Using_astropy

June 30, 2017

```
In [1]: # The following is to know when this notebook has been run and with which python version.
        import time, sys
        print(time.ctime())
        print(sys.version.split('|')[0])
```

```
Fri Jun 30 13:30:36 2017
3.6.1
```

1 G The astropy package

The Astropy Project is a community effort to develop a single core package for Astronomy in Python and foster interoperability between Python astronomy packages. More informations here: http://www.astropy.org/

!!! WARNING !!!

To install atpy, one must use the –no-deps option when using pip (otherwise updates of numpy may be performed):

pip install -U –no-deps astropy

```
In [2]: %matplotlib inline
        import numpy as np
        import matplotlib.pyplot as plt
```

1.0.1 Constants and Units

http://docs.astropy.org/en/stable/constants/index.html

http://docs.astropy.org/en/stable/units/index.html

```
In [3]: from astropy import constants as const
        from astropy import units as u
        help(const)
```

```
Help on package astropy.constants in astropy:

NAME
    astropy.constants

DESCRIPTION
    Contains astronomical and physical constants for use in Astropy or other
    places.

    A typical use case might be::

        >>> from astropy.constants import c, m_e
        >>> # ... define the mass of something you want the rest energy of as m ...
        >>> m = m_e
```

```
>>> E = m * c**2
>>> E.to('MeV')  # doctest: +FLOAT_CMP
<Quantity 0.510998927603161 MeV>
```

The following constants are available:

Name	Value	Unit	Description
G	6.67384e-11	m3 / (kg s2)	Gravitational constant
L_bol0	3.0128e+28	W	Luminosity for absolute bolometric magnitude 0
L_sun	3.846e+26	W	Solar luminosity
M_earth	5.9742e+24	kg	Earth mass
M_jup	1.8987e+27	kg	Jupiter mass
M_sun	1.9891e+30	kg	Solar mass
N_A	6.02214129e+23	1 / (mol)	Avogadro's number
R	8.3144621	J / (K mol)	Gas constant
R_earth	6378136	m	Earth equatorial radius
R_jup	71492000	m	Jupiter equatorial radius
R_sun	695508000	m	Solar radius
Ryd	10973731.6	1 / (m)	Rydberg constant
a0	5.29177211e-11	m	Bohr radius
alpha	0.00729735257		Fine-structure constant
atmosphere	101325	Pa	Atmosphere
au	1.49597871e+11	m	Astronomical Unit
b_wien	0.0028977721	m K	Wien wavelength displacement law constant
c	299792458	m / (s)	Speed of light in vacuum
e	1.60217657e-19	C	Electron charge
eps0	8.85418782e-12	F/m	Electric constant
g0	9.80665	m / s2	Standard acceleration of gravity
h	6.62606957e-34	J s	Planck constant
hbar	1.05457173e-34	J s	Reduced Planck constant
k_B	1.3806488e-23	J / (K)	Boltzmann constant
kpc	3.08567758e+19	m	Kiloparsec
m_e	9.10938291e-31	kg	Electron mass
m_n	1.67492735e-27	kg	Neutron mass
m_p	1.67262178e-27	kg	Proton mass
mu0	1.25663706e-06	N/A2	Magnetic constant
muB	9.27400968e-24	J/T	Bohr magneton
pc	3.08567758e+16	m	Parsec
sigma_T	6.65245873e-29	m2	Thomson scattering cross-section
sigma_sb	5.670373e-08	W / (K4 m2)	Stefan-Boltzmann constant
u	1.66053892e-27	kg	Atomic mass

PACKAGE CONTENTS

cgs
constant
setup_package
si
tests (package)

DATA

G = <Constant name='Gravitational constant' value=6...e-15 unit='m3 /...

```
    L_bol0 = <Constant name='Luminosity for absolute bolometr...0.0 unit='...
    L_sun = <Constant name='Solar luminosity' value=3.846e+2...rence="Alle...
    M_earth = <Constant name='Earth mass' value=5.9742e+24 unc...rence="Al...
    M_jup = <Constant name='Jupiter mass' value=1.8987e+27 u...rence="Alle...
    M_sun = <Constant name='Solar mass' value=1.9891e+30 unc...rence="Alle...
    N_A = <Constant name="Avogadro's number" value=6.02214...y=2.7e+16 uni...
    R = <Constant name='Gas constant' value=8.3144621 un...5e-06 unit='J /...
    R_earth = <Constant name='Earth equatorial radius' value=6...rence="Al...
    R_jup = <Constant name='Jupiter equatorial radius' value...rence="Alle...
    R_sun = <Constant name='Solar radius' value=695508000.0 ...rence="Alle...
    Ryd = <Constant name='Rydberg constant' value=10973731...nty=5.5e-05 u...
    a0 = <Constant name='Bohr radius' value=5.2917721092e...rtainty=1.7e-2...
    absolute_import = _Feature((2, 5, 0, 'alpha', 1), (3, 0, 0, 'alpha', 0...
    alpha = <Constant name='Fine-structure constant' value=0...ertainty=2...
    atmosphere = <Constant name='Atmosphere' value=101325 uncertainty=0.0 ...
    au = <Constant name='Astronomical Unit' value=1495978...=0.0 unit='m' ...
    b_wien = <Constant name='Wien wavelength displacement law...ainty=2.6e...
    c = <Constant name='Speed of light in vacuum' value=...rtainty=0.0 uni...
    division = _Feature((2, 2, 0, 'alpha', 2), (3, 0, 0, 'alpha', 0), 8192...
    e = <Constant name='Electron charge' value=1.6021765...rtainty=3.5e-27...
    eps0 = <Constant name='Electric constant' value=8.85418...rtainty=0.0 ...
    g0 = <Constant name='Standard acceleration of gravity...tainty=0.0 uni...
    h = <Constant name='Planck constant' value=6.6260695...ainty=2.9e-41 u...
    hbar = <Constant name='Reduced Planck constant' value=1...496649644e-4...
    k_B = <Constant name='Boltzmann constant' value=1.3806...nty=1.3e-29 u...
    kpc = <Constant name='Kiloparsec' value=3.085677581467...rtainty=0.0 u...
    m_e = <Constant name='Electron mass' value=9.10938291e...ertainty=4e-3...
    m_n = <Constant name='Neutron mass' value=1.674927351e...tainty=7.4e-3...
    m_p = <Constant name='Proton mass' value=1.672621777e-...tainty=7.4e-3...
    mu0 = <Constant name='Magnetic constant' value=1.25663...tainty=0.0 un...
    muB = <Constant name='Bohr magneton' value=9.27400968e...ainty=2e-31 u...
    pc = <Constant name='Parsec' value=3.0856775814671916...rtainty=0.0 un...
    print_function = _Feature((2, 6, 0, 'alpha', 2), (3, 0, 0, 'alpha', 0)...
    sigma_T = <Constant name='Thomson scattering cross-section...tainty=1...
    sigma_sb = <Constant name='Stefan-Boltzmann constant' value...1e-13 un...
    u = <Constant name='Atomic mass' value=1.660538921e-...tainty=7.3e-35 ...
    unicode_literals = _Feature((2, 6, 0, 'alpha', 2), (3, 0, 0, 'alpha', ...

FILE
    /home/morisset/anaconda2/envs/py3k6/lib/python3.6/site-packages/astropy/constants/__init__.py
```

In [4]:
```python
# Pretty printing
print(const.c)
```

```
Name   = Speed of light in vacuum
  Value  = 299792458.0
  Uncertainty  = 0.0
  Unit  = m / s
  Reference = CODATA 2010
```

In [5]:
```python
# .to change the unit
print(const.c.to('Mpc/yr'))
```

```
3.0660139378795275e-07 Mpc / yr
```

```
In [6]: # basic operations are managed
        const.c * 2
```

Out[6]:

$5.9958492 \times 10^{8}\ \frac{\mathrm{m}}{\mathrm{s}}$

```
In [7]: np.sqrt(const.c)
```

Out[7]:

$17314.516\ \frac{\mathrm{m^{1/2}}}{\mathrm{s^{1/2}}}$

```
In [8]: print(np.sqrt(const.c))

17314.51581766005 m(1/2) / s(1/2)
```

```
In [9]: # Following the units
        M1 = 3 * const.M_sun
        M2 = 100 * u.g
        Dist = 2.2 * u.au
        F = const.G * M1 * M2 / Dist ** 2
        print(M1)
        print(F)

5.9673e+30 kg
8.228265585123966e+21 g m3 / (AU2 s2)
```

```
In [10]: F
```

Out[10]:

$8.2282656 \times 10^{21}\ \frac{\mathrm{m^{3}\,g}}{\mathrm{AU^{2}\,s^{2}}}$

```
In [11]: # Convert in more classical unit
         print(F.to(u.N))

0.0003676693920278125 N
```

```
In [12]: q = 42.0 * u.meter
```

```
In [13]: q**2
```

Out[13]:

$1764\ \mathrm{m^{2}}$

```
In [14]: # Extract only the value
         (q**2).value

Out[14]: 1764.0
```

```
In [15]: arr = np.array([q.value, q.value]) * const.G
         print(type(arr))
         print(arr)

<class 'astropy.units.quantity.Quantity'>
[  2.80301280e-09   2.80301280e-09] m3 / (kg s2)
```

```
In [16]: arr = np.ones(2) * q * const.G
         print(type(arr))
         print(arr)
```

```
<class 'astropy.units.quantity.Quantity'>
[  2.80301280e-09   2.80301280e-09] m4 / (kg s2)
```

```
In [17]: # Resolving redondant units
         t = 3.0 * u.kilometer / (130.51 * u.meter / u.second)
         print(t)
         print(t.decompose())
```

```
0.022986744310780783 km s / m
22.986744310780782 s
```

```
In [18]: x = 1.0 * u.parsec
         print(x.to(u.km))
```

```
30856775814671.914 km
```

```
In [19]: lam = 5007 * u.angstrom
```

```
In [20]: print(lam.to(u.nm))
         print(lam.to(u.micron))
```

```
500.70000000000005 nm
0.5007000000000001 micron
```

```
In [21]: # Some transformations needs extra information, available from u.special
         print(lam.to(u.Ry, equivalencies=u.spectral()))
```

```
0.18199861205330833 Ry
```

More in http://docs.astropy.org/en/stable/units/index.html

1.0.2 Data Table

http://docs.astropy.org/en/stable/table/index.html

```
In [22]: from astropy.table import Table
```

```
In [23]: # create a table with non homogeneous types
         a = [1, 4, 5]
         b = [2.0, 5.0, 8.2]
         c = ['x', 'y', 'z']
         t = Table([a, b, c], names=('a', 'b', 'c'), meta={'name': 'first table'})
         print(t)
```

```
 a   b   c
--- --- ---
  1 2.0   x
  4 5.0   y
  5 8.2   z
```

```
In [24]: # Pretty output
         t
```

```
Out[24]: <Table length=3>
           a      b     c
         int64 float64 str1
         ----- ------- ----
             1     2.0    x
             4     5.0    y
             5     8.2    z
```

In [25]:
```
# One can change the output format
t['b'].format = '7.3f'
t['a'].format = '{:.4f}'
# and add units
t['b'].unit = 's'
t
```

Out[25]:
```
<Table length=3>
  a       b     c
          s
int64  float64 str1
------ ------- ----
1.0000   2.000    x
4.0000   5.000    y
5.0000   8.200    z
```

In [26]:
```
t.show_in_browser(jsviewer=True)
```

In [27]:
```
# access the column names
t.colnames
```

Out[27]:
```
['a', 'b', 'c']
```

In [28]:
```
# length of the table (number of rows)
len(t)
```

Out[28]:
```
3
```

In [29]:
```
# Acces one element
t['a'][1]
```

Out[29]:
```
4
```

In [30]:
```
# Modify one element
t['a'][1] = 10
t
```

Out[30]:
```
<Table length=3>
   a       b     c
           s
 int64  float64 str1
------- ------- ----
 1.0000   2.000    x
10.0000   5.000    y
 5.0000   8.200    z
```

In [31]:
```
# easy add column:
t['d'] = [1, 2, 3]
```

In [32]:
```
t
```

Out[32]:
```
<Table length=3>
   a       b     c     d
           s
 int64  float64 str1 int64
------- ------- ---- -----
 1.0000   2.000    x     1
10.0000   5.000    y     2
 5.0000   8.200    z     3
```

In [33]:
```
t.rename_column('a', 'A')
t
```

Out[33]:
```
<Table length=3>
   A       b     c     d
           s
 int64  float64 str1 int64
------- ------- ---- -----
 1.0000   2.000    x     1
10.0000   5.000    y     2
 5.0000   8.200    z     3
```

In [34]:
```
t.add_row([-8, -9.3, 'r', 10])
t
```

Out[34]:
```
<Table length=4>
   A       b     c     d
           s
 int64  float64 str1 int64
------- ------- ---- -----
 1.0000   2.000    x     1
10.0000   5.000    y     2
 5.0000   8.200    z     3
-8.0000  -9.300    r    10
```

In [35]:
```
t.add_row([-9, 40, 'q', 10])
t
```

Out[35]:
```
<Table length=5>
   A       b     c     d
           s
 int64  float64 str1 int64
------- ------- ---- -----
 1.0000   2.000    x     1
10.0000   5.000    y     2
 5.0000   8.200    z     3
-8.0000  -9.300    r    10
-9.0000  40.000    q    10
```

In [36]:
```
# Masked values
t = Table([a, b, c], names=('a', 'b', 'c'), masked=True)
t['a'].mask = [True, True, False] # True is for the masked values!!
t
```

Out[36]:
```
<Table masked=True length=3>
  a      b     c
int64 float64 str1
----- ------- ----
   --     2.0    x
   --     5.0    y
    5     8.2    z
```

In [37]:
```
t['a'].mask = [True, False, False] # True is for the masked values!!
t
```

Out[37]:
```
<Table masked=True length=3>
  a      b     c
```

```
int64 float64 str1
----- ------- ----
   --     2.0    x
    4     5.0    y
    5     8.2    z
```

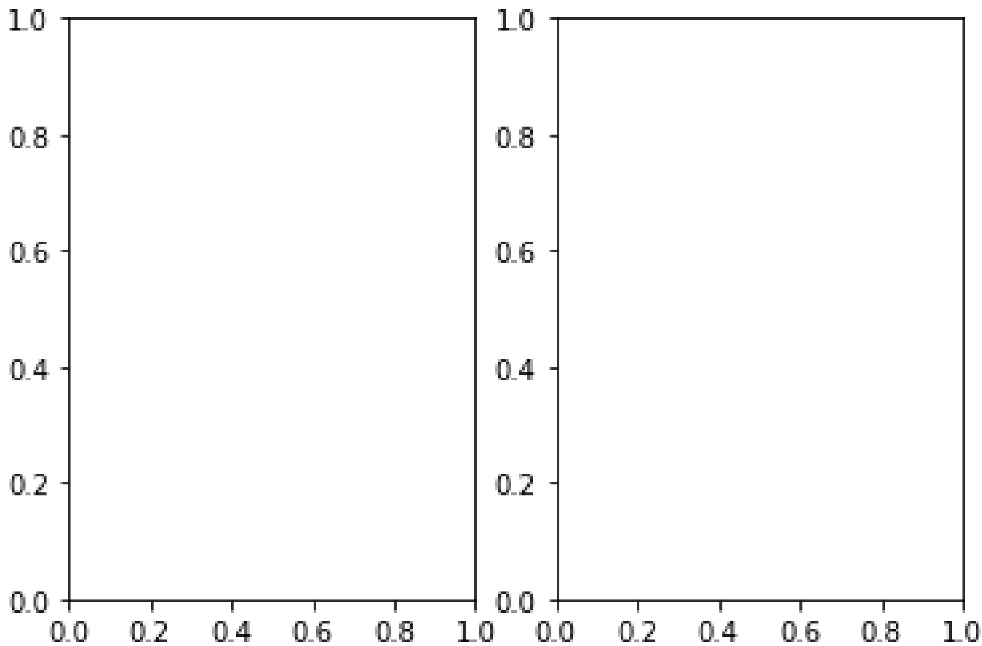
In [38]:
```
# Creat a table from a table
t2 = Table([t['a']**2, t['b']**2, t['a']**2 + t['b']**2], names=('a2', 'b2', 'a2+b2'))
t2
```

Out[38]:
```
<Table masked=True length=3>
  a2     b2    a2+b2
int64 float64 float64
----- ------- -------
   --     4.0      --
   16    25.0    41.0
   25   67.24   92.24
```

In [39]:
```
# Managing columns
from astropy.table import Column
```

In [40]:
```
# Create a table combining different formats
a = (1, 4)
b = np.array([[2, 3], [5, 6]])  # vector column
c = Column(['x', 'y'], name='axis')
f, (ax1, ax2) = plt.subplots(1,2)
d = Column([ax1, ax2], name='axis obj')
arr = (a, b, c, d)
t3 = Table(arr)  # Data column named "c" has a name "axis" in that table
t3
```

Out[40]:
```
<Table length=2>
 col0 col1 [2] axis               axis obj
int64  int64   str1                object
----- -------- ---- -----------------------------------
    1   2 .. 3    x    Axes(0.125,0.125;0.352273x0.755)
    4   5 .. 6    y Axes(0.547727,0.125;0.352273x0.755)
```



In [41]:
```
# table from a dictionnary
rr = {'a': [1, 4],
      'b': [2.0, 5.0],
      'c': ('x', 'y')}
t4 = Table(rr)
t4
```

Out[41]:
```
<Table length=2>
  a      b     c
int64 float64 str1
----- ------- ----
    1     2.0    x
    4     5.0    y
```

In [42]:
```
# Create table row by row
t5 = Table(rows=[{'a': 5, 'b': 10}, {'a': 15, 'b': 30}])
t5
```

Out[42]:
```
<Table length=2>
  a     b
int64 int64
----- -----
    5    10
   15    30
```

In [44]:
```
# Numpy structured array
arr = np.array([(1, 2.0, 'x'),
                 (4, 5.0, 'y')],
                dtype=[('a', 'i8'), ('b', 'f8'), ('c', 'S2')])
print(arr)
t6 = Table(arr)
print(t6)
```

```
[(1,  2., b'x') (4,  5., b'y')]
 a   b   c 
--- --- ---
  1 2.0   x
  4 5.0   y
```

Python arrays versus **numpy** arrays as input

There is a slightly subtle issue that is important to understand in the way that Table objects are created. Any data input that looks like a Python list (including a tuple) is considered to be a list of columns. In contrast an homogeneous numpy array input is interpreted as a list of rows:

```
In [45]: t7 = Table(((1,2,3), (4,5,6), (7,8,9)))
         t7
```

```
Out[45]: <Table length=3>
          col0  col1  col2
         int64 int64 int64
         ----- ----- -----
             1     4     7
             2     5     8
             3     6     9
```

```
In [47]: arr7 = np.array(((1,2,3), (4,5,6)))
         t7 = Table(arr7)
         print(arr7)
         print(t7)
```

```
[[1 2 3]
 [4 5 6]]
col0 col1 col2
---- ---- ----
   1    2    3
   4    5    6
```

```
In [48]: arr = np.array([(1, 2.0, 'x'),
                         (4, 5.0, 'y')],
                        dtype=[('a', 'i8'), ('b', 'f8'), ('c', 'S2')])
         t6 = Table(arr, copy=False) # pointing to the original data
         arr['a'][0] = 99
         print(arr)
         print(t6)
```

```
[(99,  2., b'x') ( 4,  5., b'y')]
 a   b   c 
--- --- ---
 99 2.0   x
  4 5.0   y
```

```
In [49]: t6.columns
```

```
Out[49]: TableColumns([('a', <Column name='a' dtype='int64' length=2>
                        99
                         4), ('b', <Column name='b' dtype='float64' length=2>
                        2.0
                        5.0), ('c', <Column name='c' dtype='bytes2' length=2>
                        x
                        y)])
```

```
In [50]: t6.colnames
```

```
Out[50]: ['a', 'b', 'c']
```

```
In [51]: # One can obtain a numpy structured array from a Table
         np.array(t6)
```

```
Out[51]: array([(99,  2., b'x'), ( 4,  5., b'y')],
               dtype=[('a', '<i8'), ('b', '<f8'), ('c', 'S2')])
```

```
In [52]: arr = np.arange(3000).reshape(100, 30)  # 100 rows x 30 columns array
         t = Table(arr)
         print(t)
```

```
col0 col1 col2 col3 col4 col5 col6 ... col23 col24 col25 col26 col27 col28 col29
---- ---- ---- ---- ---- ---- ---- ... ----- ----- ----- ----- ----- ----- -----
   0    1    2    3    4    5    6 ...    23    24    25    26    27    28    29
  30   31   32   33   34   35   36 ...    53    54    55    56    57    58    59
  60   61   62   63   64   65   66 ...    83    84    85    86    87    88    89
  90   91   92   93   94   95   96 ...   113   114   115   116   117   118   119
 120  121  122  123  124  125  126 ...   143   144   145   146   147   148   149
 150  151  152  153  154  155  156 ...   173   174   175   176   177   178   179
 180  181  182  183  184  185  186 ...   203   204   205   206   207   208   209
 210  211  212  213  214  215  216 ...   233   234   235   236   237   238   239
 240  241  242  243  244  245  246 ...   263   264   265   266   267   268   269
 270  271  272  273  274  275  276 ...   293   294   295   296   297   298   299
 ...  ...  ...  ...  ...  ...  ... ...   ...   ...   ...   ...   ...   ...   ...
2670 2671 2672 2673 2674 2675 2676 ...  2693  2694  2695  2696  2697  2698  2699
2700 2701 2702 2703 2704 2705 2706 ...  2723  2724  2725  2726  2727  2728  2729
2730 2731 2732 2733 2734 2735 2736 ...  2753  2754  2755  2756  2757  2758  2759
2760 2761 2762 2763 2764 2765 2766 ...  2783  2784  2785  2786  2787  2788  2789
2790 2791 2792 2793 2794 2795 2796 ...  2813  2814  2815  2816  2817  2818  2819
2820 2821 2822 2823 2824 2825 2826 ...  2843  2844  2845  2846  2847  2848  2849
2850 2851 2852 2853 2854 2855 2856 ...  2873  2874  2875  2876  2877  2878  2879
2880 2881 2882 2883 2884 2885 2886 ...  2903  2904  2905  2906  2907  2908  2909
2910 2911 2912 2913 2914 2915 2916 ...  2933  2934  2935  2936  2937  2938  2939
2940 2941 2942 2943 2944 2945 2946 ...  2963  2964  2965  2966  2967  2968  2969
2970 2971 2972 2973 2974 2975 2976 ...  2993  2994  2995  2996  2997  2998  2999
Length = 100 rows
```

```
In [53]: t.show_in_browser(jsviewer=True)
```

```
In [54]: # create a simple table to play with
         arr = np.arange(15).reshape(5, 3)
         t = Table(arr, names=('a', 'b', 'c'), meta={'keywords': {'key1': 'val1'}})
         t
```

```
Out[54]: <Table length=5>
           a     b     c
         int64 int64 int64
         ----- ----- -----
             0     1     2
             3     4     5
             6     7     8
             9    10    11
            12    13    14
```

```
In [55]: t['a'] = [1, -2, 3, -4, 5]  # Set all
         t
```

```
Out[55]: <Table length=5>
           a     b     c
         int64 int64 int64
         ----- ----- -----
             1     1     2
            -2     4     5
             3     7     8
            -4    10    11
             5    13    14
```

```
In [56]: t['a'][2] = 30 # set one
         t
```

```
Out[56]: <Table length=5>
           a     b     c
         int64 int64 int64
         ----- ----- -----
             1     1     2
            -2     4     5
            30     7     8
            -4    10    11
             5    13    14
```

```
In [57]: # set one row
         t[1] = (8, 9, 10)
         t
```

```
Out[57]: <Table length=5>
           a     b     c
         int64 int64 int64
         ----- ----- -----
             1     1     2
             8     9    10
            30     7     8
            -4    10    11
             5    13    14
```

```
In [58]: # Set a whole column
         t['a'] = 99
         t
```

```
Out[58]: <Table length=5>
           a     b     c
         int64 int64 int64
         ----- ----- -----
            99     1     2
            99     9    10
            99     7     8
            99    10    11
            99    13    14
```

```
In [59]: # Add a column
         t.add_column(Column(np.array([1,2,3,4,5]), name='d'))
         t
```

```
Out[59]: <Table length=5>
           a     b     c     d
         int64 int64 int64 int64
         ----- ----- ----- -----
            99     1     2     1
            99     9    10     2
            99     7     8     3
            99    10    11     4
            99    13    14     5
```

```
In [60]: # remove a column
         t.remove_column('b')
         t
```

```
Out[60]: <Table length=5>
           a     c     d
         int64 int64 int64
         ----- ----- -----
            99     2     1
            99    10     2
            99     8     3
            99    11     4
            99    14     5
```

```
In [61]: # add a row
         t.add_row([-8, -9, 10])
         t
```

```
Out[61]: <Table length=6>
           a     c     d
         int64 int64 int64
         ----- ----- -----
            99     2     1
            99    10     2
            99     8     3
            99    11     4
            99    14     5
            -8    -9    10
```

```
In [62]: # Remove some rows
         t.remove_rows([1, 2])
         t
```

```
Out[62]: <Table length=4>
           a     c     d
         int64 int64 int64
         ----- ----- -----
            99     2     1
            99    11     4
            99    14     5
            -8    -9    10
```

```
In [63]: # sort the Table using one column
         t.sort('c')
         t
```

Out[63]: <Table length=4>

```
  a     c     d
int64 int64 int64
----- ----- -----
   -8    -9    10
   99     2     1
   99    11     4
   99    14     5
```

In [64]:
```python
filter = (t['a'] > 50) & (t['d'] > 3)
print(filter)
```

```
[False False  True  True]
```

In [65]:
```python
t[filter]
```

Out[65]: <Table length=2>

```
  a     c     d
int64 int64 int64
----- ----- -----
   99    11     4
   99    14     5
```

In [66]:
```
%%writefile tab1.dat
#name    obs_date    mag_b  mag_v
M31     2012-01-02  17.0   17.5
M31     2012-01-02  17.1   17.4
M101    2012-01-02  15.1   13.5
M82     2012-02-14  16.2   14.5
M31     2012-02-14  16.9   17.3
M82     2012-02-14  15.2   15.5
M101    2012-02-14  15.0   13.6
M82     2012-03-26  15.7   16.5
M101    2012-03-26  15.1   13.5
M101    2012-03-26  14.8   14.3
```

```
Overwriting tab1.dat
```

In [67]:
```python
# directly read a Table from an ascii file
obs = Table.read('tab1.dat', format='ascii')
```

In [69]:
```python
print(obs)
```

```
name  obs_date  mag_b mag_v
---- ---------- ----- -----
 M31 2012-01-02  17.0  17.5
 M31 2012-01-02  17.1  17.4
M101 2012-01-02  15.1  13.5
 M82 2012-02-14  16.2  14.5
 M31 2012-02-14  16.9  17.3
 M82 2012-02-14  15.2  15.5
M101 2012-02-14  15.0  13.6
 M82 2012-03-26  15.7  16.5
M101 2012-03-26  15.1  13.5
M101 2012-03-26  14.8  14.3
```

```
In [70]: # Group data
         obs_by_name = obs.group_by('name')
         obs_by_name
```

```
Out[70]: <Table length=10>
         name  obs_date   mag_b   mag_v
         str4   str10    float64 float64
         ---- ---------- ------- -------
         M101 2012-01-02    15.1    13.5
         M101 2012-02-14    15.0    13.6
         M101 2012-03-26    15.1    13.5
         M101 2012-03-26    14.8    14.3
          M31 2012-01-02    17.0    17.5
          M31 2012-01-02    17.1    17.4
          M31 2012-02-14    16.9    17.3
          M82 2012-02-14    16.2    14.5
          M82 2012-02-14    15.2    15.5
          M82 2012-03-26    15.7    16.5
```

```
In [71]: print(obs_by_name.groups.keys)
```

```
name
----
M101
 M31
 M82
```

```
In [72]: # Using 2 keys to group
         print(obs.group_by(['name', 'obs_date']).groups.keys)
```

```
name  obs_date
---- ----------
M101 2012-01-02
M101 2012-02-14
M101 2012-03-26
 M31 2012-01-02
 M31 2012-02-14
 M82 2012-02-14
 M82 2012-03-26
```

```
In [73]: # Extracting a group
         print(obs_by_name.groups[1])
```

```
name  obs_date  mag_b mag_v
---- ---------- ----- -----
 M31 2012-01-02  17.0  17.5
 M31 2012-01-02  17.1  17.4
 M31 2012-02-14  16.9  17.3
```

```
In [74]: # Using a mask to select entries
         mask = obs_by_name.groups.keys['name'] == 'M101'
         print(mask)
         print(obs_by_name.groups[mask])
```

```
[ True False False]
name  obs_date  mag_b mag_v
```

```
---- ---------- ----- -----
M101 2012-01-02  15.1  13.5
M101 2012-02-14  15.0  13.6
M101 2012-03-26  15.1  13.5
M101 2012-03-26  14.8  14.3
```

```
In [75]: # Some functions can be applied to the elements of a group
         obs_mean = obs_by_name.groups.aggregate(np.mean)
         print(obs_mean)
```

```
name mag_b mag_v
---- ----- ------
M101  15.0 13.725
 M31  17.0   17.4
 M82  15.7   15.5
```

```
WARNING: Cannot aggregate column 'obs_date' with type '<U10' [astropy.table.groups]
```

```
In [76]: print(obs_by_name['name', 'mag_v', 'mag_b'].groups.aggregate(np.mean))
```

```
name mag_v  mag_b
---- ------ -----
M101 13.725  15.0
 M31   17.4  17.0
 M82   15.5  15.7
```

```
In [77]: # creat a new Table on the fly
         obs1 = Table.read("""name    obs_date    mag_b  logLx
         M31     2012-01-02  17.0   42.5
         M82     2012-10-29  16.2   43.5
         M101    2012-10-31  15.1   44.5""", format='ascii')
```

```
In [78]: # this is used to stack Tables
         from astropy.table import vstack
```

```
In [79]: tvs = vstack([obs, obs1])
         tvs
```

```
Out[79]: <Table masked=True length=13>
         name  obs_date   mag_b   mag_v   logLx
         str4   str10    float64 float64 float64
         ---- ---------- ------- ------- -------
          M31 2012-01-02    17.0    17.5      --
          M31 2012-01-02    17.1    17.4      --
         M101 2012-01-02    15.1    13.5      --
          M82 2012-02-14    16.2    14.5      --
          M31 2012-02-14    16.9    17.3      --
          M82 2012-02-14    15.2    15.5      --
         M101 2012-02-14    15.0    13.6      --
          M82 2012-03-26    15.7    16.5      --
         M101 2012-03-26    15.1    13.5      --
         M101 2012-03-26    14.8    14.3      --
          M31 2012-01-02    17.0      --    42.5
          M82 2012-10-29    16.2      --    43.5
         M101 2012-10-31    15.1      --    44.5
```

```
In [80]: %%writefile data6.dat
         Line        Iobs     lambda  rel_er   Obs_code
         H  1  4861A 1.00000    4861. 0.08000  Anabel
         H  1  6563A 2.8667     6563. 0.19467  Anabel
         H  1  4340A 0.4933     4340. 0.03307  Anabel
         H  1  4102A 0.2907     4102. 0.02229  Anabel
         H  1  3970A 0.1800     3970. 0.01253  Anabel
         N  2  6584A 2.1681     6584. 0.08686  Anabel
         N  2 121.7m 0.0044621217000. 0.20000  Liu
         O  1  6300A 0.0147     6300. 0.00325  Anabel
         TOTL  2326A 0.07900    2326. 0.20000  Adams
         C  2 157.6m 0.00856 1576000. 0.20000  Liu
         O  1 63.17m 0.13647  631700. 0.10000  Liu
         O  1 145.5m 0.00446 1455000. 0.200    Liu
         TOTL  3727A 0.77609    3727. 0.200    Torres-Peimbert
         S II  4070A 0.06174    4070. 0.200    Torres-Peimbert
         S II  4078A 0.06174    4078. 0.200    Torres-Peimbert

Overwriting data6.dat

In [81]: d = Table.read('data6.dat', format='ascii.fixed_width',
                        col_starts=(0, 12, 20, 29, 38))
         d

Out[81]: <Table length=15>
             Line      Iobs     lambda   rel_er     Obs_code
            str11    float64   float64  float64      str15
         ----------- -------- ---------- ------- ---------------
         H  1  4861A      1.0     4861.0    0.08          Anabel
         H  1  6563A   2.8667     6563.0 0.19467          Anabel
         H  1  4340A   0.4933     4340.0 0.03307          Anabel
         H  1  4102A   0.2907     4102.0 0.02229          Anabel
         H  1  3970A     0.18     3970.0 0.01253          Anabel
         N  2  6584A   2.1681     6584.0 0.08686          Anabel
         N  2 121.7m 0.004462 1217000.0     0.2             Liu
         O  1  6300A   0.0147     6300.0 0.00325          Anabel
         TOTL  2326A    0.079     2326.0     0.2           Adams
         C  2 157.6m  0.00856 1576000.0     0.2             Liu
         O  1 63.17m  0.13647  631700.0     0.1             Liu
         O  1 145.5m  0.00446 1455000.0     0.2             Liu
         TOTL  3727A  0.77609     3727.0     0.2 Torres-Peimbert
         S II  4070A  0.06174     4070.0     0.2 Torres-Peimbert
         S II  4078A  0.06174     4078.0     0.2 Torres-Peimbert

In [82]: d.group_by('Obs_code')

Out[82]: <Table length=15>
             Line      Iobs     lambda   rel_er     Obs_code
            str11    float64   float64  float64      str15
         ----------- -------- ---------- ------- ---------------
         TOTL  2326A    0.079     2326.0     0.2           Adams
         H  1  4861A      1.0     4861.0    0.08          Anabel
         H  1  6563A   2.8667     6563.0 0.19467          Anabel
         H  1  4340A   0.4933     4340.0 0.03307          Anabel
         H  1  4102A   0.2907     4102.0 0.02229          Anabel
```

```
H  1  3970A     0.18    3970.0 0.01253          Anabel
N  2  6584A   2.1681    6584.0 0.08686          Anabel
O  1  6300A   0.0147    6300.0 0.00325          Anabel
N  2 121.7m 0.004462 1217000.0     0.2             Liu
C  2 157.6m  0.00856 1576000.0     0.2             Liu
O  1 63.17m  0.13647  631700.0     0.1             Liu
O  1 145.5m  0.00446 1455000.0     0.2             Liu
TOTL  3727A  0.77609    3727.0     0.2 Torres-Peimbert
S II  4070A  0.06174    4070.0     0.2 Torres-Peimbert
S II  4078A  0.06174    4078.0     0.2 Torres-Peimbert
```

There is a lot of possibilities of joining Tables, see http://docs.astropy.org/en/stable/table/operations.html

```
In [83]: t = Table.read("ftp://cdsarc.u-strasbg.fr/pub/cats/J/other/RMxAA/45.261/digeda.dat",
                        format='ascii.cds',
                        readme='ftp://cdsarc.u-strasbg.fr/pub/cats/J/other/RMxAA/45.261/ReadMe')
```

```
Downloading ftp://cdsarc.u-strasbg.fr/pub/cats/J/other/RMxAA/45.261/digeda.dat [Done]
Downloading ftp://cdsarc.u-strasbg.fr/pub/cats/J/other/RMxAA/45.261/ReadMe [Done]
```

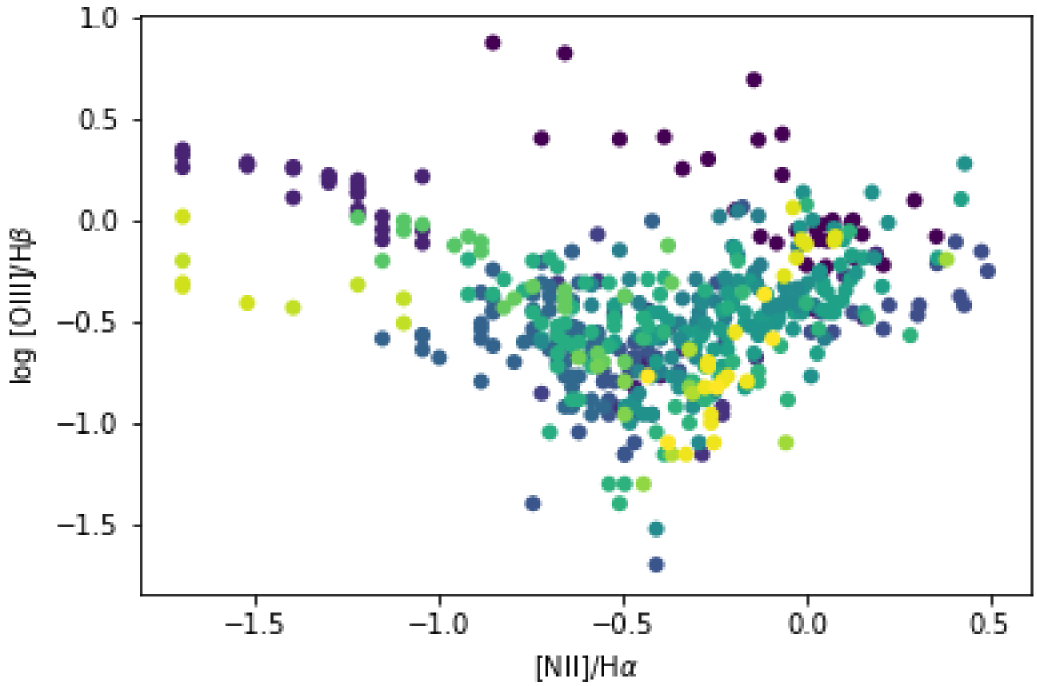
```
In [84]: t
```

```
Out[84]: <Table masked=True length=1061>
         ObsID   Pos    I3727   I4363    IHb    I4959  ... MType  Slit Region GalID  RefN
                  pc                                    ...
         int64 float64 float64 float64 float64 float64 ... int64 int64 int64  int64 int64
         ----- ------- ------- ------- ------- ------- ... ----- ----- ------ ----- -----
             1    0.03      --      --     1.0     0.2 ...    12     3      1     2     1
             2    0.03      --      --     1.0    0.33 ...    12     3      1     2     1
             3    0.05      --      --     1.0    0.32 ...    12     3      1     2     1
             4    0.06      --      --     1.0    0.12 ...    12     3      1     2     1
             5    0.07      --      --     1.0    0.27 ...    12     3      1     2     1
             6    0.12      --      --     1.0    0.31 ...    12     3      1     2     1
             7    0.13      --      --     1.0    0.29 ...    12     3      1     2     1
             8    0.15      --      --     1.0     0.3 ...    12     3      1     2     1
             9    0.15      --      --     1.0    0.57 ...    12     3      1     2     1
           ...     ...     ...     ...     ...     ... ...   ...   ...    ...   ...   ...
          1052    -1.0      --      --    0.35      -- ...     2     3      3    92    44
          1053    -1.0      --      --    0.35      -- ...     2     3      3    92    44
          1054    -1.0      --      --    0.35      -- ...     2     3      3    92    44
          1055    -1.0      --      --    0.35      -- ...     2     3      1    92    44
          1056    -1.0      --      --    0.35      -- ...     2     3      3    92    44
          1057    -1.0      --      --    0.35      -- ...     2     3      1    92    44
          1058    -1.0      --      --    0.35      -- ...     2     3      3    92    44
          1059    -1.0      --      --    0.35      -- ...     2     3      3    92    44
          1060    -1.0      --      --    0.35      -- ...     2     3      1    92    44
          1061    -1.0      --      --    0.35      -- ...     2     3      3    92    44
```

```
In [85]: t.show_in_browser(jsviewer=True)
```

```
In [86]: plt.scatter(np.log10(t['I6583']), np.log10(t['I5007']), c=t['RefN'], edgecolor='None')
         plt.xlabel(r'[NII]/H$\alpha$')
         plt.ylabel(r'log [OIII]/H$\beta$')
```

```
Out[86]: <matplotlib.text.Text at 0x7fea59a0c978>
```




```
In [87]: t = Table.read("ftp://cdsarc.u-strasbg.fr/pub/cats/VII/253/snrs.dat",
         readme="ftp://cdsarc.u-strasbg.fr/pub/cats/VII/253/ReadMe",
         format="ascii.cds")

Downloading ftp://cdsarc.u-strasbg.fr/pub/cats/VII/253/snrs.dat [Done]
Downloading ftp://cdsarc.u-strasbg.fr/pub/cats/VII/253/ReadMe [Done]

In [88]: t

Out[88]: <Table masked=True length=274>
            SNR      RAh   RAm   RAs  DE-  ... u_S(1GHz) Sp-Index u_Sp-Index   Names
                      h    min    s        ...
           str11    int64 int64 int64 str1 ...    str1    float64     str1      str26
         ----------- ----- ----- ----- ---- ... --------- -------- ---------- ----------
         G000.0+00.0    17    45    44    - ...         ?      0.8          ? Sgr A East
         G000.3+00.0    17    46    15    - ...        --      0.6         --         --
         G000.9+00.1    17    47    21    - ...         ?       --          v         --
         G001.0-00.1    17    48    30    - ...        --      0.6          ?         --
         G001.4-00.1    17    49    39    - ...         ?       --          ?         --
         G001.9+00.3    17    48    45    - ...        --      0.6         --         --
         G003.7-00.2    17    55    26    - ...        --     0.65         --         --
         G003.8+00.3    17    52    55    - ...         ?      0.6         --         --
         G004.2-03.5    18     8    55    - ...         ?      0.6          ?         --
                 ...   ...   ...   ...  ... ...       ...      ...        ...        ...
         G356.3-00.3    17    37    56    - ...         ?       --          ?         --
         G356.3-01.5    17    42    35    - ...         ?       --          ?         --
         G357.7-00.1    17    40    29    - ...        --      0.4         --  MSH 17-39
         G357.7+00.3    17    38    35    - ...        --      0.4          ?         --
         G358.0+03.8    17    26     0    - ...         ?       --          ?         --
```

```
        G358.1+00.1    17    37     0    - ...         ?       --           ?         --
        G358.5-00.9    17    46    10    - ...         ?       --           ?         --
        G359.0-00.9    17    46    50    - ...        --      0.5          --         --
        G359.1-00.5    17    45    30    - ...        --      0.4           ?         --
        G359.1+00.9    17    39    36    - ...         ?       --           ?         --
```

```
In [89]: t.show_in_browser(jsviewer=True)
```

```
In [91]: t[0:10].write('tab_cds1.tex', format='latex', overwrite=True)
```

```
In [92]: !cat tab_cds1.tex
```

```
\begin{table}
\begin{tabular}{cccccccccccccccccc}
SNR & RAh & RAm & RAs & DE- & DEd & DEm & MajDiam & --- & MinDiam & u_MinDiam & type & l_S(1GHz) & S(1GH
 & $\mathrm{h}$ & $\mathrm{min}$ & $\mathrm{s}$ &  & $\mathrm{{}^{\circ}}$ & $\mathrm{{}^{\prime}}$ & $\m
G000.0+00.0 & 17 & 45 & 44 & - & 29 & 0 & 3.5 & x & 2.5 &  & S &  & 100.0 & ? & 0.8 & ? & Sgr A East \\
G000.3+00.0 & 17 & 46 & 15 & - & 28 & 38 & 15.0 & x & 8.0 &  & S &  & 22.0 &  & 0.6 &  &  \\
G000.9+00.1 & 17 & 47 & 21 & - & 28 & 9 & 8.0 &  &  &  & C &  & 18.0 & ? &  & v &  \\
G001.0-00.1 & 17 & 48 & 30 & - & 28 & 9 & 8.0 &  &  &  & S &  & 15.0 &  & 0.6 & ? &  \\
G001.4-00.1 & 17 & 49 & 39 & - & 27 & 46 & 10.0 &  &  &  & S &  & 2.0 & ? &  & ? &  \\
G001.9+00.3 & 17 & 48 & 45 & - & 27 & 10 & 1.5 &  &  &  & S &  & 0.6 &  & 0.6 &  &  \\
G003.7-00.2 & 17 & 55 & 26 & - & 25 & 50 & 14.0 & x & 11.0 &  & S &  & 2.3 &  & 0.65 &  &  \\
G003.8+00.3 & 17 & 52 & 55 & - & 25 & 28 & 18.0 &  &  &  & S? &  & 3.0 & ? & 0.6 &  &  \\
G004.2-03.5 & 18 & 8 & 55 & - & 27 & 3 & 28.0 &  &  &  & S &  & 3.2 & ? & 0.6 & ? &  \\
G004.5+06.8 & 17 & 30 & 42 & - & 21 & 29 & 3.0 &  &  &  & S &  & 19.0 &  & 0.64 &  & Kepler, SN1604, 3C
\end{tabular}
\end{table}
```

```
In [95]: t[10:20].write('tab_cds1.ascii', format='ascii', delimiter='|', formats={'Sp-Index': '%0.2f'},
```

```
In [96]: !cat tab_cds1.ascii
```

```
SNR|RAh|RAm|RAs|DE-|DEd|DEm|MajDiam|---|MinDiam|u_MinDiam|type|l_S(1GHz)|S(1GHz)|u_S(1GHz)|Sp-Index|u_Sp-
G004.8+06.2|17|33|25|-|21|34|18.0||||S||3.0||0.60||
G005.2-02.6|18|7|30|-|25|45|18.0||||S||2.6|?|0.60|?|
G005.4-01.2|18|2|10|-|24|54|35.0||||C?||35.0|?|0.20|?|Milne 56
G005.5+00.3|17|57|4|-|24|0|15.0|x|12.0||S||5.5||0.70||
G005.9+03.1|17|47|20|-|22|16|20.0||||S||3.3|?|0.40|?|
G006.1+00.5|17|57|29|-|23|25|18.0|x|12.0||S||4.5||0.90||
G006.1+01.2|17|54|55|-|23|5|30.0|x|26.0||F||4.0|?|0.30|?|
G006.4-00.1|18|0|30|-|23|26|48.0||||C||310.0|||v|W28
G006.4+04.0|17|45|10|-|21|22|31.0||||S||1.3|?|0.40|?|
G006.5-00.4|18|2|11|-|23|34|18.0||||S||27.0||0.60||
```

```
In [98]: t[10:20].write('tab_cds2.ascii', format='ascii.fixed_width', delimiter='|', formats={'Sp-Index
```

```
In [99]: !cat tab_cds2.ascii
```

```
|         SNR | RAh | RAm | RAs | DE- | DEd | DEm | MajDiam | --- | MinDiam | u_MinDiam | type | l_S(1GH
| G004.8+06.2 |  17 |  33 |  25 |   - |  21 |  34 |    18.0 |     |         |           |    S |
| G005.2-02.6 |  18 |   7 |  30 |   - |  25 |  45 |    18.0 |     |         |           |    S |
| G005.4-01.2 |  18 |   2 |  10 |   - |  24 |  54 |    35.0 |     |         |           |   C? |
| G005.5+00.3 |  17 |  57 |   4 |   - |  24 |   0 |    15.0 |   x |    12.0 |           |    S |
| G005.9+03.1 |  17 |  47 |  20 |   - |  22 |  16 |    20.0 |     |         |           |    S |
| G006.1+00.5 |  17 |  57 |  29 |   - |  23 |  25 |    18.0 |   x |    12.0 |           |    S |
```

```
| G006.1+01.2 |   17 |   54 |   55 |     - |   23 |    5 |     30.0 |     x |     26.0 |              |     F |
| G006.4-00.1 |   18 |    0 |   30 |     - |   23 |   26 |     48.0 |       |          |              |     C |
| G006.4+04.0 |   17 |   45 |   10 |     - |   21 |   22 |     31.0 |       |          |              |     S |
| G006.5-00.4 |   18 |    2 |   11 |     - |   23 |   34 |     18.0 |       |          |              |     S |
```

The astropy Table can also read FITS files (if containing tables), VO tables and hdf5 format. See more there: http://docs.astropy.org/en/stable/io/unified.html

1.0.3 Time and Dates

The astropy.time package provides functionality for manipulating times and dates. Specific emphasis is placed on supporting time scales (e.g. UTC, TAI, UT1, TDB) and time representations (e.g. JD, MJD, ISO 8601) that are used in astronomy and required to calculate, e.g., sidereal times and barycentric corrections. It uses Cython to wrap the C language ERFA time and calendar routines, using a fast and memory efficient vectorization scheme. More here: http://docs.astropy.org/en/stable/time/index.html

1.0.4 Coordinates

The coordinates package provides classes for representing a variety of celestial/spatial coordinates, as well as tools for converting between common coordinate systems in a uniform way.

```
In [100]: from astropy import units as u
          from astropy.coordinates import SkyCoord
```

```
In [101]: c = SkyCoord(ra=10.5*u.degree, dec=41.2*u.degree, frame='icrs')
          c
```

```
Out[101]: <SkyCoord (ICRS): (ra, dec) in deg
              ( 10.5,  41.2)>
```

```
In [102]: c = SkyCoord('0 42 00 +41 12 00', frame='icrs', unit=(u.hourangle, u.deg))
          c
```

```
Out[102]: <SkyCoord (ICRS): (ra, dec) in deg
              ( 10.5,  41.2)>
```

```
In [103]: print(c.ra, c.dec)
```

```
10d30m00s 41d12m00s
```

```
In [104]: c.to_string('decimal')
```

```
Out[104]: '10.5 41.2'
```

```
In [105]: print(c.dec.to_string(format='latex'))
```

```
$41^\circ12{}^\prime00{}^{\prime\prime}$
```

$$41^\circ12{}^\prime00{}^{\prime\prime}$$

1.0.5 Modeling

astropy.modeling provides a framework for representing models and performing model evaluation and fitting. It currently supports 1-D and 2-D models and fitting with parameter constraints.

It is designed to be easily extensible and flexible. Models do not reference fitting algorithms explicitly and new fitting algorithms may be added without changing the existing models (though not all models can be used with all fitting algorithms due to constraints such as model linearity).

The goal is to eventually provide a rich toolset of models and fitters such that most users will not need to define new model classes, nor special purpose fitting routines (while making it reasonably easy to do when necessary).

http://docs.astropy.org/en/stable/modeling/index.html

1.0.6 Convolution and filtering

astropy.convolution provides convolution functions and kernels that offers improvements compared to the scipy scipy.ndimage convolution routines, including:

- Proper treatment of NaN values
- A single function for 1-D, 2-D, and 3-D convolution
- Improved options for the treatment of edges
- Both direct and Fast Fourier Transform (FFT) versions
- Built-in kernels that are commonly used in Astronomy

More on http://docs.astropy.org/en/stable/convolution/index.html