HINOTORI

(Hybrid Installation project in Nobeyama, Triple-band Oriented)

SiO masers around
WX Psc
(Yun et al. 2016)

Hiroshi Imai

Research and Education Assembly Science and Engineering Area,
International Radio Astronomy Collaboration Promotion Office
Kagoshima University

MEXT KAKENHI Category A project (FY2016—2019)

NRO 45 m system upgrade (VLBI, quasi-optics)

- **HINOTORI** ("phoenix" in Japanese)

(Hybrid Installation program in Nobeyama, Triple-band Oriented)

Scientific operation in FY2019

Combined with NAOJ Development Program (P.I. T. Manabe)

KaVA Large Programs on Circumstellar Masers

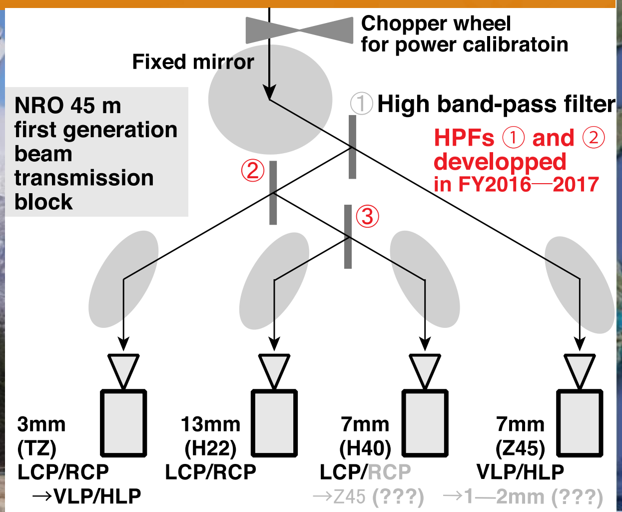
- **ESTEMA** ("family tree" in Spanish)

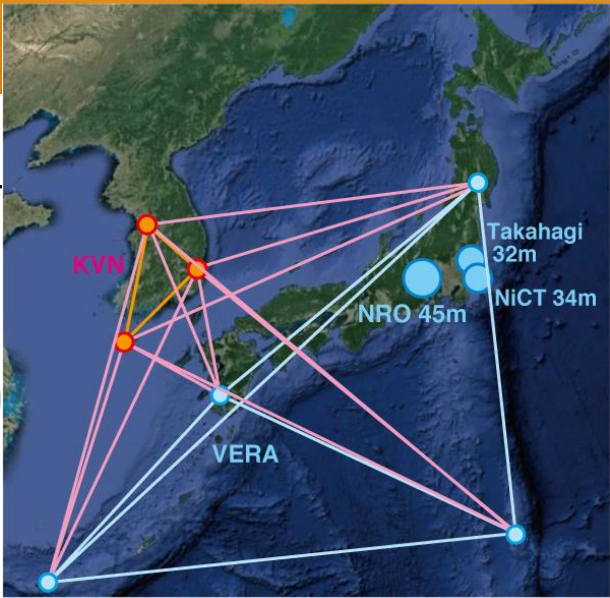
(Expanded Study on Stellar Masers)

Snapshot VLBI images of 80 evolved stars in masers during 2015—2016

- KaVA decadal monitoring observations of stellar masers

Intensive monitoring during 2017—2025(?)





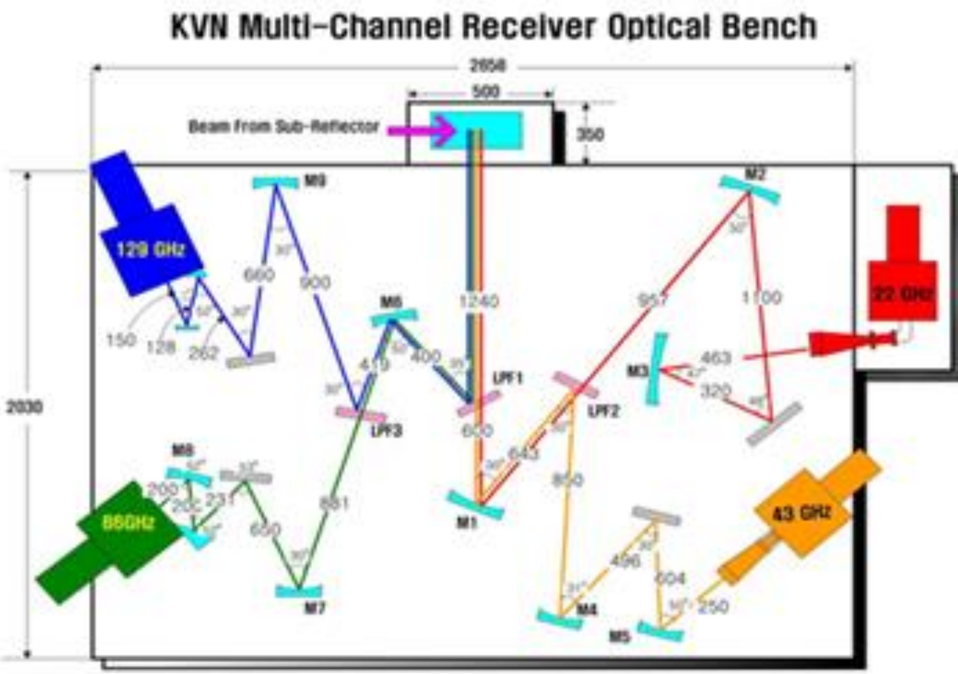
HINOTORI team

- Kagoshima University
  H. Imai※, H. Shinnaga, S. Sawada-Satoh†, A. Nakagawa, K. Mizukubo, T. Handa +α
- Osaka Prefecture University
  H. Ogawa, K. Kimura, T. Manabe, M. Chiba, Y. Nanbu, Y. Hasegawa, +β
- NAOJ Mizusawa VLBI Observatory
  T. Oyama, Y. Kono, N. Sakai, T. Hirota, Y. Tamura, K.M. Shibata, M. Honma
- NAOJ Nobeyama Radio Observatory
  T. Minamidani, M. Saito +γ
- Yamaguchi University
  K. Fujisawa, K. Niinuma, N. Matsumoto +δ
- Ibaraki University
  Y. Yonekura
- NAOJ ALMA/radio
  Y. Asaki, S. Kameno, H. Kobayashi, M. Miyoshi

Headquarters
Quasi-optics
VLBI
Polarization
VLBI data analysis
Geodesy

※Project P.I. †From 2016 October 1

Multiple radio-bands observing system



KVN quasi-optics for multi-band receiving system

- Source-frequency phase-referencing (SFPR) technique with KVN (Dodson et al. 2014; Rioja et al. 2014)
- Band-to-band calibration in ALMA
- Quasi-optics installed in KVN, Yebes (in plan), Tianma (in plan)
- Quasi-optics (K/Q) installed in VERA temporarily (in Mizusawa, Iriki)

Triple-band VLBI (KaVA @22GHz+KVN @22/43/86GHz)

Red supergiant
S Per
(Asaki et al. in prep.)

Band-to-band transfer of phase calibration solutions

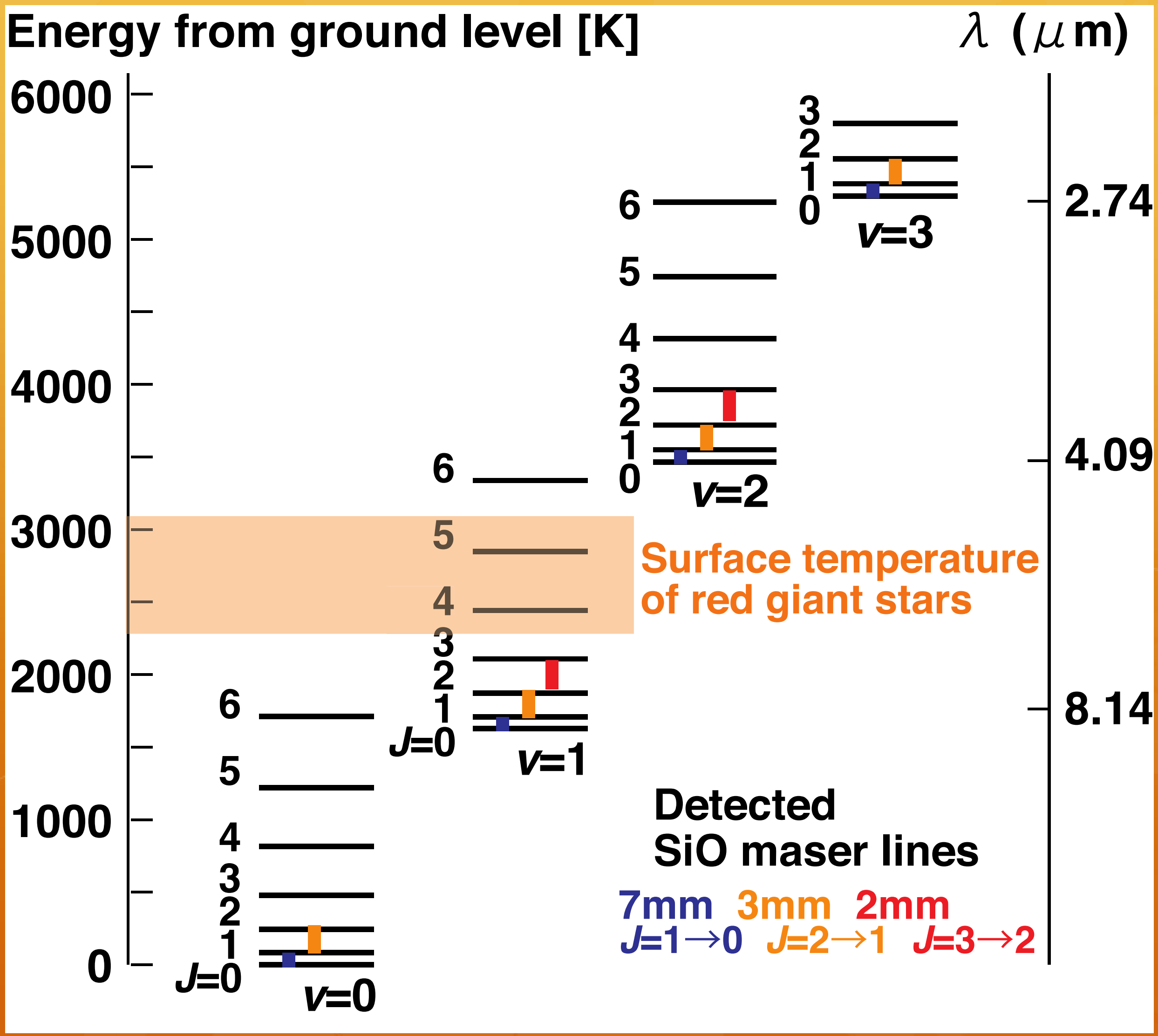
Confidential

Continuous tracing of mass loss flows of dying stars

Episodic mass ejection on decade scale?

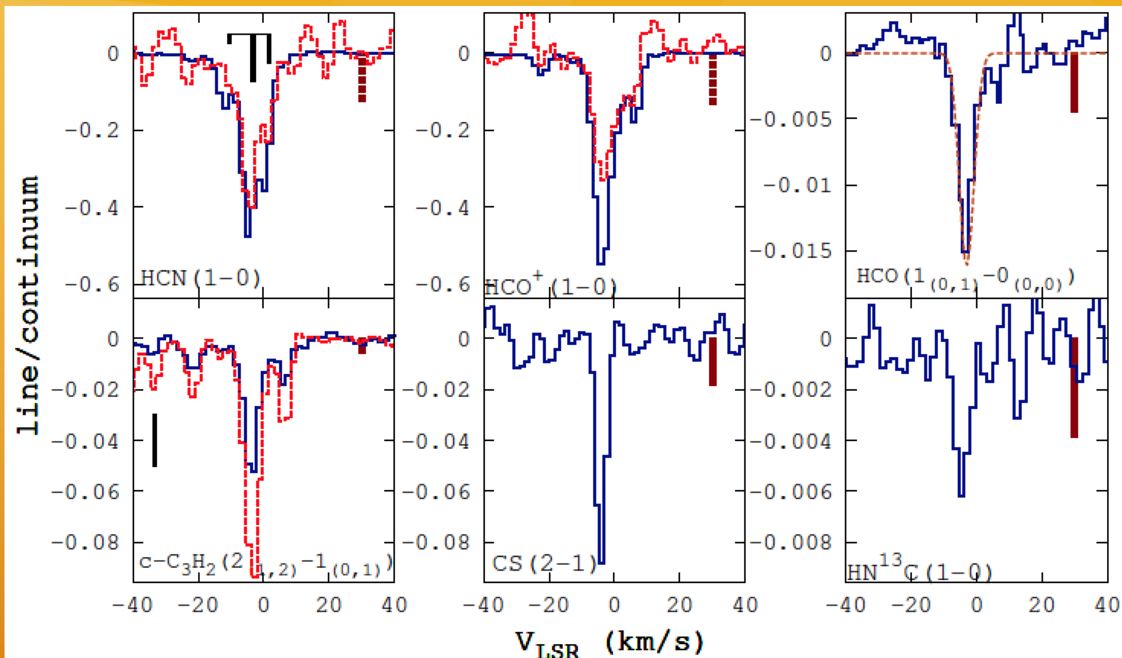
H_2O (22GHz) SiO J=1→0 v=1 (43GHz) SiO J=1→0 v=2 (43GHz)
SiO J=2→1 (86GHz, one KVN baseline)

Groves of maser lines (22, 43, 86 GHz bands)



- H_2O masers (22.2 GHz)
- SiO masers
  v=(0,) 1,2,3 *J*=1→0 (42.5—43.5 GHz)
  v=1, (2,) 3 *J*=2→1 (85.0—86.3 GHz)
- NH_3 masers (22.6—23.7 GHz)
- CH_3OH masers (23.1, 23.4, 44.1, 84.5, 88.9 GHz)
- HCN masers (88.6 GHz)

Molecular and atomic absorptions towards AGNs



^{12}C-bared line ^{13}C-beard line (x30)

Toward J1717-337 with ALMA (Ando et al. 2015)

c.f. HCN absorption towards NGC1052 (Sawada-Satoh et al. in prep.)

- Many lines
  - HCO^+ (89.2 GHz)
  - HCN (88.6 GHz)
  - SiO (86.9 GHz)
  - CH_3OH (84.5 GHz)
  - C_2H (87.3 GHz)
  - RRLs (Radio recombination lines)
- Tracing 1—10 pc molecular torus around AGNs

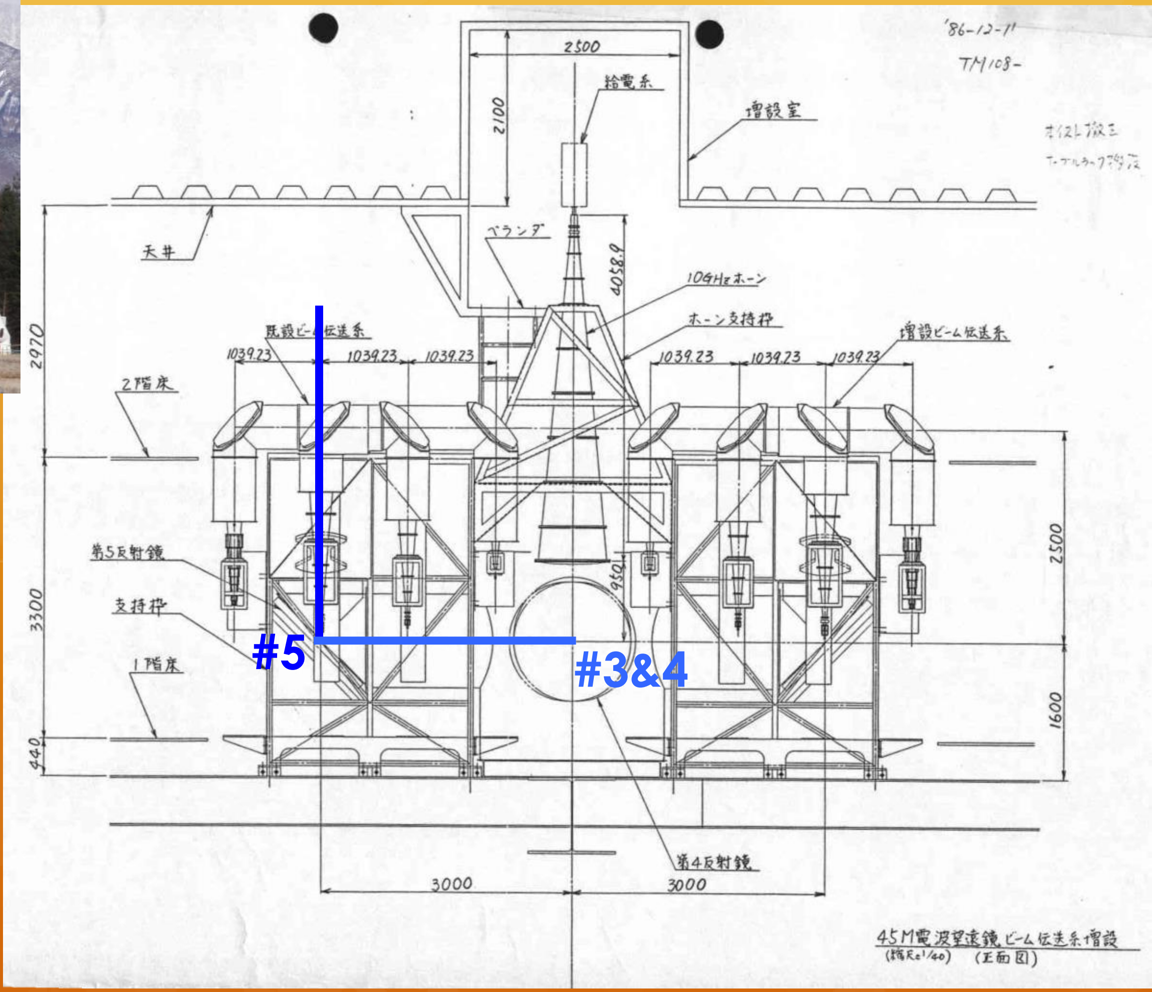
  (c.f. HI on ~100 pc)
  - Detecting high-*V* absorptions

    (*Δv*~1000 km/s → *Δf*~300 MHz)
- Foreground

  Milky Way absorptions
  - Tracing tiny clumps (<100 AU)

  ~1000 km baselines are ideal

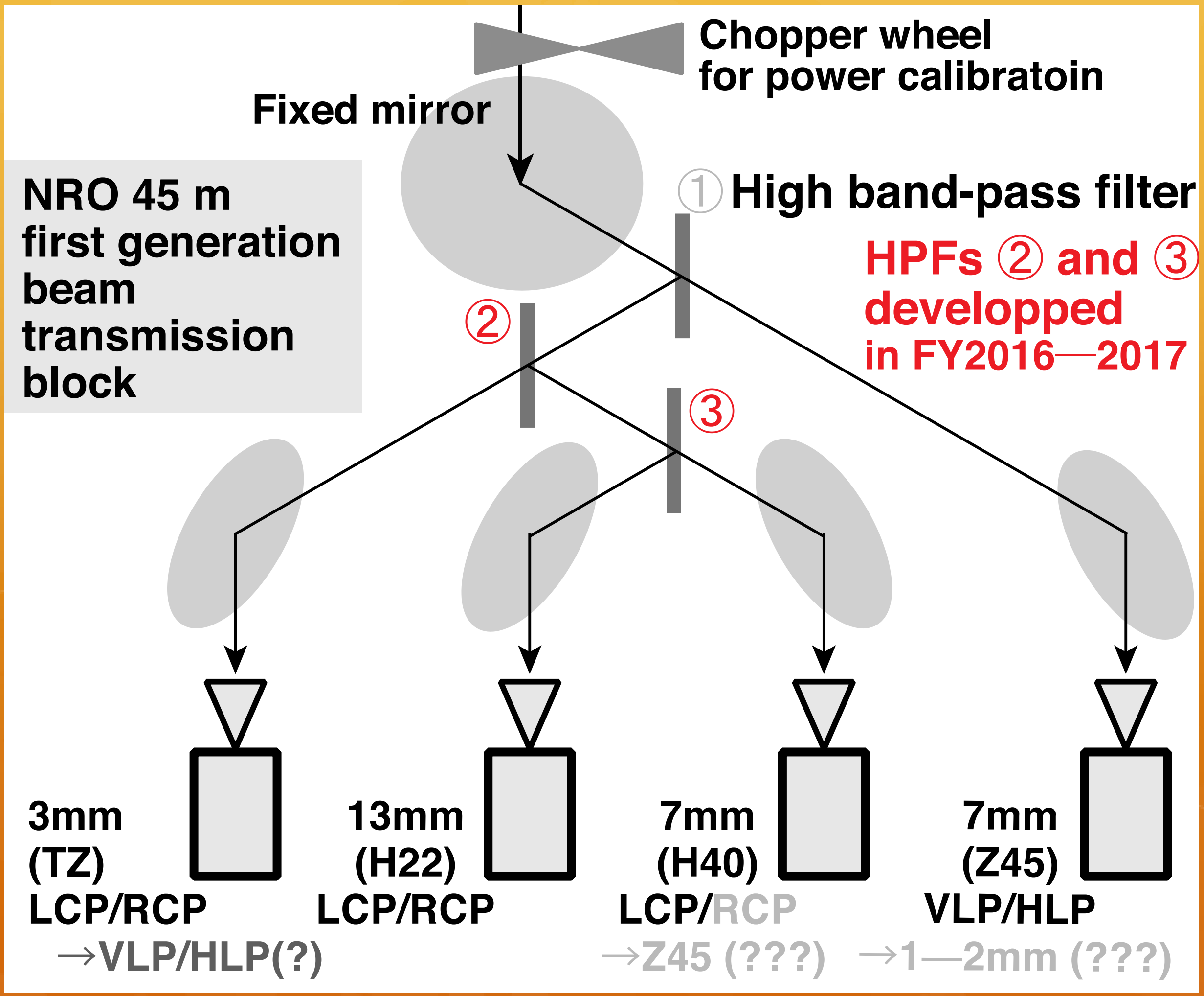
New multi-band quasi-optics in NRO 45 m telescope



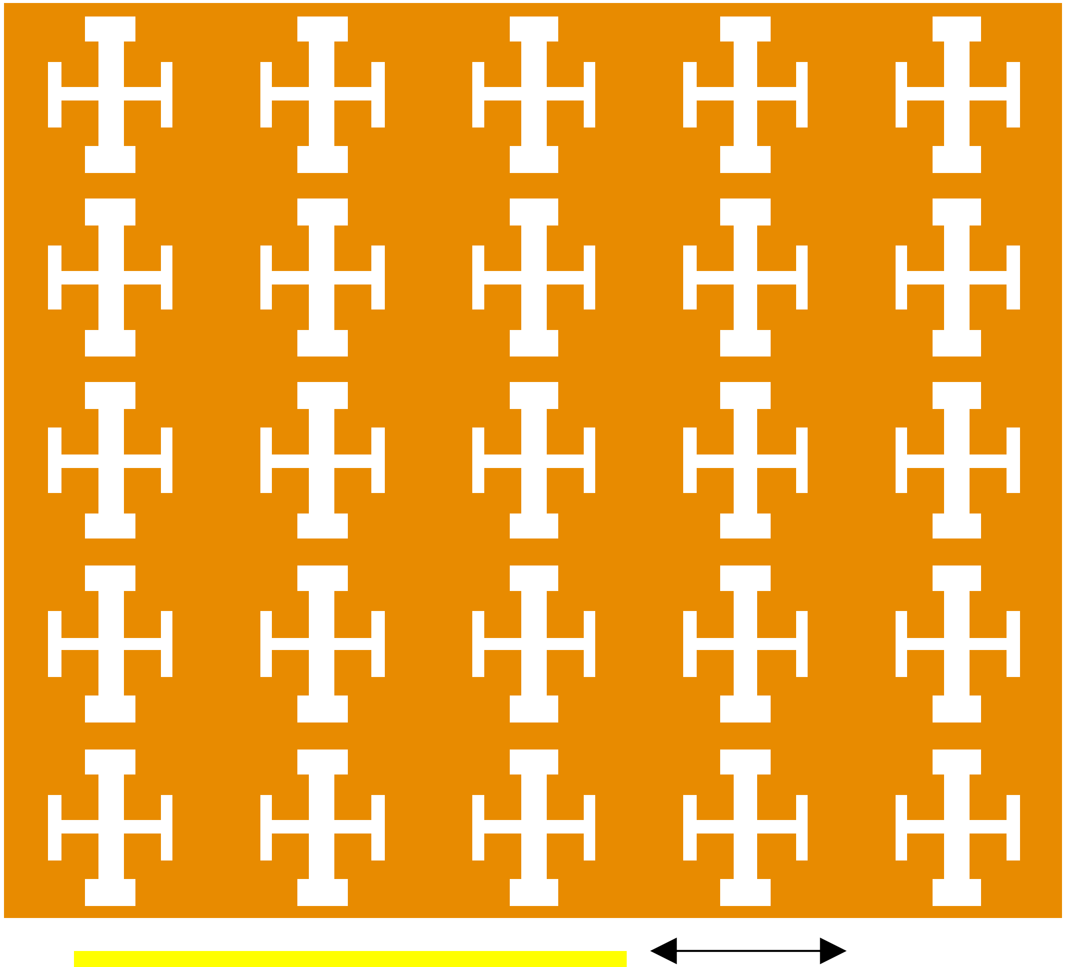
- Multiple beam transfer system with reflection mirrors (#1—5) from the Nasmyth focus
- VLBI with one of two beam blocks

Malti-band quasi optics @NRO 45m telescope

- Replacing mirrors into **band selection filters**
- Using existing receivers
  - H22@22GHz
  - H40@43GHz
- Moving/reusing decommissioned receiver (TZ: 84—116 GHz)
- 1—2mm band in the future(?)



Frequency selection filter in JCSA (Jerusalem Cross Slot Array)



1.784 mm for 86GHz
3.567 mm for 43 GHz
8.963 mm for 22 GHz

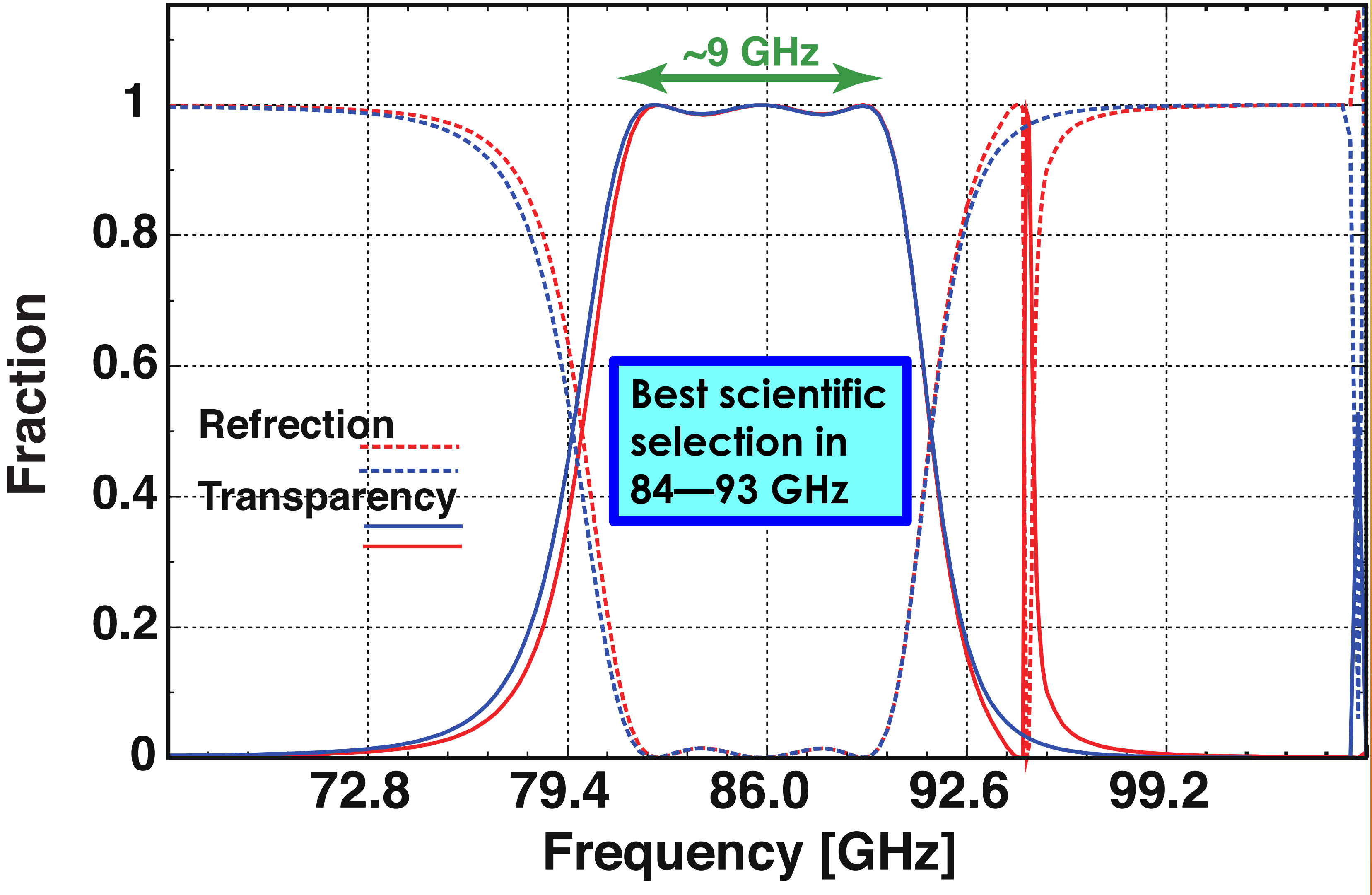
First experiment in NRO
(Irimajiri & Takano 1991)

Difficulty in structure strength for the large filter (φ~60 cm) and band width expansion

Multilayer filter in etching pattern printing (Manabe & Ogawa)

Manabe et al. 2014

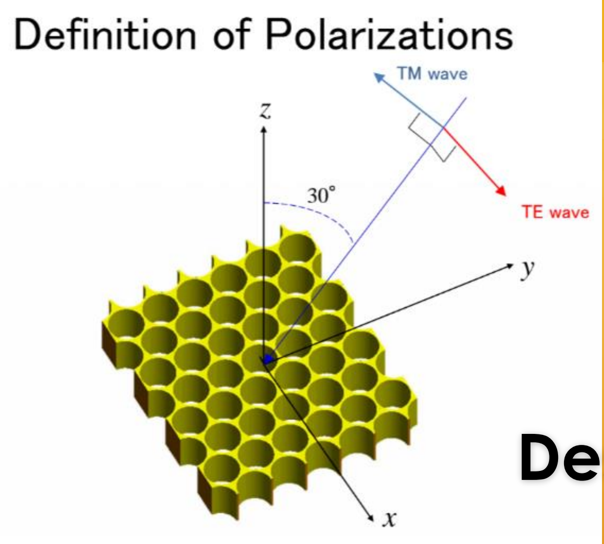
Simulated characteristics of JCSA
(Band pass in 82.7—89.3 GHz)



For vertical/horizontal linear polarization

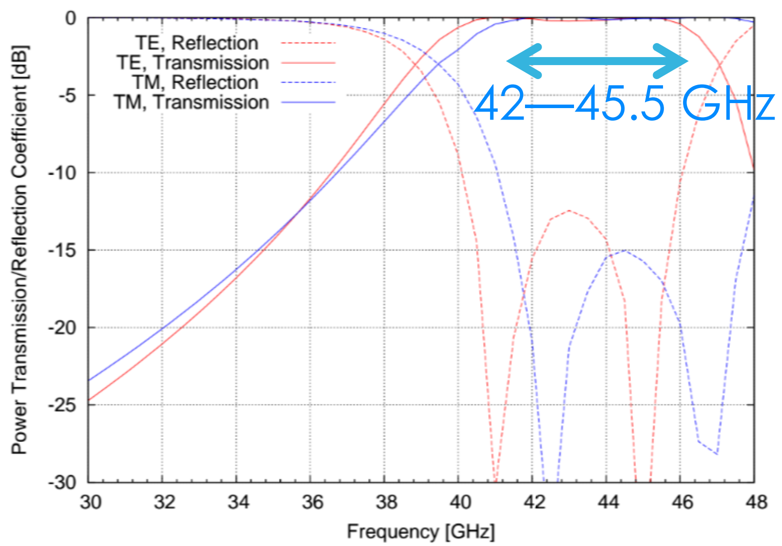
Manabe & Ogawa 2015

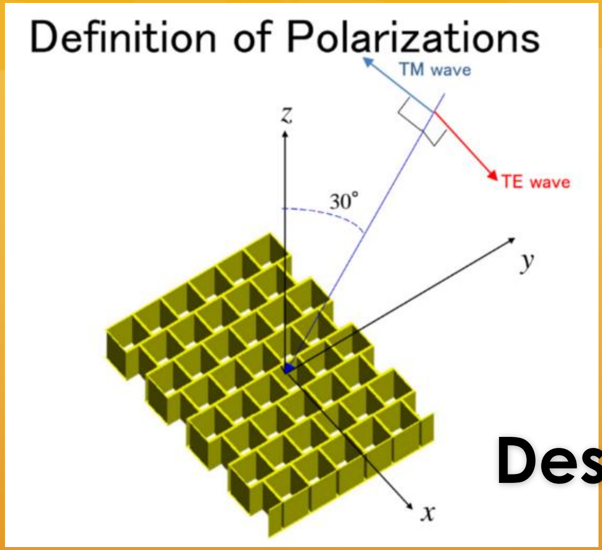
Other filter designs (Q-band, ongoing) 1/2



Design 1

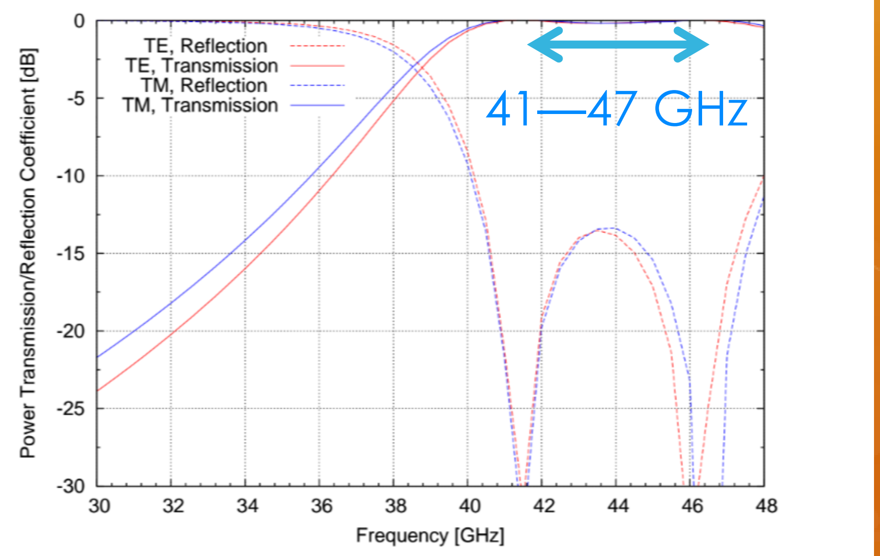
Aluminum (2.65x10^{-8} Ωm)



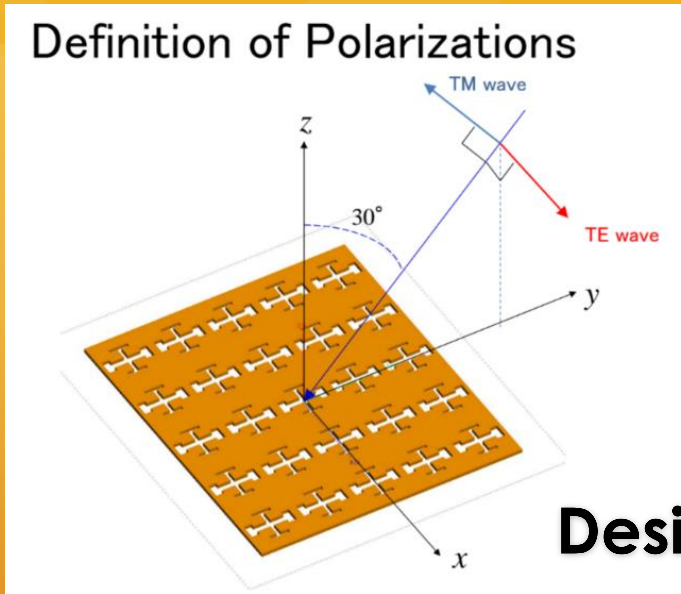


Design 2

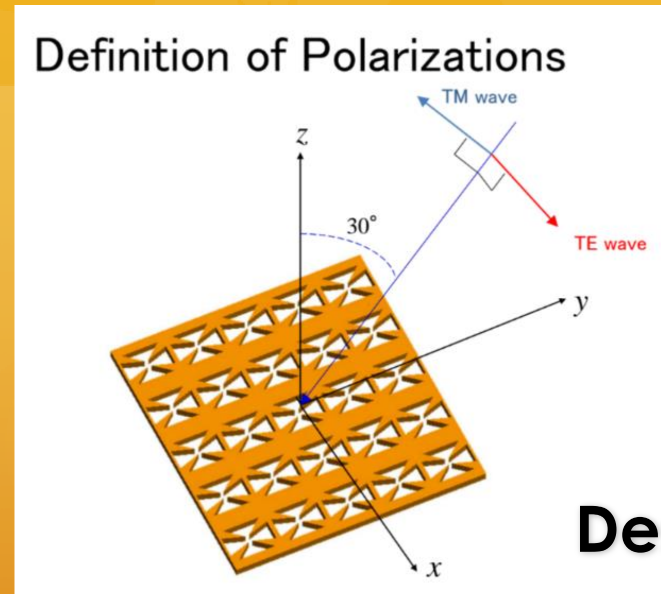
Aluminum (2.65x10^{-8} Ωm)



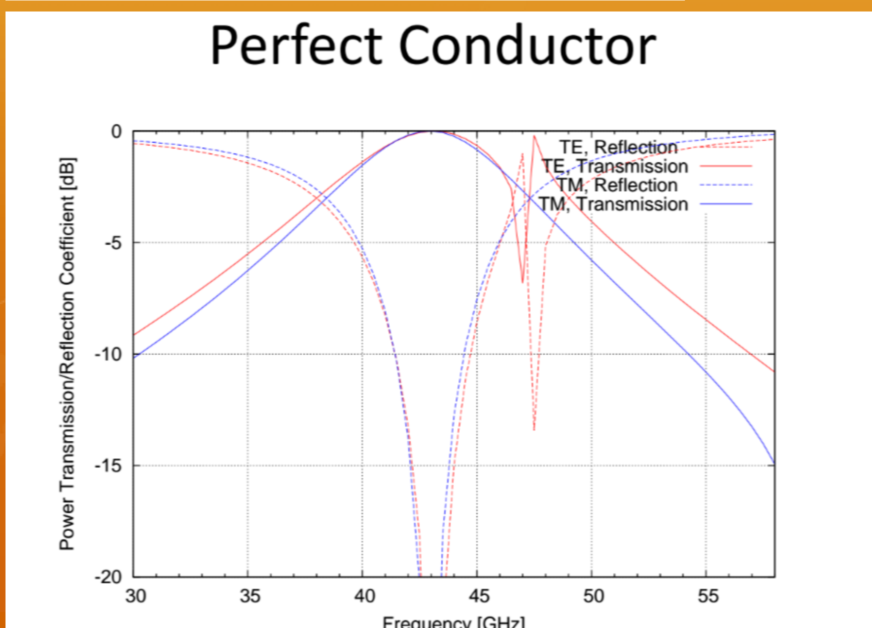
Other filter designs (Q-band, ongoing) 2/2

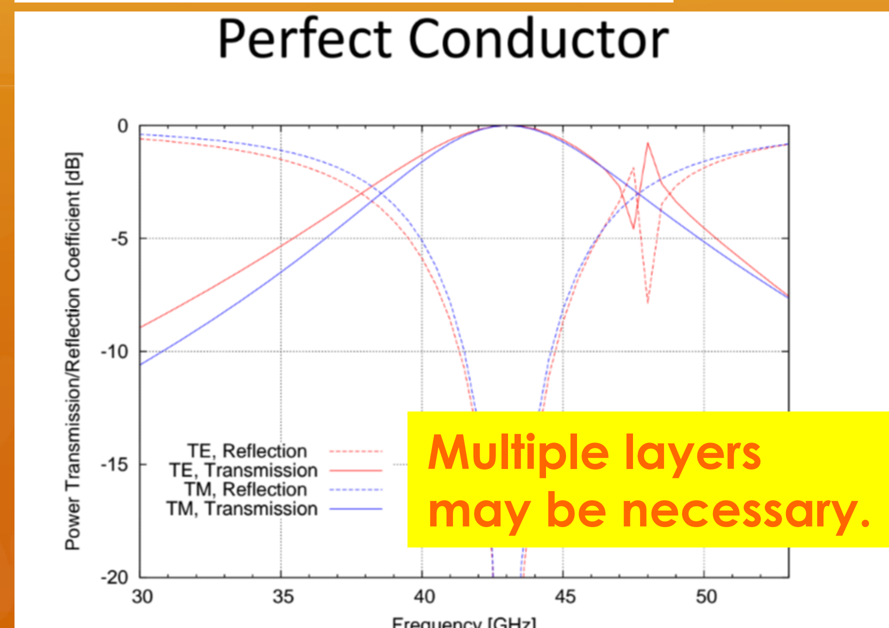


Design 3



Design 4





Multiple layers may be necessary.

Challenging issues

- Physically strong frames and filters
- Sufficiently wide filter band width

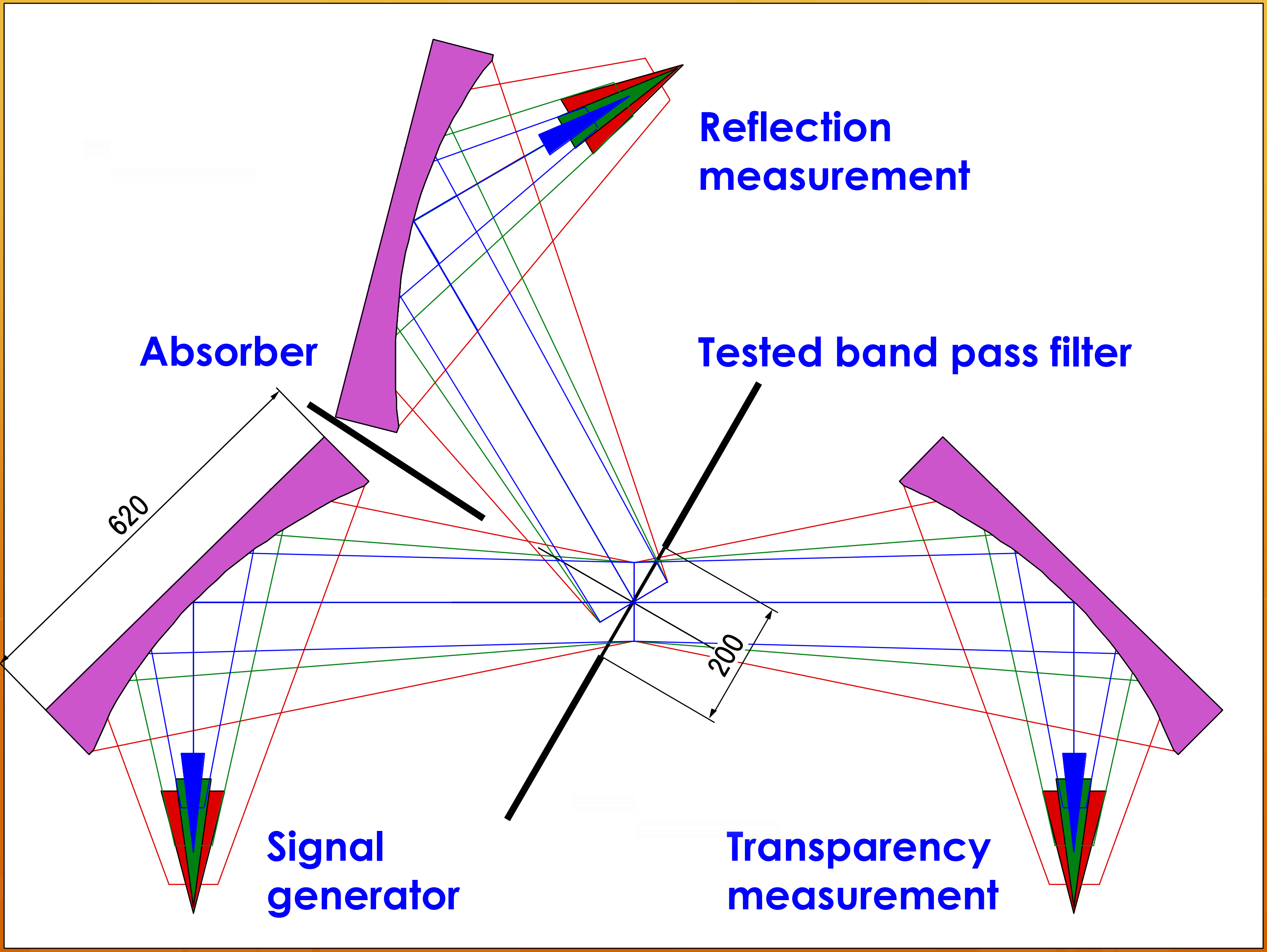
Mirror/filter setting
(frame thickness: ~1cm)

Frames, a reflection ,and a JCSA filter (Irimajiri & Takano 1995) in the NRO 45m telescope

Deformed by 1 mm
↓□
Stronger frame for operation as a slit!

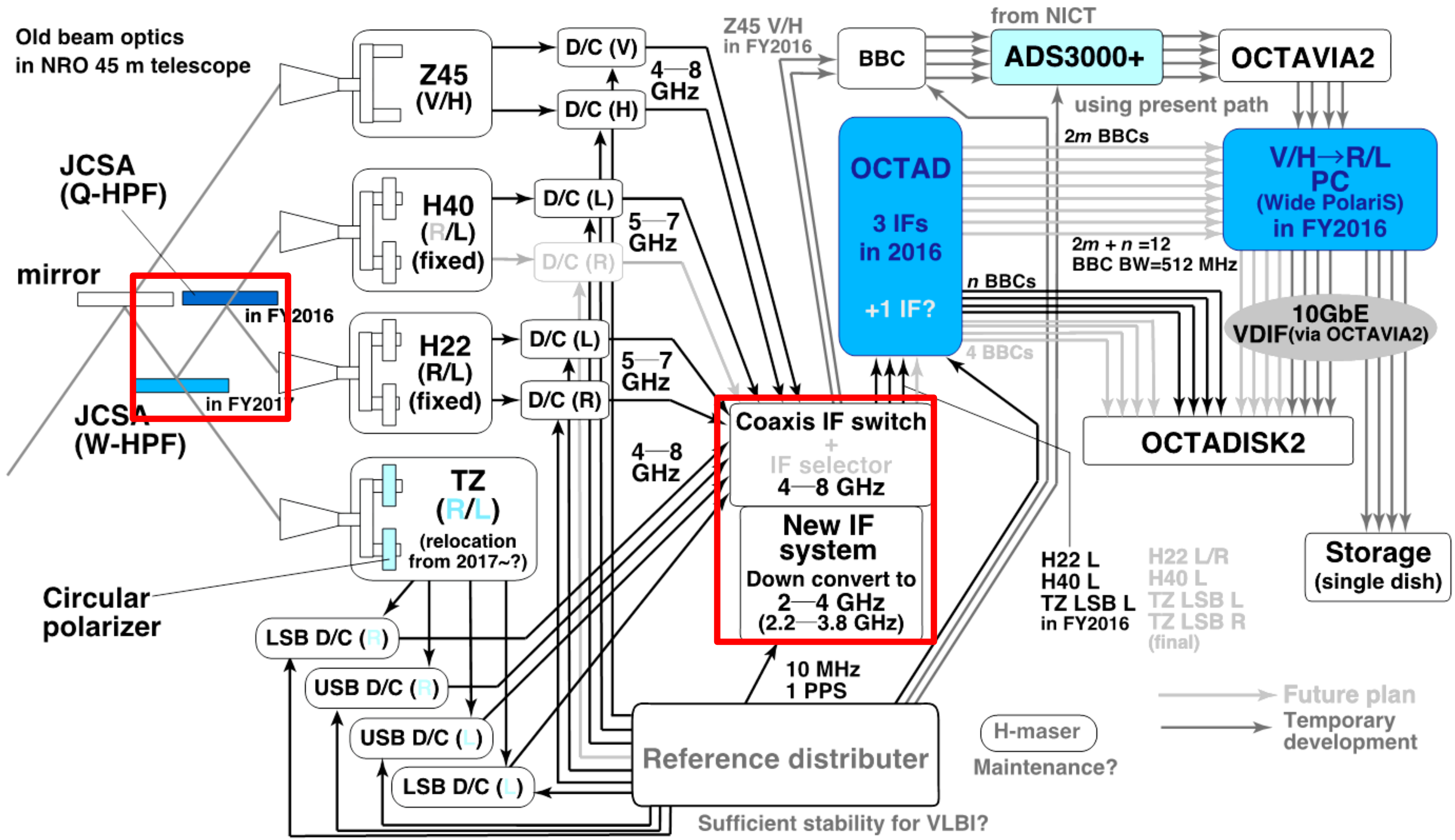
Photo on 2015 November 27

Filter measurement system @Osaka Prefecture University



Design of the new NRO signal transmission system

HINOTORI version on 2016 July 12



Band/polarization selection

		Status in 2016 May	Selection (order of priority) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Note c
H22	LCP	Available	○					○	○	○		○	○	○	○	○		
	RCP	Available	○					○				○	○			○		
H40	LCP	Available		○				○	○		○	○		○	○			
	RCP	N/A																a
TZ	VLP	Available					○								○		○	
	HLP	Available					○								○		○	
	LCP	N/A			○				○	○	○	○	○	○				
	RCP	N/A			○					○	○		○	○				
Z45	VLP	Available				○										○	○	h
	HLP	Available				○										○	○	
Note					d	b	e	f	g	d	d						i	

Timeline	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	FY2016														
						FY2017									
										FY2018?				FY2020?	

Note
- a Out of scope in HINOTORI
- b Only Z45 for polarimetric VLBI and single dish (mirror exchange is out of scope in HINOTORI mode)
- c Assuming only 3 IFs at first, and 4 IFs after funded, can be processed in OCTAD
- d Before wide PolariS gets available, with circular polarizers are installed
- e After wide PolariS gets available for VLP/HLP-->LCP/RCP conversion
- f After Q-HPF is set
- g After both Q-/W-HPF are set
- h Z45 will be replaced with H40 after NRO permits it (but it will be in open discussion after FY2019).
- i After two set of wide PolariS are installed, but useless without 6 IFs

512 MHz x 4ch /IF (final)

IF selector should be delivered.

Toward East Asian high sensitivity mm-VLBI

- **FY2016**

New VLBI backend@NRO

- **FY2017**

QO (K/Q-band) commissioning

KaVA/NRO framework

- **FY2018**

QO (K/Q/W-band) commissioning

EAVN fremework

- **FY2019**

Regular operation