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

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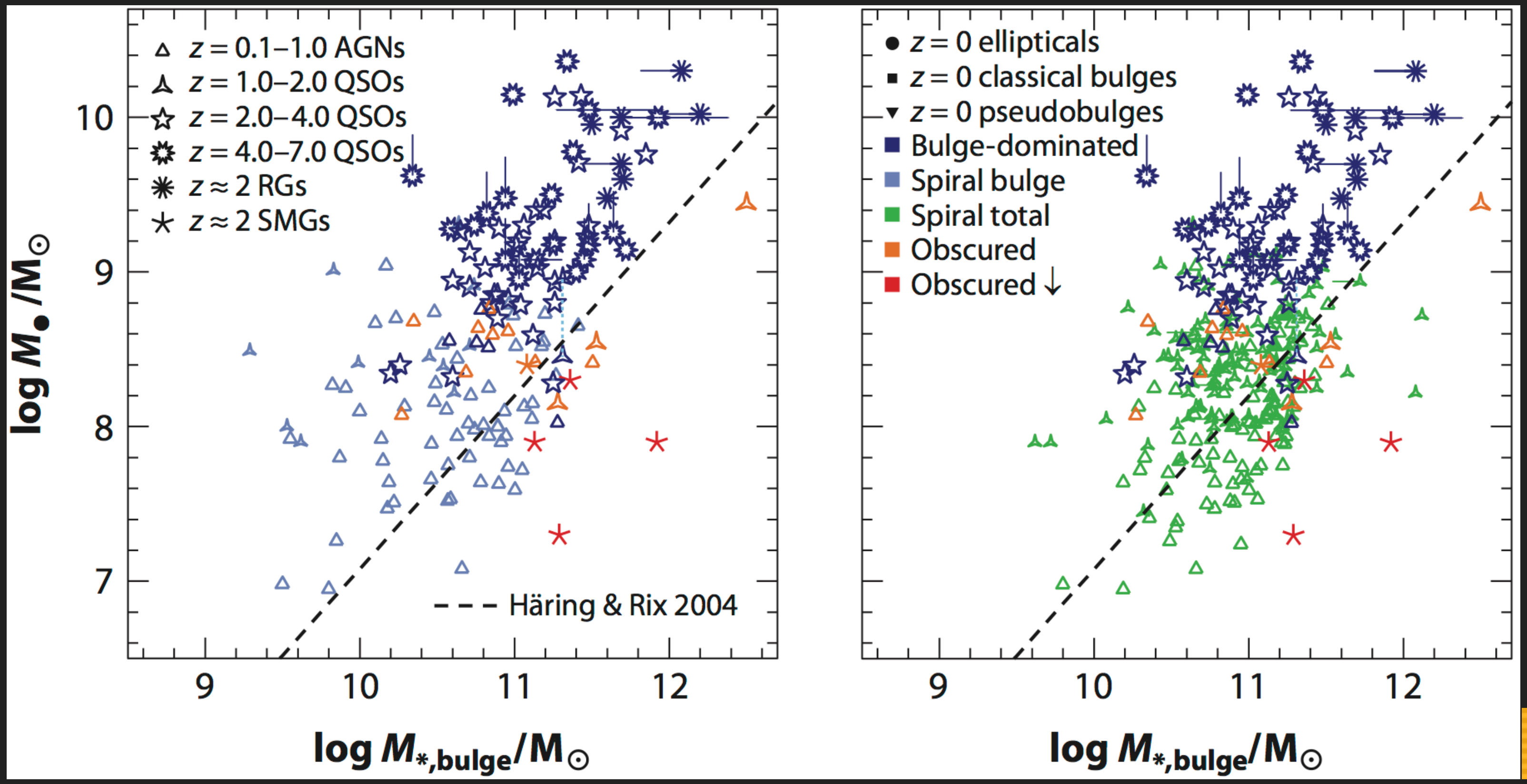
BH-GALAXY SCALING RELATION

- **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:

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



Kormendy & Ho, 2013

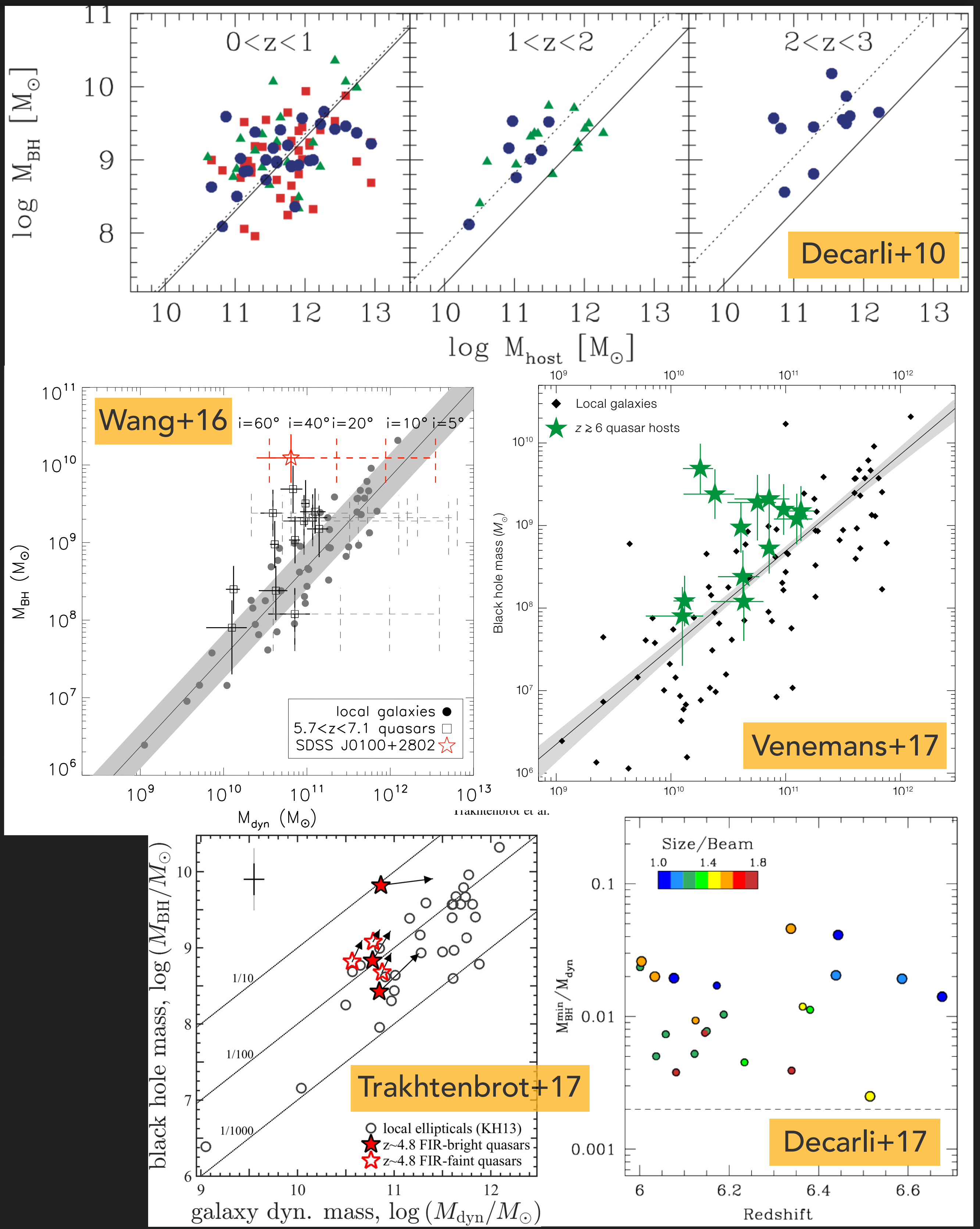
STATE OF THE ART

✳ @ **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)

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

✳ The **ALMA** revolution: extension to **very high redshift** with "dynamical" ***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**.



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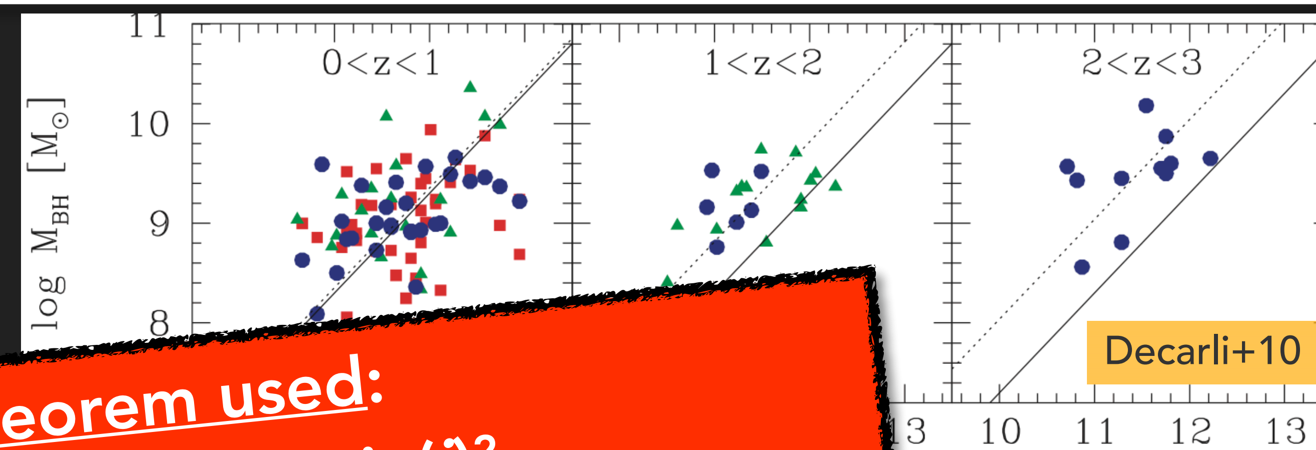
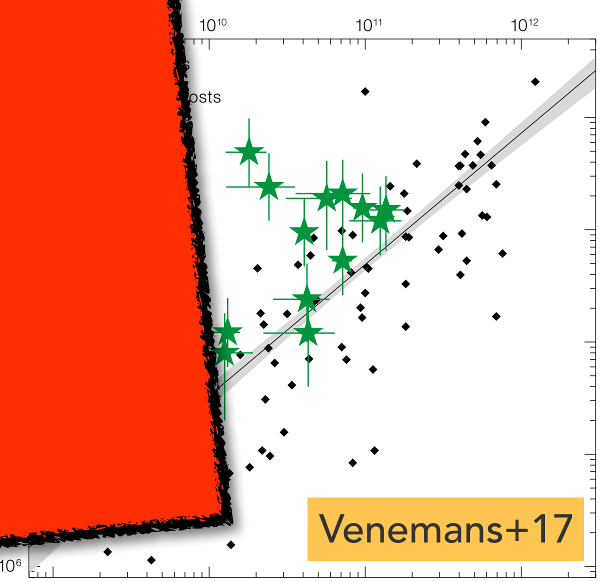
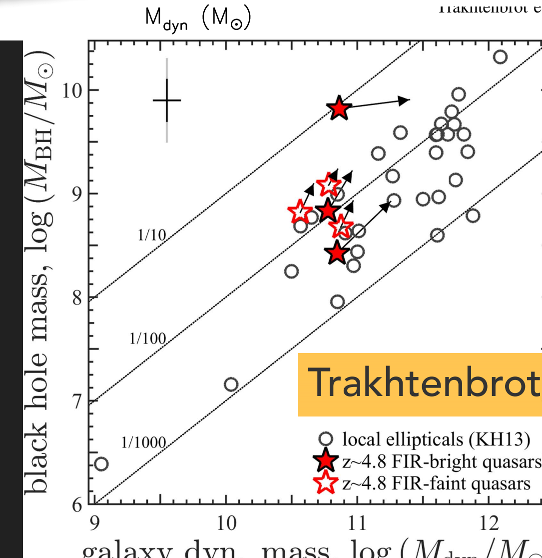
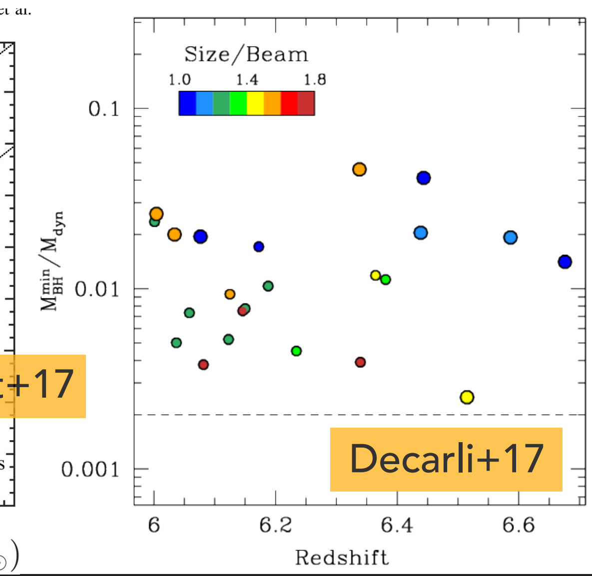








<u>**Virial theorem used:**</u>

M_{dyn} **~ FWHM² Size / sin(*i*)²**

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

<u>**Significant uncertainties!**</u>

ESTIMATION OF M_{gal} AT HIGH-z

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

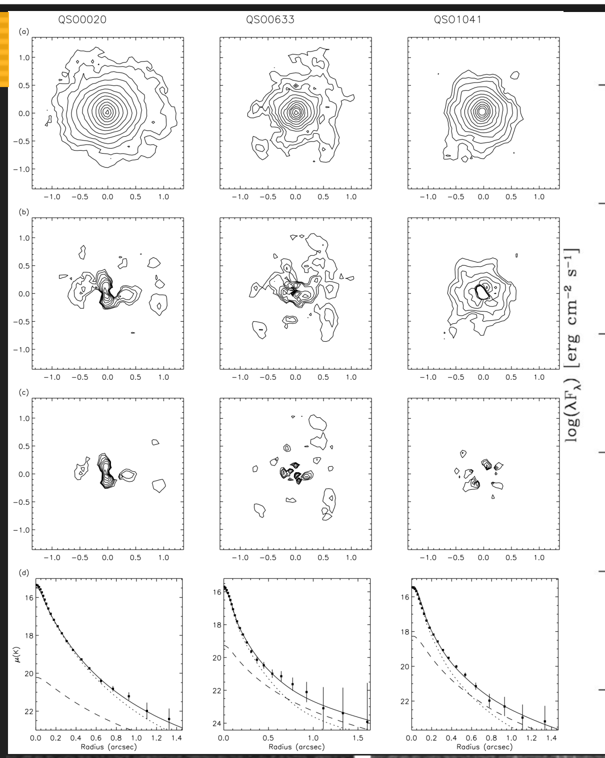
✳ Bright **quasars "hide"** their **host galaxies**: accurate subtraction of the **point-like QSO** is needed:

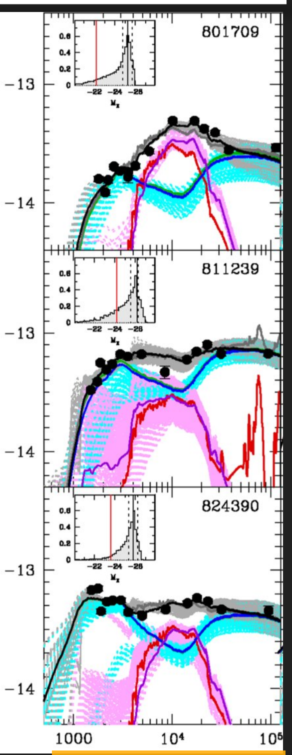
- spatial decomposition ➡ high angular resolution
- spectral decomposition ➡ assume on galaxy and AGN template.
- gravitational lensing ➡ detailed model of the system.

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

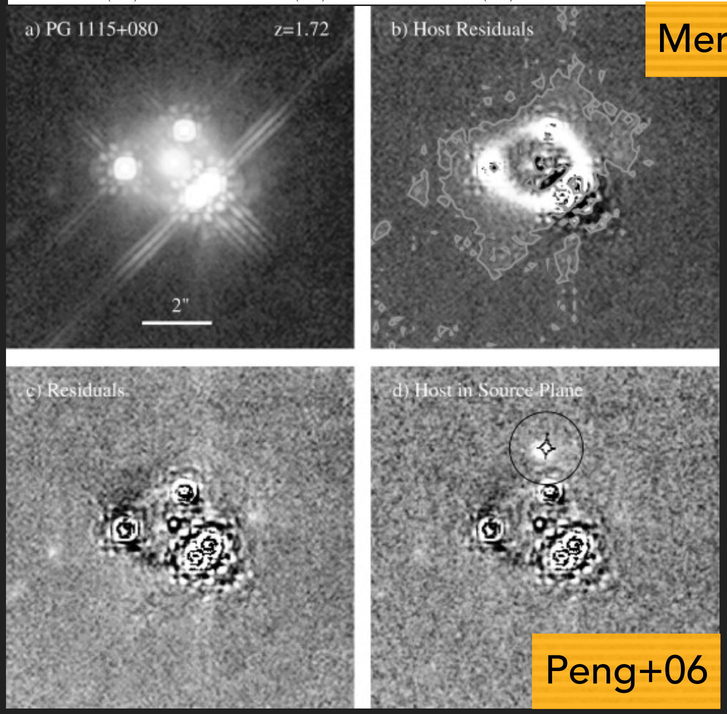
- single band M/L
- stellar population synthesis models ➡ assumptions on stellar population properties

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… f the **point-like QSO** is need…

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

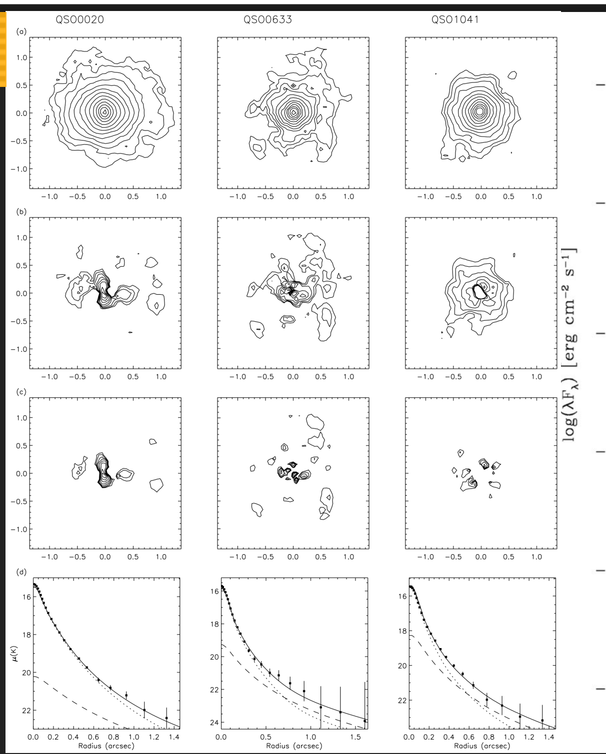
  - spatial decomposition ➡ high ang… lution
  - spectral decomposition ➡ assume on galaxy and AGN template.
  - gravitational lensing ➡ detailed model of the system.

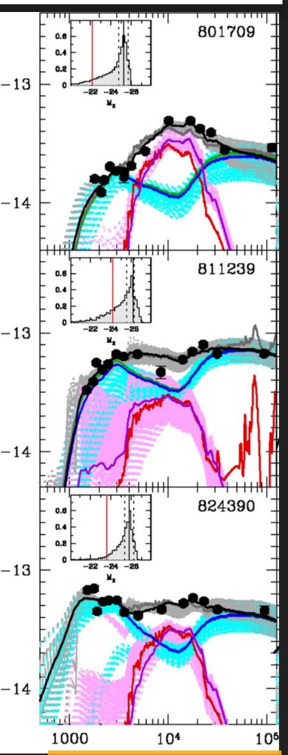
- **Photometric estimati…** …unt only **stellar m…**

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

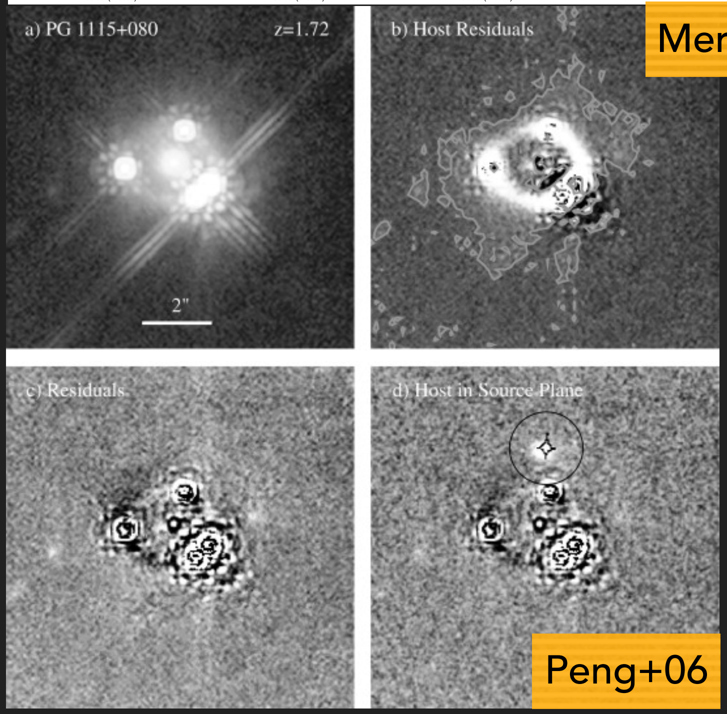
  - sin…
  - stel… …ion synthesis models ➡ assumptions on stellar population properties

Falomo+08





Merloni+10



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→J)** as tracers of **galaxy disk kinematics**

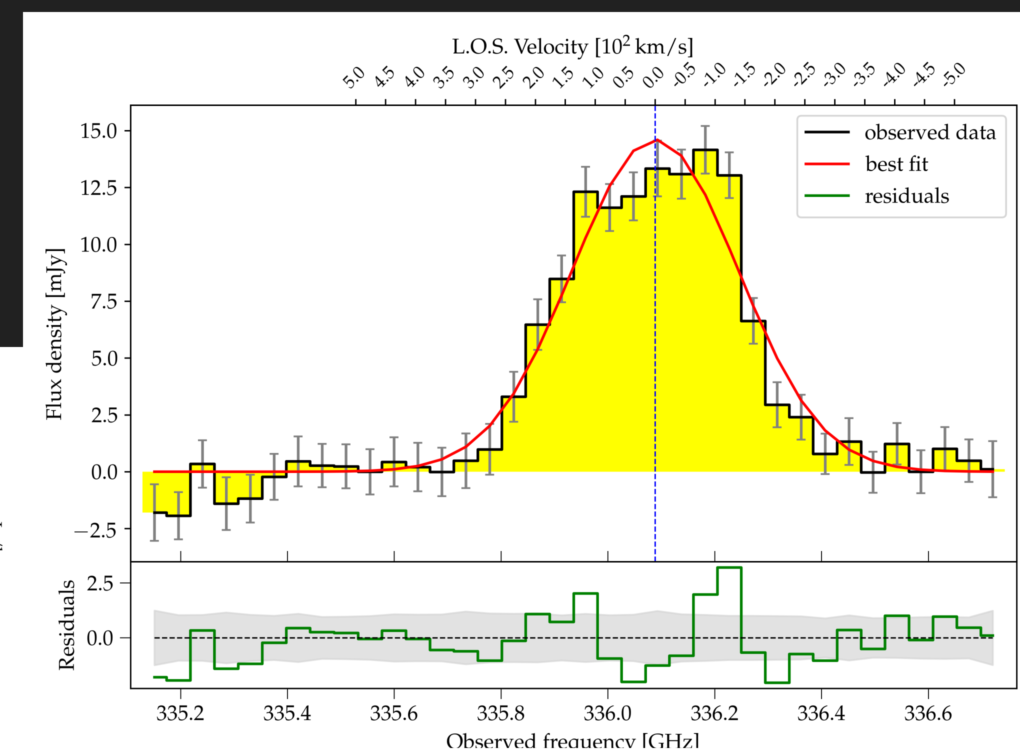
- ★Standard **data reduction** (self calibration when useful)

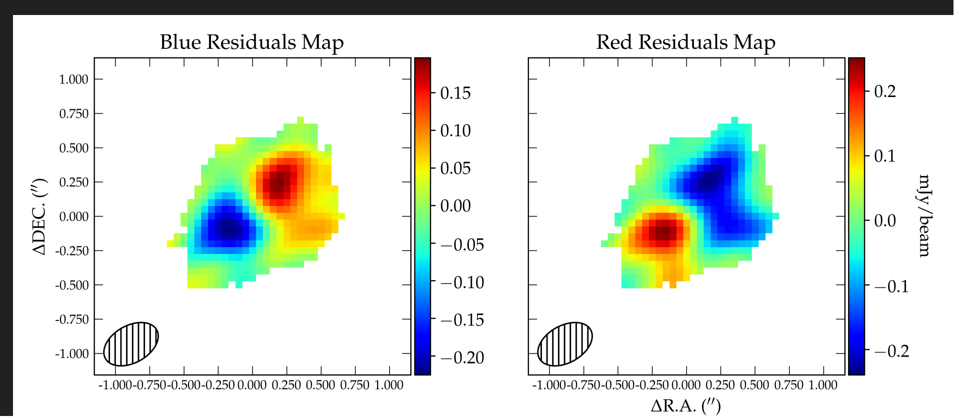
DATA ANALYSIS

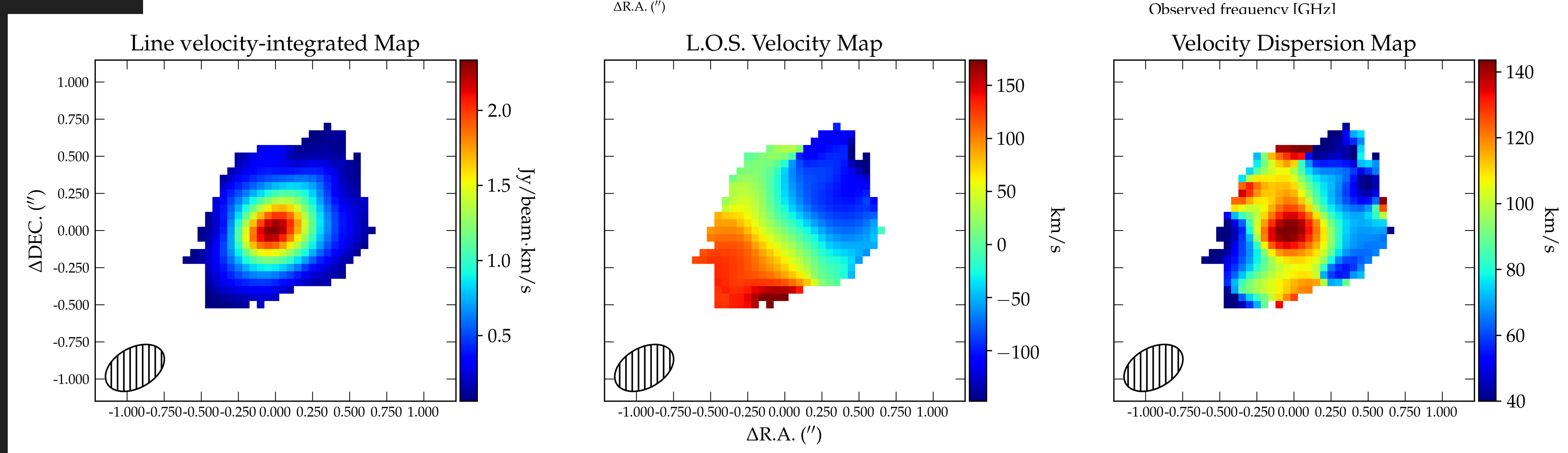
SDSS J092303.53+024739.5
@ $z_{[CII]}$=4.654876±0.000015

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

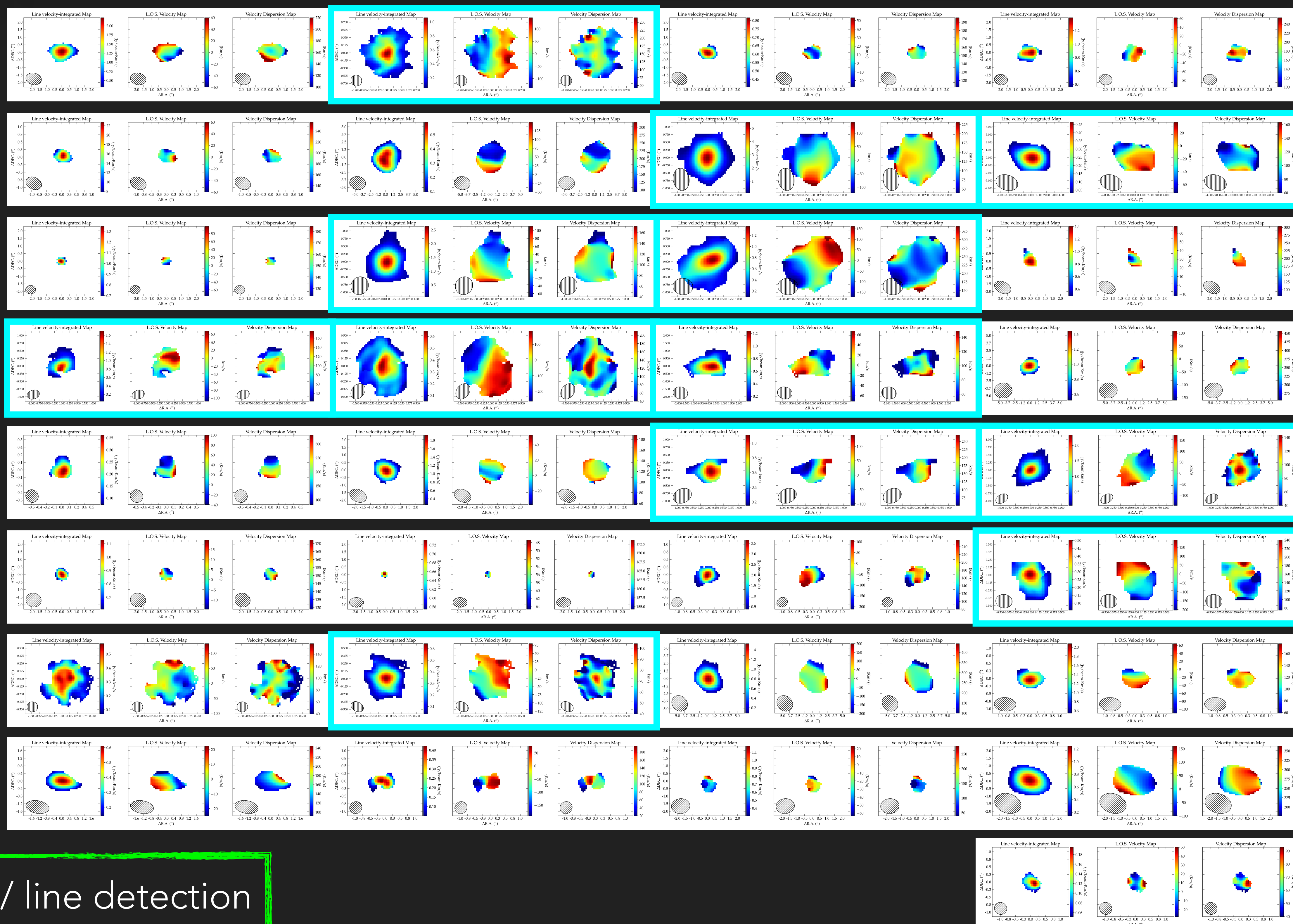
- **Test** for **spatially resolved kinematics**
  (*fit all spaxels with fixed line profile and check residuals*)





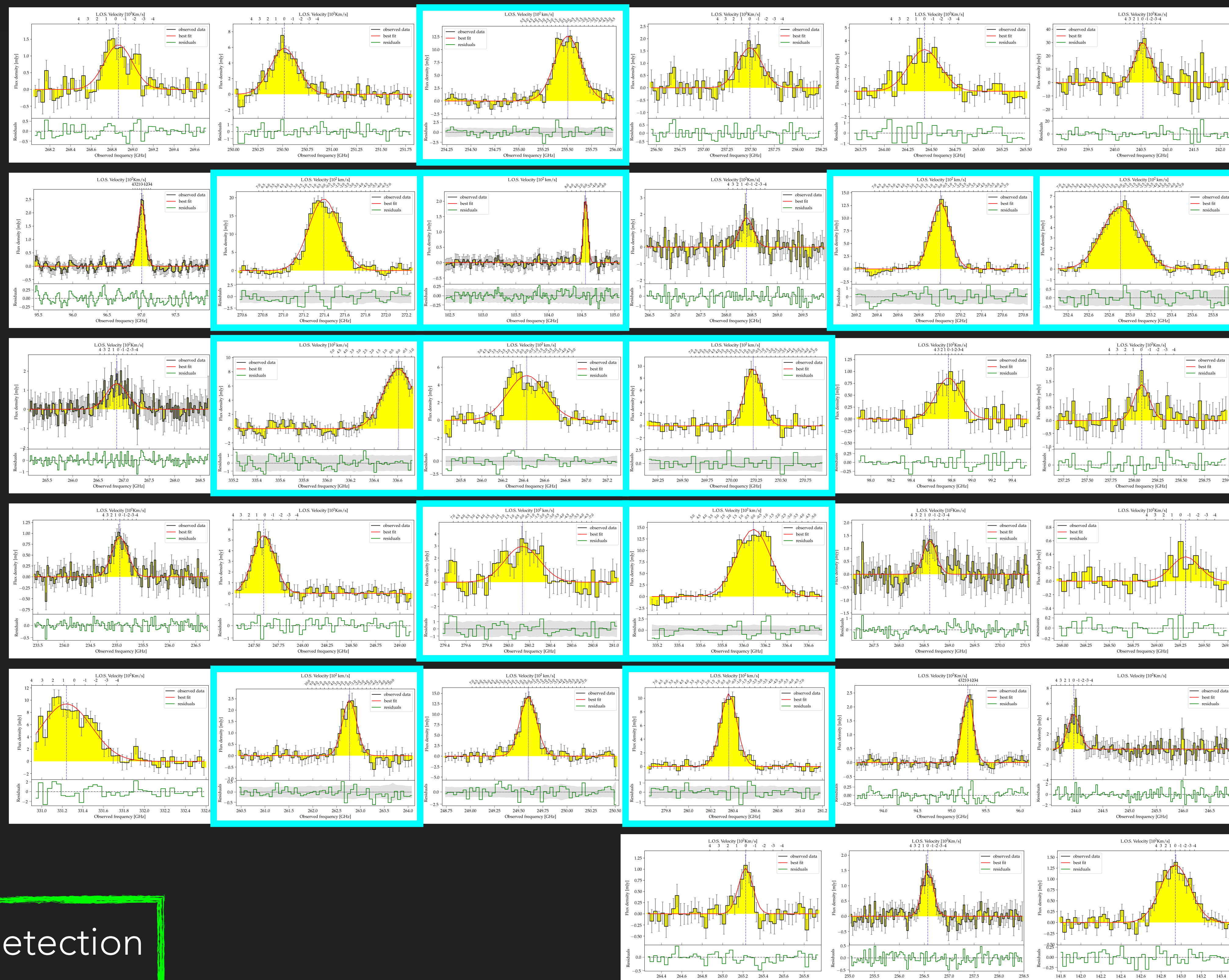


FLUX, $V_{L.O.S.}$, $\Delta V_{L.O.S.}$ MAPS



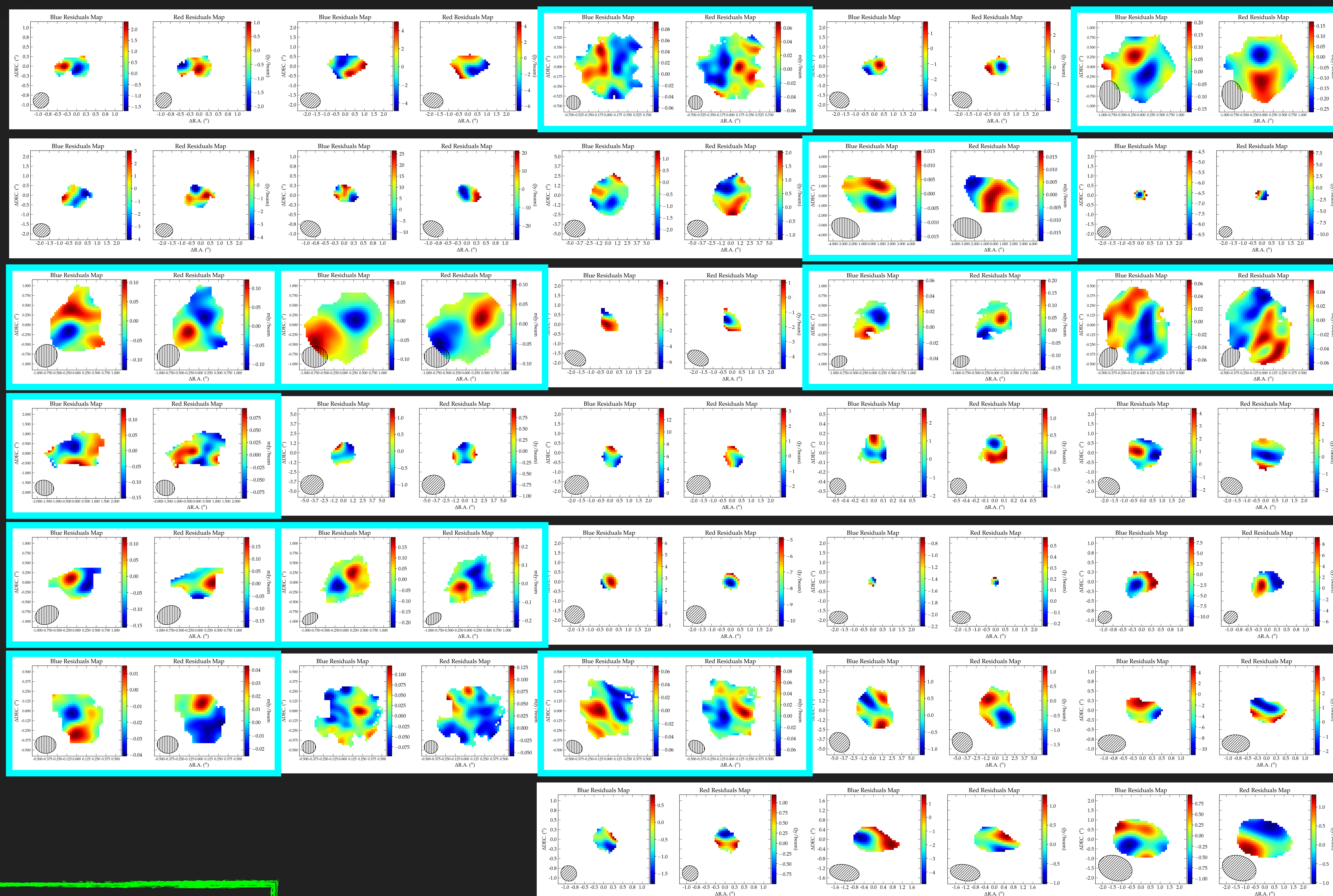
33 sources w/ line detection

INTEGRATED SPECTRA



33 sources w/ line detection

STATIALLY RESOLVED KINEMATICS



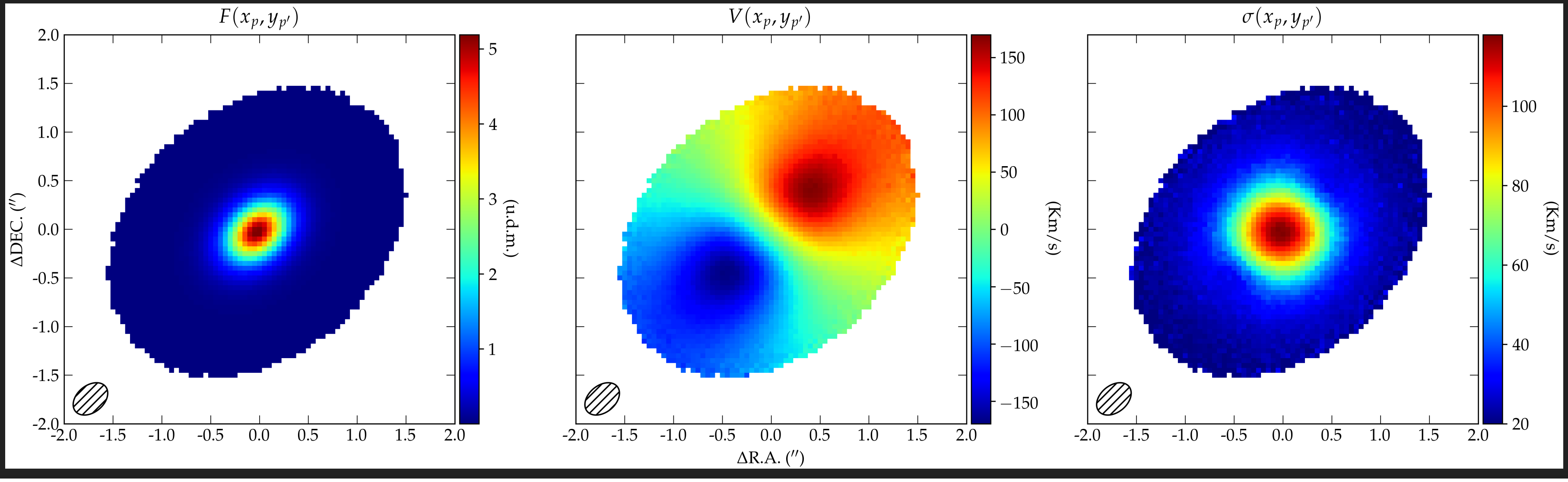
33 sources w/ line detection

KINEMATICAL MODEL

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

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

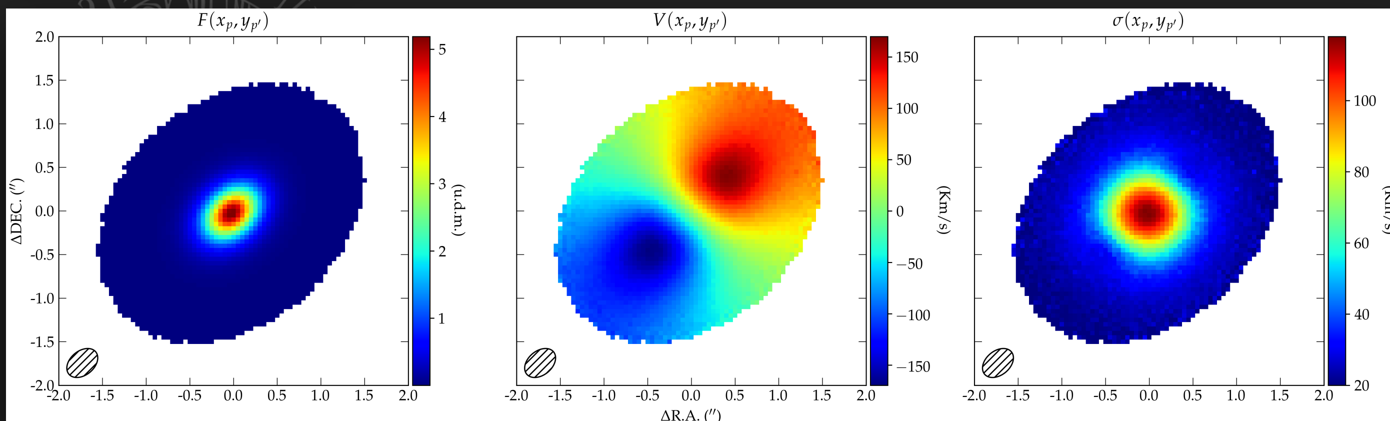
- Kinematical model to perform 2D map-fitting and to recover R_D, $M_{gal,dyn}$
  - ➡ Monte Carlo "cloud" model, assumed brightness profile and velocity field
  - ➡ Takes into account all geometrical projection and observational effects (e.g. beam smearing, binning, etc.)



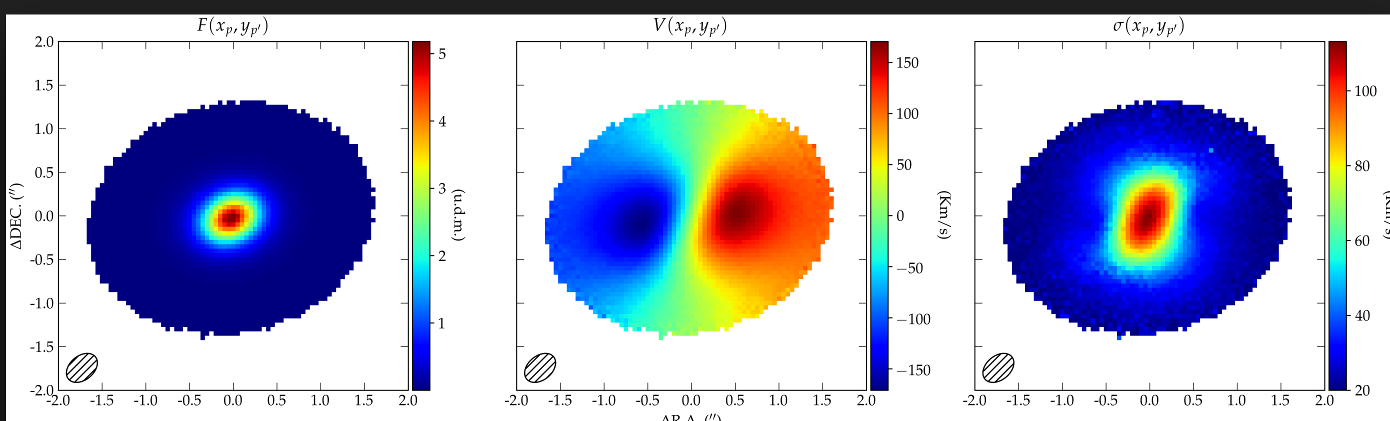
R_D=1.25″
M_{dyn}=5x10^{10} $M_\odot$
i=40°
$P.A.$ = -45 °
FWHM(PSF)= 0.4″x0.275″
B_{PA}=-50°
σ(LSF)= 20 km/s

KINEMATICAL MODEL

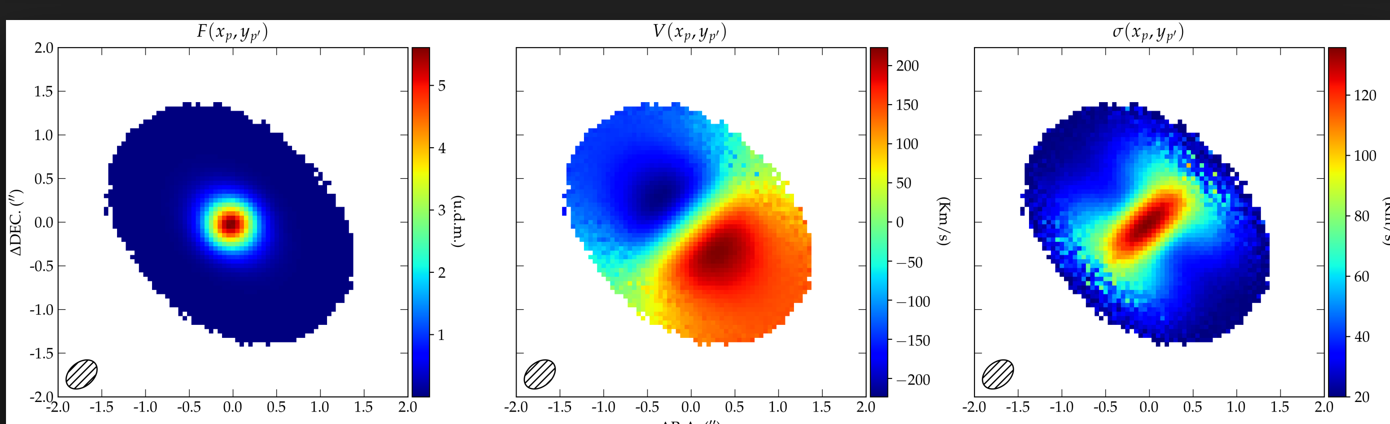
Beam smearing and/or wrong $M(r)$ makes $\boldsymbol{i}$ and $\boldsymbol{M_{dyn}}$ almost degenerate



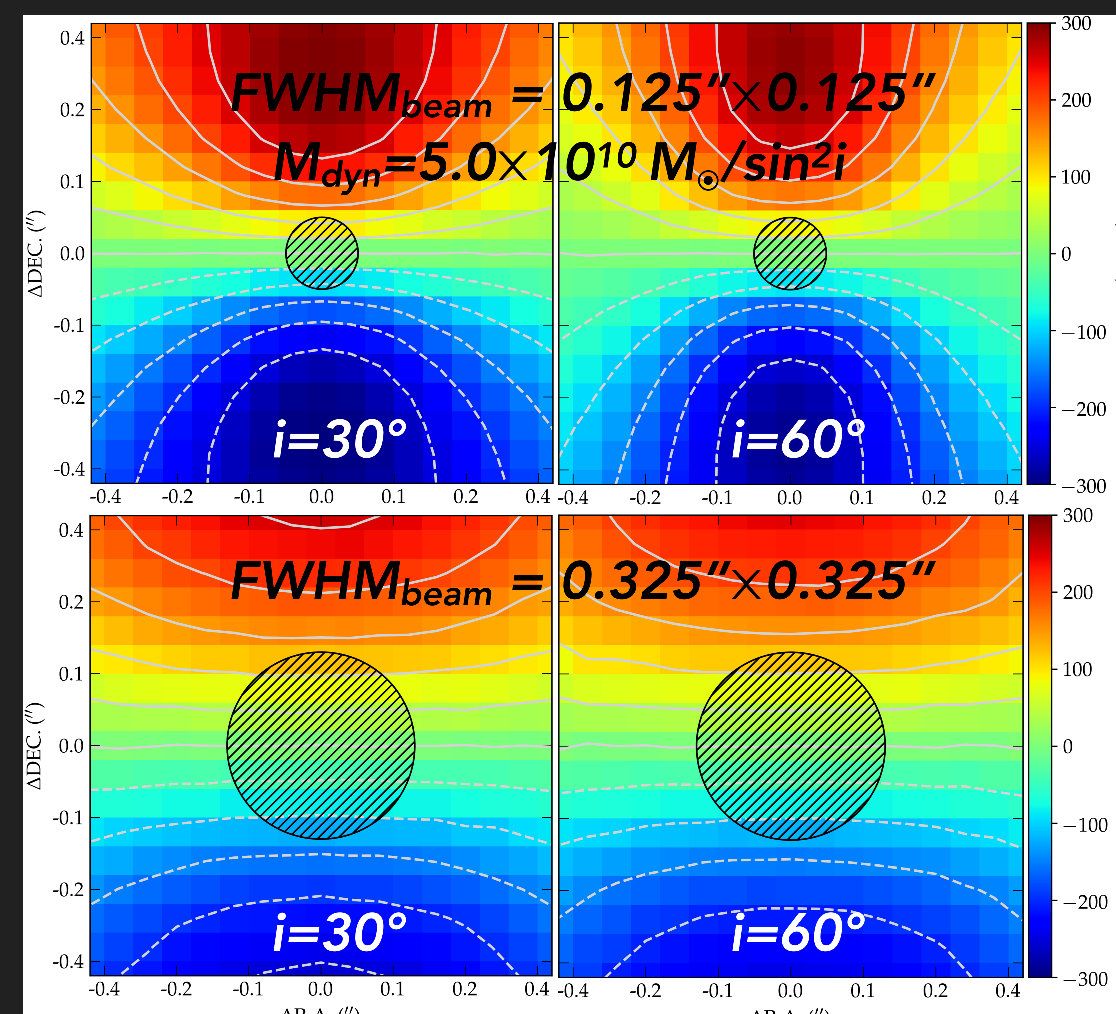
a) *i= 40°, P.A. = -45°*



b) *i=40°, P.A. = 0°*



c) *i= 60°, P.A. = 45°*



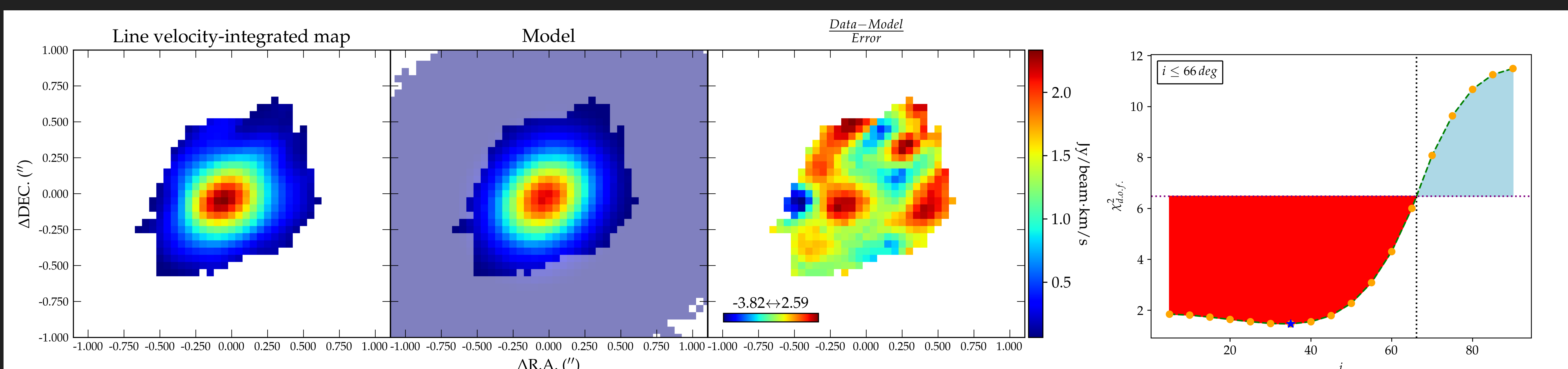
KINEMATICAL MODELING

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

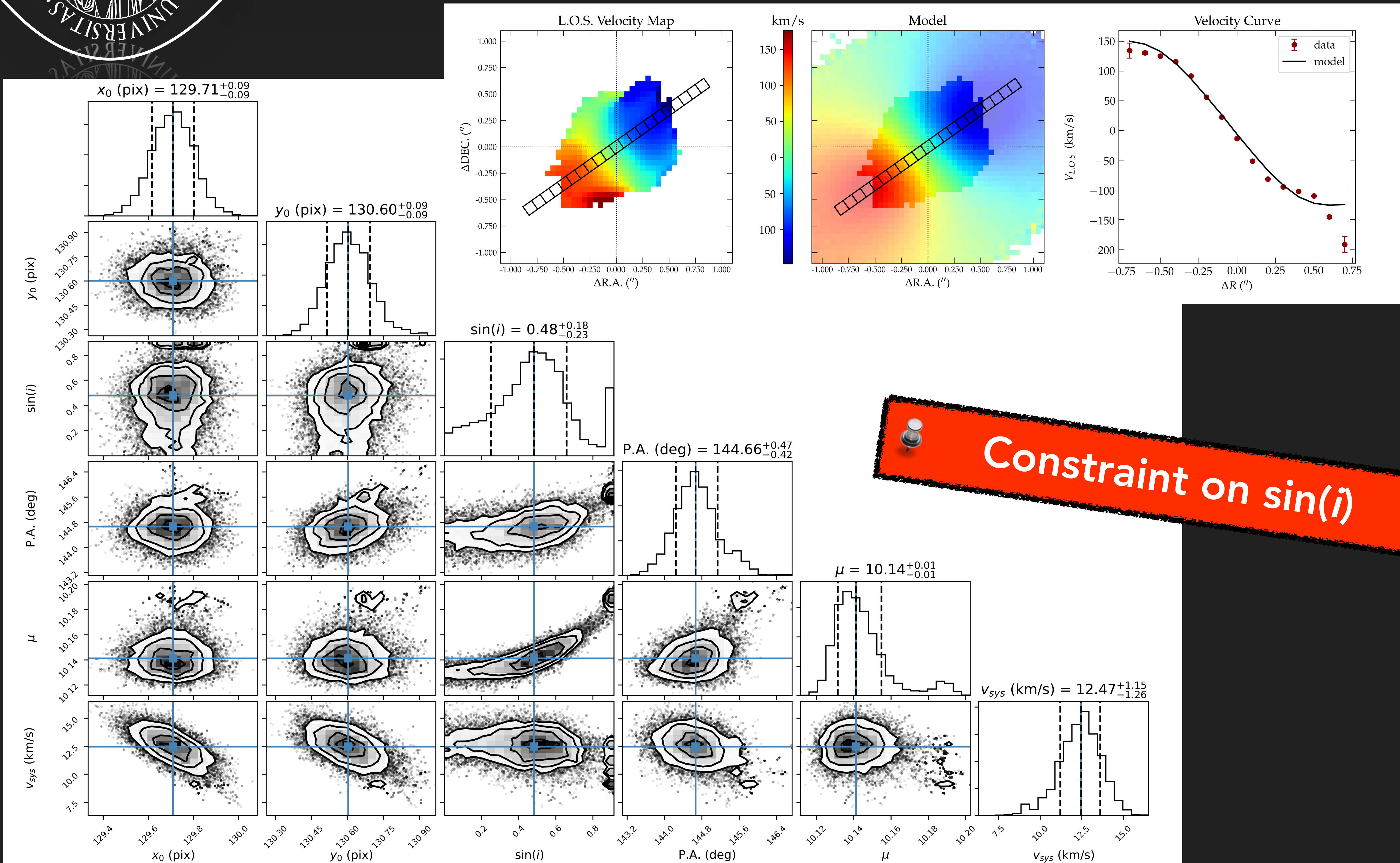
    1) **Fit line flux distribution** with exponential disk = measure scale radius R_D

- ✳ **+ 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 $M_{gal,dyn}$



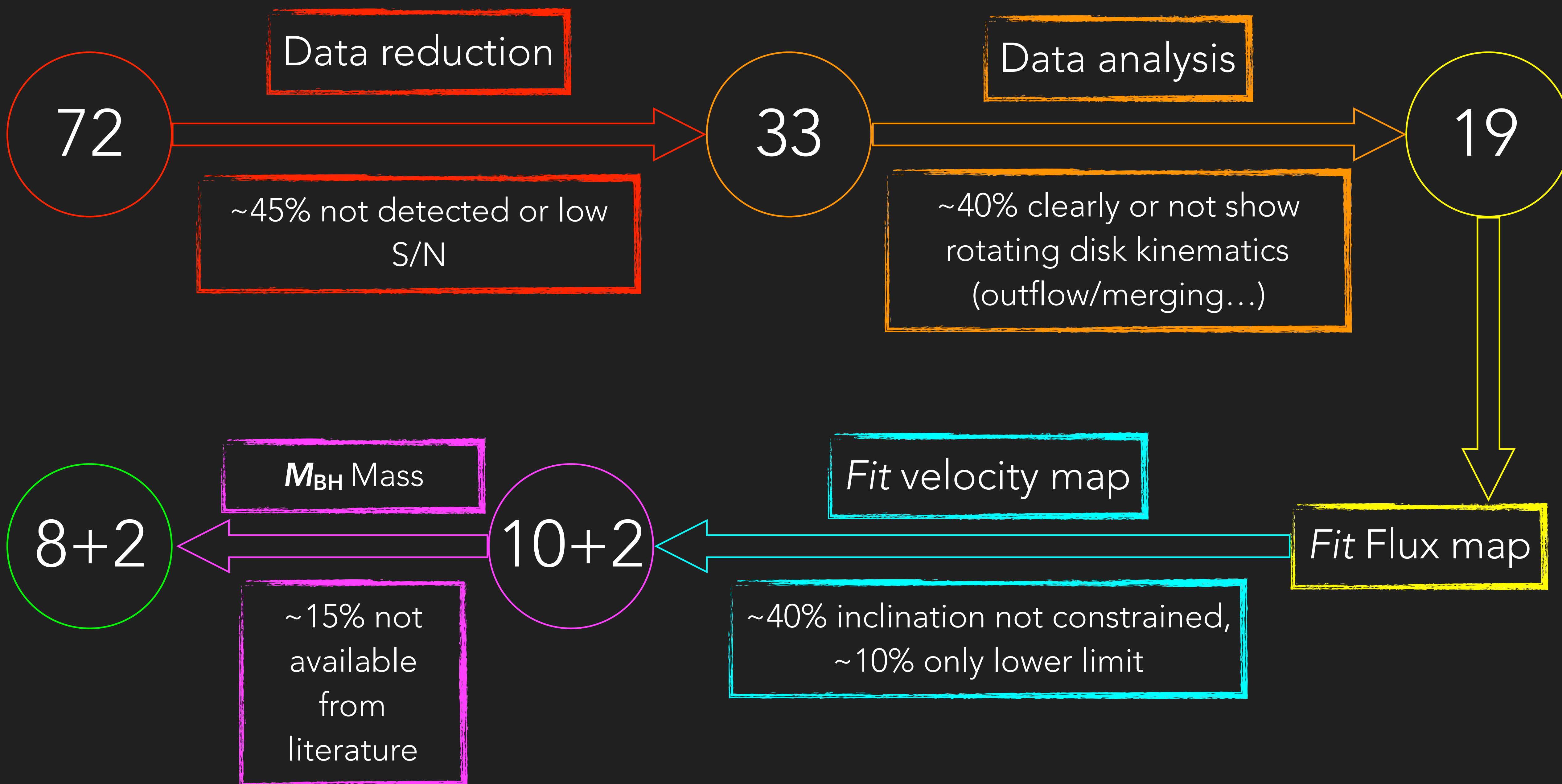
KINEMATICAL MODELING



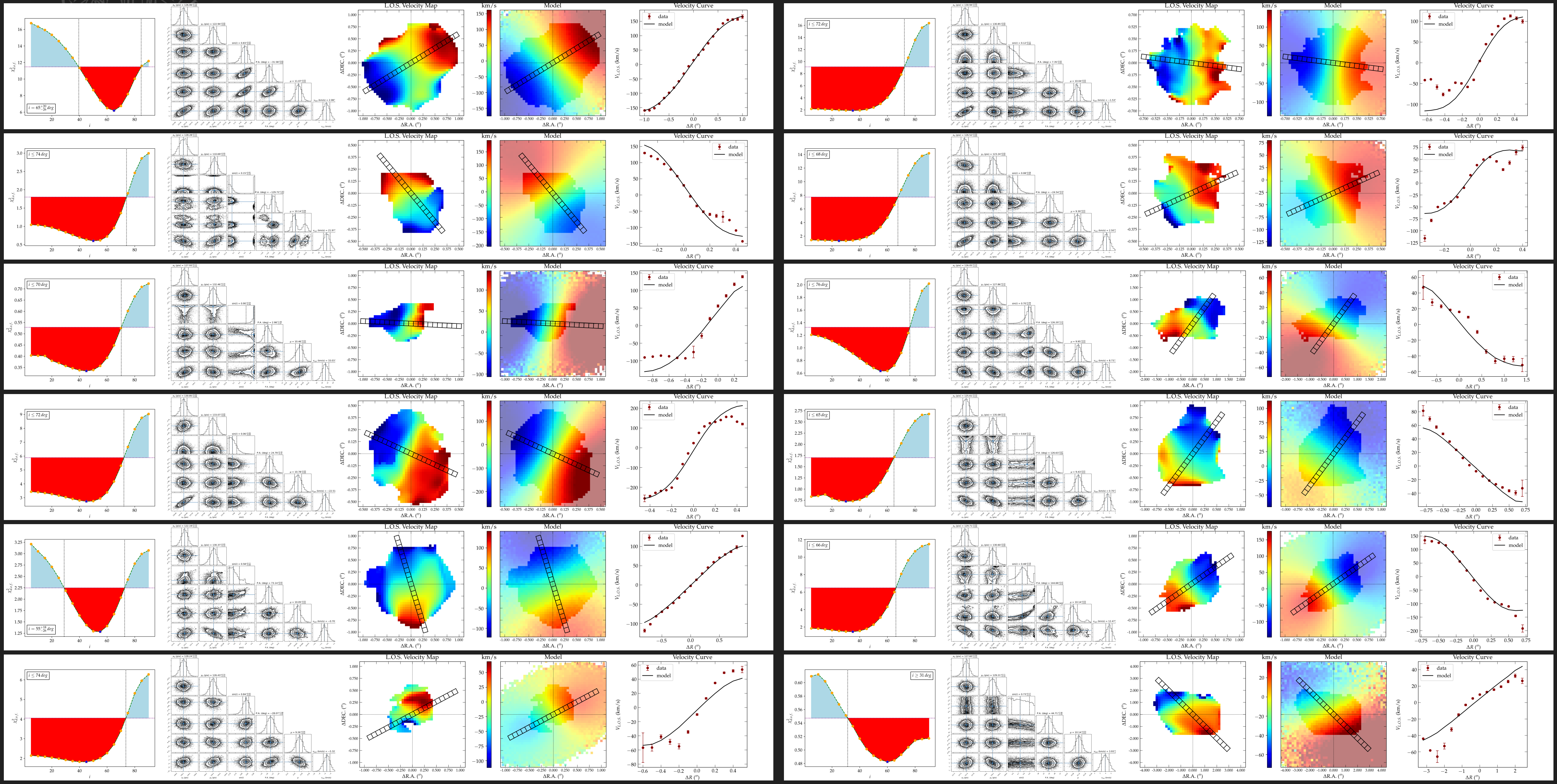
Constraint on sin(i)

OVERALL RESULTS

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



OVERALL RESULTS



12 sources

EVOLUTION OF BH-GALAXY RELATION

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

De Nicola, Marconi & Longo 2018

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

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

$z < 1$

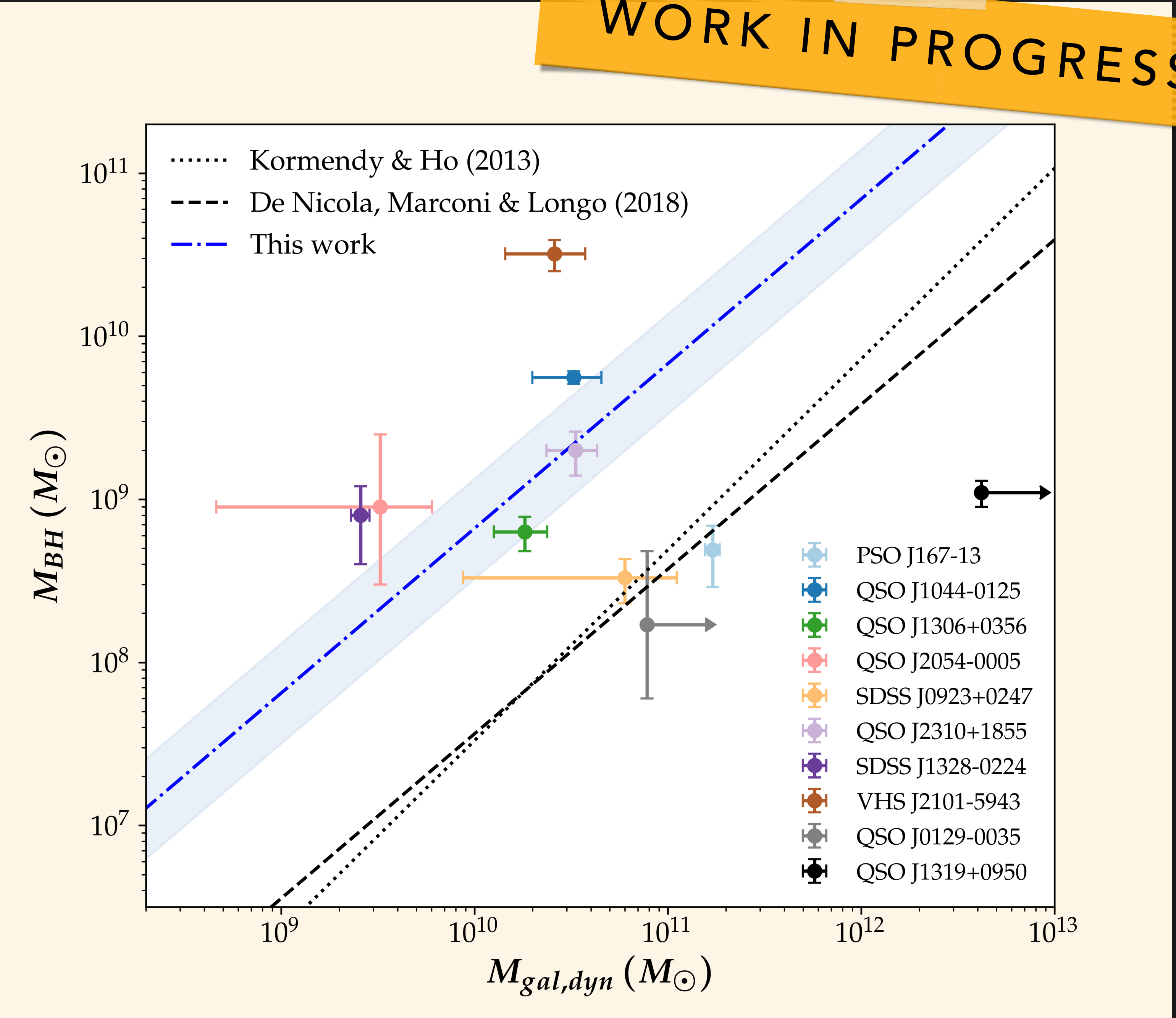
This work

$\alpha = 9.6 \pm 0.3$

$\beta \equiv \beta_{DML}$

$4 < z < 7$

WORK IN PROGRESS!

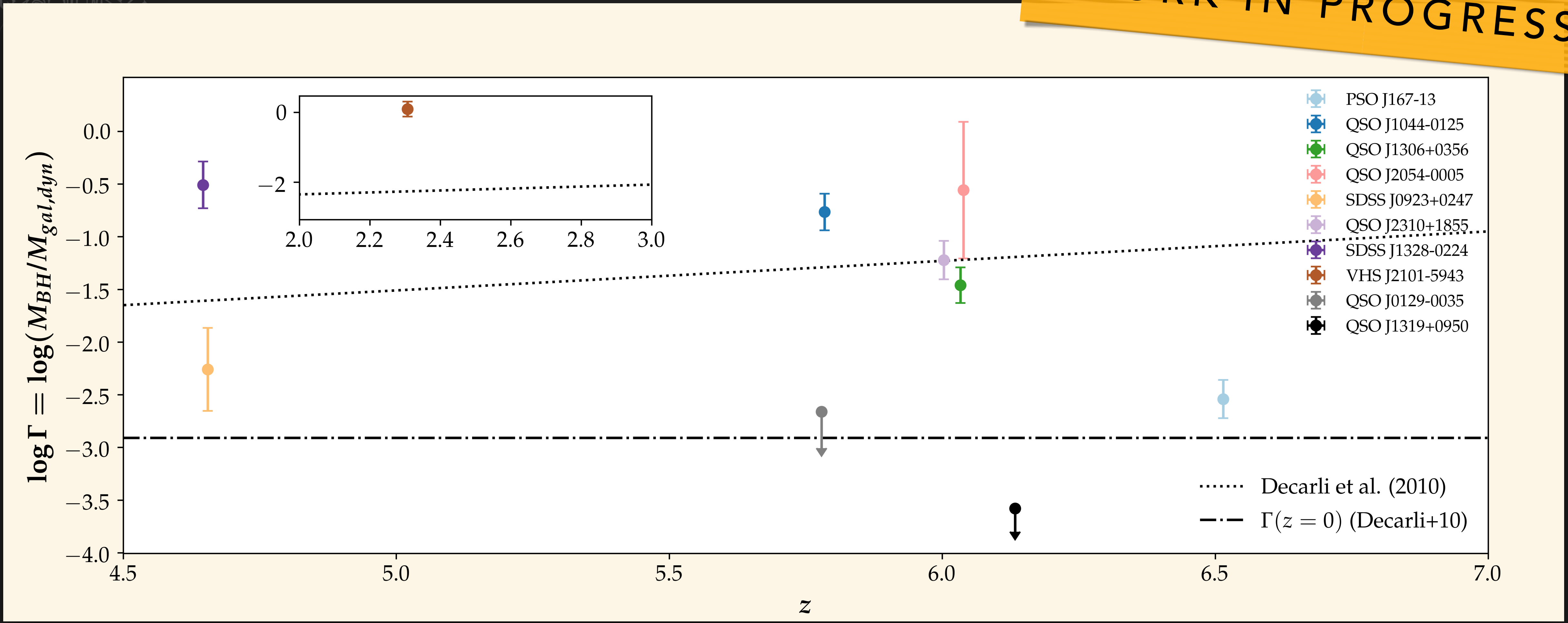


CONFIRMING THE EVOLUTION OF $z \gtrsim 1$ RELATION

(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.**

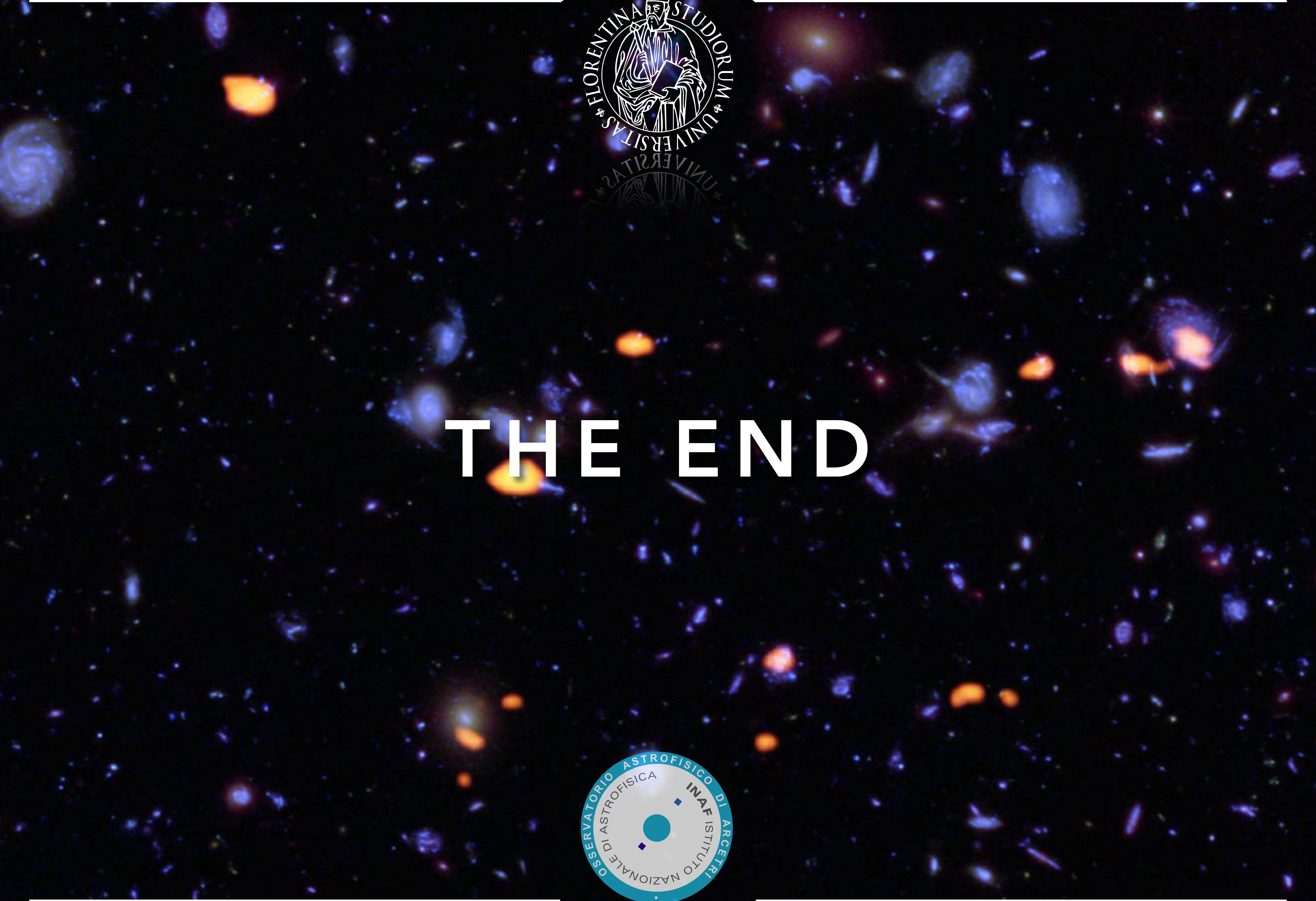
- Our result **confirms** the observed **evolution** of M_{BH}-$M_{gal,dyn}$ **relation** with **z.**

- **$\Gamma = M_{BH}/M_{gal}$** 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!

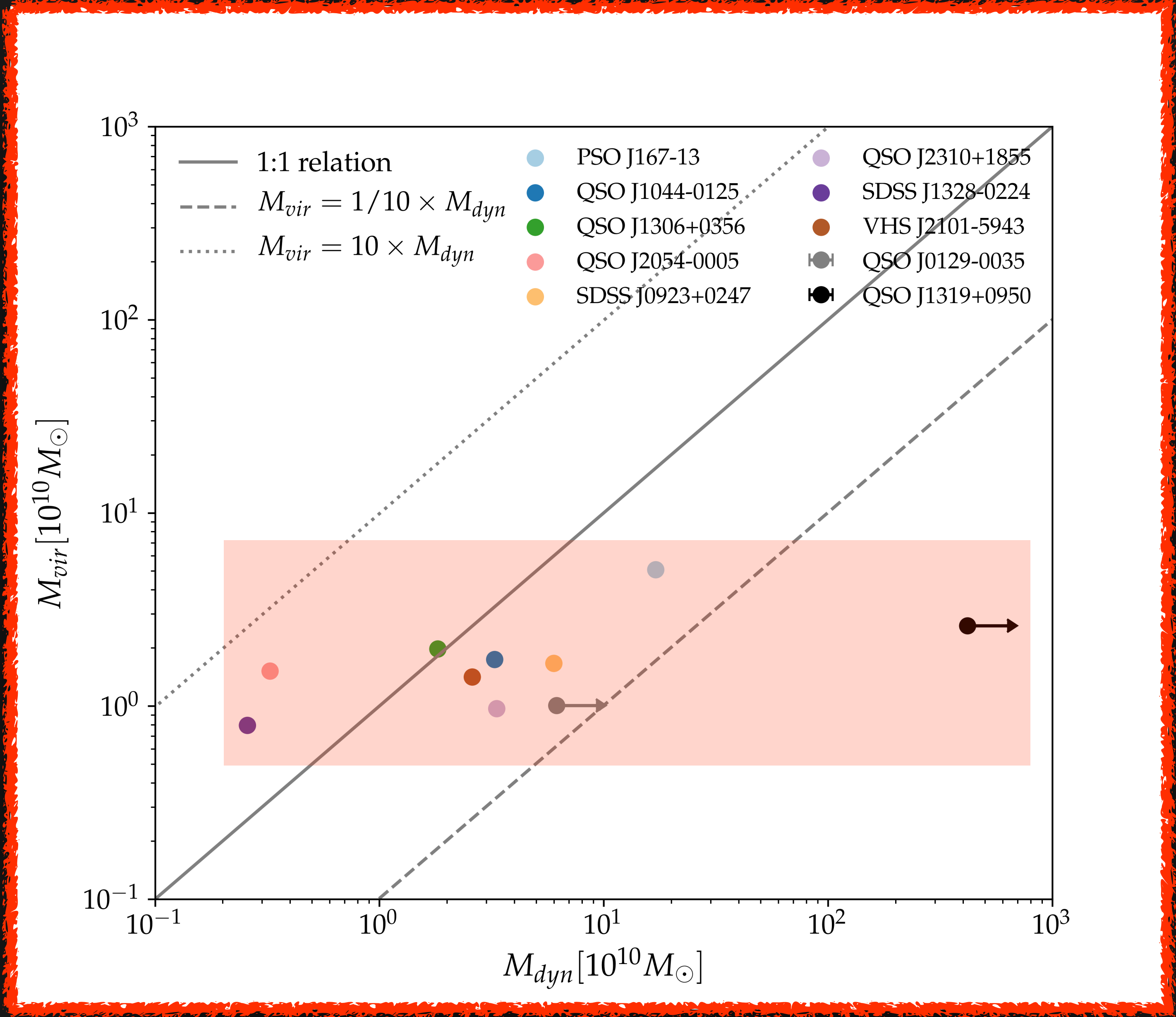
Pensabene, Marconi et al. 2018 (in prep.)


THE END

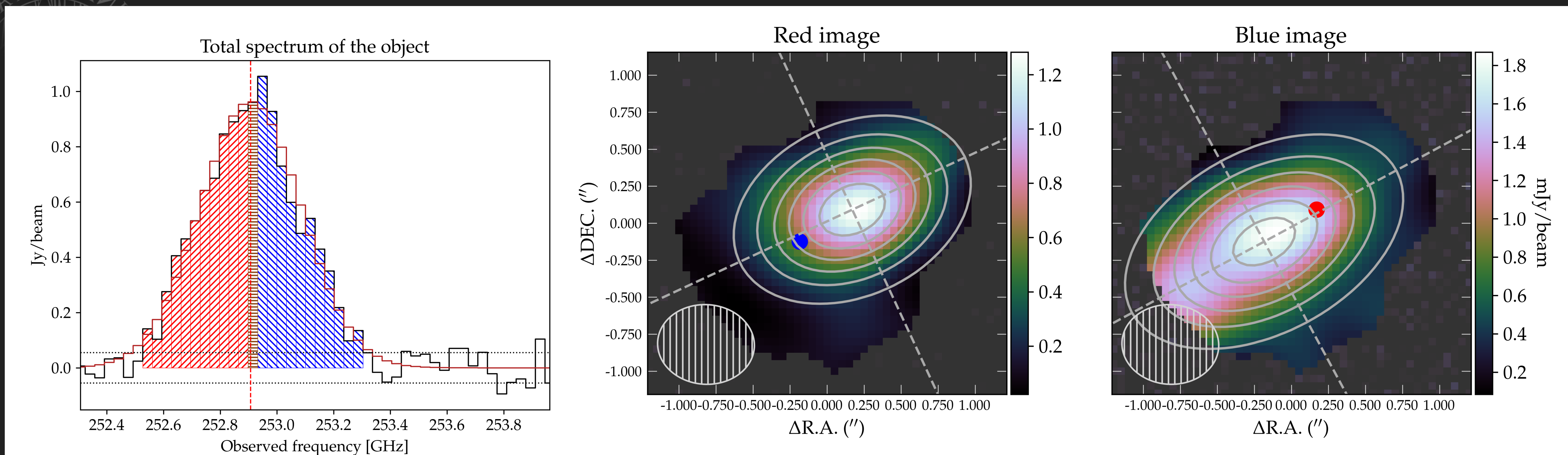
BACKUP SLIDES

COMPARISON WITH VIRAL MASSES

- Estimate ***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"

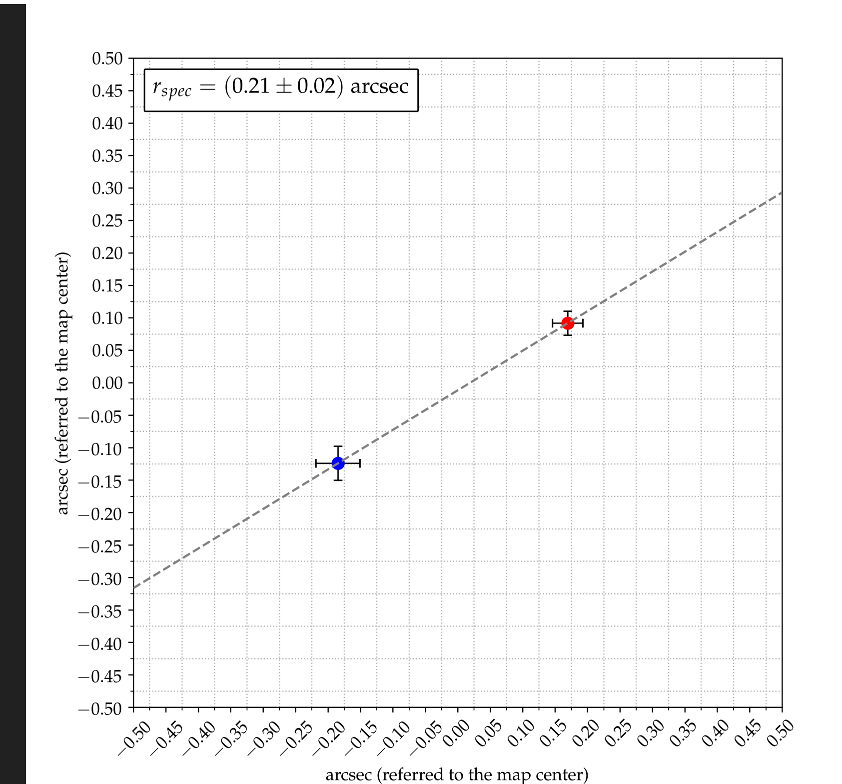


- Use "**spectroastrometry**" to measure more accurate virial masses (Gnerucci, Marconi, +11; Carniani, Marconi+13)

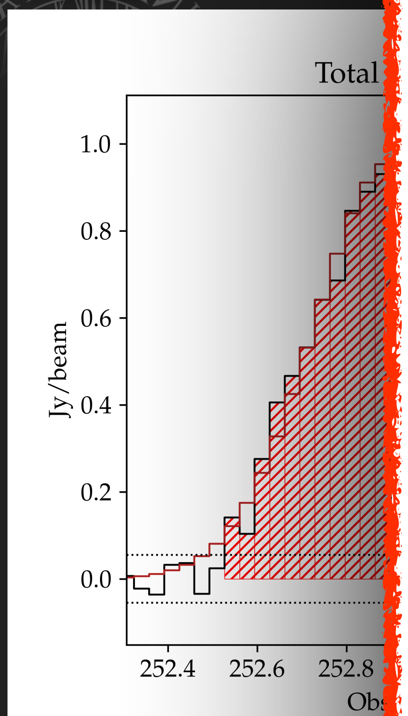
$$M_{spec} \sin^2 i \sim f_{spec}\, \mathrm{FWHM}^2\, r_{spec}$$

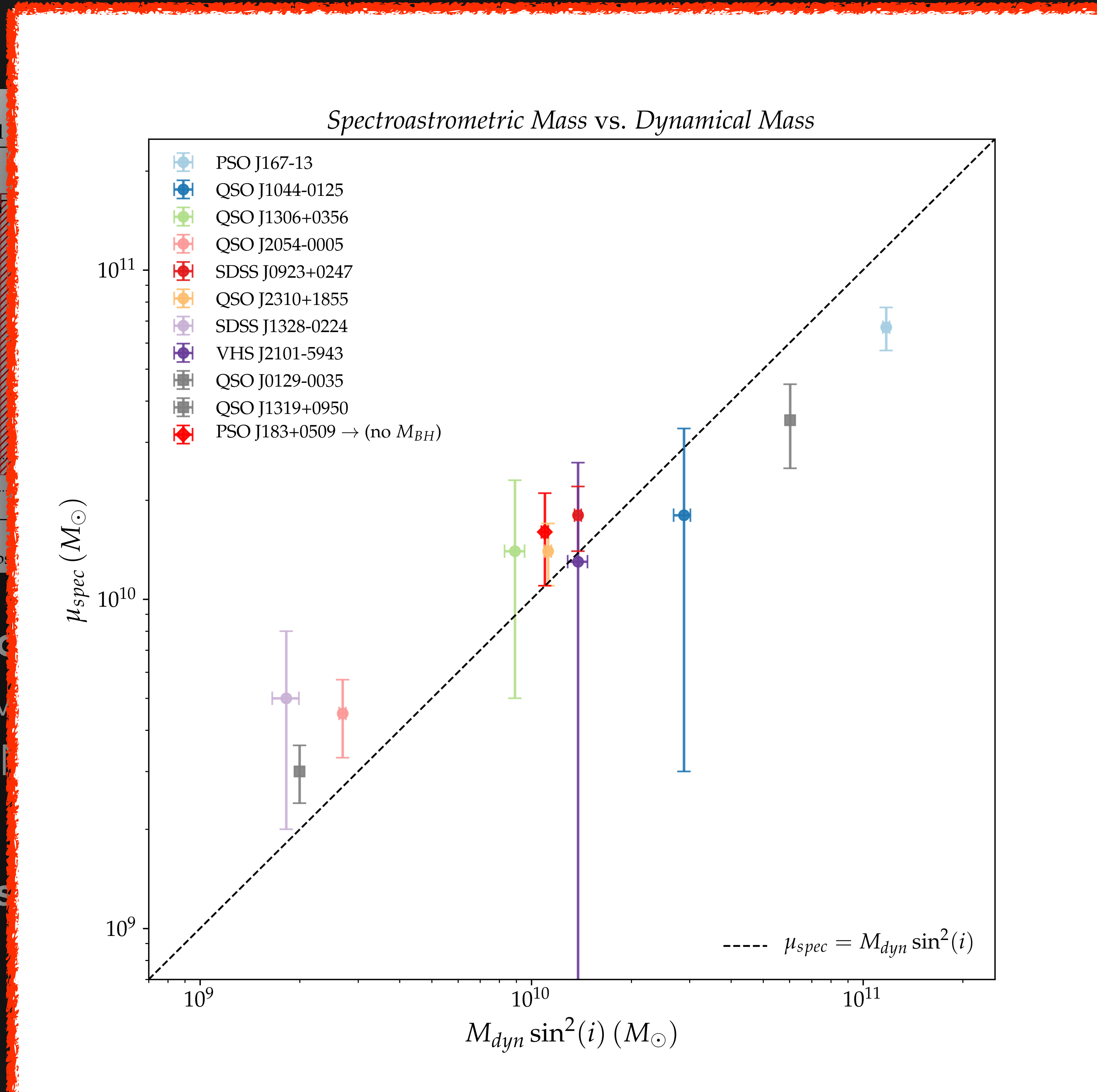
$$f_{spec} = 1.0 \pm 0.1$$

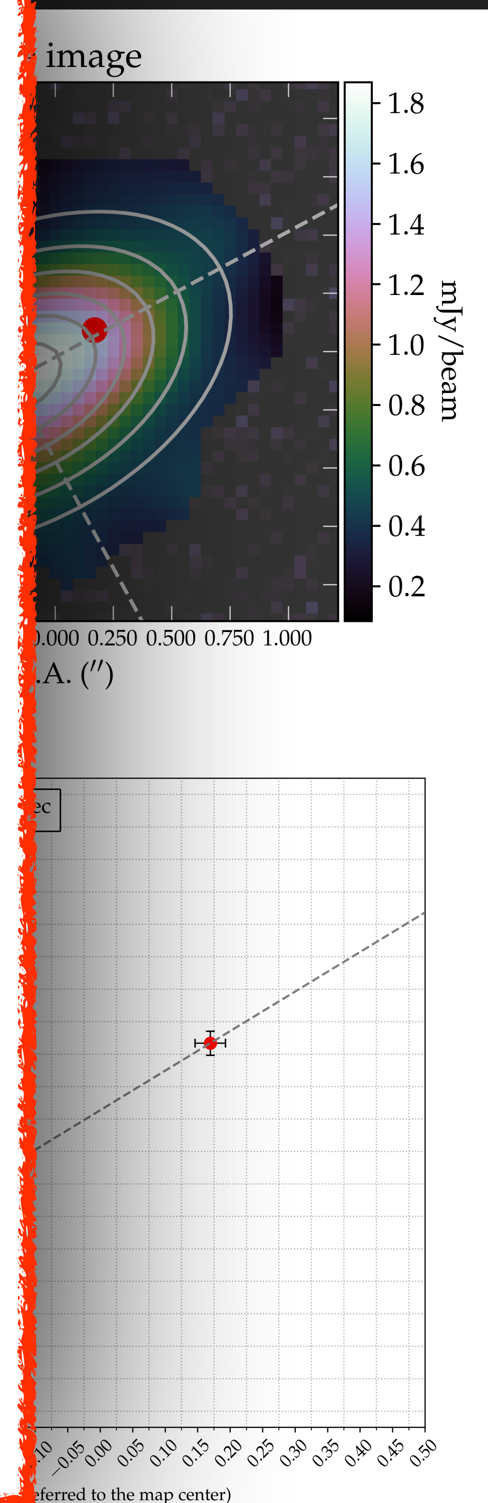
(Gnerucci, Marconi et al. 2011)



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)