Understanding the obscuring material around AGN with ALMA

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Simplest version of the AGN Unified Model

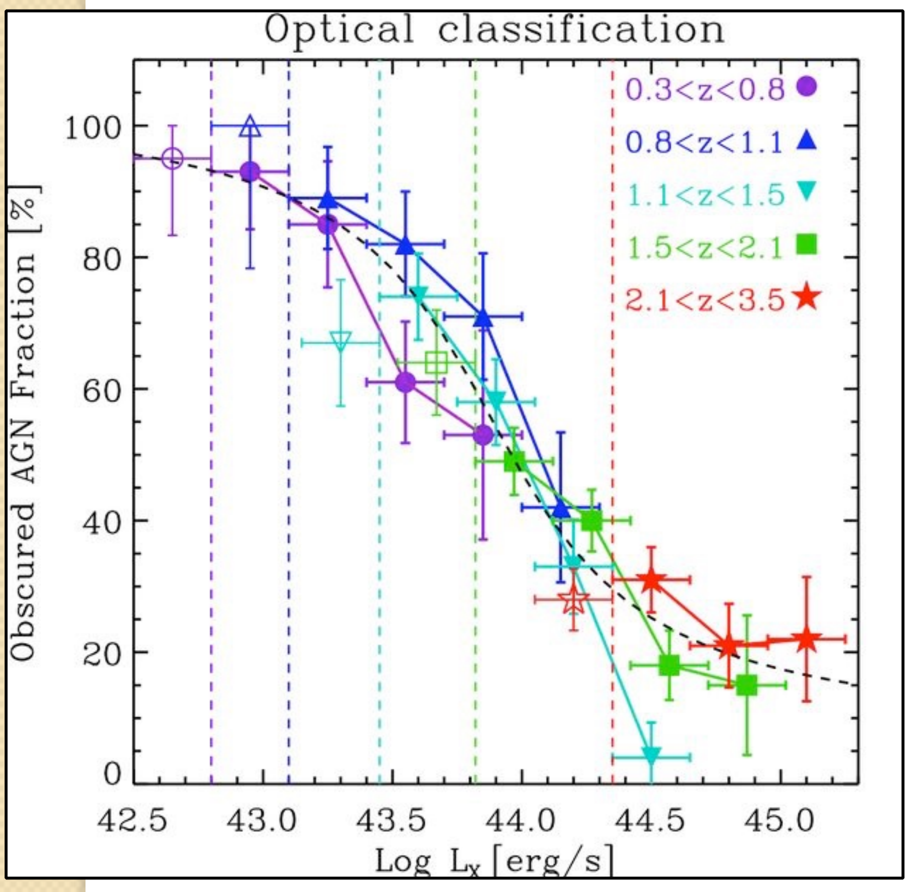
Credit: NASA WISE

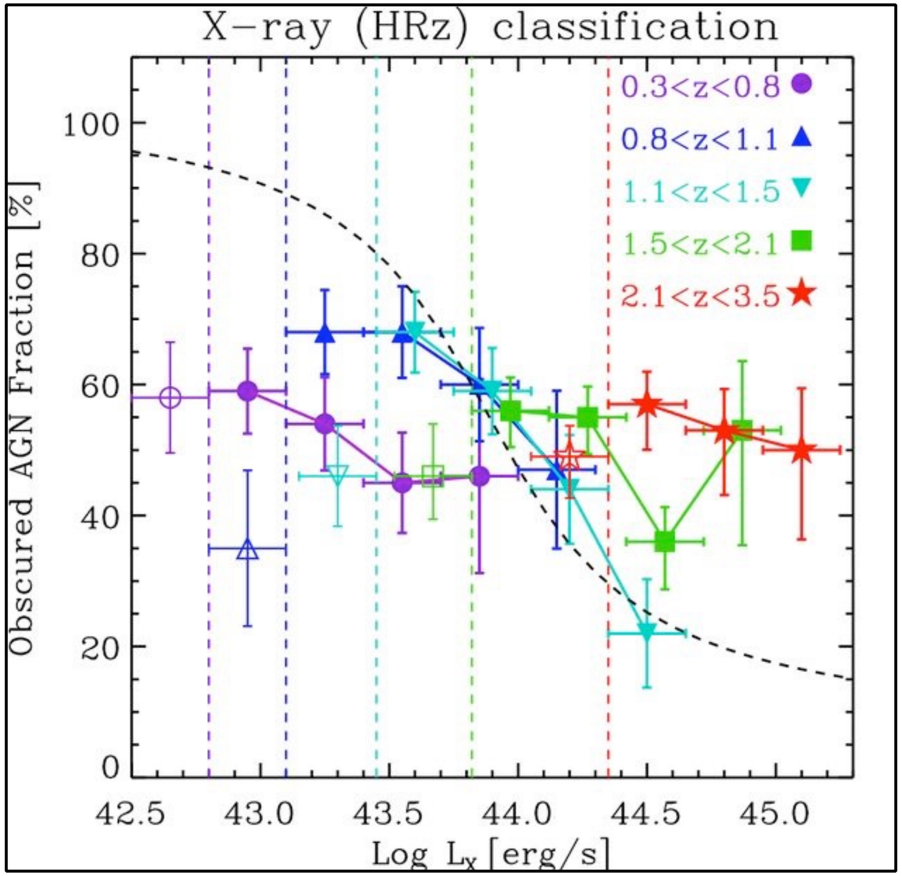
obscuring tori should show similar properties in all AGN independent of AGN luminosity, redshift, Eddington ratio, etc

Obscured AGN fraction vs. luminosity

Obscured fraction is usually derived from X-ray column densities (N_H,) and optical class (type 1 broad vs. type 2 narrow lines)

Dependence with AGN luminosity for X-ray selected samples?

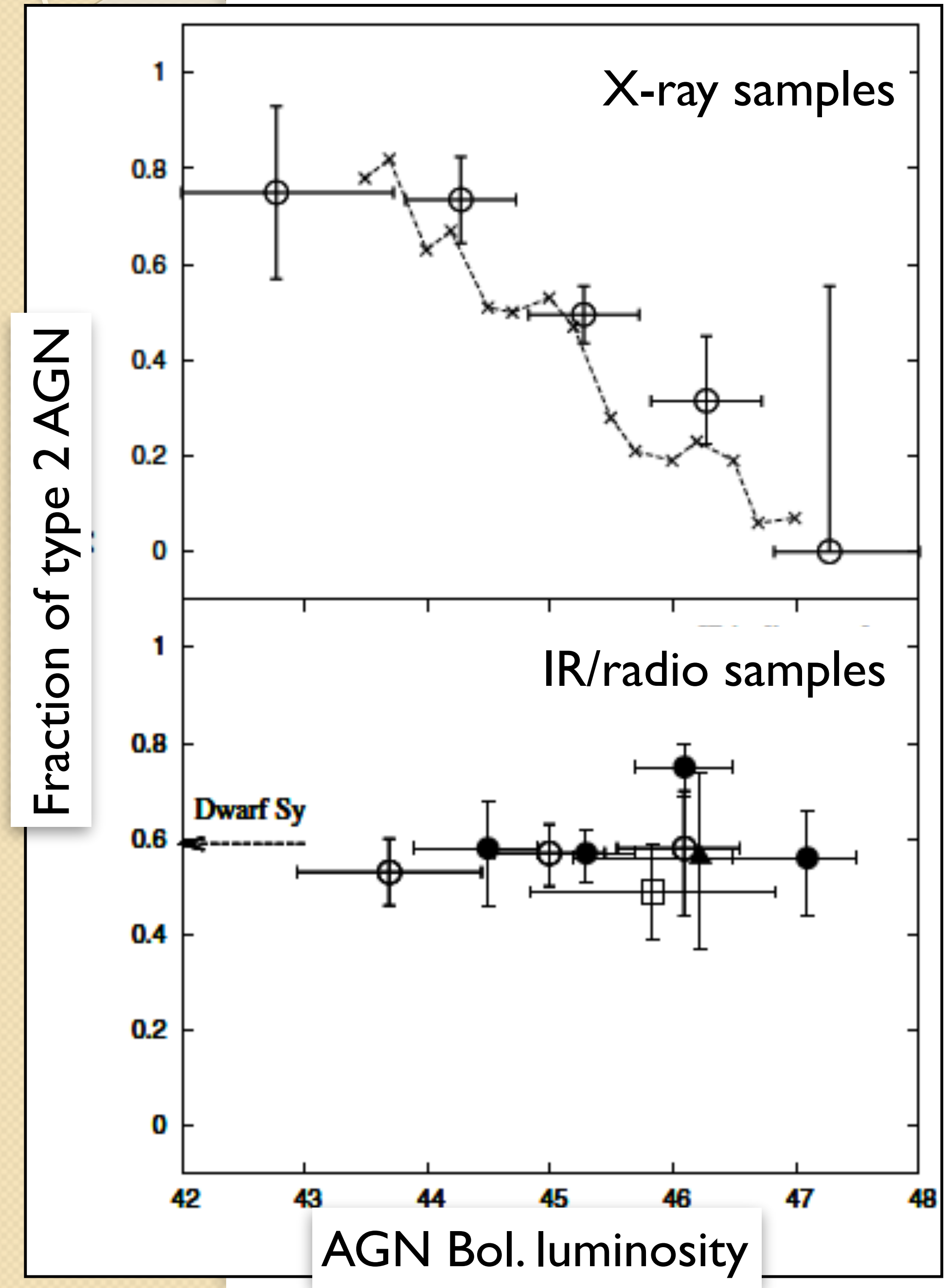




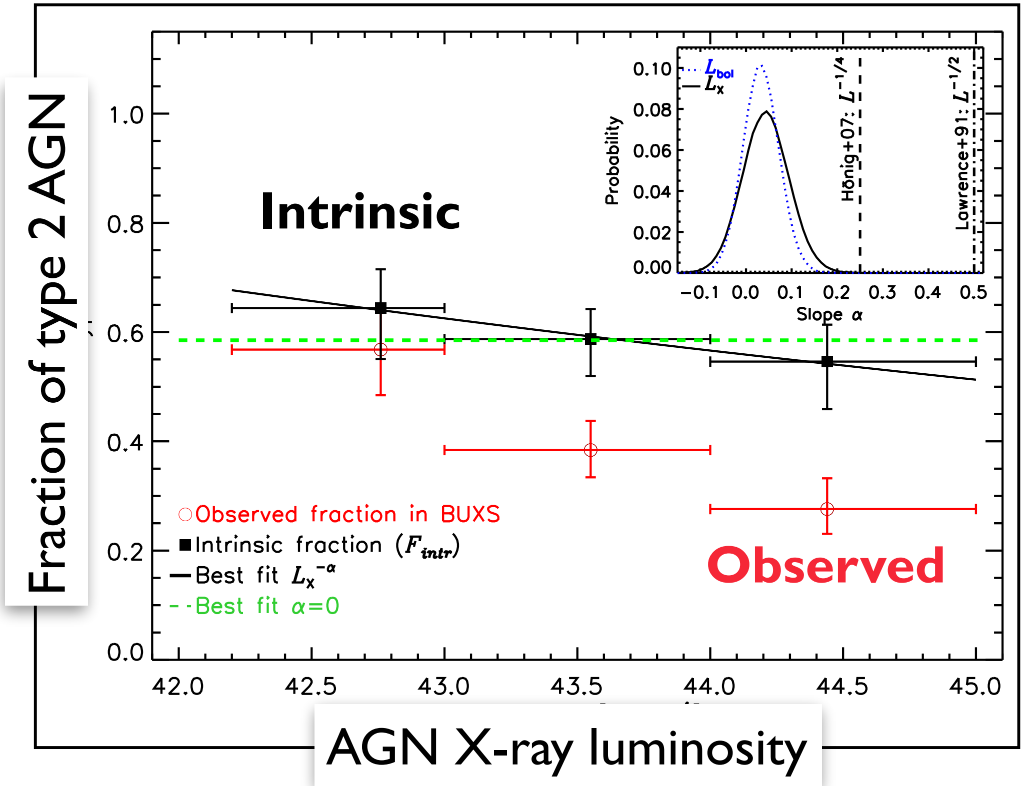
Merloni+2014, see also Lawrence & Elvis 1982, Hasinger+2005, Simpson 2005, Della Ceca+2008, Burlon+2011, Ueda+2014, Buchner+2015

Missing AGN in X-ray (<10keV) surveys

Lawrence & Elvis 2010



Mateos+2017

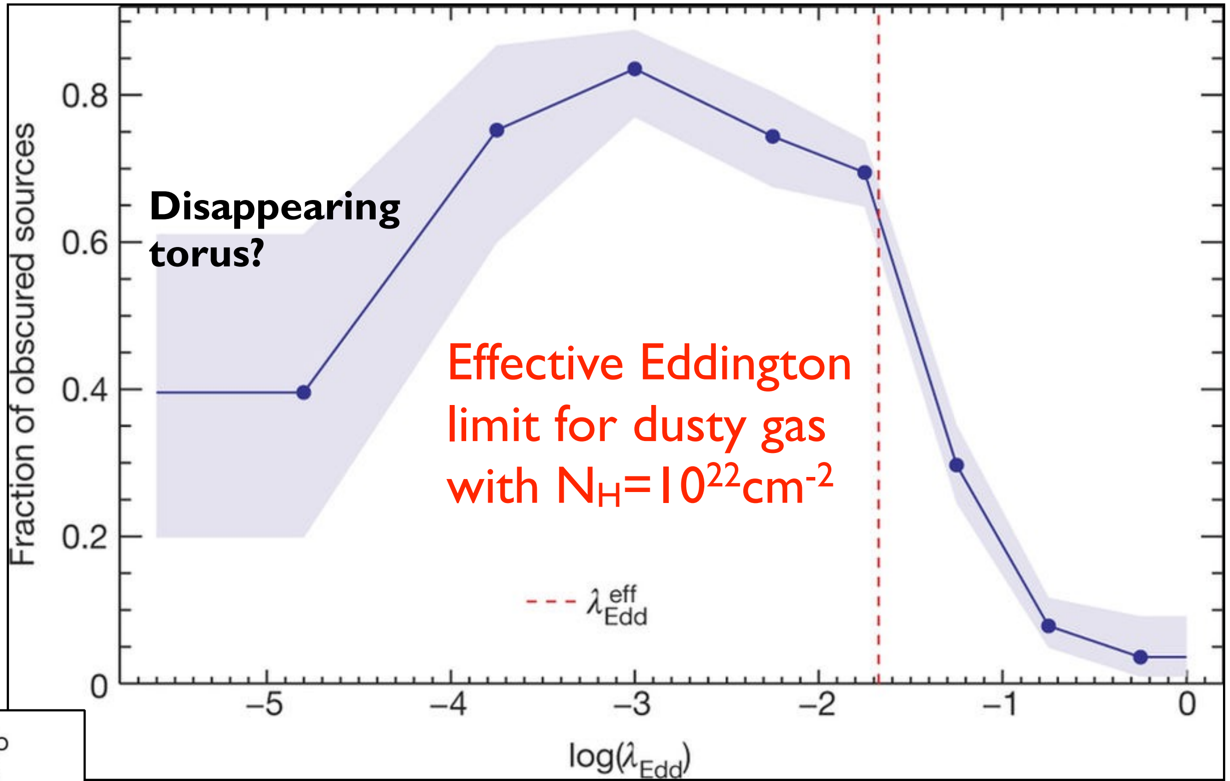


- A non-negligible fraction of luminous, heavily obscured (high covering factors) type-2 AGN are missing in X-rays
- No dependence when combining different AGN selection methods?

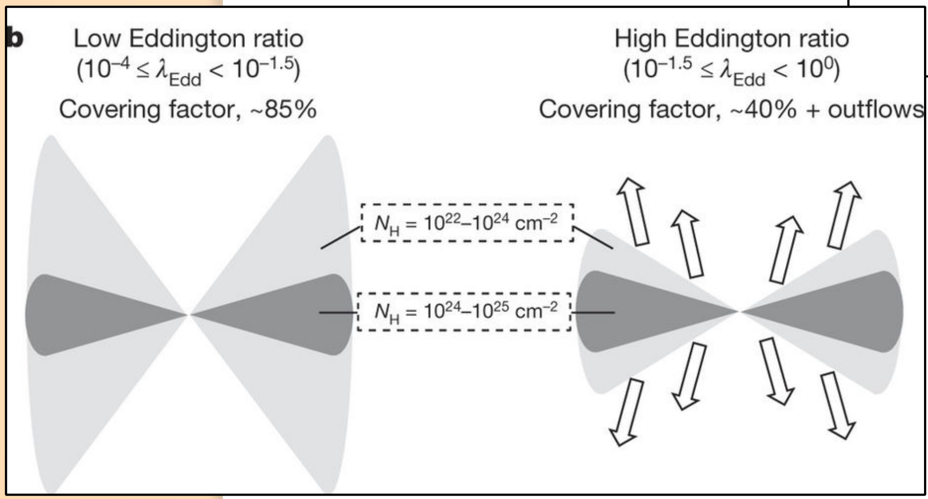
Obscured AGN fraction vs. Edd. ratio

- Sample ~400 local AGN from Swift/BAT: the covering factor of the nuclear material drops quickly at Eddington ratios of $\lambda_{Edd} \simeq 0.02-0.05$

Fraction of obscured Compton-thin [$10^{22} \leq (N_H/cm^{-2}) < 10^{24}$] sources

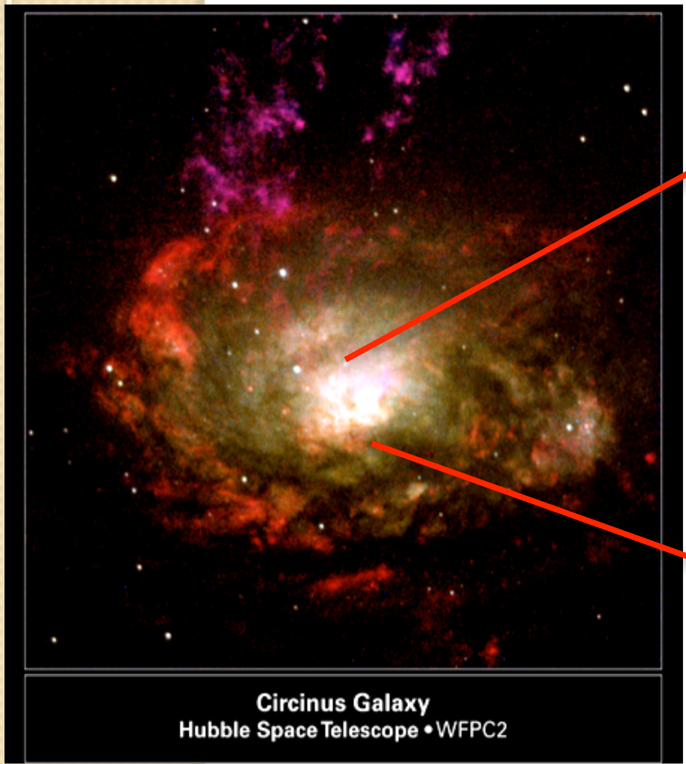


Ricci+2017



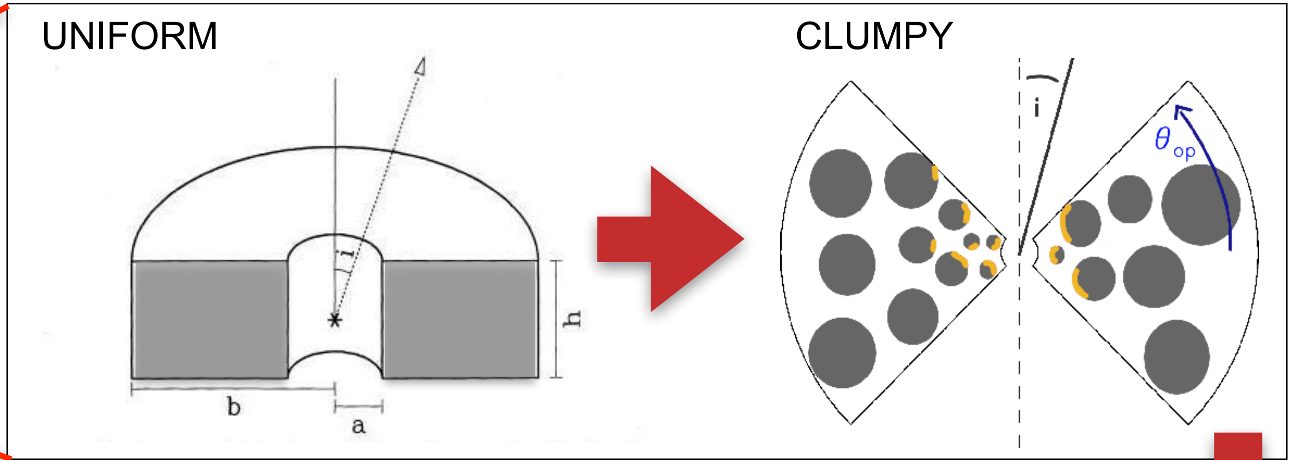
- Initially inactive BH is triggered by an accretion event, and moves to higher N_H and Edd ratio, before reaching the effective Edd ratio and expelling most of the obscuring material

Torus models to understand the obscuring material of AGN



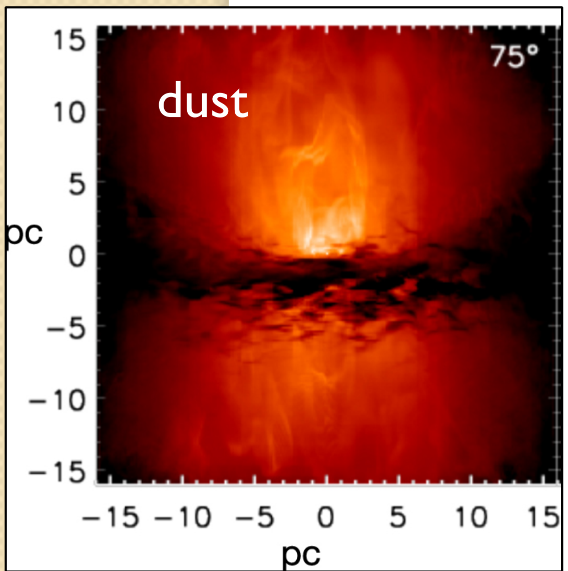
Pier & Krolik 1992

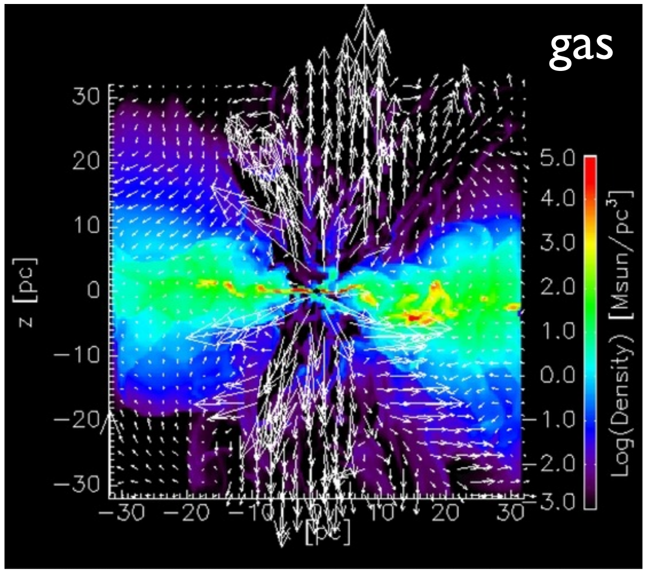
Schartmann+2008

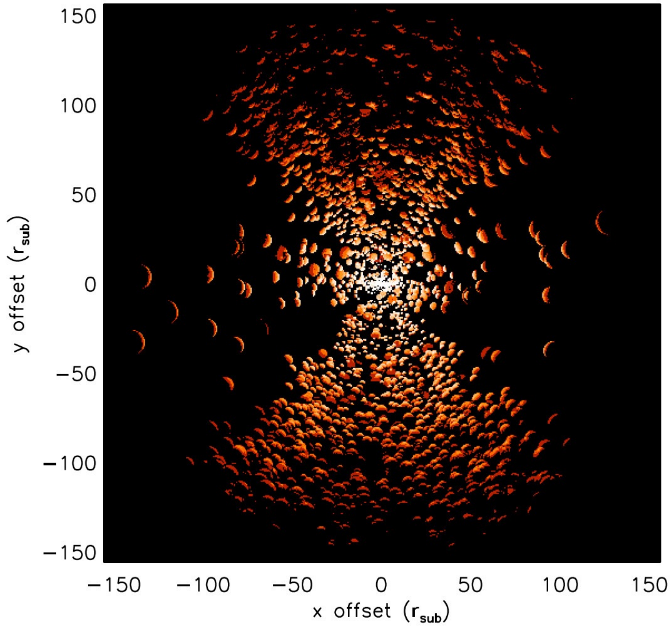


Wada 2012, 2016

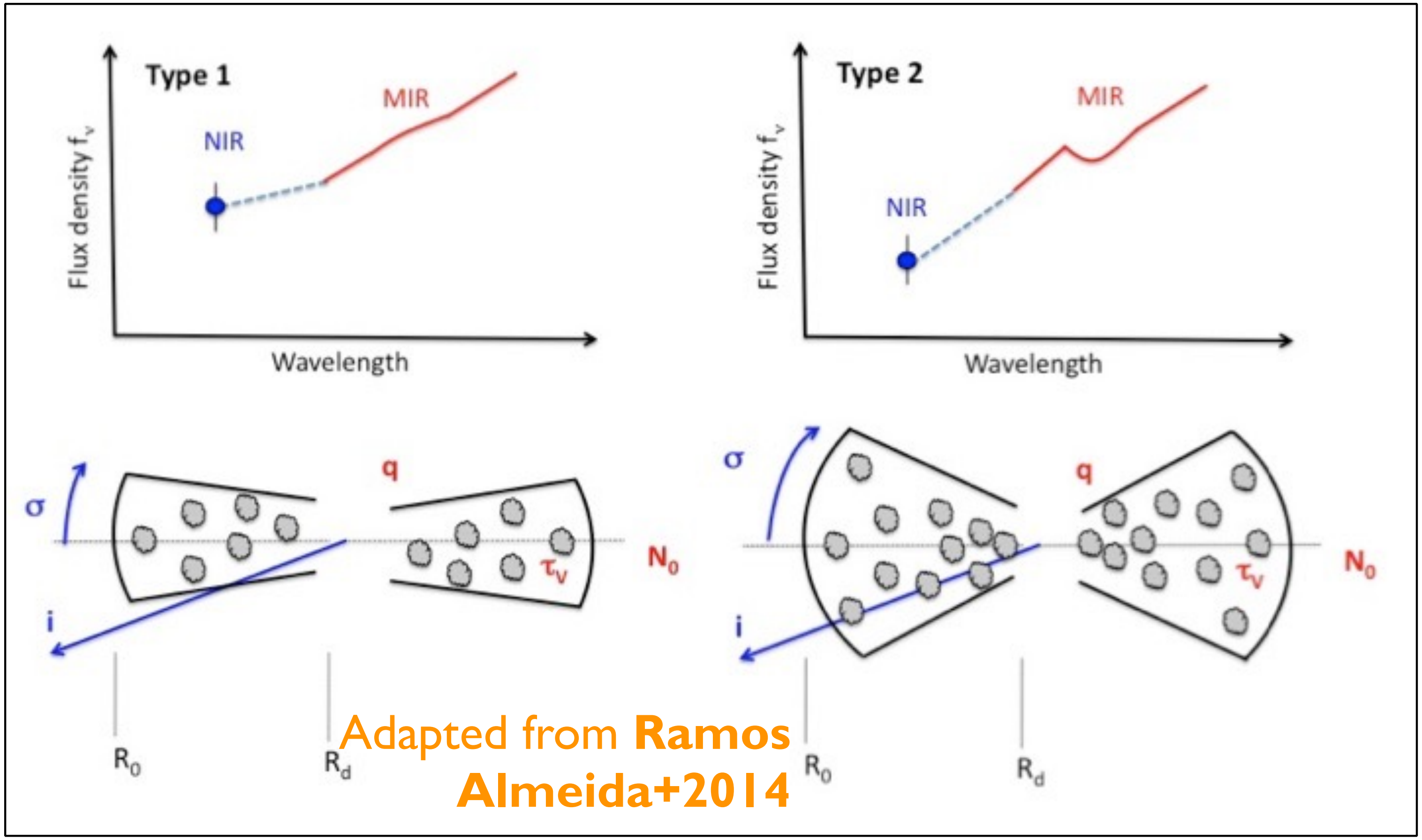
Hönig & Kishimoto 2017







Modelling the AGN IR unresolved emission



Adapted from **Ramos Almeida+2014**

$$N_{LOS}(i) = N_0 e^{-(90-i)^2/\sigma^2_{torus}}$$

$$P_{esc} \simeq e^{(-N_{LOS})}$$

β=90-i

$$f_2 = 1 - \int_0^{\pi/2} P_{esc}(\beta) cos(\beta) d\beta.$$

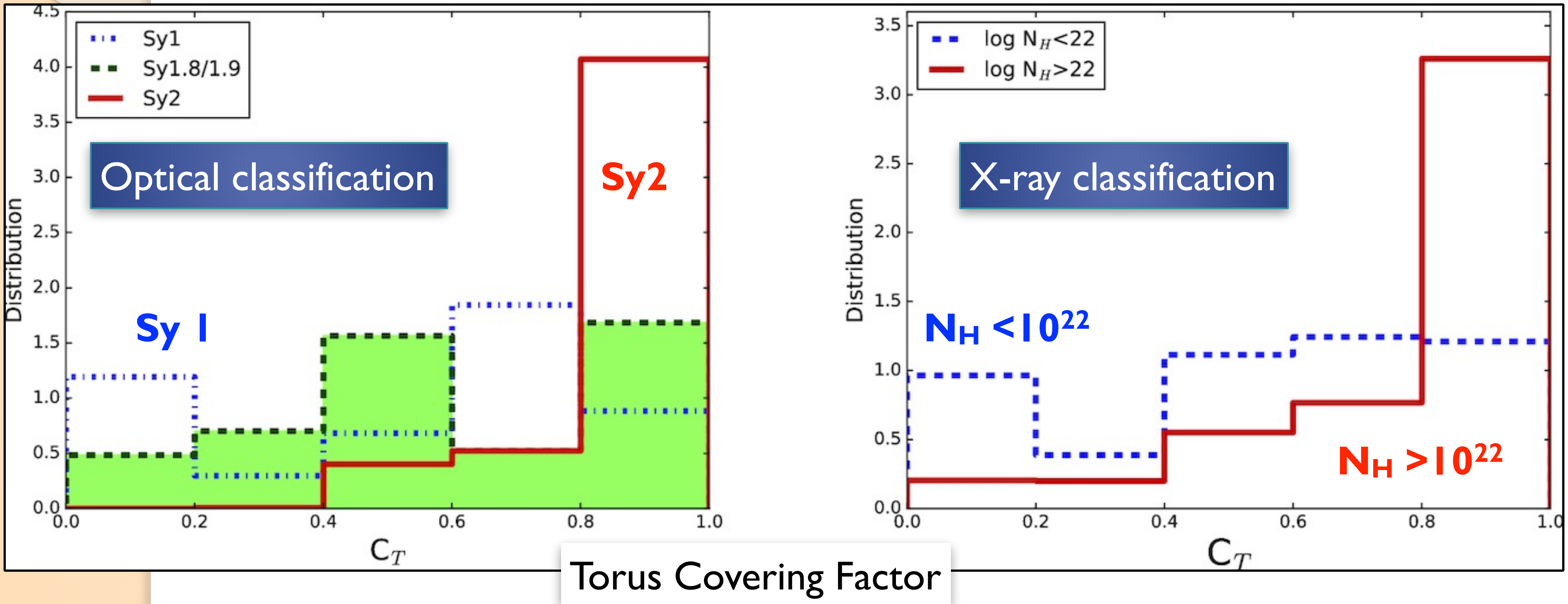
Geometrical covering factor (CF) f_2 is only a function of torus angular width and number of clouds along equatorial direction

the fraction of obscured AGN

Elitzur 2012, Nenkova+2008

Torus geometrical covering factor vs AGN type

✤Volume-limited sample of 26 nearby (D<40Mpc) Swift-BAT selected AGN



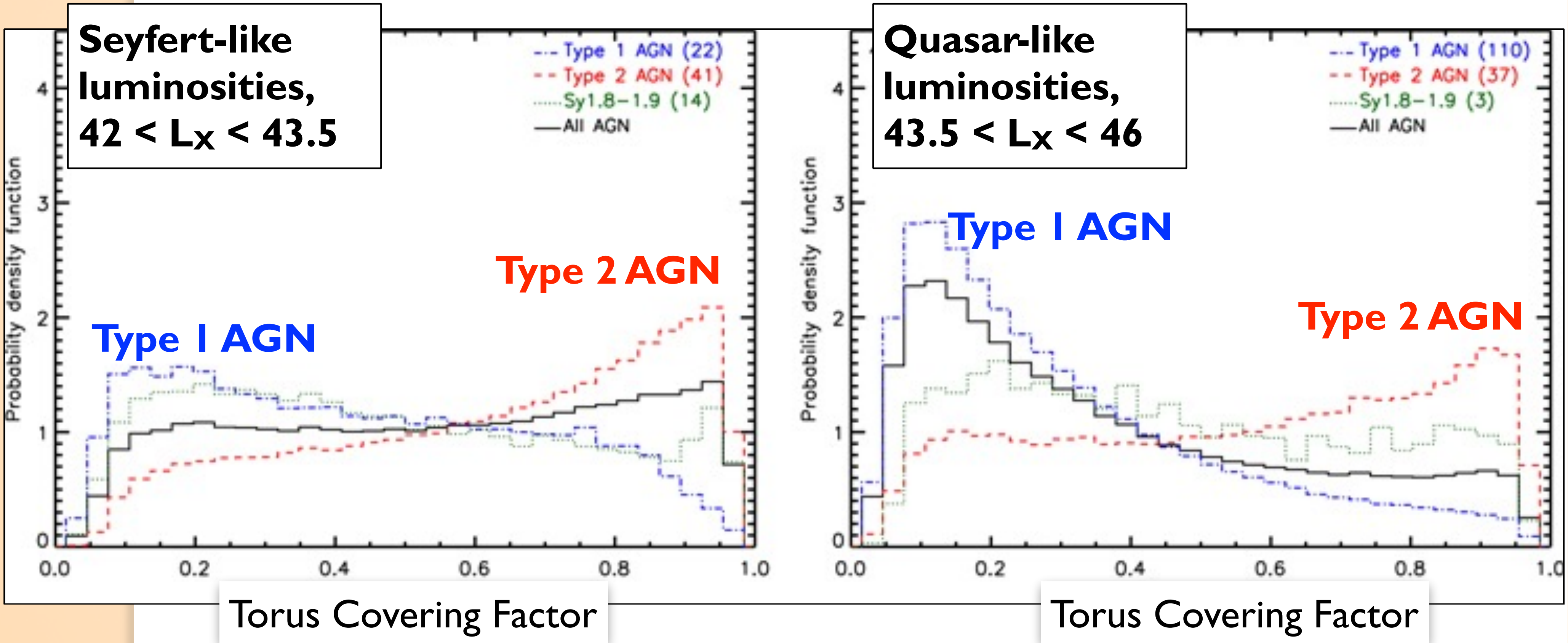
García-Bernete+2019

see also Ramos Almeida+2011, Alonso-Herrero+2011, Mor+2012, Lira+2013, Ichikawa+2015, Martínez-Paredes+2017

Torus Dust Covering Factors vs Luminosity

- Complete sample of X-ray selected AGN: 132 type 1 AGN and 78 type 2 AGN at redshifts z~0-1.7

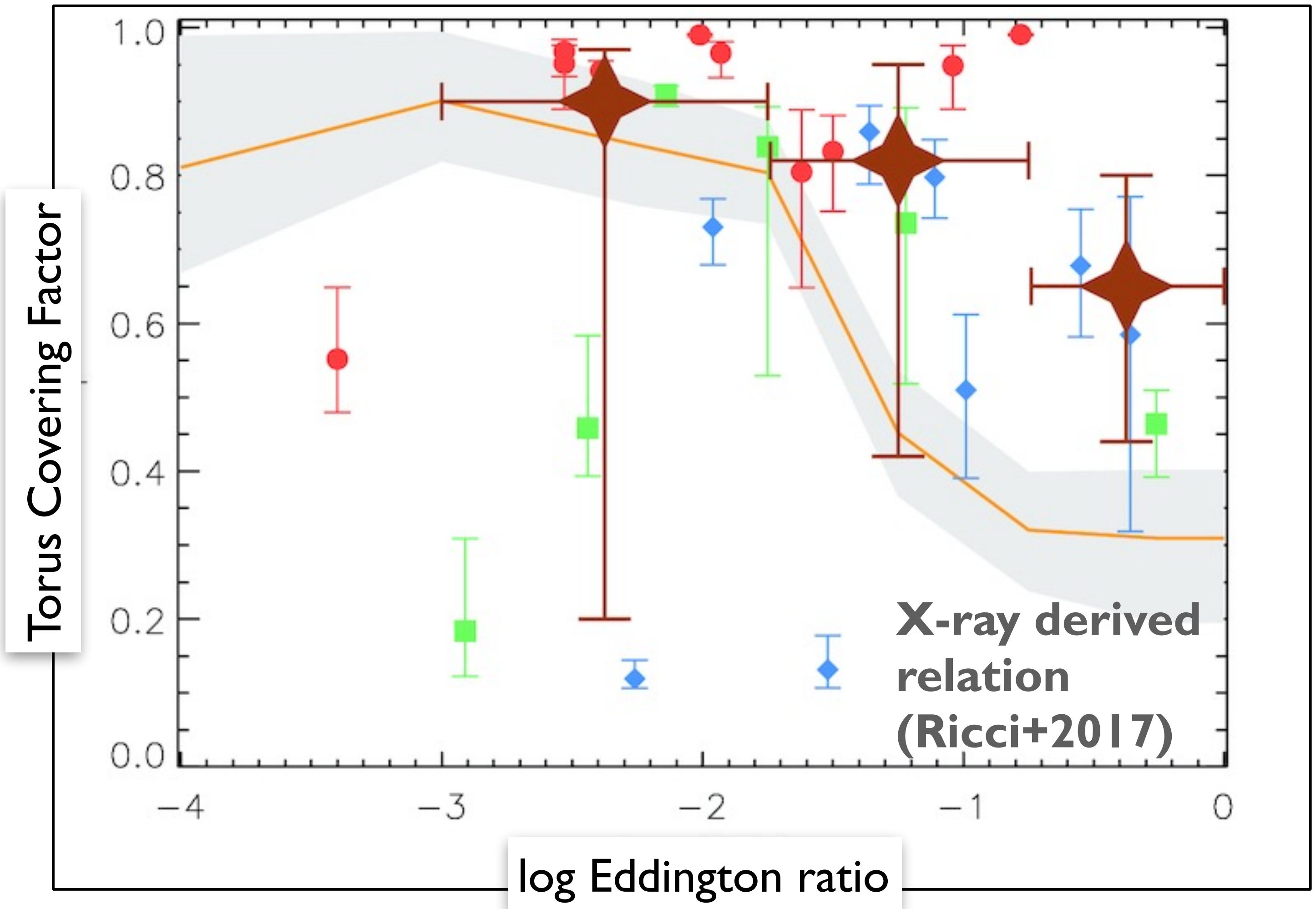
- Small CF values are preferred at high AGN luminosities but X-ray samples are not complete!



Mateos+2016, see also Mor+2009, 2012, Roseboom+2015

Torus geometrical covering factor vs Eddington ratio

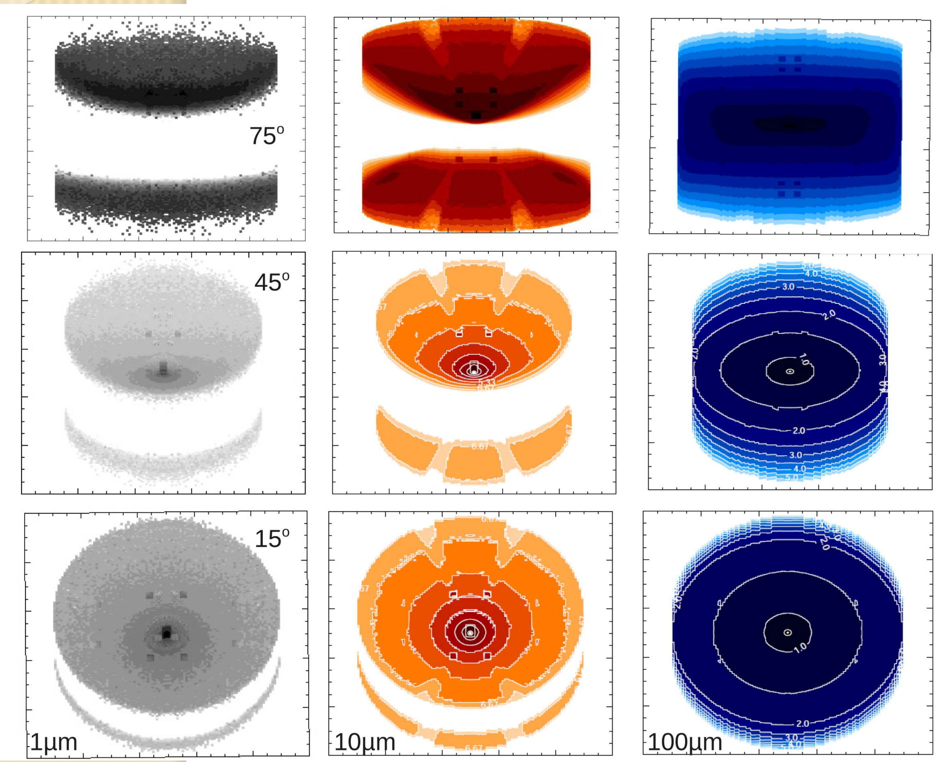
✤Volume-limited sample of 24 nearby (d<40Mpc) Swift-BAT selected AGN



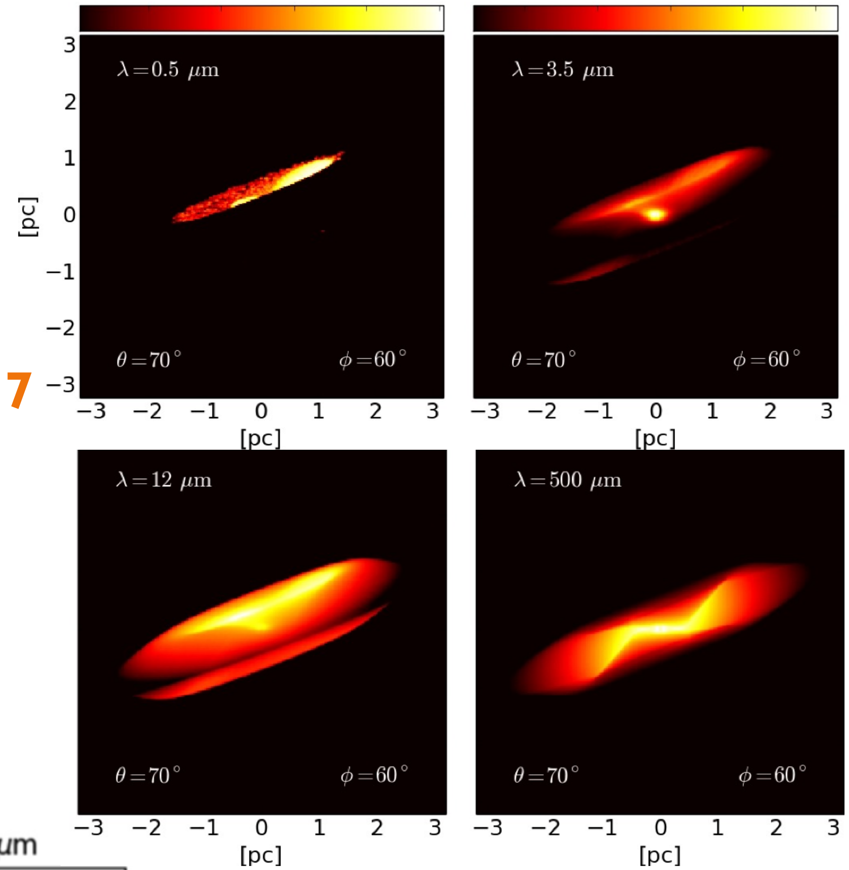
García-Bernete+2019

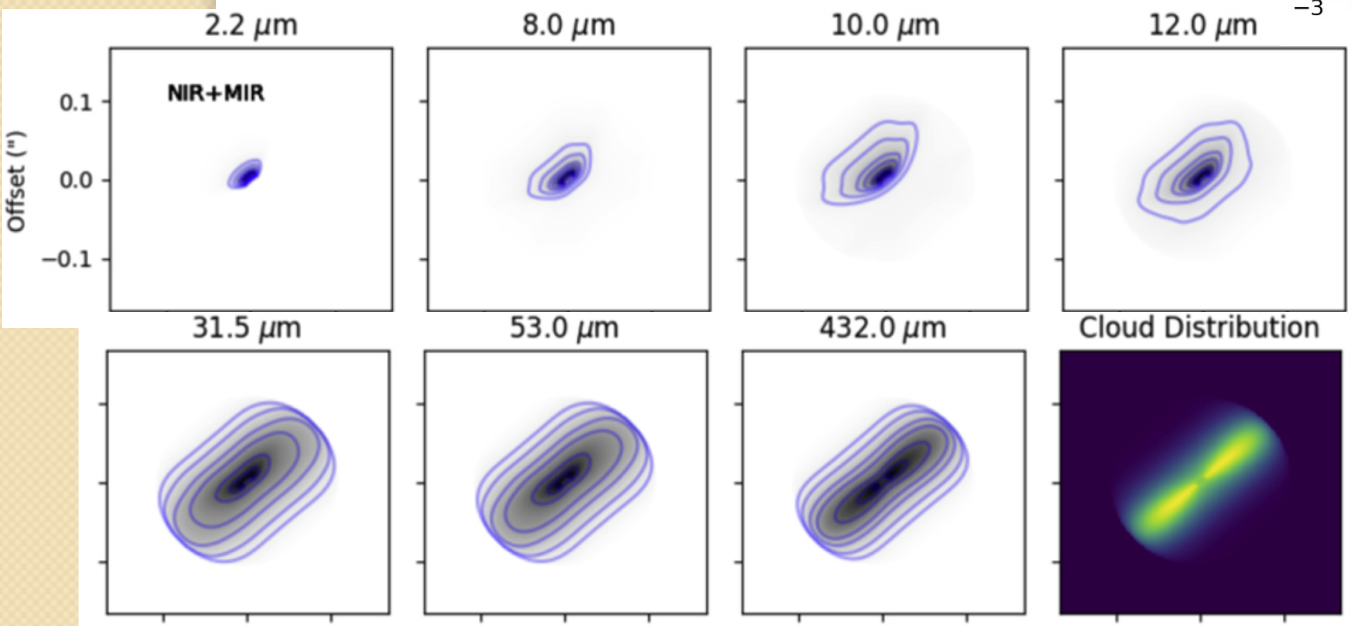
Dusty torus model images

Siebenmorgen+2015



Jud+2017



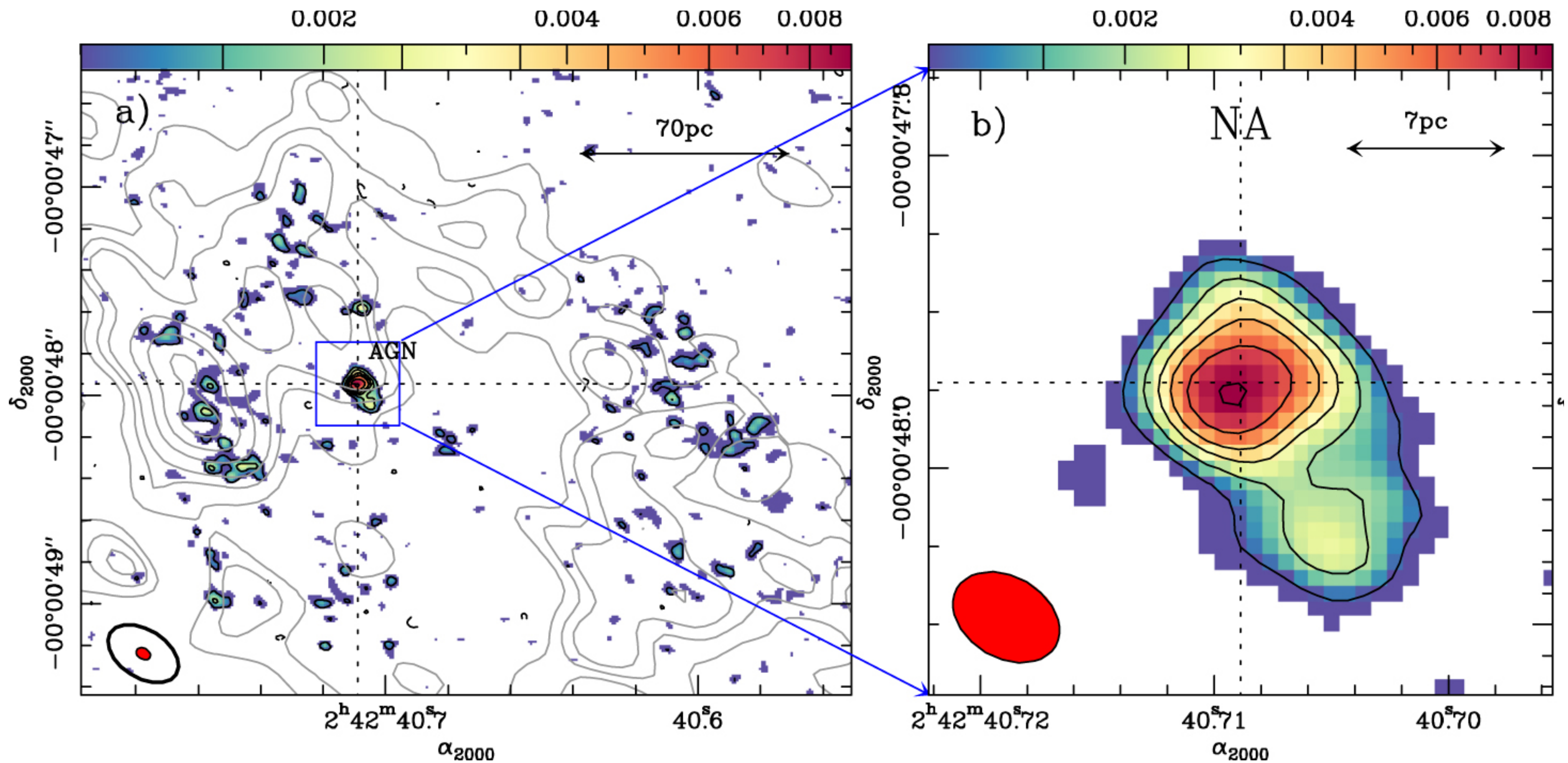


- Models predict more extended torus emission at far-infrared wavelengths

López-Rodríguez+2018

First direct detection of the torus: NGC1068

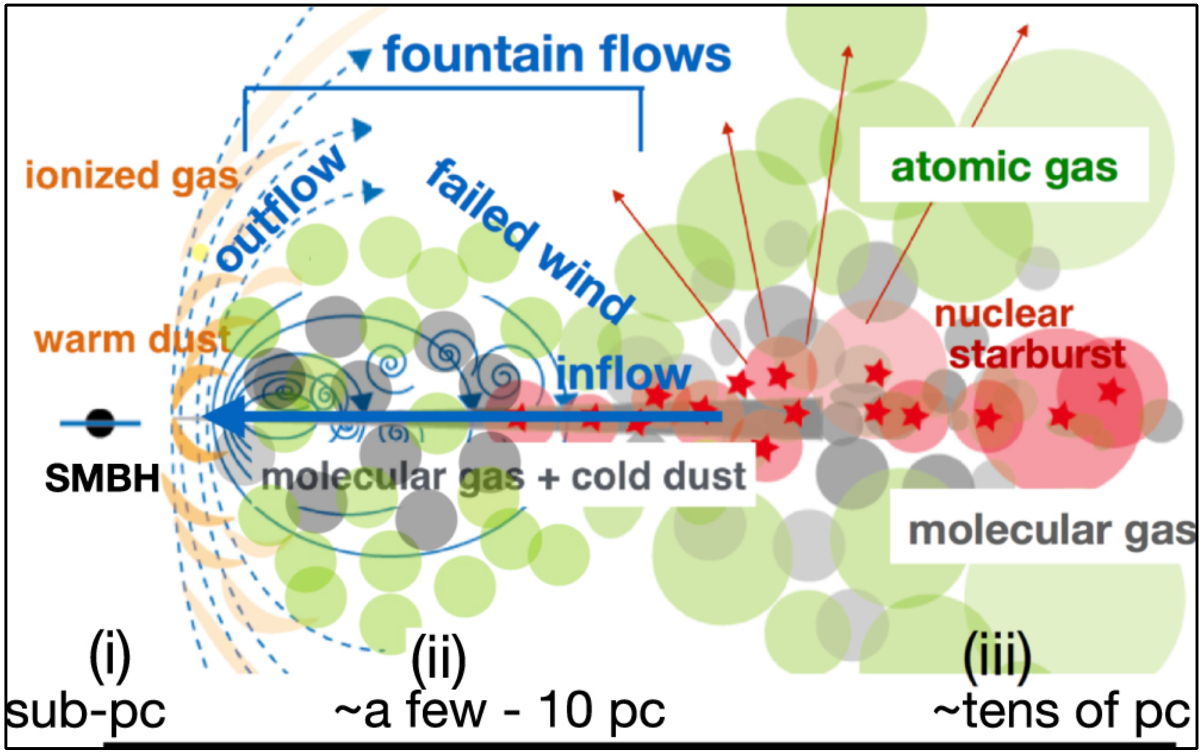
- ALMA 432μm view (0.04-0.06" res) of central 2" of NGC1068
  - **Dust and molecular gas torus (7-10pc). M_{GAS}~$10^5 M_\odot$ and M_{DUST}~$1600 M_\odot$**
  - Circumnuclear disk (300pc x 200pc) with recent SF activity



García-Burillo+2016, also Gallimore+2016, Imanishi+2018

The Galactic Activity, Torus and Outflow Survey (GATOS)

- Gas cycle (inflows/outflows) in the central regions of nearby AGN
- **Torus properties and nuclear obscuration**
- Nuclear star formation activity and role in feeding and obscuring the AGN
- Polar dust: dust chemistry and connection with outflows



Radiation-driven fountain model,
Wada+2012, 2016
Izumi+2018

GATOS members

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GATOS
GALACTIC ACTIVITY, TORUS
AND OUTFLOW SURVEY

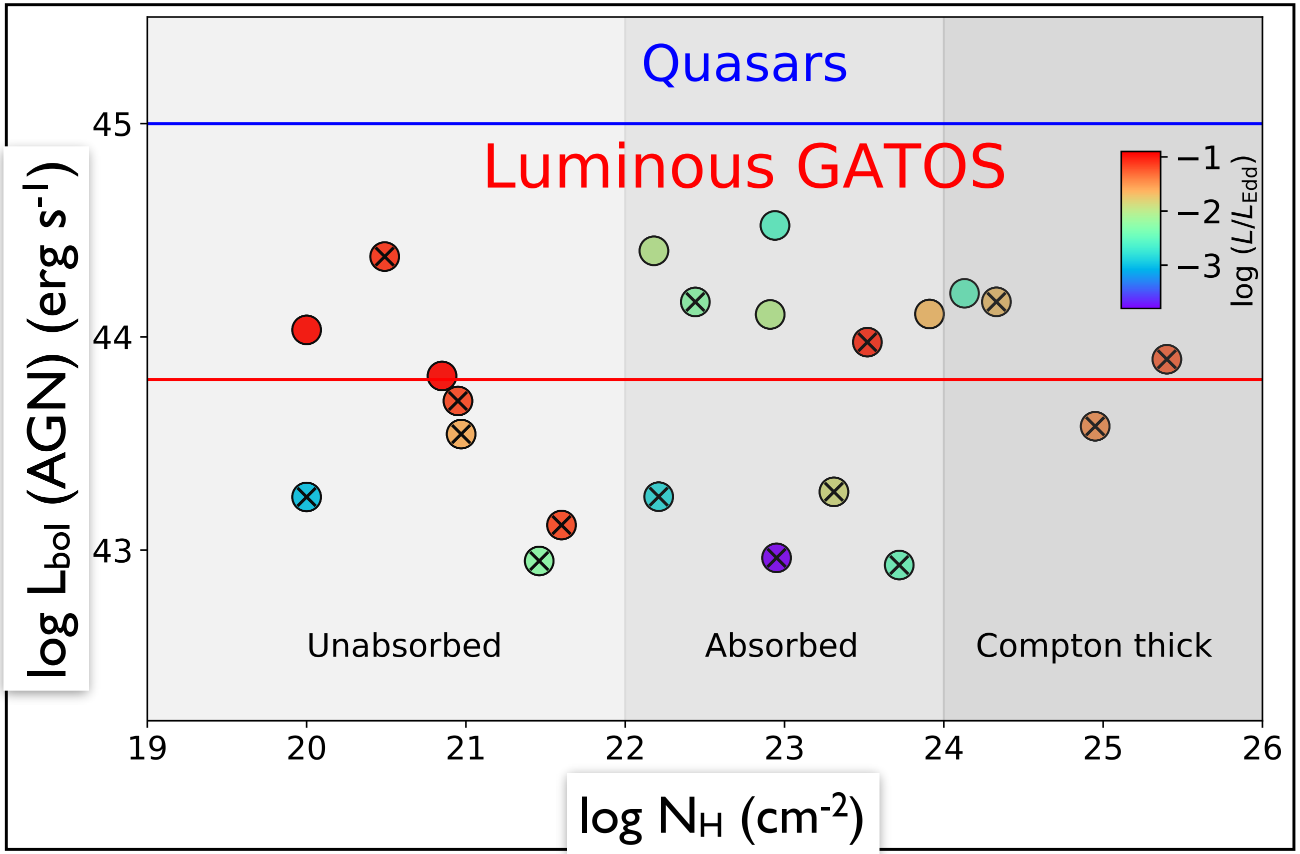
http://gatos.strw.leidenuniv.nl

GATOS Sample Selection

- Volume-limited sample (distances < 40Mpc) of Seyfert galaxies selected in **ultra-hard X-rays (14-195keV)** from the all-sky Swift/BAT catalog

- Range of AGN luminosities, column densities and Eddington ratios

- **ALMA, NOEMA, optical IFU GTC/MEGARA and VLT/MUSE** and future JWST



GATOS
GALACTIC ACTIVITY, TORUS AND OUTFLOW SURVEY

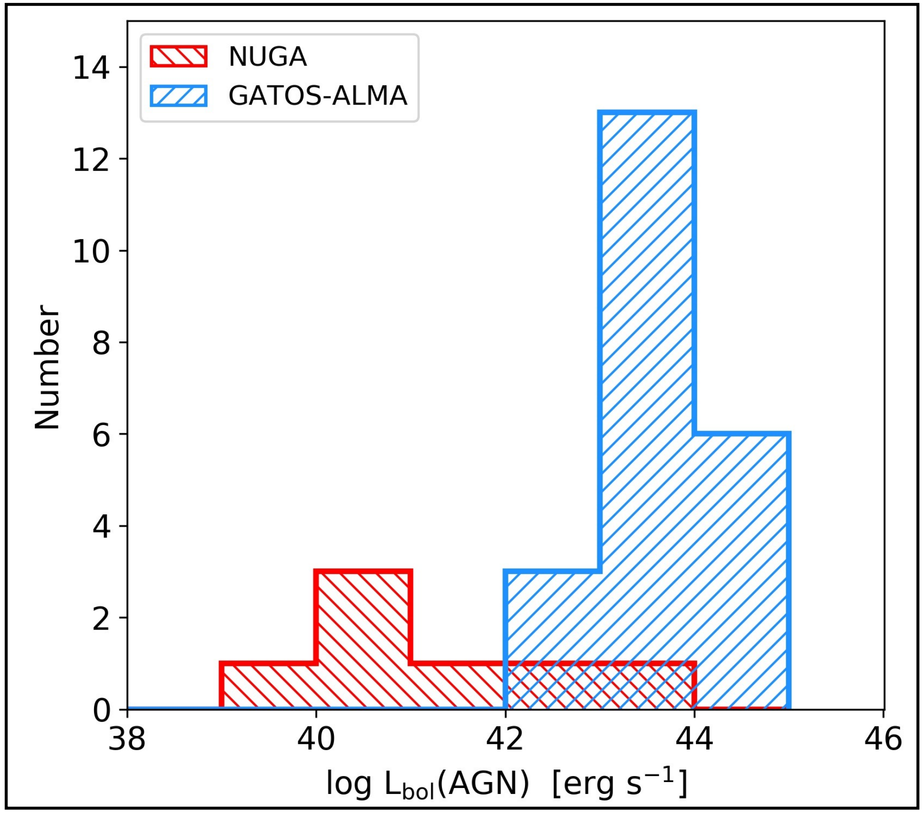
(Sub)mm observations

22 GATOS Seyferts at distances of less than 40Mpc

Best ALMA angular resolution of 0.11" ~ 7-13pc
- **nuclear (tori)**
- **circumnuclear (SF, inflows, outflows)**

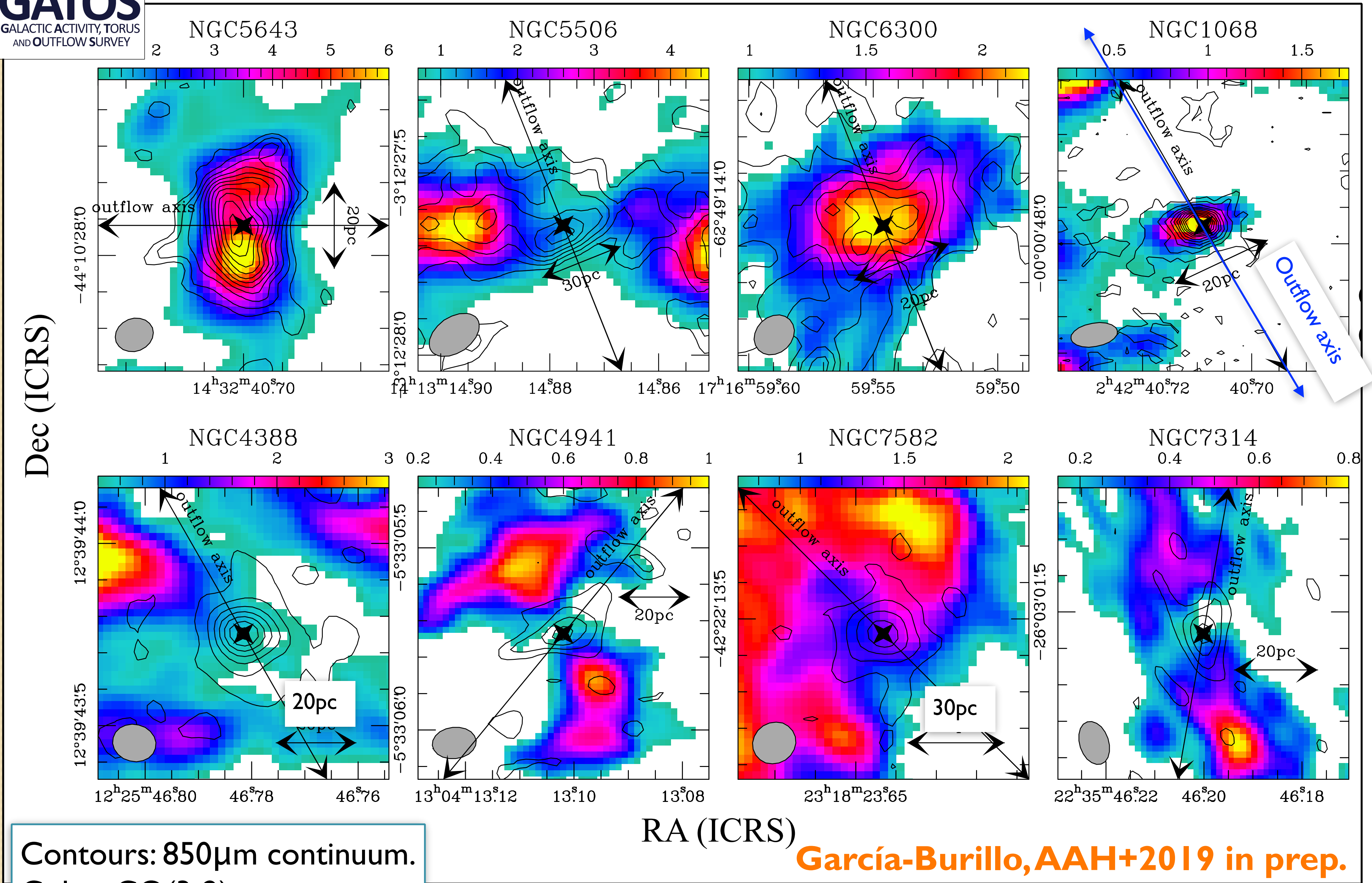
- **Band 7 (all): CO(3-2), HCO+(4-3), 850µm continuum**
  PI: García-Burillo (cycles 5-6)
  PI: Alonso-Herrero (luminous GATOS, cycle 7)

- **Band 6 (selected targets): CO(2-1), 1.3mm continuum -PI: Alonso-Herrero**



- luminosities cover the Seyfert galaxy range
- **complementary to the NUGA sample** of low luminosity AGN (Combes+2019)

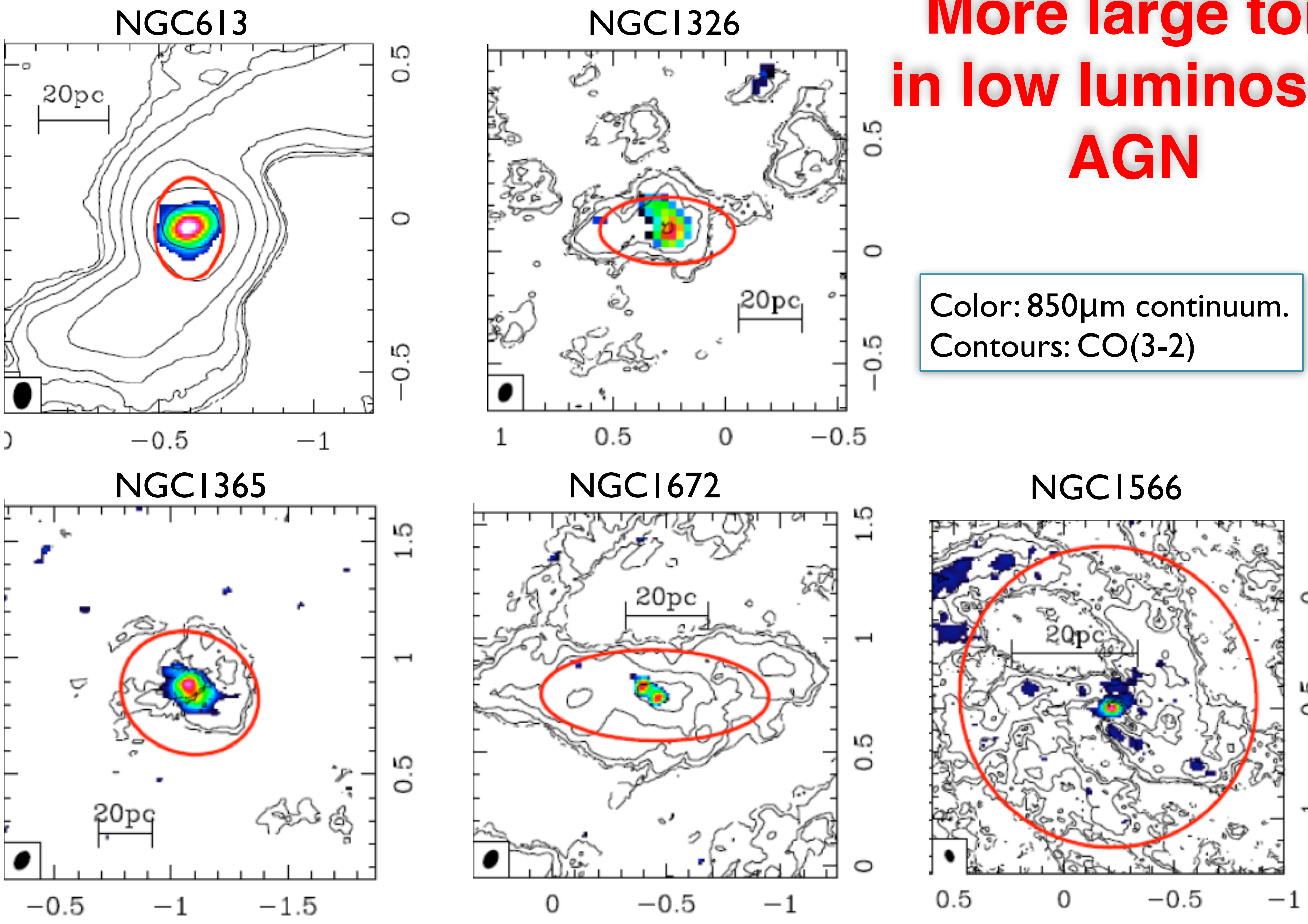
ALMA resolves dusty molecular tori in Seyferts



Contours: 850µm continuum.
Color: CO(3-2)

García-Burillo, AAH+2019 in prep.

More large tori in low luminosity AGN

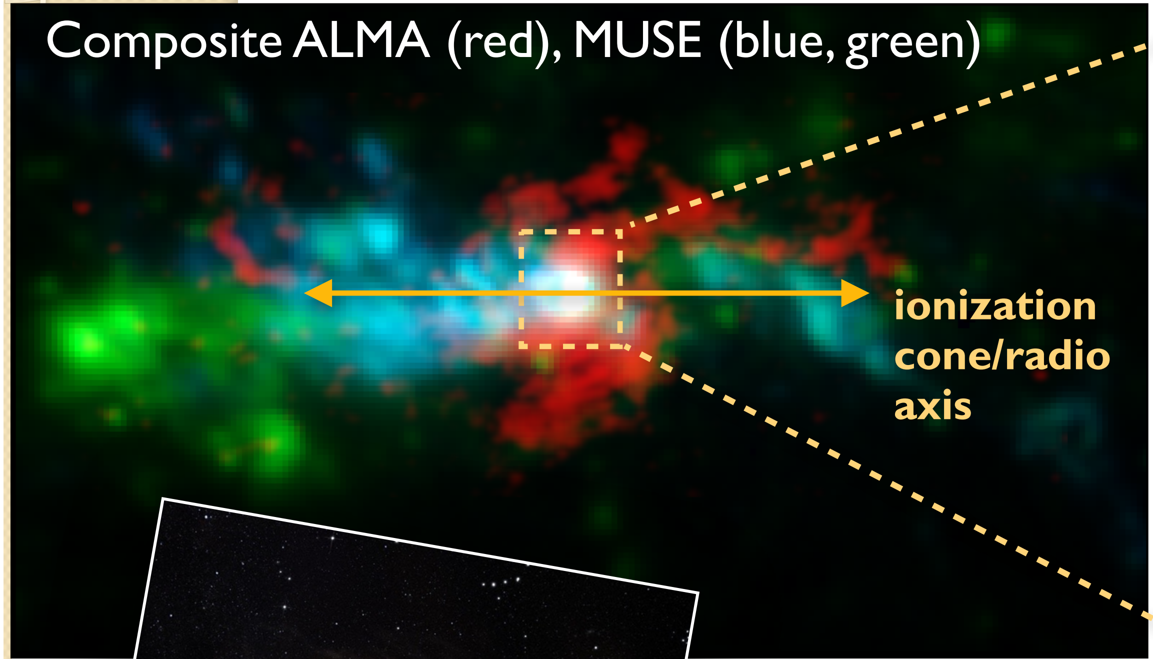


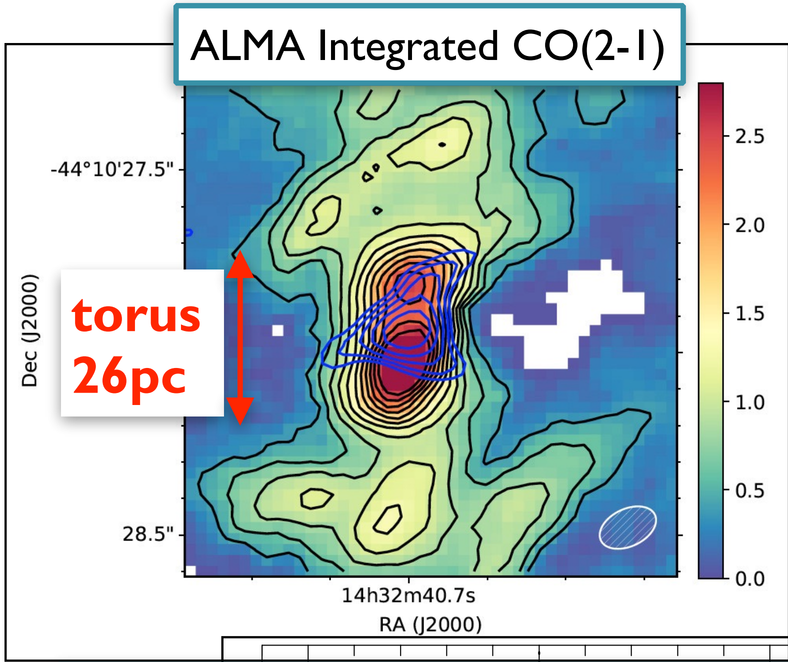
Color: 850μm continuum.
Contours: CO(3-2)

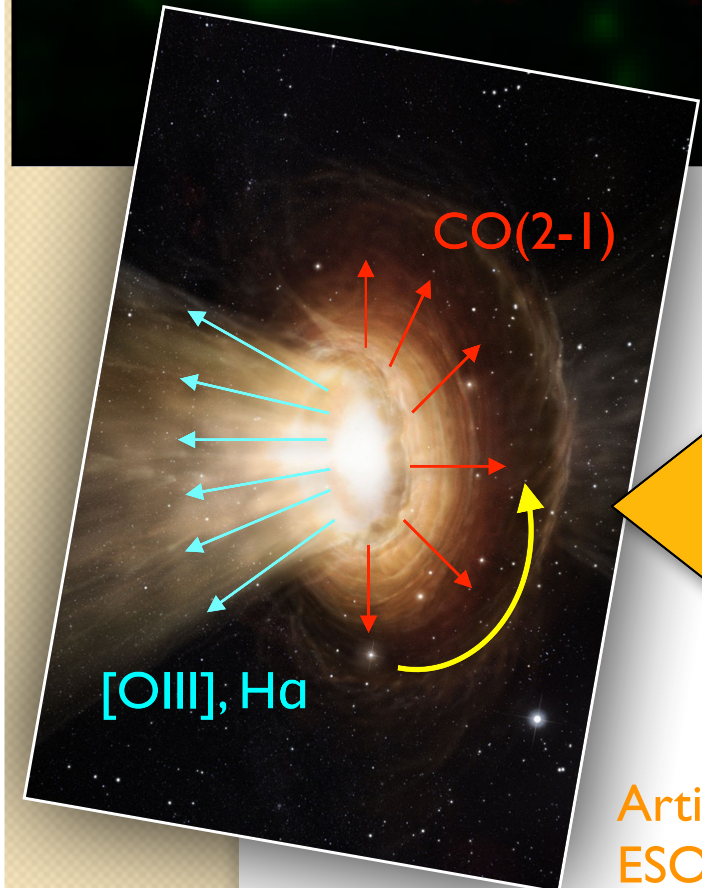
From the NUGA sample of low luminosity AGN, **Combes+2019**

A massive "outflowing" torus in NGC5643

Alonso-Herrero+2018

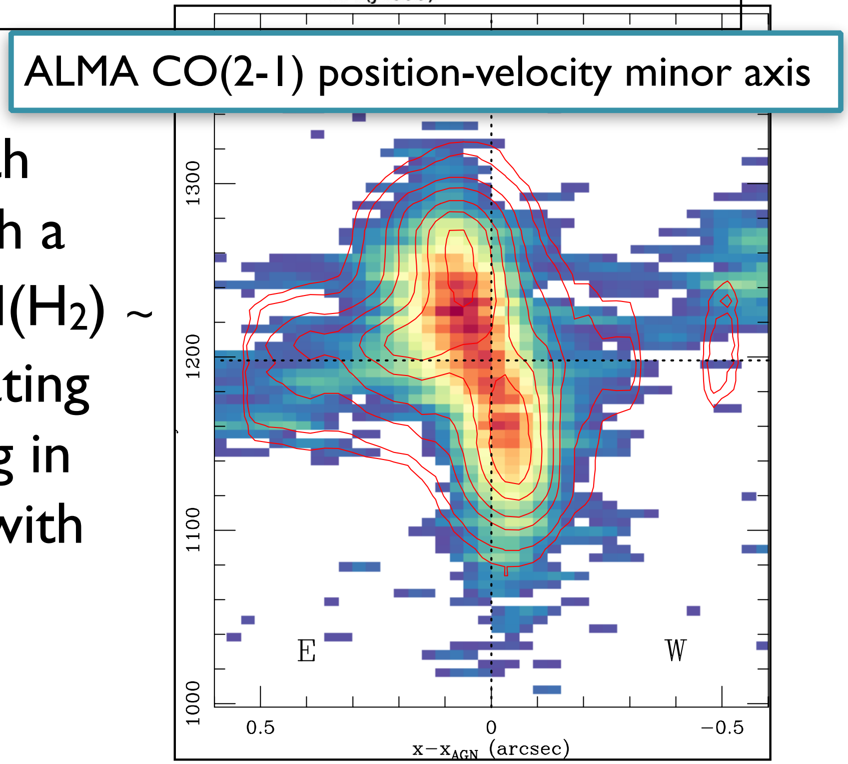




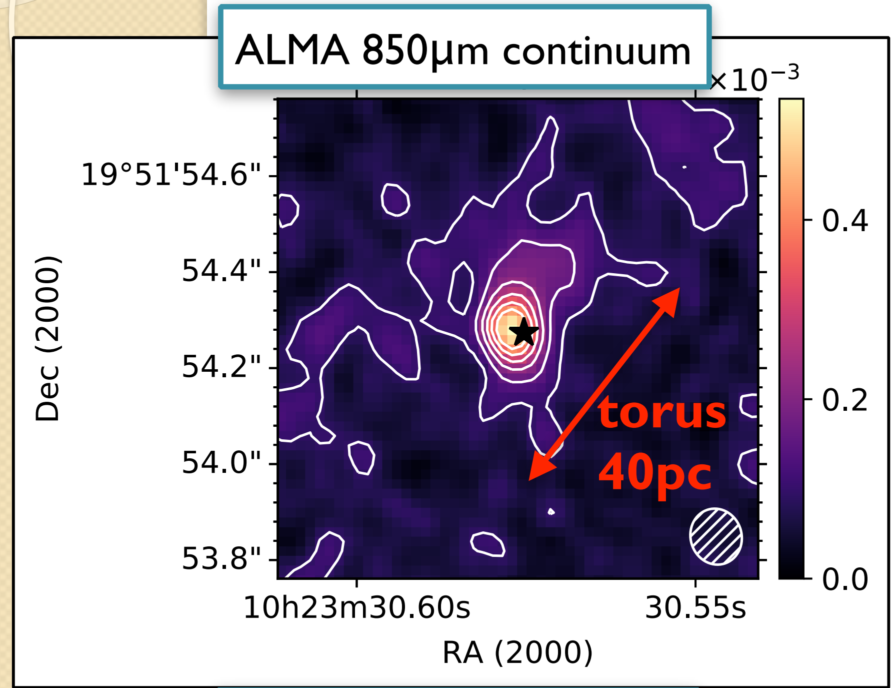


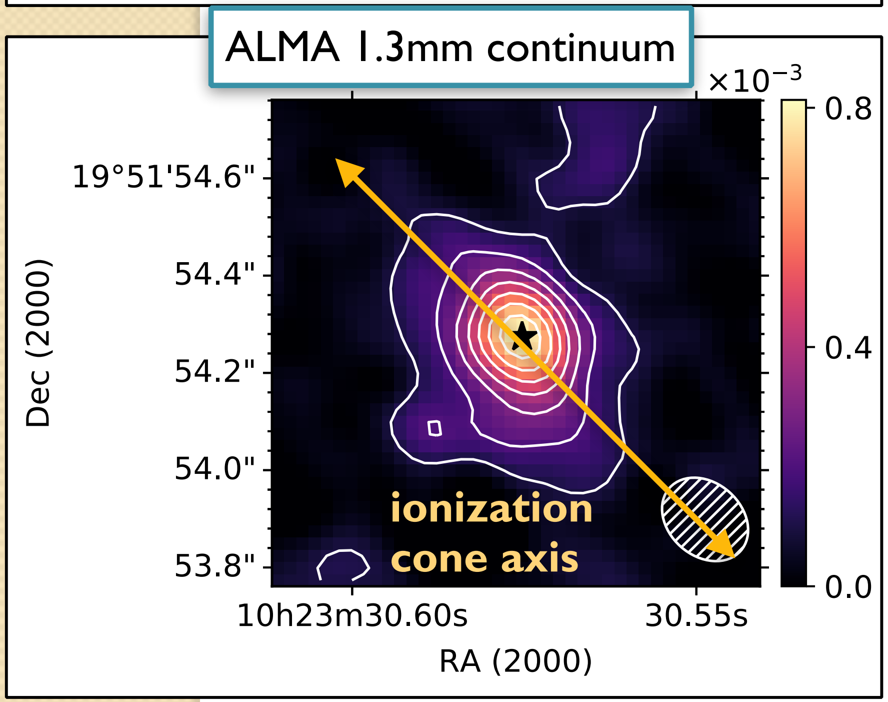
Artist Impression: ESO/M. Kornmesser

Massive torus with M_{GAS}~$10^7 M_\odot$ with a column density $N(H_2)$ ~ 8×10^{23} cm^{-2}. Rotating torus +outflowing in equatorial plane with v~100km/s

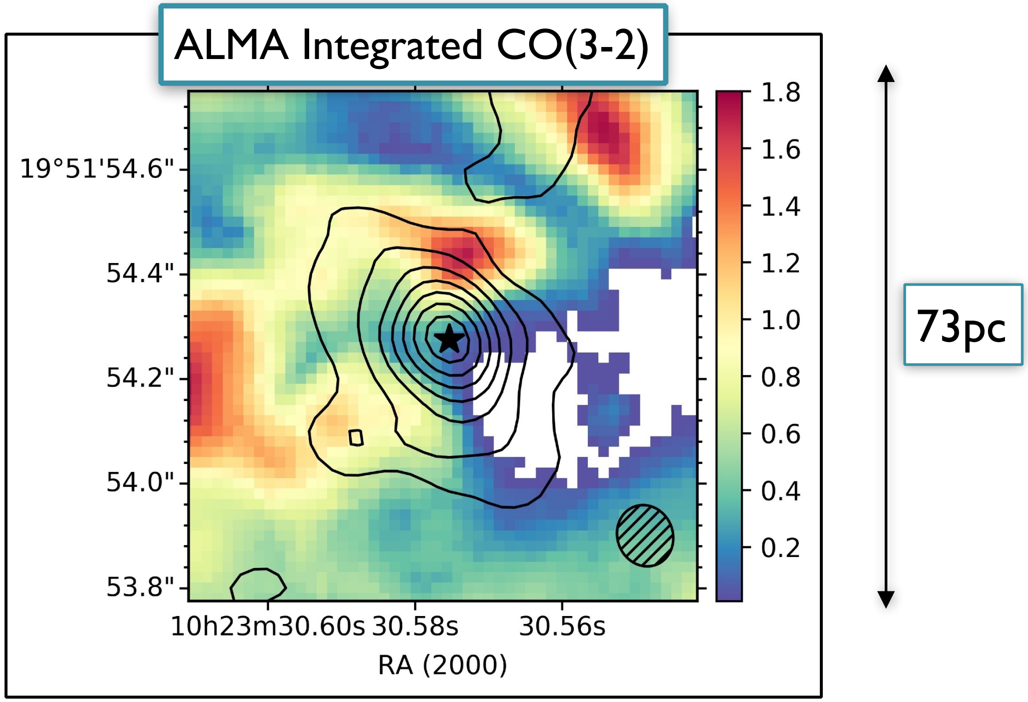


A large torus/nuclear disk in NGC3227





- At 850μm nuclear disk diameter ~40pc, perpendicular to ionization cone and with on-going/recent SF
- CO emission does not peak at AGN position, central 15pc $M(H_2) \sim 5\times10^5\ M_\odot$
- Column density $N(H_2) \sim$ a few $10^{23}\ cm^{-2}$



Alonso-Herrero+2019

Torus properties: NUGA + GATOS (I)

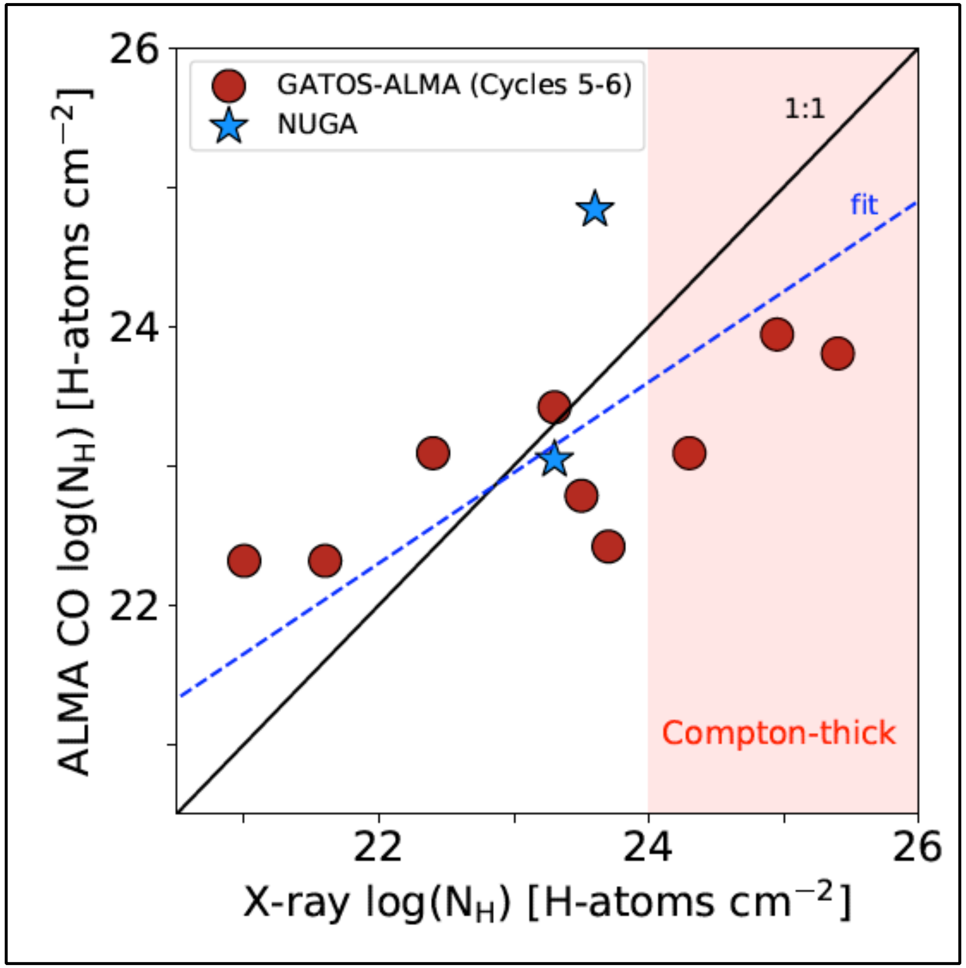
- CO(2-1), CO(3-2) and 850μm morphologies
  - large tori/disks (r=10-20pc)
  - perpendicular to ionization cone/radio axis
  - connected to molecular gas in host galaxy
  - rotating and some with evidence of outflowing material

- Molecular gas in disks/tori: $M(H_2) \sim 5 \times 10^5$-$10^7\ M_\odot$

- Column densities at AGN position correlated with X-ray column densities

ALMA resolution already probing nuclear obscuration

García-Burillo, AAH+2019 (in prep), also Combes+2019, Alonso-Herrero+2018, 2019



Conclusions

- Not clear if there is a dependence of covering factors with AGN type, L_{AGN} and/or Eddington ratios from:
  - Obscured AGN fraction
  - Modelling of nuclear infrared emission

- ALMA is imaging directly the obscuring torus
  - Large (20-40pc) massive obscuring tori ⊥ jet/ionization cone axes
  - Molecular gas column densities are correlated with X-ray N_H

ALMA angular resolution probes the obscuring material in nearby AGN

- Near future: study the obscuring material properties for a range of L_{AGN} and Eddington ratios, and relation with AGN feedback