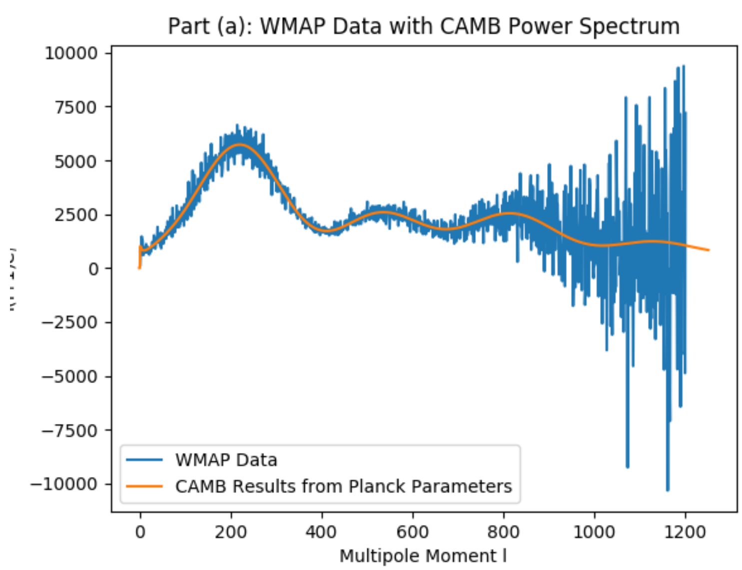
<u>Phys 641 Assignment 5</u>

This is mainly just the plots, most of the writing and explanations should be in the code

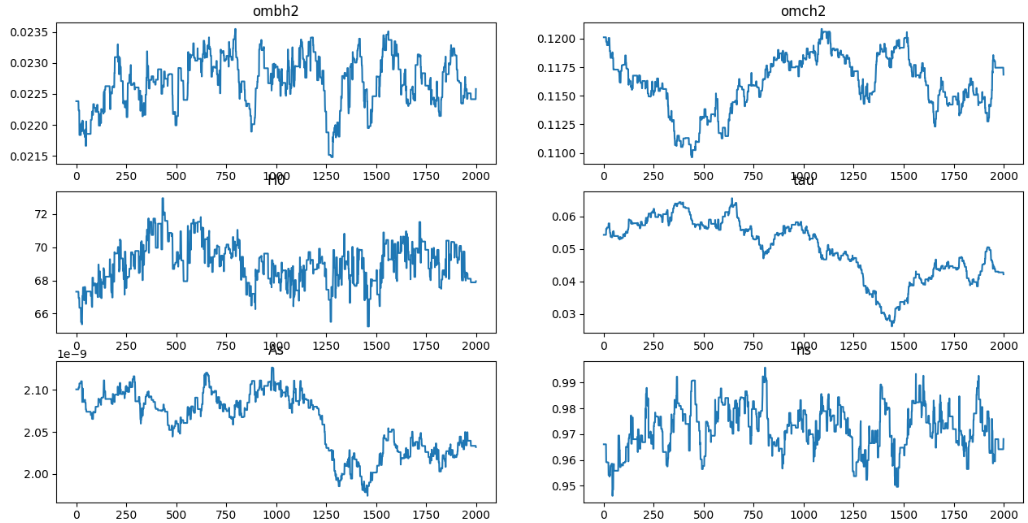
hw5.py is the main MCMC driver, plotit.py is analyzing the resulting chain. In the submitted folder I included all of the data sets produced and the plots from part c and my two attempts at part d which are just labelled by their decimal value so 003 is the file for a_{src}=0.003.

d_test.py is my program running the exact same thing as hw5.py but the only change is that I did not want to mess up my nicely running code to try to get part(d) running. Only changes between the two should be in the main MCMC driver loop and the definition of chisq

(a) This is the plot of the WMAP data and the power spectrum I get from inputting the Planck paper values of the cosmological parameters into CAMB. They seem to agree well because the CAMB power spectrum never falls outside the range of the WMAP data.



(b) This is an attempt at running a longer chain at the end of (b), at this point I had run short chains adjusting each step size for each parameter separately. Then I started scaling all of them at once. I found the scaling that adjusted each parameter the best to get a good acceptance rate and this is one of the longer runs that was produced. It did not converge.

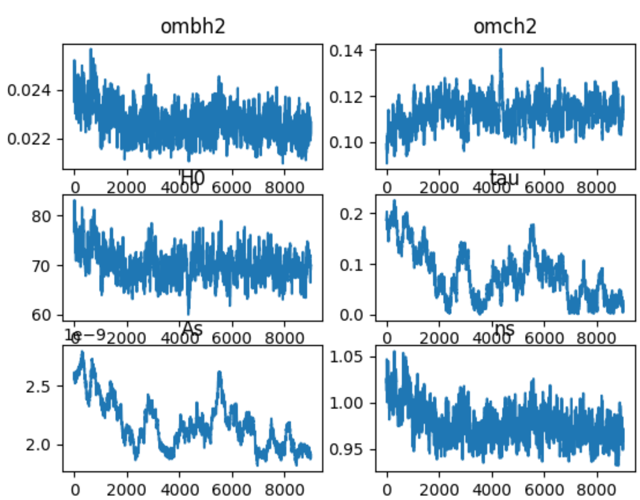


(c) I produced the covariance matrix and calculated the Cholesky and took the dot product with a vector of random variables to make as my new step size. I tried a few scalings and calculated the correlation length. Below is a quick table showing what I checked with the correlation length of each parameter and the acceptance rate given for each overall scaling that I applied to the step size

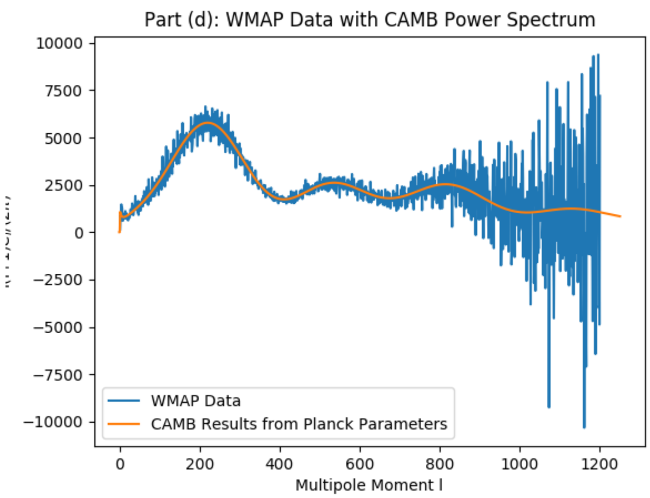
Scaling	$\Omega_b h^2$	$\Omega_c h^2$	H_0	T	A_s	n_s	Acceptance
Normal (1)	28	42	30	59	63	29	0.33
2	24	46	43	44	50	39	0.06
0.5	50	52	22	63	64	12	0.65

Looking at these, the scaling factor does not improve consistently over any one scaling and it makes the acceptance way off of what it is expected to be (25%) so I am keeping the scaling as normal.

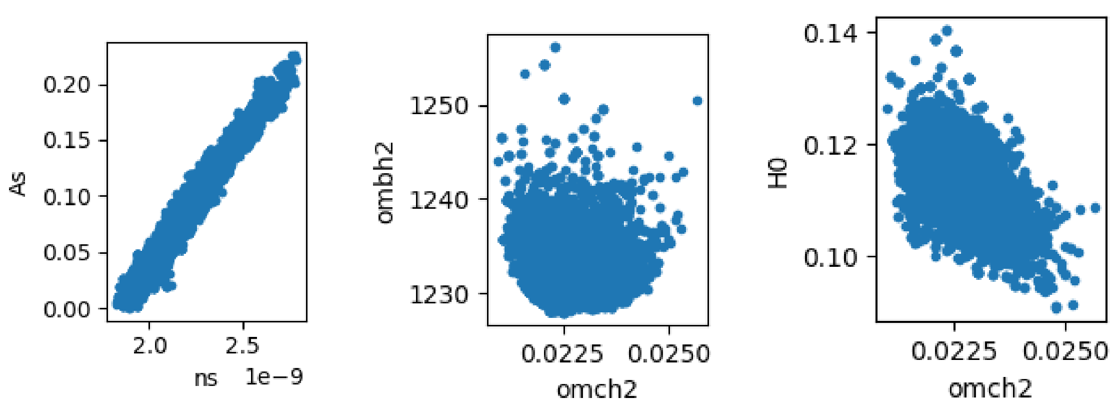
When I run with the np.dot(cholesky, np.random.randn) as the step size over 10000 events I get



Which, when I use CAMB to plot the new spectrum over the data I get (I just noticed the label is incorrect, it is not from the planck parameters now, it is from the data output)



This seems to be more converged than my previous attempts. Below are a copy of select variables plotted against each other to show that some of my variables ended up forming a tighter correlation than others which is why my convergence did not go as well as I would have liked. Visually, τ and A_s seem to be the parameters that did not really converge. This is meant just to show the variety of correlation strengths that I have with my data.



The acceptance rate is 0.3853, higher than the 25% rule of thumb
The mean values and error bars of each parameter are given below

$\Omega_b h^2$ → Mean = 2.27e-2 , Error = 6.66e-4

$\Omega_c h^2$ → Mean = 1.13e-1 , Error = 6.25e-3

H_0 → Mean = 7.02e1, Error =3.11
τ → Mean = 7.88e-2, Error =4.94e-2
A_s → Mean = 2.17e-9, Error =2.08e-10
n_s → Mean = 9.78e-1, Error =1.94e-2

(d)

NOTE: (Written after I had done the question). I realized that I probably did not do this question right because what is the text after this section is when I just changed the power spectrum then ran again rather than including it as a parameter that could change. I have attempted to fix that, by doing essentially what the cosmological parameters do. In the chisq calculation there is now a place to add a source in the predicted power spectrum, but I pretend that I do not know what that value is so it is just a constant. In the actual loop I assign a variable st as the change in the source which is the sum of the previous source with some step pulled from a small random gaussian distribution, I then calculate if it is accepted or not using this new modified chisq and if it is I accept the new value of the source.
I decided to run a shorter 5000 point loop in case this went wrong so I did not have to repeat it overnight every time. This will undoubtedly give a more reasonable value than what I had gotten before because I did not add the source in the chisq calculation whether I just assumed it was the same amplitude or not which gives a massive difference in the cosmological parameters.

One important note is that I realized that CAMB was extremely sensitive to values so when I used a_src=0.003, very early on in the loop I got 'Warning:xe at redshift zero is <1 Check input parameters and Reionization_xe', to me this means that it is past the limit for the source so 0.003 seems to be a higher end of the limit.

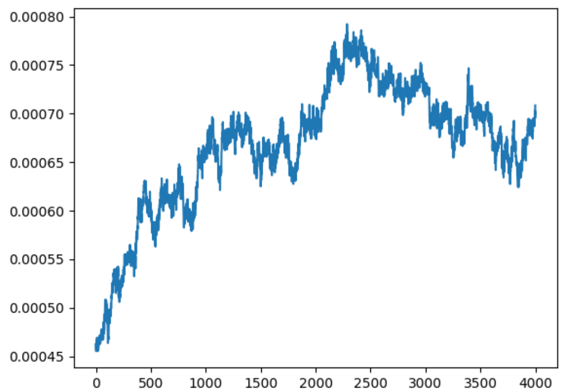
I do not have time to run long chains and check the correlation so I kind of assumed they are not correlated, even though they most likely are. If I wanted to do the correlation I would just add it as an extra row and column in my correlation matrix and then apply cholesky to the new 7x7 matrix and choose random variables based on that as the change. I am changing it by very small amounts about my initial guess (which is what I set the source to) so I am hoping that it does not cause too many problems. I recognize that if I had more time, this would be a better way tof doing it.

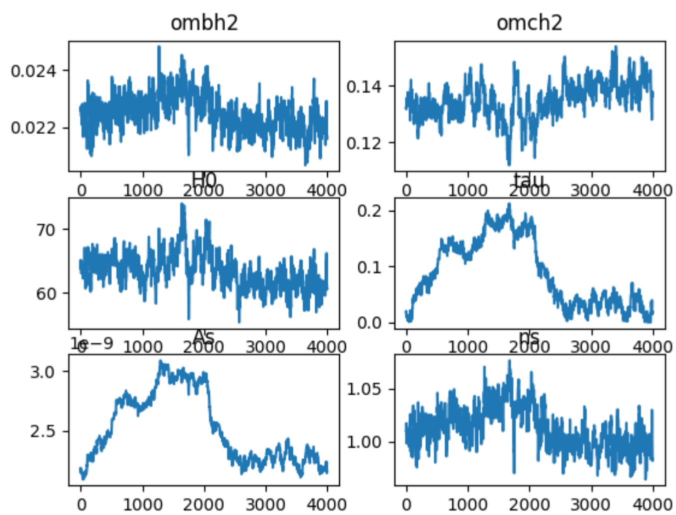
For a test with the source set at 0.0005 in d_test.py I got the following values
The acceptance rate is 0.3416
The mean values and error bars of each parameter are given below
$\Omega_b h^2$ → Mean = 2.24e-2, Error = 6.52e-4
$\Omega_c h^2$ → Mean = 1.35e-1, Error =6.48e-3
H_0 → Mean = 6.34e1, Error =2.77
τ → Mean = 8.69e-2, Error =6.00e-2
A_s → Mean = 2.52e-9, Error =1.90e-10
n_s → Mean = 1.01, Error =1.98e-2
a_{src} → Mean= 0.00067, Error =6.67e-5

The errors seems to be higher than in the no source attempt, but there does not seem to be as big a difference in the value which I would have thought, perhaps if my source value is set correctly it should not change. The a_{src} is fitted at 0.00067 while in the data it was actually added as 0.0005. The a_{src} , H_0 and τ seem to have experienced the biggest difference.

Taking a quick look at the parameters

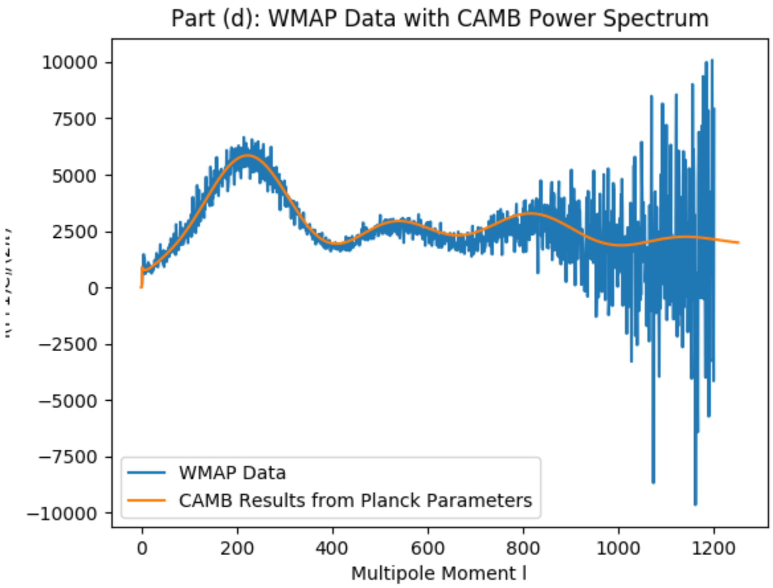
a_{src}





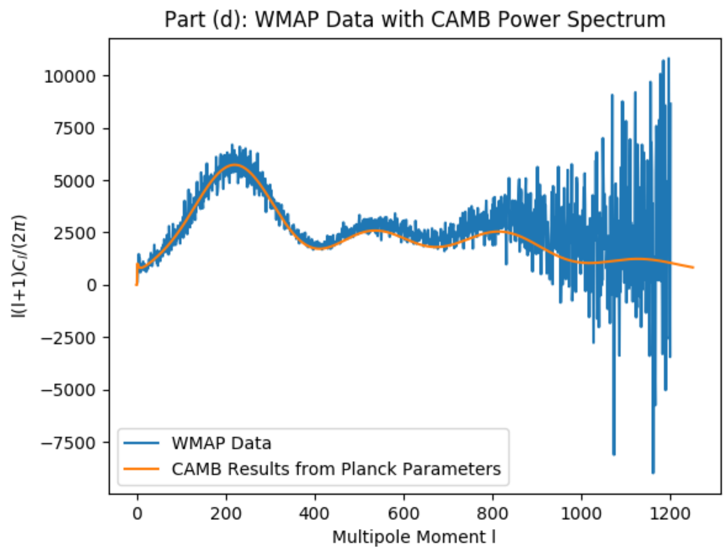
It seems like a_{src} never did converge, probably should have run for longer and as usual tau and A_s also do not seem to have converged. I think the rest were approaching the right values, but did not converge completely. If I ran the chain for longer it may have converged

When I plot the power spectrum it is visually obvious that it did not converge because the CAMB fit using the value I got out does not match the data as well as expected. This is probably mainly due to the higher a_{src} that it uses.

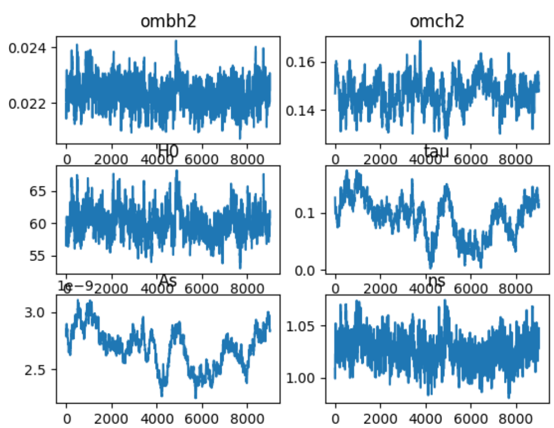


*************PREVIOUS ATTEMPT**

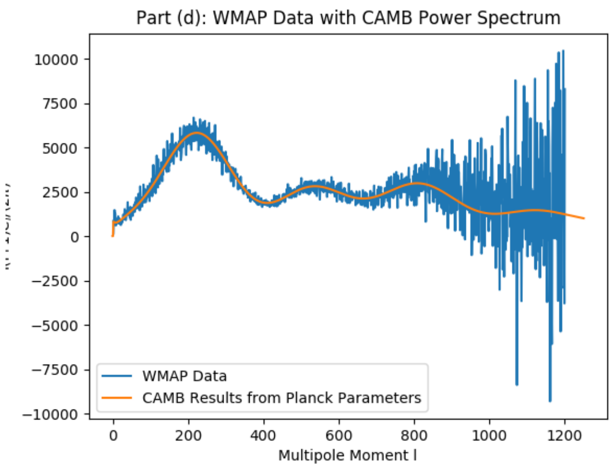
I looked at the effect of adding different size a_{src} to the data I chose a_{src}=0.00075 because I wanted the data to just start lifting from where it fit with CAMB before, but large enough difference to make the error bars bigger. I figured if I made it too big then CAMB would break down too easily because there would be no power spectrum that fit it well.
I say the limit is about 0.001 if the three first peaks are to be fitted to any accuracy because at that point the data no longer fits within the original CAMB with the Planck paper values. Specifically the third peak the CAMB curve is completely out of the range of the data. I would not reasonably want to try to use CAMB beyond this. I am sure if I ran the code long enough many times just changing a_{src} I could get a better idea of where exactly it breaks, but I know that at least I will not get reasonable values much higher than 0.001. By 0.1 the source completely dominates the power spectrum and the second peak is barely visible. I think that at this point CAMB would have trouble finding cosmological parameters that would create a fit. Below is a plot of the original CAMB from (a) with the same data but the added source of a_{src}=0.00075 added as ell^2*a_{src} to the original ell(ell+1)/(2pi)*C_l of the data files



Showing the same plots as before, but for the added source of a_{src}=0.00075. Yet again it seems that τ and A_s did not converge



When I apply this to CAMB and get a power spectrum out and then plot it with the data with the source added I get



The acceptance rate is 0.1848

The mean values and error bars of each parameter are given below

$\Omega_b h^2$ → Mean = 2.23e-2, Error = 5.06e-4

$\Omega_c h^2$ → Mean = 1.47e-1, Error =6.17e-3

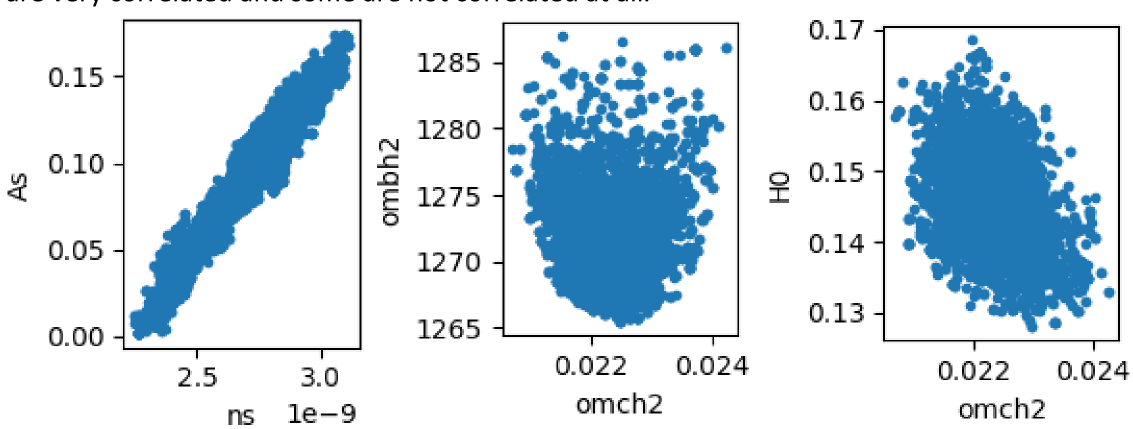
H_0 → Mean = 6.01e1, Error =2.24

τ → Mean = 9.04e-2, Error =3.47e-2

A_s → Mean = 2.69e-9, Error =1.75e-10

n_s → Mean = 1.03, Error =1.46e-2

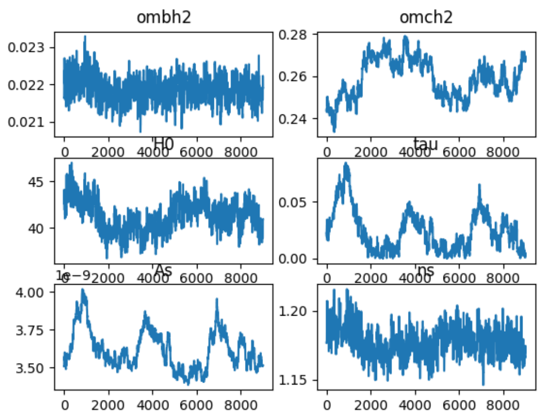
Plotting the parameters against each other, there seems to be a variety of how correlated the parameters are. Below are a select example of the correlation parameters to show that some are very correlated and some are not correlated at all.



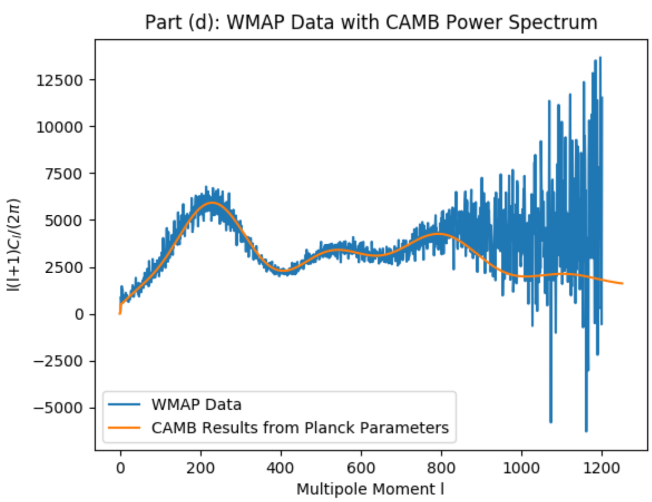
The factor that is affected the most between the no source and this source data set $\Omega_c h^2$ and H_0 . The error bars seem to have gone down slightly, but this may just be because I did not change the data set enough to make any parameter stop converging. It seems that I ran it long enough, that any parameter that was set well in the Cholesky calculation did converge, but the ones that were not set well did not converge. I can obviously set a higher value to see if I can get a larger effect.

Trying this again setting a_{src}=0.003

Compared to the no source and the a_{src}=0.00075, the $\Omega_c h^2$ no longer seems to converge as it did before. When I analyzed the data and calculated the mean and the error I did cut out the first 2000 pints so then my mean and error were based on the converged data and not the points where it was going towards the converged values.



When I apply this to CAMB and get a power spectrum out and then plot it with the data with the source added I get



The mean values and error bars of each parameter are given below

$\Omega_b h^2$ → Mean = 2.18e-2, Error = 3.51e-4

$\Omega_c h^2$ → Mean = 2.59e-1, Error =9.20e-3

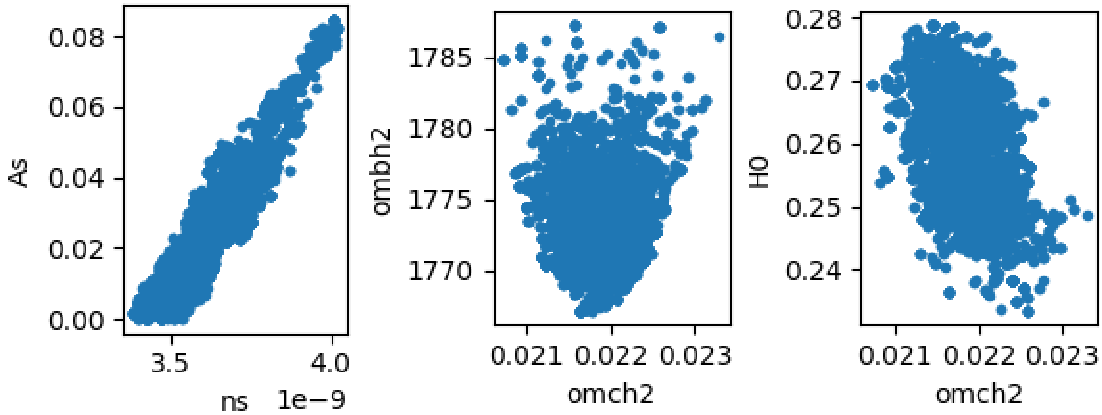
H_0 → Mean = 4.12e1, Error =1.72

τ → Mean = 2.43e-2, Error =1.82e-2

A_s → Mean = 3.62e-9, Error =1.30e-10

n_s → Mean = 1.18, Error =1.08e-2

The parameters that seem to have changed the most is $\Omega_c h^2$,H_0 and τ . All of the parameters did noticeably change compared to previous data sets with lower source values. The error bars did not change significantly again.



I think I could go to higher values and CAMB would still be able to converge for a fit, but even with a a_{src}=0.003, the parameters are really starting to diverge from how the universe actually is and the parameters that are accepted now.