# Kippenhahn Diagrams

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**The *WTTS* tab we are going to look at is the *Kippenhahn* tab. A Kippenhahn diagram is a plot of time (or model number) on the $x$ axis, mass coordinate on the $y$ axis and a colour or shading to indicate convective regions in the rest of the plot. In *WTTS* this idea is extended to allow *any* variables on the $x$ and $y$ axes, and *any* variable for the colour (mapped surface) plot.**

**First we will make a traditional Kippenhahn, then try making some fun colour plots.**

1. **Select the *Kippenhahn* tab.**
2. **You should see the usual *Star 1/2* selector, just leave this at *Star 1*.**
3. **You then have the $x$, $y$, $z$ axis settings ($z$ is the colour surface which will be plotted, equivalent to the convective regions in the canonical Kippenhahn diagram).**
4. **You can choose the variables, and whether to plot them in a linear, log or $10^x$ fashion, from the drop down menus. The variables which are available to you are the same as those in the *Internals* tab, so it is assumed you have been through that section.**
5. **The ranges can also be set in the boxes (autoscaling is again marked with an asterisk *).**
6. **For the $x$ and $y$ axes you can set the *resolution*. A setting of $100\%$ means that every point in a model is plotted, a settings of $10\%$ means that every tenth point is plotted. A lower resolution will plot more quickly, so is useful for a quick sketch. Setting *WTTS* to high resolution may take a long time to plot, especially for long model sequences, because the amount of data that must be accessed is very large. This effect will be even worse if you are using a slow hard disk or your data is being transferred across a network (you have been warned!).**
7. **The *Palette* section allows you to change the colours.**
8. **Next are the *Show...* buttons. These are *only* useful if your $y$ coordinate is the mass $M$. They allow you to plot mass boundaries (the surface, core etc.), convective boundaries and nuclear burning zones. These are really for the expert user, but perhaps you will find them useful.**

9. **The *Replot* button is where the action happens. Unlike all the other plots in *WTTS*, the Kippenhahn diagram does *not* plot itself when you change something. The reasoning behind this is that the replot may take a very long time, so if a continuous replot was to happen it would slow you and your machine to a crawl. You can also replot by pressing the *r* key.**

## 1 Traditional Kippenhahn Plots

1. **Select *Age* for the $x$ axis, *M* for the $y$ axis and *Convection* for the $z$ axis. Select *Log10* for the $z$ axis. The special variable *Convection* is actually $\max\left[\nabla_{\rm rad} - \nabla_{\rm ad}, 10^{-30}\right]$, so is positive when there is convection, and tiny when there is not. Taking the log means we show only the convective regions. Set the resolutions at $10\%$ and $10\%$. Hit replot.**

2. **You will see mostly black, which corresponds to $-30$ in the colour key. This is because $\nabla_{\rm rad} - \nabla_{\rm ad}$ is negative in these regions and the logarithm of a negative number is not possible (in this context at least!). To cope with this *WTTS* sets $\nabla_{\rm rad} - \nabla_{\rm ad}$ to something very small (in this case $10^{-30}$ which logs to $-30$). You can get around the problem by setting the $z$ range minimum to $0$. Hit *replot*.**

3. **Now you see a coloured band across the top, but it is very jerky. Set both the resolutions to $50\%$ (and hit *replot*) and there will be fewer jerks. Try $100\%$ – this is the best we can do with the current data. If we decide that we need finer spacing, we would need to re-run the evolution with smaller timesteps so that we have more data to plot.**

4. **Remove the range setting, set the resolution to $100\%$ and press *replot.* What is the depth of the convective envelope in the Sun? Does it vary over most of its lifetime?**

## 2 Enhanced Kippenhahn Plots

1. **We can compare to the work of the previous sections. Set the $y$ axis to plot the radius $R$ instead of $M$. Hit *replot*.**

2. **Now you can see that the *depth* of the envelope is nearer the $30\%$ often quoted – it depends on whether we use $R$ or $M$ as a coordinate.**

3. **You can of course plot anything in these diagrams. Try plotting model number on the $x$ axis, $M$ on the $y$ axis and $T$ on the $z$ axis. You can clearly see the temperature increase in the centre towards the end of the model run.**

4. **Plot the same thing with $R$ as the $y$ coordinate.**

5. **Replot with $M$ as the $y$ coordinate, and the oxygen abundance as the $z$ coordinate. Now try H and He as the $z$ coordinate.**