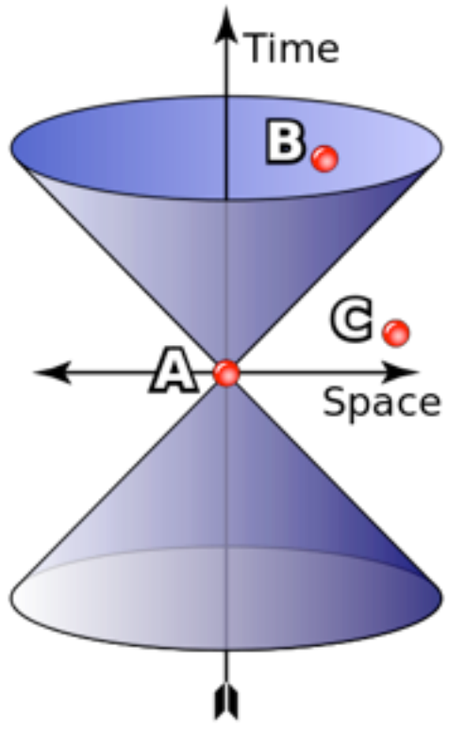
AGN jet physics and apparent opening angles



by E. Clausen-Brown,
and T. Savolainen, A. B. Pushkarev, Y. Y. Kovalev, & J. A. Zensus

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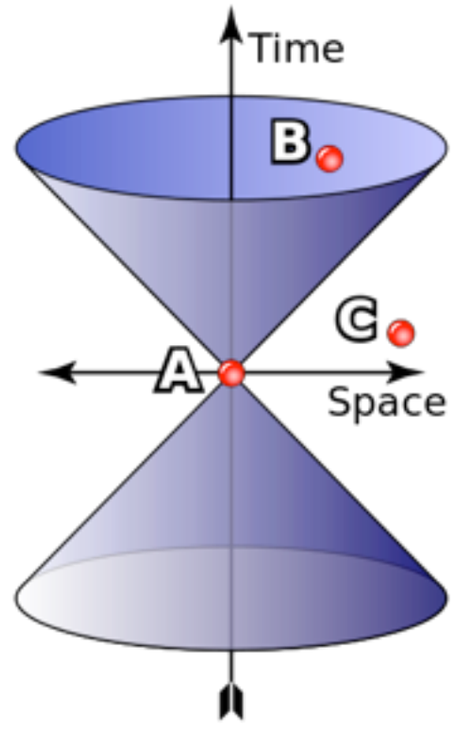

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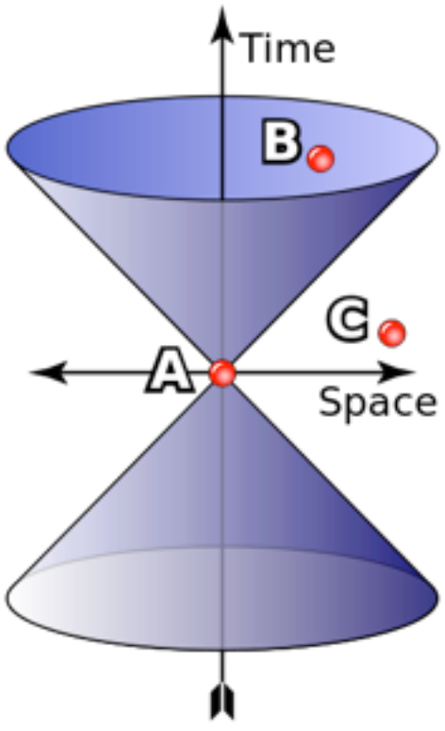
Causal connection in relativistic jets: results from the MOJAVE VLBI survey



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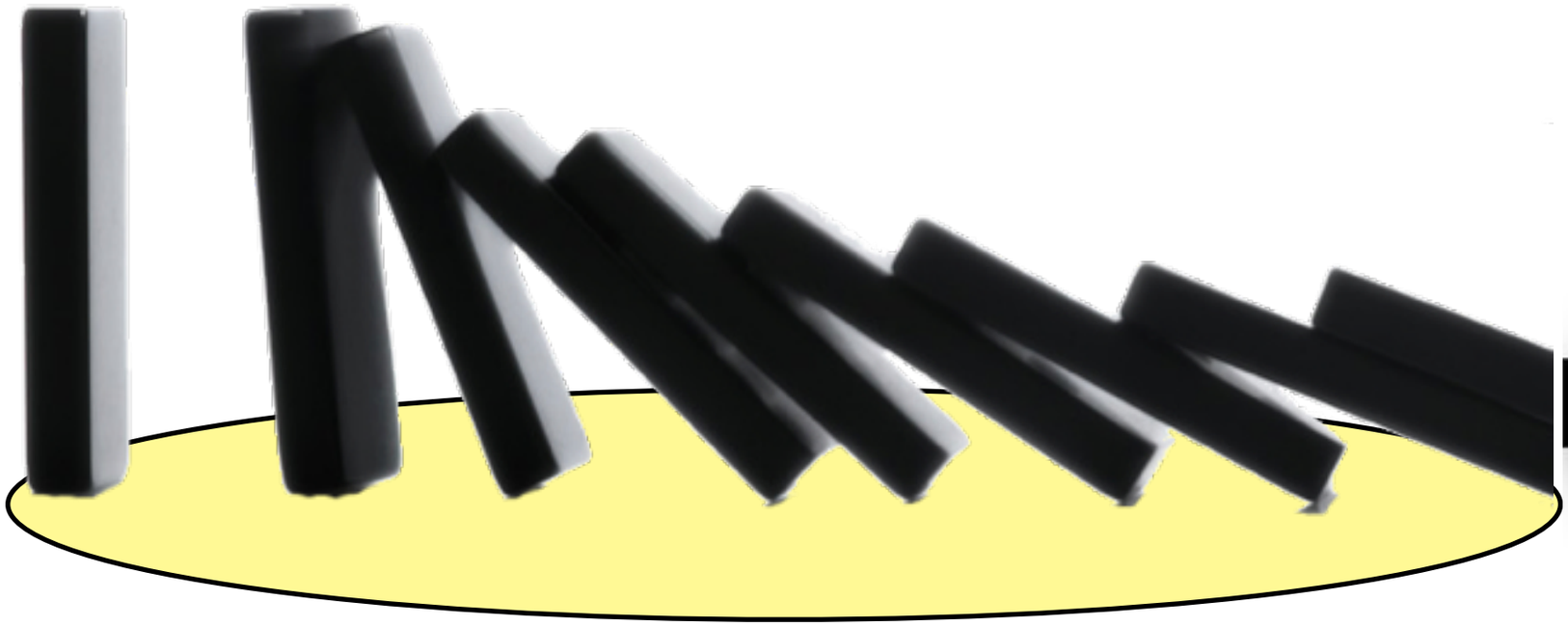
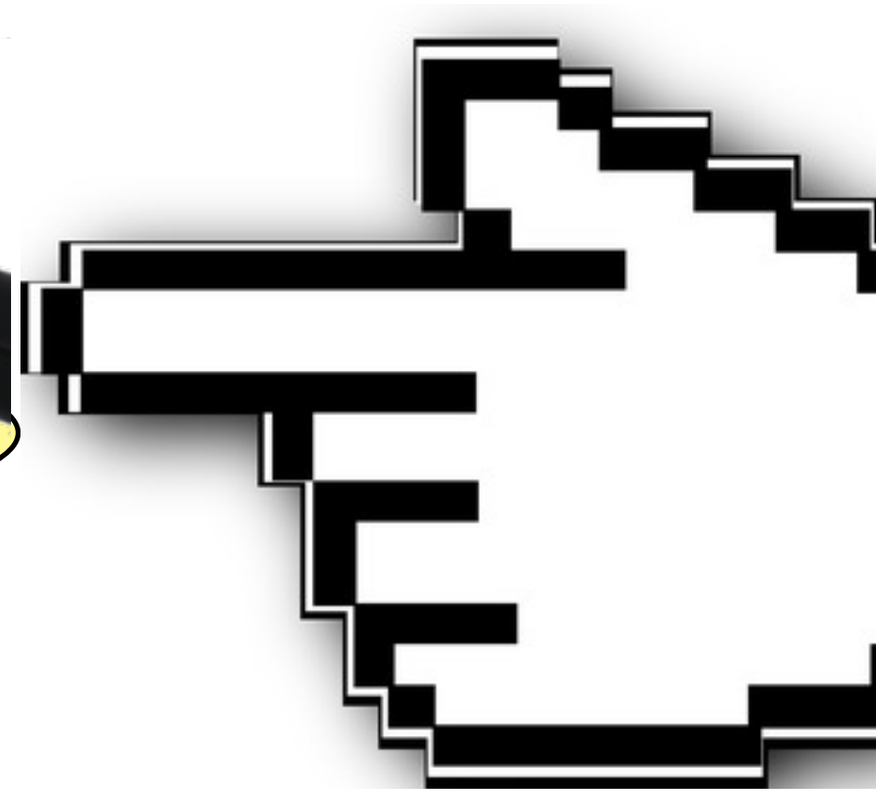
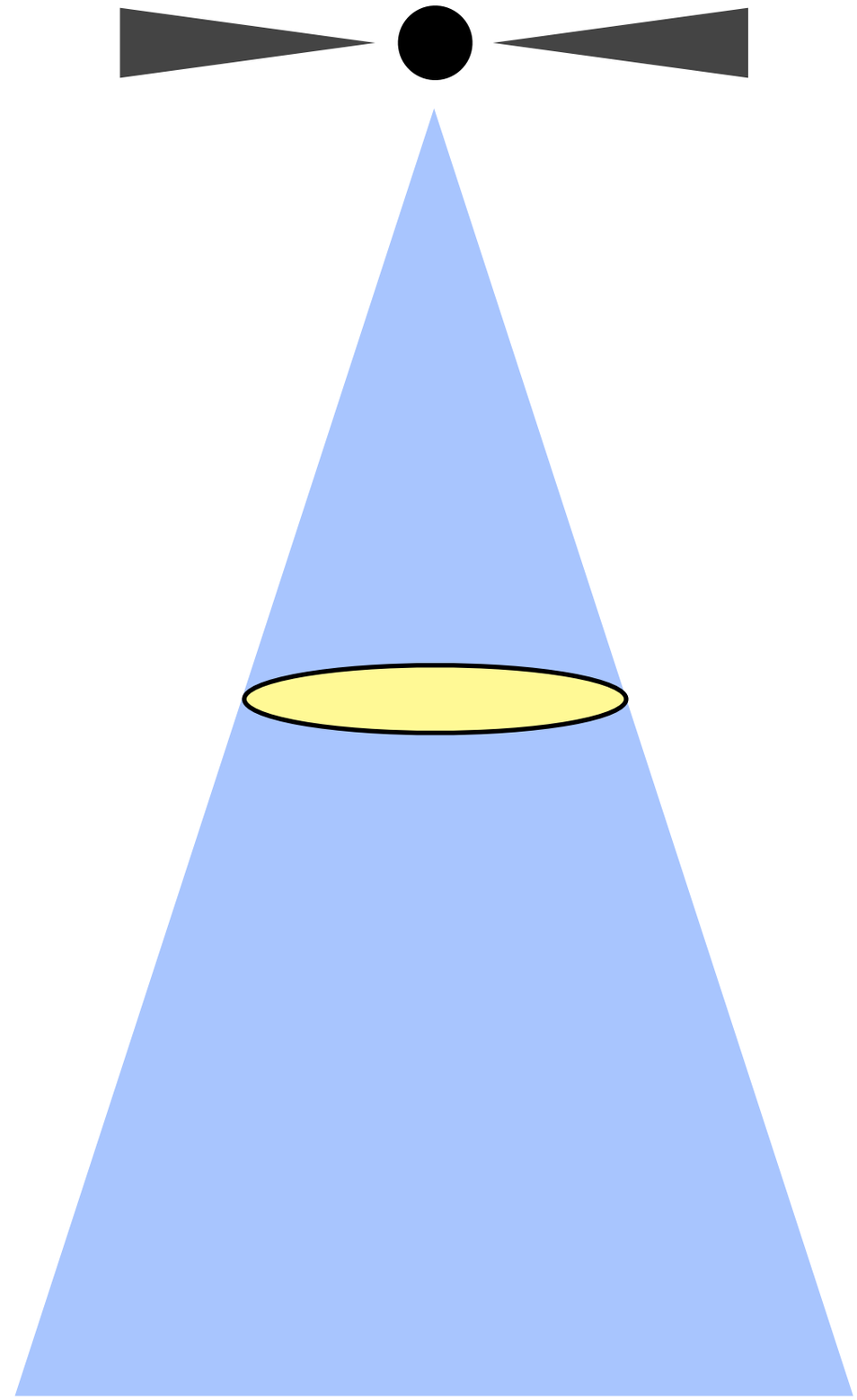
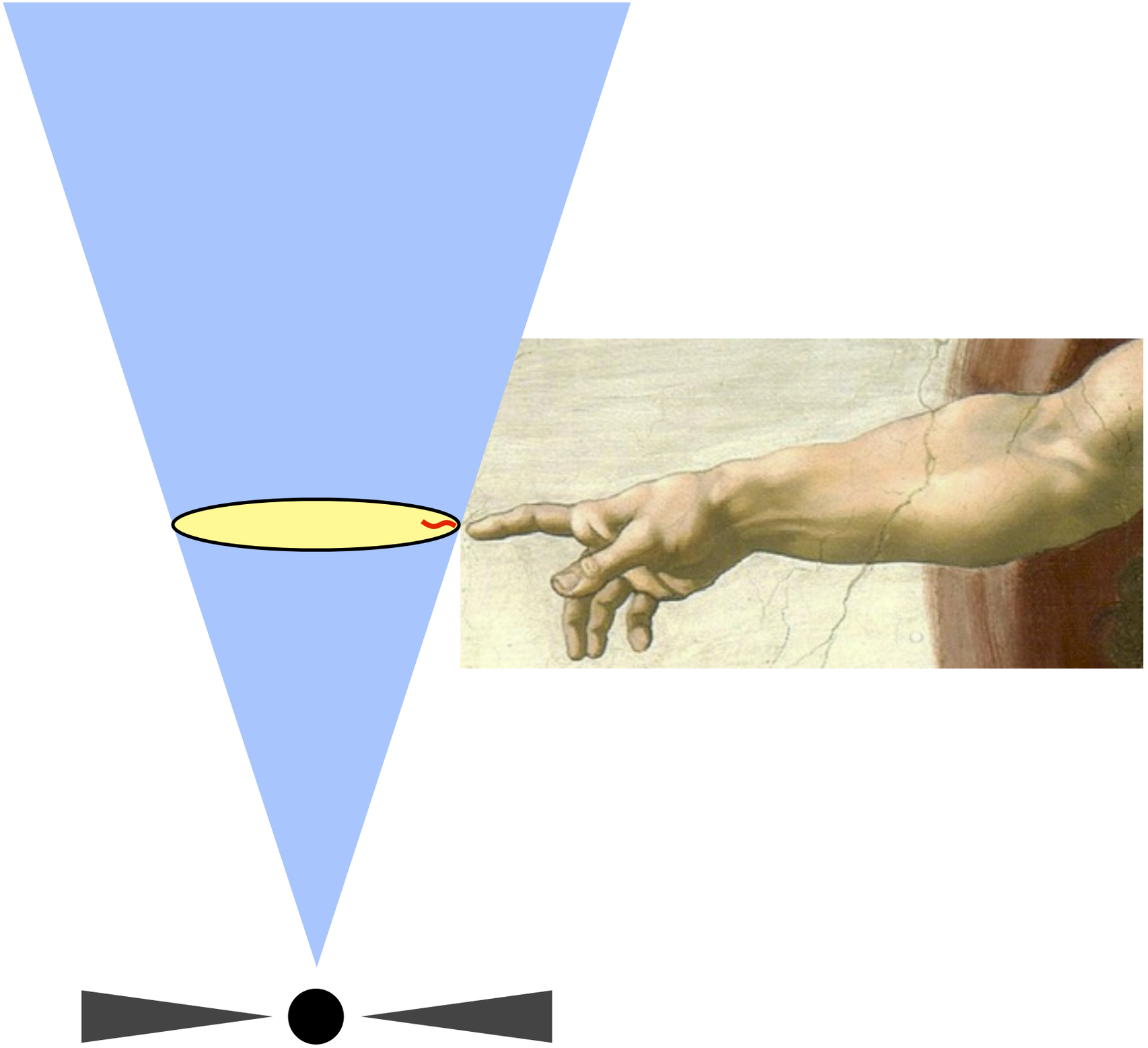
A causally connected region is...

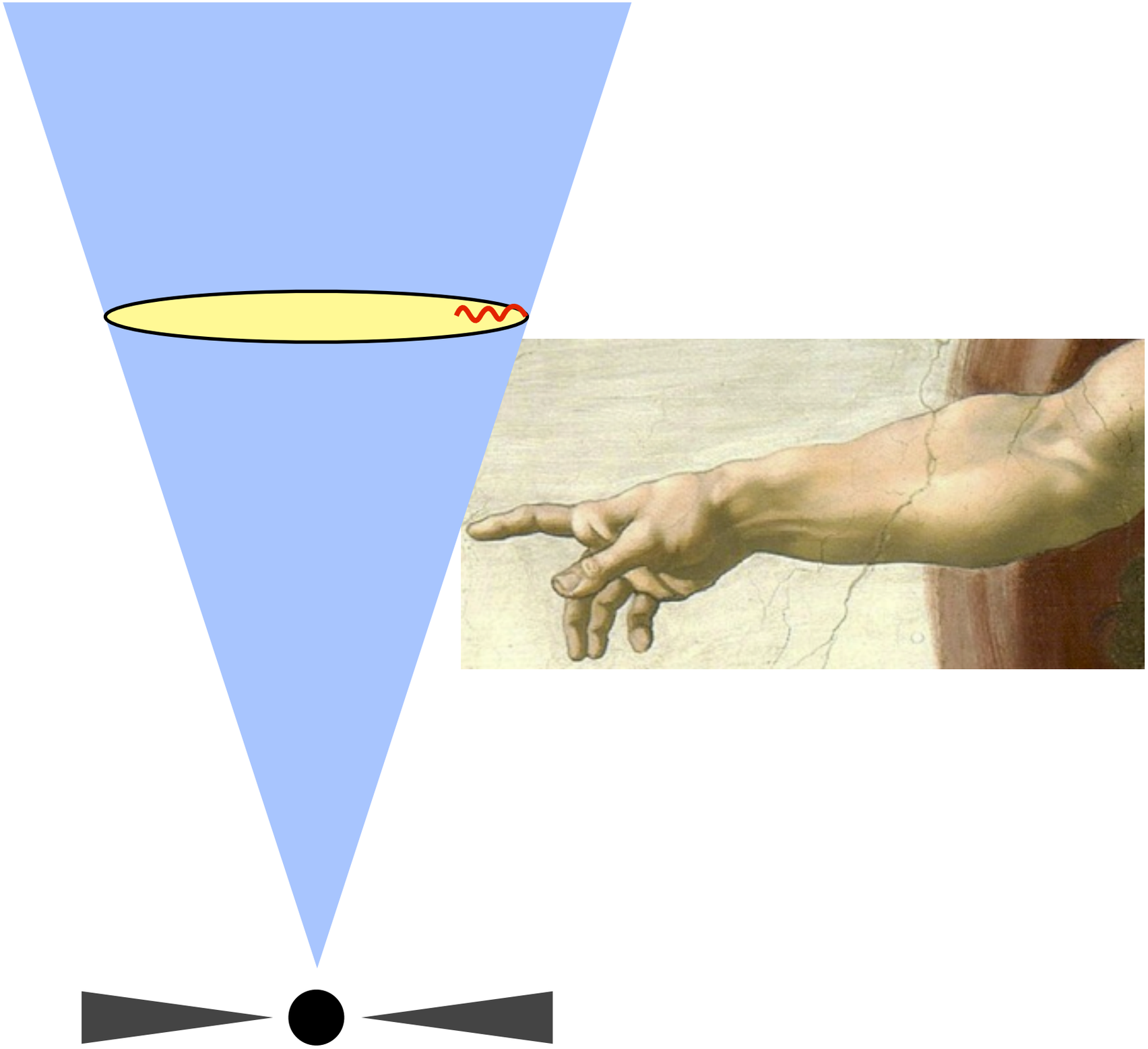


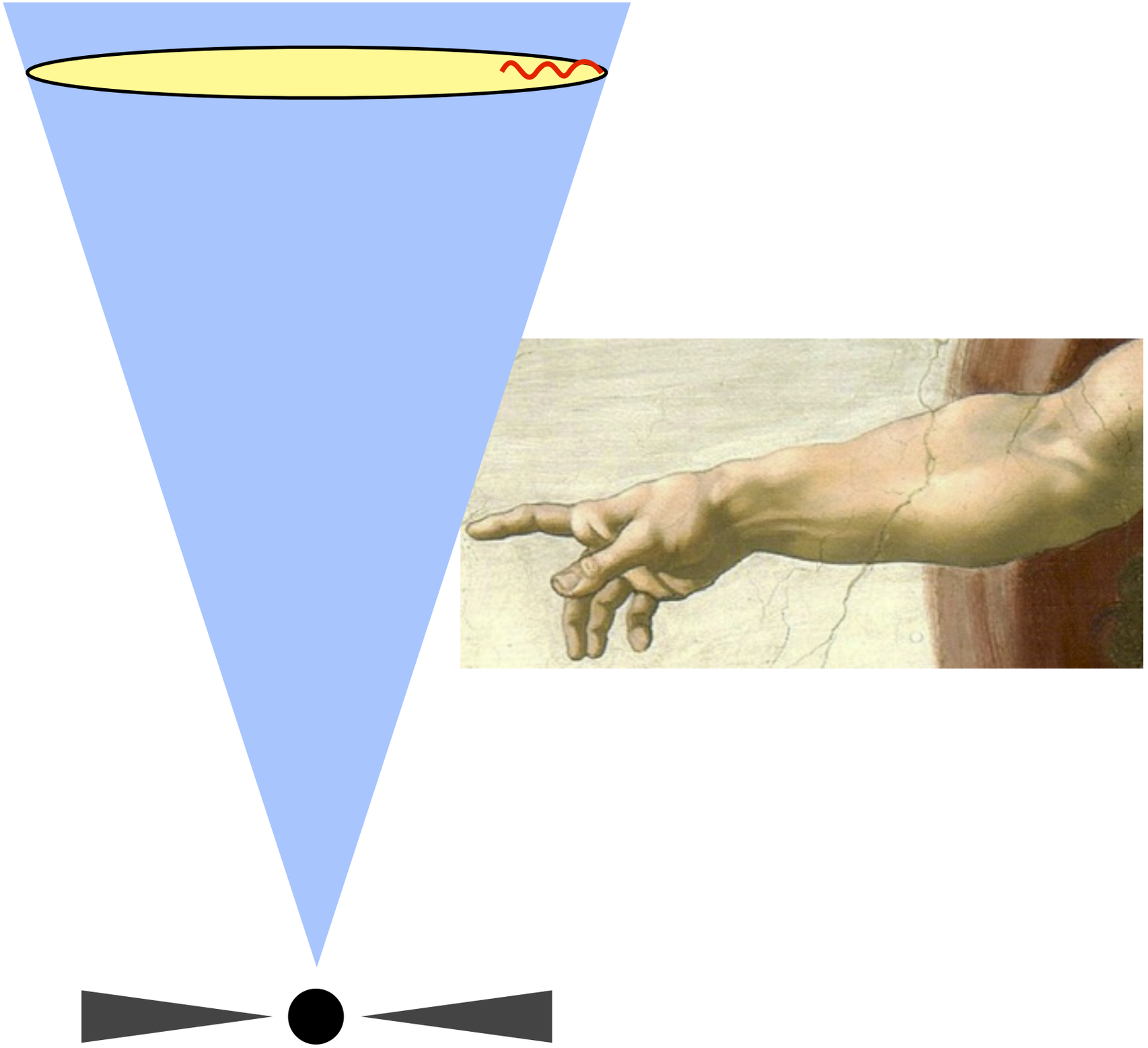


...a volume of space that a disturbance can propagate across







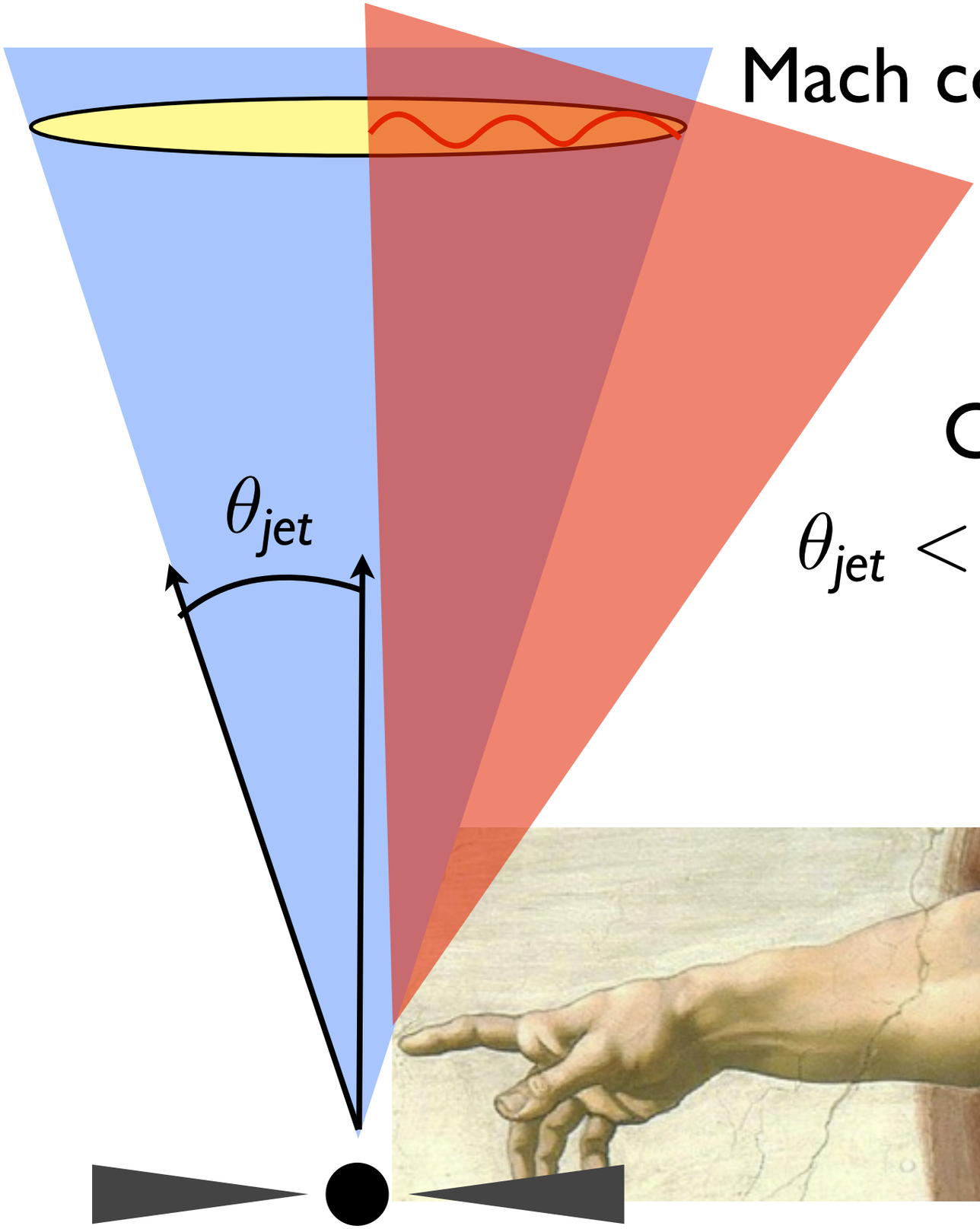


No causal connection

Mach cone

wave does **not** reach axis

causal connection



Causal contact:

$\theta_{jet} <$ Mach cone angle

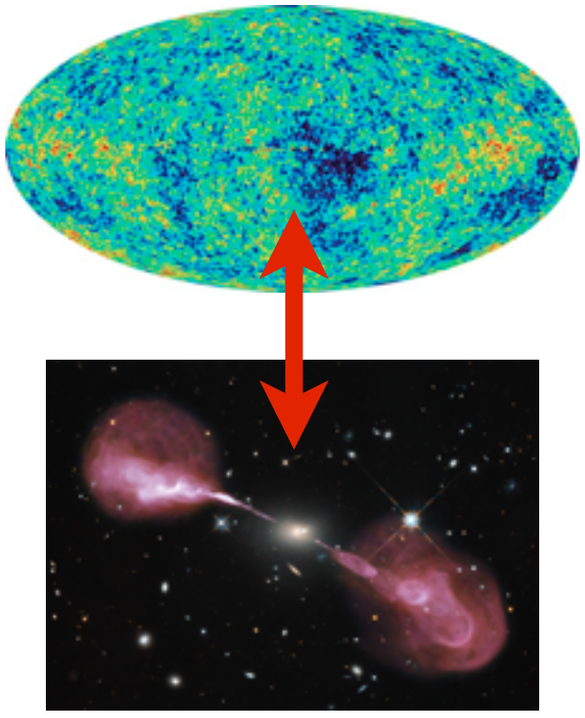
$\Gamma\theta_{jet} < \Gamma_s\beta_s$

Why is causality important?

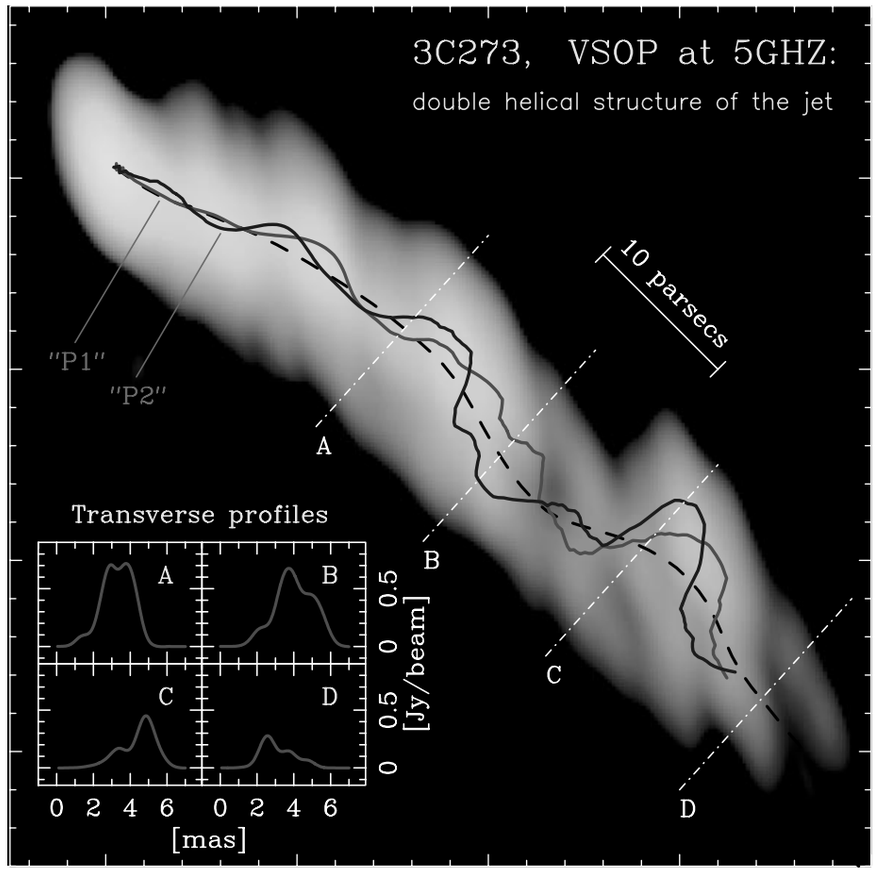
cosmology ↔ causal connection

as

relativistic jets ↔ causal connection

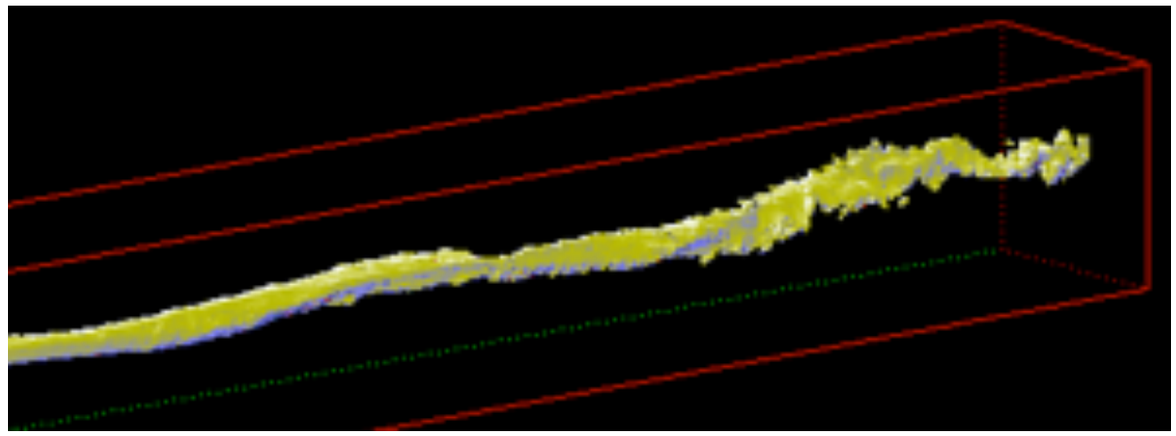


Jet stability



Lobanov & Zensus (MPIfR, 2001)

Jet stability (simulations)

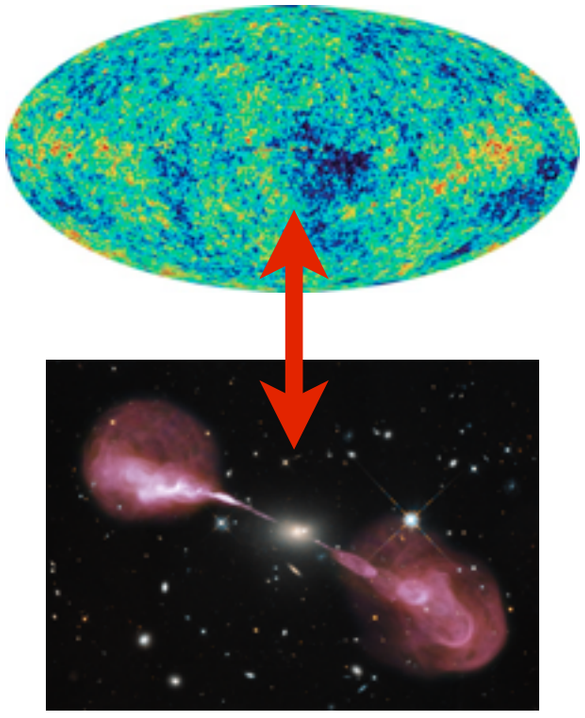


Valencia jet simulation group
& MPIfR

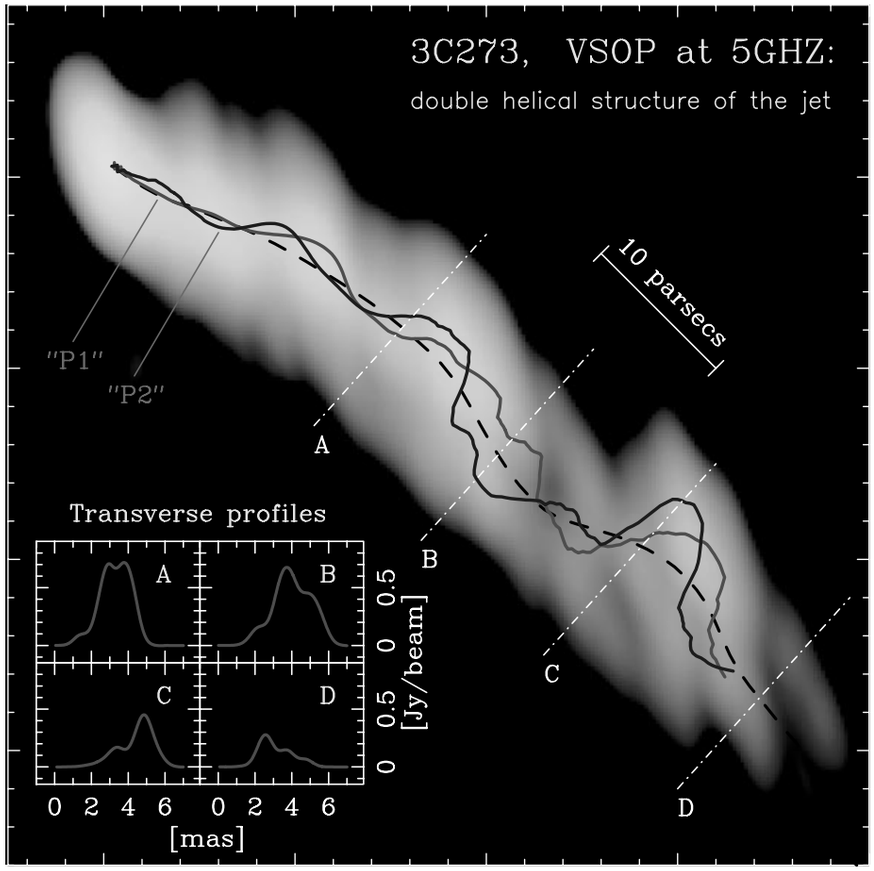
cosmology ↔ causal connection

as

relativistic jets ↔ causal connection

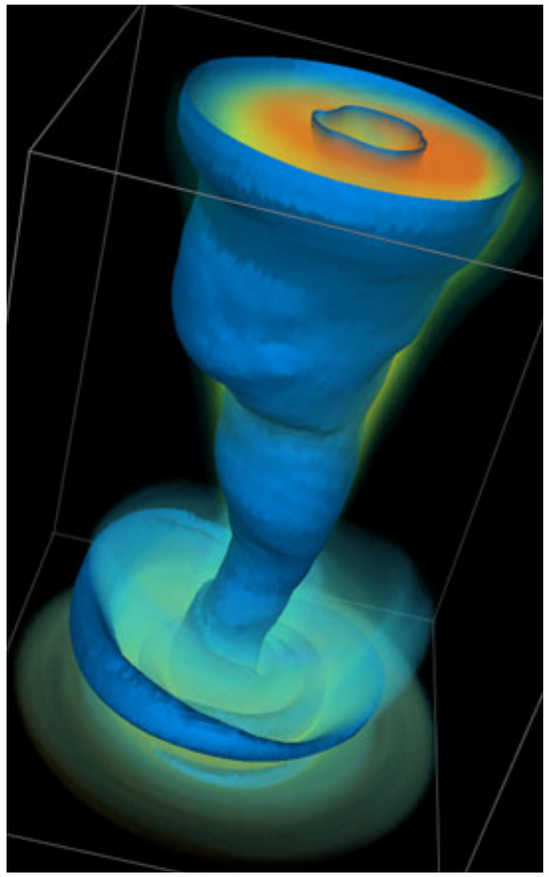


Jet stability



Lobanov & Zensus (MPIfR, 2009)

Jet production/acceleration



McKinney & Blandford (2009)

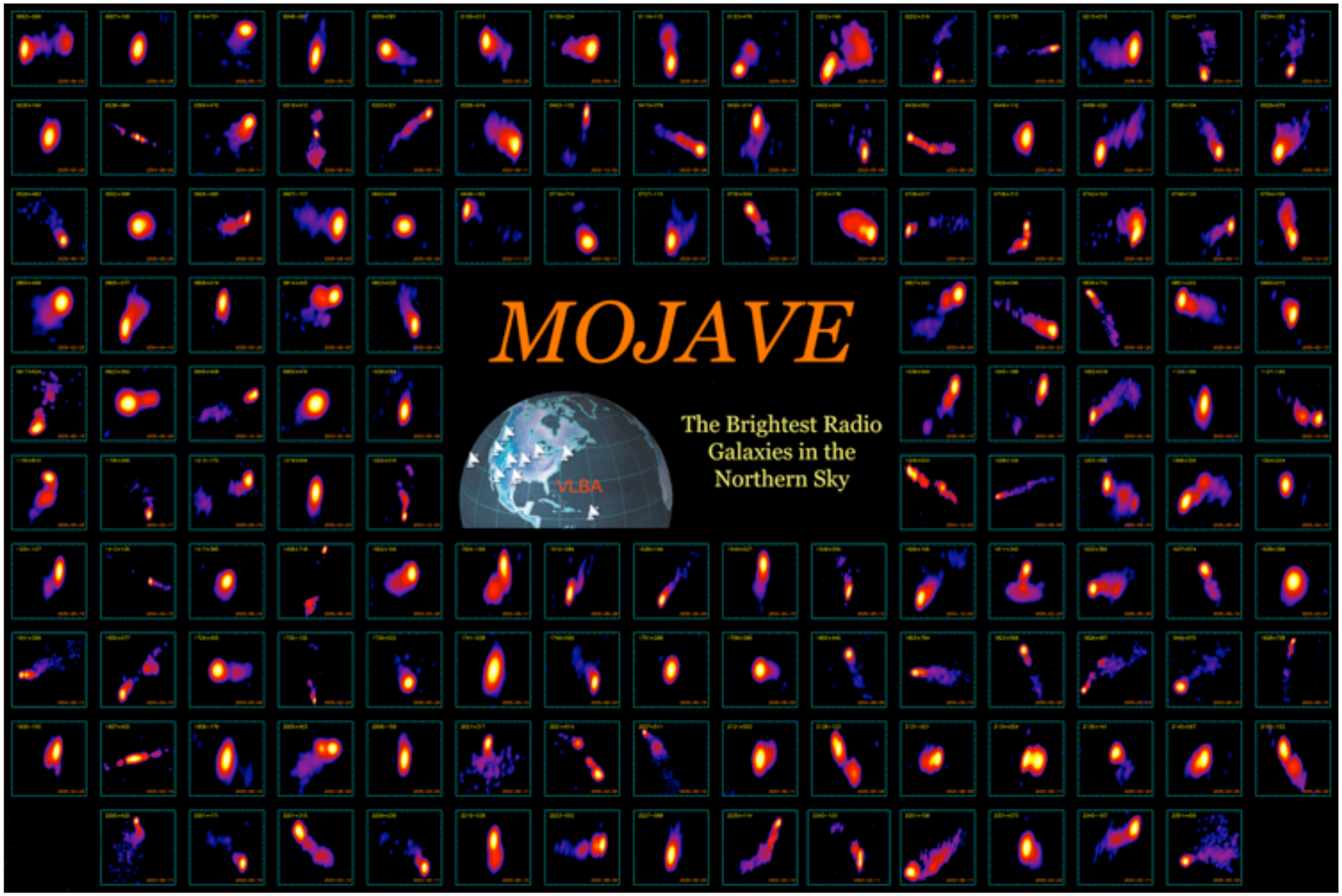
How to empirically constrain causality?

infer $\Gamma\theta_{jet}$

causality dictates $\Gamma\theta_{jet} < \Gamma_s\beta_s$

Derive P.D.F. for apparent opening angles, and fit it to MOJAVE data

$\Gamma\theta_{jet}$ is free parameter found by the best fit.



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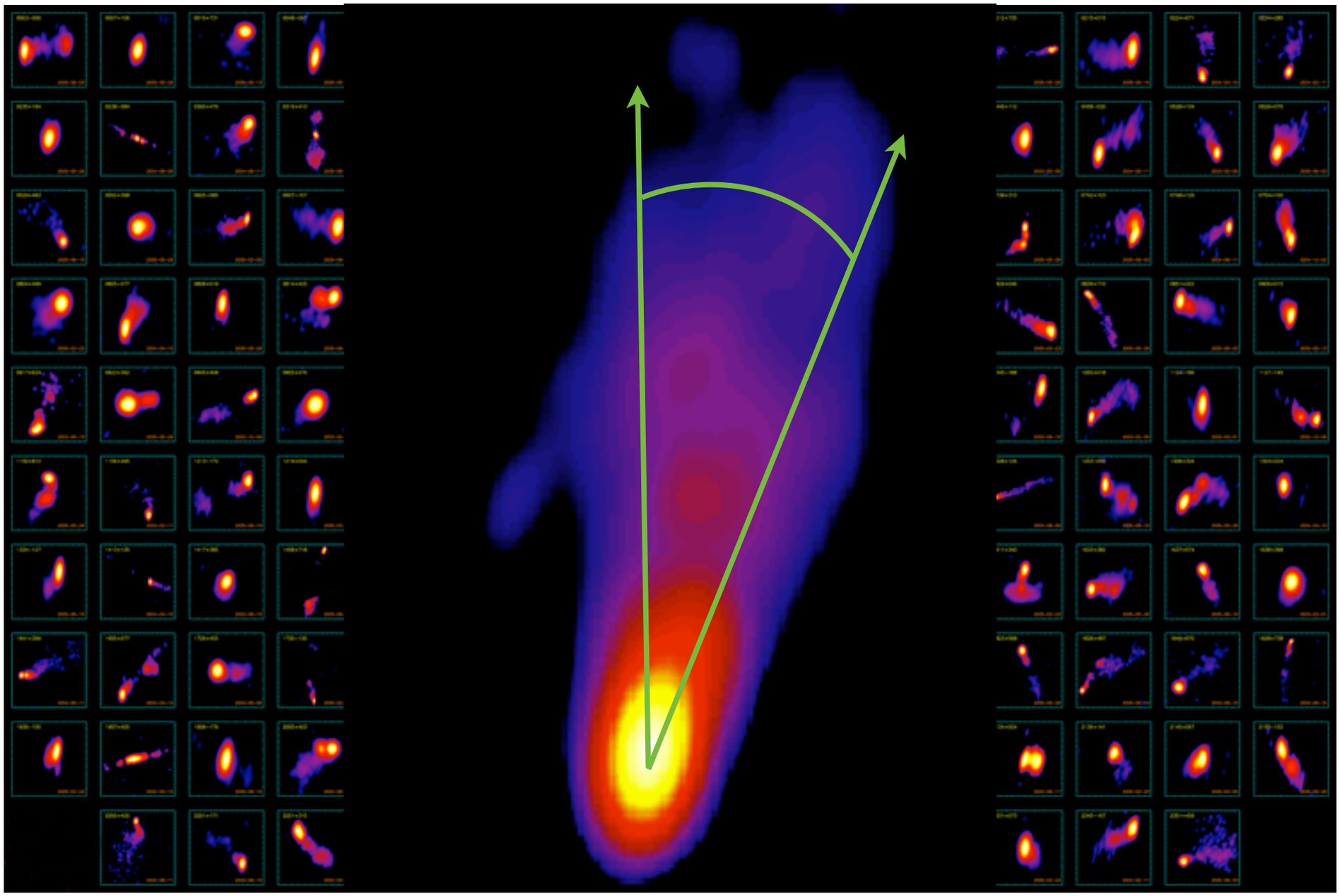


Theoretical $P(\theta_{\rm app})$

1) First we find viewing angle probability of jet

$P(\theta) = \sin\theta$ for unbiased random sample

But: flux-limited samples are highly biased towards blazars

$$P(\theta) = (\text{Doppler beaming bias}) \times \sin\theta$$

Cohen (1989), Vermeulen & Cohen (1994)

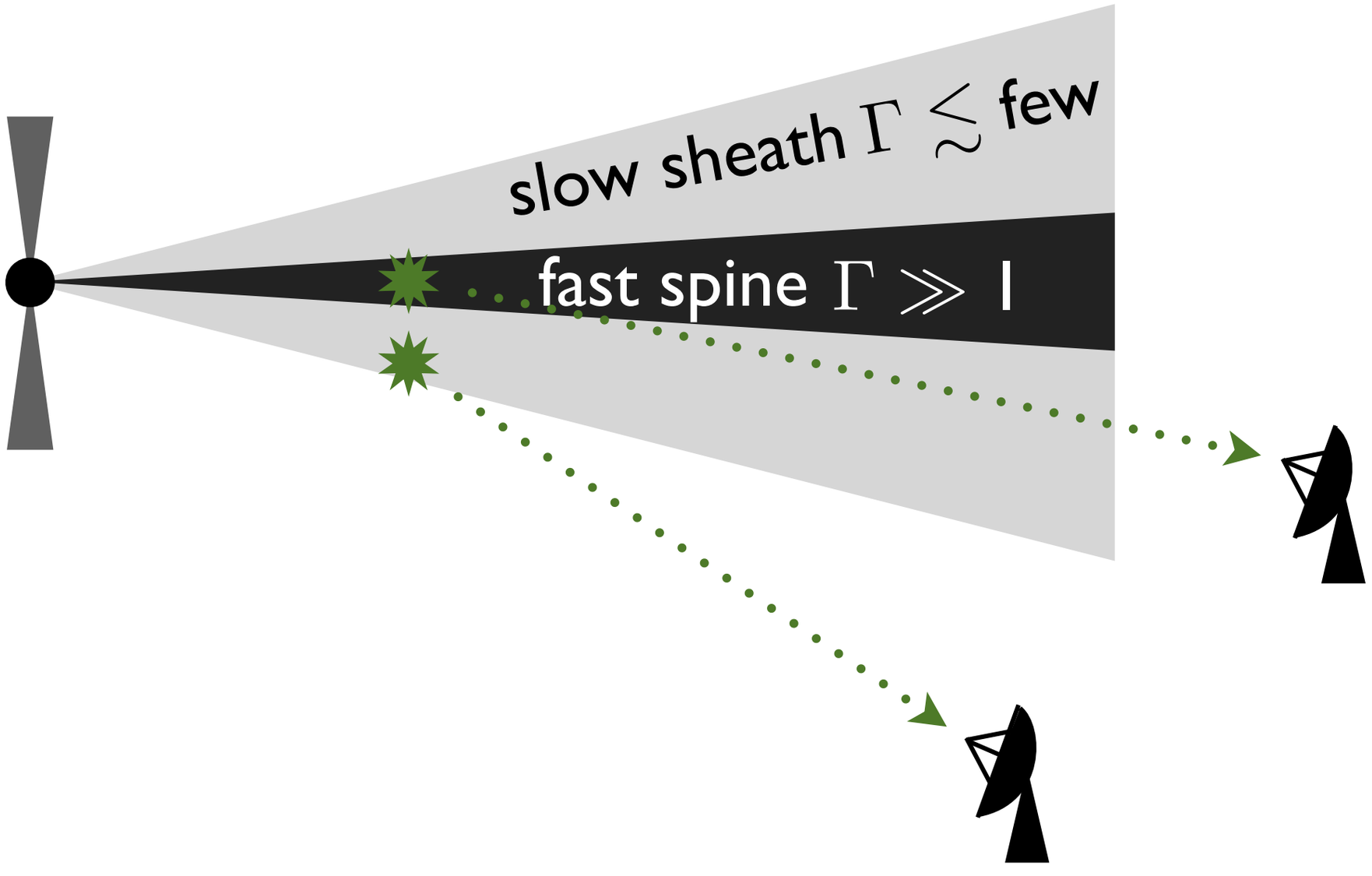
2) viewing angle prob. density → app. opening angle density

$$P(\theta_{\rm app}) = P(\theta(\theta_{\rm app})) \left| \frac{d\theta}{d\theta_{\rm app}} \right|$$

simplifying assumption:

$\Gamma\theta_{jet} =$ constant in MOJAVE sample

Next assumption:
velocity shear + Doppler beaming affect jet appearance



best fit: $\Gamma\theta_{jet} \approx 0.21 \pm 0.03$

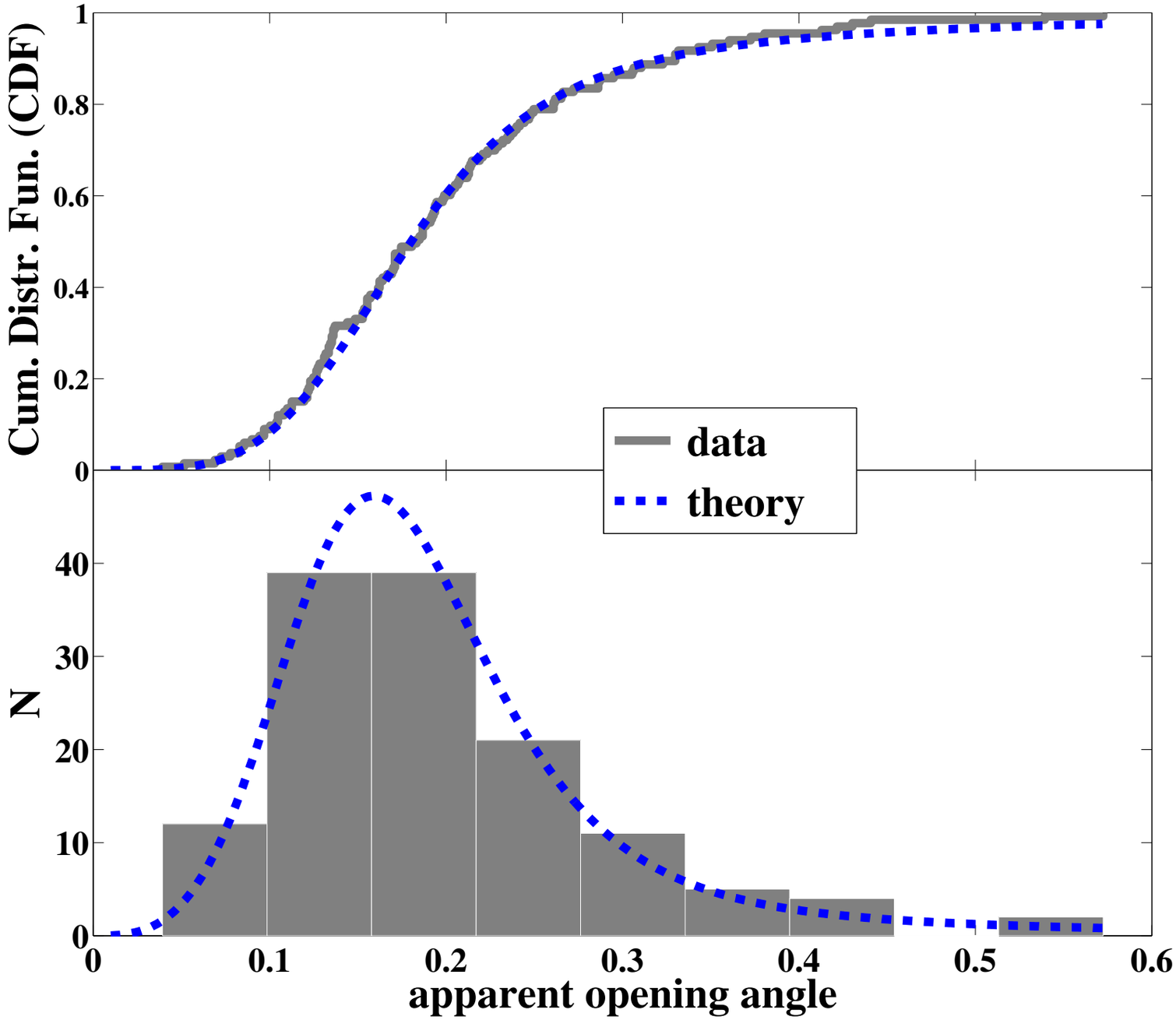
Comparison

causal connection criterion for relativistic sound speed:

$\Gamma\theta_{jet} \lesssim 0.7$

and equipartition Alfven speed:

$\Gamma\theta_{jet} \lesssim 1$



Either the signal speed is slow, or **AGN jets are causally connected**

What is $\Gamma\theta_{jet}$ for other types of relativistic outflows?

$\Gamma\theta_j$ is probably intimately connected to jet physics

AGN jets have $\Gamma\theta_{jet} \approx 0.2$

Clausen-Brown et al. (2013, in prep)
Pushkarev et al. (2009)
Jorstad et al. (2005)

GRB jets have $\Gamma\theta_j \sim$ tens

$$\rightarrow \quad \frac{\left(\Gamma\theta_j\right)_{\rm GRB}}{\left(\Gamma\theta_j\right)_{\rm AGN}} \sim 100$$

Different physics for AGN & GRBs?
GRB jet break-out?

Tchekhovskoy et al. (2010)
Komissarov et al. (2010)

Jet parameters!

$$\delta = \frac{\beta_{app} \tan \theta_{app}}{\beta(\Gamma \theta_{jet})}$$

$$\Gamma \approx \frac{\beta_{app}(1 + (\Gamma \theta_{jet})^2 \cot^2 \theta_{app})}{2(\Gamma \theta_{jet}) \cot \theta_{app}}$$

$$\theta_{ob} = \frac{2(\Gamma \theta_{jet})^2 \cot^2 \theta_{app}}{\beta_{app}(1 + (\Gamma \theta_{jet})^2 \cot^2 \theta_{app})}$$

Conclusion

- Jets are likely causally connected, as predicted by magnetic launching scenarios
- GRB jets have value of $\Gamma\theta_j$ 100 times greater than AGN jets, suggesting different physics at work

extra slides:

- ***MOJAVE*** (**M**onitoring **O**f **J**ets in **A**ctive galactic nuclei with **V**LBA **E**xperiments) is a long-term program to monitor radio brightness and polarization variations in jets associated with active galaxies visible in the northern sky