21cmfish

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A python package for doing Fisher matrix analysis with 21cmFAST.

CHAPTER

ONE

DEPENDENCIES

The main dependency is 21cmFAST. I *strongly* recommend you install `21cmFAST` first.

CHAPTER

TWO

DOCUMENTATION

See https://21cmfish.readthedocs.io for API documentation and a usage tutorial

CHAPTER

THREE

ACKNOWLEDGING

If you find `21cmfish` useful in your research please cite:

- Mason et al. 2022 (submitted)

3.1 21cmfish Documentation

3.1.1 Installation

Dependencies

The main dependency is 21cmFAST I *strongly* recommend you install `21cmFAST` first following the installation instructions there.

Both `21cmFAST` and `21cmfish` must be installed in the same environment.

Installation

At the command line:

```
$ git clone git@github.com:charlottenosam/21cmfish.git
$ cd 21cmfish
$ pip install .
```

3.1.2 Usage

This is a basic walkthrough of how to do a Fisher matrix analysis with `21cmFAST` and `21cmfish`.

Creating lightcones for your analysis

Start by creating a *.config* file for your runs. Have a look in *21cmFAST_config_files/* for examples.

- You can add any of the usual 21cmFAST AstroParams, UserParams and FlagOptions.
- At the end of the config file list the AstroParams you want to vary
- You will need to change the *output_dir* to the full path to where you want to save lightcones all other 21cmfish outputs.

To make the lightcones run:

```
python make_lightcones_for_fisher.py PATH_TO_YOUR_CONFIG_FILE.config --dry_run
```

I advise adding the *–dry_run* flag the first time you run to check the lightcones it will make before it tries to run 21cmFAST! 21cmfish can also create lightcones using multiprocessing and multithreading, which you can specify via (*–num_cores* and *–N_THREADS*. By default, 21cmfish will run on n_cpus - 1.

Process lightcones for each parameter

The *py21cmfish.Parameter()* class loads lightcones for each parameter and exports the 21cm global signal and power spectra for each lightcones, and then calculates the derivatives of these quantities needed for the Fisher matrix analysis.

Start by importing 21cmfish.

```
import py21cmfish
```

Parameters are loaded from the config file

```
astro_params_vary, astro_params_fid = p21fish.get_params_fid(config_file=data_dir+
↪'21cmFAST_config_files/EoS_mini.config')
```

Each parameter is loaded as a separate *py21cmfish.Parameter()* object into a *parameters* dictionary. For example:

```
output_dir_Park19 = data_dir+'examples/EoS_mini/'
params_EoS = {}
for param in astro_params_vary:
    params_EoS[param] = p21fish.Parameter(param=param, output_dir=output_dir)
```

If you are adding a new parameter from new lightcones, add *new=True* to generate new global signals and power spectra.

Create Fisher matrix

The Fisher matrix and its inverse are generated from the parameters dictionary:

```
Fij_matrix_PS, Finv_PS= p21fish.make_fisher_matrix(params_EoS,
                                                   fisher_params=astro_params_
↪vary,
                                                   hpeak=0.0, obs='PS',
                                                   k_min=0.1, k_max=1,
                                                   z_min=5.7, z_max=30.,
                                                   sigma_mod_frac=0.2,
                                                   add_sigma_poisson=True)
```

For more details see the examples notebook #TODO

3.1.3 Tutorials

The following introductory tutorial will help you get started with `21cmfish` to create a Fisher matrix from 21cmFAST lightcones:

[1]:
```
import os, sys
import numpy as np
import corner

# sys.path.append('../')
import py21cmfish as p21fish

import matplotlib as mpl
import matplotlib.pyplot as plt
import matplotlib.mathtext as mathtext
import matplotlib.lines as mlines

%matplotlib inline

plt.style.use(['default','seaborn','seaborn-ticks'])
mpl.rcParams['xtick.direction'] = 'in'
mpl.rcParams['ytick.direction'] = 'in'
mpl.rcParams['figure.figsize'] = (4,3)
mpl.rcParams['figure.dpi'] = 150

if os.path.exists(os.environ['WORK_DIR']+'/code/matplotlibrc'):
    from matplotlib import rc_file
    rc_file(os.environ['WORK_DIR']+'/code/matplotlibrc')

    mathtext.FontConstantsBase.sup1 = 0.5
    mathtext.FontConstantsBase.sub1 = 0.2
    mathtext.FontConstantsBase.sub2 = 0.2
```

[3]:
```
# Color palette
try:
    from palettable.tableau import Tableau_20, ColorBlind_10
    cols = ColorBlind_10.hex_colors

    col_pess  = cols[6]
    col_mod   = cols[0]
    col_alpha = 'k'
    col_mcmc  = cols[3]
    col_P19   = cols[1]

except:
    col_pess  = '0.5'
    col_mod   = 'tab:blue'
    col_alpha = 'k'
    col_mcmc  = '0.7'
    col_P19   = 'tab:orange'
```

[4]:
```
%load_ext autoreload
%autoreload 2
```

Fisher plots

This notebook loads and plots posteriors based on the 21cm power spectrum for the 21cmfish paper.

To run the notebook you must first unpack the data directories in `/examples/`

1. *EOS21 - CDM fiducial with pop II and pop III galaxies*
2. *Comparison with Park+19*
3. *Adding your own new parameter*

[23]:
```
p21fish.base_path = '/Users/cmason/Documents/Research/21cmFAST/21cmfish/'

examples_dir = p21fish.base_path+'examples/'
data_dir     = examples_dir+'data/'

noise_dir = data_dir+'21cmSense_noise/'
figs_dir  = examples_dir

print('Loading data from',data_dir)
```

```
Loading data from /Users/cmason/Documents/Research/21cmFAST/21cmfish/examples/data/
```

EOS21

This is a fiducial case from *Munoz+2021* with CDM, and with both pop II and pop III galaxies.

[7]:
```
# Find the parameters we varied and fiducials from the config file
# but you could also list these yourself (especially if you want to change the order)
print(p21fish.base_path+'21cmFAST_config_files/EoS_mini.config')
astro_params_vary, astro_params_fid = p21fish.get_params_fid(
                                      config_file=p21fish.base_path+'21cmFAST_config_
↪files/EoS_mini.config')

print('Varying parameters:',astro_params_vary)
print('Fiducial parameter values:',astro_params_fid)

assert type(astro_params_vary) == list, 'astro_params_vary must be a list'
assert type(astro_params_fid) == dict, 'astro_params_vary must be a dict'
```

```
/Users/cmason/Documents/Research/21cmFAST/21cmfish/21cmFAST_config_files/EoS_mini.config
Varying parameters: ['ALPHA_STAR', 'F_STAR10', 'ALPHA_ESC', 'F_ESC10', 'ALPHA_STAR_MINI',
↪ 'F_STAR7_MINI', 'F_ESC7_MINI', 'L_X', 'NU_X_THRESH', 'A_LW']
Fiducial parameter values: {'ALPHA_ESC': -0.3, 'F_ESC10': -1.35, 'ALPHA_STAR': 0.5, 'F_
↪STAR10': -1.25, 't_STAR': 0.5, 'F_STAR7_MINI': -2.5, 'ALPHA_STAR_MINI': 0.0, 'F_ESC7_
↪MINI': -1.35, 'L_X': 40.5, 'L_X_MINI': 40.5, 'NU_X_THRESH': 500.0, 'A_VCB': 1.0, 'A_LW
↪': 2.0}
```

Load parameters

Moderate noise

[9]:
```
# Load each parameter into a dictionary
params_EoS = {}
astro_params_vary_EoS = ['F_STAR10', 'ALPHA_STAR', 'F_ESC10', 'ALPHA_ESC',
                         'F_STAR7_MINI', 'ALPHA_STAR_MINI', 'F_ESC7_MINI', 'A_LW', 'L_X',
↪ 'NU_X_THRESH',]

for param in astro_params_vary_EoS:
    params_EoS[param] = p21fish.Parameter(param=param,
                                          output_dir=data_dir+'EOS21/',
                                          PS_err_dir=noise_dir+'21cmSense_fid_EOS21/',
                                          clobber=False, Park19=None,
                                          vb=False, new=False)
```

```
########## fisher set up for F_STAR10
    Loading global signal and power spectra from saved files
    Fiducial: F_STAR10=-1.25
########## fisher set up for ALPHA_STAR
    Loading global signal and power spectra from saved files
    Fiducial: ALPHA_STAR=0.5
########## fisher set up for F_ESC10
    Loading global signal and power spectra from saved files
    Fiducial: F_ESC10=-1.35
########## fisher set up for ALPHA_ESC
    Loading global signal and power spectra from saved files
    Fiducial: ALPHA_ESC=-0.3
########## fisher set up for F_STAR7_MINI
    Loading global signal and power spectra from saved files
    Fiducial: F_STAR7_MINI=-2.5
########## fisher set up for ALPHA_STAR_MINI
    Loading global signal and power spectra from saved files
    Fiducial: ALPHA_STAR_MINI=0.0
########## fisher set up for F_ESC7_MINI
    Loading global signal and power spectra from saved files
    Fiducial: F_ESC7_MINI=-1.35
########## fisher set up for A_LW
    Loading global signal and power spectra from saved files
    Fiducial: A_LW=2.0
########## fisher set up for L_X
    Loading global signal and power spectra from saved files
    Fiducial: L_X=40.5
########## fisher set up for NU_X_THRESH
    Loading global signal and power spectra from saved files
    Fiducial: NU_X_THRESH=500.0
```

Pessimistic noise

[10]:
```
# Load each parameter into a dictionary
params_EoS_pess = {}

for param in astro_params_vary_EoS:
    params_EoS_pess[param] = p21fish.Parameter(param=param,
                                               output_dir=data_dir+'EOS21/',
                                               PS_err_dir=noise_dir+'21cmSense_pess_EOS21/',
                                               clobber=False, Park19=None,
                                               vb=False)
```

```
########### fisher set up for F_STAR10
    Loading global signal and power spectra from saved files
    Fiducial: F_STAR10=-1.25
########### fisher set up for ALPHA_STAR
    Loading global signal and power spectra from saved files
    Fiducial: ALPHA_STAR=0.5
########### fisher set up for F_ESC10
    Loading global signal and power spectra from saved files
    Fiducial: F_ESC10=-1.35
########### fisher set up for ALPHA_ESC
    Loading global signal and power spectra from saved files
    Fiducial: ALPHA_ESC=-0.3
########### fisher set up for F_STAR7_MINI
    Loading global signal and power spectra from saved files
    Fiducial: F_STAR7_MINI=-2.5
########### fisher set up for ALPHA_STAR_MINI
    Loading global signal and power spectra from saved files
    Fiducial: ALPHA_STAR_MINI=0.0
########### fisher set up for F_ESC7_MINI
    Loading global signal and power spectra from saved files
    Fiducial: F_ESC7_MINI=-1.35
########### fisher set up for A_LW
    Loading global signal and power spectra from saved files
    Fiducial: A_LW=2.0
########### fisher set up for L_X
    Loading global signal and power spectra from saved files
    Fiducial: L_X=40.5
########### fisher set up for NU_X_THRESH
    Loading global signal and power spectra from saved files
    Fiducial: NU_X_THRESH=500.0
```

Fisher matrix analysis

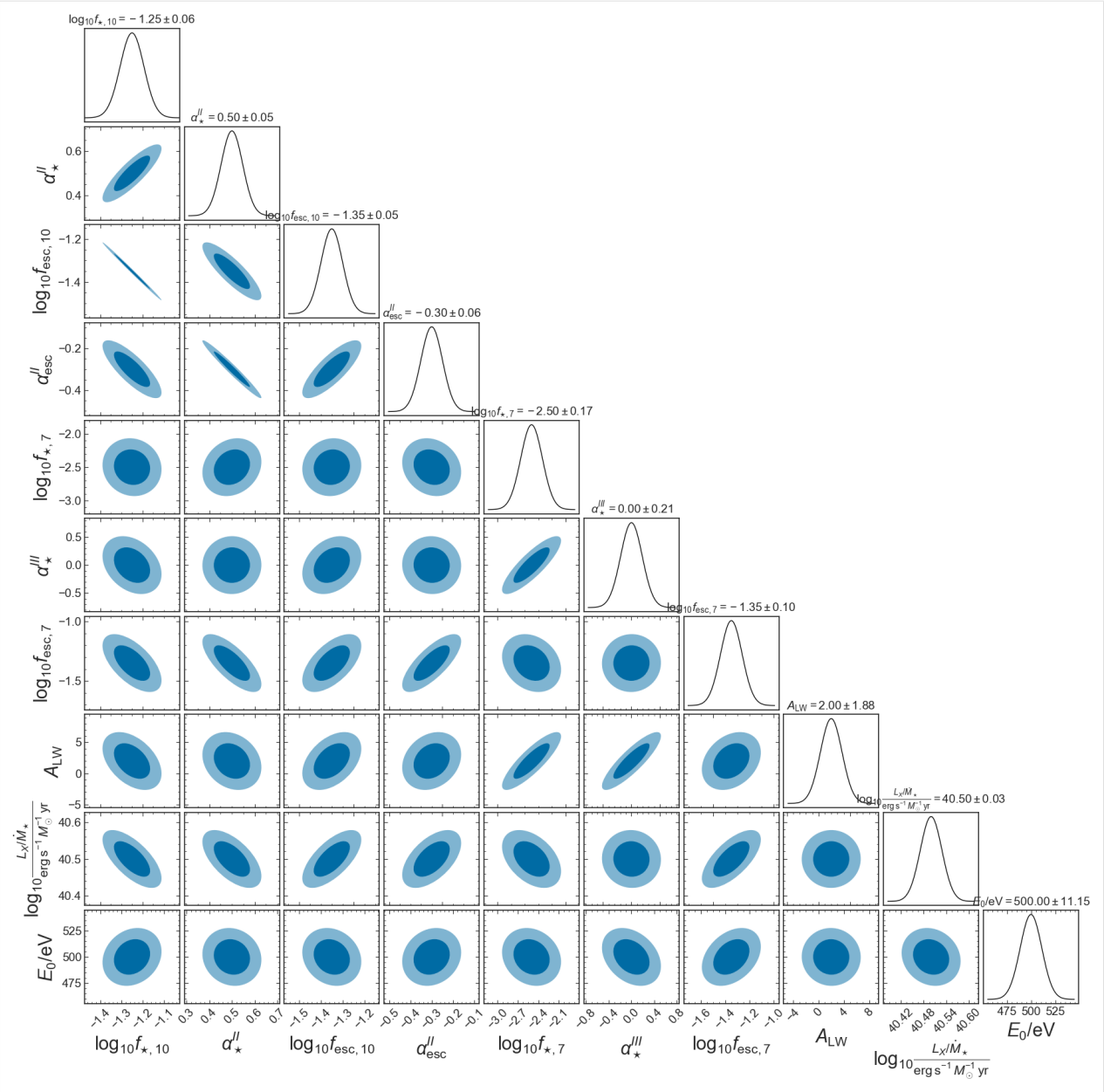
`make_fisher_matrix()` creates the Fisher matrix and its inverse from a Parameters dictionary. The resulting ellipses can be plotted with `plot_triangle()`.

[11]:
```
Fij_matrix_PS, Finv_PS = p21fish.make_fisher_matrix(params_EoS, fisher_params=astro_
↪params_vary_EoS,
                                                    hpeak=0.0, obs='PS',
                                                    k_min=0.1, k_max=1,
                                                    z_min=5., z_max=30.,
                                                    sigma_mod_frac=0.2,
                                                    add_sigma_poisson=True)

fid_params = np.array([astro_params_fid[param] for param in params_EoS])
fid_labels = np.array([p21fish.astro_params_labels[param] for param in params_EoS])
```

```
PS shape: (23, 24)
```

[12]:
```
p21fish.plot_triangle(params=astro_params_vary_EoS,
                      fiducial=fid_params,
                      labels=fid_labels,
                      cov=Finv_PS,
                      ellipse_color=col_mod,
                      title_fontsize=14,
                      xlabel_kwargs={'labelpad': 5, 'fontsize':22},
                      ylabel_kwargs={'labelpad': 5, 'fontsize':22},
                      fig_kwargs={'figsize':(18,18)});

plt.savefig(figs_dir+'corner_EoS_mini_fisher.png', bbox_inches='tight')
```

```
generating new axis
```



Add a prior

E.g. Park+2019 find $\sigma(\alpha_\star^{II}) \approx 0.07$.

To add a prior, we can add $1/\sigma^2$ to the diagonal element for that parameter (e.g. Coe 2009)

[13]:
```
sigma_alpha_star_II = 0.07
idx_alpha_star = list(params_EoS).index("ALPHA_STAR")
print(f'ALPHA_STAR is at index={idx_alpha_star}')
Fij_matrix_PS_alpha_star_prior = Fij_matrix_PS.copy()
Fij_matrix_PS_alpha_star_prior[idx_alpha_star,idx_alpha_star] += 1/sigma_alpha_star_
↪II**2.
```

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```
Finv_alpha_star_prior = np.linalg.inv(Fij_matrix_PS_alpha_star_prior)
```

```
ALPHA_STAR is at index=1
```

[14]:
```
fig, ax = plt.subplots(len(fid_params), len(fid_params), figsize=(18,18))
cols = [col_mod, col_alpha]

for i, cov in enumerate([Finv_PS, Finv_alpha_star_prior]):

    col = cols[i]
    if i == 0:
        # No prior
        resize_lims=True
        ellipse_color=col
        ellipse_kwargs=[{'alpha':0.8},{'alpha':0.2}]
        plot1D_kwargs={'c':col, 'lw':1}
    else:
        # with prior
        ls='solid'
        resize_lims=False
        ellipse_color='None'
        ellipse_kwargs=[{'edgecolor':col,'lw':2,'ls':ls},
                        {'edgecolor':col,'lw':2,'ls':ls,'alpha':0.8}]
        plot1D_kwargs={'c':col, 'lw':2, 'ls':ls}

    p21fish.plot_triangle(params=astro_params_vary_EoS,
                          fiducial=fid_params,
                          labels=fid_labels,
                          cov=cov,
                          ellipse_color=ellipse_color,
                          ellipse_kwargs=ellipse_kwargs,
                          plot1D_kwargs=plot1D_kwargs,
                          resize_lims=resize_lims,
                          title_fontsize=14,
                          xlabel_kwargs={'labelpad': 5, 'fontsize':22},
                          ylabel_kwargs={'labelpad': 5, 'fontsize':22},
                          ax=ax, fig=fig);

    p21fish.title_double_ellipses(axes=ax, labels=fid_labels,
                med=fid_params, sigma=np.sqrt(cov.diagonal()),
                title_fontsize=18, title_pad=55,
                vspace=i/5,
                color=col
                )

no_prior = mlines.Line2D([], [], color=col_mod, lw=2, label='EOS, 21cm only')
w_prior  = mlines.Line2D([], [], color=col_alpha, lw=3, ls=ls, label=r'+ LF $\alpha_\
↪star^\mathrm{II}$ prior')

ax[0,5].legend(handles=[no_prior, w_prior], loc='upper left', fontsize=24)
```

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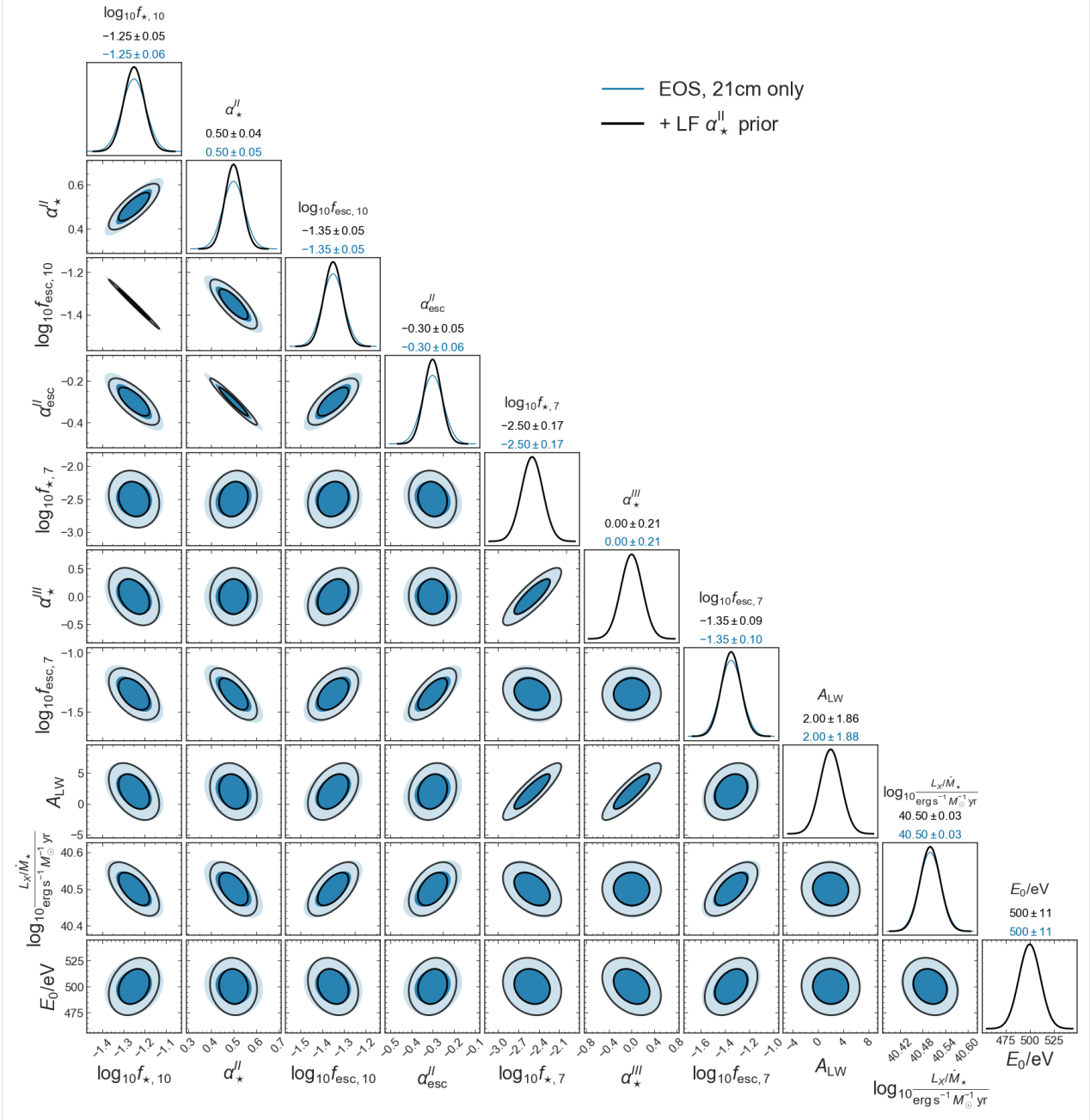
```
plt.savefig(figs_dir+'corner_EoS_mini_fisher_ALPHA_STAR_prior.png', bbox_inches='tight')
```



Pessimistic noise case

[15]:
```
Fij_matrix_PS_pess, Finv_PS_pess = p21fish.make_fisher_matrix(params_EoS_pess,
                                                              fisher_params=astro_params_
↪vary_EoS,
                                                              hpeak=0.0, obs='PS',
                                                              k_min=0.1, k_max=1,
                                                              z_min=5., z_max=30.,
                                                              sigma_mod_frac=0.2,
                                                              add_sigma_poisson=True)
```

```
PS shape: (23, 24)
```

[16]:
```
fig, ax = plt.subplots(len(fid_params), len(fid_params), figsize=(18,18))
cols = [col_pess, col_mod]

for i, cov in enumerate([Finv_PS_pess, Finv_PS]):

    col = cols[i]
    if i == 0:
        # Pessimistic
        resize_lims=True
        plot_rescale=2
        ellipse_color='None'
        ellipse_kwargs=[{'edgecolor':col,'lw':1,'ls':'dashed'},
                        {'edgecolor':col,'lw':1,'ls':'dashed','alpha':1}]
        plot1D_kwargs={'c':col, 'lw':1, 'ls':'dashed'}
    else:
        # Moderate
        ls='solid'
        resize_lims=False
        plot_rescale=4
        ellipse_color=col
        ellipse_kwargs=[{},{'alpha':0.5}]
        plot1D_kwargs={'c':col, 'lw':2}

    p21fish.plot_triangle(params=astro_params_vary_EoS,
                          fiducial=fid_params,
                          labels=fid_labels,
                          cov=cov,
                          ellipse_color=ellipse_color,
                          ellipse_kwargs=ellipse_kwargs,
                          plot1D_kwargs=plot1D_kwargs,
                          resize_lims=resize_lims,
                          plot_rescale=plot_rescale,
                          title_fontsize=14,
                          xlabel_kwargs={'labelpad': 5, 'fontsize':22},
                          ylabel_kwargs={'labelpad': 5, 'fontsize':22},
                          ax=ax, fig=fig);

    p21fish.title_double_ellipses(axes=ax, labels=fid_labels,
                med=fid_params, sigma=np.sqrt(cov.diagonal()),
                title_fontsize=18, title_pad=50,
```

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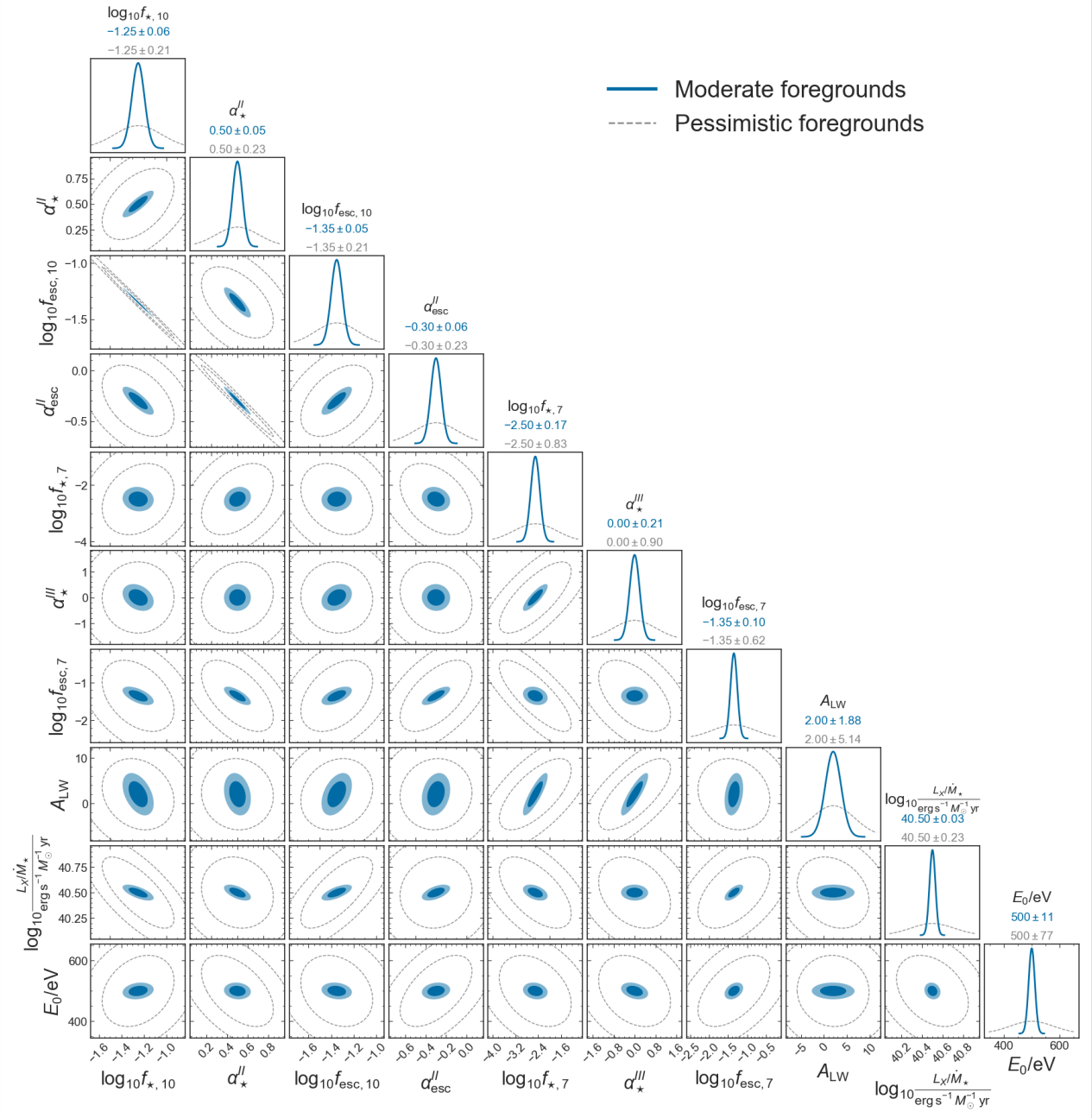
```
                vspace=i/5, color=col)

no_prior = mlines.Line2D([], [], color=col_pess, lw=2, ls='dashed', label='Pessimistic␣
↪foregrounds')
w_prior  = mlines.Line2D([], [], color=col_mod, lw=4, label=r'Moderate foregrounds')

ax[0,5].legend(handles=[w_prior, no_prior], loc='upper left', fontsize=28)

plt.savefig(figs_dir+'corner_EoS_mini_fisher_pessimistic.png', bbox_inches='tight')
```



Comparison of forecasts

S/N

[17]:
```
param_test = params_EoS['ALPHA_ESC']
param_test_pess = params_EoS_pess['ALPHA_ESC']

SNR = np.zeros((len(param_test.PS_z_HERA),2))
for i in range(len(param_test.PS_z_HERA)):
    PS = param_test.PS['CDM']['ALPHA_ESC=-0.3'][i]['delta']
    k  = param_test.PS['CDM']['ALPHA_ESC=-0.3'][i]['k'][~np.isnan(PS)]
    PS = PS[~np.isnan(PS)]

    # Get rid of nans and interp PS on HERA grid
    PS_interp = np.interp(param_test.PS_err[i]['k']*0.7,
                          k, PS)

    # Use HERA errors
    PS_err = np.array([param_test.PS_err[i]['err_mod'],
                       param_test_pess.PS_err[i]['err_mod']])

    SNR[i] = np.sqrt(np.sum((PS_interp/PS_err)**2., axis=1))

SNR_EoR = np.sqrt(np.sum(SNR[:,0][param_test.PS_z_HERA<7.]**2.)) # ~300
SNR_CD  = np.sqrt(np.sum(SNR[:,0][param_test.PS_z_HERA>=7.]**2.)) # ~300

print(SNR_EoR, SNR_CD)

plt.figure(figsize=(6.5,4))
labels = ['Moderate','Pessimistic']
cols = [col_mod, col_pess]
lss  = ['solid', 'dashed']
for i, s in enumerate(SNR.T):
    SNR_total = np.sqrt(np.sum(s**2.)) # ~300
    plt.plot(param_test.PS_z_HERA, s, c=cols[i], ls=lss[i], label=f'{labels[i]}␣
↪foregrounds, total S/N = {SNR_total:.0f}')
plt.xlabel('Redshift, z')
plt.ylabel('HERA $\Delta_{21}^2$ S/N')

plt.annotate("Reionization", xy=(7, 20),  xycoords='data',
            xytext=(7, 0.6), ha='center', fontsize=10,
            arrowprops=dict(arrowstyle="->", lw=0.5))

plt.annotate("Epoch of\nHeating", xy=(12, 4),  xycoords='data',
            xytext=(12, 0.1), ha='center', fontsize=10,
            arrowprops=dict(arrowstyle="->", lw=0.5))

plt.annotate("Cosmic\nDawn", xy=(18, 0.5),  xycoords='data',
            xytext=(18, 0.05), ha='center', fontsize=10,
            arrowprops=dict(arrowstyle="->", lw=0.5))

plt.axhline(10., lw=0.5, ls='solid', c='0.5', zorder=0)
```

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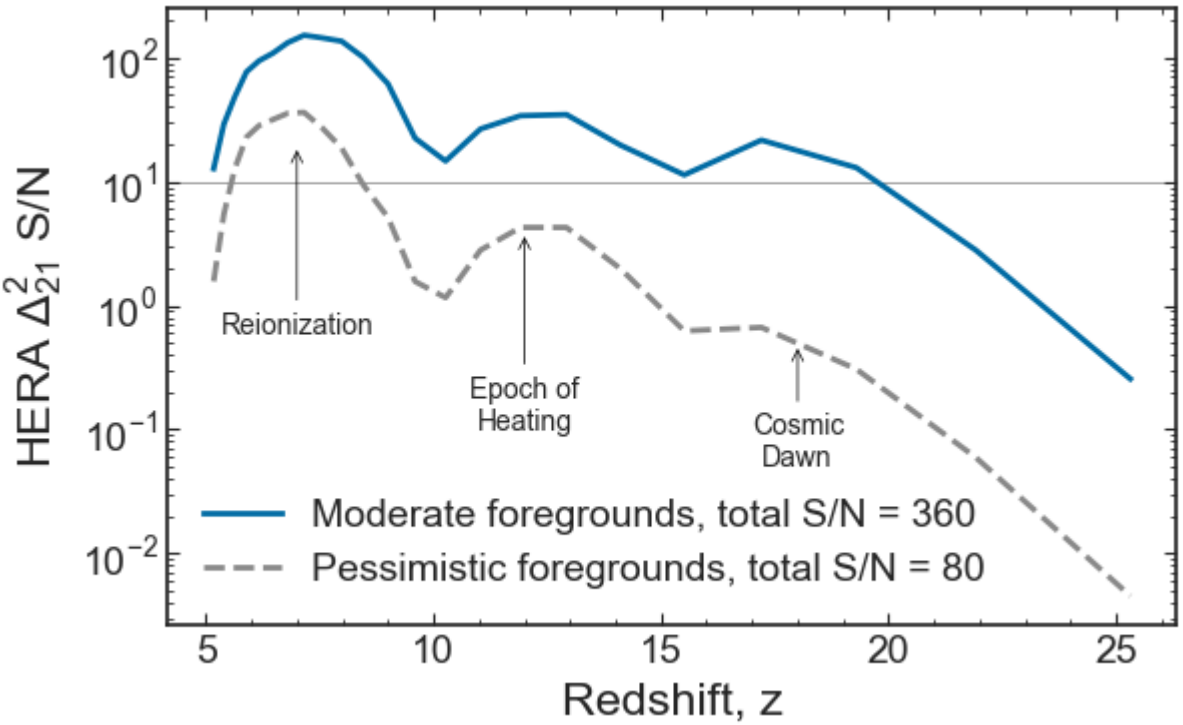
```
plt.legend()


plt.yscale('log')
plt.savefig(figs_dir+'SNR_EoS.pdf', bbox_inches='tight')
```

```
218.50718001785071 285.78849803538145
```



Errors for each parameter

[18]:
```
cols    = [col_mod, col_pess, col_mod, col_pess]
lss     = ['solid', 'dashed','solid', 'dashed']
lws     = [3,3,1.5,1.5]
markers = ['o','s','o','s']
labels  = ['Moderate foregrounds','Pessimistic foregrounds',r'+ LF $\alpha_\star^\mathrm
↪{II}$ prior','']#r'with LF $\alpha_\star^\mathrm{II}$ prior']
alphas  = [1,1,0.6,0.6]

# Add alpha star II prior
sigma_alpha_star_II = 0.07
idx_alpha_star = list(params_EoS).index("ALPHA_STAR")
print(f'ALPHA_STAR is at index={idx_alpha_star}')
Fij_matrix_PS_alpha_star_prior_pess = Fij_matrix_PS_pess.copy()
Fij_matrix_PS_alpha_star_prior_pess[idx_alpha_star,idx_alpha_star] += 1/sigma_alpha_star_
↪II**2.
Finv_alpha_star_prior_pess = np.linalg.inv(Fij_matrix_PS_alpha_star_prior_pess)
```

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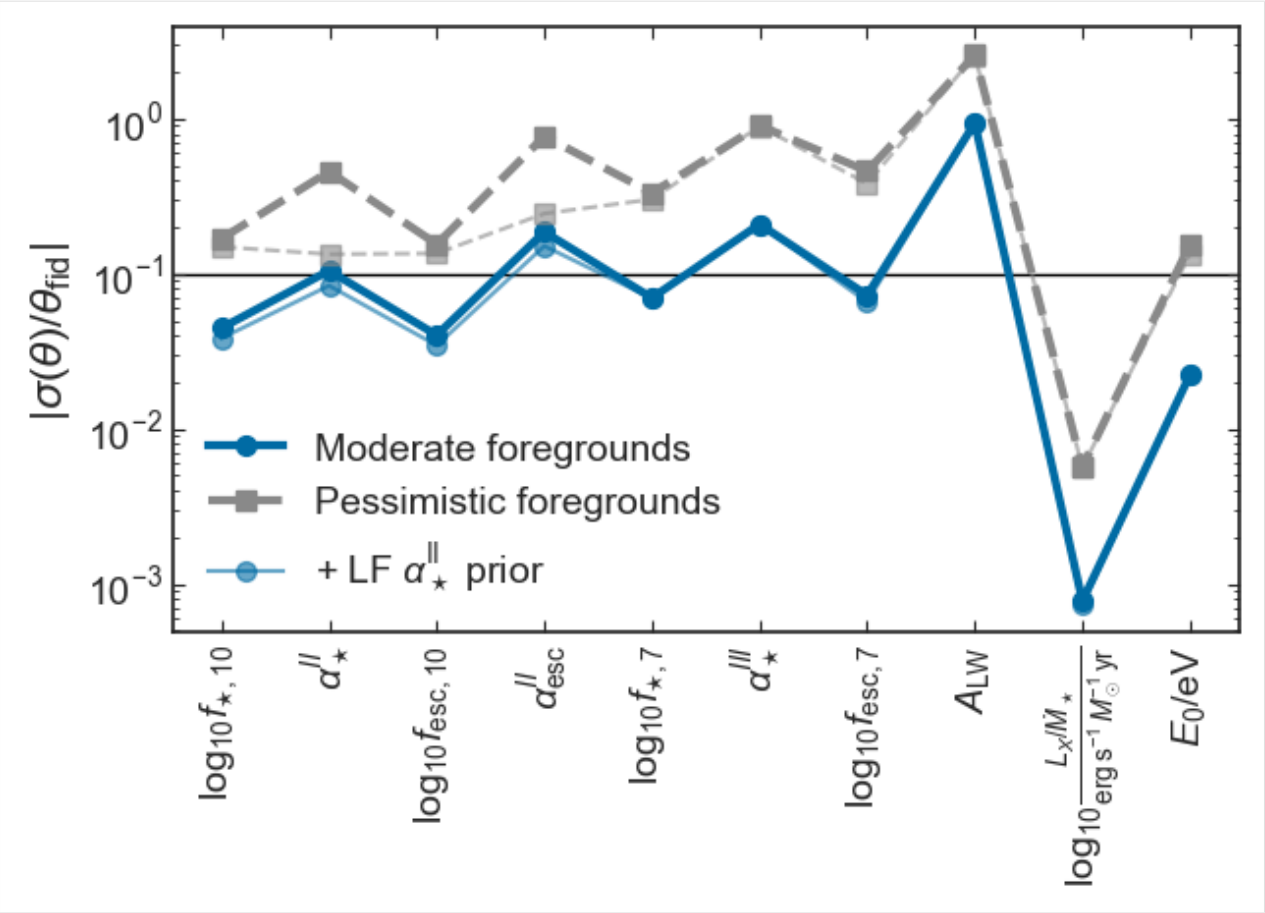
```
# Fractional error
plt.figure(figsize=(7,4))
for cc, cov in enumerate([Finv_PS, Finv_PS_pess, Finv_alpha_star_prior, Finv_alpha_star_
↪prior_pess]):
    mean = fid_params
    err  = np.sqrt(np.diag(cov))

    frac_err = np.abs(err/mean)
    frac_err[np.isinf(frac_err)] = err[np.isinf(frac_err)]#/0.01

    plt.semilogy(fid_labels, frac_err, c=cols[cc], marker=markers[cc],
                 lw=lws[cc], ls=lss[cc], label=labels[cc], ms=7, alpha=alphas[cc])

# plt.ylim(0.,2.)
plt.axhline(0.1, lw=1, c='k', zorder=0)
plt.legend()
plt.gca().set_xticklabels(fid_labels, rotation = 90, ha="center")
plt.minorticks_on()
plt.gca().tick_params(axis='x', which='minor', bottom=False, top=False)
plt.ylabel('Fractional error')
plt.ylabel(r'$|\sigma(\theta)/\theta_\mathrm{fid}|$')

plt.savefig(figs_dir+'fraction_error_EoS.pdf', bbox_inches='tight')
```

```
ALPHA_STAR is at index=1
```

```
/var/folders/sy/j00h6jjd19z46r9qd031n3080000gn/T/ipykernel_46372/693560164.py:22:␣
↪RuntimeWarning: divide by zero encountered in true_divide
  frac_err = np.abs(err/mean)
/var/folders/sy/j00h6jjd19z46r9qd031n3080000gn/T/ipykernel_46372/693560164.py:22:␣
↪RuntimeWarning: divide by zero encountered in true_divide
  frac_err = np.abs(err/mean)
/var/folders/sy/j00h6jjd19z46r9qd031n3080000gn/T/ipykernel_46372/693560164.py:22:␣
↪RuntimeWarning: divide by zero encountered in true_divide
  frac_err = np.abs(err/mean)
/var/folders/sy/j00h6jjd19z46r9qd031n3080000gn/T/ipykernel_46372/693560164.py:22:␣
↪RuntimeWarning: divide by zero encountered in true_divide
  frac_err = np.abs(err/mean)
/var/folders/sy/j00h6jjd19z46r9qd031n3080000gn/T/ipykernel_46372/693560164.py:31:␣
↪UserWarning: FixedFormatter should only be used together with FixedLocator
  plt.gca().set_xticklabels(fid_labels, rotation = 90, ha="center")
```



Parameter uncertainty as a function of z

How does noise on each parameter change as a function of z?

[20]:
```
# Rolling loop through HERA z_bins
z_bins = params_EoS['ALPHA_STAR'].PS_z_HERA
bin_i = 2

z_err = np.zeros((len(z_bins)-bin_i,len(params_EoS)))
for zz in range(len(z_bins)):
    if zz < len(z_bins) - bin_i:
        Fij_matrix_PS_z, Finv_PS_z = p21fish.make_fisher_matrix(params_EoS,
                                                                fisher_params=astro_params_vary_
↪EoS,
                                                                hpeak=0.0, obs='PS',
                                                                k_min=0.1, k_max=1,
                                                                z_min=z_bins[zz], z_max=z_
↪bins[zz+bin_i],
                                                                sigma_mod_frac=0.2,
                                                                add_sigma_poisson=True)

        z_err[zz] = np.sqrt(np.diag(Finv_PS_z))
```

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```
    try:
        print(z_err[zz])
    except:
        print(f'could not do for z_min={z_bins[zz]}')
```

```
PS shape: (3, 24)
[1.73627339e-01 3.21997284e-01 1.64274933e-01 3.54371796e-01
 6.43228227e-01 2.18440916e+00 9.14333462e-01 5.47960990e+00
 3.31960353e+00 1.41965402e+03]
PS shape: (3, 24)
[5.69850700e-01 4.33426673e-01 5.74504689e-01 4.71365660e-01
 9.38422255e-01 2.81596463e+00 1.19019524e+00 5.66340515e+00
 3.30127823e+00 1.41117918e+03]
PS shape: (3, 24)
[9.57823876e-01 6.25345235e-01 9.83876034e-01 6.19645407e-01
 2.09700055e+00 3.04682008e+00 2.35507809e+00 9.08661934e+00
 4.95058623e+00 2.28170497e+03]
PS shape: (3, 24)
[1.29039754e+00 1.11743289e+00 1.28640278e+00 1.09660340e+00
 2.43973823e+00 3.56788641e+00 2.20000473e+00 1.01747053e+01
 5.53384048e+00 3.14006363e+03]
PS shape: (3, 24)
[1.42347618e+00 1.02975807e+00 1.42237059e+00 1.00031553e+00
 2.35255424e+00 3.45803485e+00 2.42988755e+00 1.01283615e+01
 3.89155274e+00 2.44288794e+03]
PS shape: (3, 24)
[2.00898199e+00 1.03708211e+00 2.05638690e+00 1.00663800e+00
 2.80485967e+00 3.93572488e+00 2.85483480e+00 1.14190180e+01
 4.02622973e+00 2.94352950e+03]
PS shape: (3, 24)
[2.83314797e+00 1.04695408e+00 2.92667762e+00 1.07212043e+00
 3.37826162e+00 4.55540694e+00 3.16791512e+00 1.18427086e+01
 4.41766419e+00 3.82393954e+03]
PS shape: (3, 24)
[2.83715369e+00 1.27069997e+00 2.93067068e+00 1.29798668e+00
 3.37881859e+00 4.15470244e+00 3.35996461e+00 1.13491570e+01
 2.99187043e+00 1.62406559e+03]
PS shape: (3, 24)
[2.42690839e+00 9.69404819e-01 2.49015381e+00 1.00789548e+00
 3.22585525e+00 3.29751587e+00 3.35672250e+00 1.04717535e+01
 2.55887591e+00 1.15416093e+03]
PS shape: (3, 24)
[  2.18895132   0.89452448   2.26287453   0.82882134   2.89809027
   3.00959964   2.6665641    7.97997123   2.14463165 511.11476398]
PS shape: (3, 24)
[  2.30253173   1.09834841   2.39621442   0.7044284    2.7189927
   4.54343258   2.35622739   6.57932659   2.0492352  181.71146417]
PS shape: (3, 24)
[  2.47398262   1.38578634   2.51251628   0.77094446   3.27952769
   5.495576     2.45835311   7.7119268    1.9562515  197.2576004 ]
PS shape: (3, 24)
[  2.10965978   1.66444569   2.14777429   1.04804706   3.15203387
```

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```
   5.87810564   2.36037784   9.31892967   1.44931999 153.08614851]
PS shape: (3, 24)
[ 3.45878663  2.63031743  3.90317019  2.06343023  4.64134308  7.42270772
  3.78534975 23.18942052  2.13982131 84.52774824]
PS shape: (3, 24)
[  4.91226697   3.96552484   4.34806075   3.29412742   6.69401367
   6.90566649   5.92364083  51.72607217   3.02892226 166.24944922]
PS shape: (3, 24)
[  3.33283762   2.69103934   4.19583621   3.80850855   4.99314859
   4.65599166   4.08427946  47.87914369   1.49643627 155.18310369]
PS shape: (3, 24)
[  3.94727591   3.01077852   5.63330895   4.91043253   4.80404203
   4.56218837   4.98341338  55.7363171    0.566741   170.11927535]
PS shape: (3, 24)
[  4.39386608   3.29057927   6.07370211   6.35074796   3.59518085
   3.48371375   4.7130184   51.96322023   0.58270932 243.68248413]
PS shape: (3, 24)
[  7.58682717   5.22683021   7.82772596   5.82829266   3.18337457
   3.28843803   4.39499209  56.45200407   1.22915709 583.2666204 ]
PS shape: (3, 24)
[  37.35097905   21.91121519   24.35661314   12.52172589    6.06648355
    5.60374057    9.78753992  106.96693703    2.8663244  1048.04966578]
PS shape: (3, 24)
[ 221.07024477  114.79571427   81.527433     40.03929817   16.86206265
   17.62594181   37.04349478  239.18451863   28.11076634 5748.68785231]
could not do for z_min=21.909972214717644
could not do for z_min=25.308702138693505
```

[22]:
```
from palettable.colorbrewer.sequential import Blues_5, YlGn_5, RdPu_6

z_plot = (z_bins[bin_i:]+z_bins[bin_i-1:-1])/2

fig1, ax1 = plt.subplots(1,1, figsize=(6,4))

sum_err = np.zeros(len(astro_params_vary_EoS))
for pp,p in enumerate(astro_params_vary_EoS):
    if pp < 4:
        # popII
        ls = 'dashed'
        lw = 2
        colors = RdPu_6.hex_colors[::-1]
        i = pp
        alpha=1
    elif 3 < pp <= 7:
        ls = 'solid'
        lw = 3
        colors = YlGn_5.hex_colors[::-1]
        alpha=0.8
        i = pp-4
    else:
        ls = 'dotted'
        lw = 2
```

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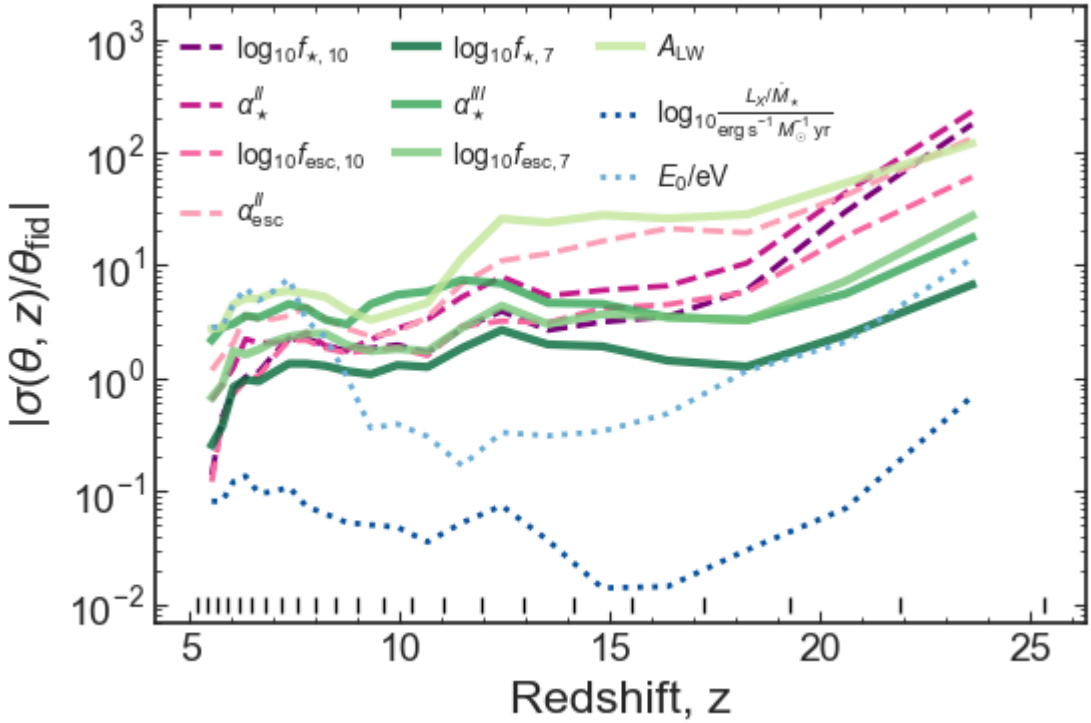
```
        colors = Blues_5.hex_colors[::-1]
        i = (pp-8)*2
        alpha=1

#     print(p, pp, i)
    frac_err = z_err[:,pp]/fid_params[pp]
    frac_err[np.isinf(frac_err)] = z_err[:,pp][np.isinf(frac_err)]

    sum_err[pp] = np.sqrt(np.mean(np.abs(frac_err)**2.))
#     print(p, sum_err[pp])

    ax1.semilogy(z_plot, np.abs(frac_err), label=fid_labels[pp],
                 c=colors[i], ls=ls, lw=lw, alpha=alpha)

ax1.legend(ncol=3, fontsize=10, handlelength=1.5, handletextpad=0.5, columnspacing=1.,␣
↪loc='upper left')

ax1.set_xlabel('Redshift, z')
ax1.set_ylabel('$\sigma$')
ax1.set_ylabel(r'$|\sigma(\theta, z)/\theta_\mathrm{fid}|$')


plt.plot(z_bins, [0.01]*len(z_bins), '|', color='k')

plt.ylim(7e-3, 2e3)
plt.savefig(figs_dir+'fraction_error_EoS_z.pdf', bbox_inches='tight')
```

```
/var/folders/sy/j00h6jjd19z46r9qd031n3080000gn/T/ipykernel_46372/1430737097.py:30:␣
↪RuntimeWarning: divide by zero encountered in true_divide
  frac_err = z_err[:,pp]/fid_params[pp]
```



Comparison to Park+19

Compare Fisher matrix with Park+2019 fiducial to their MCMC (21cm power spectrum only)

[24]:
```
output_dir_Park19 = data_dir+'Park19/'
PS_err_dir_Park19 = noise_dir+'21cmSense_noise_Park19/'

astro_params_vary_Park19, astro_params_fid_Park19 = p21fish.get_params_fid(
                                                    config_file=p21fish.base_path+
↪'21cmFAST_config_files/Park19.config')

# Reorder to match Park+19
astro_params_vary_Park19 = ['F_STAR10', 'ALPHA_STAR',
                            'F_ESC10', 'ALPHA_ESC',
                            'M_TURN', 't_STAR',
                            'L_X', 'NU_X_THRESH']
```

[25]:
```
# Load parameters
params_Park19 = {}
for param in astro_params_vary_Park19:

    params_Park19[param] = p21fish.Parameter(param=param,
                                            output_dir=output_dir_Park19,
                                            HII_DIM=128, BOX_LEN=250,
                                            min_redshift=5.9,
                                            PS_err_dir=PS_err_dir_Park19,
                                            clobber=False, Park19='real',
```

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```
                                                vb=False, new=False)
```

```
########### fisher set up for F_STAR10
    Loading global signal and power spectra from saved files
    Fiducial: F_STAR10=-1.3
########### fisher set up for ALPHA_STAR
    Loading global signal and power spectra from saved files
    Fiducial: ALPHA_STAR=0.5
########### fisher set up for F_ESC10
    Loading global signal and power spectra from saved files
    Fiducial: F_ESC10=-1.0
########### fisher set up for ALPHA_ESC
    Loading global signal and power spectra from saved files
    Fiducial: ALPHA_ESC=-0.5
########### fisher set up for M_TURN
    Loading global signal and power spectra from saved files
    Fiducial: M_TURN=8.7
########### fisher set up for t_STAR
    Loading global signal and power spectra from saved files
    Fiducial: t_STAR=0.5
########### fisher set up for L_X
    Loading global signal and power spectra from saved files
    Fiducial: L_X=40.5
########### fisher set up for NU_X_THRESH
    Loading global signal and power spectra from saved files
    Fiducial: NU_X_THRESH=500.0
```

Make Fisher matrix

[26]:
```
Fij_matrix_PS_Park19, Finv_PS_Park19 = p21fish.make_fisher_matrix(params_Park19,
                                                                  fisher_params=astro_
↪params_vary_Park19,
                                                                  hpeak=0.0, obs='PS',
                                                                  k_min=0.1, k_max=1,
                                                                  z_min=5.7, z_max=30.,
                                                                  sigma_mod_frac=0.2,
                                                                  cosmo_key='CDM',
                                                                  add_sigma_poisson=True)

fid_params_Park19 = np.array([astro_params_fid_Park19[param] for param in params_Park19])
fid_labels_Park19 = np.array([p21fish.astro_params_labels[param] for param in params_
↪Park19])
```

```
PS shape: (12, 23)
```

Load Park19 chains and compare

Load their 21cm-only chains and compare the contours

[28]:
```
Park19_chains = np.load(f'{data_dir}Park19/Park19_chains.npz')
print(Park19_chains['params'])

# Make posteriors from the covariance matrix
mean = fid_params_Park19.copy()
cov  = Finv_PS_Park19.copy()
fisher_chain = np.random.multivariate_normal(mean, cov, size=10000)

# Corner plot
fig = plt.figure(figsize=(15,15))

colors = [col_mcmc,col_P19]
lws = [1.5,3]

# Plot 2 sigma confidence interval (https://corner.readthedocs.io/en/latest/pages/sigmas.
↪html)
levels = 1.0 - np.exp(-0.5 * np.array([1,2,]) ** 2)

for cc, chain in enumerate([Park19_chains['chains'],fisher_chain]):

    if cc == 0:
        # MCMC
        ls='solid'
        lw=lws[cc]
        hist_kwargs = {'lw':lw,'ls':ls,'density':True}
        color=colors[cc]
        smooth=None
        fill_contours    = False
        no_fill_contours = True
        contour_kwargs = {'linewidths':lw,'linestyles':ls}
        contourf_kwargs={}
        zorder=10
    else:
        # fisher
        ls='solid'
        lw=lws[cc]
        hist_kwargs = {'lw':lw,'density':True,'histtype':'stepfilled', 'alpha':0.8}
        fill_contours=True
        no_fill_contours=False
        color=colors[cc]
        smooth=1
        contour_kwargs = {'linewidths':0.}
        contourf_kwargs = {}
        zorder=0

    corner.corner(chain, fig=fig,
                labels=fid_labels_Park19,
                smooth=smooth,
                color=color, use_math_text=True,
```

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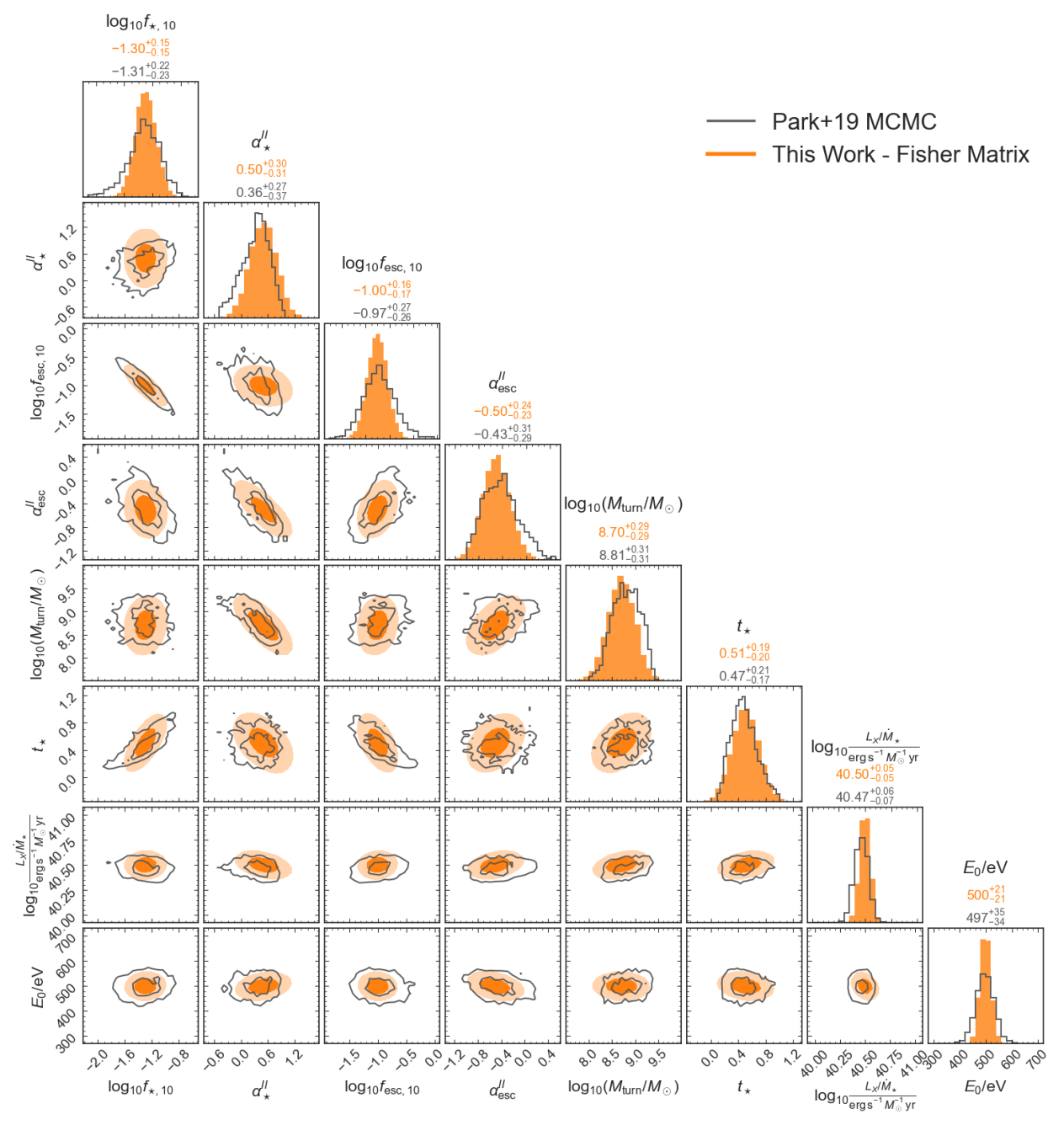
```
                plot_datapoints=False, plot_density=False,
                no_fill_contours=no_fill_contours, fill_contours=fill_contours,
                hist_kwargs=hist_kwargs,
                contour_kwargs=contour_kwargs,contourf_kwargs=contourf_kwargs,
                levels=levels,
                range=[1,1,1,1,1,1,(40.,41.),(300,700)], # throws out a couple of␣
↪outlier points in the chains [better for Lx]
                show_titles=True,
                zorder=zorder
                );

    # Format the quantile display
    ax = np.reshape(fig.axes, (chain.shape[1],chain.shape[1]))

    p21fish.title_double_ellipses(axes=ax, labels=fid_labels_Park19,
                    chain=chain,
                    med=None, sigma=None,
                    title_fontsize=18, title_pad=58,
                    vspace=cc/5,
                    color=color
                    )

lab_P19 = mlines.Line2D([], [], color=col_mcmc, ls='solid', lw=lws[0]+1, label='Park+19␣
↪MCMC')
lab_TW  = mlines.Line2D([], [], color=col_P19, lw=lws[1]+1, label=r'This Work - Fisher␣
↪Matrix')

fig.get_axes()[5].legend(handles=[lab_P19, lab_TW], loc='center left', fontsize=24)

plt.savefig(figs_dir+'corner_Park19_fisher_compare_2sigma.png', bbox_inches='tight')
```

```
['F_STAR10' 'ALPHA_STAR' 'F_ESC10' 'ALPHA_ESC' 'M_TURN' 't_STAR' 'L_X'
 'E0']
```


Park+19 MCMC
This Work - Fisher Matrix
$\log_{10} f_{\star,10}$
$-1.30^{+0.15}_{-0.15}$
$-1.31^{+0.22}_{-0.23}$
$\alpha^{II}_{\star}$
$0.50^{+0.30}_{-0.31}$
$0.36^{+0.27}_{-0.37}$
$\log_{10} f_{esc,10}$
$-1.00^{+0.16}_{-0.17}$
$-0.97^{+0.27}_{-0.26}$
α^{II}_{esc}
$-0.50^{+0.24}_{-0.23}$
$-0.43^{+0.31}_{-0.29}$
$\log_{10}(M_{turn}/M_{\odot})$
$8.70^{+0.29}_{-0.29}$
$8.81^{+0.31}_{-0.31}$
$t_{\star}$
$0.51^{+0.19}_{-0.20}$
$0.47^{+0.21}_{-0.17}$
$\log_{10}\frac{L_X/\dot{M}_{\star}}{\mathrm{erg\,s^{-1}}\,M_{\odot}^{-1}\,\mathrm{yr}}$
$40.50^{+0.05}_{-0.05}$
$40.47^{+0.06}_{-0.07}$
E_0/eV
500^{+21}_{-21}
497^{+35}_{-34}

Adding a new parameter

If you want to add your own new parameter, you should:

1. Create lightcones varying that parameter.
    1. Create a config file for the parameters you want to change (take one of the examples in `../21cmFAST_config_files/` and replace the `astro_params_vary` list with your list of new parameters.
    2. Note that the fiducial parameter value for your new parameter will be the 21cmFAST default unless the fiducial value is specified in the config file. If you want a non-default fiducial parameter value you will need to create a new set of lightcones with your parameter's fiducial included in `astro_params`.
    3. Create the lightcones using `scripts/make_lightcones_for_fisher.py`
2. Load your new parameter by adding it to the dictionary *as above*

See more details on running `scripts/make_lightcones_for_fisher.py` in the docs

[ ]:

[ ]:

3.1.4 API

This page details the classes and methods provided by the `py21cmfish` module.

Parameters Class

class py21cmfish.**Parameter**(*param*, *HII_DIM=200*, *BOX_LEN=400*, *min_redshift=5.0*, *n_chunks=24*, *k_PEAK_order=2.0*, *output_dir='/home/docs/checkouts/readthedocs.org/user_builds/21cmfish/checkouts/stable/examples/da*
PS_err_dir='/home/docs/checkouts/readthedocs.org/user_builds/21cmfish/checkouts/stable/example
Park19=None, *k_HERA=True*, *cosmology='CDM'*, *clobber=False*, *new=False*, *fid_only=False*, *vb=True*)

Class for creating derivatives given 21cm parameters

derivative_global_signal(*save=True*, *plot=True*, *ax=None*)

Calculate global signal derivatives

derivative_power_spectrum(*save=True*, *plot=True*, *ax=None*)

Calculate power spectrum derivatives

Parameters

- **save** (*bool, optional*) – Save PS derivative to file?
- **plot** (*bool, optional*) – Plot PS derivatives as a function of redshift
- **ax** (*Union[None, plt.Axes]*) – Matplotlib axes to plot on. If *None*, make a new figure with subplots

get_HERA_k_bins_for_PS(*plot=False*)

Given k centers, find the bin edges and length to give to powerbox

Because 21cmsense interpolates PS onto k grid based on HERA baselines etc, we must generate our PS and Poisson noise on that *same* k grid in order to get the errors for the Fisher.

(Because if we used e.g. smaller k bins, our Poisson error would be too large)

get_global_signal(*save=True*, *plot=False*)
Get global signal and parameters and save to a file

get_lightcones(*regex=''*)
Load lightcones and theta params

get_power_spectra(*n_psbins=50*, *k_min=None*, *k_max=None*, *save=True*)
Make 21cm power spectra from redshift chunk list (bin edges)

Parameters

- **n_psbins** (*int*) – Number of k bins
- **k_min** (*float, optional*) – Minimum k value for PS [in 1/Mpc]
- **k_max** (*float, optional*) – Maximum k value for PS [in 1/Mpc]
- **save** (*bool*) – Save PS to file?

load_21cmsense(*Park19=None*)
Load 21cmsense errors from a given directory and save arrays to self

Parameters

- **PS_err_dir** (*str, optional*) – Directory where 21cmSense output is stored
- **Park19** (*str, optional*) – Use Park+19 z bins https://ui.adsabs.harvard.edu/abs/2019MNRAS.484..933P/abstract 'approx' = use our approximation of Park19 noise bins 'real' = use noise from Jaehong

load_Poisson_noise()
Load Poisson noise from PS

make_PS_fid_HERA_grid()
Make fiducial PS in 21cmsense k bins [Mpc^-1]

Fisher matrix functions

py21cmfish.fishy.**Fij**(*dObs_dtheta_i*, *dObs_dtheta_j*, *sigma_obs=1.0*, *sigma_mod=0.0*, *sigma_poisson=0.0*, *axis=None*)
Make fisher matrix elements

Parameters

- **dObs_dtheta_i** (*array_like*) – derivative wrt theta_i
- **dObs_dtheta_j** (*array_like*) – derivative wrt theta_j
- **sigma_obs** (*array_like*) – measurement uncertainties in the observations
- **sigma_mod** – modelling uncertainty
- **axis** (*None or int or tuple of ints, optional*) – Axis or axes along which a sum is performed. The default, axis=None, will sum all of the elements of the input array. If axis is negative it counts from the last to the first axis.

Returns **F_ij fisher matrix element**

Return type float

py21cmfish.fishy.**fisher_correlations**(*Fij_matrix*, *fisher_params*, *plot=True*)
Fisher correlation matrix

Parameters

- **Fij_matrix** (*array_like*) – Fisher information matrix
- **fisher_params** (*list*) – ordered list of parameters in the fisher matrix
- **plot** (*bool*) – heatmap plot

Returns

Return type R_ij_fisher correlation matrix

py21cmfish.fishy.**get_ellipse_params**(*i: int*, *j: int*, *cov: numpy.array*)

Extract ellipse parameters from covariance matrix. Based on Coe 2009

Parameters

- **i** (*int*) – index of parameter 1
- **j** (*int*) – index of parameter 2
- **cov** (*array_like*) – covariance matrix

Returns

Return type ellipse a, b, angle in degrees

py21cmfish.fishy.**make_fisher_matrix**(*params_dict*, *fisher_params*, *hpeak=0.0*, *obs='GS'*, *sigma=None*, *sigma_mod_frac=0.0*, *k_min=None*, *k_max=None*, *z_min=None*, *z_max=None*, *axis_PS=None*, *cosmo_key='CDM'*, *add_sigma_poisson=False*)

Make Fisher matrix and its inverse from global signal or powerspectra

Parameters

- **params_dict** (*dict*) – Dictionary of parameter objects
- **fisher_params** (*list*) – List of parameter strings to use for Fisher matrix (these strings must be the keys to params_dict)
- **hpeak** (*float*) – TODO
- **obs** (*str*) – 'GS' - global signal, 'PS' - power spectrum
- **sigma** (*None,array*) – TODO
- **sigma_mod_frac** (*float*) – Fraction of modelling error in PS e.g. 0.2 adds a 20% error on the PS in quadrature to the 21cmsense error
- **k_min** (*None,float*) – Minimum k to use for PS [1/Mpc]
- **k_max** (*None,float*) – Maximum k to use for PS [1/Mpc]
- **z_min** (*None,float*) – Minimum redshift to use for PS
- **z_max** (*None,float*) – Maximum redshift to use for PS
- **axis_PS** (*None,int*) – TODO
- **cosmo_key** (*None,str*) – TODO
- **add_sigma_poisson** (*bool*) – TODO

Returns

Return type Fisher matrix, Finv matrix

py21cmfish.fishy.**plot_ellipse**(*ax*, *par1*, *par2*, *parameters*, *fiducial*, *cov*, *resize_lims=True*, *positive_definite=[]*, *N_std=[1.0, 2.0, 3.0]*, *plot_rescale=4.0*, *kwargs=[{'ls': '-'}]*, *color='tab:blue'*, *default_kwargs={'lw': 0}*)

Plot N-sigma ellipses, from Coe 2009.

Parameters

- **ax** (*matpotlib axis*) – axis upon which the ellipses will be drawn
- **par1** (*string*) – parameter 1 name
- **par2** (*string*) – parameter 2 name
- **parameters** (*list*) – list of parameter names
- **fiducial** (*array_like(ndim,)*) – fiducial values of parameters
- **cov** (*array_like(ndim,ndim,)*) – covariance matrix
- **color** (*string*) – color to plot ellipse with
- **positive_definite** (*list of string*) – convenience input, parameter names passed in this list will be cut off at 0 in plots.

Returns **list of float**

Return type sigma_x, sigma_y, sigma_xy

py21cmfish.fishy.**plot_triangle**(*params*, *fiducial*, *cov*, *fig=None*, *ax=None*, *positive_definite=[]*, *labels=None*, *resize_lims=True*, *N_std=[1.0, 2.0]*, *plot_rescale=4.0*, *ellipse_color='tab:blue'*, *ellipse_kwargs=[{}, {'alpha': 0.5}]*, *title_fontsize=20*, *xlabel_kwargs={'fontsize': 18, 'labelpad': 5}*, *ylabel_kwargs={'fontsize': 18, 'labelpad': 5}*, *fig_kwargs={'figsize': (8, 8)}*, *plot1D_kwargs={'c': 'black', 'lw': 1}*)

Make a triangle plot from a covariance matrix

Based on https://github.com/xzackli/fishchips-public/blob/master/fishchips/util.py

Parameters

- **params** (*list of strings*) – List of parameter strings
- **fiducial** (*array*) – Numpy array consisting of where the centers of ellipses should be
- **cov** (*numpy array*) – Covariance matrix to plot
- **fig** (*optional, matplotlib figure*) – Pass this if you already have a figure
- **ax** (*array containing matplotlib axes*) – Pass this if you already have a set of matplotlib axes
- **positive_definite** (*list*) – List of parameter strings which are positive definite
- **resize_lims** (*bool*) – Resize ellipse limits to scale of the errors [default = True]
- **N_std** (*list*) – List of number of standard deviations to plot
- **labels** (*list*) – List of labels corresponding to each dimension of the covariance matrix
- **ellipse_kwargs** (*dict*) – Keyword arguments for passing to the 1-sigma Matplotlib Ellipse call. You can change this to change the color of your ellipses, for example.
- **xlabel_kwargs** (*dict*) – Keyword arguments which are passed to *ax.set_xlabel()*. You can change the color and font-size of the x-labels, for example. By default, it includes a little bit of label padding.

- **ylabel_kwargs** (*dict*) – Keyword arguments which are passed to *ax.set_ylabel()*. You can change the color and font-size of the y-labels, for example. By default, it includes a little bit of label padding.
- **fig_kwargs** (*dict*) – Keyword arguments which are passed to *figure*. E.g. figsize
- **plot1D_kwargs** (*dict*) – Keyword arguments which are passed to *plt.plot()* for 1D gauss plot

Returns matplotlib figure and axis array

Return type fig, ax

py21cmfish.fishy.**title_double_ellipses**(*axes*, *labels*, *chain=None*, *med=None*, *sigma=None*, *title_fontsize=18*, *title_pad=58*, *vspace=0.0*, *color='k'*)

Plot title with parameter constraints from 2 covariance matrixes/chains

Parameters

- **axes** (*matpotlib axess*) – axes upon which the titles will be added
- **labels** (*list(ndim,)*) – list of parameter names
- **chain** (*array_like(ndim,), optional*) – MCMC chain of parameters
- **med** (*array_like(ndim,), optional*) – list of median values
- **sigma** (*array_like(ndim,)*) – list of sigmas
- **color** (*string*) – color to plot ellipse with

Returns

Return type None

Power spectra functions

py21cmfish.power_spectra.**compute_power**(*box*, *length*, *n_psbins*, *log_bins=True*, *k_min=None*, *k_max=None*, *ignore_kperp_zero=True*, *ignore_kpar_zero=False*, *ignore_k_zero=False*)

Calculate power spectrum for a redshift chunk

TODO

Parameters

- **box** – lightcone brightness_temp chunk
- **length** – TODO
- **n_psbins** (*int*) – number of k bins

Returns

- **k** (*1/Mpc*)
- **delta** (*mK^2*)
- **err_delta** (*mK^2*)

py21cmfish.power_spectra.**get_k_min_max**(*lightcone*, *n_chunks=24*)

Get the minimum and maximum k in 1/Mpc to calculate powerspectra for given size of box and number of chunks

py21cmfish.power_spectra.**powerspectra**(*brightness_temp*, *n_psbins=50*, *nchunks=10*, *k_min=0.1*, *k_max=1.0*, *logk=True*)

Make power spectra for given number of equally spaced chunks

Output: k : 1/Mpc delta : mK^2 err_delta : mK^2

py21cmfish.power_spectra.**powerspectra_chunks**(*lightcone*, *nchunks=10*, *chunk_indices=None*, *n_psbins=50*, *k_min=0.1*, *k_max=1.0*, *logk=True*, *model_uncertainty=0.15*, *error_on_model=True*, *ignore_kperp_zero=True*, *ignore_kpar_zero=False*, *ignore_k_zero=False*, *remove_nans=True*, *vb=False*)

Make power spectra for given number of equally spaced redshift chunks OR list of redshift chunk lightcone indices

Output: k : 1/Mpc delta : mK^2 err_delta : mK^2

TODO this isn't using k_min, k_max…

py21cmfish.power_spectra.**powerspectra_np**(*brightness_temp*, *n_psbins=50*, *nchunks=10*, *k_min=0.1*, *k_max=1.0*, *logk=True*)

Make power spectra for given number of equally spaced chunks

JBM: same as powerspectra but for input in numpy format. Also outputs errors in delta

3.1.5 Release History

v0.1.0 (2022-12-14)

- Initial Release

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