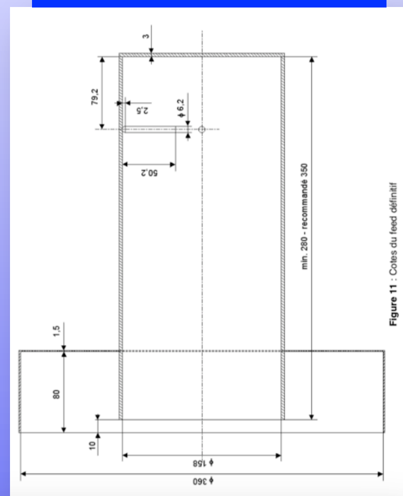
PAON-4

R. Ansari, J.E Campagne, D.Charlet, M. Moniez, C. Paillet, O. Perderau, M. Taurigna, J.M. Martin, F. Rigaud, P. Colom, Ph. Abbon, Ch. Magneville, J. Pezzani, C. Viou, S.A Torchinsky, Q. Huang, J. Zhang

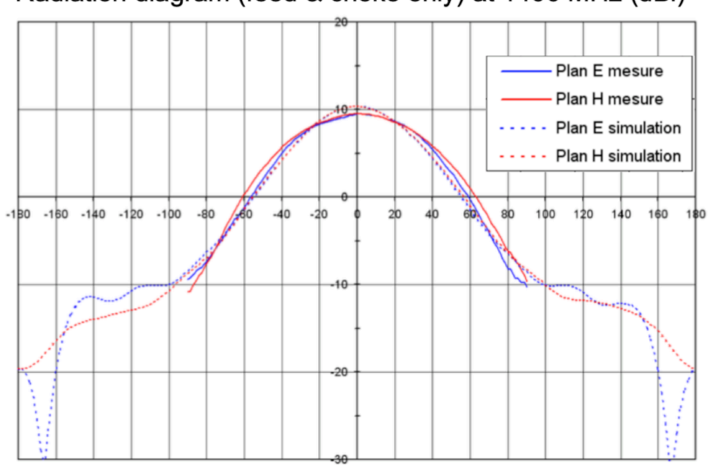
Paraboles à l'Observatoire de Nançay

Design

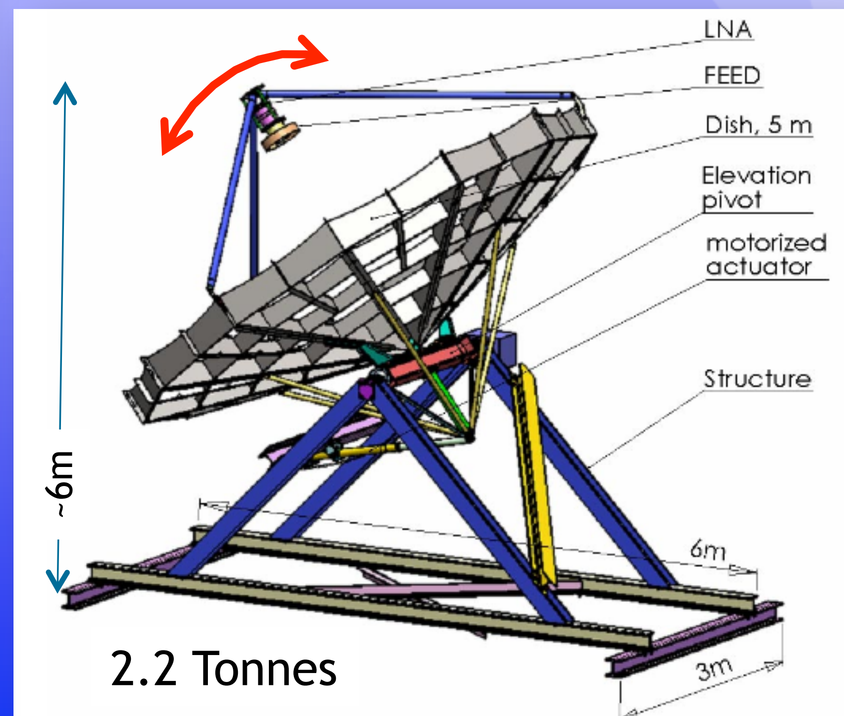
2 polarisations



Radiation diagram (feed & choke only) at 1400 MHz (dBi)



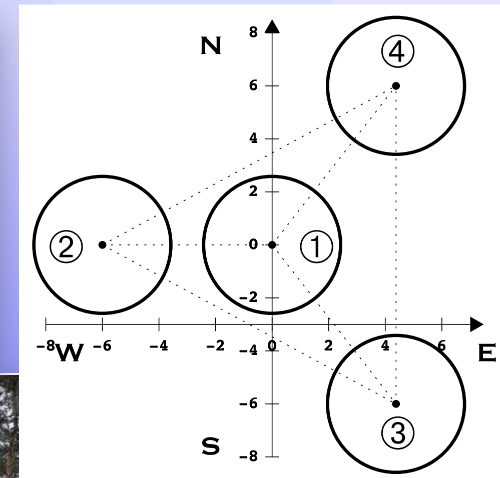
Roughness ~ $\lambda/50$ @ 21cm
$\varnothing$ = 5m, F/$\varnothing$ = 0.4
Life time > 10 y
Motorisation CEM 15°N-38°S



Reflector mounting @ Meudon

Roughness ~ $\lambda/70$ rms
(20pts measures/petal)

Mounting @ Nancay



600h – 15p Sept. 2013 – June 2014

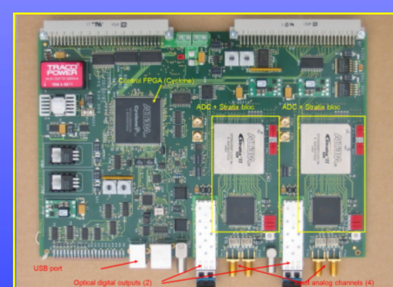
Electronic designed in 2006-7

- Collaboration LAL / IRFU
- Wide bandwidth: 250 MHz (1250-1500) MHz
- Digital system & use of FPGA: high processing power, low consumption and cost
- Filtering, digitization, FFT « on the fly », transfer and processing in PC

Analog electronic module

Filtering / 1.5GHz → 0-250MHz
LO clock / Amplifier / Mixer (IRFU)

Digitizer Frequency Separator (ADC Board)



4 channel / 8bit 500 MHz sampling / on the fly FFT / 2 high speed (~5Gbit/s) optical data transfer / Firmware@LAL

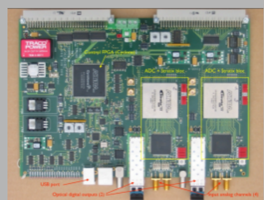
Acquisition and Processing Computer Cluster

PCI-Express receptor ~100 Mo/s (Firmware@LAL) / Acquisition/ control software (LAL-IRFU) parallel (multi-thread, multi-node)

OO/C++

Electronics on site

~50m

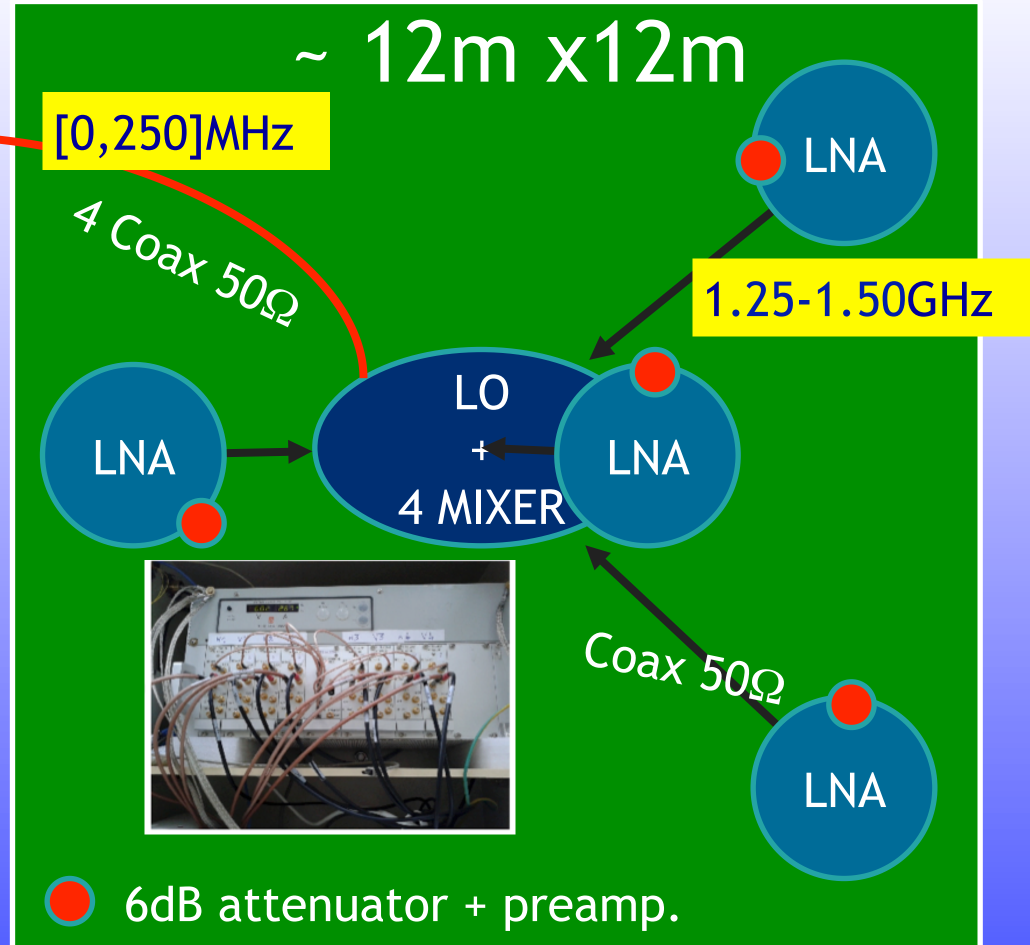


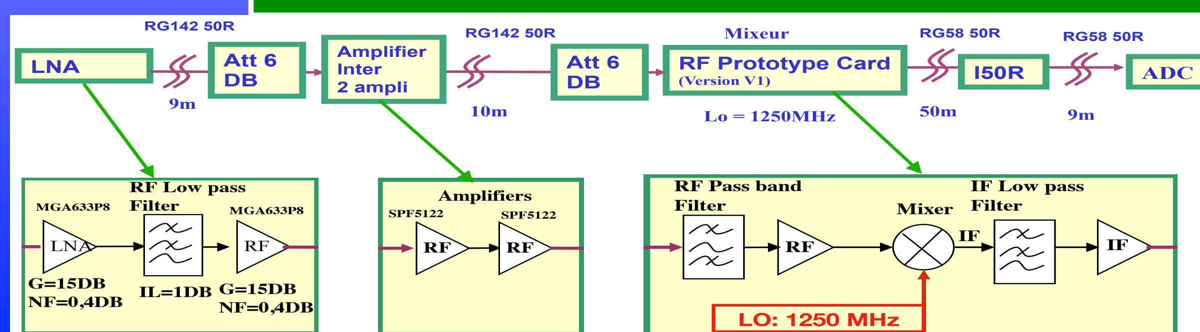
EMBRACE Container

Optical Fibre (digital signal)

300m

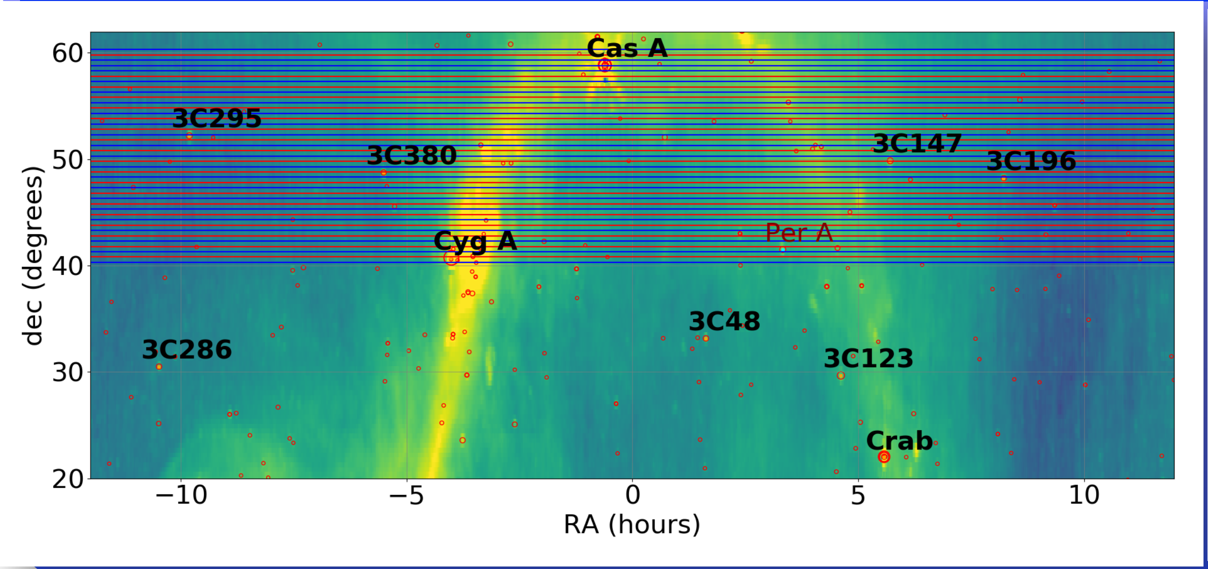
Correlator

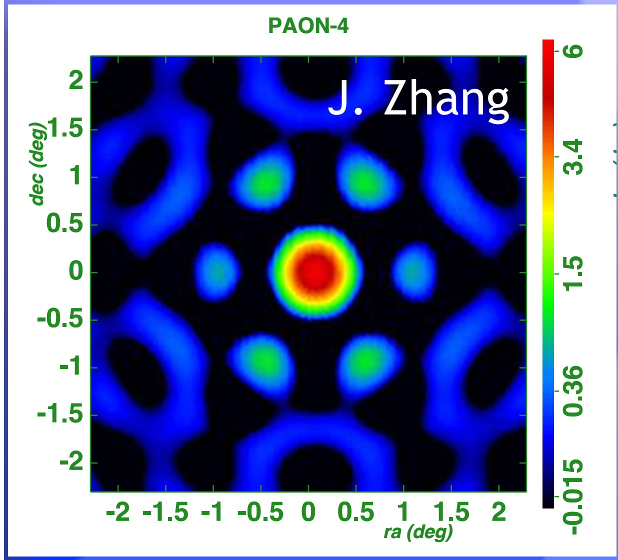




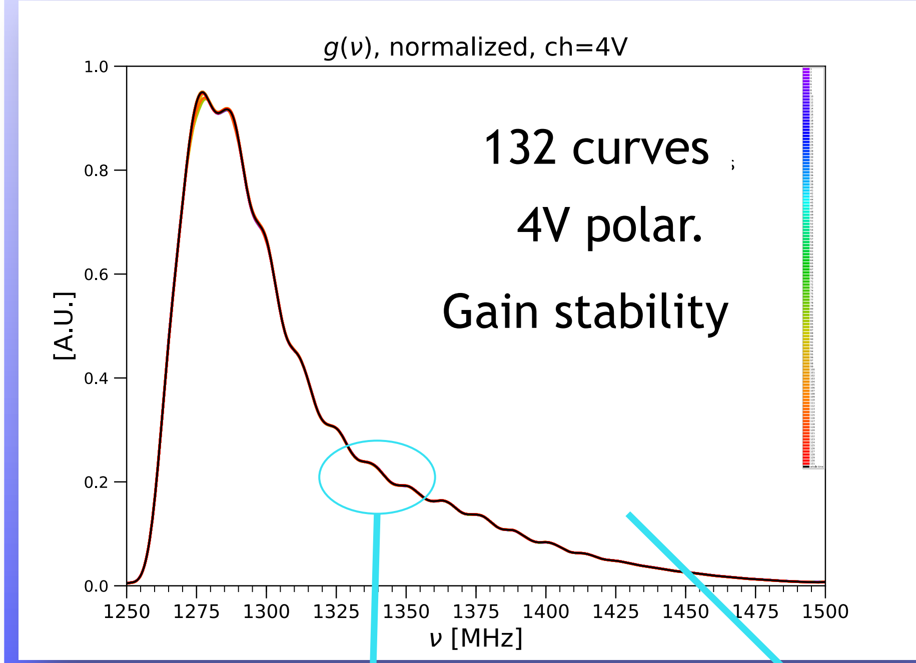
Data recording parameters

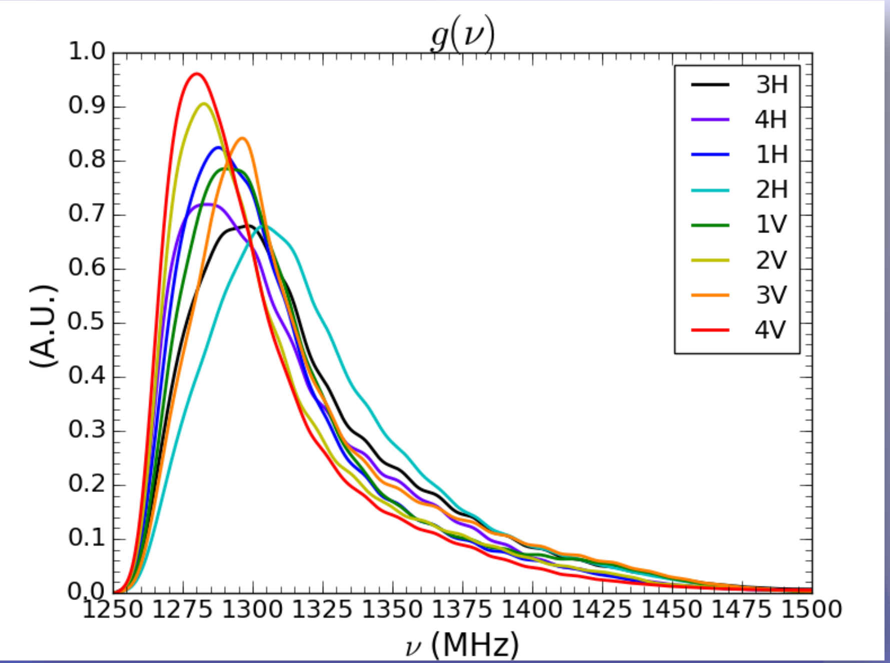
- Transit interferometer : declination fixed during at least 24h and sometimes weeks
- Reported analysis from Fall 2016 to July 2019
- Bandwidth [1250,1500]MHz, $\Delta\nu$ = 61kHz
- FFT done either by FPGA or by the online software (raw)
- Trigger rate ≲ 5kHz ⇒ ≲ 10% live time (0.5 To/h raw)
- 4x2 polar: 8 auto, 28 cross done by online software averaged ~ 5sec.





Gain(ν,t)= G(ν)xG(t)

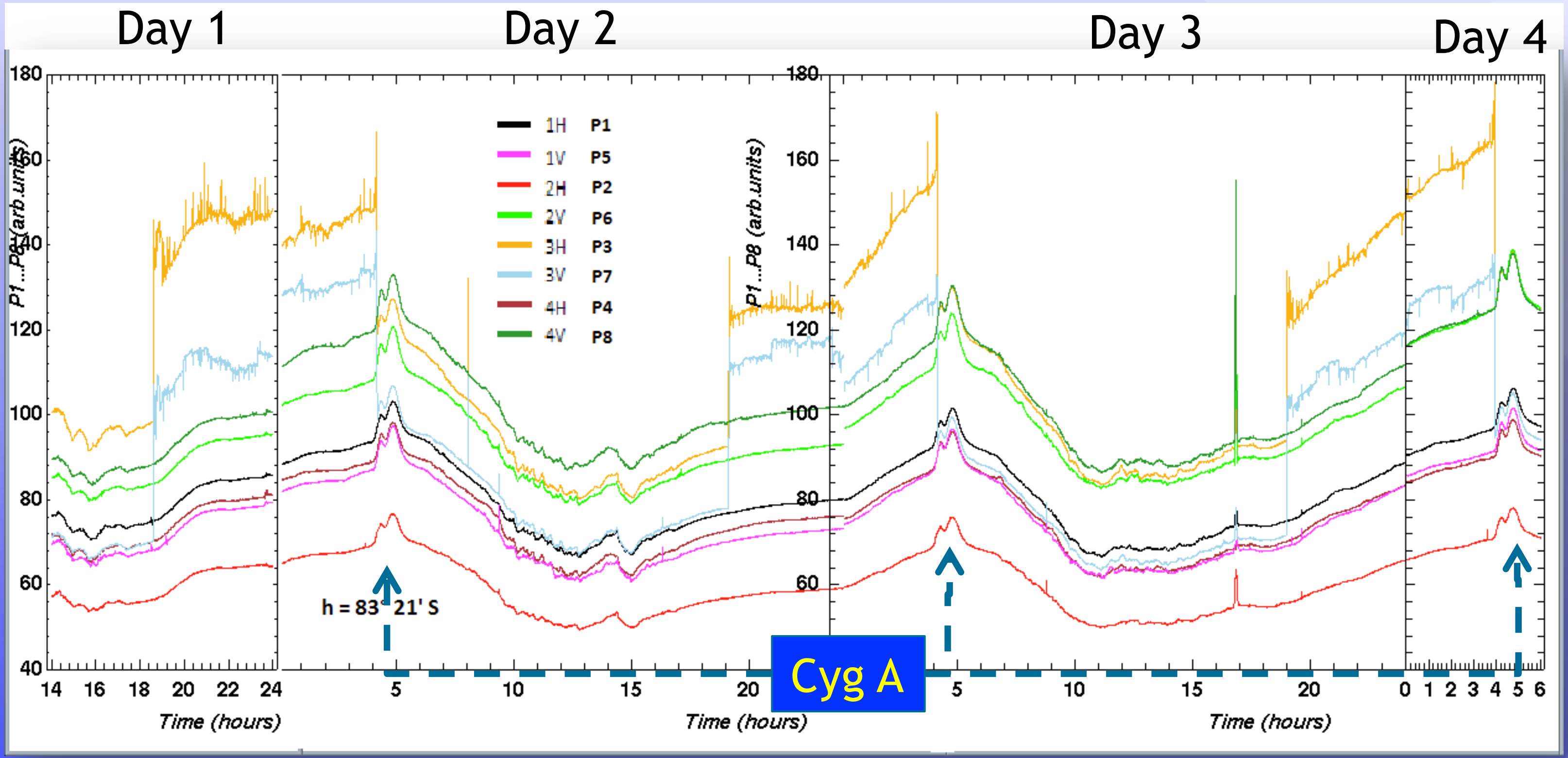




Modulation ~ 13 MHz due to 8.5 m cables between LNA and LO/mixer

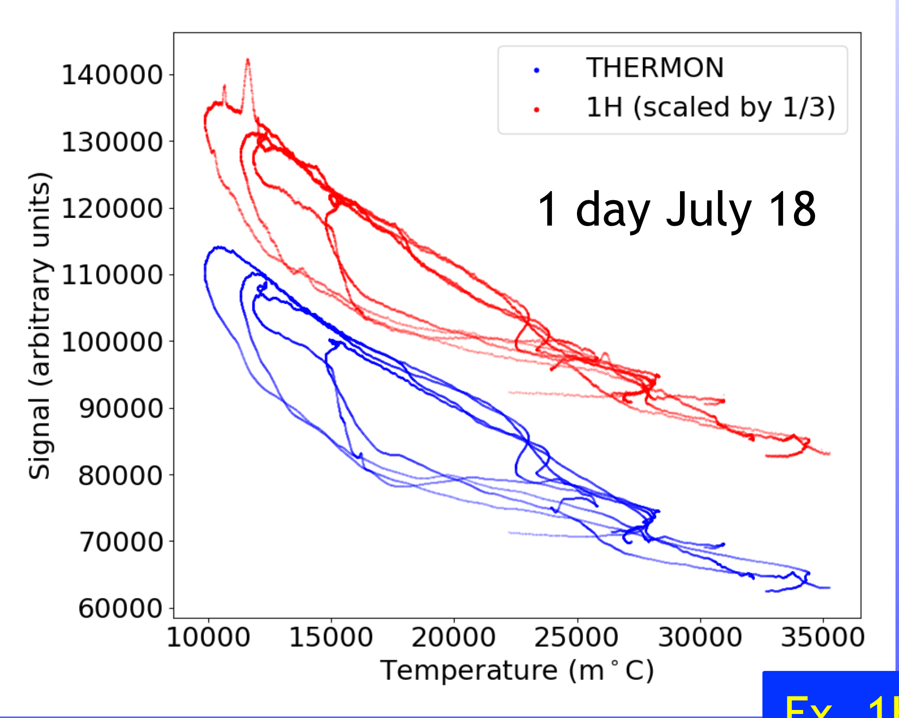
Gain drop due to 50m cable from LO/Mixer to ADC

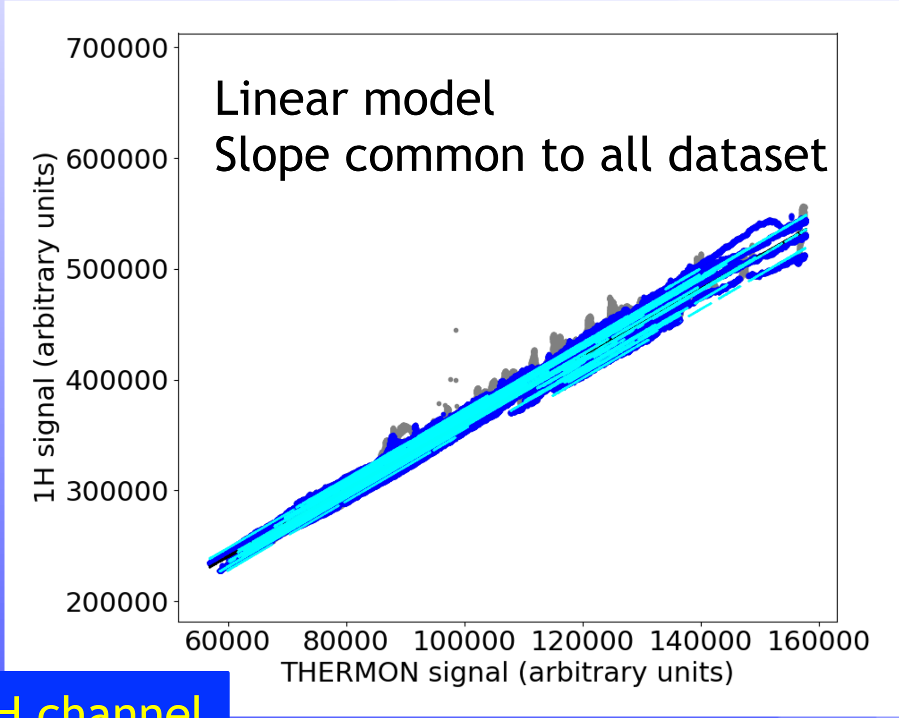
Gain(ν,t)= G(ν)xG(t)



1. Smooth variations along the days and nights
2. Sudden augmentations & drops

G(t): temperature variations



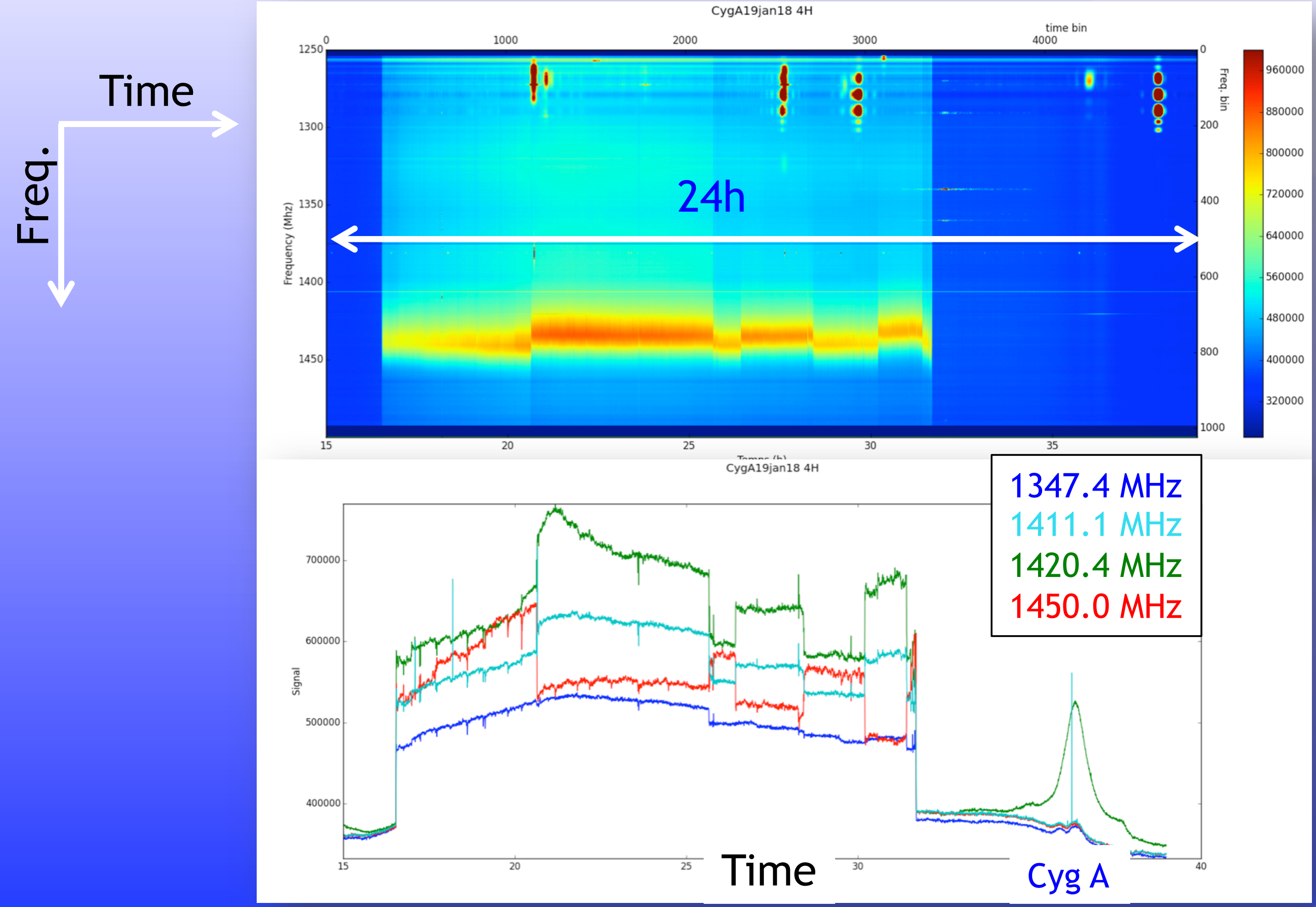


Ex. 1H channel

THERMON: same electronic as the 8 probes but connected to a 50Ω load

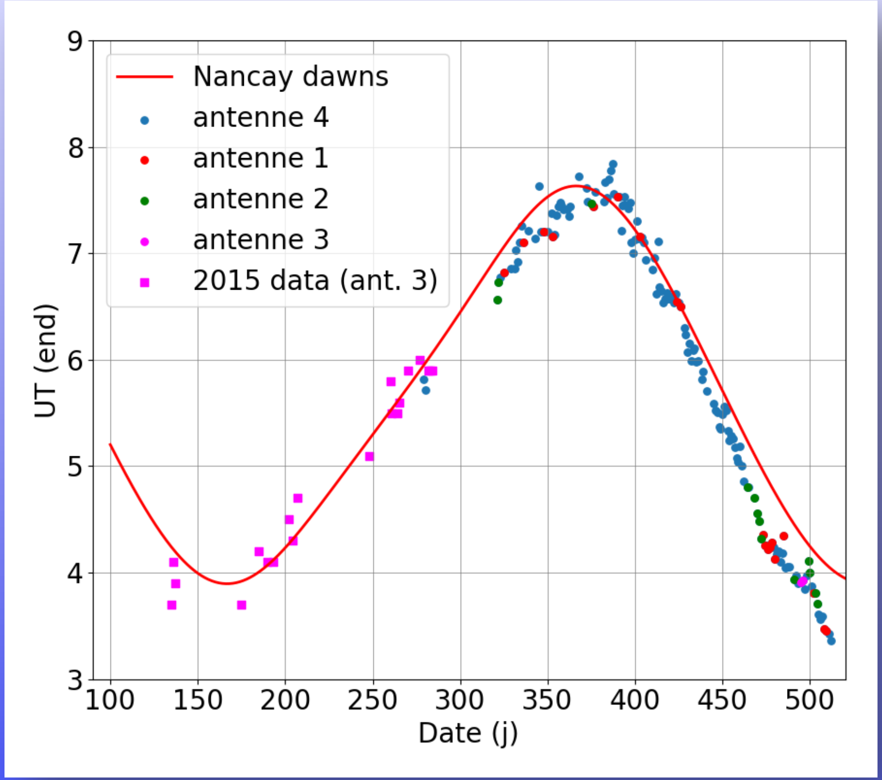
Gain correction reduces variations from 25-30% to 3-5%

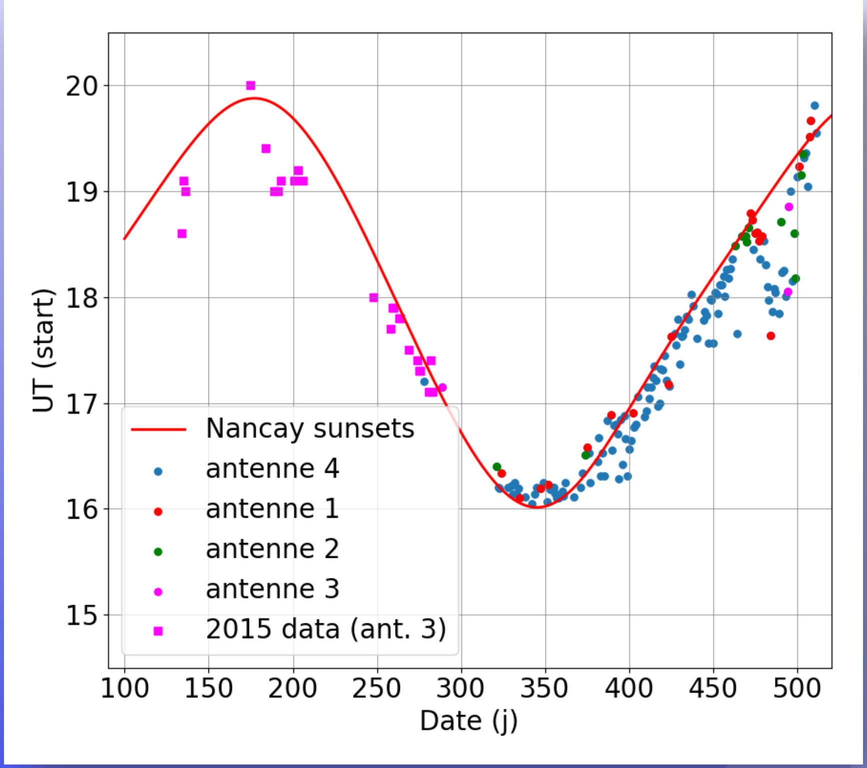
G(t): sudden up/down variations



vs dawn hour

vs sunset hour





During 2017-18 investigations have been conducted as the problem was much more frequent especially for antenna 4. Looking at 2015 data reveals that Antenna 3 was already affected.

The culprit is…

After several hypothesis investigations:
Electronics failure, power filtering failure, local RFI, animals with GPS emitter…

3-4th May 18: on the feed of antenna 4, we saw clearly some bird droppings, and once people saw it taking off.

Time-Frequency maps corrected

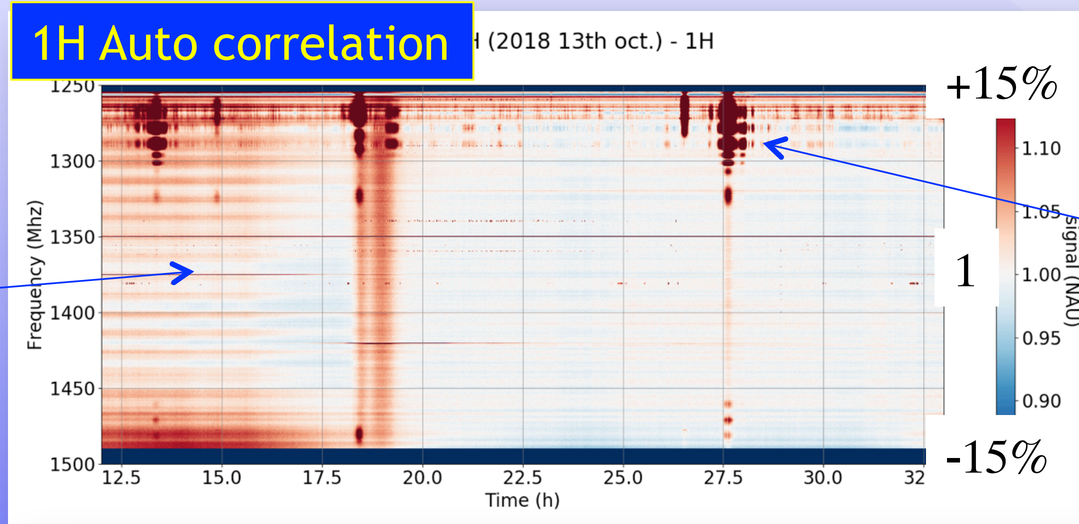
Residuals of 13MHz wiggles of the G(ν)

Satellites

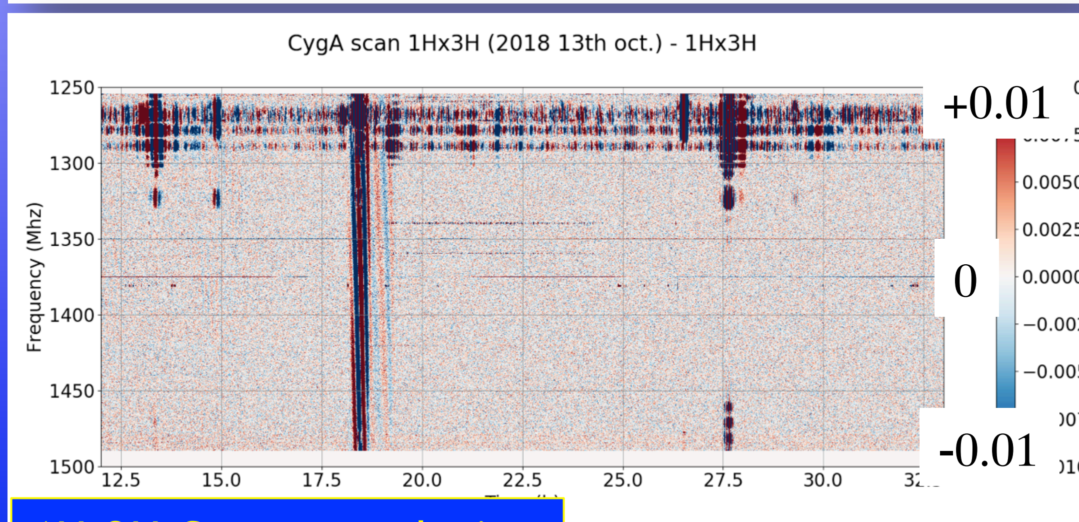
Time

Freq.

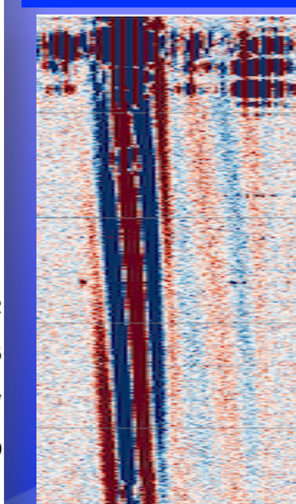
1H Auto correlation



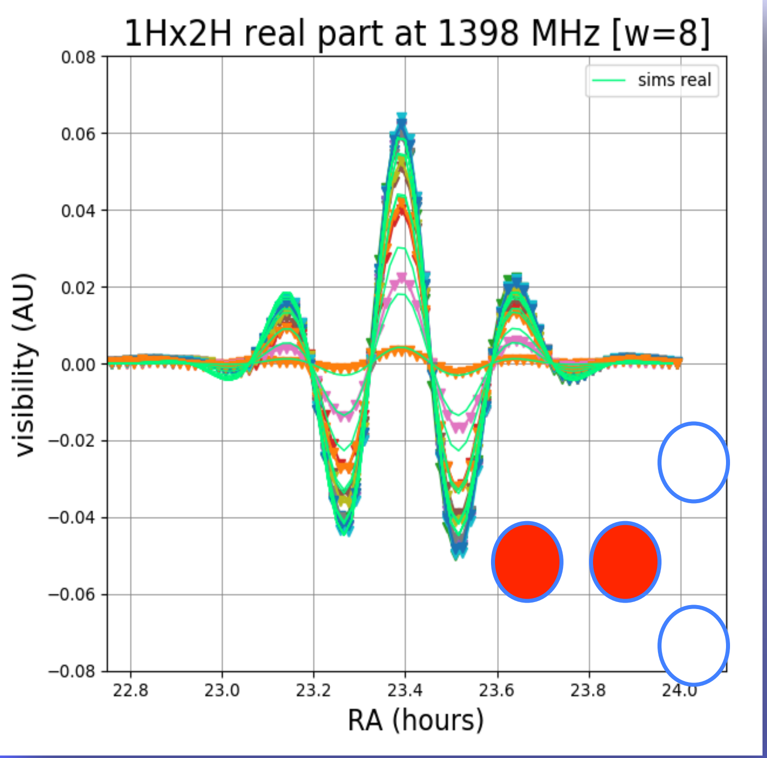
1H-3H Cross correlation

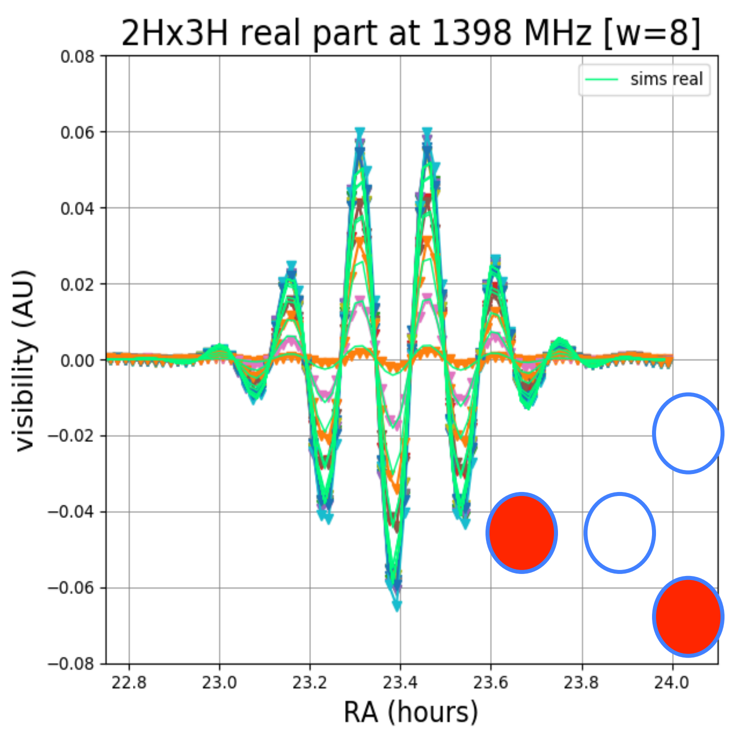


Zoom Cyg A transit



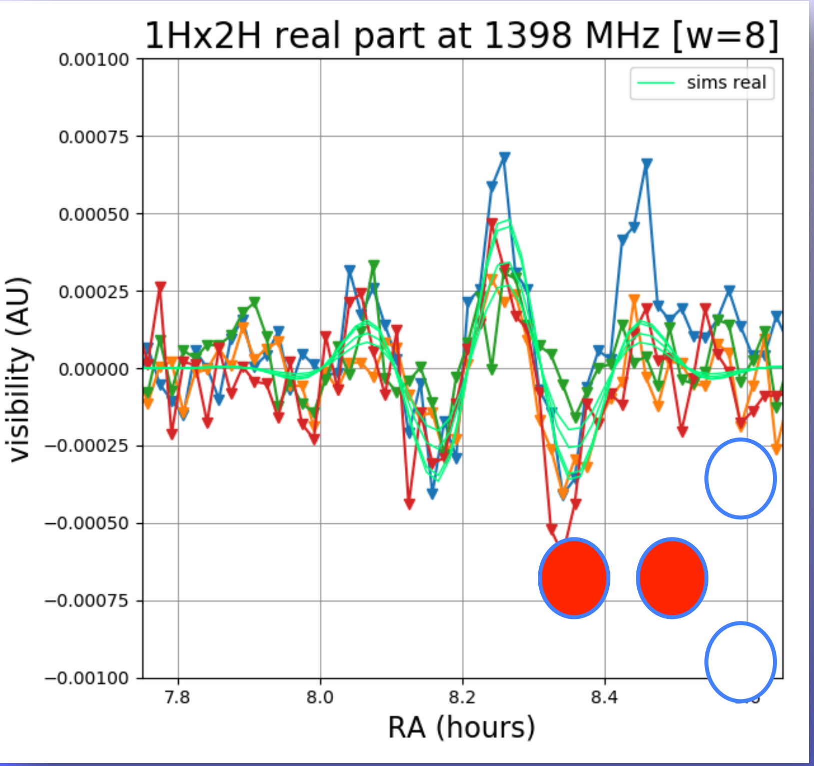
Transits of Cas A ~ 6K

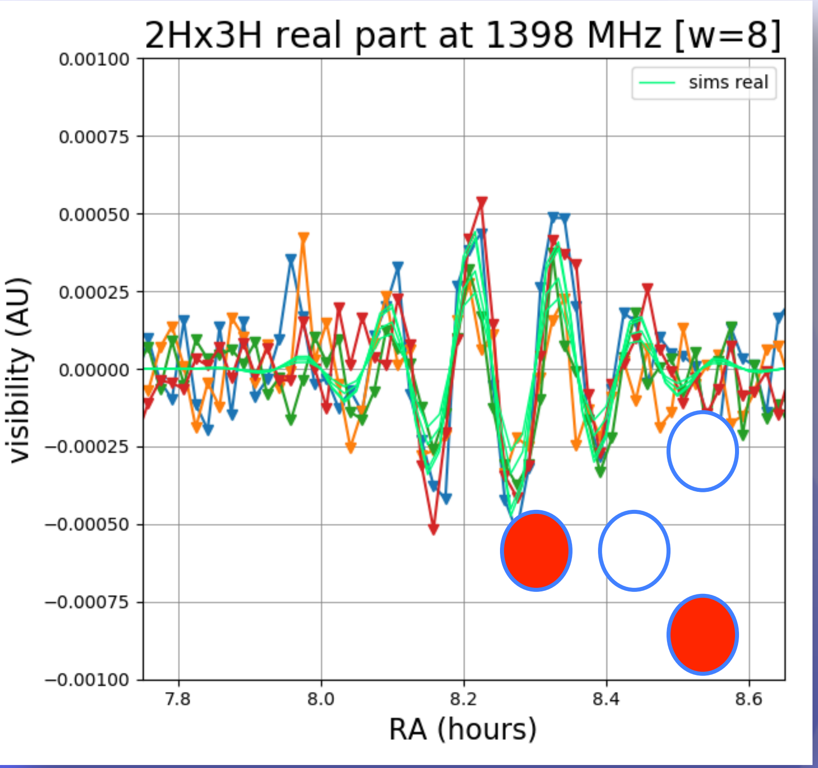




Good matching data-simulation of transits taken at different elevations around Cas A declination

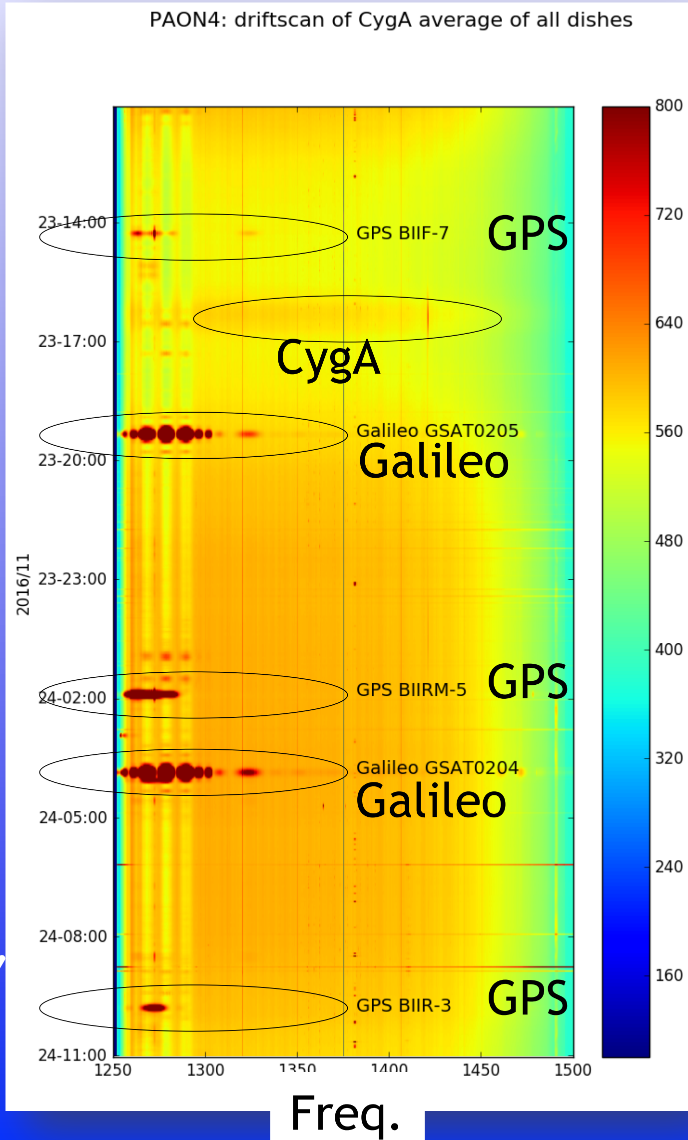
Transits of 3C196 ~ 60mK





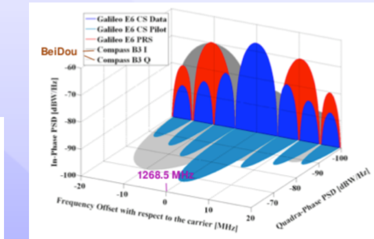
Good matching also too for weak sources

Satellites

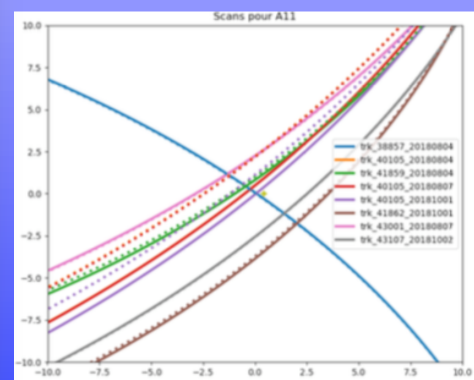


Strong signal < 1330MHz

Galileo & Beidou~ 1278 MHz
GPS L2 ~ 1227 MHz => 1273MHz



Use for geometry/phase calibration



Trajectories from SPG4

http://www.celestrak.com/NORAD/elements

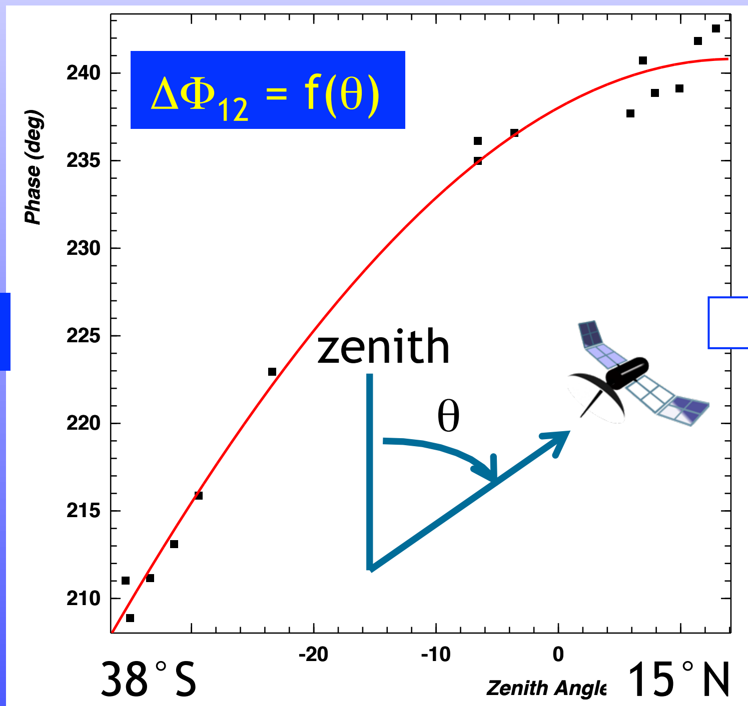
O(50%) 24h observations with 2 satellites

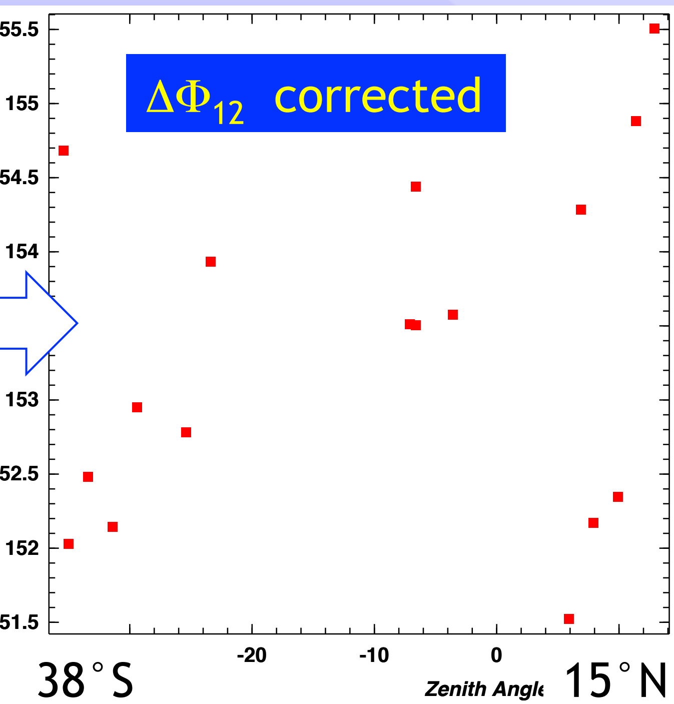
Phases

$$\varphi_{ij}(\mathbf{n_{b,ij}}, \Delta\Phi_{ij}; h) = -2\pi \left(\frac{\nu}{c}\right) \mathbf{n_s}.\mathbf{n_{b,ij}} + \Delta\Phi_{ij}$$

Geometry Instrumental

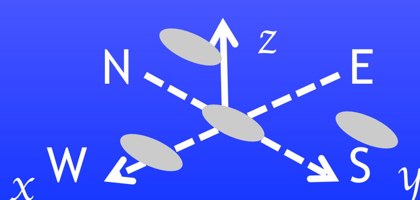
30°



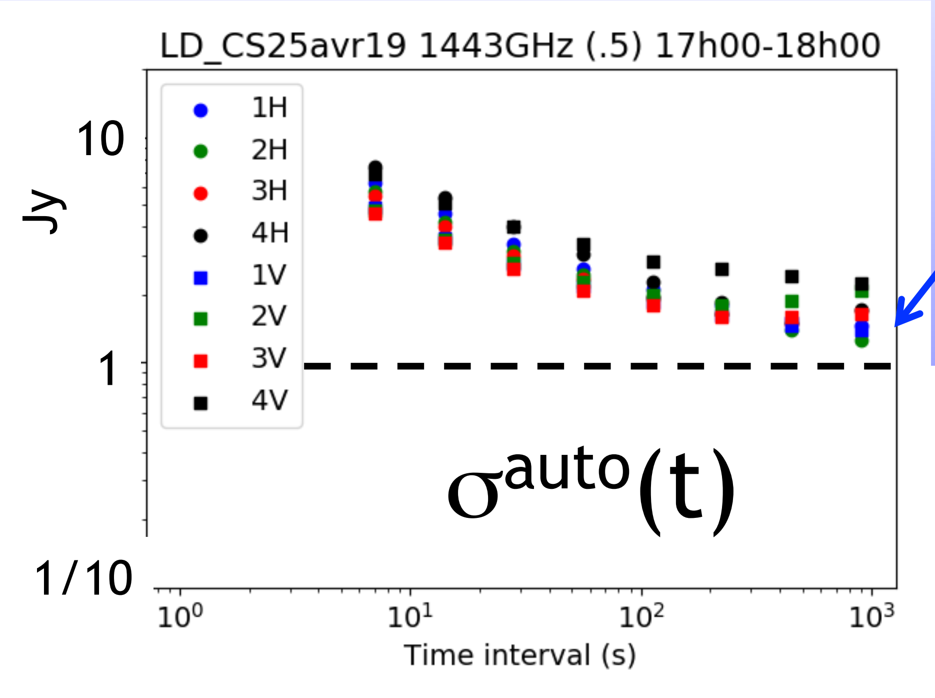


± 2°

Δz_{12} = 5.5 cm
Δy_{12} = 1.4 cm

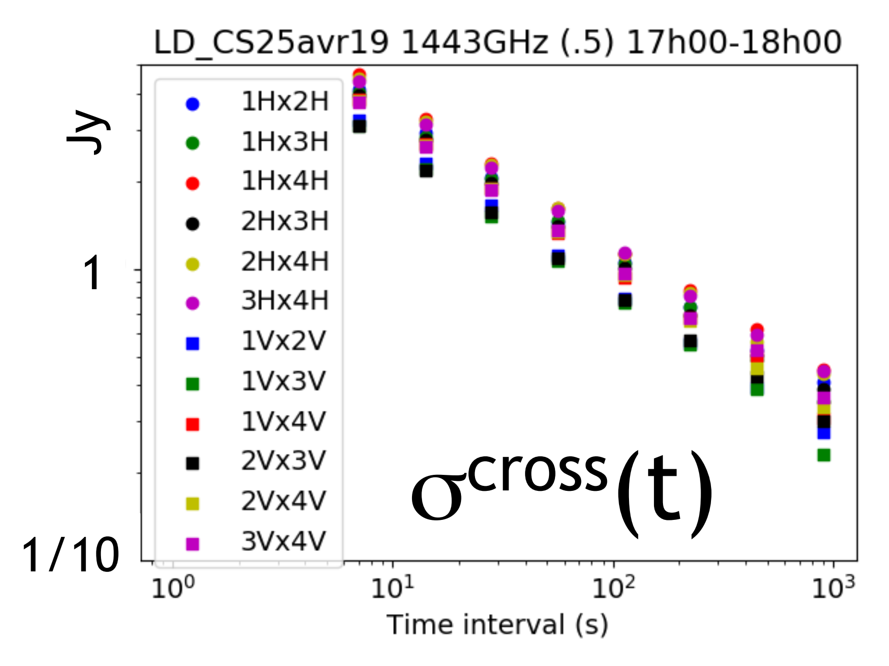


Noise evolution on Sky



Saturation possible explanations:
Gain variations with time
Diffuse sky brightness evolution

1 Jy ~ 6mK



Correlated noise has been subtracted as it is stable in time during few hours.

Antenna Temperature

Polar.	$T_a^{CasA}(K)$ (a)	$T_a^{CygA}(K)$ (a)	$D^{CasA}(m)$ (a)	$D^{CygA}(m)$ (a)	$T_a^{CasA}(K)$ (b)
1H	116	147	4.03	4.35	144
2H	127	129	4.12	4.38	133
3H	130	122	4.05	4.28	138
4H	161	152	4.17	4.21	185
1V	113	100	4.30	4.08	103
2V	108	92	4.27	4.18	100
3V	103	111	4.33	4.07	98
4V	143	151	4.38	4.00	180

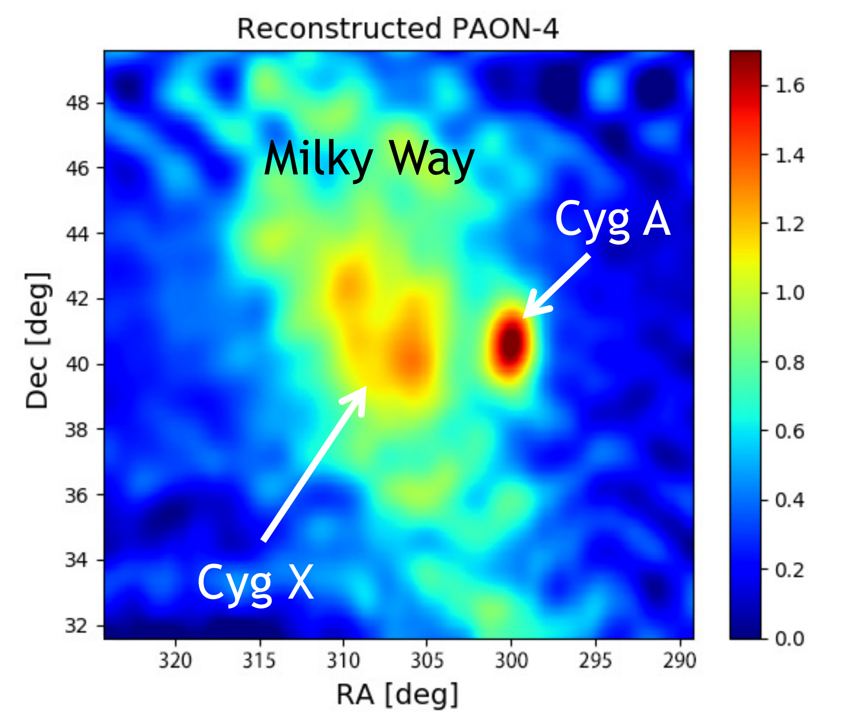
a) Uses satellites & Cas A, Cyg A transits @ 1396MHz during 20 days from Jan 19 to July 19
b) Uses Cas A transits @ 1440 MHz all along July 18 to Jan 19

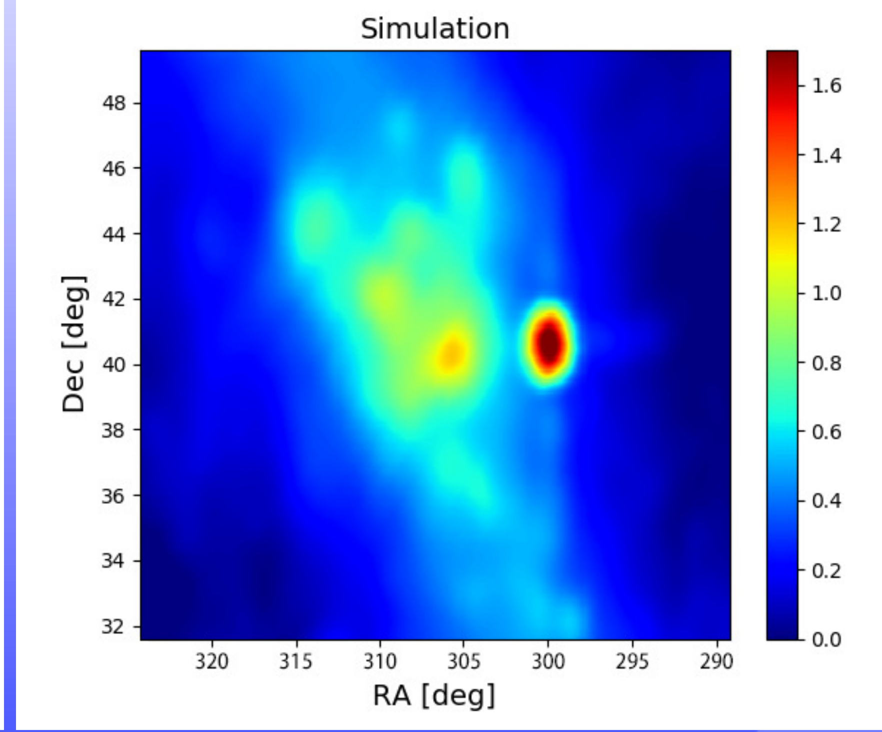
- H-type polarisations ~ 20% noisier than V-type
- 60-70 K due to electronics: may be the sign of ground temperature leakage throw the dish mesh

Sky map around Cyg A @ 1400MHz

35°x 18°

SSM, FWHM = 4.3°

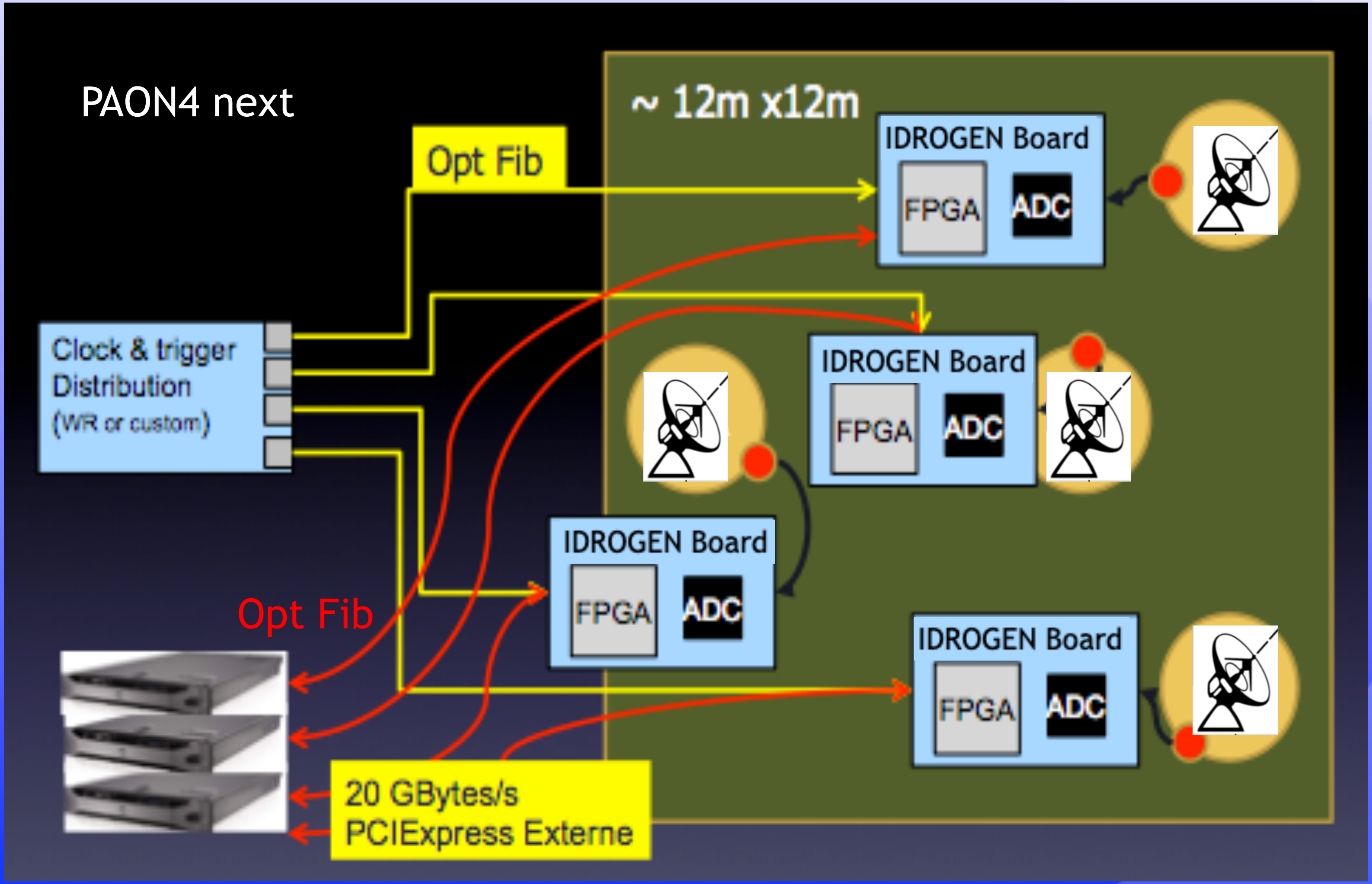




16th Nov- 1st Dec 2016: 11 scans of 24h - steps of δ = 1°

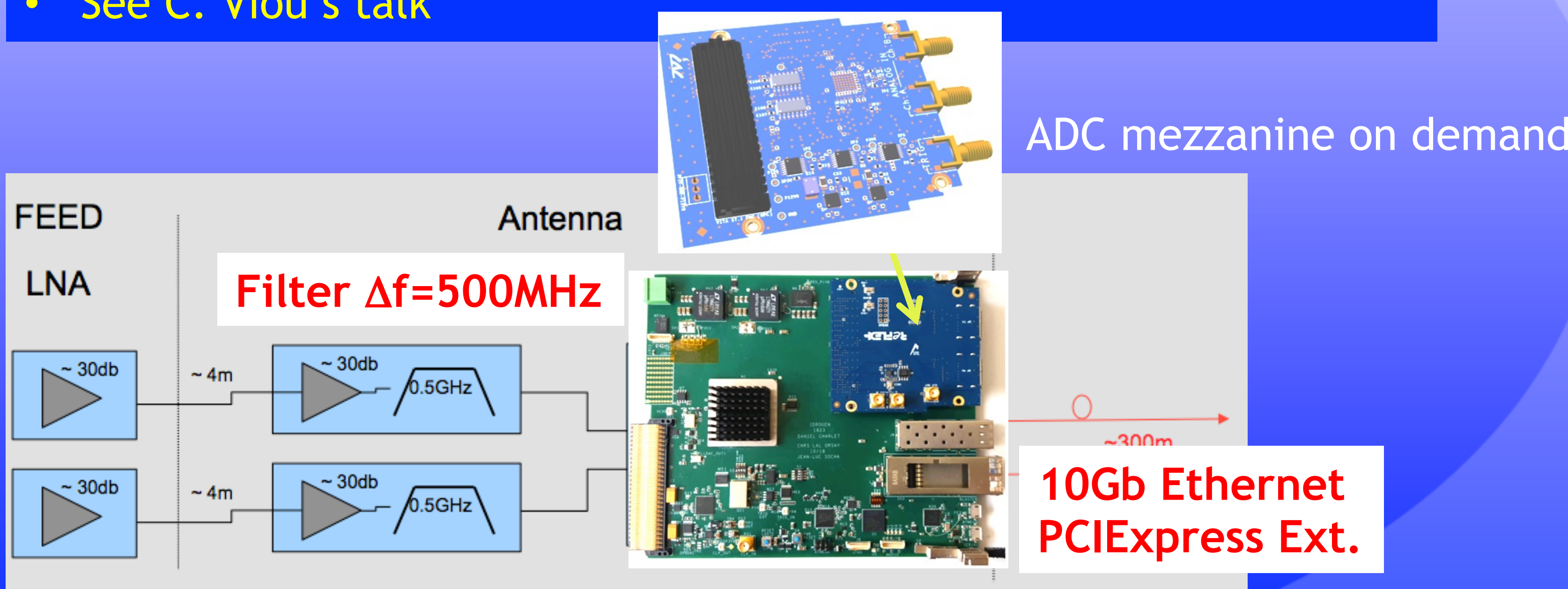
Q. Huang

Towards IDROGEN/White Rabbit architecture



Towards IDROGEN LAL/USN

- No more LO/Mixer
- No more 50m coax. Cables
- 250MHz => 500MHz possible bandwidth
- Digital signal on Optical fibres to the correlator
- Clock synchronisation thanks to the White Rabbit switch/protocol
- Ready mid-2020 for PAON4, part of the DAQGEN/IN2P3 project
- See C. Viou's talk

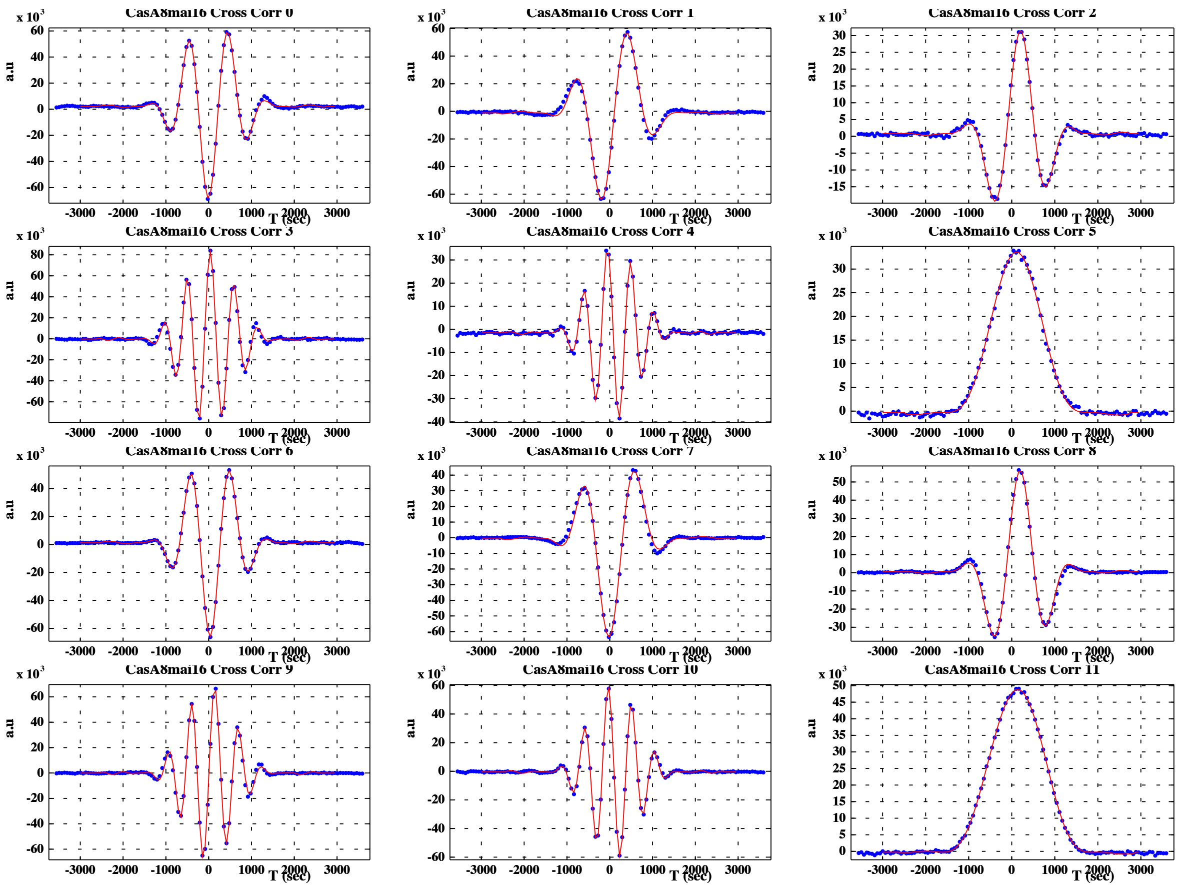


Summary

- PAON4 is running since mid-2015 and the reported analysis is based on observations from Fall 2016 to July 2019 in transit mode (>24h Sky scans at the same declination).
- The dish concept has proven to be robust all over the winter & wind conditions, but certainly is not scalable for larger projects.
- The present electronics is working since 2007 and will be replaced in 2020 by IDROGEN/White rabbit architecture to digitize the analogue signal as closed as possible right after the LNA.
- We have set-up methods to clean/correct Time-frequencies maps G(ν), G(T), RFI
- We have used bright sources & satellites transits to calibrate the instrument (geometry/instrumental phases)
- The antenna temperature is of the order of 110-130K and the noise decreases as $1/\sqrt{\Delta t}$ for the cross-correlations
- Fringe shapes are well reproduced from our simulation for 6K bright sources (Cas A , Cyg A) as well as for the 60mK 3C196 source
- Preliminary Sky map around Cyg A is well reproduced our simulation
- Stay tuned!

https://arxiv.org/abs/1910.07956 submitted to MNRAS

Back-up

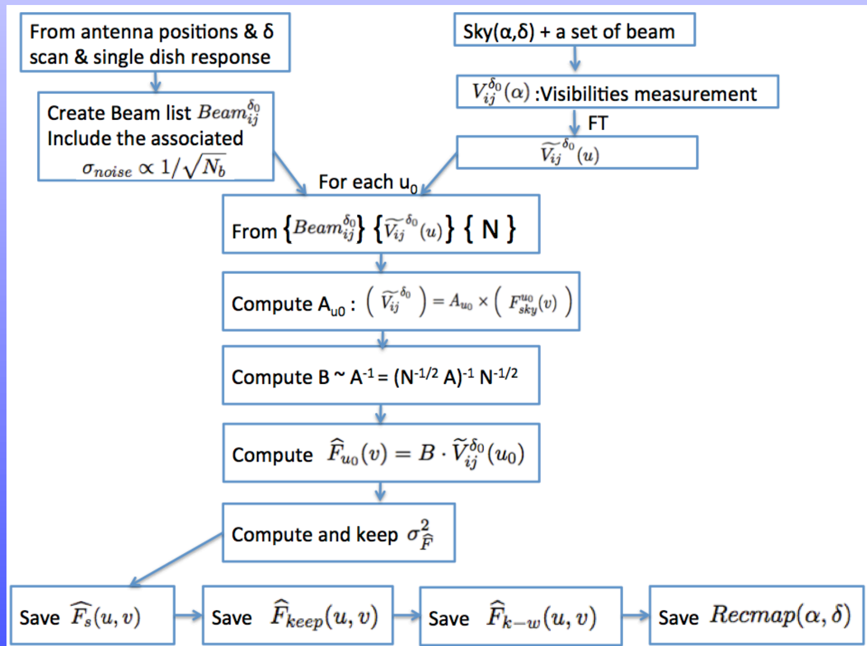

CasA8mai16 Cross Corr 0
CasA8mai16 Cross Corr 1
CasA8mai16 Cross Corr 2
CasA8mai16 Cross Corr 3
CasA8mai16 Cross Corr 4
CasA8mai16 Cross Corr 5
CasA8mai16 Cross Corr 6
CasA8mai16 Cross Corr 7
CasA8mai16 Cross Corr 8
CasA8mai16 Cross Corr 9
CasA8mai16 Cross Corr 10
CasA8mai16 Cross Corr 11
a.u
x 10³
T (sec)

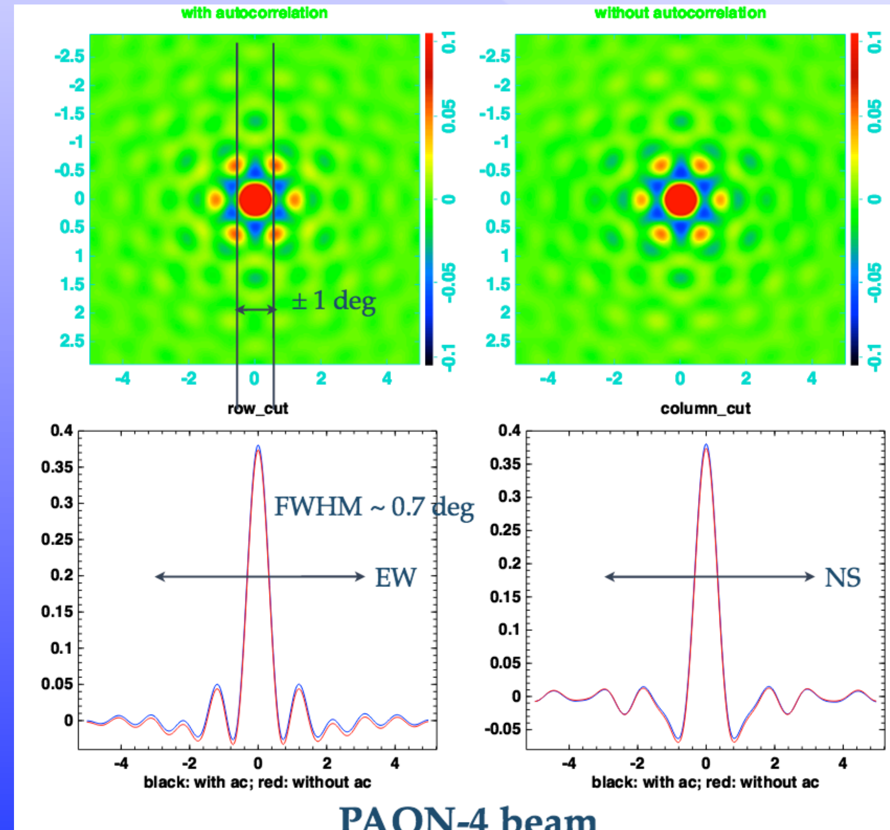
PAON4: inauguration 2 Avril 2015

visite de la Station de Nançay par la direction du LAL et inauguration en présence du Directeur de l'Observatoire de Paris

PAON4: map making (1)

Jiao Zhang thèse en co-tutelle avec la Chine



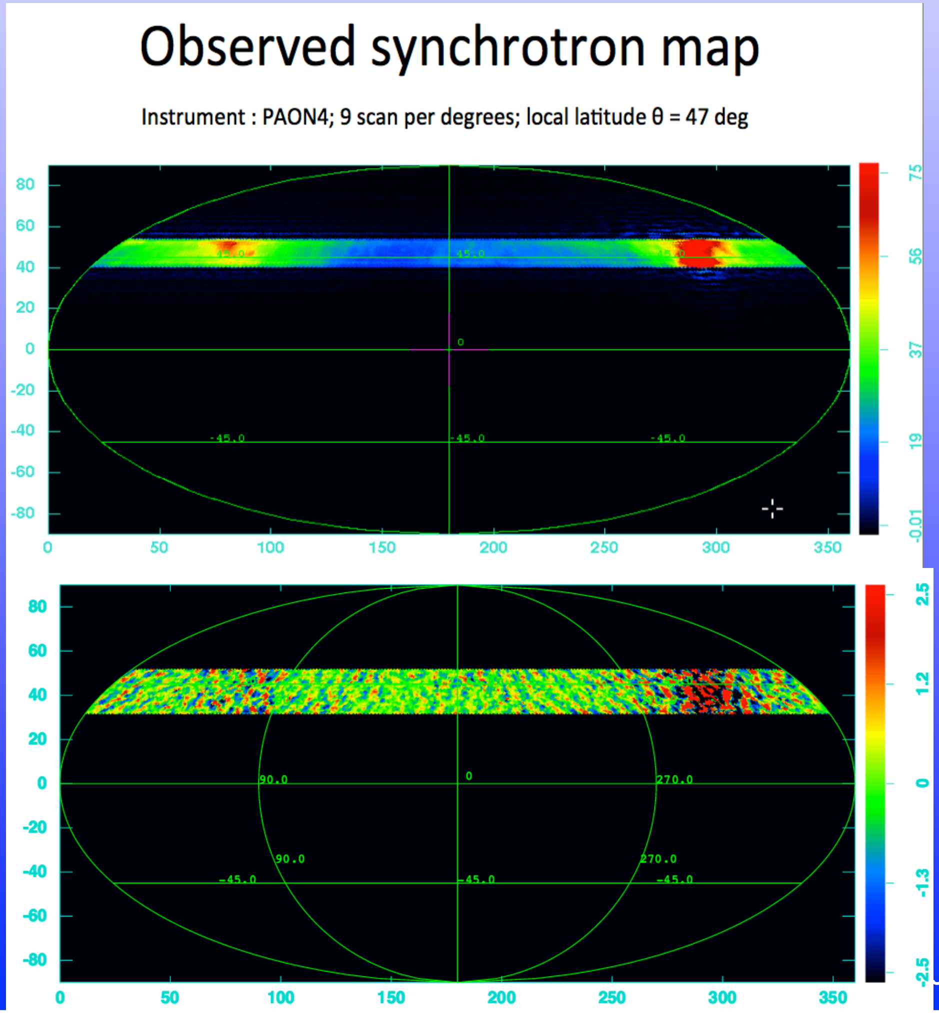


Généralisé en Ham. Sphérique (Ylm)

L'usage du Transit à plusieurs élévations permet de séparer les modes « m »

PAON4: map making (2)

Jiao Zhang thèse en co-tutelle avec la Chine



Une fois que l'instrument est stable avec les caractéristiques actuelles.

Avec auto-correlations

Sans auto-correlations

BAO en radio

O($10^{5\text{-}6}$ m^2)
$\Delta\theta \sim 1/10''$
O(μJy)

A la manière des relevés optiques

- Identification des sources d'émissions HI (21 cm), détermination de la position angulaire et du décalage vers le rouge - Détermination de la fonction de corrélation à deux points ou le spectre P(k) à partir du catalogue des objets identifiés

O(10^4 m^2)
$\Delta\theta \sim 1/10°$
O(100μJy)

A la manière des observations du CMB

- Cartographie à trois dimensions de l'émission HI (21 cm) T21(α,δ,z) - Estimation et soustraction des avant-plans, détermination du spectre P(k,z) sur les données du cube 3D
- Grand FOV~10-100 deg^2, O(100) paraboles ∅ ~ 5m
- bande fréq. large >100 MHz
- Sensibilité à atteindre < O(mK)
- Avant plan ~ O(°K), T_{sys} typique ~ 50 °K (n.b. le sol rayonne à 300 °K)

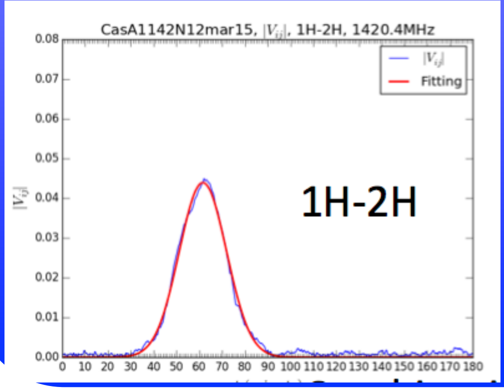
PAON4: analyse d'un transit

Qizhi Huang

Modèle simple pour reconstruire (extension de PAON2):

- Les orientations des antennes
- La géométrie de l'interféromètre
- Le rayon effectif des paraboles
- Les décalages de phase dans les câbles
- …
- Température système

$$V_{ij}(\theta) = \sqrt{G_i G_j} I_0 \exp\left\{-\frac{(\theta - \theta_{s,ij})^2}{2\sigma_{ij}^2}\right\} \exp\left\{i\frac{2\pi}{\lambda}[L_{ew,ij}\sin\theta - L_{ns,ij}\cos\theta] + i\Delta\Phi_{ij}\right\}$$



Gain, beam geom.

Phase: interf. Geom, câbles…

		T_{inst}	$N_d x N_b$	D_{dish} (m)	z_{min}	z_{max}	S (deg²)
single dish	GBT	29	1x1(7)	100	0.54	1.09	100
	Parkes	23	1x13	64	0.00	0.23	5,000
	BINGO	*50*	*1x50*	*25*	*0.13*	*0.48*	*5,000*
	FAST	*20*	*1x20*	*500*	*0.42*	*2.55*	*2,000*
interferometer	CHIME 4, 100 m cyl.	50	1280x1	20	0.77	2.55	25,000
	Tianlai 8, 120 m cyl.	50	2048x1	15	0.00	2.55	25,000
	HIRAX	50	1024x1	5	0.77	2.55	15,000
interf. + autocor.	*SKA1-MID*	*20*	*190x1*	*15*	*0.00*	*3.06*	*25,000*
	SKA1-SUR	*30*	*96x36*	*15*	*0.23*	*1.38*	*25,000*

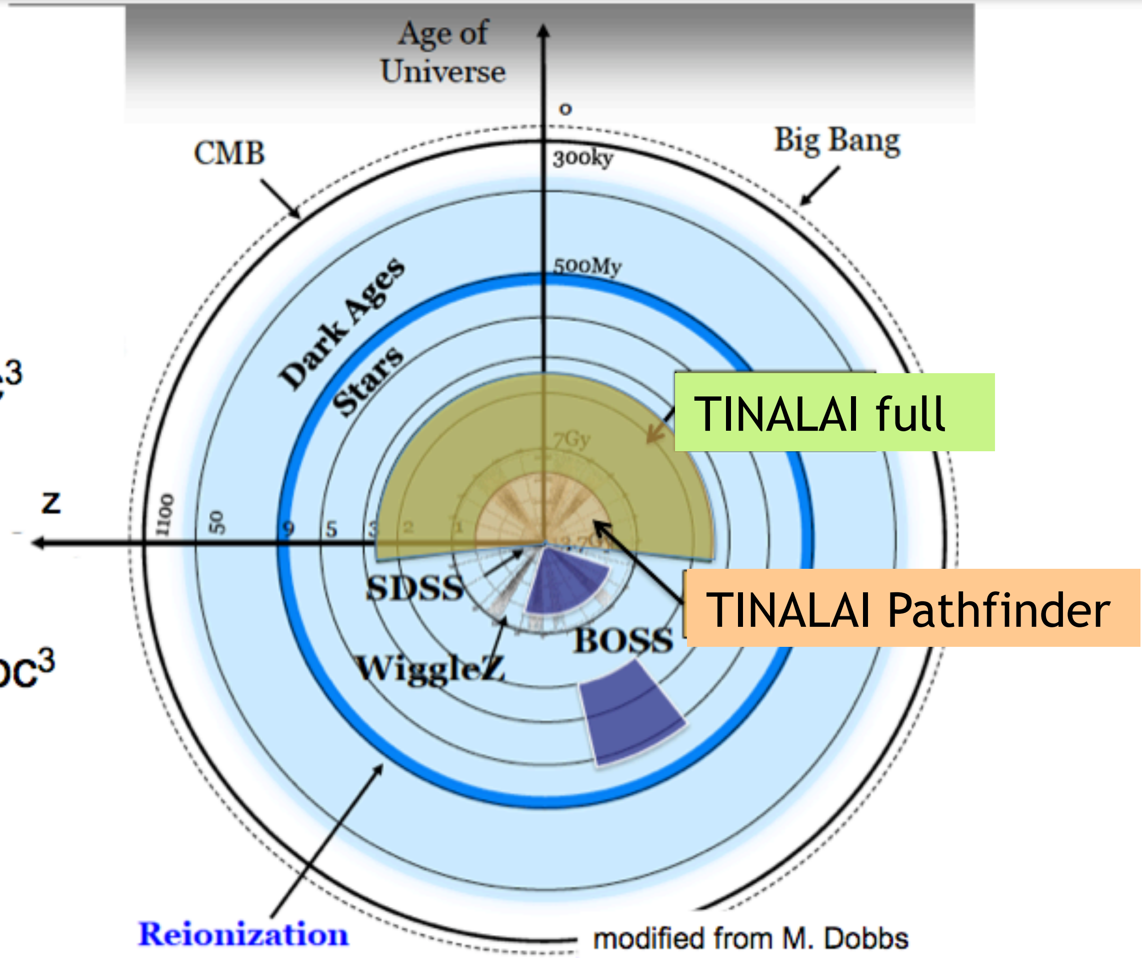
from Bull *et al.* ApJ 803 (2015)

21 cm surveys can explore huge comoving volumes

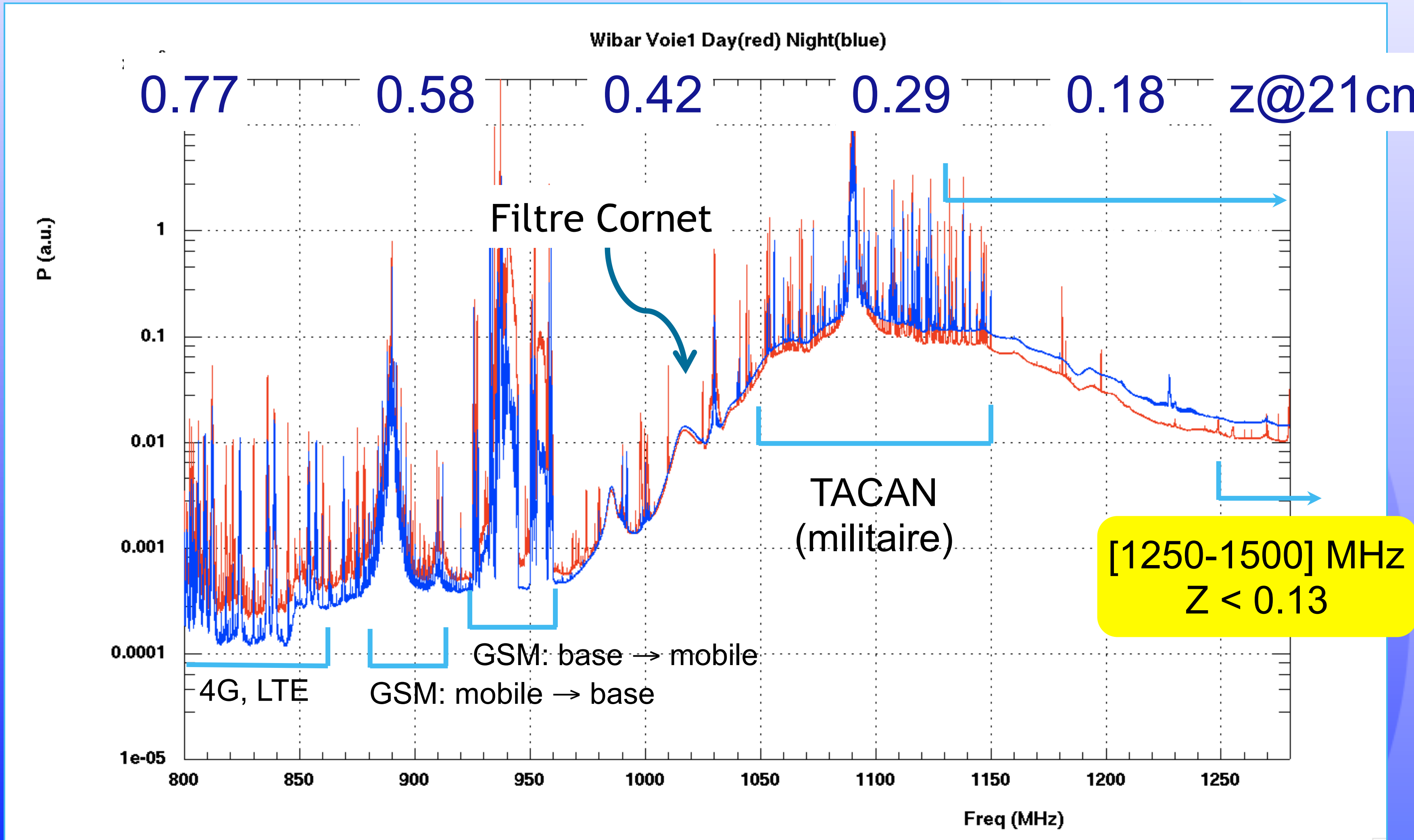
1 h^{-3} Gpc^3

↓

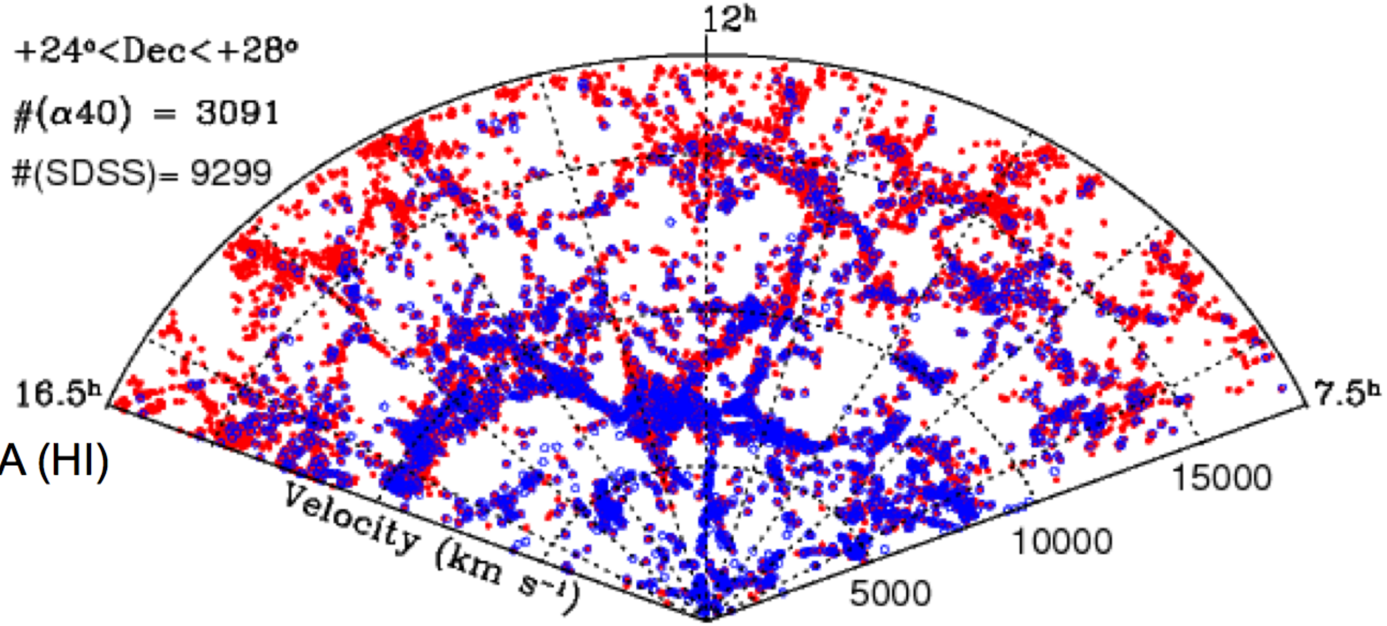
200 h^{-3} Gpc^3



RFI @ NRT (WIBAR spectrum)

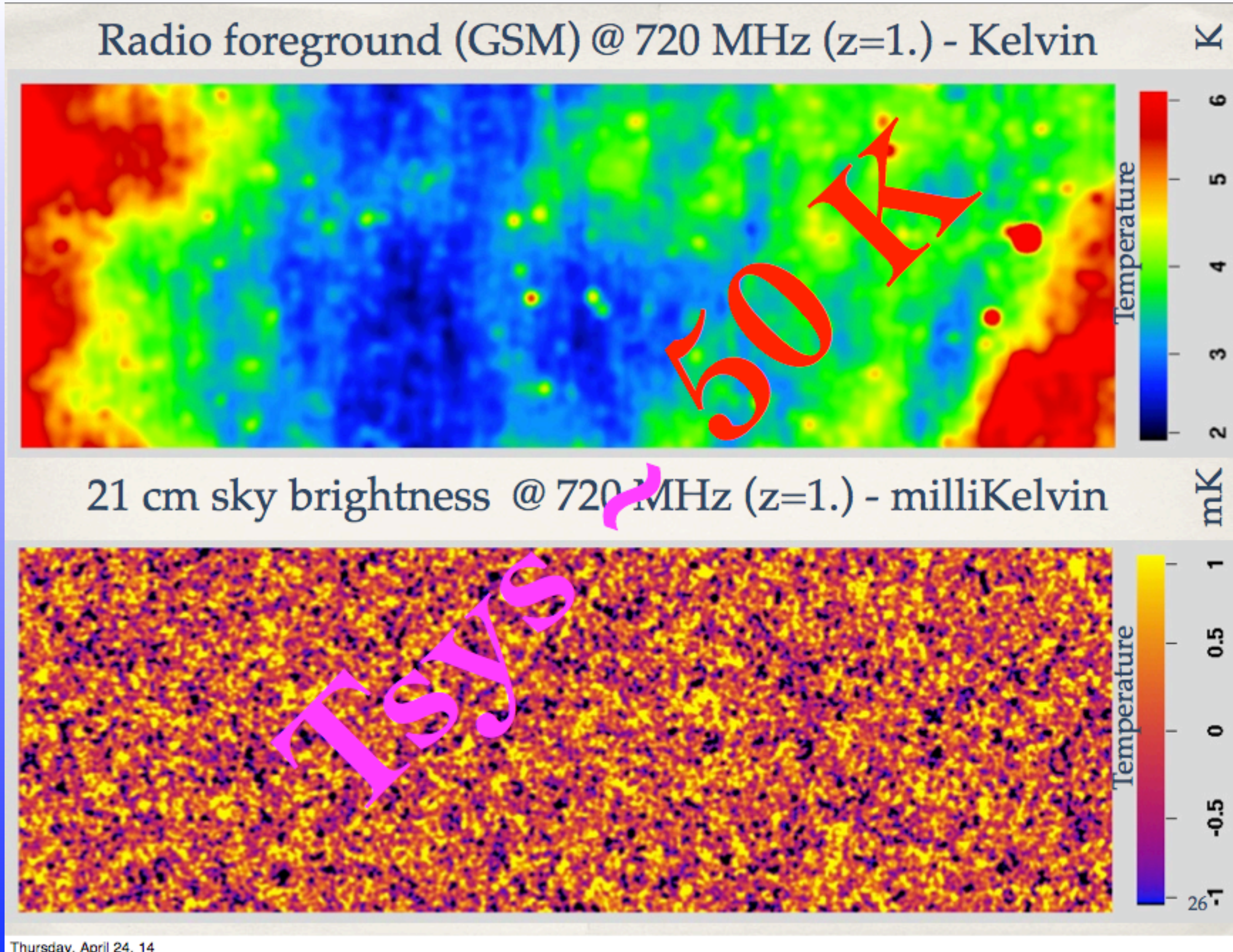


HI and Optical Surveys Detect Similar Structure to z ~ 0.07



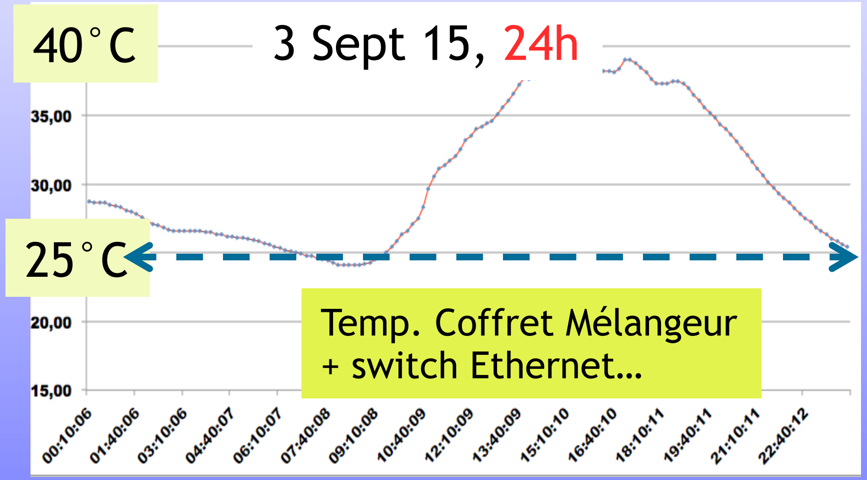
- ALFALFA (HI)
- SDSS

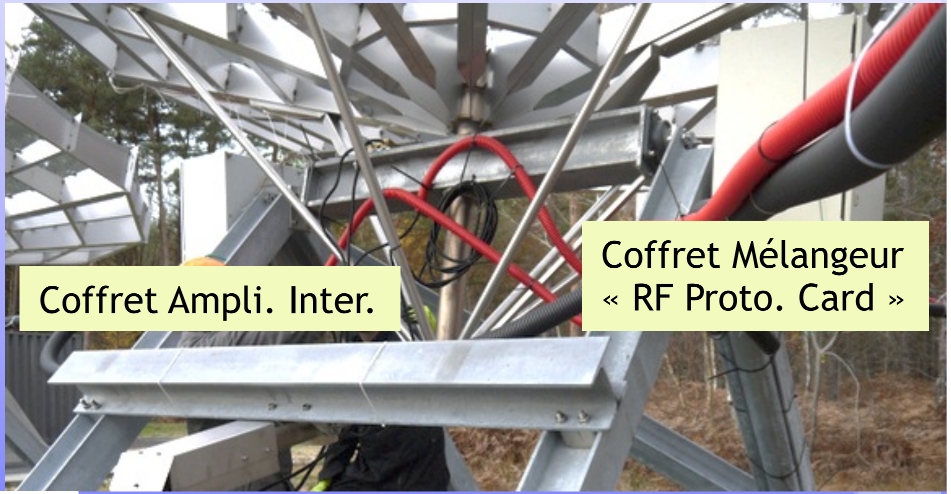
Haynes et al. (2011)

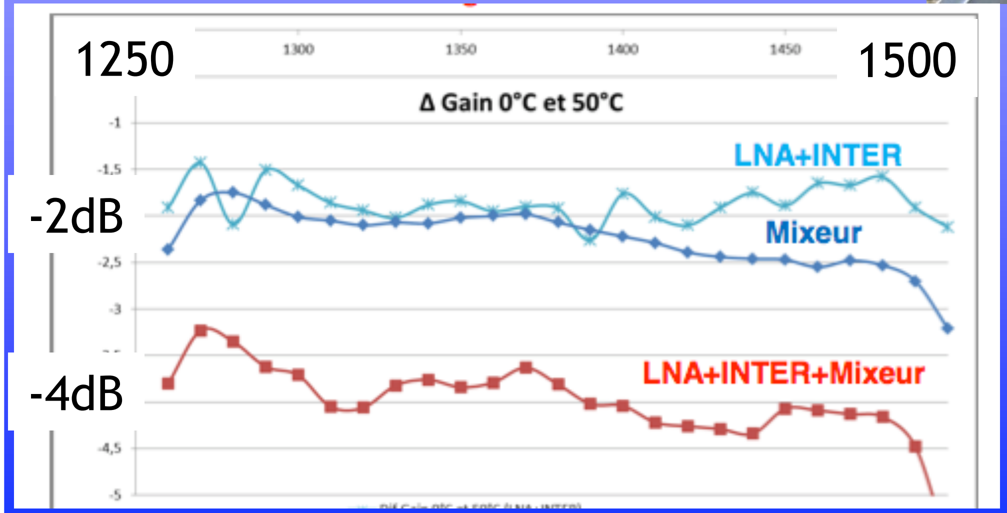


Radio foreground (GSM) @ 720 MHz (z=1.) - Kelvin
K
Temperature
6
5
4
3
2
50 K
21 cm sky brightness @ 720 MHz (z=1.) - milliKelvin
~
mK
Temperature
1
0.5
0
-0.5
-1
26
Tsys
Thursday, April 24, 14

PAON4: tests en étuve @ Saclay





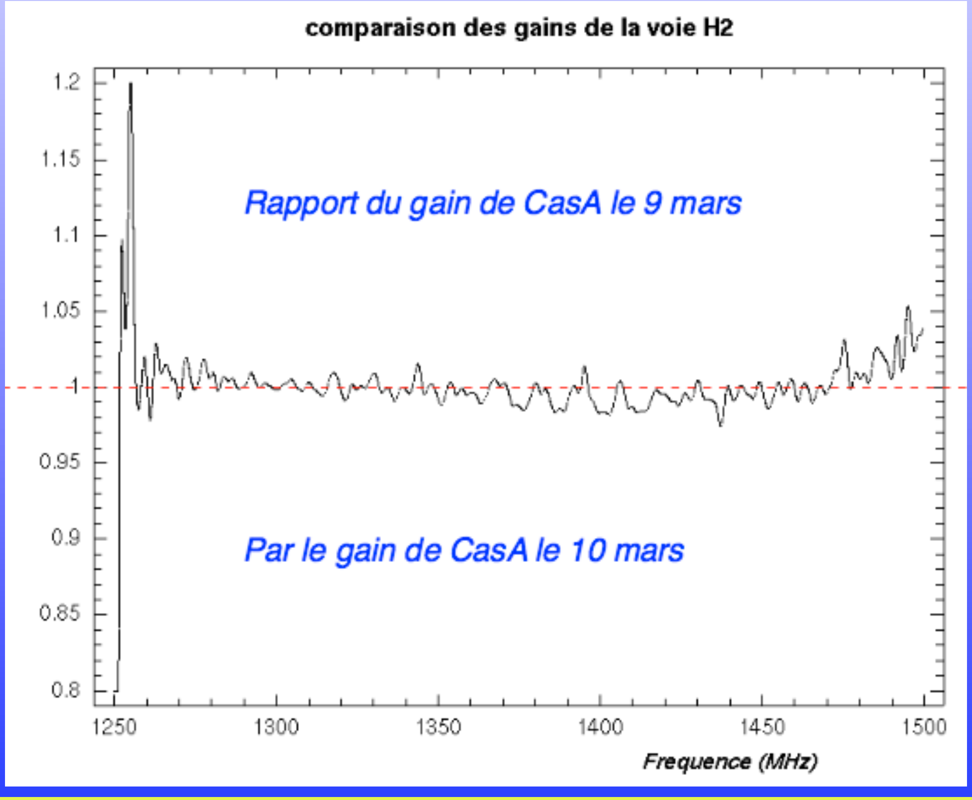


Chaine analogique gain total de 90dB:

- Variation -4dB entre 0°C et 55°C
- Contribution identique entre LN+Amp Inter et Mélangeur

PAON4: stabilité relative

Th. Etourneau
Mag. Orsay 1e année



Gain à peu près stable d'un jour à l'autre…