GREAT data reduction

SOFIA school/April 21st 2023

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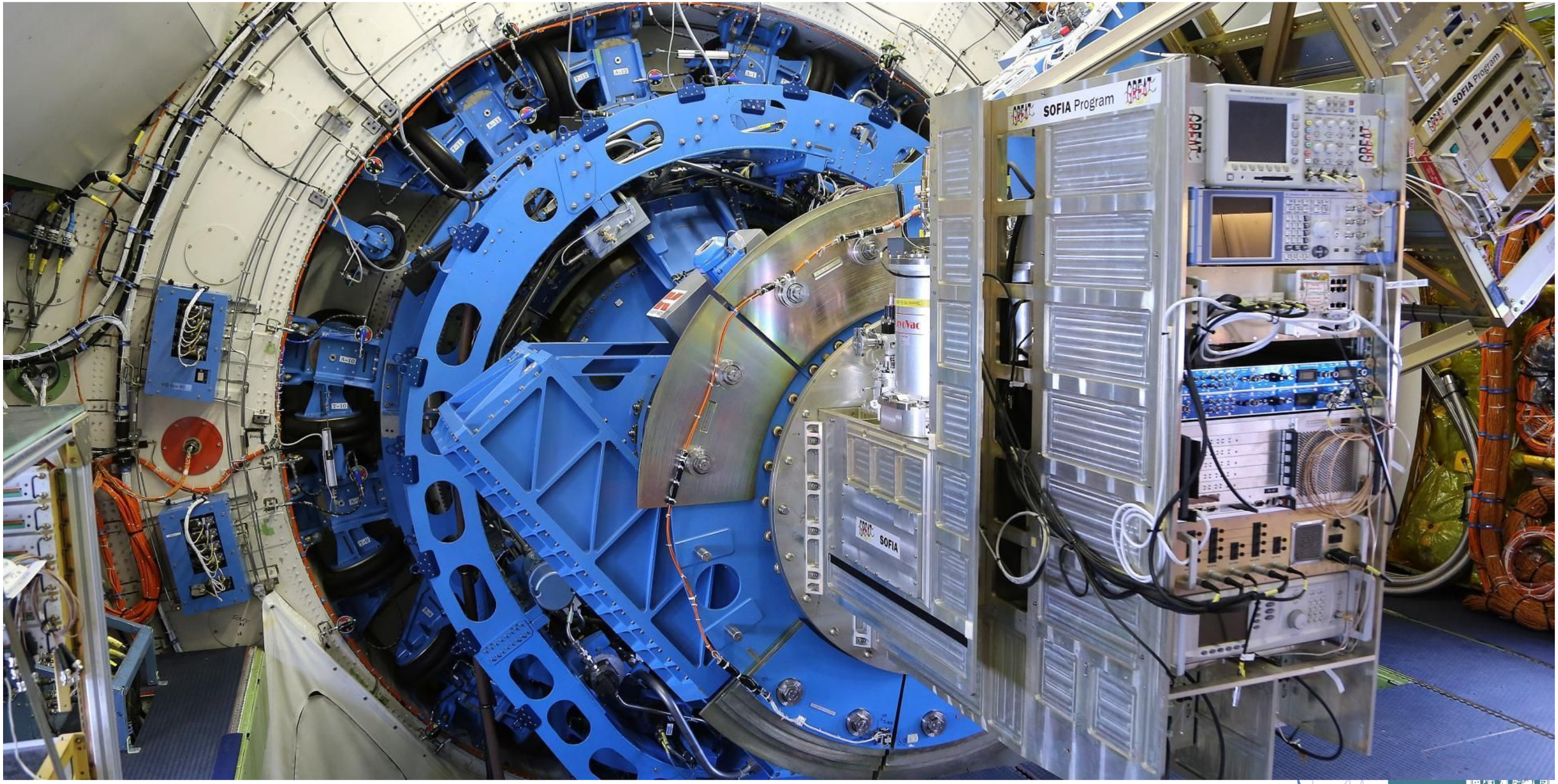

SOFIA Program
GREAT
SOFIA

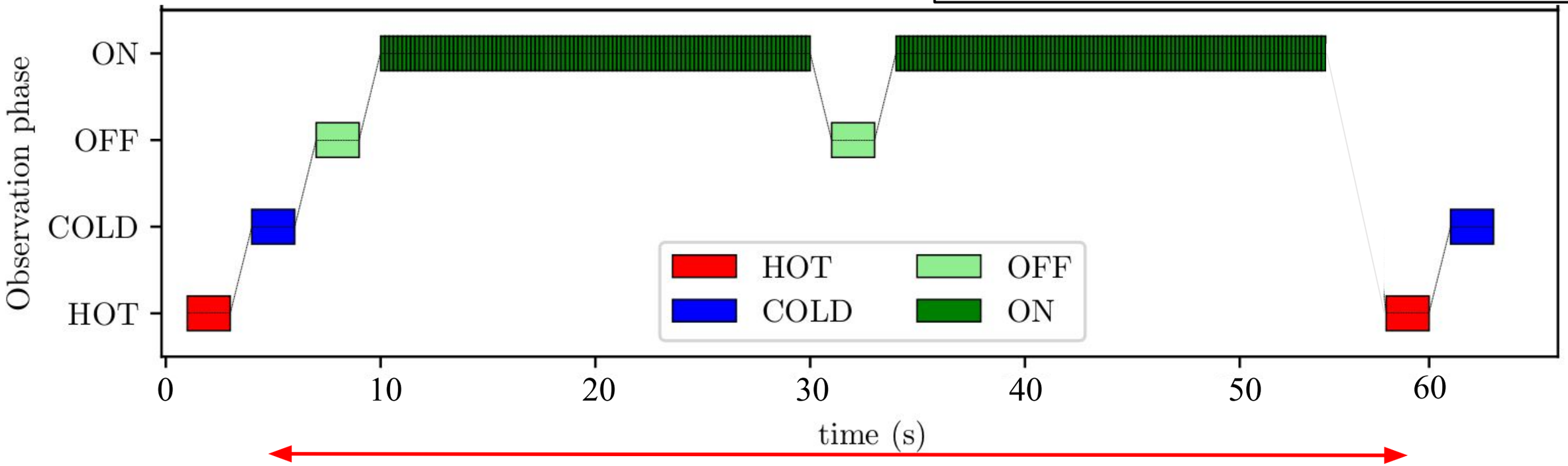
Talk outline

- Heterodyne observations
- GREAT data levels in archive
  - level 3
    - Ta* scale
    - main beam temperature scale
  - Level 4
    - gridded maps
    - averaged spectra
- GREAT reduction process
  - PI instrument, no dedicated pipeline, reduction via hand crafted gildas scripts
- Known issues
  - Mitigation
- Demo code
  - class scripts
  - using astropy tools

Observation details: Heterodyne mapping observation

upGREAT stability times:
Total power stability time ~ 30 seconds
Gain stability time ~ 5 minutes

Total power stability time



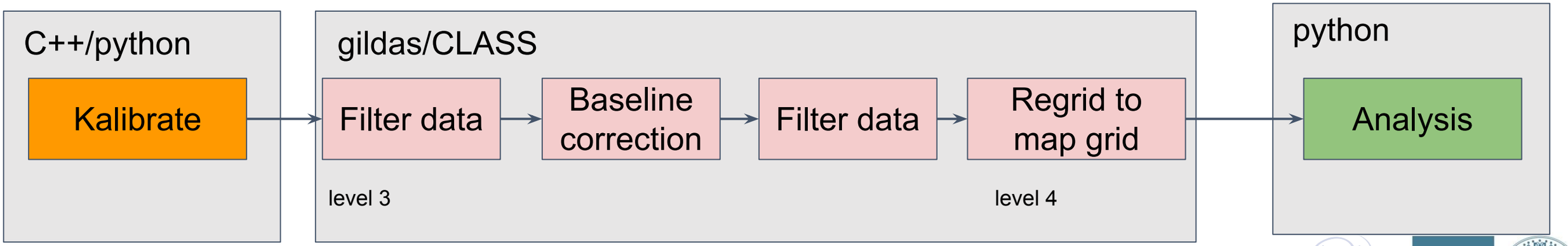
Gain stability time

Data reduction process

GREAT/SOFIA atmospheric calibration*

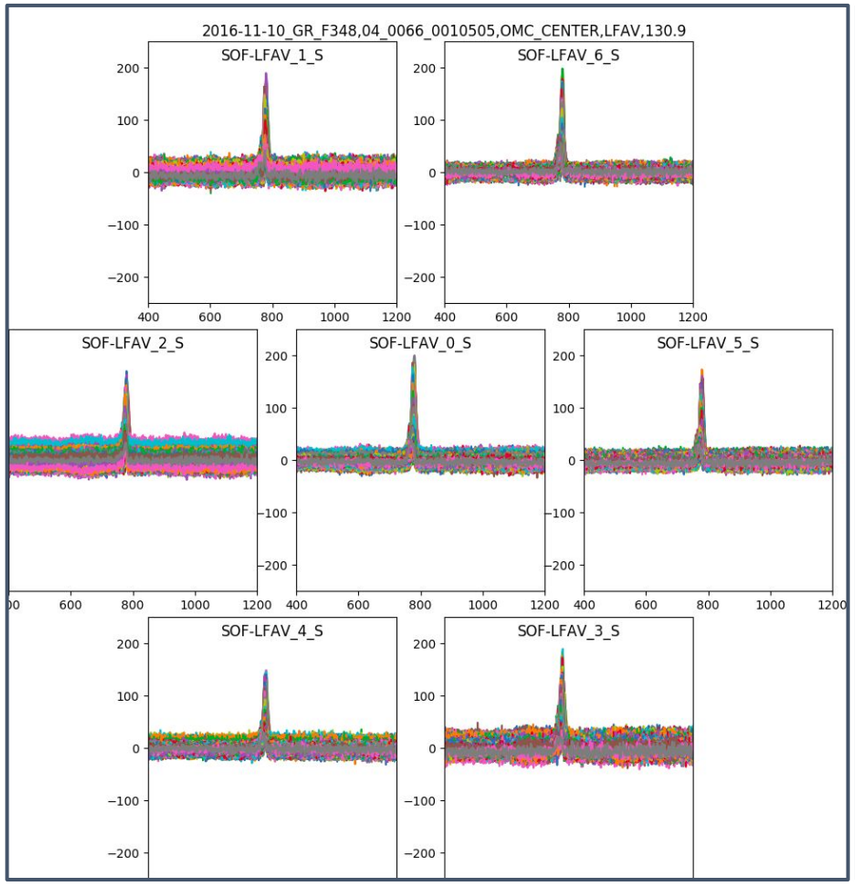
X. Guan[1], J. Stutzki[1], U. U. Graf[1], R. Güsten[2], Y. Okada[1], M. A. Requena-Torres[2], R. Simon[1], and H. Wiesemeyer[2]

- Kalibrate code used to convert raw counts to rayleigh jeans corrected temperature scale and correct for atmospheric transmission
- Data written to gildas/CLASS data format
- Baseline correction and data filtered for outliers
- Velocity cube generated within class

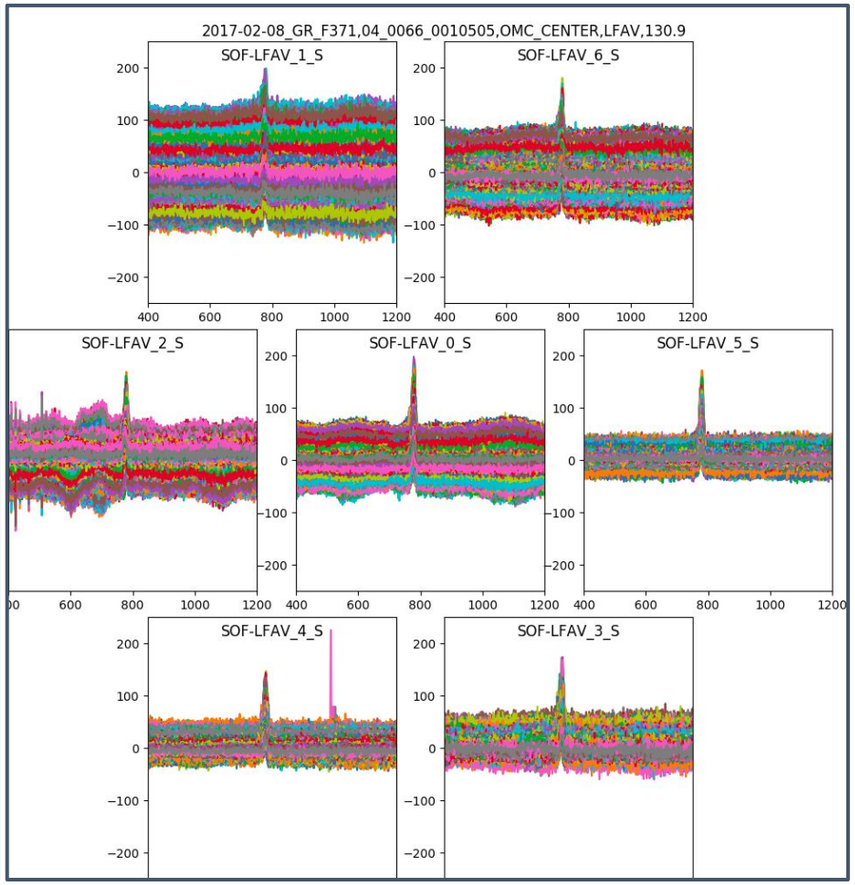


Data quality overview

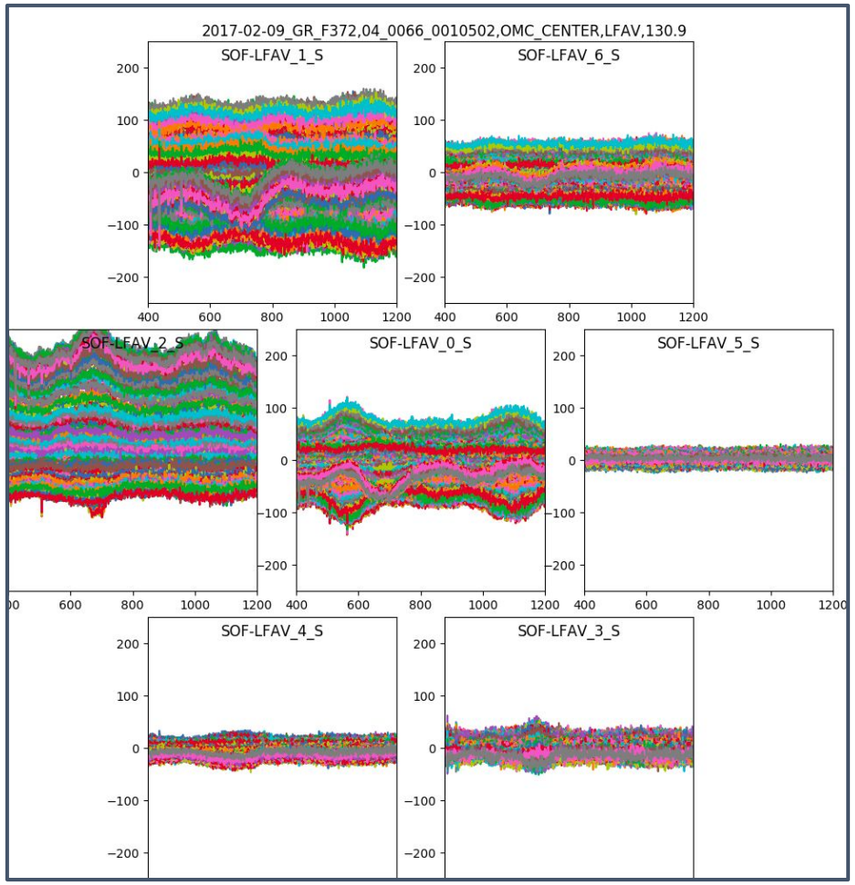
Good



Bad

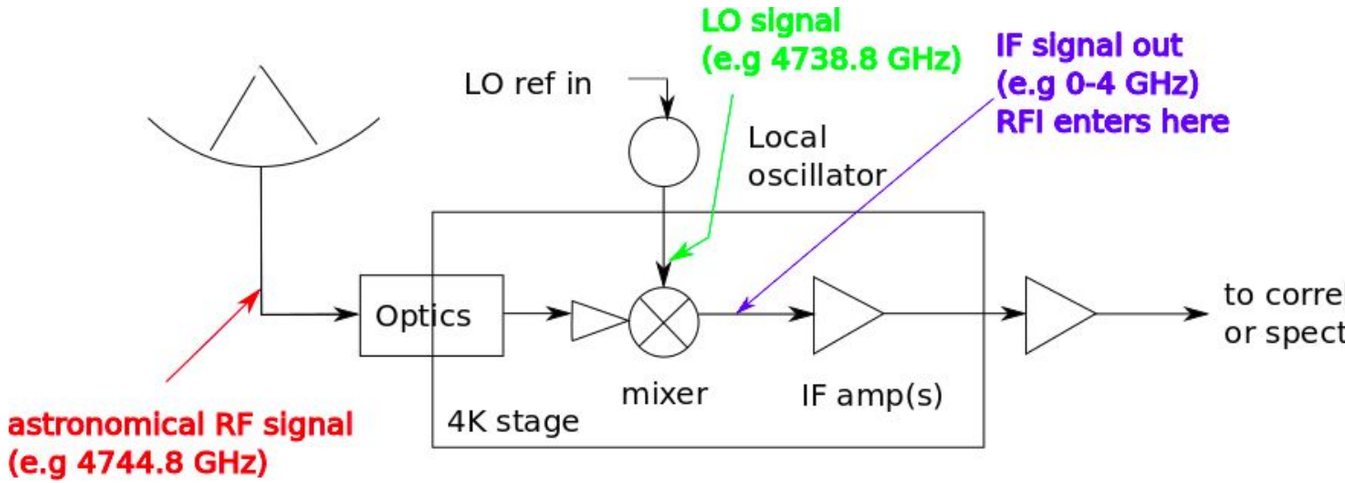


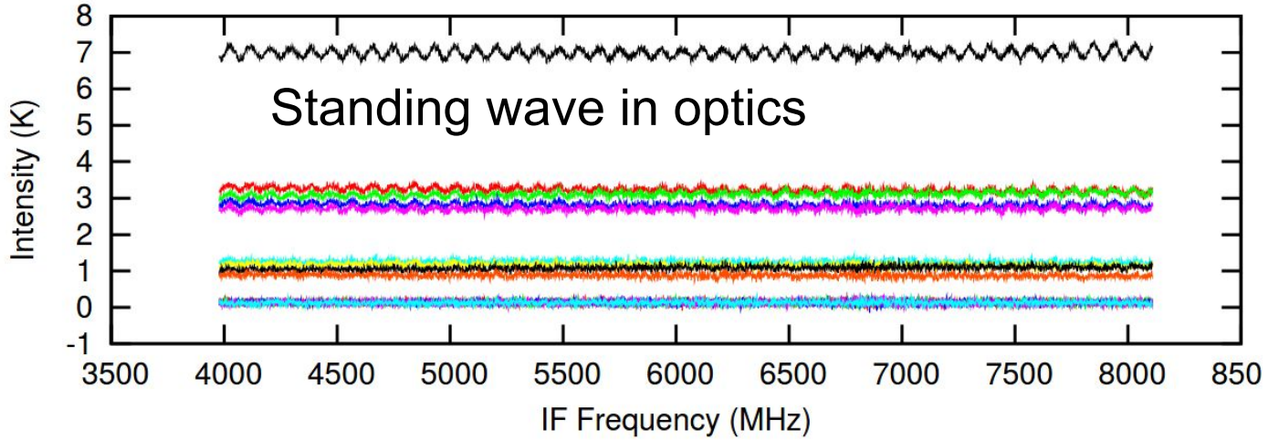
Worse

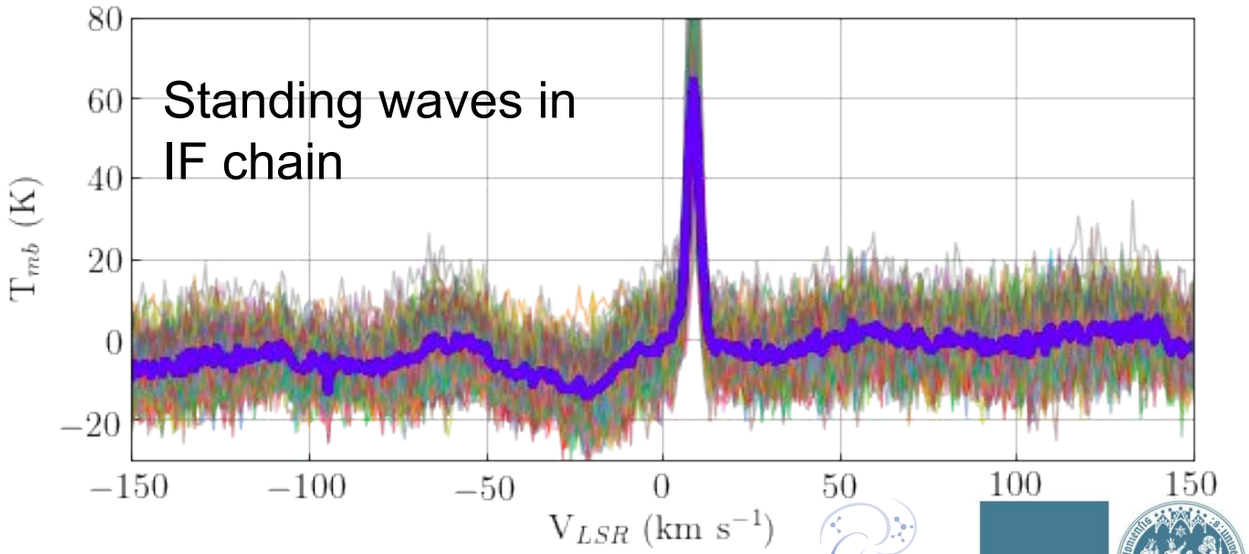


Baseline correction

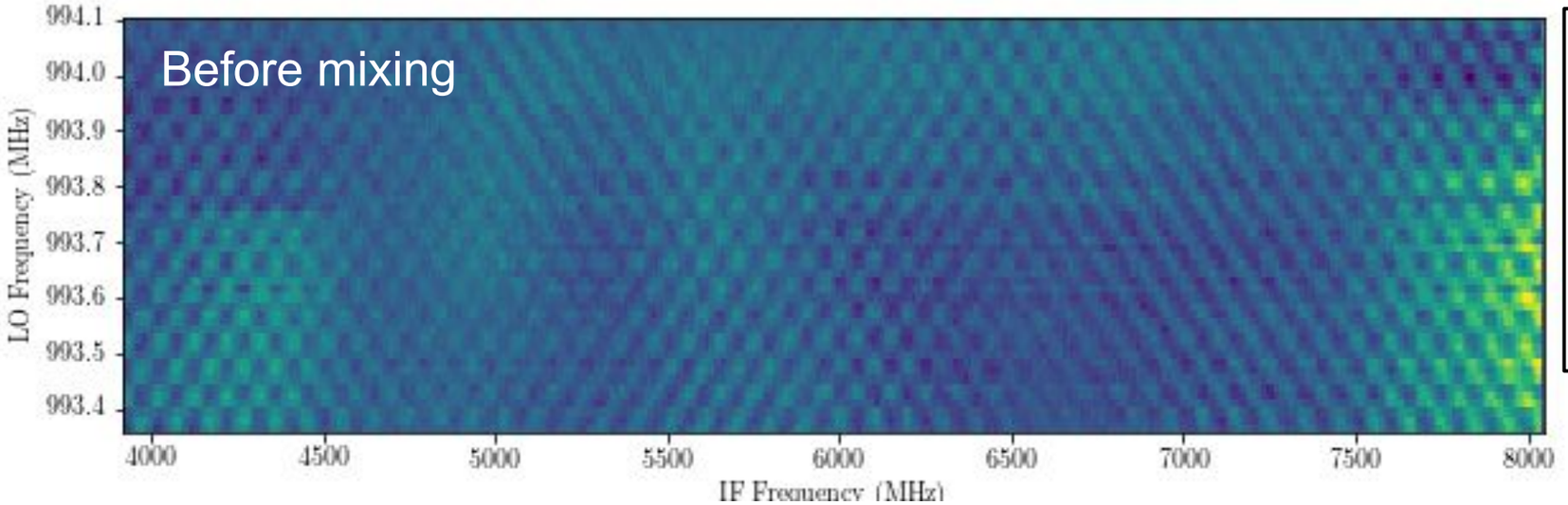
- Classic problem in heterodyne receivers
- Data can be corrupted by receiver systematics
  - Reflections from secondary mirror
  - Reflections from calibration loads
  - Reflections in IF chain (after mixing)





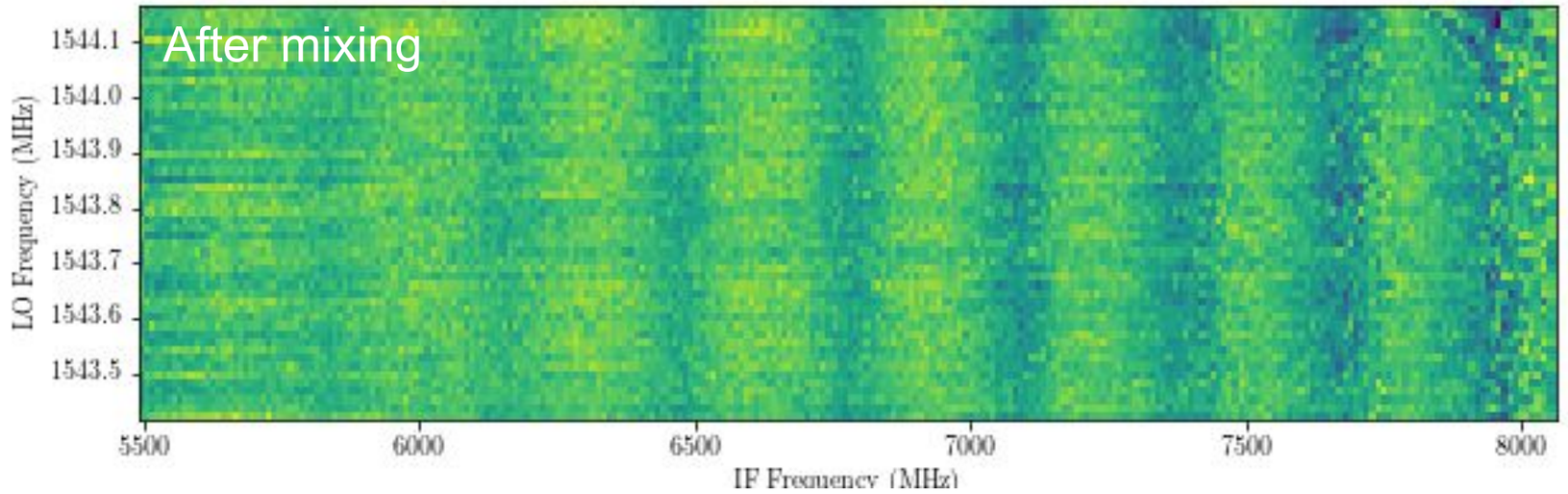


Baseline correction: standing waves physics



Standing waves in optics

- Sinusoidal like but can have a modulated amplitude due to interference between sidebands
- Amplitude/phase is LO dependent due to sideband interference
- Period corresponds to cavity in optics

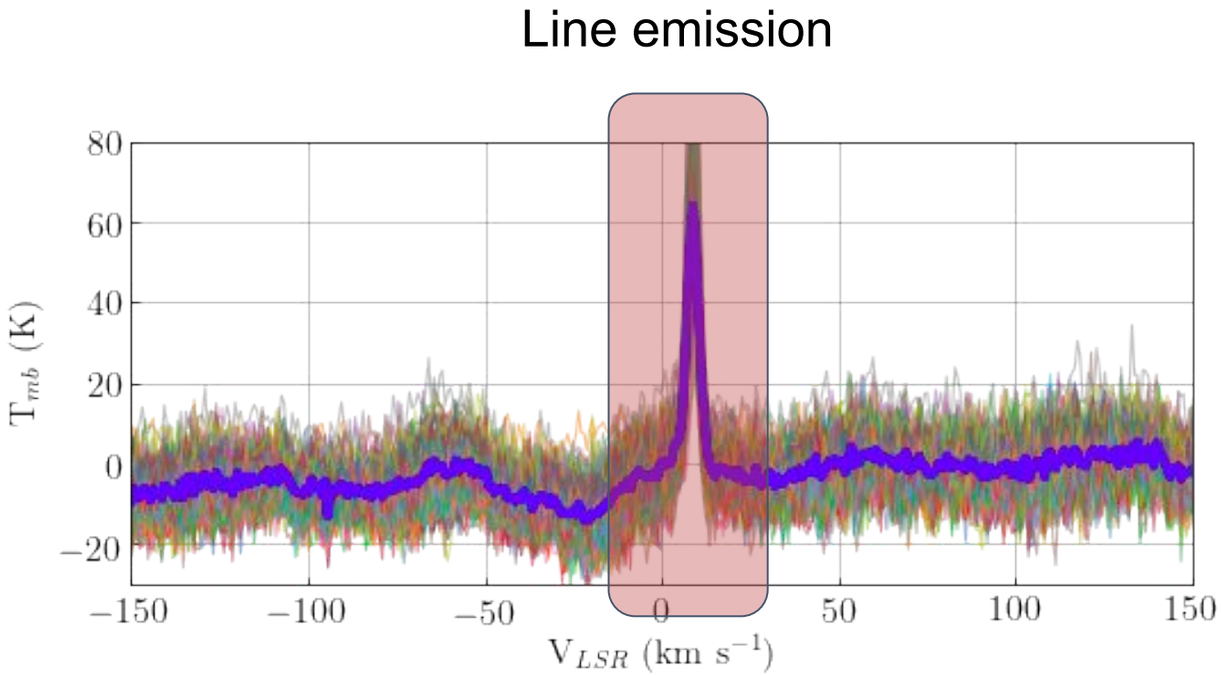


Standing waves in IF chain

- Irregular pattern across band, dependent on reflection properties of IF chain component (see here)
- Phase/amplitude LO independent
- Phase/amplitude dependent on electrical state of the calibration phases (stable system = no baseline effects)

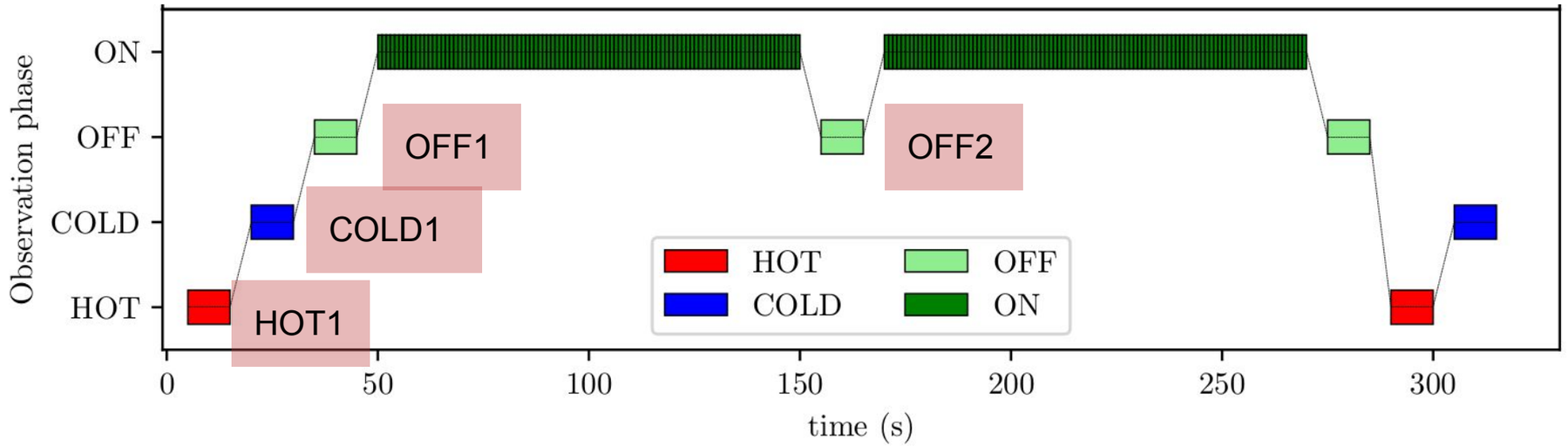
Baseline correction

- Typical step in heterodyne data processing processing
- Standard approach is to flag the line region and run a polynomial fit on the remaining baseline
- Where the baseline has local variations fitting a polynomial can corrupt the line emission
- Particular problem for regions with broad lines (e.g. M51 / galactic center)
- Alternative approach needed



Baseline correction: scaled spline

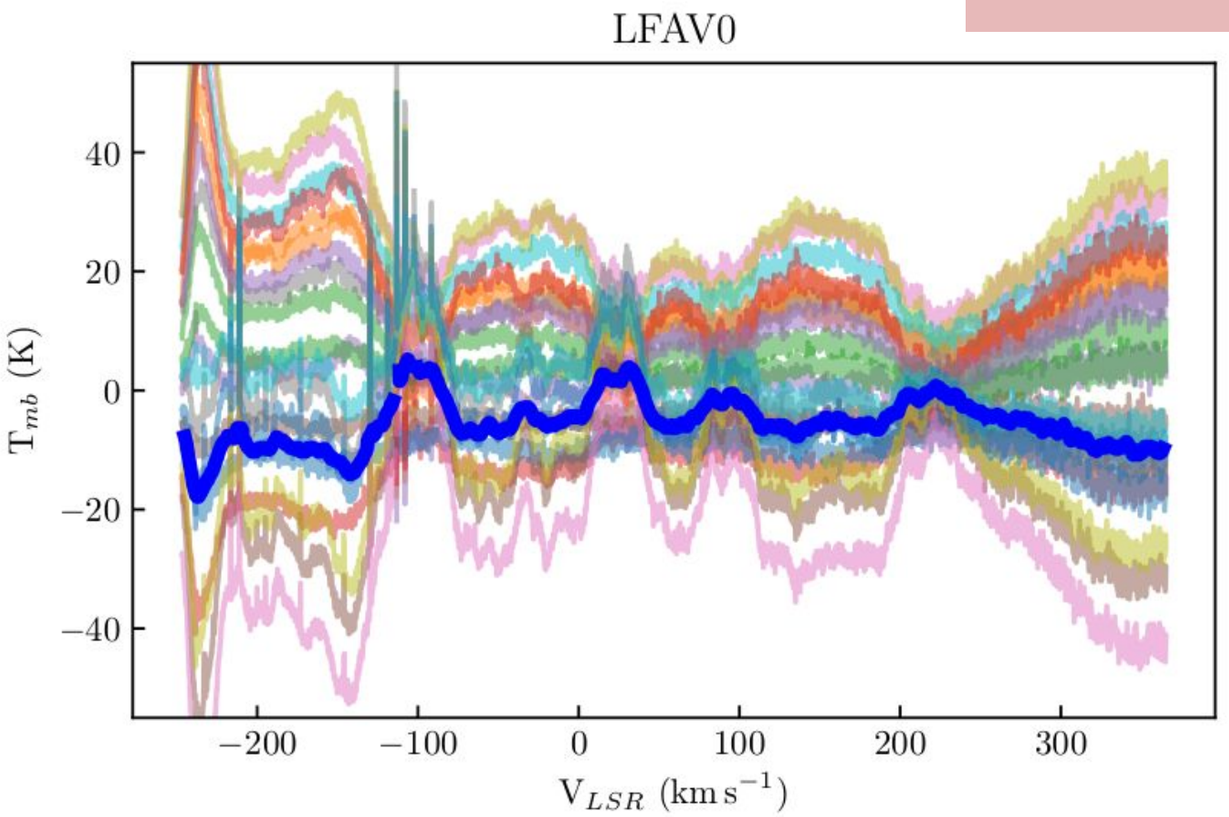
- From HIFI experience, a scaled splined based on off spectra observations worked well (see Do kester HEB standing waves paper)
- This approach was used for the Orion data set
- Residuals between OFF spectra used to generate a catalog of baseline shapes, under the assumption that OFF1-OFF2 spectra have similar baseline shapes to ON-OFF spectra

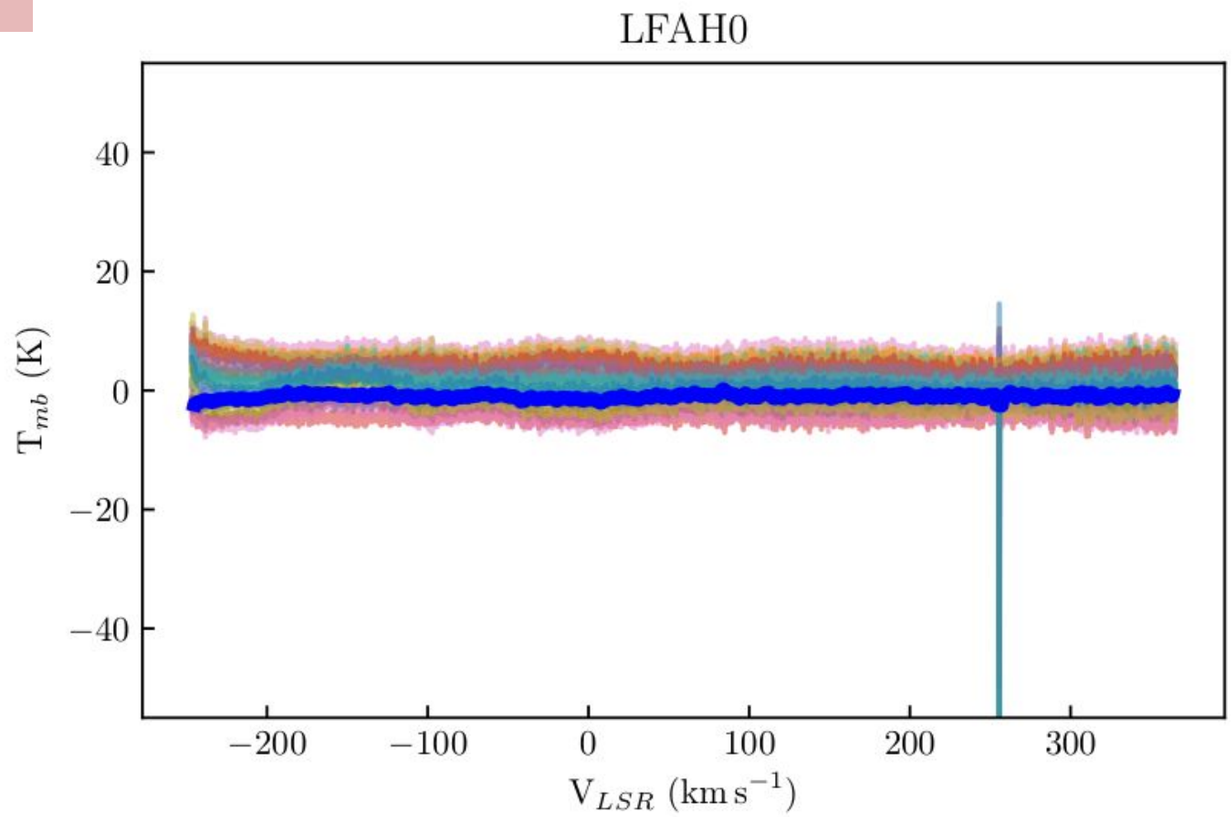


OFF1-OFF2
HOT1-HOT2
= BASELINE

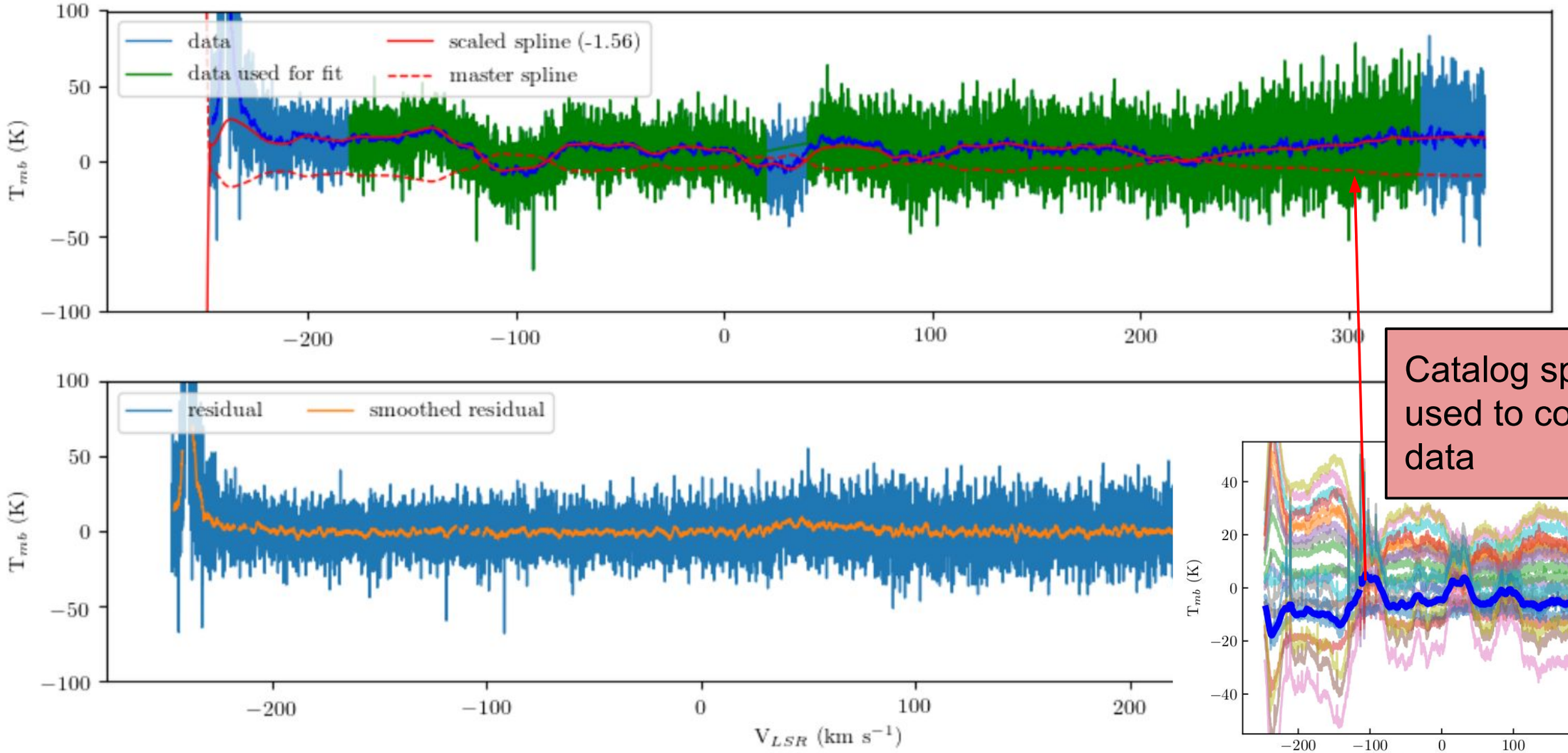
Baseline correction: OFF catalog example

OFF(i)-OFF(j)
HOT1-HOT2





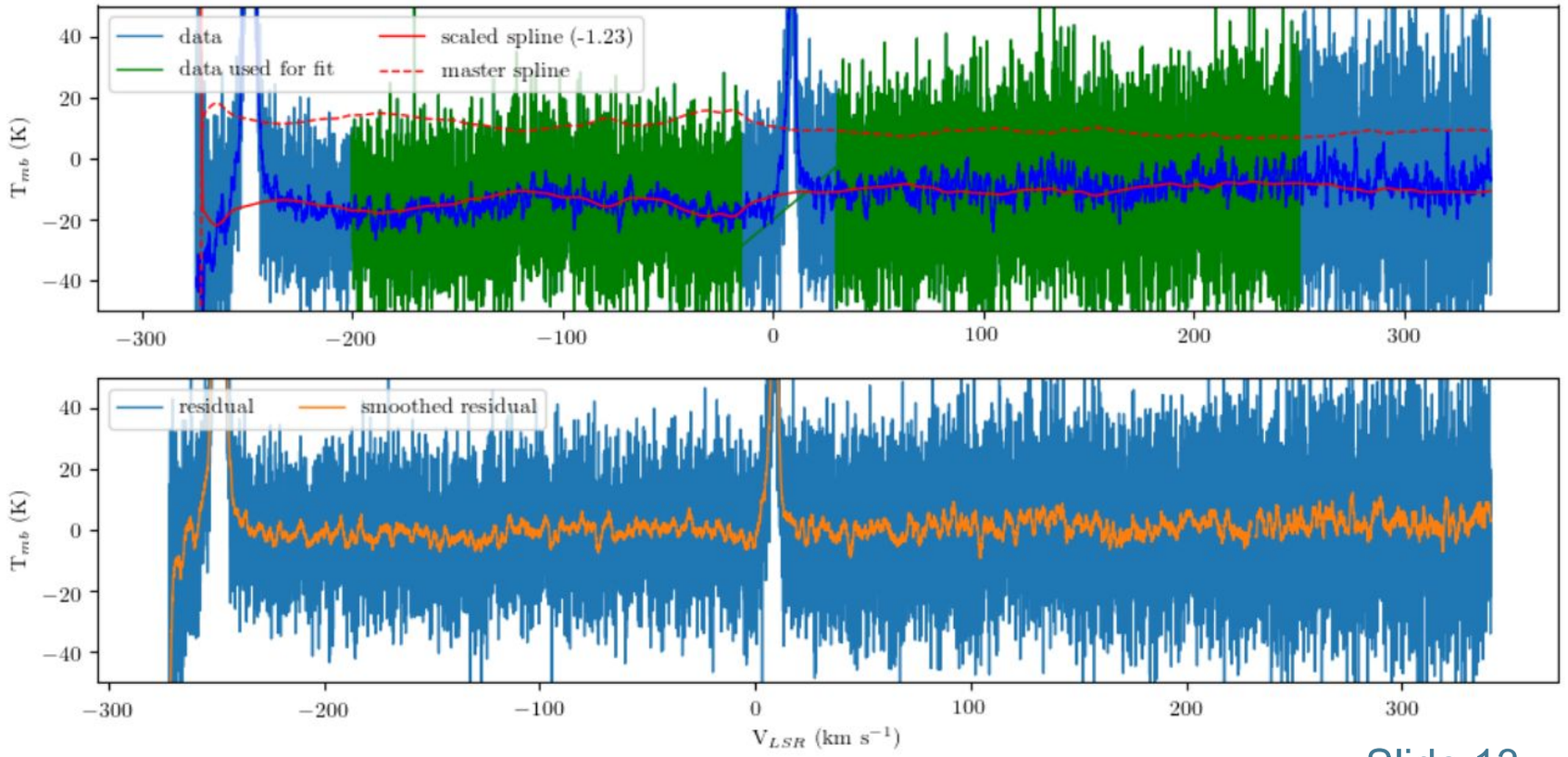
Baseline correction: fitting spline to data



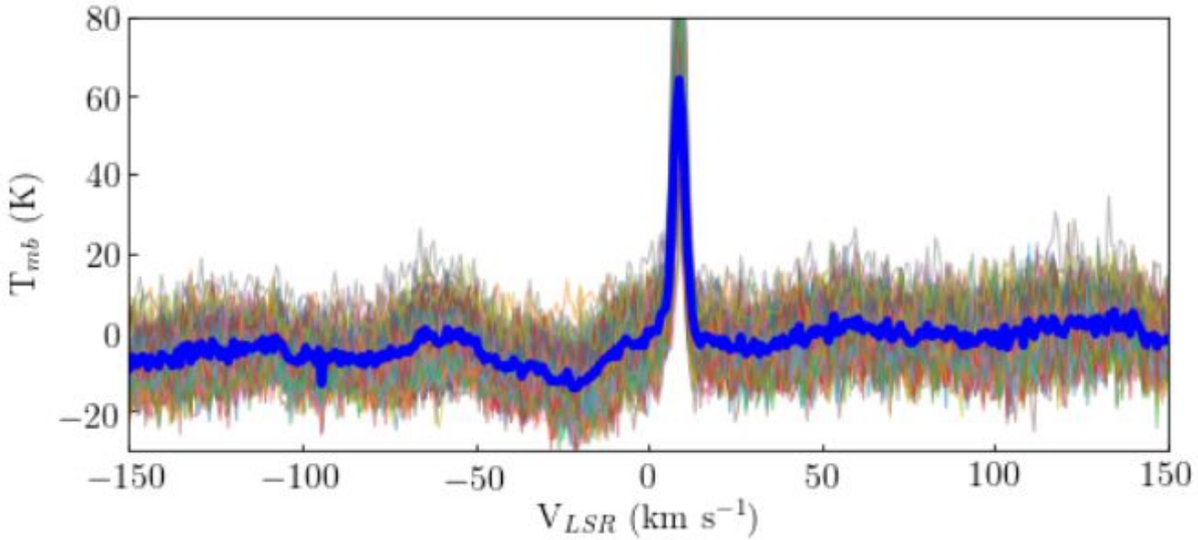
Catalog spline used to correct data

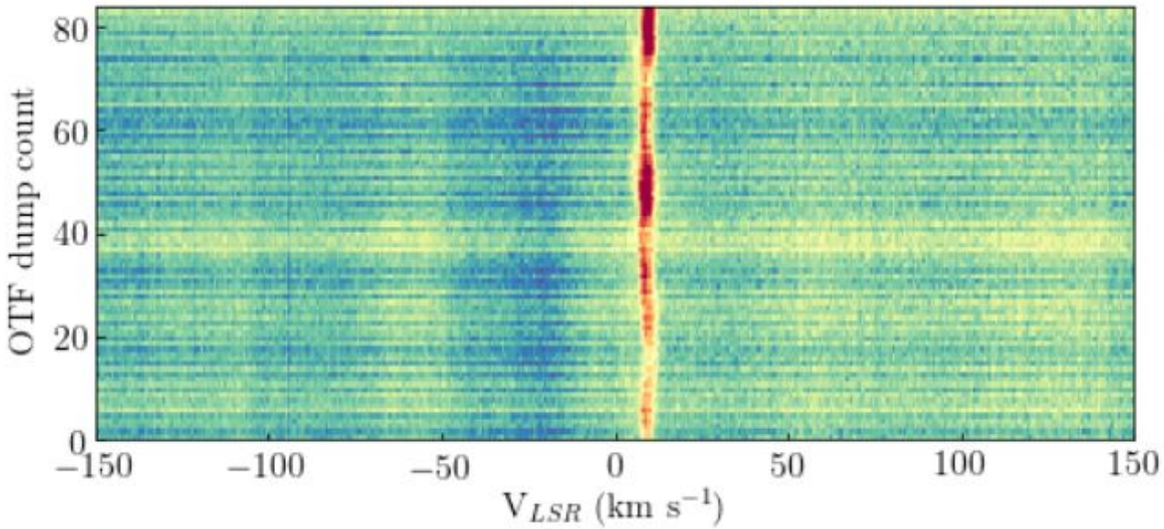
Baseline correction: spline correction process

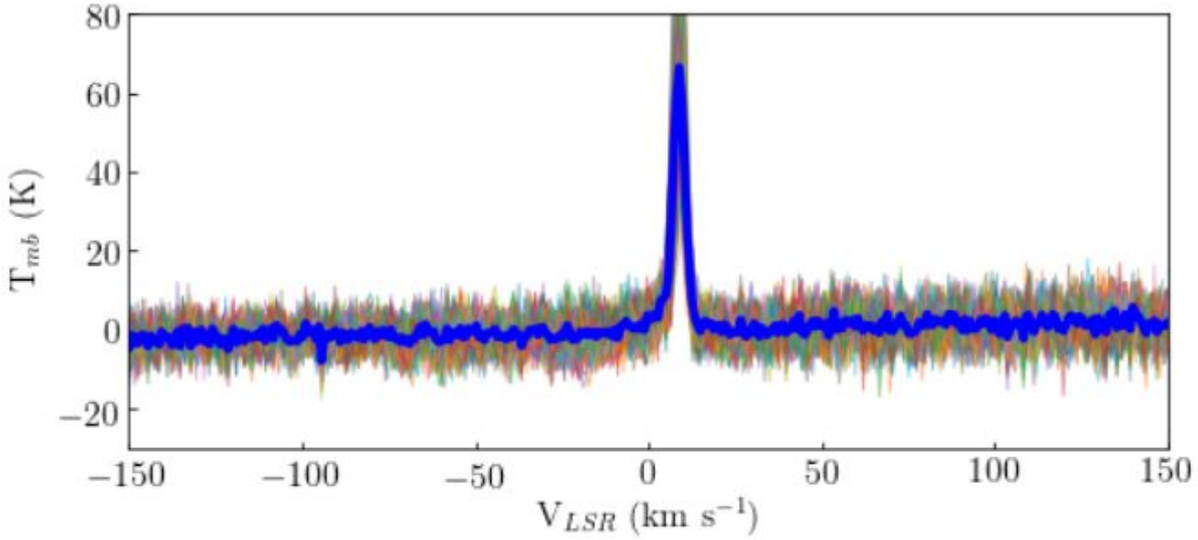
Generate OFF catalog → Fit spline to each OFF residual spectra → Scale each catalog spline to find best fit to ON-OFF data → subtract scaled spline to correct spectra

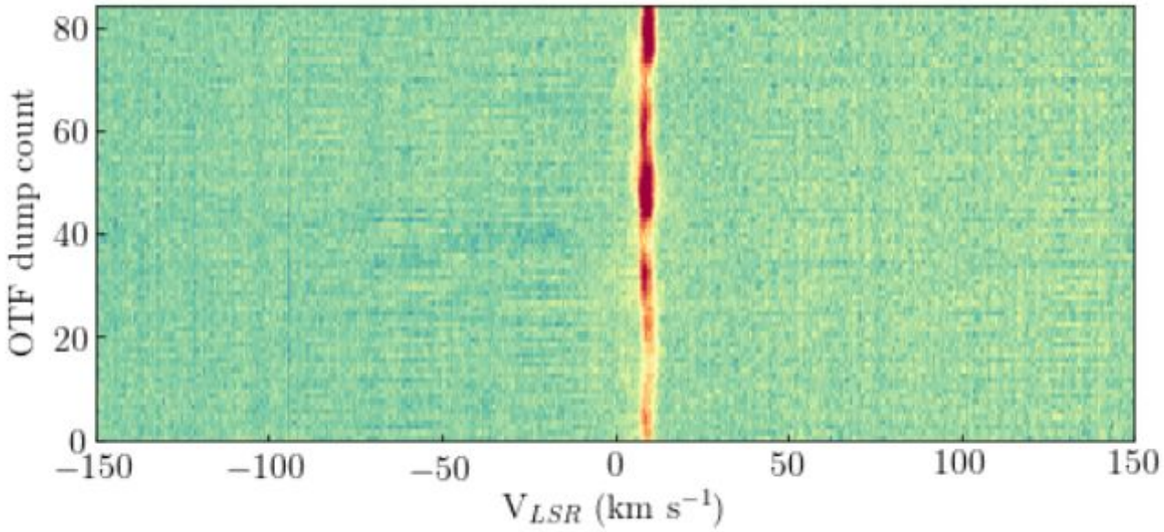


Baseline correction: spline correction outcome



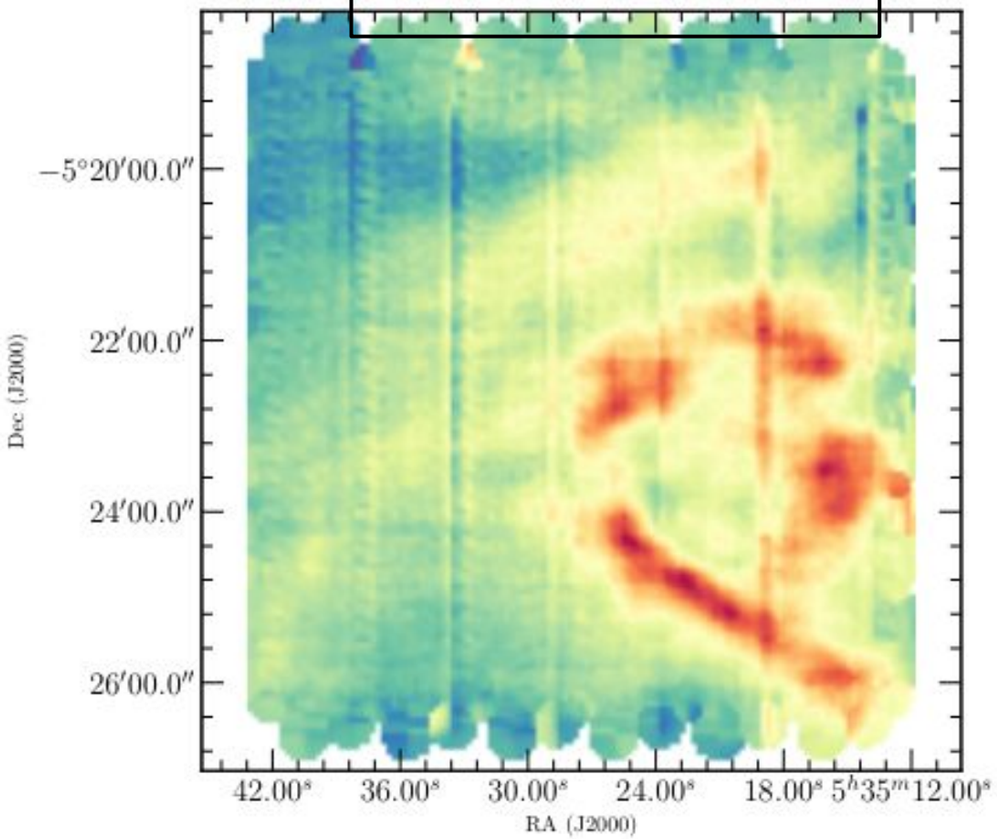




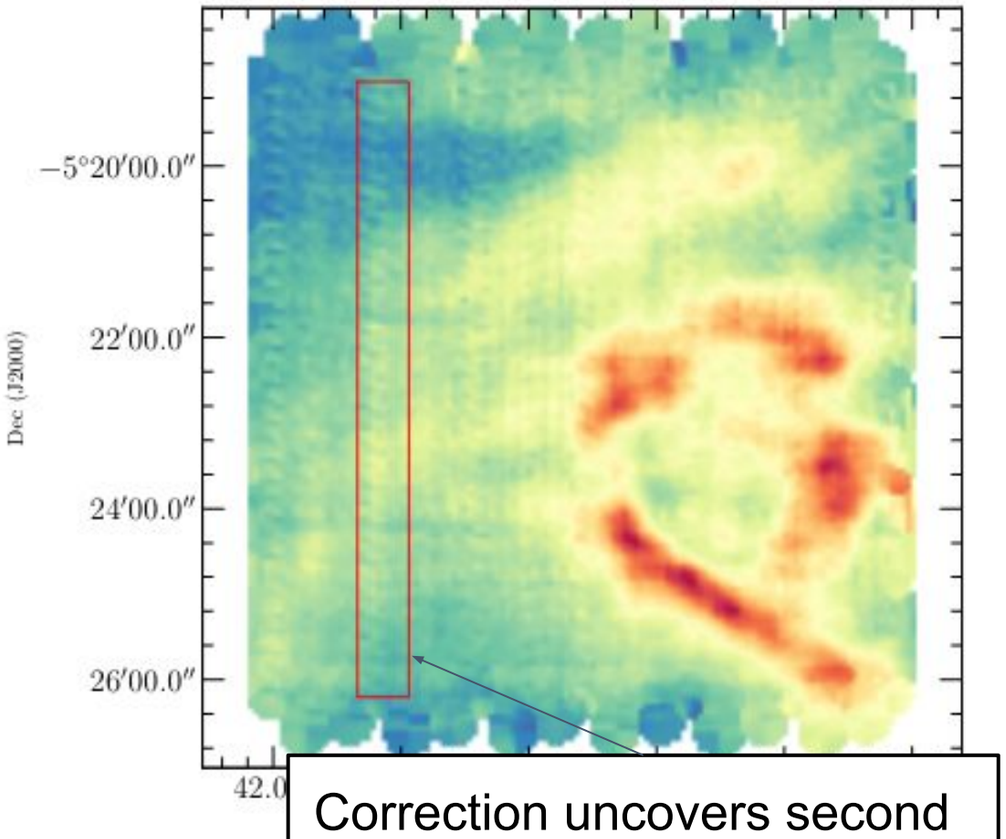


Baseline correction: spline correction outcome

Center tile with polynomial correction

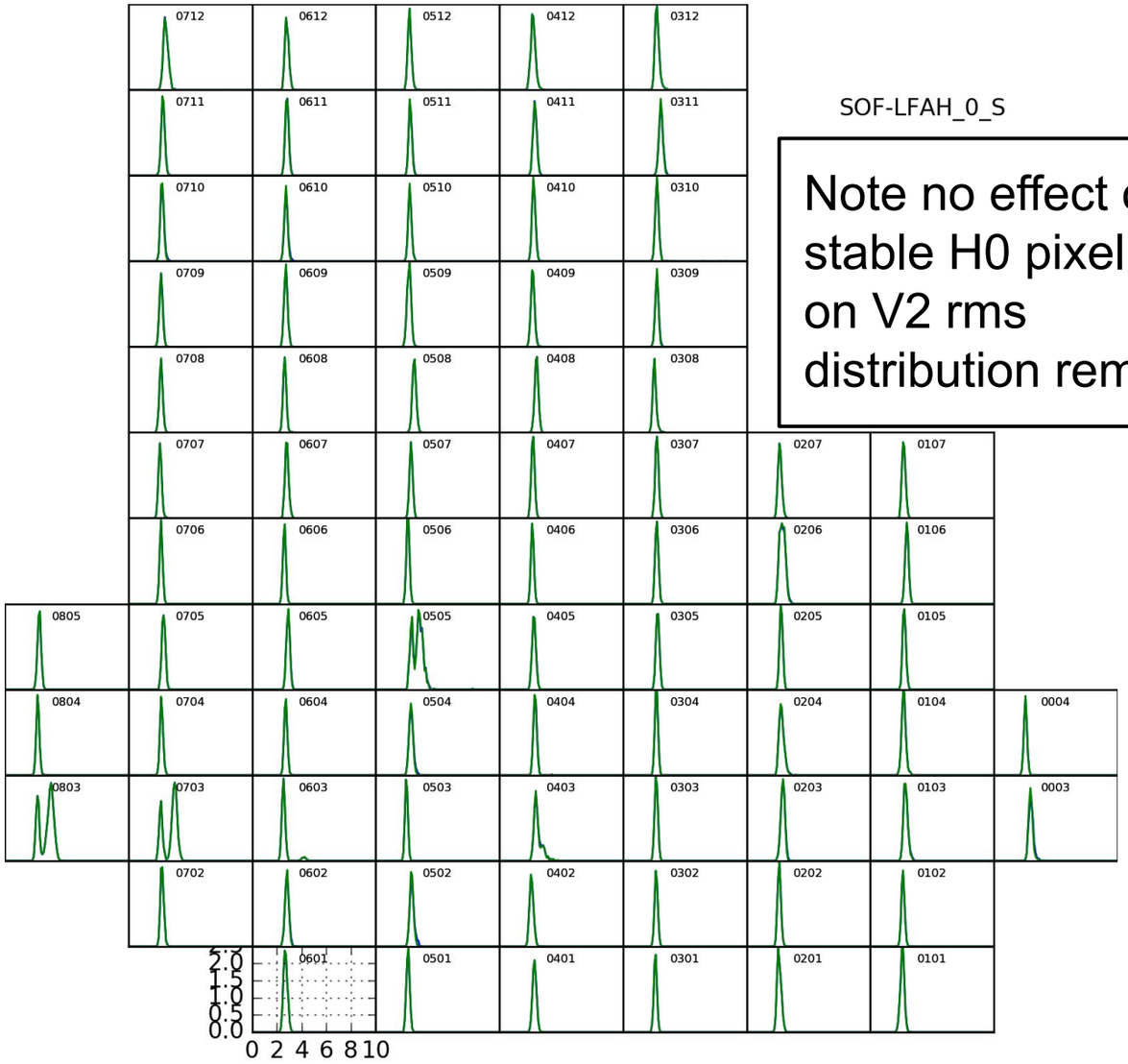


Center tile with spline correction

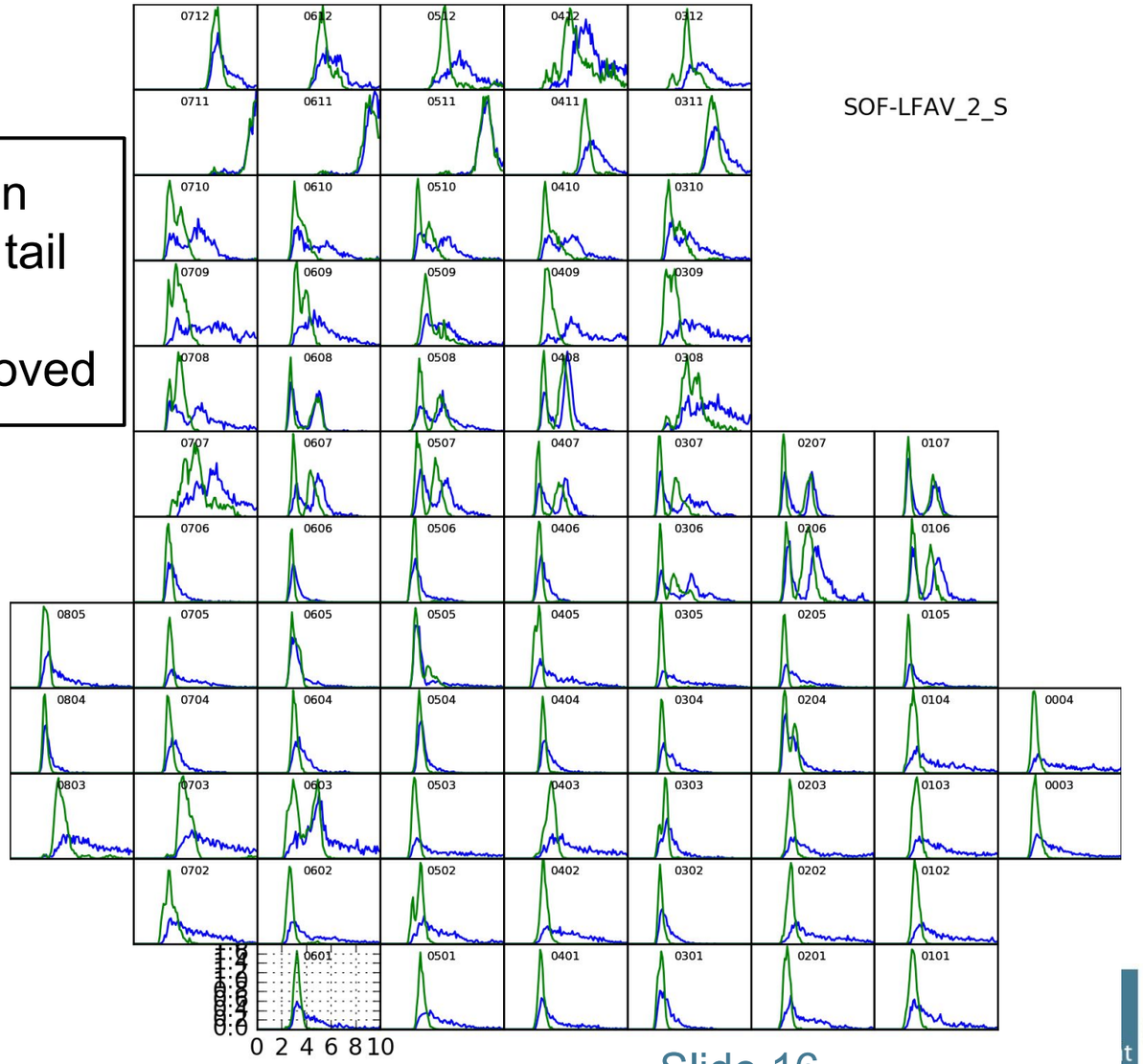


Correction uncovers second order effects in data: gain instability

Baseline correction: spline correction RMS before/after

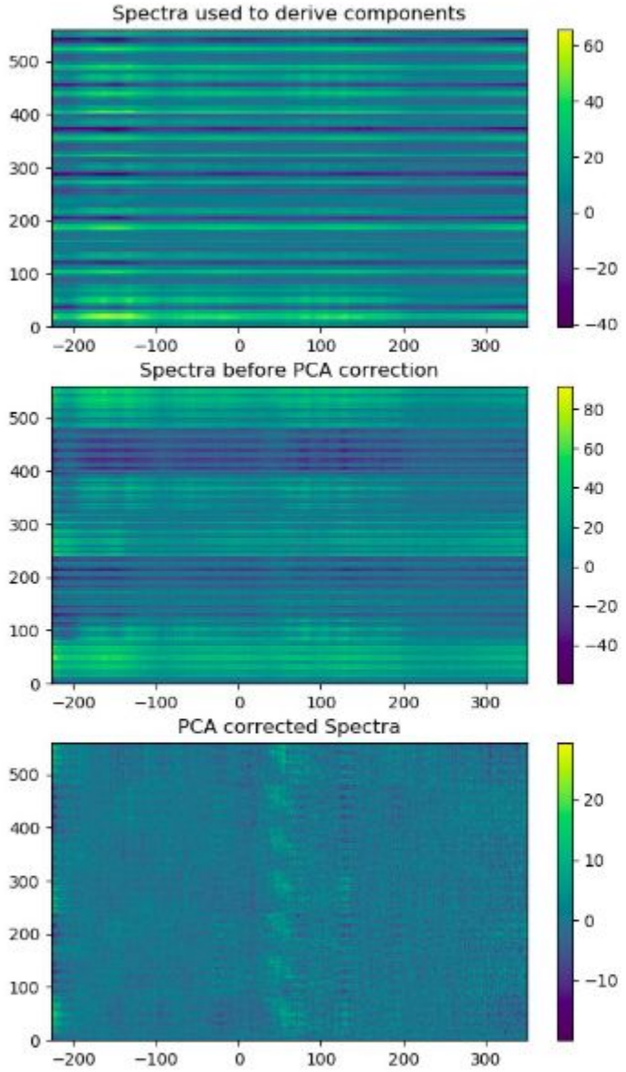


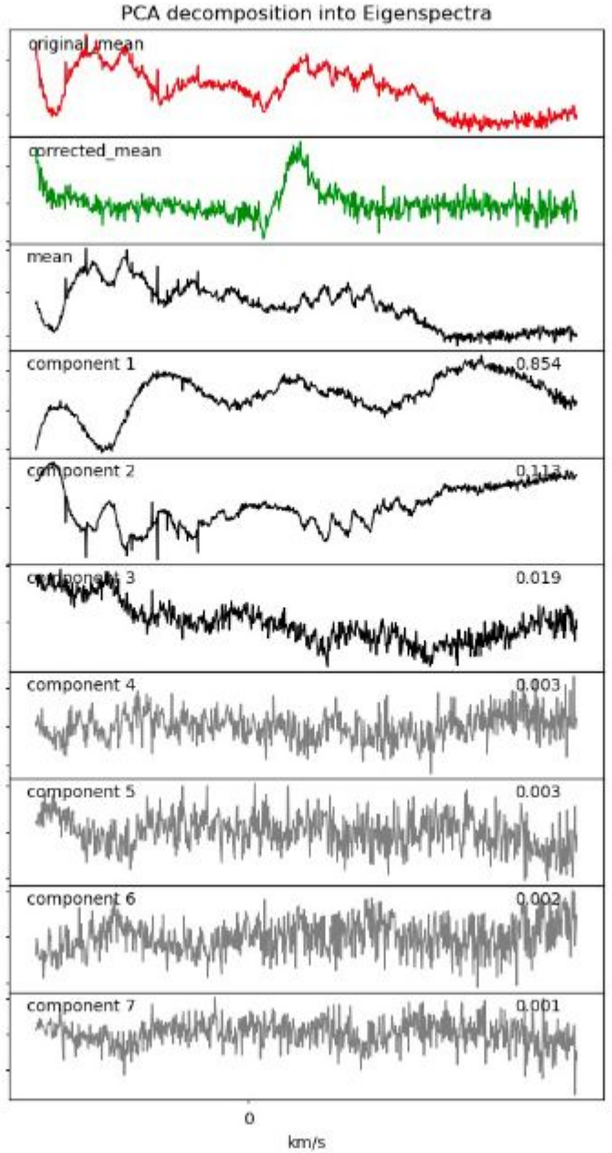
Note no effect on stable H0 pixel, tail on V2 rms distribution removed



Alternative options/Spline code

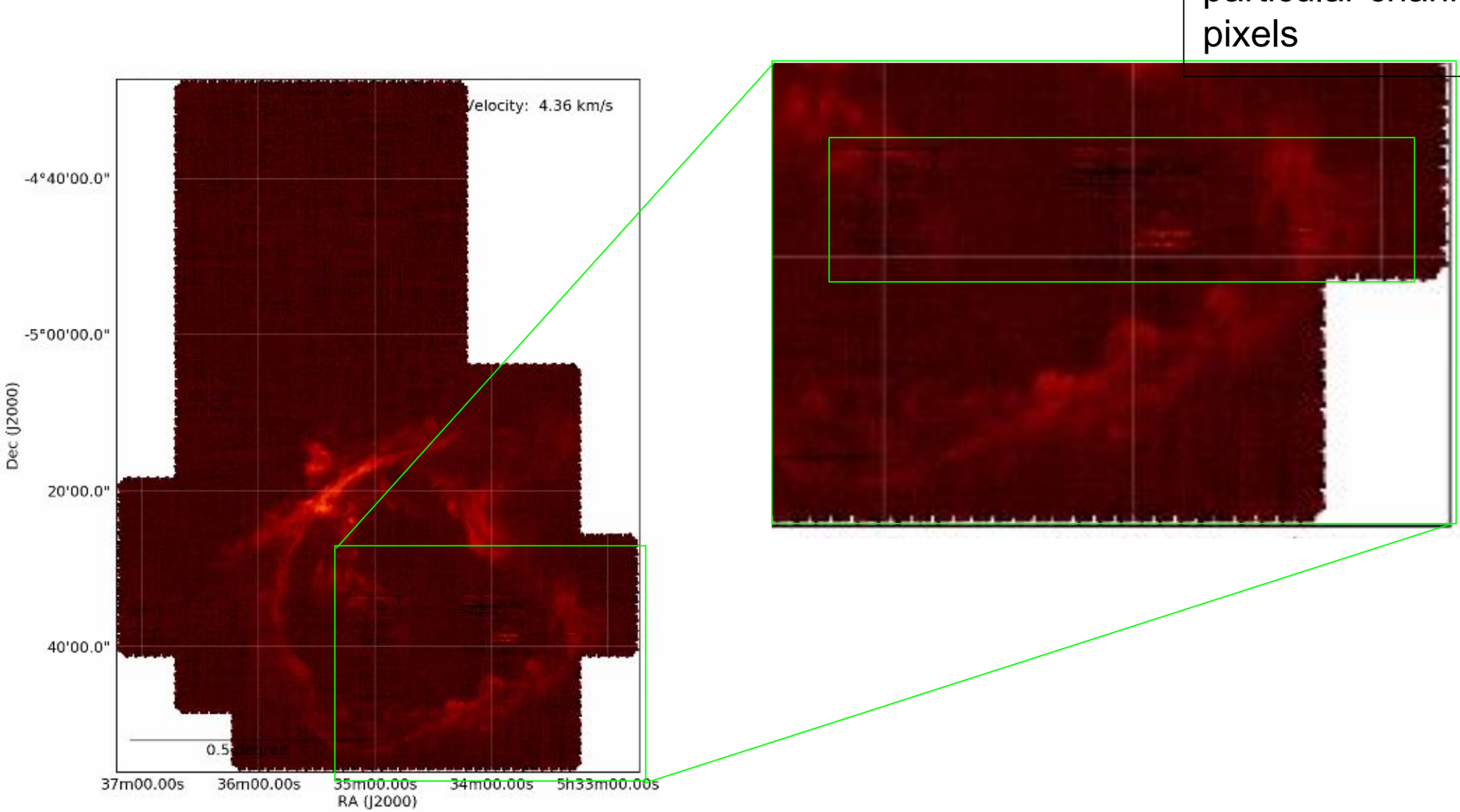
- using sky-diff spectra opens up a number of alternative options for baseline correction
  - recent efforts by feedback team have focussed on principle components methods
- spline fitter demos available here:
  - https://github.com/KOSMAsubmm/kosma_gildas_dlc/blob/main/tests/test_spline_reduction.gildas





Data quality: radio interference

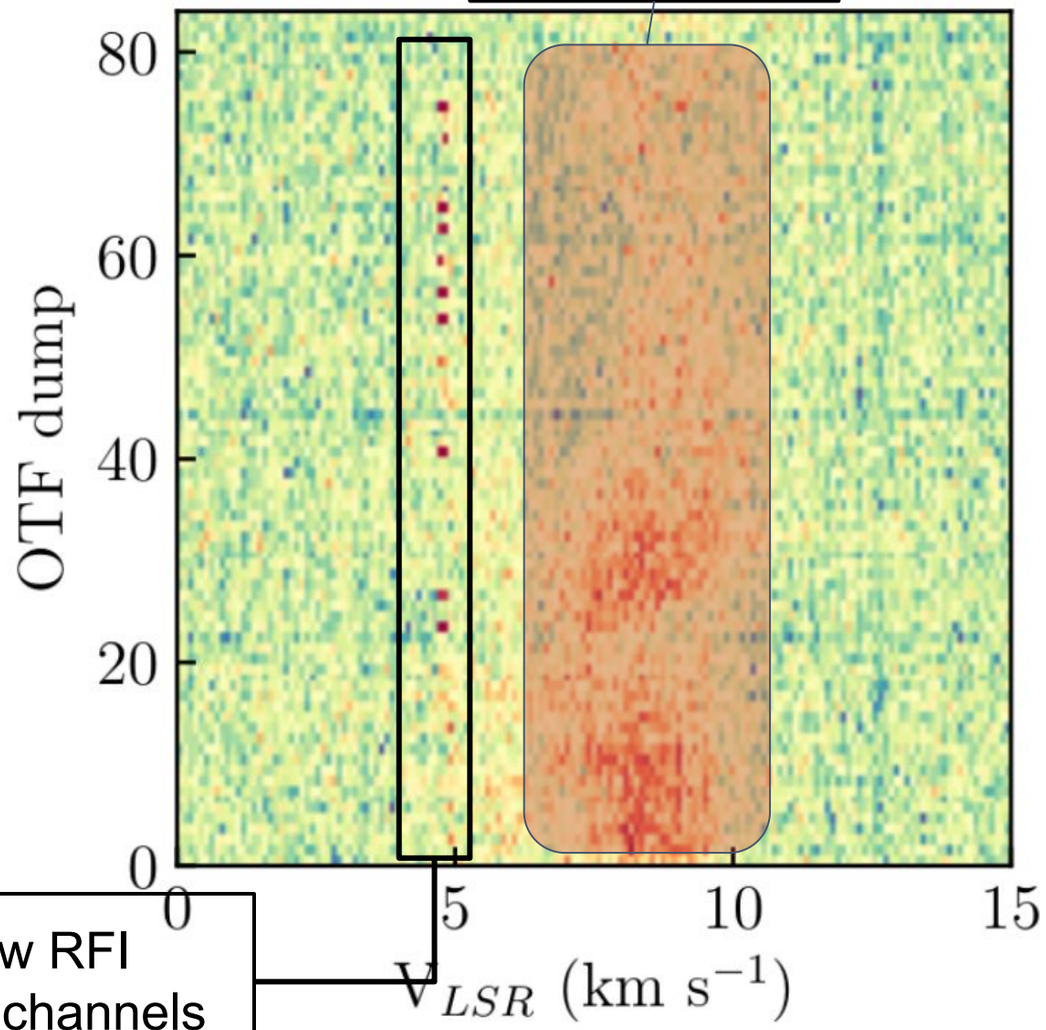
Scratches seen in map at particular channels for particular pixels



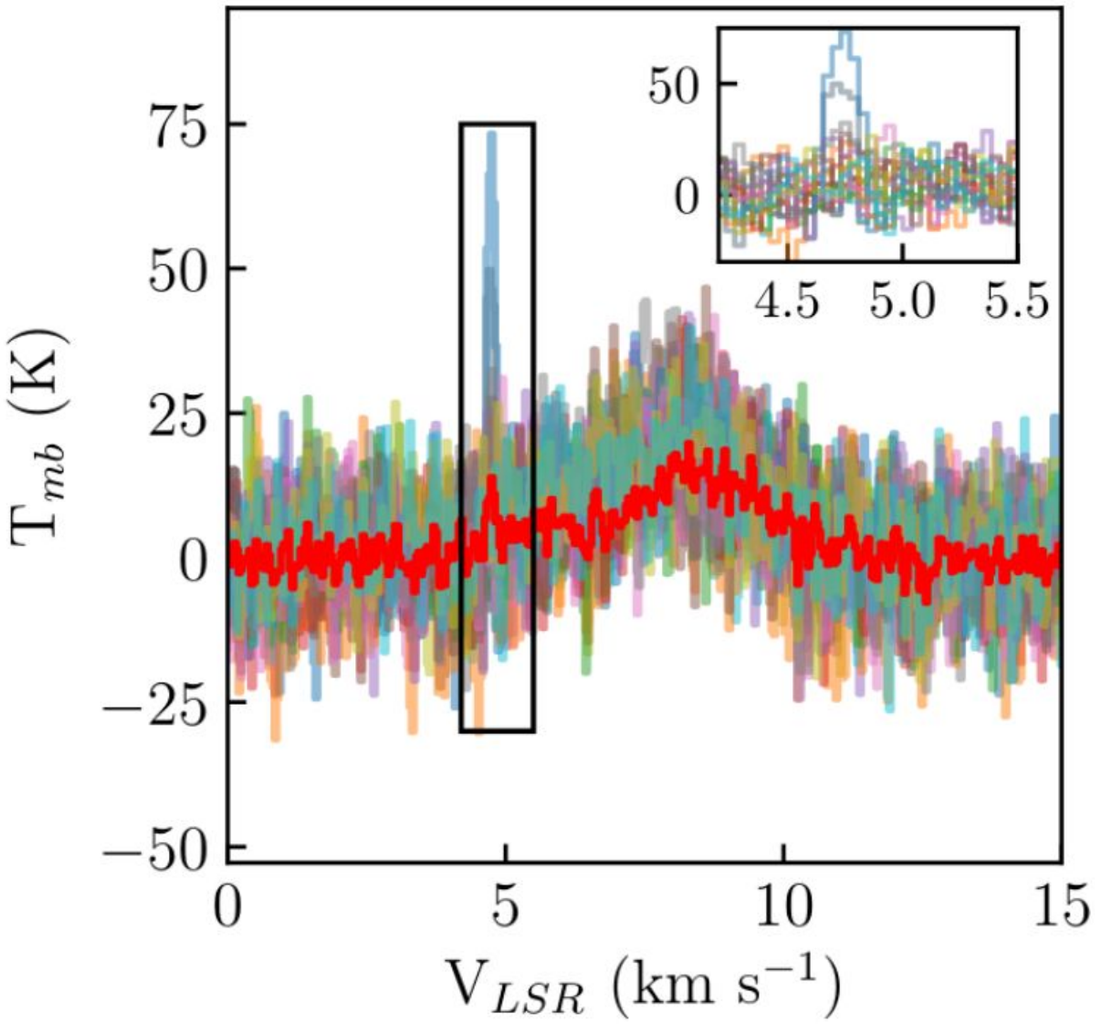
Data quality: radio interference

RFI corresponds to 1.9 GHz emission, a known mobile phone frequency

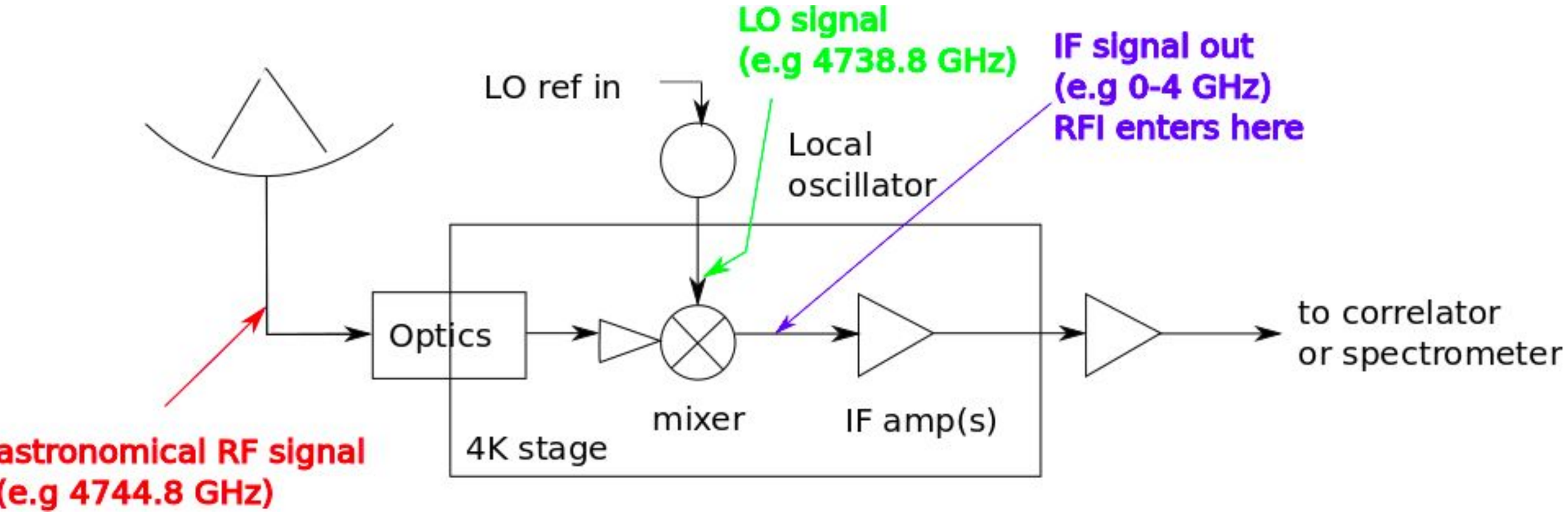
Line emission



Red show RFI affected channels

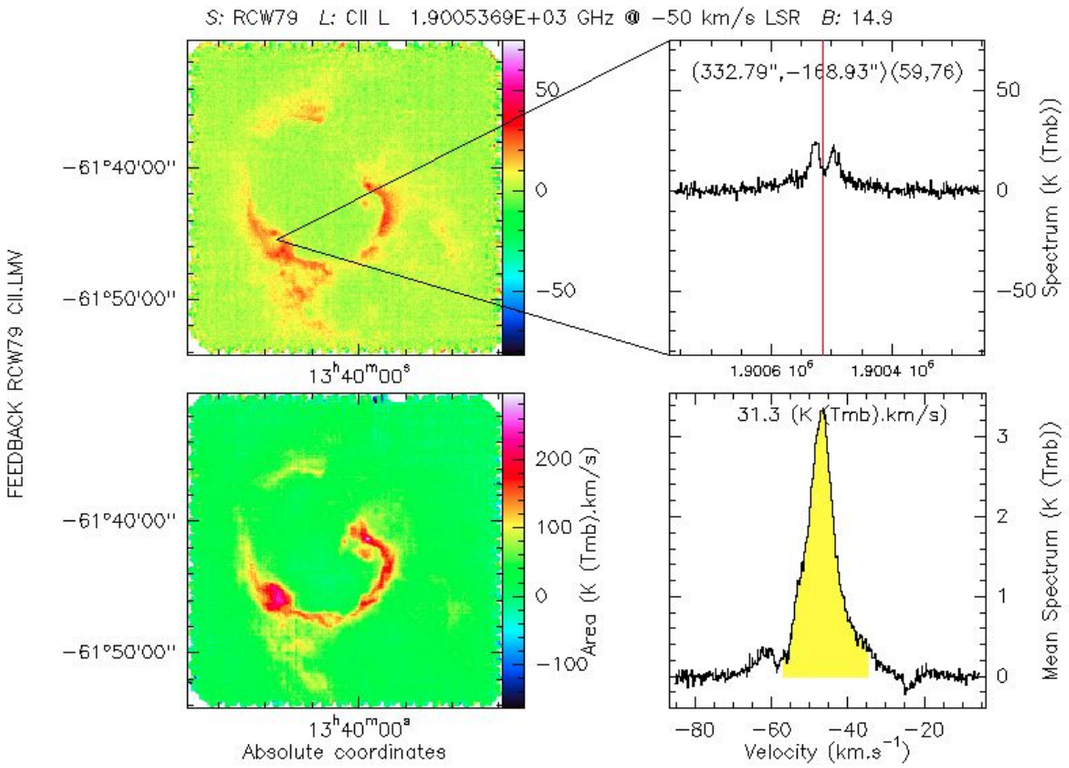


Data quality: radio interference



Example GREAT data packet

- FEEDBACK data release from 2021, available at the following link:
- https://irsa.ipac.caltech.edu/data/SOFIA/GREAT/OC9C/20210807_F766/proc/p10803/data/2021-08-07_GR_F766_07_0077_09221_1900536.9.great.tar



pdf files describing observations and reduction

class script

class files

```
Inflight_Log_GREAT_Cycle_9_07_0077.pdf
Release_of_GREAT_Cycle_9_data_07_0077.pdf
Overview_Project_07_0077_OC9BC_rel5.pdf
Data_Reduction_07_0077_ATielens_OC9BC_rel5.pdf
Cycle9_GR_OT_07_0077_OC9BC_CII.class
07_0077_data-release4_OC9BC-README.txt
RCW79_OC9BC_CII_map.class
FEEDBACK_RCW79_CII.png
2021-08-07_GR_F766_07_0077_09221_1900536.9_Tmb.great
2021-08-07_GR_F766_07_0077_09221_1900536.9_Tant.great
```

Time for a live demo

Wrap up

- Released data in archive is of good quality
- Use class scripts to inform on reduction steps
- Moving to fits early once resampled and map is made in class my preferred approach
- For instrument scientists going forward
  - don’t use gildas as a data format
  - fixed format data, can’t add additional meta data without significant work
  - time series lightly supported
  - Future Cologne project (CCAT) will write fits or an alternative format (hdf5,parquet) directly