CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

Chandra Imaging of the Circumnuclear Regions of Nearby AGNs

Mapping the past history of AGNs

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AGN Timing from Images

- Time variability studies limited to maximum scales of decades

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  from few 100 yrs

  Sgr A*

  nucleus of ESO 428-G014

  to ~$10^{4\text{-}5}$ yrs

  NGC 4151

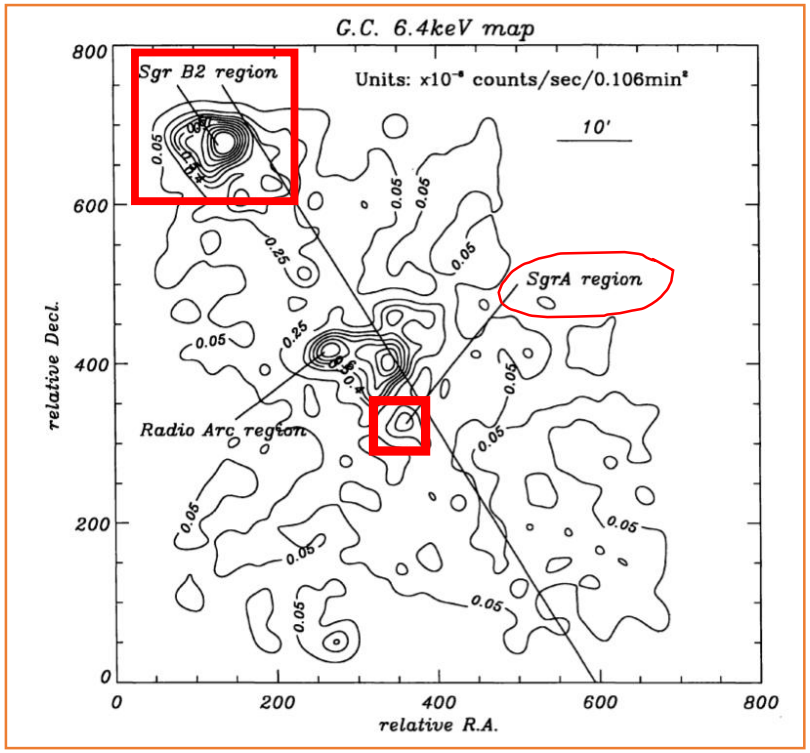
  ESO 428-G014

  NGC 5252 (Dadina et al. 2010)

  IC 2497 / Hanny's Voorwerp

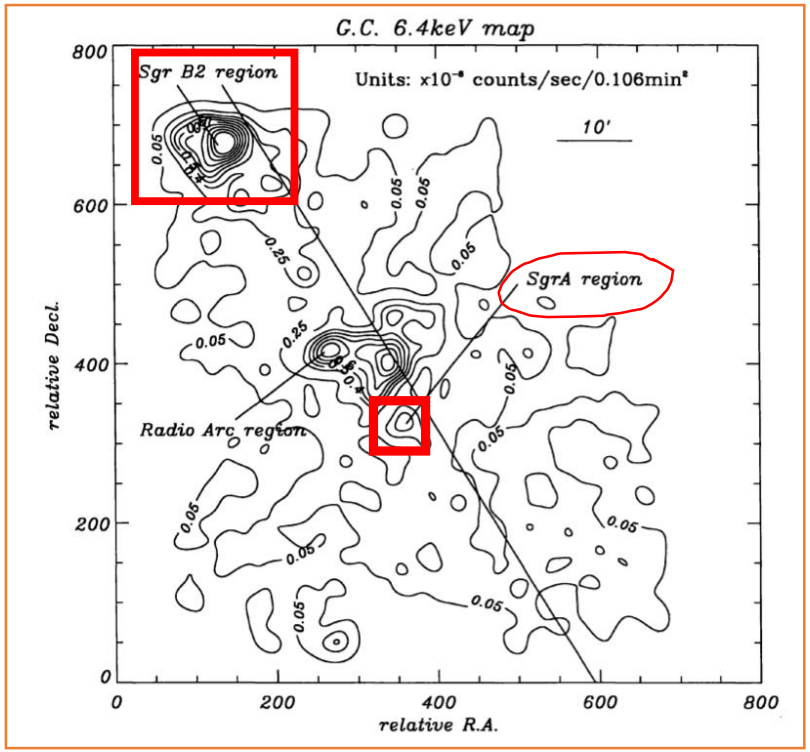
Sgr A*- 10^4 flare 300 yrs ago

- ASCA 2-10 keV diffuse emission and Fe Kα map Koyama et al. 1996



Sgr A*- 10^4 flare 300 yrs ago

- ASCA 2-10 keV diffuse emission and Fe Kα map Koyama et al. 1996
- Fe Kα emission of molecular cloud Sgr B2 ➔ 2-10 keV L_X~2 x 10^{39} erg s^{-1} **compare with Sgr A*~10^{35} erg s^{-1}**
- Distance of ~90 pc sets flare time of ~300 yr



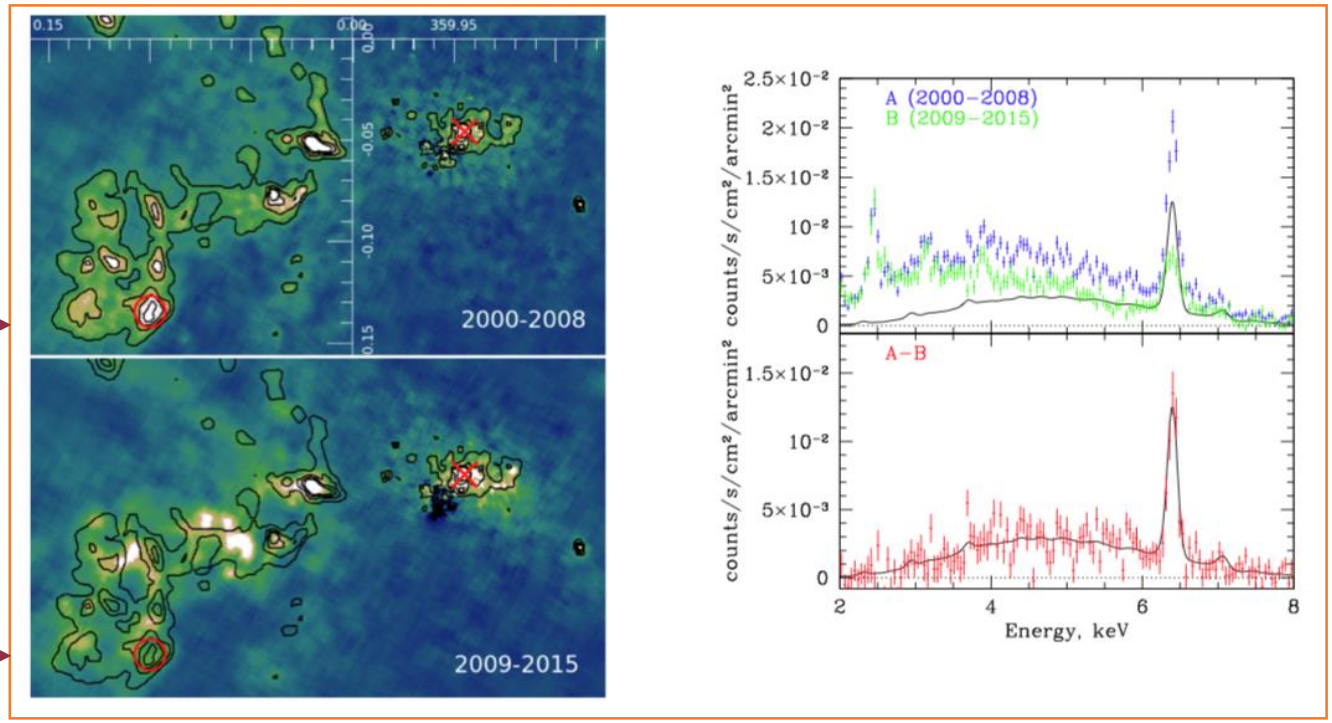
Sgr A* - X-ray echo

2000-2008

A

2009-2015

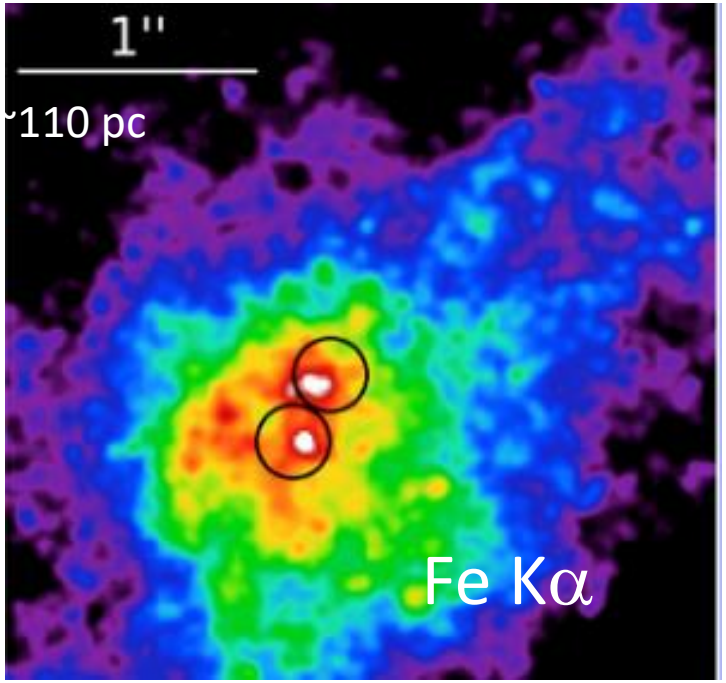
B

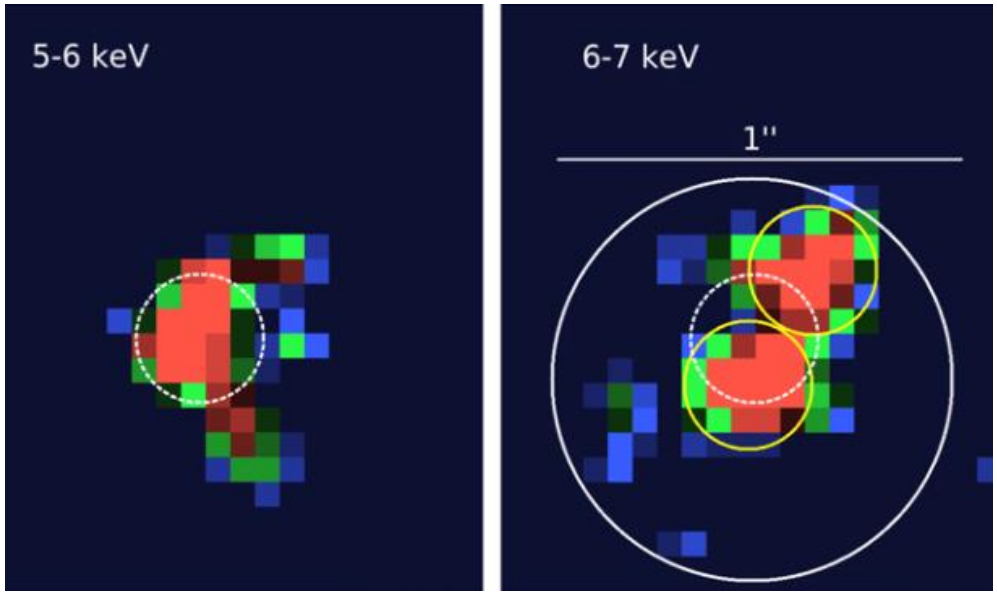


Churazov et al 2017

Variability in *Chandra* images and spectra of molecular clouds ~ 100 pc from Sgr A*

ESO 428-G014 - X-ray echo?

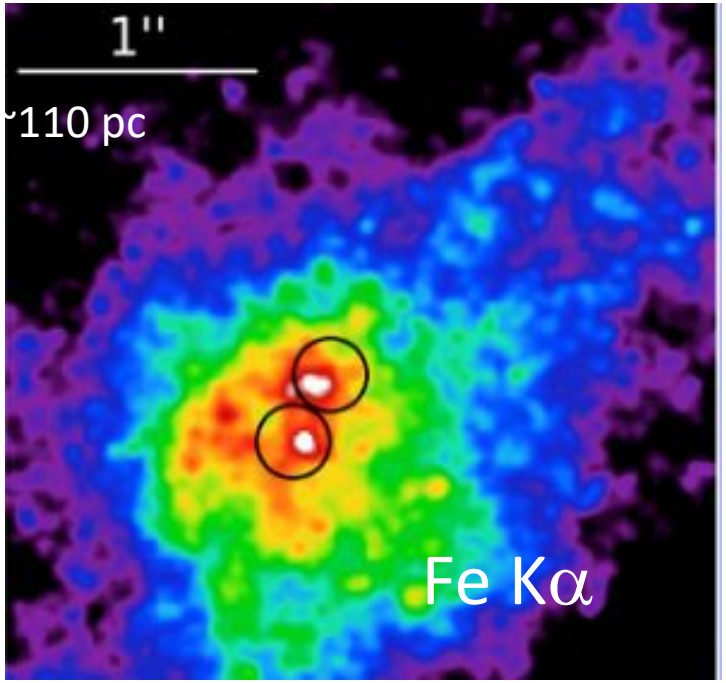




Fabbiano et al. 2019

Two nuclear knots detected in Fe Kα but not hard continuum

ESO 428-G014 - X-ray echo?



- ~30 pc projected separation
  light travel time > ~90 yr
- If analogous to MW light echo the two knots would be visible within the first ~200 yr
  Churazov et al. 2017c
- Evolution timescale depends on the distribution and densities of the clouds

Two nuclear knots detected in Fe Kα but not hard continuum

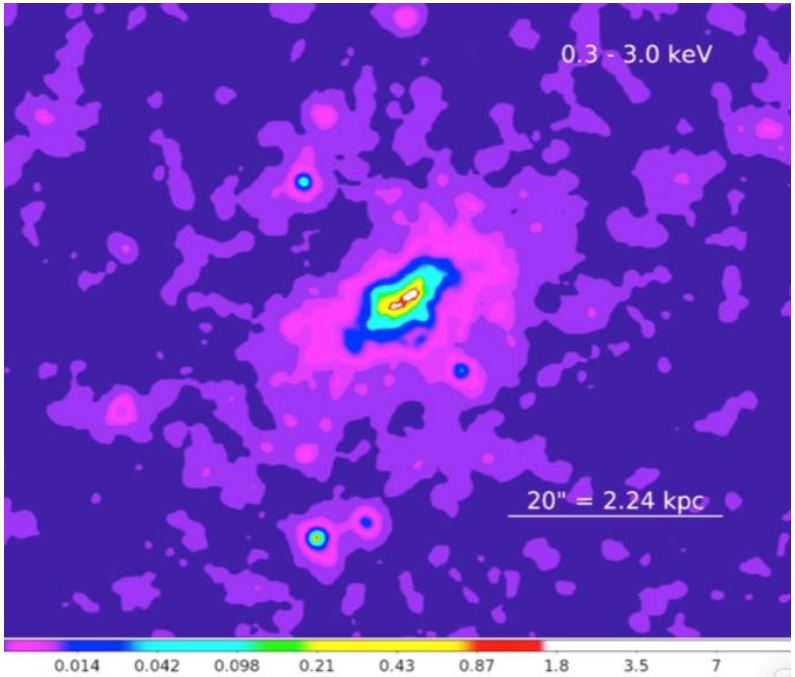
Long-duration AGN activity

The kpc-extended ionization cones of AGN suggest prolonged activity / Interaction of AGN photons with the ISM

Long-duration AGN activity

The kpc-extended ionization cones of AGN suggest prolonged activity / Interaction of AGN photons with the ISM

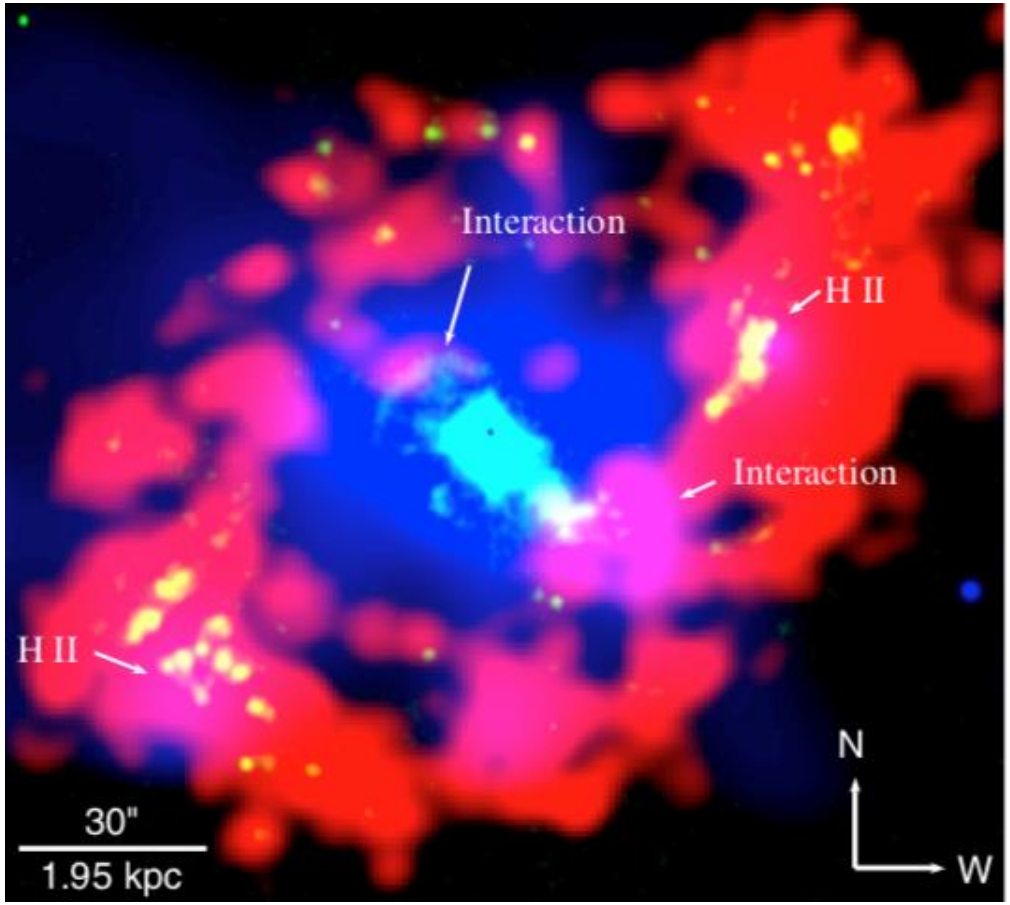
- Example: ESO 428-G014
  - extended-ray emission to scales of ~5 kpc
  - Based on the light travel time, the AGN must have been active for ~10^4 yr



Fabbiano et al. 2018

The hot bubble of NGC 4151

- NGC 4151
  Wang et al. 2010
  - ➢Fills HI ‘cavity’



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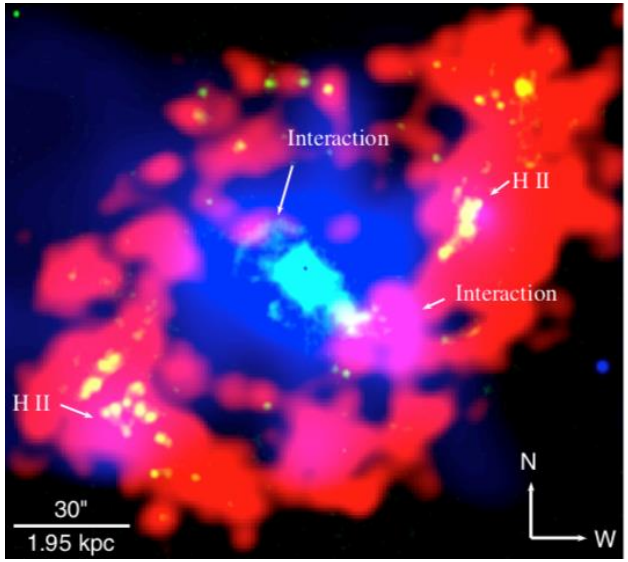
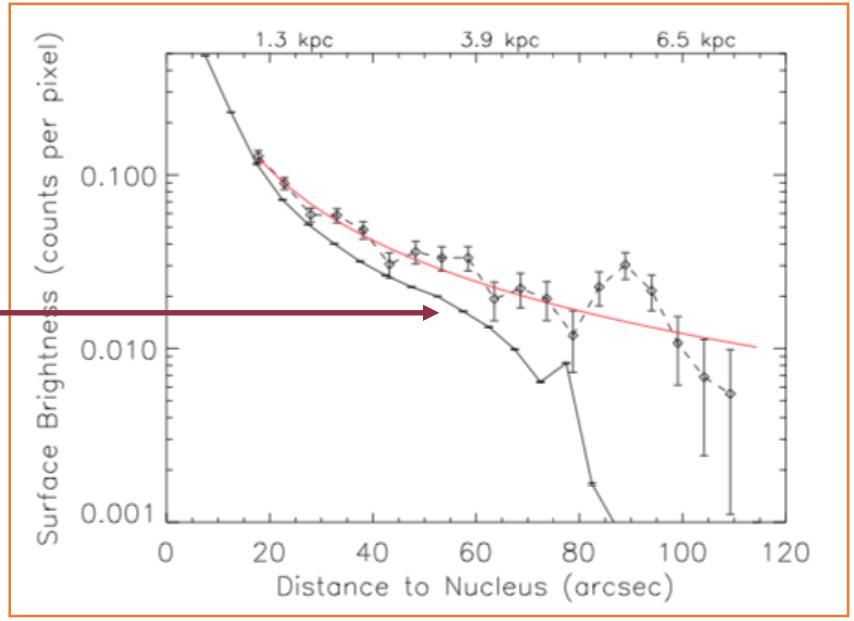


Stellar profile



The hot bubble of NGC 4151

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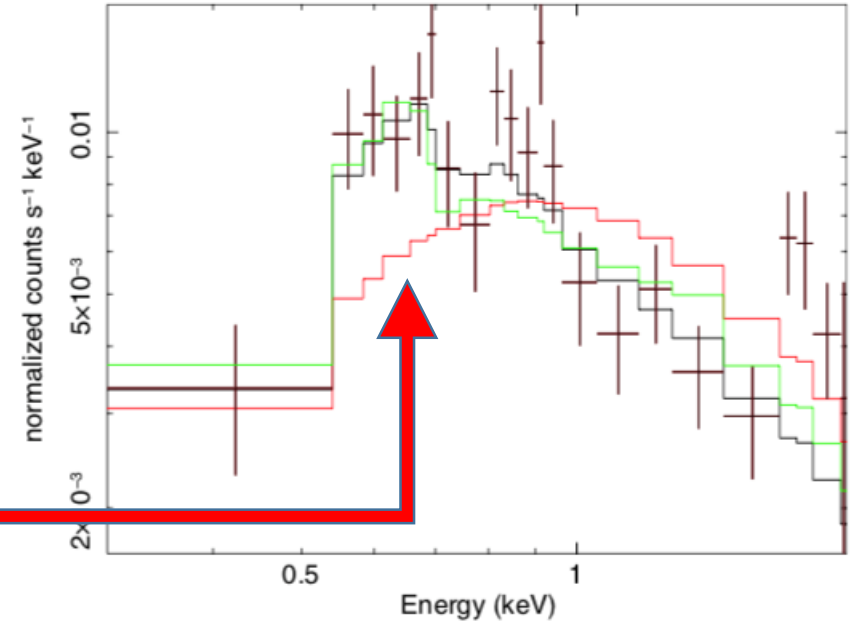
  - ➢Cannot be due to electro scattering of nuclear power-law



The hot bubble of NGC 4151

Photoionization

For:
$n = 2\ cm^{-3}$ (H I)
$R \sim 3$ kpc
$L_{ion} \sim 6\times10^{45}\ erg\ s^{-1} \sim L_{Edd}$

Light-travel time to H I
$t_c \sim 10^4$ yr
$t_{rec} \sim 1.5 \times 10^4$ yr

An Eddington outburst
$t_{Edd} < 1.5 \times 10^4$ yr ago

Thermal

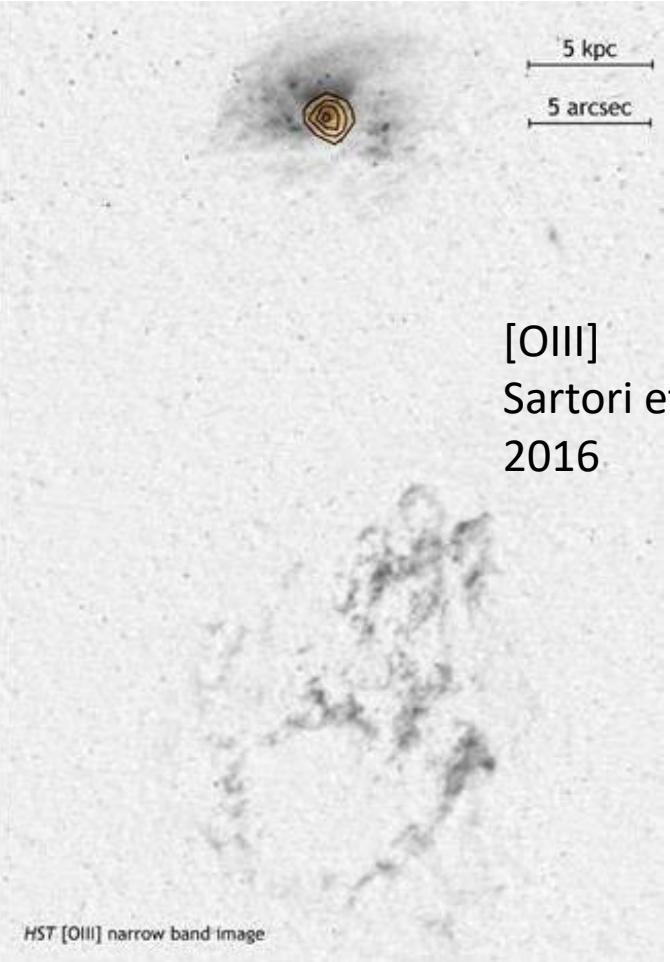
$kT = 0.25 \pm 0.07$ keV
$E_{th} \sim 3 \times 10^{54}$ erg
$L_{bol} = 7.3 \times 10^{43}$
$L_{bol}/L_{Edd} \sim 0.01$
$t_{heath} \sim 4 \times 10^4$ yr $< t_{cool} \sim 10^8$ yr

If there is excape + adiabatic cooling
$t \sim 10^5$ yr

Continuous heating for
$4 \times 10^4 - 10^5$ yrs

The Case of Hanny's Voorwerp

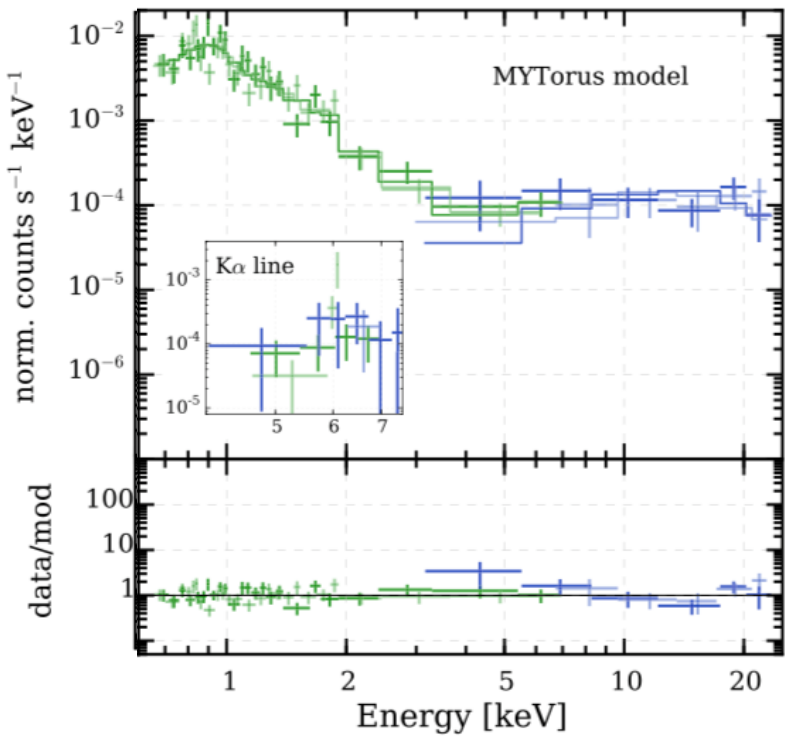
- Detection of emission line region 20 kpc S of 'quiet" spiral IC 2497
  - ➢Quasar outburst ~10^5 yr ago
    Lintott et al. 2009

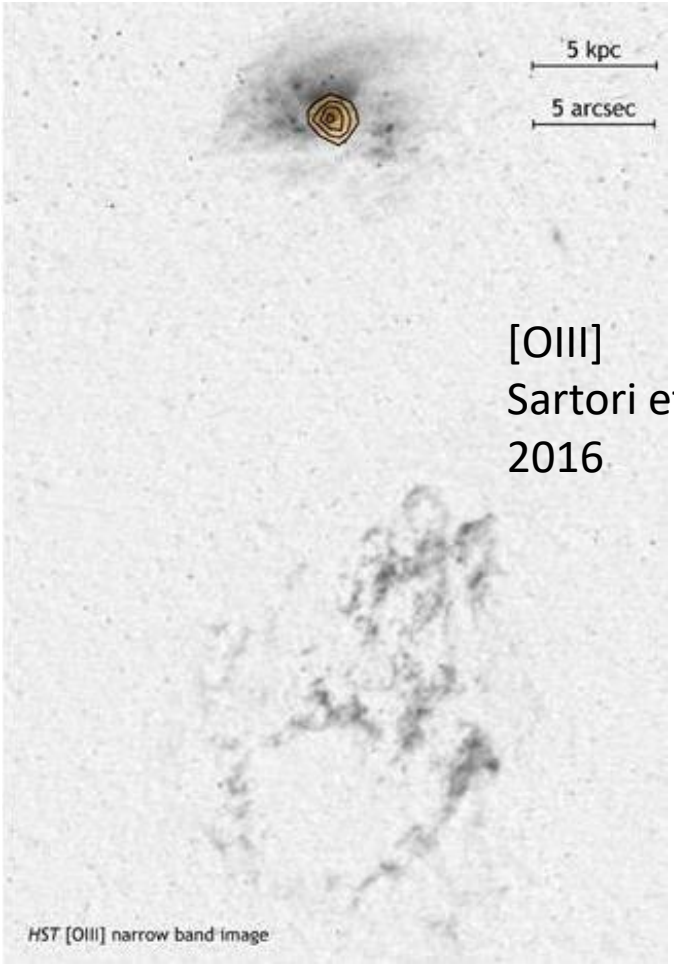


[OIII]
Sartori et al. 2016

The Case of Hanny's Voorwerp

- It turns out IC 2497 is not quiescent, it is a CT AGN Sartori et al. 2018





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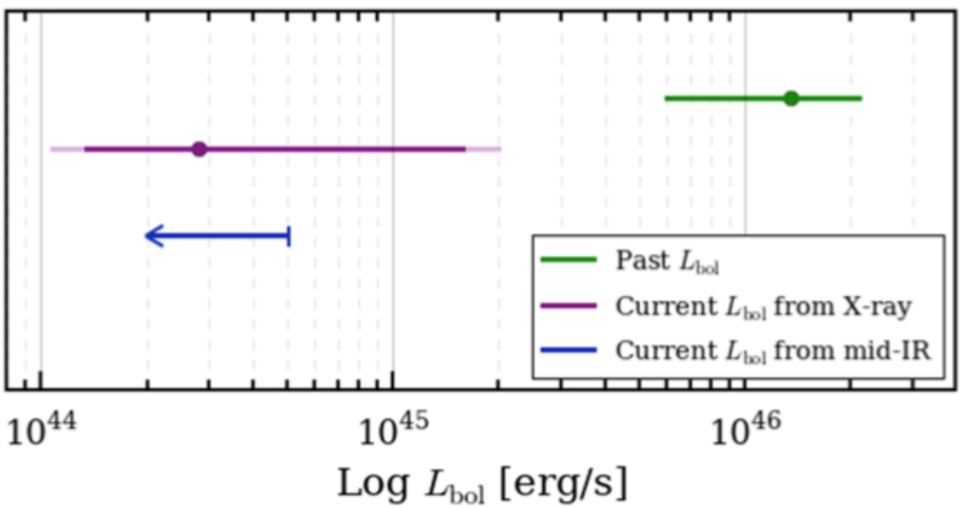
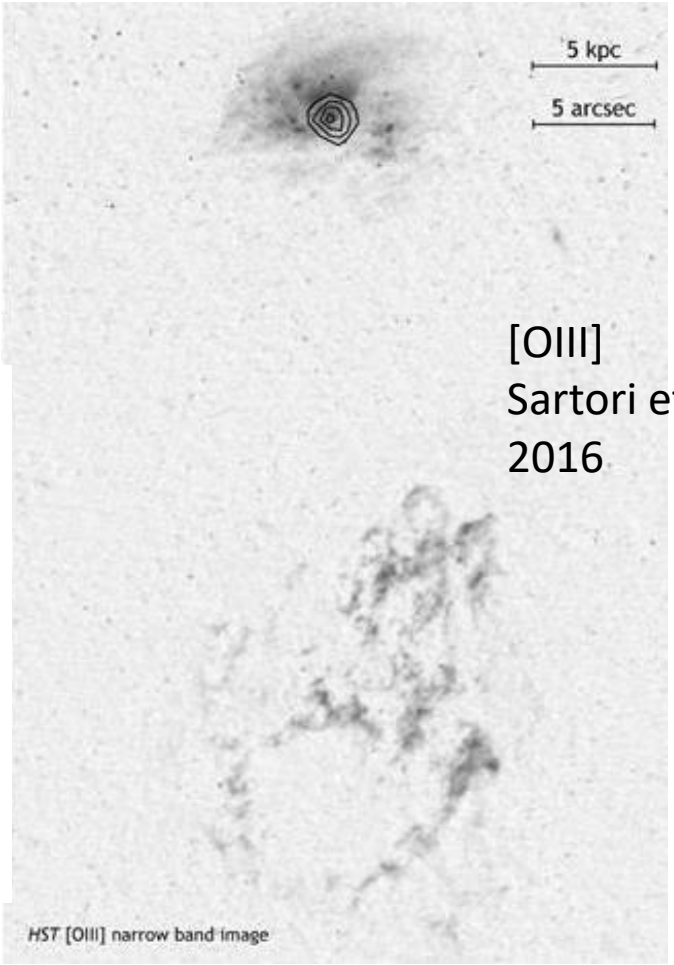
- But still not luminous as it was 10^5 yrs ago
  Sartori et al. 2018

IC 2497 AGN





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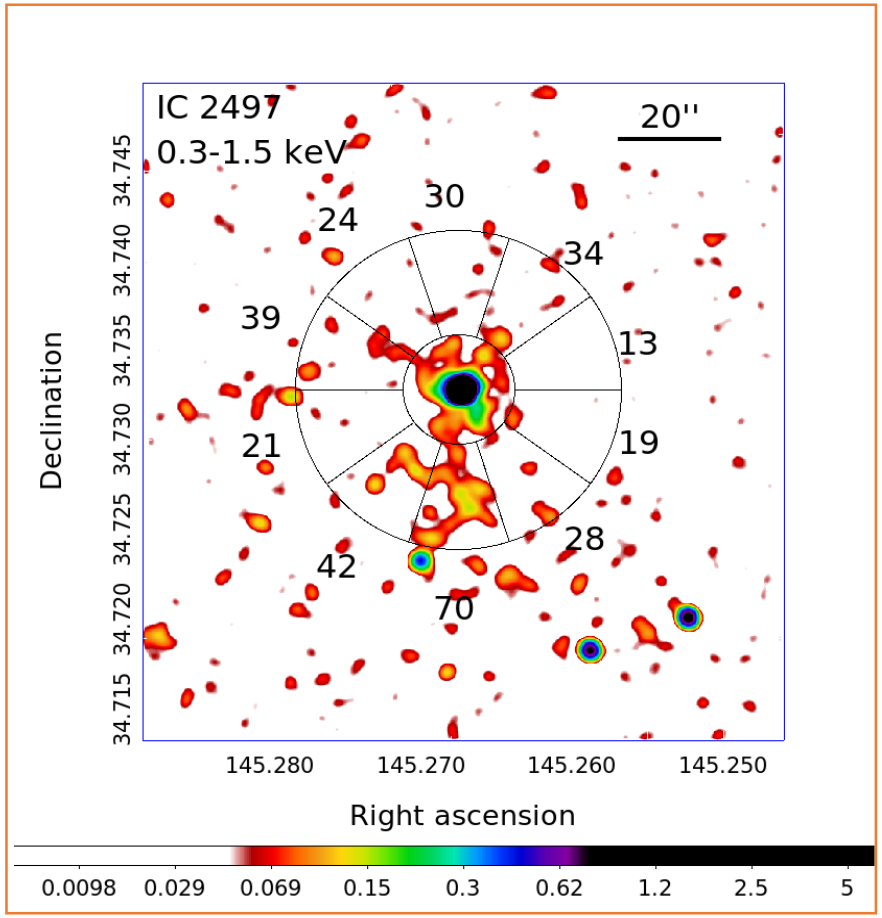
- Chandra's view of the 'ionization cone of IC 2497
- 5σ feature
- $L_X \sim 1.2 \times 10^{40}$ erg s^{-1} (0.3-3.0 keV)



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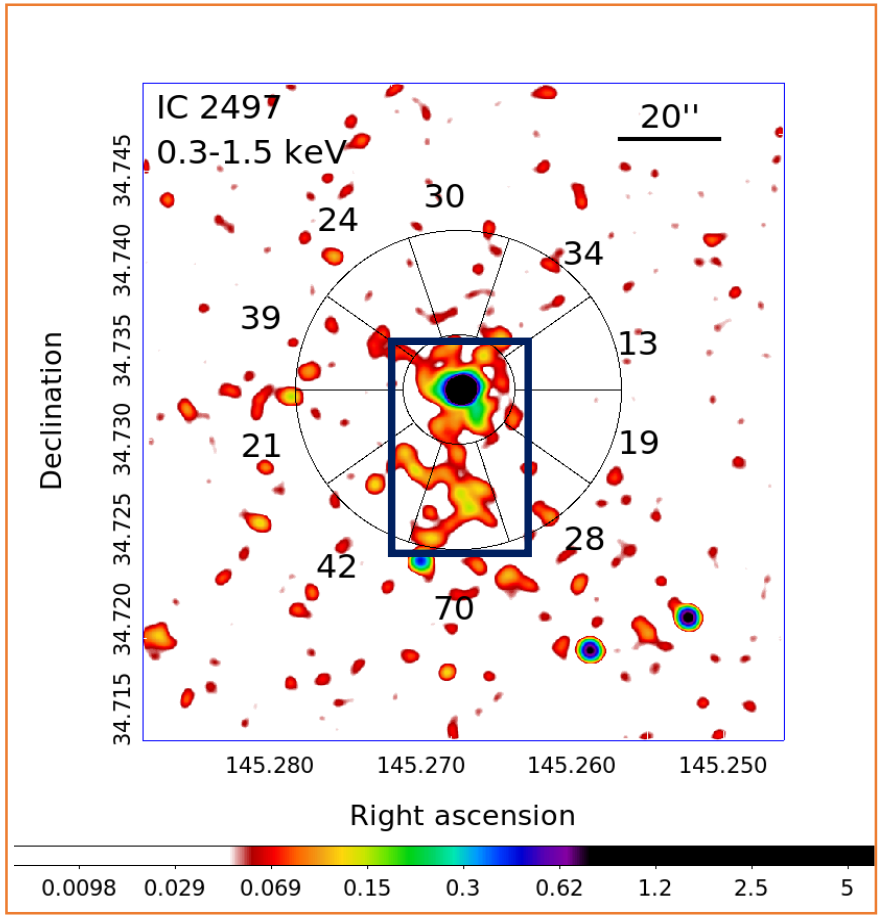

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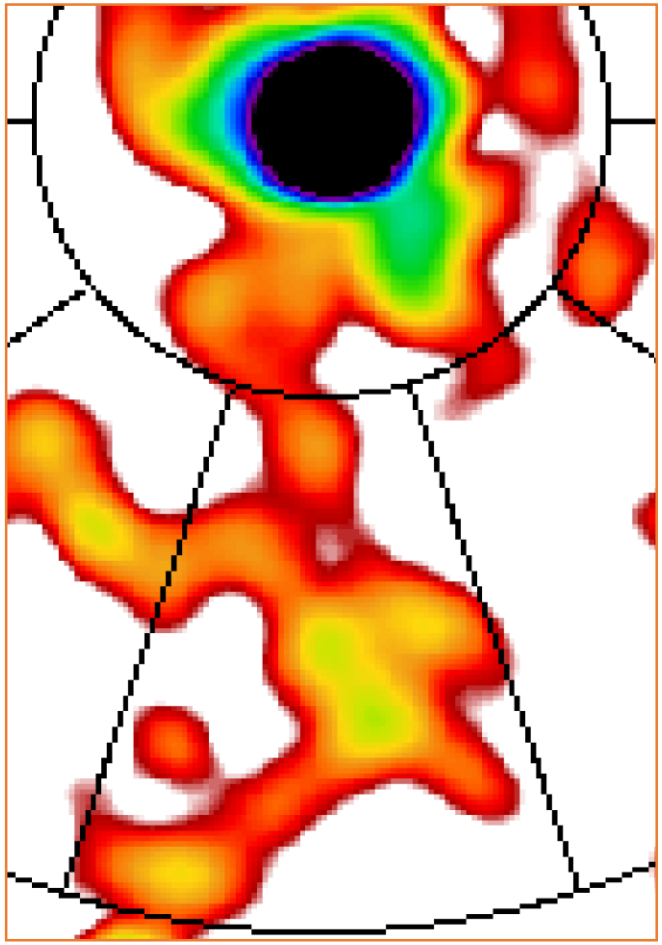

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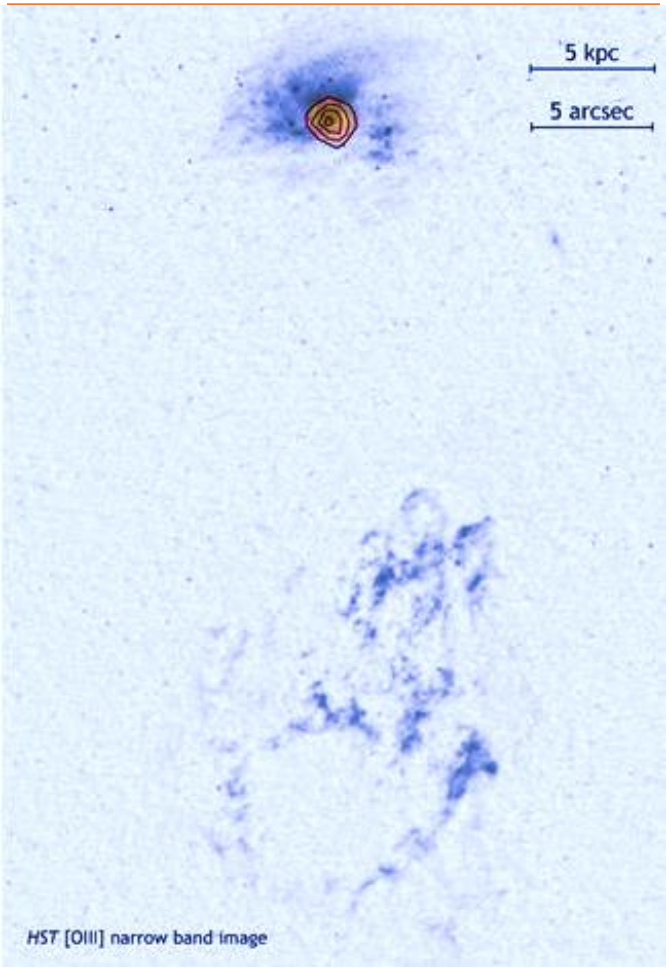

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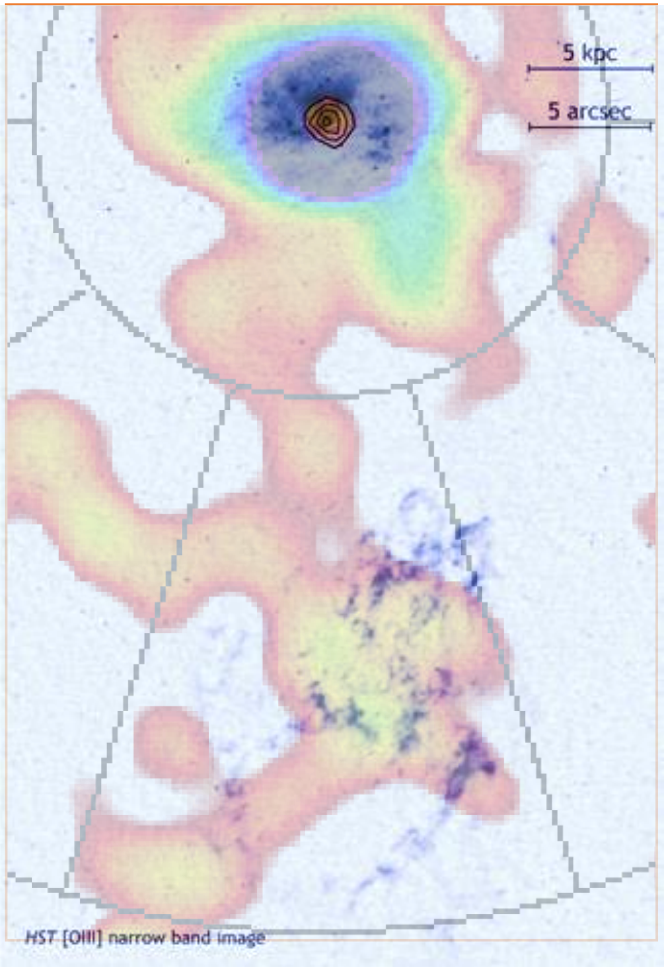

The Timing of Hanny's Voorwerp

- Light travel time ~ 10^5 yr
- Recombination time
  - [OIII] ~ a few 10^3 yr
    Lintott et al. 2009; Keel et al. 2012
  - X-rays ~ 2 x 10^7 yr
    Fabbiano & Elvis 2019

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➔ Extended X-ray emission better diagnostic of total activity

➔ [OIII] emission diagnostic of time-limited burst of activity

Conclusions

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➔ Long timescales of quasi-continuous activity ~ $10^{4\text{-}5}$ yr

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- From the Hanny's Voorwerp case

➔ Extended X-ray emission better diagnostic of total activity

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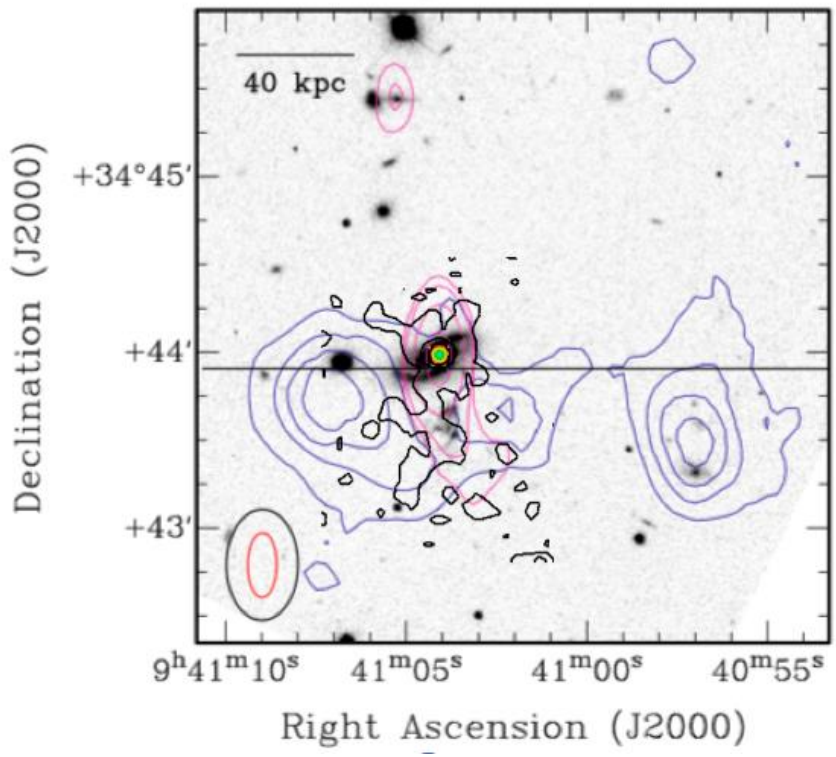
The Case of Hanny's Voorwerp

- …general correspondence with radio continuum
- Similar to other CT AGNs
  e.g. ESO 428-G014
  Fabbiano et al 2017-2018

Blue – HI
Pink – 1.4 GHz
Jozsa et al. 2009



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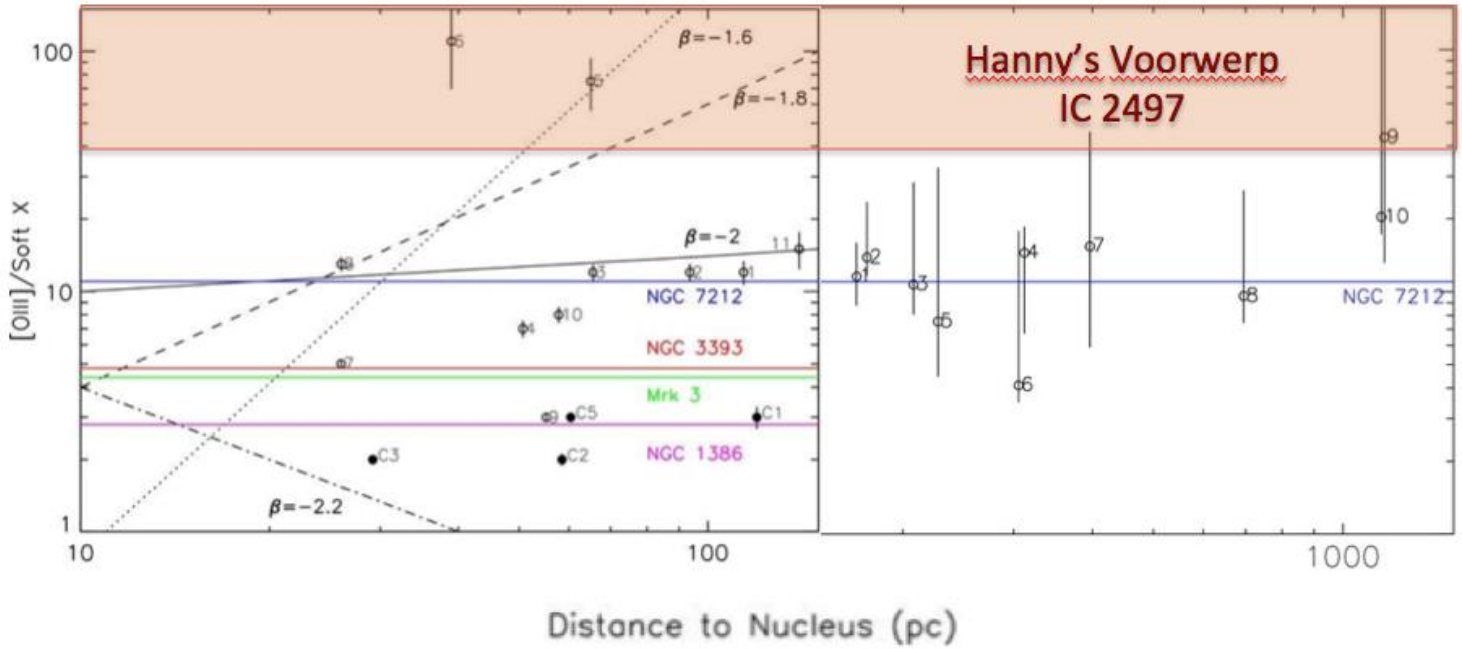

- Fairly high [OIII] / soft X-ray ratio (low ionization parameter U - Bianchi et al 2006)