Max-Planck-Institut
für Radioastronomie

RadioNet

DIGITALLABOR
01001010

Fast Fourier Transform Spectrometer (FFTS)

Past, Present and Future

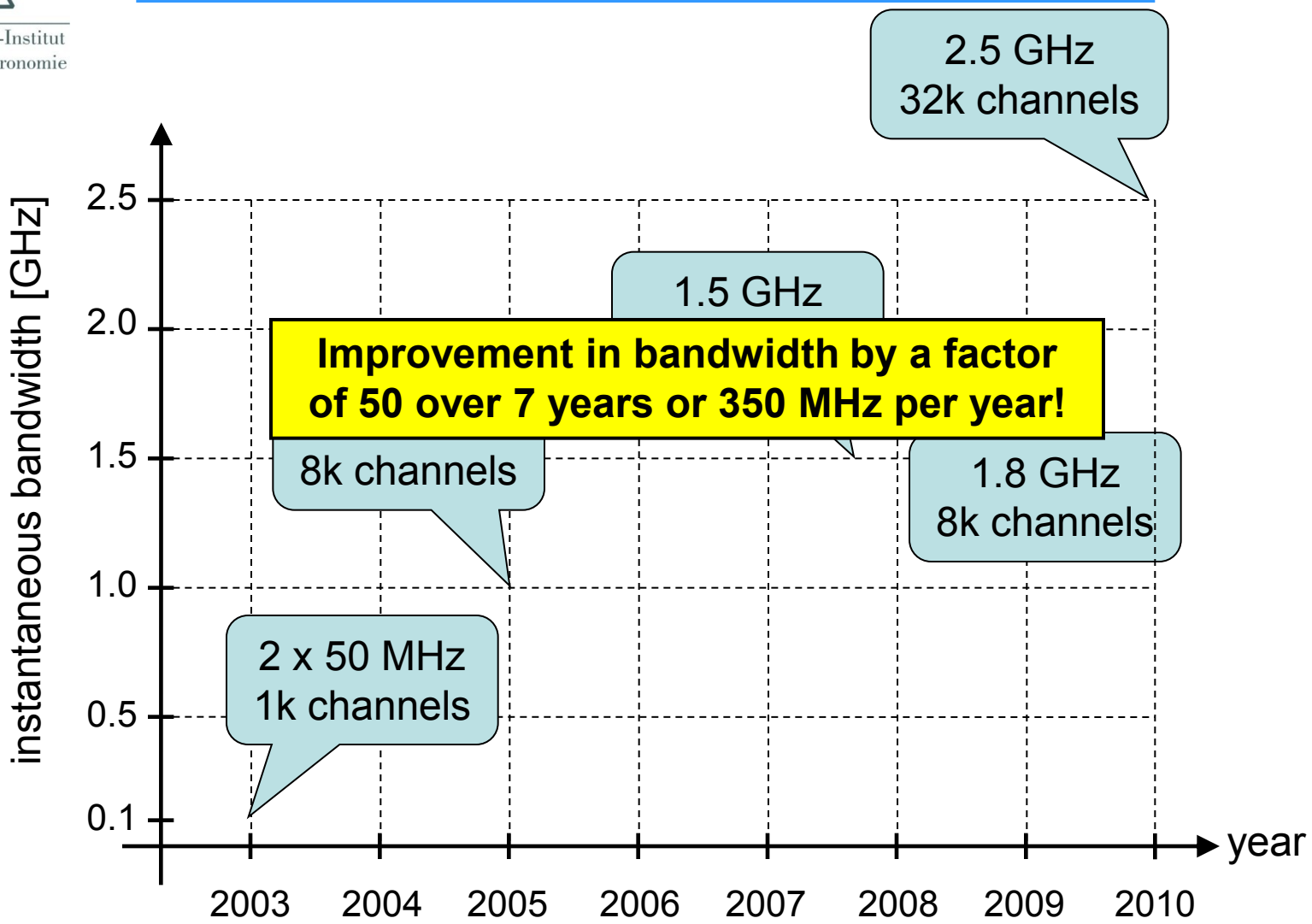
Bernd Klein

Max-Planck-Institut für Radioastronomie, Bonn
- Germany -

Max-Planck-Institut
für Radioastronomie

DIGITALLABOR

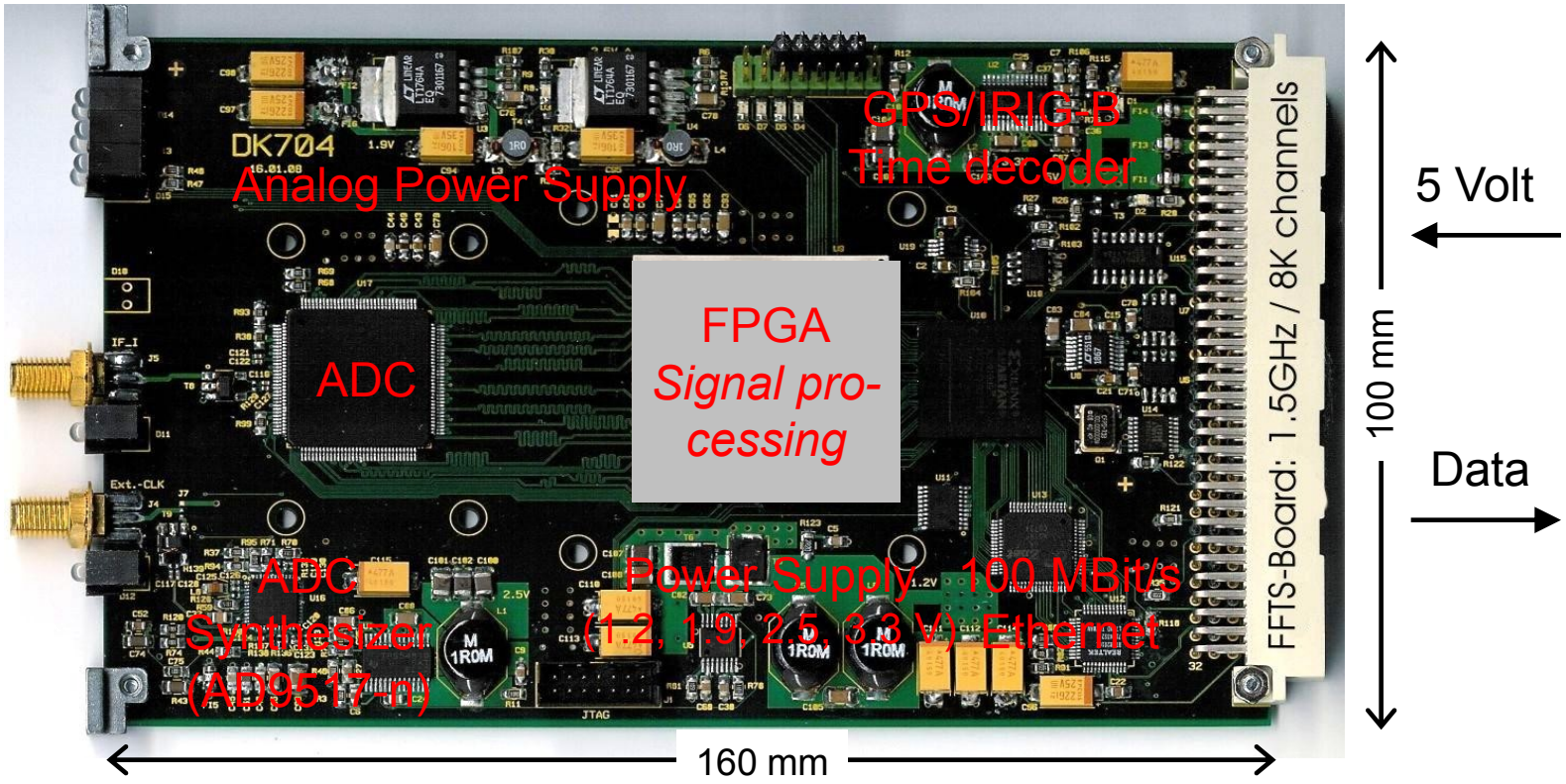
FFTS :: *A short "history"*



Max-Planck-Institut
für Radioastronomie

DIGITALLABOR

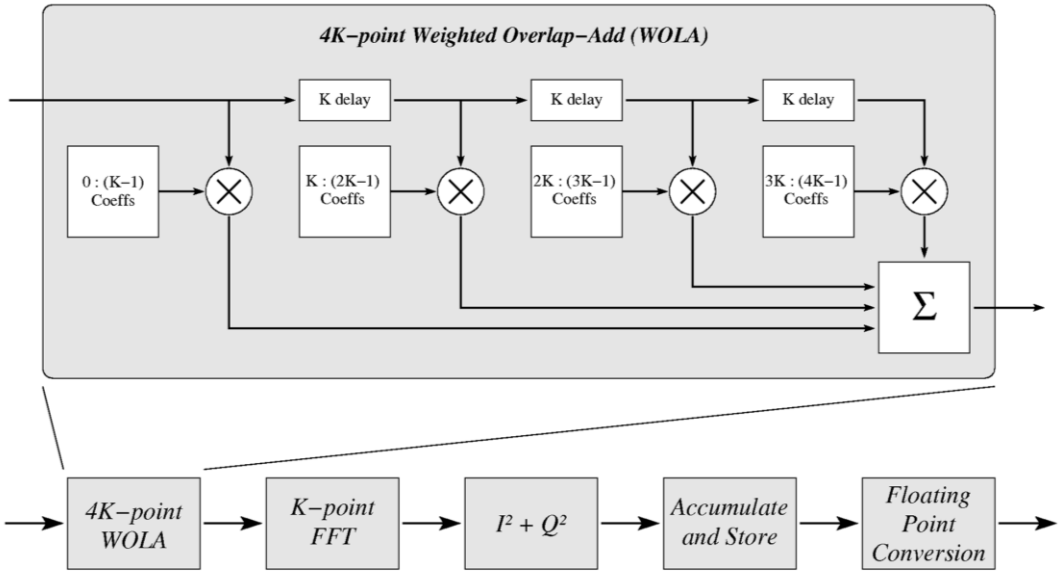
FFTS :: *1.5 GHz bandwidth Board*

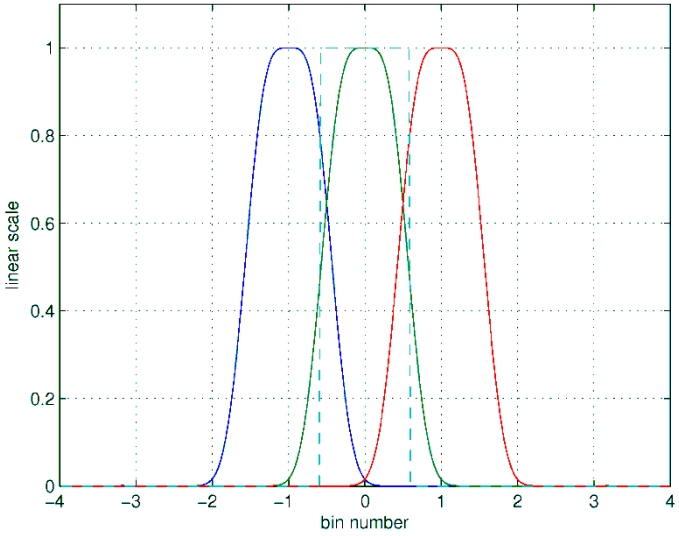


- Instantaneous bandwidth: 0.1 – 1.8 GHz
- Spectral resolution @ 1.5 GHz: 212 kHz
- Calibration- and aging free digital processing

FFTS :: *Signal Processing*

Unlike the conventional windowed-FFT processing, a more efficient polyphase pre-processing algorithm has been developed with significantly reduced frequency scallop, less noise bandwidth expansion, and faster sidelobe fall-off.





Frequency response of the optimized FFT signal processing pipeline

Equivalent noise bandwidth = 1.16 x frequency spacing

Max-Planck-Institut
für Radioastronomie

FFTS :: *FPGA configurations*

DIGITALLABOR

Today, implemented FFTS board / FPGA configurations are:

- 1 x 1.5 GHz bandwidth, 1 x 8192 spectral channels, ENBW: 212 kHz (default core)
- 1 x 1.8 GHz bandwidth, 1 x 8192 spectral channels, ENBW: 255 kHz

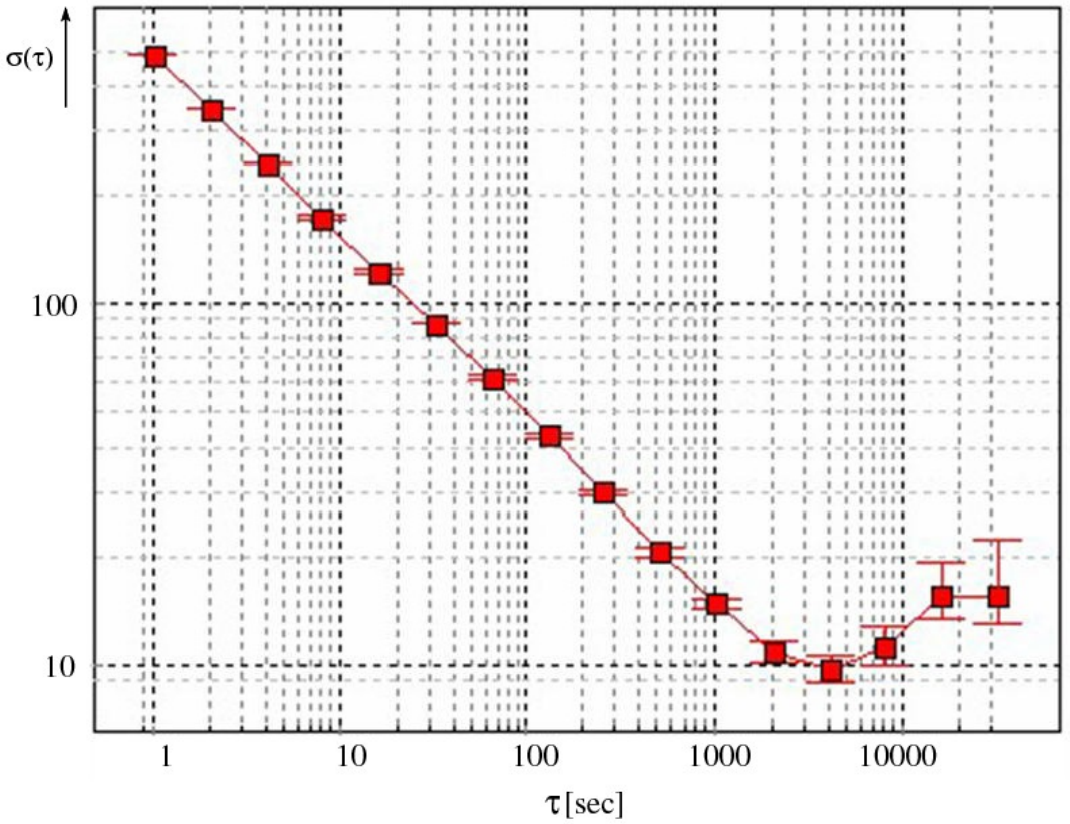
- 1 x 750 MHz bandwidth, 1 x 16382 spectral channels, ENBW: 53 kHz
- 1 x 500 MHz bandwidth, 1 x 16384 spectral channels, ENBW: 35 kHz
- 1 x 100 MHz bandwidth, 1 x 16384 spectral channels, ENBW: 7 kHz
- 1 x 50 MHz bandwidth, 1 x 16384 spectral channels, ENBW: ~4 kHz

The Equivalent Noise Bandwidth (ENBW) is the width of a fictitious rectangular filter such that the power in that rectangular band is equal to the (integrated) response of the actual filter.

Max-Planck-Institut
für Radioastronomie

FFTS :: *Stability*

DIGITALLABOR



The spectroscopic Allan variance between two 1 MHz broad channels, separated by 800 MHz within the band, was determined to be stable on a timescale of ~4000 s.

Max-Planck-Institut
für Radioastronomie

AFFTS :: *Array-FFTS for APEX*

DIGITALLABOR

Atacama Pathfinder EXperiment
APEX

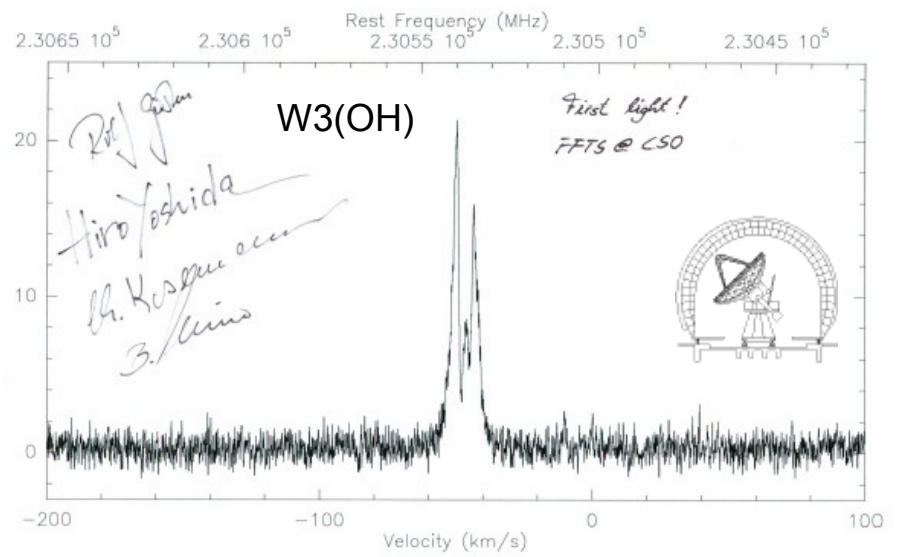
Bandwidth: 32 x 1.5 GHz = 48 GHz (option 58 GHz)
Spec. channels: 32 x 8k = 256k channels @ 212 kHz

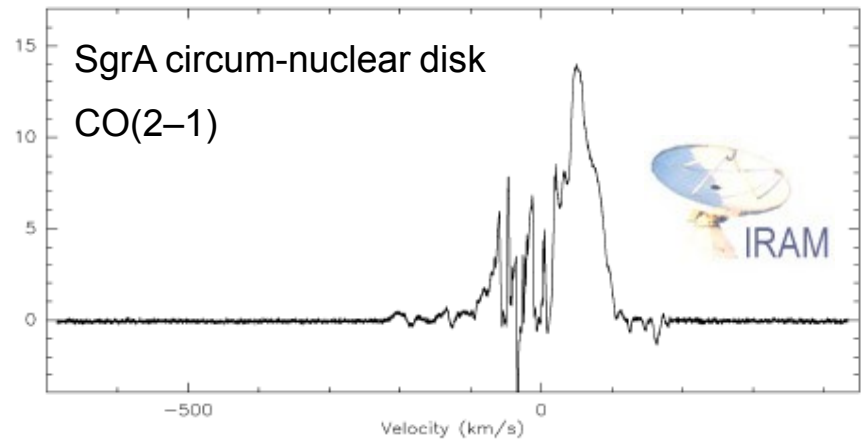
Max-Planck-Institut für Radioastronomie

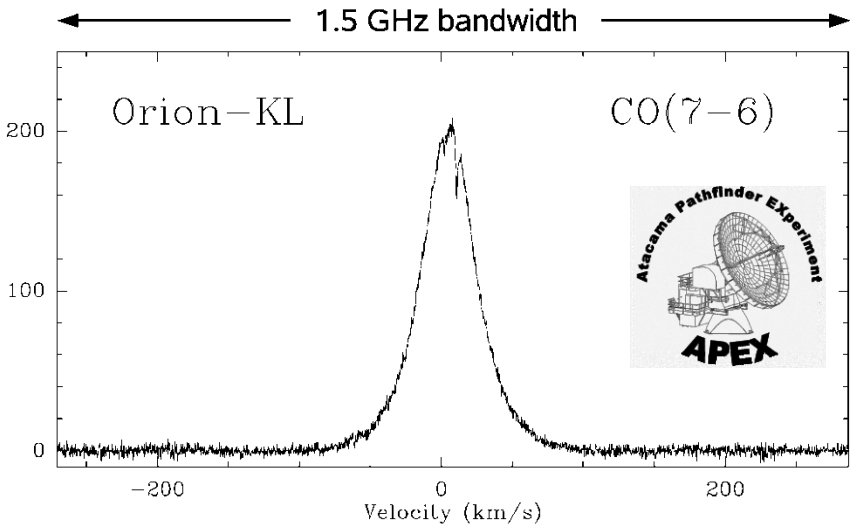
DIGITALLABOR

FFTS :: *in world-wide use*

The superior performance, high sensitivity and reliability of MPIfR FFT spectrometers has now been demonstrated at many telescopes world-wide.







Spectrum towards Orion-KL. The high-excitation CO(7-6) transition at 806 GHz was observed with the central pixel of the CHAMP+ array.

Further details:

- B. Klein, et al., Proceedings of the 19th ISSTT, Groningen 28-30 April 2008
- http:://www.mpifr-bonn.mpg.de/staff/bklein

Max-Planck-Institut
für Radioastronomie

FFTS :: *Contact, Distribution*

DIGITALLABOR 01001010

Contact:

For further information about the MPIfR FFT spectrometer,
future developments and applications, please contact
Bernd Klein (bklein@mpifr.de) or
Rolf Güsten (rguesten@mpifr.de) at the
Max-Planck-Institut für Radioastronomie in Bonn, Germany.

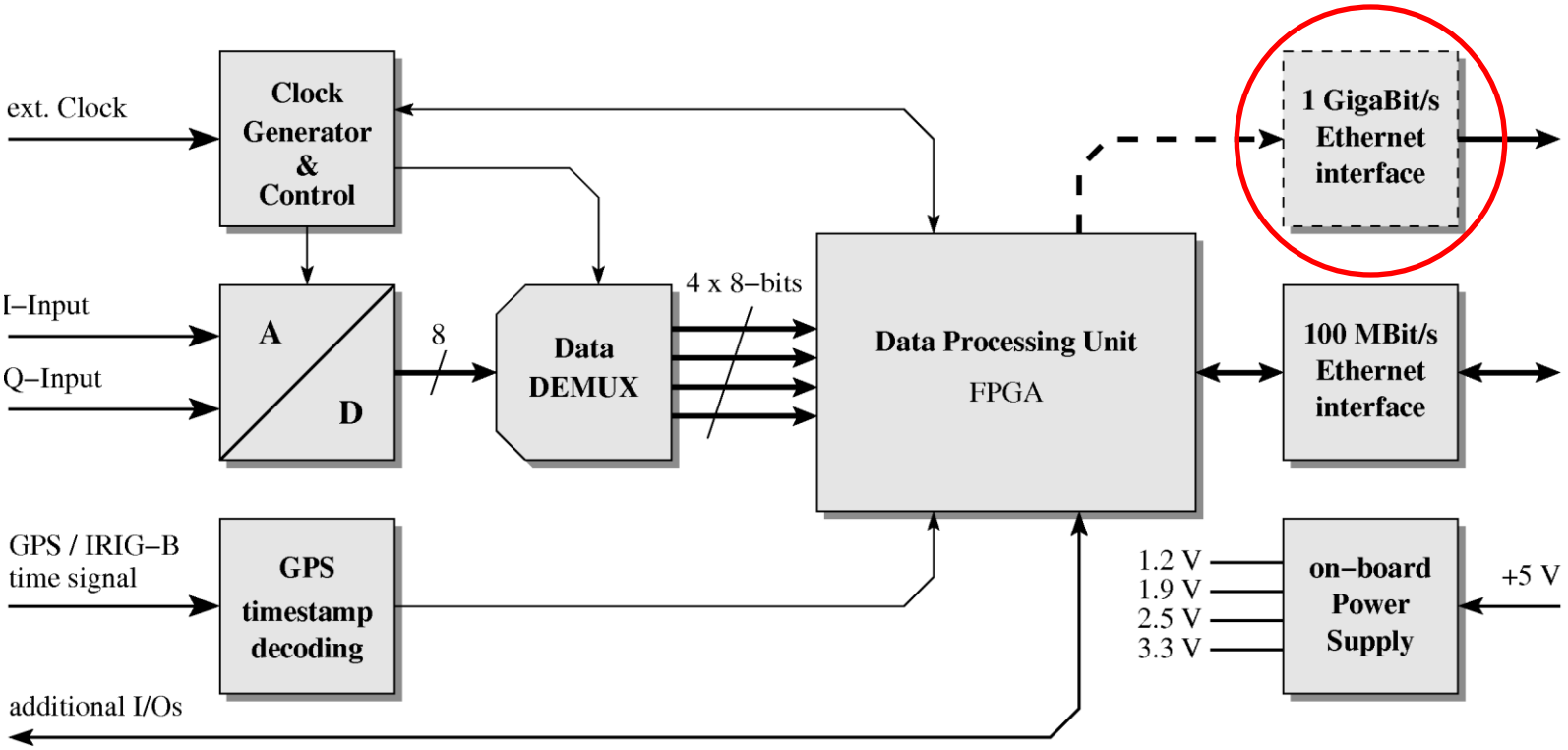
Distribution:

NEW! Radiometer Physics GmbH http://www.radiometer-physics.de NEW!

EFFTS :: *The Effelsberg FFTS*

Applications:

- Spectroscopy :: 16 x 100 - 500 MHz bandwidth, 8192 and 16384 channels
- Pulsar Search :: 16 x 250 MHz bandwidth, 512 channels, 32/64µs dumping



Max-Planck-Institut
für Radioastronomie

EFFTS :: *The analyzer board*

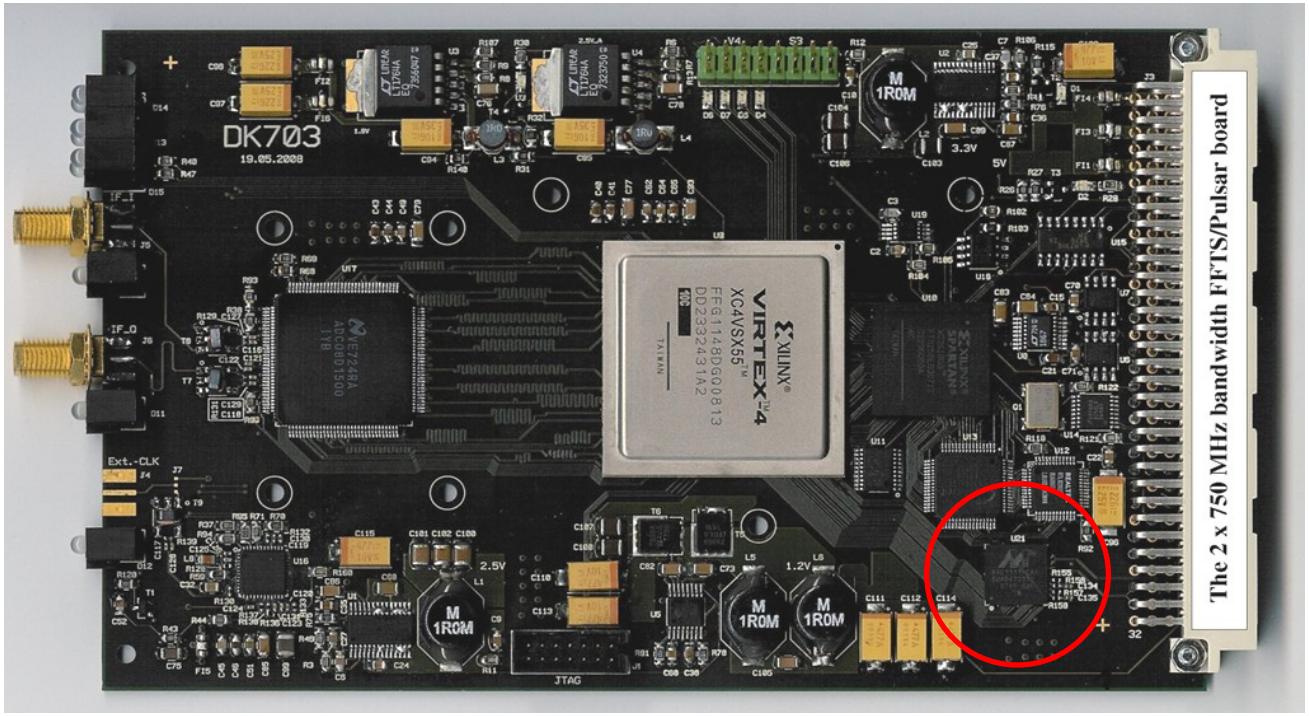
DIGITALLABOR

Board modifications:

- Dual input ADC :: National ADC08D1500, 2 x 750 MHz bandwidth
- GigaBit Ethernet:: Marvell 88E1111, UDP: 85 MBytes/sec cont.

I-Input

Q-Input



TCP 100 Mbits/s

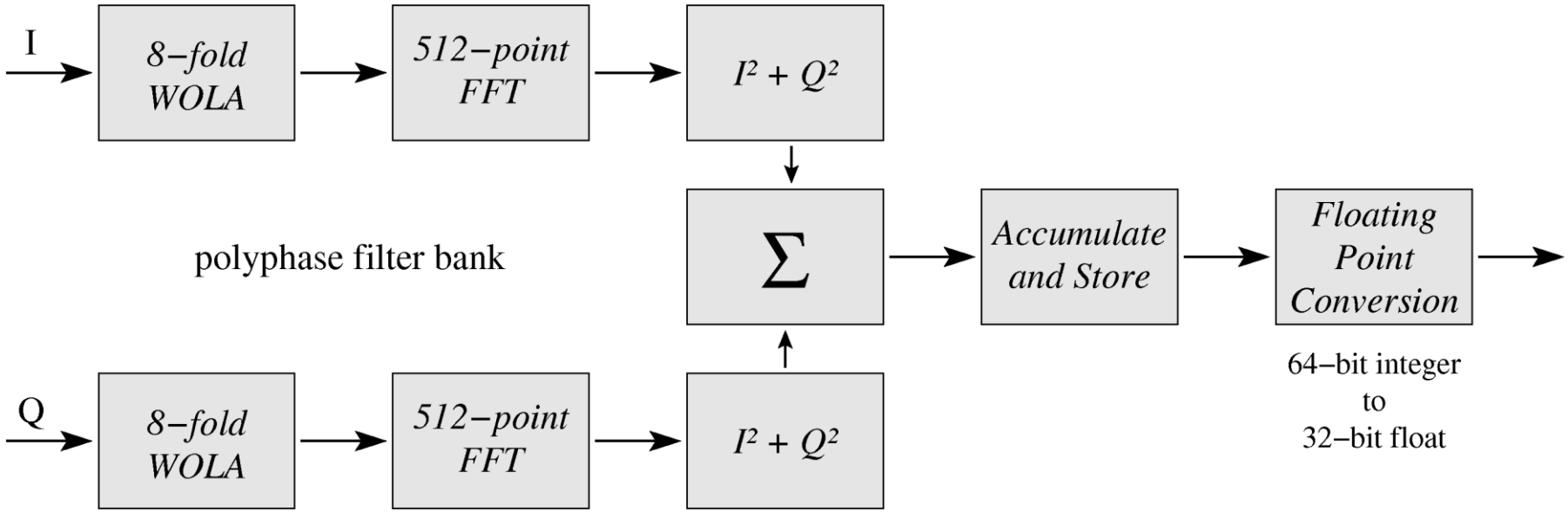
UDP 1 Gbits/s

Marvell GigaBit chip

EFFTS :: *pulsar signal processing*

Performance:

- FPGA processing :: 250 MHz bandwidth & 8-tab polyphase filterbank with 512 channels, ENBW: 515 kHz
- Dump time [µs] :: 32, 64 or 128, 16 x 512 channels (32-bit float) 1k Bytes tail (dump counter, GPS/IRIG-B time,...)
- Data rate @ 32µs :: ~64 MBytes/sec



Max-Planck-Institut
für Radioastronomie

EFFTS :: *The Effelsberg FFTS*

DIGITALLABOR
01001010

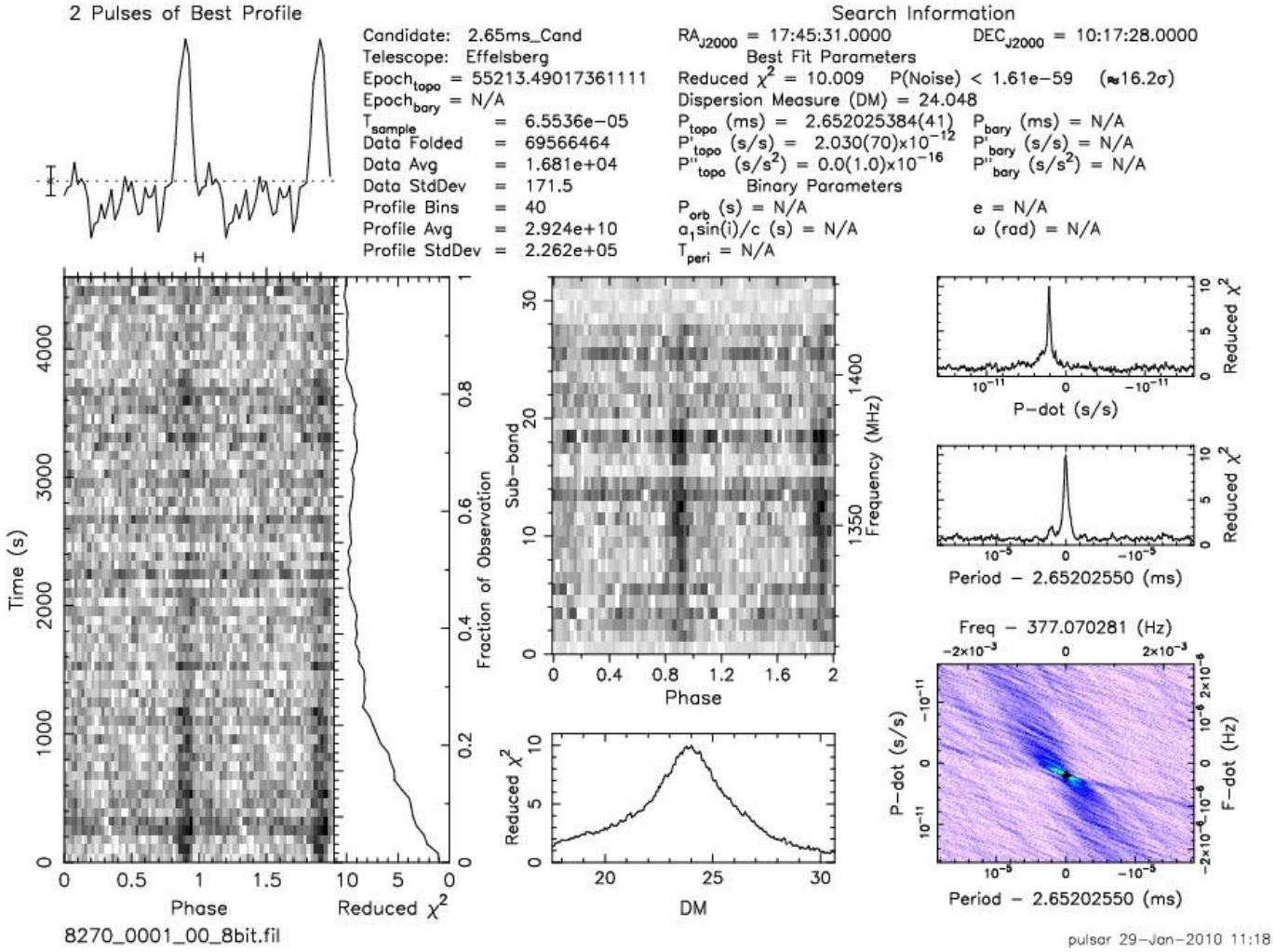
Norbert Tacken

Max-Planck-Institut
für Radioastronomie

EFFTS :: *Pulsar discovery*

DIGITALLABOR

PSR J1745+10 - first MSP discovery in Effelsberg, P = 2,65 ms



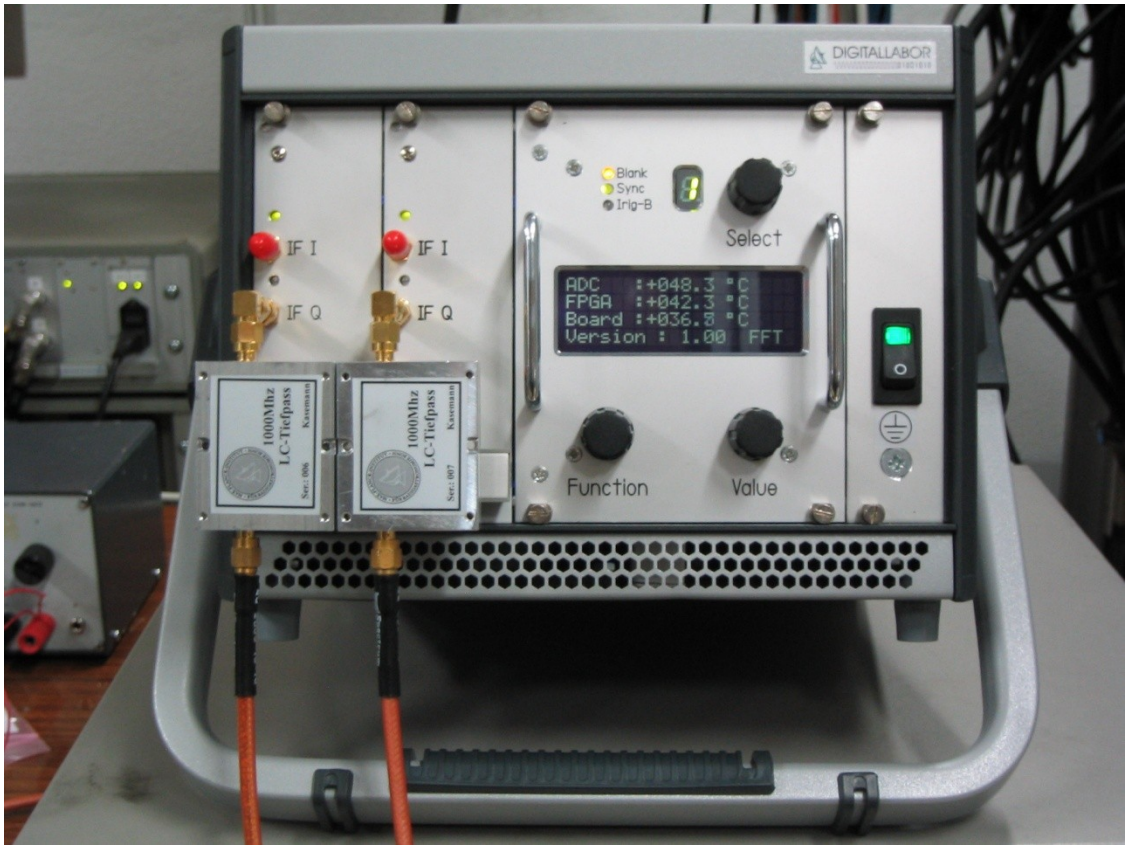
Max-Planck-Institut
für Radioastronomie

FFTS :: *The Laboratory version*

DIGITALLABOR

LAB-FFTS:

2 x 1.8 GHz bandwidth, 8192 spectral channels, ENBW: 255 kHz
4 x 750 MHz bandwidth, 16384 spectral channels, ENBW: 53 kHz



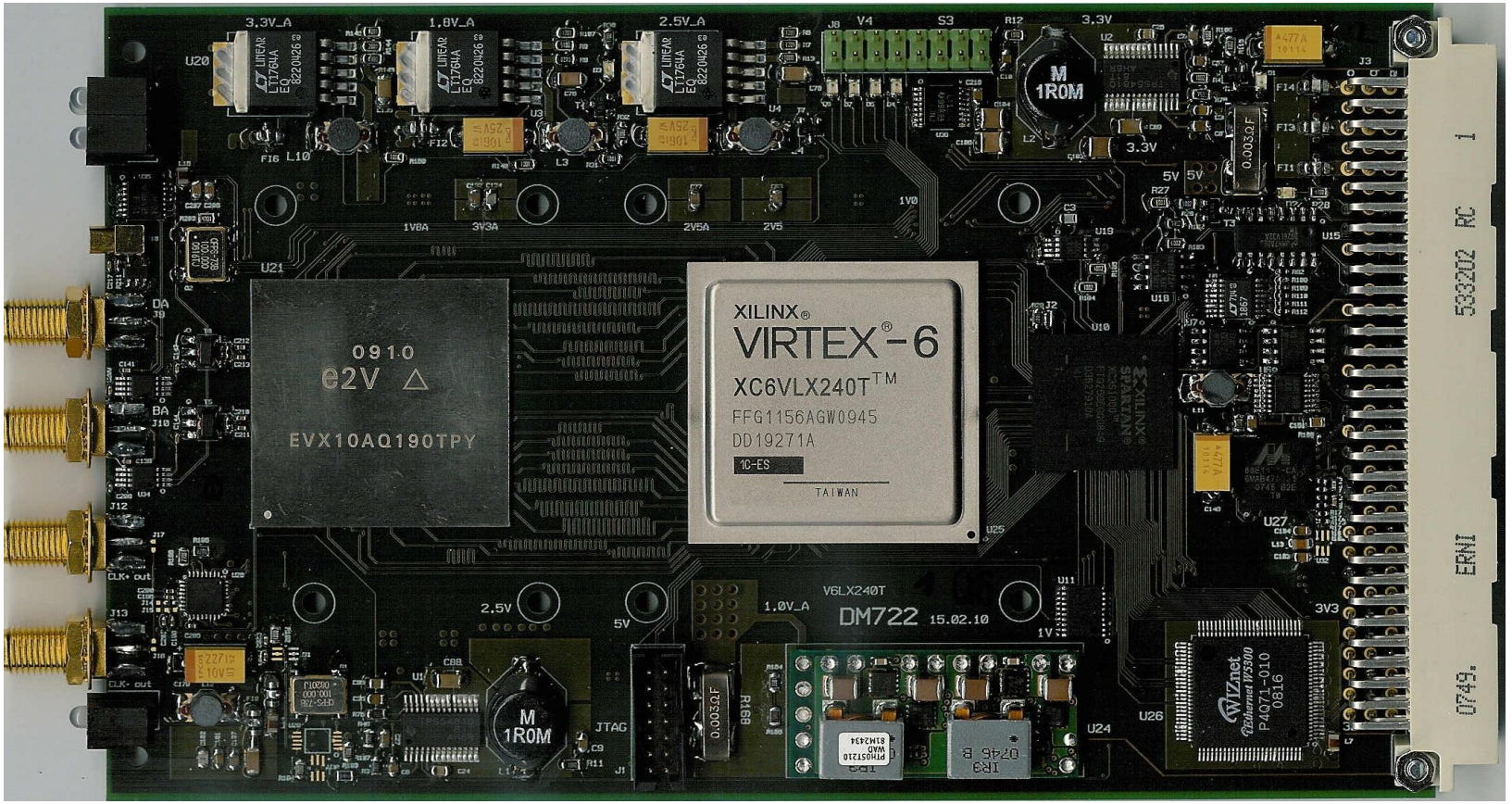
Max-Planck-Institut
für Radioastronomie

XFFTS :: *The newest board*

DIGITALLABOR

GREAT

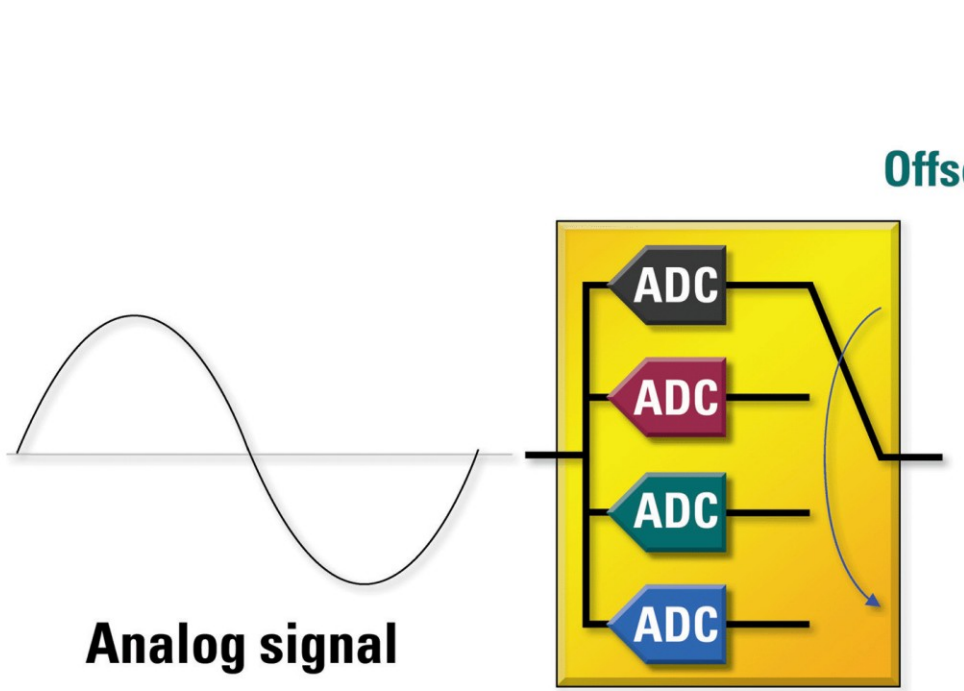
XFFTS: 2.5 GHz bandwidth / 32768 channels (ENBW 88.5 kHz)

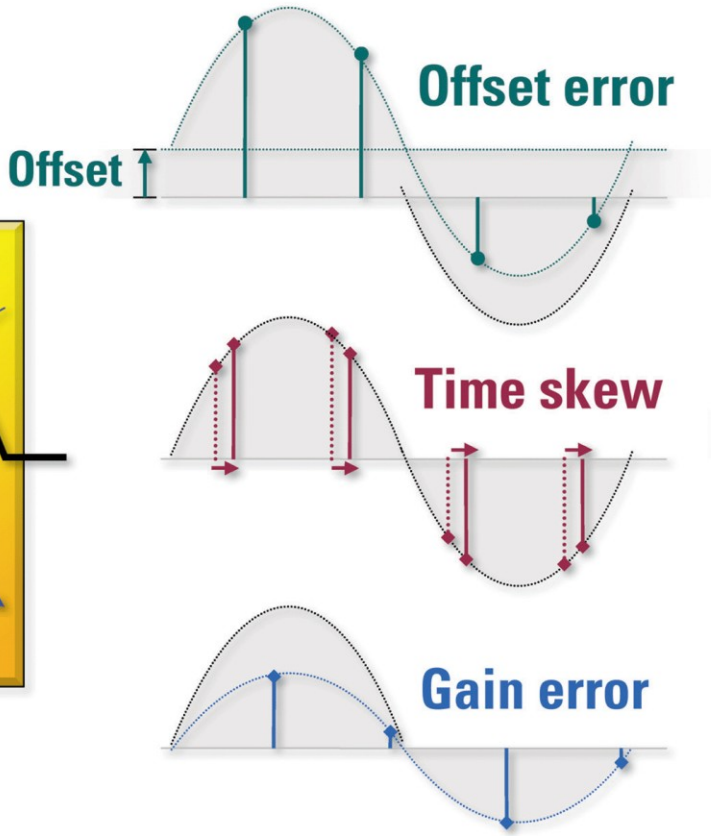


E2V 5 GS/s 10-bit ADC, XILINX Virtex-6 LX240T
[40 nm, 1.0 volt core voltage, >240‘000 logic cells, 768 DSP48 slices]

XFFTS :: *ADC interleaving*

ADC: e2v scientific instruments **10-Bit, 4 x 1.25 GS/s**

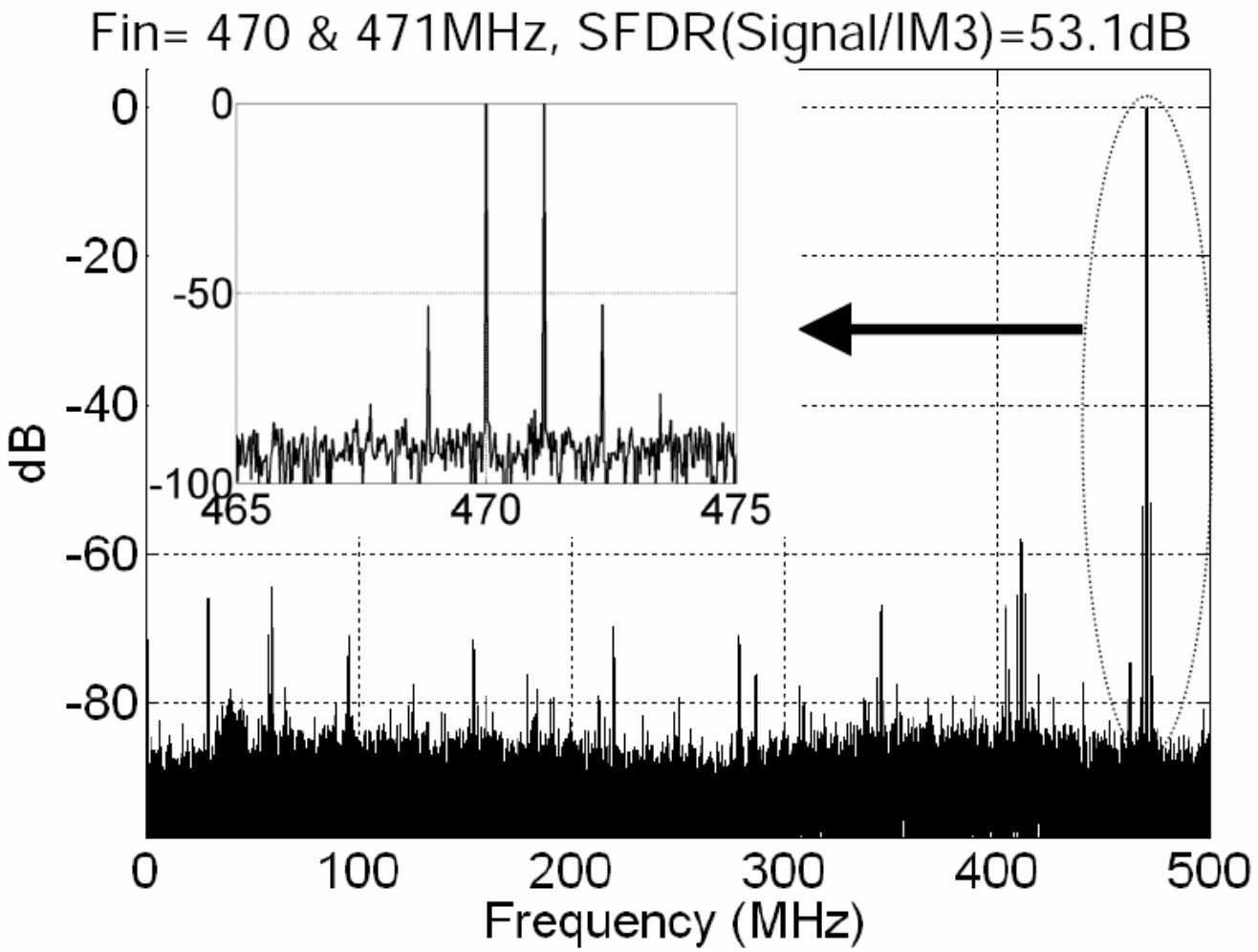




Max-Planck-Institut
für Radioastronomie

XFFTS :: *ADC interleaving*

DIGITALLABOR



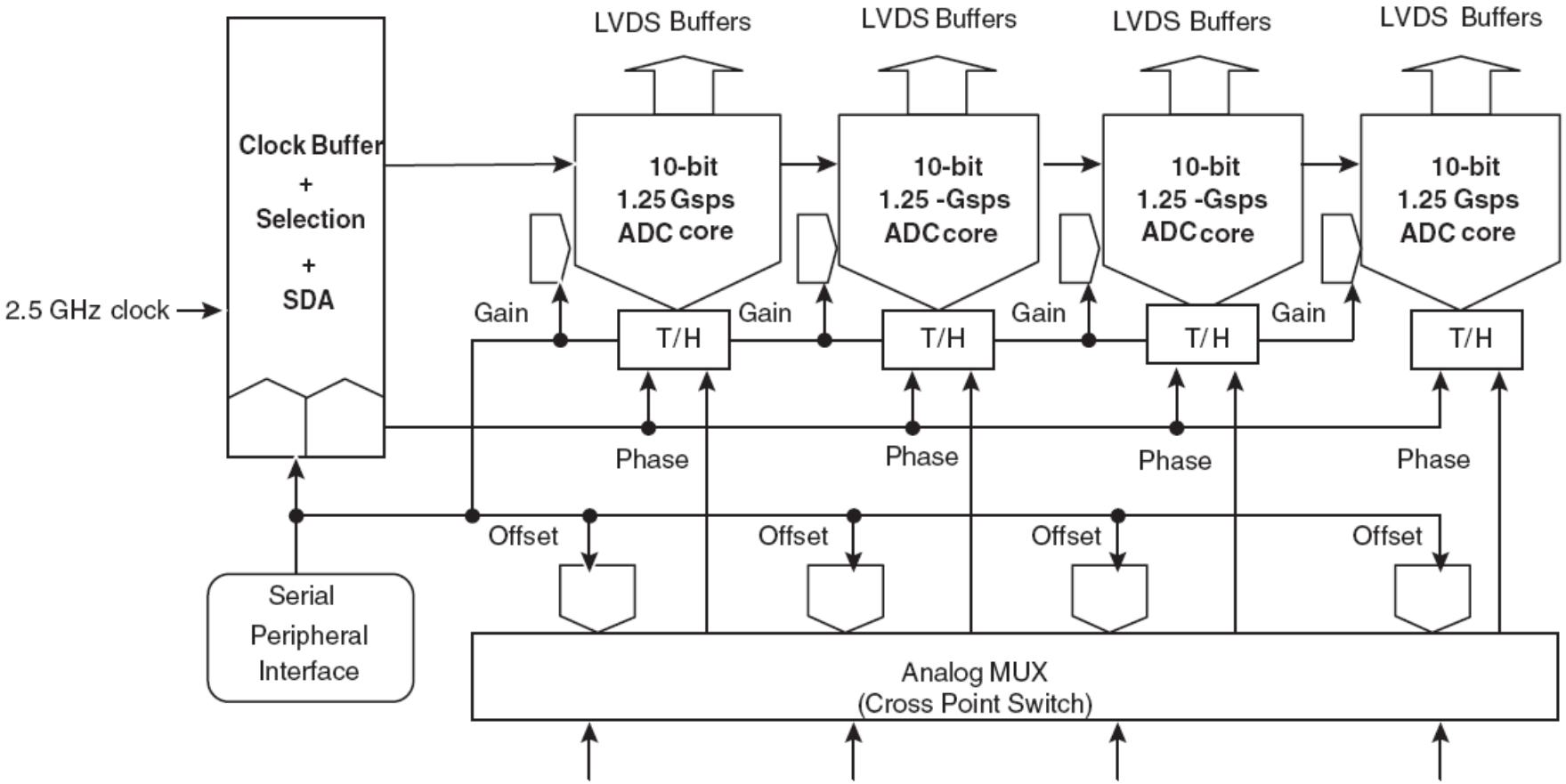
Max-Planck-Institut
für Radioastronomie

DIGITALLABOR

XFFTS :: *ADC interleaving*

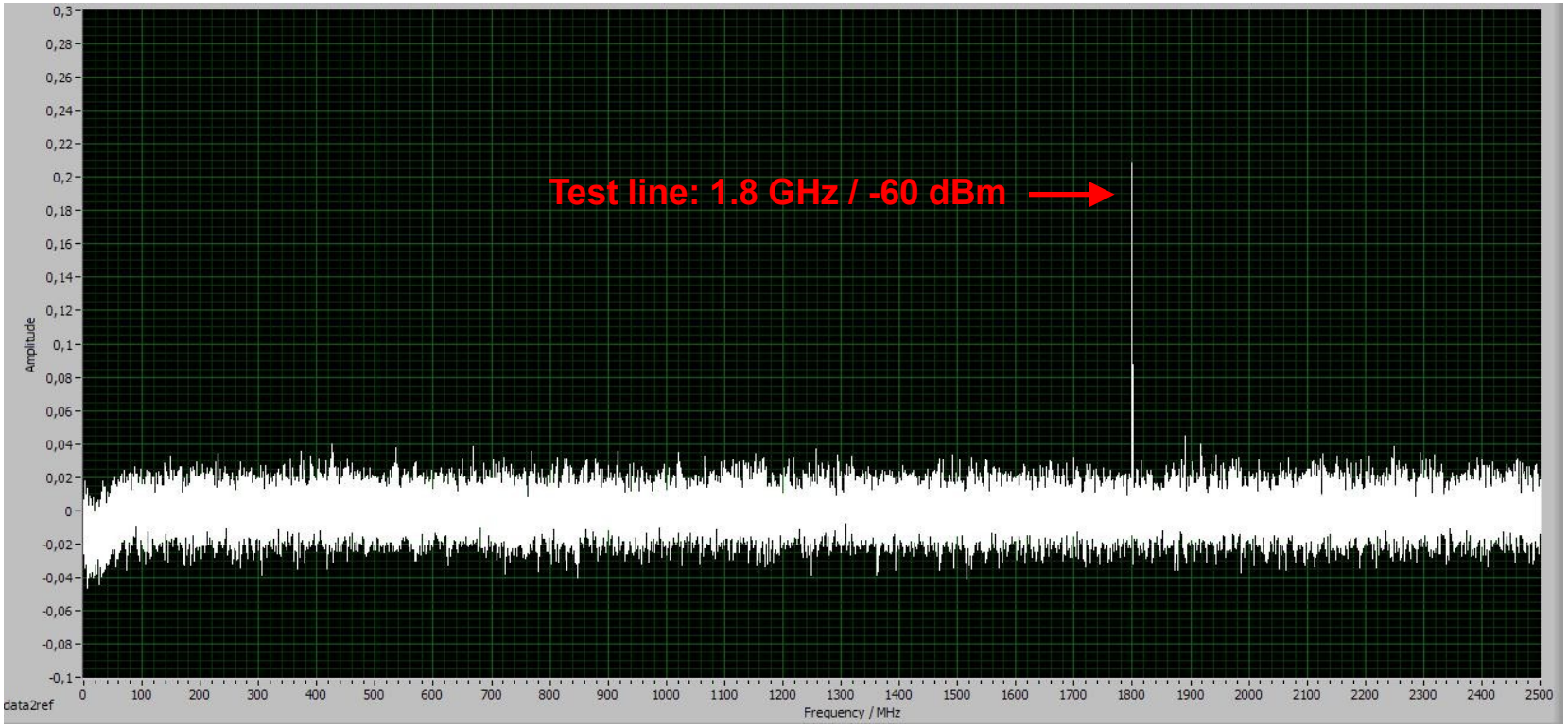
ADC: e2v **10-Bit, 4 x 1.25 GS/s**

e2v scientific instruments



XFFTS :: *ADC interleaving*

XFFTS: 2.5 GHz bandwidth / 10-bit / 32768 channels (ENBW 88.5 kHz)



2.5 GHz instantaneous bandwidth

Max-Planck-Institut
für Radioastronomie

XFFTS @ APEX :: *IF-Processor*

DIGITALLABOR
01001010

Atacama Pathfinder EXperiment
APEX

XIF: 2 x 4 GHz @ 6 GHz center frequency ⇒ 4 x 2.5 GHz (XFFTS)

Installation & Commissioning: June 2010

Max-Planck-Institut
für Radioastronomie

XFFTS @ APEX

DIGITALLABOR

Atacama Pathfinder EXperiment
APEX

XFFTS: 4 x 2.5 GHz, 4 x 32768 spectral channels, ENBW: 88,5 kHz

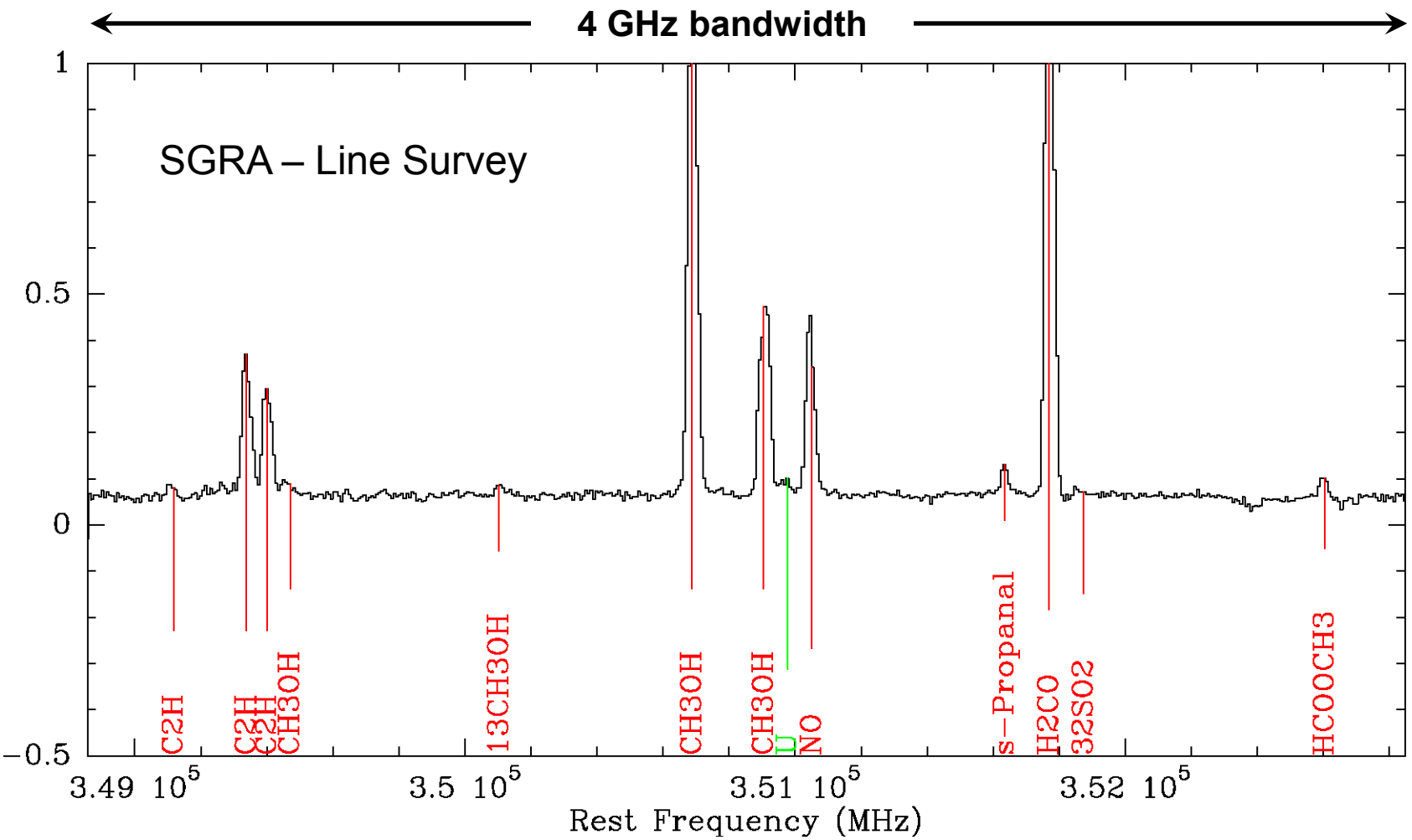
Installation & Commissioning: June 2010

Max-Planck-Institut
für Radioastronomie

APEX :: Flash345 + XIF + XFFTS

DIGITALLABOR
01001010

Atacama Pathfinder EXperiment
APEX



APEX :: Flash345 + XIF + XFFTS

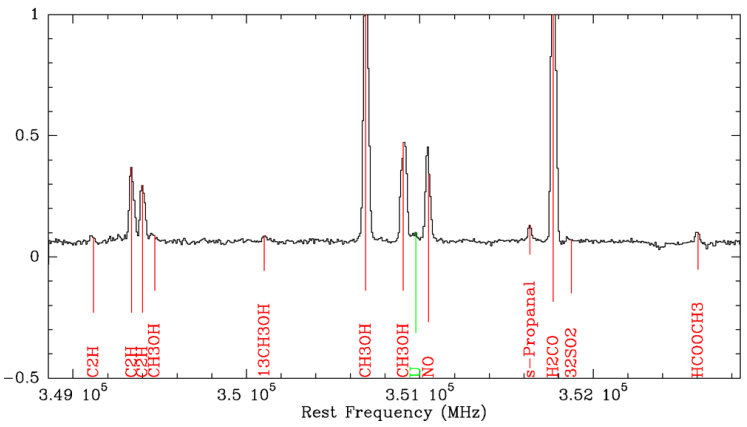
Max-Planck-Institut für Radioastronomie

DIGITALLABOR

8 GHz of bandwidth in one setup

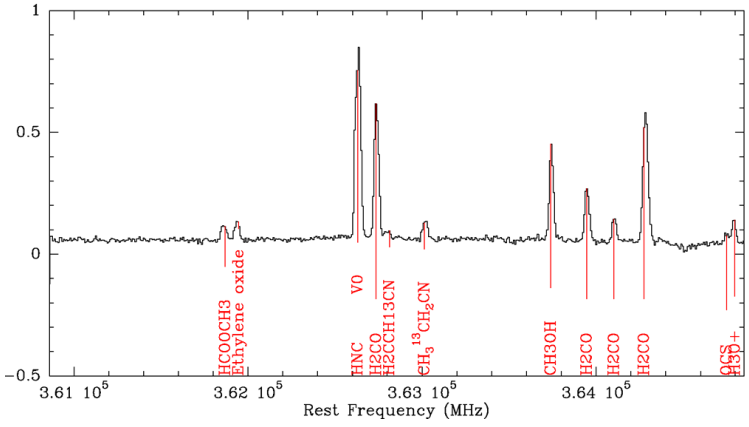
lower sideband

4 GHz bandwidth



upper sideband

4 GHz bandwidth



12 GHz spacing

Flash345: updated receiver with IRAM 2SB SIS mixer

iram Institut de Radioastronomie Millimétrique

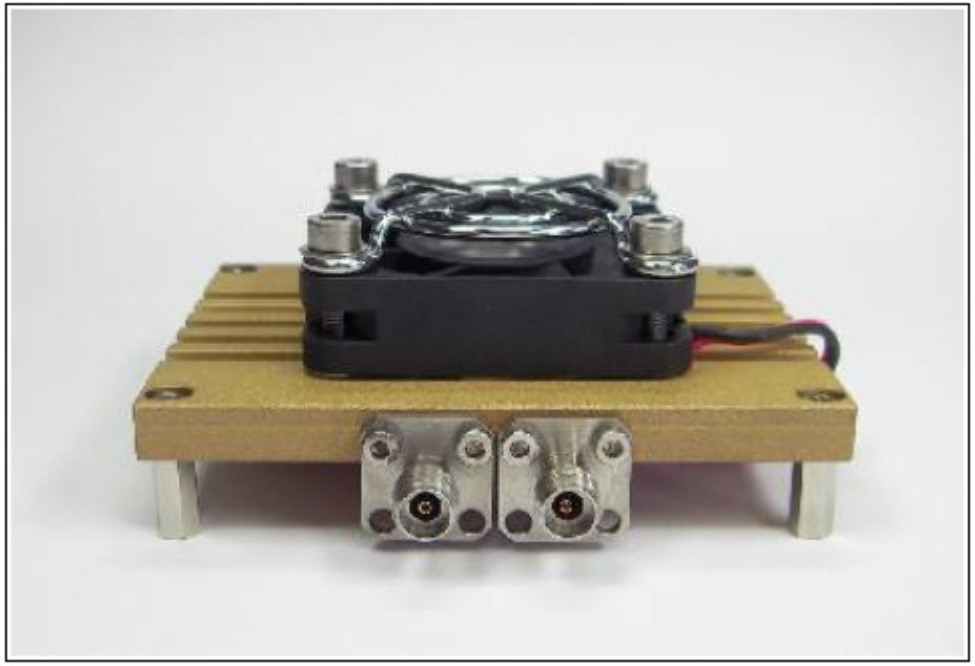
Max-Planck-Institut
für Radioastronomie

FFT-Spectrometer :: *An Outlook*

New ADCs: e.g., ADC30 from MICRAM

- **30 GS/s sampling, 15 GHz Nyquist bandwidth**
- **6 bit resolution, effective bits (ENOB): > 4.5 @ 14 GHz**
- **> 20 GHz analog bandwidth, allows direct IF sampling**
- **But – is this highly interleaved ADC good enough for Radioastronomy ??? We will see…**

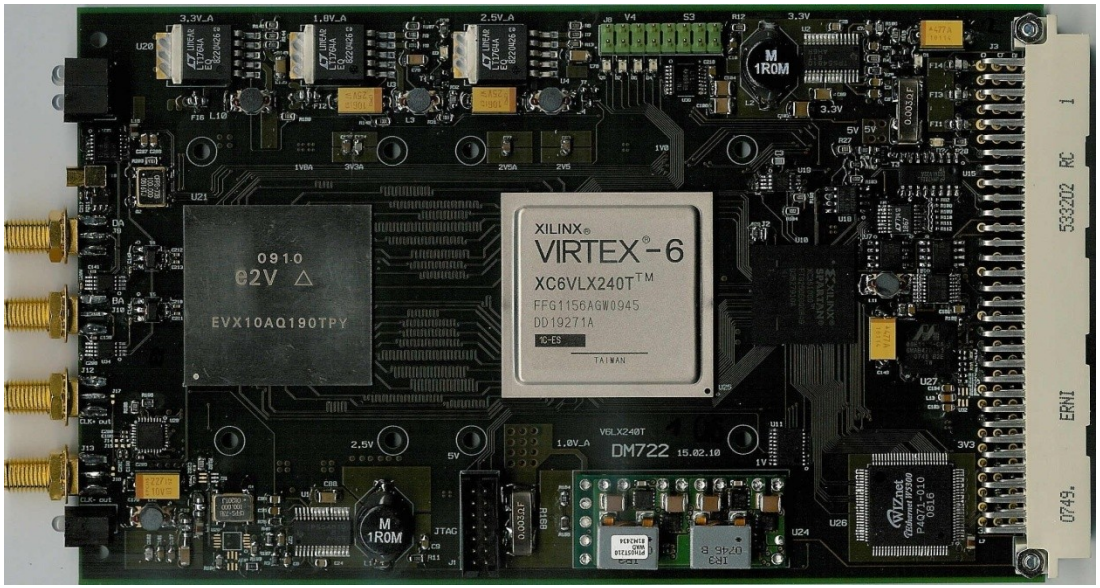
ADC30 Module



MICRAM

FFT-Spectrometer :: *An Outlook*

XFFTS2: support for 4 x 10 GBit/s Ethernet



UniBoard **ROACH1/2** **PC-Clusters** **GPU-Clusters**

FFT-Spectrometer :: *Summary*

Advantages of our new generation of compact FFT spectrometers:

- ✓ FFTS offer high instantaneous bandwidth up to 2.5 GHz with many thousands frequency channels, thus offering wideband observations with high spectral resolution without the complexity of the IF processing in a hybrid configuration.
- ✓ They provide very high stability by exclusive digital signal processing. Allan stability times of > 1000 seconds have been demonstrated routinely.
- ✓ Our optimized polyphase FFT signal processing pipeline provides a nearly loss-free time to frequency transformation with significant reduced frequency scallop, less noise bandwidth expansion, and faster side lobe fall-off.
- ✓ Field-operations of our FFTS over the last 4 years have proven to be very reliable, with calibration- and aging-free digital processing boards, which are swiftly re-configurable by Ethernet for special observation modes.
- ✓ Low space and power requirements – thus safe to use at high altitude (e.g. APEX at 5100-m) as well as on spacecrafts (Sofia) and future satellites (Millimetron?).
- ✓ Production cost are low compared to traditional spectrometers through use of only commercial components.