Open and reproducible paleomagnetic data analysis using IPython

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Calculate and graphically display the confidence interval on the minimum rate estimate implied by the Monte Carlo sampled pairs of sampled ages and paleolatitudes from the two poles

The pairs of sampled ages and poles can be used to calculate rates (with the total number of rates being set by `samplesize` in the input box above). The rate calculated above of 24.0 cm/year can now be given confidence bounds by taking 2.5 percentile and 97.5 percentile of the Monte Carlo simulated rates.

In [32]:

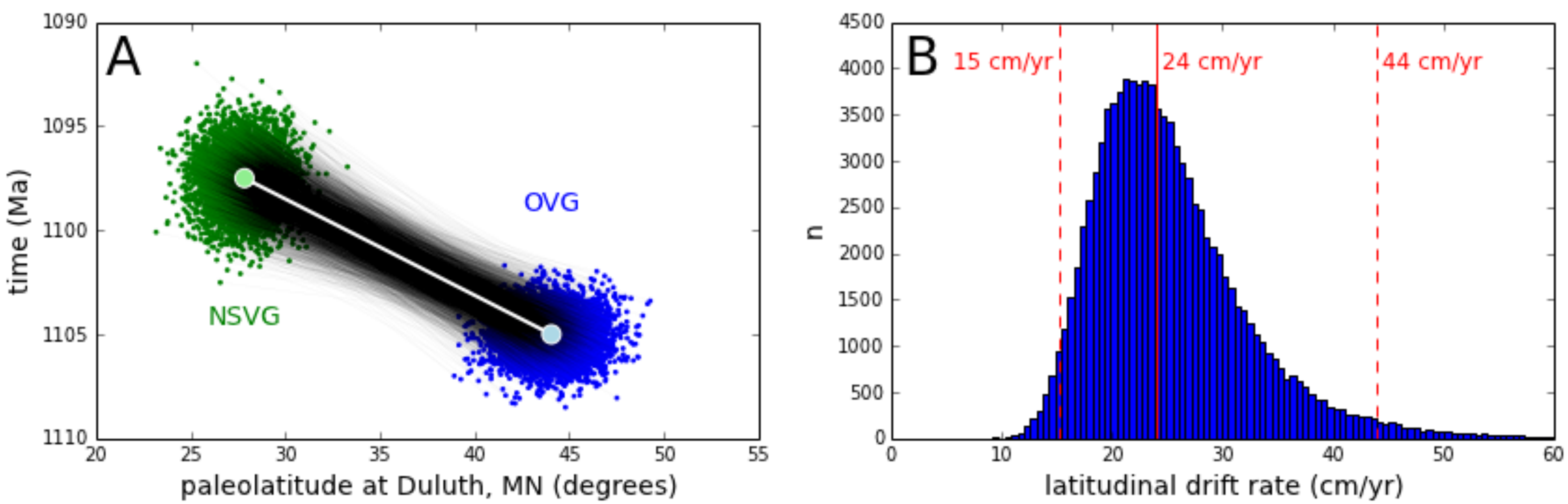
```
#calculating the change in paleolatitude between the Monte Carlo pairs
pole1_pole2_Delta_degrees=[]
pole1_pole2_Delta_kilometers=[]
pole1_pole2_Delta_myr=[]
pole1_pole2_degrees_per_myr=[]
pole1_pole2_cm_per_yr=[]

for n in range(samplesize):
    Delta_degrees=pole1_MCpaleolat[n]-pole2_MCpaleolat[n]
    Delta_Myr=pole1_MCages[n]-pole2_MCages[n]
    pole1_pole2_Delta_degrees.append(Delta_degrees)
    degrees_per_myr=Delta_degrees/Delta_Myr
    cm_per_yr=((Delta_degrees*111)*100000)/(Delta_Myr*1000000)
    pole1_pole2_degrees_per_myr.append(degrees_per_myr)
    pole1_pole2_cm_per_yr.append(cm_per_yr)
```

In [33]:

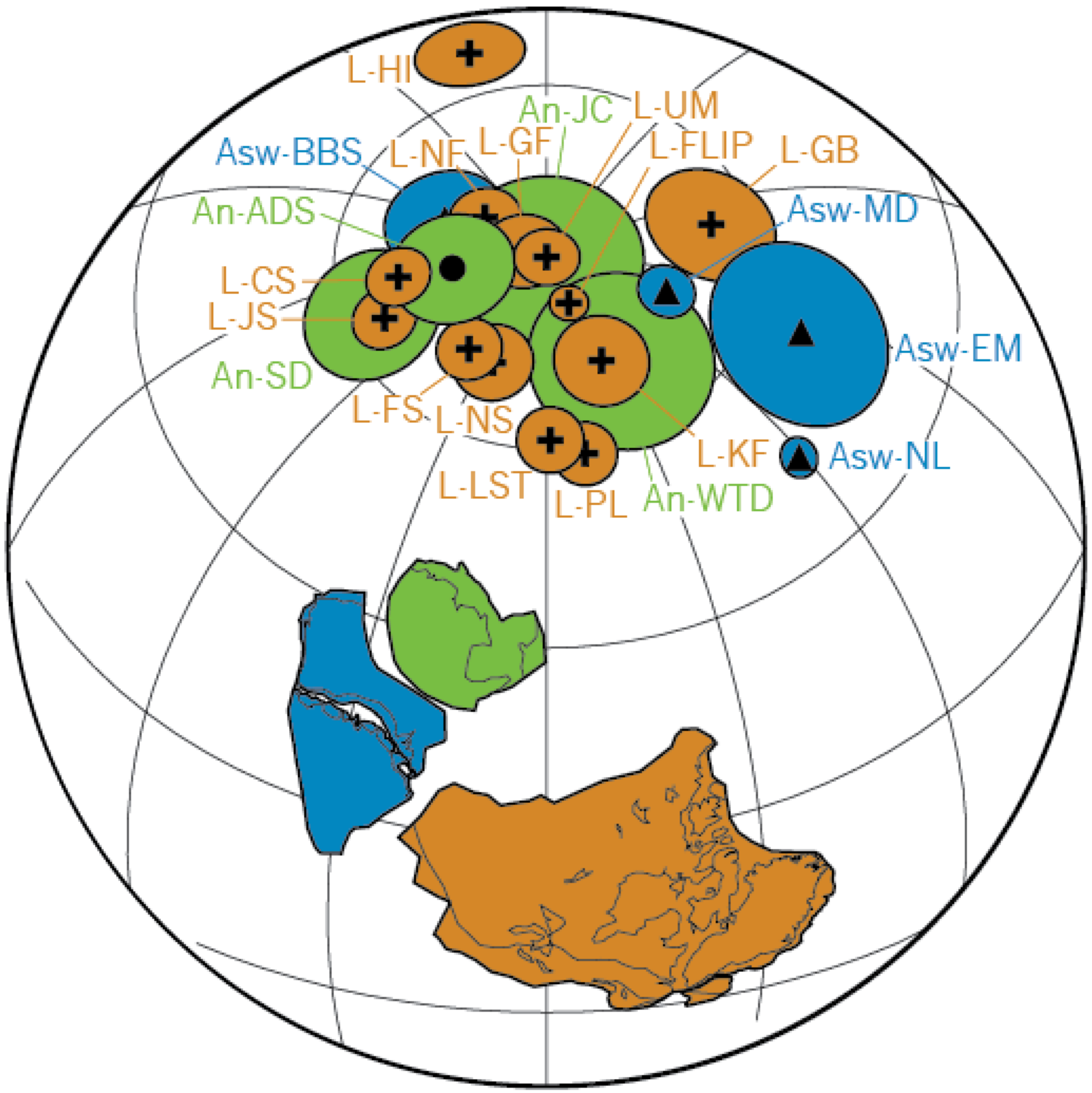
```
twopointfive_percentile=stats.scoreatpercentile(pole1_pole2_cm_per_yr,2.5)
fifty_percentile=stats.scoreatpercentile(pole1_pole2_cm_per_yr,50)
ninetysevenpointfive_percentile=stats.scoreatpercentile(pole1_pole2_cm_per_yr,97.5)
print "2.5th percentile is: " + str(twopointfive_percentile)
print "50th percentile is: " + str(fifty_percentile)
print "97.5th percentile is: " + str(ninetysevenpointfive_percentile)
```

```
2.5th percentile is: 15.1860289306
50th percentile is: 23.9833375899
97.5th percentile is: 44.0185724854
```

We can see here that the 50th percentile from th
percentile give a 95% confidence range of 15.2 t
`samplesize` when code was executed) pole pairs
being marked. This plot is Figure 4 of the manuscri



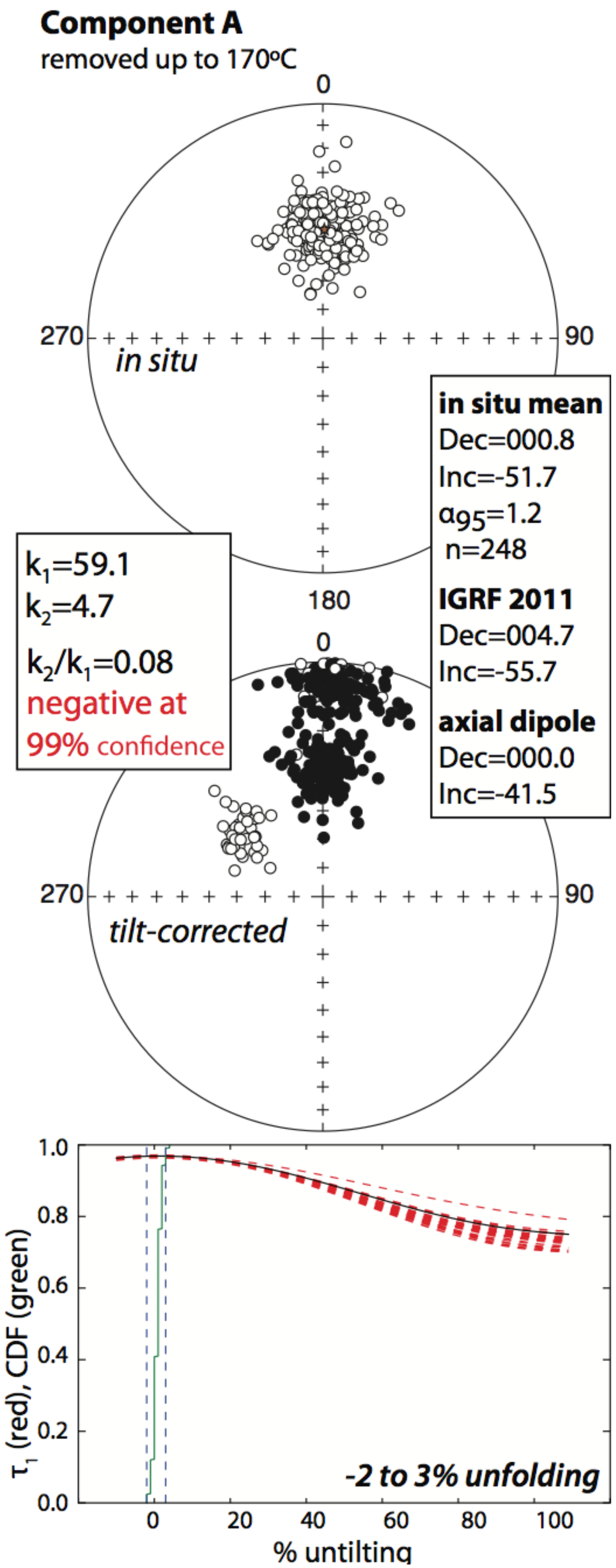
We develop magnetic data to understand the Earth. Our resulting data-driven insights need to be told with:



Swanson-Hysell et al., 2012

- the data itself (which need to be robustly archived <u>MagIC!</u>)
- data analysis (statistical summaries, comparisons, tests, simulations)
- models
- plots, images and other visualizations
- descriptive text

An example workflow



A complex disconnected set of tools to make this figure

Paleomag *least-square fits*

Sheepshaver *OS9 emulator*

Paleomac *equal area plots and Fisher statistics*

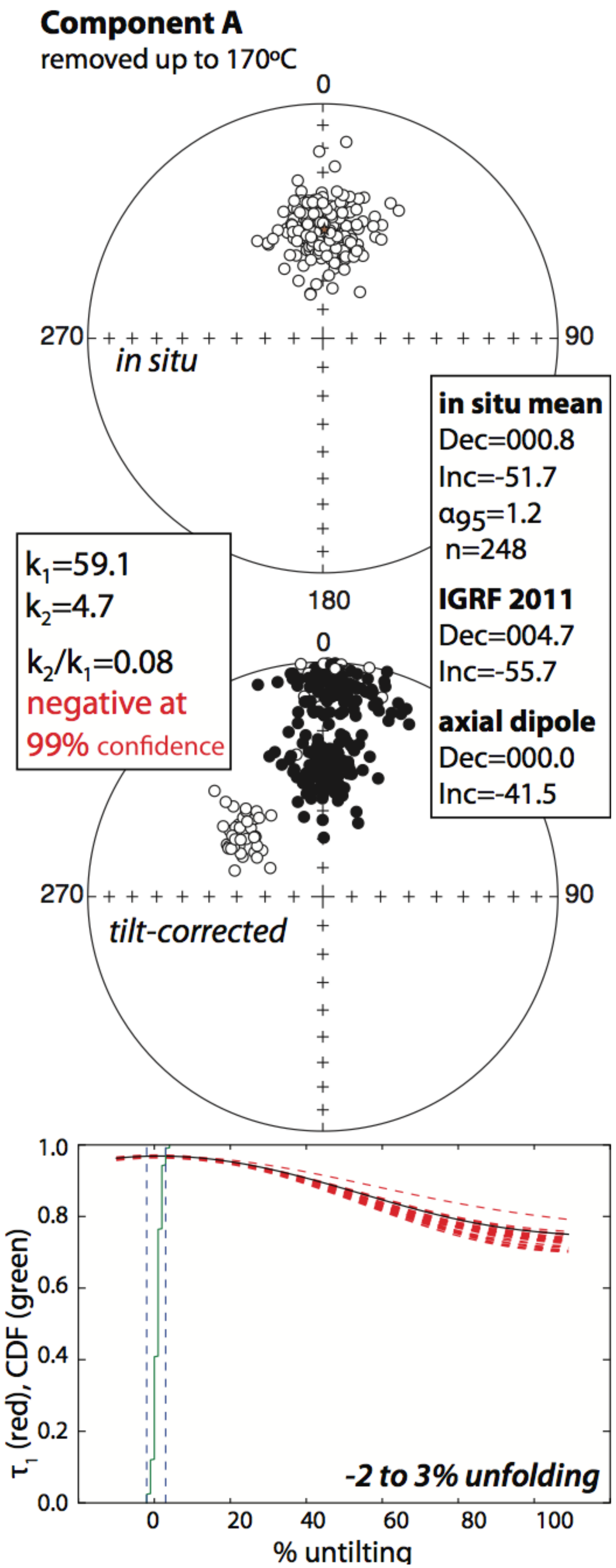
PmagPy *non-parametric statistical tests*

Adobe Illustrator *figure compilation*

LaTEX *document compilation*

Swanson-Hysell et al., 2012

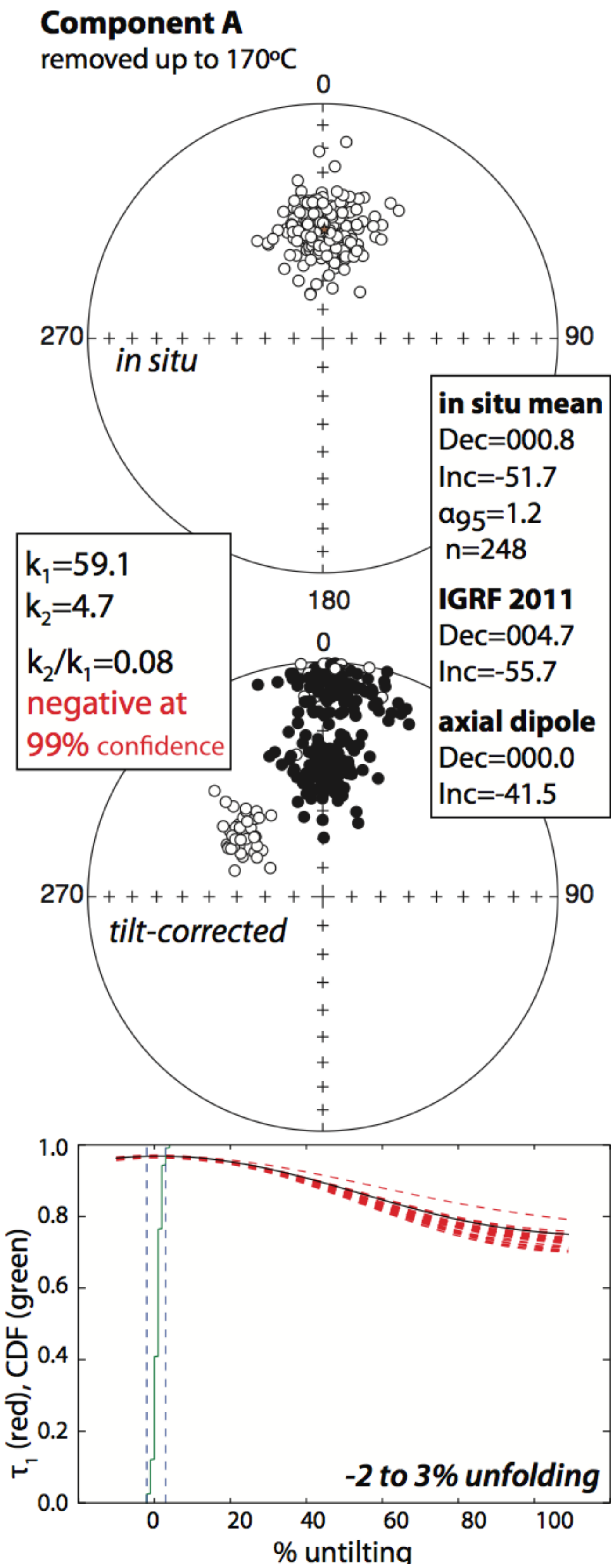
An example workflow



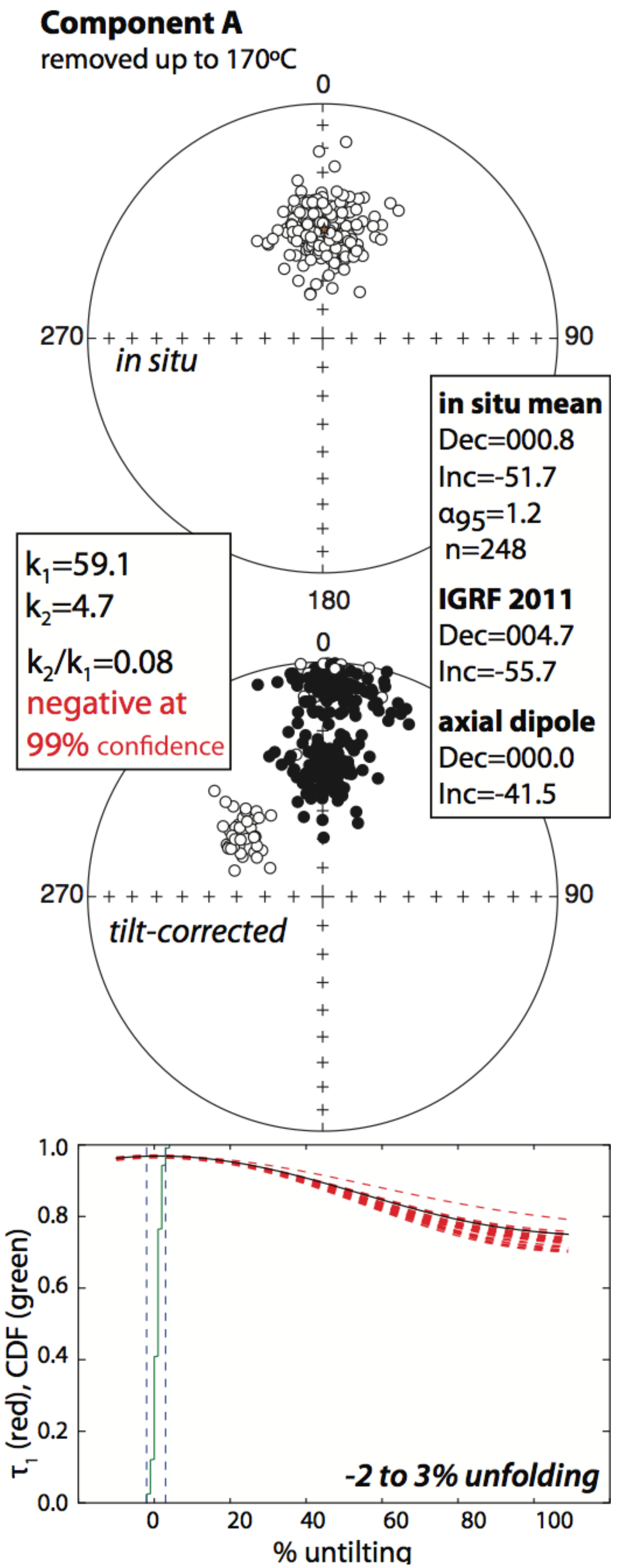
A complex disconnected set of tools to make this figure

- difficult to fully document work flow
- laborious to reproduce
- hinders communication (particularly mid-stream)

Swanson-Hysell et al., 2012



What if all of these data, statistical results, plots and underlying code could be presented in a single easily-shared document?

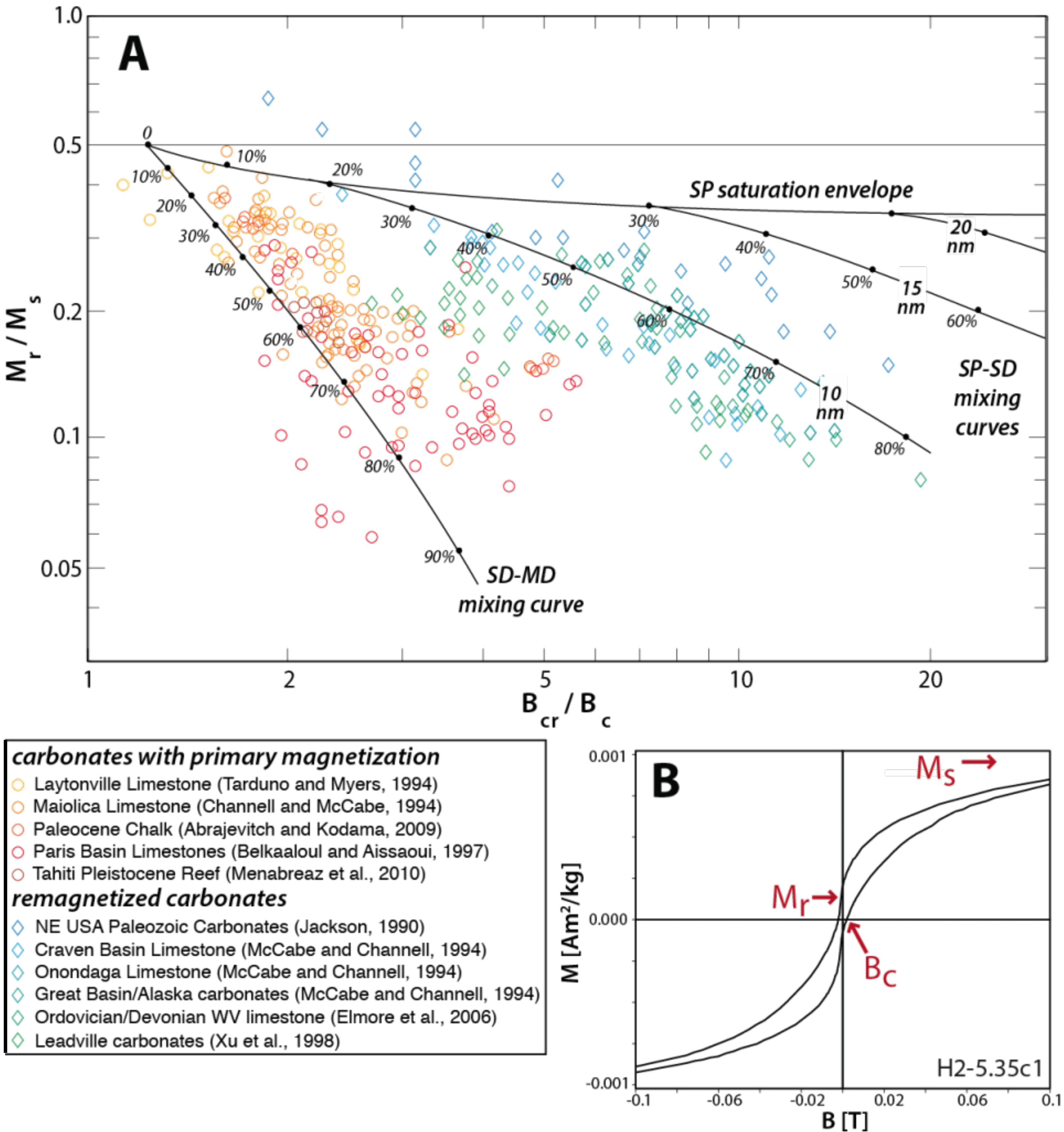


What if all of these data, statistical results, plots and underlying code could be presented in a single easily-shared document?

the IPython notebook

OPEN and REPRODUCIBLE

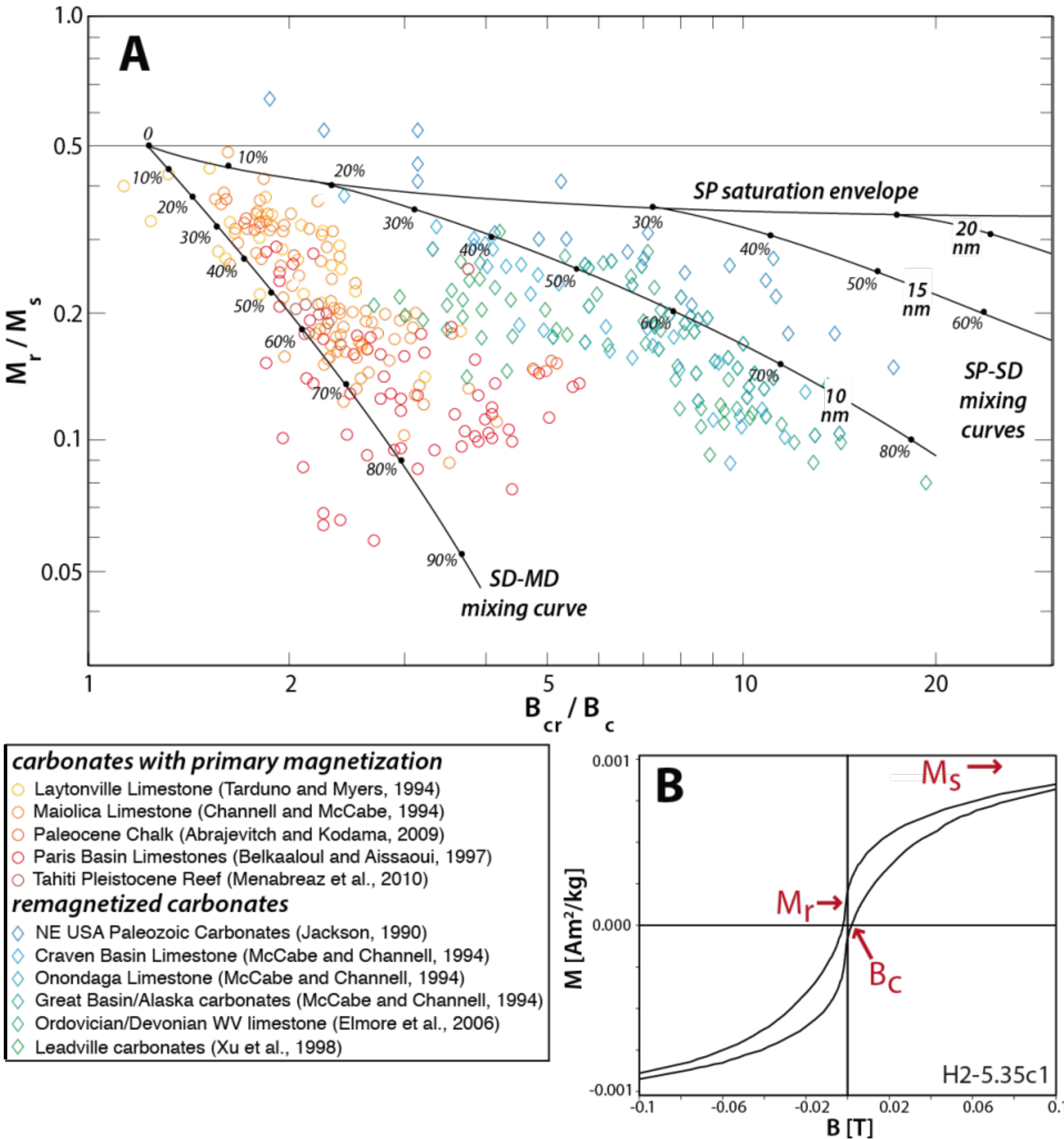
Sharing compilations and plots



Swanson-Hysell et al., 2012

Jackson and Swanson-Hysell, 2012

Sharing compilations and plots



Andrew Roberts <andrew.roberts@anu.edu.au>
to irm, me

4/22/13

"I wonder if you would be happy to send me the data that you presented in Figure 1a of Jackson& Swanson-Hysell (2012)? I would like to re-plot this figure to avoid copyright issues but would do so with full citation.

Best wishes, Andrew"

Swanson-Hysell et al., 2012

Jackson and Swanson-Hysell, 2012

http://www.swanson-hysell.org/publications/carbonate-hysteresis-compilation/

Data sets from carbonate formations with interpreted primary magnetization

Tarduno1994b Laytonville Limestone (primary magnetization)

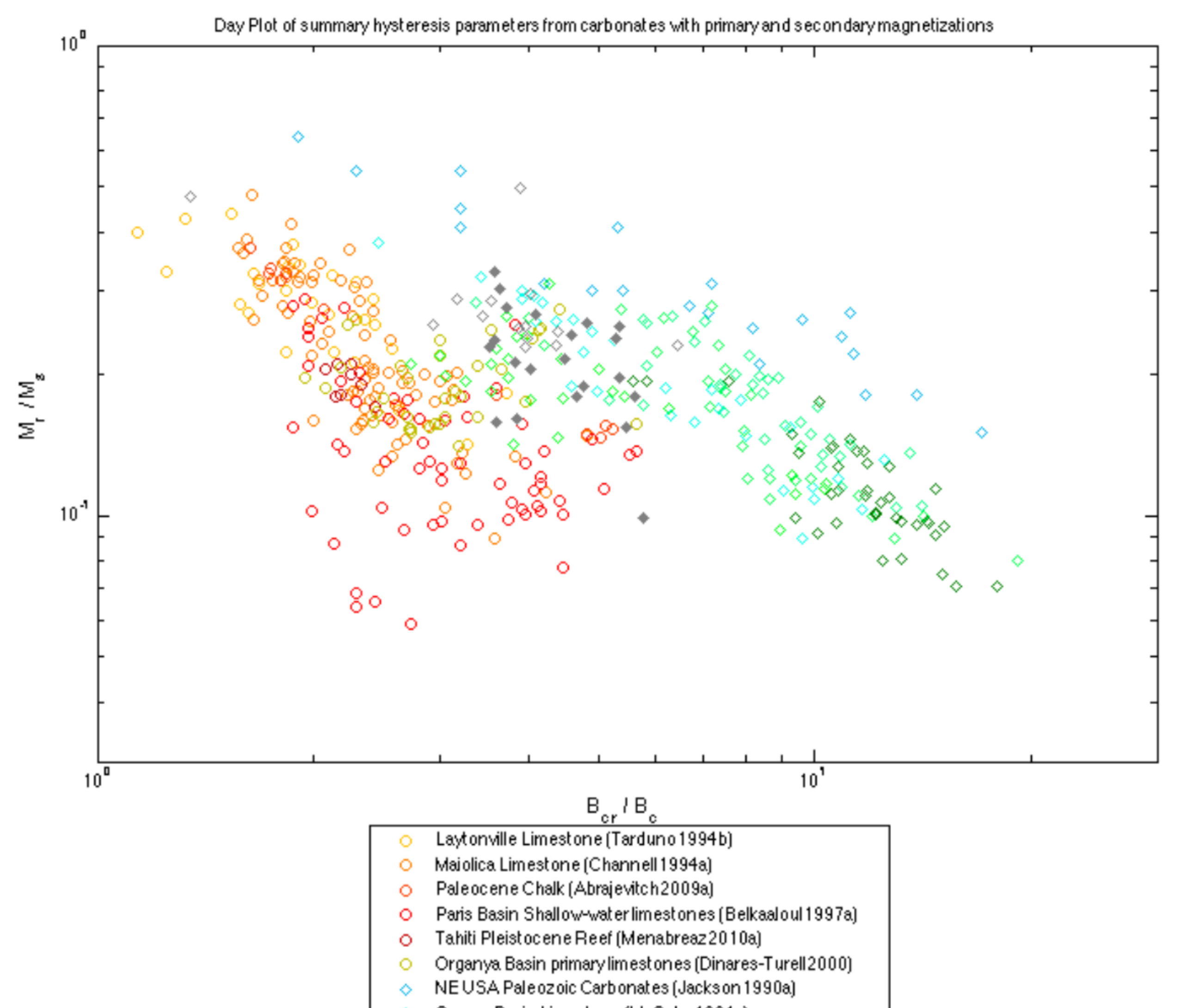
Tarduno, J. A., and Myers, M., 1994, A primary magnetization fingerprint from the Cretaceous Laytonville Limestone: Further evidence for rapid oceanic plate velocities: Journal of Geophysical Research, v. 99, n. B11, p. 21,691–21,703, http://dx.doi.org/10.1029/94JB01939

These data are from the Laytonville Limestone–a Cretaceous pelagic Limestone from northern California in an accreted terrain. Some samples contain hematite (Red Laytonville Limestone) and are not included in the compilation. White limestones with neglible hematite are compared in the paper to reference pelagic limestone data and are indistinguishable. A primary magnetization for the Laytonville Limestone is supported by the fact that the trend in inclination matches the expected sense of motion predicated by the North American APW path. Download .csv file of data for the White Laytonville Limestone

```
[Tarduno1994b_Bcr_Bc Tarduno1994b_Mr_Ms]=textread('Tarduno1994b_white.csv','','delimiter',','
```

DAY PLOT LOG AXES

```
DayPlotLog = figure;
%loglog non-remag as circles
loglog(Tarduno1994b_Bcr_Bc,Tarduno1994b_Mr_Ms,'o','MarkerEdgeColor', [1 .75 0])
hold on
loglog(Channell1994a_Bcr_Bc,Channell1994a_Mr_Ms,'o','MarkerEdgeColor', [1 0.5 0])
loglog(Abrajevitch2009a_Bcr_Bc,Abrajevitch2009a_Mr_Ms,'o','MarkerEdgeColor', [1 0.25 0])
loglog(Belkaaloul1997a_Bcr_Bc,Belkaaloul1997a_Mr_Ms,'o','MarkerEdgeColor', [1 0 0])
loglog(Menabreaz2010a_Bcr_Bc,Menabreaz2010a_Mr_Ms,'o','MarkerEdgeColor', [.75 0 0])
loglog(DT2000primary_Bcr_Bc,DT2000primary_Mr_Ms,'o','MarkerEdgeColor', [.75 .75 0])

%loglog remag as diamonds
loglog(Jackson1990a_Bcr_Bc,Jackson1990a_Mr_Ms,'d','MarkerEdgeColor', [0 .7 .9])
loglog(McCabe1994a_Craven_Bcr_Bc,McCabe1994a_Craven_Mr_Ms,'d','MarkerEdgeColor', [0 1 .9])
loglog(McCabe1994a_Onondaga_Bcr_Bc,McCabe1994a_Onondaga_Mr_Ms,'d','MarkerEdgeColor', [0 1 .7]
loglog(McCabe1994a_GreatBasin_Alaska_Bcr_Bc,McCabe1994a_GreatBasin_Alaska_Mr_Ms,'d','MarkerEd
loglog(Elmore2006a_Bcr_Bc,Elmore2006a_Mr_Ms,'d','MarkerEdgeColor', [0 1 .3])
loglog(Xu1998a_Bcr_Bc,Xu1998a_Mr_Ms,'d','MarkerEdgeColor', [0 1 .1])
loglog(DT2000remag_Bcr_Bc,DT2000remag_Mr_Ms,'d','MarkerEdgeColor', [0 .5 0])
loglog(S_H2012a_core_Bcr_Bc,S_H2012a_core_Mr_Ms,'d','MarkerEdgeColor',[0.5 0.5 0.5],'MarkerFa
loglog(S_H2012a_outcrop_Bcr_Bc,S_H2012a_outcrop_Mr_Ms,'d','MarkerEdgeColor',[0.5 0.5 0.5])
axis([1 30 .03 1])

legend('Laytonville Limestone (Tarduno1994b)','Maiolica Limestone (Channell1994a)','Paleocene
'Paris Basin Shallow-water limestones (Belkaaloul1997a)','Tahiti Pleistocene Reef (Menabreaz2
'NE USA Paleozoic Carbonates (Jackson1990a)','Craven Basin Limestone (McCabe1994a)','Onondaga
'Great Basin/Alaska remag carbonates (MacCabe1994a)','Ordovician/Devonian WV limestone (Elmor
'Organya Basin remag limestones (Dinares-Turell2000)','Bitter Springs Fm core (Swanson-Hysell
'Bitter Springs Fm outcrop (Swanson-Hysell2012a)','location','southoutside')
xlabel('B_c_r / B_c','FontSize',12)
ylabel('M_r / M_s','FontSize',12)
title('Day Plot of summary hysteresis parameters from carbonates with primary and secondary r
```

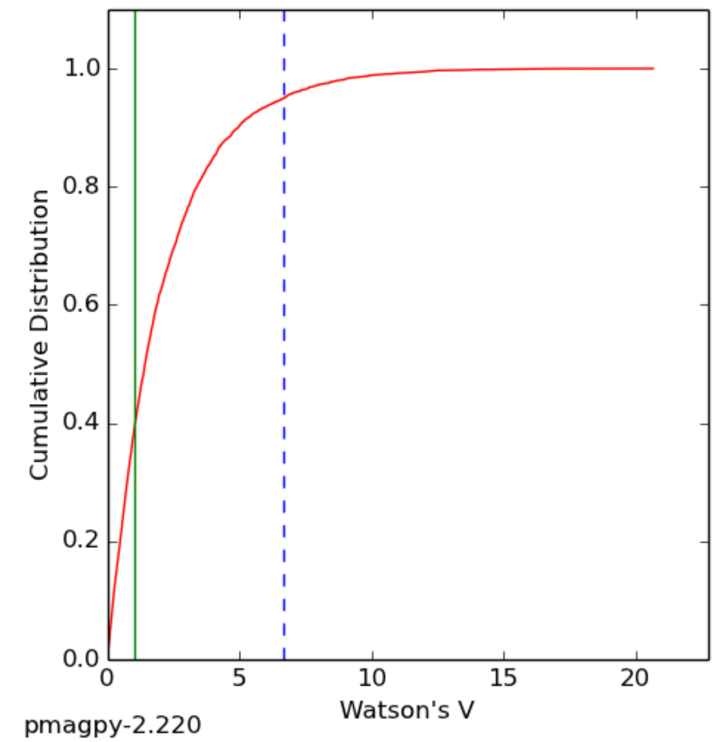


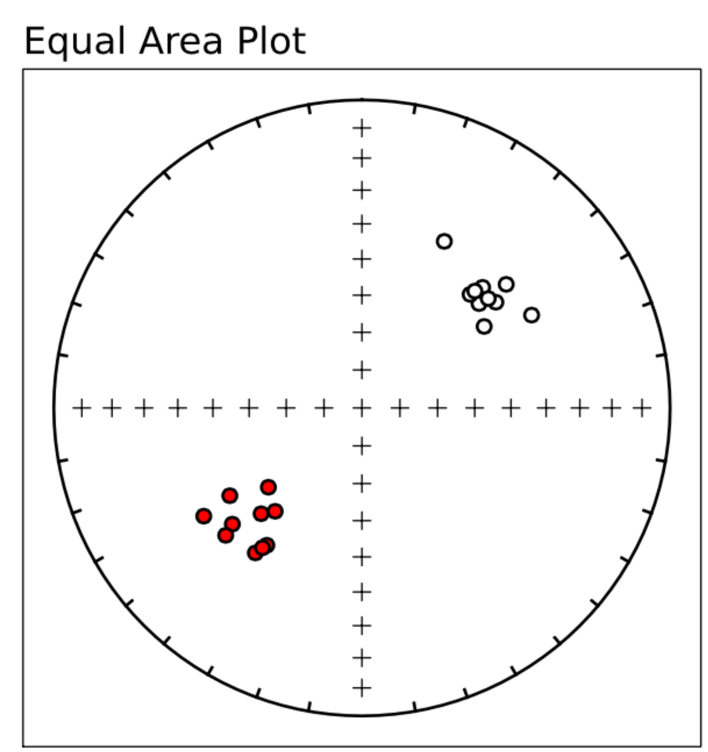
PUBLIC **ltauxe / PmagPy**

Python-based tools for Paleomagnetic research http://scripps.ucsd.edu

Pmag_Workspace — Python — 80×18

```
Nicks-MacBook-Pro:Pmag_Workspace polarwander$ revtest_MM1990.py -f Fisher_data1.
txt -f2 Fisher_data2.txt
be patient, your computer is doing 5000 simulations...

Results of Watson V test:

Watson's V:           1.0
Critical value of V:  6.7
"Pass": Since V is less than Vcrit, the null hypothesis that the two populations
 are drawn from distributions that share a common mean direction (antipodal to o
ne another) cannot be rejected.

M&M1990 classification:

Angle between data set means: 2.7
Critical angle of M&M1990:   6.8
The McFadden and McElhinny (1990) classification for this test is: 'B'
 S[a]ve to save plot, [q]uit without saving:
```





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Source Code for Module fisher

```
 #!/usr/bin/env python
 import pmag,sys
-def spitout(kappa):
     dec,inc= pmag.fshdev(kappa)  # send kappa to fshdev
     print '%7.1f %7.1f ' % (dec,inc)
     return
-def main():
     """
     NAME
         fisher.py

     DESCRIPTION
         generates set of Fisher distribed data from specified distribution
```

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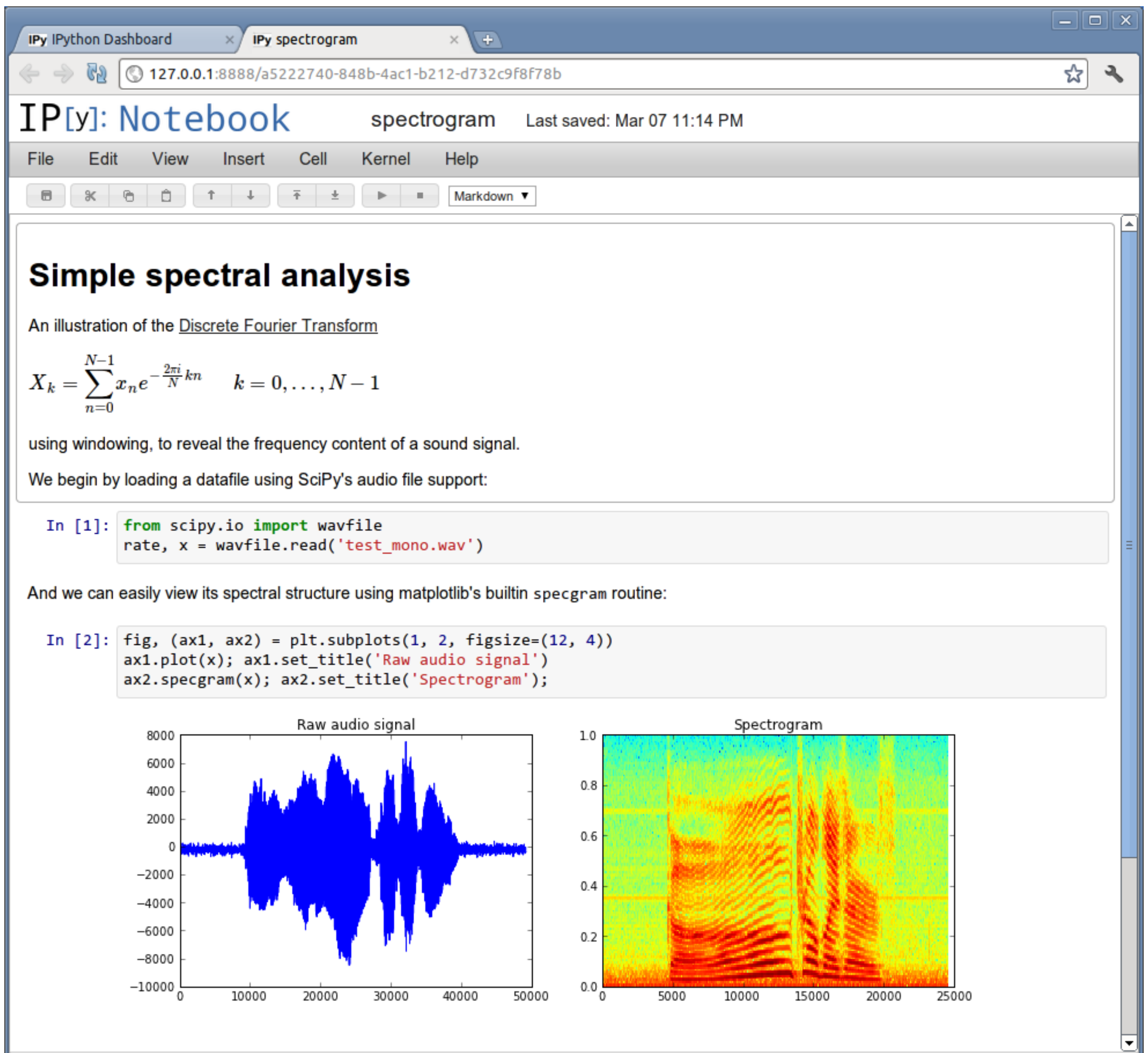
The IPython notebook

A browser-based interactive computational environment where you can combine code execution, text, mathematics, plots and rich media into a single document



- Interactive
- Exploratory
- Collaborative
- Open
- Reproducible

www.IPython.org

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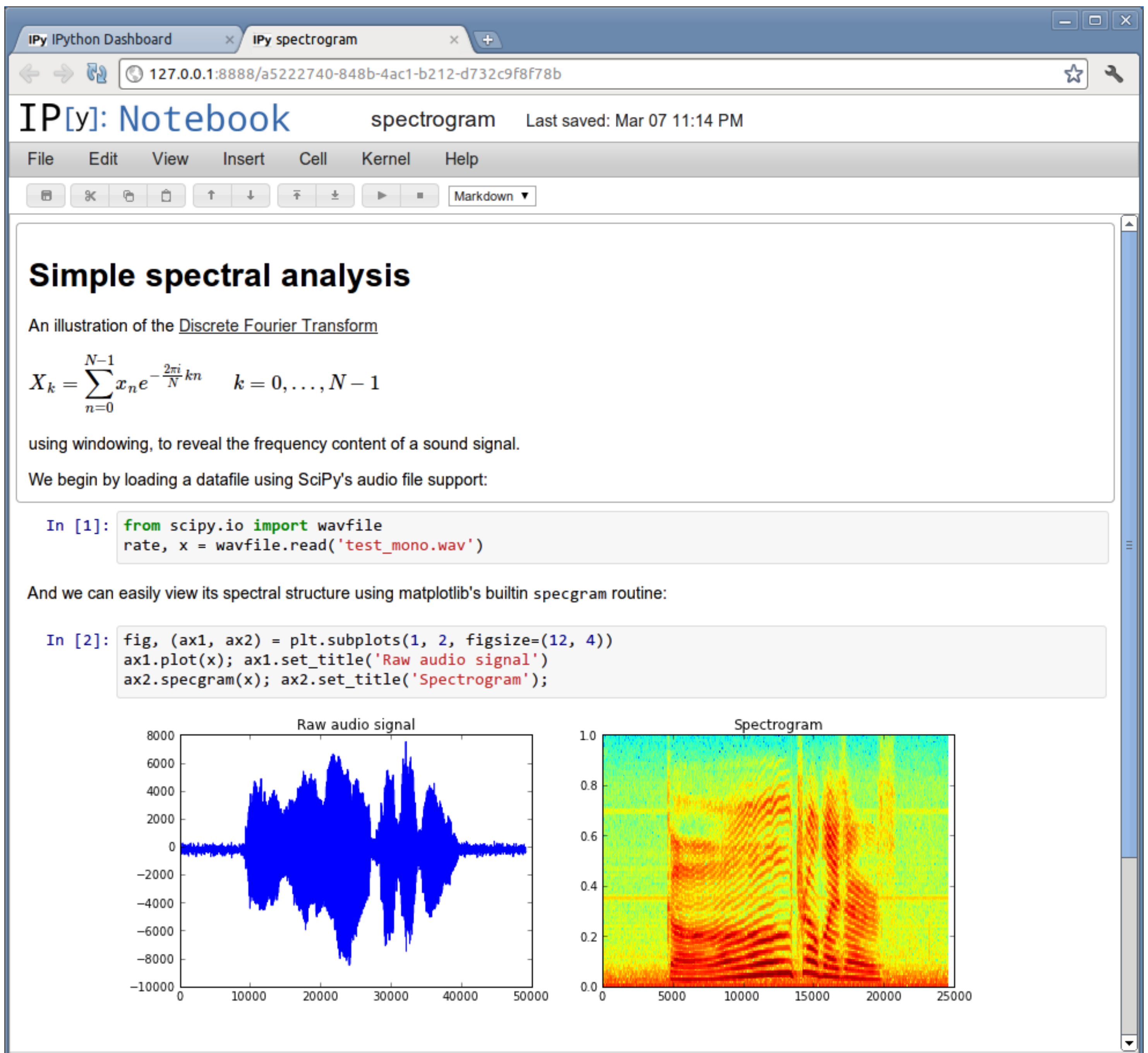

www.IPython.org

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- pmag.py

```python
def fshdev(k):
    """
    returns a direction from distribution with mean declination of 0, inclination of 90 and kappa of k
    """
    R1=random.random()
    R2=random.random()
    L=numpy.exp(-2*k)
    a=R1*(1-L)+L
    fac=numpy.sqrt((-numpy.log(a))/(2*k))
    inc=90.-2*numpy.arcsin(fac)*180./numpy.pi
    dec=2*numpy.pi*R2*180./numpy.pi
    return dec,inc
```

- pmagplotlib.py

```python
def plotNET(fignum):
    """
    draws circle and tick marks for equal area projection
    """
#
# make the perimeter
#
    pylab.figure(num=fignum)
    pylab.clf()
    if not isServer: pylab.figtext(.02,.01,version_num)
    pylab.axis("off")
```

PUBLIC ltauxe / **PmagPy**

Python-based tools for Paleomagnetic research http://scripps.ucsd.edu

- pmag.py
- pmagplotlib.py

PUBLIC Swanson-Hysell / **PmagPy_IPython**

Pmag function libraries for use within IPython notebooks

- IPmag.py

Import and display data

Import Simpson Island paleomagnetic data

The data file FlowDataAll.csv has data in this format:

SITE, STRAT_HEIGHT, DEC_GEO, INC_GEO, Dec_TC, INC_TC, A95, n, Plat, ABS_Plat, VGP_lat, VGP_long

where:

SITE is the name of the site and corresponds to an individual lava flow where in the first part of the site name (e.g. SI1) corresponds to the name of a stratigraphic section while the second part (e.g. (11.8 to 26.4)) corresponds to the stratigraphic ranges within the measured section over which the flows is exposed.

STRAT_HEIGHT is the cumulative stratigraphic height of the Simpson Island stratigraphy starting with the base of the SI1 section (see map in the main manuscript).

Table of Simpson Island paleomagnetic data

In [3]:
```
data = pandas.read_csv('../2014_Osler_Data/SimpsonIsland_OslerData.csv')
#write these data to a latex file for the supplemental PDF
with open('OslerData.txt','w') as f:
    f.write(data.to_latex(index=False,columns=['Site','Strat_Height','Site_Lat','Site_Long','Dec_Geo','Inc_Geo','Dec_TC','Inc
display(HTML(data.to_html()))
```

	Site	Strat_Height	Site_Lat	Site_Long	Dec_Geo	Inc_Geo	Dec_TC	Inc_TC	A95	n	Plat	ABS_Plat	VGP_lat	VGP_long
0	SI1(11.8 to 26.4)	11.8	48.8122	-87.6620	120.3	-77.1	79.7	-70.5	2.7	7	-54.7	54.7	33.1	229.6
1	SI1(28.3 to 29.2)	28.3	48.8107	-87.6623	141.0	-67.4	109.8	-66.8	3.9	7	-49.4	49.4	45.8	210.9
2	SI1(29.2 to 29.7)	29.2	48.8104	-87.6622	131.2	-69.1	99.7	-66.2	5.7	3	-48.6	48.6	39.6	214.5
3	SI1(33.3 to 37.1)	33.3	48.8100	-87.6623	127.7	-72.3	92.6	-68.1	7.7	5	-51.2	51.2	37.2	220.5
4	SI1(40.6 to 42.5)	40.6	48.8095	-87.6626	134.9	-77.7	85.4	-73.3	3.5	6	-59.0	59.0	38.2	231.6
5	SI1(42.5 to 44.4)	42.5	48.8095	-87.6627	103.0	-71.6	77.8	-63.5	4.5	6	-45.1	45.1	25.8	222.3
6	SI1(58.1 to 64.1)	58.1	48.8086	-87.6622	114.4	-70.8	86.1	-64.4	8.7	5	-46.2	46.2	30.8	218.8
7	SI1(87.6 to 88.5)	87.6	48.8073	-87.6620	134.3	-75.8	89.9	-71.9	1.9	6	-56.9	56.9	39.0	227.7
8	SI1(88.5 to 89.2)	88.5	48.8071	-87.6619	128.2	-74.6	88.9	-70.0	5.0	5	-53.9	53.9	36.9	224.9
9	SI1(89.2 to 91.5)	89.2	48.8070	-87.6618	120.1	-72.8	87.0	-67.2	7.6	5	-49.9	49.9	33.6	221.8
10	SI1(91.5 to 92.6)	91.5	48.8069	-87.6618	118.4	-74.8	82.8	-68.5	3.0	6	-51.8	51.8	32.7	225.5

Swanson-Hysell et al., 2014

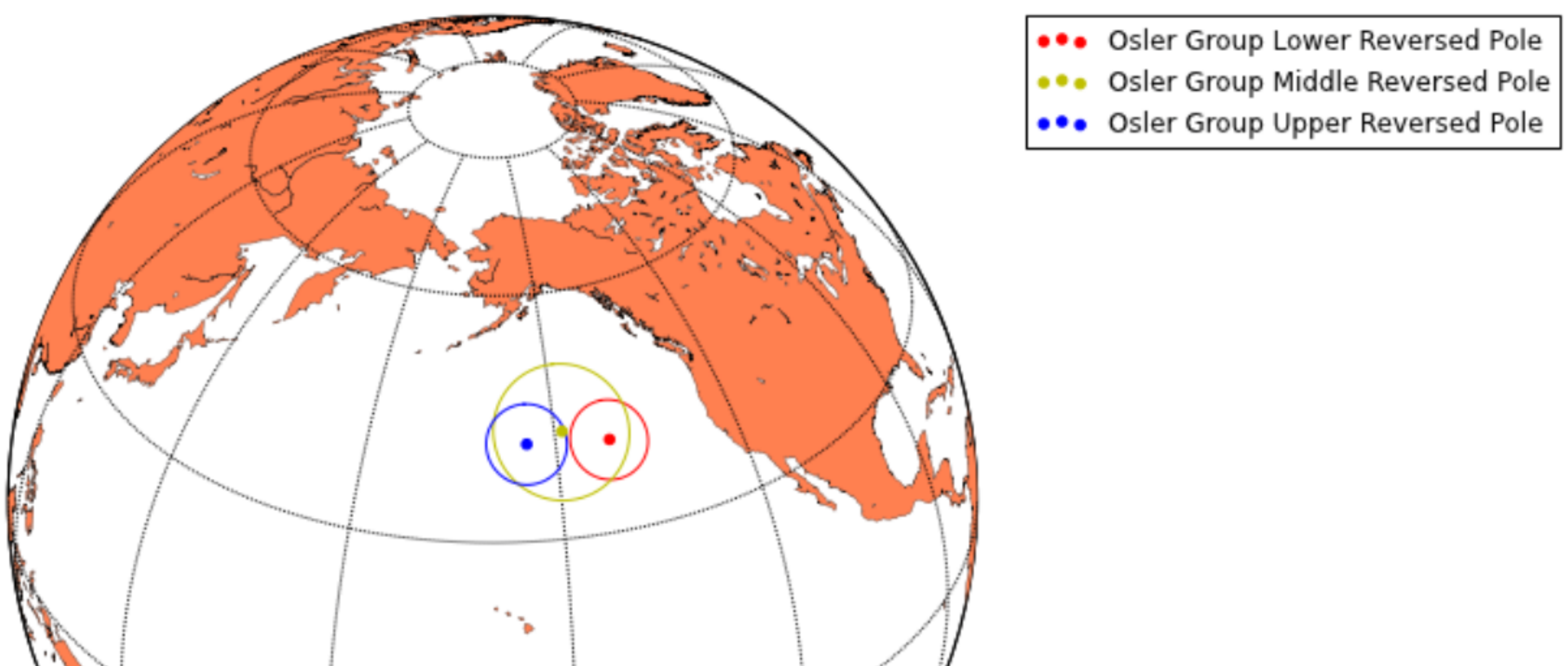
Inline statistical results and plots

Calculating and plotting mean pole positions

The code below calculates the Fisher mean parameters for poles of the stratigraphically grouped virtual geomagnetic poles (VGPs) and then plots them on a "view from space" globe. Note that while where the textual output says "dec" it actually refers to pole longitude and where it says "inc" it actually refers to pole latitude since the pmag.fisher_mean function is being conducted on VGPs.

In [15]:
```
LowerThird_MeanPole=pmag.fisher_mean(SI_LowerThird_Poles)
MiddleThird_MeanPole=pmag.fisher_mean(SI_MiddleThird_Poles)
UpperThird_MeanPole=pmag.fisher_mean(SI_UpperThird_Poles)

IPmag.poleplot(m,UpperThird_MeanPole['dec'],UpperThird_MeanPole['inc'],
               UpperThird_MeanPole['alpha95'],color='b',label='Osler Group Upper Reversed Pole')

#show the plot
legend(bbox_to_anchor=(1.05, 1), loc=2, borderaxespad=0.)
plt.show()
```

```
The Fisher mean parameters for the LowerThird mean pole are:
Plong = 218.637832609 Plat = 40.937318541
A95 = 4.76006232039 k= 31.4671112908

The Fisher mean parameters for the MiddleThird mean pole are:
Plong = 211.261736125 Plat = 42.7378078852
A95 = 8.1783359746 k= 16.9030328287

The Fisher mean parameters for the UpperThird mean pole are:
Plong = 205.410227513 Plat = 41.5645761829
A95 = 4.80394668574 k= 27.2260167637
```



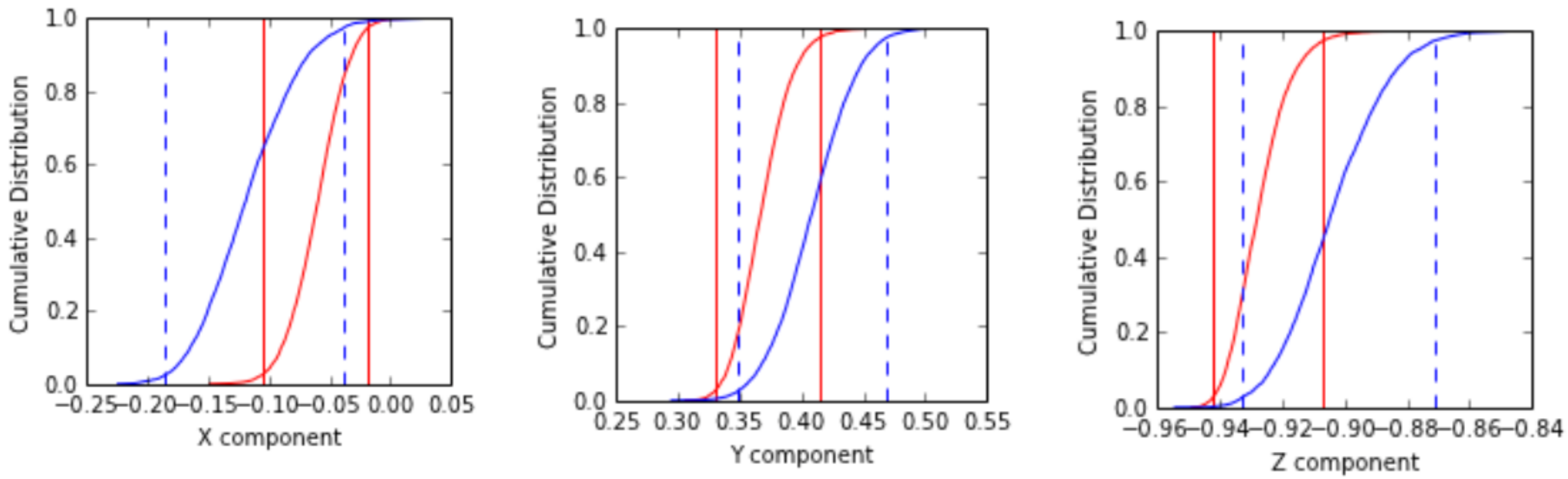
Swanson-Hysell et al., 2014

Inline statistical results and plots

Common mean tests between SI_LowerThird_Directions and SI_MiddleThird_Directions:

In [6]:
```
IPmag.iWatsonV(SI_LowerThird_Directions,SI_MiddleThird_Directions)
IPmag.iBootstrap(SI_LowerThird_Directions,SI_MiddleThird_Directions)
```

```
Results of Watson V test:

Watson's V:           2.6
Critical value of V:  6.2
"Pass": Since V is less than Vcrit, the null hypothesis
that the two populations are drawn from distributions
that share a common mean direction can not be rejected.

M&M1990 classification:

Angle between data set means: 4.1
Critical angle for M&M1990:   6.3
The McFadden and McElhinny (1990) classification for
this test is: 'B'

===============

Here are the results of the bootstrap test for a common mean
```



Swanson-Hysell et al., 2014

Inline text and graphics

Paleogeographic work outside of this IPython notebook using the software package GPlates.

For details on working with paleomagnetic data in GPlates check out this tutorial.

The steps necessary to develop the reconstruction using these Osler Volcanic Group poles are detailed below.

(1) Develop .rot file that rotates Laurentia such that the Osler poles are at geographic north. In the text for the .rot file below the Osler_lowerthird pole is assigned to 1110 Ma, the Osler_middlethird pole is assigned to 1107.5 and the Osler_upperthird pole is assigned to 1105 Ma.

The .rot file has the format:

moving plate ID number	age in millions of years	latitude of Euler pole	longitude of Euler pole	angle	fixed plate	comment

In this .rot file, the fixed reference frame is 000 and 001 (which could be split into a relative and absolute reference frame that seperates out TPW), while the plate ID for Laurentia is 199.

```
001  0.0    0.0     0.0     0.0  000 ! \\
001 3900.0    0.0     0.0     0.0  000 ! \\
199  0.0    0.0     0.0     0.0  001 ! \\
199 1105.0    0.0  115.4   48.4  001 !Put Osler-upperthird at N for Laurentia \\
199 1107.5    0.0  121.3   47.3  001 !Put Osler-middlethird at N for Laurentia \\
199 1110.0    0.0  128.7   49.0  001 !Put Osler-lowerthird at N for Laurentia \\
```

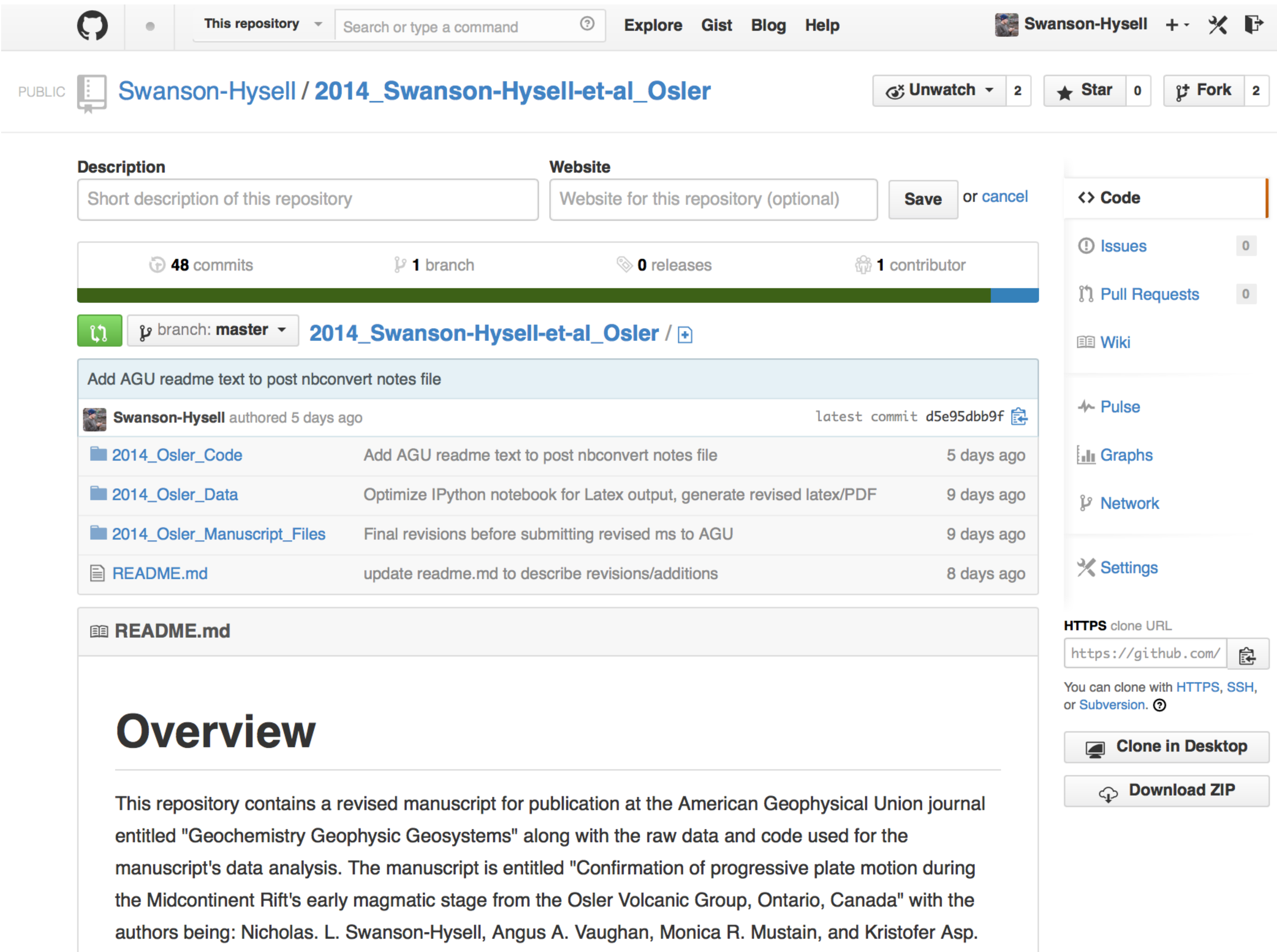
(2) Open the following feature collections in GPlates: 199-Laurentia nogrid.dat, OslerPoles.gpml and Osler.rot where 199-Laurentia nogrid.dat is the outline of Laurentia in the late Proterozoic and OslerPoles.gpml contains the three calculated Osler paleomagnetic poles. An animation from 1110 to 1105 Ma yields the following reconstruction shown here with a time slice for Osler_lowerthird (red), Osler_middlethird (yellow) and Osler_upperthird (blue).

In [23]:
```
from IPython.display import SVG
SVG("Paleogeo.svg")
```

Out[23]:

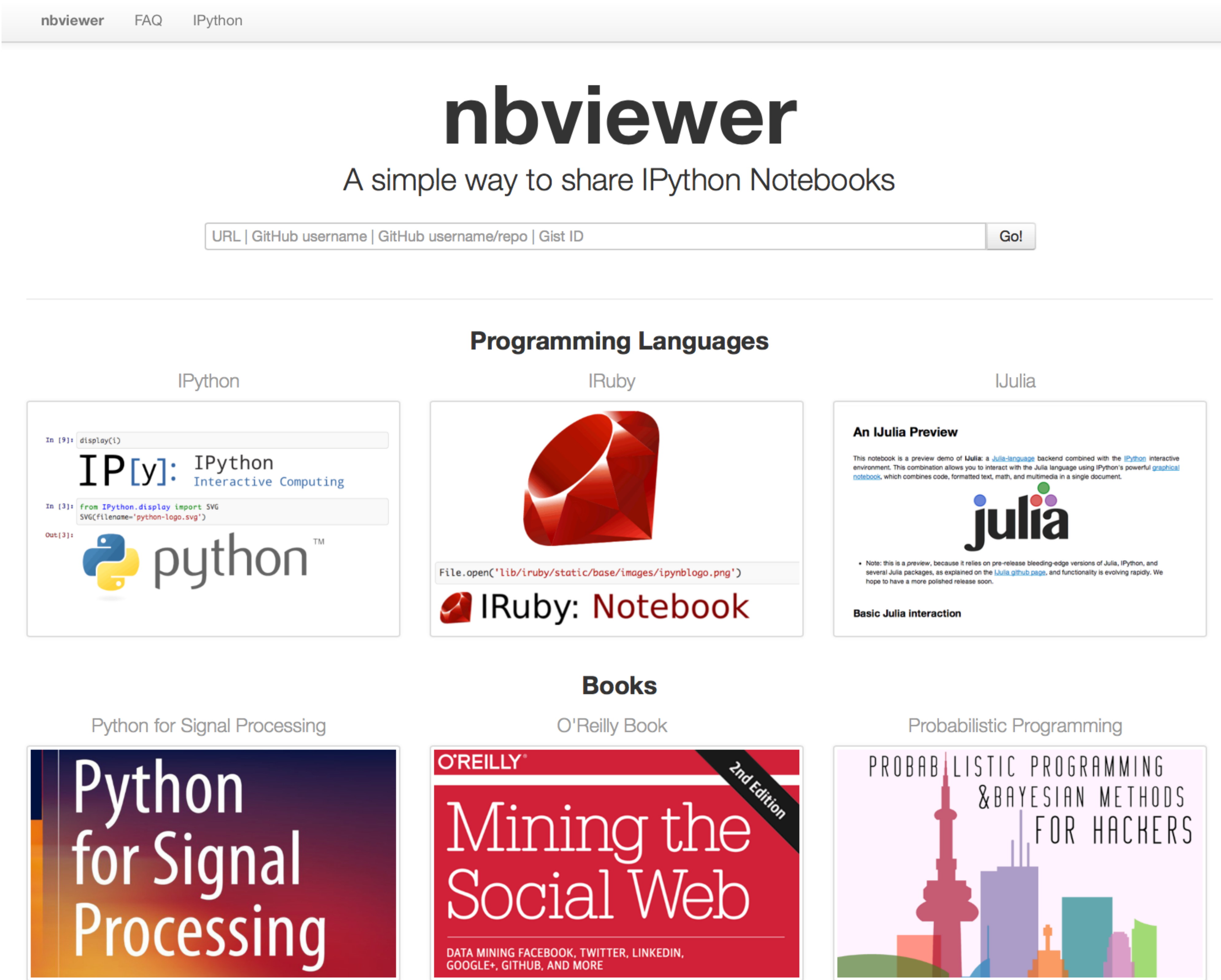
Swanson-Hysell et al., 2014

Easily versioned controlled and made available in an archive like Github



Easily viewed/shared as static html

http://nbviewer.ipython.org

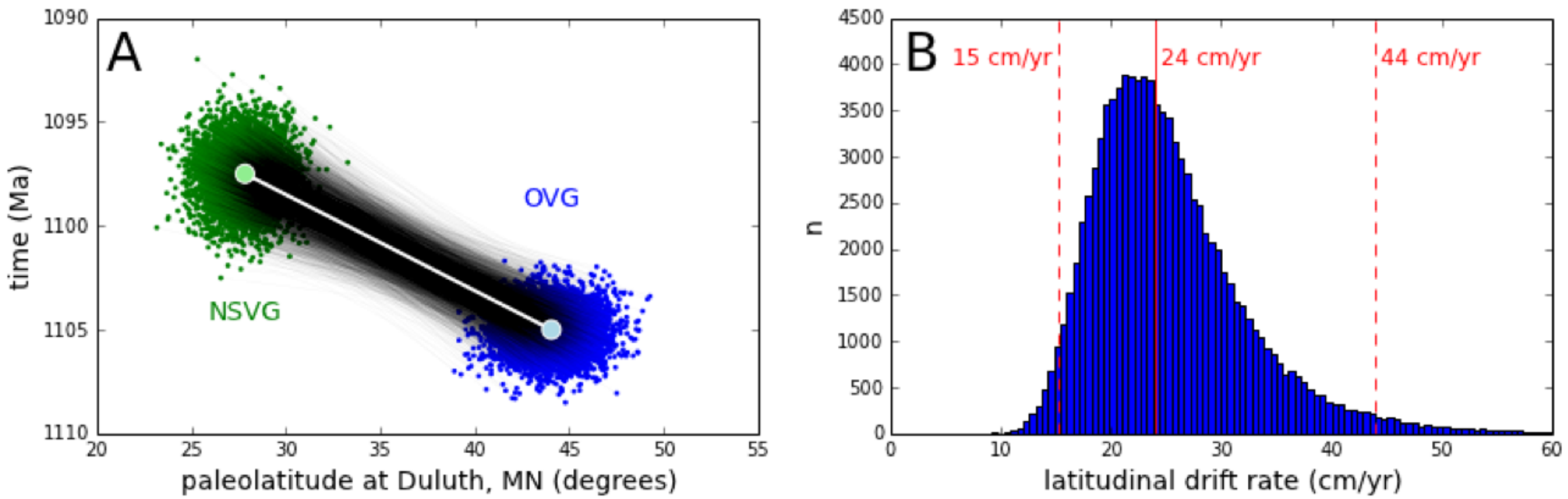


Easily exported to PDF

9.5 Calculate and graphically display the confidence interval on the minimum rate estimate implied by the Monte Carlo sampled pairs of sampled ages and paleolatitudes from the two poles

The pairs of sampled ages and poles can be used to calcuate rates (with the total number of rates being set by `samplesize` in the input box above). The rate calculated above of 24.0 cm/year can now be given confidence bounds by taking 2.5 percentile and 97.5 percentile of the Monte Carlo simulated rates.

```
In [32]: #calculating the change in paleolatitude between the Monte Carlo pairs
         pole1_pole2_Delta_degrees=[]
         pole1_pole2_Delta_kilometers=[]
         pole1_pole2_Delta_myr=[]
         pole1_pole2_degrees_per_myr=[]
         pole1_pole2_cm_per_yr=[]


        plt.xlabel('latitudinal drift rate (cm/yr)',size=14)
        plt.xlim([0,60])
        plt.ylim([0,4500])
        plt.savefig('../2014_Osler_Manuscript_Files/2014_Osler_Figures/MonteCarlo.pdf',
                    bbox_inches='tight')
        plt.show()
```



Swanson-Hysell et al., 2014

Live Demo

Questions?

Open and reproducible paleomagnetic data analysis using IPython

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Abstract
For research to be truly reproducible all of the code used to produce results needs to be thoroughly documented and openly presented in addition to the data. Given that many scientific workflows include a variety of software tools to conduct data analysis and visualization, the level of documentation necessary to fully reproduce plots and statistical analyses is rarely achieved. In this talk, I will describe how the language-agnostic IPython notebook environment (http://ipython.org) can remove impediments for documenting the work flow of paleomagnetic data analysis in conjunction with functions developed through the PmagPy open source software project.