Greenland Telescope:
Single-dish science, instrumentation requirements

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Nimesh Patel

October 2018, Thule AFB

23 May 2019, EAO Futures meeting, Nanjing

Outline:

- Current status
- Single dish science goals
- Summit Station
- Future receivers development


Nimesh Patel

October 2018, Thule AFB

Completion of mechanical assembly of the Greenland Telescope
10 August 2017

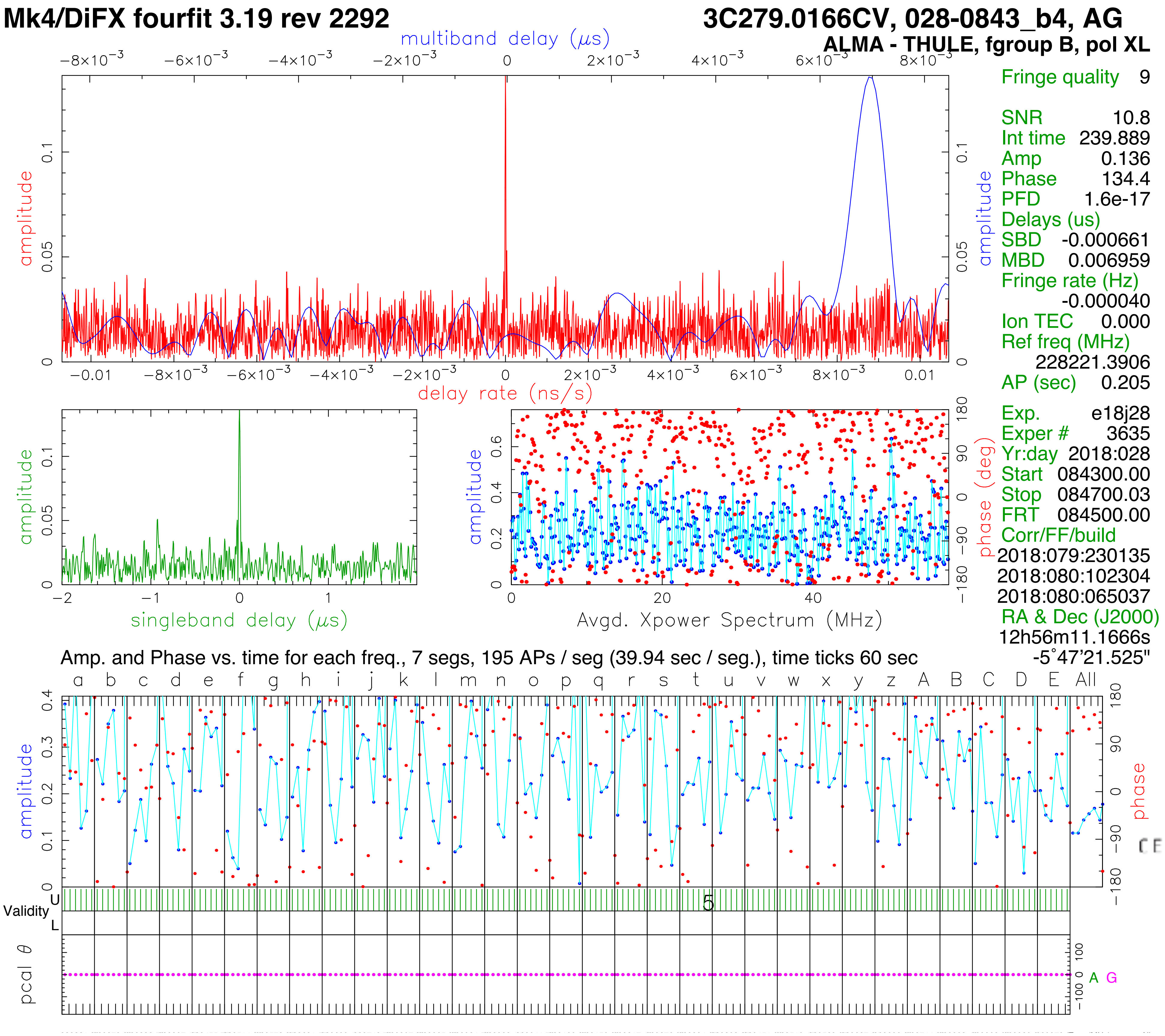
October 2017

Thule Phase 1 Activities 2017-2019

- Antenna assembly (mechanical + electrical) completed at Thule Air Base, Greenland - September 2017
- Hydrogen maser installed in September 2017
- Servo tuning and tests in progress - October 2017
- Fringes demonstrated at Maunakea, with SMA + JCMT, using 230 GHz receivers and VLBI backend
- 86 & 230 GHz receivers installed in late November 2017
- Pointing calibration in November 2017

- Joined the EHT run in April 2018

First fringes on ALMA-Thule baseline, 28 January 2018



Mk4/DiFX fourfit 3.19 rev 2292

3C279.0166CV, 028-0843_b4, AG
ALMA - THULE, fgroup B, pol XL

Fringe quality	9
SNR	10.8
Int time	239.889
Amp	0.136
Phase	134.4
PFD	1.6e-17
Delays (us)	
SBD	-0.000661
MBD	0.006959
Fringe rate (Hz)	-0.000040
Ion TEC	0.000
Ref freq (MHz)	228221.3906
AP (sec)	0.205
Exp.	e18j28
Exper #	3635
Yr:day	2018:028
Start	084300.00
Stop	084700.03
FRT	084500.00
Corr/FF/build	2018:079:230135 2018:080:102304 2018:080:065037
RA & Dec (J2000)	12h56m11.1666s -5°47'21.525"

Amp. and Phase vs. time for each freq., 7 segs, 195 APs / seg (39.94 sec / seg.), time ticks 60 sec

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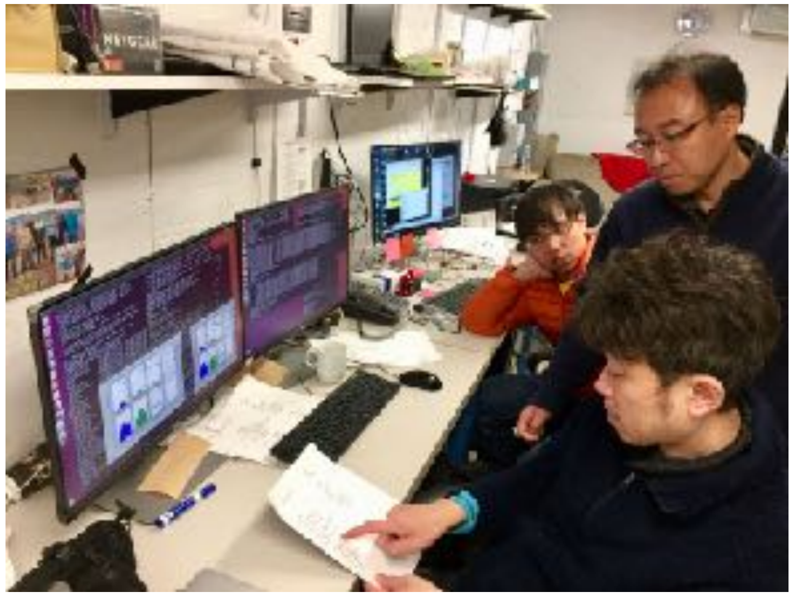

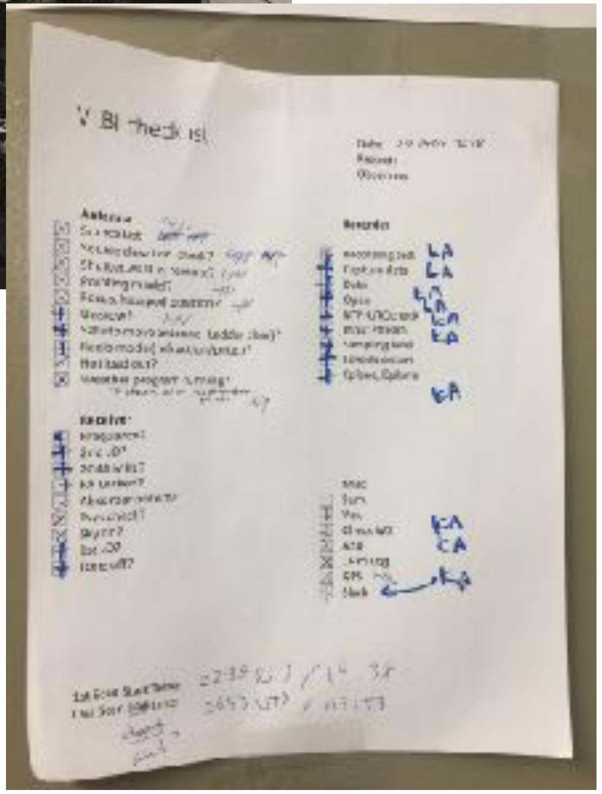

VLBI checklist

Antenna

Recorder

Receiver

EHT observing run April 2018

Keiichi Asada (ASIAA)
Hiroaki Nishioka (ASIAA)
ChenYu Yu (ASIAA)
Nimesh Patel (CfA)

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31 March - 9 April 2019, Global Millimeter-wave VLBI Array observations at 86 GHz

- VLBA_PT
- VLBA_LA
- VLBA_FD
- VLBA_OV
- VLBA_KP
- VLBA_BR
- VLBA_MK
- GLT
- GBT_VLBA
- EFLSBERG
- ONSALA60
- YEBES40M
- PICOVEL
- METSAHOV
- NOEMA1
- ALMA
- KVNYS
- KVNUS
- KVNTN

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Hydrogen maser house

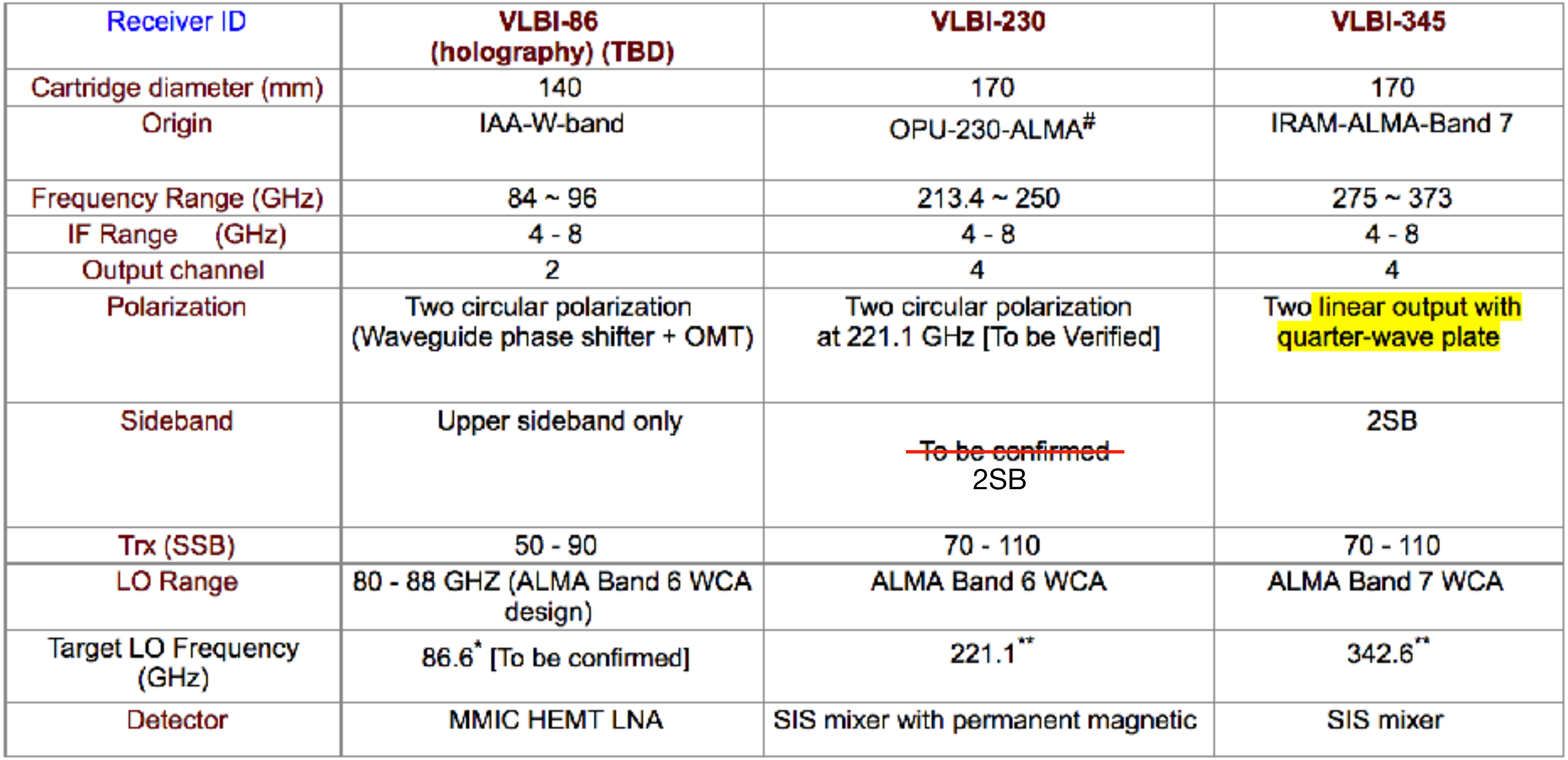
Control room, weather station

Current Instrumentation

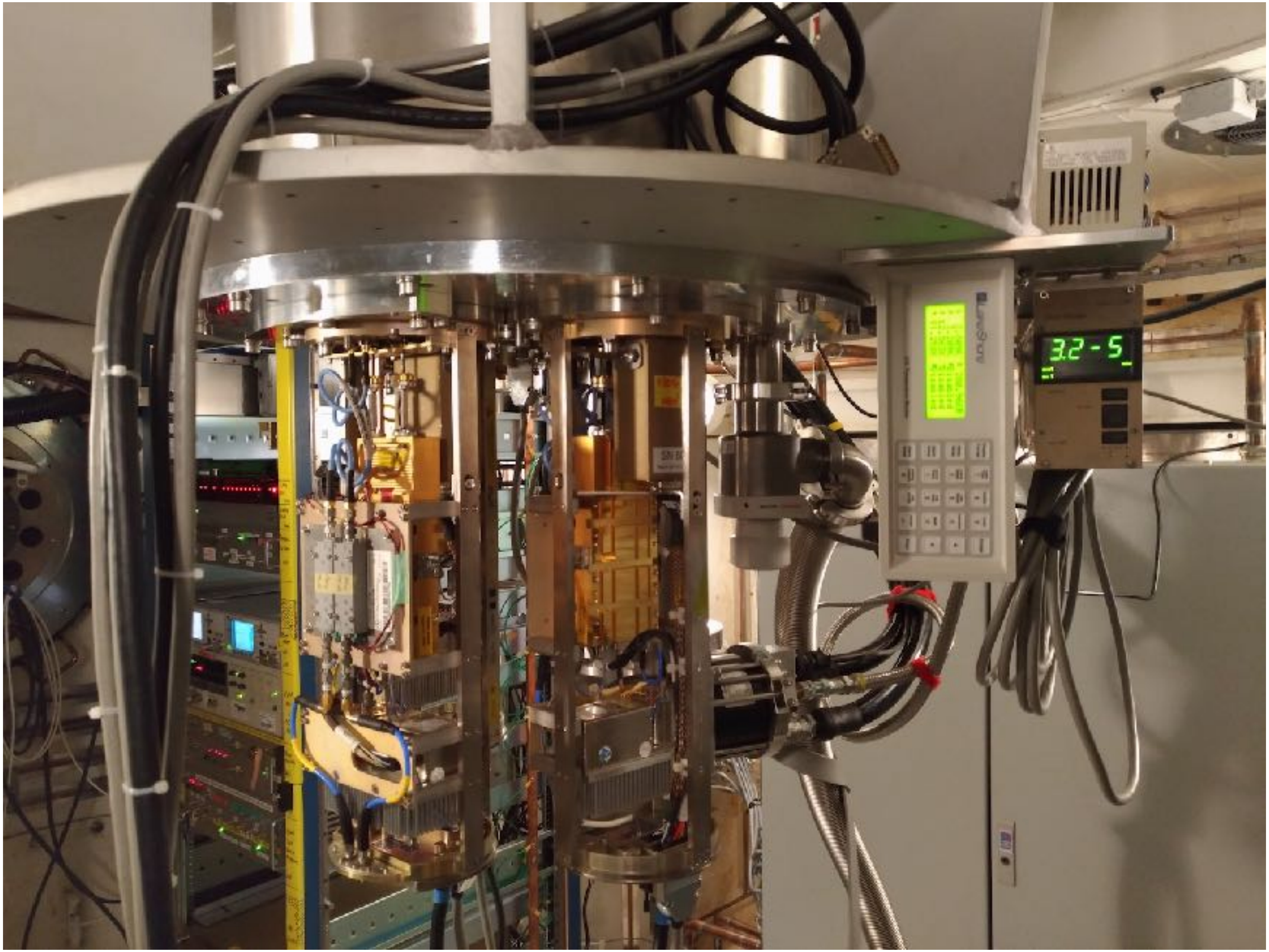
VLBI Receivers

Johnson Han (ASIAA)

A. Key Characters

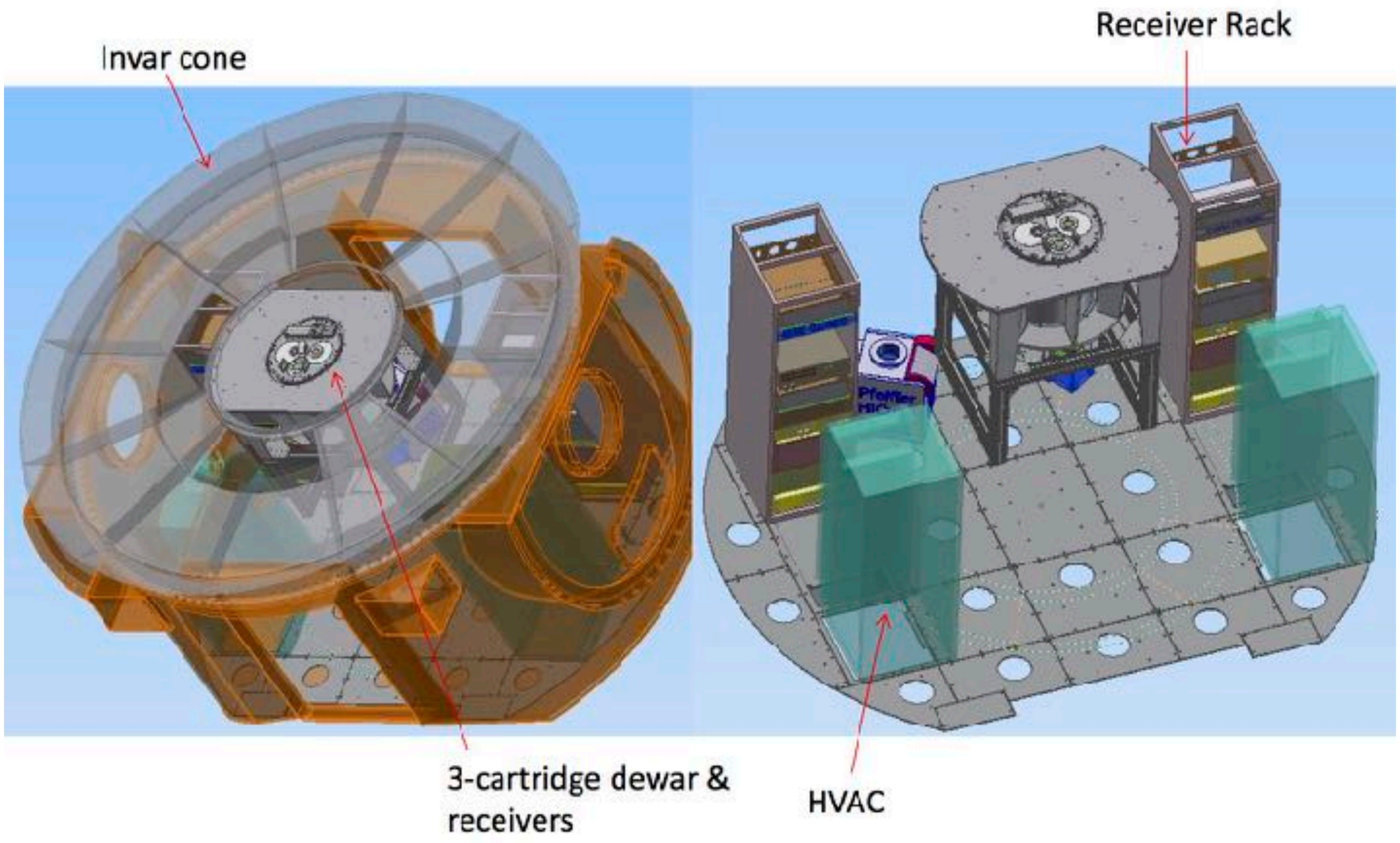


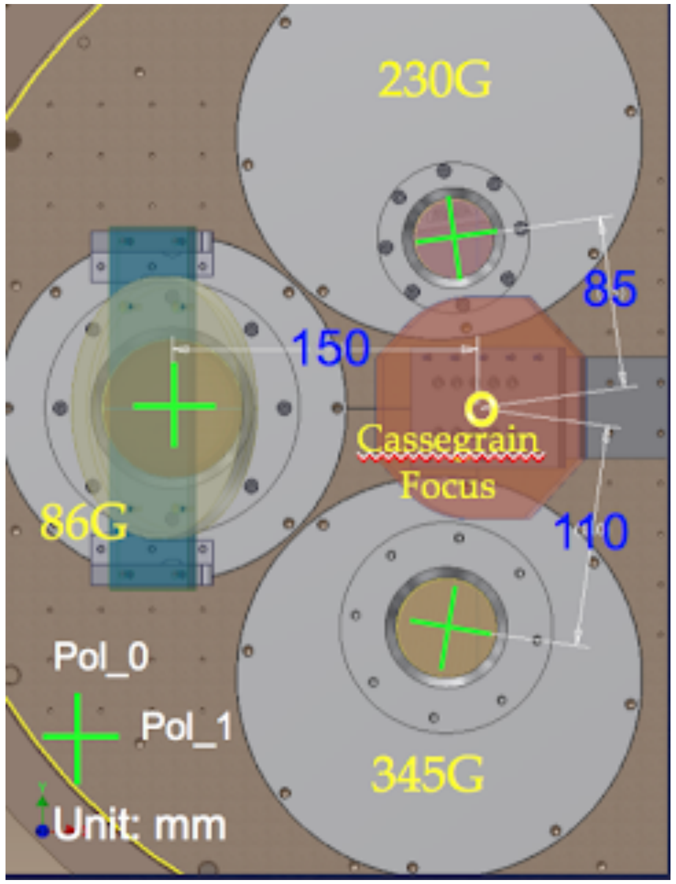
Receiver ID	VLBI-86 (holography) (TBD)	VLBI-230	VLBI-345
Cartridge diameter (mm)	140	170	170
Origin	IAA-W-band	OPU-230-ALMA[#]	IRAM-ALMA-Band 7
Frequency Range (GHz)	84 ~ 96	213.4 ~ 250	275 ~ 373
IF Range (GHz)	4 - 8	4 - 8	4 - 8
Output channel	2	4	4
Polarization	Two circular polarization (Waveguide phase shifter + OMT)	Two circular polarization at 221.1 GHz [To be Verified]	Two linear output with quarter-wave plate
Sideband	Upper sideband only	~~To be confirmed~~ 2SB	2SB
Trx (SSB)	50 - 90	70 - 110	70 - 110
LO Range	80 - 88 GHZ (ALMA Band 6 WCA design)	ALMA Band 6 WCA	ALMA Band 7 WCA
Target LO Frequency (GHz)	86.6[*] [To be confirmed]	221.1[**]	342.6[**]
Detector	MMIC HEMT LNA	SIS mixer with permanent magnetic	SIS mixer


3.2 - 5

Rx-Cabin Space

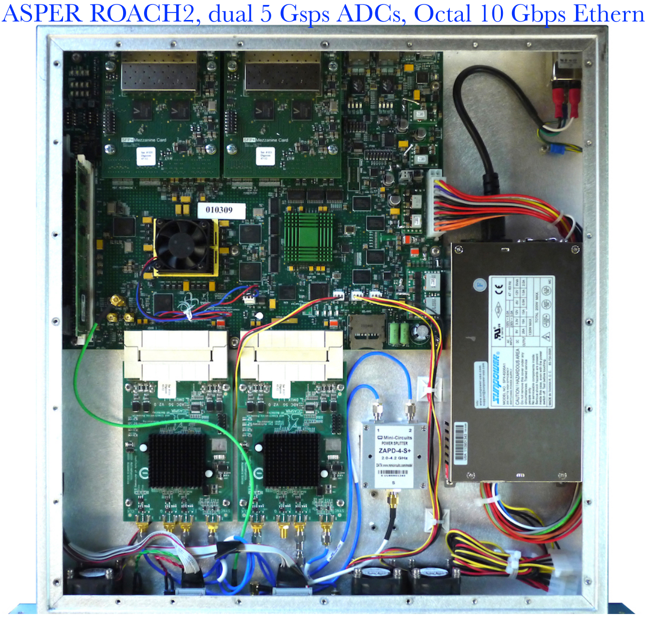
Johnson Han (ASIAA)





Two ROACH2 spectrometers, each with two IF inputs of 2.048 GHz b/w, 32768 channels

CASPER ROACH2, dual 5 Gsps ADCs, Octal 10 Gbps Ethernet



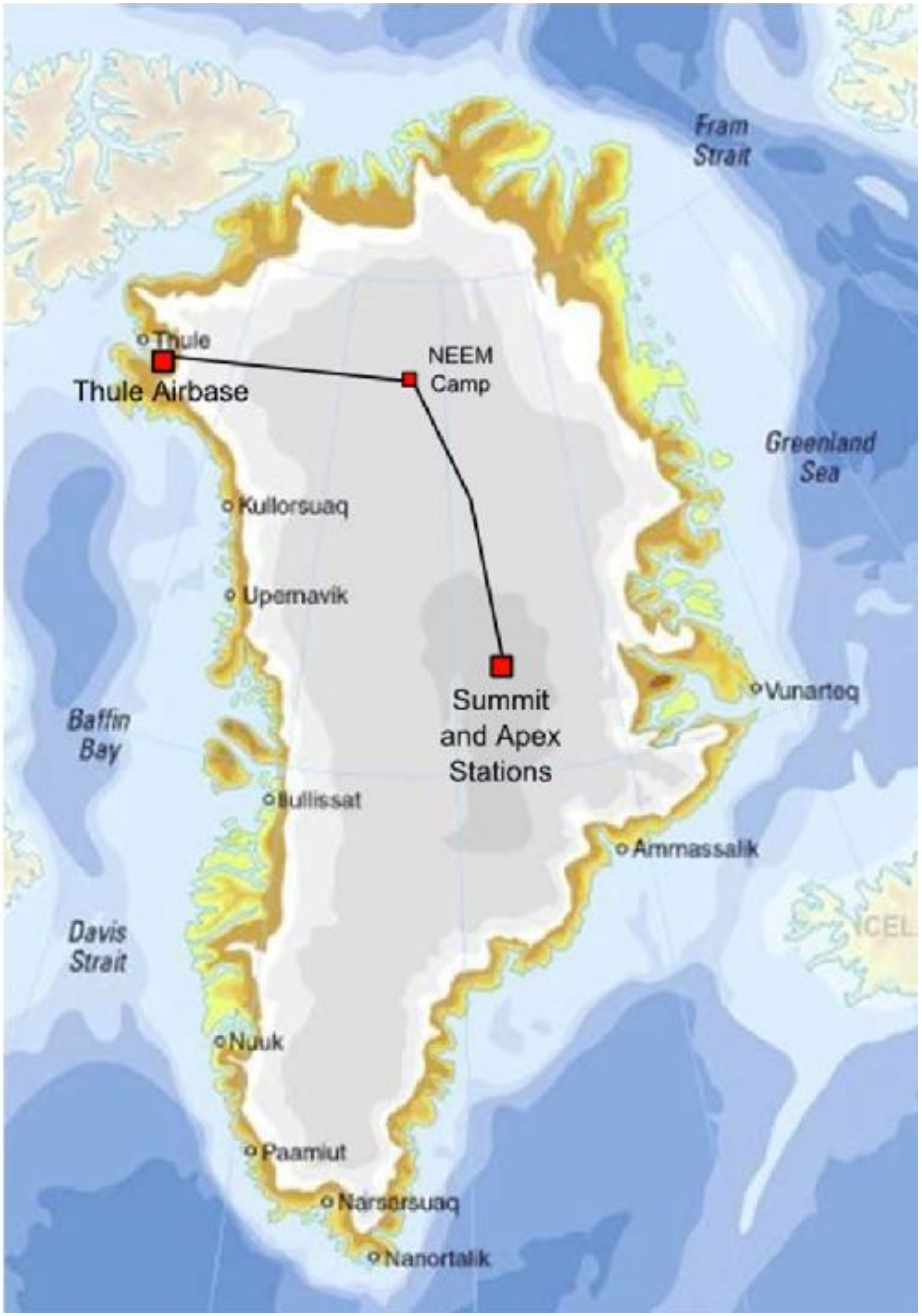
Summit Station

Thule Air Base

Position:
76.5° North, 68.7° West
Altitude: 77 m
Temperature: 5 C to – 25 C (average)

Summit Station

Position:
72.5° North, 38.5° West
Altitude: 3,200 m
Temperature: - 10 C to - 50 C (average)



View from level-2 platform

Beginning of Ice sheet (traverse)

Publications of the Astronomical Society of the Pacific, 129:025001 (11pp), 2017 February
doi:10.1088/1538-3873/129/972/025001

3.5 Year Monitoring of 225 GHz Opacity at the Summit of Greenland

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Abstract

We present the 3.5 years monitoring results of 225 GHz opacity at the summit of the Greenland ice sheet (Greenland Summit Camp) at an altitude of 3200 m using a tipping radiometer. We chose this site as our submillimeter telescope (Greenland Telescope) site, because conditions are expected to have low submillimeter opacity and because its location offers favorable baselines to existing submillimeter telescopes for global-scale Very Long Baseline Interferometry. The site shows a clear seasonal variation with the average opacity lower by a factor of two during winter. The 25%, 50%, and 75% quartiles of the 225 GHz opacity during the winter months of November through April are 0.046, 0.060, and 0.080, respectively. For the winter quartiles of 25% and 50%, the Greenland site is about 10%–30% worse than the Atacama Large Millimeter/submillimeter Array (ALMA) or the South Pole sites. Estimated atmospheric transmission spectra in winter season are similar to the ALMA site at lower frequencies (<450 GHz), which are transparent enough to perform astronomical observations almost all of the winter time with opacities <0.5, but 10%–25% higher opacities at higher frequencies (>450 GHz) than those at the ALMA site. This is due to the lower altitude of the Greenland site and the resulting higher line wing opacity from pressure-broadened saturated water lines in addition to higher dry air continuum absorption at higher frequencies. Nevertheless, half of the winter time at the Greenland Summit Camp can be used for astronomical observations at frequencies between 450 GHz and 1000 GHz with opacities <1.2, and 10% of the time show >10% transmittance in the THz (1035 GHz, 1350 GHz, and 1500 GHz) windows. Summer season is good for observations at frequencies lower than 380 GHz. One major advantage of the Greenland Summit Camp site in winter is that there is no diurnal variation due to the polar night condition, and therefore the durations of low-opacity conditions are significantly longer than at the ALMA site. Opacities lower than 0.05 or 0.04 can continue for more than 100 hr. Such long stable opacity conditions do not occur as often even at the South Pole; it happens only for the opacity lower than 0.05. Since the opacity variation is directly related to the sky temperature (background) variation, the Greenland Summit Camp is suitable for astronomical observations that need unusually stable sky background.

Key words: atmospheric effects – site testing

Online material: color figure

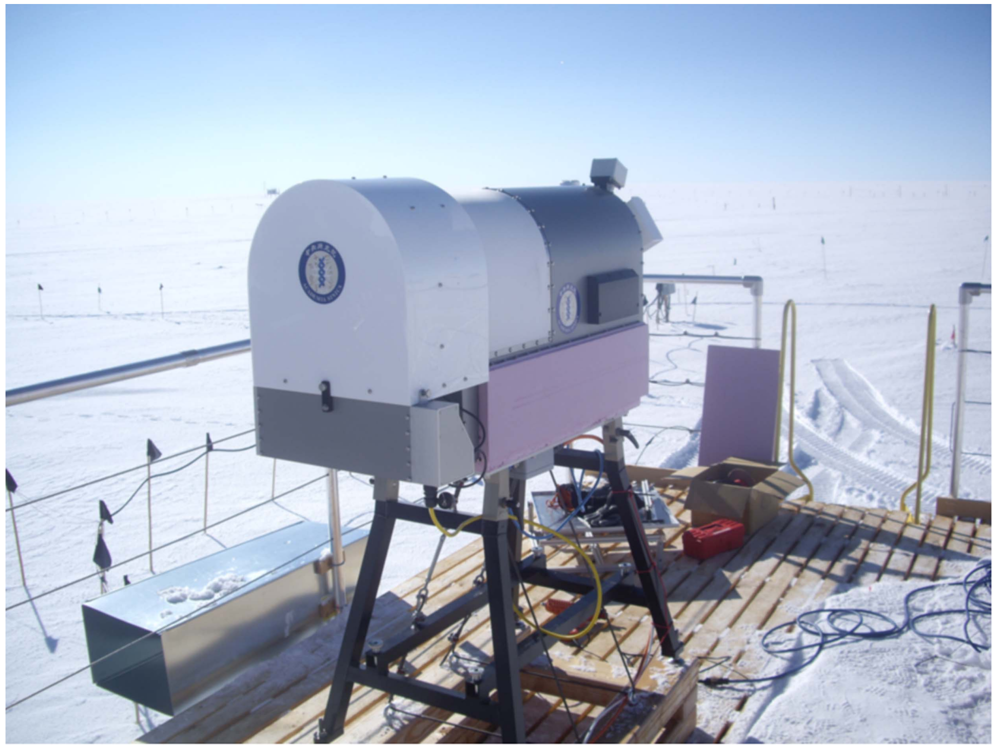


Figure 1. 225 GHz tipping radiometer located on the roof of the Mobile Science Facitily (MSF) at the Greenland Summit Camp. (A color version of this figure is available in the online journal.)

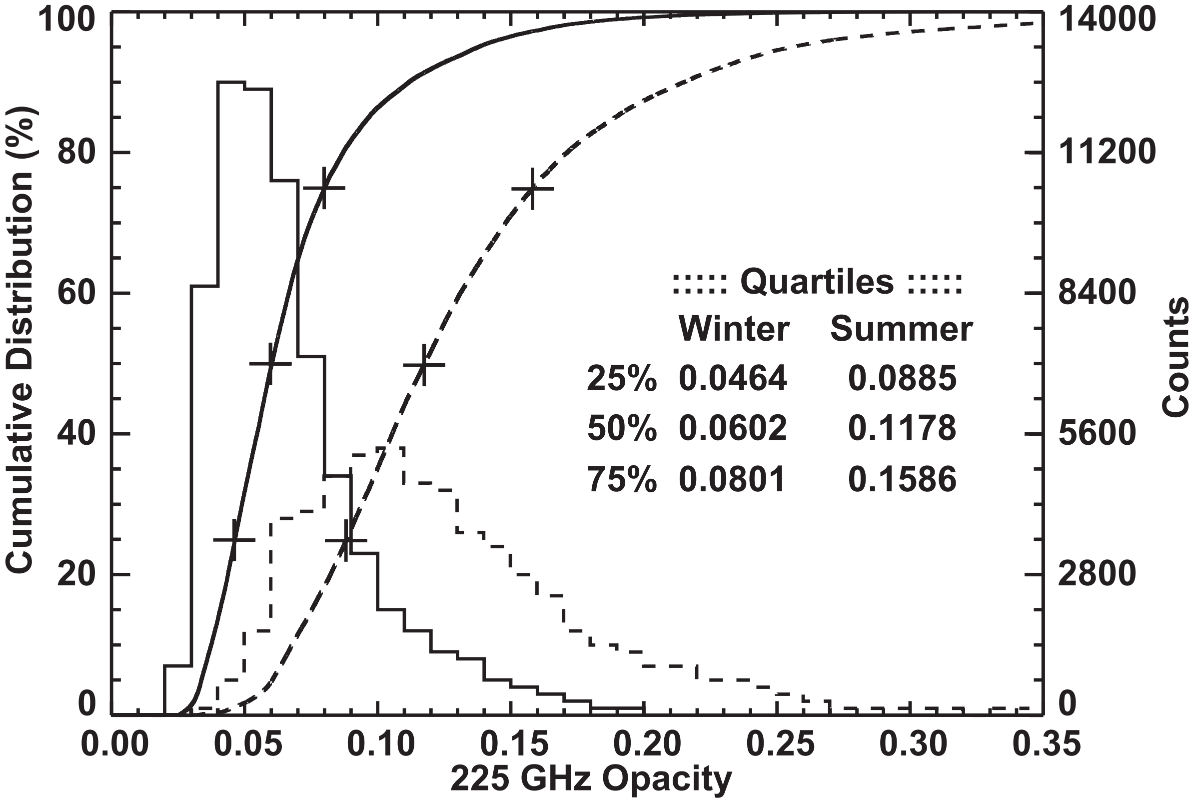


Figure 4. Cumulative distribution plots and histograms of 225 GHz opacity in winter (solid lines) and summer (dashed lines). The vertical axis on the left-hand side is for the cumulative distribution plots, and that on the right-hand side is for the histograms. Crosses on the cumulative distribution plots are the opacity quartiles of each season. The quartile for winter and summer are also listed in the figure.


THE U.S. NATIONAL SCIENCE FOUNDATION WELCOMES YOU TO THE SUMMIT OF THE GREENLAND ICE SHEET
SUMMIT STATION
72° 35' N, 38° 25' W
ELEVATION 10,530 FEET
NSF
CH2MHILL Polar Services

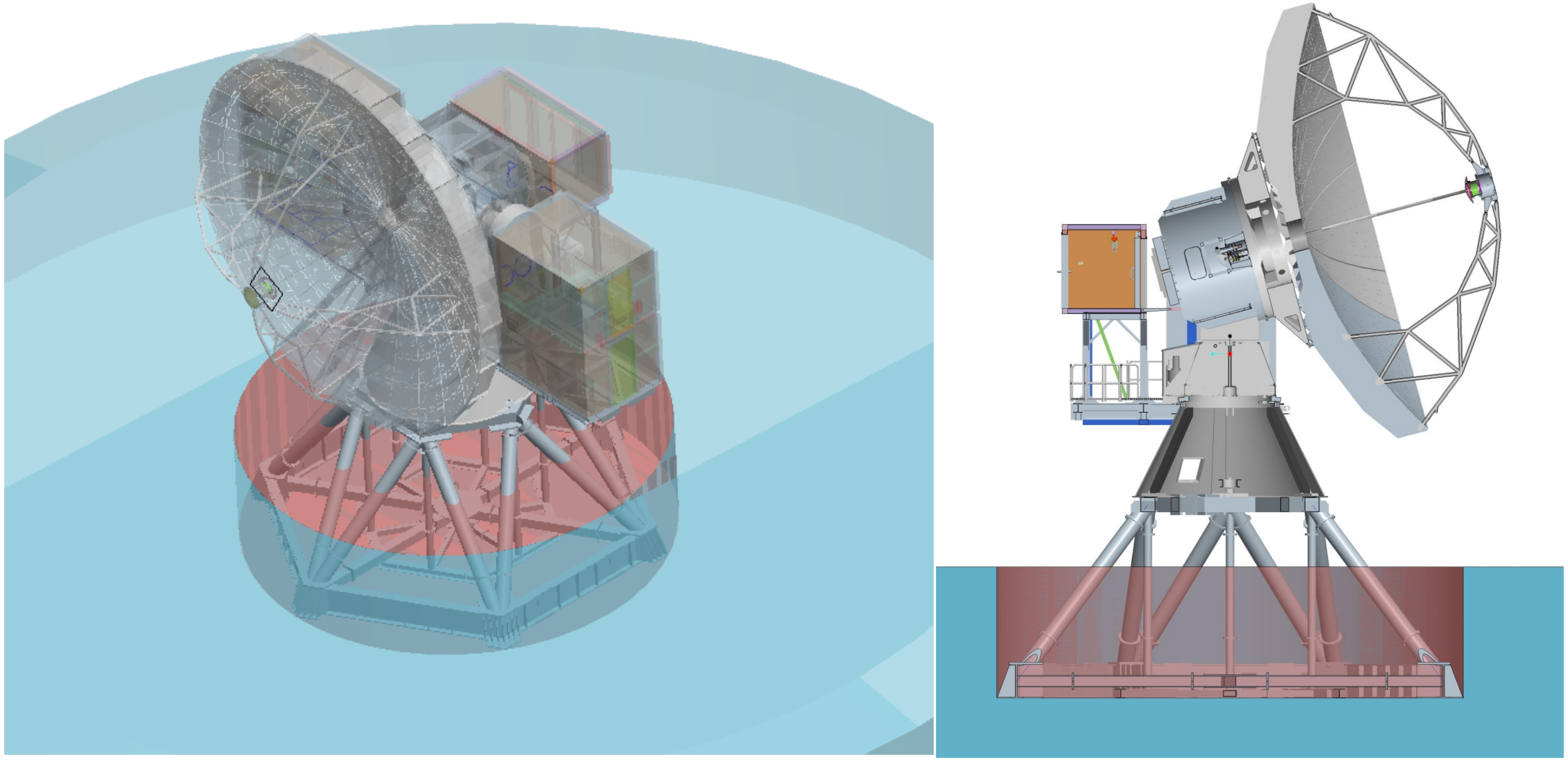


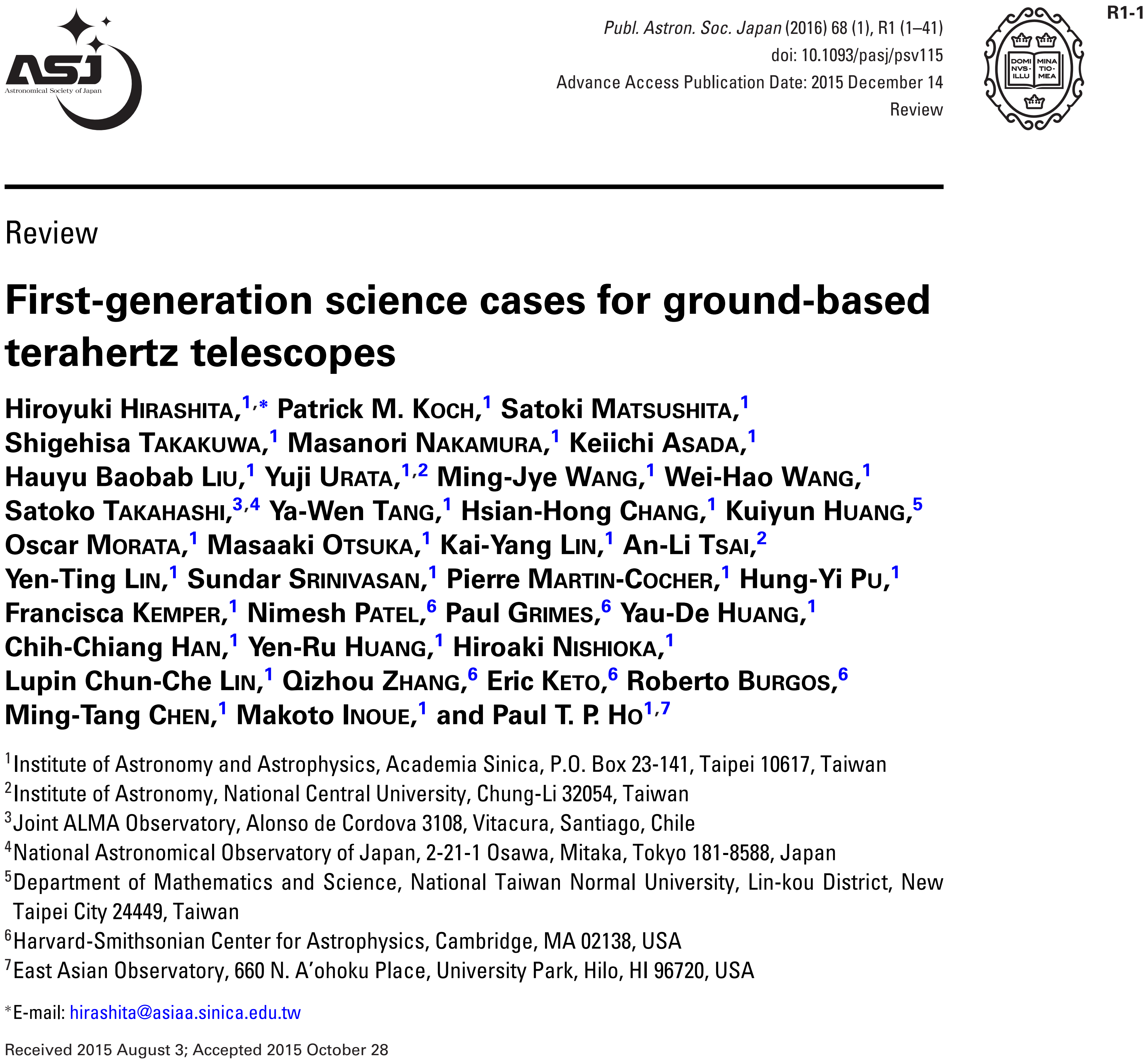
Figure 5: Model of the GLT on the space frame partially embedded in the snow foundation (design of space frame and snow pad in progress). Isometric view showing all 4 side containers and receiver transfer container on the back (Left); sectional side view (Right)

Raffin P., 2014 SPIE paper

Single dish science

Science goals:

1) M87 VLBI
2) Single-dish Submm and THz projects



R1-1

Publ. Astron. Soc. Japan (2016) 68 (1), R1 (1–41)
doi: 10.1093/pasj/psv115
Advance Access Publication Date: 2015 December 14
Review

Review

First-generation science cases for ground-based terahertz telescopes

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Abstract

Ground-based observations at terahertz (THz) frequencies are a newly explorable area of astronomy in the coming decades. We discuss science cases for a first-generation 10-m class THz telescope, focusing on the Greenland Telescope as an example of such a facility. We propose science cases and provide quantitative estimates for each case. The largest advantage of ground-based THz telescopes is their higher angular resolution ($\sim 4''$ for a 10-m dish), as compared to space or airborne THz telescopes. Thus, high-resolution mapping is an important scientific argument. In particular, we can isolate zones of interest for Galactic and extragalactic star-forming regions. The THz windows are suitable for observations of high-excitation CO lines and [N II] 205-μm lines, which are scientifically relevant tracers of star formation and stellar feedback. Those lines are the brightest lines in the THz windows, so they are suitable for the initiation of ground-based THz observations. THz polarization of star-forming regions can also be explored since it traces the dust population contributing to the THz spectral peak. For survey-type observations, we focus on "sub-THz" extragalactic surveys, the uniqueness of which is detecting galaxies at redshifts $z \sim 1$–2, where the dust emission per comoving volume is the largest in the history of the Universe. Finally we explore possibilities of flexible time scheduling, which enables us to monitor active galactic nuclei, and to target gamma-ray burst afterglows. For these objects, THz and submillimeter wavelength ranges have not yet been explored.

Key words: dust, extinction — galaxies: ISM — ISM: lines and bands — submillimeter: general — telescopes

- Diffuse ISM
    - Molecules
    - NII line at 205 μm
- Dust continuum: star-forming regions
    - Polarization at THz frequencies
- Bolometer surveys of high redshift galaxies
- Flux monitoring of AGN sources
- Gamma ray bursts
- Spectral-line surveys
- Water maser surveys

- (A) Chemistry and evolution in the diffuse and dense ISM

CO 13-12 line, NII line
1.5 THz heterodyne (multipixel) receiver

- (B) Collective effects of star-formation in extragalactic sources

650, 850 GHz ; Improve on Herschel resolution
Bolometer arrays

- (C) Time variable submillimeter Universe

VLBI receivers

Table 2. Representative terahertz lines.

Species	Frequency (THz)	Transition	Excitation energy (K)
CO	1.037–1.497	(9–8)–(13–12)	248.87486–503.134028
HCO^+	1.070–1.337	(12–11)–(15–14)	333.77154–513.41458
HCN	1.0630–1.593	(12–11)–(18–17)	331.68253–726.88341
H_2D^+	1.370	$1_{0,1}$–$0_{0,0}$	65.75626
N II	1.461	$^3P_1$–$^3P_0$	–
CH	1.471	$N = 2, J = 3/2–3/2, F = 2^+–2^-$	96.31131
HD_2^+	1.477	$1_{1,1}$–$0_{0,0}$	70.86548

Table 3. Luminous protostellar sources for the THz line experiment.

Name	L_{bol} ($L_\odot$)	D (pc)	α(J2000.0) (h m s)	δ(J2000.0) (° ′ ″)	References*
L1448-mm	4.4	250	03 25 38 87	30 44 05.4	1,2
NGC1333 IRAS 2A	19.0	250	03 28 55.58	31 14 37.1	1,2
SVS 13	32.5	250	03 29 03.73	31 16 03.80	2,3
NGC1333 IRAS 4A	4.2	250	03 29 10.50	31 13 31.0	1,2
L1551 IRS 5	22	140	04 31 34.14	18 08 05.1	4,5
L1551 NE	4.2	140	04 31 44.47	18 08 32.2	5,6
L1157	5.8	325	20 39 06.28	68 02 15.8	1,7

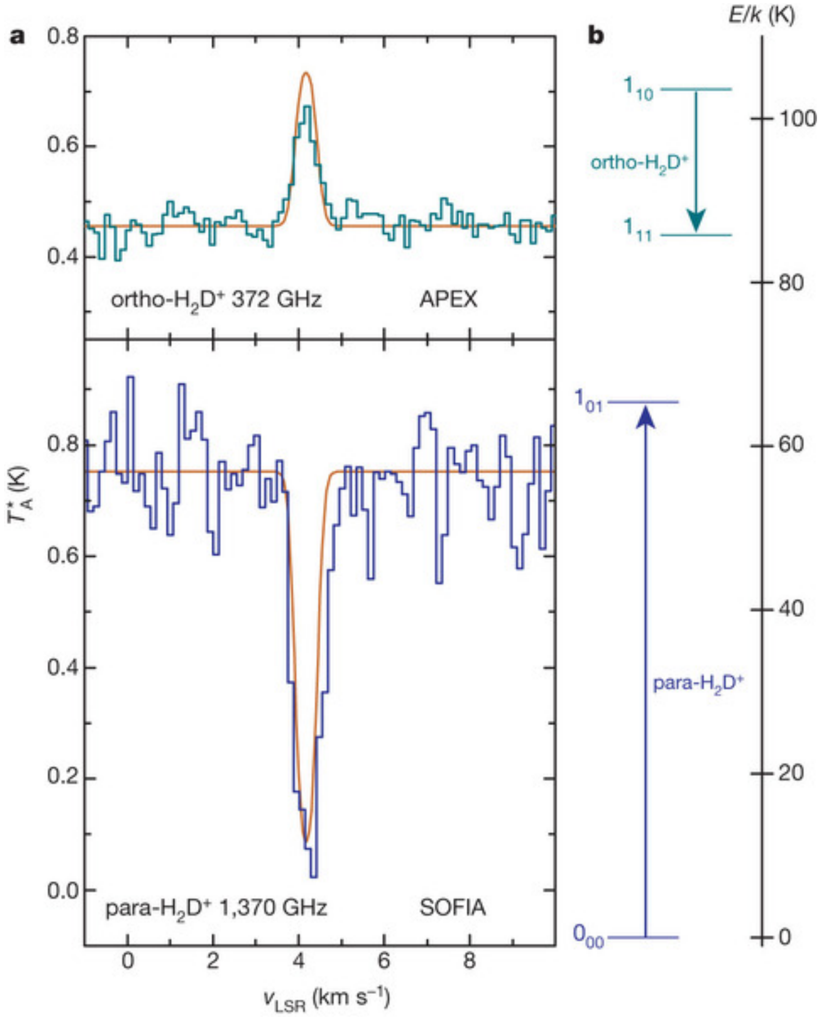
*References: (1) Jørgensen et al. (2007); (2) Enoch et al. (2009); (3) Chen, Launhardt, and Henning (2009); (4) Takakuwa et al. (2004); (5) Froebrich (2005); (6) Takakuwa et al. (2012); (7) Shirley et al. (2000).

H_2D^+ observations give an age of at least one million years for a cloud core forming Sun-like stars

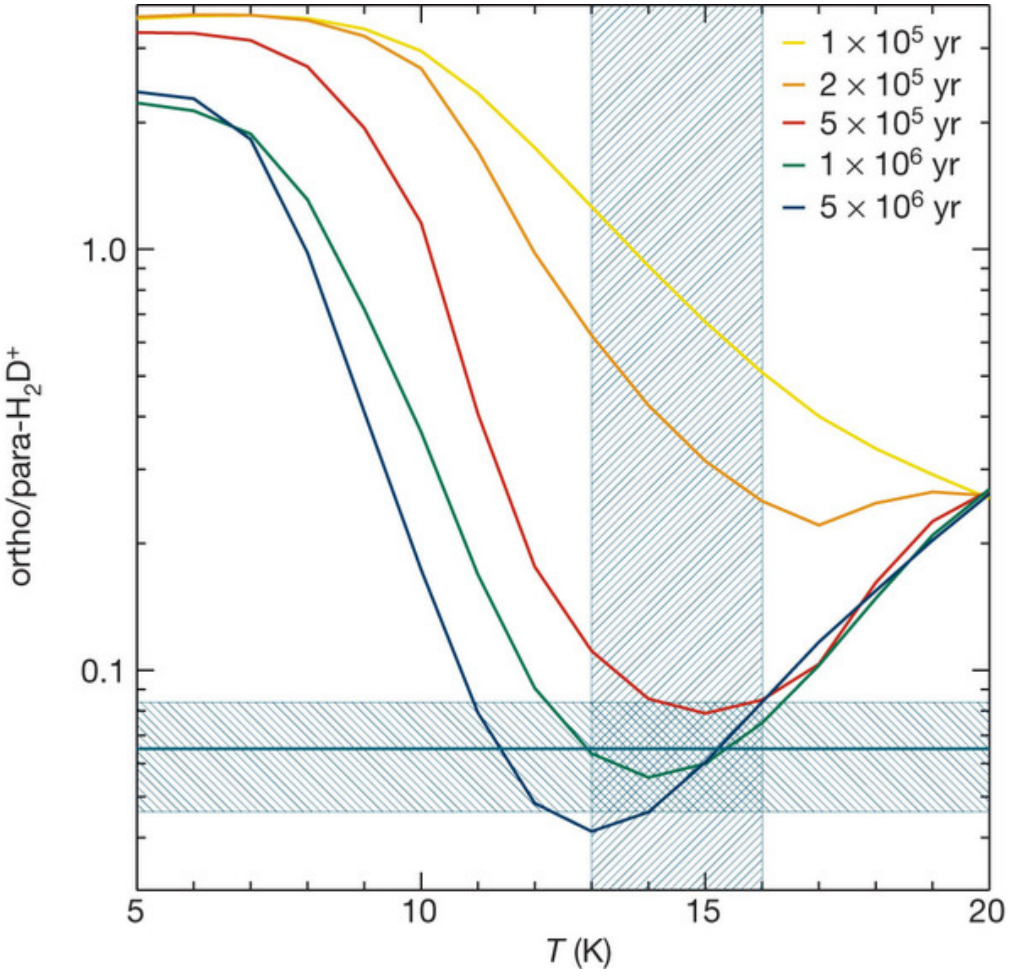
Sandra Brünken, Olli Sipilä, Edward T. Chambers, Jorma Harju, Paola Caselli, Oskar Asvany, Cornelia E. Honingh, Tomasz Kamiński, Karl M. Menten, Jürgen Stutzki & Stephan Schlemmer

Nature **516**, 219–221 (11 December 2014) doi:10.1038/nature13924

Figure 1: Observed and modelled H_2D^+ spectra.



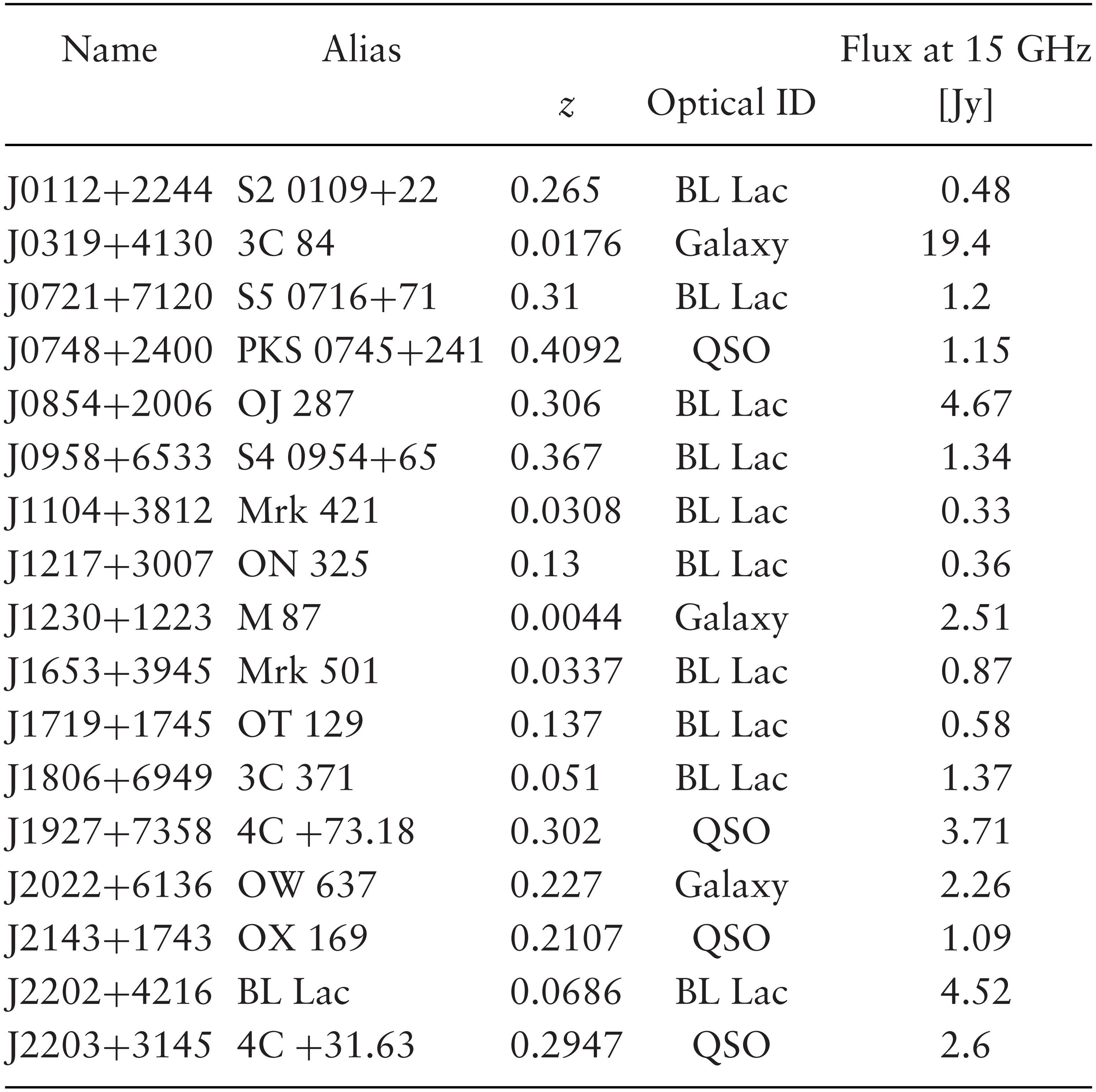
a, The histograms show the ortho-H_2D^+ (top) and para-H_2D^+ (bottom) rotational ground-state lines as observed with A SOFIA/GREAT, respectively; the orange lines show the modelled line profiles. Intensities are given as antenna temper denotes the velocity with respect to the local standard of rest. **b**, Energy level diagram (in units of temperature, *E*/*k*, wh constant) of the lowest rotational states of ortho- and para-H_2D^+.



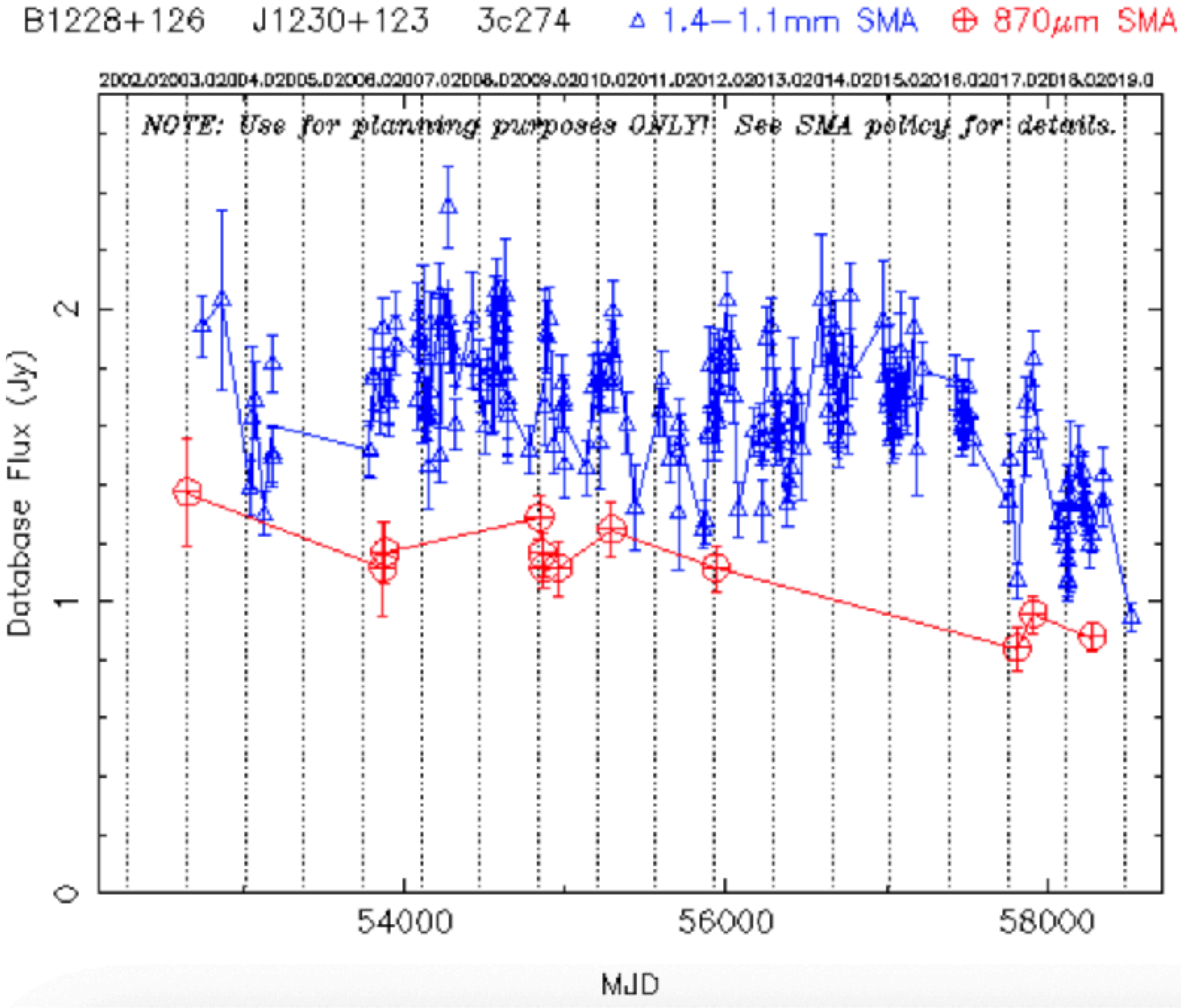
At kinetic temperatures *T* above ~12 K, the ortho/para H_2D^+ ratio is completely determined in reactions with ortho- and para-H_2, and it is closely tied to the evolution of the ortho/para H_2 ratio. The shaded vertical region indicates the temperature range applicable to the dense core surrounding IRAS 16293-2422 A/B (at radial distances from the core centre of 3,000–6100 AU), while the horizontal shade indicates the observed ortho/para H_2D^+ ratio. Together, these limits suggest a dense core age of at least one million years. The gas density, $n(H_2) = 10^5$ cm^{-3}, and the visual extinction, $A_V = 10$ mag, are kept constant in this model.

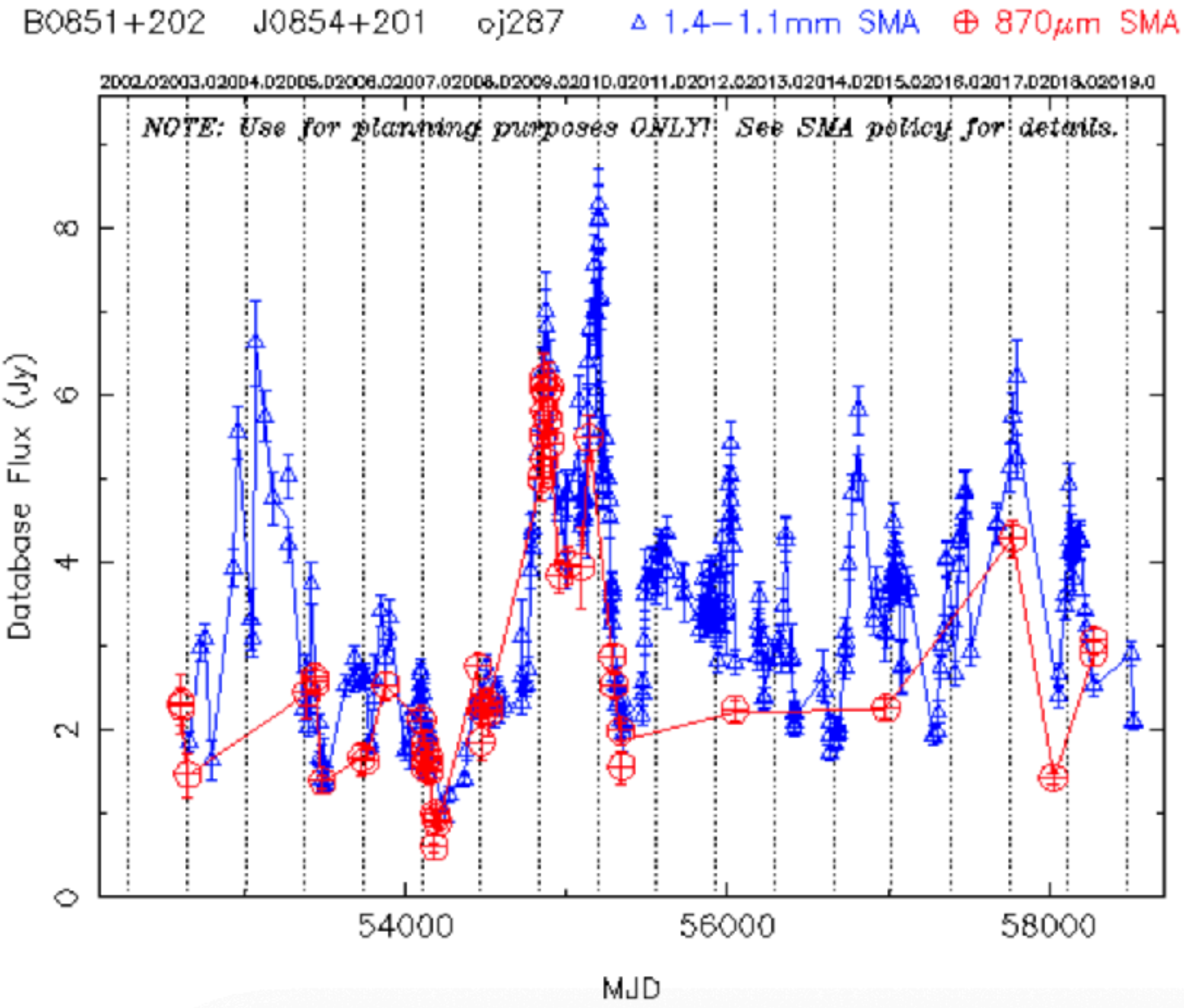
Time variable AGN sources

Table 7. Candidate AGNs for monitoring observations with the GLT.



Name	Alias	z	Optical ID	Flux at 15 GHz [Jy]
J0112+2244	S2 0109+22	0.265	BL Lac	0.48
J0319+4130	3C 84	0.0176	Galaxy	19.4
J0721+7120	S5 0716+71	0.31	BL Lac	1.2
J0748+2400	PKS 0745+241	0.4092	QSO	1.15
J0854+2006	OJ 287	0.306	BL Lac	4.67
J0958+6533	S4 0954+65	0.367	BL Lac	1.34
J1104+3812	Mrk 421	0.0308	BL Lac	0.33
J1217+3007	ON 325	0.13	BL Lac	0.36
J1230+1223	M 87	0.0044	Galaxy	2.51
J1653+3945	Mrk 501	0.0337	BL Lac	0.87
J1719+1745	OT 129	0.137	BL Lac	0.58
J1806+6949	3C 371	0.051	BL Lac	1.37
J1927+7358	4C +73.18	0.302	QSO	3.71
J2022+6136	OW 637	0.227	Galaxy	2.26
J2143+1743	OX 169	0.2107	QSO	1.09
J2202+4216	BL Lac	0.0686	BL Lac	4.52
J2203+3145	4C +31.63	0.2947	QSO	2.6


B1228+126 J1230+123 3c274 △ 1.4–1.1mm SMA ⊕ 870μm SMA
2002.0 2003.0 2004.0 2005.0 2006.0 2007.0 2008.0 2009.0 2010.0 2011.0 2012.0 2013.0 2014.0 2015.0 2016.0 2017.0 2018.0 2019.0
NOTE: Use for planning purposes ONLY! See SMA policy for details.
Database Flux (Jy)
0
1
2
54000
56000
58000
MJD


B0851+202 J0854+201 oj287 △ 1.4−1.1mm SMA ⊕ 870μm SMA
2002.0 2003.0 2004.0 2005.0 2006.0 2007.0 2008.0 2009.0 2010.0 2011.0 2012.0 2013.0 2014.0 2015.0 2016.0 2017.0 2018.0 2019.0
NOTE: Use for planning purposes ONLY! See SMA policy for details.
Database Flux (Jy)
0
2
4
6
8
54000
56000
58000
MJD

Future instruments

Development of 1.5 THz Cartridge-type Multi-pixel Receiver Based on HEB Mixers

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Abstract— **A design of 2 × 2 NbN-based hot-electron-bolometer (HEB) mixer array receiver cartridge has been demonstrated here by using multiple local oscillator (LO) beams. In our design, the 1.5 THz LO beam is split into four uniform sub-beams with a spacing of 18 mm by using a power distributor, then arrives at a four-pixel silicon lens with twin slot antenna (TSA) through a large-area beam splitter. An additional four-pixel HDPE lens is located at 120 mm in front of the silicon lens to increase the size of beam waist for fitting to the aperture parameter of sub-reflector of GLT. Some cryogenic tests of cartridge have been carried out. In this article, we report the design, assembly, thermal analysis, and some testing results of cartridge.**

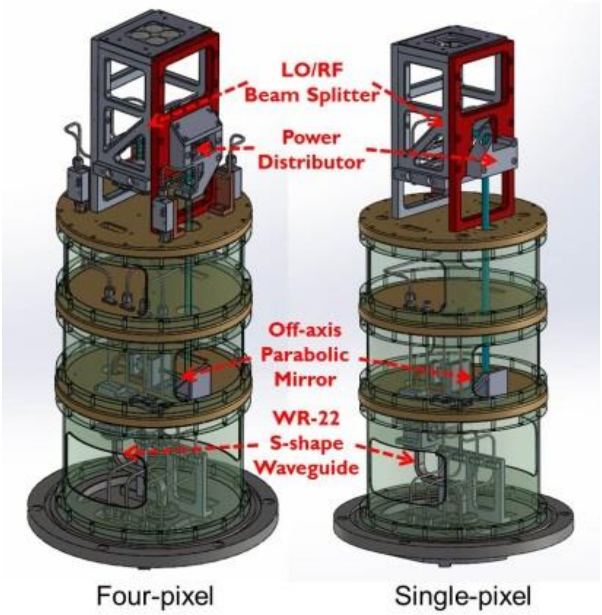

Fig. 1 The schematic diagram of the single-pixel and four-pixel cartridge design.

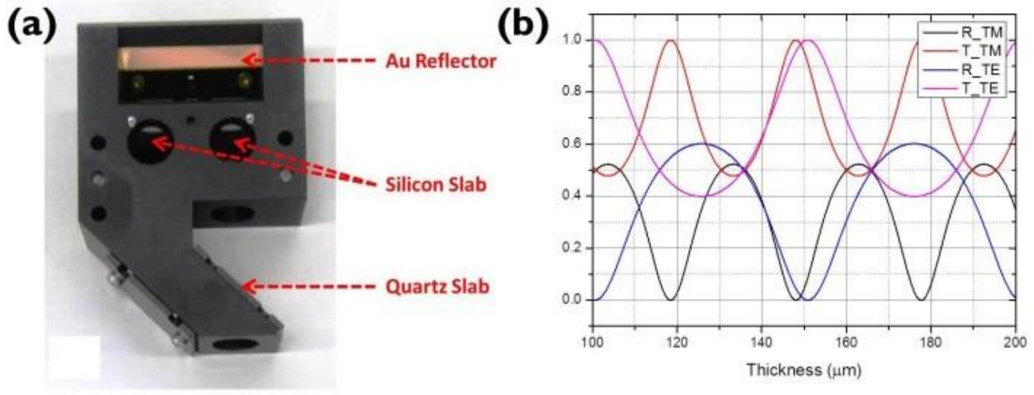

Fig. 2 (a) The four-pixel power distributor module. (b) The calculated transmittance and reflectance of polarizing beam splitters versus thickness.

Progress on the CAmbridge Emission Line Surveyor (CAMELS)

Christopher N. Thomas[1,*], Ray Blundell[2], D. Glowacka[1], David J. Goldie[1], Paul Grimes[2], Eloy de Lera Acedo[1], Scott Paine[2], Stafford Withington[1] and Lingzhen Zeng[2]
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[2]*Smithsonian Astrophysical Observatory, 60 Garden Street, Cambridge, MA 02138, USA*

Abstract— **The aim of CAmbridge Emission Line Surveyor (CAMELS) is to provide an operational demonstration of an Integrated Filter Bank Spectrometer (IFBS) for mm-wave astronomy. The prototype will observe from 103-114.7 GHz, providing of order 500 channels with a spectral resolution of 3000. In this paper we discuss the design of the instrument and ongoing work towards its realisation. Fabrication of a first set of devices to verify the key technologies has recently been completed. We will present results from a measurement campaign to characterise resonator performance and describe our planned optical tests.**

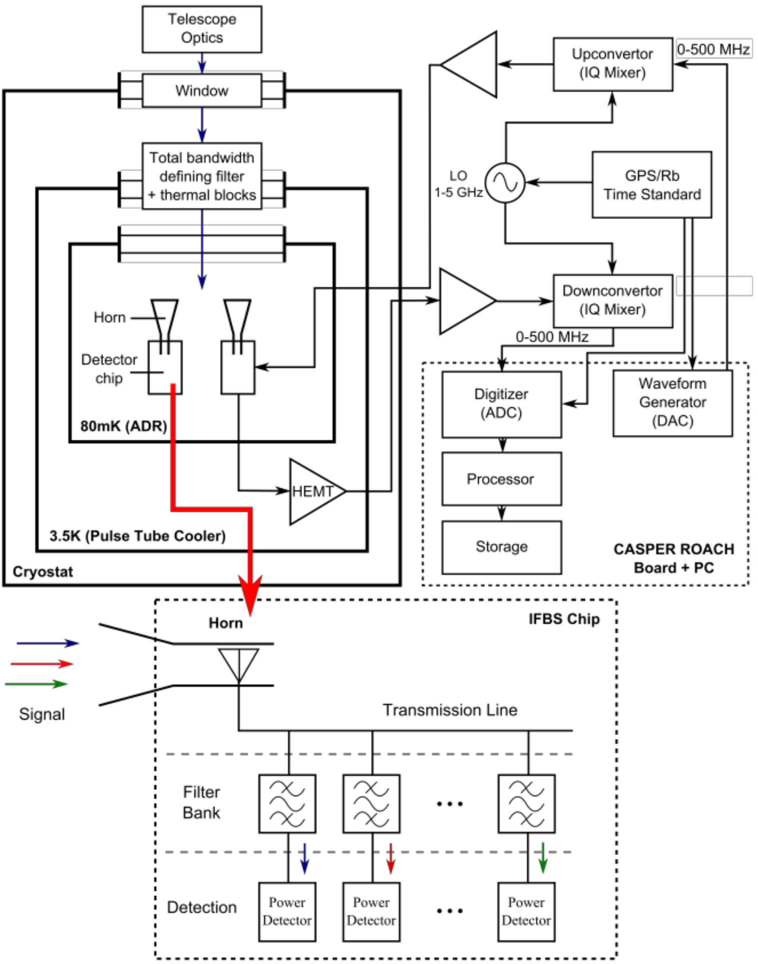

Fig. 1 System block diagram of the CAMELS instrument.

III. OPTICAL DESIGN

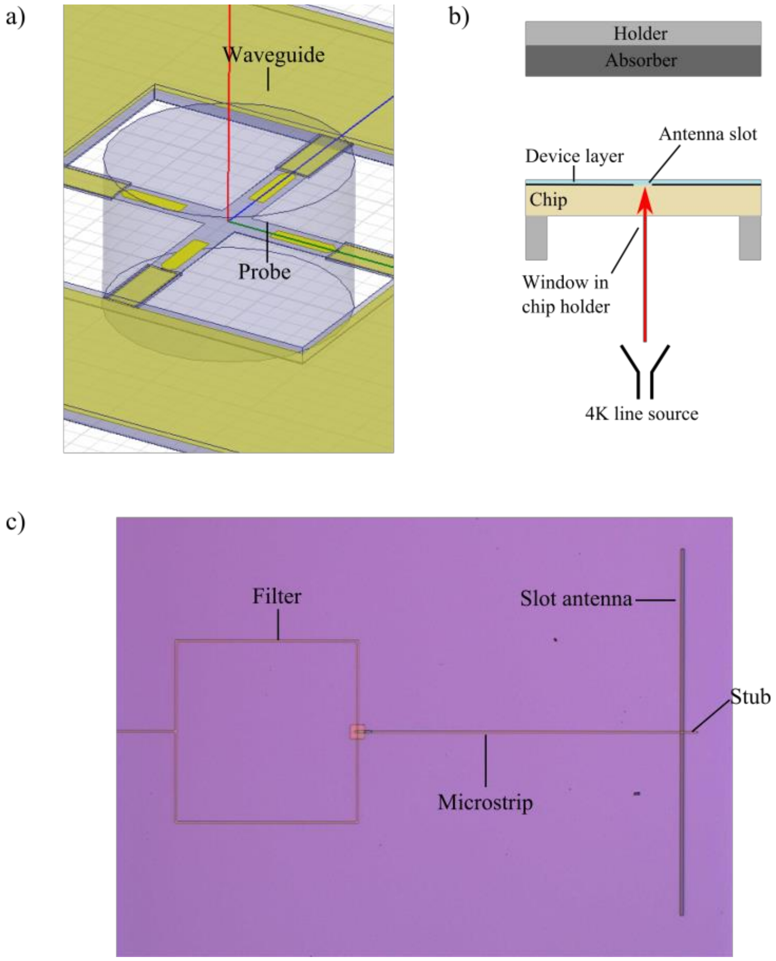

Fig. 2 Details of antennas for CAMELS chips. a) Proposed 4-probe horn coupling. b) Concept for test devices. c) Photo of realised antenna on test device.

Qanaaq high school students visit, 5 May 2019

Mahalo!