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14. ABSTRACT USPL Laboratory Update: Reconfigured and now achieving 6.5 TW. Propagate laser to 2k & 5k site has begun. Progress on Nonlinear Propagation: Media with second and third harmonic generation present mathematical complexities in previous results that have been now simplified. Work on competing nonlinearities and propagation: We have deviated from Farnum/Kutz work to include a more uniform definition for dispersion. We have kept the 2 nd order derivatives in time for a finer look at dispersion. Under SEVA and other assumptions or equations reduce to a form previously published but little computational work on them is available. Computational efforts underway: New results from a RK5 & FFT methodology and 6-pt Crank-Nicholson for our simplest form. We will move to solve the more complicated forms numerically in the future. Couple this work with plasma work by out group.					
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DoD Center of Excellence to Support Theory and Experiments on Filamentation Topics for DDR&E's Recent MURI Initiatives

**DEPS USL Workshop
14 June 2012**

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and A. Lucero**

**Air Force Research Laboratory
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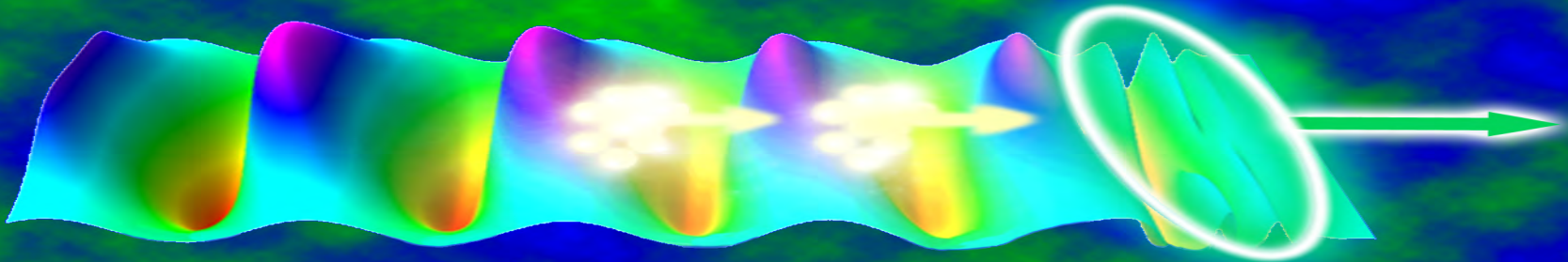
Overview



- USPL Laboratory design, building, and updates at AFRL/RD
- Progress on Nonlinear Propagation
 - AFOSR MURI Collaboration
- Theoretical and Computational efforts underway
 - New results from a RK5 & FFT methodology and 6-pt Crank-Nicolson scheme
- Summary and Conclusions



Unique Characteristics To Potentially Exploit In USPL



A laser pulse traveling through a plasma, indicated by the ellipse at right, accelerates bunches of free electrons (center) in its wake

P. Preuss, BELLA: The Next Stage in Laser Wakefield Acceleration, Lawrence Berkley National Laboratory News Center, April 15, 2008.
<http://newscenter.lbl.gov/feature-stories/2008/04/15/bella-the-next-stage-in-laser-wakefield-acceleration/>

- **USPL Characteristics: Very short pulse durations (notionally 10ps-10fs)**
 - High peak intensity and electric fields and broad spectral bandwidth
- **Effects**
 - Self induced nonlinear optics
 - Multiphoton ionization (filamentation) plasma creation
 - Material modification / damage
 - Multi-spectral generation (RF, THz, EUV, x-rays, e^+e^- pairs)
 - Electron acceleration



Importance of Laser Filaments

Operational uses

- Filamentation process is the leading candidate to localize electromagnetic fields for sensing, imaging, and non-imperceptible communications (Low probability of intercept communication)
- Design new models for non-kinetic attack which offer covert and limited or no collateral damage
- New knowledge is required to address the problem of efficient and effective communication through plasma shields which isolate the space shuttle on atmosphere re-entry and clearly isolate the United States Air Force super-sonic vehicle from ground communications

Capability Sought

- That fs induced filaments may act as an effective waveguide in both the longitudinal and transverse directions
- If it is plausible to confine external EM fields, both CW and pulsed sources, within a small extended filament that can be constructed in free space
 - for covert sensing in detail, imaging and materials investigation

Basic Science

- We seek to understand fs pulses leading to filamentation and resultant plasmas
- fs induced filamentation with external EM field interactions and resultant plasmas are excellent basic science medium to attempt to answer the fundamental questions posed above



USPL Technologies Research:



- **DoD via HEL-JTO is rethinking USPL investment strategy, DDR& expending \$15M, “Femtosecond (fs) filamentation as leading candidate to localize electromagnetic (EM) fields”**
 - Sensing, imaging, and non-imperceptible communications (e.g. hypersonic UAVs)
- **AFRL/RD Based Defense S&T Strategy for Mid-Term 2017-2022**
 - Low collateral damage, non-lethal
- **Capabilities Sought:**
 - DoD USPL Investment Strategy
 - Interaction of USPL induced filaments with High E-Fields
 - Covert sensing in detail, imaging and materials investigation
 - New USPL mathematical and computational models



We are not interested in!



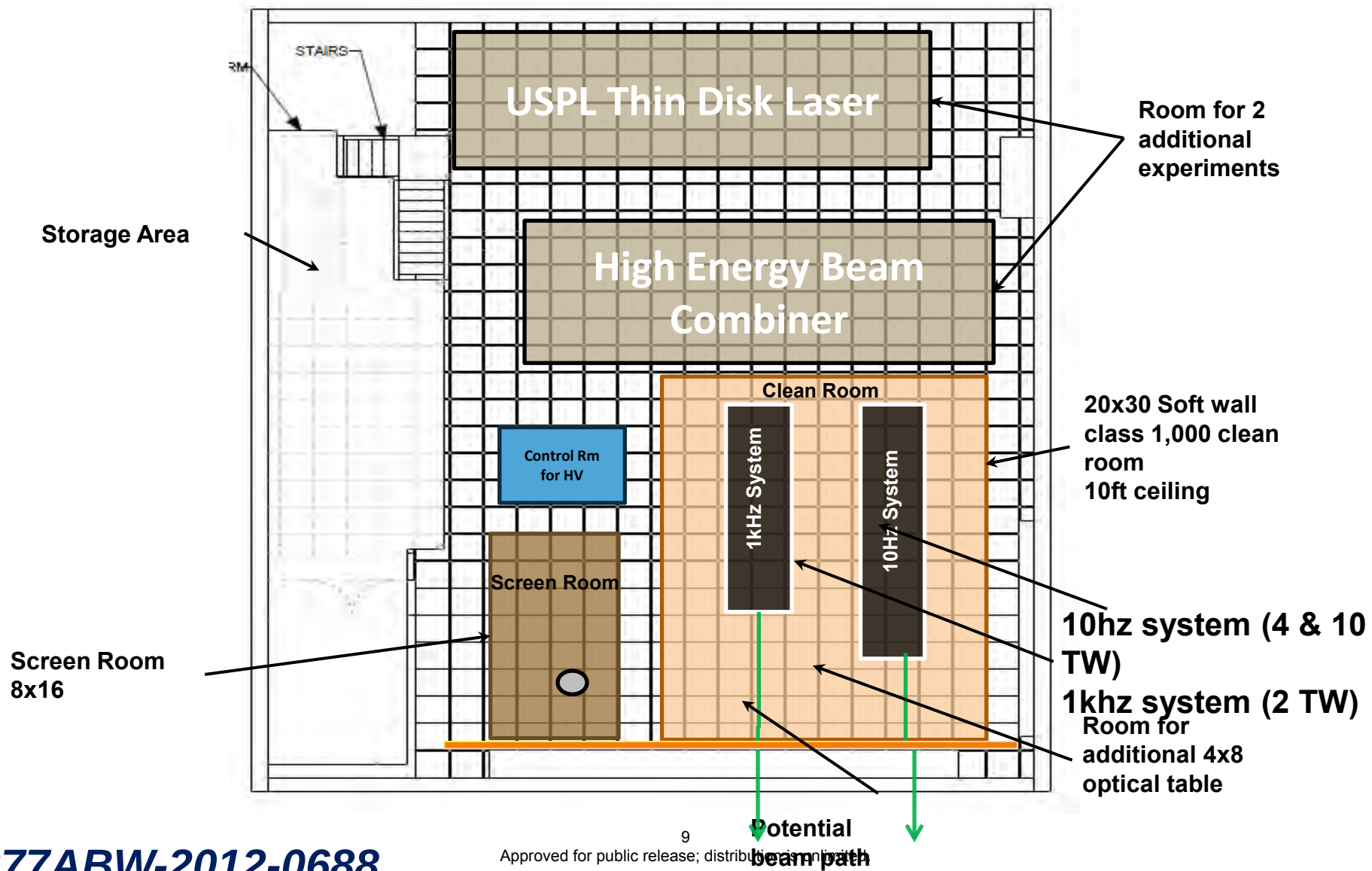


Nor This!





Ultra Short Laser Lab Layout Plan

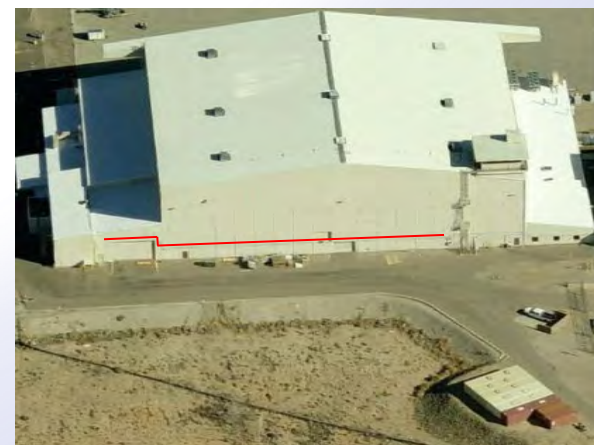




Our Building History in 2010



- Turn on Pump Lasers from Bldg. 243
- Demolition lab
- Addition Electrical Supply

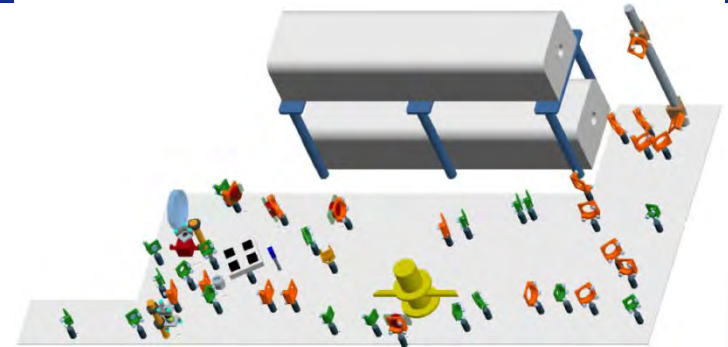




Original Drawings New Paint and a Raised Floor



- Move Temporary shed of water chiller
- Temporary Cooling
- Drawings to transfer optics
- Paint
- Raised Floor





Electrical/Plumbing/Optics



- Additional Power 2-Electrical Panels
- Water Manifolds
- Transfer Optics to Breadboards
- Disassemble Screen



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Moving Day June 2010



- Move 20ft & 16ft Optical tables
- Optics/Lasers
- Equipment





Brining It All In!



- Place 6 optical tables in lab

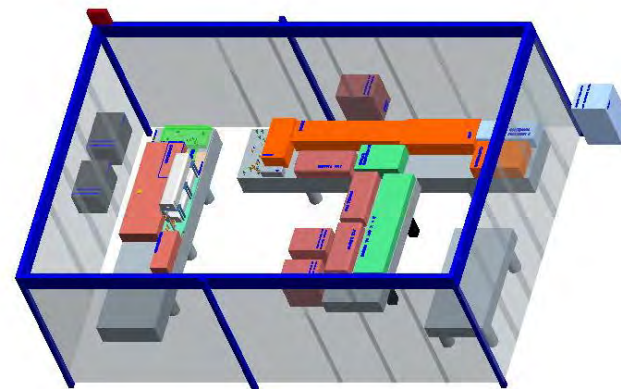




Original Placement



- Optical tables in Lab & floating (3)
- Water manifolds
- Lab automation
- Clean room being built
- Work in Process



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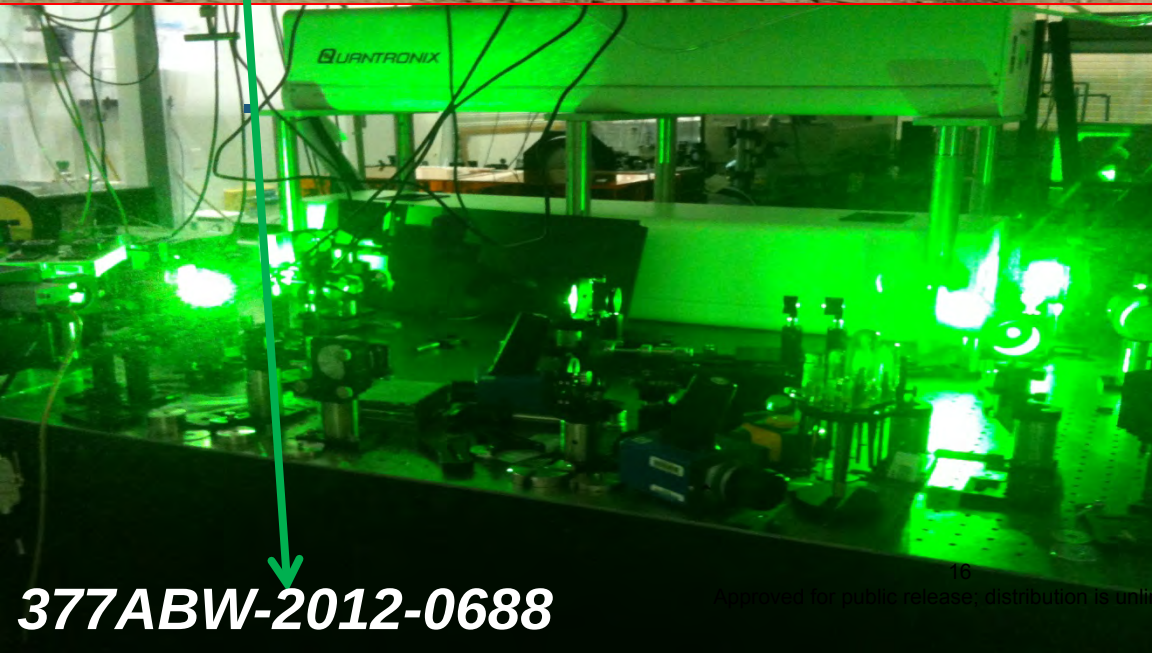


AFRL/RDLA

RANGE: 2k and 5k pre-designated ranges



Propagation



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Krispy Kreme Dream Team



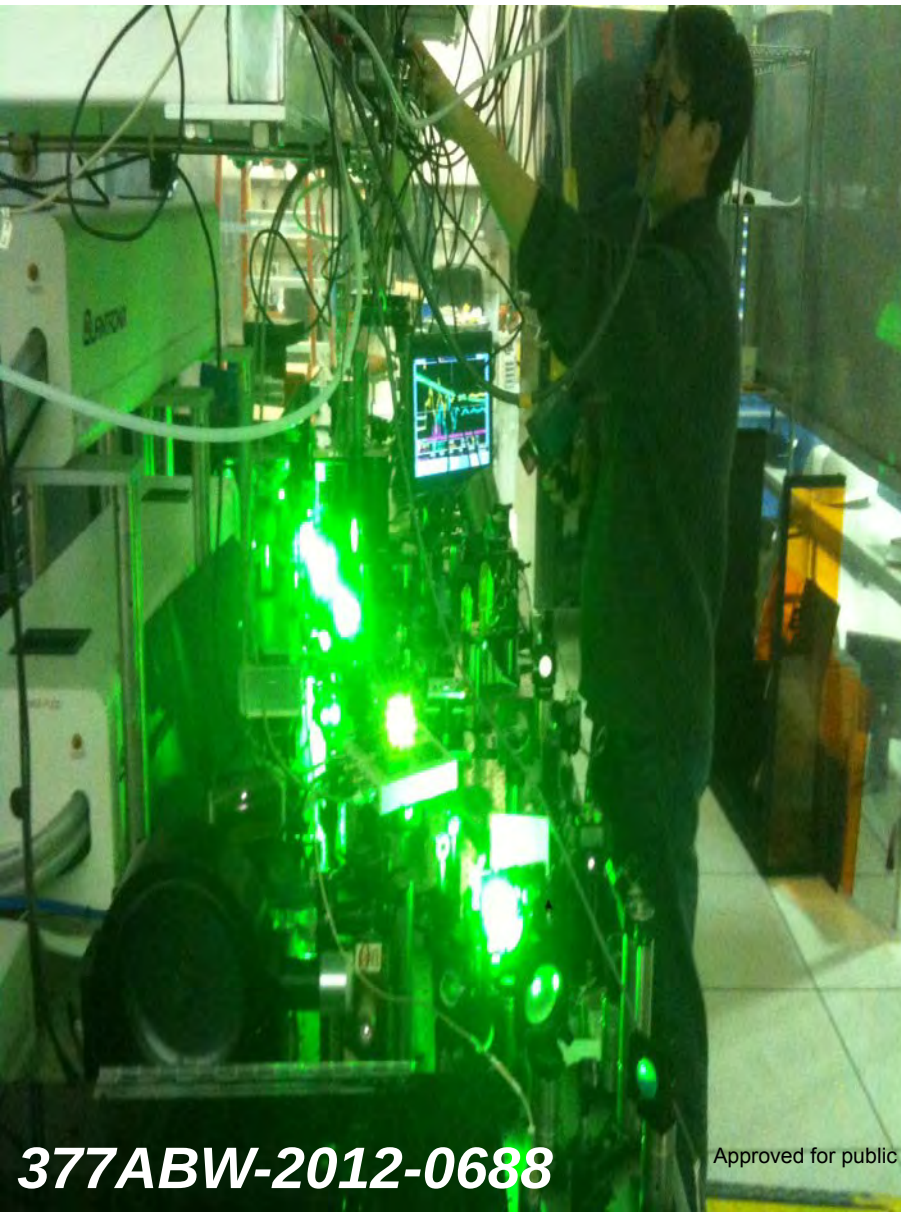
- The USPL Lab was only possible due to the following Team





AFRL/RDLA USPL

Filamentation Team Update



60 fs at 800 nm
20 – 400 mJ, ~ 6.5 TW Max
sustained, continuous filament bundles
(15-20 filaments at 250 mJ)
measured out to 10m



9-inch filament bundle propagation
through kV-level E-Field

Studying the interaction of electric fields
(RF, AC and Optical) with the filament

USPL Group: Dr. Erik Bochove, Dr. W.P. Latham, Professor M.R. Zunoubi, Dr. Andreas Schmitt-Sody, Mr. Adrian Lucero, Mr. Chunte Lu, and Mr. N. Wolfe

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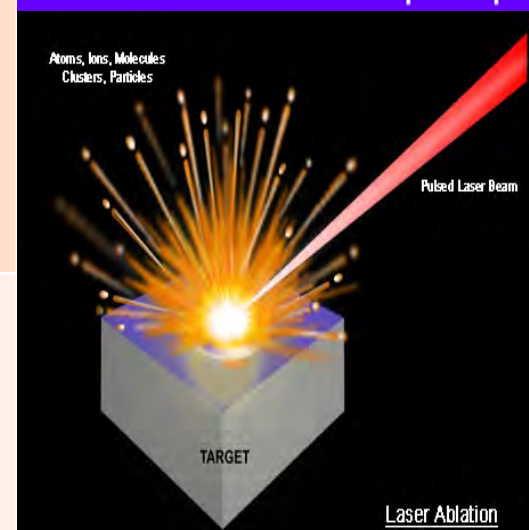
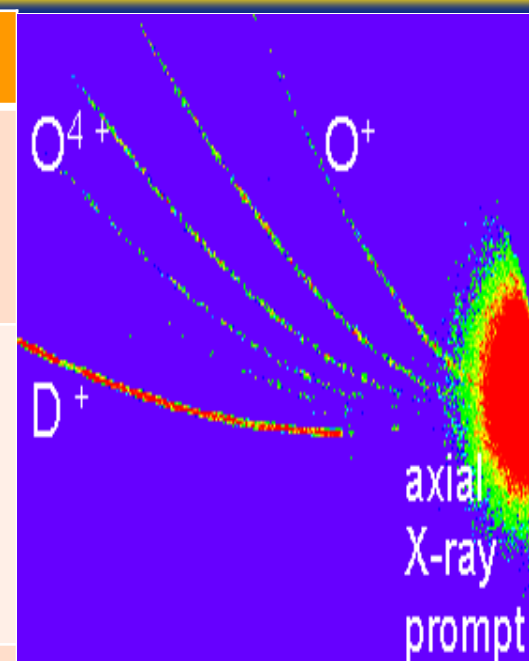
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USPL Technologies Research: In Support of DoD DDR&E MURI



Research Objectives	Areas of Discovery
Write HEL/JTO USPL strategic investment strategy	Military Utility of USPL Wednesday 13 June 2012 Afternoon, Ultrashort Laser Physics, Novel Material Interactions and Measurements 2:05-2:30 FOUO-C
Demonstrate filamentation shorting in high voltage transformers for counter electronics	Effect may trigger circuit fault leading to electrical grid shut down. Wednesday 13 June 2012 Afternoon Ultrashort Laser Physics, Novel Material Interactions and Measurements 2:30-2:55 FOUO-C
Characterize fs-laser filament physics necessary for coupling/confining external EM-Fields	Microwave and RF guiding with a single filament Wednesday 13 June 2012 Afternoon Ultrashort Laser Physics, Novel Material Interactions and Measurements 2:30-2:55 FOUO-C
Develop computational models for fs propagation as an extended free space waveguide	New mathematical & computational models within in the framework of specific observed USPL phenomenon and V&V Thursday 14 June 2012 Morning, Non-Linear Propagation Physics , 8:10-8:35 & 8:35-9:00



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Why Do We Care?

Iraq Diary: Jammers Beat Bombers (Which May Be Bad News) Read More

<http://www.wired.com/dangerroom/2007/09/iraq-diary-jamm/#ixzz0qvWArigQ>





Navy: More Bomb-Blasting Ray Guns, Please

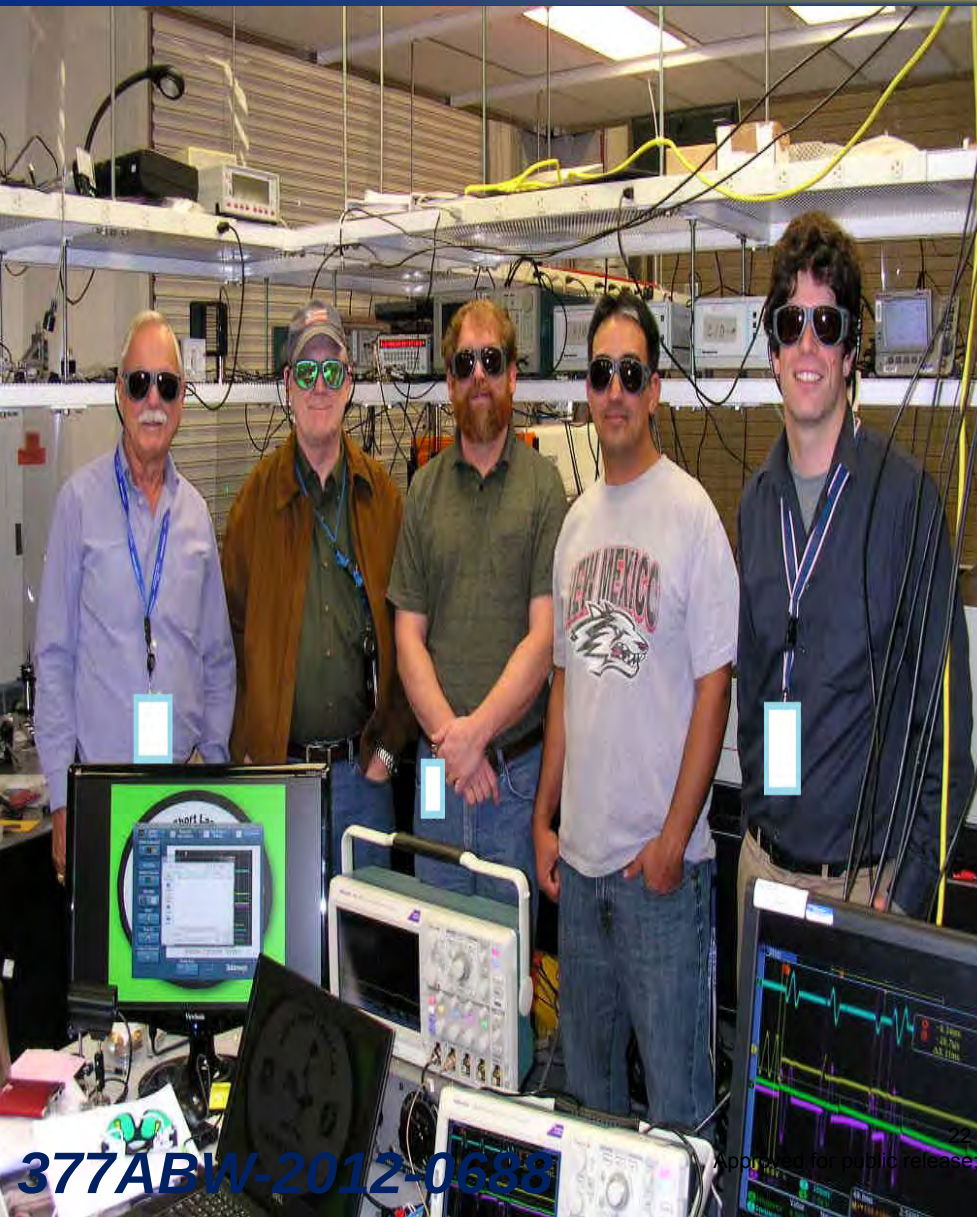


<http://www.wired.com/dangerroom/2010/06/militarys-mystery-ray-gun-to-zap-bombs-change-the-face-of-this-war/#ixzz0qvVH5T8z>





AFRL/RDLA_RHDO USPL Filamentation Team



60 fs at 800 nm

60 – 140 mJ, ~ 2.1 TW Max

**sustained, continuous filament bundles
(8-10 filaments at 140 mJ)**

measured out to 4m



**9-inch filament bundle propagation
through kV-level E-Field**

**Measuring the filament interaction
with a very high E-Field allows us to
begin to describe the physics of the
filaments**

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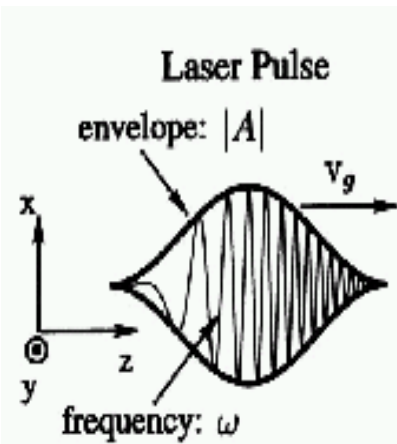


Filamentation Characterization



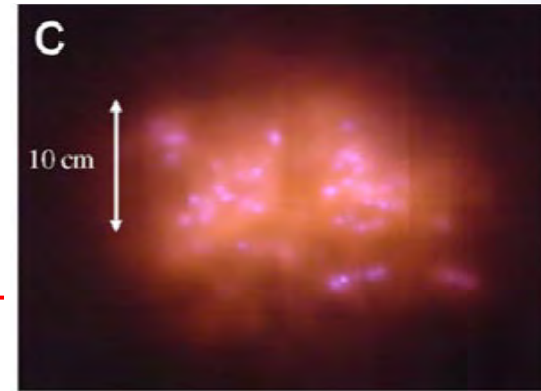
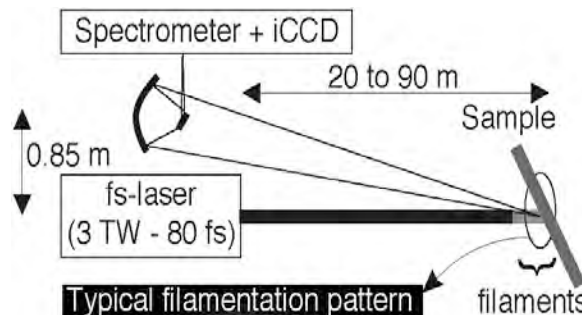
Dr. Andreas Schmitt-Sody NRC Fellow

- High power, femtosecond laser beams propagating through air form extremely long filaments due to nonlinear self-focusing ($\chi^{(3)}$) dynamically balanced by ionization and defocusing.



$$n_{\text{eff}} = n_0 + \delta n_{\text{gas}} + \delta n_{\text{plasma}} \approx 0$$

$$P_{\text{cr}} \sim \lambda^2 / 8 n_0 n_2$$



Typical filamentation pattern



A. Couairon and A. Mysyrowicz, Femtosecond filamentation in transparent media, Physics Reports, Elsevier, pp 47 – 189, 441 (2007)
www.elsevier.com/locate/physrep



Propagation Into The Hangar

~80fs at 800 nm and 100 mJ

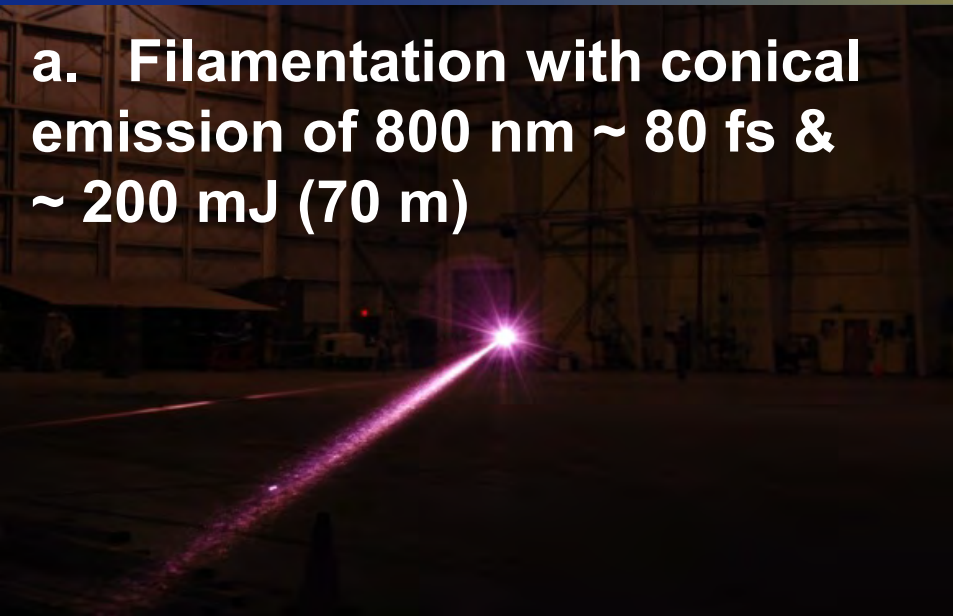




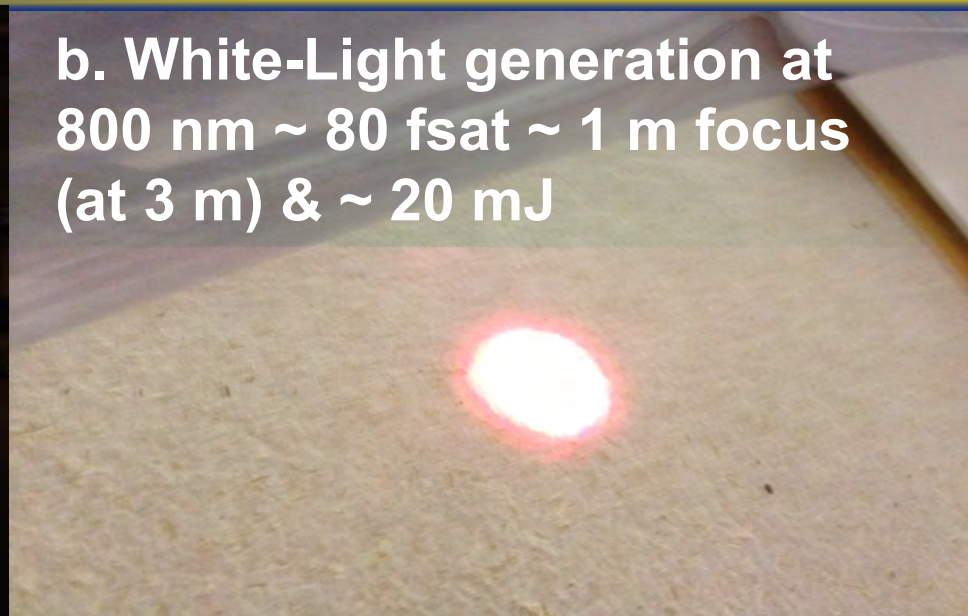
Propagation Into The Hangar



a. Filamentation with conical emission of 800 nm ~ 80 fs & ~ 200 mJ (70 m)



b. White-Light generation at 800 nm ~ 80 fs at ~ 1 m focus (at 3 m) & ~ 20 mJ





Heater-Igniter Experiments



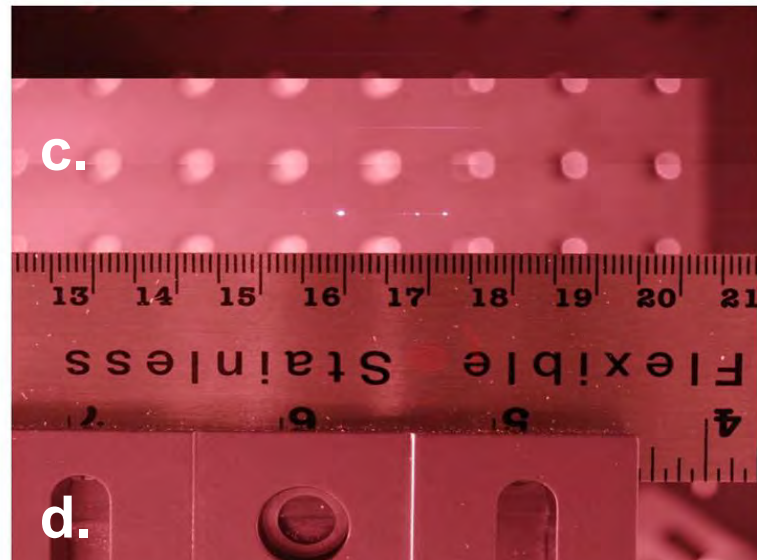
MURI AFRL/UA Collaborative Experiments

1. Purpose is to extend the life time and the number of ions within the filament.
2. Igniter pulse was 400 nm at ~ 100 fs and ~ 1 -2 mJ
3. The delay between the igniter and the heater pulses was between 100 – 500 ps
- 4.

Igniter:
Faint plasma

Igniter +heater:
increase in
brightness, e.g.
more plasma

Heater: avalanche
breakdown and
bubbles.



a. Heater at 800 nm ~ 200 ps
& ~ 200 mJ



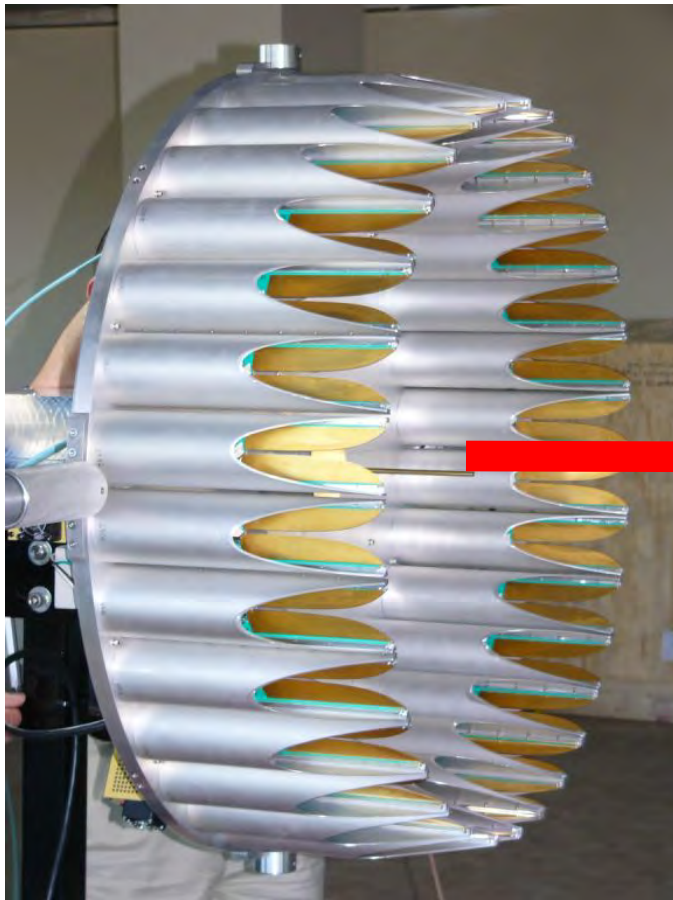


Work In the late 90's





Fields and Plasma Filaments



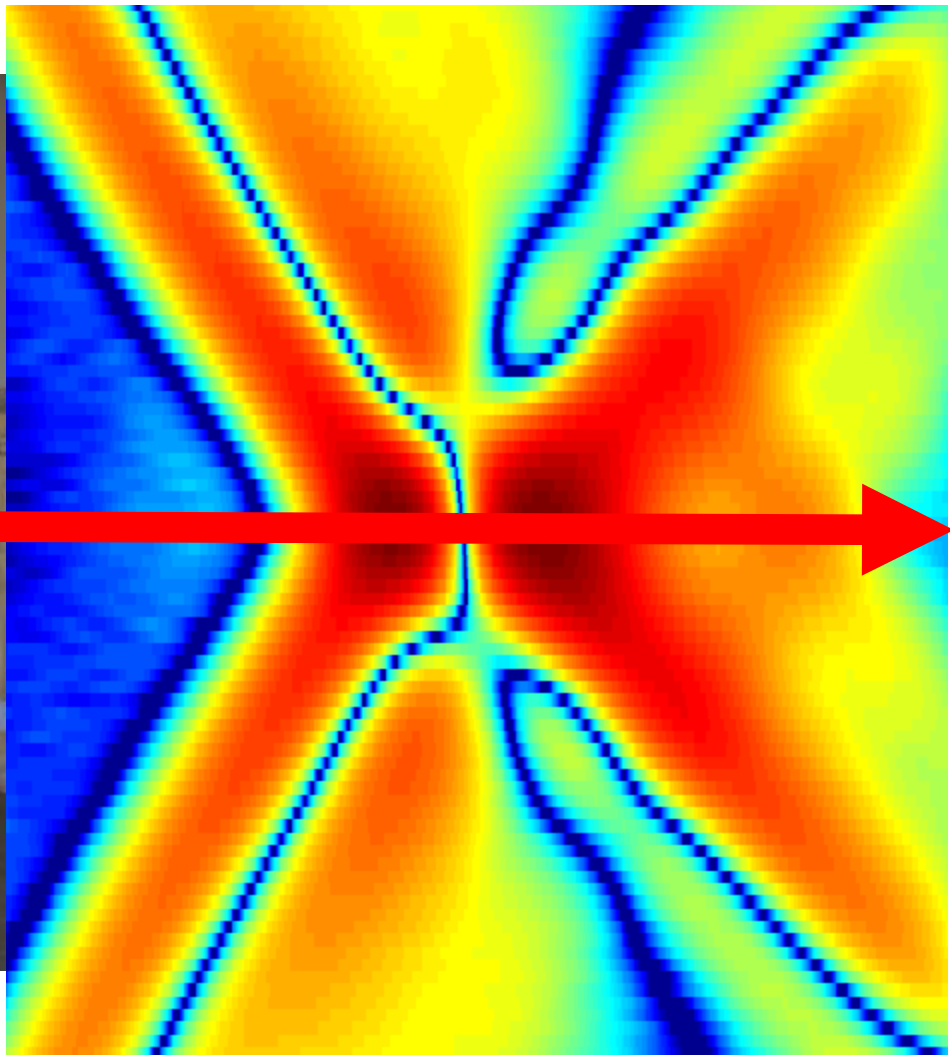
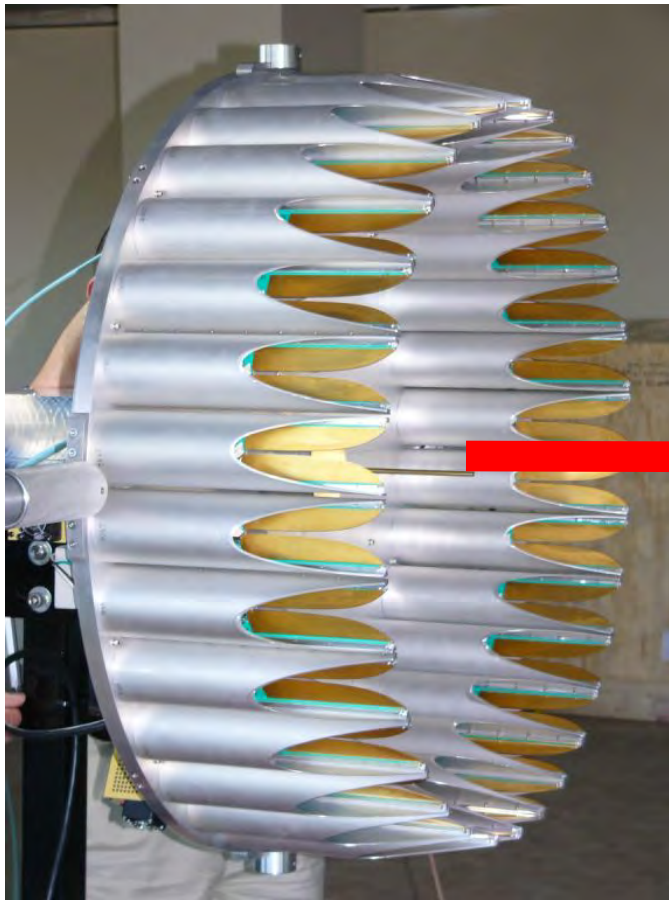
Fire laser through center

of circular array





Fields and Plasma Filaments





Summary and Conclusions



- **USPL Laboratory Update**
 - Reconfigured and now achieving 6.5 TW
 - Propagate laser to 2k & 5k site has begun
- **Progress on Nonlinear Propagation**
 - Media with second and third harmonic generation present mathematical complexities in previous results that have been now simplified
- **Work on competing nonlinearities and propagation**
 - We have deviated from Farnum/Kutz work to include a more uniform definition for dispersion
 - We have kept the 2nd order derivatives in time for a finer look at dispersion.
 - Under SEVA and other assumptions our equations reduce to a form previously published but little computational work on them is available
- **Computational efforts underway**
 - New results from a RK5 & FFT methodology and 6-pt Crank-Nicholson for our simplest form
 - We will move to solve the more complicated forms numerically in the future
 - Couple this work with plasma work by our group

QUESTIONS?

Ultrashort Pulse Laser Lab



The New Mexico State Bird

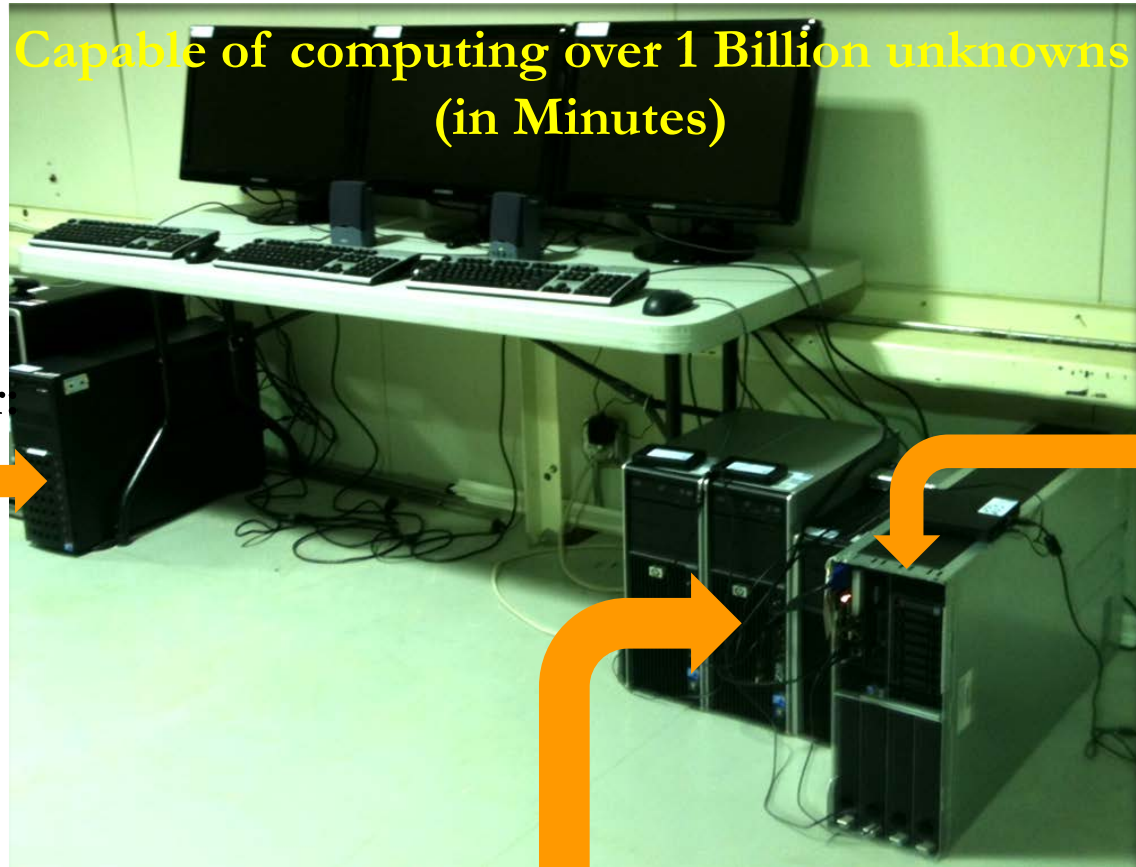
We may be short, but at least we're quick



BACK UP SLIDES



High-Performance GPU Computing Enclave



Capable of computing over 1 Billion unknowns
(in Minutes)

24-Core CPU Supercomputer

- 18 GBs of dedicated memory
- Over 3 Teraflops/s floating point performance

Tesla Compute Machine:

- 48 GBs of dedicated memory
- Over 9 Teraflops/s floating point performance

Basic HP Desktops (×3):

- 18 GBs of dedicated memory
- Over 3 Teraflops/s floating point performance

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A Numerical Approach to Solving Our Equations



- By introducing a coordinate system which moves with an average group velocity, $v'_g = \frac{2}{k'_1 + k'_2}$, in equations (I.) and (II.) where:

$$\xi = \varepsilon z, \quad \tau = (t - z/v'_g), \quad \delta = \frac{1}{2}(k'_1 - k'_2)$$

- These equations may be cast into a compact form:

$$i\partial_\tau U + i\delta\partial_\xi U + i\Gamma_1 U + fU^*V e^{-iR\delta\xi} + [a|U|^2 + b|V|^2]U = 0$$

$$i\partial_\tau V + i\delta\partial_\xi V + i\Gamma_2 V + gV^2 e^{iR\delta\xi} + [c|V|^2 + d|U|^2]V = 0$$



A Numerical Approach to Solving Our Equations



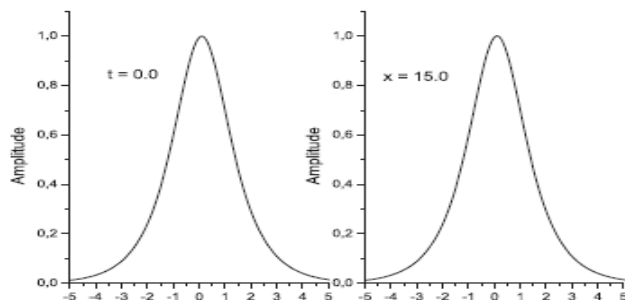
- Using a new 6-point unconditionally stable FD –TD scheme, we write:

$$i \frac{U_i^{j+1} - U_i^j}{\tau} + i\delta \frac{U_{i+1}^{j+1} + U_{i+1}^j - U_{i-1}^{j+1} - U_{i-1}^j}{4h} \\ + i\Gamma_1 \frac{U_i^{j+1} + U_i^j}{2} + f \frac{U_i^{*j+1} + U_i^{*j}}{2} \frac{V_i^{j+1} + V_i^j}{2} e^{-iR\xi_i^j} \\ + \left(a|U_i^{j+1/2}|^2 + b|V_i^{j+1/2}|^2 \frac{U_i^{j+1} + U_i^j}{2} \right) = 0$$

$$i \frac{V_i^{j+1} - V_i^j}{\tau} - i\delta \frac{V_{i+1}^{j+1} + V_{i+1}^j - V_{i-1}^{j+1} - V_{i-1}^j}{4h} \\ + i\Gamma_2 \frac{V_i^{j+1} + V_i^j}{2} + g \left(\frac{U_i^{j+1} + U_i^j}{2} \right)^2 e^{iR\xi_i^j} \\ + \left(c|V_i^{j+1/2}|^2 + d|U_i^{j+1/2}|^2 \frac{V_i^{j+1} + V_i^j}{2} \right) = 0$$

- Some early results for coupled NLSE applied to multi-mode optic fibers using a Matlab implementation (Note: a dispersion term was added in the form of ∂_{zz})

Soliton Solution (includes dispersion and nonlinearity)



Effect of dispersion on Gaussian pulse (includes dispersion term only)

