East-Asia AGN Workshop 2017

4-6 December 2017 in Kagoshima, Japan

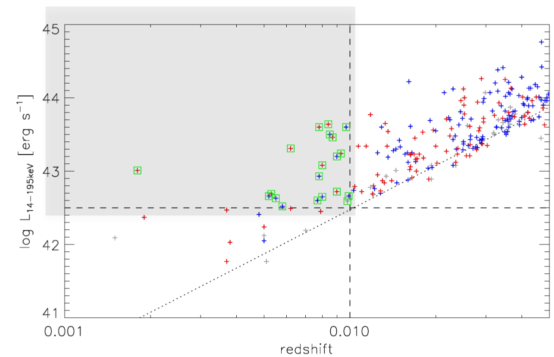
Local Luminous AGN with Matched Analogs (LLAMA): Nuclear stellar properties of Swift BAT AGN and matched inactive galaxies

Ming-Yi Lin (MPE IR group -> KIAA BHOLE project), R.I. Davies, E.K.S. Hicks, L. Burtscher, A. Contursi, R. Genzel, M. Koss, D. Lutz, W. Maciejewski, F. Müller-Sánchez, G. Orban de Xivry, C. Ricci, R. Riffel, R.A. Riffel, D. Rosario, M. Schartmann, A. Schnorr-Müller, T. Shimizu, A. Sternberg, E. Sturm, T. Storchi-Bergmann, L. Tacconi and S. Veilleux

2018, MNRAS, in press

LLAMA

- **L**ocal **L**uminous **A**GN with **M**atched **A**nalogs
- Select AGNs from the 58-month Swift-BAT catalog.
  - $L_{14\text{-}195} > 10^{42.5}$ erg/s
  - D < 40 Mpc (z < 0.01)



- Finding a matched sample of inactive galaxies
  - host galaxy morphology (Hubble type),
  - inclination (axis ratio),
  - 2MASS H-band luminosity (the proxy of stellar mass).
- Volume-limit sample: 20 AGNs & 19 matched inactive galaxies
- Key Sciences: understanding feeding and feedback in AGN with molecular and ionized gas

LLAMA

- 235hr ESO Large Program (PI: R.I. Davies)
- Studying the nuclear regions
  - VLT/X-Shooter (complete): SPS, UVB-VIS-NIR
    (L. Burtscher & D.J. Rosario)
  - VLT/SINFONI-AO (ongoing): kinematics & photometry, H+K band
    (M-Y Lin & T. Shimizu)

- Studying the kpc-scale regions
  - APEX & JCMT (complete): CO(2-1)
    (PI: D.J. Rosario, MNRAS in press)
  - HST Cycle 25 (ongoing): dust map
    (PI: D.J. Rosario)
  - Narrow-band imaging (in prep)

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    SINFONI P93: 8 AGNs & 5 matched inactive galaxies (8 pairs)
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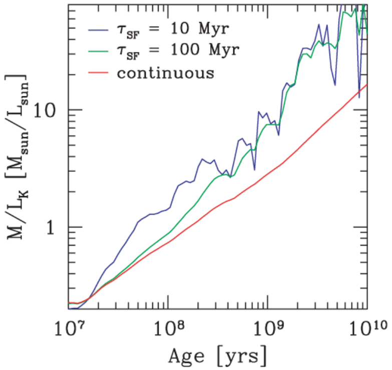
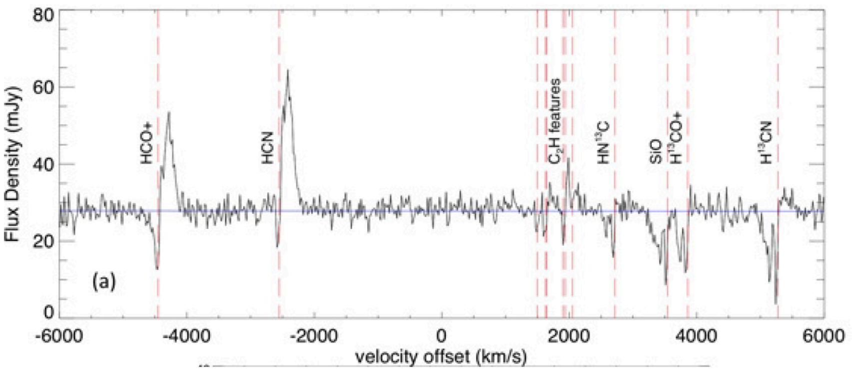
Evidences for nuclear SF around AGN

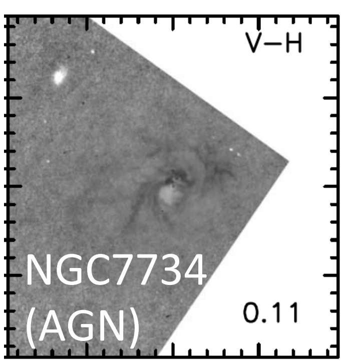
- PAH features
- Hydrogen recombination lines
- M/L (constrain the age of SF)
- Molecular abundances of nuclear disk is similar to SNe remnant. (e.g. NGC 3079)
- Nuclear thick-disk geometry (e.g. Wada's "radiation-driven fountain" model):
  - covering factor of AGN tori on the los X-ray absorption
  - Gas kinematics (e.g. H_2 , HCN, etc.)

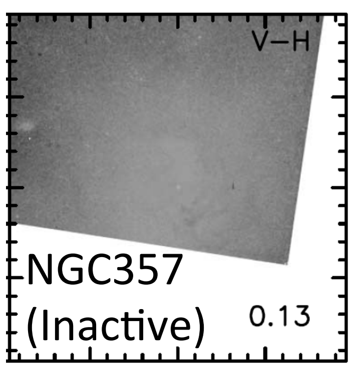


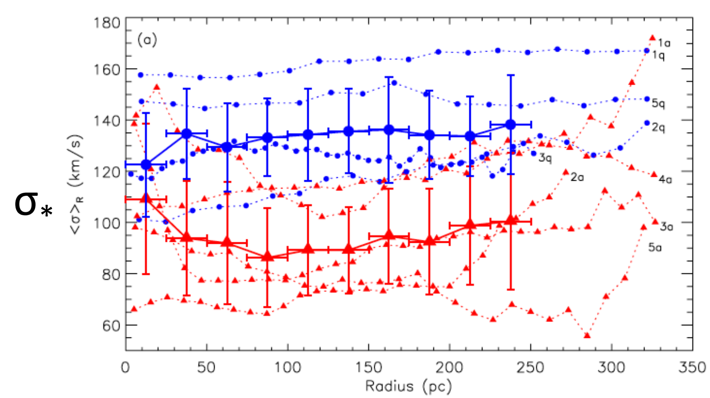


AGN-inactive galaxy pair studies in literature

- > 200 pc (e.g. Martini+2003)
  - No significant difference in the frequency of bars or interactions
  - The only difference is that several inactive galaxies appear to completely lack dust structure in their circumnuclear region, while none of the AGNs lack this structure.
- 10-200 pc (e.g. Hicks+2013)
  - More centrally concentrated nuclear stellar surface brightness and lower stellar velocity dispersion have been found in AGNs.
  - However, a caveat is that their active and inactive galaxies do not match in dynamical mass properly.

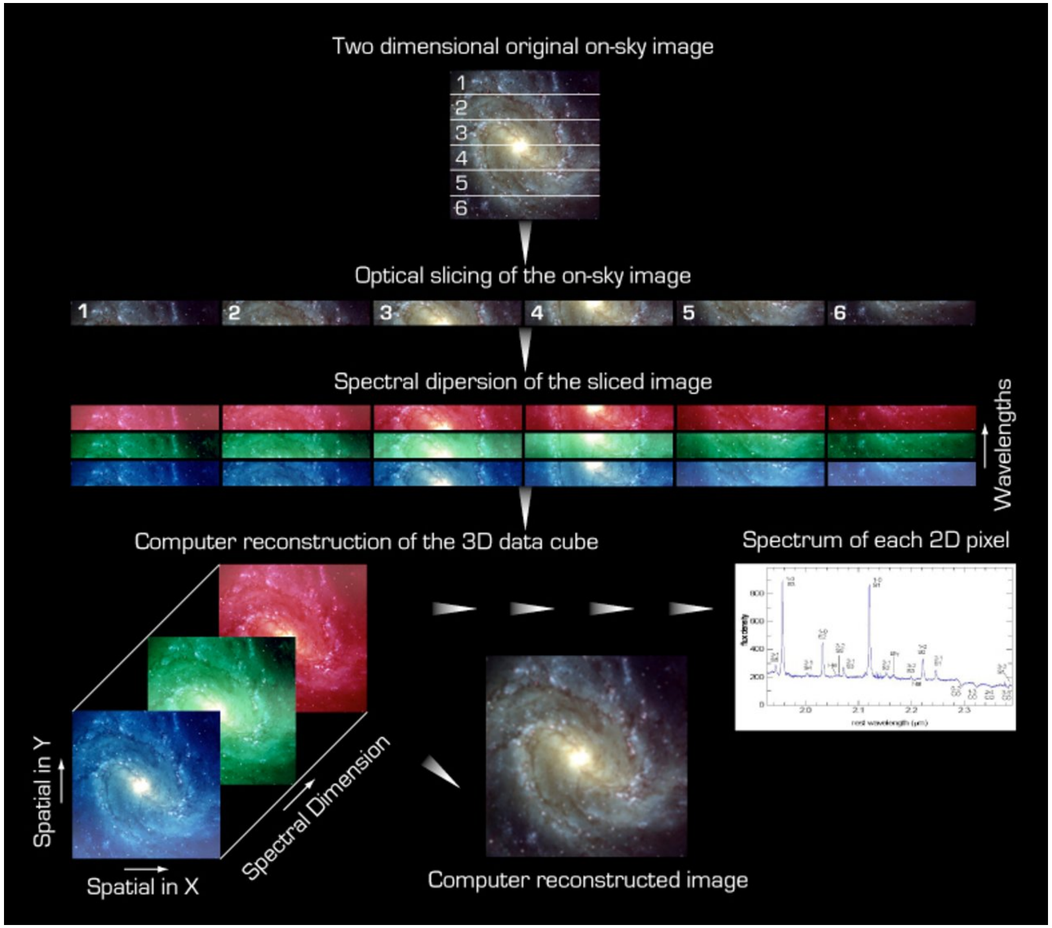






Observations

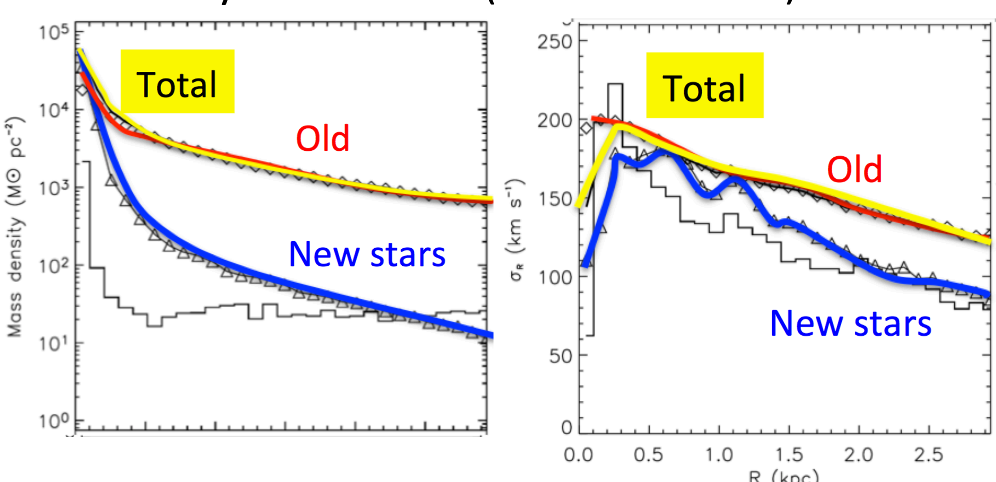
- SINFONI/VLT (AO mode) is a near-infrared (1.1 -- 2.45 μm) integral field spectrograph fed by an adaptive optics module.



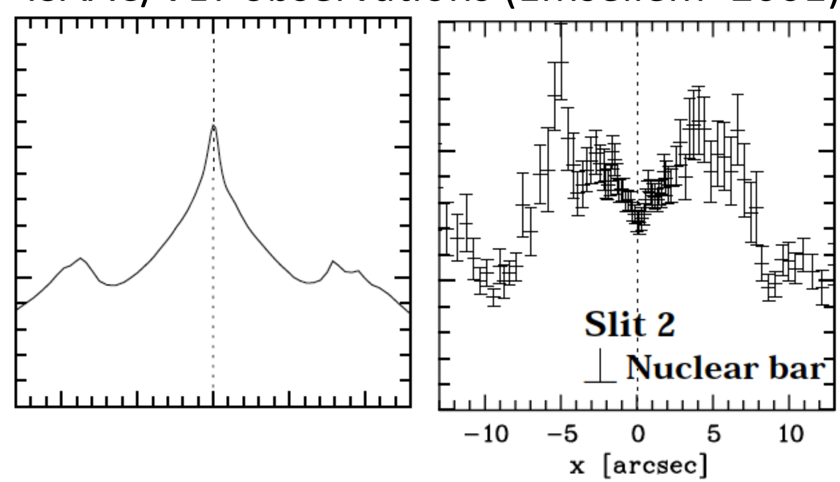
Scientific goals with stellar absorption CO(2-0)

- (1) Looking for the difference between the AGNs and matched inactive galaxies
  - Photometric (e.g. Σ_*)
  - Kinematics (e.g. v, σ, v/σ, $(v^2+\sigma^2)^{1/2}$)
- (2) Looking for nuclear SF from stellar perspectives
  - Nuclear stellar excess
  - σ_* drop

N-body simulations (Wazniak+2003)

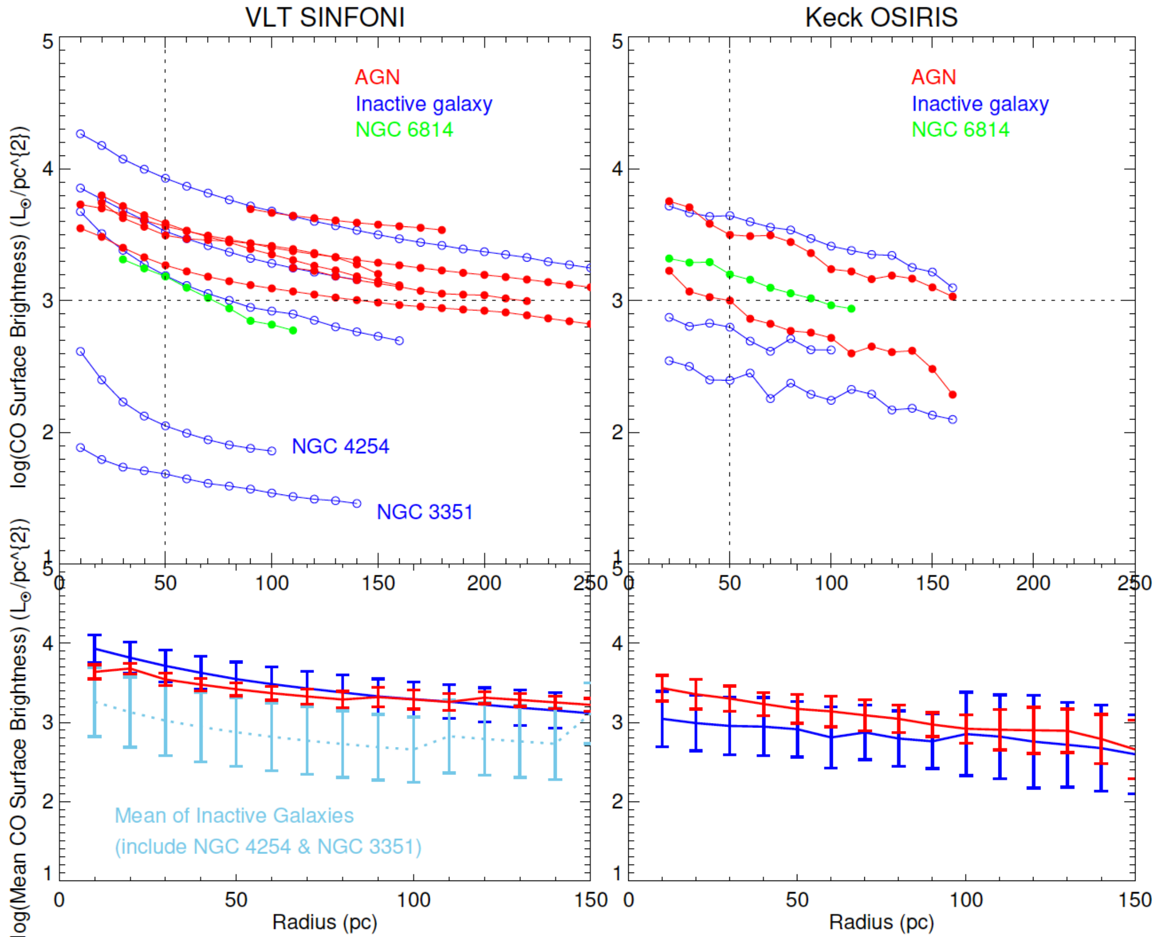


ISAAC/VLT observations (Emsellem+2001)



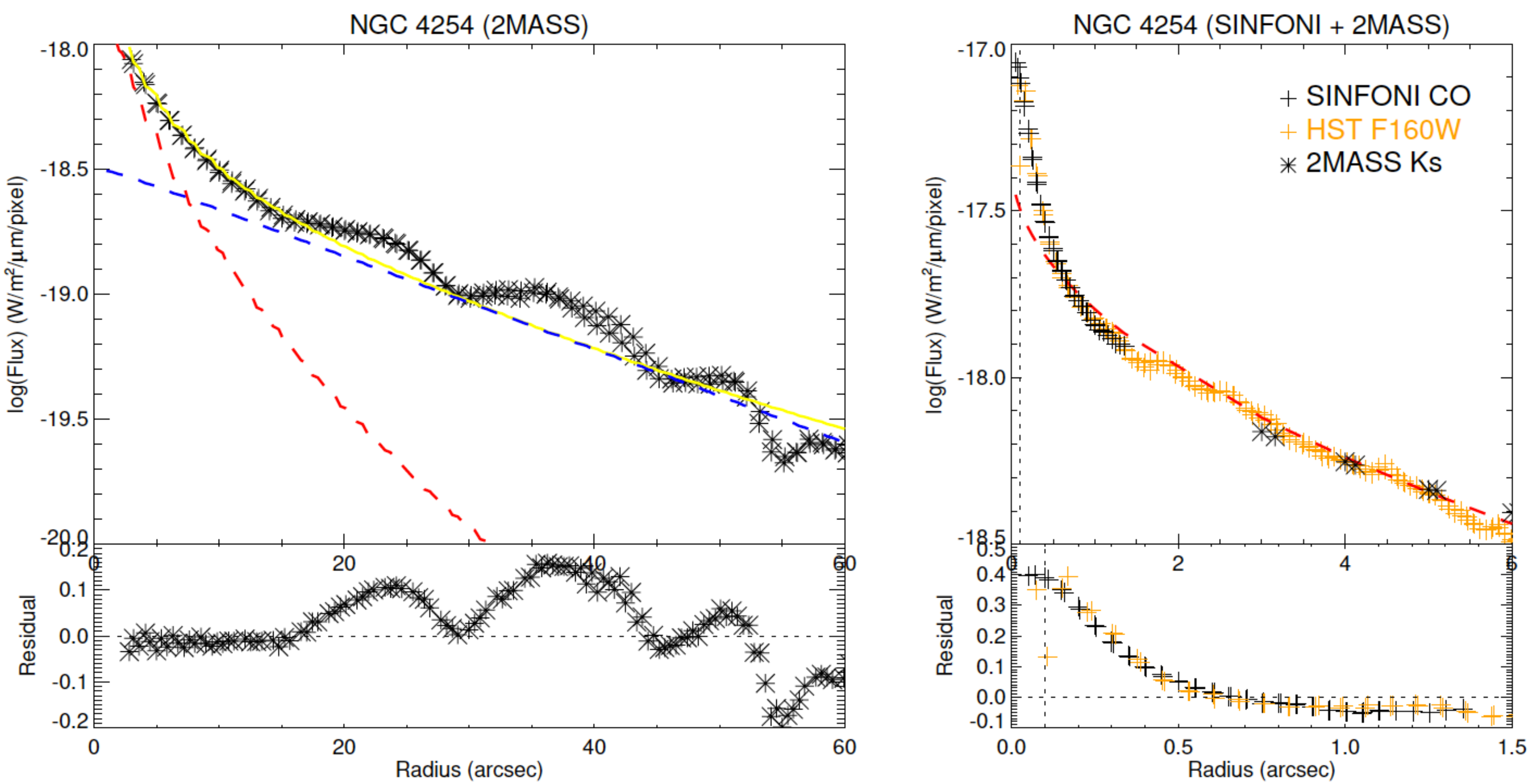
Photometric: Surface brightness

- Exclude the NGC 4254 & NGC 3351, there is NO difference between AGN and matched inactive galaxies.



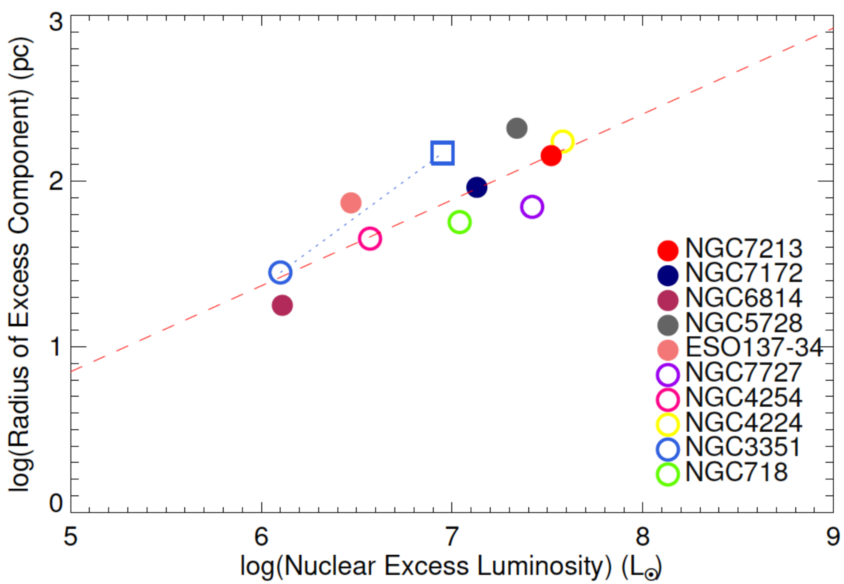
Photometric: Nuclear stellar excess

- Know the bulge contribution within SINFONI FOV.
  - Bulge/Bar/Disk decomposition by GALFIT
- 10/13 galaxies show nuclear stellar excess.



Photometric: Nuclear stellar excess

- Fitting Gaussian profile to the nuclear excess component.
- NO difference in nuclear excess between AGN and matched inactive galaxies.
- Size-luminosity relation is similar to those NSC in Elliptical galaxies. However the size is larger, suggesting they are likely to be extended nuclear stellar disk.



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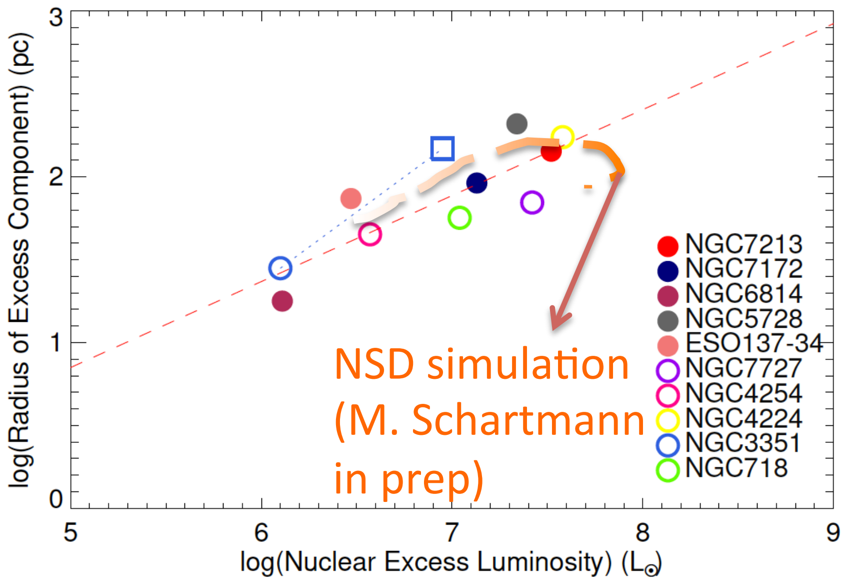
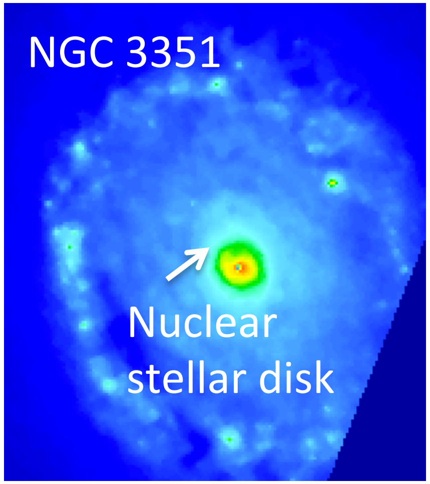
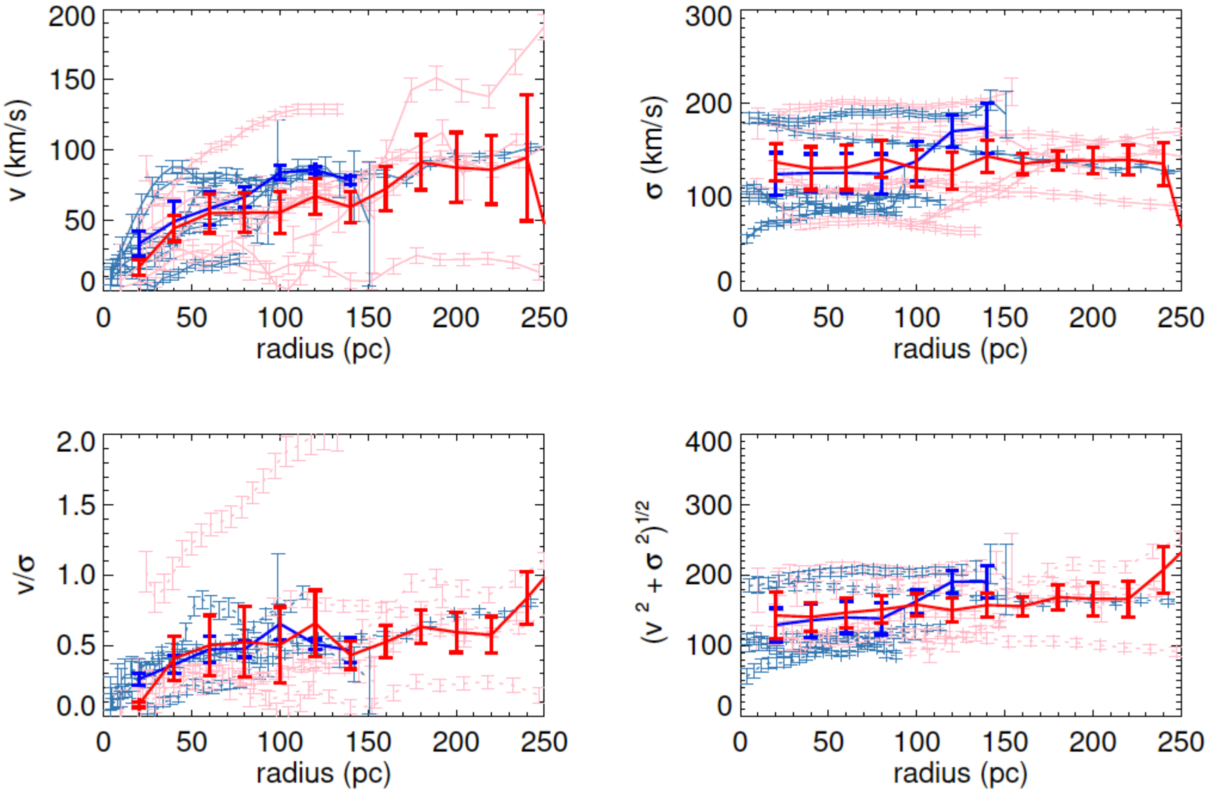




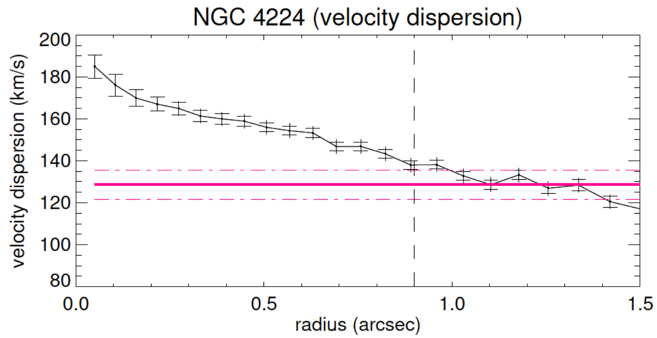
Kinematic: Nuclear stellar kinematics

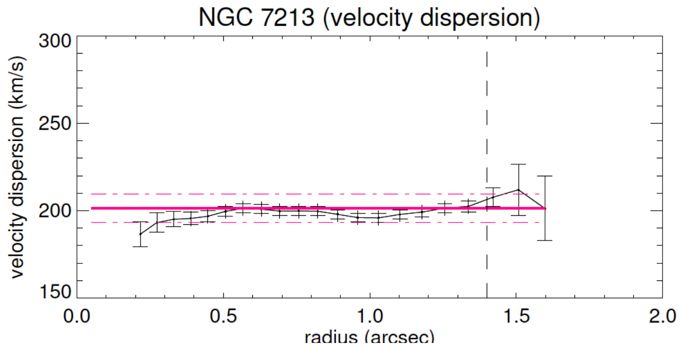
- NO difference in stellar kinematics between AGN and matched inactive galaxies.
- Radial velocity dispersion is very flat. Only few galaxies show velocity dispersion drop.

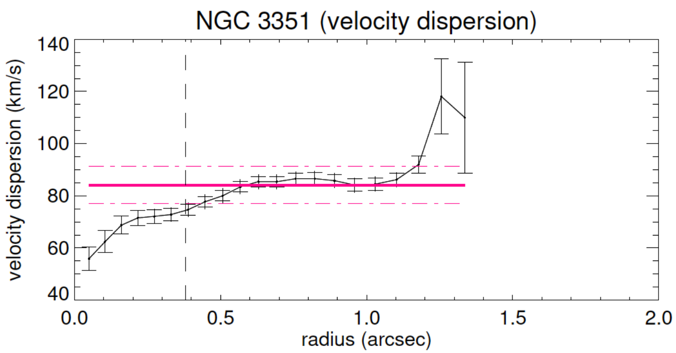


SF indication from nuclear stellar kinematics

- Explain three velocity dispersion trends: increasing, flat, decreasing







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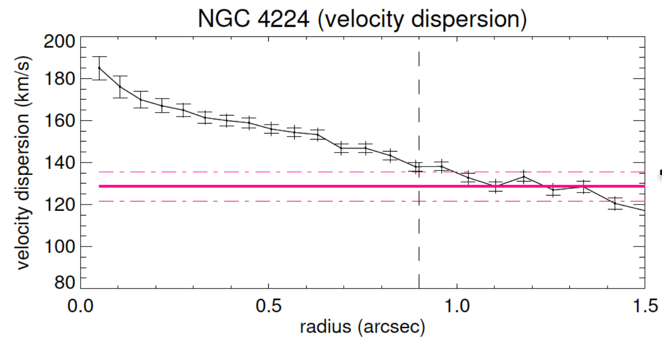
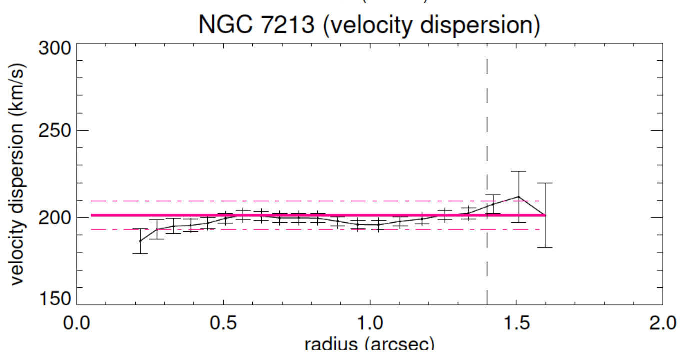
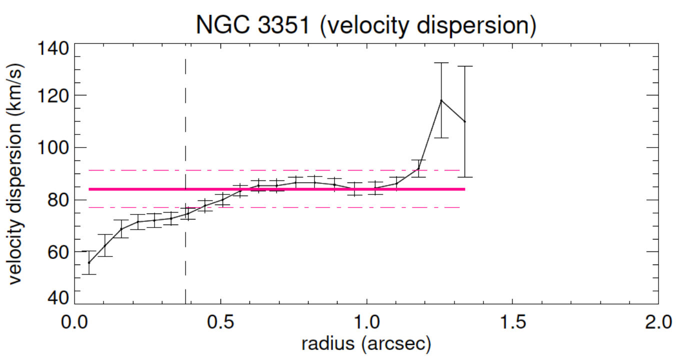


Represent the gravitational potential of host galaxy.

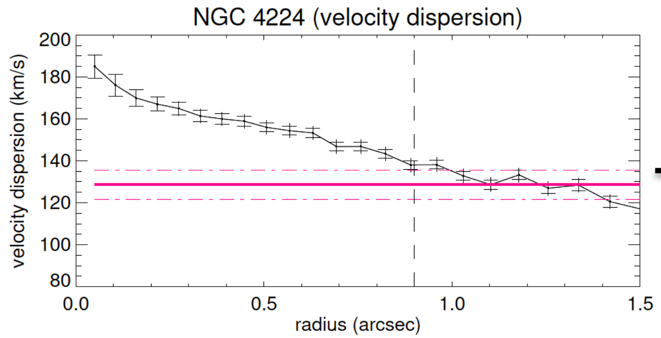




Dynamical cold young stars overcome the old stars.

SF indication from nuclear stellar kinematics

- Explain three velocity dispersion trends: increasing, flat, decreasing



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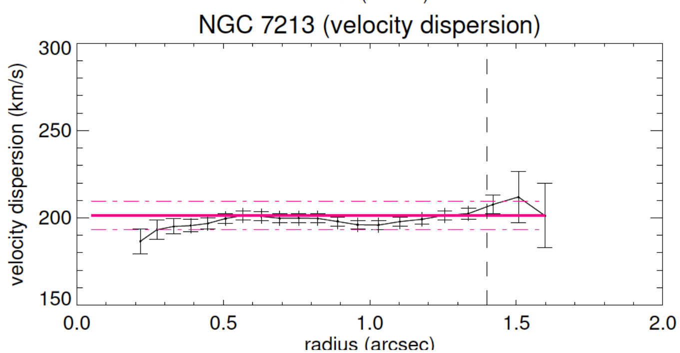
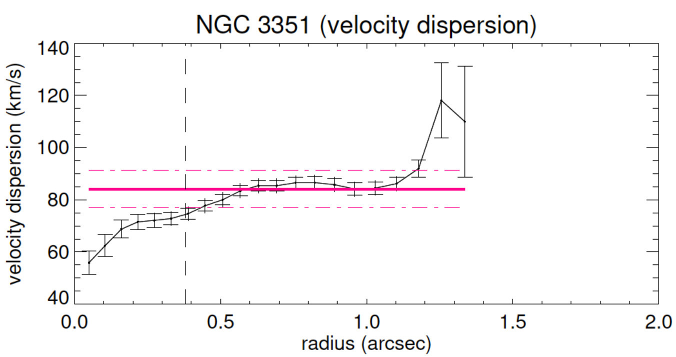


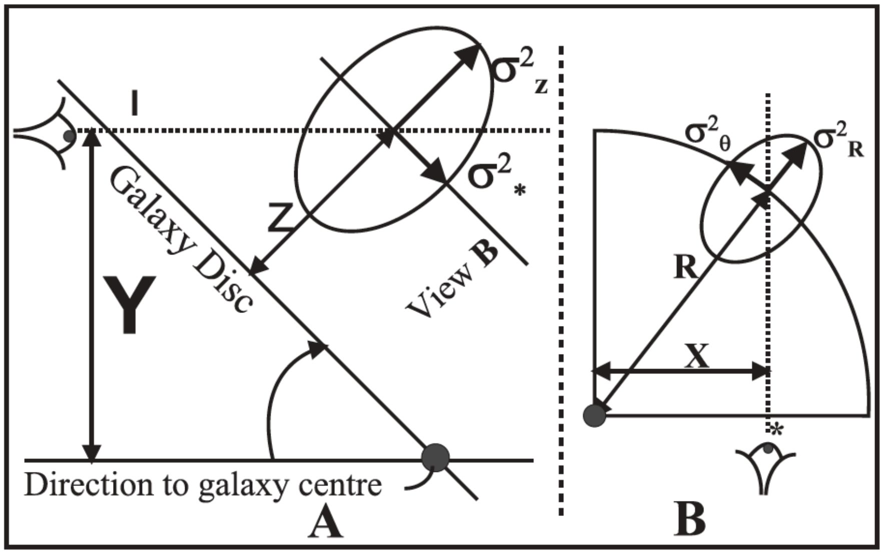
→ Combination of galaxy potential and small fraction of young stars.



→ Dynamical cold young stars overcome the old stars.

SF indication from nuclear stellar kinematics

- Dispersion projection in a plane parallel to stellar disk.



$$\sigma_{los}^2 = \sigma_*^2 \cos^2\theta + \sigma_z^2 \sin^2\theta$$

$$\sigma_*^2 = \sigma_\theta^2 (X^2/R^2) + \sigma_R^2 (1-X^2/R^2)$$

$$\sigma_z^2 (r) = 2\pi G\Sigma(r)h_z$$

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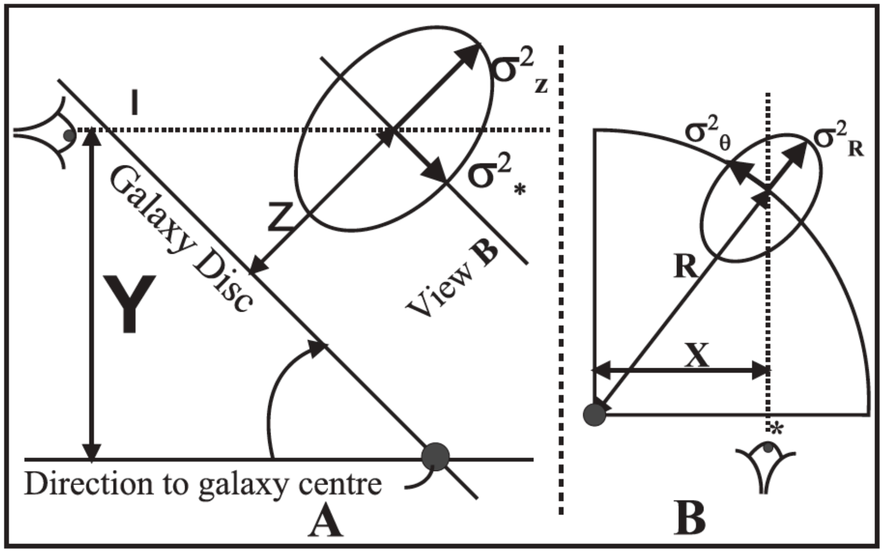

Toy model assumptions:
(1) the disk is close to face on,

$\sigma_{los}^2 =$ ~~$\sigma_*^2 \cos^2\theta$~~ $+ \sigma_z^2 \sin^2\theta$

~~$\sigma_*^2 = \sigma_\theta^2 (X^2/R^2) + \sigma_R^2 (1 - X^2/R^2)$~~

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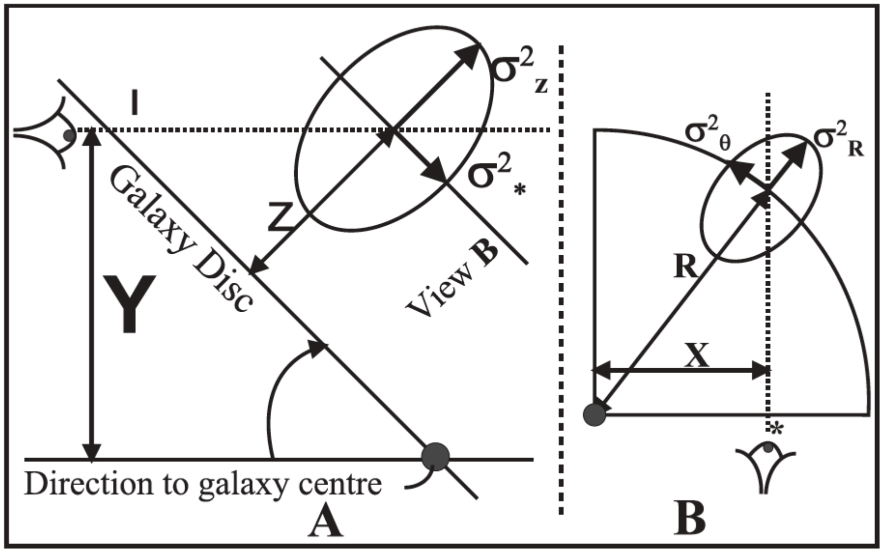

Toy model assumptions:
(1) the disk is close to face on,
(2) The disk is geometrically thinner, e.g. pseudo-bugle.

↓

$\sigma_{los}(r) \sim \Sigma(r)$ (surface brightness)

$$\sigma_{los}^2 = \cancel{\sigma_*^2 \cos^2\theta} + \sigma_z^2 \sin^2\theta$$

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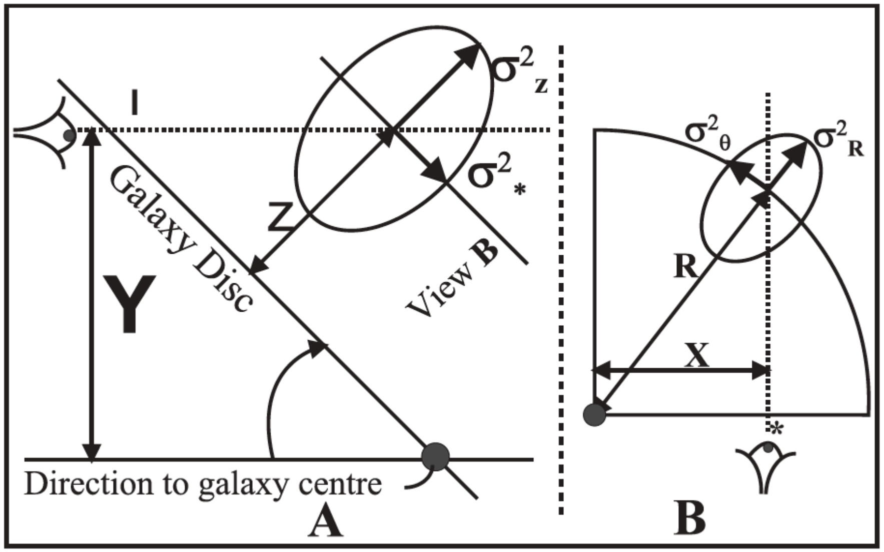

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(1) the disk is close to face on,
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↓

$\sigma_{los}(r) \sim \Sigma(r)$ (surface brightness)

↓

Once the $\Sigma_{bulge}(r)$ is known, we can constrain intrinsic $\sigma_{bulge}(r)$.

$\sigma_{los}^2 =$ ~~$\sigma_*^2 \cos^2\theta$~~ $+ \sigma_z^2 \sin^2\theta$

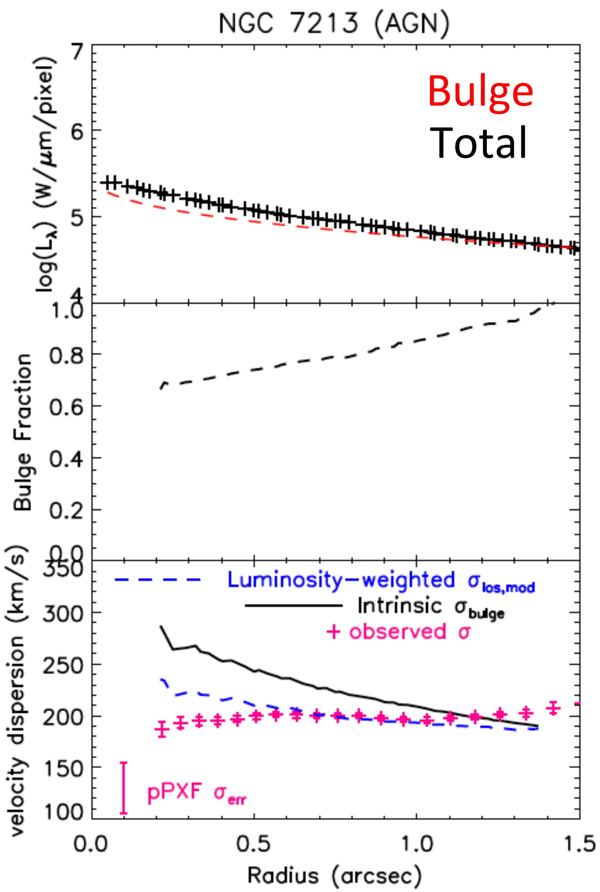
~~$\sigma_*^2 = \sigma_\theta^2 (X^2/R^2) + \sigma_R^2 (1-X^2/R^2$~~$)$

$\sigma_z^2 (r) = 2\pi G\Sigma(r)$~~$h_z$~~

SF indication from nuclear stellar kinematics

- Explaining the flat velocity dispersion

$$\sigma^2_{los,mod}(r) = \sigma^2_{z,bulge}(r) \times (\frac{L_{bulge}(r)}{L_{total}(r)}) + \sigma^2_{z,new}(r) \times (1 - \frac{L_{bulge}(r)}{L_{total}(r)})$$



Assuming $\sigma_{z,new}$ is 30-40 km/s (from NGC 3351, which young stars dominate in the nuclear regions)

↓

Our model can explain the velocity dispersion trend in NGC 7213, and its host galaxy is close to face-on (26°).

<u>-> consistent to our assumption.</u>

Summary

- (1) Looking for the difference between the AGNs and matched inactive galaxies
  - No evidence for the difference in the stellar kinematics, stellar surface brightness, and nuclear stellar luminosity excess between the active and matched inactive galaxies.
- (2) Looking for nuclear SF from stellar perspectives
  - Most galaxies have nuclear excess flux, the size-luminosity relation suggests they are likely to be nuclear stellar disk.
  - Although the SF may have an impact in the observed kinematics, their fraction is too small to dominate over the bulge and compensate the increase in dispersion at small radii, so no dispersion drop is seen.