Exploring LSST calibration strategies with GPS satellites and atmospheric modeling

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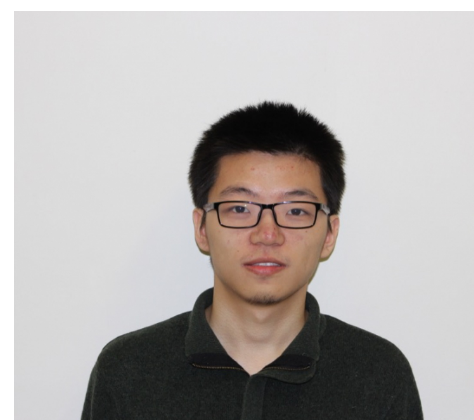
University of Pittsburgh

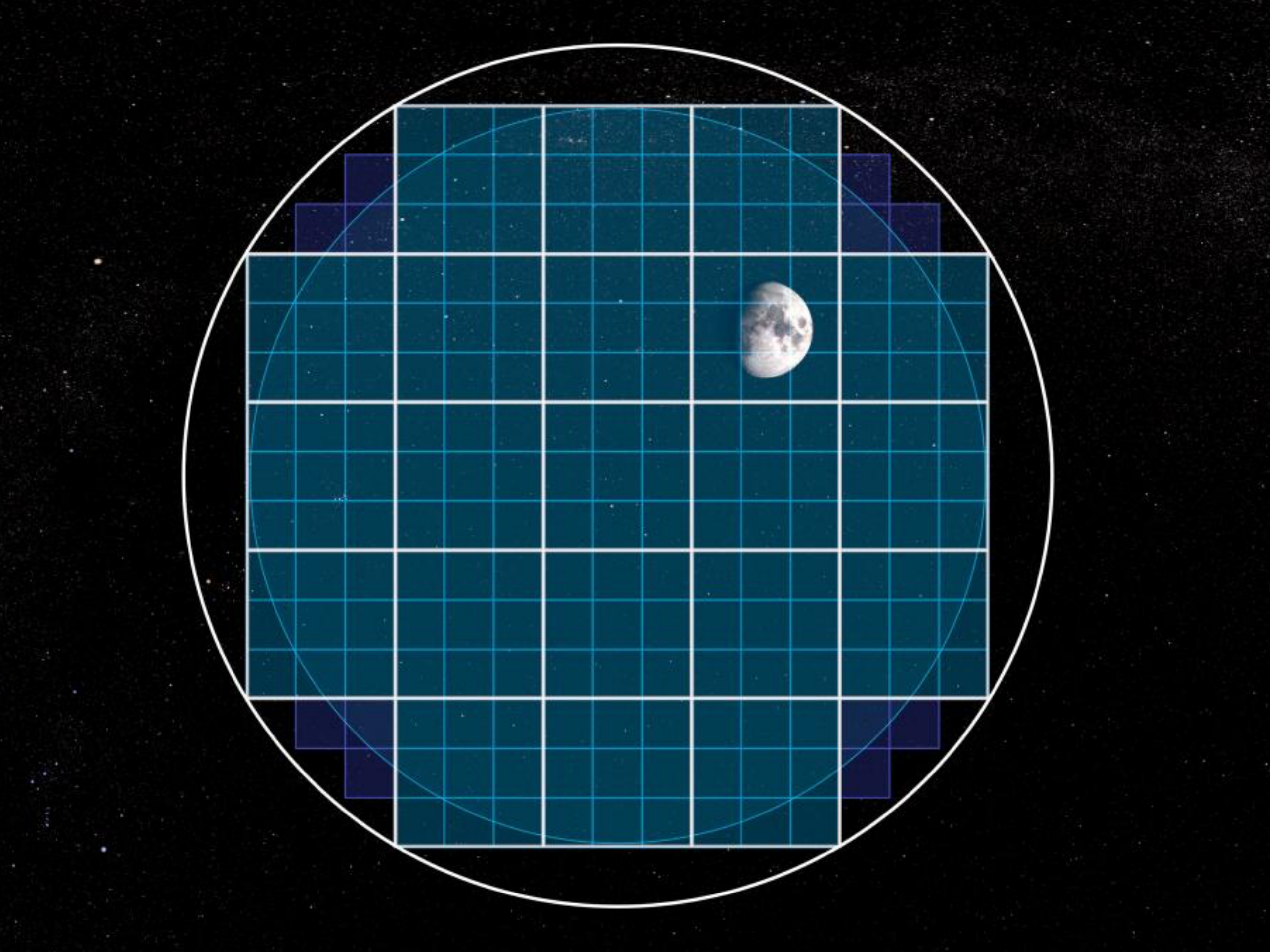
UConn Astro-Lunch
2019 - 02 - 04

MWV Group

- Supernova host galaxy properties (IFU)
- Peculiar supernova classification
- Cosmological bias estimation
- LSST preparations with DESC
- Photometric calibrations / image simulation
- PISCO / SweetSpot / SDSS surveys



LSST Project/NSF/AURA



LSST	DES
First Light in 2021	2013-2018
8.4-meter telescope	4-meter telescope
9.6 square degree FOV	3.8 square degree FOV
3.2 gigapixel	520 megapixels
1,000 visits / night over 10 years	50 visits / night over 5 yrs
0.5 % Photometric repeatability	1 % Photometric repeatability
18,000 deg^2 coverage	5,000 deg^2 coverage
6 Filters *ugrizY*	5 filters *grizY*
15 to 20 TB a night over 10 years	400 Gb a night

Two years and counting down!

- First light in 2021 – full operation in 2023
- Photometric calibration is a primary goal
  - Sub milli-mag photometry!
- There is no obvious cadence choice
- We need tools that can handle the data flow
- Image simulation still in progress

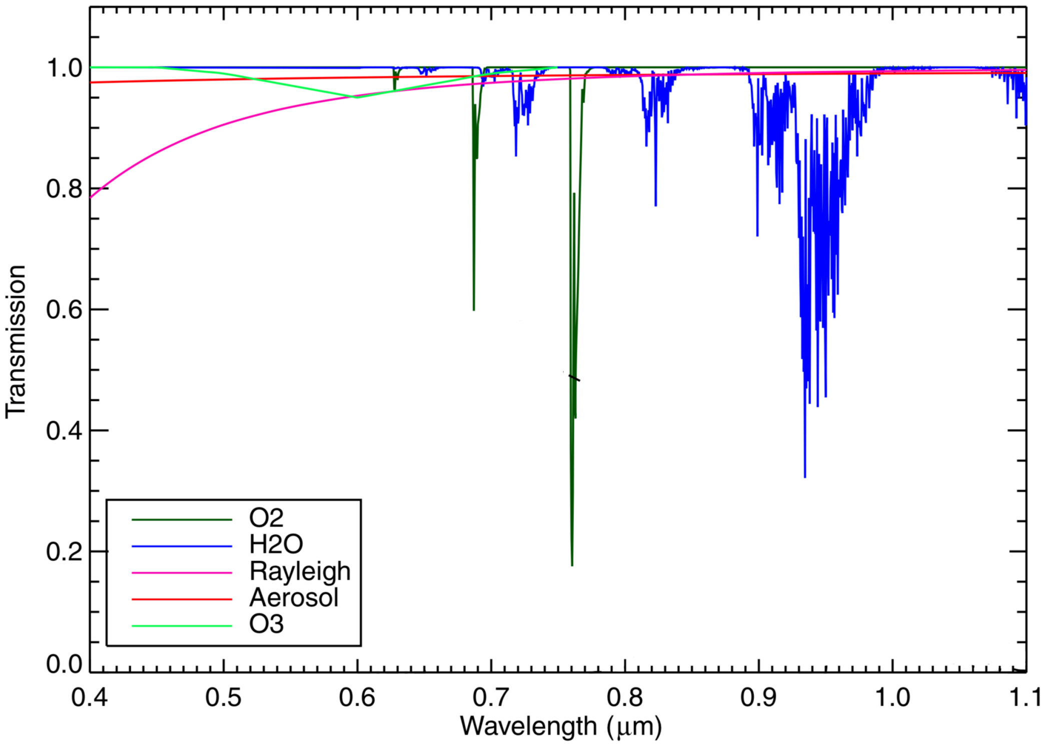
Project Goal

"Use dual band GPS measurements of localized PWV to simulate the atmospheric absorption due to H_2O as a function of date and time."

Project deliverable must also be:

1. Easily extensible to user definable locations
2. Intuitive and simple to use
3. Conducive to a collaborative effort

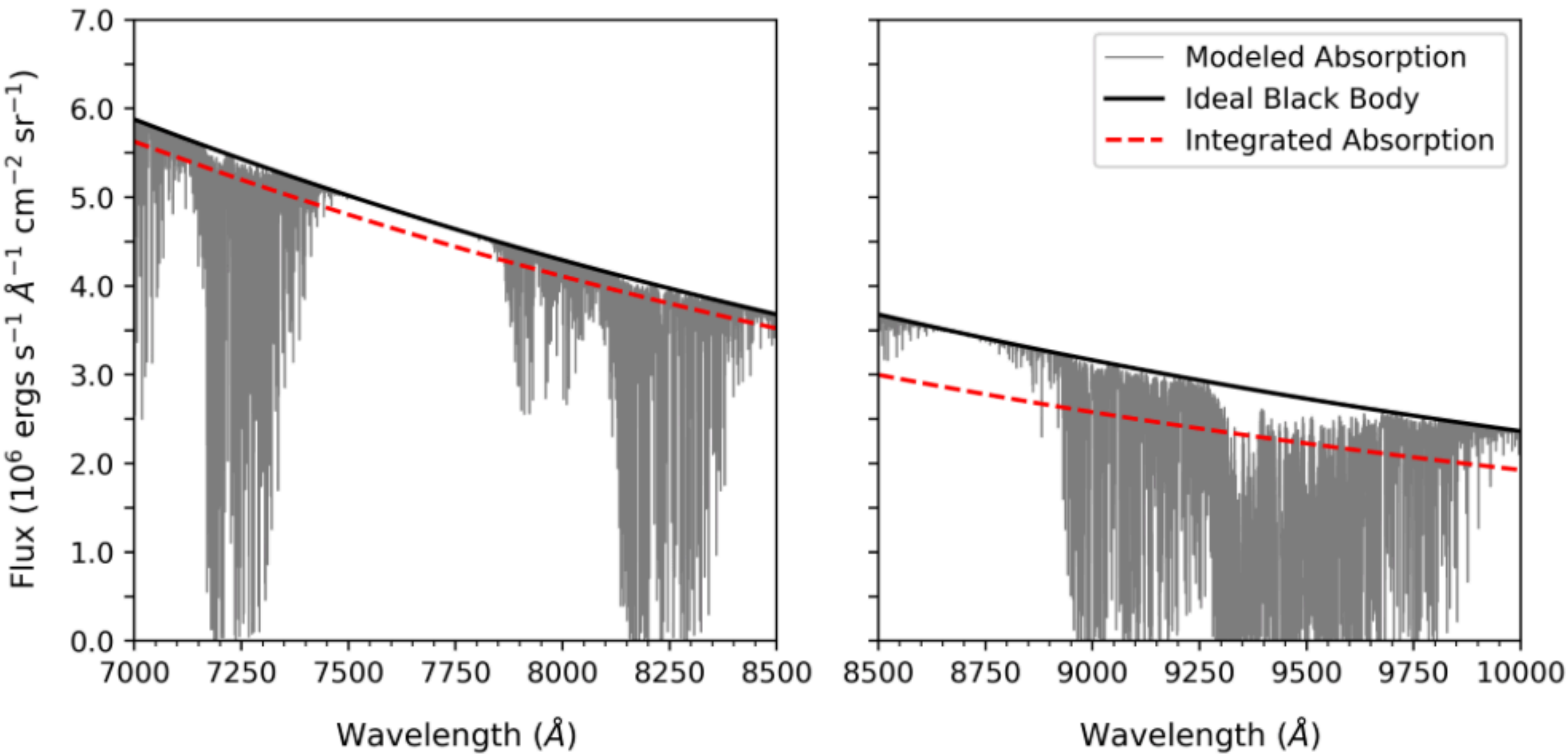
Why PWV?



- Dominates 700 to 1,200 nm
- 0_2 Has Fewer Features
- Aerosols and Rayleigh scattering have smoother seasonal transmission

Blake, Shaw 2011

Image Calibration



Perrefort, Wood-Vasey et al. 2018

Image Calibration

- Images are traditionally calibrated against catalogs

$$i = i_0 + k_i' \cdot \mathrm{X} + k_i''(b - v) \cdot \mathrm{X}$$
$$z = z_0 + k_z' \cdot \mathrm{X} + k_z''(b - v) \cdot \mathrm{X}$$

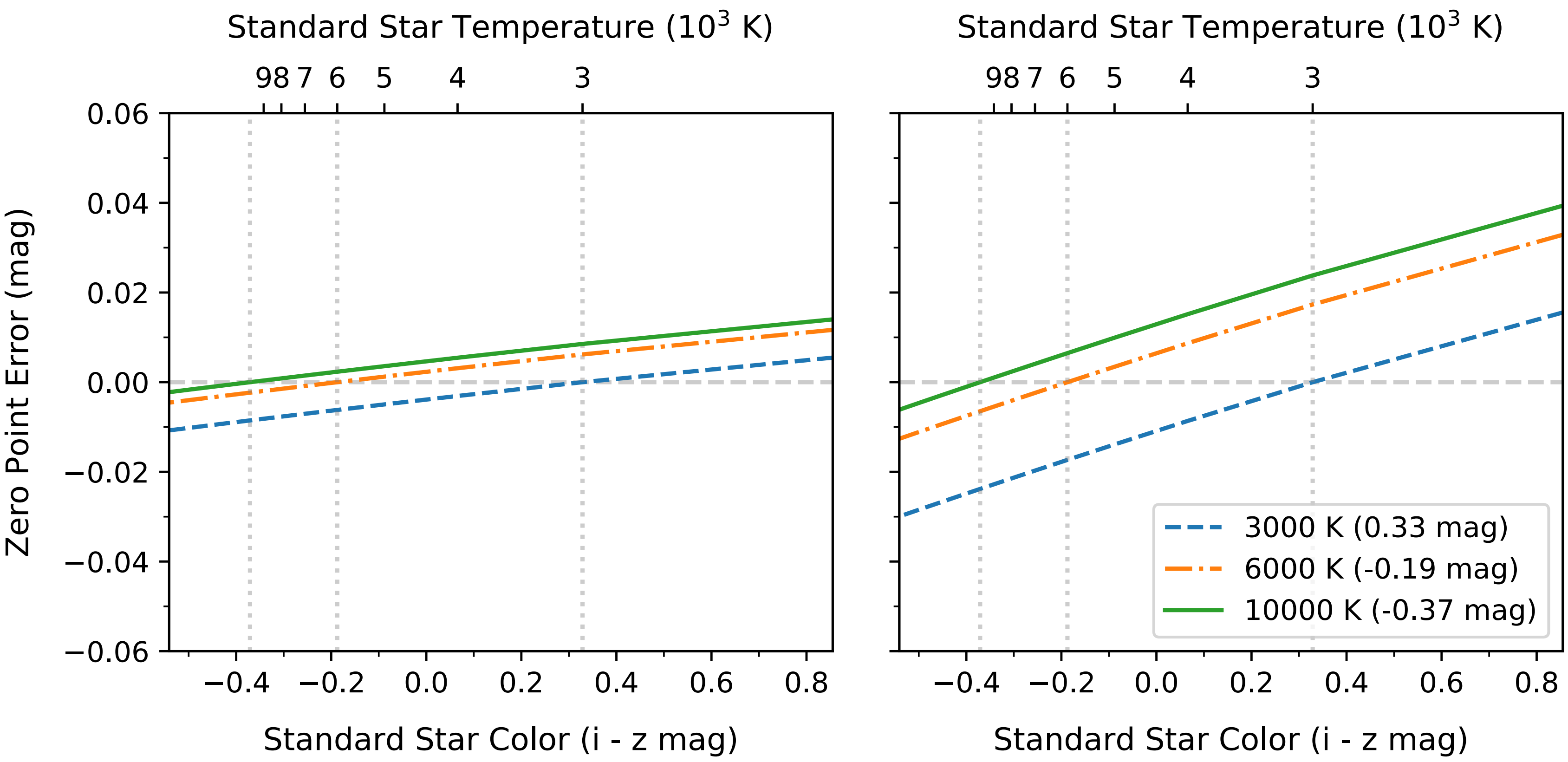
- Isolate color airmass term:

$$\Delta z = k_z'' \, \Delta(b - v) \cdot \mathrm{X} + \Delta z_0$$
$$\Delta i = k_i'' \, \Delta(b - v) \cdot \mathrm{X} + \Delta i_0$$

- Correction for atmosphere:

$$C = \frac{\int_{\lambda_i}^{\lambda_j} S(\lambda) \cdot T(\lambda) \, d\lambda}{\int_{\lambda_i}^{\lambda_j} S(\lambda) \, d\lambda}$$

Image Calibration



Perrefort, Wood-Vasey et al. 2018

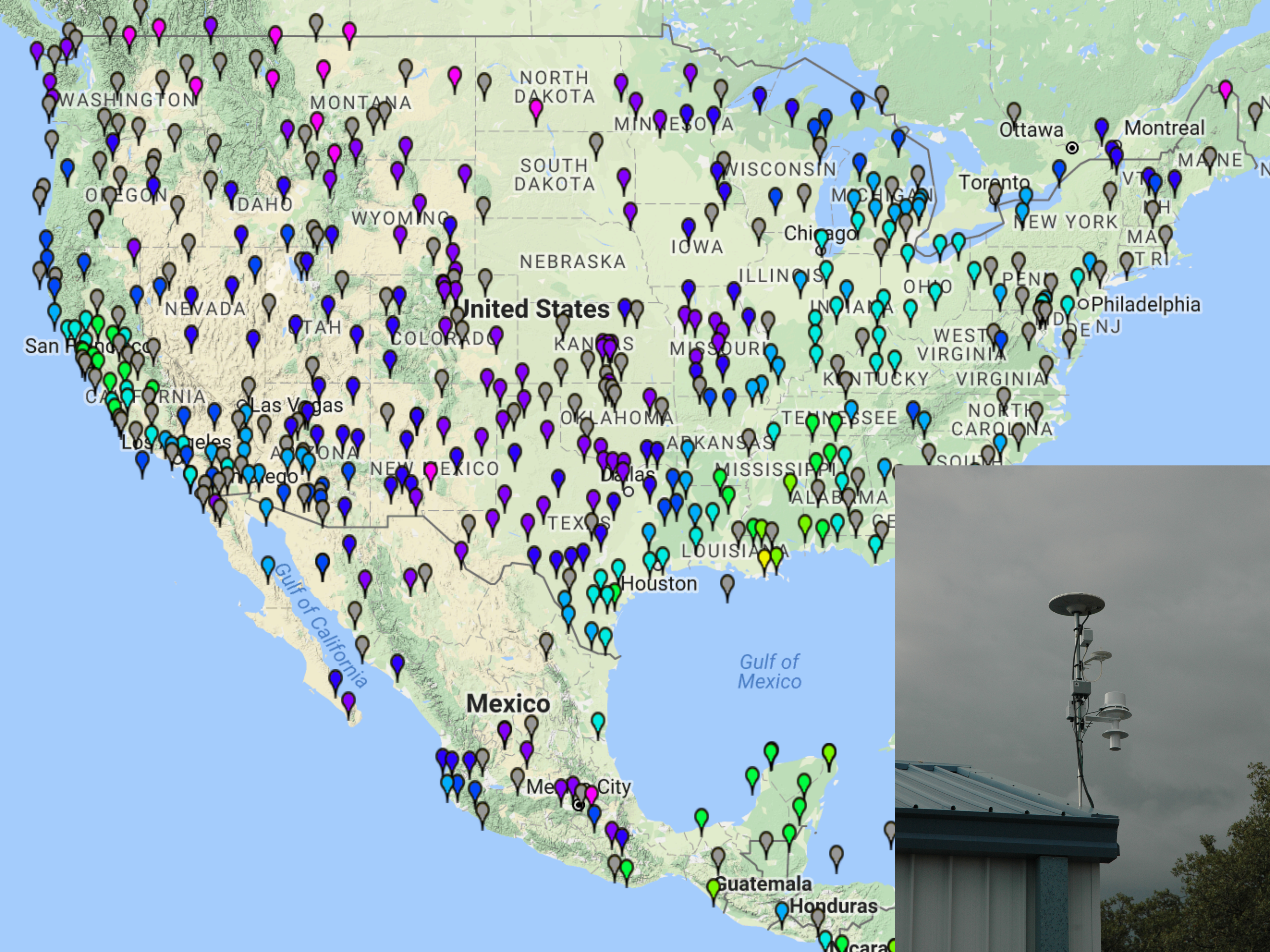
Dual Band GPS

- Dual band signals pick up phase shift
  - Clock shift
  - Doppler effect
  - Atmospheric contribution

  (Clock shift and Doppler effect: Frequency Independent)

- Zenith Total Delay (ZTD)
  - Zenith Hydrostatic Delay (ZHD)
  - Zenith Wet Delay (ZWD)

- PWV = Q(T) * ZWD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VIRGINIA
San Francisco
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Dallas
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Houston
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pwv_kpno 1.0.0 Documentation Examples Validation Need Help? Source Code Search

version 1.0.0 python 2.7, 3.5+ license GPL v3.0 build passing coverage 73% astro-ph.im arXiv:1806.09701

What is pwv_kpno?

pwv_kpno is a science focused Python package that provides access to models for the atmospheric absorption due to H_2O. The strength of H_2O absorption features are strongly correlated with measurements of localized PWV column density. By measuring the delay of dual-band GPS signals traveling through the atmosphere, it is possible to determine the PWV column density along line of sight. **pwv_kpno** leverages this principle to provide atmospheric models for user definable sites as a function of date, time, and airmass.

How it Works

The SuomiNet project is a meteorological initiative that provides semi-hourly PWV measurements for hundreds of GPS receivers worldwide. The **pwv_kpno** package uses published SuomiNet data in conjunction with MODTRAN models to determine the modeled, time-dependent atmospheric transmission. By default, the package provides access to the modeled transmission function at Kitt Peak National Observatory. However, the package is designed to be easily extensible to other locations within the SuomiNet Network. Additionally, **pwv_kpno** provides access to atmospheric models as a function of PWV, which is independent of geographical location. Default atmospheric models are provided from 3,000 to 12,000 Angstroms at a resolution of 0.05 Angstroms.

Contributing and Attribution

pwv_kpno is open source software released under the GNU General Public License. Issues raised on GitHub and pull requests from contributors are welcome. Additionally, pull requests introducing dafault configuration files for new sites are also welcome.

If you use **pwv_kpno** as part of any published work or research, we ask that you please cite Perrefort, Wood-

Acknowledgements

This work is based in part on observations taken at Kitt Peak National Observatory, National Optical Astronomy Observatory (NOAO Prop. IDs: 2011B-0482 and 2012B-0500; PI: Wood-Vasey), which is operated by the Association of Universities for Research in Astronomy (AURA) under a cooperative agreement with the National Science Foundation.

...d in part by the US Department of ... under DE-SC0007914.

Additional Resources

1. An up time monitor for the SuomiNet web server can be found here.

2. To learn more about the SuomiNet project, see suominet.ucar.edu.

3. For an additional example on the correlation between GPS signals and atmospheric modeling, see Blake and Shaw, 2011.

https://mwvgroup.github.io/pwv_kpno/

pwv_kpno 1.0.0 Documentation Examples Validation Need Help? Source Code Search

PWV KPNO

version 1.0.0 | python 2.7, 3.5+ | license GPL v3.0 | build passing | coverage 73% | astro-ph.im arXiv:1806.09701

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This work
Peak Nati
Observato
PI: Wood-
Universiti
cooperati
Foundatic

https://mwvgroup.github.io/pwv_k

arXiv.org > astro-ph > arXiv:1806.09701

Search or Article ID All fields (Help | Advanced search)

Astrophysics > Instrumentation and Methods for Astrophysics

pwv_kpno: A Python Package for Modeling the Atmospheric Transmission Function due to Precipitable Water Vapor

Daniel Perrefort, W. M. Wood-Vasey, K. Azalee Bostroem, Kirk Gilmore, Richard Joyce, Charles Corson

(Submitted on 25 Jun 2018)

We present a Python package, pwv_kpno, that provides models for the atmospheric transmission due to precipitable water vapor (PWV) above Kitt Peak National Observatory (KPNO). Using the package, ground based photometric observations taken in the *ugrizy* bands $(3,000 < \lambda < 12,000$ \AA) can be corrected for atmospheric effects due to PWV. Atmospheric transmission in the optical and near-infrared is highly dependent on the PWV column density along line of sight. By measuring the delay of dual-band GPS signals through the atmosphere, the SuomiNet project provides accurate PWV measurements for hundreds of locations around the world. We installed a dual-band GPS system at KPNO in the spring of 2015. The pwv_kpno package uses published SuomiNet data in conjunction with MODTRAN models to determine the modeled atmospheric transmission function at Kitt Peak. In addition, we demonstrate that we can successfully predict the PWV at KPNO from nearby dual-band GPS stations on the desert floor. We thus can provide atmospheric transmission functions for observations taken from 2010 onward. This software is modular and is intended to be extensible to other observatories.

Subjects: Instrumentation and Methods for Astrophysics (astro-ph.IM)
Cite as: arXiv:1806.09701 [astro-ph.IM]
(or arXiv:1806.09701v1 [astro-ph.IM] for this version)

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pwv-kpno 1.0.0

```
pip install pwv-kpno
```

Latest version

Last released: Sep 3, 2018

Models the atmospheric transmission function for KPNO

Project description

Overview

pwv_kpno is a Python package for modeling the atmospheric absorption due to H_2O at Kitt Peak National Observatory. It provides atmospheric models from 3,000 to 12,000 Angstroms for years 2010 onward. Understanding atmospheric effects is important when calibrating ground based astronomical observations. Traditionally, determining the detailed atmospheric transmission function at a given date and time required performing dedicated spectrographic observations. **pwv_kpno** provides an alternative that can be performed at the user's convenience.

Package Features

- Automatic download and parsing of new SuomiNet Data
- PWV transmission model for given date, time, and airmass
  - 3,000 to 12,000 Å at 0.5 Å resolution
- PWV transmission model for given PWV
- Transmission models can be easily binned
- Guided process for adding and sharing user defined sites
- Black body spectral energy distribution with atmospheric features
- Full, online documentation, examples, and validation overview

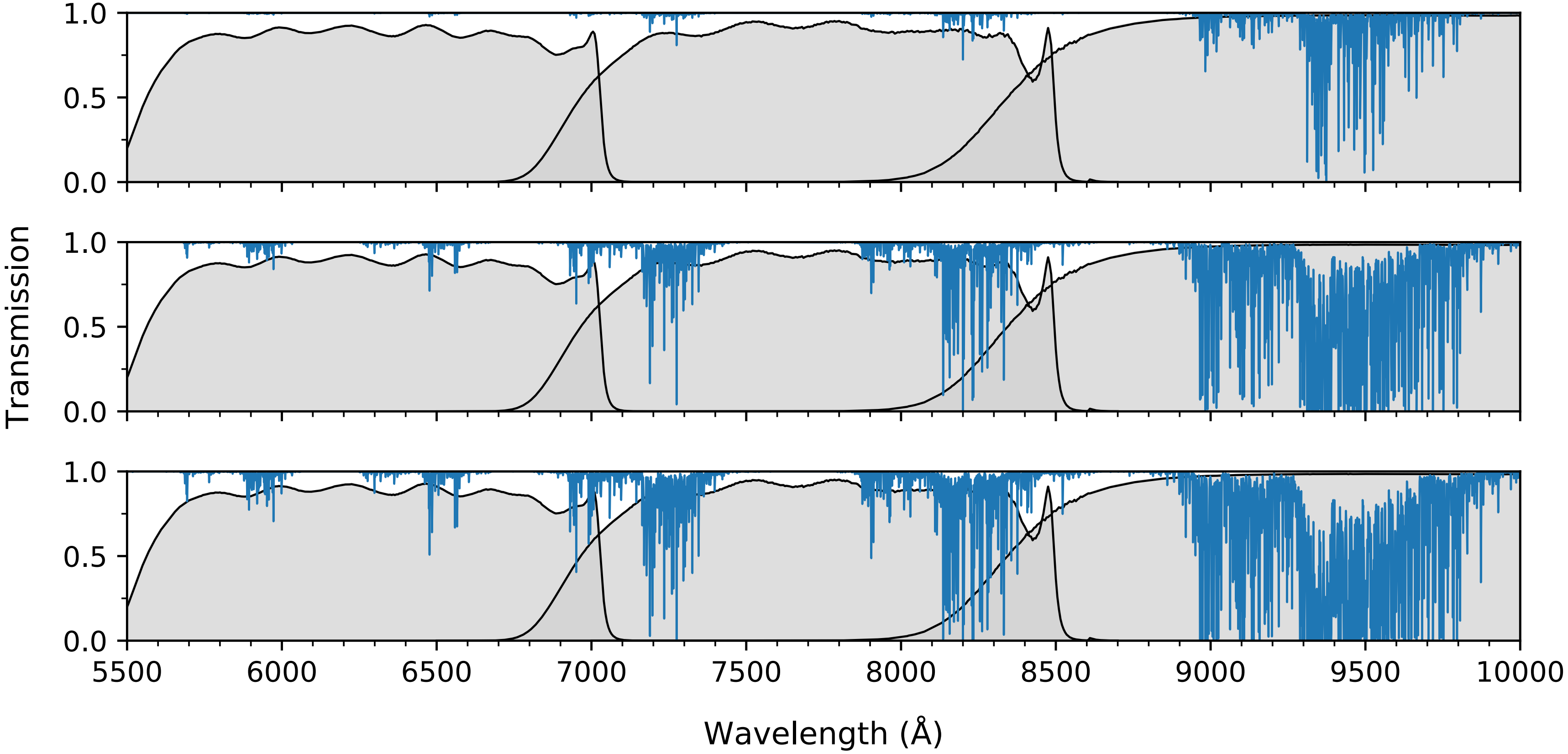
Download Data from SuomiNet:

```
>>> from pwv_kpno import pwv_atm
>>> pwv_atm.update_models()
```

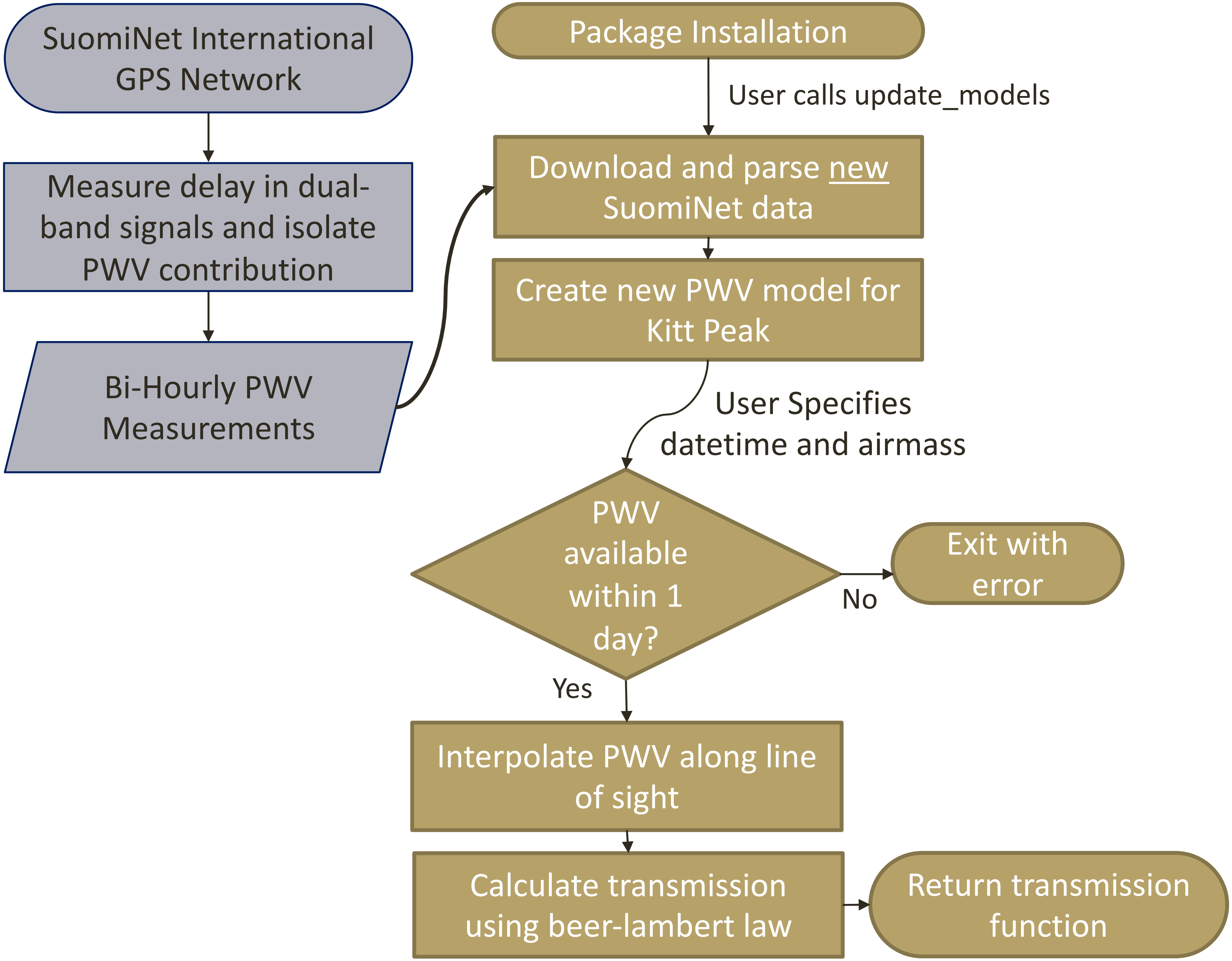
Model the Atmosphere:

```
>>> from datetime import datetime
>>> from pwv_kpno import pwv_atm
>>> import pytz
>>>
>>> obsv_date = datetime(year=2013,
>>>                      month=12,
>>>                      day=15,
>>>                      hour=5,
>>>                      minute=35,
>>>                      tzinfo=pytz.utc)
>>>
>>> pwv_atm.trans_for_date(date=obsv_date, airmass=1.2)

 wavelength  transmission  transmission_err
  Angstrom
 ---------- ------------- ----------------
    3000.00 0.999999991637 1.3506621821e-08
    3000.05 0.999999991637 1.3507332141e-08
    3000.10 0.999999991637 1.3507963636e-08
        ...           ...              ...
```

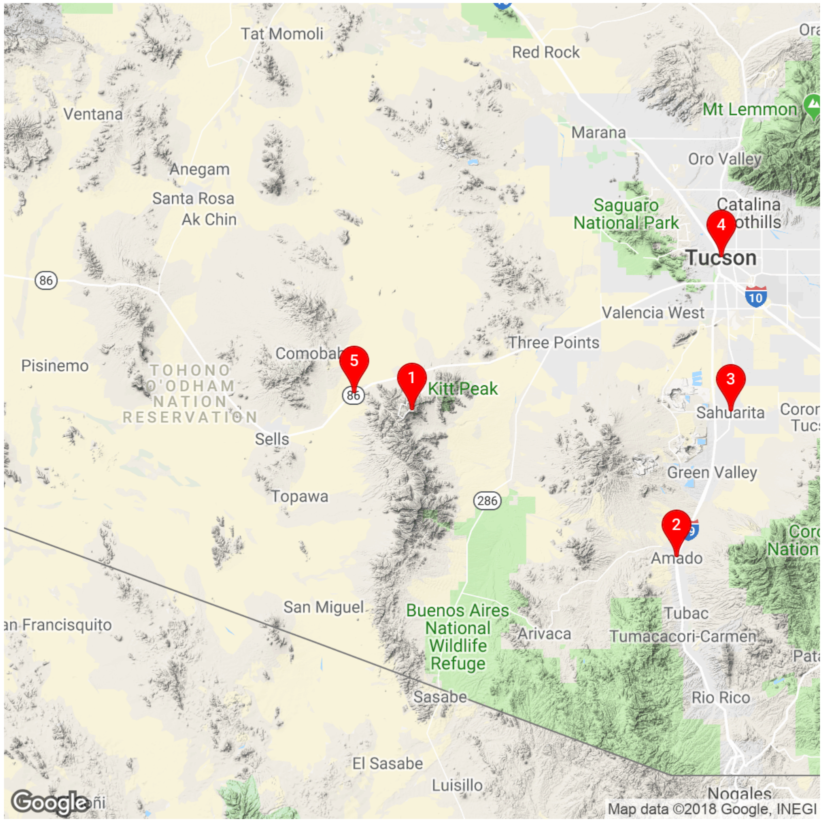


From install to transmission function in minutes.
So how does it work?
And how well?

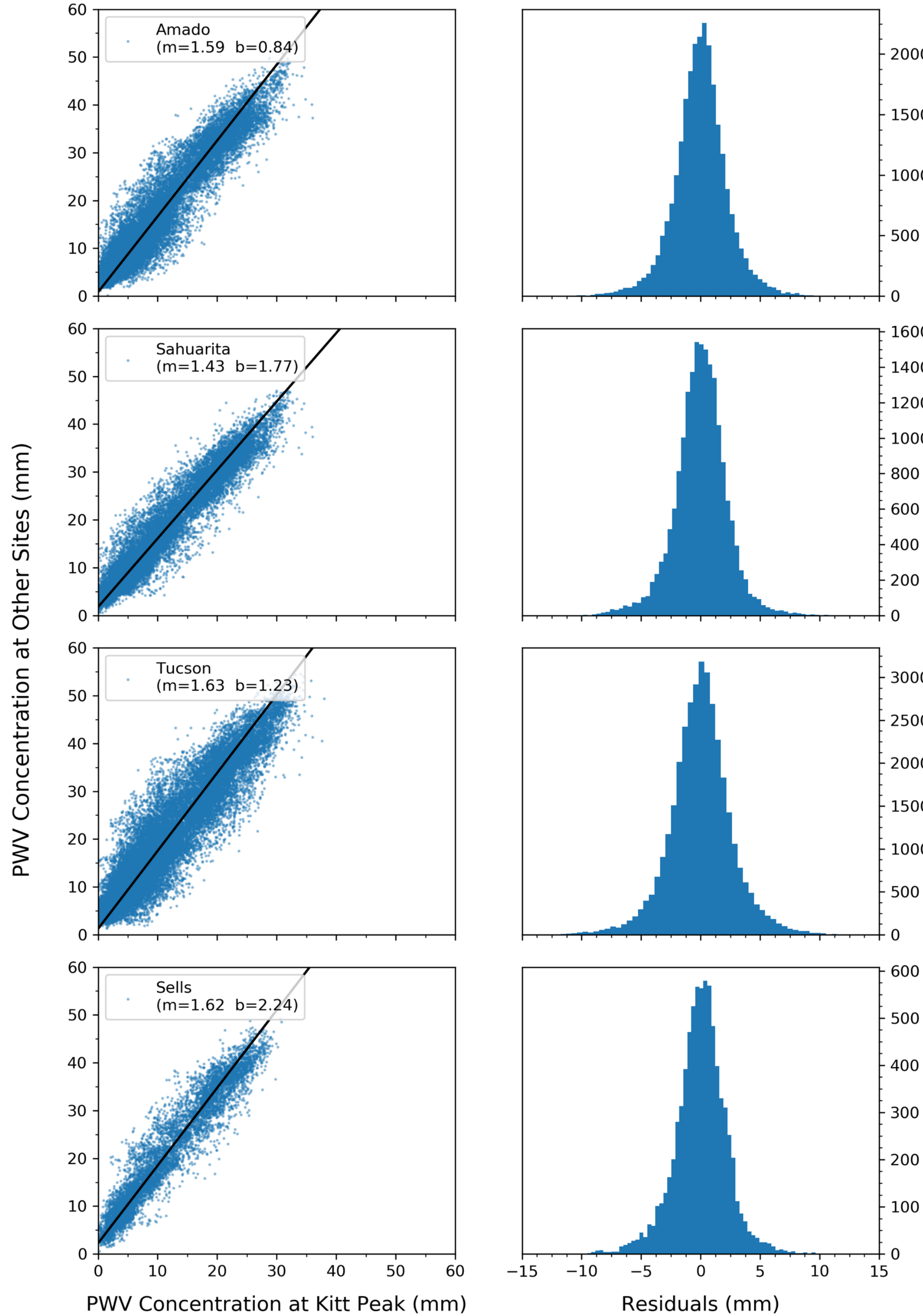


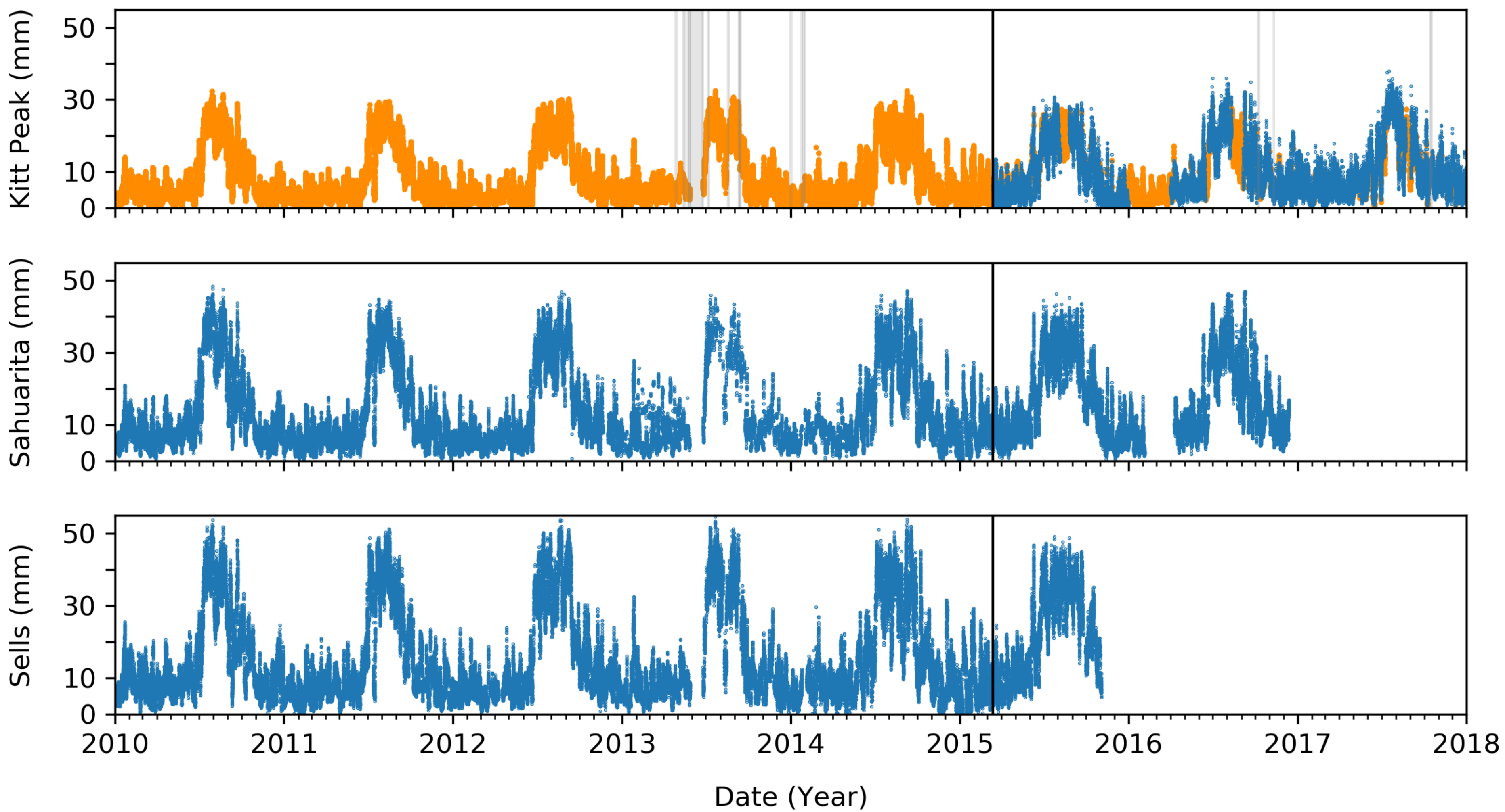
SuomiNet International GPS Network
Measure delay in dual-band signals and isolate PWV contribution
Bi-Hourly PWV Measurements
Package Installation
User calls update_models
Download and parse new SuomiNet data
Create new PWV model for Kitt Peak
User Specifies datetime and airmass
PWV available within 1 day?
No
Exit with error
Yes
Interpolate PWV along line of sight
Calculate transmission using beer-lambert law
Return transmission function

```
>>> from pwv_kpno import pwv_atm
>>> pwv_atm.update_models()
```



1. Kitt Peak National Observatory (KITT)
2. Amado Arizona (AZAM)
3. Sahuarita Arizona (P014)
4. University of Arizona (SA46)
5. Tohono O'odham Community College (SA48)

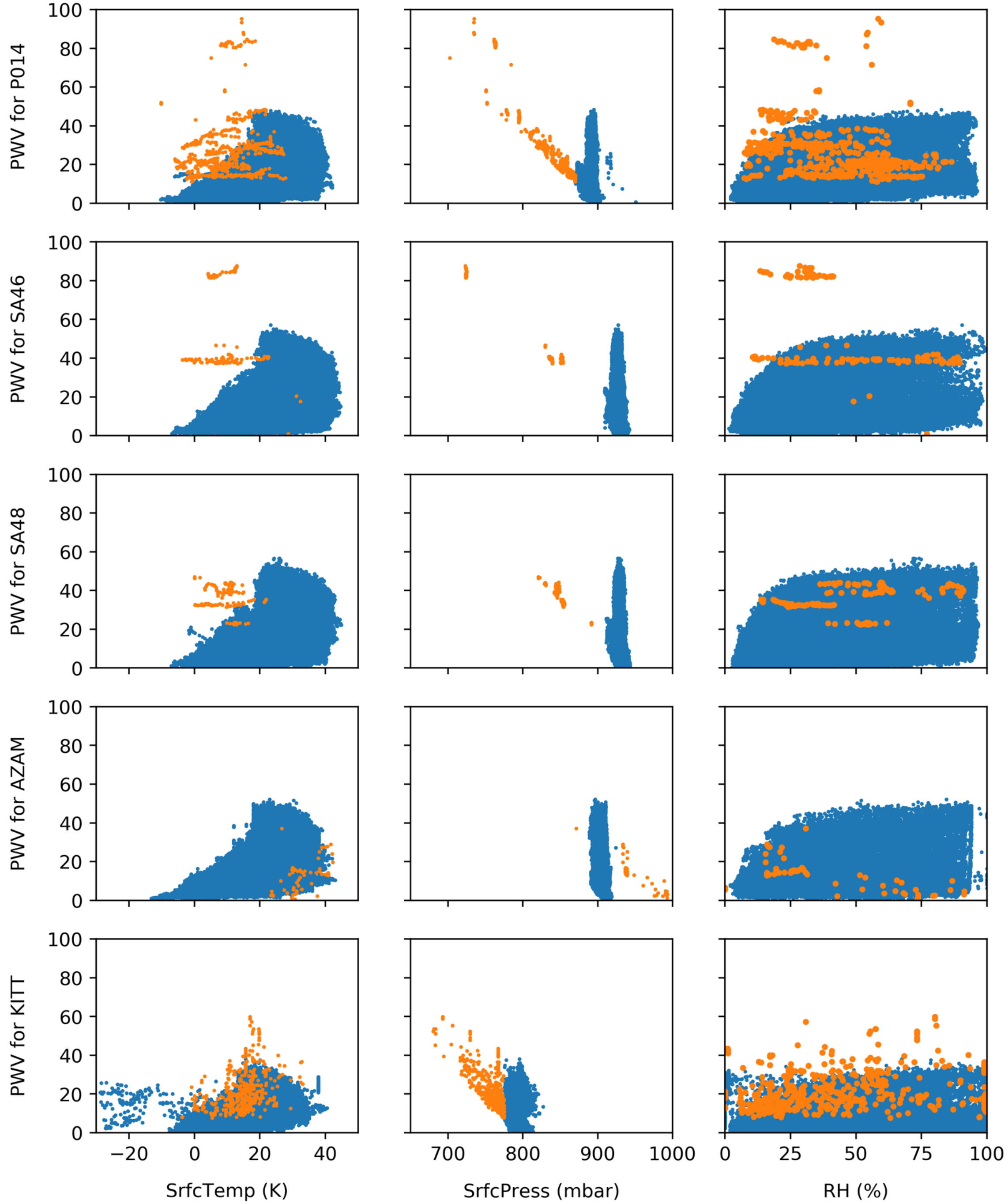




- Atmospheric Models for each site are averaged together
- Users can include as many or as few supplementary sites as desired
- No modeling for data gaps of 1 day or longer

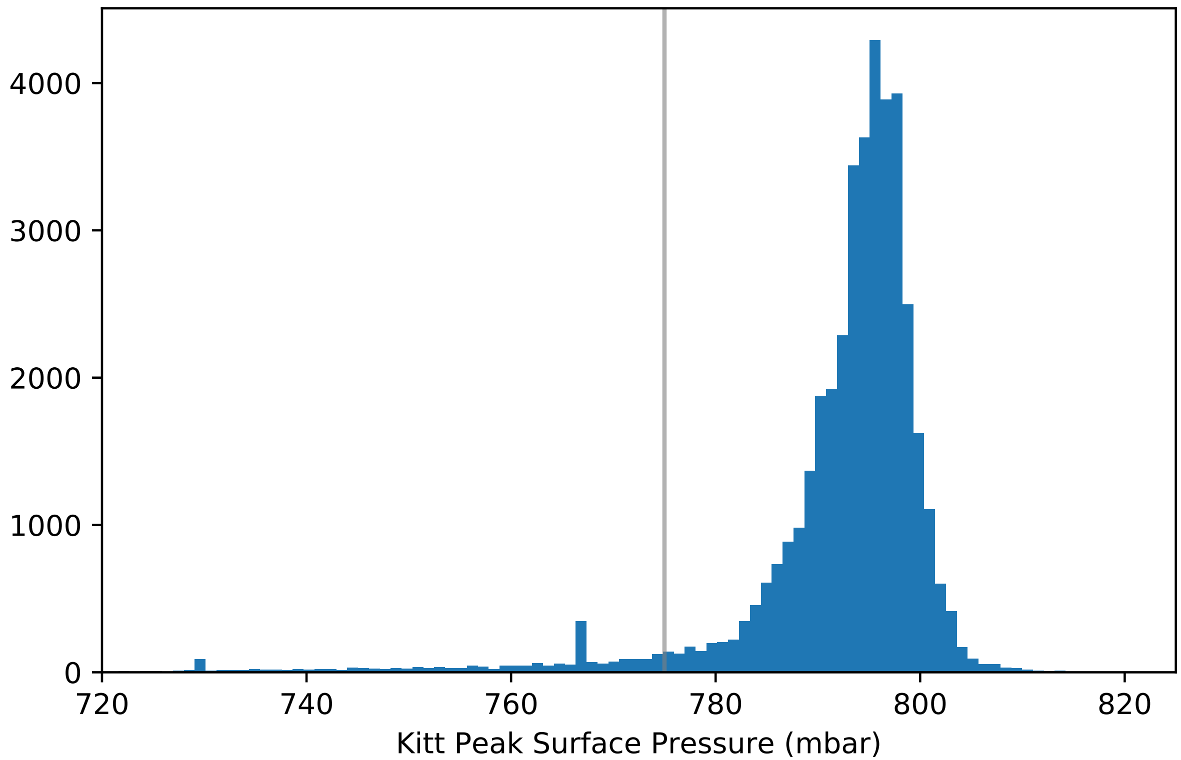
SuomiNet Data Isn’t Perfect

- Rounding Error in public data
  - Add *0.025* to all reported errors
- Unidentified error increase in 2013
- Duplicate data records (uncommon)
  - Isolated to specific instance
  - Ignore disagreements, keep agreements
- Hourly data for Conus, but daily for international
- Subject to PWV spikes for hardware malfunctions



Available Data:

1. Date
2. PWV
3. PWV Error
4. Zenith Delay
5. Temperature
6. Pressure
7. Relative Humidity



Site Name	Receiver ID Code	Lower Pressure Cut	Upper Pressure Cut
Kitt Peak Az	KITT	775 mbar	1000 mbar
Amado Az	AZAM	880 mbar	925 mbar
Sahuarita AZ	P014	870 mbar	1000 mbar
Tuscon Az	SA46	900 mbar	1000 mbar
Sells Az	SA48	910 mbar	1000 mbar

3. Visualizing Data Cuts

For various reasons, you may wish to apply cuts to the SuomiNet measurements used by **pwv_kpno**. The most obvious use case would be to ignore a period of time when a SuomiNet weather station was experiencing technical difficulties, or if there is some unexplained, unphysical spike in the measurements. For convenience, we demonstrate how to visually explore various choices in data cuts.

Following SuomiNet's naming convention, values that can be cut include the PWV (`'PWV'`), PWV error (`'PWVerr'`), surface pressure (`'SrfcPress'`), surface temperature (`'SrfcTemp'`), and relative humidity (`'SrfcRH'`). The current data cuts can be accessed via the `settings` object.

```
>>> from pwv_kpno.package_settings import settings
>>>
>>> print(settings.data_cuts)

  {'AZAM': {'SrfcPress': [[880, 925]]},
   'KITT': {'SrfcPress': [[775, 1000]], 'date': [[1451606400.0, 1459468800.0]]},
   'P014': {'SrfcPress': [[870, 1000]]},
   'SA46': {'SrfcPress': [[900, 1000]]},
   'SA48': {'SrfcPress': [[910, 1000]]}
  }
```

These data cuts can be changed by directly modifying the `data_cuts` attribute. For example, if we wanted to ignore measurements taken between two dates, we can specify those dates as UTC timestamps and run

```
>>> data_cuts['AZAM'] =
>>>     {'SrfcPress': [
>>>         [timestamp_start, timestamp_end]
>>>      ]
>>>     }
>>> }
```

Custom Site Modeling

```
>>> from pwv_kpno.package_settings import ConfigBuilder
>>>
>>> new_config = ConfigBuilder(
>>>     site_name='cerro_tololo',
>>>     primary_rec='CTIO',
>>>     sup_rec=[]
>>> )
>>>
>>> new_config.save_to_ecsv('./cerro_tololo.ecsv')
```

Includes options for:

1. Site name (Site ID)
2. Primary and supplemental receivers
3. H_2O cross sections
4. Data Cuts

Custom Site Modeling

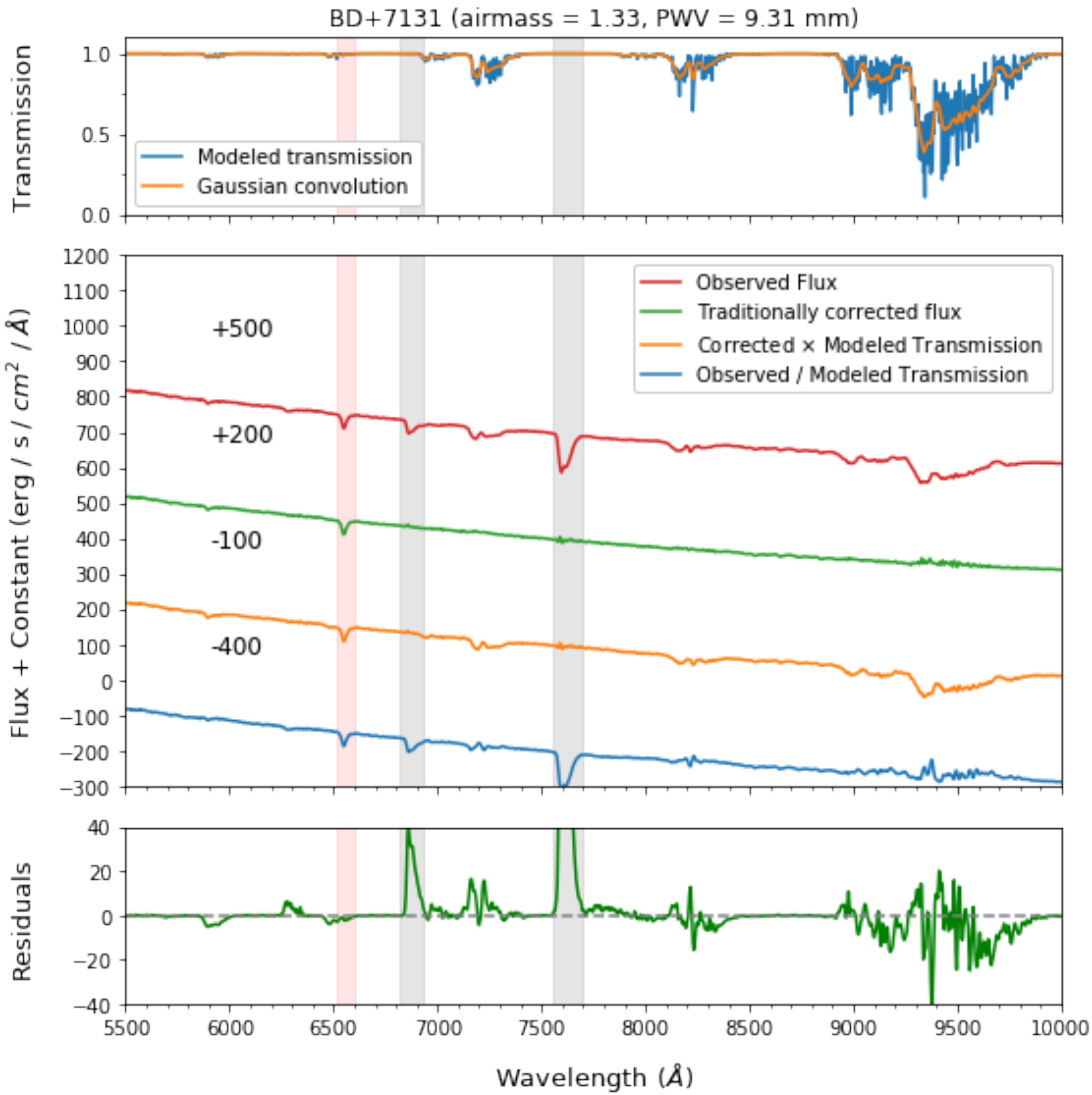
```
>>> from pwv_kpno.package_settings import ConfigBuilder
>>>
>>> new_config = ConfigBuilder(
>>>     site_name='cerro_tololo',
>>>     primary_rec='CTIO',
>>>     sup_rec=[],
>>>     wavelength=custom_wavelengths, # Array of wavelengths in Angstroms
>>>     cross_section=custom_cross_sections # Array of cross sections in cm^2
>>> )
>>>
>>> new_config.save_to_ecsv('./cerro_tololo.ecsv')
```

Add your new site to the package:

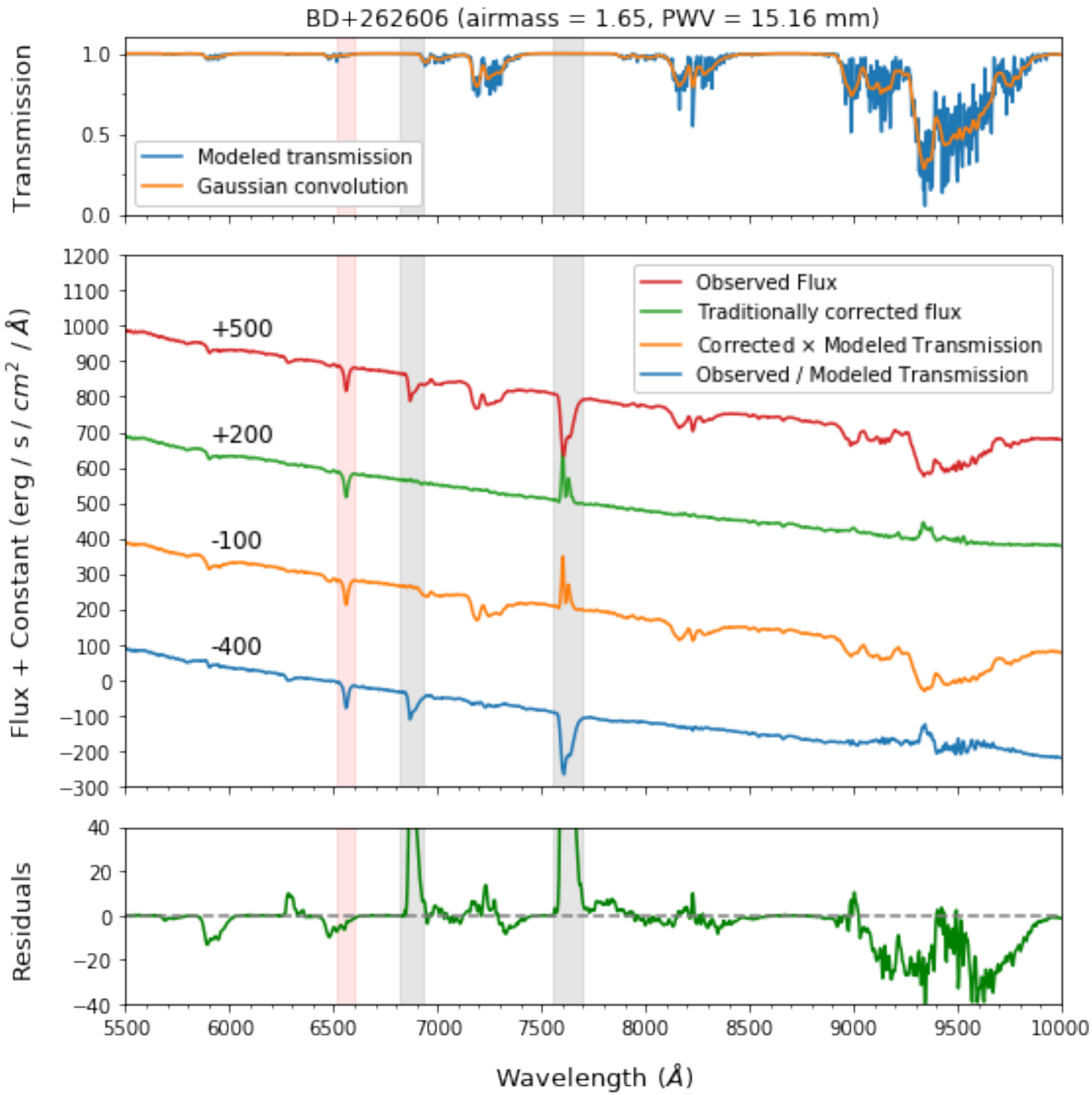
```
>>> from pwv_kpno.package_settings import settings
>>> settings.import_site_config('./cerro_tololo.ecsv')
```

Easily switch between different sites:

```
>>> settings.set_site('cerro_tololo')
>>> print(settings.site_name)
```



BD+7131 (airmass = 1.33, PWV = 9.31 mm)
Transmission
Modeled transmission
Gaussian convolution
Flux + Constant (erg / s / cm² / Å)
Observed Flux
Traditionally corrected flux
Corrected × Modeled Transmission
Observed / Modeled Transmission
+500
+200
-100
-400
Residuals
Wavelength (Å)



BD+262606 (airmass = 1.65, PWV = 15.16 mm)
Transmission
1.0
0.5
0.0
Modeled transmission
Gaussian convolution
Flux + Constant (erg / s / cm^2 / Å)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
−100
−200
−300
+500
+200
-100
-400
Observed Flux
Traditionally corrected flux
Corrected × Modeled Transmission
Observed / Modeled Transmission
Residuals
40
20
0
−20
−40
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
Wavelength (Å)

Moving Forward

- We can do it – but how well? How does this apply to milli-mag levels?
- How does this compare to other calibration methods?
- Can this be combined with other ongoing efforts?
- Primary challenge is acquiring appropriate data
  - (Contributions welcome!)

Thank You!

Calculating Transmission

- Optical depth of material

$$T \equiv e^{-\tau} \quad s.t. \quad \tau = \sum_{i=1}^{N} \tau_i = \sum_{i=1}^{N} \tau_i = \sum_{i=1}^{N} \sigma_i \int_0^l n_i(z)dz$$

- In terms of PWV:

$$\tau_{PWV} = \sigma \frac{(N_a \cdot \rho_{PWV})}{\mu_{PWV}} PWV_z \, X^{.6}$$

N_a = 6.02 E23 *(1 / mol)*
μ_{PWV} = 18.0152 (*g / mol)*
ρ_{PWV} = 0.99997 (*g / cm*^3)