Post-processing and analysis tools for BOUT++

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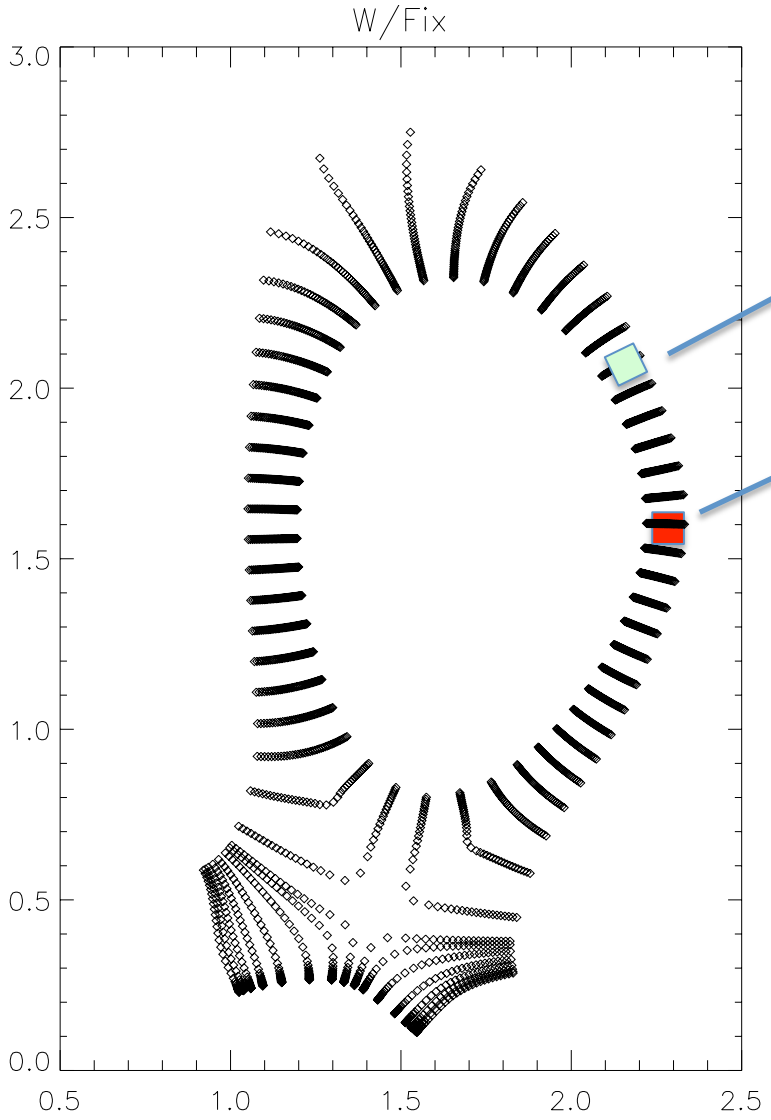
Presented at BOUT++ Workshop
LLNL, Sep 14-16, 2011

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Security, LLC, Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
LLNL-PRES-501055

Post-processing can be done in any data analysis tool, as long as output data are imported there

- IDL (Interactive Data Language)
  - Strong data analysis, graphics; reasonable numerical capabilities
  - Popular in experimental plasma physics community
  - Existing libraries, e.g., GKV (by W. Nevins)
  - Native support for netCDF
  - For PDB using pdb2idl package (by B. Dudson)
- Have used also
  - Python (freeware from www.python.org)
  - MATLAB
  - VISIT
  - Mathematica
  - Basis
- Ultimately, this is a matter of what you have and what you like to use

Importing data into post-processing program one would need to collect from separate data files



Data file #1

Data file #2

Output data files correspond to individual patches

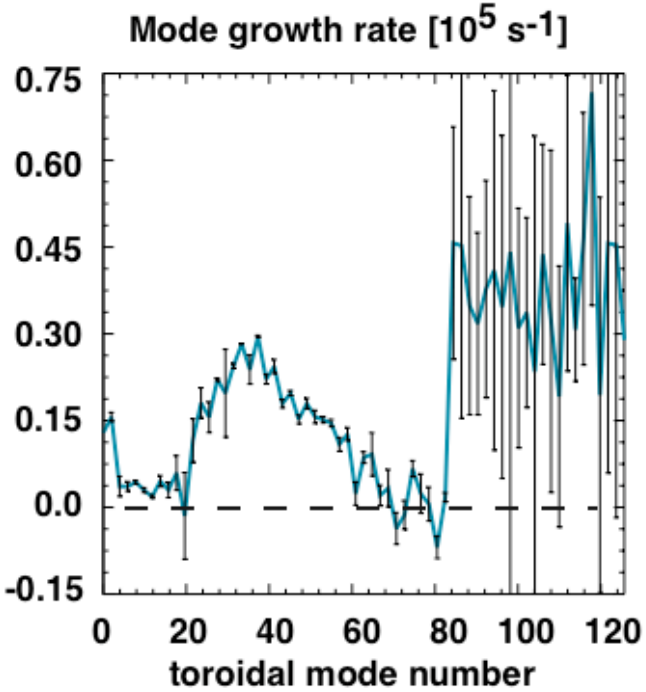
Often would like to concatenate in a single array

In IDL can be done by the program collect in *BOUT-1.0/tools/idllib/collect.pro*

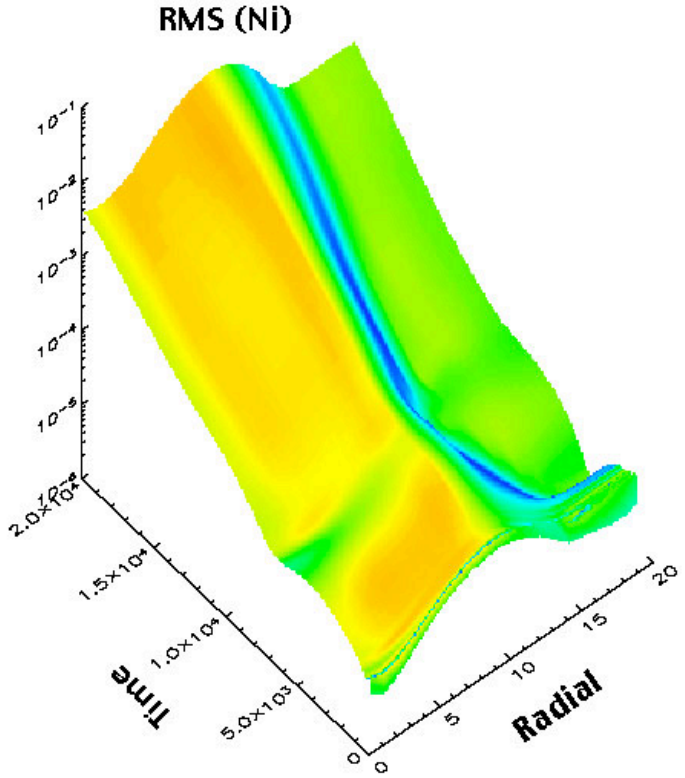
Code results analysis is similar to experimental science

- Plotting
  - 1D
  - 2D contour plots
  - 3D surface
  - Movies
- Statistical analysis
  - Distribution functions
  - Moments
  - Histograms
  - Correlations, trends
- FFT and other transformations

Examples of 1D and 2D plots for finding instability growth rates

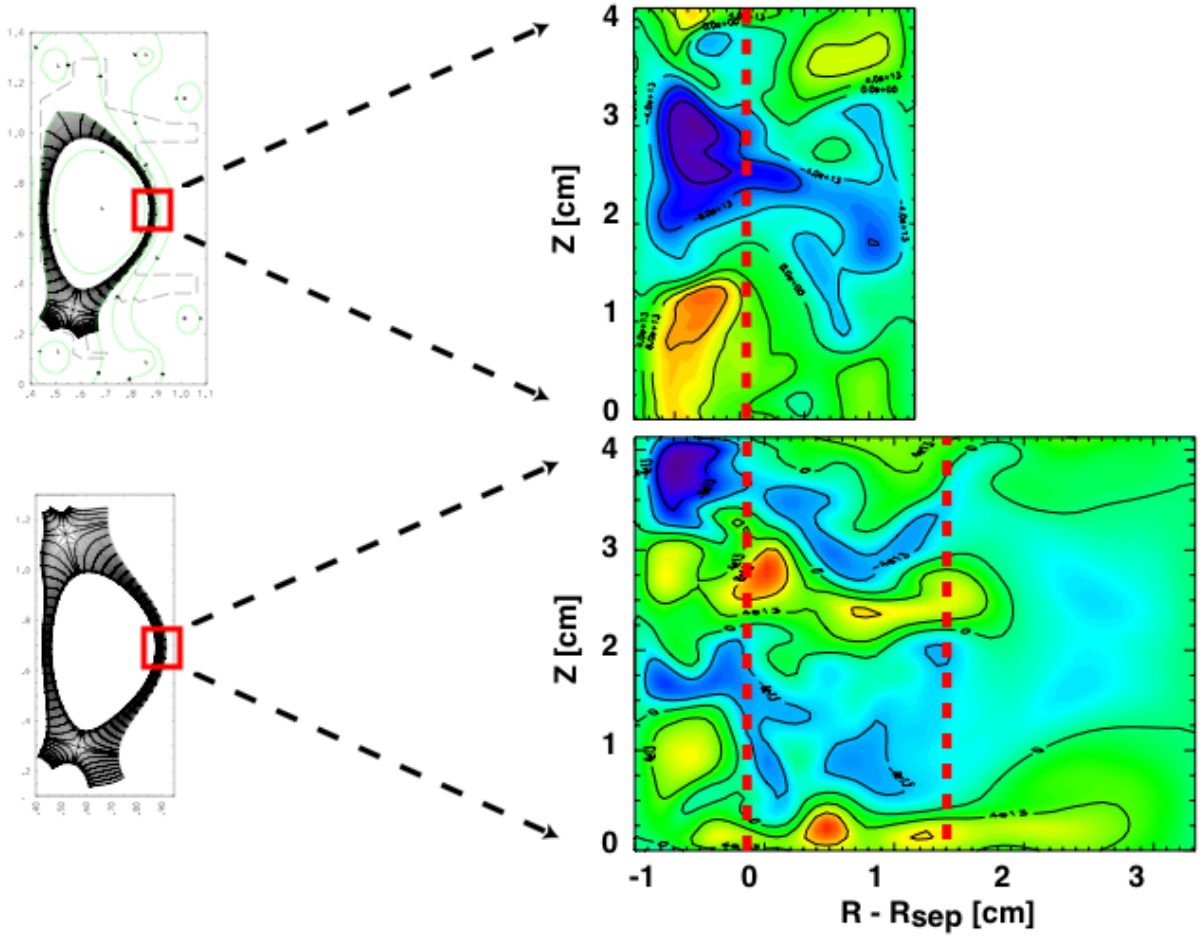


PLOT (from GKV)



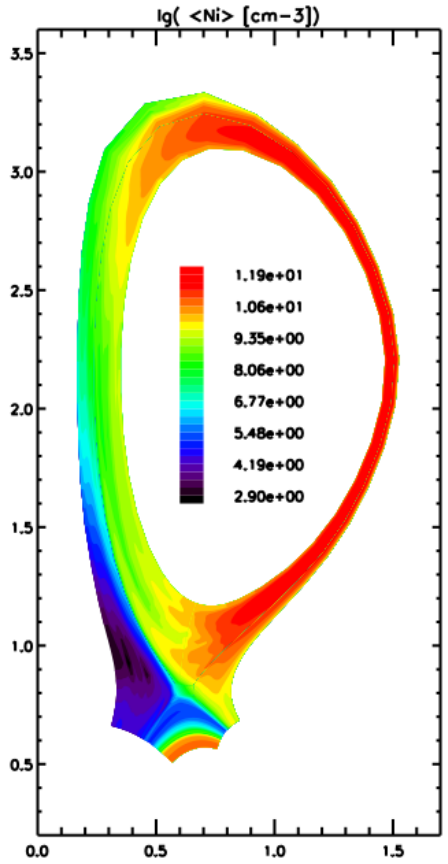
SHADE_SURF

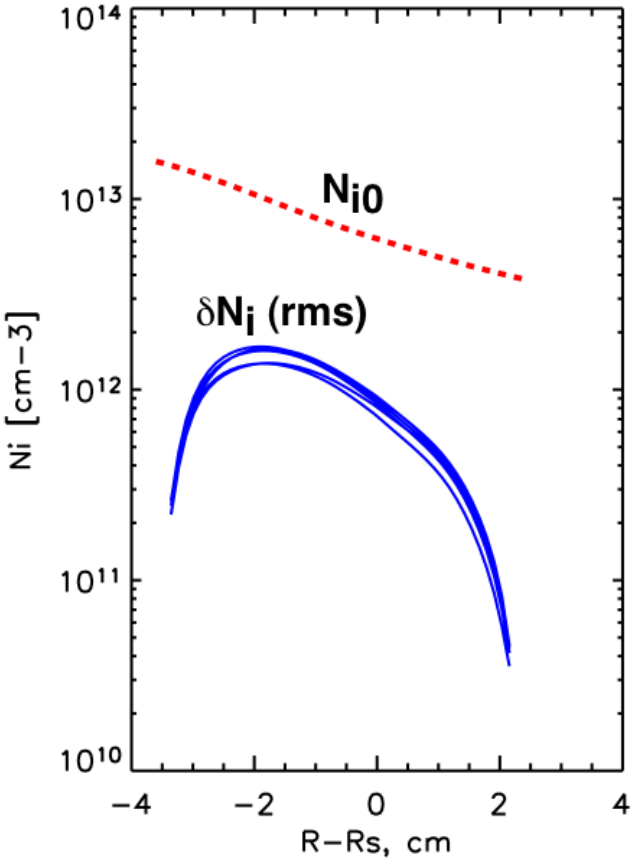
2D contour plots of density fluctuations



CONTOUR

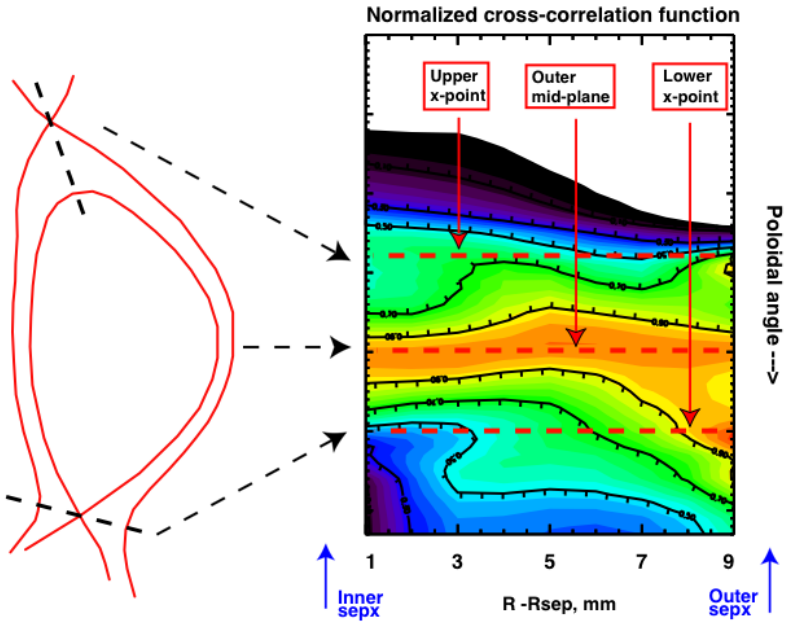
1D and 2D plots for spatial distribution of fluctuations strength



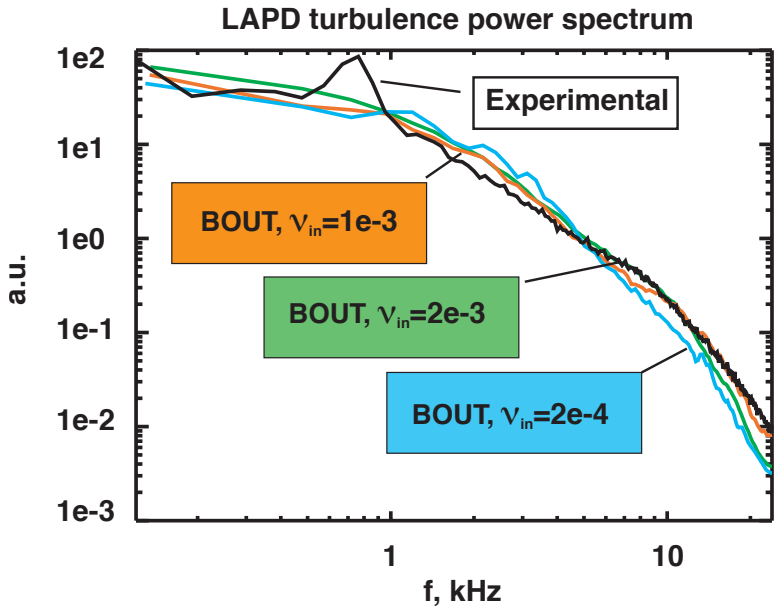


More complex example of CONTOUR

Statistical tools in IDL allow constructing correlation functions, spectra, histograms

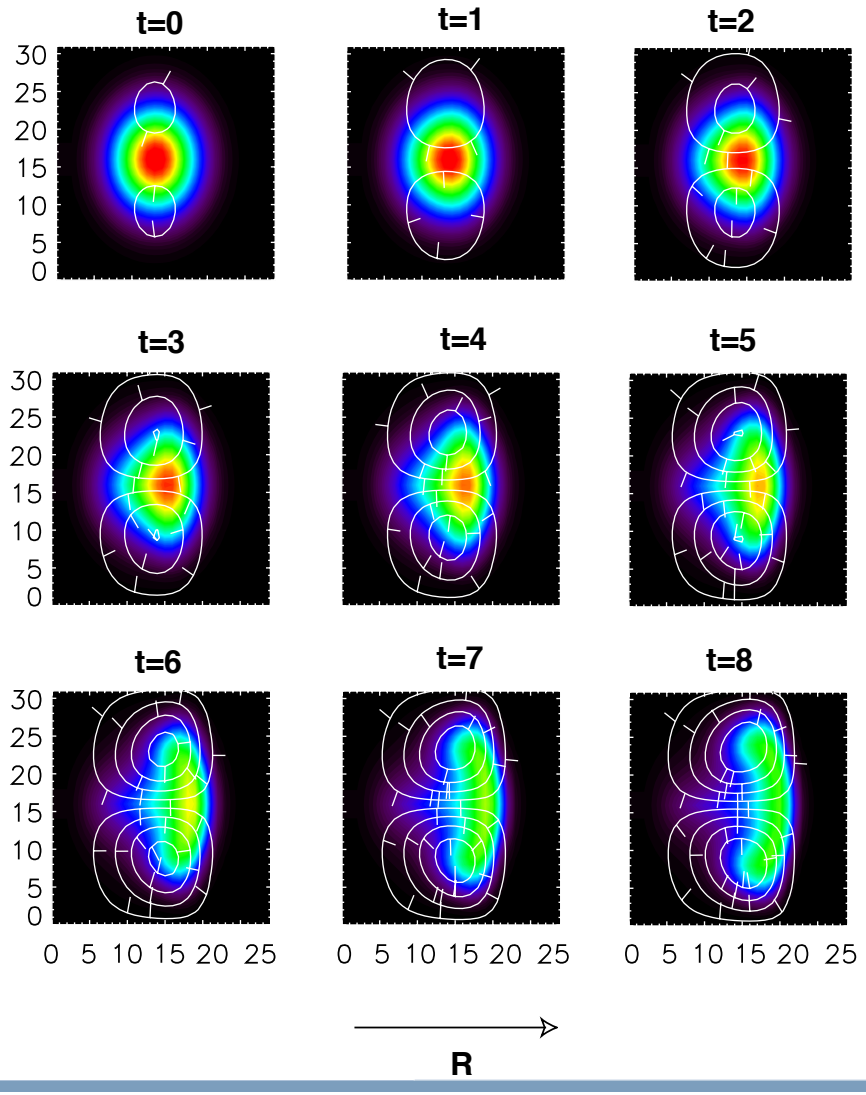


CONTOUR



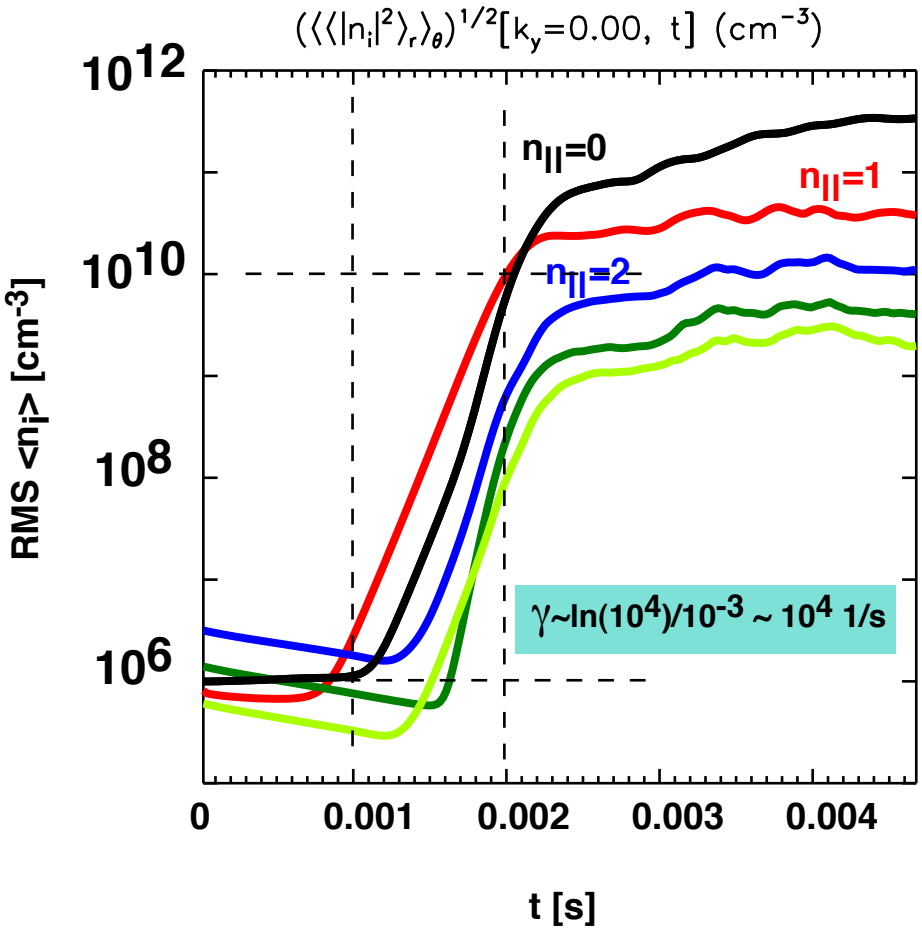
Plotting density and potential contours together plasma blobs modeling

Filament cross-section - color ni, lines phi



Twice using
CONTOUR

Fourier transform is a powerful tool for data analysis



Advanced statistical tools are available in GKV library by W. Nevins

Bicoherence is a measure of strength of coupling between considered modes

For three Fourier modes that satisfy sum rules

$$\omega_1 + \omega_2 = \omega_3 \qquad k_1 + k_2 = k_3$$

bispectrum is defined as ensemble average

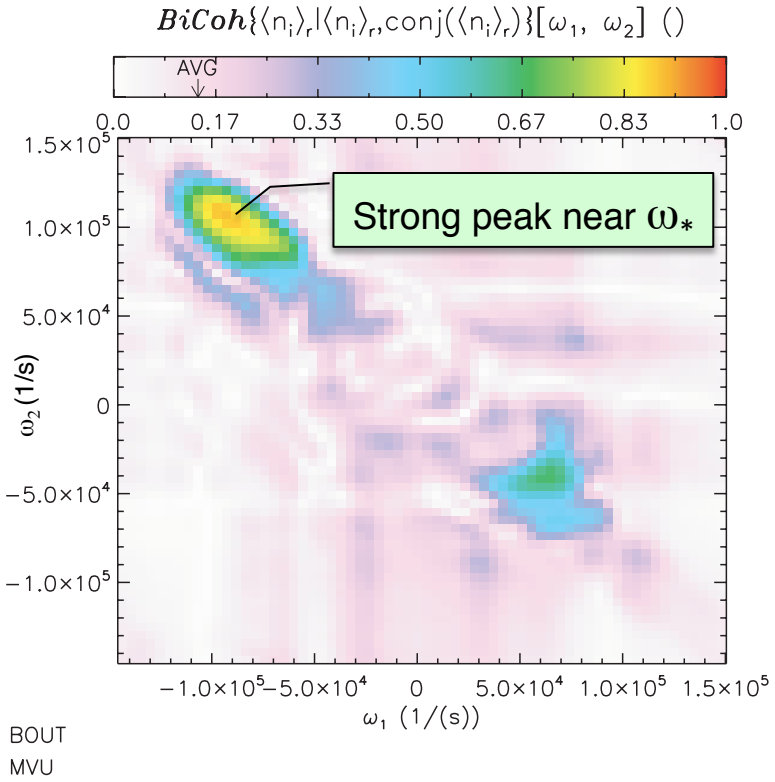
$$S(\omega_1,\omega_2) = \left\langle \hat{Y}^*(\omega_3,k_3)\,\hat{Y}(\omega_1,k_1)\,\hat{Y}(\omega_2,k_2) \right\rangle$$

bicoherence is defined as

$$b(\omega_1,\omega_2) = \frac{|\,S(\omega_1,\omega_2)\,|}{\sqrt{|\,\hat{Y}^*(\omega_3,k_3)\,|^2\,|\,\hat{Y}(\omega_1,k_1)\hat{Y}(\omega_2,k_2)\,|^2}}$$

Considering three modes (n_z,m_θ)

W_1=(1,25), W_2=(-1,-24), W_3=(0,1)



Fusion Energy Sciences

Making scientific animations in IDL is nontrivial and time consuming – however using a movie may be powerful

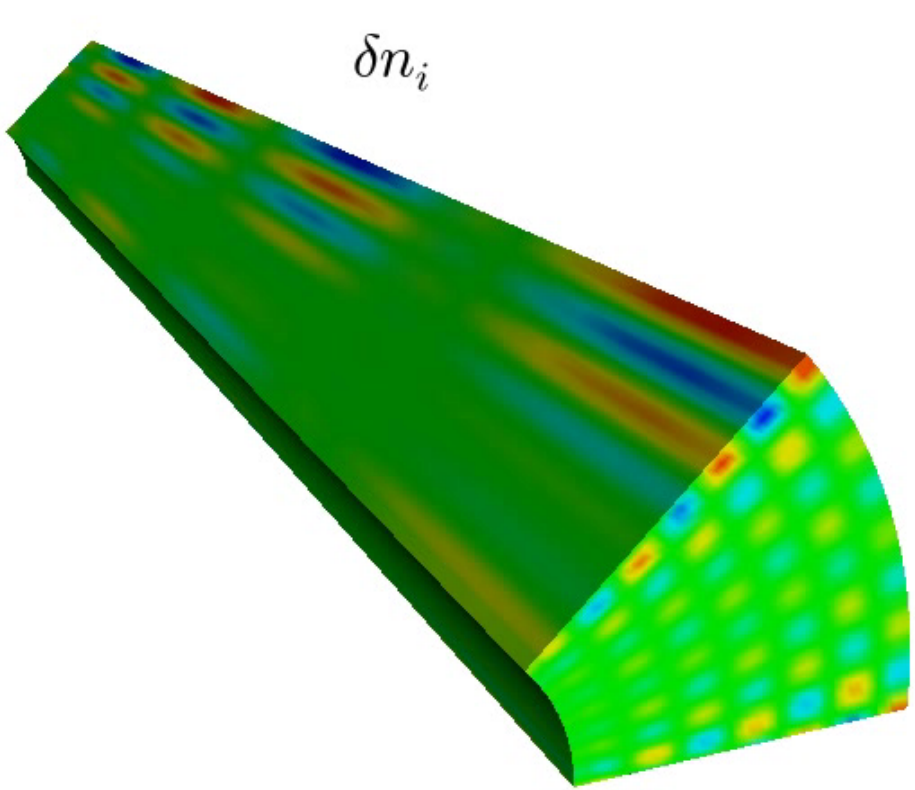
- Quick and dirty – IDL routine XINTERANIMATE or something similar

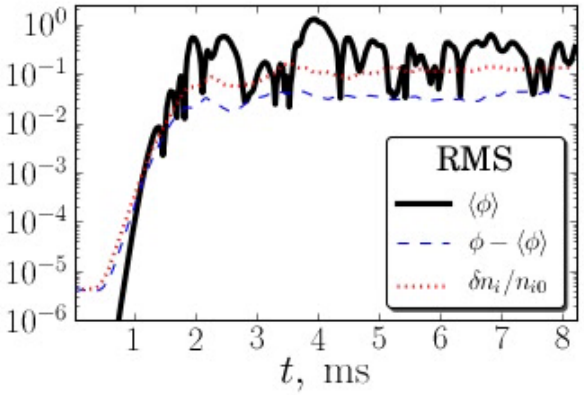
- Better way, for high quality:
  - First prepare frames
  - Then convert to a movie, e.g., on Apple with
    - QuickTime Pro
    - GraphicConverter

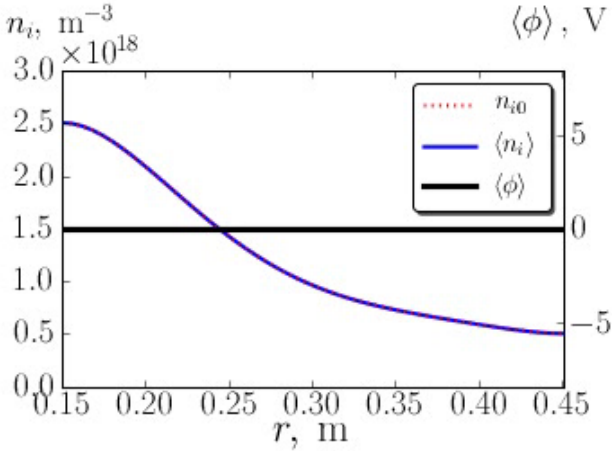
- Compatibility always an issue – Mac vs. PC, different versions of PowerPoint, movie player, operating system etc

- No way to guarantee that your movie will play on another computer!

Example of excellent animation







Made with VISIT by P. Popovich (UCLA) for LAPD simulation

Suggested exercises for practice

In examples/interchange-instability

- **Show exponential mode growth**
- **Find the growth rate**
- **Show eigenmode spatial form**

Advanced:

- **Plot spatial spectrum of the mode**

```
.run pdb2idl.pro
.run moment_xyzt.pro

ni1_xyzt = collect(path="data_1", var="Ni")
moment_xyzt, ni1_xyzt, rms=ni1rms_xyt

ni10_xyzt = collect(path="data_10", var="Ni")
moment_xyzt, ni10_xyzt, rms=ni10rms_xyt

tt = collect(path="data_10", var="t_array")
wci = collect(path="data_10", var="wci")
tsec = tt[1:*] / wci


;;-1D plot example
plot, tsec, ni1rms_xyt[5,32,*], /yl, chars=2, xticks=3, xtitle='time [s]', ytitl
e='RMS <Ni>'
wait, 3

;;-2D plot example
CONTOUR, REFORM(ni1rms_xyt[*,*,5]), xtitle='radial index', ytitle='poloidal inde
x', title='RMS <Ni>', nlev=30,/fil,/xst, chars=2
wait, 3

;;-3D plot example
LOADCT,39 ;;-set a certain color-table
SHADE_SURF, REFORM(ni1rms_xyt[*,32,*]),/zl, chars=2,$
xtitle='radial index', ytitle='time index', title='RMS <Ni>'
```