



**Tips for controls:****General:**

- Use the Save/Load feature in the File menu to save a configuration for lecture or homework.
- Go to the Options menu to edit the colors of the harmonics.
- Be sure to try all the different tabs at the top of the simulation.

**Discrete Tab:**

- Change the amplitudes by dragging the amplitude bar, clicking where you want it to go, or typing a number into the text box above each bar. Use tab or shift-tab to move between text boxes.
- Use the horizontal zoom buttons () to see the periodicity of the wave forms.
- Use the vertical zoom buttons () or the Auto scale checkbox to keep the Sum graph from going off scale.
- The wavelength and period tools are moveable.
- Mousing over a Fourier component in the Amplitudes graph or over a wavelength or period tool highlights the corresponding harmonic in the Harmonics graph.

**Discrete to Continuous Tab:**

- The indicators for the spacing between Fourier components ( $k_1$ ) and spacing between wave packets ( $\lambda_1$ ) are moveable.

**Important modeling notes / simplifications:**

- We use the convention for the wave number  $k$  normally used in Physics:  $k = 2\pi/\lambda$ , rather than the convention used in Spectroscopy:  $k = 1/\lambda$ .
- In the Discrete to Continuous tab,  $\sigma_k$  and  $\sigma_x$  are the standard deviations of the gaussian curves in fourier and position space, respectively. They obey the uncertainty relation  $\sigma_x\sigma_k = 1$ . To get the uncertainty relation more commonly seen in textbooks,  $\Delta x\Delta k = 1/2$ , you need to divide both  $\sigma_k$  and  $\sigma_x$  by  $\sqrt{2}$ . That is,  $\Delta k = \sqrt{\langle k^2 \rangle - \langle k \rangle^2} = \sigma_k / \sqrt{2}$  and  $\Delta x = \sqrt{\langle x^2 \rangle - \langle x \rangle^2} = \sigma_x / \sqrt{2}$ . We use  $\sigma_k$  rather than  $\Delta k$  because in earlier versions that used the latter, students interpreted it as “the change in k.” Also, it’s easier to indicate the width on the graphs with the standard deviation than with the uncertainty.

**Insights into student use / thinking:**

- Students with no background in Fourier Analysis or Quantum Mechanics can learn a lot from the first two tabs. The third tab usually requires more guidance.
- Students often confuse functions of space and time and use the terms “wavelength” and “period” interchangeably. Switching between the two (or both), and using the wavelength and period tools help them make the distinction clearer.
- Students often think that wavelength and period are properties of a specific location on the graph. Moving the wavelength and period tools can help them see that this is not the case.
- In interviews, students *love* space & time mode (see “Function of” under “Graph controls”). Once they find it, they keep the simulation in this mode for the rest of the time they use the simulation, even when it’s inconvenient.

**Suggestions for sim use:**

- Check the [PhET activities database](#) for lesson plans.
- Use the first tab to help students learn the basics of sinusoidal waves.
- Use as a supplement to mathematical instruction on Fourier analysis to help students gain a more conceptual and qualitative understanding of what it really means.
- Create beats by setting any two adjacent amplitudes to 1 (with all others set to zero), and notice that the sound of two nearby frequencies superimposed is much lower than the frequency of either one alone. This is the “difference tone” or “Tartini tone.”<sup>1</sup>
- Try the “Wave Game” tab. Start at a fairly low level, play a game or two, and then move up to a higher level. If you can win a couple in a row, move on up. How high a level can you consistently “win” (figure out the solution without getting any hints?) Describe any strategies you used. Is it pure trial and error, or do you have a method?
- For tips on using PhET sims with your students see: [Guidelines for Inquiry Contributions](#) and [Using PhET Sims](#)
- The simulations have been used successfully with homework, lectures, in-class activities, or lab activities. Use them for introduction to concepts, learning new concepts, reinforcement of concepts, as visual aids for interactive demonstrations, or with in-class clicker questions. To read more, see [Teaching Physics using PhET Simulations](#)
- For activities and lesson plans written by the PhET team and other teachers, see: [Teacher Ideas & Activities](#)

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<sup>1</sup> *The Science of Sound*, Rossing, Moore, and Wheeler, 3<sup>rd</sup> Ed. (2001), Section 8.6