Low Noise Amplifier Developments and Related Activities at The University of Manchester

Gary Fuller
School of Physics & Astronomy and
UK ALMA Regional Centre Node
The University of Manchester

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ARIG: Advanced Radio Instrumentation Group

- Cross School Research Group
- Lead by
  - Prof. Danielle George, School of Electrical and Electronic
  - Prof. Gary Fuller, School of Physics & Astronomy, Jodrell Bank Centre for Astrophysics
- Post-docs and PhD students
- Developing new laboratory providing cryogenic (<1 K) testing 20 GHz – 400 GHz
- Builds on previous experience at Jodrell Bank Observatory
  - Planck Low Frequency Instrument
- Focus on low noise amplifiers (LNAs)

Partners

- Rutherford Appleton Laboratories
  - Prof. Brian Ellison
- Cahill Radio Astronomy Laborato
  - Prof. A. Readhead
  - Dr. K. Cleary
- Northrop Grumman Corporation (NGC), LA
- WIN Semiconductors, Taiwan

Caltech
CRAL
Cahill Radio Astronomy Lab

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Projects

- Low frequency LNAs
  - 15 GHz to 50 GHz
  - Band 5, 6 & 7 on the Square Kilometre Array
  - Commercial foundry – WIN Semiconductors
    - Also IF amplifiers
- High frequency LNAs, >50 GHz
  - 67 -116 GHz
  - 125 GHz to 373 GHz
    - ALMA
    - NGC InP 35nm process
- GCRF Programmes

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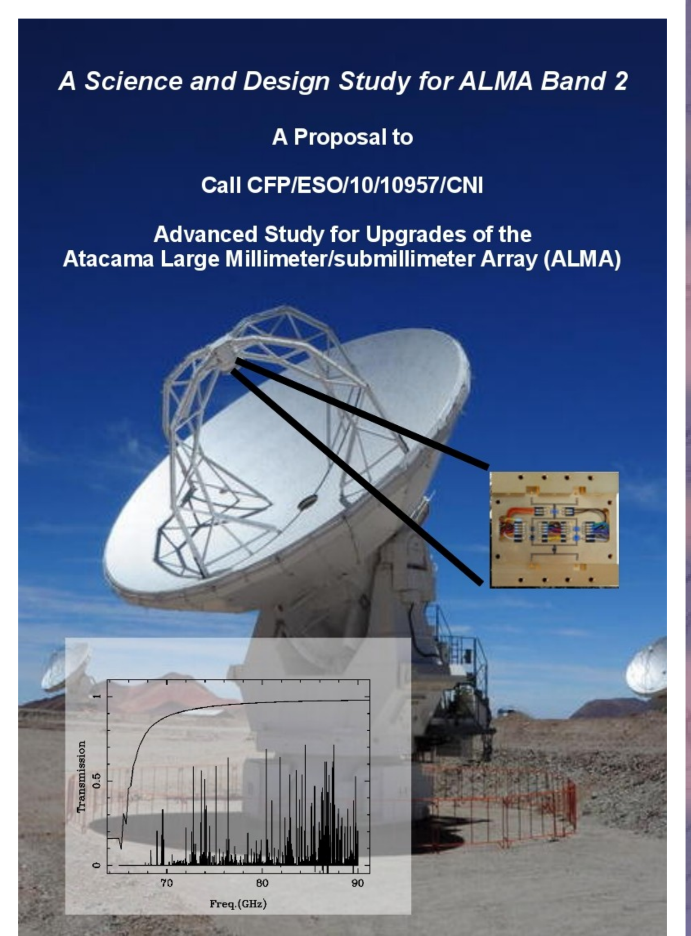
ALMA Band 2+3 Project

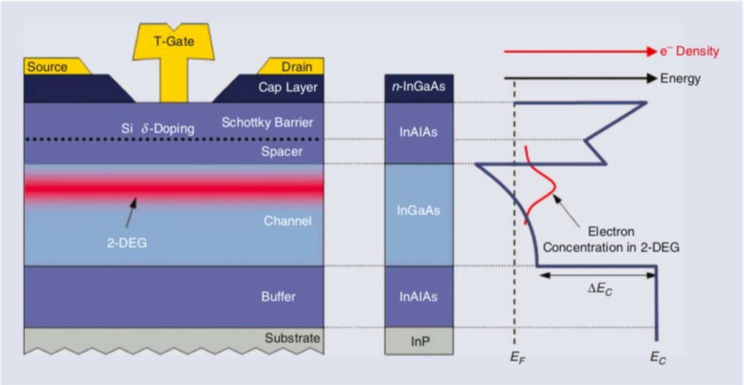
- ESO ALMA Development Study
  - A Science and Design Study for ALMA Band 2
  - Proposal submitted: Dec 2010
  - Project started: June 2012
  - Completed: July 2014
    - Delivered:
      - Science case
      - Plan for LNA development
      - OMT & Feedhorn designs
      - Optics & cryogenics studies
      - Initial system design and analys

PI: Gary Fuller
Collaboration:
The University of Manchester
INAF
Science & Technology Facilities Council Rutherford Appleton Laboratory
iram Institut de Radioastronomie Millimétrique

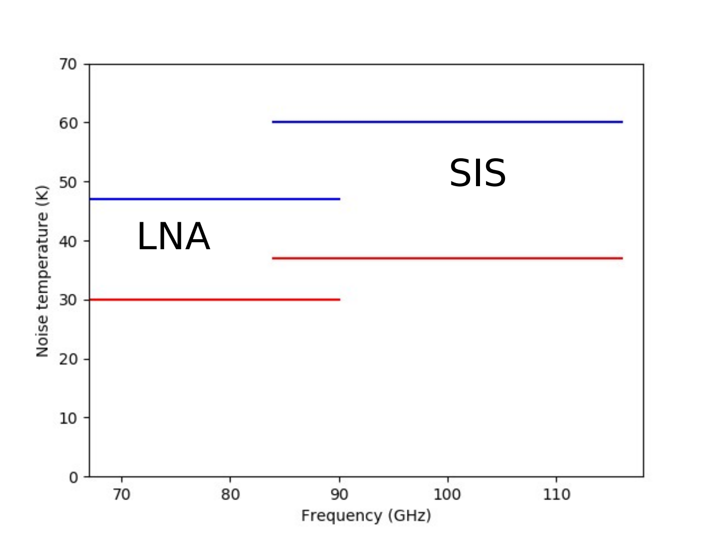


Why LNAs?

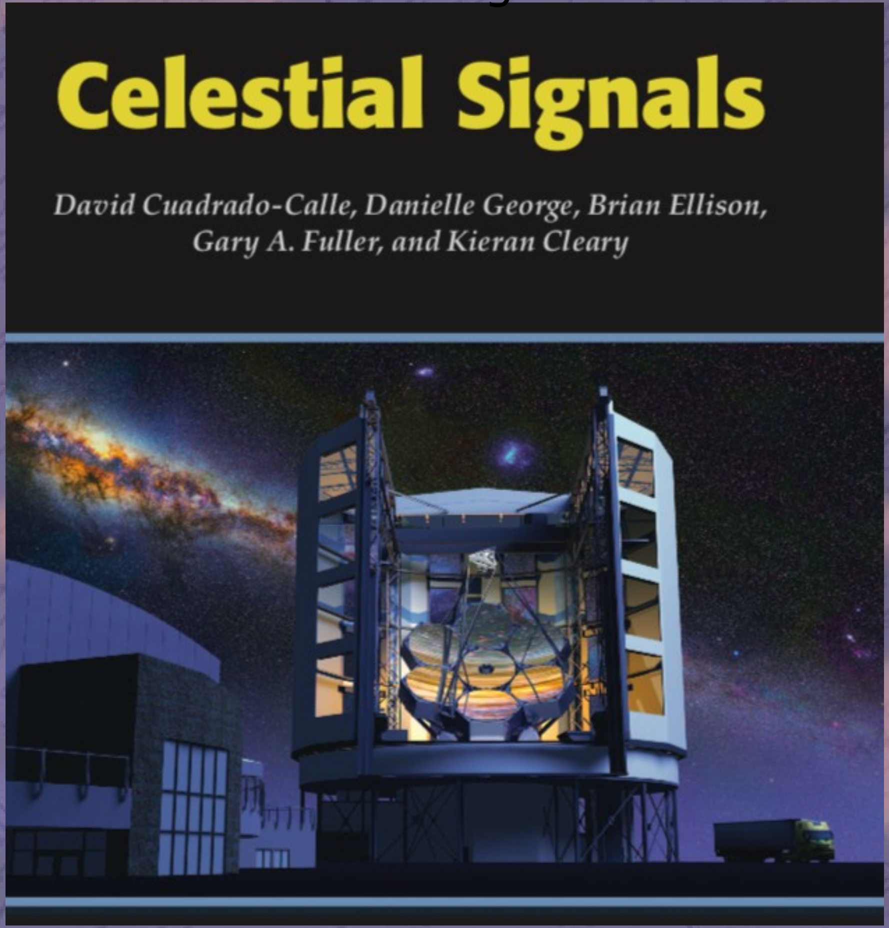
- Higher operating temperature
- Simpler FPA construction
- Typically for frequencies about 50 GHz receivers use SIS mixers due to noise performance
- But technology advances…..



Microwave Magazine



Cuadrado-Calle et al, 2017, IEEE Microwave Magazine



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Band 2+3 Level 1 Science Drivers

- Cold, dense, quiescent gas
  - Deuterated species J=1-0 transitions
- Closing the redshift desert
- Galaxy evolution

arXiv:1602.02414

The Science Case for ALMA Band 2 and Band 2+3

G. A. Fuller [1], A. Avison[1], M. Beltrán[2], V. Casasola[3], P. Caselli[4], C. Cicone[5], F. Costagliola[6], C. De Breuck[7], L. Hunt[2], I. Jimenez-Serra[7], R. Laing[7], S. Longmore[8], M. Massardi[3], R. Paladino[3], S. Ramstedt[9], A. Richards[1], L. Testi[2,7,10], D. Vergani[11], S. Viti[12], J. Wagg[13]

9th February 2016

Abstract

We discuss the science drivers for ALMA Band 2 which spans the frequency range from 67 to 90 GHz. The key science in this frequency range are the study of the deuterated molecules in cold, dense, quiescent gas and the study of redshifted emission from galaxies in CO and other species. However, Band 2 has a range of other applications which are also presented. The science enabled by a single receiver system which would combine ALMA Bands 2 and 3 covering the frequency range 67 to 116 GHz, as well as the possible doubling of the IF bandwidth of ALMA to 16 GHz, are also considered.

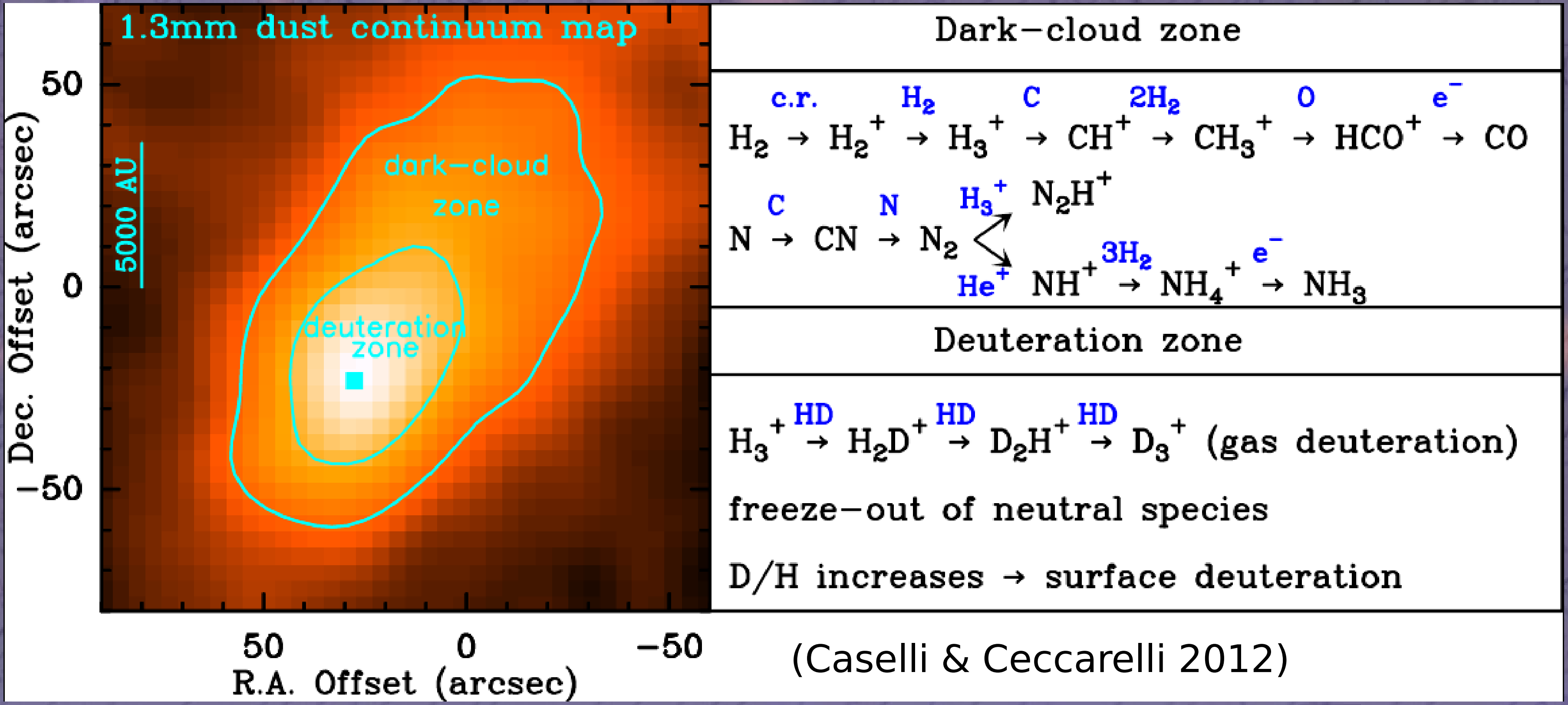
Deuteration Probing Cold Dense Gas

At T<20K $H_3^+ + HD \rightarrow H_2D^+ + H_2 + 230K$

$$H_2D^+ + N_2 \rightarrow N_2D^+ + H_2$$

$$H_2D^+ + CO \rightarrow DCO^+ + H_2$$

~10^5 enhancement over cosmic [D/H] of 10^{-5}



(Caselli & Ceccarelli 2012)

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Cold, Dense, Quiescent Gas: D-containing Species in Band 2

Deuterated Species					
Molecule		Freq. (GHz)	Molecule		Freq. (GHz)
CH_2D^+	1(1,0)-1(1,1)	67.273	$DN^{13}C$	J=1-0	
$D^{13}CO^+$	J=1-0	70.733	DNC	J=1-0	76.306
$D^{13}CN$	J=1-0	71.175	DOC^+	J=1-0	76.386
DCO^+	J=1-0	72.039	N_2D^+	J=1-0	77.108
C_2D	N=1-0	72.108	NH_2D	1(1,1)0 - 1(0,1)0	85.926
DCN	J=1-0	72.415			

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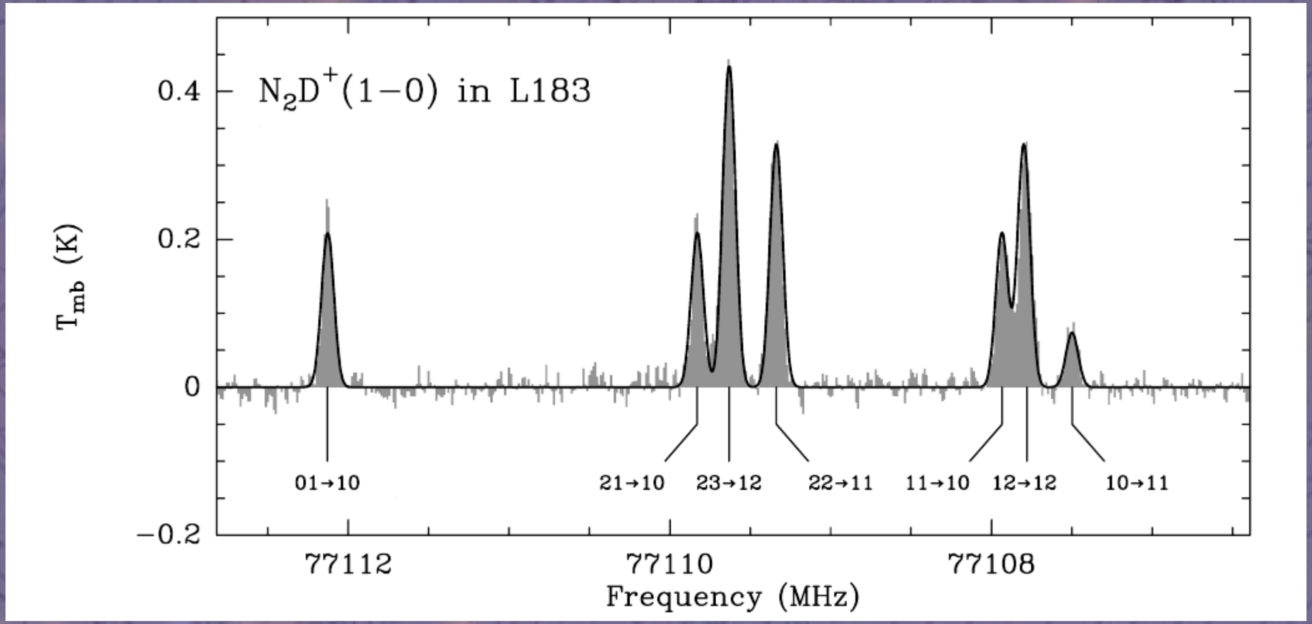
N_2D^+ J=1-0, 77.1 GHz



Isolated hyperfine component – sensitive probe of velocity and turbulence.

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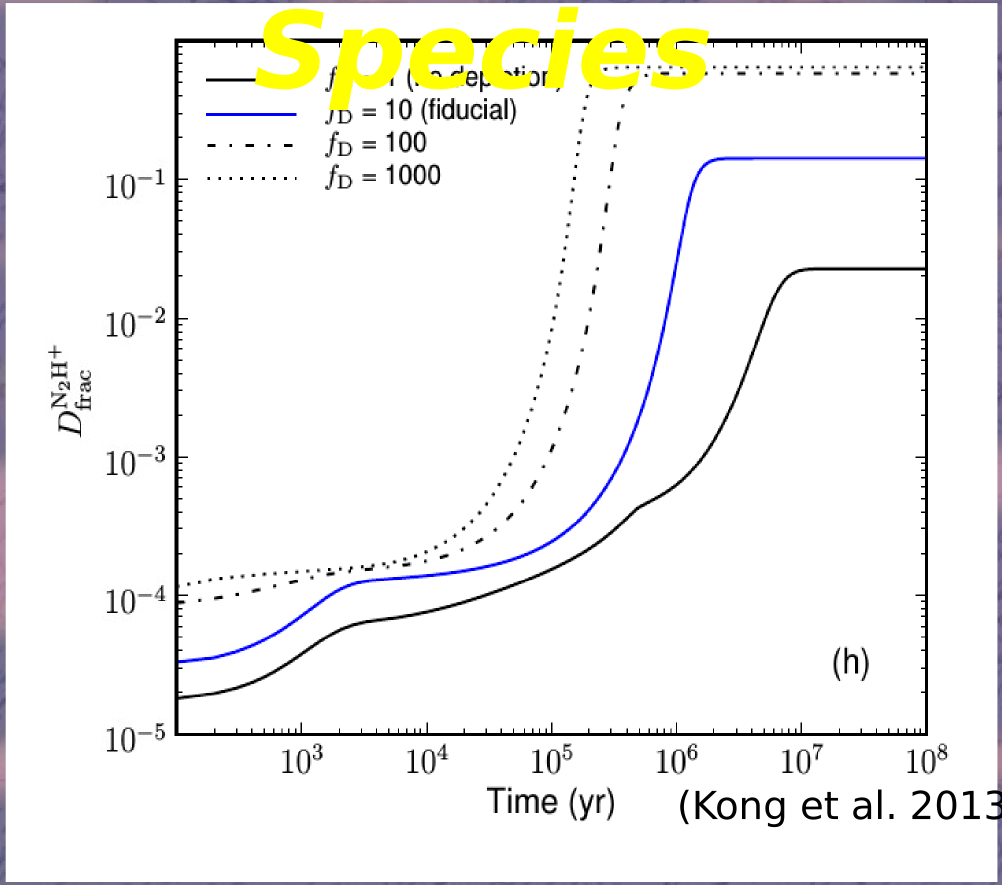
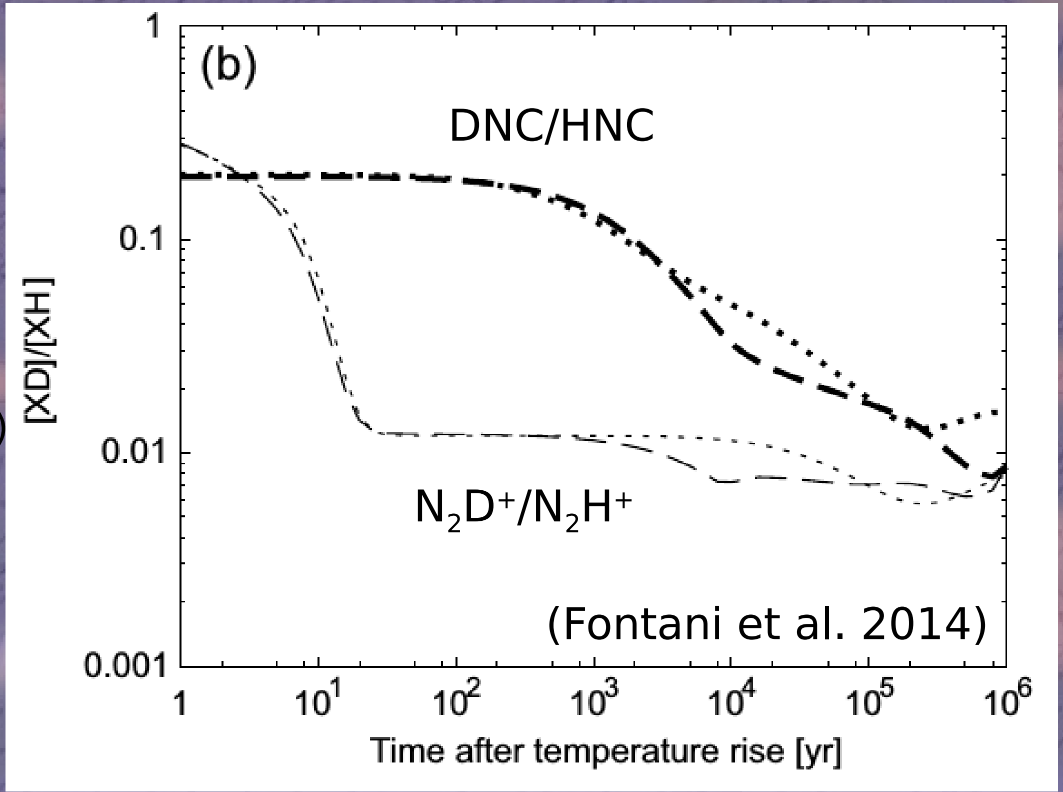
Evolution of Deuterium Species





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Applications of D Species

- Evolutionary history of gas
  - Classification of massive protostars
- Kinematics of gas on the verge of collapse
- CO snowline in proto-planetary disks
- Tracing ionization
  - Gas-magnetic field coupling
  - Cosmic ray heating rates – galactic & extragalactic
- In solar system (and proto-planetary disks ?) trace transport of volatiles

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Efficiency for Deuterium Observations

Species: HCN, HCO^+, HNC, N_2H^+
DCN, DCO^+, DNC, N_2D^+

Band	Number of Lines	D Species	Deuteration ratios
2+3	5	2	DNC/HNC
4	3	3	–
5	2	0	–
6	4	4	–
7	4	2	–

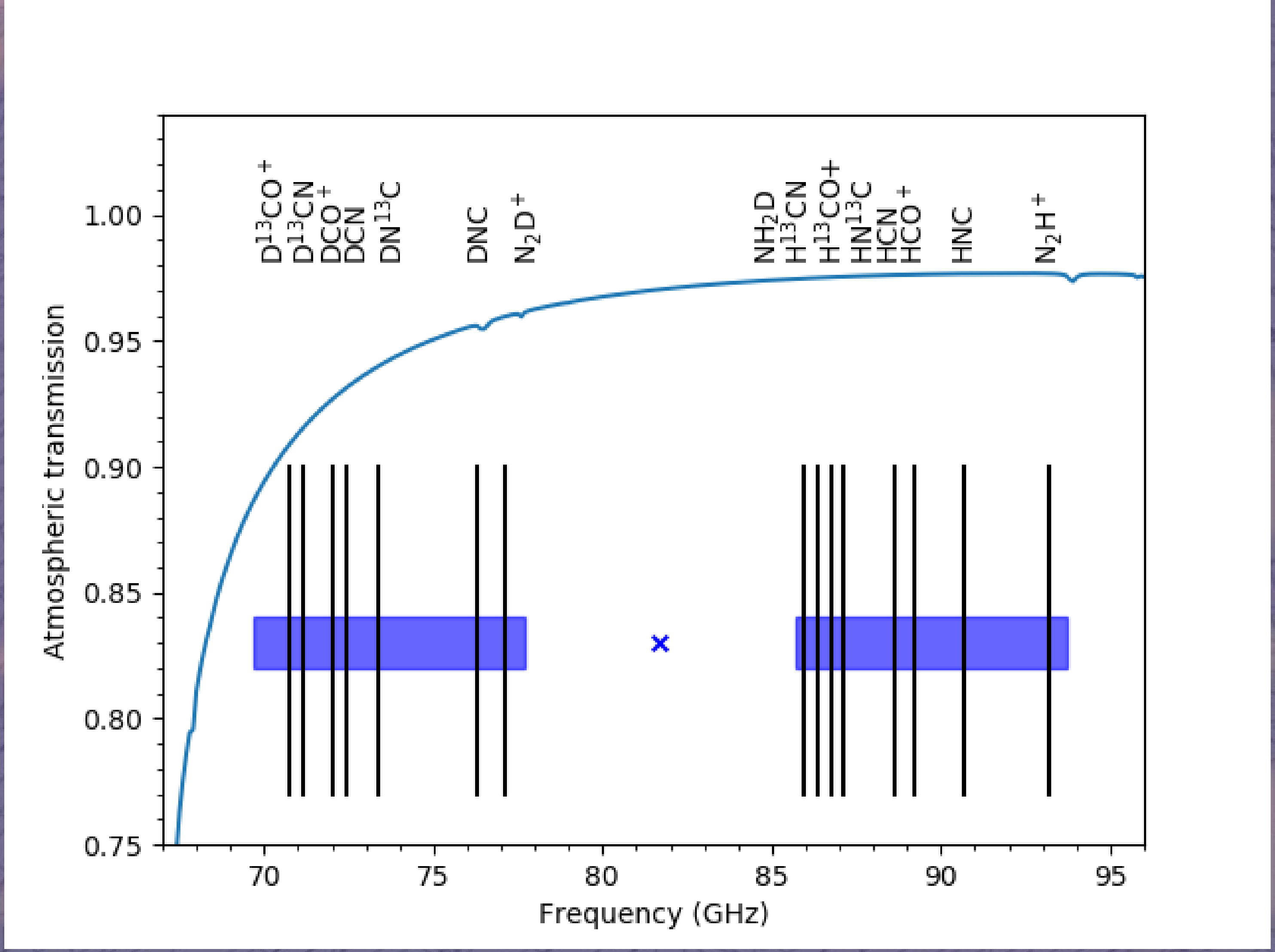
Current 8 GHz 2SB

Number of transitions from
H and D species in a single observation

Band	Number of Lines	D Species	Deuteration ratios
2+3	8	4	DNC/HNC, N2D+/N2H+ DCO+/HCO+ DCN/HCN
4	3	3	–
5	3	0	–
6	4	4	–
7	5	2	–

16 GHz 2SB

Band 2 Deuterium Set-Up



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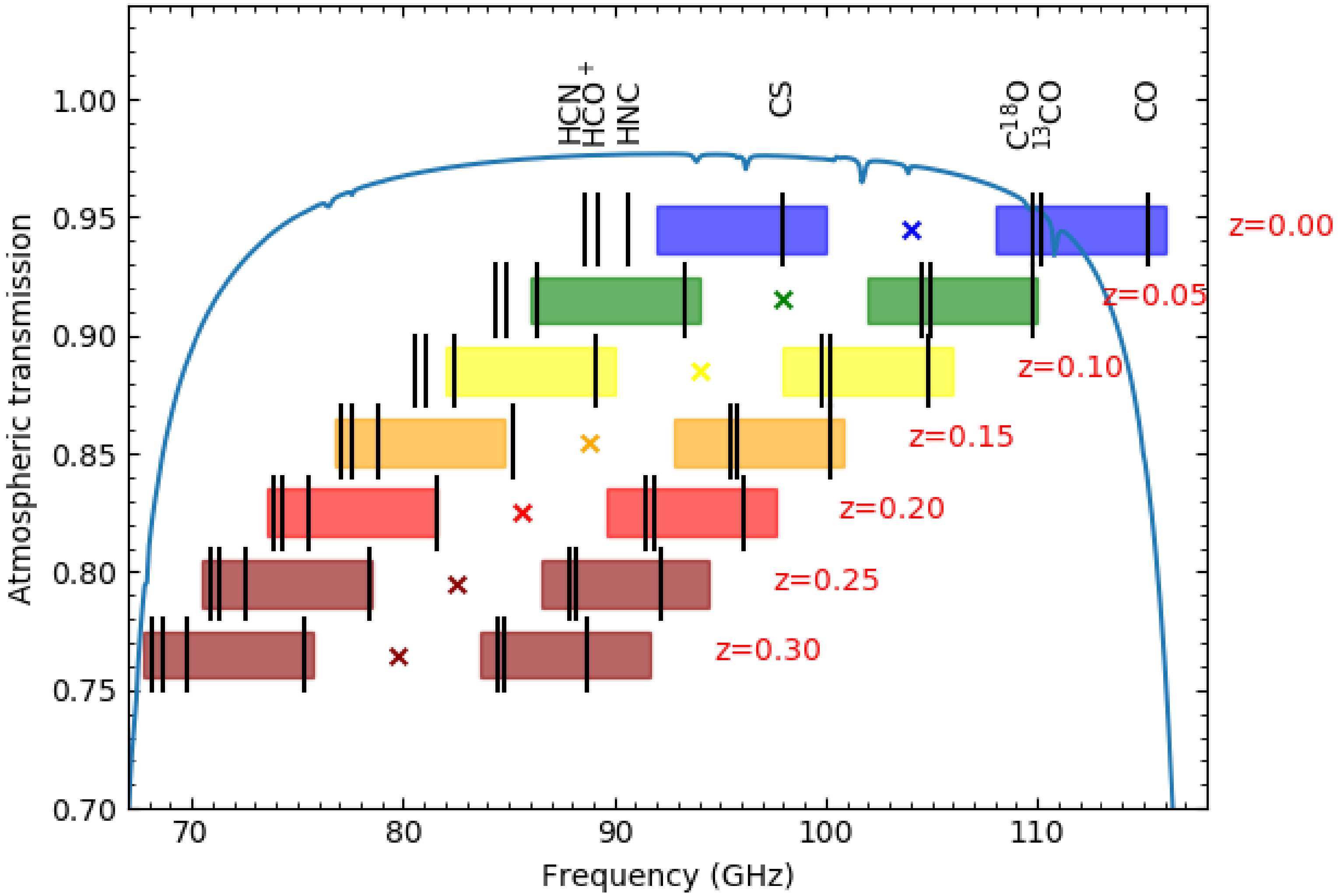
Evolution of Galaxies

Band 2+3 can trace both the dense and diffuse gas in galaxies in a single setting.



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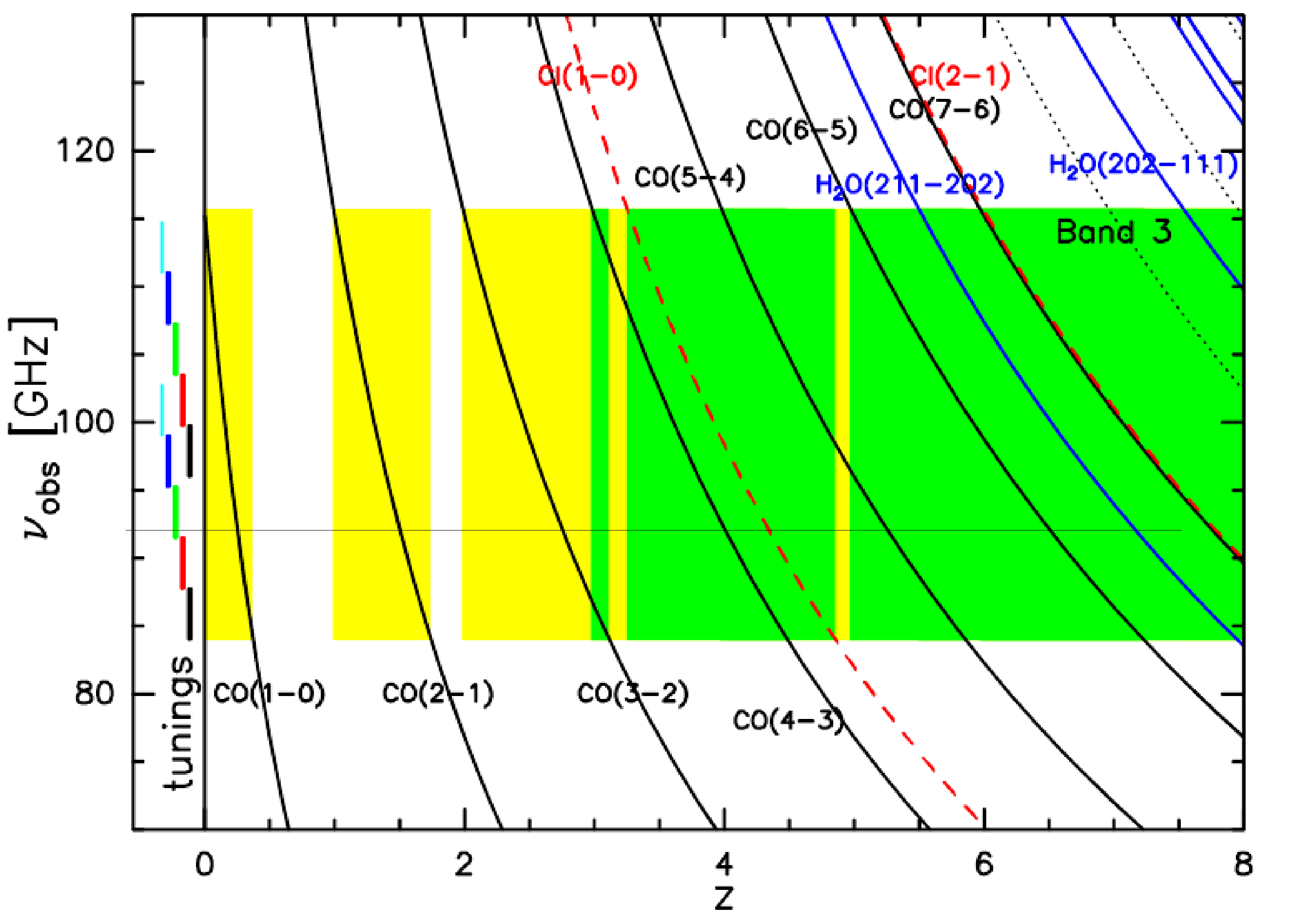
Redshift Searches with Band 2+3



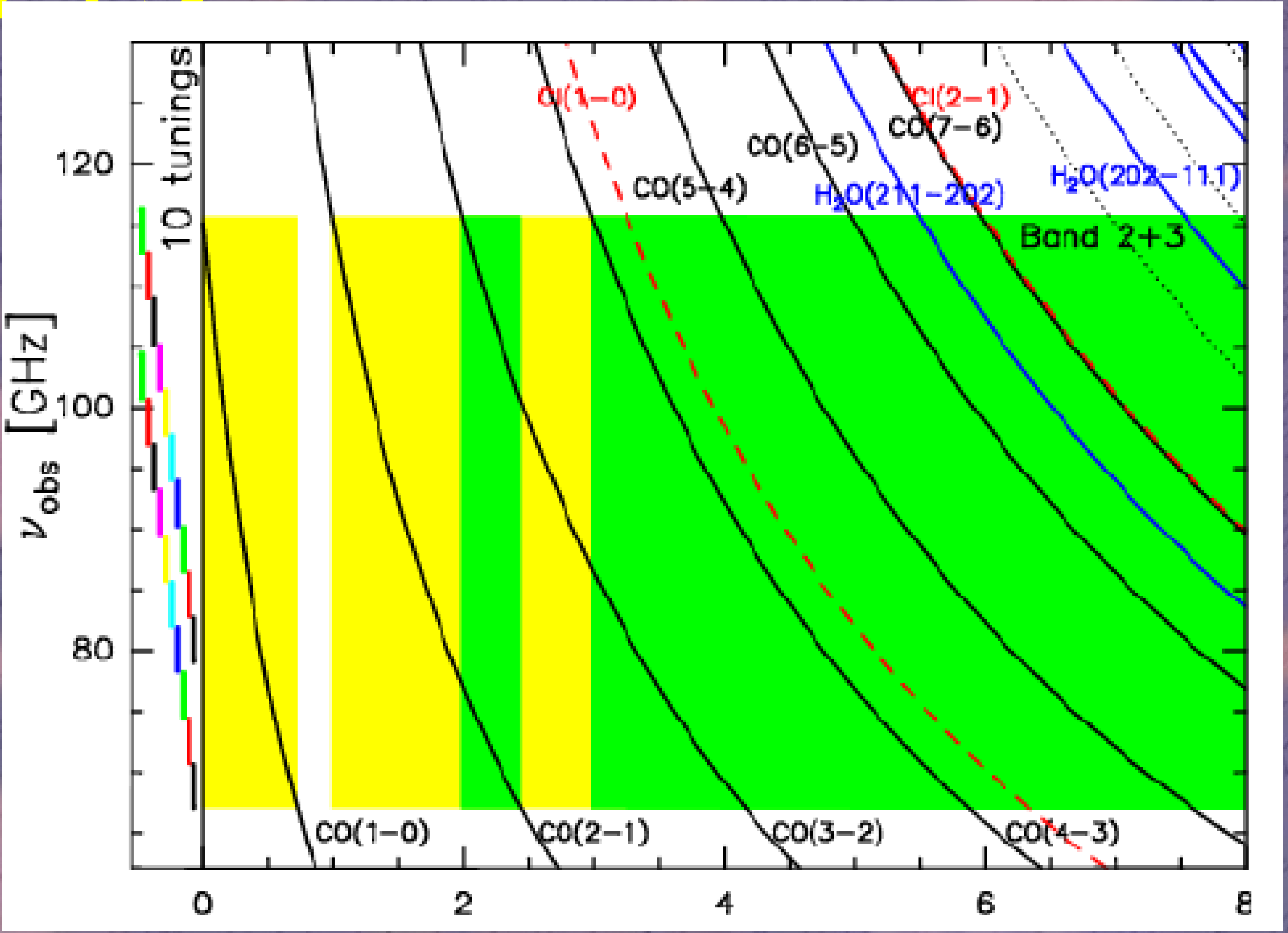
2 lines:
Unambiguous redshifts

1 line

(Weiss et al 2013)

Band 3 only: Desert 0.37<z<0.99, 1.74<z<2.0

Redshift Searches with Band 2+3



2 lines:
Unambiguous redshifts

1 line

Coverage well matched to distribution of dusty galaxies. Implies increase success rate from ~70% to ~100% I surveys compared to 50% for optical surveys.
(Weiss et al 2013)

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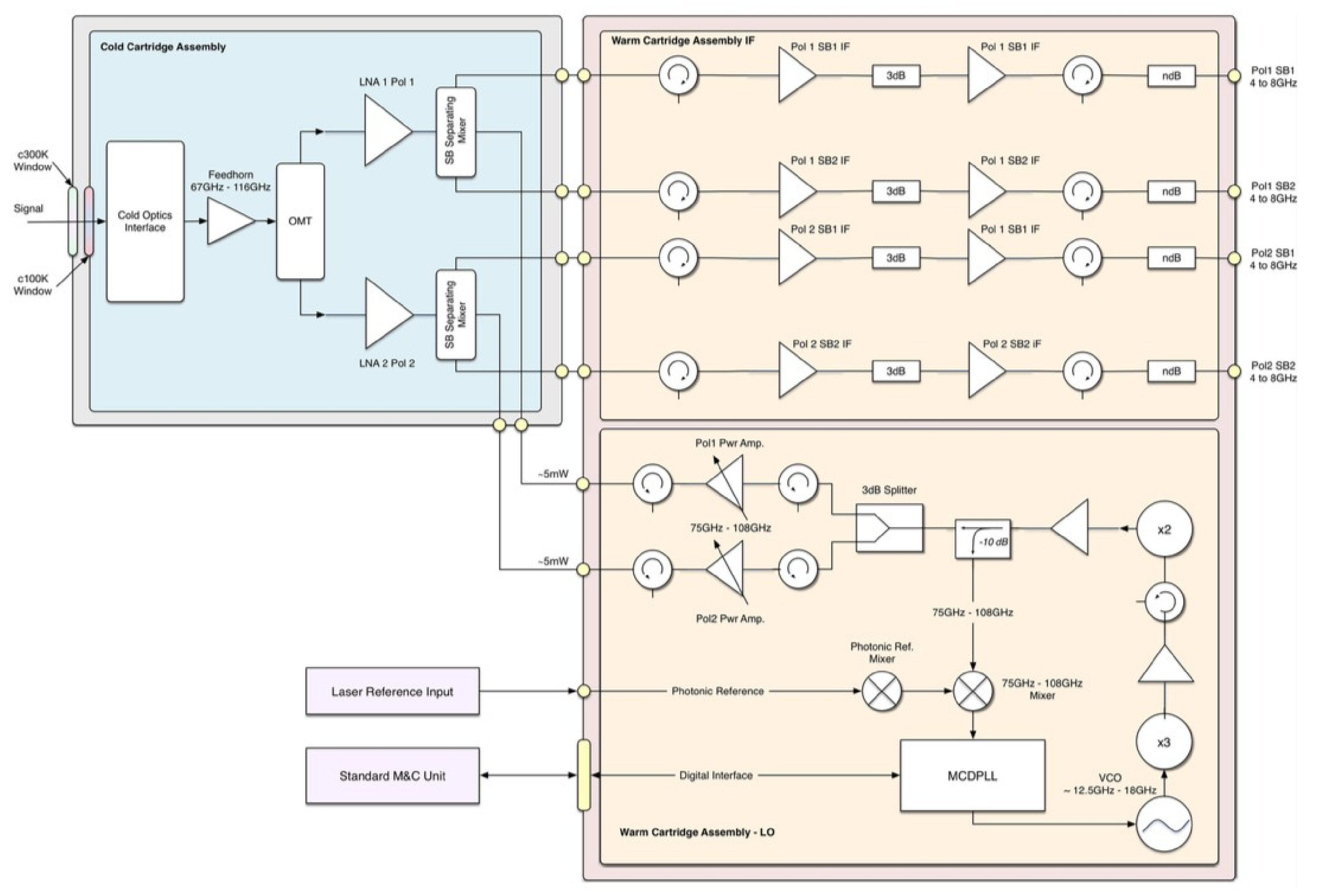
Band 2+3 System



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Band 2+3 Performance Breakdown

Component	TP (K)	Gain dB	NET (K)
Window	300	-0.05	3.47
1st Filter	100	-0.08	1.76
2nd Filter	15	-0.10	0.36
Optics	15	-0.007	0.03
Feedhorn	15	-0.06	0.22
OMT	15	-0.24	0.91
LNA	15	35.00	30.52
Waveguide	200	-1.00	0.02
Mixer	15	-7.00	0.22
RT IF	300	60.00	0.34
Total		**86.47**	**37.85**

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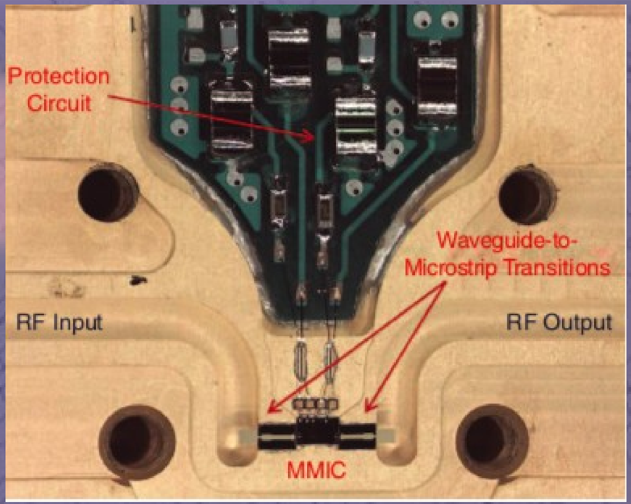
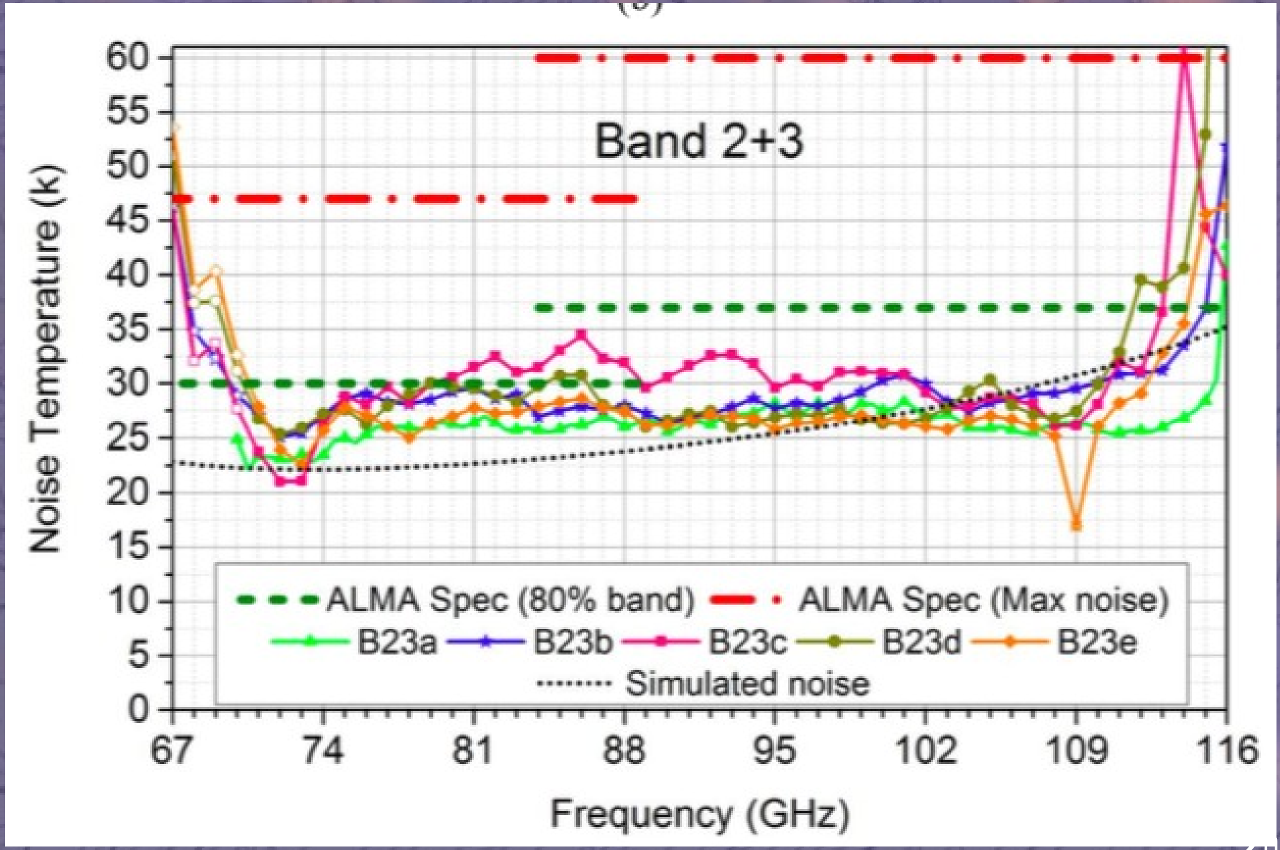
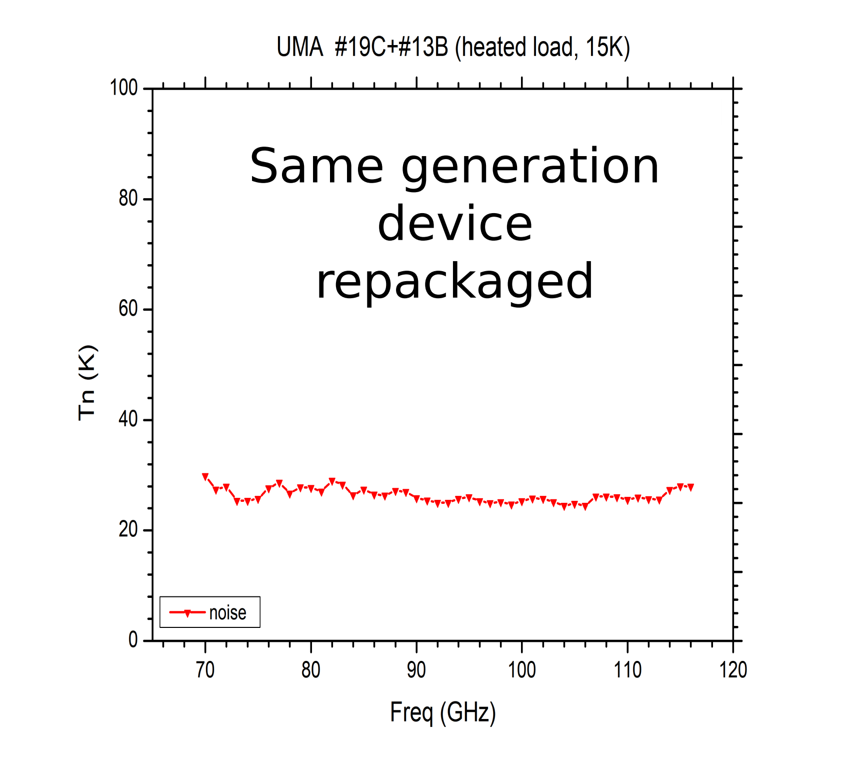
ALMA Band 2+3 LNAs

- NGC 35nm InP process

Cuadrado-Calle et al. 2017, IEEE Transactions







2^{nd} Generation devices produced and being tested

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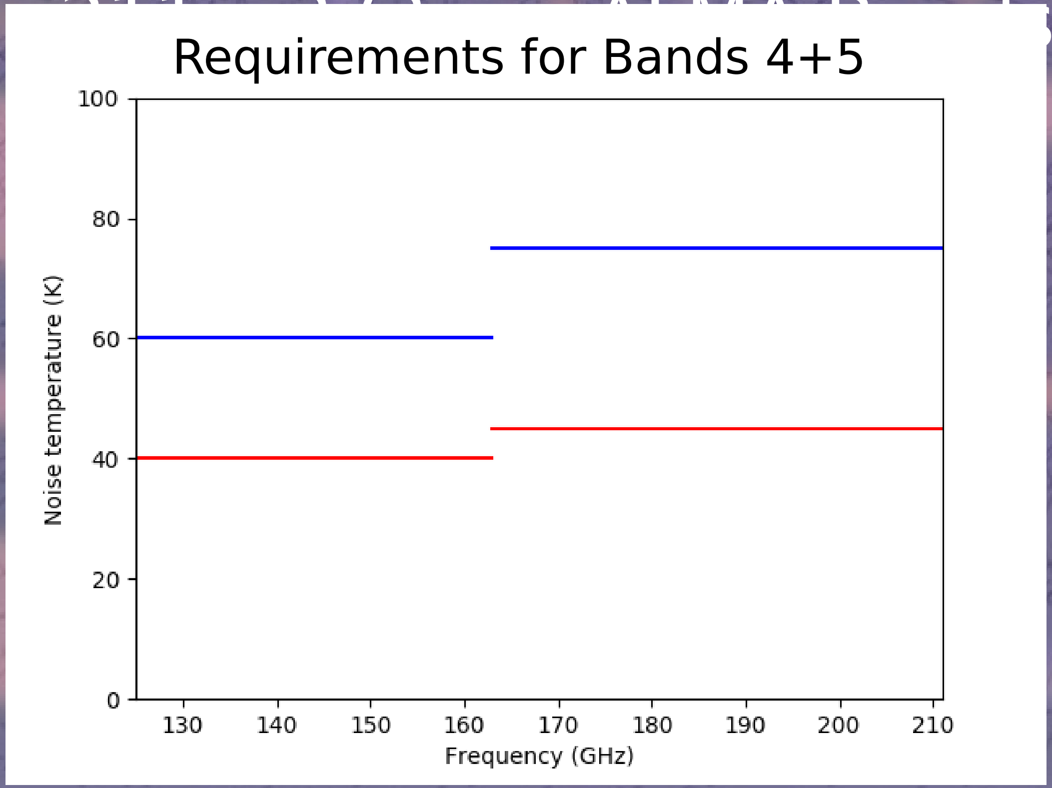
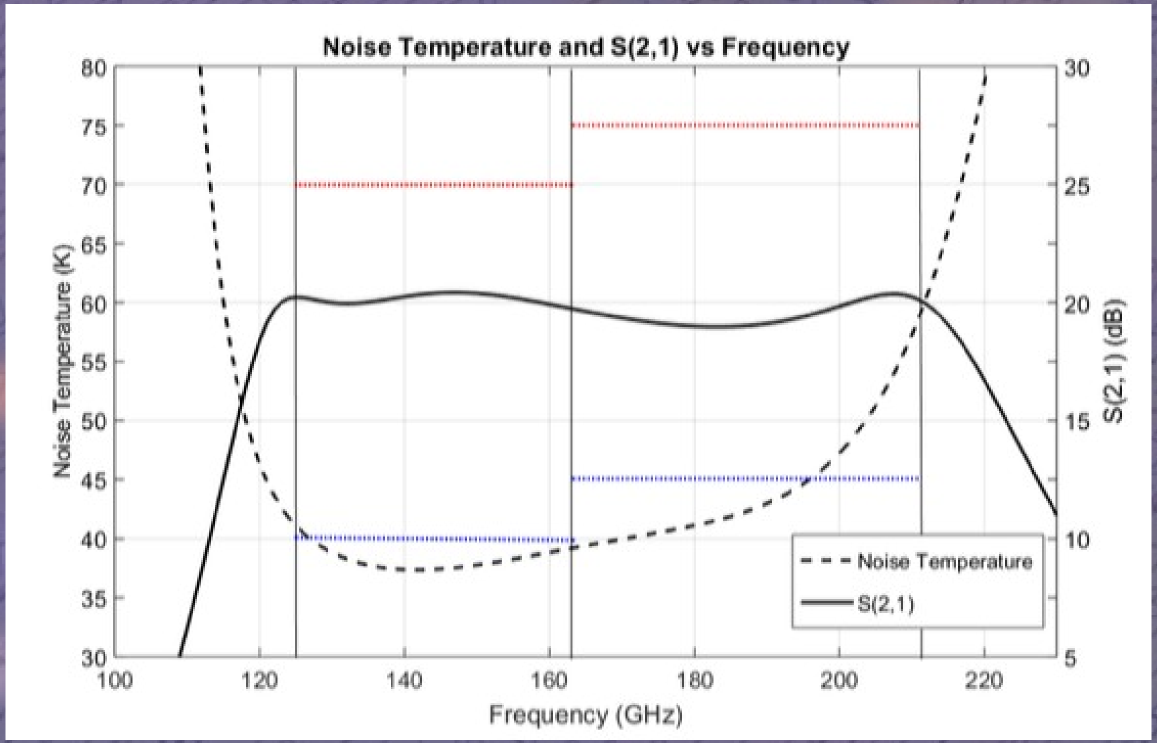
Looking to the Future

LNAs for

- 125 – 211 GHz
- ALMA Bands 4 + 5
- 211 – 273
- ALMA Bands 6

This is still the 35nm process
Have access to new 25nm processes





White et all sumbitted

Global Challenges Research Fund

- `The Global Challenges Research Fund (GCRF) is a five year, £1.5bn resource funding stream, announced as part of the 2015 spending review, to ensure that UK research takes a leading role in addressing the problems faced by developing countries. ’
- Projects fully funded by the UK
- Manchester-RAL-INAOE/LMT Astronomy Science, Technical and Engineering Collaboration : ASTEC
  - Conversion of existing receiver to demonstrate 345 GHz observations with LMT
- Other follow-on opportunities

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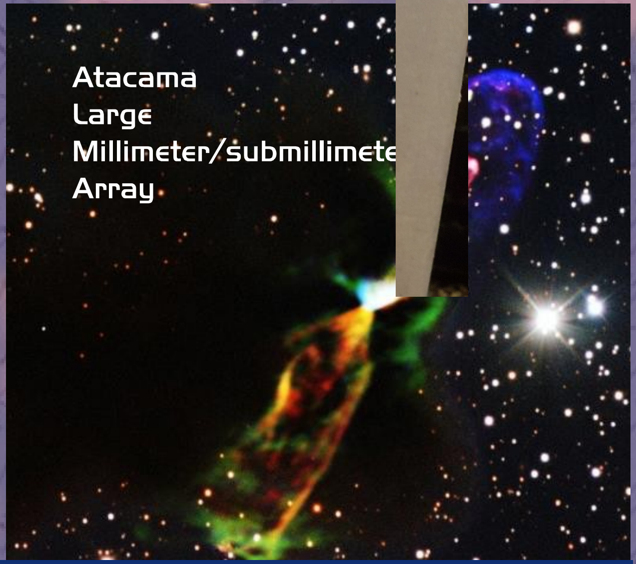
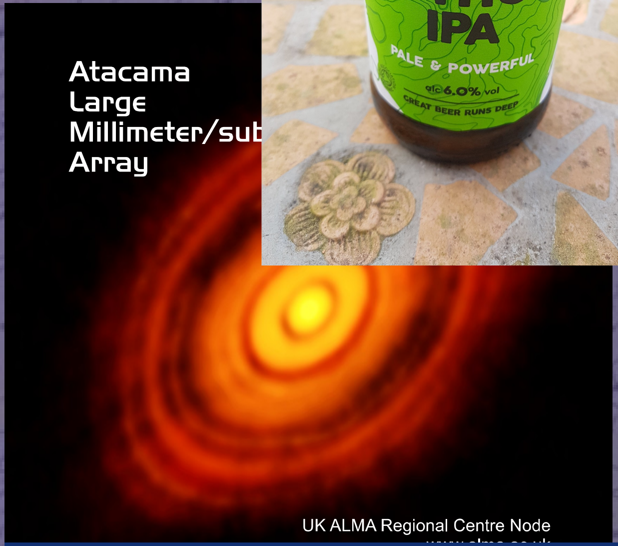
GCRF Impact and Outreach





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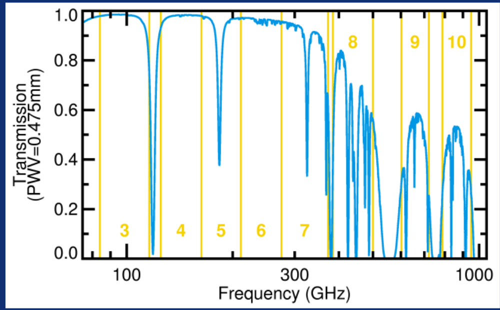

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Band	ν (GHz)	λ (mm)	Major Spectral Lines
1	31-45	6.7-9.5	
2	67-90	3.3-4.5	
3	84-116	2.6-3.6	CO 1-0
4	125-163	1.8-2.4	
5	163-211	1.4-1.8	
6	211-275	1.1-1.4	CO 2-1
7	275-373	0.80-1.1	CO 3-2, [C II] (z=5)
8	385-500	0.60-0.78	
9	602-720	0.42-0.50	CO 6-5, [C II] (z=3)
10	787-950	0.32-0.38	CO 7-6, CO 8-7, [C II] (z=2)

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This multiwavelength image shows gas being ejected from the a region where a star is forming in the centre of HH 46/47. The jet of gas to the upper right, which is coloured pink and blue, can be seen in visible light. The region to the lower left is obscured in visible light by a dark dust cloud, but ALMA is able to detect millimetre radiation from the hidden gas, which is coloured orange and green.

Credit: ESO/ALMA (ESO/NAOJ/NRAO)/H. Arce. Acknowledgements: Bo Reipurth.

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HL Tau is a protostar surrounded by a disc of gas and dust. ALMA's submillimetre image of this disc showed that it contains multiple ring structures. Planets may be forming in the gaps between the rings.

Credit: ALMA (ESO/NAOJ/NRAO).