A SPIN-OFF FROM THE UNIVERSITY OF HEIDELBERG
INSTITUTE OF ENVIRONMENTAL PHYSICS

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SkySpec Instrument Series

ACCURATE AND FLEXIBLE SPECTRAL OBSERVATIONS OF SCATTERED AND DIRECT SUN LIGHT

SkySpec Compact

SkySpec 1D

SkySpec 2D

The **SkySpec** instrument series performs fast, flexible and reliable atmospheric observations with the passive DOAS (Differential Optical Absorption Spectroscopy) method; according to VDI standard 4212. Ultra violet (UV) and visible (Vis) radiation spectra of direct and scattered sunlight in multiple viewing directions are acquired and analysed to obtain information on the spatial distributions of various trace gases (e.g. NO_2, O_3, SO_2, HCHO, H_2O, HONO, IO, BrO, Glyoxal) and aerosols in the troposphere as well as the stratosphere. Also other high precision spectroscopic applications are possible (e.g. surface reflection spectroscopy).

Airyx offers four basic instrument models: the **1D-**, the **2D-**, the **Compact-** and the **Mini-SkySpec**. For each of these, covered spectral range and resolution can be customized and adapted to the needs of the user. With our long experience of several decades in scientific and commercial spectroscopy we optimize spectrometer configurations and setups to achieve best possible measurements with high light throughput and best achievable noise level. All spectrometers are actively temperature stabilised to ensure maximum spectral stability. Besides the single spectrometer configuration we also offer double spectrometer systems to cover a larger spectral range with optimum spectral properties.

All **SkySpecs** feature motorised prism scanners to automatically realise viewing elevation angles from -10° to 190°. A quartz glass tube protects the scanner from environmental effects and guarantees minimum dirt accumulation (in comparison to exposed lenses) and a very simple cleaning. There are no moving parts on the outside of 1D instrument telescopes which assures reliable long-term operation in harsh environments or remote areas and long instrument life times. The telescope features an inclination sensor with automatic elevation adjustment, which allows fast and easy deployment without the need for levelling the instrument. Precise measurements on moving platforms (e.g. ships) are possible due to the fast response and high precision of the elevation adjustment. The narrow vertical field of view (FOV) of the telescope (<0.4°) is optimal for further data processing like concentration profile retrievals and other radiative transfer calculations at high vertical resolution.

The **2D-SkySpec** instrument features a second motorised axis to vary the horizontal (azimuthal) viewing direction. It enables the user to capture horizontal trace gas concentration gradients and to perform measurements of direct sunlight.

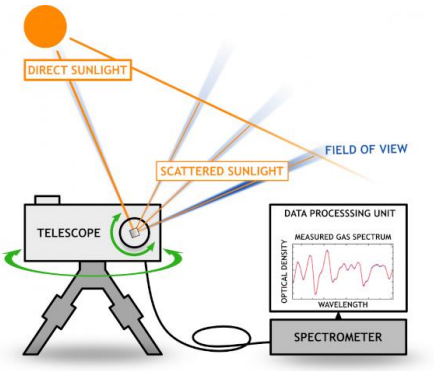
1D- and **2D**-telescope unit versions v250 or later support stand-alone use and combination with arbitrary spectrometers, providing great flexibility regarding spectroscopic applications other than passive DOAS. Furthermore, humidity is monitored within these units automatically to reduce maintenance efforts.

MEASUREMENT GEOMETRIES

- Multi Axis (MAX)-DOAS measurements for vertical profiling of tropospheric aerosols and trace gases.
- Direct Sun DOAS measurements (2D-model only), for the retrieval of stratospheric and tropospheric trace gas total columns.
- Zenith Sky measurements for detection of stratospheric gases

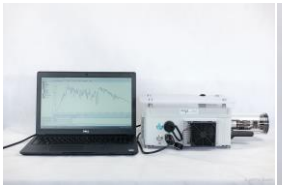
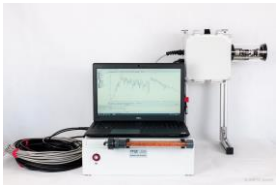
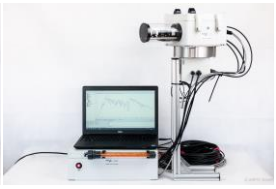
APPLICATIONS

- Air quality monitoring in urban, rural and pristine environments
- Emission plume studies and total flux measurements of power plants, industrial complexes or volcanoes
- Scientific studies (e.g. validation of satellite data and retrievals)
- Spectral analysis of surface reflections
- Long-term measurements with low maintenance



Scheme of SkySpec measurement geometry and principle (2D version is shown here)

SKYSPEC MODEL SPECIFICATIONS

Model	 Mini	 Compact	 1D	 2D
Measurement PC	External	Embedded	External	External
Direct sun mode available	No	No	No	Yes
Data communication	USB	LAN / WiFi	USB	USB
Azimuth angle range and accuracy	Fixed	Fixed	Fixed	-5° to 185°, ± 2°[*5]
Camera options[*1]	None or single		None or single	None, single or dual
Weight	≈ 7 kg		≈13 kg	≈ 14 kg
Size of telescope unit	47 x 26 x 16 cm^3		37 x 23 x 13 cm^3	37 x 23 x 32 cm^3
Telescope stand-alone possible	No		Yes [*6]	
Size of spectrometer unit	Embedded in telescope		40 x 35 x 13 cm^3	
Operation temperature	-10°C to 40°C		-30°C to 50°C (telescope unit)	
GPS option	Yes		No	
Calibration lamp[*2]	External handheld lamp[*3]		Integrated and/or external handheld lamp [*3]	
Spectrometers	Single		Single or dual (UV and Vis)	
Typical spectral range	300–460 nm [*4]		300-405 nm (UV) and 420–565 nm (Vis) [*4]	
Typical spectral resolution (FWHM)	0.6 nm [*4]		UV: 0.45 nm and 0.6 nm (Vis) [*4]	
Available detectors	UV: back-thinned CCD, Vis: back-thinned CCD or CMOS			
Elevation angle range and accuracy	-10° to 190°, ± 0.2°(automatic adjustment with inclination sensor)			
Field of view FWHM, Vertical x Horizontal	Scattered skylight: 0.3°x 1°, direct sunlight (SkySpec2D with diffusor system only): 10° x 10°			
Tripod & Adapter	Adapter for telescope and outdoor tripod[*3]			
Power consumption	<30 W (100 W max.), supply voltage 9-15 V, 110 – 220V AC power supply incl., operation with battery battery[*1] possible			
Housing material	Polycarbonate (IP64)			
Additional sensors	Ambient temperature, pressure, humidity in spectrometer housing, temperature on electronic board			

[*1]Wide field of view (≈90°) cameras on telescope housing e.g. for monitoring of cloud conditions
[*2]Mercury (HG) gas lamp for spectrometer wavelength calibration. Re-calibration typically not necessary for due to stable in-house calibration.
[*3]Available accessory
[*4]Customizable, contact us for more information.
[*5]Accuracy applies if azimuth is automatically calibrated from sun position
[*6]Instrument version v250 or later, control over RS232, enables switching between devices and connection to arbitrary spectrometers

SELECTED PUBLICATIONS CONTAINING RESULTS FROM SKYSPEC MEASUREMENTS

- Kreher et al.: Intercomparison of NO_2, O_4, O_3 and HCHO slant column measurements by MAX-DOAS and zenith-sky UV-Visible spectrometers during the CINDI-2 campaign, Atmos. Meas. Tech., https://doi.org/10.5194/amt-2019-157, 2020.
- Tirpitz et al.: Intercomparison of MAX-DOAS vertical profile retrieval algorithms: studies on field data from the CINDI-2 campaign, Atmos. Meas. Tech., https://doi.org/10.5194/amt-2019-456, 2021.
- Wang et al.: Inter-comparison of MAX-DOAS measurements of tropospheric HONO slant column densities and vertical profiles during the CINDI-2 Campaign, Atmos. Meas. Tech., https://doi.org/10.5194/amt-2019-464, 2020.
- Lampel, J., Zielcke, J., Schmitt, S., Pöhler, D., Frieß, U., Platt, U., and Wagner, T.: Detection of O_4 absorption around 328 and 419 nm in measured atmospheric absorption spectra, Atmos. Chem. Phys., 18, 1671–1683, https://doi.org/10.5194/acp-18-1671-2018, 2018.
- Lampel, J., Wang, Y., Hilboll, A., Beirle, S., Sihler, H., Puķīte, J., Platt, U., and Wagner, T.: The tilt effect in DOAS observations, Atmos. Meas. Tech., 10, 4819–4831, https://doi.org/10.5194/amt-10-4819-2017, 2017.

TYPICAL SENSITIVITIES

Data based on MADCAT campaign data (see Lampel et al. 2015, doi:10.5194/amt-8-3767-2015)
Integration time: 60 s (≈ 1000 scans), Saturation: 60 %, surface volume mixing ratios (VMR) assume 10 km light path.

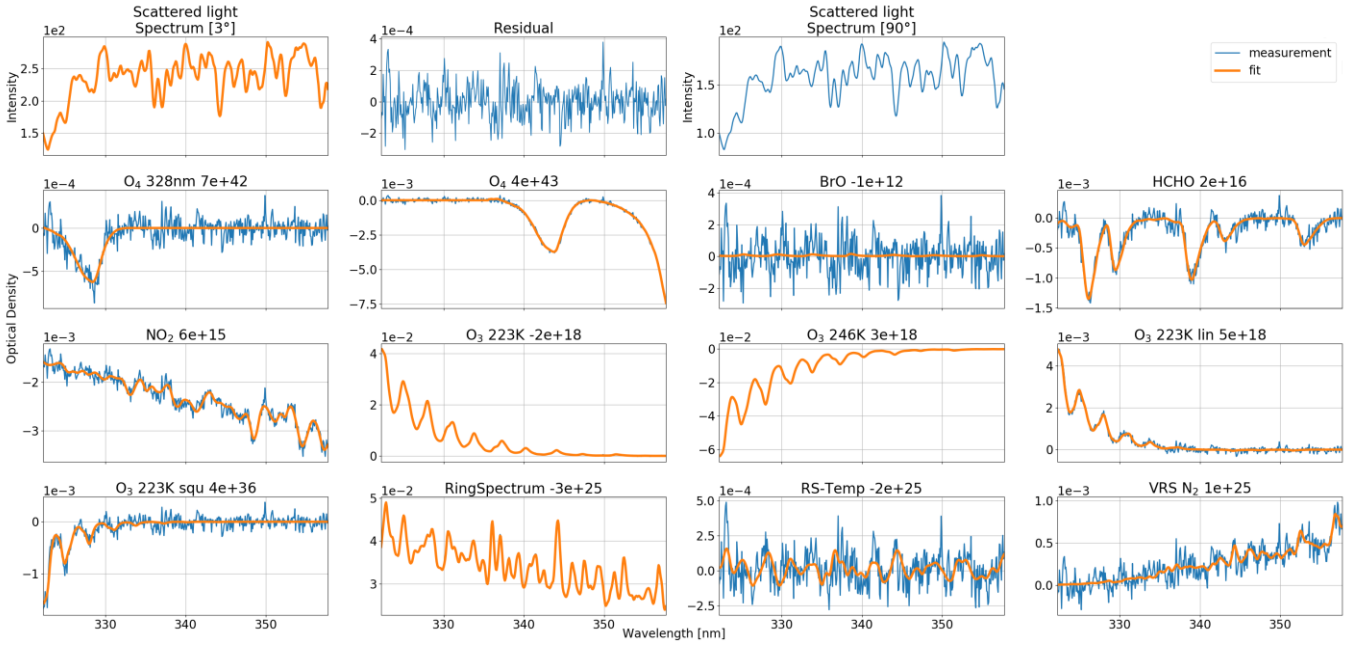
Parameter	Quantity / unit	NO_2	SO_2	HCHO	BrO	H_2O	O_4	HONO	IO	Glyoxal
Limit of detection	Slant column / molec cm^{-2}	7e14	7e15	5e15	2e13	1e22	1e41[*1]	4e14	1e13	3e14
	Surface VMR / pptv	30	300	200	0.7	0.05 [*2]	-	15	0.6	20
Measured SNR (urban)	SNR	285	< 0.6	2	0.5	30	300	5	< 0.5	< 2.5
	Assumed slant column / molec cm^{-2}	2e17	4e15	1e16	1e13	3e23	3e43[*1]	2e15	5e12	5e14

*[*1] in units of molec² cm⁻⁵*
*[*2] in units of %*

ADVANTAGES

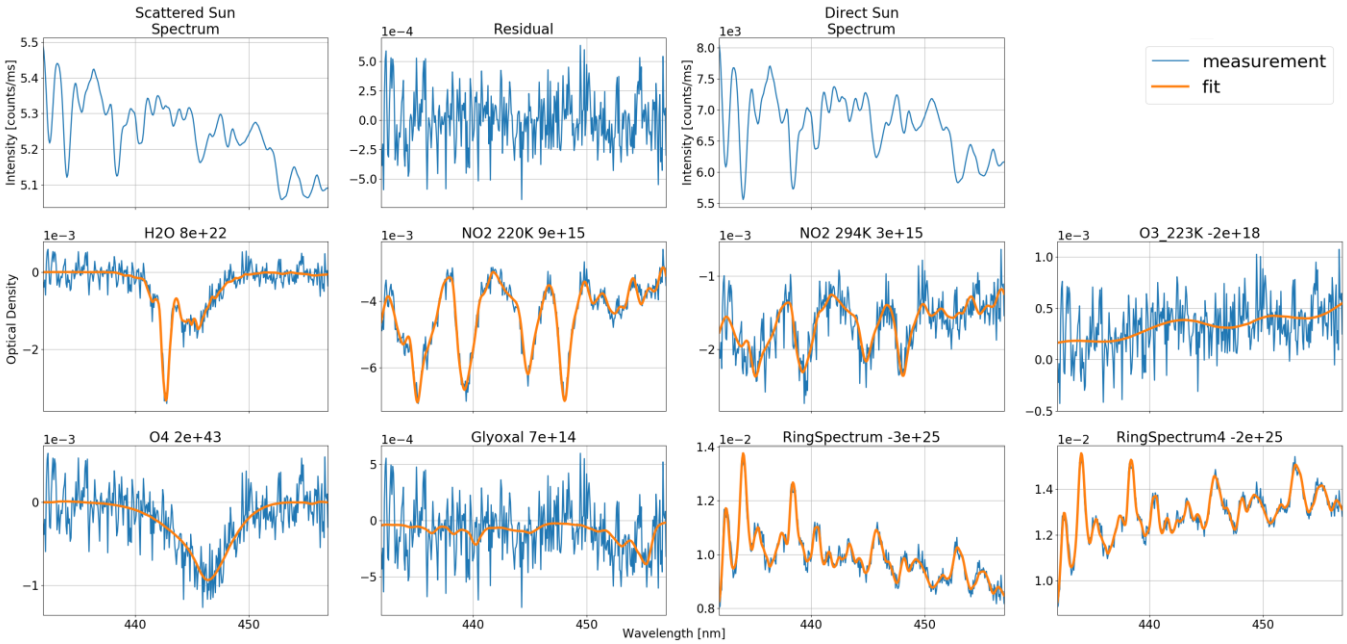
BENEFITS	PROPERTIES & INNOVATION
High measurement accuracy	• Low spectrometer stray-light (< 0.1%) due to optimized optical bench and color filters • Individual spectrometer fine adjustment to achieve best spectral resolution at high light throughput and sufficient spectral sampling (min. 5 Pixel over FWHM of line function). • Detector nonlinearity correction included • Temperature stabilized spectrometers (precision better than 0.02°C), assures stable spectral properties. • Optimized optical fiber bundle setup for high light throughput, small field of view and high spectral resolution. Particularly, high light throughput for UV is achieved to realize a similar signal intensity for UV and visible light. • Built-in mercury (HG) lamp systems available for automatized wavelength calibration. • Continuous monitoring and fast active correction of telescope elevation angle allow measurements at changing environments and on moving platforms (ships, cars, bicycles). • Prism telescope guarantees best spectral light deflection, avoiding varying spectral reflection properties for different light polarizations (as occurring e.g. for mirrors). • The small vertical field of view (< 0.3°) is optimal for further data processing involving radiative transfer calculations (e.g. vertical profile retrievals) • Diffusor plate system assures high spectral quality of direct-sun data (2D-model only)
Simple setup & maintenance	• Automatic, fast and accurate telescope elevation position due to built-in inclination sensor including temperature correction (correct temperature effects of elevation sensor) • Fast instrument power-up • Simple telescope cleaning, low optic contamination, low levels of light intensity from other viewing directions • Prism telescope rotates in a closed quartz glass tubing without any outside moving parts to avoid mechanical problems and failure of the telescope resulting in long lifetime and operation in harsh environmental conditions (strong wind and snow). • Integrated telescope heating (activates below 5°C), allows operation at low temperatures by melting snow and ice and operation even in polar regions (down to -30°C). • Telescope and spectrometer units are sealed air tight and include desiccant to avoid water condensation on the optics and inside the spectrometer. Spectrometer units indoor installation (1D / 2D systems) are equipped with an additional desiccant system which dries the air diffusing to the inside of the spectrometer unit. This allow easy maintenance of the desiccant. • 1D & 2D telescopes since instrument version v250 can also be used stand-alone and connected to arbitrary spectrometers. • Weather proof IP64 housings. • Easily adaptable measurement routine provides high flexibility
Custom Configuration	• Individual spectrometer configurations for the customer needs (spectral range, spectral resolution) • Optimizing spectrometer configuration for optimal measurement quality, avoiding spectral under-sampling (an often underestimated problem) • Different fibre and cable lengths are available • Optical systems for optimised direct-sun and automatic wavelength calibration • Components separately available
Low power consumption	• Typical power consumption of 20 to 30w for low operation costs • Allow simple, mobile operation • 12V supply voltage allows battery for operation as uninterrupted power supply solution.

EXAMPLE SPECTRA DATA ANALYSIS – SCATTERED SUNLIGHT



Example fit scattered sun light using a stationary 1D SkySpec instrument (from Lampel et al., ACP 2018, 4 minute exposure time, recorded near Plymouth, England).

EXAMPLE SPECTRA DATA ANALYSIS – DIRECT SUNLIGHT



Example fit direct sun light using a stationary 2D SkySpec instrument. The light diffuser system for direct sun measurements guarantees an optimal spectral mixing avoiding systematic spectral residual structures. Here, a direct sun spectrum recorded at a Solar Azimuth Angle (SZA) of 54° is chosen as reference spectrum and evaluated against a scattered light spectrum recorded at an SZA of 47° at an elevation of 40°, each for one minute total exposure time.