General_Python

February 28, 2017

1 Using Python for Data

These notes can be found here: http://bit.ly/2mGVk1D

1.1 Useful Packages

- `numpy`: Adds ability to deal with multi-dimensional arrays and vectorized math functions
- `scipy`: Extends `numpy` by adding common scientific functions such as ODE integration, statistical analysis, linear algebra, and FFT
- `matplotlib`: A useful plotting package
- `astroML`: Common statistical analysis and machine learning tools used in astronomy

1.2 Installing python

The easiest way to install python on any OS is to use anaconda python. This will install a local version of python on your system so you don't need to worry about needing admin to install new packages. Most of the packages listed above are installed by default with anaconda. For this class we will be using python 3, and I recommend you use this version for you research (unless you have a very good reason to use python 2). In these notes I have marked where the syntax or behavior has changed between python 2 and 3.

1.3 Text editors

Although there are numerous IDEs (e.g. IDLE, Spyder) for python, for most everyday use you will likely be writing python code in a text editor and running your programs via the command line. In this case it is important to have a good text editor that supports syntax highlighting and possibly live linting (syntax and style checking). I use the atom text editor, a 'hackable' text editor that offers a large range of add-ons to support your coding style. If you decide to use atom you will want the following add-ons: `language-python`, `linter`, `linter-python`, and the python packages `pylama` and `pylama-pylint` installed. As a bonus the atom editor has full support for `git` and `git-hub`.

1.4 Coding style

When working on code with others, it is helpful to define a coding style for a project. That way the code is written in a predictable way and it is easy to read. Many projects use PEP 8 as a starting point for a style.

1.5 Basic syntax examples

For a general overview of python's syntax head over to codecademy and take their interactive tutorial. This class will highlight some of the more important things.

1.5.1 importing packages

Any package or code from another `.py` file can be imported with a simple `import` statement. By default all imported code has its own name space, so you don't have to worry about overwriting existing functions. The final line of this code block is a "magic" `Jupyter` function needed to make interactive plots inside of `Jupyter notebooks`.

```
In [1]: import numpy as np
        import scipy as sp
        import matplotlib.pyplot as plt
        %matplotlib notebook
```

1.5.2 math

Basic math opperations work (mostly) as expected:

```
In [2]: # addition
        print(1 + 1)

        # subtraction
        print(1 - 1)

        # multiplication
        print(3 * 4)

        # division
        print(5 / 4)

        # integer division
        print(5 // 4)

        # exponents
        print(2**5)

        # modulo
        print(5 % 2)
```

```
2
0
12
1.25
1
32
1
```

Note: In python 2 division defaults to integer division if both values are integers! This was an easy error to make (and difficult to debug/notice) so the default was changed in python 3 and the `//` opperator was introduced for integer division.

1.5.3 data containers

Data inside of python can be stored in several different types of contains. The most basic ones are:

- `list`: an indexed data structure that can hold any objects as an element
- `tuple`: same as a `list` except the data is immutable
- `dictionary`: objects stored as a {`key: value`} set (note: any immutable object can be used as a key including a tuple)

```
In [3]: # a list
        example_list = [1, 2, 3]

        # a tuple
        example_tuple = (1, 2, 3)

        # a dictionary
        example_dict = {'key1': 1, 'key2': 2, ('key', 3): 3}
```

Elements in these objects can be accessed using an zero-based index (`list` and `tuple`) or key (`dict`).

```
In [4]: print(example_list[0], example_list[-1])
        print(example_tuple[1])
        print(example_dict['key1'], example_dict[('key', 3)])
```

```
1 3
2
1 3
```

Each of these objects have various methods that can be called on them to do various things. To learn what methods can be called you can look at the python documentation (e.g. https://docs.python.org/3/tutorial/datastructures.html) or you can inspect the object directly and use python's `dir` and `help` functions to get the methods and doc string.

Note: Methods that start with __ or _ are private methods that are not designed to be called directly on the object.

```
In [5]: # print the names for all the methods of a list
        print(dir(example_list))

        print('=========')

        # print the help text for the `pop` method
        help(example_list.pop)
```

```
['__add__', '__class__', '__contains__', '__delattr__', '__delitem__', '__dir__', '__doc__', '__eq__', '__format_
=========
Help on built-in function pop:

pop(...) method of builtins.list instance
    L.pop([index]) -> item -- remove and return item at index (default last).
    Raises IndexError if list is empty or index is out of range.
```

1.5.4 Slicing lists

Many times it is useful to slice and manipulate lists. The format for slicing a list is: `list[start_index:end_index:step_size]`

Note: `end_index` in not inclusive.

```
In [6]: a = [0, 1, 2, 3, 4, 5, 6, 7, 8, 9]

        # print the full list
        print(a)

        # print the first 3 elements
        print(a[:3])
```

```
        # print the middle 4 elements
        print(a[3:7])

        # print the last 3 elements
        print(a[7:])

        # you can also use neg index
        print(a[-3:])

        # print only even index
        print(a[::2])

        # print only odd index
        print(a[1::2])

        # print the reverse list
        print(a[::-1])
```

```
[0, 1, 2, 3, 4, 5, 6, 7, 8, 9]
[0, 1, 2]
[3, 4, 5, 6]
[7, 8, 9]
[7, 8, 9]
[0, 2, 4, 6, 8]
[1, 3, 5, 7, 9]
[9, 8, 7, 6, 5, 4, 3, 2, 1, 0]
```

1.5.5 Looping over `lists` and `dicts`

There are several ways to loop over a `list` or `dict` depending on what values you want access to.

Note: Two of the print statements in this example using string formatting. `'{0} {2} {1}'.format(a, b, c)` will replace {0} with `a` (the 0th argument of the format function), {1} with `b`, and {2} with `c`.

```
In [7]: # loop over values in a list
        for i in example_list:
            print(i)
        print('=========')

        # loop over valeus in a list with index
        for idx, i in enumerate(example_list):
            print('{0}: {1}'.format(idx, i))
        print('=========')

        # loop over keys in dict
        for i in example_dict:
            print(i)
        print('=========')

        # loop over values in dict
        for i in example_dict.values():
            print(i)
        print('=========')

        # loop over keys and values in dict
```

```
        for key, value in example_dict.items():
            print('{0}: {1}'.format(key, value))
```

```
1
2
3
=========
0: 1
1: 2
2: 3
=========
('key', 3)
key2
key1
=========
3
2
1
=========
('key', 3): 3
key2: 2
key1: 1
```

Note: In python 2 the final loop would have been over `example_dict.iteritems()`.

1.5.6 list/dict comprehension

If you need to make a `list` or `dict` as the result of a loop you can use comprehension.

Note comprehension is faster than a normal loop since the iteration uses the `map` function that is compiled in `C`.

```
In [8]: # slower method
        list_loop = []
        dict_loop = {}
        for i in a:
            list_loop.append(i**2)
            dict_loop['key{0}'.format(i)] = i

        print(list_loop)
        print(dict_loop)
```

```
[0, 1, 4, 9, 16, 25, 36, 49, 64, 81]
{'key5': 5, 'key3': 3, 'key4': 4, 'key7': 7, 'key8': 8, 'key0': 0, 'key6': 6, 'key2': 2, 'key1': 1, 'key
```

```
In [9]: # faster method
        list_comp = [i**2 for i in a]
        dict_comp = {'key{0}'.format(i): i for i in a}
        print(list_comp)
        print(dict_comp)
```

```
[0, 1, 4, 9, 16, 25, 36, 49, 64, 81]
{'key5': 5, 'key3': 3, 'key4': 4, 'key7': 7, 'key8': 8, 'key0': 0, 'key6': 6, 'key2': 2, 'key1': 1, 'key
```

1.6 Writing reusable code

It is always best to keep your code DRY (don't repeat yourself). If you find yourself writing the same block of code more than 2 times you should think about extracting it to a function. If you need to create a custom object that has its own methods assigned to it you should create a custom class.

1.6.1 functions

```
In [10]: def cube(x):
             result = x ** 3
             return result

         print(cube(3))
```

```
27
```

Note: In python functions use a local name space, so don't worry about reusing variable names. Only if a variable is not in the local name space will the function look to the global name space. If the function argument is immutable changes will be local in scope, otherwise it will not.

```
In [11]: # numbers passed into a function are immutable
         def alpha(x):
             x = x + 1
             return x

         x = 1
         print(alpha(x))
         print(x)

         print('=======')

         # lists passed into a function are not immutable!
         def beta(x):
             x[0] = x[0] + 1
             return x

         x = [1]
         print(beta(x))
         print(x)
```

```
2
1
=======
[2]
[2]
```

1.6.2 classes

Classes are useful when you will have multiple instances of an object type:

```
In [12]: class Shape:
             # the `__init__` method is run when an instance of the class is inialized
             def __init__(self, x, y, cx=0.0, cy=0.0):
                 self.name = 'rectangle'
                 self.x = x
                 self.y = y
                 self.cx = cx
                 self.cy = cy

             def area(self):
                 return self.x * self.y
```

```
    def move(self, dx, dy):
        self.cx += dx
        self.cy += dy

    def get_position(self):
        return '[x: {0}, y: {1}]'.format(self.cx, self.cy)


# make a sub-class of Shape
class Square(Shape):
    # This will override the `__init__` method of the super-class
    def __init__(self, x, cx=0.0, cy=0.0):
        self.name = 'square'
        self.x = x
        self.y = x
        self.cx = cx
        self.cy = cy
    # all methods that are not overridden are inherited from the super-class

# make another sub-class of Shape
class Circle(Shape):
    # This will override the `__init__` method of the super-class
    def __init__(self, r, cx=0.0, cy=0.0):
        self.name = 'circle'
        self.r = r
        self.cx = cx
        self.cy = cy

    # This will override the `area` method of the super-class
    # The block quote at the top of the function will be return when `help` is called
    def area(self):
        '''Return the area of the circle'''
        return np.pi * self.r**2

# Make some instance of each class
shape_list = [Shape(1, 2), Square(3), Circle(5)]
for sdx, s in enumerate(shape_list):
    # move each instace a different amount
    s.move(sdx, sdx)
    # print the results of different method calls
    print('{0} area: {1}, position: {2}'.format(s.name, s.area(), s.get_position()))
```

```
rectangle area: 2, position: [x: 0.0, y: 0.0]
square area: 9, position: [x: 1.0, y: 1.0]
circle area: 78.53981633974483, position: [x: 2.0, y: 2.0]
```

As demonstrated before, you can show all the methods available to a class by using the `dir` function. If a docstring is defined (triple quote comment on the first line of a function) it will be displayed if `help` is called on the function.

```
In [13]: print(dir(Circle))
         print('=========')
         print(help(shape_list[2].area))
```

```
['__class__', '__delattr__', '__dict__', '__dir__', '__doc__', '__eq__', '__format__', '__ge__', '__getattribute_
=========
```

```
Help on method area in module __main__:

area() method of __main__.Circle instance
    Return the area of the circle

None
```

1.6.3 `if __name__ == '__main__':`

Sometimes you want a file to run a bit of code when called directly form the command line, but not call that code if it is imported into another file. This can be done by checking the value of the global variable `__name__`, when a bit of code it directly run `__name__` will be `'__main__'`, when imported it will not.

```
In [14]: if __name__ == '__main__':
             # code that is only run when this file is directly called from the command line
             # This is a good place to put example code for the functions and classes defined in the fi
             print('An example')
```

```
An example
```

1.6.4 `with` blocks

When working with objects that have `__enter__` and `__exit__` methods defined (most commonly the `open` function), you can use a `with` block to automatically call `__enter__` at the start and `__exit__` at the end. A typical use case is automatically closing files after you are done reading/writing data:

```
In [15]: with open('data.csv', 'r') as file:
             print(file.readline())

         print('=======')

         # This line should fail since the file is autmatically closed by the `with` block
         print(file.readline())
```

```
ID, x, y, sy, sx, pxy

=======


        ---------------------------------------------------------------------------

        ValueError                                Traceback (most recent call last)

        <ipython-input-15-086d4600dfd9> in <module>()
          5
          6 # This line should fail since the file is autmatically closed by the `with` block
    ----> 7 print(file.readline())


        ValueError: I/O operation on closed file.
```

1.7 Numpy

NumPy extends Python to provide n-dimensional arrays along with a wealth of statistical and mathematical functions.

```
In [16]: # creating a 2D array
         b = np.array([[1, 2, 3], [4, 5, 6], [7, 8, 9]])
         print(b)
```

```
[[1 2 3]
 [4 5 6]
 [7 8 9]]
```

There are several ways to create arrays of a given size:

```
In [17]: # a 3D array of zeros
         zero = np.zeros((2, 2, 3))
         print(zero)

         print('========')

         # a 2D array of ones
         one = np.ones((2, 4))
         print(one)

         print('========')

         # a 2D empty array
         empty = np.empty((3, 3))
         print(empty)
```

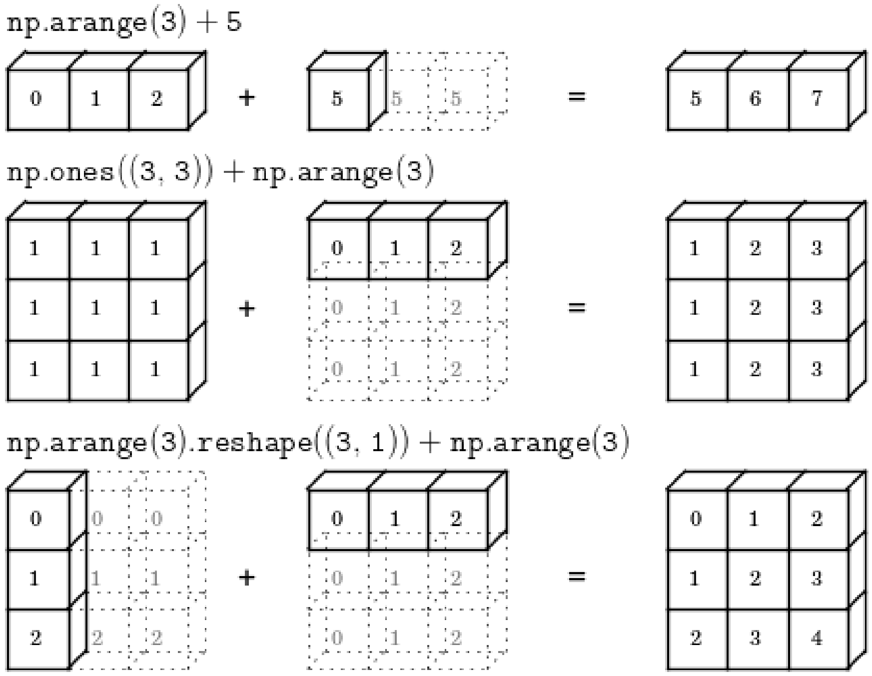
```
[[[ 0.  0.  0.]
  [ 0.  0.  0.]]

 [[ 0.  0.  0.]
  [ 0.  0.  0.]]]
========
[[ 1.  1.  1.  1.]
 [ 1.  1.  1.  1.]]
========
[[ 0.  0.  0.]
 [ 0.  0.  0.]
 [ 0.  0.  0.]]
```

Note: empty fills the array with whatever happened to be in that bit of memory earlier!

1.7.1 Basic operations

Arrays typically act element by element or try to cast the operations in "obvious" ways:



-image ref: http://www.astroML.org

In [18]:
```
print(b)
print('========')

# element wise addition
print (b + b)
print('========')

# multipy all elements by 3
print (3 * b)
print('========')

# row wise addition
d = np.array([1, 2, 3])
print(d)
print (b + d)
print('========')

# column wise addition
e = np.array([[1], [2], [3]])
print(e)
print (b + e)
print('========')

# outter addition
print(d + e)
```

```
[[1 2 3]
 [4 5 6]]
```

```
 [7 8 9]]
========
[[ 2  4  6]
 [ 8 10 12]
 [14 16 18]]
========
[[ 3  6  9]
 [12 15 18]
 [21 24 27]]
========
[1 2 3]
[[ 2  4  6]
 [ 5  7  9]
 [ 8 10 12]]
========
[[1]
 [2]
 [3]]
[[ 2  3  4]
 [ 6  7  8]
 [10 11 12]]
========
[[2 3 4]
 [3 4 5]
 [4 5 6]]
```

1.7.2 Methods

Arrays also have methods such as `sum()`, `min()`, `max()` and these also take axis arguments to operate just over one index.

```
In [19]: # sum of all elements
         print(b.sum())

         # sum along the columns
         print(b.sum(axis=0))

         # sum along the rows
         print(b.sum(axis=1))
```

```
45
[12 15 18]
[ 6 15 24]
```

1.7.3 Slices

Works the same as lists, just provide a slice for each dimension:

```
In [20]: print(b[0, 0:2])
         print('=======')

         print(b[:, 0:2])
         print('=======')

         print(b[0:2, 2:])
```

```
[1 2]
=======
[[1 2]
 [4 5]
 [7 8]]
=======
[[3]
 [6]]
```

1.7.4 Iterating

When using an array as an iterator it will loop over the first index of the array (e.g. for a 2d array it loops row-by-row). Loop over the resulting object to loop over the second index, etc...

```
In [21]: for row in b:
             print(row)
             print('-------')
             for col in row:
                 print(col)
             print('=======')
```

```
[1 2 3]
-------
1
2
3
=======
[4 5 6]
-------
4
5
6
=======
[7 8 9]
-------
7
8
9
=======
```

1.7.5 Masking arrays

Many times you want to find the values in an array to pass a particular condition (e.g. `B-V < 0.3`). This can be done with array masks:

```
In [22]: mask = b >= 5
         print(mask)
         print(b[mask])
```

```
[[False False False]
 [False  True  True]
 [ True  True  True]]
[5 6 7 8 9]
```

You can also combine multiple masks with the bitwise comparison opperators (`&`, |, `~`, `^`):

```
In [23]: mask2 = b <= 7
         print(mask2)

         # and
         print(b[mask & mask2])

         # or
         print(b[mask | mask2])

         # xor
         print(b[mask ^ mask2])

         # not
         print(b[~mask | mask2])
```

```
[[ True  True  True]
 [ True  True  True]
 [ True False False]]
[5 6 7]
[1 2 3 4 5 6 7 8 9]
[1 2 3 4 8 9]
[1 2 3 4 5 6 7]
```

You can also create masks based on parts of an array (e.g. the frist column) and apply it to other parts of the array (e.g. the second column):

```
In [24]: # mask of the first column only
         mask3 = b[:, 0] <= 4
         print(mask3)

         # apply that mask to each of the columns
         print(b[:, 0][mask3])
         print(b[:, 1][mask3])
         print(b[:, 2][mask3])
```

```
[ True  True False]
[1 4]
[2 5]
[3 6]
```

1.7.6 Looking at source code

`Numpy` also as a function that lets you take a look at source code:

```
In [25]: np.source(plt.figure)
```

```
In file: /Users/coleman/anaconda/envs/python3/lib/python3.5/site-packages/matplotlib/pyplot.py

def figure(num=None,  # autoincrement if None, else integer from 1-N
           figsize=None,  # defaults to rc figure.figsize
           dpi=None,  # defaults to rc figure.dpi
           facecolor=None,  # defaults to rc figure.facecolor
           edgecolor=None,  # defaults to rc figure.edgecolor
           frameon=True,
           FigureClass=Figure,
           **kwargs
```

```
        ):
    """
    Creates a new figure.

    Parameters
    ----------

    num : integer or string, optional, default: none
        If not provided, a new figure will be created, and the figure number
        will be incremented. The figure objects holds this number in a `number`
        attribute.
        If num is provided, and a figure with this id already exists, make
        it active, and returns a reference to it. If this figure does not
        exists, create it and returns it.
        If num is a string, the window title will be set to this figure's
        `num`.

    figsize : tuple of integers, optional, default: None
        width, height in inches. If not provided, defaults to rc
        figure.figsize.

    dpi : integer, optional, default: None
        resolution of the figure. If not provided, defaults to rc figure.dpi.

    facecolor :
        the background color. If not provided, defaults to rc figure.facecolor

    edgecolor :
        the border color. If not provided, defaults to rc figure.edgecolor

    Returns
    -------
    figure : Figure
        The Figure instance returned will also be passed to new_figure_manager
        in the backends, which allows to hook custom Figure classes into the
        pylab interface. Additional kwargs will be passed to the figure init
        function.

    Notes
    -----
    If you are creating many figures, make sure you explicitly call "close"
    on the figures you are not using, because this will enable pylab
    to properly clean up the memory.

    rcParams defines the default values, which can be modified in the
    matplotlibrc file

    """

    if figsize is None:
        figsize = rcParams['figure.figsize']
    if dpi is None:
        dpi = rcParams['figure.dpi']
    if facecolor is None:
```

```
    facecolor = rcParams['figure.facecolor']
if edgecolor is None:
    edgecolor = rcParams['figure.edgecolor']

allnums = get_fignums()
next_num = max(allnums) + 1 if allnums else 1
figLabel = ''
if num is None:
    num = next_num
elif is_string_like(num):
    figLabel = num
    allLabels = get_figlabels()
    if figLabel not in allLabels:
        if figLabel == 'all':
            warnings.warn("close('all') closes all existing figures")
        num = next_num
    else:
        inum = allLabels.index(figLabel)
        num = allnums[inum]
else:
    num = int(num)  # crude validation of num argument

figManager = _pylab_helpers.Gcf.get_fig_manager(num)
if figManager is None:
    max_open_warning = rcParams['figure.max_open_warning']

    if (max_open_warning >= 1 and len(allnums) >= max_open_warning):
        warnings.warn(
            "More than %d figures have been opened. Figures "
            "created through the pyplot interface "
            "(`matplotlib.pyplot.figure`) are retained until "
            "explicitly closed and may consume too much memory. "
            "(To control this warning, see the rcParam "
            "`figure.max_open_warning`)." %
            max_open_warning, RuntimeWarning)

    if get_backend().lower() == 'ps':
        dpi = 72

    figManager = new_figure_manager(num, figsize=figsize,
                                    dpi=dpi,
                                    facecolor=facecolor,
                                    edgecolor=edgecolor,
                                    frameon=frameon,
                                    FigureClass=FigureClass,
                                    **kwargs)

    if figLabel:
        figManager.set_window_title(figLabel)
        figManager.canvas.figure.set_label(figLabel)

    # make this figure current on button press event
    def make_active(event):
        _pylab_helpers.Gcf.set_active(figManager)
```

```
        cid = figManager.canvas.mpl_connect('button_press_event', make_active)
        figManager._cidgcf = cid

        _pylab_helpers.Gcf.set_active(figManager)
        fig = figManager.canvas.figure
        fig.number = num

        # make sure backends (inline) that we don't ship that expect this
        # to be called in plotting commands to make the figure call show
        # still work.  There is probably a better way to do this in the
        # FigureManager base class.
        if matplotlib.is_interactive():
            draw_if_interactive()

        if _INSTALL_FIG_OBSERVER:
            fig.stale_callback = _auto_draw_if_interactive

    return figManager.canvas.figure
```

2 Astropy

The package is the magic that will make your astronomy code easier to write. There are already functions for many of the things you would want to do, e.g. `.fits` reading/writing, data table reading/writing, sky coordinate transformations, cosmology calculations, and more.

2.1 Reading tables

You won't want to type most data directly into your python code, instead you can use `astropy.table` (see also: http://docs.astropy.org/en/stable/table/) to read the data in from a file. The following data types are directly supported:

- fits
- ascii
- aastex
- basic
- cds
- daophot
- ecsv
- fixed_width
- html
- ipac
- latex
- rdb
- sextractor
- tab
- csv
- votable

For other formats you can extend the existing `table` class to support it.

```
In [26]: import astropy
         print(astropy.__version__)
```

```
1.2.1
```

```
In [27]: from astropy.table import Table
         t = Table.read('data.csv', format='ascii.csv')
         print(t)
         print('==========')
         print(t.info)
         print('==========')
         print(t.colnames)
```

```
ID  x   y   sy  sx  pxy
--- --- --- --- --- -----
  1 201 592  61   9 -0.84
  2 244 401  25   4  0.31
  3  47 583  38  11  0.64
  4 287 402  15   7 -0.27
  5 203 495  21   5 -0.33
  6  58 173  15   9  0.67
  7 202 479  27   4 -0.02
  8 202 504  14   4 -0.05
  9 198 510  30  11 -0.84
 10 158 416  16   7 -0.69
 11 165 393  14   5   0.3
 12 201 442  25   5 -0.46
 13 157 317  52   5 -0.03
 14 131 311  16   6   0.5
 15 166 400  34   6  0.73
 16 160 337  31   5 -0.52
 17 186 423  42   9   0.9
 18 125 334  26   8   0.4
 19 218 533  16   6 -0.78
 20 146 344  22   5 -0.56
==========
<Table length=20>
name  dtype
---- -------
  ID   int64
   x   int64
   y   int64
  sy   int64
  sx   int64
 pxy float64

==========
['ID', 'x', 'y', 'sy', 'sx', 'pxy']

/Users/coleman/anaconda/envs/python3/lib/python3.5/site-packages/astropy/table/column.py:263: FutureWar
  return self.data.__eq__(other)
```

The columns of `t` can be accessed by name:

```
In [28]: print(t['ID', 'pxy'])
```

```
ID  pxy
--- -----
  1 -0.84
  2  0.31
```

```
  3  0.64
  4 -0.27
  5 -0.33
  6  0.67
  7 -0.02
  8 -0.05
  9 -0.84
 10 -0.69
 11   0.3
 12 -0.46
 13 -0.03
 14   0.5
 15  0.73
 16 -0.52
 17   0.9
 18   0.4
 19 -0.78
 20 -0.56
```

And math can be applied:

```
In [29]: print(np.sqrt(t['sx']**2 + t['sy']**2))

sx
-------------
61.6603600379
25.3179778023
39.5600808897
16.5529453572
21.5870331449
17.4928556845
27.2946881279
14.5602197786
31.9530906173
17.4642491966
14.8660687473
 25.495097568
52.2398315464
17.0880074906
34.5253530033
31.4006369362
42.9534631898
27.2029410175
17.0880074906
22.5610283454
```

If you have multiple data tables you can also stack them (vertically or horizontally) or join them (see http://docs.astropy.org/en/stable/table/operations.html)