September 05-07 @Pyeongchang, Korea
The 11th East Asian VLBI Workshop

KaVA Imaging Survey of 44.1 GHz CH_3OH Masers in the Large Program of Star Formation

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On behalf of (Affiliation: 2. KASI, 3. Yamaguchi Univ., 4. SKA Africa) :

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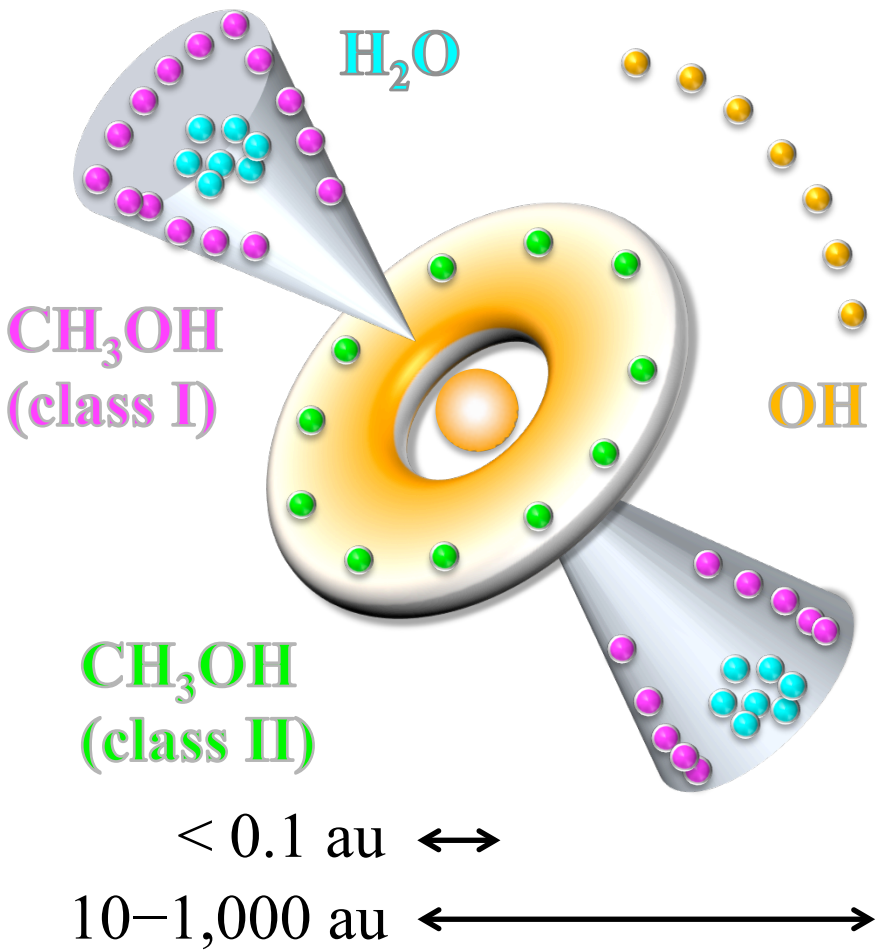
MASERs in high-mass SFRs



- Bright and compact emission
  - **3-D velocity** structure with VLBI
  - **Flux variability** and ***B*** **field**
- OH, CH_3OH, H_2O, H_2CO, etc
  - SiO is rare (e.g., Zapata+ 09)

Maser	Freq. [GHz]	Sites
OH	1.6, 1.7, 4.7, 6.0, 13.4, ...	Edge of HII region
CH_3OH (class II)	6.7, 12.2, 19.9, 23.1, 107, ...	Disk
CH_3OH (class I)	9.9, 25.0, 36.2, 44.1, 95.2, ...	Outflow
H_2O	22.2, 321, ...	Jet / outflow

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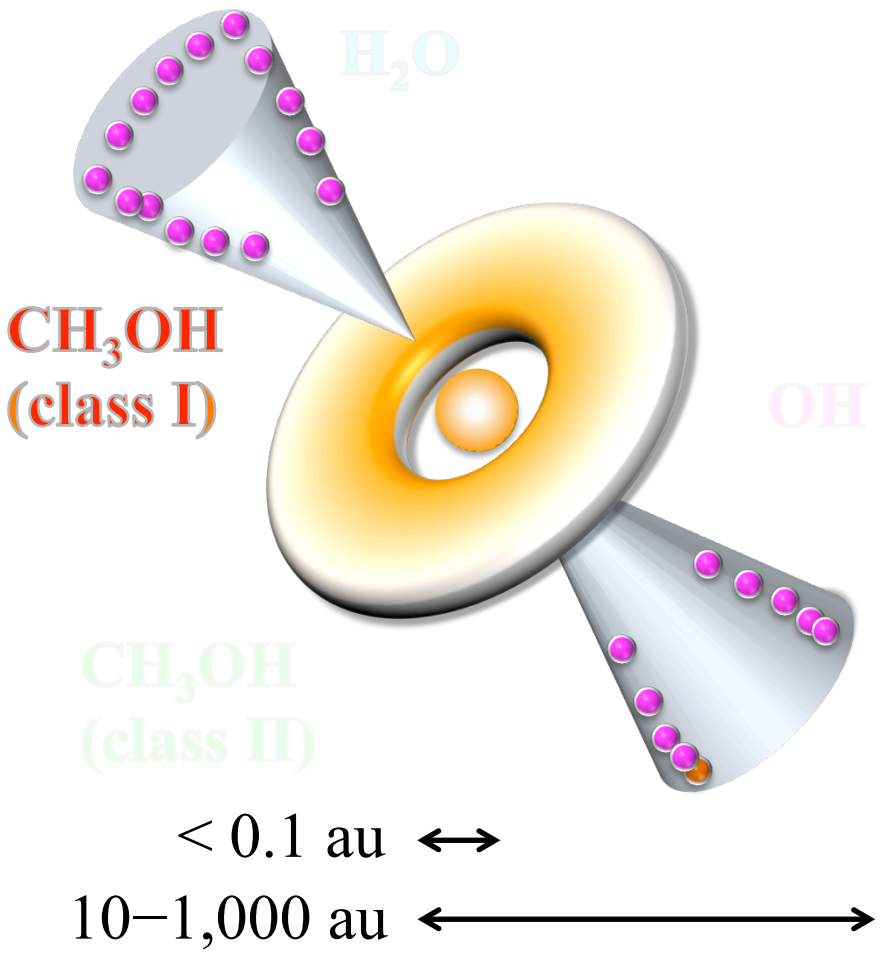

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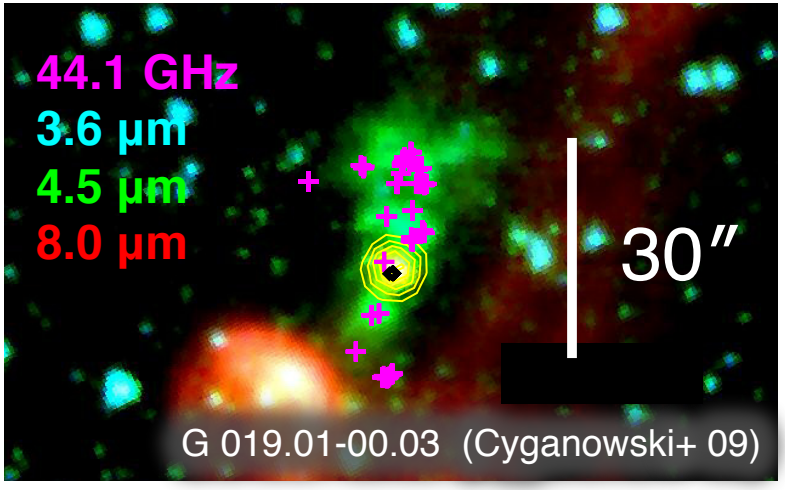
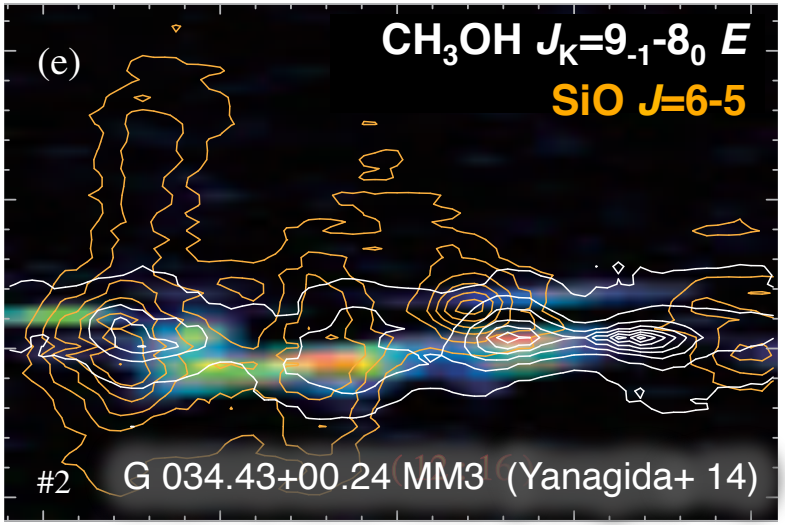
Class I CH_3OH masers

- Possibly trace low-velocity old/weak outflows (LVOs)
  - Associated with **shock/EGO** (e.g., Kurtz+ 04; Cyganowski+ 09)
  - **Narrow** LSR **velocity range** (Fontani+ 10)
  - **Anti-correlation** toward **SiO** thermal lines (Yanagida+ 14)

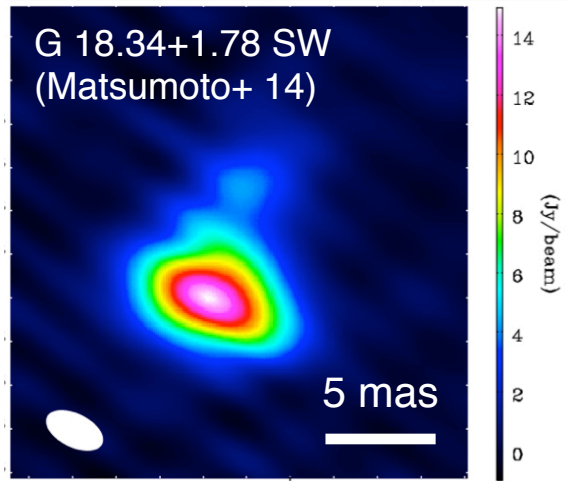
☞Unique probe in HMSFRs unlike other masers

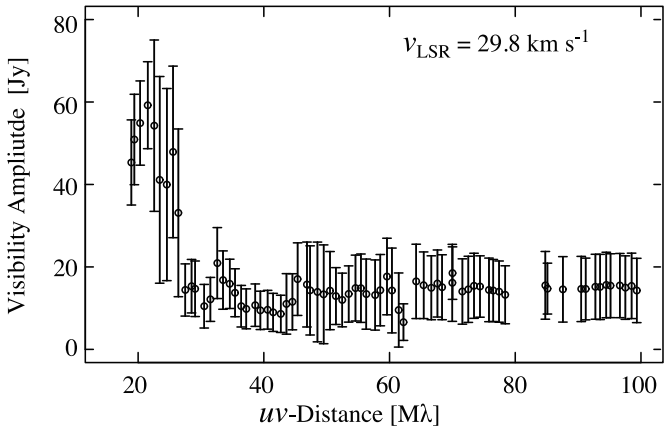




Advantage of KaVA

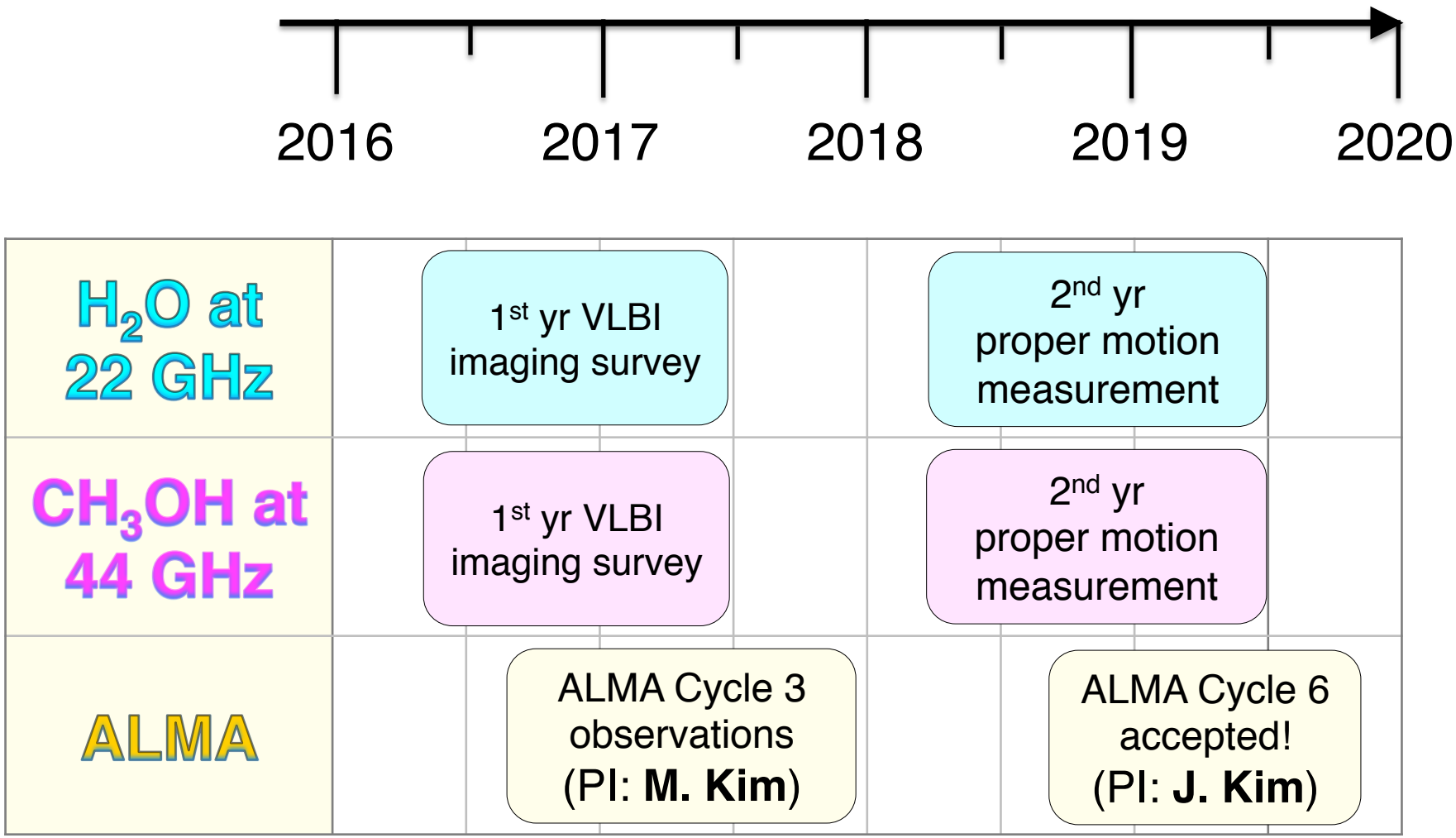
- Short baselines formed mainly by KVN stations
  - Overcome the "resolved out" due to extended spot/feature
- First VLBI detection of class I CH_3OH masers （Matsumoto+ 14）
  - Until the first KaVA result at 44.1 GHz coming, **never detected with any other instruments** (Lonsdale+ 98)
- Estimated the size of spots
  - Revised 4 orders of mag. at most, compared to pervious ones (with VLA by Kogan & Slysh 98)





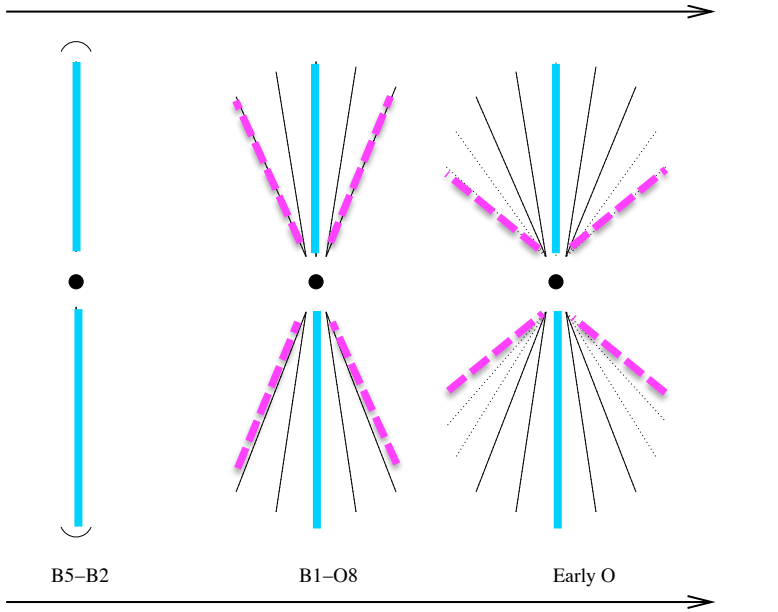
Matsumoto+ (14)

Timetable of KaVA LP



Outcomes expected in the LP

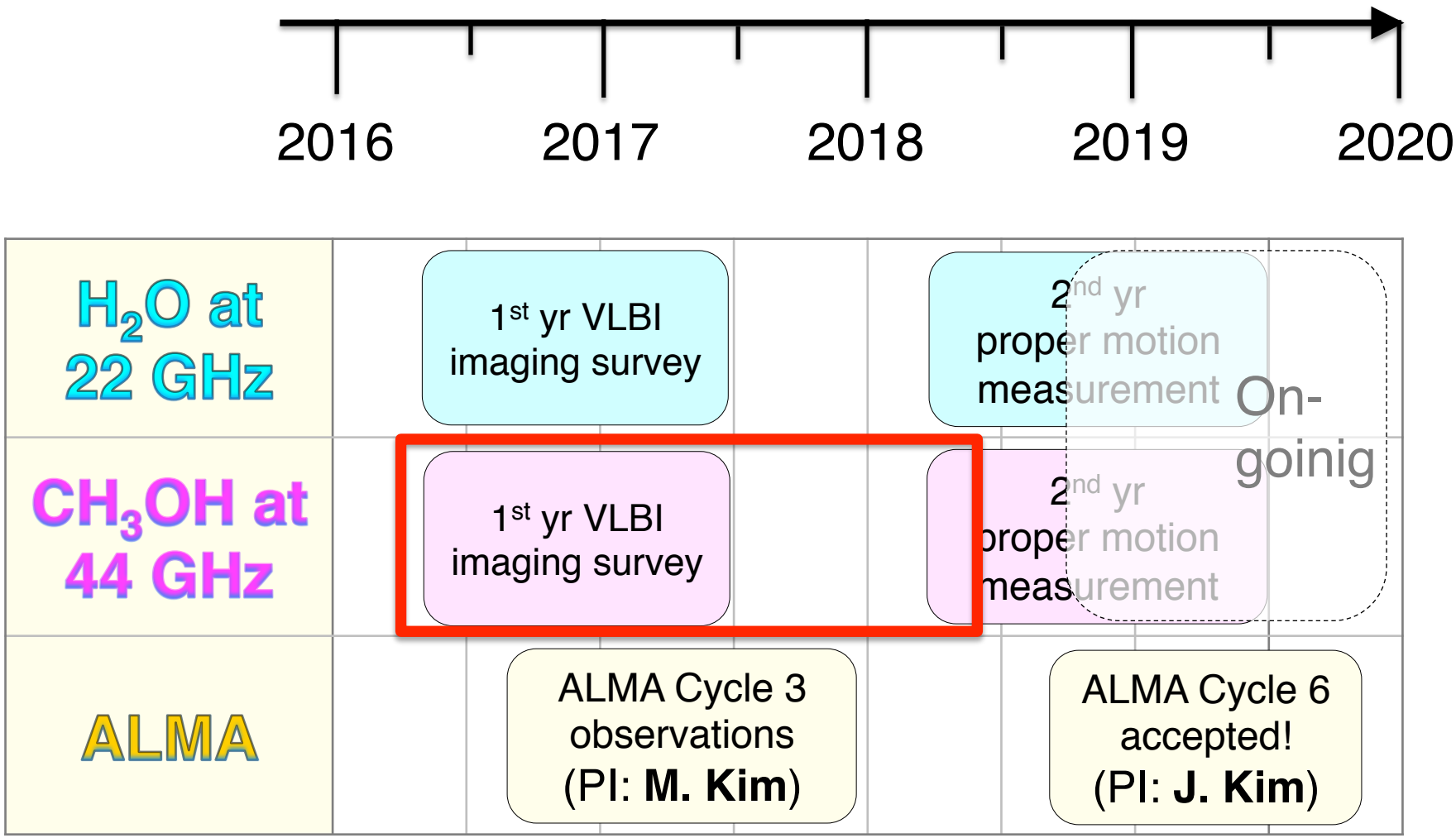
- The first understanding of **3-D velocity structure**
  - Direct verification for the association with LVOs
- **Statistics** of CH_3OH masers: e.g., **motion**, **size**
- Precise estimation **dynamical parameters**
  - e.g., LVO momemtum rate
- Unveil the **evolution of jet/outflow** system
  - Traced by H_2O/CH_3OH maser proper motions



Beuther & Shepherd (05)

Time

Topics here


2016
2017
2018
2019
2020
H_2O at 22 GHz
1st yr VLBI imaging survey
2nd yr proper motion measurement
On-goinig
CH_3OH at 44 GHz
1st yr VLBI imaging survey
2nd yr proper motion measurement
ALMA
ALMA Cycle 3 observations (PI: **M. Kim**)
ALMA Cycle 6 accepted! (PI: **J. Kim**)

KaVA LP in Star Formation at 44.1 GHz

1) 1st yr : Imaging survey

Observations in 1st yr

[**Duration**] 2016 March – 2017 Feb

[**Targets**] 19 sources

– Fringes had been already verified with KVN

[**Mode**] snap-shot imaging via 2 sources/day

[**Integration time**] ~2-3 hrs/source

[**Image noise rms**] ~50-200 mJy/beam

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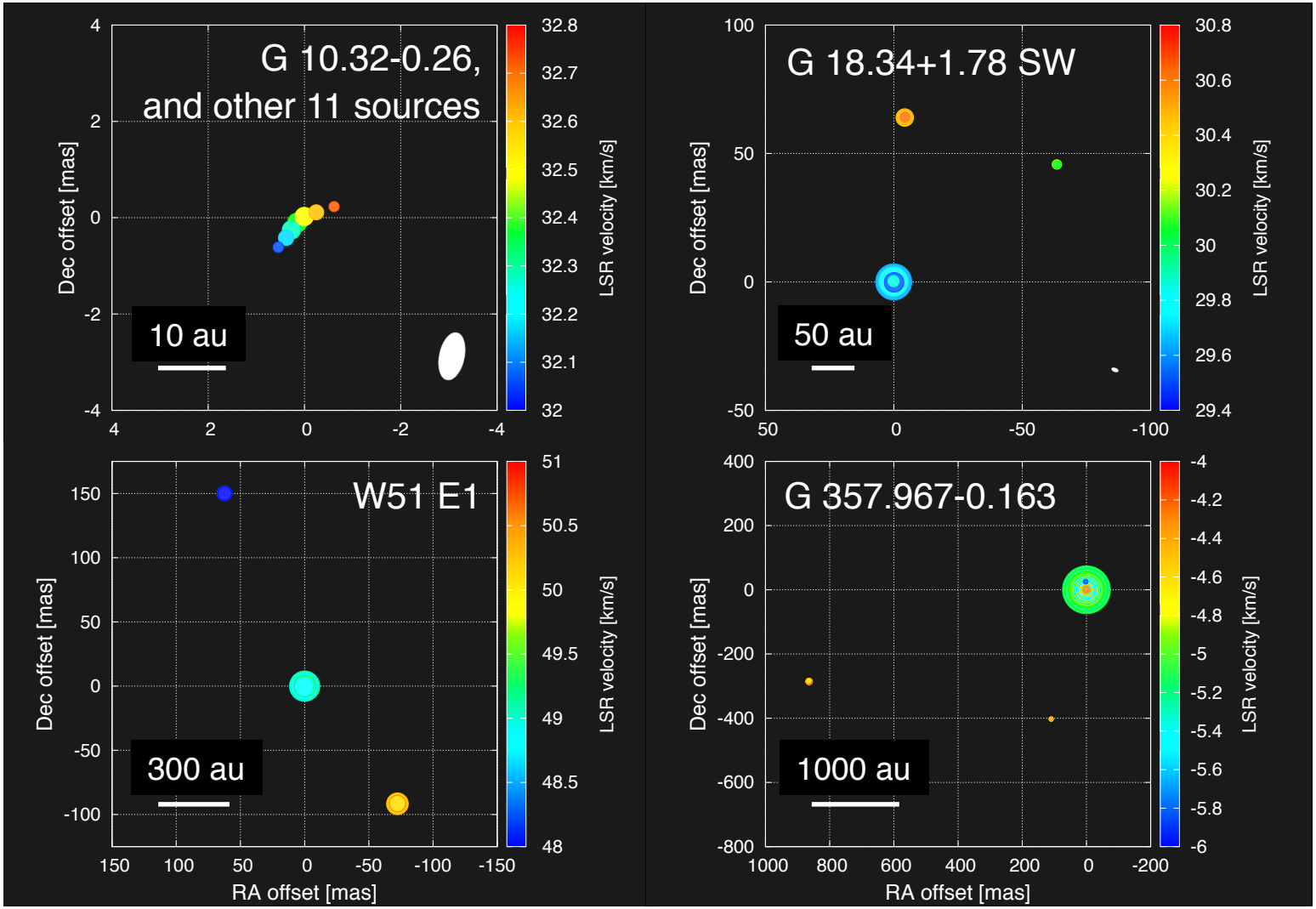
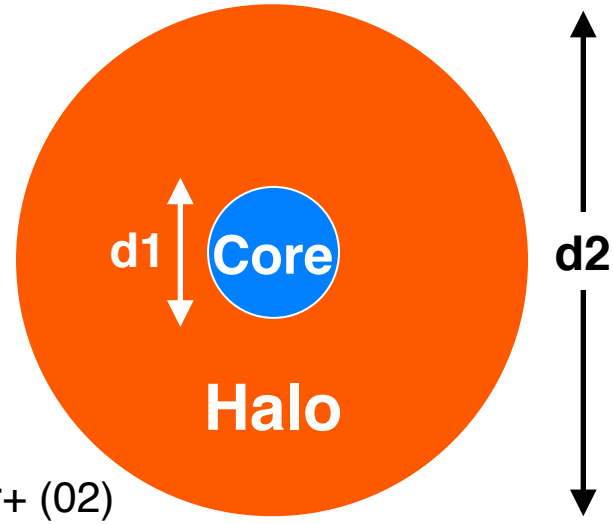
Results : VLBI imaging

Obtained in 16/19 sources

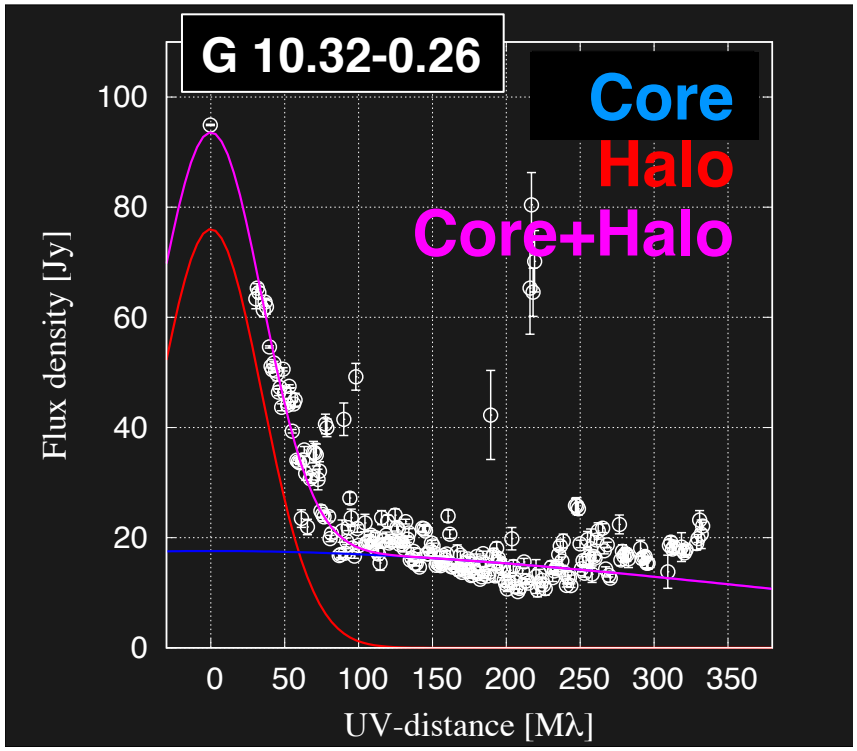


Results : Size and T_b estimations

- Fitted using 2-gaussian: **Core**/**Halo** components (Minier+ 02)
- Estimated T_b
  - The maximum one is more one mag. order of brighter



Minier+ (02)

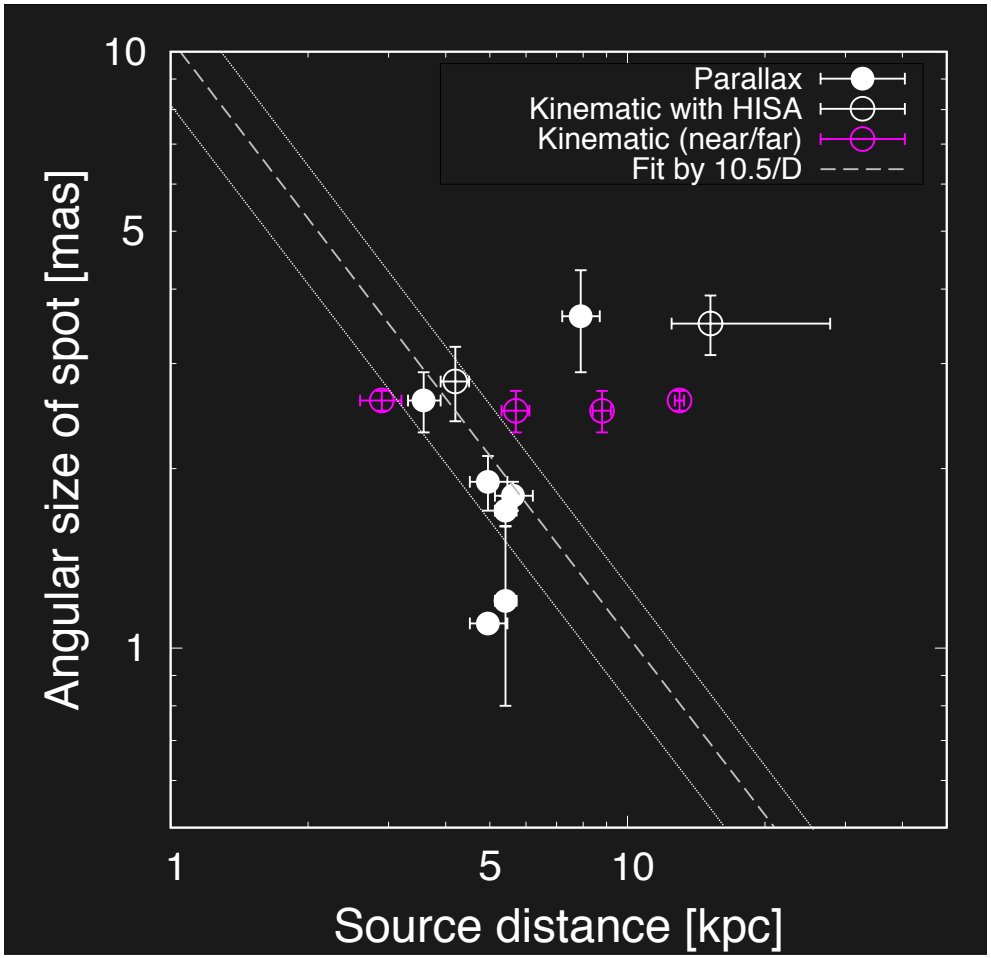


☞Estimated sizes & T_b:

Core : 0.5 au, T_b= 3.9 x 10^{11} K

Halo : 5.5 au, T_b= 5.6 x 10^{10} K

Discussion :
Relation in Size vs Distance



- Roughly aligned by $\propto D^{-1}$
  - Correlation –0.70
    - *p*-value 0.12

☞ **<u>Intrinsic size is possibly the same</u>** in all sources

- Problems: uncertainty in some source distances
  - 6 src : Parallax
  - 2 src : Kin. via HISA
  - 2 src : Kin. still near/far

KaVA LP in Star Formation at 44.1 GHz

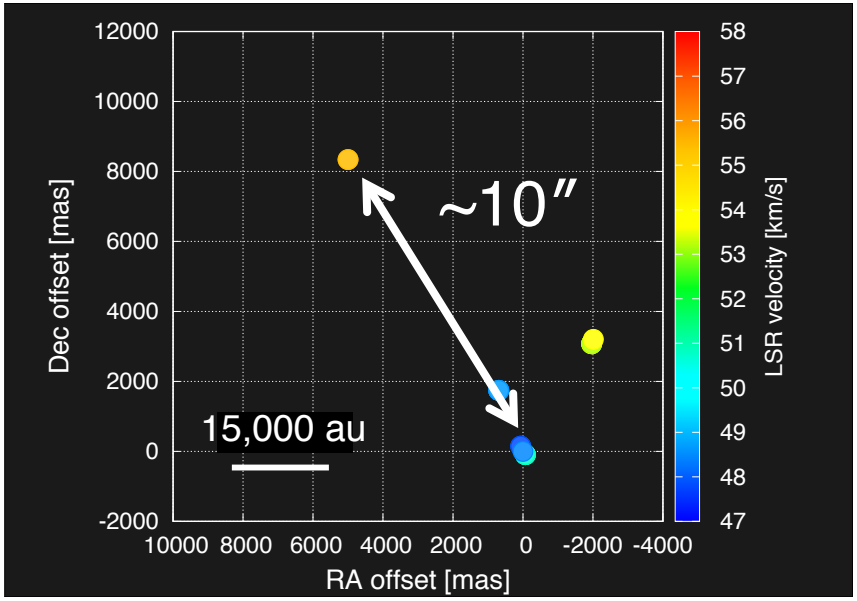
2) 2nd yr : Proper motions

Observation in 2nd yr

Purpose	Trial to measure proper motions
Date	April 12, 2018, 15:45 – 23:00 UT
Targets	G357.967, G018.34SW, G049.49 (At least, 3 maser features were detected in 1st)
Frequency	IF1: 43.877 – 44.005 / IF2: 44.005 – 44.133 GHz
Spectral	128 MHz in IF2 dividied by 8,192 ch
Requested	Accumulation period of **0.2 sec**

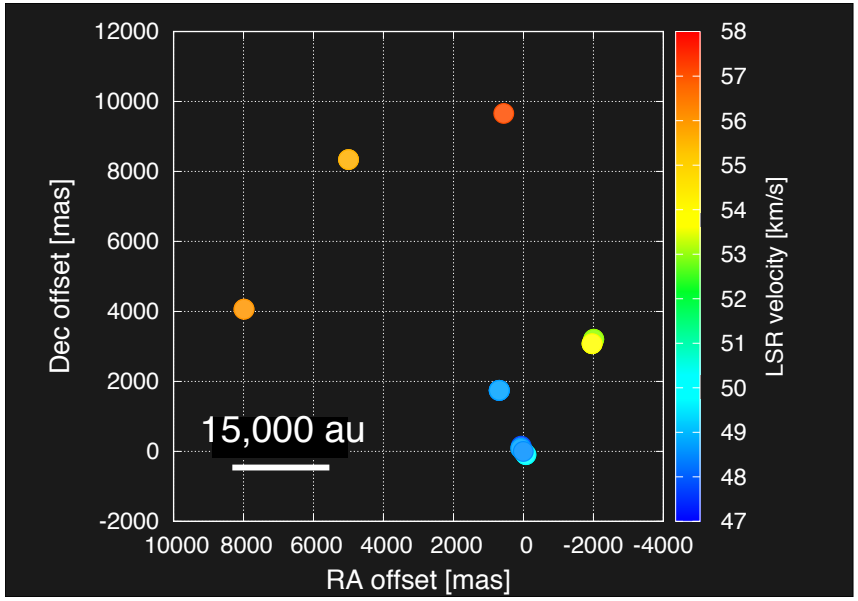
Result and Comparison

April 12, 2018



rms noise ~ 30 mJy beam^{-1}

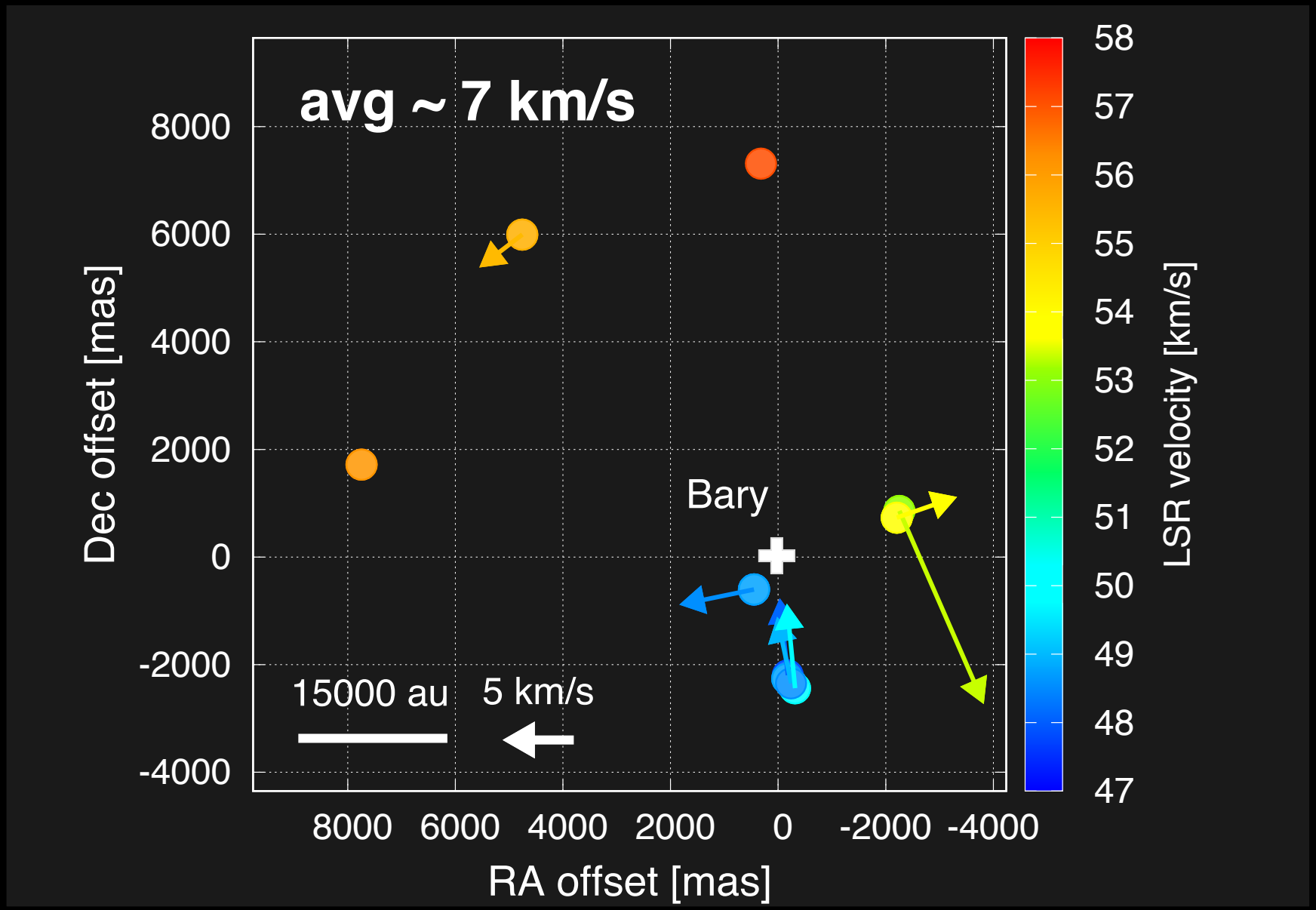
April 19, 2016



rms noise ~ 30 mJy beam^{-1}

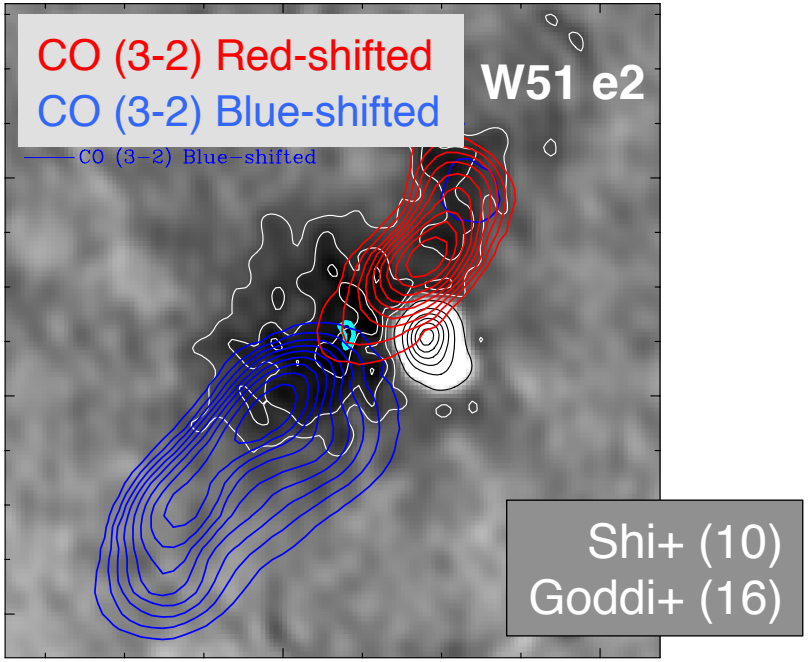
Unfortunately, a few maser fatures have been missed in 2018 yr ..., even with the same image sensitivity and non-drastic flux variations.

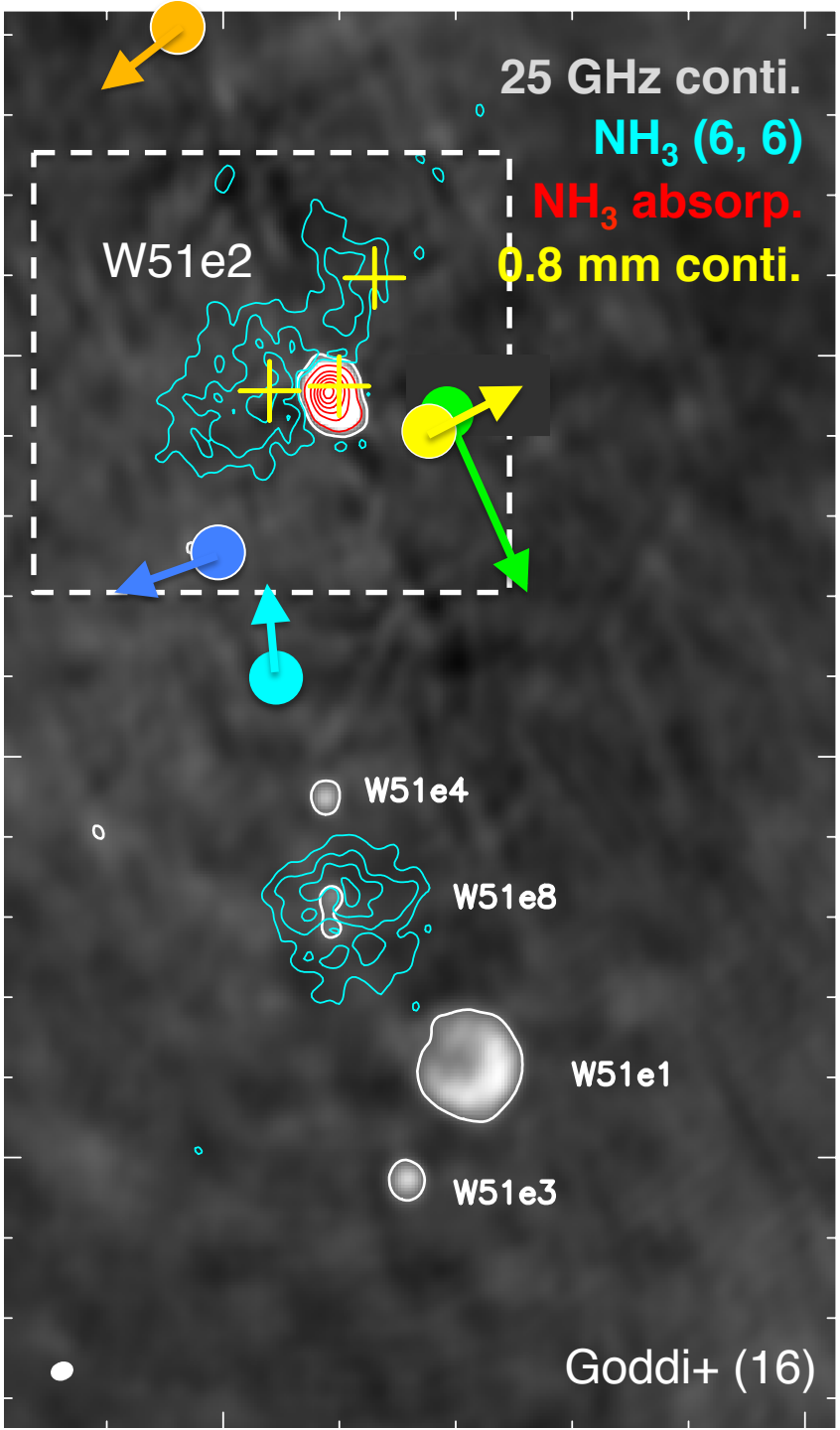
(Tentative) Proper motion



Where / What?

- Some features might be associated with NW-SE outflow/jets?
- Others might be associated with other source?





Summary

- KaVA SFR LP for understanding 3-D velocity structure around HMPSs via H_2O/CH_3OH masers
  - ✔ [**1st yr**] VLBI imaging survey & Statistics of sizes
    [**2nd yr**] VLBI monitor to measure proper motions