Extra material for MUSE project

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1. Multicolor images from MUSE

2. Other half-finished Orion spectra projects

This is a brain dump of planned and semi-abandoned projects related to the MUSE, PPAK, and longslit spectra, which are beyond the scope of the t^2 paper.

2.1. Balmer and Paschen jump temperatures

The Balmer jump can be measured from the PPAK spectra. The Paschen jump can be measured from the MUSE spectra.

A pilot investigation of the Balmer jump (BJ) is presented in Figure 3. Spectra are extracted by averaging over areas ranging in size from 2/9 to 1 square arcminutes (shown by solid line), with the spectra of individual fibers shown by the cloud of points. Each spectrum is shown twice, at two different magnifications (red and black lines) to emphasize faint and bright lines. The location (x, y) in arcsec from θ^1 Ori C, size (w, h) in arcsec, and number of fibers N for each region are shown above each panel. The intensity of the BJ is estimated manually by smoothly extrapolating the continuum to either side (**This is not good enough – see below**) and compared with the intensity of the H(12–2) Balmer line.

What we really need to do is to fit the sum of an atomic continuum plus a scattered stellar continuum to the observations. The atomic continuum (free-bound plus 2-photon) can be modeled with Cloudy for different temperatures, densities, and this will also give us the Balmer line spectrum. The stellar continuum needs to be multiplied by the effective scattering albedo, which we can assume to be a power law in wavelength, but the index may vary with position.

An example is shown in Figure 4, which shows the stellar spectrum (top) and the H II region spectrum (bottom). There are a few details to iron out:

1. We need to increase the number of H levels used, so as to get more of the higher Balmer lines. *How can Cloudy deal with the pseudo-continuum of lines as one approaches the limit without using an infinite amount of memory?*
2. The Cloudy reflected spectrum seems to already include a dust-scattered stellar component (note the absorption wings visible around the H and He emission lines). But we require the atomic continuum to be separate from the scattered continuum since they need to be varied independently (the size and color index of the effective albedo need to be free parameters). *How can we get the pure atomic continuum from the Cloudy output? Maybe just turn off scattering for the model*

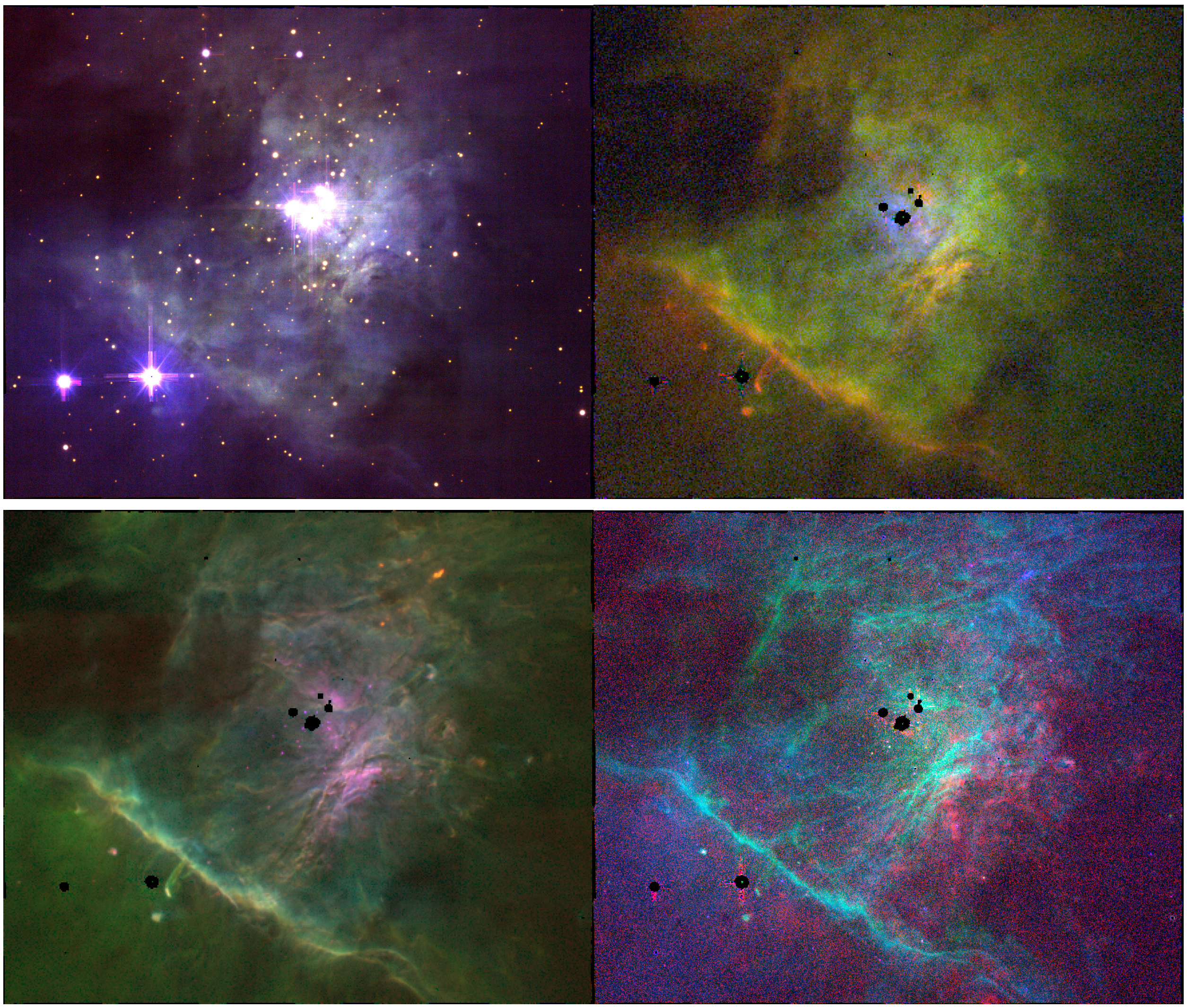


Fig. 1.— Some MUSE images of Orion

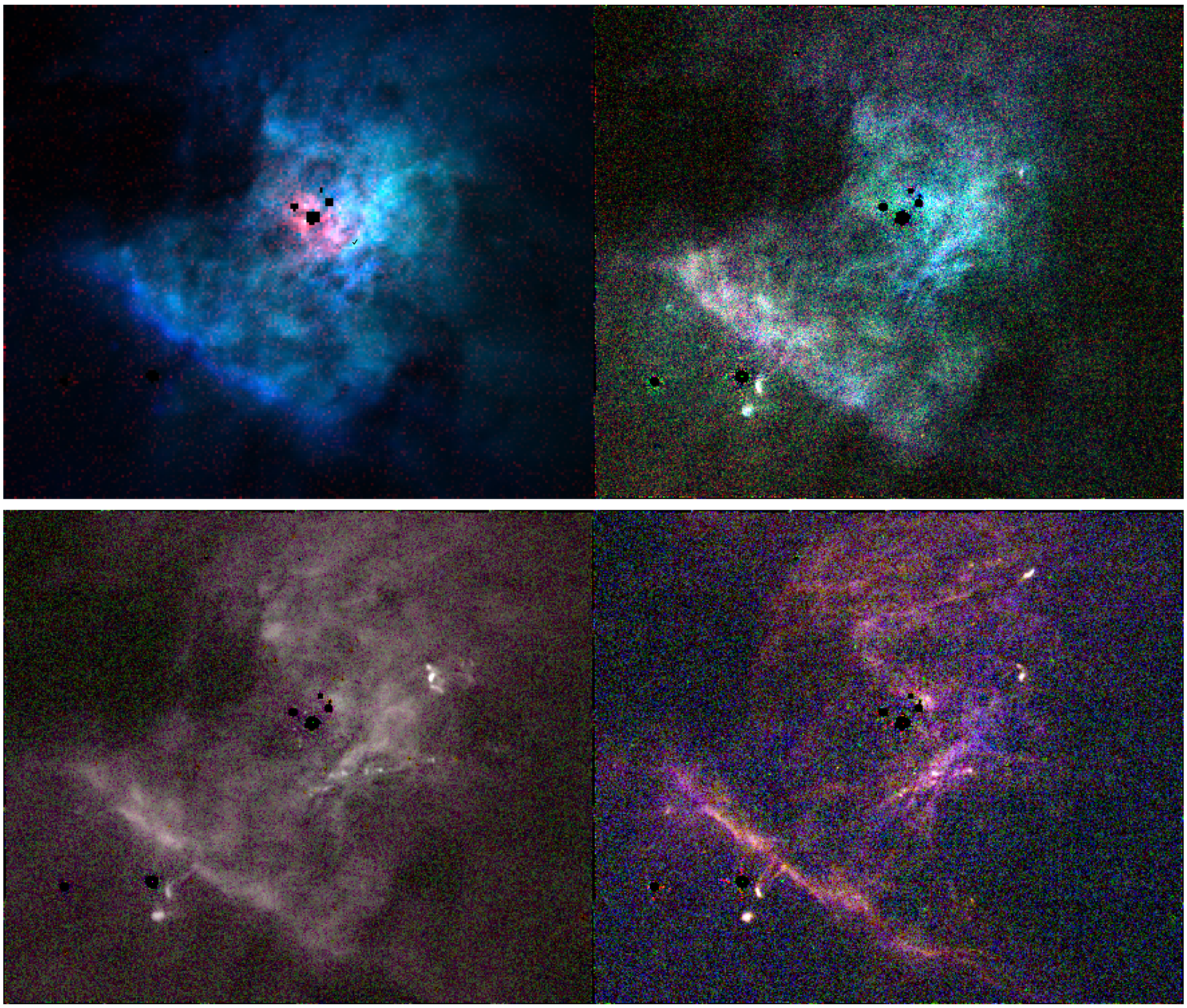


Fig. 2.— Some more MUSE images of Orion

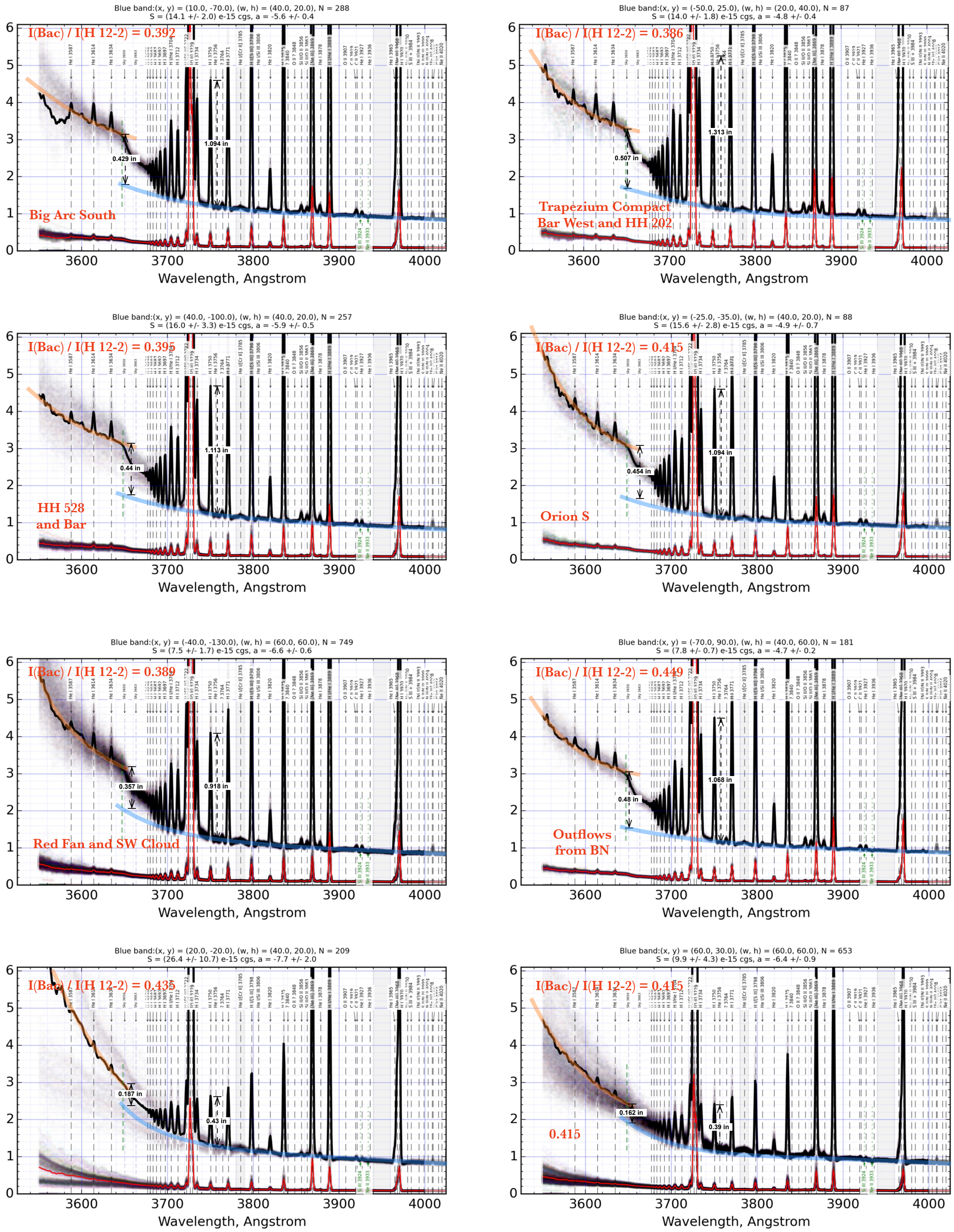


Fig. 3.— Pilot investigation of Balmer jump from PPAK spectra.

3. Also note that we had to increase the default Cloudy resolution to get that nice spectrum. See Appendix 3.1.

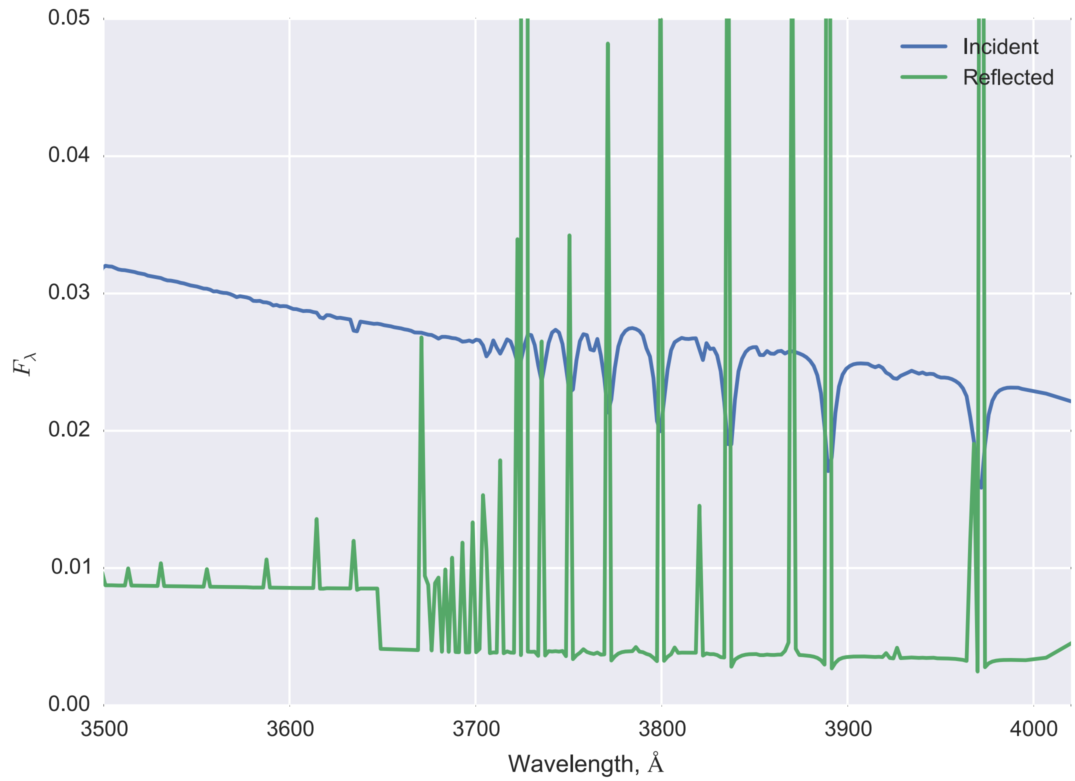


Fig. 4.— Cloudy model of the Balmer jump and nearby spectrum. Blue line is the stellar spectrum, which is a composite of Tlusty atmosphere models for the Trapezium stars (A, B, C1, C2, and D). Green line is the "Reflected" continuum diffusely emitted from the inner face of the Cloudy model.

2.2. Stellar absorption lines in the scattered spectrum

The figure shows the observed spectra of the Trapezium stars, together with some comments from 2015-Jan.

Stellar O II absorption lines from θ^2 Ori A in the scattered continuum mean that it is very difficult to detect the O II recombination lines on the far side of the Bright Bar. In the Huygens region, this is not such an issue since there is almost zero O II absorption in θ^1 Ori C.

The He II 4686 absorption line is very problematic in θ^1 Ori C because it varies with rotation phase and probably also with viewing angle, so different parts of the nebula will see different strengths. However, we can certainly use it in the region around θ^2 Ori A.

He II 4542 is very strong (depth 0.2) in θ^1 Ori C and seems constant. However, we can only use it with the PPAK data since MUSE does not go that far to the blue. The same applies to the Si III 4483 line, which could in principal be diagnostic of the fraction of scattered light coming from the cooler Trapezium stars θ^1 Ori A,B,D

There is also the N III 6663 line, which is very strong in some parts of the nebula (absorption depth of 0.08) but is absent on the spectra of the brightest OB stars (only seen in θ^1 Ori E and with depth of only 0.05). So I have no idea where this is coming from. *Could there be an hidden luminous cooler giant in Orion S that is leaking out light?*

He II 5411 has some potential, but is contaminated by [Fe III] emission.

C IV 5801.35, 5811.97 are clearly seen in θ^1 Ori C spectrum and much weaker in θ^2 Ori A, absent in other trapezium stars. Unfortunately, they are very weak in the nebula. Requires integration over 15x15 arcsec box to have much s/n

Finally, there are the Balmer lines, which show weak underlying stellar absorption wings. The best ones are H(9–2) 3798 and H(10–2) 3771 because the emission lines are getting weaker to the blue, but the absorption lines are holding up in strength and the scattered continuum is getting stronger. Once you go to higher Balmer lines than that you run into the [O II] lines and then they get too close together. So this is all inaccessible to MUSE, and besides the wavelength resolution in MUSE is not so good. But can be done with PPAK and even better with Adal's longslit spectra.

2.3. Three different O++ temperatures

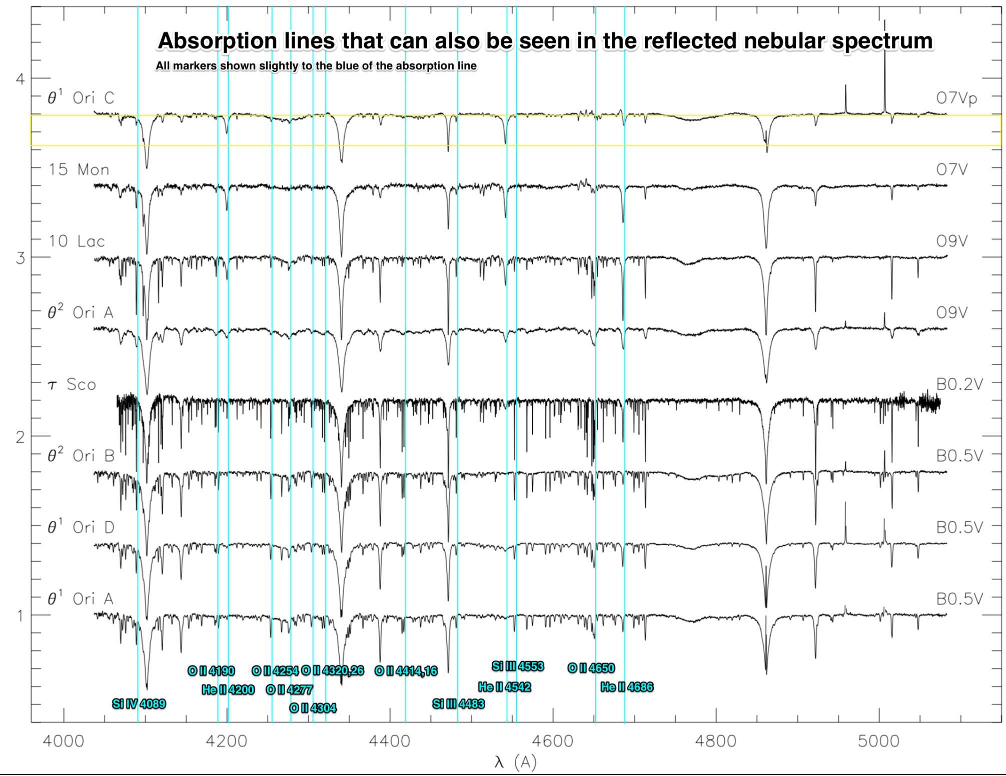
3. Code and input file listings

3.1. Cloudy input script for Figure 4

Based on an earlier script of Gary's from the [N I] project, but stops at i-front, since we are not interested in the PDR

```
title constant pressure H+ region/pdr
c
```

Trapezium star spectra from Simón Díaz et al (2006)



The He II 4542 line is strongest in theta 1 C, about 3x weaker in theta 2 A, and absent in the others. So it can be used to track the fraction of the continuum that is scattered th1C.

The Si III lines are seen in all th1A, th1D, but very weak in th1C, so can be used to track fraction of continuum that is scattered th1A,B,D. Although this assumes that there is no Si III emission from the nebula.

Once that is done, we can estimate the absorption EW of the O II lines in the nebular spectrum. This is needed to correct the observed O II emission line EW for absorption lines in the underlying scattered continuum.

In the region around th2A we can use the He II 4686 line to track the scattered continuum and use that to correct the O II. For instance, EW(4651) ~= 0.7 EW(4686) for th2A. However, the O II absorption is so strong that we probably won't be able to recover any emission from that region.

For the Trapezium, we cannot use 4686 because th1C has an inverse P Cyg profile, which depends on phase, and presumably on viewing angle. And we don't know what the average profile seen by the nebula is.

Fig. 5.— Note from Evernote about scattered absorption lines

```
c commands controlling continuum =========
c the incident continuum is two parts
c star and flux of photons striking it
c
c the trapezium cluster
c parameters for C, A & D from Simon-Diaz+ 2006
c theta 1 C
table star tlusty OBstar 3-dim 39000 g=4.10 z=-0.1
luminosity total solar 5.31
c theta 1 C_2 - binary companion to C: see individual/orion-stars.html
table star tlusty OBstar 3-dim  25000 g=3.86 z=-0.1
luminosity total solar 4.2
c theta 1 A
table star tlusty OBstar 3-dim 30000 g=4.0 z=-0.1
luminosity total solar 4.45
c theta 1 D
table star tlusty OBstar 3-dim 32000 g=4.2 z=-0.1
luminosity total solar 4.47
c theta 1 B - new parameters from Will: see individual/orion-stars.html
table star tlusty OBstar 3-dim 18000 g=4.1 z=-0.1
luminosity total solar 3.25
c this adds the observed hot brems, its temperature and the flux of
c photons striking the cloud
brems 6
phi(h) 10
c add cosmic rays, which are important in the pdr
cosmic rays, background
c
c commands controlling geometry  =========
c this sets the separation from the star and the face of the cloud
radius 17.4507
stop temperature 4000 linear
c this is typical of a gmc, larson 1981
stop Av 5 point
c this sets the thickness of the HII region & PDR
stop thickness 0.5 linear parsec
c constant total pressure, so like orion_hii_open
constant pressure
c this will result in a milli gauss B-field in molecular region
magnetic field -5 gauss
c other commands for details     =========
c mimic existence of unmodeled molecular gas
double
c iterate since lines optically thick
iterate
c the observed microturbulence, partially a flow, so not included in pressure
turbulence 5 km/sec no pressure linear
c
c commands for density & abundances =========
c this is the log of the initial H density, cm-3
hden 4
c this will speed up the calculation a bit
init file="ism.ini"
```

```
c this uses HII region abundances, but no grains
abundances hii region no grains
grains orion
c turn on PAHs, with an abundance that depends on H0 fraction,
c as suggested by long-slit observations of Orion bar,
c with an abundance 3x larger than default built into the code
grains PAH function 3
c
c commands controlling output    =========
c print lots of faint CO lines
print line faint -4
save continuum "trap.con" units microns last
save dr last "trap.dr"
save overview "trap.ovr"
save linelist "trap.lin" "linelist.dat" last no hash
c
save line emissivity "trap.ems"
H  1  4861.36
totl  5199
O  1  6300
N  2  6584
Blnd  6720
end of lines
```

Note that the figure was produced with a custom continuum, which is much finer around the Balmer jump wavelength. This requires editing the file `continuum_mesh.ini` in the Cloudy source tree. The edited version is as follows:

```
10 08 08 //the magic number for this format file
#
# change history, 2010 Aug 08, use 0.005 resolution to low energy limit;
# had been 0.1 between low energy limit and 2e-5 Ryd, but many molecular
# features are present in this energy range
# change from resolution to resolving power, resolving power = 1/resolution
#
# This file defines the continuum resolving power used by the code.
# It is designed to be edited by a person and allows any continuum
# resolving power to be entered.
#
# The resolution is defined as r = delta E/E
# The resolving power is defined as E/delta E = 1/r
#
# here E is the photon energy at the center of the frequency cell and
# delta E is the width of the frequency cell.
#
# the command
# set continuum resolution
# proves a way to change the resolution of the entire continuum
# by a constant factor without editing this file.  This file
# provides a way to change the resolution of only parts of the
# continuum, and to change the default behavior of the code.
#
```

```
# if the continuum resolution is changed either with the
# set continuum command, or by changing this file, it will be necessary
# to recompile the stellar atmosphere and grain opacity files if you
# want to use those
#
# Each line is an ordered pair of numbers,
# The first is the upper limit of an energy interval in Rydbergs
# and the second number is the resolving power (E/delta E).
# The code's execution time is pretty much set by the number of
# continuum points, so increasing the resolving power will require more time.
#
# The numbers must be linear quantities
#
# There is no limit to the number of bounds since the arrays
# are dynamically allocated.
#
# this is the first range, and has a lower limit of the low-energy
# bound of the code.  The continuum mesh will have a resolving power of 200
# (a resolution of 0.005) between the low-energy limit and 600 Ryd.
#
# WJH 05 Mar 2015: Increase resolution 10 x around Balmer jump: 4000 - 3500 A = 0.228 - 0.261 Ryd
#
0.228     200
0.261     2000
600.     200
#
# the last number must have an upper bound of zero, which is
# interpreted as the upper energy bound of the code
# so the resolving power over the energy range from 600 Ryd to
# the high-energy limit of the code will be 33.33333
0        33.333333
```

3.2. Tables and scripts for MUSE reduction and analysis

`wavsec-startwavs.tab`: starting wavelength of each section that the full cube is split into

```
Section     CRVAL3
0           4595.00
1           5191.70
2           5788.40
3           6385.10
4           6981.80
5           7578.50
6           8175.20
7           8771.90
```

List of lines that we try and extract from the MUSE datacube

```
Ion         wav0        strength    blue cont   red cont    comment
N II        4607.16     4           1           1           NEW-11-07 blend [Fe III], O II
```

N II	4630.54	4	1	0	NEW-11-07
O II	4641.81	4	1	0	NEW-11-07 blend N III
O II	4650.00	4	1	0	blend 4649.13,50.84
[Fe III]	4658.10	3	0	1	
O II	4676.24	5	1	1	blend with 4673.73
He II	4685.68	-4	1	1	absorption line
[Fe III]	4701.62	4	1	1	
He I	4713.14	3	1	1	blend with [Ar IV] 4711.37
[Fe III]	4733.93	4	1	0	
[Ar IV]	4740.17	4	0	1	
[Fe III]	4754.83	4	1	1	
[Fe III]	4769.6	4	1	1	
[Fe III]	4777.88	4	1	1	blend with [Fe II] 4774.74
N II	4803.287	4	1	1	
[Fe II]	4814.534	4	1	1	NEW-11-07 blend N II, S II
H I	4861.32	1	1	1	
[Fe III]	4881.073	4	1	1	NEW-11-07
[Fe II]	4889.704	5	1	1	
[Fe II]	4905.339	5	1	1	
He I	4921.93	3	1	1	
[Fe III]	4930.50	4	0	1	blend with [O III] 4931.32
[O III]	4958.91	1	1	1	
[O III]	5006.84	1	1	1	
He I	5015.68	3	0	1	
Si II	5041.03	4	1	0	
He I	5047.74	4	0	1	No good cont!
Si II	5055.98	4	0	1	
O I	5146.61	5	1	1	
[Fe II]	5158.81	5	1	1	NEW-11-07
[Ar III]	5191.82	4	1	0	
[N I]	5199.00	4	0	1	Blend 5197.98,200.26
[Fe II]	5261.61	4	1	0	
[Fe III]	5270.40	3	0	1	
O I	5298.89	5	1	1	NEW-11-07
[Fe II]	5333.646	5	1	1	NEW-11-07
[Fe II]	5376.452	5	1	1	NEW-11-07
[Fe III]	5412.00	5	1	1	NEW-11-07 + He II abs
O II	5433.49	6	1	1	NEW-11-07
S II	5453.81	6	1	1	NEW-11-07
[Cl III]	5517.71	3	1	1	
[Cl III]	5537.88	3	1	1	
N II	5551.95	6	1	0	NEW-11-07
O I	5555.03	5	0	1	NEW-11-07
[O I]	5577.34	4	1	1	Sky contamination
O III	5592.37	-5	1	1	Absorption line
N II	5666.629	5	1	1	NEW-11-07
N II	5679.558	5	1	1	NEW-11-07
Si III	5739.73	5	1	1	NEW-11-07
[N II]	5755.08	4	1	1	
DIB	5781	-4	1	0	Diffuse interstellar band
He II	5784.947	-5	0	1	Abs blend O II 5783.788
C IV	5801.35	-5	1	1	Absorption line
C IV	5811.97	-5	1	1	Absorption line

He I	5875.62	1	1	1	
C II	5889.78	4	1	0	NEW-11-07
N III	5896.1	-5	0	1	Absorption line
N III	5901.2	-5	1	1	Absorption line
XXX	5906.00	5	0	1	Unidentified
N III	5918.5	-5	1	1	Absorption line
C II	5889.78	4	1	1	Na I sky blend
N II	5931.78	4	1	1	Blend with 5927.81
N II	5941.65	4	1	1	Blend with 5940.24
N II	5952.39	4	1	0	
Si II	5957.56	4	0	1	Blend with O I 5958.39
Si II	5978.93	4	1	1	
[Ni III]	6000.2	6	1	1	Very weak
O I	6046.23	4	1	1	
[Fe II]	6133.433	4	1	1	plus sky?
C II	6151.43	5	1	1	
DIB	6278.00	-2	1	0	Diffuse interstellar band
[O I]	6300.30	3	1	1	
[S III]	6312.06	3	1	1	
Si II	6347.11	4	1	1	
[O I]	6363.78	3	1	0	
Si II	6371.36	4	0	1	
[Ni III]	6401.5	6	1	1	Blend with Ne I 6402.25
C II	6461.95	6	1	1	NEW-11-07
[N II]	6527.24	6	1	0	NEW-11-07
[Ni III]	6533.8	6	0	1	NEW-11-07
[N II]	6548.05	2	1	1	
H I	6562.79	1	1	1	
C II	6578.05	5	1	0	
[N II]	6583.45	2	1	1	
N III	6633.9	-4	1	1	Absorption line
Si III	6662.90	-5	1	0	Abs + em [Ni II] 6666.80
[Ni II]	6666.80	6	0	1	NEW-11-07
He I	6678.15	2	1	1	
[S II]	6716.44	3	1	1	
[S II]	6730.816	3	1	1	
O I	7001.92	3	1	1	
He I	7065.28	2	1	1	
[Ar III]	7135.78	1	1	1	super strong
[Fe II]	7155.14	4	1	0	NEW-11-07
He I	7160.13	4	0	1	NEW-11-07
[Fe II]	7172.00	5	1	1	NEW-11-07
C II	7231.34	3	1	0	
C II	7236.42	3	0	1	
O I	7254.15	3	1	1	Blend with 7254.45,54.53
He I	7281.35	3	1	1	
He I	7298.050	4	1	1	NEW-11-07
[O II]	7318.39	1	1	1	Also 7319.99
[O II]	7329.66	1	0	1	Also 7330.73
O II	7340.7	5	1	1	NEW-11-07
O II	7369.029	6	1	1	NEW-11-07 blend C II 7370.0
[Ni II]	7377.83	4	1	1	
[Fe II]	7388.18	5	1	1	NEW-11-07

```
[Ni II]     7411.61     5           1           1
N I         7423.64     6           1           1           NEW-11-07
N I         7442.30     5           1           1
[Fe II]     7452.54     4           1           1
N I         7468.31     4           1           1
He I        7499.85     5           1           1           NEW-11-07
C II        7530.57     5           1           1           NEW-11-07
[Ar III]    7751.10     1           1           1
He I        7816.13     4           1           1
Ca I]       7890.07     4           1           1
[Cr II]     8000.08     5           1           1           NEW-11-07
[Cl IV]     8045.62     4           1           1           HIGH IONIZATION!
XXX         8189        4           1           1           Could be Fe I?
N I         8223.14     4           0           1           Also 8210.72,16.34
XXX         8243        4           1           1           Could be O I? or Fe II?
H I         8437.96     3           1           0           Pa 18
O I         8446.36     2           0           1           Also  8444.25, 8444.7
H I         8467.25     2           0           1           Pa 17
H I         8502.48     2           1           1           Pa 16
H I         8545.38     2           1           1           Pa 15
[Cl II]     8578.69     3           1           0           Blend with 8582
H I         8598.39     2           1           1           Pa 14 plus 2nd order ghost
[Fe II]     8616.95     3           1           1
H I         8665.02     2           1           1           Pa 13
N I         8680.28     4           1           0           Plus 83.40, 86.15
N I         8703.25     4           1           0
N I         8711.70     4           0           1           Also 8718.83
[C I]       8727.13     4           1           0           Different!
H I         8750.47     2           1           1           Pa 12
H I         8862.79     2           1           1           Pa 11
Ne I        8892.22     4           1           1
H I         9014.91     2           1           1           Pa 10
XXX         9032        5           1           1           Unidentified fluorescent
Ca I]       9052.16     5           1           0
[S III]     9068.90     1           1           1
Ca I]       9095.09     5           1           0
XXX         9204.17     5           1           0           Unidentified O II?
He I        9210.28     4           0           1
H I         9229.01     2           1           1           Pa 9
XXX         9267        5           1           1           Unidentified
```

extract-em-line.py: extract emission lines from cube

```python
from __future__ import print_function
import sys
import numpy as np
from astropy.table import Table
from astropy.io import fits
from astropy.wcs import WCS
from misc_utils import sanitize_string
sys.path.append('/Users/will/Dropbox/OrionWest/')
from extract_utils import (find_wavsec, trim_to_window, extract_line_maps, linetab)
```

```python
def save_linemap_files(wav, species, mapdir='LineMaps', usecont=[1, 1]):
    full_width = 24.0  # Angstrom
    wavsec = find_wavsec(wav)
    wavsec_blue = find_wavsec(wav - full_width/2)
    wavsec_red = find_wavsec(wav + full_width/2)
    if (wavsec_blue != wavsec) or (wavsec_red != wavsec):
        print('Uh, oh - line straddles wavsecs', wavsec_blue, wavsec, wavsec_red)
        wavsecs = set([wavsec_blue, wavsec, wavsec_red])
        fn = 'muse-hr-data-wavsec-edge{}{}.fits'.format(*wavsecs)
    else:
        fn = 'muse-hr-data-wavsec{}.fits'.format(wavsec)
    try:
        hdulist = fits.open(fn)
    except:
        # Maybe we have the cube in the BigFiles folder
        hdulist = fits.open('BigFiles/' + fn)
    hdu = hdulist['DATA']
    print('Using', fn)
    wfull = WCS(hdu.header)
    helio_hdr = fits.open('muse-hr-window-wfc3-f656n.fits')[0].header
    cube, w = trim_to_window(wav, hdu.data, wfull, dwav=full_width/2)
    print('Cube shape:', cube.shape)
    maps, spec =  extract_line_maps(wav, cube, w, helio_hdr, usecont)
    wavid = str(int(wav+0.5))
    # Save the maps to FITS file
    for mapid, mapdata in maps.items():
        mhdu = fits.PrimaryHDU(header=w.celestial.to_header(), data=mapdata)
        mname = '{}/{}-{}-{}.fits'.format(mapdir, mapid, species, wavid)
        mhdu.writeto(mname, clobber=True)
    sname = '{}/spec1d-{}-{}.tab'.format(mapdir, species, wavid)
    # And save the spectrum to TSV file
    Table(spec).write(sname, format='ascii.tab')


try:
    # Otionally specify a single line
    wav_wanted = int(sys.argv[1])
except:
    wav_wanted = None

for row in linetab:
    if wav_wanted is not None and wav_wanted != int(0.5 + row['wav0']):
        # jump all unwanted lines if command line argument was given
        continue
    print(row['Ion'], row['wav0'])
    save_linemap_files(row['wav0'], sanitize_string(row['Ion']),
                       usecont=[row['blue cont'], row['red cont']])
```

`plot-em-line-spec.py`: plots average spectrum for each line

```
from astropy.table import Table
from misc_utils import sanitize_string
from matplotlib import pyplot as plt
import seaborn as sns

linetab = Table.read('basic-line-list.tab', format='ascii.tab')

for row in linetab:
    wav = row['wav0']
    wavid = str(int(wav+0.5))
    species = sanitize_string(row['Ion'])
    sname = 'Linemaps/spec1d-{}-{}.tab'.format(species, wavid)
    spec = Table.read(sname, format='ascii.tab')
    for xkey, xlabel in [['vhel', 'Heliocentric velocity, km/s'],
                         ['wav', 'Observed air wavelength, Angstrom']]:
        fig, ax = plt.subplots(1, 1)
        ax.plot(spec[xkey], spec['flux'])
        ax.plot(spec[xkey], spec['cont'])
        if xkey == 'wav':
            ax.set_xlim(row['wav0']-8.0, row['wav0']+8.0)
        else:
            ax.set_xlim(-300.0, 300.0)
        ax.set_ylim(0.0, None)
        ax.set_xlabel(xlabel)
        ax.set_ylabel('Mean flux per pixel')
        ax.set_title('{} {:.2f}'.format(row['Ion'], row['wav0']))
        fig.set_size_inches(5, 5)
        fig.savefig(sname.replace('.tab', '-{}.pdf'.format(xkey)))
        del(fig)
        del(ax)
```

multibin-map.py: Rebin the MUSE line maps at multiple resolutions

```
from __future__ import print_function
import sys
from distutils.dep_util import newer, newer_group
import numpy as np
from rebin_utils import downsample, oversample
from astropy.io import fits

nlist = [1, 2, 4, 8, 16, 32, 64, 128, 256]
mingoods = [2, 2, 2, 2, 2, 2, 2, 2, 2]

def pad_array(a, n):
    """Pad 2d array `a` to nearest multiple of `n` in each dimension"""
    newshape = n*np.ceil(np.array(a.shape).astype(float)/n)
    b = np.zeros(newshape, dtype=a.dtype)
    b[:a.shape[0], :a.shape[1]] = a
    return b


try:
```

```
    infile = sys.argv[1]
except:
    sys.exit('Usage: {} FITSFILE'.format(sys.argv[0]))


hdu = fits.open(infile)[0]
hdr = hdu.header
# Maximum binning
nmax = nlist[-1]

# Pad arrays to nearest multiple of nmax
im = pad_array(hdu.data, nmax)
w = np.ones_like(im)

continuum = fits.open('muse-hr-image-wfc3-f547m.fits')['DATA'].data
starmask = continuum > 30
m =  np.isfinite(hdu.data) & (~starmask)
m = pad_array(m, nmax)

for n, mingood in zip(nlist, mingoods):
    im[~m] = 0.0
    outfile = infile.replace('.fits', '-bin{:03d}.fits'.format(n))
    if n == nlist[0]:
        # Do dependency checking on the first iteration
        if not newer(infile, outfile):
            # Bail out if dependency not newer than target
            sys.exit(outfile + ' is already up to date.')
    print('Saving', outfile)
    # Save both the scaled image and the weights, but at the full resolution
    fits.HDUList([
        fits.PrimaryHDU(),
        fits.ImageHDU(data=oversample(im, n), header=hdr, name='scaled'),
        fits.ImageHDU(data=oversample(w, n), header=hdr, name='weight'),
    ]).writeto(outfile, clobber=True)
    # Now do the rebinning by a factor of two
    [im,], m, w = downsample([im,], m, weights=w, mingood=mingood)
```

Run the above script on all extracted lines:

```
linelist=LineMaps/linesum-*[0-9][0-9][0-9][0-9].fits
for line in $linelist; do
    echo "Processing $line"
    time python multibin-map.py $line > ${line}-multibin.log
done
```