

# *In Summary*

Attempt to capture the information in all the talks

# Our Hosts: Arcetri

People

- ~ 120 employees:
- 60 astronomers/technology staff
- 30 technical-administrative
- 30 PhD/post-doc (15-20 calls/year)

Close cooperation with the Astronomy group of UniFi



Univ. di Firenze  
Dip. Di Fisica



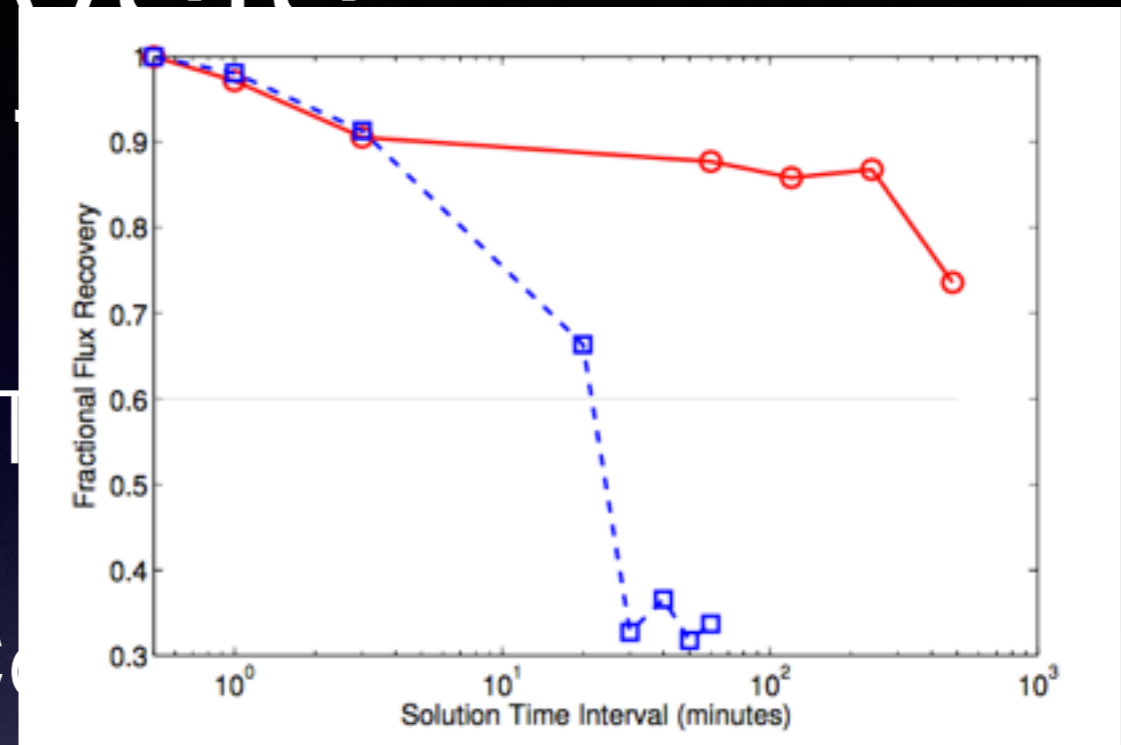
# Analysis

- Maria Rioja: SFPR and FTP methods
  - Sensitivity through Coherence
    - (120-fold increase (300% in diameter)  
cf 4-fold in BW (40%))
  - Astrometry — Weak Sources



# Analysis

- Maria Rioja: SFPR and FT
- Sensitivity through Co



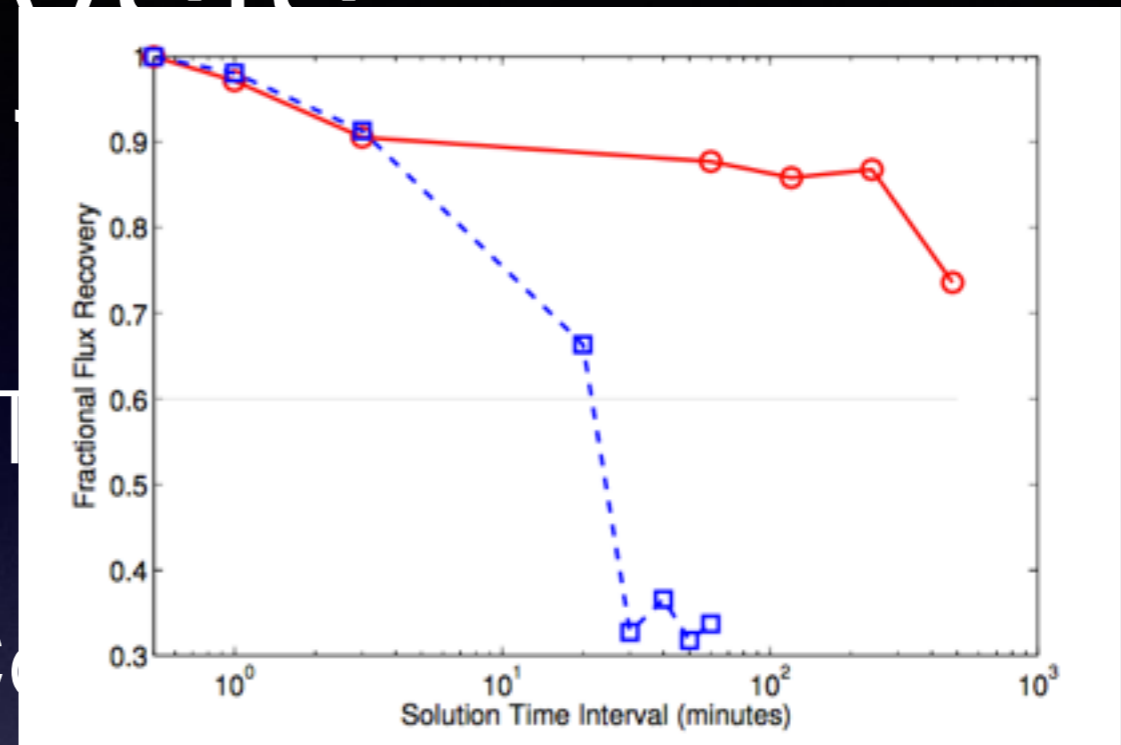
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# Analysis

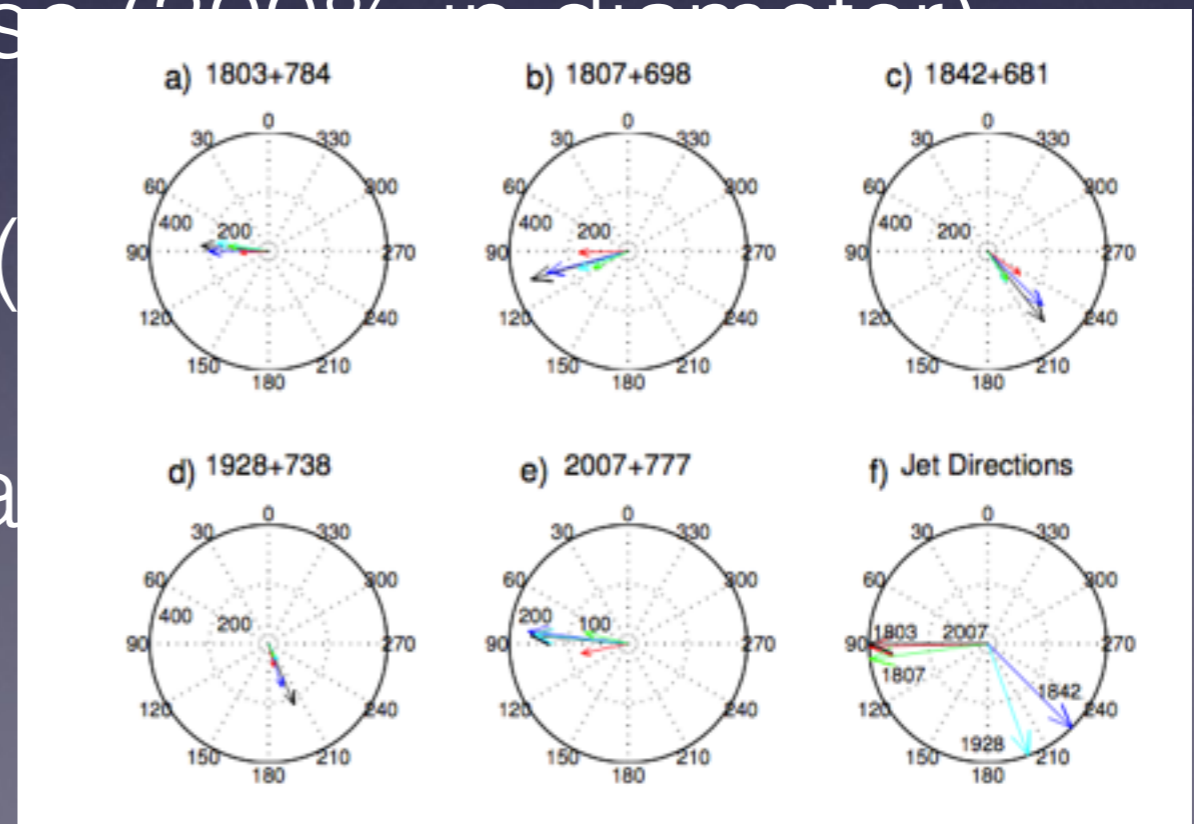
- Maria Rioja: SFPR and FT
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(120-fold increase in diameter)

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- Astrometry — Wea

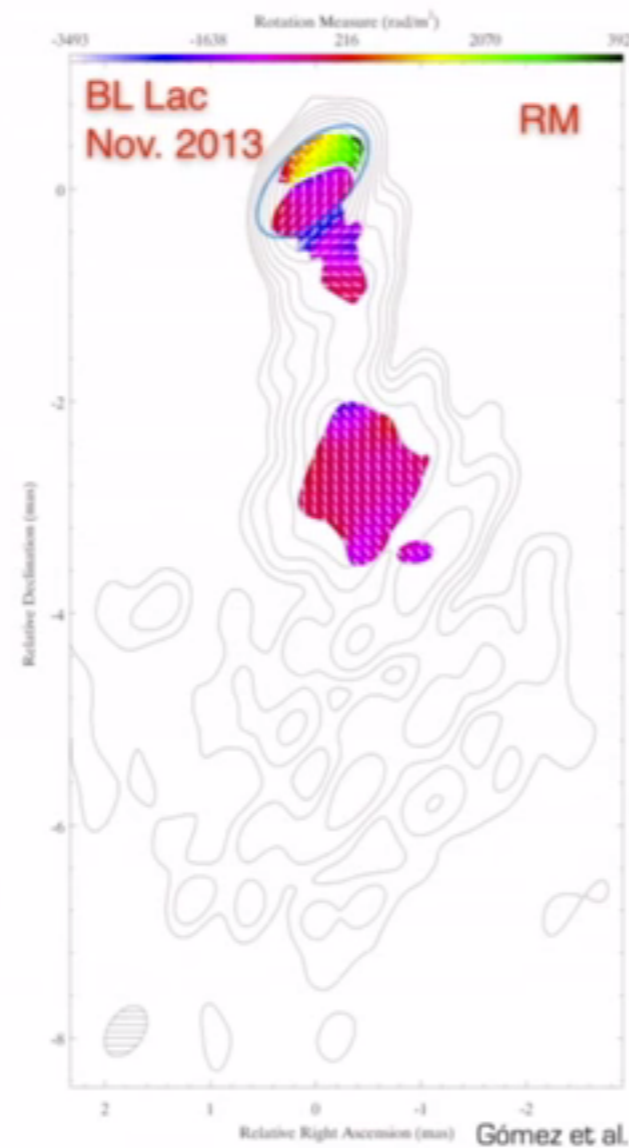


# Continuum

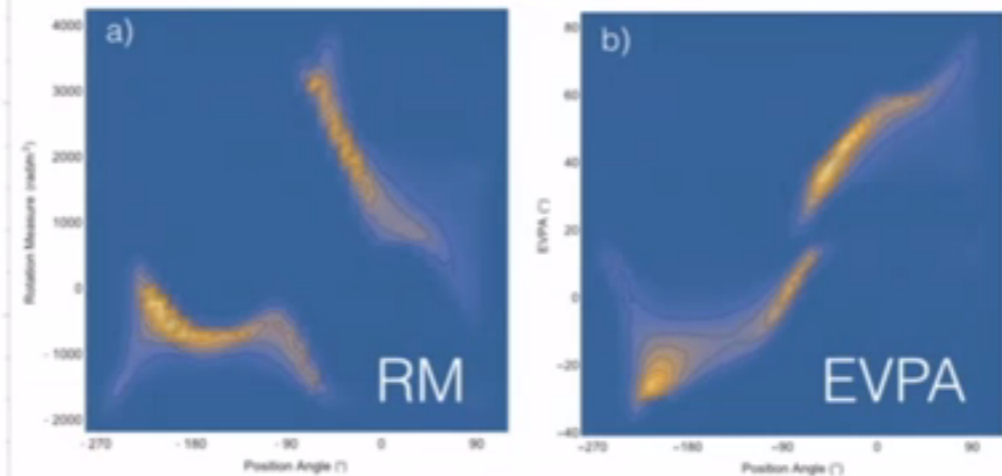
- Jose Luis on Science: Very interesting probes of the AGN jet physics, particularly with registration
- Sol on MFPR: New analysis technique. Not completed, but promising
- Pablo on Pulsars: Exploration of the unknown



## FARADAY ROTATION STUDIES FROM MULTI-FREQUENCY OBSERVATIONS

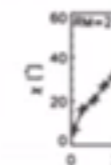


### 2D Histograms



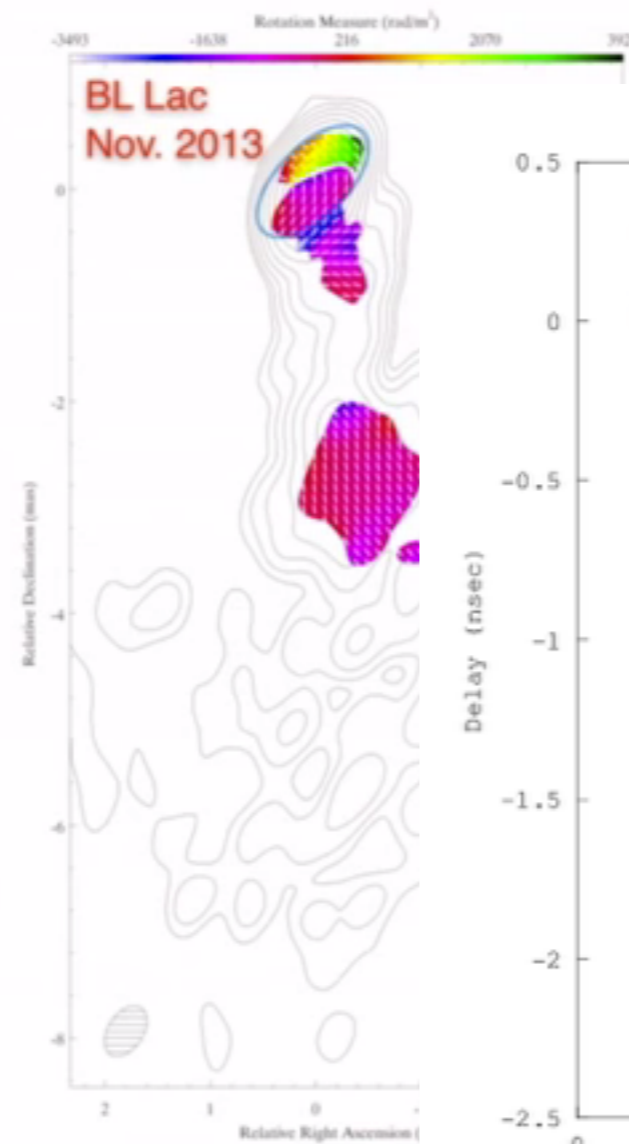
The core area shows a point symmetric structure in RM and EVPA, as shown in the 2D histograms as a function of position angle wrt the core in the selected area.

**The polarization structure is consistent with the existence of a helical magnetic field threading the jet.**



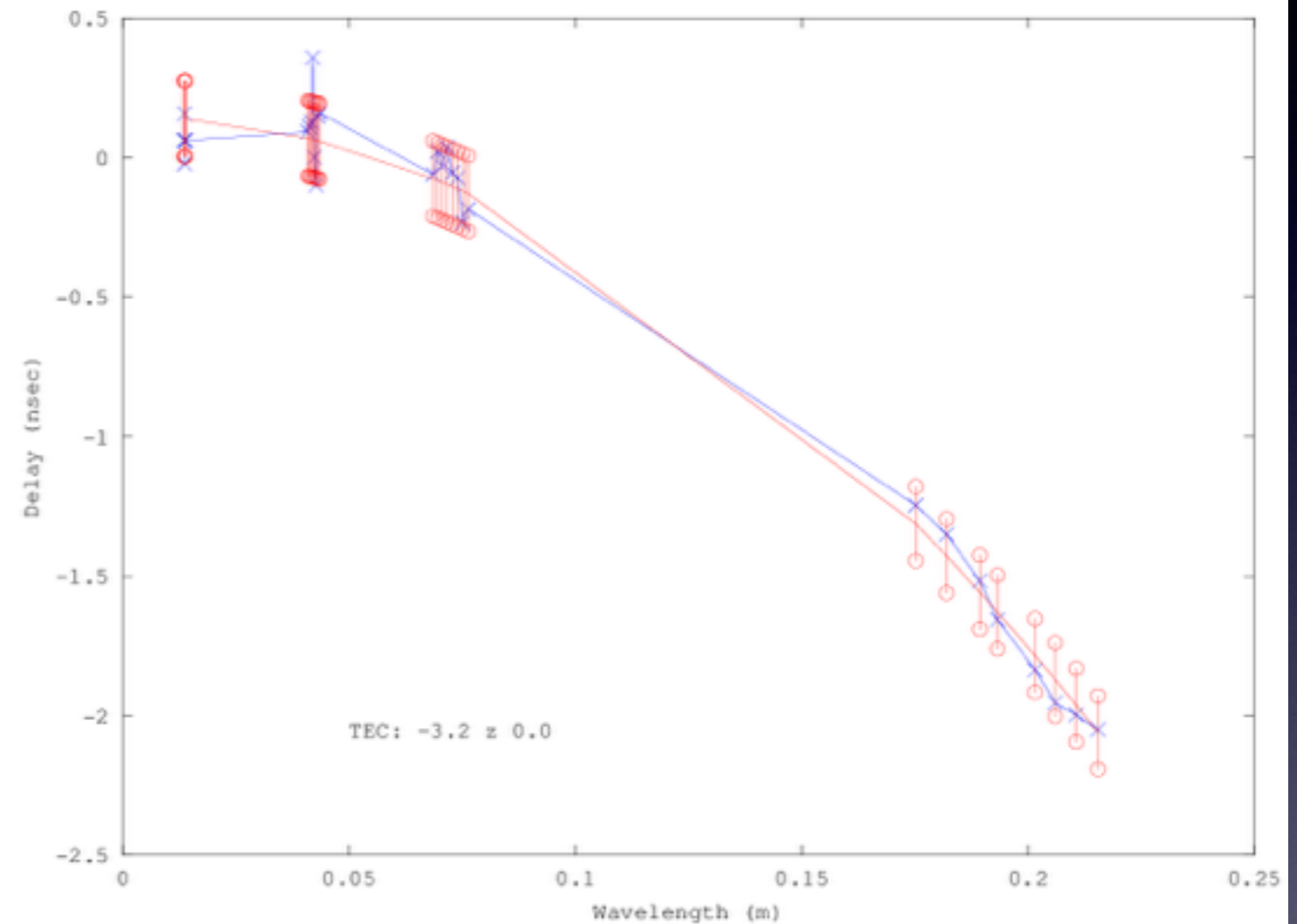
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## 2D Histograms

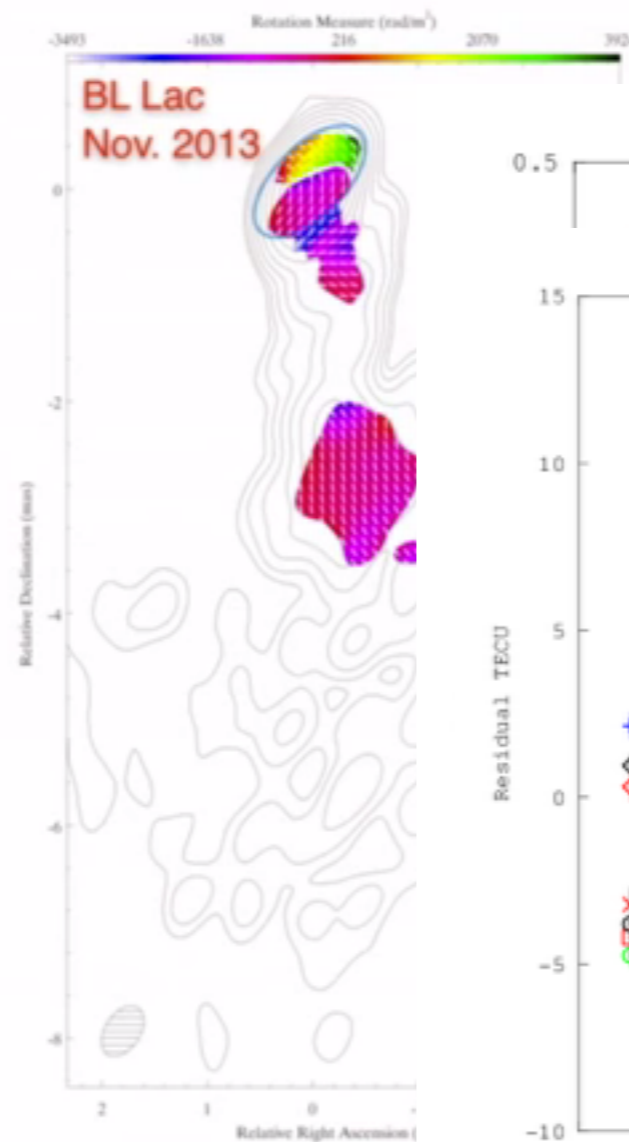
Antenna No.: 1 Scan No.: 0



- Jose Luis on the AGN
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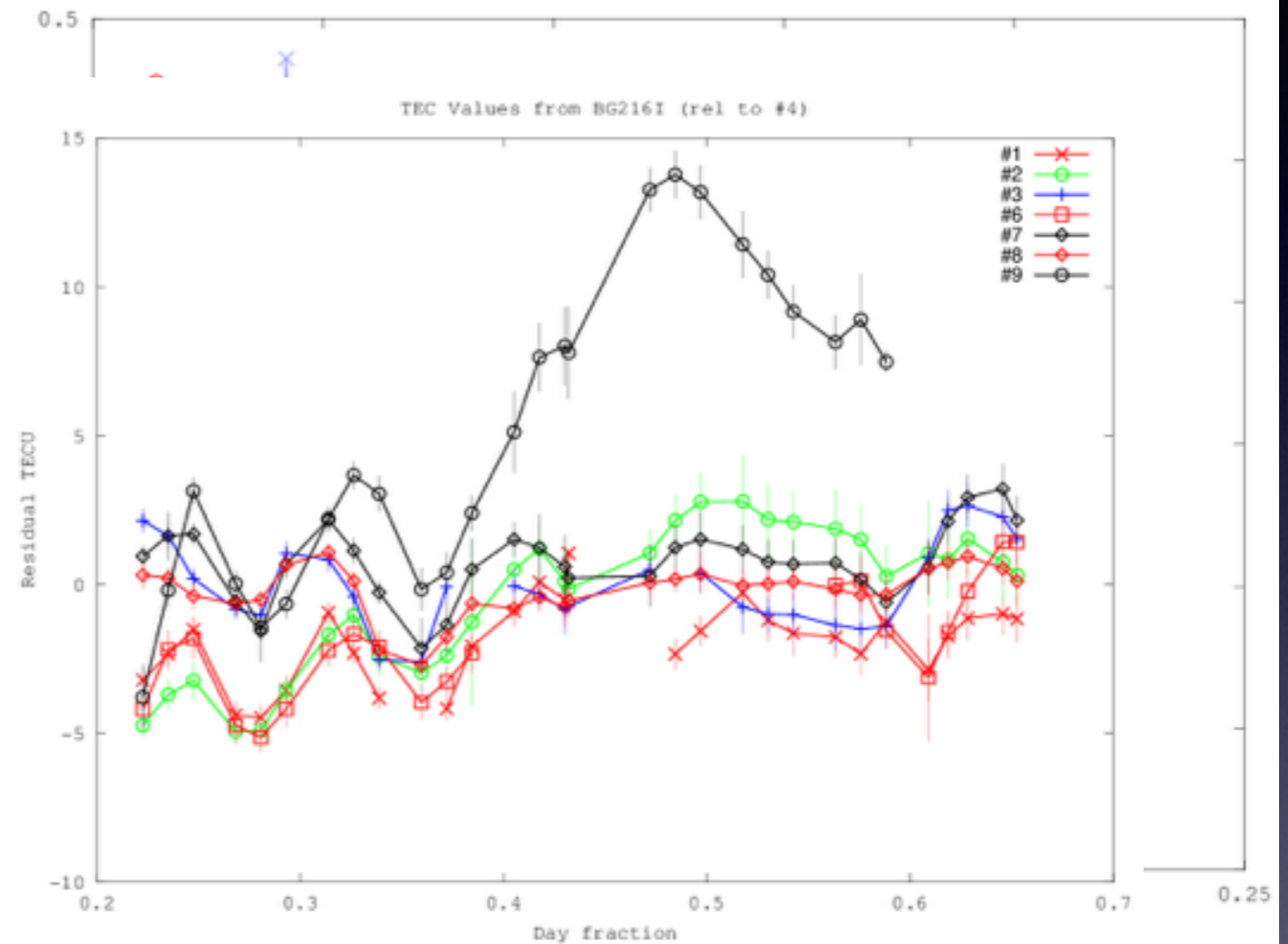


## FARADAY ROTATION STUDIES FROM MULTI-FREQUENCY OBSERVATIONS



### 2D Histograms

Antenna No.: 1 Scan No.: 0



- Jose Luis on the AGN
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## FARADAY ROTATION STUDIES FROM MULTI-FREQUENCY OBSERVATIONS



Introduction

Why mm-?

Experience & Challenges

Future

## (Near) Future of mm- Pulsar Astronomy



- Efforts to test General Relativity and other theories of Gravity by imaging directly Sgr A\* with mm-VLBI
- Includes the search for pulsars around Sgr A\*, complementing the results by the black hole imaging. Pulsars potentially allow to measure the mass, spin and quadruple moment of the black hole with un...
- Global collaboration Event Horizon Teles...

0.25

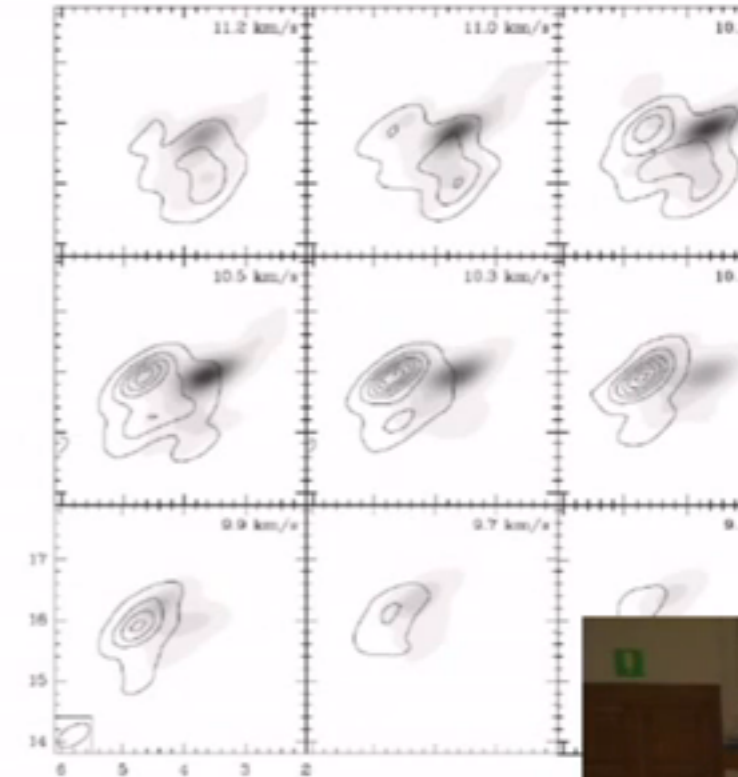
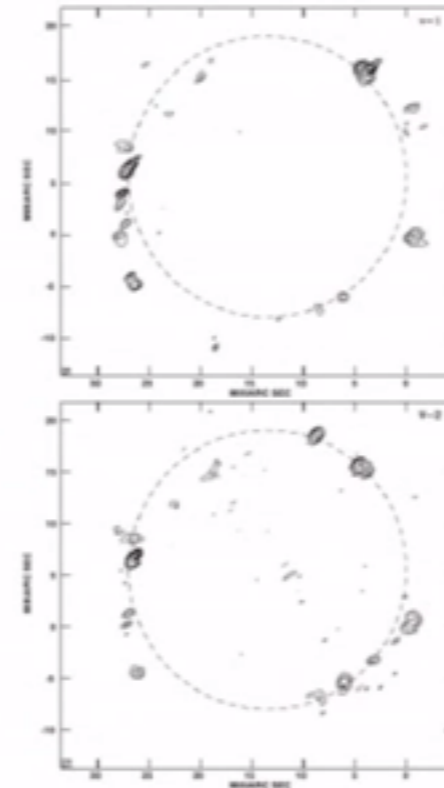
# Lines

- Valentin on evolved stars:
- Luca on SFR:
- Anita on multiple masers and physical conditions



- Valentin on evolution
- Luca on SFR:
- Anita on multiple conditions

## Collisional vs. radiative pumping – coincident spots for $v=1,2$ J



Apparently similar distributions

but  $v=2$  ring is slightly smaller and peaks very rarely appear in




2:32:09 / 3:27:11


Desmurs et al. (2000, AA 360, 189), Soria-Ruiz et al. (2004, AA426, 13)

- Valentin on evolution
- Luca on SFR:
- Anita on multiple conditions

Collisional



ots for  $v=1,2$  J



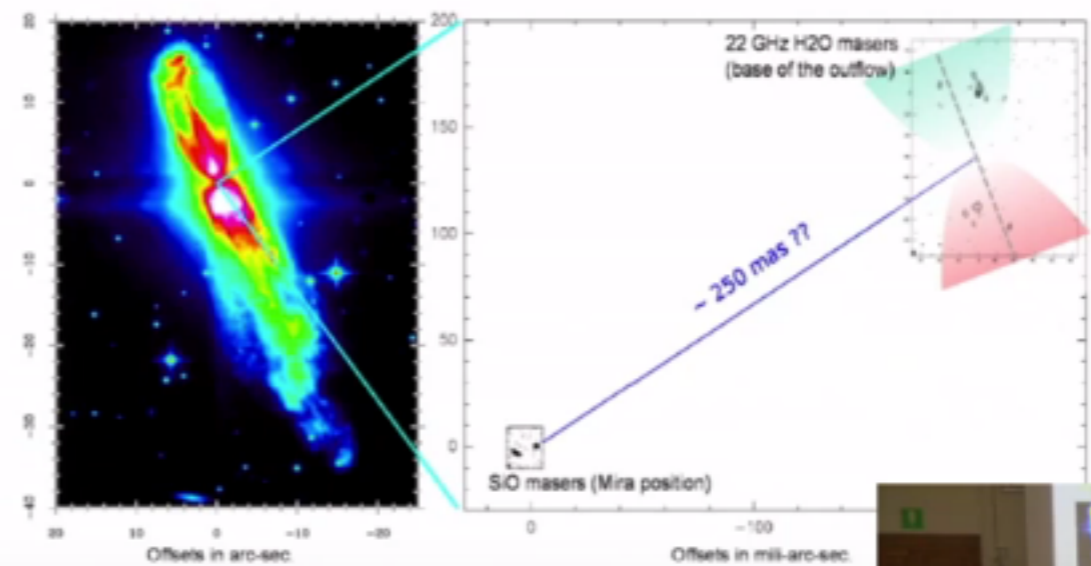
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- Luca on SFR:
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### Attempts to accurately place H<sub>2</sub>O and SiO masers in OH 231.8+4.2



More recent (accurate?) information place them quite far away  
~~First observations performed more than ten years ago, result~~

2:48:10 / 3:27:11

Apparently similar distributions  
 but  $v=2$  ring is slightly smaller and peaks very rarely appear in

2:32:09 / 3:27:11

Desmurs et al. (2000, AA 360, 189), Soria-Ruiz et al. (2004, AA426, 131)



Attempts to accurately place H<sub>2</sub>O and SiO masers in OH 231.8+4.2



- Valenti
- Luca
- Anita



Conclusions: maser VLBI @ 3mm  
 Targets: 85 – 87 GHz methanol masers, flux: 1 – 10 Jy  
 7 sigma single baseline detection thresholds full members in sight  
 Click for [DRA22 maser list calculator](#)

Δν = 500 MHz	σ = 20 mJy						
Field	P. de Bona	Pico Veleta	Tolosa	Onsala	Metzger	VLBA	VLBA
Efessberg	30	63	71.86	124	126	61.126	182
P. de Bona	30	39	31.89	85	126	61.126	18
Pico Veleta	30	39	31.89	85	126	61.126	18
Tolosa			71.86	124	126	61.126	18
(Wester/Summers)			61.72	140	126	61.126	18
Onsala				126	126	61.126	18
Metzger				126	126	61.126	18
VLBA						61.126	18

Δν = 500 MHz , 7σ = 100 mJy

The "Source Frequency Phase Referencing" technique by M. J. Rioja & R. Dodson is very effective in this respect !!!

appear i

004, AA426, 13

Attempts to accurately place H<sub>2</sub>O and SiO masers in OH 231.8+4.2



- Valenti
- Luca
- Anita

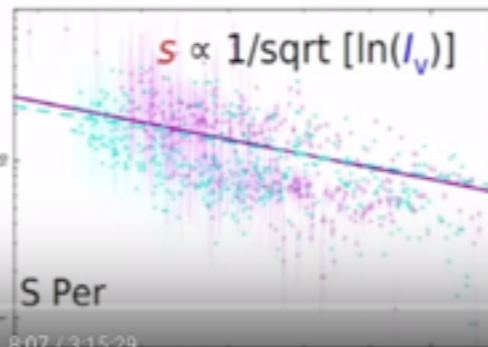
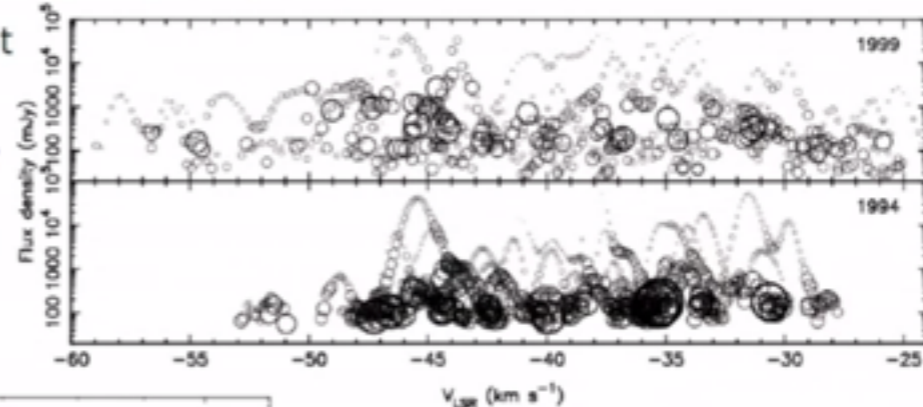
Conclusions: maser VLBI @ 3mm  
 Targets: 85 - 87 GHz methanol masers, flux: 1 - 10 Jy

Source	Flux	Position	Notes
Efremberg	1.5	12h 58m 10.0s	
P. de Buzze	3.0	12h 58m 10.0s	
Polaris	1.0	12h 58m 10.0s	
Yebes	1.5	12h 58m 10.0s	
Westerlund 2	1.0	12h 58m 10.0s	
Orion	1.0	12h 58m 10.0s	
Methuselah	1.0	12h 58m 10.0s	
VLBA	1.0	12h 58m 10.0s	

The "Source" technique is very

Shrinking of brighter masers

- Component size  $s$
- Intensity  $I_V$
- Brighter spots are smaller



- "Amplification-bounded" beaming from ~spherical

Richards+11  
 Elitzur+92



- Valenti
- Luca
- Anita

### Attempts to accurately place H<sub>2</sub>O and SiO masers in OH 231.8+4.2



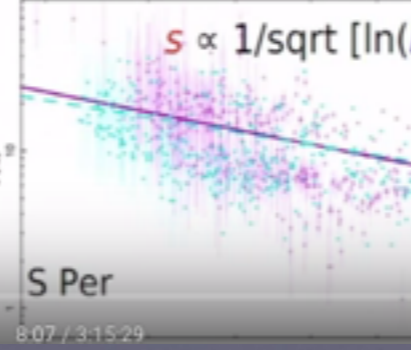
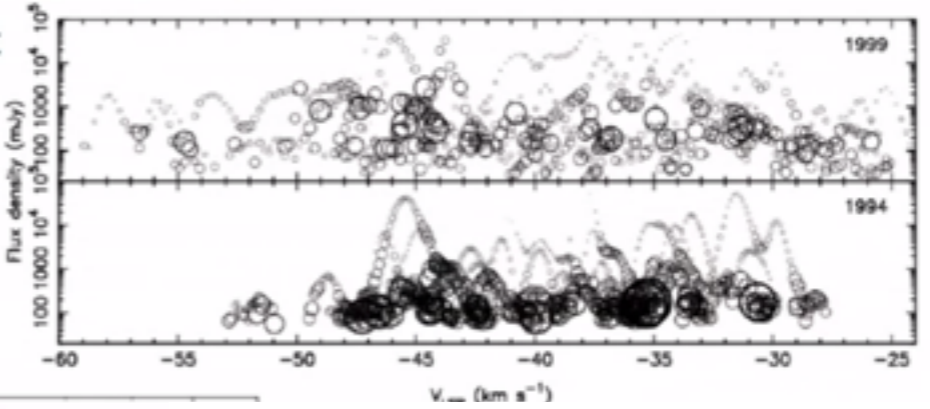
Conclusions: maser VLBI @ 3mm  
 Targets: 85 – 87 GHz methanol masers, flux: 1 – 10 Jy  
 7 sigma single transition detection threshold (all masers in sight)

Star	500 MHz	20 GHz	85 GHz	86 GHz	87 GHz	VLBA	VLBA
Effeberg							
P. de Buzze	30						
Pico Velata		43					
Tadpole		30					
Tadpole (Westerlund 2)			45.72	45	45	100	100
Onsala						100	100
Methuselah						175000	100000
VLBA						175000	100000

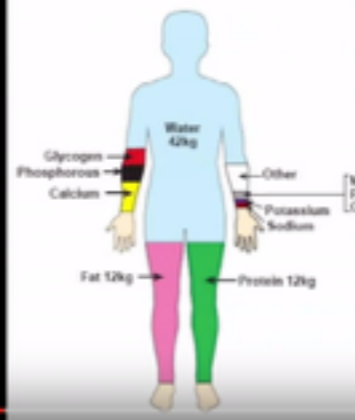
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### Shrinking of brighter masers

- Component size  $s$
- Intensity  $I_v$
- Brighter spots are smaller



### Why astronomers need water



- We are wet (& mostly made in stars)!
- Stars are wet!
- Water masers reveal kinematics:
  - Dust formation zone (with SiO)
    - Nucleation to full-size
  - Acceleration zone
- Evolved star winds have simpler kinematics than YSO's!
  - Best laboratory comprehensive models
    - Gray, Sobolev, Neufeld
  - Apply to SFR



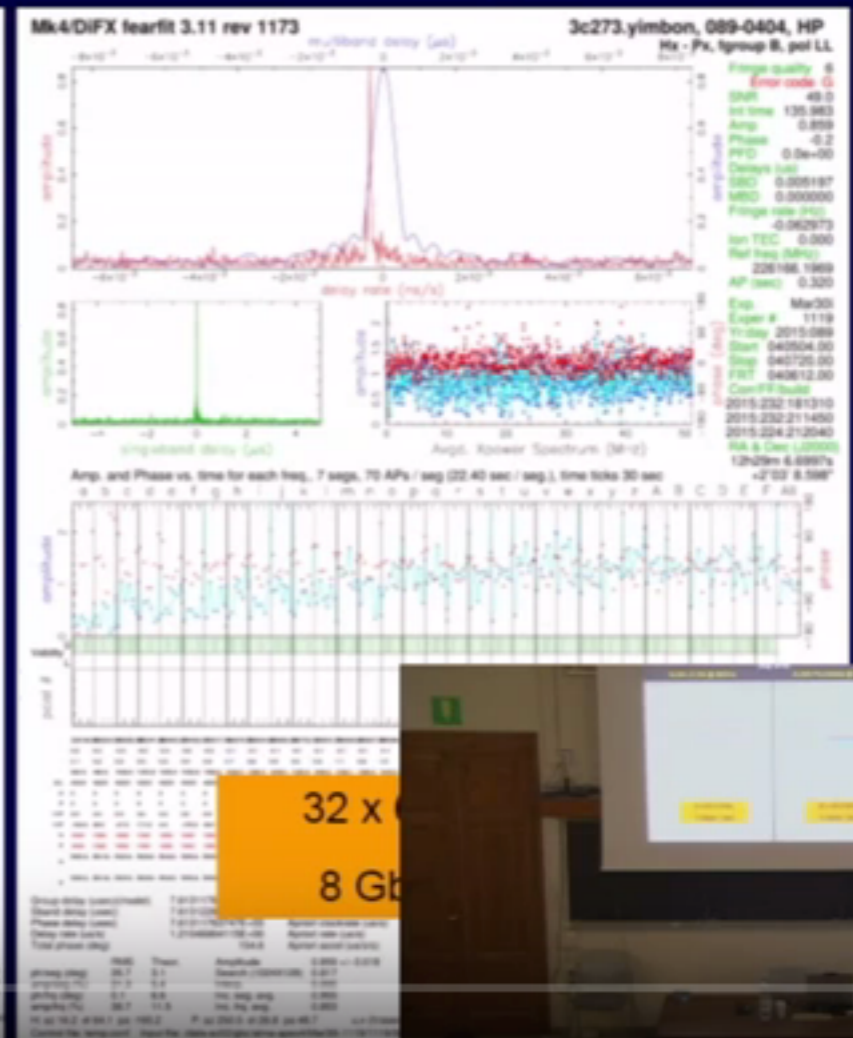
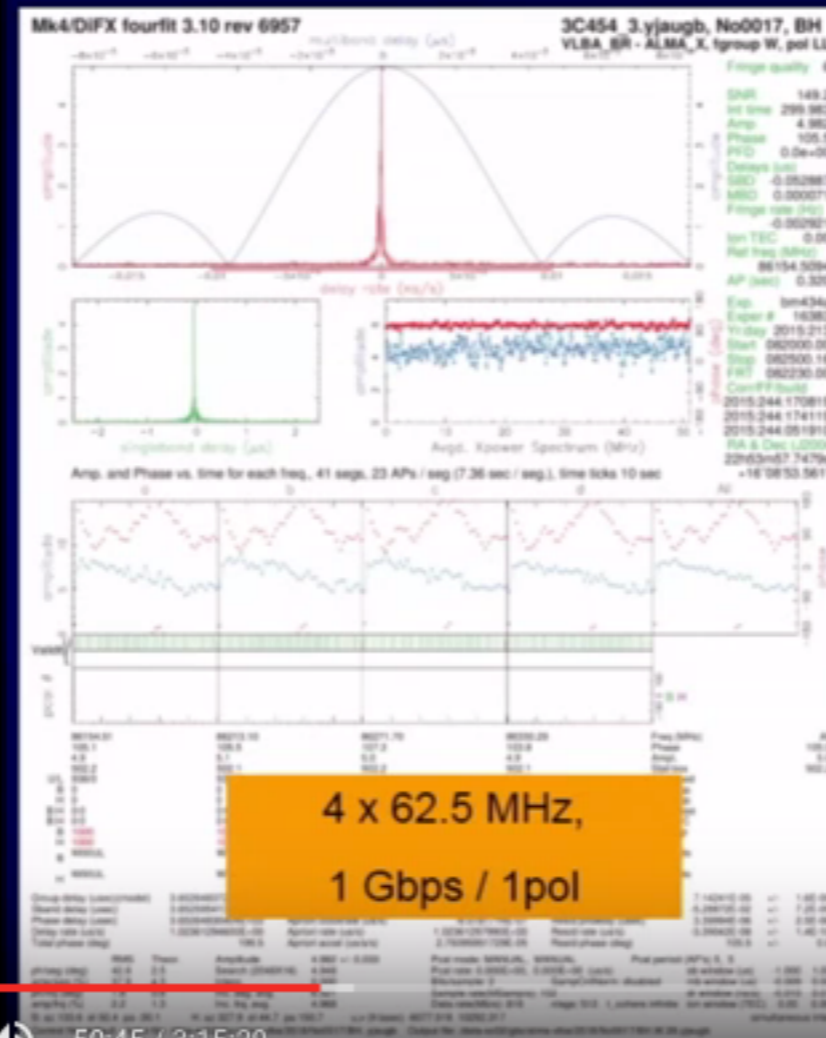
# Reports

- Thomas Kr
- DY Byun
- Robert Laing
- Alexey Rudnitsky
- VLBA (Thomas)

First VLBI fringes with phased ALMA at 86 and 230 GHz  
(Aug. 2015)

ALMA-VLBA @ 86GHz

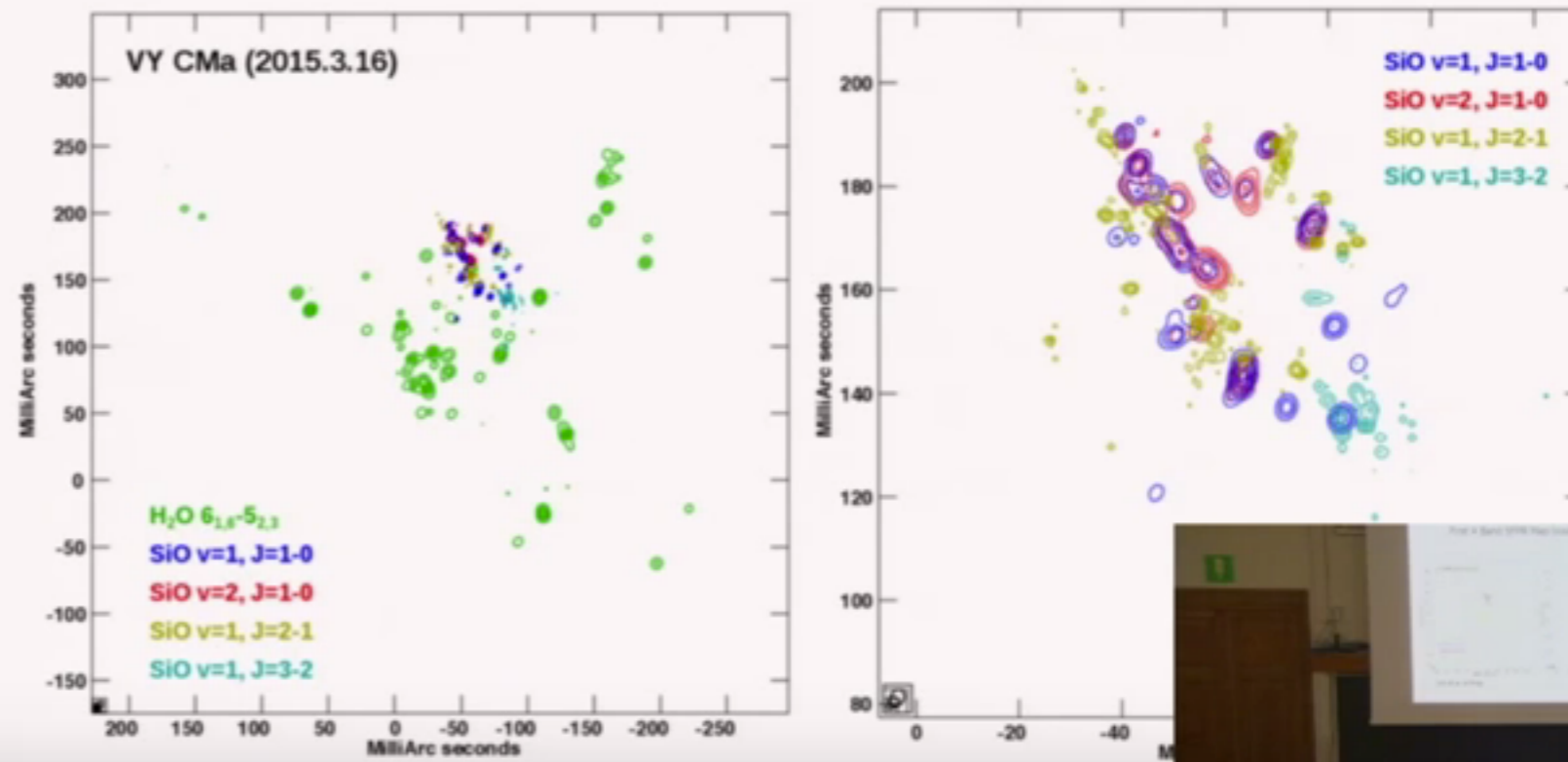
ALMA-PicoVeleta @ 230GHz



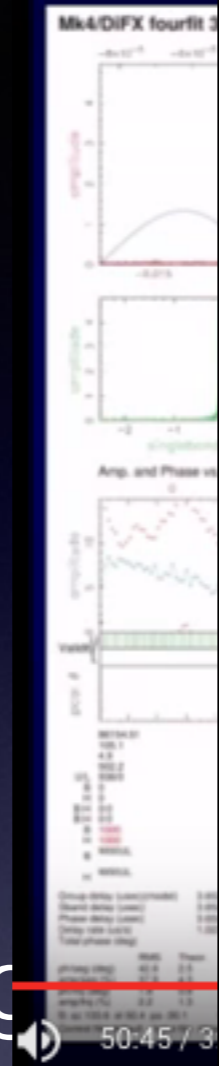
- Thomas Kr
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### First 4 Band SFPR Map towards VY CMA



Cho et al. in Prep



50:45 / 3

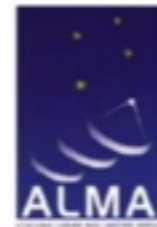
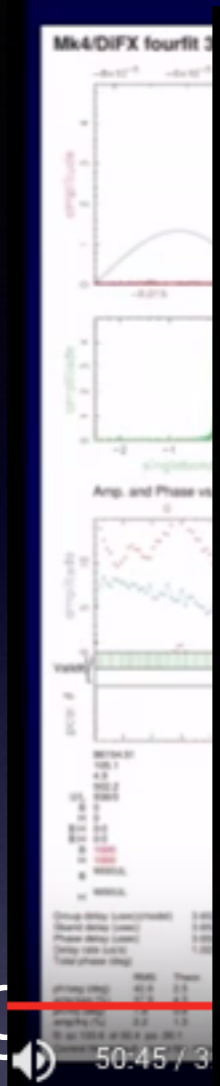
1:12:25 / 3:15:29

- Thomas Kr
- DY Byun
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- Thomas Kr
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## Dictionary

- ALMA Phasing Project
  - Hardware and software to use ALMA as a phased array
  - Led by MIT/Haystack, with NRAO; MPIfR and OSO in Europe; ASIAA, NAOJ
  - Majority funding from NSF + in-kind contributions
- Event Horizon Telescope Collaboration
  - Collaboration for VLBI at 230 (and 345?) GHz
  - Prime targets are Sgr A\* event horizon and the M87 jet
  - New receivers for existing telescopes (NSF+)
- BlackHoleCam
  - ERC synergy grant
  - Black hole imaging + pulsars + theory
- Infrastructure for VLBI at (sub-)mm wavelengths
  - Open facility for VLBI at wavelengths of 7mm or below.
  - GMVA
  - HSA



## Dictionary

### Multifrequency observations with ALMA: Subarrays

- 4 independently-tunable subarrays
  - Main array + ACA
  - Software currently being tested
  - In principle up to 6 subarrays (= number of laser synthesizers)
  - One phased sum
- Strictly simultaneous observations
  - Possible using different subarrays
  - In principle, can use paired antennas observing at different frequencies to correct phase (CARMA C-PACS; 2010).

- Thomas Kr
- DY Byun
- Robert Laino
- Alexey Rudnitsky
- VLBA (Thomas)



Dictionary



# Multi-frequency Imaging

If brightness  $I_{kpq}$  in a given point  $(x_p, y_q)$  can be represented as

$$I_{kpq} = (I_0)_{pq} \left( \frac{\nu_k}{\nu_0} \right)^{\alpha_{pq}}$$

Then the spectral index  $\alpha_{pq} = \alpha(x_p, y_q)$  can be represented as

$$I_{kpq} = (I_0)_{pq} e^{\xi_k \alpha_{pq}} \approx (I_0)_{pq} (1 + \alpha_{pq} \xi_k)$$

and, hence,  $(I_1)_{pq} = \alpha_{pq} (I_0)_{pq}$

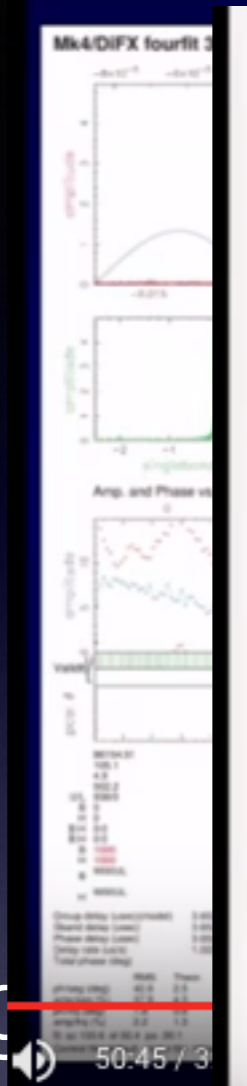
Considering metrics as

$$\rho = \sum_{k=1}^K \sum_{n=0}^{M-1} \sum_{m=0}^{M-1} w_{knm} |V_{knm} - \hat{V}|$$

A dirty map in a give point will be:

$$(D_m)_{pq} = \sum_{k=1}^K D_{kpq} (\beta_k)^m - \sum_{k=1}^K \sum_{l=0}^{M-1} \sum_{t=0}^{M-1} B_{k,p-i,q-l} (\beta_k)^m ((\hat{I}_0)_{pq})$$

- Thomas Kr
- DY Byun
- Robert Laino
- Alexey Rudnitsky
- VLBA (Thomas)



MilliArc seconds

- 4 i
- St



## Dictionary

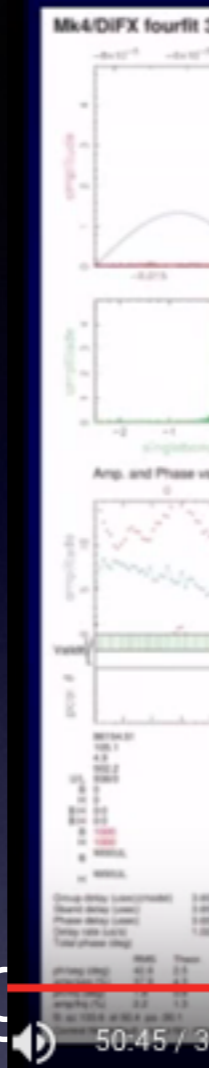
# Multi-frequency Imaging

## VLBA Funding Climate

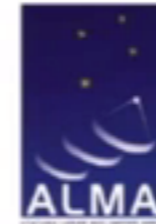
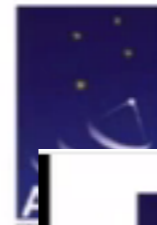
- 2012 Portfolio Review: NSF divestiture
- NRAO/AUI response is here. 50% divestiture  
<https://www.nrao.edu/pr/2012/portf>
- NRAO/AUI are pursuing other sources of funding
- USNO daily EOP obs. Sponsored proposals
- AUI contract to manage NRAO is being re-evaluated
- Results will be known before 2016.
- Post-2016: VLBA open-sky time is likely to be reduced
- Scheduling will be more complicated.

- Thomas Kravchenko
- DY Byun
- Robert Laing
- Alexey Rudnitsky
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MilliArc seconds



## Dictionary

# Multi-frequency Imaging

VLBA Funding Clim

VLBA Recent Upgrade

[science.nrao.edu/facilities/vlba/publications/mem](http://science.nrao.edu/facilities/vlba/publications/mem)

- C-wide 4-8 GHz, Methanol masers: Galactic
- K band HEMT amps replaced, now 70K Tsys:
- RDBE Backend, Xcube network switch: PFB,
- 2 Gbps recording: MK5B/PFB, vdif/DDC to
- Tsys, pulsecal, SEFD calibration: all via
- VME control computer & pointing replacement in progress.
- VLBA is over 20 years old. Current f  
Reliability of Operation  
Maintenance of Infrastructure

# Characterisation

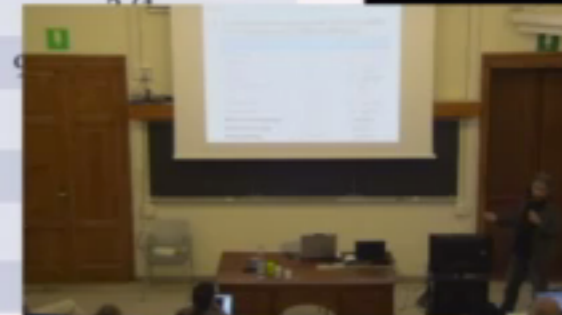
- Andrei
- Dodson



# Cha

- ❑ Combined aspects of imaging at 86+ GHz makes SFPR a very attractive option for AGN and BH studies:

Imaging consideration:	Generic dependence on $\nu$	86/230 GHz: SFPR GMVA/EHT
Fringe spacing	$\propto \nu^{-1}$	1/3 (1/3)
Scattering	$\propto \nu^{-2}$	1/9 (1/27)
AGN opacity	$\propto \nu^{-1}$	1/3 (1/81)
Phase noise	$\propto \nu^{+1}$	<b>10/1 (10/81)</b>
Effective antenna area	$\propto \nu^{-1/2}$	$\sqrt{3}/1$
SEFD	$\propto \nu^{+1}$	10/1
Amplitude noise	$\propto \nu^{+3/2}$	10/1
Filling of uv-plane	$\propto \nu^{+1}$	10/1
Effective structural sensitivity	$\propto \nu^{+1/2}$	10/1
Effective dynamic range	$\propto \nu^{-3/2+\alpha}$	10/1
Effective resolution	$\propto \nu^{+1/4-\alpha}$	10/1



- Andrei
- Dodson

# Cha

## SFPR for Imaging at 86 GHz

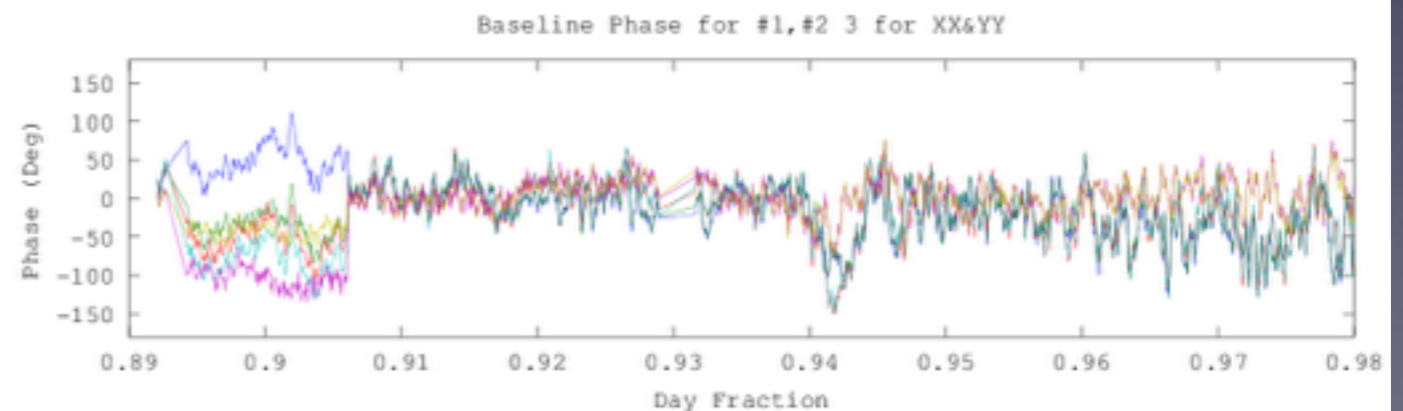
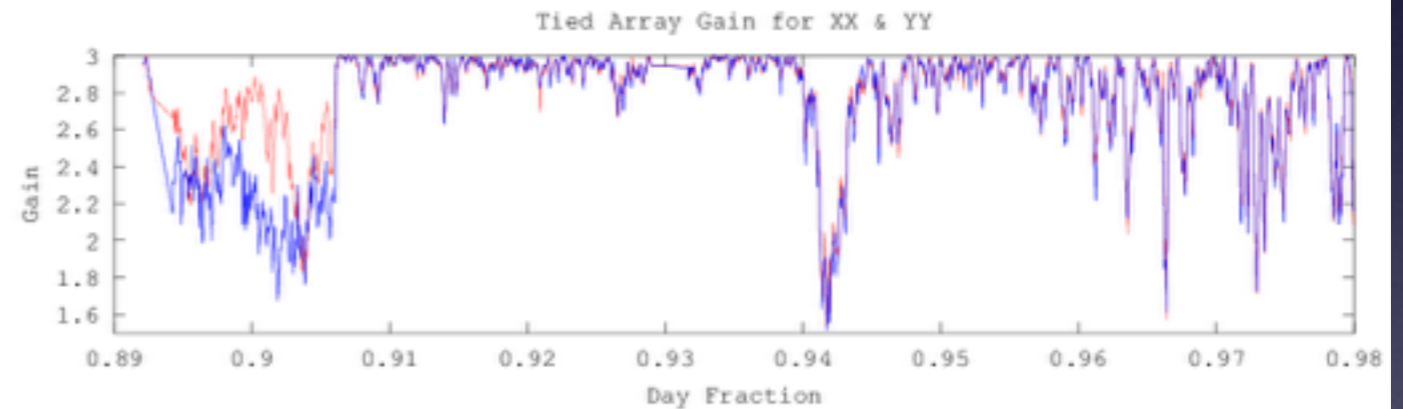


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SEFD  
Ampl  
Filling  
Effect  
Effect  
Effect

- Andrei
- Dodson



# Hardware

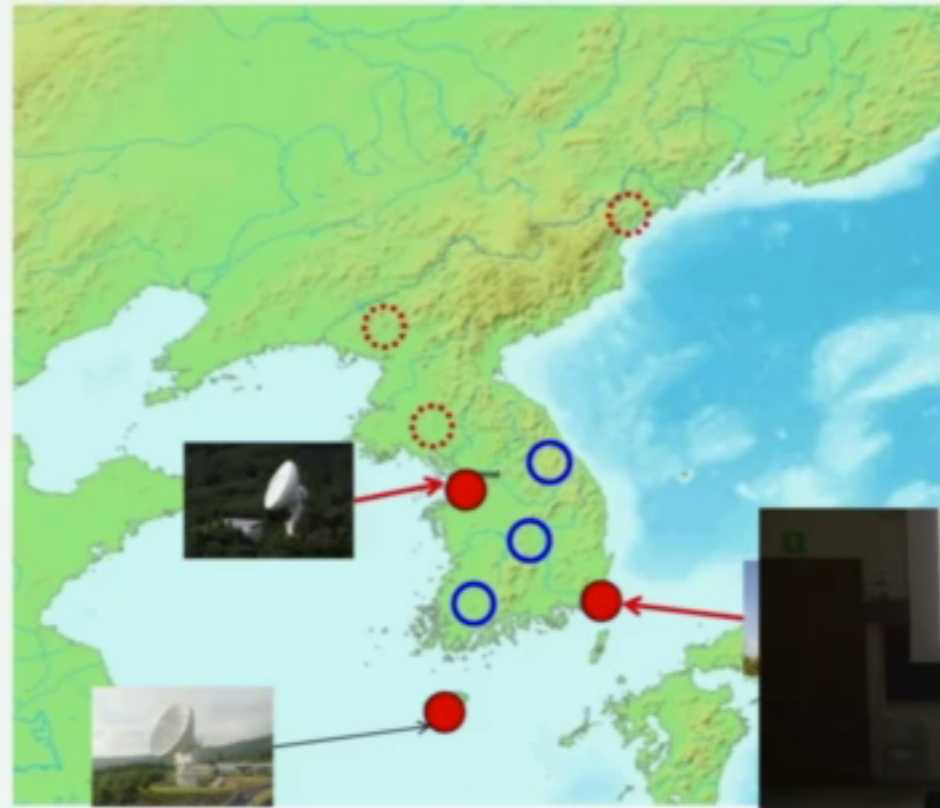
- Han x2
- Jung
- Orfei
- Pisano



## My dream

3 more 21m radio telescope for E-KVN

Dream comes true !!!!!

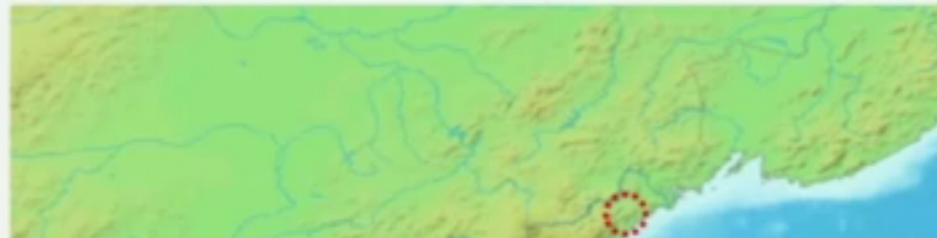


- Han x2
- Jung
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Dream comes true !!!!!



## Losses of transmission and reflection at at LPFs

TABLE 3  
MEASURED LOSSES OF LPP1 AND LPP2 IN THE 22/43 GHz BANDS

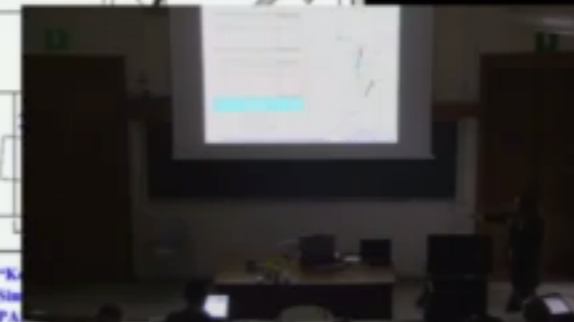
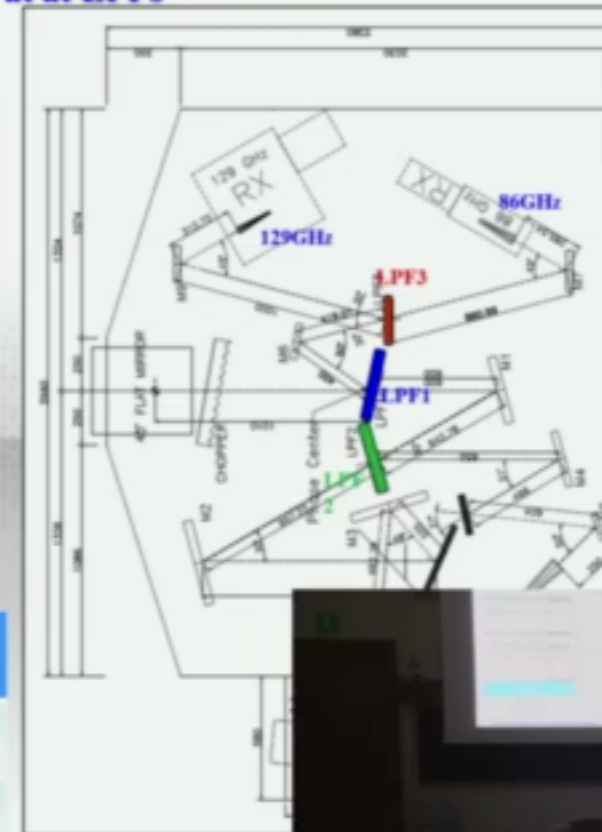
Frequency (GHz)	LPP1		LPP2		LPP1+LPP2	
	LCP (%)	RCP (%)	LCP (%)	RCP (%)	LCP (%)	RCP (%)
21.5	0.70	1.16	2.48	3.11	3.15	4.20
22	0.80	0.80	2.53	2.57	3.30	3.32
23	0.47	0.46	2.63	2.57	3.07	3.01
42.36	1.08	1.08	3.02	5.38	4.03	6.35
43.11	1.29	0.88	3.01	2.90	4.23	3.74
43.86	1.48	1.15	1.82	1.82	3.24	2.93

TABLE 4  
MEASURED LOSSES OF LPP1 AND LPP3 IN THE 86/129 GHz BANDS

Frequency (GHz)	LPP1+flat mirror		Flat mirror+LPP3		LPP1+LPP3	
	LCP (%)	RCP (%)	LCP (%)	RCP (%)	LCP (%)	RCP (%)
86	5.1	5.9	4.1	4.0	8.3	9.6
90	7.3	8.2	4.7	4.7	11.4	12.7
94	7.5	8.8	6.0	6.4	13.2	14.9
129	4.7	5.3	1.7	1.7	5.3	5.6
134	6.5	6.3	1.6	1.8	6.5	6.6
138	7.3	7.2	1.7	1.5	7.7	7.9
142	8.7	8.9	1.9	1.5	10.4	10.6

Freq. [GHz]	Transmission and/or Reflection Loss [%] (LPP1+LPP2/LPP3)	Tnoise @300K [K]
22	3.30 (Transmission only)	9.90
43	3.74 (Transmission + Reflection)	11.1
86	9.60 (Reflection + Transmission)	28.8
129	5.60 (Reflection only)	16.8

Needed cooling down to cryogenic temperature

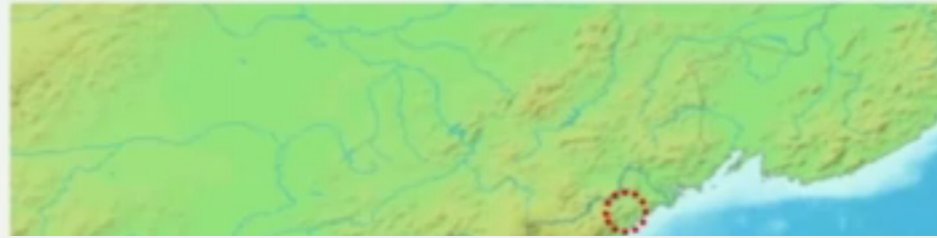


- Han x2
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## Losses of transmission and reflection at LPFs

### Three Phase Referencing Methods in KVN

**FAS** conventional PR

**FPT + FAS**

1. phase scaling of calibrator
2. apply conventional PR

**FPT**

Frequency Phase Transfer

Calibrator Target

M87 M84

1.8 dB

22 GHz



KVN



Live

43GHz 43GHz

Calibrator Target

M87 M84

1.8 dB

22 GHz



KVN

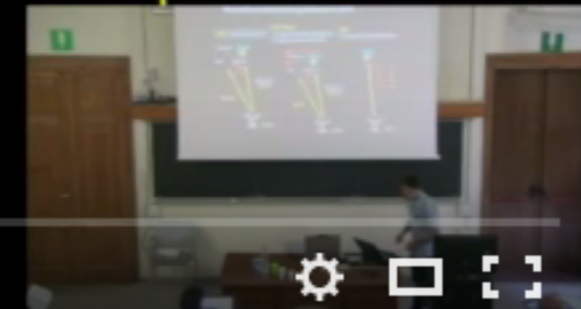
Target

129GHz x6

89GHz x4

43GHz x2

22GHz ref.





# My dream

3 more 21m radio telescope for E-KVN

Dream comes true !!!!!



## Losses of transmission and reflection at LPFs

### Three Phase Referencing Methods in KVN

FAS conventional PR

FPT + FAS

1. phase scaling of calibrator
2. apply conventional PR

FPT

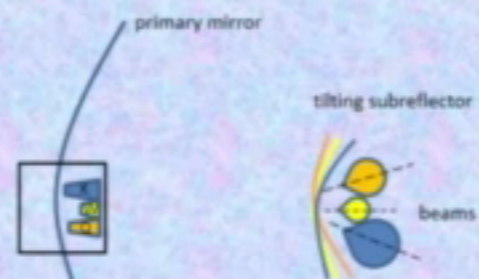
Frequency Phase Transfer

Calibrator Target

43GHz → 43GHz

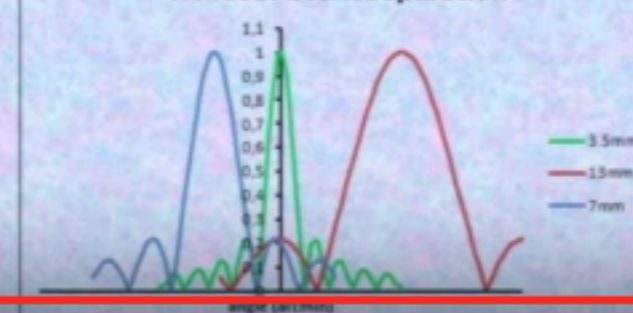
Target

### TRI-FEED NEAR SIMULTANEITY IN ITALY: READY



Tri-feed beams parameter		
	SRT (arcmin)	Med/Nota (arcmin)
FWHM 13 mm	0.85	1.8
FWHM 7 mm	0.48	0.9
FWHM 3.5 mm	0.25	0.5
W-K Beam separation	1.32	2
W-Q Beam separation	0.72	1.1
W to Q bands horn distance	31 mm	
W to K bands horn distance	58 mm	

### Tri-feed: beam separation



Tri-feed beams switching		
	SRT (s)	Med/Nota (s)
W to K switching time	1	0.5
W to Q switching time		

- Han x2
- Jung
- Orfei
- Pisano

Live

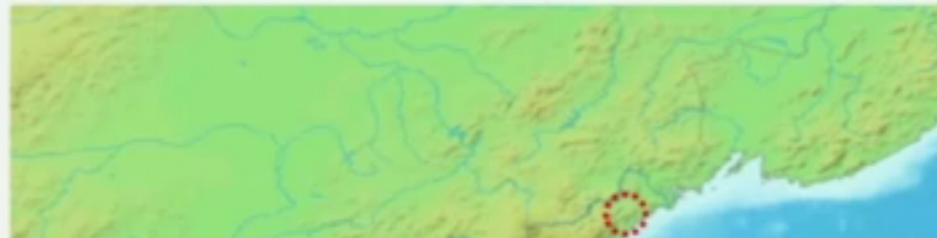
ERATEC - Firenze October 5-7, 2015



## My dream

3 more 21m radio telescope for E-KVN

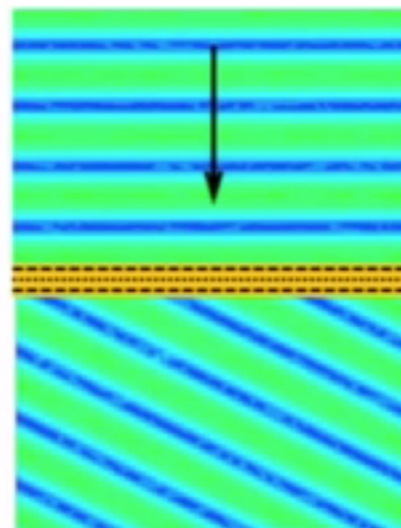
Dream comes true !!!!!



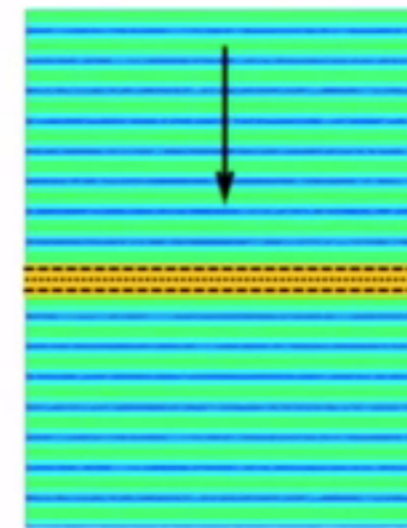
## Losses of transmission and reflection at LPFs

### Three Phase Referencing Methods in KVN

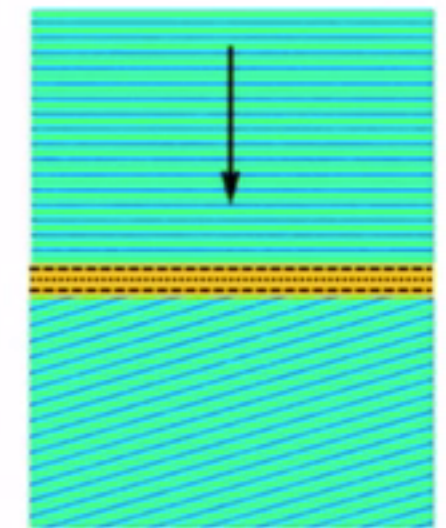
#### Mesh Trichroic for triple-feed simultaneity: Conceptual idea



$$v_1 \pm \Delta v_1$$



$$v_2 \pm \Delta v_2$$



$$v_3 \pm \Delta v_3$$

- The frequency-dependent differential phase-shift, respect to a (ex: centre), would create the required off-axis phase-fronts a
- Real converging beams will require additional optimisation

→ This is an ongoing development

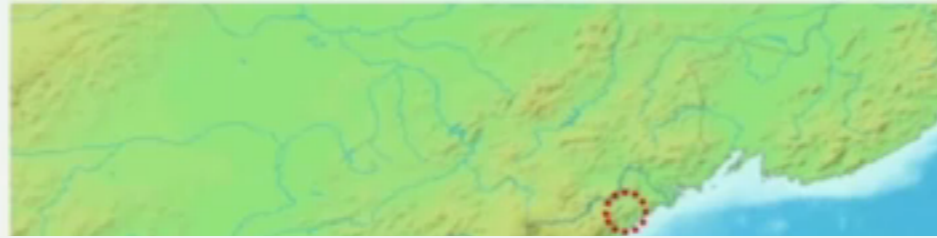
- Han x2
- Jung
- Orfei
- Pisano



## My dream

3 more 21m radio telescope for E-KVN

Dream comes true !!!!!

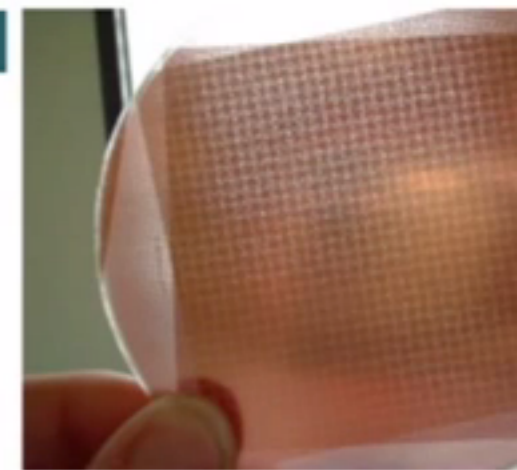
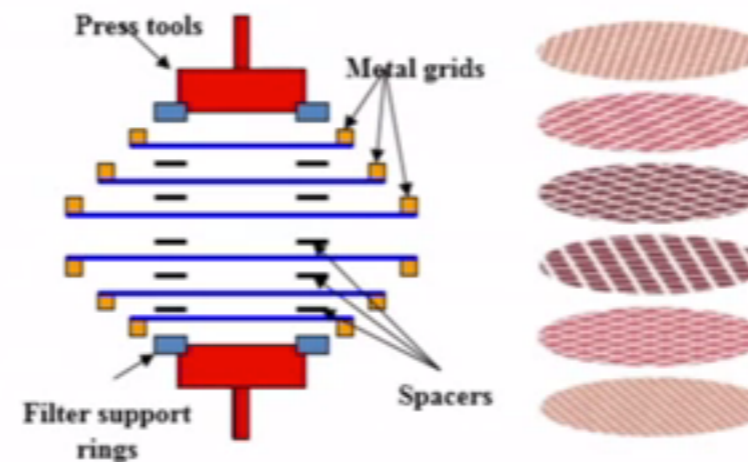


## Losses of transmission and reflection at LPFs

### Through Plane Filter for Millimeter Wave

#### Mesh Technology: Manufacture 1/2

#### Free standing (air-gap) multiple metal mesh devices



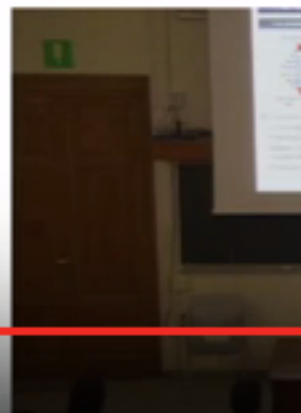
#### The manufacturing process

- Copper evaporation on polymer substrate
- Photolithographic etching to form metal grid pattern
- Randomly oriented grids precisely spaced and mounted together to form a single composite filter.
- Air/vacuum gap filters use annular metal spacers

- The  
(ex  
- Rea

3:06:30 2:54:10 / 3:15:29

- Han x2
- Jung
- Orfei
- Pisano





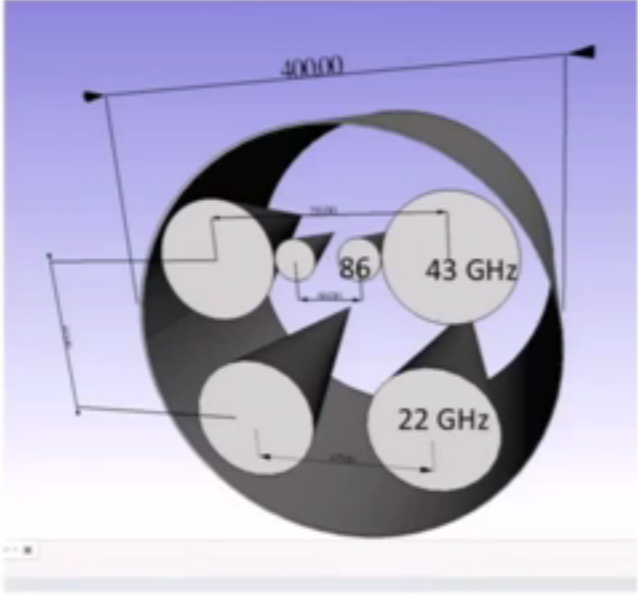
# Hardware

- Hovatta
- Nesti
- Miroslav
- Alef

# Hardware

- Hovatta
- Nesti
- Miroslav
- Alef


## Multifrequency setup



- All horns in a single cylinder
- Switching between frequencies done by changing pointing offsets
  - Between 43-86 GHz takes about 0.9-1.2s depending on elevation
  - Addition period of

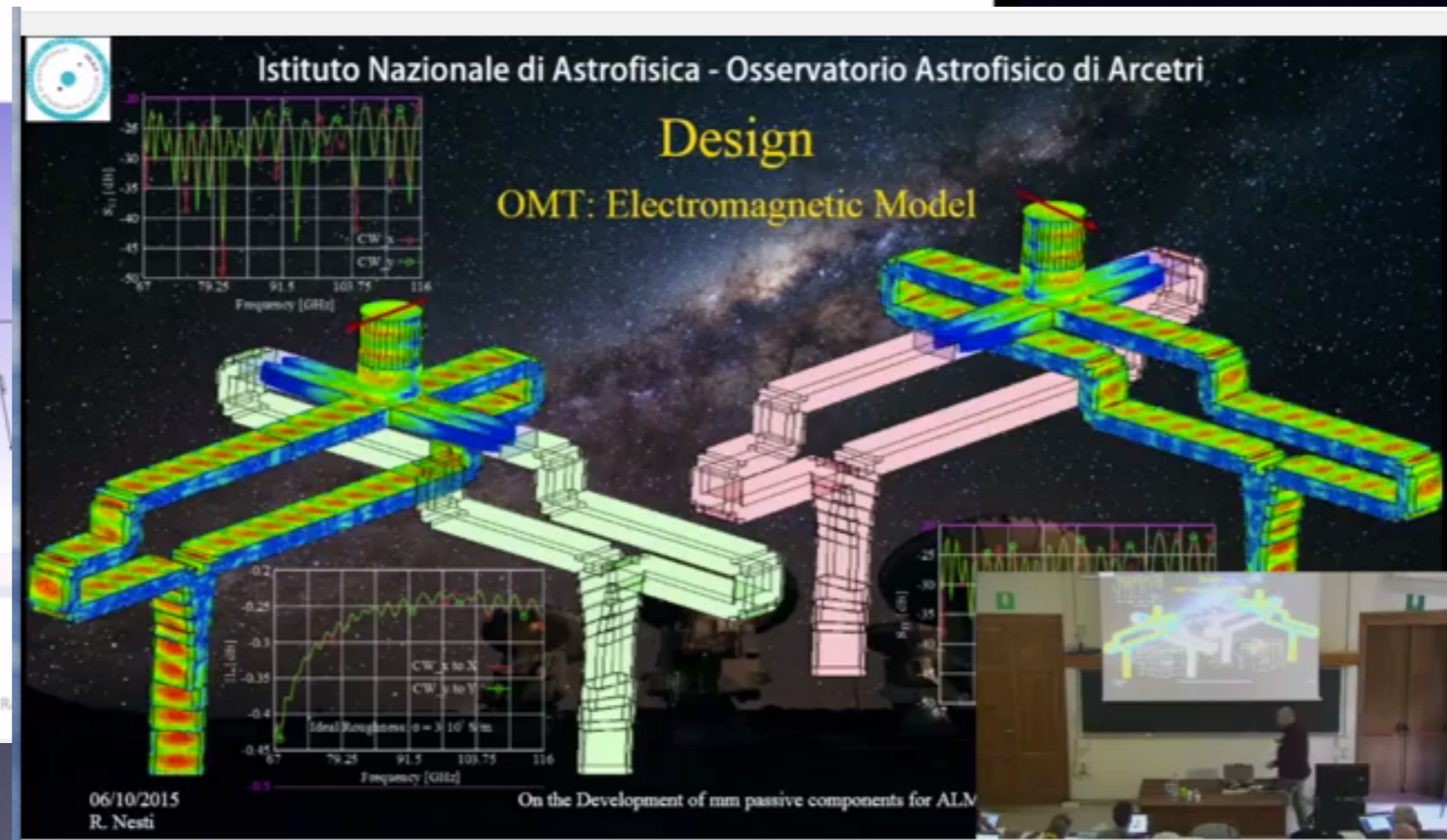
→ Short end transfer (Middleberg)

ERATec 5.-7.10.2015 talvikki.hovatta@aalto.fi



# Hardware

- Hovatta
- Nesti
- Miroslav
- Alef





# Hardware

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- Nesti
- Miroslav
- Alef

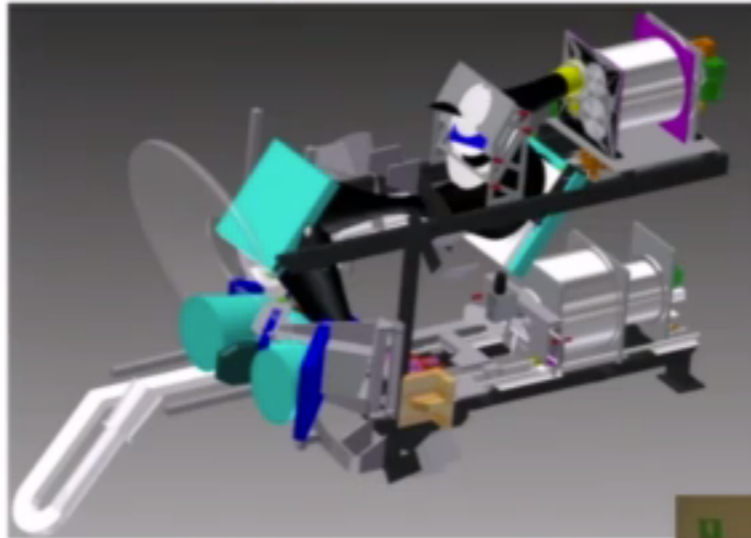
Istituto Nazionale di Astrofisica - Osservatorio Astrofisico di Arcetri

Design

CHALMERS  
Chalmers University of Technology

Onsala Space Observatory


Design alternatives



- Triple band layout with dichroic filters – not applicable due
- Dual Band with dichroic filters
- Dual band layout: wide band feed and single band feed with
- Triple band feed

06/10/201  
R. Nesti

ERATec workshop  
Florence, 5 – 7 October



# Hardware

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- Alef

Istituto Nazionale di Astrofisica - Osservatorio Astrofisico di Arcetri

Design

CHALMERS  
Chalmers University of Technology

Onsala Space Observatory

Design alternatives

### New Opportunities

- can develop multi-wavelength VLBI now!
- backends with very high data rates (see JRA **PINA**: DBBC3 with up to 128 Gbps; 4x 4GHz dual pol - 32Gbps)
- High bit-rate recorders: Mark 6 (64 Gbps w. 4 units @EHT)
- Broad-band LNAs and feeds
- **Scientific opportunities:**
  - multi-wavelength VLBI mapping
  - multi-wavelength spectroscopy
  - multi-wavelength polarimetry
  - multi-wavelength single-dish
  - geodetic VGOS compatibility
- **New: no different LOs and huge sky frequen**

Live