

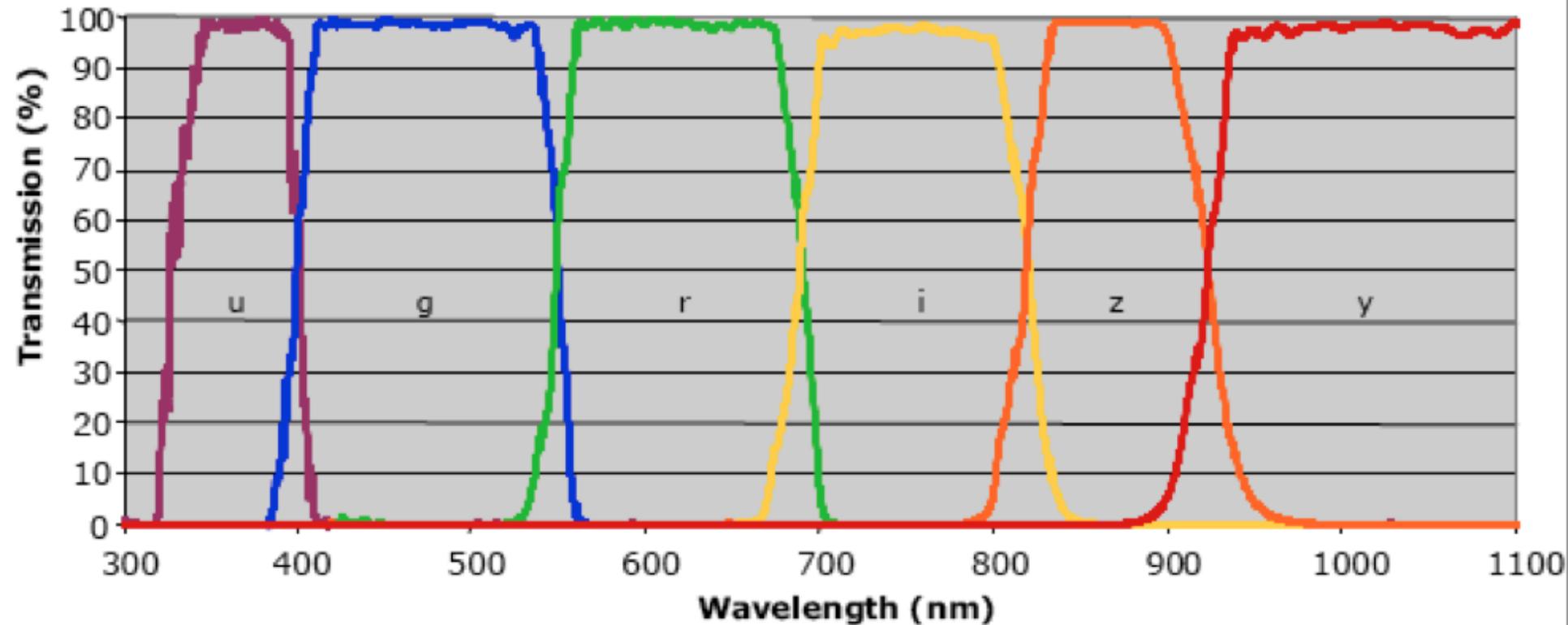
Modtran-LibRadTran Comparison

Sylvie Dagoret-Campagne
David Kirk Gilmore

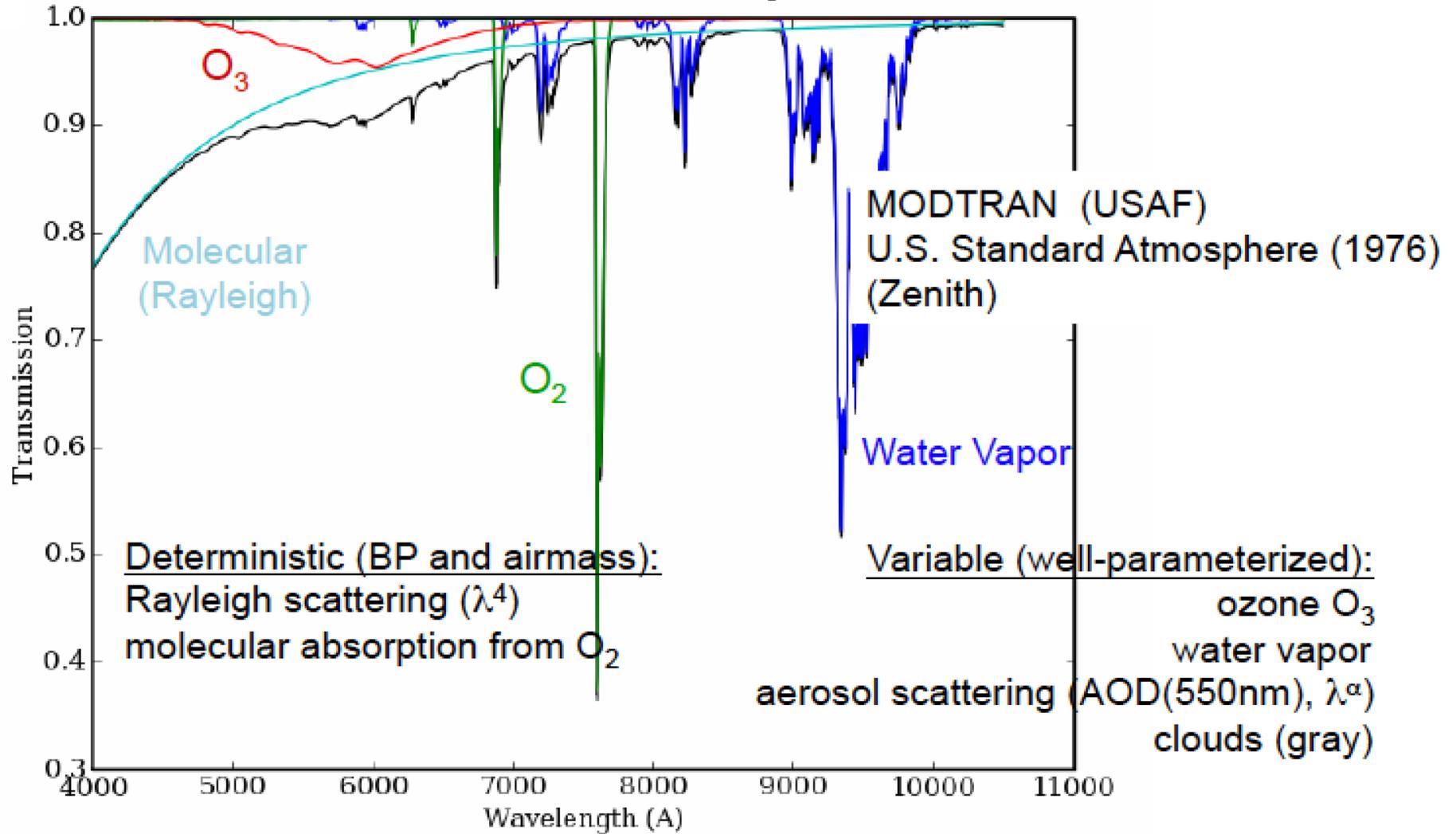
DESC-PCWG
LPNHE, Oct. 2, 2018



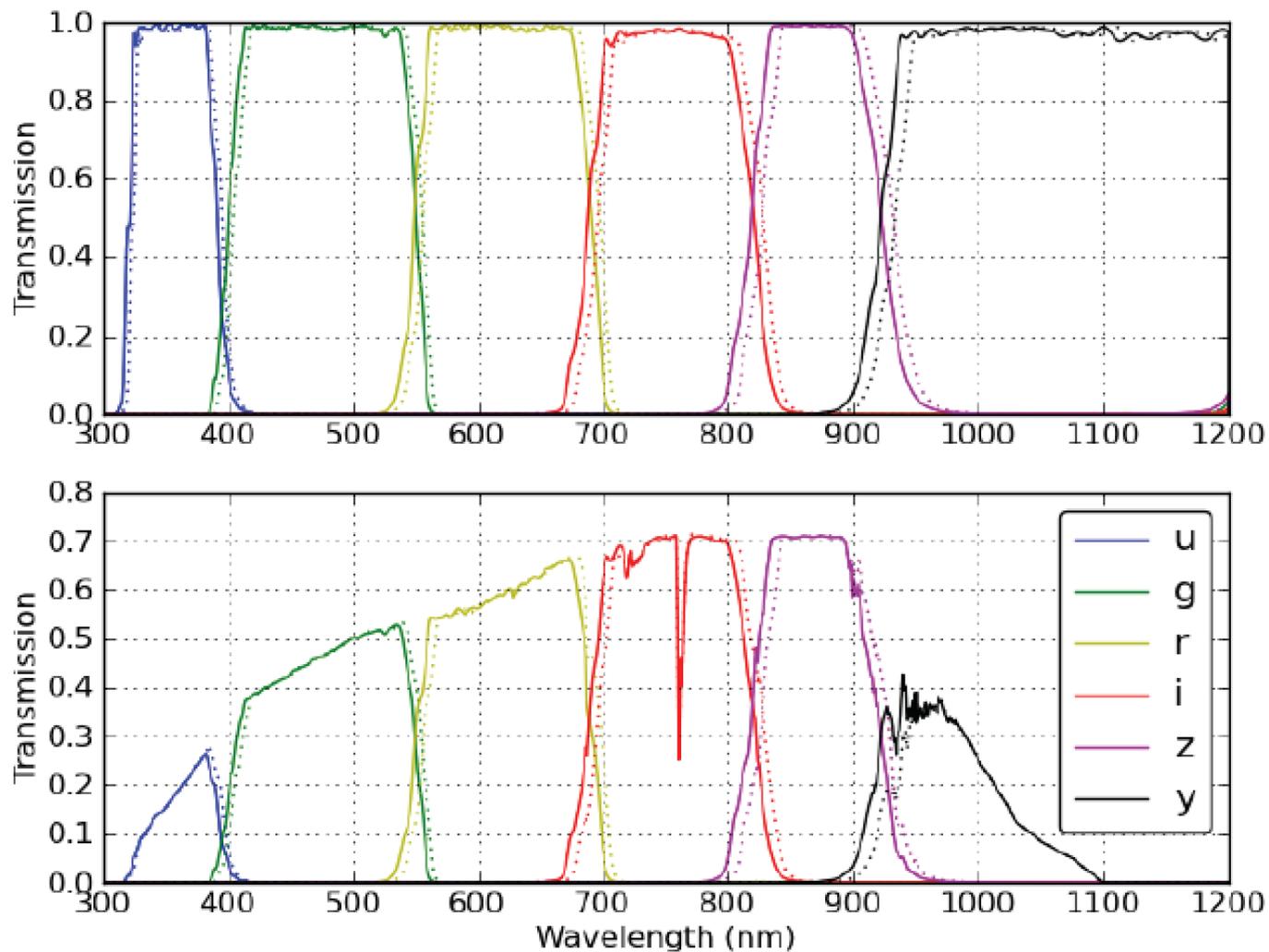
Proof of Concept LSST Filter Set (2006)



MODTRAN Transmission Templates



Baseline filter curves and a potential (1% of the central wavelength) shift due to nonuniformity in the filter bandpass.



Goal



Questions :

- 1) Do atmospheric models implemented in Modtran/ libRadtran show significant magnitude biases in LSST Filters?**
- 2) Can atmospheric parameters be tuned so that libRadTran transmission function accurately reproduce those of Modtran ?**

Magnitude Compariston Study :

- Series of 5000 star pickles-like SED which magnitudes are representative of star statistics for LSST
- Magnitude and errors calculated with LSST_SIMS/photUtils

Atmospheric models:

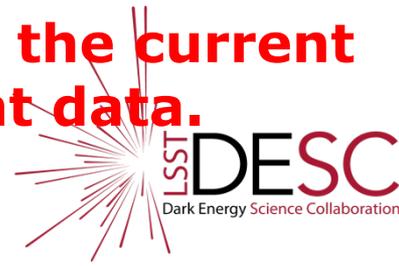
- Modtran 5 profiles simulated for 14 airmasses
 - Fixed ozone, PWV, O_2 , O_3 , scattering, No aerosols
- LibRadTran, v2.0.1 at any airmass
 - Tune ozone, PWV parameters to reproduce the transmission curve of Modtran

Outline



- I. Transmission profiles comparison before parameter tuning
- II. Parameter tuning
 - SED used (realistic 5000 Pickles-like SED)
 - PWV in Y filter
 - Ozone in R filter
- III. Transmission profile comparison after parameter tuning
- IV. Oxygen absorption
- V. Conclusion

Two basic questions come from uncertainties in the current understanding of atmospheric models and current data.



What is the systematic error floor?

What are the sources of errors on calibrated fluxes/magnitudes?

Discussion about atmospheric modeling has generated several packages that have been used to analyze various atmospheric constituents:

ModTran (MT) - program designed to model atmospheric propagation of electromagnetic radiation

LibRadTran (RT)- collection of C and Fortran functions and programs for calculation of solar and thermal radiation in the Earth's atmosphere

Poloka – SNLS

Pickles - HST Astrometry (Catalogs/Libraries)

Source Extractor - program that builds a catalogue of objects from an astronomical image.

DM Stack – DESC/LSST Data Management Stack to analyze images,

LSSTSilS/PhotUtils – To compute LSST magnitudes

Basic Differences with LibRadTran and Modtran

- LibRadTran (RT) can generate:
 - Pure molecular scattering without absorption (**sc**)
 - Pure absorption (all absorbing components) without molecular scattering (**ab**)
 - O₂ line cannot be removed
 - H₂O and O₃ can be tuned at will
 - both molecular and absorption (**sa**)
- Modtran (MT) generates independently
 - Molecular scattering (**sc**) and each molecular absorption (**ab**) component
- For all analysis in this presentation, aerosols and clouds are turned off

Calculation of Magnitude difference



$$F_{\Delta\lambda}^{ADU} = \frac{\pi D^2}{4 \cdot g_{el} h c} \int_{\Delta} T_{atm}(\lambda) \cdot T_{throu}(\lambda) \cdot T_{Filt}(\lambda) \cdot \epsilon_{CCD}(\lambda) \cdot S_{\lambda}^E(\lambda) \lambda d\lambda$$

$T_{atm}(\lambda)$: RT or MT atmospheric transparency

$T_{throu}(\lambda)$: LSST optical throughput

$T_{filt}(\lambda)$: LSST Filter transmission

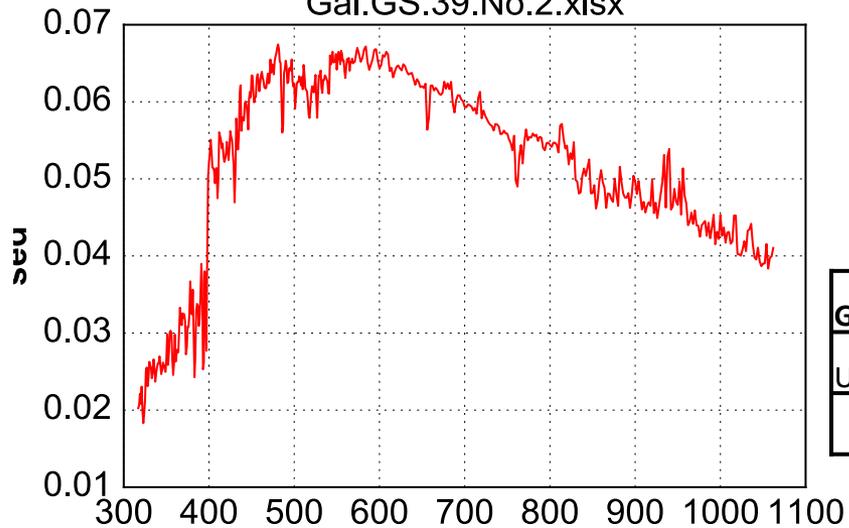
$\epsilon_{CCD}(\lambda)$: *LSST quantum efficiency*

$S_{\lambda}^E(\lambda) \propto \lambda^{\alpha}$, generic SED

$$M_F = -2.5 \log_{10}(F_{\Delta\lambda}^{ADU})$$

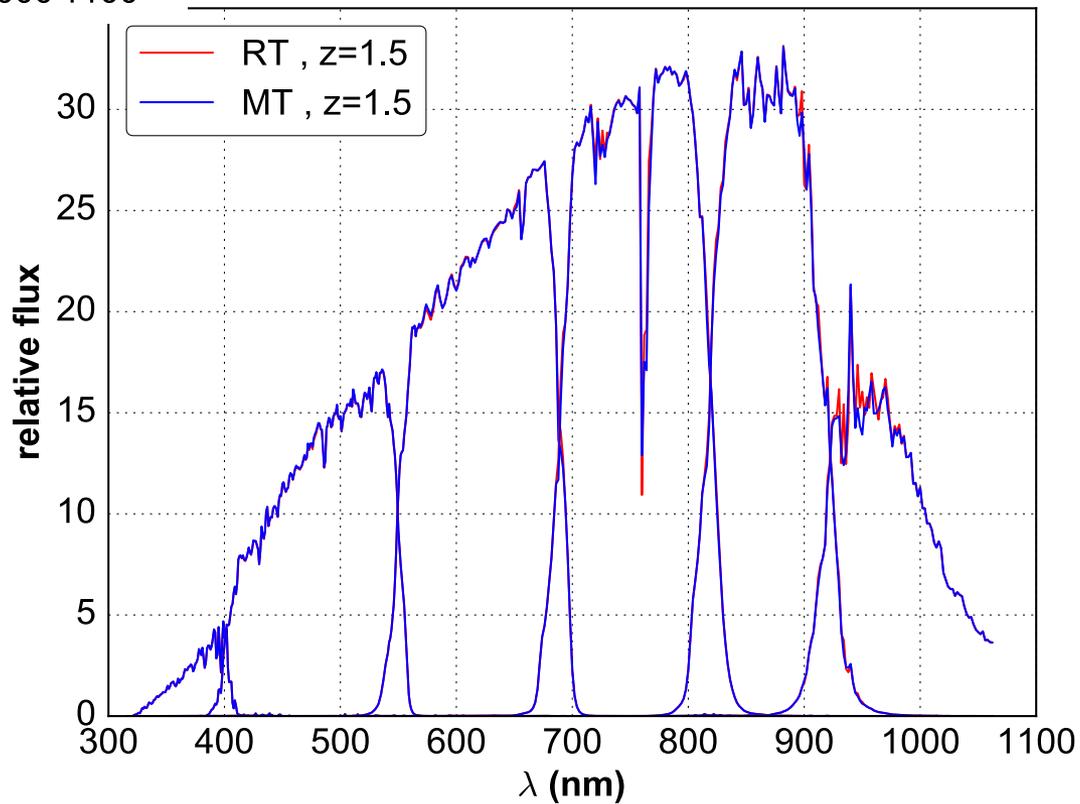
$$\Delta M = M_F(RT) - M_F(MT)$$

Gal.GS.39.No.2.xlsx



Gal.GS.39.No.2.xlsx					
U (mmag)	G(mmag)	R(mmag)	I(mmag)	Z(mmag)	Y4(mmag)
2.27	2.38	-1.65	-7.67	-7.12	-14.78

Gal.GS.39.No.2.xlsx



Results of differences in millimag between Modtran and LibRadTran on Selected Stars and Galaxies

Star.B1.No.3.xlsx

U (mmag)	G(mmag)	R(mmag)	I(mmag)	Z(mmag)	Y4(mmag)
2.26	2.49	-0.75	-6.58	-5.75	-21.81

Gal.S0.template.xlsx

U (mmag)	G(mmag)	R(mmag)	I(mmag)	Z(mmag)	Y4(mmag)
2.24	2.27	-0.7	-6.83	-5.62	-18.11

Gal.GS.39.No.2.xlsx - (Gunn&Stryker)

U (mmag)	G(mmag)	R(mmag)	I(mmag)	Z(mmag)	Y4(mmag)
2.27	2.38	-1.65	-7.67	-7.12	-14.78

Pick.UK.No.2.22.xlsx (F5IV)

U (mmag)	G(mmag)	R(mmag)	I(mmag)	Z(mmag)	Y4(mmag)
2.3	2.46	-0.49	-6.98	-5.42	-12.89

Pick.UK.50.No.4.xlsx

U (mmag)	G(mmag)	R(mmag)	I(mmag)	Z(mmag)	Y4(mmag)
2.42	2.54	-0.38	-6.99	-5.47	-12.58

Pickles.No.1.110.xlsx

U (mmag)	G(mmag)	R(mmag)	I(mmag)	Z(mmag)	Y4(mmag)
2.26	2.33	-0.55	-6.94	-5.39	-12.73

gal_z0 Ga.BC.95.No1.z.ALL_pad0.xlsx (Bruzual&Charlot)

U (mmag)	G(mmag)	R(mmag)	I(mmag)	Z(mmag)	Y4(mmag)
2.25	2.63	-1.34	-7.84	-7.01	-14.1

gal_z1 Ga.BC.95.No1.z.ALL_pad0.xlsx

U (mmag)	G(mmag)	R(mmag)	I(mmag)	Z(mmag)	Y4(mmag)
2.7	2.48	-1.74	-7.66	-7.94	-13.54

gal_z2 Ga.BC.95.No1.z.ALL_pad0.xlsx

U (mmag)	G(mmag)	R(mmag)	I(mmag)	Z(mmag)	Y4(mmag)
	1.57	-1.69	-7.74	-7.03	-14.31

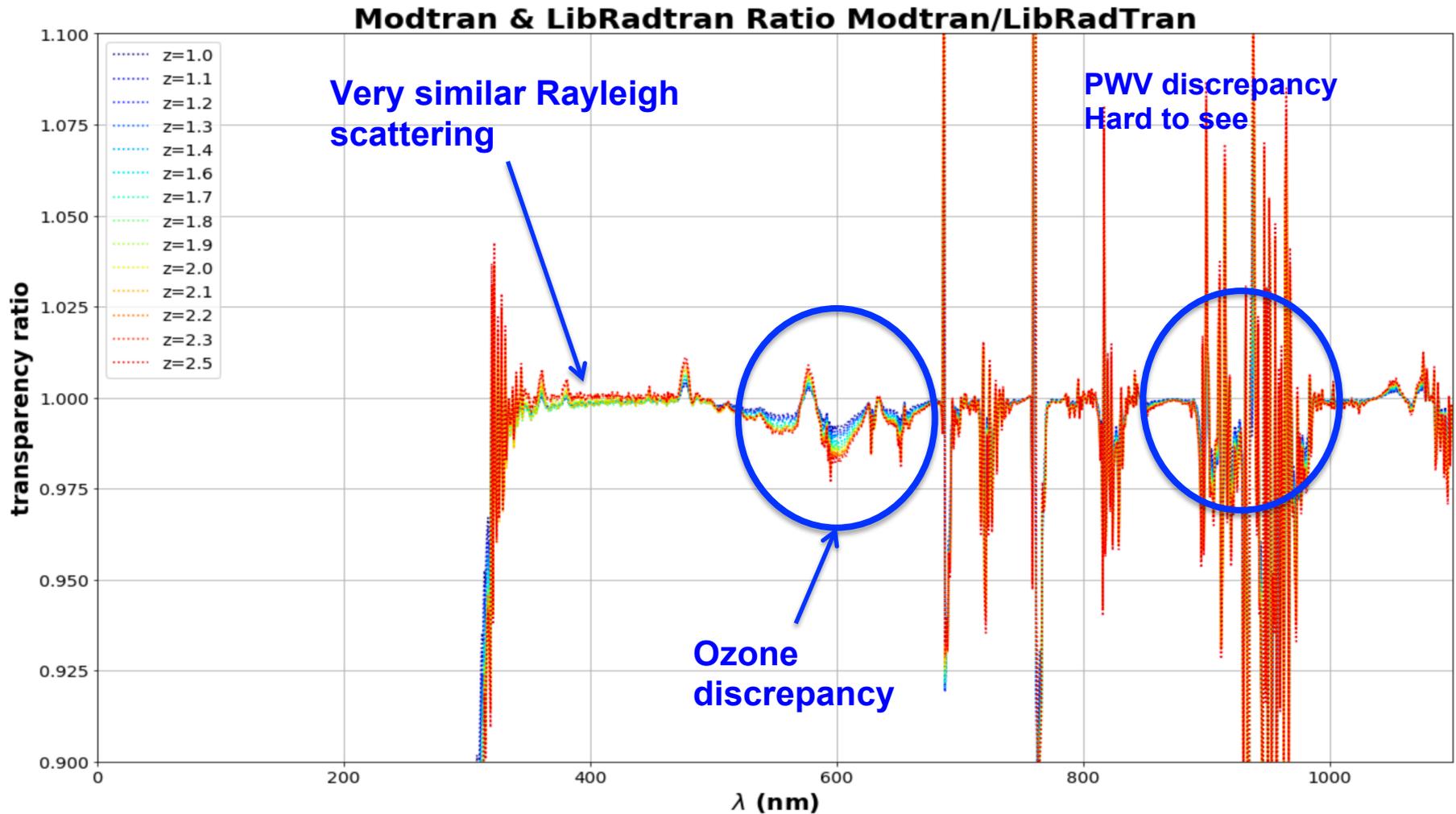
gal_z3 Ga.BC.95.No1.z.ALL_pad0.xlsx

U (mmag)	G(mmag)	R(mmag)	I(mmag)	Z(mmag)	Y4(mmag)
	-0.98	-1.76	-7.81	-7.04	-13.77

gal_z4 Ga.BC.95.No1.z.ALL_pad0.xlsx

U (mmag)	G(mmag)	R(mmag)	I(mmag)	Z(mmag)	Y4(mmag)
		-3.35	-7.76	-6.97	-13.85

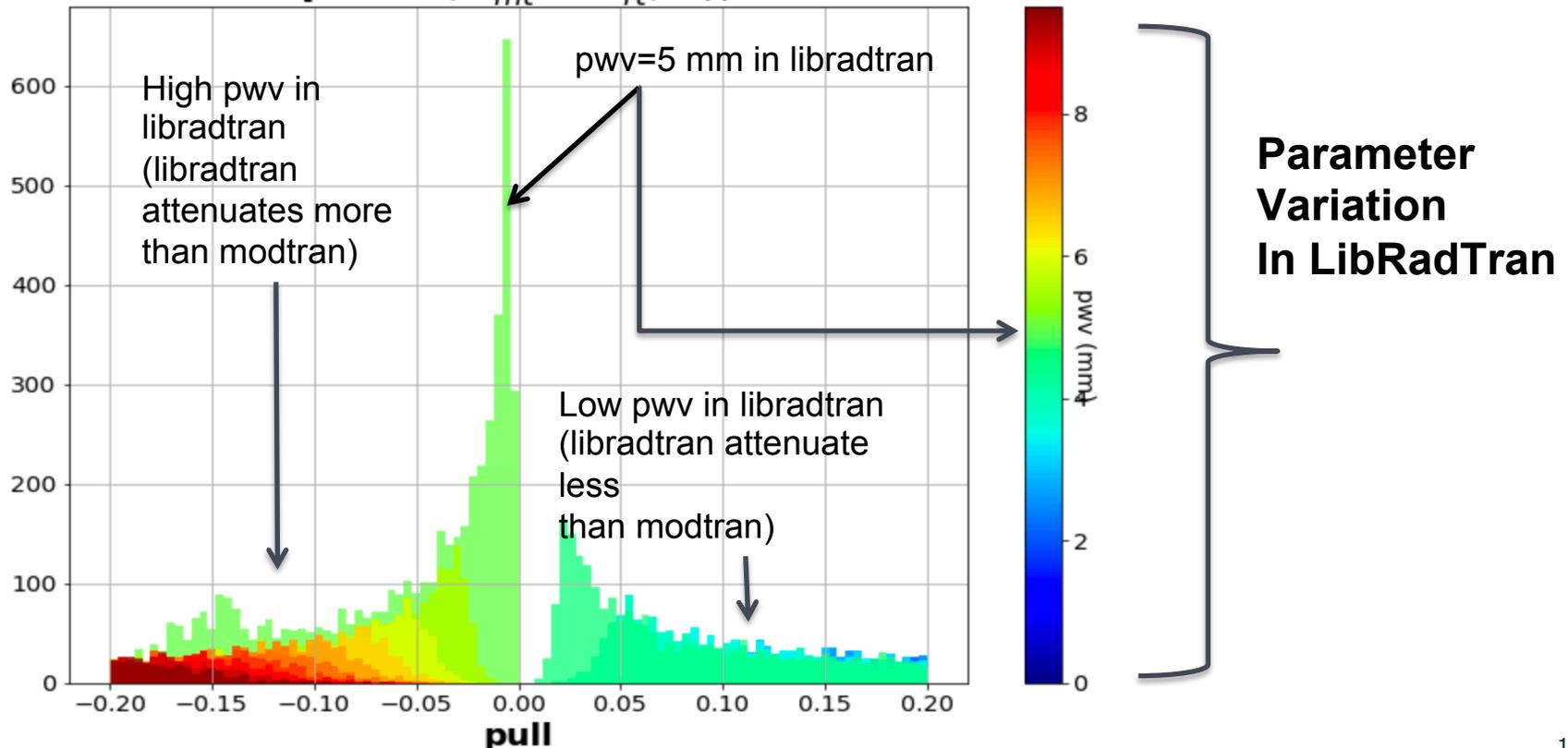
I. Transmission profile comparison before parameter tuning : Modtran profile / libRadTran profile



II. Pull distribution

$$pull = \left(\frac{M_i^F(MT) - M_i^F(RT, param)}{\sigma_M} \right)$$

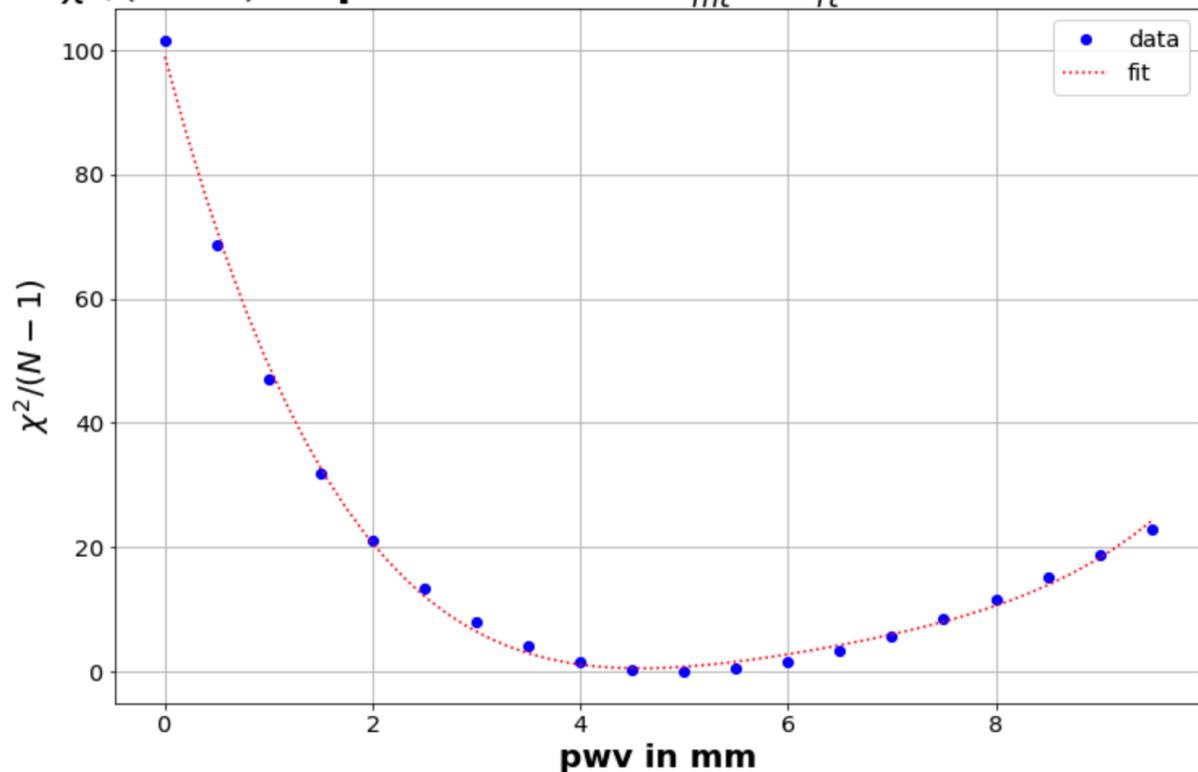
Pulls Distribution $pull \equiv (M_{mt}^Y - M_{rt}^Y)/\sigma_M$ for airmass $z=1.2$



II. χ^2 Minimization

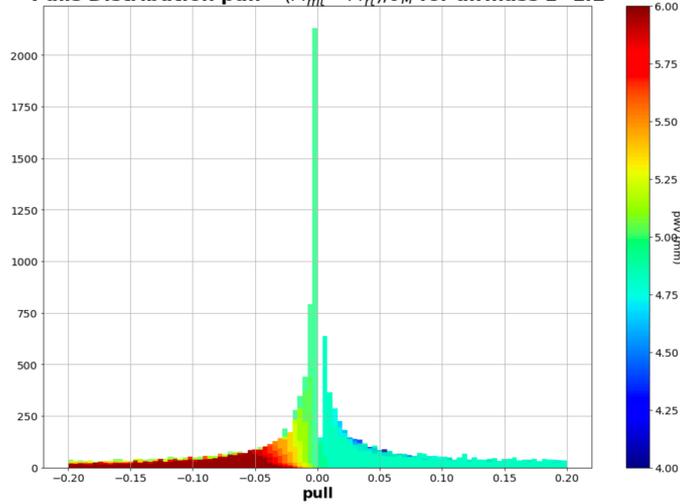
$$\chi^2 = \frac{1}{N-1} \sum_{SED-idx-i}^N \left(\frac{M_i^F(MT) - M_i^F(RT)}{\sigma_M} \right)^2$$

$\chi^2/(N-1)$ vs pwv for $\Delta M^Y = M_{mt}^Y - M_{rt}^Y$ for airmass $z=1.2$

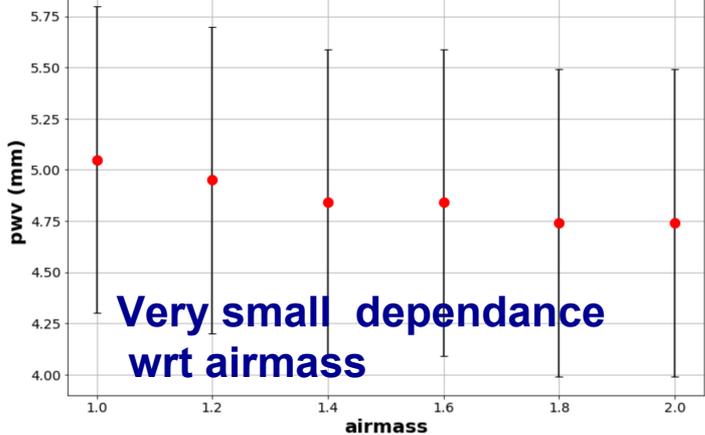


II. Optimal PWV in Y filter

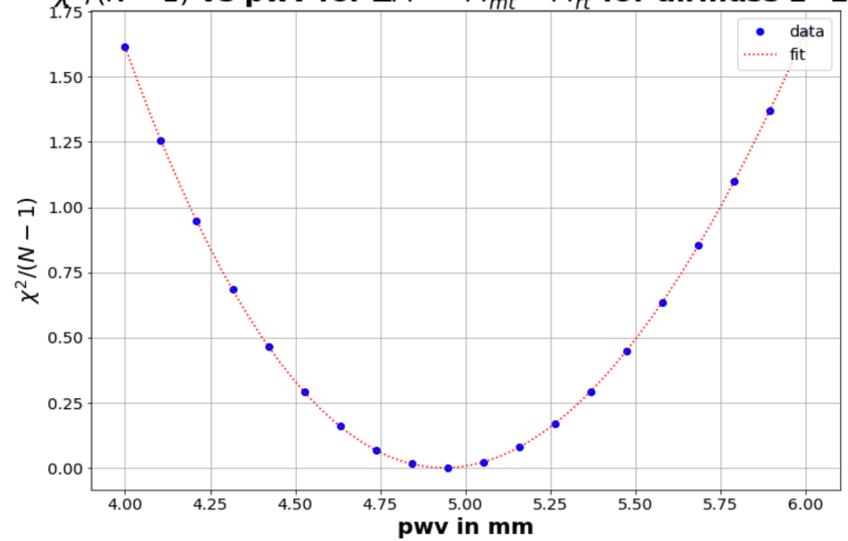
Pulls Distribution $\text{pull} \equiv (M_{mt}^Y - M_{rt}^Y) / \sigma_M$ for airmass $z=1.2$



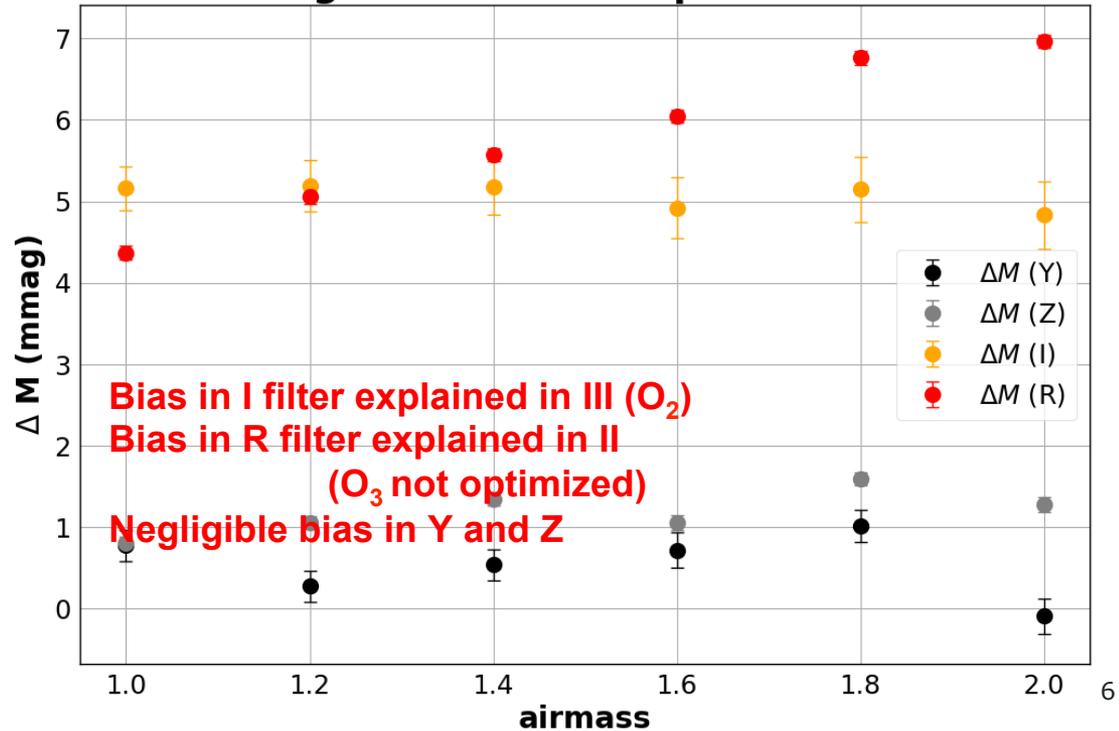
Optimal Precipitable water vapor



$\chi^2 / (N - 1)$ vs pwv for $\Delta M^Y = M_{mt}^Y - M_{rt}^Y$ for airmass $z=1.2$



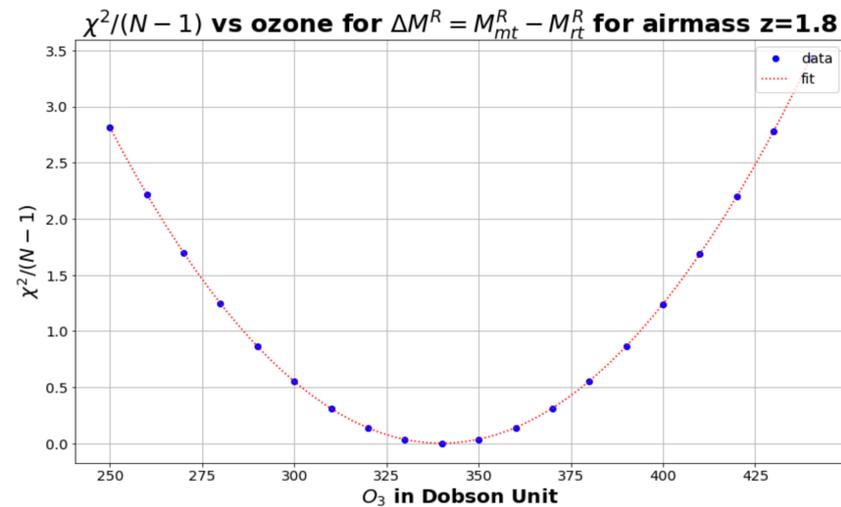
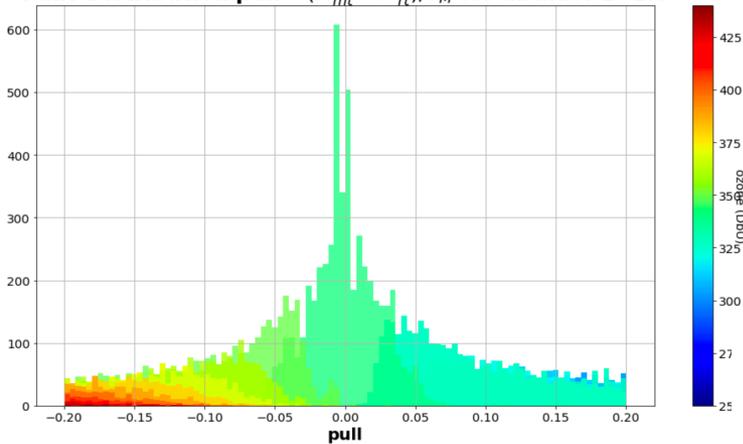
Magnitude bias at optimal PWV



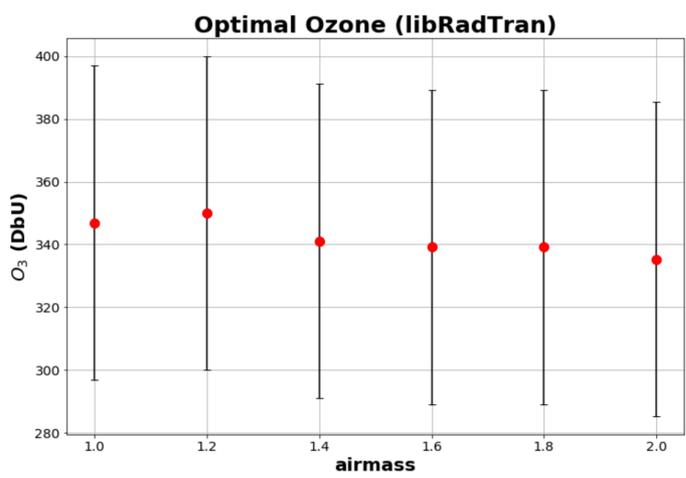
II. Optimal Ozone



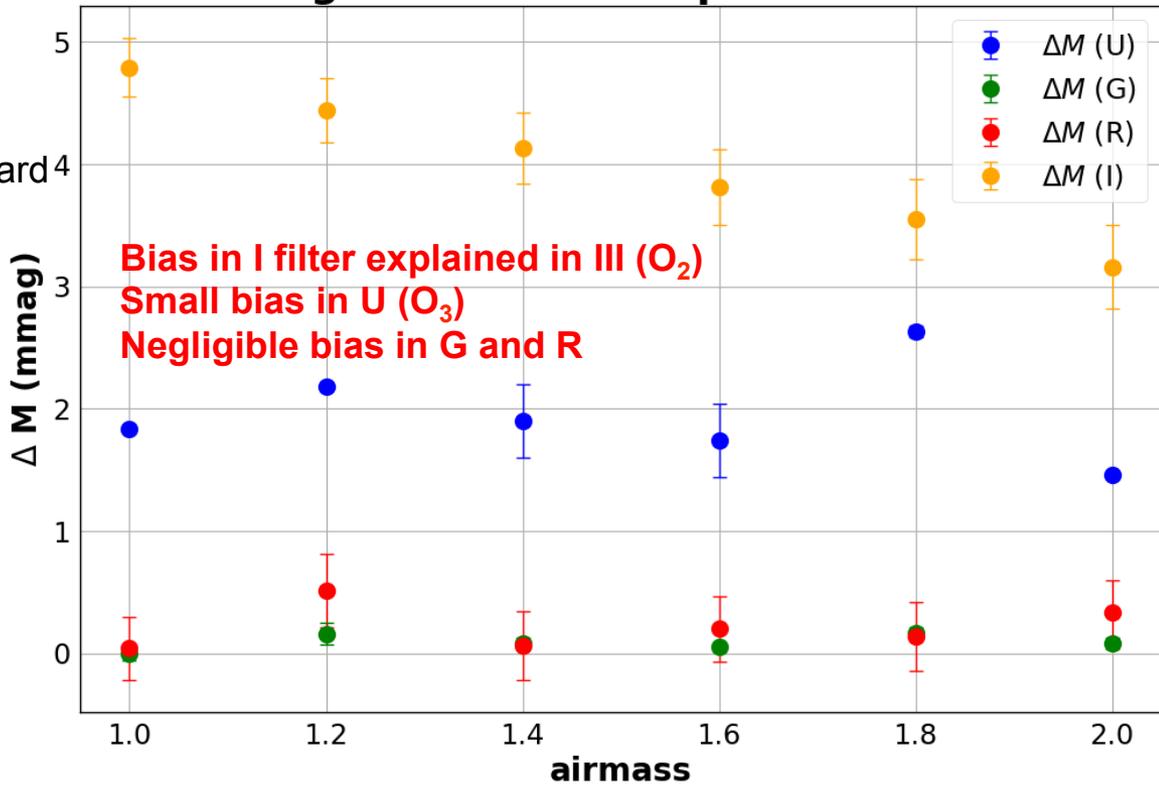
Pulls Distribution $\text{pull} \equiv (M_{mt}^U - M_{rt}^U) / \sigma_M$ for airmass $z=1.8$



One Dobson unit being equivalent to one layer of pure ozone 0.01 mm thick at standard temperature and pressure.

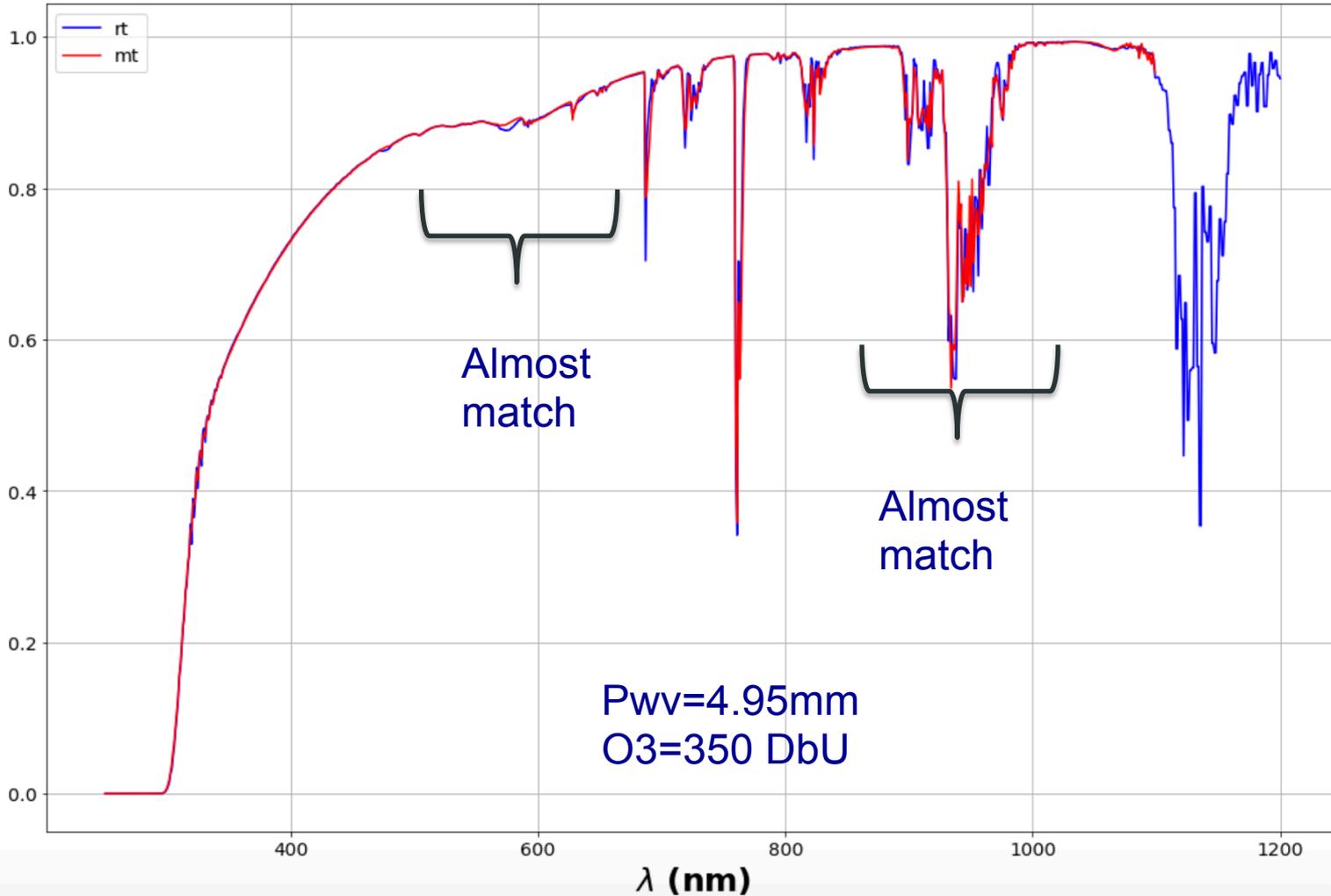


Magnitude bias at optimal Ozone

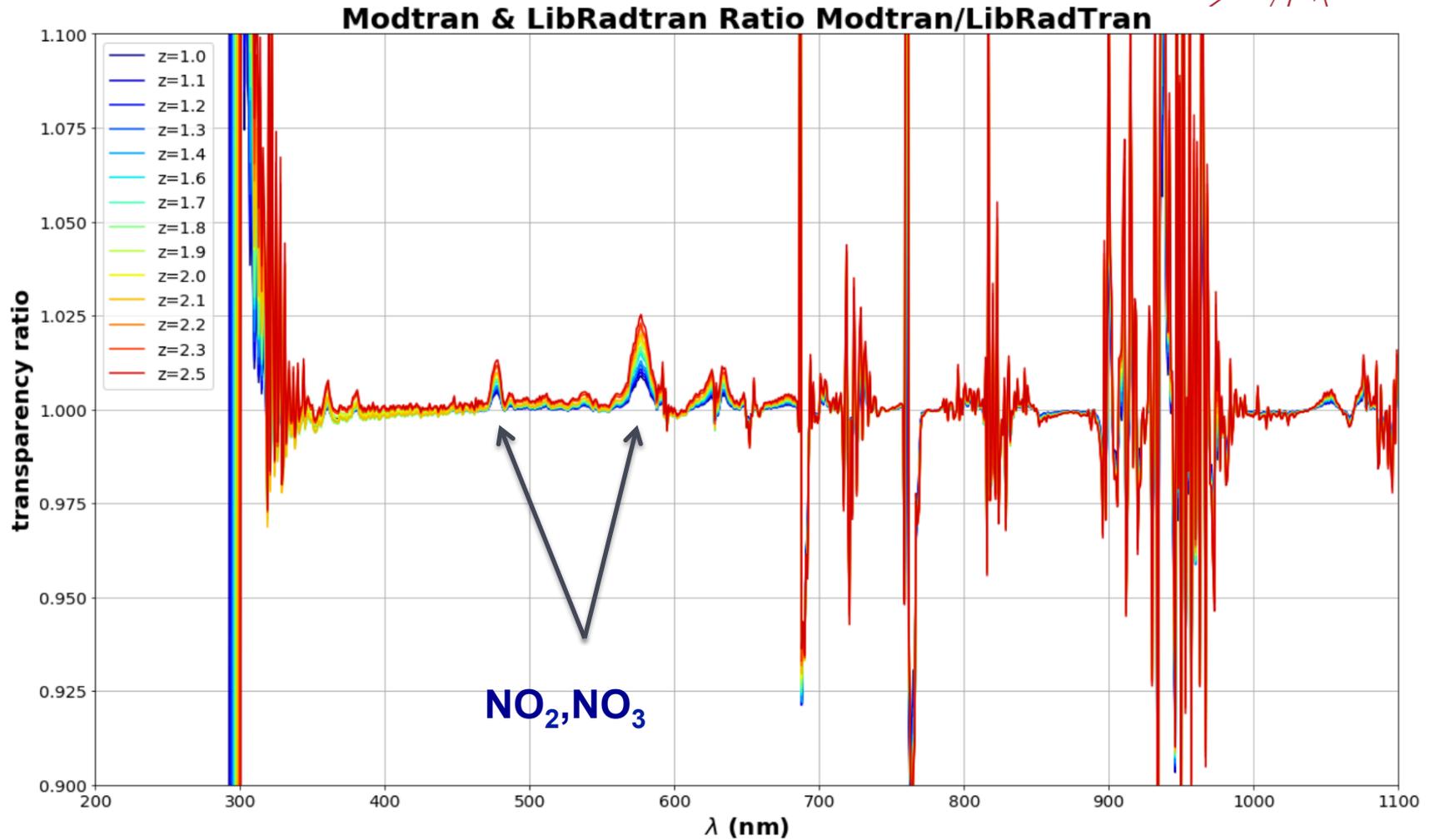


III Tuned Transmission curves

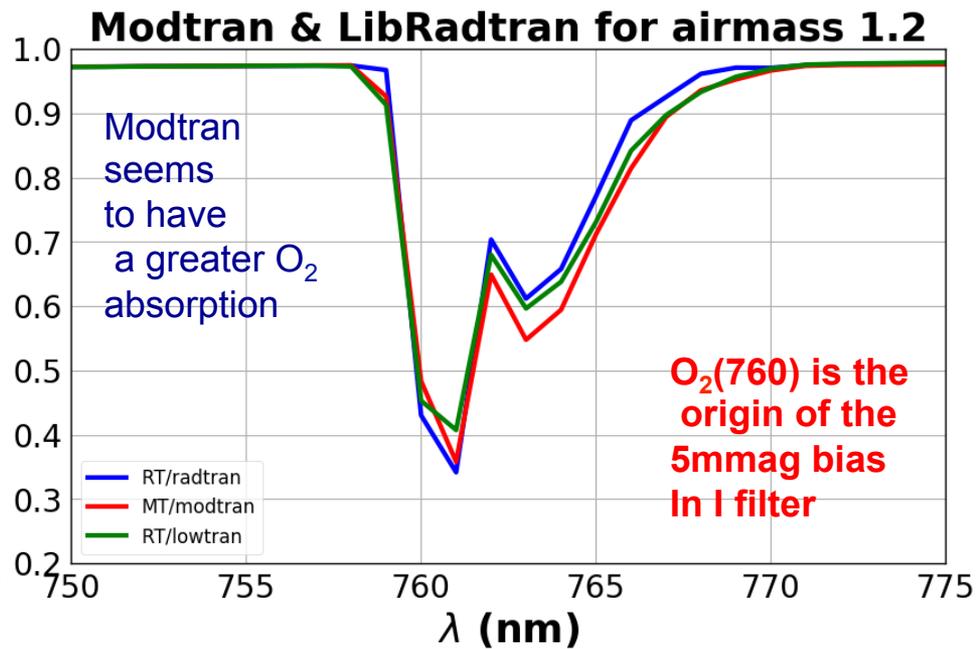
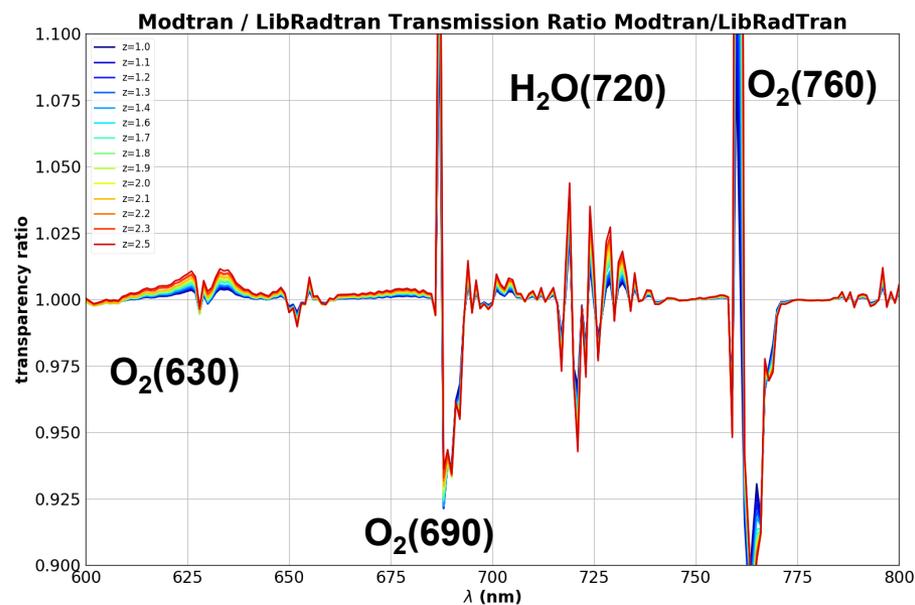
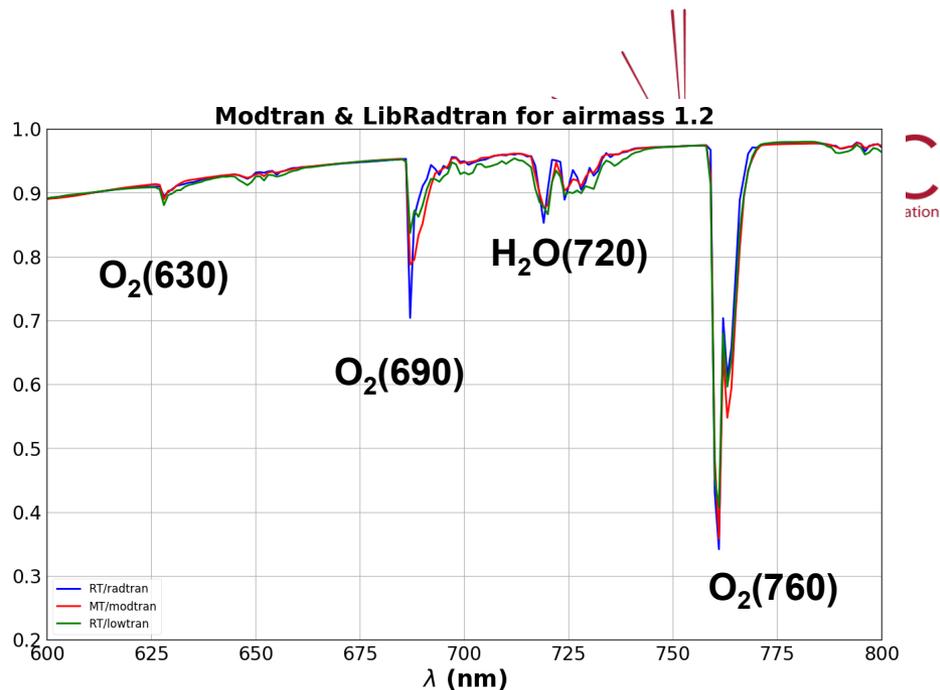
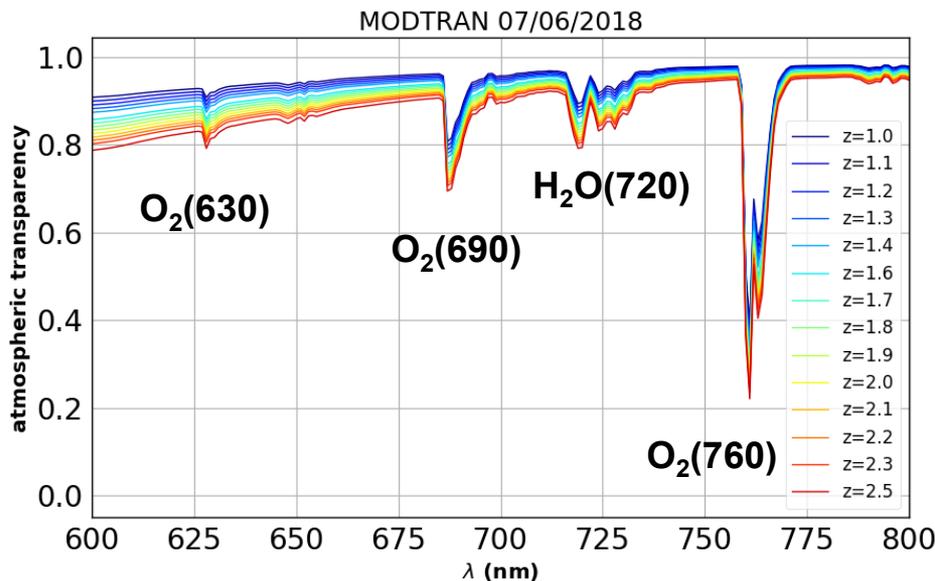
Modtran & LibRadtran for airmass 1.2



IV. Tuned Transmission curves ratio



IV. Oxygen



Conclusion



- Good matching of Modtran/LibRadTran atmospheric transmission in airmass range [1,2] within LSST magnitude required accuracy
- **U band:** Rayleigh scattering, Ozone Huggins cutoff match within 1mmag
- **G,R band:** transparency matching better than 1 mmag
- **Z,Y band:** transparency matching of the order of 1 mmag
- **I band:**
 - Modtran seems to have a greater O₂ absorption than LibRadTran(abs model radtran and lowtran)
 - $\Delta M(I) \approx 5$ mmag
 - This significant discrepancy on O₂ is being explored

2 **Comparison of atmospheric**
3 **transparency in Modtran and**
4 **LibRadTran**

5 *S. Dagoret-Campagne¹ and K. Gilmore²*
6 *(LSST Dark Energy Science Collaboration)*

7 ¹LAL, Univ. Paris-Saclay, CNRS/IN2P3, Université Paris-Saclay, Orsay, France

8 ²SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA

9 (Dated: September 18, 2018, version : V0.5, DESC-LSST-Note-LAL-2018-09-002)

10 We compare atmospheric light transmission for Modtran and LibRadTran in the LSST wave-
11 length range.

12 **1. Introduction**

13 Reliable and realistic atmospheric transmission models are required to achieve milli-mag
14 photometric calibration at LSST. Atmospheric light transport codes provide such accu-
15 rate models well tested over decade by earth sciences. However slight discrepancies in
16 modelisation may have an impact on the photometric calibration accuracy. We propose
17 to compare the atmospheric transmission predicted by two light transfer codes : Mod-

Links to the Code/Data

- Code:
- LibRadTran simulation template for LSST site:
 - <https://github.com/LSSTDESC/PC5AtmosphericExtinction>
- Code for the analysis MT/RT comparison under ipython (jupyter notebook):
 - <https://github.com/sylvielsstfr/PC5AtmStudies/blob/master/MTRTFirstComp/ThirdMTRTComparison.ipynb>
- Python interface to HITRAN: hapi.py
 - <http://hitran.org/hapi/>
- Data and Presentations:
- git repository
- <https://github.com/DarkEnergyScienceCollaboration/PC5AtmosphericExtinction>

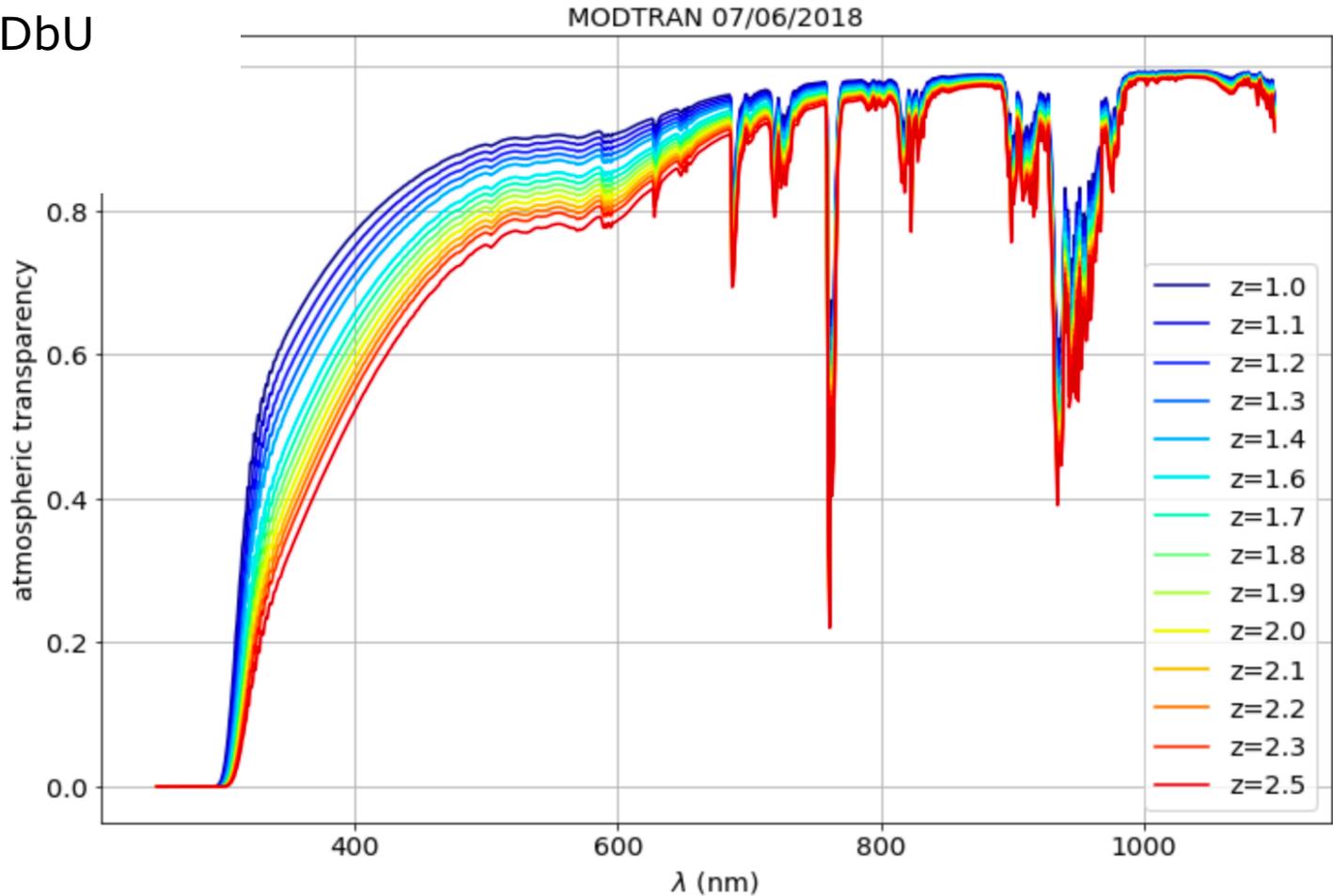
BACKUP



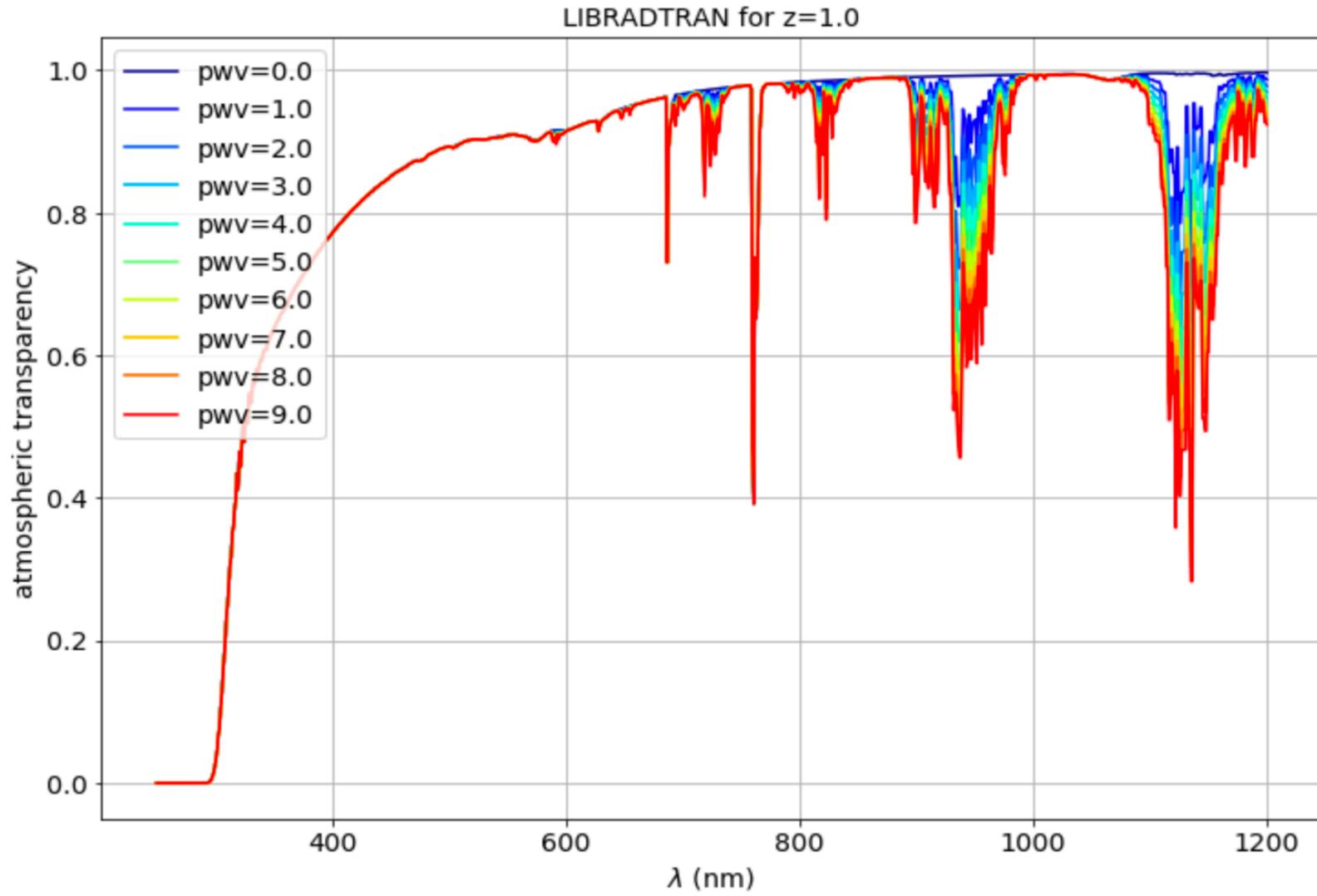
I. Modtran-5 simulation for 14 airmass



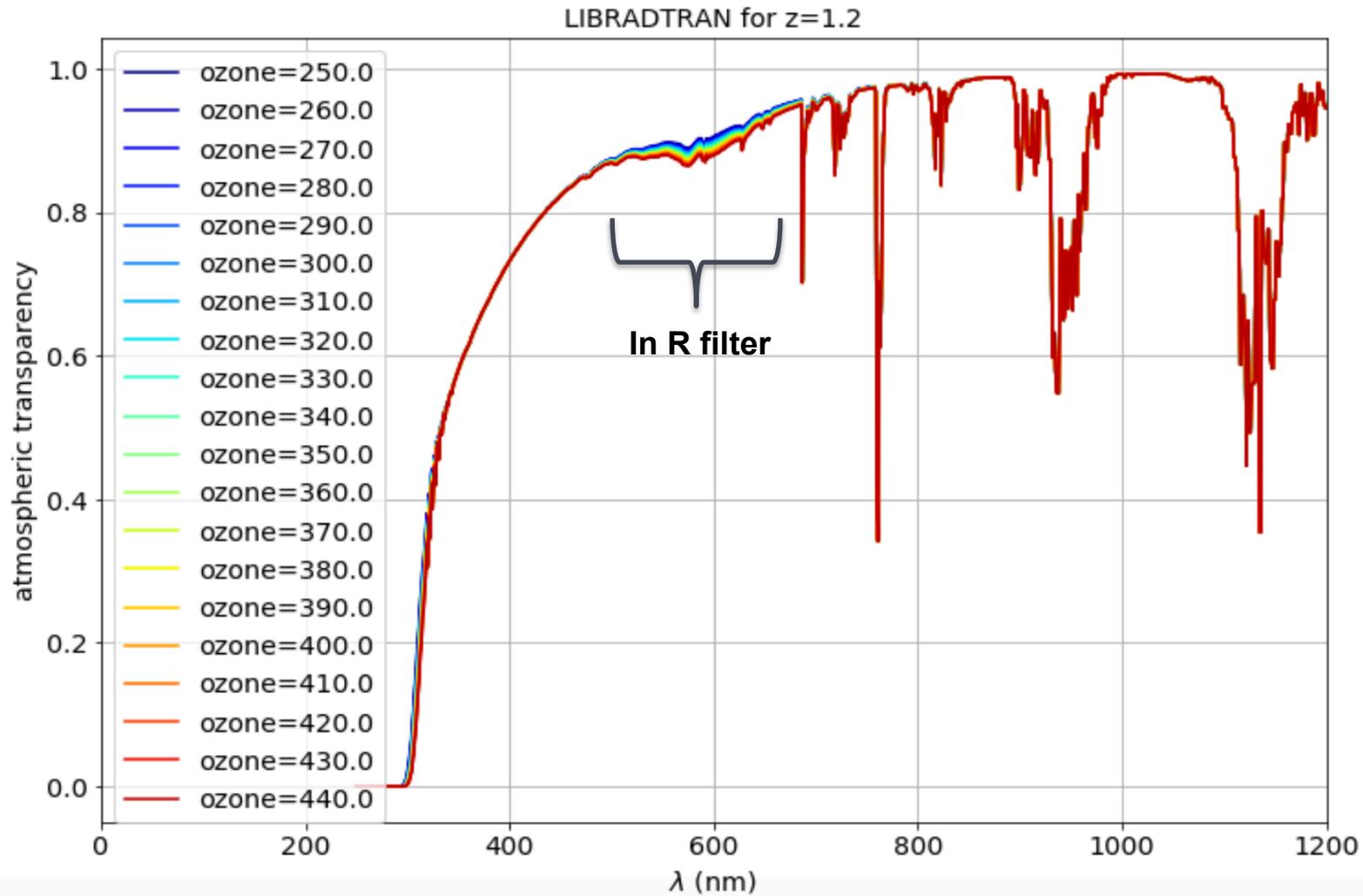
No aerosols
Ozone=300 DbU
PWV= 4mm



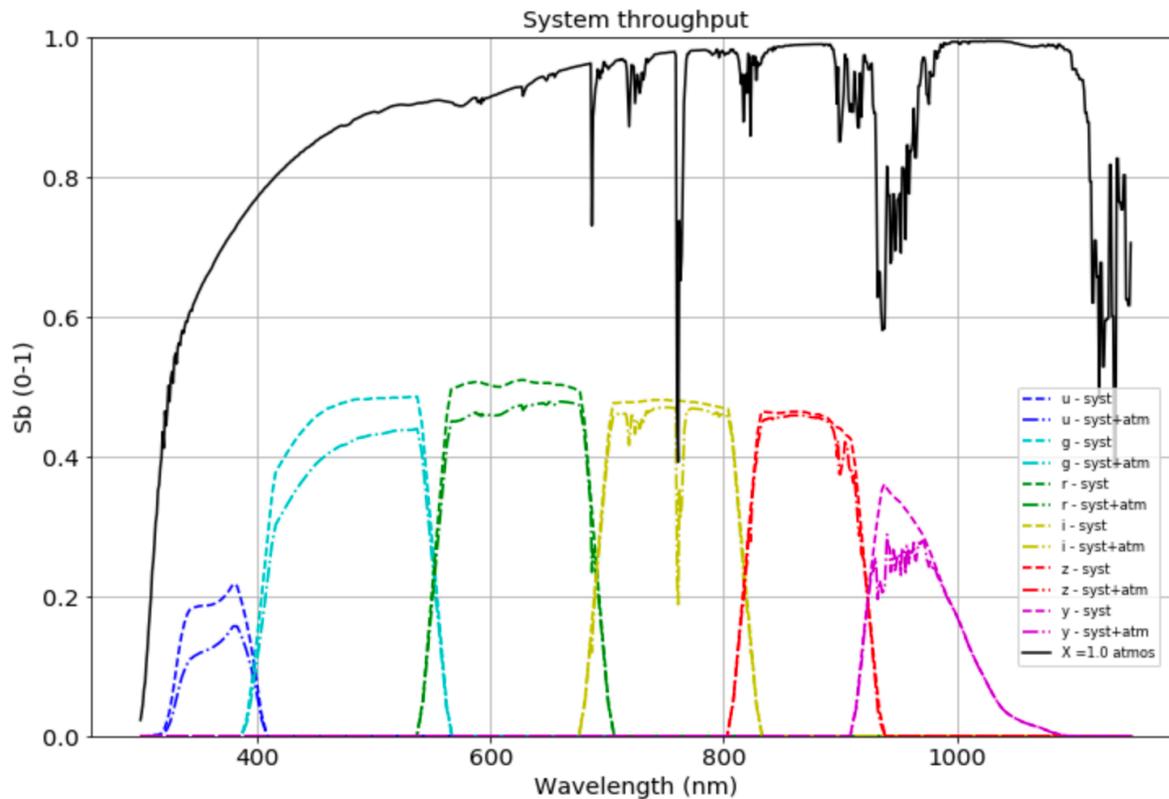
II. PWV variation in LibRadTran



II. Ozone Variation

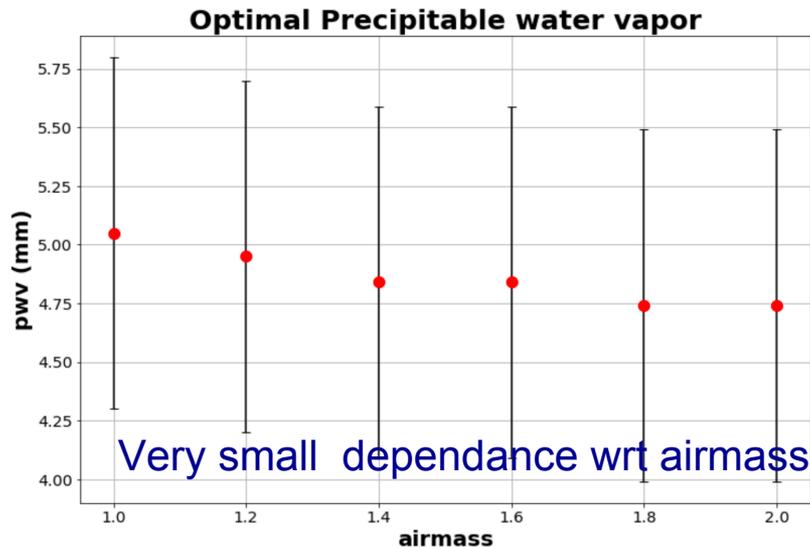
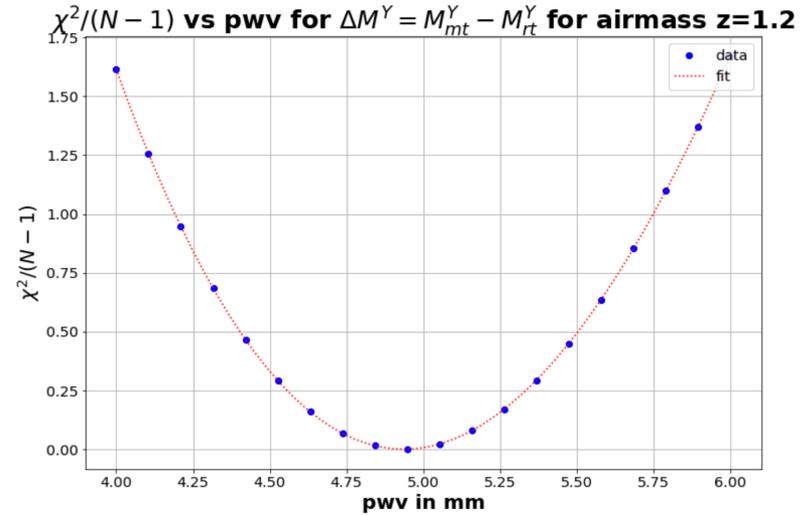
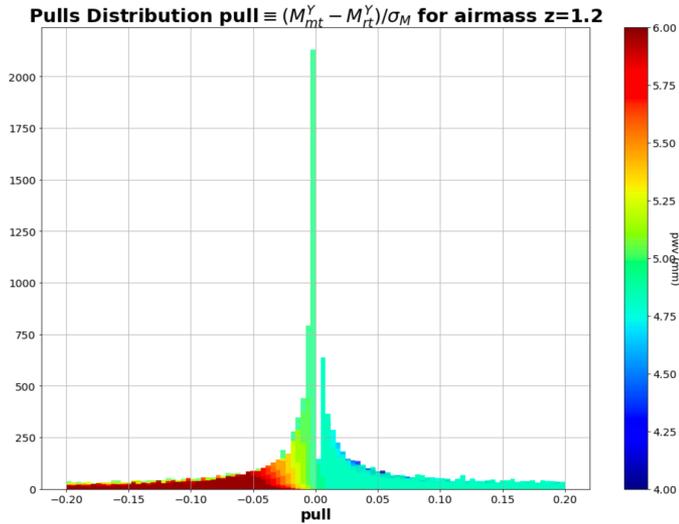


II. LSST Throughput



Use PhotUtils:
Official throughput
Compute
magnitudes and
errors from
PhotUtils (LSST-
SIMS)
Use seeing and
Sky Brightness
(Cadence
Minion1016)

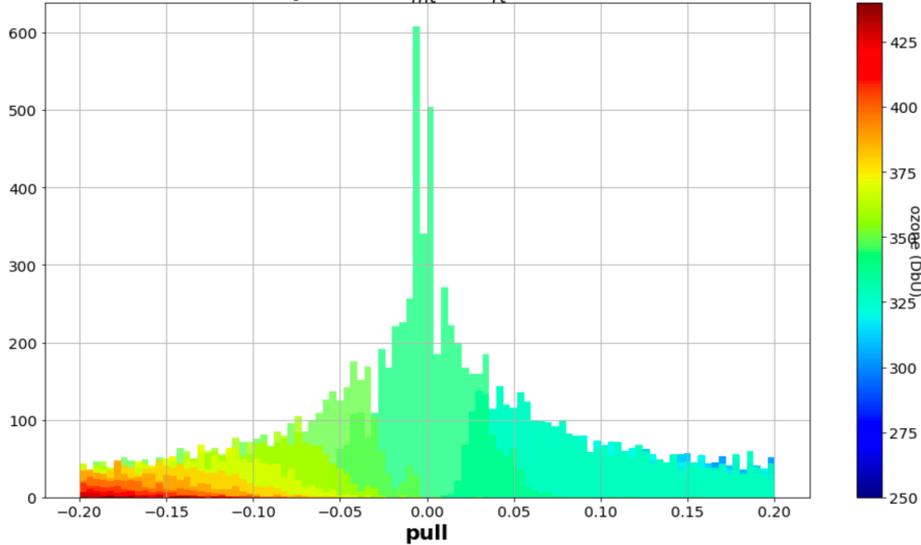
II. Optimal PWV



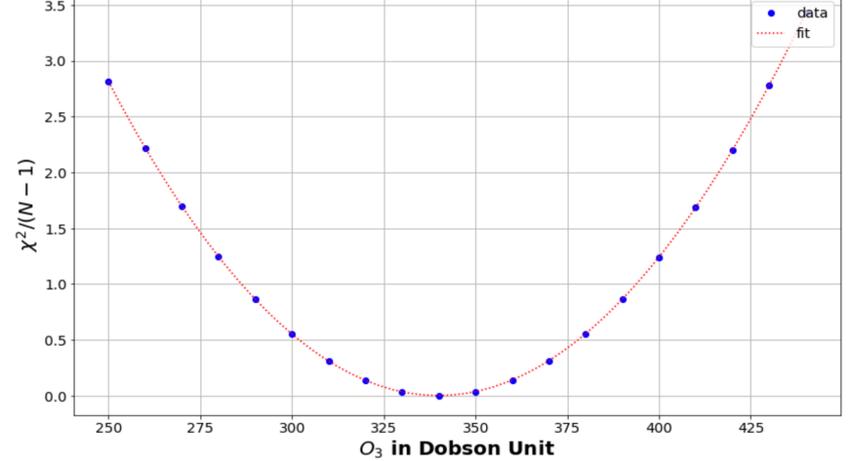
Band	ΔM (mmag), $z=1.2$
Y	0.28 ± 0.19
Z	1.06 ± 0.07
I	5.19 ± 0.31
R	5.06 ± 0.09

II. Optimal Ozone

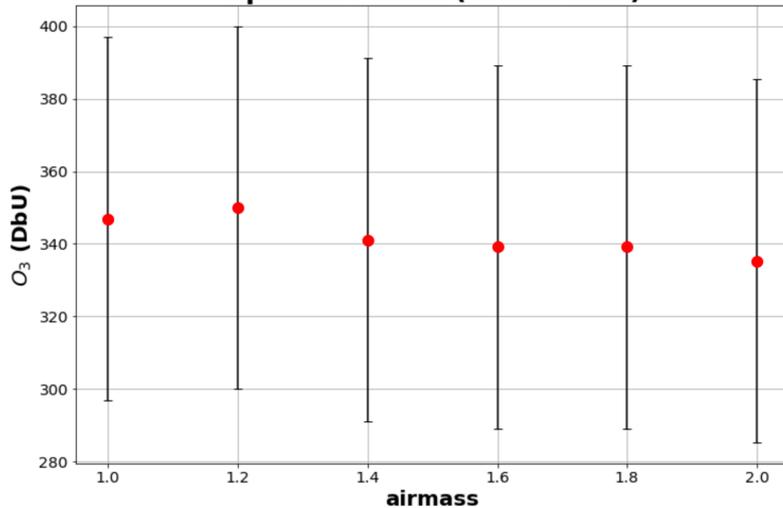
Pulls Distribution $\text{pull} \equiv (M_{mt}^U - M_{rt}^U)/\sigma_M$ for airmass $z=1.8$



$\chi^2/(N-1)$ vs ozone for $\Delta M^R = M_{mt}^R - M_{rt}^R$ for airmass $z=1.8$



Optimal Ozone (libRadTran)



Band	ΔM (mmag), $z=1.2$
U	2.18 ± 0.03
G	0.16 ± 0.09
R	0.51 ± 0.30
I	4.44 ± 0.26