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High Frequency Low Noise Amplifiers

Gary Fuller
UK ALMA Regional Centre Node
& Advanced Radio Instrumentation Group
Jodrell Bank Centre for Astrophysics
University of Manchester

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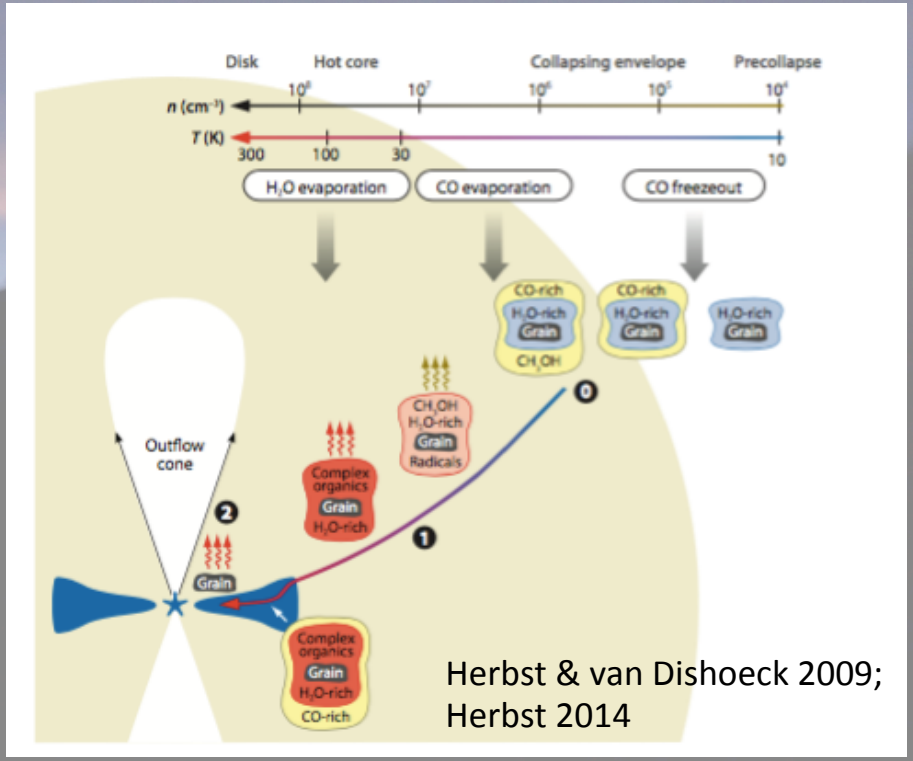
The Heterodyne Future

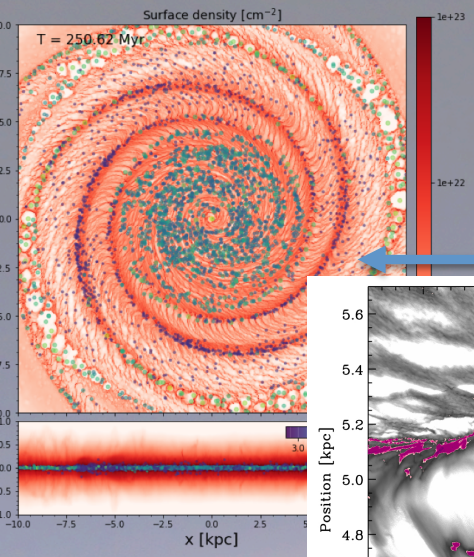
- Bigger & Faster
  - More spatial and spectral pixels
- Goals
  - Kinematics
  - Physical properties
  - Chemical properties



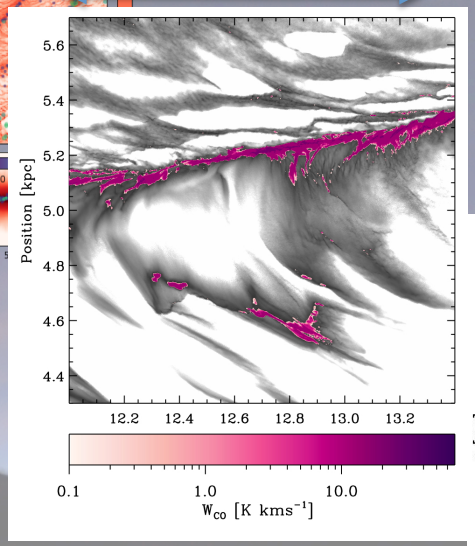
Herbst & van Dishoeck 2009; Herbst 2014

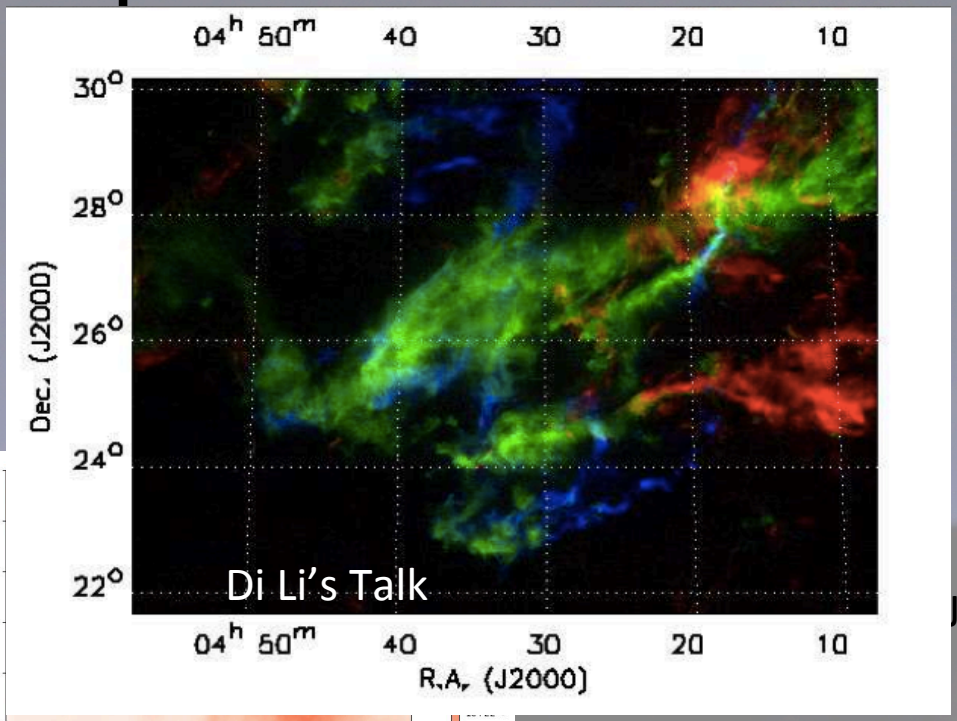
Star Formation is a multi-scale process

20 kpc

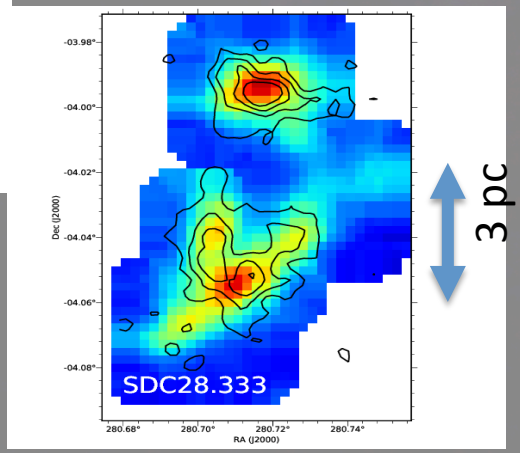


1 kpc





J=2-1



3 pc

Simulations from En Chen & Rowan Smith

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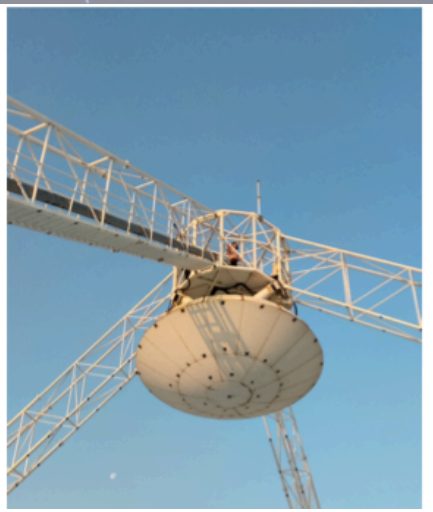
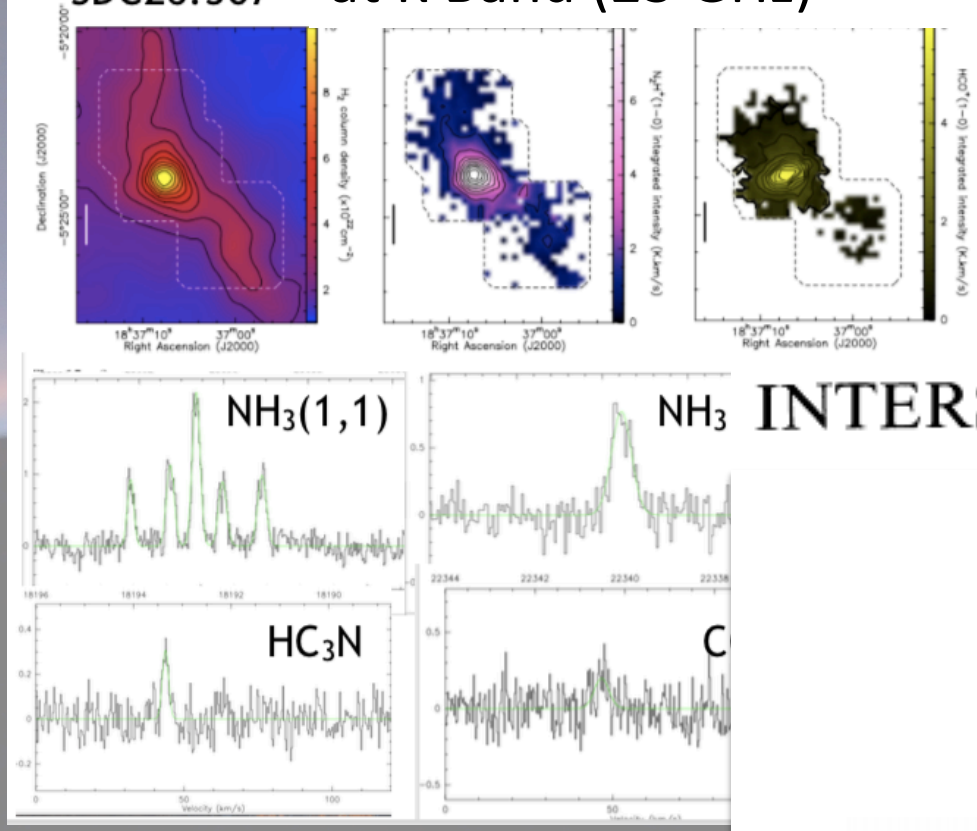
Spectral Dimension

SHAO Tianma 65m Observations at K Band (23 GHz)





INTERSTELLAR AMMONIA

Ann. Rev. Astron. Astrophys. 1983. 21: 239–70

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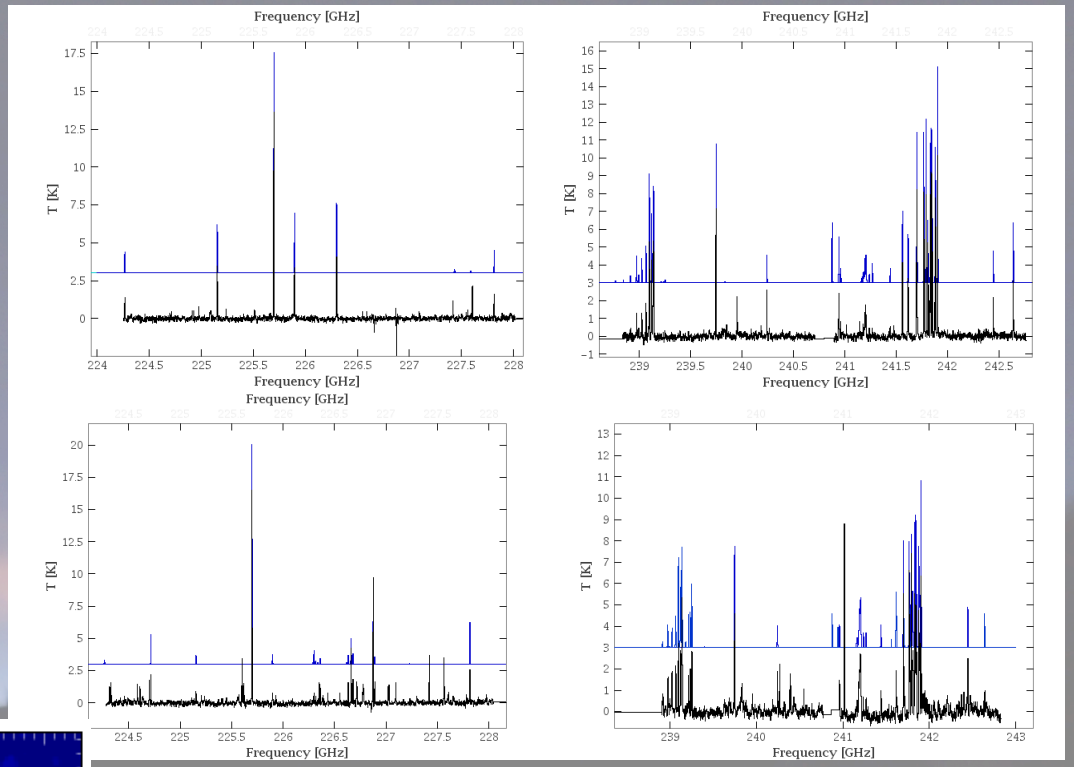
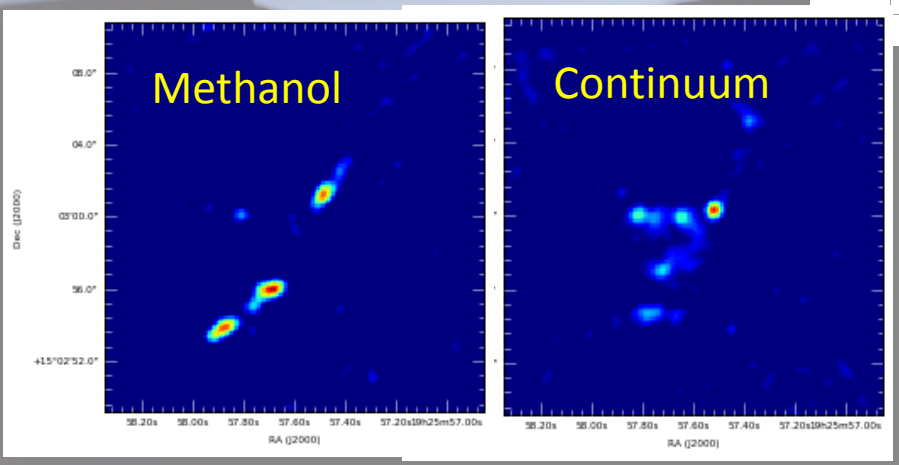
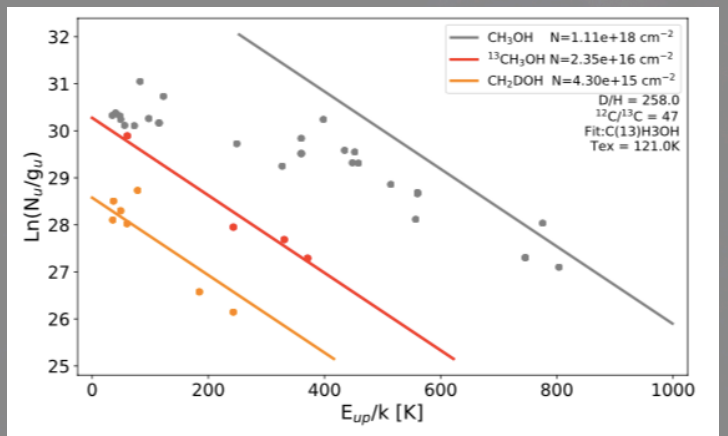
Wealth of Information

- ALMA survey of 38 high mass protostars

(Frimpong, Fuller in prep.)







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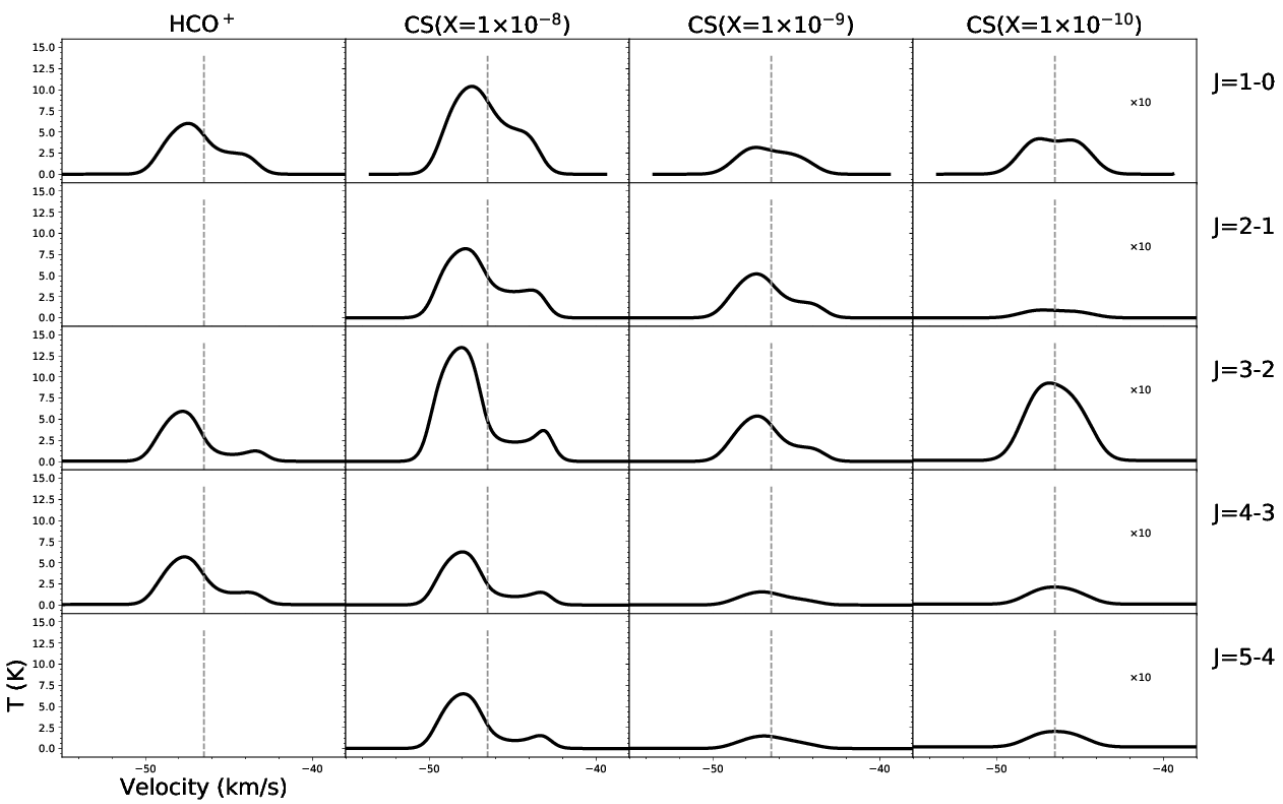
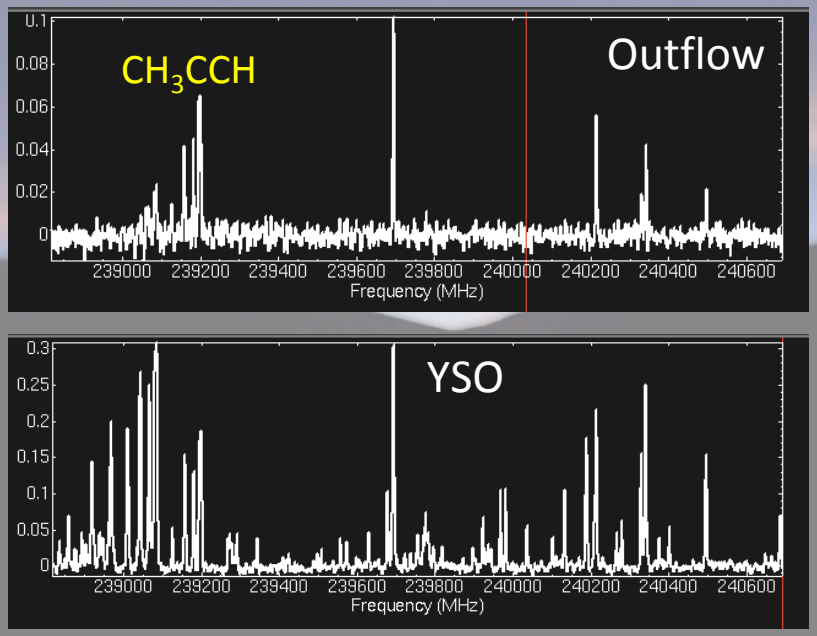
Multi-transition Studies of Infall

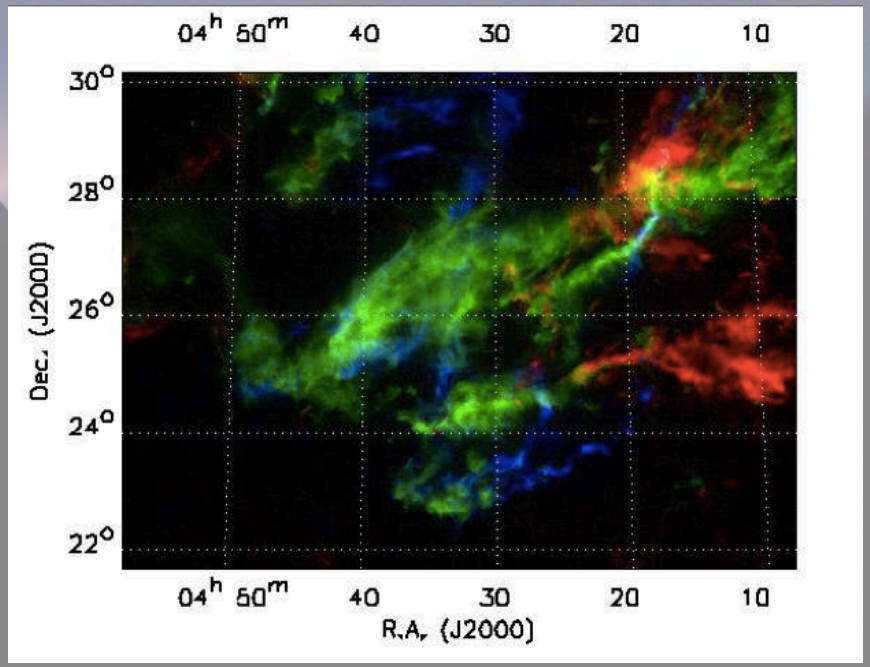


Xie et al in prep.

The Heterodyne Future

- Constraining the physics & chemistry
- Connecting the scales
  - Tracing the flow





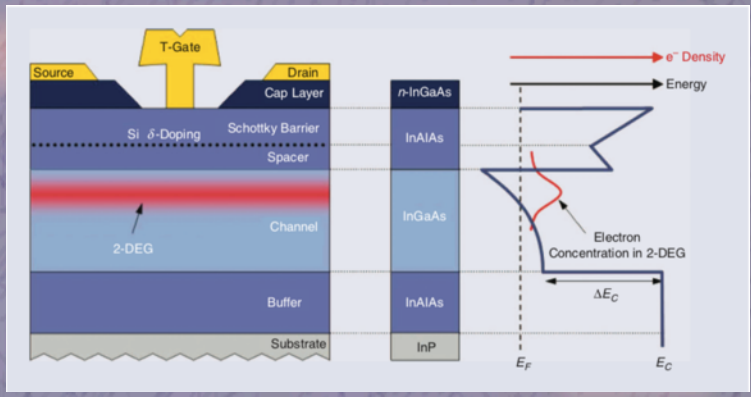
(Narayanan et al 2008; Qian et al. 2012)

ARIG: Advanced Radio Instrumentation Group

- Cross School Research Group
- Lead by
  - Prof. Danielle George, School of Electrical and Electronic Engineering
  - Prof. Gary Fuller, School of Physics & Astronomy, Jodrell Bank Centre for Astrophysics
- 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)
- Recent investment:
  - £290k STFC Capital Equipment - VNA extender heads to up 220 GHz
  - £190k SKA Equipment – Cryo Probe station

Collaborators:

- Rutherford Appleton Laboratories
- Cahill Radio Astronomy Laboratory, Caltech
- Northrop Grumman Corporation (NGC)
- WIN Semiconductors, Taiwan



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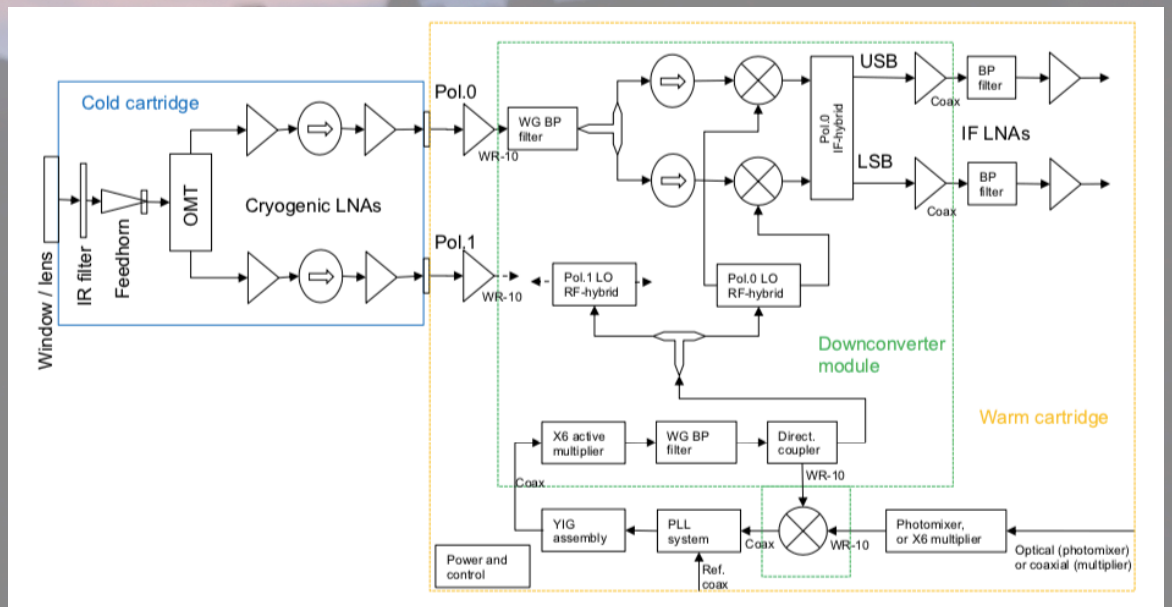
Advances of LNAs

- Higher operating temperatures than SIS mixers
  - 15-20 K compared with 4 K
- Simplified system design
  - Better suited to multiple pixel arrays



ALMA in a nutshell

- **Atacama Large Millimeter/sub-millimeter Array**
- Aperture synthesis array optimised for wavelengths of 1cm – 0.3mm (35 – 950 GHz)
- **High, dry site**, Chajnantor Plateau, Chile (5000m)
- 54 12m + 12 7m antennas
- Baselines from ~15m to 16km; reconfigurable
- **Resolution**/ arcsec ≈ 0.2(λ/mm)/(max baseline/km)
- Field of view / arcsec ≈ 17 (λ/mm) [12m dish]
- **Phase-stable**: fast switching, water-vapour radiometers, LO distribution
- **Sensitive**, wide-band (currently 8 GHz) SIS receivers; full polarization
- **Flexible** digital correlator giving wide range of spectral resolutions.

ALMA Construction

- Global collaboration
- Led by ESO (Europe), National Radio Astronomy Observatory (North America) and National Astronomical Observatory of Japan (37.5:37.5:25).
  - Contracts with industry (e.g. antennas, site infrastructure, ..)
  - Institutes (e.g. receiver bands)
- Approximate construction cost $1.3 billion
- Detailed design and construction ~2000 - 2013

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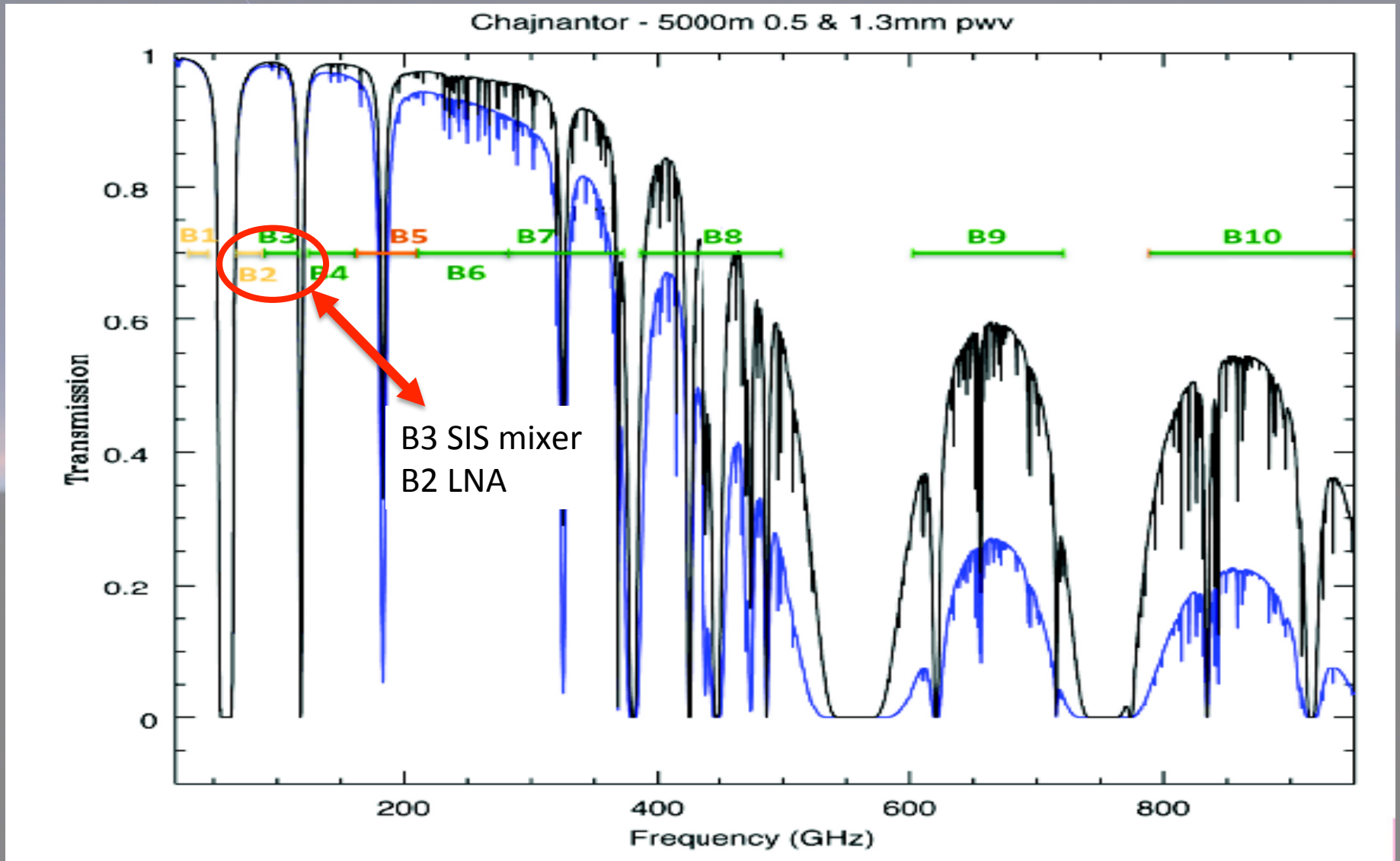
ALMA Transmission Windows



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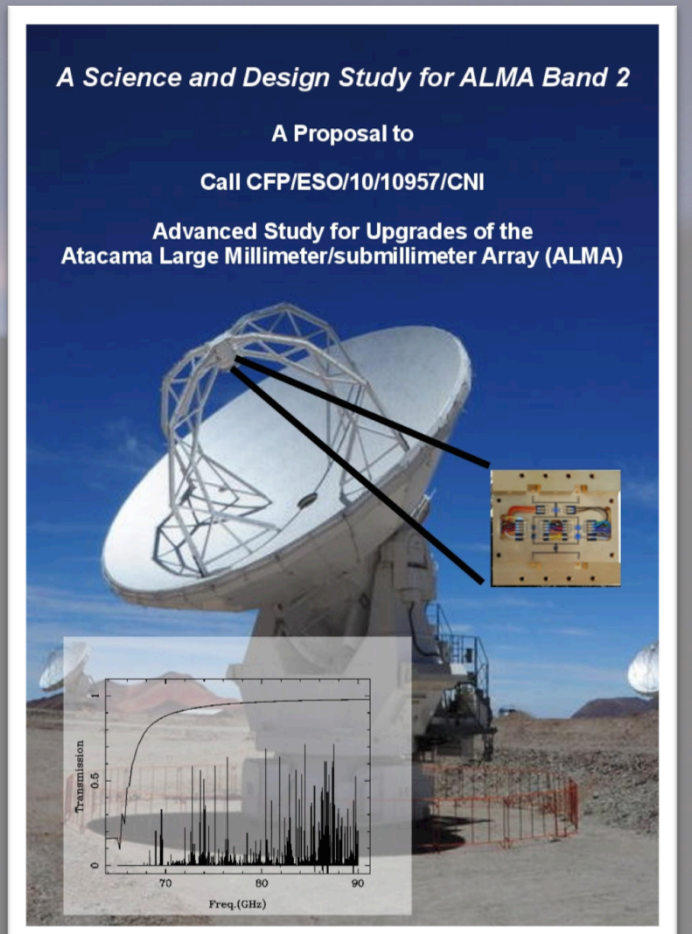
ALMA Band 2 Project

- 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 analysis

PI: Gary Fuller
Collaboration:
MANCHESTER 1824 The University of Manchester
INAF
Science & Technology Facilities Council Rutherford Appleton Laboratory
iram Institut de Radioastronomie Millimétrique



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Science Case

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.

arXiv:1602.02414

Affiliations

[1]Jodrell Bank Centre for Astrophysics & UK ALMA Regional Centre Node, School of Physics and Astronomy, The University of Manchester, Oxford Road, Manchester, M13 9PL, UK
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[11]INAF Osservatorio Astronomico di Bologna, via C. Ranzani 1, 40127, Bologna, Italy
[12]Department of Physics and Astronomy, University College London, WC1E 6BT London, UK
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Italian Science Case for ALMA Band 2+3*

M. T. Beltrán[1], E. Bianchi[1], J. Brand[2], V. Casasola[1], R. Cesaroni[1], C. Codella[1], F. Fontani[1], L. Gregorini[3], G. Guidi[1], L. Hunt[1], E. Liuzzo[2], A. Marconi[4], M. Massardi[2], L. Moscadelli[1], R. Paladino[2], L. Podio[1], I. Prandoni[2], V. Rivilla[1], K. L. J. Rygl[2], L. Testi[1,5]

2015 arXiv:1509.02702

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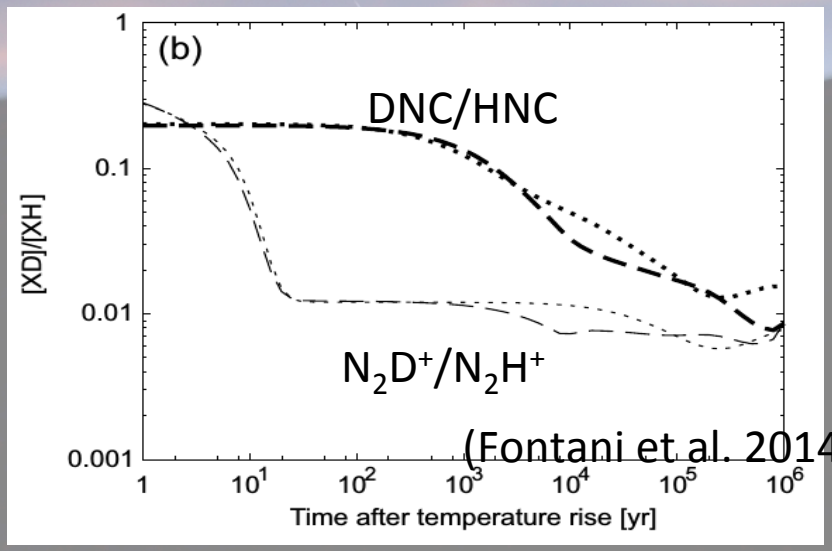
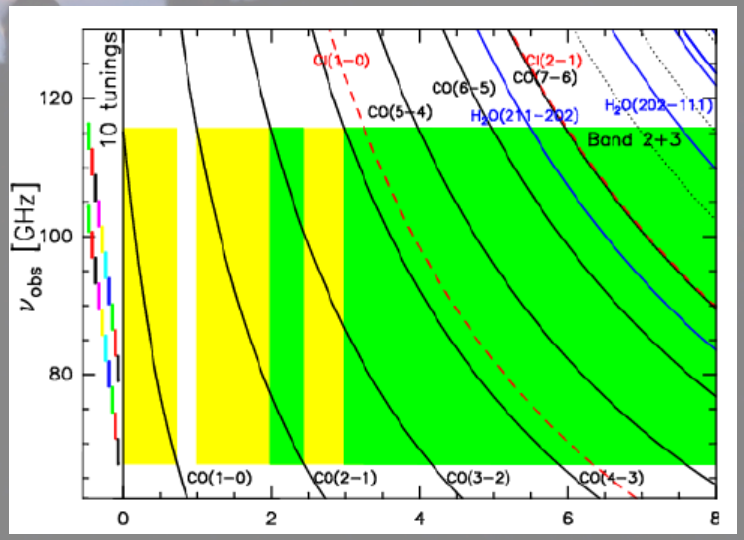
Level 1 Science Drivers

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



(Fontani et al. 2014)



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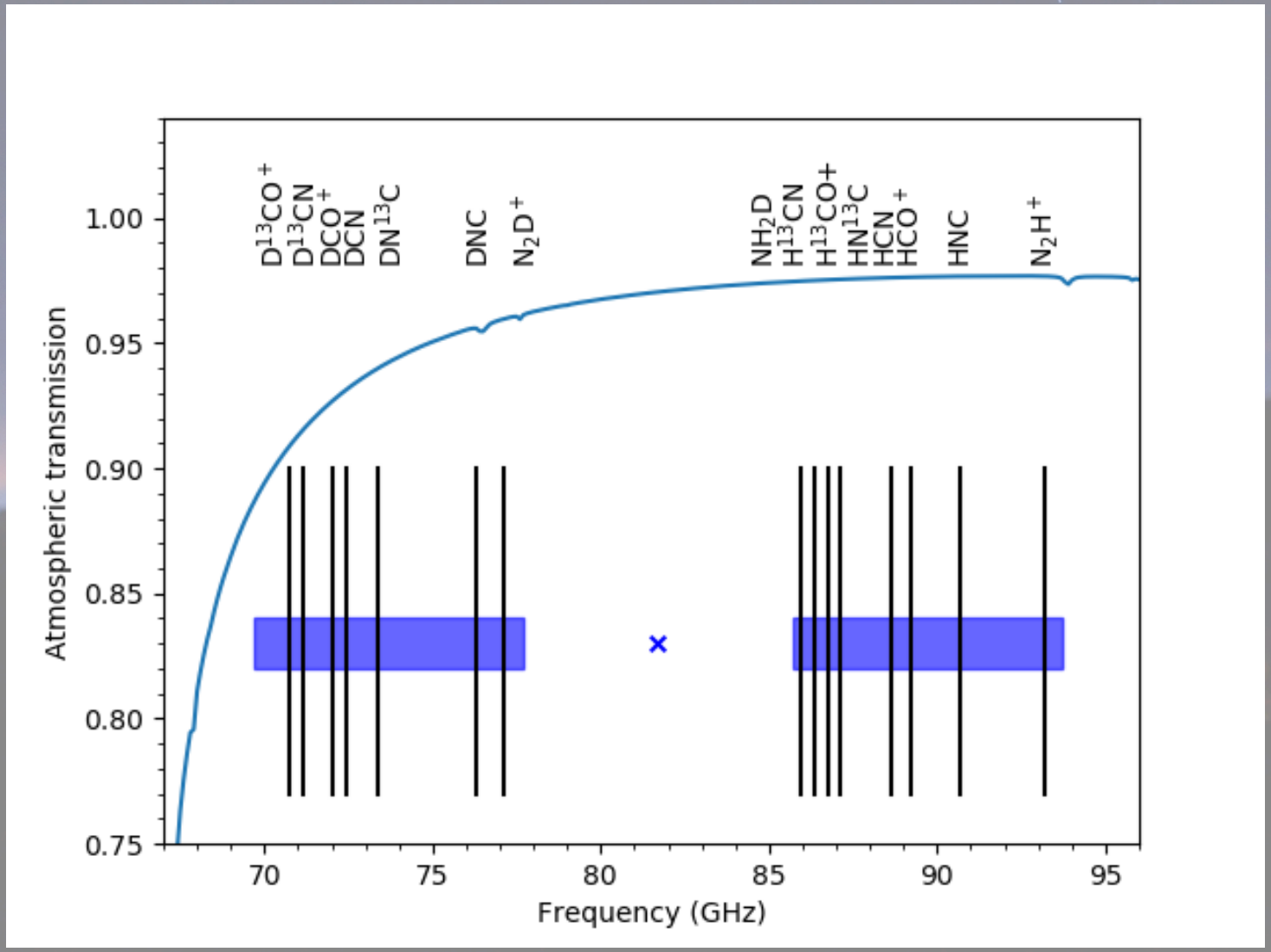
Deuteration Machine



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Efficiency

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

8 GHz 2SB

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	–

16 GHz 2SB

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	–

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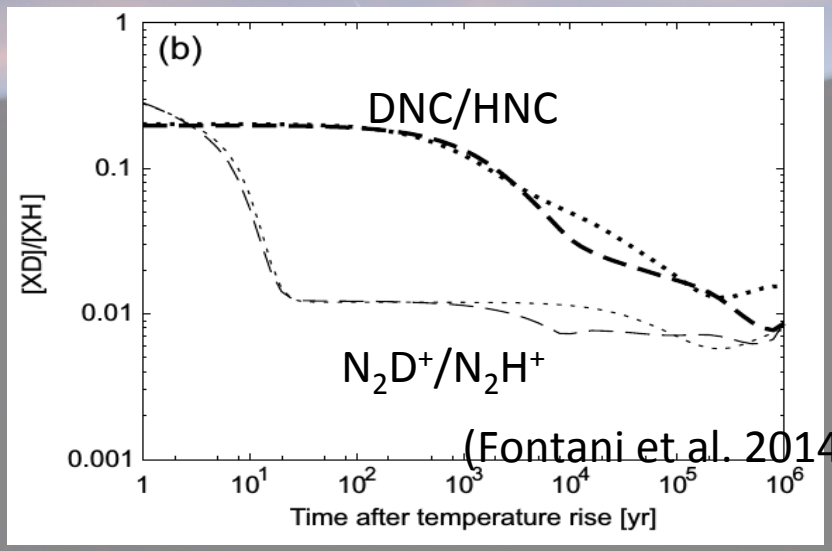
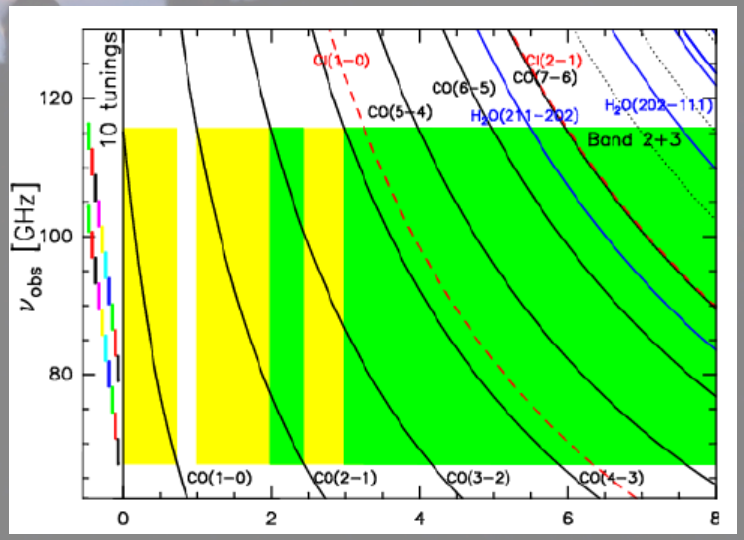
Level 1 Science Drivers

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



(Fontani et al. 2014)



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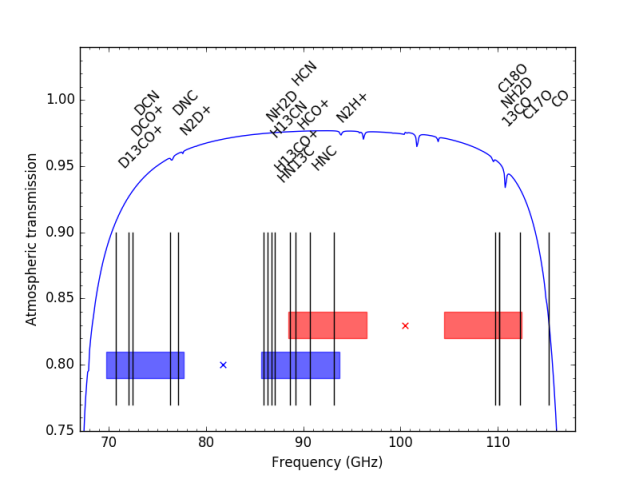
Band 2+3

- Band 2: 67 – 90 GHz, LNA
- Band 3: 84 – 116 GHz, SiS
  - UK/ESO Design study -> Combined Band 2+3 system desirable, feasible, but challenging
  - Science advantages esp. with 16 GHz BW upgrade
  - Operational advantages



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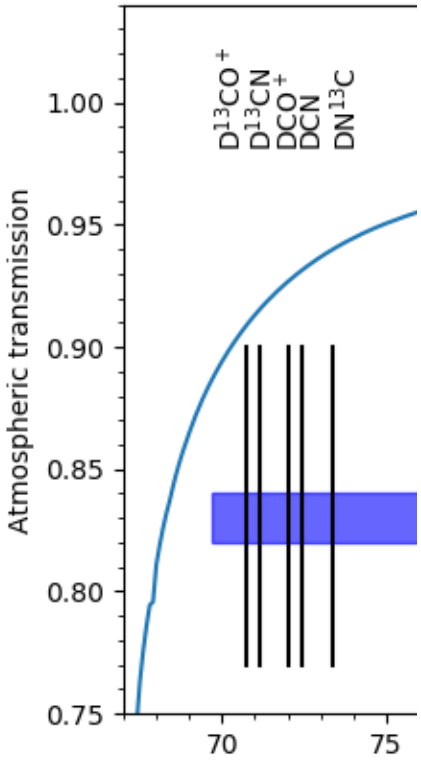
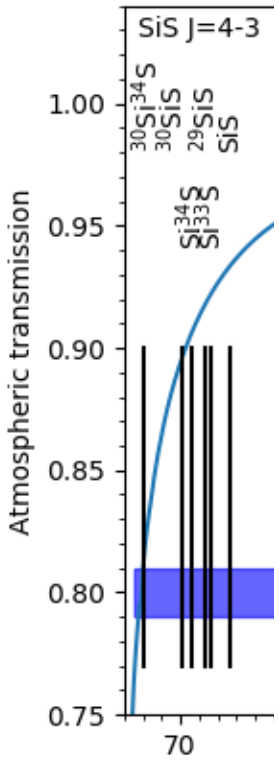
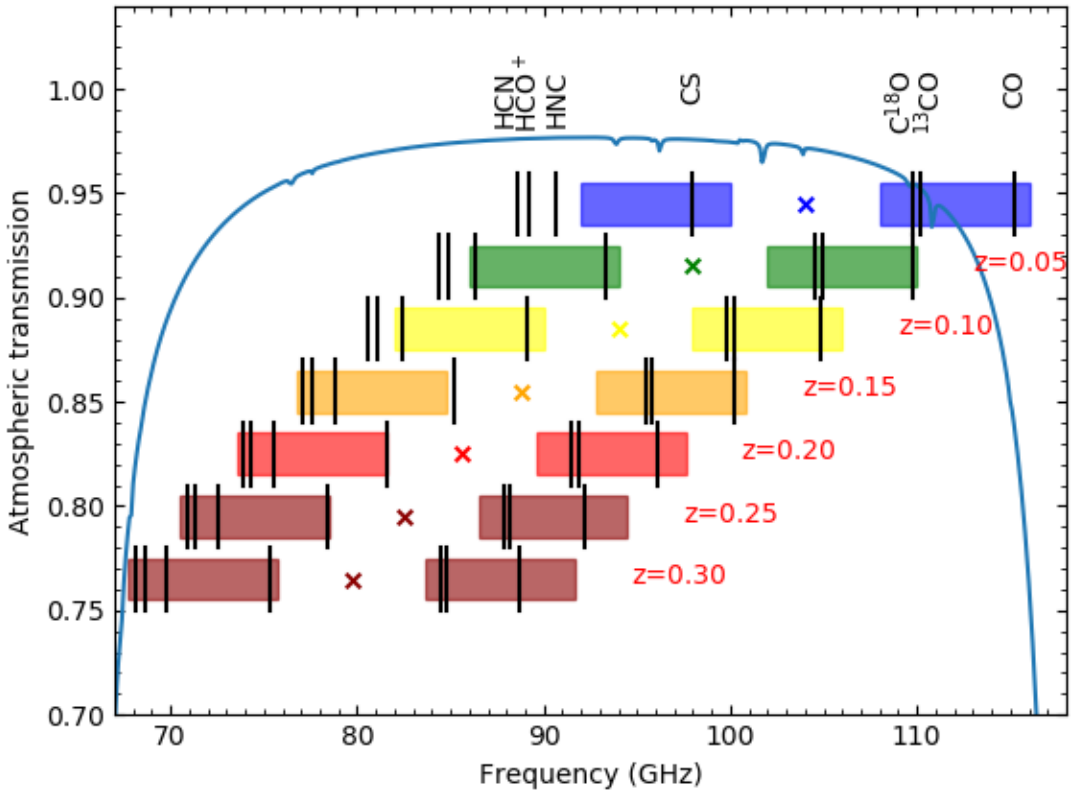
Fun with Band 2+3







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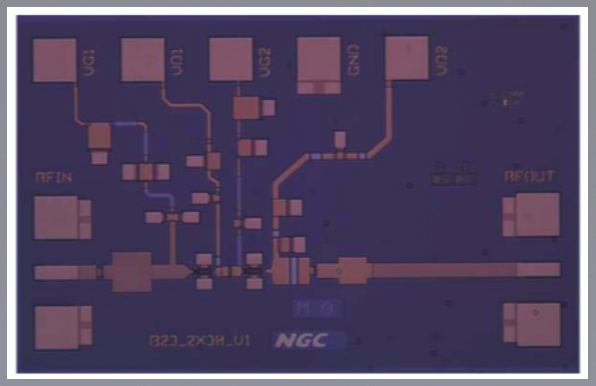
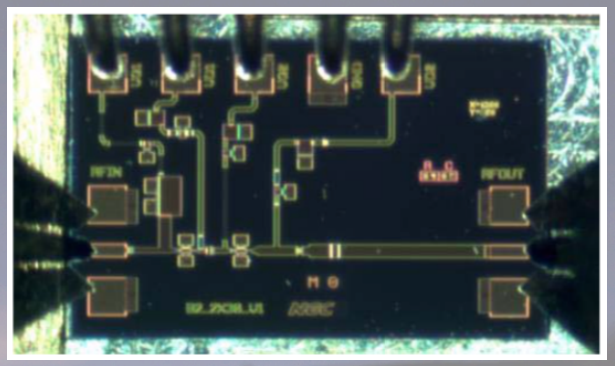
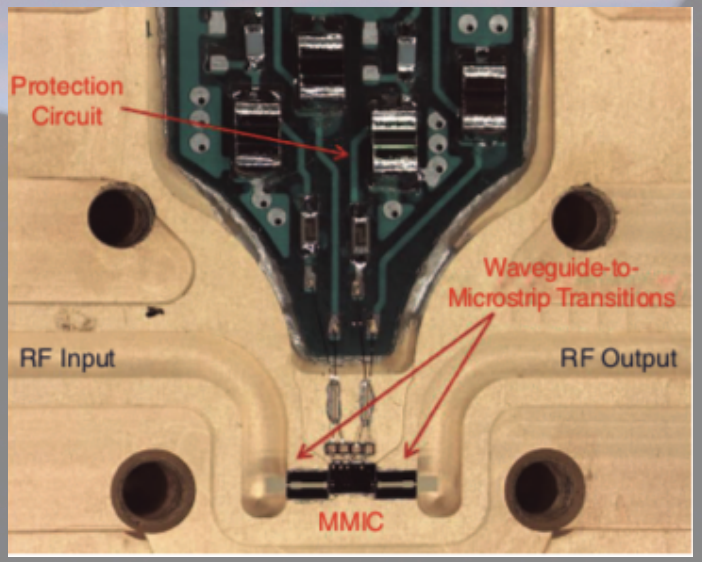
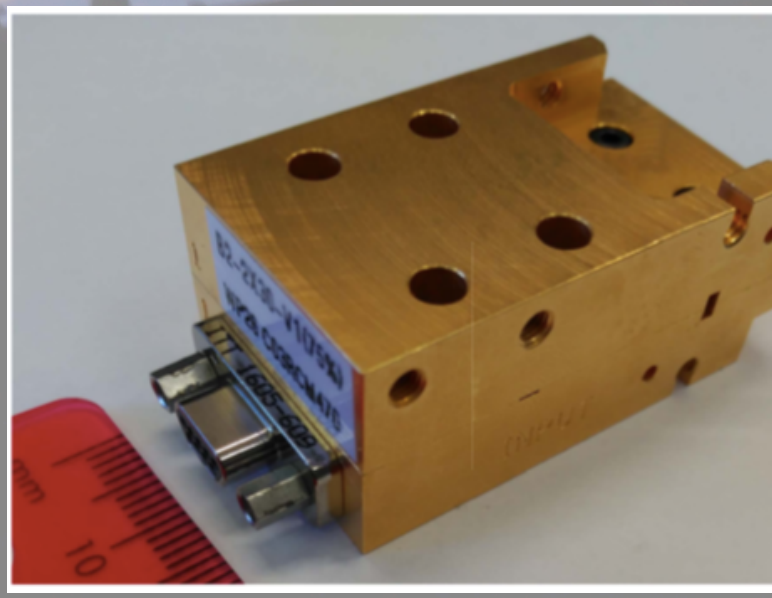
InP Devices

- Manchester-Caltech/JPL-NGC Collaboration
- InP HEMT
- 35nm process

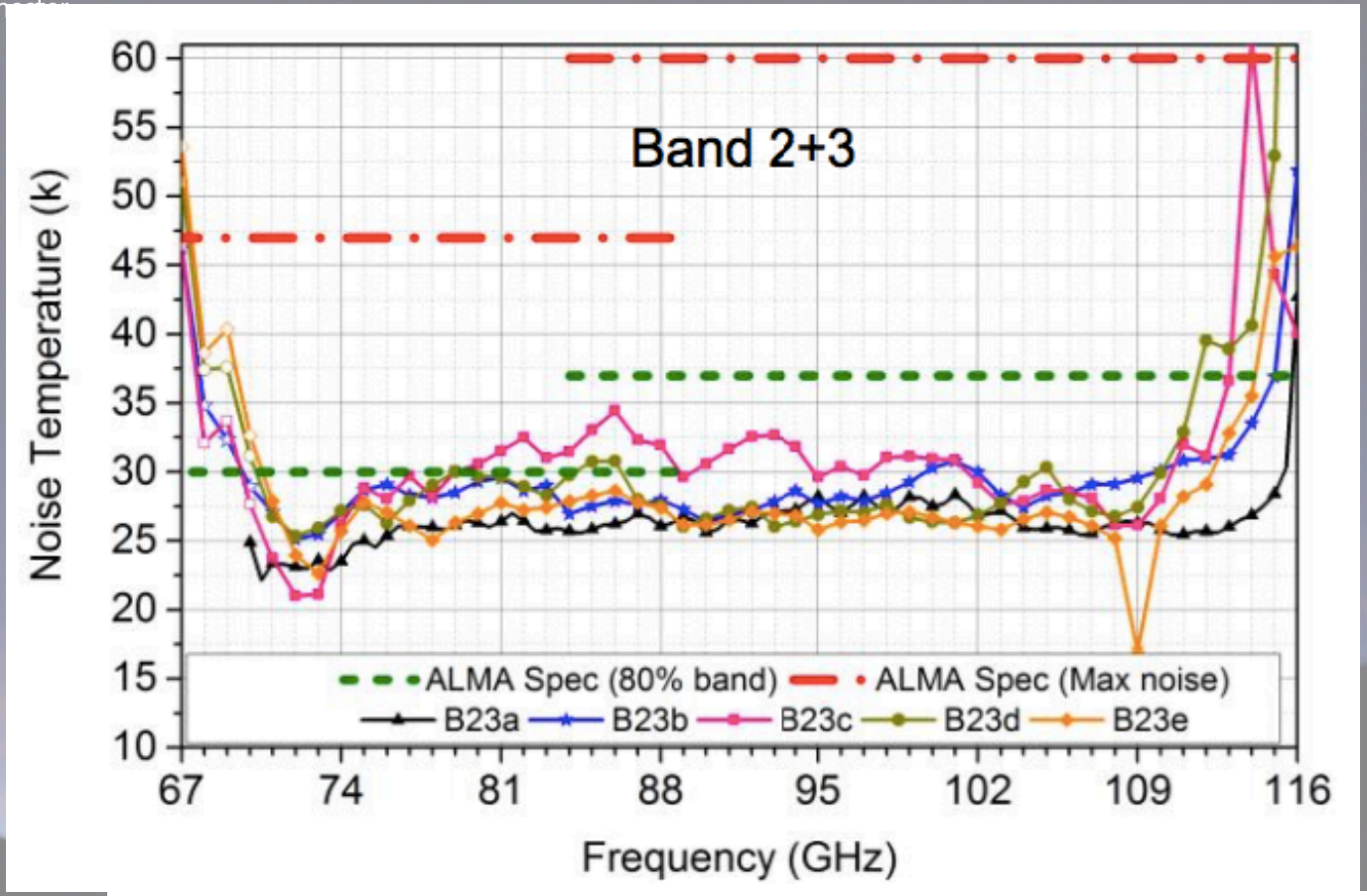








LNA Performance

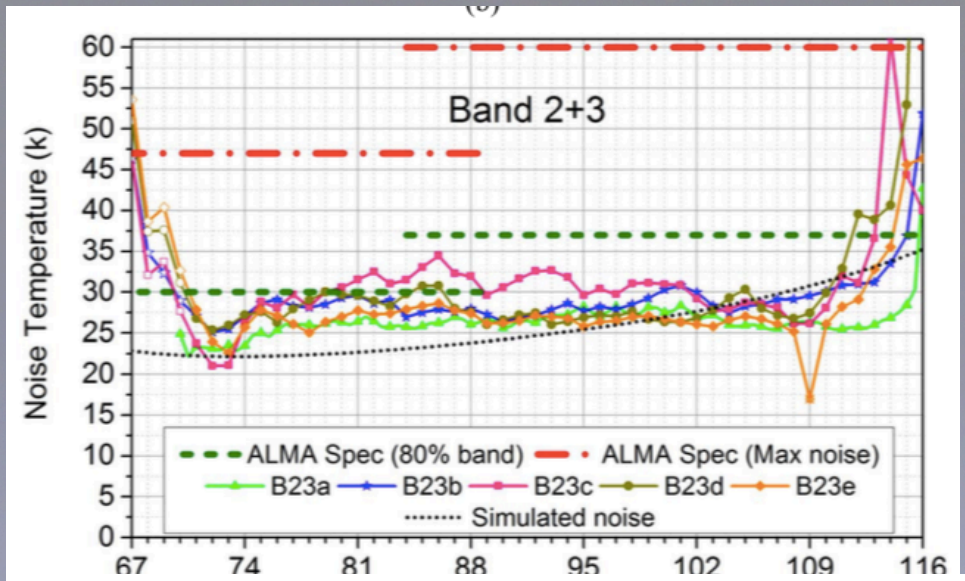


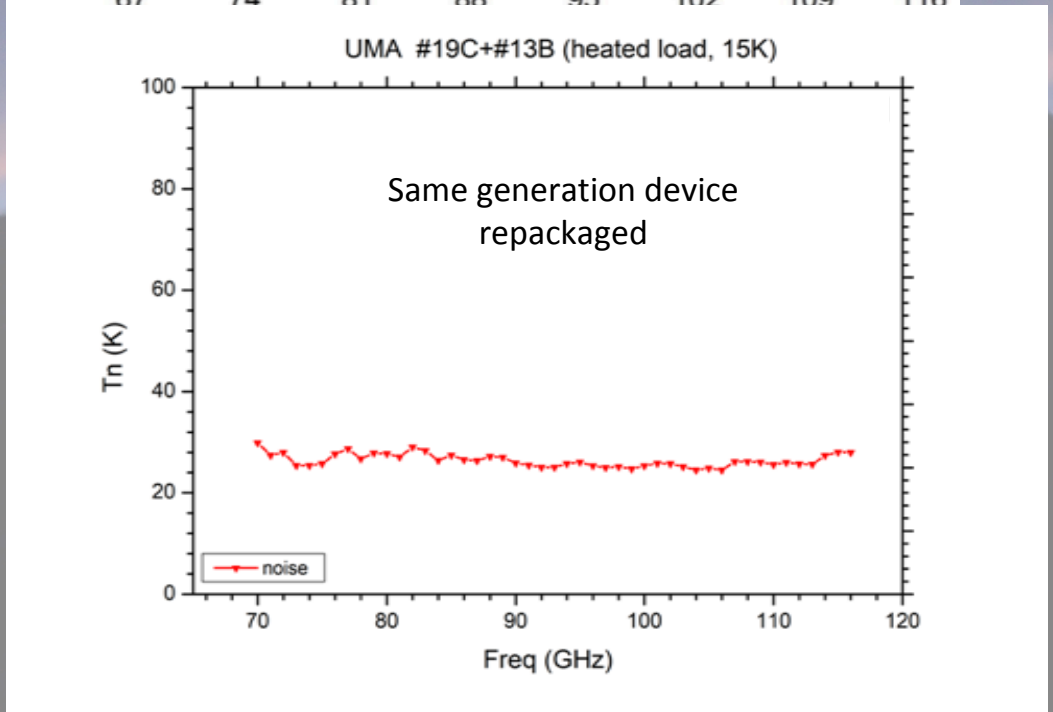
IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 65, NO. 5, MAY 2017 1589

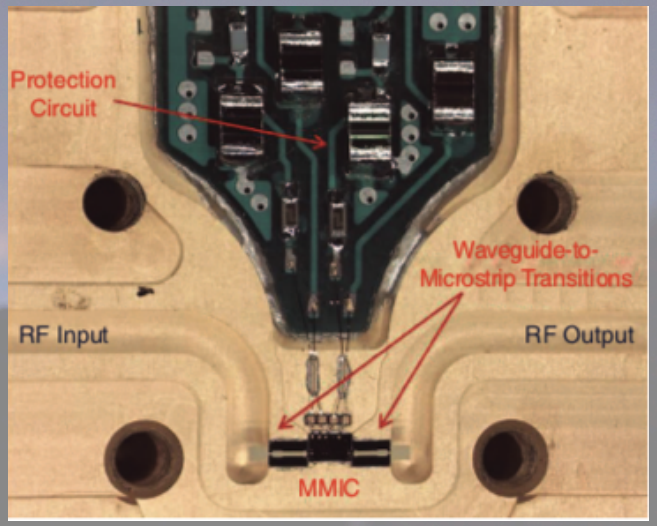
Broadband MMIC LNAs for ALMA Band 2+3 With Noise Temperature Below 28 K

David Cuadrado-Calle, *Member, IEEE*, Danielle George, *Member, IEEE*, Gary A. Fuller, Kieran Cleary, Lorene Samoska, *Senior Member, IEEE*, Pekka Kangaslahti, *Member, IEEE*, Jacob W. Kooi, *Member, IEEE*, Mary Soria, Mikko Varonen, *Member, IEEE*, Richard Lai, *Fellow, IEEE*, and Xiaobing Mei

ALMA Band 2+3 LNAs







2nd Generation devices produced and being tested

Have new designs for 3rd generation devices – Fabrication end of 2019

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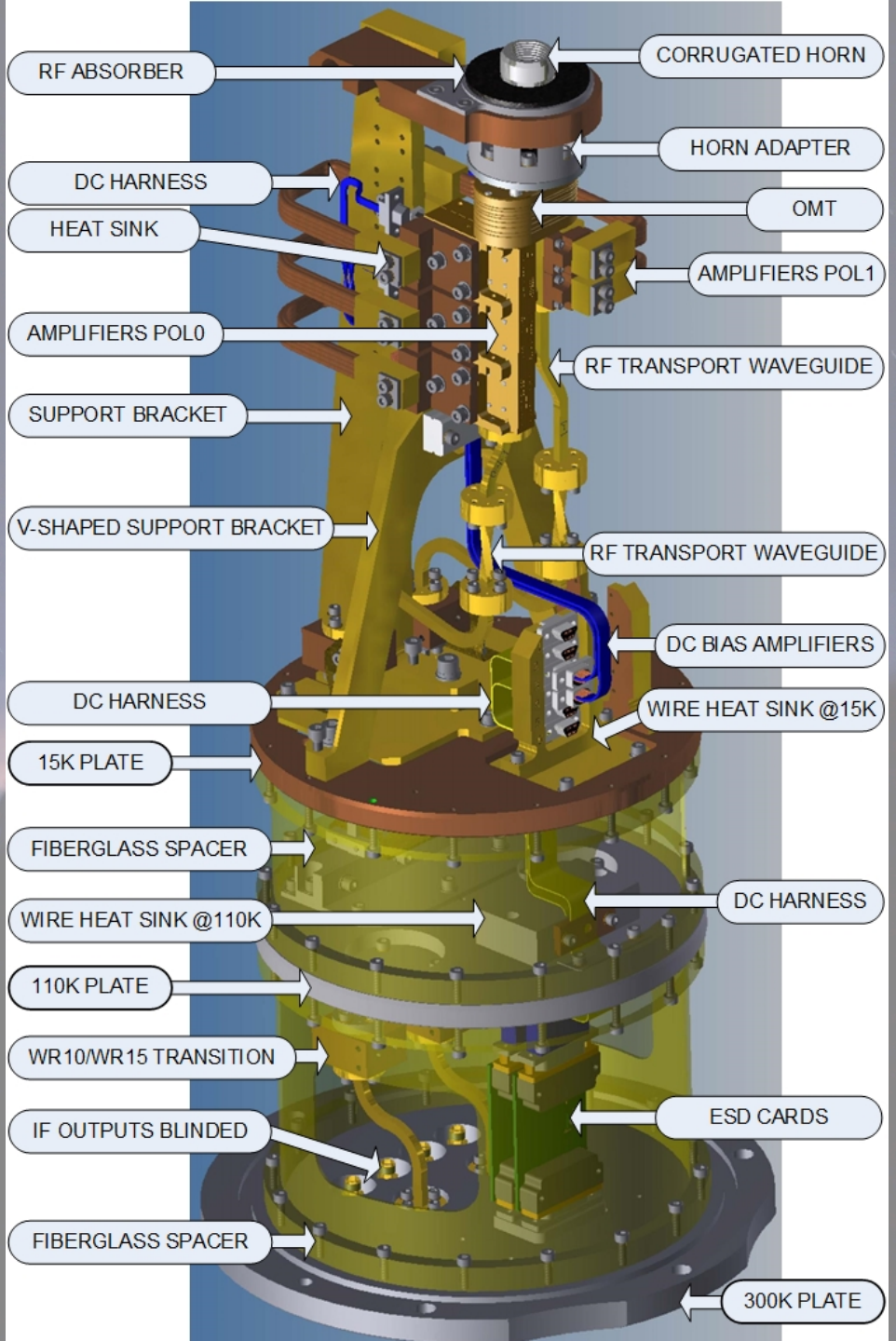
ALMA Band 2 Demonstration Cartridge



Yagoubov et al. 2018, 8th ESA Workshop on Millimetre-wave Technology & Applications

A&A paper in prep.

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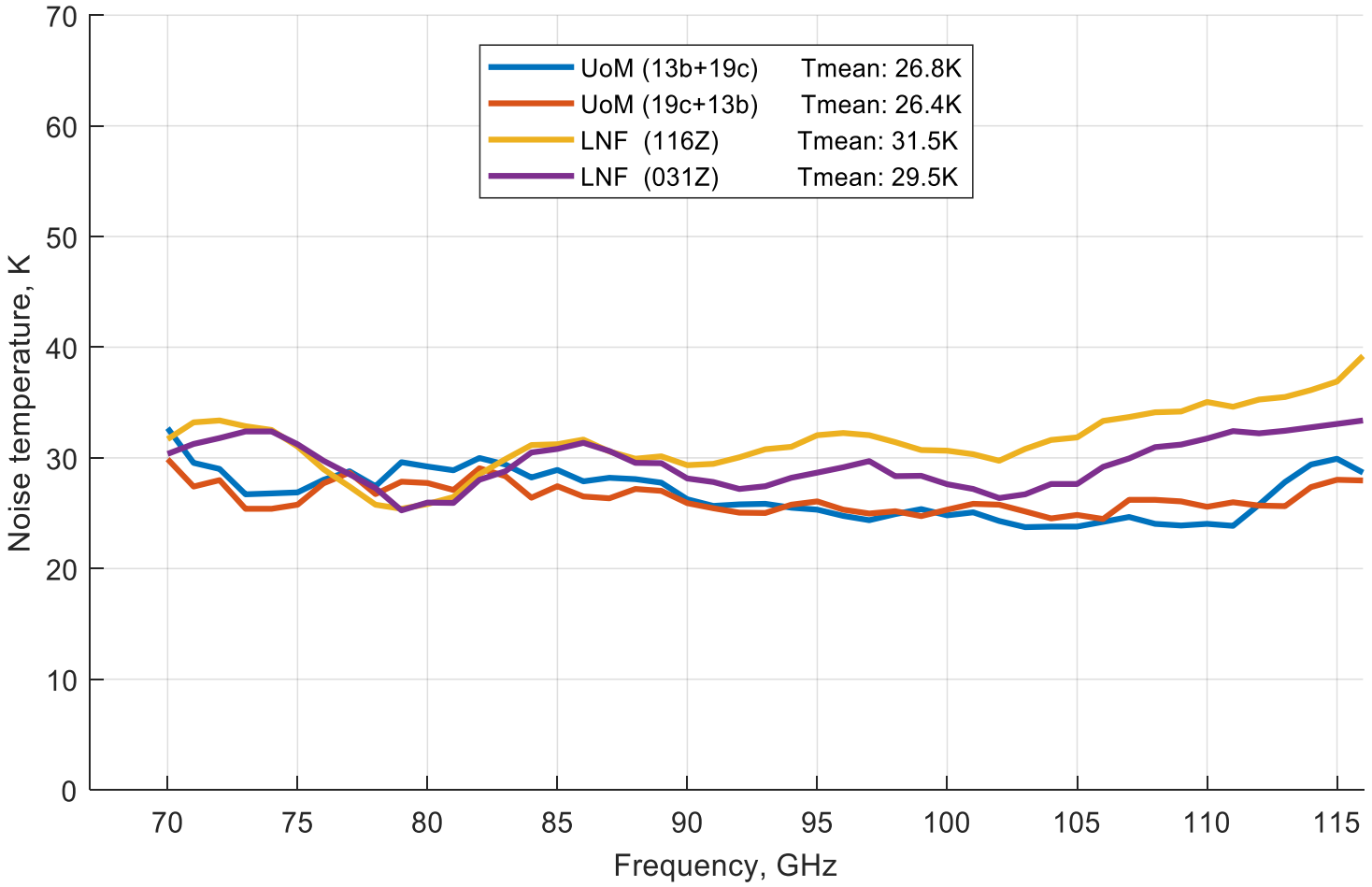
Yebes Measurements at 15 K



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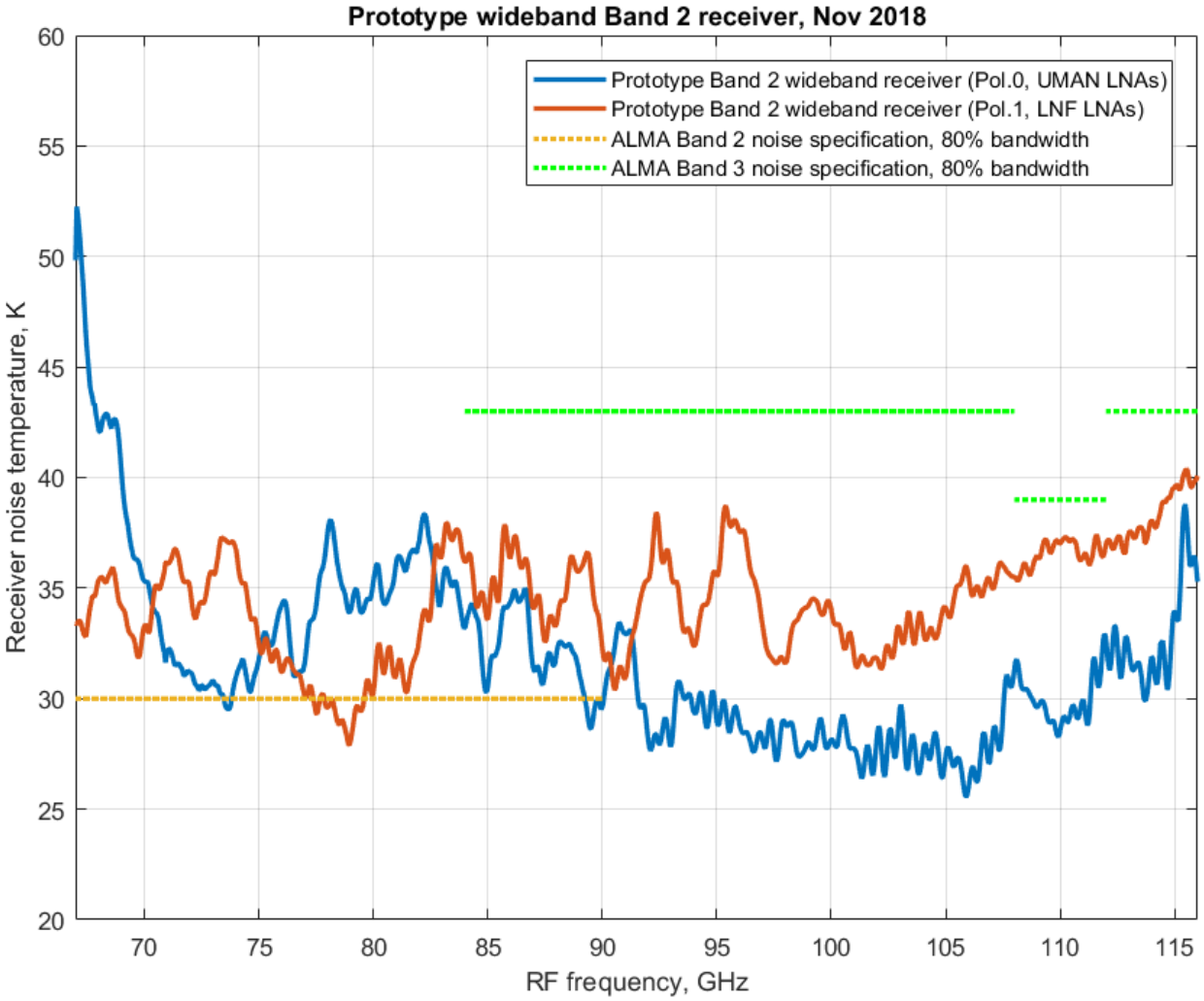
November 2018 Cartridge Tests



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Band 2+3 Current Status

- ESO has tendered for WCA & CCA
  - ESO will provide LNAs & some other critical components
- ALMA Board has approved construction of prototype Band 2 cartridge
  - Gate review in about 12 months

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ALMA 2030

- Priority for receiver upgrades (noise and bandwidth)
  1. 200-425 GHz (Bands 6, 7, into 8)
  2. <200 GHz (Bands 5 and below)
  3. > 425 GHz (Bands 8 and above)
- Digital system & correlator upgrade
  - At least 8 GHz per SB
- Longer term
  - Longer baselines
  - More 12m antennas
  - Focal plane arrays

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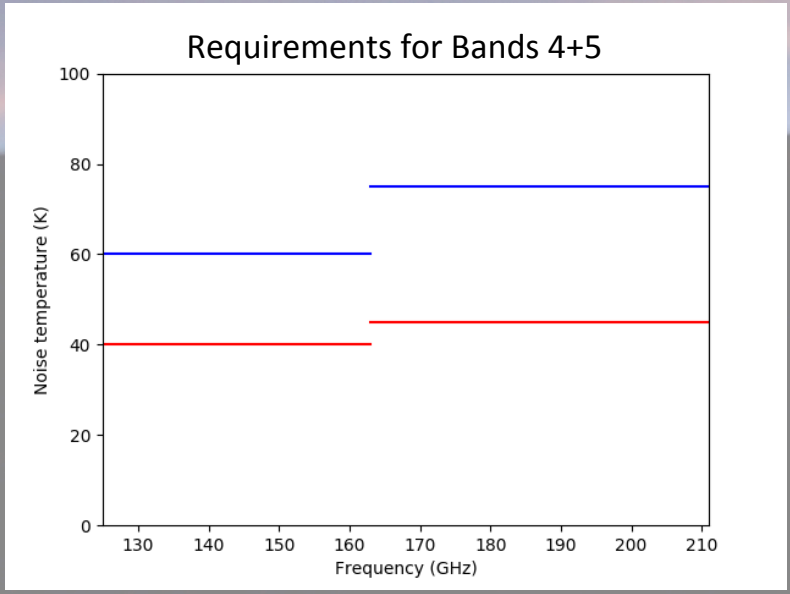
Moving up in Frequency

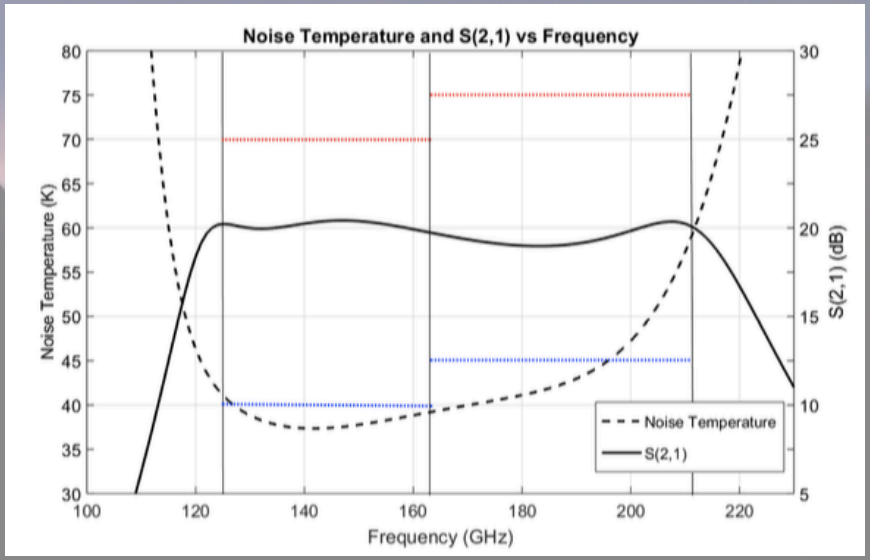
LNAs for

- 125 – 211 GHz ALMA Bands 4 + 5
- 211 – 373 GHz ALMA Bands 6 + 7

ESO Technical development programme funded project.

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





White et al submitted to Experimental Astronomy

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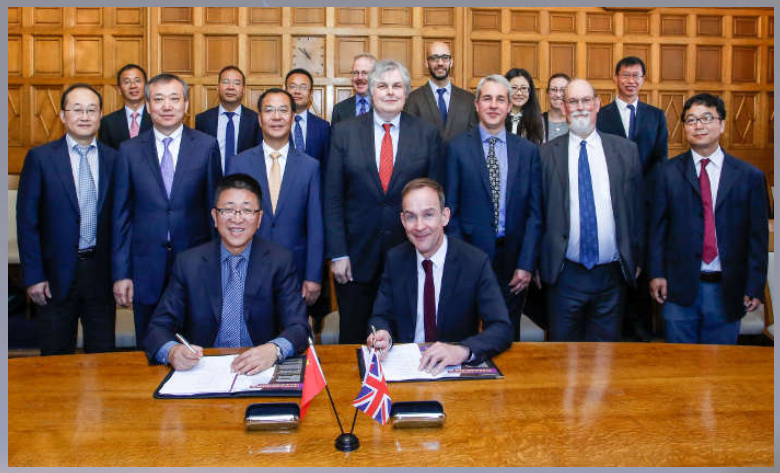
RAAIR Collaboration

- Radio Astronomy Advanced Instrumentation Research
- 3 year, £3million collaboration
  - China Electronics and Technology Corporation 38 (CETC-38) – Jodrell Bank Centre for Astronomy
  - Signed June 2018
- £1million Millimetre Wave Technology Project
  - Lead by Danielle George & Gary Fuller

  1) Frequency scalable pixel modules

  2) Phased Array Feed receivers at 100 GHz
  - Post-doc
  - 3 PhD students plus visitors



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Looking Forward

- Pushing the frequency range of LNAs
- Application of LNAs in FPAs & PAFs
  - Higher levels of integration
  - Looking at a scalable pixel approach
- New foundries
  - WIN Semiconductor
  - Glasgow University – 10nm features on InP
    - Producing demonstration wafer for ARIG
- Continuing to work on LNAs for SKA band 5/6 (5-50 GHz)

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ARIG

- PDRAs
  - Will Mcgenn
  - Claudio Jarufe (UdChile –> Manchester, Nov 18)
- Students
  - Daniel White
  - Danielius Banys
- Ex-members
  - David Cuadrado-Calle (Manchester –> RAL, June 2018)