Dependencies

This notebook requires Python packages listed in the `requirements.txt` file in the repository.
We recommend using a virtual environment to install them:

```
pip install -r requirements.txt
```

In [17]:
```
import bilby
import matplotlib.pyplot as plt
from bilby.core.prior import ConditionalLogUniform, LogUniform, Tru
from bilby.core.prior import PriorDict, Uniform, Constraint,Conditi
import bilby.gw.prior
import numpy as np
from BNSPriorDict_ChirpMassLambda import BNSPriorDict_chirpmass_lam
```

In [24]:
```
# Setup injection for now
# Specify the output directory and the name of the simulation.
outdir = "outdir"
# Now we try to sample and see what the error is in generating the
label = "bns_example"
bilby.core.utils.setup_logger(outdir=outdir, label=label)

# Set up a random seed for result reproducibility.  This is optiona
np.random.seed(88170235)
```

In [25]:
```
# We are going to inject a binary neutron star waveform.  We first
# dictionary of parameters that includes all of the different wavef
# parameters, including masses of the two neutron stars (mass_1, ma
# aligned spins of both NSs (chi_1, chi_2), etc.
mass_1_source = 1.5
mass_2_source = 1.3
lambda_1 = 545
lambda_2 = 1346
injection_parameters = dict(
    mass_1_source=1.5,
    mass_2_source=1.3,
    chi_1=0.02,
    chi_2=0.02,
    luminosity_distance=250.0,
    theta_jn=0.4,
    psi=2.659,
    phase=1.3,
    geocent_time=1126259642.413,
    ra=1.375,
    dec=-1.2108,
    lambda_1=545,
    lambda_2=1346,
)
```

In [26]:
```
# Calculate lambda_tilde
```

```
lambda_tilde = bilby.gw.conversion.lambda_1_lambda_2_to_lambda_tild
print(lambda_tilde)
chirp_mass_source = bilby.gw.conversion.component_masses_to_chirp_m
print(chirp_mass_source)
```

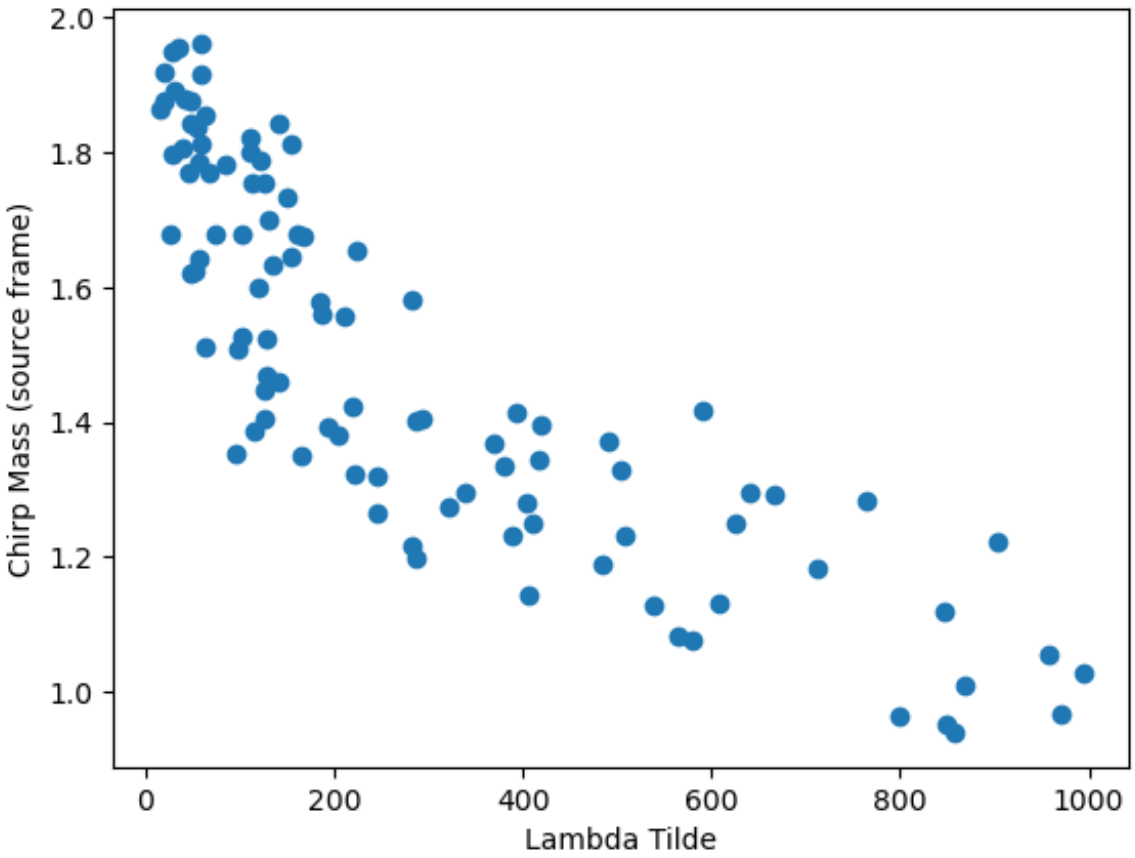
```
867.9931562541493
1.2150360414642816
```

In [27]:
```
# We setup the prior dict using the interpolated prior from the fil
priors_gw = BNSPriorDict_chirpmass_lambda_tilde(MCL_filename='./MCL_
# Delta lambda tilde is defined with a uniform prior
priors_gw['delta_lambda_tilde'] = Uniform(name='delta_lambda_tilde'
# Define the other priors for inference
priors_gw['luminosity_distance'] = 250.0 #bilby.gw.prior.UniformSou
# Fix everything to injected values other than Mchirp and lambda_ti
priors_gw['dec'] = - 1.2108 #Cosine(name='dec')
priors_gw['ra'] = 1.375 #Uniform(name='ra', minimum=0, maximum=2 *
priors_gw['theta_jn'] = 0.4 #Sine(name='theta_jn')
priors_gw['psi'] =  2.659 #Uniform(name='psi', minimum=0, maximum=n
priors_gw['phase'] = 1.3 #Uniform(name='phase', minimum=0, maximum=
priors_gw['chi_1'] = 0.02 #bilby.gw.prior.AlignedSpin(name='chi_1',
priors_gw['chi_2'] = 0#bilby.gw.prior.AlignedSpin(name='chi_2', a_p
priors_gw['mass_ratio'] =1.3/1.5 #bilby.gw.prior.UniformInComponent
priors_gw['mass_1'] = Constraint(name='mass_1', minimum=0.5, maximu
priors_gw['mass_2'] = Constraint(name='mass_2', minimum=0.5, maximu
```

```
22:00 bilby INFO    : No prior given, using default BNS priors in /U
sers/smag0001/opt/anaconda3/lib/python3.10/site-packages/bilby/gw/pr
ior_files/aligned_spins_bns_tides_on.prior.
22:00 bilby INFO    : Interpolating chirp_mass_source and lambda_til
de prior from file.
```

In [28]:
```
# Check that the prior is loaded by sampling from it
samples = priors_gw.sample(100)
# Plot the prior samples
plt.scatter(samples['lambda_tilde'], samples['chirp_mass_source'])
plt.xlabel('Lambda Tilde')
plt.ylabel('Chirp Mass (source frame)')
```

Out[28]:
```
Text(0, 0.5, 'Chirp Mass (source frame)')
```



In [29]:
```
# Fix most of the priors to their injected values
for key in [
    "psi",
    "geocent_time",
    "ra",
    "dec",
    "chi_1",
    "chi_2",
    "theta_jn",
    #"luminosity_distance",
    "phase",
]:
    priors_gw[key] = injection_parameters[key]

print(priors_gw)
```

```
{'mass_1': Constraint(minimum=0.5, maximum=5, name='mass_1', latex_l
abel='$m_1$', unit=None), 'mass_2': Constraint(minimum=0.5, maximum=
5, name='mass_2', latex_label='$m_2$', unit=None), 'mass_ratio': Del
taFunction(peak=0.8666666666666667, name=None, latex_label=None, uni
t=None), 'luminosity_distance': DeltaFunction(peak=250.0, name=None,
latex_label=None, unit=None), 'dec': -1.2108, 'ra': 1.375, 'theta_j
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       6.89001244e-03, 6.88824214e-03, 6.88596802e-03, 6.88181351e-0
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       6.64833963e-03, 6.61081403e-03, 6.56958011e-03, 6.52424099e-0
3,
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3,
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       5.36895744e-03, 5.29305581e-03, 5.21882976e-03, 5.14405107e-0
3,
       5.06972607e-03, 4.99477723e-03, 4.92167416e-03, 4.85119169e-0
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       4.77833639e-03, 4.70648663e-03, 4.63625580e-03, 4.56409816e-0
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       4.49438444e-03, 4.42885339e-03, 4.35815145e-03, 4.29185579e-0
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       4.22226589e-03, 4.15544561e-03, 4.08744994e-03, 4.02257417e-0
3,
       3.95964997e-03, 3.89518867e-03, 3.82949143e-03, 3.76718697e-0
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       3.69790556e-03, 3.63659989e-03, 3.57518804e-03, 3.51397808e-0
3,
       3.45351912e-03, 3.39365532e-03, 3.33377717e-03, 3.27278670e-0
3,
       3.21783878e-03, 3.15844952e-03, 3.10363966e-03])), 'delta_lam
bda_tilde': Uniform(minimum=-1000, maximum=1000, name='delta_lambda_
tilde', latex_label='$\\delta\\tilde{\\Lambda}$', unit=None, boundar
y=None), 'chi_1': 0.02, 'chi_2': 0.02, 'geocent_time': 1126259642.41
3}
```

In [31]:
```
# Set the duration and sampling frequency of the data segment that
# to inject the signal into. For the
# TaylorF2 waveform, we cut the signal close to the isco frequency
```

```
duration = 32
minimum_frequency=40
sampling_frequency = 2048
start_time = injection_parameters["geocent_time"] + 2 - duration

# Fixed arguments passed into the source model. The analysis starts
waveform_arguments = dict(
    waveform_approximant="IMRPhenomPv2_NRTidal",
    reference_frequency=50.0,
    minimum_frequency=minimum_frequency,
)
```

In [34]:
```
# Create the waveform_generator using a LAL Binary Neutron Star sou
waveform_generator = bilby.gw.WaveformGenerator(
    duration=duration,
    sampling_frequency=sampling_frequency,
    frequency_domain_source_model=bilby.gw.source.lal_binary_neutro
    parameter_conversion=convert_to_lal_binary_neutron_star_paramet
    waveform_arguments=waveform_arguments,
)
```

```
22:01 bilby INFO    : Waveform generator initiated with
  frequency_domain_source_model: bilby.gw.source.lal_binary_neutron_
star
  time_domain_source_model: None
  parameter_conversion: BNSPriorDict_ChirpMassLambda.convert_to_lal_
binary_neutron_star_parameters_mchirp
```

In [35]:
```
# Set up interferometers.  In this case we'll use three interferome
# (LIGO-Hanford (H1), LIGO-Livingston (L1), and Virgo (V1)).
# These default to their design sensitivity and start at 40 Hz.
interferometers = bilby.gw.detector.InterferometerList(["H1", "L1",
for interferometer in interferometers:
    interferometer.minimum_frequency = 40
interferometers.set_strain_data_from_power_spectral_densities(
    sampling_frequency=sampling_frequency, duration=duration, start
)
interferometers.inject_signal(
    parameters=injection_parameters, waveform_generator=waveform_ge
)
```

```
22:01 bilby INFO    : Injected signal in H1:
22:01 bilby INFO    :   optimal SNR = 7.19
22:01 bilby INFO    :   matched filter SNR = 8.42-0.86j
22:01 bilby INFO    :   mass_1_source = 1.5
22:01 bilby INFO    :   mass_2_source = 1.3
22:01 bilby INFO    :   chi_1 = 0.02
22:01 bilby INFO    :   chi_2 = 0.02
22:01 bilby INFO    :   luminosity_distance = 250.0
22:01 bilby INFO    :   theta_jn = 0.4
22:01 bilby INFO    :   psi = 2.659
22:01 bilby INFO    :   phase = 1.3
22:01 bilby INFO    :   geocent_time = 1126259642.413
22:01 bilby INFO    :   ra = 1.375
22:01 bilby INFO    :   dec = -1.2108
22:01 bilby INFO    :   lambda_1 = 545
22:01 bilby INFO    :   lambda_2 = 1346
22:01 bilby INFO    : Injected signal in L1:
22:01 bilby INFO    :   optimal SNR = 5.82
22:01 bilby INFO    :   matched filter SNR = 5.35+0.19j
22:01 bilby INFO    :   mass_1_source = 1.5
22:01 bilby INFO    :   mass_2_source = 1.3
22:01 bilby INFO    :   chi_1 = 0.02
22:01 bilby INFO    :   chi_2 = 0.02
22:01 bilby INFO    :   luminosity_distance = 250.0
22:01 bilby INFO    :   theta_jn = 0.4
22:01 bilby INFO    :   psi = 2.659
22:01 bilby INFO    :   phase = 1.3
22:01 bilby INFO    :   geocent_time = 1126259642.413
22:01 bilby INFO    :   ra = 1.375
22:01 bilby INFO    :   dec = -1.2108
22:01 bilby INFO    :   lambda_1 = 545
22:01 bilby INFO    :   lambda_2 = 1346
22:01 bilby INFO    : Injected signal in V1:
22:01 bilby INFO    :   optimal SNR = 6.17
22:01 bilby INFO    :   matched filter SNR = 7.63-0.39j
22:01 bilby INFO    :   mass_1_source = 1.5
22:01 bilby INFO    :   mass_2_source = 1.3
22:01 bilby INFO    :   chi_1 = 0.02
22:01 bilby INFO    :   chi_2 = 0.02
22:01 bilby INFO    :   luminosity_distance = 250.0
22:01 bilby INFO    :   theta_jn = 0.4
22:01 bilby INFO    :   psi = 2.659
22:01 bilby INFO    :   phase = 1.3
22:01 bilby INFO    :   geocent_time = 1126259642.413
22:01 bilby INFO    :   ra = 1.375
22:01 bilby INFO    :   dec = -1.2108
22:01 bilby INFO    :   lambda_1 = 545
22:01 bilby INFO    :   lambda_2 = 1346
```

Out[35]:
```
[{'plus': array([ 0.00000000e+00-0.00000000e+00j,  0.00000000e+00-
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81e-26j,
          0.00000000e+00-0.00000000e+00j]),
  'cross': array([ 0.00000000e+00+0.00000000e+00j,  0.00000000e+00
+0.00000000e+00j,
          0.00000000e+00+0.00000000e+00j, ...,
         -2.06658968e-26+8.63920388e-26j, -2.06849070e-26+8.638374
36e-26j,
          0.00000000e+00+0.00000000e+00j])},
 {'plus': array([ 0.00000000e+00-0.00000000e+00j,  0.00000000e+00-
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          0.00000000e+00-0.00000000e+00j, ...,
         -8.66842781e-26-2.07358035e-26j, -8.66759549e-26-2.075487
81e-26j,
          0.00000000e+00-0.00000000e+00j]),
  'cross': array([ 0.00000000e+00+0.00000000e+00j,  0.00000000e+00
+0.00000000e+00j,
          0.00000000e+00+0.00000000e+00j, ...,
         -2.06658968e-26+8.63920388e-26j, -2.06849070e-26+8.638374
36e-26j,
          0.00000000e+00+0.00000000e+00j])},
 {'plus': array([ 0.00000000e+00-0.00000000e+00j,  0.00000000e+00-
0.00000000e+00j,
          0.00000000e+00-0.00000000e+00j, ...,
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81e-26j,
          0.00000000e+00-0.00000000e+00j]),
  'cross': array([ 0.00000000e+00+0.00000000e+00j,  0.00000000e+00
+0.00000000e+00j,
          0.00000000e+00+0.00000000e+00j, ...,
         -2.06658968e-26+8.63920388e-26j, -2.06849070e-26+8.638374
36e-26j,
          0.00000000e+00+0.00000000e+00j])}]
```

In [37]:
```
# Initialise the likelihood by passing in the interferometer data (
# and the waveform generator
likelihood = bilby.gw.GravitationalWaveTransient(
    interferometers=interferometers,
    waveform_generator=waveform_generator,
)
```

In [ ]:
```
# WHY DOES THIS WORK!!!!!!
priors_gw = dict(priors_gw)


#nsteps = 2000


# Run sampler.  In this case we're going to use the `nestle` sample
# For production runs use dynesty
# This will be very slow depending on your chosen signal
result = bilby.run_sampler(
```

```
    likelihood=likelihood,
    priors=priors_gw,
    sampler="nestle",
    nlive=200,
    injection_parameters=injection_parameters,
    outdir=outdir,
    label=label,
    npool=1,
)
```

```
22:03 bilby INFO    : Running for label 'bns_example', output will b
e saved to 'outdir'
22:03 bilby INFO    : Using lal version 7.3.1
22:03 bilby INFO    : Using lal git version Branch: None;Tag: lalsui
te-v7.19;Id: 84d780c102cf51ea1fdf7a1cbf0a626a5eca0d0a;;Builder: Dunc
an Macleod <duncan.macleod@ligo.org>;Repository status: CLEAN: All m
odifications committed
22:03 bilby INFO    : Using lalsimulation version 5.2.1
22:03 bilby INFO    : Using lalsimulation git version Branch: None;T
ag: lalsuite-v7.19;Id: 84d780c102cf51ea1fdf7a1cbf0a626a5eca0d0a;;Bui
lder: Duncan Macleod <duncan.macleod@ligo.org>;Repository status: CL
EAN: All modifications committed
22:03 bilby INFO    : Analysis priors:
22:03 bilby INFO    : chirp_mass_source=Interped(xx=array([0.803015
, 0.80904515, 0.8150753 , 0.82110545, 0.82713561,
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       0.86331652, 0.86934667, 0.87537682, 0.88140697, 0.88743712,
       0.89346727, 0.89949742, 0.90552758, 0.91155773, 0.91758788,
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       0.95376879, 0.95979894, 0.96582909, 0.97185924, 0.97788939,
       0.98391955, 0.9899497 , 0.99597985, 1.00201   , 1.00804015,
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       1.16482409, 1.17085424, 1.17688439, 1.18291455, 1.1889447 ,
       1.19497485, 1.201005  , 1.20703515, 1.2130653 , 1.21909545,
       1.22512561, 1.23115576, 1.23718591, 1.24321606, 1.24924621,
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       1.34572864, 1.35175879, 1.35778894, 1.36381909, 1.36984924,
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       1.70753773, 1.71356788, 1.71959803, 1.72562818, 1.73165833,
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```

```
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2,
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```
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ndary=None)
22:03 bilby INFO    : lambda_tilde=ConditionalInterped(condition_fun
c='BNSPriorDict_ChirpMassLambda.conditional_func_y', name=None, late
x_label=None, unit=None, boundary=None, xx=array([  3.51005 ,   8.53
0151,  13.550251,  18.570352,  23.590452,
```

```
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22:03 bilby INFO    : luminosity_distance=250.0
22:03 bilby INFO    : dec=-1.2108
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22:03 bilby INFO    : theta_jn=0.4
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22:03 bilby INFO    : phase=1.3
22:03 bilby INFO    : chi_1=0.02
22:03 bilby INFO    : chi_2=0.02
22:03 bilby INFO    : geocent_time=1126259642.413
22:03 bilby INFO    : Analysis likelihood class: <class 'bilby.gw.li
kelihood.base.GravitationalWaveTransient'>
22:03 bilby INFO    : Analysis likelihood noise evidence: -94806.536
77287433
22:03 bilby INFO    : Single likelihood evaluation took nan s
22:03 bilby INFO    : Using sampler Nestle with kwargs {'method': 'm
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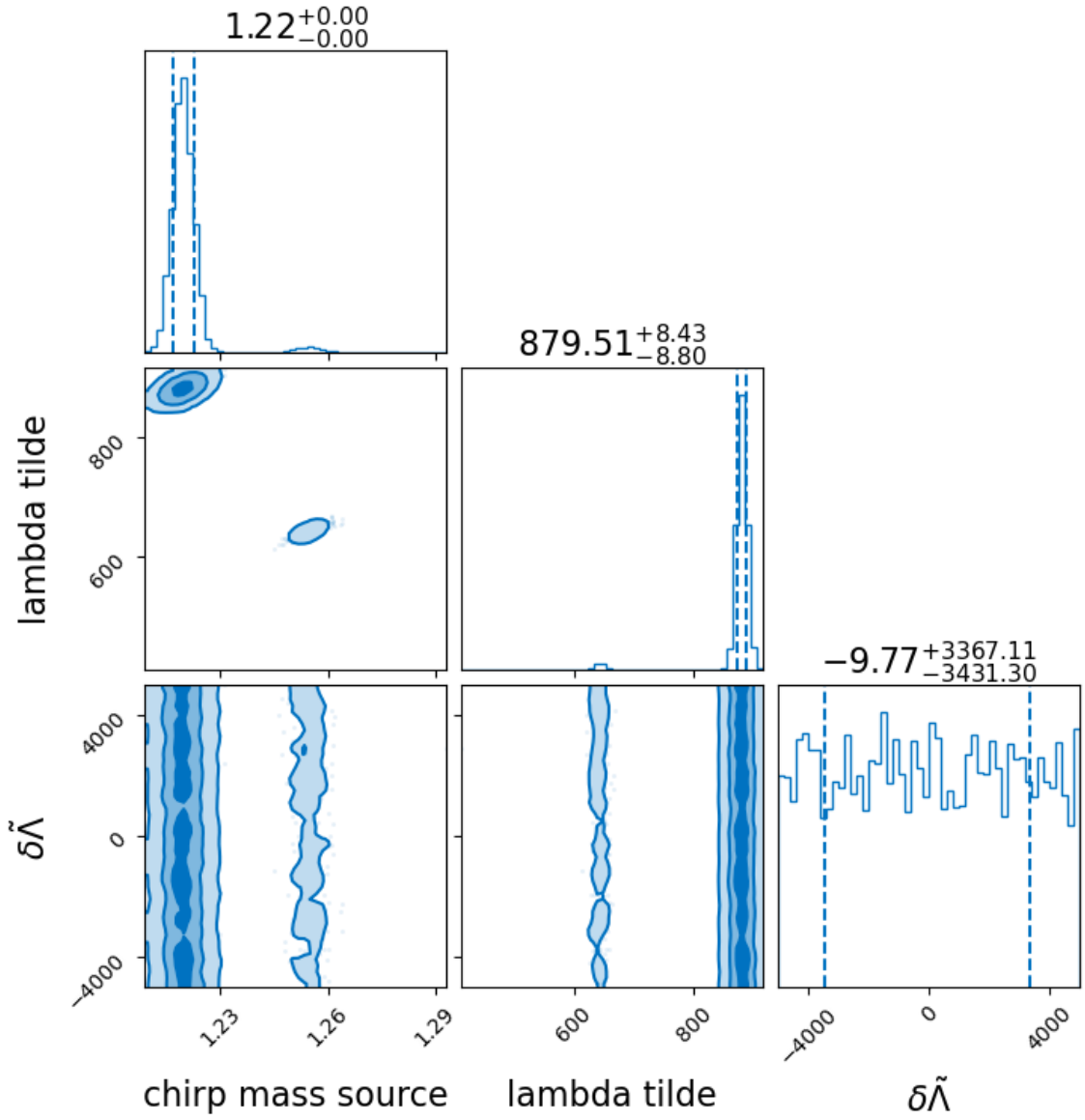
ter': None, 'maxcall': None, 'dlogz': None, 'decline_factor': None,
'rstate': None, 'callback': <function print_progress at 0x7fdc905bc7
90>, 'steps': 20, 'enlarge': 1.2}
it=  1121 logz=-33.0272594
```

In [16]:
```
result.plot_corner()
```

Out[16]:



In [ ]:
```
# Convert the posterior using bilby's standard conversion function
result.posterior = bilby.gw.conversion.generate_all_bns_parameters(
#priors = bilby.gw.prior.BNSPriorDict()

# Some hacky stuff bellow, for some reason bilby doesn't like to se
# so I convert the priors back to uniform
# This works fine in parallel bilby so I'm not sure what the issue

# Overwrite custom priors with uniform to save the bilby object
priors_gw['lambda_tilde'] = Uniform(name='lambda_tilde',minimum=0,m
priors_gw['chirp_mass_source'] = Uniform(name='chirp_mass_source',m
```

In [ ]:
```
# Again, something that should be fixed at some point!

# Create a new serializable result object
serializable_result = bilby.core.result.Result(
    label=label,
    outdir=outdir,
    sampler='nestle',
    search_parameter_keys=['chirp_mass_source', 'mass_ratio', 'lamb
    fixed_parameter_keys=[],
    priors=priors_gw,
```

```
    posterior=result.posterior,
    log_evidence=result.log_evidence,
    log_evidence_err=result.log_evidence_err,
    log_noise_evidence=result.log_noise_evidence,
    log_bayes_factor=result.log_bayes_factor,
    log_likelihood_evaluations=result.log_likelihood_evaluations,
    log_prior_evaluations=result.log_prior_evaluations,
    sampling_time=result.sampling_time,
    meta_data=result.meta_data
)

# Save using standard bilby format
serializable_result.save_to_file()
```

In [ ]:
```
# Just in case save the posteriors to a dat too!
result.save_posterior_samples()
```