



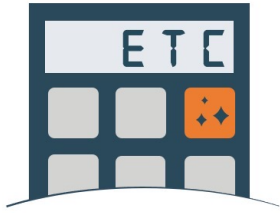
# The ESO Exposure Time Calculator

Henri M. J. BOFFIN



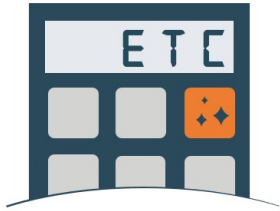
ETC Project manager:  
ETC Software engineers:

Jakob Vinther  
Lars Lundin, David Huerta  
(former: Gurvan Bazin)

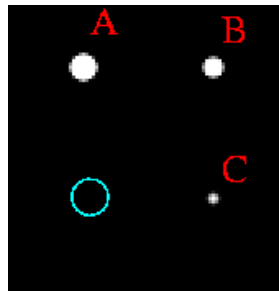


# Time is precious

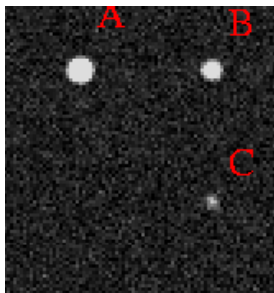




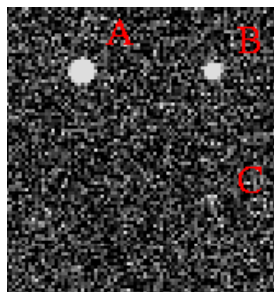
# Signal-to-noise



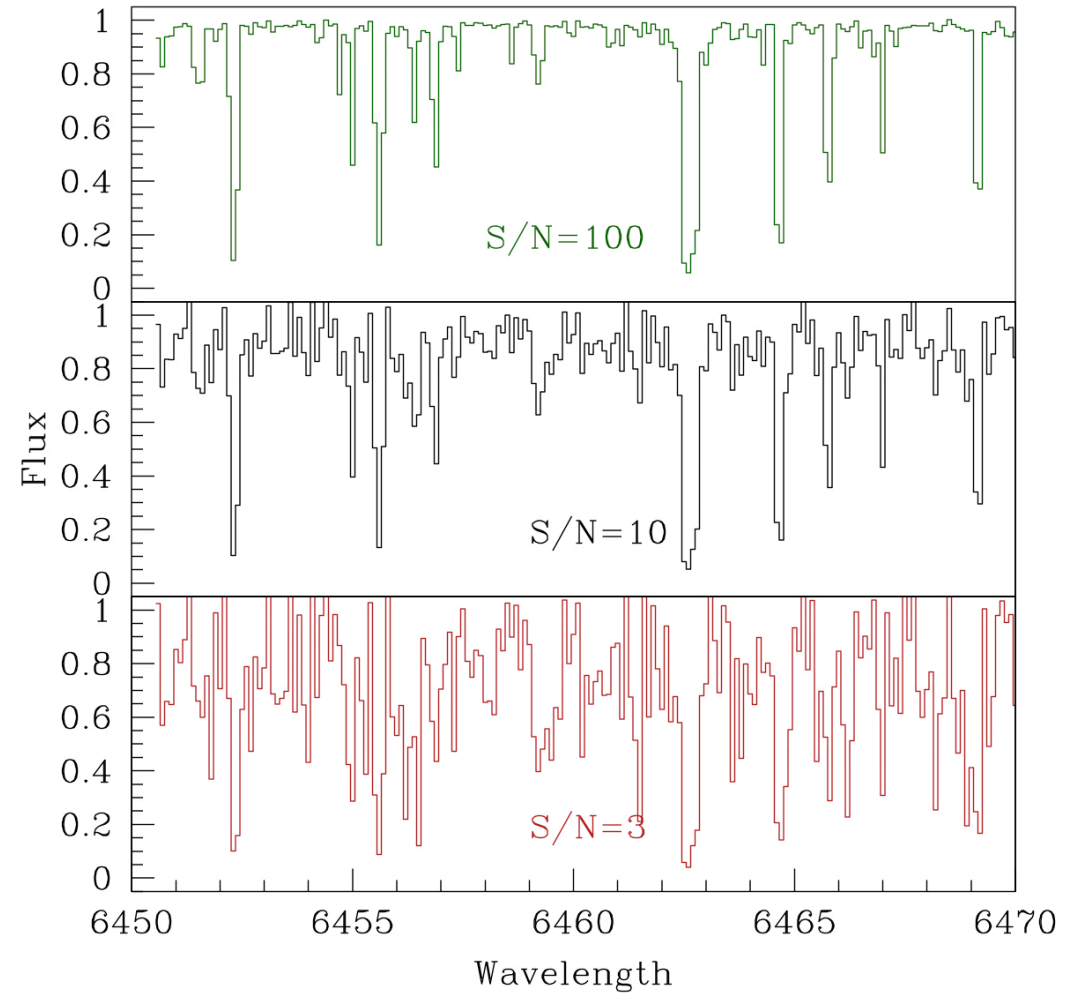
$t \sim 1111 \text{ s}$

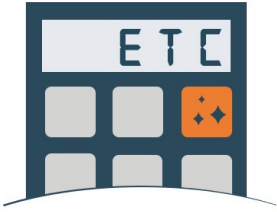


$t \sim 11 \text{ s}$



$t = 1 \text{ s}$





# What is an ETC?

- Predict **exposure time** to get required quality (**S/N**)
- Phase 1 - call-for-proposals (NOW!)
- Phase 2 - planning obs. details (making OBs)
- Astron. community / ESO
  - before, during, after observations
  - instrument studies, development, commissioning
- **Doesn't include overheads!**

**KMOS Exposure Time Calculator**

Infrared Mode Version P102

**Target Input Flux Distribution**

Template Spectrum: GGV (P3600) (4400-21)  Kuchib  Robbitt  p=1

Upload Spectrum:  Select  Target Magnitude and Mag. System:  (K, Y) = 22.00  Vega  AB

Blackbody: Temperature: 12000.00 K  All  AB

Power Law: Index:  Flux:   $F(\lambda) = \lambda^{20}$  Magnitudes are given per arcsec<sup>2</sup> for extended sources

Emission Line: Lambda:  nm Flux:   $10^6$  ergs/cm<sup>2</sup> (per arcsec<sup>2</sup> for extended sources) FWHM:  nm

Spatial Distribution:  Point Source  Extended Source (per pixel)  Extended Source, area  $\Omega$  1.00 arcsec<sup>2</sup>

**Sky Conditions**

Override almanac: sky parameters and use instead typical fixed sky model parameters except Moon phase and airmass

Moon FLI: 0.50 Airmass: 1.50

FWV: 10.0 mm Probability > 95% of realizing the FWV  $\leq$  10.0 mm

Seeing Image Quality: Seeing: 1.00 arcsec FWHM in Y-band at zenith (use this value in the proposal) Probability 87% of realizing the seeing  $\leq$  1 arcsec

RQ:  arcsec FWHM at the airmass and wavelength of observation (to be used for the OB contrast set)

**Instrument Setup**

Grating:  Range to pixel: 10384.00 - 24800.00 nm Reference wavelength: 2192 nm The numeric results will refer to this wavelength.

**Results**

S/N ratio: S/N = 5.000 DIT = 100.000 s

Exposure Time: NDET =

The total exposure time is the product of DIT (Detector Integration Time) by NDET (number of DITs). Instrument and telescope overheads are not taken into account.

Plots:  Toggle All / No Plots

- Resultant spectrum including background
- Object spectrum only
- Background emission spectrum
- Sky radiance spectrum in physical units (ph/m<sup>2</sup>/micron/arcsec<sup>2</sup>)
- Sky transmission spectrum
- S/N as a function of wavelength
- Total efficiency and wavelength range
- Input spectrum in physical units

Submit Print

**KMOS Exposure Time Calculator**

Infrared Mode Version P102

Show detailed S/N formula

**Target Setup**

Target flux distribution type: blackbody

Target geometry: Point source

Target magnitude: Known = 22.00

**Sky Conditions**

Airmass: 1.50

Moon illumination FLI: 0.50

Moon-target separation:  $\alpha$  45.00 degrees

FWV: 10.0 mm

FWV Probability: 95 % of realizing the FWV  $\leq$  10.0 mm

Seeing: 1.00 arcsec 100% probability (use this value as the proposal)

Seeing Probability: 87 % of realizing the seeing  $\leq$  1.00 arcsec

show sky model configuration details

**Image Quality**

Image Quality (FWHM) = 0.76 arcsec (to be used for OB contrast set)

show details of the IQ calculations

**Instrument Setup**

Grating: K

Detector read-out mode: normal

Detector parameters: 200x1.50 e-/pixel/DIT, Dark=0.01 e-/pixel/s

Observation Setup

User requested: Compute NDET for a given S/N and DIT

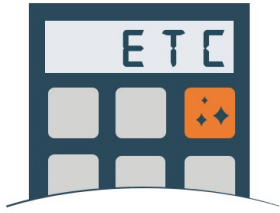
**KMOS Transmission Model**

Reference wavelength	2192.0 nm
Wavelength range	1934.00 - 2480.00 nm
Dispersion	0.200 nm/pixel
Pixel scale	200.000 mas/pixel
Number of pixels in wavelength range	3076 pixels
Signal-to-noise ratio	(at reference wavelength): 5.000
Detector integration time for one exposure	DIT 100.000 s
Number of detector integrations (rounded up)	NDET 6442
Total exposure time (without overhead)	644200.000 s
Max. intensity at central pixel per DIT (subject+sky) (at ref. wave.)	100.025 e-/DIT
Detector persistence threshold	10000 e-
Detector saturation limit	120000 e-
Ratio of S/N reference area	0.762 arcsec
Number of pixels in S/N reference area	40 pixels
Object signal in S/N reference area	(at reference wavelength): 10007.005 e-
Object signal in S/N reference area per DIT (at ref. wavelength)	100.070 e-/DIT
Final sky background signal per DIT	(at reference wavelength): 22.27 e-/DIT
Overall transmission	(at reference wavelength): 22.27 %

Warning: Please be aware that without a custom filter in a one-hour execution time limit for Service Mode OBs, and that the times returned here do not include instrument overheads, times for sky measurements, etc. Thus, care must be taken to allow for these additional times when constructing complete OBs.

**Signal-to-Noise Ratio per Step in Wavelength**

ASCII Interactive PDF [log\(y\) plot](#) [log\(x\) PDF](#)

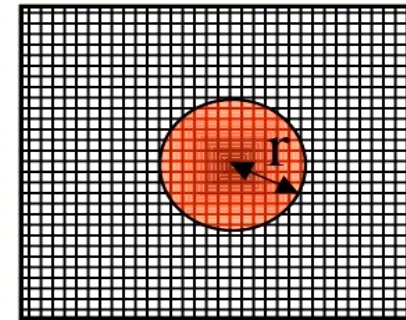


# Signal

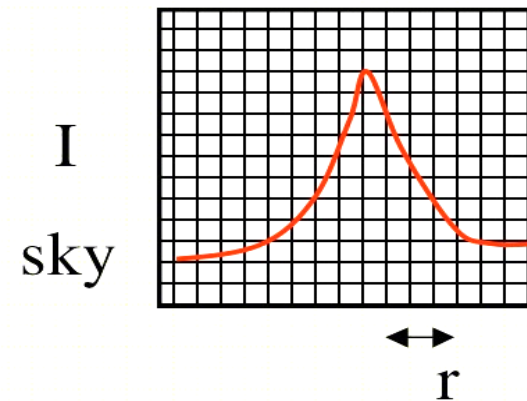
- $\text{Signal} = R_* \cdot t$   
↕  
time

detected e-/second

- Consider the case where we count all the detected e- in a circular aperture with radius  $r$ .



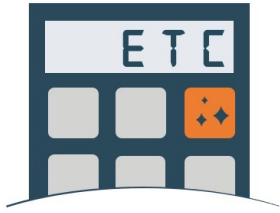
Radius: large enough to encompass all flux, but not too big to reduce noise.



**PSF**

Non-AO:  
Gaussian with  
FWHM  $\sim$  seeing

Source: Michael Bolte (UCOLICK)



# Noise sources

$$\sqrt{R_* \cdot t} \quad \Rightarrow \quad \text{shot noise from source}$$

$$\sqrt{R_{sky} \cdot t \cdot \pi r^2} \quad \Rightarrow \quad \text{shot noise from sky in aperture}$$

$$\sqrt{RN^2 \cdot \pi r^2} \quad \Rightarrow \quad \text{readout noise in aperture}$$

$$\sqrt{\text{Dark} \cdot t \cdot \pi r^2} \quad \Rightarrow \quad \text{shot noise in dark current in aperture}$$

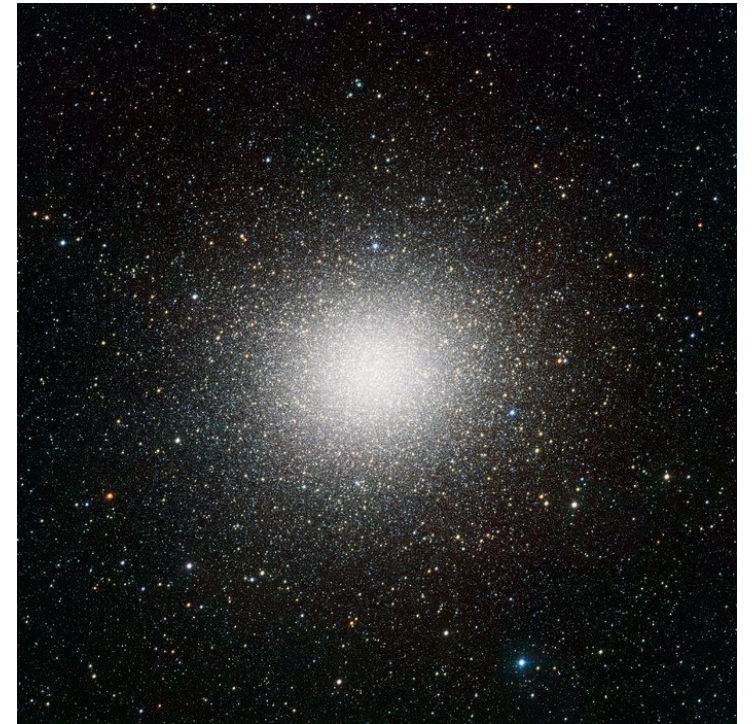
$R_* = e^-/\text{sec}$  from the source

$R_{sky} = e^-/\text{sec}/\text{pixel}$  from the sky

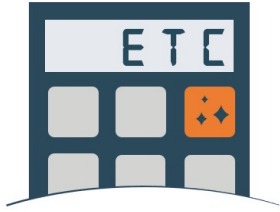
$RN = \text{read noise}$  (as if  $RN^2 e^-$  had been detected)

$\text{Dark} = e^-/\text{second}/\text{pixel}$

Source: Michael Bolte (UCOLICK)

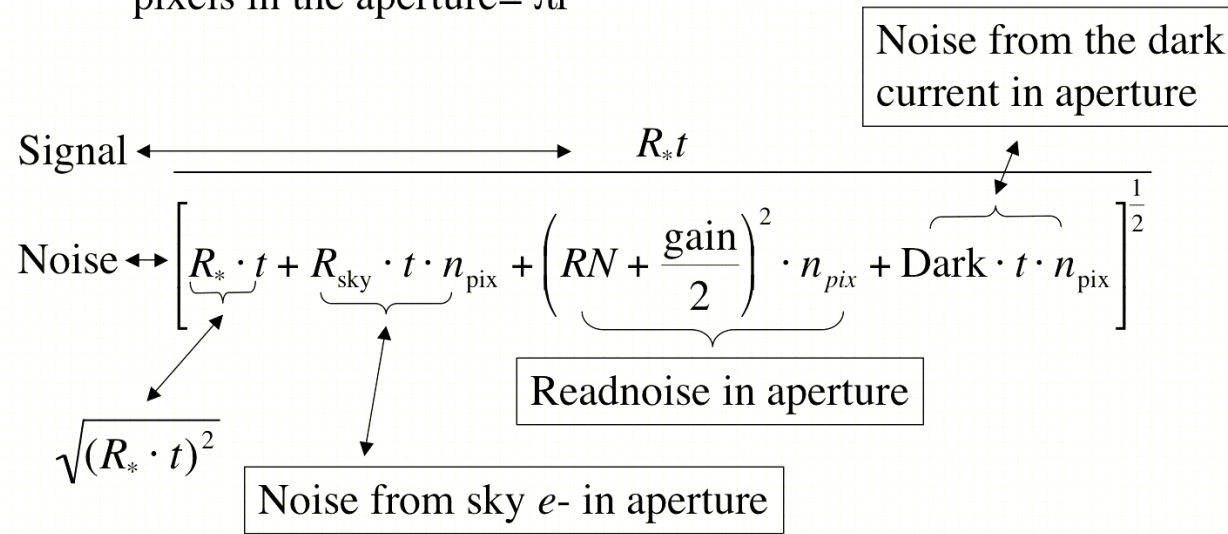


Credit:ESO/INAF-VST/OmegaCAM. Acknowledgement: A. Grado, L. Limatola/INAF-Capodimonte Observatory



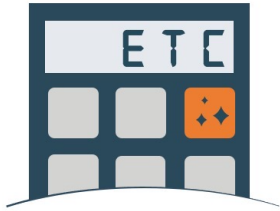
# Signal-to-noise

S/N for object measured in aperture with radius  $r$ :  $n_{\text{pix}} = \#$  of pixels in the aperture  $= \pi r^2$



All the noise terms added in quadrature  
*Note: always calculate in e-*

Source: Michael Bolte (UCOLICK)



# Exposure Time Calculators

## Target Input Flux Distribution

<input checked="" type="radio"/> Template Spectrum	AOV (Pickles)	Redshift z = 0.00	Target Magnitude and Mag.System: <input checked="" type="radio"/> Vega <input type="radio"/> AB <small>Magnitudes are given per arcsec<sup>2</sup> for extended sources</small>
<input type="radio"/> MARCS Stellar Model	Teff=4000 log(g)=0.5 [Fe/H]=0 M=1		
<input type="radio"/> Upload Spectrum	Select...		
<input type="radio"/> Blackbody	Temperature: K		
<input type="radio"/> Power Law	Index: $F(\lambda) \propto \lambda^{index}$		
<input type="radio"/> Emission Line	Lambda: nm Flux: $10^{16}$ ergs/cm <sup>2</sup> (per arcsec <sup>2</sup> for extended sources) FWHM: nm		

Spatial Distribution:  Point Source  Extended Source

## Sky Conditions

Override almanac sky parameters and use instead typical fixed sky model parameters except Moon phase and airmass

Moon FLI: 0.50 Airmass: 1.50

## Seeing/Image Quality:

Seeing: 1.00 arcsec FWHM in V-band at zenith (use this value in the proposal)  
Probability 87% of realizing the seeing  $\leq$  1 arcsec

IQ: arcsec FWHM at the airmass and wavelength of observation (to be used for the OB constraint set)

## Instrumental Setup

Resolution:  Standard  
 High

Filter: v\_HIGH

Detector:  MIT red-optimized CCD  
 E2V blue-optimized CCD

Readout mode: 200kHz, 2x2, low

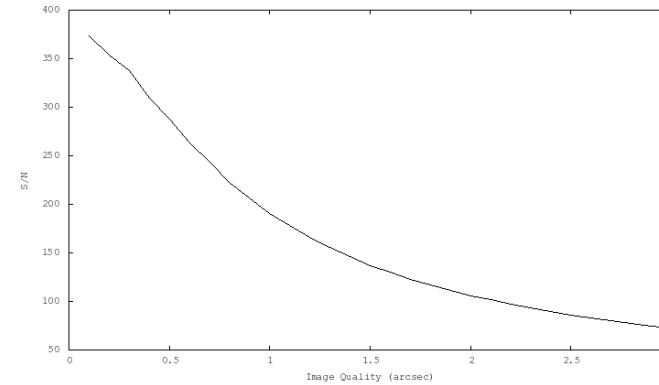
Polarimetry:  No Polarimetry  
 Linear or Circular Polarisation

## Results

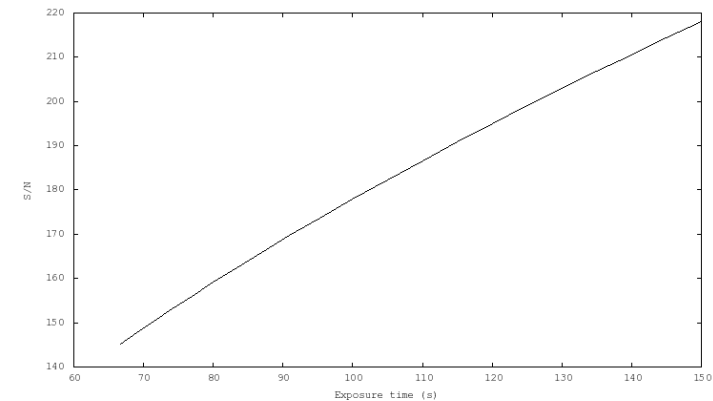
S/N:

Exposure Time: 100.0 s

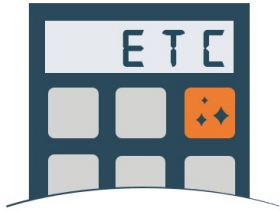
## S/N vs Seeing



## S/N vs Exp. Time







# ESO ETCs

[www.eso.org/observing/etc](http://www.eso.org/observing/etc)

[etc.eso.org](http://etc.eso.org)

**KMOS Exposure Time Calculator**

Infrared Mode Version P102

**Target Input Flux Distribution**

Template Spectrum:   Redshift:  Target Magnitude and Mag. System:  =   Vega  
 MARCS Stellar Model:   Redshift:  Target Magnitude and Mag. System:  =   Vega  
 Upload Spectrum:   Redshift:  Target Magnitude and Mag. System:  =   Vega  
 Blackbody:  K Magnitudes are given per arcsec<sup>2</sup> for extended sources  
 Power Law: Index:   $F(\lambda) = \lambda^{index}$   
 Emission Line: Lambda:  nm Flux:   $10^x$  ergs/cm<sup>2</sup> (per arcsec<sup>2</sup> for extended sources) FWHM:  nm

**Spatial Distribution**

Point Source  
 Extended Source (per pixel)  
 Extended Source, area  $\Omega$ :  arcsec<sup>2</sup>

**Sky Conditions**

Override almanac: sky parameters and use instead typical fixed sky model parameters except Moon phase and airmass  
 Moon FLI:  Airmass:   
 FWHM:  arcsec Probability > 95% of realizing the FWHM  $\leq$  10.0 mm  
 Seeing Image Quality:  
 Seeing:  arcsec FWHM in Y-axis or zenith (use this value in the proposal) Probability 87% of realizing the seeing  $\leq$  1 arcsec  
 RQ:  arcsec FWHM at the airmass and wavelength of observation (to be used for the OB constraint set)

**Instrument Setup**

Grating:  Range to pixel:  -  nm  
 Reference wavelength:  nm The numeric results will refer to this wavelength.

**Results**

S/N ratio: S/N =  DIT =  s  
 Exposure Time: NDET =  s

The read exposure time is the product of DIT (Detector Integration Time) by NDET (number of DITs). Instrument and telescope overheads are not taken into account.

**Plots**  Toggle All / No Plots

Resultant spectrum including background  
 Object spectrum only  
 Background emission spectrum  
 Sky radiance spectrum in physical units (ph/m<sup>2</sup>/micron/arcsec<sup>2</sup>)  
 Sky transmission spectrum  
 S/N as a function of wavelength  
 Total efficiency and wavelength range  
 Input spectrum in physical units

Submit Reset

Send questions and comments to [web-help@eso.org](mailto:web-help@eso.org)

**KMOS Exposure Time Calculator**

Infrared Mode Version P102

**Show detailed S/N formula**

**Target Setup**

Target flux distribution type: blackbody  
 Target geometry: Point source  
 Target magnitude: K = 22.00

**Sky Conditions**

Airmass: 1.50  
 Moon illumination FLI: 0.50  
 Moon-Target separation: 45.80 degrees  
 FWHM: 1.00 arcsec  
 DM Probability: 1.95 % of realizing the DM  $\leq$  10.00 mm  
 Seeing: 1.00 arcsec (90% probability from DM value as the proposal)  
 Seeing Probability: 87 % of realizing the seeing  $\leq$  1.00 arcsec  
 show sky model configuration details

**Image Quality**

Image Quality (FWHM) = 0.76 arcsec (to be used for OB constraint set)  
 show details of the IQ calculations

**Instrument Setup**

Grating: K  
 Detector read-out mode: normal  
 Detector parameters: 200x1.50 e-/pixel/DIT, Dark=0.01 e-/pixel/s

**Observation Setup**

User requested: Compute NDET for a given S/N and DIT

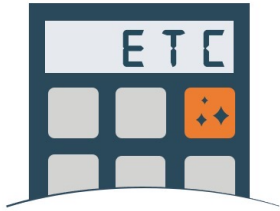
**KMOS Transmission Model**

Reference wavelength: 2192.0 nm  
 Wavelength range: 1934.00 - 2480.00 nm  
 Dispersion: 0.200 nm/pixel  
 Pixel scale: 200.000 mas/pixel  
 Number of pixels in wavelength range: 3176 pixels  
 Signal-to-noise ratio (at reference wavelength): 5.000  
 Detector Integration Time for one exposure: DIT = 100.000 s  
 Number of detector integrations (rounded up): NDET = 6442  
 Total exposure time (without overhead): INT-DIT = 64420.000 s  
 Max. intensity at central pixel per DIT (subject to sky): 100.025 e-/DIT  
 Detector persistence threshold: 10000 e-  
 Detector saturation limit: 12000 e-  
 Ratio of S/N reference area: 0.762 arcsec  
 Number of pixels in S/N reference area: 40 pixels  
 Object signal in S/N reference area (at reference wavelength): 140172.885 e-  
 Object signal in S/N reference area per DIT (at ref. wavelength): 125.768 e-/DIT  
 Total sky background signal per DIT (at reference wavelength): 125.768 e-/DIT  
 Overall transmission (at reference wavelength): 22.27 %

**Warning:** Please be aware that without a custom filter in a one-hour execution time limit for Service Mode OBs, and that the times returned here do not include instrument overheads, times for sky measurements, etc. Thus, care must be taken to allow for these additional times when constructing complete OBs.

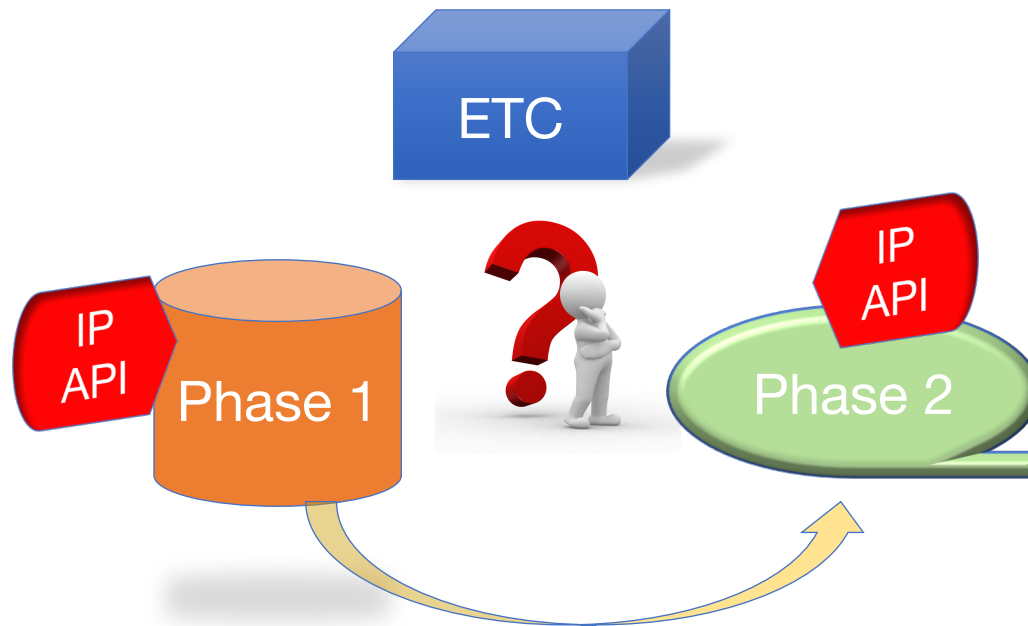
**Signal-to-Noise Ratio per Step in Wavelength**

ASCII Interactive PDF [log\(y\) plot](#) [log\(y\) PDF](#)



# Current situation

- Phase 1/2 is online, use similar look & feel
- ETC is still independent – different look & feel; no links to P1/P2



**KMOS Exposure Time Calculator**

**Target Input Flux Distribution**

- Template Spectrum:  Radshift:  Target:
- MARCS Stellar Model:  Radshift:  Target:
- Upload Spectrum:  Radshift:  Target:
- Blackbody: Temperature:  K
- Power Law: Index:   $F(\lambda) = \lambda^{\text{Index}}$
- Emission Line: Lambda:  nm; Flux:   $10^{16}$  ergs/cm<sup>2</sup> (per arcsec<sup>2</sup> for extended sources); FWHM:  nm

**Sky Conditions**

- Override altimate sky parameters and use instead typical fixed sky model parameters except for:
  - Moon FL:  Altimax:
- FWHM:  mm Probability > 95% of realising the FWHM > 10.0 mm
- Saving Image Quality:
  - Saving:  arcsec: FWHM in V-band at zenith (use this value in the proposal) Probability 87% of realising the saving < 1 arcsec
  - RQ:  arcsec: FWHM at the altimate and wavelength of observation (to be used for the proposal)

**Instrument Setup**

- Grating:  Range to plot:  -  nm
- Reference wavelength:  nm The numeric results will refer to this wavelength

**Results**

- S/N ratio:  DIT:  s
- Exposure Time:  s

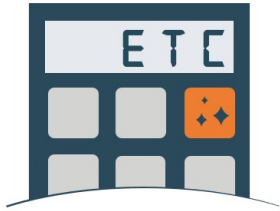
**KMOS Transmission Model**

Reference wavelength	: 2182.0 nm
Wavelength range	: 1934.00 - 2460.00 nm
Dispersion	: 8.200 nm/pixel
Pixel size	: 200.000 mas/pixel
Number of pixels in wavelength range	: 3175 pixels
Signal-to-noise ratio (at reference wavelength)	: 5.000
Detector integration time for one exposure	: 100.000 s
Number of detector integrations (rounded up)	: 64842
Total exposure time (without overheads)	: 6484200.000 s
Max. intensity at central pixel per DIT (object+sky) (at ref. wavel.)	: 219.825 e-/DIT
Detector persistence threshold	: 18000 e-
Detector saturation limit	: 124000 e-
Ratio of S/N reference area	: 8.762 arcsec
Number of pixels in S/N reference area	: 46 pixels
Object signal in S/N reference area (at reference wavelength)	: 18017.885 e-
Object signal in S/N reference area per DIT (at ref. wavelength)	: 2.088 e-/DIT
Total sky background signal per DIT (at reference wavelength)	: 159.788 e-/pixel/DIT
Overall transmission (at reference wavelength)	: 22.27 %

**Signal-to-Noise Ratio per Step in Wavelength**

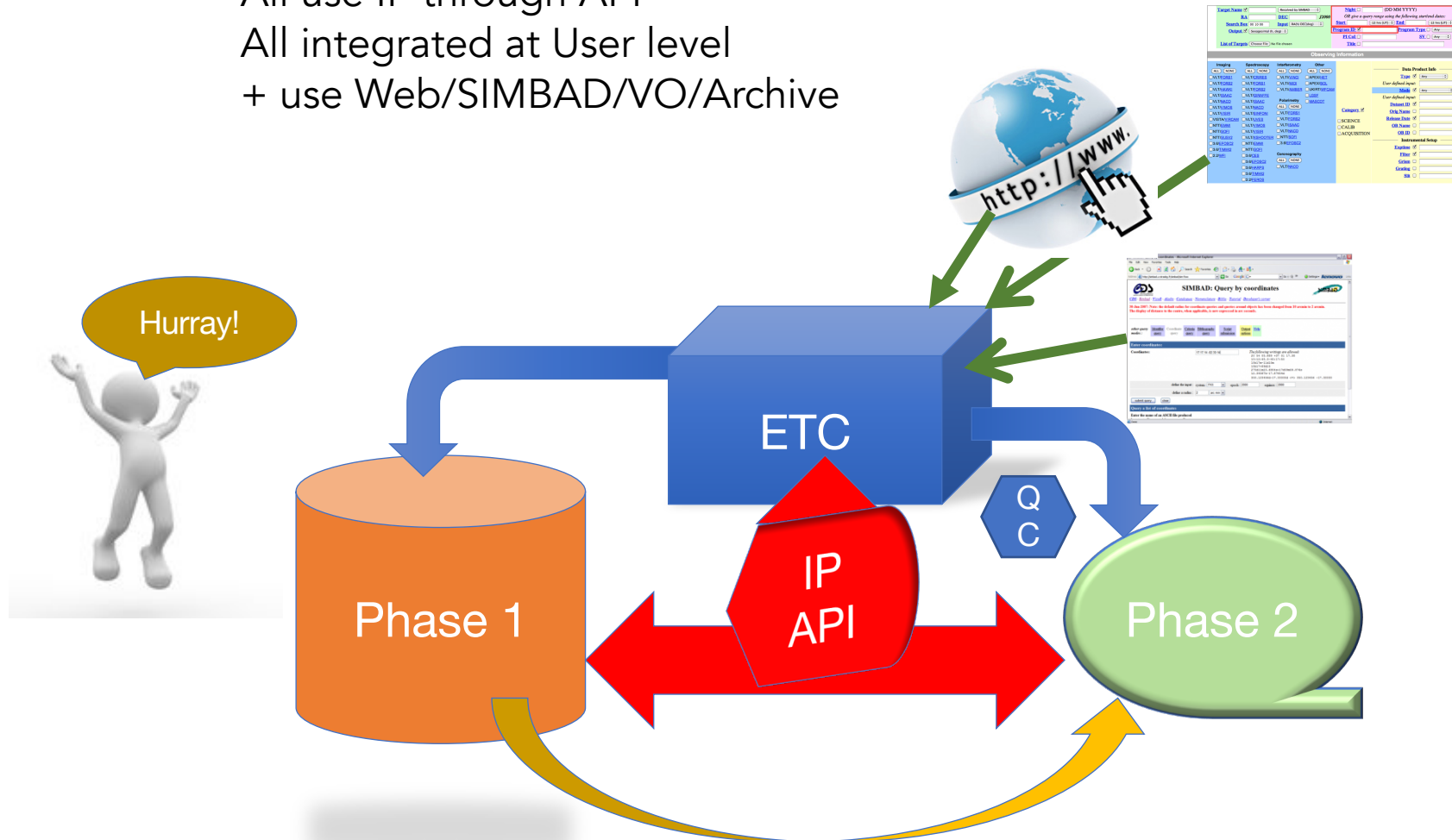
Warning: Please be aware that without a waiver there is a one-hour execution time limit for Service Mode QM, and that the times returned here do not include instrument overheads, time for sky measurements, etc. This, care must be taken to allow for these additional times when constructing complete QM.

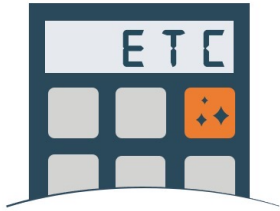
ASCII Interactive PDF [log1y plot](#) [log1y PDF](#)



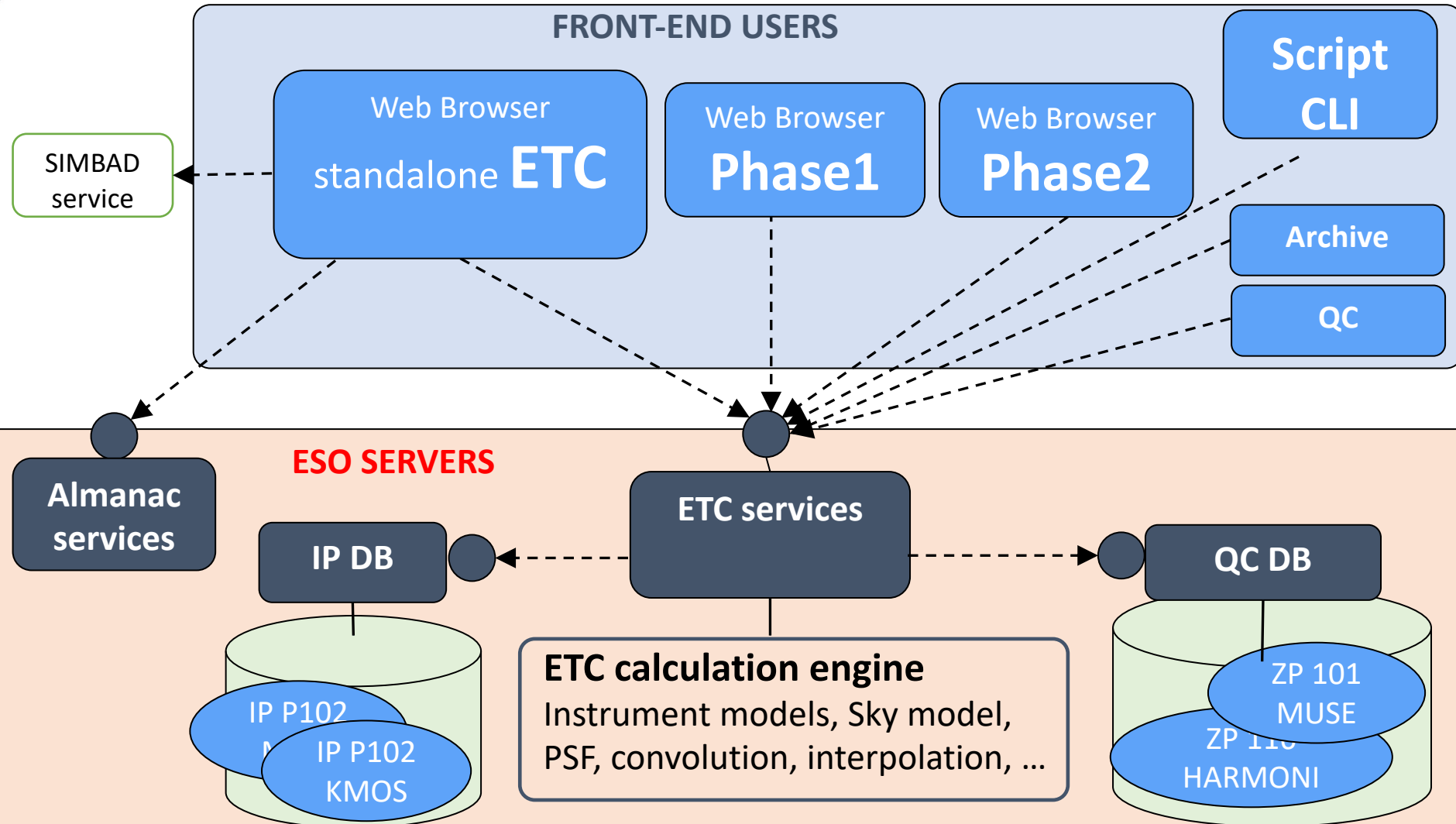
# Ideal → ETC 2.0

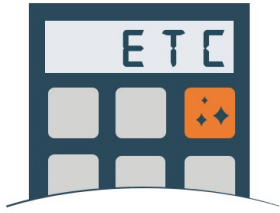
All use IP through API  
All integrated at User level  
+ use Web/SIMBAD/VO/Archive





# ETC 2.0 clients and resources





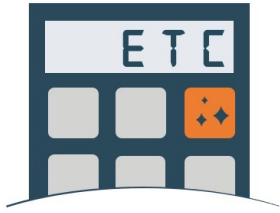
# ETC 2.0 technologies

## □ Front-end Angular framework

- One-page-web application framework
- Also used in the new Phase1/2 web interface (P1/P2)
- Follow same standards and re-use components

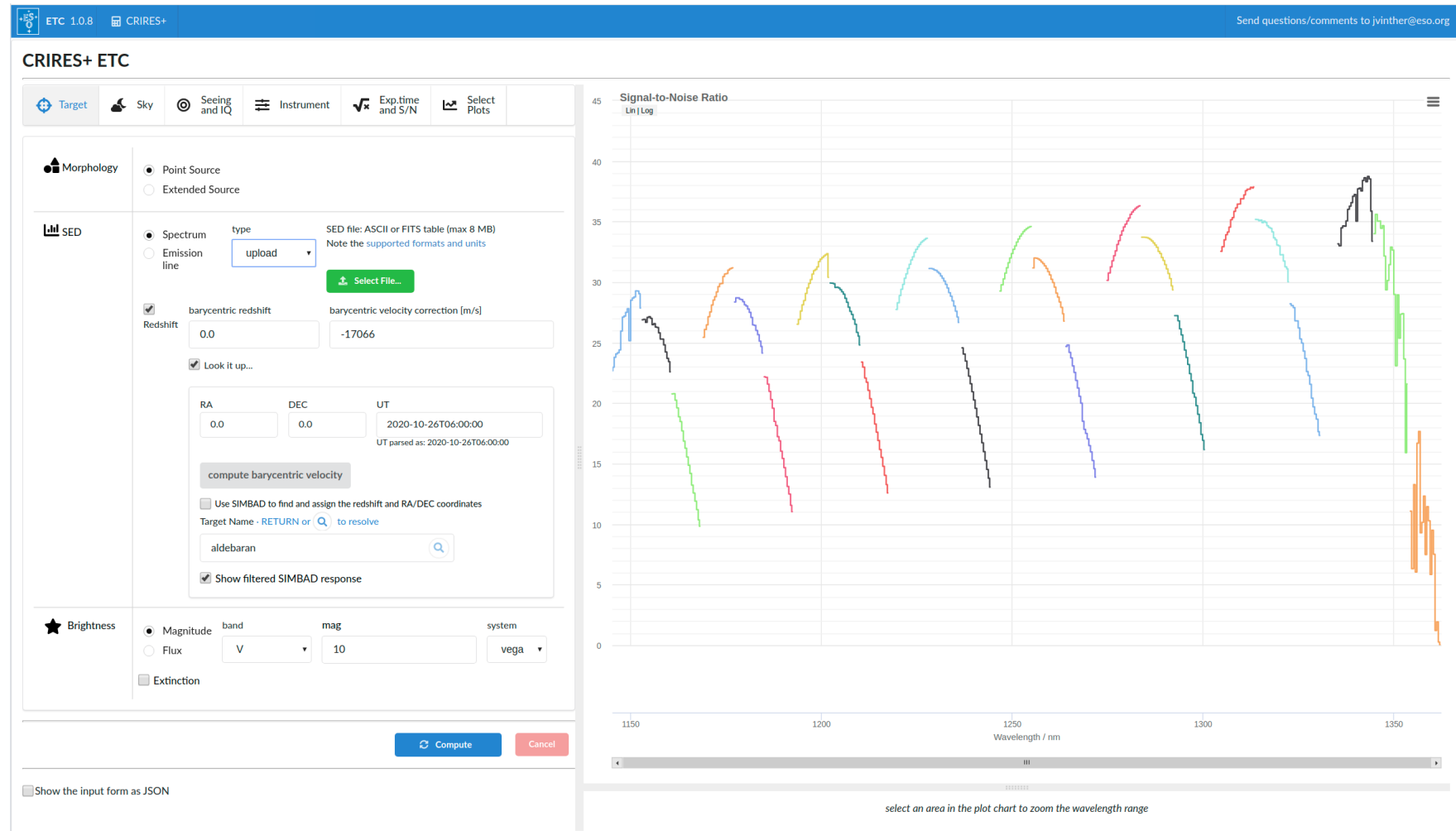
## □ Back-end Python

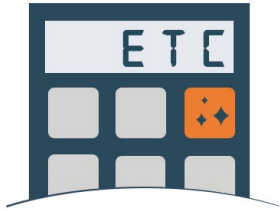
- Concise code
- Libs for scientific computing: NumPy, SciPy, AstroPy
- Django web framework
  - Python
  - Routing, database abstraction layers,...



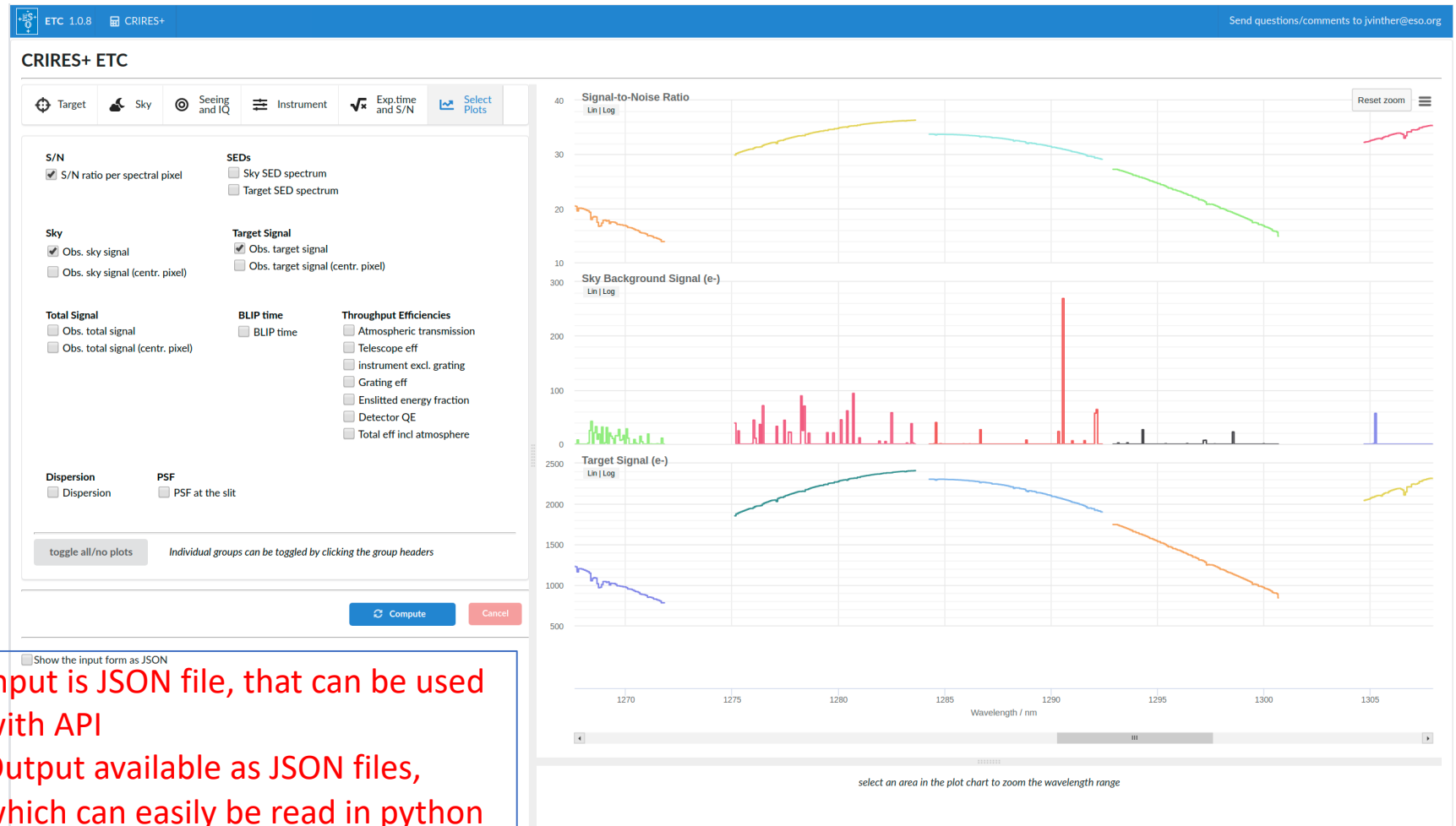
# ETC 2.0

<https://etctestpub.eso.org/observing/etc/crises>

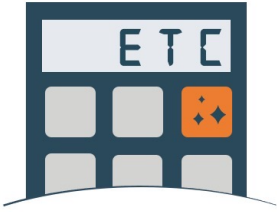




# ETC 2.0



- Input is JSON file, that can be used with API
- Output available as JSON files, which can easily be read in python



- `wget --post-file=input.json https://etctestpub.eso.org/observing/etc/etcapi/Crires2/ -O output.json`
- `etc_cli.py`
- `etc_json2ascii.py`
  
- `etc_plotreader.py`

`usd-help@eso.org`