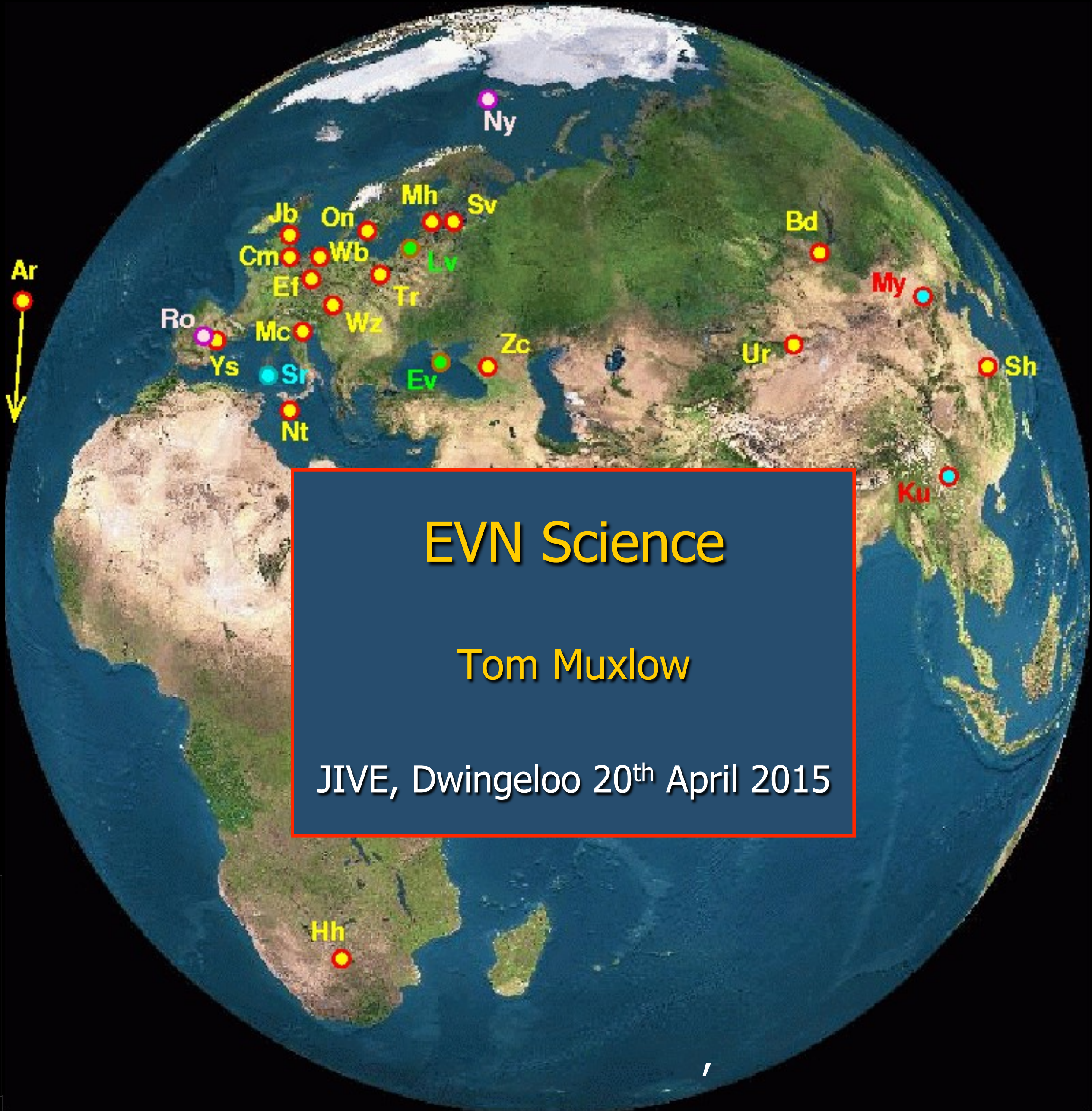
EVN Science

Tom Muxlow

JIVE, Dwingeloo 20th April 2015



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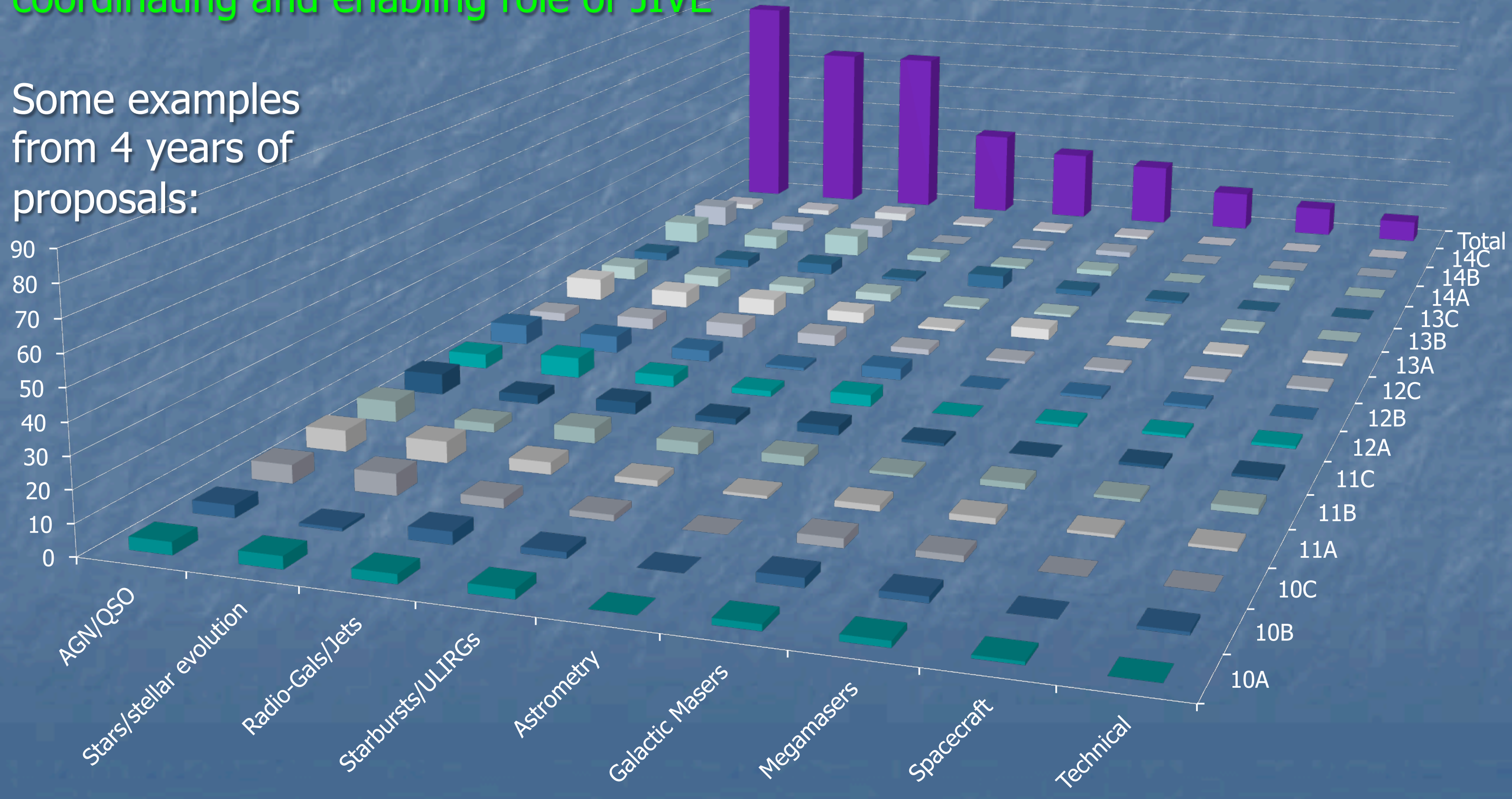
EVN Science

Breakdown of submitted proposal science areas over the past four years.

Expansion and development of EVN in recent years has radically increased the sensitivity and imaging capabilities over a wide range of frequency bands → Common user instrument → Science deliverability transformed by the coordinating and enabling role of JIVE

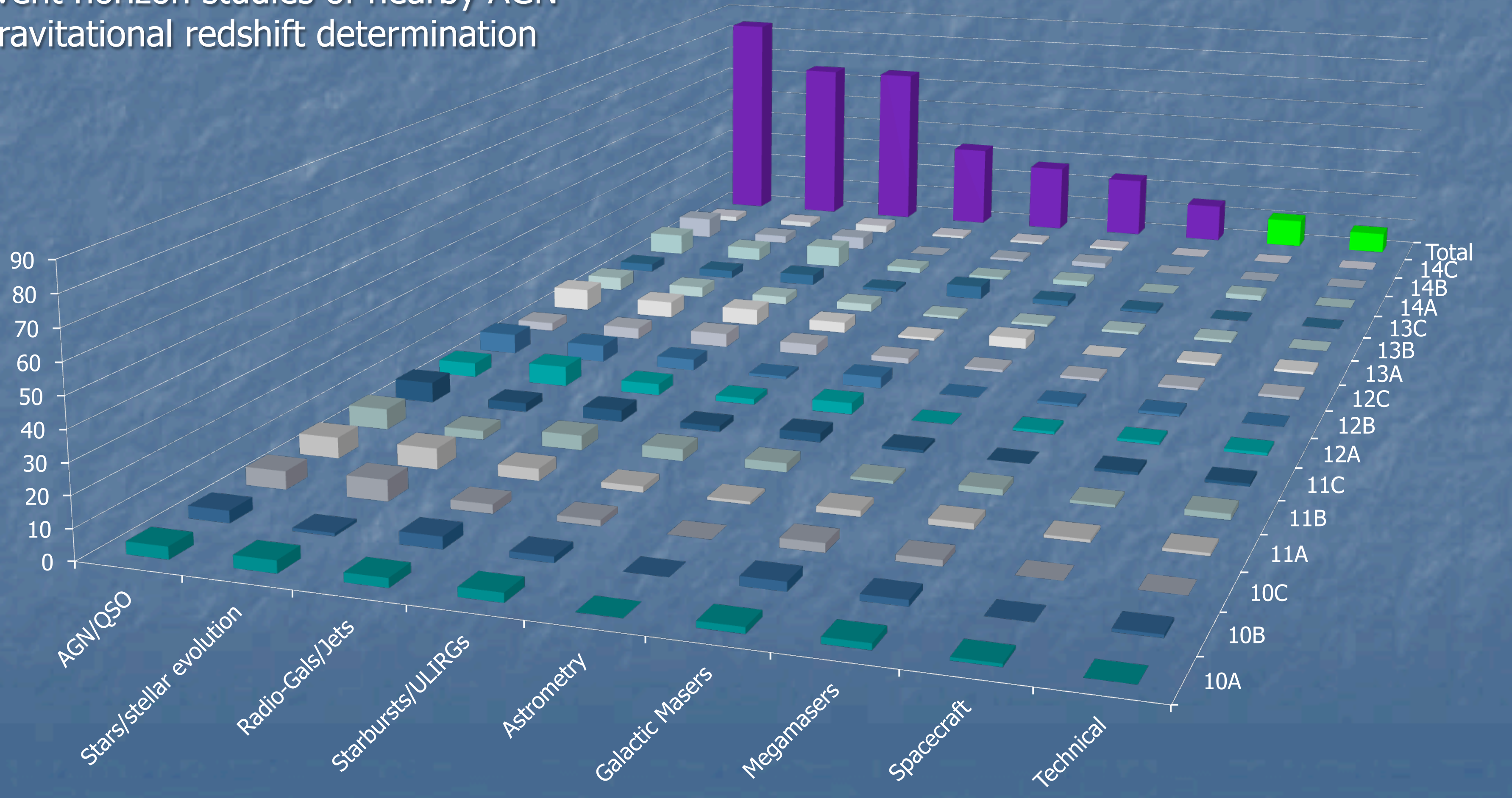
Some examples from 4 years of proposals:



EVN Science

Spacecraft & Technical:

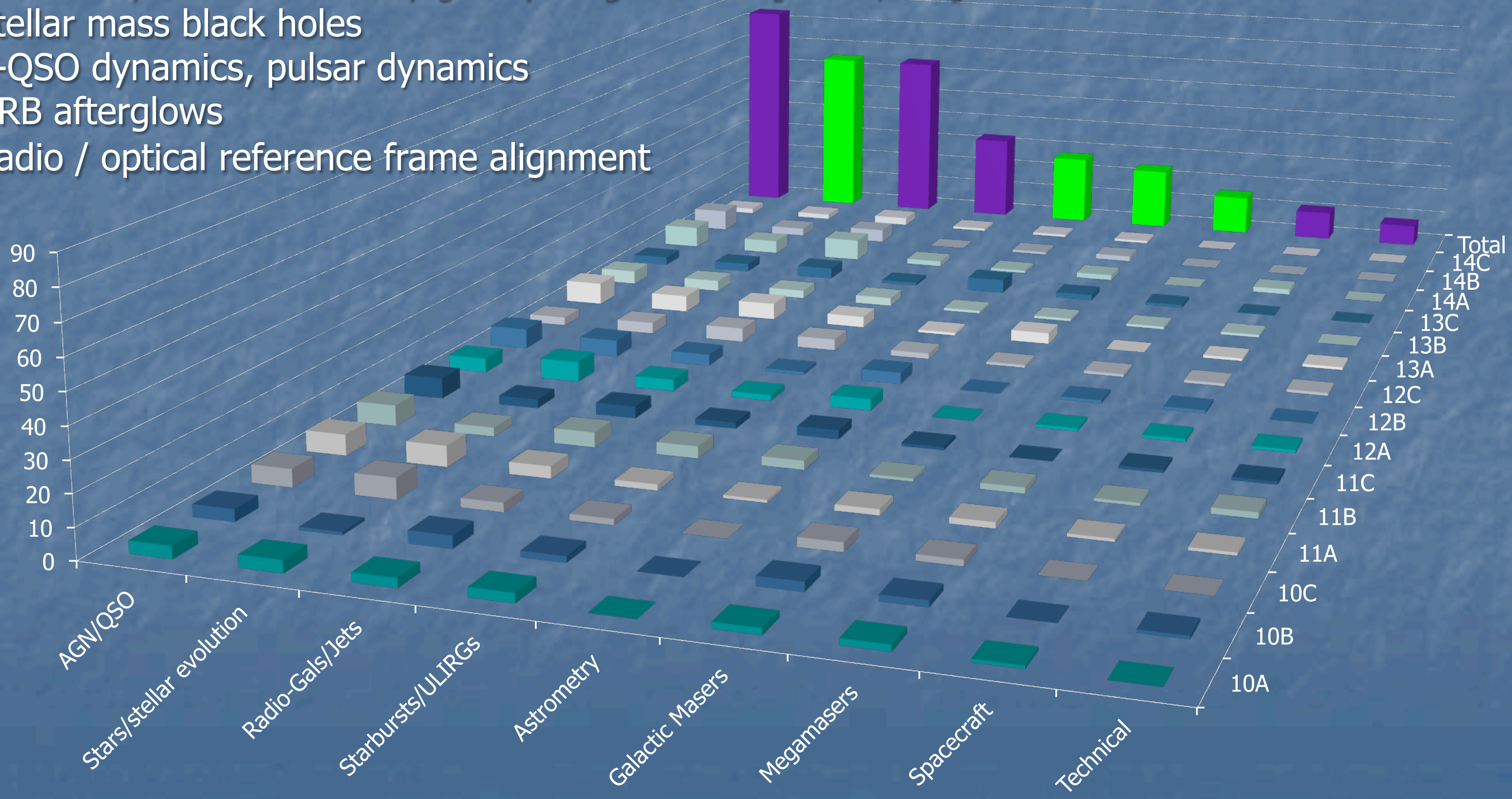
Ultra-high precision astrometry
Geodetic studies
Planetary physics
Radio jet dynamics
Event horizon studies of nearby AGN
Gravitational redshift determination



EVN Science

Stellar Evolution, Masers and Astrometry:

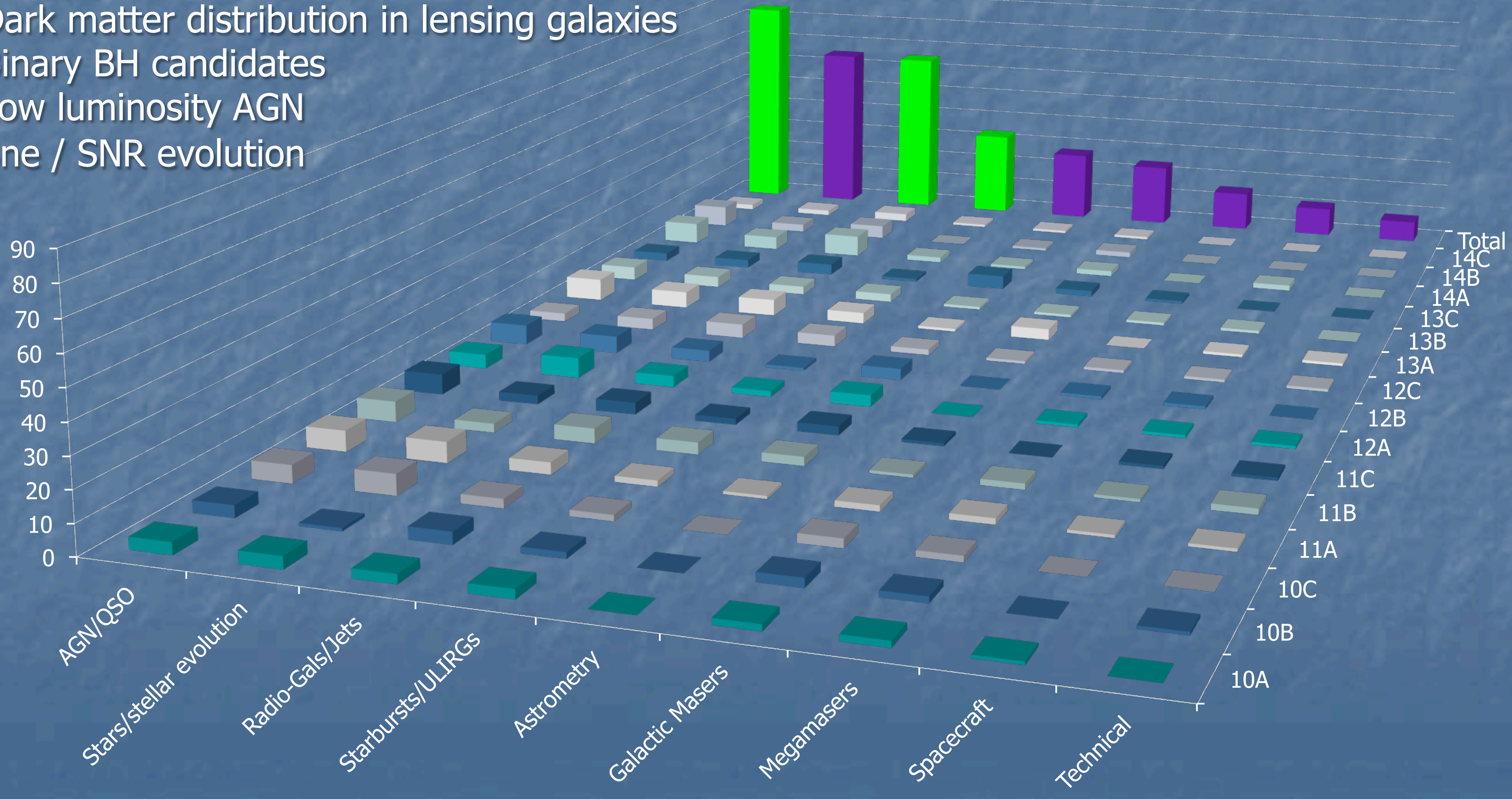
Classical, γ-ray novae and X-ray binary dynamics
Massive S-F regions magnetic fields & proto-stellar gas dynamics [Water, Methanol, Excited OH]
Parallax towards Methanol masers
OH maser / IR distances to evolved stars
Nuclear dynamics in nearby galaxy megamasers [Water, OH]
Stellar mass black holes
μ-QSO dynamics, pulsar dynamics
GRB afterglows
Radio / optical reference frame alignment



EVN Science

AGN, QSO, Radio Galaxies, Jets, ULIRGS and Starbursts:

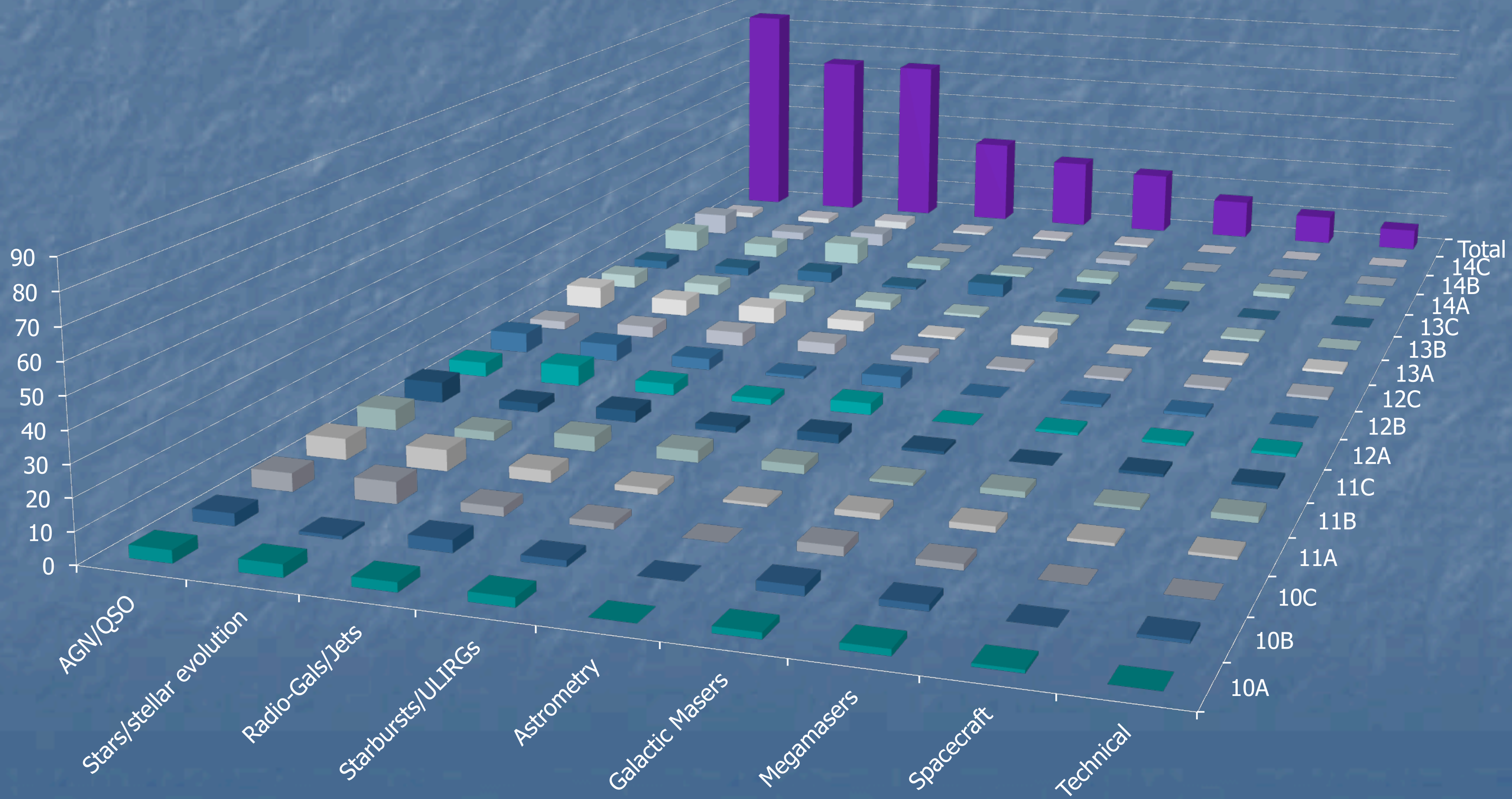
High redshift AGN, AGN evolution and BH growth
Earliest radio sources
X-ray & γ-ray blazars
Double-doubles and restarted AGN
AGN feedback and star-formation in nearby and distant galaxies
Dark matter distribution in lensing galaxies
Binary BH candidates
Low luminosity AGN
Sne / SNR evolution



EVN Science

Recent EVN science explored by detailed talks in this meeting

Talk presents some interesting (& historical) projects not covered elsewhere – illustrating what image resolution, sensitivity, and fidelity can achieve….
EVN+ EVN, VLBA, Global, (e-)Merlin



Outline

Galactic:

Equatorial Outflow in SS433 Doolin & Blundell, 2009, ApJ, 698,L23

Classical Nova V959 Mon Chomiuk et al., 2014, Nature, 514, 339

Extra-galactic:

AGN jets, star-formation, and feedback – classical VLBI studies:

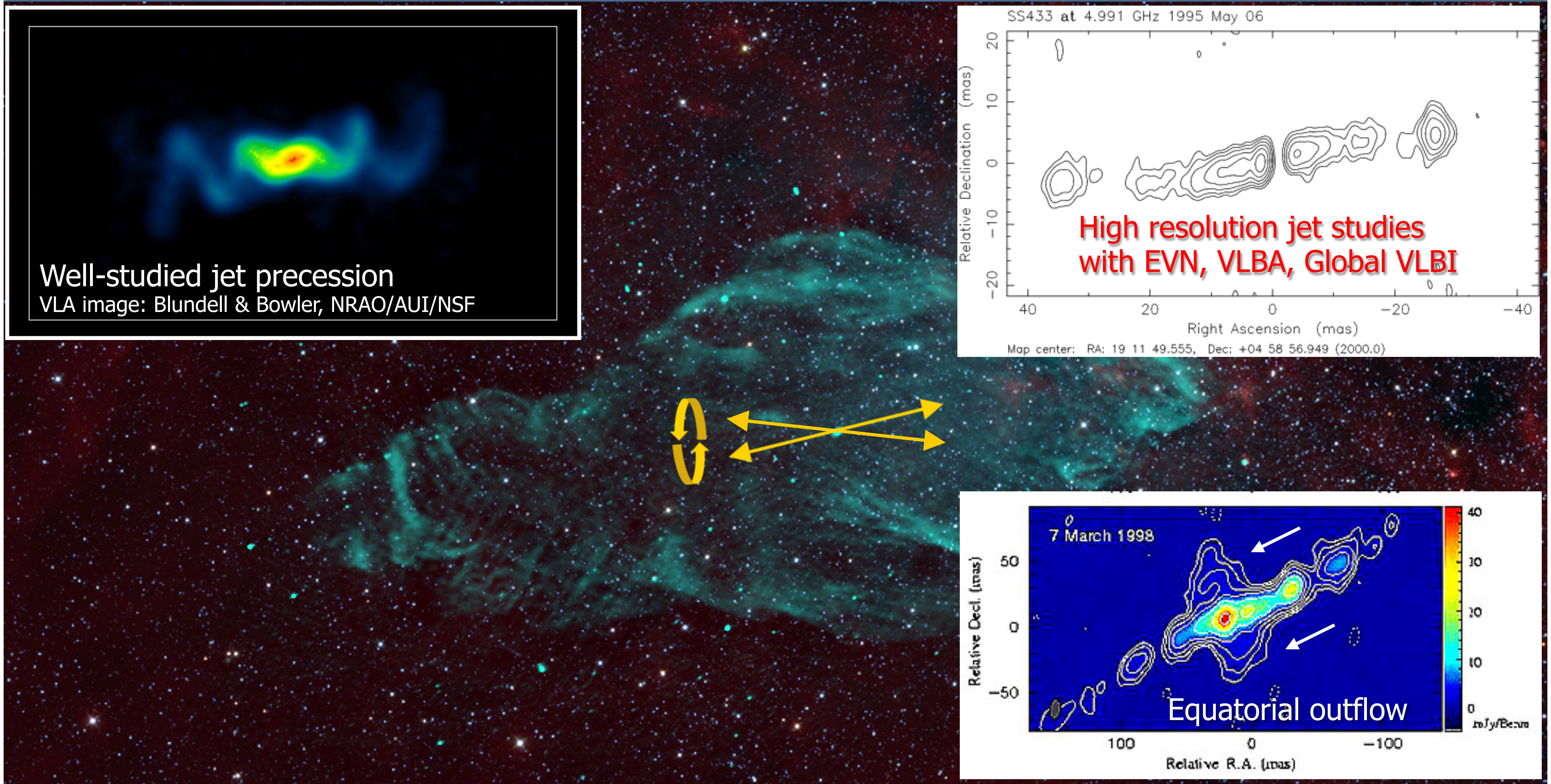
3C48 jet structure – beaming and bending…. An et al, 2010, MNRAS 402,87

Deep fields – distant starbursts/AGN feedback   Garrett / e-MERGE Consortium

M87 revisited – Sub- to super-luminal motion and back in the M87 jet
Asada et al., 2014, Ap J 781, L2 – L7 (2014)

Ultimate resolution, ultimate fidelity?   – a postscript…..

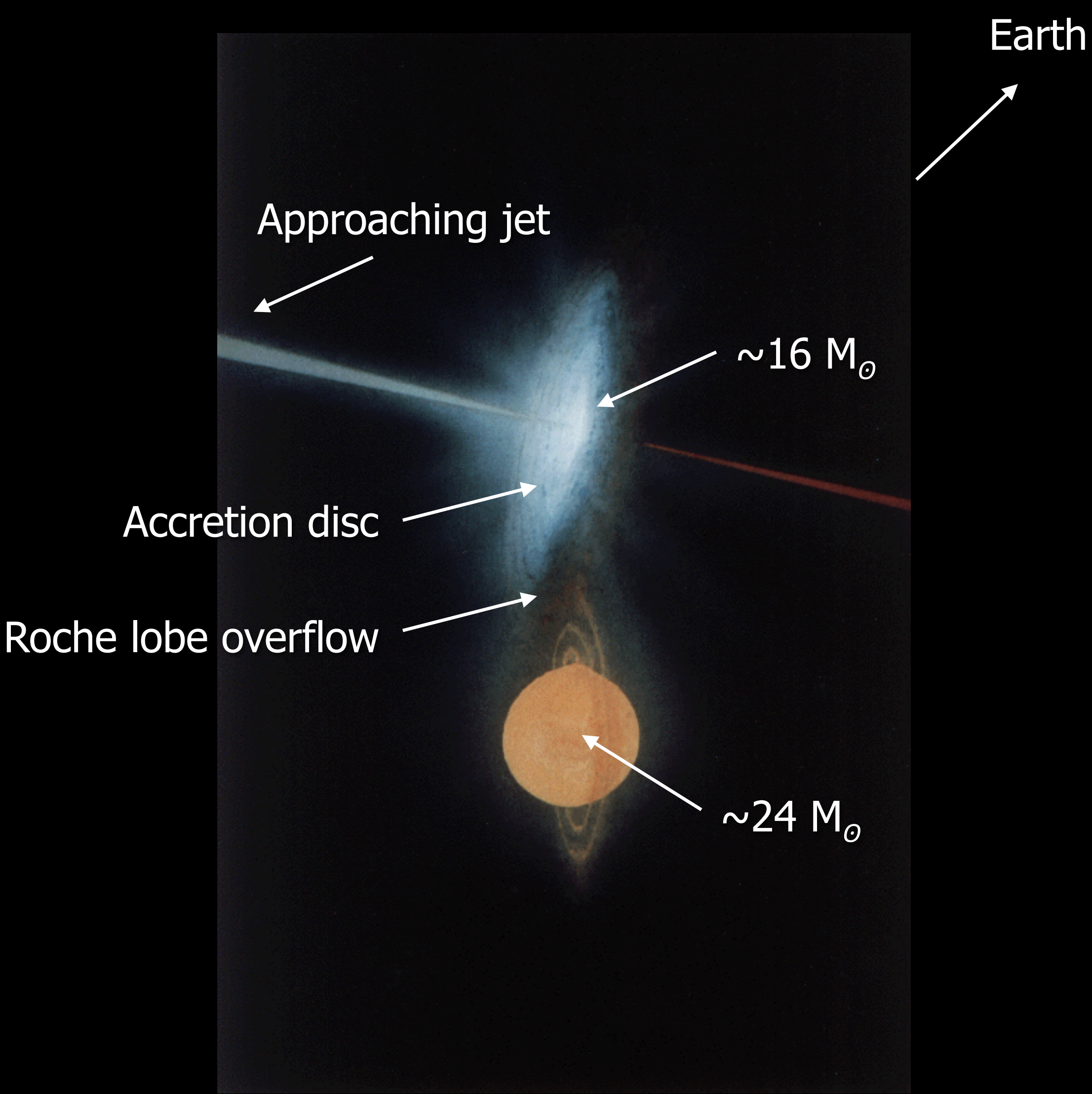
Equatorial Outflow in SS433

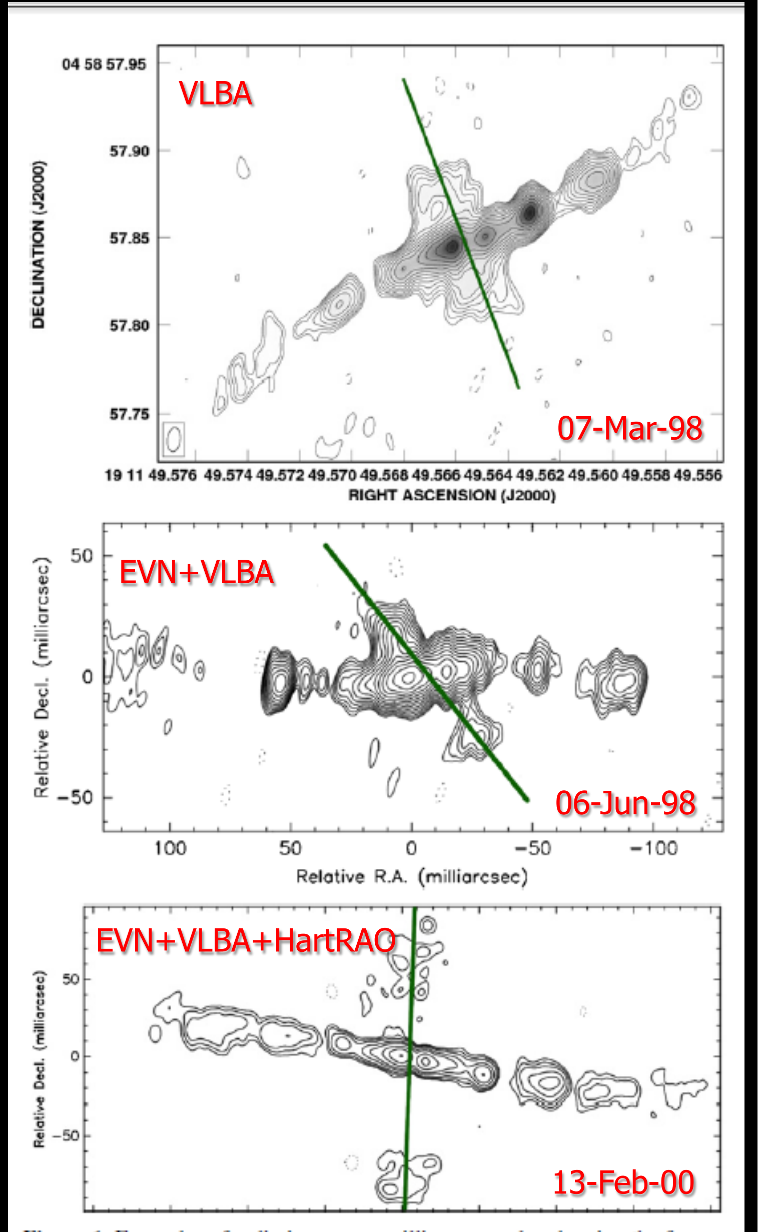


Very Large Array continuum mosaic of W50 at 1.5 GHz [Green] (Dubner et al 1998)
Background: NASA Wide Field Survey Explorer [Red] (WISE)

E-W extension nebula ~ 1° (~ 50 pc) from injection of precessing relativistic jets from SS 433.
D~5.5 kpc – remnant from a supernova which occurred about 20,000 years ago

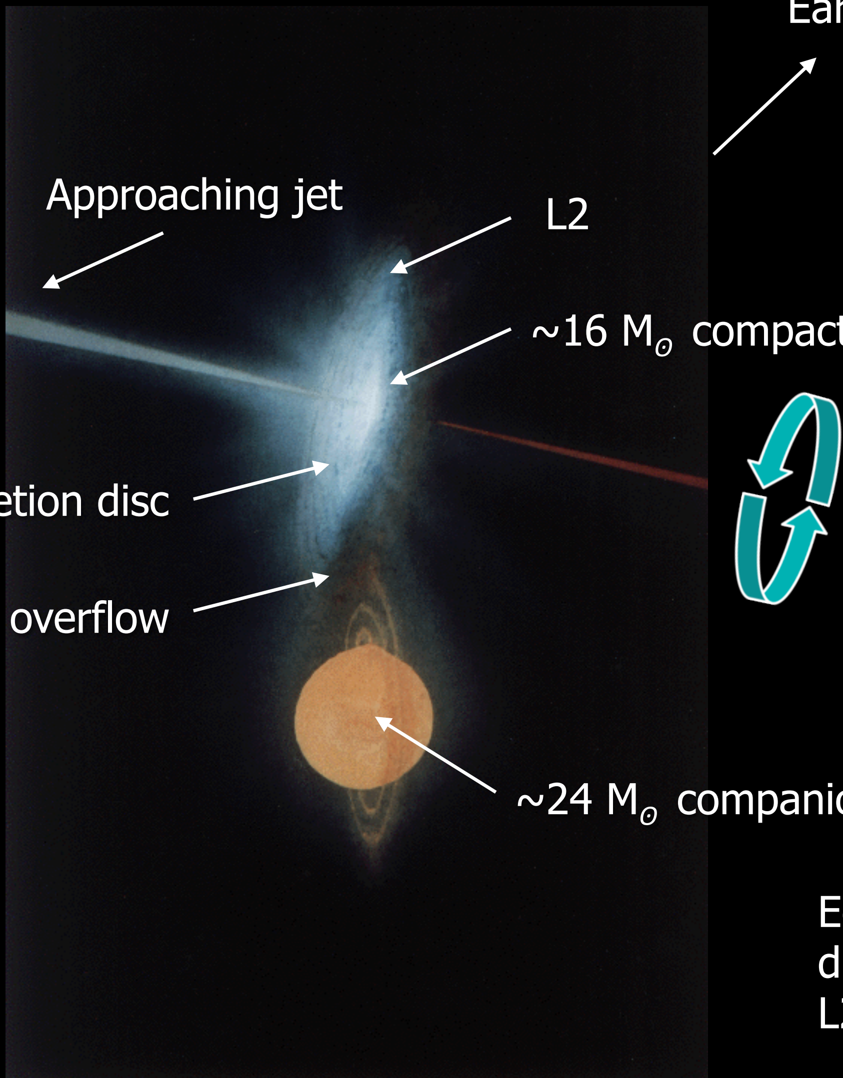
Equatorial Outflow in SS433





Doolin & Blundell, 2009, ApJ, 698,L23

Equatorial Outflow in SS433



Precession period 162.375 days
Velocity ~0.26c

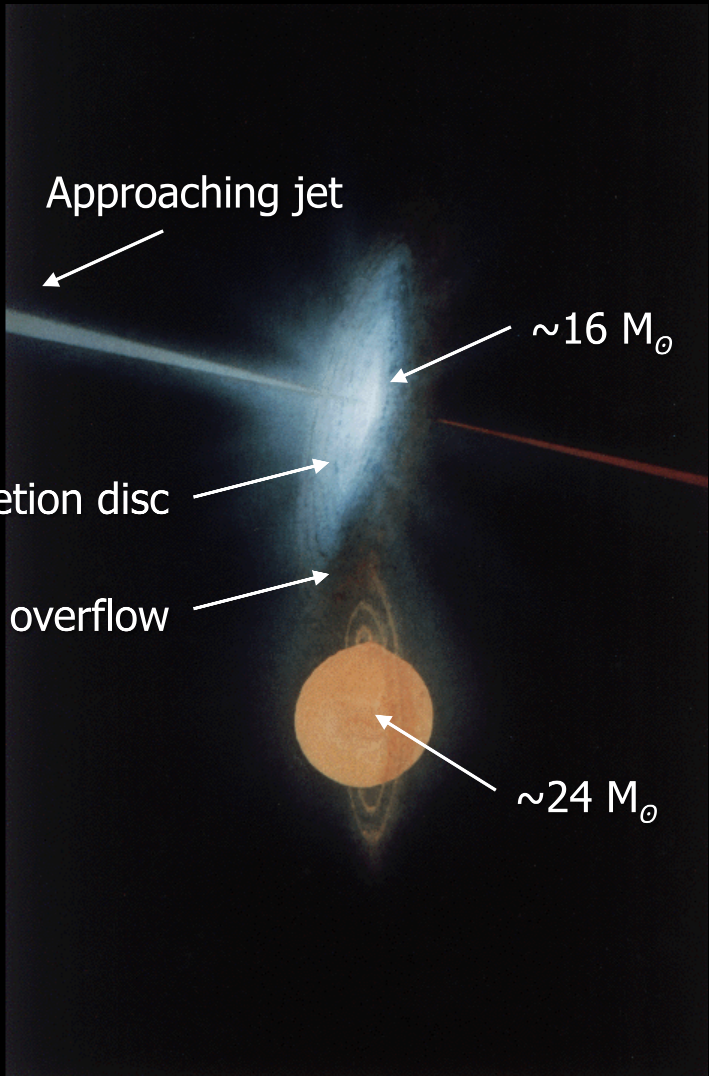
Equatorial outflow from excretion disk fed by overflow of gas from the L2 point in the binary system

Excretion disk also detected optically in Balmer Hα

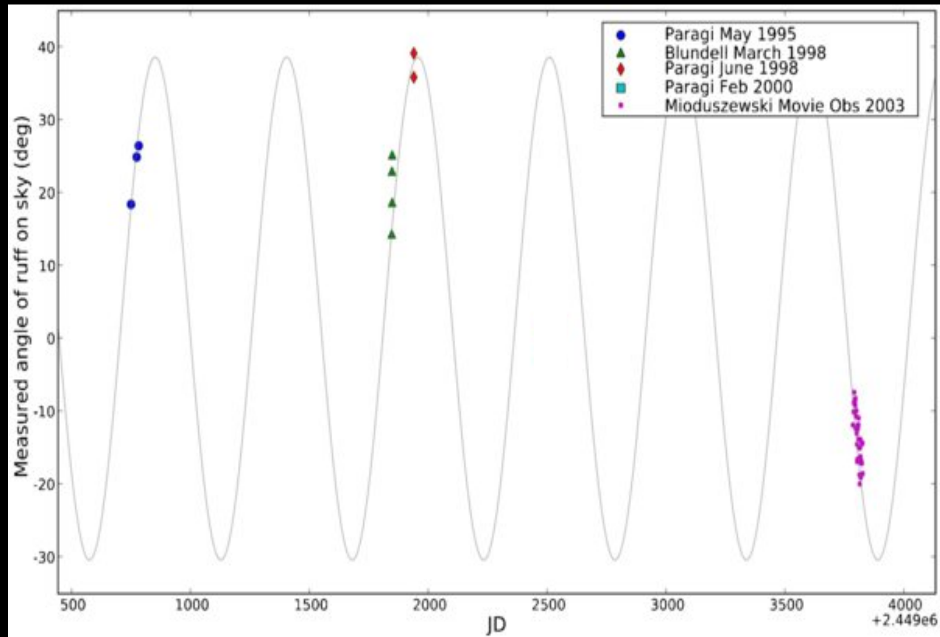
Doolin & Blundell, 2009, ApJ, 698,L23

Equatorial Outflow in SS433

Earth



Position angle of outflowing material is seen to precess with time



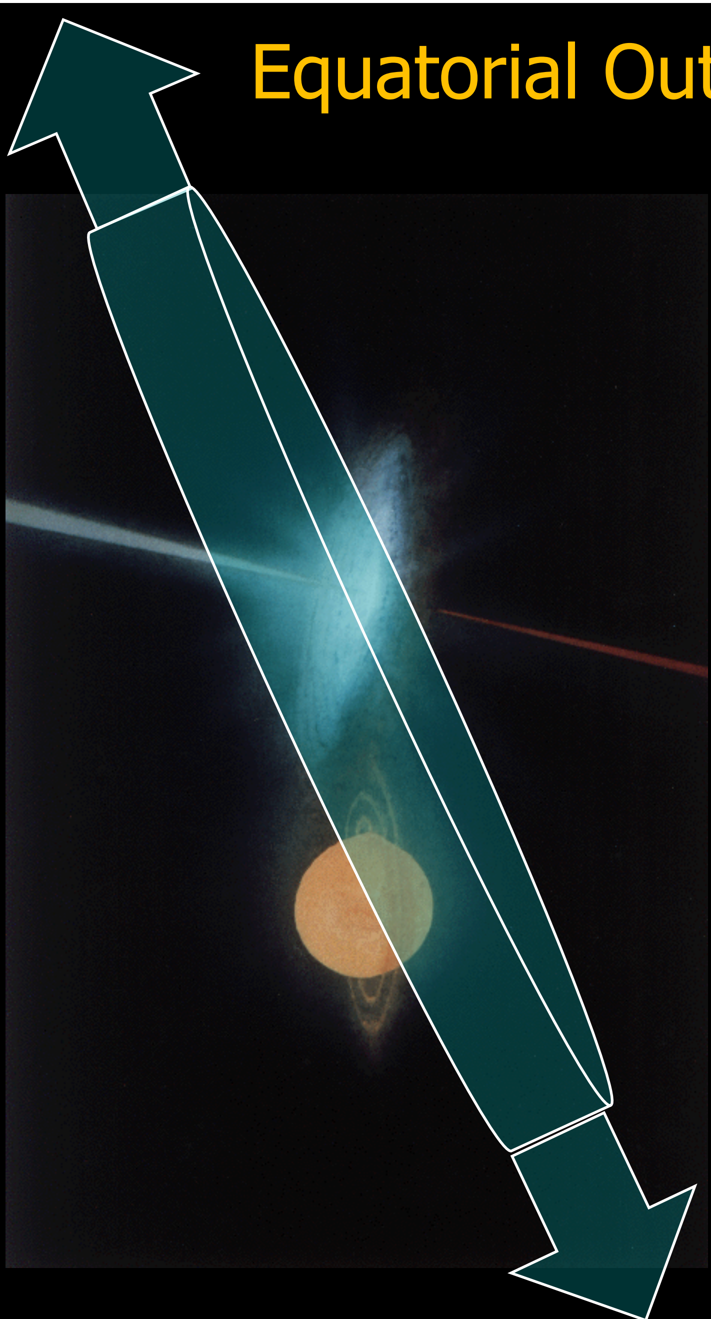
Periodicity of precession = 552.5 days
Unrelated to jet precession or binary orbit periods

Some data do not fit this precession period – this may be due to eccentricity in the binary orbit

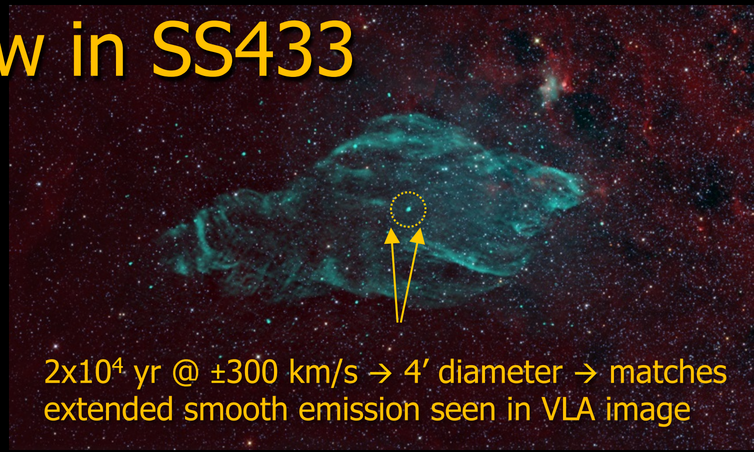
Mioduszewski et al 2004, BAAS, 36,967

Doolin & Blundell, 2009, ApJ, 698,L23

Equatorial Outflow in SS433



Ionized disc wind $v \geq 300$km/s



3-D simulations modelling excretion disk outflow. Plane inclined to binary by 34.5^o

~10^{-4} $M_\odot$/yr – Greater than mass flow down jets → dominates mass loss from system

Excretion disk centred on centre of mass for the binary system

Equatorial outflow from excretion disk fed by overflow of gas from the L2 point in the binary system

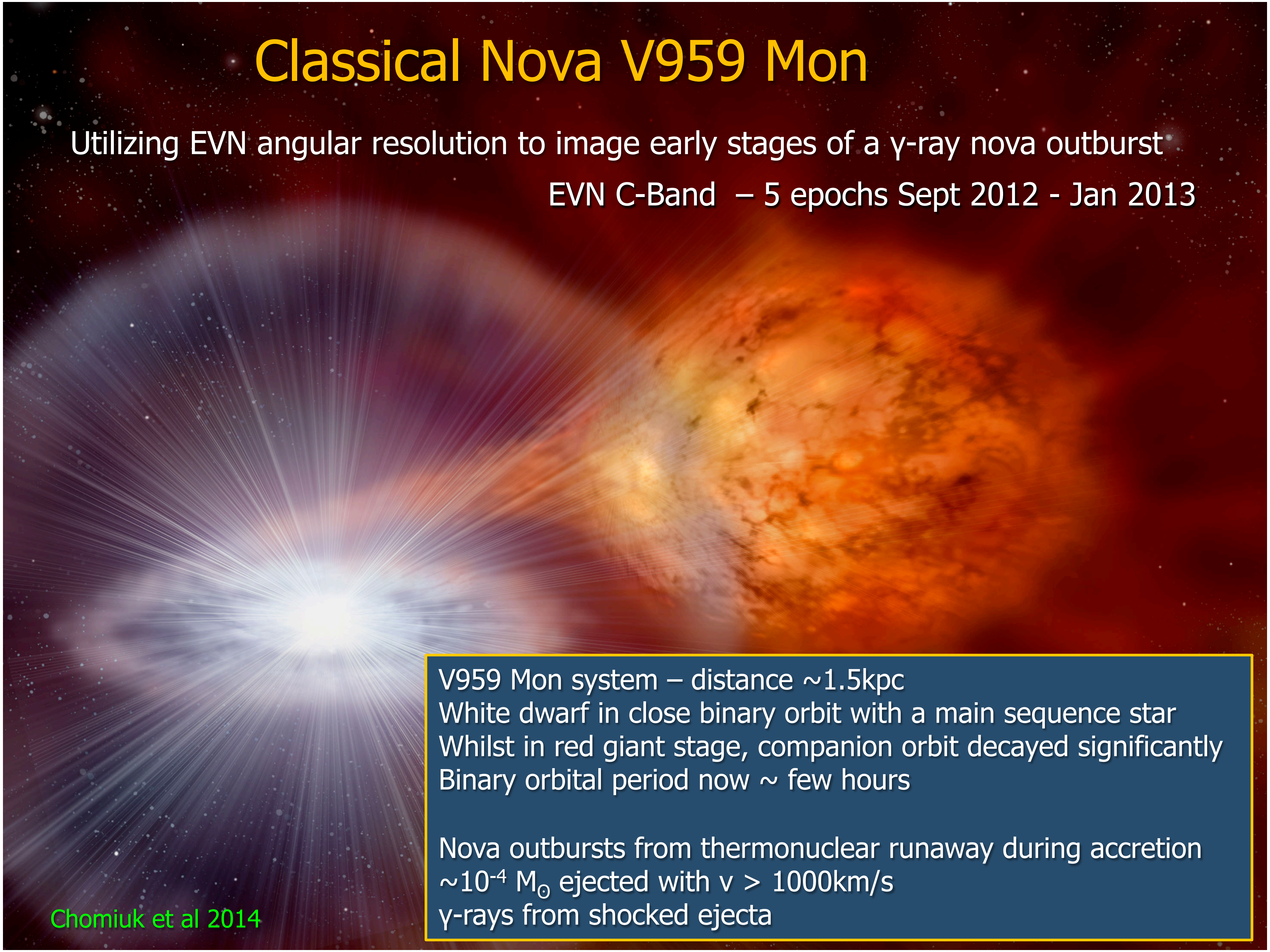
Paragi et al, 2002, 6th EVN Symposium

Doolin & Blundell, 2009, ApJ, 698,L23

Classical Nova V959 Mon

Utilizing EVN angular resolution to image early stages of a γ-ray nova outburst

EVN C-Band – 5 epochs Sept 2012 - Jan 2013

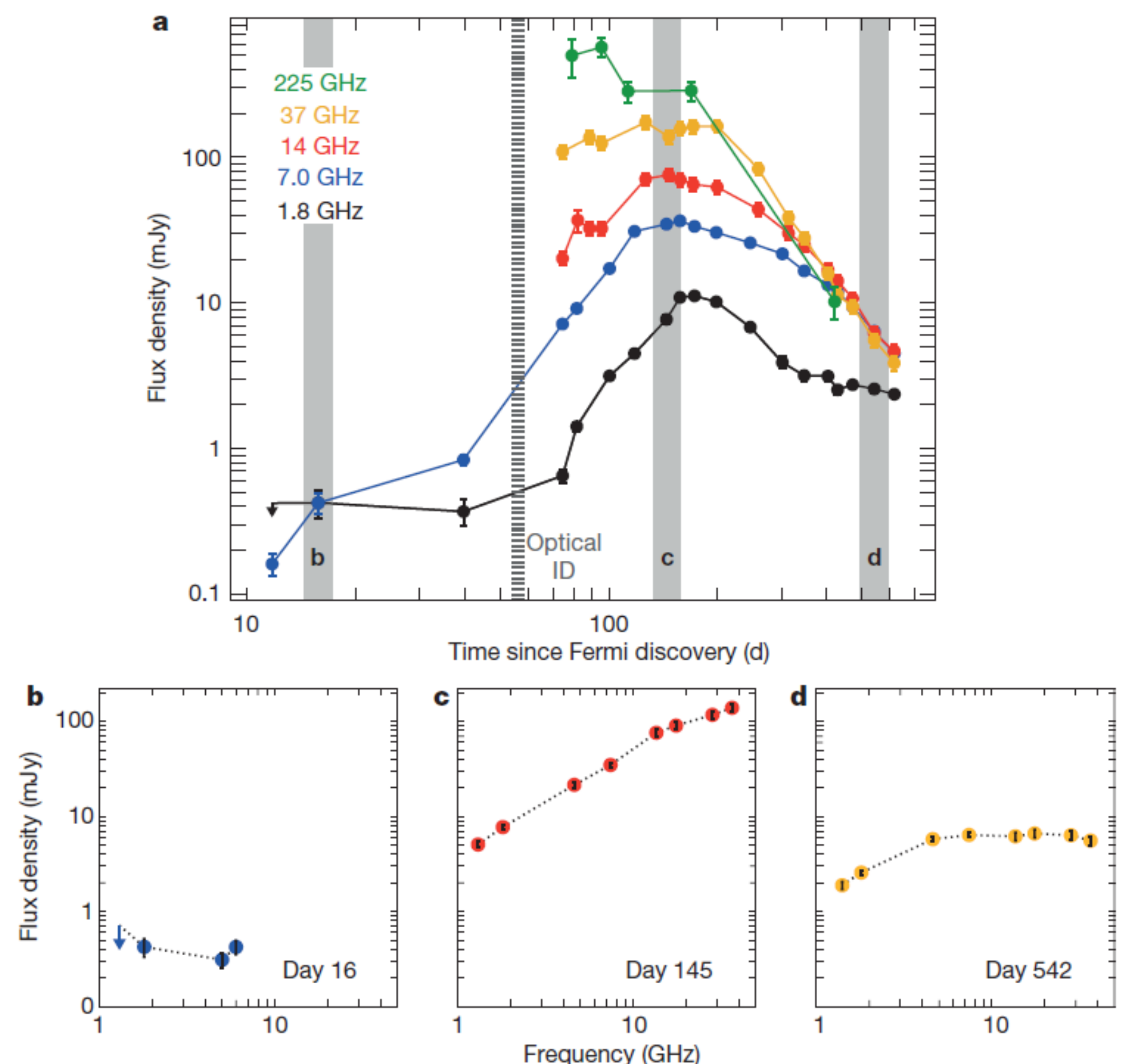


V959 Mon system – distance ~1.5kpc
White dwarf in close binary orbit with a main sequence star
Whilst in red giant stage, companion orbit decayed significantly
Binary orbital period now ~ few hours

Nova outbursts from thermonuclear runaway during accretion
$\sim 10^{-4}\ M_{\odot}$ ejected with $v > 1000$km/s
γ-rays from shocked ejecta

Chomiuk et al 2014

Classical Nova V959 Mon



Fermi γ-ray detection 19th June 2012 – Day 0

Initially flat spectrum (Day 16)

Transitions to optically thick thermal spectrum (Day 145)

Fades to late optically thin thermal spectrum (Day 542)

Chomiuk et al 2014

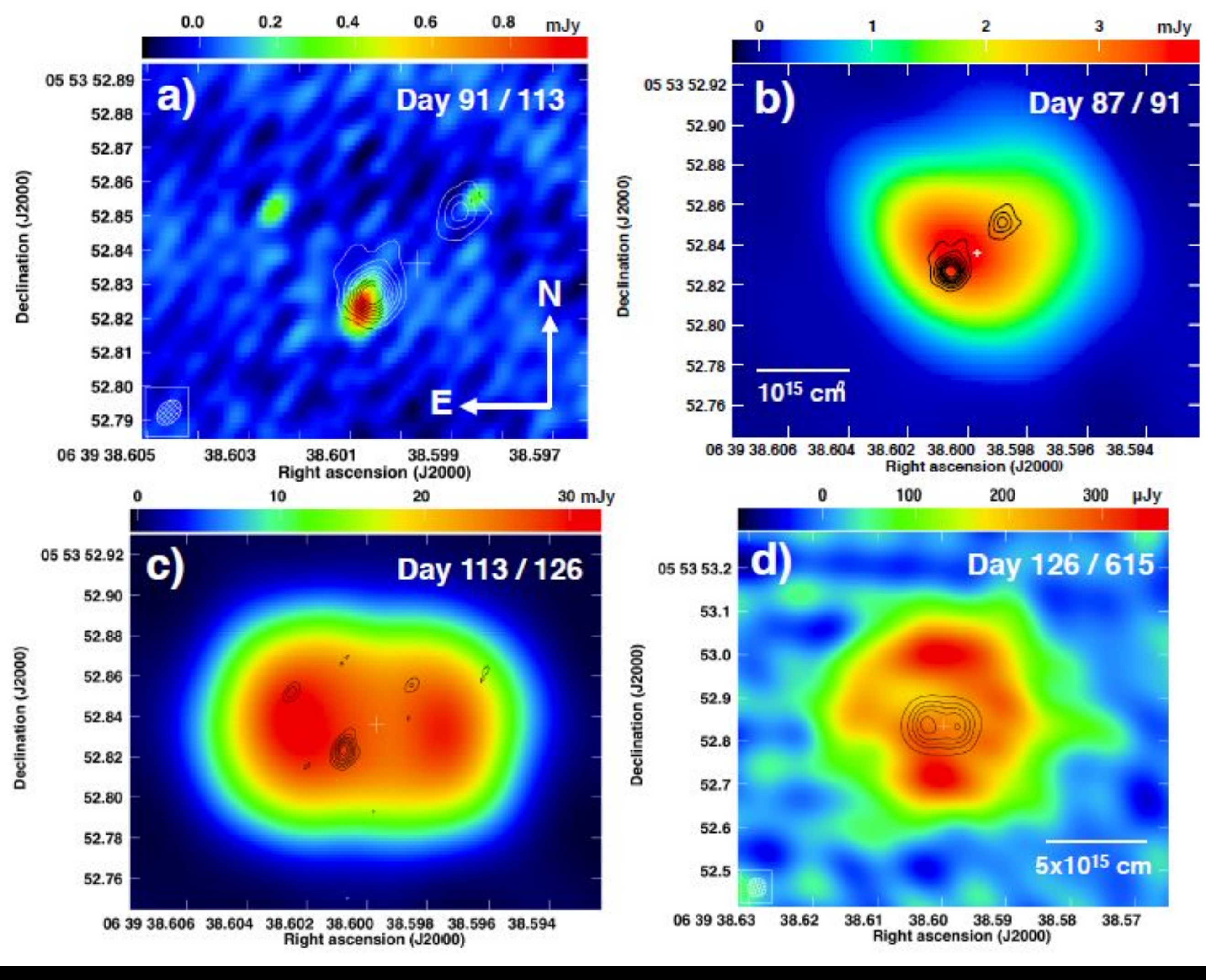
Classical Nova V959 Mon

a) EVN 1.7GHz images at day 91 (contoured) & 113 (colour) days showing diagonal expansion ~0.5mas/day

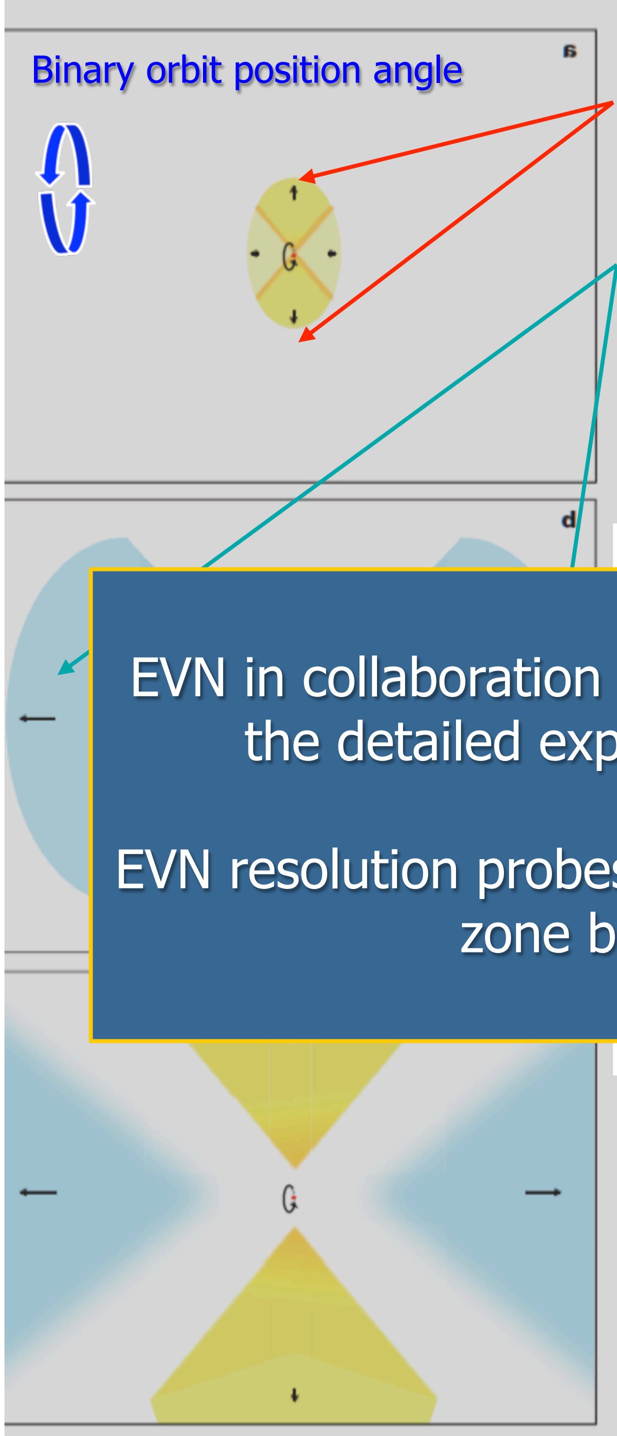
b) e-Merlin 5.8GHz image at day 87(colour). Contours EVN image from day 91

c) ~1 month later. JVLA 36.5GHz image at day 126 (colour) and EVN at day 113 (contoured)

d) Geometry of emission now swaps from E-W to N-S. JVLA 17.5GHz image from day 615 colour) with day 126 image shown contoured



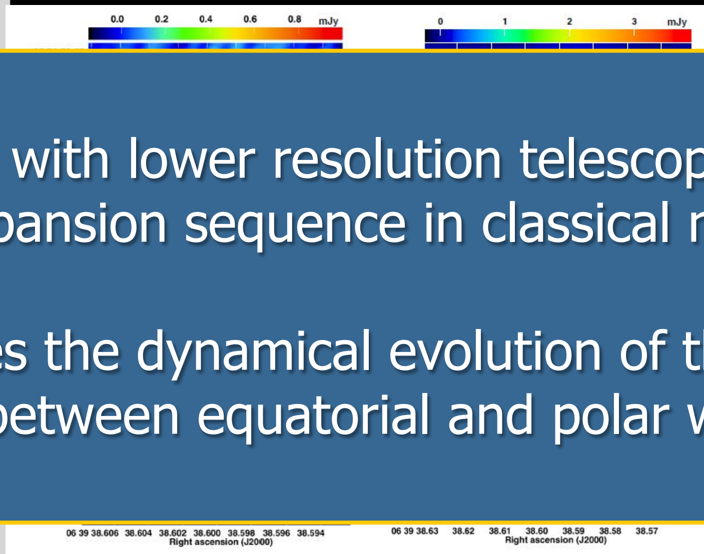
Chomiuk et al 2014

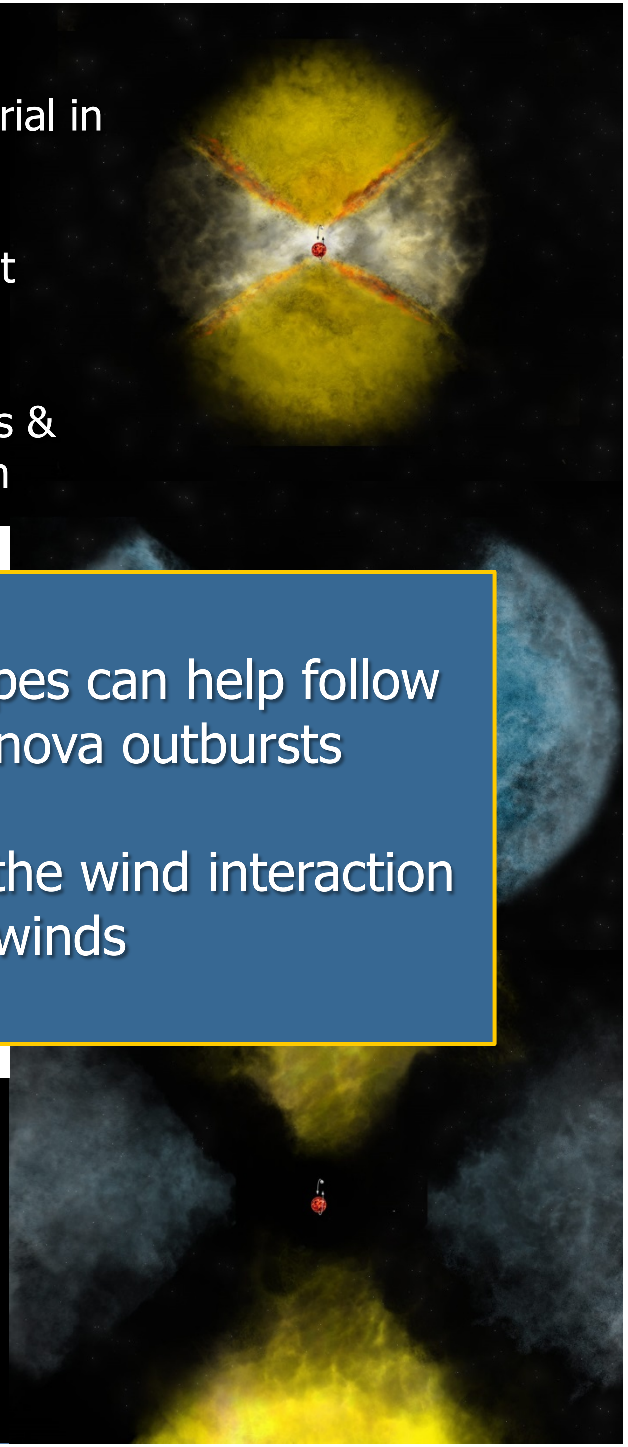


Nova envelope reacts with binary producing slow wind of dense material in the equatorial plane

White dwarf powers low density fast polar wind → thermal emission

Differential velocity produces shocks & compact non-thermal VLBI emission





EVN in collaboration with lower resolution telescopes can help follow the detailed expansion sequence in classical nova outbursts

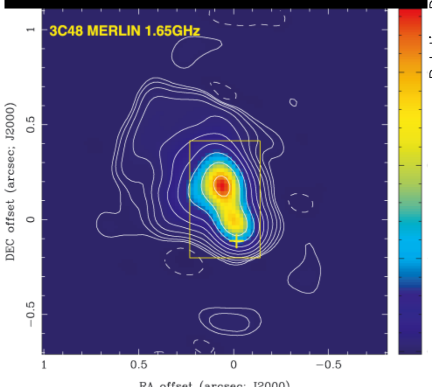
EVN resolution probes the dynamical evolution of the wind interaction zone between equatorial and polar winds

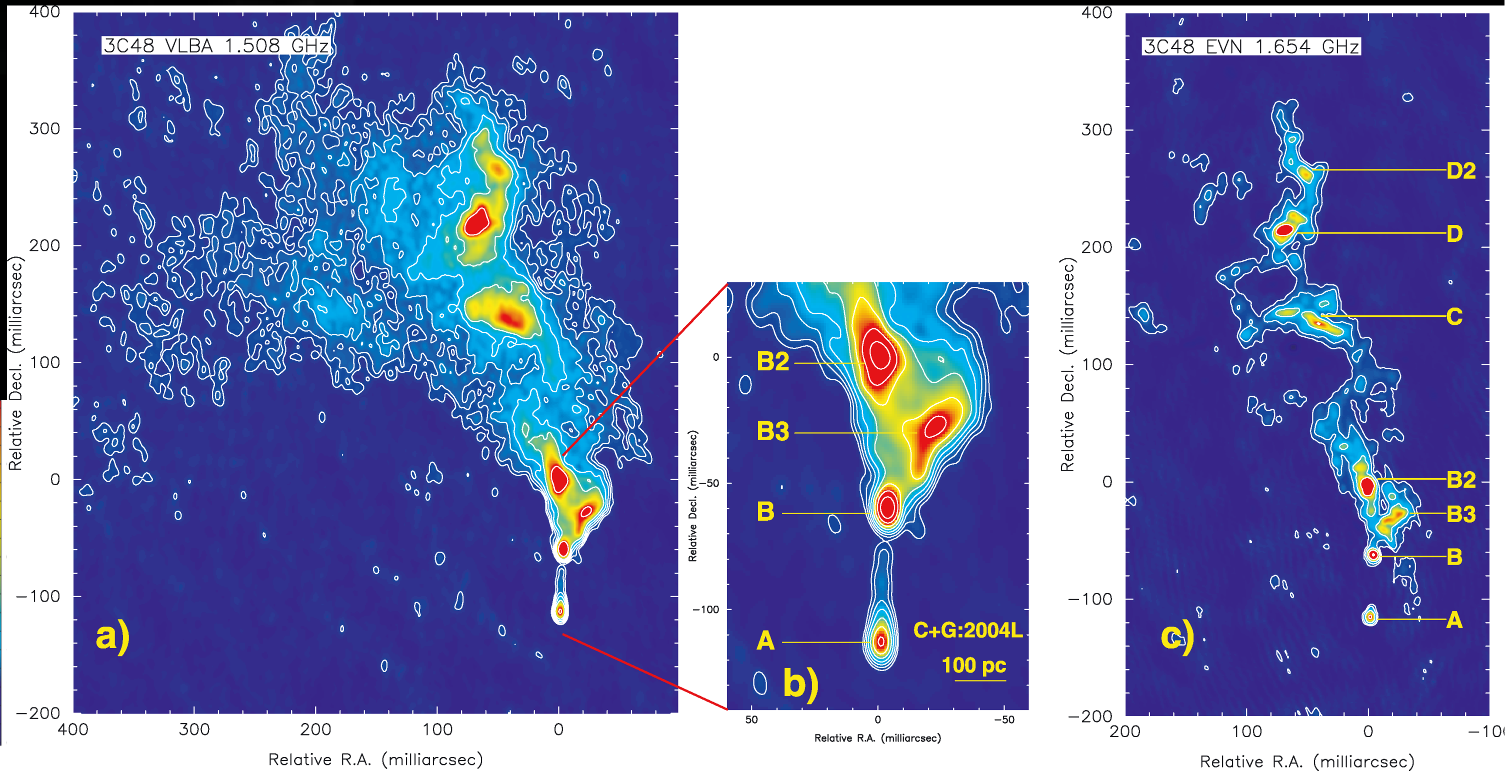
Once white dwarf wind ceases, polar fast outflow detaches and fades – equatorial slower outflow begins to dominate the radio emission – become optically thin

3C48

EVN – VLBA – MERLIN study of a high-z beamed jet in a CSS quasar

An et al, 2010, MNRAS 402,87



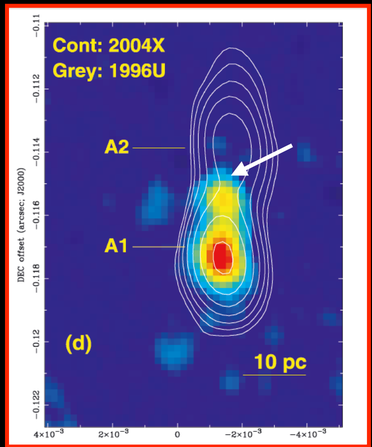


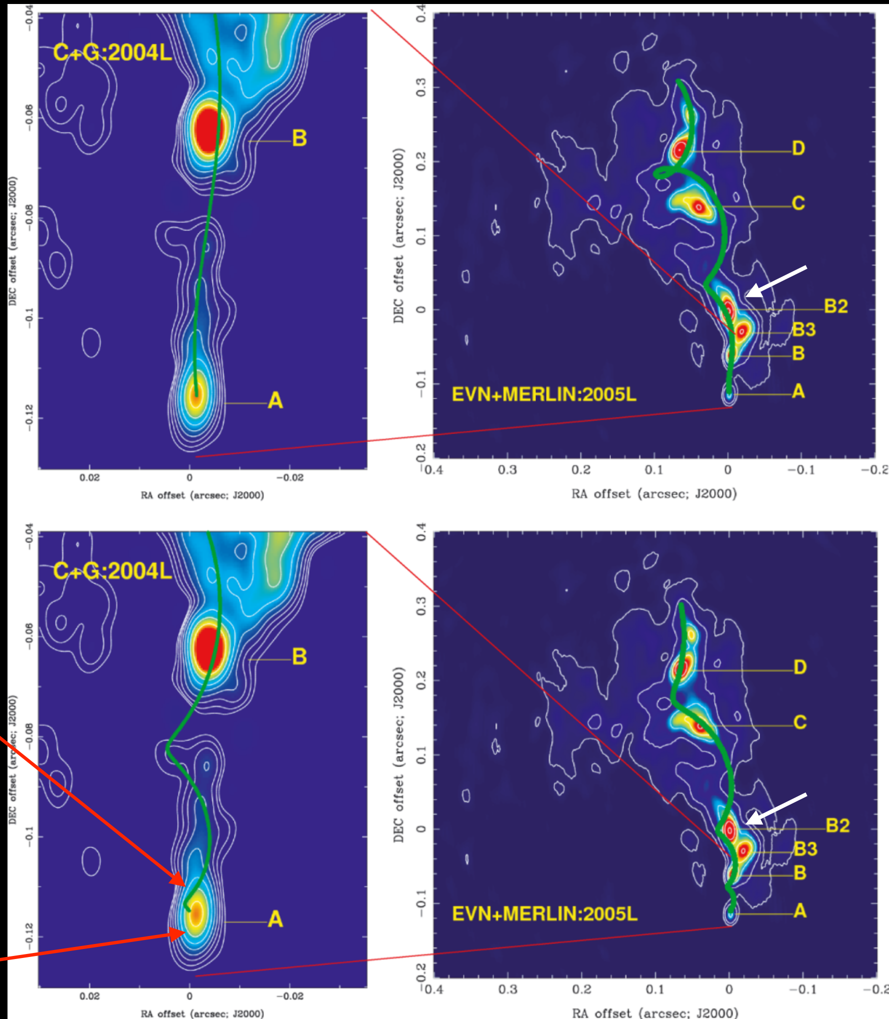
3C48

Comparison of VLBI images from epochs separated by 8.4yr shows northward motion for A2 with an apparent transverse velocity βapp = 3.7 ± 0.4*c* and 1.4 ±0.3c to NE for B2

The apparent superluminal motion

→ relativistic jet plasma moves at a velocity of 0.96*c* if the jet is viewed at an inclination angle<20



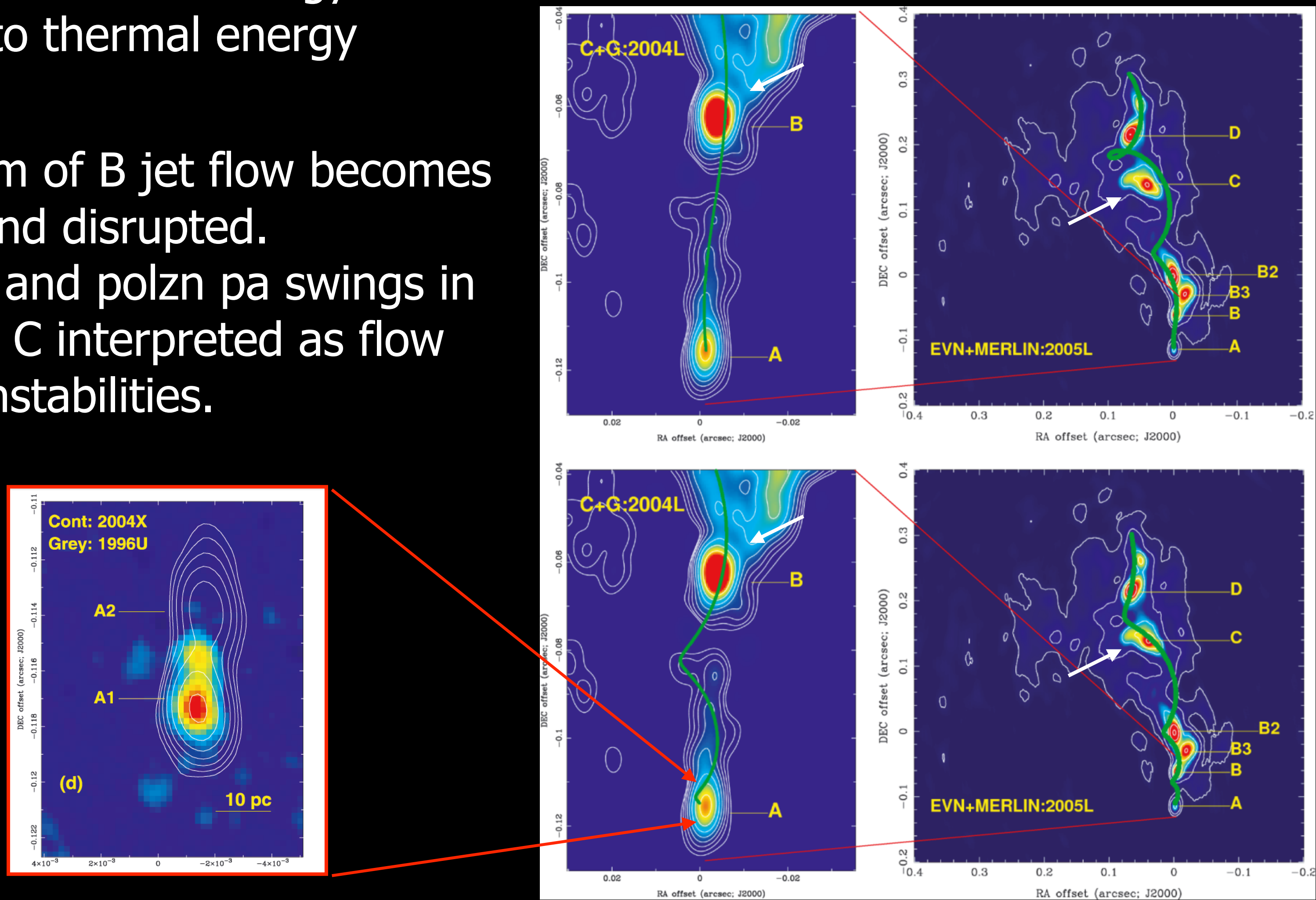


Component B is a stationary re-confinement shock where jet pressure = surrounding lobe.

3C48

Jet slows and kinetic energy converted to thermal energy

Downstream of B jet flow becomes turbulent and disrupted. Kinematics and polzn pa swings in component C interpreted as flow with fluid instabilities.

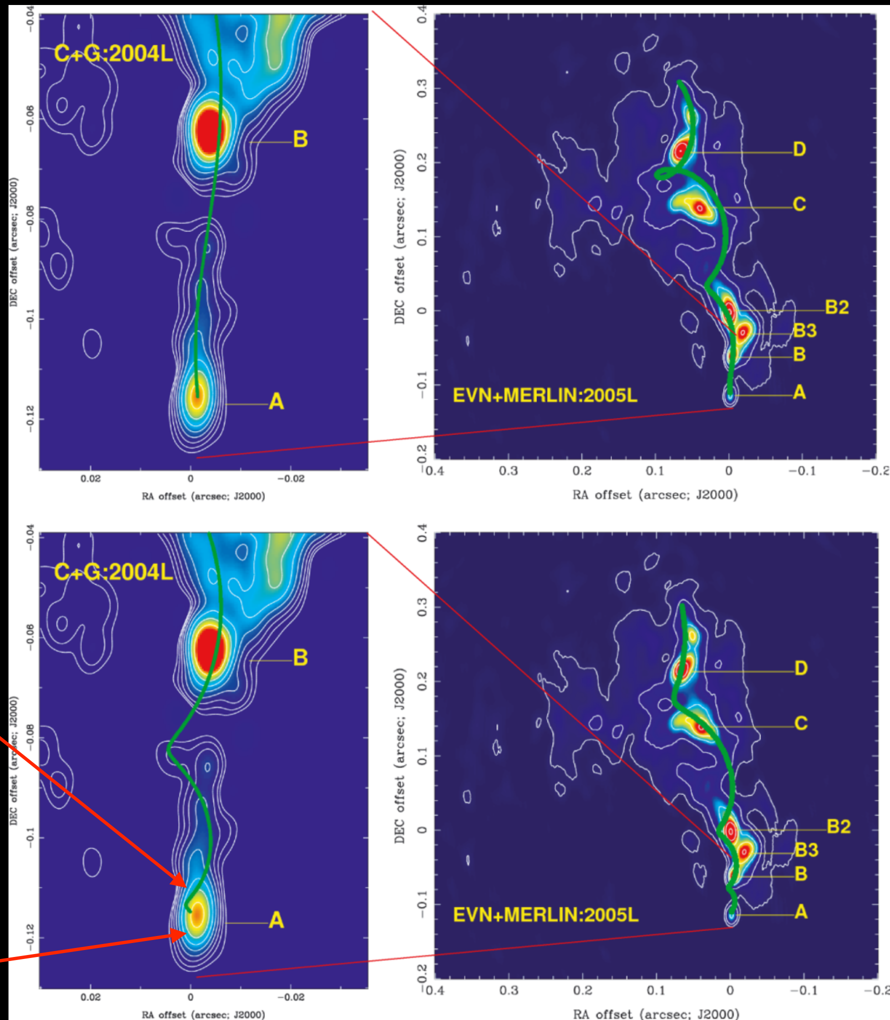


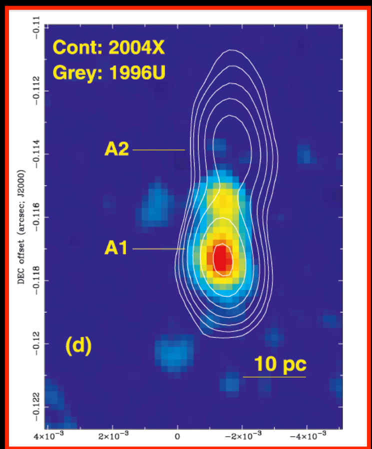
Helical-model fits overlaid on the total intensity images.

3C48

Lower panel: Ridge line of the fitted jet trajectory from a K-H instability model (green lines) overlaid on the 1.5-GHz VLBA (left) and 1.65-GHz EVN+MERLIN images (right)

Upper panel: Ridge line of a fitted precessing jet model

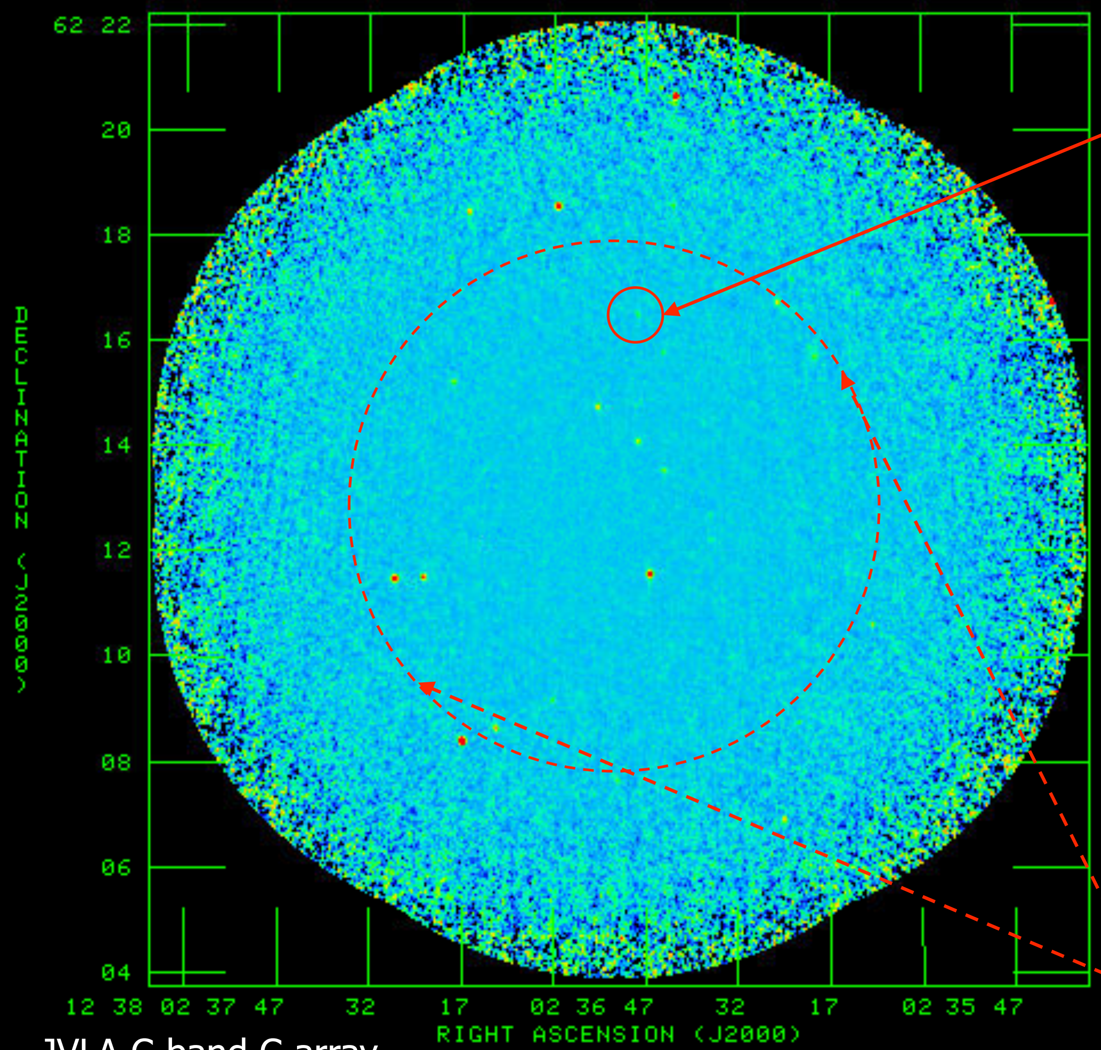




e-MERGE: Ultra-Deep Study of GOODS-N

The power of combination imaging.....

Utilizing EVN's sensitivity & capability to select AGN from starbursts + wide-field imaging from JIVE software correlator



JVLA C-band C-array

Deep high resolution EVN+ e-MERLIN L-Band images of starburst galaxies and AGN:

J123646+621629

~60 hrs e-MERLIN data
+ archival MERLIN+VLA
(~15% of allocated data)

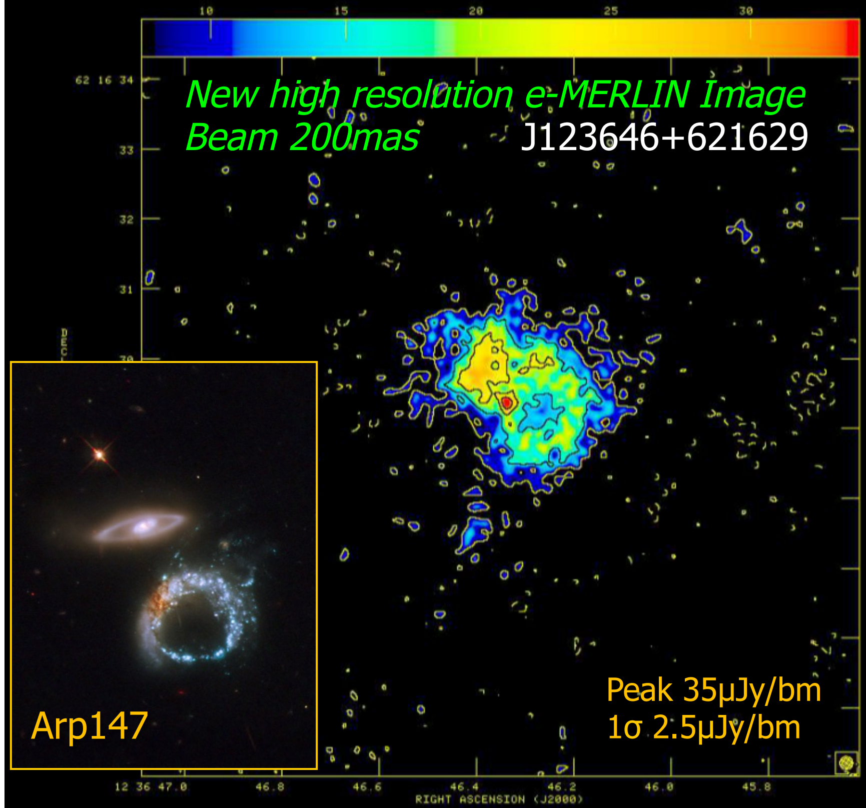
New ultra deep EVN study to 3μJy (EG078) over central region to image faint AGN population

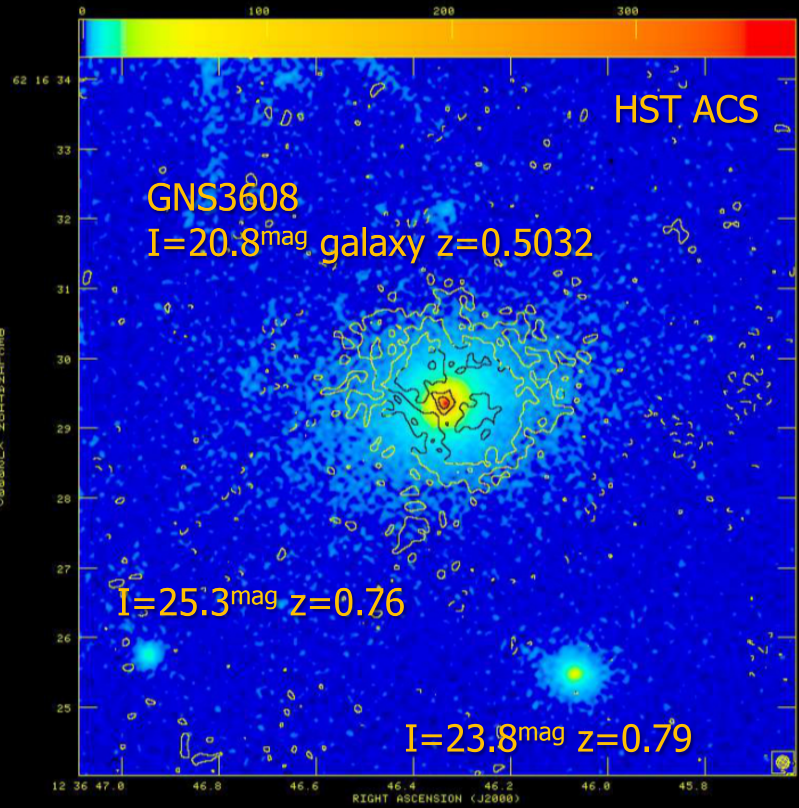
...and feedback from embedded faint AGN in starbursts

{See talk by Mike Garrett}

~600 starburst + ~300 AGN radio sources complete to ~3μJy

e-MERGE: Ultra-Deep Study of GOODS-N





Extended steep-spectrum (α>1.62) starburst with embedded AGN? ($S_{1.4}$ = 393μJy).

→ Ring of star-formation – interacting galaxies?

Radio emission extends across face of massive spheroidal galaxy

$L_{1.4}$ =8.5x10^{23} W/Hz → Star-formation rate ~200 M⊙/yr (0.1-100M⊙ assuming Salpeter IMF)

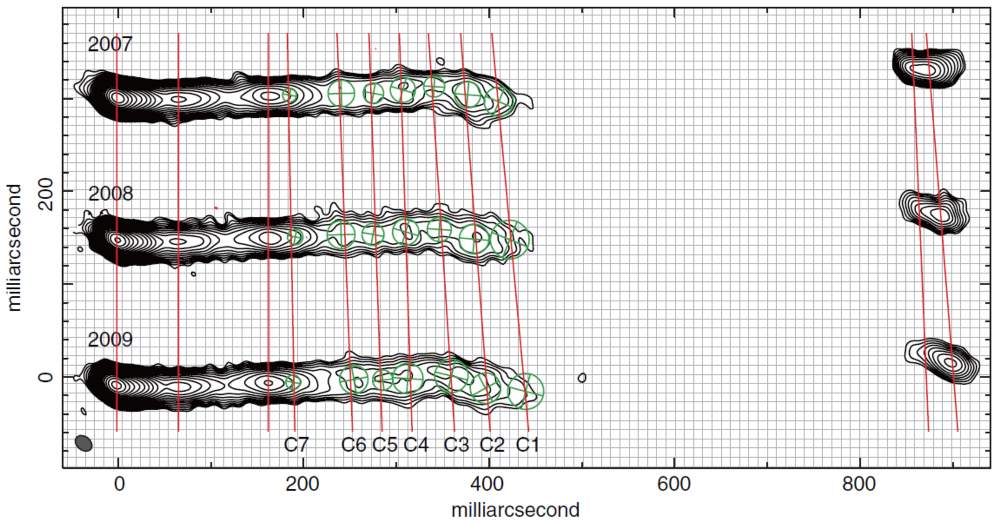
Bright galaxy core shows BL emission → Optical AGN activity

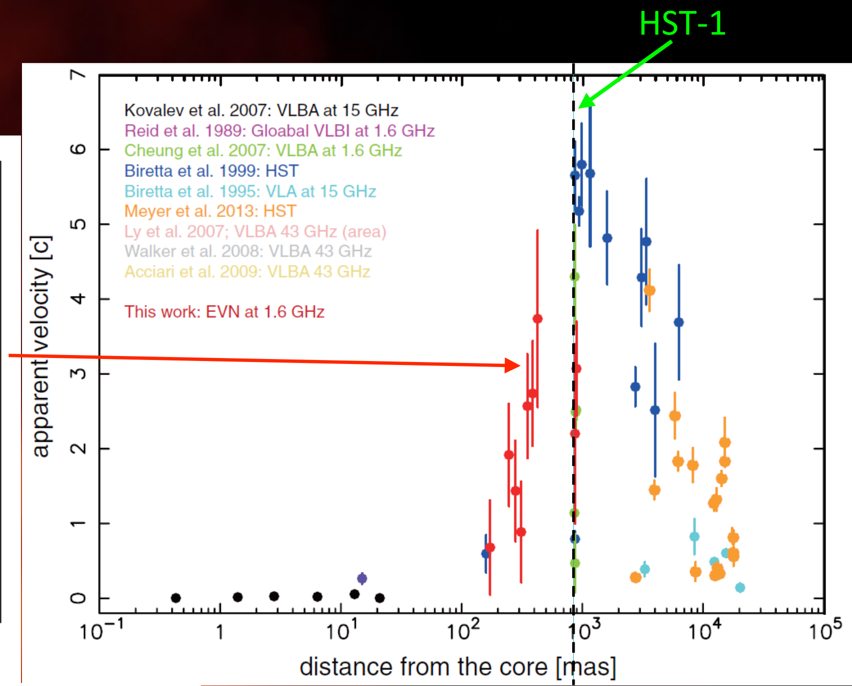
AGN or nuclear starburst? – EVN to look for faint radio core…

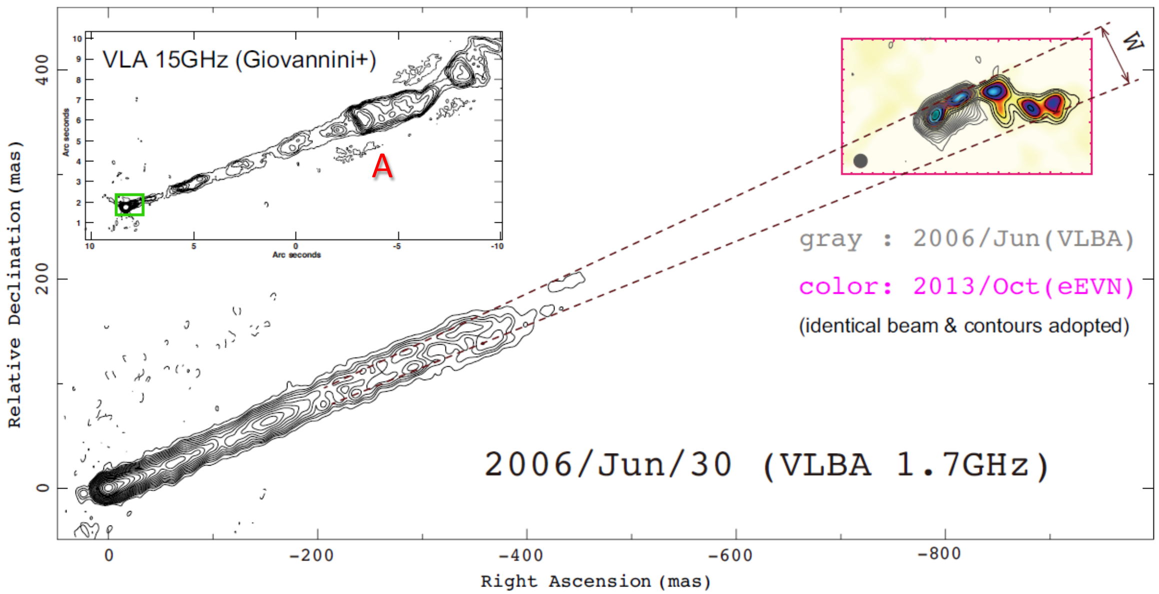
M87 Revisited

Asada et al *2014 Ap J 781, L2*

The power of high fidelity imaging.....







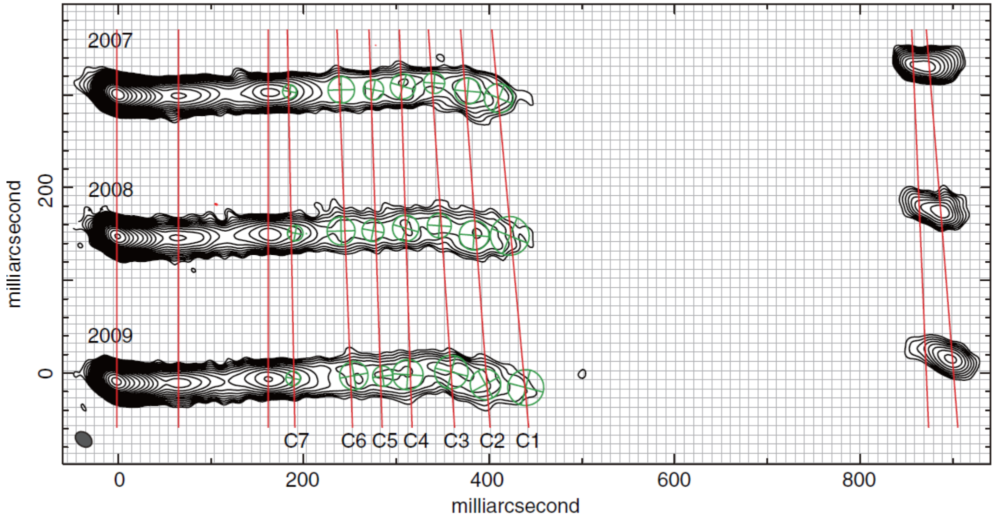
Component velocities increase continuously out to a distance of ~10^6 Rs (HST-1) – and then decline downstream of the knot

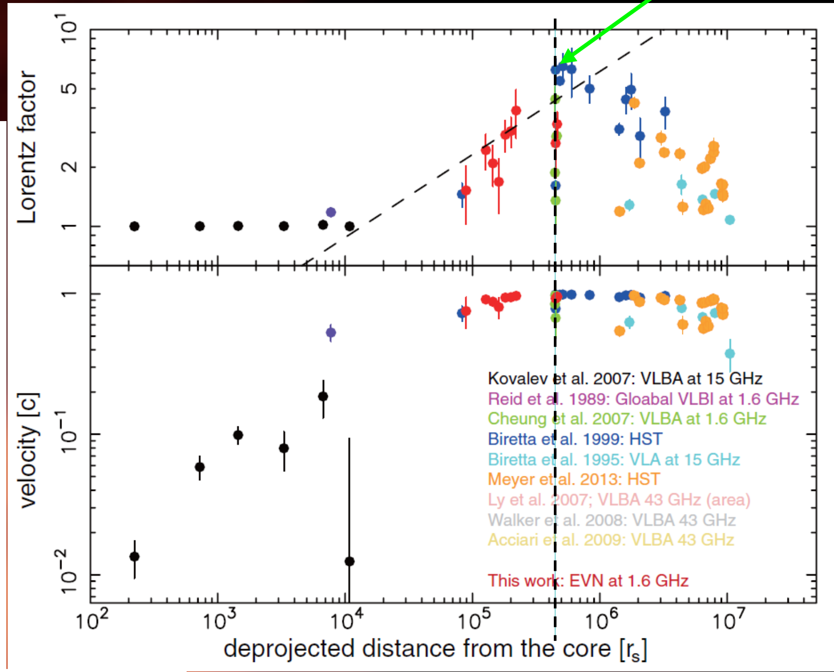
At knot A (~10^4 mas)
– velocites ~0.5c

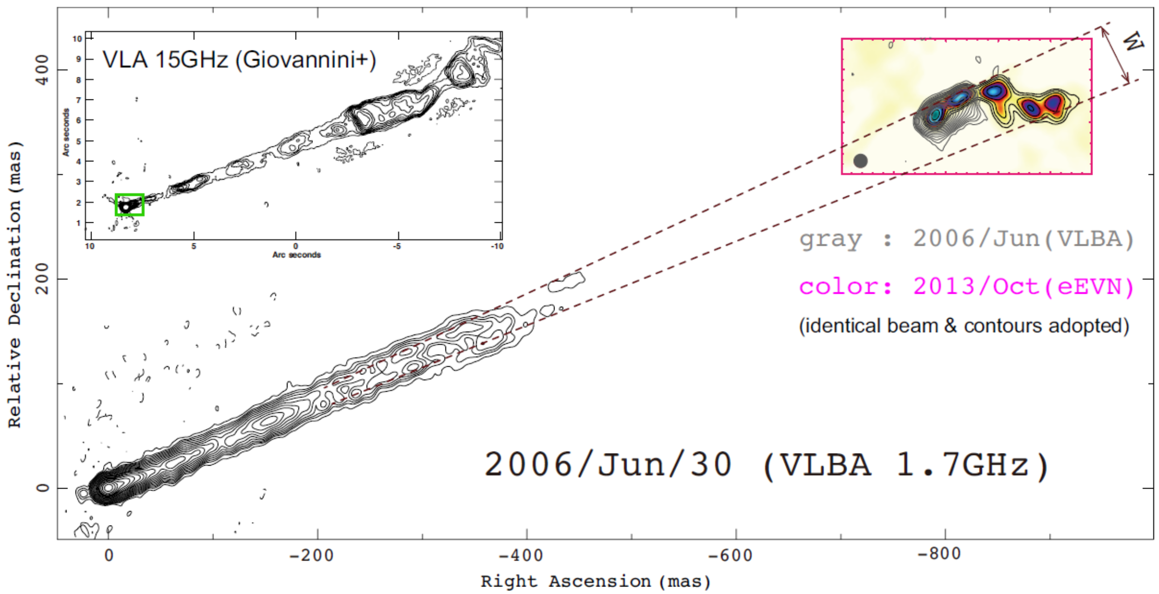
M87 Revisited

Asada et al *2014 Ap J 781, L2*

The power of high fidelity imaging.....







Acceleration and collimation zone of jets extends over the whole scale within the sphere of influence of the supermassive black hole

HST-1 at Bondi radius jet expansion becomes unconfined, streamlines parabolic → conical

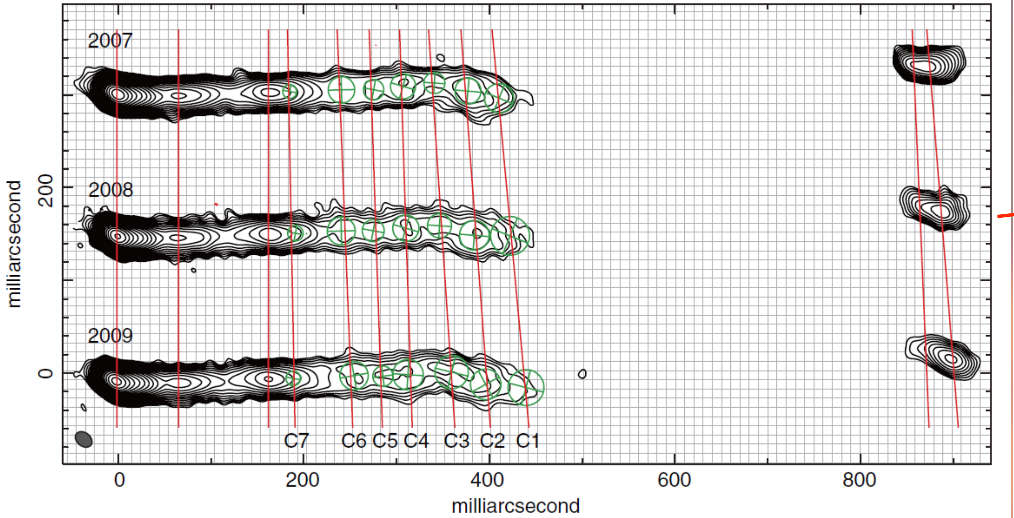
EVN images jet acceleration zone

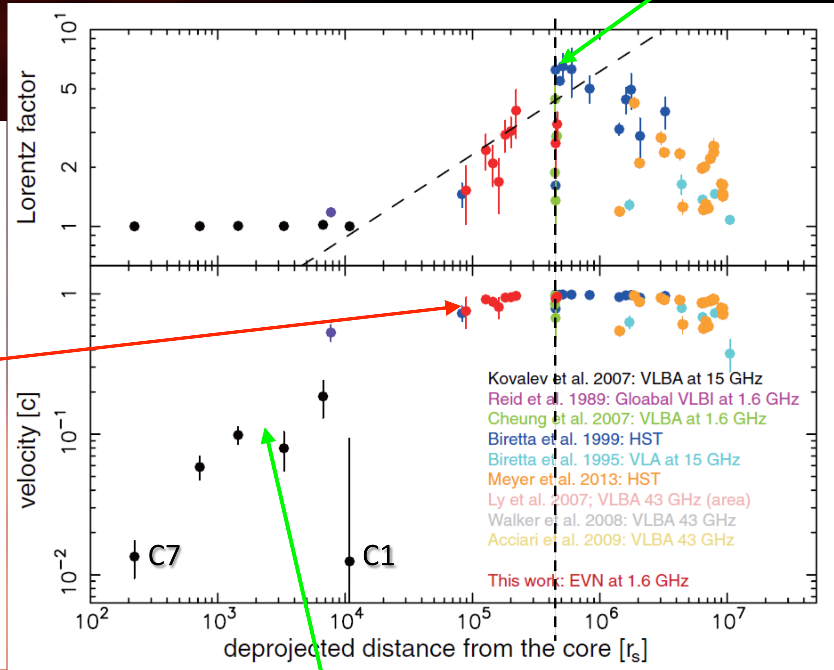
M87 Revisited

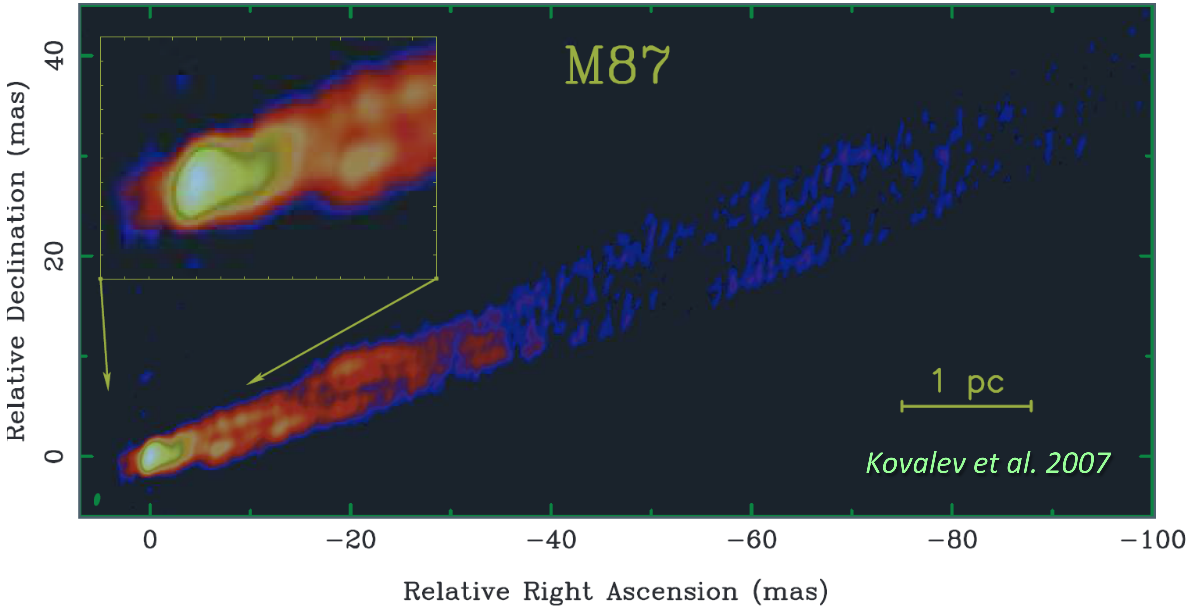
Asada et al *2014 Ap J 781, L2*

The power of high fidelity imaging.....

Inner jet (<10^4 Rs) intrinsically one-sided?







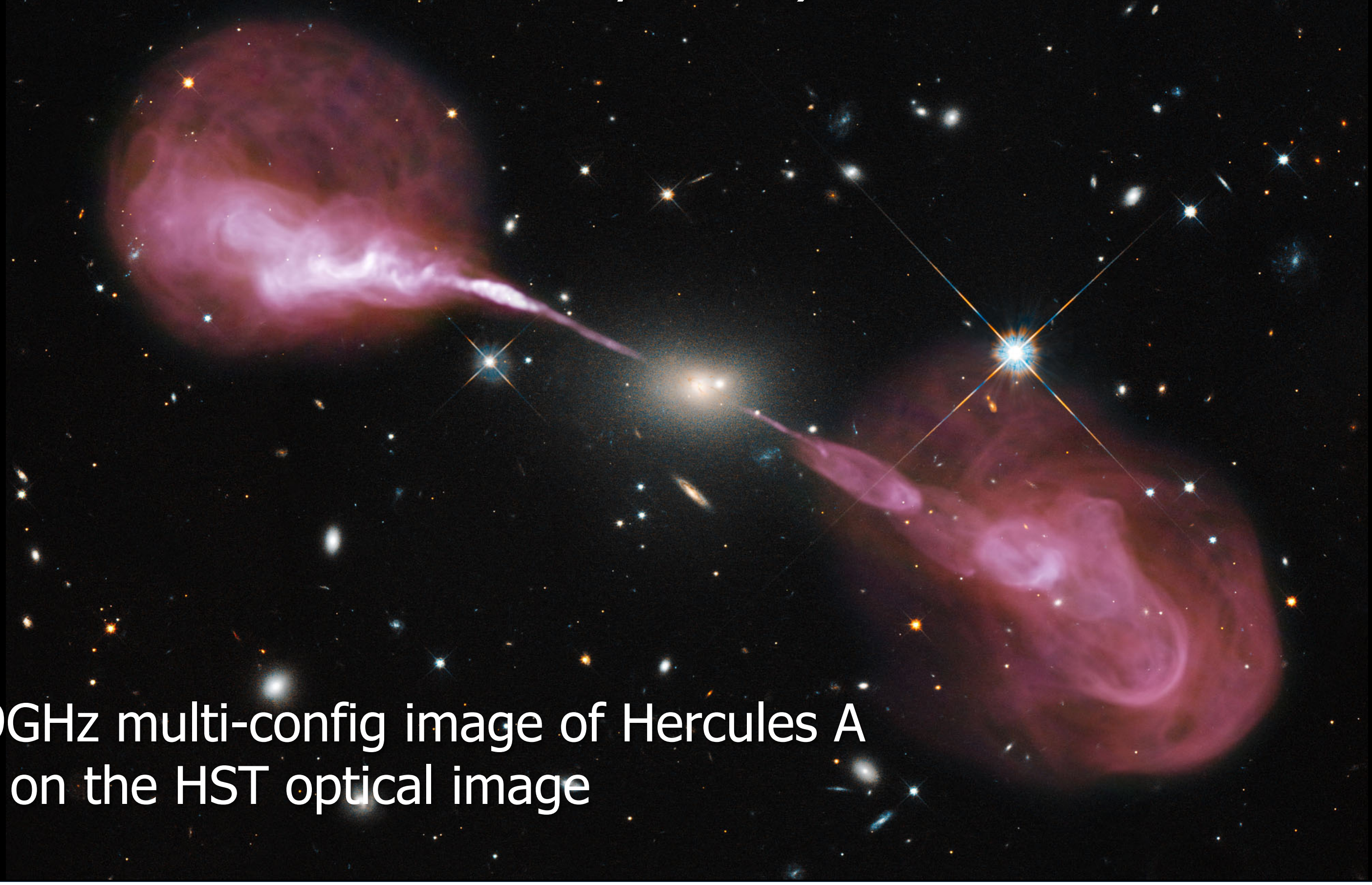
Global VLBI / VLBA images jet collimation and inner acceleration zone

Intrinsically one-sided, or are we missing the fast central jet spine?

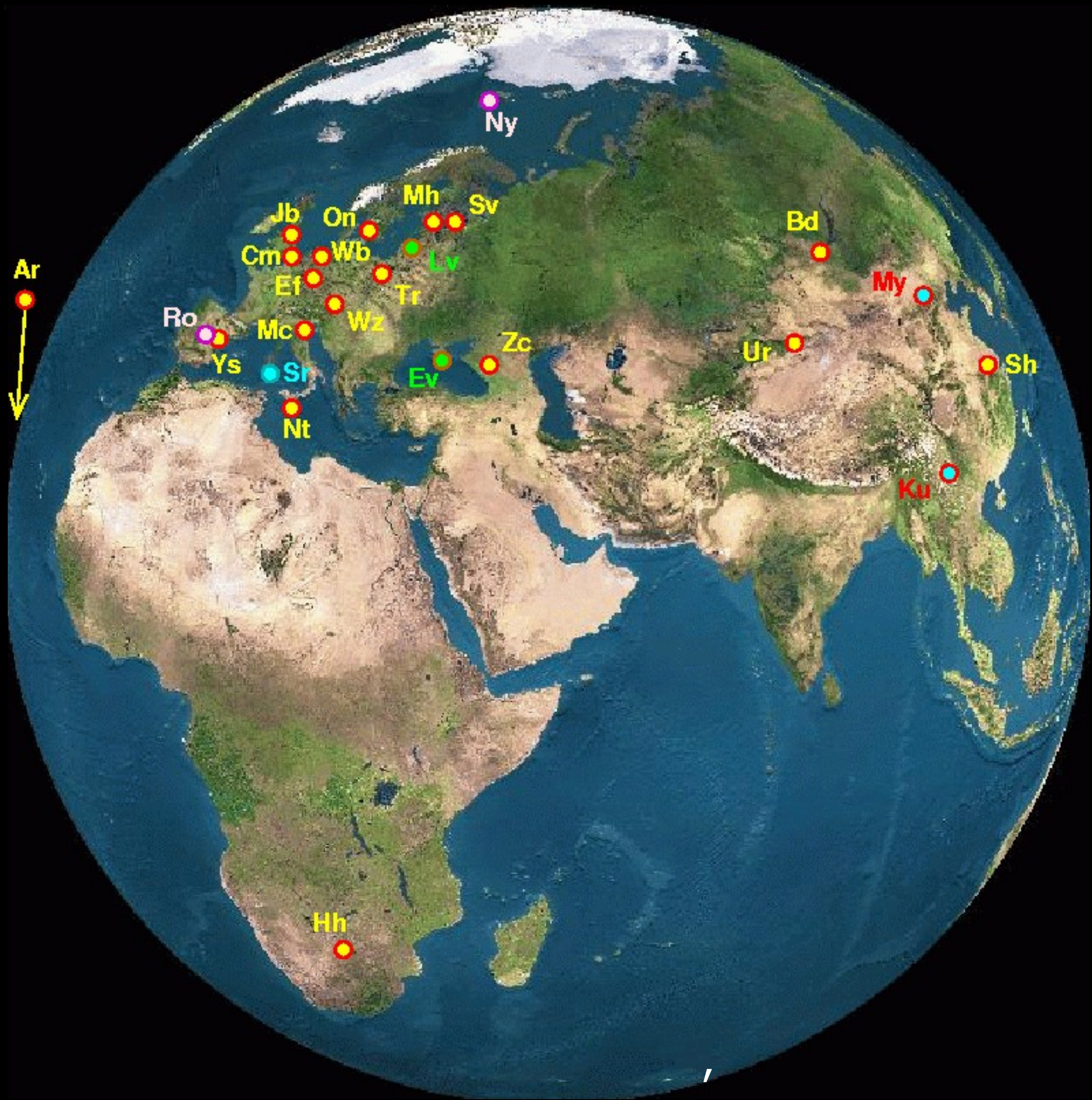
Ultimate resolution, ultimate fidelity? – a postscript…

Radio astronomy imaging techniques have progressed massively over the past years. Given virtually complete uv-coverage, ultra high fidelity imaging is now relatively routine, if still perhaps computationally challenging…

Our imaging telescopes have become mature and reliable
(We can at least calibrate them very well !!)

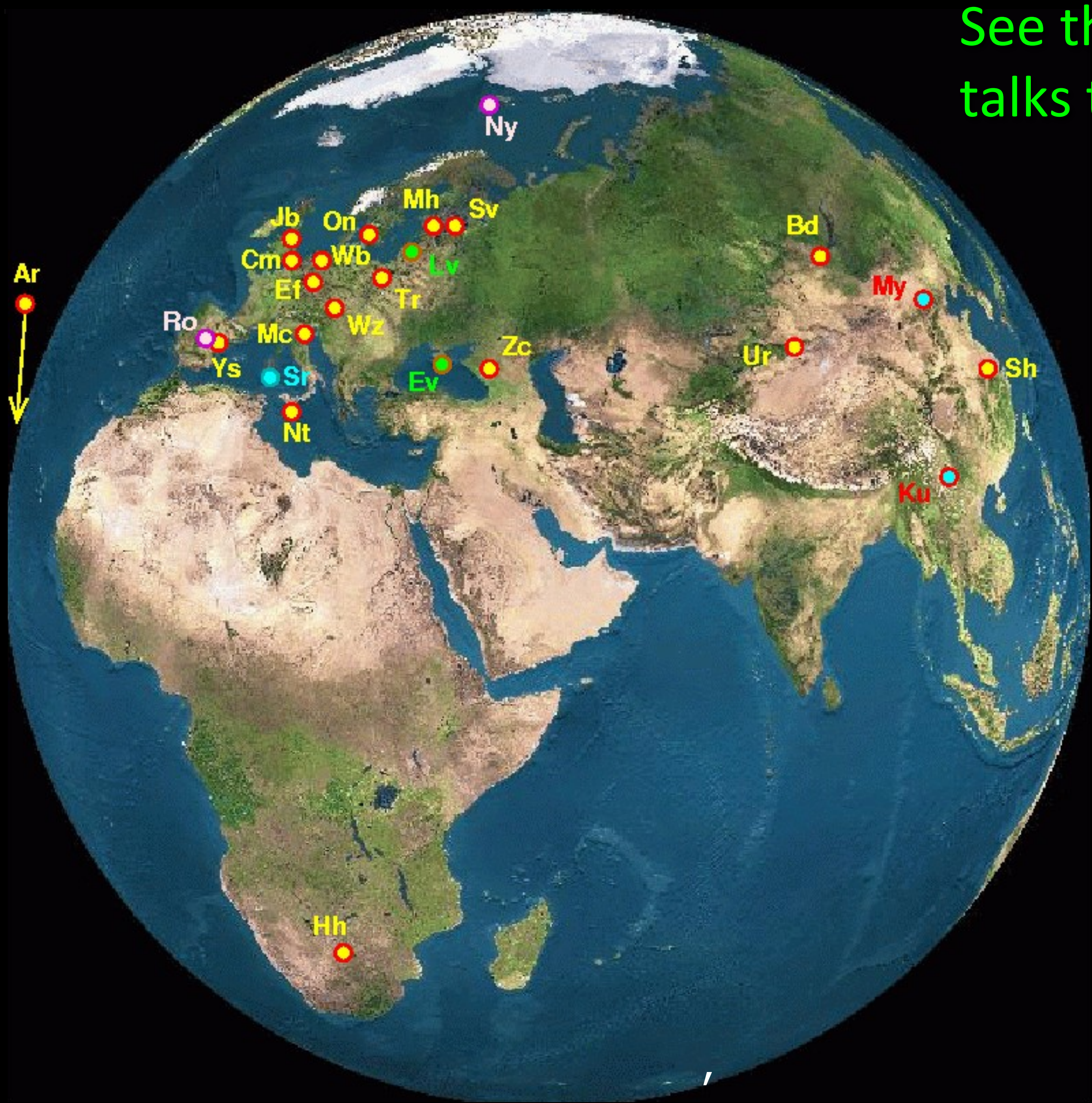


JVLA 4-9GHz multi-config image of Hercules A
Overlaid on the HST optical image



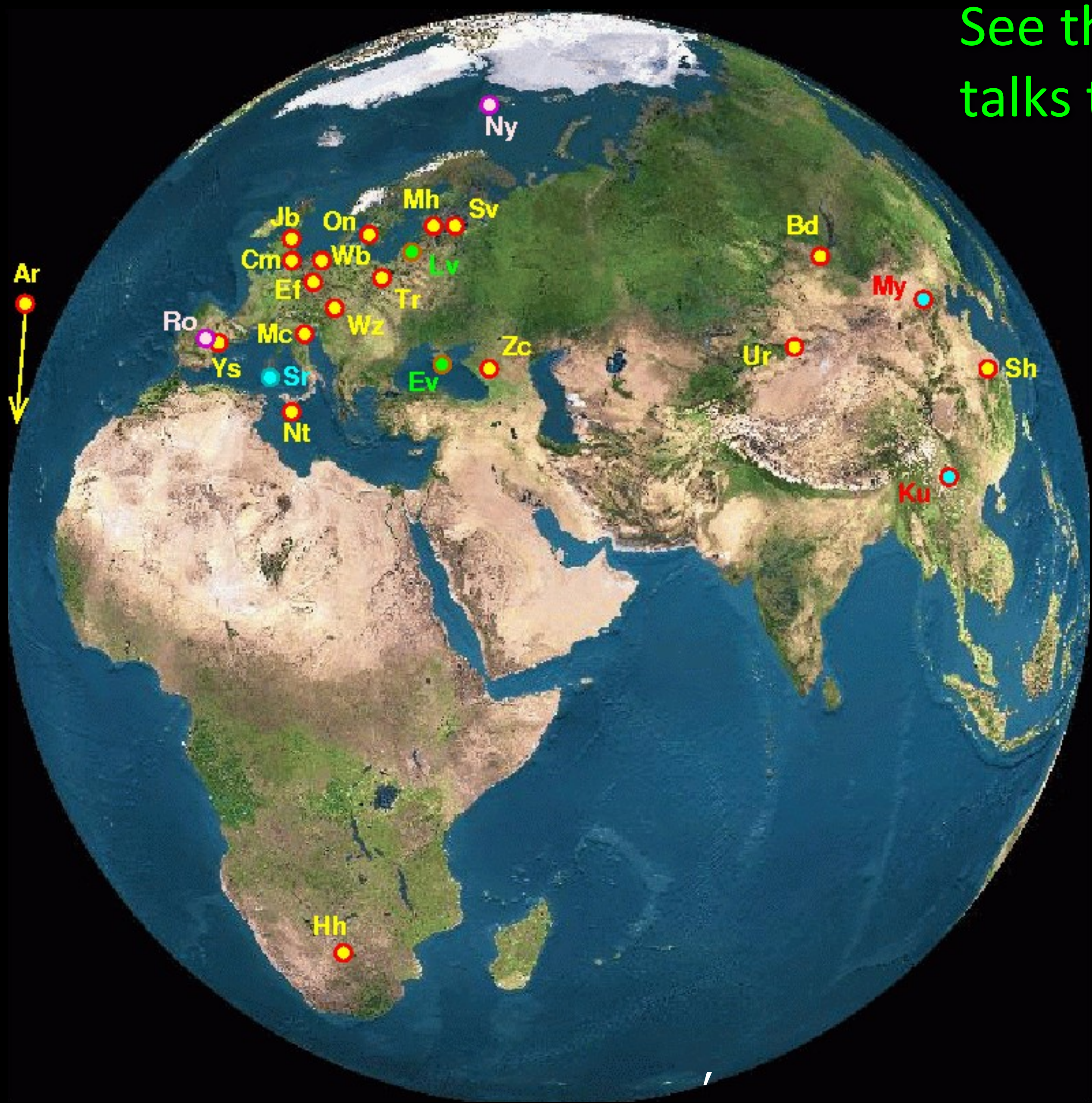
On the ground, the full EVN has unrivalled uv-coverage

See the detailed talks to follow....



The ultimate image fidelity is breathtaking....

See the detailed talks to follow….



And there are more telescopes and bandwidth still to come…..

[redacted]