

## Instructions for parametrized diastolic filling (PDF) formalism based fitting for Doppler transmitral flow contours

To fully appreciate the conceptual framework for performing PDF analysis of transmitral flow, and before using this program, users are **VERY STRONGLY URGED** to go the publications tab on our website: <http://cbl1.wustl.edu/publications.htm>

And read publication:

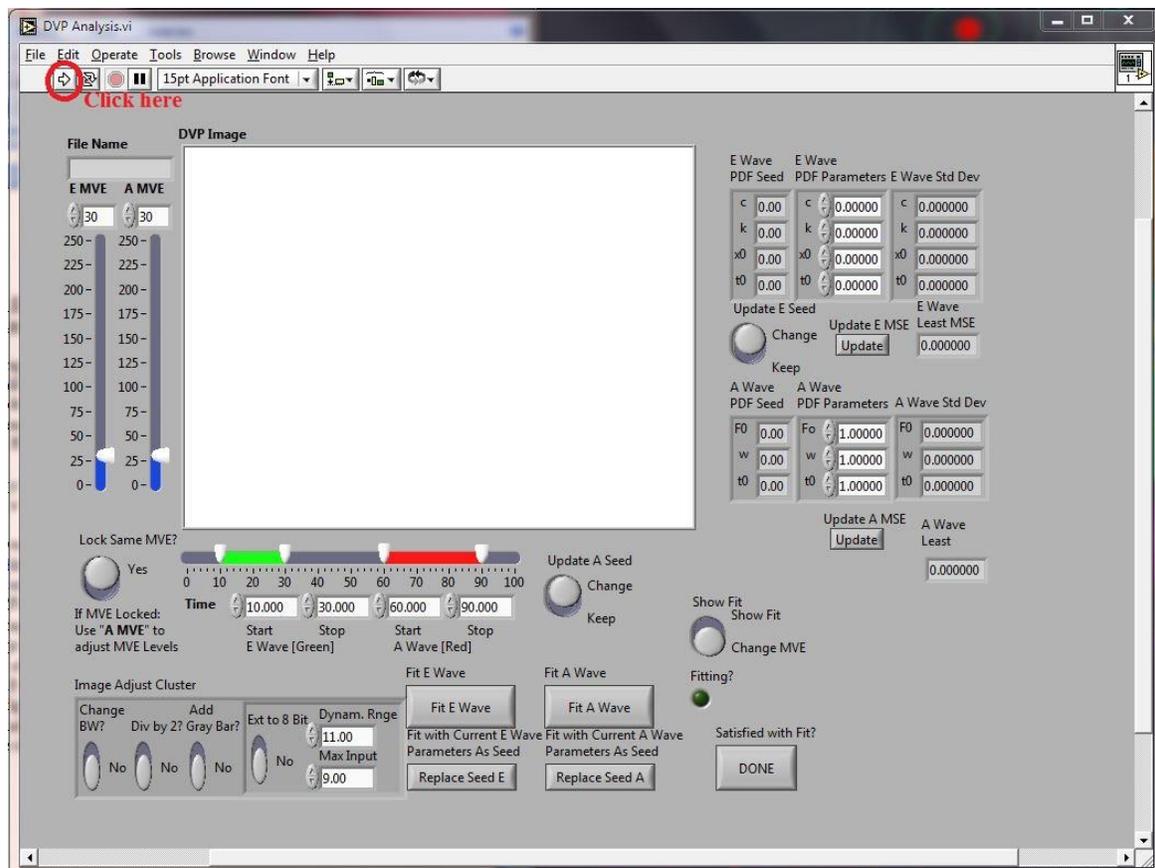
**1987:** Kovács SJ, Jr., Barzilai B, Perez J. Evaluation of diastolic function with Doppler echocardiography: the PDF formalism. *Am. J. Physiol*, 252, H178-H187, 1987.

**1994:** Hall AF, Kovács SJ, Jr. Automated method for characterization of diastolic transmitral Doppler velocity contours: Early rapid filling. *Ultrasound in Medicine & Biology*, 20, 107-116, 1994.

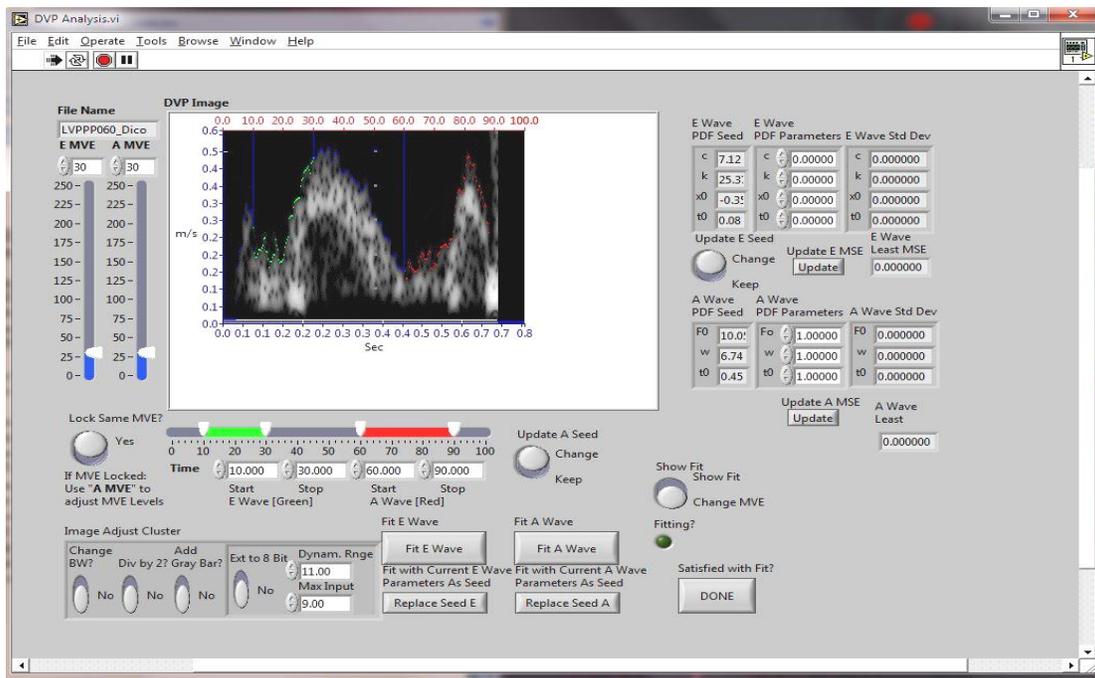
**2000:** Kovács SJ, Jr., Meisner JS, Yellin EL. Modeling of diastole. *Cardiol Clin* 18(3):459-87, Aug. 2000.

The following step-by-step instructions are for performing the PDF model fitting on cropped E- and A- waves obtained from the MATLAB code above. All these instructions are for a computer using the Windows operating system. The PDF fit is done using the program: "DVP Analysis.vi." written in LabVIEW. After installing the LabVIEW program please create a folder called 'dvpinfo' in your C: drive. This folder will contain the outputs of your PDF fit, i.e. the PDF parameters ( $x_0$ ,  $c$  and  $k$ )

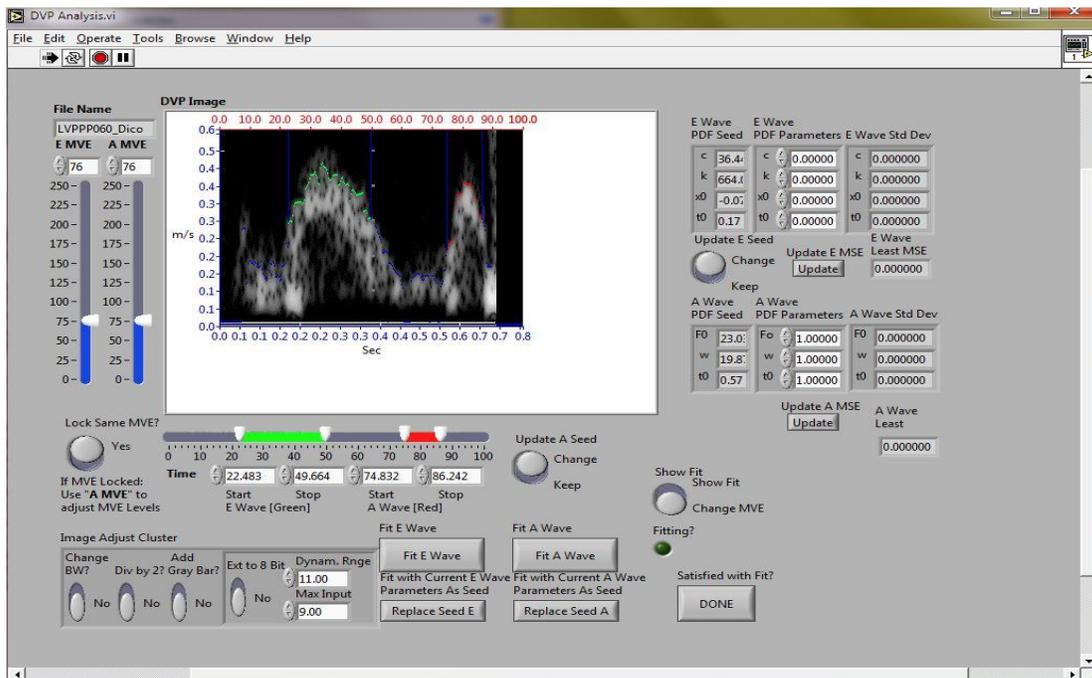
1. Open "DVP Analysis.vi." Fig 1. below shows the vi. To load an echo image click on the white arrow at the top left of the vi. This will open a window which will allow you to select the .bmp file to be analyzed.



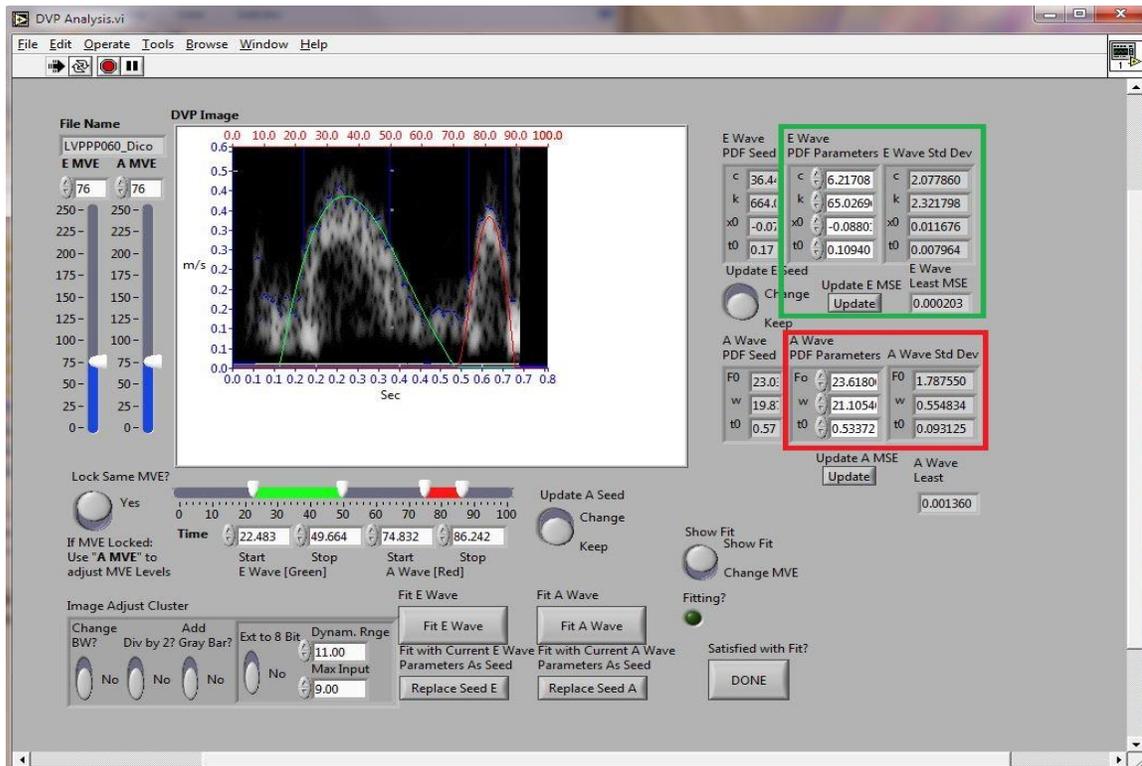
- Once the image is displayed as shown in Fig. 2 below, the program automatically selects the pixels of the maximum velocity envelope to be fit. These are shown in green, blue, and red.



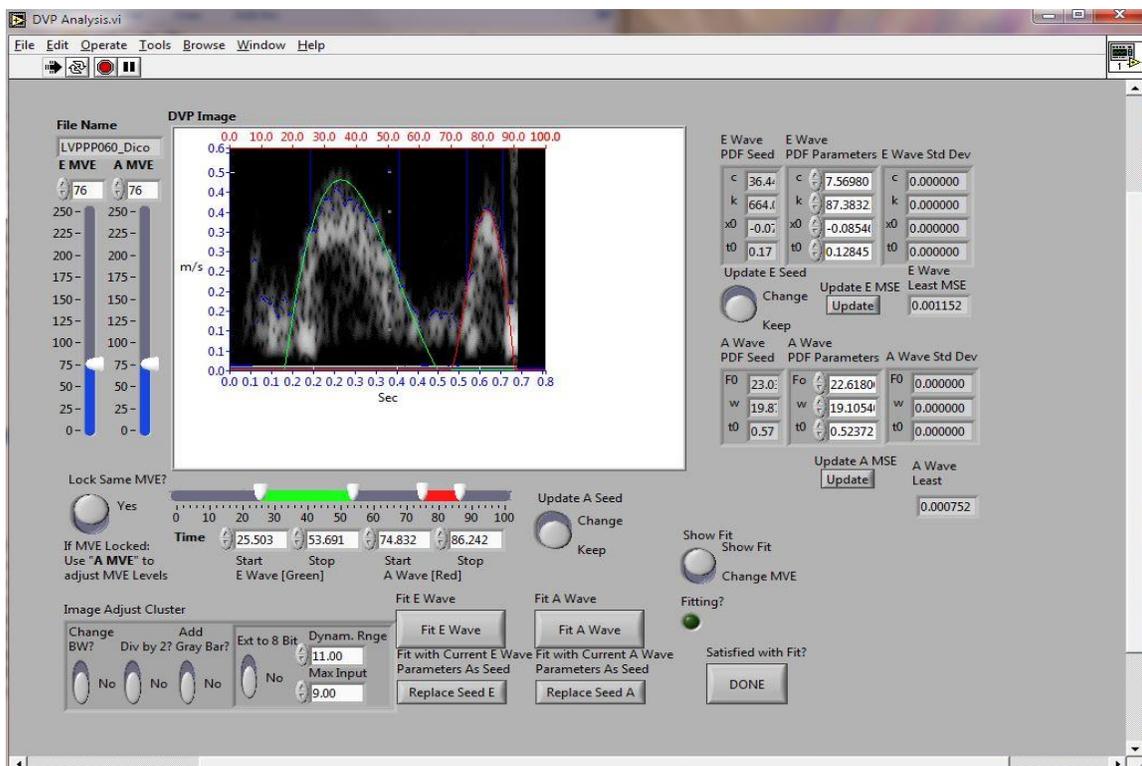
- Because the contour may include noise, in the next step the user can modify the selected pixels such that they accurately correspond to the physiologic wave contour. To do this, first select the MVE (maximum velocity envelope) threshold level using the sliders on the left of the image (Usually, only the right slider is used). Increasing the threshold value will select pixels with higher brightness in the entire image containing both E-and A- waves. The next step is to select the time interval over which the pixels are to be fit. This is done using the sliders at the bottom of the image. After the threshold has been selected, position the E-wave start slider such that it intersects the acceleration portion of the E-wave at or above half the peak velocity so that likelihood of noise generated by the leaflet moving through the sample volume is excluded. This is shown in Fig. 3. below (Some E-waves are 'clean' and the E-wave start slider can be placed near the onset of the E-wave). Select the E-wave end slider such that at least half of the deceleration slope is included. It is self evident, that inclusion of MVE pixels that constitute noise will alter the fit. The selected E-wave MVE interval used as input to the fitting will be shown in green dots. Similarly adjust the time sliders for the A-wave. The A-wave selected pixels will be shown by red dots.



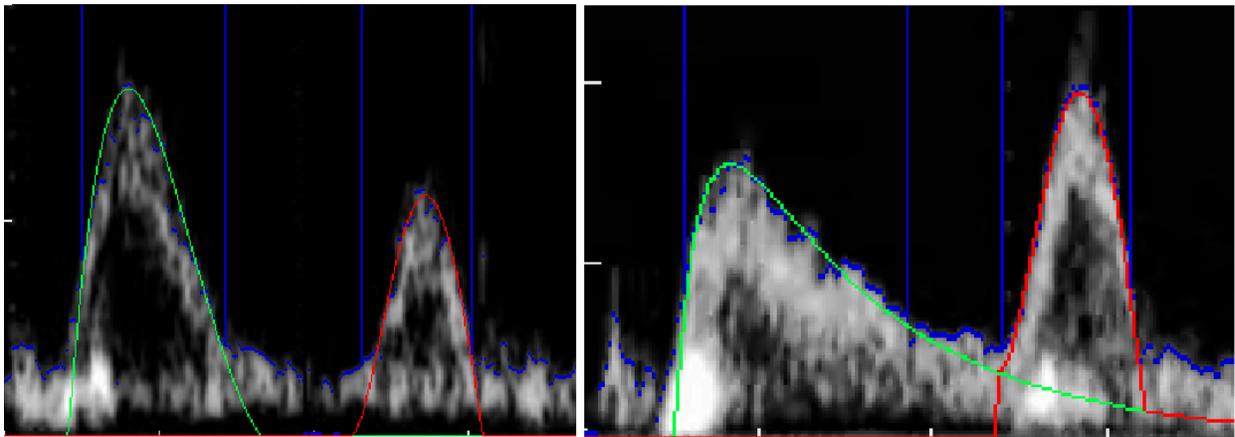
- Once the MVE has been selected by positioning of the left and right sliders for both the E- and A-waves, click on 'Fit E-wave' and 'Fit A-wave' to perform the PDF fitting. To see the fits, move the slider under 'Show fit' to 'Show fit' (from 'Change MVE'). An example of the fit is shown in Fig 4. below. The PDF parameters associated with the fit are in the right side of the image (shown in green for E-wave and red for A-wave).



- If the automated fit is not a good approximation for the E-wave (because it misses the valve opening (bright white pixels at base) as shown in Fig 4) then the fit can be modified in 2 ways. The first way is to modify the threshold and time sliders as described in Step 3 and repeat Step 4.



6. If the fit is still sub- optimal (usually because too many noise pixels are being fit) then the PDF fit can be modified manually by directly altering varying the parameters. To modify the E-wave parameters, either click on the text box containing  $c$ ,  $k$  or  $x_o$  and enter a new numerical value. Or use the up and down arrows on the side of the boxes to change the value. As you modify the PDF parameters the model predicted fit (green line) will change. You can change all the 3 parameters values including  $t_o$  to get the visually optimal fit. Once the optimal fit is obtained click on 'Update' below the PDF parameter boxes to get the updated value of MSE (Mean Square Error). Similarly the A-wave parameters can be modified manually. An example of a modified fit is shown above in Fig. 5.
7. Once the optimal fit for the E- and A-waves is obtained click on 'Done'. This will open a new window called 'print.vi'. You can either save it as an .xps or .pdf file or print it out. Additionally, 6 files will be saved in the 'dvpinfo' folder. Of these 6 files 2 will be images, one showing the MVE and the other showing the fit. The other 4 files will be text files. One of these files (filename ending: \* NewParameters dB.txt) will have the PDF parameters which can be used for subsequent analysis, statistics etc.
8. The solution to the equation of motion for the velocity of the oscillator (PDF formalism) has kinematic regimes determined by the relative value of the parameters of the oscillator. Note  $x_o$  is an initial condition, it is NOT a property of the oscillator. The regimes are: underdamped motion ( $c^2 < 4k$ ), critically damped motion ( $c^2 = 4k$ ) and overdamped motion ( $c^2 > 4k$ ). In these relations the mass  $m$ , that appears in Newton's Law has been set such that  $m=1$ . So the PDF parameters are computed per unit mass. Velocity contour examples for underdamped and overdamped regimes of motion are shown below.



Under damped E- wave

Over damped E-wave

*Note (CAUTION)*

The PDF formalism should not be used to fit merged E- and A-waves. At least half of the E-wave down slope (deceleration segment) should be distinctly visible in the image to get reliable PDF parameters. In determining that fit to the E-wave is appropriate, be guided by E-wave onset and termination. Said another way, attempt to achieve a final fit where the PDF determined contour has an acceleration and deceleration time as close as is realistically possible when compared to the conventional (triangle based) fit. If needed, modifications can be made using Step 6. Above are 2 examples of E-wave fit showing the underdamped and overdamped fit regime is determined by the relative value of  $c$  and  $k$  as detailed above.