Millimeter/Submillimeter VLBI with the Event Horizon Telescope (EHT)

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courtesy Vincent L. Fish & Sheperd Doeleman
MIT Haystack Observatory
on behalf of a large international collaboration

Image courtesy ALMA (ESO/NAOJ/NRAO)

Sagittarius A*

Black hole in the center of the Galaxy

$M = 4 \times 10^6\ M_{Sun}$, $d = 8$ kpc ==> $R_{Sch} = 10\ \mu as$

In terms of angular size, largest event horizon as viewed from Earth

Need to observe at mm wavelengths due to interstellar scattering by electrons (and for resolution)

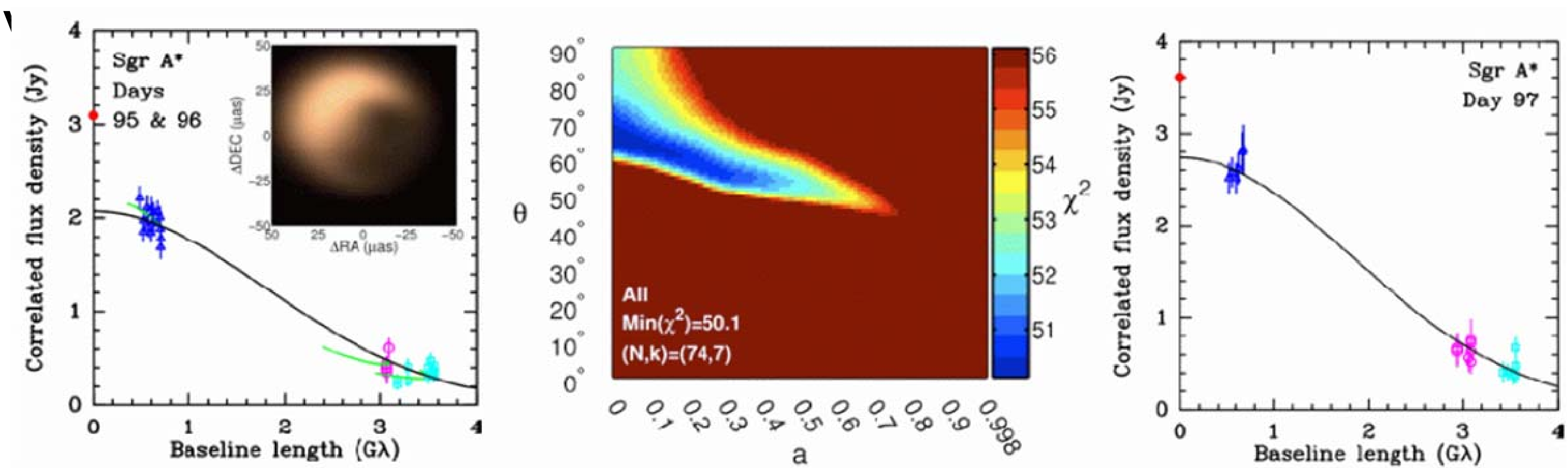
ALMA-Hawaii fringe spacing @230 GHz = 3 R_{Sch}

Beginnings of Event Horizon Telescope

Current 230 GHz VLBI observations of Sgr A* indicate:

- Very compact structure (~4 R_{Sch})
- Variable compact structure
- Constraints on black hole spin, disk inclination/orientation

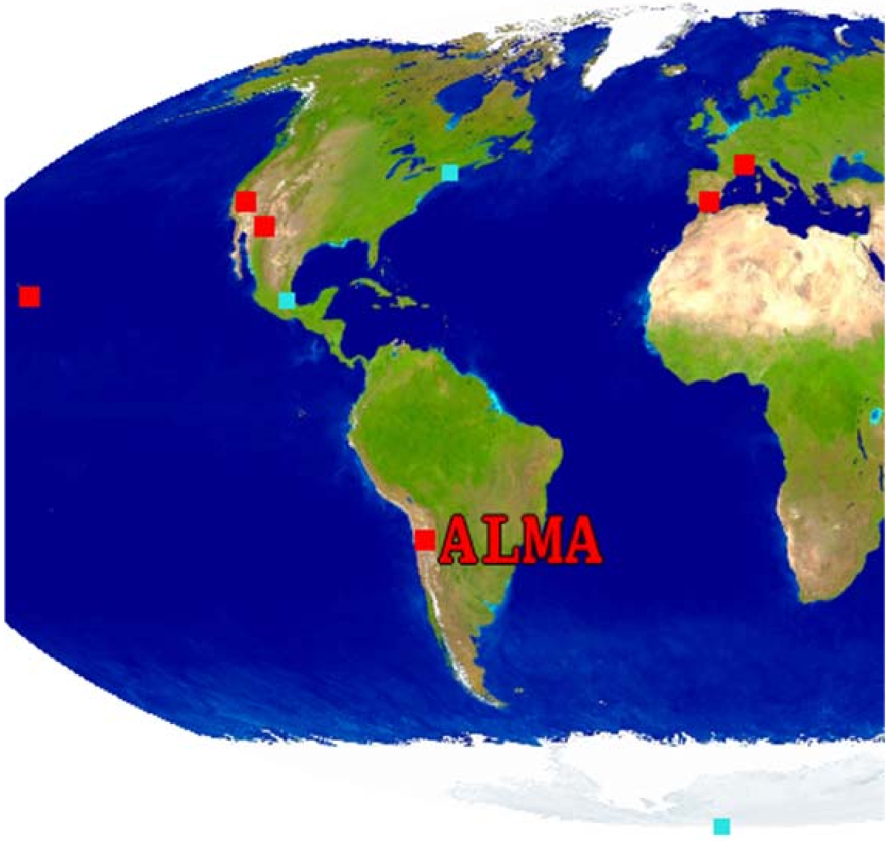
Results so far from 3 stations (Hawaii, CARMA, ARO/SMT)



(Fish et al 2011, Broderick et al 2011)

Event Horizon Telescope

Collaboration of existing and new (sub)millimeter telescopes performing VLBI observations of Sgr A* and black holes in other galactic nuclei (including M87)



Angular Resolution

Band	Frequency Range(GHz)	ALMA Extended (mas)	VLBI Array	ALMA-Hawaii VLBI (mas)
1	31.3-45	100	VLBA+...	0.2
3	84-116	50	VLBA+...	0.1
6	211-275	20	EHT	0.03
7	275-373	15	EHT	0.02

VLBI increases resolution of ALMA by a factor of ~500

ALMA is a very sensitive station for VLBI, with an equivalent collecting area of an 84m dish

ALMA Sensitivity and Phase Correction

8 GHz bandwidth, dual polarization, 25 antennas:

S/N ~ 850 in 10 sec for a 3 Jy source (e.g., Sgr A*)

S/N > 30 for S > 100 mJy

No problem determining phase solutions to within a few degrees or better per antenna

Can combine with water vapor radiometer data and fast-switching techniques for fainter sources

ALMA Phased Array Processor

Project approved by ALMA board; funding via NSF & international groups

Numerous components to project: software, hardware, firmware, hydrogen maser, optical fiber link, VLBI recorder, VLBI correlator modifications (poster JP1.12, S. Doeleman)

Multinational collaboration:

- US -- Haystack, NRAO, CfA
- Asia -- ASIAA, NAOJ
- Europe -- MPIfR
- Chile -- U. Concepción

Timeline:

- Begin 2011
- Testing 2014
- Commissioning observations 2015

Thank you

Scientific Targets

Black hole science (Event Horizon Telescope)

Pulsars & magnetars

AGN & jet physics

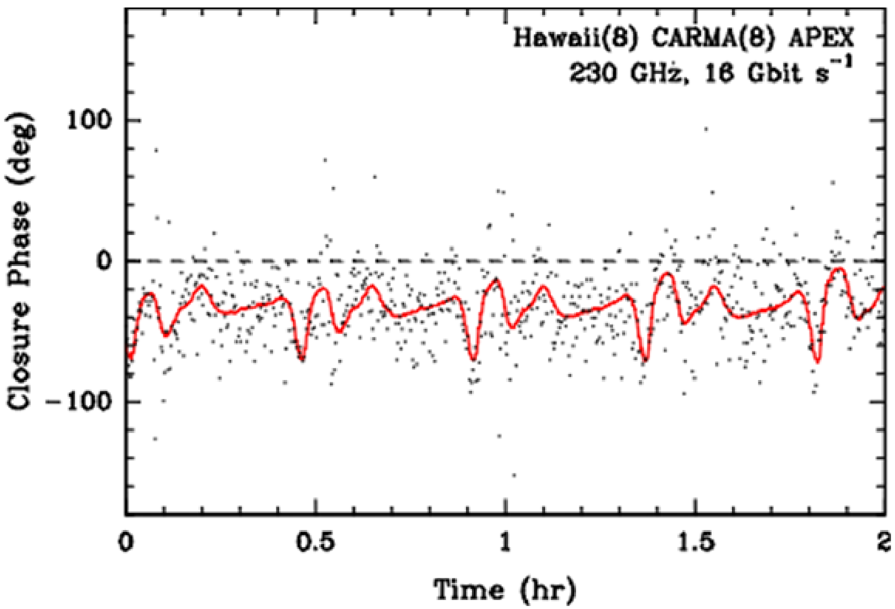
Spectral line science

Tracking Structural Changes in Sgr A*

Rapid variability (mm, NIR, X-ray) in Sgr A*

Period of innermost stable circular orbit is 4-30 min (depending on spin of black hole)

Closure phases can track these rapid structural changes



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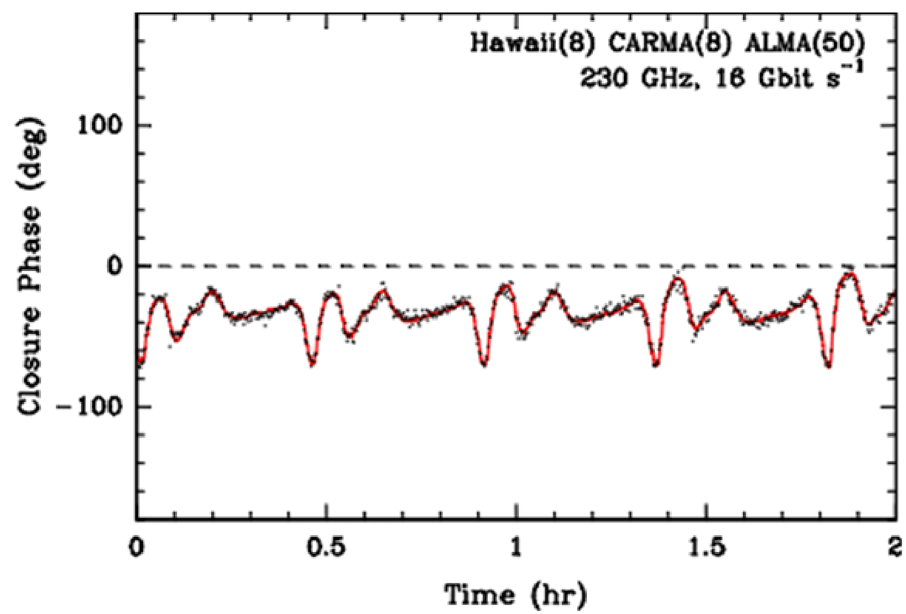
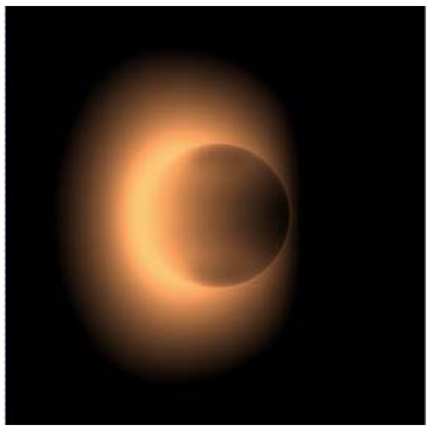
Sensitivity of phased ALMA is required



Testing General Relativity

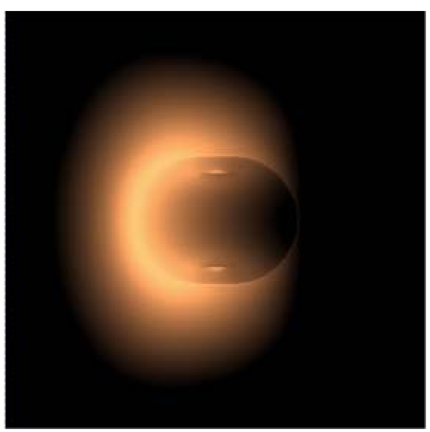
Baselines to ALMA will be essential for testing GR



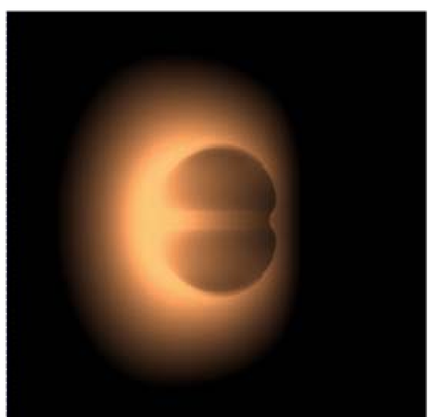
ε = 0 (GR)

Images courtesy
A. Broderick
T. Johannsen
D. Psaltis

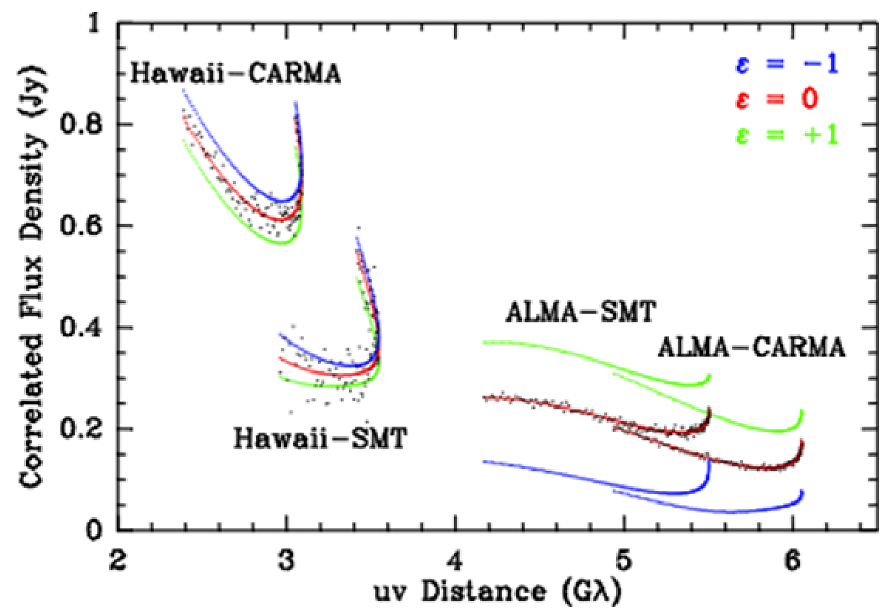
ε = 1



ε = -1



Simulated data



Pulsars

Precise timing of pulsars can be a sensitive test of GR

The Galactic Center is a good place to observe:

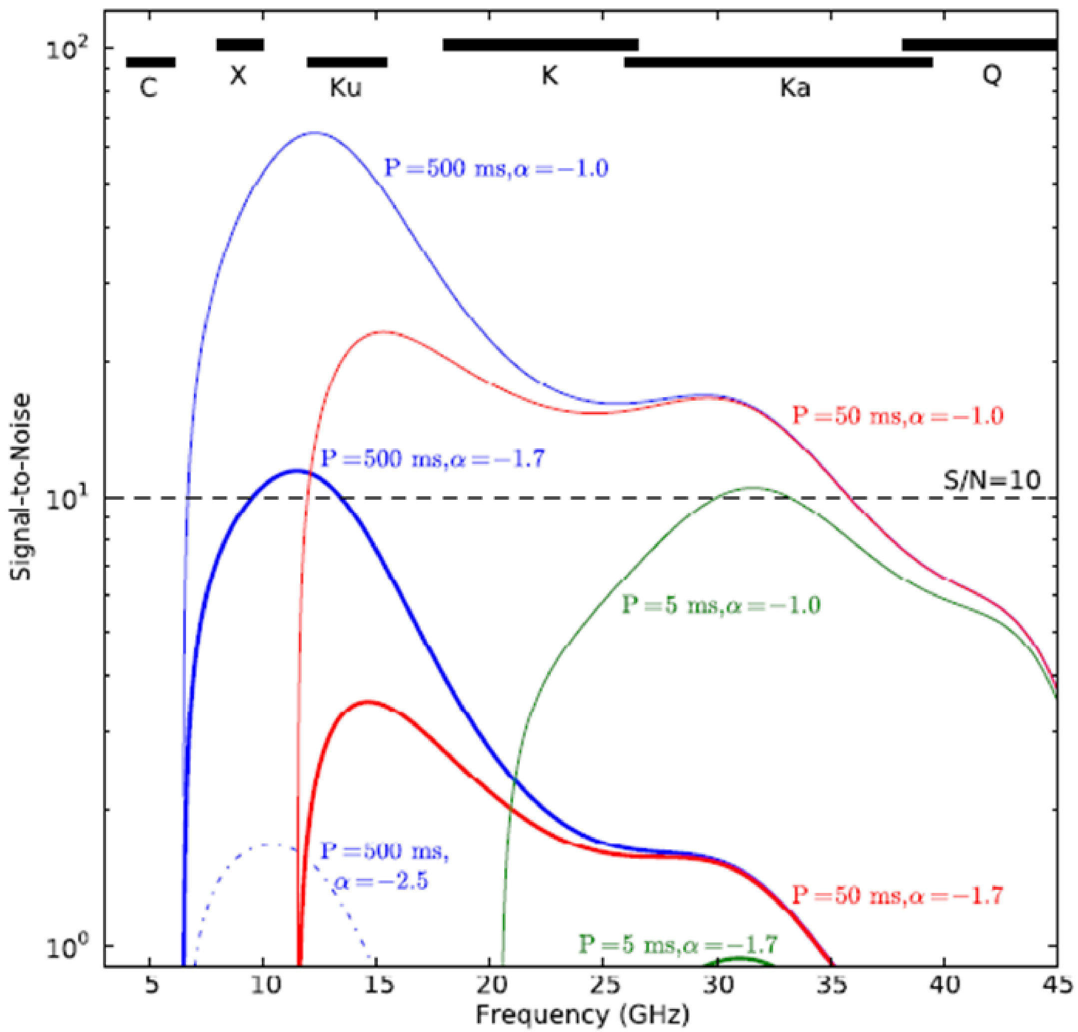
- Pulsars around Sgr A* (Pfahl & Loeb 2004)
- Pulsar-black hole binaries (Fauchere-Giguère & Loeb 2011)

High frequency observations are required due to huge dispersion measure, which smears pulses

Commensal observing possible with other scientific observations

Pulsars

Usually observed at lower frequencies because flux density falls off rapidly



Detectability thresholds of Galactic Center pulsars with the GBT (Macquart et al 2010)

ALMA detection threshold: 2 μJy in 10 hours at 43 GHz

Pulsars

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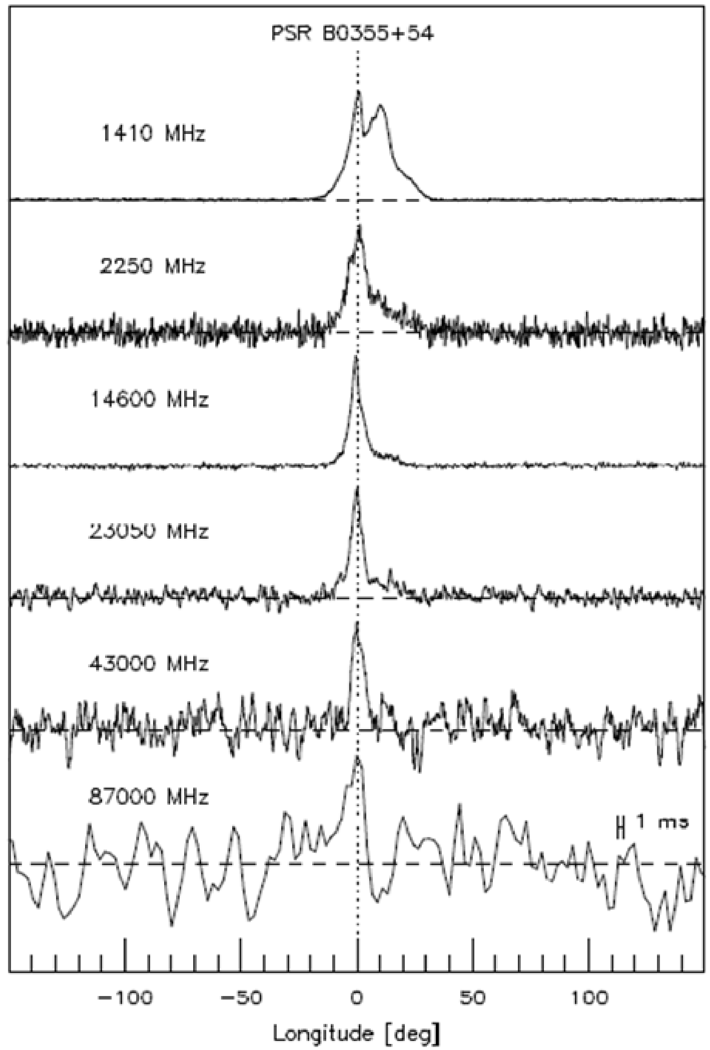
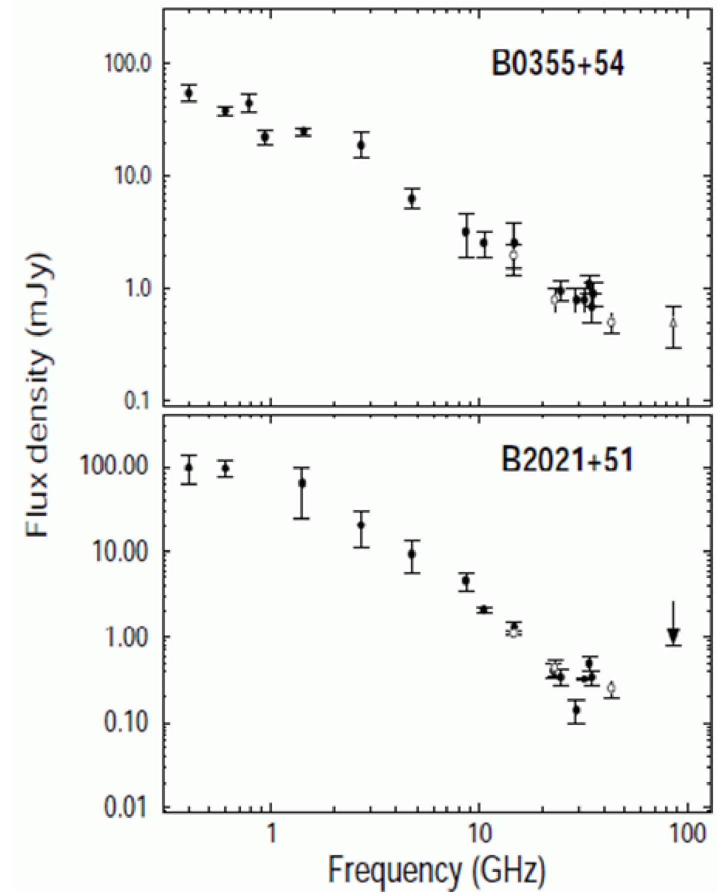
Nevertheless, some pulsars are detectable in the millimeter





(Morris et al 1997)

Pulsars

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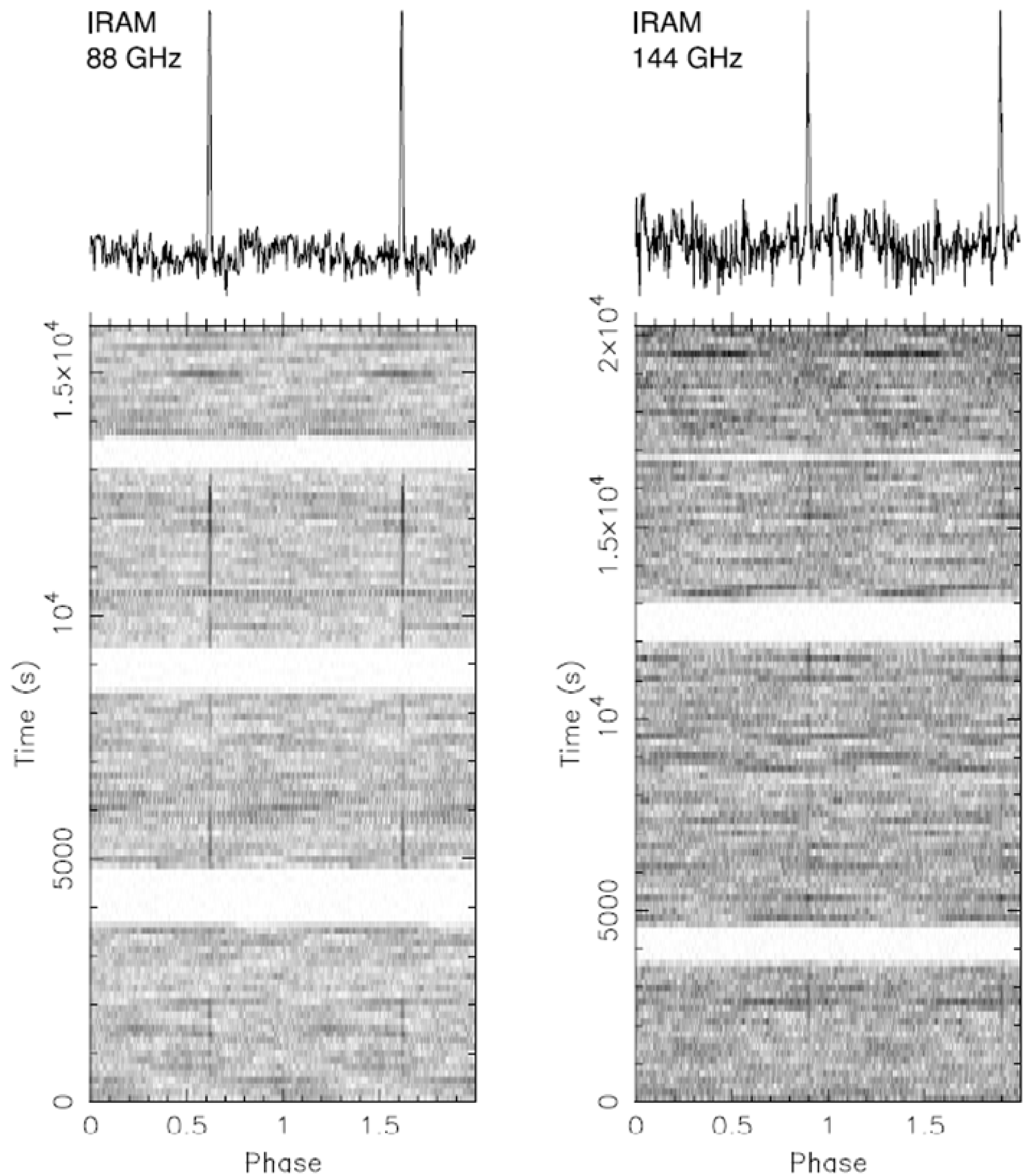
Magnetars have been detected as high as 144 GHz



Magnetar XTE J1810-197 (Camilo et al 2007)

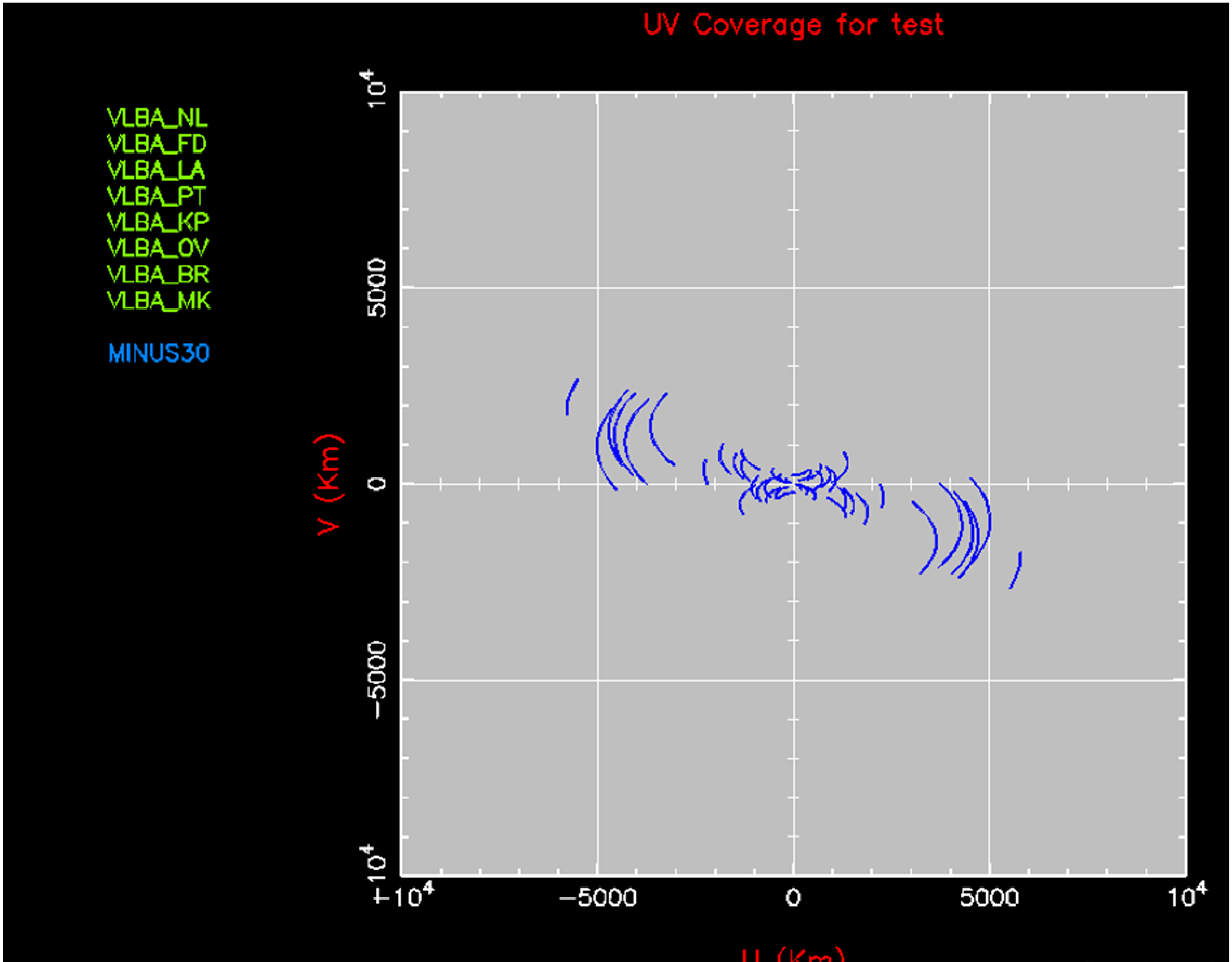
7 mm and 3 mm Bands

Inclusion of ALMA with the VLBA (and other telescopes) will improve image fidelity and astrometric accuracy in the 7 mm and 3 mm bands

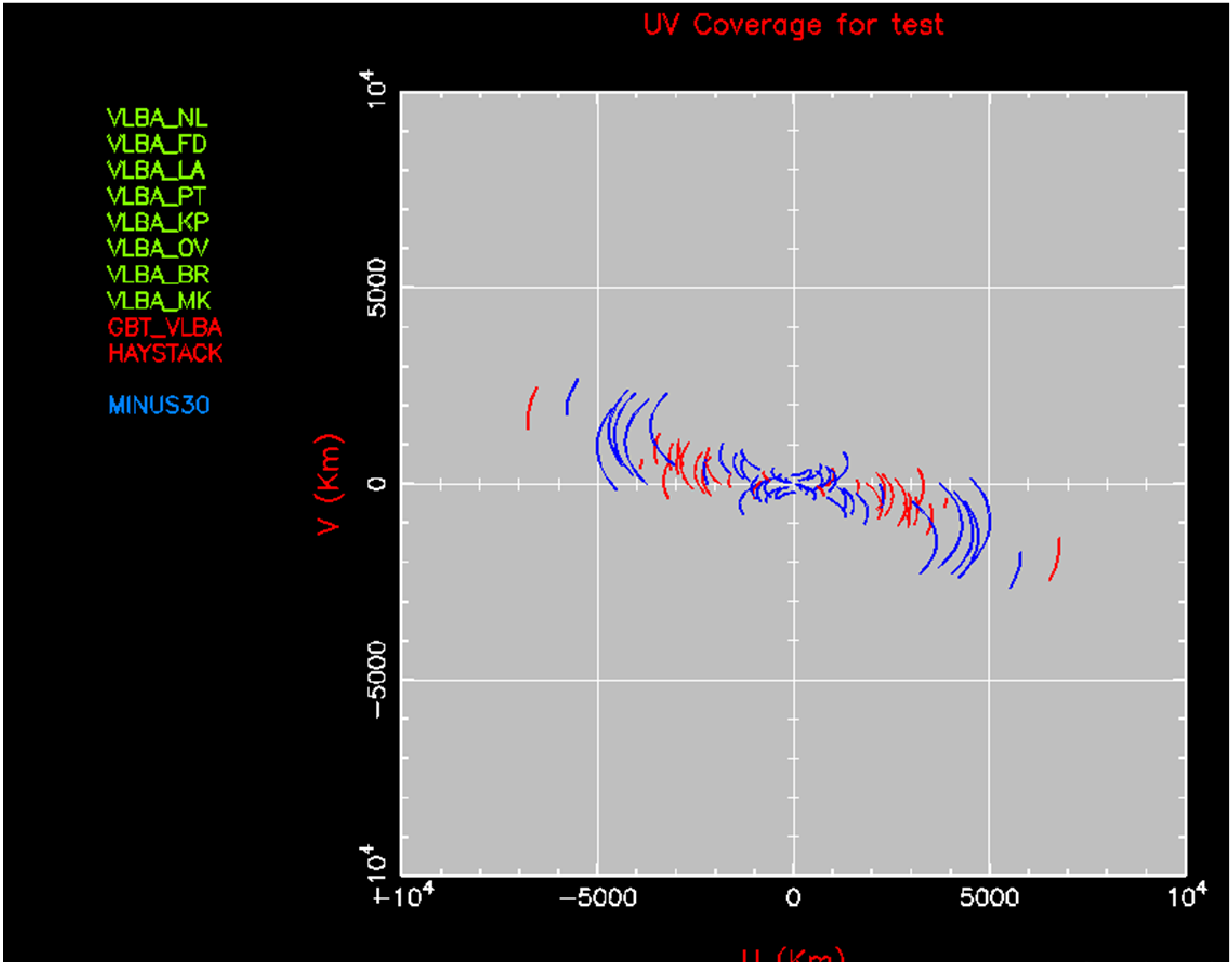
Increased sensitivity

Better (u,v) coverage, especially in the north-south direction

86 GHz (u,v) coverage



86 GHz (u,v) coverage



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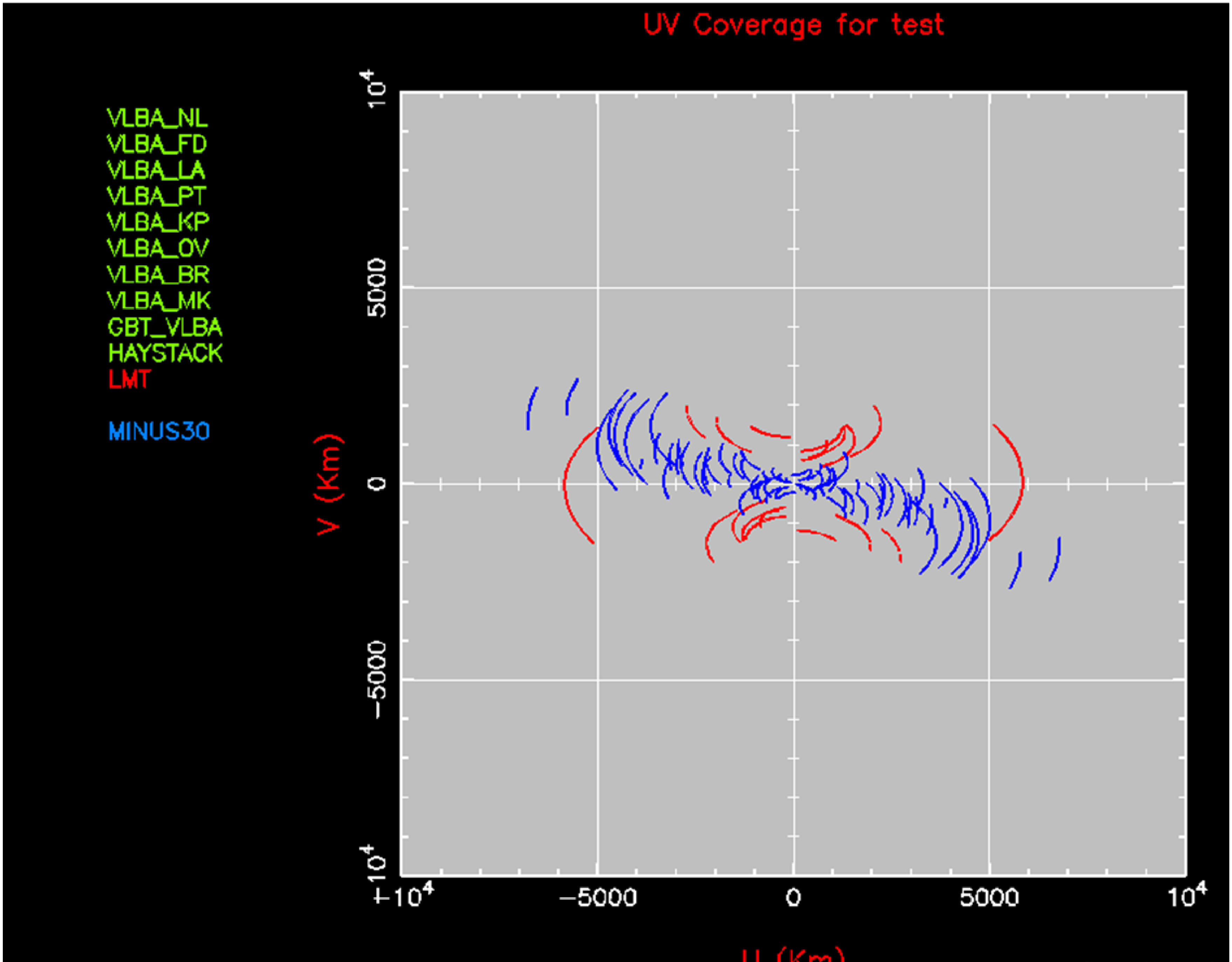

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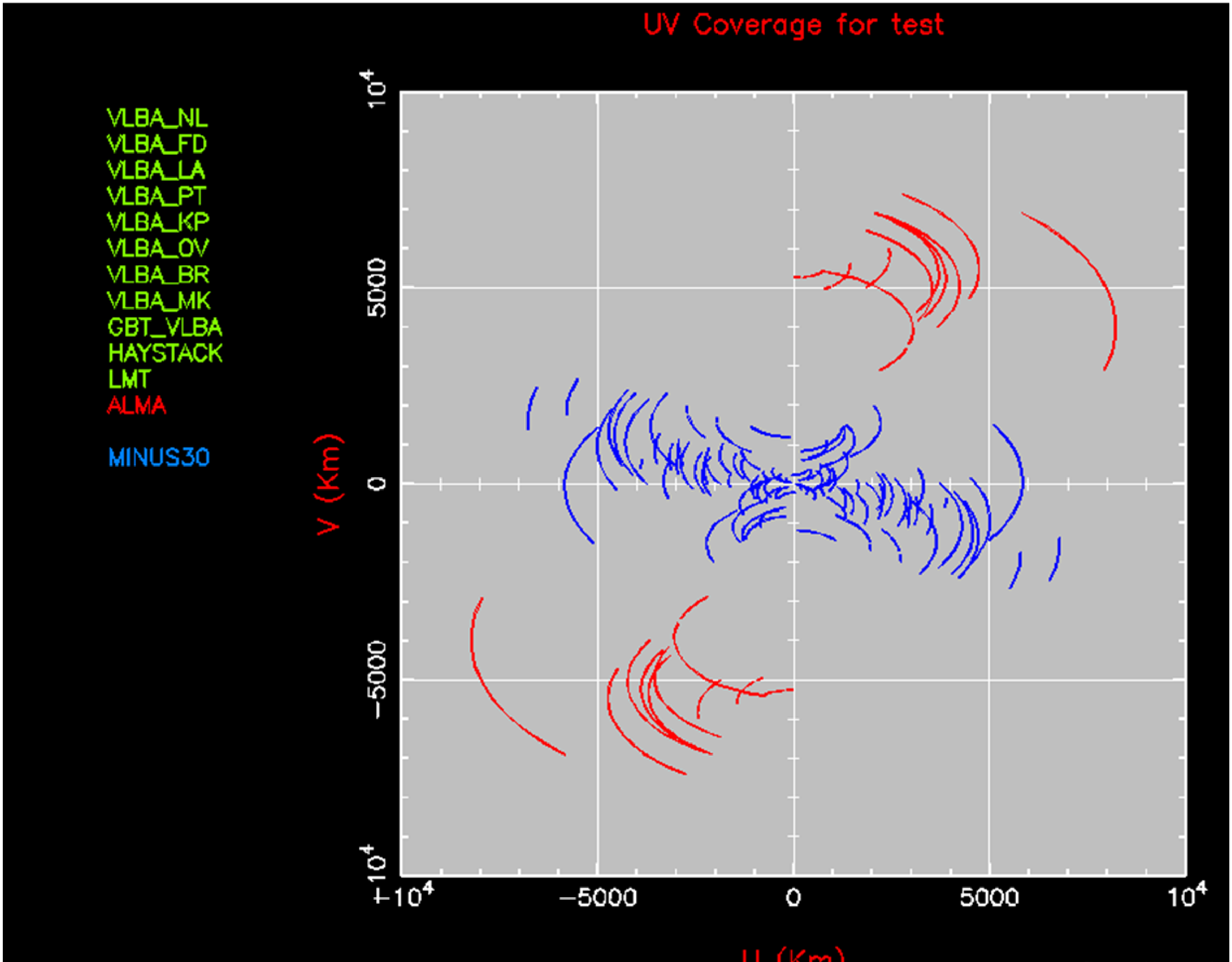
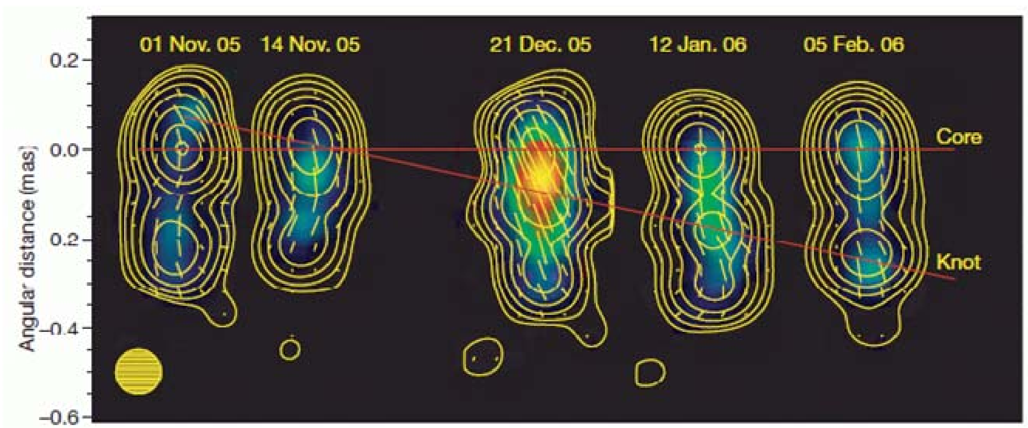
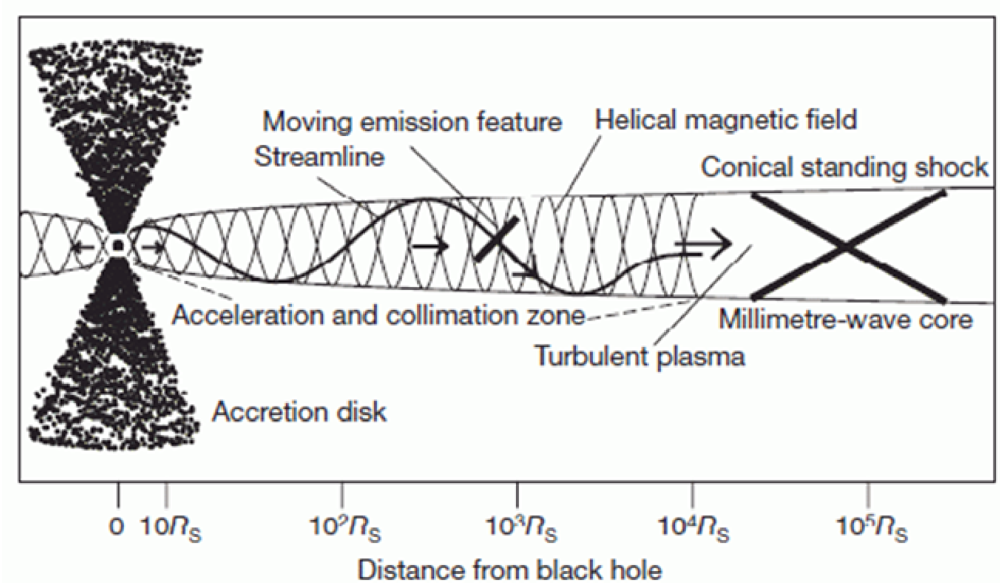


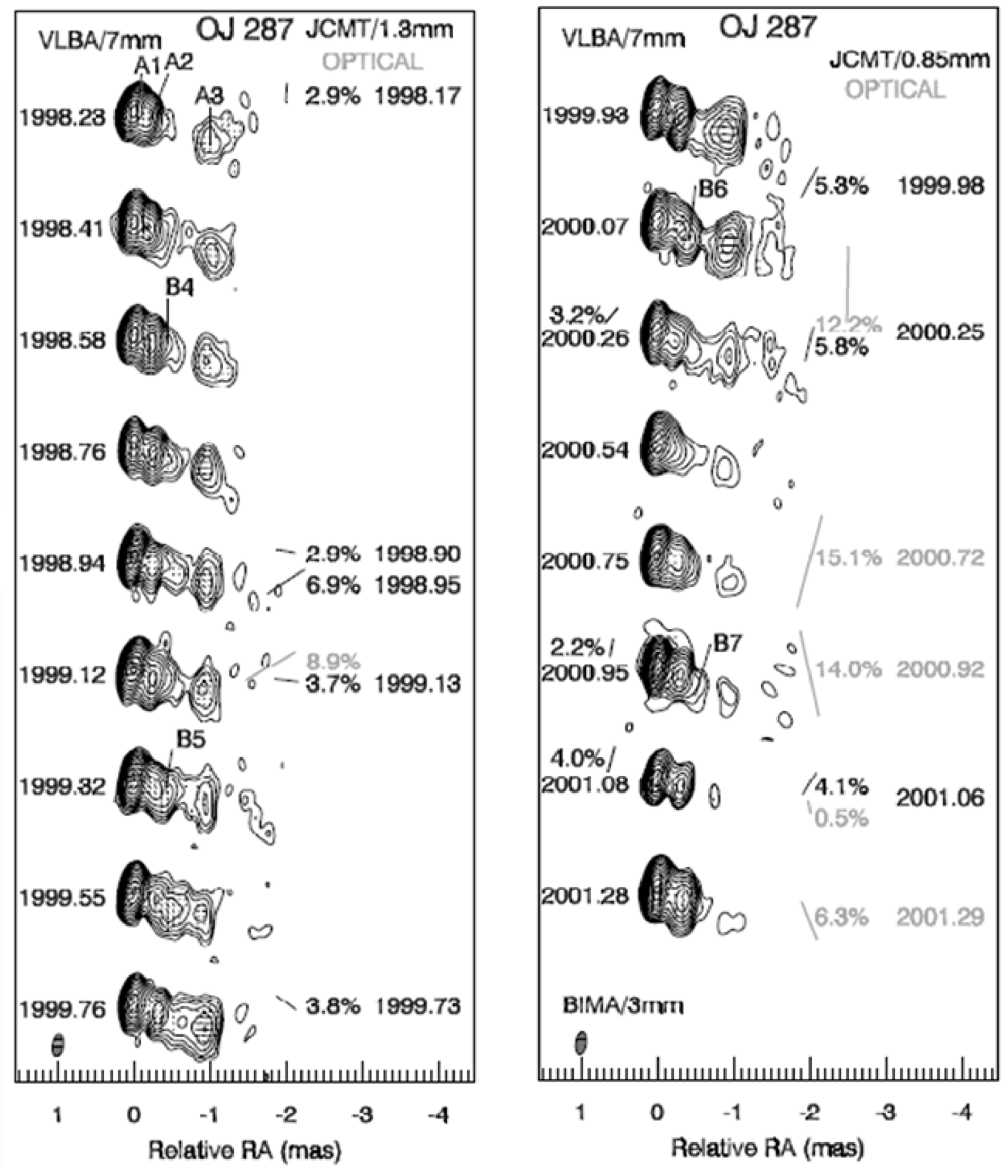
AGN and Jets

Phased ALMA will supplement VLBI at 7 mm and 3 mm



(Marscher et al 2008)



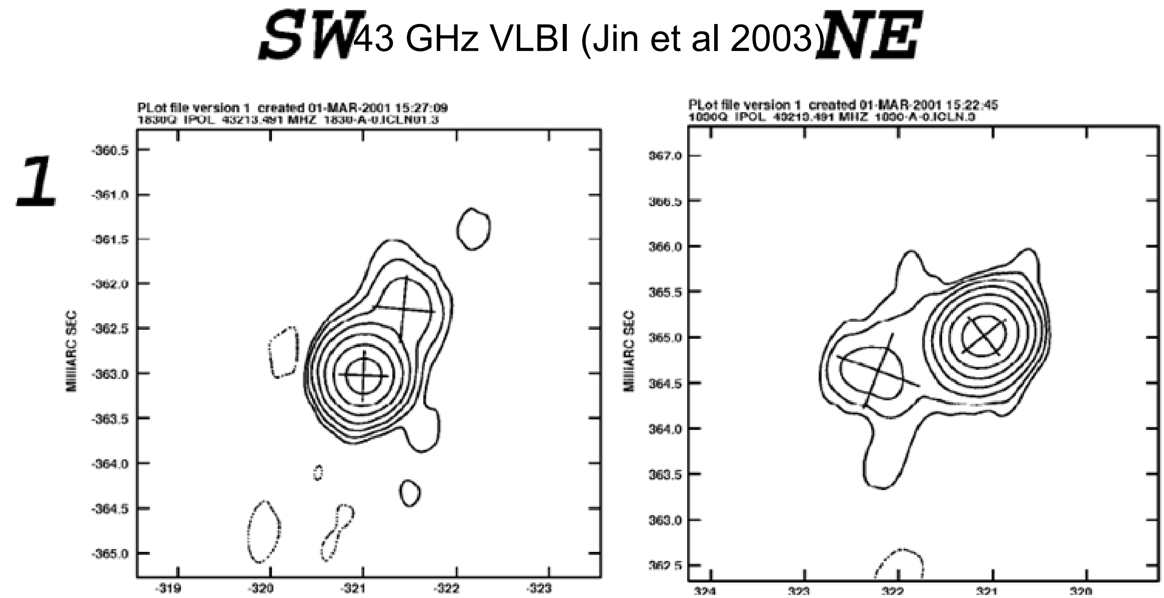


(Jorstad et al 2005)

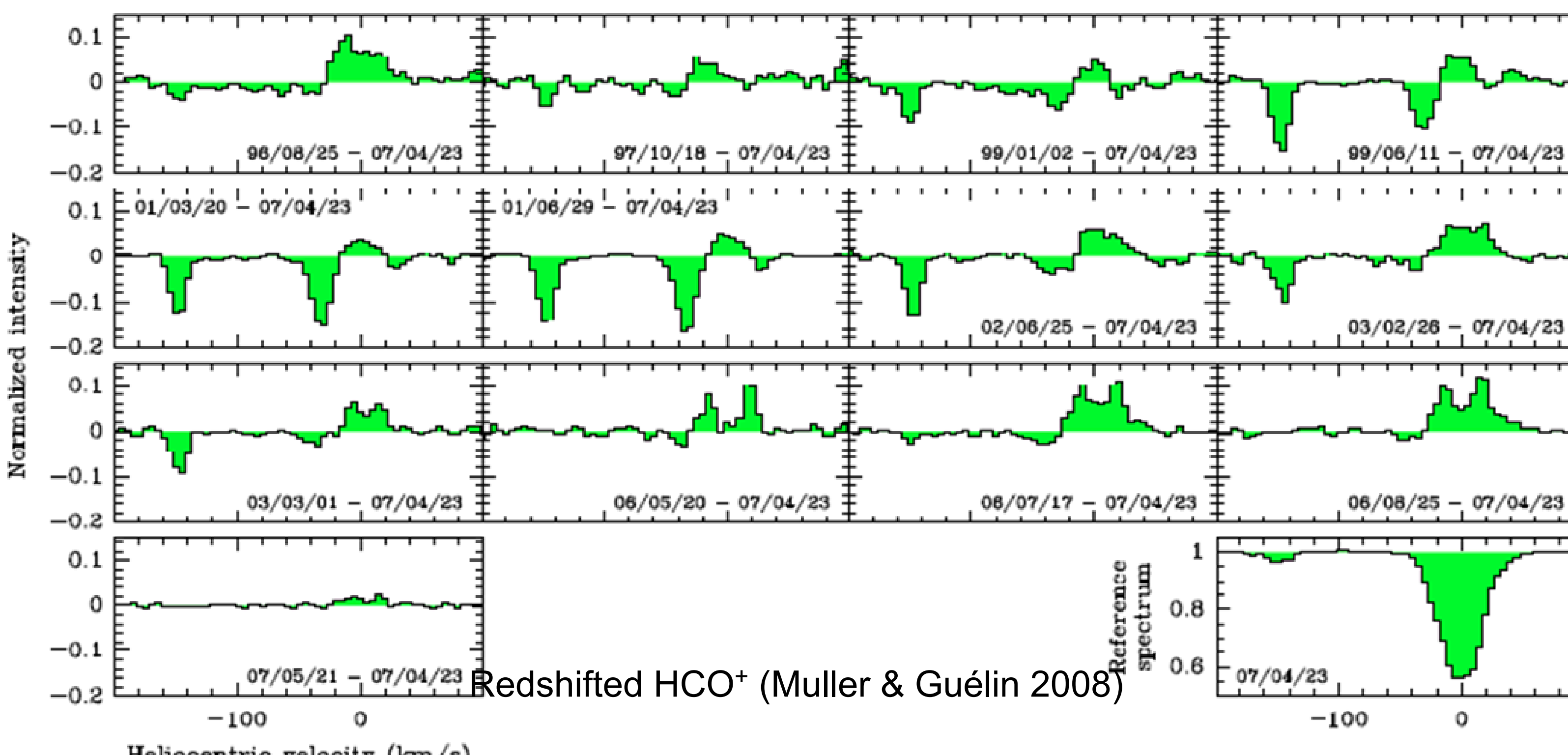
Spectral Line VLBI

VLBI can measure absorption against background continuum sources

PKS 1830-211 absorbing material at redshift z = 0.89 (pc scale absorbers)



43 GHz VLBI (Jin et al 2003)



Redshifted HCO^+ (Muller & Guélin 2008)

Spectral Line VLBI

SiO masers: 43 & 86 GHz bands in common with VLBA
129 GHz VLBI (Doeleman et al. 2002)

Weak 86 GHz SiO masers in LMC -- VLBI with Mopra, ATCA, (SEST), ...

Other species/transitions possible in higher bands with EHT

Source and transition selection are important -- will overresolve some masers on long baselines to ALMA

Summary

ALMA phasing system project has been approved

Design underway, expected operational ~2015

Will enable new science:

- Black hole/GR studies
- AGN/jet physics
- Pulsars & magnetars
- Absorption systems
- Masers
- ...