高速通信回線を用いた超高感度電波干渉計

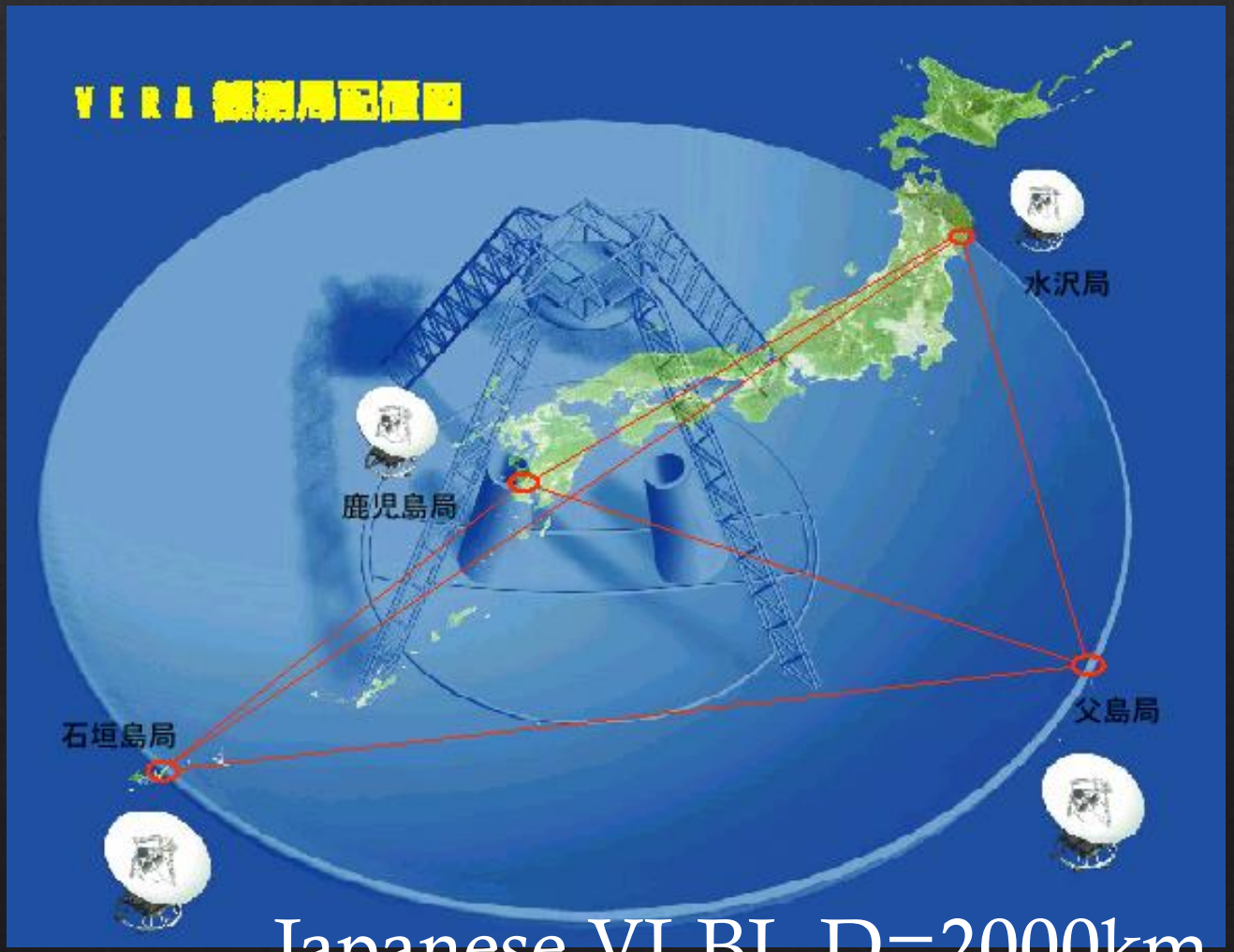
国立天文台　河野裕介

OCTAVEグループ

(JAXA, NICT, GSI, 山口大、岐阜大、北大、茨城大)

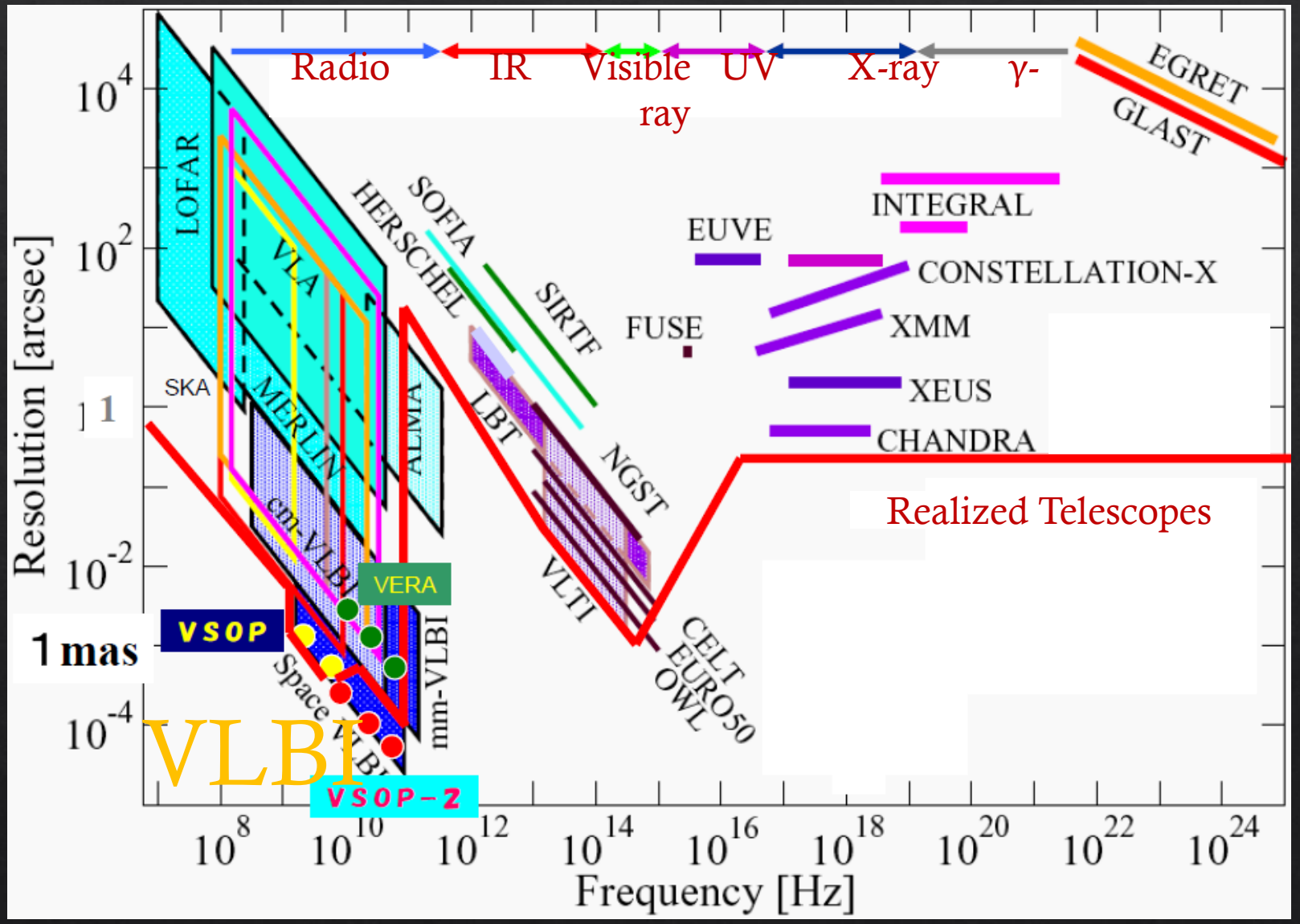
SKA-EWG

VLBI (Very Long Baseline Interferometry)



Japanese VLBI, D=2000km

Resolution of telescopes

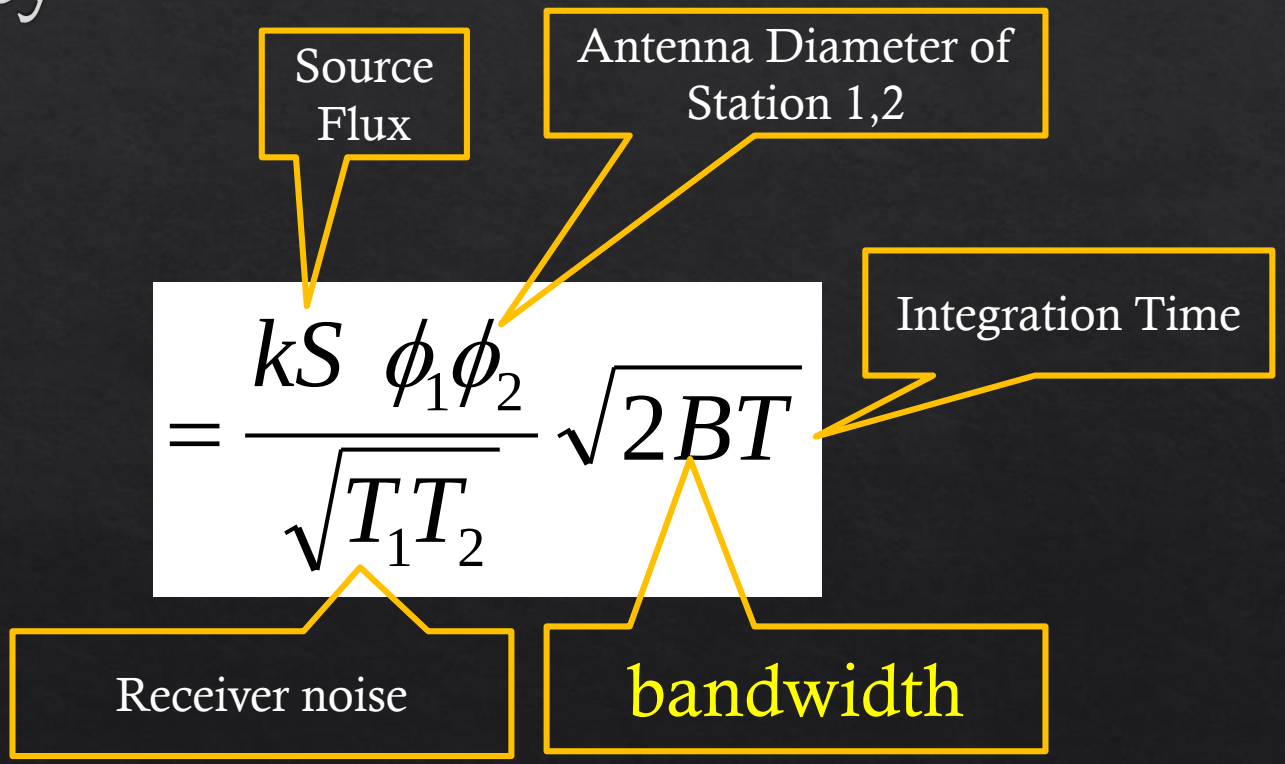


High Resolution

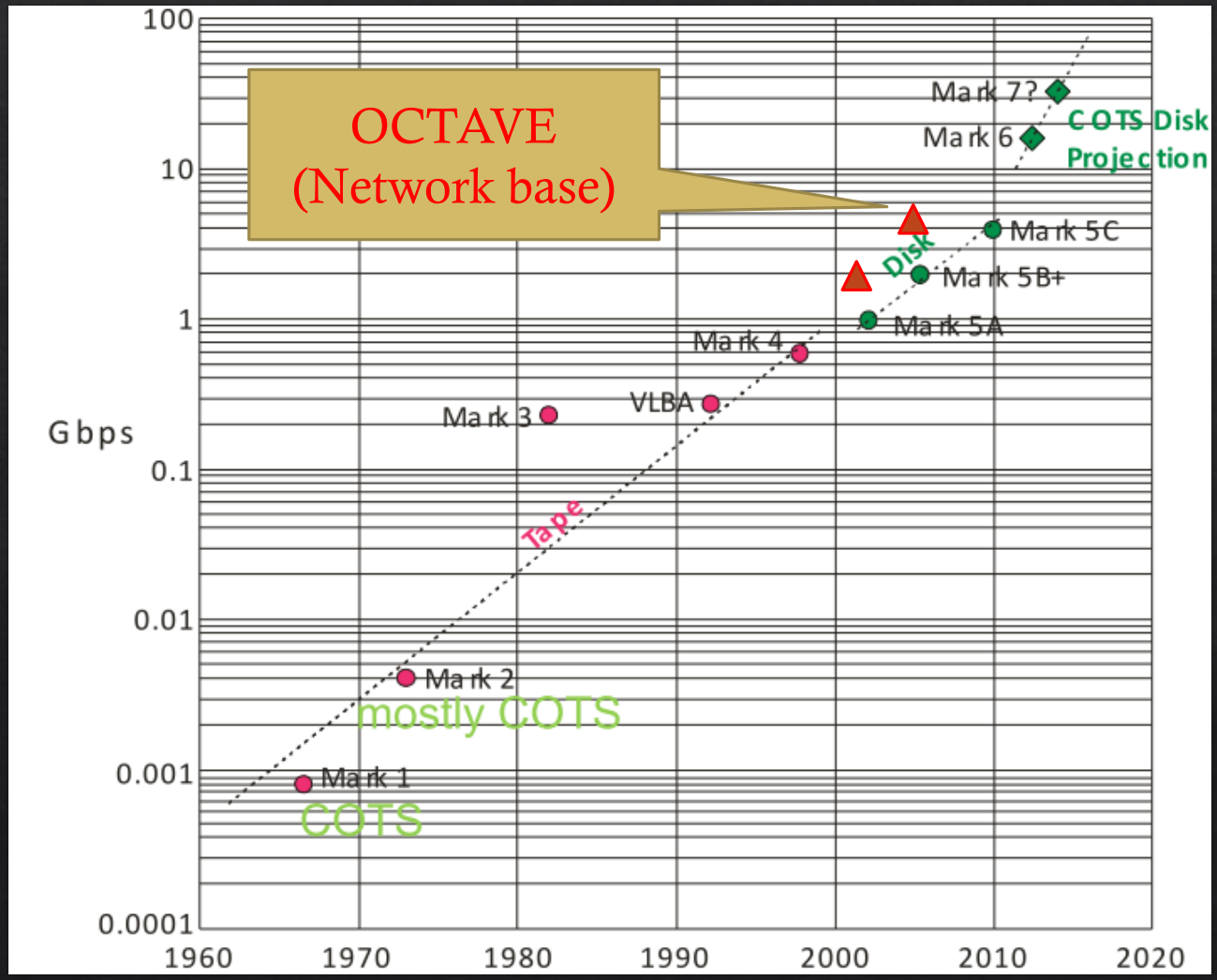
Lobanov, A.P. 2003, SKA Memo 38

Key Specification of Telescopes

- Sensitivity



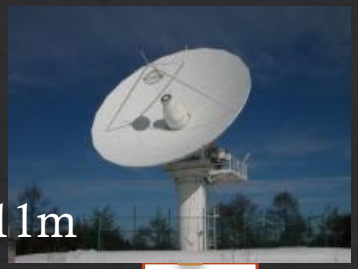
Recoding rate capability vs time



Whitney 2011

OCTAVE : Optically Connected Array for VLBI Exploration

- SINET4
- JGN-X
- Local Access line



Tomakomai11m

H.U

Yamaguchi 32m

Y.U

Wideband
10GbE Network

Kashima34m

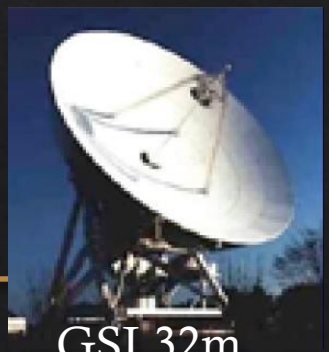
NAOJ
Correlation
Center

Otemachi

NIFS

Gifu11m

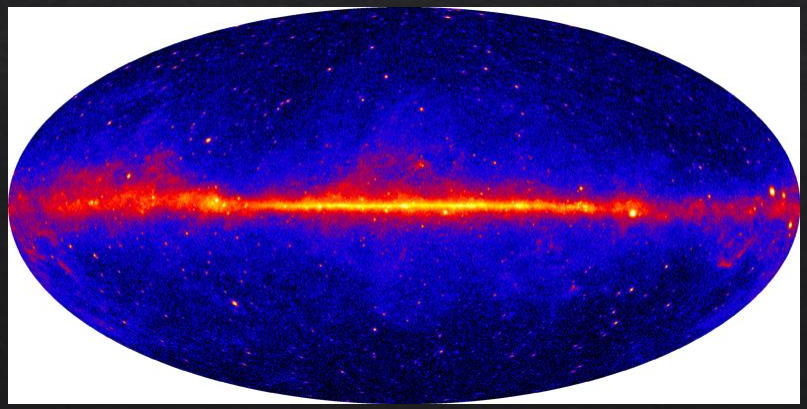
KEK



GSI 32m

VLBI Observation of *Fermi*/LAT Un-associated Gamma-ray Sources

- Identify the un-identified γ-ray sources using "high sensitivity" VLBI
  - search for new γ-ray emitting VLBI sources



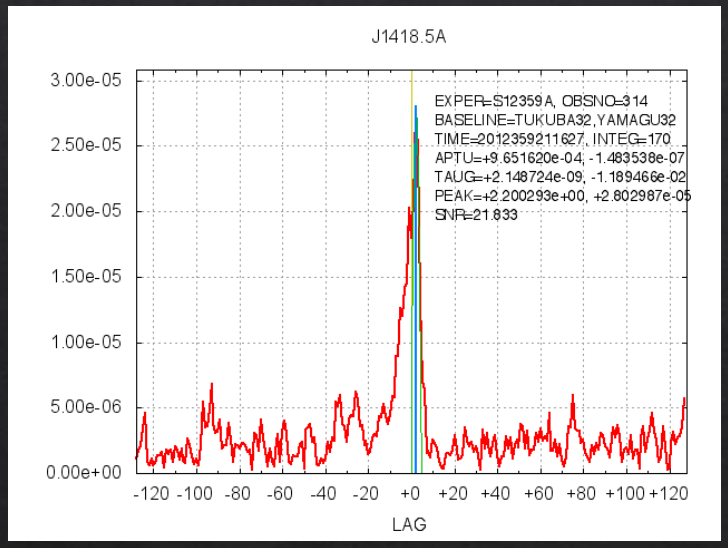
Fermi/LAT 3-years all sky map, Fermi Webpage

Niinuma+2013

VLBI observation for Fermi-FoVs

- Obs. Status:
  - Date: 2012 Dec 1, 2, 3, 8, 24, total of 70-hrs
  - 1-baseline: Yamaguchi – Tsukuba (~800 km)
  - Freq. (ΔB): 8.4 (0.512) GHz
  - Maximum angular resolution: 9 mili-arcsec
  - T_int: 3 min (for every sources)
  - S_{ν_min}: ~ 2 mJy (T_{B_min} > 3 x 10^5) : observations
    (~ 0.8 mJy (T_{B_min} ~ 1.4 x 10^5) : calculation)
- Target:
  - We conducted observations for 150 un-IDs
    (= 845 sources which are 70% of all our targets)
    * all δ >= 0 deg sources, and several δ < 0 deg sources

Detection of new VLBI sources



new VLBI source within Fermi-FoV

- Total of 27 new VLBI sources
  - 17 detections
  - 10 marginal detections
- All VLBI sources were found one by one for each un-IDs
  - These VLBI sources are
    - possible counterpart to each unIDs?
    - γ-ray emitting blazars?
  - Further multi-ν VLBI obs. will be planed to know morphology and radio spectra

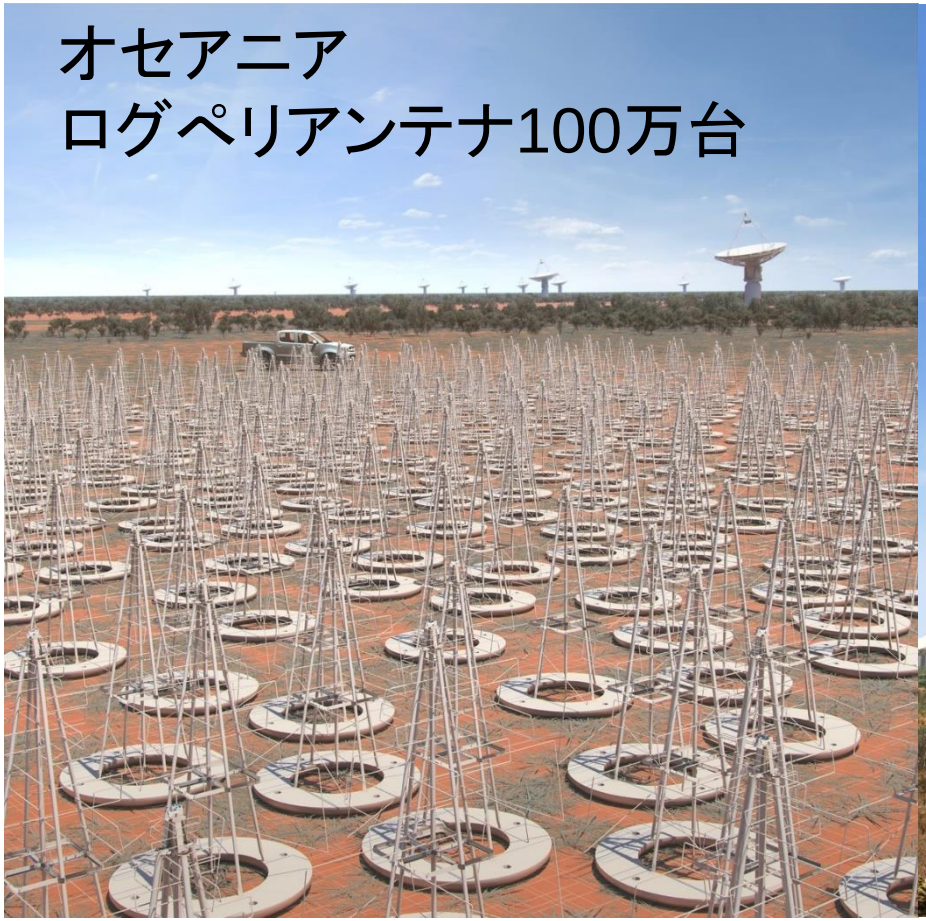
Niinuma+2013 won YSA2013

将来計画
SKA
Square Kilometer Array

SKA-JP-EWG

SKA-JP
Square Kilometre Array
Japanese Consortium

SKA



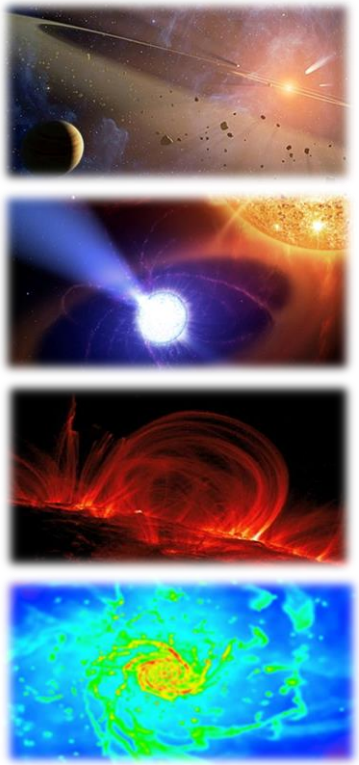
https://www.skatelescope.org/multimedia/image/

SKA-JP
Square Kilometre Array Japanese Consortium

2. SKA計画のサイエンス

SKA1&2ヘッドラインサイエンス

	SKA1	SKA2
The Cradle of Life & Astrobiology MID	Proto-planetary disks; imaging inside the snow/ice line (@ < 100pc), Searches for amino acids.	Proto-planetary disks; sub-AU imaging (@ < 150 pc), Studies of amino acids.
	Targeted SETI: airport radar 10^4 nearby stars.	Ultra-sensitive SETI: airport radar 10^5 nearby star, TV ~10 stars.
Strong-field Tests of Gravity with Pulsars and Black Holes MID(LOW)	1st detection of nHz-stochastic gravitational wave background.	Gravitational wave astronomy of discrete sources: constraining galaxy evolution, cosmological GWs and cosmic strings.
	Discover and use NS-NS and PSR-BH binaries to provide the best tests of gravity theories and General Relativity.	Find all ~40,000 visible pulsars in the Galaxy, use the most relativistic systems to test cosmic censorship and the no-hair theorem.
The Origin and Evolution of Cosmic Magnetism MID(LOW)	The role of magnetism from sub-galactic to Cosmic Web scales, the RM-grid @ 300/deg2.	The origin and amplification of cosmic magnetic fields, the RM-grid @ 5000/deg2.
	Faraday tomography of extended sources, 100pc resolution at 14Mpc, 1 kpc @ z ≈ 0.04.	Faraday tomography of extended sources, 100pc resolution at 50Mpc, 1 kpc @ z ≈ 0.13.
Galaxy Evolution probed by Neutral Hydrogen MID	Gas properties of 10^7 galaxies, <z> ≈ 0.3, evolution to z ≈ 1, BAO complement to Euclid.	Gas properties of 10^9 galaxies, <z> ≈ 1, evolution to z ≈ 5, world-class precision cosmology.
	Detailed interstellar medium of nearby galaxies (3 Mpc) at 50pc resolution, diffuse IGM down to N_H < 10^17 at 1 kpc.	Detailed interstellar medium of nearby galaxies (10 Mpc) at 50pc resolution, diffuse IGM down to N_H < 10^17 at 1 kpc.



資料提供: 赤堀 (SKAO) 2015

SKA-JP
Square Kilometre Array
Japanese Consortium

SKA

- 集光面積 1 km 級の電波干渉計
- 周波数 50 MHz から 25 GHz
- 開口アンテナ 100万台、15m鏡 2500台
- 最大基線長 3000 km
- アフリカ南部とオセアニアに建設
- 第1期 (SKA1)
  - 650 M Euro
  - 建設開始 2017–
- 第2期(SKA2)
  - >1500 M Euro
  - 建設2023-

SKA-JP
Square Kilometre Array
Japanese Consortium

1. SKA計画の概要

SKA計画の組織

SKA関係国

❖SKAメンバー

- 10ヶ国が出資
- 英予算獲得(23M€+120M€)
- フランス・ポルトガル参加準備
- 日米露韓西などが関心

❖SKA機構

- 本部:英Jodrell Bank観測所内

資料提供: 赤堀 (SKAO) 2015

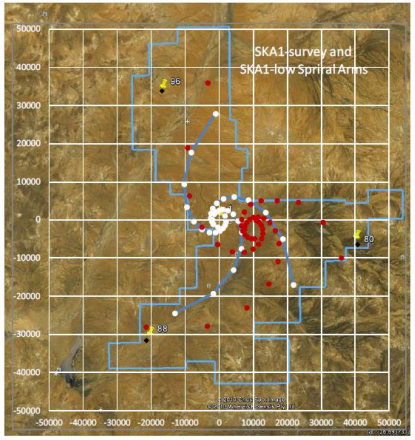
SKA-JP
Square Kilometre Array
Japanese Consortium

ワークパッケージ

Signal and Data Transport

SKA1-Low データレート

- ❖アンテナからコアに集約
  - 10Gbps / コア
  - 合計10Tbps



Data rate into Correlator/ Beamformer	10Gb/s per 35m Station 10Tb/s total	≥10Tb/s total	The performance of the SKA-low depends on the total data rate to the central processing. This can be increased as required.

SKA1-Mid データレート

❖アンテナから

– 50~100Gbps x 200台
(合計17 Tbps)

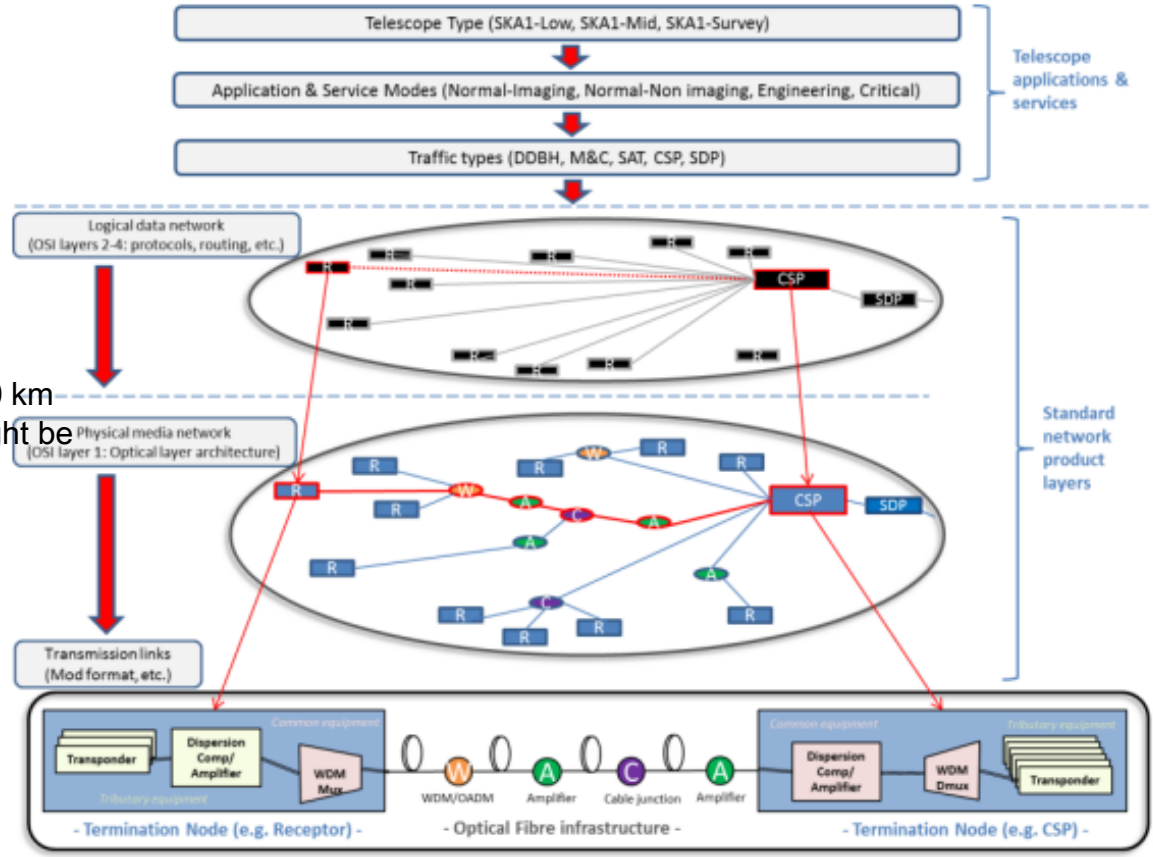
Band #.	Band (GHz)	RF BW (MHz)	IF BW (GHz)	# of Ifs	# of bits	Data Rate Gb/s
1*	0.35 – 1.05	700	1	2	8	48
2*	0.95 – 1.76	808	1	2	8	48
3	1.65 – 3.05	1403	2.5	2	6	90
4	2.8 – 5.18	2380	2.5	2	4	60
5	4.6 – 13.8	9200	2.5	4	3	90

japan.skatelescope.org/ska-location/africa/

SKA-JP
Square Kilometre Array
Japanese Consortium

バックボーン回線

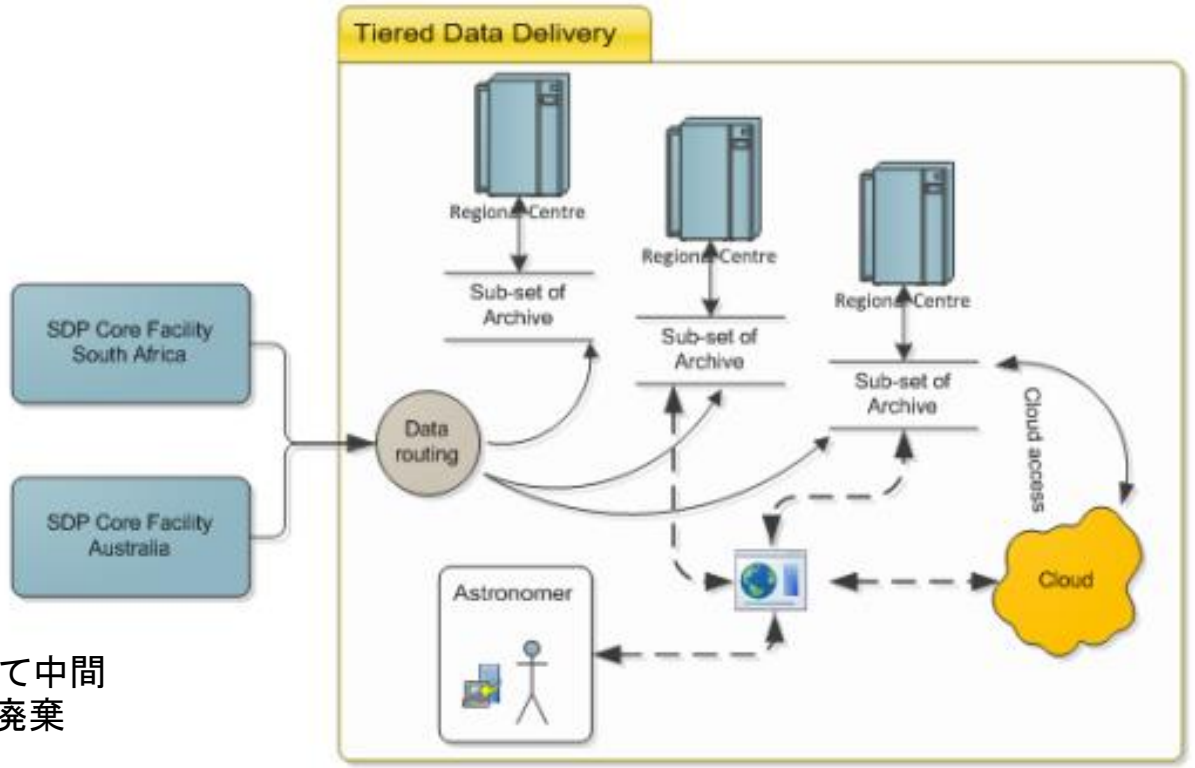
- アンテナ→相関器
- DWDM
  - 10GbE x N
- シングルモードファイバ
  - G.652
- 光増幅
  - Optical amplifiers required every 70-80 km (£5-10k each). Clean-up repeaters might be required (£30k-40k each).



SKAからのデータ展開

❖リージョナルセンターにアーカイブ

– Data distribution by working closely with various global National Research and Education Networks (NRENs);



データが膨大すぎて中間
データすら半日で廃棄

一般回線との相違

- **片方向**
  - 運用回線(10Mbps) は双方向
- **Point-to-point & 事前に既知**
- **レート固定、非バースト的**
- **非圧縮**
- **高ビットエラーレート耐性**
  - noise-like,　loss rate of 0.1%

一般回線と同じ:　省電力、低コスト

SKA-JP
Square Kilometre Array
Japanese Consortium

通信装置

1. **Turnkey solution,**

   “may well be simply beyond the available budget”

2. **Custom solution**

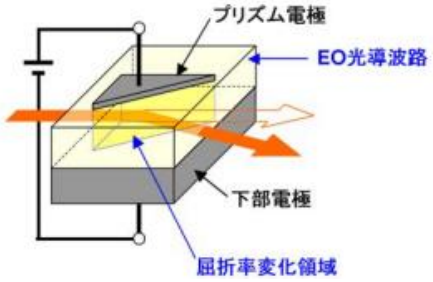
   “Custom implementations built from commercial COTS building blocks”

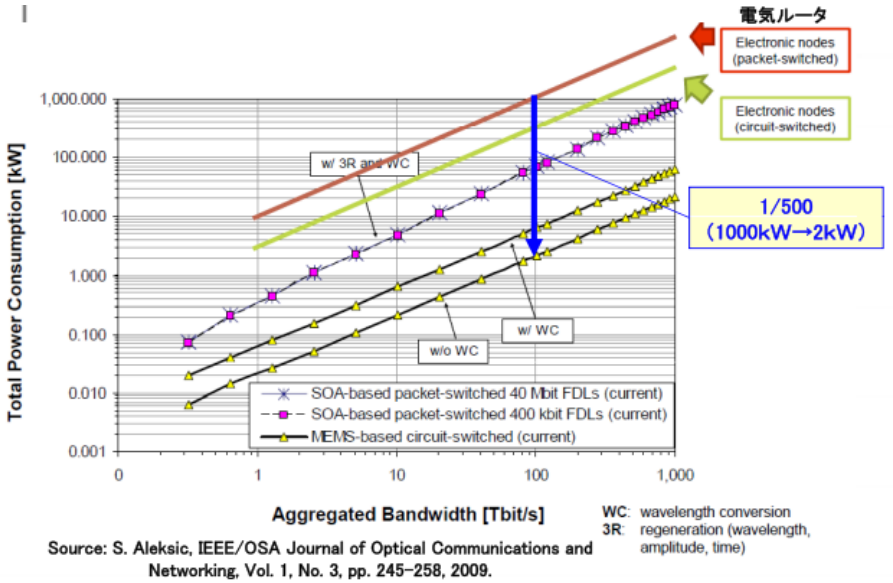
   “an order of magnitude cheaper”

IT省電力化

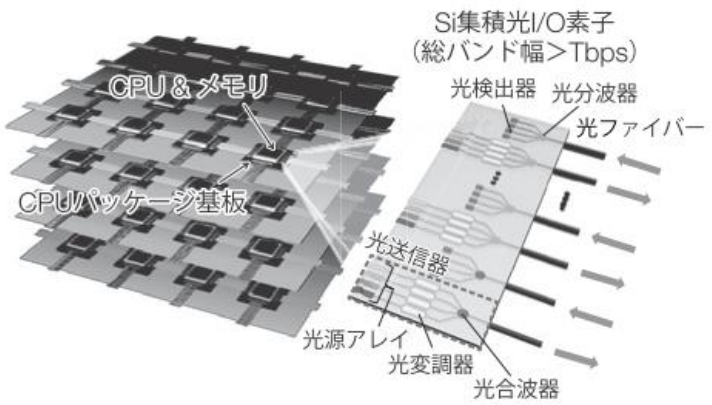
❖光スイッチ

– PLZT, Yamanaka et al 2011





❖シリコンフォトニクス

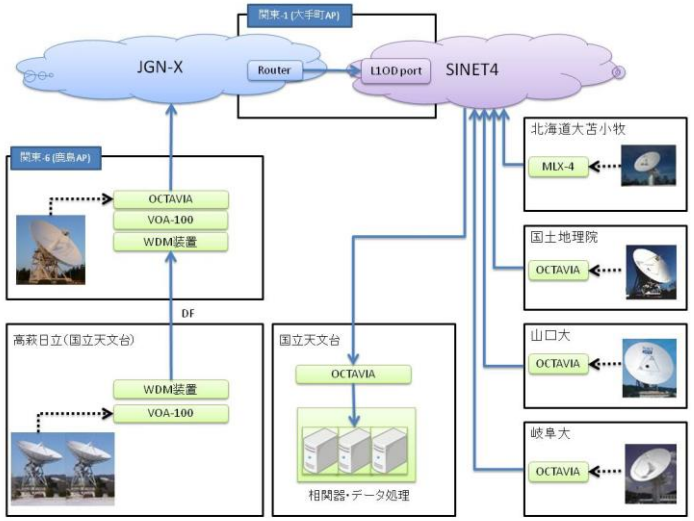


田中他, FUJITSU 64, 5 (2013,09)

図-1 Si集積光I/O素子を用いた大容量CPU間光インタコネクト

OSP (Octave for SKA PF)

- ❖高速ネットワークを使った光結合ネットワーク
- ❖超広帯域32Gbps(4GHz-BW x 2ch)
  - OCTADベース
  - SINET5, 次期JGN
  - 光スイッチによるプロセッサ制御
- ❖SKAサイエンステストベッドにも



SKA-JP
Square Kilometre Array
Japanese Consortium

まとめ

- 光結合VLBI
  - 現状
- SKA
  - 国際プロジェクト
  - 日本の参加を検討中
    - 通信は有力な候補