Calibrating DECam data: the DECal and aTmCam calibration systems

Jennifer Marshall
Ting Li
Munnerlyn Astronomical Instrumentation Lab
Mitchell Institute for Fundamental Physics and Astronomy
Department of Physics and Astronomy
Texas A&M University
Ambitious science goals of modern wide-field imaging systems require precise measurements:
- DES has photometric precision requirement of 2% across entire survey area, with a goal of <1%

Reaching this goal will require careful calibration of data:
- But it can be reached: see Ting Li’s poster at this meeting

We have now commissioned two instruments that can be used to measure the DECam total system response:
- DECal: the daily flat field and spectrophotometric calibration systems
- aTmCam: the Atmospheric Transmission Monitoring Camera
DECal daily flat field system

- Flat field screen
- Daily flat field system
  - LED flat field lamps
- Spectrophotometric calibration system
  - Long fiber bundle
  - Monochromator (with spectrometer monitor)
  - Monitor photodiodes
DECal spectrophotometric calibration system

- Flat field screen
- Daily flat field system
  - LED flat field lamps
- Spectrophotometric calibration system
  - Long fiber bundle
  - Monochromator (with spectrometer monitor)
  - Monitor photodiodes
Result: DES system throughput

- Measured system throughput ~5 times since Fall 2012
- Not much change in system throughput (good news!)
aTmCam

- Located on CTIO summit (next to 1m dome)
- Autonomous operation each night
- Photometrically measure atmospheric features in 4 narrowband filters
- Automatically fit atmospheric model to measurements
- Produces an atmospheric throughput model once per hour
Atmospheric transmission

- Constituents
  - Precipitable water vapor
  - Aerosols
  - (Ozone)
  - Rayleigh scattering
- Measure A stars in narrowband filters
- Fit model of atmospheric transmission to data
- Correct for atmospheric absorption to 10%
  - Enables photometric precision <1%!

Li+2012
<1% photometric precision

- DES-calibrated photometry: nights with high water vapor

- Without aTmCam calibration, photometric errors (on a wet night) are 9 mmag (M stars)
- With aTmCam, can calibrate to <2 mmag!

Top: Δz from two exposures on different nights

Middle: points from above averaged in bins; polynomial fit to theoretically calculated errors (based on aTmCam measurements)

Bottom: Residuals after photometric correction are <2 mmag
<1% photometric precision

- The atmosphere is also a problem for SNe:
  - Change in water vapor from 3 to 10 mm results in >1% photometric errors in z and Y bands

Top: Ratio of atmospheric transmission at PWV 3mm and PWV 10mm
Bottom: Systematic errors on SN Ia photometry due to change in PWV as a function of redshift
Conclusions

- DECal+aTmCam form a complete system response measurement system for DECam
  - DECal: top of telescope down to detector
  - aTmCam: top of telescope up through atmosphere
- Together with standard photometric calibration procedures, enable <1% photometric precision of DECam photometry
- Data products available to community
  - aTmCam results may be useful to observers at other CTIO telescopes
Stars: sources and error budget

<table>
<thead>
<tr>
<th>Sources</th>
<th>range</th>
<th>color terms</th>
<th>unit: mmag / mag in g-r</th>
<th>10mmag ~ 1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument</td>
<td>center → edge</td>
<td>&lt;5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Airmass</td>
<td>1 → 2</td>
<td>15</td>
<td>20</td>
<td>5-10</td>
</tr>
<tr>
<td>PWV</td>
<td>0 → 10(mm)</td>
<td>0</td>
<td>0</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Aerosol optical depth</td>
<td>0 → 0.2(??)</td>
<td>&lt;5</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Ozone</td>
<td>260-300(??) DU</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Pressure</td>
<td>772-784 hpa</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
</tbody>
</table>

Note: color term is JUST first order correction when assuming that error is linear to g-r color!
Supernova: sources and error budget

SED and redshift dependent PtV errors in mmag for $0<z<1$ ~ 10mmag ~ 1%

<table>
<thead>
<tr>
<th>Sources</th>
<th>range</th>
<th>u</th>
<th>g</th>
<th>r</th>
<th>i</th>
<th>z</th>
<th>Y</th>
<th>Addition info</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument</td>
<td>center→edge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DECal</td>
</tr>
<tr>
<td>Airmass</td>
<td>1→2</td>
<td>60</td>
<td>55</td>
<td>15</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>DECam+libRadTran</td>
</tr>
<tr>
<td>PWV</td>
<td>0→10(mm)</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>40</td>
<td>50</td>
<td>GPS/aTmCam+libRadTran</td>
</tr>
<tr>
<td>Aerosol optical depth</td>
<td>0→0.2(??)</td>
<td>10</td>
<td>40</td>
<td>10</td>
<td>5</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>aTmCam+libRadTran</td>
</tr>
<tr>
<td>Ozone</td>
<td>260-300(??) DU</td>
<td>&lt;2</td>
<td>&lt;5</td>
<td>&lt;2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>No need</td>
</tr>
<tr>
<td>Pressure</td>
<td>772-784 hpa</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>No need</td>
</tr>
</tbody>
</table>