Constraining the atmospheric transmission with spectroscopic data

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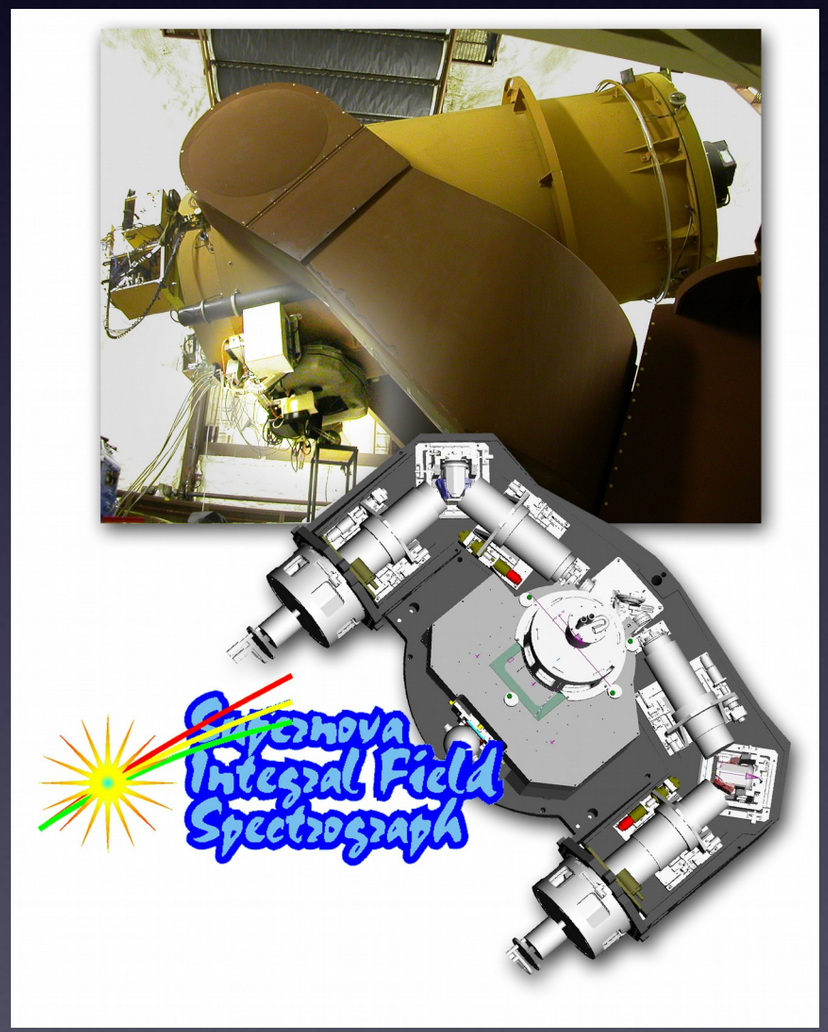
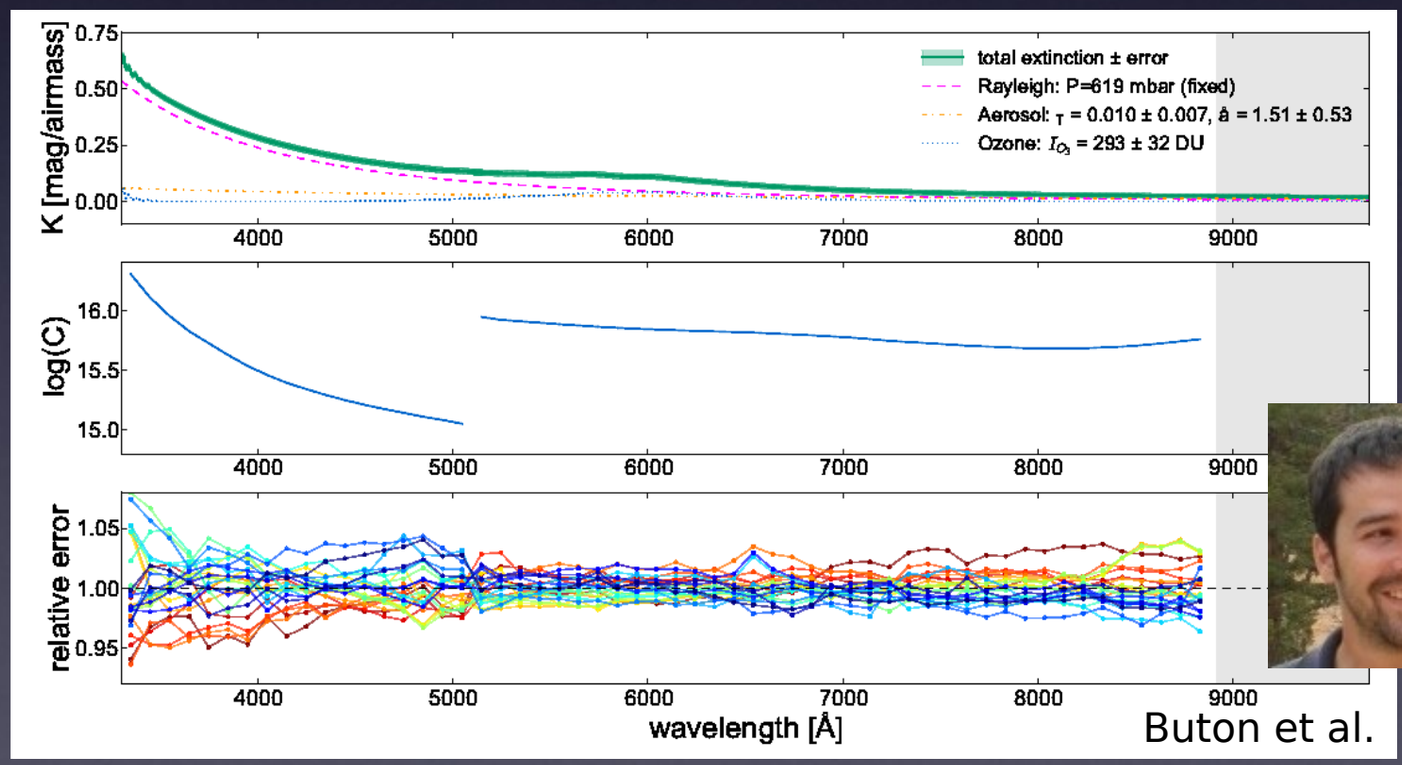
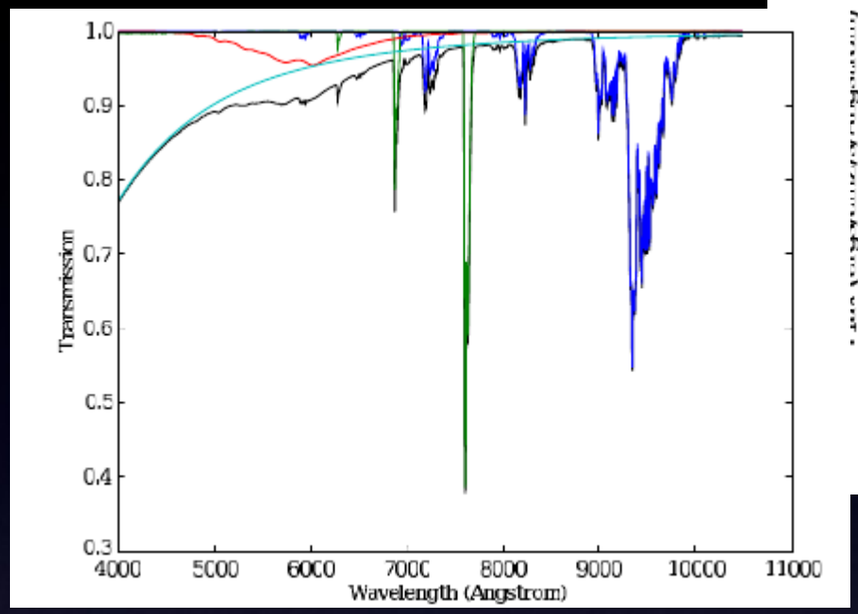
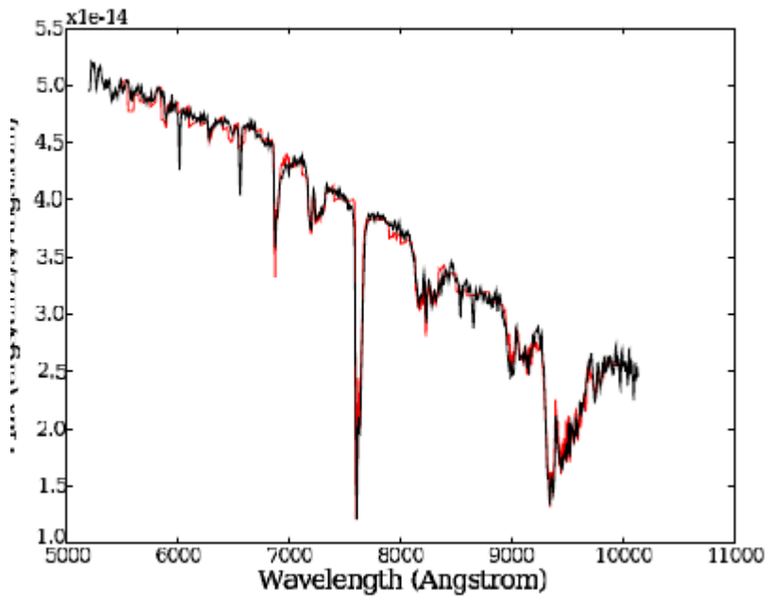


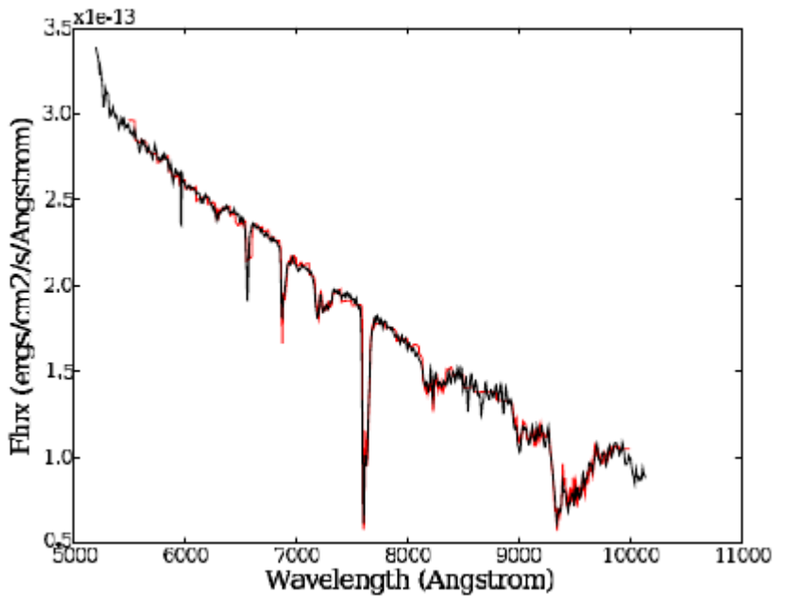


Buton et al.

Lots has been done already :





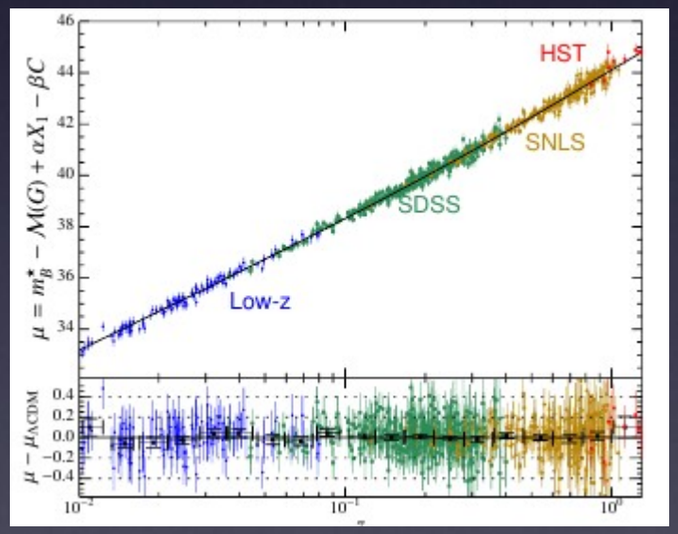


Fitting the atmospheric transmission alone
(Burke et al.)

Similarity with what comes next is intentional

Cloud transmission simulations
& measurements

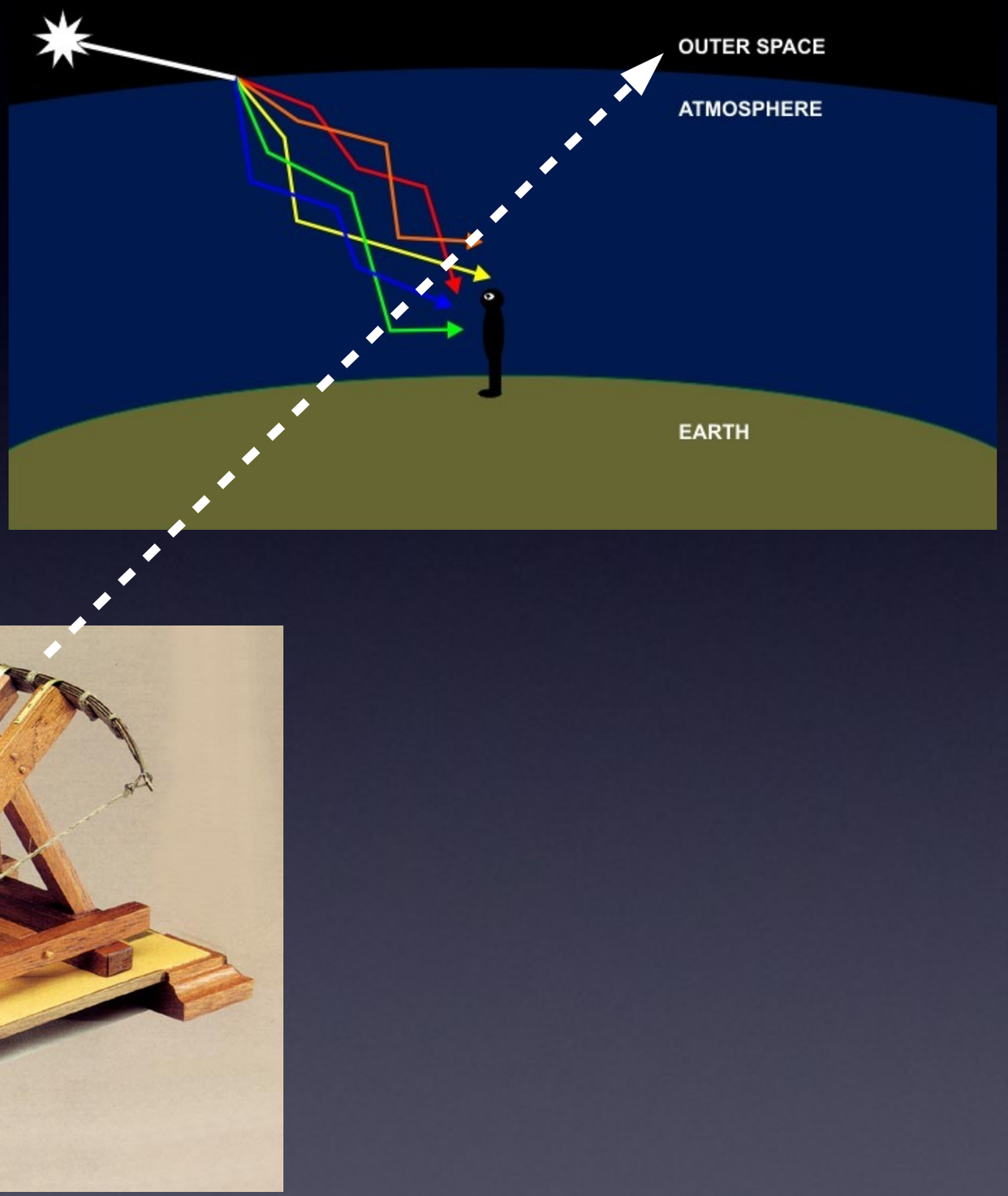
APC

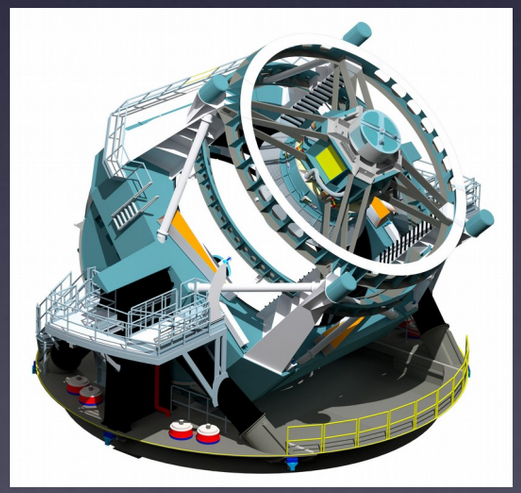


“Simple” photometric approach
PanSTARRS, SDSS, SNLS ...

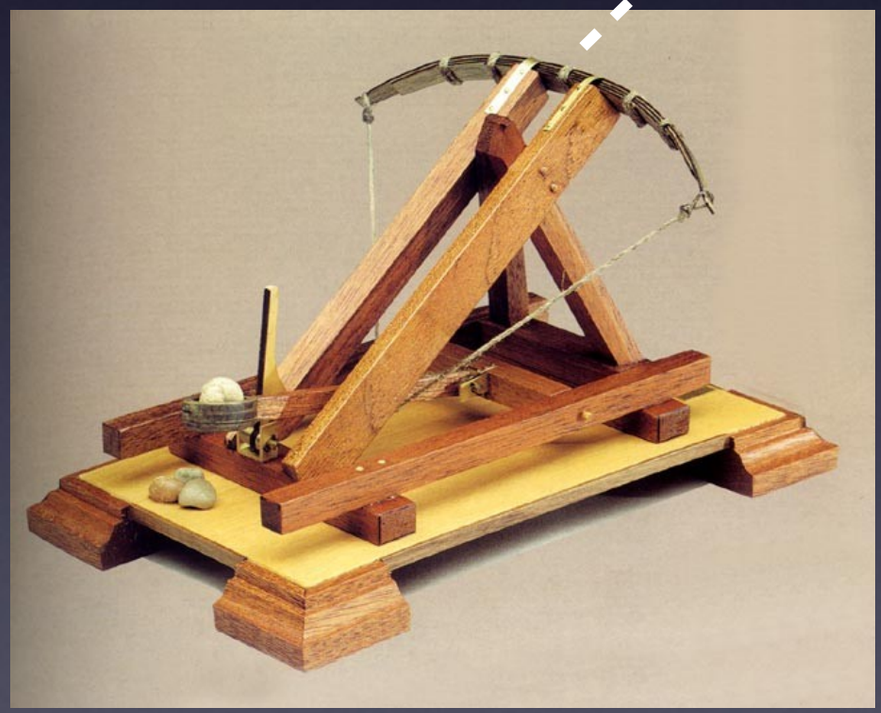
See also G. Blanc's talk

I have even heard about LSST *cunning plan*:





+



The pragmatic (but less fun) photometric approach:

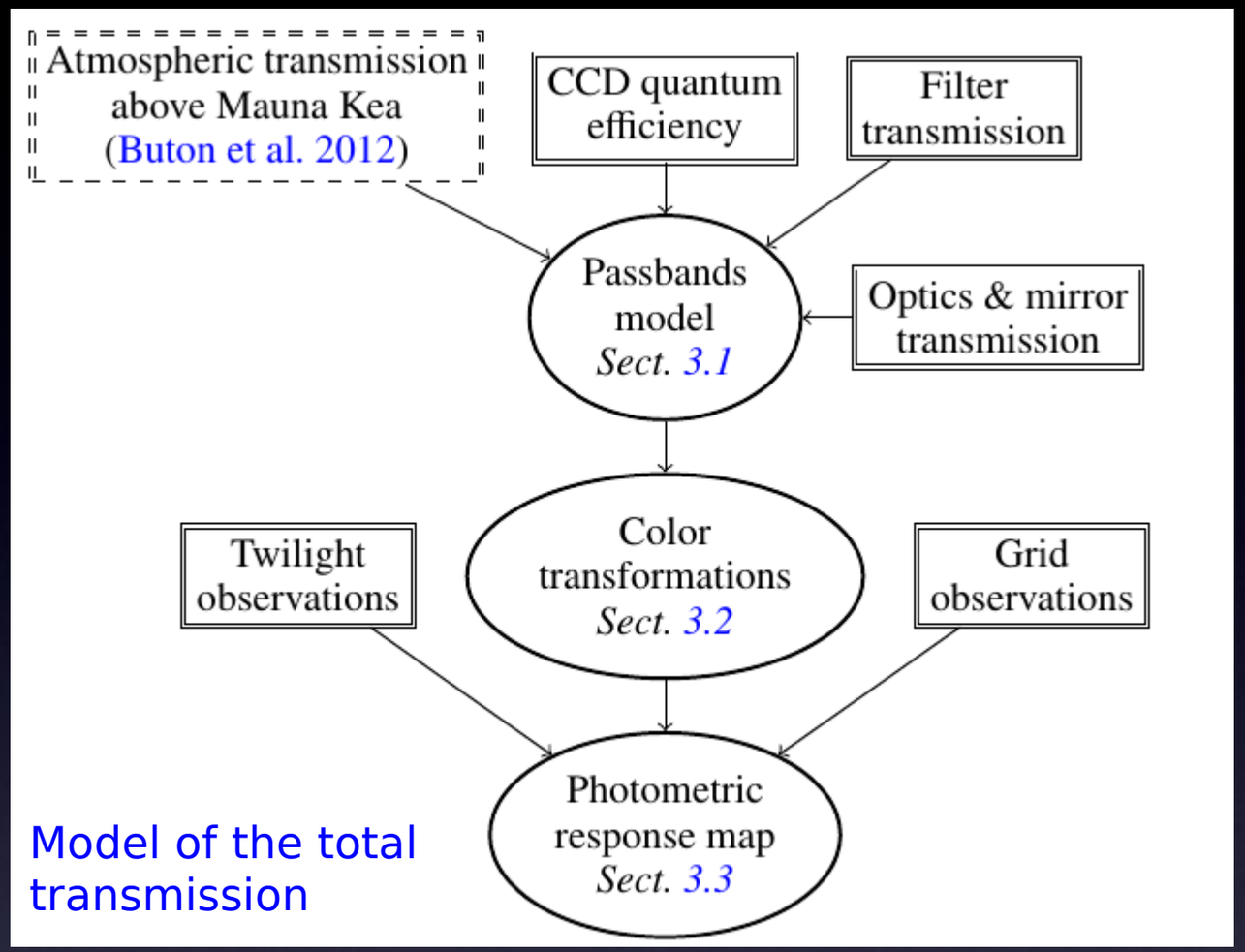
cf Betoule 2013 for example

Observe many stars

$$m_{|x} = -2.5 \log_{10} \frac{\int_\lambda \lambda T_{|x}(\lambda) S(\lambda) d\lambda}{\int_\lambda \lambda T_{|x}(\lambda) S_{\mathrm{ab}}(\lambda) d\lambda}$$

model

STD star



The pros:

Many stars: good constraint on the PSF

Many stars: large statistical power

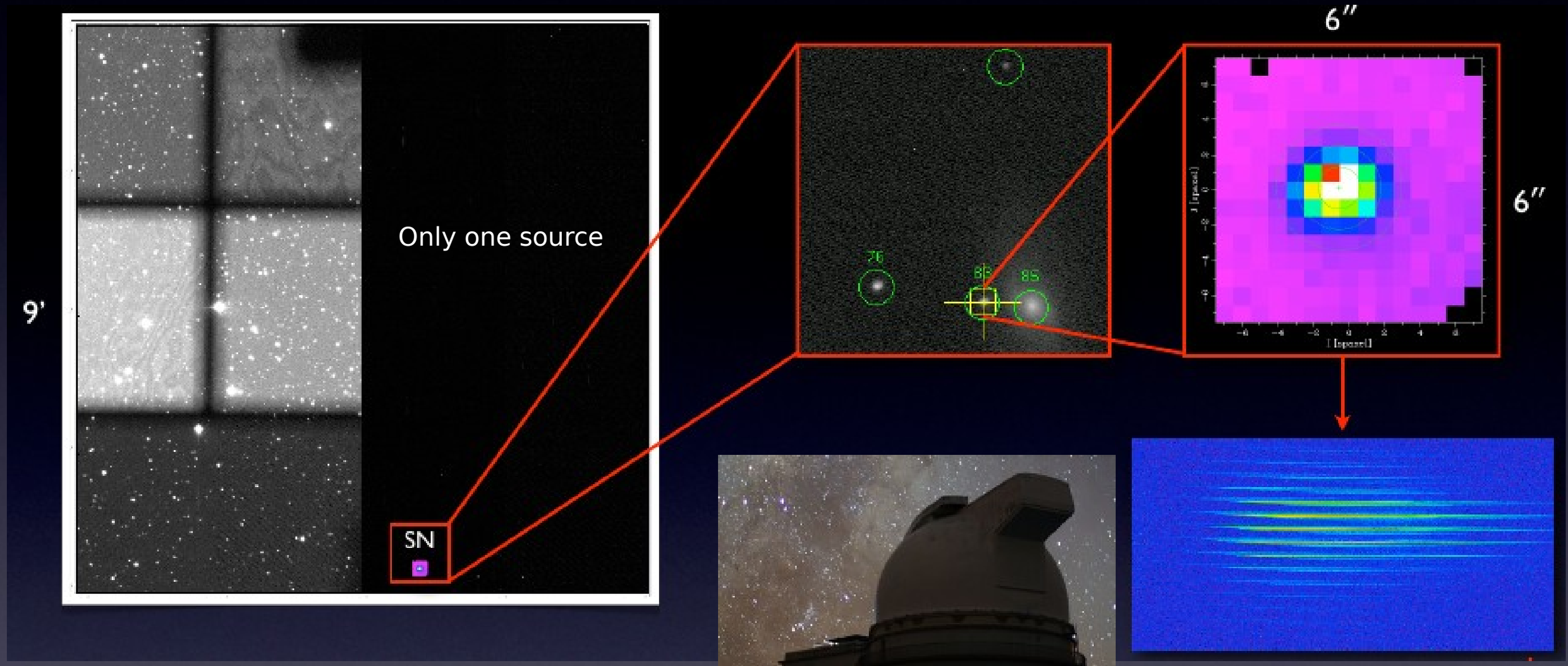
Calibration to a few mmags

The cons:
some information lost in the collection process

Spectroscopy to get rid of the Integral

$$S_i(\lambda, \hat{z}_i, t) = S_i^{\star}(\lambda, t) \times C(\lambda, t) \times T_{\mathrm{atm}}(\lambda, \hat{z}_i, t), \qquad (1)$$

... Comes at a price.



Same photons than for photometry ...

... but...

... x1000 more pixels

4285 standard stars spectra over 7 years: a good starting point

$$S_i(\lambda, \hat{z}_i, t) = S_i^{\star}(\lambda, t) \times C(\lambda, t) \times T_{\mathrm{atm}}(\lambda, \hat{z}_i, t), \qquad (1)$$

Standard stars spectra from **CALSPEC**

Enough data to free this constraint

Enlarge the spectro-photometric standards catalog

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Standard stars spectra from **CALSPEC**

Instrument transmission stable throughout a night

$$C(\lambda, t) = C(\lambda)$$

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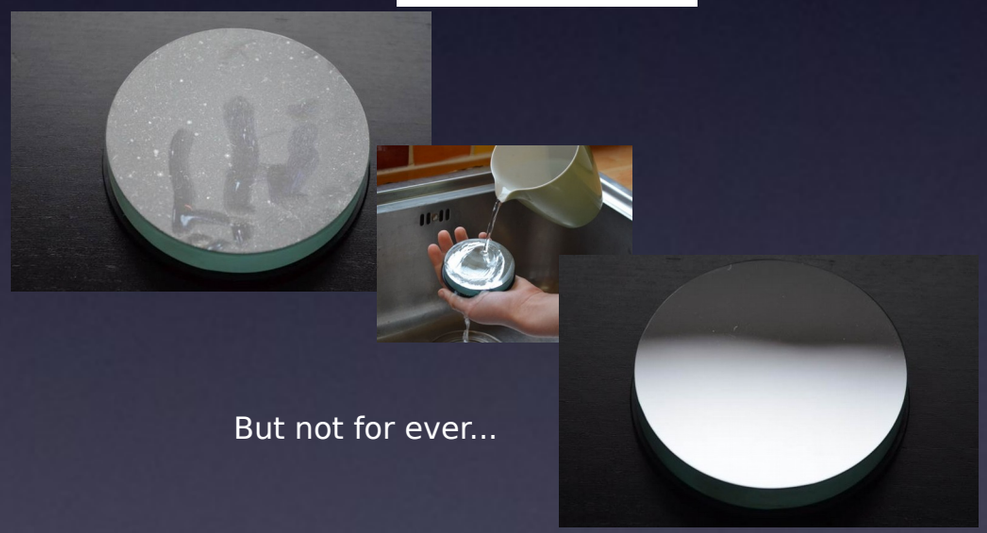


But not for ever...

4285 standard stars spectra over 7 years: a good starting point

$$S_i(\lambda, \hat{z}_i, t) = S_i^{\star}(\lambda, t) \times C(\lambda, t) \times T_{\mathrm{atm}}(\lambda, \hat{z}_i, t), \quad (1)$$

Standard stars spectra from **CALSPEC**

Enough data to free this constraint

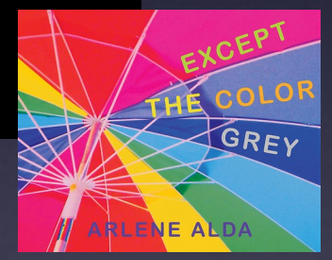
Enlarge the spectro-photometric standards catalog

Instrument transmission stable throughout a night

$$C(\lambda, t) = C(\lambda)$$

Atmospheric transmission: shape stable throughout the night + gray term

$$T_{\mathrm{atm}}(\lambda, \hat{z}_i, t) = \overline{T}_{\mathrm{atm}}(\lambda, \hat{z}_i) \times \delta T_i(\lambda, \hat{z}_i, t)$$



Gray assumption can be TESTED

SNf choice: the physical approach

$$\log \frac{S_i(\lambda, \hat{z}_i, t)}{S_i^{\star}(\lambda, t)} = \log C(\lambda) - 0.4 \times K_{\rm atm}(\lambda, \hat{z}_i) + \log \delta T_i(\lambda, \hat{z}_i, t)$$

$$K_{\rm atm}(\lambda, \hat{z}) = \sum_j X^{\rho_j}(\hat{z}) \times k_j(\lambda)$$

$$K_{\rm atm}(\lambda, \hat{z}) = \sum_j X^{\rho_j}(\hat{z}) \times k_j(\lambda)$$

Rayleigh scattering
0 param

Aerosols
2 params

Ozone transmission
2 params

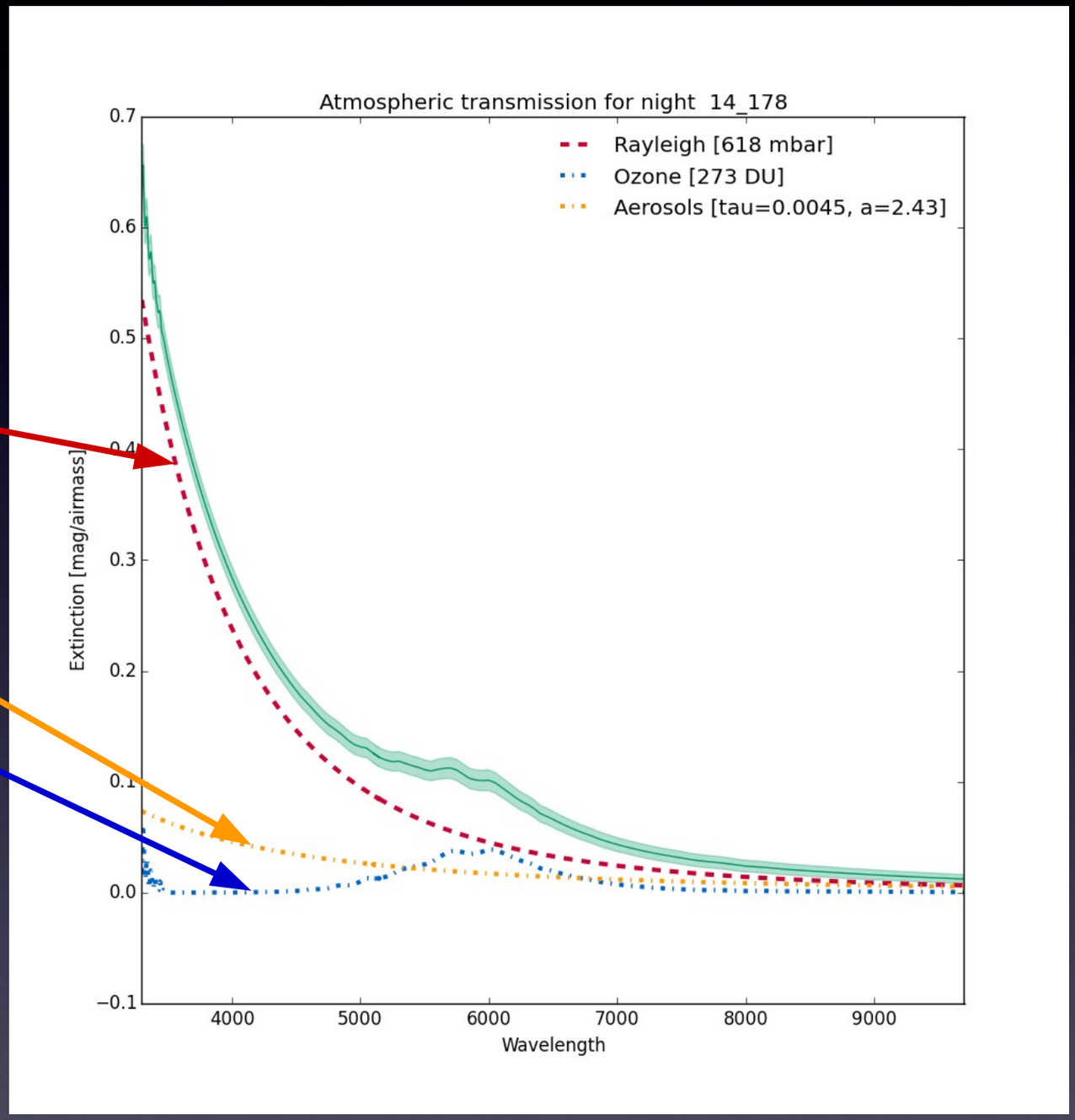
Telluric lines

Saturation index < 1.

Treated independently

Grey clouds

$$\delta T(\lambda, \hat{z}, t) = \delta T(\hat{z}, t)$$



Atmospheric transmission from standard stars

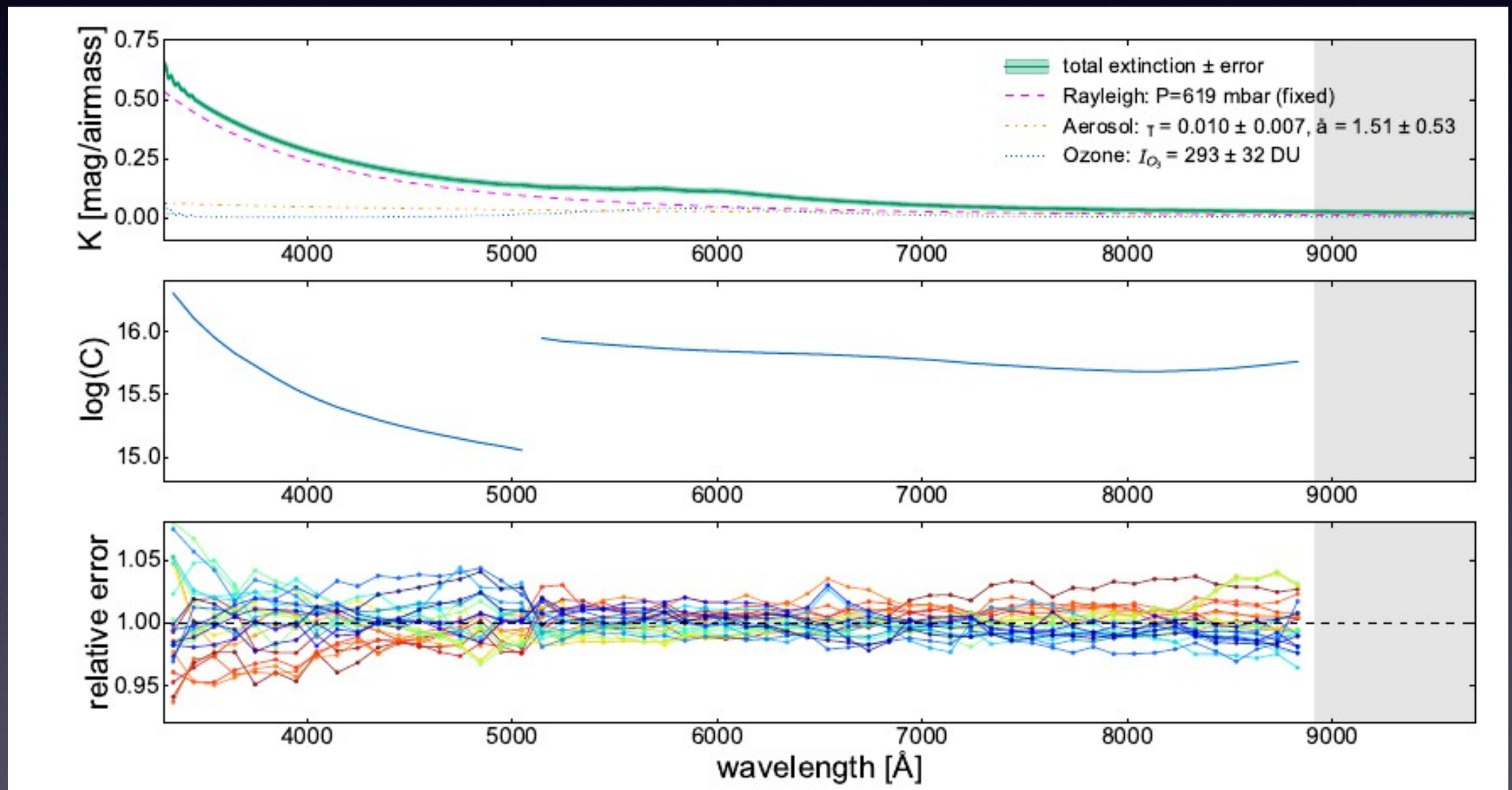
$$\mathcal{R}_i = \log C(\lambda) - 0.4 \times K_{\rm atm}(\lambda, \hat{z}) + \log \delta T_i(\hat{z}, t) - \log \frac{S_i(\lambda, \hat{z}, t)}{\overline{S}_i(\lambda)}$$

$$\chi^2 = \sum_i \mathcal{R}_i \cdot V_i^{-1} \cdot \mathcal{R}_i^{\rm T}$$

3% correlated error between meta-slices from extraction procedure

Priors to help the physical model

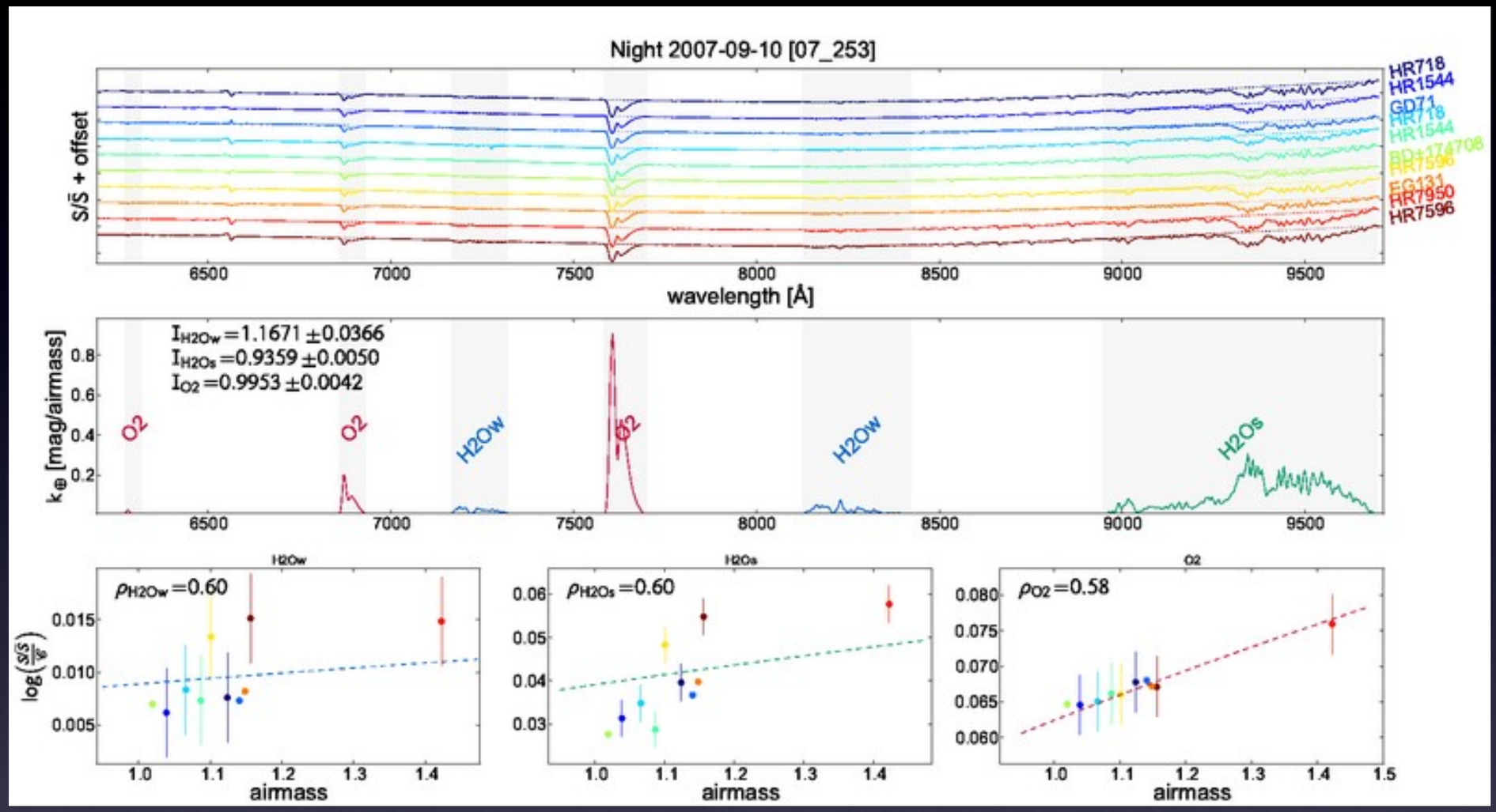
$$\Psi^2 = \left(\frac{I_{\rm O_3} - I^\star_{\rm O_3}}{\sigma^\star_{I_{\rm O_3}}}\right)^2 + \left(\frac{\mathring{\rm a} - \mathring{\rm a}^\star}{\sigma^\star_{\mathring{\rm a}}}\right)^2 + \left(\frac{\ln(\tau/\tau^\star)}{\varsigma^\star_\tau}\right)^2$$



Residuals < 5% for a given night

A word about telluric lines

Telluric absorption estimated in a separate high resolution step



Can be adjusted simultaneously with the transmission model

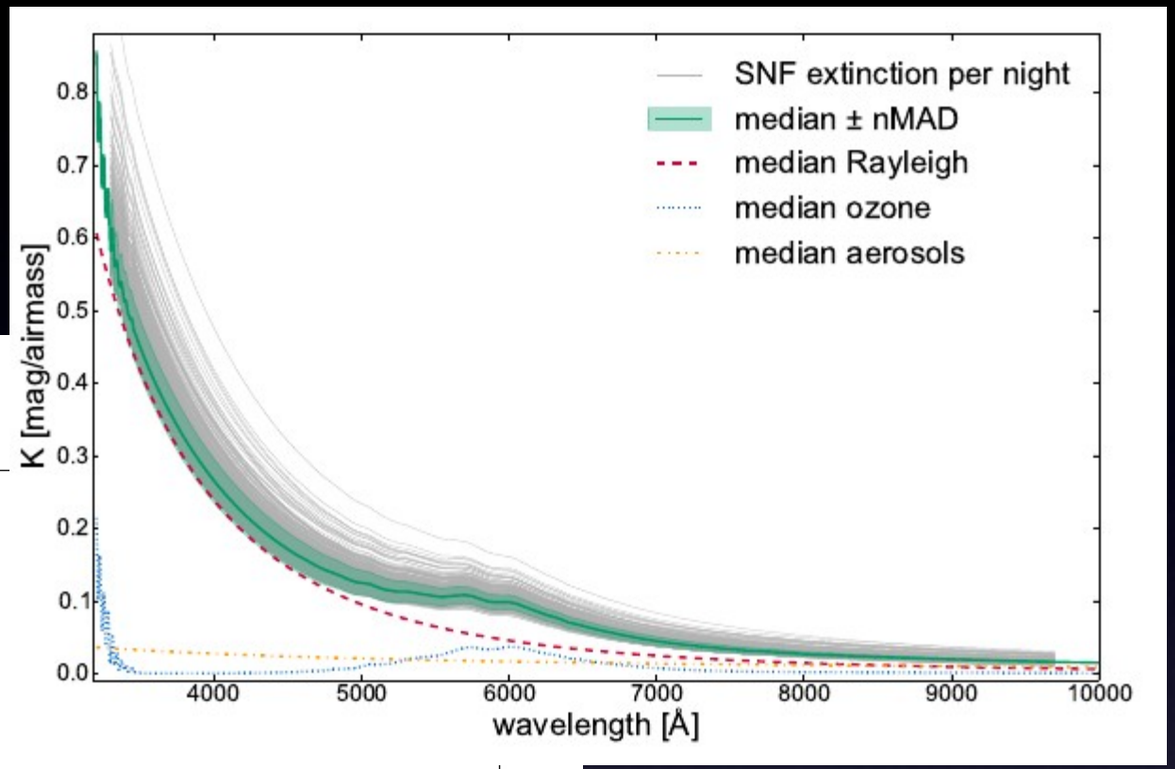
Variation of the saturation parameter can be neglected

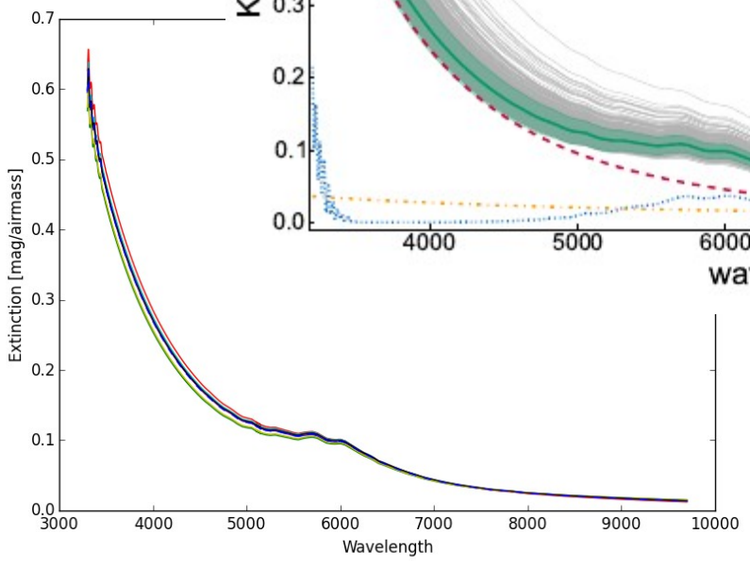
$$\log\left(-2.5\times\log\frac{S_i(\lambda,\hat{z},t)/\overline{S}_i(\lambda)}{\mathscr{C}_i(\lambda,\hat{z},t)}\right)=\log k_\oplus(\lambda)+\rho\times\log X_i(\hat{z}).$$

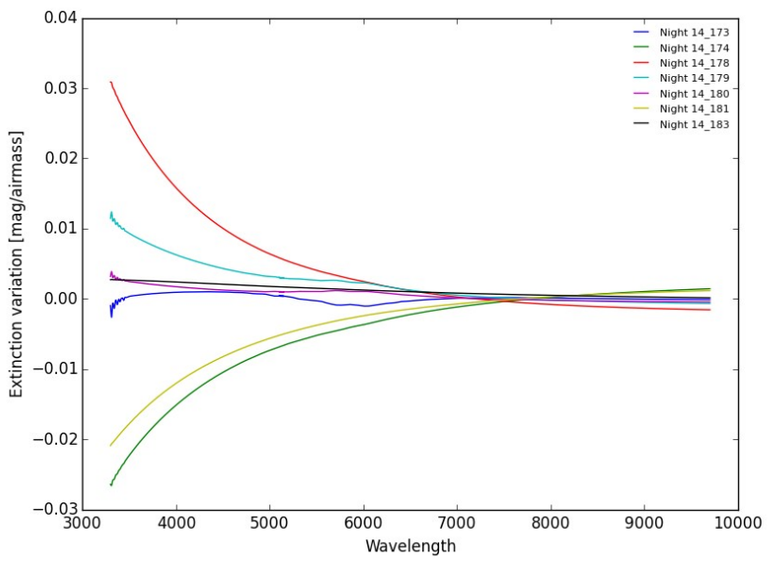
They need to be accounted for if <1% photometric calibration is considered

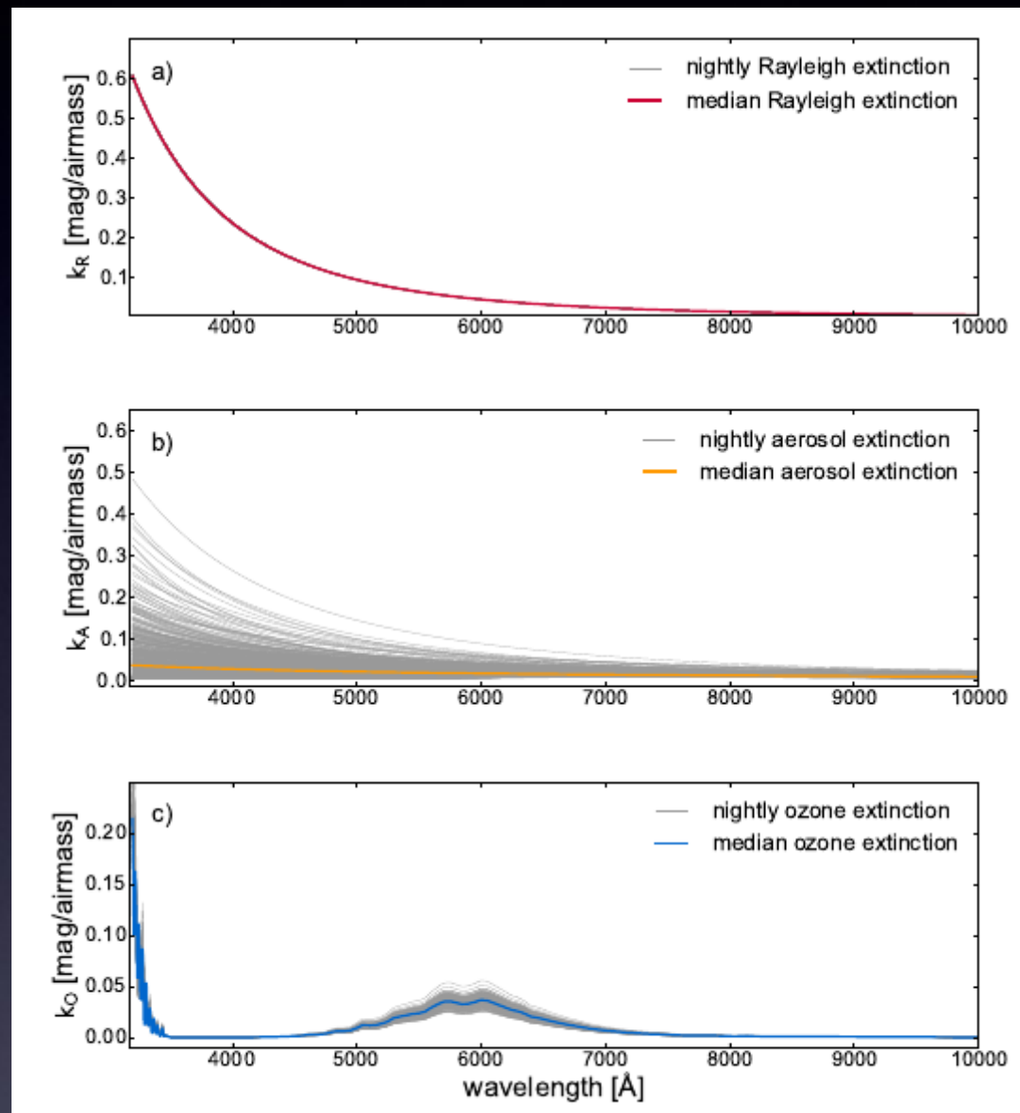
Average and variation

A few % color variation from night to night









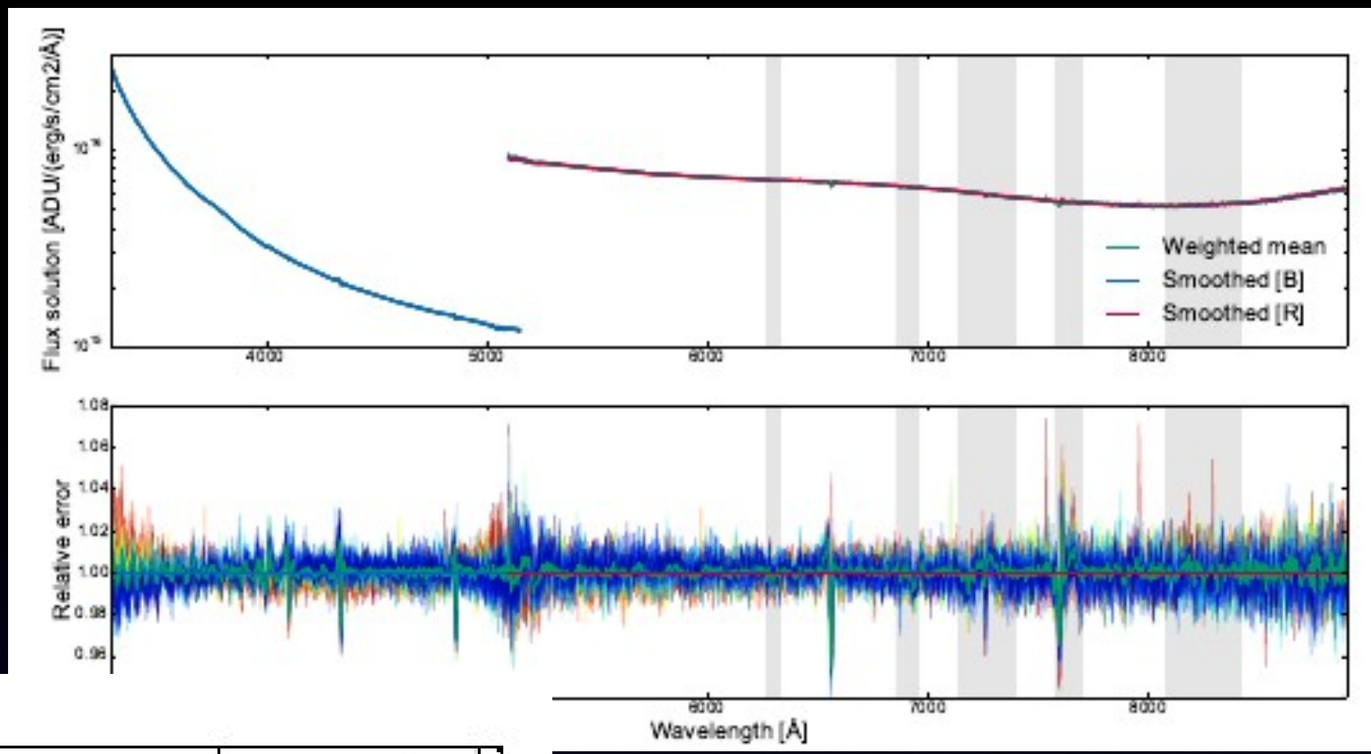
Main variation in the UV

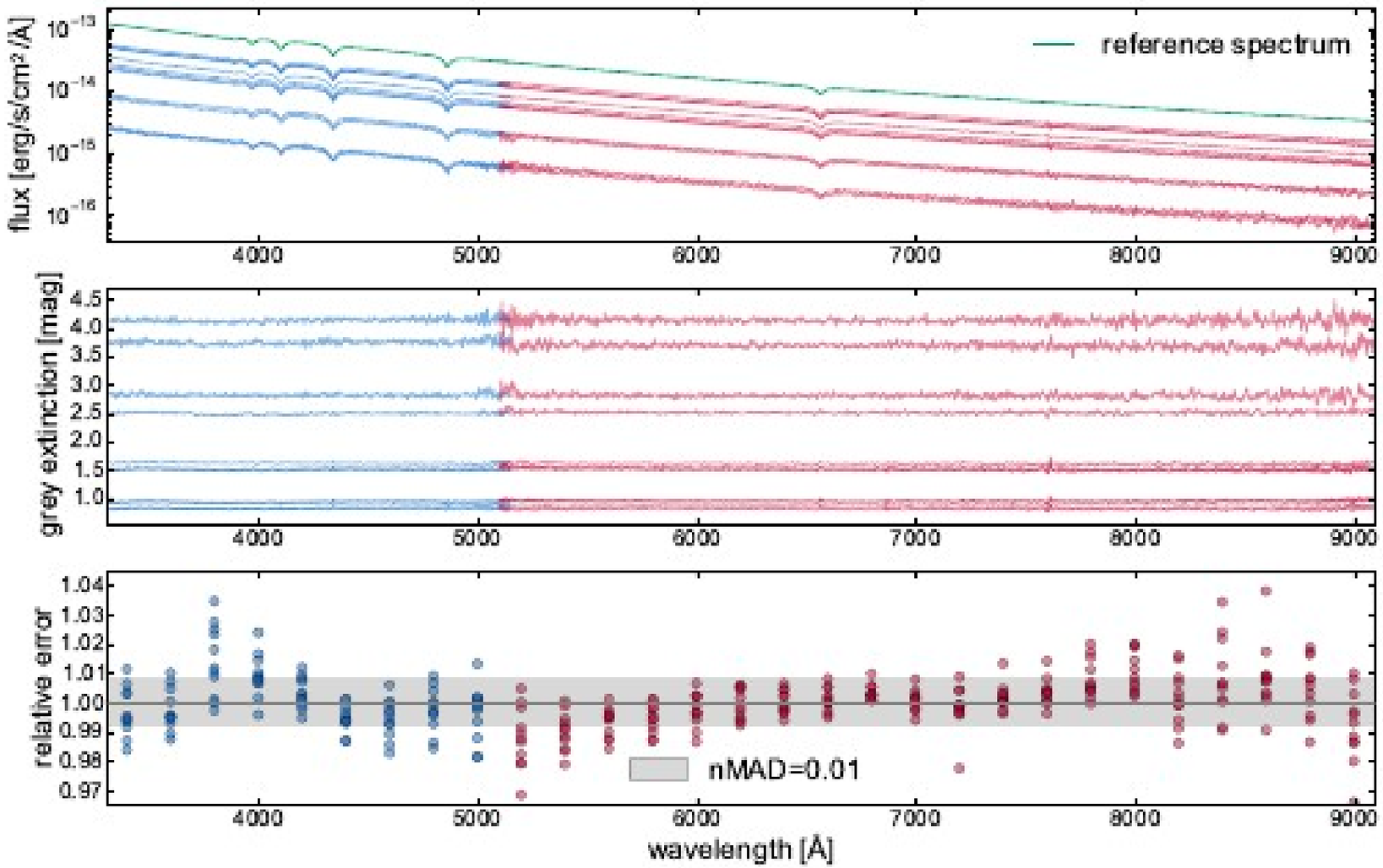
Probably aerosols

Ozone variability needs to be accounted for

The gray component

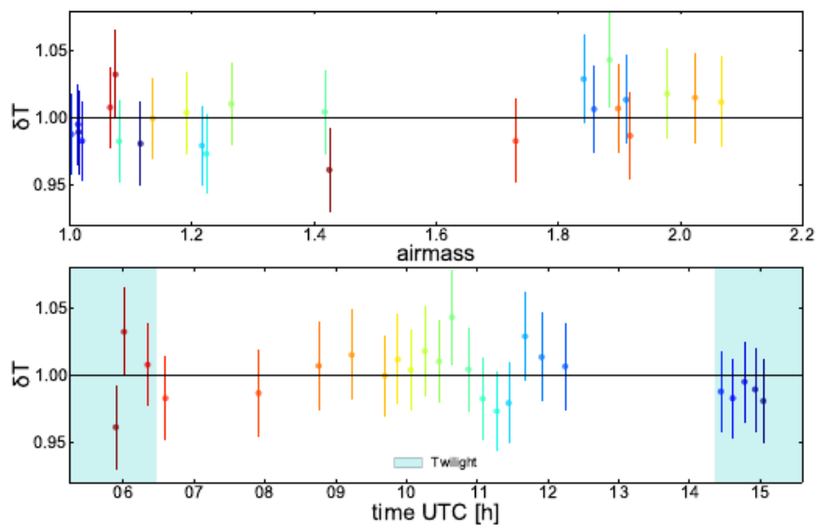
Residual in the instrumental calibration <1%
and
grey





The atmospheric transmission variation during a night is VERY grey

Captures even large transmission variations



And from there ?

CFHT + SnDICE + SNf joint observations:

7 full nights

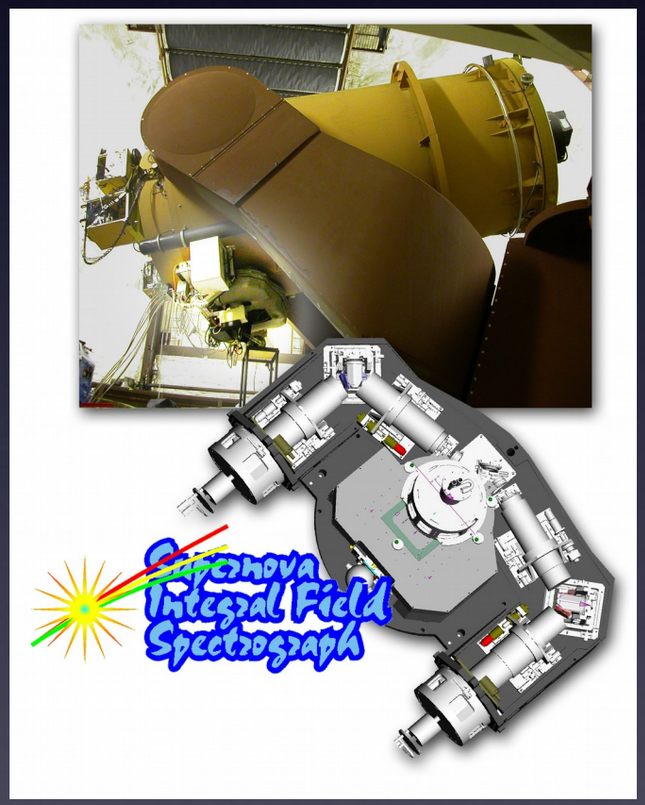
3 different Standard Stars

Spectroscopy of faint SNLS tertiaries

Low and high airmass

“Simultaneous” exposures

+



The usual method

$$\mathrm{ADU}_b^{\mathrm{meas}} = A\Delta T \int_0^{\infty} F_\nu(\lambda) T_b(x, y, alt, az, t, \lambda) \lambda^{-1} d\lambda$$

$$T_b(x, y, alt, az, t, \lambda) = T_b^{\mathrm{inst}}(x, y, t, \lambda) \times T^{\mathrm{atm}}(alt, az, t, \lambda)$$

CFHT

SnDICE

SNfactory

But an unusual gang

Why LSST should care:

CFHT + SnDICE + SNf joint observations:

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3 different Standard Stars

Spectroscopy of faint SNLS tertiaries

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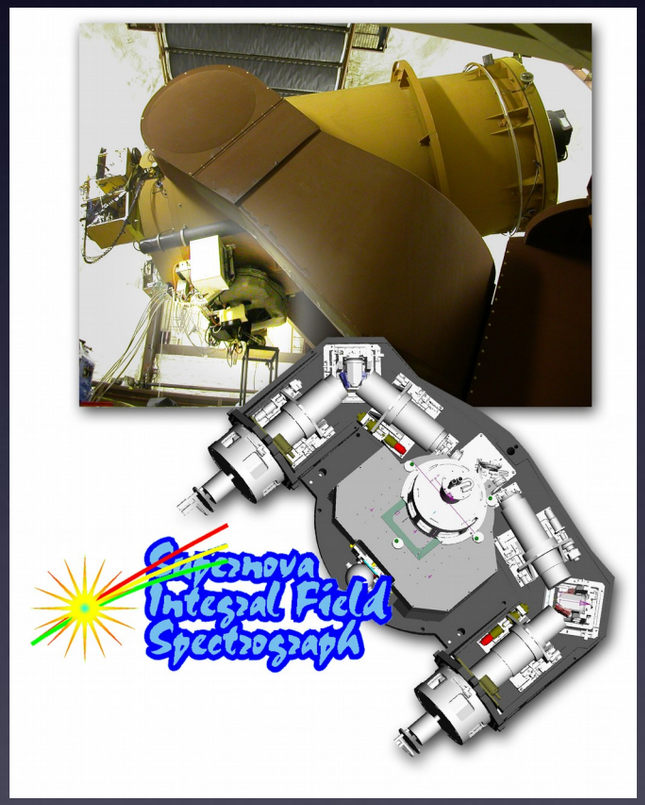


Very powerful dataset:

Transfer instrumental calibration to the stars

SnDICE proof of concept

But also probe CALSPEC spectra

Calibration oriented atmospheric transmission model

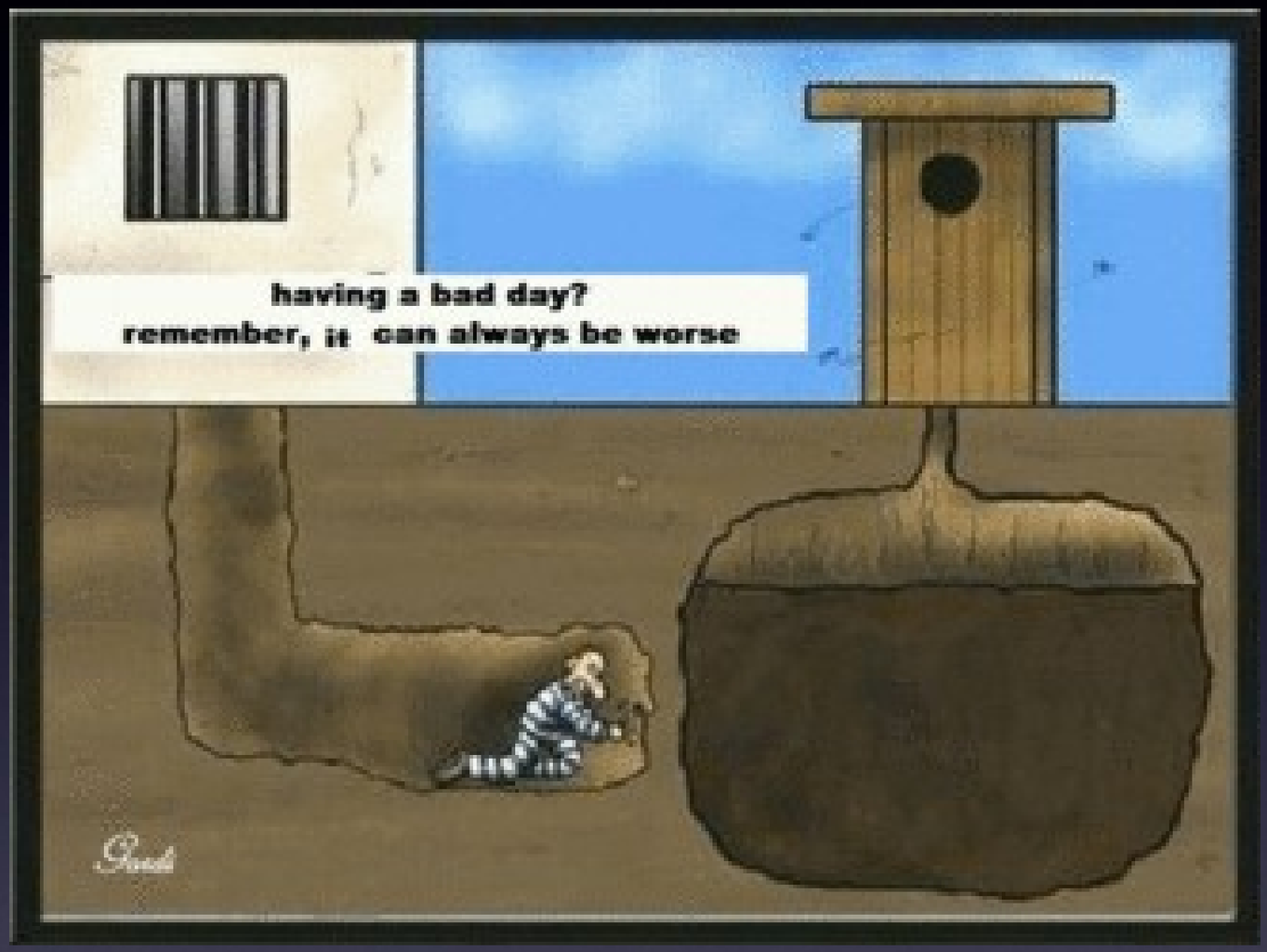
Can we constrain small color variations
with photometry alone ?

Probe short time scale atmospheric variation

+ all SNf dataset: potential to increase the STD stars catalog

(work already started)

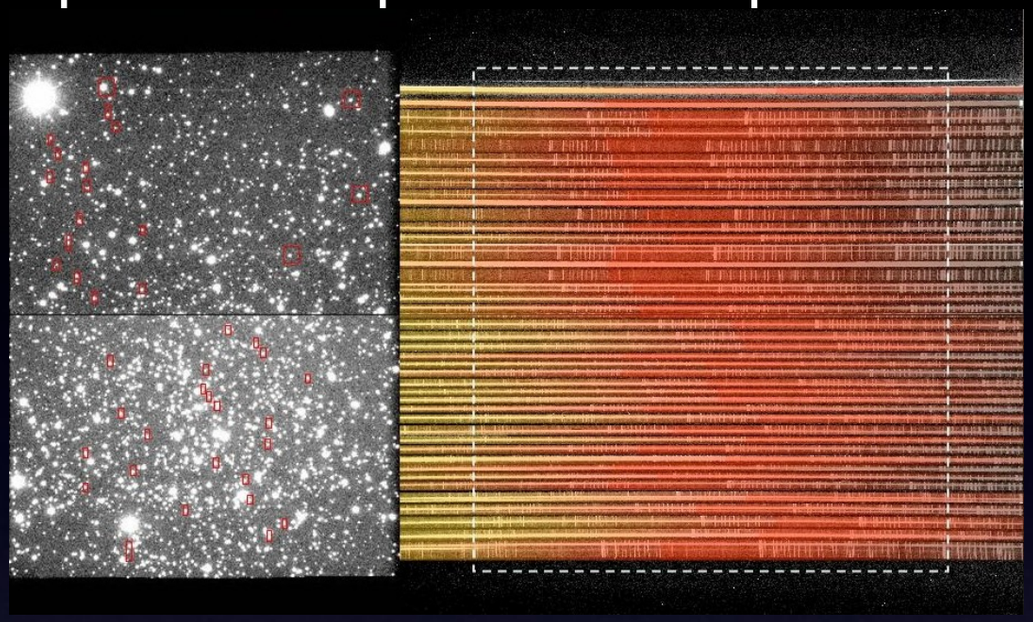
Work in progress : stay tuned...



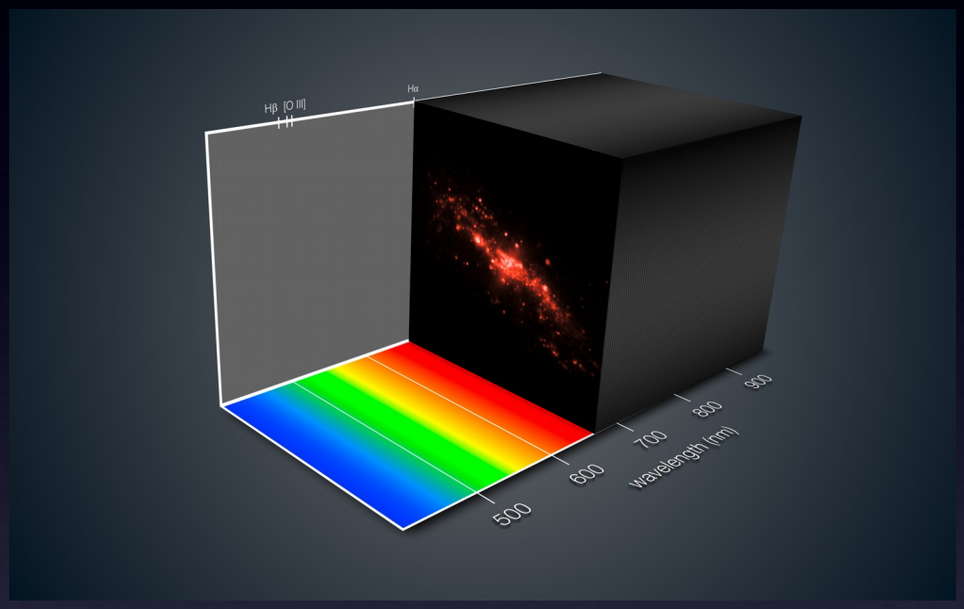
... it is going to be interesting, regardless

Some last words for the future

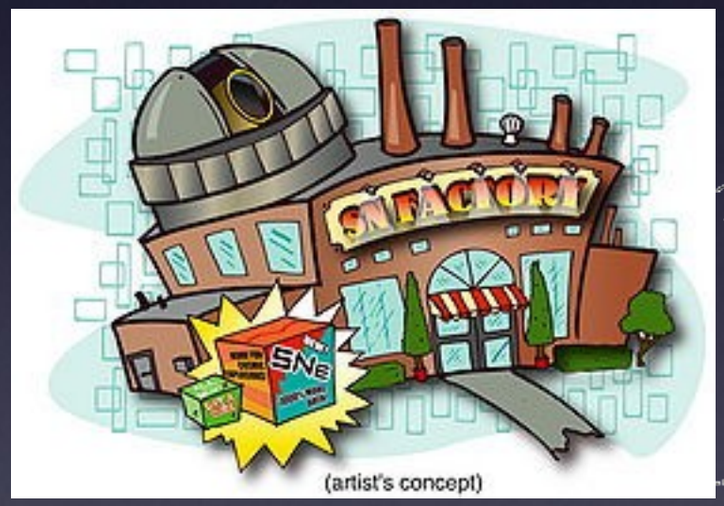
LSST spectroscopic follow up



Number of targets asks for a MOS



Number of transients asks for
a fast screening spectrograph



Few mmag calibration: binding all stars under the same system

One Spectrograph to bring them all and in the darkness bind them