

Solving Einstein's Equations through Computational Science

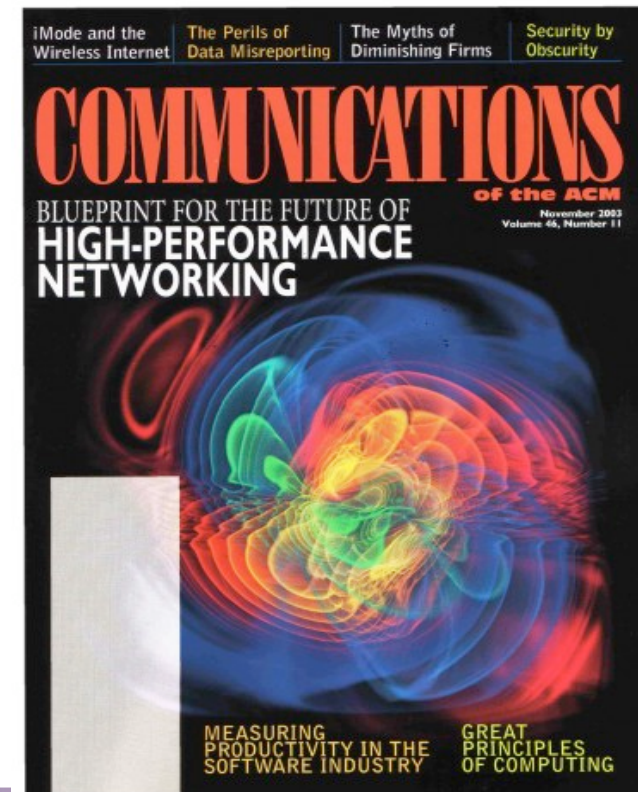
*Advancing Computational Science through GR
(my side career)*

Edward Seidel

Director, Center for Computation &
Technology, LSU

Cray Professor of Physics and
Computer Science, LSU

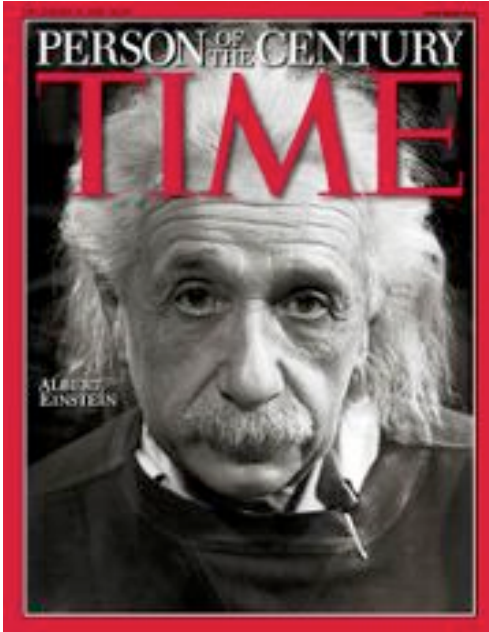
IEEE 2006 Sidney Fernbach Award
Lecture, SC2006



AT LOUISIANA STATE UNIVERSITY



Powerful Beyond Imagination

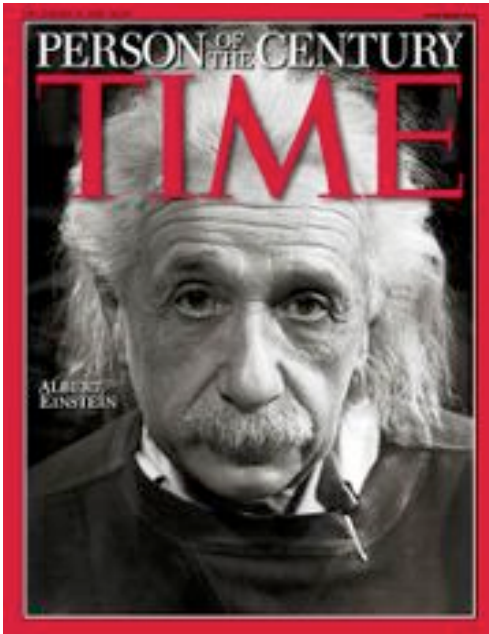


“Computers are incredibly fast, accurate, and stupid. Human beings are incredibly slow, inaccurate, and brilliant. Together they are powerful beyond imagination.”

SC06 Tag Line



Powerful Beyond Imagination

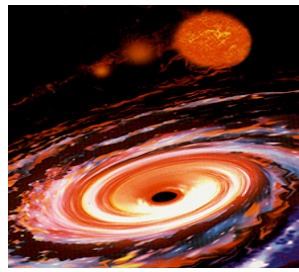


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50 years later: Computers are $\sim 2^{35}$ times faster now! Extending human intelligence (a la Kurzweil) to allow us to solve equations Einstein could not! He would be very pleased with progress!



Einstein's Equations and Gravitational Waves

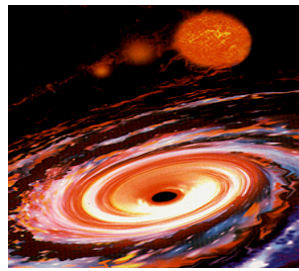


Two major motivations/directions for numerical relativity

- Exploring Einstein's General Relativity
- Developing theoretical lab to probe this fundamental theory
 - Fundamental theory of Physics
 - Among most complex equations of physics
 - Dozens of coupled, nonlinear hyperbolic-elliptic eqs: 1000's of terms
 - Barely have capability to solve after a century
 - Predict black holes, gravitational waves, etc, but want much more

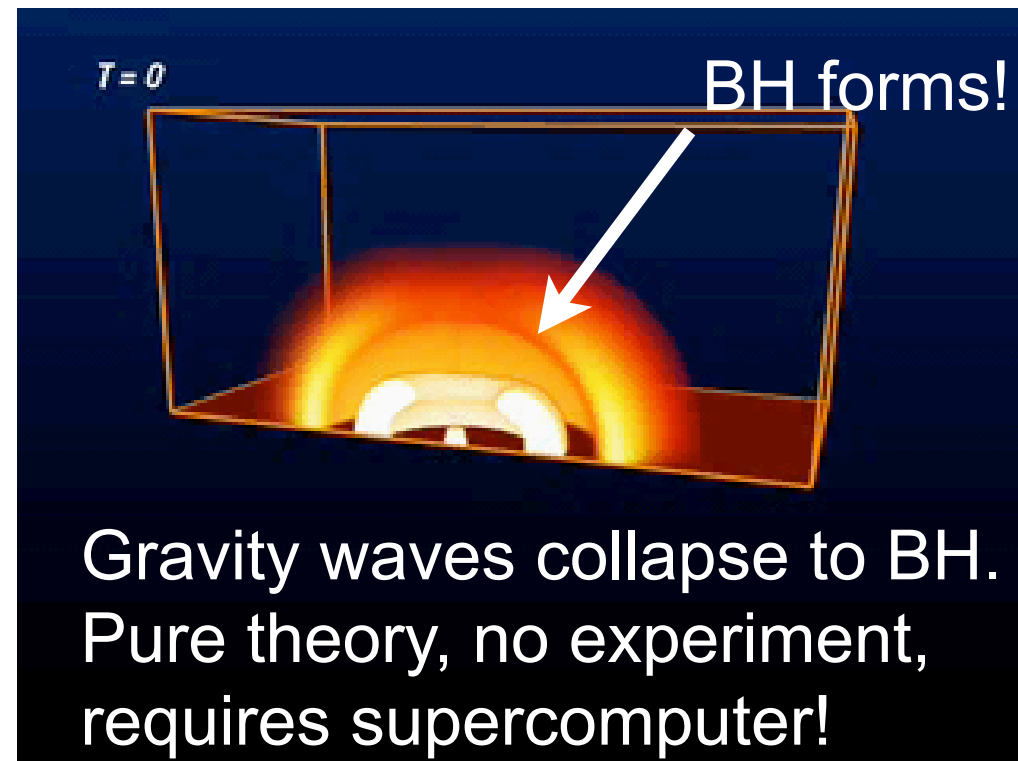


Einstein's Equations and Gravitational Waves



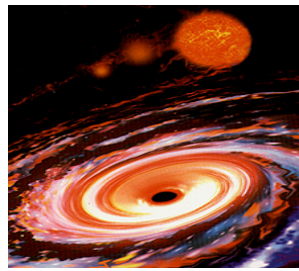
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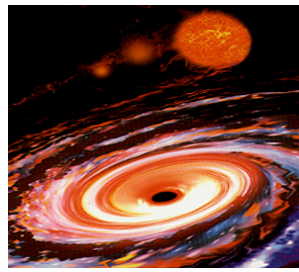


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- Exciting new field about to be born: Gravitational Wave Astronomy
 - LIGO, VIRGO, GEO, LISA, ... ~ \$1 Billion worldwide!
 - Fundamentally new information about Universe
 - A last major test of Einstein's theory: do they exist?
 - Eddington: "Gravitational waves propagate at the speed of thought"
 - 1993 Nobel Prize Committee: Hulse-Taylor Pulsar (indirect evidence)
 - 20xx Nobel Committee: ??? (For actual detection...)



Einstein's Equations and Gravitational Waves



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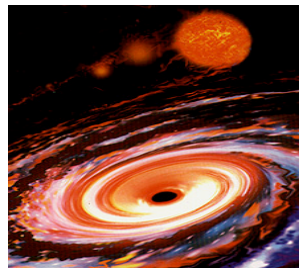
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Kaehler viz, ZIB, AEI

Christian Ott, et al. AEI & U Arizona. ~ First 3D GR SN...



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*One century later, breakthroughs happening at the same time!
HPC + grids + algorithm + theory all essential ingredients.*

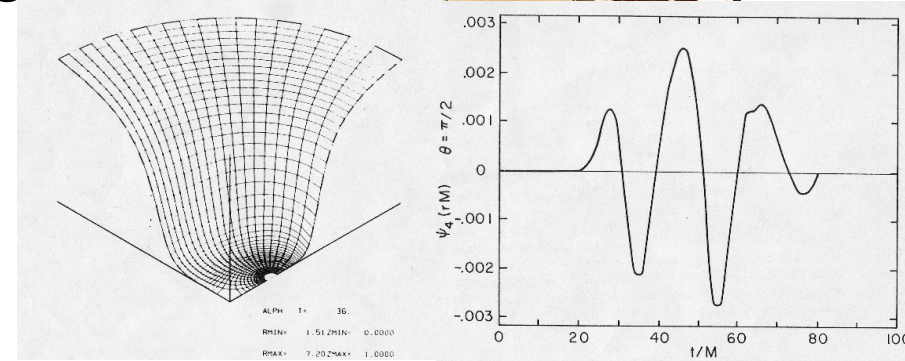


Very Early Experiments



Larry Smarr Role

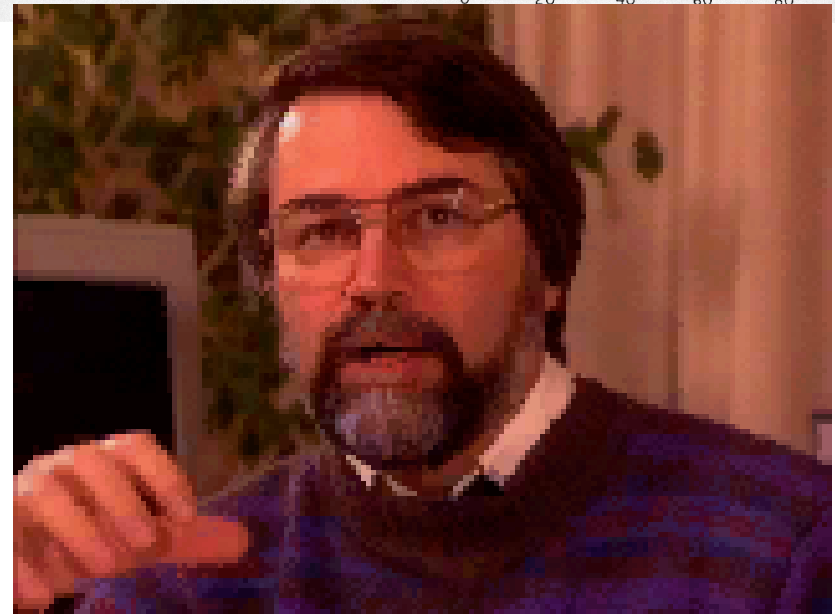
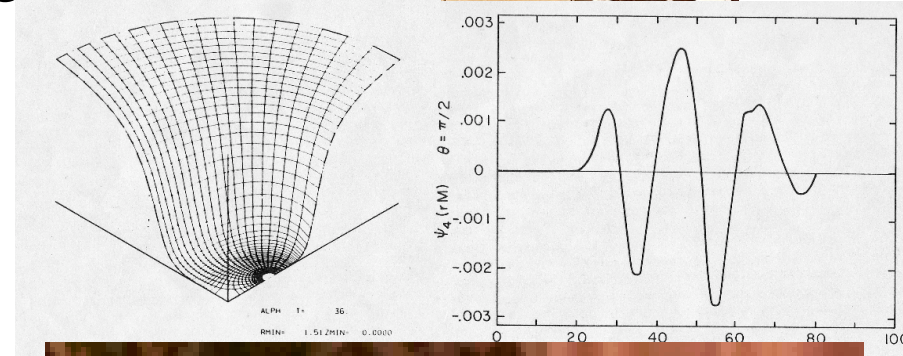
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 - Foundations of modern numrel
 - “Done by X-mas!”
 - Computing on “iPod-class” supercomputer
- Max-Planck facilities
 - US Supercomputer famine
 - National centers program
- Much of modern-day HPC grew out of this; inspiration for more





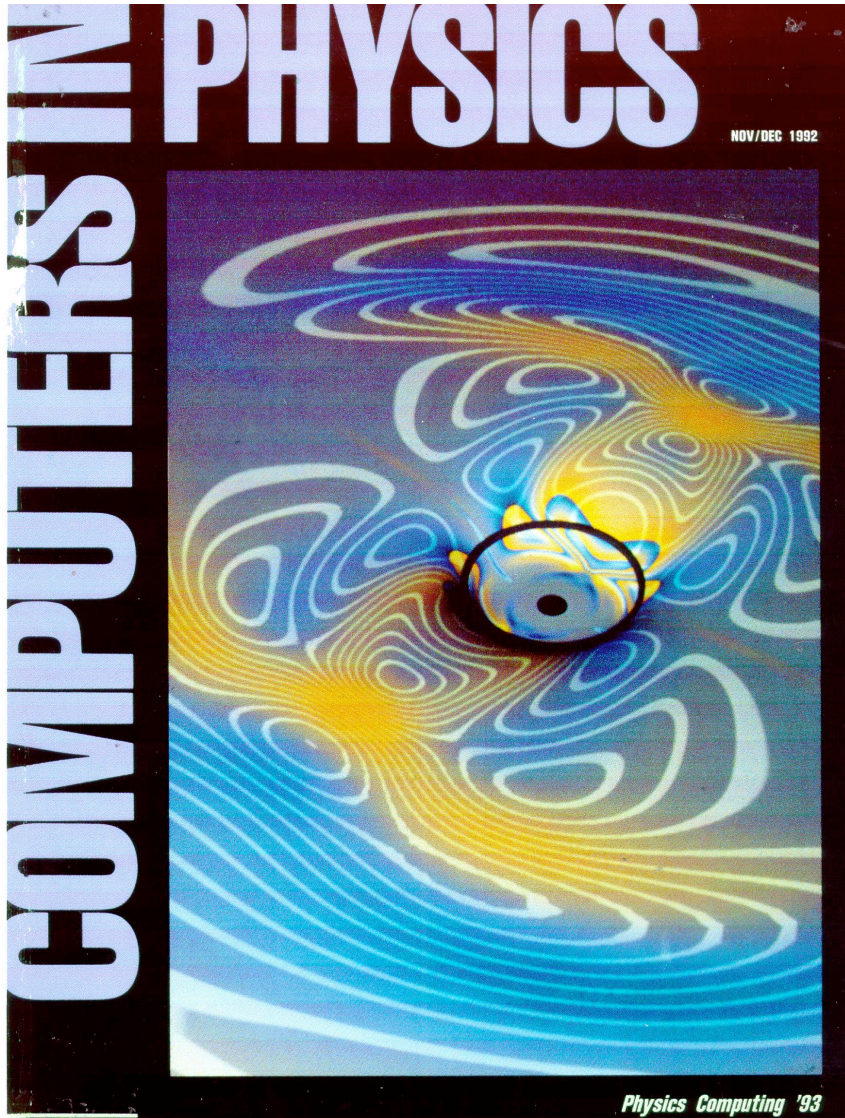
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Computational Needs for 3D Numerical Relativity



The diagram shows two 3D grid planes representing spacetime. The top plane, labeled $t=10$, shows a single black hole with red wavy lines representing gravitational waves emanating from it. The bottom plane, labeled $t=0$, shows two black holes in the process of merging, with a grid that is distorted and compressed between them.

- Get physicists + CS people together
- Initial Data: 4 coupled nonlinear elliptics
- Choose Gauge (coordinates)
- Evolution
 - Dozens of nonlin. hyperbolic eqs.
 - Coupled with elliptic eqs.
 - 100's of 3D arrays, TByte, TFlop crucial, PByte/PFlop soon needed
- Interpret Physics

Dynamic interplay between theoretical, algorithmic, technology advances!

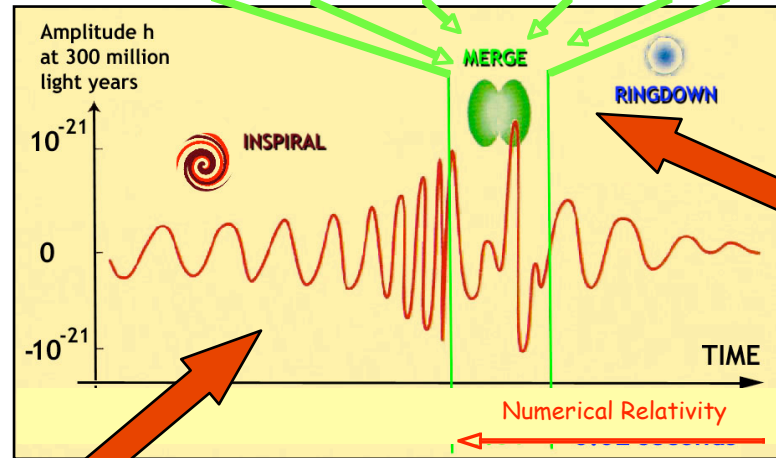


Gravitational Wave Physics

Computing Nature via HPC

Analysis & Insight

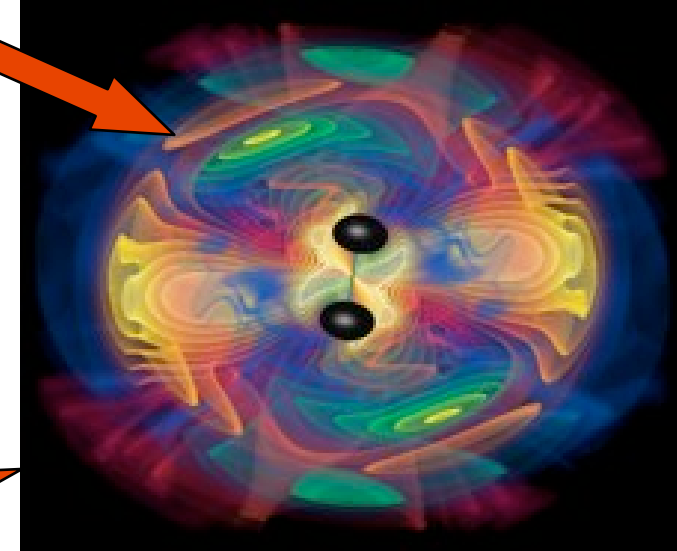
Teraflop Computation, AMR, Elliptic-Hyperbolic, ???



Observations



Models



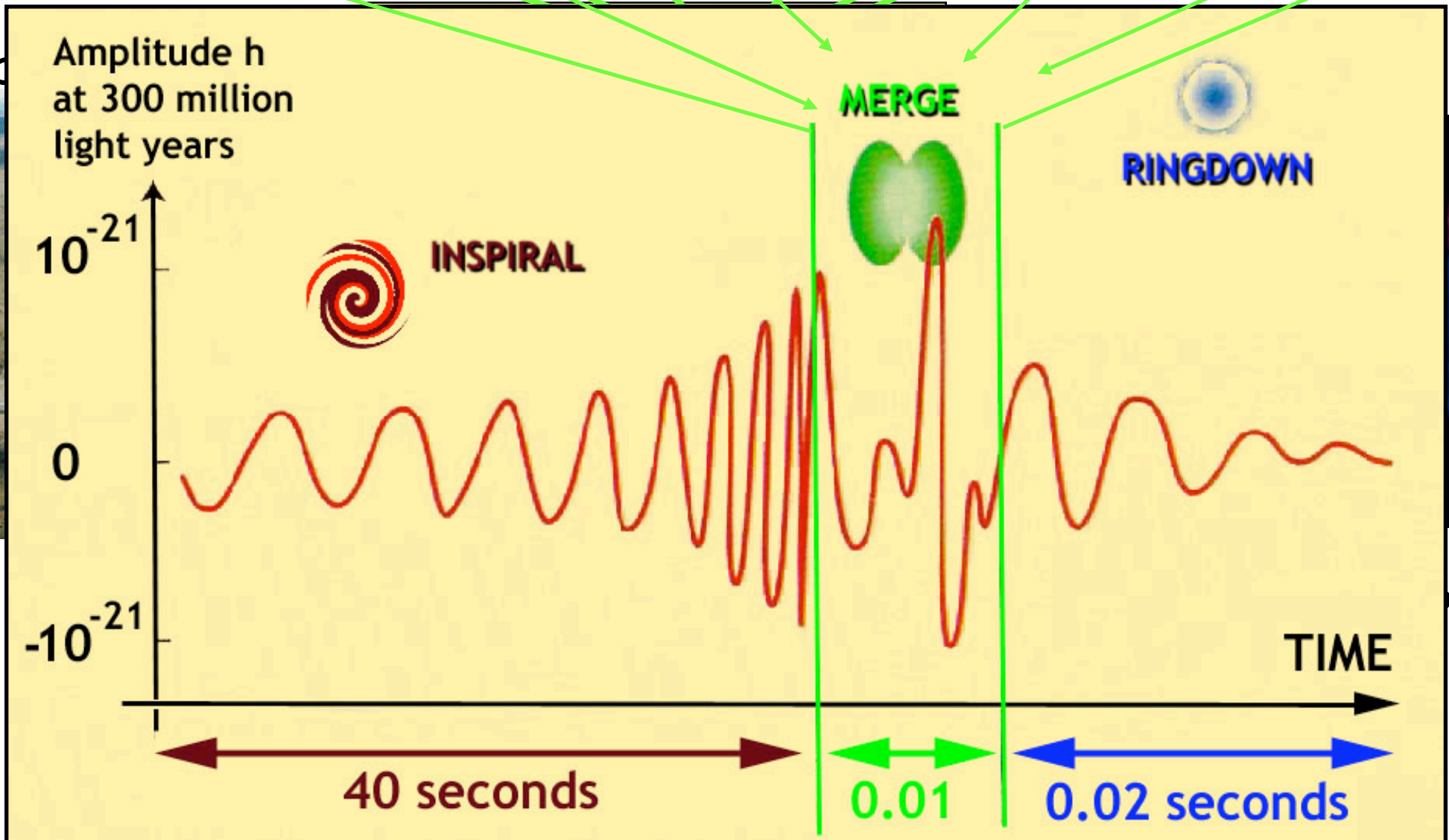
LSU/AEI Collaboration
(Seidel/Rezzolla)



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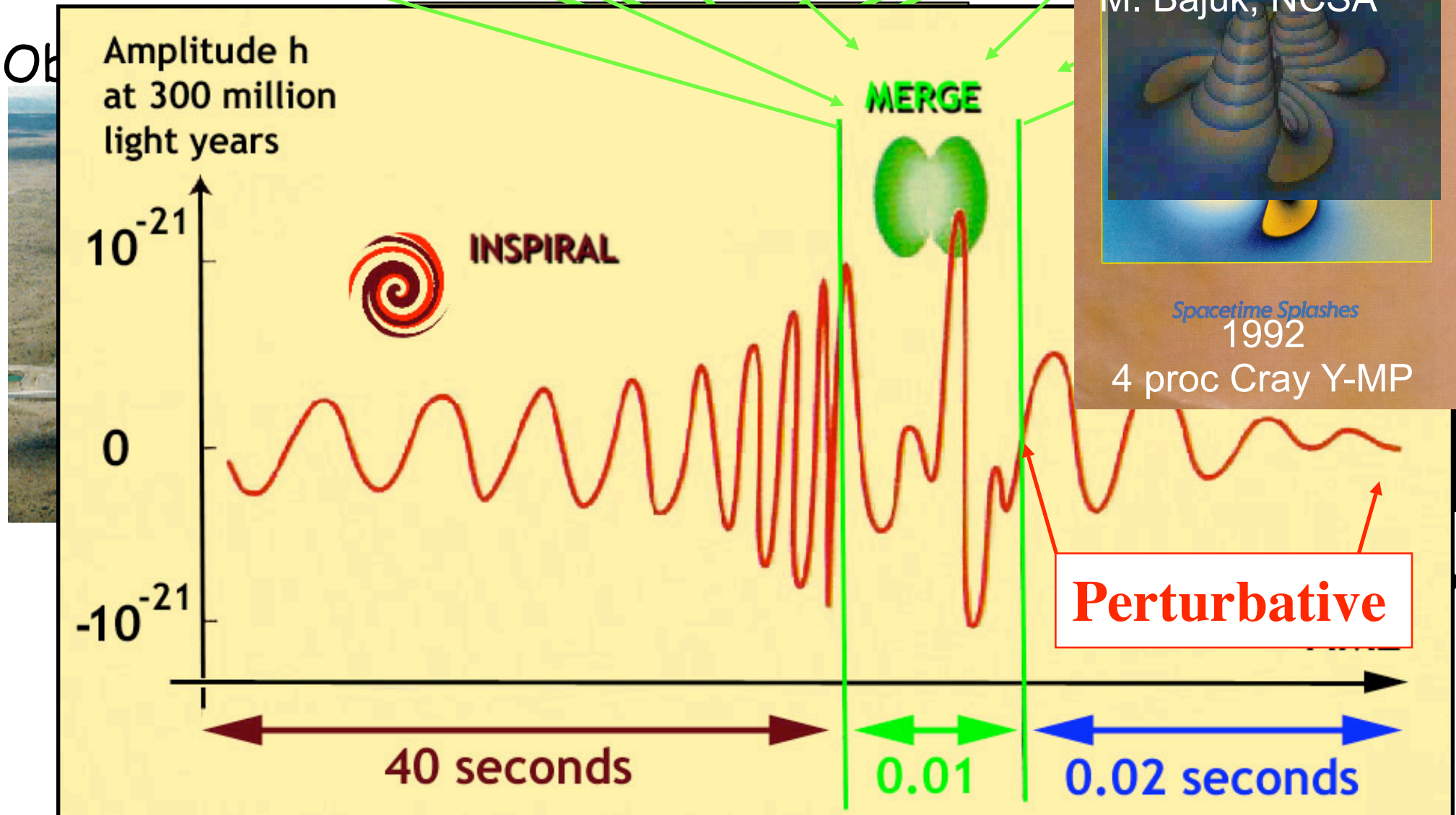
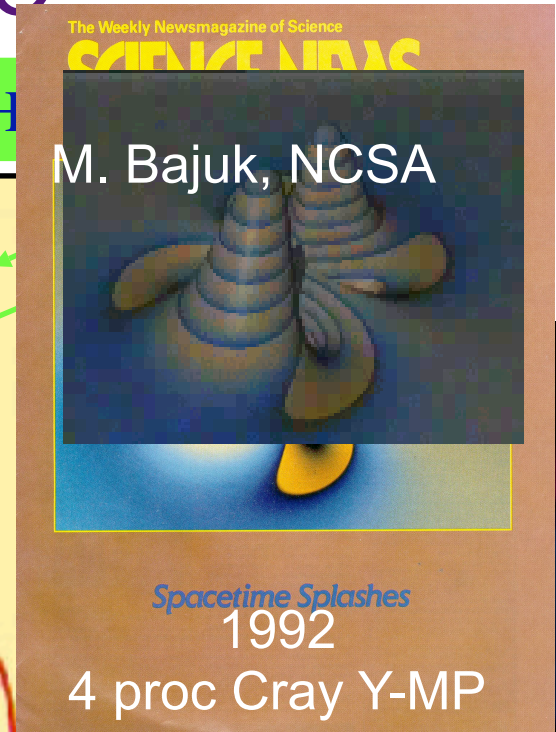




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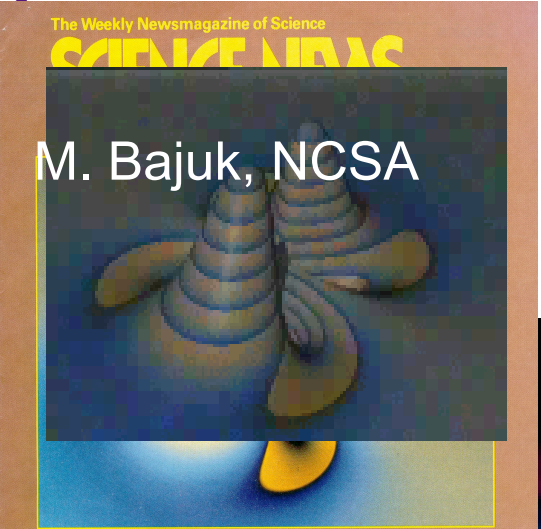




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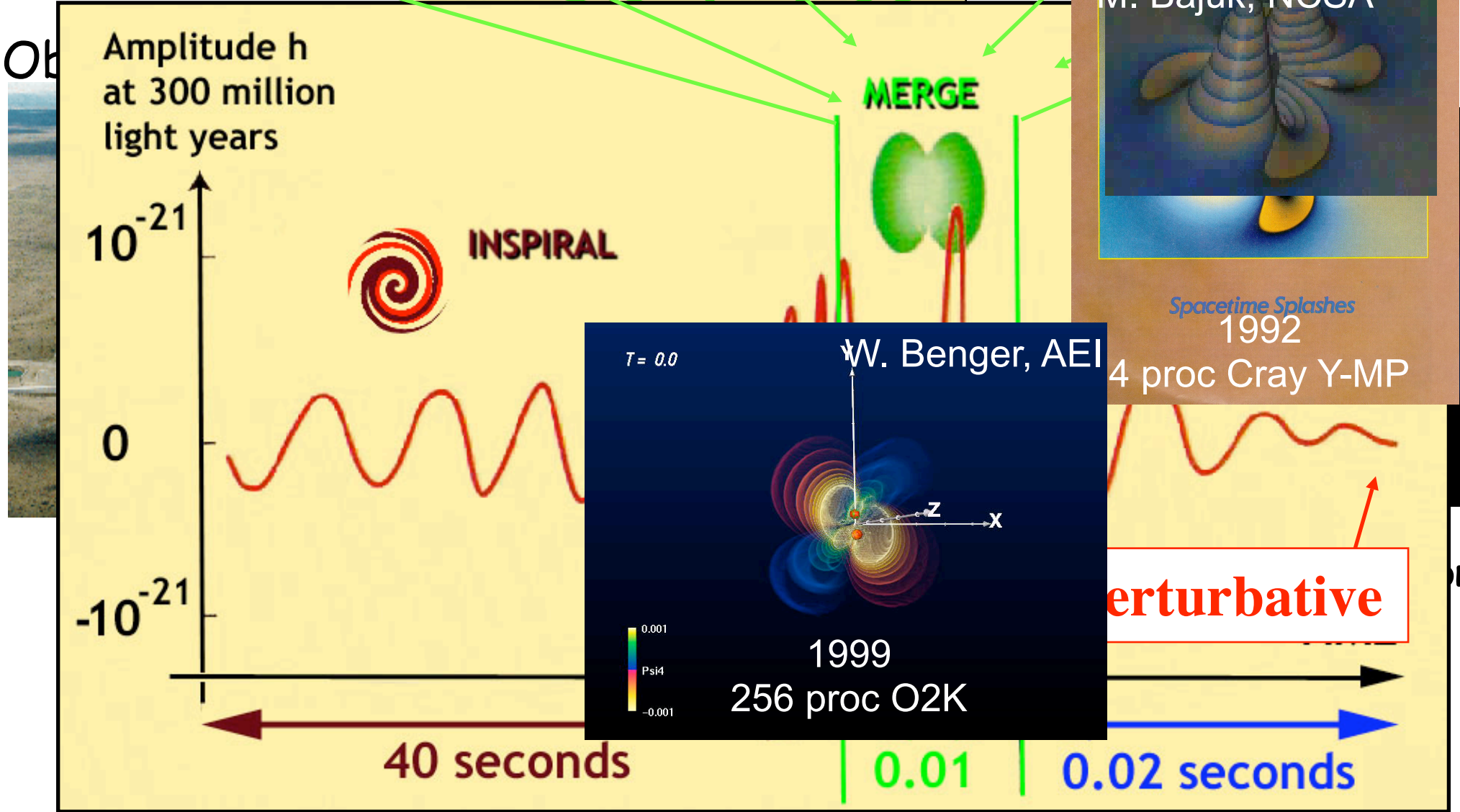
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Spacetime Splashes
1992

4 proc Cray Y-MP

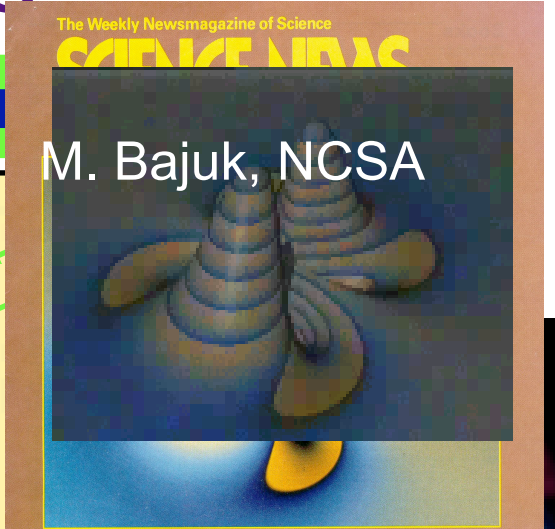




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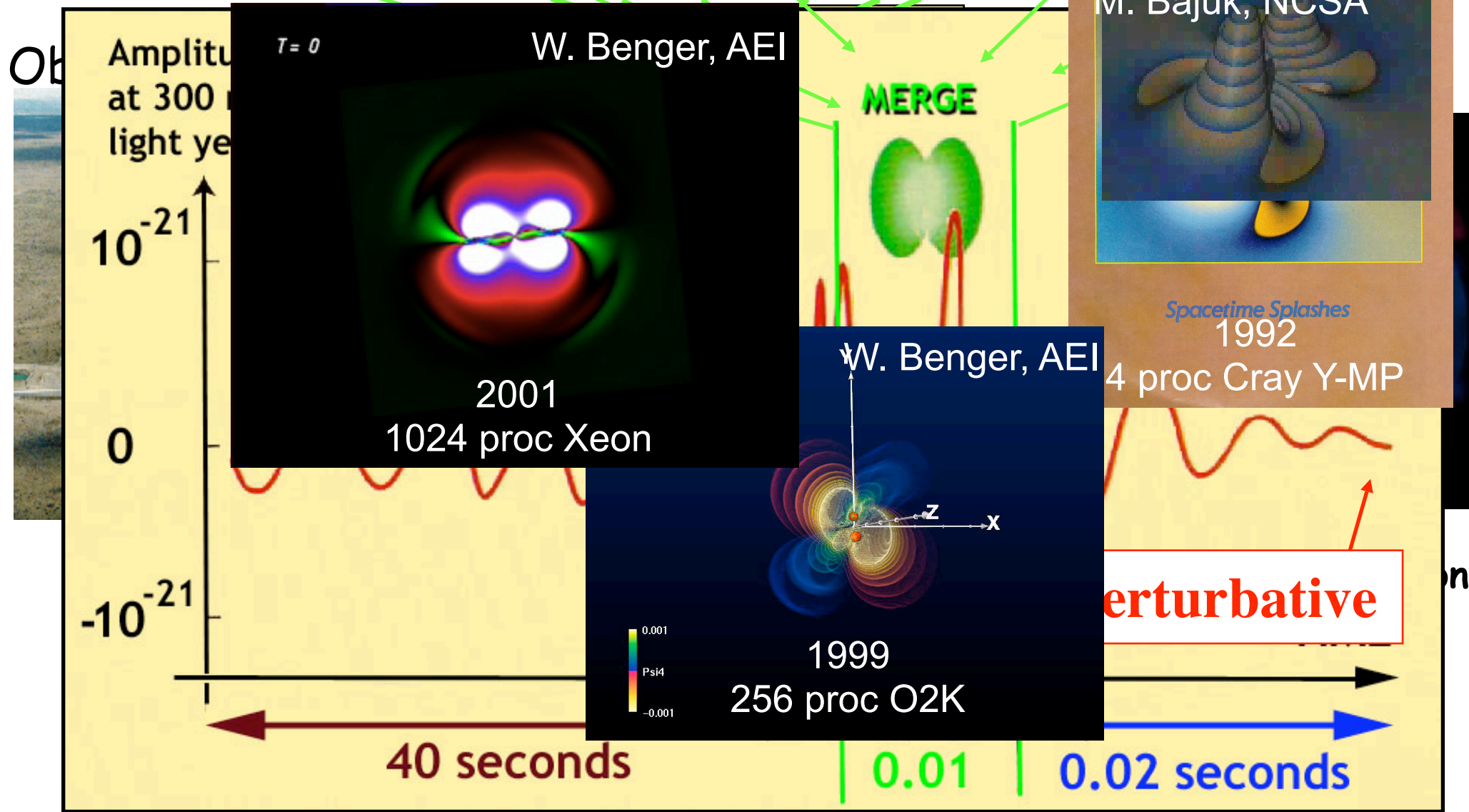


M. Bajuk, NCSA

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erturbative

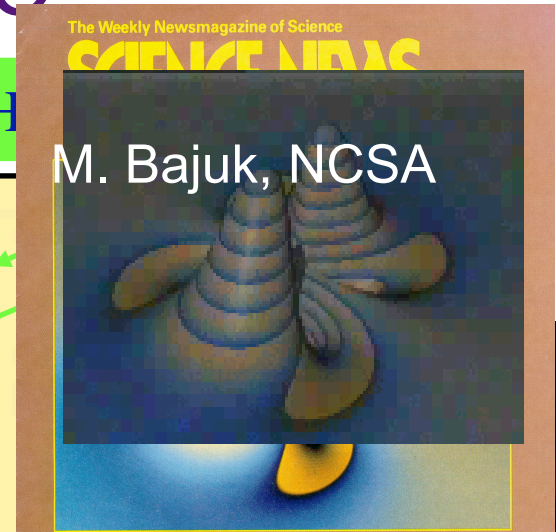




Gravitational Wave Physics

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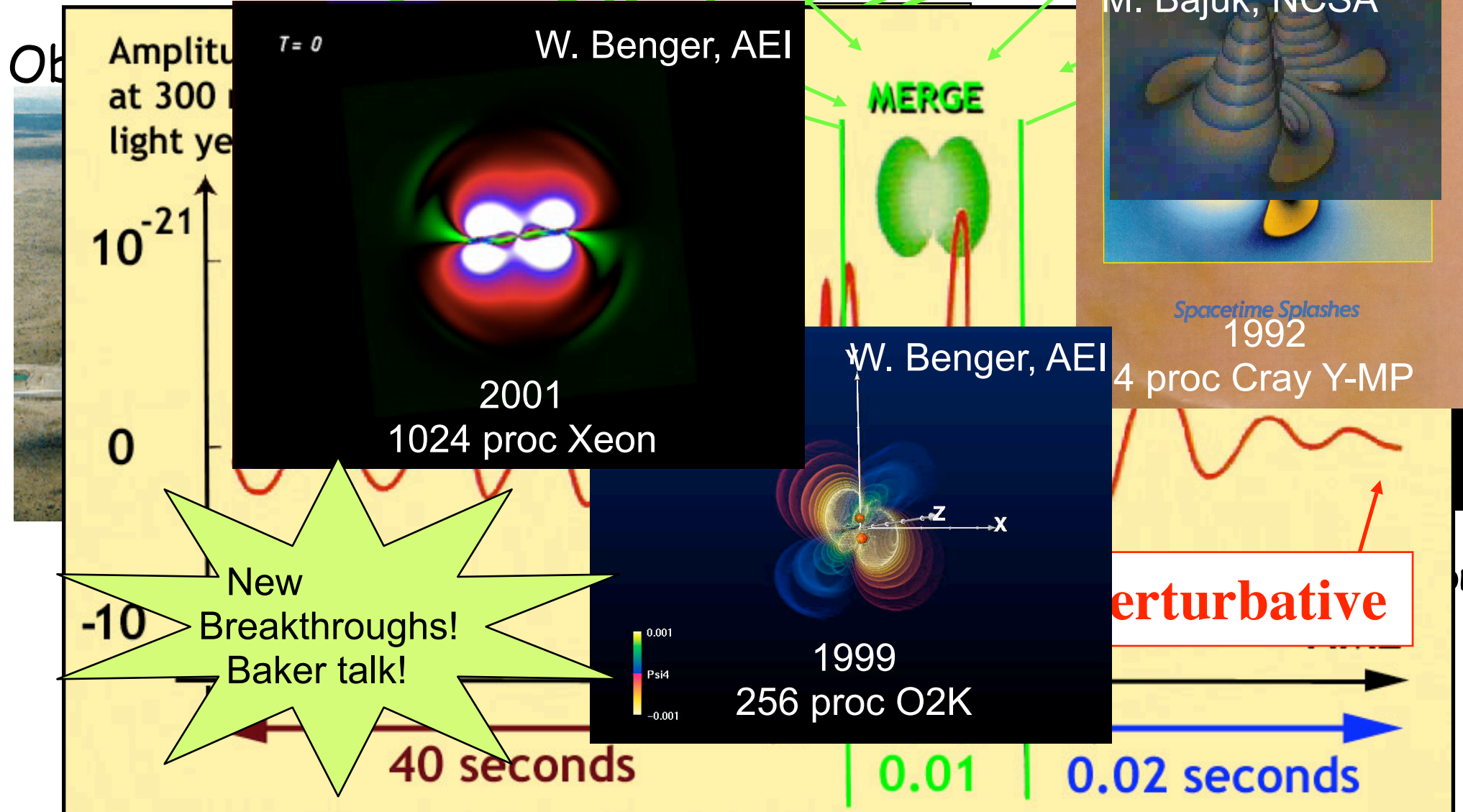
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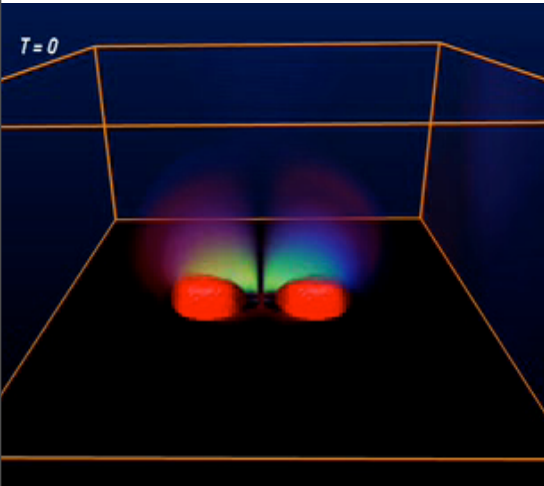
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Grand Challenge Collaborations

Science and Eng. Go Large Scale: Needs Dwarf Capabilities



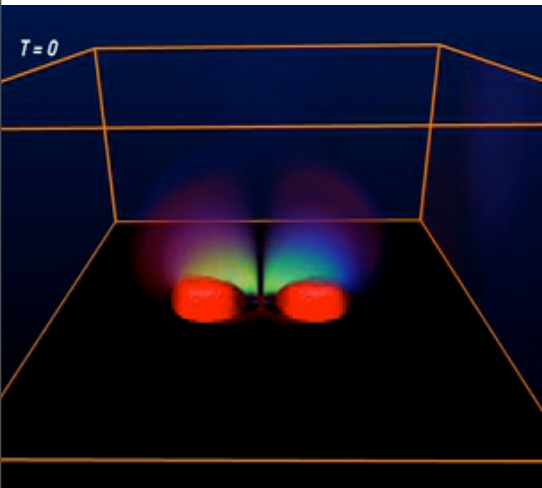
NASA Neutron Star Grand Challenge

- 5 US Institutions,
3years, \$1.4M
- Solve problem of
colliding neutron
stars (try...)



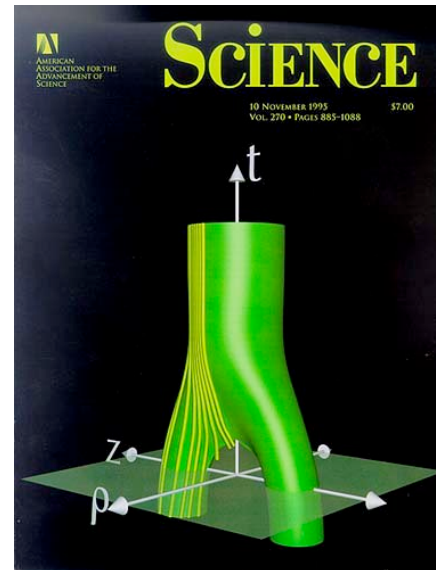
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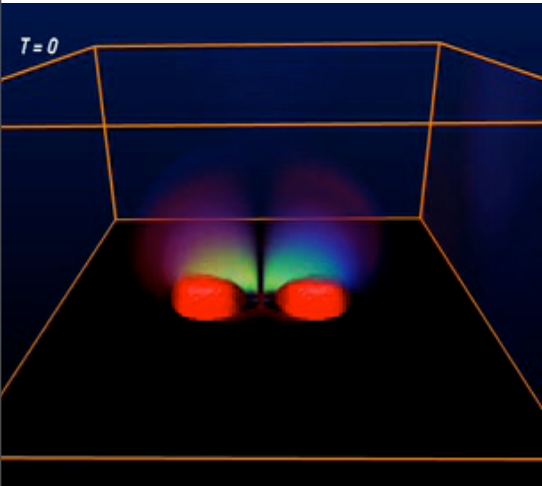
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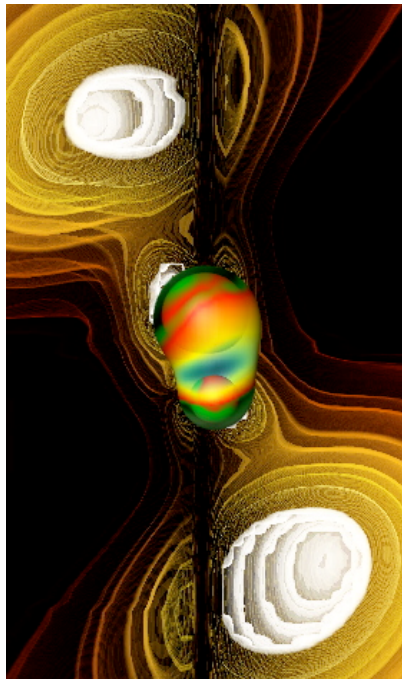
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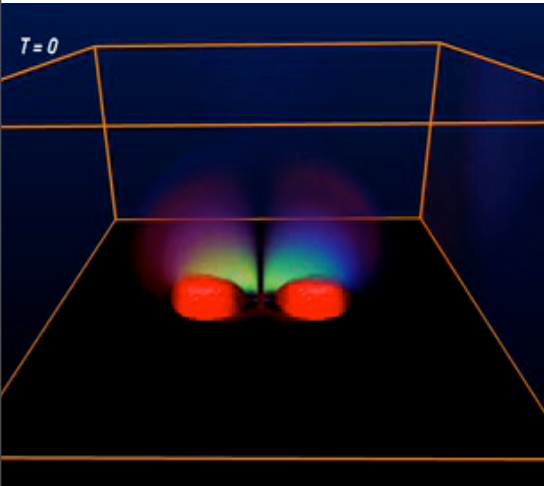
EU Network Astrophysics

- 10 EU Institutions, 3 years, €1.5M
- Continue these problems
- *Entire Community becoming Grid enabled*



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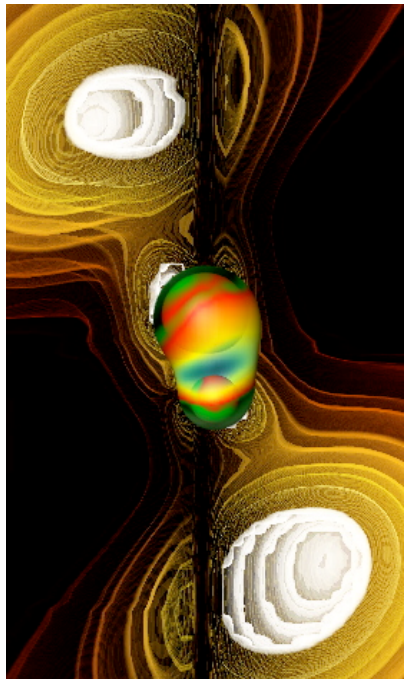
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Examples of Future of Science & Engineering

- Require large scale simulations, and collaborations
- Bring together cross disciplinary teams
- Demands on software engineering
- Solving problems simply beyond reach until now...



Early Experiments



Event Horizons of *Dynamic* Black Holes

NSF Black Hole Grand Challenge Era



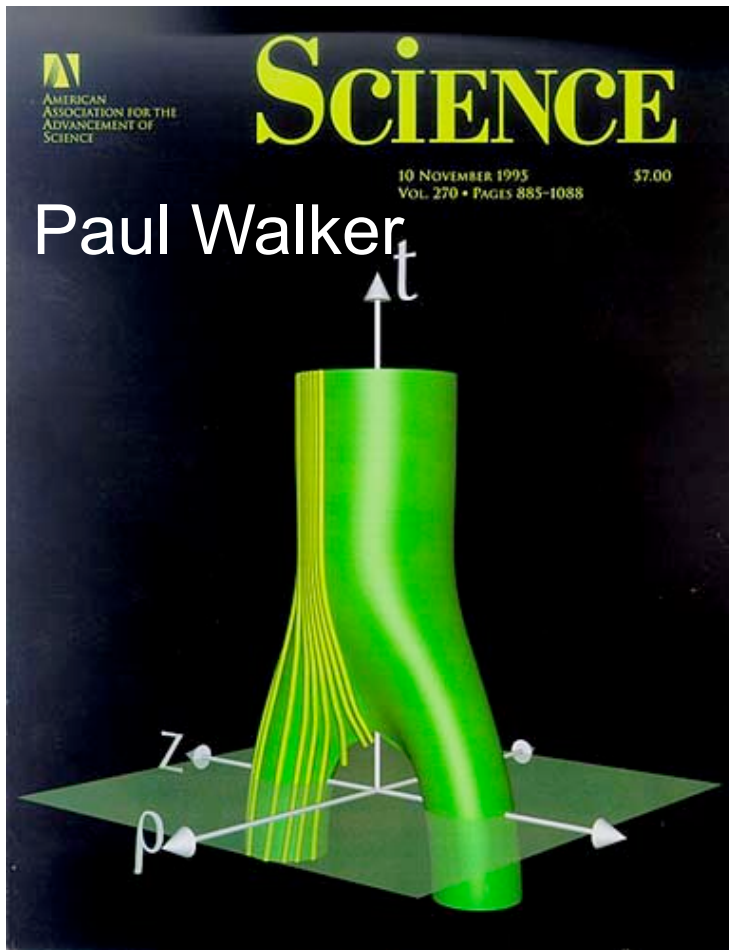
“Pair of Pants” of colliding black holes.

Sketched by Hawking ~ 1970, first studied numerically by Smarr 1975, computed quantitatively on Y-MP



Event Horizons of *Dynamic* Black Holes

NSF Black Hole Grand Challenge Era

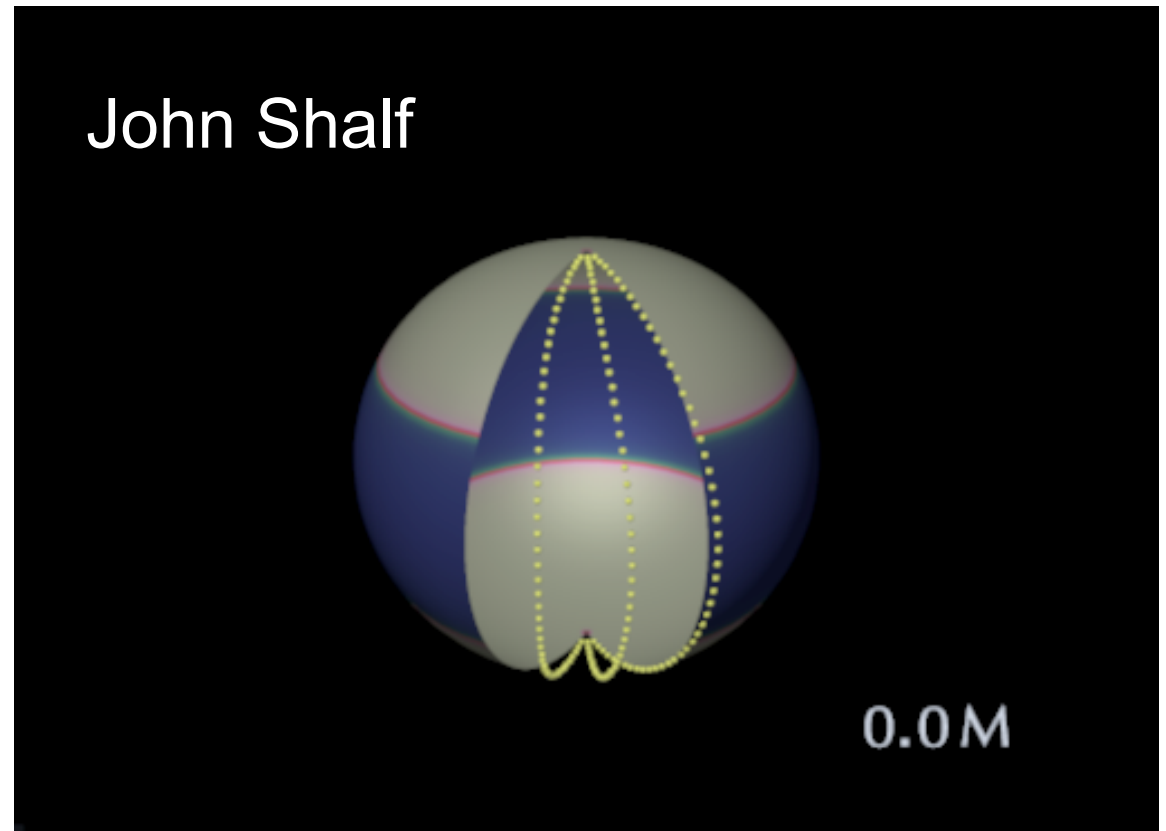


Paul Walker

“Pair of Pants” of colliding black holes.

Sketched by Hawking ~ 1970, first studied numerically by Smarr 1975, computed quantitatively on Y-MP

Axisymmetric Rotating
Black Holes
Horizon oscillations discovered,
visualized for first time



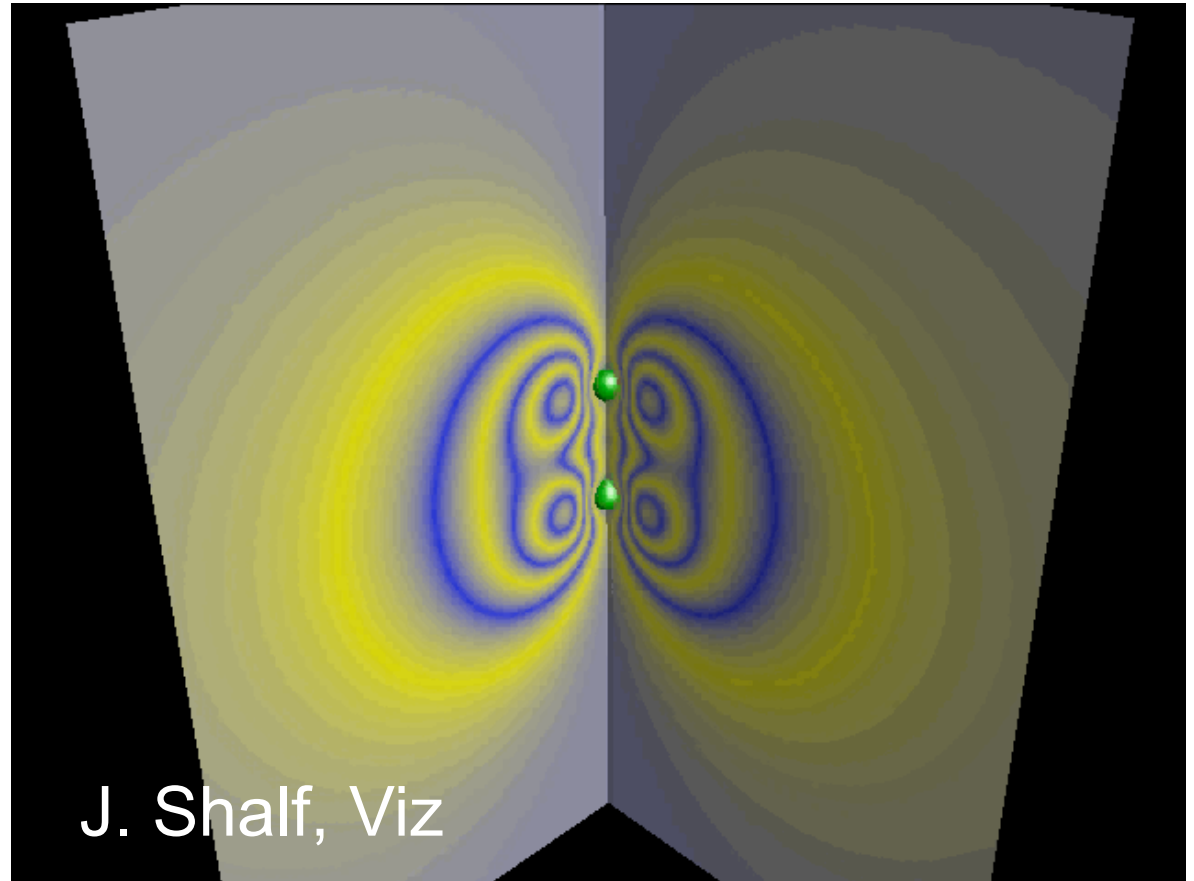
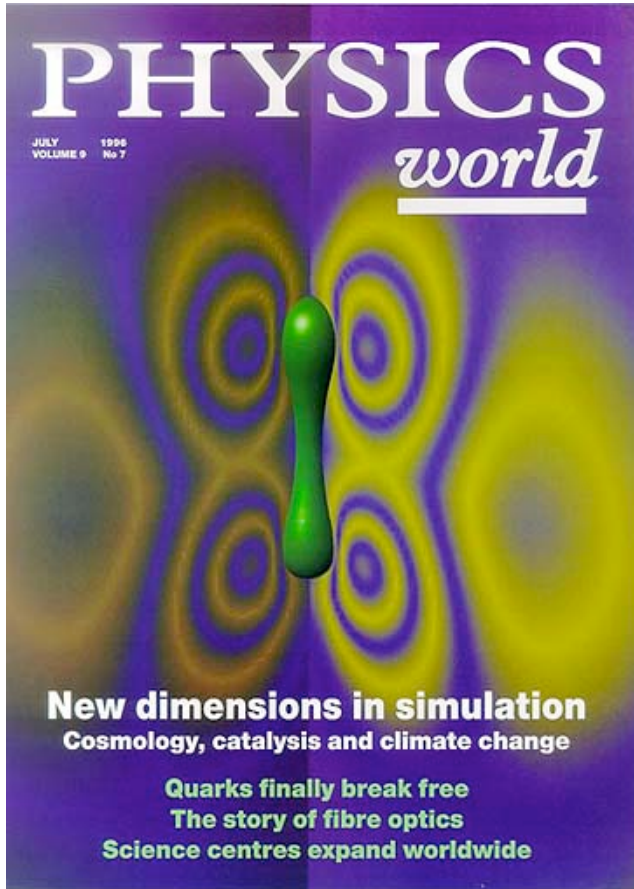
John Shalf

0.0 M



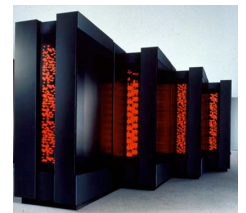
First 3D Black Hole Collisions, 1994

NSF Black Hole Grand Challenge Era



Event Horizon in green Ψ_4 (gravitational waves) in blue-yellow

- Smarr thesis now a “test problem” for 3D
- Possible due to 2D studies, 512 node CM-5





Relativity Workbench (1992)

Inspired by Mike Norman

- Above work very tedious! Want workflow, resource selection, live viz, etc
- Choose resources, compute initial data, visualize
- Evolve, visualize
- Archive, store results
- Early grid, portal ideas!

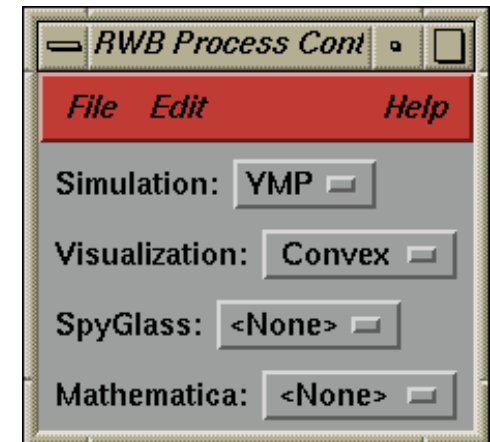


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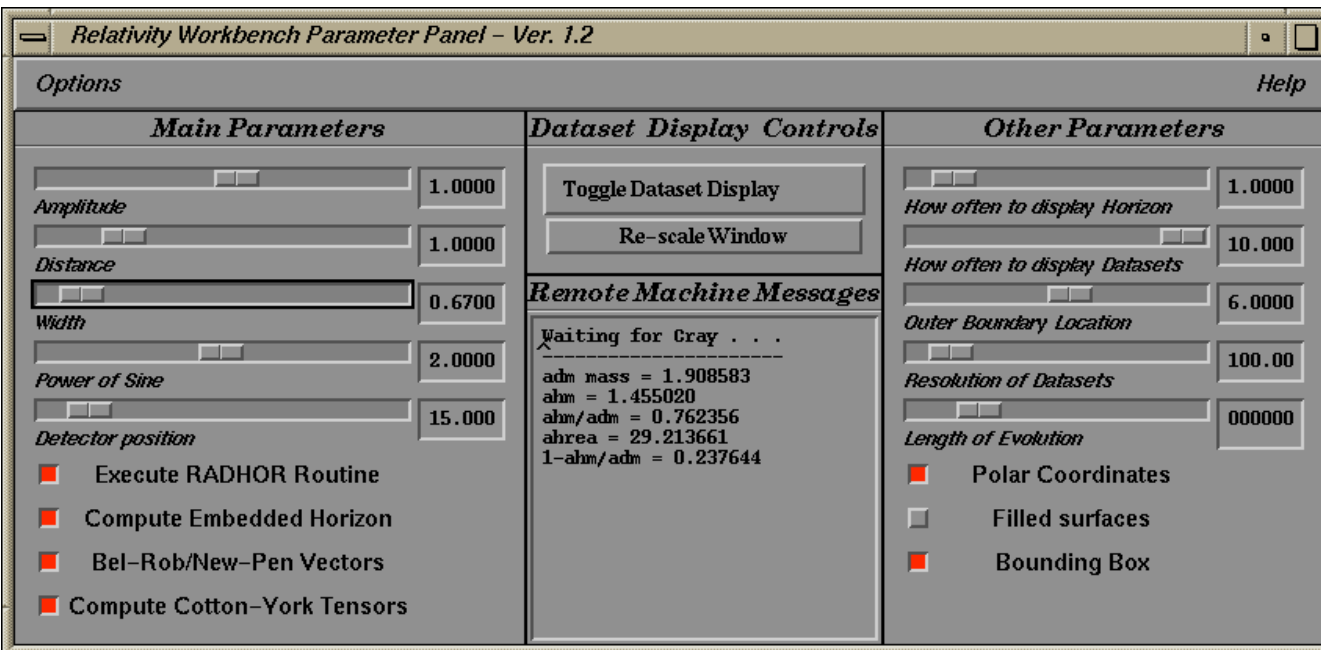
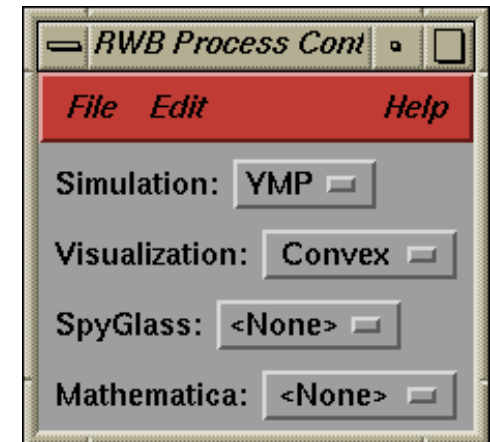


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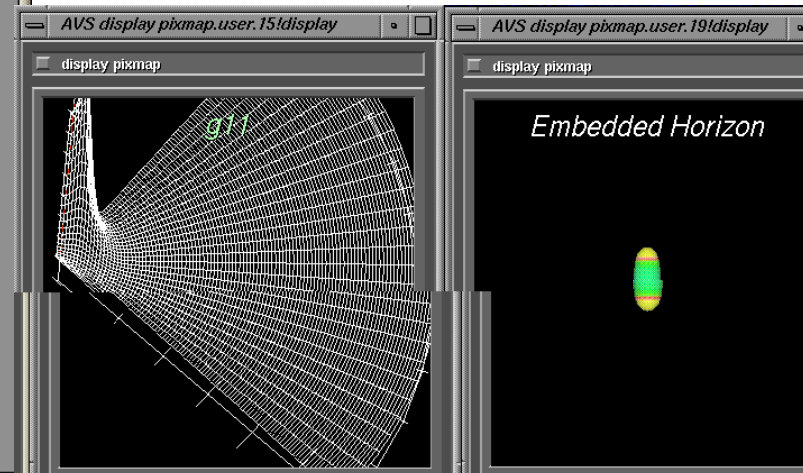
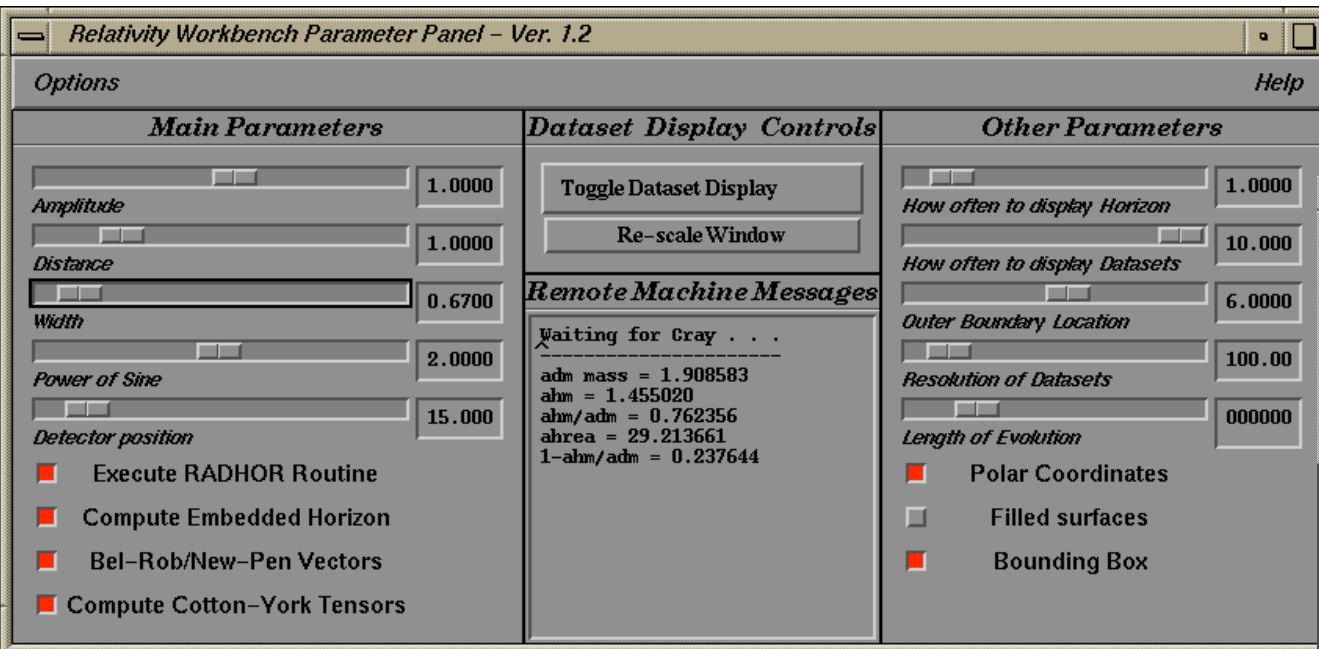
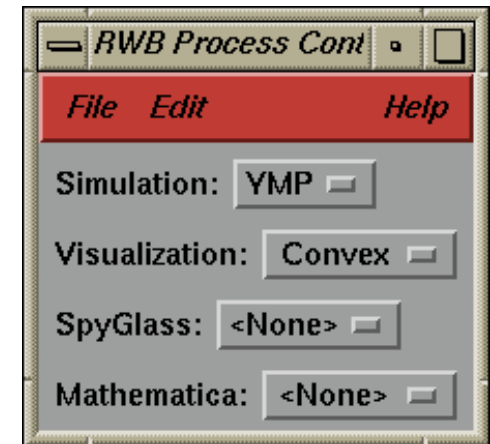


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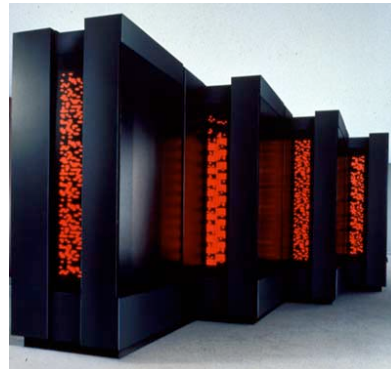




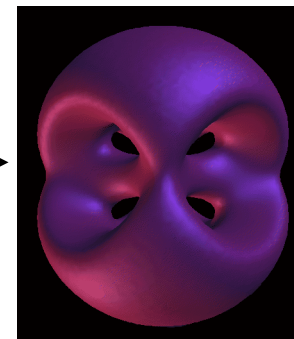
CAVE, SC93, 94, 97

- Golden Age of numerical relativity, but takes so long!
 - Visualizing results: could not wait for physics!
- Developed 3D visualization during simulation
 - Why? Better science, better understanding, fewer errors

G, H codes for EEs. CM-5 allowed 3D!



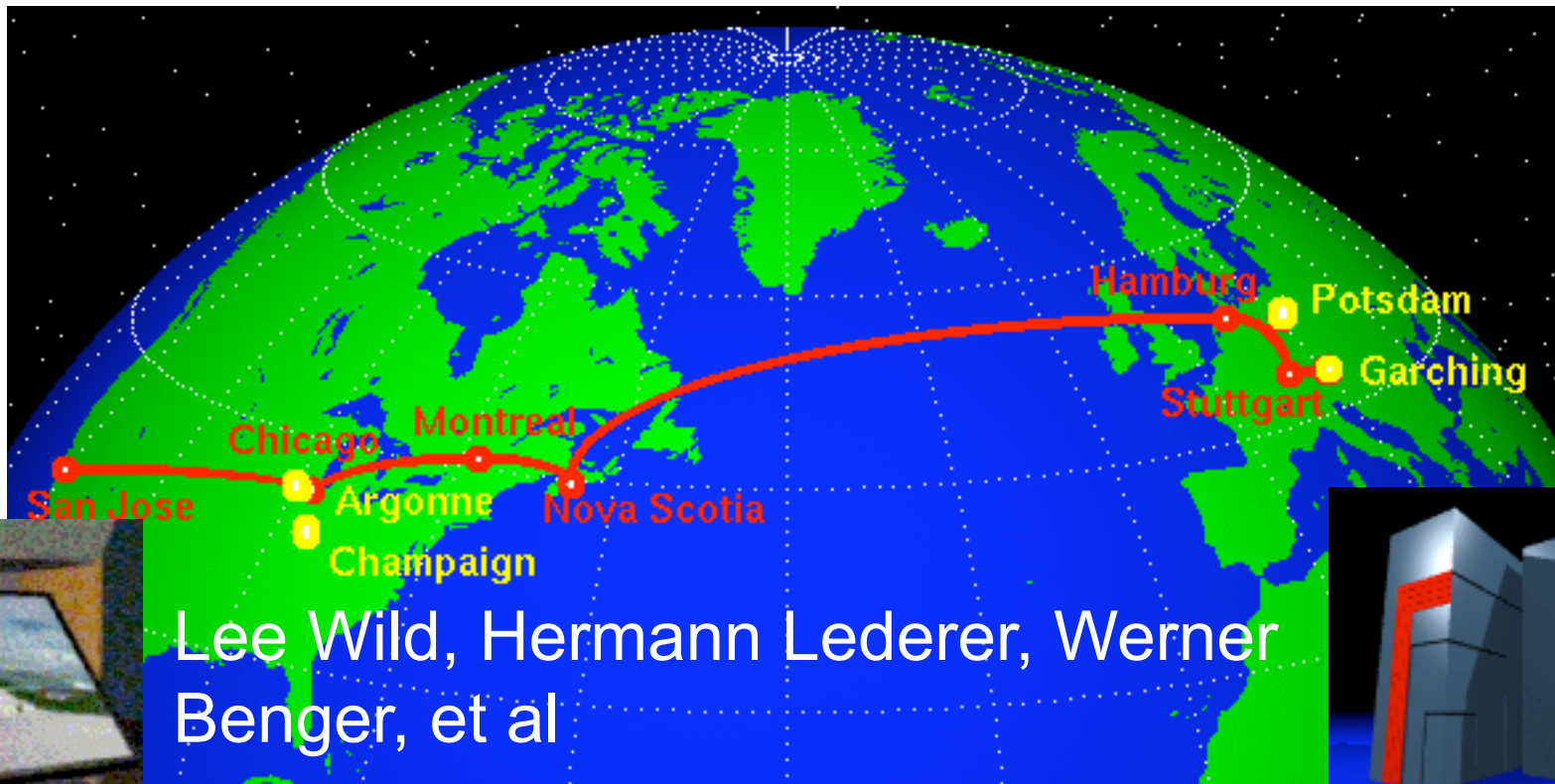
CM-5



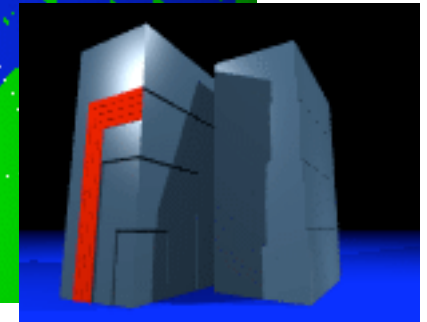
CAVE

Joan Massó,
John Shalf, Tom
DeFanti, Trina
Roy, Jon
Goldman,
Carolina Cruz-
Neira, et al

- SC97: Garching, Germany - San Jose
- Wanted multiple views of all functions (50 3D arrays!), different viz targets, ease of use



Lee Wild, Hermann Lederer, Werner Benger, et al



- Moved to Germany 1996
 - Collaborators in US, machines in DE, USA
 - Needed remote viz & I/O, collaborative tech
 - High speed networks now become important

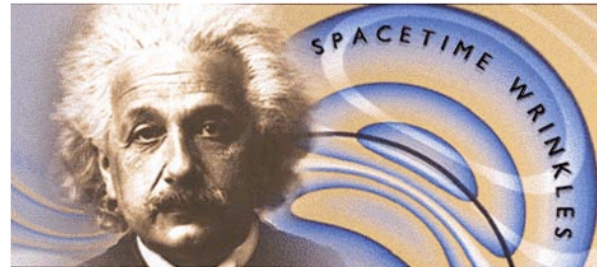


Education & Outreach

- Spacetime Wrinkles exhibit for Mosaic
 - Early driver for WWW development
 - 1994: only a few thousand web pages!
 - Wanted to be sure there was content!
- Top google hit for “general relativity” till last week!

Expo/Science & Industry/Spacetime Wrinkles

SPACETIME WRINKLES



In 1905, Albert Einstein published his famous Special Theory of Relativity and overthrew commonsense assumptions about space and time. Relative to the observer, both are altered near the speed of light: distances appear to stretch; clocks tick more slowly.

A decade and a year later, Einstein further challenged conventional wisdom by describing gravity as the warping of spacetime, not a force acting at a distance. Since then, Einstein's revolutionary insights have largely stood the test of time. One by one, his predictions have been borne out by experiment and observation.

But it wasn't until much later that scientists accepted one of the most dramatic ramifications of Einstein's theory of gravitation: the existence of black holes from whose extreme gravity nothing, not even light, can escape. Major advances in computation are only now enabling scientists to simulate how black holes form, evolve, and interact. They're betting on powerful instruments now under construction to confirm that these exotic objects actually exist.

You might like to take a two-minute video tour of this exhibit's contents. However, the Quicktime movie is rather large (12.3 MB!), so be patient when downloading. It could take several minutes. (Further information on downloading movies can be obtained from the [Technical Corner](#) and [Navigation Tips](#).)



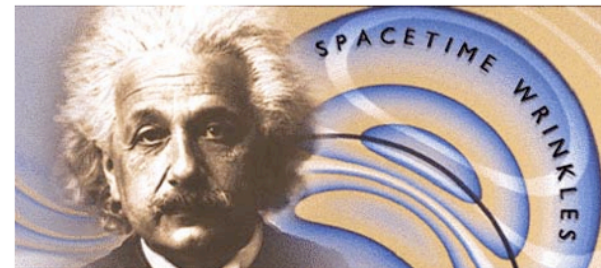
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SC95 I-WAY (Grids 0)

- Pivotal event
 - “Metacomputing” discussed for few years (Catlett, Smarr, et al)
 - EE’s could use all SCs available: how?
- Tom DeFanti, Ian Foster, et al
 - Networks, software layers
 - NCSA relativity group among apps
 - Single MPI job across NCSA, PSC, SDSC, Cornell, viz’d in CAVE
 - Projects “successful”, Heros of SC95!
- Software projects emerge
 - Globus Toolkit and Grids
 - Cactus Toolkit for applications: learn from above

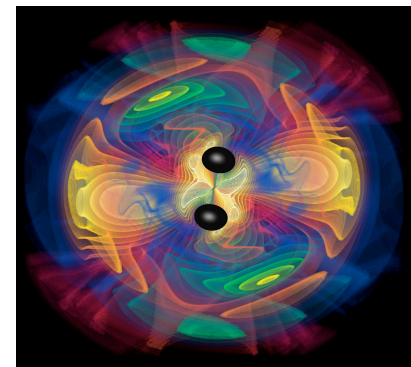
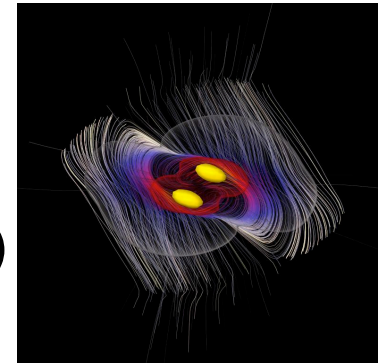




Lessons Learned

Computational Science is Hard

- Requires incredible mix of technologies & expertise!
- Many scientific/engineering components
 - Physics, astrophysics, CFD, engineering,...
- Many numerical algorithm components
 - Finite difference? Finite volume? Finite elements?
 - Elliptic equations: multigrid, Krylov subspace,...
 - Mesh refinement, multipatch
- Many different computational components
 - Parallelism (HPF, MPI, PVM, ???)
 - Architecture (MPP, DSM, Vector, PC Clusters, FPGA, ???)
 - I/O (generate TBs/simulation, checkpointing...)
 - Visualization of all that comes out!
- New technologies
 - Grid computing
 - Steering, data archives
 - Symbolic code generation to do all above (possible!)
- *Abstractions: enable all disciplines, areas of CS...*





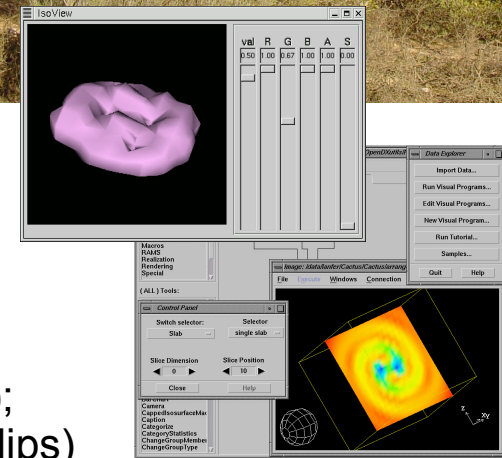
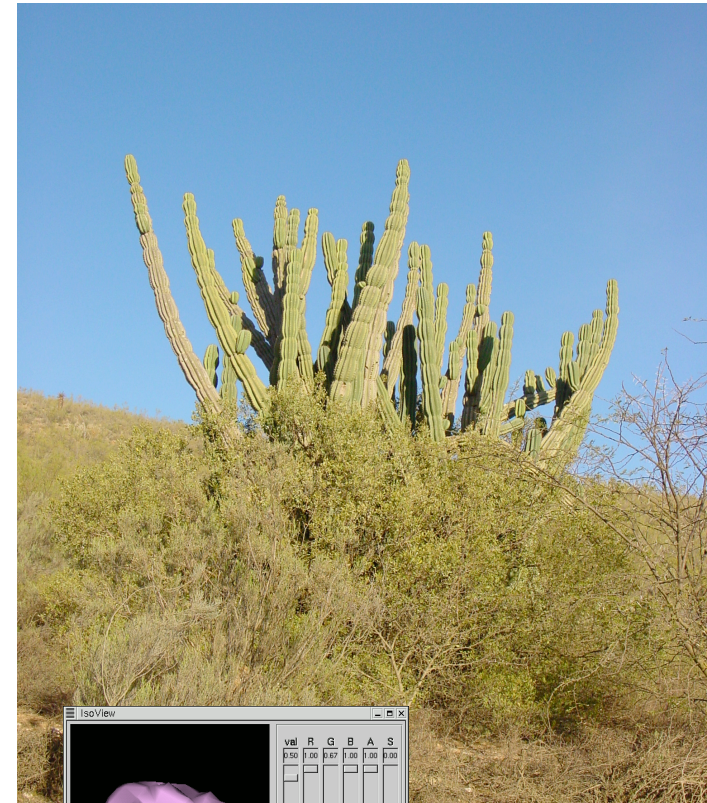
More Modern Approaches



Cactus Emerges after GC, IWAY

- Free, modular, portable environment for collaboratively developing parallel, HPC multi-D simulations (Component-based)
- Developed for Numerical Relativity, now general framework for parallel computing
- Finite difference, AMR (Carpet, Samrai, Grace), new FE/FV, multipatch, unstructured meshes
- Interfaces to advanced I/O, elliptic solvers
- Active user and developer communities, main development now at LSU and AEI.
- Open source, documentation, etc
- Very influential: ESMF, other frameworks

Paul Walker (JP Morgan), Joan Massó (Grid Systems), John Shalf (LBNL);
Tom Goodale (Cardiff/LSU), Gabrielle Allen (LSU), Gerd Lanfermann (Phillips)



Microsoft, SGI, Intel, Sun, HP support...

www.CactusCode.org



Cactus Structure

Core “flesh” with plug-in “thorns”

Plug-In “Thorns”
(modules)

Fortran/C/C++

input/output

interpolation

SOR solver

wave evolvers

multigrid

coordinates

extensible APIs

ANSI C

parameters

scheduling

Core “Flesh”

error handling

make system

grid variables

boundary conditions

Computational
Tools !!

AMR, unigrid,
unstructured

remote steering

Your Physics !!

black holes

equations of state



Cactus Structure

Core "flesh" with plug-in "thorns"

Abstractions, interfaces:

- Users don't want to write MPI!
- Plug in different AMR, parallel I/O, elliptic solvers

Plug-In "Thorns"
(modules)

Fortran/C/C++

input/output
interpolation

SOR solver

wave evolvers

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Users and Toolkits

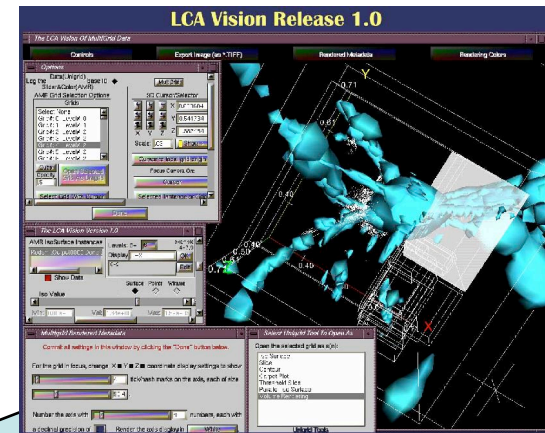
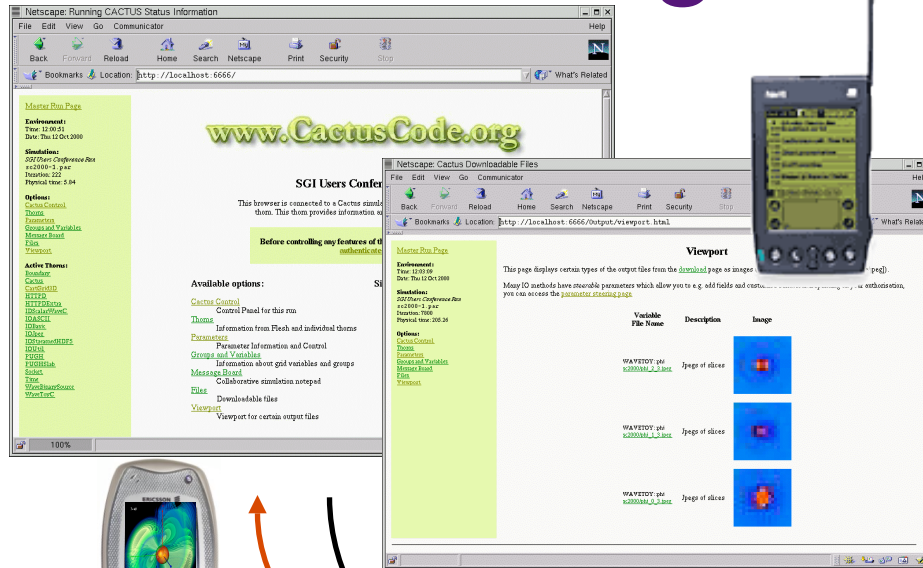
- Many numerical relativity groups around the world
 - Over 100 publications
 - Maya, Whisky, Lazarus, ...
- Others:
 - CFD
 - Quantum Gravity
 - Chemical Engineering
 - Crack Propagation
 - Environmental modeling
 - Plasma physics
 - Computer science
 - Astrophysics
 - Cosmology
 - [Biology/Materials]



- **Toolkits**
 - Cactus Computational Toolkit
 - Einstein Toolkit
 - Many modules
 - *Kranc generates entire Cactus codes from Mathematica: Sascha Husa, AEI, Jena*
 - CFD Toolkit (CCT, KISTI booth)
 - (Biology Toolkit)
- **Teaching**
 - Over 30 student thesis/diploms



Notification, Remote Interactive Viz & Steering

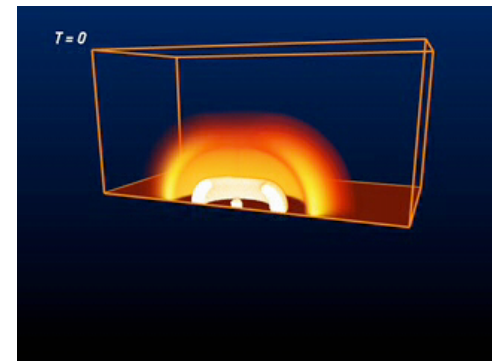
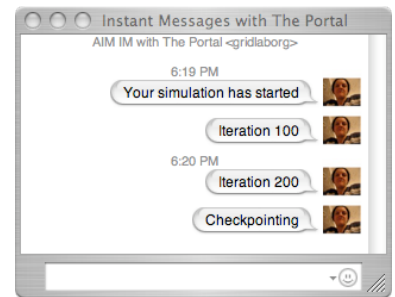
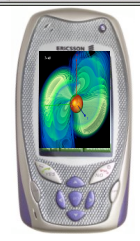


Any Viz Client:
LCA Vision, OpenDX

Changing steerable parameters

- Parameters
- Physics, algorithms
- Performance

Streaming HDF5
Autodownsample

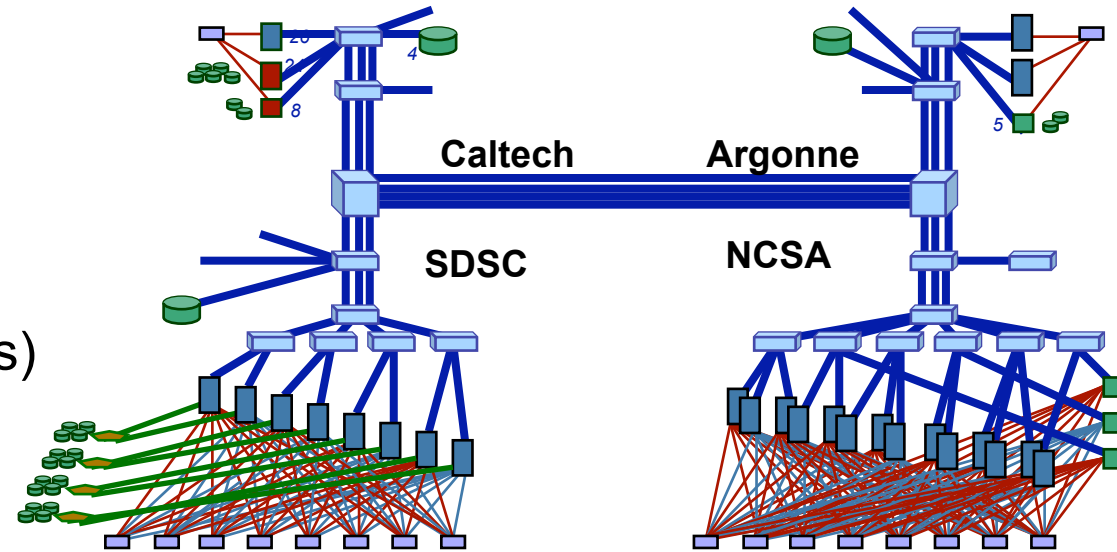


TiKSL & GriKSL DFN grants at AEI, now EnLIGHTened and other



Grids: Bringing all Together

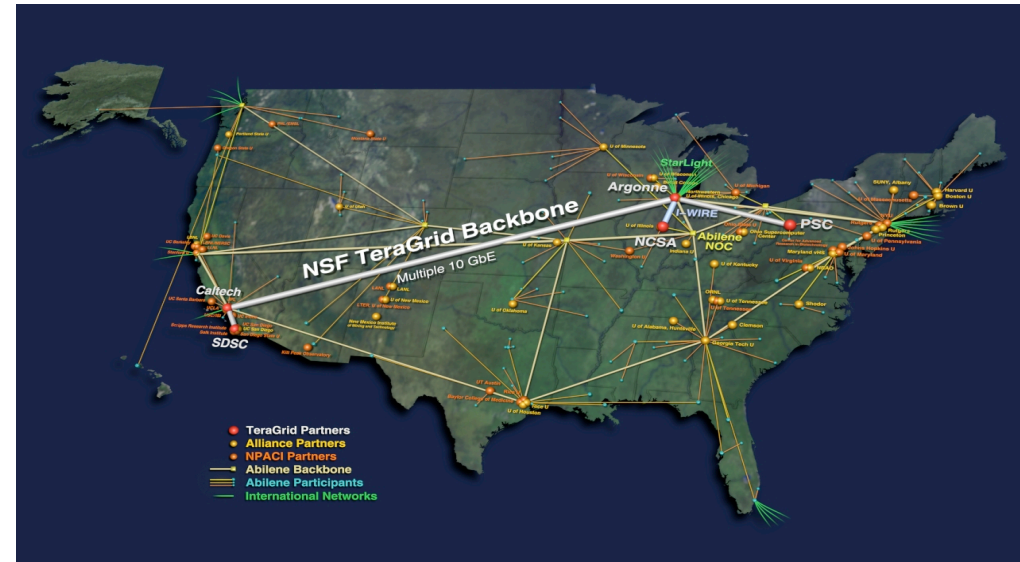
- Computational Devices Scattered Across the World
 - Compute servers (double 18 months)
 - Networks (double each 9 months)
 - Sensors (exploding field)
- Experiments, feedback
 - DDDAS scenarios
- How to take advantage of this for science, engineering, business, art?
 - Harness multiple sites and devices
 - Deploy cyberinfrastructure: Globus, Unicore, many others
 - Increasingly application/community specific





Grids: Bringing all Together

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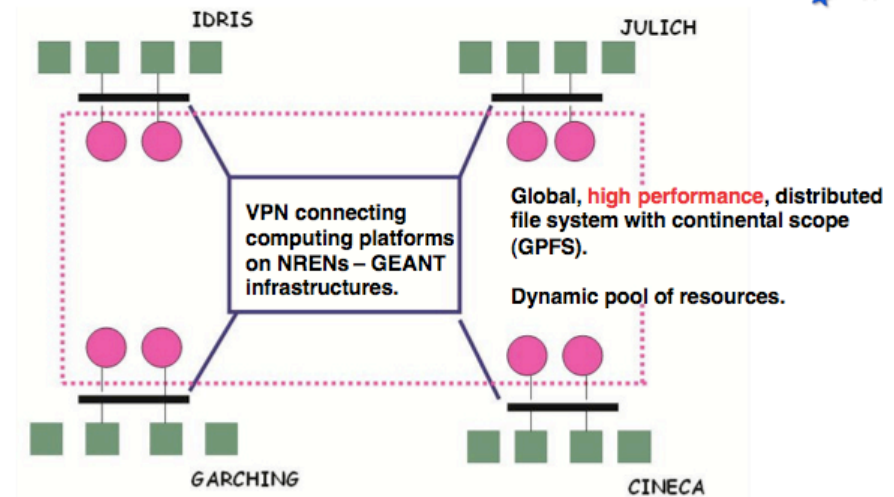




Grids: Bringing all Together



The DEISA super-cluster (phase 1)



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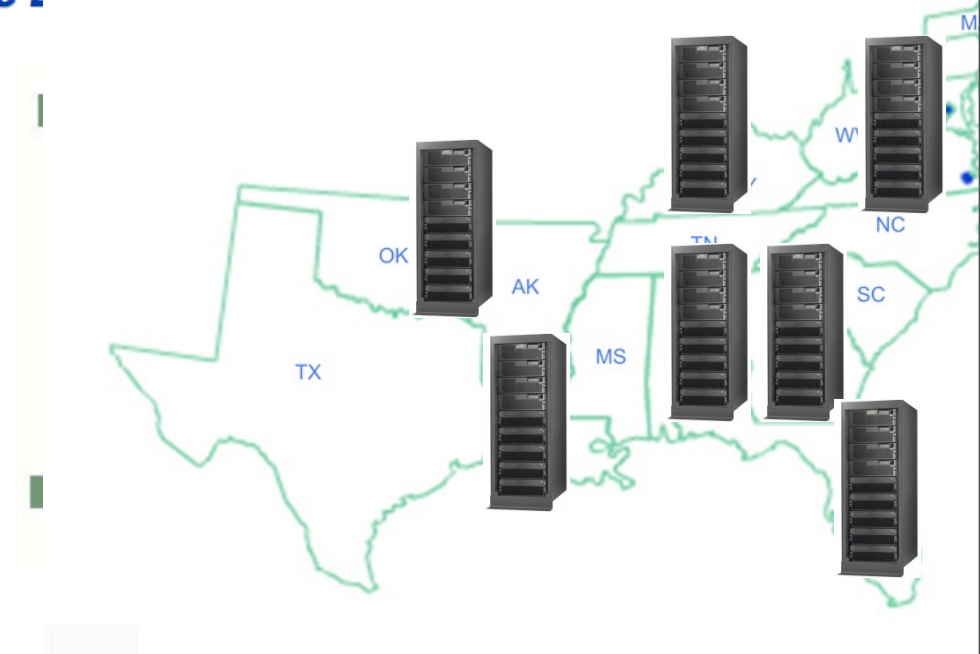


Grids: Bringing all Together

★ Distributed

The I

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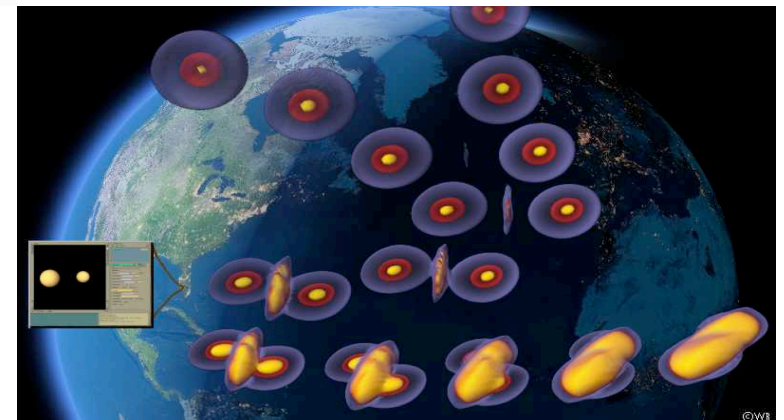
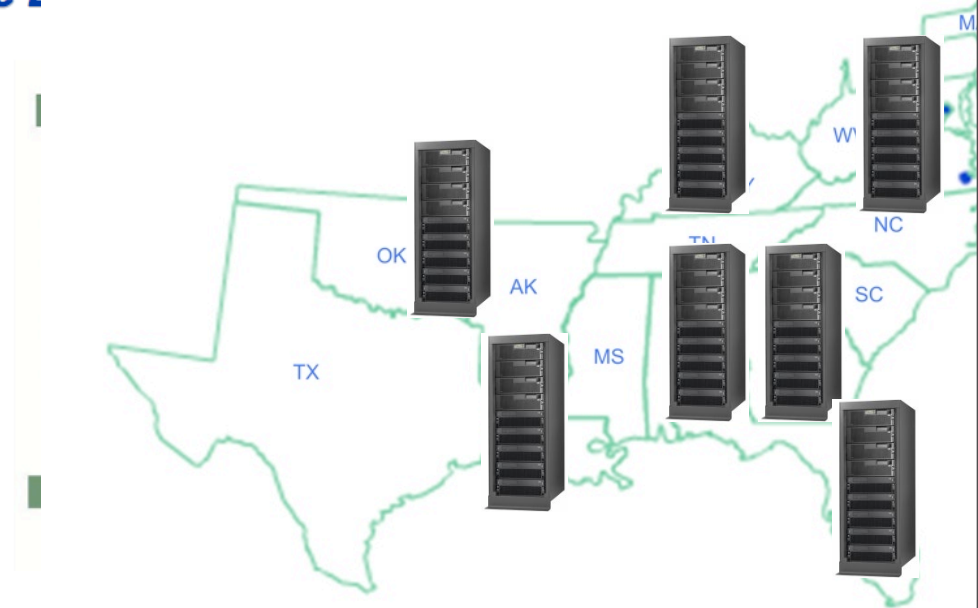


Grids: Bringing all Together

★ Distributed

The L

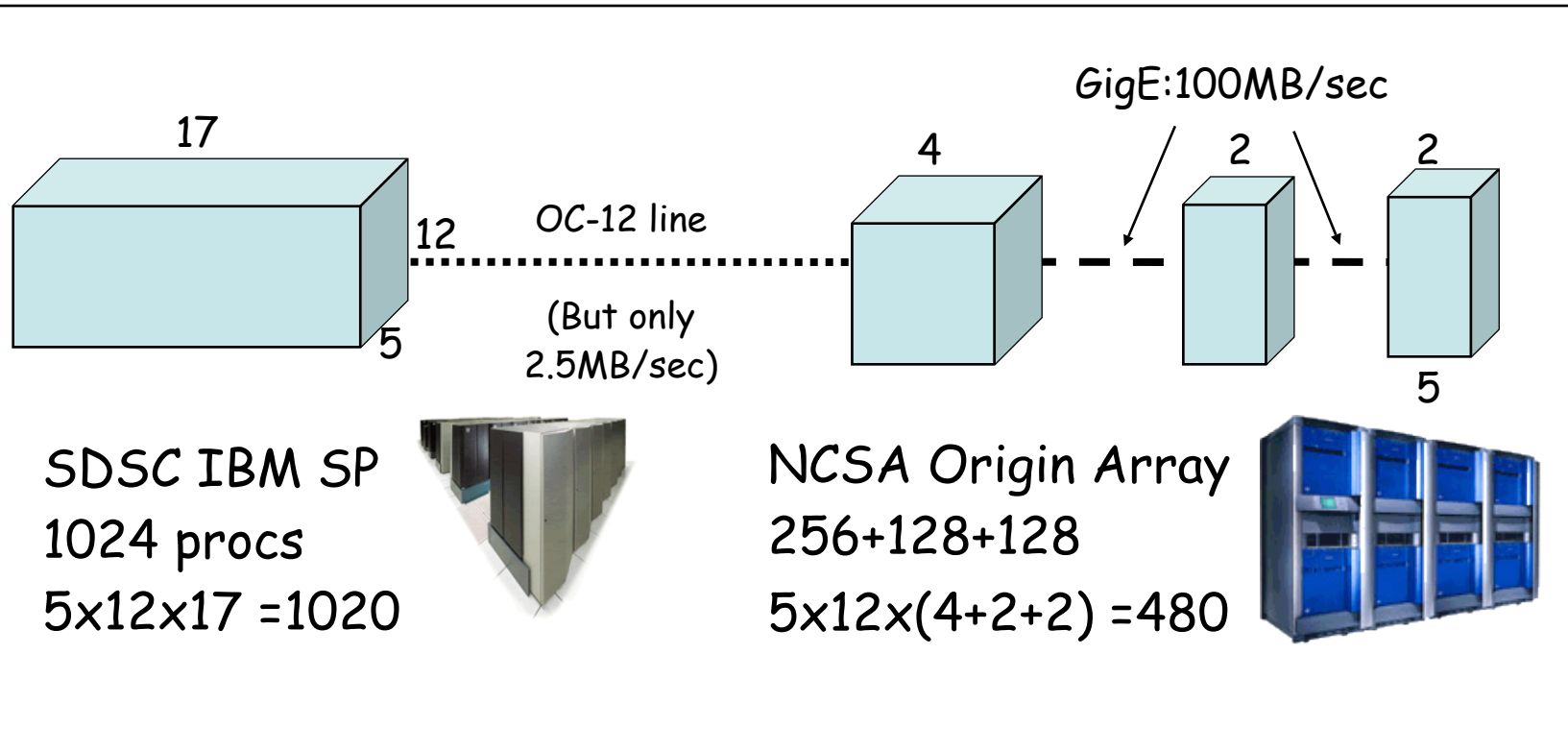
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Gordon Bell Prize, 2001



Grids 1: Dynamic, Adaptive, Distributed Computing



Thomas Dramlitsch



Matei Ripeanu

Cactus + MPICH-G2

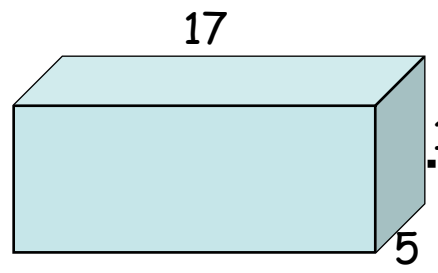
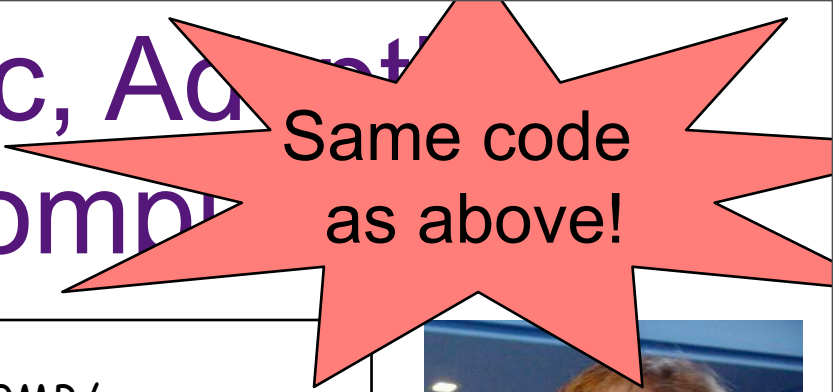
Communications dynamically adapt to application and environment

Any Cactus application. Scaling: 15% -> 85%

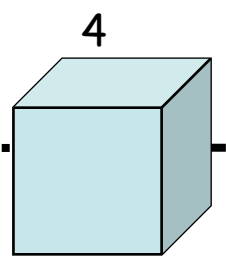
"Gordon Bell Prize" (SC01)



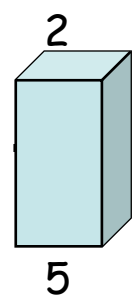
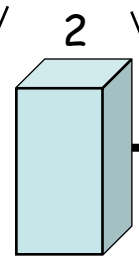
Grids 1: Dynamic, Adaptive Distributed Computation



12
OC-12 line
(But only 2.5MB/sec)



GigE:100MB/sec



SDSC IBM SP
1024 procs
 $5 \times 12 \times 17 = 1020$



NCSA Origin Array
 $256 + 128 + 128$
 $5 \times 12 \times (4 + 2 + 2) = 480$



Thomas
Dramlitsch



Matei
Ripeanu

Cactus + MPICH-G2

Communications dynamically adapt to application and environment

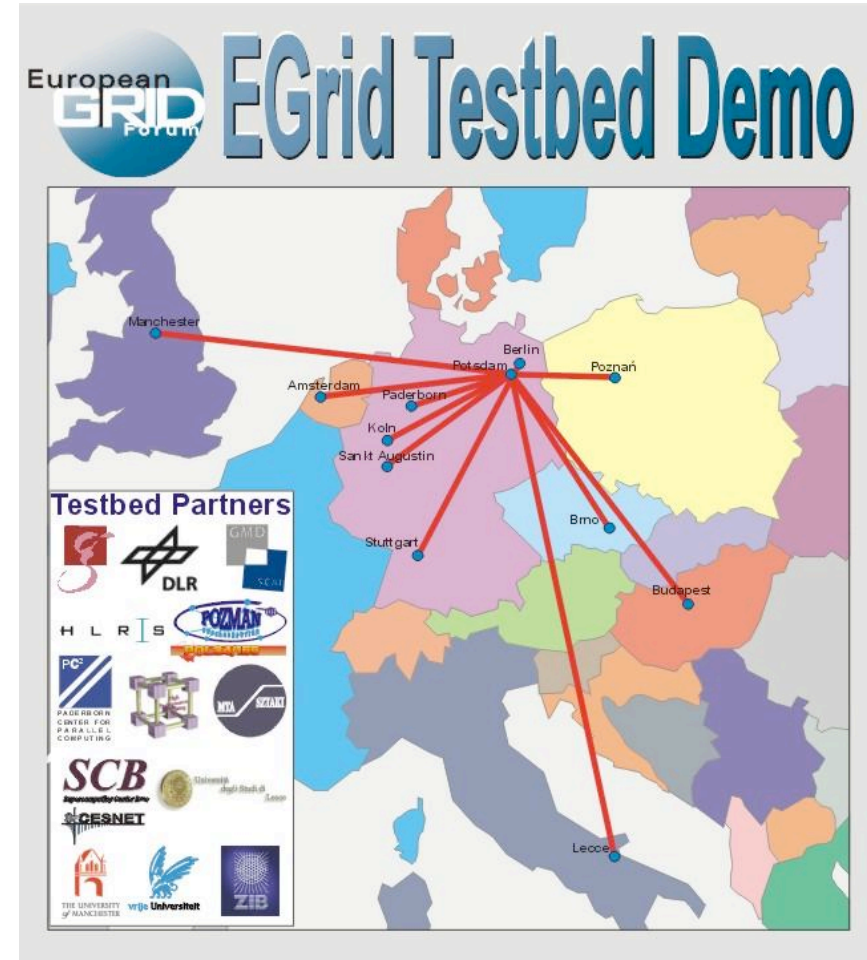
Any Cactus application. Scaling: 15% -> 85%

"Gordon Bell Prize" (SC01)



Grids 2: New Dynamic Scenarios

- Cactus Worm (SC2000)
 - Cactus simulation starts, launched from portal
 - Migrates itself to another site
 - Registers new location
 - User tracks/steers, using HTTP, streaming data, etc...
- These EGrid demonstrations led to GridLab, merger of GF/EGrid to form GGF





Grid Applications 3: Be Creative

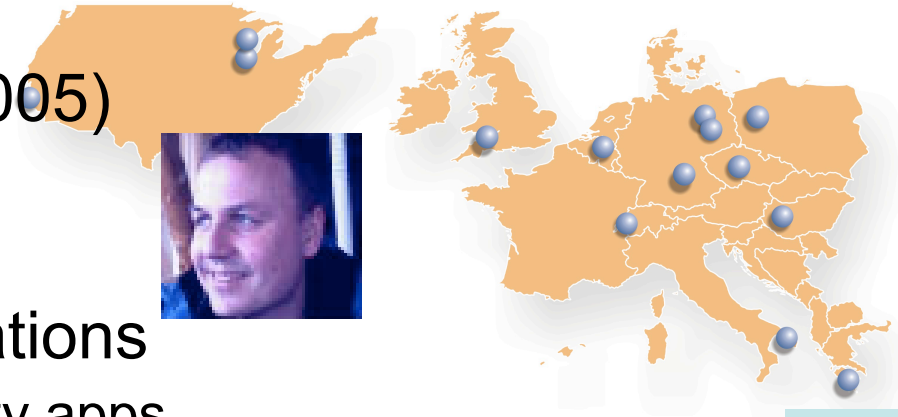
- Intelligent Parameter Surveys
 - May control other simulations! DDDAS...
- Automatic Component Loading
 - Needs of process change, discover/load/execute new component somewhere
- Dynamic Staging: move to faster/cheaper/bigger machine (“Grid Worm”)
 - Need more memory? Need less? Going too slow?
 - EGrid Cactus worm demo SC 2001 ---> GridLab and GF + EGrid = GGF
- Automatic “Look Ahead”, convergence testing
 - spawn off and run coarser resolution to predict future, study convergence
- Spawn Independent/Asynchronous Tasks
 - send to cheaper machine, main simulation carries on
- Routine Profiling
 - best machine/queue, choose resolution parameters based on queue
- DDDAS: injecting data into the above, feed back to experiment
- Dynamic Load Balancing: inhomogeneous loads, multiple grids
- Model-Model coupling: very important in DDDAS, modern apps



Grids 4: GridLab



- EU 5th Framework (2002-2005)
 - 6 Million Euros
 - Led by Jarek Nabrzyski
- Focused on tools for applications
 - Cactus and numerical relativity apps
 - Gravitational Wave Data Analysis (Triana)
 - Dynamic scenarios: Early DDDAS combine GW + Numrel
- Dynamic grid apps, infrastructure, users all can:
 - Be aware of environment: services, allocation, bandwidth?
 - Decide: migrate, spawn, access data
 - Publish information: what is the app/user doing?
- 12 workpackages, including:
 - Grid services, apps, testbed, **GAT**, **Portals**, brokers, mobile...



Successful 5th Framework project --- came from GR, Cactus, other EU projects, early Globus work

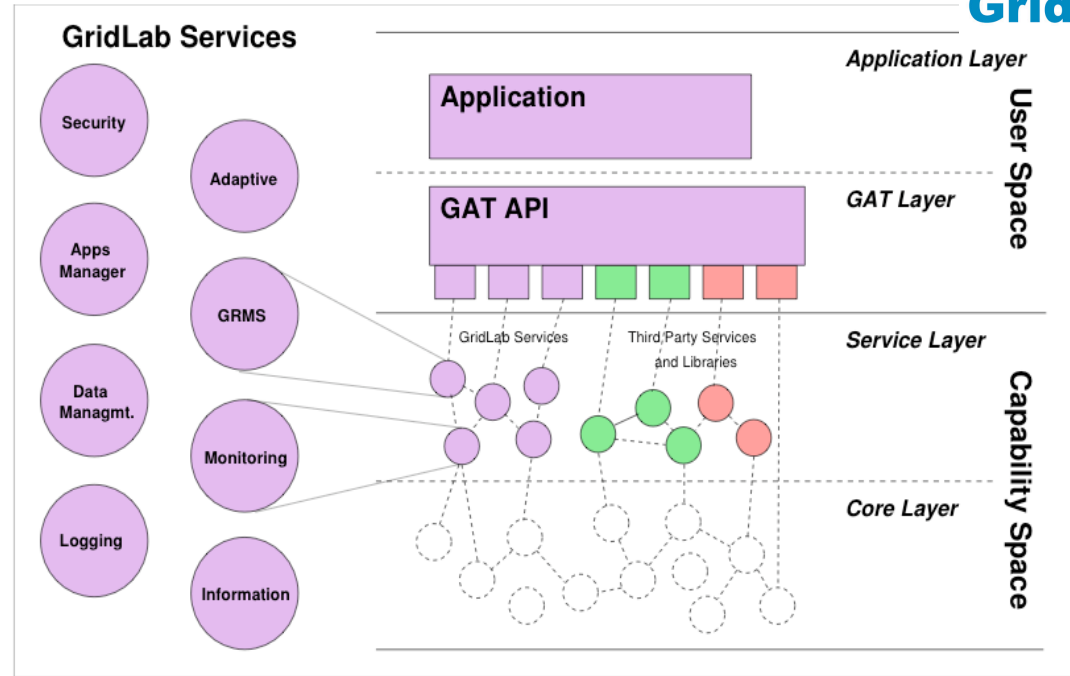
PSNC
 AEI
 ZIB
 MASARYK
 SZTAKI
 ISUFI
 Cardiff
 NTUA
 VU
 Chicago
 ISI
 Wisconsin
 Sun
 Compaq



Grid Application Toolkit & SAGA



- Abstract programming interface between apps and Grid services: “Cactus for Grid”. Adaptors! App runs everywhere with same code
- Designed for what apps need (move file, run remote task, migrate, write to remote file)
- Motivated by numerical relativity
- GAT led to OGF Working Group to develop a “Simple API for Grid Applications” or SAGA
 - Focus on scientific and engineering applications, simplicity
 - Better API based on use case studies
- **SAGA is centerpiece for OGF at application level**
 - 60-day comment period now for specification
- OMII calling for proposals to implement SAGA
- C++ implementation at LSU ongoing



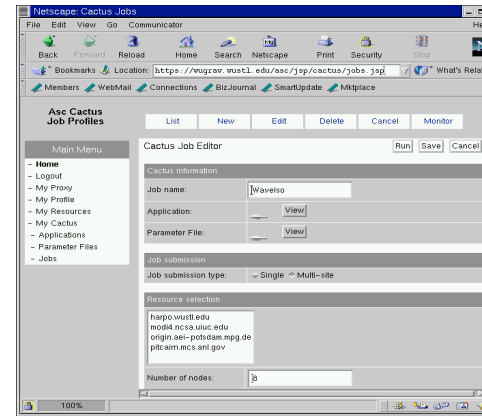


GridSphere



Information Society
Technologies

- GridSphere portal framework, developed in GridLab at AEI
 - Origins in '92 relativity workbench, NSF ASC project
- Generic JSR 168 compliant portlet container
- Architecture for “pluggable” web applications
- Core portlets, Grid Portlets, Cactus Portlets, D-Grid, LSU projects
- Over 250 subscribed to user mail list, around 500 unique web visits/month



 powered by gridsphere



Michael
Russell,
PSNC



Oliver
Wehrens,
AEI, LSU



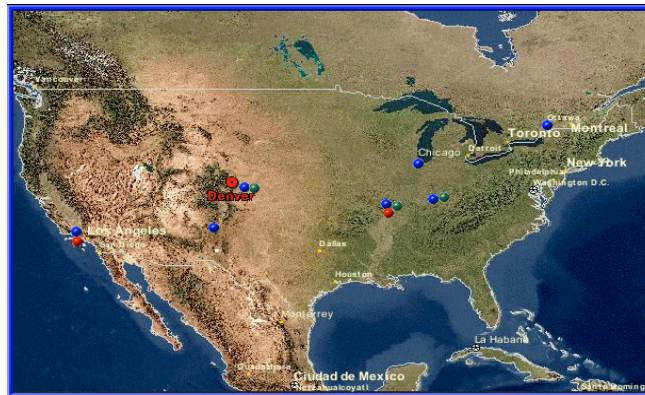
Jason
Novotny,
SDSC



Return to Future: Properly Engineered Software

Task Farming, Spawning & Migration combined

Main Cactus BH Simulation starts in Berkeley

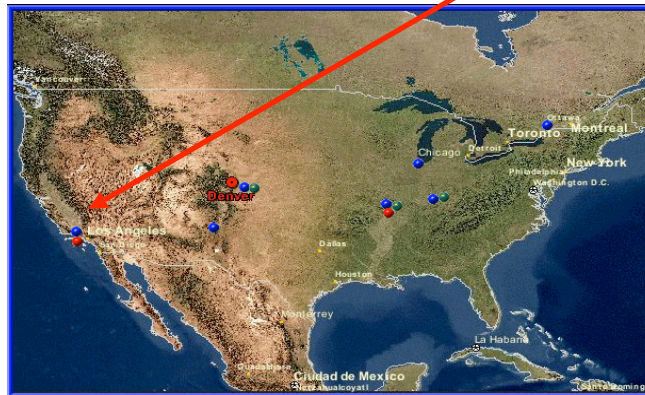




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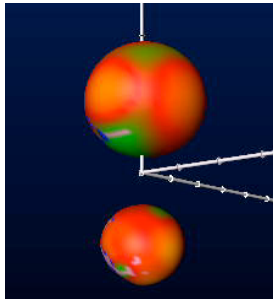




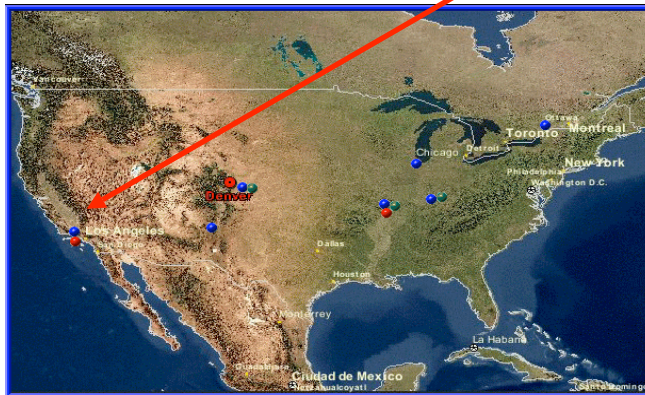
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Task Farming, Spawning & Migration combined

All analysis tasks spawned automatically
to free resources worldwide



Main Cactus BH Simulation
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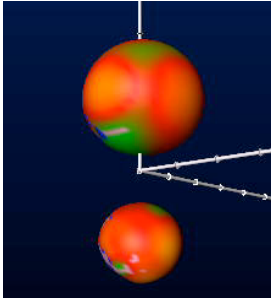




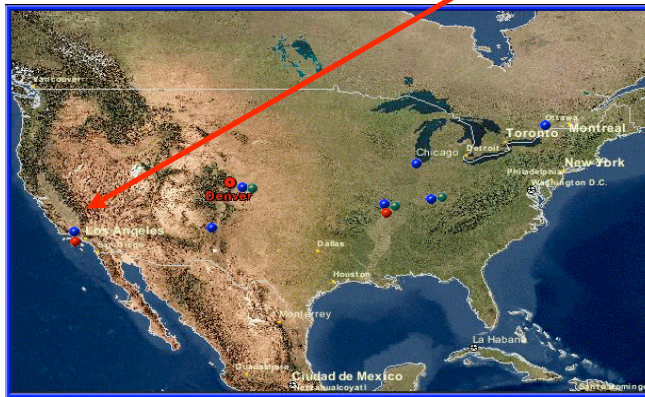
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Dozens of small jobs sent
out to test parameters

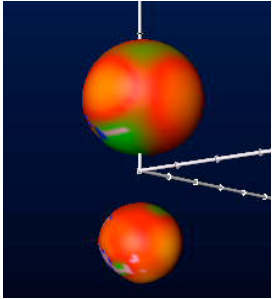




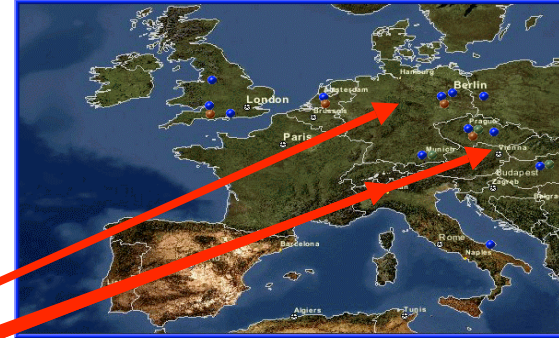
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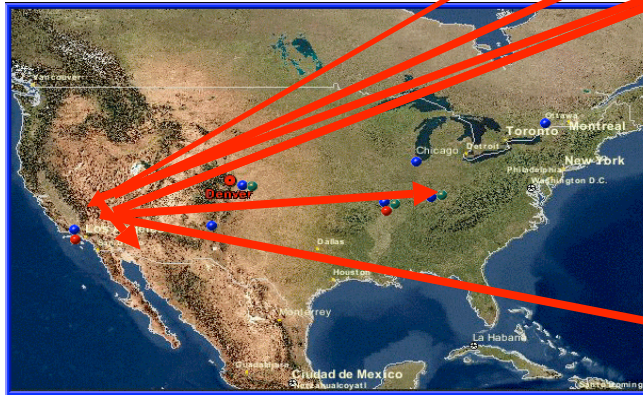
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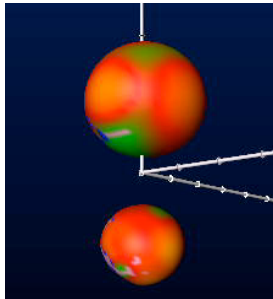




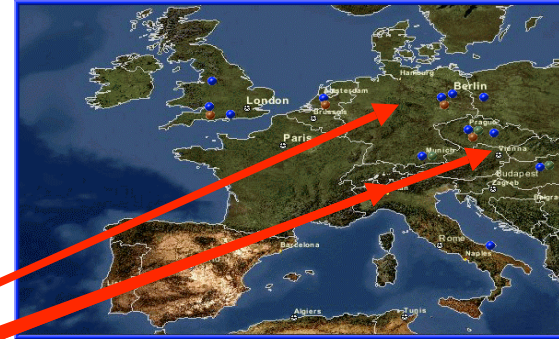
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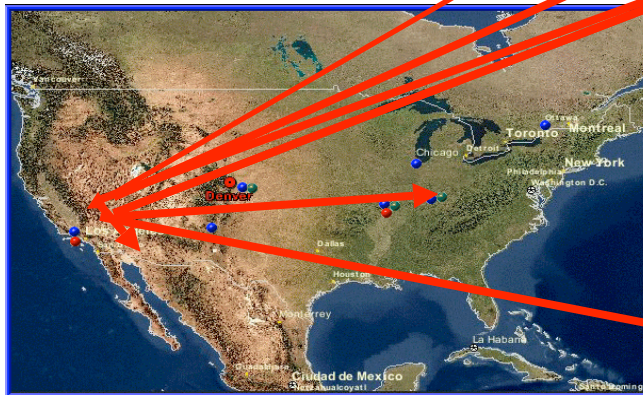
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Data returned for main job

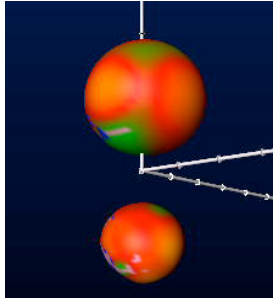




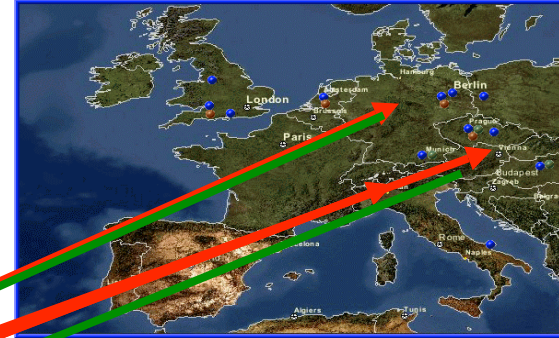
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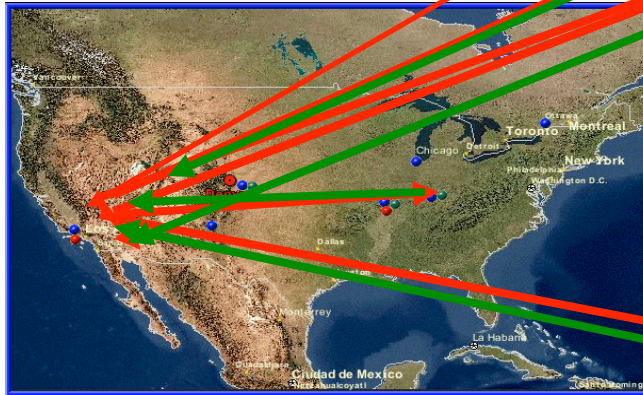
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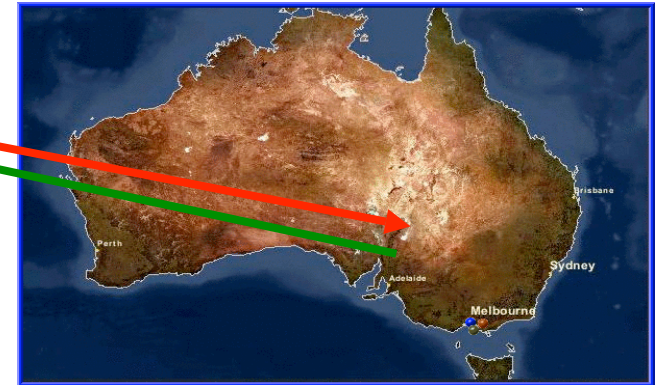
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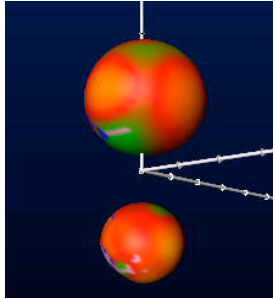




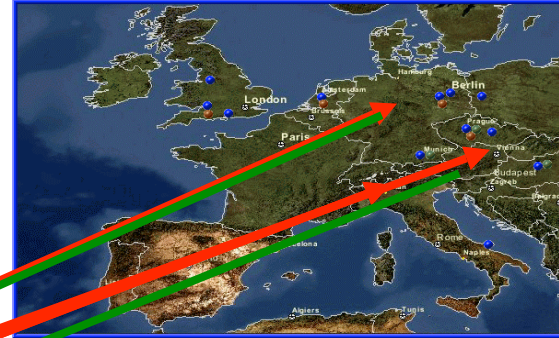
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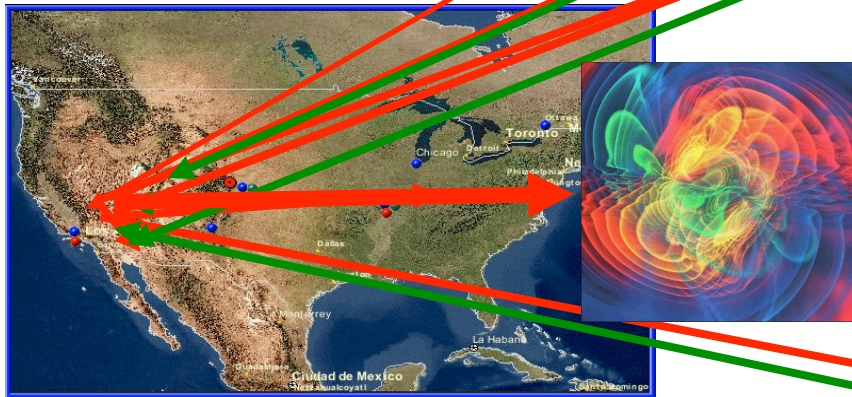
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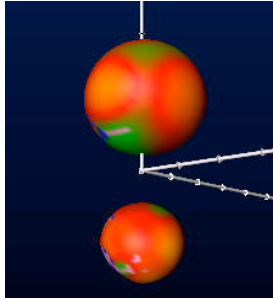
Huge job generates remote data to be
visualized in Baltimore



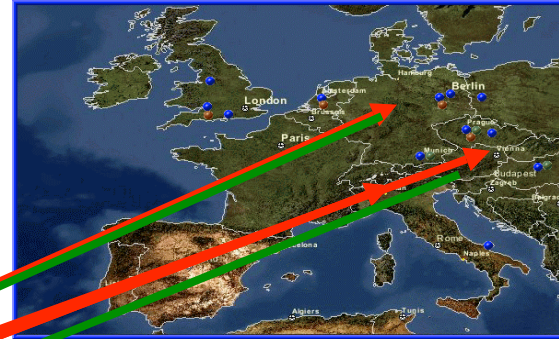
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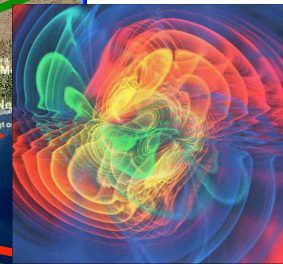
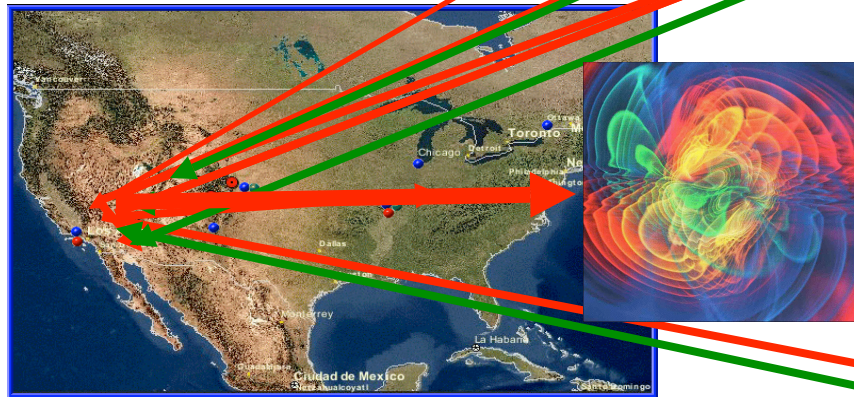
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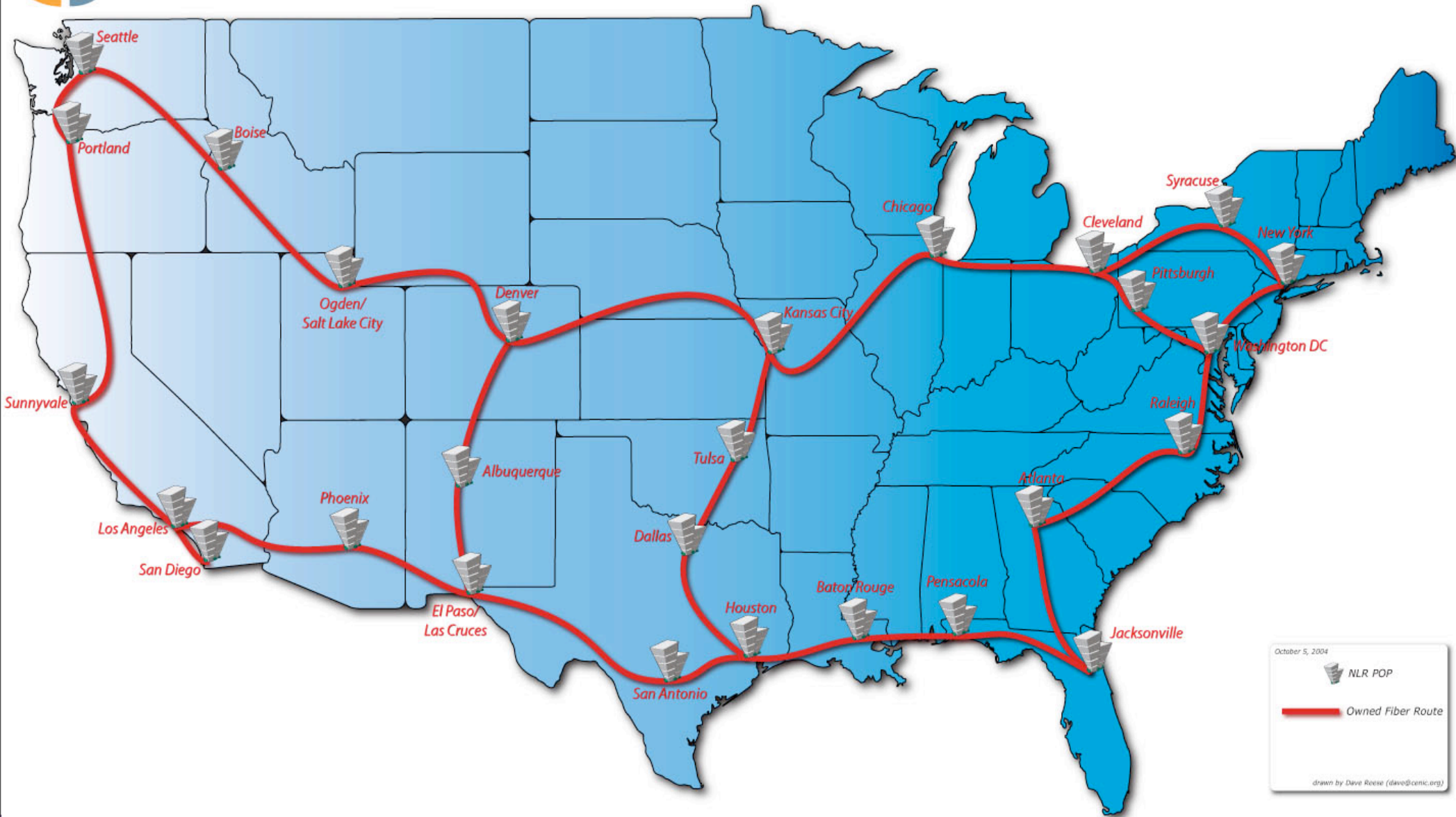


Huge job generates remote data to be
visualized in Baltimore


Physics code to do all this can be
generated via symbolic algebra!




National LambdaRail Architecture

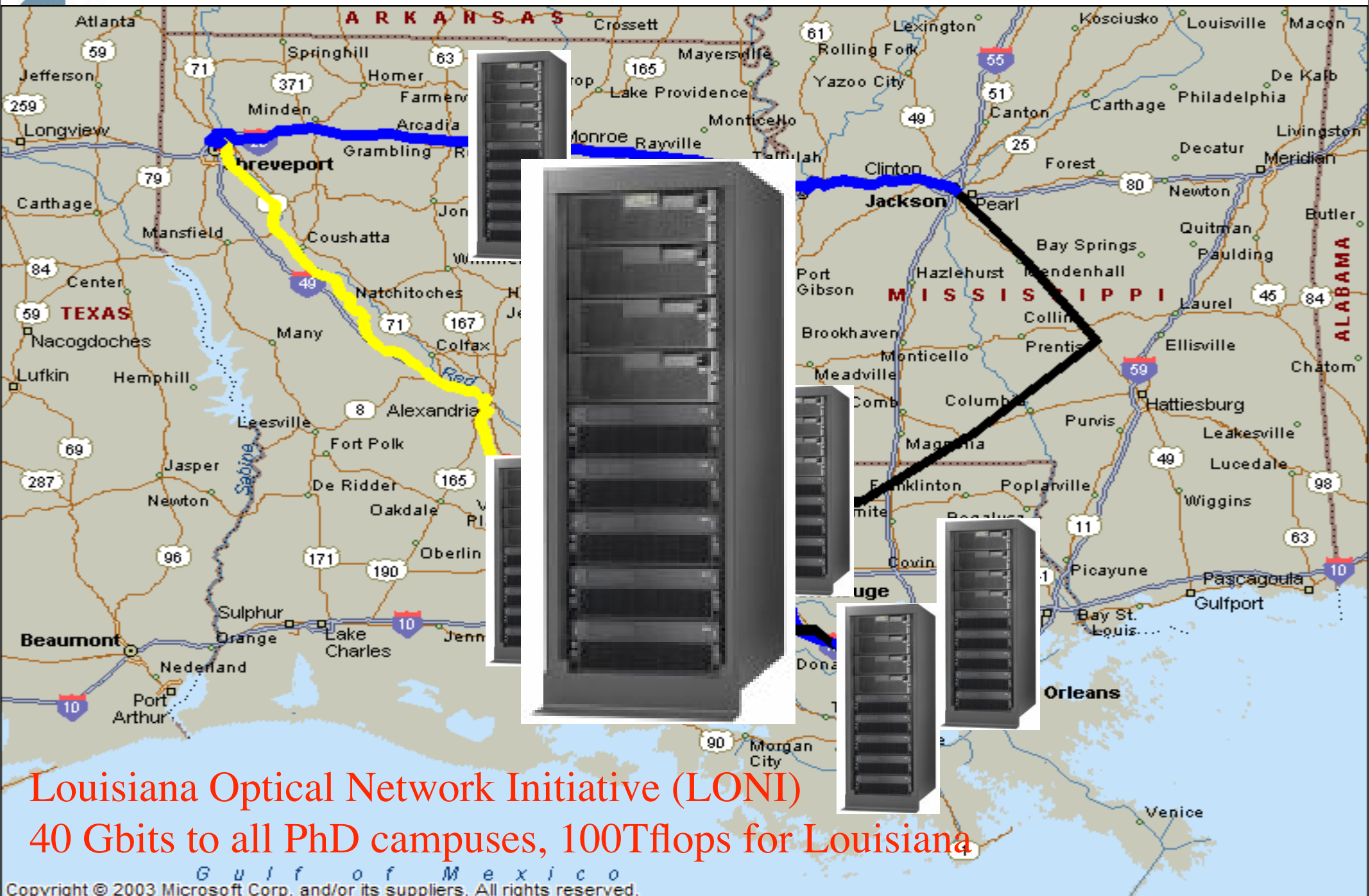


October 5, 2004

 NLR POP

 Owned Fiber Route

drawn by Dave Reese (dave@cmic.org)



Louisiana Optical Network Initiative (LONI)
40 Gbits to all PhD campuses, 100Tflops for Louisiana

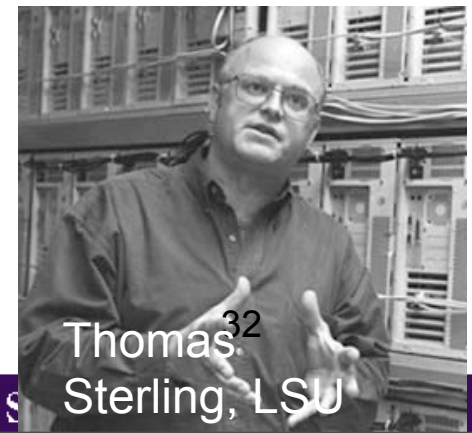
Gulf of Mexico



Optical Nets Enable Old & New Paradigms

Huge BH simulation, outputs ~TBs data, must be interactively viz'd & analyzed by international collaboration

- Many practical problems found above go away!
- New Distributed Computing, Data, and Viz Services
 - Data larger than memory, disk slow: multiple streaming data servers
 - Co-scheduling machines, data, and network for single event: MacLaren HARC
 - Lambda Provisioning: Karmous-Edwards EnLIGHTened NSF project
 - Same application must work with multiple nets, services: GAT/SAGA
- High Resolution: not science w/o details, analysis
 - Uncompressed HD stream: near latency-free remote viz at 1.5Gbit/sec
 - Video for colleagues: see details, read equations
 - Sterling HPC class: from LSU but LA, AR, Brno (Czech)



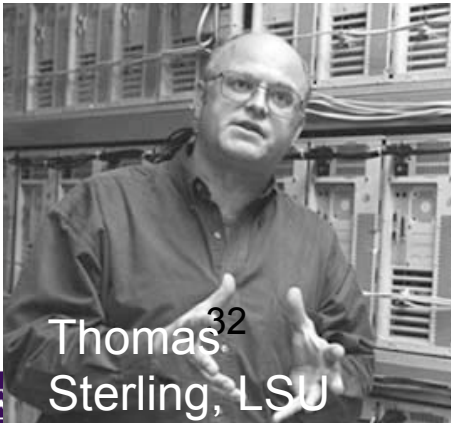
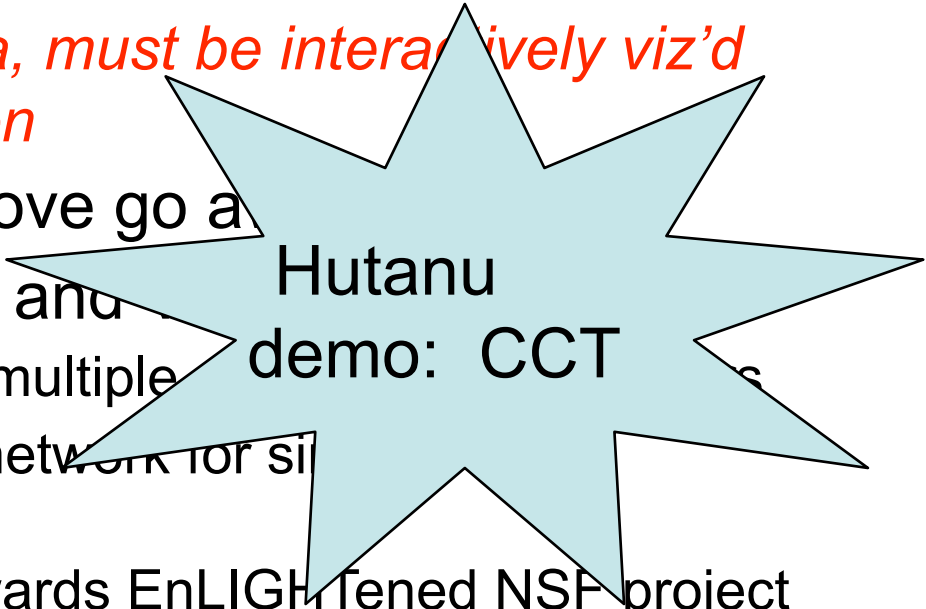
Thomas³²
Sterling, LSU



Optical Nets Enable Old & New Paradigms

Huge BH simulation, outputs ~TBs data, must be interactively viz'd & analyzed by international collaboration

- Many practical problems found above go a
- New Distributed Computing, Data, and
 - Data larger than memory, disk slow: multiple
 - Co-scheduling machines, data, and network for sil
 - MacLaren HARC
 - Lambda Provisioning: Karmous-Edwards EnLIGHTened NSF project
 - Same application must work with multiple nets, services: GAT/SAGA
- High Resolution: not science w/o details, analysis
 - Uncompressed HD stream: near latency-free remote viz at 1.5Gbit/sec
 - Video for colleagues: see details, read equations
 - Sterling HPC class: from LSU but LA, AR, Brno (Czech)



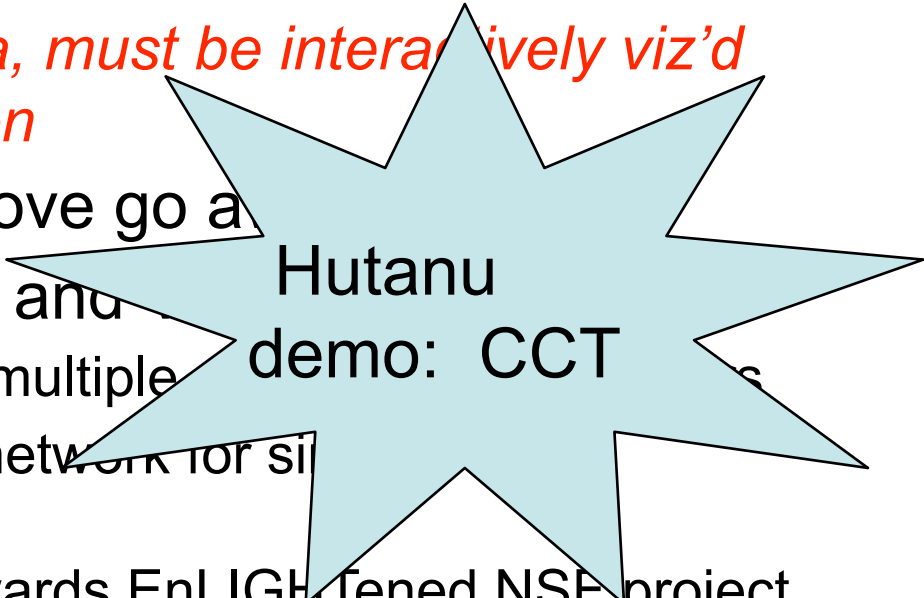
Thomas³²
Sterling, LSU



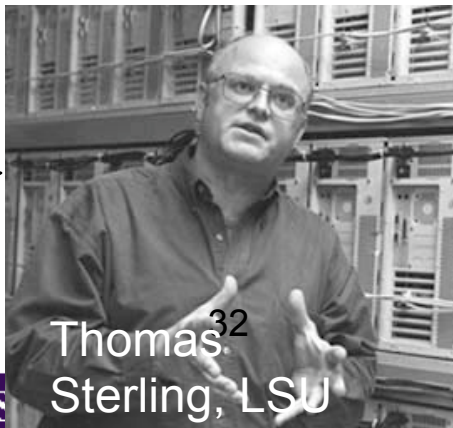
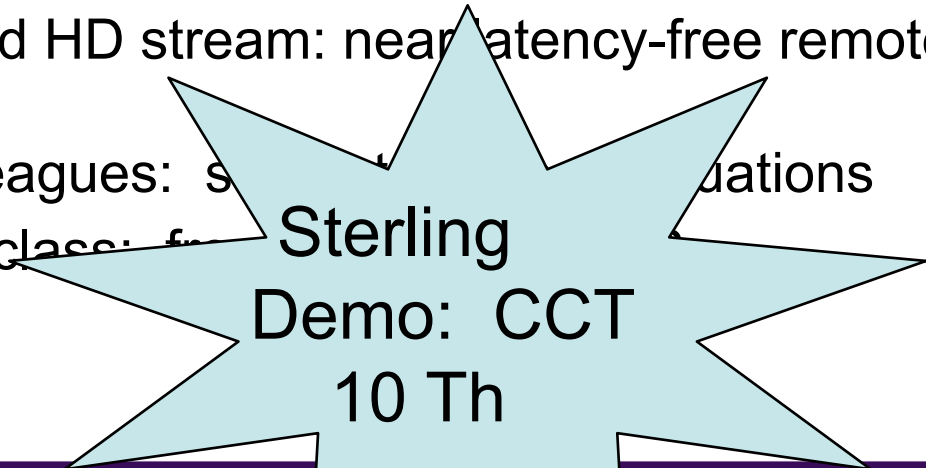
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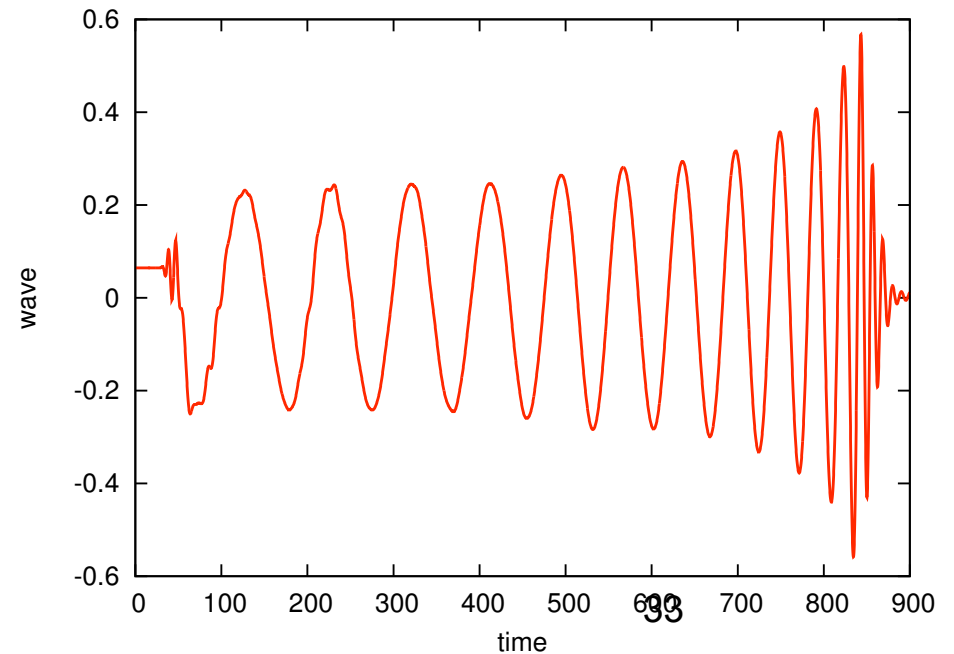
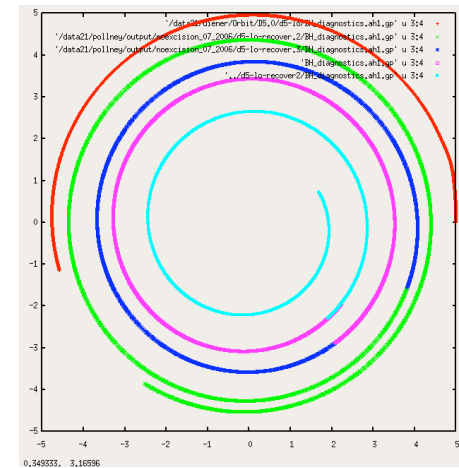
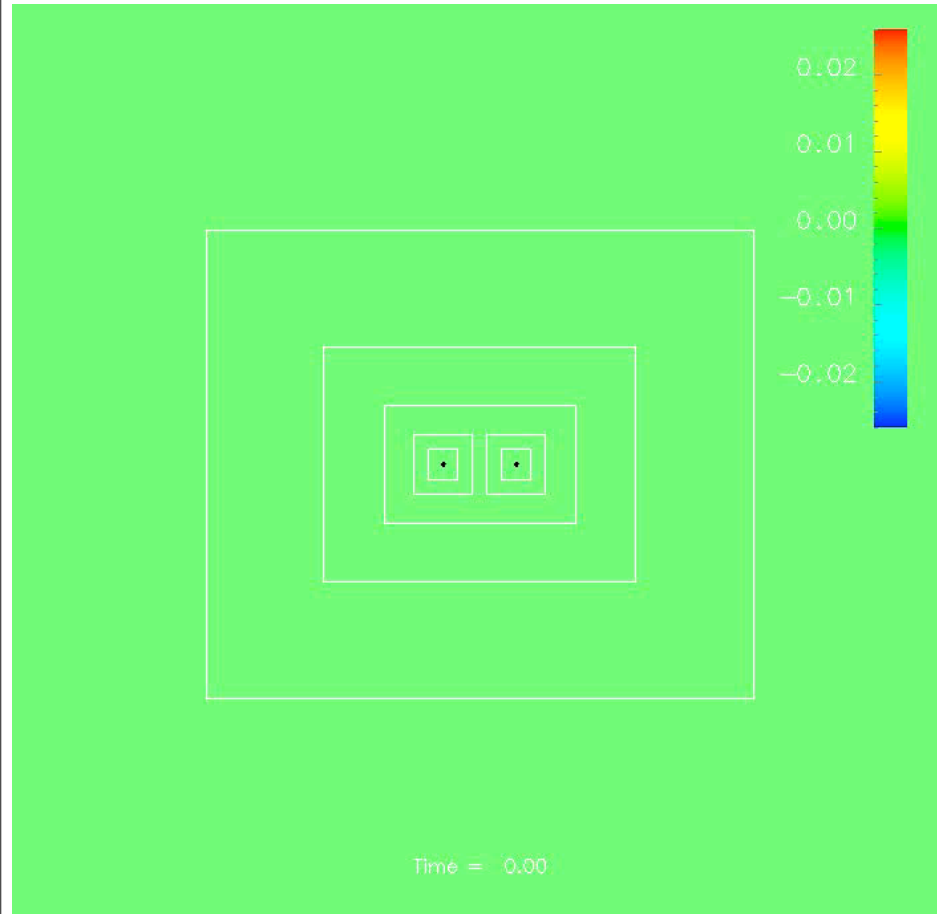
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State of Art Black Hole Binaries

Many groups orbiting BHs!



Peter Diener, LSU

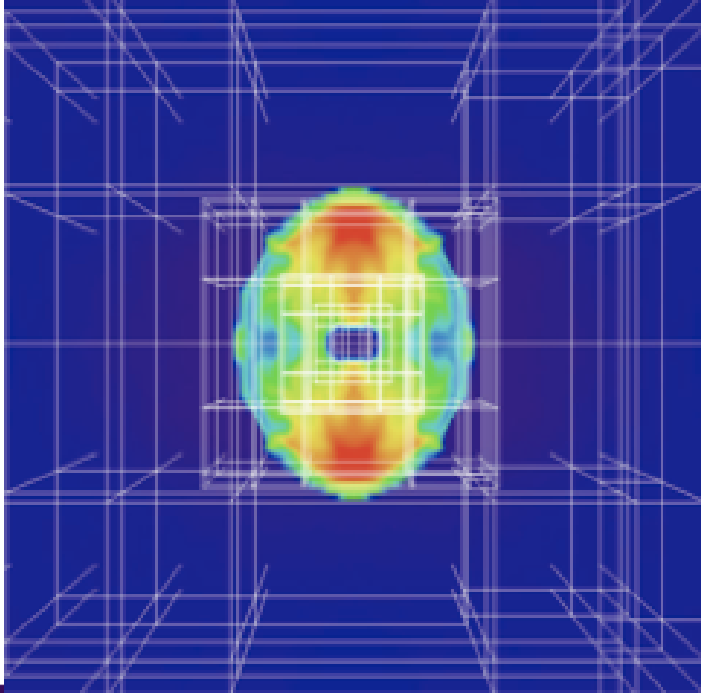


Full GR Iron Core Collapse

Connecting Numerical Relativity with Supernova Theory

- Cactus 3D refined grid with Carpet AMR driver & 9 refinement levels
 - Resolves entire pre-collapse core (~3000 km) and final proto-neutron star (~30km)
 - Whisky GR Hydro code developed by AEI, Southampton, Trieste, Valencia, Thessaloniki collaboration
 - Microphysics

Christian Ott, AEI & U. Arizona



- Closing in on Holy Grail of 3D GR core-collapse simulations
- First consistent 3D GR core-collapse of rotating iron cores
- Cores stay very axisymmetric until “bounce”, then waves boosted by GR

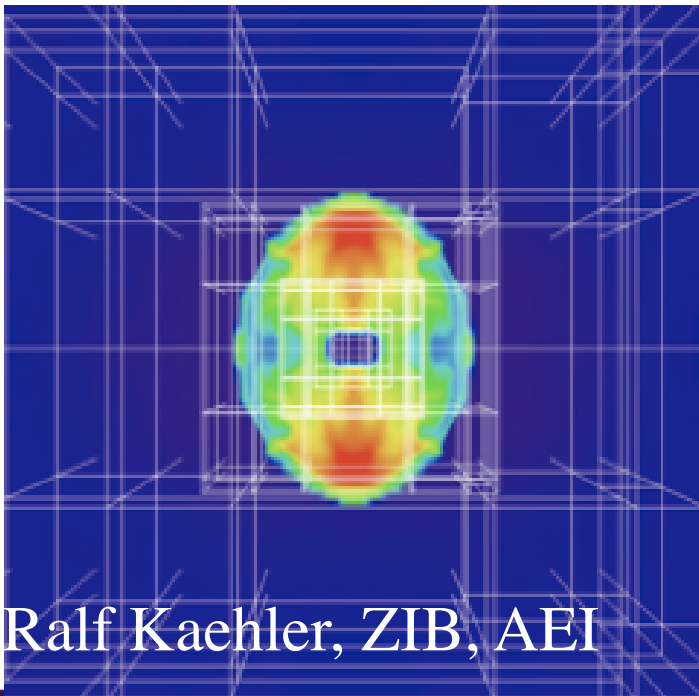


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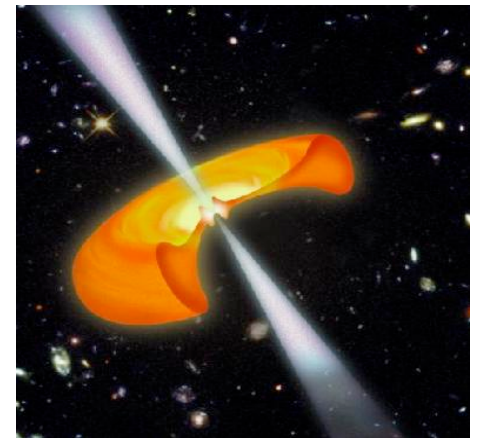
Ralf Kaehler, ZIB, AEI

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Relativistic Astrophysics in 2010

- Full 3D GR simulations of binary systems for dozens or orbits and merger to final black hole
 - All combinations of black holes, neutron stars, and exotic objects like boson stars, quark stars, strange stars
 - Full 3D GR simulations of core collapse, supernova explosions, accretion onto NS, BH
 - Gamma-ray bursts
- All likely to be observed by LIGO, GEO, Virgo
- Resolve from 10,000 km down to 100 m on a domain of $1,000,000 \text{ km}^3$ for 100 secs of physical time
 - ~20Kflops per gridpoint, ~500 grid functions
 - 16 levels of refinement
 - Weeks on Pflops/sec sustained performance
 - 100 TB memory (size of checkpoint file needed)
 - PBytes storage for full analysis of output





Petascale Challenges for GR (*Scary*)

- Basic numerical algorithms in place (new!)
 - Dozens of groups compute GR, share common tools for petascale
- Most AMR codes scale to ~ 64 processors, but petascale machine will have 500K processors!
 - Serious work to do on scaling, dynamic loadbalancing, fault tolerance, software environments, debugging tools
- Consider novel ways to break up jobs
 - Farming off non-parallelizable analysis tasks, viz, coupling codes, spawning, integrating with data analysis
 - Consider petascale machine as your grid!
- Handling all the data: storing, retrieving, visualizing, analyzing. Lambda provisioning for steering, migration, viz
- Parameter space! Metadata to describe 10^{6+} simulations



CCT Focus Areas and Research Clusters



Assistant Director for Computing Applications:
G. Allen

Projects, Programs, Initiatives

Core Computational Science: G. Allen

<i>Scientific Computing</i> (Katz, ECE)	<i>Distributed Systems</i> (Allen, CS)	<i>Computational Mathematics</i> (Brenner, Math)	<i>Visualization</i> (Ullmer, CS)
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Coast to Cosmos (C2C): J. Tohline

<i>Numerical Relativity & Astrophysics</i> (Tohline, Physics)	<i>Engineering Applications</i> (White, PetEng)	<i>Coast & Environment</i> (Twilley, SCE)
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Human & Social World (HSW): S. Beck

<i>Emerging Applications</i> (Beck, Music)	<i>Technology Adoption</i> (Hirshheim, ISDS)
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Material World: J. Pullin

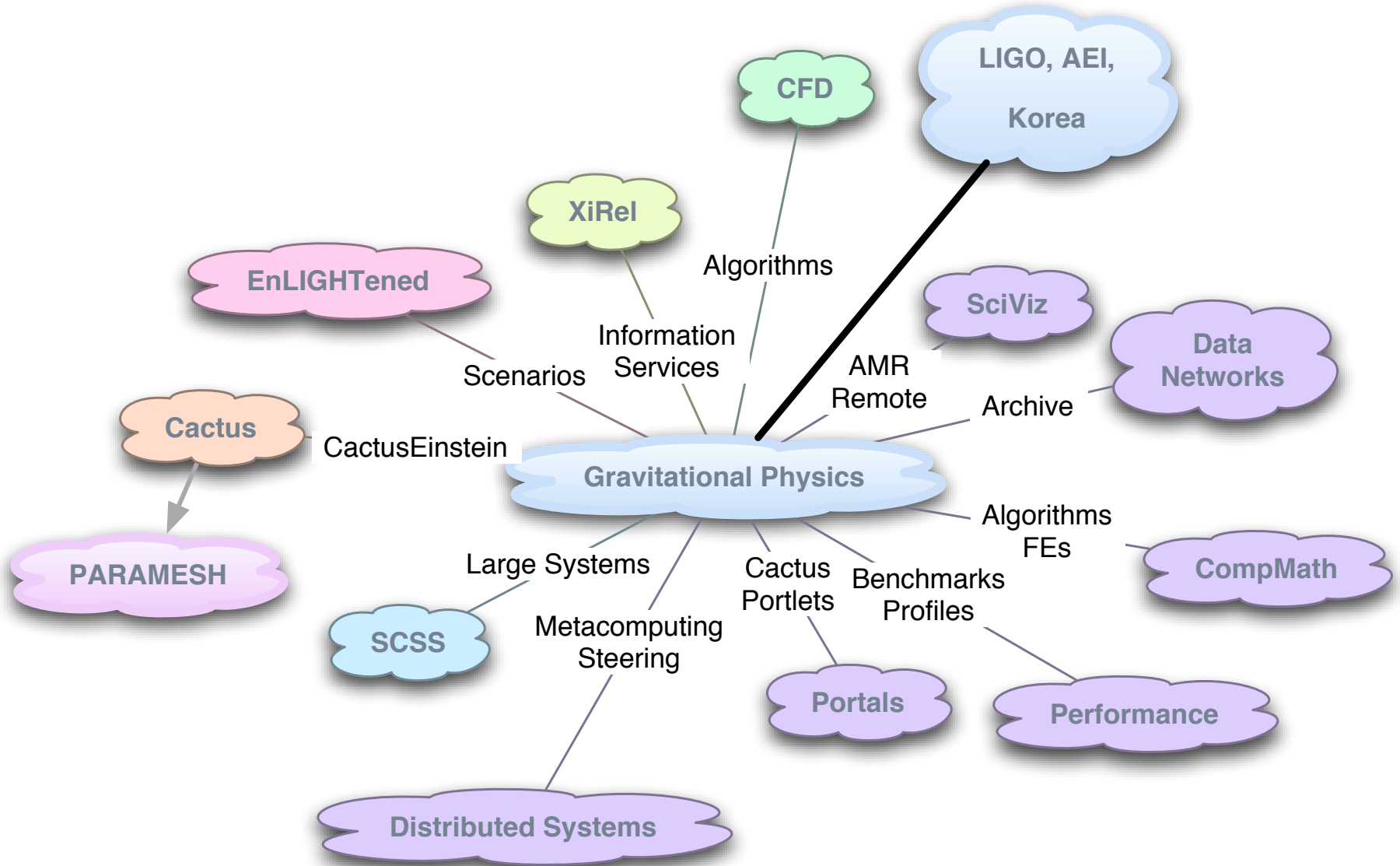
Materials / Chemistry / Biology
(Jha, CCT)



CCT Focus Areas and Research Clusters



Projects, Programs, Initiatives

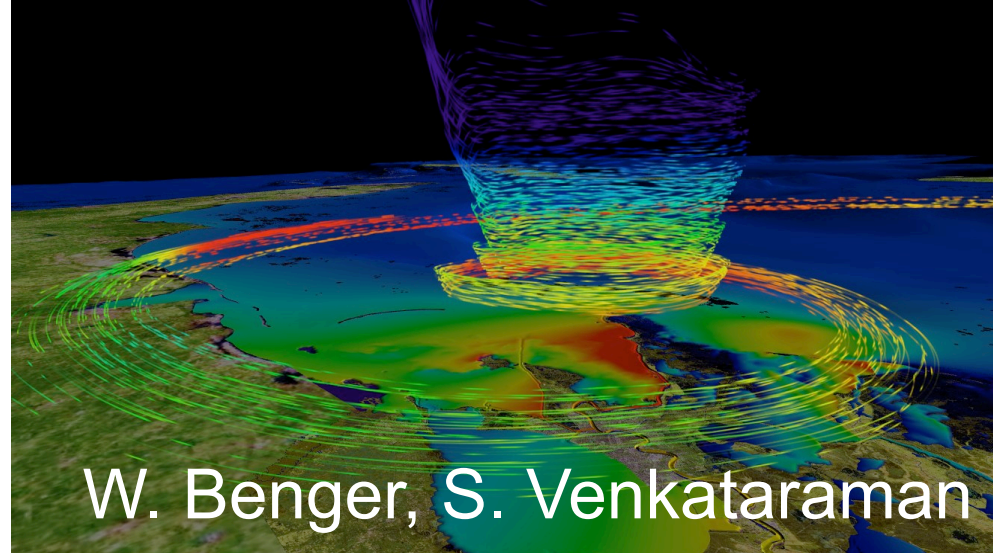
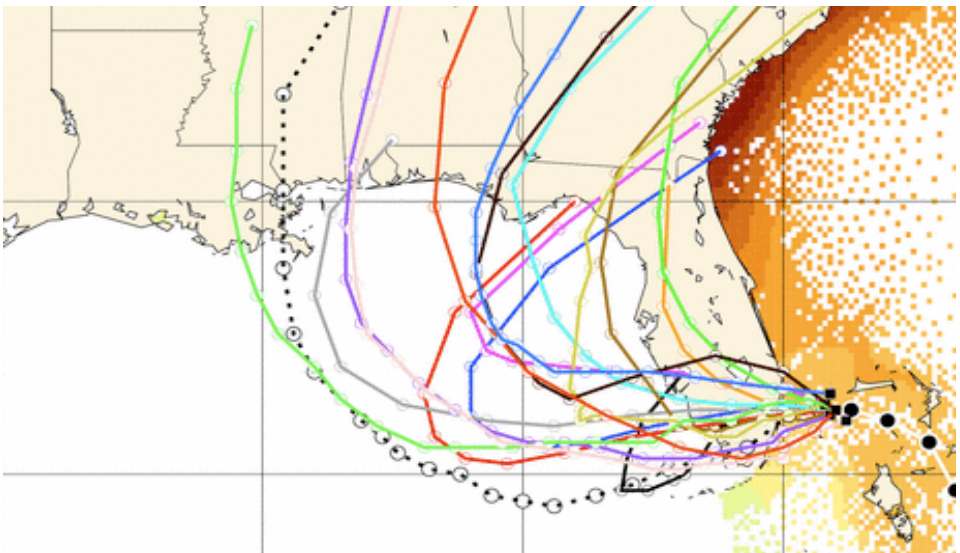




Ideas Apply to Coastal Modeling



- Event driven computing: GWs detected, hurricane coming, etc!
- Respond to data, observation, computational resources: DDDAS
 - Use computer simulations to model winds and water: surge and waves, farm on grid, couple models, data acquisition, ensembles, invoke new algorithms
- Need to have lots of CPUs ready to go!
- Where should we evacuate? Where should we rebuild?



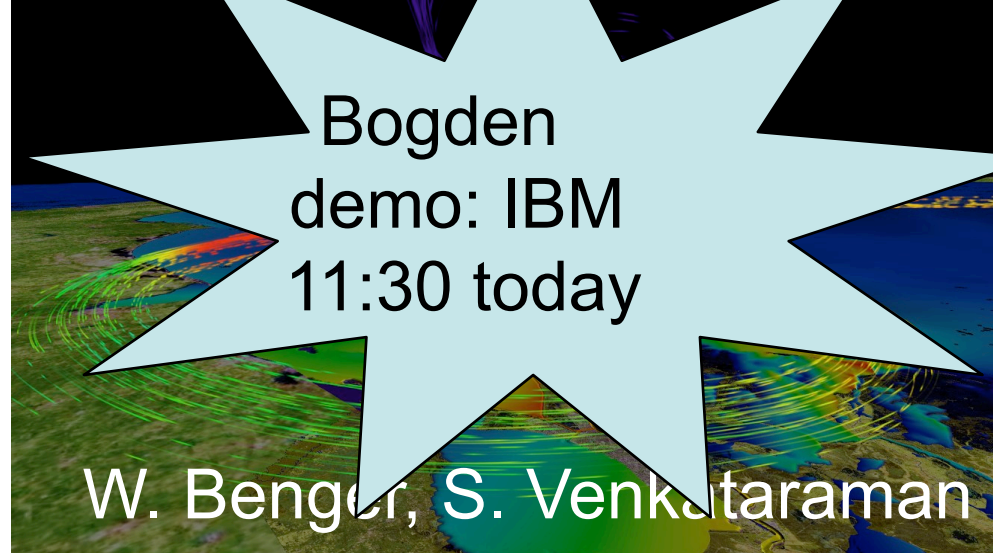
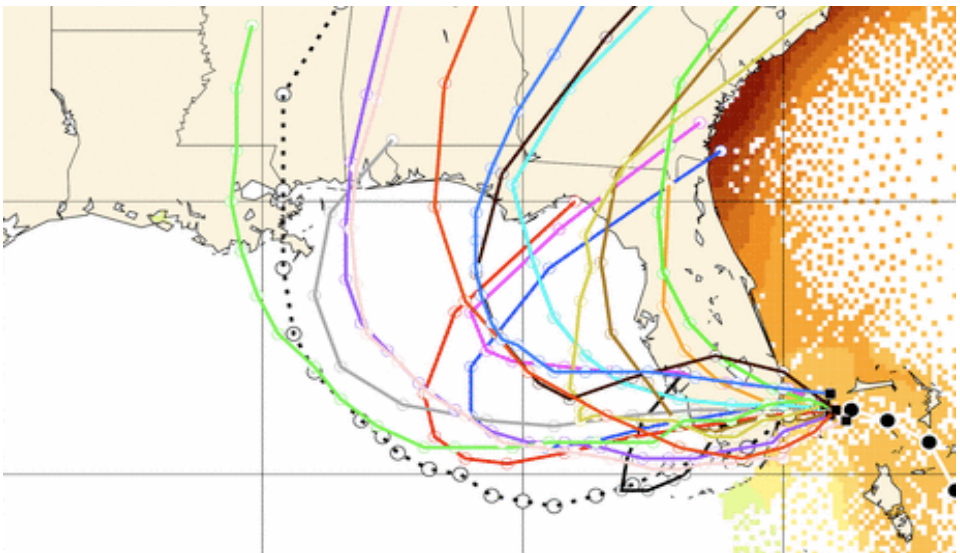
W. Benger, S. Venkataraman



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Bogden
demo: IBM
11:30 today

W. Benger, S. Venkataraman



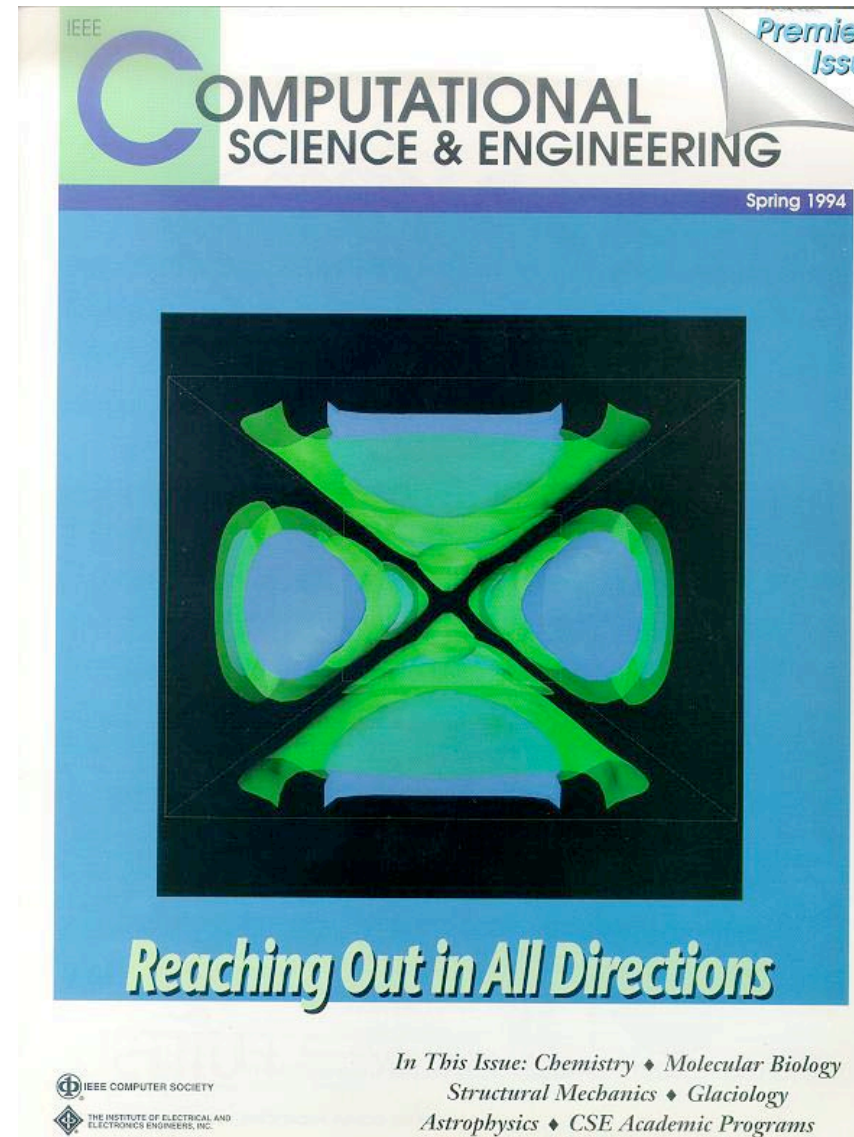
Lessons Learned for Future

- Be creative: “Imagination is more important than knowledge.” Albert E.
- Petascale machines
 - 500K processors is a universe unto itself
 - Consider not just scaling, but code-coupling, spawning, data integration, DDDAS ideas
- Abstractions are critical for
 - application scientists, computer scientists
 - collaborations
- Scientists, hardware, software, technology groups need to work together



Summary

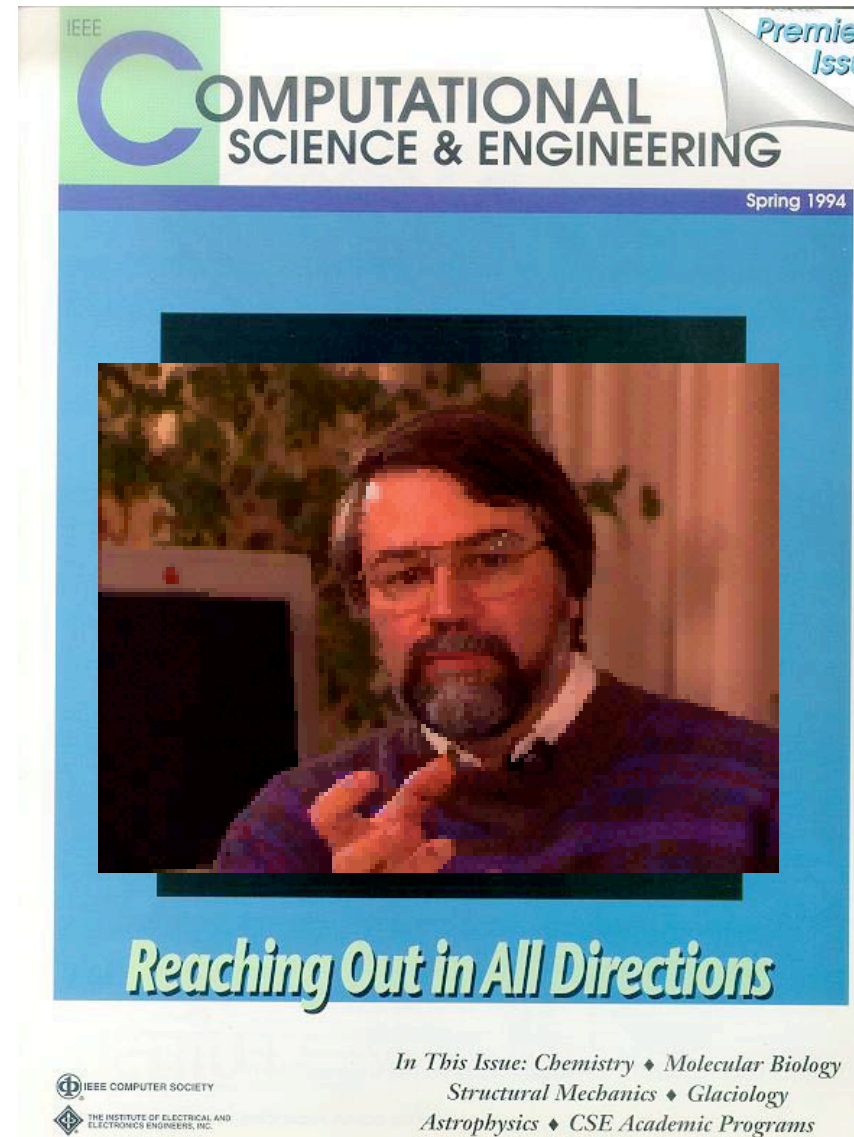
- Major breakthroughs in numerical relativity
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 - Sharing software
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- Look forward to tackling them with you!





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Thanks

- NCSA & environs
 - Larry Smarr, Paul Walker, Joan Massó, John Shalf, Wai-Mo Suen (WashU), Ian Foster (ANL/UC)
- AEI, ZIB, RZG
 - Gabrielle Allen, Werner Benger, Thomas Damlitsch, Tom Goodale, Ralf Kaehler, Hartmut Kaiser, Ian Kelley, Thomas Radke, Gerd Lanfermann, Andre Merzky, Bernard Schutz, Oliver Wehrens, Michael Russell, Jason Novotny, Christian Ott, many others...
- GridLab
 - Jarek Nabrzyski, Giovanni Aloisio, Peter Kacsuk, Thilo Kielmann, Ludek Matyska, Alexander Reinefeld, Ian Taylor...
- LSU
 - CCT family (esp. Peter Diener, Erik Schnetter), Gov. Blanco
- NSF, DOE, DFN-Verein, EU, MPG, DFG
- Microsoft, Intel, SGI, Cisco, IBM, Sun, HP