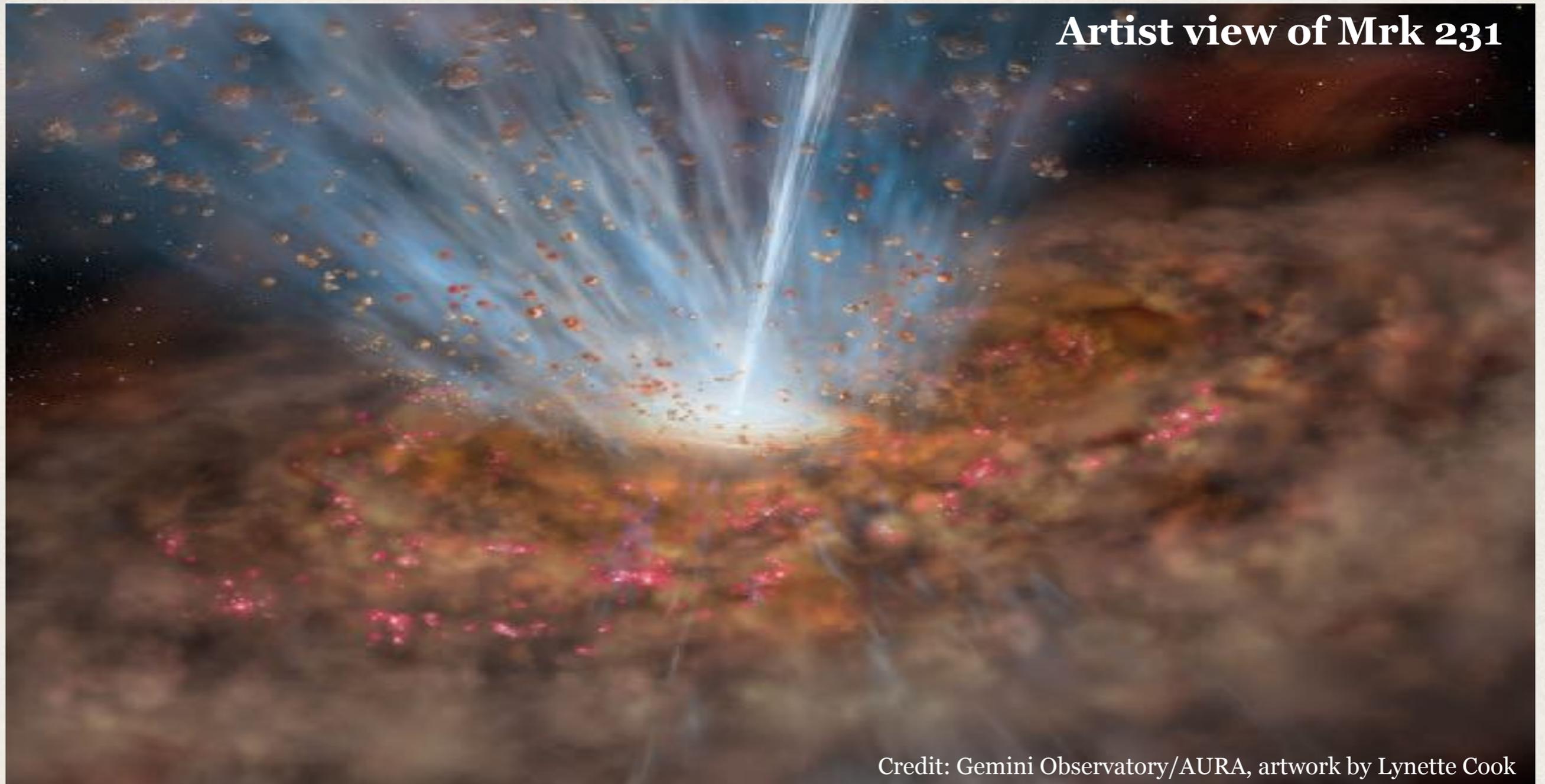


Artist view of Mrk 231



Credit: Gemini Observatory/AURA, artwork by Lynette Cook

# Probing AGN feedback in Mrk231 through high-res UV-to-midIR and radio observations

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Angela Bongiorno (INAF - OAR)

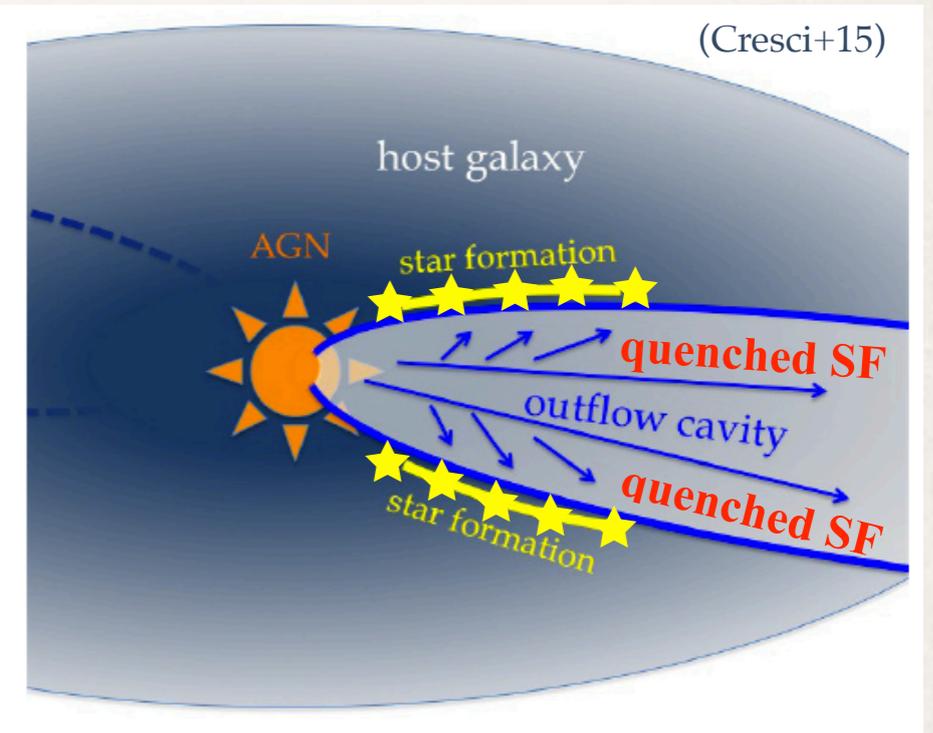
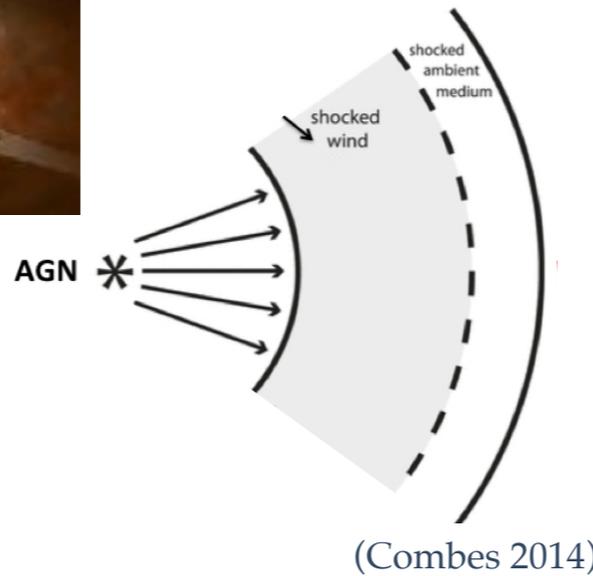
F. Fiore, E. Piconcelli, M. Perez-Torres, E. Brocato, G. Raimondo et al.

Prague - Ewass - June 2017

# AGN-galaxy coevolution

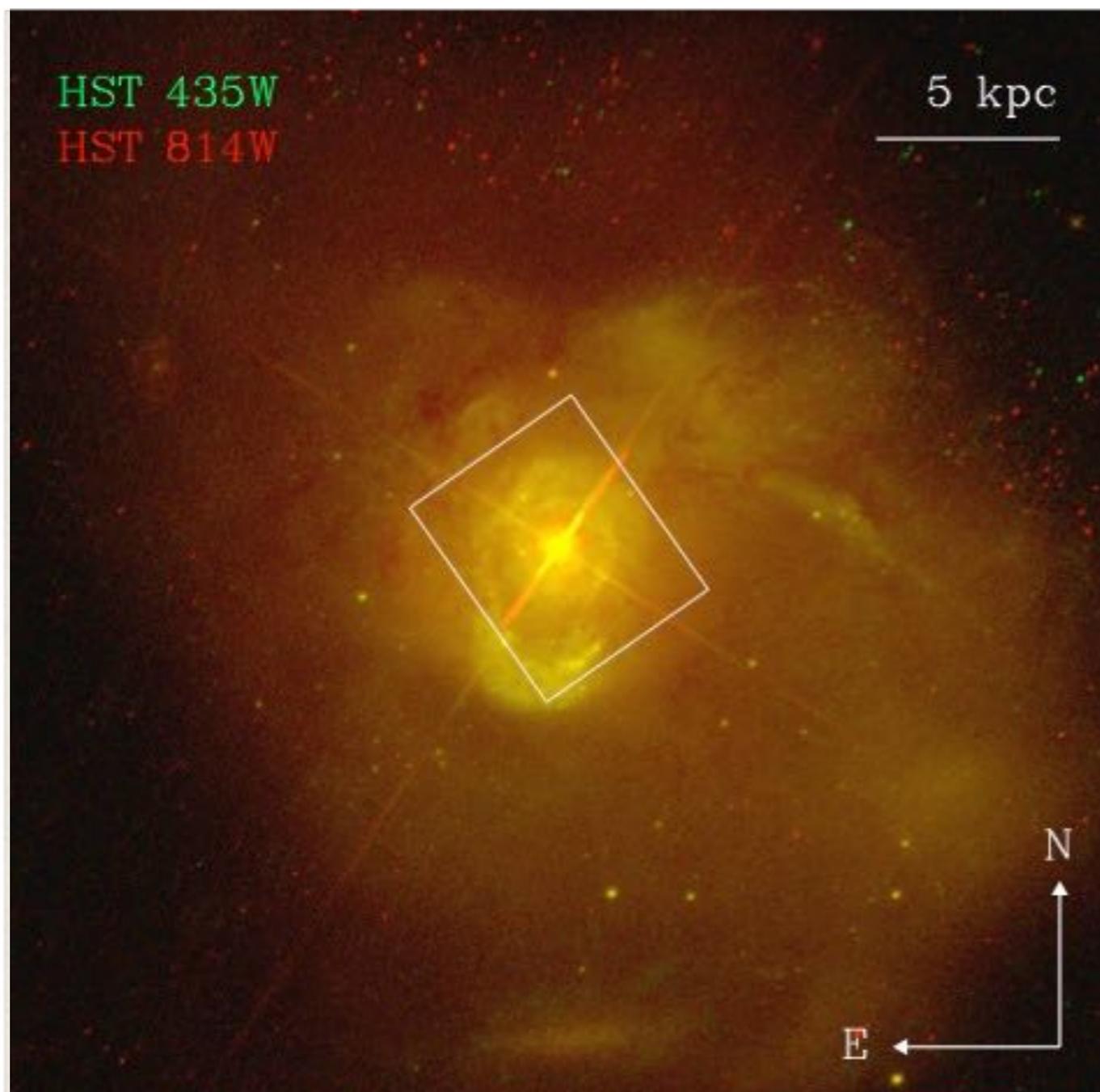


## AGN-DRIVEN WINDS and OUTFLOW



- ❖ **“Negative Feedback”**: the outflow may inhibit SF in the host by clearing/heating the interstellar gas (Zubovas & King 2012)
- ❖ **“Positive Feedback”**: the outflow might also be responsible for inducing SF in the host through gas compression at its edges (e.g. Silk 2013, King 2005; Imanishi & Fabian 2012)

# Markarian 231 as unique test case for AGN feedback in action

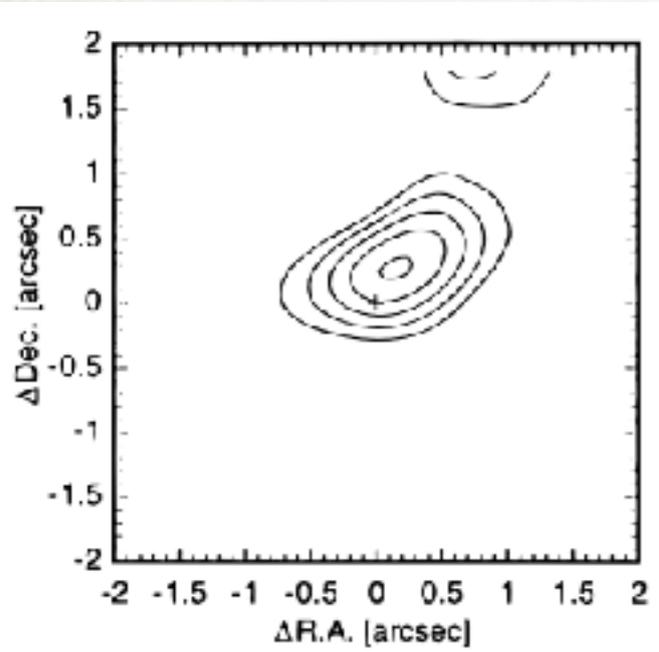


- ❖ nearest QSO ( $z=0.042$ )
- ❖ most luminous ULIRG in the local Universe  $L_{\text{IR}}=3.6 \cdot 10^{12} L_{\odot}$
- ❖  $>40\%$   $L_{\text{bol}}$  in SB activity
- ❖ late-state merger
- ❖ X-ray under-luminous AGN:  $L_x=10^{43}$  erg/s
- ❖ BAL QSOs
- ❖ Expanding shells on Kpc scales

**THIS IS EXACTLY WHERE  
WE DO EXPECT  
FEEDBACK**

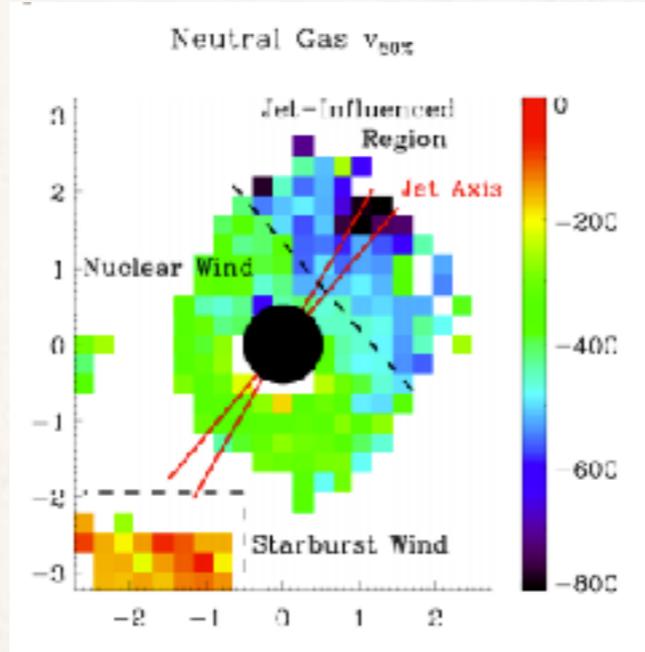
# Mrk 231: powerful outflows

★ ionized



(Krabbe 1997)

★ neutral



(Rupke & Veilleux 2010)

Outflows observed in all the gas components:

- **ionized:** NW d~0.7 Kpc
- **neutral:** NW d~1 Kpc
- **molecular:** SW d~0.7 Kpc

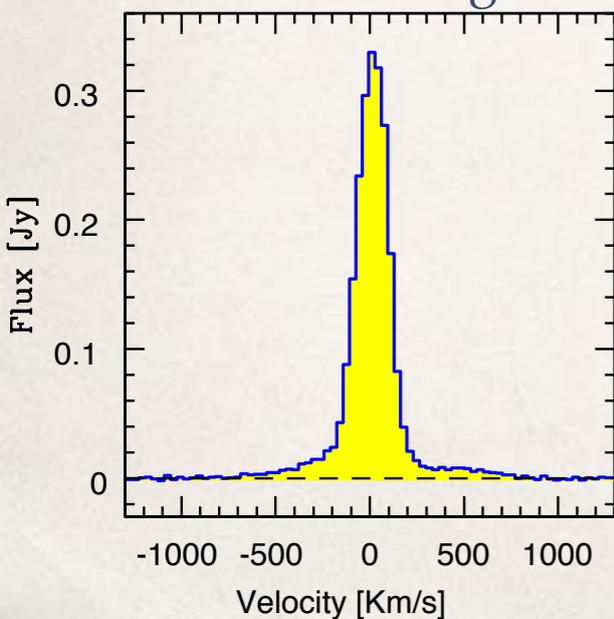
**First evidence of massive molecular OUTFLOW!**

(Feruglio C. et al. 2010, feruglio C. et al. 2015)

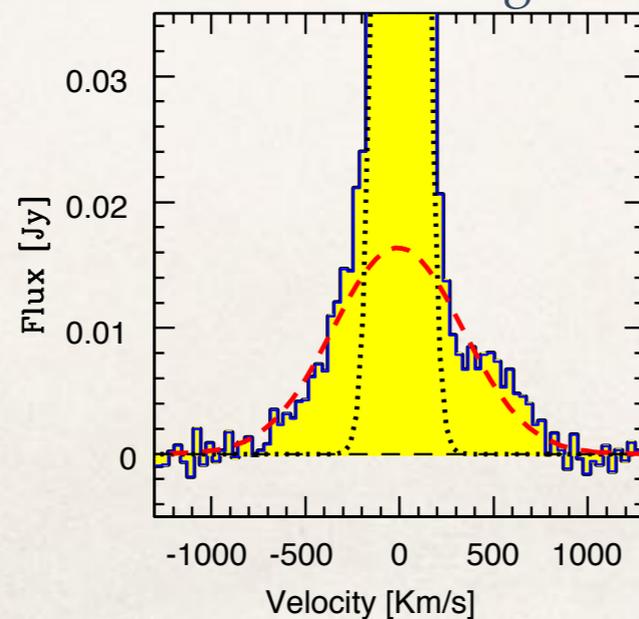
- ✦  $\dot{M}_{\text{out}} [700 M_{\odot}/\text{yr}] > \text{SFR} [200 M_{\odot}/\text{yr}]$
- ✦ Outflow Kinetic power  $\sim 6\%$  AGN  $L_{\text{bol}}$  (as expected for a shock wave produced by radiation pressure onto the ISM)

★ molecular CO(1-0), CO(2-1) and CO(3-2)

Blue wing



Red wing

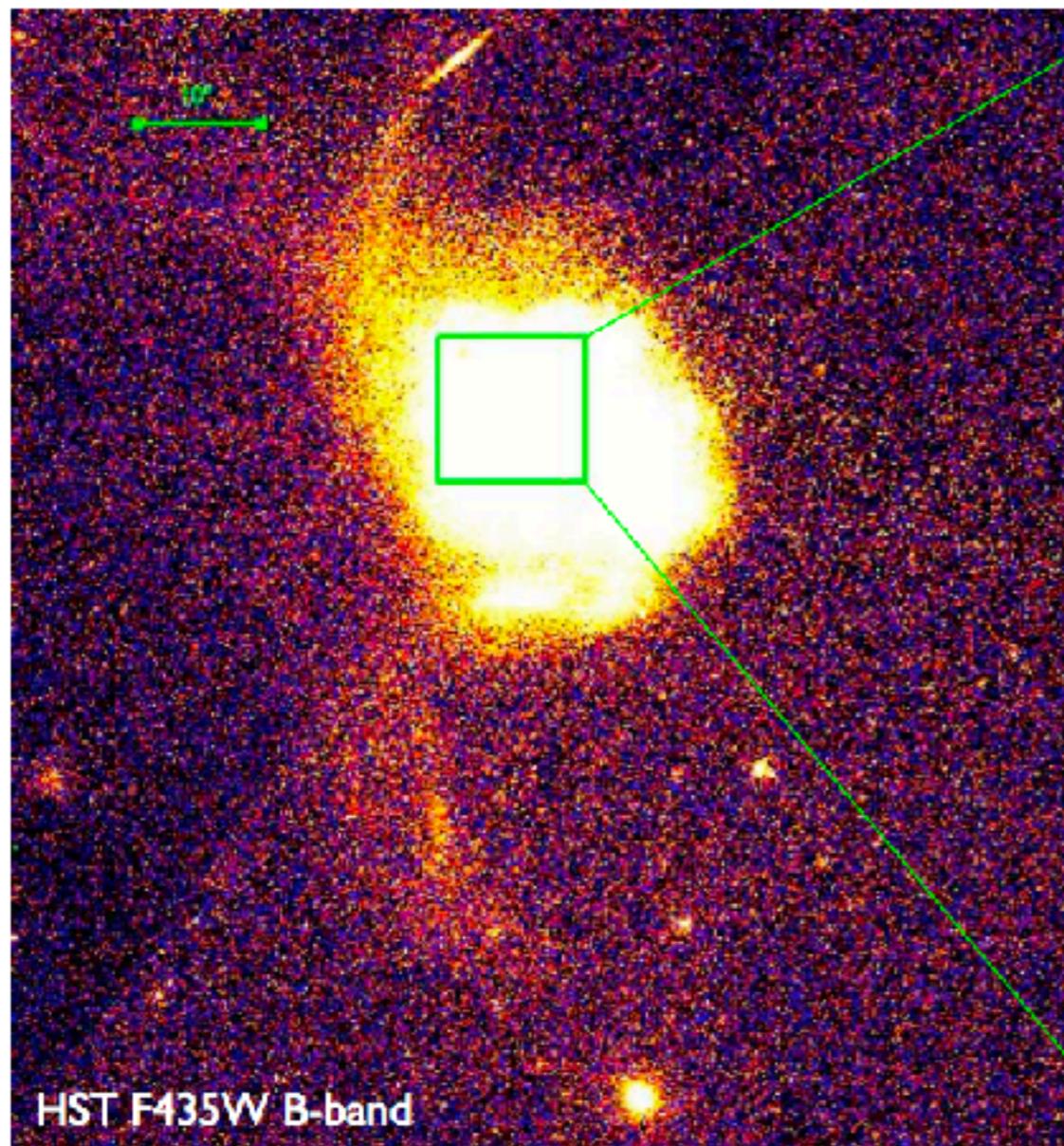


# Sub-arcsec res. multi- $\lambda$ campaign

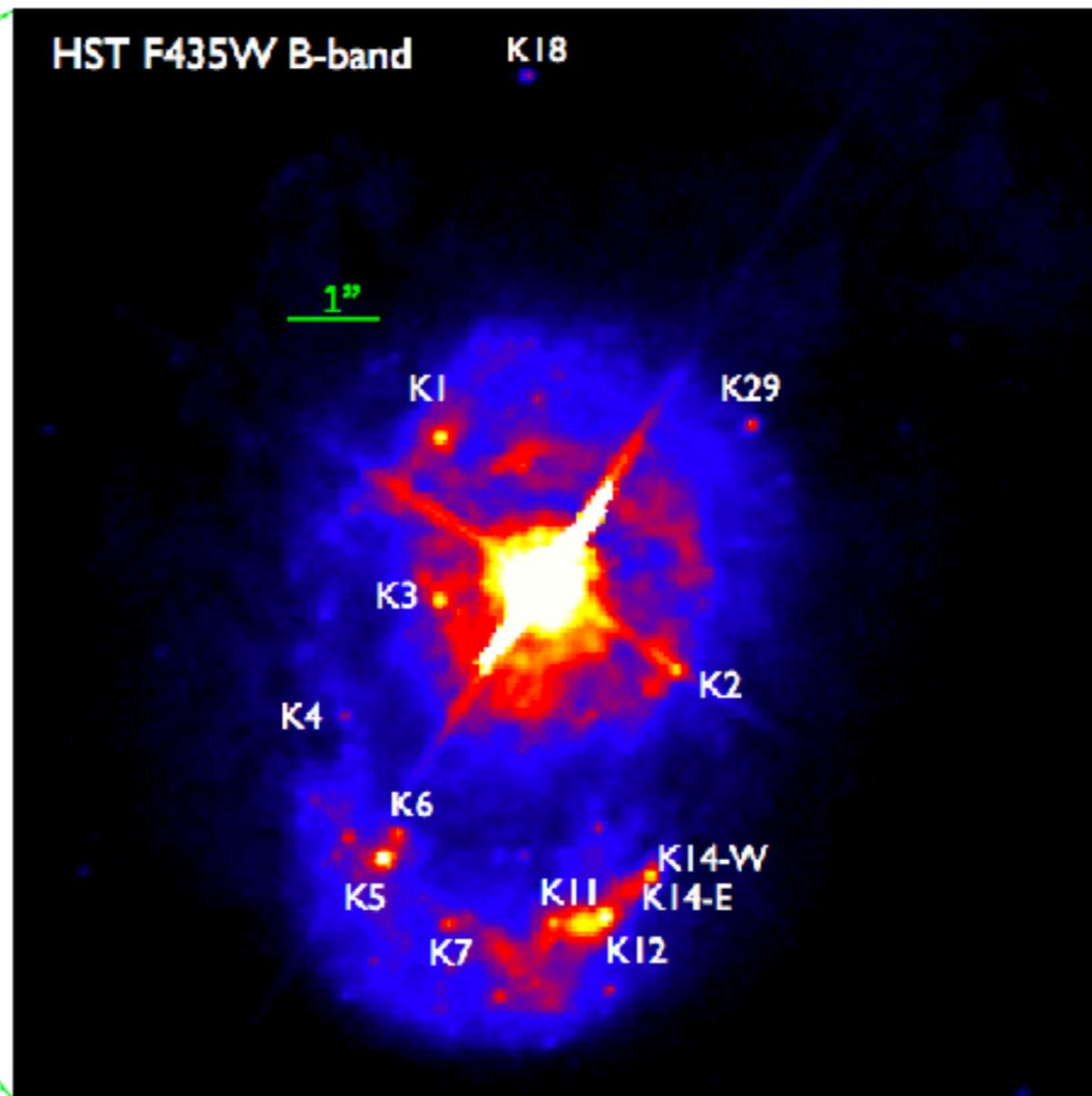
## STUDY AGN FEEDBACK MARKS ON THE HOST GALAXY INNER REGION

Telescope/Instrument	Config.	Filter	$\lambda_{cent}$	Exp. time [sec]	Pixel scale ["/px]
NIR	LBT/PISCES	AO	J	33 min	0.019
	LBT/PISCES	AO	Ks	20 min	0.019
May2017!! mid-IR	LBT/LMIRCAM	AO	L	30 min	0.0101
	LBT/LMIRCAM	AO	L <sub>narrow-1</sub>	1h	0.0101
	LBT/LMIRCAM	AO	L <sub>narrow-2</sub>	1h	0.0101
	LBT/NOMIC	AO	7.9 $\mu$ m	1h	0.018
UV-OPT	HST/NICMOS	NIC2	F160W	43 min	0.05
	HST/ACS	ACS/WFC	F814W	14 min	0.05
	HST/ACS	ACS/WFC	F435W	24 min	0.05
	HST/ACS	ACS/HRC	F330W	19 min	0.025
	HST/WFC3	UVIS1	F225W	23 min	0.04
RADIO	VLA	B-conf	1.4 GHz	3.5h	beam=2.05"×1.72"
	JVLA	B-conf	32.5 GHz		beam=0.18"×0.17"

# Sub-arcsec res. multi- $\lambda$ campaign



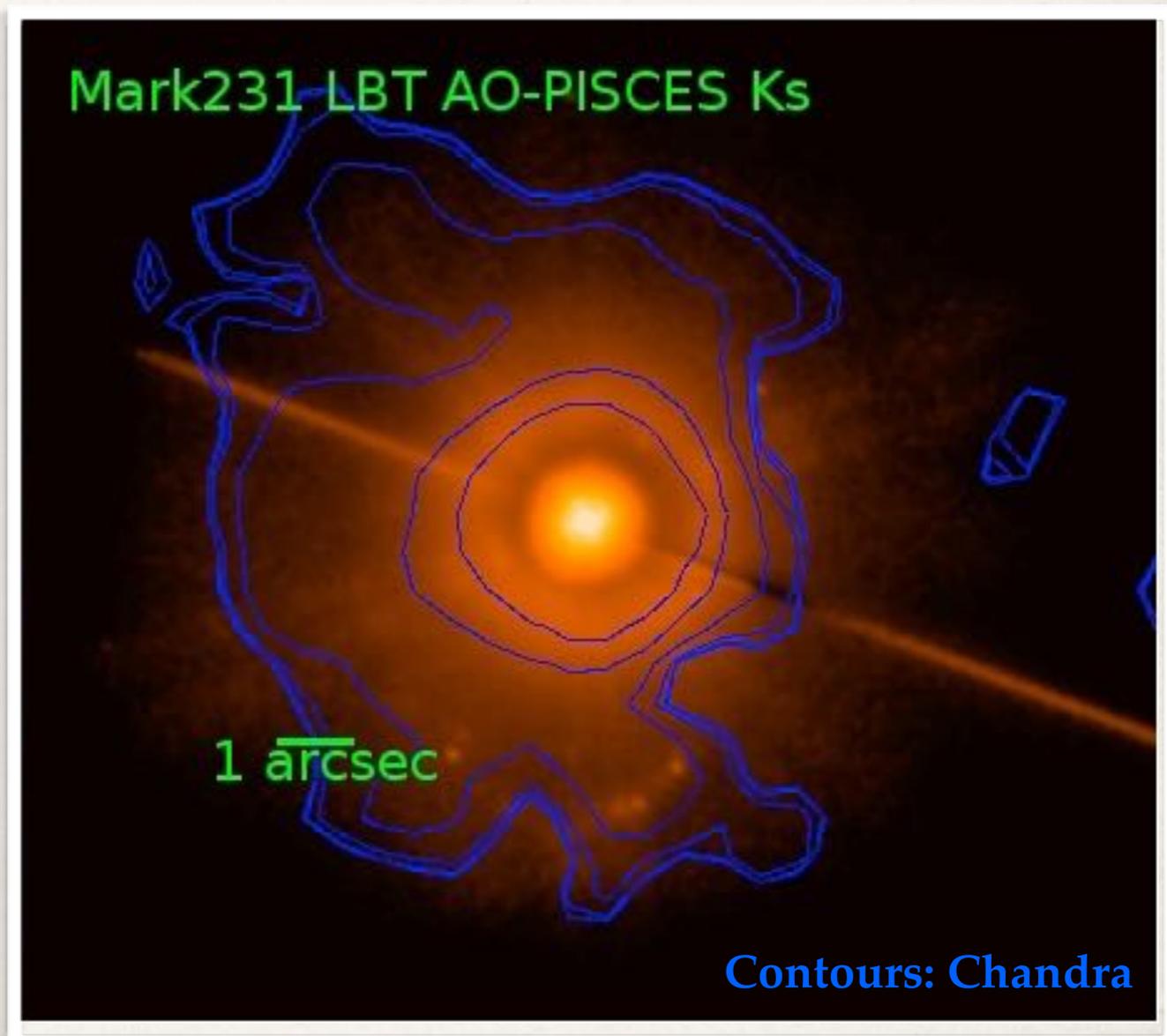
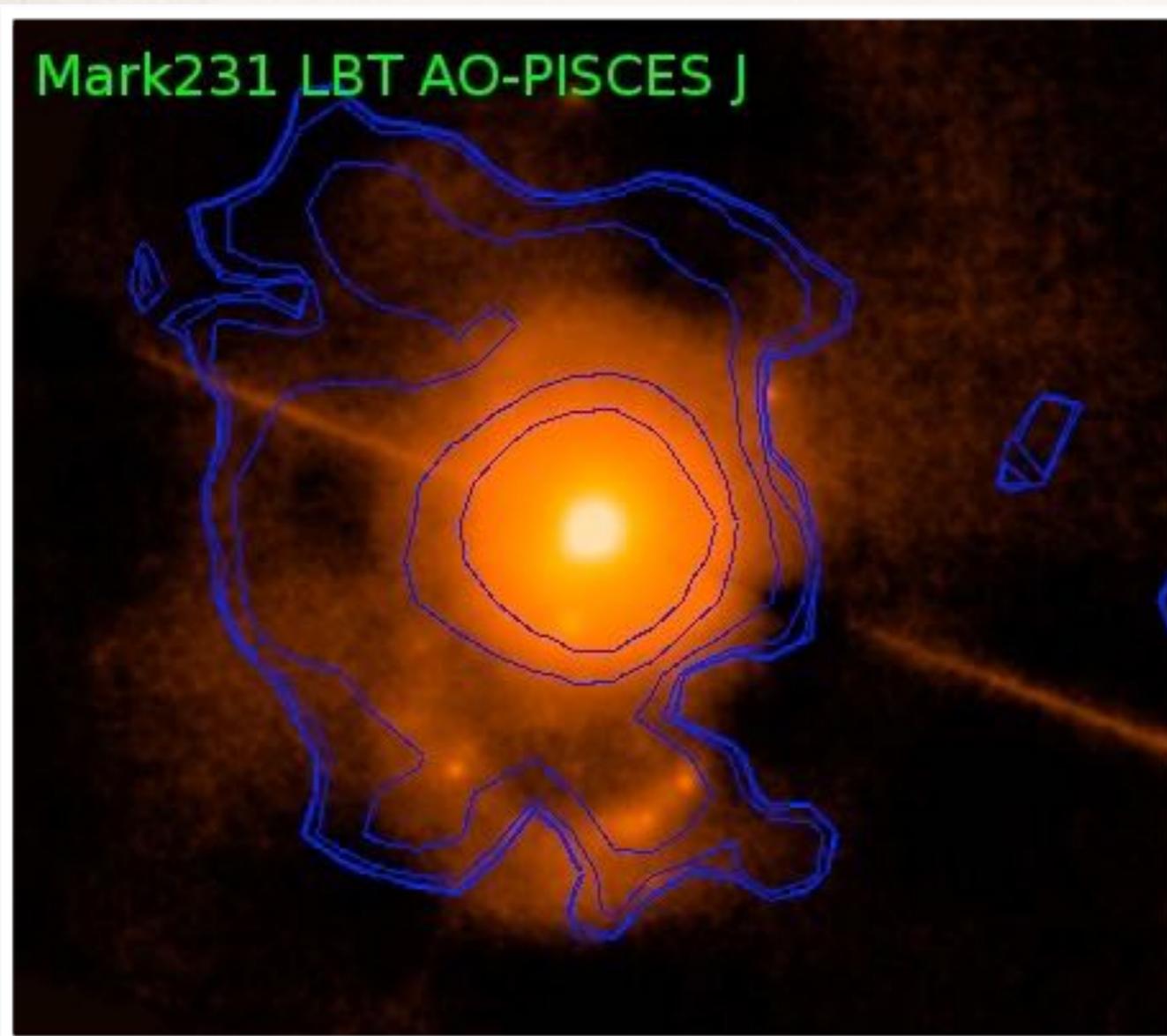
FOV=1.5' x 1.5'



FOV=20" x 20"

# Sub-arcsec res. multi- $\lambda$ campaign

Adaptive Optic J- and K-band observations

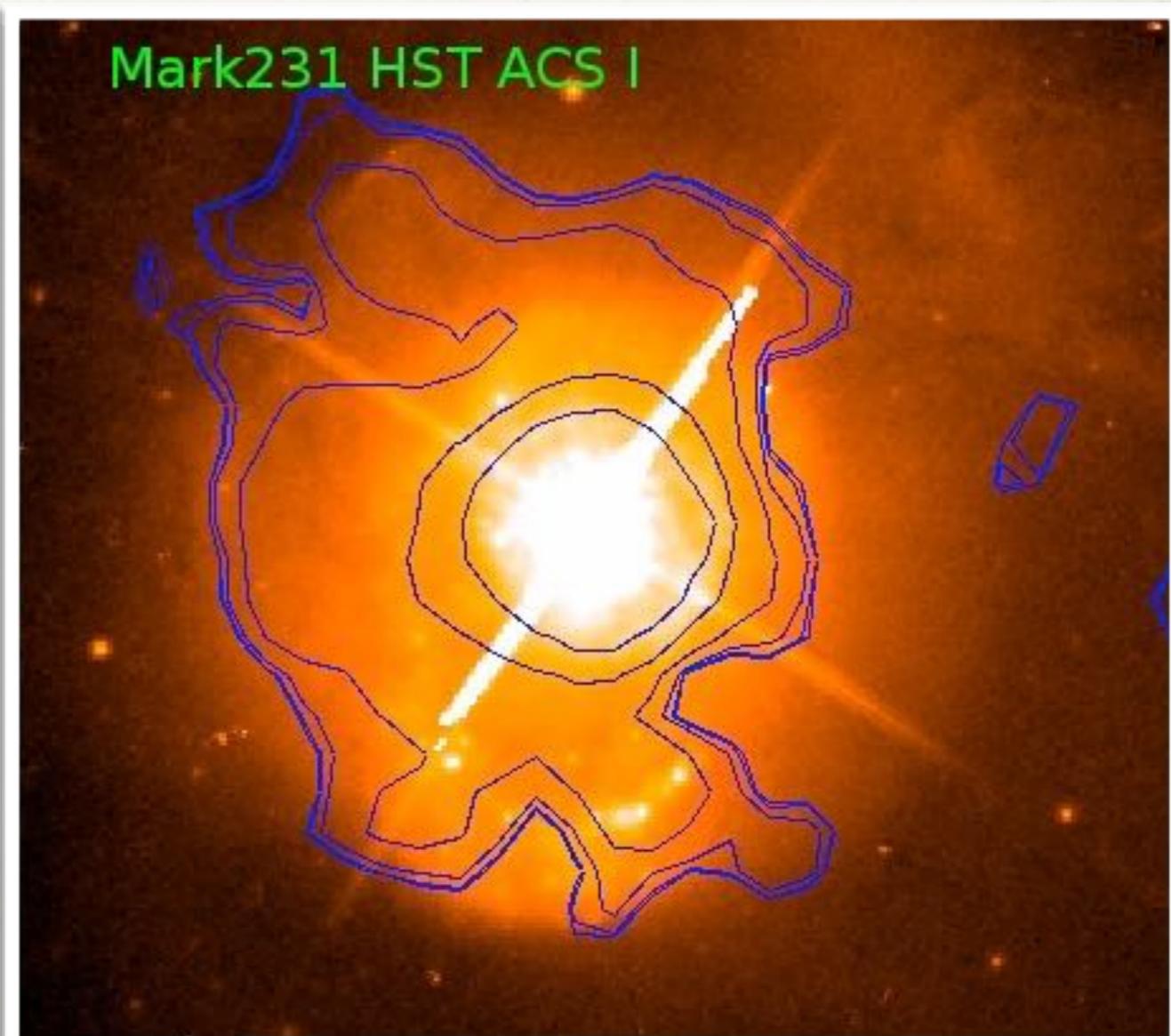
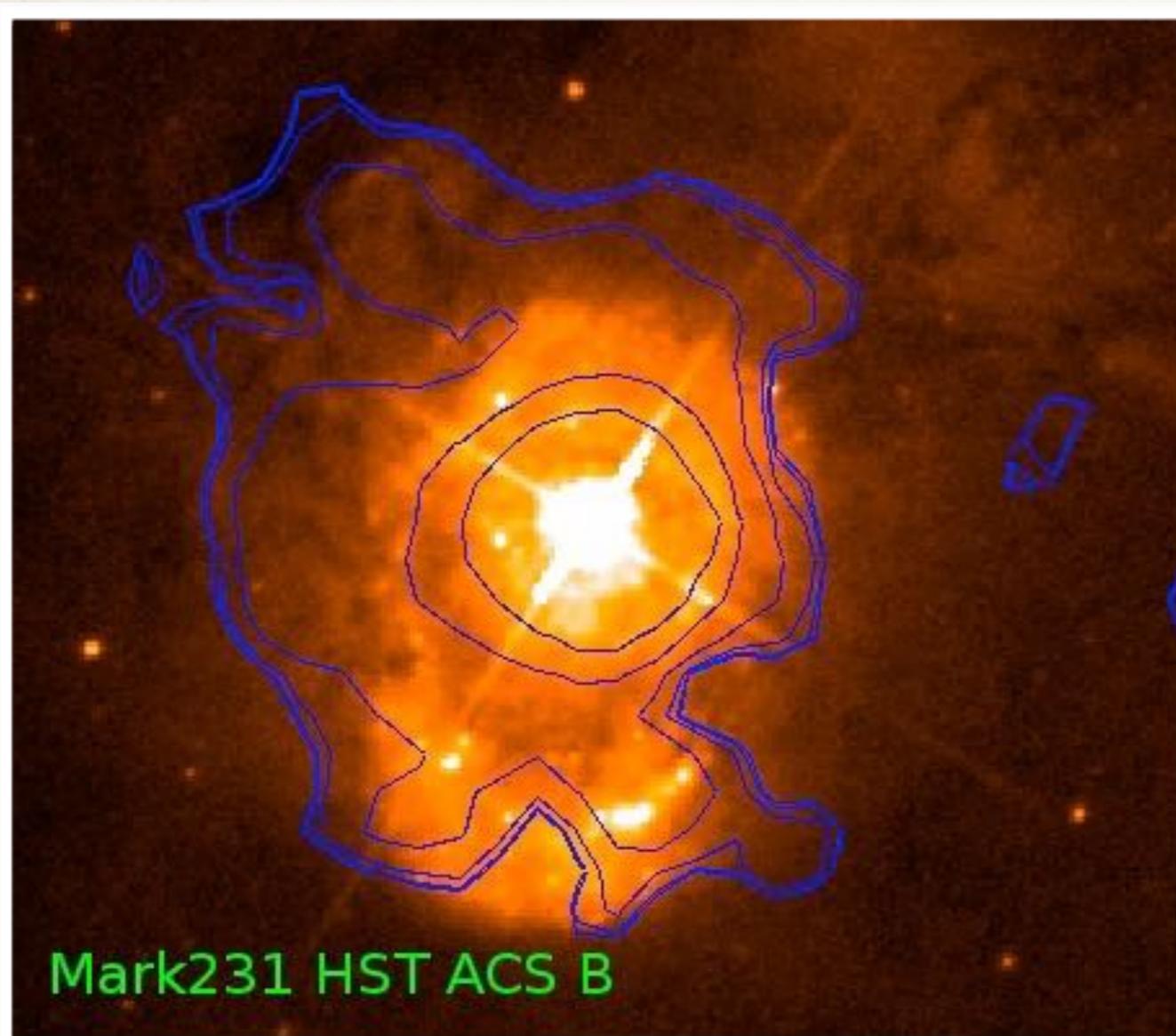


PISCES @ LBT scale= $0.0195''$  / pixel

(Bongiorno et al., in prep.)

# Sub-arcsec res. multi- $\lambda$ campaign

Adaptive Optic J- and K-band observations

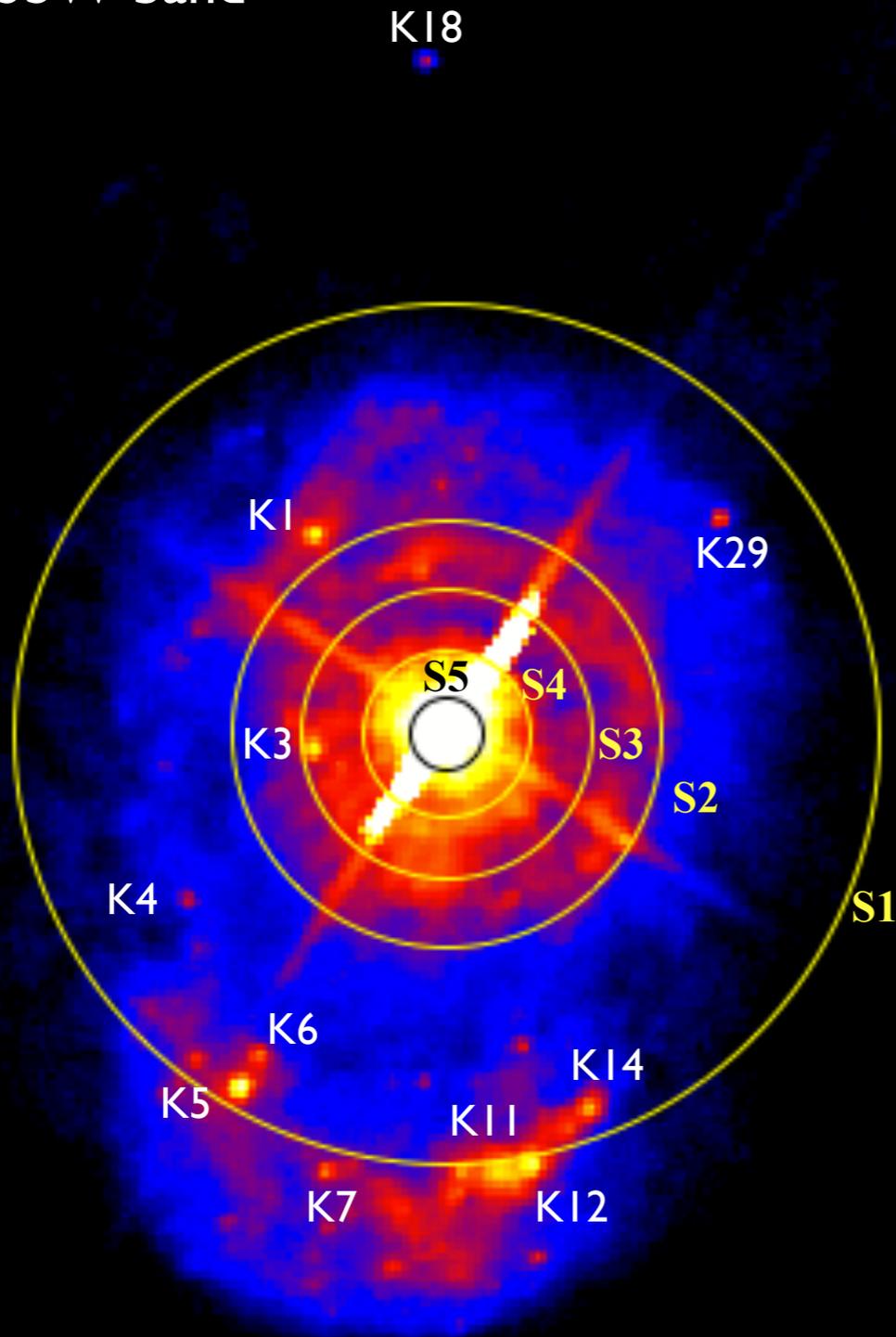


**PISCES @ LBT scale=0.0195" / pixel**

(Bongiorno et al., in prep.)

# AGN feedback marks on the host galaxy

HST F435W band



## KNOTS and SHELLS

### 5 shells with several knots

**S5: @ 0.3'' (0.2 kpc) - MOST INTERNAL**

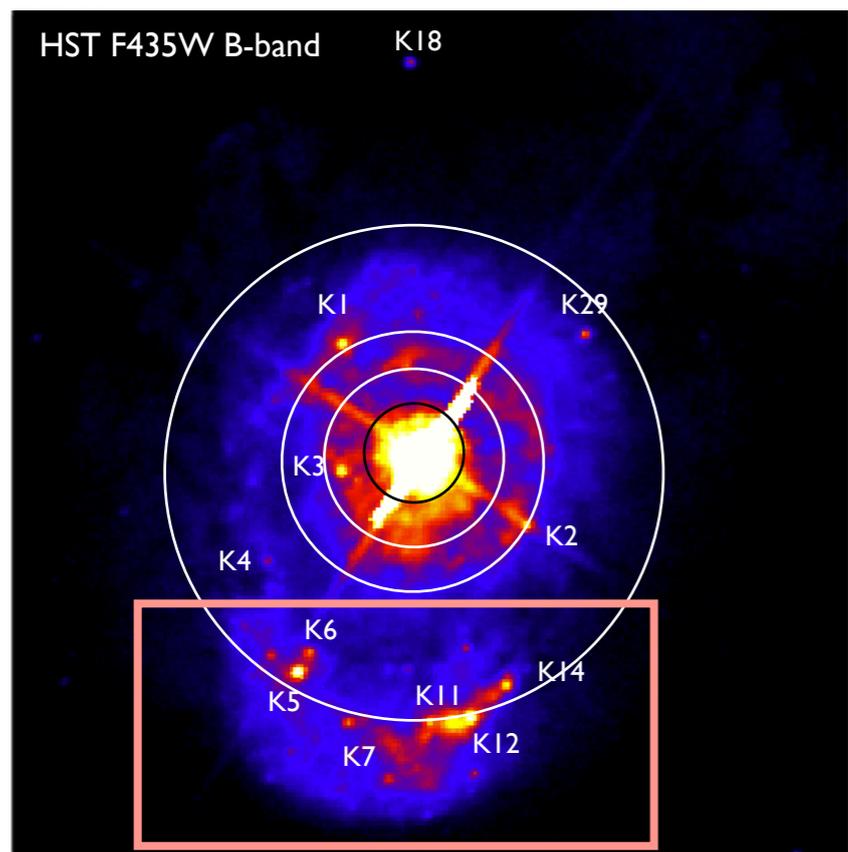
**S4: @ 0.7'' (0.6 kpc) - CO OF scale**

**S3: @ 1.2'' (1.0 kpc) - neutral OF scale**

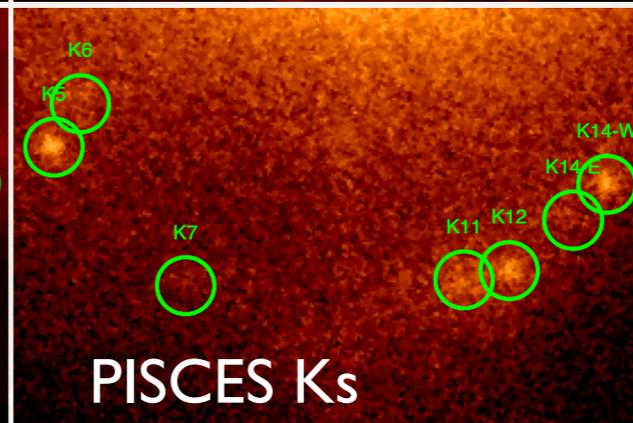
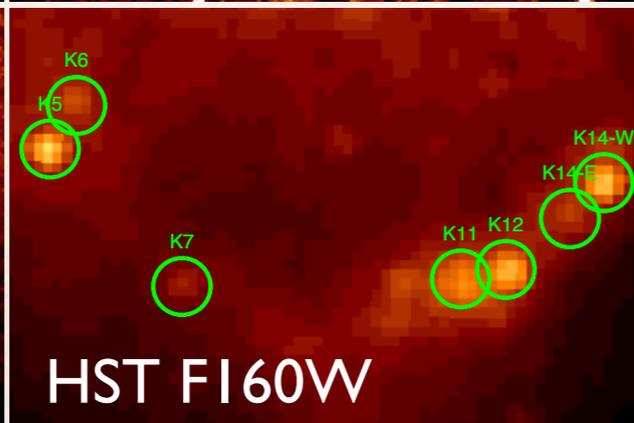
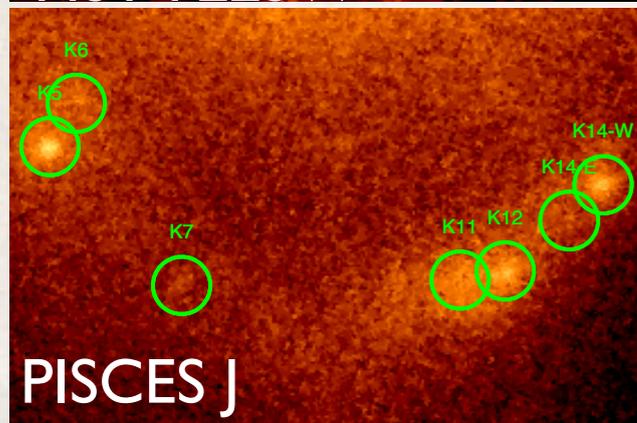
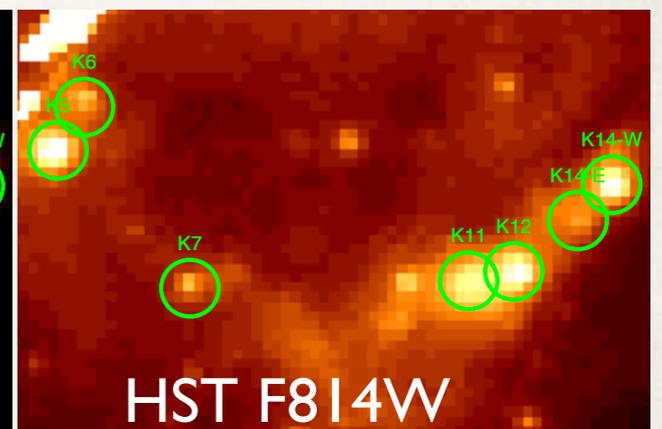
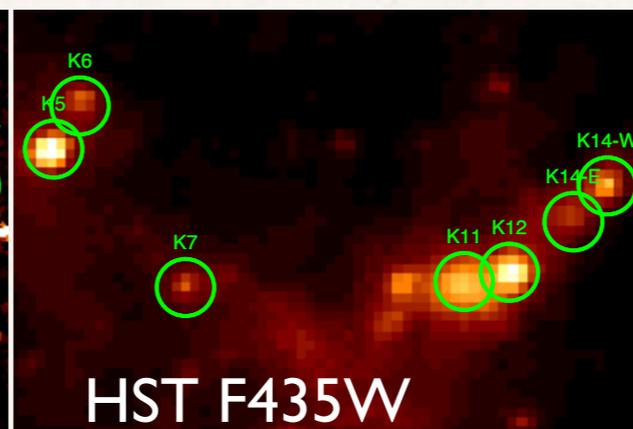
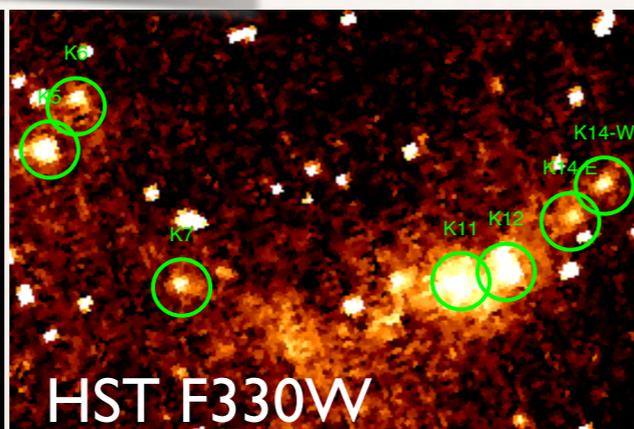
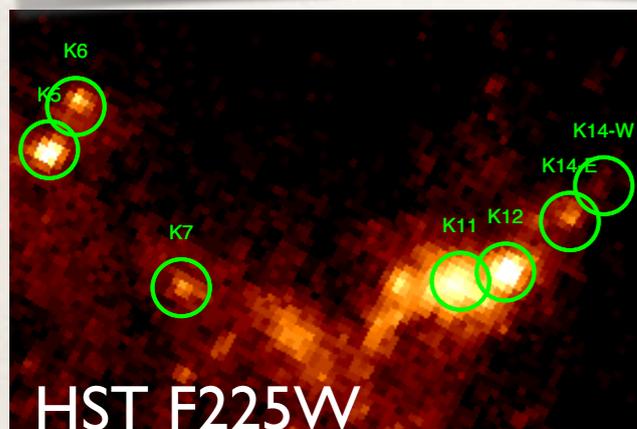
**S2: @ 1.8'' (1.5 kpc)**

**S1: @ 3.5'' (2.9 Kpc) - MOST EXTERNAL**

# AGN feedback marks on the host galaxy

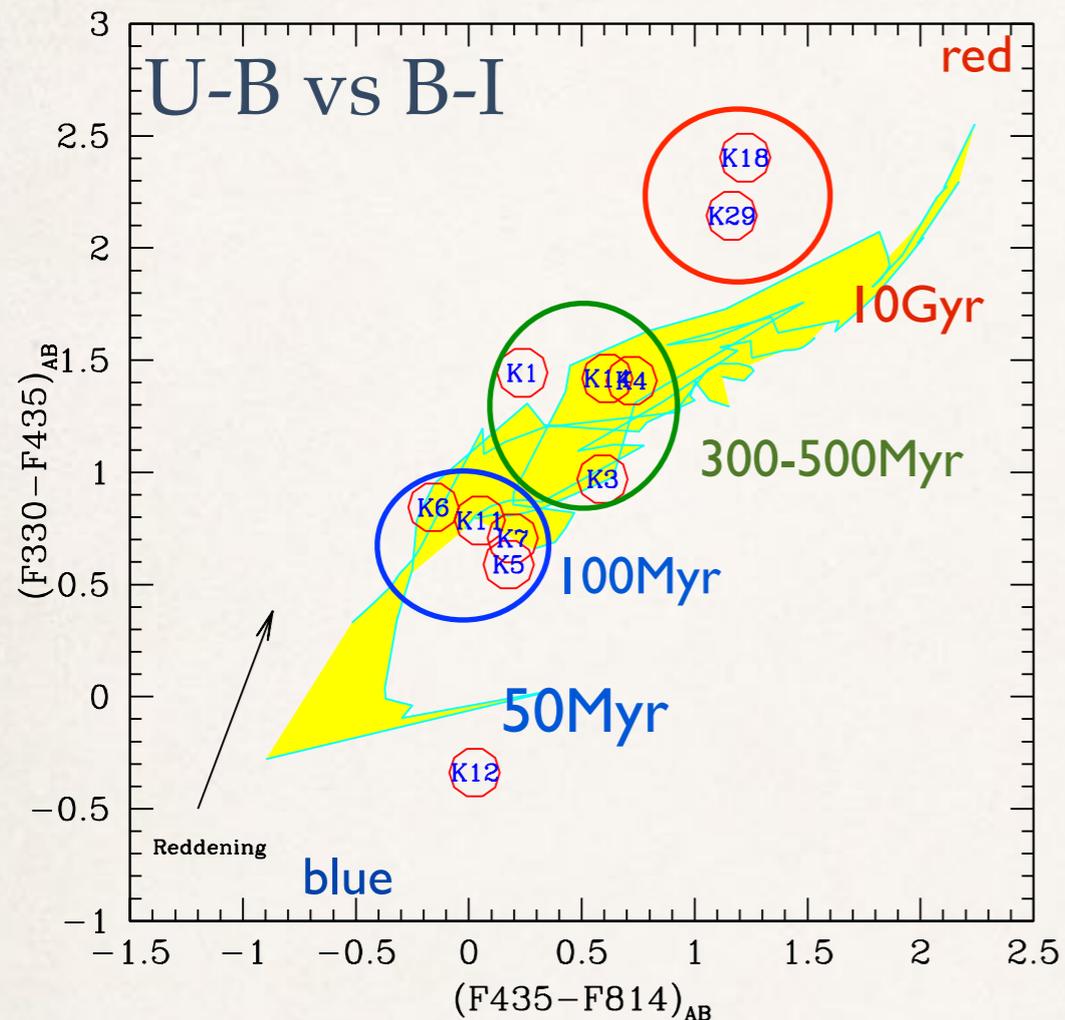


## KNOTS and SHELLS



(Bongiorno et al., in prep.)

# AGN feedback marks on the host galaxy



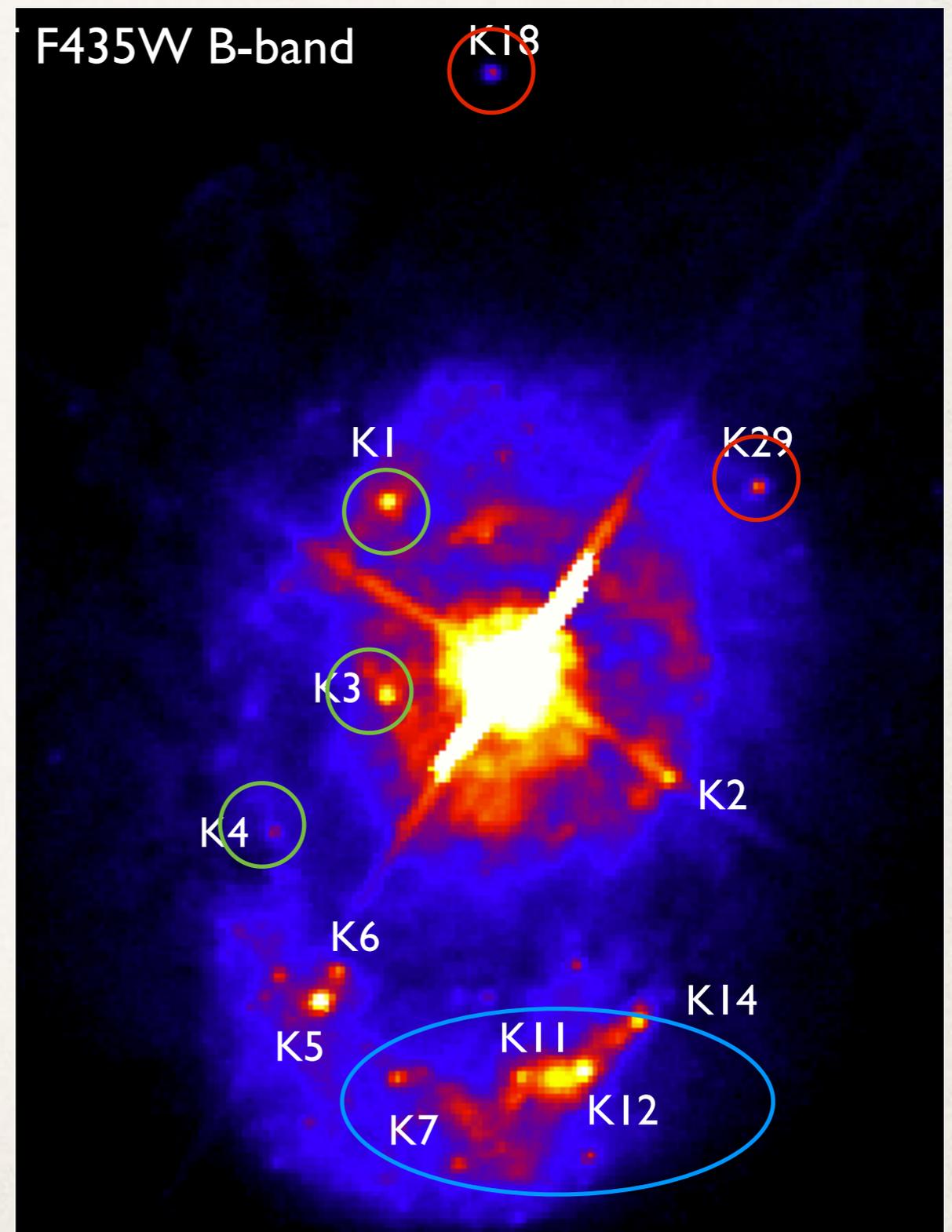
**k12:** very young ~ 50 Myr

**k6 k11 k7 k5:** young ~100 Myr

**k1 k3 k4 k14:** intermediate

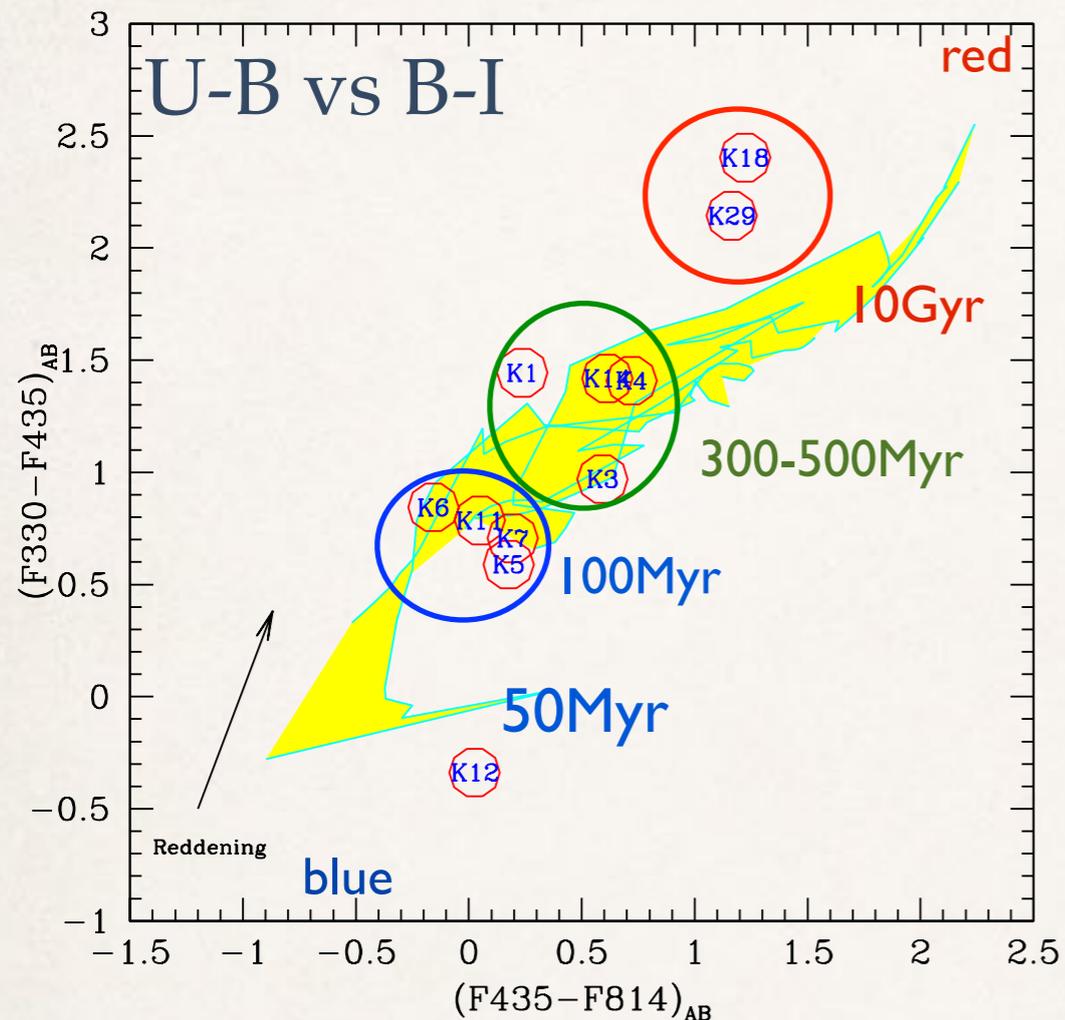
**k18 k29:** old > Gyr

only lower limits ...  
not accounting for dust!



(Bongiorno et al., in prep.)

# AGN feedback marks on the host galaxy



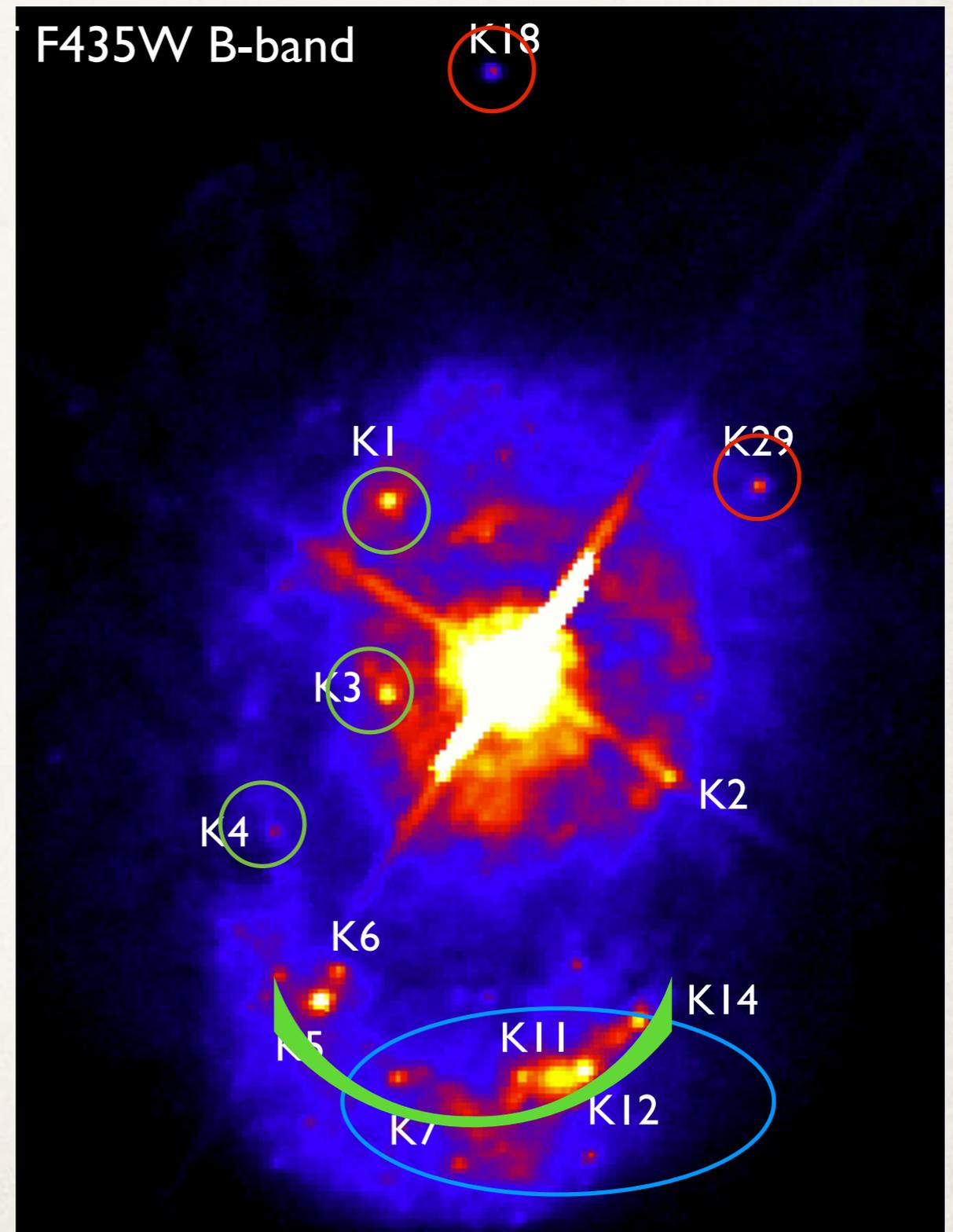
**k12:** very young ~ 50 Myr

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**k1 k3 k4 k14:** intermediate

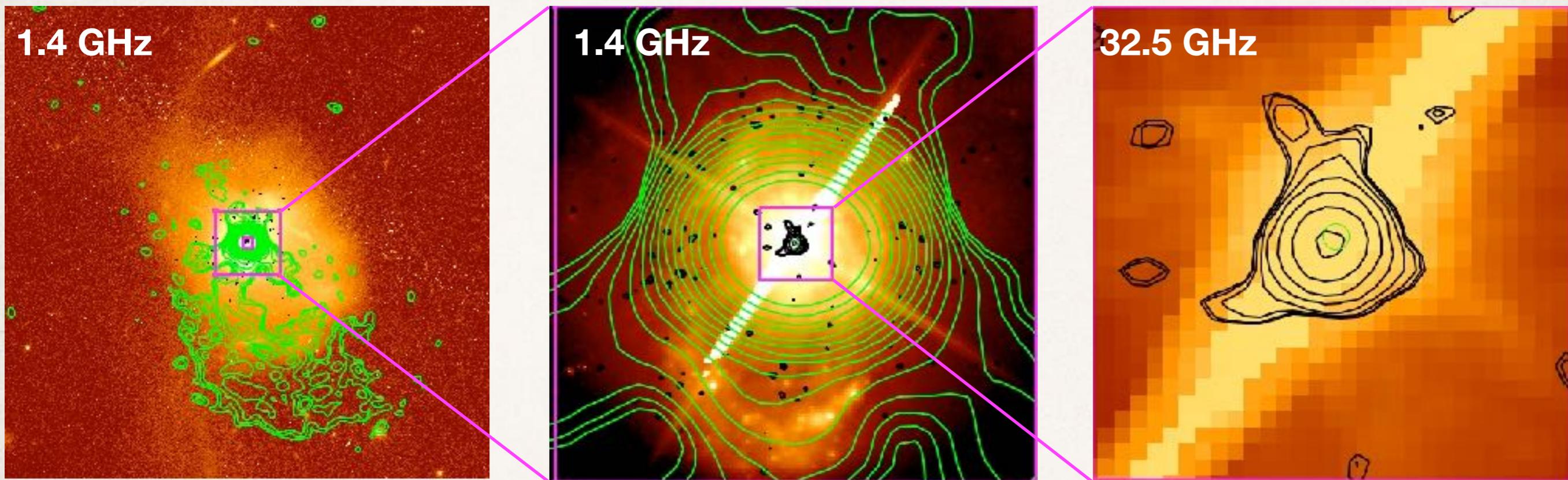
**k18 k29:** old > Gyr

only lower limits ...  
not accounting for dust!



(Bongiorno et al., in prep.)

# Mrk231 radio emission



- Bulk of the continuum radio emission (88%) is centered in the nucleus (230mJy / 265mJy)
- Wide angle jet-like diffuse component extending to the south up to 30 " (25 Kpc)
- Radio emission strongly resembles the arc-like shape of S1 (positive feedback)

- Most of the high frequency radio emission is located in the center
- Short exposure time + very steep spectral index of the jet-like feature

Hint of  
RADIO-induced POSITIVE FEEDBACK

(Bongiorno et al., in prep.)

# AGN feedback marks on the host

**NEW (extended)**  
**KNOWT at  $d = 0.6''$**   
 **$\sim$  CO outflow scale**

Visible only in UV (Extremely BLUE)  
**blob of recent SF ?**

Hint of  
WIND induced POSITIVE FEEDBACK

HST F225W

WFC3 F225W  
2012

ACS F330W  
2003

ACS F435W  
2006

ACS F814W  
2006

NIC2 F160W  
2003

# Summary

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- ❖ Winds are fundamental ingredient to explain AGN phenomenon and might have a profound impact on galaxy life
- ❖ Study AGN feedback marks on the inner region of the galaxy
- ❖ Mrk231 is the perfect laboratory to study feedback in action: nearest QSO known with ubiquitous presence of outflows in all the gas components!
- ❖ **Detailed multi-band high-resolution study of Mrk231:**
  - ❖ Complex morphology with shells and knots
  - ❖ Hint of SF induced by the molecular outflow (wind induced positive feedback) at the edge of the molecular outflow
  - ❖ Hint of SF induced by the radio jet (radio induced positive feedback)

**THIS IS ALL PRELIMINARY ... a lot more to come...**

mid-IR observations with LBT LMIRCAM and NOMIC to be analyzed (PAH)