ELECTROMAGNETICS

5 March 2013

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Integrity ★ Service ★ Excellence

Report Documentation Page

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NAME: Dr. Arje Nachman

BRIEF DESCRIPTION OF PORTFOLIO:

Interrogation (Modeling/Simulation) of Linear/Nonlinear Maxwell's Equations

LIST SUB-AREAS IN PORTFOLIO:

Theoretical Nonlinear Optics
Wave Propagation Through Complex Media
Fundamentals of Antenna Design/Operation
Fundamentals of Effects of EM Exposure on Circuitry

Scientific Challenges

- ## Nonlinear Optics

Fundamental modeling/simulation research which addresses concerns with femtosecond filament arrangements and plasma channel characteristics.

Advances in modeling/simulation of fiber and solid state lasers (with new BRI emphasis on nonequilibrium carrier distributions) to guide the development of compact, high energy systems.

- ## RF Effects on Circuitry

Identification of waveforms which produce various realizations of circuit upset (includes chaos)—See front page of 17 Dec 2012 Defense News.

Complicated by the fact that effects are likely to be dictated by the activity of the circuit (eg, routines being run by laptop).

Scientific Challenges

- **Wave Propagation Through Complex Media**

Increased emphasis on imaging through Random/Turbulent media

Also ongoing research provides optimism regarding a class of composite magnetic materials displaying significantly reduced losses

- **Antenna Design/Operation**

Suitable *PARTNERSHIPS* of MATERIALS and GEOMETRY can deliver man-made composites which exhibit novel EM attributes.
Such METAMATERIALS include: NIMs, PBGs, “Unidirectional” composites, and P-T Symmetric media (new MURI).

Growing reliance on small UAVs drives the need to miniaturize antennas and make them more responsive.

MURIs

This portfolio has an existing MURI called "Ultrashort Laser Pulses" (co-managed with Dr. Riq Parra) at the 2.5 year mark

Dr Moloney (MURI PI) organized/hosted biannual int'l USLP conference (COFIL)

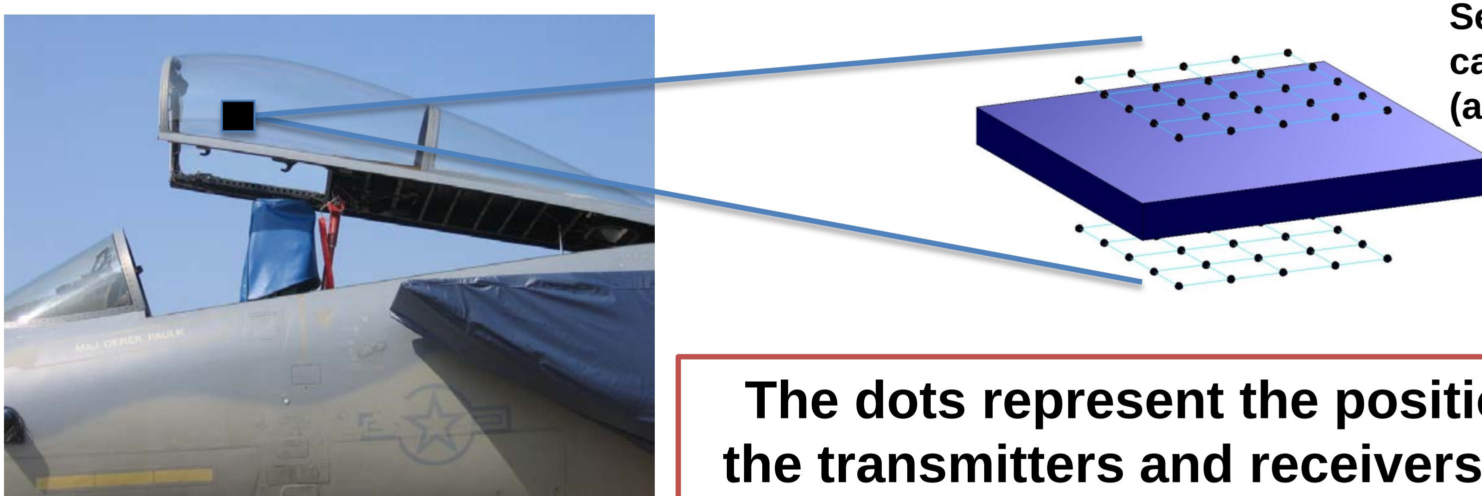
A second MURI (co-managed with Dr. John Luginsland) called "High Power, Low-Loss, Artificial Materials for Transformational Electromagnetics" began September 2012

A third MURI (co-managed with Dr. Charles Lee) on "Photonic Synthetic Matter" emphasizes P-T Symmetry

Drs. Colton, Cakoni and Monk – Math/Univ. of Delaware

Non-Destructive Testing of Airplane Canopies

Due to parts of the canopy being exposed to different amounts of ultraviolet radiation, the electric permittivity in general depends on position.



Section of canopy (a dielectric)

The dots represent the positions of the transmitters and receivers on the measurement array.

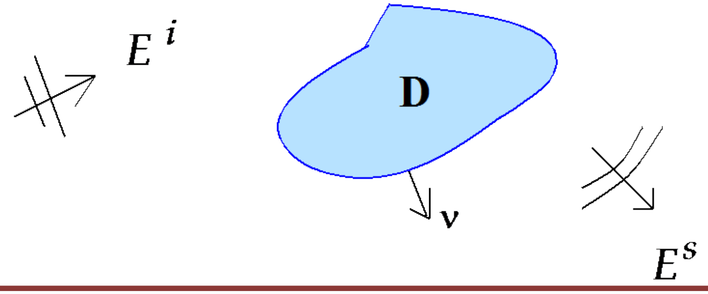
Optimization of the number & configuration of the multi-static measuring array is a subject for future investigation

Transmission Eigenvalues
The Scattering Problem

An incident wave E^i with wave number k>0 is scattered by an anisotropic dielectric with support D, with relative electric permittivity

$$N(x) = \frac{\epsilon(x)}{\epsilon_0}, \quad 3<|N(x)|<10$$

and constant magnetic permeability μ_0 .



$$k^2 = \epsilon_0 \mu_0 \omega^2$$

$\omega > 0$ is the frequency

Transmission Eigenvalue Solution

Assume $E^i(x)$ given and the far field pattern of the scattered field is defined by

$$E^S(x,d,p,k)=\frac{e^{ikr}}{r}E_\infty(\hat{x},d,p,k)+O\left(\frac{1}{r^2}\right)$$

d is the direction of incident field

Assume that D known: want to obtain information about $N(x)$.

To this end we solve the far field equation

$$\int_\Omega E_\infty(\hat{x},d,g(d),k)\,ds(d)=\frac{ik}{4\pi}(\hat{x}\times q)\times\hat{x}\;e^{-ik\hat{x}\cdot z}$$

for g where $z \in D$ and q is a vector for the polarization of the rhs dipole in R^3.

Transmission Eigenvalues

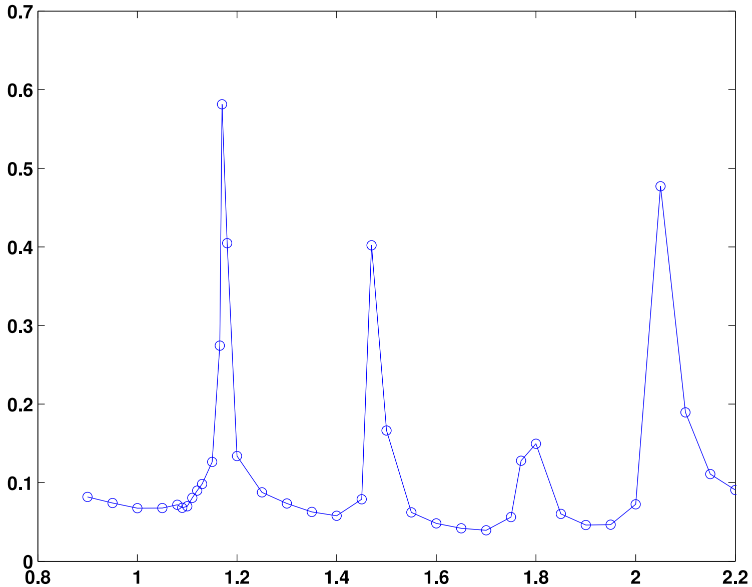
Determination of Transmission Eigenvalues

- **If k isn't a transmission eigenvalue, a bounded solution g of the far field equation can be found.**
- **At a transmission eigenvalue, the solution g of the far field equation is very large.**
- **By plotting the L^2-norm of g vs the wave number k, we can determine the transmission eigenvalues.**
- **Since transmission eigenvalues defined via a system of PDEs involve the permittivity tensor N(x), the eigenvalues contain information on this tensor.**

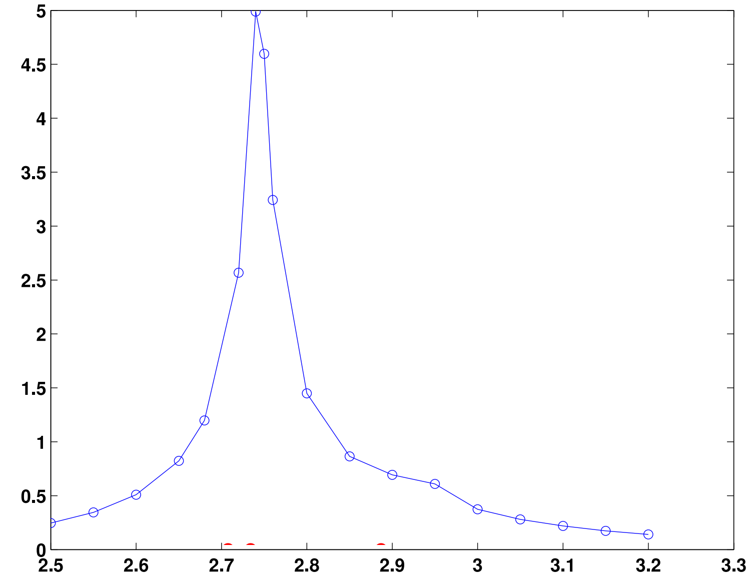
Determination of Transmission Eigenvalues

Solving far-field equation gives peaks at the transmission eigenvalues

N=16



N=5



Red dots indicate exact transmission eigenvalues.
Peaks in the norm of *g* indicate transmission eigenvalues from measured data.

Transmission Eigenvalues

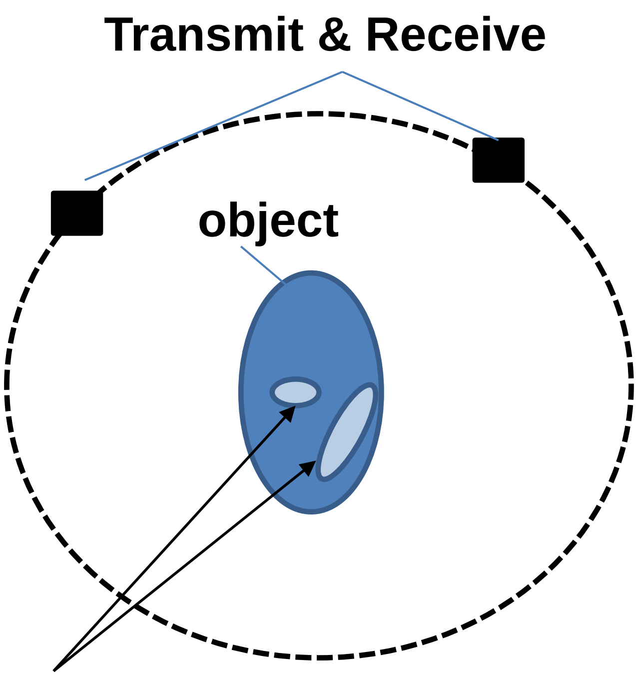
Applications to Nondestructive Testing

It was shown by *Cakoni-Gintides-Haddar* that transmission eigenvalues depend monotonically on the lowest eigenvalue of the relative permittivity tensor as well as on the volume of possible cavities.

In 2012 Drs. Jeremy Knopp and Adam Cooney from AFRL/RX (the Materials Directorate) awarded a contract to my PIs at the University of Delaware to investigate the use of transmission eigenvalues for the nondestructive testing of airplane canopies.

Future Transmission Eigenvalue Research

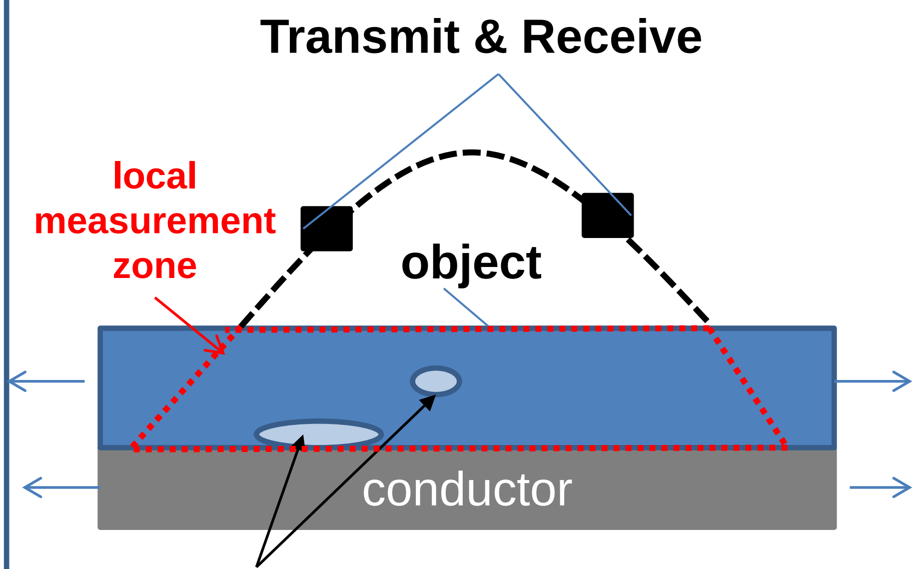
Traditional Scattering Problem of an Internal Defect



Buried mechanical or electromagnetic "defects"

The standard problem of a transmissive object

Conducting Half-Space Problem of an Internal Defect



Buried mechanical or electromagnetic "defects"

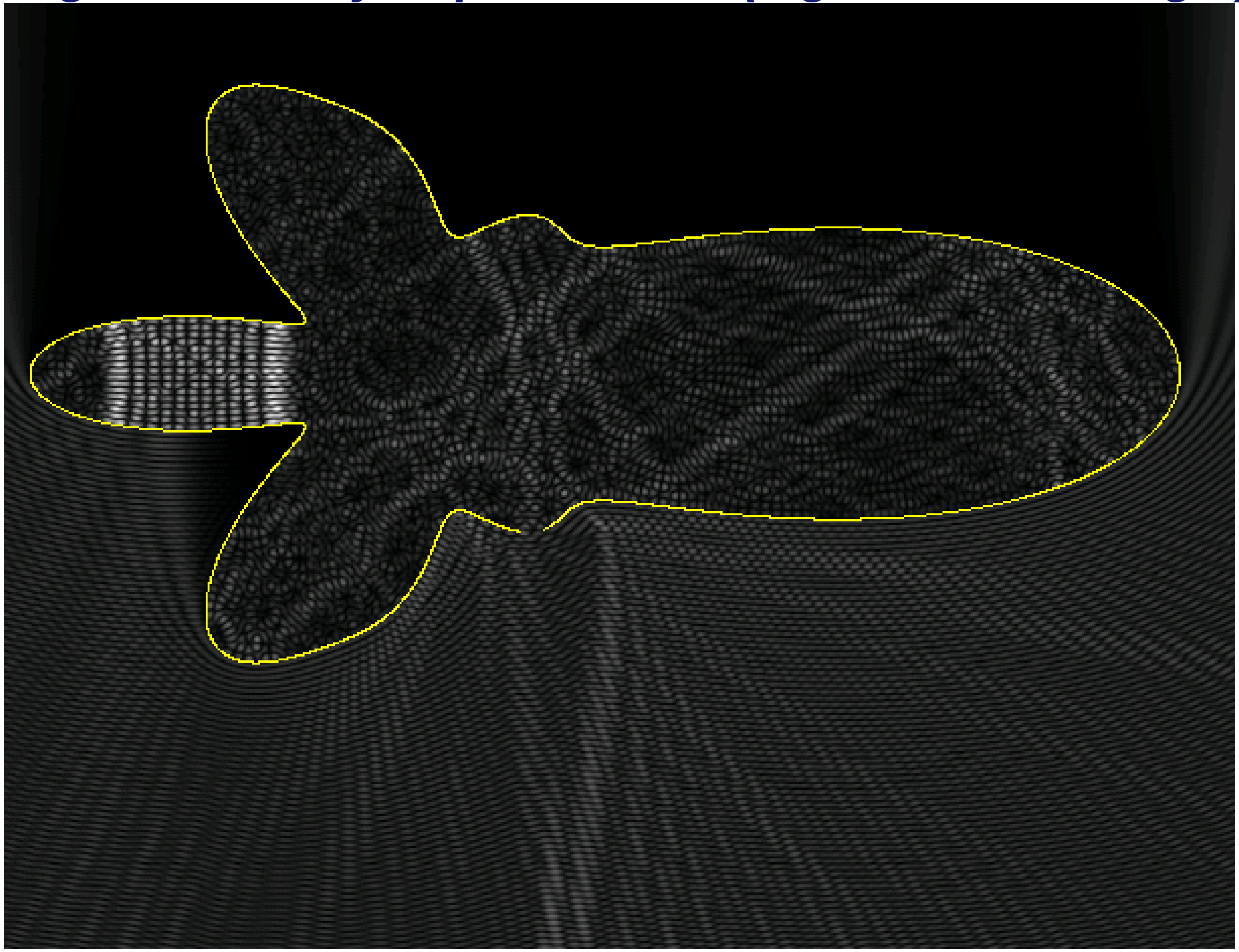
Object is transmissive but backed by conductor. Energy that would have been transmitted is reflected back to the single side.

Think of something similar to thermal protection foam/tiles on (now retired) space shuttle.
Goal of inspections: determine if protective foams/tiles are damaged or compromised. Rather than surround the entire (very large) system, localized measurements taken at each location so problem is essentially as shown above on the right.

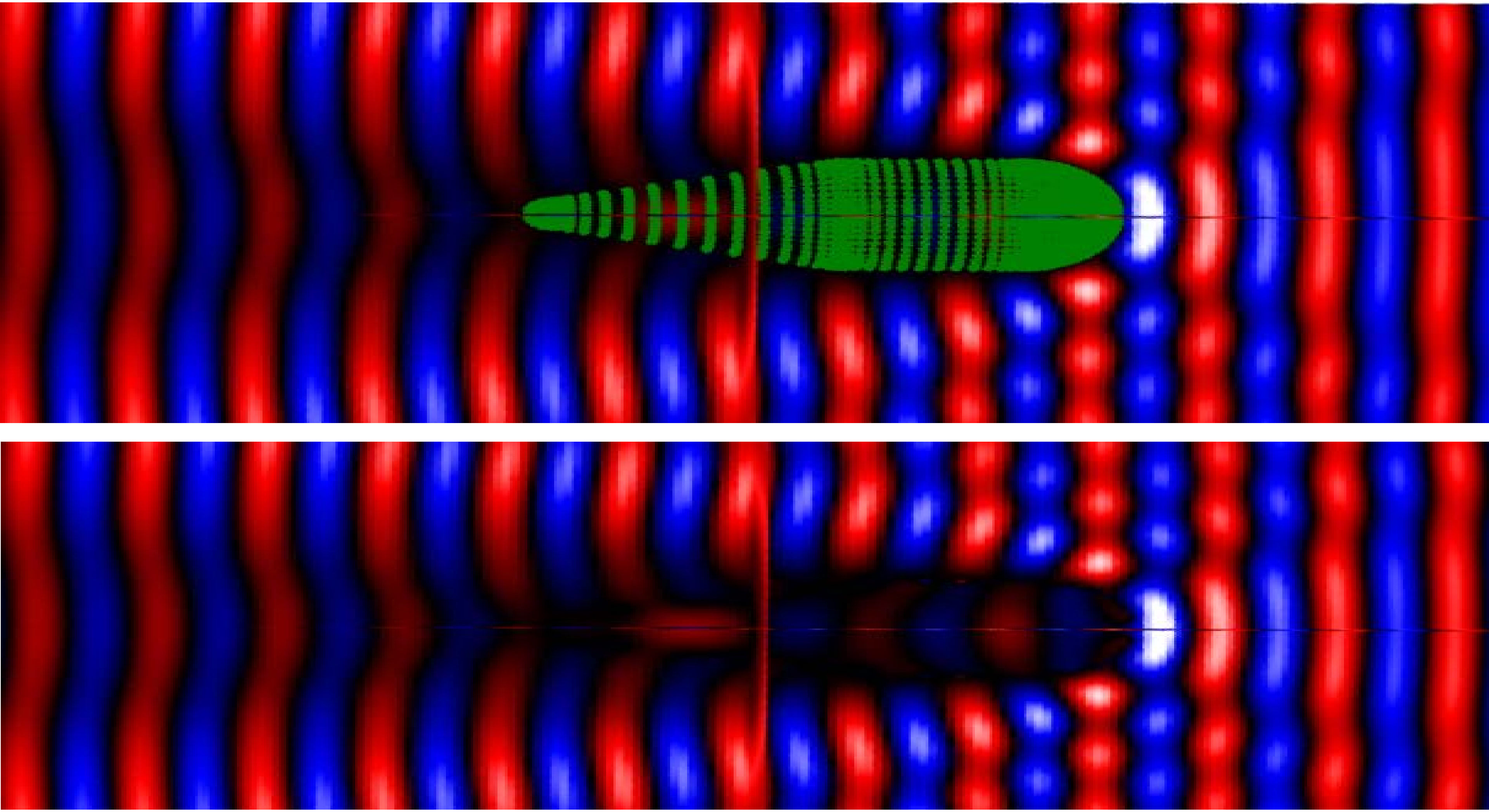
CEM for Enclosures

Dr Oscar Bruno (Math/Caltech and MathSys)

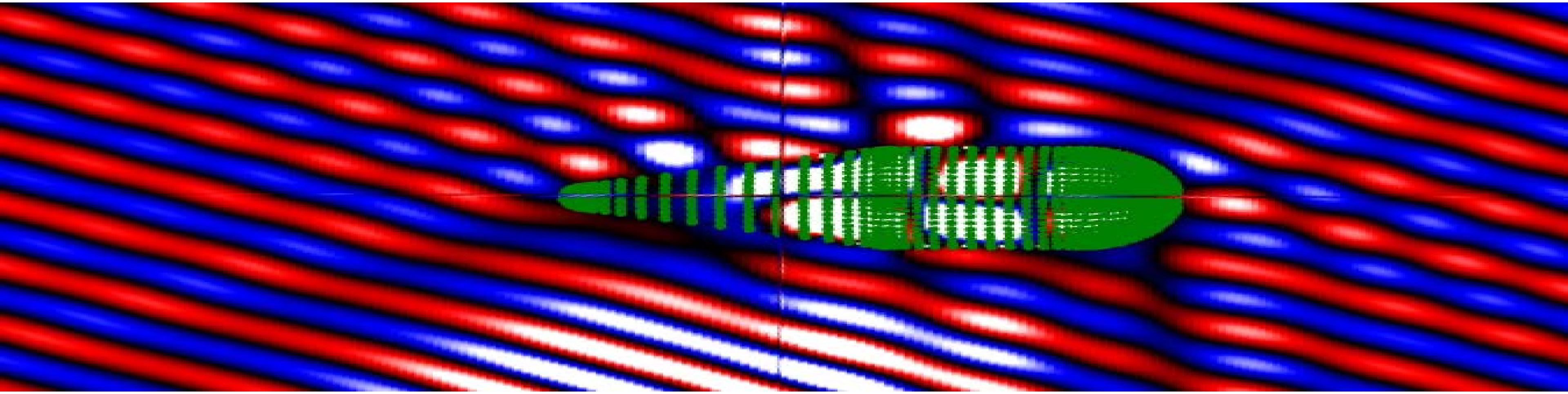
Localized cavity field more intense than incident field
High sensitivity to parameters (e.g. incidence angle)

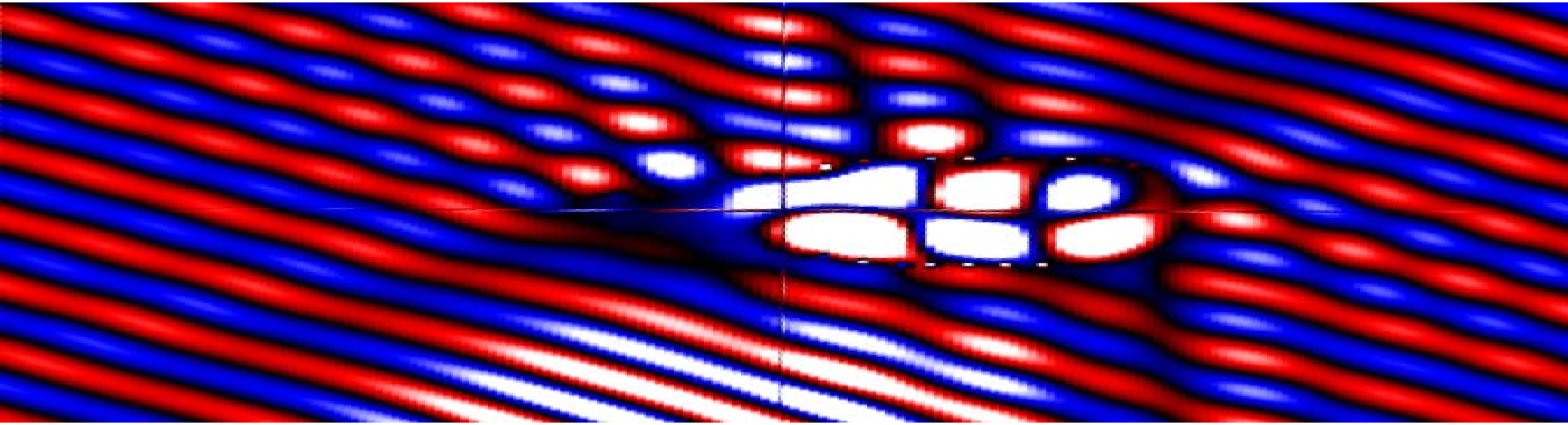


Incidence: 0 degrees



Incidence: 60 degrees





Cavity-Field Issues

– Geometrical complexity; corner/edge resolution

– Models of subsystems within enclosures

  – Printed circuits

  – Other structures and substructures (e.g., metal coated dielectrics)

  – Wire arrays

– Dr Bruno's numerical solvers produce extremely accurate solutions for geometries that contain singularities (edges, corners) at all frequencies for three-dimensional problems involving non-trivial geometries.

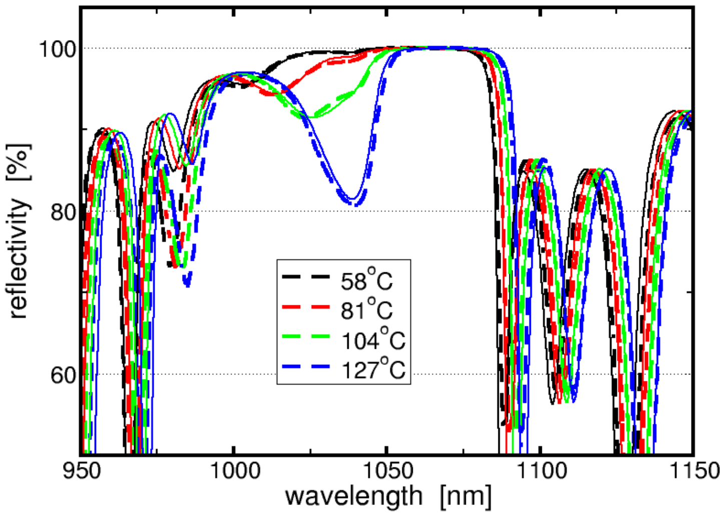
This is a unique capability: not aware of other solvers capable of producing such quality solutions.

6.1 progress being captured in user-friendly code (Phase II STTR) within AFOSR T&E program (Dr Michael Johnson/Seek Eagle)

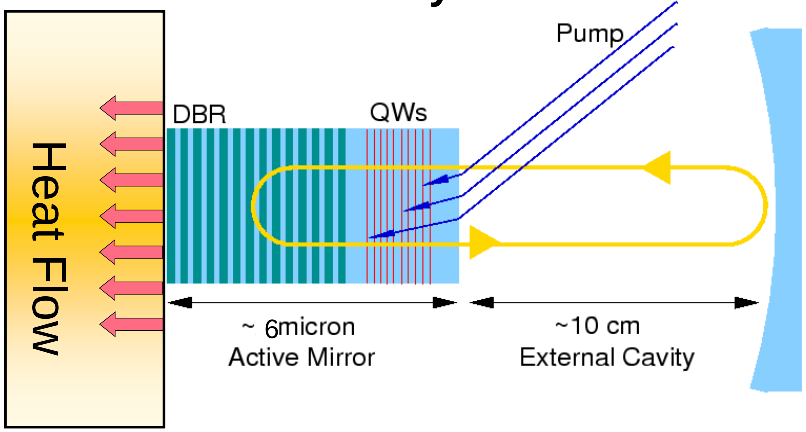
OPSL Breaks 100W Milestone

Dr Jerome Moloney - Optical Sciences and Mathematics - University of Arizona

Temperature Dependent Reflectivity
(Semiconductor Chip Quality Control)

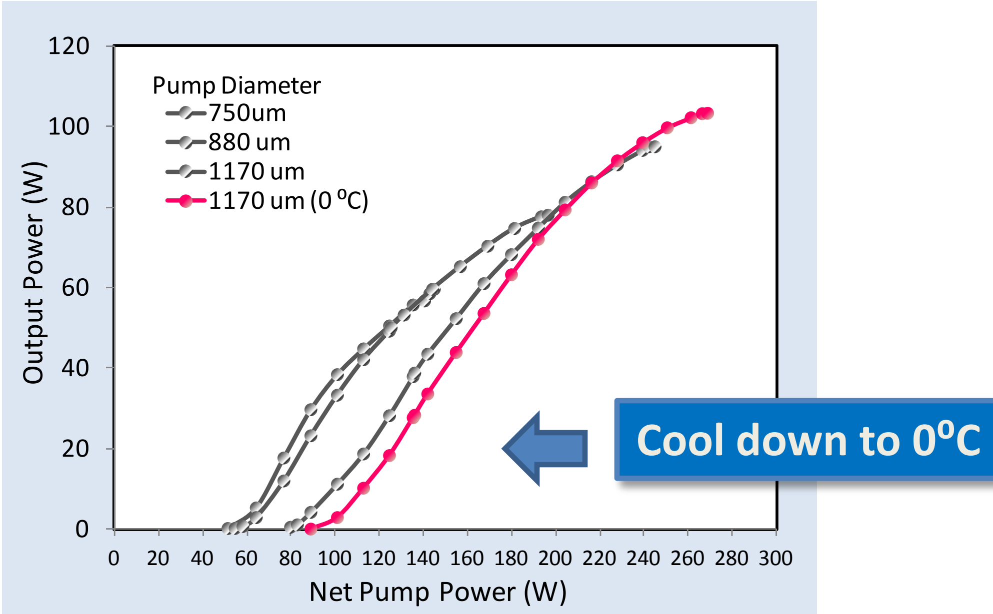


OPSL Cavity Schematic



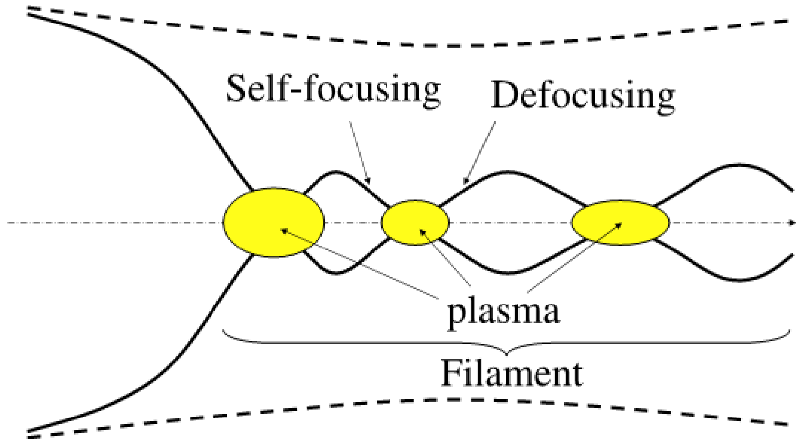
- Quantum design enables breakthrough
- Many-body theory plus thermal analysis
- Fast track iteration with grower

Output Power for Different Pump Spots



Optical filament dynamics

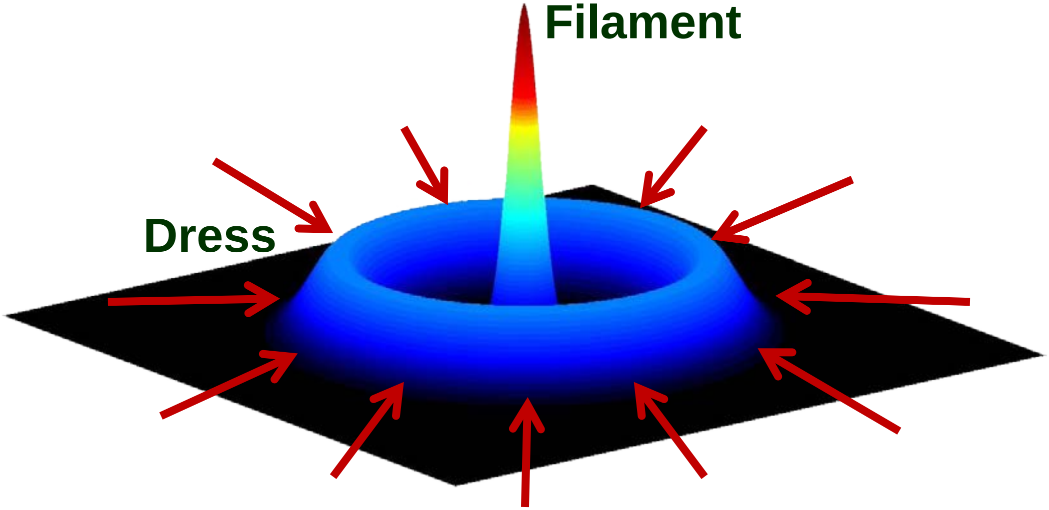
Dr Demetrios Christodoulides/UCF



An optical filament establishes itself through a balance of Kerr self-focusing and defocusing processes caused by multi-photon produced plasma. To maintain this balance the filament must expend its own energy, and as expected once its power dips below a certain threshold it eventually vanishes.

Are there ways by which the longevity of a filament can be extended?

Dressed Optical Filaments



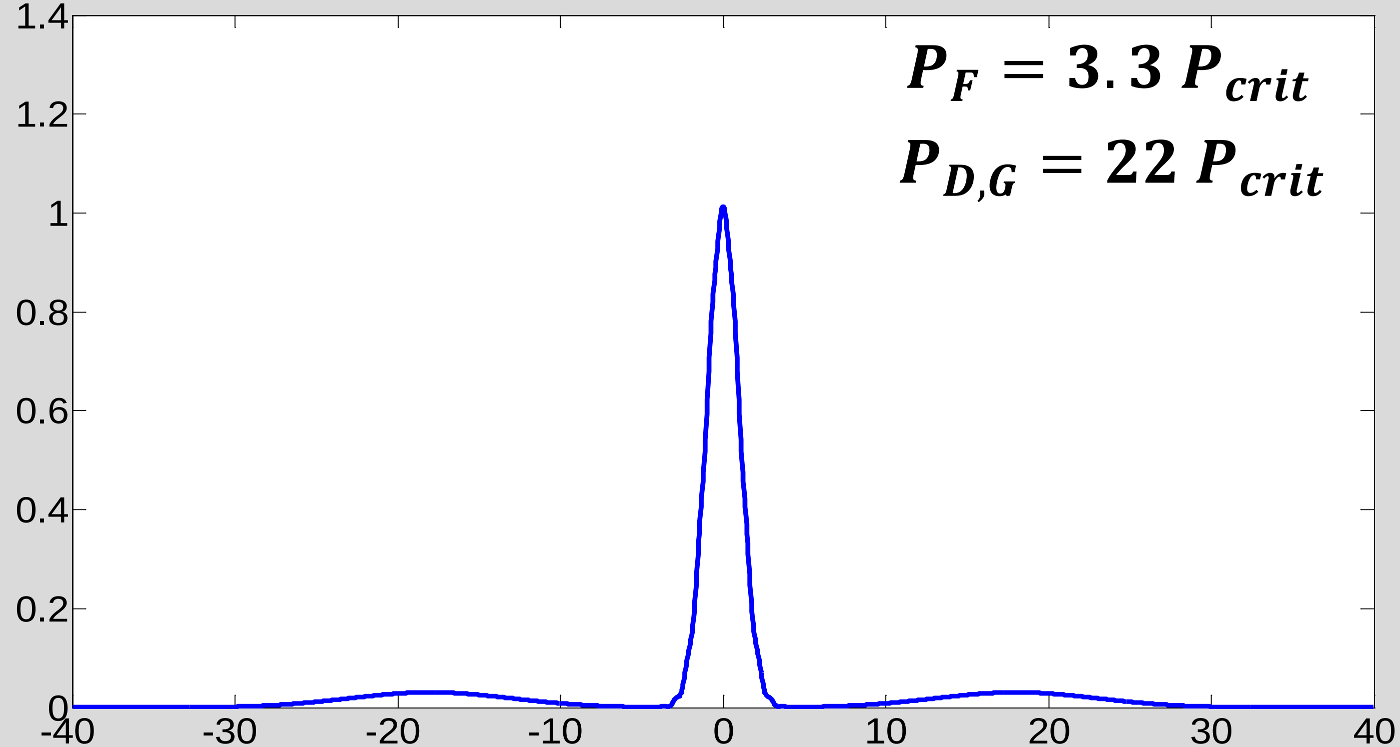
Energy from the dress flows inwards to aid the filament.

- **Power is spread over large area**
- **Dressing beam maintains a low intensity profile:** dress beam itself does not induce lasting nonlinear effects and therefore does not develop a filament during propagation

A Gaussian Dressed Filament

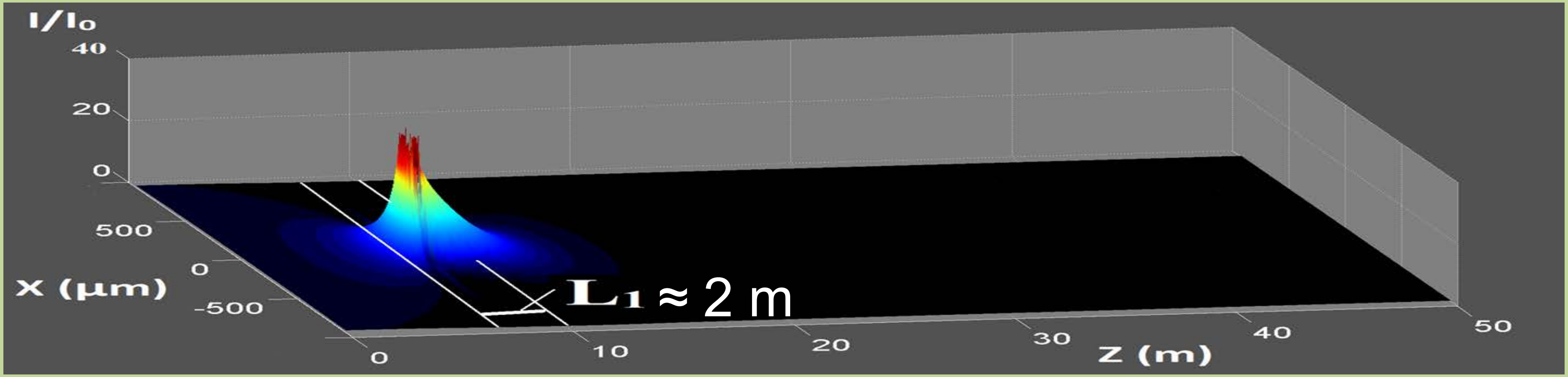
$$E_{total}(r,t,z=0) = E_{filament} + E_{Gaussian\ dress}$$

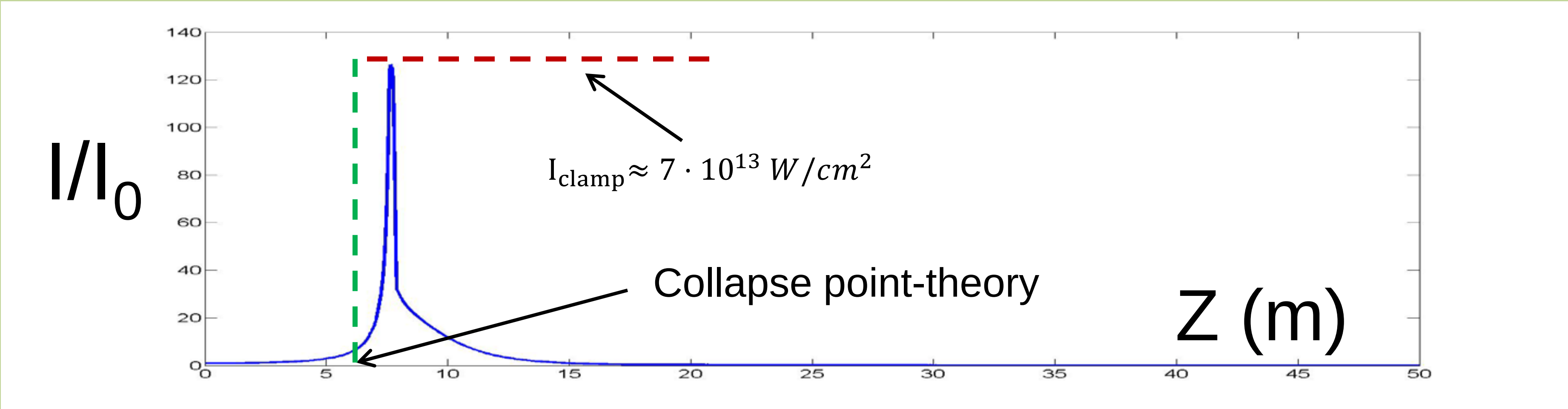
I/I$_0$



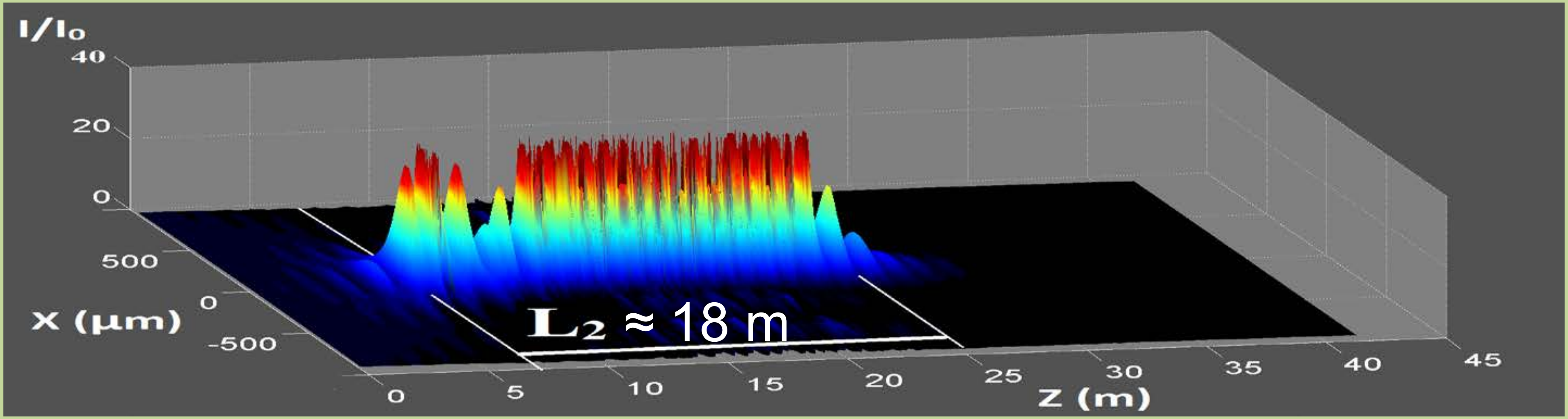
X (mm)

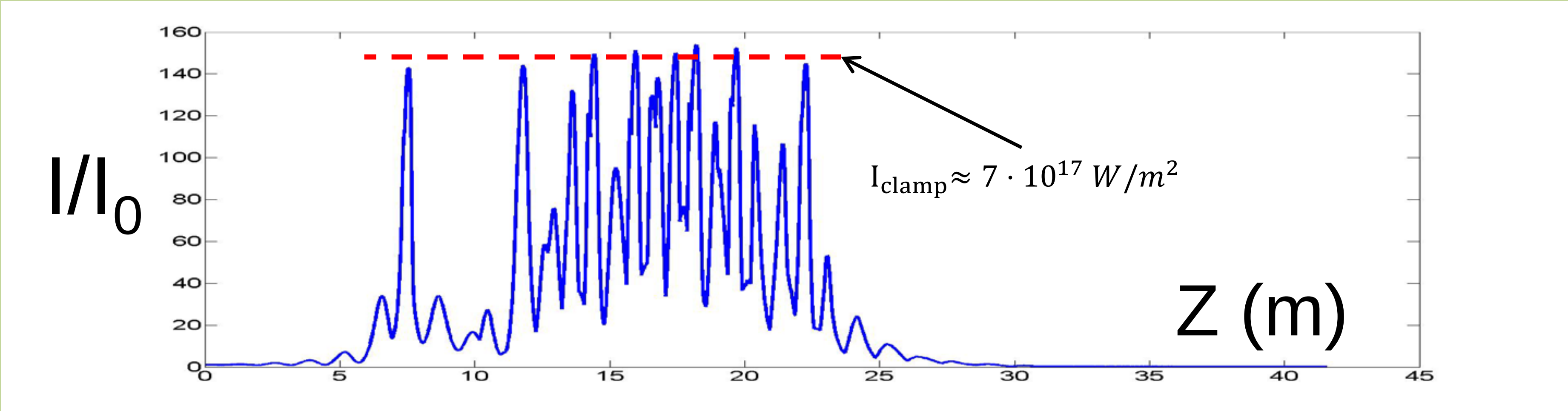
Undressed Filament Propagation



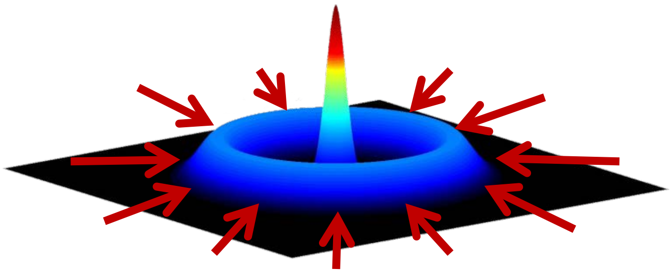


Dressed Filament Propagation





Conclusions



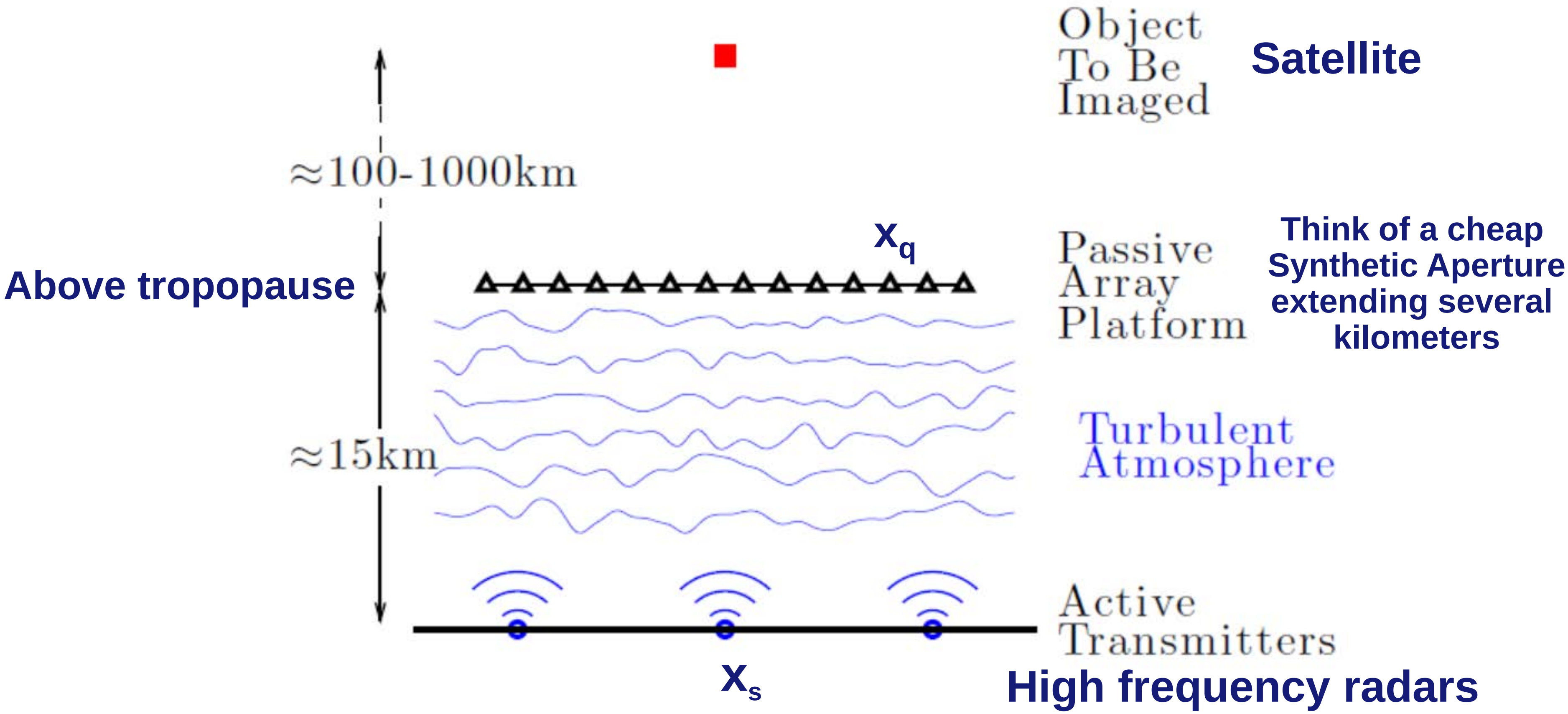
- The longevity of an optical filament can be extended by judiciously providing an auxiliary beam that acts as a secondary energy reservoir throughout propagation

- Several questions remain:

What will be an optimal dressed beam?
Does it depend on the medium involved?
Can one extend the filamentation process by 2-3 orders in distance?

Space Object Imaging

Dr George Papanicolaou, Math/Stanford



Correlation-Based Imaging in Strongly Scattering Random Media

The array response matrix *p(t,x$_r$;x$_s$)* consists of the signals recorded by the *r*th receiver when the *s*th source emits a short pulse. Using the formulas below for the cross-correlation produces images as if the medium between the sources and the passive array was homogeneous and the auxiliary passive array was an active one made up of both sources and receivers.

$$c_T(\tau,\vec{x}_q,\vec{x}_{q'}) = \int_0^T \sum_{s=1}^{N_s} p(\tau,\vec{x}_q;\vec{x}_s)p(t+\tau,\vec{x}_{q'};\vec{x}_s)dt,$$

$$I(\vec{y}^S) = \sum_{q,q'=1}^{N_q} c_T\left(T(\vec{x}_q,\vec{y}^S)+T(\vec{y}^S,\vec{x}_q),\vec{x}_q,\vec{x}_{q'}\right)$$

ELECTROMAGNETICS LAB TASKS

Dr. Brad Kramer(AFRL/RY), "Electromagnetic Materials and Antennas"

Model Electromagnetically Small Antennas: superdirective, wide-band, conformal

Dr. Ilya Vitebskiy (AFRL/RY) "Metamaterials for the Enhancement of Light-Matter Interaction"

Performance enhancement of various transceivers

Dr. Saba Mudaliar (AFRL/RY), "EM Scattering Studies" *

Predict scattering from clutter and rough surfaces

Dr. Kris Kim (AFRL/RY), "Predict Far-Field RCS via Near-Field Data" *

(Dr.) Jason Parker (AFRL/RY), "Moving Target Radar Feature Extraction"

Dr. Nicholas Usechak (AFRL/RY), "Spatial Effects in Multi-Section Semiconductor Lasers" **

Investigate control of amplitude-phase coupling in Quantum Dot laser systems

Dr. Timothy Clarke (AFRL/RD), "Modeling of HPM Effects on Digital Electronics"

Mathematical models predicting effects (upset) on digital electronics when exposed to various incident EM pulses

Dr. Danhong Huang (AFRL/RV), "Models for Ultrafast Carrier Scattering in Semiconductors"

Model IR amplifier for extremely weak signals and distant targets

Dr. Analee Miranda (AFRL/RY), "Detection and Imaging of Underground Facilities Using SAR Data"

Dr. Matthew Grupen (AFRL/RY), "Electronic Band Structure for High Speed Quantum Electron Device Simulation"

Modeling/Simulation of quantum tunneling devices

Dr. Iyad Dajani (AFRL/RD), "Time Dynamics of SBS in Fiber Amplifiers with Frequency Modulation"

SBS suppression research to realize higher power in narrow linewidth fiber amplifiers

Dr. Erik Bochove (AFRL/RD) "Modeling of Large Nonlinear Passively Phased Fiber Laser Arrays"

*=Renewal for FY13 **=FY13 Star Team

Connections with Other Organizations

- **ONR**

MURI (U Maryland) "Exploiting Nonlinear Dynamics for Novel Sensor Networks" managed by Dr. Michael Shlesinger, ONR

I serve on this ONR MURI panel

MURI (U Pennsylvania) "Negative Index Media"

Attended review of ONR (Dr. Mark Spector) NIM Metamaterials MURI

MURI "Random Lasers and Rogue Waves"

FY13 topic from Dr. Michael Shlesinger, ONR

I serve on this ONR MURI panel

Connections with Other Organizations

- **ARO**

  MURI (Univ. Central Florida) "UltraShort Laser Pulse Propagation" managed by Dr. Rich Hammond, ARO

  - Dr Hammond served on my FY10 USLP MURI evaluation panel and I served on his FY11 USLP MURI panel

- **NRO**
  - Extensive discussions/visits regarding impact of 6.1 research on NRO needs