THE ALMA VIEW OF THE HIGH REDSHIFT RELATION BETWEEN SUPERMASSIVE BLACK HOLES AND THEIR HOST GALAXIES

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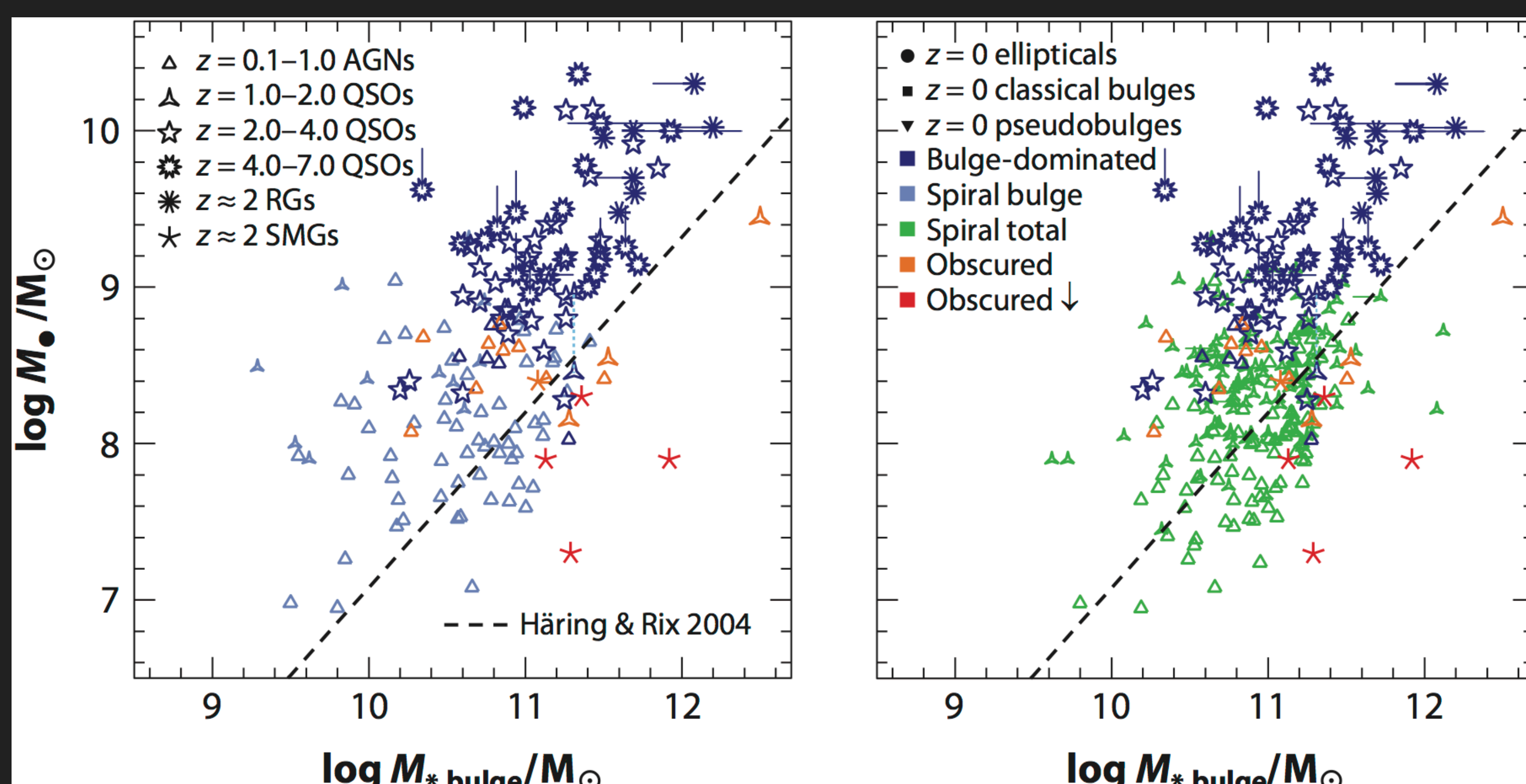
BH-GALAXY SCALING RELATION

✳ **AGNs** are powered by **accretion of matter onto a SMBH**. The energy released in this process is ≳ galactic bulge binding energy.

➡ Relation between M_{BH} and the global properties of the host galaxy:

$$\text{Log } M_{BH} = \alpha + \beta \text{ Log } M_{gal}$$



Kormendy & Ho, 2013

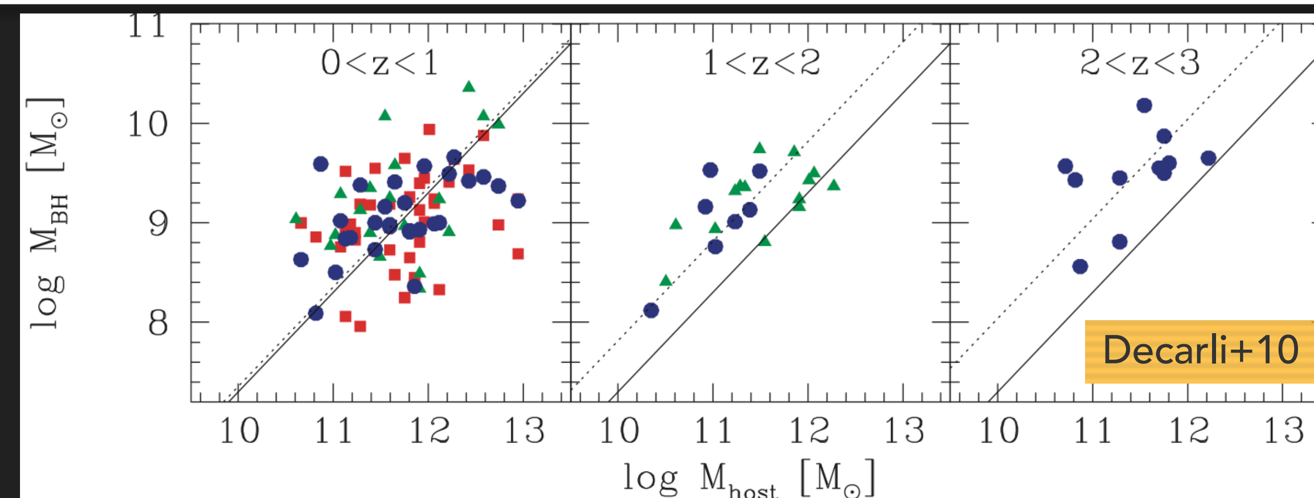
STATE OF THE ART

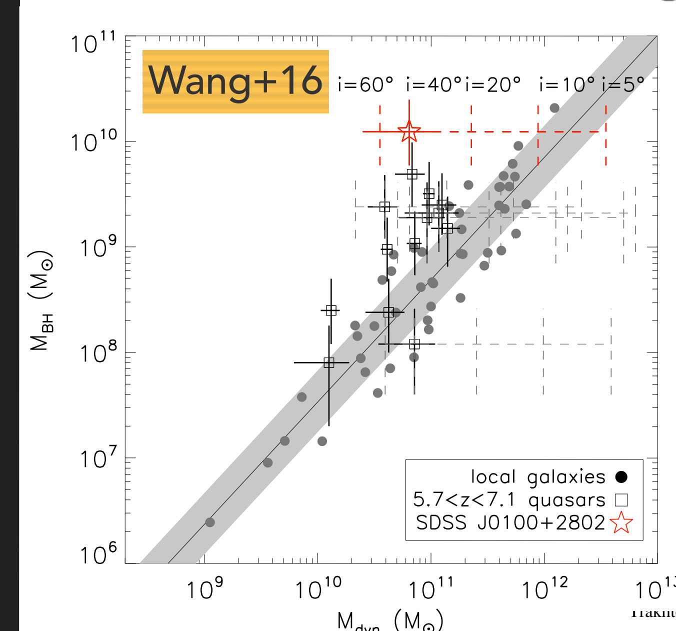
* @ **z <1-3,** the galaxies host **BHs** that are up to ~7 times **more massive** with respect to the local ones
(Peng+06, Treu+04,07 , Woo+06,08, Bennert+10,11, Decarli+09,10, Alexander+09, Merloni+10)

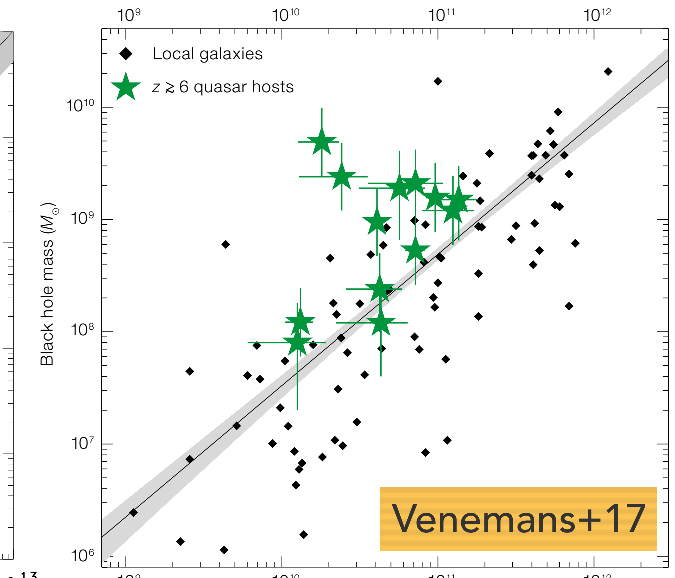
* $\boldsymbol{M_{BH}/M_{gal}}$ increases at higher $\boldsymbol{z}$ ➡ $\boldsymbol{M_{BH}}$ up to ~10% of $\boldsymbol{M_{gal}}$
(Wu+07, Ho+07, Maiolino+09, Walter+09)

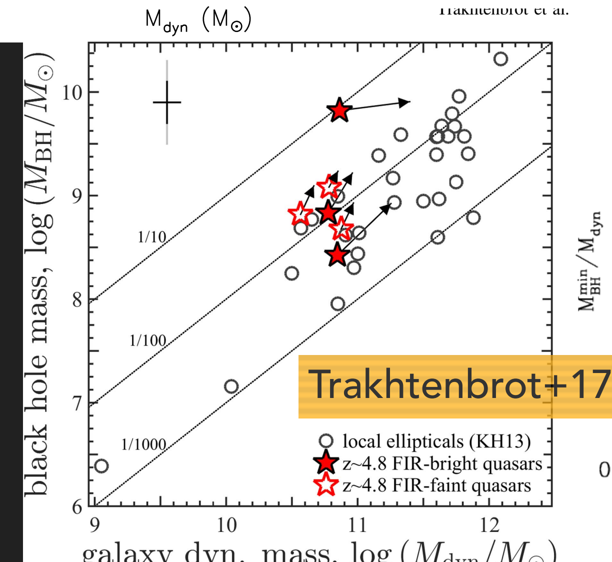
* The **ALMA** revolution: extension to **very high redshift** with "dynamical" $\boldsymbol{M_{gal}}$
(e.g. Maiolino+05, Walter+09, Wang+13, 16, Willott+13,15, Venemans+12,16,17, Banados+15, Decarli+17, Trakhtenbrot+17)

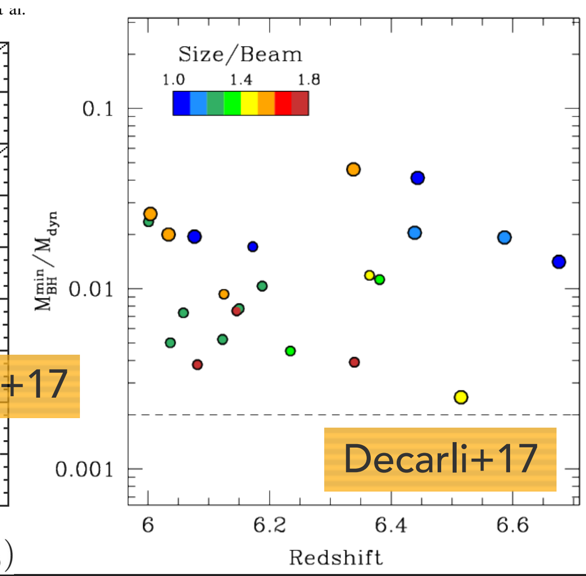
➡ **BH** growth **precedes** the **galaxy mass assembly**.











STATE OF THE ART

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  (Peng+06, Tr… Decarli+09, …

- ***M_{BH}/M_{gal}*** … to ~10% o…
  (Wu+07, Ho+0…

- The **ALMA** … **high redshi…** … ***M_{gal}***
  (e.g. Maiolino+05, Walter+09, Wang+13, 16, Willott+13,15, Venemans+12,16,17, Banados+15, Decarli+17, Trakhtenbrot+17)

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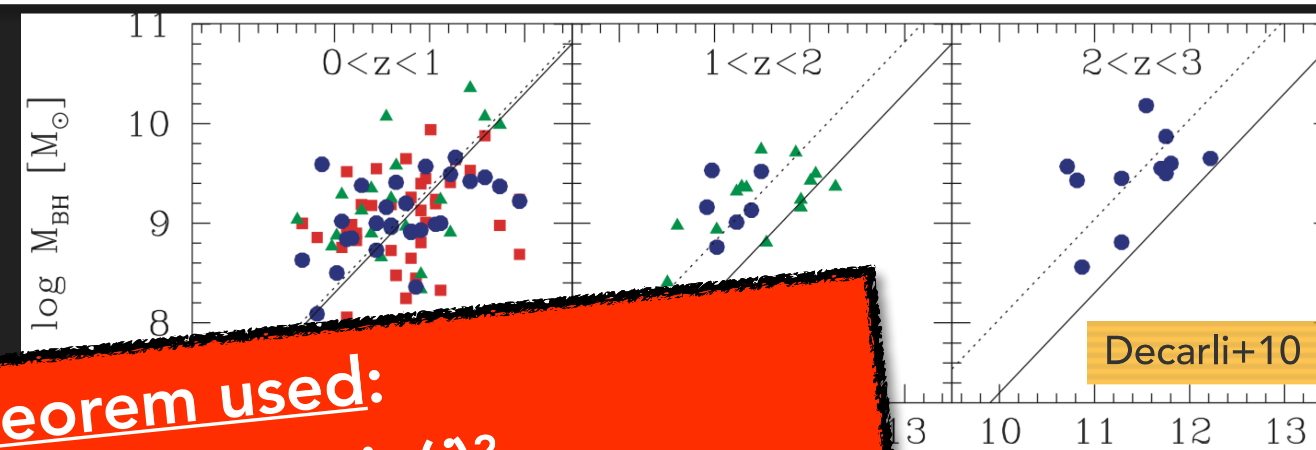
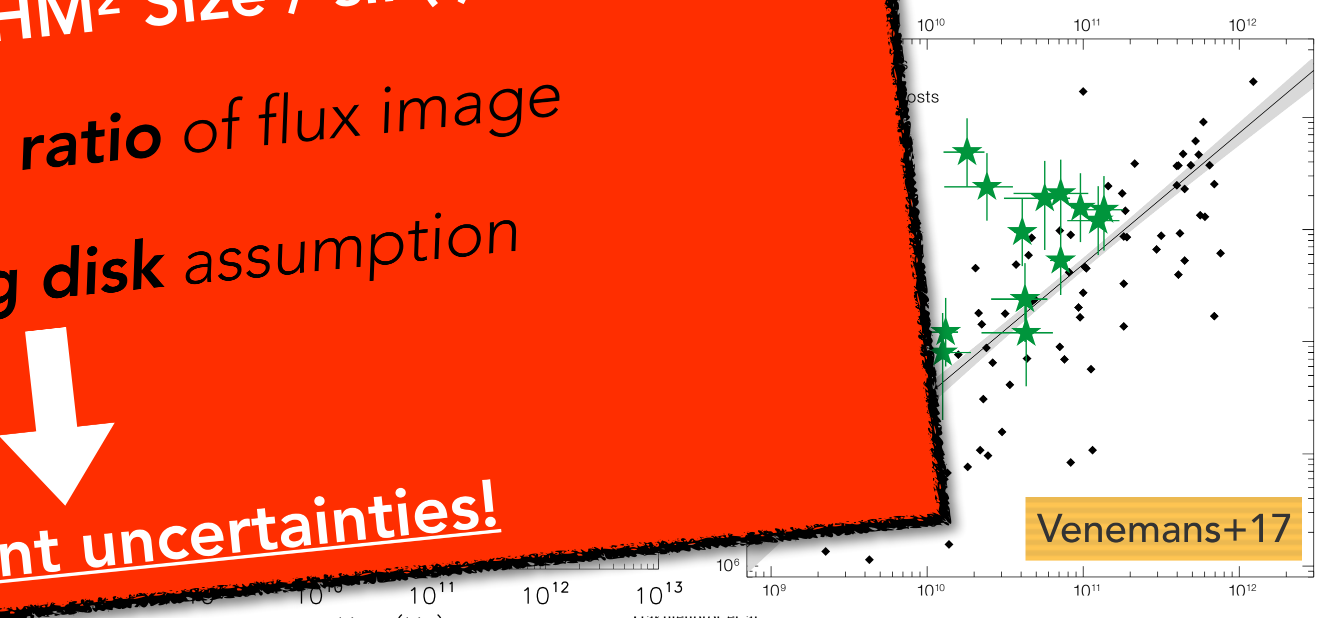
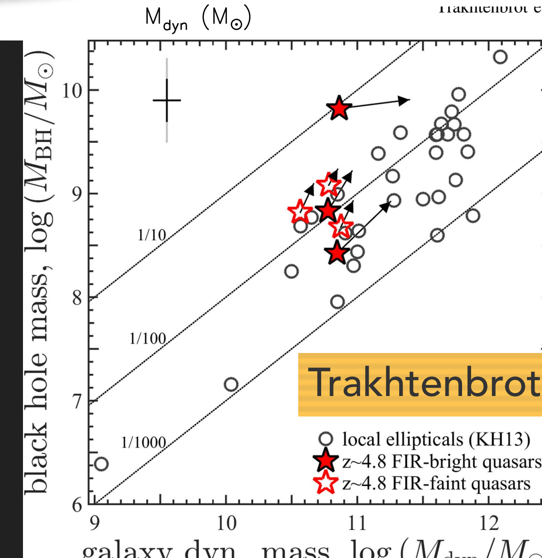
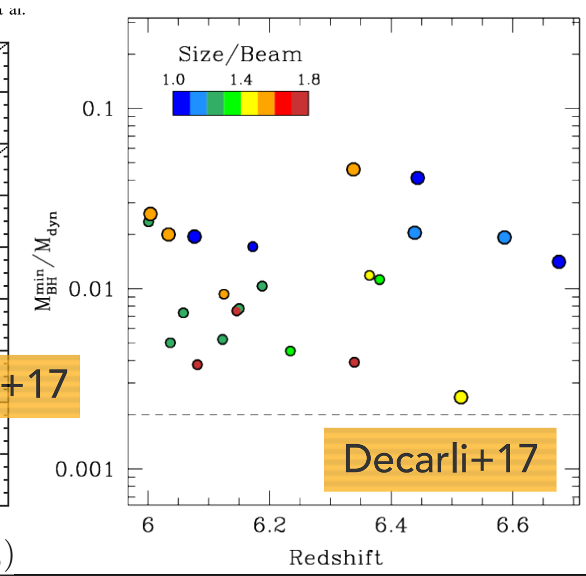








Virial theorem used:

M_{dyn} ~ FWHM² Size / sin(i)²

- **inclination** from **axial ratio** of flux image
- **no check** on **rotating disk** assumption

Significant uncertainties!

ESTIMATION OF M_{gal} AT HIGH-z

✳ Only **luminous AGN** observable at **high z** (*bias*)

✳ Bright **quasars "hide"** their **host galaxies**: accurate subtraction of the **point-like QSO** is needed:

◉ spatial decomposition ➡ high angular resolution

◉ spectral decomposition ➡ assume on galaxy and AGN template.

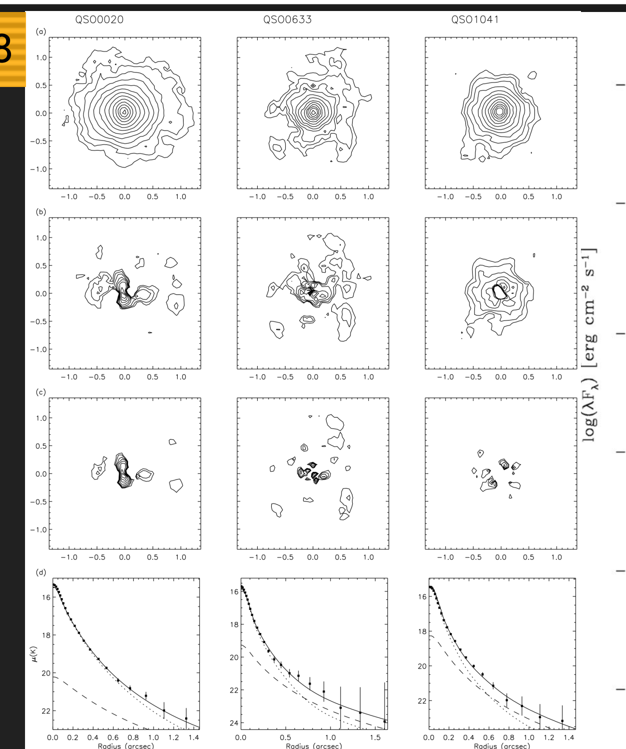
◉ gravitational lensing ➡ detailed model of the system.

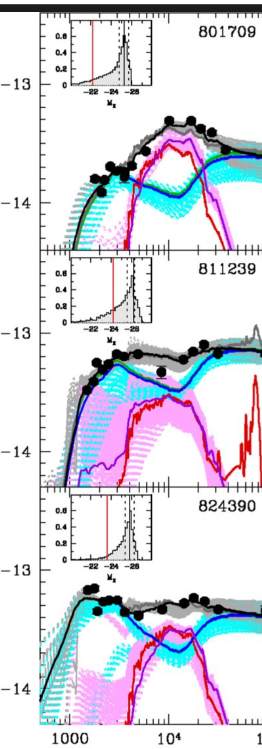
✳ **Photometric estimations** take into account only **stellar mass content** (*bias*):

◉ single band M/L

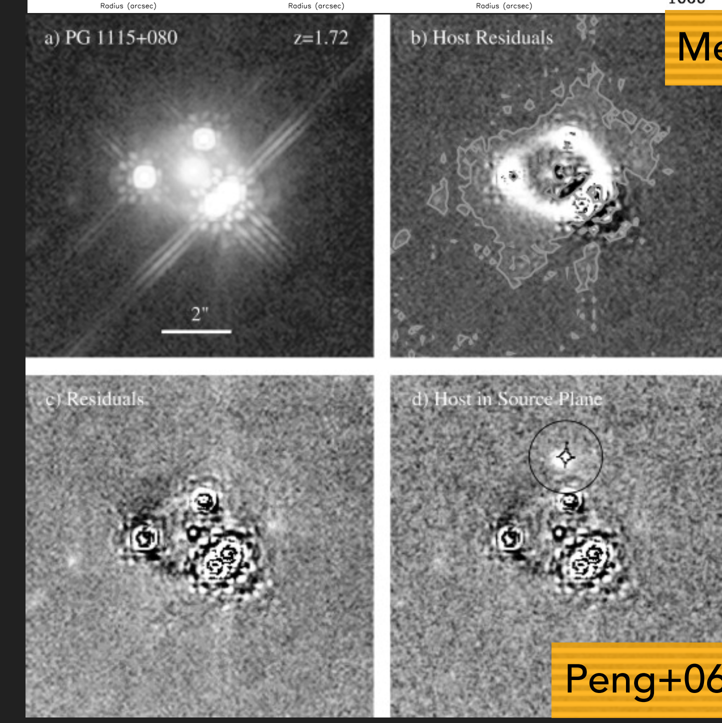
◉ stellar population synthesis models ➡ assumptions on stellar population properties

Falomo+08





Merloni+10



Peng+06

ESTIMATION OF M_{gal} AT HIGH-z

✳ Only **luminous AGN** observable at **high z** (*bias*)

✳ Bright **quasars "hide"** their **host galaxies**: accu... **point-like QSO** is nee...

Use **sub-mm/FIR** bands with **ALMA!**

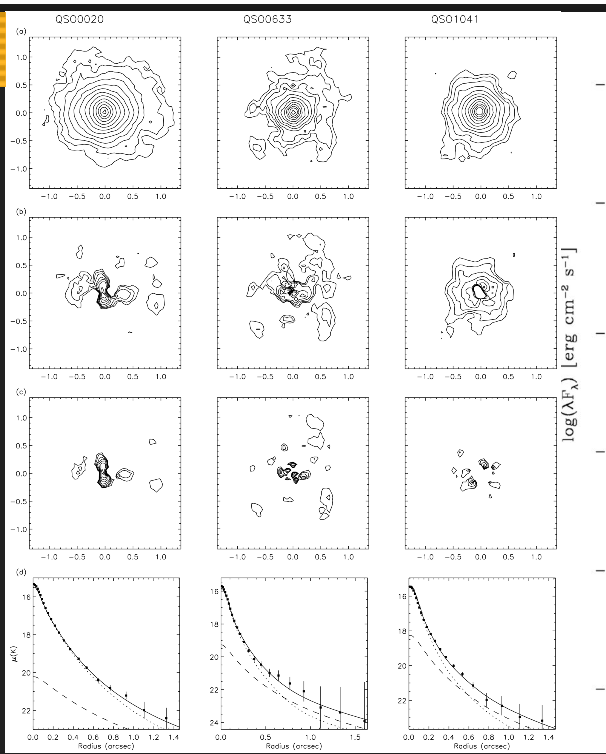
- spatial decomposition ➡ high ang... ...ution
- spectral decomposition ➡ assume on galaxy and AGN template.
- gravitational lensing ➡ detailed model of the system.

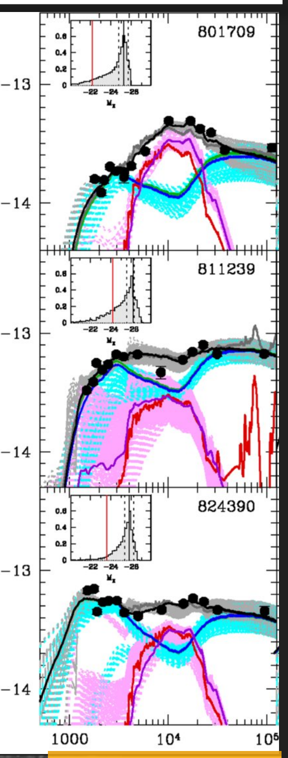
✳ **Photometric estimatio**... ...unt only **stellar** ...

The most distant **QSOs may not have converted** a large fraction of their **gas** into **stars**

- sin...
- stel... ...synthesis models ➡ assumptions on stellar population properties

Falomo+08





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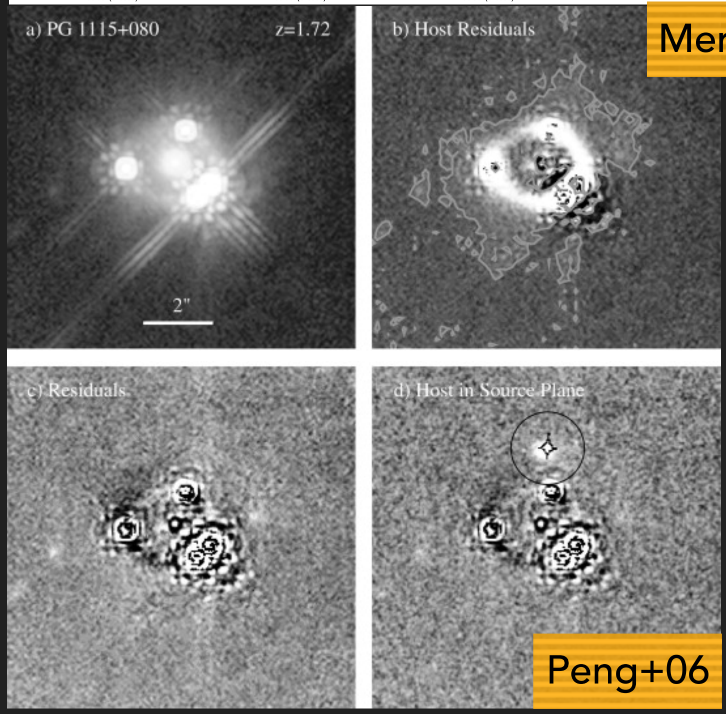


Peng+06

$M_{gal,dyn}$ ESTIMATION WITH **ALMA**

- Measure **dynamical masses** of **quasar host galaxies** in **submm band** (AGN do not "hide" host galaxy if radio quiet)

- **Full kinematical modelling** instead of virial estimates for better accuracy and reliability

- Sample of **72 QSO** from **ALMA archive** in **$2 < z < 7$** range

- Use **[CII] 158μm** or **CO ($J+1 \rightarrow J$)** as tracers of **galaxy disk kinematics**

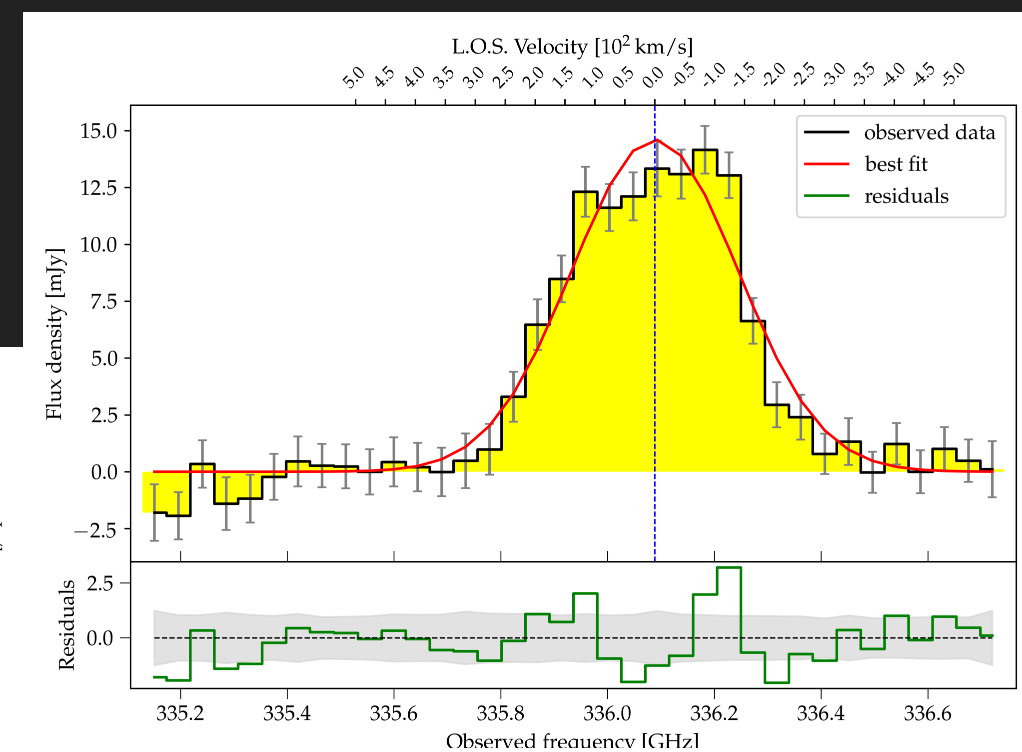
- Standard **data reduction** (self calibration when useful)

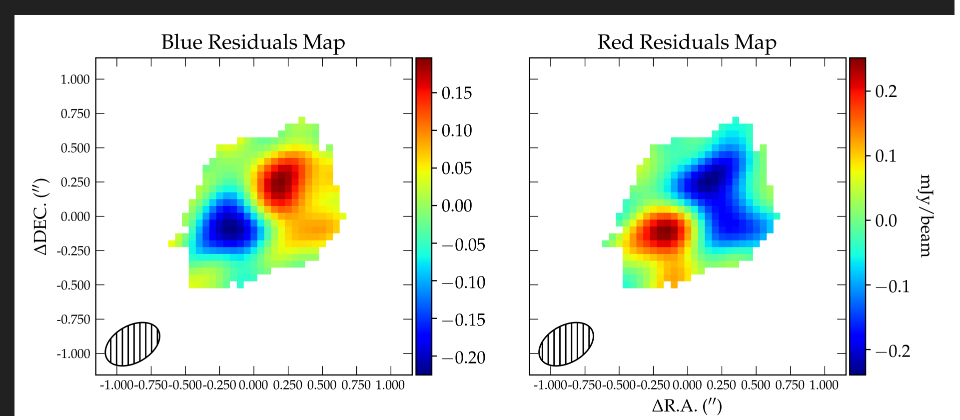
DATA ANALYSIS

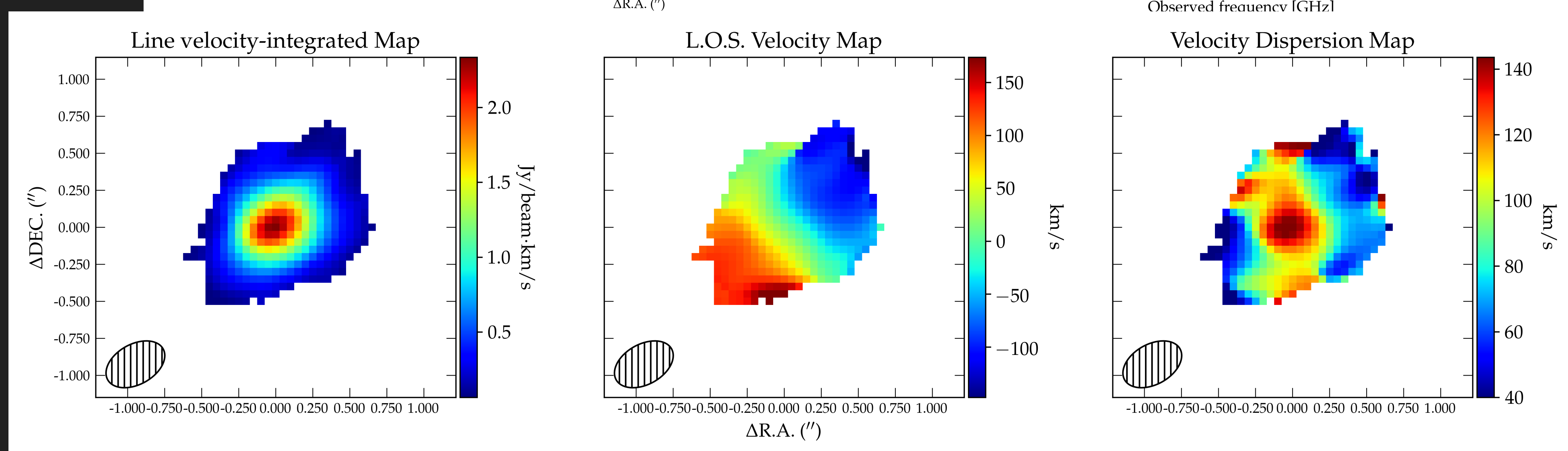
SDSS J092303.53+024739.5
@ $z_{[CII]}$=4.654876±0.000015

- **Line fitting** spaxel by spaxel
  (*new algorithm for "cleaner" maps*)

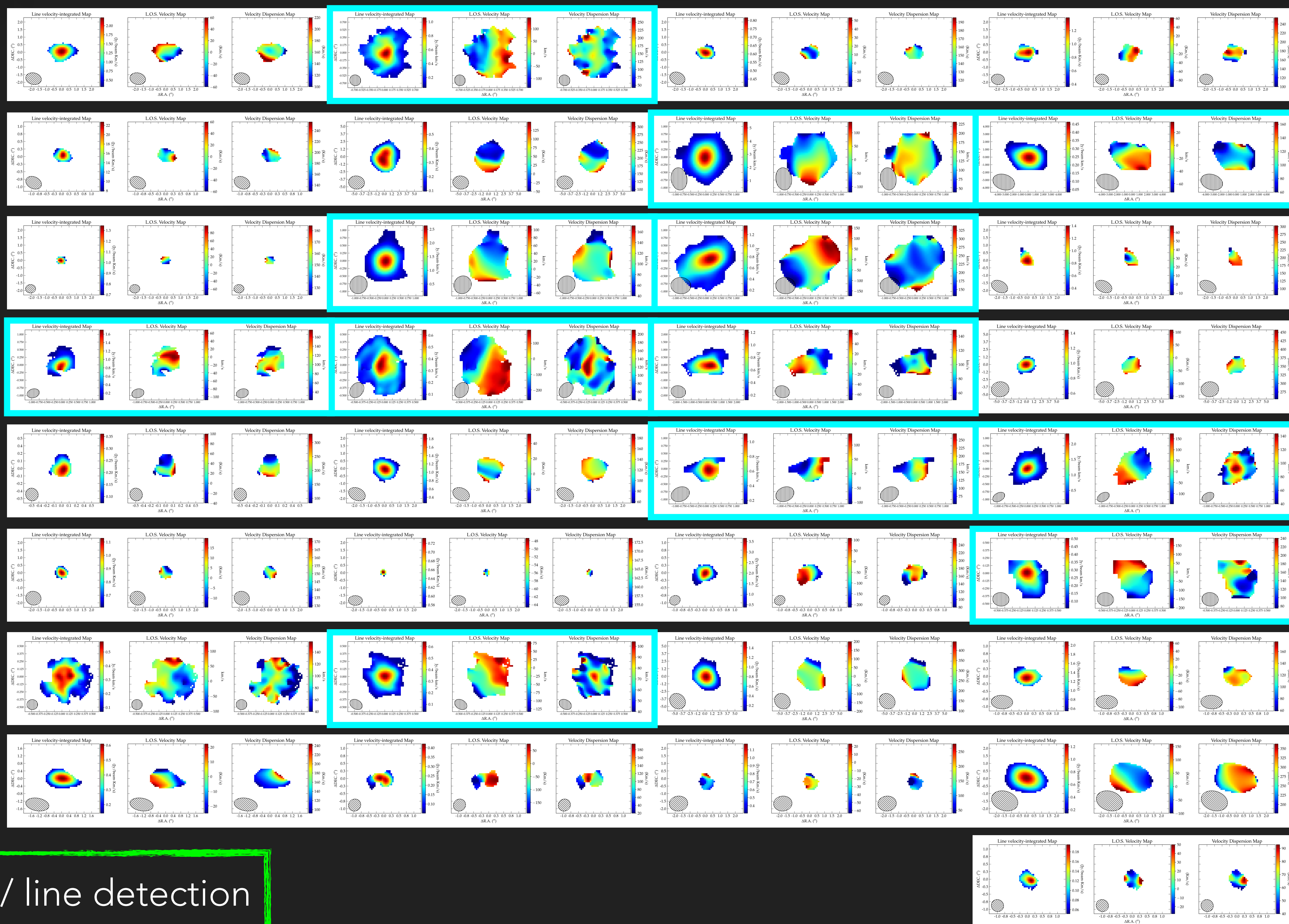
- **Test** for **spatially resolved kinematics**
  (*fit all spaxels with fixed line profile and check residuals*)





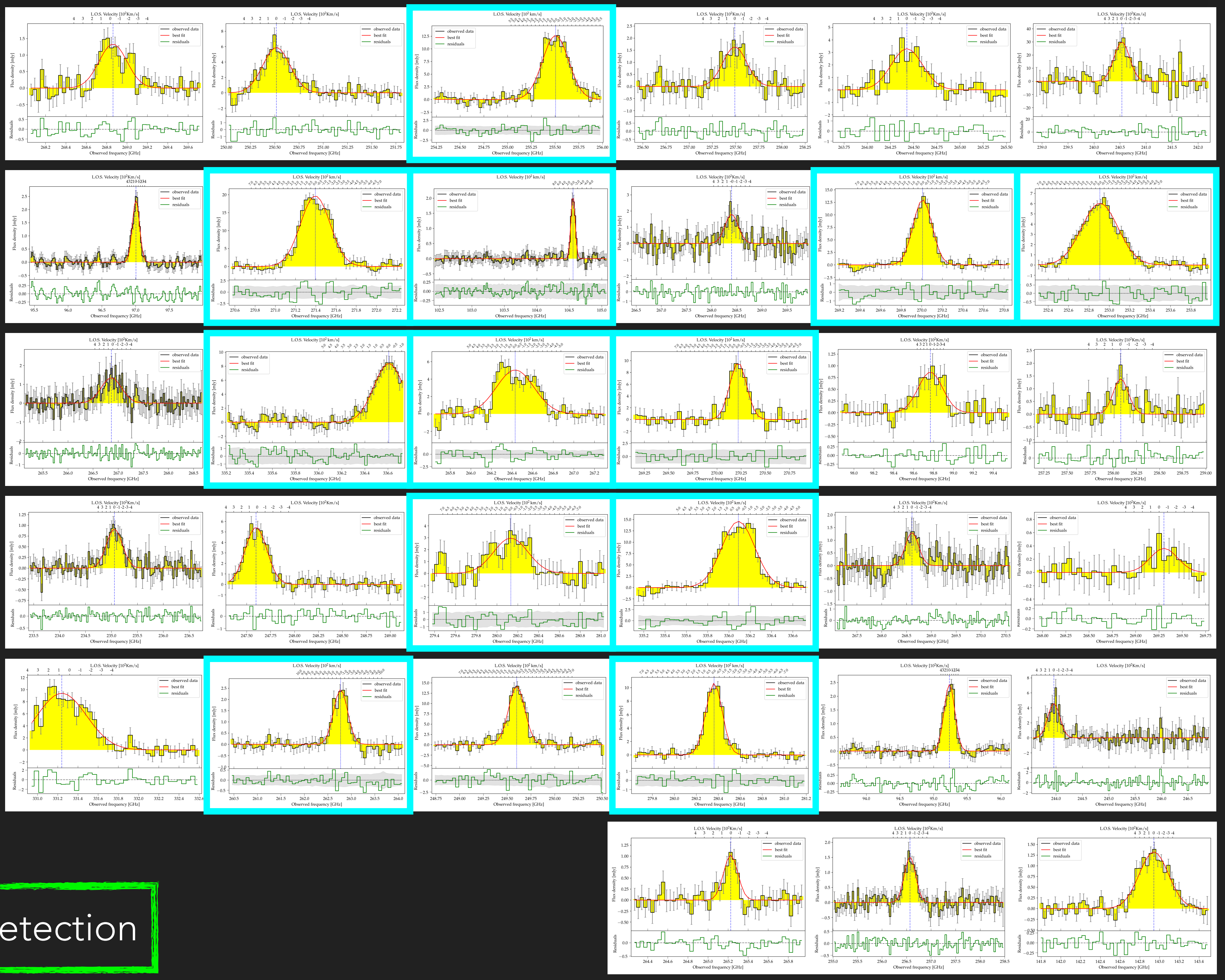


FLUX, $V_{L.O.S.}$, $\Delta V_{L.O.S.}$ MAPS



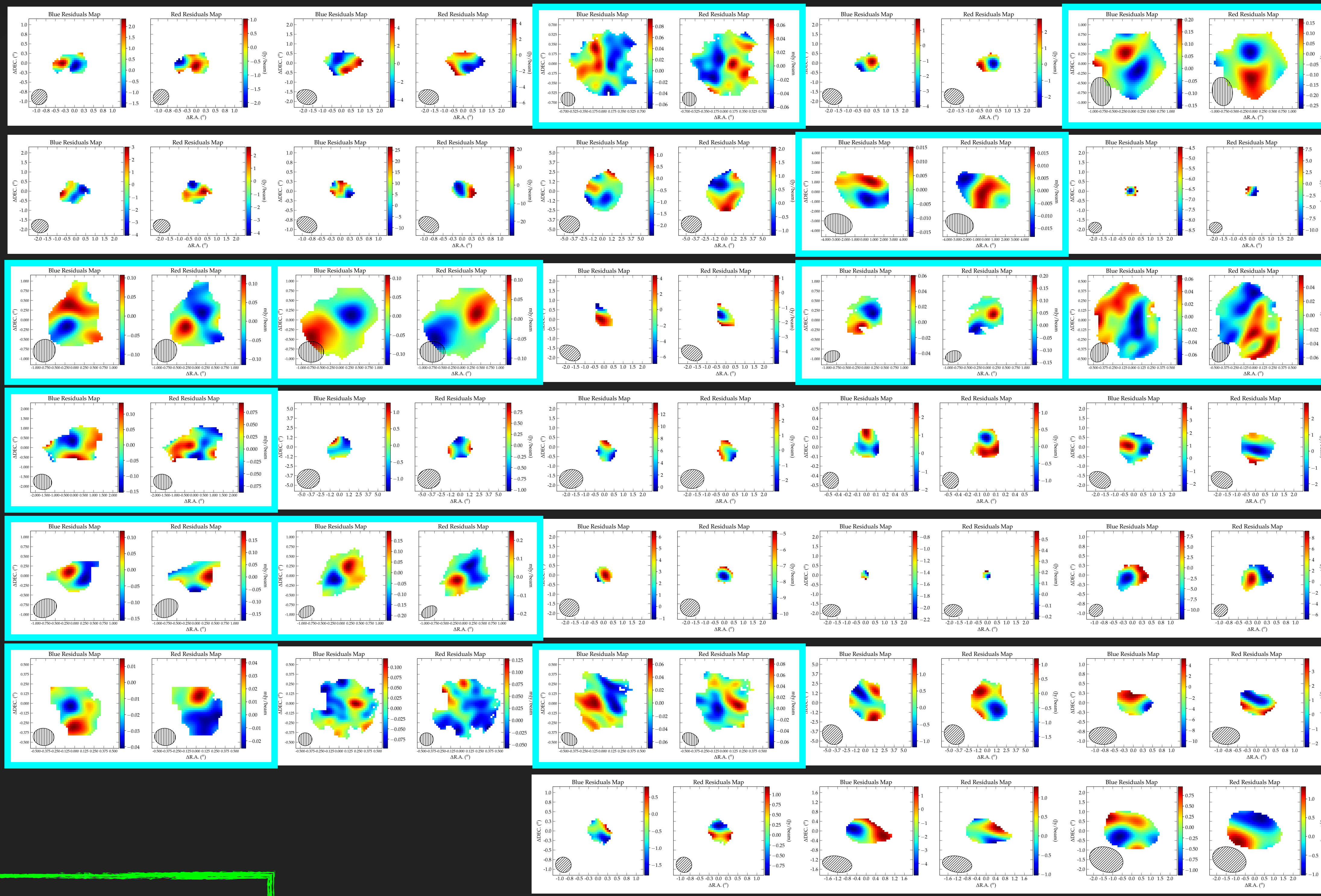
33 sources w/ line detection

INTEGRATED SPECTRA



33 sources w/ line detection

STATIALLY RESOLVED KINEMATICS



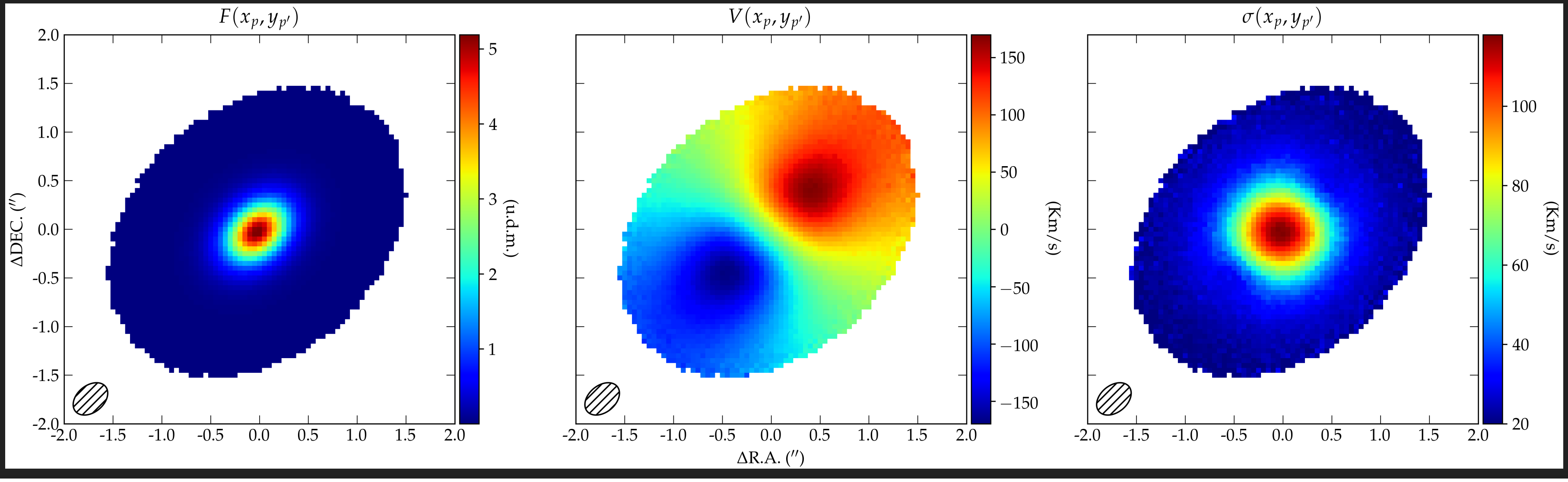
33 sources w/ line detection

KINEMATICAL MODEL

- **Dynamical mass estimate** by modelling observed velocity field
  - ➡ **ASSUMPTION**: rotating thin disks with exponential surface brightness profile

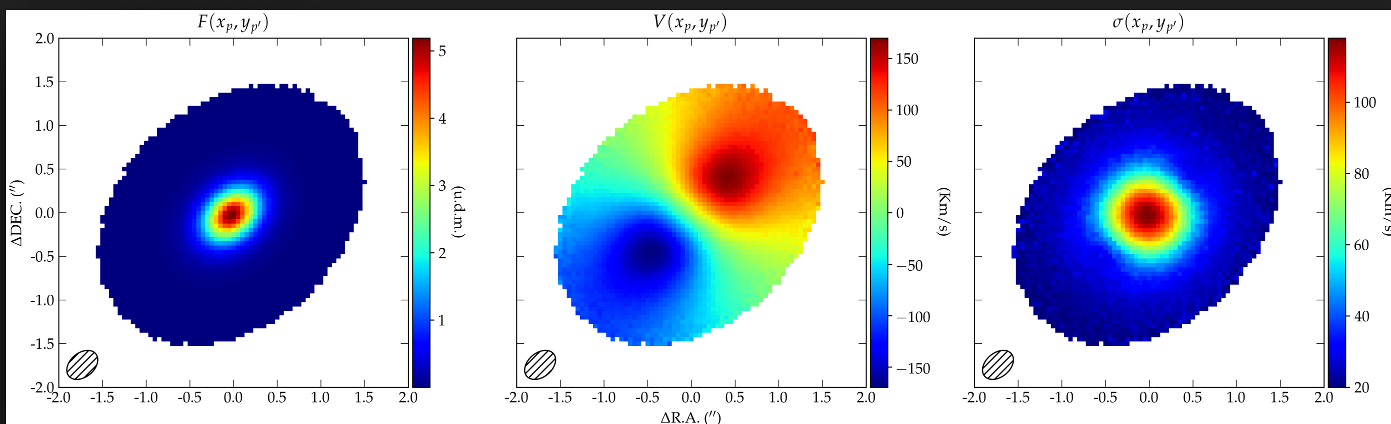
$$I(r) = I_0 \exp(-r/R_D) \qquad V^2(r) = \frac{2GM_{dyn}}{R_D} y^2 [I_0(y)K_0(y) - I_1(y)K_1(y)]$$

- Kinematical model to perform 2D map-fitting and to recover R_D, $M_{gal,dyn}$
  - ➡ Monte Carlo "cloud" model, assumed brightness profile and velocity field
  - ➡ Takes into account all geometrical projection and observational effects (e.g. beam smearing, binning, etc.)

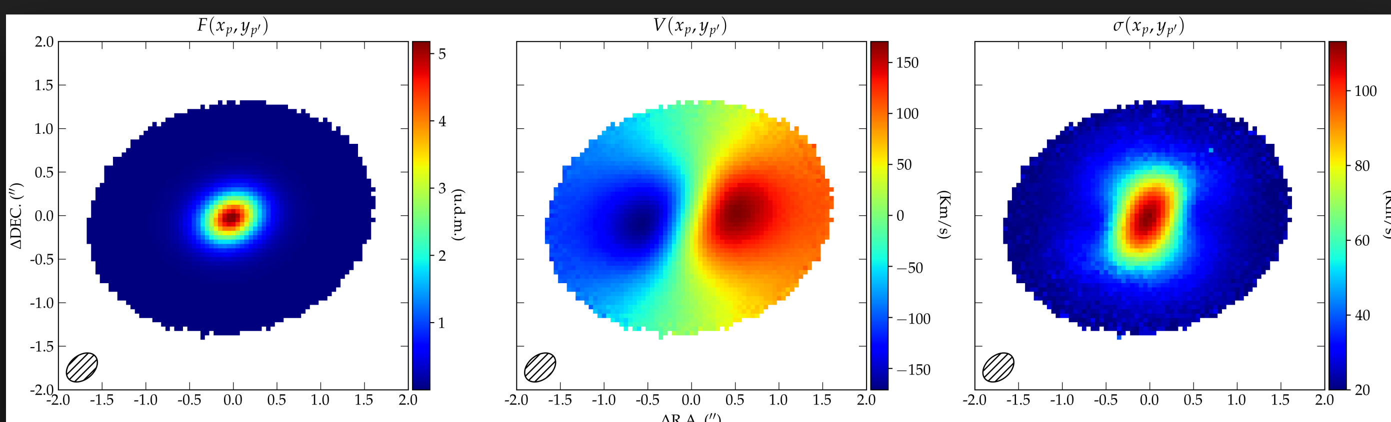


R_D=1.25″
M_{dyn}=5x10^{10} $M_{\odot}$
i=40°
$P.A.$ = -45 °
FWHM(PSF)= 0.4″x0.275″
B_{PA}=-50°
σ(LSF)= 20 km/s

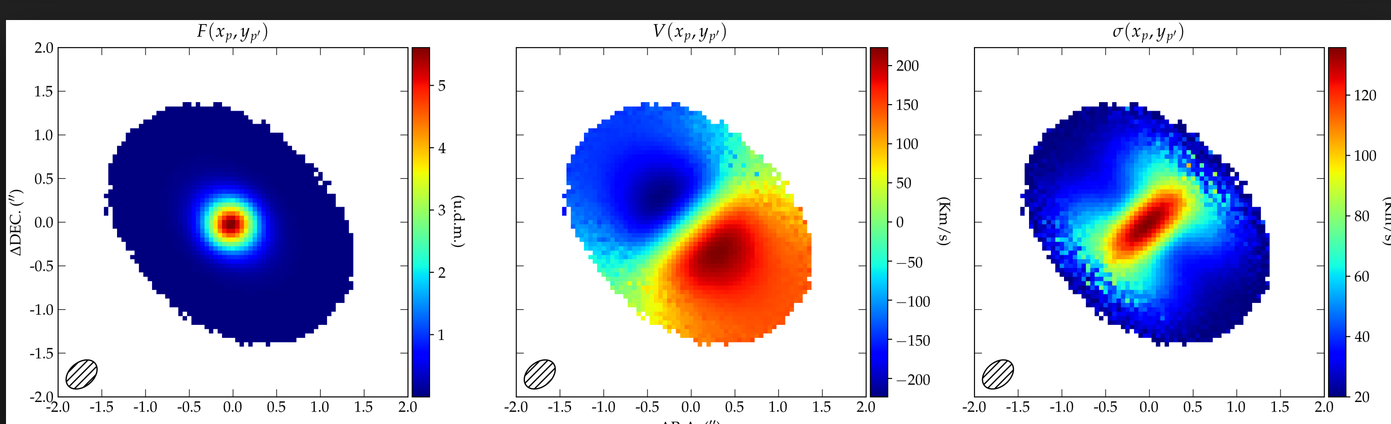
KINEMATICAL MODEL



a) *i= 40°, P.A. = -45°*

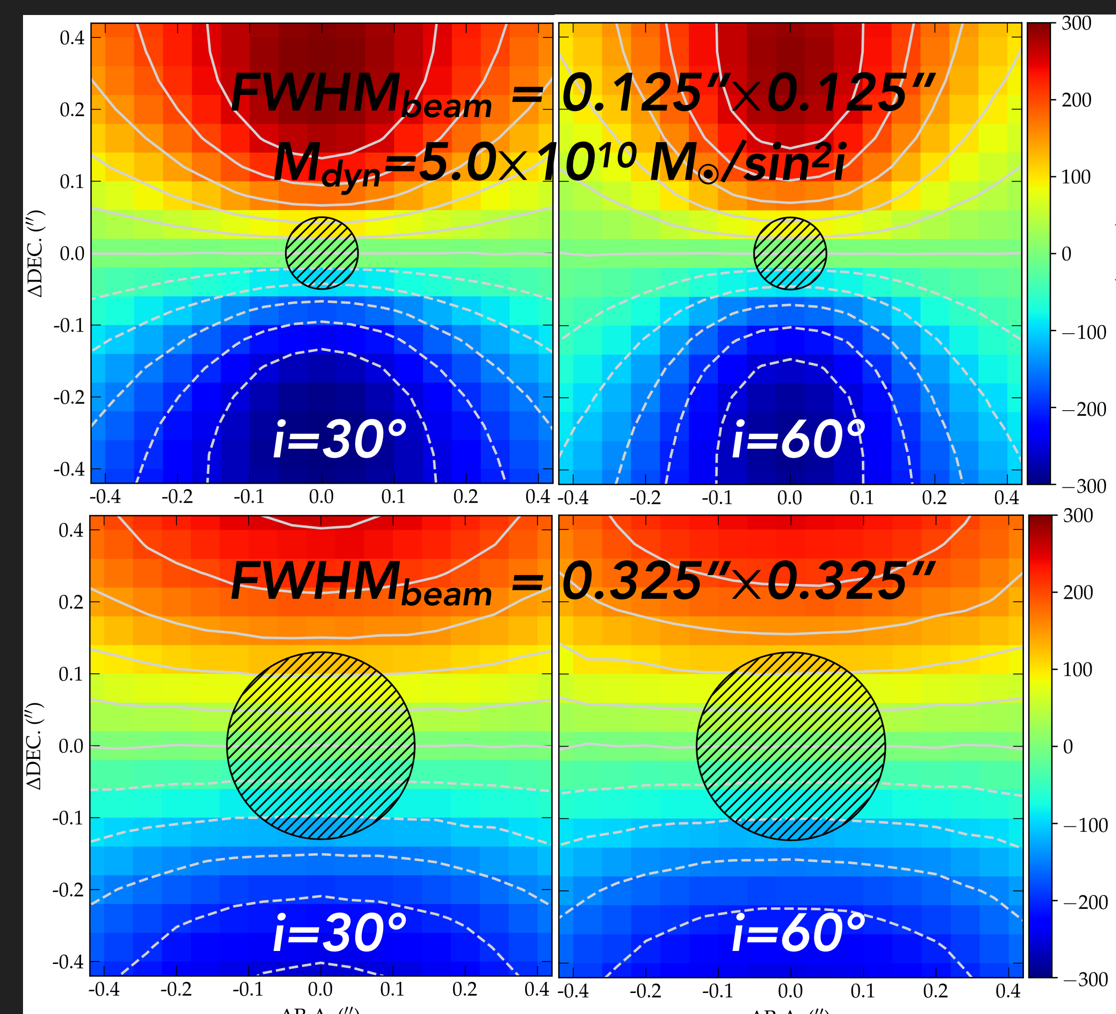


b) *i=40°, P.A. = 0°*



c) *i= 60°, P.A. = 45°*

Beam smearing and/or wrong *M*(*r*) makes ***i*** and ***M***$_{dyn}$ almost degenerate



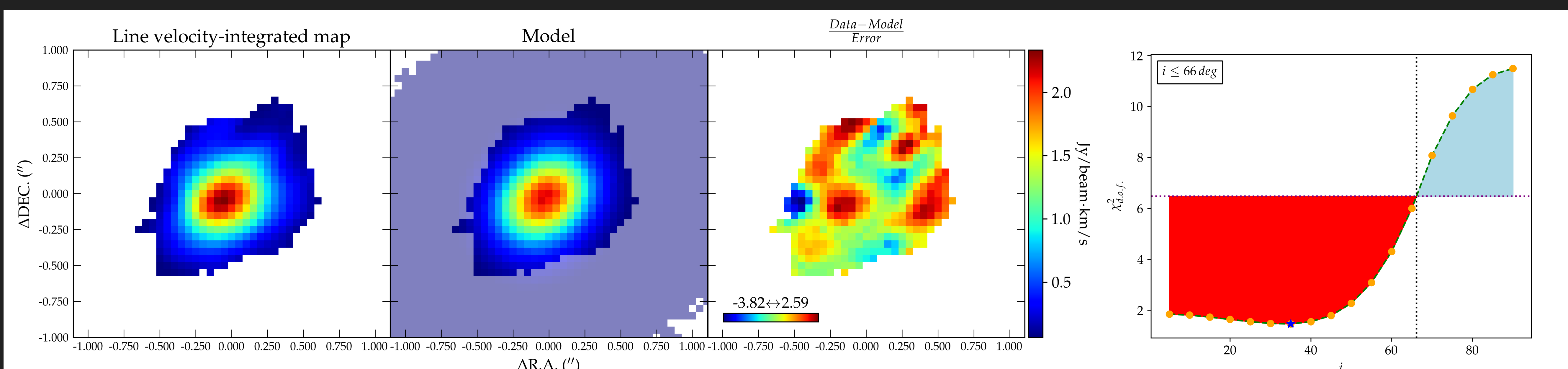
KINEMATICAL MODELING

✳ **Standard approach (2steps)** (e.g. Cresci et al. 2009,…):

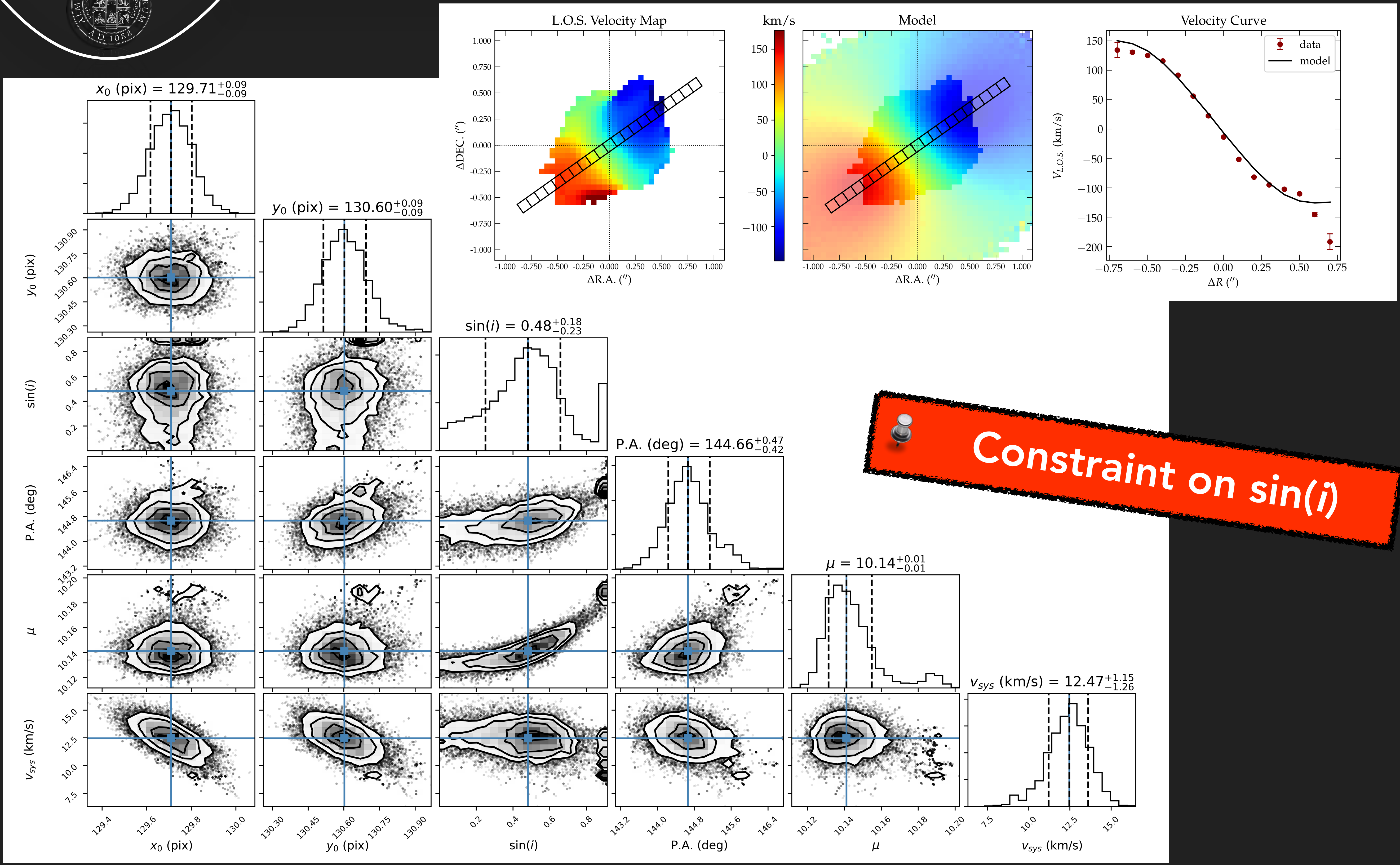
1) **Fit line flux distribution** with exponential disk = measure scale radius ***R_D***

✳ **+ Bayesian method (MCMC):** assumes prior on inclination from morphology (axial ratio)

2) **Fit velocity field** with exponential mass & line flux distribution with fixed ***R_D*** = measure dynamical mass ***$M_{gal,dyn}$***



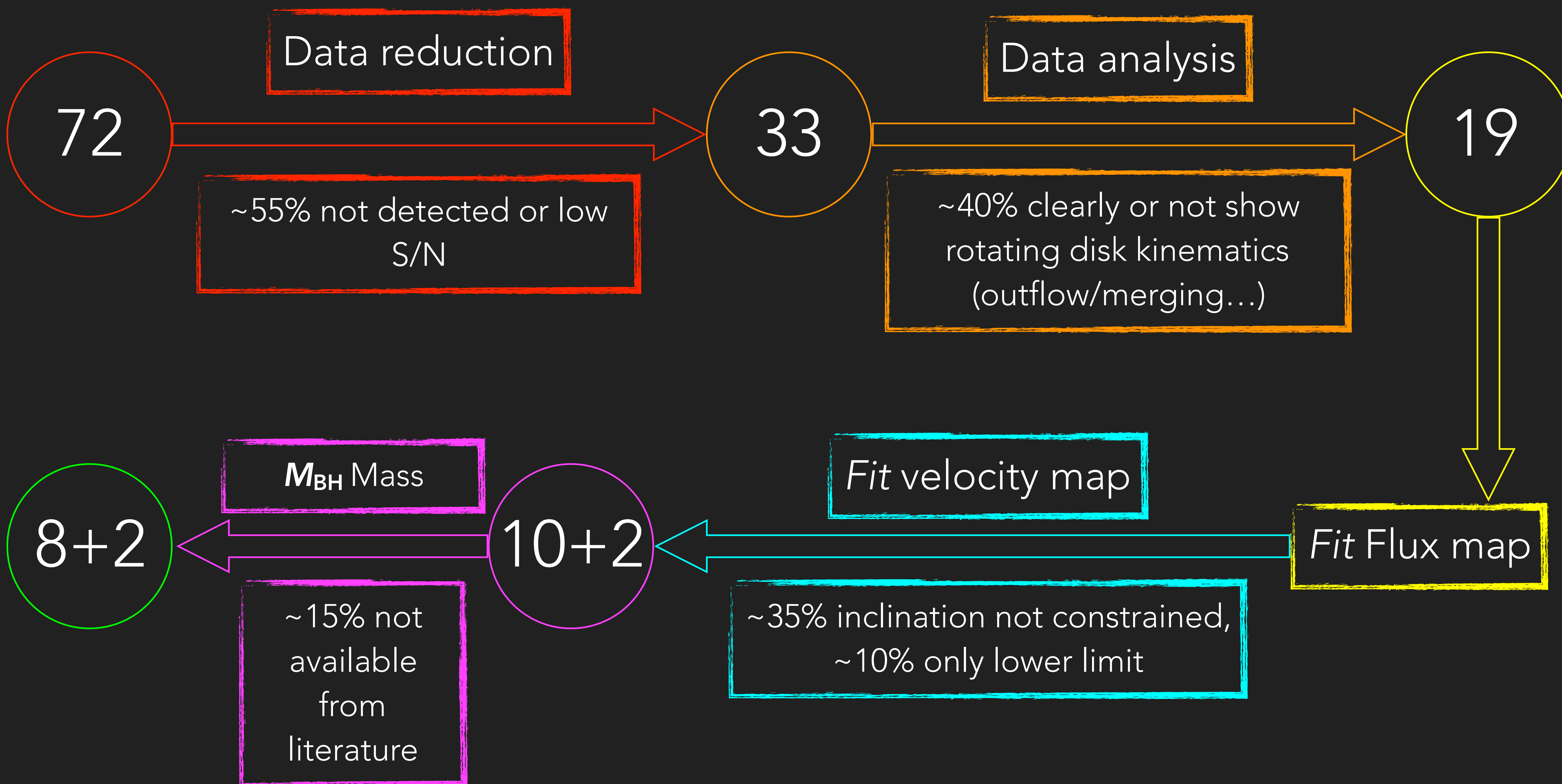
KINEMATICAL MODELING



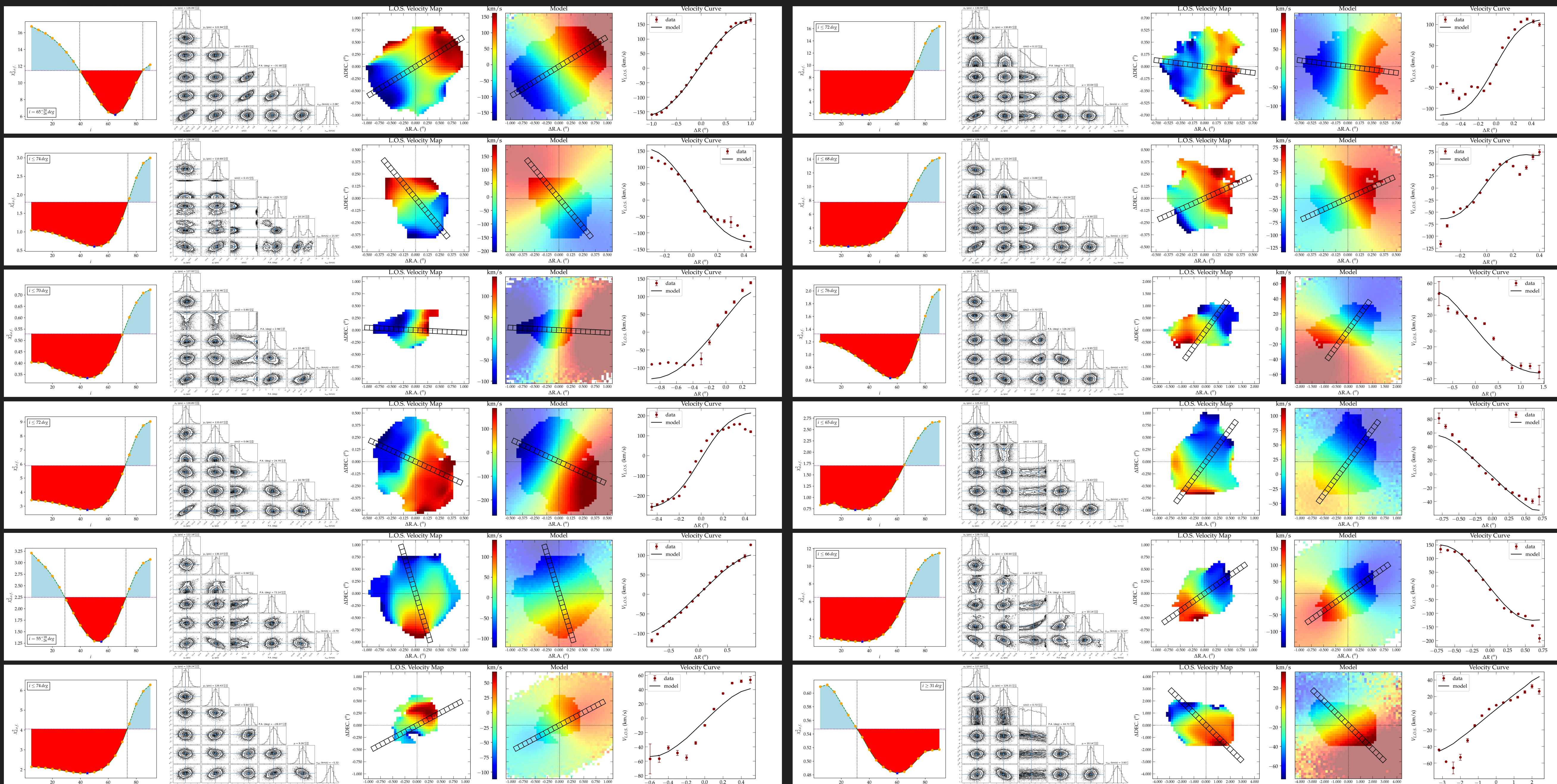
Constraint on sin(i)

OVERALL RESULTS

- Sample of **72 QSOs** at **2 < z < 7** from **ALMA** archive.



OVERALL RESULTS



12 sources

EVOLUTION OF BH-GALAXY RELATION

$\log M_{BH} = \alpha + \beta (\log M_{gal} - 10.8)$

De Nicola, Marconi & Longo 2018

$\alpha_{DML} = 8.37 \pm 0.06$

$\beta_{DML} = 1.01 \pm 0.07$

z < 1

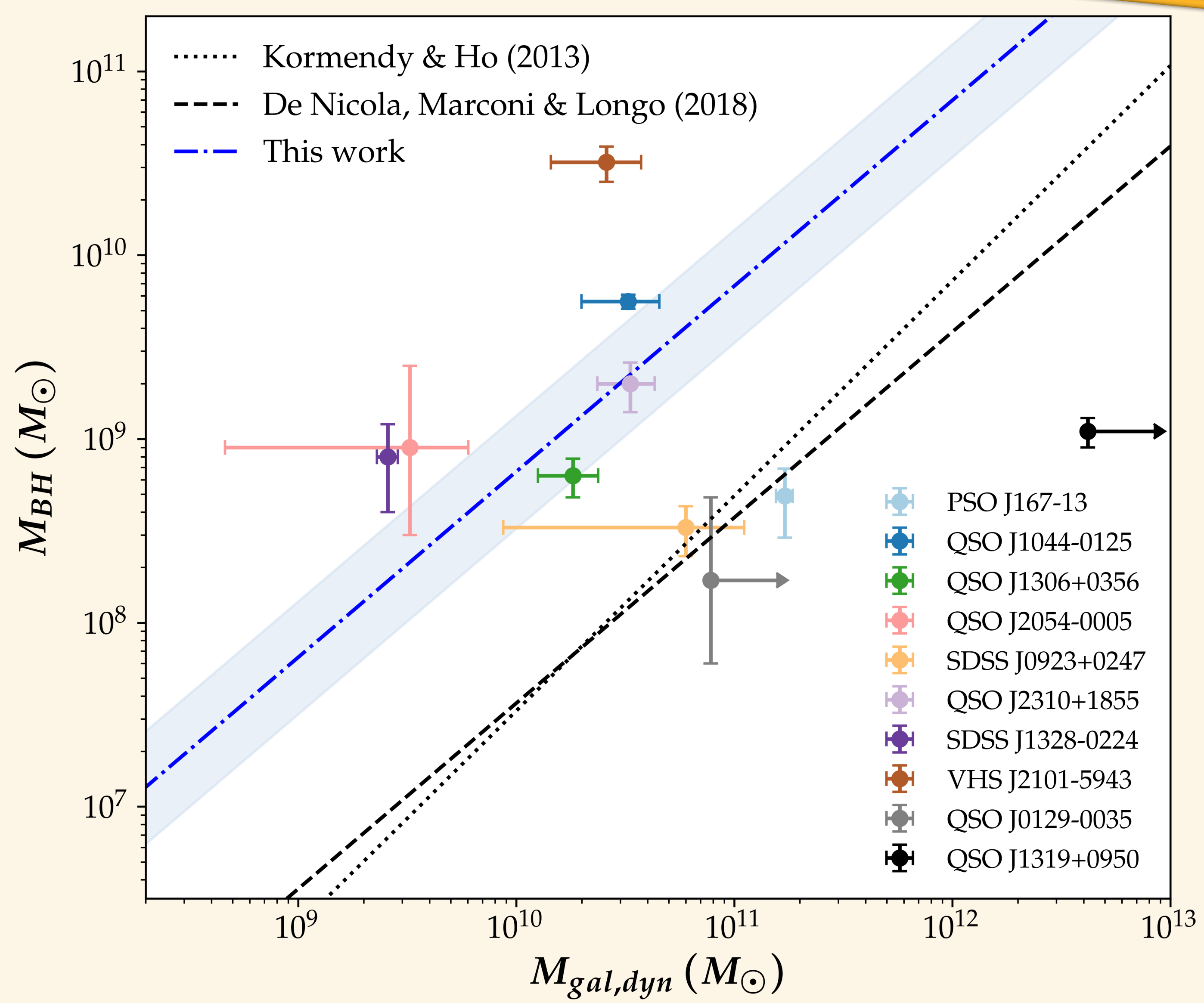
This work

$\alpha = 9.6 \pm 0.3$

$\beta \equiv \beta_{DML}$

4 < z < 7

WORK IN PROGRESS!

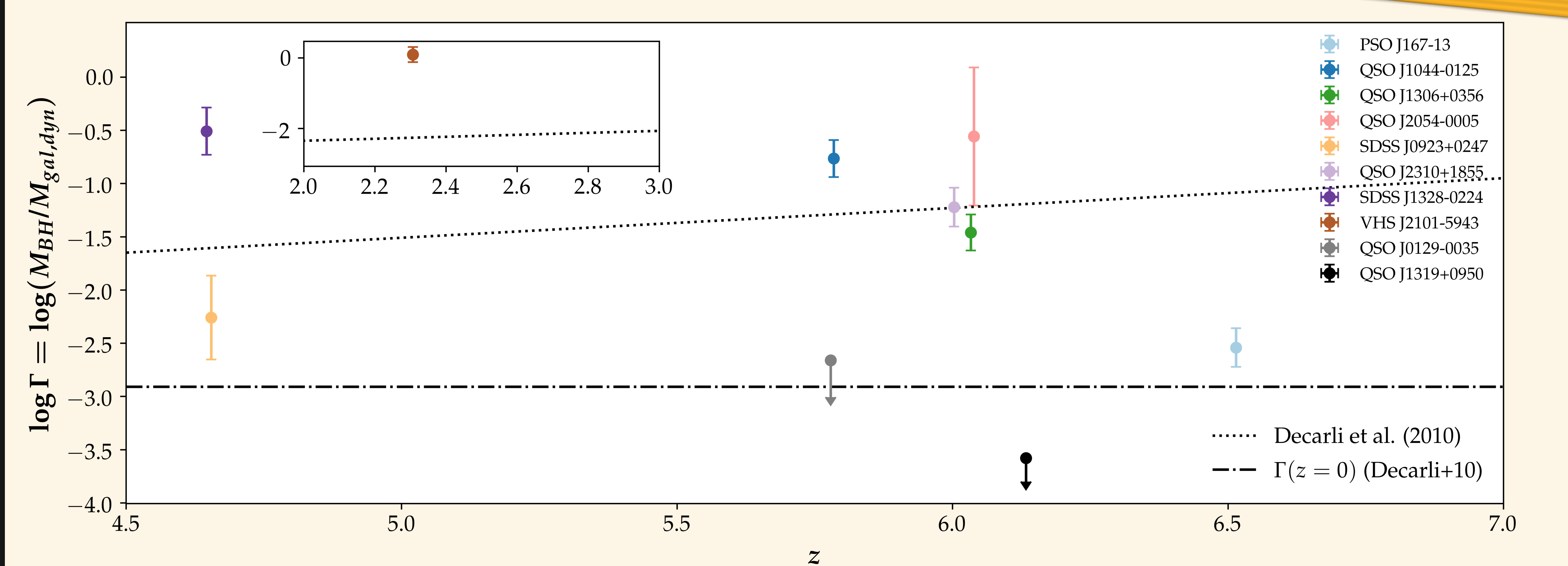


CONFIRMING THE EVOLUTION OF $z \gtrsim 1$ RELATION

(E.G. VENEMANS+17, DECARLI+17, TRAKHTENBROT+17)

EVOLUTION OF $M_{BH}/M_{gal,dyn}$

WORK IN PROGRESS!



Decarli et al., 2010

$$\log \Gamma = (0.28 \pm 0.06)z - (2.91 \pm 0.06)$$

$z \lesssim 3$

CONSISTENT WITH EXTRAPOLATION OF Γ INCREASE AT $z<3$

SUGGESTS TO SEARCH **FOR A Γ** DECREASE AT $z \gtrsim 6$?

CONCLUSIONS

- **ALMA sensitivity** and spatial **resolution** allow to obtain **spatially resolved kinematical** maps of quasar host galaxies **up to $z>6$ ➡ $M_{gal,dyn}$ estimation** is **possible** also for **high-z galaxies**!!

- On a "blind" search <1/3 of the **galaxies have rotating disk kinematics** that allow to **estimate galaxy masses.**

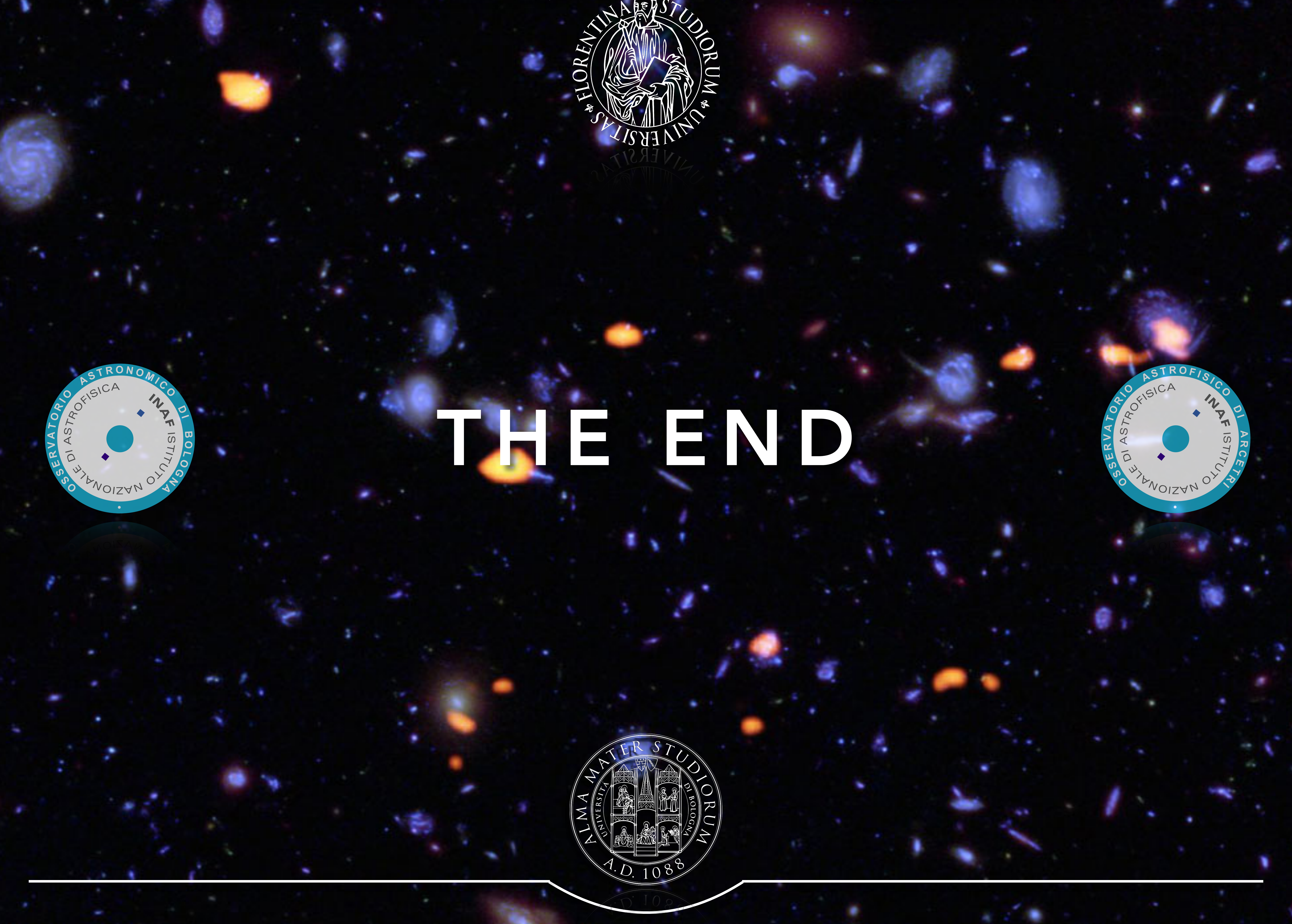
- Our result **confirms** the observed **evolution** of M_{BH}-$M_{gal,dyn}$ **relation** with **z.**

- $\Gamma = M_{BH}/M_{gal}$ ratio is **~10x the local value at z~4-7, consistent** with extrapolation of **Γ**(z) from $z<3$.

- **Important** to study $z>6$ because **BH growth w.r.t. to host galaxy might be revealed.**

Stay tuned!

Pensabene, Marconi et al. 2019 (in prep.)

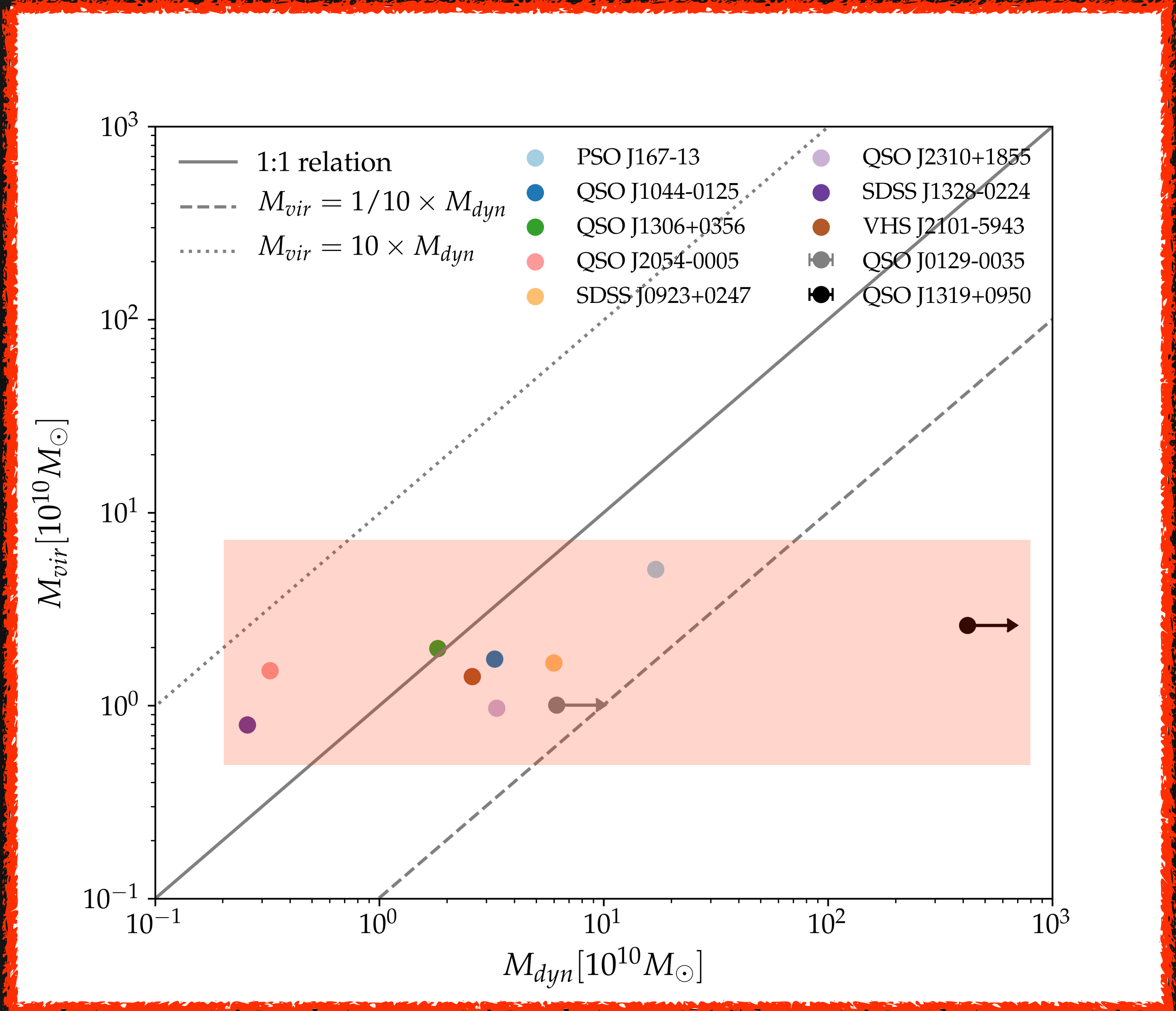


THE END

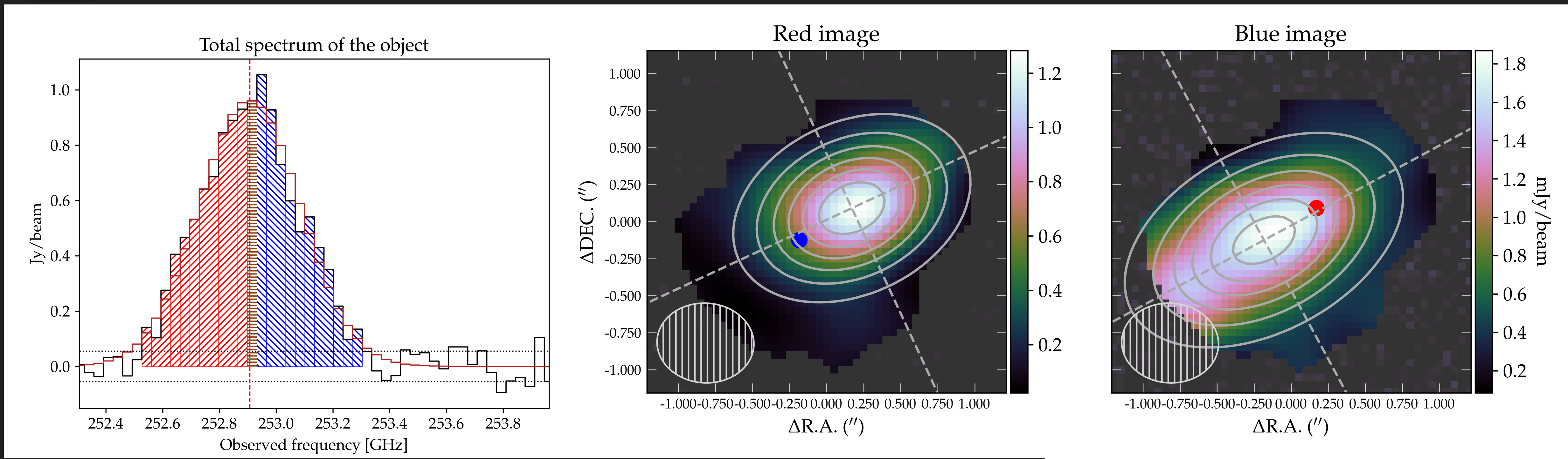
BACKUP SLIDES

COMPARISON WITH VIRAL MASSES

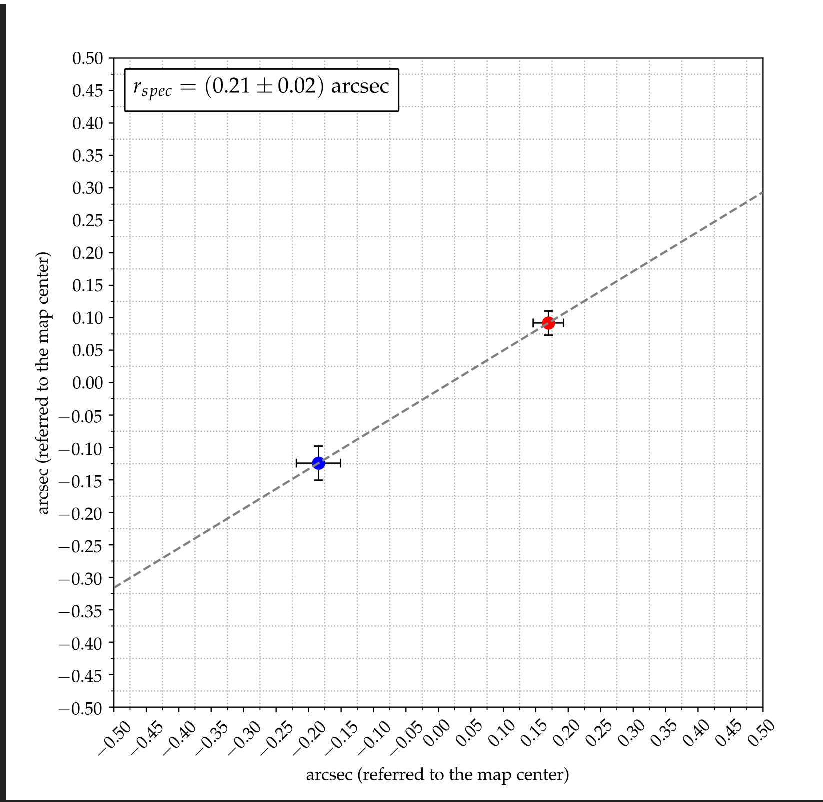
- Estimate $\boldsymbol{M_{vir}}$ with, e.g., Wang+13 virial relation
- **No linear 1:1 relation between M_{dyn} and M_{vir}**
- With no kinematical map it is not possible to verify if disk is rotating (not an easy task!)



VIRIAL MASSES-"spectroastrometry"



* Use "**spectroastrometry**" to measure more accurate virial masses (Gnerucci, Marconi, +11; Carniani, Marconi+13)

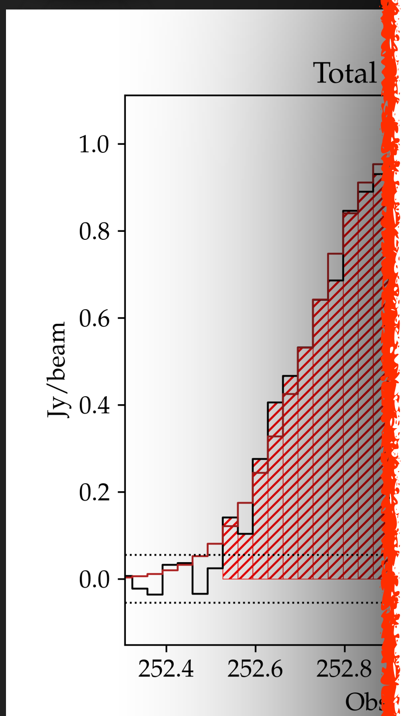


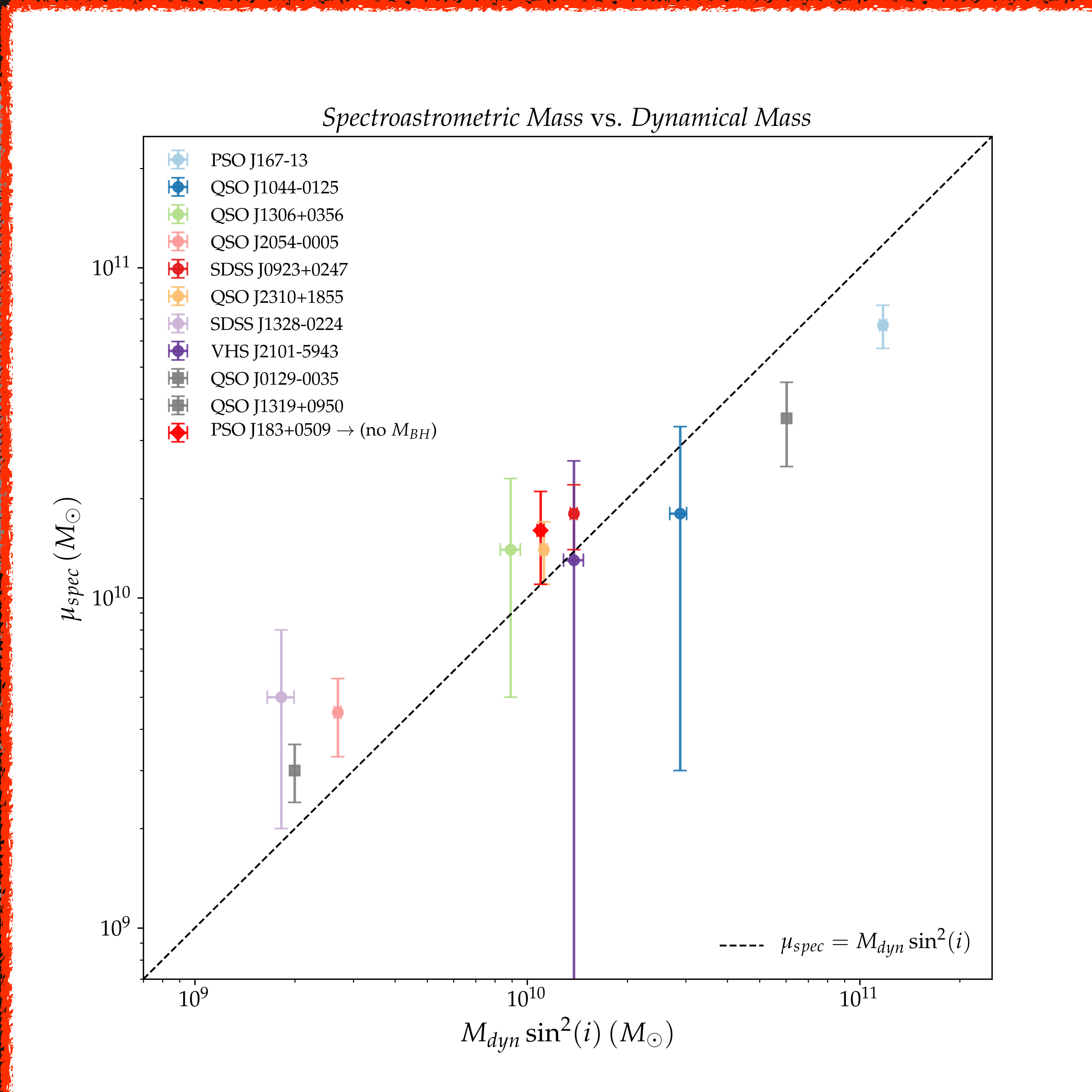
$$M_{spec} \sin^2 i \sim f_{spec}\, FWHM^2\, r_{spec}$$

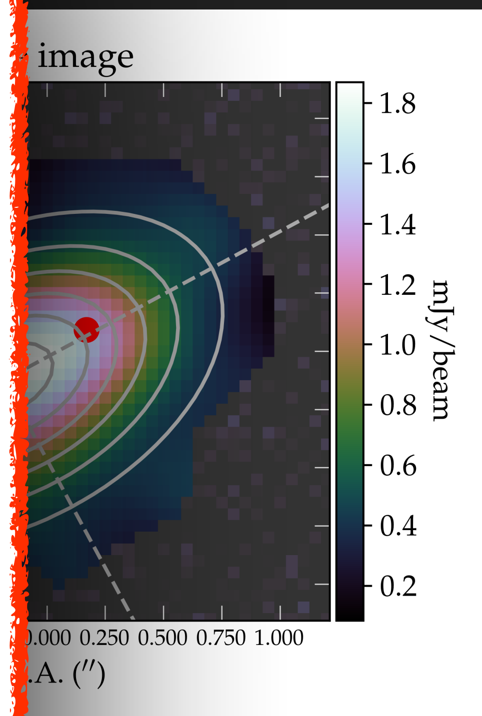
$$f_{spec} = 1.0 \pm 0.1$$

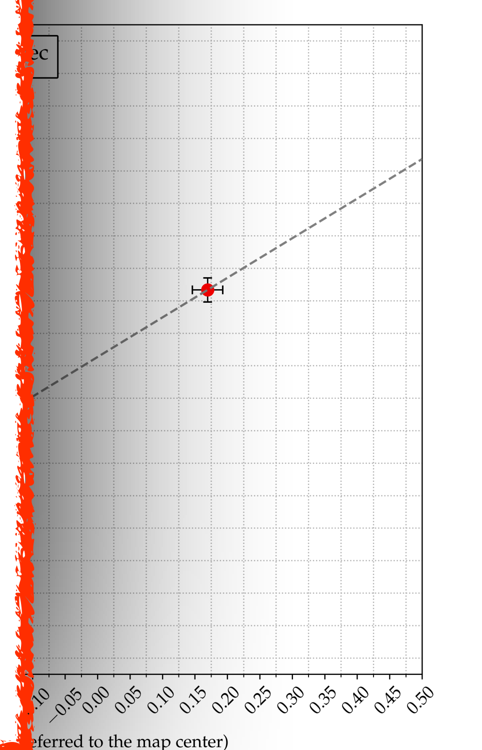
(Gnerucci, Marconi et al. 2011)

VIRIAL MASSES-“spectroastrometry”









✳ Use “**spec**
accurate v
Carniani, I

Ms

BHs VIRIAL MASSES

- Homogeneous M_{BH} virial mass estimation → **single-epoch spectroscopy** method - combines the width of lines originating from **BLR** (e.g. MgII, CIV) with **continuum** emitted by the **AGN**: data available only for **6 sources**. *(De Rosa+11,+14, Shao+17, Trakhtenbrot+11, Shen+18)*

$$M_{\rm BH} = f\,\frac{(\Delta V)^2 R}{G}$$

$$\log\left(\frac{M_{\rm BH}}{M_\odot}\right) = 6.6 + 2\log\left(\frac{\rm FWHM(MgII)}{10^3\,\rm km\,s^{-1}}\right) + 0.5\log\left(\frac{\lambda L_\lambda(3000\,\mathring{A})}{10^{44}\,\rm erg\,s^{-1}}\right)$$

(Bongiorno et al. 2014)

- **Remaining masses derived** from the **literature**.

  (Venemans+15, Willott+15, Banerji+15)