Sorting Mock Galaxy Observations with Unsupervised Methods

Bobby Bickley, Phys. 555 2020

In [1]:
```
#Imports
from six.moves import urllib
from sklearn.decomposition import PCA
from scipy.io import loadmat
from matplotlib import pyplot
from sklearn.metrics import confusion_matrix
import itertools
from sklearn import preprocessing
import keras
from IPython.display import clear_output
from sklearn.linear_model import LogisticRegression
from keras.layers import Input, Dense
from keras.models import Model
import itertools
import numpy as np
import matplotlib.pyplot as plt
from astropy.io import fits
import tarfile
from keras.layers import Input, Dense, Conv2D, MaxPooling2D, UpSampling2D, Flatten
from keras.models import Model
from keras import backend as K
import os, sys
from sklearn import svm, datasets
from sklearn.model_selection import train_test_split
import cv2
from skimage.transform import resize
from sklearn.cluster import KMeans
from sklearn.manifold import TSNE
```

```
Using TensorFlow backend.
/Users/robertbickley/anaconda3/lib/python3.7/site-packages/tensorflow/python/frame
work/dtypes.py:516: FutureWarning: Passing (type, 1) or '1type' as a synonym of ty
pe is deprecated; in a future version of numpy, it will be understood as (type,
(1,)) / '(1,)type'.
  _np_qint8 = np.dtype([("qint8", np.int8, 1)])
/Users/robertbickley/anaconda3/lib/python3.7/site-packages/tensorflow/python/frame
work/dtypes.py:517: FutureWarning: Passing (type, 1) or '1type' as a synonym of ty
pe is deprecated; in a future version of numpy, it will be understood as (type,
(1,)) / '(1,)type'.
  _np_quint8 = np.dtype([("quint8", np.uint8, 1)])
/Users/robertbickley/anaconda3/lib/python3.7/site-packages/tensorflow/python/frame
work/dtypes.py:518: FutureWarning: Passing (type, 1) or '1type' as a synonym of ty
pe is deprecated; in a future version of numpy, it will be understood as (type,
(1,)) / '(1,)type'.
  _np_qint16 = np.dtype([("qint16", np.int16, 1)])
/Users/robertbickley/anaconda3/lib/python3.7/site-packages/tensorflow/python/frame
work/dtypes.py:519: FutureWarning: Passing (type, 1) or '1type' as a synonym of ty
pe is deprecated; in a future version of numpy, it will be understood as (type,
(1,)) / '(1,)type'.
  _np_quint16 = np.dtype([("quint16", np.uint16, 1)])
/Users/robertbickley/anaconda3/lib/python3.7/site-packages/tensorflow/python/frame
work/dtypes.py:520: FutureWarning: Passing (type, 1) or '1type' as a synonym of ty
pe is deprecated; in a future version of numpy, it will be understood as (type,
(1,)) / '(1,)type'.
  _np_qint32 = np.dtype([("qint32", np.int32, 1)])
/Users/robertbickley/anaconda3/lib/python3.7/site-packages/tensorflow/python/frame
work/dtypes.py:525: FutureWarning: Passing (type, 1) or '1type' as a synonym of ty
pe is deprecated; in a future version of numpy, it will be understood as (type,
(1,)) / '(1,)type'.
  np_resource = np.dtype([("resource", np.ubyte, 1)])
/Users/robertbickley/anaconda3/lib/python3.7/site-packages/tensorboard/compat/tens
orflow_stub/dtypes.py:541: FutureWarning: Passing (type, 1) or '1type' as a synony
m of type is deprecated; in a future version of numpy, it will be understood as (t
ype, (1,)) / '(1,)type'.
```

In [2]:
```
#PlotLosses class borrowed from class exercises
class PlotLosses(keras.callbacks.Callback):
    def on_train_begin(self, logs={}):
        self.i = 0
        self.x = []
        self.losses = []
        self.val_losses = []
        self.fig = plt.figure()
        self.logs = []
    def on_epoch_end(self, epoch, logs={}):
        self.logs.append(logs)
        self.x.append(self.i)
        self.losses.append(logs.get('loss'))
        self.val_losses.append(logs.get('val_loss'))
        self.i += 1
        clear_output(wait=True)
        plt.plot(self.x, self.losses, label="train")
        plt.plot(self.x, self.val_losses, label="validation",linestyle='--')
        plt.legend()
        plt.show();
plot_losses = PlotLosses()
```

In [3]:
```
#My own function to grab data from an image file, which is a tarball of the 4 camera
def im_look(filename,cam):
    sci_tar = tarfile.open(filename)
    membs=sci_tar.getmembers()
    im_dat = fits.getdata(sci_tar.extractfile(membs[cam]))
    sci_tar.close()
    return im_dat
```

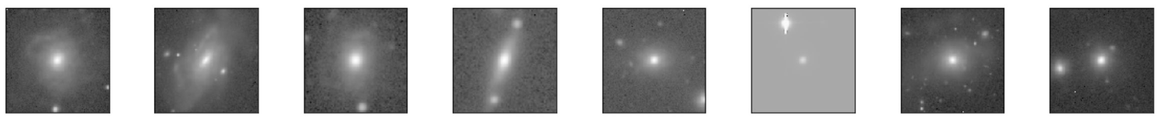
In [4]:
```
#Retrieve galaxy image data from wherever it is stored on your machine
data_dir = '/Users/robertbickley/Documents/UVic/y1/ML/project/sci_ims_1/'
data_files = os.listdir(data_dir)
if '.DS_Store' in data_files: data_files.remove('.DS_Store')
data_files = [data_dir+i for i in data_files]
inp = np.array([resize(im_look(f,c),(128,128)) for f in data_files for c in range(4)
```

Please note: to produce the figures in this notebook, I used a smaller dataset of ~4000 images, so that I could complete it in an interactive session. For the results shown in my presentation, I will be using a sample 10x larger than that, ~40,000 images, to get more robust results. Running with 40,000 images is not possible in an interactive session, however.

In [5]:
```
#normalize
inp = [i-np.amin(i) for i in inp]
inp = [i/np.amax(i) for i in inp]
inp_flat = np.reshape(inp,(-1,16384))
```

In [6]:
```
#Visualize thumbnails of a few of the galaxies
n = 8  # how many galaxies we will display
plt.figure(figsize=(20, 4))
for i in range(n):
    ax = plt.subplot(2, n, i + 1)
    plt.imshow(np.log10(np.reshape(inp_flat[i],(128,128))))
    plt.gray()
    ax.get_xaxis().set_visible(False)
    ax.get_yaxis().set_visible(False)
```

```
/Users/robertbickley/anaconda3/lib/python3.7/site-packages/ipykernel_launcher.py:
6: RuntimeWarning: divide by zero encountered in log10
```

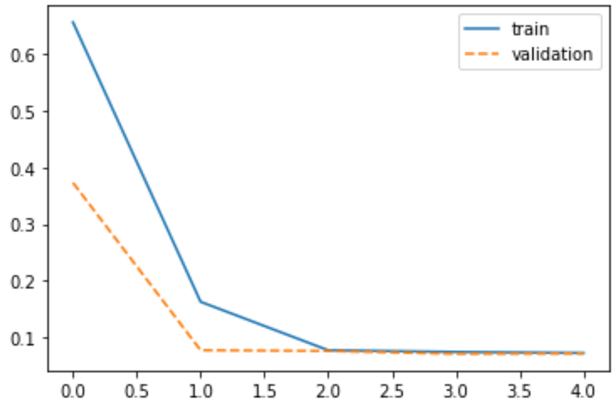


In [7]:
```
#Split the data
inp_tr,inp_va = train_test_split(inp_flat,test_size=.2,random_state=0)
```

In [8]:
```
#Define a deep, under-complete autoencoder with only dense layers
encoding_dim = 128
# this is our input placeholder
input_img = Input(shape=(16384,))
encoded = Dense(2048, activation='relu')(input_img)
encoded = Dense(512, activation='relu')(encoded)
z = Dense(encoding_dim, activation='relu', name = 'latent_layer')(encoded)
z= keras.layers.BatchNormalization()(z)
decoded = Dense(512, activation='relu')(z)
decoded = Dense(2048, activation='relu')(decoded)
decoded = Dense(16384, activation='sigmoid')(decoded)
# this model maps an input to its encoded representation
encoder = Model(input_img, z)
# this model maps an input to its reconstruction
autoencoder = Model(input_img, decoded)
autoencoder.summary()
```

```
WARNING:tensorflow:From /Users/robertbickley/anaconda3/lib/python3.7/site-packages
/keras/backend/tensorflow_backend.py:74: The name tf.get_default_graph is deprecat
ed. Please use tf.compat.v1.get_default_graph instead.

WARNING:tensorflow:From /Users/robertbickley/anaconda3/lib/python3.7/site-packages
/keras/backend/tensorflow_backend.py:517: The name tf.placeholder is deprecated. P
lease use tf.compat.v1.placeholder instead.

WARNING:tensorflow:From /Users/robertbickley/anaconda3/lib/python3.7/site-packages
/keras/backend/tensorflow_backend.py:4138: The name tf.random_uniform is deprecate
d. Please use tf.random.uniform instead.

WARNING:tensorflow:From /Users/robertbickley/anaconda3/lib/python3.7/site-packages
/keras/backend/tensorflow_backend.py:133: The name tf.placeholder_with_default is
deprecated. Please use tf.compat.v1.placeholder_with_default instead.

_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
input_1 (InputLayer)         (None, 16384)             0
_________________________________________________________________
dense_1 (Dense)              (None, 2048)              33556480
_________________________________________________________________
dense_2 (Dense)              (None, 512)               1049088
_________________________________________________________________
latent_layer (Dense)         (None, 128)               65664
_________________________________________________________________
batch_normalization_1 (Batch (None, 128)               512
_________________________________________________________________
dense_3 (Dense)              (None, 512)               66048
_________________________________________________________________
dense_4 (Dense)              (None, 2048)              1050624
_________________________________________________________________
dense_5 (Dense)              (None, 16384)             33570816
=================================================================
Total params: 69,359,232
Trainable params: 69,358,976
Non-trainable params: 256
_________________________________________________________________
```

In [9]:
```
#For this example, only allowing for 5 epochs. Performance does not improve with mor
autoencoder.compile(optimizer='adadelta', loss='binary_crossentropy')
autoencoder.fit(inp_tr, inp_tr,
                epochs=5,
                batch_size=32,
                shuffle=True,
                validation_data=(inp_va, inp_va),callbacks=[plot_losses])
```



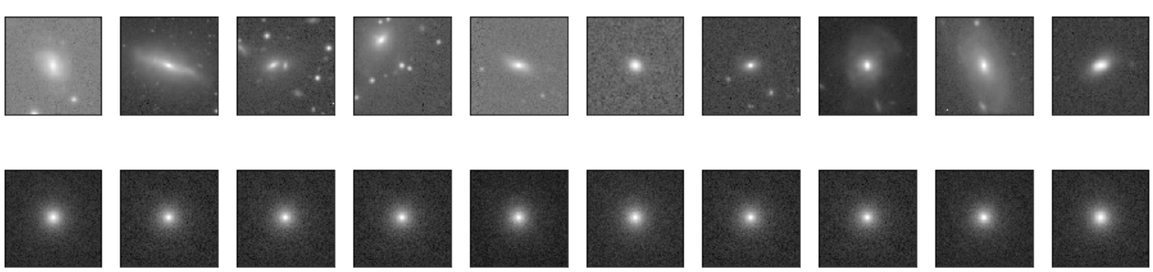
Out[9]: <keras.callbacks.History at 0x1c50a81ed0>

In [10]:
```
#Make dense encoder predictions on the data
decoded_tr = autoencoder.predict(inp_tr)
decoded_va = autoencoder.predict(inp_va)
print('The size of the latent validation set == ', np.shape(decoded_va))
```

```
The size of the latent validation set ==  (788, 16384)
```

In [11]:
```
n = 10  # how many digits we will display
plt.figure(figsize=(16,4))
for i in range(n):
    # display original
    ax = plt.subplot(2, n, i + 1)
    plt.imshow(np.log10(inp_va[i].reshape(128, 128)))
    plt.gray()
    ax.get_xaxis().set_visible(False)
    ax.get_yaxis().set_visible(False)
    # display reconstruction
    ax = plt.subplot(2, n, i + 1 + n)
    plt.imshow(np.log10(decoded_va[i].reshape(128, 128)))
    plt.gray()
    ax.get_xaxis().set_visible(False)
    ax.get_yaxis().set_visible(False)
plt.show()
```

```
/Users/robertbickley/anaconda3/lib/python3.7/site-packages/ipykernel_launcher.py:
6: RuntimeWarning: divide by zero encountered in log10
```



In [12]:
```
#With the limited success of a dense-only autoencoder, let's try a CNN autoencoder
#Autoencoder CNN
input_img = Input(shape=(128, 128, 1))  # adapt this if using `channels_first` image

x = Conv2D(16, (3, 3), activation='relu', padding='same')(input_img)
x = MaxPooling2D((2, 2), padding='same')(x)
x = Conv2D(8, (3, 3), activation='relu', padding='same')(x)
x = MaxPooling2D((2, 2), padding='same')(x)
x = Conv2D(4, (3, 3), activation='relu', padding='same')(x)
z = MaxPooling2D((2, 2), padding='same', name='latent_layer')(x)
z= keras.layers.BatchNormalization()(z)

x = Conv2D(4, (3, 3), activation='relu', padding='same')(z)
x = UpSampling2D((2, 2))(x)
x = Conv2D(8, (3, 3), activation='relu', padding='same')(x)
x = UpSampling2D((2, 2))(x)
x = Conv2D(16, (3, 3), activation='relu', padding='same')(x)
x = UpSampling2D((2, 2))(x)
x = Conv2D(16, (3, 3), activation='sigmoid', padding='same')(x)
decoded = Conv2D(1, (3, 3), activation='sigmoid', padding='same')(x)

autoencoder = Model(input_img, decoded)
autoencoder.compile(optimizer='adadelta', loss='binary_crossentropy')

# this model maps an input to its encoded representation
encoder = Model(input_img, z)

# this model maps an input to its reconstruction
autoencoder = Model(input_img, decoded)

autoencoder.summary()
```

```
WARNING:tensorflow:From /Users/robertbickley/anaconda3/lib/python3.7/site-packages
/keras/backend/tensorflow_backend.py:3976: The name tf.nn.max_pool is deprecated.
Please use tf.nn.max_pool2d instead.

WARNING:tensorflow:From /Users/robertbickley/anaconda3/lib/python3.7/site-packages
/keras/backend/tensorflow_backend.py:1834: The name tf.nn.fused_batch_norm is depr
ecated. Please use tf.compat.v1.nn.fused_batch_norm instead.

WARNING:tensorflow:From /Users/robertbickley/anaconda3/lib/python3.7/site-packages
/keras/backend/tensorflow_backend.py:2018: The name tf.image.resize_nearest_neighb
or is deprecated. Please use tf.compat.v1.image.resize_nearest_neighbor instead.
```

Layer (type)	Output Shape	Param #
input_2 (InputLayer)	(None, 128, 128, 1)	0
conv2d_1 (Conv2D)	(None, 128, 128, 16)	160
max_pooling2d_1 (MaxPooling2	(None, 64, 64, 16)	0
conv2d_2 (Conv2D)	(None, 64, 64, 8)	1160
max_pooling2d_2 (MaxPooling2	(None, 32, 32, 8)	0
conv2d_3 (Conv2D)	(None, 32, 32, 4)	292
latent_layer (MaxPooling2D)	(None, 16, 16, 4)	0
batch_normalization_2 (Batch	(None, 16, 16, 4)	16
conv2d_4 (Conv2D)	(None, 16, 16, 4)	148

In [13]:
```
#Since we will be using the CNN autoencoder for our next steps, we define an encoder
encoder = Model(input_img,z)
encoder.summary()
```

```
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
input_2 (InputLayer)         (None, 128, 128, 1)       0
_________________________________________________________________
conv2d_1 (Conv2D)            (None, 128, 128, 16)      160
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 64, 64, 16)        0
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 64, 64, 8)         1160
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 32, 32, 8)         0
_________________________________________________________________
conv2d_3 (Conv2D)            (None, 32, 32, 4)         292
_________________________________________________________________
latent_layer (MaxPooling2D)  (None, 16, 16, 4)         0
_________________________________________________________________
batch_normalization_2 (Batch (None, 16, 16, 4)         16
=================================================================
Total params: 1,628
Trainable params: 1,620
Non-trainable params: 8
_________________________________________________________________
```

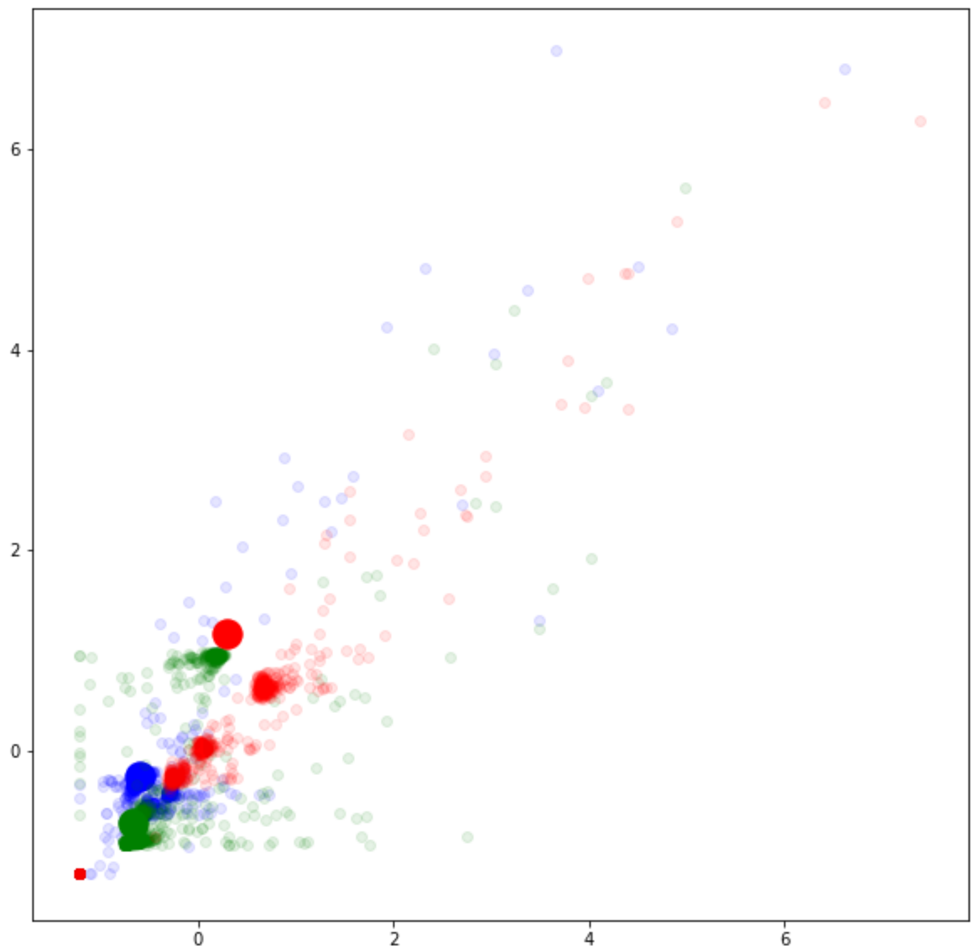
In [14]:
```
#Because this model takes 2D input, we un-reshape our data back to its original size
inp_tr2D = np.reshape(inp_tr, (len(inp_tr), 128, 128, 1))
inp_va2D = np.reshape(inp_va, (len(inp_va), 128, 128, 1))
```

In [15]:
```
#Training code is commented out because the model was trained in an earlier session.
# autoencoder.compile(optimizer='adadelta', loss='binary_crossentropy')
# autoencoder.fit(inp_tr2D, inp_tr2D,
#                 epochs=100,
#                 batch_size=128,
#                 shuffle=True,
#                 validation_data=(inp_va2D, inp_va2D),callbacks=[plot_losses])
# autoencoder.save_weights('autoenc_model.h5')

#Instead, we load the saved weights from a file
autoencoder.load_weights('autoenc_model.h5')
```

In [16]:
```
#Make predictions using the new encoder
encoded_va = encoder.predict(inp_va2D)
encoded_tr = encoder.predict(inp_tr2D)
```

In [17]:
```
#Now, we will feed the encoded data into a Kmeans algorithm, first with K=3, as an e
K = 3
#Change the reshape statement to reflect the sizes of your training and testing set
kmeans = KMeans(n_clusters=K).fit(encoded_tr.reshape(3152,-1))
Kmean_tr=kmeans.predict(encoded_tr.reshape(3152,-1))
Kmean_va=kmeans.predict(encoded_va.reshape(788,-1))
```

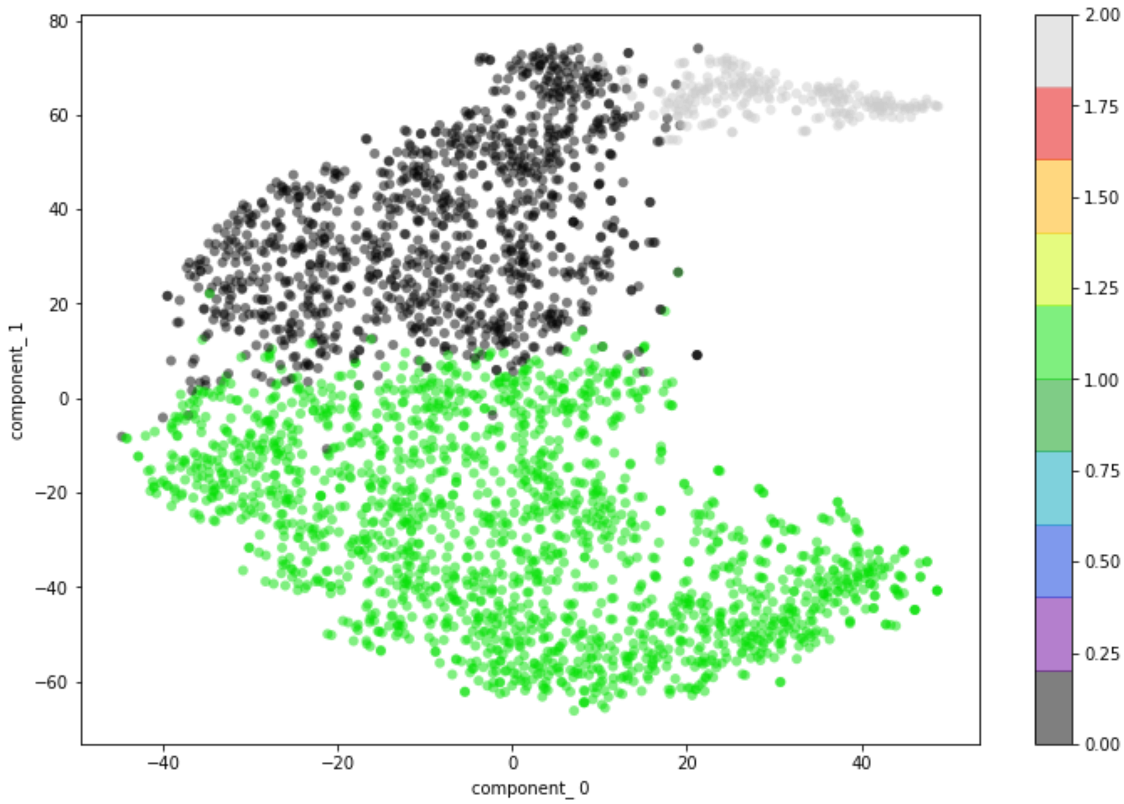
In [18]:
```
#Data visualization attempt 1: select two features from the data, and plot the cente
comp_x = 0
comp_y = 1
colors = ['b','g','r','c','m','y','black']
fig1 = plt.figure(figsize=[10,10])
for k1 in range(K):
    plt.scatter(kmeans.cluster_centers_[k1,comp_x],kmeans.cluster_centers_[k1,comp_y
    plt.scatter(encoded_va.reshape(788,-1)[Kmean_va==k1][comp_x],encoded_va.reshape(
plt.show()
```



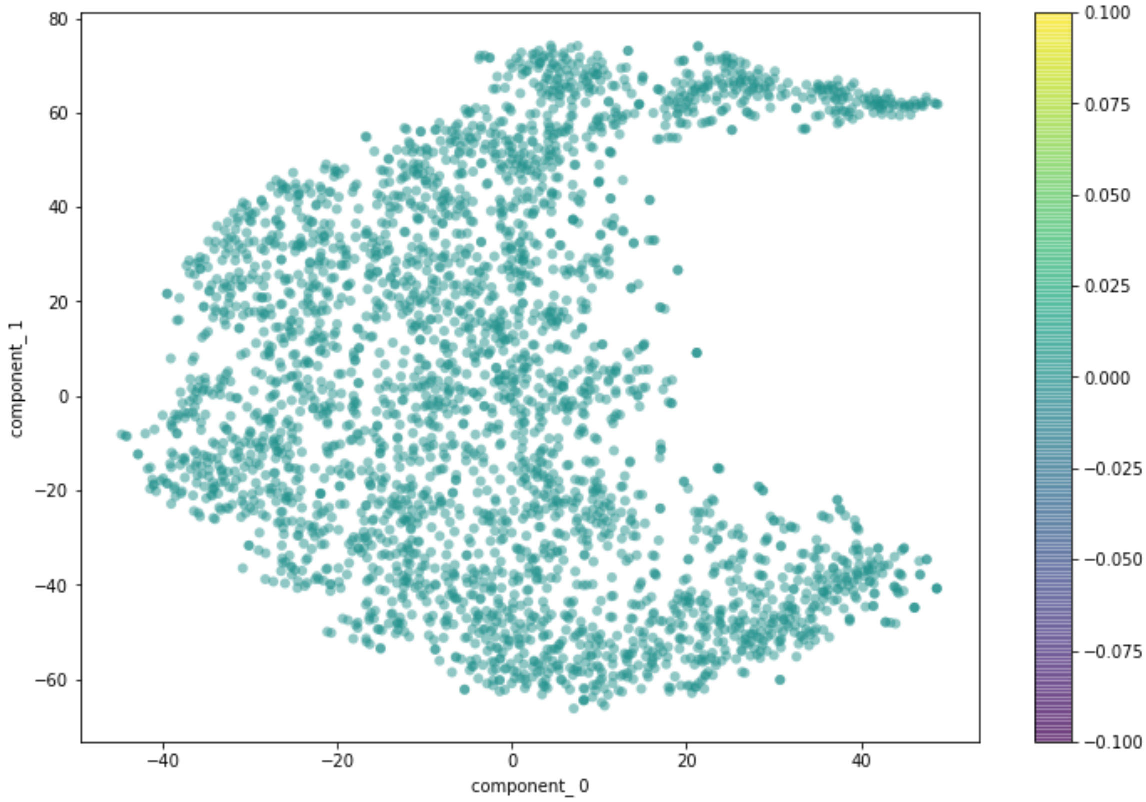
In [19]:
```
#Data visualization improvement: use T-SNE to project the data onto two dimensions
tsne = TSNE(n_components=2)
tsne.fit(encoded_tr.reshape(3152,-1))
tsne_results_tr= tsne.fit_transform(encoded_tr.reshape(3152,-1))
```

In [20]:

```
#Make a plot of the T-SNE result
#t-SNE plot
comp_x=0
comp_y=1
plt.figure(figsize=(12,8))
plt.scatter(tsne_results_tr[:,comp_x], tsne_results_tr[:,comp_y], edgecolor='none',
plt.xlabel('component_ '+ str(comp_x))
plt.ylabel('component_ '+str(comp_y))
plt.colorbar()
plt.show()
```

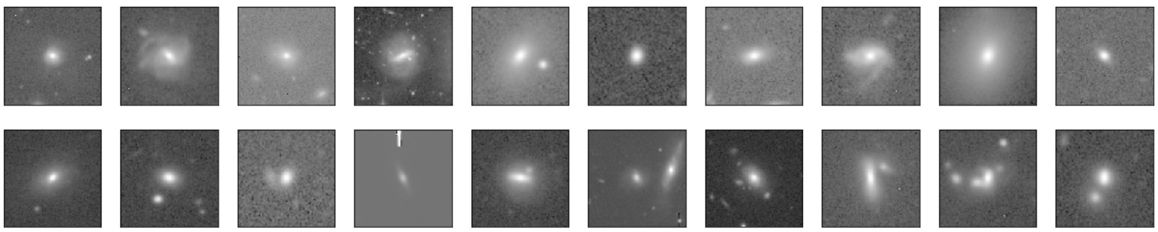


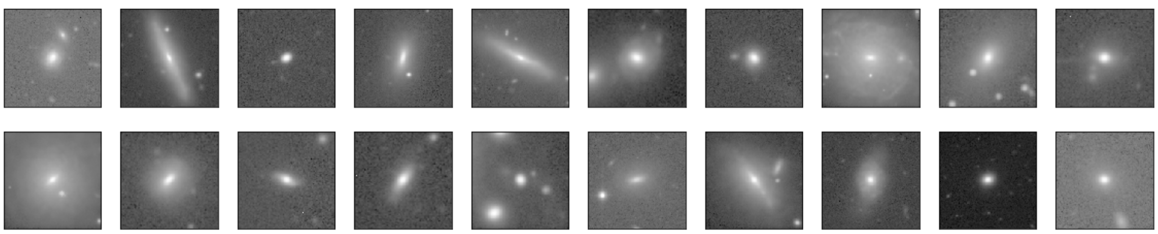
In [21]:
```
#How do we compare to our naively-defined artifact metric, the zero-flux-pixel fract
#Take naive "artifact" statistic of f_zer, and split them into the same two sets as
f_zers = [len(np.argwhere(im>1))/(len(im)**2) for im in inp]
fr_tr,fr_va = train_test_split(f_zers,test_size=.2,random_state=0)
#alt t-SNE plot to show separation of naively-defined artifacts
plt.figure(figsize=(12,8))
plt.scatter(tsne_results_tr[:,comp_x], tsne_results_tr[:,comp_y], edgecolor='none',
plt.xlabel('component_ '+ str(comp_x))
plt.ylabel('component_ '+str(comp_y))
plt.colorbar()
plt.show()
```

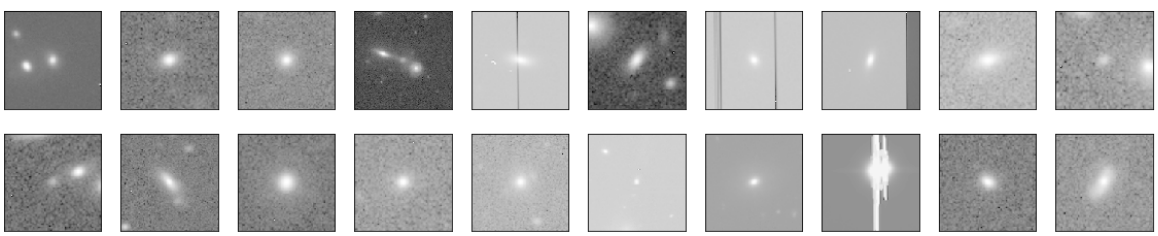


In [22]:
```
#Let's inspect images that were placed into each of the three classes
for n in range(3):
    fig, axs = plt.subplots(2,10,figsize=(20, 4))
    count = 0
    #Plotting 2x10 images for each Kmean cluster
    for i in range(2):
        for j in range(10):
            plt.gray()
            axs[i][j].imshow(np.log10(np.reshape(inp_tr[Kmean_tr==n][count],(128,128
            axs[i][j].get_xaxis().set_visible(False)
            axs[i][j].get_yaxis().set_visible(False)
            count +=1
    plt.show()
```

```
/Users/robertbickley/anaconda3/lib/python3.7/site-packages/ipykernel_launcher.py:
9: RuntimeWarning: divide by zero encountered in log10
  if __name__ == '__main__':
```





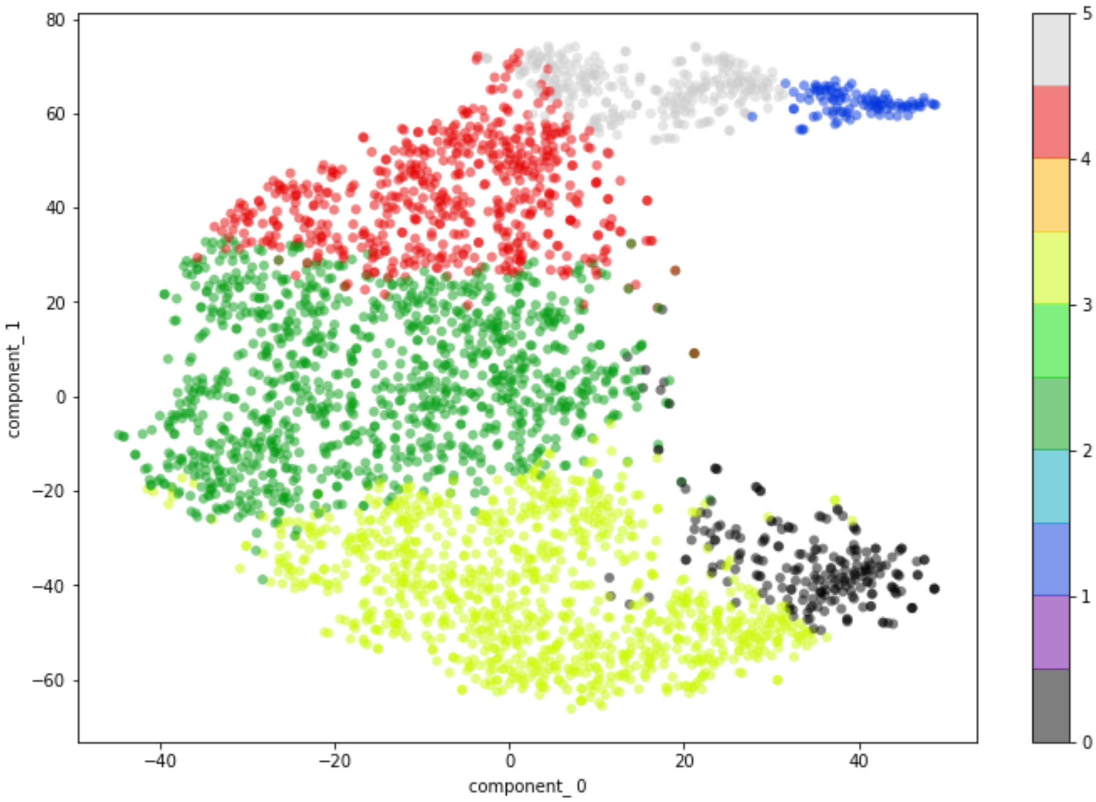


With K = 3, the third category (last two rows above) captures the visible artifacts, though with a coarse brush. A larger number of "normal" images are also included.

In [23]:
```
#Now, we'll repeat the last few steps with our final K-value, 6
K=6
# fit the n first components of pca  by Kmean
kmeans = KMeans(n_clusters=K).fit(encoded_tr.reshape(3152,-1))
Kmean_tr=kmeans.predict(encoded_tr.reshape(3152,-1))
Kmean_va=kmeans.predict(encoded_va.reshape(788,-1))
```

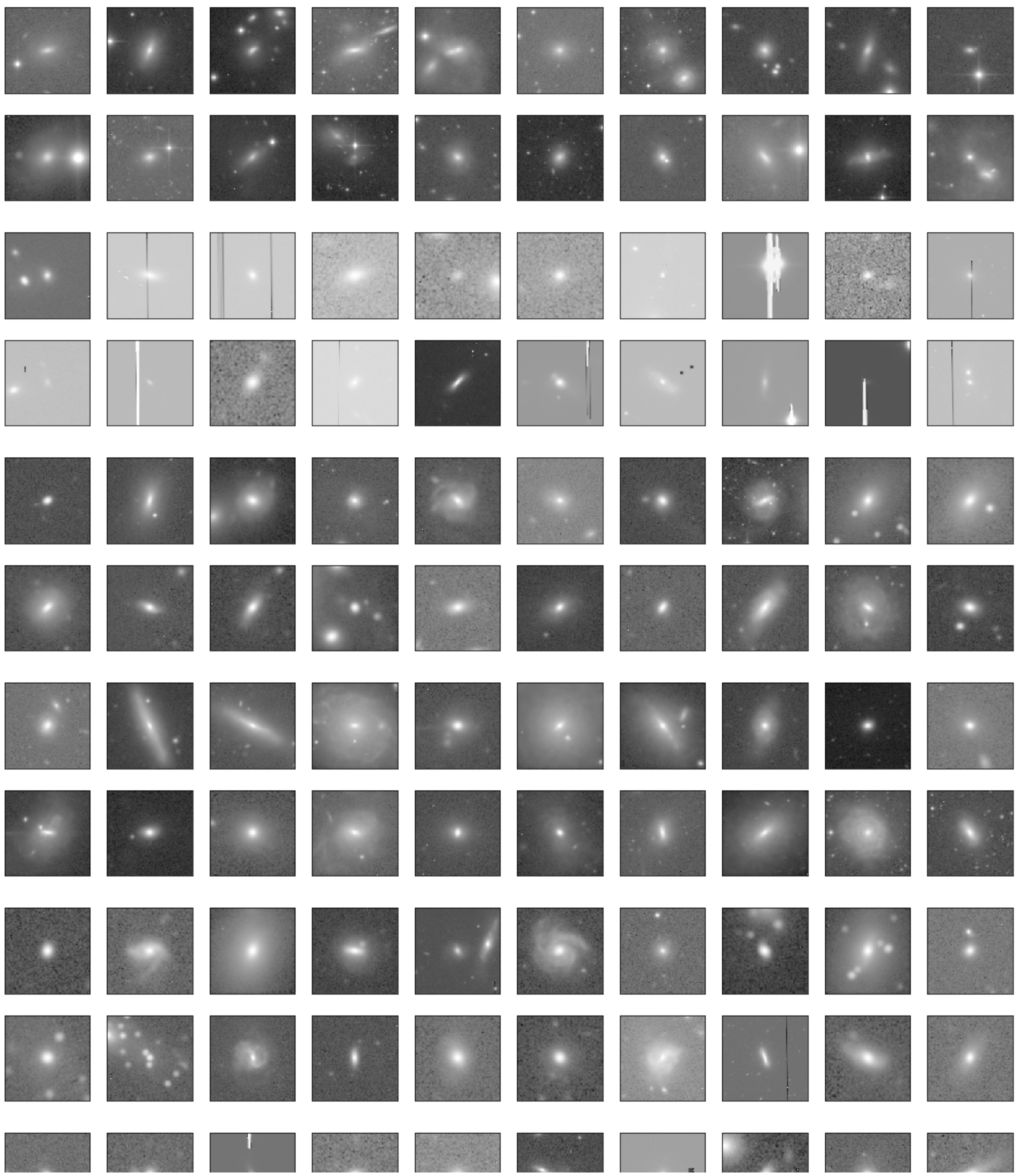
In [24]:
```
#Improved data visualization method using T-SNE
comp_x=0
comp_y=1
plt.figure(figsize=(12,8))
plt.scatter(tsne_results_tr[:,comp_x], tsne_results_tr[:,comp_y], edgecolor='none',
plt.xlabel('component_ '+ str(comp_x))
plt.ylabel('component_ '+str(comp_y))
plt.colorbar()
```

Out[24]: <matplotlib.colorbar.Colorbar at 0x1c6657d710>



In [25]:
```
#Once again visually inspecting the Kmeans classifications
for n in range(6):
    fig, axs = plt.subplots(2,10,figsize=(20, 4))
    count = 0
    #Plotting 2x10 images for each Kmean cluster
    for i in range(2):
        for j in range(10):
            plt.gray()
            axs[i][j].imshow(np.log10(np.reshape(inp_tr[Kmean_tr==n][count],(128,128
            axs[i][j].get_xaxis().set_visible(False)
            axs[i][j].get_yaxis().set_visible(False)
            count +=1
    plt.show()
```

```
/Users/robertbickley/anaconda3/lib/python3.7/site-packages/ipykernel_launcher.py:
9: RuntimeWarning: divide by zero encountered in log10
  if __name__ == '__main__':
```



With K = 6, there is a small tradeoff, but with net positive results. While a few, less-catastrophic artifact images are included in other categories, the second category (rows 3 and 4 in the image above) contains a much higher density of artifact images than with other categories.

In [ ]: