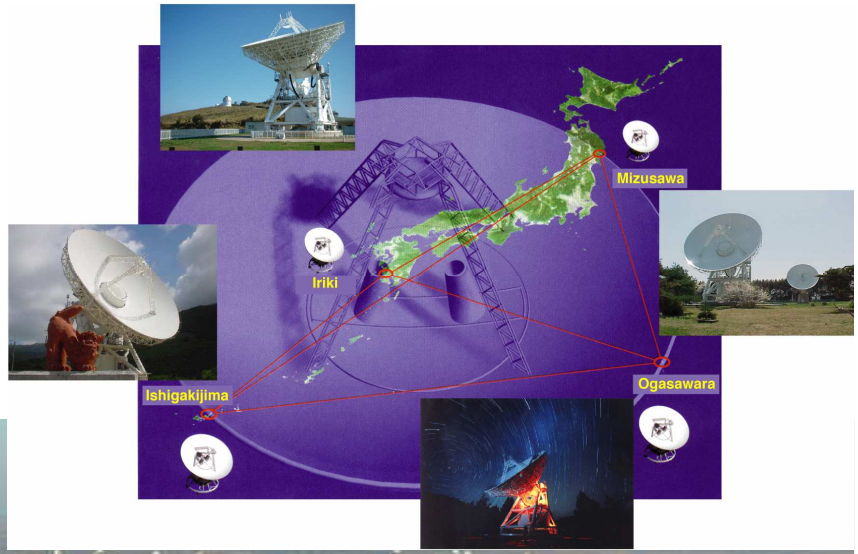
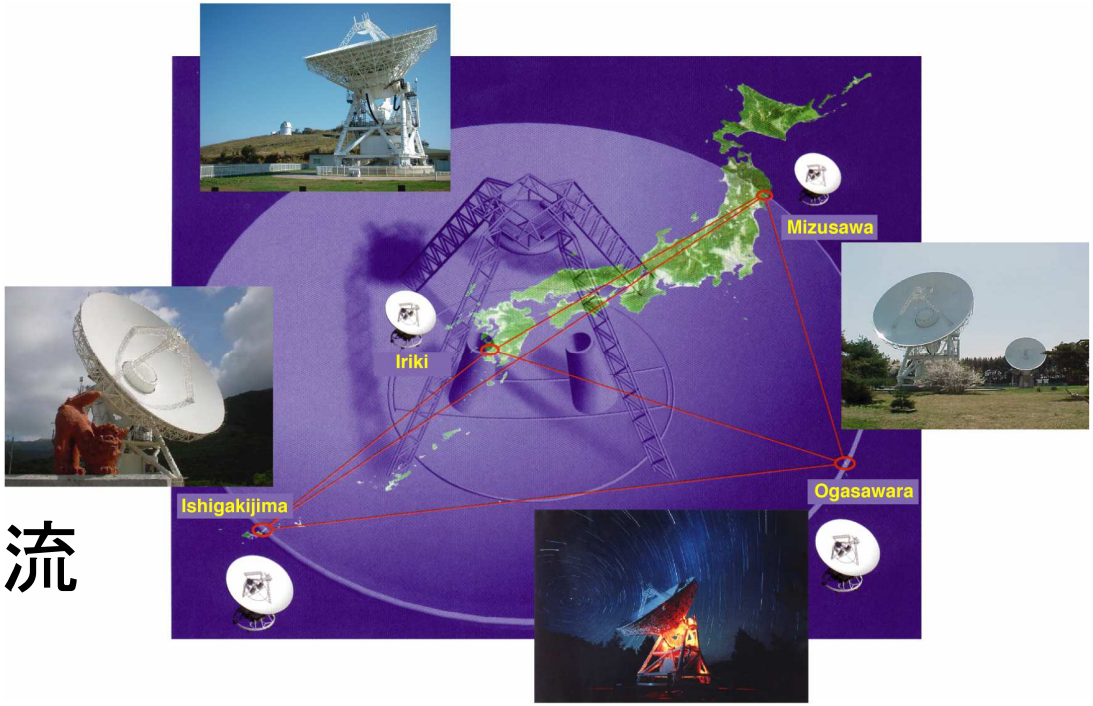
SKAによる
電波アストロメトリ



アンテナ
4台から
2000台へ

今井 裕
鹿児島大学大学院理工学研究科

8年後のSKA
参加を目指して



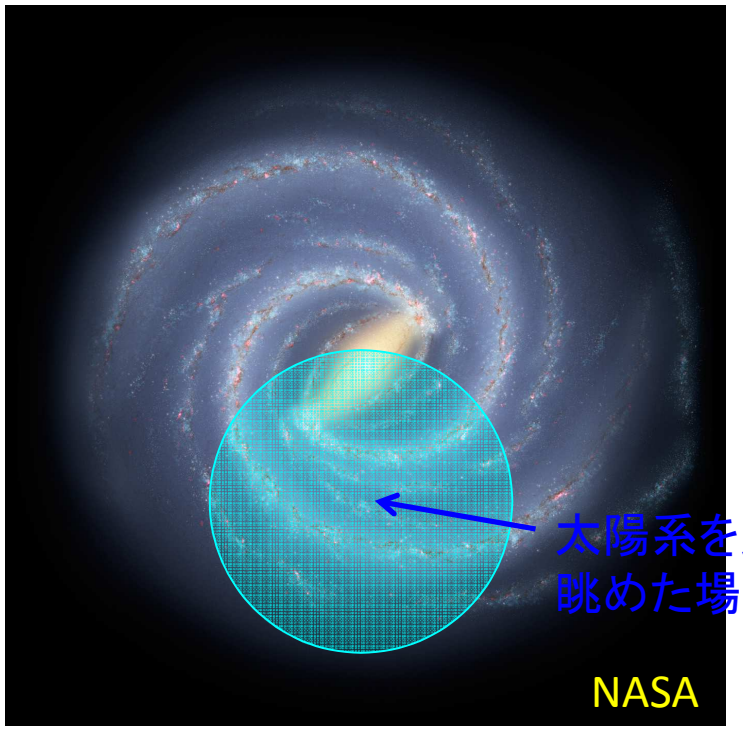
1994年の
水沢観測センターへ合流
→2002年VERA完成

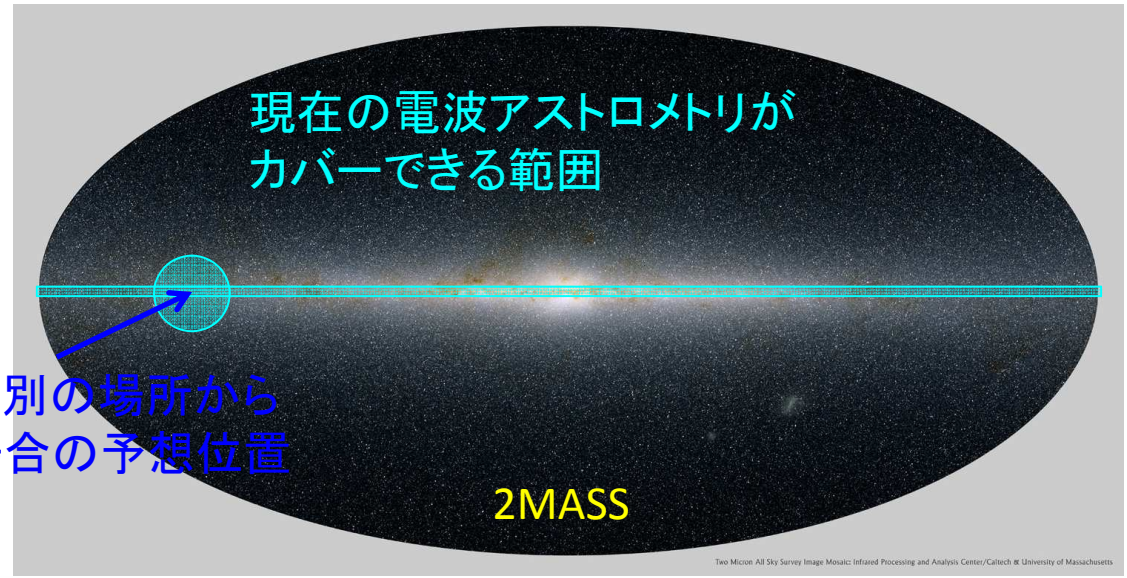
2012年のパース長期滞在
→2020年頃SKA (Phase 2) 合流（目標）

銀河系の歴史を紐解くための次世代電波アストロメトリ

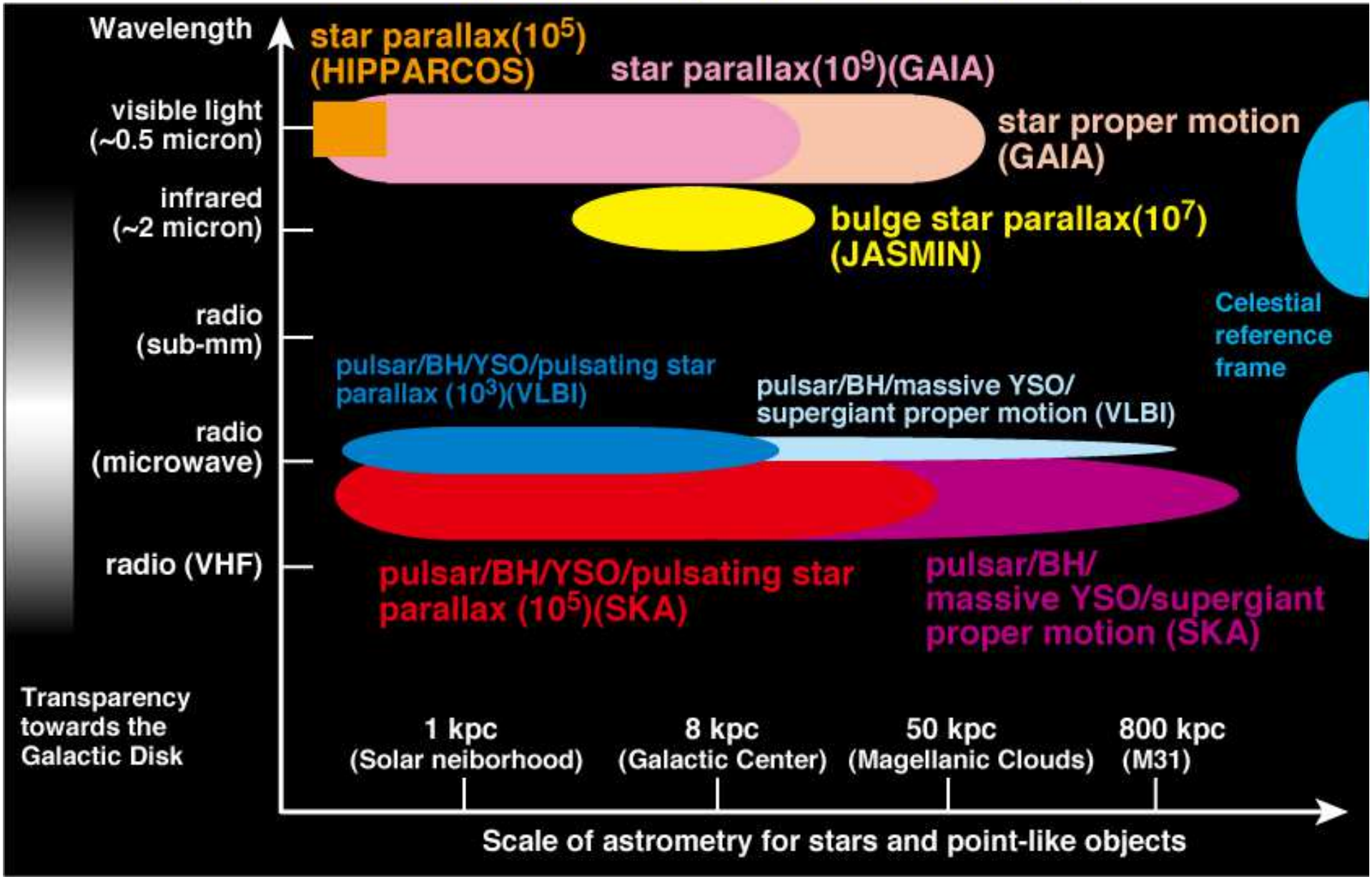
- ✧ 10,000天体以上の銀河系電波源測量　近傍銀河も(固有運動)
  - ✧ 広視野・多天体同時 *絶対座標*・固有運動計測
  - ✧ 多彩な長波長電波源（BH、パルサー、メーザー源[OH, CH_3OH]、フレア星）
  - ✧ 銀河系の広範囲をカバー（銀河系バルジ、マゼラン雲、局所銀河群）
- ✧ 高精度・高安定度を持つ時空座標系の構築
  - ✧ クェーサー準拠座標系の維持、銀河回転による「光行差」の計測
  - ✧ 重力レンズ効果、星間シンチレーション、突発天体の監視

※パルサーを使った重力波検出には
年周視差・固有運動計測が不可欠





Scientific scope of SKA astrometry



SKAによる天の川銀河測量に関する試算

- VERAアストロメトリ (最高効率の場合)
  - １天体年周視差計測の所要時間（概算）: ４時間x6回/年 × 1.5年=36時間/計測
  - 全体の天体数: 600天体/１５年間 → 600 x 36 / 15 = 1440時間 / 年

  計測所要時間はこれより長い。しかし、計測数をもっと増やせるはず
- SKAの場合 (15 m鏡 2000台を仮定）
  - Tsys ~50 K (VERAの半分程度)、η_A~0.7 (VERAの1.3倍）
  - 輝線周波数幅は1/14 (22 GHz/1.6 GHz)
  - 基線感度その１:　1000 x 15 m 鏡 (core station) ― 36 x 15 m 鏡 (remote station)

  → VERAの約80倍の感度、データ校正段階で**VERAがカバーする距離の9倍をカバー**
  - 基線感度その2:　remote ― remote → VERAの約17倍の感度
  - 検出感度:　27 remote stations + core → VERAの約300倍の検出感度

  → 同じ積分時間ならば **VERAがカバーする距離の17倍をカバー**

  → 観測時間換算で90 000倍の効率
  - 角分解能:　(22 GHz / 1.6 GHz) x (2300 km/ 10000 km) = 3.2

  → 信号雑音比 が 3.2倍必要　→　同じ感度ならば10倍の積分時間が必要
- 銀河系測量の効率
  - **距離は3.2倍**で同じ精度**→ 90倍の効率**
  - 複数天体同時測量（1-3天体同時、平均2天体？）**→ 180倍の効率**

SKA年間運用総時間の0.6 %程度で実行可能のはず。

Baseline and array sensitivity in SKA1

- Baseline sensitivity (for calibration)

mJy-level continuum calibrators useful (~10 mJy at present)

$$\sigma_{i,j} = \frac{\sqrt{SEFD_i SEFD_j}}{\sqrt{2\Delta\nu t_{\rm int}}} \approx 0.03[\rm mJy] \frac{\sqrt{\left(SEFD_{\rm core}/2.1\rm Jy\right)\left(SEFD_{\rm remote}/42\rm Jy\right)}}{\sqrt{\left(\Delta\nu/0.5\rm GHz\right)\left(t_{\rm int}/100\rm s\right)}}$$

c.f. SEFD=42 Jy @Parkes 64-m L-band

- Image sensitivity (core-remote baselines only)

10 mJy-level OH masers as astrometry targets (~1 Jy)

$$\sigma_{\rm image} \leq \frac{\sigma_{\rm baseline}}{N_{\rm station}\sqrt{\Delta t/t_{\rm int}}} \approx 1.9[\rm mJy] \frac{1}{\left(N_{\rm station}/4\right)\sqrt{\left(\Delta t/400\rm s\right)}\sqrt{\left(\Delta v/1\rm km\ s^{-1}\right)}}$$

Number of continuum reference sources

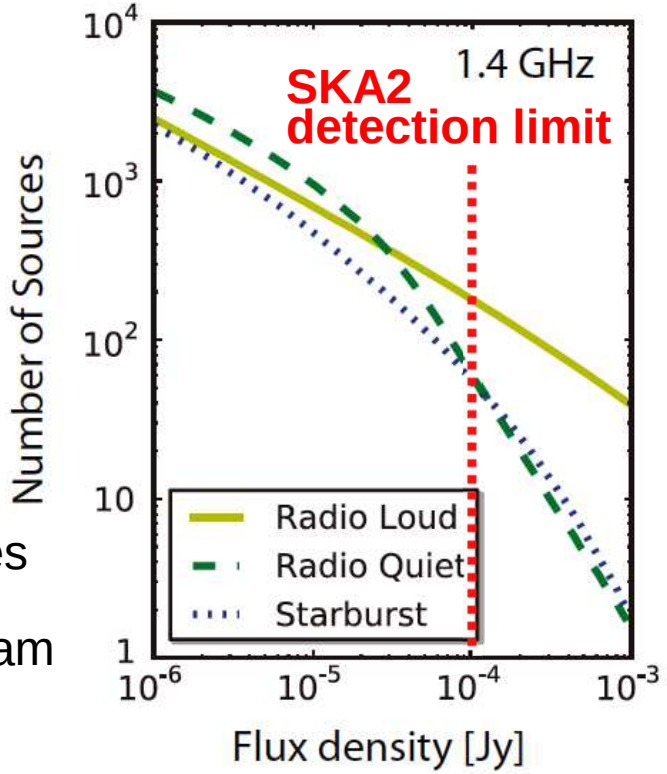
- Residual contributed from the atmosphere
  - Dynamic component (Asaki et al. 2007)

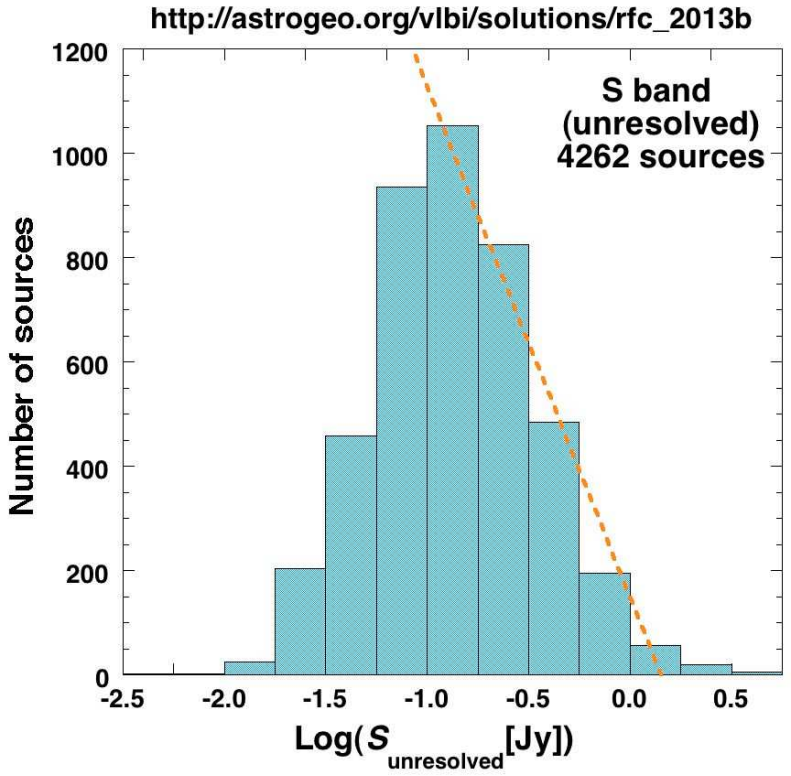
    $\Delta\vartheta_{(\text{target} - \text{reference})} < 24^\circ$ @1.5 GHz for 10 μas-level astrometry
  - **Static component (ionosphere) should be taken into account.**

    →multiple calibrators
- **~30 000 calibrators with S_ν>0.5 mJy** (estimated from rfc_2013b)

  → Calibrators for all targets at longest within 1° .2

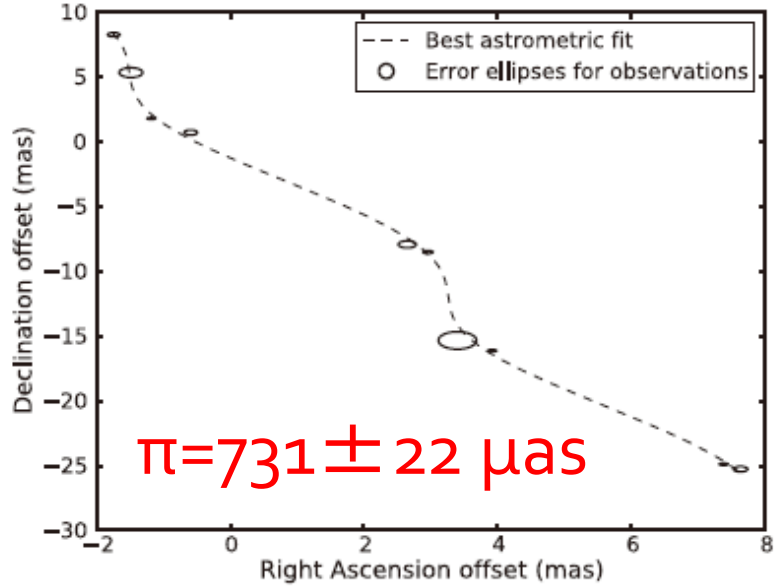
Number of Reference sources per primary 15-m antenna beam (0.7°)
(SKA Memo 135)

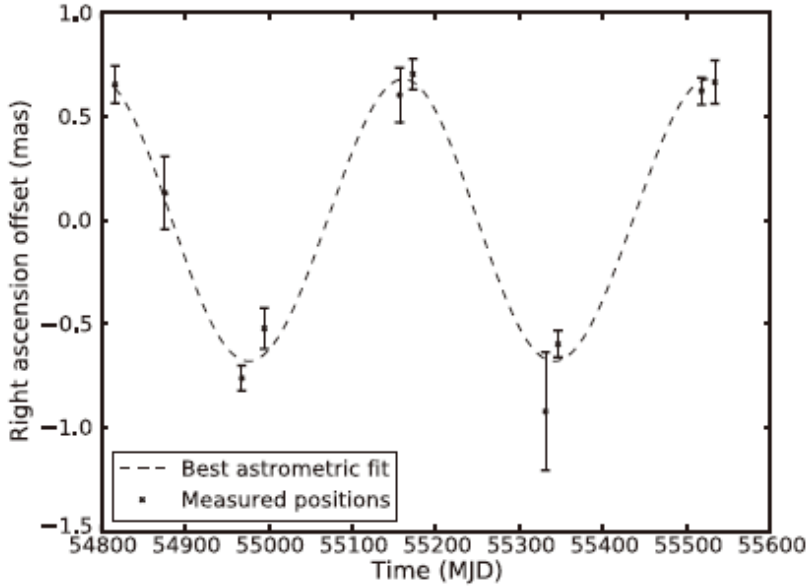




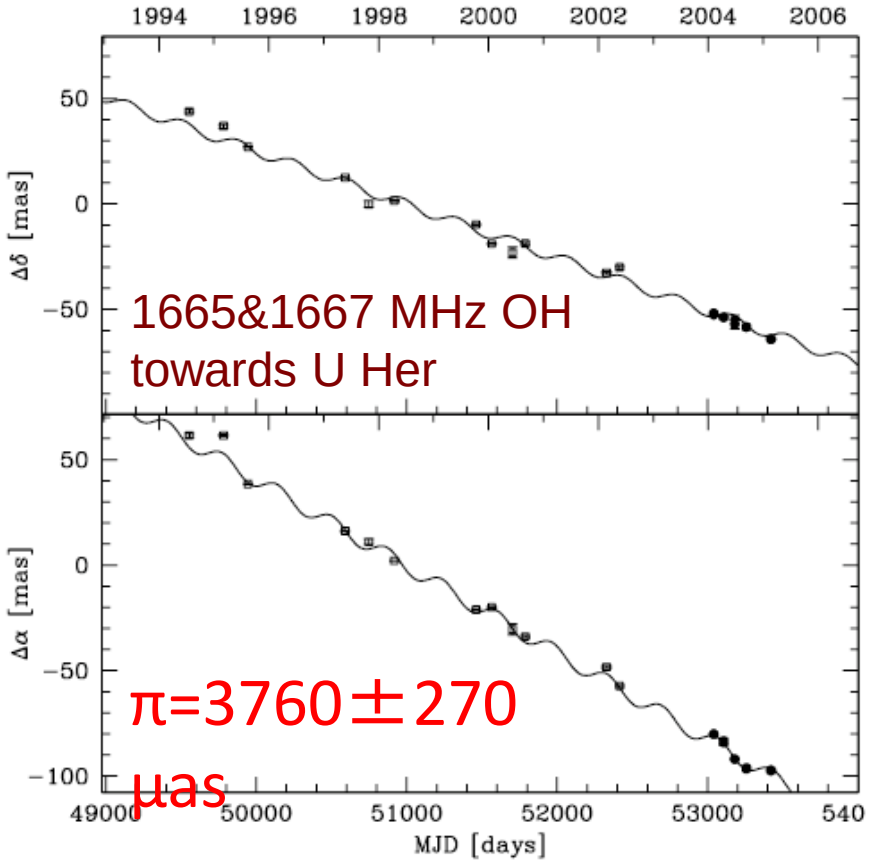
Trigonometry of OH masers

Pulsar astrometry at L-band:
J1023+0038 (Deller et al. 2012)





- Only three papers!
  - van Langevelde et al. 2000; Vlemmings et al. 2003, 2007
  - Towards 6 Mira variables
- **Possible, but challenging!**



Testing L-band astrometry (EVN, LBA, VLBA)

- OH maser + QSO(s) within a single beam

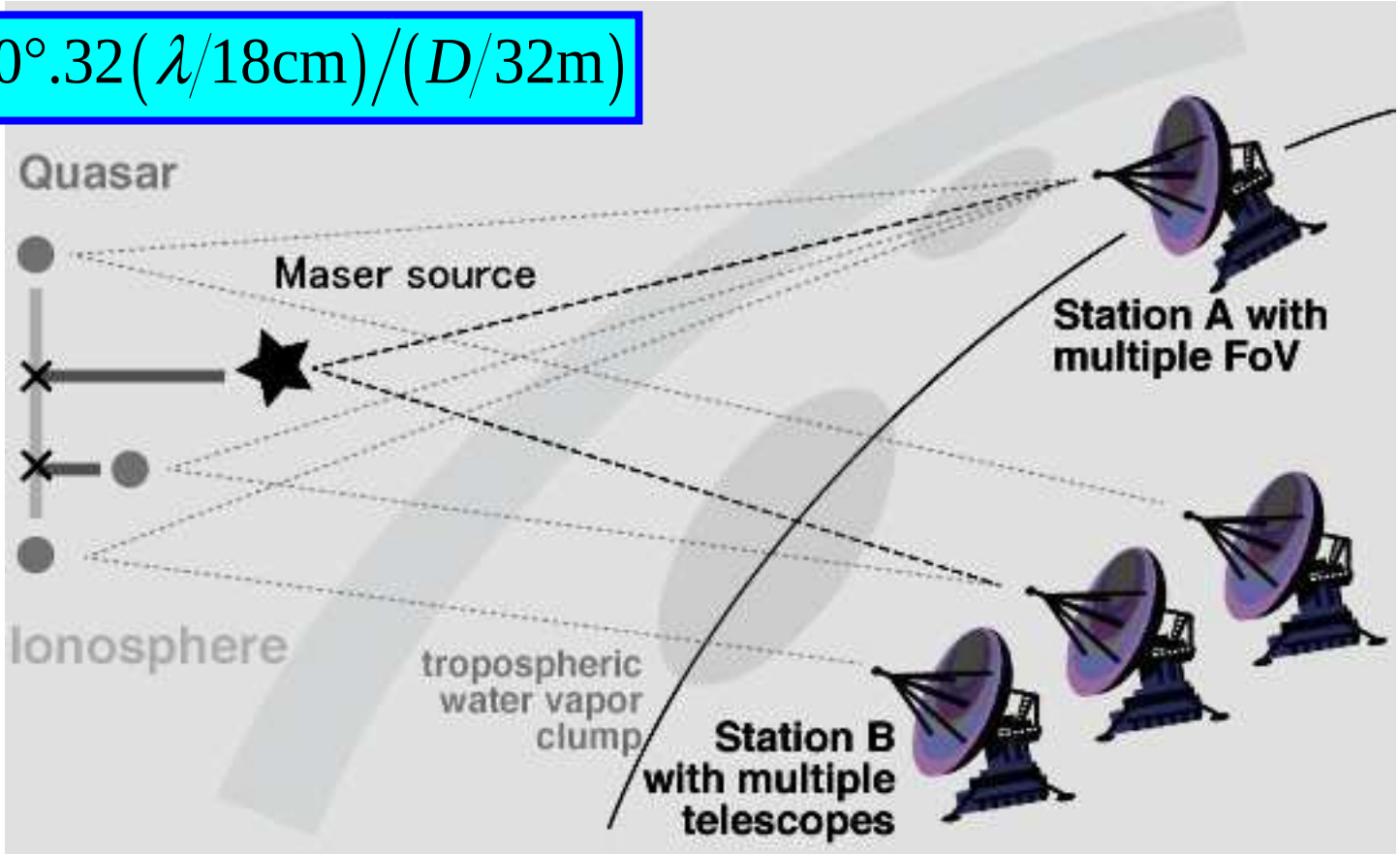
For perfect phase-referencing

A few pairs available from the OH maser catalog (Engels 2012)

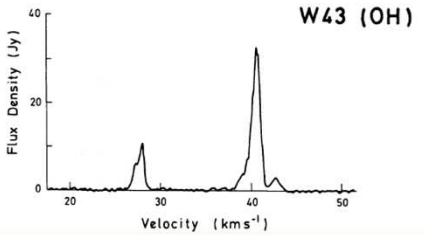
- More calibrators within $X(<5)$ deg from

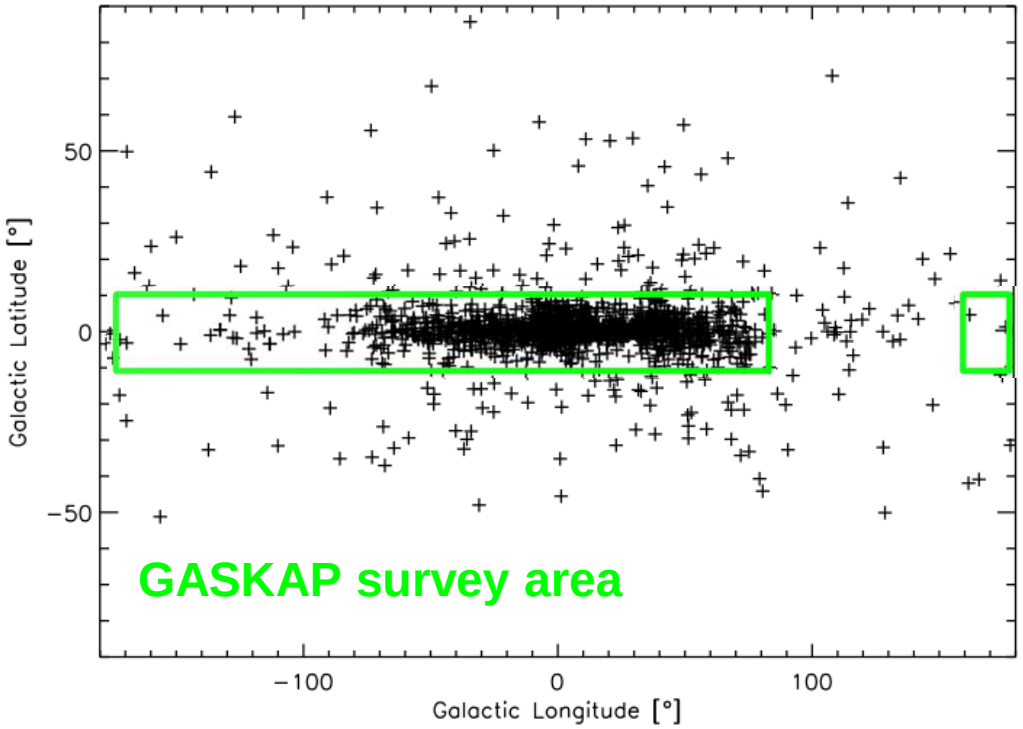
For estimating error contribution due to different angles

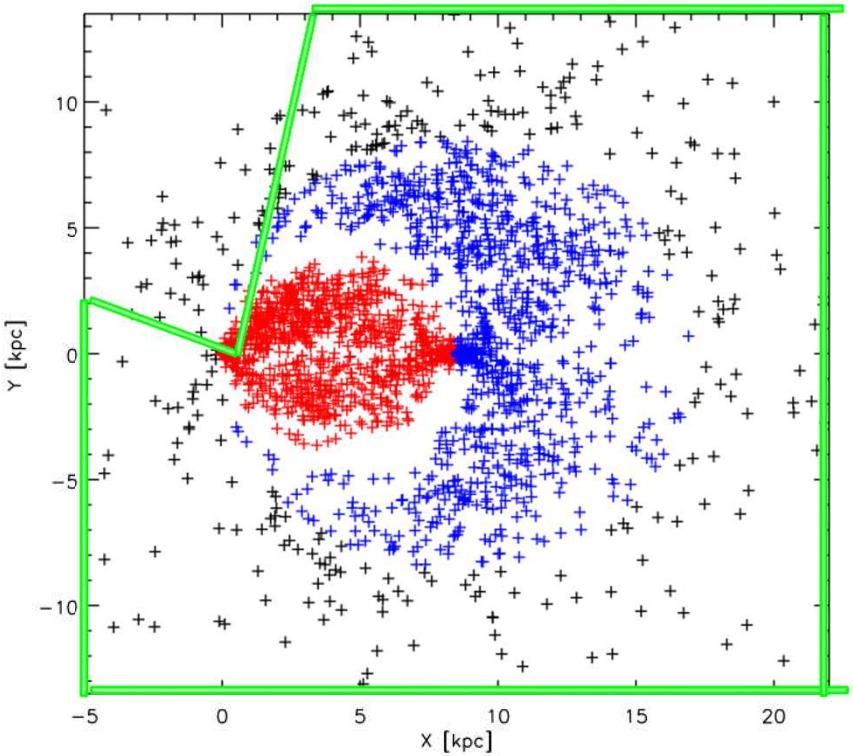
$$\theta_{\mathrm{FoV}} \approx 0^{\circ}.32\left(\lambda/18\mathrm{cm}\right)/\left(D/32\mathrm{m}\right)$$



Stellar 1612 MHz OH maser sources distributed in the whole Milky Way







- From young population (supergiants), to old population (Mira variables, OH/IR stars, post-AGB stars
  - Any location: Galactic thick disk, bulge, halo (globular clusters)
  - ~10 000 Galactic OH masers promising

2245 catalogued source, http://www.hs.uni-hamburg.de/~st2b102/maserdb

SPLASH (Southern Parkes Large Area Survey in Hydroxyl)

Dawson et al.

- ~100 1612-MHz OH maser sources within 10° x 4° area

→ > 3000 OH masers along Galactic plane detecte

SPLASH sensitivity (~300 mJy at 6-σ)

- Mildly localized distribution

→ mixture of SFRs and OH/IR stars

SKA primary beam

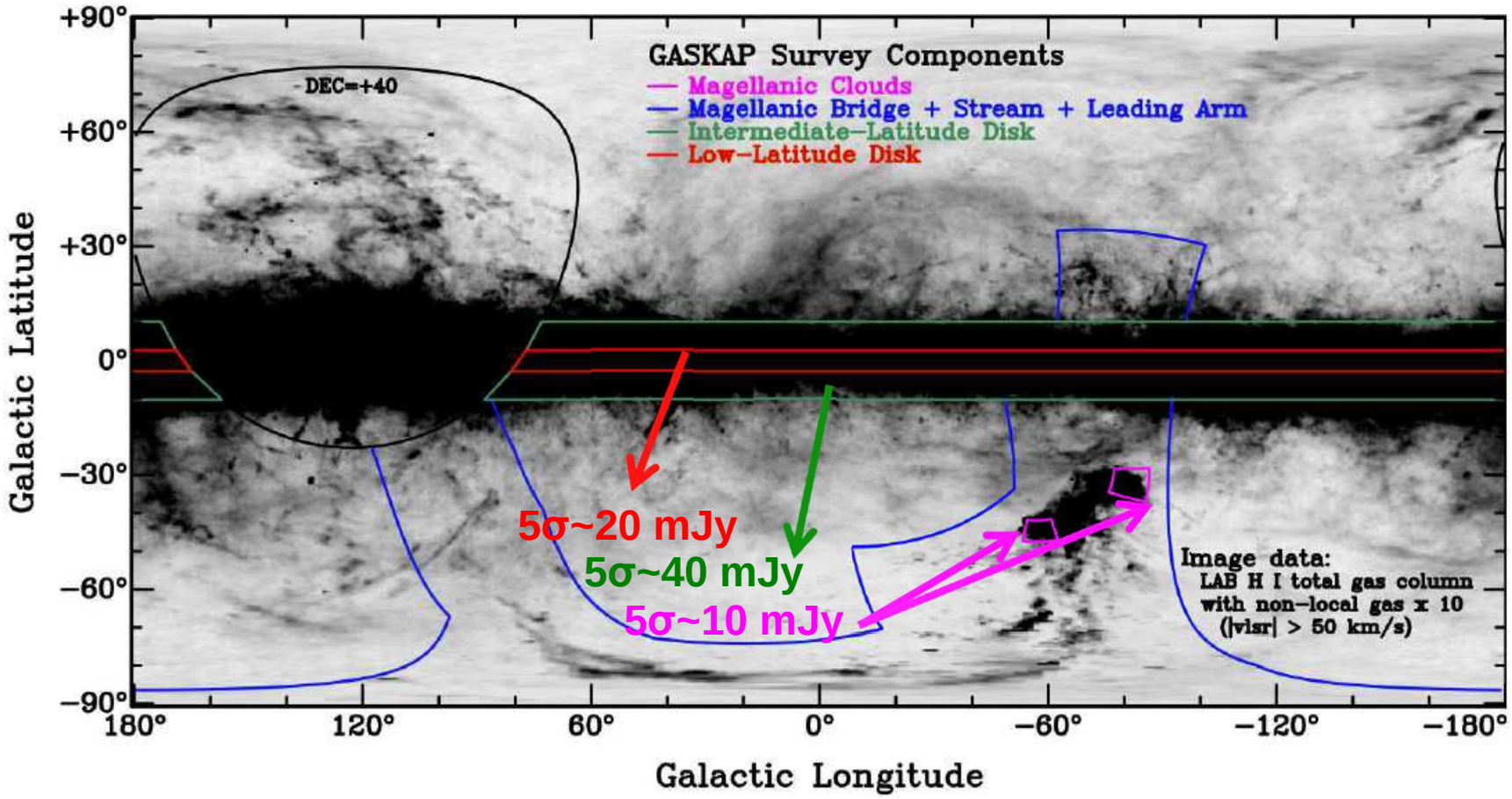
Masers:
- 1612 MHz (106 sources)
- 1665 MHz (42 sources)
- 1667 MHz (45 sources)
- 1720 MHz (9 sources)

Not available in proceedings, sorry.

GASKAP Galactic ASKAP Spectral Line Survey

Dickey et al. 2013 **will start from 2015**

- Simultaneous mapping of HI and OH
- Galactic dynamics probed by OH masers
- Present sits of star formation and stellar mass loss in the Milky Way

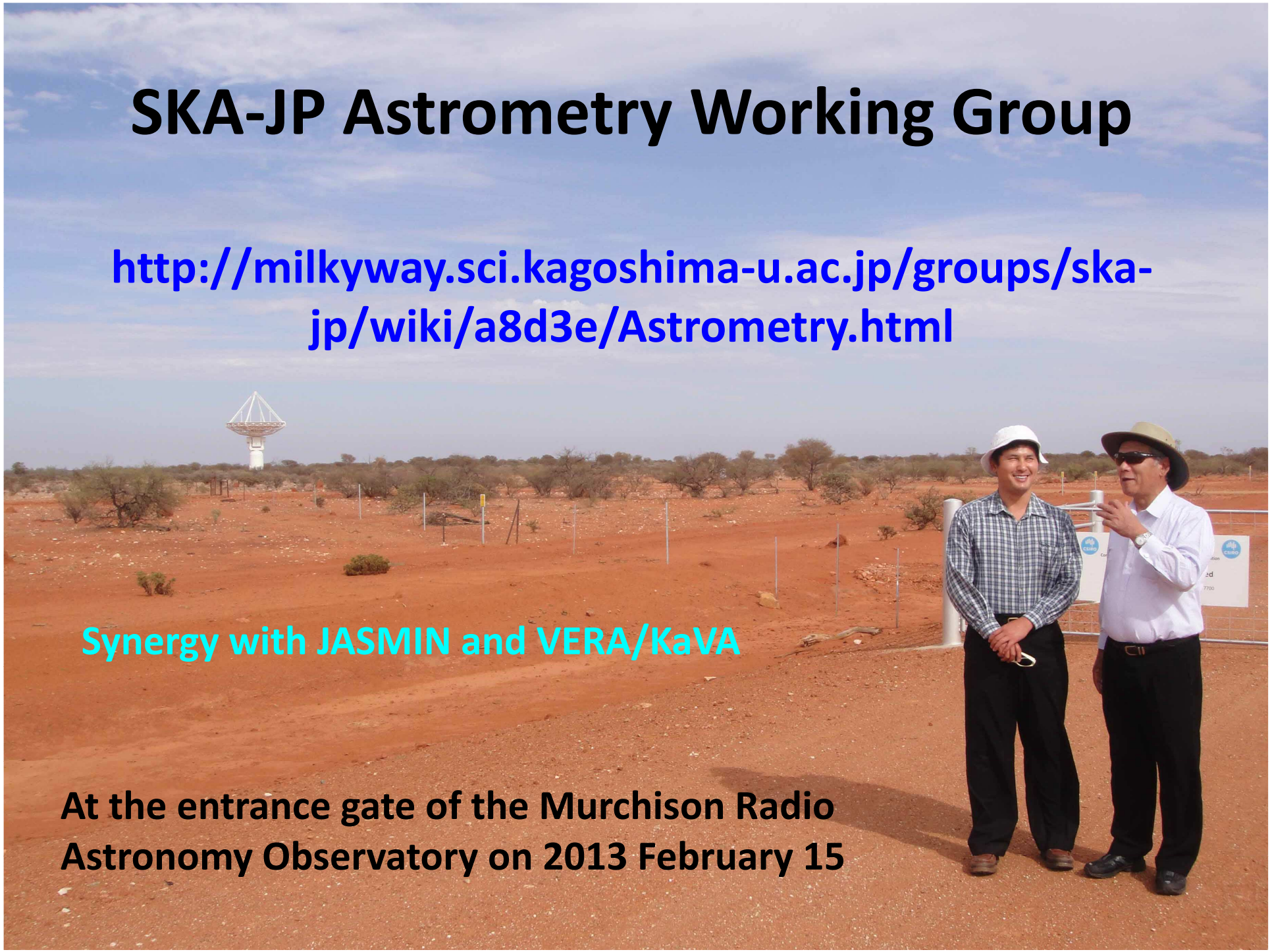


Issues

- No documents of specifications for VLBI in SKA
- Feedback to the latest baseline design by this September
  - **Recording phased-up signals onto hard disks**
  - **Optical fiber links between SKA core and existing telescopes**
- Limited chance of VLBI in SKA
  - Field of view: How about SKA1-survey?
  - **Remote stations (stations in EAVN?)**
- Moderate-length baselines are necessary.
  - **<3000(?) km for OH masers**
  - Common sky coverage, good (u,v) coverage
- Demonstrations of OH maser astrometry
  - Supported by JSPS grant-in-aid (挑戦的萌芽研究)
  - With EVN, LBA, and VLBA (medium-size project?)
- Synergy with pulsar teams

SKA-JP Astrometry Working Group

http://milkyway.sci.kagoshima-u.ac.jp/groups/ska-jp/wiki/a8d3e/Astrometry.html



Synergy with JASMIN and VERA/KaVA

At the entrance gate of the Murchison Radio Astronomy Observatory on 2013 February 15