Title: Jets and the radio emission from supermassive black holes

Date: Nov 11, 2014 09:00 AM

URL: http://pirsa.org/14110074

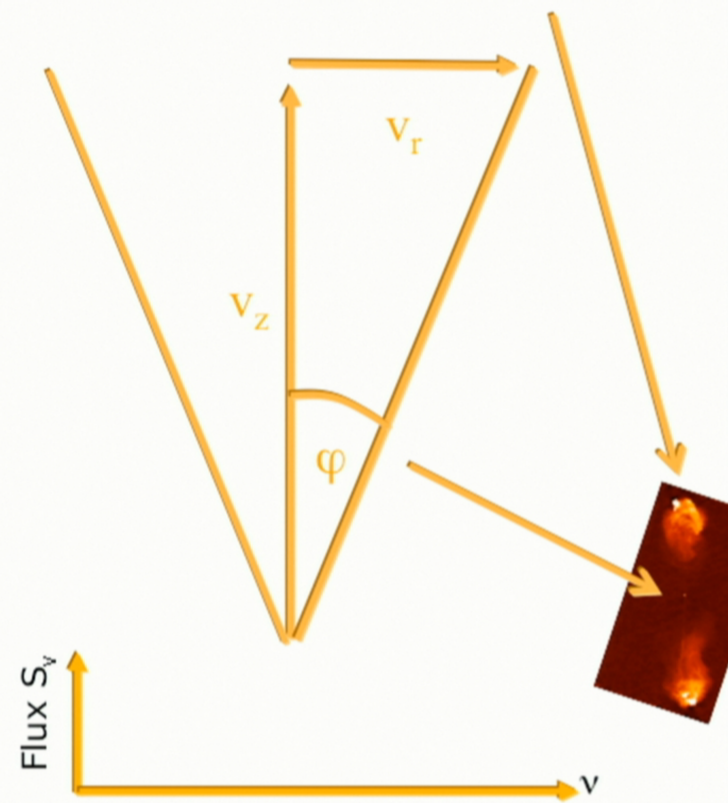
Abstract:


Radio Emission from Jets
Heino Falcke
Radboud University
Nijmegen, NL
&
ASTRON, Dwingeloo
Max-Planck-Institut für Radioastronomie, Bonn
Sjoert van Velzen, Christiaan Brinkerink
Monika Moscibrodzka, Geoff Bower,
Charles Gammie, et al.
VLA/HST

The Spectrum of Jets: Synchrotron Emission

Radboud University Nijmegen

- Conical isothermal flow with constant speed (Mach cone):
  - $n \propto R^{-2}$, $B \propto R^{-1}$, $T \sim const$
  - Blandford & Königl (1979)
- Emission from $\tau=1$ surface.
- Synchrotron emission naturally predicts:
  - flat spectrum: $S_\nu \propto const$
  - core shift: $R_{core} \propto \nu^{-1}$
- Jet-disk symbiosis
  - Jet power $\propto$ Mdot
  - Falcke & Biermann (1995), Falcke, Körding, Markoff (2005)
  - Scaling: $S_\nu \propto Q_j^{1.4} \propto M_{dot}^{1.4}$
  - Max jet freq. mass-dependent
  - Predicts radio-optical and fundamental plane relations



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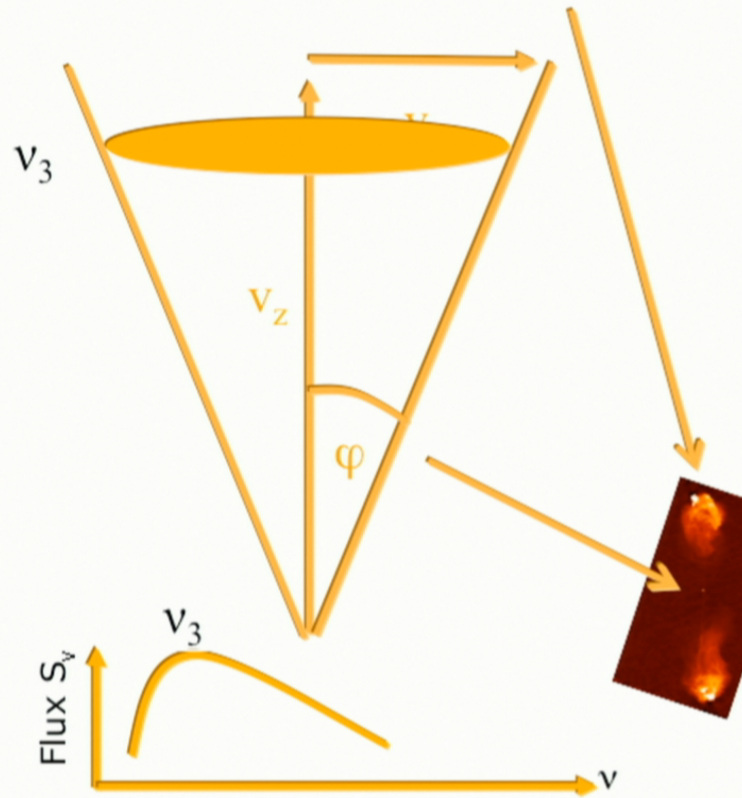

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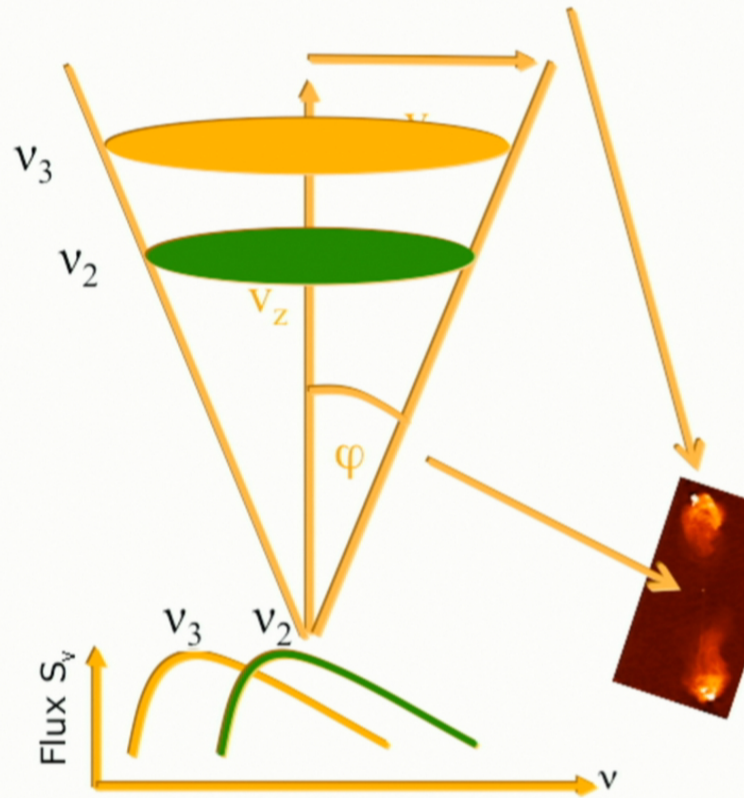

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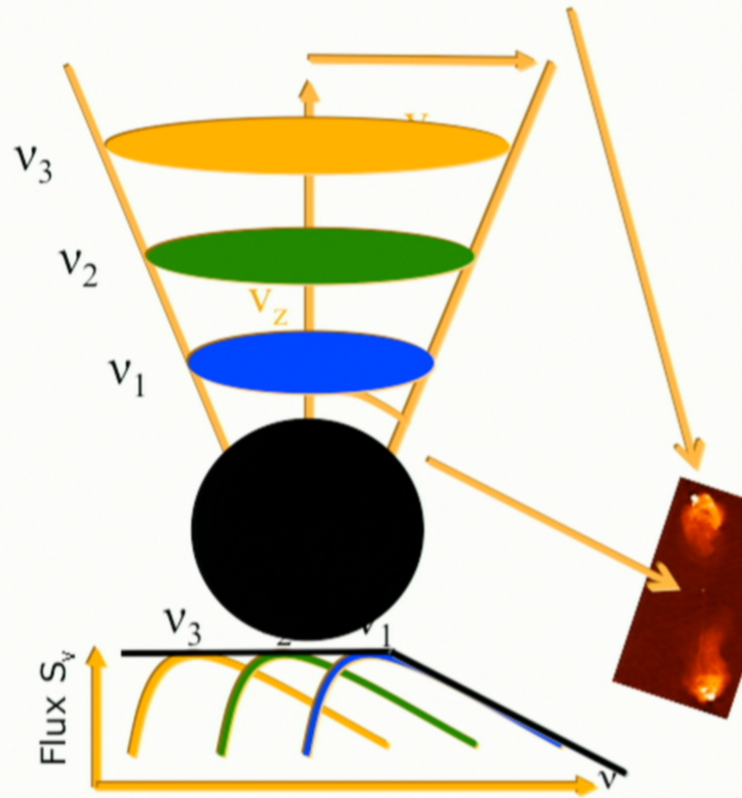

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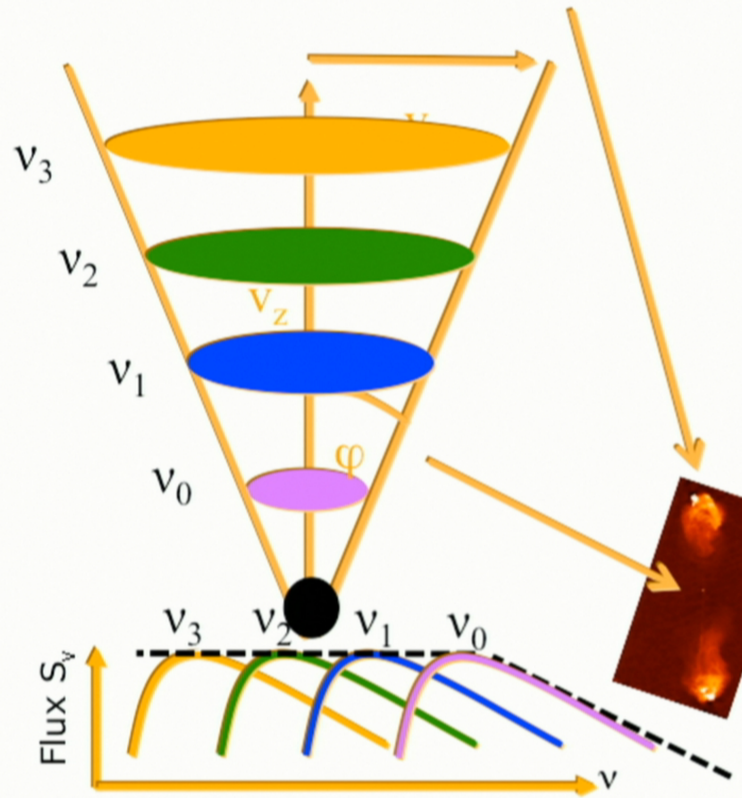

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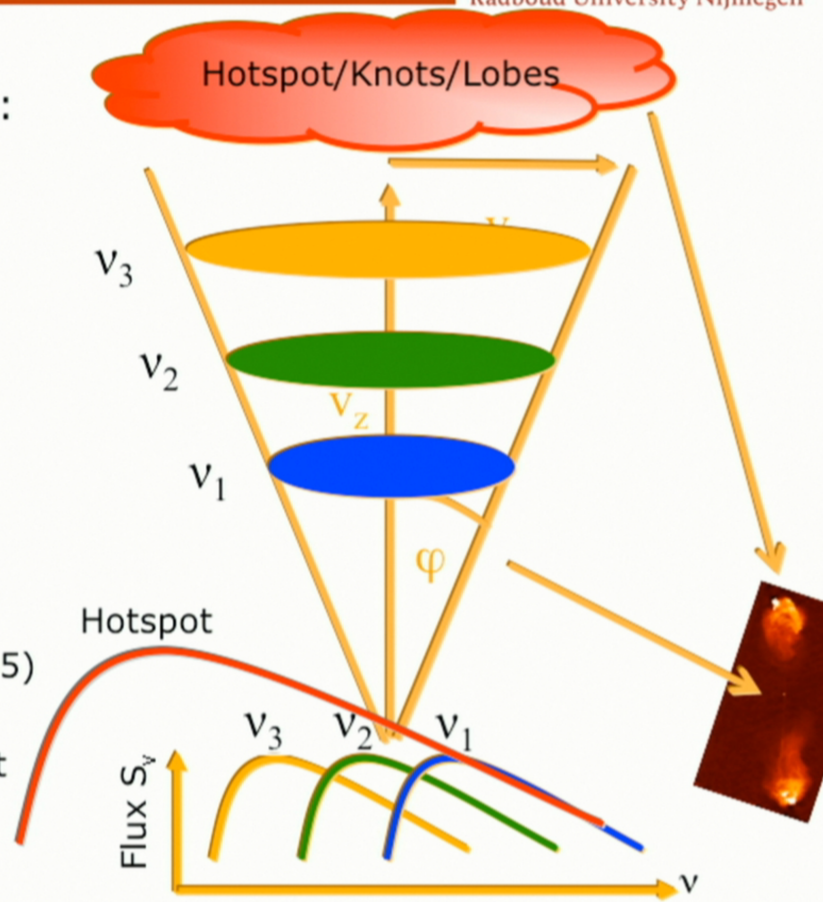
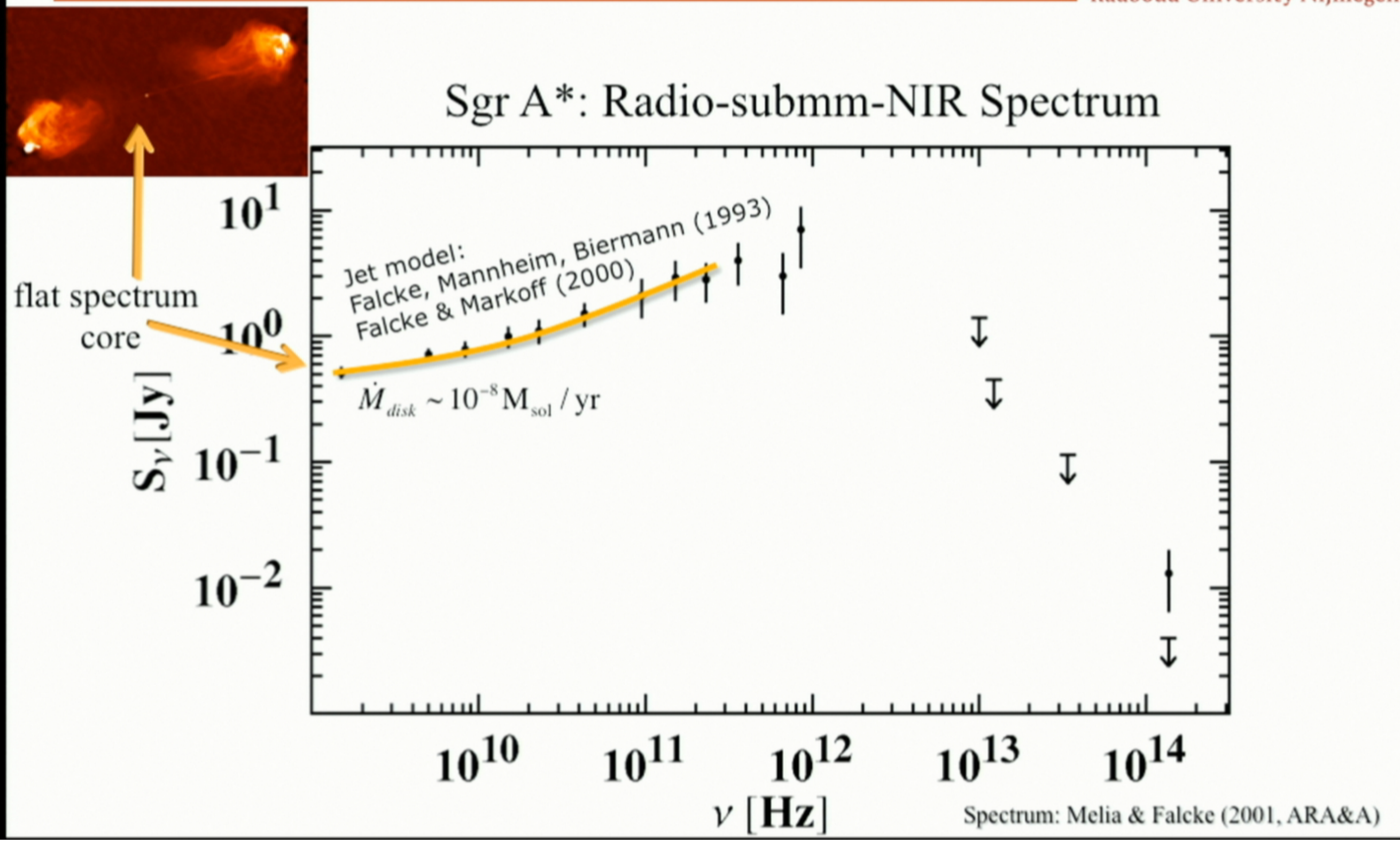


Sgr A*: flat-spectrum core and submm-bump

Radboud University Nijmegen



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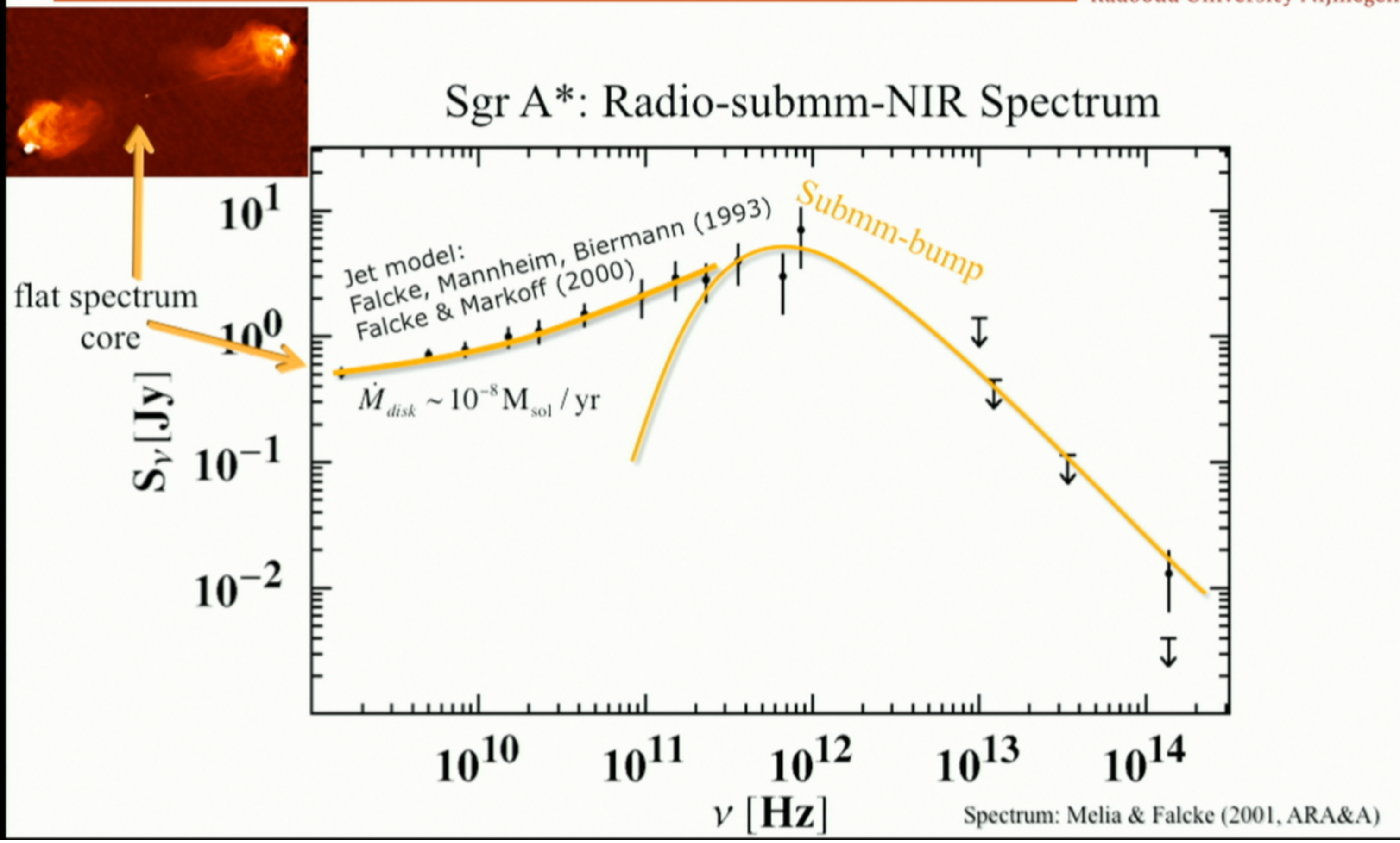

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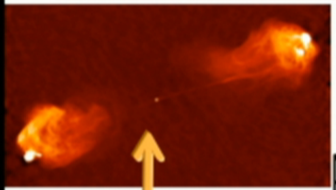

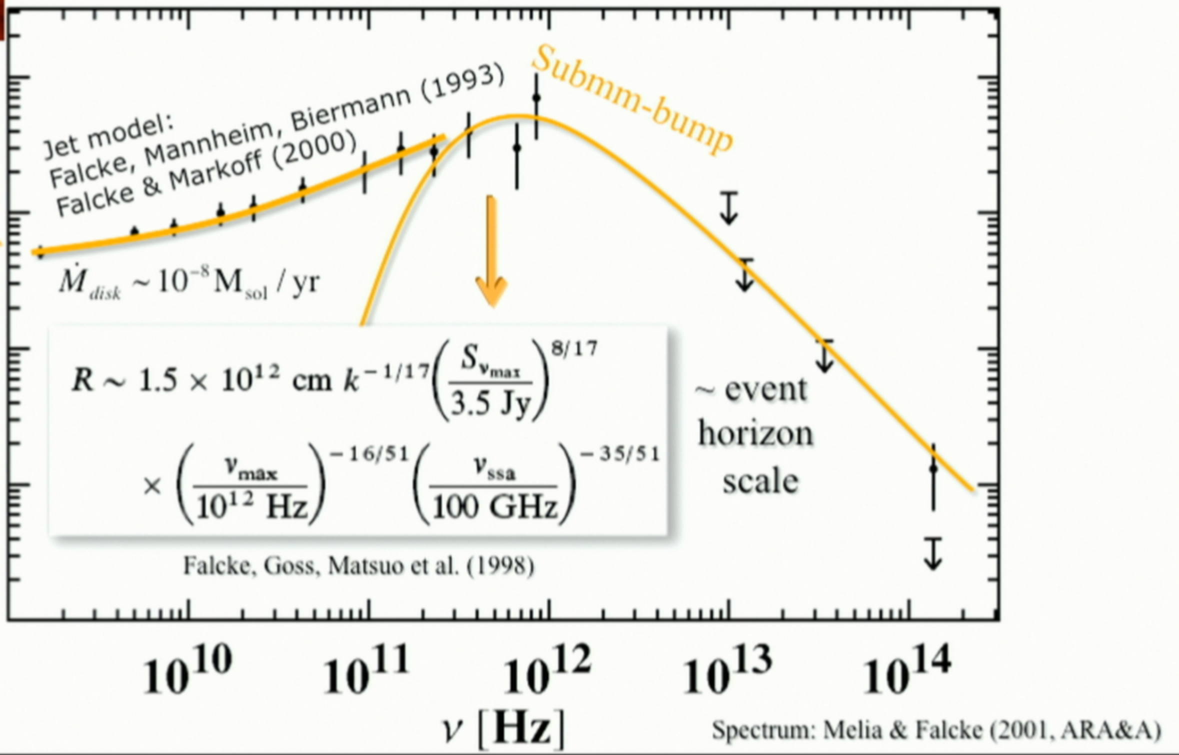

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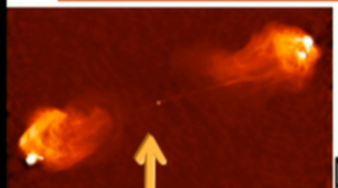

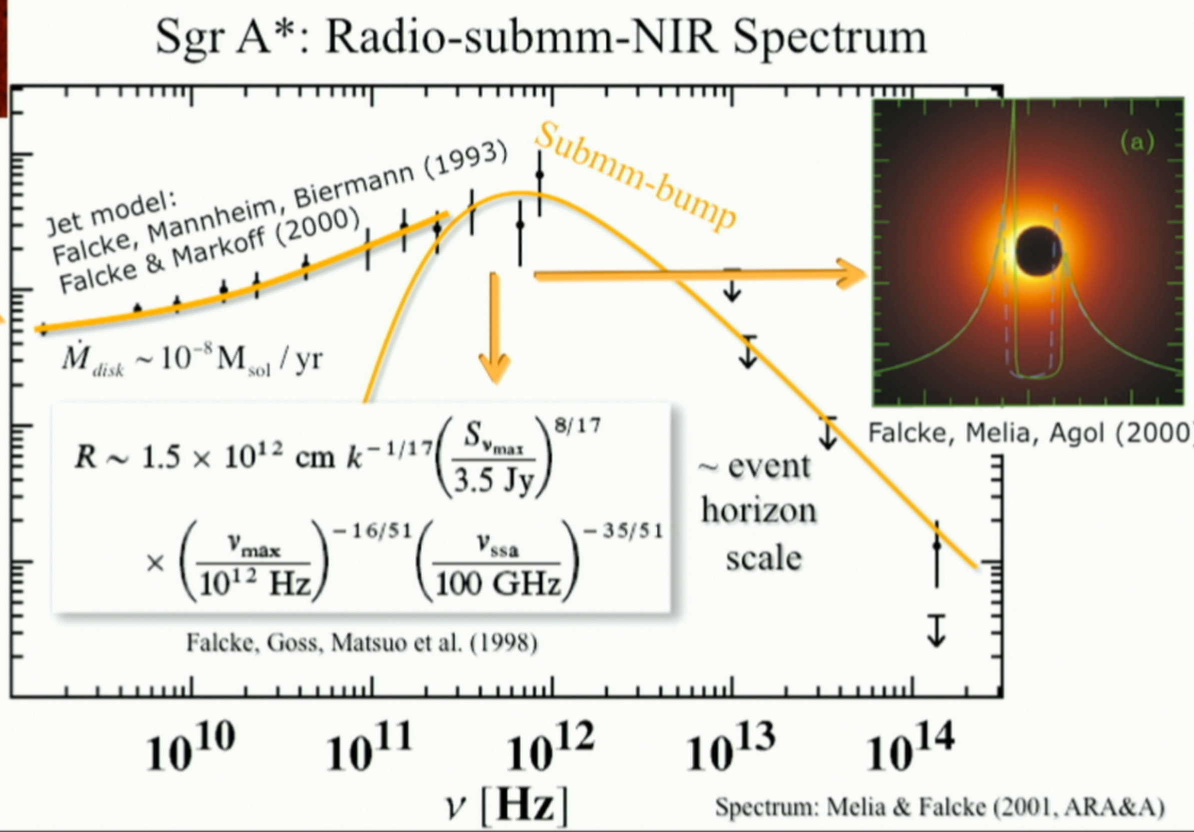

Basic Questions

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- How are jets made?
  - magnetic fields
- What powers them?
  - BH spin vs. disk power?
- What makes them shine?
  - Electrons: where and how hot?

⇒ Study jets at all power levels

Powerful Jets from Supermassive Black Holes: Fanaroff-Riley type I & II

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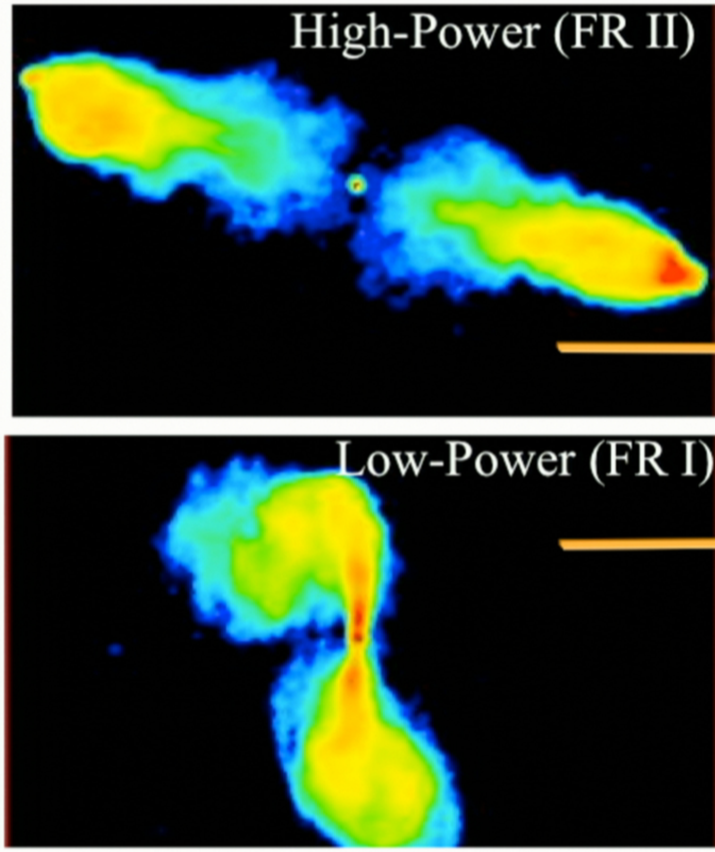
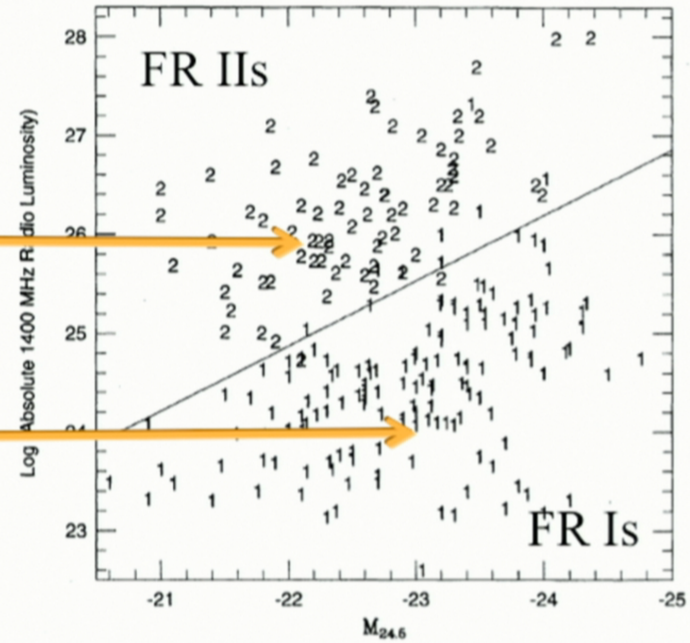
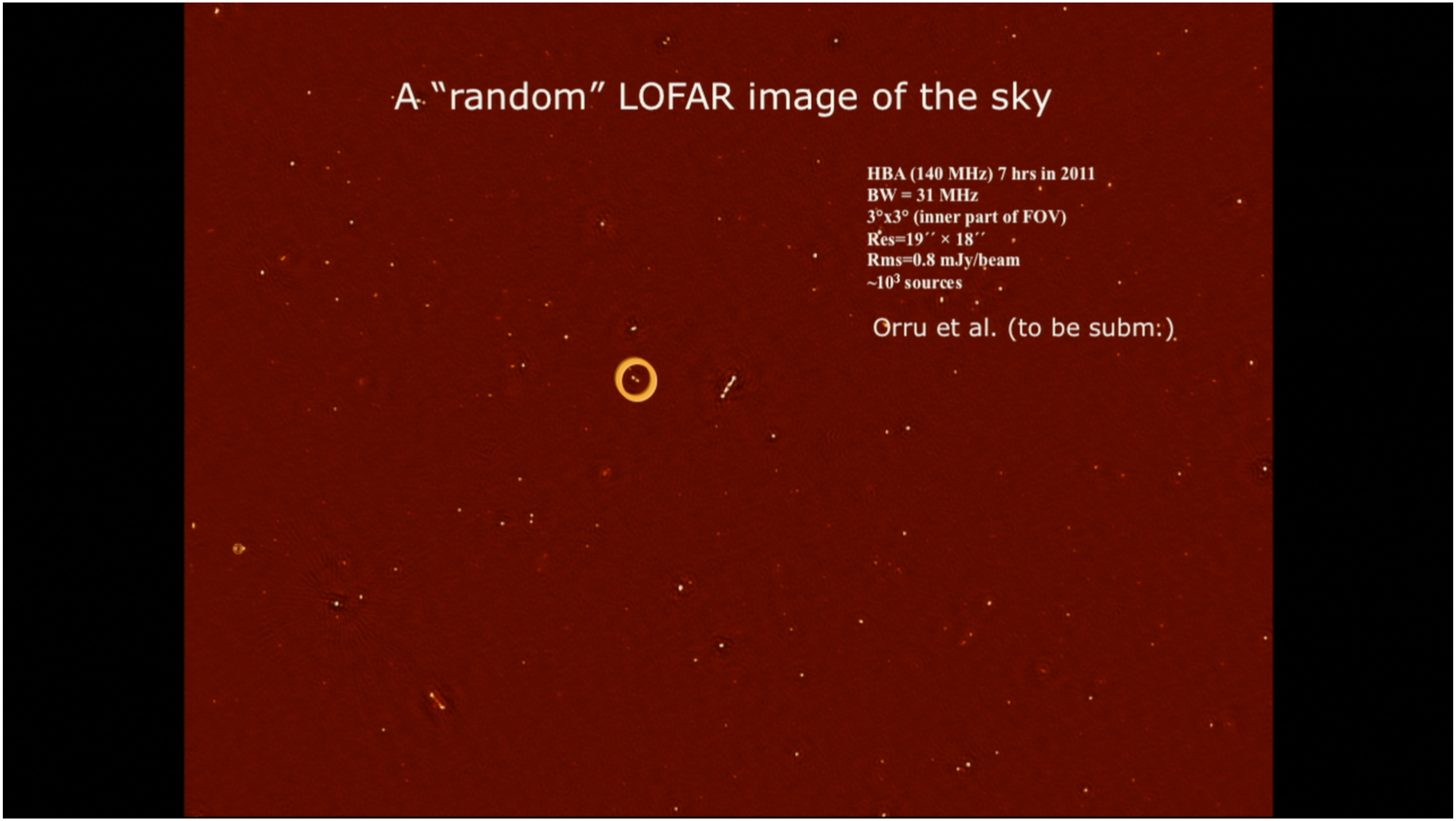


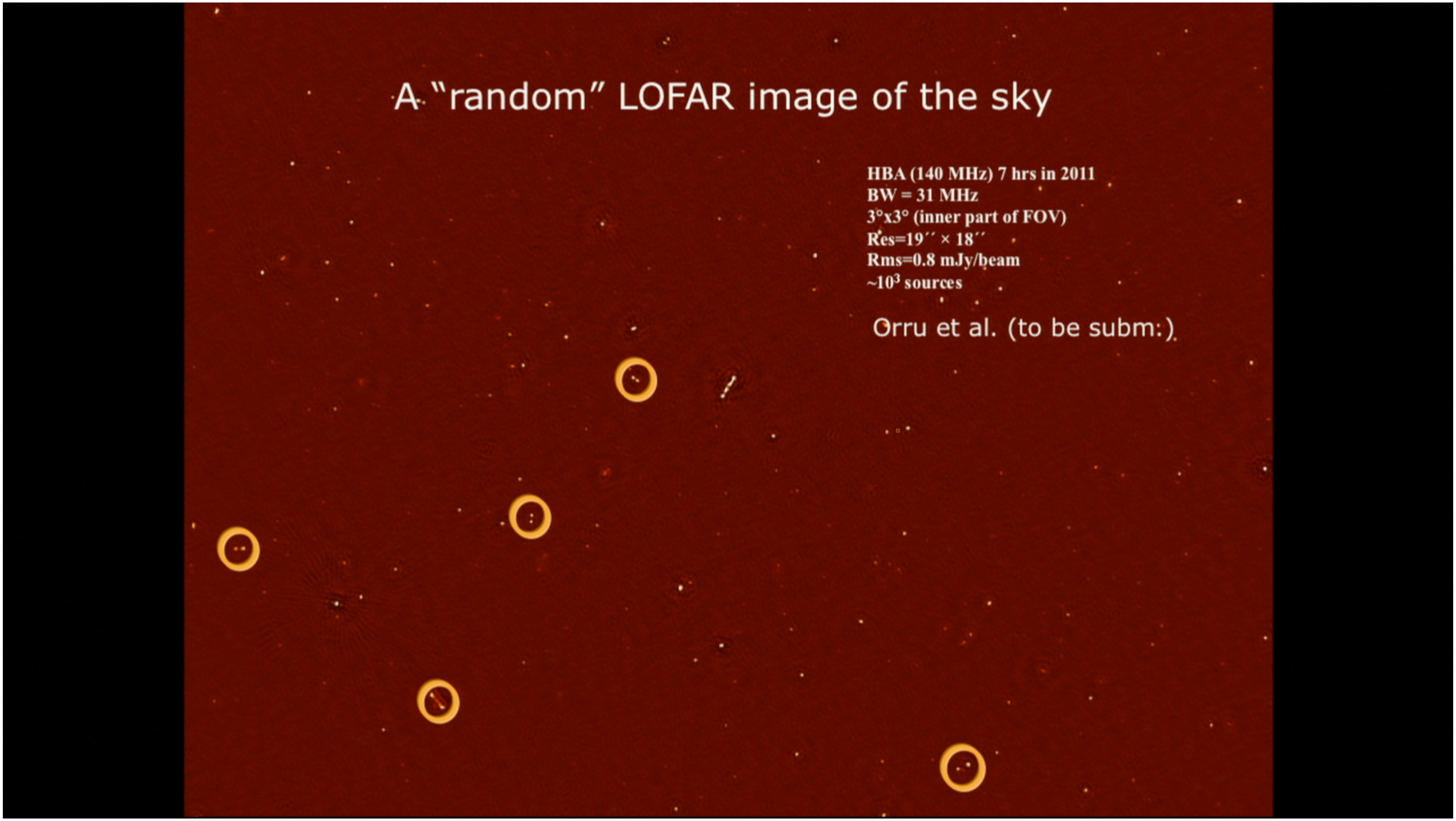
DRAGN Atlas (Leahy)

Radio luminosity vs. host galaxy magnitude



Ledlow & Owen (1996)


A "random" LOFAR image of the sky
HBA (140 MHz) 7 hrs in 2011
BW = 31 MHz
3°x3° (inner part of FOV)
Res=19´´ × 18´´
Rms=0.8 mJy/beam
~10³ sources
Orru et al. (to be subm.)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10^4 Dubbeltjes ("Doubeltjes") in FIRST (VLA)

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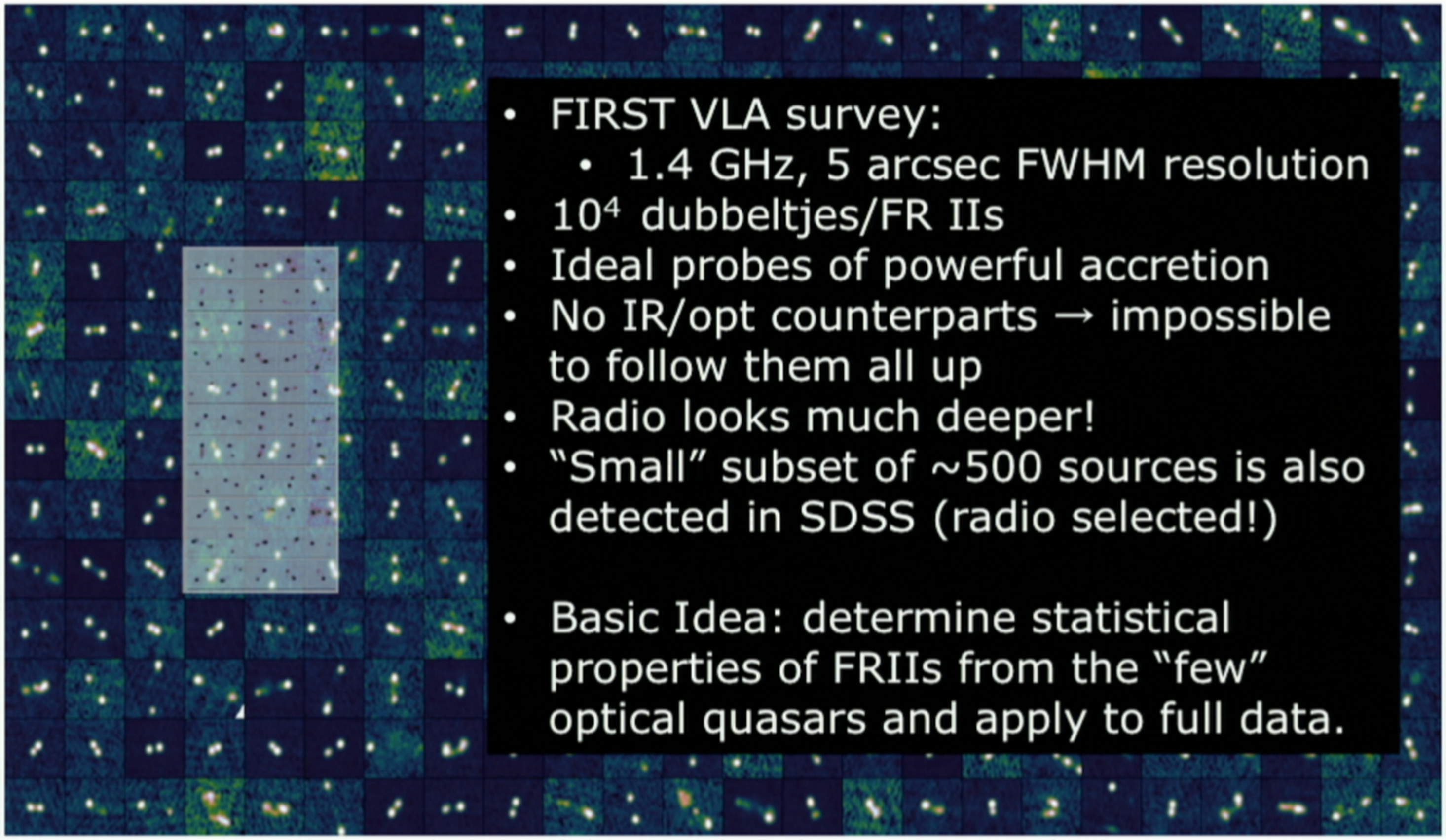

- FIRST VLA survey:
  - 1.4 GHz, 5 arcsec FWHM resolution
- 10^4 dubbeltjes/FR IIs
- Ideal probes of powerful accretion
- No IR/opt counterparts → impossible to follow them all up
- Radio looks much deeper!
- "Small" subset of ~500 sources is also detected in SDSS (radio selected!)

- Basic Idea: determine statistical properties of FRIIs from the "few" optical quasars and apply to full data.

Van Velzen, Falcke, Körding (2014, in press)

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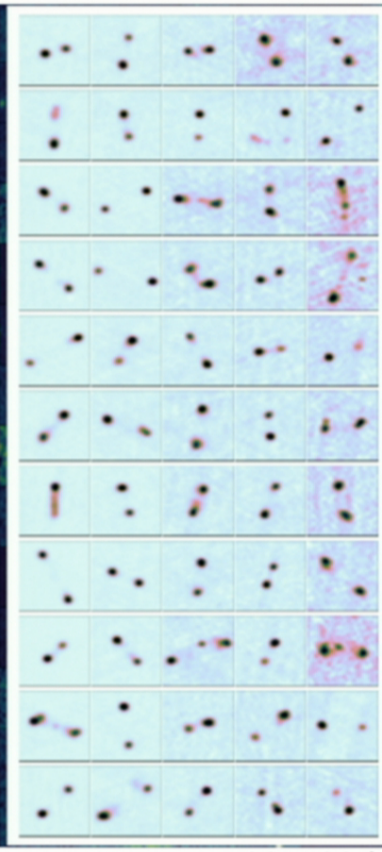

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Jet-Disk Symbiosis in FRII radio galaxies

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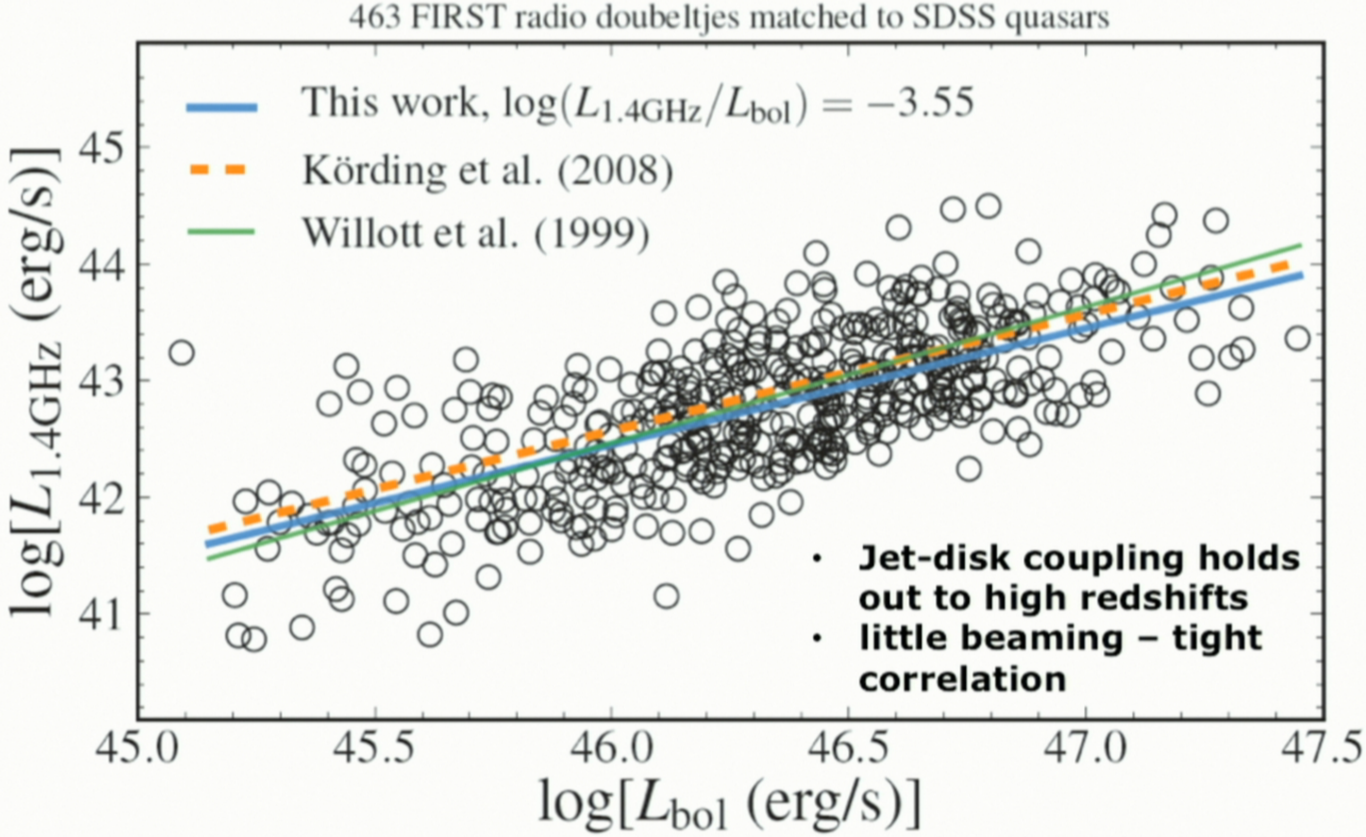

- **Jet-disk coupling holds out to high redshifts**
- **little beaming – tight correlation**

van Velzen & Falcke (2013, A&AL)

The Spin contribution to jet-disk coupling

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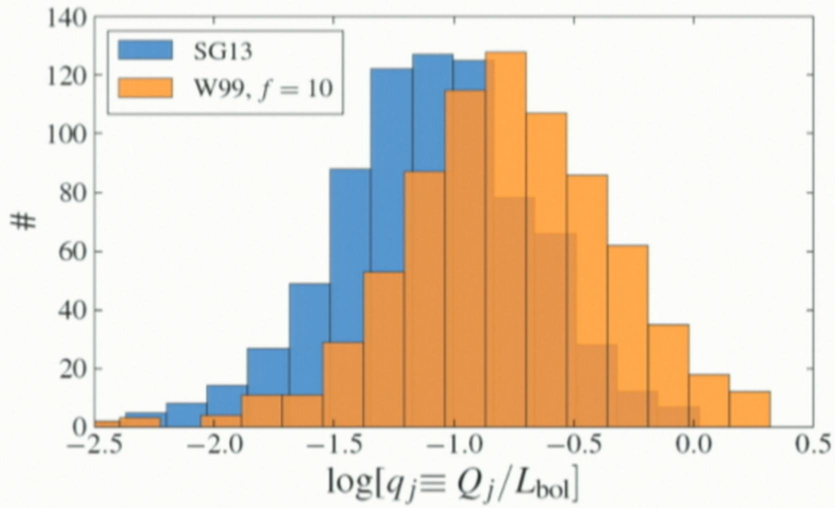
- Tight linear optical-radio correlation
- Jet power ∝ disk luminosity
  - Q_{jet}/L_{disk} ~ 10-20%
  - Q_{jet}~2-8% Mdot c^2 (for Kerr BHs)
- Scatter around correlation is factor 3. We would have seen factor >10 easily.
- Hence accretion rate is main factor

σ ~ 0.5 dex



Van Velzen & Falcke (2013)

The Spin contribution to jet-disk coupling

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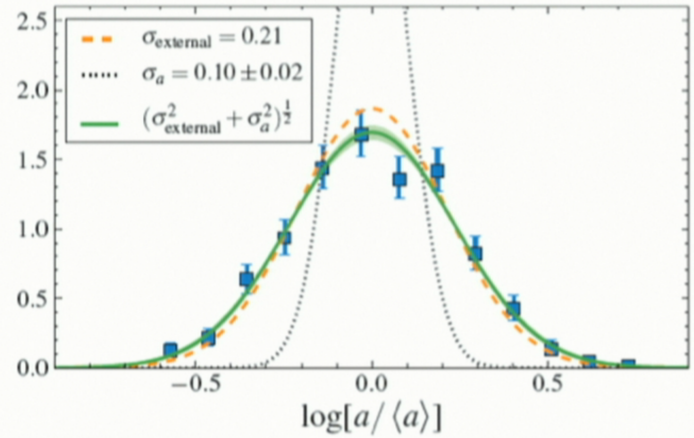
- Scatter around correlation can come from
  - Environment - quantify with lobe-to-lobe scatter: 0.39 dex
  - Optical variability: 0.15 dex
  - Variation of spin (a)?
- For Blandford-Znajek mechanism:
  - Jet power ∝ a^2
- Maximum contribution to spin scatter
  - $\sigma_{spin} \leq 0.1$ dex



⇒Either supermassive black holes all have same spin or spin is a weak factor:

$$Q_{jet}(a) \propto L_{disk}(a) \propto f(a)$$

van Velzen & Falcke (2013, A&AL)

Log N - log S for radio-selected FRIIs

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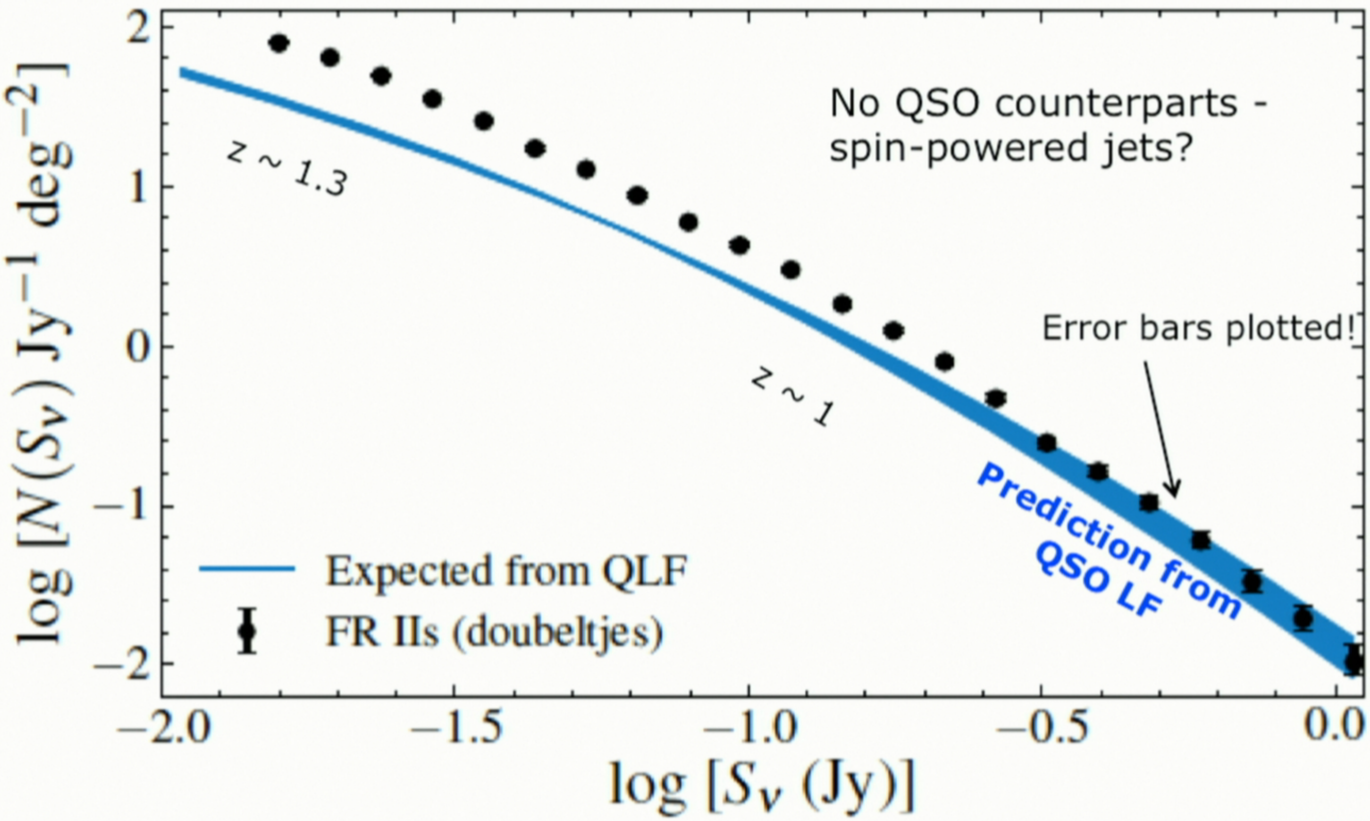

Van Velzen et al. (2014, in press)

Log N - log S for radio-selected FRIIs

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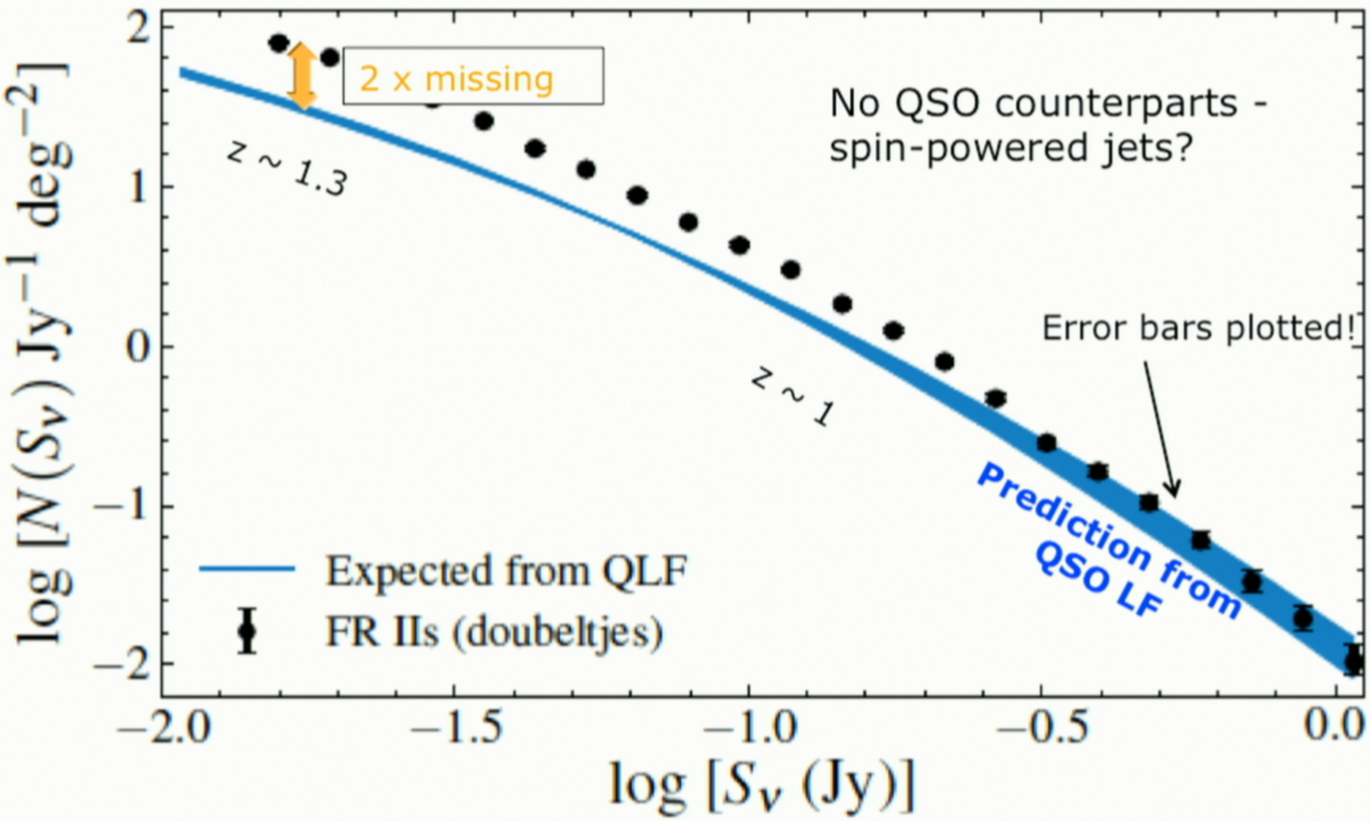

Van Velzen et al. (2014, in press)

Log N - log S for radio-selected FRIIs with active radio cores

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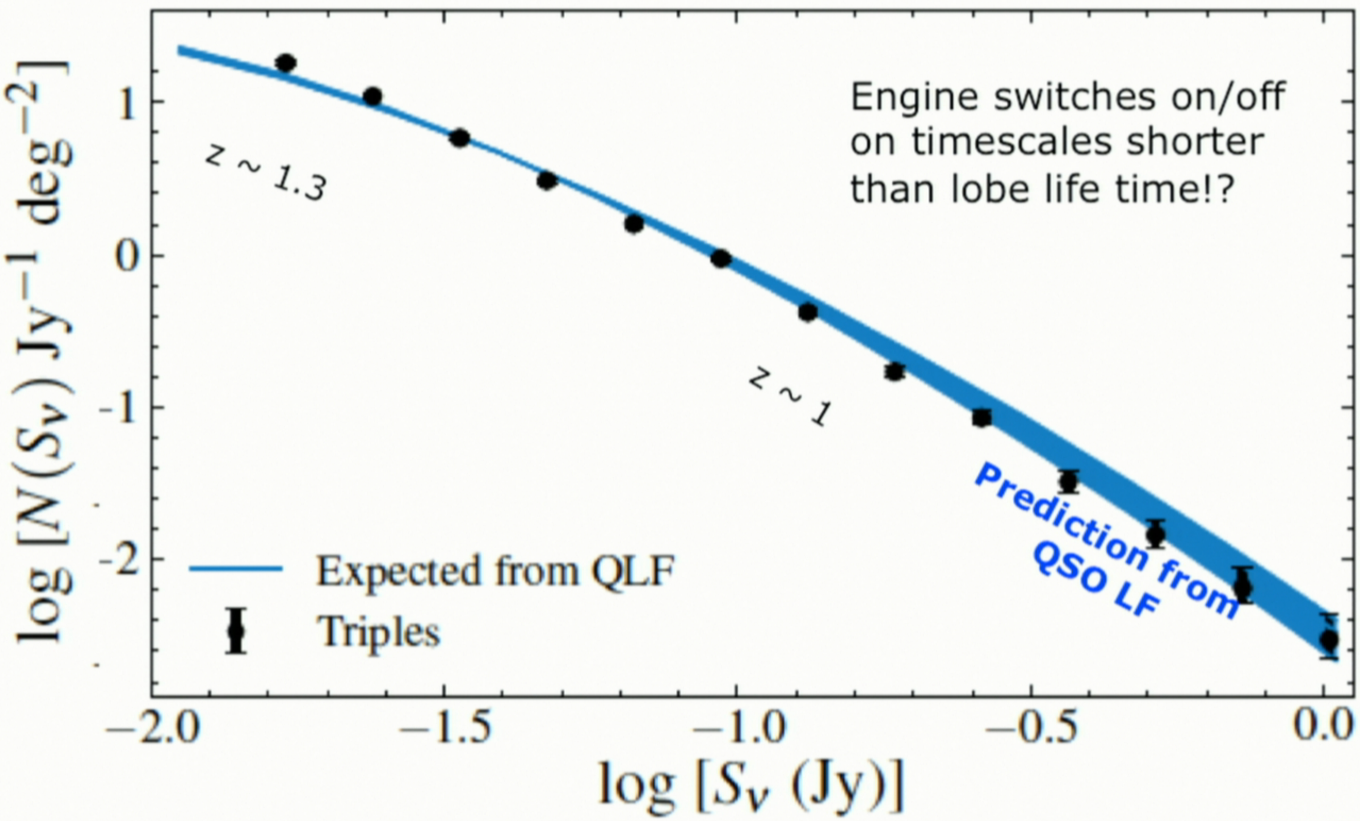

Van Velzen et al. (2014, in press)

Radio loudness in low-luminosity AGN (and XRBs)

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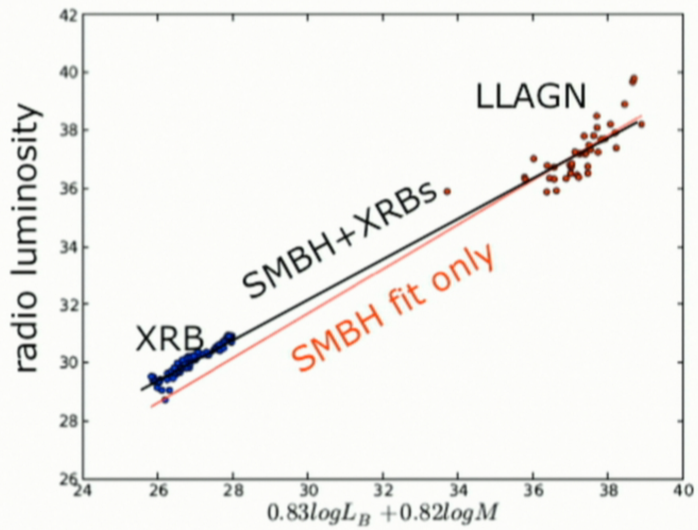
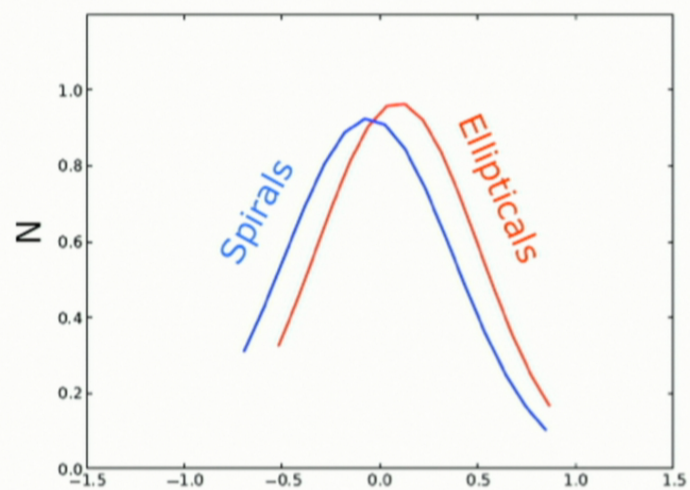
Fundamental plane
bolometric (OIII/X-ray) – vs radio



Mass-corrected bolometric luminosity

Radio-loudness distribution



mass-corrected radio-loudness

⇒ **tight correlation between bolometric luminosity and radio jet**

⇒ **hardly difference in radio loudness**

⇒ **little room for spin (if disk emits!)**

Saikia, Körding, Falcke (2014, subm.)

ALMA + VLA observations of Galactic Center

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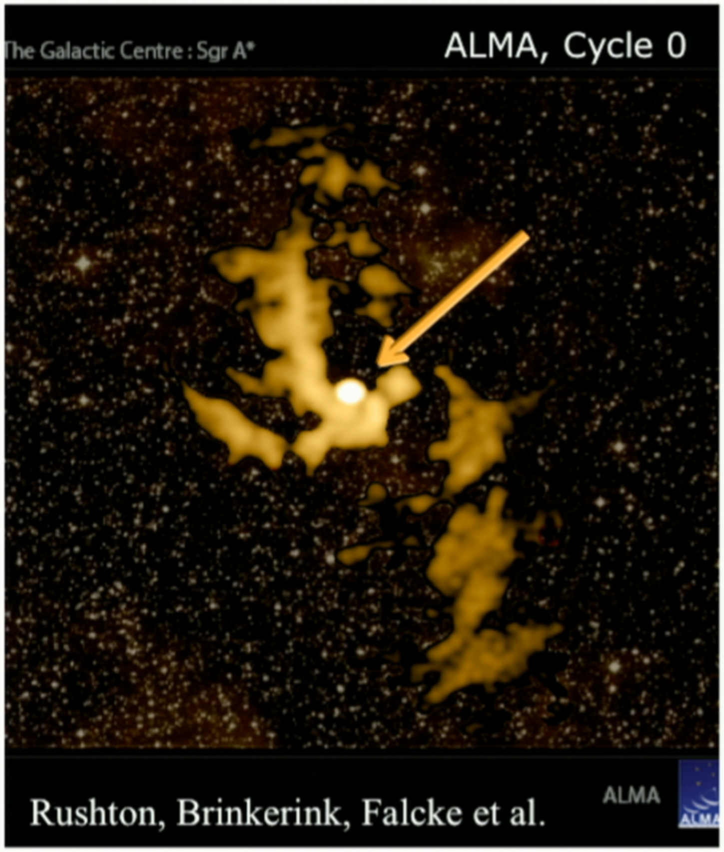
- ALMA Cycle 0 program
  - May 18th, 2013
  - eight-hour track
  - 100 GHz, 250 GHz, 340 GHz (bands 3,6,7)
  - Quasi-simultaneous, 30-second band switching
  - 19 antennas
- Simultaneous JVLA observations:
  - 18, 25, 27, 37, 39, and 48 GHz
  - multiple sub-bands per frequency band



43 – 22 GHz Time Lag

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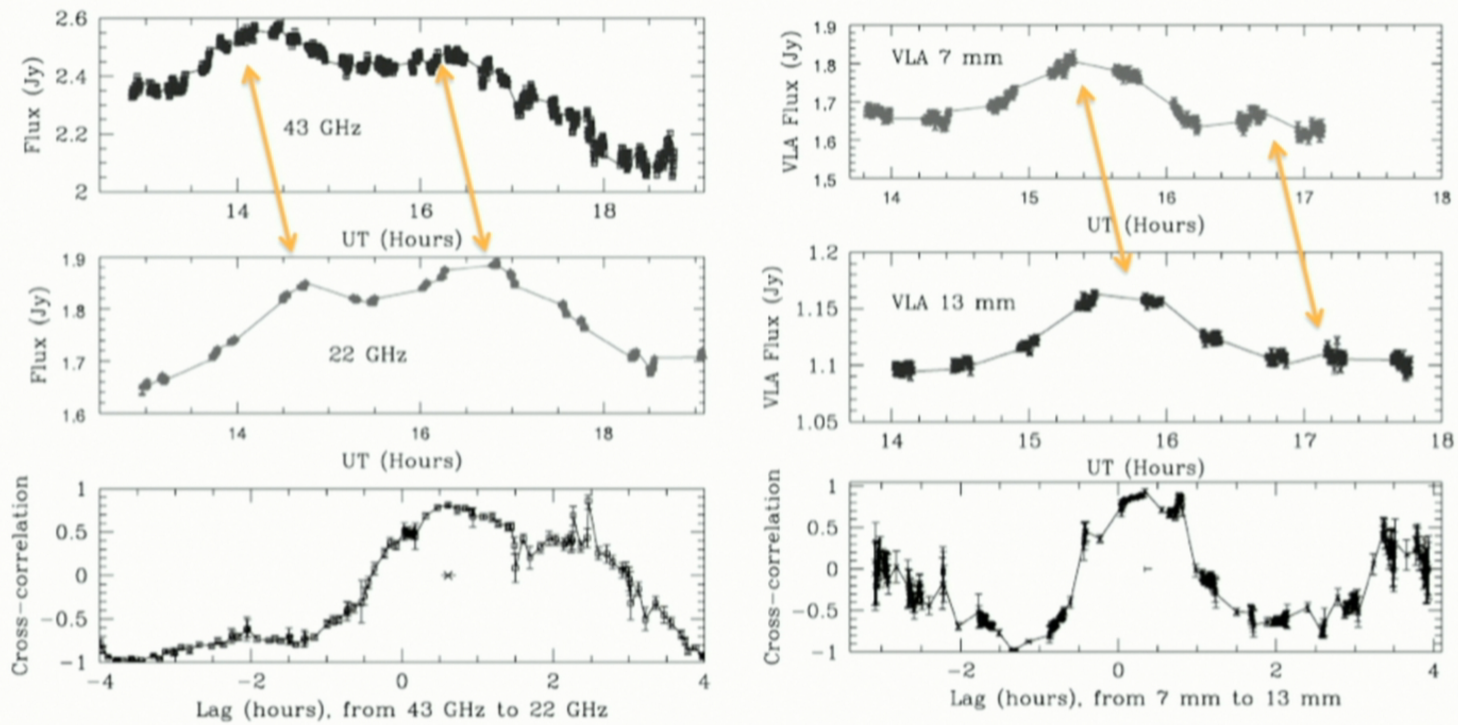

Yusef-Zadeh et al. (2008)

Frequency-Dependent Time Lags from VLA+ALMA

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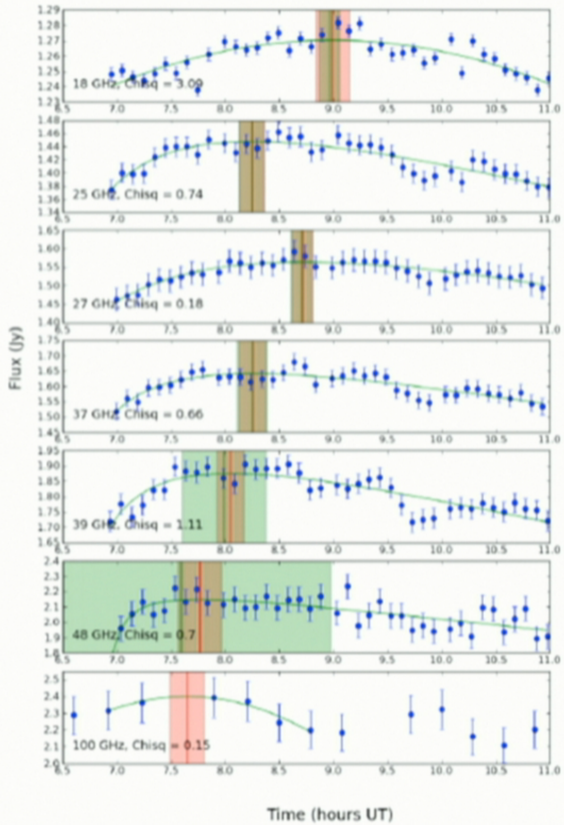

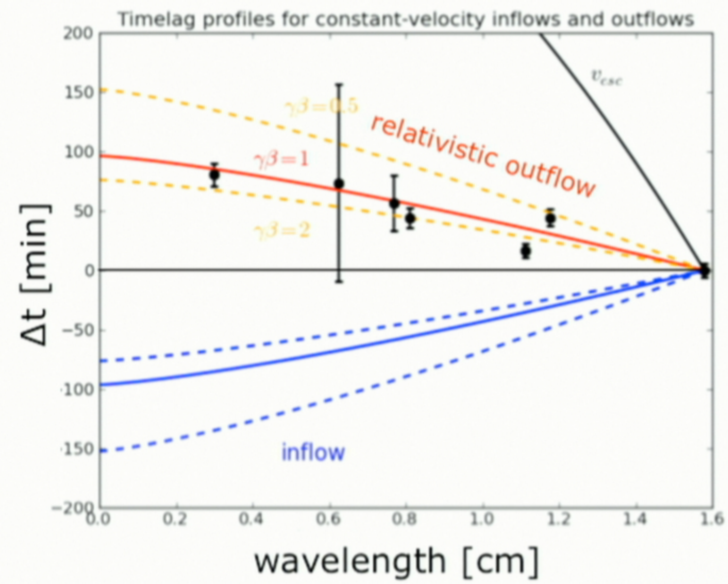

Shorter wavelengths lead longer wavelengths:
$\Delta t/\lambda$=(62±12) min/cm

Shorter wavelengths = smaller size
⇒ **outflow,v ≳ 0.75 c**

Brinkerink et al. (2014, subm.)

Where is the jet in simulations?

Radio is not fit in standard GRMHD sims.

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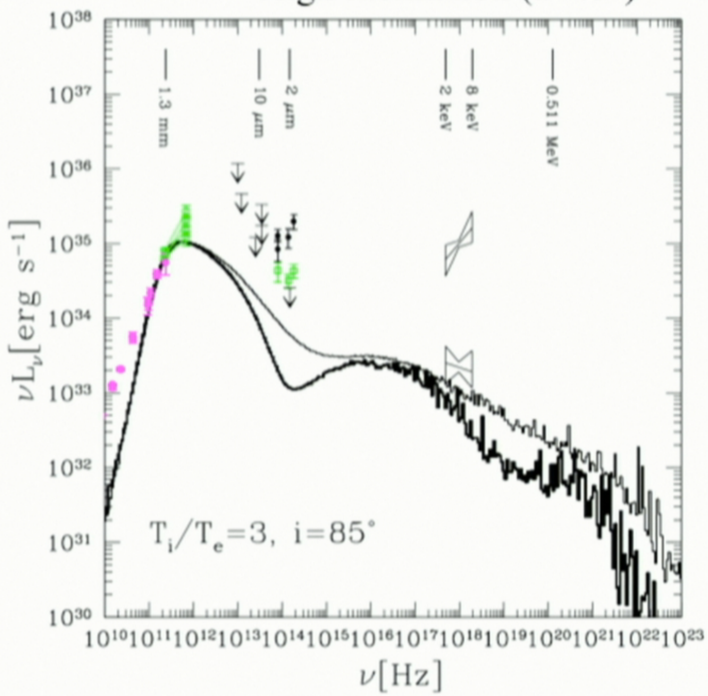
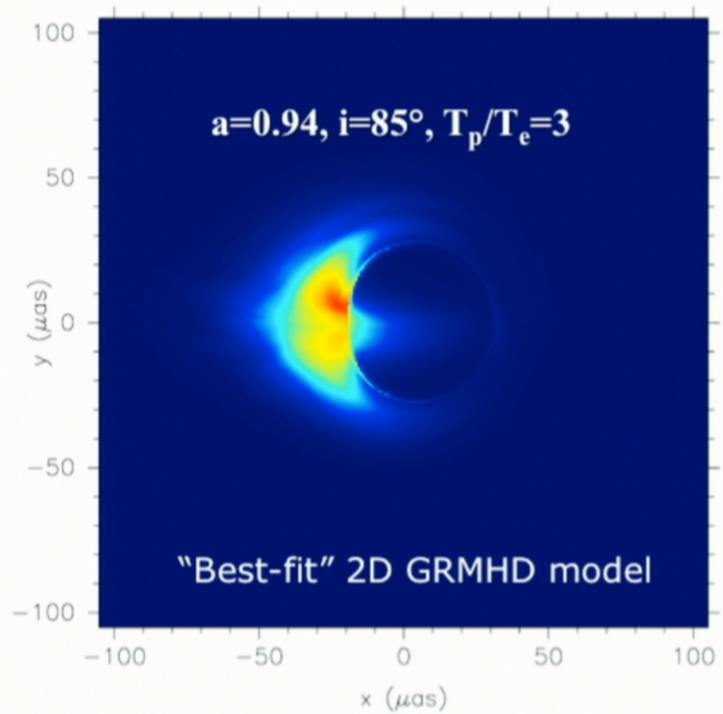
⇒High spin (a>0.9)

⇒High Inclination (a>45°)

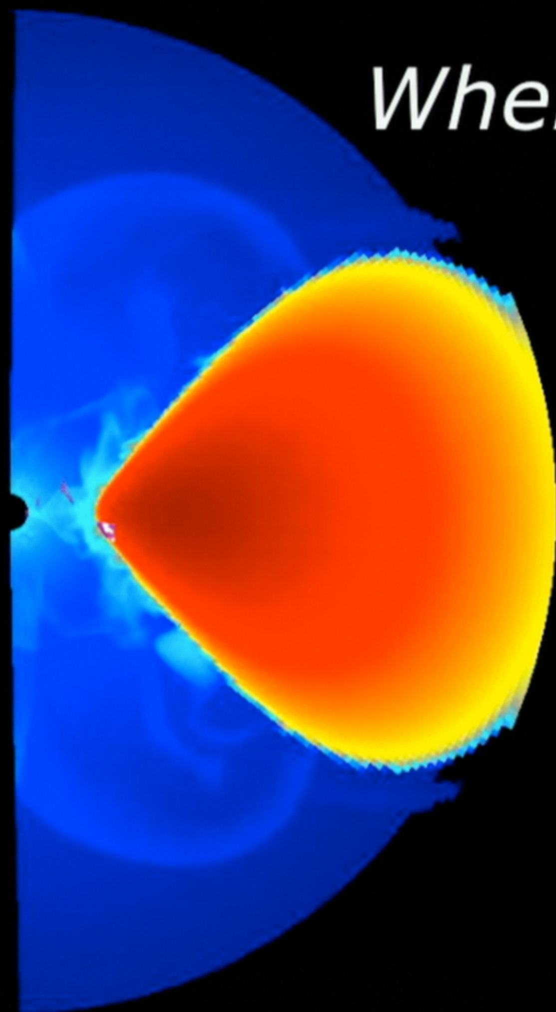


230 GHz

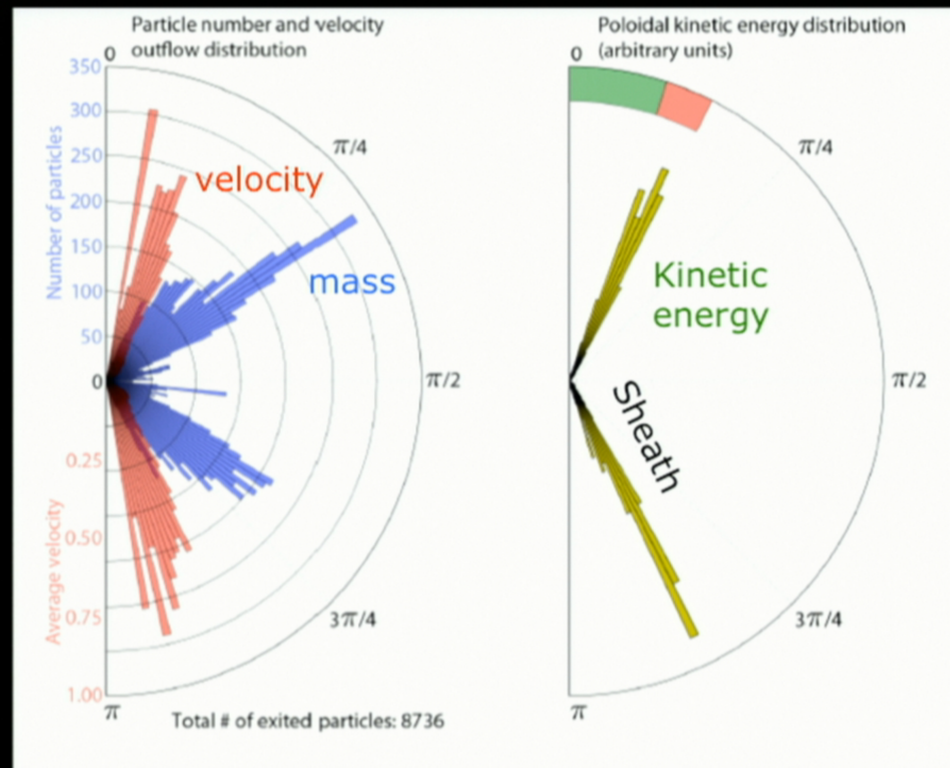


Mościbrodzka, Gammie, Dolence et al. (2009)

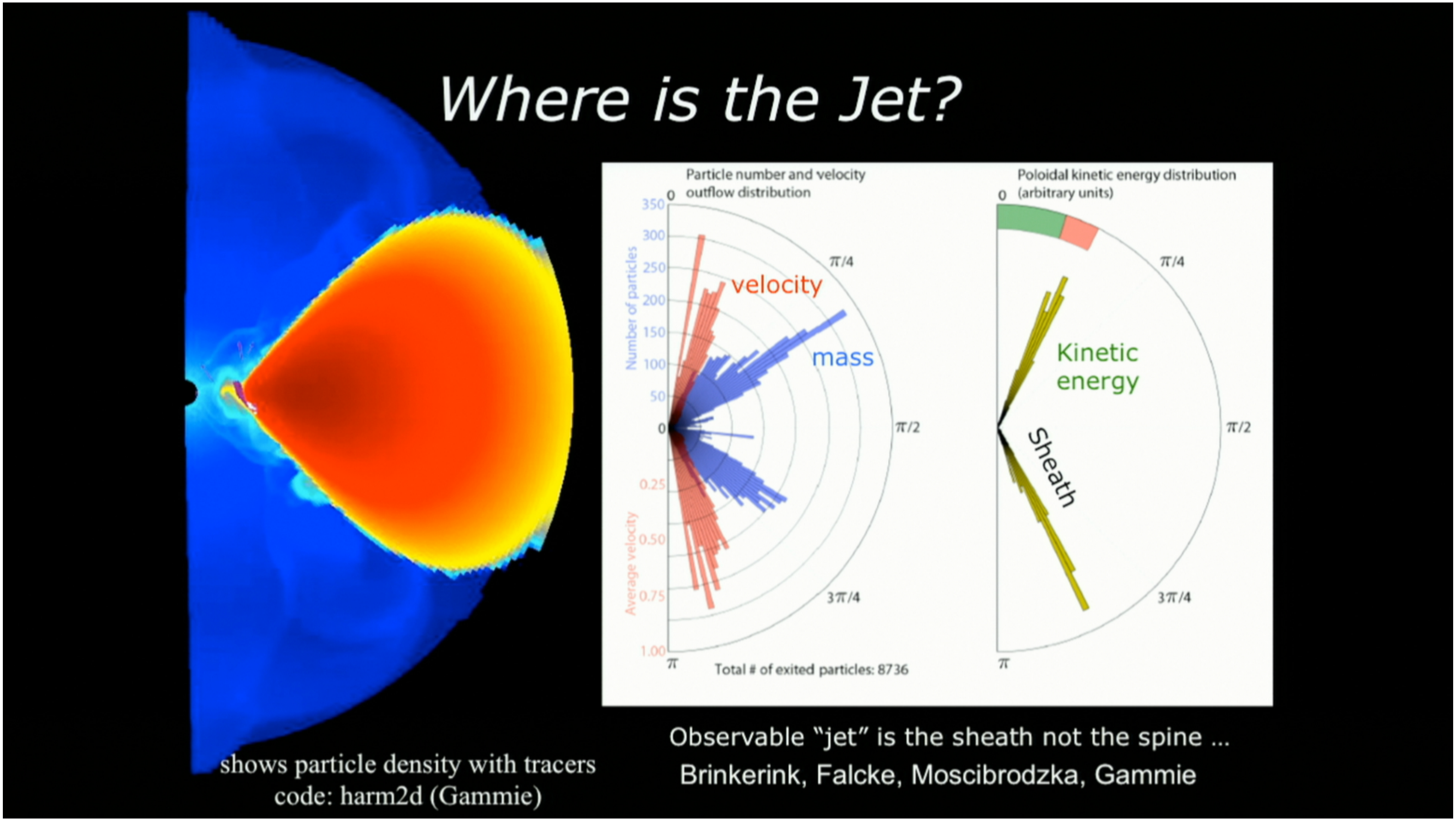
Where is the Jet?



shows particle density with tracers
code: harm2d (Gammie)



Observable "jet" is the sheath not the spine ...
Brinkerink, Falcke, Moscibrodzka, Gammie


Where is the Jet?
Particle number and velocity outflow distribution
Number of particles
350
300
250
200
150
100
50
0
0.25
0.50
0.75
1.00
Average velocity
0
π/4
π/2
3π/4
π
velocity
mass
Total # of exited particles: 8736
Poloidal kinetic energy distribution (arbitrary units)
Kinetic energy
Sheath
shows particle density with tracers
code: harm2d (Gammie)
Observable "jet" is the sheath not the spine ...
Brinkerink, Falcke, Moscibrodzka, Gammie

Isothermal jet + ADAF: Radio Spectra & Size in 2D GRMHD

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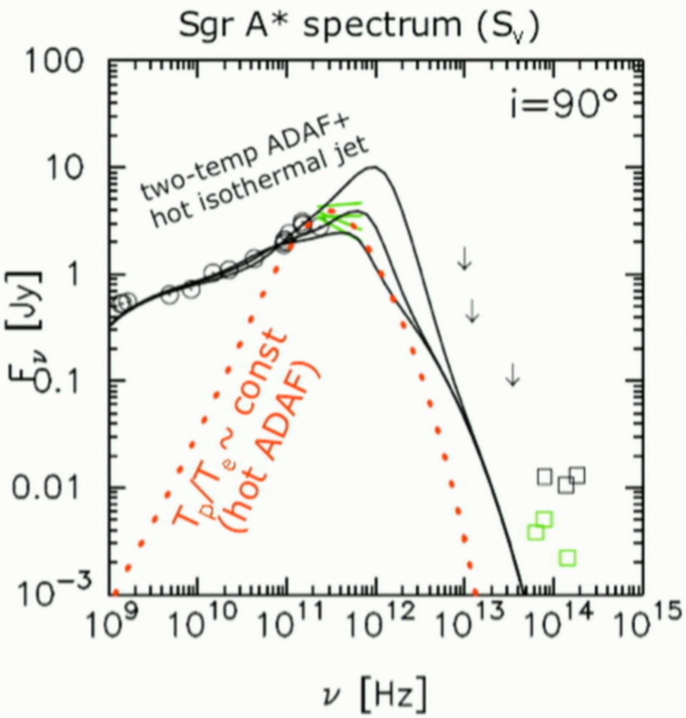
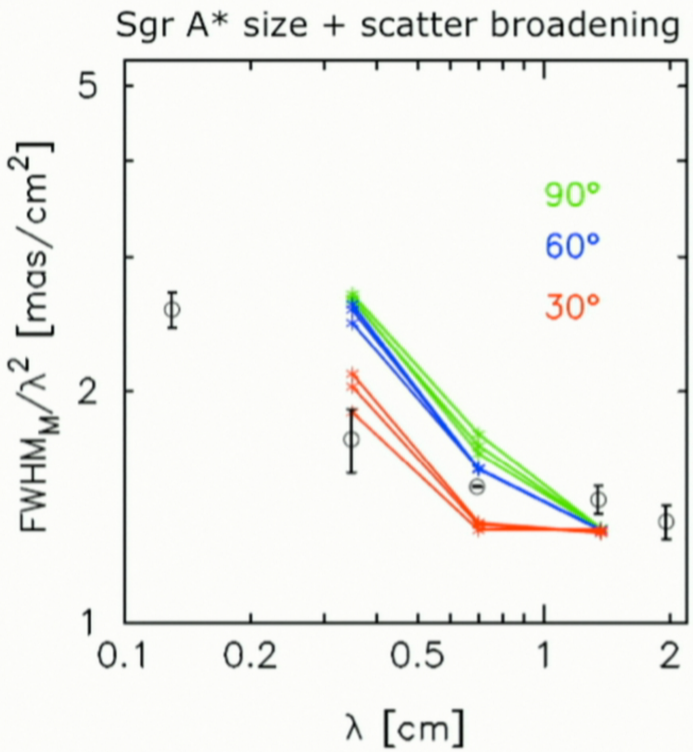




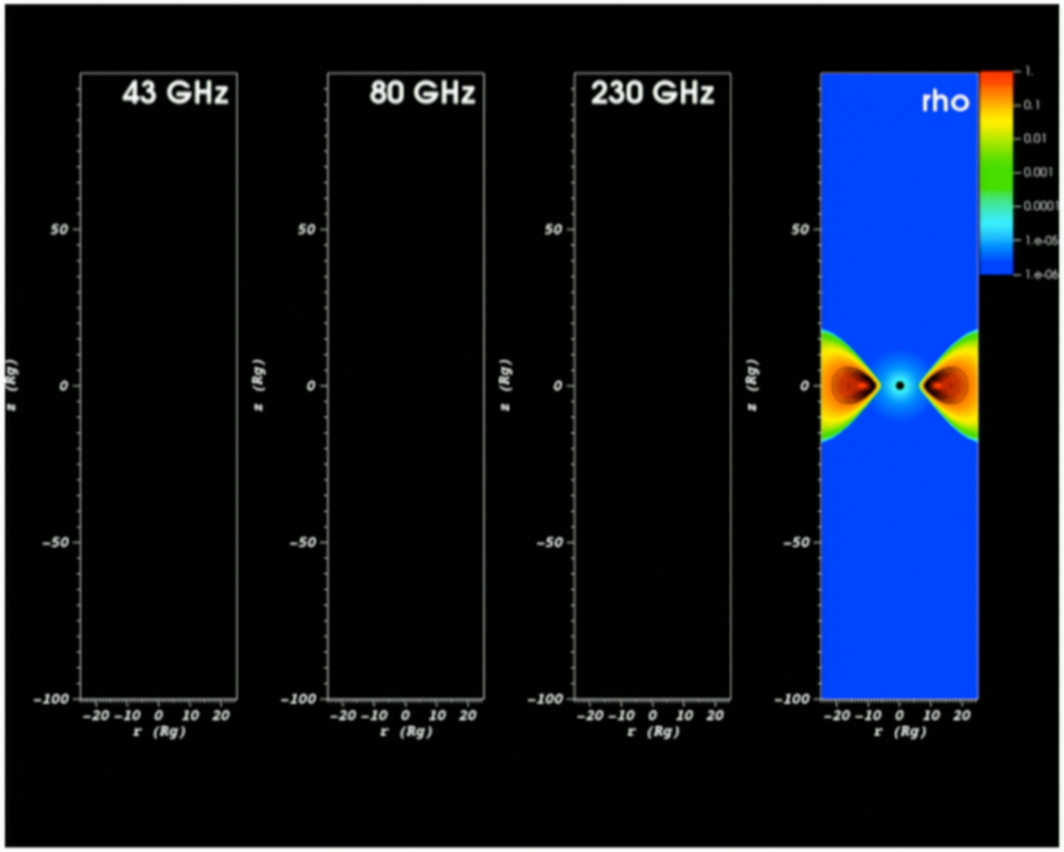
Moscibrodzka & Falcke (2013, A&A)
Moscibrodzka et al. (2014, A&A)

2D GRMHD Jet Emission Movie 90° inclination

Radboud University Nijmegen

unscattered images

Rings are due to 2D nature of simulations



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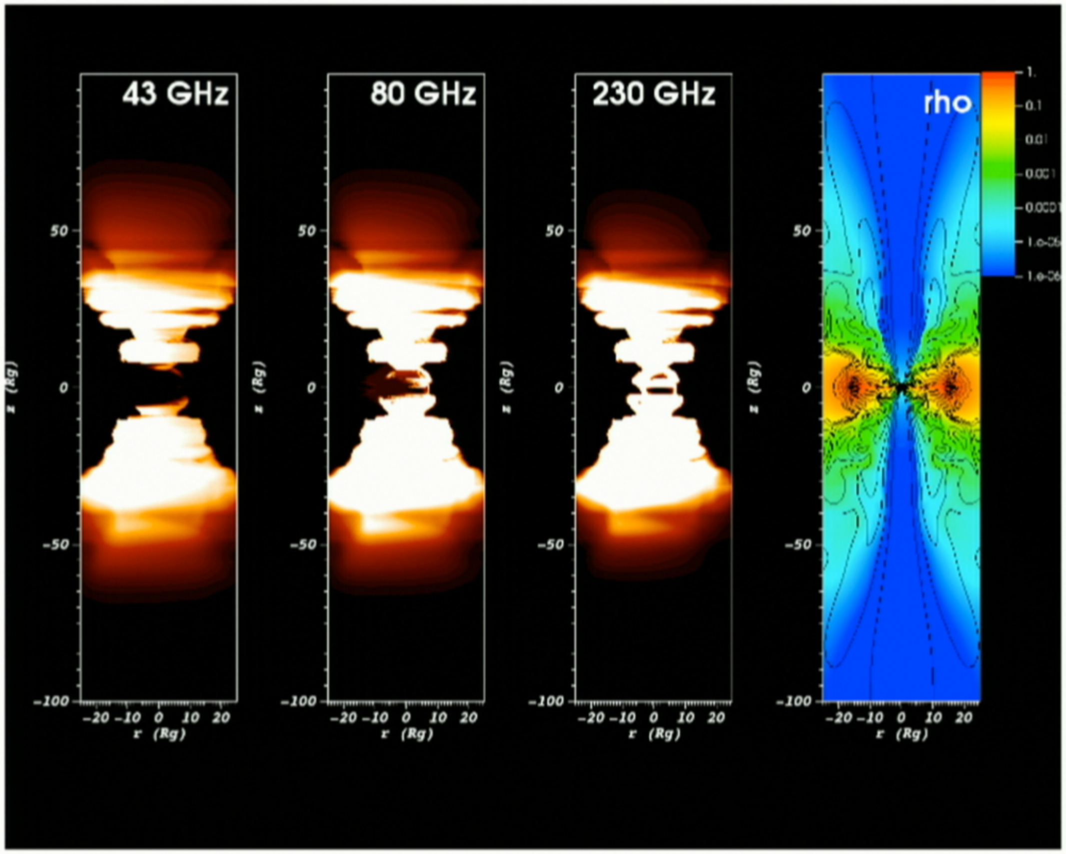

Moscibrodzka & Falcke (2013)

Closure phases for jet or disk 3D GRMHD models …

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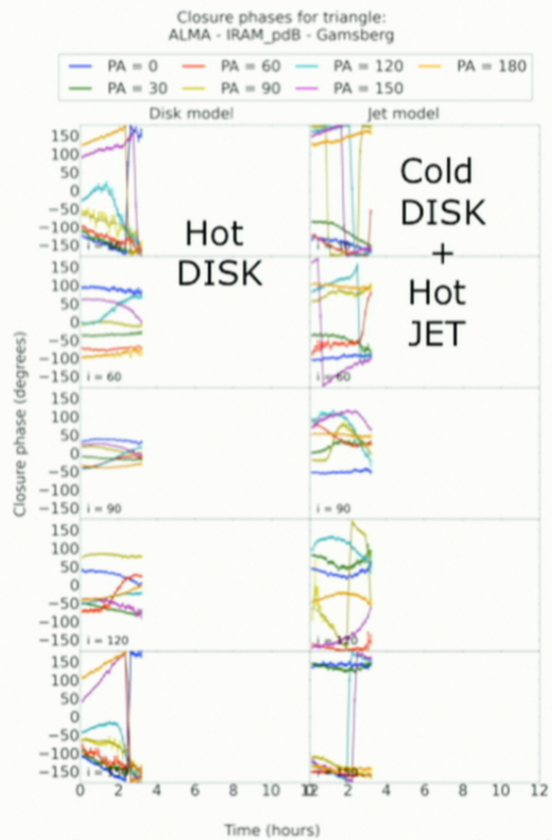
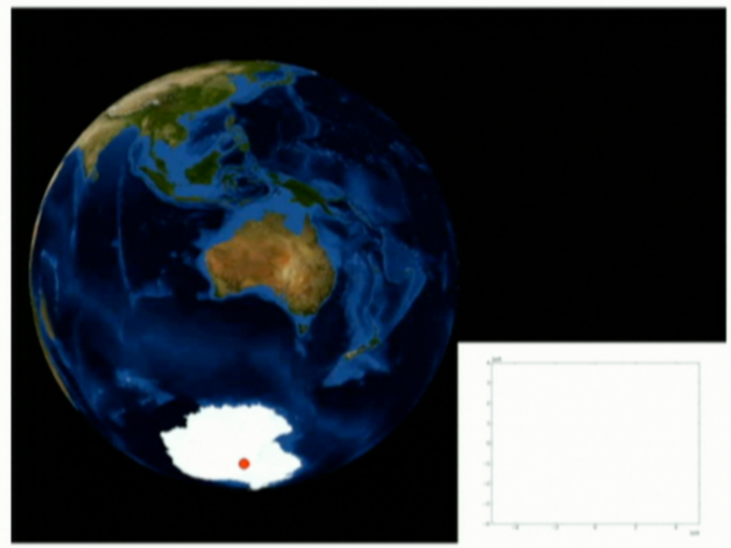
- Different inclination and PA -





Brinkerink, Fraga-Encinas, Moscibrodzka, …

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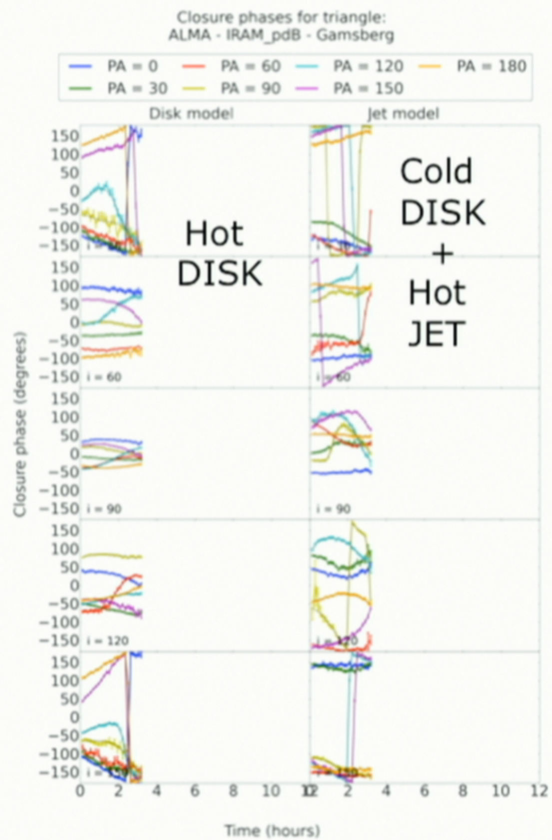
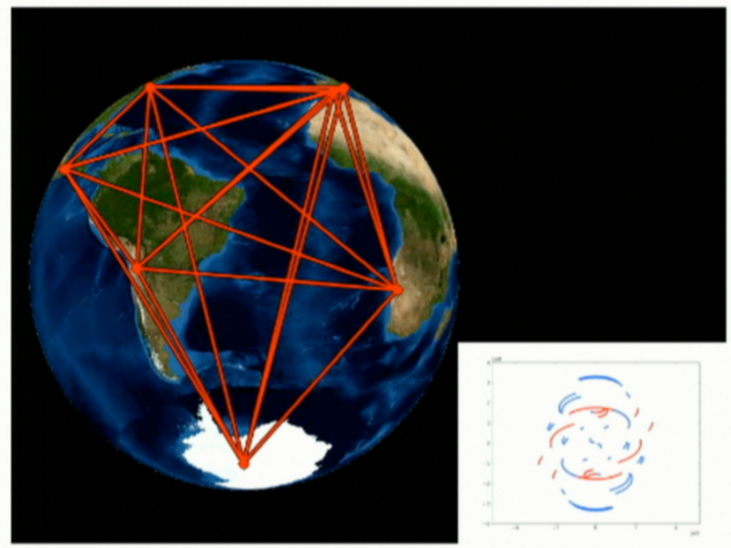
- Different inclination and PA -





Brinkerink, Fraga-Encinas, Moscibrodzka, ...

Summary

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- Radio-loud jets (FRIIs) correlate tightly with disk luminosity
  - If engine switches off, QSO disappears for a while, lobes remain
- Little room for variations in disk/jet ratio due to spin!
  - Linear dependence of jet power and disk luminosity in spin possible
- Radio-loudness claimed in LLAGN is most likely a simple mass effect ("fundamental plane of BHs") – again no spin effect
  - Radio-loudness in quasars likely due to state-changes in disk ...
- The radio core in Sgr A* is well explained by a jet model
  - size-frequency, asymmetry, and time-lags suggest outflow
- Jet in GRMHD is the sheath (funnel wall) not the spine (or funnel)!
  - isothermal sheath in GRMHD recovers BK and FB model naturally
  - explains flat-radio spectrum of jets and Sgr A*
  - difference between jet and disk model boils down to proton-electron coupling
  - Sheath is linear in accretion rate - also linear in spin?
- Understanding jet emission is crucial for good astrophysical model of Sgr A*!

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