Physical Symposium Wuppertal

Chirped Pulse Microwave Spectrometer

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Laborastrophysik

Universität Kassel

Introduction

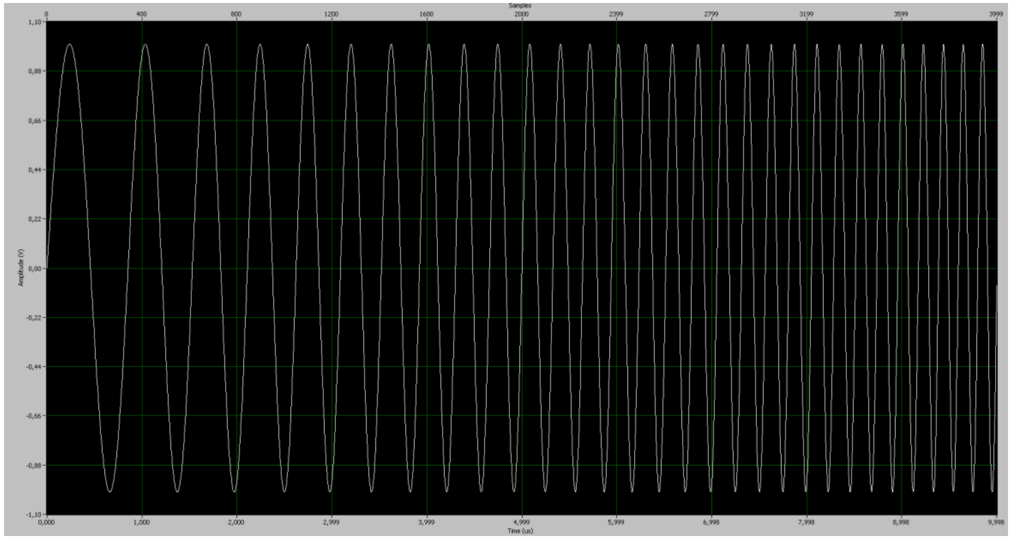
Chirps

- Signals with rising or falling frequency (up/down-chirps)

- Consider linear chirps with instantaneous frequency

$$\boxed{f_{inst}(t) = f_0 + \alpha \cdot t}$$

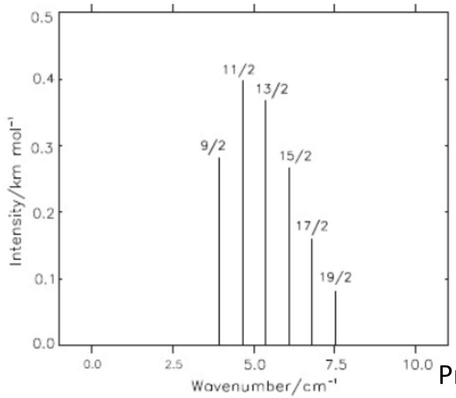
- sweep rate $\alpha = \frac{bandwidth}{pulse\ duration}$

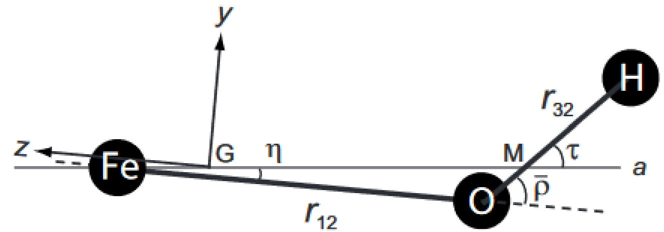


→ induce molecular transitions by sweeping through the frequency

Motivation

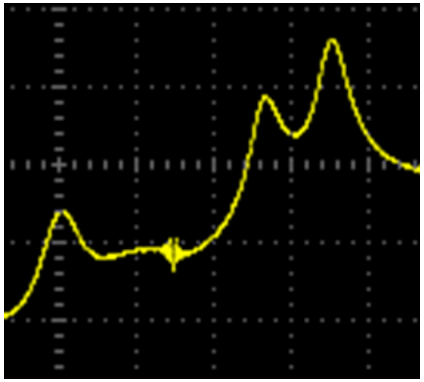
- Absorption or emission spectroscopy of molecules of astrophysical and astrochemical relevance e.g.
  - HCN / HNC
  - FeOH
  - CH_3CN
  - $C_3H_6O_3$





Predicted rotational spectrum ($X^6\Delta$@10K) [HBJ] and possible geometry of FeOH [HNW]

- Fast and broadband scanning with sweep rates up to $\alpha \approx 100\,\frac{\mathrm{GHz}}{\mathrm{s}}$



- Detection of several molecular transitions with one chirp

- Same molecule production conditions for one chirp when using supersonic jets and laser ablation techniques

[HNW] T. Hirano, U. Nagashima, G. Winnewisser, P. Jensen, *Electronic structures and rovibronically averaged geometries of the X^6A_i' and A^6A_i'' states of FeOH*, The Journal of Chemical Physics, 132, 094303 (2010)
[HBJ] T. Hirano, P.R. Bunker et al., *The predicted spectrum of FeOH in its Renner-degenerate X^6A_i' and A^6A_i'' A electronic states*, Journal of Molecular Spectroscopy, 256, 2009, 45-52

Contents

Twin-channel Arbitrary Waveform Generator (AWG)

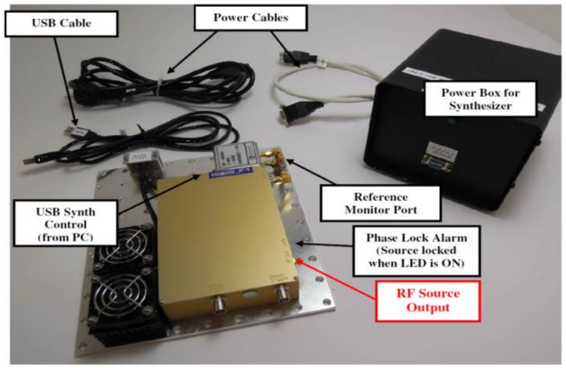
- Generation of arbitrary signals by sampling stored waveforms → chirps
- 400 MSamples/s sample rate
- 145 MHz analog bandwidth → chirp bandwidth

NI PXIe-5451 AWG [N1]

VDI Synthesizer

- output frequency between 8 GHz and 20 GHz
- output power 16 dBm – 20 dBm

→ Use synthesizer RF as carrier for the chirps

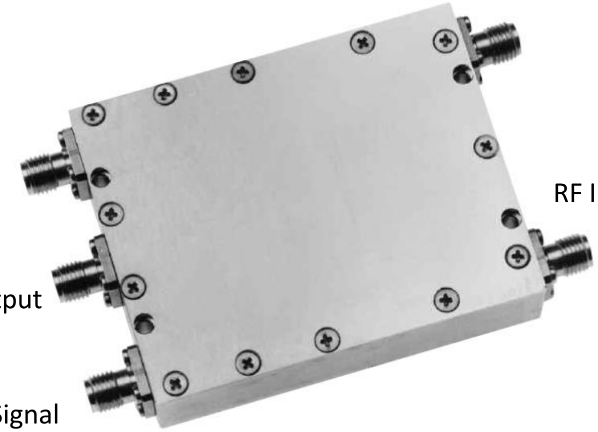


VDI S0037 Synthesizer [V0]

[N] http://www.ni.com/datasheet/pdf/en/ds-235
[V0] VDI S0037 und VDI S0051 Users Guide, Virginia Diodes, Inc. 2014
[V] http://www.vadiodes.com/en/products/frequency-synthesizer-and-frequency-counter

I/Q-Modulator

- Mixing of the chirps (I/Q-waveform) with carrier signal
- Output signal: $cos(2\pi[f_{Chirp} + f_{Carrier}]t)$
- 2 – 26 GHz RF input and output
- DC – 500 MHz IF-bandwidth



IQ-Modulator MITEQ-SM0226LC1MDQ [M]

Signal detection

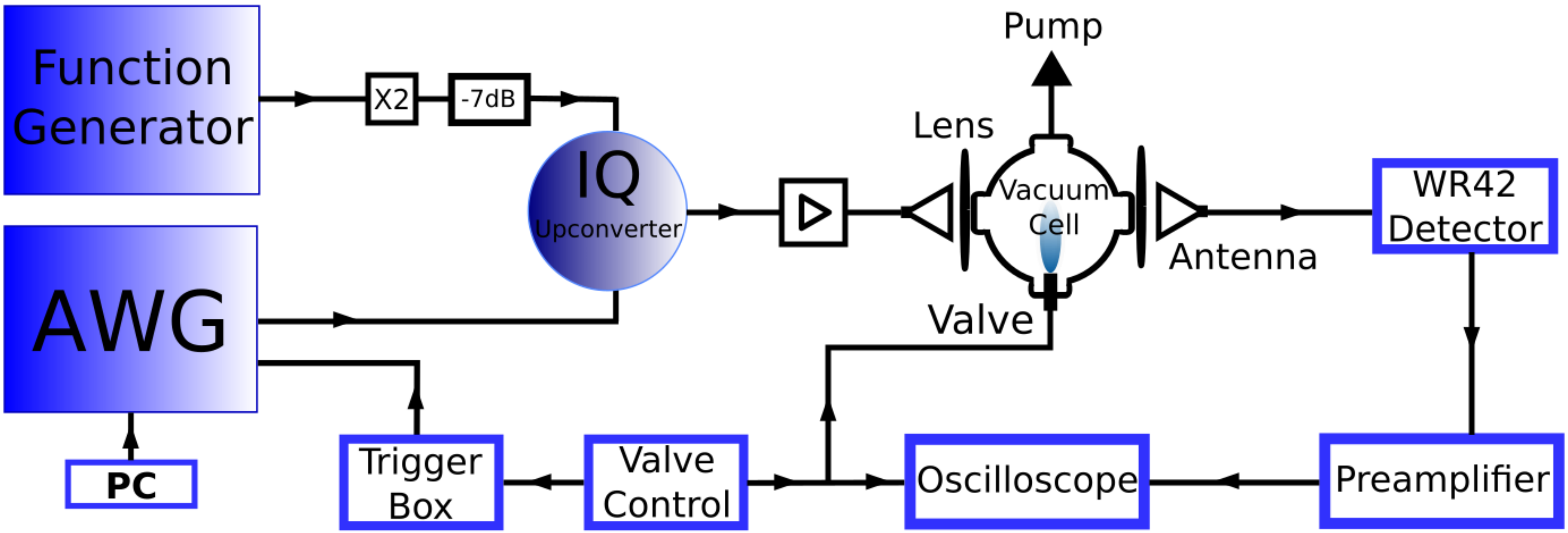
Detector	WR-42	WR-8.0
Frequency range [GHz]	18.0-26.5	90-140

- Measurements above 140 GHz are available as well with a terahertz chain

WR42 Detektor [MR]

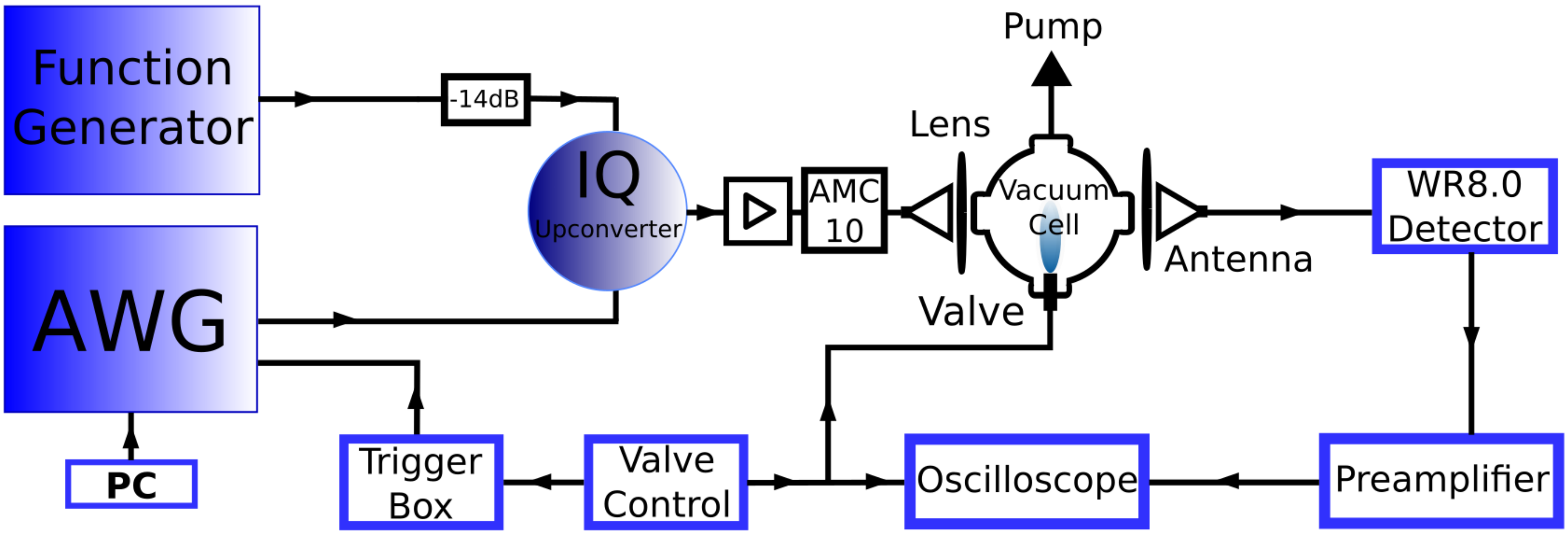
[M] https://www.miteq.com/docs/MITEQ-SM0226LC1MD.PDF
[MR] http://www.microwaveresourcesinc.com/MRI-11.HTM
[VDID] http://vadiodes.com/en/products/detectors?id=212

K-Band

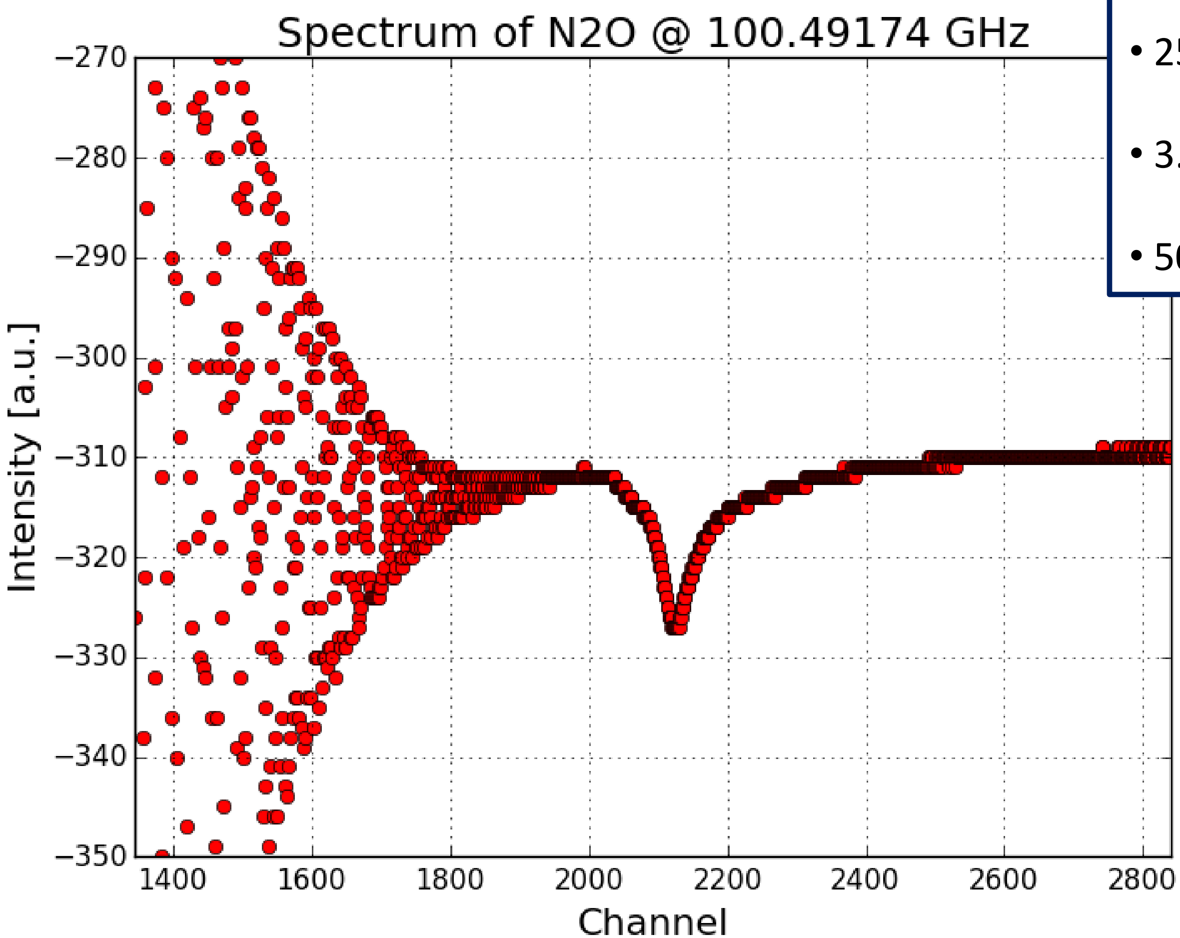


○ Teflon windows and lenses are used

W-Band

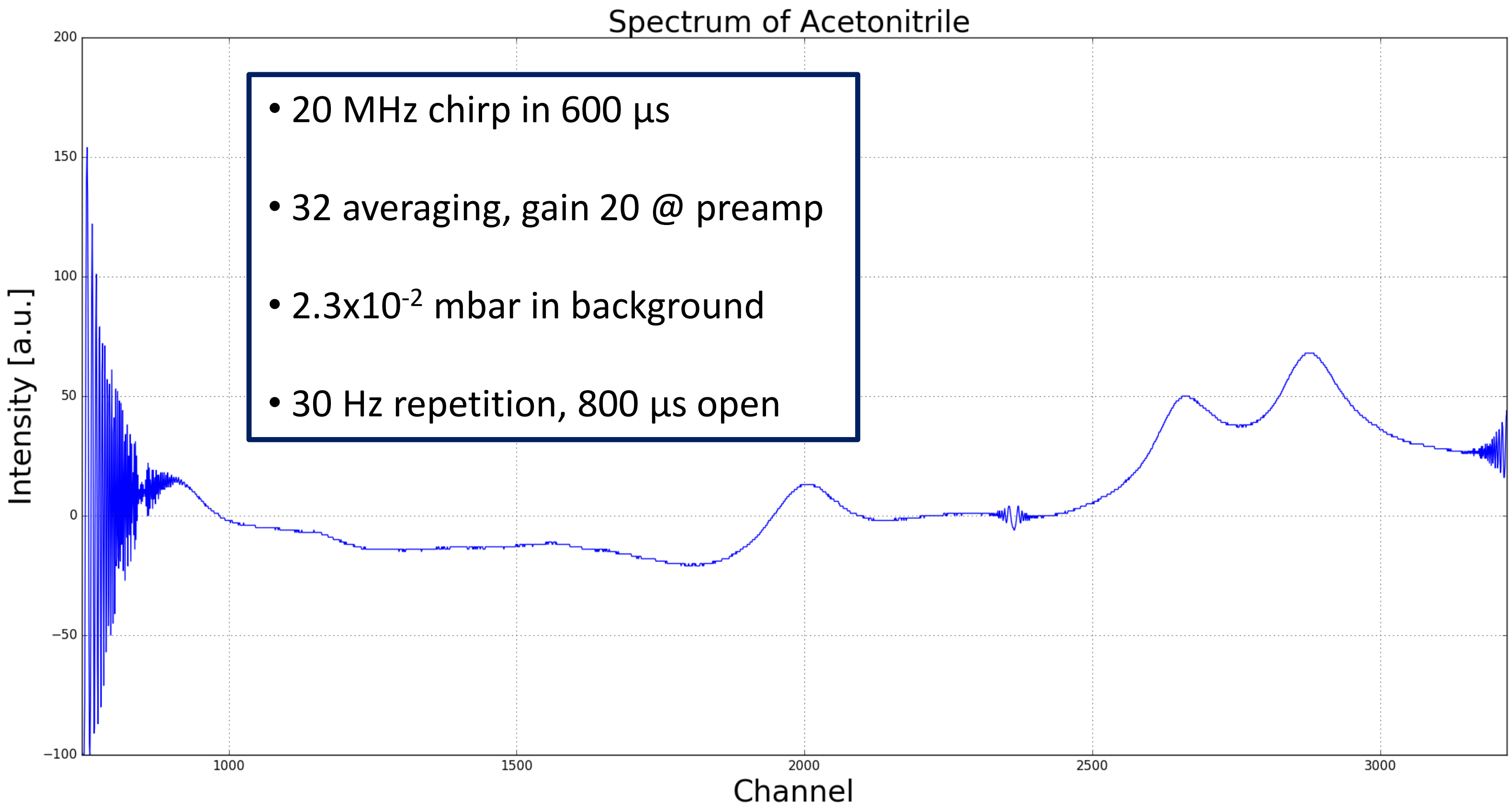


○ foil windows and teflon lenses are used



- 50.0-50.66667MHz chirp in 600 µs
- 256 averaging, gain 20 @ preamp
- 3.3×10^{-2} mbar in background
- 50 Hz repetition, 800 µs open

[JPL] NASA - JPL Molecular Spectroscopy - CALTECH (California Institute of Technology), JPL Molecular Spectroscopy Database - Catalog Browser Form, http://spec.jpl.nasa.gov/ftp/pub/catalog/catform.html

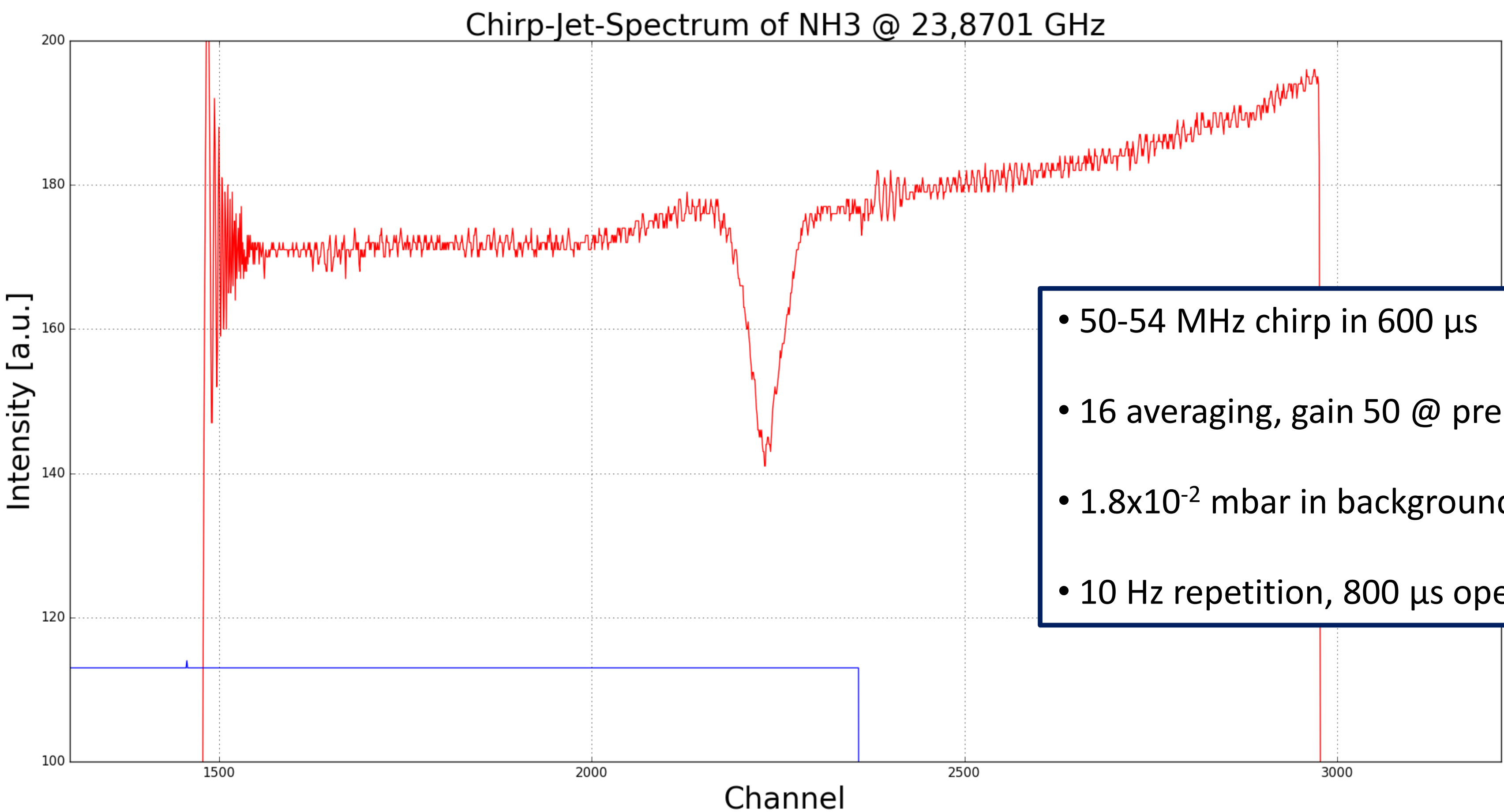


- 20 MHz chirp in 600 µs
- 32 averaging, gain 20 @ preamp
- 2.3×10^{-2} mbar in background
- 30 Hz repetition, 800 µs open

→ Four acetonitrile transitions are detected between 91.96998 GHz and 91.98998 GHz

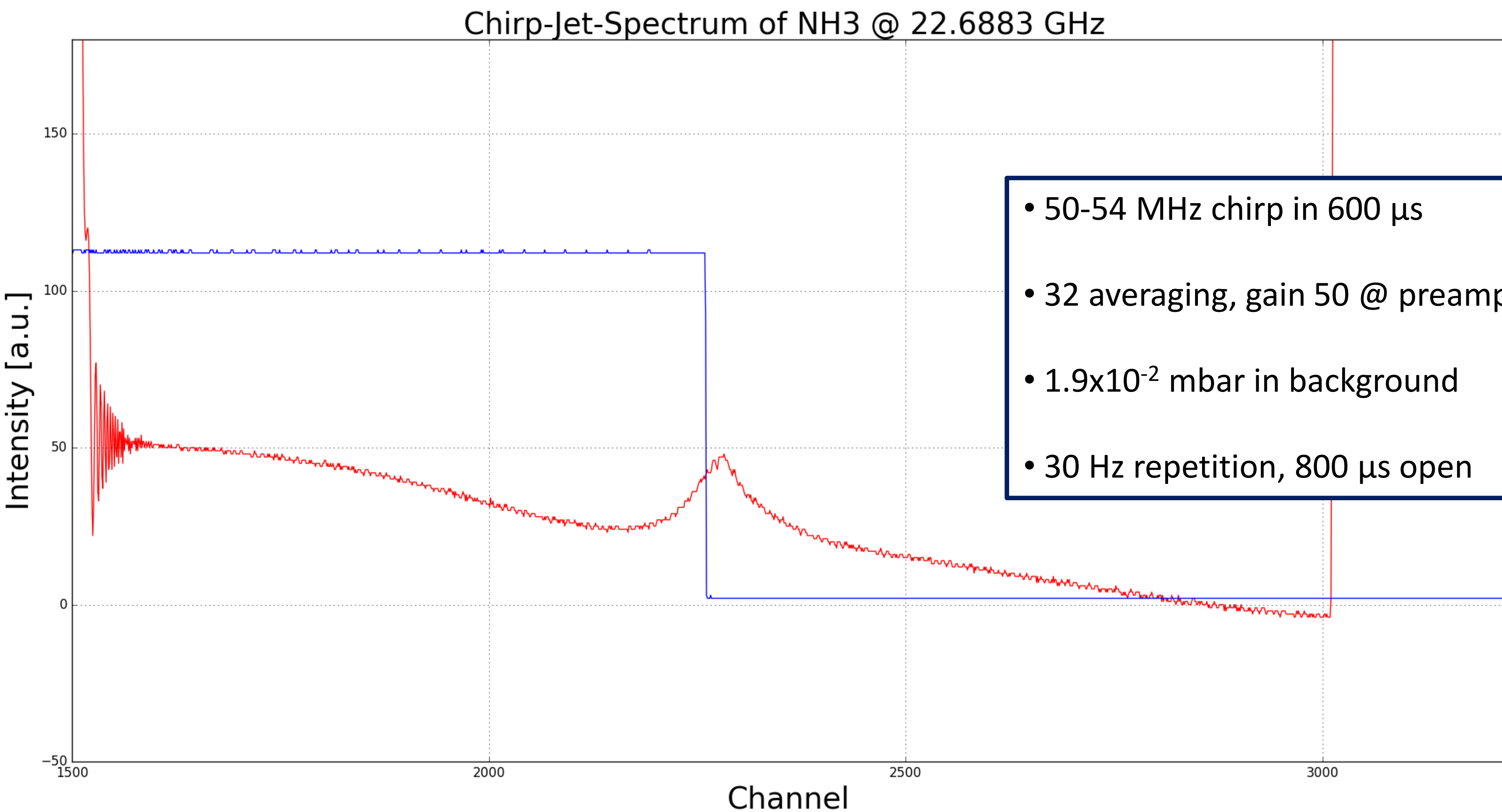
[JPL] NASA - JPL Molecular Spectroscopy - CALTECH (California Institute of Technology), JPL Molecular Spectroscopy Database - Catalog Browser Form, http://spec.jpl.nasa.gov/ftp/pub/catalog/catform.html

Ammonia measurements (15 % in He)



- 50-54 MHz chirp in 600 µs
- 16 averaging, gain 50 @ preamp
- 1.8×10^{-2} mbar in background
- 10 Hz repetition, 800 µs open

[JPL] NASA - JPL Molecular Spectroscopy - CALTECH (California Institute of Technology), JPL Molecular Spectroscopy Database - Catalog Browser Form, http://spec.jpl.nasa.gov/ftp/pub/catalog/catform.html



- 50-54 MHz chirp in 600 µs
- 32 averaging, gain 50 @ preamp
- 1.9×10^{-2} mbar in background
- 30 Hz repetition, 800 µs open

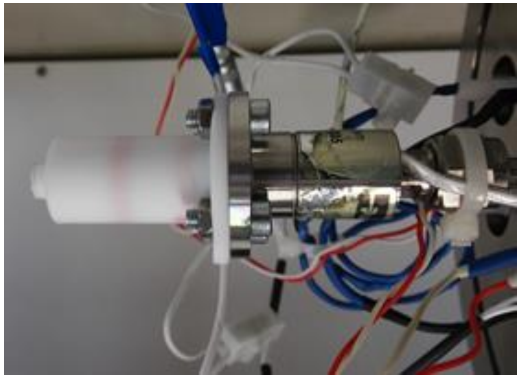
[JPL] NASA - JPL Molecular Spectroscopy - CALTECH (California Institute of Technology), JPL Molecular Spectroscopy Database - Catalog Browser Form, http://spec.jpl.nasa.gov/ftp/pub/catalog/catform.html

Outlook

- Optimization of experimental setup and techniques concerning power, bandwidth and measurement time

- Use of faster nozzles in order to obtain shorter pulses and therefore reduce measurement time

- Use of a discharge nozzle to produce astrophysical and astrochemical interesting molecules

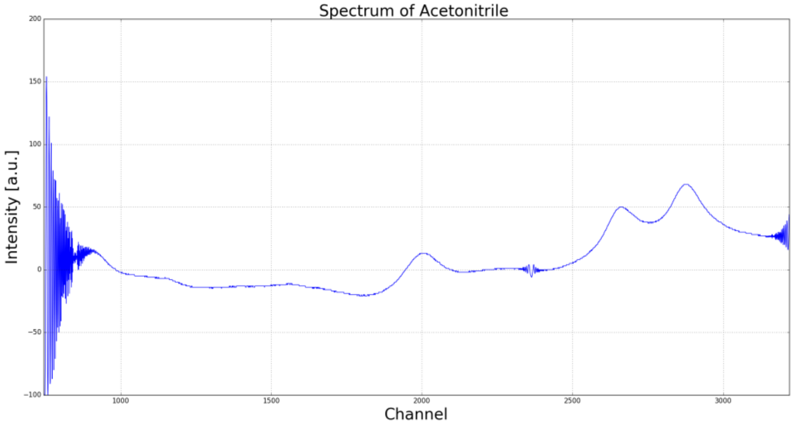


- Measurement of HCN, HNC, FeOH, CH_3CN, ...

- Extension of the setup to emission spectroscopy with acquisition of molecular FID signals

Summary

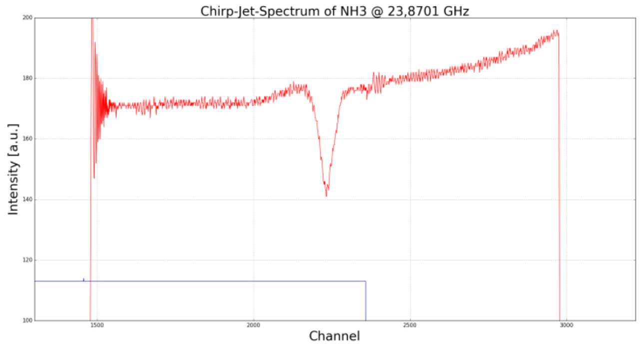
- Design layout of a chirped pulse microwave spectrometer



- Fast and broadband investigation of molecular transitions

- Using the spectrometer in combination with supersonic jets

  → improved investigation of rotational and inversion transitions



- Investigation of ammonia, acetonitrile and nitrous oxide via chirp jet measurements

Thank you for your attention !

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