

VLBI観測と マルチメッセンジャー天文学

本間 希樹 (国立天文台 水沢VLBI観測所)

Contents

- 自己紹介、観測所紹介など
- VLBIの紹介(装置面、研究面)
- マルチメッセンジャー天文学の可能性

自己紹介など

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職名：教授、所長(2015年4月～)

専門：電波天文学



水沢(奥州市)の位置



水沢本館と桜

国立天文台水沢の主な施設

電波望遠鏡



奥州宇宙遊学館

木村記念館



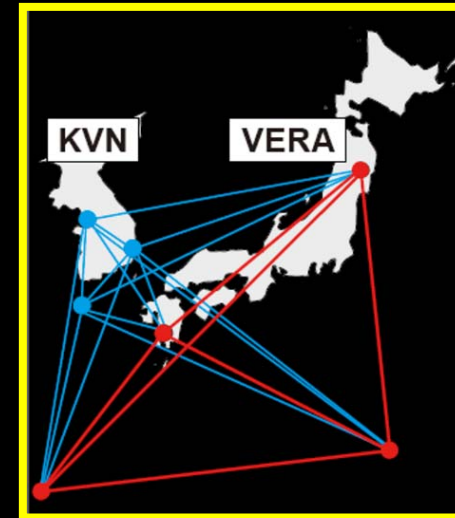
スパコン「アテルイ」

VLBI (Very Long Baseline Interferometry) 超長基線電波干涉計

VERA



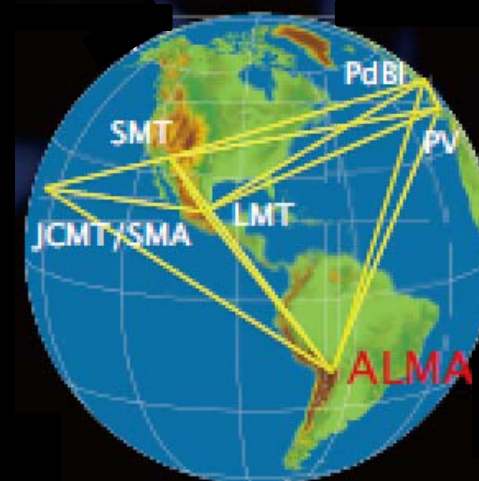
KaVA



EAVN

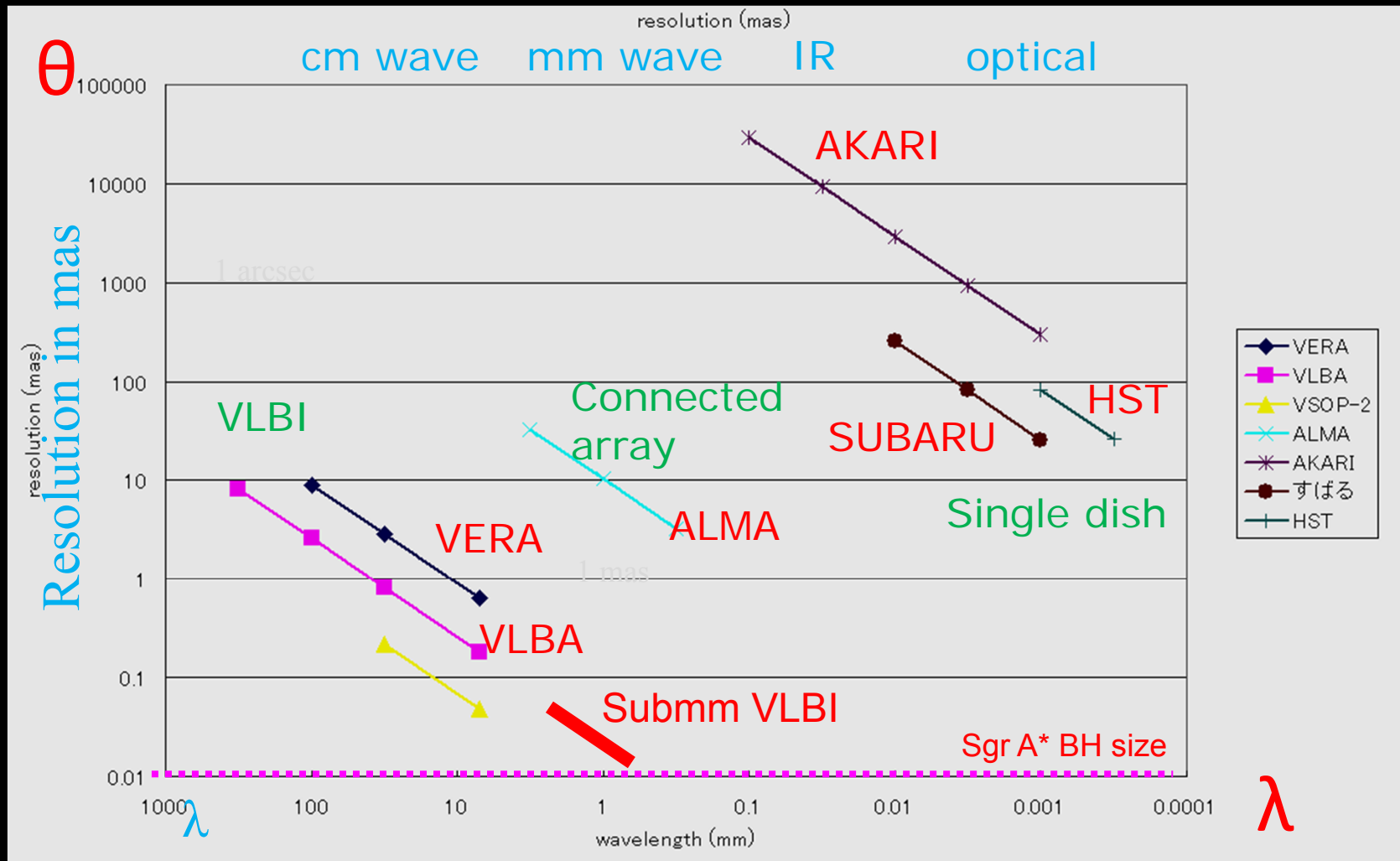


EHT



Angular resolution of telescopes

- angular resolution: $\Theta \sim \lambda / D$



VLBIの特徴

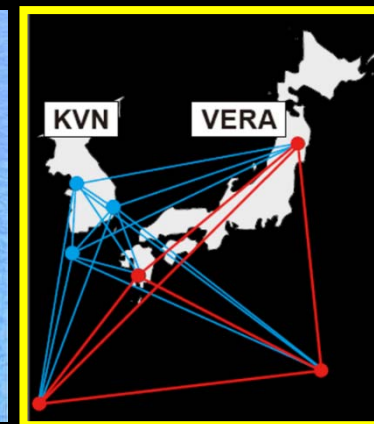
- 長所 高い分解能（全波長帯で最高）
- 短所 低い感度...
- 見える天体は高輝度・非熱的放射のみ
 - メーザー 星、星形成、AGN周辺ガス
 - シンクロトロン AGN、SNR/パルサー etc.

装置的な特徴

- 基本プロセス
各局でGbps程度のレートで記録 → 相関処理
 - 時間分解能は極めて高い（最大ns）
 - 視野は狭い（通常 秒角程度）
 - 結果に時間がかかる（相関処理まで3週間）
- **ピンポイントのフォローアップは得意**
サーベイ・探査や、位置の不明な天体は苦手

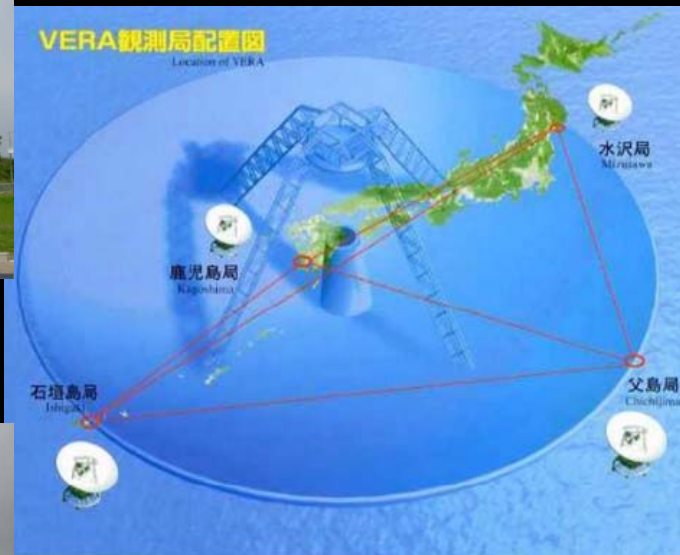
水沢に関連したVLBI装置

- VERA
フル運用、位置天文
- KaVA
月100時間、イメージング
- EAVN
試験整備中、2018以降
- EHT
年10日ほど、最高分解能

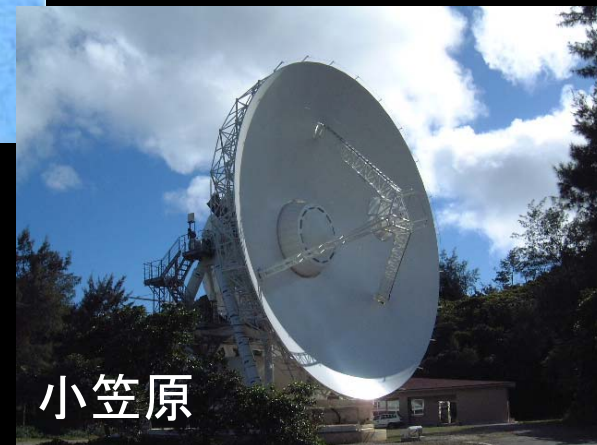


VERA: VLBI Exploration of Radio Astrometry

位置天文観測に特化



VERA

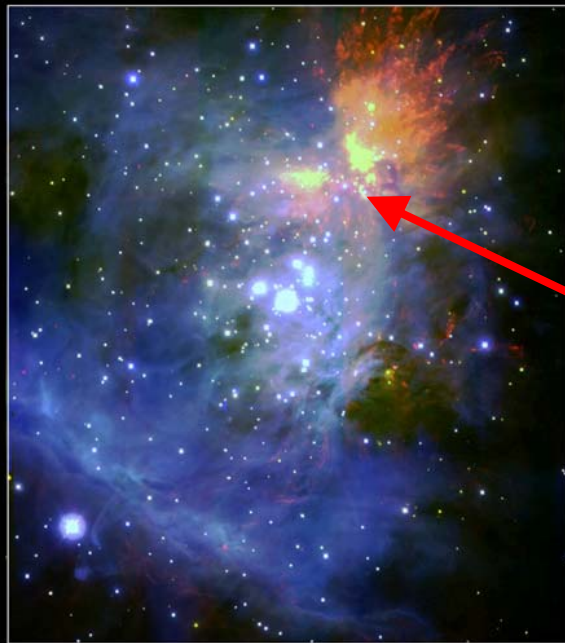


The first parallax : obtained in 2007

- A few first parallaxes reported in 2007 (Orion KL)

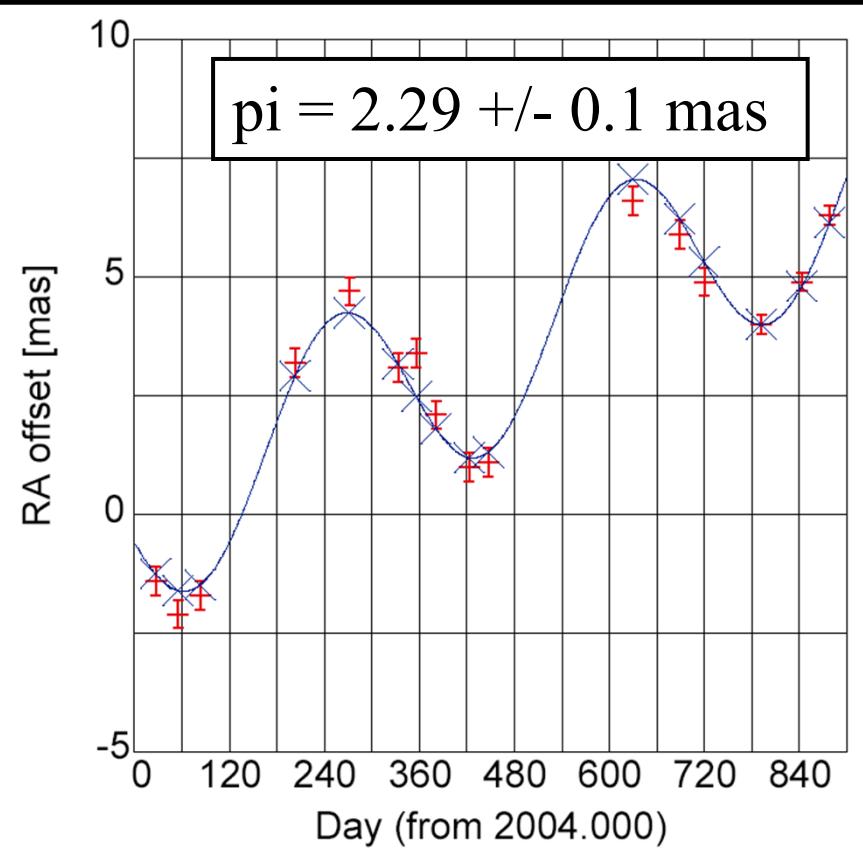
Hirota et al. (2007)

$D = 437 \pm 19$ pc



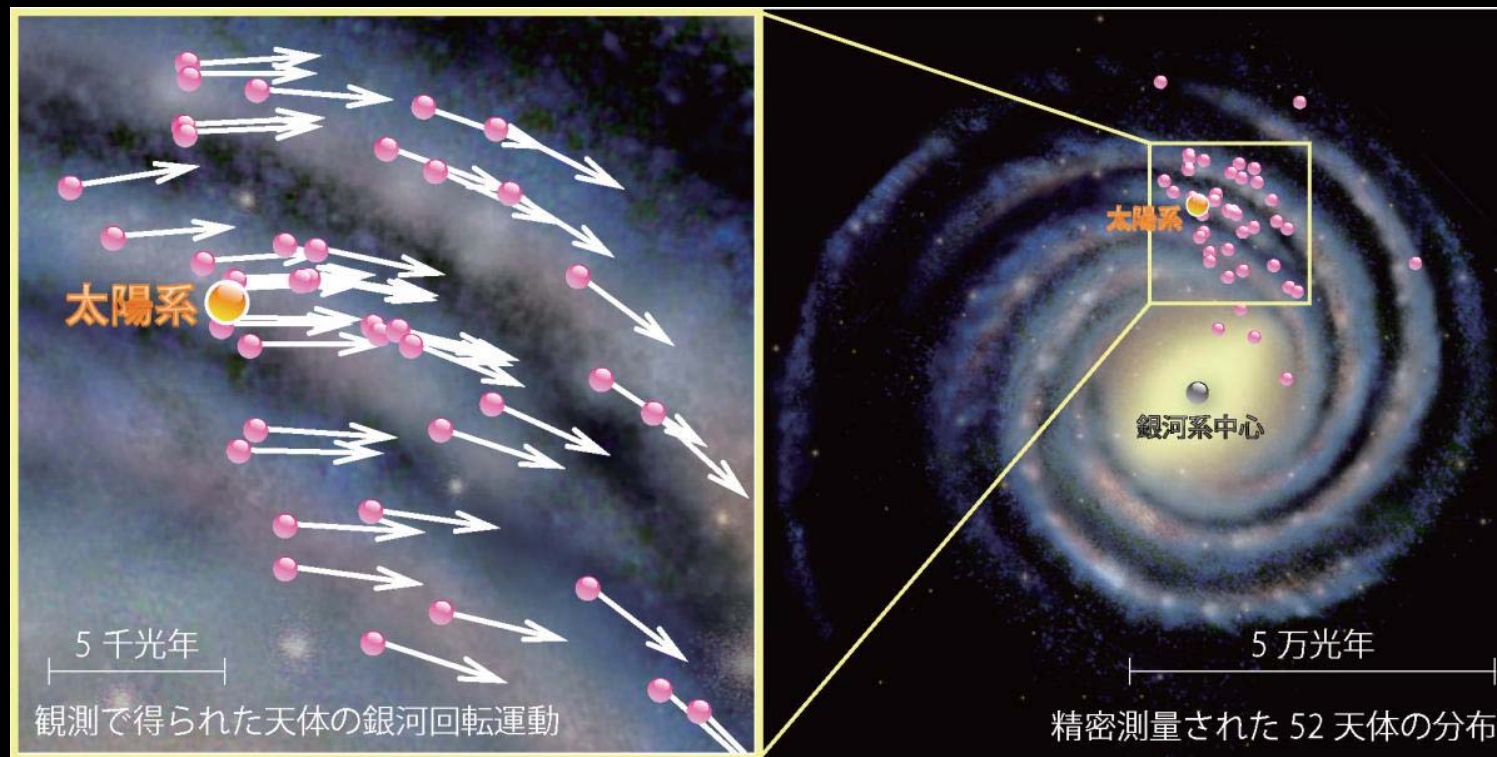
Orion Nebula
Subaru Telescope, National Astronomical Observatory of Japan
January 28, 1999
CISCO (J, K' & H₂ (v=1-0 S(1)))

Orion nebula with Subaru



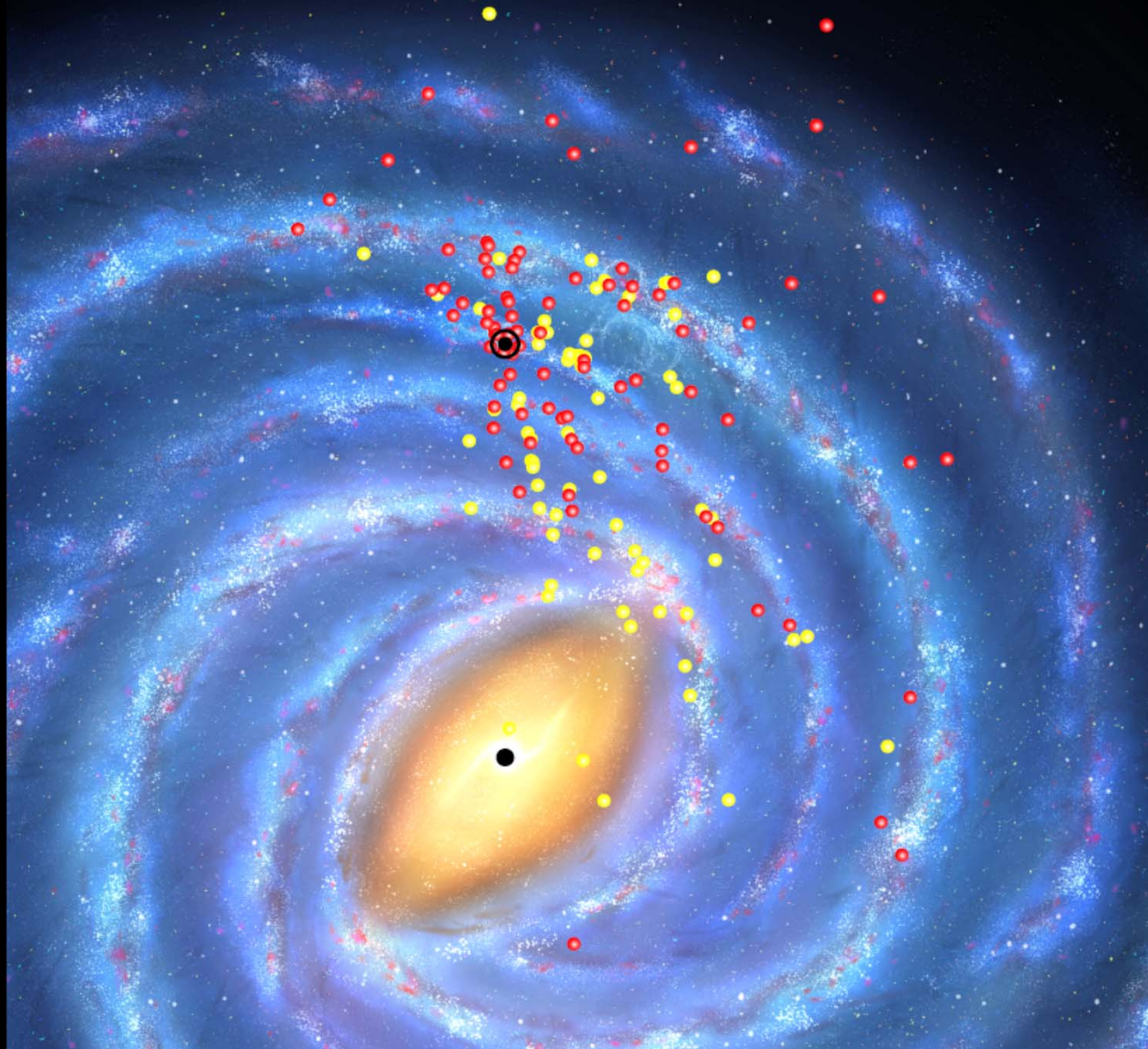
Galaxy's fundamental constants

- Combined with VLBA/EVN data, we have determined Galactic parameters using 52 sources.



First Galactic parameter analysis by using more than 50 sources with VLBI astrometry (Honma et al. 2012)

Maser astrometry as of 2016



159 sources from VLBA/VERA/EVN (86 sources from VERA)

VLBI位置天文による銀河定数

最新(2016)

143 sources

$R_0 = 8.26 \pm 0.24$ kpc

$\Omega_0 = 28.84 \pm 0.37$ km/s/kpc

$\Theta_0 = 238 \pm 8$ km/s

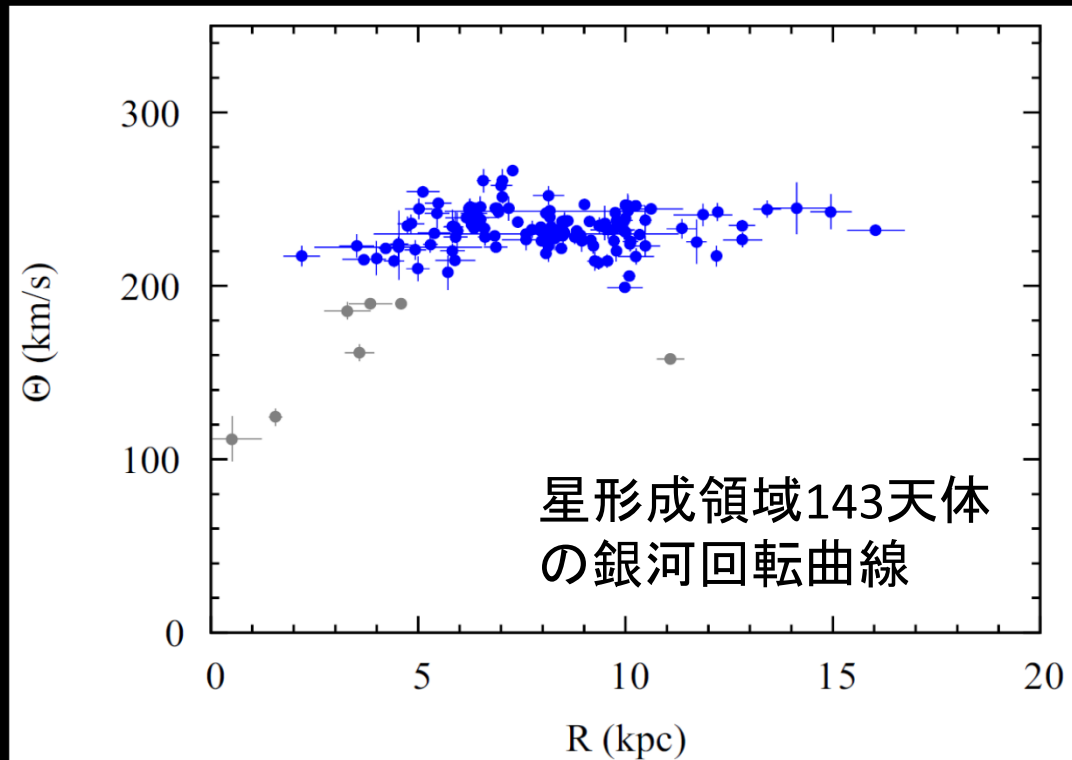
Honma+ 12

52 sources

$(8.05 \pm 0.45$ kpc)

$(29.57 \pm 0.78$ km/s/kpc)

$(238 \pm 14$ km/s)



Japanese VLBI Network (JVN)

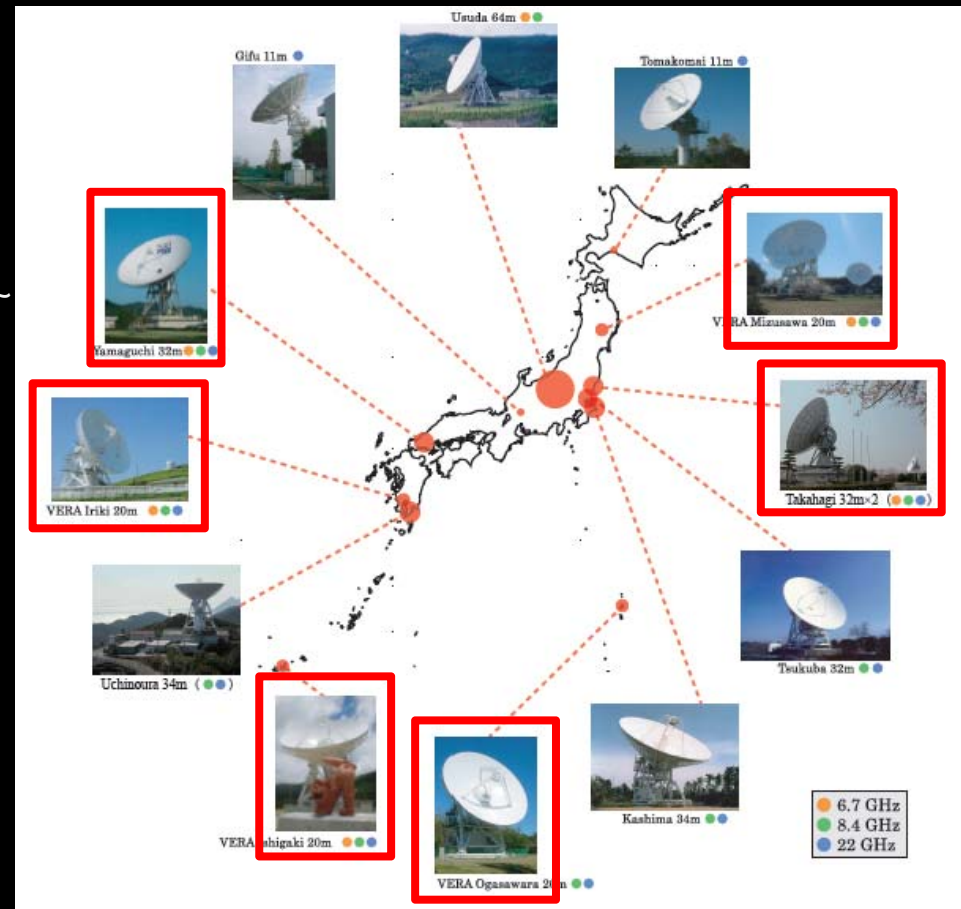
Specifications

- 13 telescopes (11m ~ 64m)
- Baseline 50 - 2500 km
- Frequency 6.7/8/22 GHz
- Sensitivities (8 GHz, 128 Mbps) ~ 3 mJy
- High-Speed e-VLBI (2 Gbps) sub-array

Participating institutions

Hokkaido, Ibaraki, Tsukuba, Gifu
Osaka Pref., Yamaguchi, Kagoshima Univ.
+ GSI, JAXA/ISAS, NAOJ, NiCT

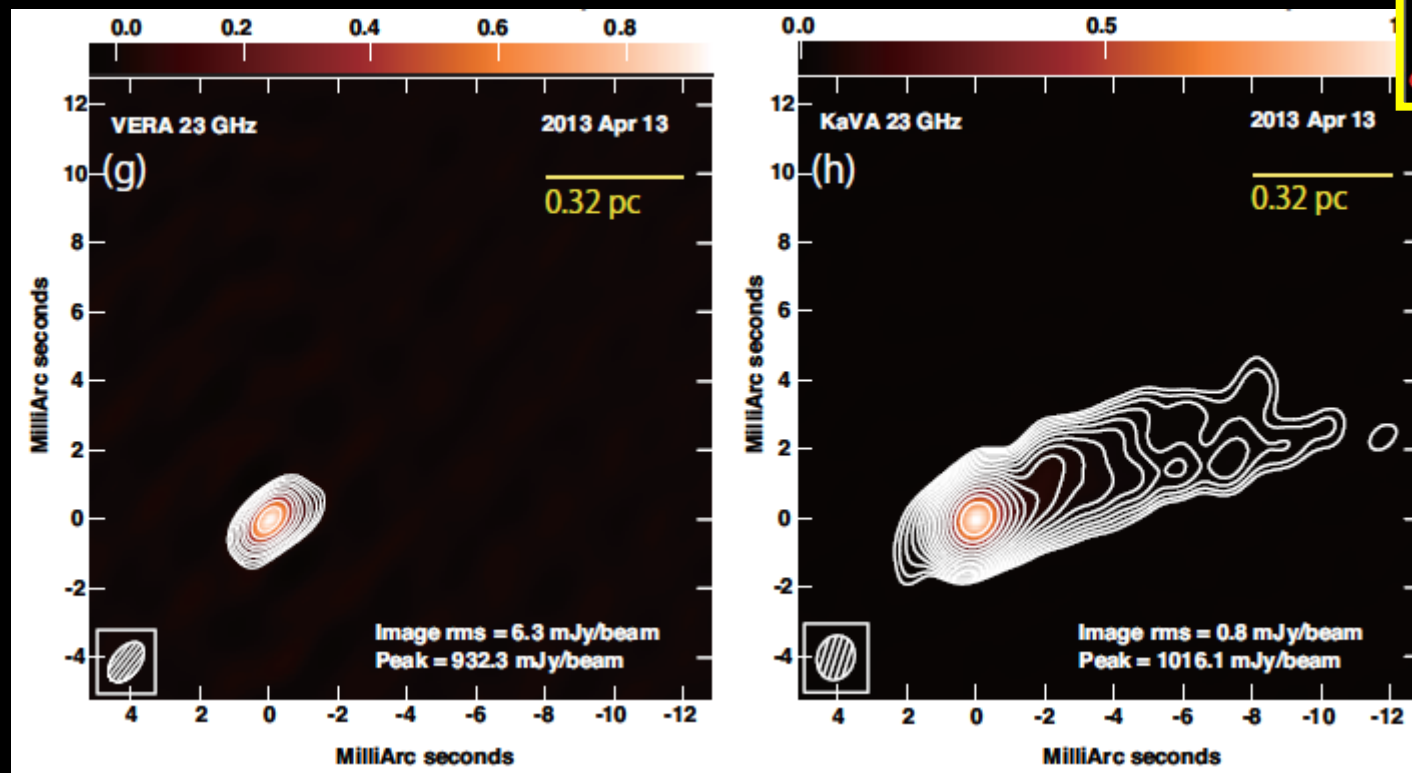
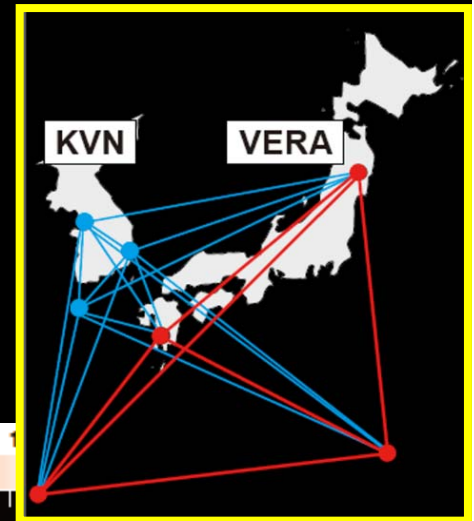
単一鏡でのモニター + VLBIイメージング



JVN Stations

KaVA

- KVN and VERA Array
- 短基線の充実により撮像力が劇的に向上



VERA

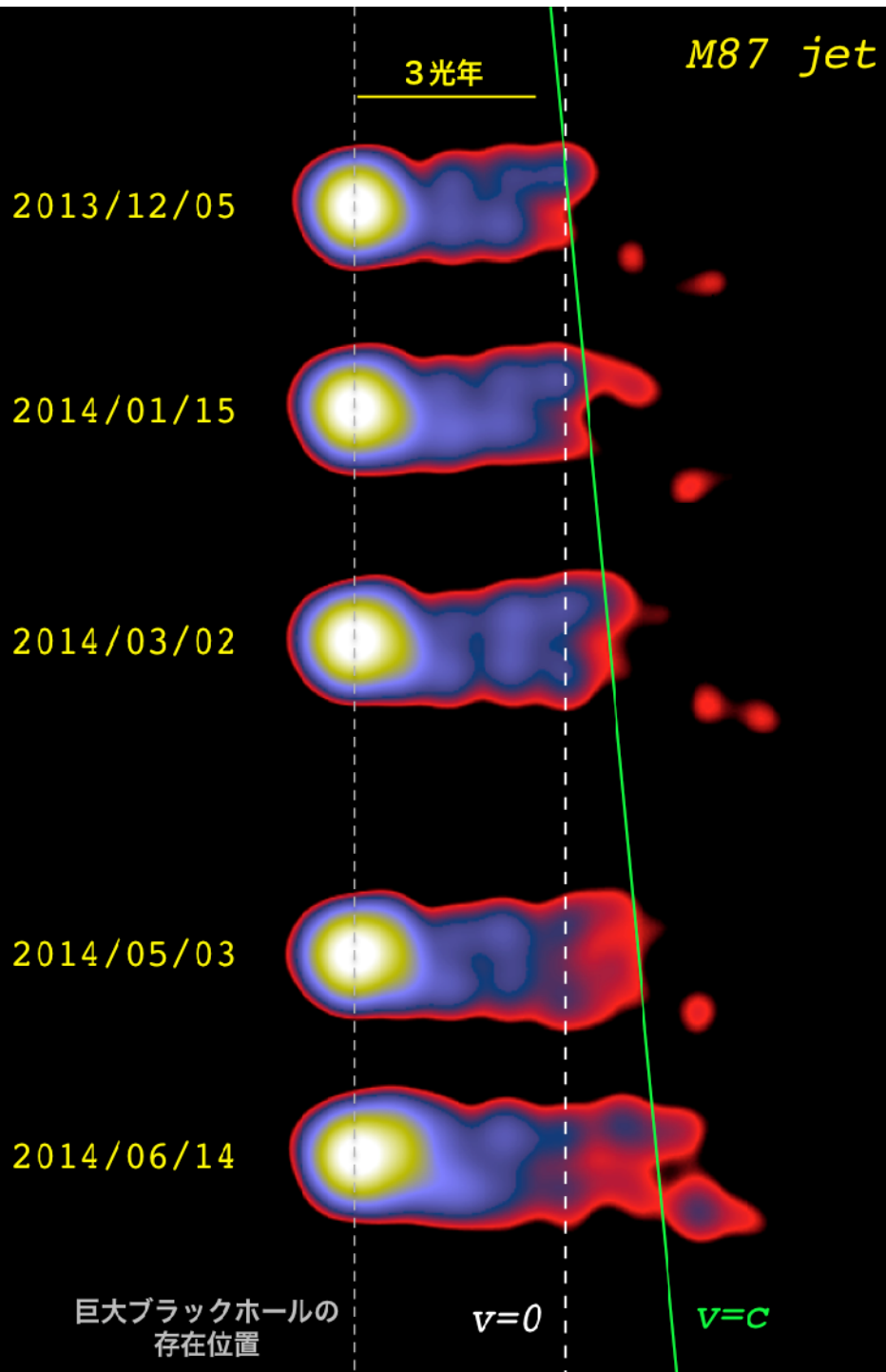
KaVA

KaVAがブラックホール近傍でのジェット超光速運動を検出

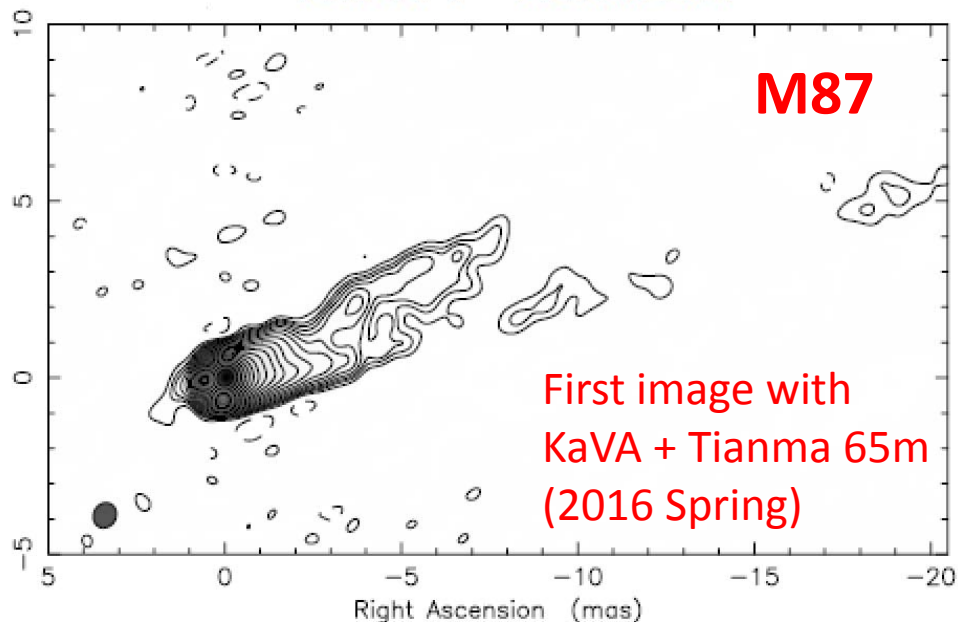


M87 with HST

Hada et al(2016)



KaVA+Tianma



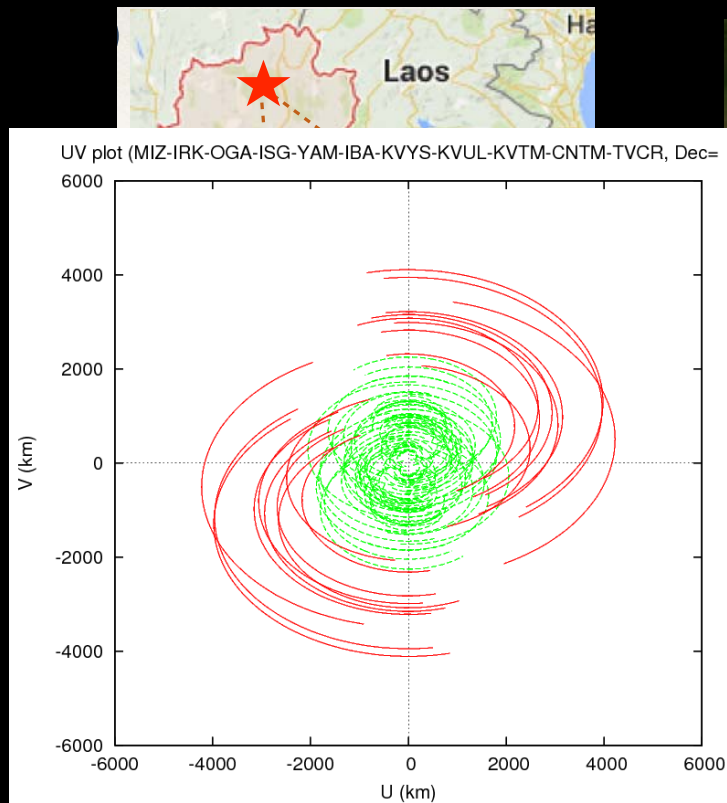
The East-Asian VLBI Network

(Image Credit: Reto Stöckli, NASA Earth Observatory)

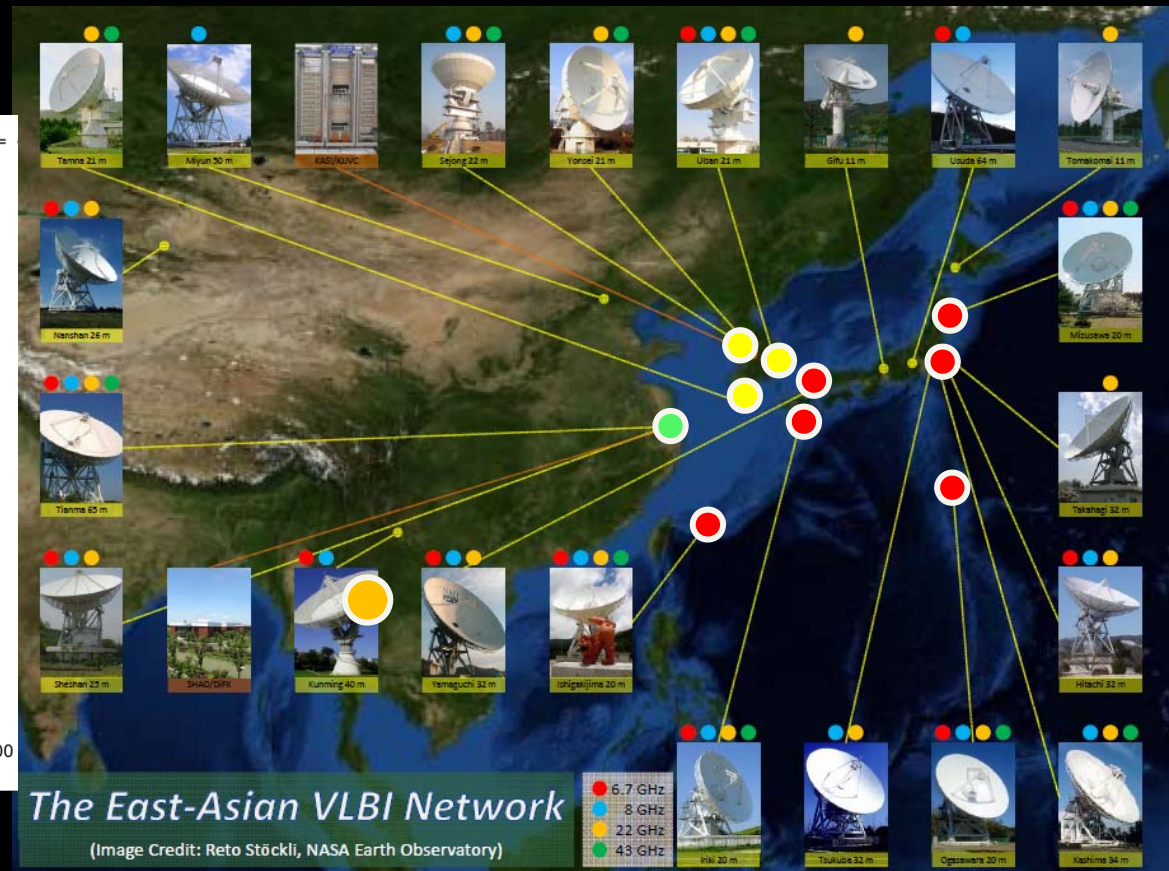
- 6.7 GHz
- 8 GHz
- 22 GHz
- 43 GHz

EAVN + TVN

- Baseline doubled, astrometry accuracy doubled



EAVN UV coverage with one of TVN stations



The radio telescope in Thailand should have a big impact !

FAST 500m in China



Comparison of SKA, EAVN and other array

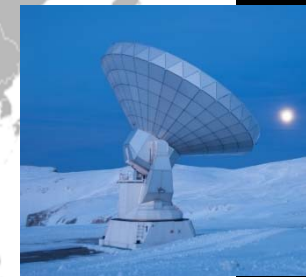
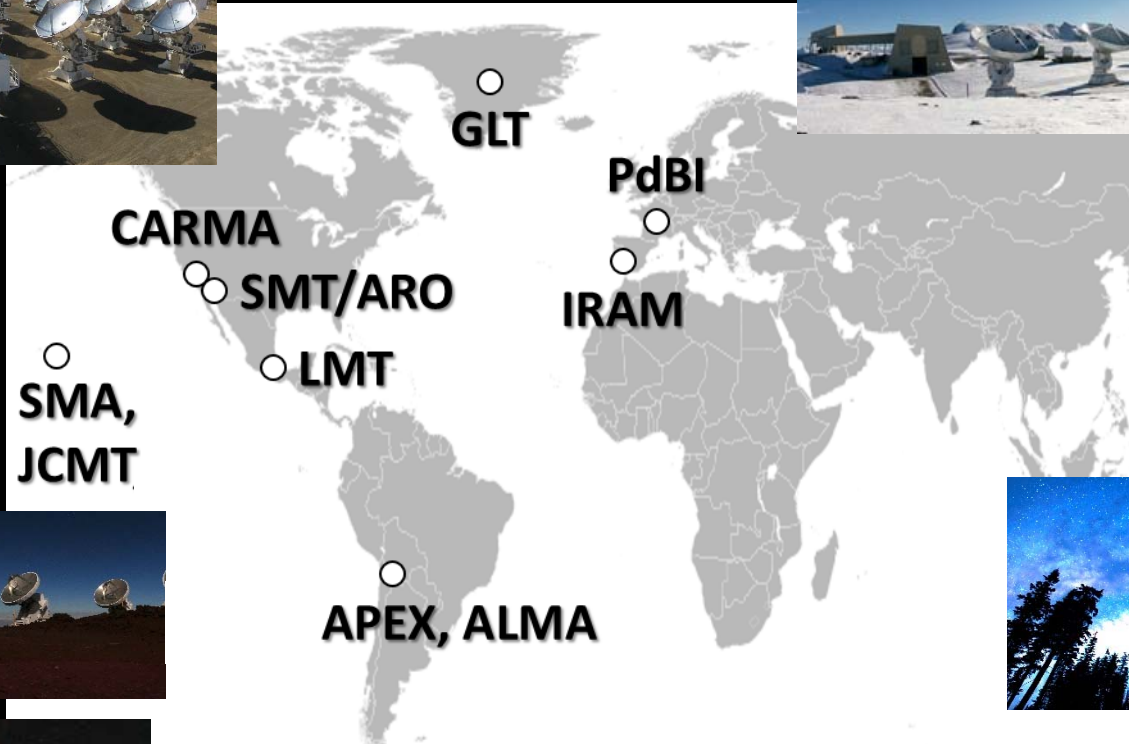
	EAVN	EAVN +FAST	EAVN+Q T,FAST	EVN	VLBA+ GBT+ VLA	Global VLBI (EA/Eu/ US)	SKA-1 (mid)	SKA-2 (mid)
Operating from	2018?	2022?	2022?	Operating	Operating	?	2023?	2028??
Max. Baseline (km)	5000	5000	5000	2000- 10000	8000	10000	150	3000
Collecting area (m ²)	15000	86000	96000	20000	26000	61000 ~ 142000	32600	440000

FAST 500m corresponds to an effective diameter of 300m

QT: Planned new 110m in Urumqi

EHT (Event Horizon Telescope)

視力300万でブラックホールの直接撮像を！



○ South Pole (SPT)



EHT with ALMA

- ALMA
12m x 54台、6m x 12台
圧倒的な感度を持つ

ALMA (NRAO/ESO/NAOJ)



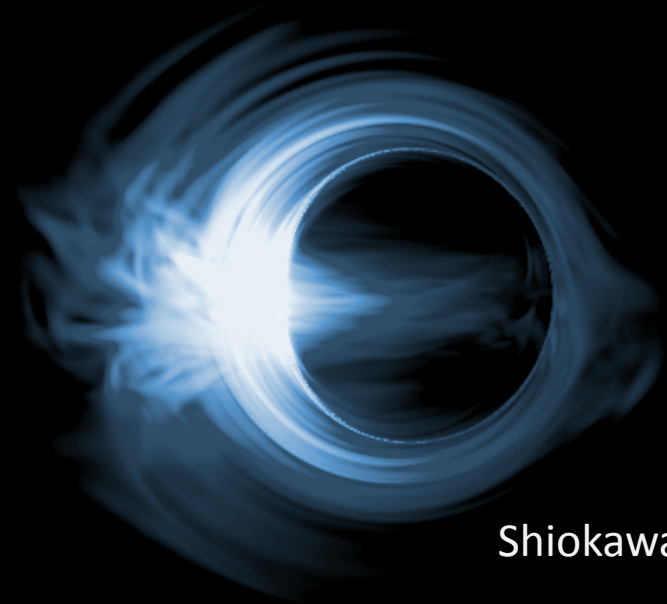
ALMAを含むEHT観測が2017年4月にスタート！

ブラックホールシャドローの検出

- 降着円盤を背景に「黒い穴」としてブラックホールを見る



Fukue et al



Shiokawa et al

ブラックホールの想像図

巨大ブラックホールの見かけの大きさ

天体	質量 (太陽比)	距離 (1pc~3.3光年)	視半径
Sgr A*	4×10^6	8 kpc	10 μ as
M87	6×10^9	15 Mpc	7 μ as
M104	1×10^9	10 Mpc	2 μ as
Cen A	5×10^7	4 Mpc	0.25 μ as

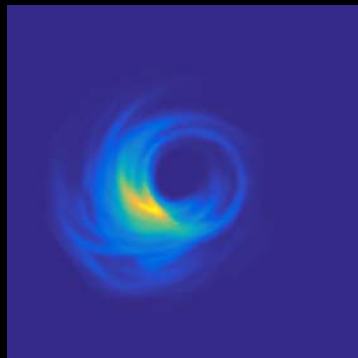


シャドウの大きさ: ブラックホール視半径の1~5倍程度
10 μ asの分解能があればシャドウが見える

→ 波長1mm程度で地球サイズの干渉計が必要

EHT のイメージングを巡る競争

現在日米で3つのチームが、よりよりブラックホールの画像取得を目指した解析手法を開発中。



仮定した画像

スパース
モデリング
(ours)

MEM

CHIRP

EHTによる撮像シミュレーション例
異なる手法で結果が再現されれば、結果の確実性が増す

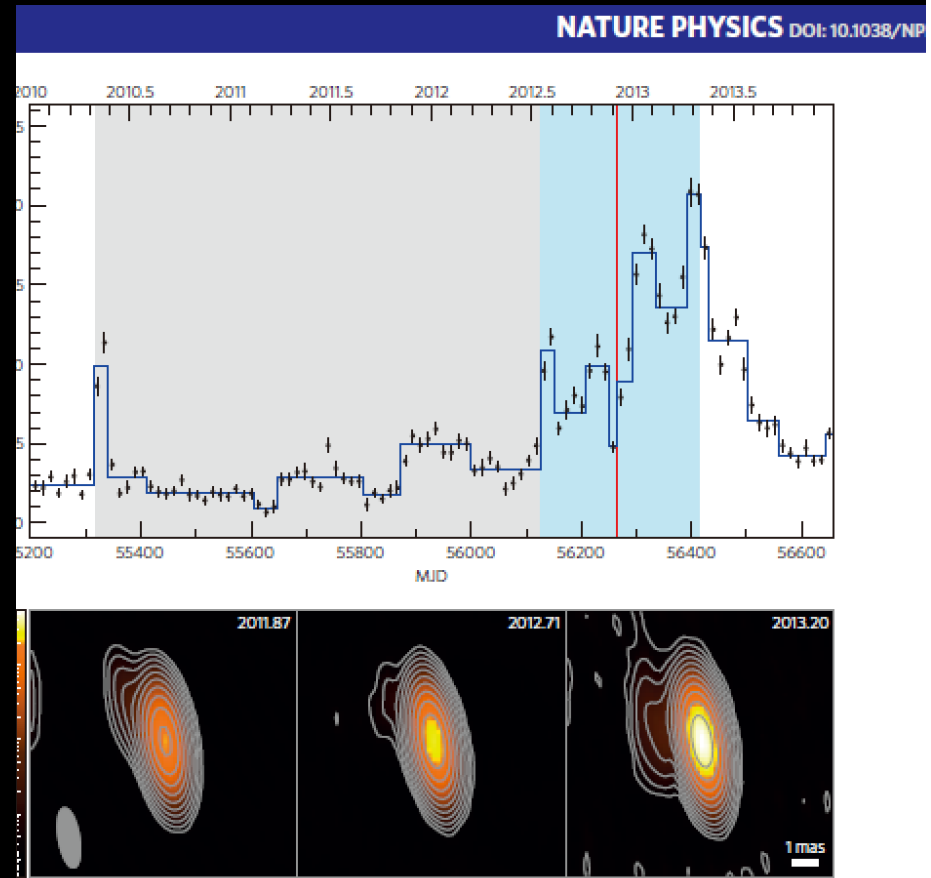
Multi-messenger astronomy with VLBI

- ガンマ線AGN (ブレイザー、電波銀河)
電波、光、X/ γ 線、 ν ?
- 近場のブラックホール (Sgr A, M87など)
- FRB等の突発天体

PeV Neutrino from AGN ?

- HESE-35 (PeV event) by Ice Cube
- Mas-scale jet detected in PKS1414 in the same period (γ -ray active phase)

Association between blazar activity and PeV neutrino ?



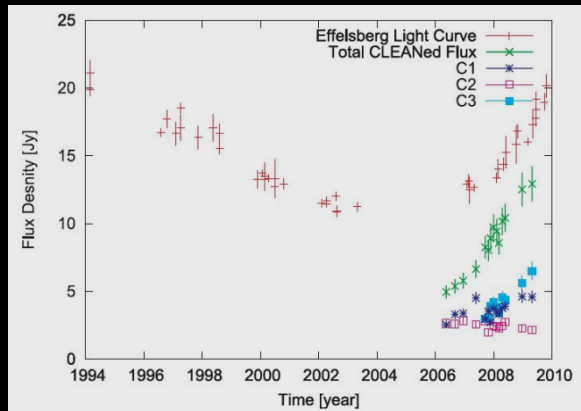
Kadler+(2016)

Gamma-ray emitting AGNs

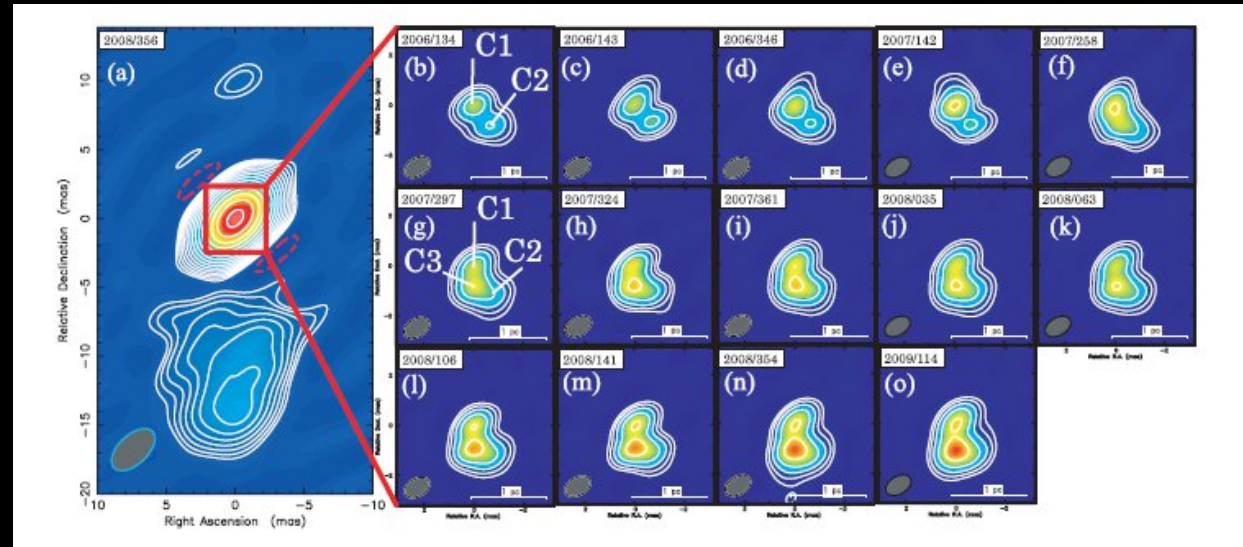
- Example : 3C84, radio jet detection (VERA) after γ -ray flare (Fermi)

VLBI map (2 x 2 pc), at 22 GHz

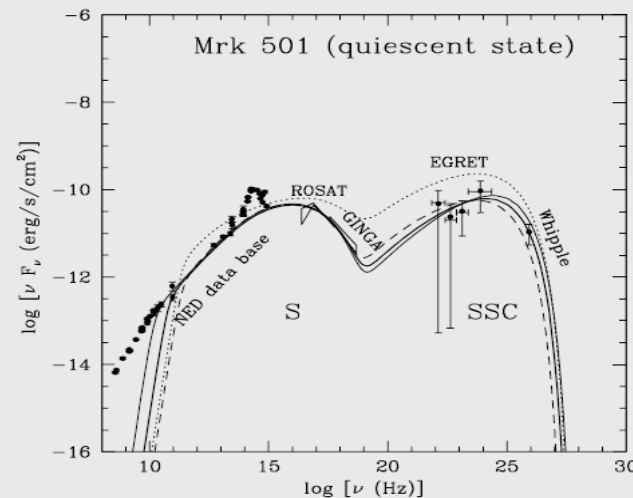
Nagai+(2010)



Radio light curve



cm + (sub-)mm VLBI will lead comprehensive understanding (higher resolution & lower optical depth ...)

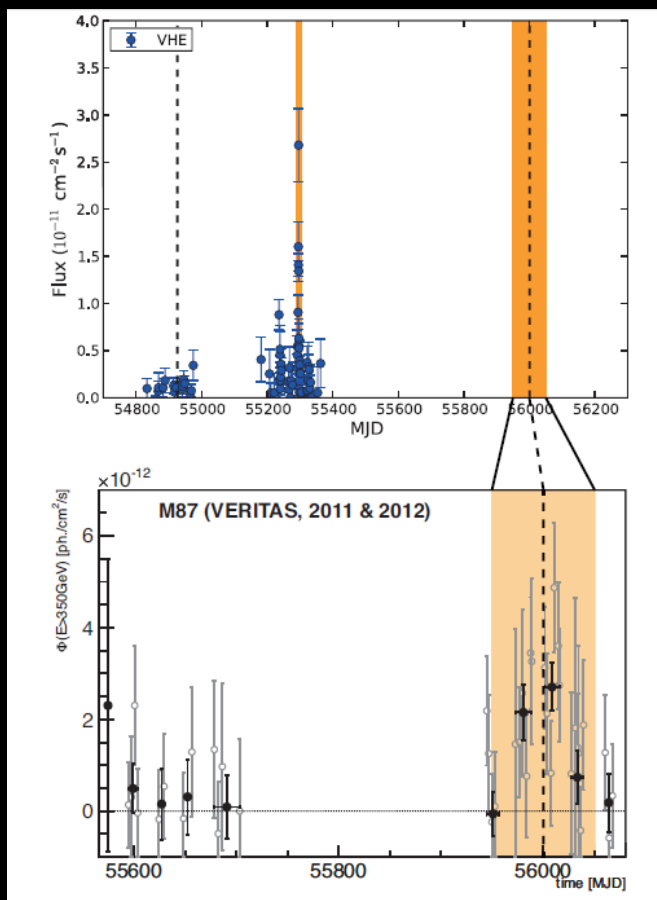


SSC model for Mrk 501 (Kino+2001)

γ -ray emitting region: <1000 AU

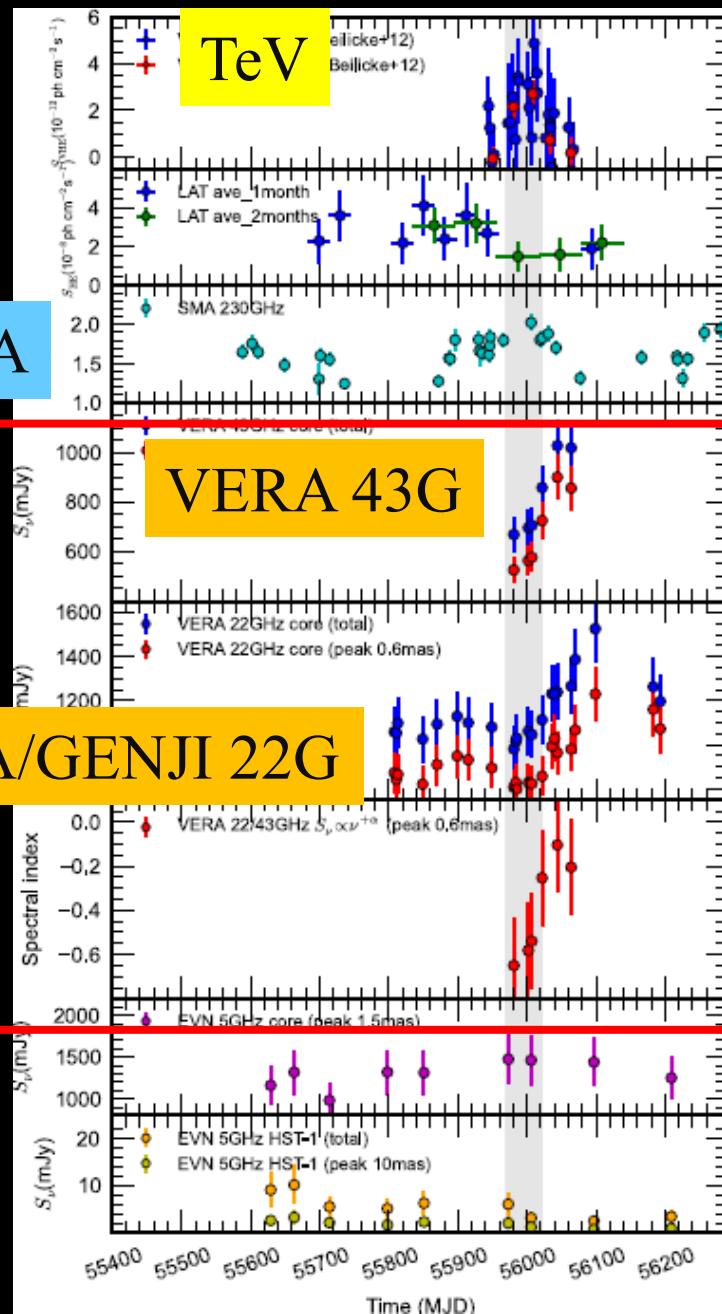
M87 Radio+Gamma

M87: VERITAS によるTeV 増光の検出 (2012/3月)



M87 VERITAS

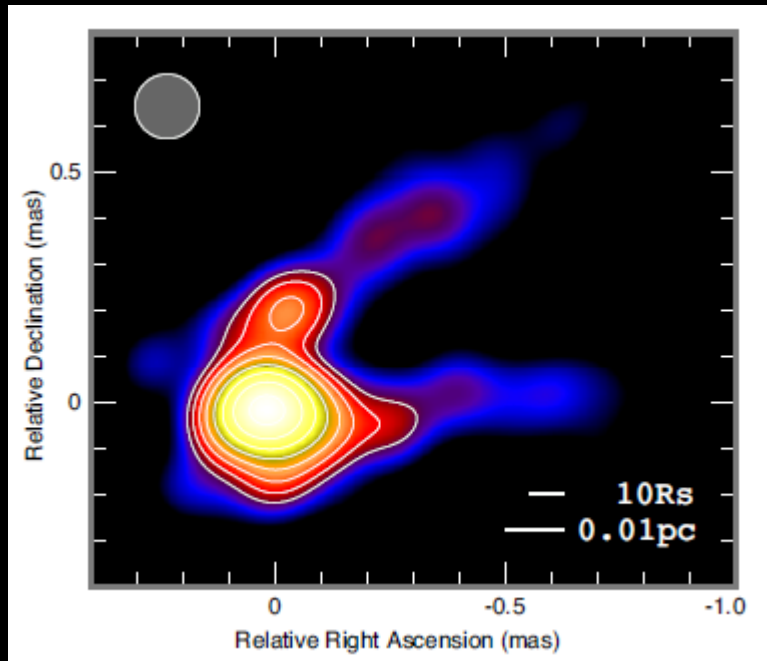
SMA



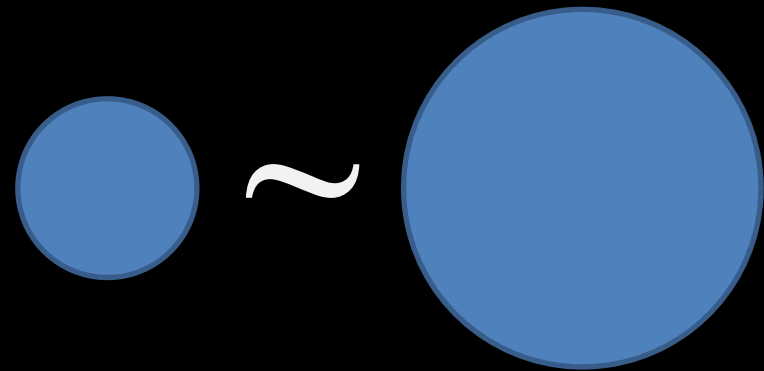
Hada et al (2014)

Size limit to TeV emitting region ?

- Lower limit : $\sim 50 R_s$ from EHT (Akiyama+2015)
- Upper limit : $\sim 100 R_s$ from VERA (Hada+2014)



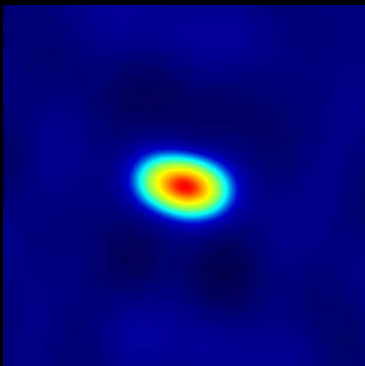
M87@43G Hada+(2013)



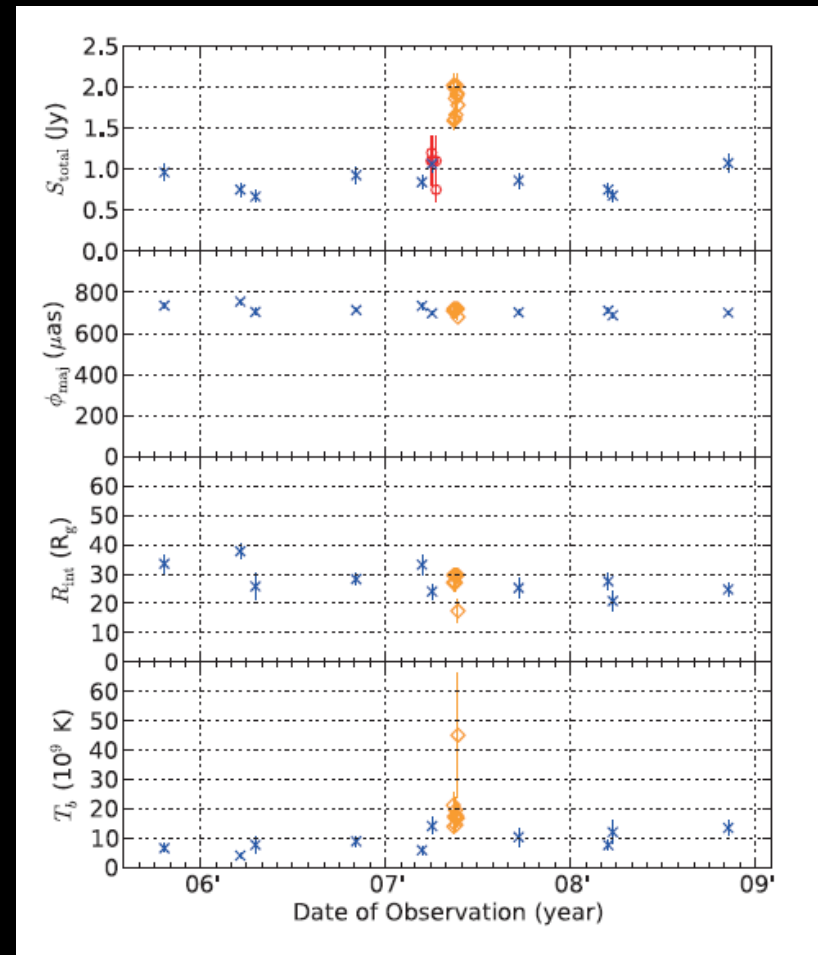
Expected size ?

Sgr A* long-term variation

- Scale : less than 70 Rs
 - Long-term variability:
~ $\pm 15\%$ (0.7 – 1 Jy)
 - Radio-loud state in May 07
 $S \sim 2$ Jy at 43G (Lu +2010)
 - Size is basically constant
- > Brightness temperature change !



VERA image

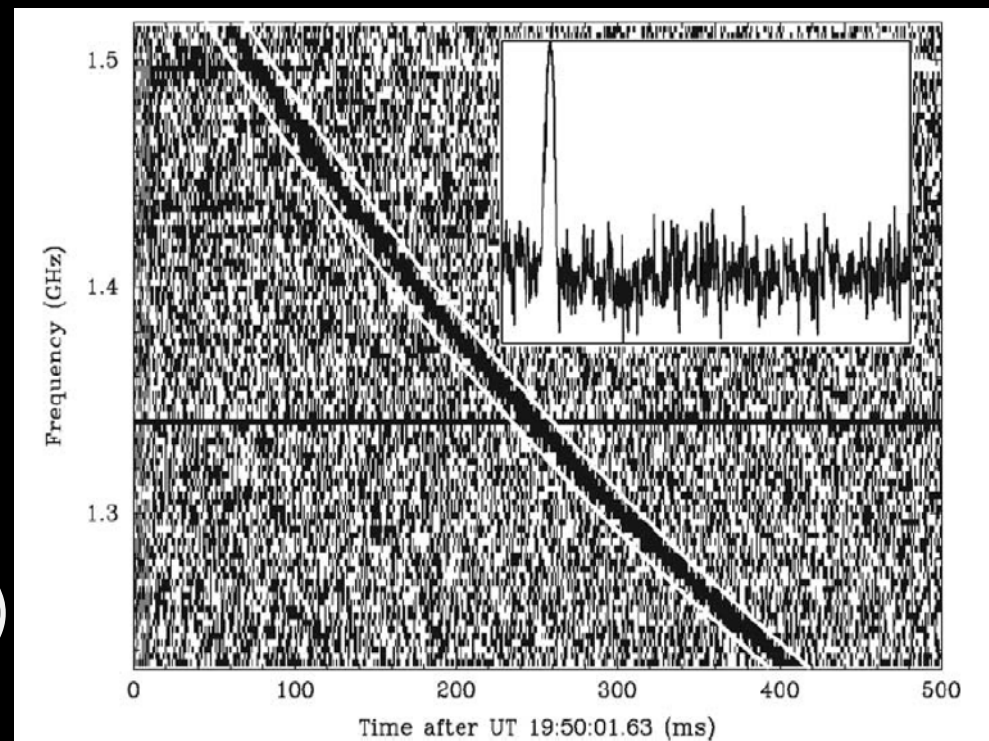


Blue : VERA (Akiyama+13)

Orange : VLBA (Lu+10)

Time domain astronomy with FRB

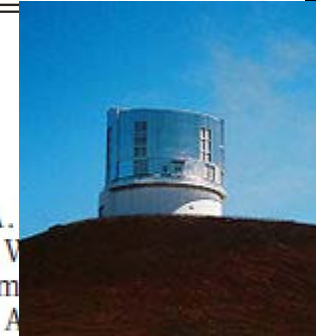
- FRB (Fast Radio Burst): millisecond radio burst with large DM (Dispersion Measure)
- Origin is still unknown
- Candidates vary from cosmological source (e.g., mergers of compact sources) to man-made artificial noise (such as microwave oven)



The Lorimer Burst (Lorimer+ 2007)

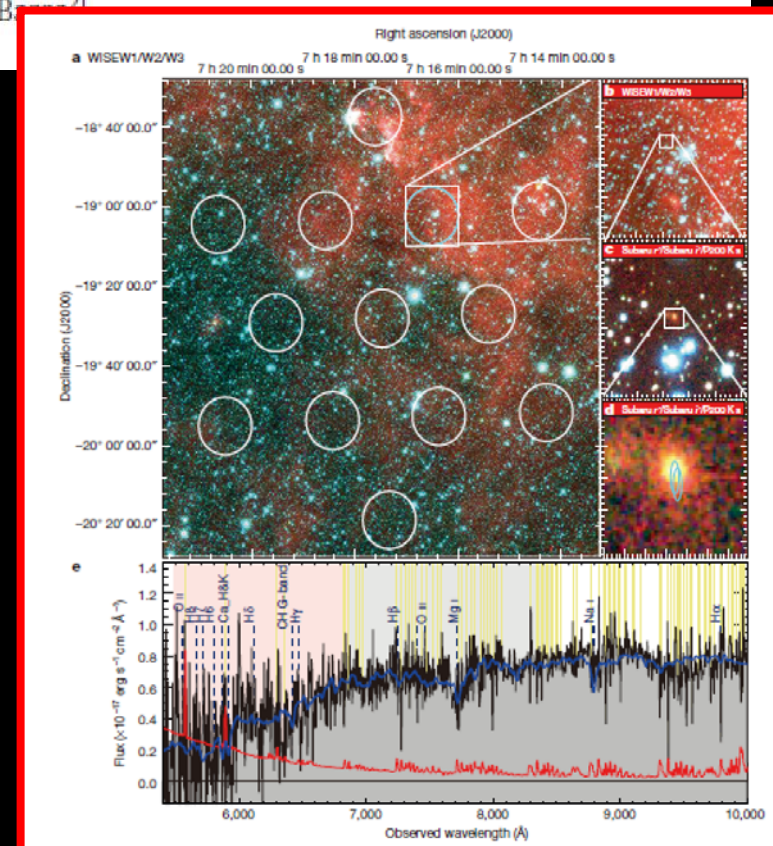
The host galaxy of a fast radio burst

E. F. Keane^{1,2,3}, S. Johnston⁴, S. Bhandari^{2,3}, E. Barr², N. D. R. Bhat^{3,5}, M. Burgay⁶, M. Caleb^{2,3,7}, C. Flynn^{2,3}, A. M. Kramer^{8,9}, E. Petroff^{2,3,4}, A. Possenti⁶, W. van Straten², M. Bailes^{2,3}, S. Burke-Spolaor¹⁰, R. P. Eatough⁸, B. W. T. Totani¹¹, M. Honma^{12,13}, H. Furusawa¹², T. Hattori¹⁴, T. Morokuma^{15,16}, Y. Niino¹², H. Sugai¹⁶, T. Terai¹⁴, N. Tomita¹⁷, S. Yamasaki¹¹, N. Yasuda¹⁶, R. Allen², J. Cooke^{2,3}, J. Jencson¹⁸, M. M. Kasliwal¹⁸, D. L. Kaplan¹⁹, S. J. Tingay^{3,5}, A. R. Wayth^{3,5}, P. Chandra²⁰, D. Perrodin⁶, M. Berezina⁸, M. Mickaliger⁹ & C. B. ...²¹



FRB (Parkes) →
 Radio afterglow (ATCA) →
 Elliptical galaxy (Subaru) →
 Redshift of 0.5 (Subaru) →
 cosmological origin !

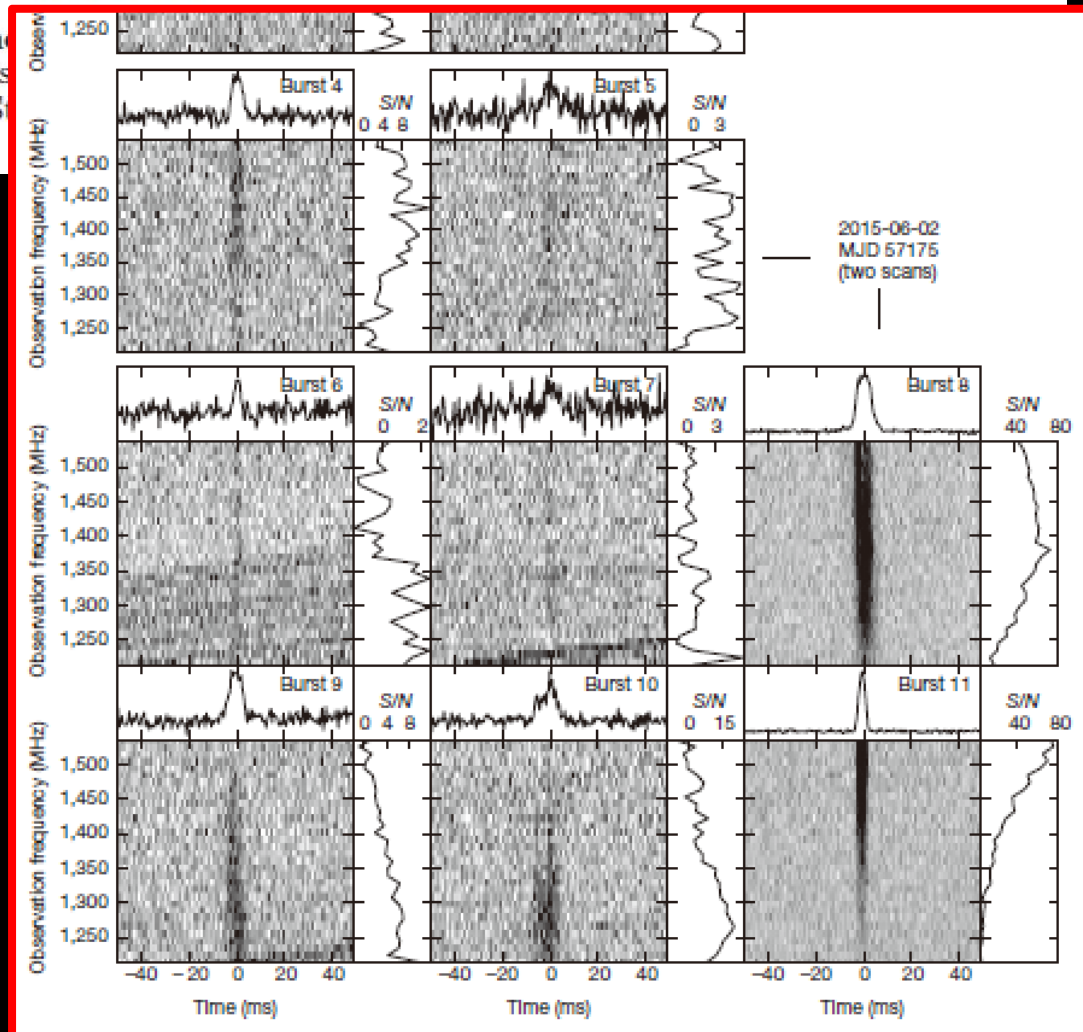
But debate still on-going...
 Need FRB localization



A repeating fast radio burst

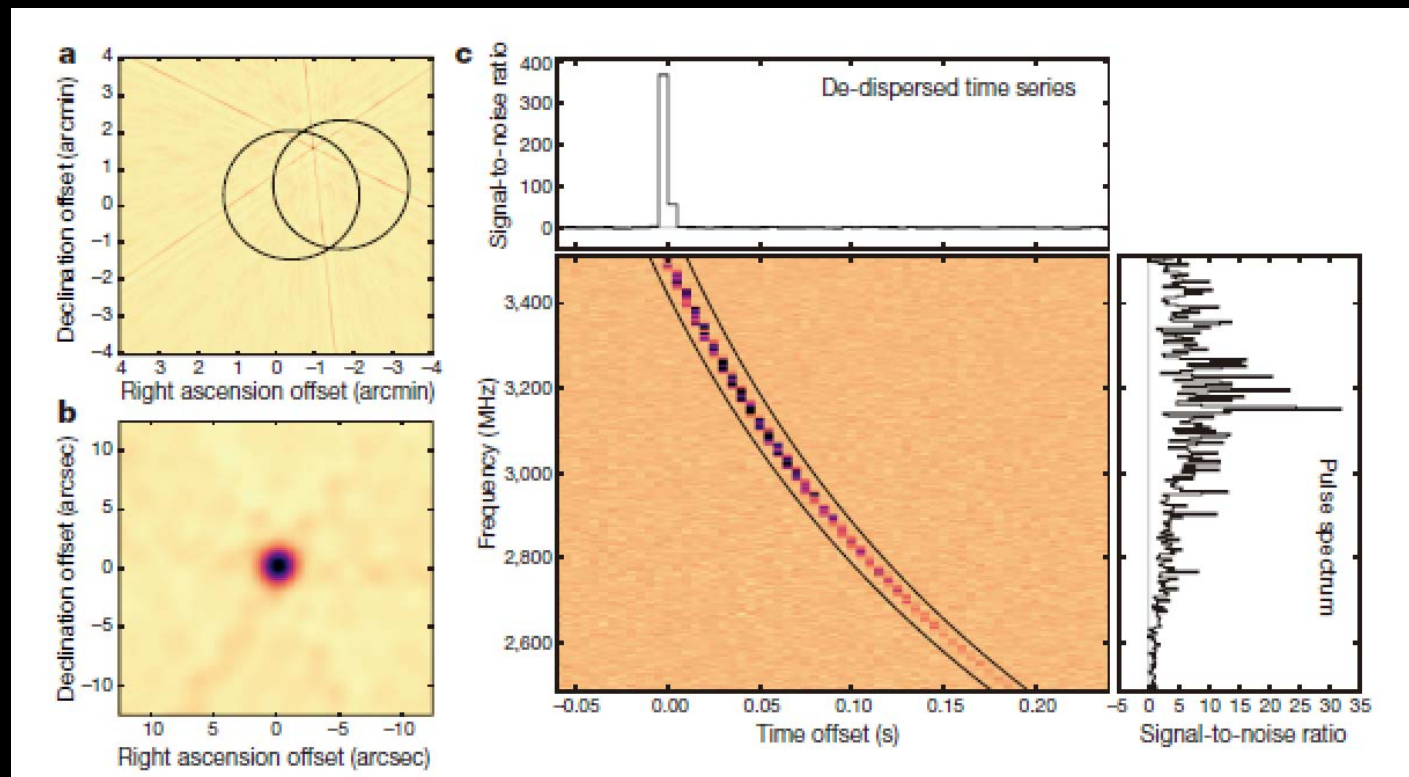
L. G. Spitler¹, P. Scholz², J. W. T. Hessels^{3,4}, S. Bogdanov⁵,
J. Deneva¹⁰, R. D. Ferdman², P. C. C. Freire¹, V. M. Kaspi⁶,
S. M. Ransom¹³, A. Seymour¹⁴, I. H. Stairs^{2,15}, B. W. Stappers⁷

- Repeating FRB !
- A non-coalescence origin (at least this case ?)



A direct localization of a fast radio burst and its host

S. Chatterjee¹, C. J. Law², R. S. Wharton¹, S. Burke-Spolaor^{3,4,5}, J. W. T. Hessels^{6,7}, G. C. Bower⁸, J. M. Cordes¹, S. P. Tendulkar⁹, C. G. Bassa⁶, P. Demorest³, B. J. Butler³, A. Seymour¹⁰, P. Scholz¹¹, M. W. Abruozzo¹², S. Bogdanov¹³, V. M. Kaspi⁹, A. Keimpema¹⁴, T. J. W. Lazio¹⁵, B. Marcote¹⁴, M. A. McLaughlin^{4,5}, Z. Paragi¹⁴, S. M. Ransom¹⁶, M. Rupen¹¹, L. G. Spitler¹⁷ & H. J. van Langevelde^{14,18}



First direct localization of repeating FRB

Young pulsar+SN in a dwarf SF Galaxy ?

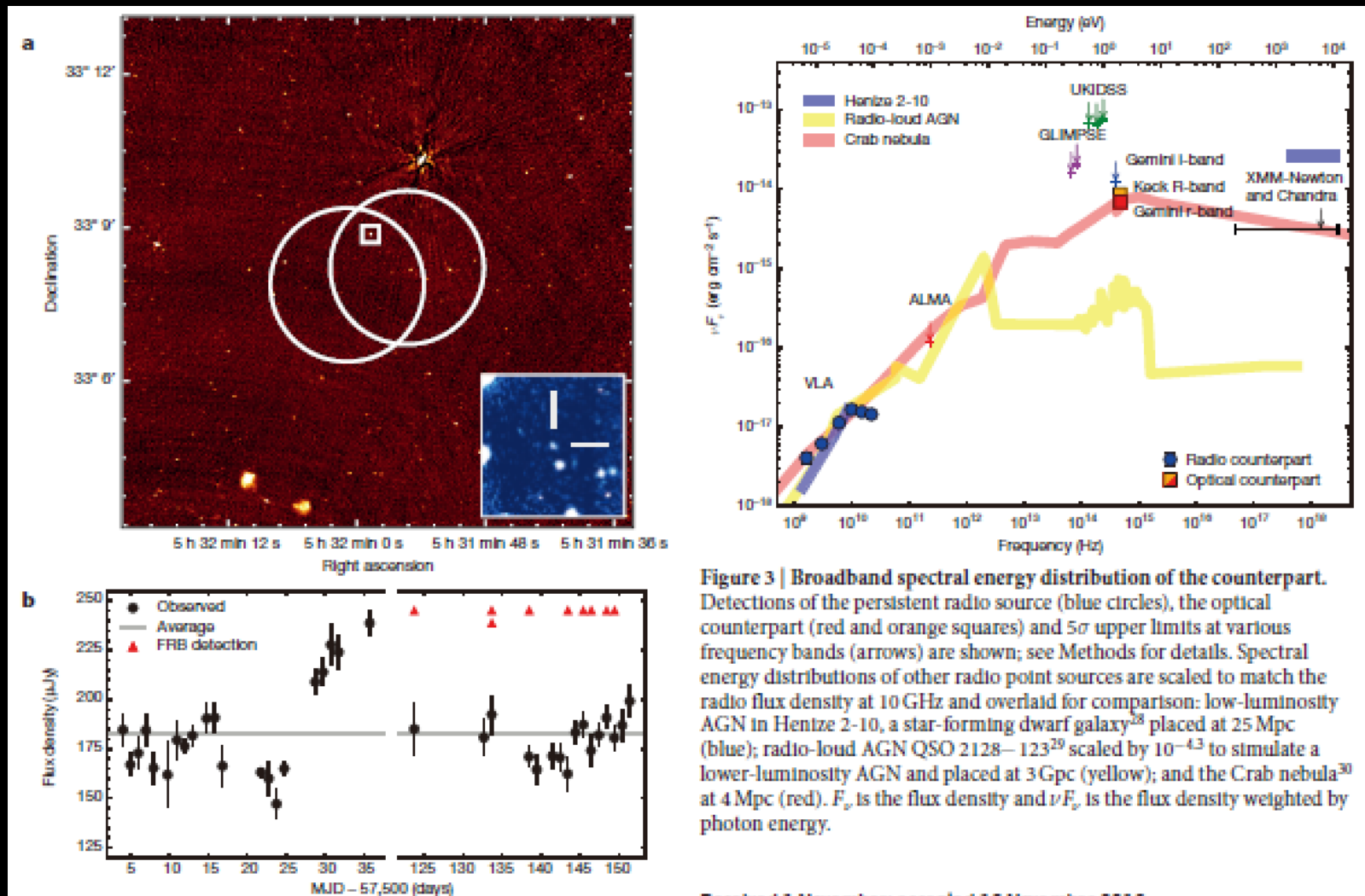
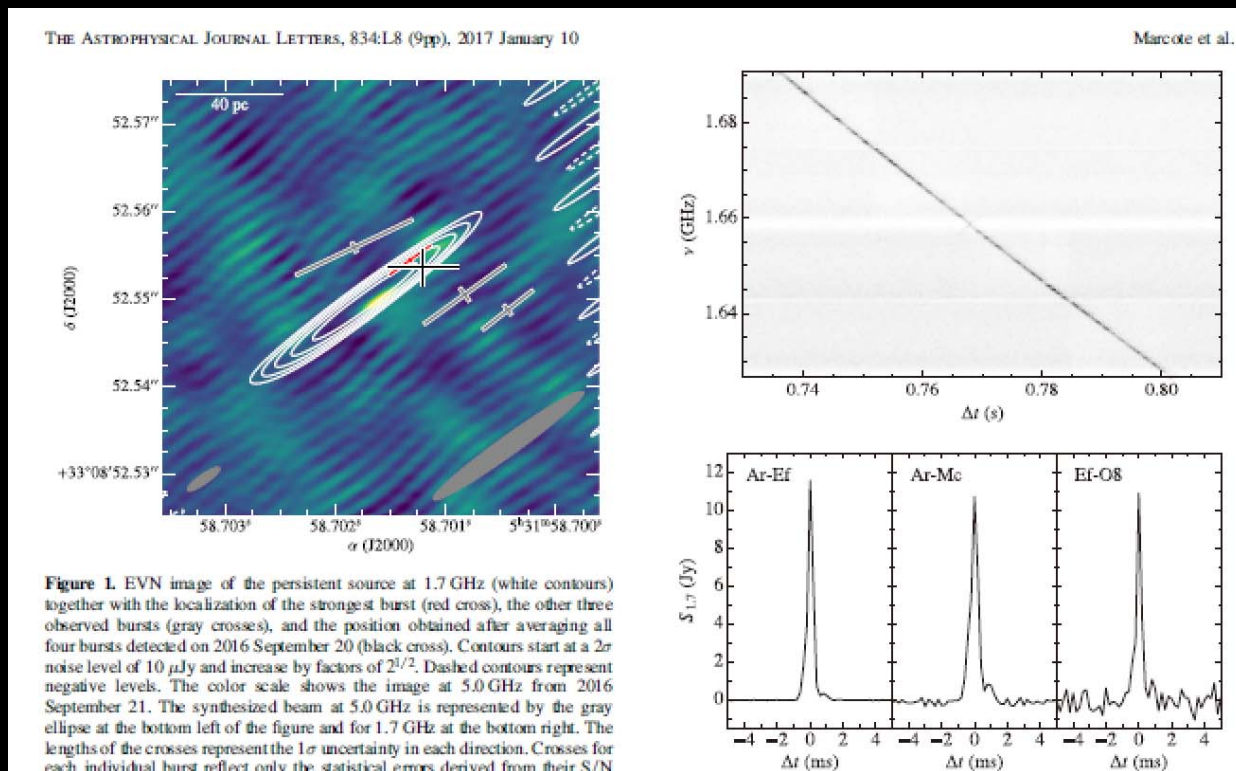


Figure 3 | Broadband spectral energy distribution of the counterpart. Detections of the persistent radio source (blue circles), the optical counterpart (red and orange squares) and 5σ upper limits at various frequency bands (arrows) are shown; see Methods for details. Spectral energy distributions of other radio point sources are scaled to match the radio flux density at 10 GHz and overlaid for comparison: low-luminosity AGN in Hentze 2-10, a star-forming dwarf galaxy²⁸ placed at 25 Mpc (blue); radio-loud AGN QSO 2128-123²⁹ scaled by $10^{-4.3}$ to simulate a lower-luminosity AGN and placed at 3 Gpc (yellow); and the Crab nebula³⁰ at 4 Mpc (red). F_ν is the flux density and νF_ν is the flux density weighted by photon energy.

Received 1 November; accepted 16 November 2016

FRB121102 detection with VLBI

- Detected with EVN (European VLBI Network)



Marcote+
(2017)

Position consistency between transient and persistent emission

ただし、このようなVLBI観測ができるのはrepeating burstのみ...

何らかの方法でターゲット候補を絞れればVLBIもできる？

VLBIでやってみたことがある方、
ご相談ください

