Sky subtraction for observations without plain sky information

S. Noll[1] (stefan.noll@uibk.ac.at), **W. Kausch[1], C. Szyszka[1], A.M. Jones[1], M. Barden[1], and S. Kimeswenger[2,1]**

[1]Institute for Astro- and Particle Physics, University of Innsbruck, Austria

[2]Instituto de Astronomía, Universidad Católica del Norte, Antofagasta, Chile

Motivation:

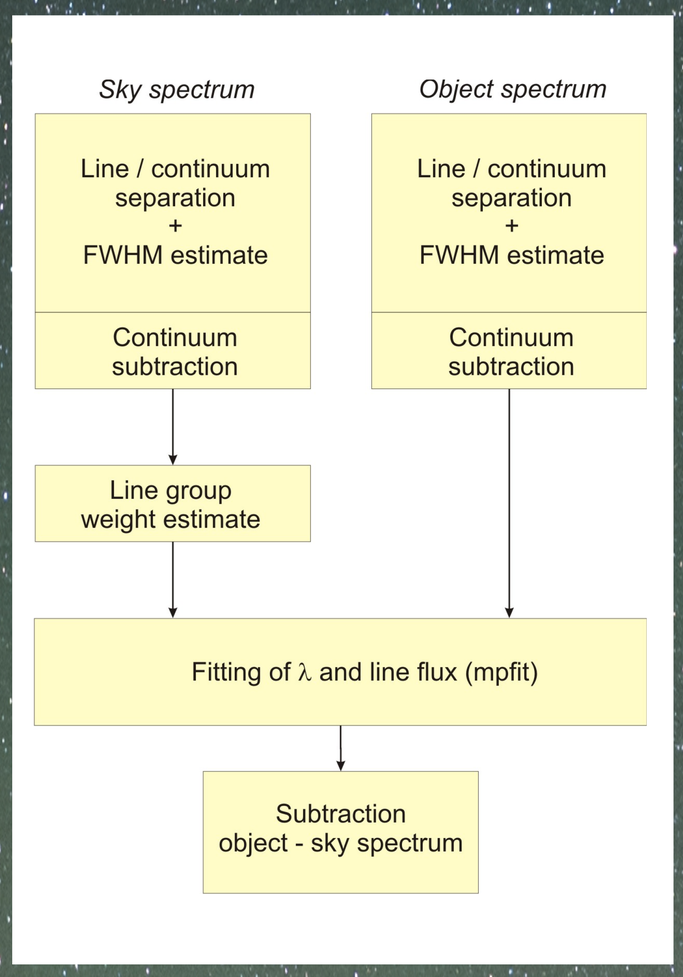
Near-IR: dominated by non-thermal airglow line radiation, which shows high temporal and spatial variability

Data reduction:

- Standard method: sky subtraction in 2D spectra by interpolation of airglow emission at object position
- Case: no 2D plain sky information (1D spectra, extended objects)
- Approach: use of reference sky spectrum taken at similar time and position
- Problem: very expensive in terms of observing time and the quality of the sky subtraction can still be quite poor if the exposure times are long.
- Solution: optimisation of reference sky to airglow emission in science spectrum by a fitting approach

→ **SKYCORR** software of the Innsbruck group of the Austrian ESO In-Kind Project

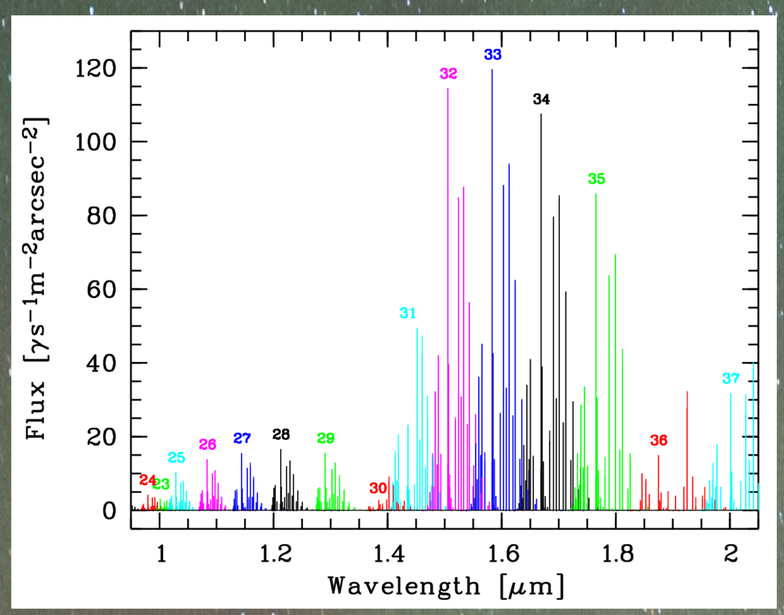
- Similar approach: Davies (2007, MNRAS 375, 1099) (but simpler and only for VLT SINFONI)



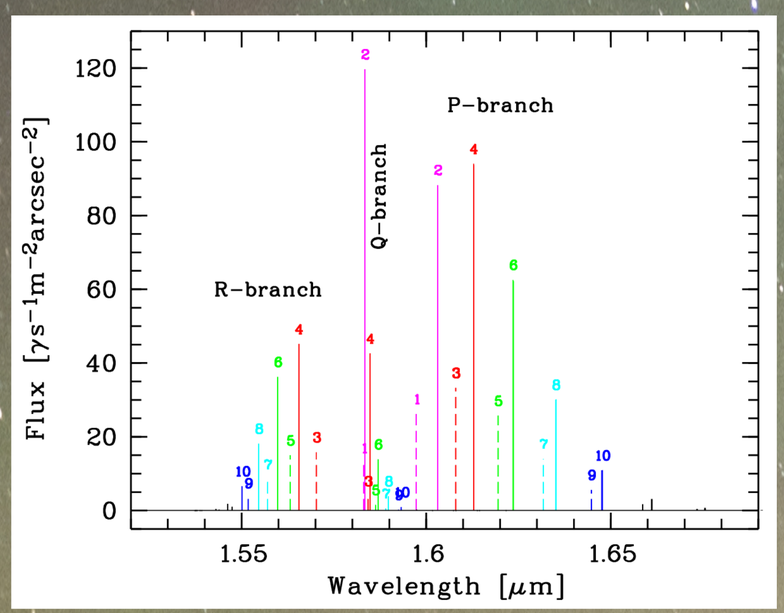
(A) SKYCORR workflow

Properties of SKYCORR:

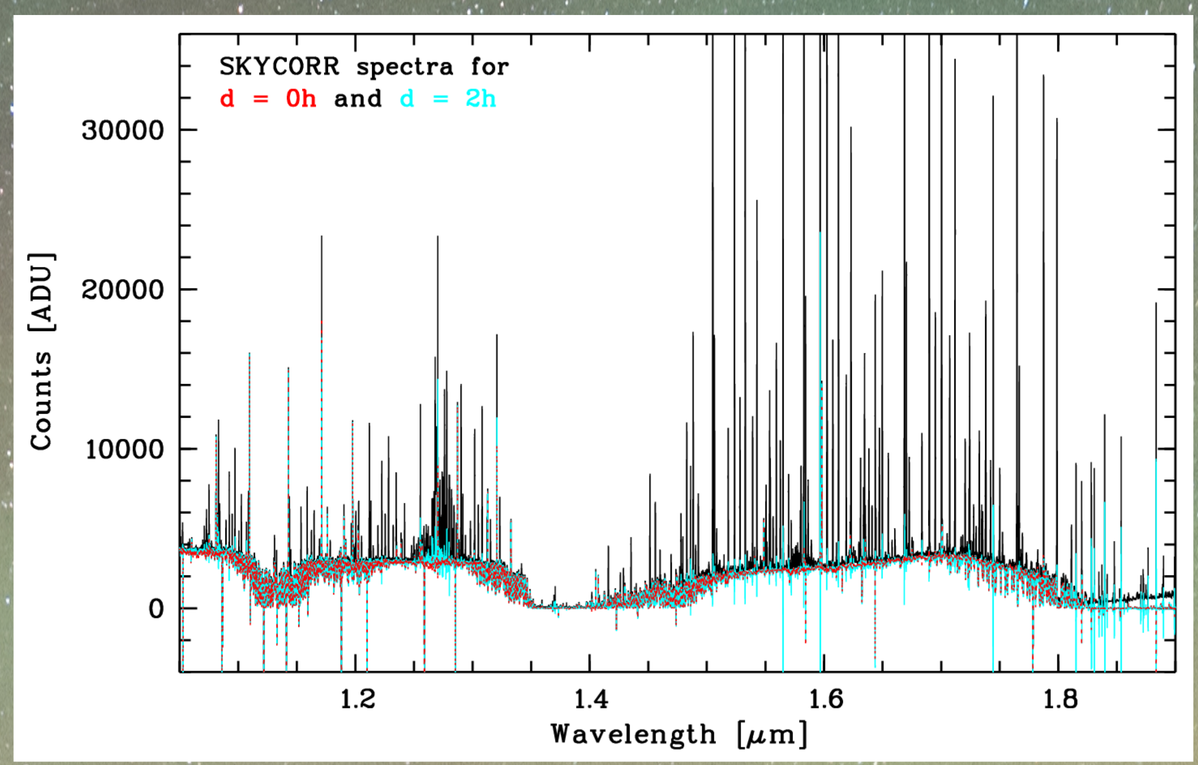
- One executable to be run with an ASCII parameter list as input
- Programming language: C with ESO CPL library
- Instrument independent
- Possible input: 1D FITS images, FITS tables, ASCII tables (same format for input science and reference sky spectrum)
- Line finder for isolated lines and FWHM estimate
- Separation of lines and continuum by line pixel identification via line finder and airglow line list (Noll et al. 2012, A&A 543, A92), and subsequent continuum interpolation
- Grouping of airglow lines with similar variability patterns (for physically motivated, robust correction): *A* groups (same electronic/vibrational band; Fig. B) and *B* groups (similar rotational upper level in different bands of same type; Fig. C)
- Grouped lines between 0.3 and 2.5 µm: all OH bands, several O_2 bands, groups of atomic lines (O, Na)
- For each pixel: calculation of *A* and *B* group contribution
- Airglow variability model for Cerro Paranal (Noll et al. 2012) for initial estimate of line group weights
- Derivation of line scaling factors for each pixel in the reference sky spectrum by a fitting approach (χ^2 minimisation algorithm: MPFIT by C. Markwardt[†])
- Identification and exclusion of outliers (object lines, bad pixels, telluric absorption)
- Correction of wavelength grid by fitting of Chebyshev polynomials and sophisticated rebinning using asymmetric damped sinc kernels (no line broadening)
- No scaling of continuum (different components), since separation of object and sky continuum is impossible.
  → No problem in the near-IR (very weak continuum)
- Corr. obj. spec. = input obj. spec. – scaled sky lines – unscaled sky continuum



(B) Numbered *A* groups of OH ro-vibrational bands in the near-IR



(C) *B* groups of OH rotational transitions illustrated for *A* group 33 (Fig. B), i.e. the OH(4-2) band



(D) SKYCORR-corrected VLT X-Shooter examples (only J and H band shown): solid black: input science spectrum, dotted red: correction for sky spectrum derived from the same 2D spectrum, solid cyan: correction for sky spectrum taken 2 h after the science spectrum. The relatively strong, uncorrected peaks are caused by bad pixels. The regions of high line density originate from water vapour absorption bands (not corrected by SKYCORR, but see poster P77).

Performance:

- Tests for different instruments (FORS, SINFONI, X-Shooter), wavelength ranges, and resolutions
- For observations very close in time and position, sky line subtraction is as good as the standard 2D method.
- For increasing time difference, there is decreasing quality but still weak residuals (per cent level) (Fig. D).
- Possible issues with pseudo continua by high line density (e.g. O_2 band at 1.27 µm, Fig. D)
- Changing bright continua (e.g. thermal telescope emission in the K band) can cause significant residuals.
- Code demonstration at demo booth D01

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[†]http://www.physics.wisc.edu/~craigm/idl/cmpfit.html

Image: Christoph Malin