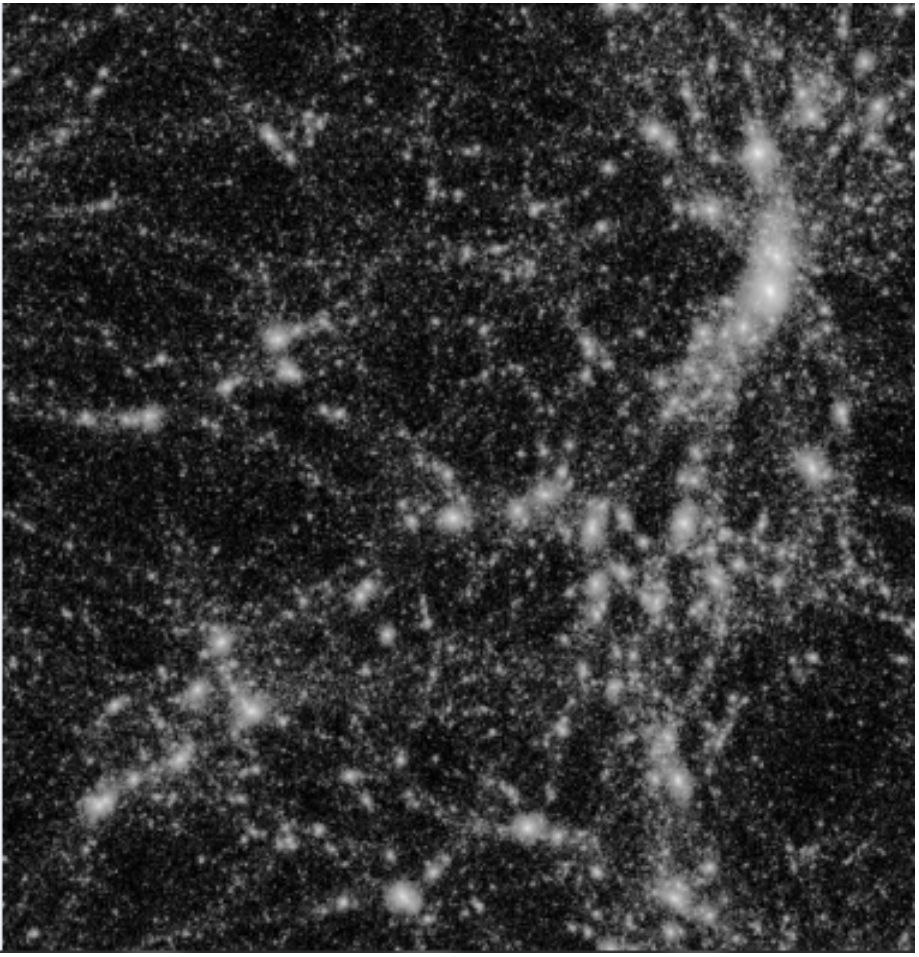


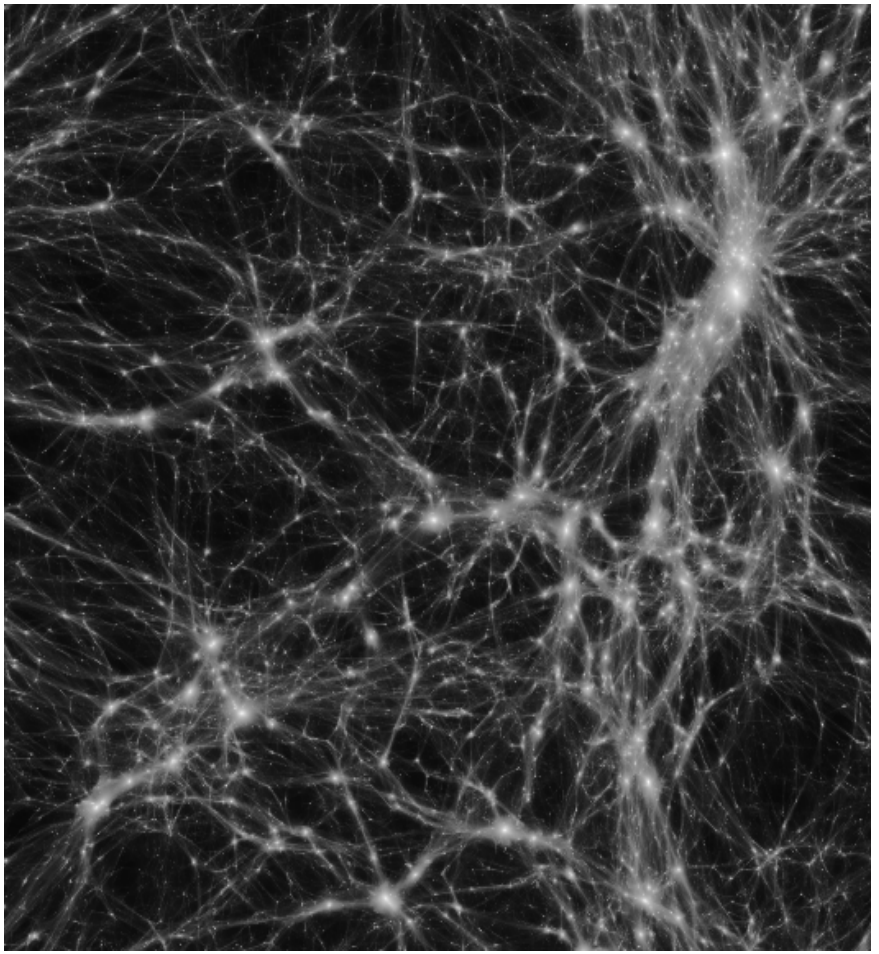
传统直接投射



优化方法基于拓扑特征

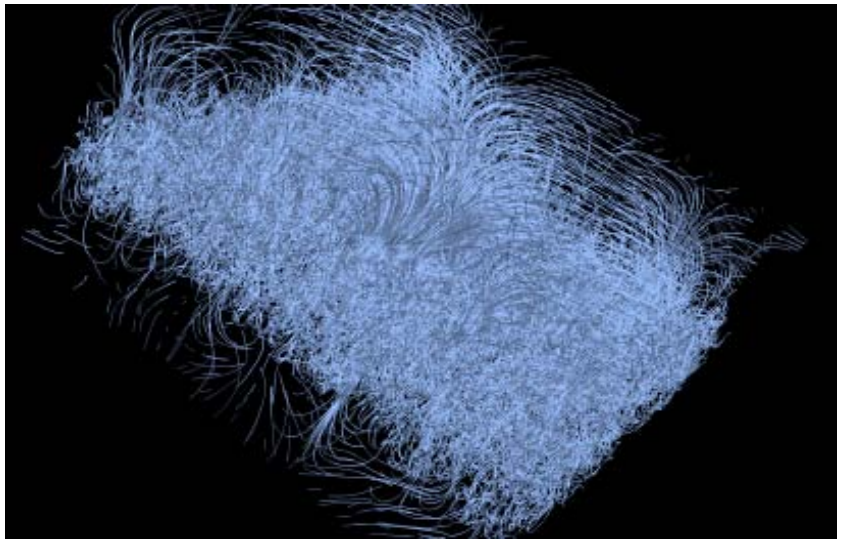
特征可视化优化结果比较





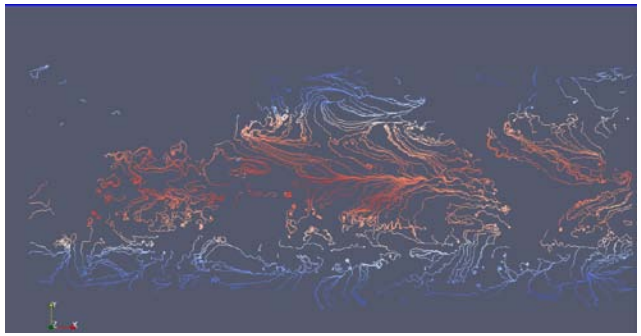
大规模流场可视化

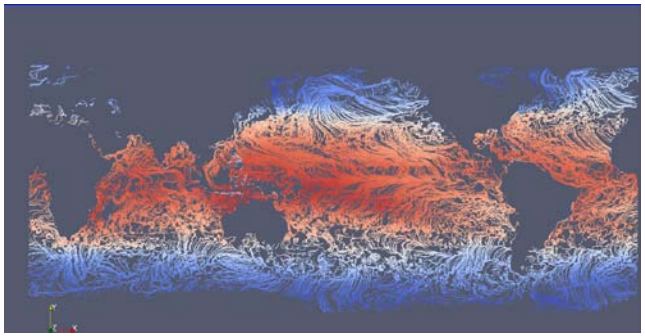
- 流线是流场可视化中最常用的方法
- 问题：
  - 流线多了造成视觉混乱，流线少了会丢失征信息



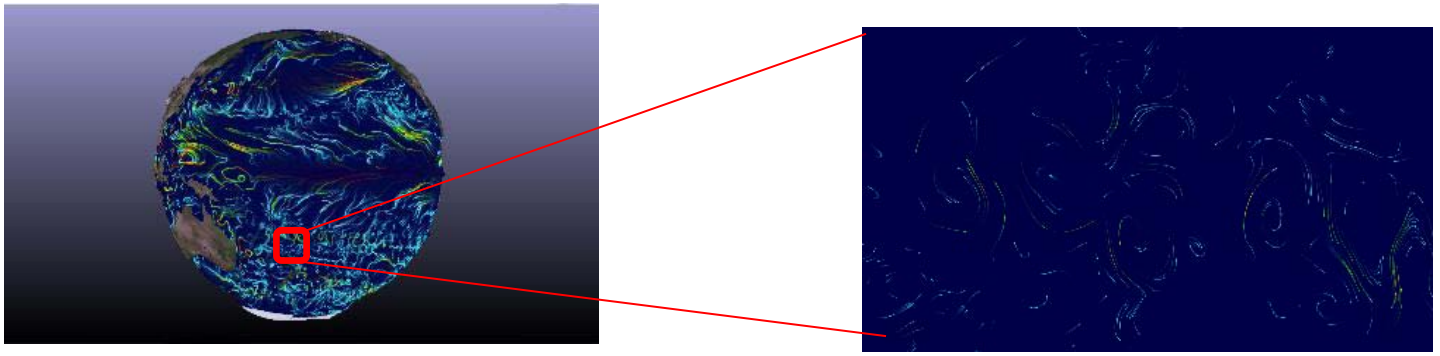
流线种子点选取

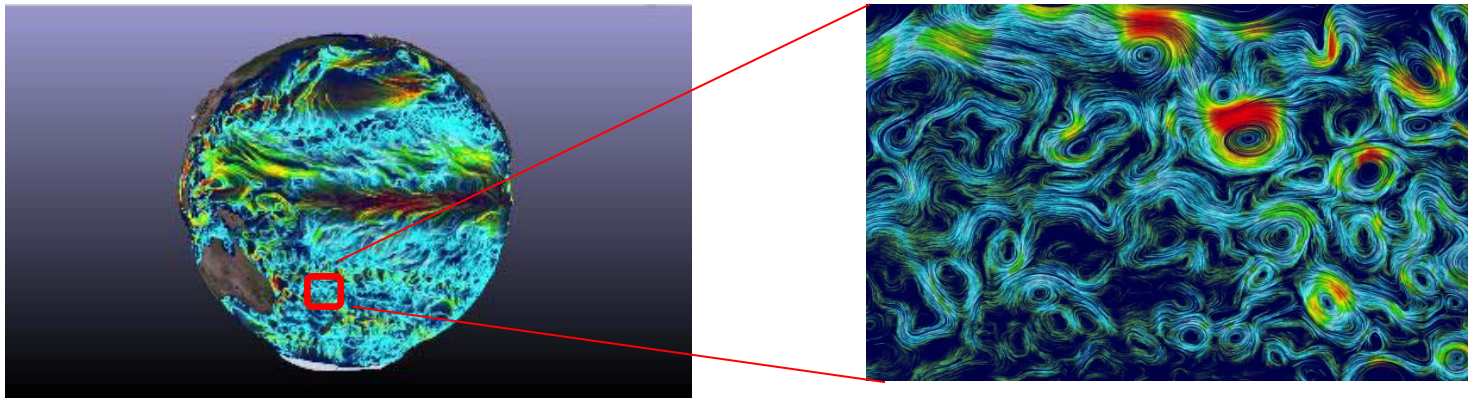
- 难点：种子点的位置决定了流线的位置，种子点的多少决定了流线的多少。种子点过多，流线过多而混乱；种子点过少，流场信息丢失
- 解决方案：结合流场中的临界点检测与流场区域信息熵，提出一种改进的种子点放置方法，能够避免出现大量空白，同时尽可能多的展示流场的特征信息。





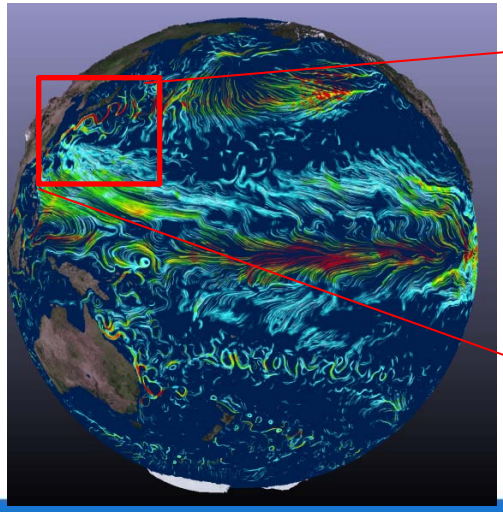
大规模流场可视化全局与局部的困境

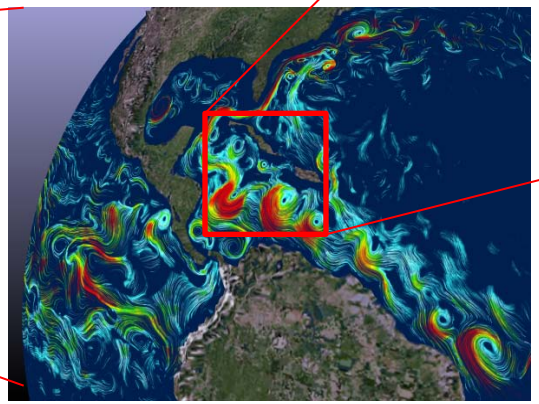


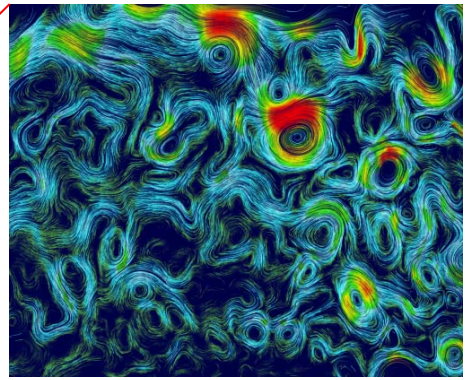


自适应方法

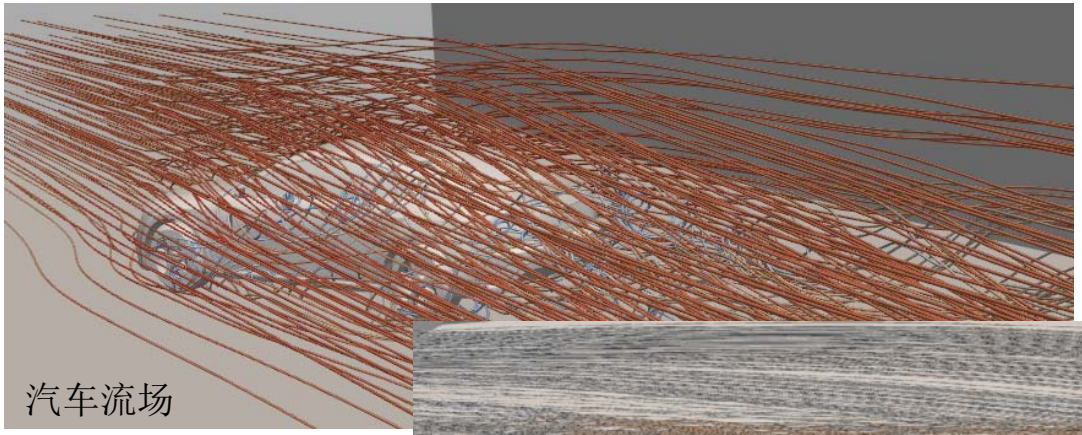
- 基于视窗的自适应层次细节流线可视化
  - 可见视窗内区域设置种子点
    - 大幅度减少计算量，实现交互响应
  - 按图像空间动态自适应生成和回收种子点
    - 高精度刻画流场特征
    - 解决视觉混淆难题



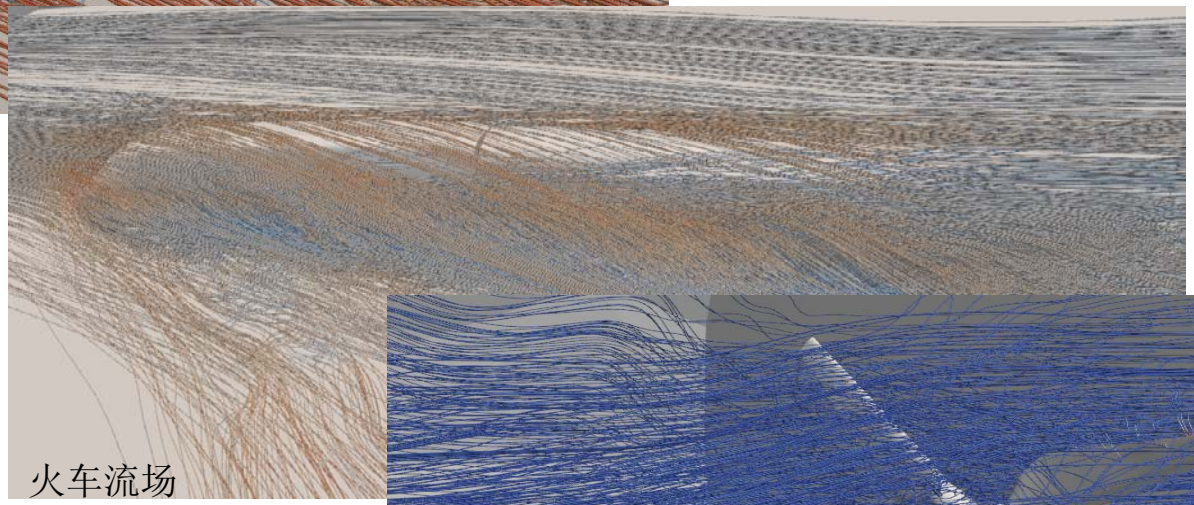




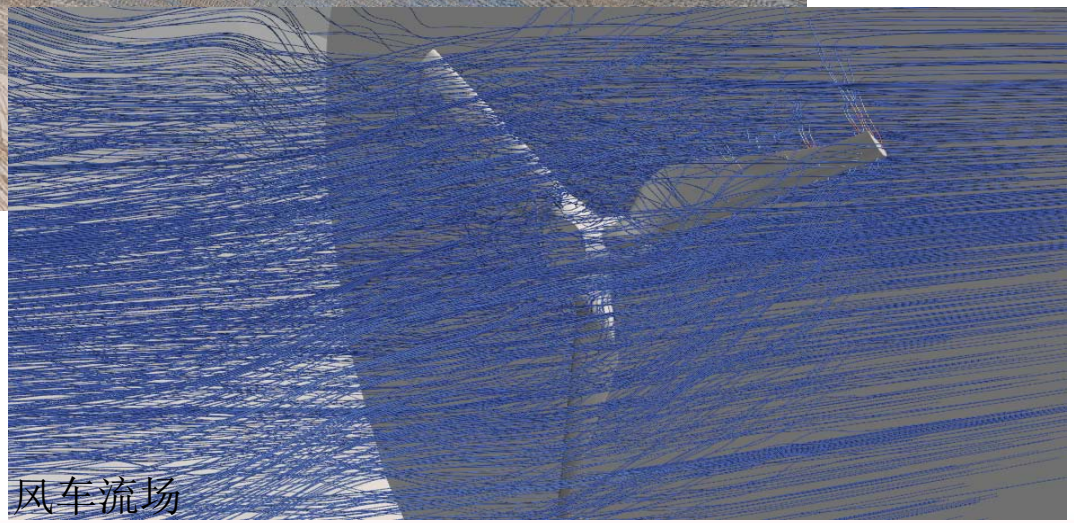
三维流场更复杂



汽车流场

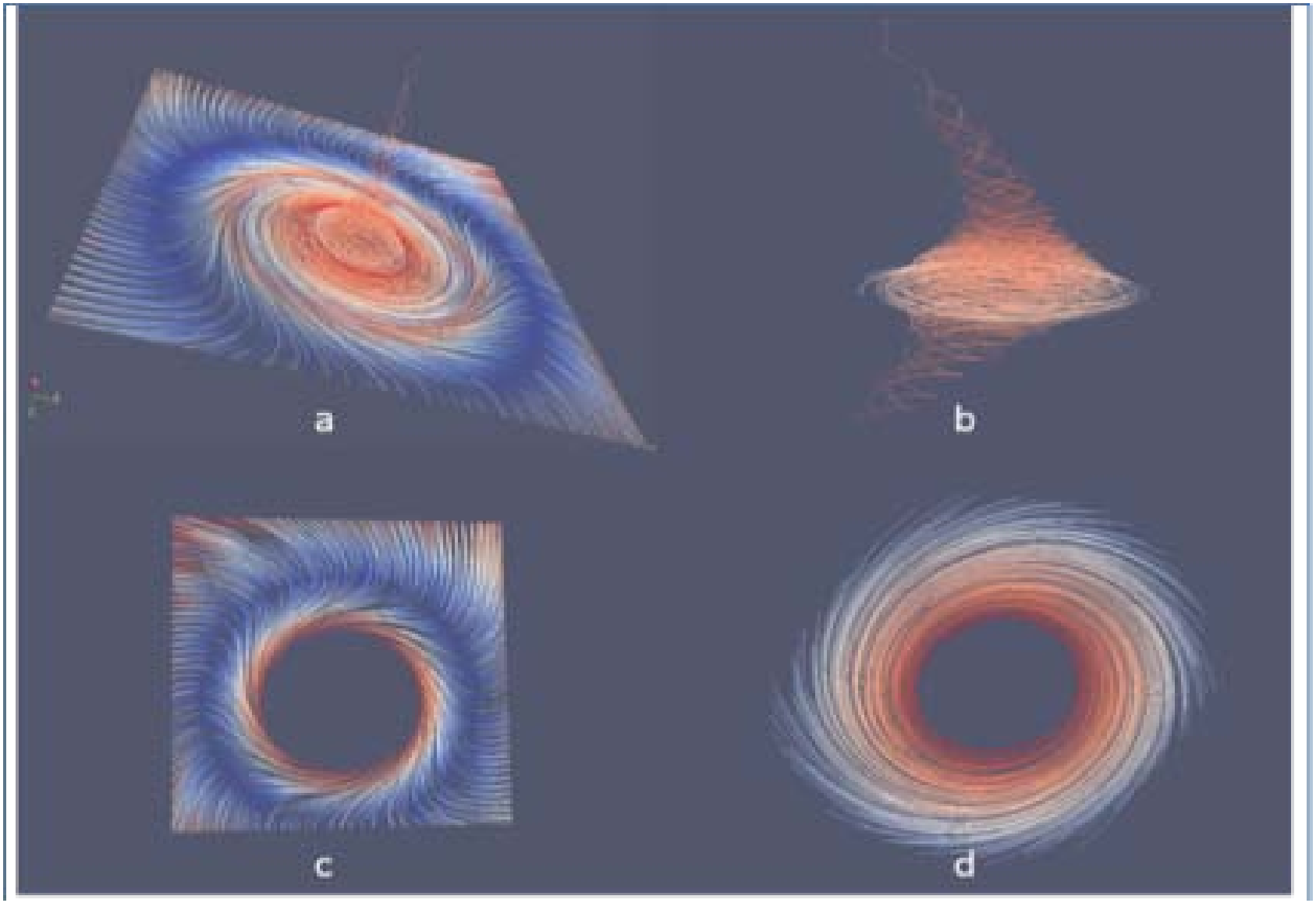


火车流场

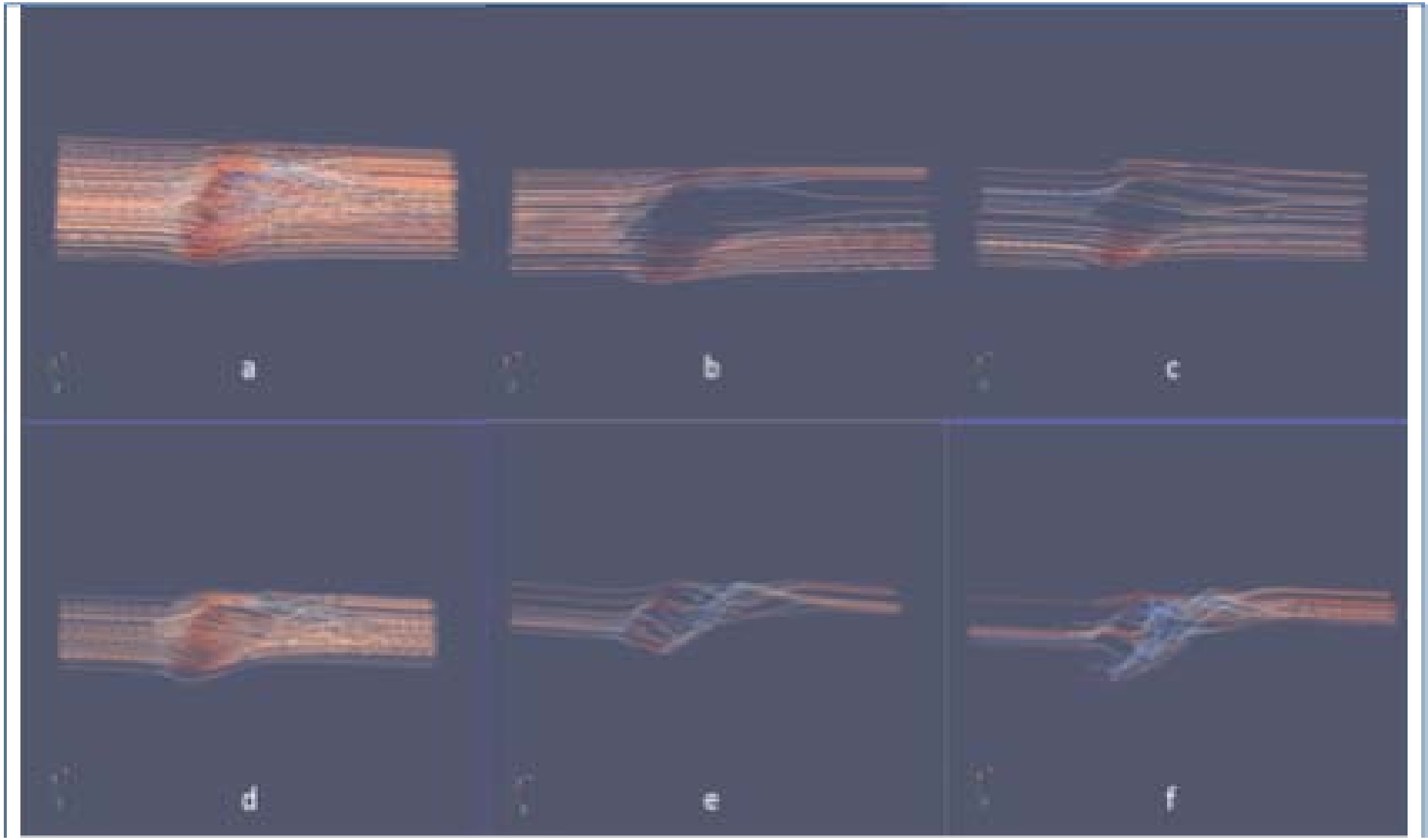


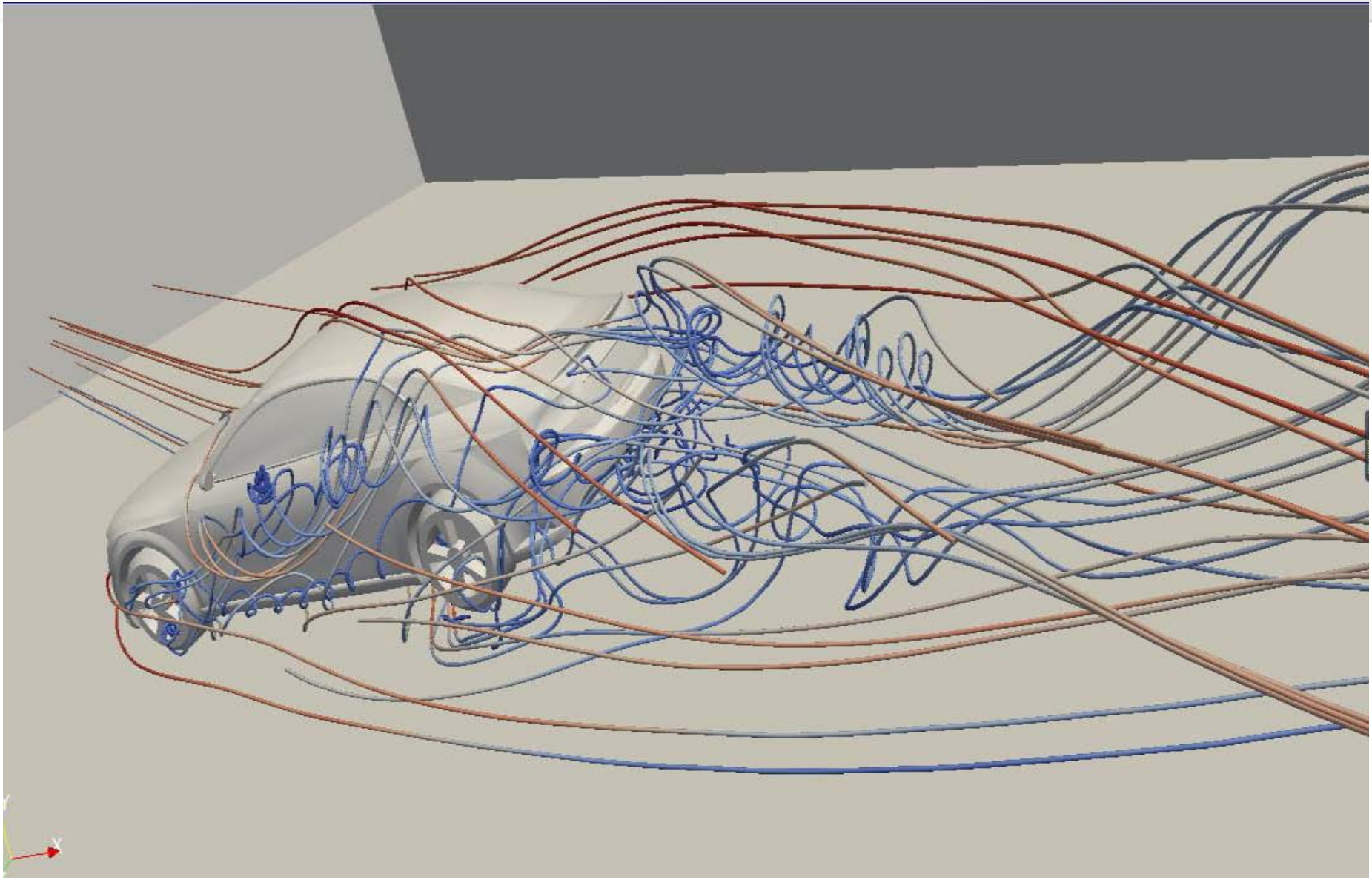
风车流场

飓风

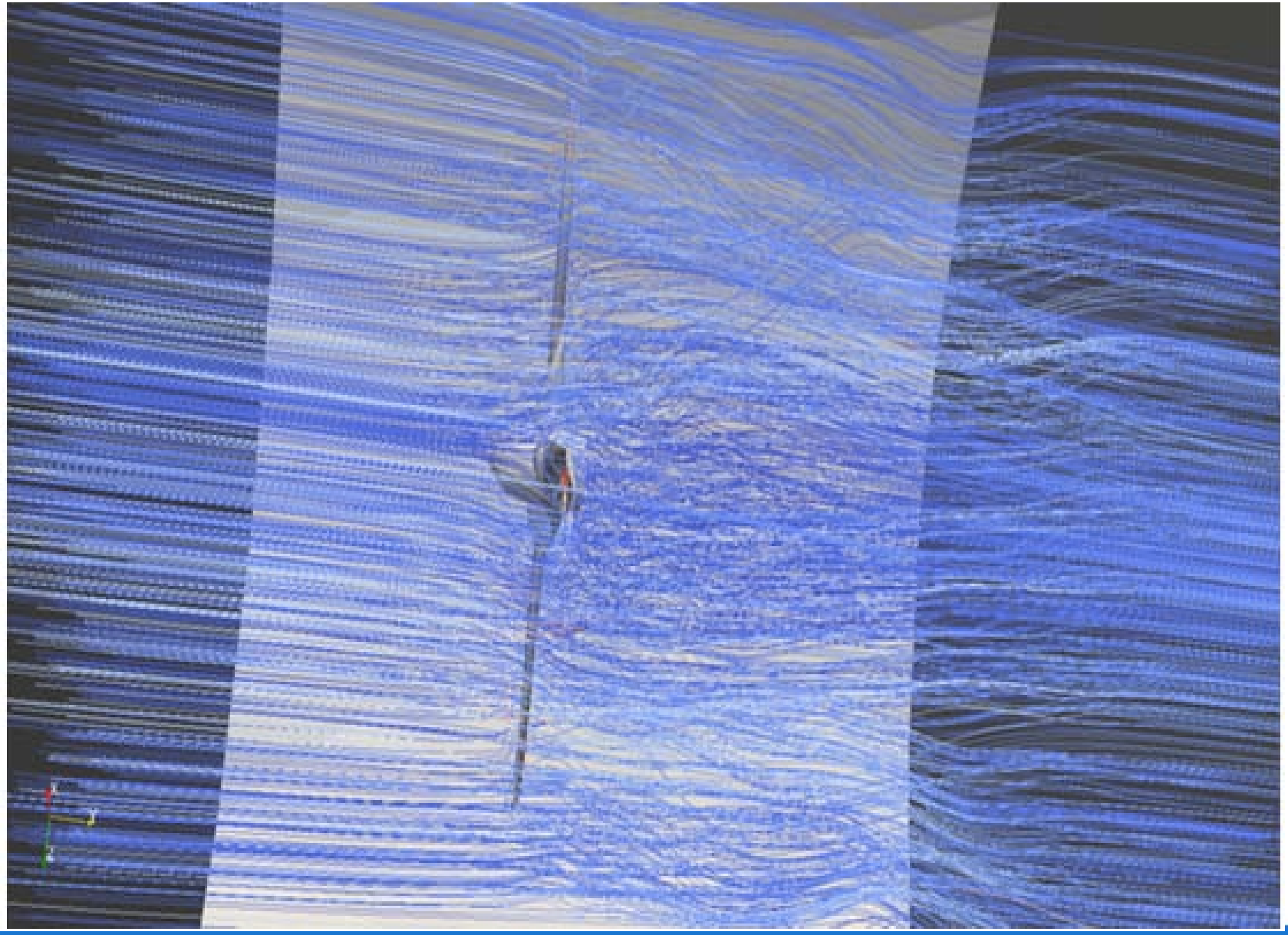


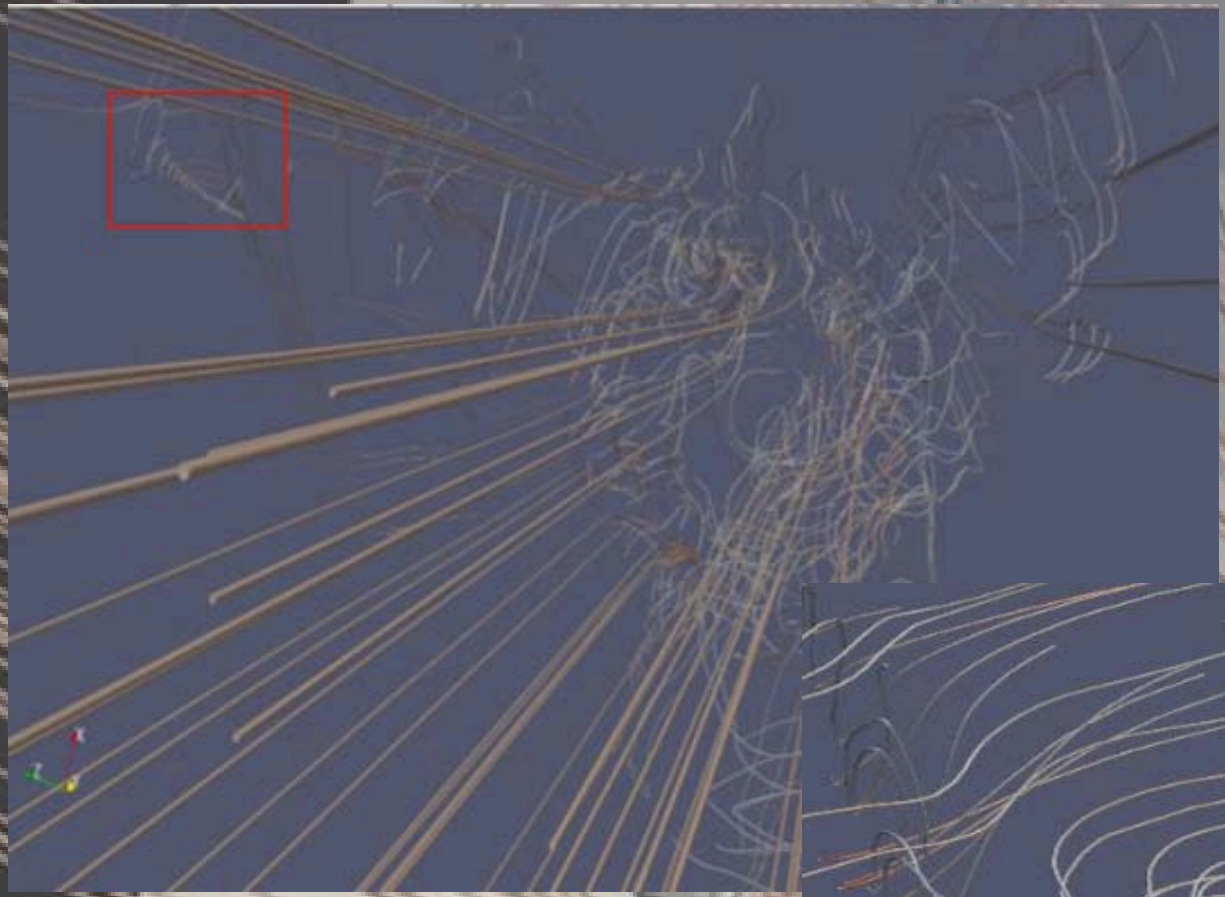
汽车侧风流场

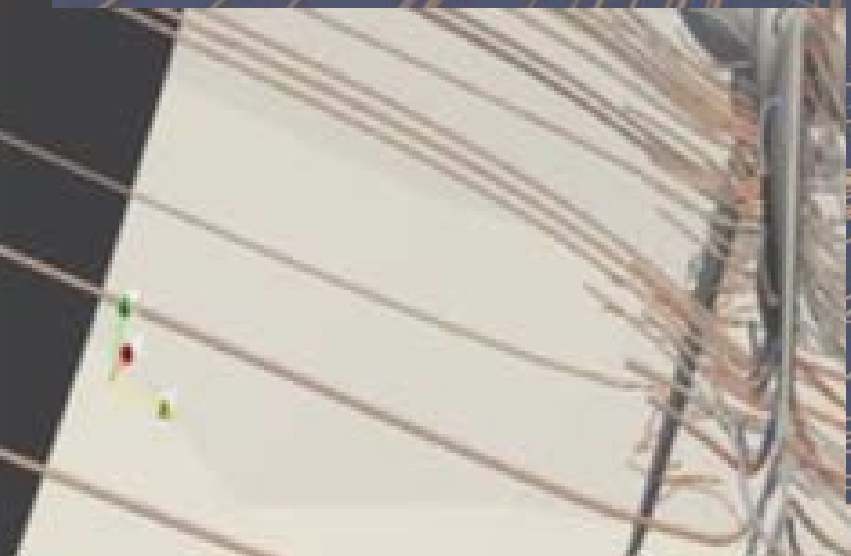



Y
X

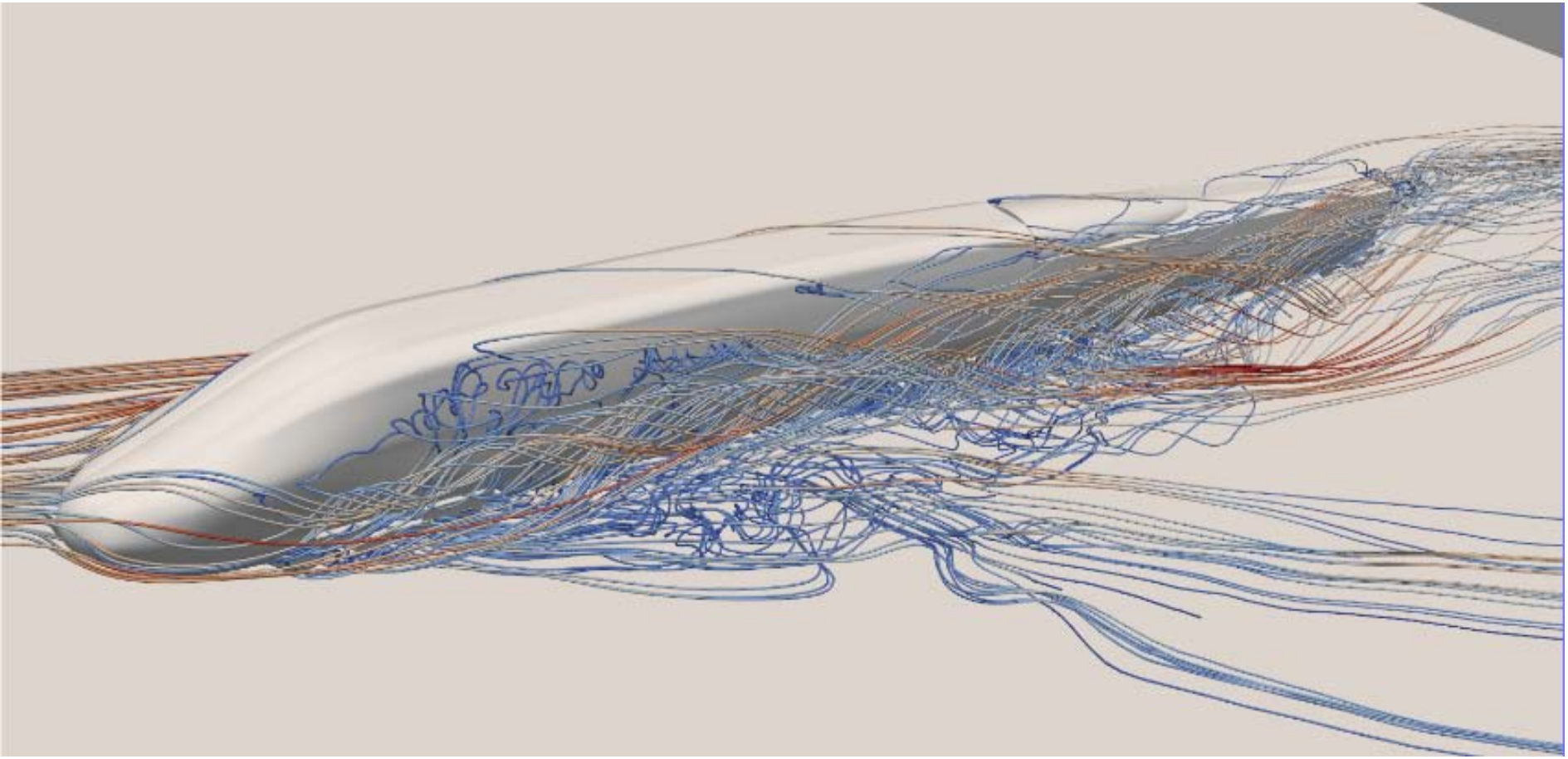
风车叶片流场







侧风高铁流场



谢　谢

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