African VLBI Network (AVN): Unique Cases and Capabilities

James O. Chibueze
Centre for Space Research,
North West University, Potchefstroom, South Africa.

NWU®

VLBI Regional Workshop, Mexico City, 2019.

Mike Gaylard's brain-child

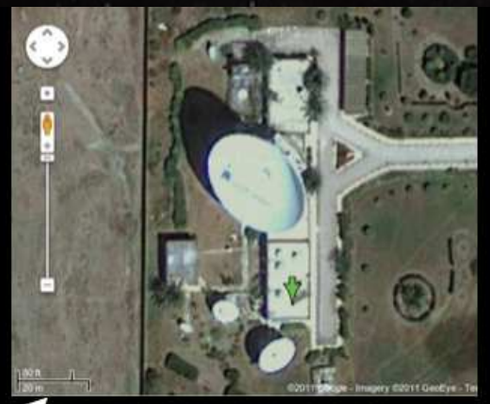
Objectives

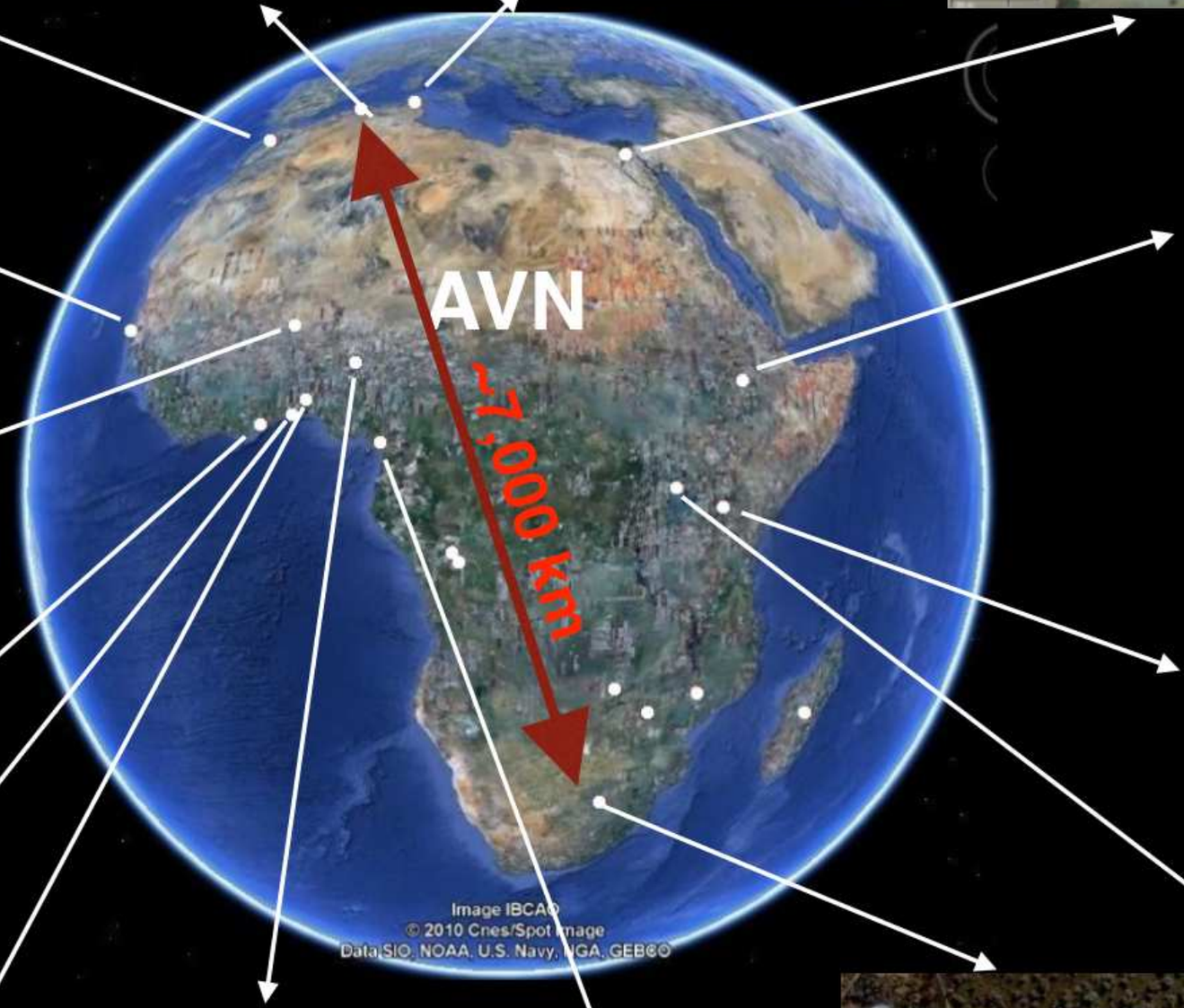
- Develop a network of VLBI-capable radio telescopes on the African continent
- Africa (led by South Africa) to co-host the Square Kilometre Array telescope with Australia, 9 African countries to host stations in SKA2 (including SA):

– Develop the skills, regulations and institutional capacity needed in SKA partner countries to optimise African participation in SKA2 and enable participation in SKA pathfinder technology development and science

– Skills and knowledge transfer in African partner countries to build, maintain and operate radio telescopes independently

– Bring new science opportunities to Africa on a relatively short time scale and develop strong RA science communities.




AVN
~7,000 km
Image IBCAO
© 2010 Cnes/Spot Image
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

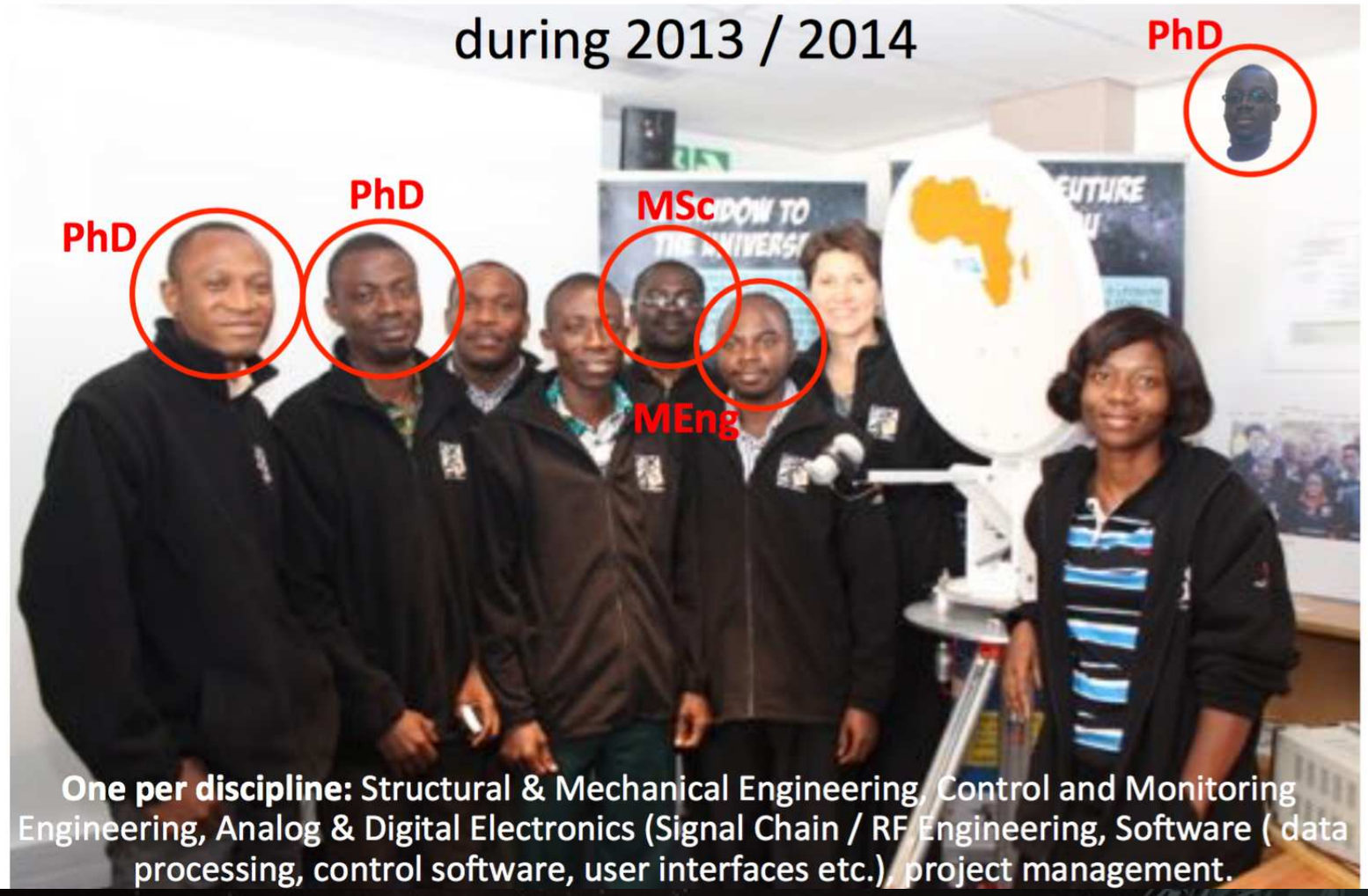

Lanlate


32m
11m
32m
11m
11m
18m
18m
32m

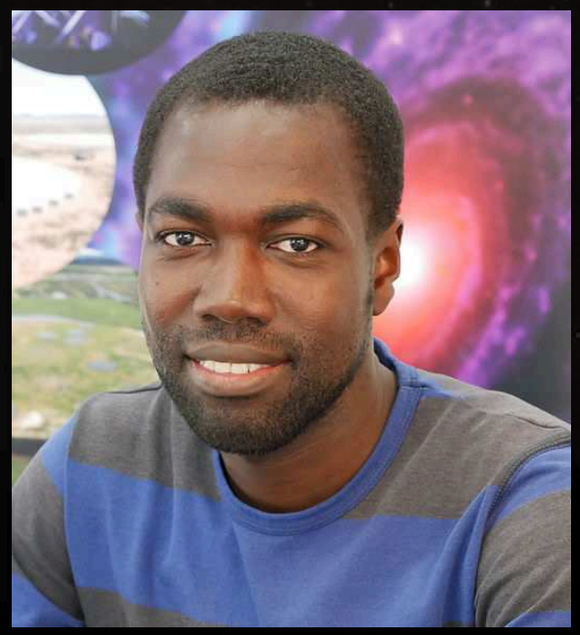
Starting point — GHANA

"VLBI = Science + Politics"

Ghana core essential observatory team trained in SA during 2013 / 2014

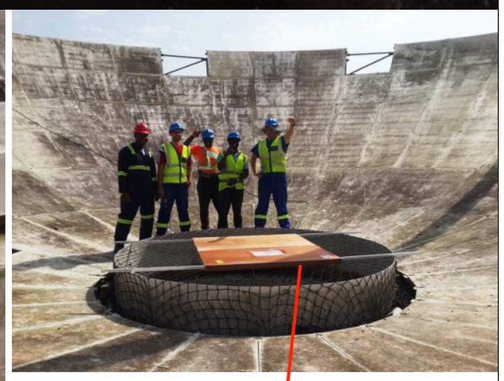


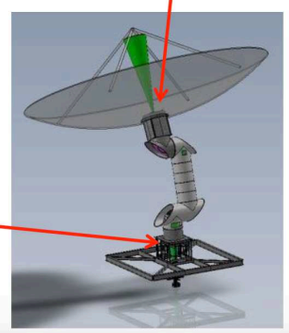
One per discipline: Structural & Mechanical Engineering, Control and Monitoring Engineering, Analog & Digital Electronics (Signal Chain / RF Engineering, Software (data processing, control software, user interfaces etc.), project management.



Conversion process

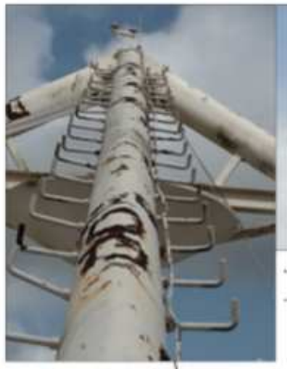
Structural and mechanical





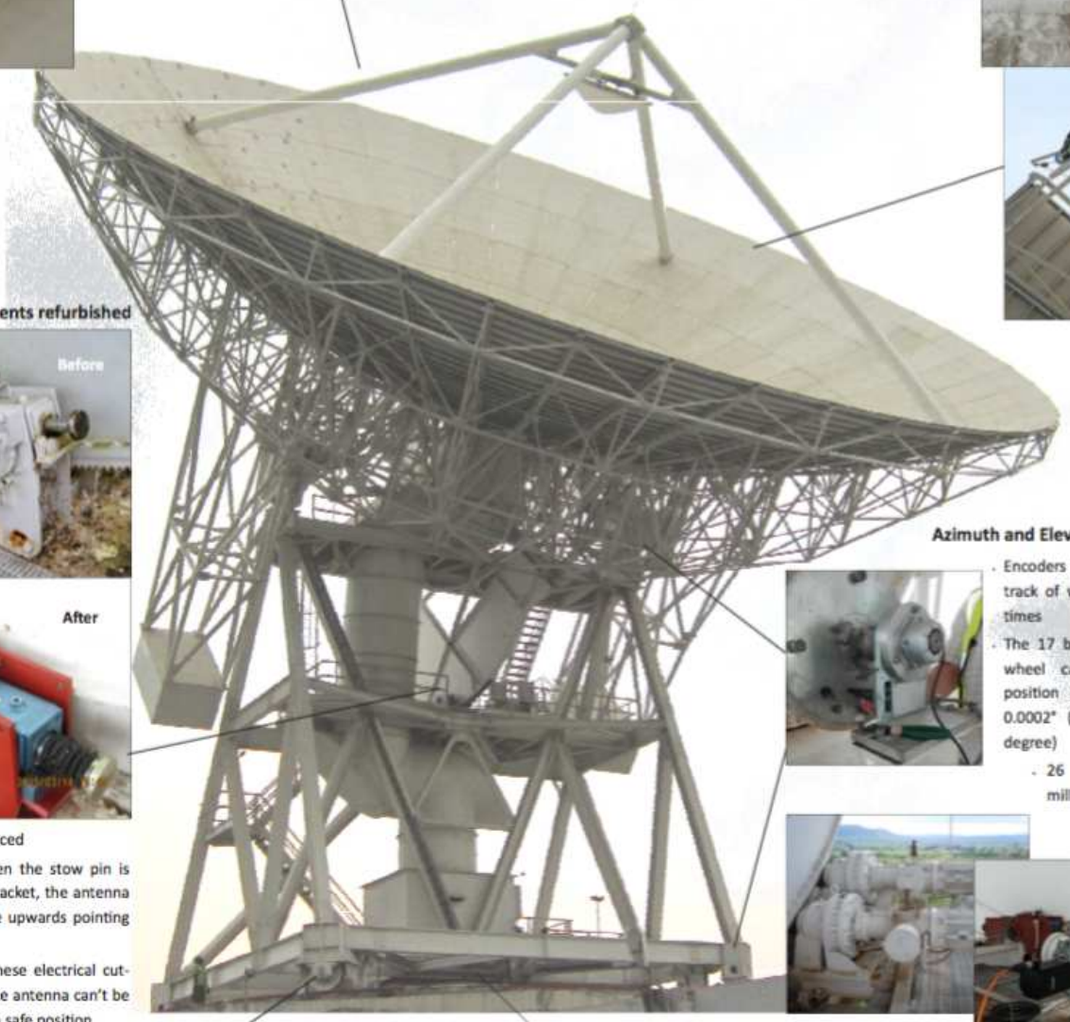
Rust, algae removal and painting

Subreflector support ("quadrupod") legs replaced



- The quadrupod houses the secondary mirror, or subreflector
- The position and angle of the subreflector must be maintained accurately in order for signals to pass down the beam waveguide and onto the receiver

Surface panels repaired and refurbished



Elevation safety components refurbished

- Stow pin bracket (red) replaced
- Stow pin refurbished: When the stow pin is placed into the stow pin bracket, the antenna is manually locked into the upwards pointing position
- Limit switches replaced: These electrical cut-out switches ensure that the antenna can't be commanded to go beyond a safe position
- Shock absorbers replaced: These cushion a hard stop, in case of limit switch failure

Azimuth and Elevation encoders replaced

- Encoders are responsible for keeping track of where the antenna is at all times
- The 17 bit azimuth encoder on the wheel can report the horizontal position of the antenna to within 0.0002° (two ten-thousandths of a degree)
  - 26 bits on elevation = six millionths of a degree!

Antenna jacked to realign the centre

- 230 ton movable mass jacked with hand-operated hydraulic jacks
- Antenna moved sideways by 7mm, to realign the structure and the feed horn

Jacking up

Pushing sideways

Replacement of pintle pads

- When the antenna moves, the rotating part and the stationary part meet at the 'pintle post'
- Low friction pads are installed at the interface to enable smooth sliding

New motors and control system

- Modernisation of control system for astronomy purposes

Crude oil discovery in Ghana (2007), production (2010)

rupod legs have to be rigid enough to
d in the correct position, at the correct
ght path down the beam waveguide.

quadrupod...

From left: Alex and Sampson in undergoing welding training according to AWS D1.1 techniques. Test plate produced by Sampson. Inspecting the test welds using radiography. Radiography inspection plate.

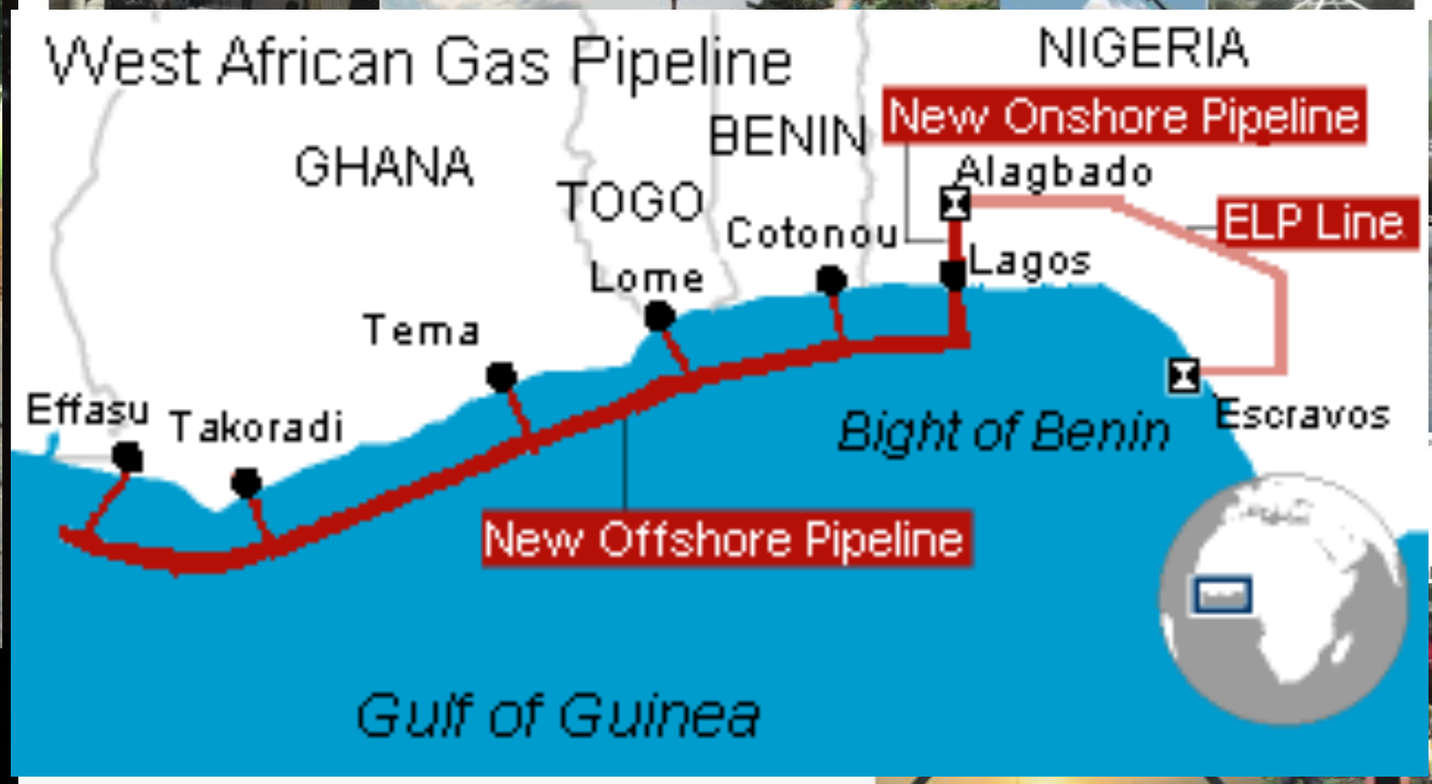
of training certification — Sampson Saah

he tube sections — Rolling and welding tube sections — Visual inspection of longitudinal welds — Joining two tubes together — Quarter-lengths done!

Done! — Rungs, cross-brace attachments, and primer — Visual inspection of flange welds — Attaching end flanges — Full lengths appearing! — A tight spot! Visual inspection of root welds.

Manufacturing of quad legs for replacement in Ghana

GAEC workshop manager Severin Azankpo (studying towards MEng in SA), with welders in training in Ghana (Alex Narh (GAEC) and Sampson Saah (GAEC))

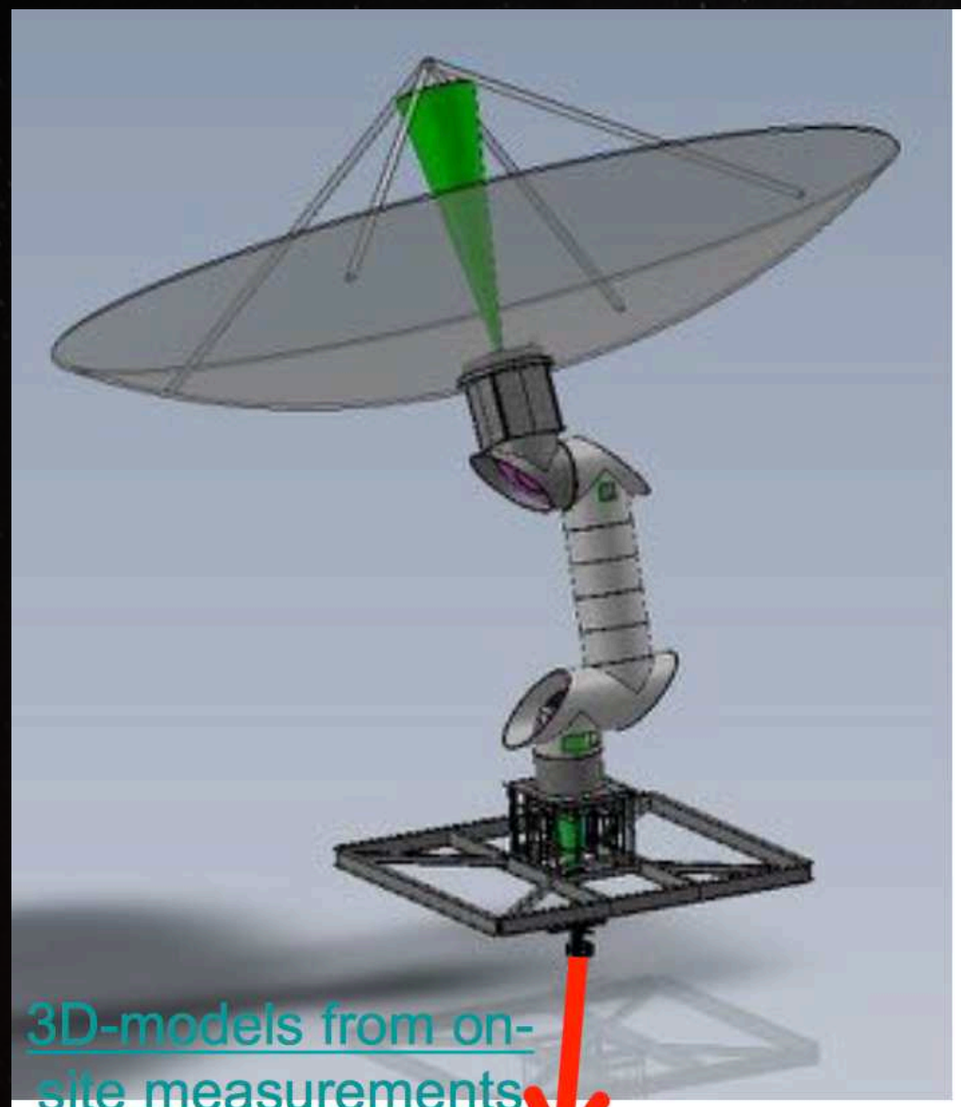


of risk needs lots of planning

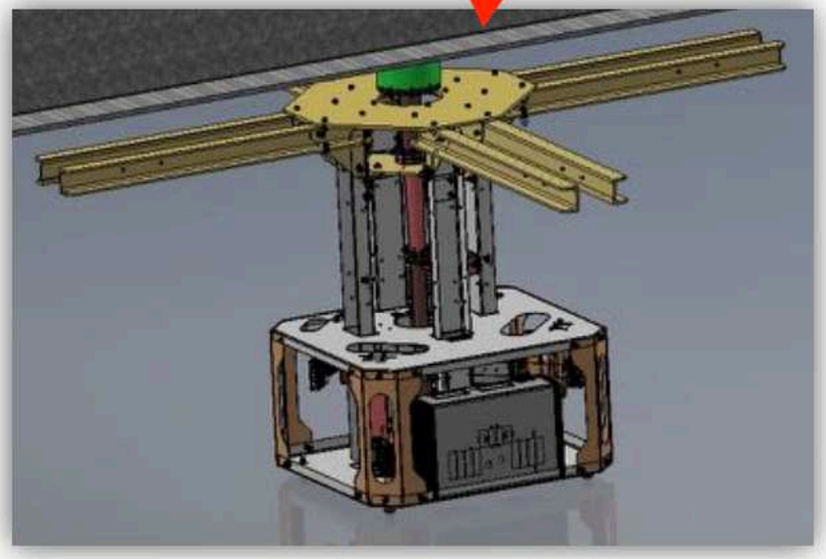
old structure at its weakest points

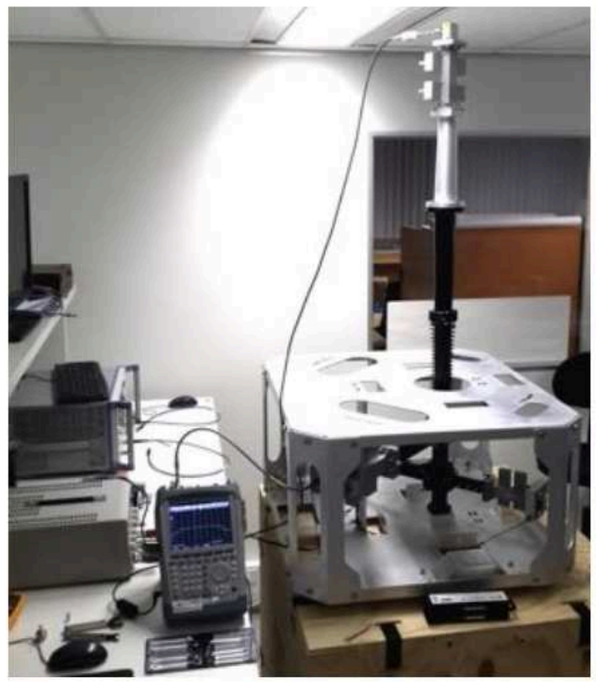
llation Team

Ambient temperature receiver



3D-models from on-site measurements

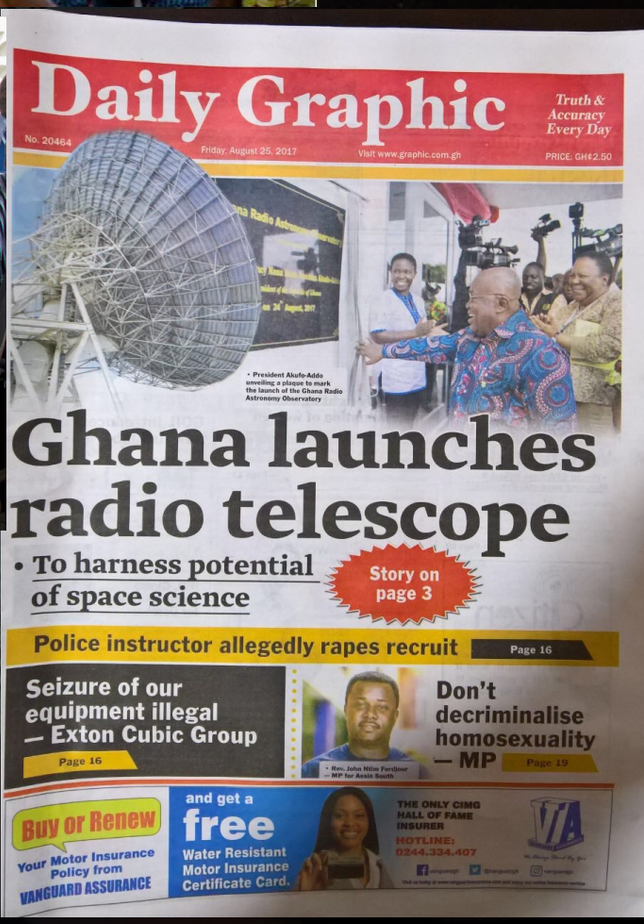




First test drive after first re-engineering phase

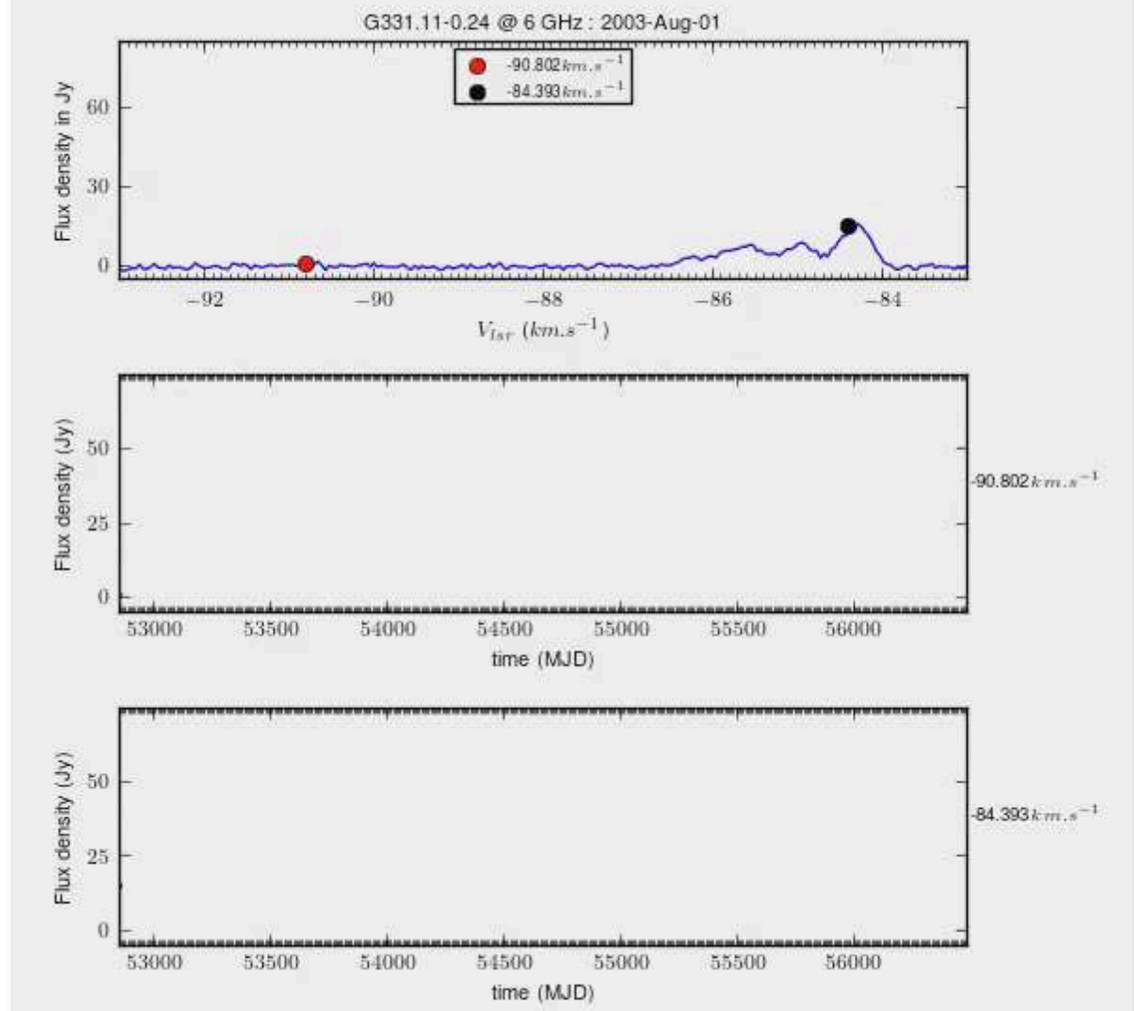
- **32-m, beam wave-guide**
- **0.1 deg**
- **Long**
- **C-band (4 — 8 GHz)**
- **Continuum and spectral line observations**
- **Very Long Baseline Interferometry (VLBI) capabilities**

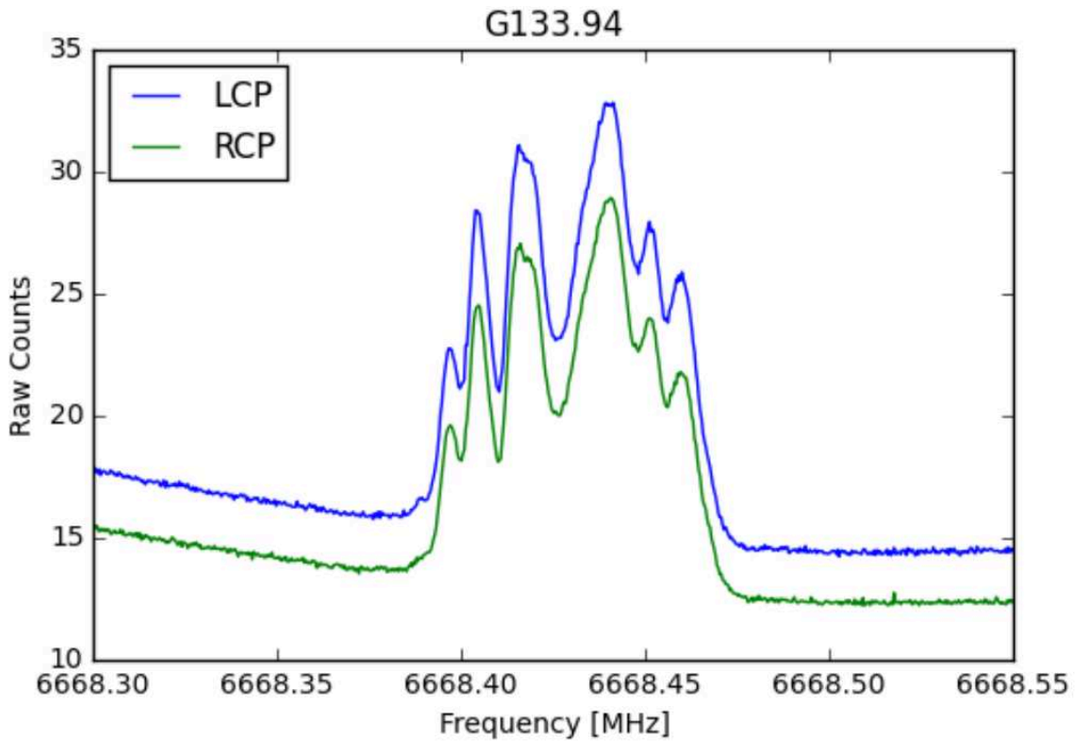
Presidential inauguration and announcement of the initial science results held on August 24th, 2017

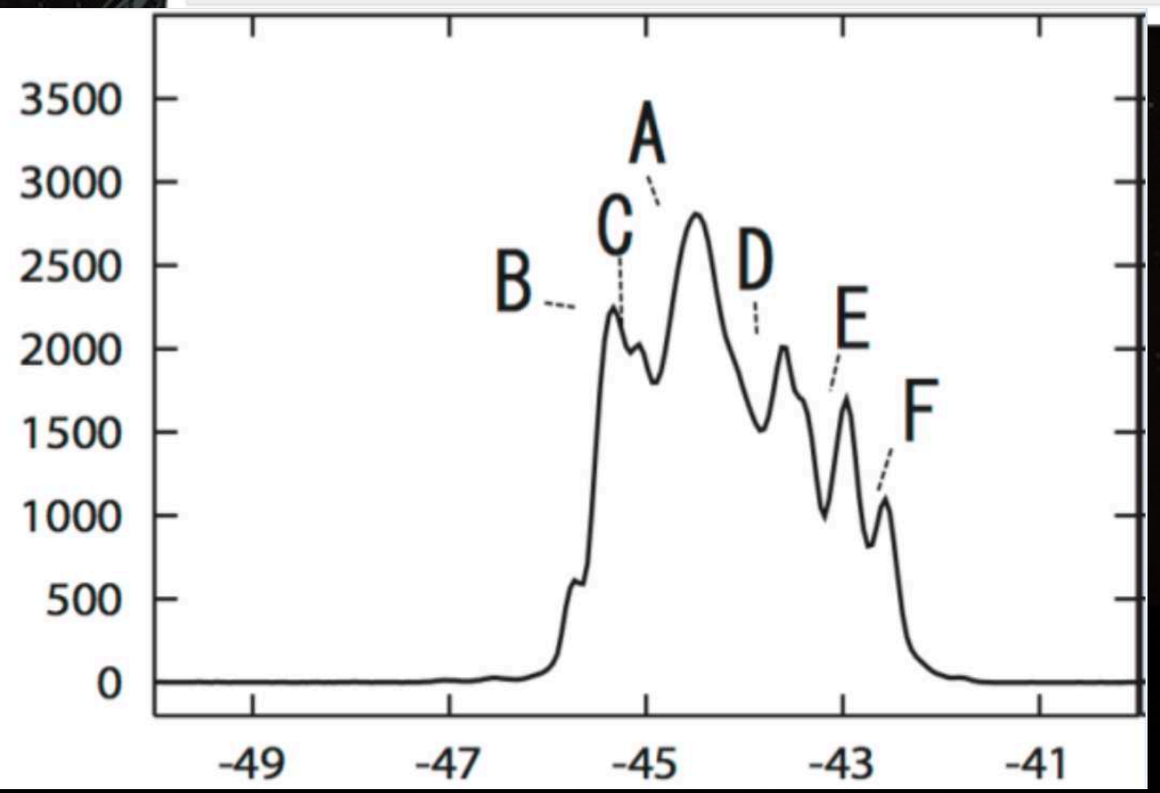


Science cases

- 6.7 GHz methanol (CH3OH) masers
- Pulsar observations
- VLBI observational studies of radio sources







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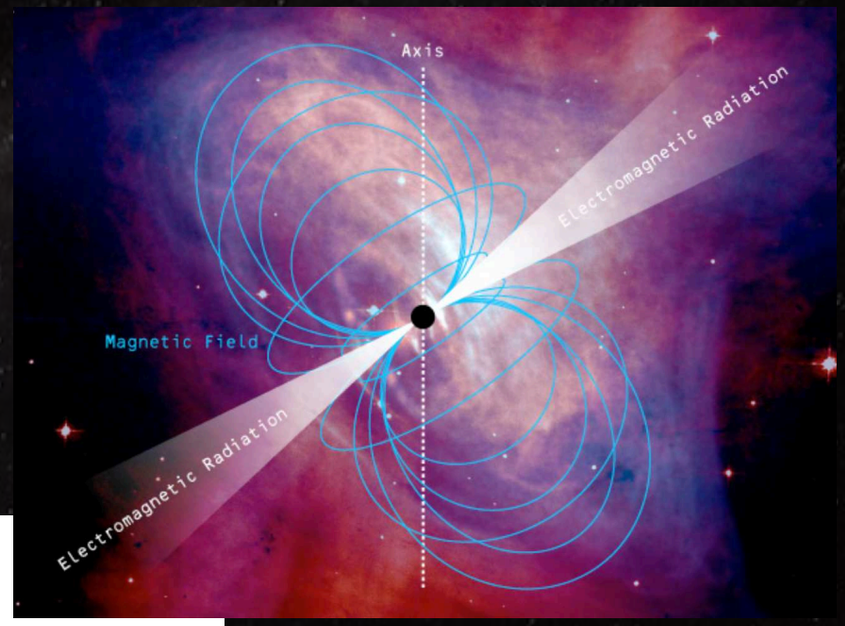

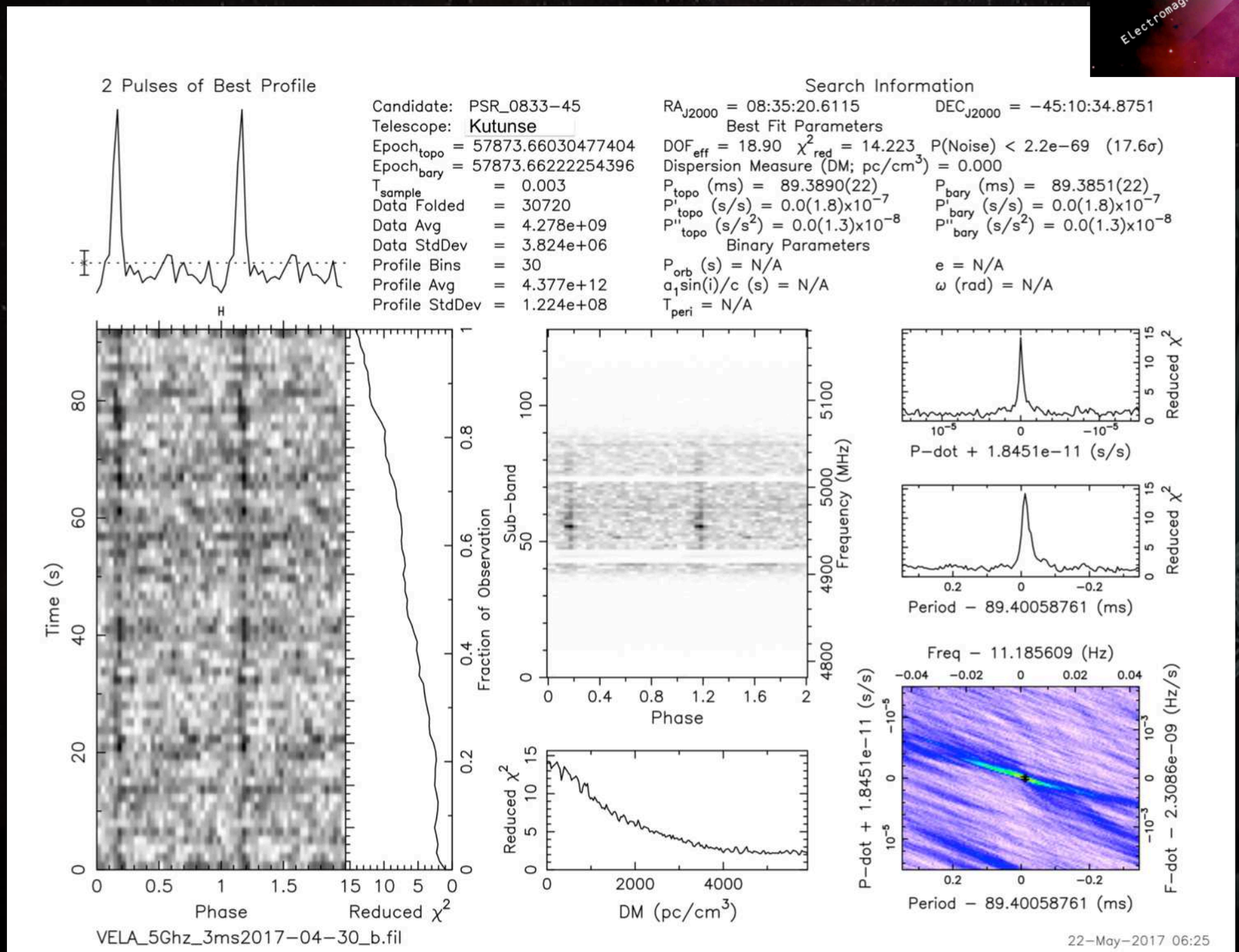

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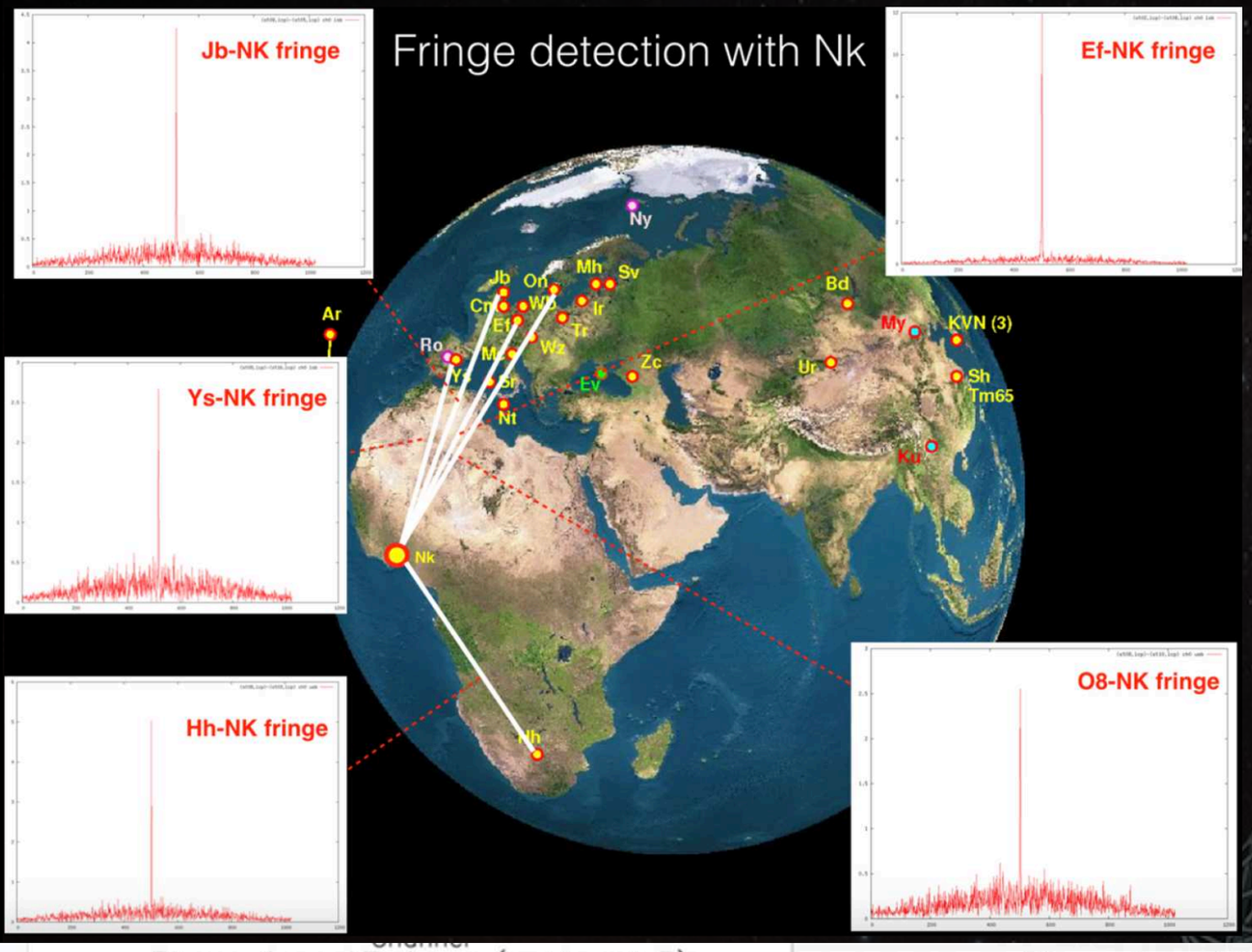
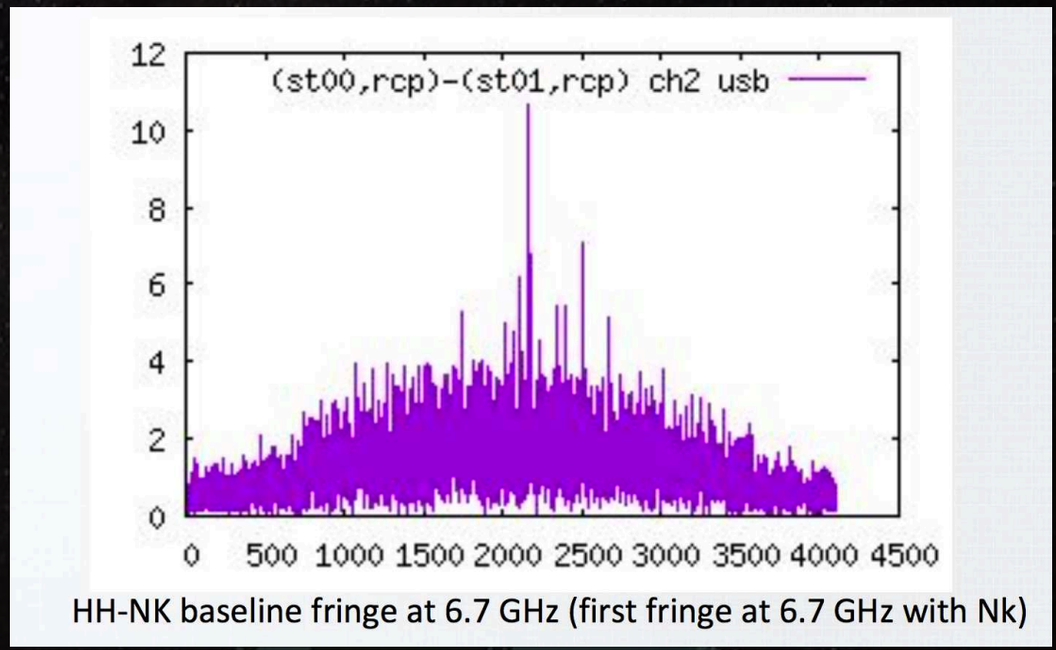
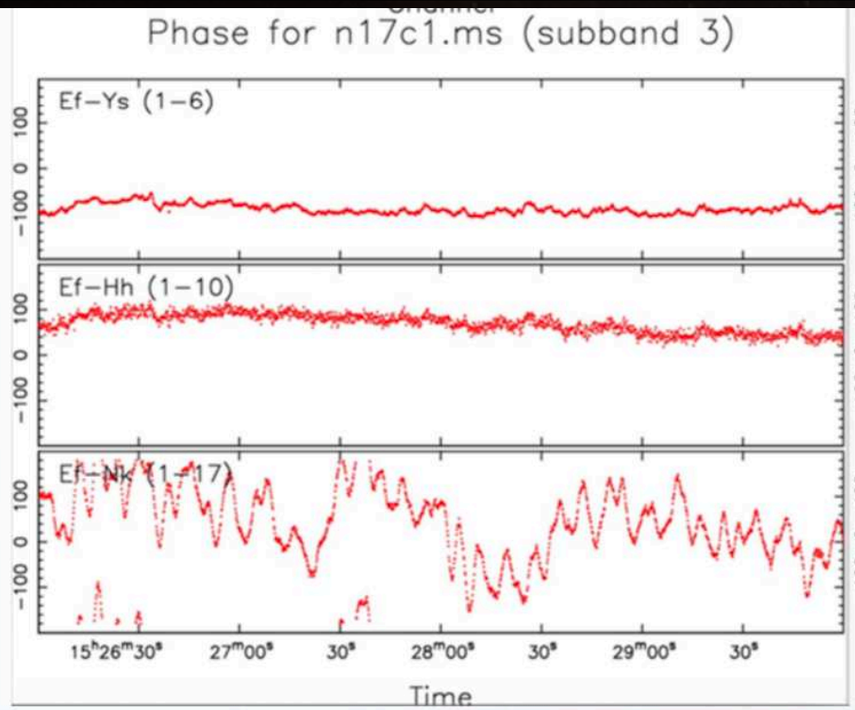
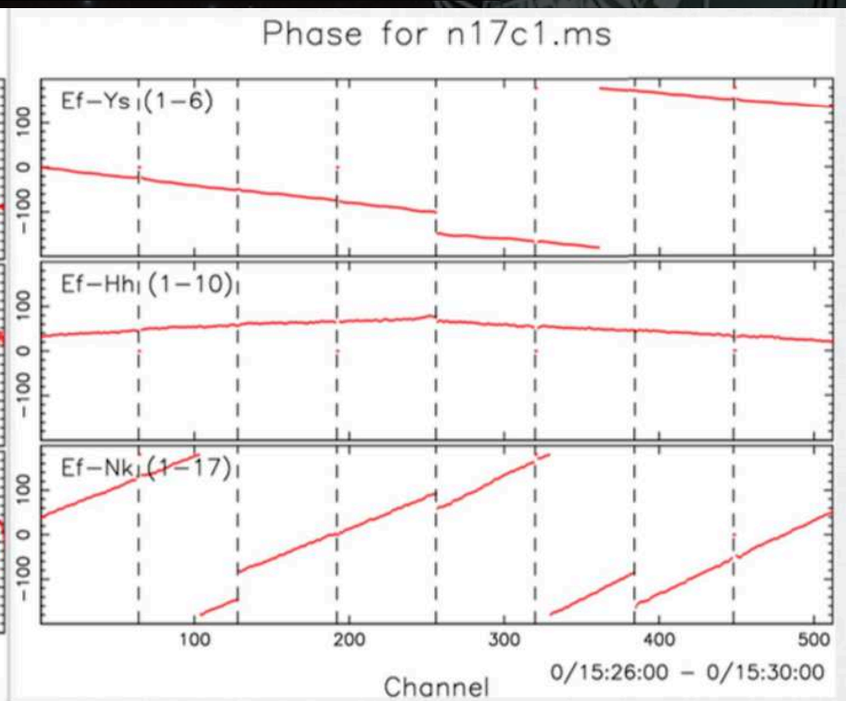


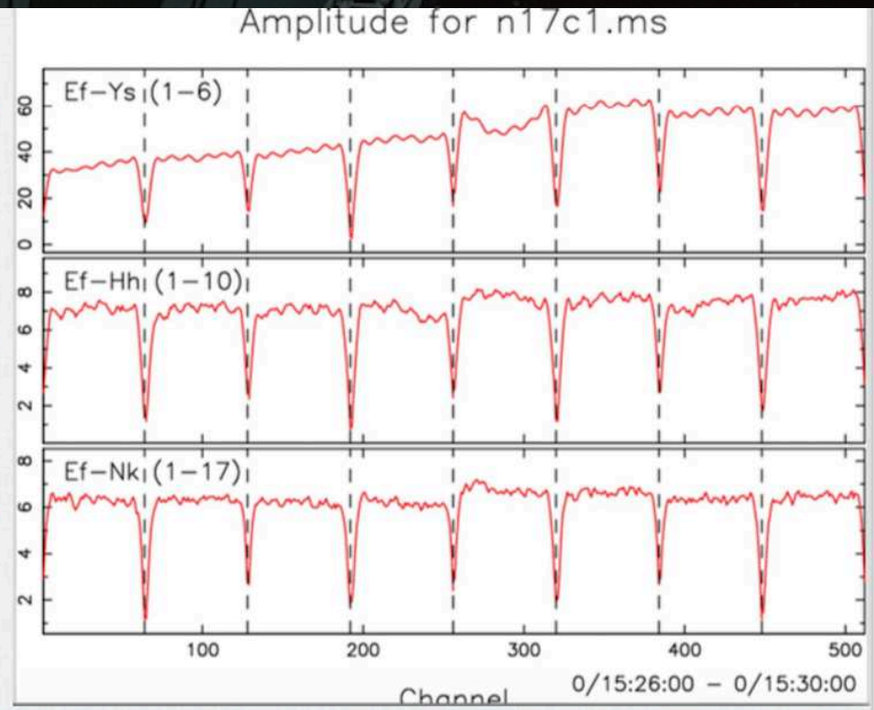


HH-NK baseline fringe at 6.7 GHz (first fringe at 6.7 GHz with Nk)

Paco's talk and impact of a Ribidium clock

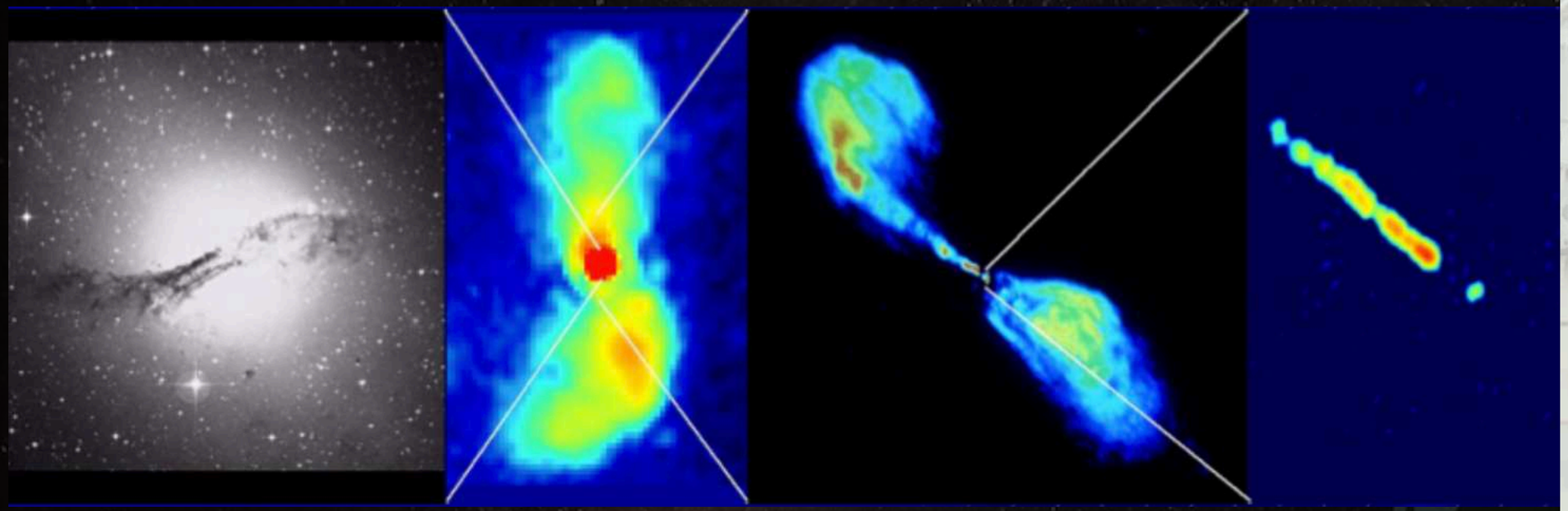


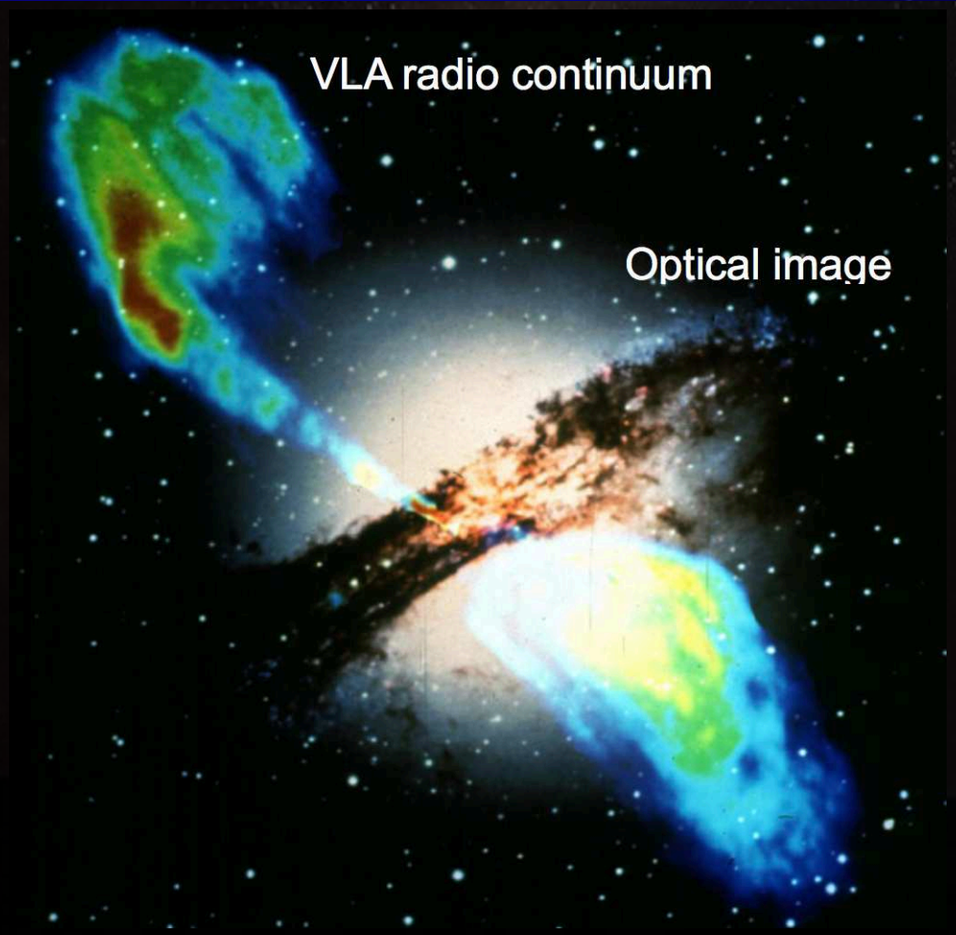


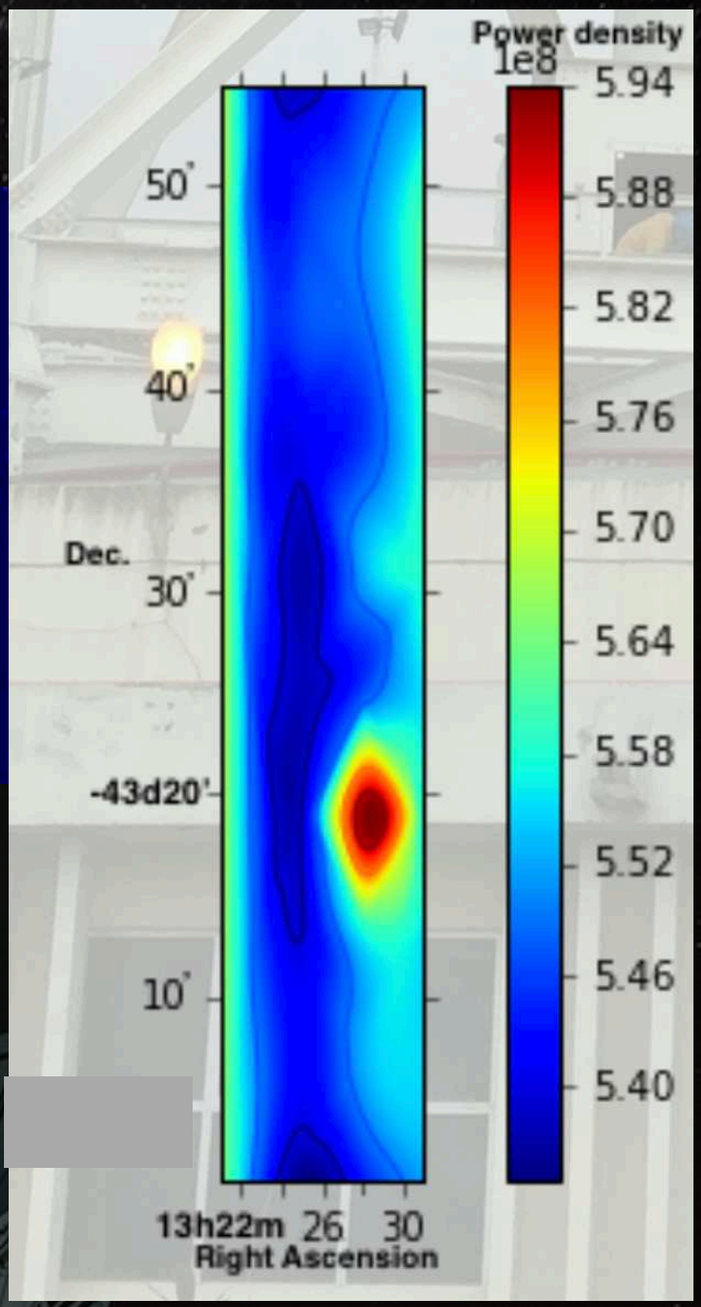


- Some extras - mosaic maps

Centaurus A







Useful for training/DARA

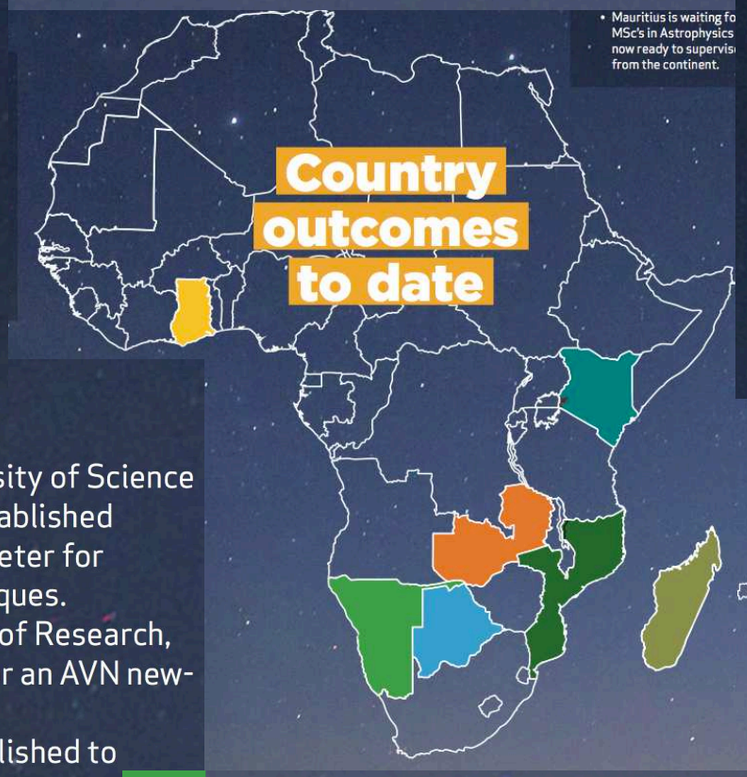
- Maser observations
- SCHED preparation and execution
- Mini projects

Zambia

- A technical team from the SKA office visited Zambia to undertake a feasibility study to assess the suitability of the 29.6 metre dish at Mwembeshi for conversion to carry out VLBI research.
- Zambia has appointed the National Remote Sensing Centre (NRSC) as the coordinators for SKA/AVN activities in Zambia.
- The Conversion project to establish the Mwembeshi telescope is planned to start in early 2017.

Kenya

- Kenya is negotiating the use of the Longonot telecommunication station for radio astronomy.
- The Newton Fund training programme in Kenya is under way.



Mauritius

- The country is setting up an instrument hosting arrangement for an ionospheric scintillator between the University of Mauritius and the South African National Space Agency.
- Data on the ionosphere will be useful for imaging using AVN and SKA data.
- The CALLISTO instrument for solar observations has been up and running for nearly 5 years.
- A new solar instrument for producing solar data will be installed soon through the establishment of a MoU between the University of Mauritius and the University of Reunion.
- Mauritius is a popular venue for Joint Exchange Development Initiatives (JEDI) and regularly host international scientists for these workshops.
- Funding has been secured for the Teaching Interferometer for Galactic Radio Emission project (TIGRE).
- Mauritius is waiting for a critical number of students (around 15) to start their MSc's in Astrophysics with Radio Astronomy and Applications. · The country is now ready to supervise PhDs in Astrophysics and this too is open to students from the continent.

Botswana

- Botwana appointed the Botswana International University of Science and Technology (BIUST) as the custodian of a newly established Astrophysics training laboratory and 2-dish interferometer for training in radio astronomy instrumentation and techniques.
- Several discussions have taken place with the Ministry of Research, Science and Technology and efforts to identify a site for an AVN new-build telescope are underway.
- Governance and technical committees have been established to ensure progress towards SKA readiness.

Madagascar

- The Minister of Higher Education and Scientific Research of Madagascar said that Astrophysics is a relatively new field of study within the country. It is working hard to build competency in the field of Radio Astronomy. The Faculty of Science at the University of Antananarivo has since 2014 offered a MSc programme in Astrophysics, in order to build the necessary capability in the specialised field of signal treatment.
- To date, 13 Madagascan students have studied for MSc or PhD degrees on SKA SA bursaries.

Mozambique

- An agreement was reached at country-to-country bilateral level to establish an Astrophysics training laboratory and 2-dish training interferometer at the Eduardo Mondlane University in Maputo and support the University with curriculum development for Astrophysics.
- A ring-fenced bursary allocation will facilitate the establishment of a radio astronomy community to ensure SKA readiness.

Namibia

- The Namibian Government has prioritised space science. In this regard the National Commission on Research, Science and Technology (NCRST) has established a Space Science Council to give strategic direction to selected interventions.
- The Newton Fund training programme has kicked off in Namibia.
- Discussions with stakeholders to agree on the AVN new-build programme and identify potential sites are underway.

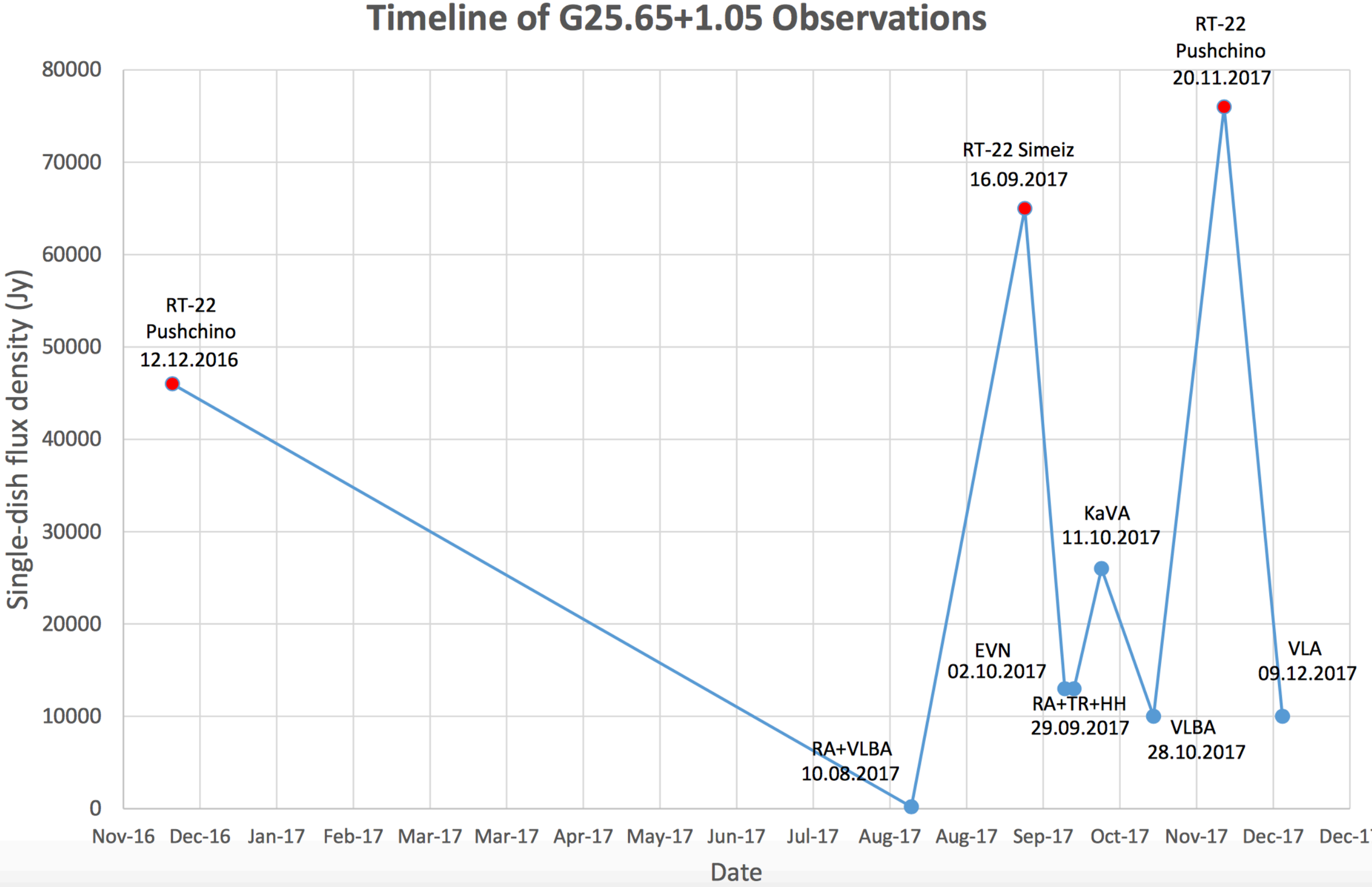
Single-dish collaboration ideas

VLBI Regional Workshop, Mexico City, 2019.

Maser Monitoring Organisation (M2O)
#boringbutrewarding

G25 case presented by Stan Kurtz

NWU

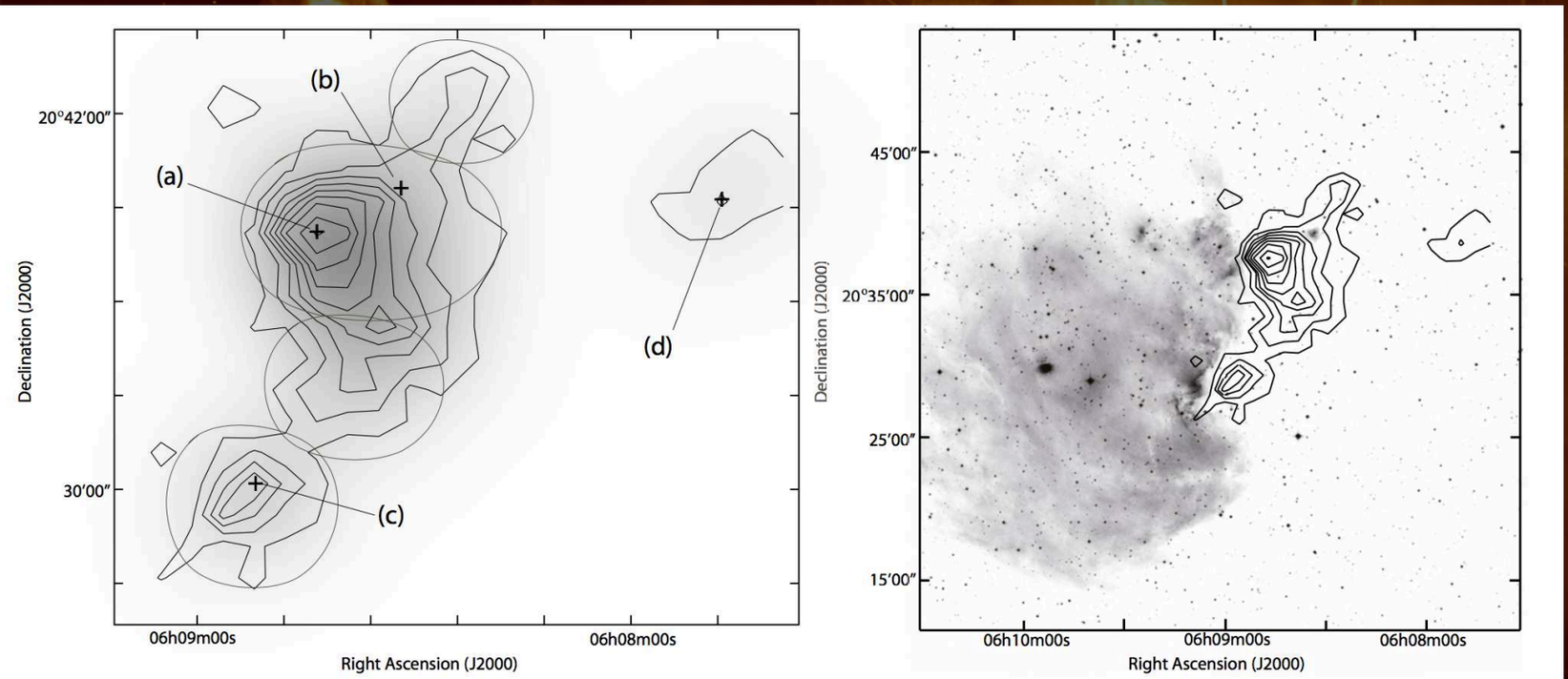


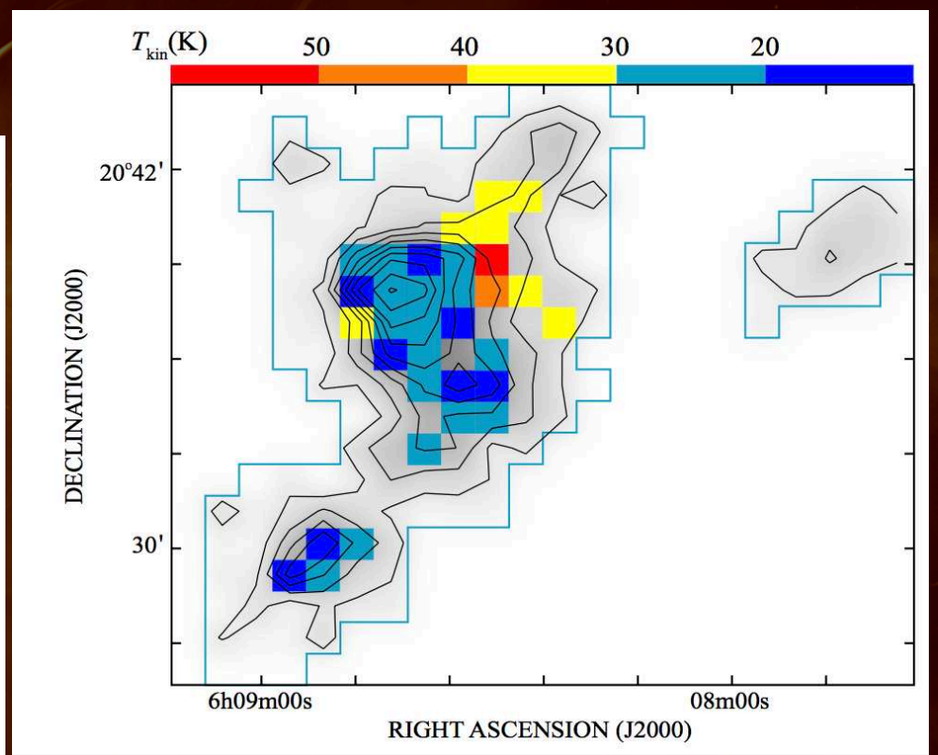
Pulsar ‘global’ monitoring
Ben Stappers

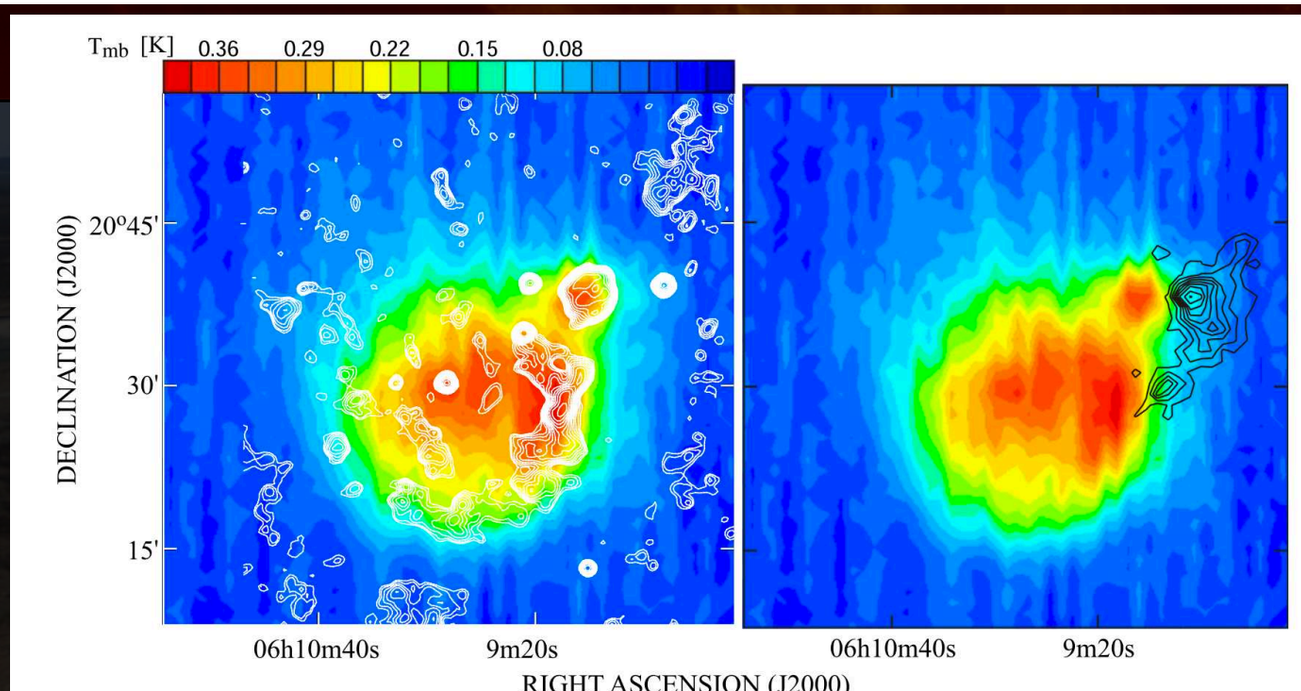
Install pulsar timing systems in as many telescopes as possible and use them for pulsar monitoring observations.

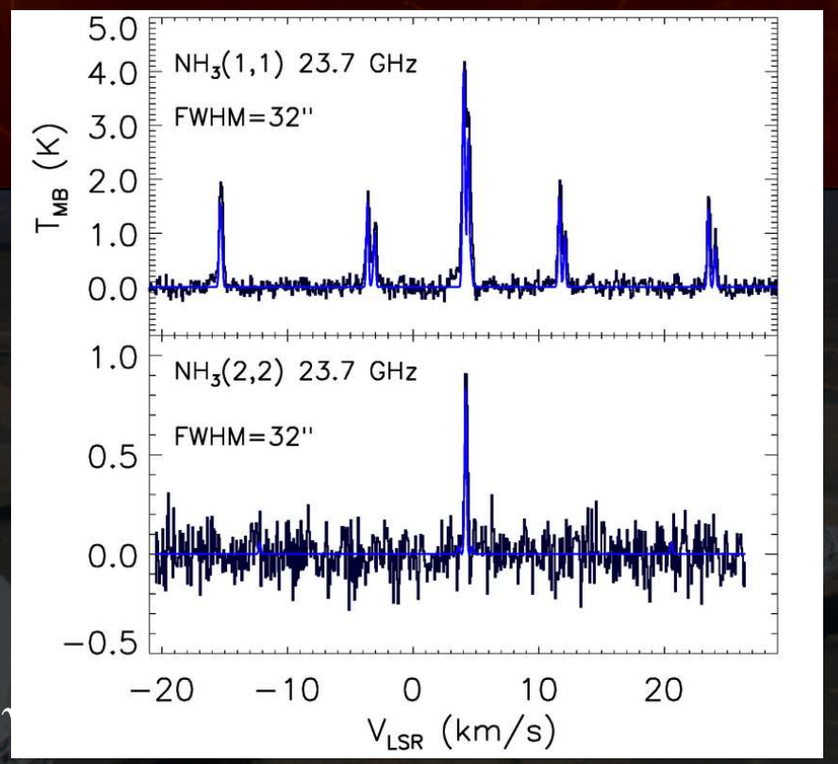
Giant Molecular Cloud (GMC) studies

- Gas temperature distribution
- Star formation scenario (sequential, spontaneous)
- Other physical conditions
- Evidence of cloud-cloud collision









Quick look

>> Science goals drive sustainability (e.g. ALMA - exploring our cosmic origin, EHT - Imaging the event horizon of blackholes)

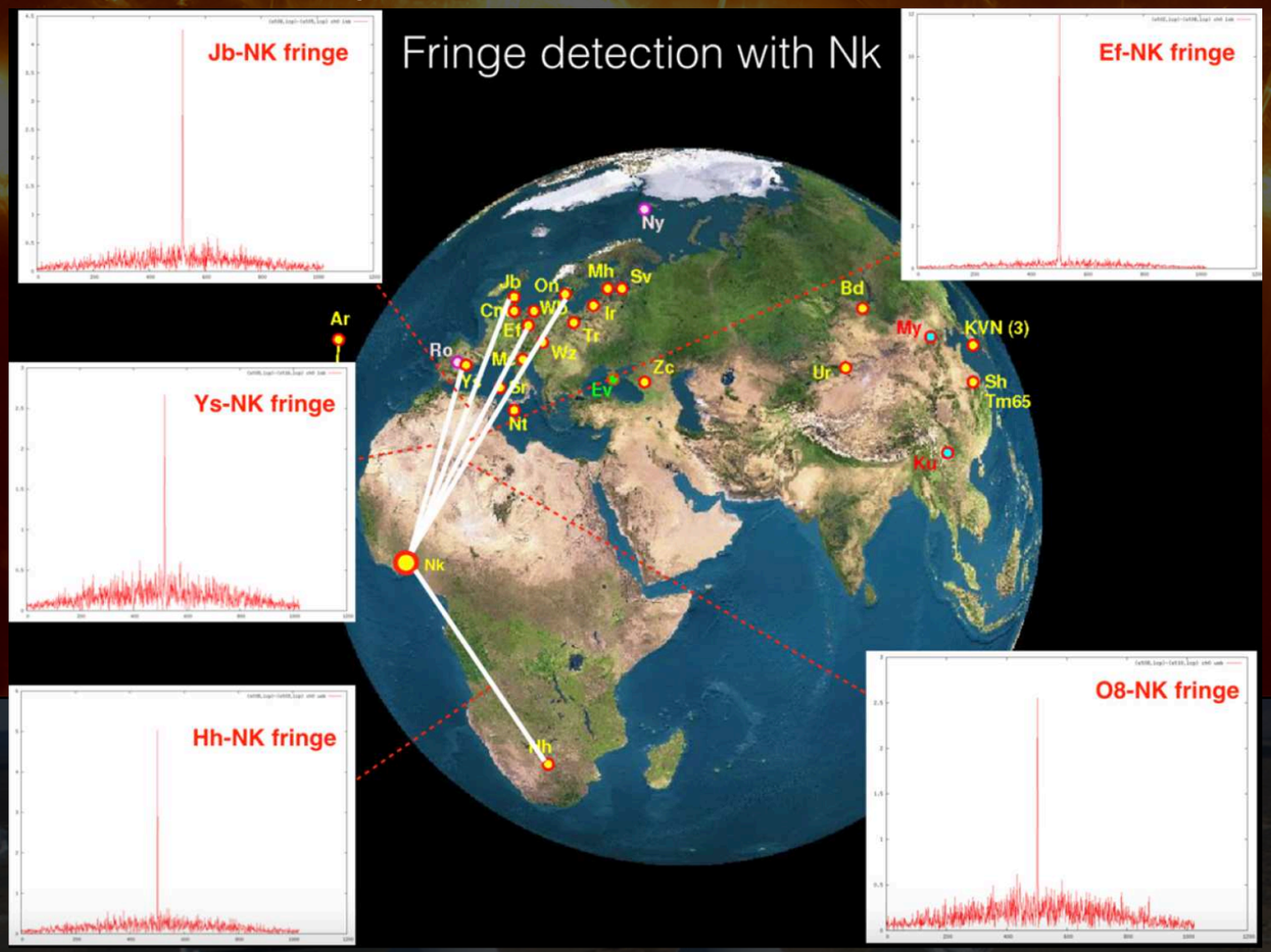
>> African VLBI Network needs a unique science driver

>> Flex VLBI Network to localize and study galactic and extra-galactic transients

>> Case study of proposed science goal

AVN - comes alive with Hh-Nk

- First fringes detected and H-maser clock (to replace Rubidium clock currently used)
- VLBI science-ready afterward



What should constitute AVN VLBI science legacy/goals?

Bridging the EVN - HartRAO, SKA-VLBI and what?

VLBI Regional Workshop, Mexico City, 2019.

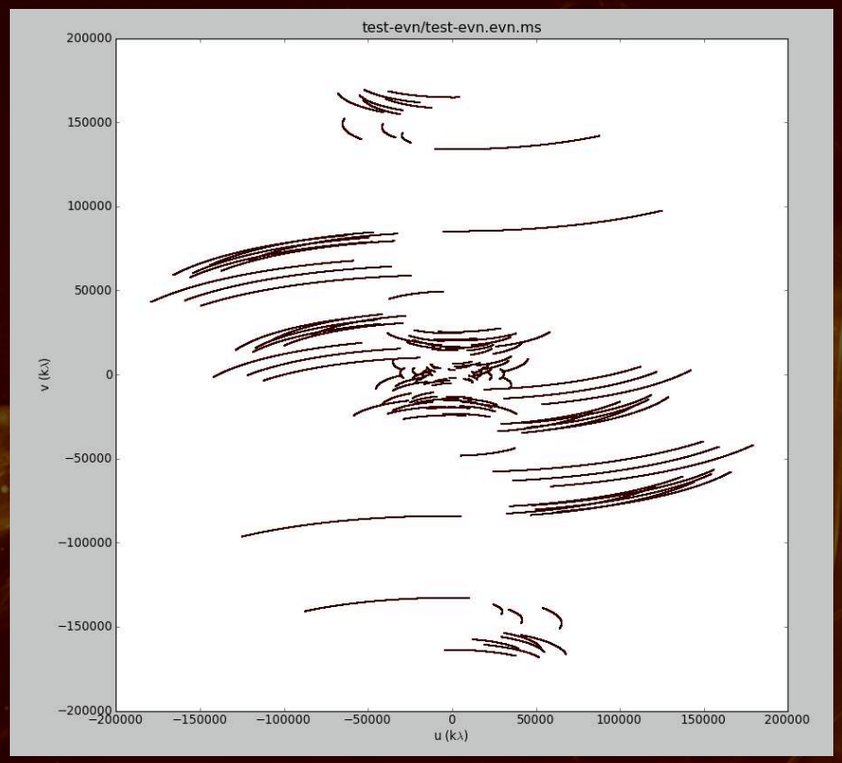
VLBI for Galactic Transient Localization/Follow-ups

- ⋆ Flexibility in scheduling VLBI experiment to catch time-limited events
- ⋆ Proper coordination with correlation centre (JIVE)
- ⋆ Ys, Sr, Hh, Nk (short baseline of Ys-Sr, missing one station not the end of the world)

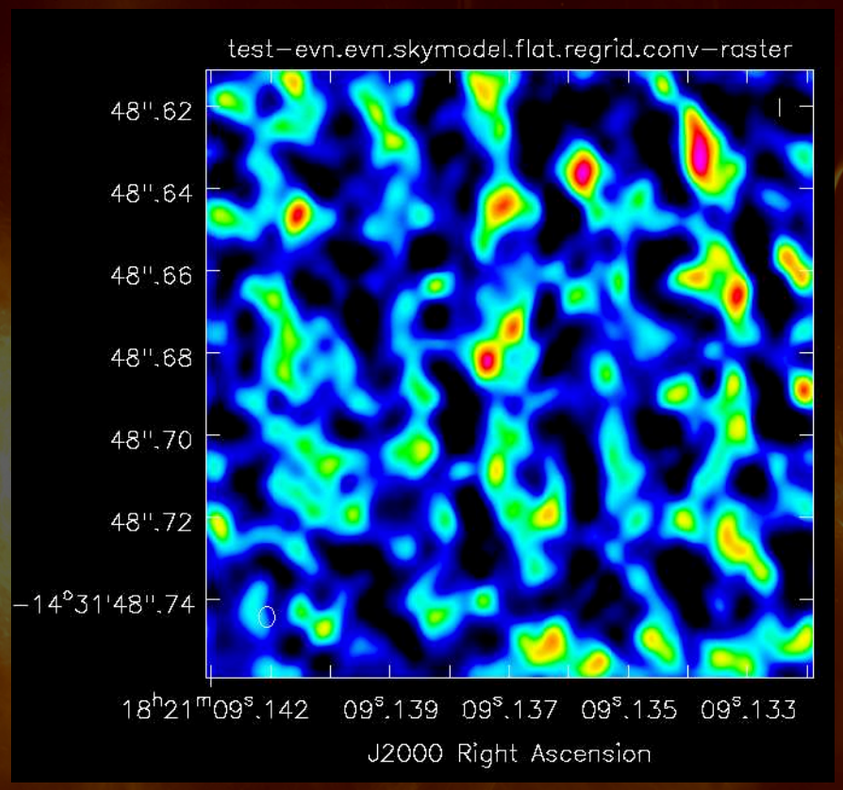
Flex VLBI Network (FVN)?


Sardinia Radio Telescope

Test of imaging fidelity



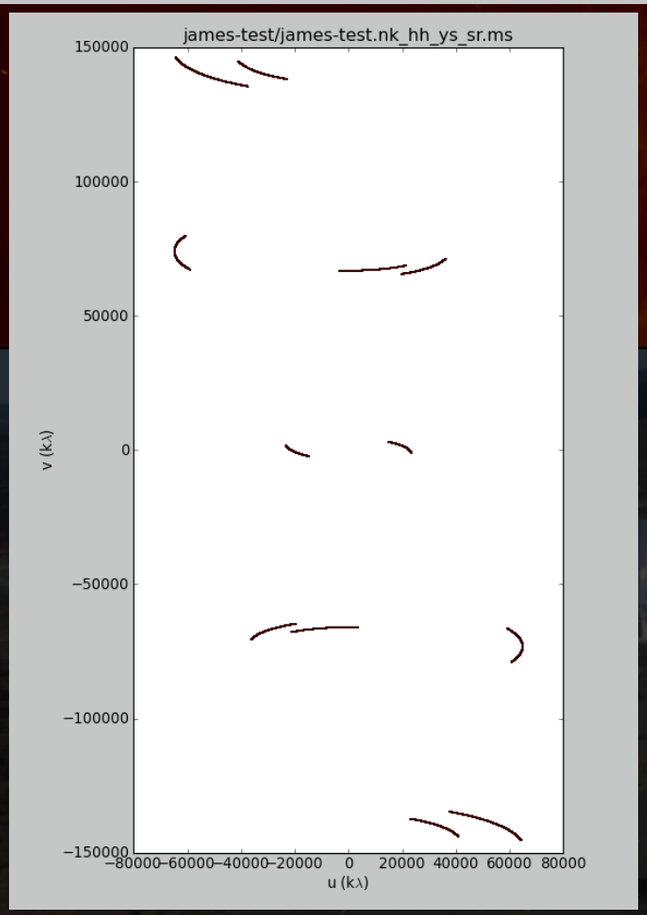
EVN



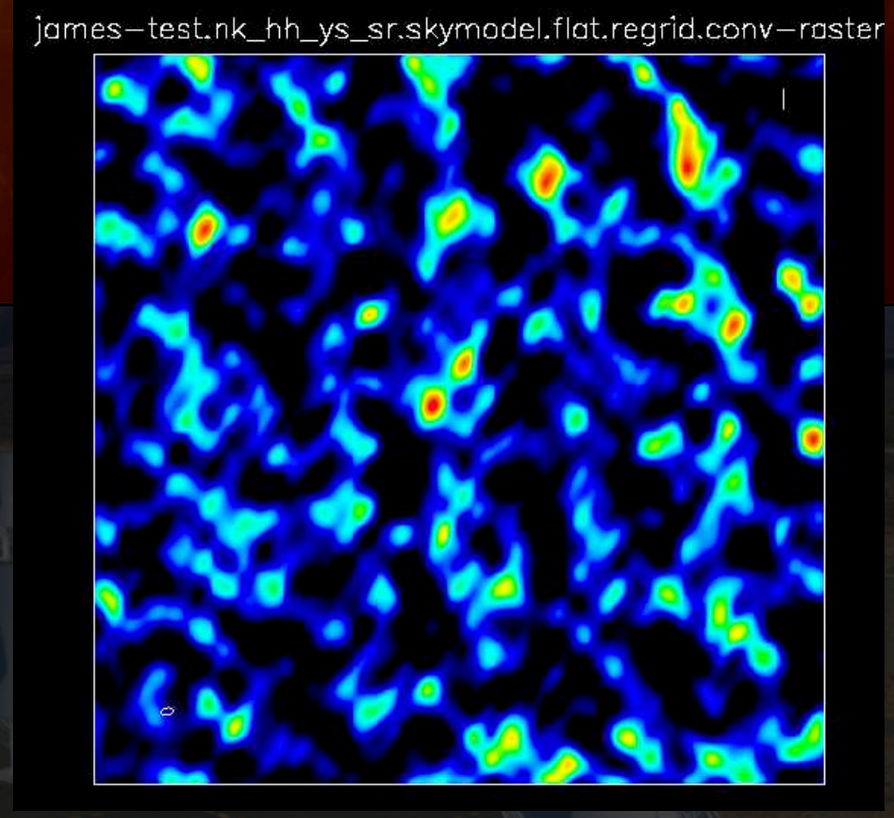
G16.58 6.7 GHz CH_3OH masers

Simulated 3 hrs obs with EVN & FVN

SRT offers good sensitivity!

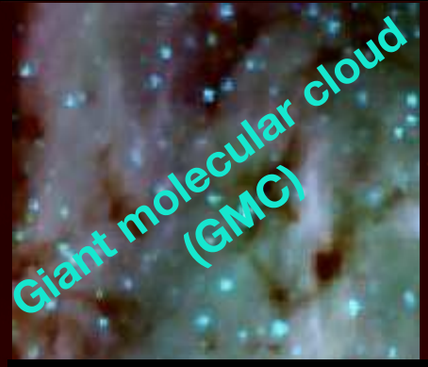


FVN

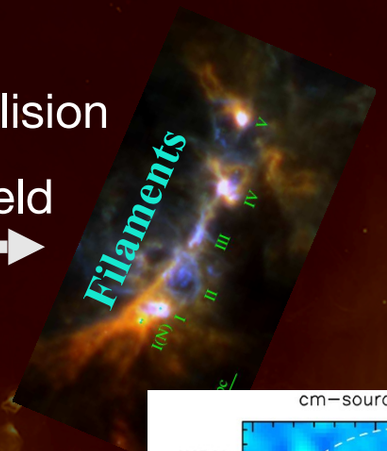


Overview of high-mass stars

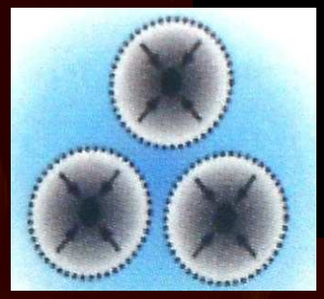
- Their formative process only vaguely understood
- Usually located few kpc from our solar system except for Orion KL (~420 pc) and Cepheus A (~600 pc).
- Form in complex environment (proximity of other massive protostars)
- Multiple theories attempting to explain massive star formation
- Recent observations tend to support disk-outflow system



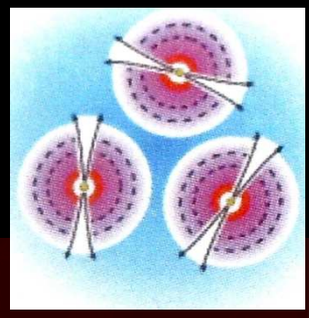
Cloud-cloud collision & magnetic field



Fragmentation



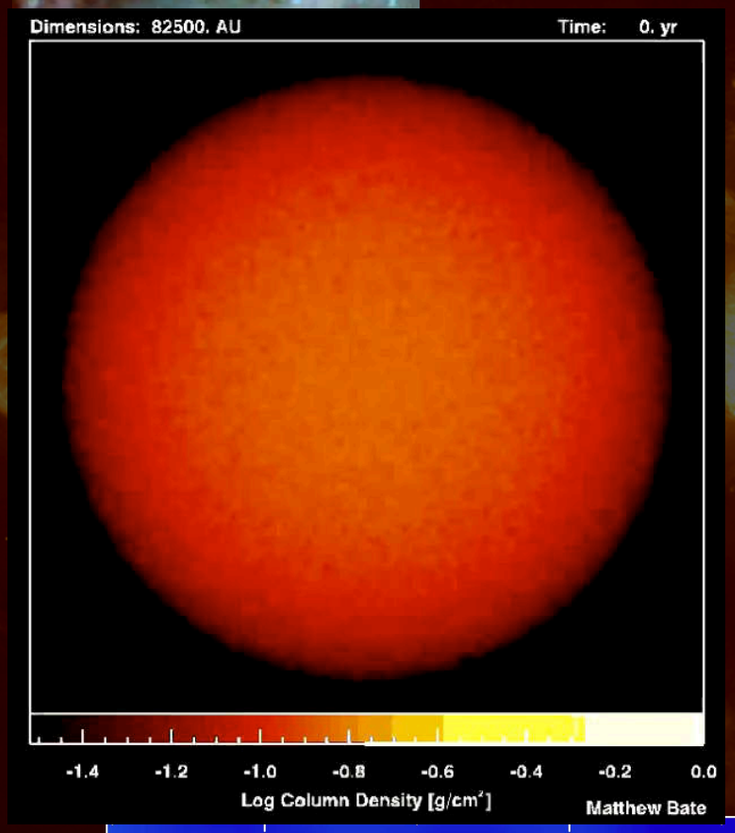
Maser activities periodic ejections

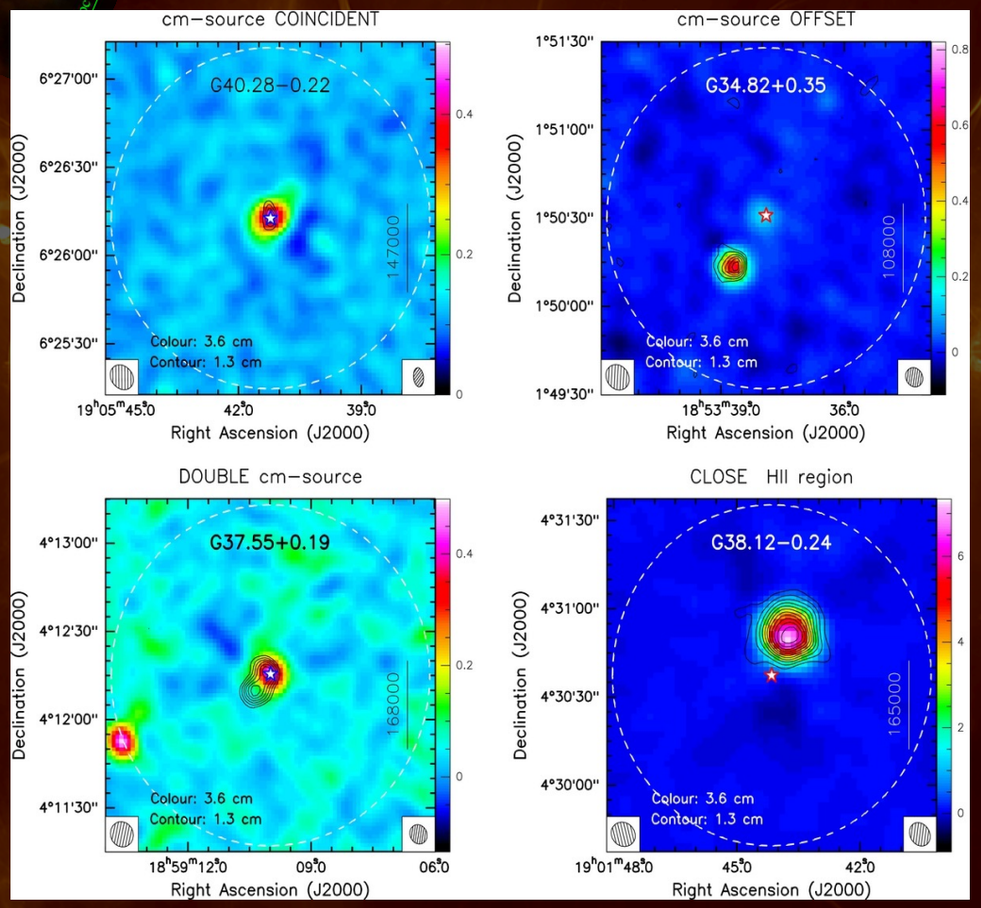


Hot core formation

[NGC 6334IN SM2 Hot Core]

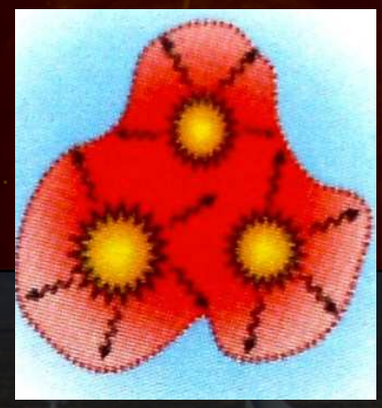
Free-free emission



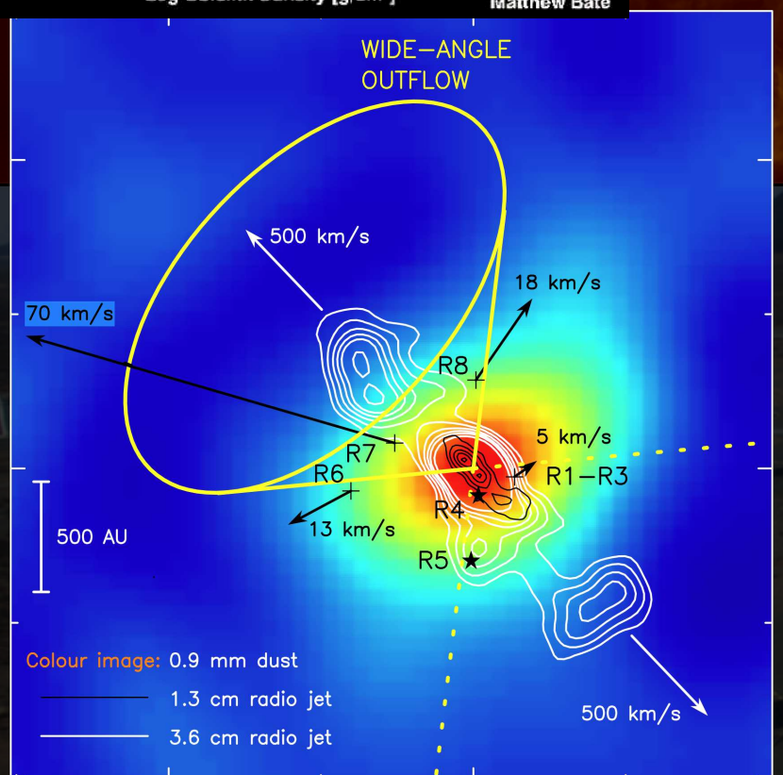


Hypercompact HII region

Disk formation



Ultra-compact HII region [100 K, ~ 0.1 pc in size] (keeps expanding as the MYSO evolves and emits more energetic photons).



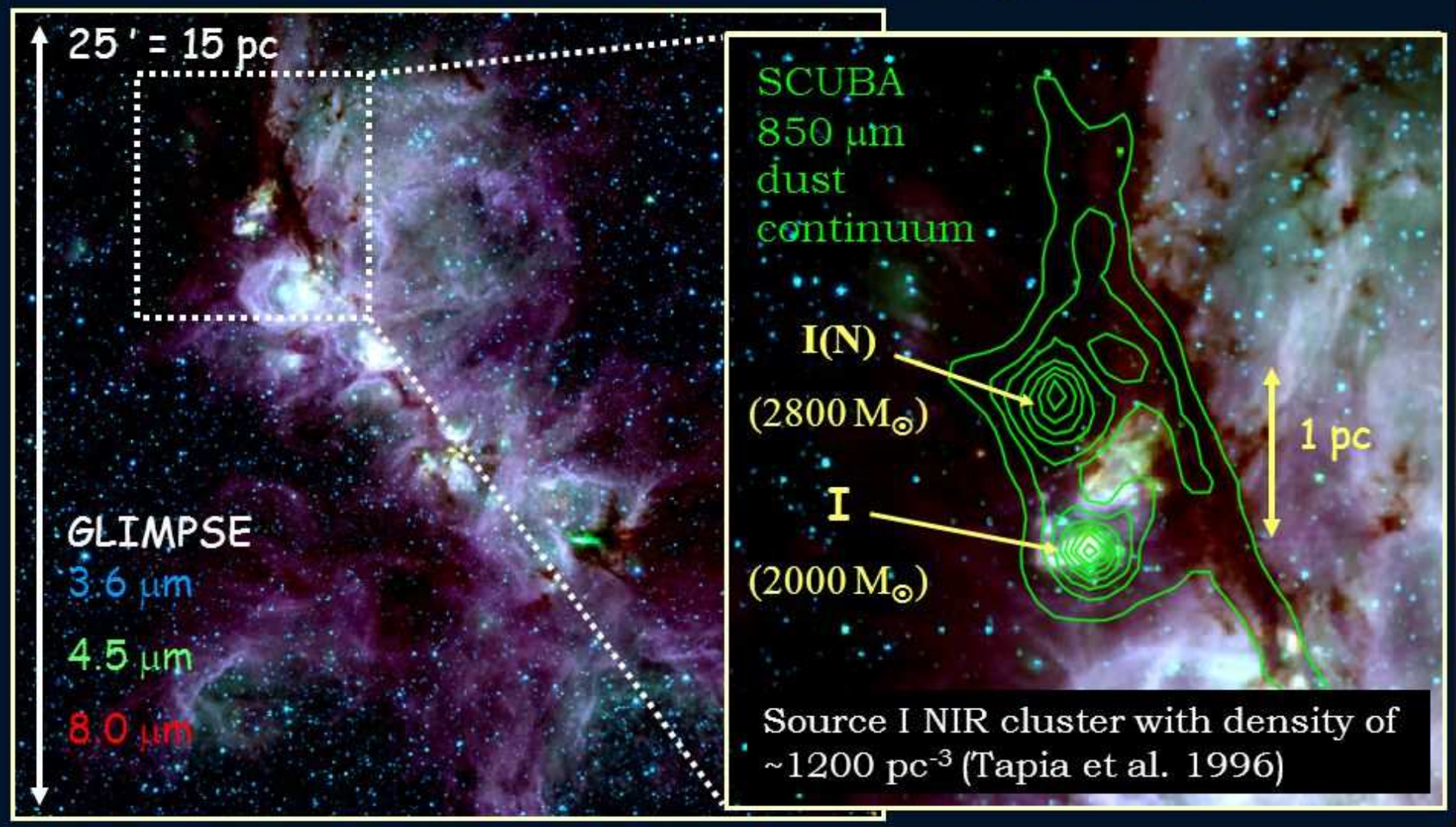
High-velocity jet formation

Low-velocity bipolar outflow (collimated)

[Cepheus A HW3d & NGC 6334IN SMA]

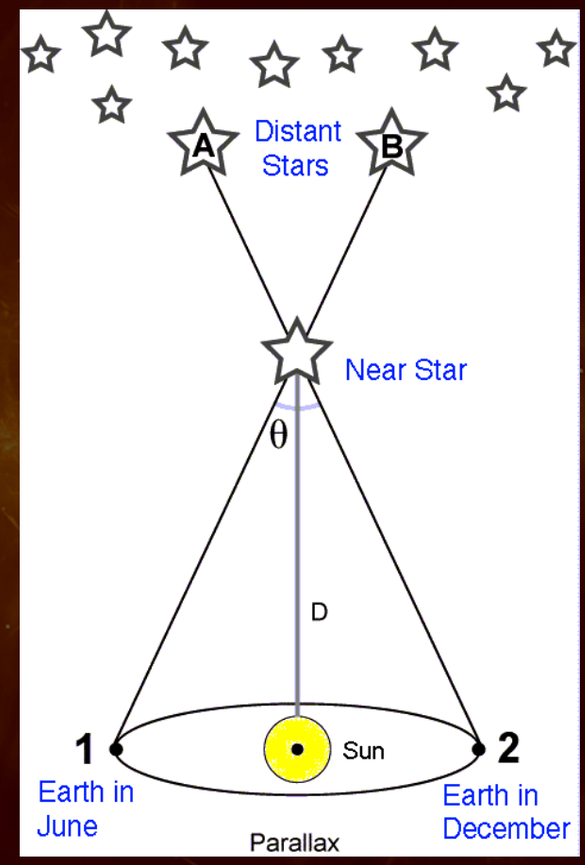
VLBI Regional Workshop, Mexico City, 2019.

The NGC6334 Star Forming Complex

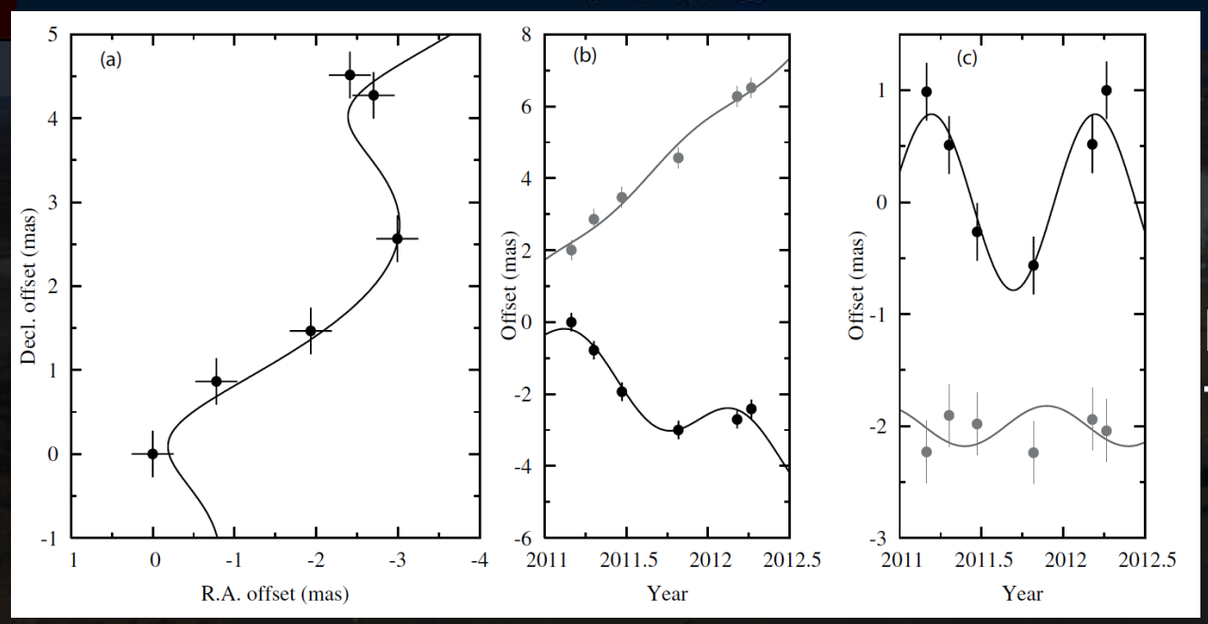


- NGC 6334 I luminosity $3 \times 10^5 L_\odot$, I(N) two orders of magnitude less
- Based on infrared, I(N) speculated to be less evolved than I

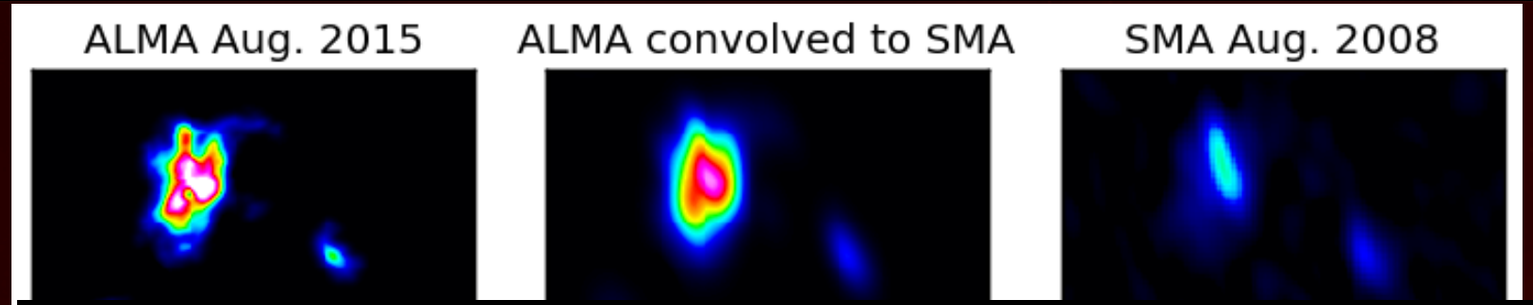
2



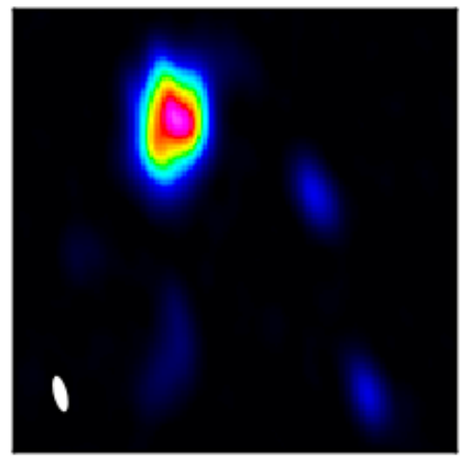
Credit: C. Brogan



NGC 6334I(N) [1.26 kpc] with VERA by Chibueze et al. (2014) adopted for NGC 6334I

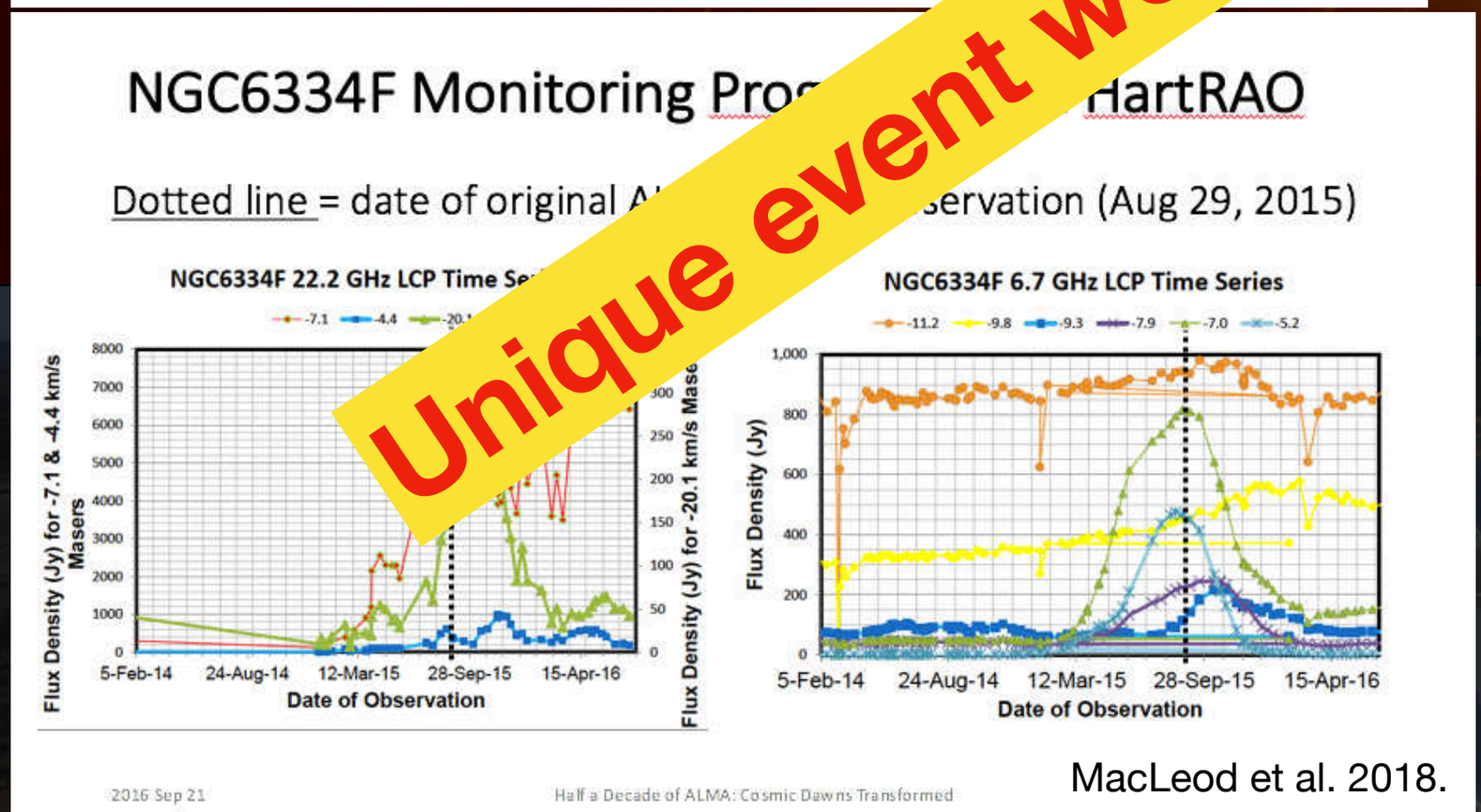


Central protostar undergoes a burst in accretion rate from 10^{-3} to 10^{-1} $M_{sun}\,yr^{-1}$ as a massive (0.55 M_{sun}) gas fragment approaches and enters the protostellar sink cell.

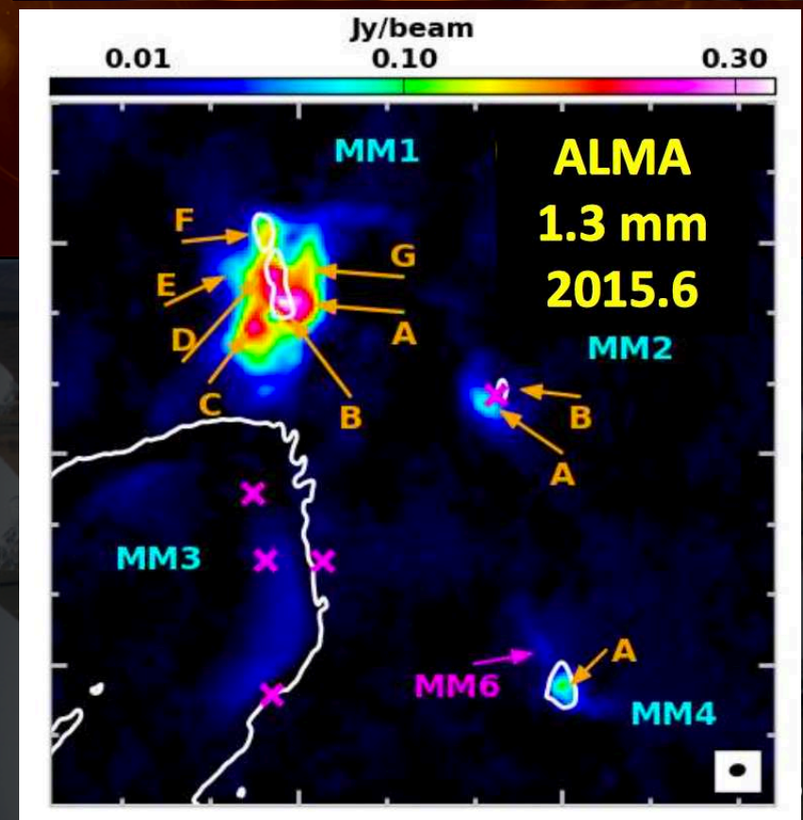


Hunter et al. 2017.

Unique event worth following up!!!



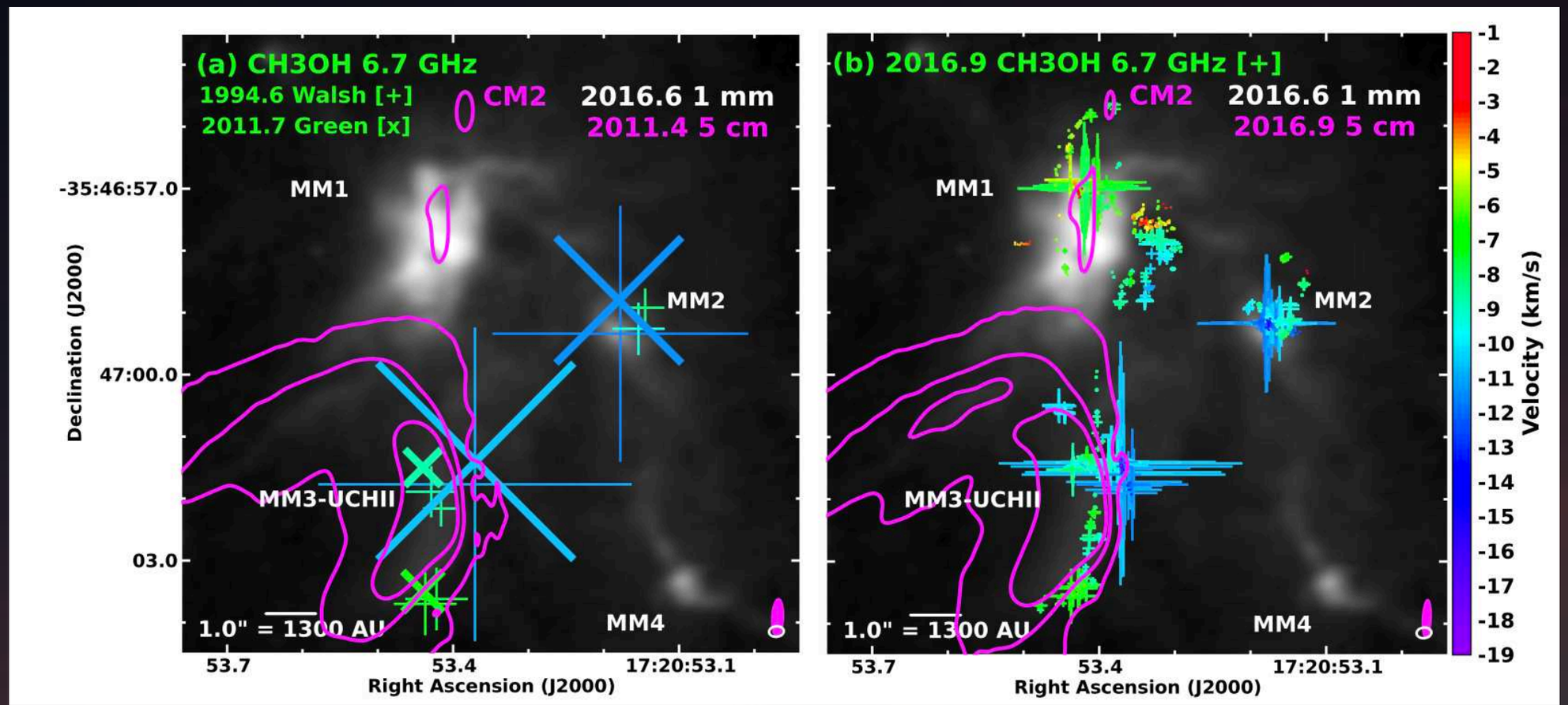
MacLeod et al. 2018.

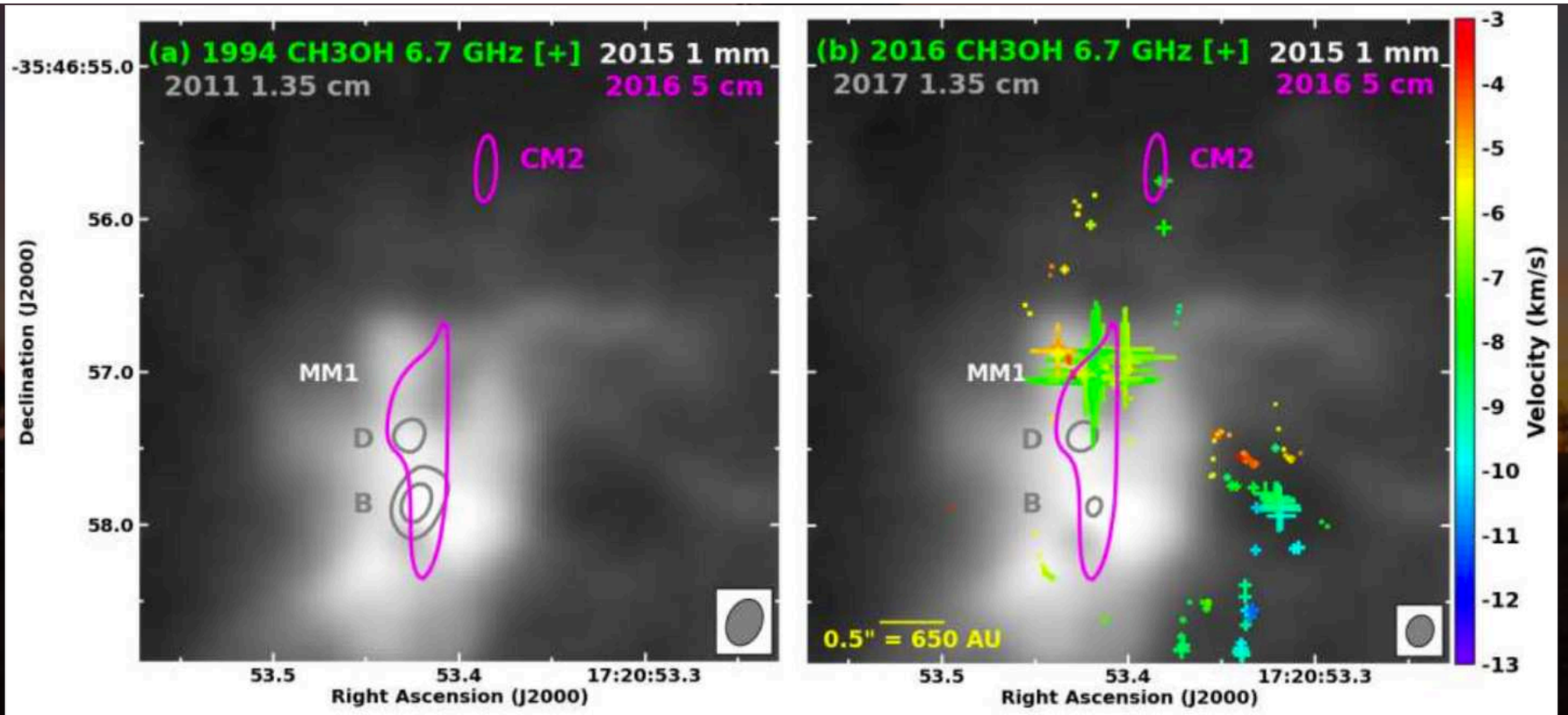


Follow-up observations

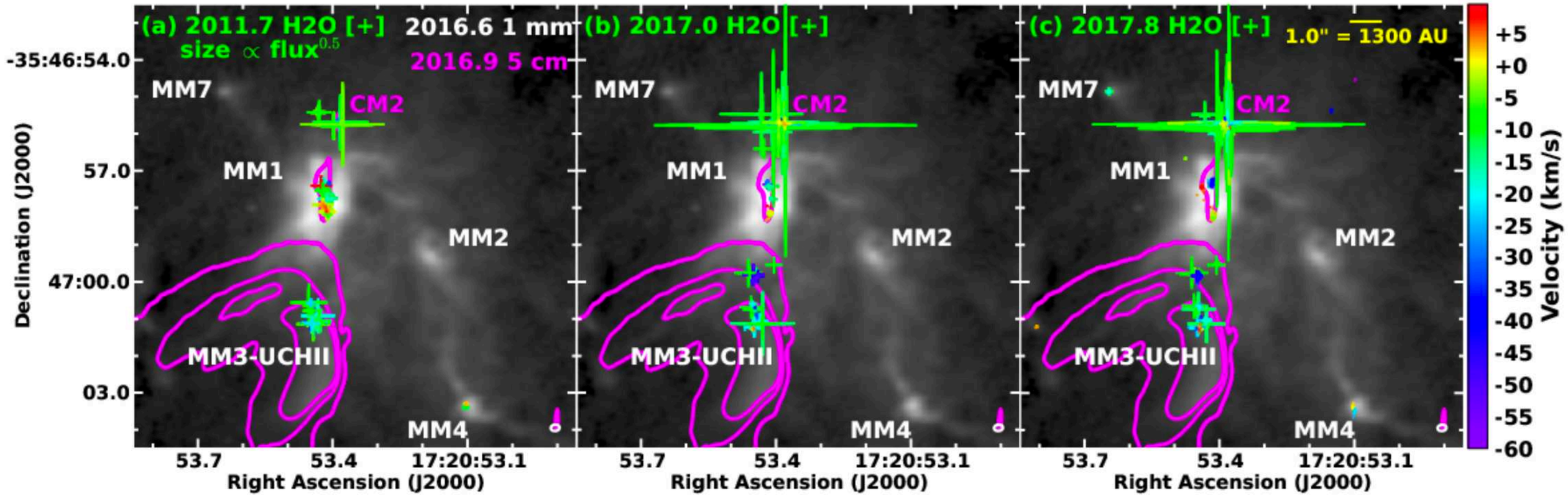
ALMA (DDT & Standard proposals), JVLA (C, K, Q bands), KaVA (K band)

(Hunter et al. 2018, Brogan et al. 2018, Chibueze et al. 2019 in prep)

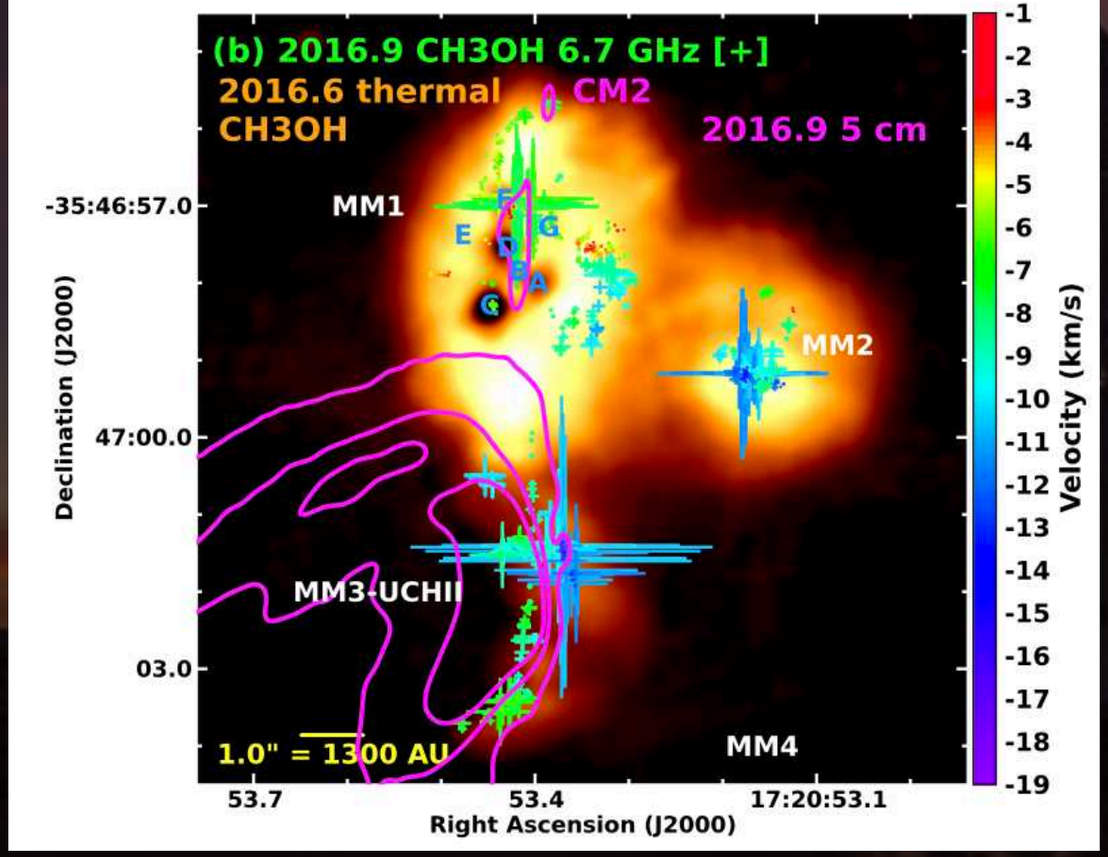




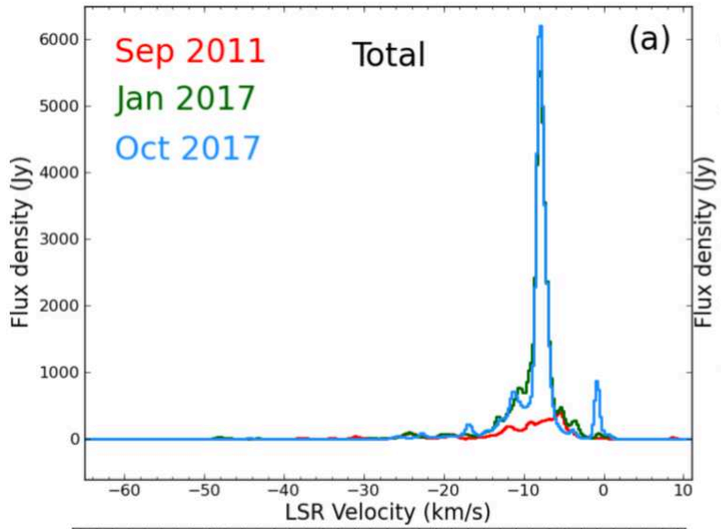
6.7 GHz CH3OH masers emergence

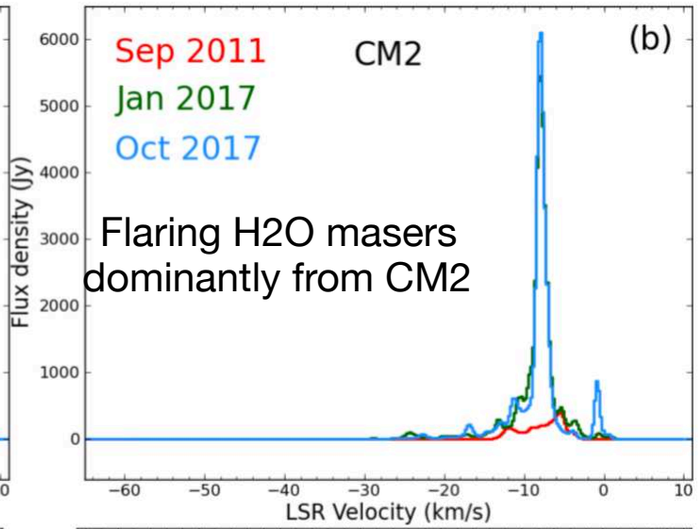


22 GHz H2O masers

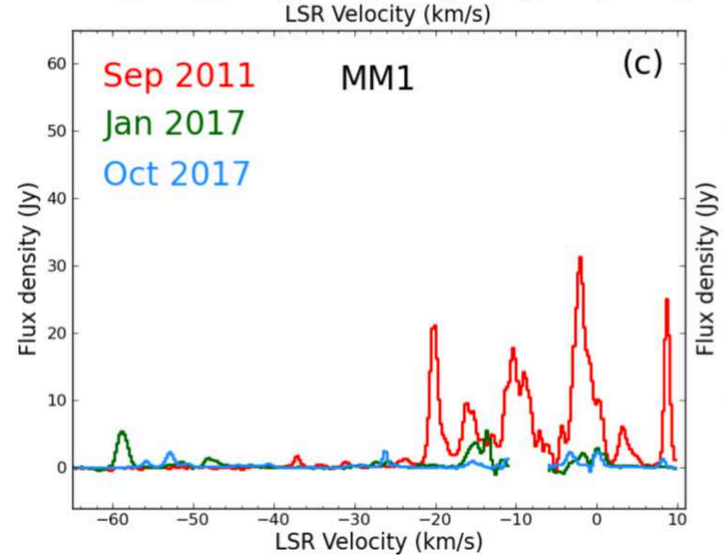


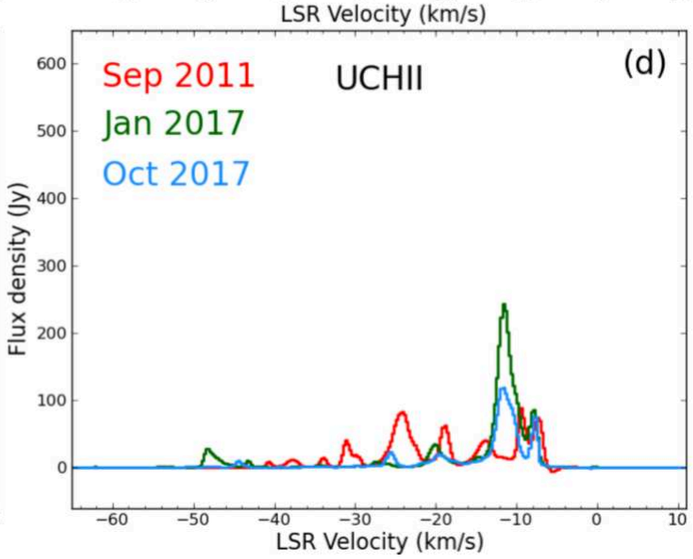
Thermal CH3OH transition 11(2)–10(3) with an E_{lower} ~ 177 K



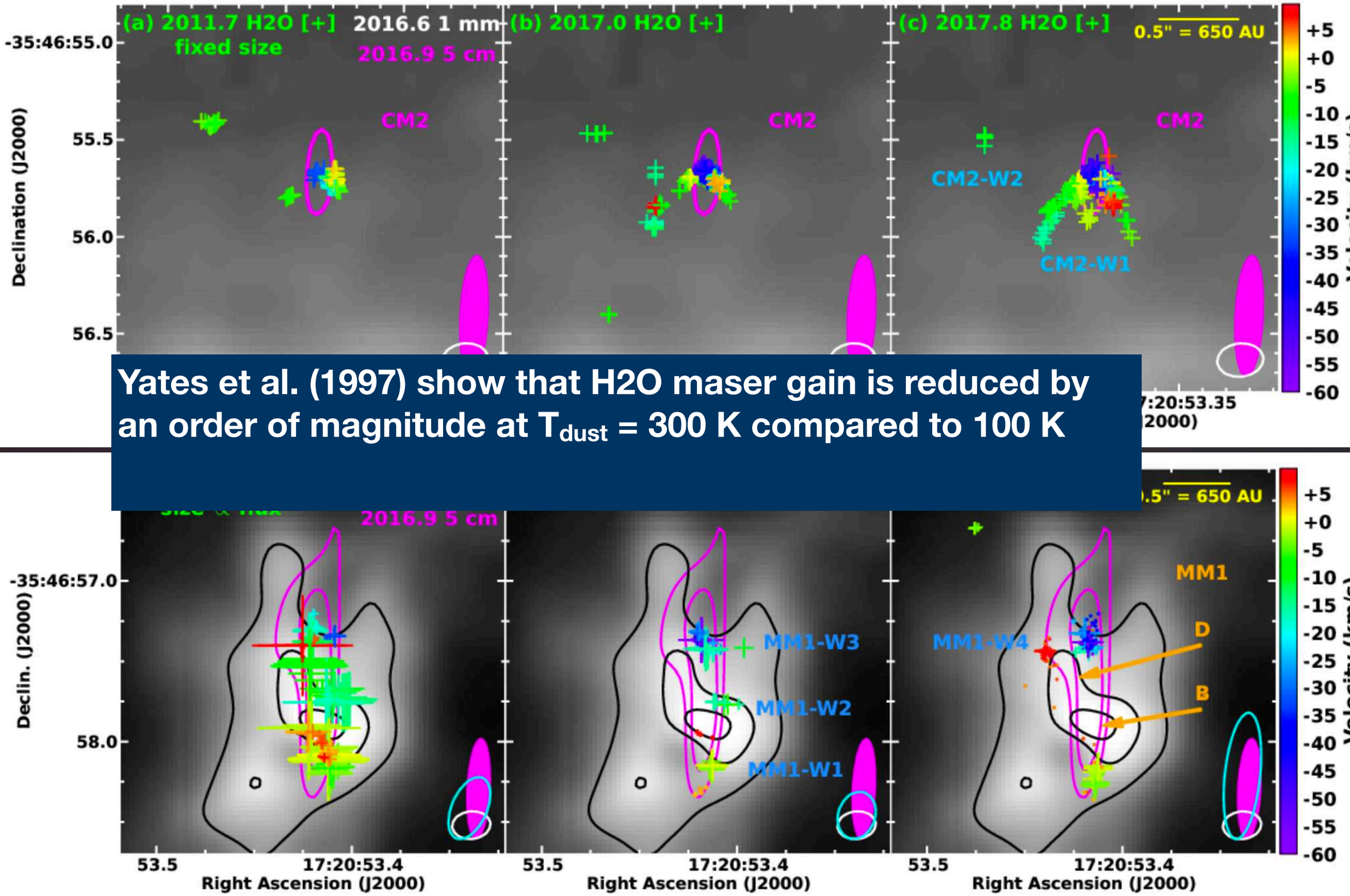


Flaring H2O masers dominantly from CM2





Shock enhancement and thermal destruction of H2O

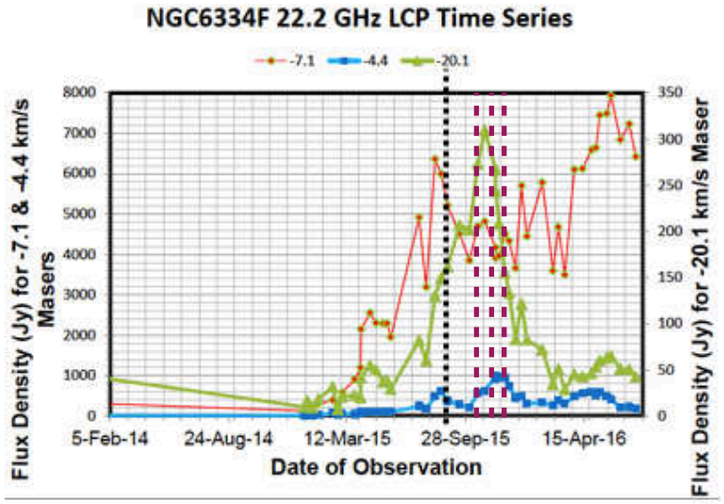


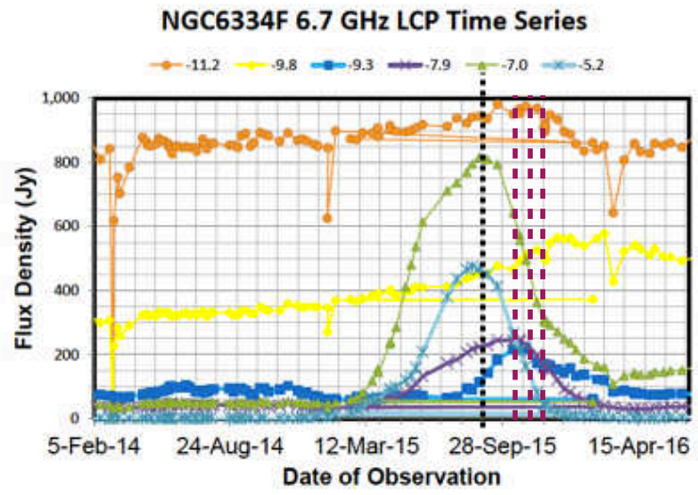
Yates et al. (1997) show that H2O maser gain is reduced by an order of magnitude at T_{dust} = 300 K compared to 100 K

Credit: National Astronomical Observatory of Japan/ Korea Astronomy and Space Science Institute/ And You Inc.

NGC6334F Monitoring Programme at HartRAO

Dotted line = date of original ALMA Band 6 observation (Aug 29, 2015)





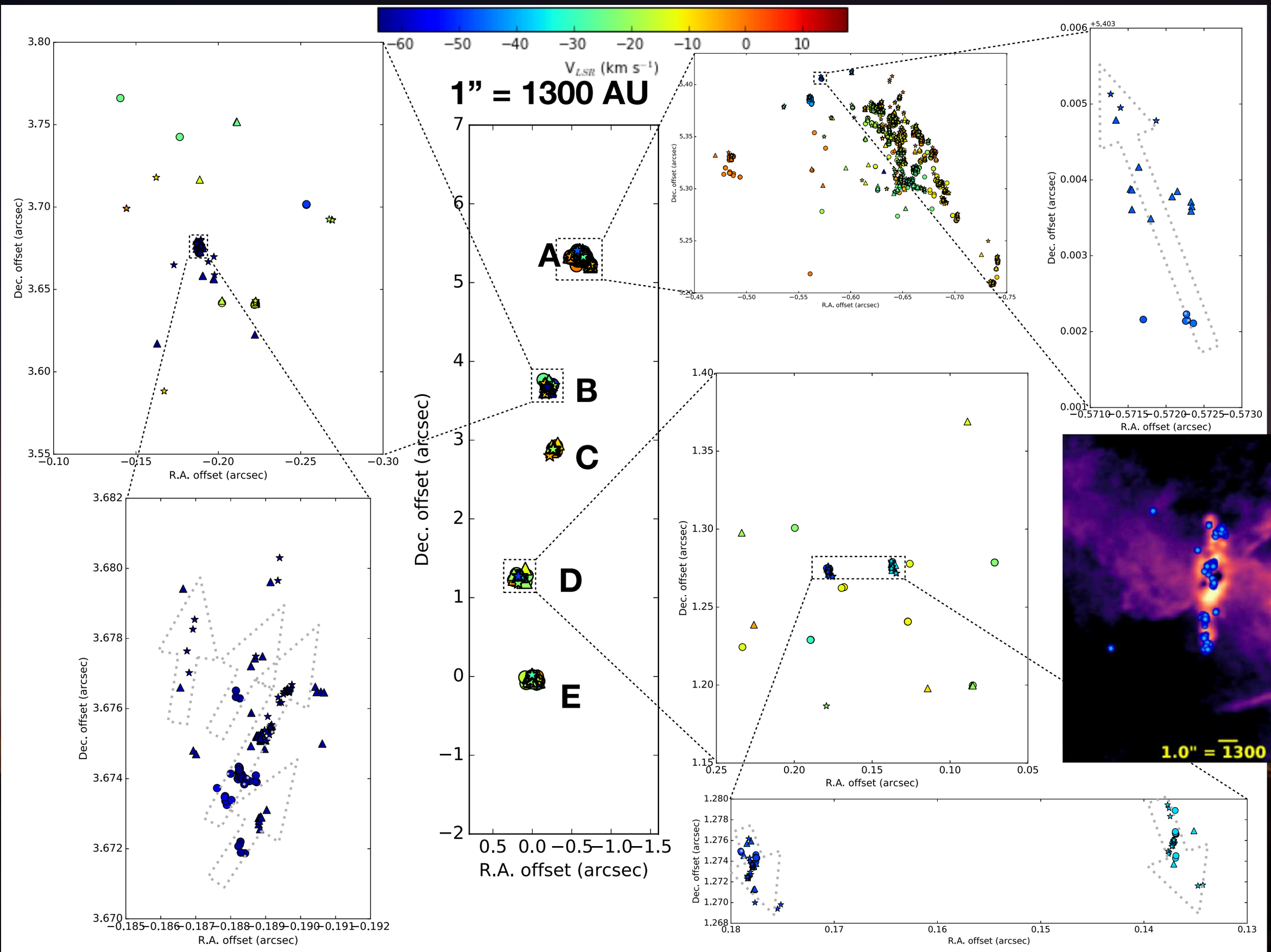
3 epochs

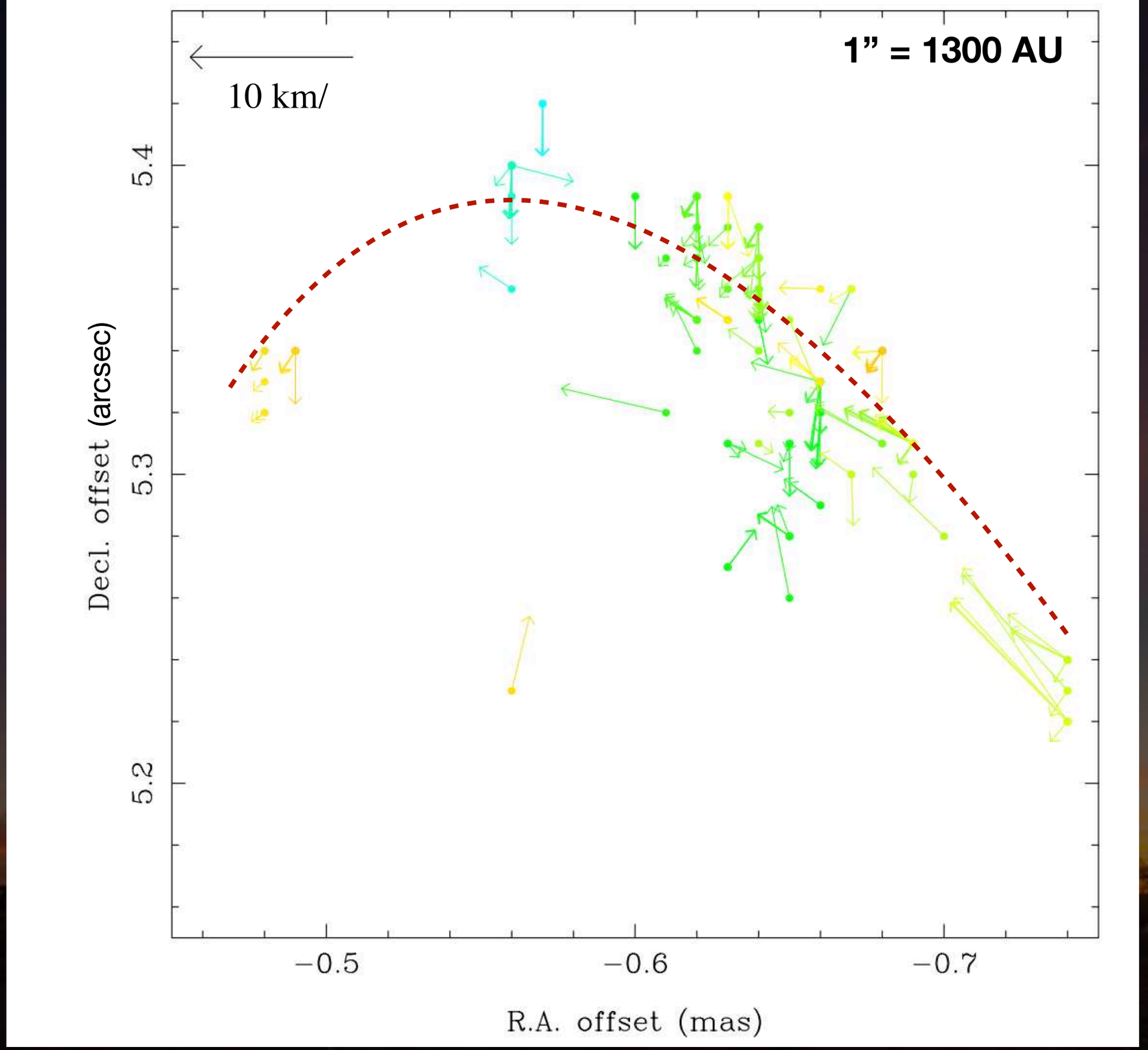
R15325 Nov 21, 2015

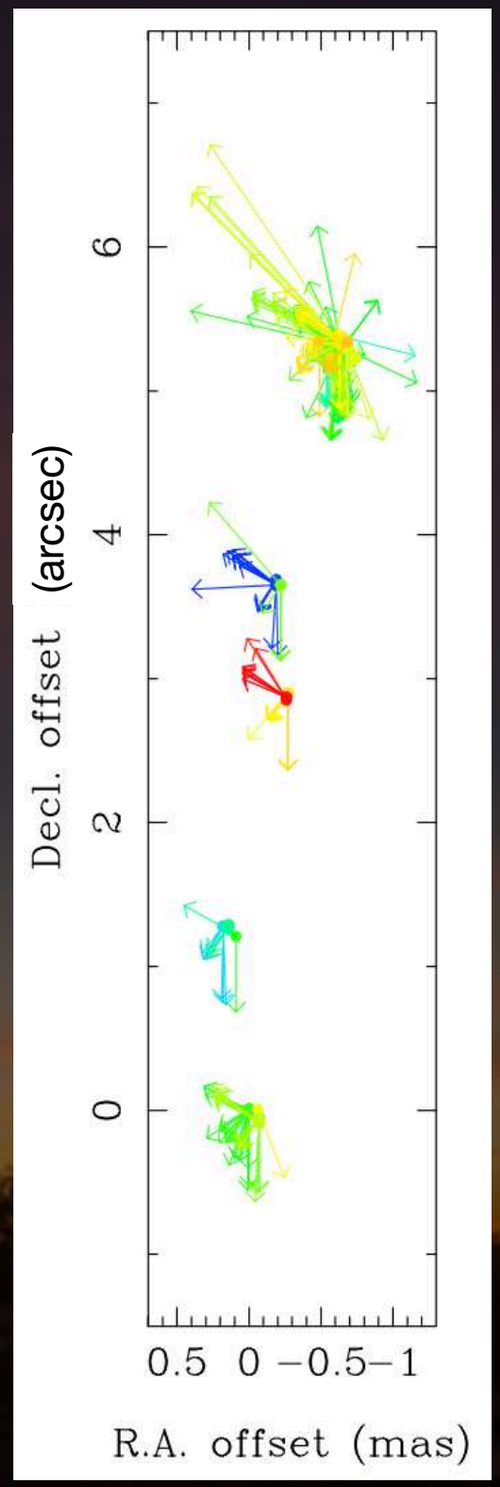
R15349 Dec 15, 2015 24 days

R16004 Jan 04, 2016 20 days

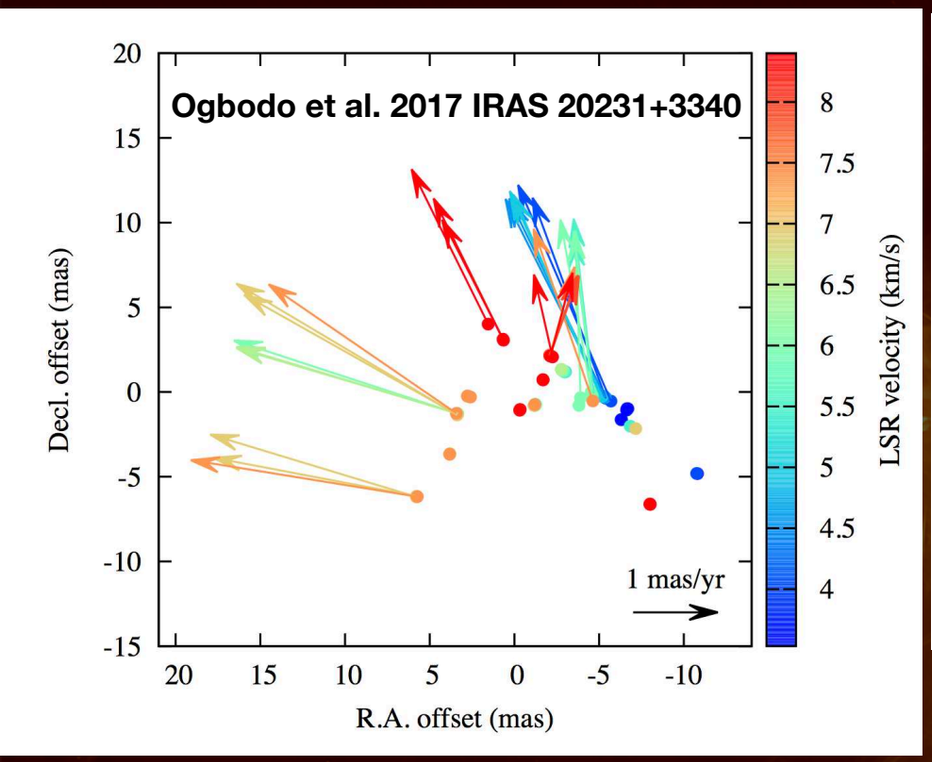
KaVA (Korean VLBI Network + Japanese VERA)
Chibueze et al. 2018 (in prep.)

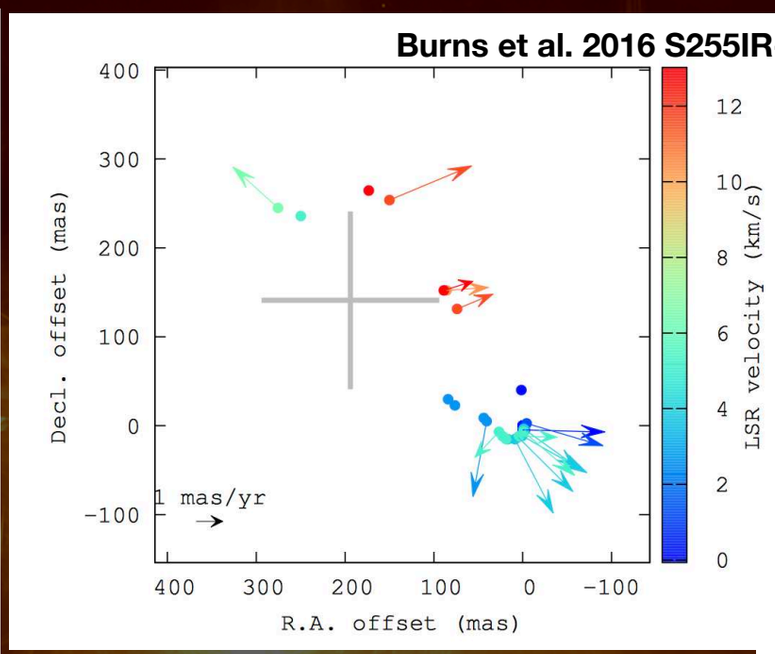


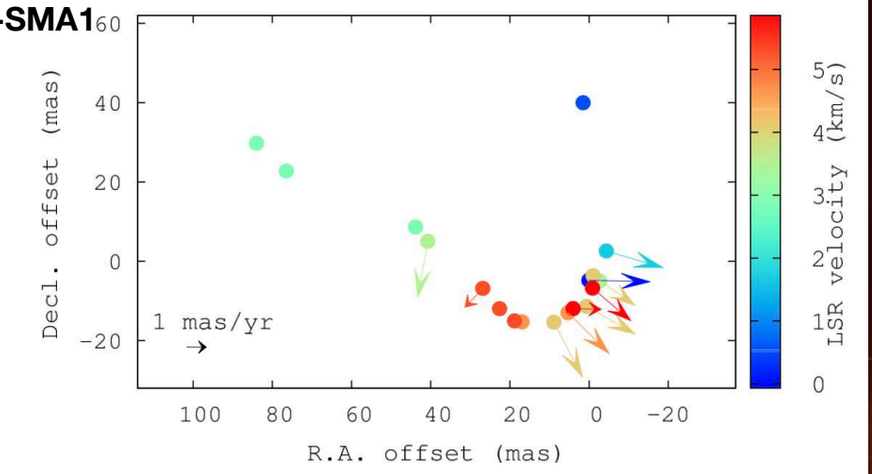

1” = 1300 AU
10 km/
Decl. offset (arcsec)
5.4
5.3
5.2
−0.5
−0.6
−0.7
R.A. offset (mas)

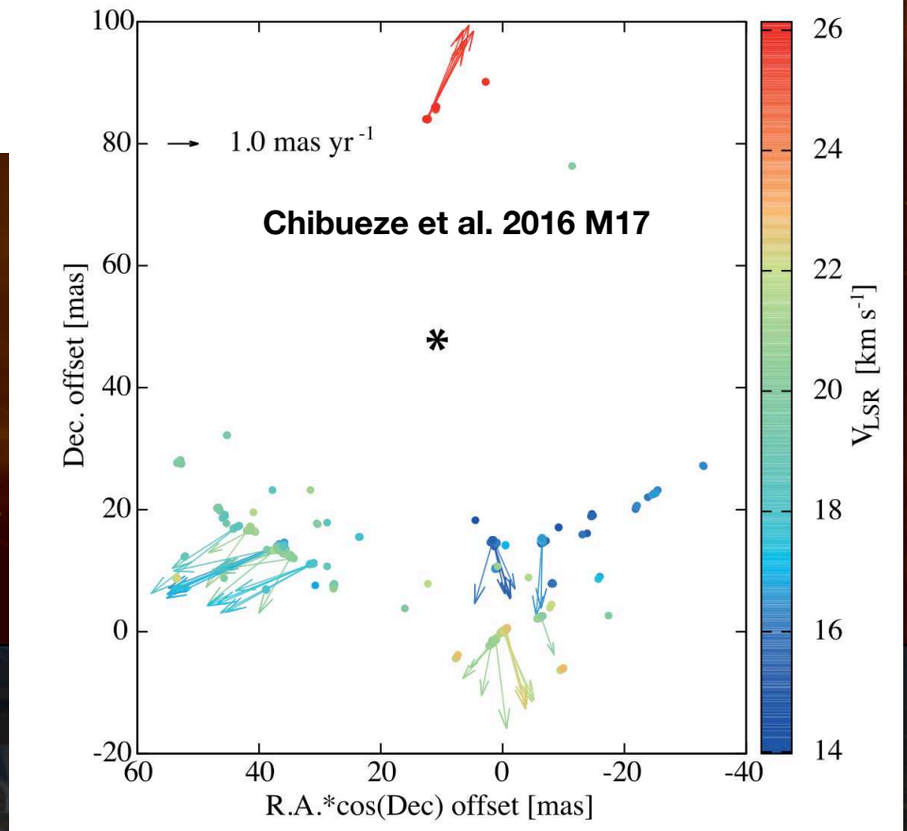

Decl. offset (arcsec)
6
4
2
0
0.5
0
−0.5
−1
R.A. offset (mas)

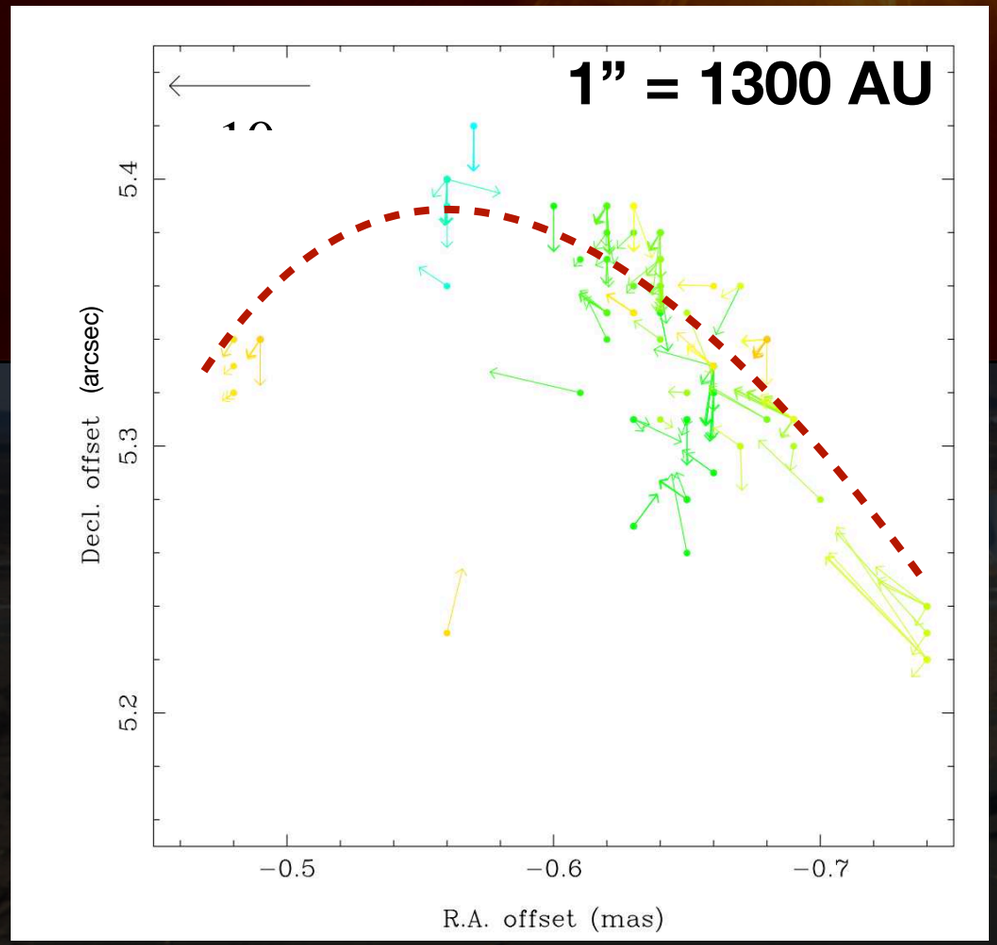
Examples of proper motions with bow-shock morphologies











Summary

- Dish conversion is a great idea. However, it should not be a mere demonstration of engineering prowess. Proper consultation with possible science user community is crucial for optimization of the instrument.
- Collaboration opportunities abound.
- FVN needed to flexibly schedule and catch spectacular events, both galactic and extra-galactic
- Unique avenue for AVN to lead world-class discoveries rather than only playing complementary role to EVN
- Follow-ups at other wavelengths will be of benefit