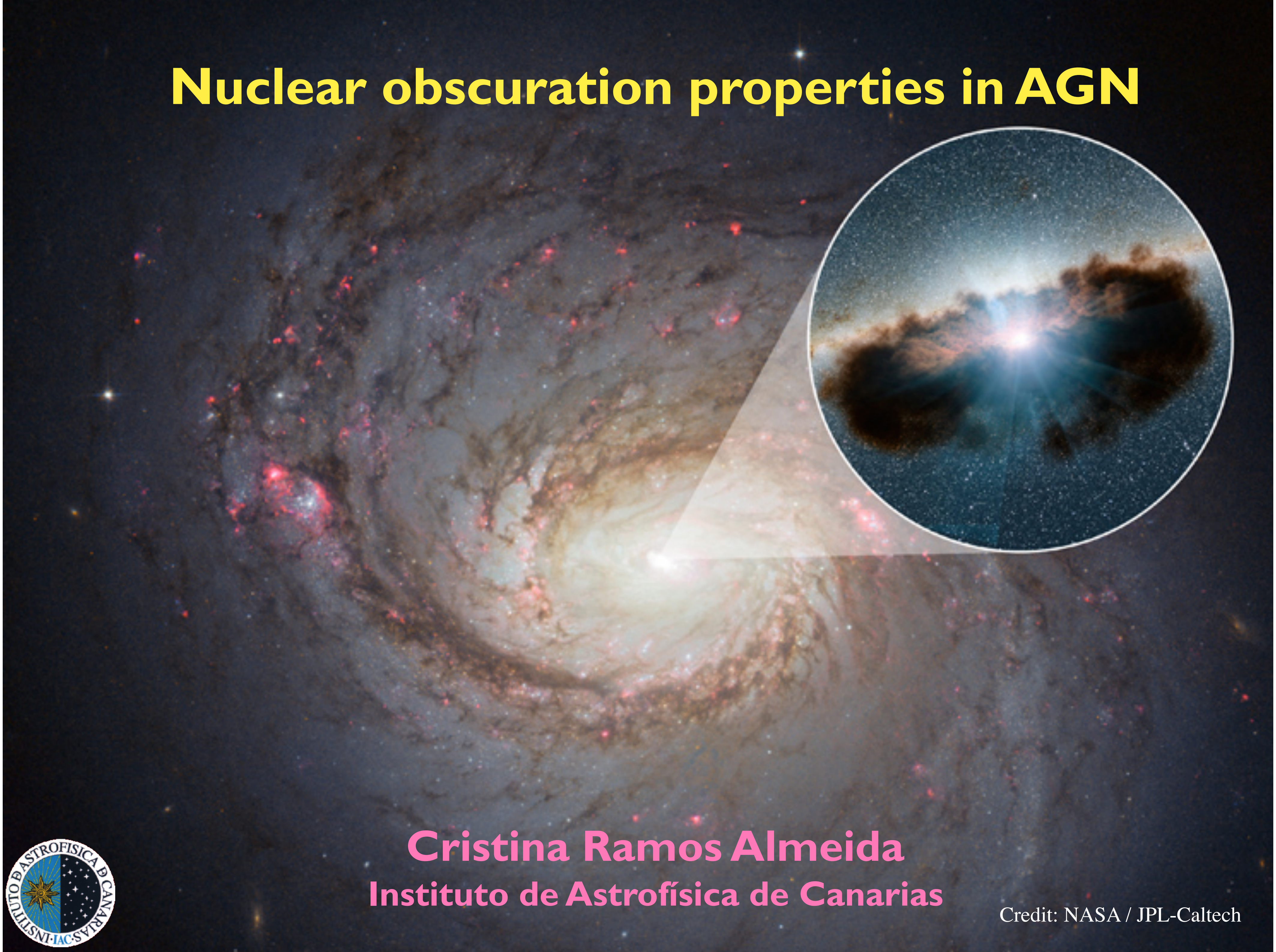
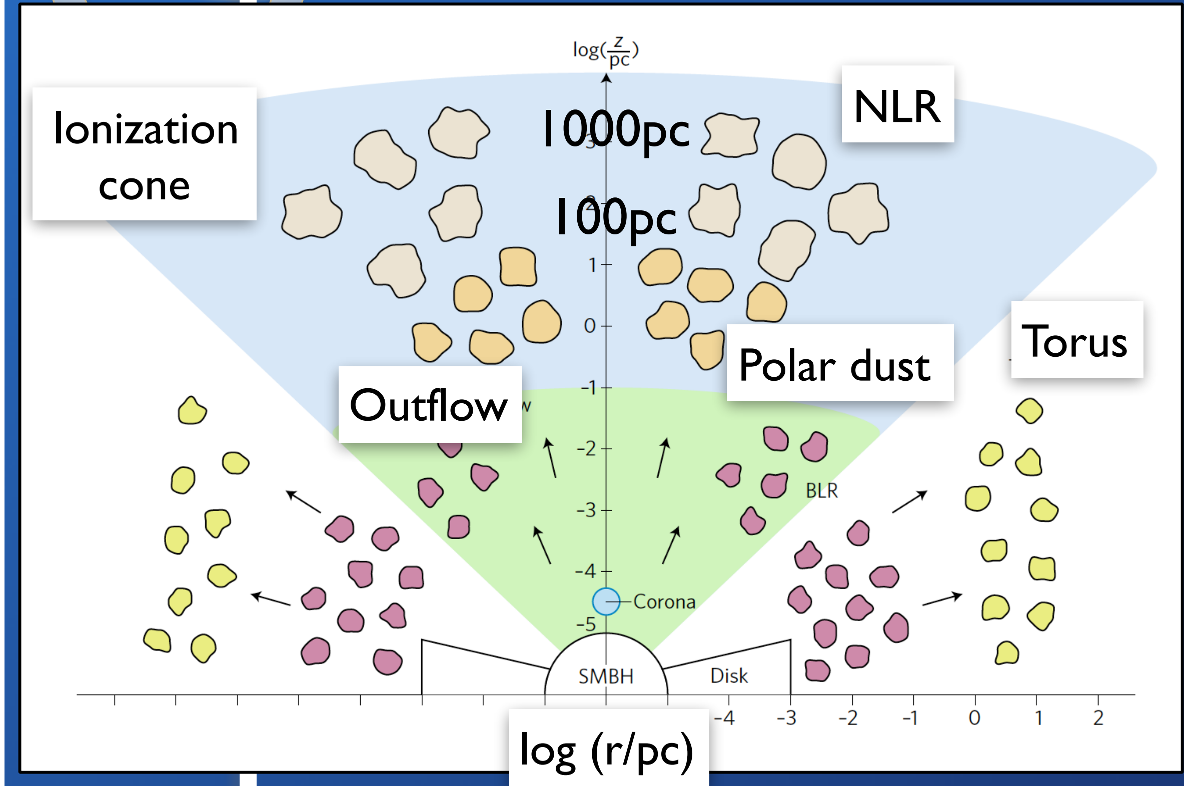
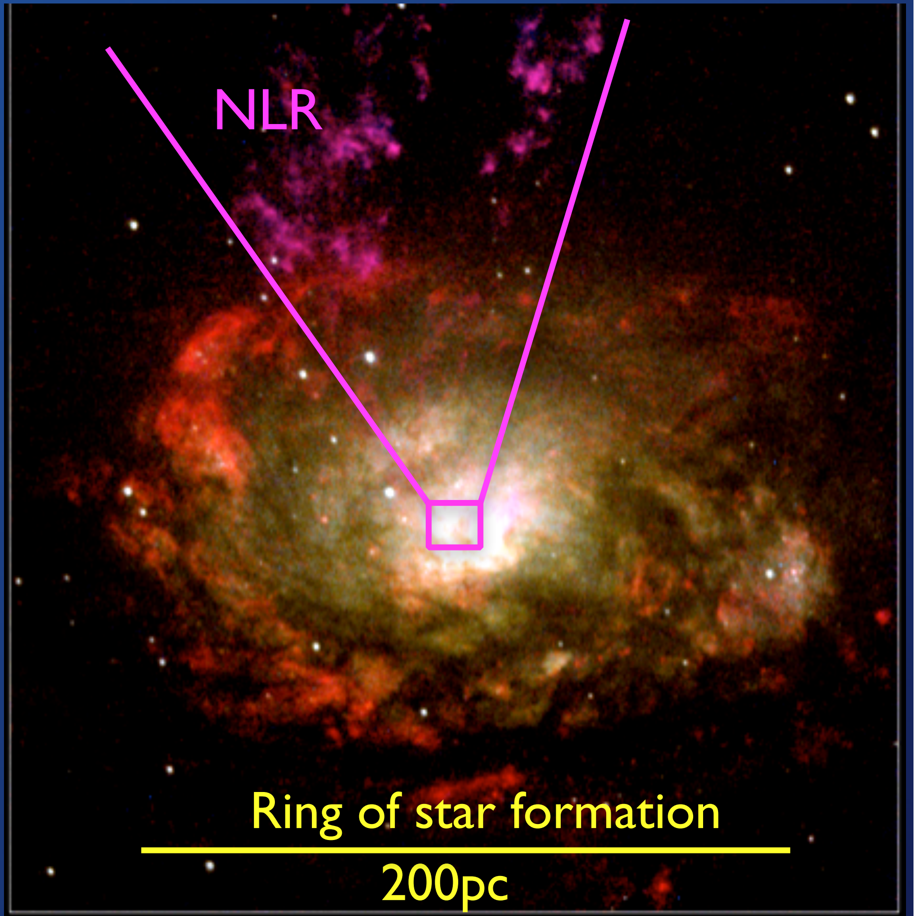

Nuclear obscuration properties in AGN
Cristina Ramos Almeida
Instituto de Astrofísica de Canarias
Credit: NASA / JPL-Caltech

Physical scales of nuclear dust

Ramos Almeida & Ricci 2017



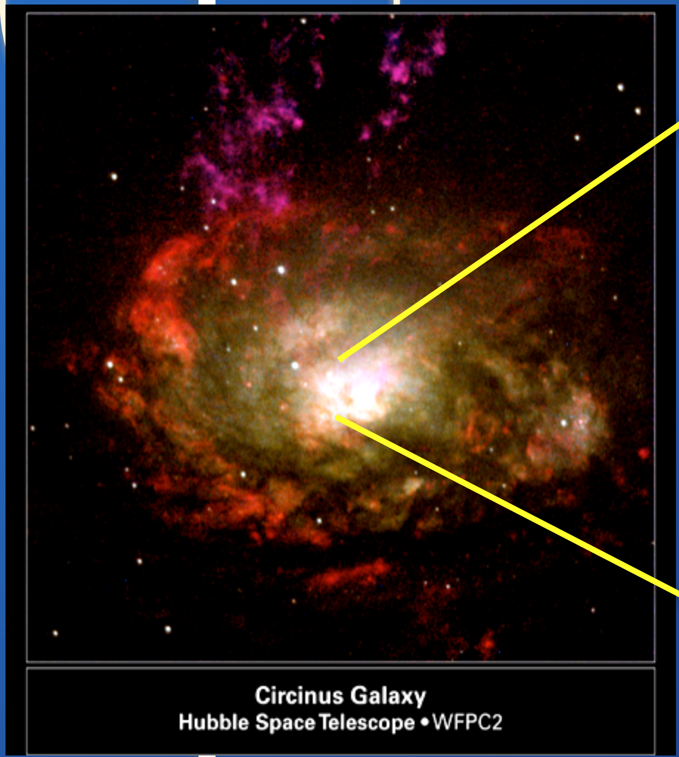
1pc 100pc



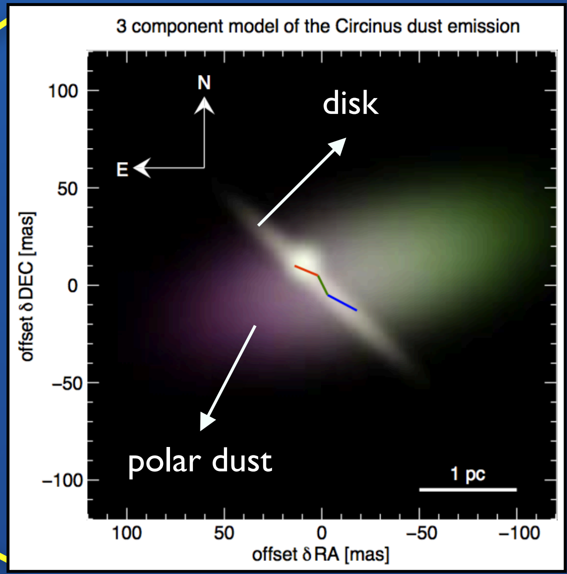
Circinus Galaxy
Hubble Space Telescope • WFPC2

- Torus: a few to tens of parsecs.
- Polar dust: up to a few hundred parsecs.
- Circumnuclear disk (CND): a few tens/hundreds parsecs.

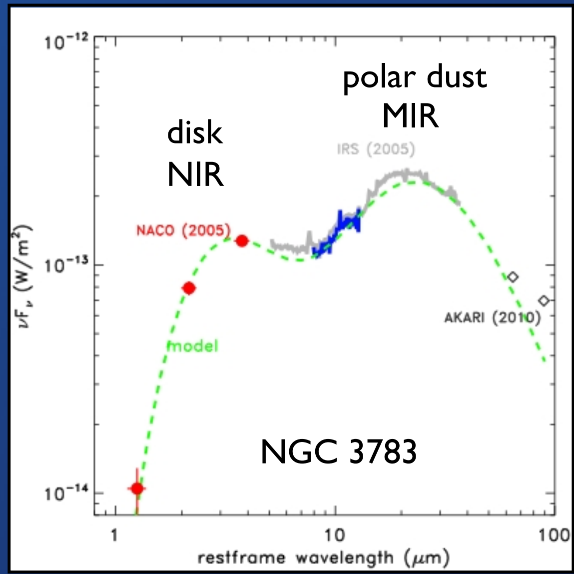
How does the torus look like: observations



Tristram+2014

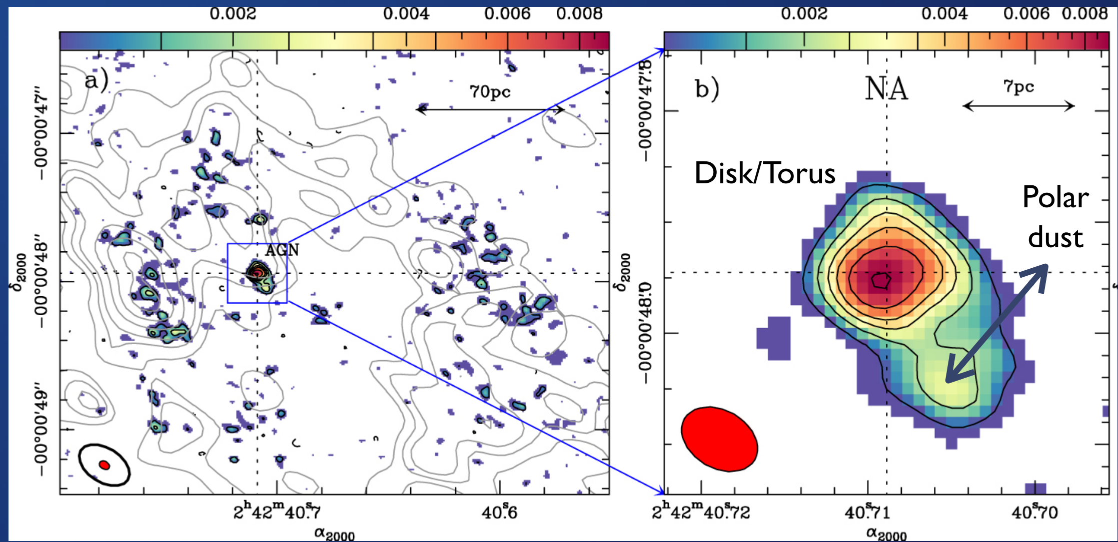


Hönig+2013

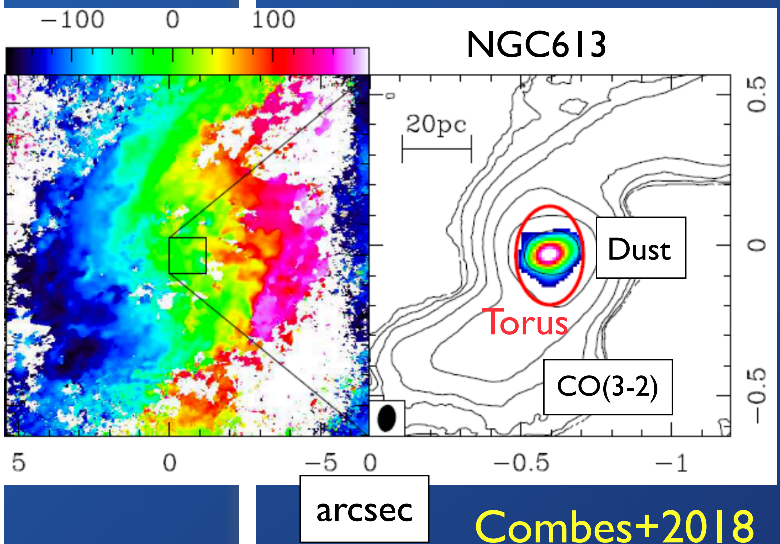


HOT/WARM DUST

García-Burillo+2016

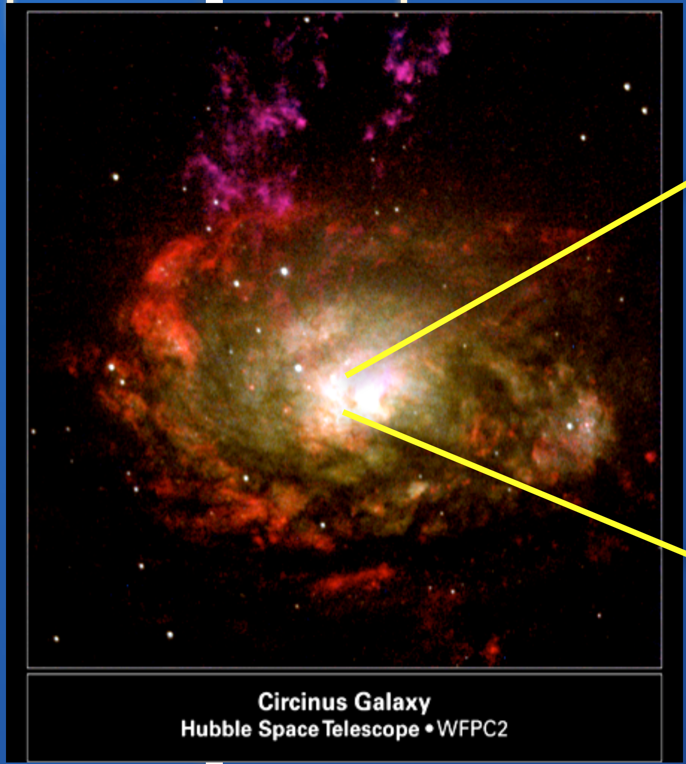


COLD DUST/GAS

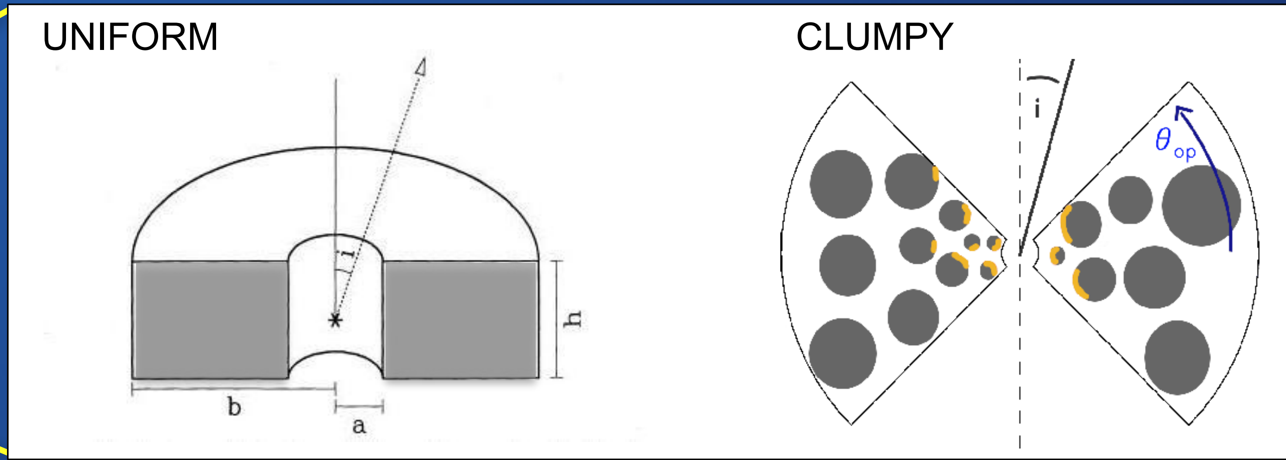


Combes+2018

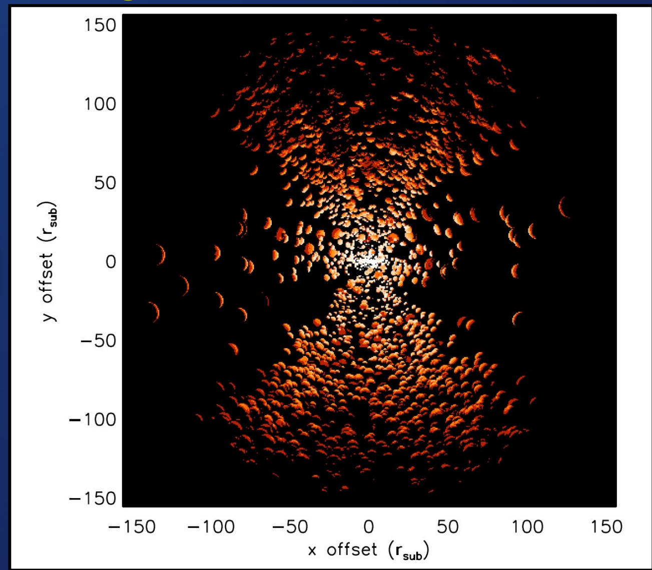
How does the torus look like: models



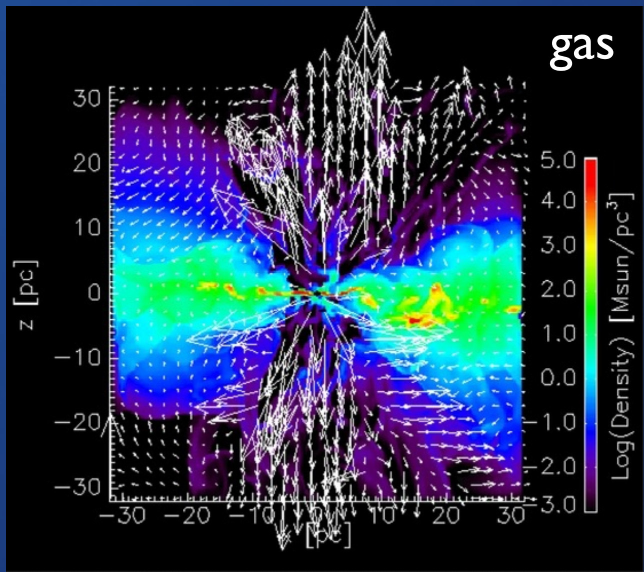
Pier & Krolik 1992 — Schartmann+2008

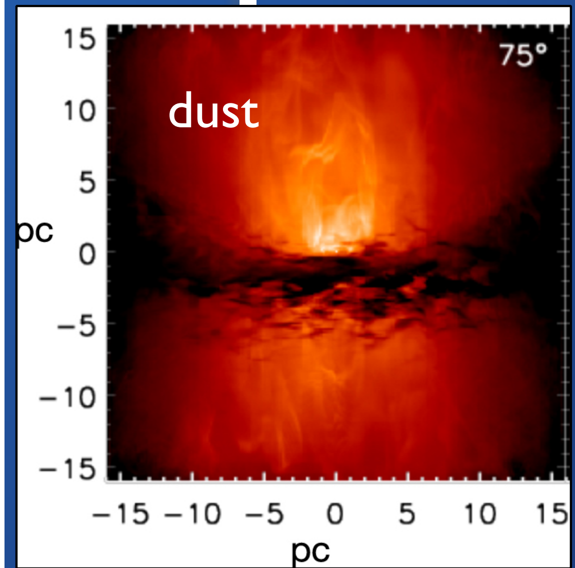


Hönig & Kishimoto 2017



Wada 2012, 2016

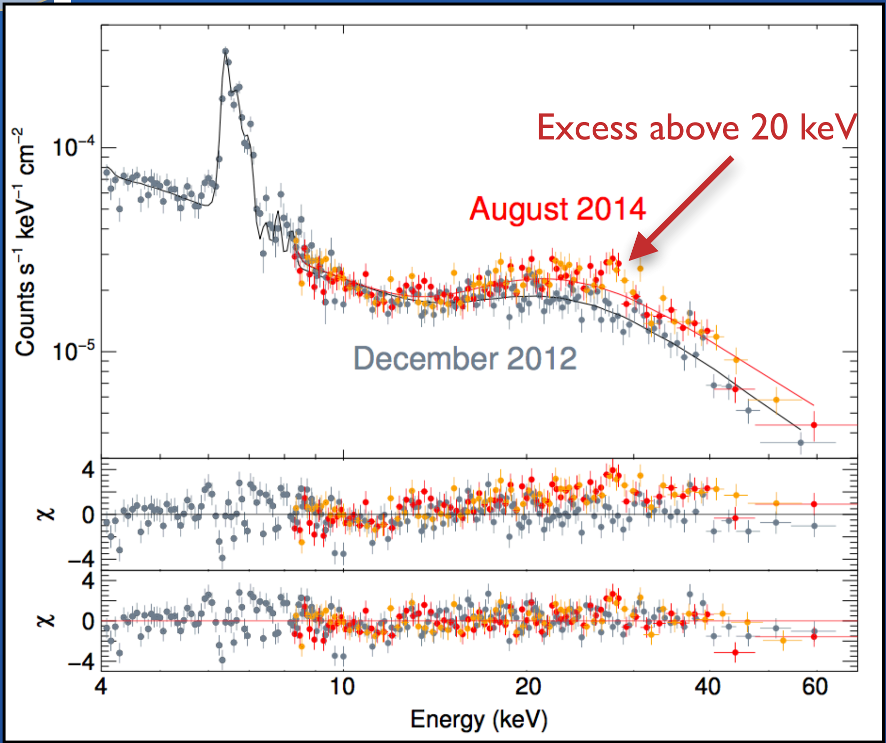




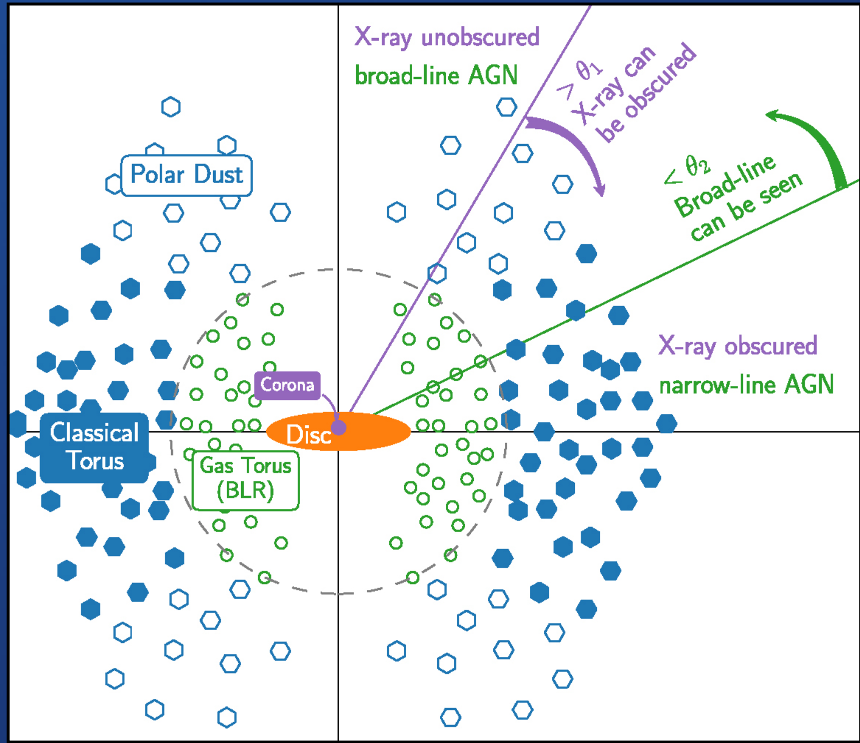
How does the torus look like: observations

Smooth → Clumpy

Observationally supported (e.g. X-rays; Markowitz+2014; Marinucci+2016; Liu+2018).



Marinucci+2016

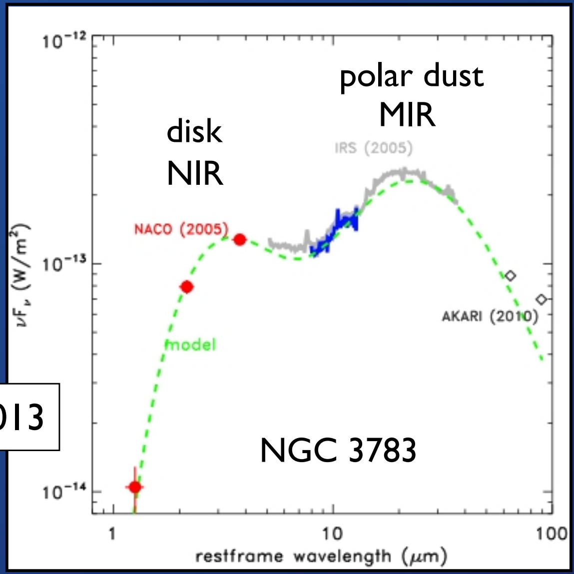


Liu+2018

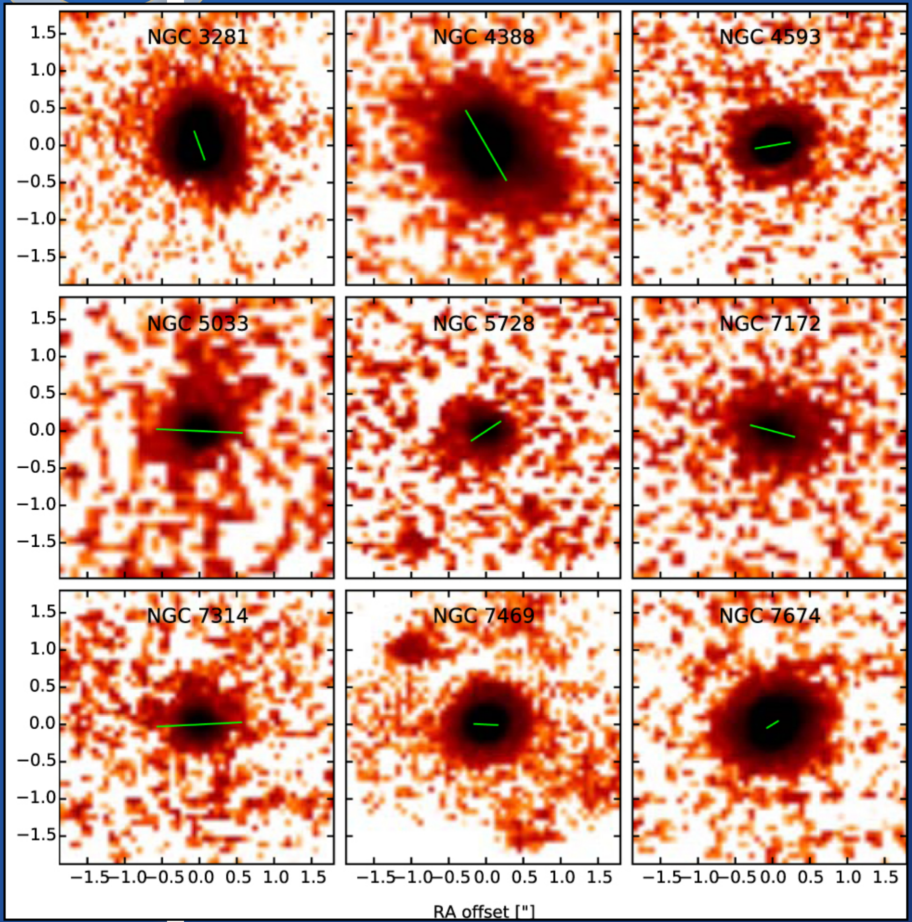
Changing-look AGN in optical more likely due to intrinsic variability (Tuesday talks).

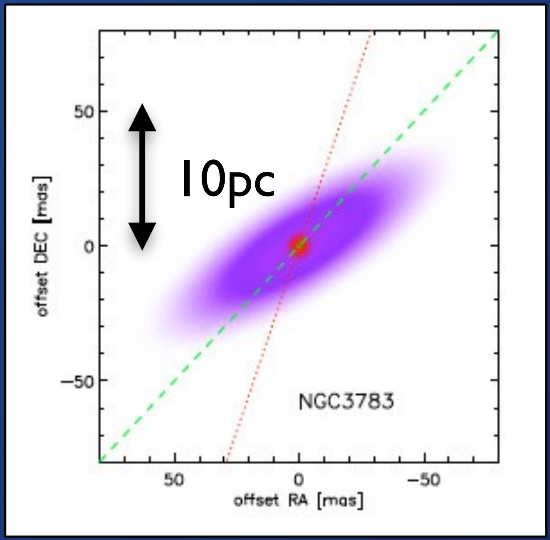
How does the torus look like: observations

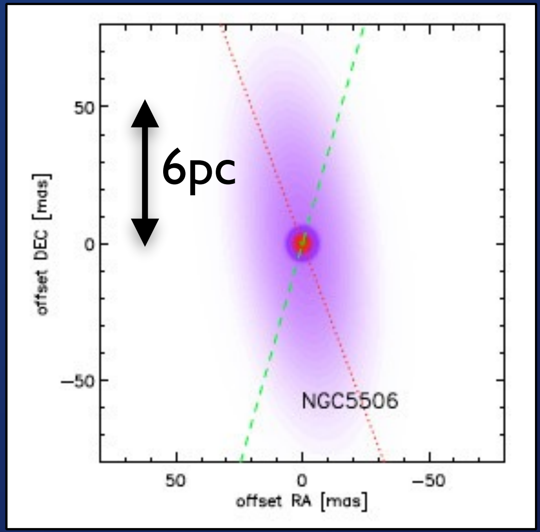
Some AGN show a significant fraction of MIR emission along the polar direction.



Hönig+2013





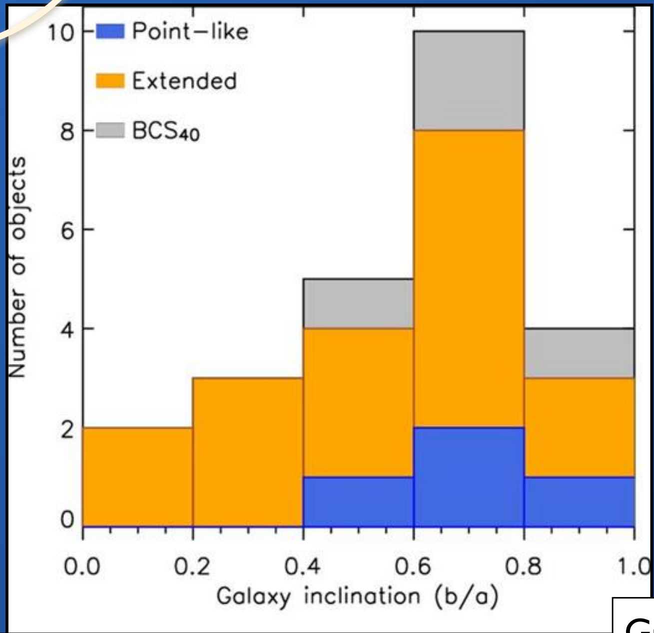


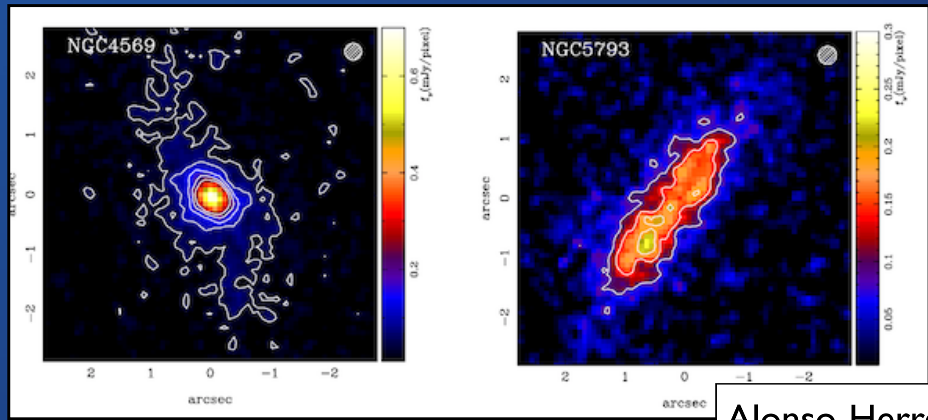
Modelling MIR interferometry: López-Gonzaga+2016, Hönig+2012, 2013, Tristram+2014, Leftley+2018

MIR imaging: Asmus+2014,2016, Radomski+2003, Packham+2004, Mason+2006, Alonso-Herrero+2016, García-Bernete+2016

How does the torus look like: observations

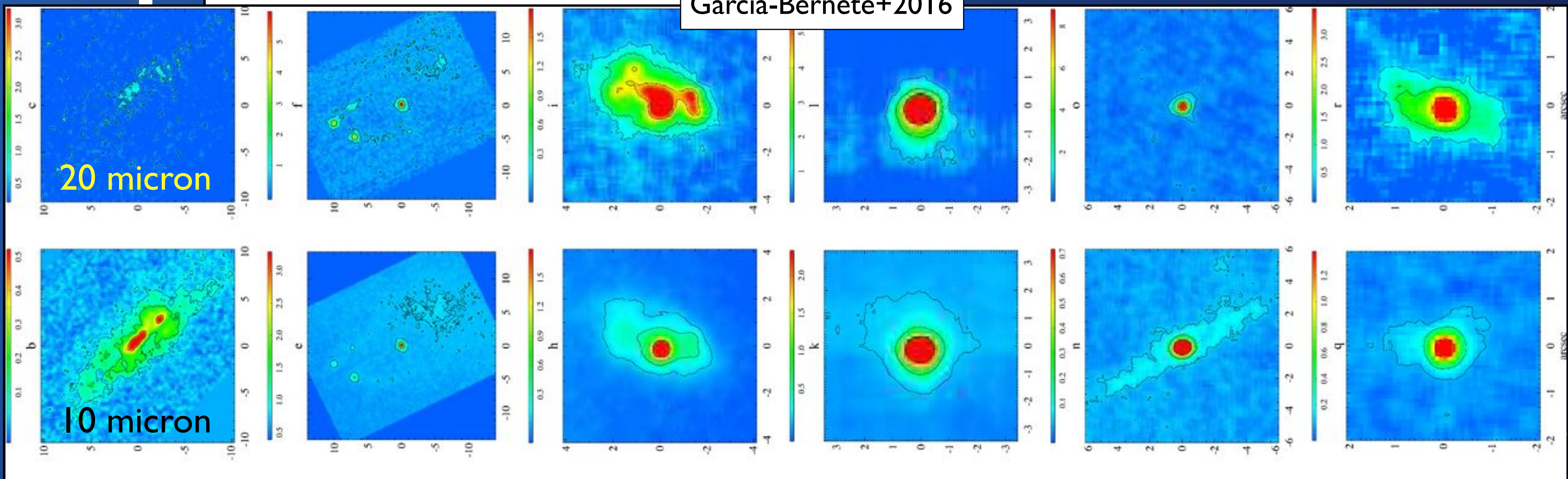
MIR emission of Seyfert galaxies = point source + faint extended emission (inner ~400 pc) in 80% of X-ray selected sample (García-Bernete et al. 2016).





Alonso-Herrero+2016

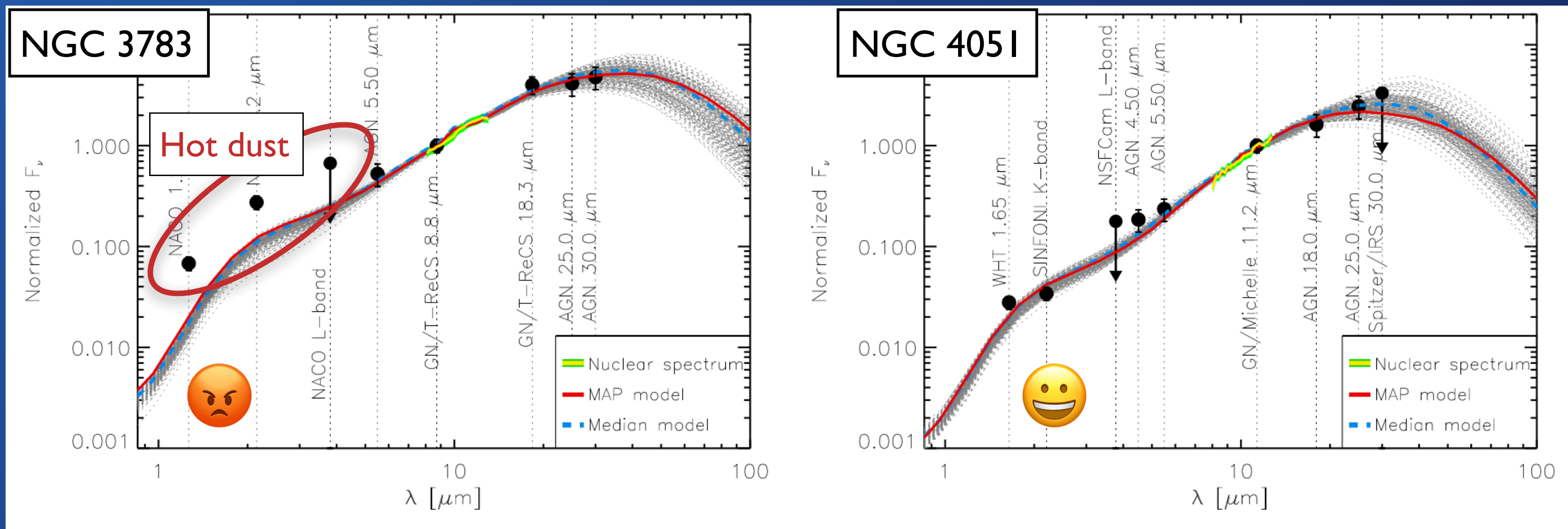
García-Bernete+2016



How does the torus look like: models

Simplest torus models (e.g. CLUMPY) reproduce NIR+MIR SED of most Seyfert galaxies, but some of them show NIR excess (e.g. NGC 3783).

1) Polar dust (Hönig+2013; Tristram+2014)
2) Graphite-rich dusty clouds @inner torus wall (Mor & Netzer 2012)
3) Host galaxy



García-Bernete et al. in preparation

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1) Polar dust (Hönig+2013; Tristram+2014).
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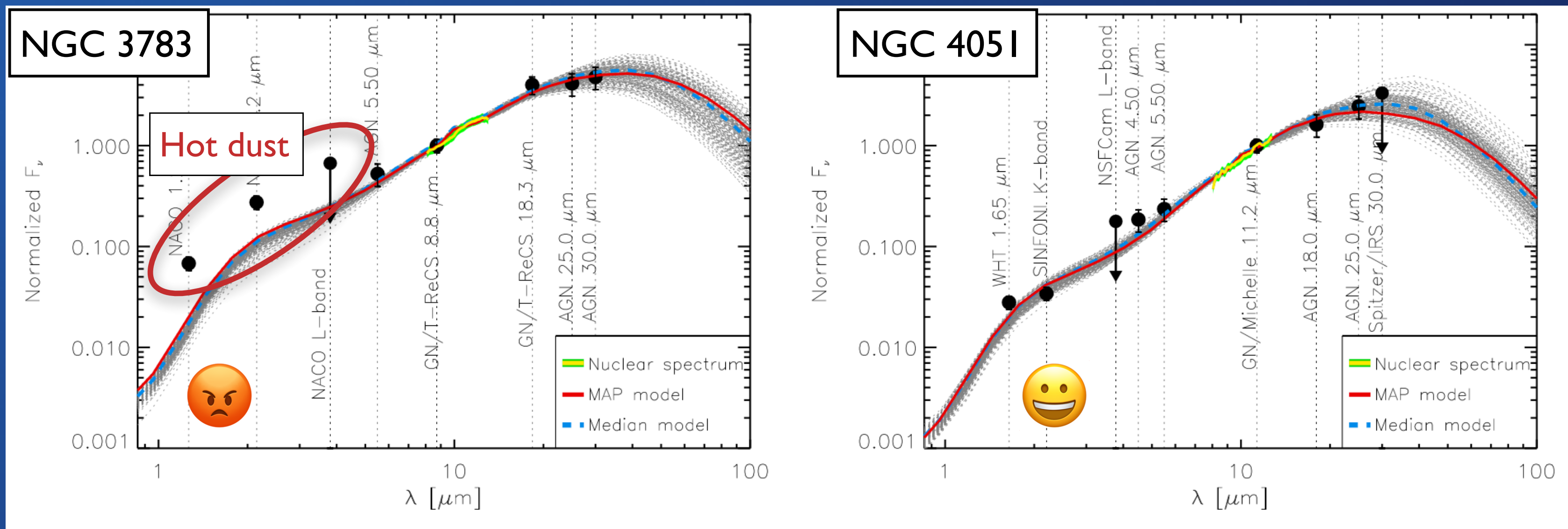
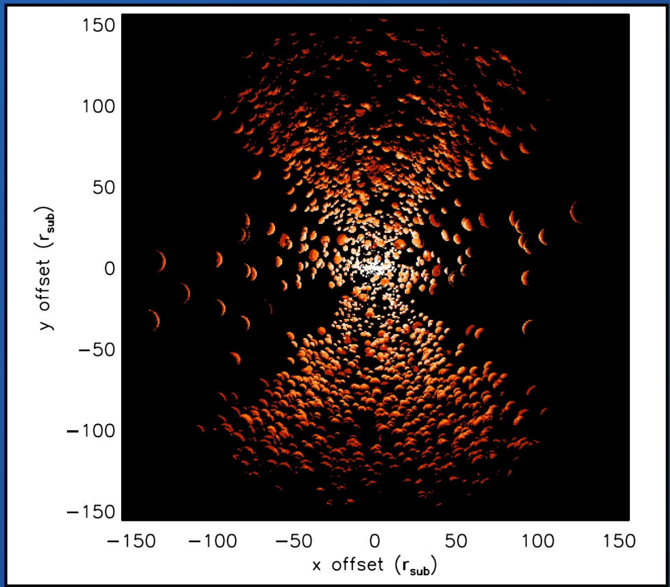


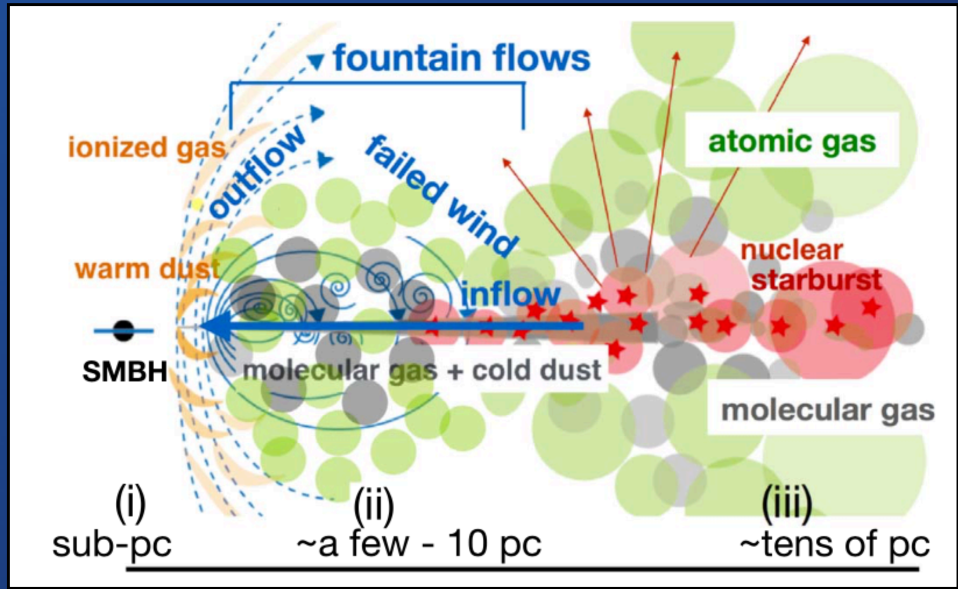
García-Bernete et al. in preparation.

How does the torus look like: models

Torus → Inflowing disk (NIR) + outflowing wind (MIR)

See e.g. Wada 2012, 2016; Hönig & Kishimoto 2017





Hönig & Kishimoto+2017

CAT3D-WIND

Radiative transfer model

Wada+2016

Radiation-driven fountain

Multi-phase hydrodynamic model

How does the torus look like: models

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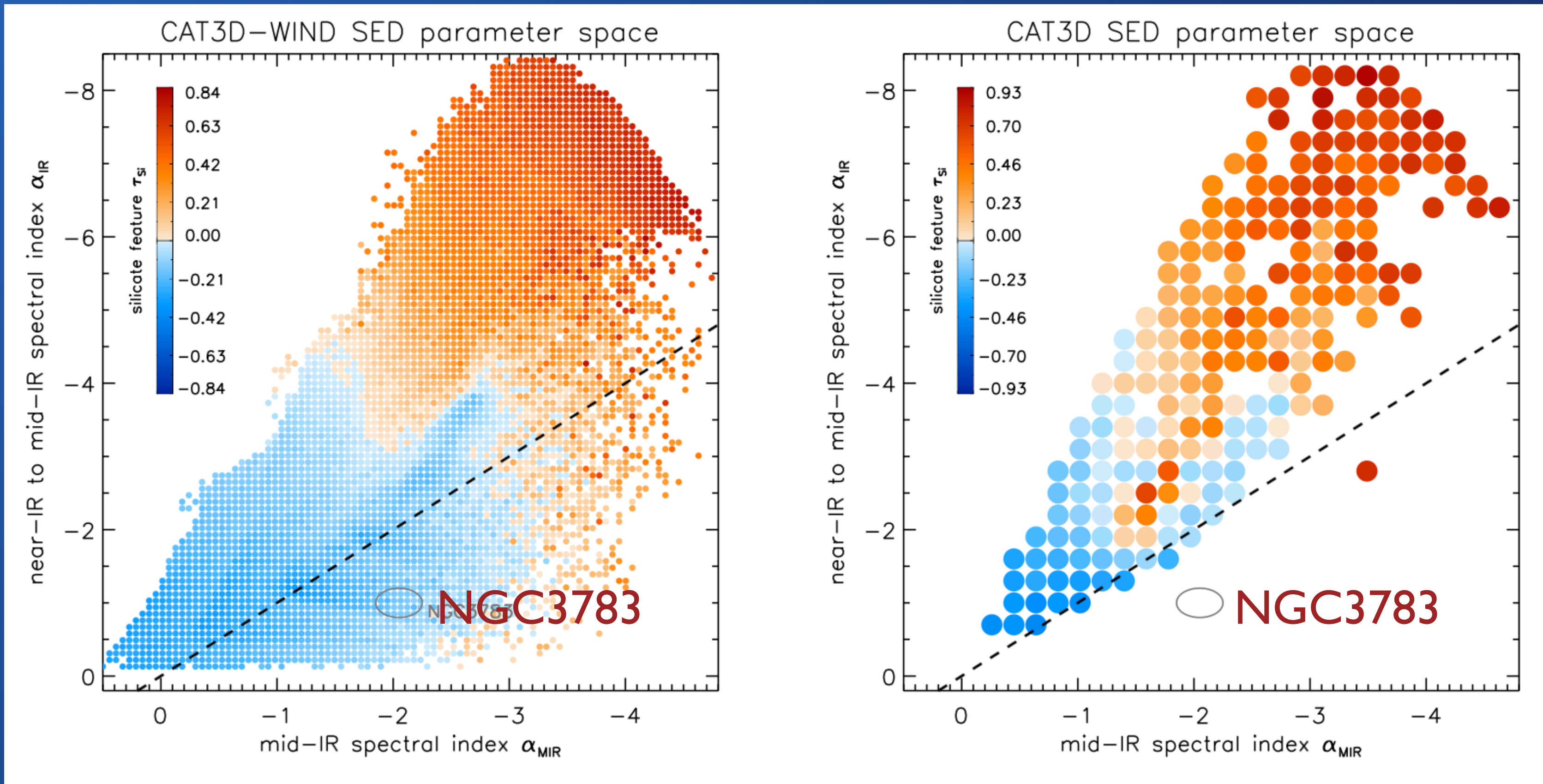

Hönig & Kishimoto+2017

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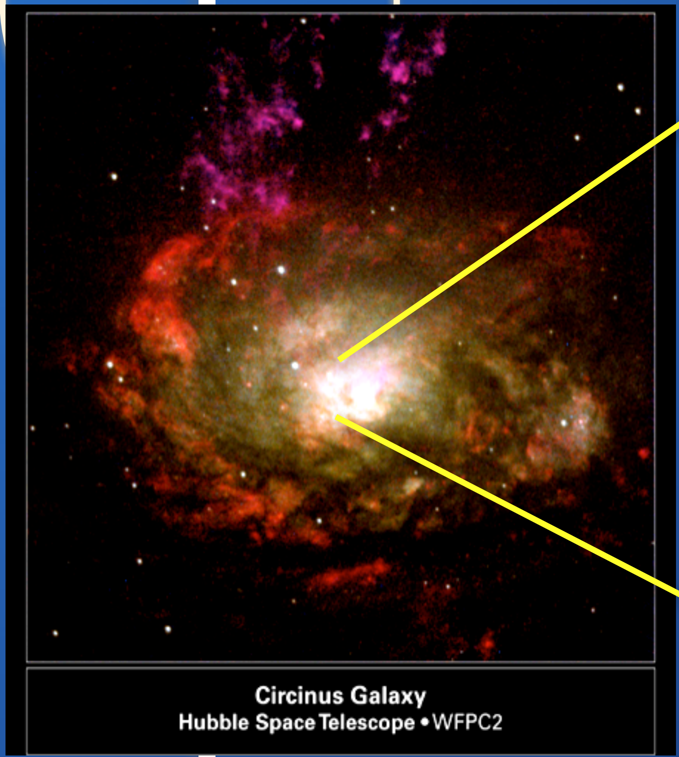
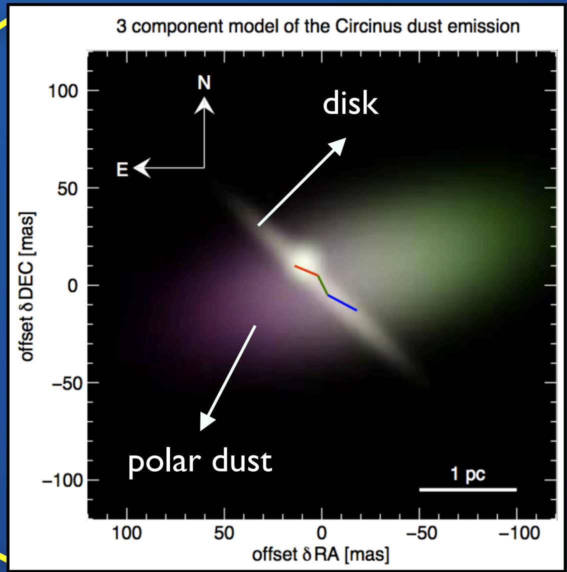
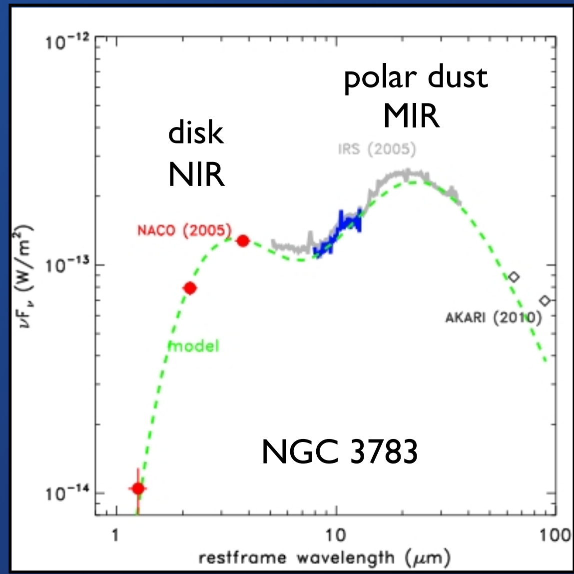


Tristram+2014

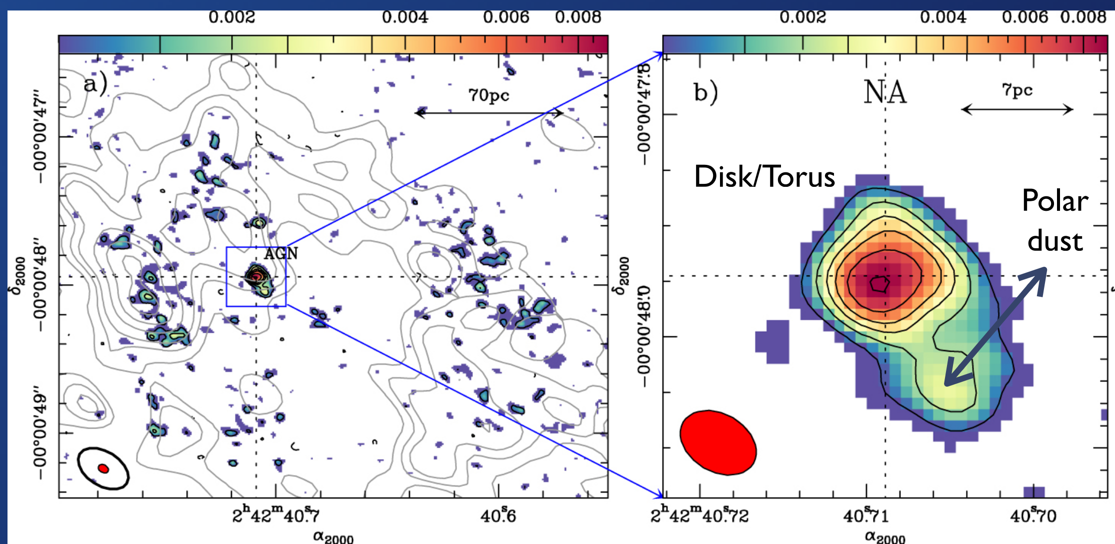


Hönig+2013



HOT/WARM DUST

García-Burillo+2016



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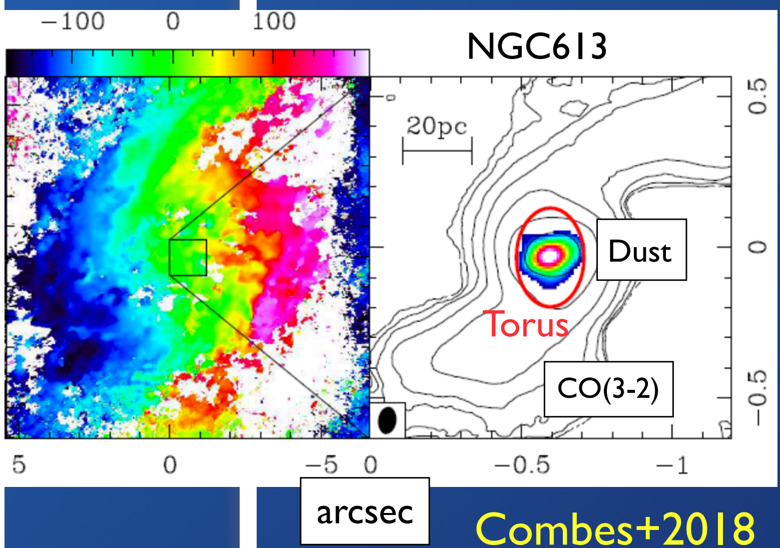


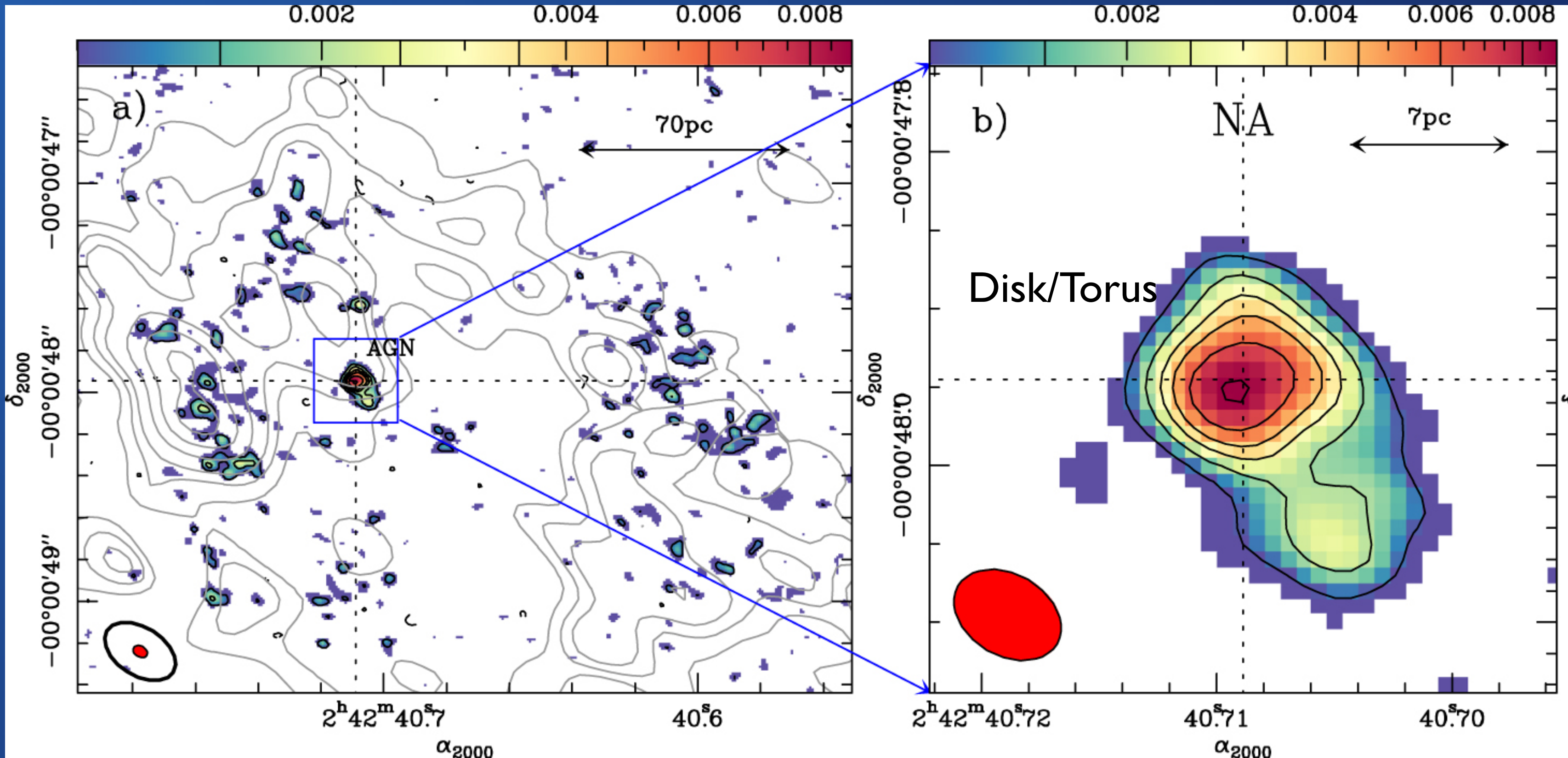
Combes+2018

First direct detection of the torus: NGC1068

Dust and molecular torus now detected in several AGN.

ALMA 432 μm view (0.05-0.07” resolution) of central 2”

- Dust and molecular gas torus (major axis 7-10 pc).
- Torus M_{GAS}~$10^5 M_\odot$
- CND (300 pc x 200 pc) with recent SF activity.



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

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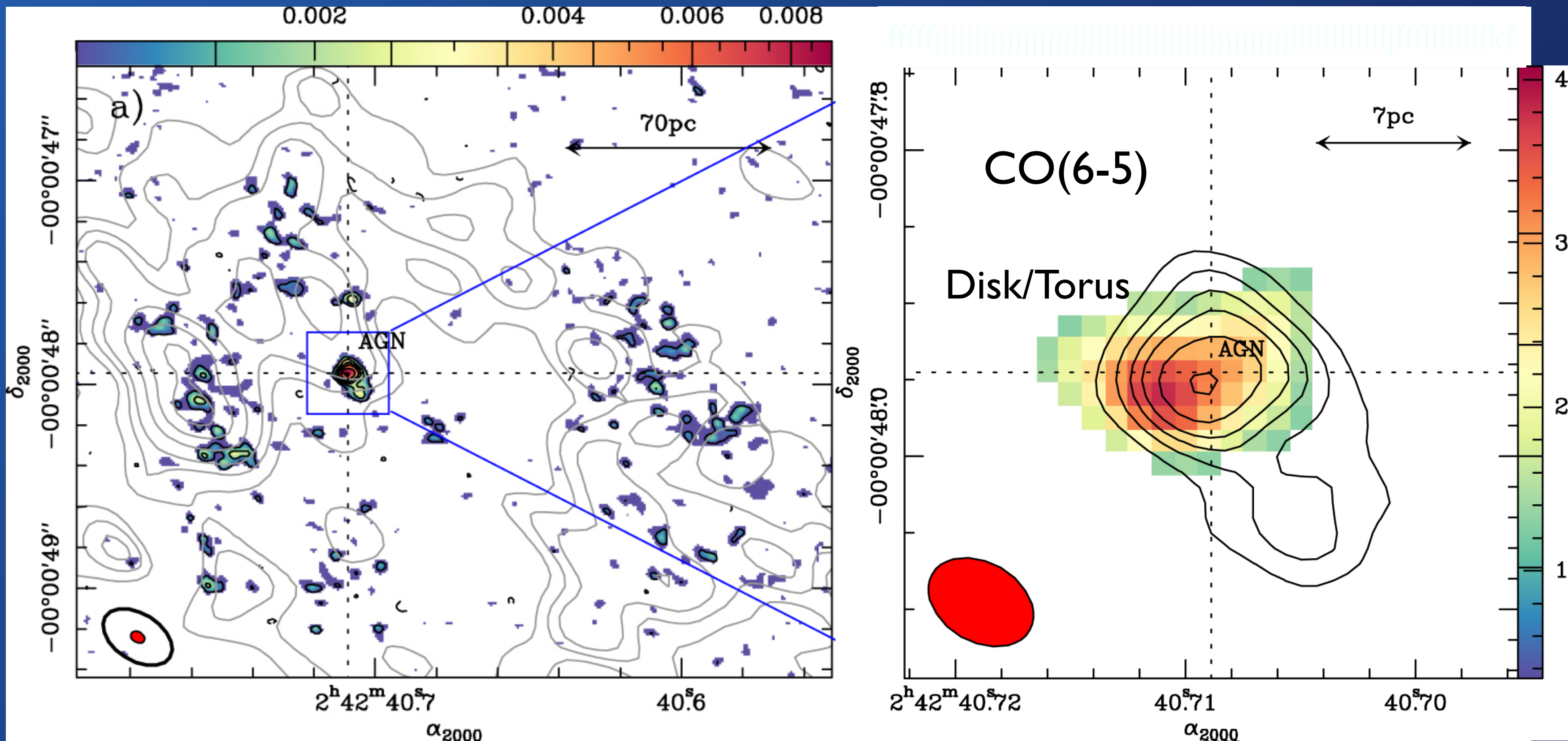


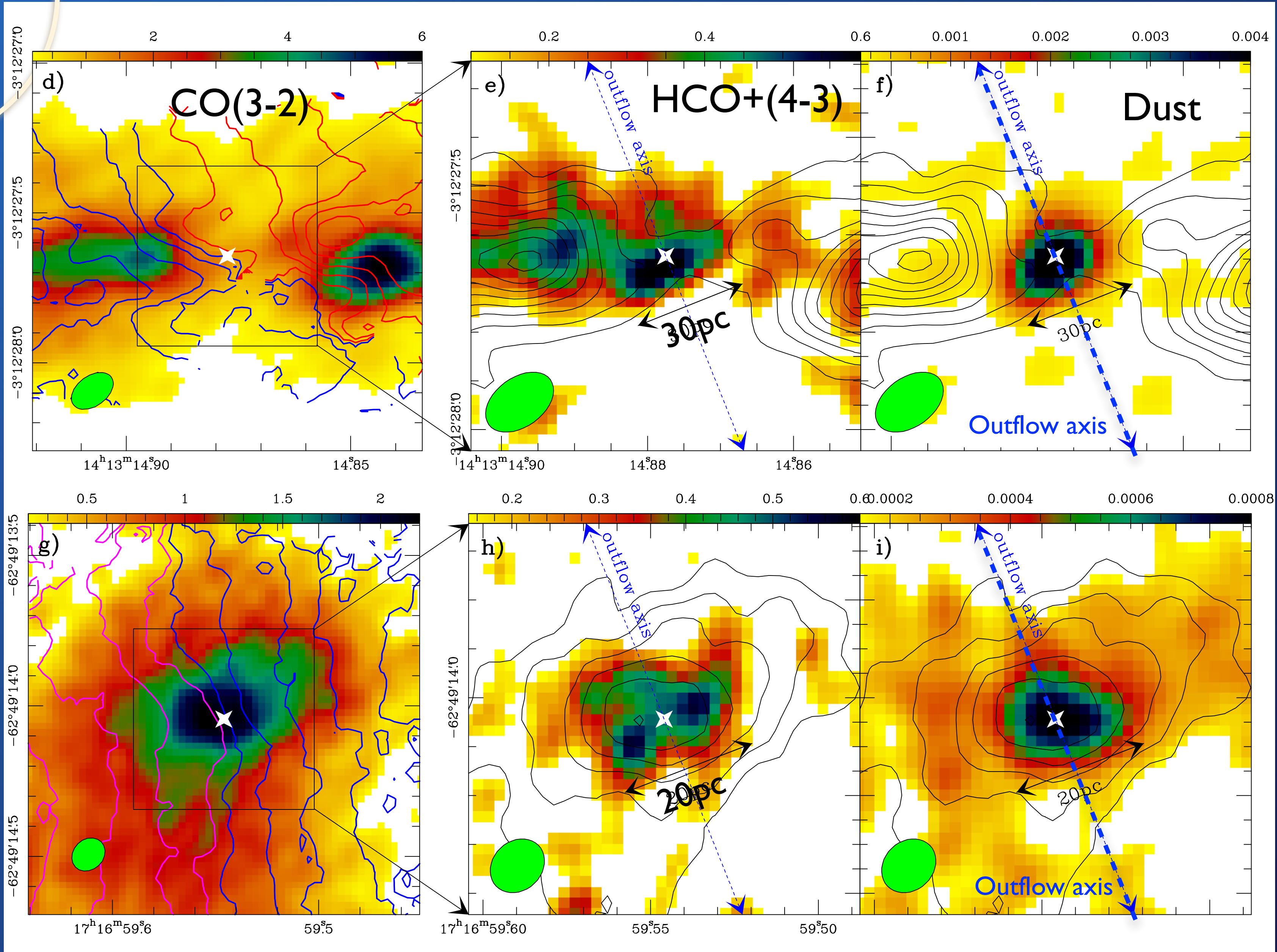
García-Burillo+2016 also Gallimore+2016; Imanishi+2016,2018

Large tori detected with ALMA

GATOS
GALACTIC ACTIVITY, TORUS AND OUTFLOW SURVEY

NGC5506

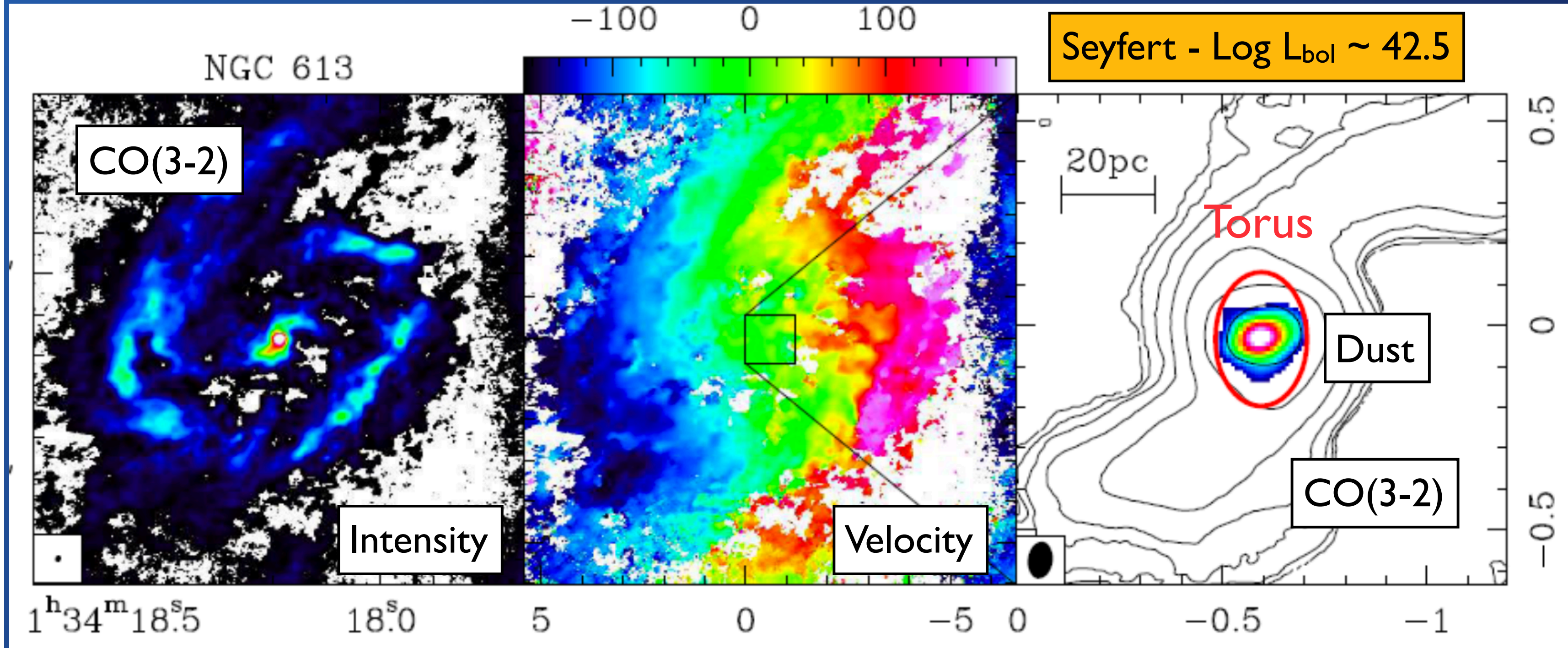
NGC6300



García-Burillo & GATOS 2019 in prep.

Large tori detected with ALMA

Galaxy	Radius (pc)	S(CO)dV Jy km/s	Mass[a] 10^7 $M_\odot$	inc(°) torus	PA(°) torus	inc(°)[b] gal	Beam (pc)	$\log NH_2$ (cm^{-2})	M_{cent} 10^6 $M_\odot$	off-centring (pc)
NGC 613	14±3	56±20	3.9±1.4	46±7	0±8	36	6.2	25.3±.001	10.	42.
NGC 1326	21±5	18±2	0.95±0.1	60±5	90±10	53	5.3	23.9±.02	0.3	21.
NGC 1365	26±3	10±3	0.74±0.2	27±10	70±10	63	6.3	23.5±.01	0.	86.
NGC 1433	–	–	–	–	–	67	2.9	23.5±0.1	0.04	–
NGC 1566	24±5	72±10	0.88±0.1	12±12	30±10	48	1.7	24.5±.01	0.1	7.
NGC 1672	27±7	80±9	2.5±0.3	66±5	0±10	28	4.0	24.3±.01	0.4	27.
NGC 1808	6±2	46±6	0.94±0.1	64±7	65±8	84	3.1	24.6±.004	0.5	58.



Combes, García-Burillo et al. 2018

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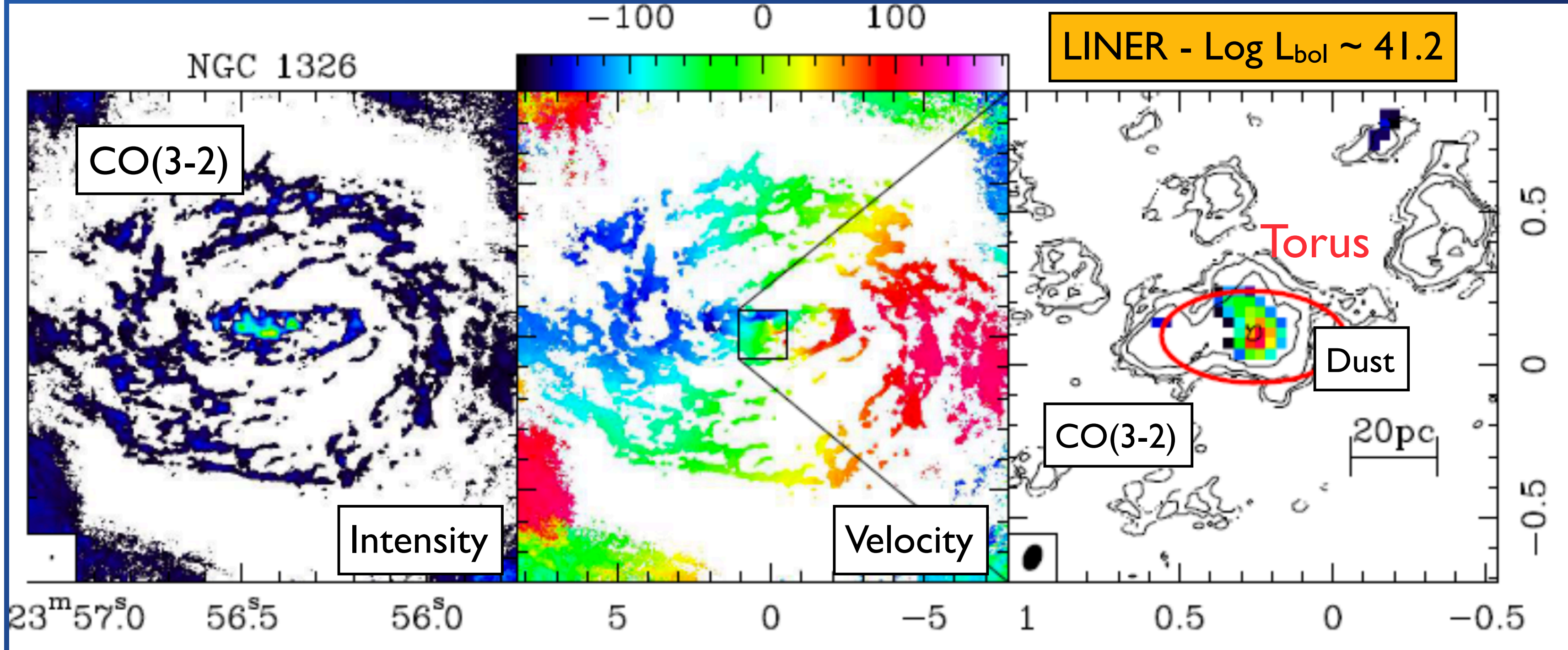
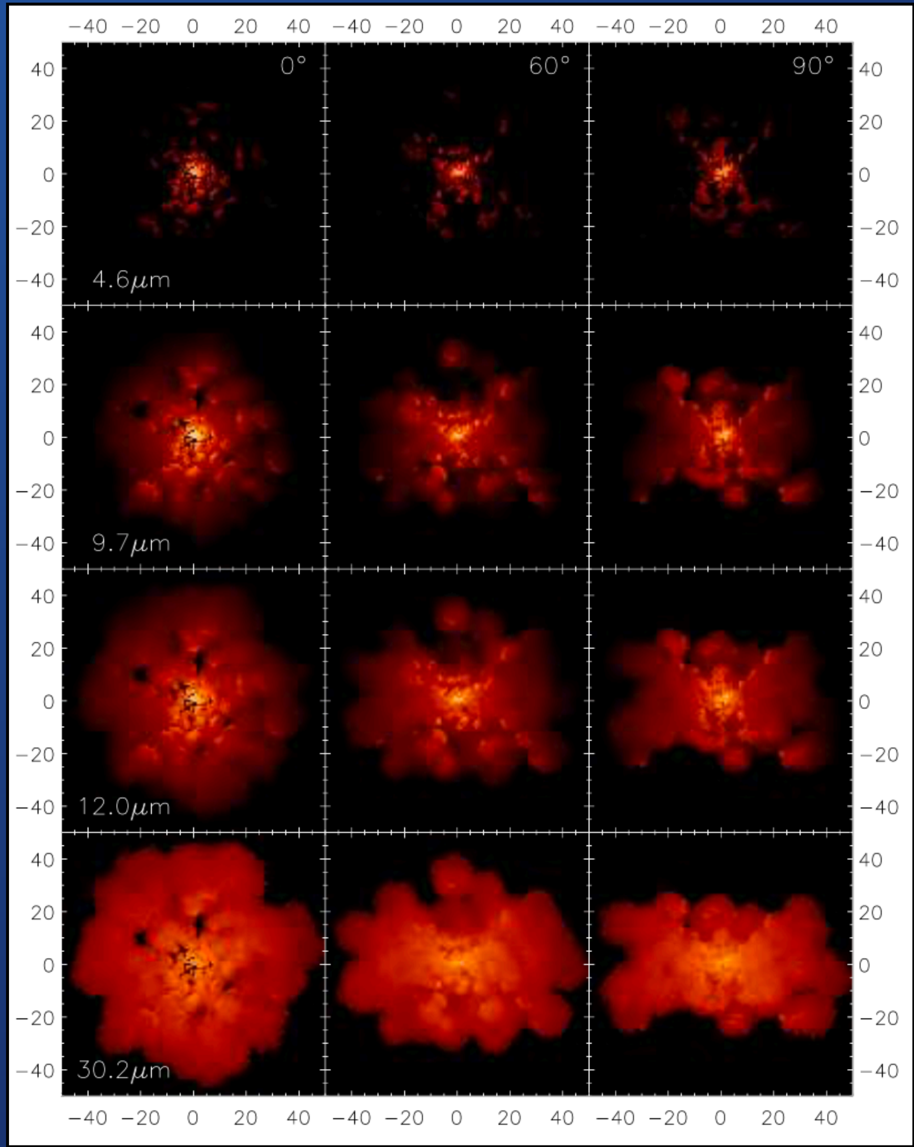


Combes, García-Burillo et al. 2018

Large vs small torus (hot vs cold)

Schartmann+2008



Near/mid-infrared
hot dust
r<10 pc

Far-infrared/sub-mm
cold dust
10<r<30

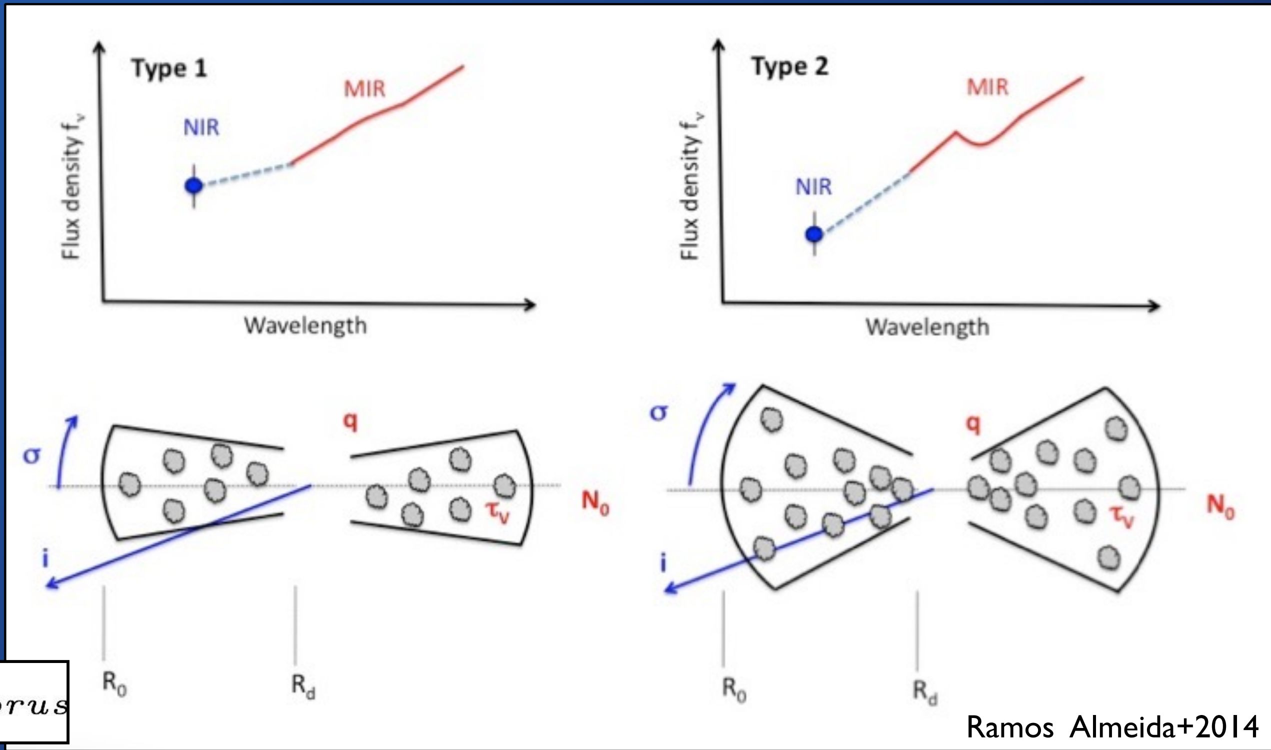
Simplest version of the AGN Unified Model

Credit: NASA WISE

with the obscuring tori having similar properties in all AGN independent of AGN luminosity, redshift, Eddington ratio, etc

Distinguishing among covering factors

- Geometrical covering factor (f_2) = function of torus angular width and number of clouds along equatorial direction.



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

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

ß=90-i

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

Elitzur 2012

Distinguishing among covering factors

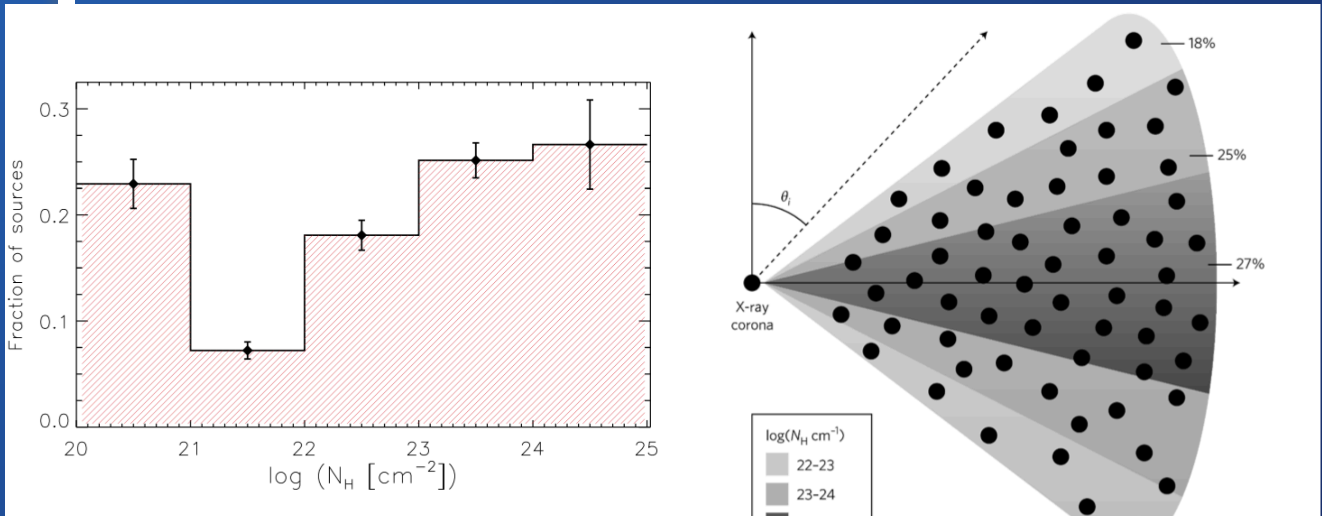
- Geometrical covering factor (f_2) = function of torus angular width and number of clouds along equatorial direction.

- Dust reprocessing efficiency-derived covering factor = $C_T \propto L_{IR}/L_{bol}$

  - Torus anisotropy needs to be accounted for (Stalevski et al. 2016).

Distinguishing among covering factors

- Geometrical covering factor (f_2) = function of torus angular width and number of clouds along equatorial direction.
- Dust reprocessing efficiency-derived covering factor = $C_T \propto L_{IR}/L_{bol}$
- Fraction of obscured AGN (f_{obs}) as proxy for the covering factor of gas+dust.



Ramos Almeida & Ricci 2017

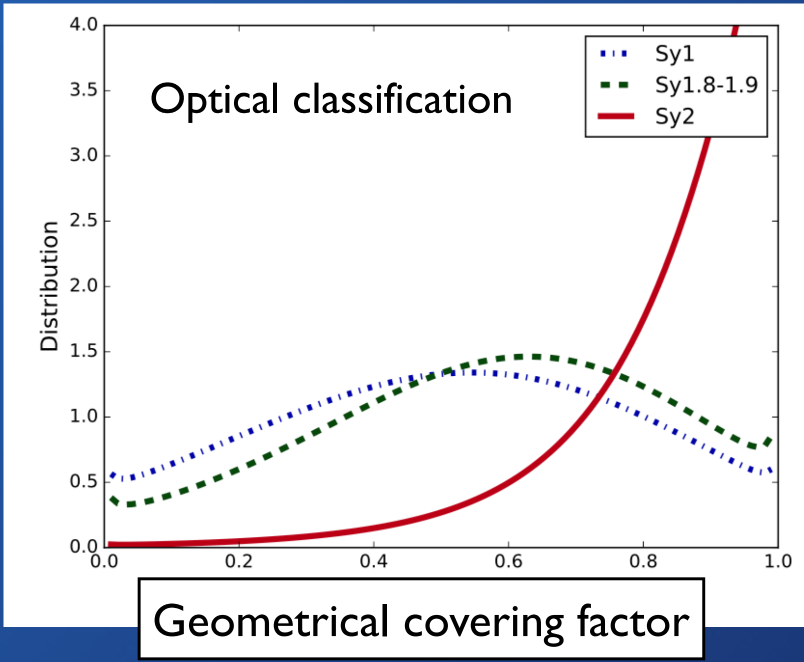
70% of local AGN obscured (Ricci+2015)

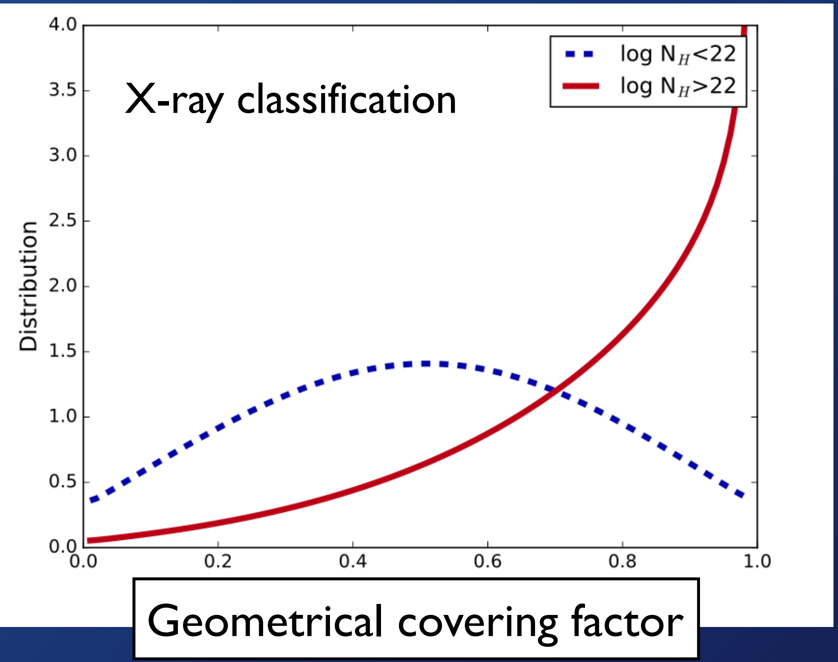
X-ray obscuration produced by multiple absorbers @different spatial scales.

f_{obs} always smaller for large column densities ($N_H > 10^{23}$ cm^{-2}) - dense gas surrounding the nuclei mostly concentrated on a thin disk (Wada 2015).

Different covering factor for Type1 and Type 2 AGN

Sy2/absorbed AGN tori have larger covering factors than Sy1/unabsorbed AGN - X-ray selected samples of AGN.





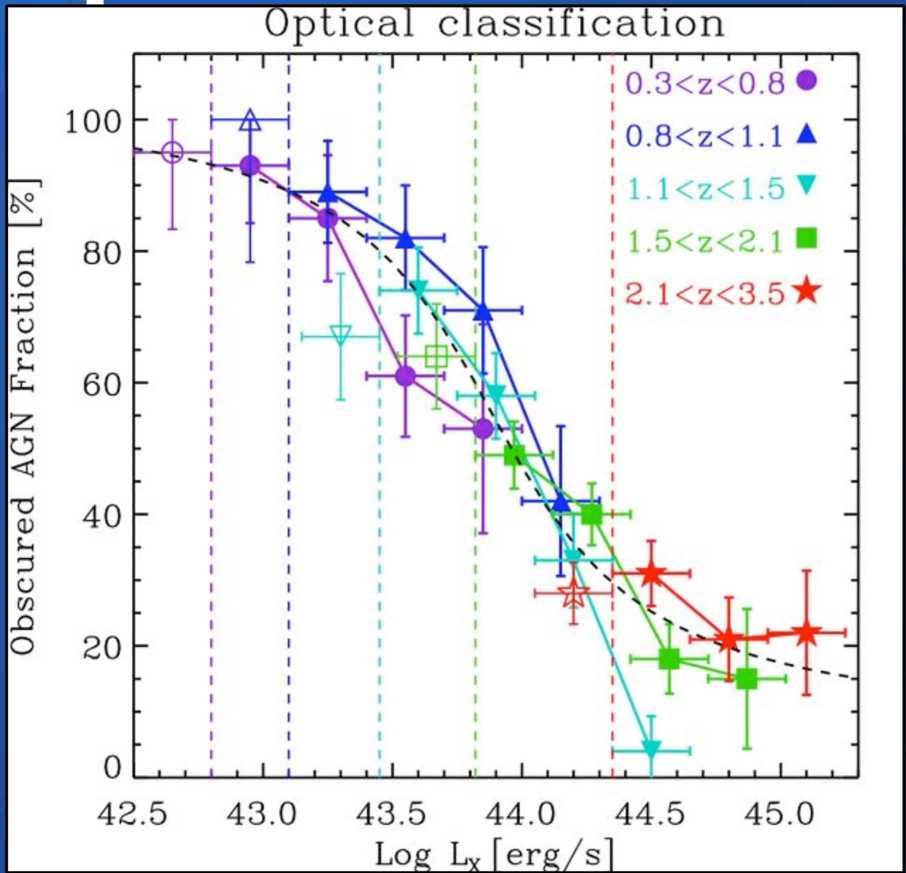
García-Bernete+2019, in preparation

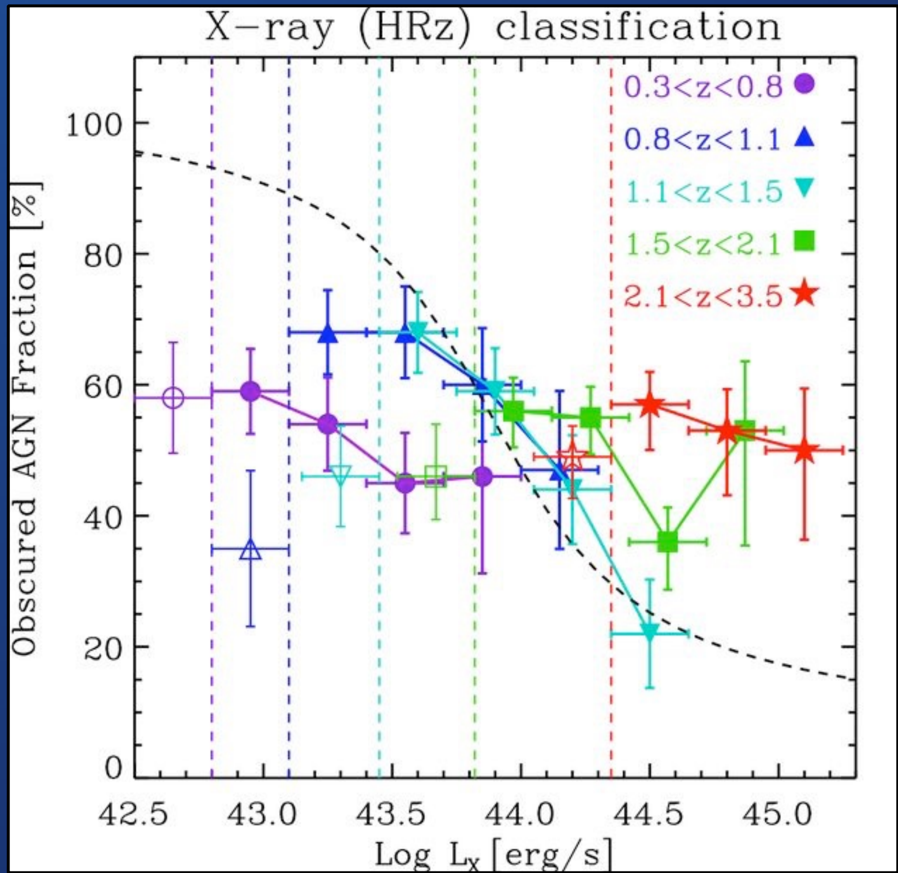
Also Ramos Almeida+2011, Alonso-Herrero+2011, Mor+2012, Ichikawa+2015, Mateos+2016, Martínez-Paredes+2017, Ichikawa+2018.

The Obscured AGN fraction

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

Dependence with AGN luminosity? with redshift?



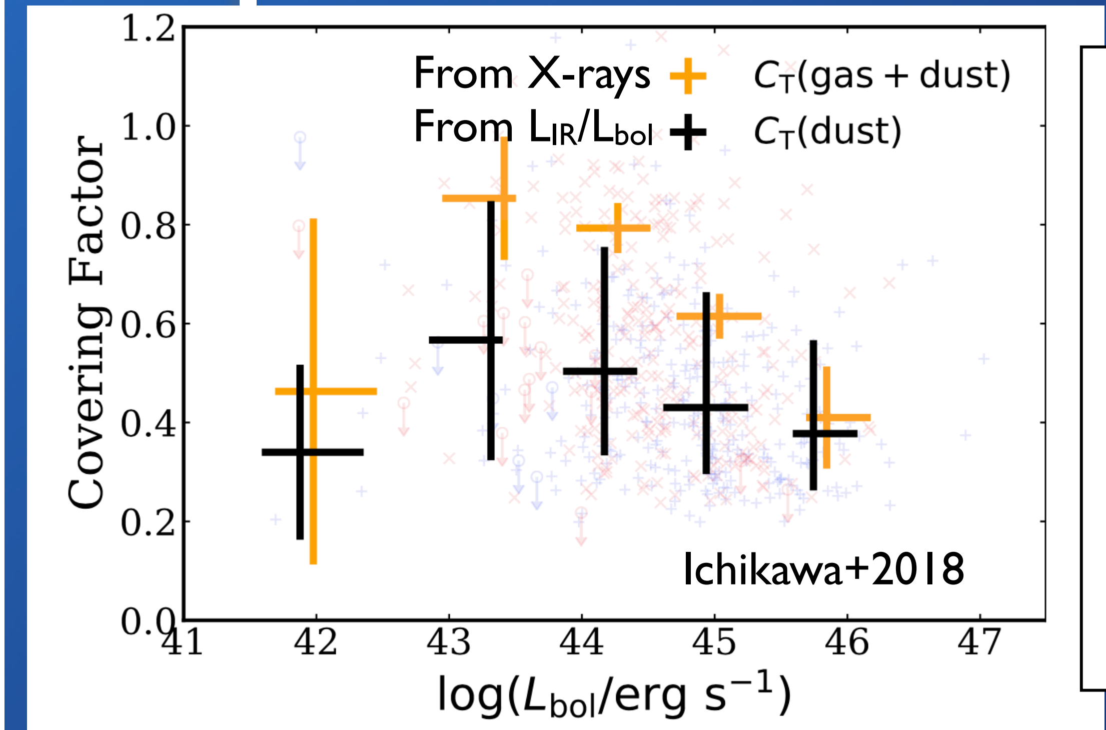


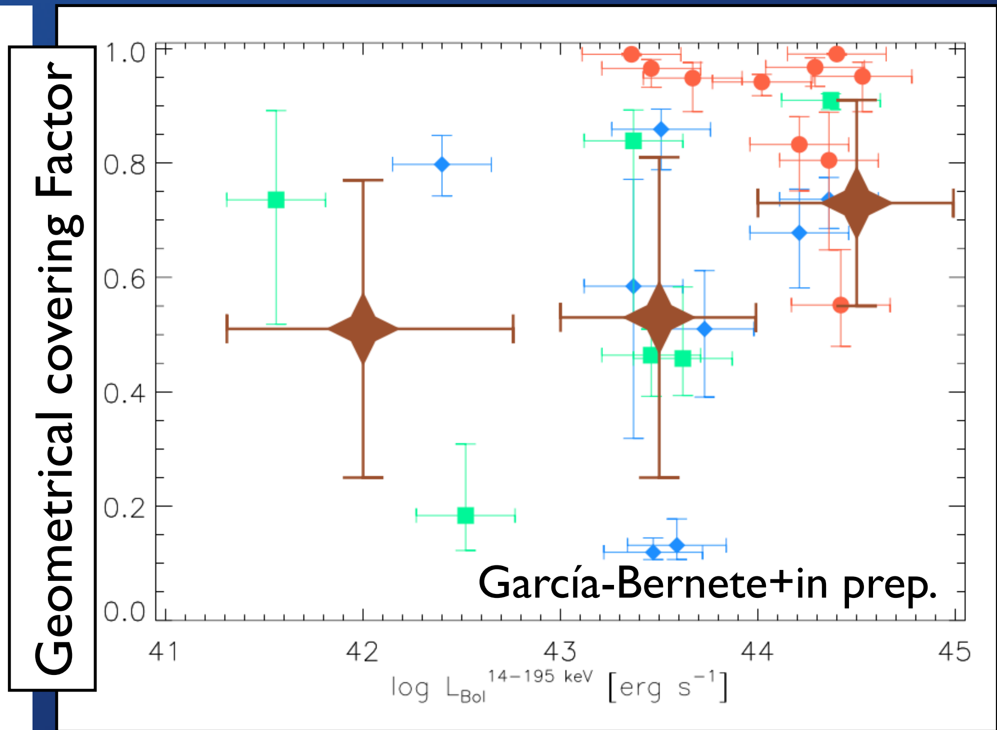
Merloni+2014 - also Lawrence & Elvis 1982, Hasinger+2005, Simpson 2005, Della Ceca+2008, Burlon+2011, Ueda+2014, Buchner+2015…

Covering Factors vs Luminosity

Samples of X-ray selected AGN: different estimations of covering factor, different sample sizes, different spatial resolutions.

Covering factor practically constant for Seyfert-like luminosities.





587 X-ray selected AGN
SED Spectral decomposition
Low-angular resolution data

24 X-ray selected AGN
Near-IR and mid-IR nuclear SEDs
High-angular resolution data

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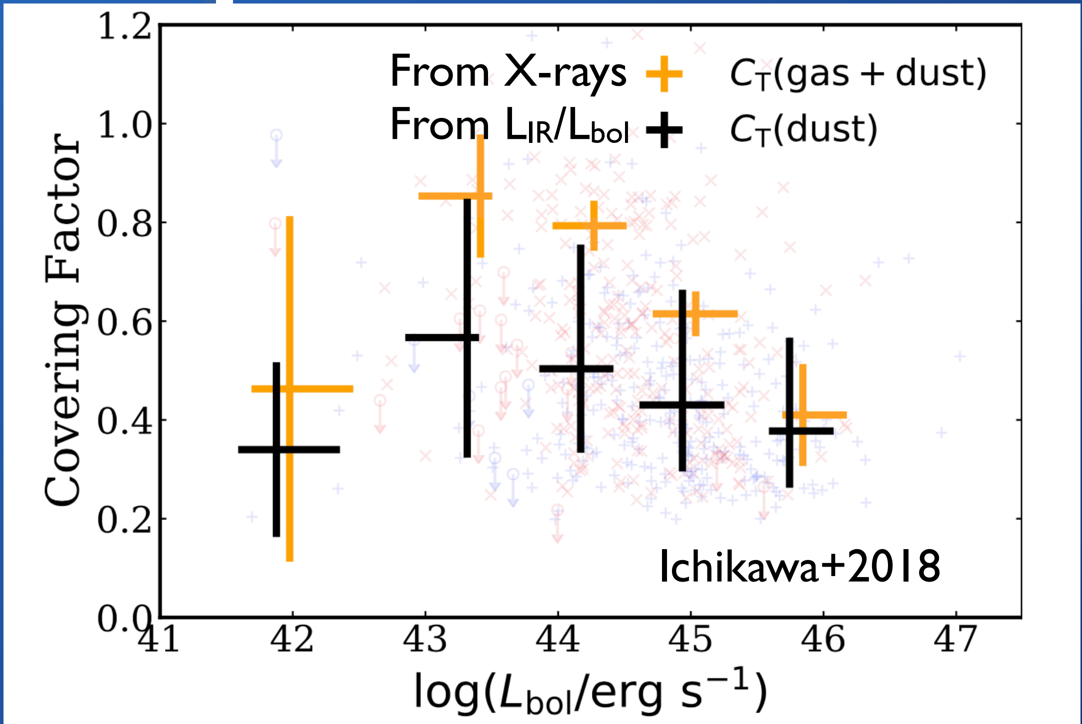
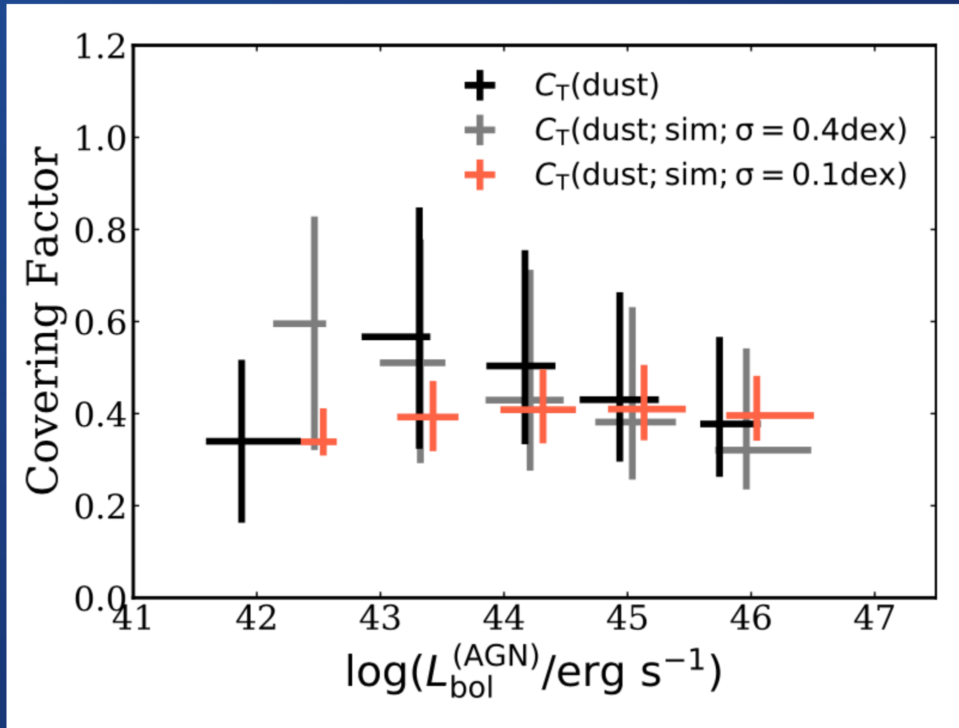




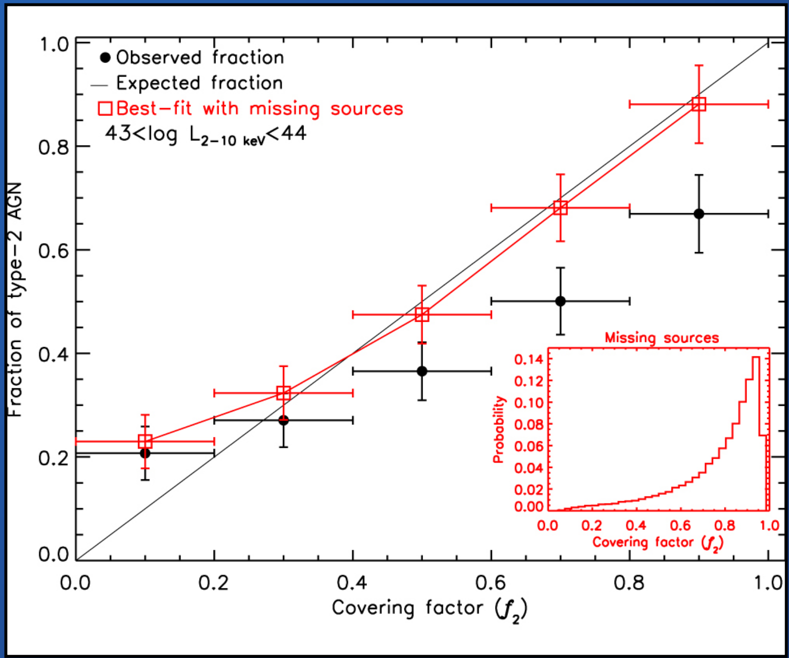
587 X-ray selected AGN
SED Spectral decomposition
Low-angular resolution data

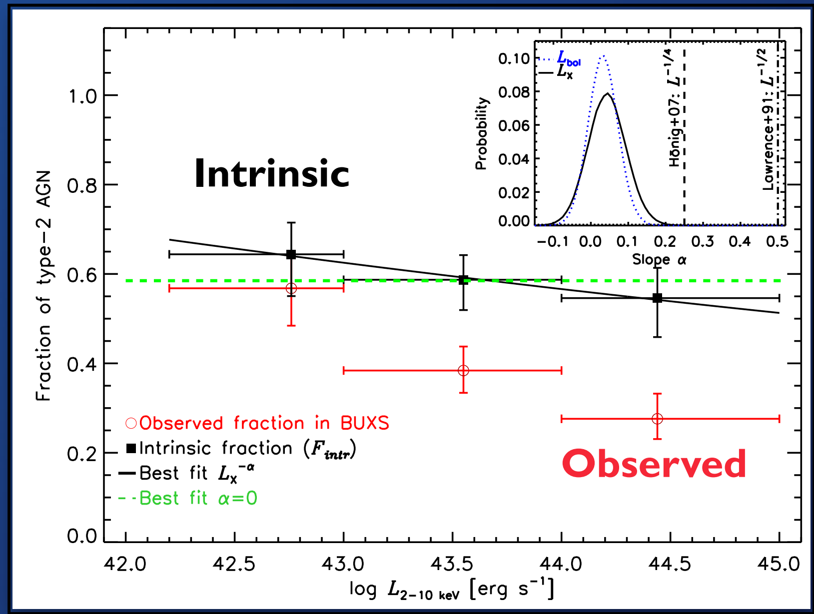
Real vs simulated data - larger scatter in L_{IR} - L_X explains luminosity dependence of covering factor.

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

Less obscured AGN at high luminosities?

Mateos+2017



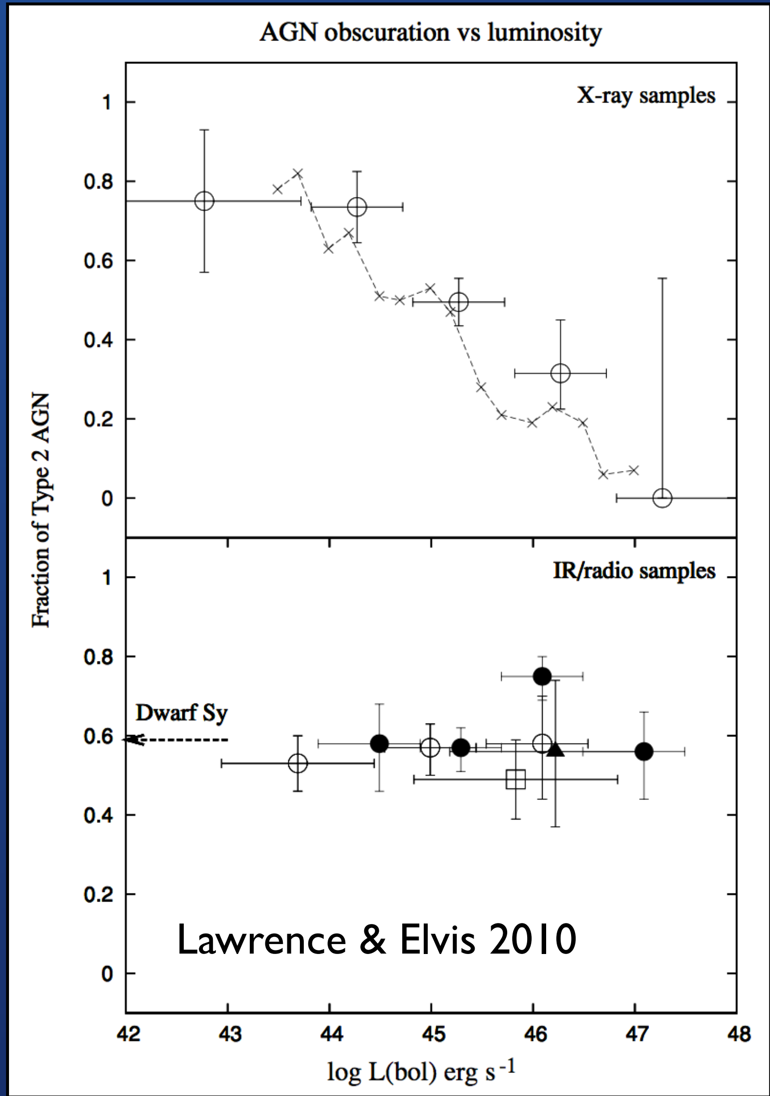


- A non-negligible fraction of X-ray undetected luminous, heavily obscured (high covering factors) type-2 AGN (at energies < 10 keV).
- Weak luminosity dependence (solid line).

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

Less obscured AGN at high luminosities?

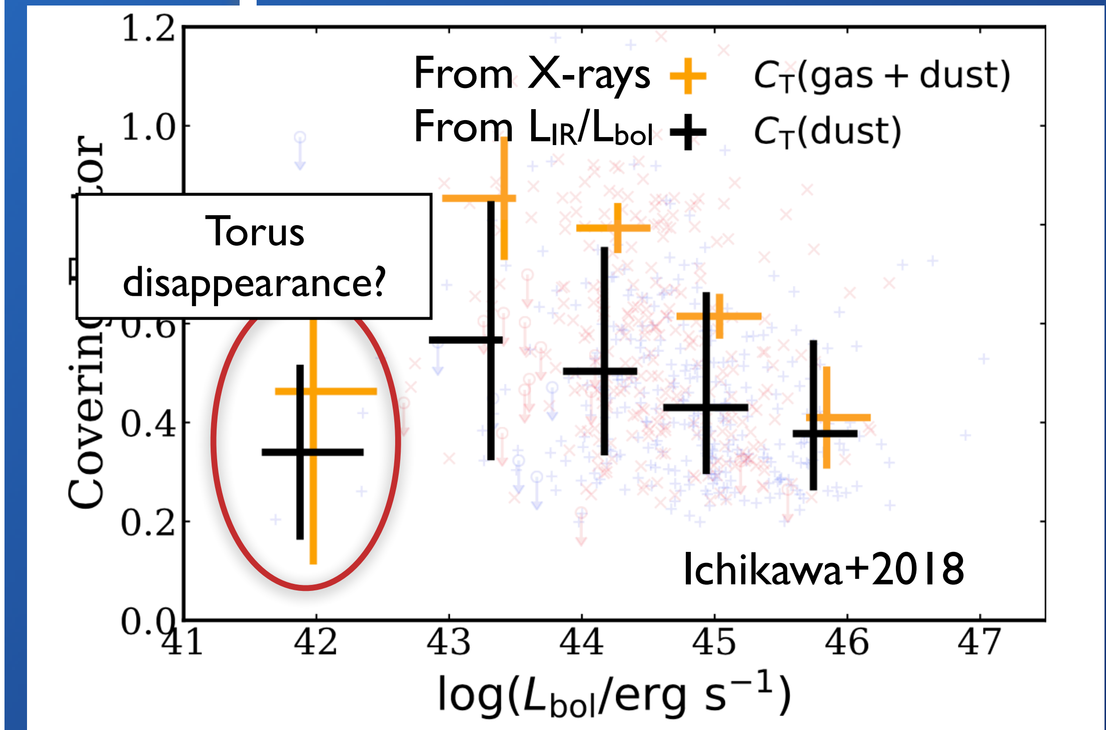
- Luminosity dependence of the obscuring fraction vanishes when using MIR-(e.g. Assef+2015) and radio-selected samples (e.g. Willott+2000).
- X-ray observations of e.g. infrared-selected samples needed to uncover missing sources.

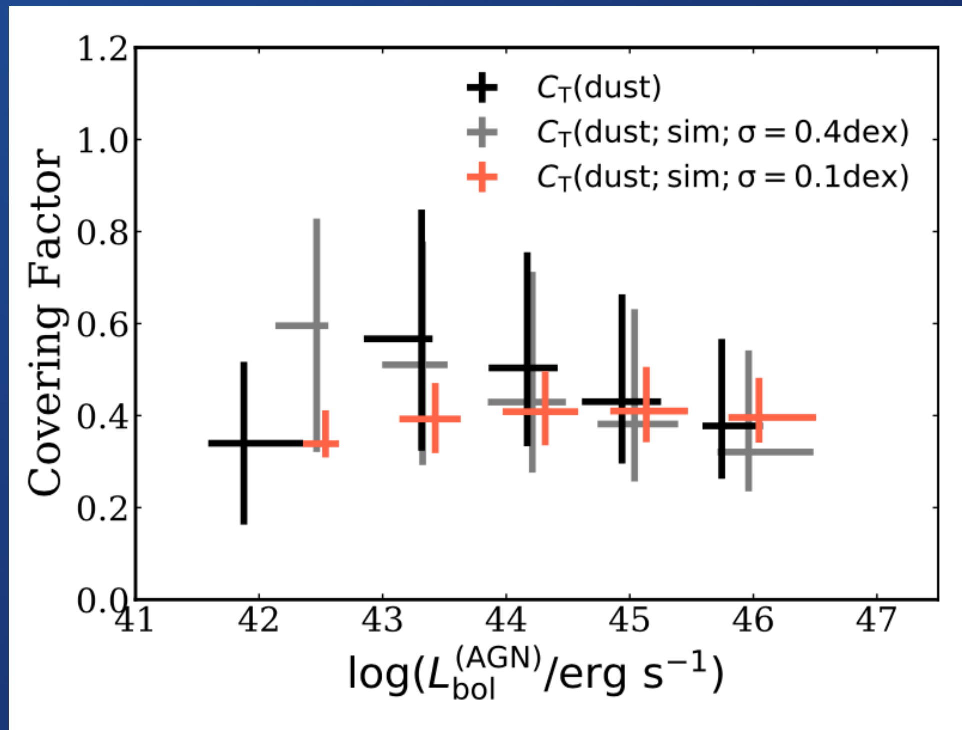


Covering Factors vs Luminosity

Complete samples of X-ray selected AGN: different estimations of covering factor, different sample sizes, different spatial resolutions.

Covering factor practically constant for Seyfert-like luminosities.

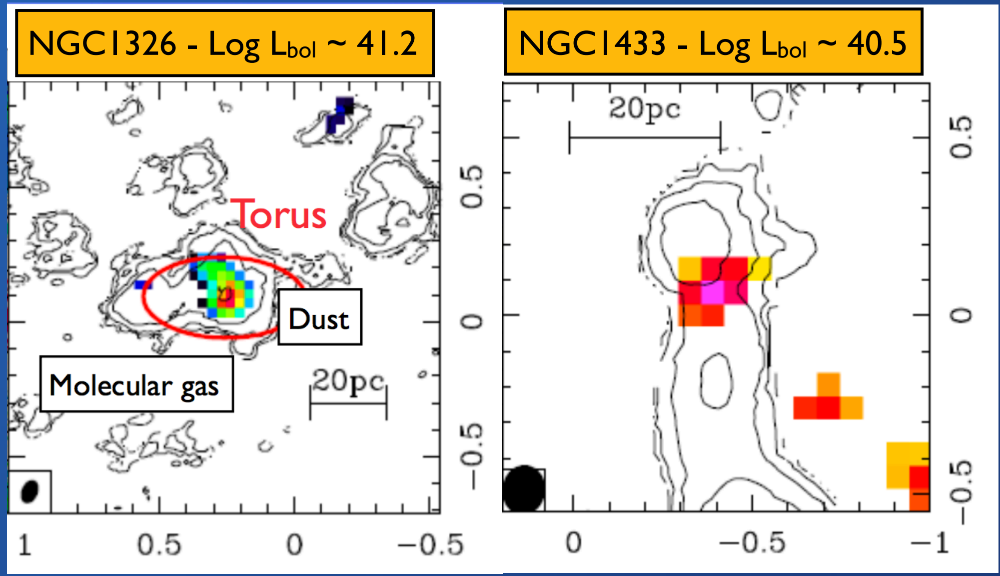




587 X-ray selected AGN
SED Spectral decomposition
Low-angular resolution data

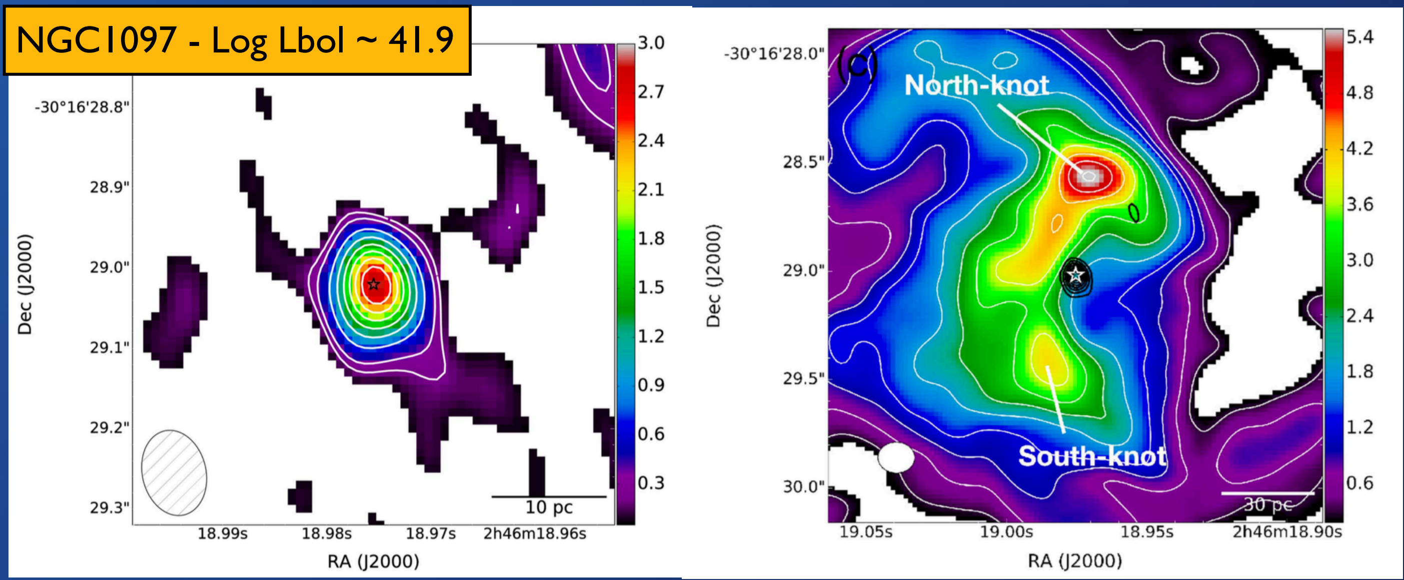
Real vs simulated data - larger scatter in L_{IR} - L_X explains luminosity dependence of covering factor.

Torus disappearance at low luminosities?



Combes+2018

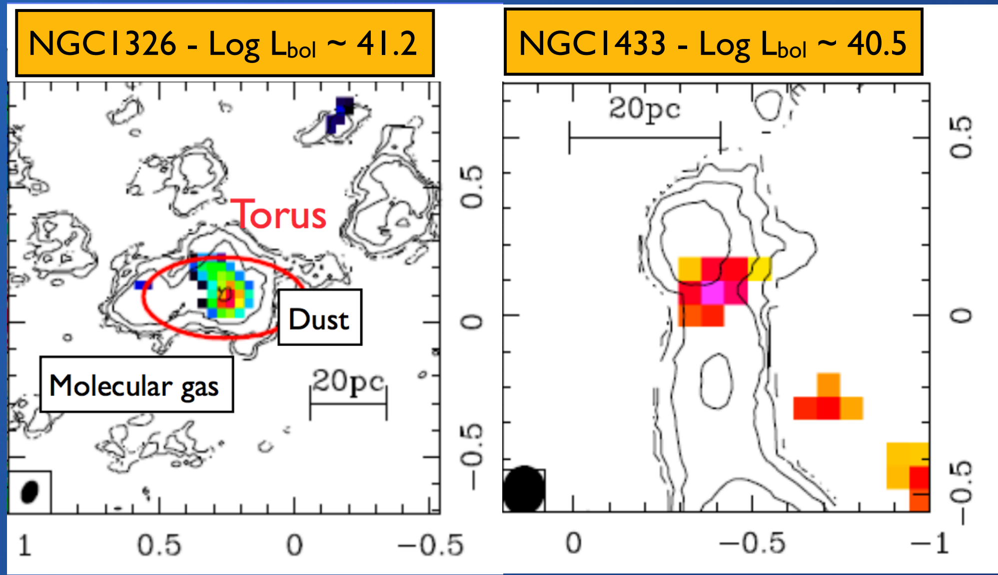
Izumi+2017



Band 7 continuum

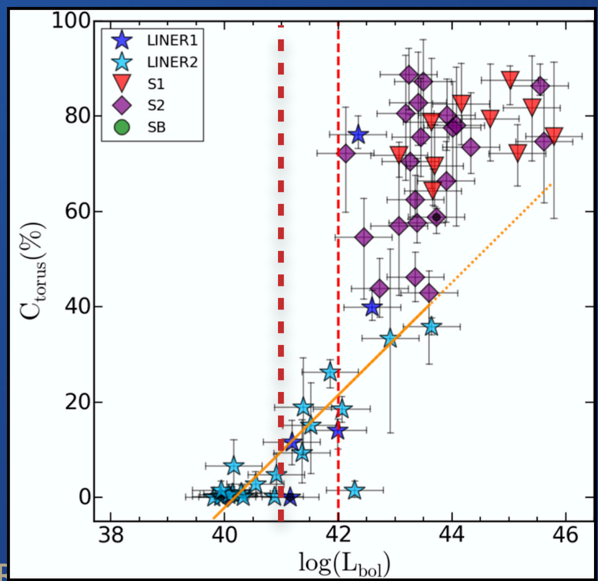
CO(3-2)

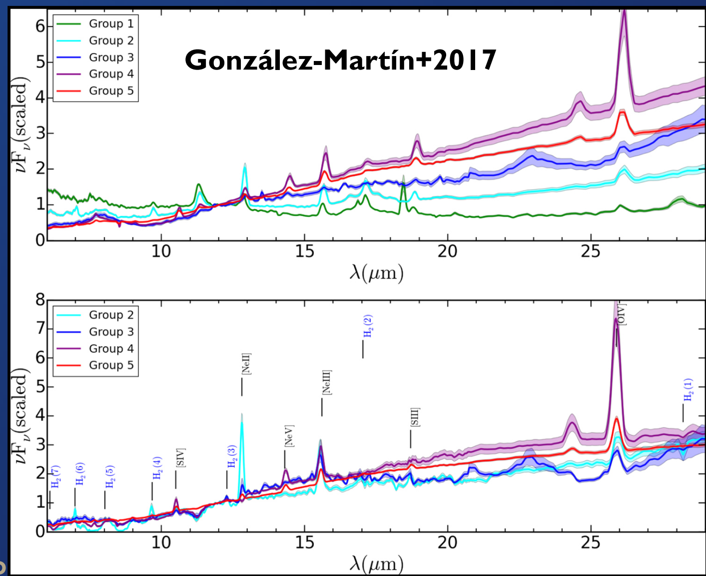
Torus disappearance at low luminosities?



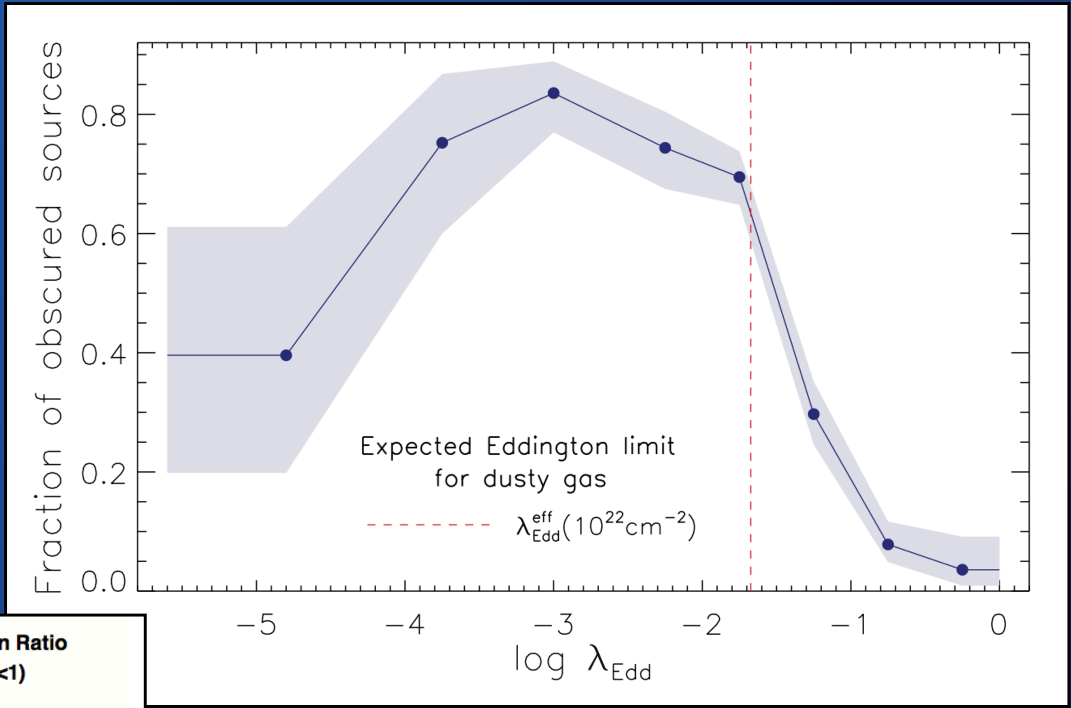
Combes+2018

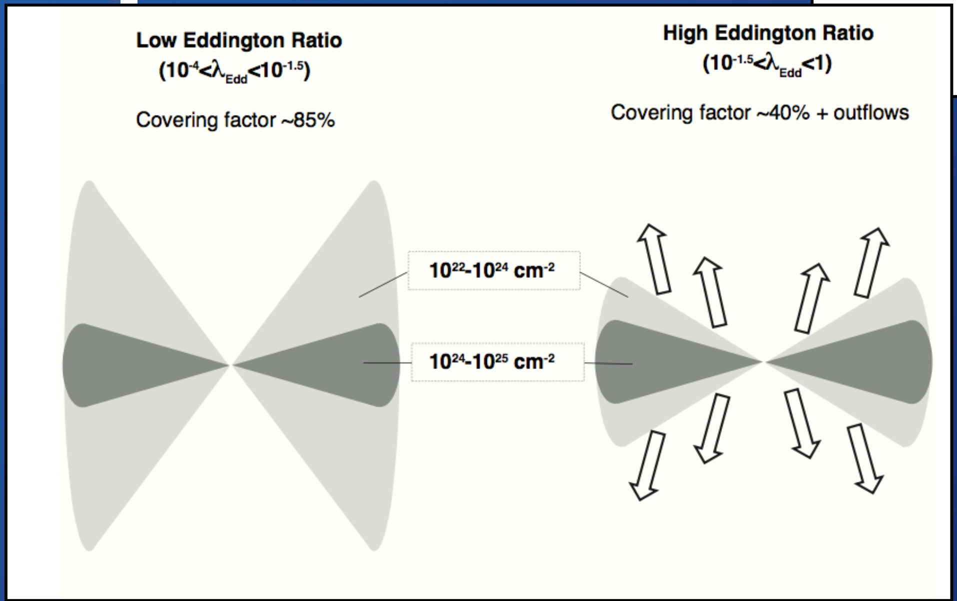
Consistent with MIR studies of low-luminosity AGN (González-Martín+2015, 2017) - no torus below Log L_{bol} ~ 41 — lower L_{bol} than theoretically predicted (Elitzur 2012).





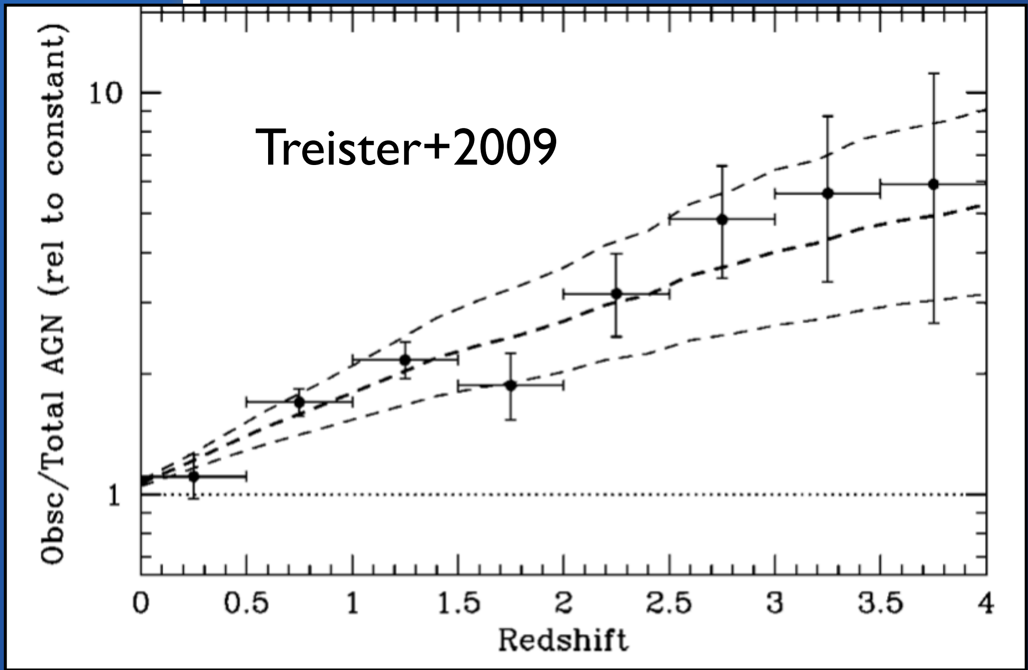
Eddington ratio dependence of the covering factor

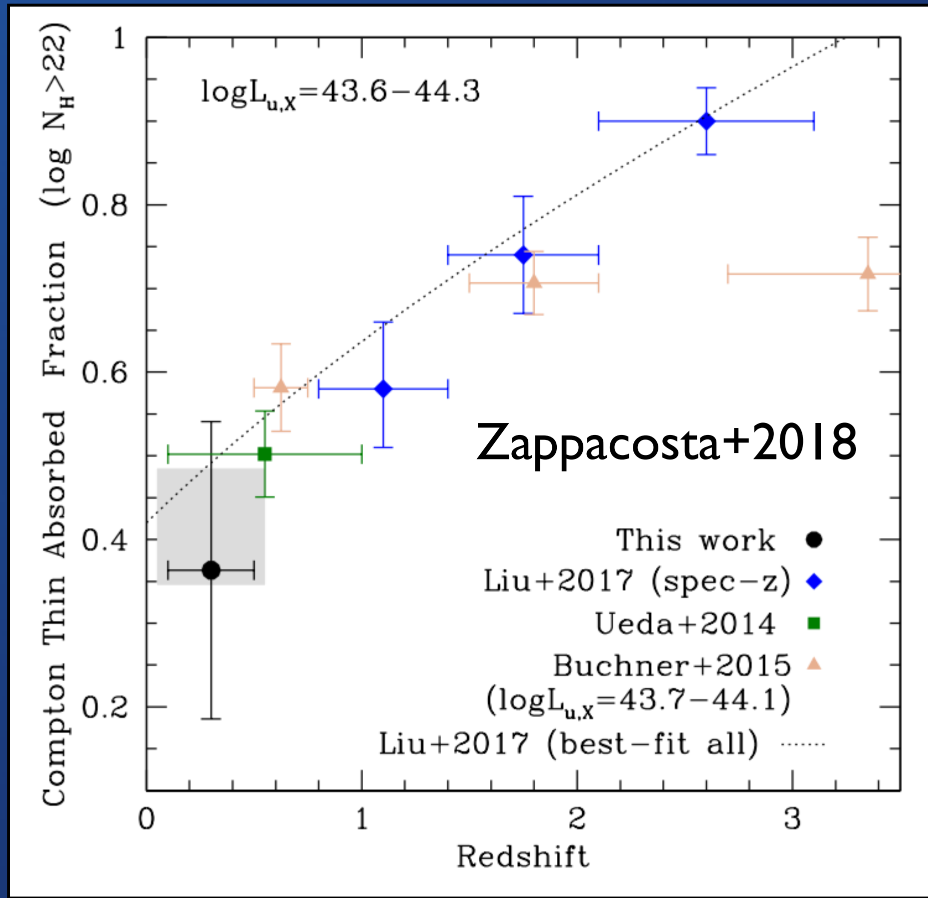




Ricci+2017, Nature

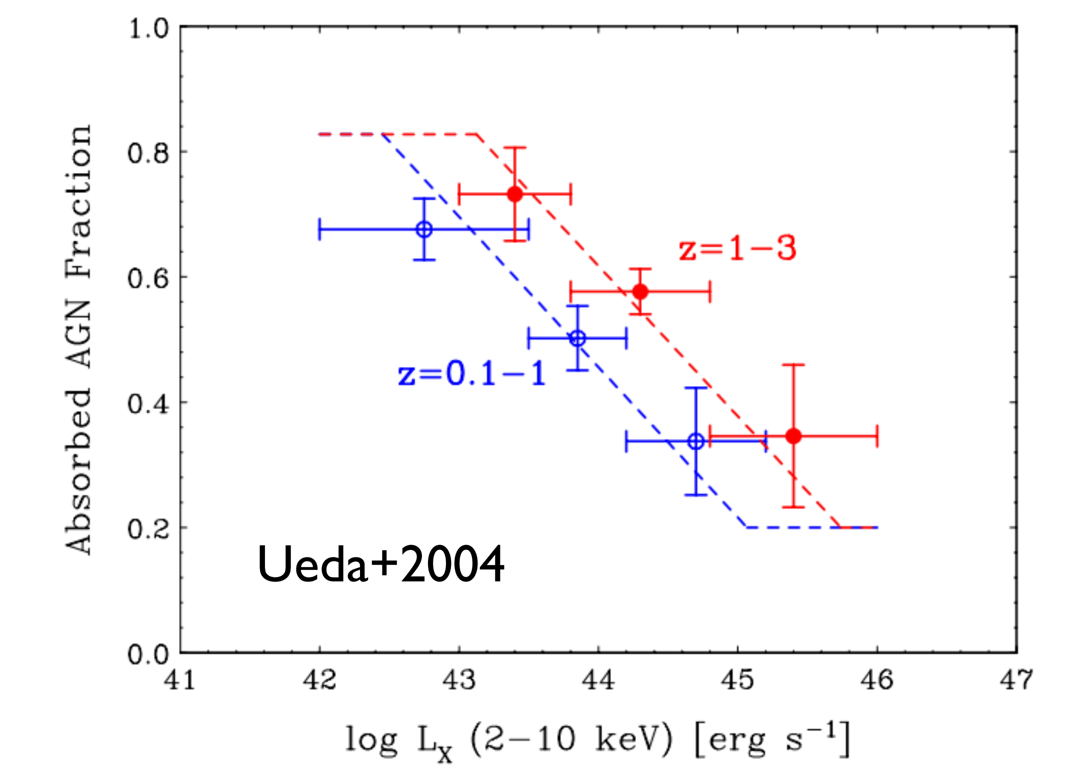
Redshift dependence of the covering factor

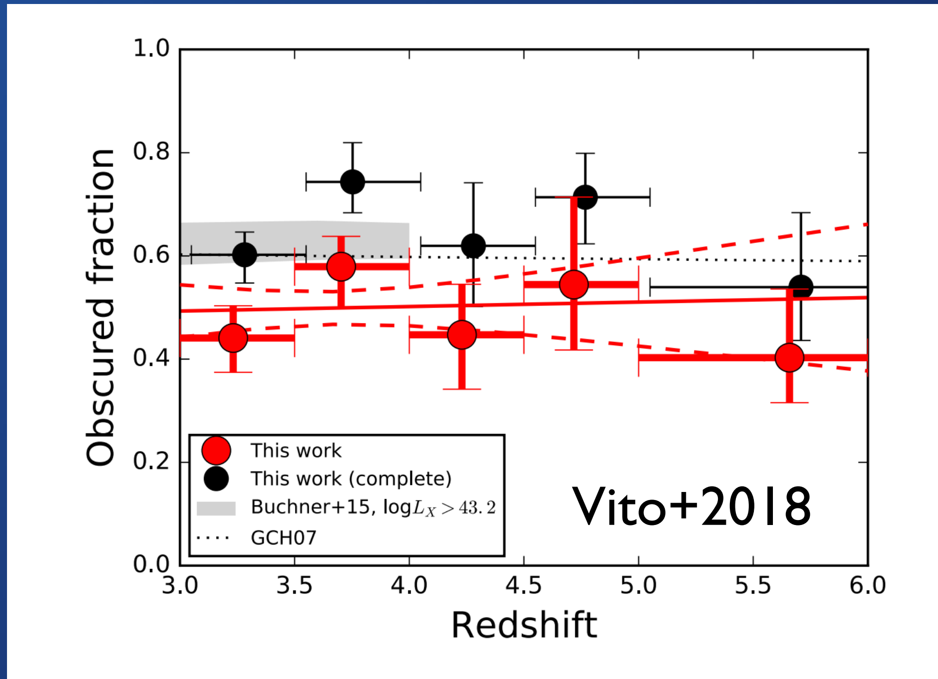




The intrinsic fraction of obscured AGNs increases with redshift.

Redshift dependence of the covering factor



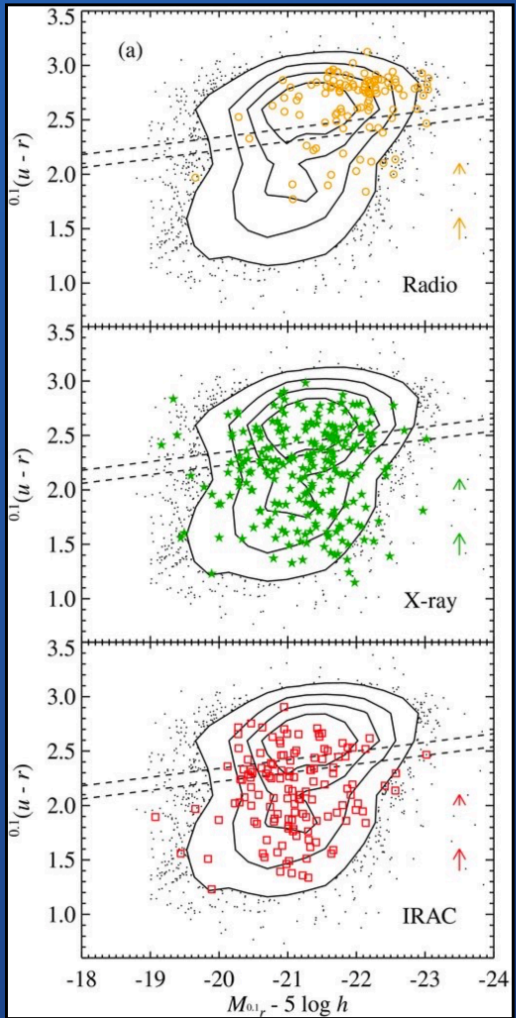


No significant evolution from z=3 to z=6

The intrinsic fraction of obscured AGNs does not increase with redshift.

Host galaxy dependence of the covering factor

- Different sample selection implies different host galaxies — different SMBH stages?

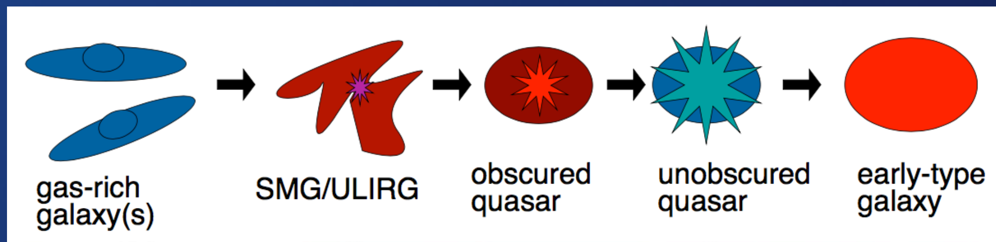


Hickox+2009

- Radio-loud AGN - massive ellipticals.

- X-ray AGN - higher fraction of spiral galaxies as compared to optically-selected AGN (Koss+2011).

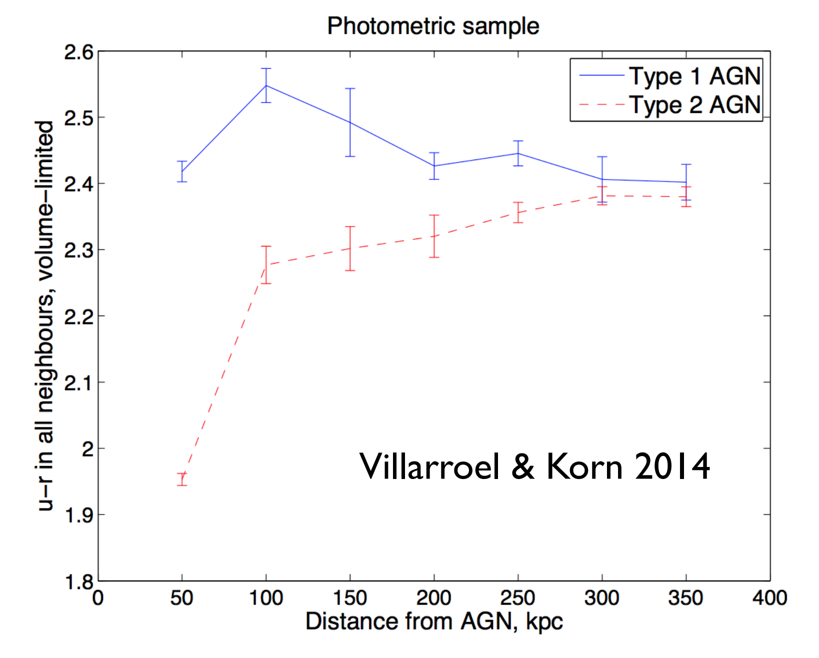
- IR AGN - less massive galaxies, more mergers = highly obscured AGN (Donley+2018).



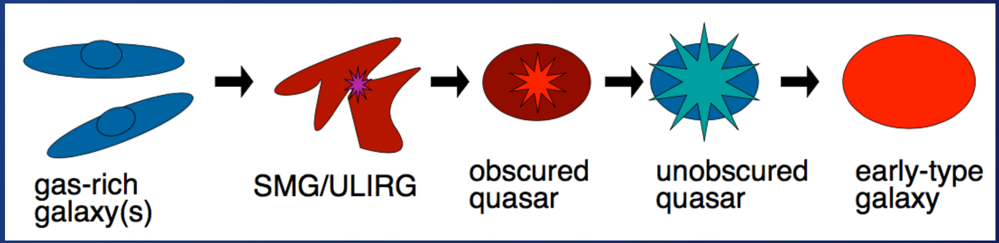
Alexander & Hickox+2012

Host galaxy dependence of the covering factor

- Host galaxy and environment playing a role in AGN classification (Donoso+2014, Villarroel & Korn 2014, Kouloudiris 2014, Trippe+2014, Bitsakis+2015, Villarroel+2017).

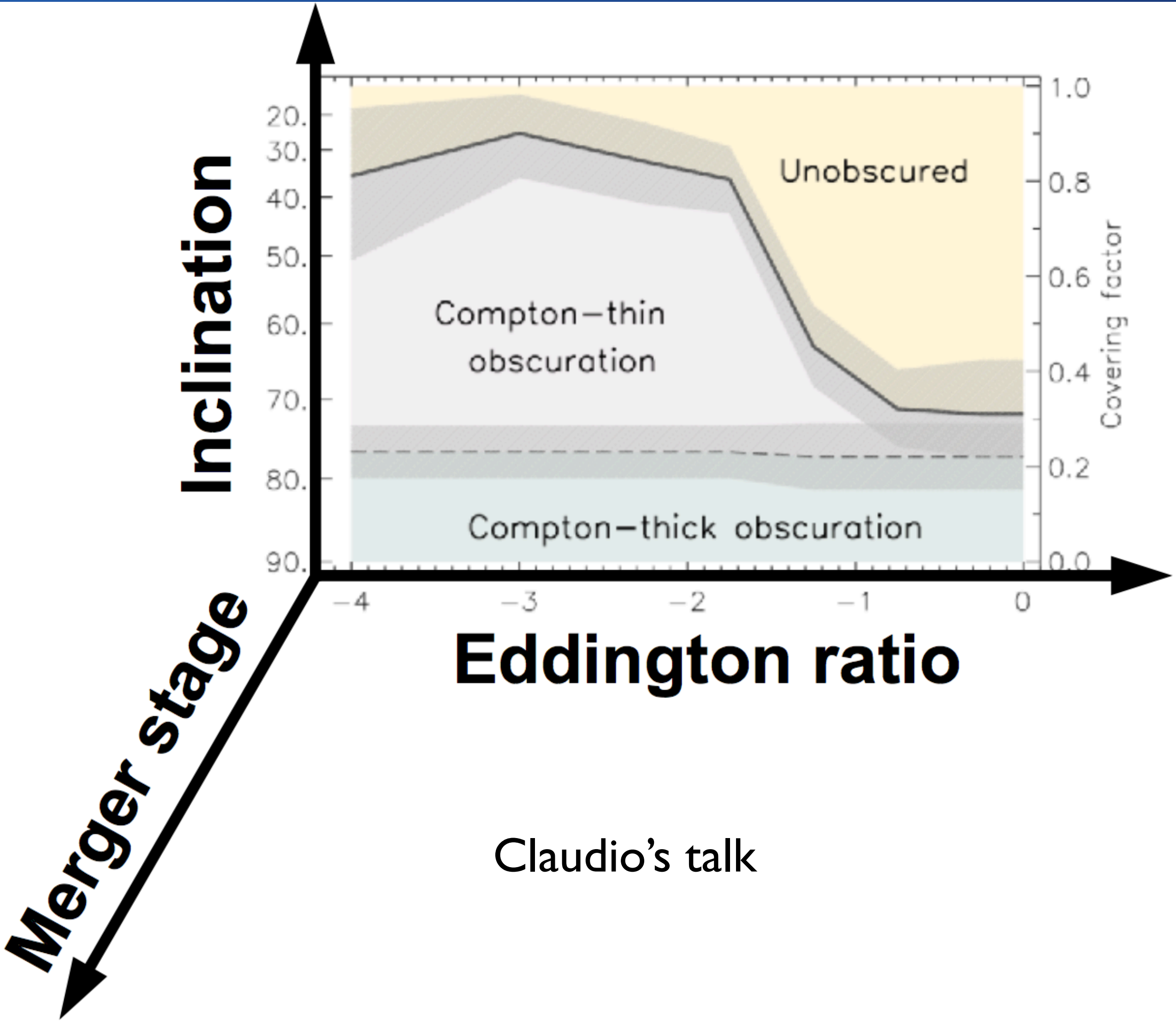


Type-1/type-2 different phases of AGN evolutionary sequence.



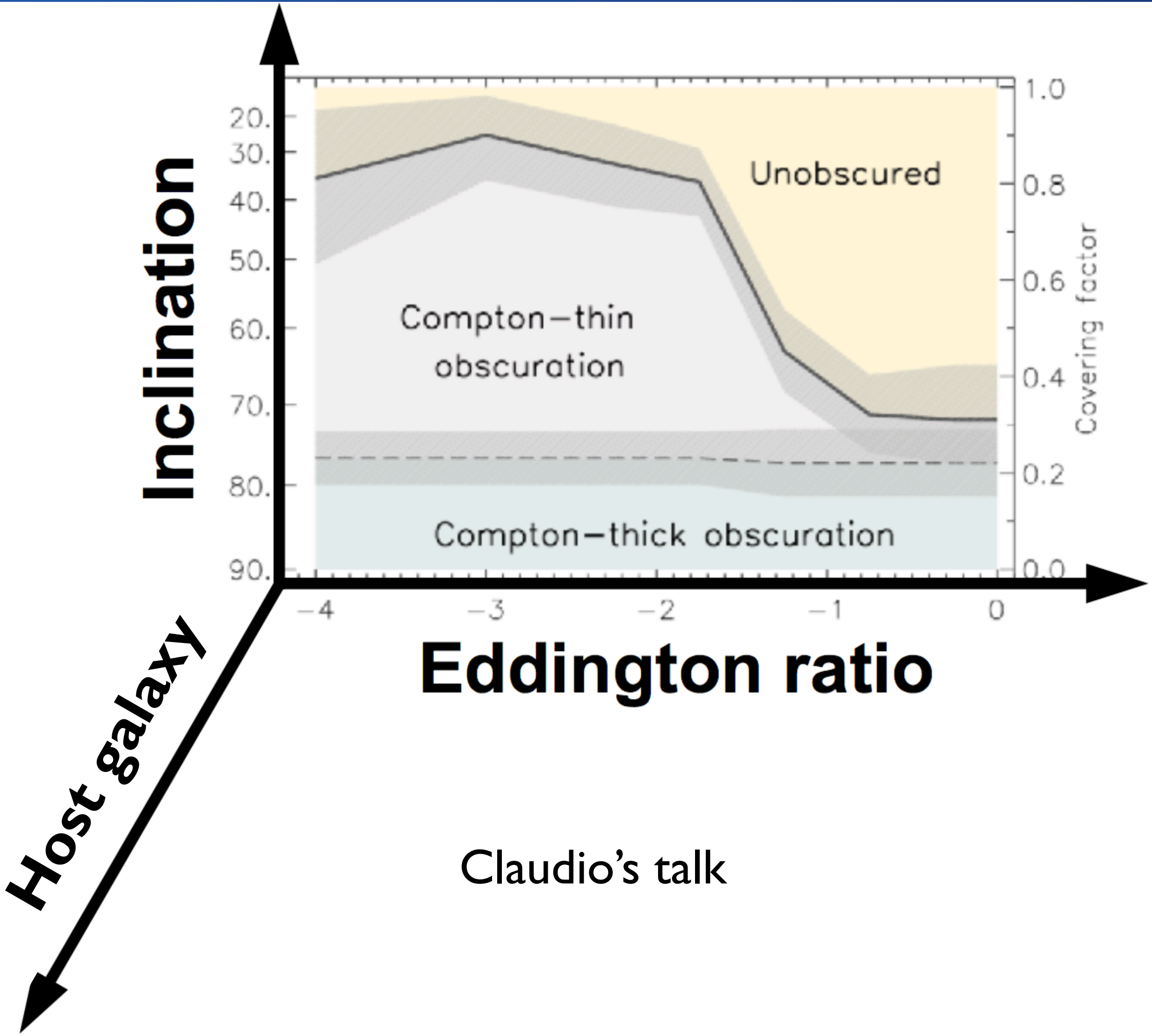
Alexander & Hickox+2012

Host galaxy dependence of the covering factor



Claudio's talk

Host galaxy dependence of the covering factor

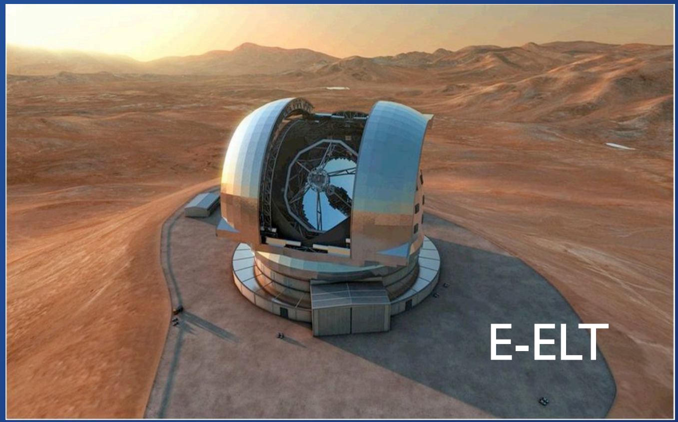


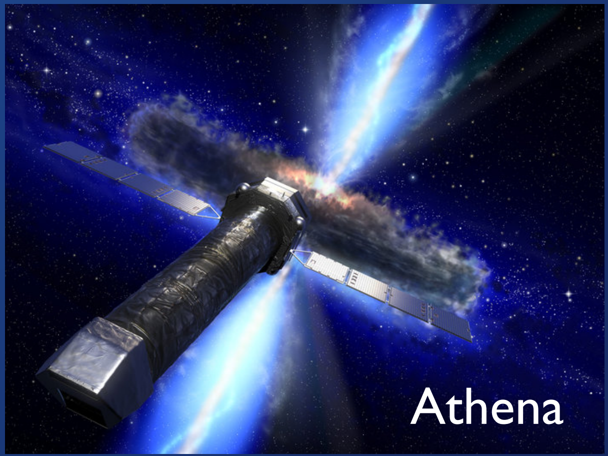
Claudio's talk

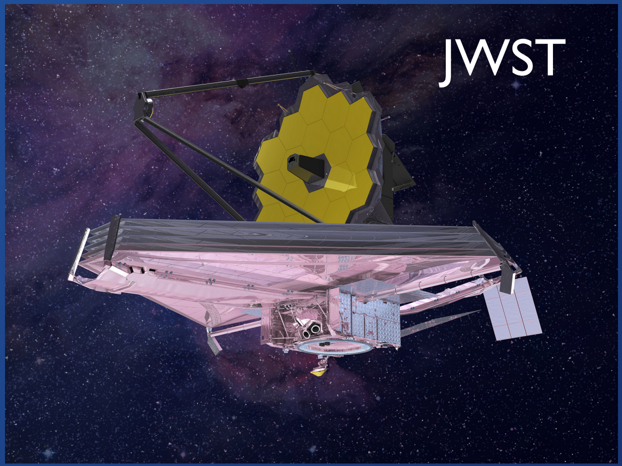
What's next?

- Statistics needed to infer general torus properties (X-ray and IR-selected samples with covering factors derived in different manners).
- Detailed studies of nearby AGN required to improve our understanding of torus physics.
- ALMA observations of AGN (dust continuum, molecular & neutral gas) to understand the multi-phase nature of the torus.
- Matched control samples/twin galaxies to study the properties of dust and gas - need to understand the duty cycles.

The future







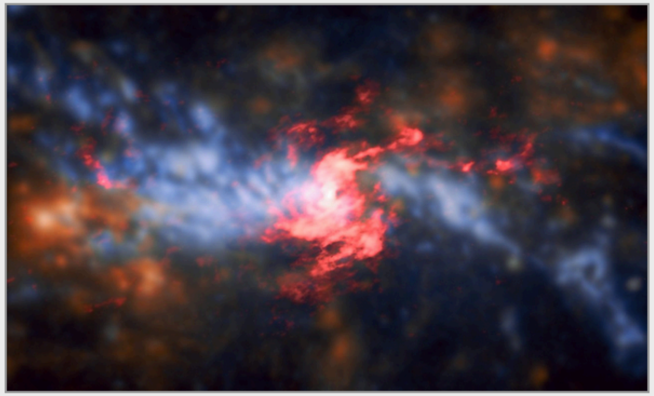
ewass Lyon 2019

Symposium S5

24-25 June 2019

The ALMA view of nearby AGN: lessons learnt and future prospects

Aims and scope



It is now well established that growing supermassive black holes (SMBHs) play a fundamental role in the evolution of their host galaxies. Feedback from active SMBHs can affect the galaxies interstellar medium in various forms: consuming, heating, sweeping out and/or disrupting the gas available to form new stars. Unfortunately, directly studying the influence of active galactic nuclei (AGN) feedback on galaxy evolution is extremely challenging because of the short timescales of nuclear activity. Therefore, to directly probe the AGN-host galaxy connection we need to look at the structure and kinematics of the parsec-scale gas and dust surrounding the accreting SMBHs.

Our knowledge of the nuclear environment of AGN has increased tremendously since ALMA started scientific operations seven years ago. The combination of angular resolution and sensitivity provided by ALMA permits to peer into the central region of nearby AGN and, for the first time, obtain images of the parsec-scale dusty torus. Thanks to ALMA we also have advanced in our understanding of the gas flow cycle, in particular how the molecular gas reservoirs of the galaxies (100-200 parsecs) are connected with the torus and AGN central