ALMAの状況と将来計画

菊池健一（国立天文台）

2016/03/07-08, 第*16*回 ミリ波サブミリ波受信機ワークショップ（於電通大）

ALMA

- Atacama Large Millimeter/submillimeter Array
- 南米チリのアタカマ高地（標高5,000m）に建設した66台のアンテナ群「アタカマ大型ミリ波サブミリ波干渉計」

- 22ヶ国が参加する国際プロジェクト
- 「初期利用観測」を 2011 年に開始
- 2012年以降、300 を超える論文が発表されている (Nature誌11編、Science誌5編を含む)

ALMAの観測周波数帯

Band No.	RF Range, GHz		RX Type	IF Range, GHz		Ratio, RF/IF
1	35-50*	15	SSB	4-12	8	1.9
2	67-90*	23	SSB	4-12	8	2.9
3	84-116	32	2SB	4-8	8	4.0
4	125-163	38	2SB	4-8	8	4.8
5	163-211	48	2SB	4-8	8	6.9
6	211-275	64	2SB	5-10	10	6.4
7	275-373	98	2SB	4-8	8	12
8	385-500	115	2SB	4-8	8	14
9	602-720	118	DSB	4-12	16	7.4
10	787-950	163	DSB	4-12	16	10

ALMAの観測周波数帯

Band No.	RF Range, GHz		RX Type	IF Range, GHz		Ratio, RF/IF
1	35-50*	15	SSB	4-12	8	1.9
2	67-90*	23	SSB	4-12	8	2.9
3	84-116	32	2SB	4-8	8	4.0
4	125-163	38	2SB	4-8	8	4.8
5	163-211	48	2SB	4-8	8	6.9
6	211-275	64	2SB	5-10	10	6.4
7	275-373	98	2SB	4-8	8	12
8	385-500	115	2SB	4-8	8	14
9	602-720	118	DSB	4-12	16	7.4
10	787-950	163	DSB	4-12	16	10

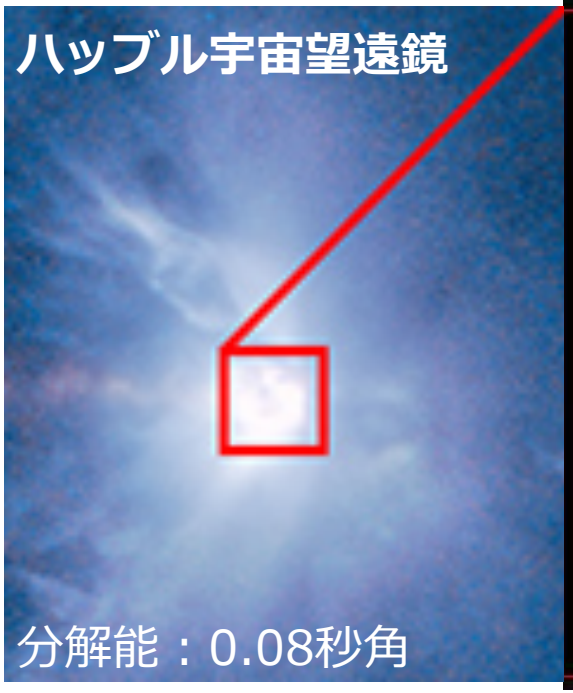
ALMAの観測周波数帯

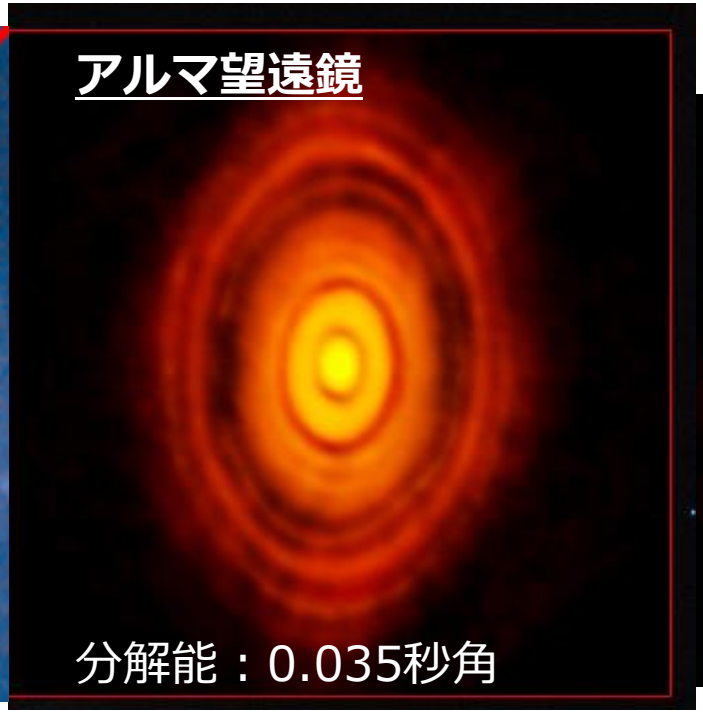
Band No.	RF Range, GHz		RX Type	IF Range, GHz		Ratio, RF/IF
1	35-50*	15	SSB	4-12	8	1.9
2	67-90*	23	SSB	4-12	8	2.9
3	84-116	32	2SB	4-8	8	4.0
4	125-163	38	2SB	4-8	8	4.8
5	163-211	48	2SB	4-8	8	6.9
6	211-275	64	2SB	5-10	10	6.4
7	275-373	98	2SB	4-8	8	12
8	385-500	115	2SB	4-8	8	14
9	602-720	118	DSB	4-12	16	7.4
10	787-950	163	DSB	4-12	16	10

ALMA 共同利用観測

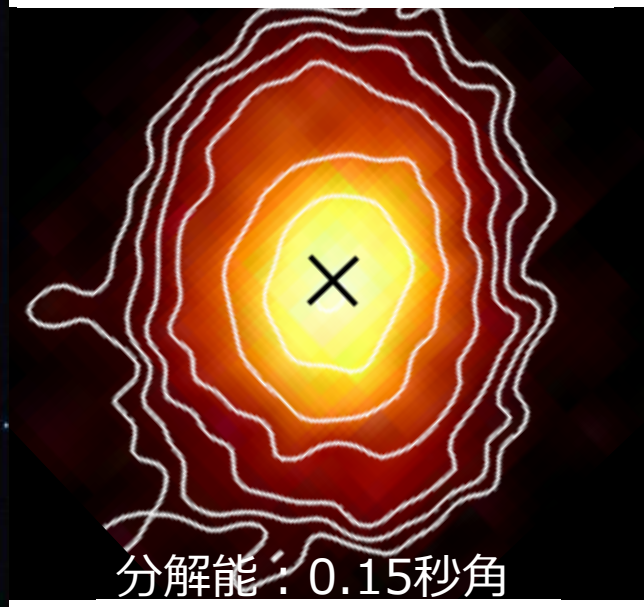
	Cycle 0 2011.10-2012.12	Cycle 1 2013.01-2014.05	Cycle 2 2014.06-2015.09	Cycle 3 2015.10-(2016.09)
Time (12-m time)	500 hours	800 hours	2000 hours	2100 hours (for 12 months)
Bands	100, 230, 345, 690 GHz (Bands 3,6,7,9)		100, 150, 230, 345, 450, 690 GHz (Bands 3,4,6,7,8,9)	100, 150, 230, 345, 450, 690, 900 GHz (Bands 3,4,6,7,8,9,10)
Antennas	> 16 x 12m	• 32 x 12m • 9 x 7m • 2 x 12m TP	• 34 x 12m • 9 x 7m • 2 x 12m TP	• 36 x 12m • 10 x 7m • 2 x 12m TP
Baselines	Max 400 m	Max 1 km	Max 1 km (B8,9) Max 1.5 km (B3,4,6,7)	Max 2 km (B8, 9,10) Max 5 km (B7) Max 10 km (B3, 4, 6)
Other capabilities			• Spectral scan • Polarization	• Spectral scan • Polarization

超高解像度観測
「視力2000」で惑星の誕生現場を撮影



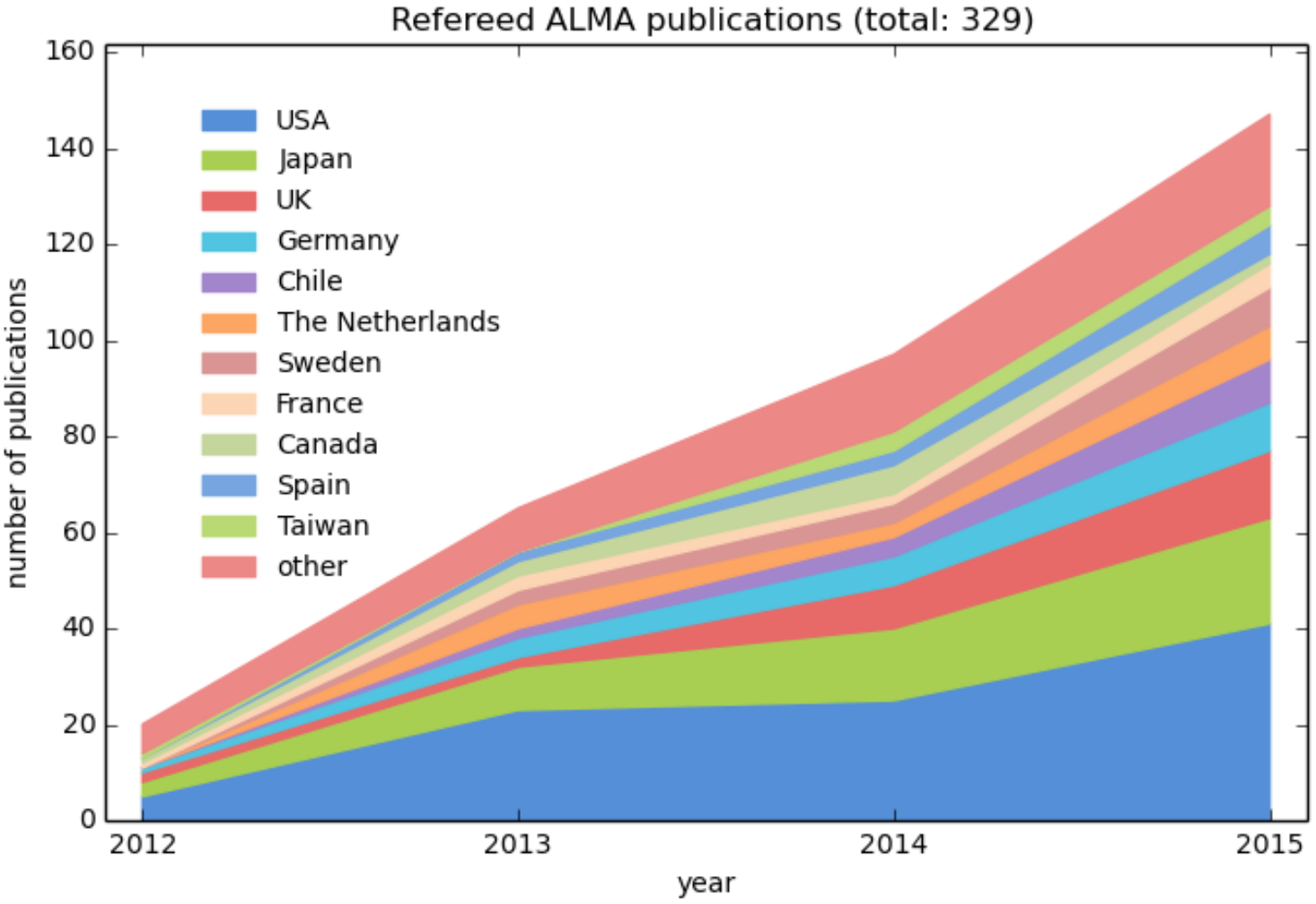


CARMA *(Kwon et al. 2011)*

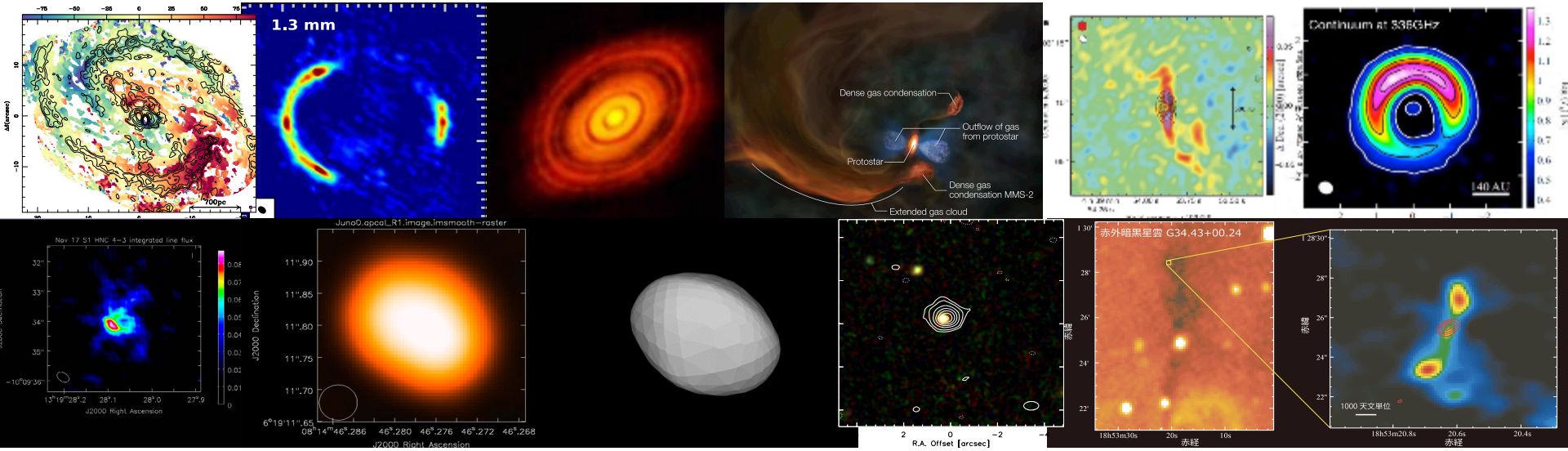


- 星雲の奥深くに潜む惑星誕生現場を明瞭に撮影。惑星ができている証拠である円盤内の何本もの溝を、世界で初めて撮影に成功。
- ハッブル宇宙望遠鏡やCARMAなど、既存の最高性能望遠鏡の画像を大きく凌駕する観測成果。

ALMA 論文数の推移(各年の論文数)



Concept of ALMA Development



ALMA is already producing 300+ papers.

ALMA's lifetime is 30+ years (we still have 25+ years to go)

What will be the important next addition/upgrade to ALMA?

ALMA Future Development Studies and Projects

Concept of ALMA Development

Motivated by science – e.g.

1. a complete new addition to the array,
2. extension of existing capabilities (e.g. higher sensitivity, wider bandwidth, improved image quality, better dynamic range)
3. improvements to existing systems (in hard- or software).

- Near term (~ 5 yr) EA studies and development
  - Band 1 (led by ASIAA (Taiwan))
  - Terahertz studies
  - ALMA Calibration Source
- Longer term (~ 10 yr) EA studies and development
  - Multi-beam receiver (+ spectrometer)
  - Ultra-wideband receiver

Priorities for EA

- **Studies & Small Projects**
  - ALMA Calibration Source
    - Calibration at bands 3,6,7
  - High Critical Current Density (Jc) SIS Junction Device Development (including THz devices)
  - GPU Spectrometer for TP array (with KASI)
    - Supplements the ACA correlator
- **Projects**
  - Band 1 project (lead: ASIAA, Collaboration: NAOJ, U of Chile, NRAO, HIA)
    - Baseline capability (35-50GHz)
- **ASTE development project (but extendable to ALMA)**
  - Multi-beam receiver (with KASI)

Collaboration with EU/NA

- **Studies & Small Projects**
  - Band 2 (NA), Combining Band 2 and 3 (EU)
    - EA contribution: Optics design
- **Projects**
  - Band 5
    - EA contribution: Front end integration at the OSF

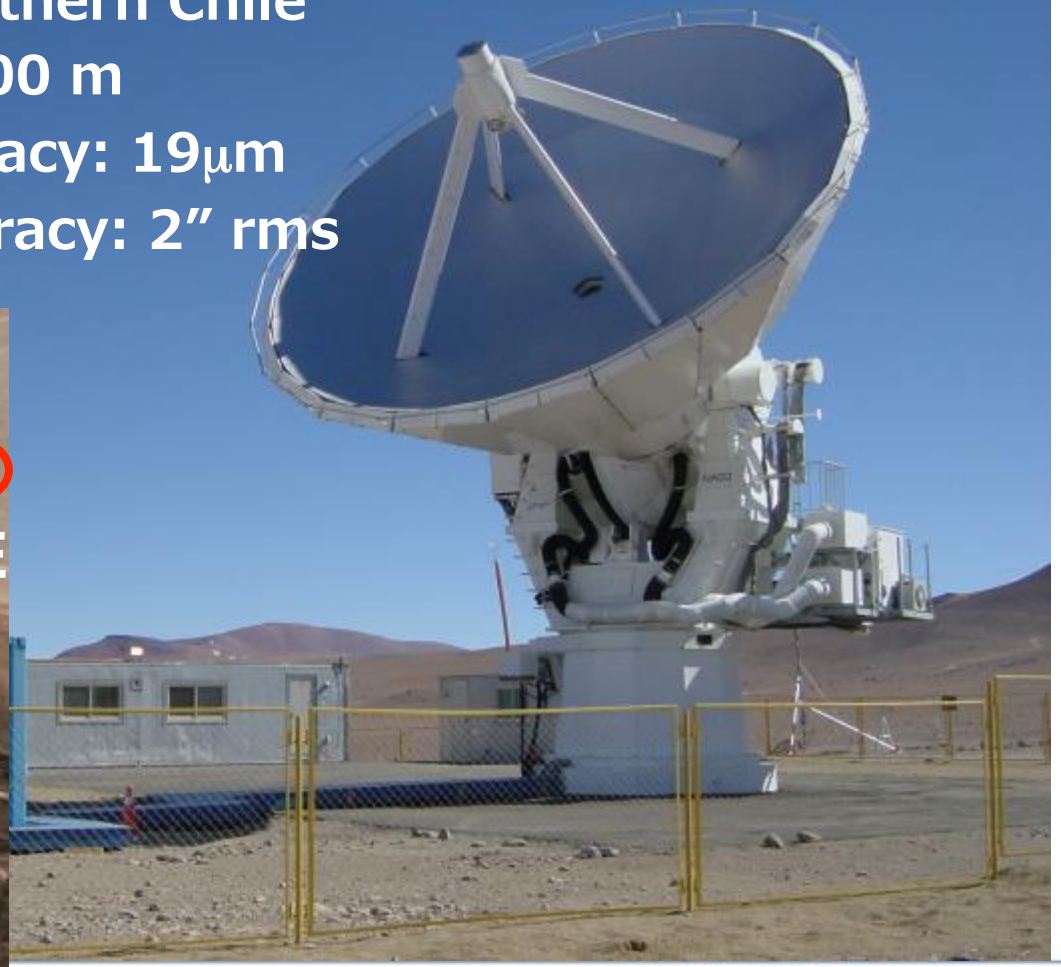
Timeline

	2016	2017	2018	2019
Band 1 (w/ ASIAA)	• CDR/Proj Review • MRR			• AIV
Calibration Source	• 100GHz source testing		• 200-300 GHz source delivery	
TP Spectrometer (w/ KASI)	• Seek board approval • PDR	• CDR	• AIV	
High Jc SIS Device	• research	• research		
Multi-beam for ASTE (w/ KASI)	• PDR/CDR	• Installation		

ASTE 10m Telescope

Atacama Submillimeter Telescope Experiment

Location: Pampa la Bola, Atacama Desert
Northern Chile
Altitude : 4,800 m
Surface accuracy: 19μm
Pointing accuracy: 2” rms



ASTE in the era of ALMA

- Synergy with ALMA
  - **To maximize the science output of ALMA from EA**, operation/instrument plans of ASTE to reflect opinions from the community.
  - **Test bench for new technologies**
    - Multi-beam heterodyne receiver, ALMA Band11, etc

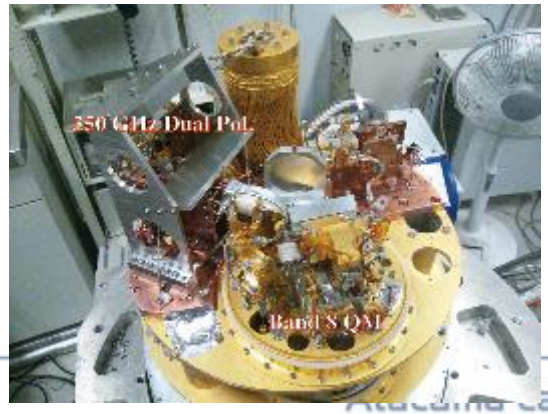
    → possibility of future development projects of ALMA
    - TES bolometer camera + Polarimeter, DESHIMA/ MOSAIC, etc

    → Complementary to the ALMA

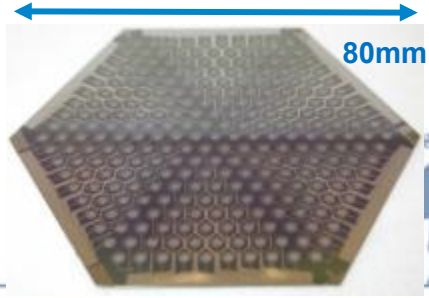
ASTE Current Receivers

Instrument	Type	Freq. [GHz]	HPBW [arcsec]	Npix	Npol
CATS345	Heterodyne	324-372	22	1	1
DASH345	Heterodyne	324-372	22	1	2
Band8	Heterodyne	400-500	17	1	2
THz-RX	Heterodyne	800-900	10	1	1
		1300-1500	7	1	1
TES Camera	Bolometer	270	28	169	-
		350	22	271	-

CATS345

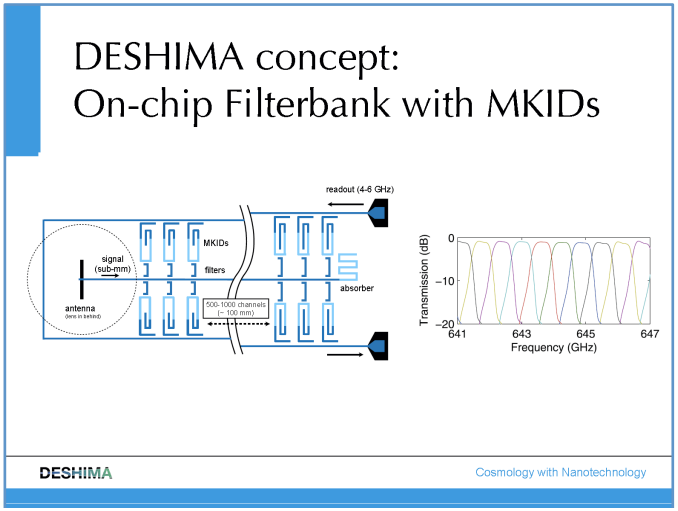


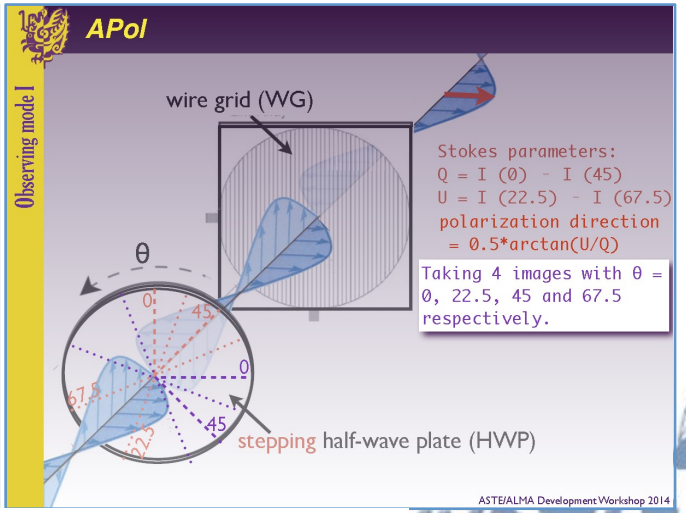
270GHz TES bolometer array



Candidates for ASTE Future Instruments

Instrument	PI	Type	Npix	Freq. [GHz]	Resolution [df/f or Hz]	Note
DESHIMA	A. Endo (TU Delft)	MKIDs	7	326-905	500	
"A-Pol" added on ASTECAM	H. Li (CUHK)	Polari meter	-	240-370 330-710	-	• WG+HWP • Stokes: Q/U
Multi-beam RX + Spectrometer	JW. Lee (KASI)	Heter odyne	32 (Max. 64)	300-500	7.6 kHz (BW 4GHz)	• Single Pol. • 2SB





Reference: ASTE/ALMA Development Workshop 2014
http://alma-intweb.mtk.nao.ac.jp/~diono/meetings/ASTE_ALMA_2014/program.html

本ワークショップでの発表

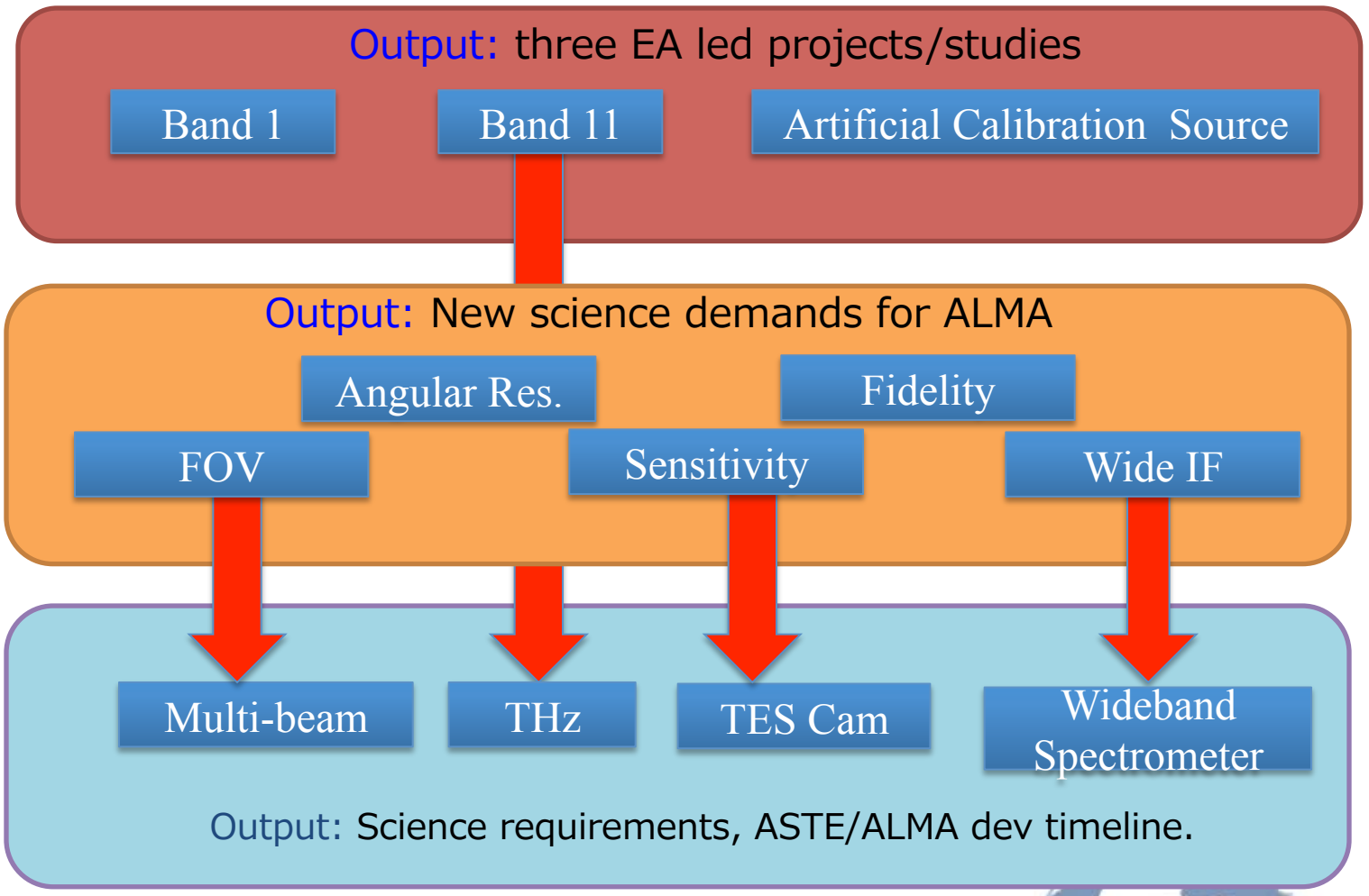
- **伊藤哲也**「ASTE 3カートリッジデュアに対応した DASH345 および Band8 受信機の改修」
- **Alvaro Gonzarez** “Design of ALMA band 1 (35-50 GHz), 2 (67-90 GHz) and 2+3 (67-116 GHz) optics at NAOJ”
- **金子慶子**「40GHz帯コルゲートホーンの試作」
- **池谷瑞基**「SISミキサの広帯域化に向けたNb/Al/AlOx/Al/Nb接合の研究」
- **稲田素子**「ASTE 新３カートリッジデュア評価試験」
- **上月雄人**「275-500GHz SIS ミクサの設計」
- **Matthias Kroug** “High-Jc SIS Mixers for a 300-500 GHz Receiver”
- **小嶋崇文**「冷却プローバーを用いたSIS接合のキャパシタンス測定」
- **高橋宏明**「冷却TRL校正による電波天文用マイクロ波帯低雑音アンプの特性評価手法の確立」
- **Alvaro Gonzarez** “Novel reconfigurable beam measurement system and measurements in the 1.25-1.57 THz band”

East Asian ALMA Development

2011
EA ALMA
Development WS

2013
EA ALMA
Development WS

2014
EA ASTE/ALMA
Development WS



ALMA Science Advisory Committee Recommendation for 2030

1. **Better archive and tools**
2. **Improving Rx with wider bandwidths**
   - Goal to correlate the entire band in one observation
3. **Longer baselines**
   - Real-time correlation (instead of VLBI techniques)
4. **Long-term research on wide-field imaging**
   - Multi-beam receivers

EA ALMA Future Development

1. Near term (~< 5 yr) studies and development
   - Band 1 (led by ASIAA)
   - Terahertz studies
   - ALMA Calibration Source

2. Longer term studies and development
   - Multi-beam receiver (+ spectrometer)
   - Ultra-wideband receiver