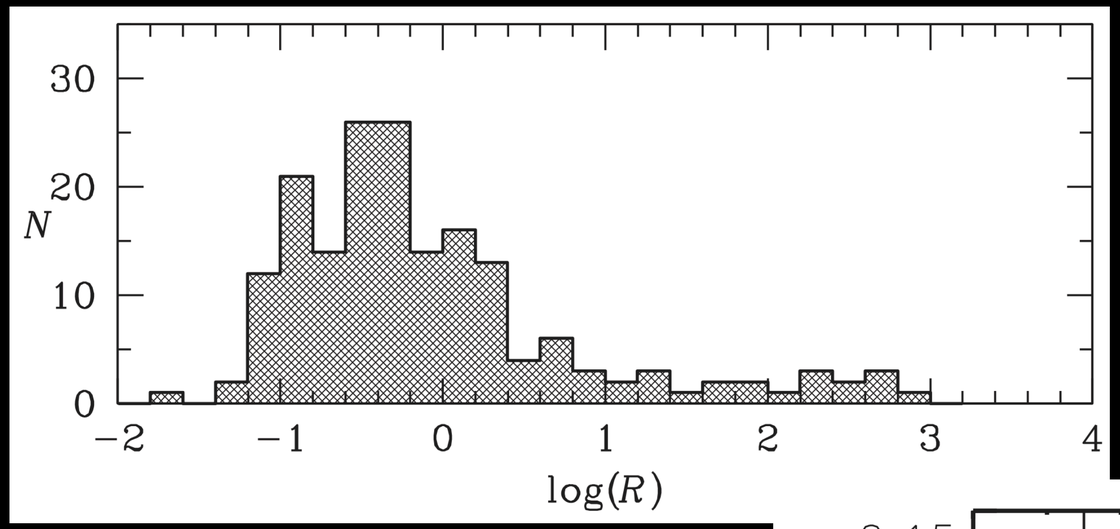
JETS FROM (COSMIC) DAWN TO NOON:

HOW TO FIND THE HIDDEN YOUNG JETS

Tullia Sbarrato
INAF - Osservatorio Astronomico di Brera

tullia.sbarrato@inaf.it

RADIO-LOUD AGN ACROSS COSMIC TIME



Kellermann et al. 2016

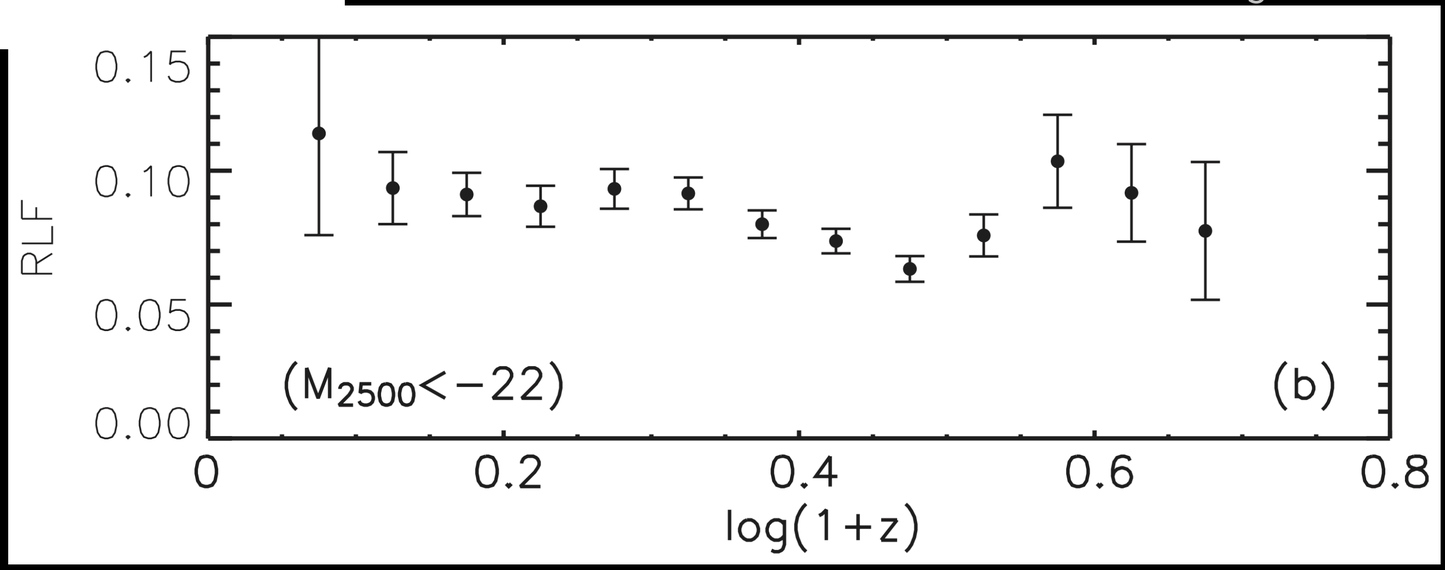
radio-loudness: jet-to-nucleus ratio

$$R = \frac{F_{5\,\mathrm{GHz}}}{F_{4400\,\text{Å}}}$$

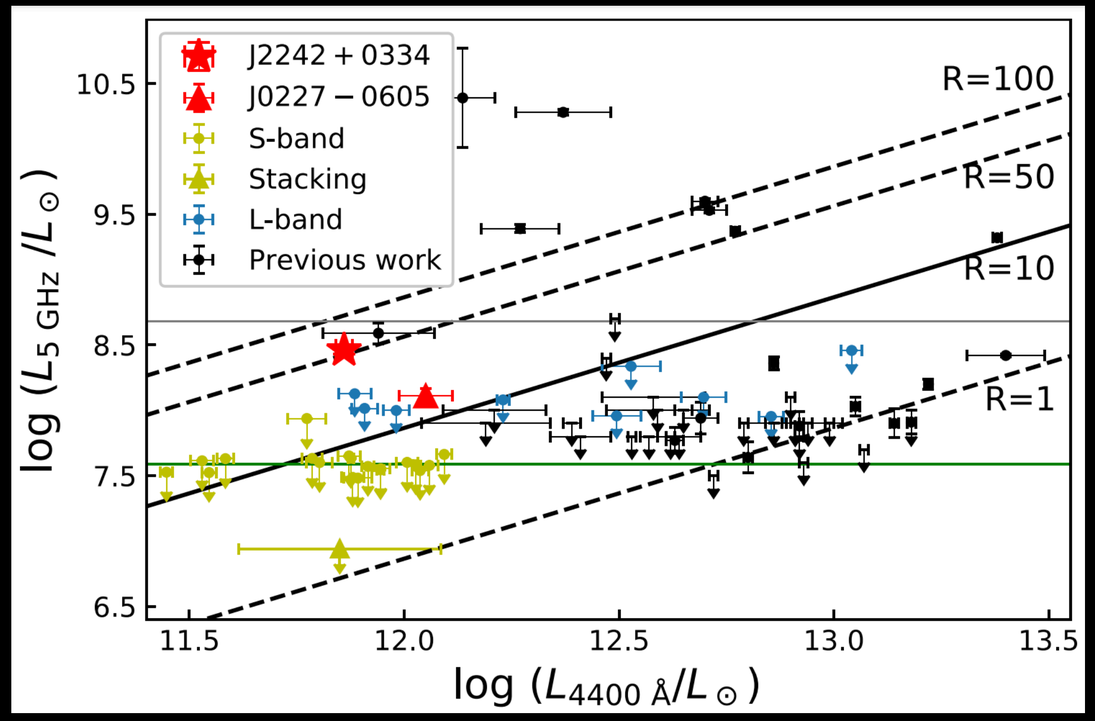
tracer of jet presence

— when extreme, traces jet orientation —

Jiang et al. 2007



RADIO-LOUDNESS AND JETS AT HIGH-Z



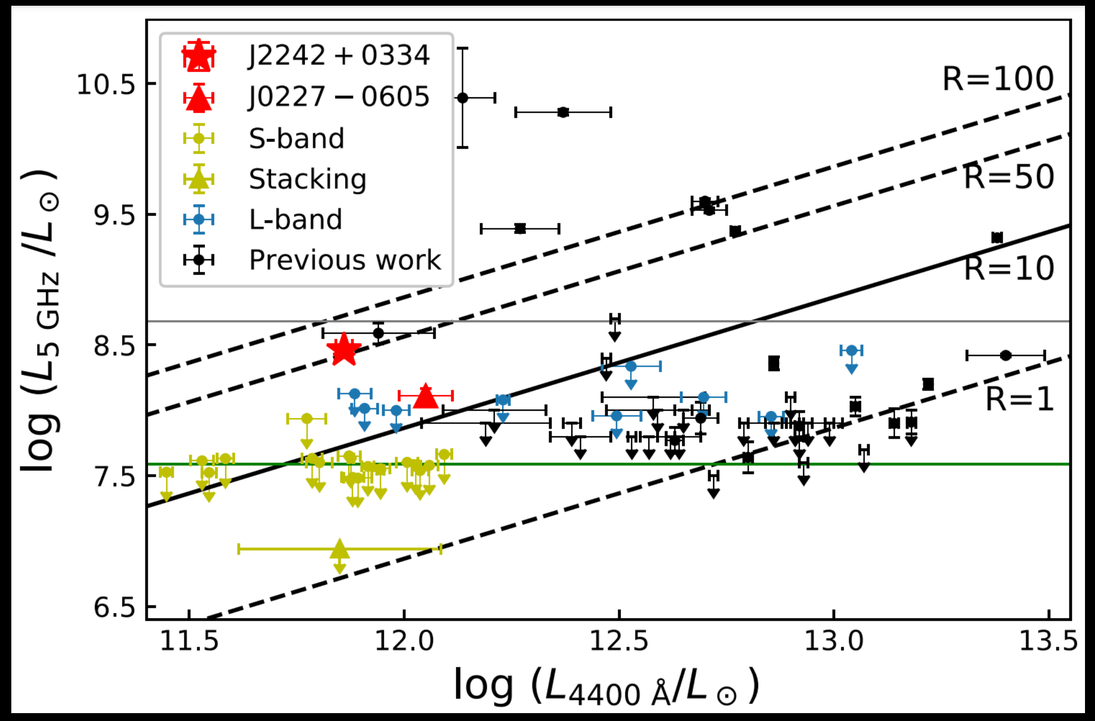
Liu et al. 2021

155/236 z>5.7 quasars with radio detection:

radio-loudness fraction: 9.4 ± 5.7%

consistent with local Universe

RADIO-LOUDNESS AND JETS AT HIGH-Z



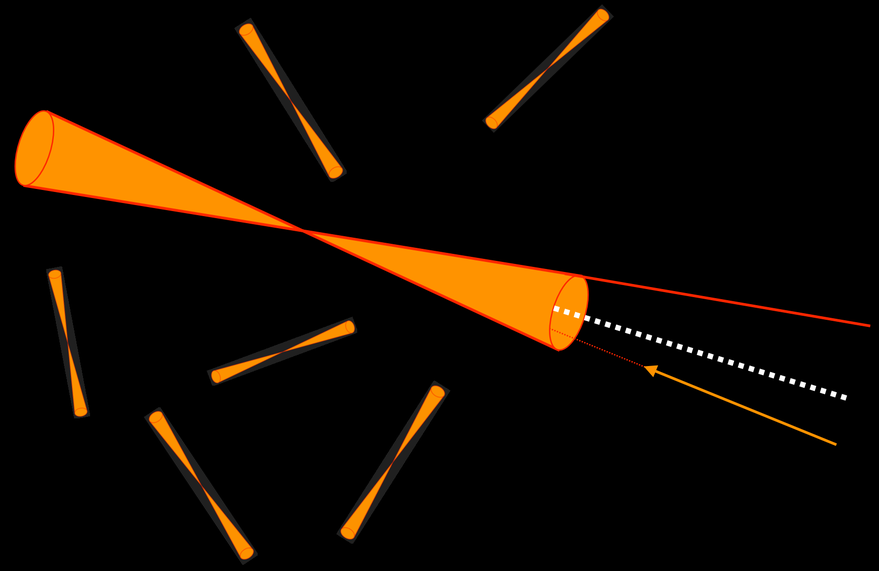
Liu et al. 2021

155/236 z>5.7 quasars with radio detection:

radio-loudness fraction: 9.4 ± 5.7%

consistent with local Universe

known jet orientation ⟶ infer jetted population

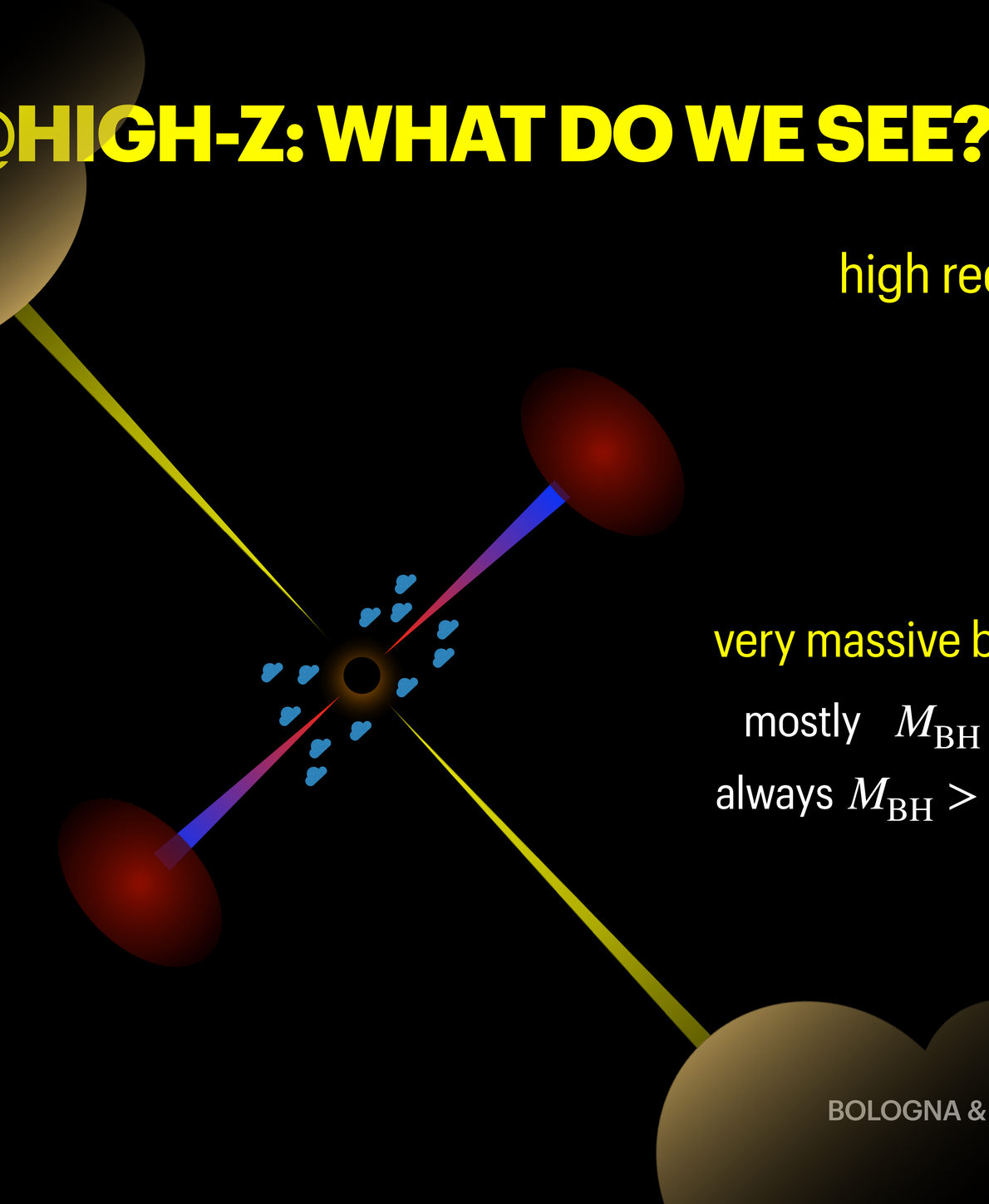


radio flux is close to catalogs flux limits

look for more aligned jets!

JETTED AGN @HIGH-Z: WHAT DO WE SEE?

high redshift: z>4



quasars:

broad emission lines

bright big blue bump

high accretion rate

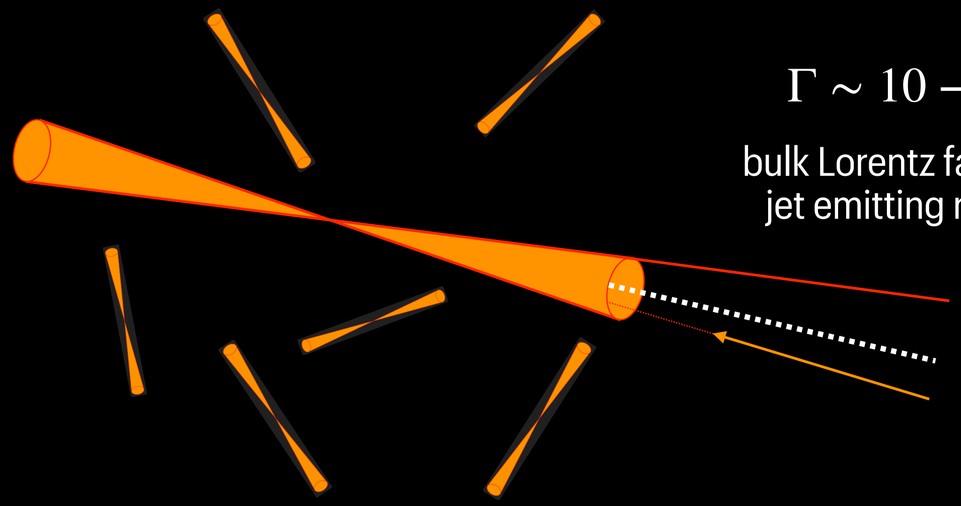
$\lambda_{\rm Edd} > 10\,\%$

very massive black holes:

mostly $M_{\rm BH} > 10^9 M_\odot$

always $M_{\rm BH} > 5 \times 10^8 M_\odot$

BLAZARS AS JET TRACERS



$\Gamma \sim 10 - 15$

bulk Lorentz factor of
jet emitting region

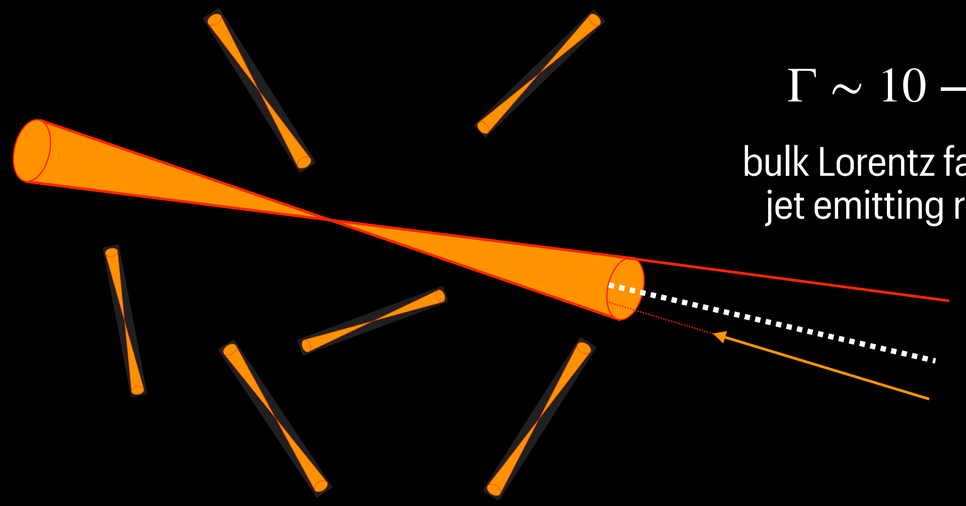
viewing angle:

$\theta_v < 1/\Gamma$

analogous jetted AGN,
randomly oriented:

$2\Gamma^2 \sim 200 - 450$

BLAZARS AS JET TRACERS



$\Gamma \sim 10 - 15$

bulk Lorentz factor of jet emitting region

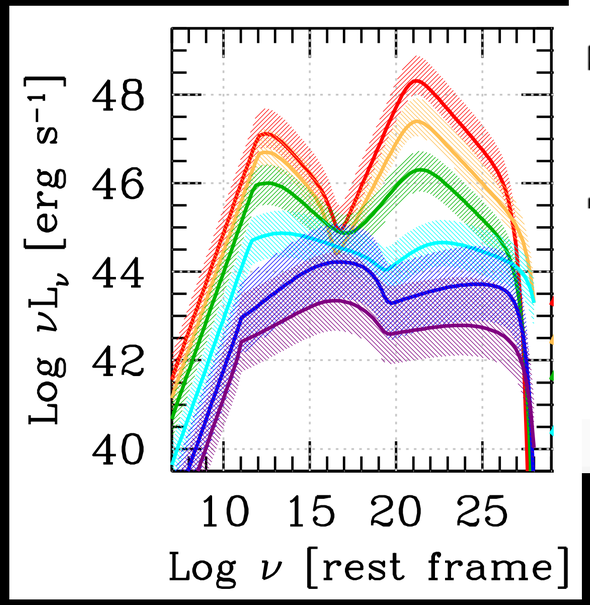
Ghisellini et al. 2017

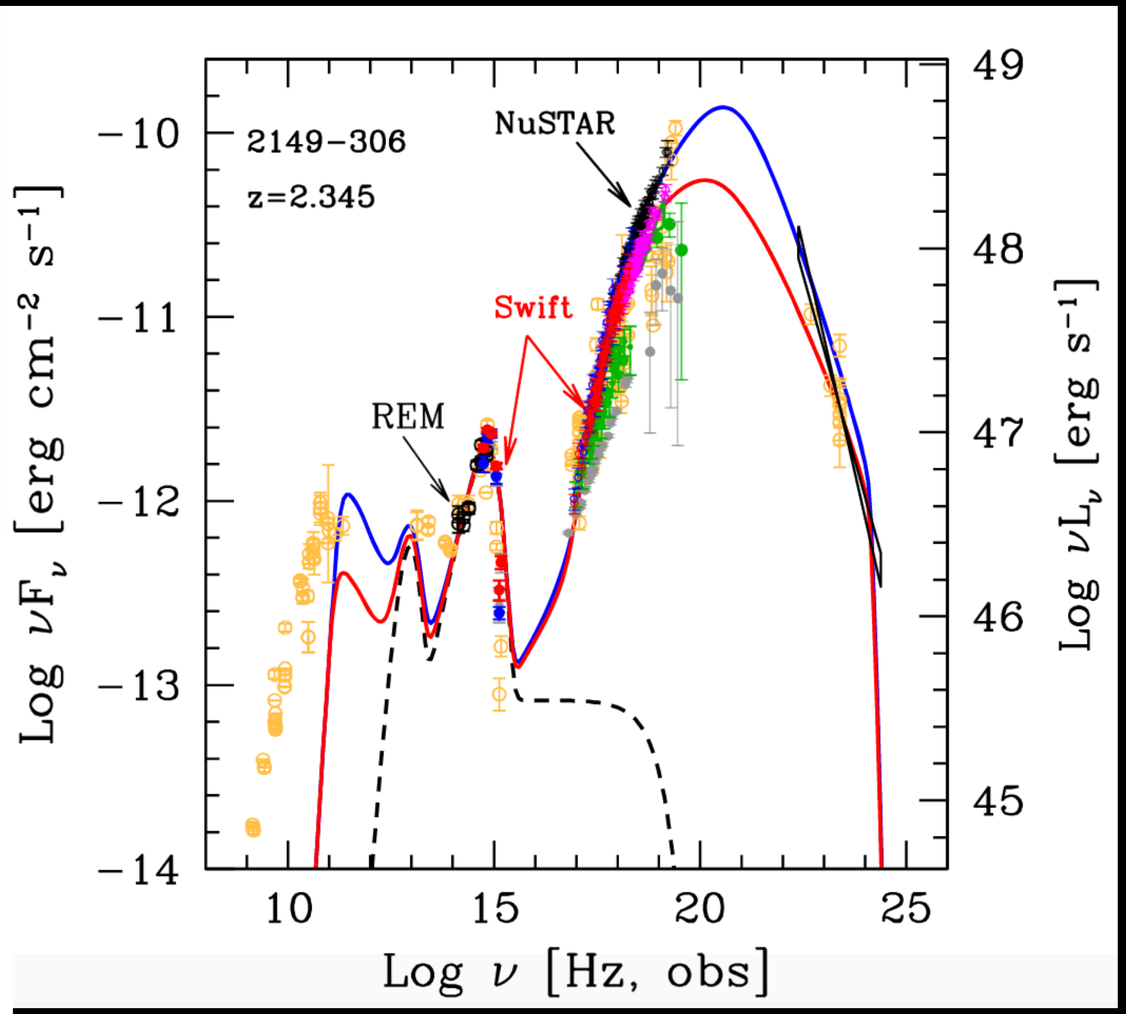
viewing angle:

$\theta_v < 1/\Gamma$

analogous jetted AGN, randomly oriented:

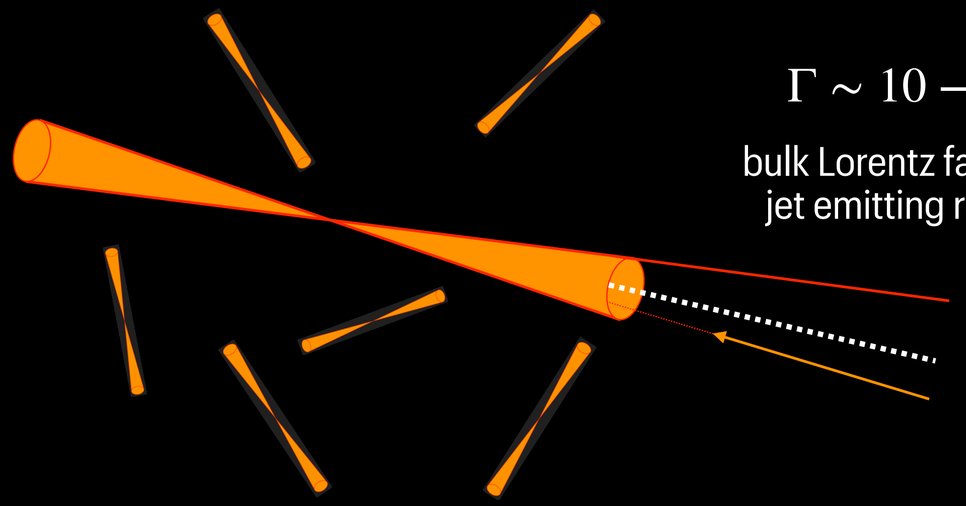
$2\Gamma^2 \sim 200 - 450$





Tagliaferri et al. 2015

BLAZARS AS JET TRACERS



$\Gamma \sim 10 - 15$

bulk Lorentz factor of jet emitting region

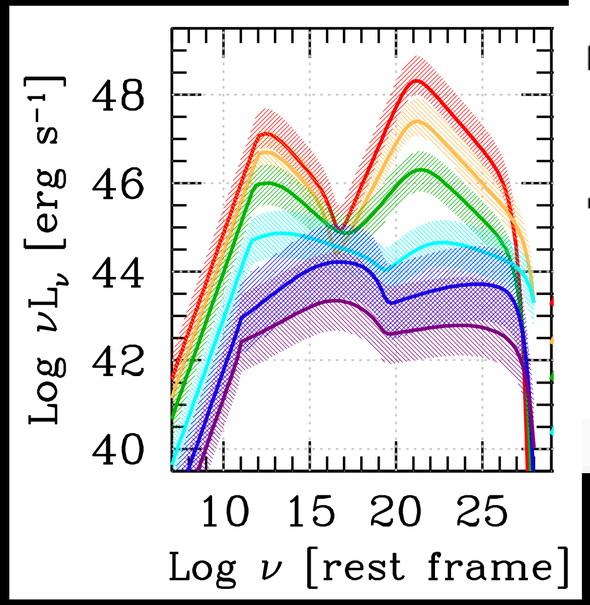
Ghisellini et al. 2017

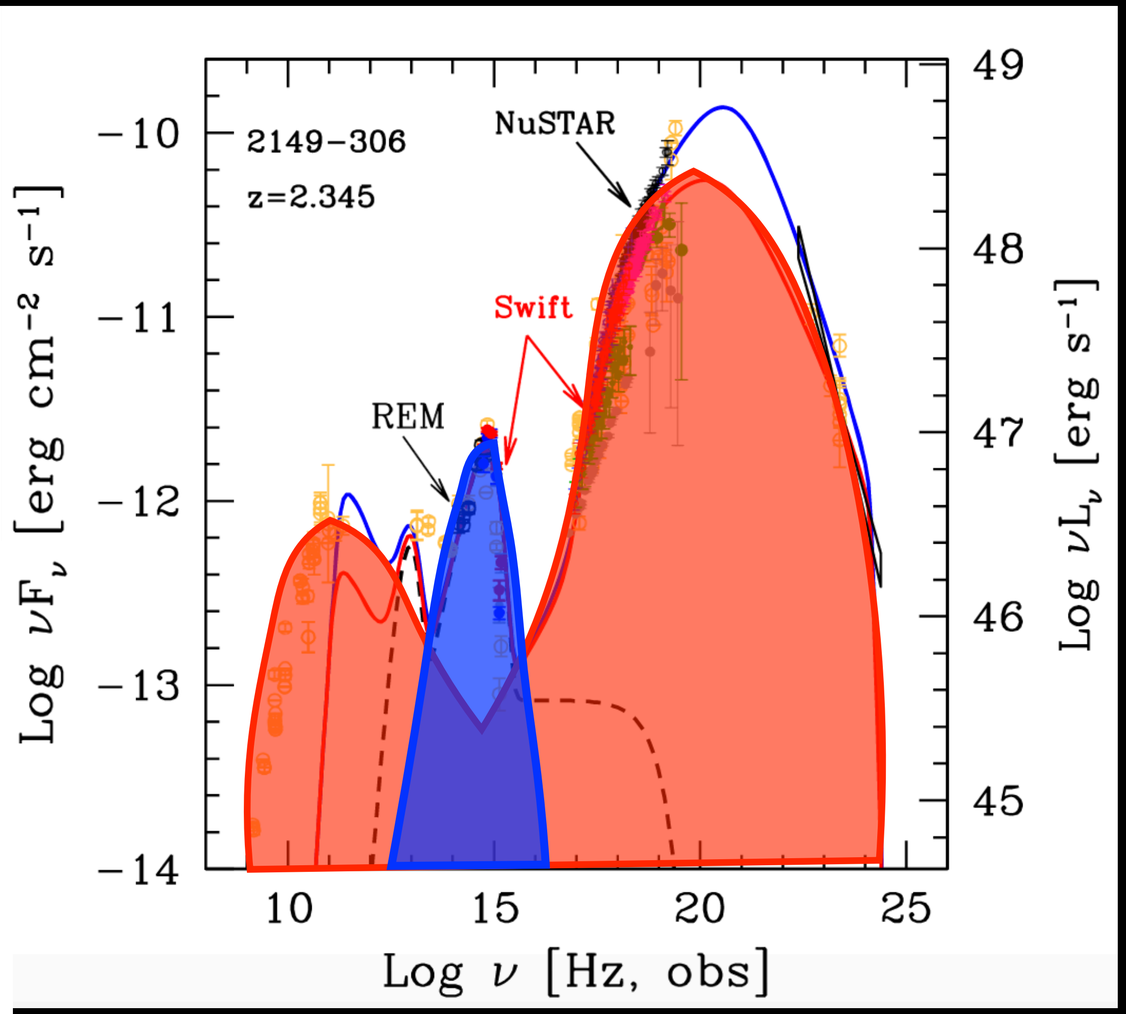
viewing angle:

$\theta_v < 1/\Gamma$

analogous jetted AGN, randomly oriented:

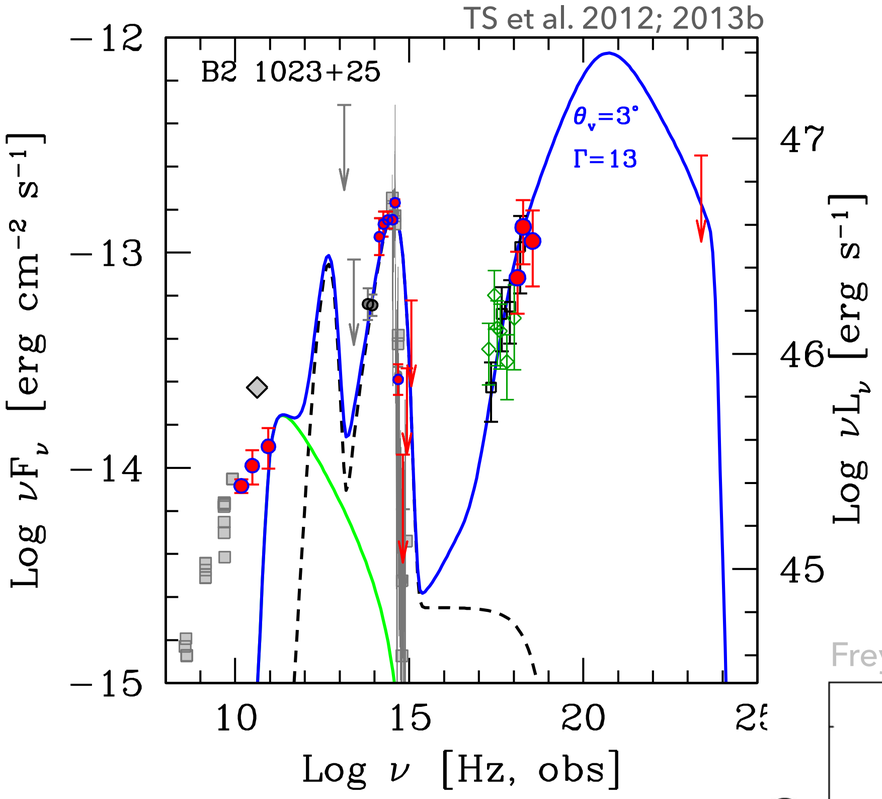
$2\Gamma^2 \sim 200 - 450$

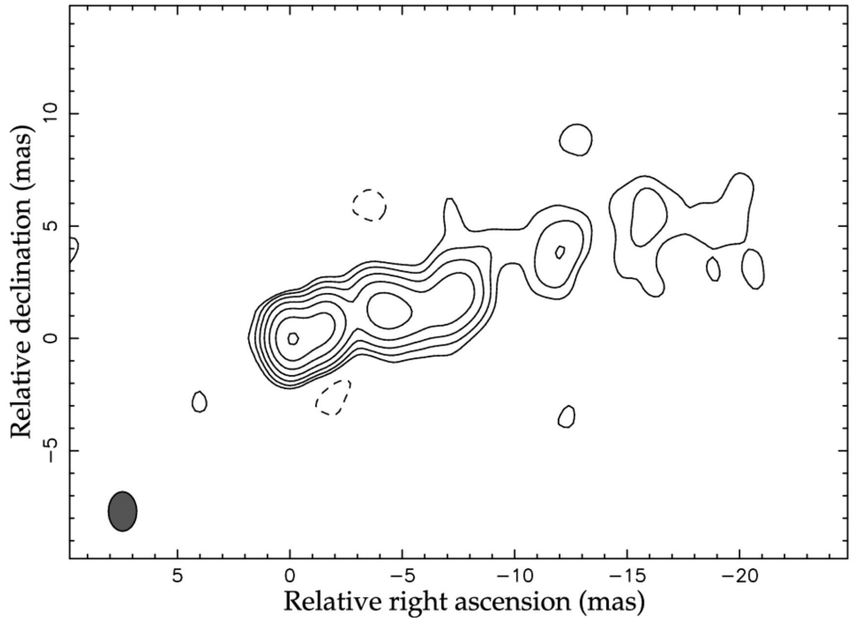




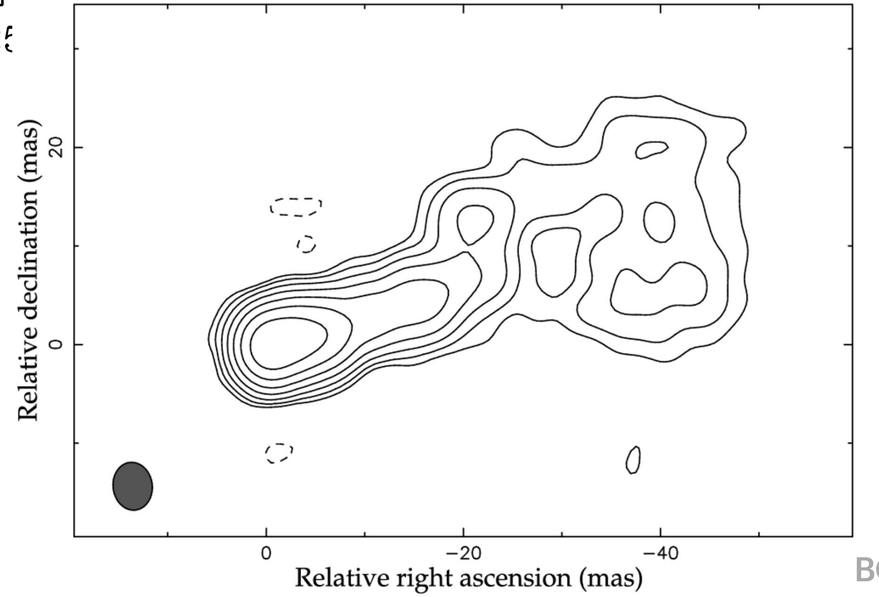
Tagliaferri et al. 2015

TS et al. 2012; 2013b





Frey et al. 2015



archetypal high-z blazar:

$z = 5.3$

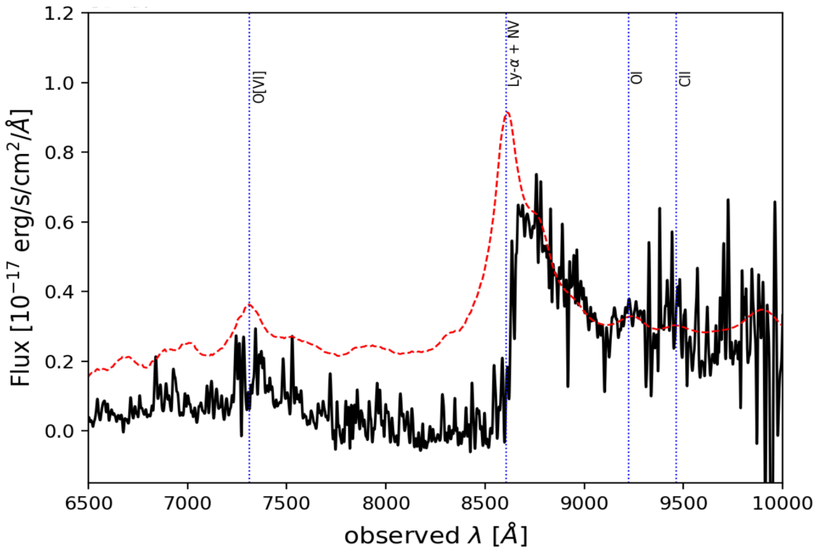
$M_{\rm BH} > 10^9 M_\odot$

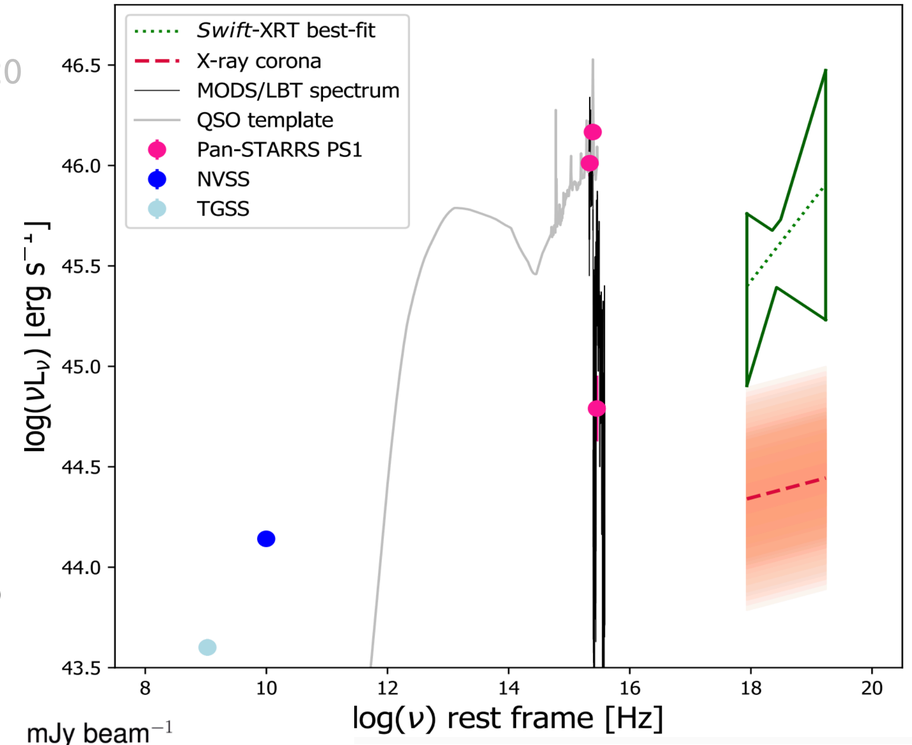
first z>6 blazar:

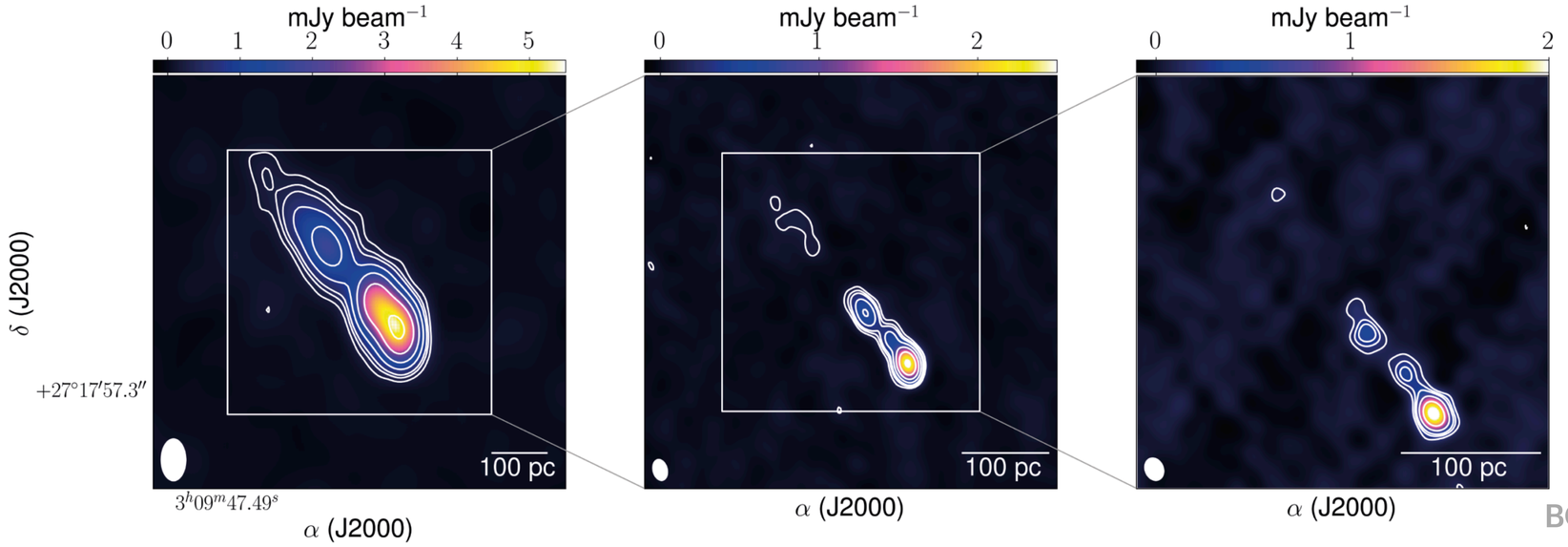
$z = 6.1$

$M_{\rm BH} \simeq 10^9 M_\odot$

Belladitta et al. 2020

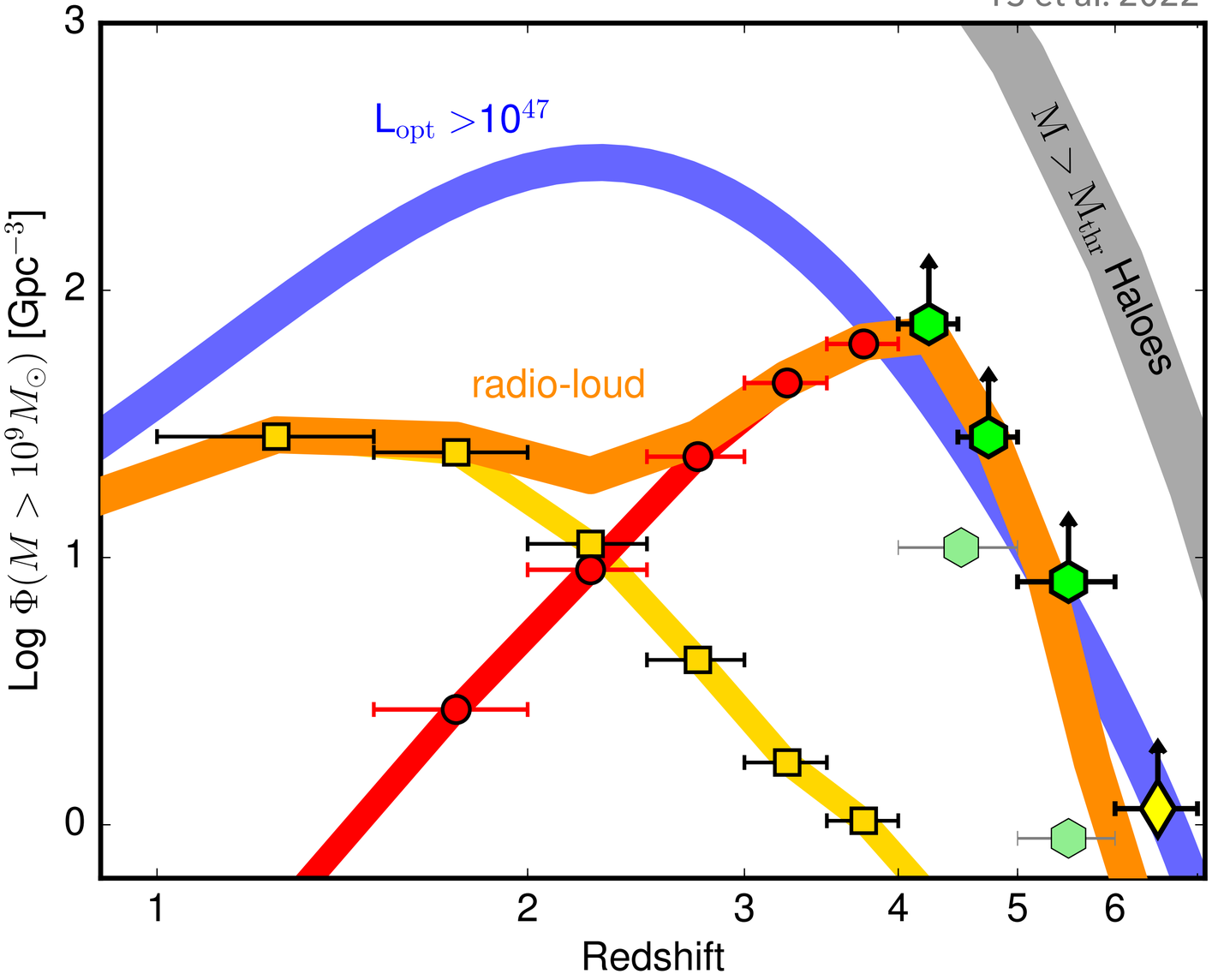






Spingola et al. 2020

TS et al. 2022

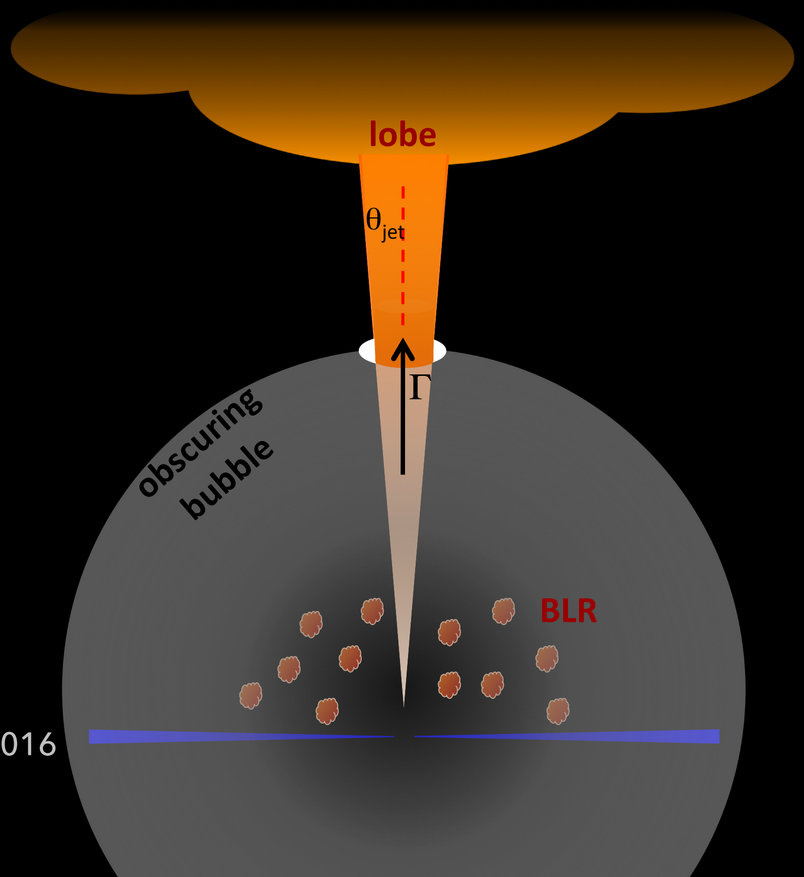


MASSIVE SMBHS SEEM TO PREFER FORMING/LIVING IN JETTED AGN AT VERY HIGH REDSHIFT

ISSUE 1: JETS OVER-REPRESENT RADIO-LOUD AGN

only from “our” 12 blazars

infer the presence of **~4000** analogous jetted sources!



Ghisellini & TS, 2016

radio-loudness

$$R = \frac{F_{\rm radio}}{F_{\rm opt}} > 100$$

31

radio-detected (>1mJy):

53

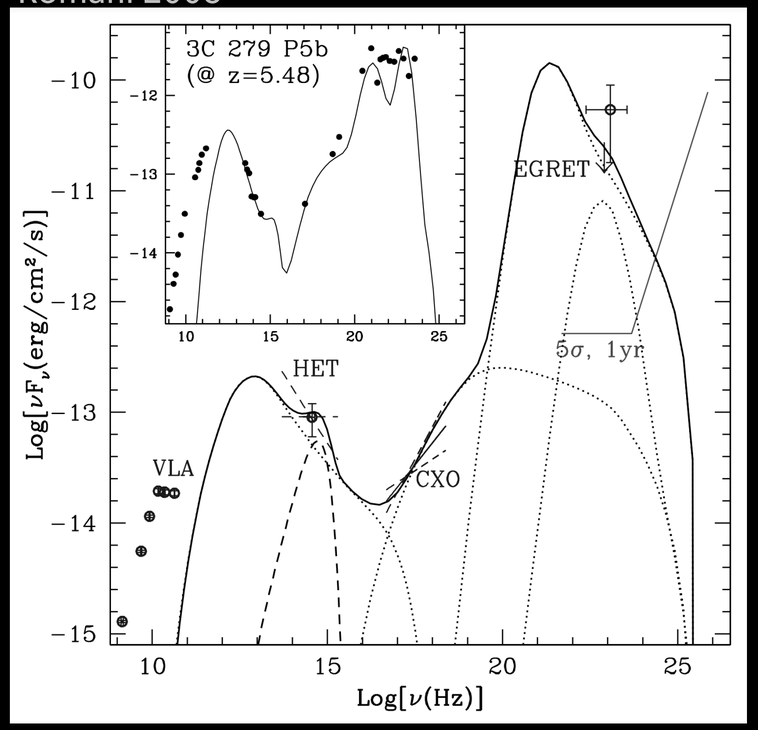
QUASARS AT Z>4 MIGHT BE OVER-OBSCURED!

(see also Gilli et al. 2022)

ISSUE 2: THEIR NATURE IN DIFFERENT BANDS

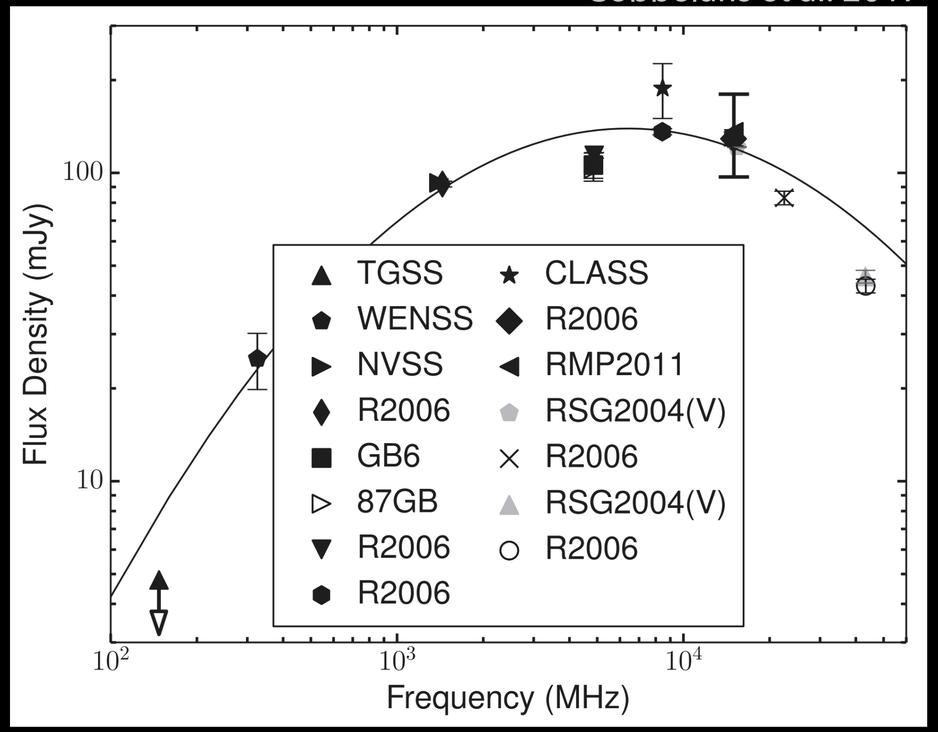
some quasars are classified as blazars according to high-energy features but have a peaked radio spectrum (CSS/GPS-like)

Romani 2006



Be careful:
you won't always find the radio flat spectra you would expect!

Coppejans et al. 2017

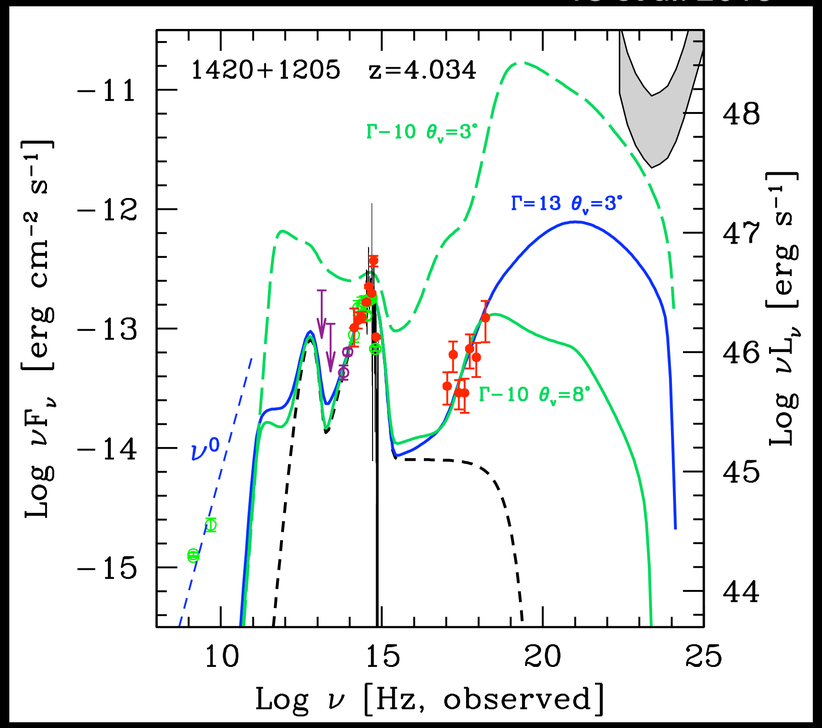


ARE JETS YOUNGER AT HIGH-Z?
VERY REASONABLE!

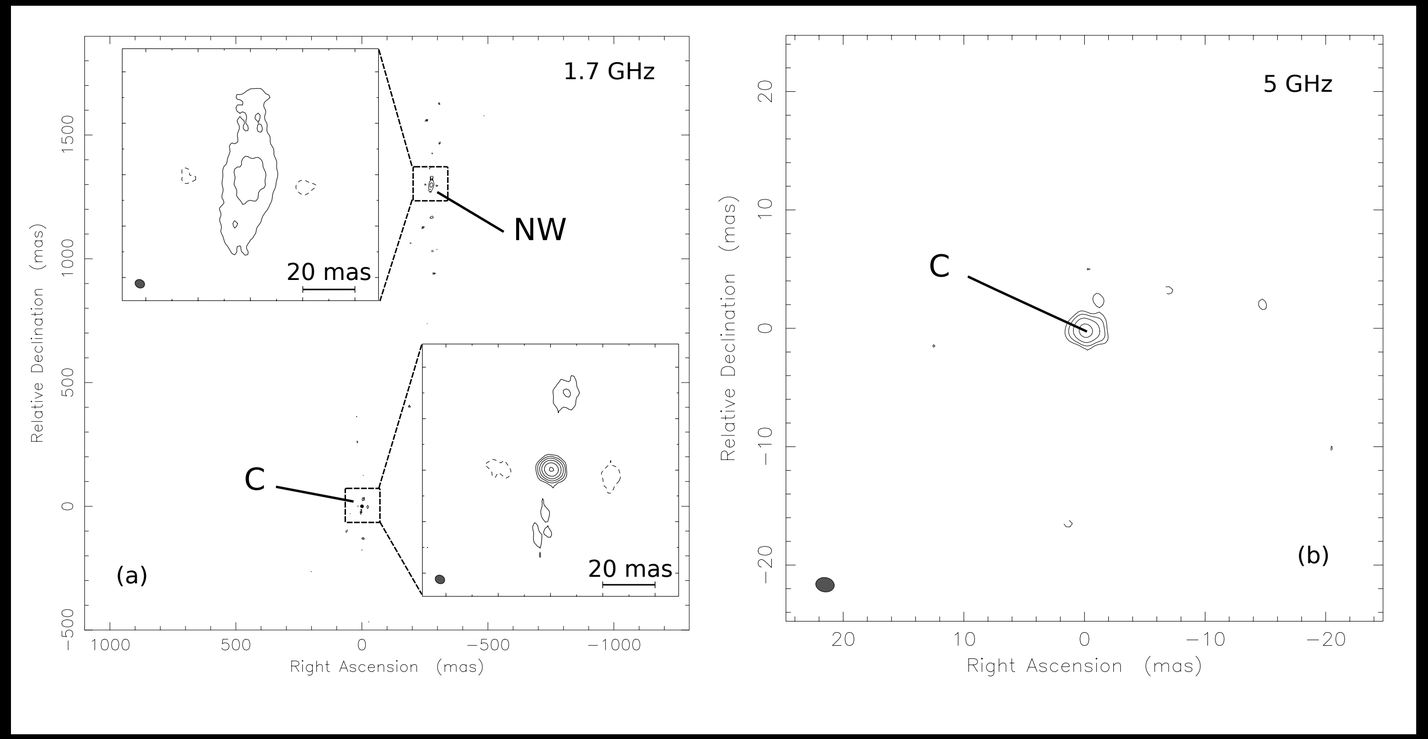
ISSUE 2: THEIR NATURE IN DIFFERENT BANDS

some quasars are classified as blazars with broad-band SED (driven by X-rays) and appear misaligned in high-res radio!

TS et al. 2015



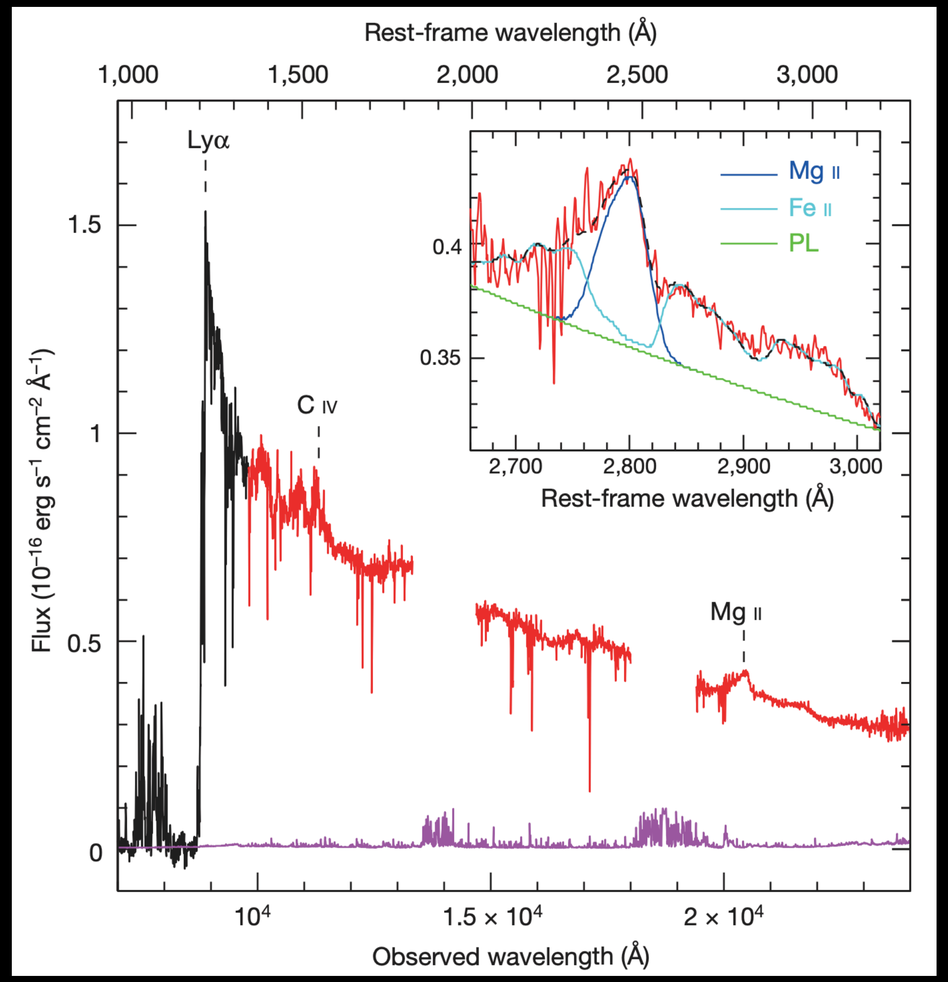
Cao et al. 2015



DO JETS BEND MORE EASILY IN THE EARLY UNIVERSE?

ISSUE 3: RADIO-QUIET, YET POWERFUL JETS!

Wu et al. 2015



SDSS J0100+2802

z=6.3

radio-quiet with VLBA: $R = 0.45$

$M_{\rm BH} > 10^{10} M_\odot$

ISSUE 3: RADIO-QUIET, YET POWERFUL JETS!

one-sided jet emission ~12-14 arcsec (~70kpc) long

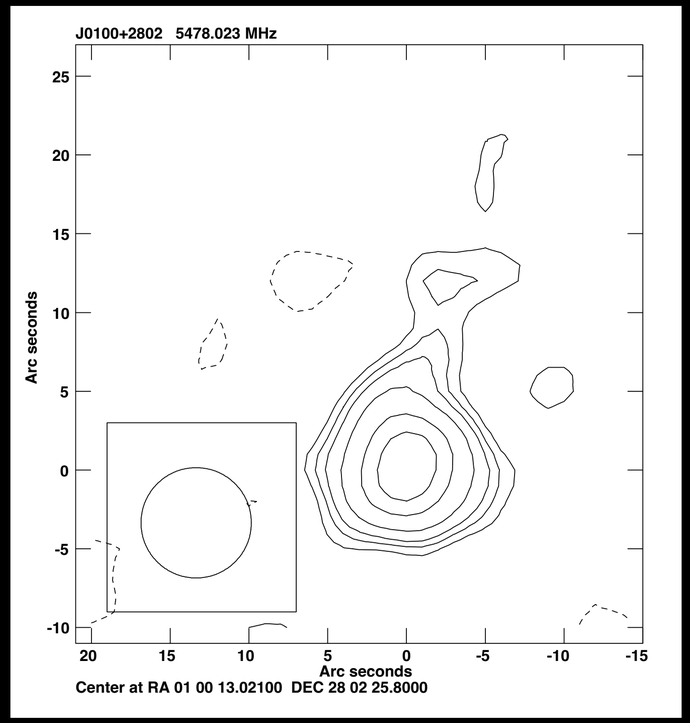
TS et al. 2021

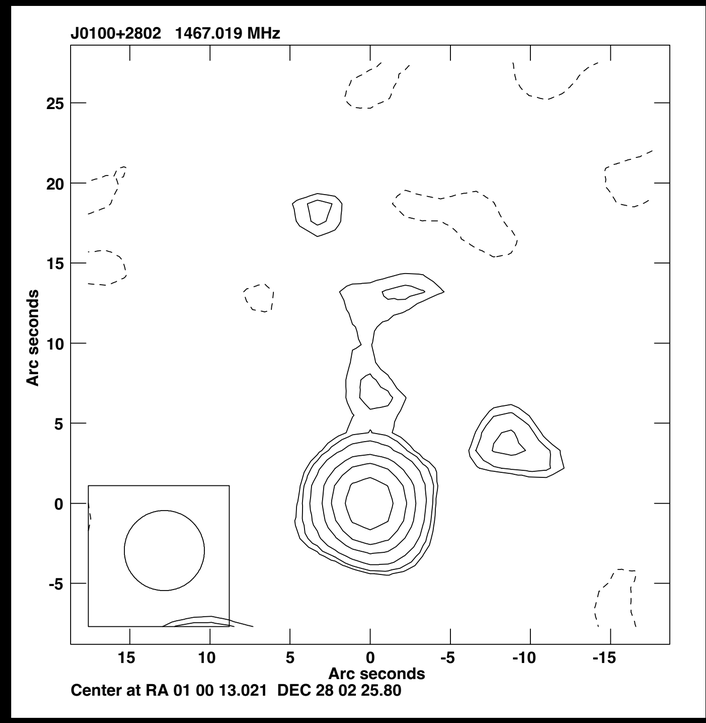
$$@\,1.5\,\mathrm{GHz}: \quad \mathrm{Log}\,\frac{P_c}{\mathrm{W/Hz}} = 25.45$$

$$\mathrm{Log}\,\frac{P_t}{\mathrm{W/Hz}} = 25.84$$

$$@\,5\,\mathrm{GHz}: \quad \mathrm{Log}\,\frac{P_c}{\mathrm{W/Hz}} = 25.61$$

$$\mathrm{Log}\,\frac{P_t}{\mathrm{W/Hz}} = 25.70$$





$$P_{\mathrm{jet}} \sim 9 \times 10^{45} - 4 \times 10^{47}\,\mathrm{erg/s}$$

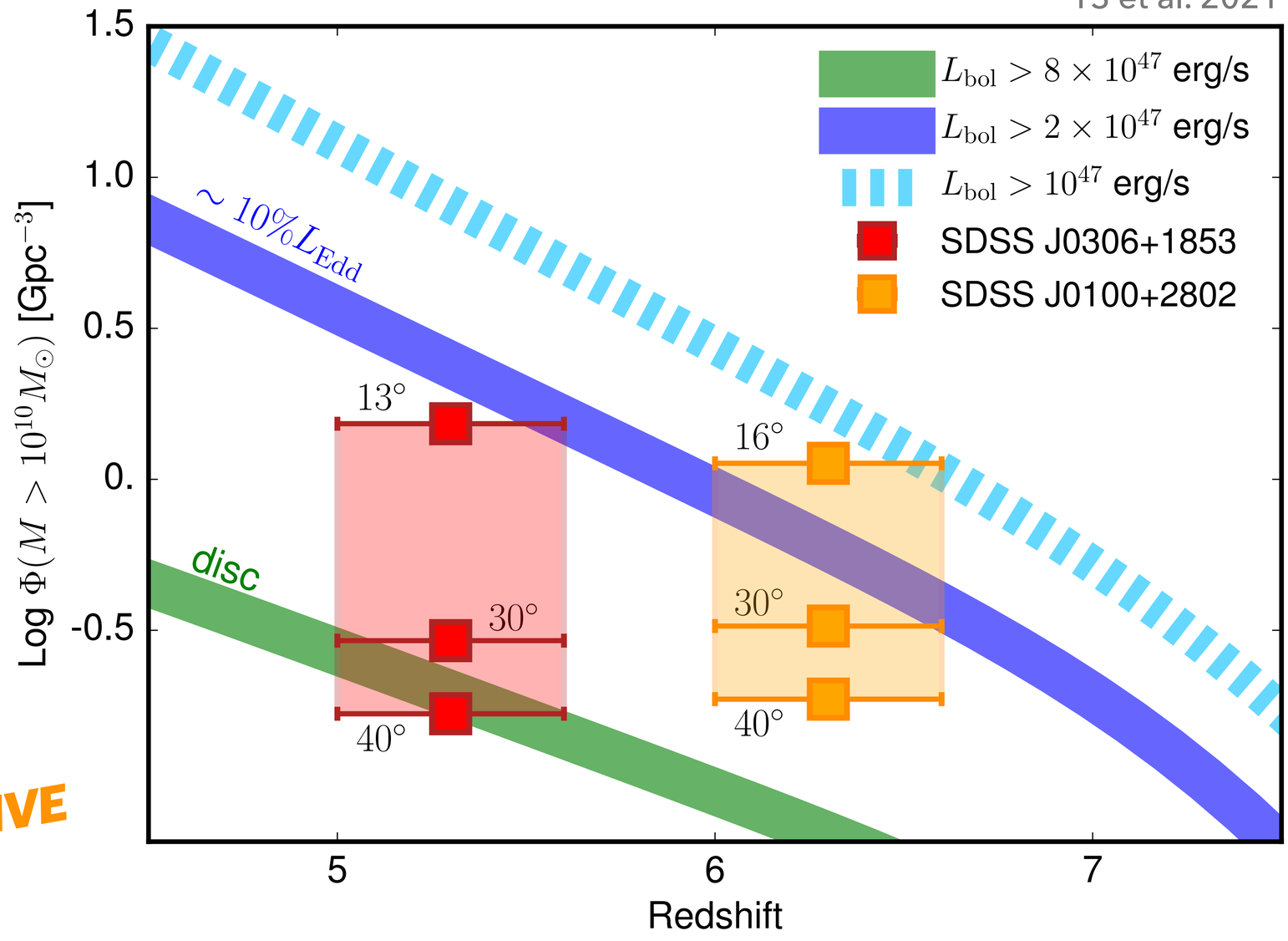
$$\theta_{\mathrm{v}} \sim 16^{\circ} - 30^{\circ}$$

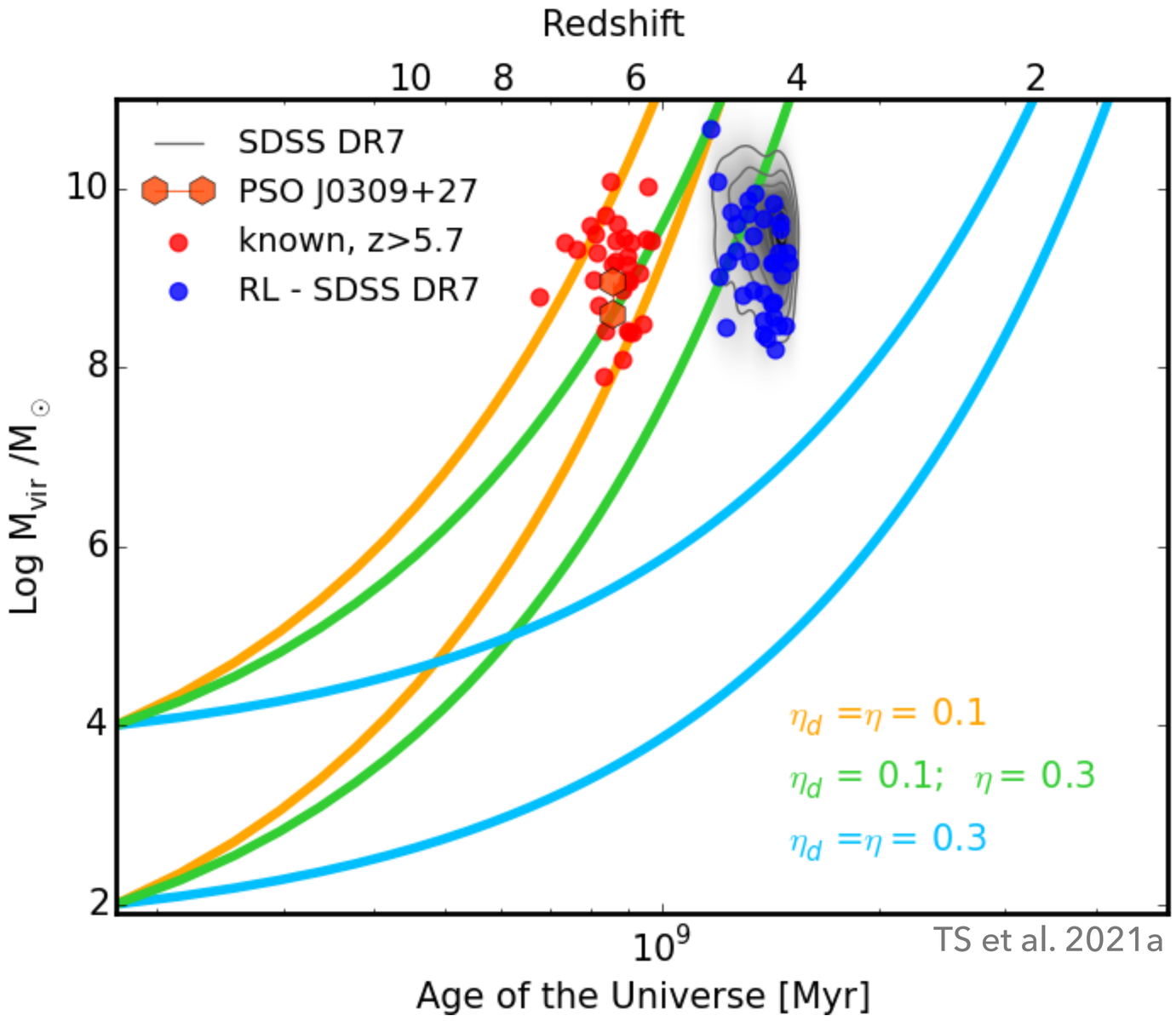
radio-loudness is not a reliable tracer of jet presence at high-z!

TS et al. 2021

radio-loudness is not a reliable tracer of jet presence at high-z!

HOW CAN JETS PLAY A ROLE IN FORMING AND "GROWING" EARLY SUPERMASSIVE BLACK HOLES?





$$L_{\rm d} = \eta_{\rm d}\dot{M}c^2$$

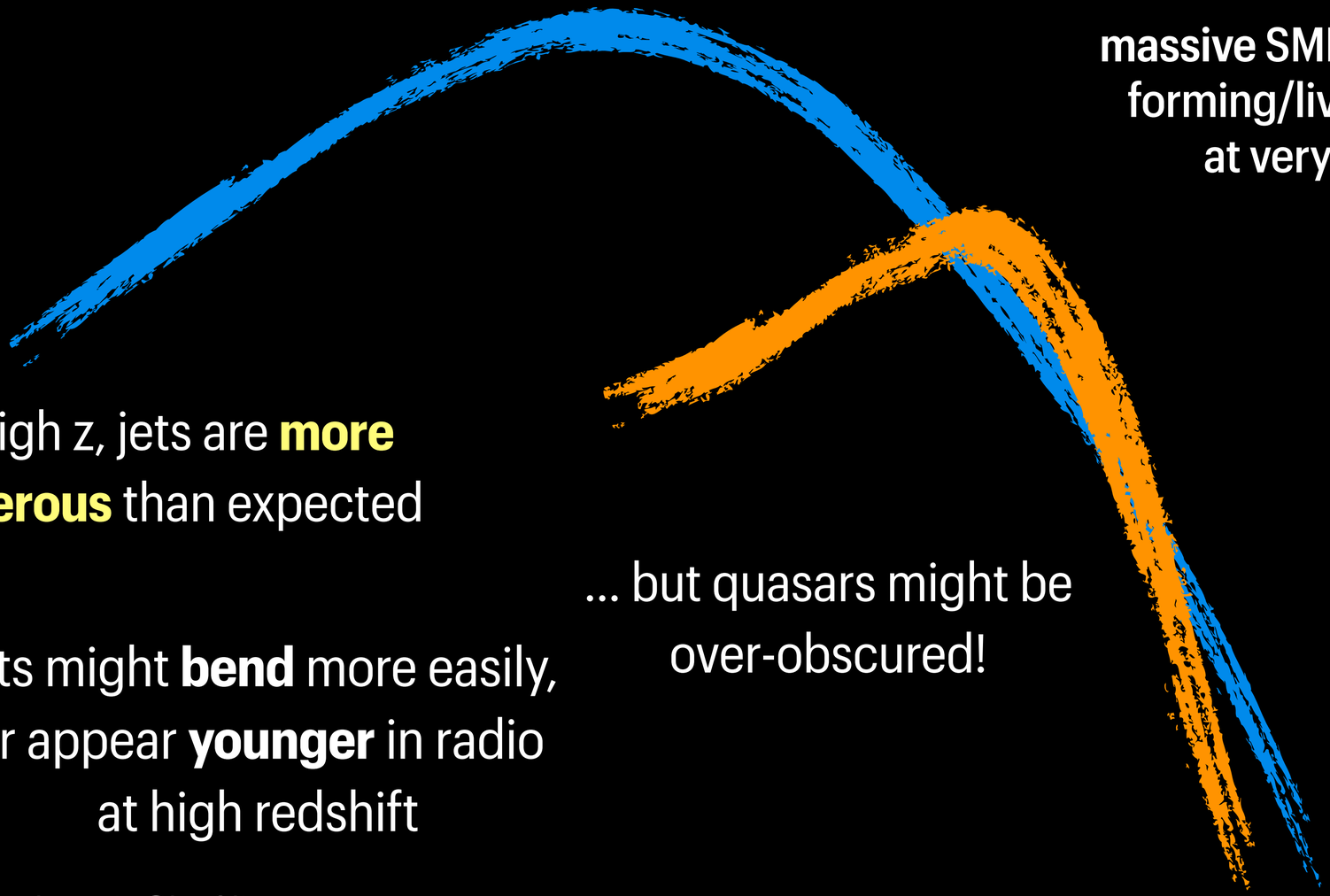
$$\eta = \eta_{\rm d} + \eta_{\rm j}$$

the very presence of these extremely massive jetted sources would imply seed black holes of masses $> 10^7 M_\odot$

JET EXPLOITS PART OF THE GRAVITATIONAL ENERGY RELEASED TO LAUNCH?

JET INTERACTS WITH SMBH ENVIRONMENT? TRIGGERS MATTER INFALL?

SO MANY JETTED QUASARS!



massive SMBHs seem to prefer forming/living in jetted AGN at very high redshift

at high z, jets are **more numerous** than expected

... but quasars might be over-obscured!

not consistent with the observed radio-loudness fraction!

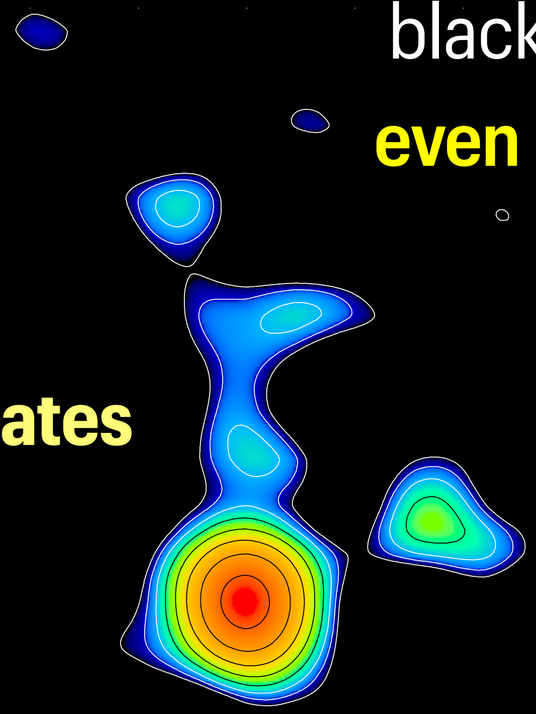
jets might **bend** more easily, or appear **younger** in radio at high redshift

tullia.sbarrato@inaf.it

SO MANY JETTED QUASARS!

at high z, jets are more numerous than expected

all extremely massive black holes might host jets, **even if they are radio-quiet!**



radio-loudness **underestimates** the jetted population at high redshift

jets might play a crucial role in fast evolution of massive black holes