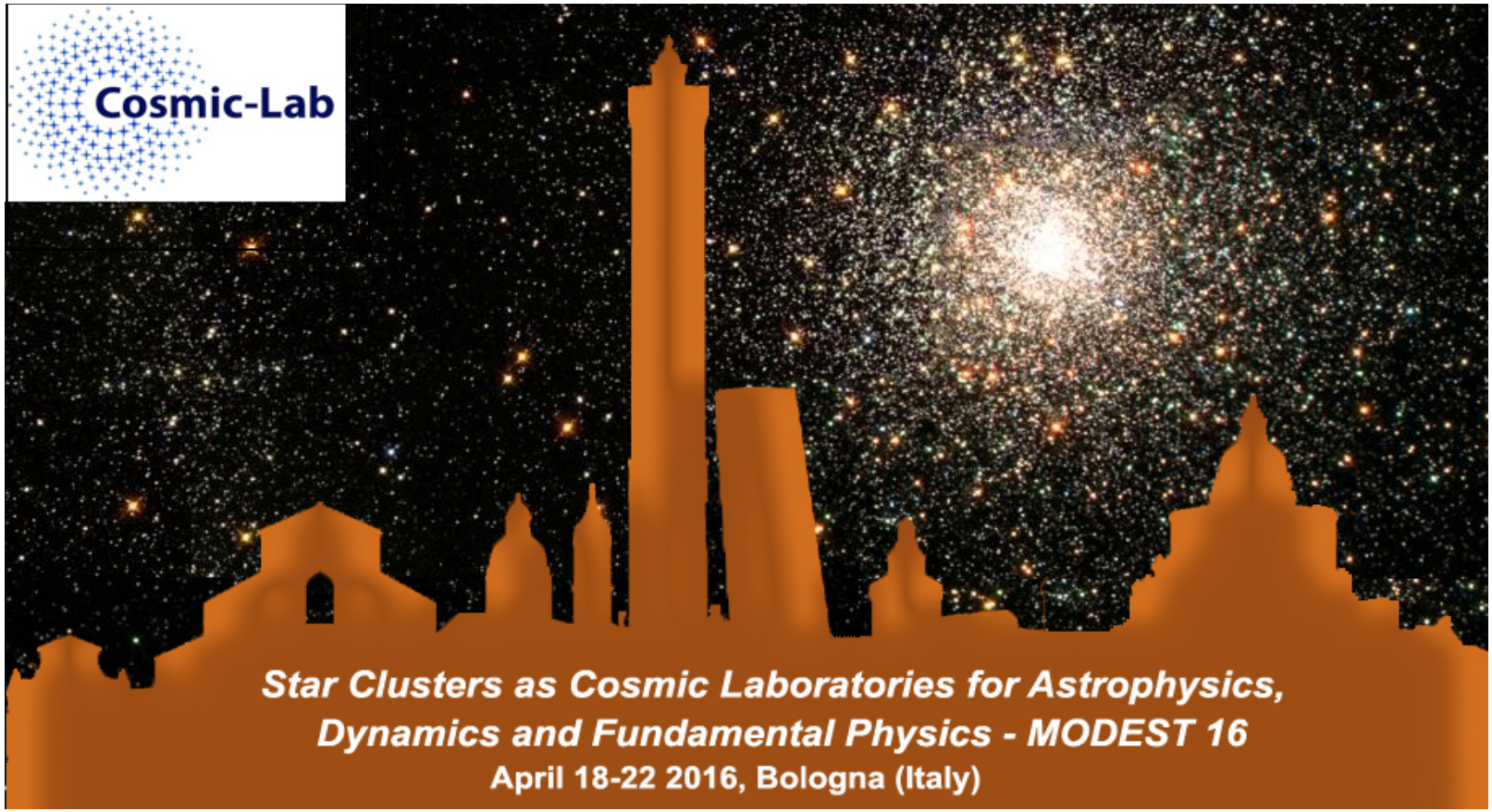

Searching for IMBHs in GCs with SINFONI

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Bologna, April 20, 2016

✦ IMBHs in GCs: several fingerprints predicted

(Baumgardt et al. 2005; Miocchi 2007; Heggie et al. 2007; Trenti et al. 2007, 2010; Dukier & Bailyn 2003; Maccarone 2004, 2007; Gill et al. 2008; Vesperini & Trenti 2010; Noyola & Baumgardt 2011; Umbreit & Rasio 2013; ...)

1) shallow density cusp at the very centre

2) steep inner cusp in the velocity dispersion (VD) profile

4) a few stars accelerated to very high-velocities (even v ~ 100 km/s)

3) universal & large ratio of core to half-mass radii (r_c/r_h >0.1)

5) quenching of mass segregation

6) X-ray and radio emission

✦ IMBHs in GCs: not confirmed yet

- **non univocal fingerprints:**
  - density cusp during evolution also in GCs with no IMBH (Vesperini & Trenti 2010)
  - VD cusp due to pressure anisotropy (Alice Zocchi talk)
  - quenching of mass segregation: degeneracy with binaries (Gill et al. 2008
  - high-velocity stars or non-cluster members?
  - **uncertainties on expected X-ray and radio emission** (gas density? accretion efficiency?) → Tom talk

- **challenging observations** (sub-arcsec BH sphere of influence)

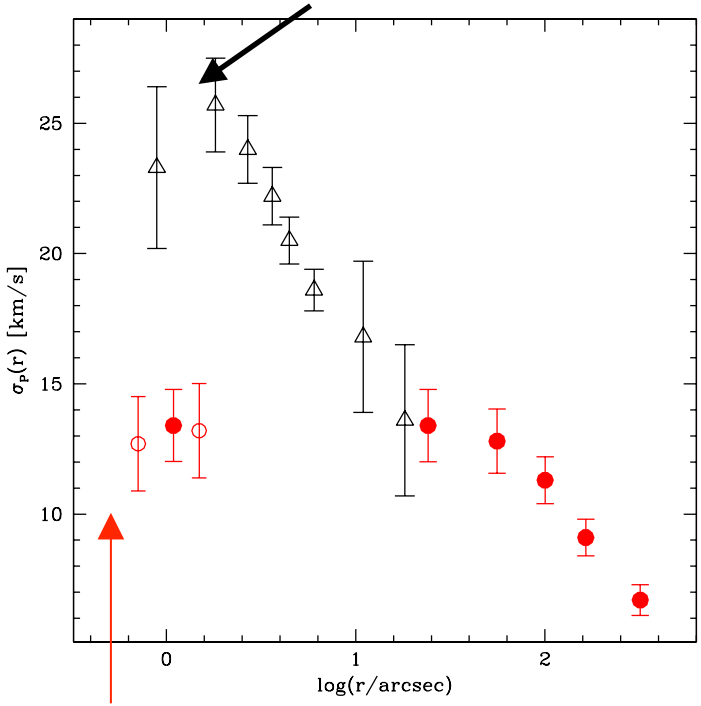
especially for the detection of a **central VD cusp**...

CONVINCING detection of an IMBH

an IMBH is the MOST LIKELY (if not THE ONLY) explanation of what we observe

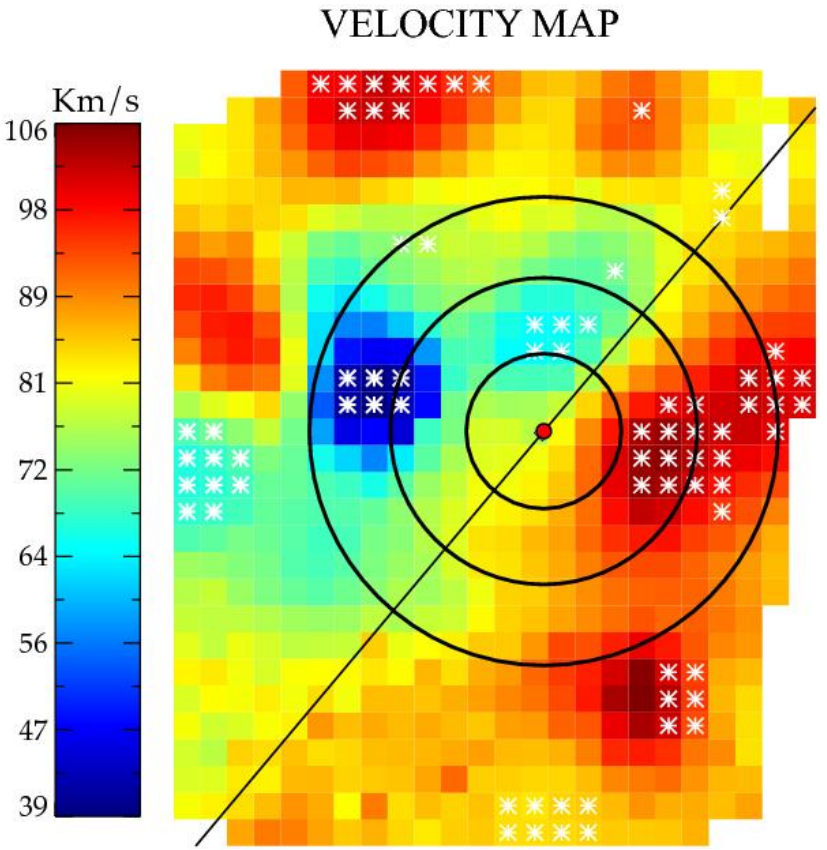
NGC 6388

Lützgendorf et al. (2011)
(M_{BH} ~ 1.7 10^4 $M_\odot$)



Lanzoni et al. (2013)
(no IMBH)

integrated-light spectra
(ARGUS: seeing-limited IFU)



Lützgendorf et al. 2011

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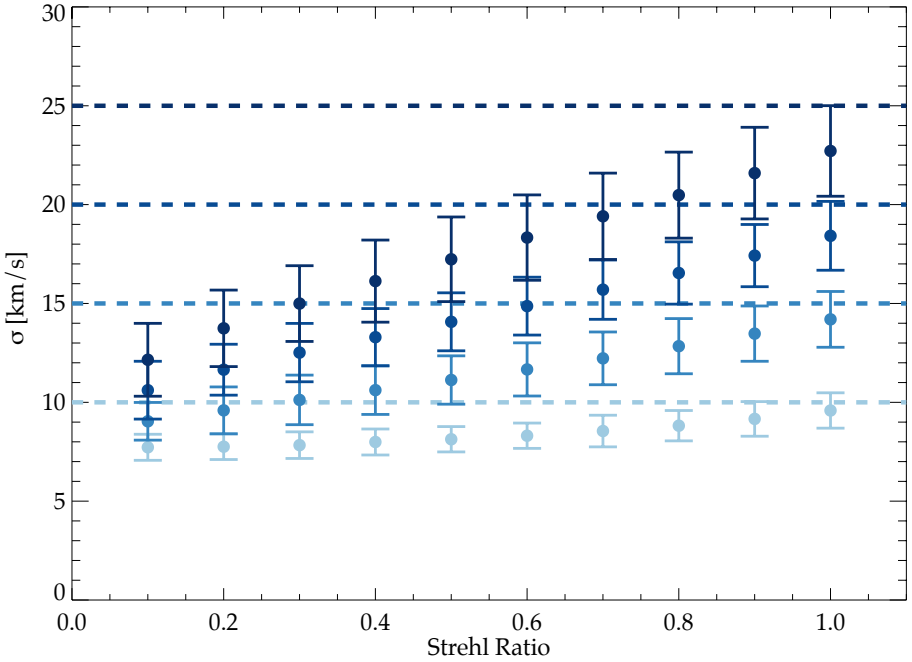
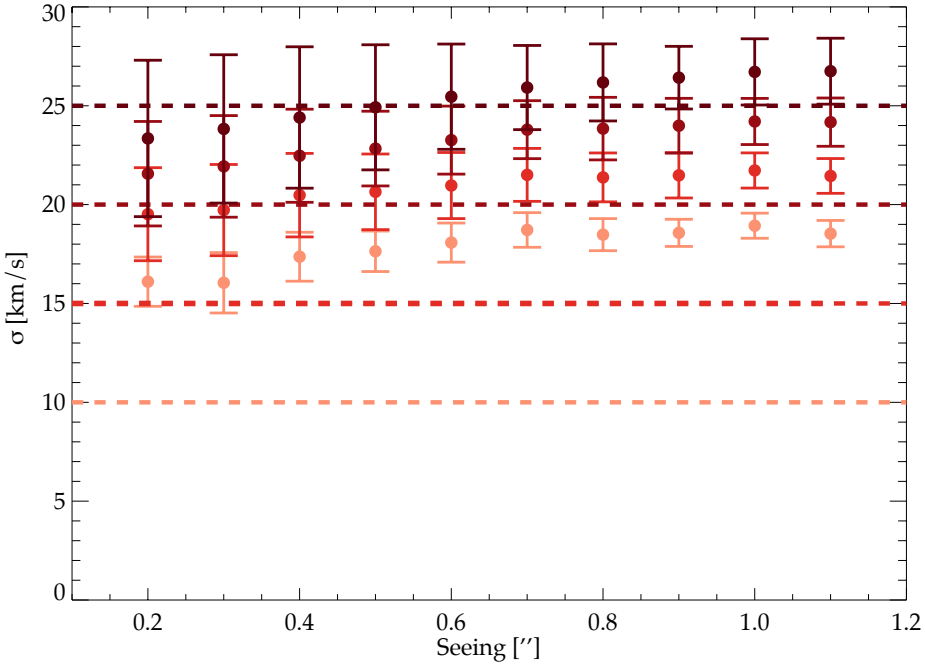
RV of the 3 bright stars fixed to the measured values

(Lutzgendorf et al. 2015)

SINFONI



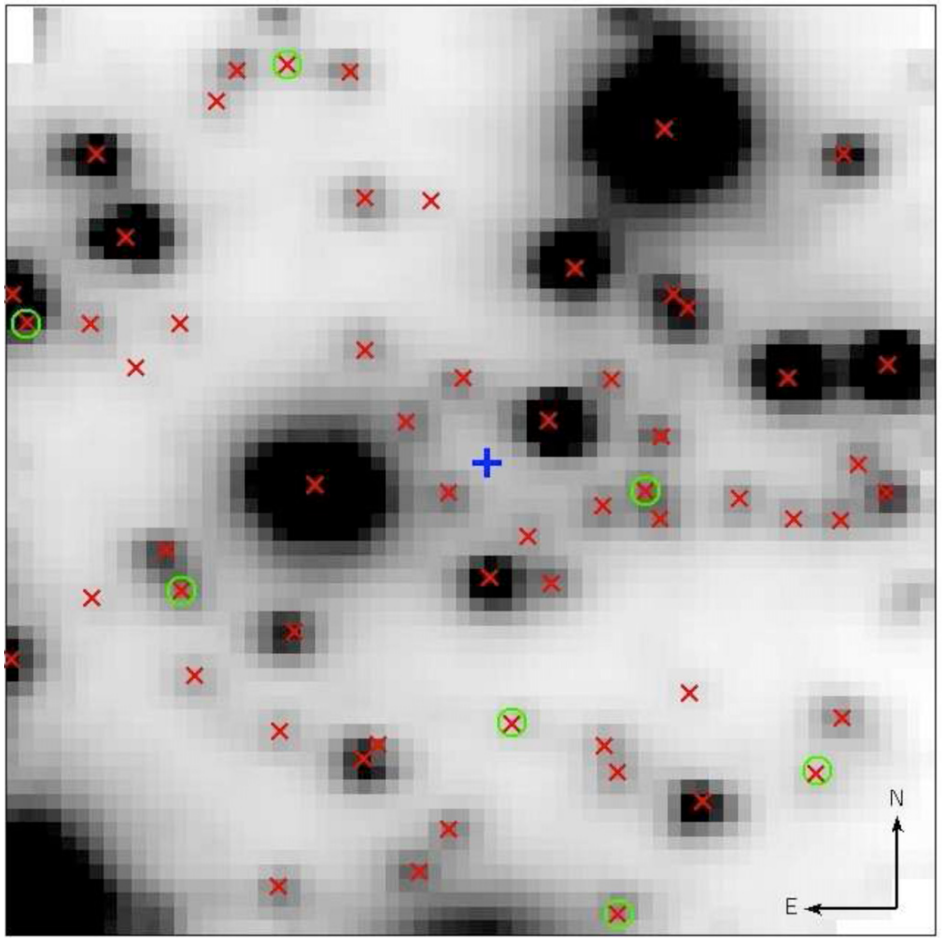
ARGUS



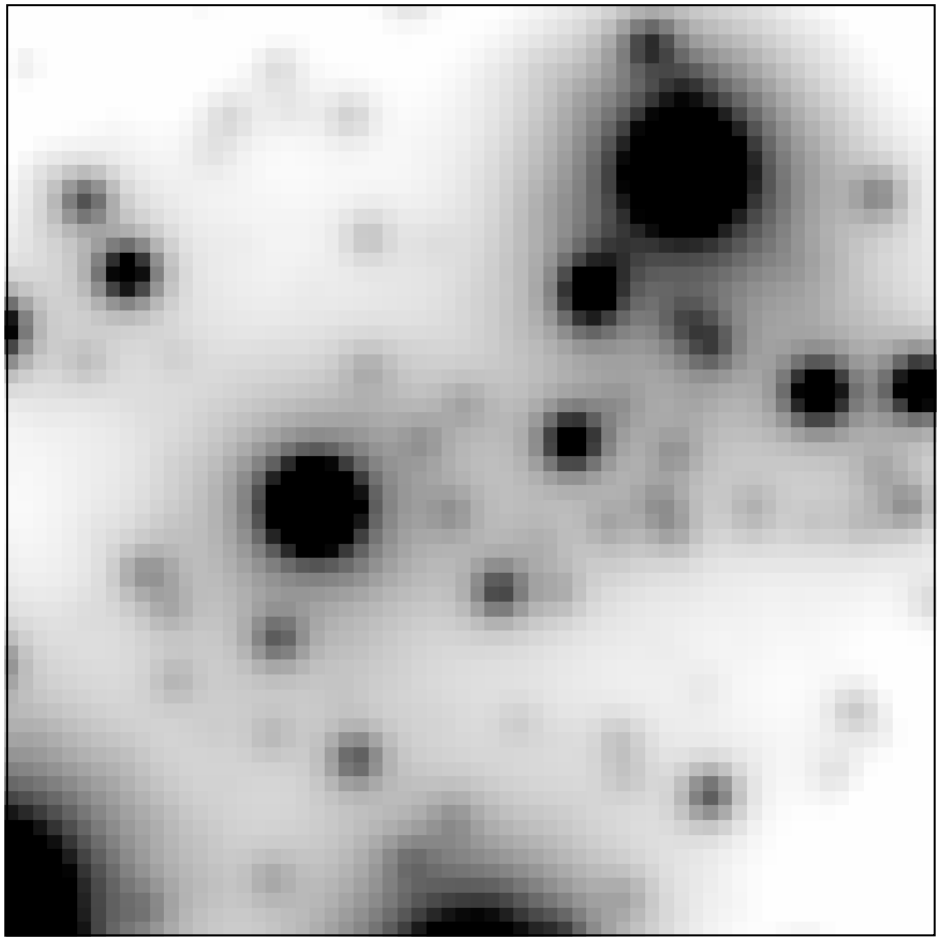
if true VD is σ=10 km/s

- SINFONI measures 8-10 km/s
- ARGUS measures 16-20 km/s

SINFONI OBSERVATIONS



SINFONI SIMULATIONS



simulations wrt observations:

- much larger "halos"

- faint stars less defined

→ **incorrect PSF**
(PSF wings over-estimated)

(Lutzgendorf et al. 2015)

How to measure velocity dispersion (VD) in Galactic GCs?

1) no gas => only **stellar** velocity dispersion

2) close to Earth => stars are **resolved**

(with **a few** bright giants in the spectrograph slit/FOV)

→ VD from the line broadening in **integrated-light** spectra: prone to bias

→ VD from

- **proper motions** of **individual** stars (VD on the plane of the sky)
- **radial velocities** of **individual** stars (VD along the line of sight)

VD from proper motions (PMs) or radial velocities **(RVs)** of **individual** stars

* **large samples** of measures (PMs or RVs)

IMBHs: VD cusp **at r<1”-2”** from the cluster centre

* **large samples** of measures (PMs or RVs) at **at r<1”-2”**

VERY hard in over-crowded environments (as GC centres)!

VD from **proper motions** of **individual** stars → Andrea Bellini & Laura Watkins talks on Thursday

VD from **radial velocities** of **individual** stars → **this talk**

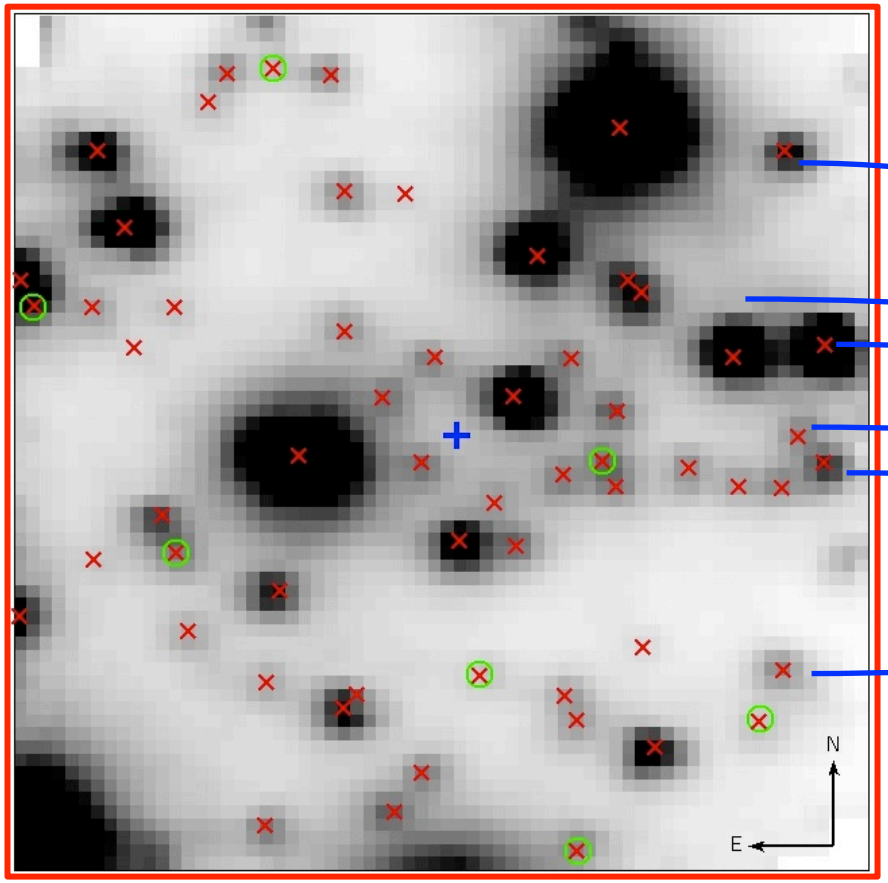
see also Sebastian Kamann talk on Thursday

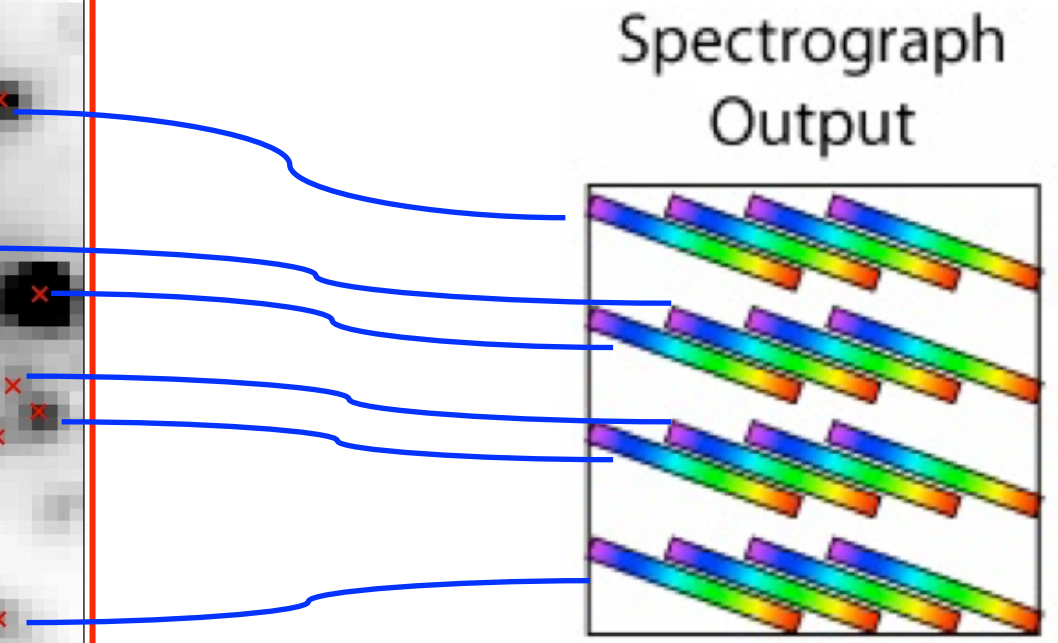
Central VD from individual radial velocities in Galactic GCs

AO-assisted IFU spectroscopy (SINFONI@VLT, OSIRIS@Keck)

Unconventional use → extract a spectrum for each resolved star (=> AO)
(instead of integrated-light spectroscopy)

SINFONI RECONSTRUCTED IMAGE



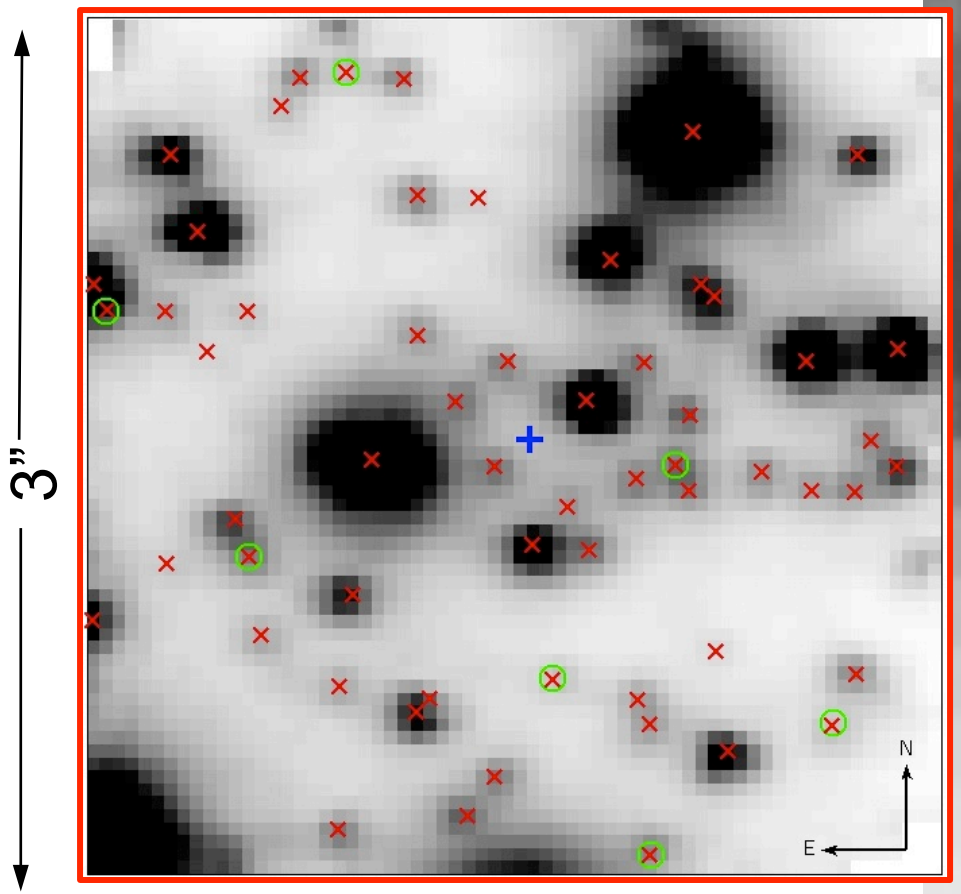


One spectrum for every (exposed) spaxel

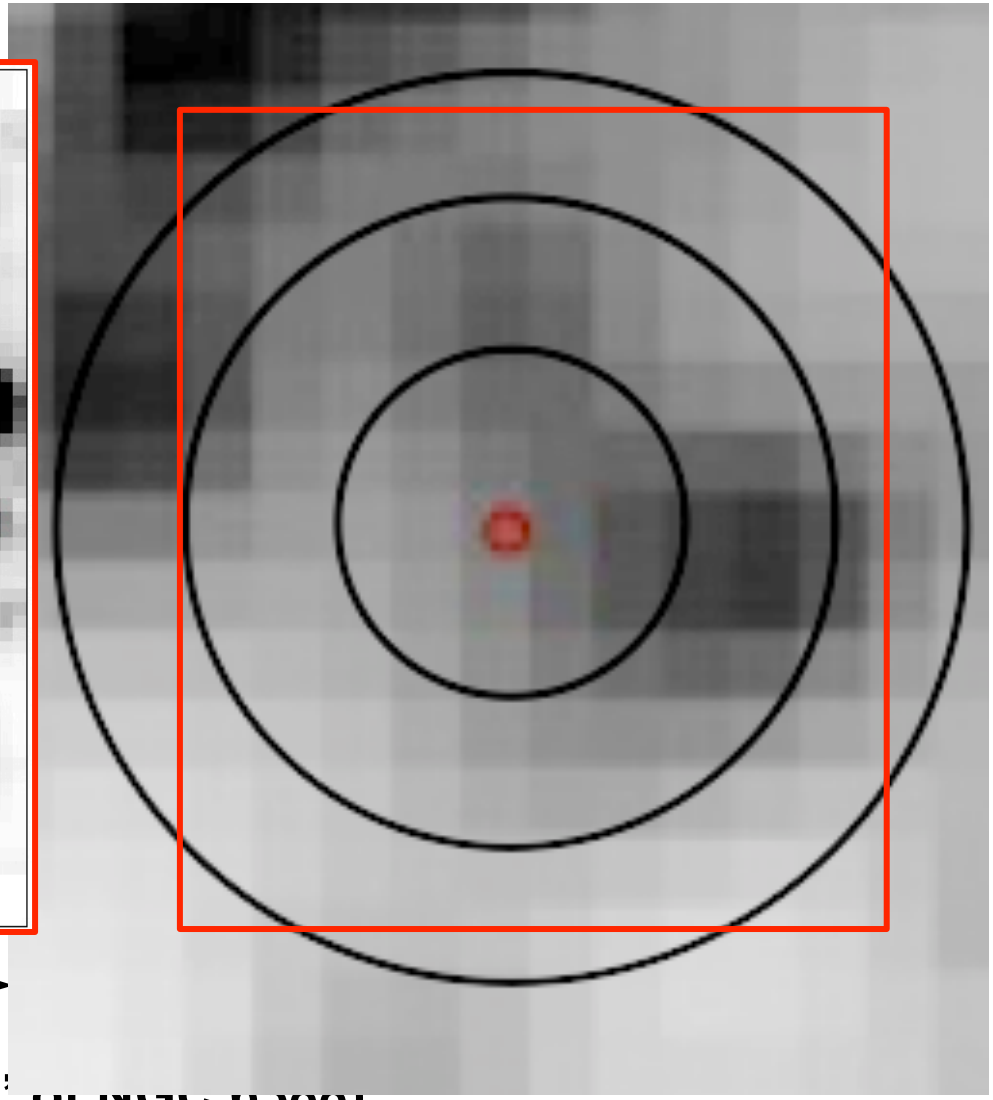
SINFONI

AO-assisted IFU, 0.1” spatial resolution, FoV=3.2”x3.2”

SINFONI RECONSTRUCTED



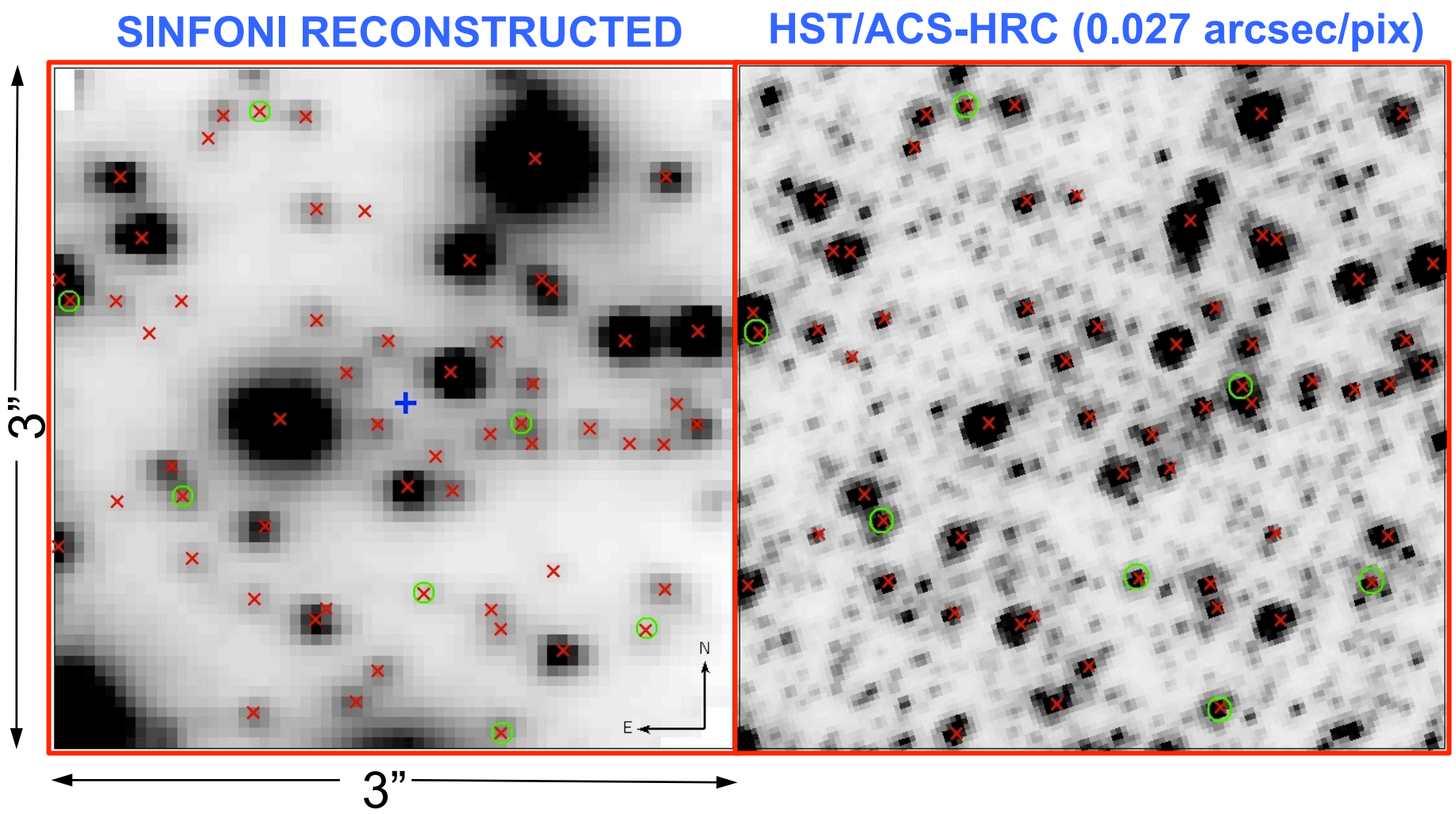
SEEING-LIMITED IFU (ARGUS)



(central 3”X3”

SINFONI

AO-assisted IFU, 0.1” spatial resolution, FoV=3.2”x3.2”



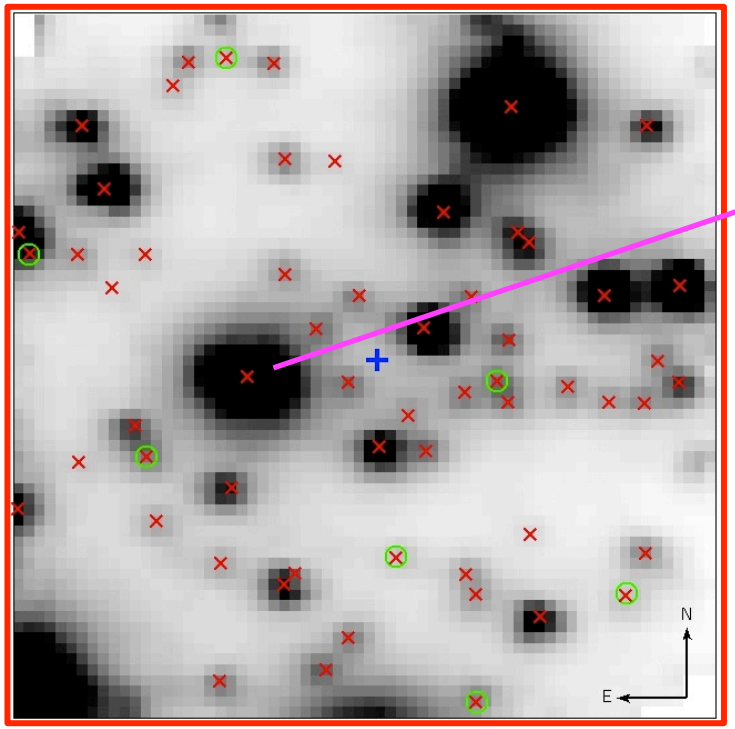
(central 3”X3” of NGC 6388)

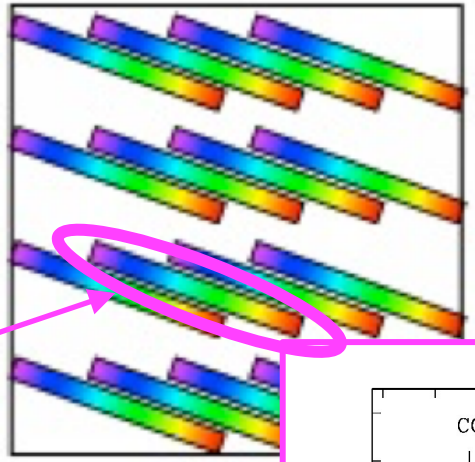
SINFONI

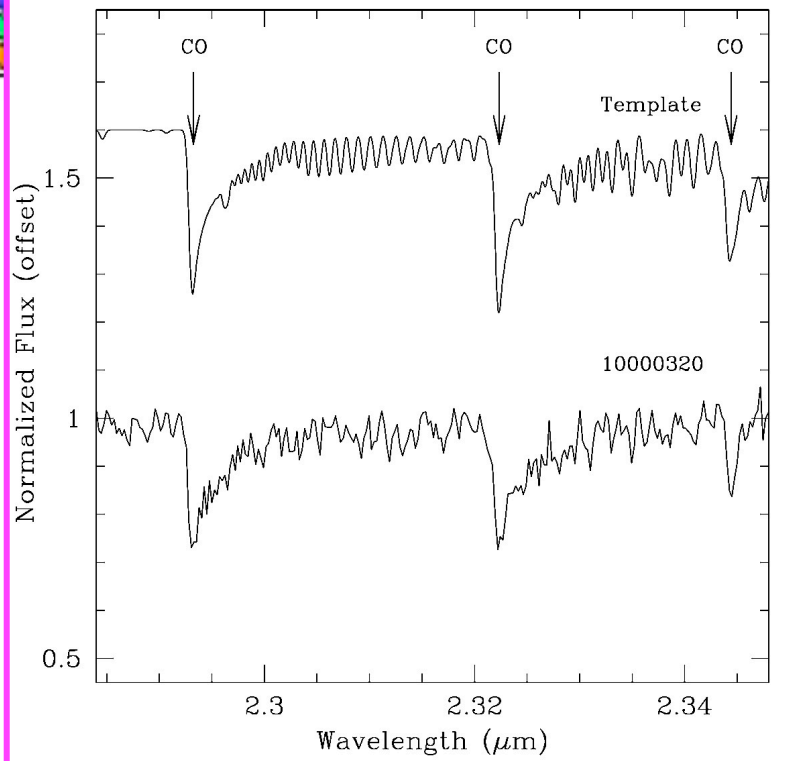
AO-assisted IFU, 0.1” spatial resolution, FoV=3.2”x3.2”

K-band grating (1.95-2.45 μm) → **CO band-heads**

SINFONI RECONSTRUCTED IMAGE



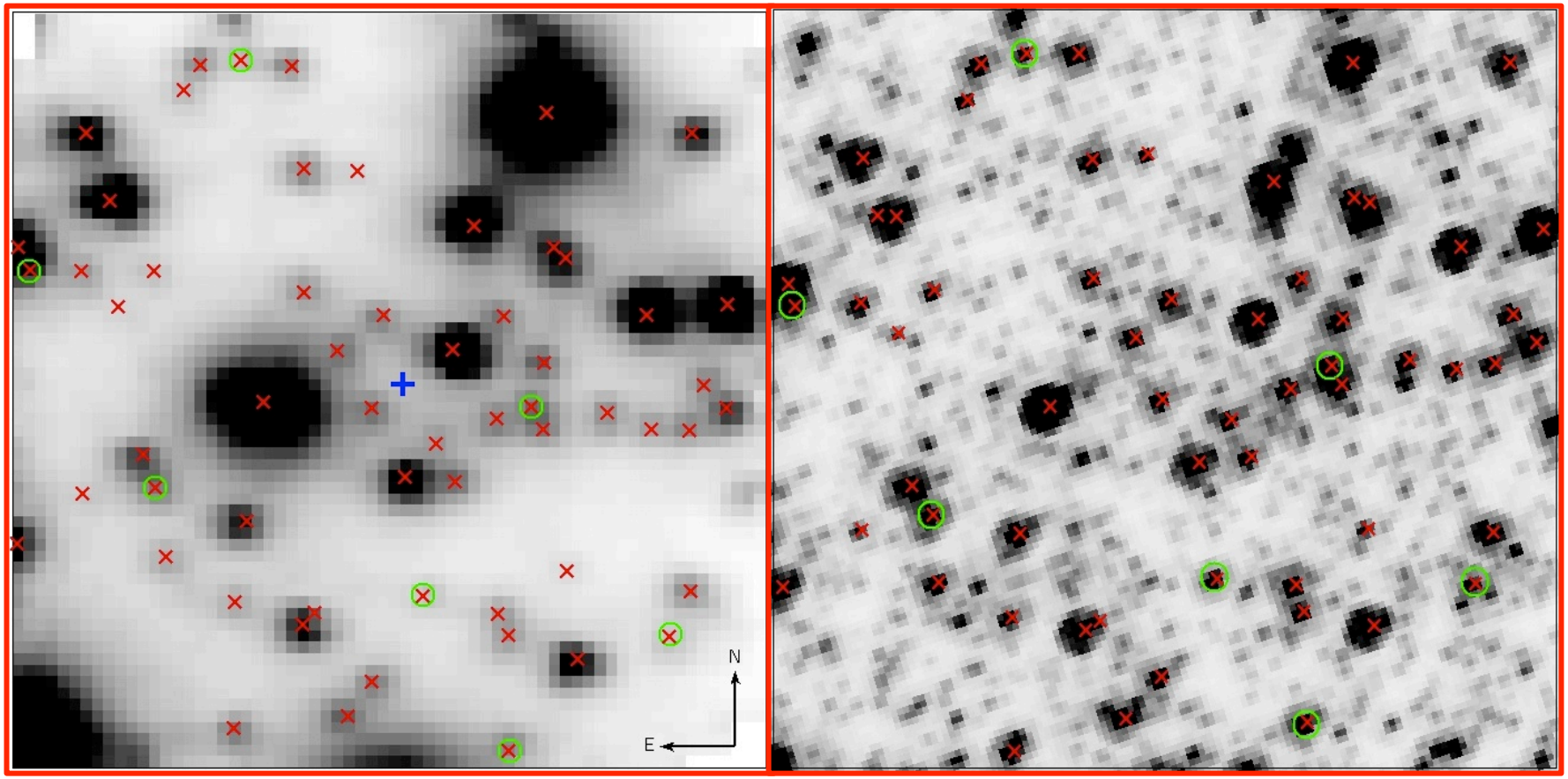




NGC 6388 (r_c=7”, ρ_0= 2.3 10^5 $L_\odot/pc^3$)

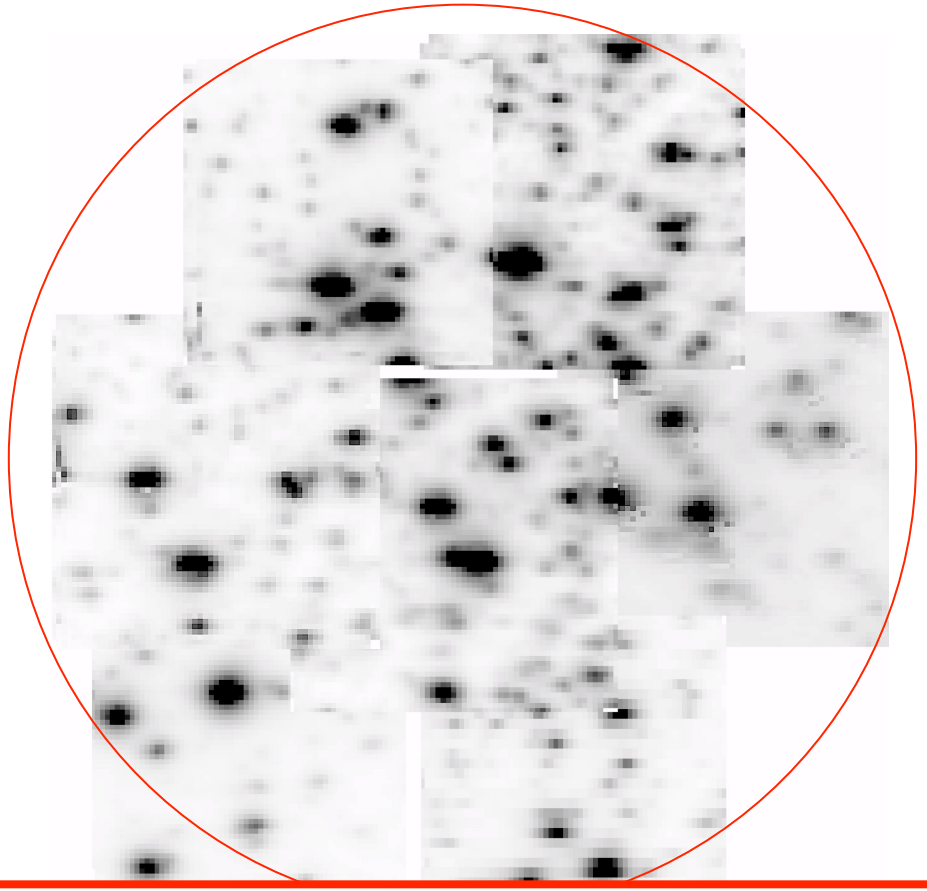
→ **RVs of 52 individual stars at r<2” (~0.13 pc) !!!**

SINFONI RECONSTRUCTED **HST/ACS-HRC (0.027 arcsec/pix)**



NGC 2808 (r_c=15”, ρ_0= 0.5 10^5 $L_\odot/pc^3$)

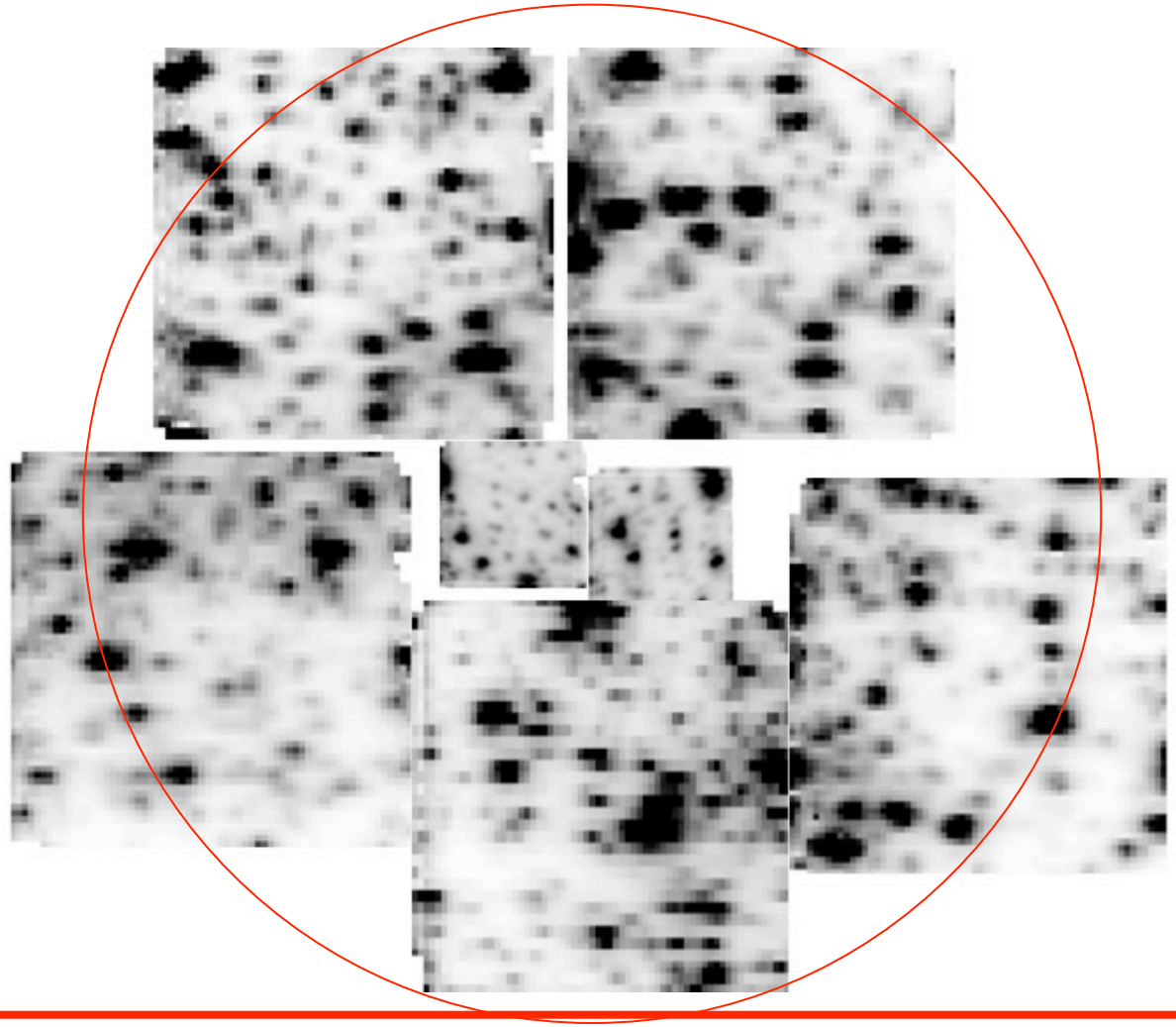
mosaic of 7 SINFONI fields



→ RVs of 800 individual stars at r<12” (~0.6 pc) !!!

NGC 6441 (r_c=8”, ρ_0= 1.8 10^5 $L_\odot/pc^3$)

mosaic of 2 HR + 5 LR SINFONI fields



→ RVs of 700 individual stars at r<17” (~ 1pc) !!!

ENTIRE radial profile: a MULTI-INSTRUMENT approach

SINFONI

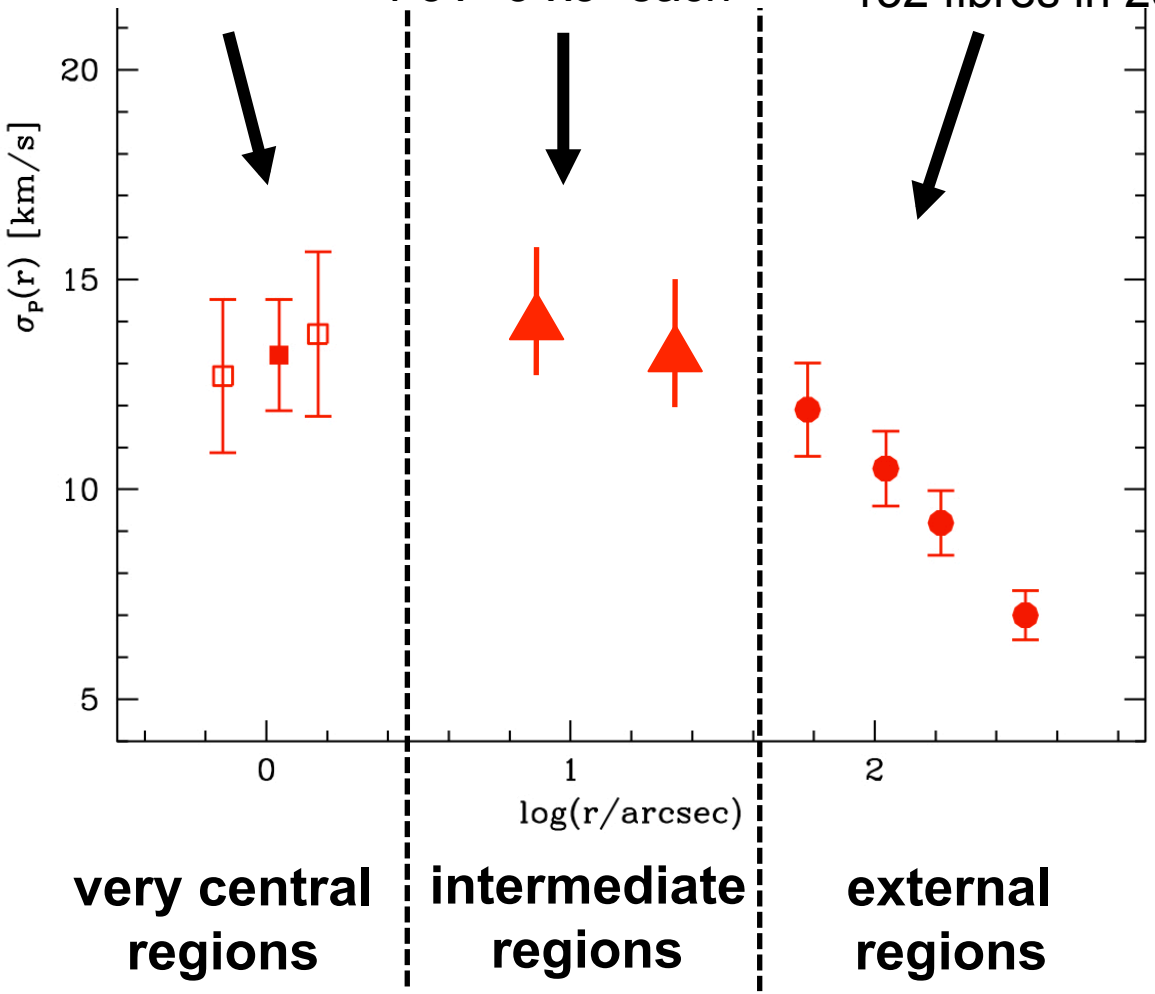
AO-assisted IFU

KMOS

24 deployable IFUs
FoV=3”x3” each

FLAMES

multi-object
132 fibres in 25’



very central regions

intermediate regions

external regions

THE DATA-SET

✦ **ESO Large Programme 193.D-0232 (PI: Ferraro):**

194 hours
KMOS + FLAMES
30 Milky Way GCs
2/3 acquired and 1/3 partially analyzed

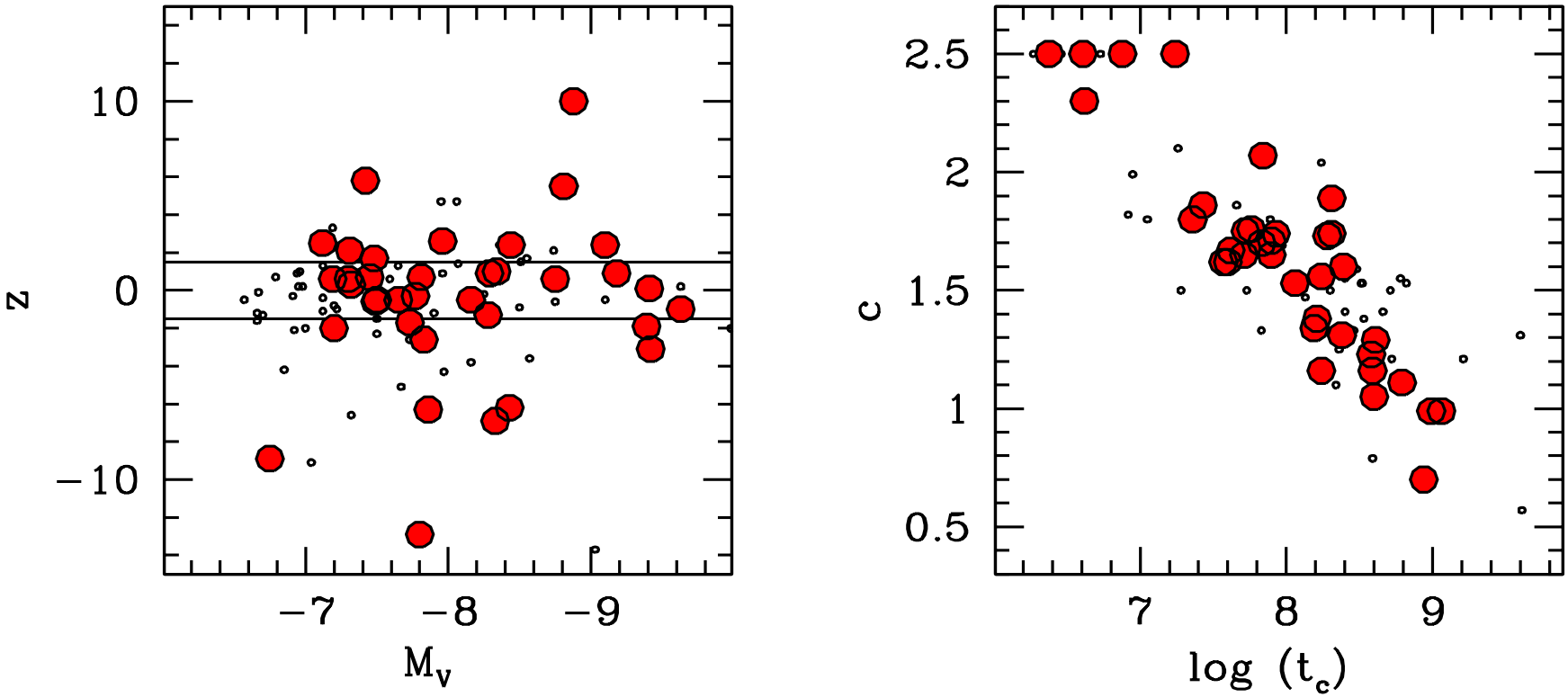
✦ **ESO Large Programme 195.D-0750 (PI: Ferraro):**

101 hours
SINFONI
15 high-density Milky Way GCs
½ acquired

✦ **a few additional programmes @Keck:**

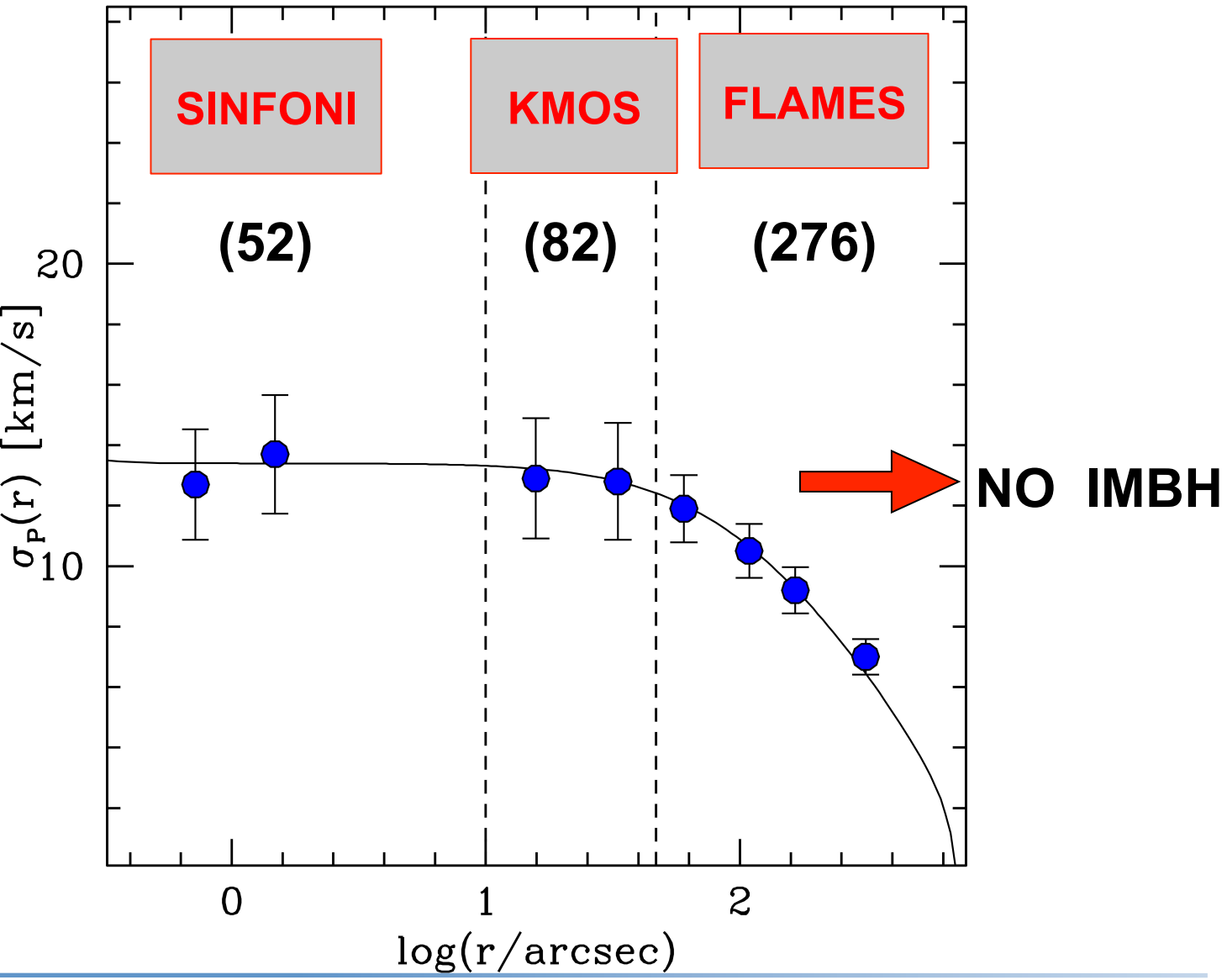
OSIRIS + MOS-FIRE + DEIMOS

THE TARGETS (~30)

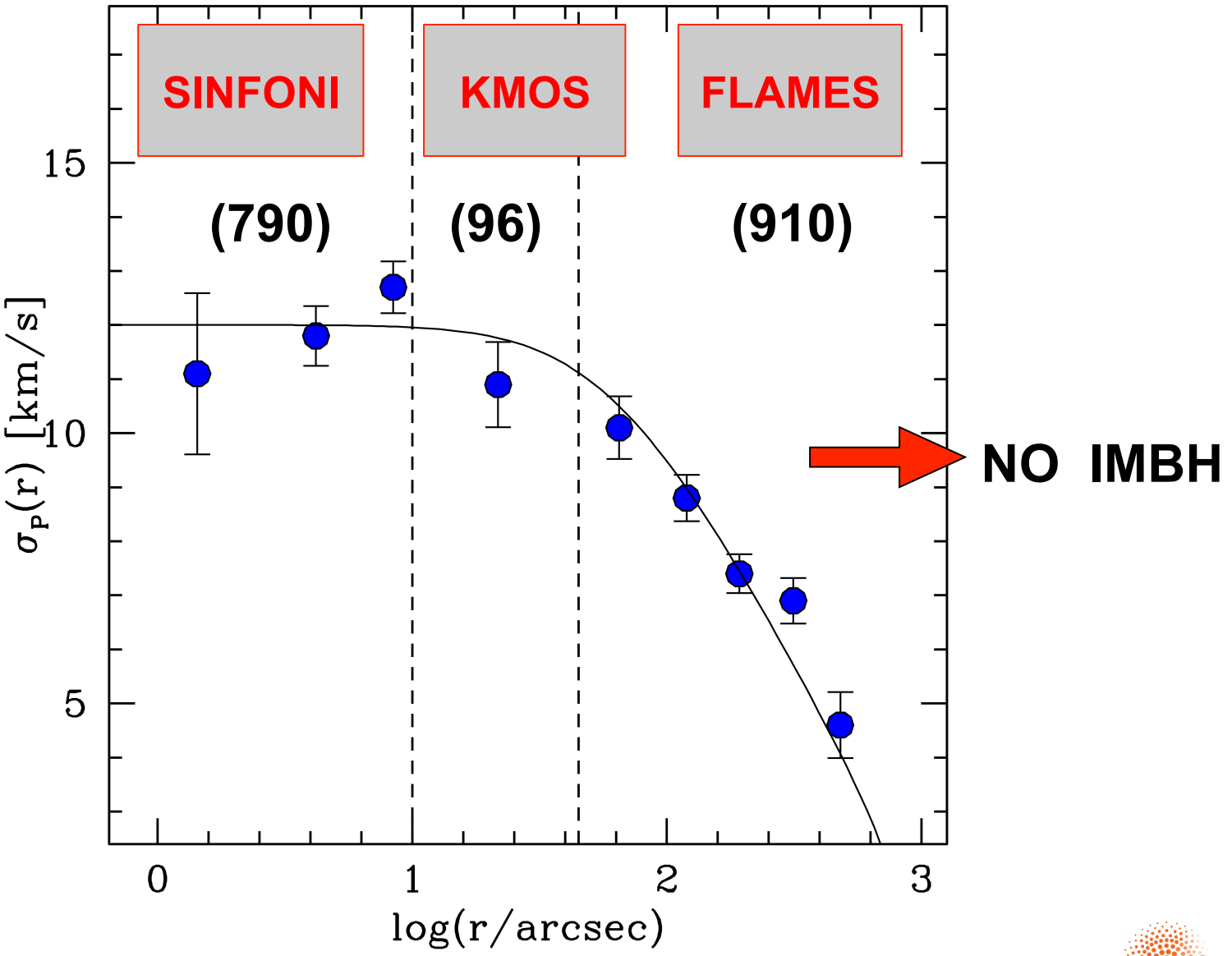


- massive (M > 5x10^5 $M_\odot$)
- spanning large ranges of log **ρ**, c and relaxation times
- covering different stages of dynamical evolution, including PCC
- spanning different environmental conditions (bulge/disk & halo populations)

NGC 6388


SINFONI
KMOS
FLAMES
(52)
(82)
(276)
20
10
$\sigma_P(r)$ [km/s]
0
1
2
log(r/arcsec)
NO IMBH

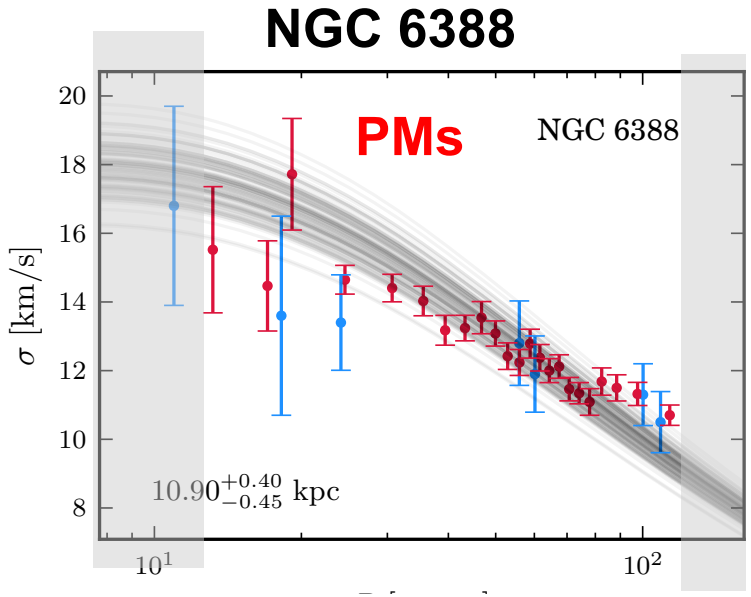
NGC 2808 (preliminary)

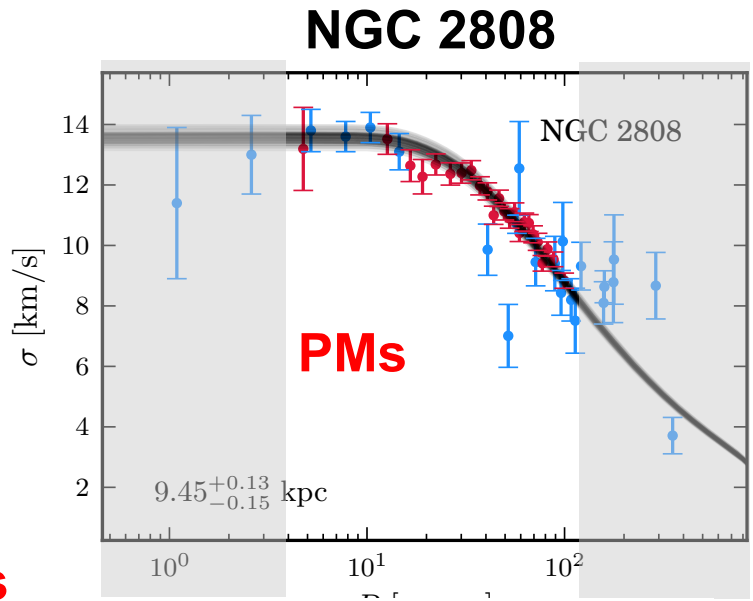


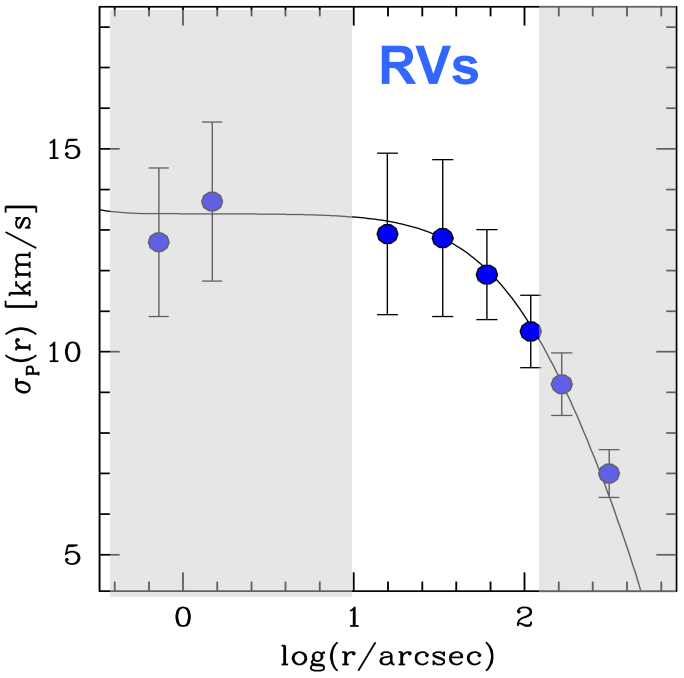
Cosmic-Lab

erc

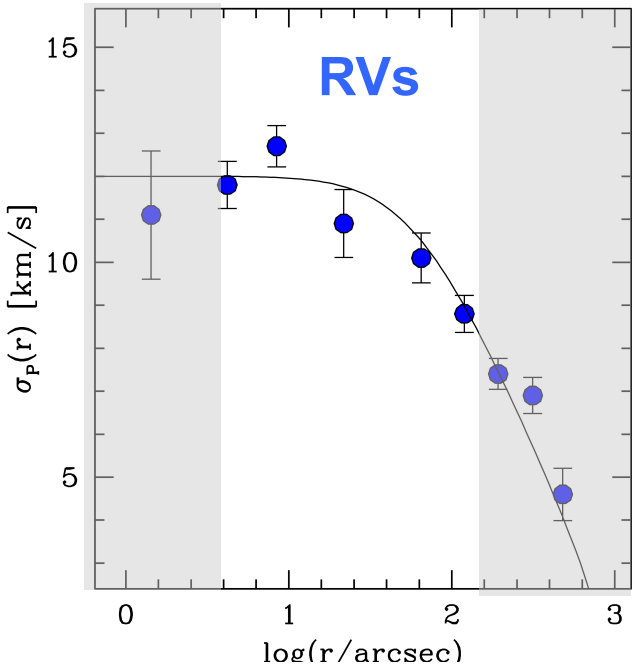
HSTPROMO PMs (Watkins et al. 2015)



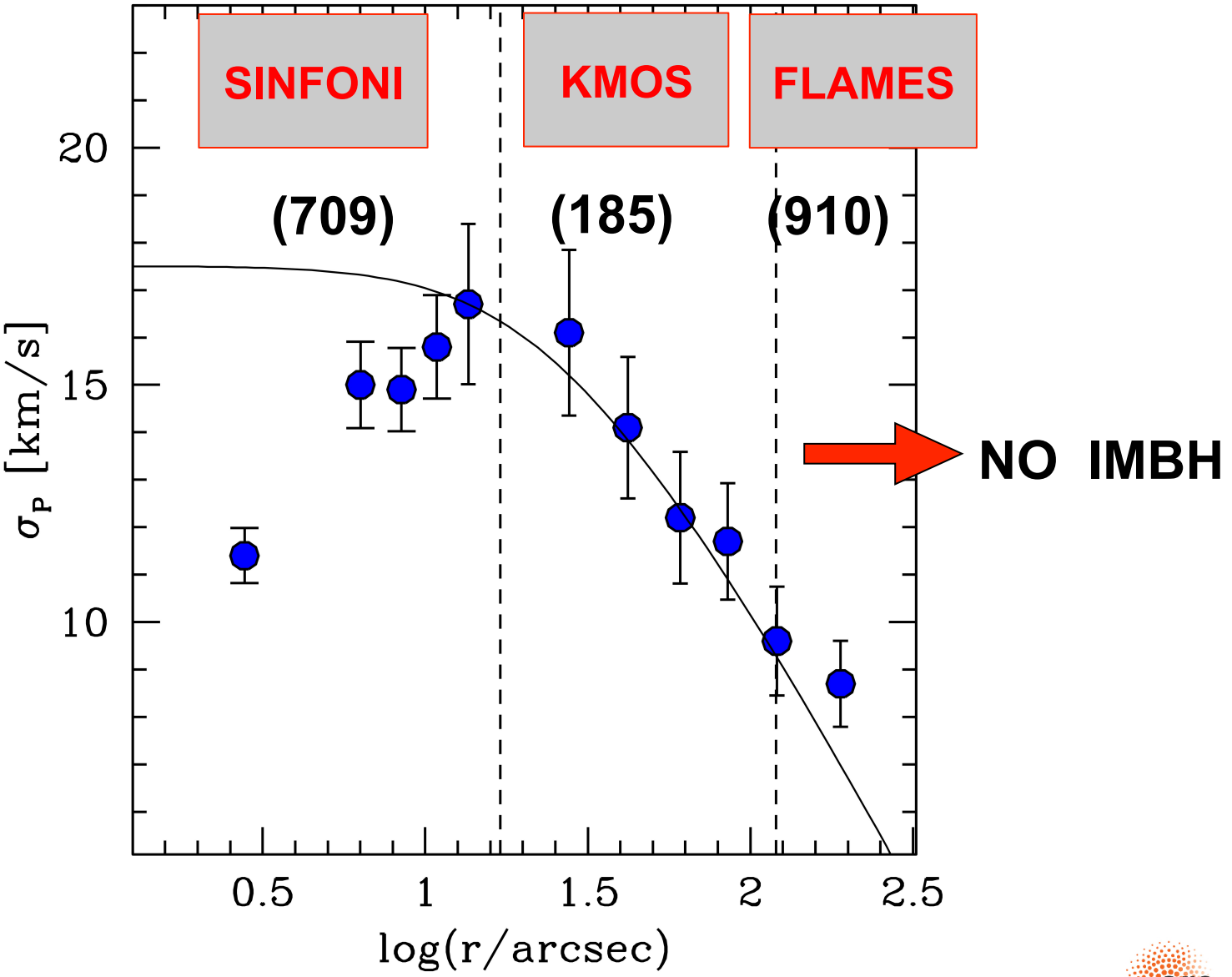




centres & outskirts non sampled by PMs



NGC 6441 (preliminary)

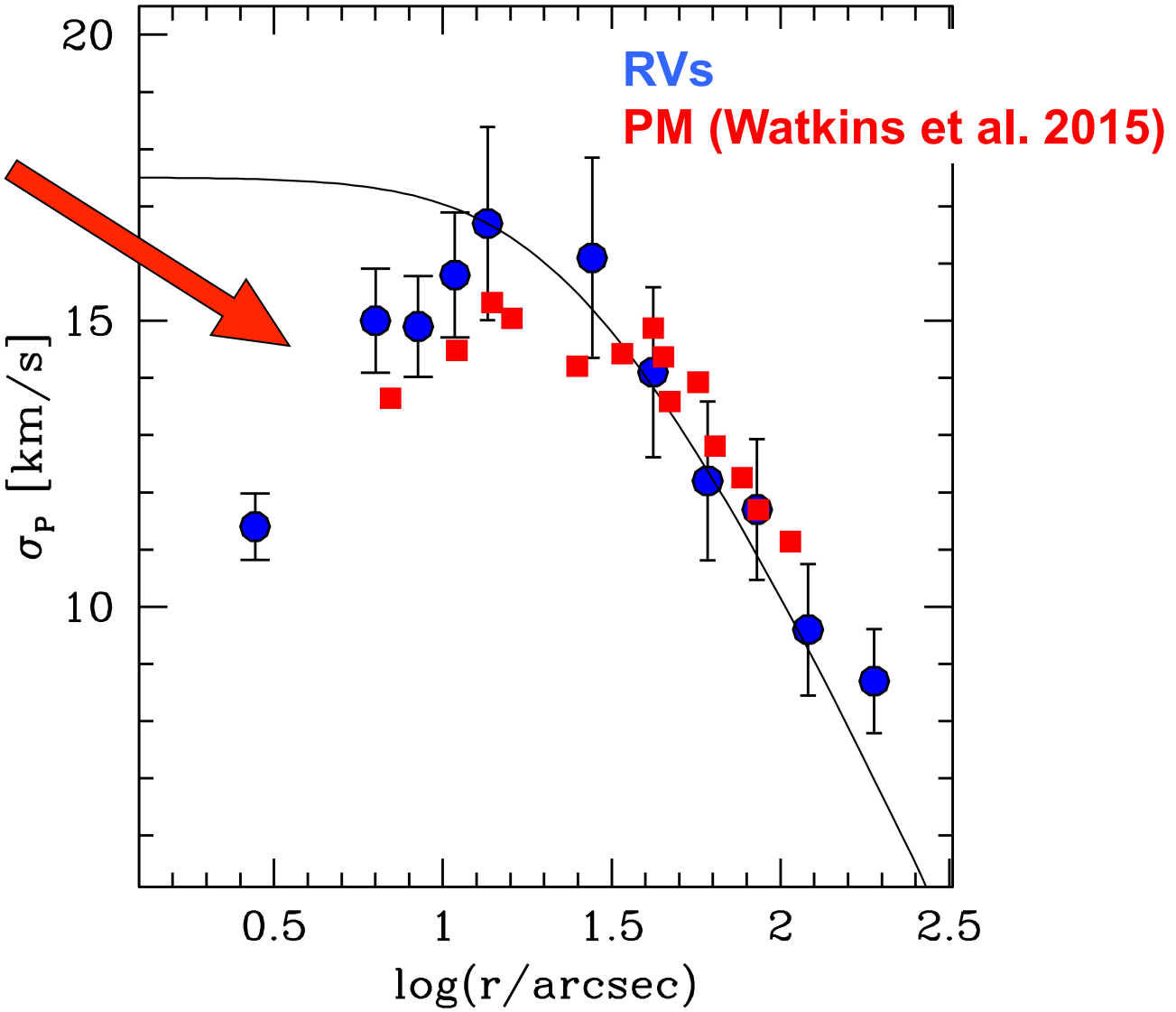


Cosmic-Lab

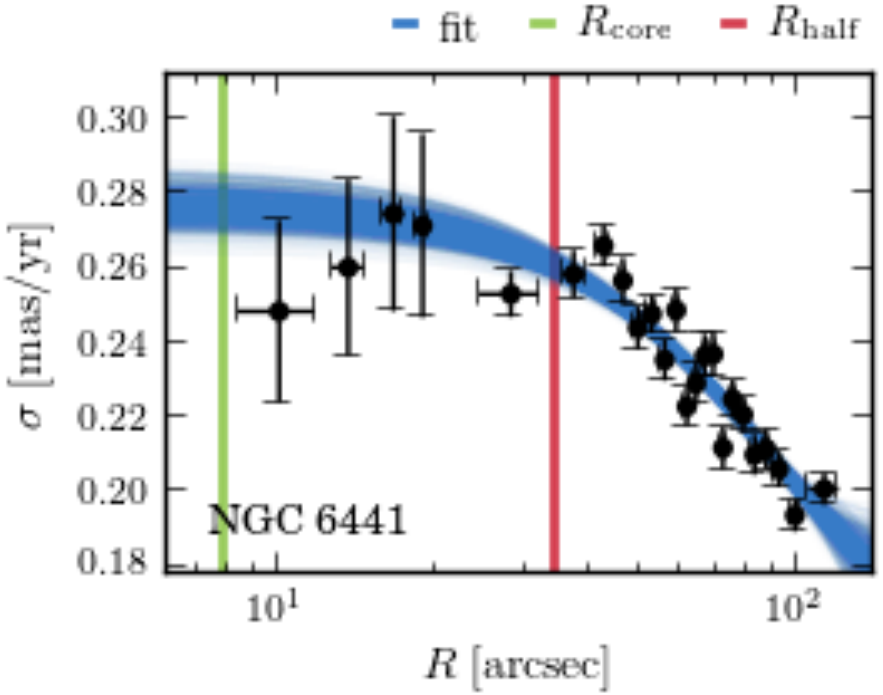
erc

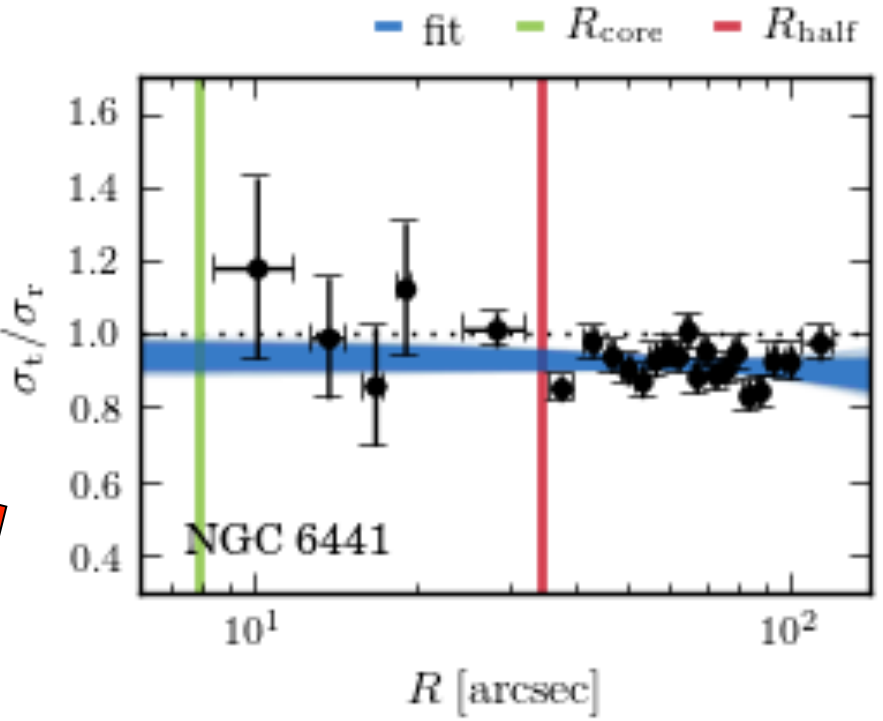
NGC 6441 (preliminary)

central drop confirmed by PMs



NGC 6441: PMs (Watkins et al. 2015)





tangential anisotropy effect?

CONCLUSIONS

- RVs of individual stars with AO-assisted IFU spectroscopy: very effective to determine central (few arcsec) VD
- No evidence of central VD cusp (NGC6388, NGC2808, NGC6441)
- Interesting features are emerging (central VD drop: NGC6441, NGC2808)
- Synergy with PM measurements is crucial → 3D kinematics!

Thank you for your attention!