Using_astropy

January 10, 2021

[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])
```

```
Tue Nov 24 12:18:28 2020
3.7.9 (default, Aug 31 2020, 07:22:35)
[Clang 10.0.0 ]
```

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/

The astropy group received US$ 1 million last year to found astropy for 3 years.

https://www.slideshare.net/KelleCruz/astropy-project-update-for-adass

https://learn.astropy.org/

[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

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

```
4.0.2
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	6.6743e-11	m3 / (kg s2)	Gravitational constant
N_A	6.02214076e+23	1 / (mol)	Avogadro's number
R	8.31446262	J / (K mol)	Gas constant
Ryd	10973731.6	1 / (m)	Rydberg constant
a0	5.29177211e-11	m	Bohr radius
alpha	0.00729735257		Fine-structure constant
atm	101325	Pa	Standard atmosphere
b_wien	0.00289777196	m K	Wien wavelength displacement law constant
c	299792458	m / (s)	Speed of light in vacuum
e	1.60217663e-19	C	Electron charge
eps0	8.85418781e-12	F/m	Vacuum electric permittivity
g0	9.80665	m / s2	Standard acceleration of gravity
h	6.62607015e-34	J s	Planck constant
hbar	1.05457182e-34	J s	Reduced Planck constant
k_B	1.380649e-23	J / (K)	Boltzmann constant
m_e	9.1093837e-31	kg	Electron mass
m_n	1.6749275e-27	kg	Neutron mass
m_p	1.67262192e-27	kg	Proton mass
mu0	1.25663706e-06	N/A2	Vacuum magnetic permeability
muB	9.27401008e-24	J/T	Bohr magneton
sigma_T	6.65245873e-29	m2	Thomson scattering cross-section
sigma_sb	5.67037442e-08	W / (K4 m2)	Stefan-Boltzmann constant
u	1.66053907e-27	kg	Atomic mass
GM_earth	3.986004e+14	m3 / (s2)	Nominal Earth mass parameter

```
      GM_jup   1.2668653e+17     m3 / (s2)     Nominal Jupiter mass parameter
      GM_sun   1.3271244e+20     m3 / (s2)     Nominal solar mass parameter
      L_bol0     3.0128e+28          W         Luminosity for absolute
bolometric magnitude 0
      L_sun      3.828e+26           W         Nominal solar luminosity
     M_earth   5.97216787e+24        kg        Earth mass
      M_jup    1.8981246e+27         kg        Jupiter mass
      M_sun    1.98840987e+30        kg        Solar mass
     R_earth      6378100            m         Nominal Earth equatorial radius
      R_jup       71492000           m         Nominal Jupiter equatorial radius
      R_sun      695700000           m         Nominal solar radius
        au     1.49597871e+11        m         Astronomical Unit
       kpc     3.08567758e+19        m         Kiloparsec
        pc     3.08567758e+16        m         Parsec
    ========== ============== ================ =========================

PACKAGE CONTENTS
    astropyconst13
    astropyconst20
    astropyconst40
    cgs
    codata2010
    codata2014
    codata2018
    config
    constant
    iau2012
    iau2015
    si
    tests (package)
    utils

SUBMODULES
    codata
    iaudata

FUNCTIONS
    set_enabled_constants(modname)
        .. deprecated:: 4.0
            The set_enabled_constants function is deprecated and may be removed
in a future version.
                Use Use 'astropy.physical_constants' and
'astropy.astronomical_constants' instead.

        Context manager to temporarily set values in the ``constants``
        namespace to an older version.
        See :ref:`astropy-constants-prior` for usage.
```

```
        Parameters
        ----------
        modname : {'astropyconst13', 'astropyconst20'}
            Name of the module containing an older version.

DATA
    G = <<class 'astropy.constants.codata2018.CODATA2018…e-15 unit='m3 /…
    GM_earth = <<class 'astropy.constants.iau2015.IAU2015'> nam…it='m3 /…
    GM_jup = <<class 'astropy.constants.iau2015.IAU2015'> nam…it='m3 / s…
    GM_sun = <<class 'astropy.constants.iau2015.IAU2015'> nam…it='m3 / s…
    L_bol0 = <<class 'astropy.constants.iau2015.IAU2015'> nam…0.0 unit='…
    L_sun = <<class 'astropy.constants.iau2015.IAU2015'> nam…0.0 unit='W…
    M_earth = <<class 'astropy.constants.iau2015.IAU2015'> nam…eference=…
    M_jup = <<class 'astropy.constants.iau2015.IAU2015'> nam…eference='I…
    M_sun = <<class 'astropy.constants.iau2015.IAU2015'> nam…eference='I…
    N_A = <<class 'astropy.constants.codata2018.CODATA2018…ainty=0.0 uni…
    R = <<class 'astropy.constants.codata2018.CODATA2018…y=0.0 unit='J /…
    R_earth = <<class 'astropy.constants.iau2015.IAU2015'> nam…0.0 unit=…
    R_jup = <<class 'astropy.constants.iau2015.IAU2015'> nam…0.0 unit='m…
    R_sun = <<class 'astropy.constants.iau2015.IAU2015'> nam…0.0 unit='m…
    Ryd = <<class 'astropy.constants.codata2018.CODATA2018…nty=2.1e-05 u…
    a0 = <<class 'astropy.constants.codata2018.CODATA2018…certainty=8e-2…
    alpha = <<class 'astropy.constants.codata2018.CODATA2018…ertainty=1…
    atm = <<class 'astropy.constants.codata2018.CODATA2018…ncertainty=0…
    au = <<class 'astropy.constants.iau2015.IAU2015'> nam…=0.0 unit='m' …
    b_wien = <<class 'astropy.constants.codata2018.CODATA2018…certainty=…
    c = <<class 'astropy.constants.codata2018.CODATA2018…rtainty=0.0 uni…
    e = <<class 'astropy.constants.codata2018.EMCODATA20…uncertainty=0.0…
    eps0 = <<class 'astropy.constants.codata2018.EMCODATA20…nty=1.3e-21 …
    g0 = <<class 'astropy.constants.codata2018.CODATA2018…tainty=0.0 uni…
    h = <<class 'astropy.constants.codata2018.CODATA2018…certainty=0.0 u…
    hbar = <<class 'astropy.constants.codata2018.CODATA2018…certainty=0…
    k_B = <<class 'astropy.constants.codata2018.CODATA2018…rtainty=0.0 u…
    kpc = <<class 'astropy.constants.iau2015.IAU2015'> nam…ived from au …
    m_e = <<class 'astropy.constants.codata2018.CODATA2018…tainty=2.8e-4…
    m_n = <<class 'astropy.constants.codata2018.CODATA2018…tainty=9.5e-3…
    m_p = <<class 'astropy.constants.codata2018.CODATA2018…tainty=5.1e-3…
    mu0 = <<class 'astropy.constants.codata2018.CODATA2018…ty=1.9e-16 un…
    muB = <<class 'astropy.constants.codata2018.CODATA2018…nty=2.8e-33 u…
    pc = <<class 'astropy.constants.iau2015.IAU2015'> nam…ived from au +…
    sigma_T = <<class 'astropy.constants.codata2018.CODATA2018…ertainty=…
    sigma_sb = <<class 'astropy.constants.codata2018.CODATA2018…y=0.0 un…
    u = <<class 'astropy.constants.codata2018.CODATA2018…ertainty=5e-37 …

FILE
    /Users/christophemorisset/anaconda3/lib/python3.7/site-
packages/astropy/constants/__init__.py
```

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

```
  Name   = Speed of light in vacuum
  Value  = 299792458.0
  Uncertainty  = 0.0
  Unit  = m / s
  Reference = CODATA 2018
```

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

```
3.0660139378555056e-07 Mpc / yr
```

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

[6]: $8.9875518 \times 10^{16}\ \frac{\mathrm{m^2}}{\mathrm{s^2}}$

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

[7]: $17314.516\ \frac{\mathrm{m^{1/2}}}{\mathrm{s^{1/2}}}$

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

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

[9]:
```python
# 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)
```

```
5.965229612094153e+30 kg
8.225977685950412e+21 g m3 / (AU2 s2)
```

[10]:
```python
F
```

[10]: $8.2259777 \times 10^{21}\ \frac{\mathrm{m^3\,g}}{\mathrm{AU^2\,s^2}}$

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

```
0.0003675671602160826 N
```

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

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

[13]: $1764 \mathrm{m}^2$

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

```
1764.0
1764.0
```

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

```
<class 'astropy.units.quantity.Quantity'>
[2.803206e-09 2.803206e-09] m3 / (kg s2)
```

[16]:
```
arr2 = np.ones(2) * q
arr2[1] = q*3
arr2
```

[16]: $[42, \ 126] \mathrm{m}$

[17]:
```
arr = np.ones(2) * q * const.G
print(type(arr))
print(arr)
```

```
<class 'astropy.units.quantity.Quantity'>
[2.803206e-09 2.803206e-09] m4 / (kg s2)
```

[18]:
```
# 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
```

[19]:
```
x = 1.0 * u.parsec
print(x.to(u.km))
```

```
30856775814913.67 km
```

[20]:
```
lam = 5007 * u.angstrom
```

[21]:
```
print(lam.to(u.nm))
print(lam.to(u.micron))
```

```
500.70000000000005 nm
0.5007000000000001 micron
```

[22]:
```
# Some transformations needs extra information, available from u.special
print(lam.to(u.GHz, equivalencies=u.spectral()))
```

```
598746.6706610745 GHz
```

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

[23]:
```
from astropy.table import Table
```

[24]:
```
# 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
```

[25]:
```
# Pretty output
t
```

[25]:
```
<Table length=3>
  a      b     c
int64 float64 str1
----- ------- ----
    1     2.0    x
    4     5.0    y
    5     8.2    z
```

[26]:
```
# One can change the output format
t['b'].format = '7.3f'
t['a'].format = '{:.4f}'
# and add units
t['b'].unit = 's'
t
```

[26]:
```
<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
```

[27]:
```
t.show_in_browser(jsviewer=True)
```

[28]:
```
# access the column names
t.colnames
```

[28]: ['a', 'b', 'c']

[29]:
```
# length of the table (number of rows)
len(t)
```

[29]: 3

[30]:
```
# Acces one element
t['a'][1]
```

[30]: 4

[31]:
```
# Modify one element
t['a'][1] = 10
t
```

[31]:
```
<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
```

[32]:
```
# easy add column:
t['d'] = [1, 2, 3]
```

[33]:
```
t
```

[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
```

[34]:
```
t.rename_column('a', 'A')
t
```

[34]:
```
<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
```

[35]:
```
t.add_row([-6.6, -9.3, 'r', 10])
t
```

[35]:
```
<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
-6.0000  -9.300    r    10
```

[36]:
```
t.add_row([-9, 40, 'q', 10.1])
t
```

[36]:
```
<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
-6.0000  -9.300    r    10
-9.0000  40.000    q    10
```

[37]:
```
# Masked values
t2 = Table(t, masked=True)
```

```
t2['A'].mask = [True, True, False, False, False, False] # True is for the␣
↪masked values!!
t2
```

[37]:
```
<Table masked=True length=5>
   A       b     c     d
           s
 int64  float64 str1 int64
------- ------- ---- -----
     --   2.000    x     1
     --   5.000    y     2
 5.0000   8.200    z     3
-6.0000  -9.300    r    10
-9.0000  40.000    q    10
```

[38]:
```
t2['A'].mask = [True, False, False, False, False, False] # True is for the␣
↪masked values!!
t2
```

[38]:
```
<Table masked=True length=5>
   A       b     c     d
           s
 int64  float64 str1 int64
------- ------- ---- -----
     --   2.000    x     1
10.0000   5.000    y     2
 5.0000   8.200    z     3
-6.0000  -9.300    r    10
-9.0000  40.000    q    10
```

[39]:
```
# 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
```

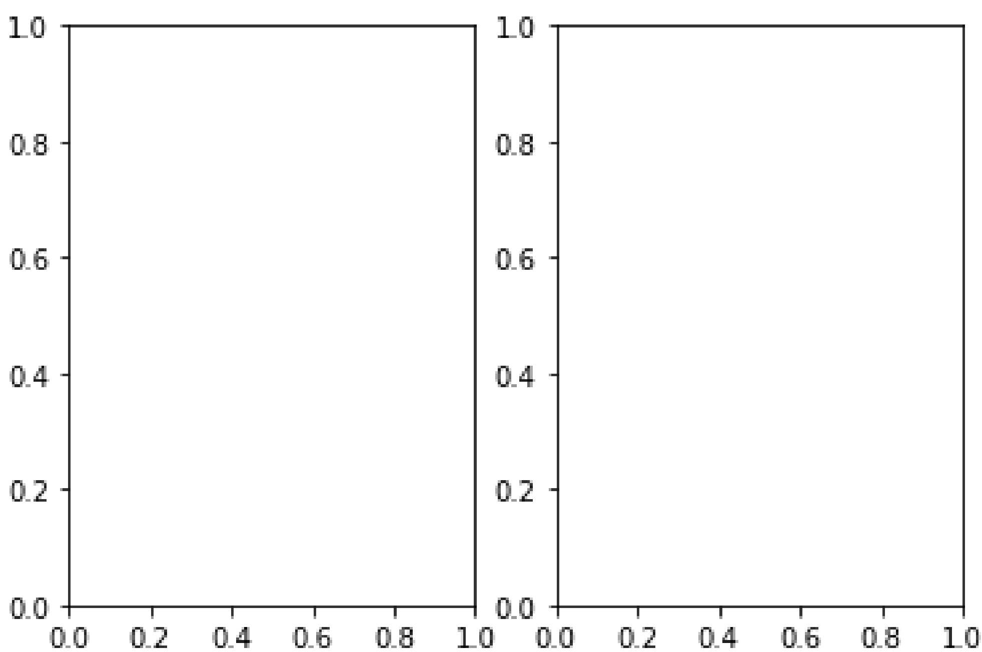
[39]:
```
<Table length=5>
   a2       b2       a2+b2
            s
 int64   float64   float64
-------- -------- ---------
  1.0000    4.000    5.0000
100.0000   25.000  125.0000
 25.0000   67.240   92.2400
 36.0000   86.490  122.4900
 81.0000 1600.000 1681.0000
```

[40]:
```
# Managing columns
from astropy.table import Column
```

[41]:
```
# Create a table combining different formats
a = (1, 4)
b = np.array([[2, 5, 4, 5,6, 3], [5,  7, 6]])  # vector column
c = Column(['x', 'y'], name='axis')
f, (ax1, ax2) = plt.subplots(1,2)
d = Column([ax1, ax2], name='axis obj')
tup = (a, b, c, d)
t3 = Table(tup)  # Data column named "c" has a name "axis" in that table
t3
```

```
/Users/christophemorisset/anaconda3/lib/python3.7/site-
packages/ipykernel_launcher.py:3: VisibleDeprecationWarning: Creating an ndarray
from ragged nested sequences (which is a list-or-tuple of lists-or-tuples-or
ndarrays with different lengths or shapes) is deprecated. If you meant to do
this, you must specify 'dtype=object' when creating the ndarray
  This is separate from the ipykernel package so we can avoid doing imports
until
```

[41]:
```
<Table length=2>
 col0        col1         axis                  axis obj
int64       object        str1                   object
----- ------------------ ---- ------------------------------------------
    1 [2, 5, 4, 5, 6, 3]    x    AxesSubplot(0.125,0.125;0.352273x0.755)
    4          [5, 7, 6]    y AxesSubplot(0.547727,0.125;0.352273x0.755)
```



[42]:
```python
# table from a dictionnary
rr = {'a': [1, 4],
      'b': [2.0, 5.0],
      'c': ('x', 'y')}
t4 = Table(rr)
t4
```

[42]:
```
<Table length=2>
  a      b     c
int64 float64 str1
----- ------- ----
    1     2.0    x
    4     5.0    y
```

[43]:
```python
# Create table row by row
t5 = Table(rows=[{'a': 5, 'b': 10}, {'c': 15, 'b': 30}])
t5
```

[43]:
```
<Table length=2>
  a     b     c
int64 int64 int64
----- ----- -----
    5    10    --
   --    30    15
```

[44]:
```python
# 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:

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

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

[46]:
```
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
```

[47]:
```
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
```

[48]:
```
t6.columns
```

[48]:
```
<TableColumns names=('a','b','c')>
```

[49]:
```
t6.colnames
```

[49]:
```
['a', 'b', 'c']
```

[50]:
```
# One can obtain a numpy structured array from a Table
np.array(t6)
```

[50]:
```
array([(99, 2., b'x'), ( 4, 5., b'y')],
      dtype=[('a', '<i8'), ('b', '<f8'), ('c', 'S2')])
```

[51]:
```python
arr = np.arange(9000).reshape(100, 90)  # 100 rows x 90 columns array
t = Table(arr)
print(t)
```

```
col0 col1 col2 col3 col4 col5 col6 … col83 col84 col85 col86 col87 col88 col89
---- ---- ---- ---- ---- ---- ---- … ----- ----- ----- ----- ----- ----- -----
   0    1    2    3    4    5    6 …    83    84    85    86    87    88    89
  90   91   92   93   94   95   96 …   173   174   175   176   177   178   179
 180  181  182  183  184  185  186 …   263   264   265   266   267   268   269
 270  271  272  273  274  275  276 …   353   354   355   356   357   358   359
 360  361  362  363  364  365  366 …   443   444   445   446   447   448   449
 450  451  452  453  454  455  456 …   533   534   535   536   537   538   539
 540  541  542  543  544  545  546 …   623   624   625   626   627   628   629
 630  631  632  633  634  635  636 …   713   714   715   716   717   718   719
 720  721  722  723  724  725  726 …   803   804   805   806   807   808   809
 810  811  812  813  814  815  816 …   893   894   895   896   897   898   899
   …    …    …    …    …    …    … …     …     …     …     …     …     …     …
8010 8011 8012 8013 8014 8015 8016 …  8093  8094  8095  8096  8097  8098  8099
8100 8101 8102 8103 8104 8105 8106 …  8183  8184  8185  8186  8187  8188  8189
8190 8191 8192 8193 8194 8195 8196 …  8273  8274  8275  8276  8277  8278  8279
8280 8281 8282 8283 8284 8285 8286 …  8363  8364  8365  8366  8367  8368  8369
8370 8371 8372 8373 8374 8375 8376 …  8453  8454  8455  8456  8457  8458  8459
8460 8461 8462 8463 8464 8465 8466 …  8543  8544  8545  8546  8547  8548  8549
8550 8551 8552 8553 8554 8555 8556 …  8633  8634  8635  8636  8637  8638  8639
8640 8641 8642 8643 8644 8645 8646 …  8723  8724  8725  8726  8727  8728  8729
8730 8731 8732 8733 8734 8735 8736 …  8813  8814  8815  8816  8817  8818  8819
8820 8821 8822 8823 8824 8825 8826 …  8903  8904  8905  8906  8907  8908  8909
8910 8911 8912 8913 8914 8915 8916 …  8993  8994  8995  8996  8997  8998  8999
Length = 100 rows
```

[52]:
```python
t.show_in_browser(jsviewer=True)
```

[53]:
```python
# 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
```

[53]:
```
<Table length=5>
  a     b     c
int64 int64 int64
----- ----- -----
    0     1     2
    3     4     5
    6     7     8
```

```
    9     10     11
   12     13     14
```

[54]:
```
t['a'] = [1, -2, 3, -4, 5]  # Set all
t
```

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

[55]:
```
t['a'][2] = 30 # set one
t
```

[55]:
```
<Table length=5>
  a     b     c
int64 int64 int64
----- ----- -----
    1     1     2
   -2     4     5
   30     7     8
   -4    10    11
    5    13    14
```

[56]:
```
# set one row
t[1] = (8, 9, 10)
t
```

[56]:
```
<Table length=5>
  a     b     c
int64 int64 int64
----- ----- -----
    1     1     2
    8     9    10
   30     7     8
   -4    10    11
    5    13    14
```

[57]:
```
# Set a whole column
t['a'] = 99
t
```

[57]:

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

[58]:

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

[58]:

```
<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
```

[59]:

```
# remove a column
t.remove_column('b')
t
```

[59]:

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

[60]:

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

[60]:

```
<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
```

[61]:
```
# Remove some rows
t.remove_rows([1, 2])
t
```

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

[62]:
```
# sort the Table using one column
t.sort('c')
t
```

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

[63]:
```
filter = (t['a'] > 50) & (t['d'] > 3)
print(filter)
```

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

[64]:
```
t[filter]
```

[64]:
```
<Table length=2>
  a     c     d
int64 int64 int64
----- ----- -----
   99    11     4
   99    14     5
```

[65]:
```
%%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
```

[66]:
```
# directly read a Table from an ascii file
obs = Table.read('tab1.dat', format='ascii')
```

[67]:
```
obs
```

[67]:
```
<Table length=10>
name  obs_date   mag_b   mag_v
str4    str10   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
```

[68]:
```
# Group data
obs_by_name = obs.group_by('name')
obs_by_name
```

[68]:
```
<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
```

[69]:

```
print(obs_by_name.groups.keys)
```

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

[70]:

```
# 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
```

[71]:

```
# 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
```

[72]:

```
# 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
```

[73]:
```
# 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 15.000000000000002 13.725000000000001
 M31               17.0 17.400000000000002
 M82 15.699999999999998               15.5

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

[74]:
```
print(obs_by_name['name', 'mag_v', 'mag_b'].groups.aggregate(np.mean))
```

```
name       mag_v              mag_b
---- ------------------ ------------------
M101 13.725000000000001 15.000000000000002
 M31 17.400000000000002               17.0
 M82               15.5 15.699999999999998
```

[75]:
```
# 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')
```

[76]:
```
# this is used to stack Tables
from astropy.table import vstack
```

[77]:
```
tvs = vstack([obs, obs1])
tvs
```

[77]:
```
<Table 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
```

[78]:
```
%%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
```

[79]:
```
d = Table.read('data6.dat', format='ascii.fixed_width',
               col_starts=(0, 12, 20, 29, 38))
d
```

[79]:
```
<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
```

[80]:
```
d.group_by('Obs_code')
```

[80]:
```
<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

1.0.3 Pandas and Table

[81]:
```
df = t.to_pandas()
```

[82]:
```
df
```

[82]:

	a	c	d
0	-8	-9	10
1	99	2	1
2	99	11	4
3	99	14	5

[83]:
```
t2 = Table.from_pandas(df)
t2
```

[83]:
```
<Table length=4>
  a     c     d
int64 int64 int64
----- ----- -----
   -8    -9    10
   99     2     1
```

```
99     11      4
99     14      5
```

1.0.4 Downloading from CDS

Look for data on "Diffuse gas" at Vizier: https://vizier.u-strasbg.fr/viz-bin/VizieR

[84]:
```python
t = Table.read("https://cdsarc.unistra.fr/ftp/J/other/RMxAA/45.261/digeda.dat",
               format='ascii.cds',
               readme='https://cdsarc.unistra.fr/ftp/J/other/RMxAA/45.261/
 ↪ReadMe')
```

[85]:
```python
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')
```

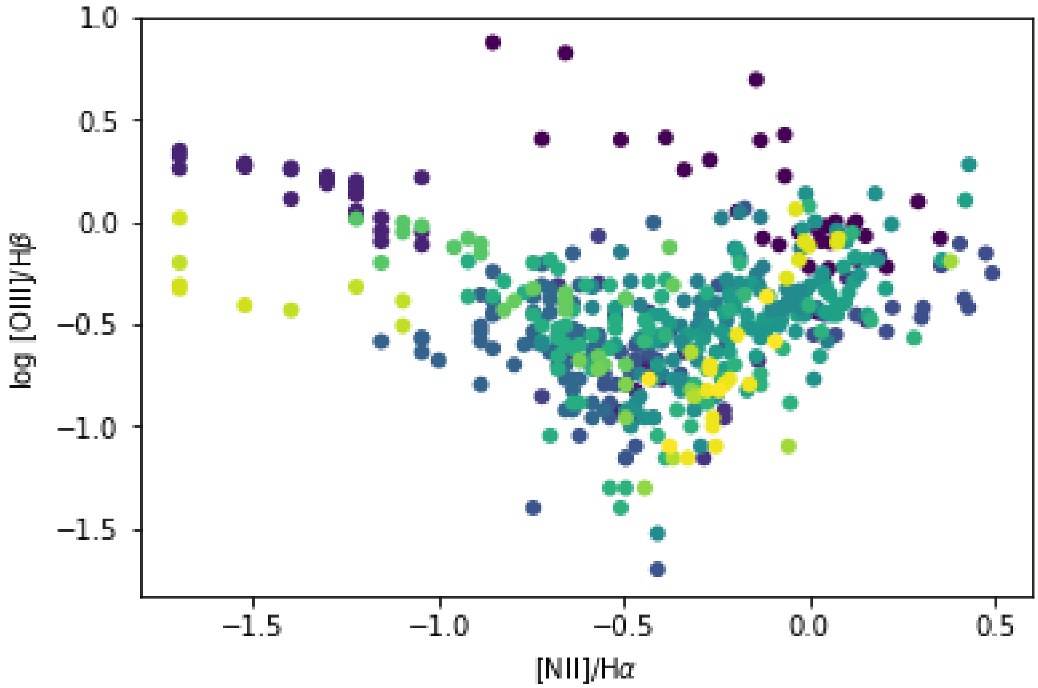
[86]:
```python
t
```

[86]:
```
<Table 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
```

[87]:
```python
t.show_in_browser(jsviewer=True)
```

[88]:
```
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$\beta$')
```

[88]:
```
Text(0, 0.5, 'log [OIII]/H$\\beta$')
```



[89]:
```
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")
```

[90]:
```
t
```

[90]:
```
<Table 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    - …          ?       --           ?          --
```

[91]:
```python
t.show_in_browser(jsviewer=True)
```

[92]:
```python
t[0:10].write('tab_cds1.tex', format='latex', overwrite=True,␣
 ↪formats={'Sp-Index': '%0.2f'})
```

[93]:
```python
!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(1GHz) & u_S(1GHz) & Sp-Index & u_Sp-Index & Names \\
 & $\mathrm{h}$ & $\mathrm{min}$ & $\mathrm{s}$ &  & $\mathrm{deg}$ &
$\mathrm{arcmin}$ & $\mathrm{arcmin}$ &  & $\mathrm{arcmin}$ &  &  &  &
$\mathrm{Jy}$ &  &  &  \\
G000.0+00.0 & 17 & 45 & 44 & - & 29 & 0 & 3.5 & x & 2.5 &  & S &  & 100.0 & ? &
0.80 & ? & Sgr A East \\
G000.3+00.0 & 17 & 46 & 15 & - & 28 & 38 & 15.0 & x & 8.0 &  & S &  & 22.0 &  &
0.60 &  & \\
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 &  & 0.60 &
? &  \\
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 &  & 0.60 &
&  \\
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 & ? &
0.60 &  &  \\
G004.2-03.5 & 18 & 8 & 55 & - & 27 & 3 & 28.0 &  &  &  & S &  & 3.2 & ? & 0.60 &
? &  \\
```

```
G004.5+06.8 & 17 & 30 & 42 & - & 21 & 29 & 3.0 &  &  &  & S &  & 19.0 &  & 0.64
&  & Kepler, SN1604, 3C358 \\
\end{tabular}
\end{table}
```

[94]:
```
t[10:20].write('tab_cds1.ascii', format='ascii', delimiter=';',␣
↪formats={'Sp-Index': '%0.2f'}, overwrite=True)
```

[95]:
```
!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-Index;Names
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;;
```

[96]:
```
t[10:20].write('tab_cds2.ascii', format='ascii.fixed_width', delimiter='',␣
↪formats={'Sp-Index': '%0.2f'}, overwrite=True)
```

[97]:
```
!cat tab_cds2.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-Index     Names
 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
```

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

1.0.5 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

1.0.6 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.

[98]:
```
from astropy import units as u
from astropy.coordinates import SkyCoord
```

[99]:
```
c = SkyCoord(ra=10.5*u.degree, dec=41.2*u.degree, frame='icrs')
c
```

[99]:
```
<SkyCoord (ICRS): (ra, dec) in deg
    (10.5, 41.2)>
```

[100]:
```
c = SkyCoord('0 42 00 +41 12 00', frame='icrs', unit=(u.hourangle, u.deg))
c
```

[100]:
```
<SkyCoord (ICRS): (ra, dec) in deg
    (10.5, 41.2)>
```

[101]:
```
print(c.ra, c.dec)
```

```
10d30m00s 41d12m00s
```

[102]:
```
c.to_string('decimal')
```

[102]:
```
'10.5 41.2'
```

[103]:
```
print(c.dec.to_string(format='latex'))
```

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

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

1.0.7 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

More examples: https://learn.astropy.org/rst-tutorials/Models-Quick-Fit.html

1.0.8 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

1.0.9 CCD reduction

Ccdproc is is an Astropy affiliated package for basic data reductions of CCD images. It provides the essential tools for processing of CCD images in a framework that provides error propagation and bad pixel tracking throughout the reduction process.

https://ccdproc.readthedocs.io/en/latest/