gradients

June 15, 2021

[99]:
```
%load_ext autoreload
%autoreload 2
%aimport
```

```
The autoreload extension is already loaded. To reload it, use:
  %reload_ext autoreload
Modules to reload:
all-except-skipped

Modules to skip:
```

[100]:
```
%matplotlib inline
```

[101]:
```
from relaxed.plot_defaults import *
```

[102]:
```
import astropy
from pathlib import Path
import numpy as np
import matplotlib.pyplot as plt
import re
from astropy.table import Table
import astropy.table
import json
from scipy import stats
from copy import deepcopy
import scipy
import warnings

import matplotlib as mpl
from sklearn.model_selection import train_test_split
```

[103]:
```
from relaxed.analysis import setup, get_quantiles, gaussian_conditional,␣
↪get_am, get_an_from_am, get_lam, get_ma, get_gradient, get_fractional_tdyn
```

1 Data

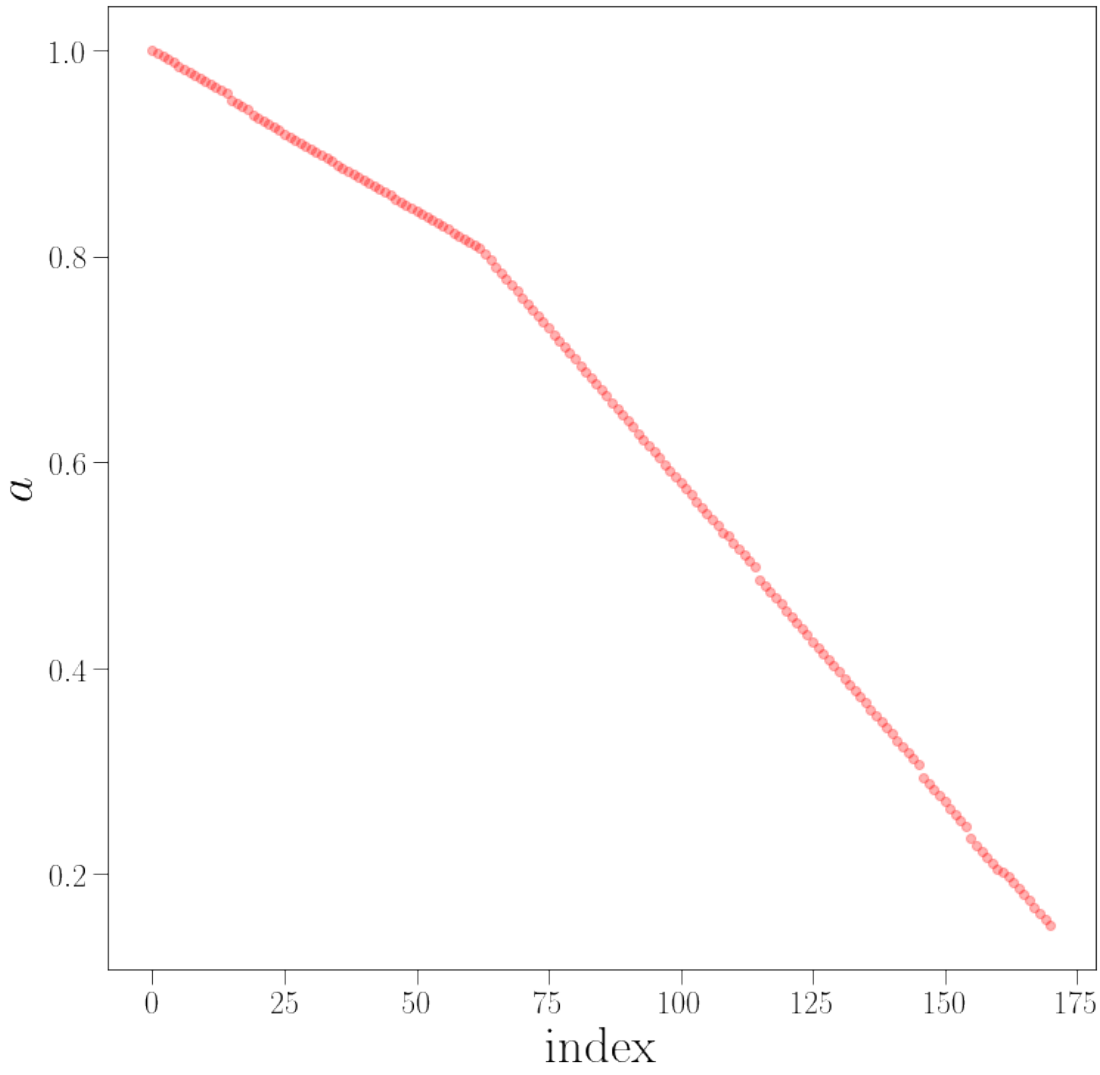
[41]:
```
# catalog
hcat, indices, scales = setup('m11', path='../../output')

# get ma
ma = get_ma(hcat.cat, indices)

# obtain a_m
am, mass_bins = get_am('m11', min_mass=0.1, path='../../output')
```

[42]:
```
plt.figure(figsize=(12, 12))
plt.plot(scales, 'ro', alpha=0.3)
plt.ylabel(r"$a$", size=35)
plt.xlabel(r"\rm index", size=35)
# notice change in spacing below
```

[42]:
```
Text(0.5, 0, '\\rm index')
```



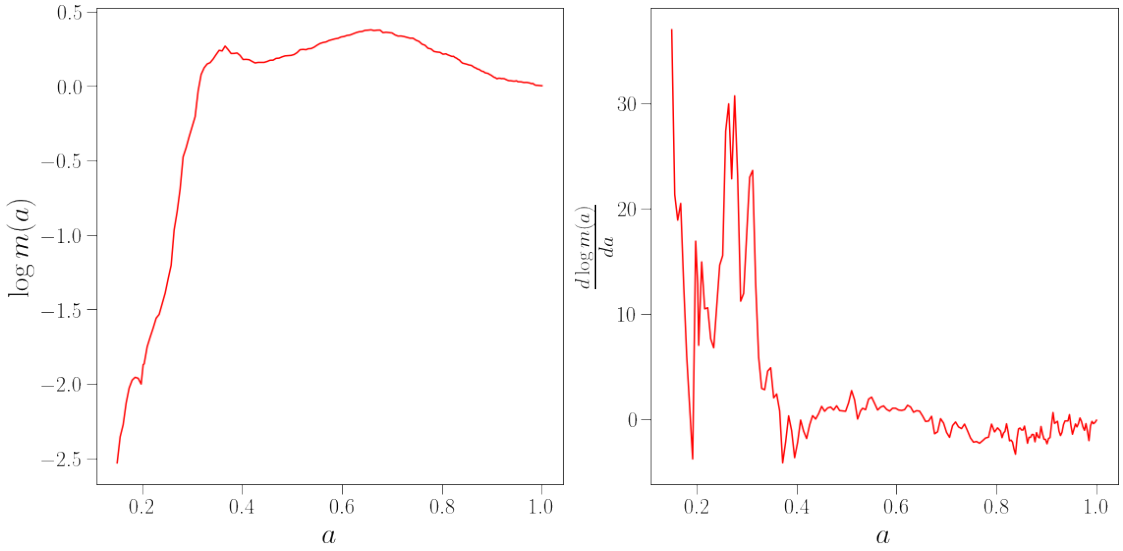
2 Calculate gradients

2.1 numpy

[43]:
```
fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(16, 8))
idx = 0
x = scales
grad = np.gradient(np.log(ma[idx, :]), x, edge_order=2)
ax1.plot(x, np.log(ma[idx, :]), 'r-')
ax2.plot(x, grad, 'r-')

ax1.set_xlabel(r"$a$", size=30)
ax2.set_xlabel(r"$a$", size=30)
```

```
ax1.set_ylabel(r"$\log m(a)$", size=30)
ax2.set_ylabel(r"$\frac{d\log m(a)}{da}$", size=30)
plt.tight_layout()
```



2.2 vary k

[119]:
```
scales
```

[119]:
```
array([1.00035, 0.99735, 0.99435, 0.99135, 0.98835, 0.98535, 0.98235,
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       0.93135, 0.92835, 0.92535, 0.92235, 0.91935, 0.91635, 0.91335,
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       0.82635, 0.82335, 0.82035, 0.81735, 0.81435, 0.81135, 0.80835,
       0.80235, 0.79635, 0.79035, 0.78435, 0.77835, 0.77235, 0.76635,
       0.76035, 0.75435, 0.74835, 0.74235, 0.73635, 0.73035, 0.72435,
       0.71835, 0.71235, 0.70635, 0.70035, 0.69435, 0.68835, 0.68235,
       0.67635, 0.67035, 0.66435, 0.65835, 0.65235, 0.64635, 0.64035,
       0.63435, 0.62835, 0.62235, 0.61635, 0.61035, 0.60435, 0.59835,
       0.59235, 0.58635, 0.58035, 0.57435, 0.56835, 0.56235, 0.55635,
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       0.46235, 0.45635, 0.45035, 0.44435, 0.43835, 0.43235, 0.42635,
       0.42035, 0.41435, 0.40835, 0.40235, 0.39635, 0.39035, 0.38435,
```

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       0.37835, 0.37235, 0.36635, 0.36035, 0.35435, 0.34835, 0.34235,
       0.33635, 0.33035, 0.32435, 0.31835, 0.31235, 0.30635, 0.29435,
       0.28835, 0.28235, 0.27635, 0.27035, 0.26435, 0.25835, 0.25235,
       0.24635, 0.23435, 0.22835, 0.22235, 0.21635, 0.21035, 0.20435,
       0.20235, 0.19835, 0.19235, 0.18635, 0.18035, 0.17435, 0.16835,
       0.16235, 0.15635, 0.15035])
```

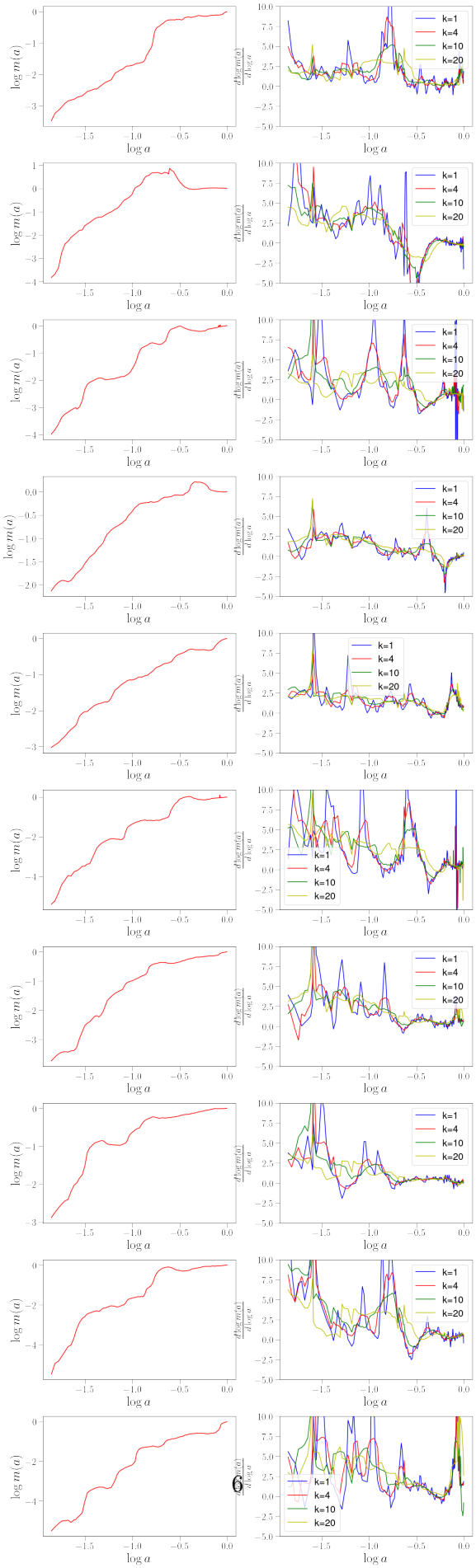
[112]:
```
fig, axes = plt.subplots(10, 2, figsize=(15, 50))
indices = np.random.randint(0, len(ma), 10)
ks = [1, 4, 10, 20]
colors = ['b', 'r', 'g', 'y', 'm']
x = np.log(scales)

for i, idx in enumerate(indices):
    ax1, ax2 = axes[i, :]
    ax1.plot(x, np.log(ma[idx, :]), 'r-')

    for c,k in zip(colors, ks):
        grad = get_gradient(np.log(ma[[idx], :]), x, k=k)
        ax2.plot(x, grad[0], f'{c}-', label=f"k={k}")


    ax2.set_ylim(-5, 10)
    ax1.set_xlabel(r"$\log a$", size=30)
    ax2.set_xlabel(r"$\log a$", size=30)


    ax1.set_ylabel(r"$\log m(a)$", size=30)
    ax2.set_ylabel(r"$\frac{d\log m(a)}{d \log a}$", size=30)
    ax2.legend(loc='best')
plt.tight_layout()
```

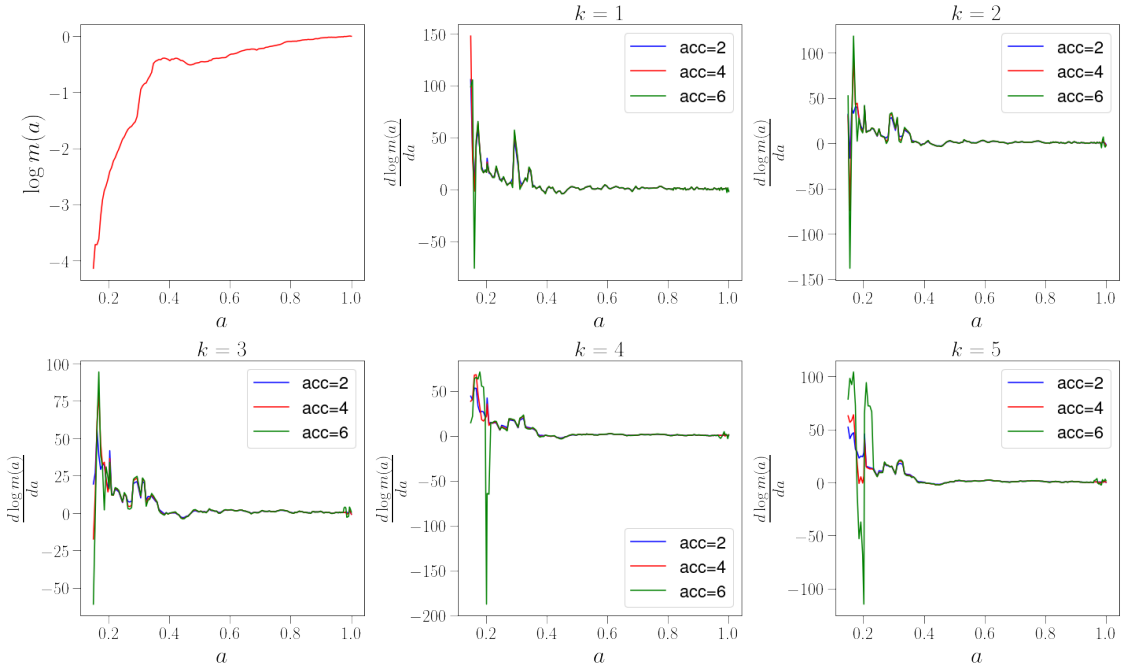

log m(a)
log a
d log m(a) / d log a
k=1
k=4
k=10
k=20

2.3 Fix k, vary accuracy

[45]:
```
idx = np.random.randint(len(ma))
```

[48]:
```
fig, axes = plt.subplots(2, 3, figsize=(20, 12))
axes = axes.flatten()
ax1 = axes[0]
axs = axes[1:]
x = scales
ks = [1,2,3,4,5]
accs = [2, 4, 6]
colors = ['b', 'r', 'g']
ax1.plot(x, np.log(ma[idx, :]), 'r-')
for k, ax in zip(ks, axs):
    for c, acc in zip(colors, accs):
        grad = get_gradient(np.log(ma[[idx], :]), x, k=k, acc=acc)
        ax.plot(x, grad[0], f'{c}-', label=f"acc={acc}")
    ax.set_xlabel(r"$a$", size=30)
    ax.set_ylabel(r"$\frac{d\log m(a)}{da}$", size=30)
    ax.legend(loc='best')
    ax.set_title(fr"$k={k}$")

ax1.set_xlabel(r"$a$", size=30)
ax1.set_ylabel(r"$\log m(a)$", size=30)
plt.tight_layout()
```



3 Correlation between gradients and cvir, xoff, t/u

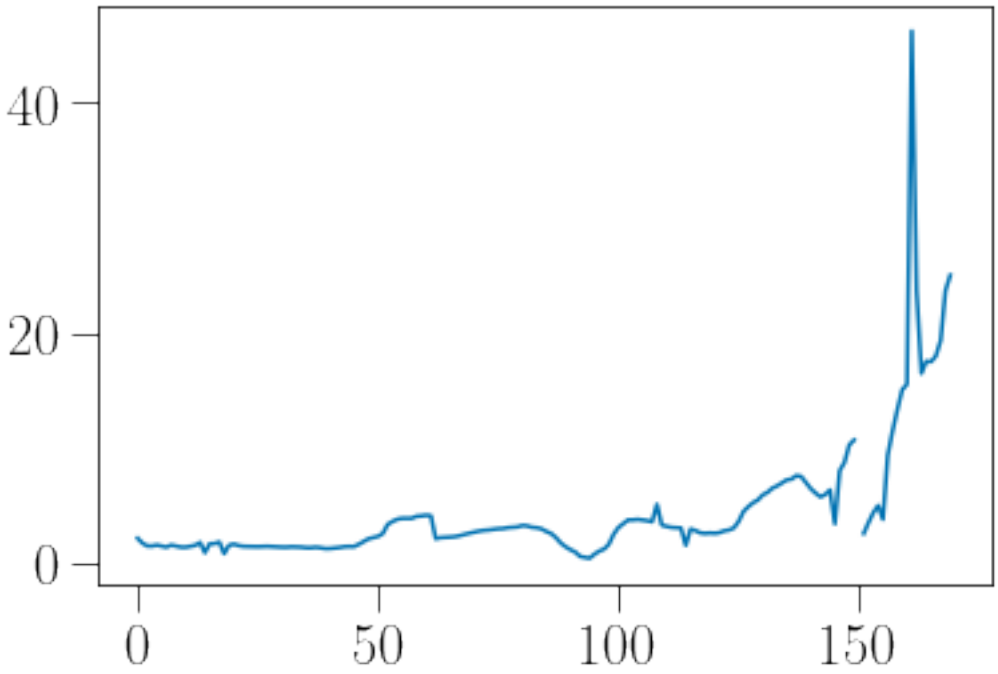
[79]:
```
names = ['m11', 'm12']
params = ['cvir', 'x0', 't/|u|']
latex_params = ['c_{\\rm vir}', 'x_{\\rm off}', 't/|u|']
colors = ['r','b', 'g']
markers = np.array(['.', 'x'])
```

[127]:
```
np.sum(np.isnan(grads[:, -10]))
```

[127]: 80

[128]:
```
plt.plot(grads[9, :])
```

[128]: [<matplotlib.lines.Line2D at 0x7ff8a0e19e50>]



[115]:
```
ks = [4, 10, 20]
fig, axes = plt.subplots(len(ks), len(names),figsize=(len(names)*7,7*len(ks)))
for p, k in enumerate(ks):
    for i, name in enumerate(names):
        hcat, indices, scales = setup(name)
```

```
        ma = get_ma(hcat.cat, indices)
        ax = axes[p, i]
        max_scales = [0.]*len(params)
        tdyn = np.mean(hcat.cat['tdyn']) / 10**9 #Gyr which astropy also␣
↪returns by default
        grads = get_gradient(np.log(ma), scales, k=k, acc=2)


        for j, param in enumerate(params):
            latex_param = latex_params[j]
            color = colors[j]
            param_values = hcat.cat[param]

            # get correlations
            corrs = []
            for s in range(len(scales)):
                corrs.append(stats.spearmanr(param_values, grads[:,s],␣
↪nan_policy="omit")[0])
            corrs = np.array(corrs)

            pos = corrs > 0
            neg = ~pos
            corrs = abs(corrs)

            # plot positive corr and negative corr with different markers.
            if sum(pos) > 0:
                label = f'${latex_param}$' if sum(pos) > sum(neg) else None
                ax.plot(scales[pos], corrs[pos], color=color,␣
↪marker=markers[0], label=label, markersize=7)

            if sum(neg) > 0:
                label = f'${latex_param}$' if sum(pos) < sum(neg) else None
                ax.plot(scales[neg], corrs[neg], color=color,␣
↪marker=markers[1], label=label, markersize=7)

            max_scales[j] = scales[np.nanargmax(abs(corrs))]


        # draw a vertical line at max scales
        for j, s in enumerate(max_scales):
            color = colors[j]
            ax.axvline(s, linestyle='--', color=color)


        ax.set_ylim(0, 1.0)
        ax.set_xlim(0, 1.0)
```

```
        ax.set_title(f"{name}, k={k}", size=22)
        ax.set_ylabel(f"$\\rho(\\cdot, \\Gamma(a))$", size=22)
        ax.set_xlabel(f"$a$", size=22)
        ax.tick_params(axis='both', which='major', labelsize=16)

        # add additional x-axis with tydn fractional scale
        ax2 = ax.twiny()
        ax2.set_xlim(ax.get_xlim())
        ax2.set_xticks(ax.get_xticks())

        fractional_tdyn = get_fractional_tdyn(ax.get_xticks(), tdyn,␣
↪sim_name='Bolshoi')
        fractional_tdyn = np.array([f'{x:.2g}' for x in fractional_tdyn])
        ax2.set_xticklabels(fractional_tdyn, size=16)
        ax2.set_xlabel("$\\tau_{\\rm dyn}$", size=22)

        ax.legend(loc='best', prop={'size': 18})

        ax.set_xlim(0.15, 1)
        ax2.set_xlim(0.15 , 1)
plt.tight_layout()
plt.show()
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/Users/imendoza/code/nbody-relaxed/relaxed/analysis.py:173: RuntimeWarning:
divide by zero encountered in true_divide
  z = (1 / scale) - 1
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/Users/imendoza/code/nbody-relaxed/relaxed/analysis.py:173: RuntimeWarning:
divide by zero encountered in true_divide
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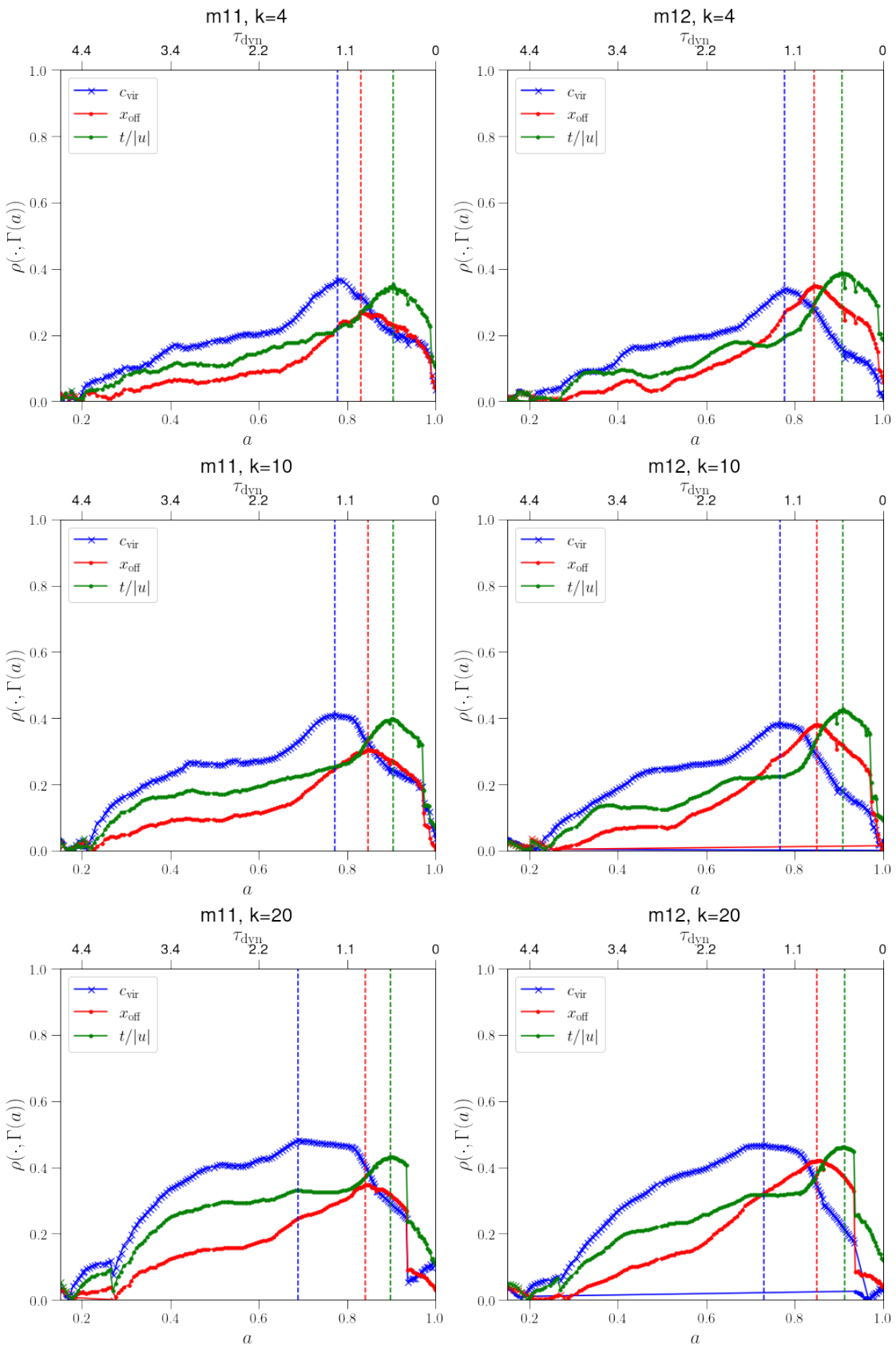
m11, k=4
m12, k=4
m11, k=10
m12, k=10
m11, k=20
m12, k=20
$\tau_{\rm dyn}$
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$\rho(\cdot, \Gamma(a))$
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3.1 focus on one bin correlations

[ ]:
```
ks = [4, 10, 20]
fig, axes = plt.subplots(len(ks), len(names),figsize=(len(names)*7,7*len(ks)))
for p, k in enumerate(ks):
    for i, name in enumerate(names):
        hcat, indices, scales = setup(name)

        ma = get_ma(hcat.cat, indices)
        ax = axes[p, i]
        max_scales = [0.]*len(params)
        tdyn = np.mean(hcat.cat['tdyn']) / 10**9 #Gyr which astropy also␣
↪returns by default

        for j, param in enumerate(params):
            latex_param = latex_params[j]
            color = colors[j]
            param_values = hcat.cat[param]
            grads = get_gradient(np.log(ma), scales, k=k, acc=2)

            # get correlations
            corrs = []
            for s in range(len(scales)):
                corrs.append(stats.spearmanr(param_values, grads[:,s],␣
↪nan_policy="omit")[0])
            corrs = np.array(corrs)

            pos = corrs > 0
            neg = ~pos
            corrs = abs(corrs)

            # plot positive corr and negative corr with different markers.
            if sum(pos) > 0:
                label = f'${latex_param}$' if sum(pos) > sum(neg) else None
                ax.plot(scales[pos], corrs[pos], color=color,␣
↪marker=markers[0], label=label, markersize=7)

            if sum(neg) > 0:
                label = f'${latex_param}$' if sum(pos) < sum(neg) else None
                ax.plot(scales[neg], corrs[neg], color=color,␣
↪marker=markers[1], label=label, markersize=7)

            max_scales[j] = scales[np.nanargmax(abs(corrs))]
```

```
        # draw a vertical line at max scales
        for j, s in enumerate(max_scales):
            color = colors[j]
            ax.axvline(s, linestyle='--', color=color)


        ax.set_ylim(0, 1.0)
        ax.set_xlim(0, 1.0)
        ax.set_title(f"{name}, k={k}", size=22)
        ax.set_ylabel(f"$\\rho(\\cdot, \\Gamma(a))$", size=22)
        ax.set_xlabel(f"$a$", size=22)
        ax.tick_params(axis='both', which='major', labelsize=16)

        # add additional x-axis with tydn fractional scale
        ax2 = ax.twiny()
        ax2.set_xlim(ax.get_xlim())
        ax2.set_xticks(ax.get_xticks())

        fractional_tdyn = get_fractional_tdyn(ax.get_xticks(), tdyn,␣
↪sim_name='Bolshoi')
        fractional_tdyn = np.array([f'{x:.2g}' for x in fractional_tdyn])
        ax2.set_xticklabels(fractional_tdyn, size=16)
        ax2.set_xlabel("$\\tau_{\\rm dyn}$", size=22)

        ax.legend(loc='best', prop={'size': 18})

        ax.set_xlim(0.15, 1)
        ax2.set_xlim(0.15 , 1)
plt.tight_layout()
plt.show()
```