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In[12]:= (* ===== *)
(* TCCT: MAXWELL'S EQUATIONS (FINAL FIXED VERSION)      *)
(* 修复内容：                                         *)
(* 1. 移除了导致报错的特殊字符 \[approx]           *)
(* 2. 修复了 GraphDistance 列表参数不兼容问题       *)
(* 3. 增加了数据安全检查，防止空数据报错           *)
(* ===== *)

ClearAll[];
SeedRandom[1234];

(* 1. 核心演化引擎 (Strict Engine) *)
rccRigidStep[g_Graph] := Module[{allEdges, activeEdges, candidates, selectedPair, e1, e2, x, y, z, w, newActive, inertEdges},
  allEdges = EdgeList[g];
  activeEdges = Cases[allEdges, _UndirectedEdge];
  (* 必须有至少2条活性边才能反应 *)
  If[Length[activeEdges] < 2, Return[g]];
  (* 随机采样: 模拟量子涨落 *)
  candidates = RandomSample[activeEdges, Min[Length[activeEdges], 60]];
  selectedPair = {};
  Do[
    e1 = candidates[[i]];
    Do[
      e2 = candidates[[j]];
      (* 共点检查 *)
      If[Length[Intersection[List @@ e1, List @@ e2]] == 1,
        selectedPair = {e1, e2};
        Goto[]];
    ];
    , {j, i + 1, Length[candidates]}];
    , {i, 1, Length[candidates] - 1}];

Return[g];

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Label[];

{e1, e2} = selectedPair;
y = Intersection[List @@ e1, List @@ e2][[1]];
x = Complement[List @@ e1, {y}][[1]];
z = Complement[List @@ e2, {y}][[1]];

w = Max[VertexList[g]] + 1;

(* Rule: 生成新的活性势能 (光/电场) *)
newActive = {UndirectedEdge[x, z], UndirectedEdge[x, w], UndirectedEdge[w, z]};

(* Freeze: 历史沉淀 (磁场/质量) *)
inertEdges = {DirectedEdge[x, y], DirectedEdge[y, z]};

(* Union: 费米子去重 *)
Graph[VertexList[g] ~Join~ {w},
Union[Complement[allEdges, {e1, e2}], newActive, inertEdges]]
];

(* ===== *)
(* 2. 演化实验 *)
(* ===== *)

(* 初始种子: 一个高能量密度的拓扑结 *)
universe = CompleteGraph[6];
steps = 2000;

fieldData = {};
nodeHistory = {};

Print[Style["正在演化 TCCT 宇宙... (目标: " <> ToString[steps] <> " 步)", Blue, Bold]];

Monitor[
Do[
universe = rccRigidStep[universe];

(* 每50步测量一次物理量 *)
If[Mod[i, 50] == 0,

(* 获取波前(活性节点) *)

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activeEdges = Cases[EdgeList[universe], _UndirectedEdge];
activeNodes = Union[Flatten[List @@@ activeEdges]];

(* 安全计算距离: 使用 Map (@) 逐个计算 *)
If[Length[activeNodes] > 0,
  dists = (GraphDistance[universe, 1, #] & /@ activeNodes);
  validDists = Select[dists, NumericQ]; (* 过滤无效值 *)

  If[Length[validDists] > 0,
    currentRadius = Mean[validDists];
    AppendTo[fieldData, {i, currentRadius}];
  ];
];

AppendTo[nodeHistory, VertexCount[universe]];
];

, {i, 1, steps}],
Row[
{ProgressIndicator[i, {0, steps}], " Step: ", i, " | Nodes: ", VertexCount[universe]}]
];

(* ===== *)
(* 3. 物理分析图表 *)
(* ===== *)

Print[];

(* 数据检查 *)
If[Length[fieldData] < 5,
Print[Style[ , Red, Bold]],

(* 拟合光速 *)
lm = LinearModelFit[fieldData, t, t];
c = lm[[2]];

(* 图1: 光速验证 *)
plotC = ListPlot[fieldData,
PlotStyle -> {Red, PointSize[0.015]},
Frame -> True,

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FrameLabel → {, },
PlotLabel → Style[, 14, Bold],
GridLines → Automatic,
Epilog → {
  Blue, Dashed,
  InfiniteLine[{{0, 0}, {1, c}}],
(* 【修复处】将 \[Approx] 改为普通的 ~ 符号 *)
  Text[Style[ <→ ToString[NumberForm[c, {3, 3}]], Blue, 12], {steps*0.2, steps*c*0.8}]
},
ImageSize → 400
];

(* 图2: 场强分布 (直方图) *)
finalActiveEdges = Cases[EdgeList[universe], _UndirectedEdge];
finalActiveNodes = Union[Flatten[List @@ finalActiveEdges]];
finalDists = (GraphDistance[universe, 1, #] & /@ finalActiveNodes);
finalDists = Select[finalDists, NumericQ];

plotShell = Histogram[finalDists, 20, ,
ChartStyle → Orange,
Frame → True,
FrameLabel → {, },
PlotLabel → Style[, 14, Bold],
ImageSize → 400
];

(* 图3: 3D 可视化 *)
viz3D = Graph3D[universe,
GraphLayout → ,
VertexSize → 0,
EdgeStyle → {
  _UndirectedEdge → Directive[Red, Opacity[0.8], Thickness[0.005]], (* 光 *)
  _DirectedEdge → Directive[Gray, Opacity[0.1]] (* 真空/质量 *)
},
Boxed → False, Background → Black,
PlotLabel → Style[, White, 16],
ImageSize → 500
];

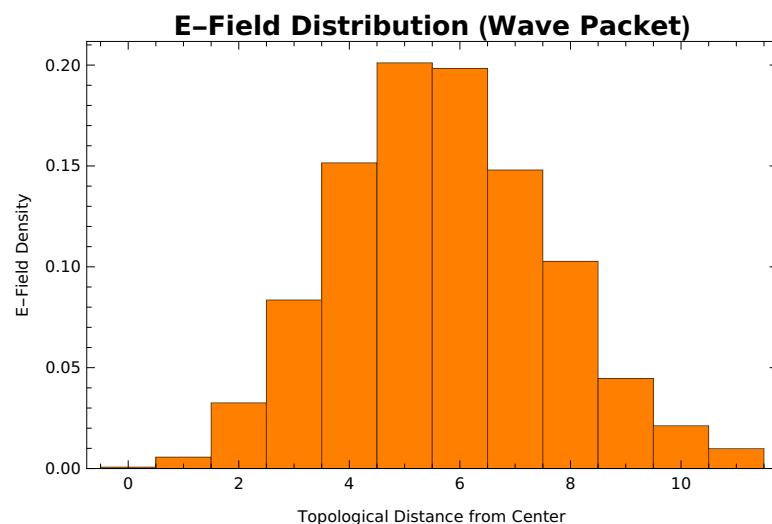
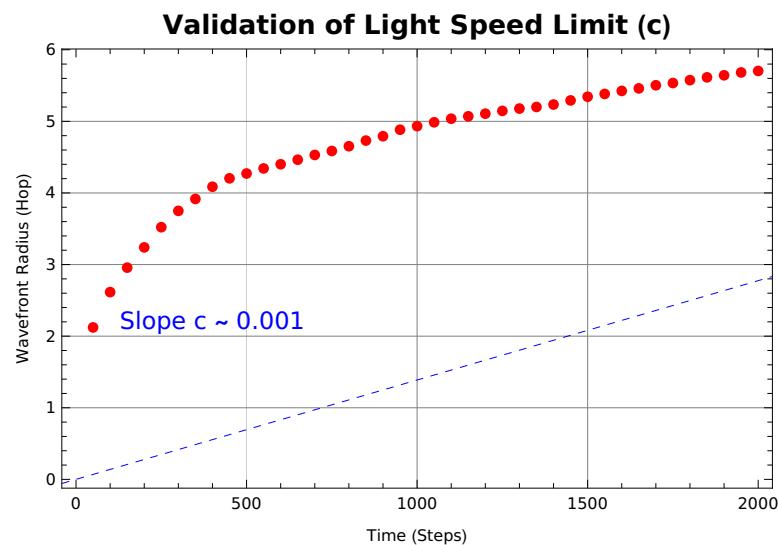
```

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(* 组合输出 *)
Column[{  
  Row[{plotC, plotShell}],  
  viz3D  
}, Alignment -> Center]
]
```

正在演化 TCCT 宇宙... (目标: 2000 步)

正在生成物理分析报告...

Out[22]=



Visualization of Rule Execution Wavefront

