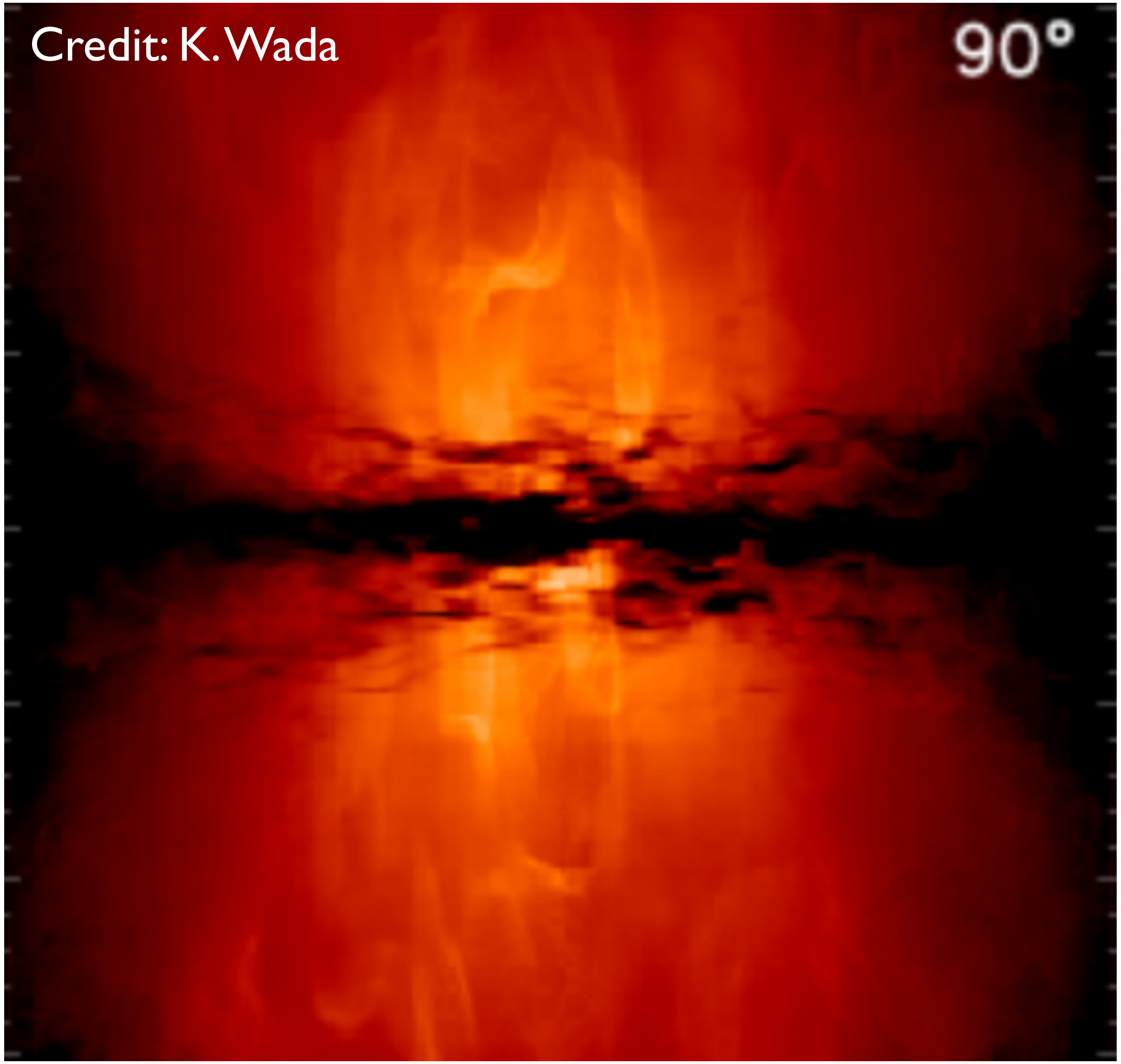
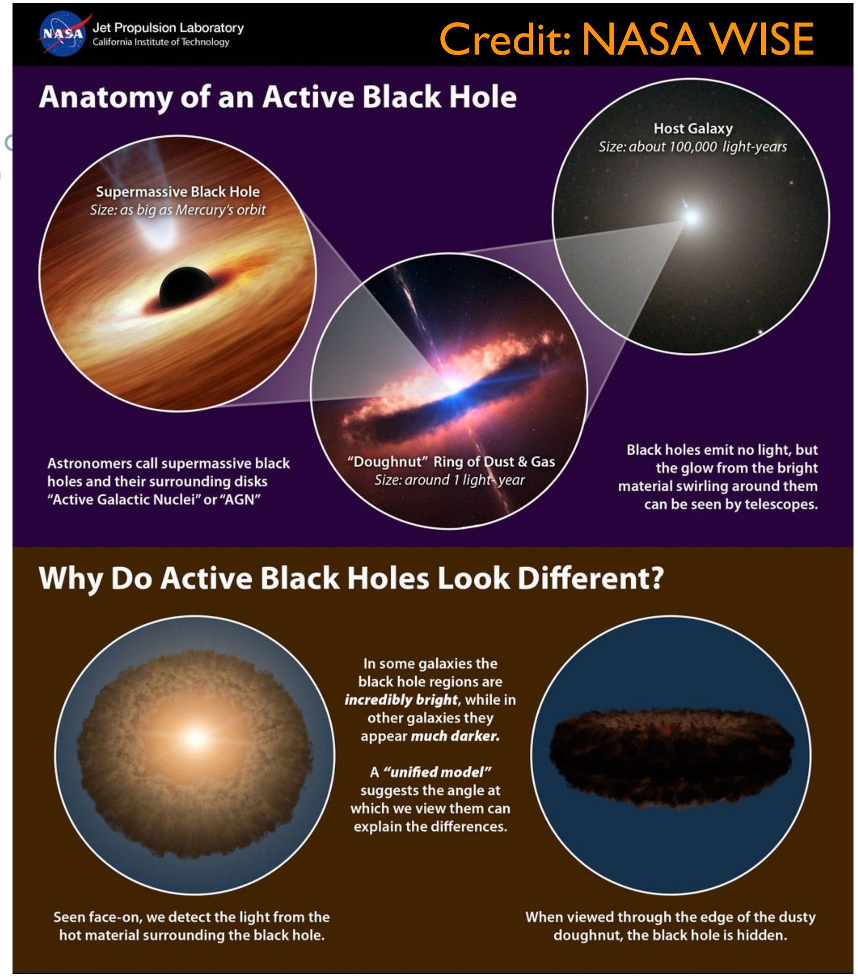


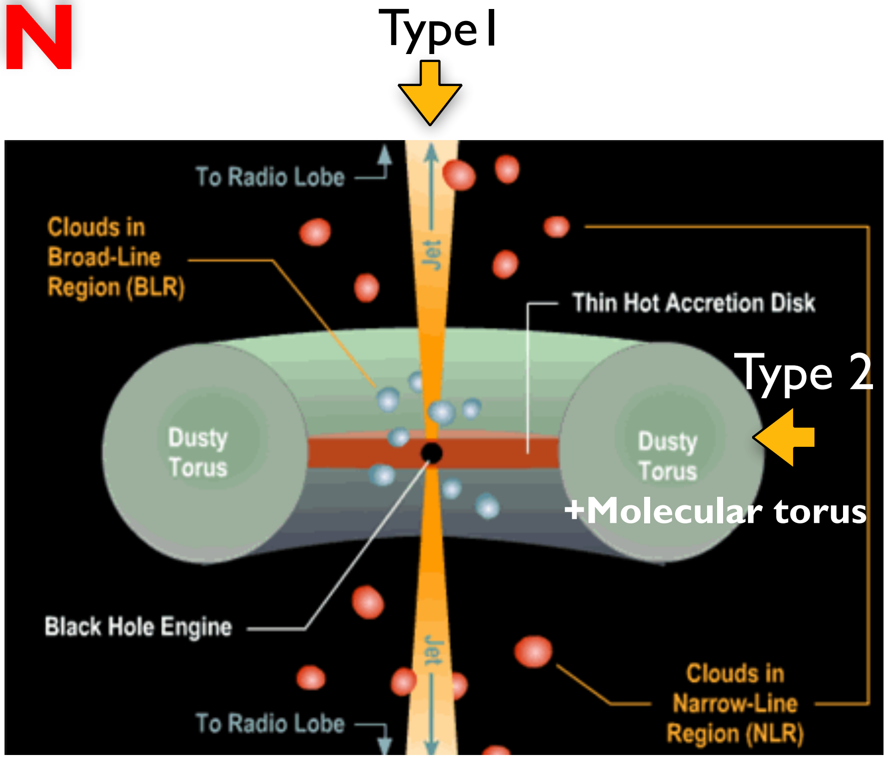
Dust in Active Galactic Nuclei: a close look at the torus and its surroundings

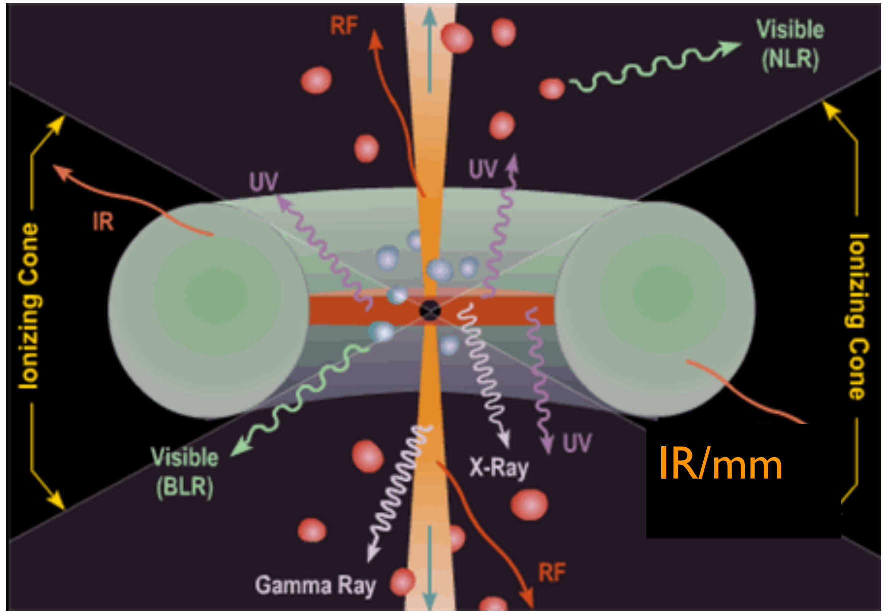
CENTRO DE ASTROBIOLOGÍA
ASOCIADO AL NASA ASTROBIOLOGY INSTITUTE

Almudena Alonso Herrero

Unified Model for AGN





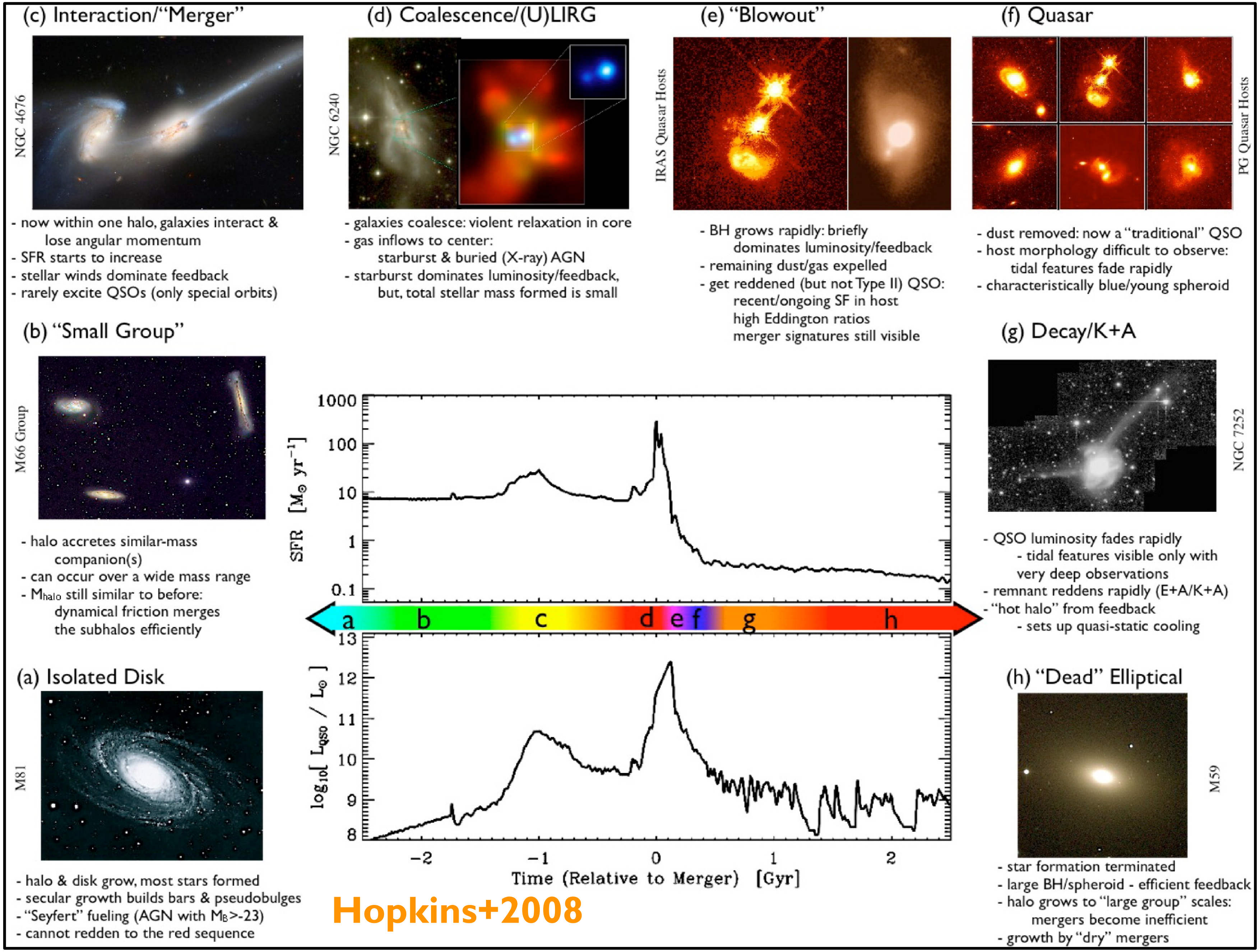


The idea of a Unified Model for AGN was put forward by Antonucci & Miller in 1985

The torus of dust and molecular gas is the key ingredient

Image credit: Brooks/Cole Thomson Learning via AstronomyOnline.org

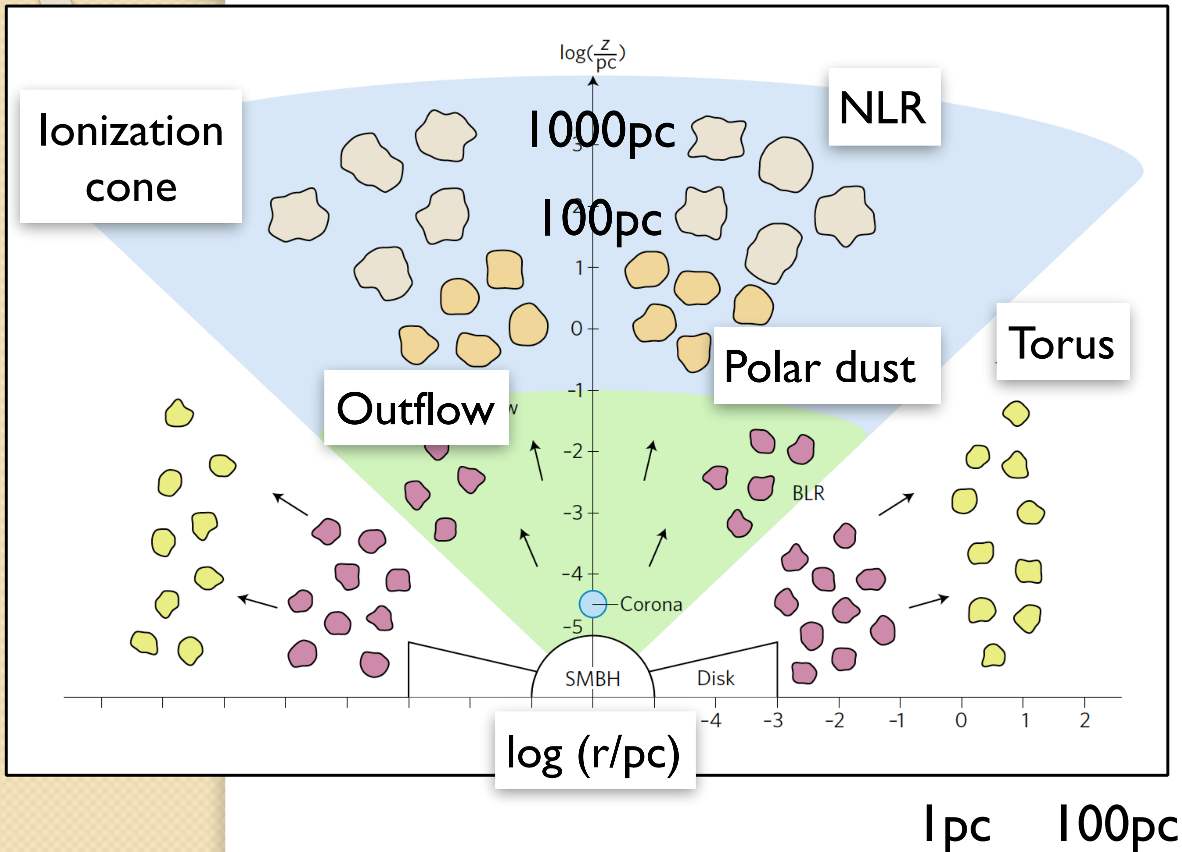
Importance of the dust-obscured AGN phase in galaxy evolution

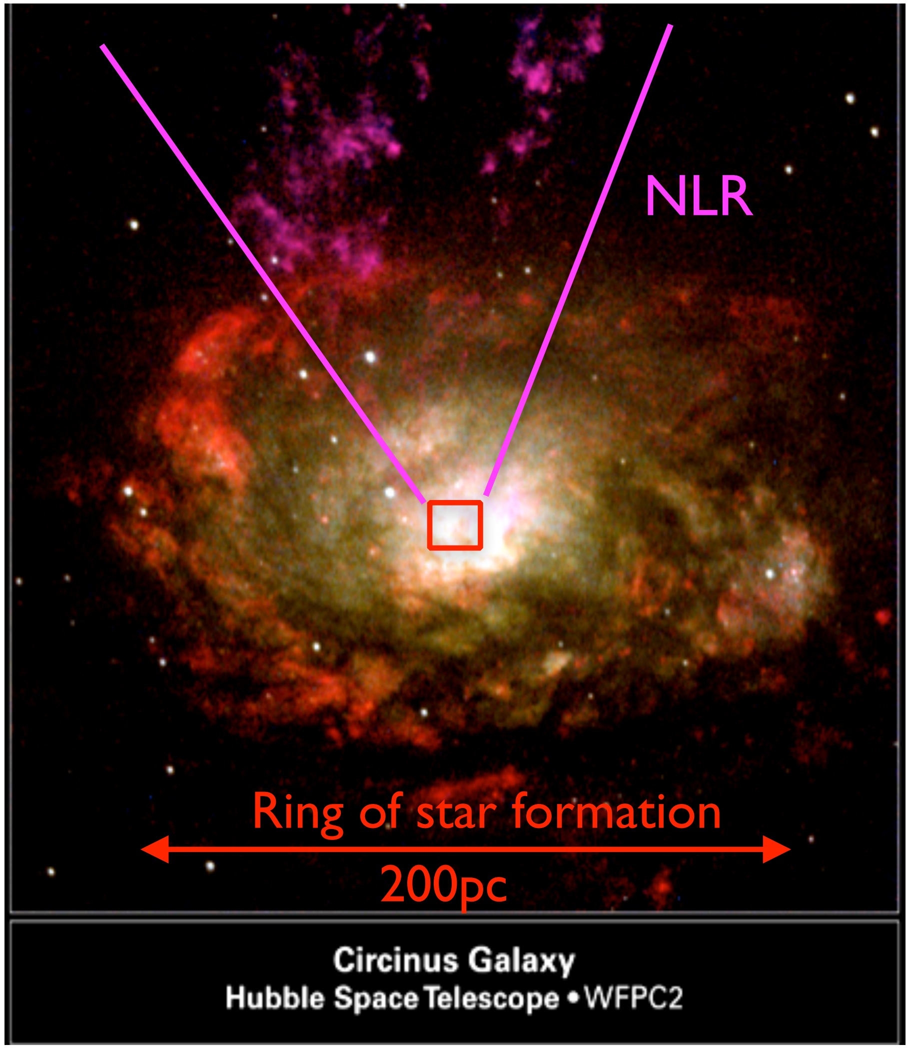


Hopkins+2008

Different physical scales of dust in nuclear regions of Active Galaxies

Ramos Almeida & Ricci 2017



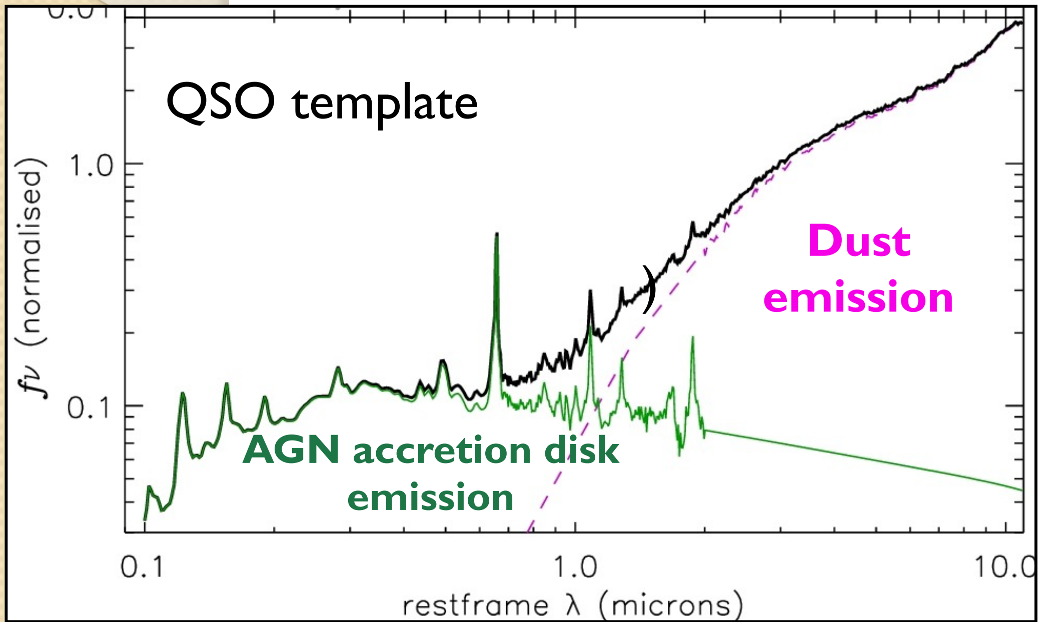


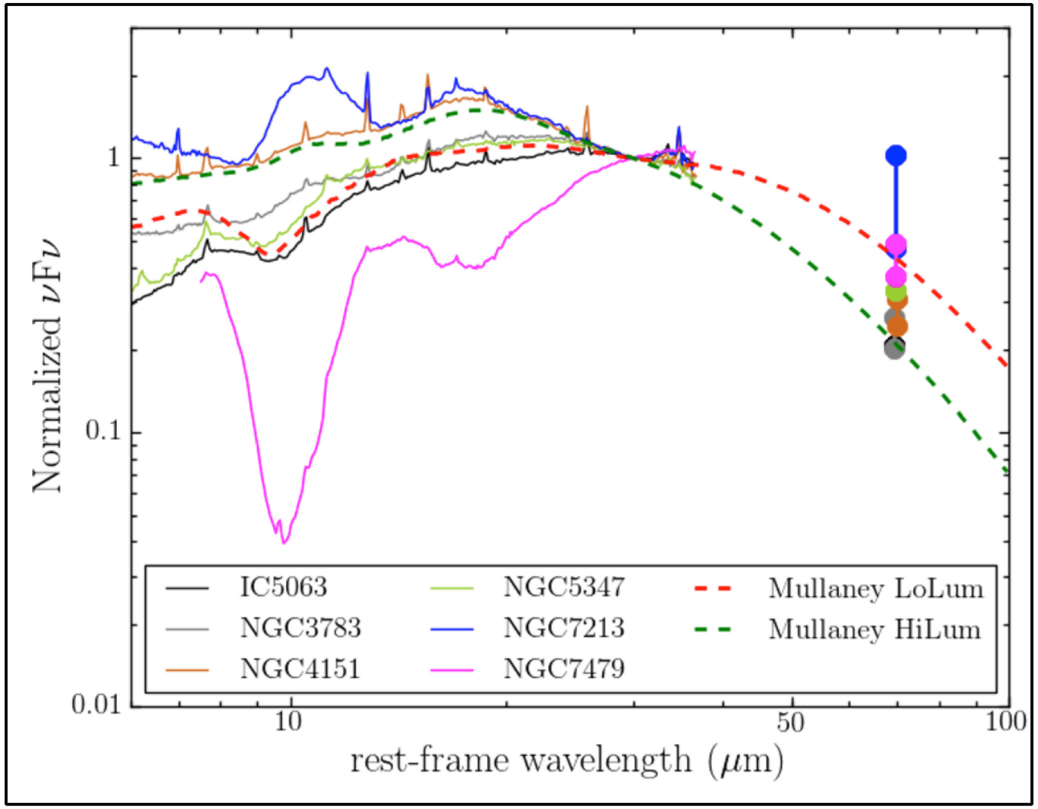
- Torus: a few to tens of parsecs
- Polar dust: up to a few hundred parsecs
- Circumnuclear disks: a few hundred parsecs to up to 1 kpc

Thermal IR emission of radio quiet AGN + angular resolution

Hernán-Caballero+2016, Elvis+1994, 2012, Glikman+2006, Richards+2001, 2006, Hill+2014, Kim+2015

García-González+2016, and templates from Mullaney+2011





- ✤Ground-based imaging/spectroscopy: NIR AO (<0.1”), MIR diffraction limited (~0.3”)
- ✤Interferometry (<0.1”)
- ✤MIR/FIR: SOFIA(~3”), Herschel (3-10”), ALMA (0.3-0.04”)

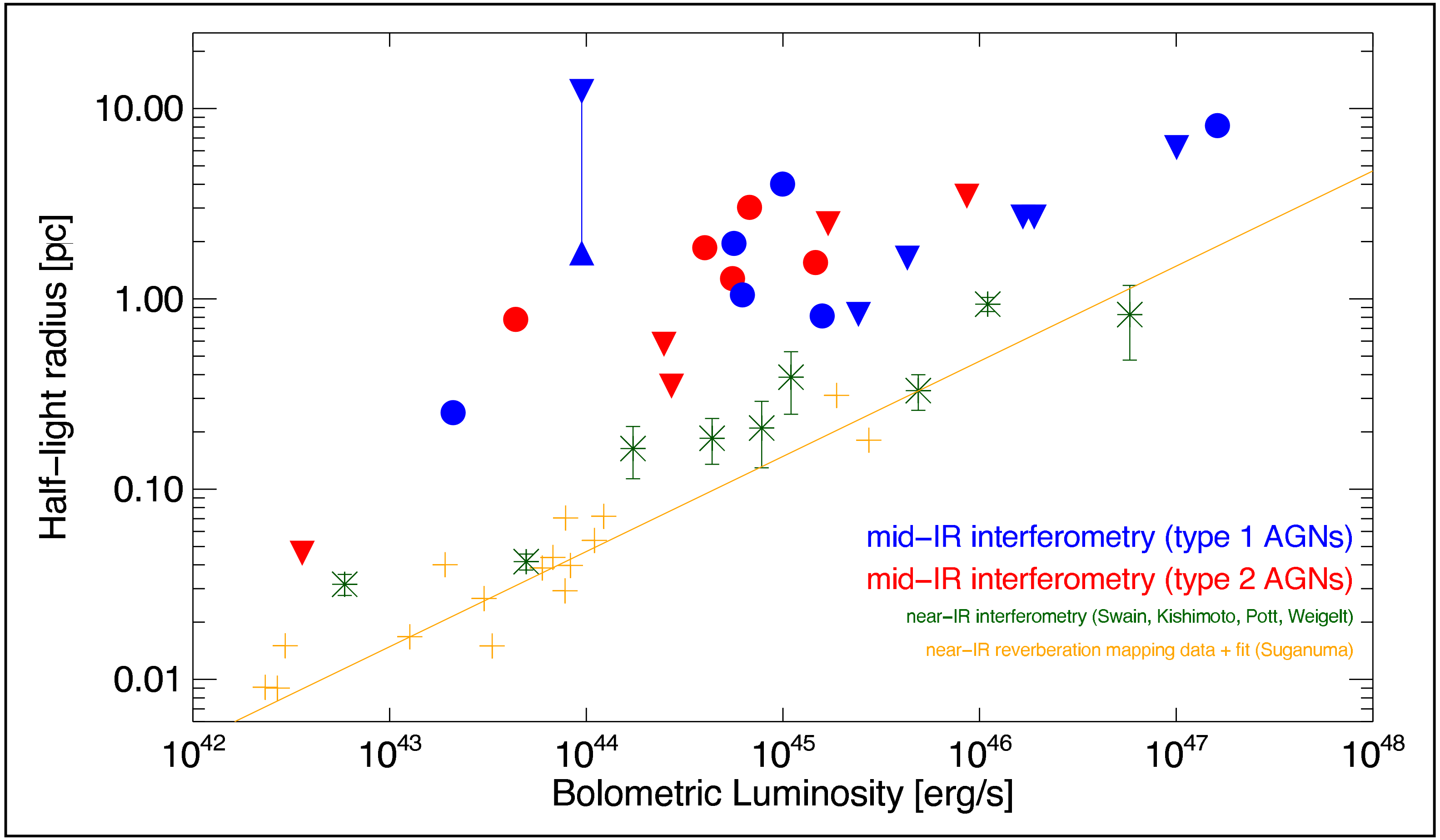
Outline of the talk

What we have learned in the last ~5 years - an incomplete review and only for radio-quiet AGN

- A few surprises about the dusty molecular torus of nearby AGN
- A new paradigm: the dynamical torus
- Properties of the AGN dust: grains, dust composition, PAH
- Properties of the torus in distant AGN: dust covering factors and evolution

Structure of the torus (in 2013)

- Small torus sizes at 12µm, ~3x smaller than expected Barvainis 1987
- No differences between type 1 and type 2
- Larger scatter for torus sizes at 12µm than in the near-infrared



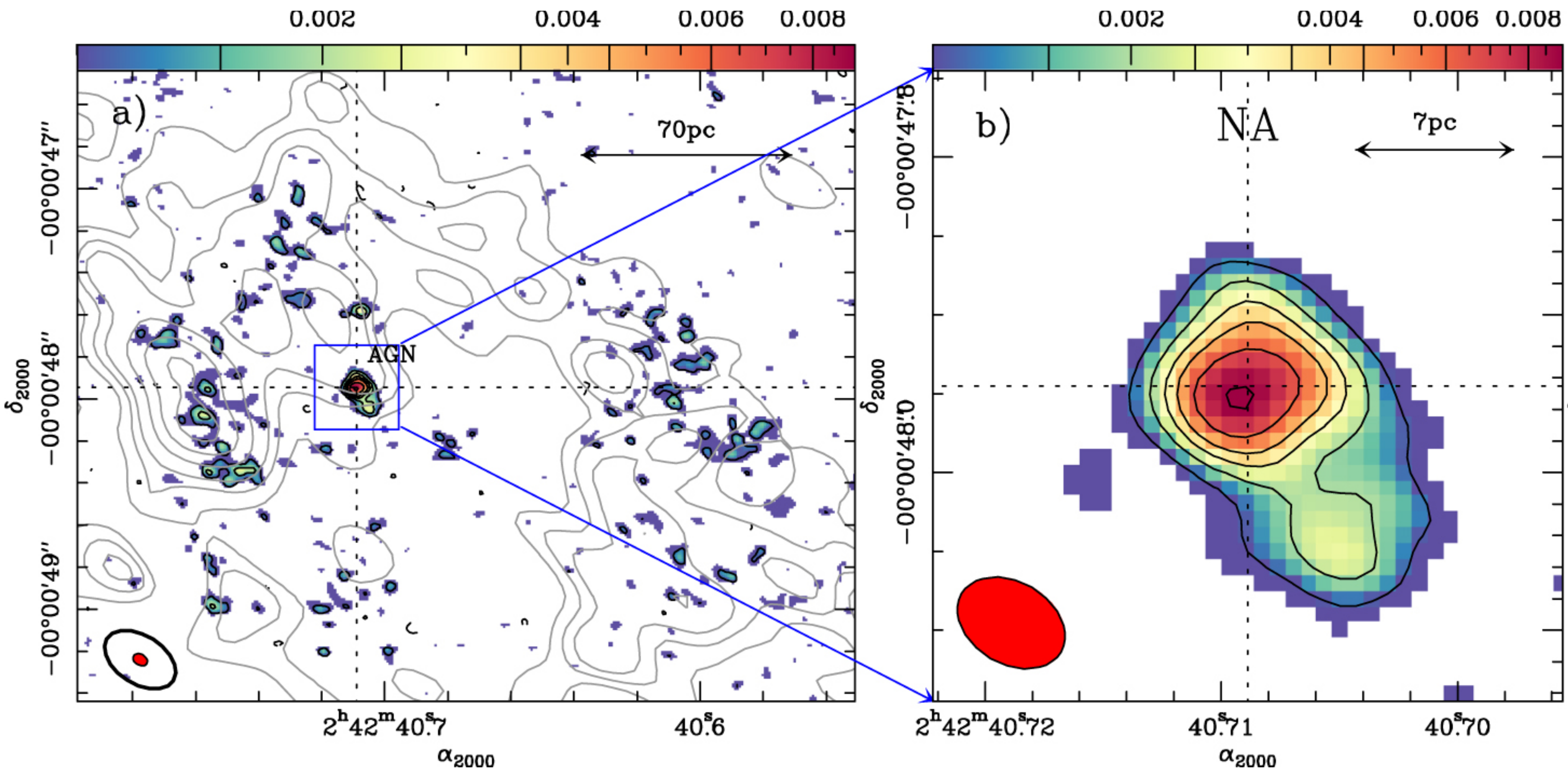
Burtscher+2013

First direct detection of the torus: NGC1068

The Unified Model torus has been detected only in a handful of AGN

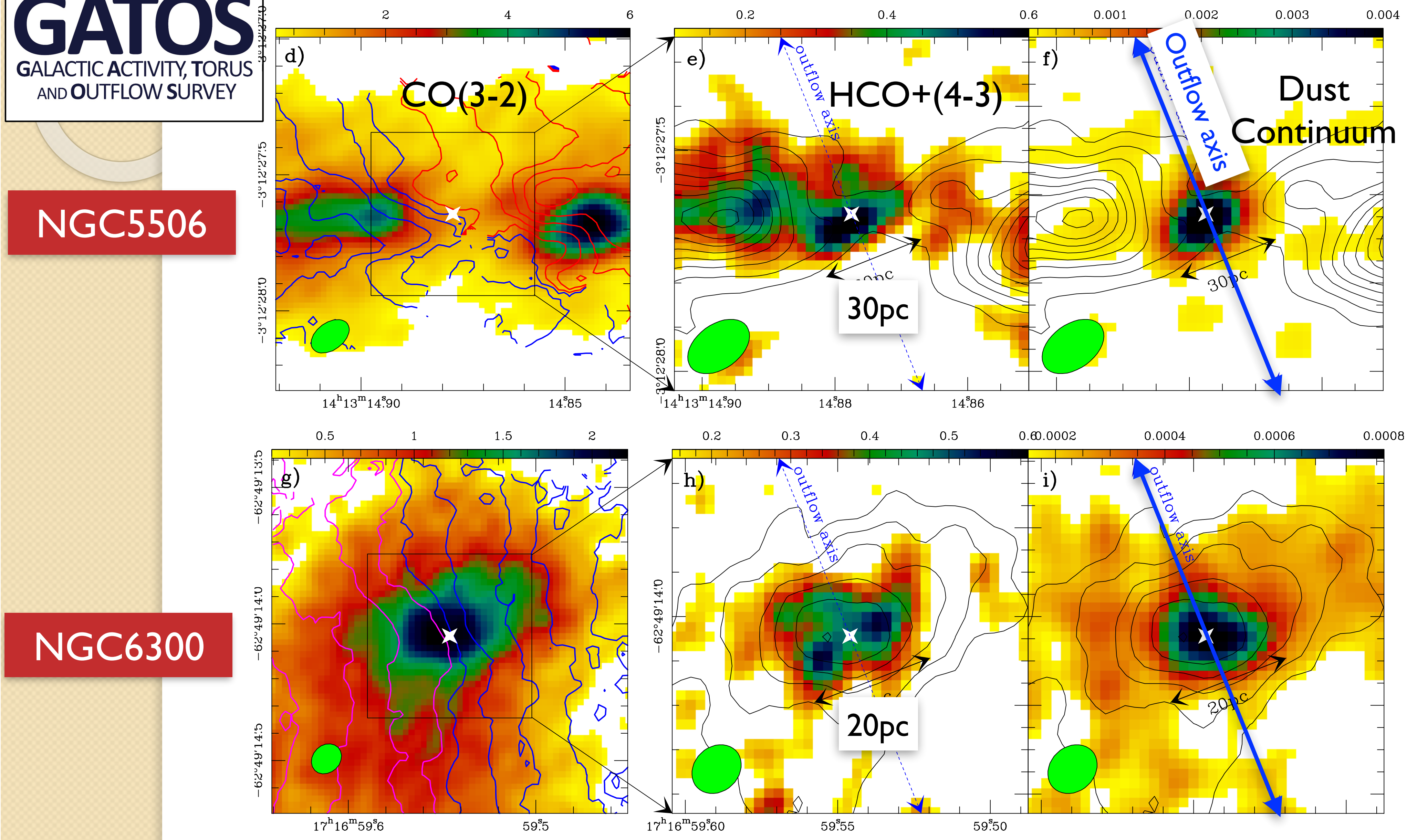
ALMA 432μm view (0.04-0.06" res) of central 2" of NGC1068

- **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 and 2018 in prep, also Gallimore+2016, Imanishi+2018

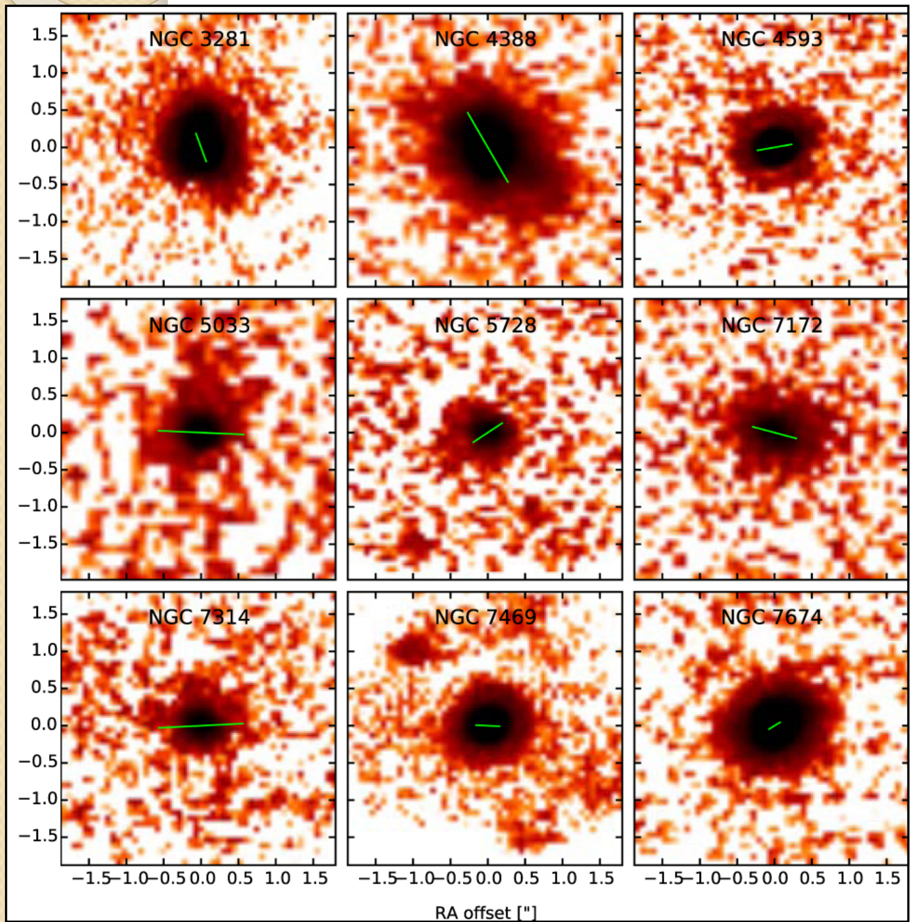
More large tori detected with ALMA

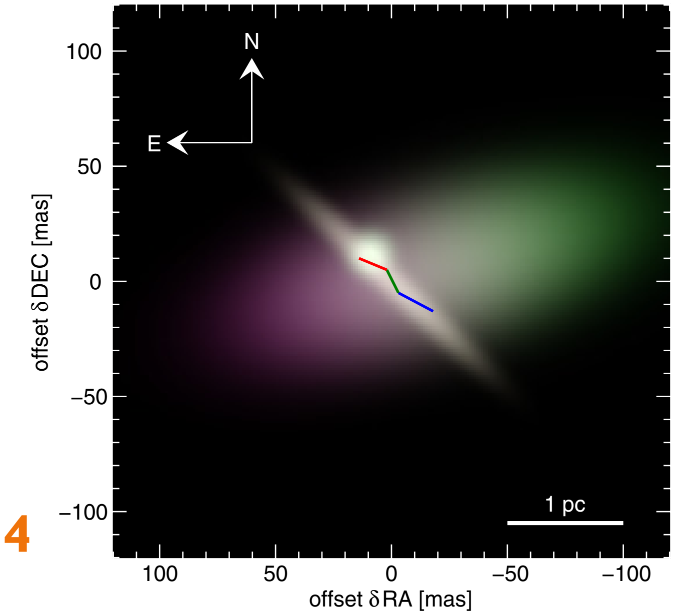


García-Burillo+2018 in prep.

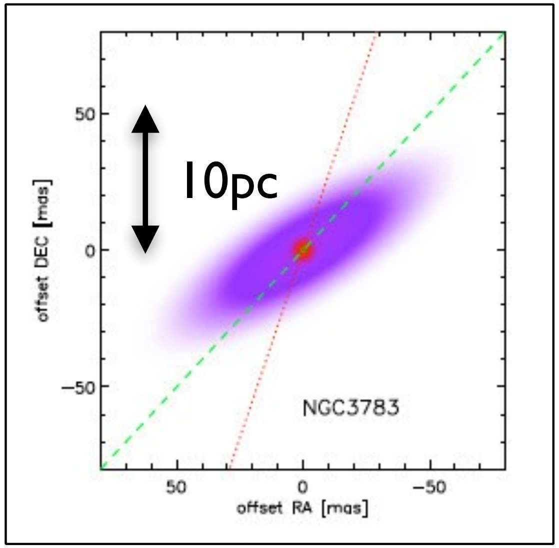
Polar Dust Emission in AGN

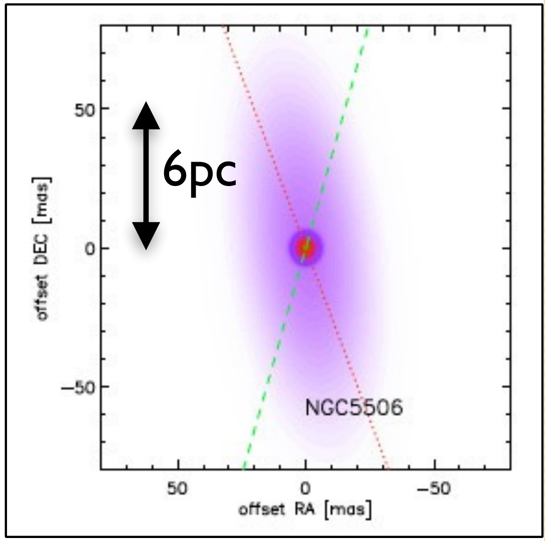
- Compact MIR emission **(interferometry up to a few pc, imaging up to a few 100pc's)**
- Some AGN show a significant fraction of their MIR emission along the polar direction





Tristram+2014

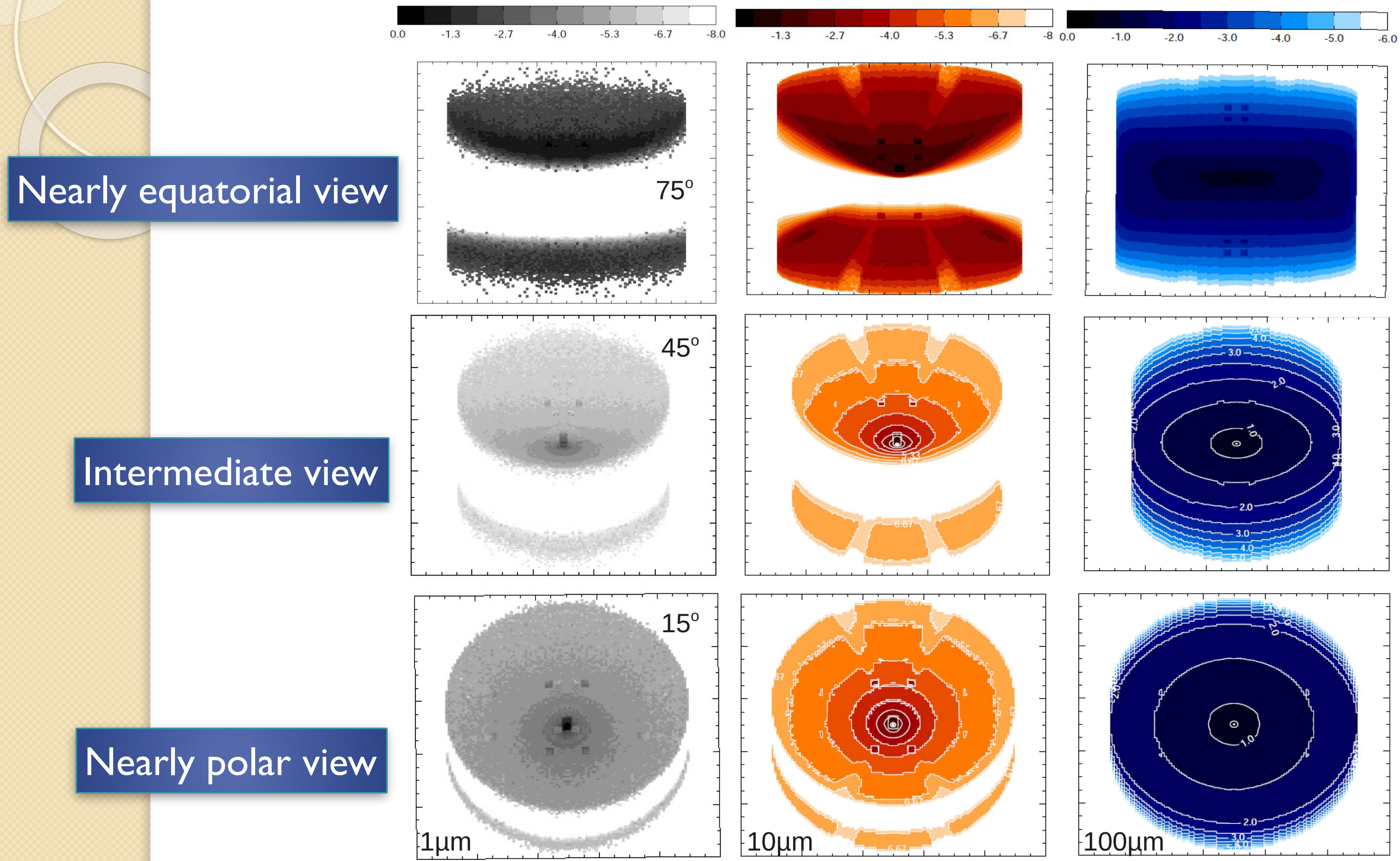




MIR imaging: Asmus+2016 Radomski +2003, Packham+2004, Alonso-Herrero +2016, García-Bernete+2016

Modelling MIR interferometry: López-Gonzaga+2016, also Tristram+2009, Hönig+2012, 2013, Leftley+2018

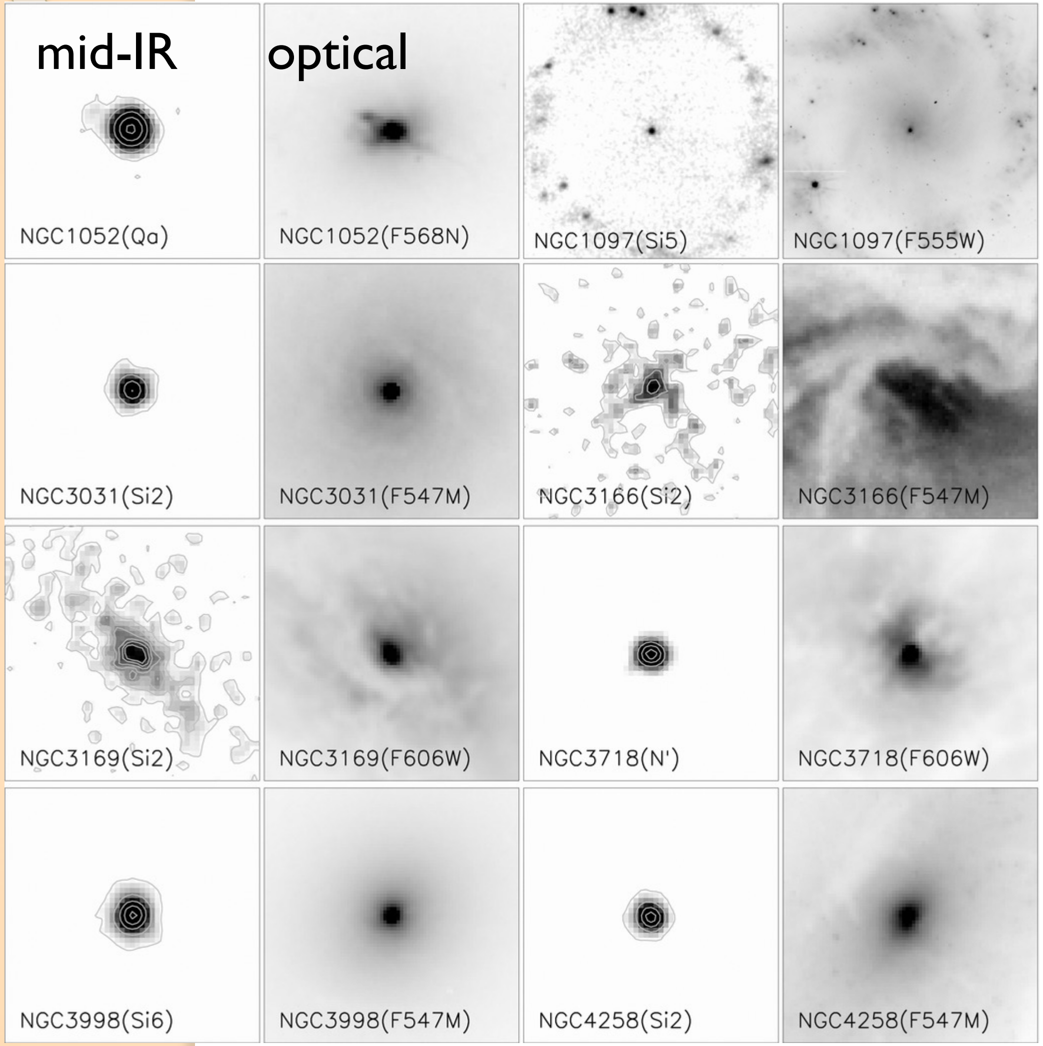
Dusty torus model images



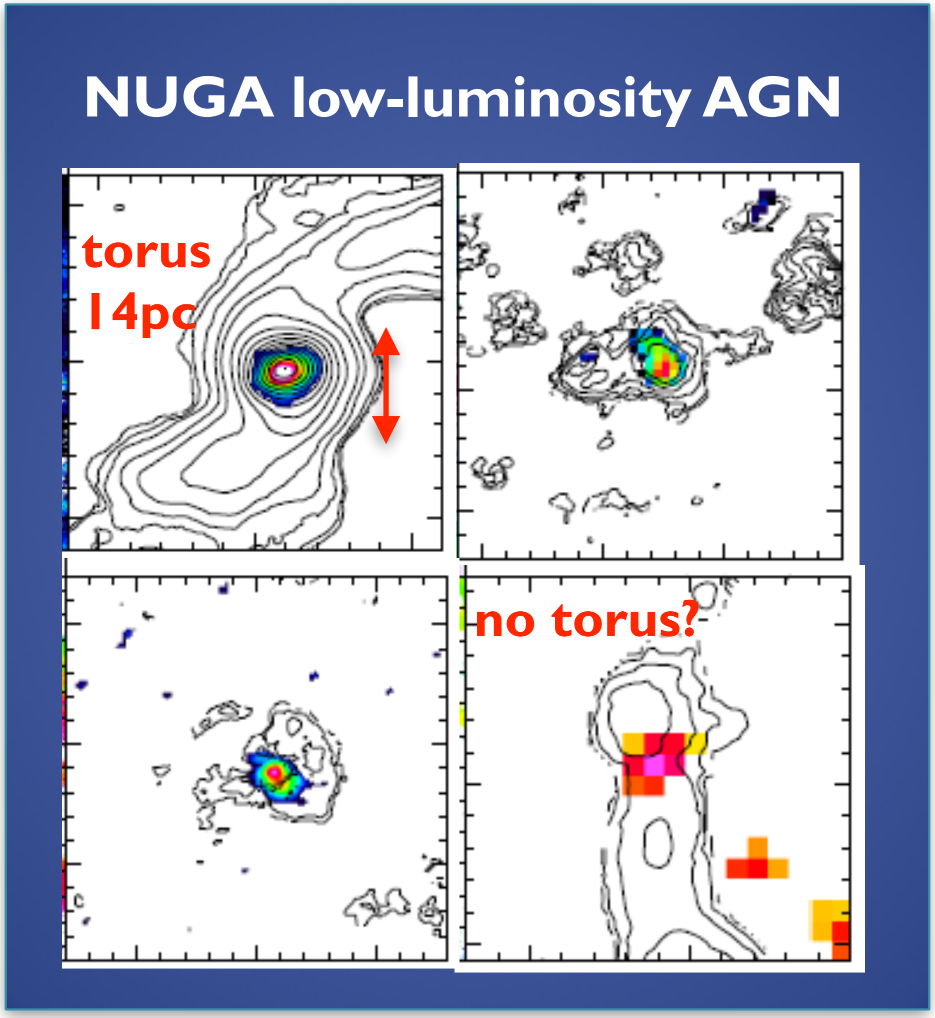
Siebenmorgen+2015, also Hönig+2006, Schartmann+2008, Stalevski+2016, Wada+2016, Jud+2017, Lopez-Rodriguez+2018a

Disappearing torus at low AGN luminosities?

- Torus predicted to disappear at L_{bol} (AGN)< 10^{42}erg/s: Elitzur & Shlosman 2006



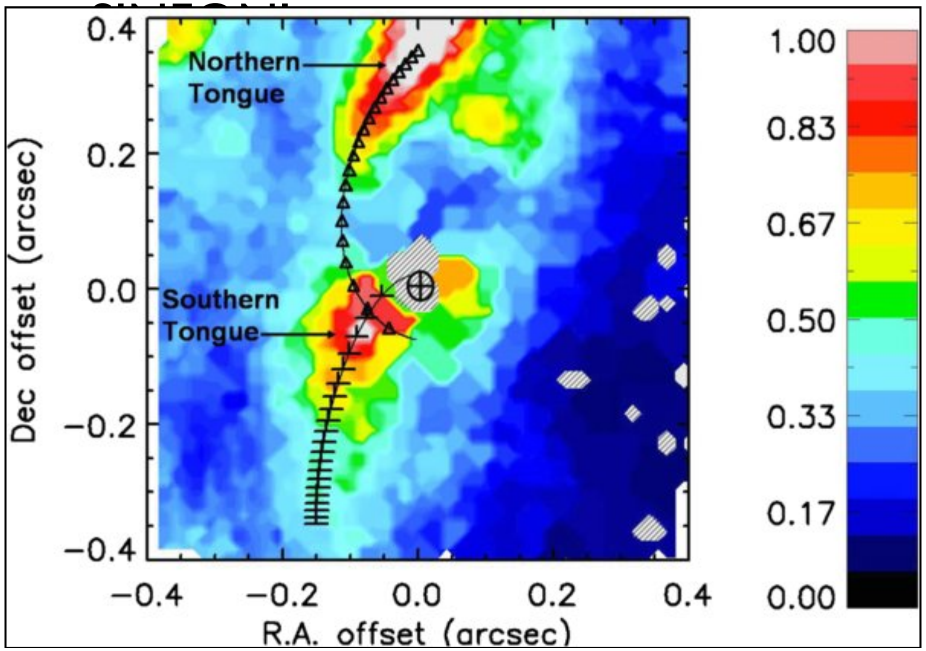
Mason+2012: Mid-infrared emission

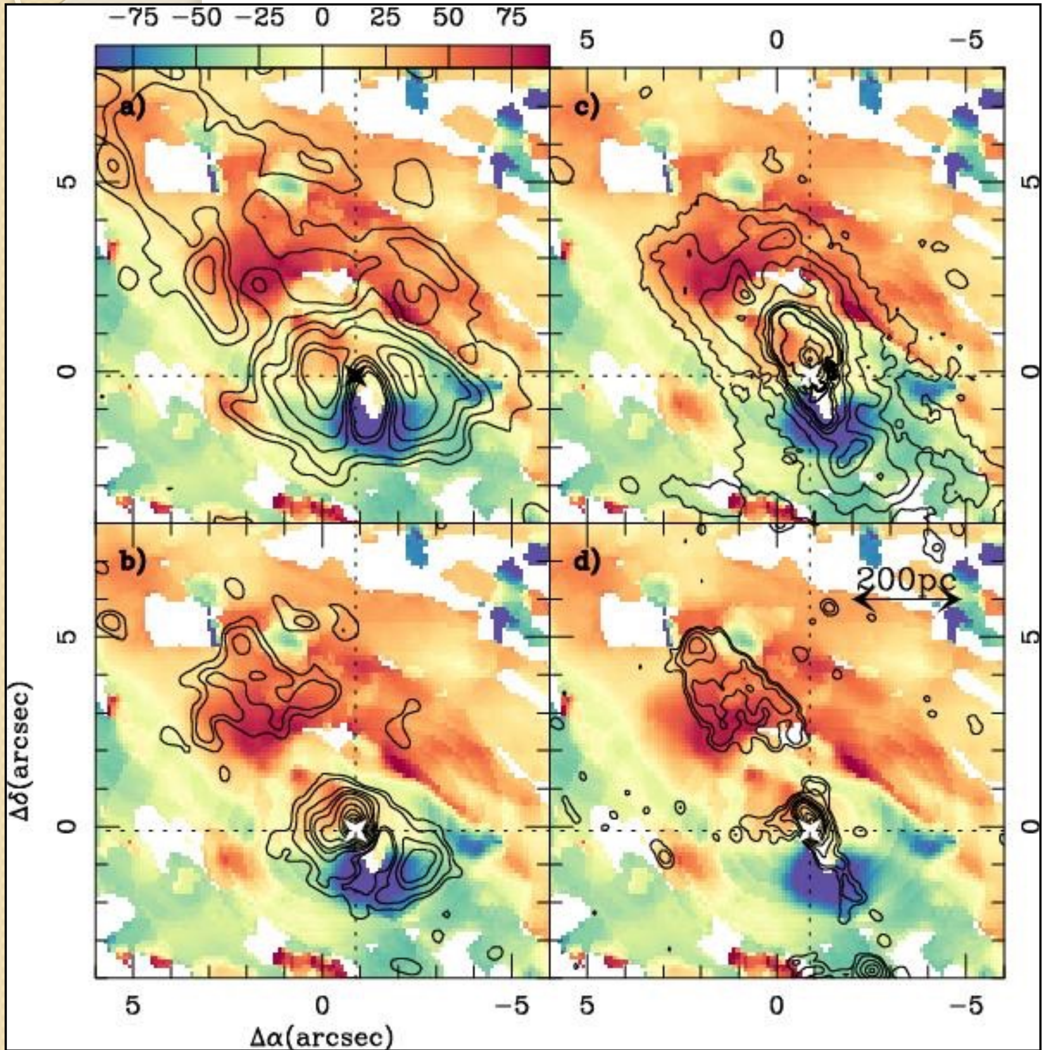


Combes+2018, in prep: ALMA 832µm continuum in color + CO(2-1) contours

Inflows/Outflows in NGC1068

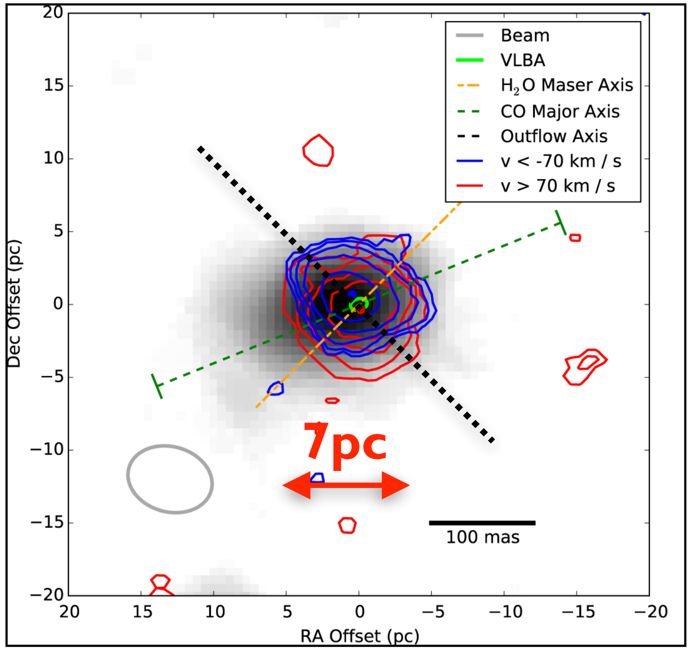
Müller-Sánchez+2009: Inflows detected in H_2 at 2.12μm with





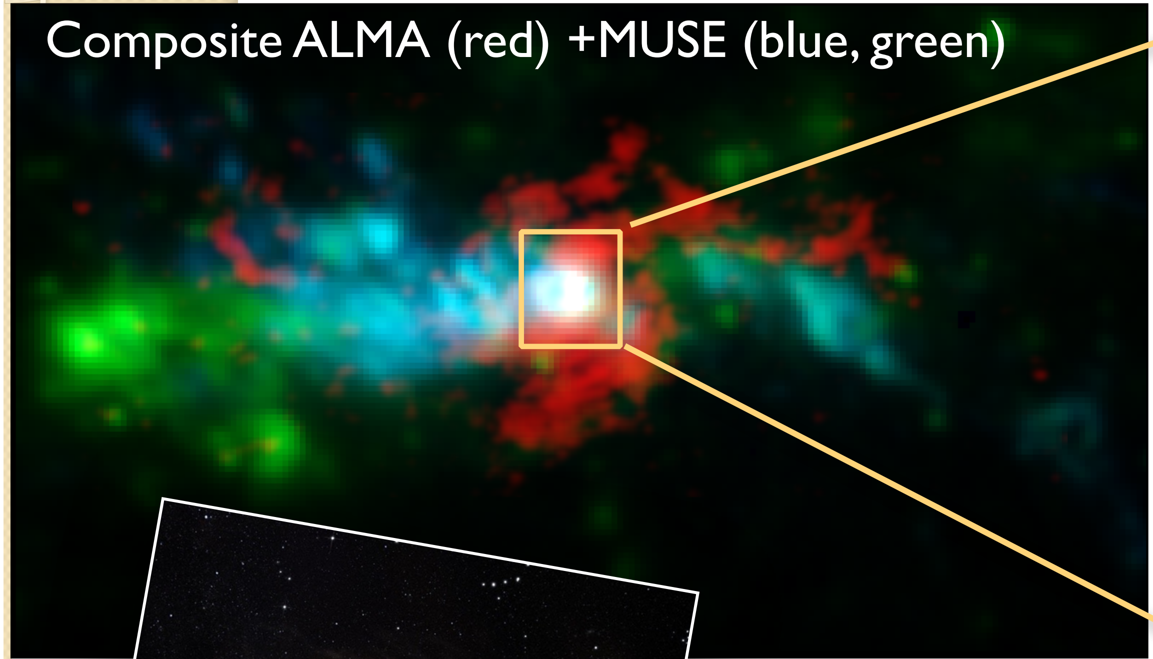
García-Burillo+2014: Outflows detected in CO(3-2) with ALMA on scales 50pc to 400pc from the AGN. Outflow rate in CND ~ 63 $M_\odot$/yr

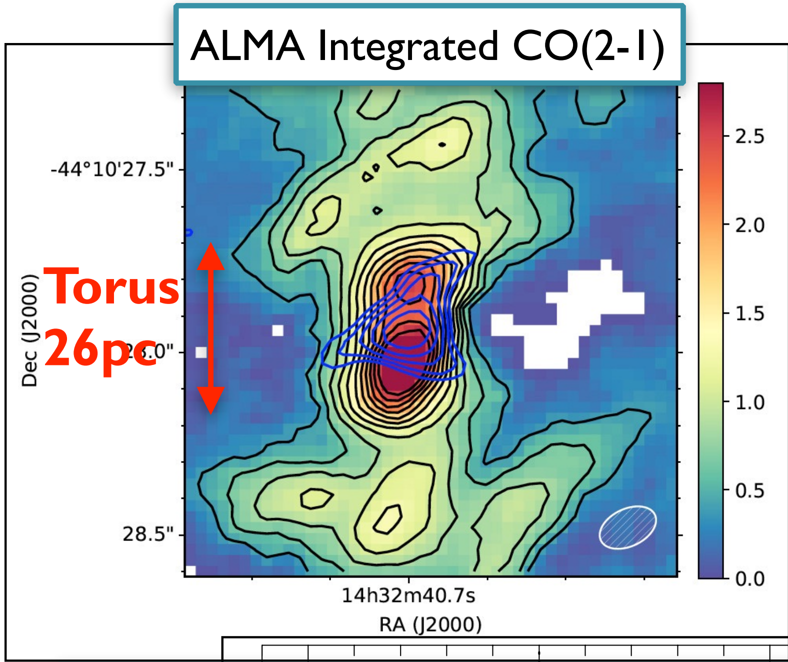
Gallimore+2016: outflowing torus with ALMA

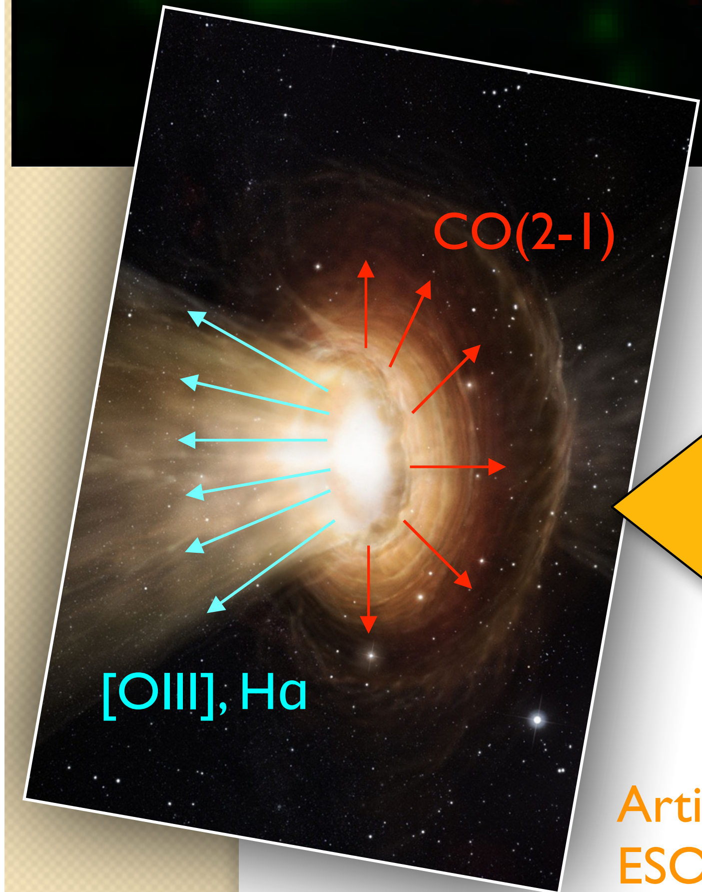


A massive "outflowing" torus in NGC5643

Alonso-Herrero+2018

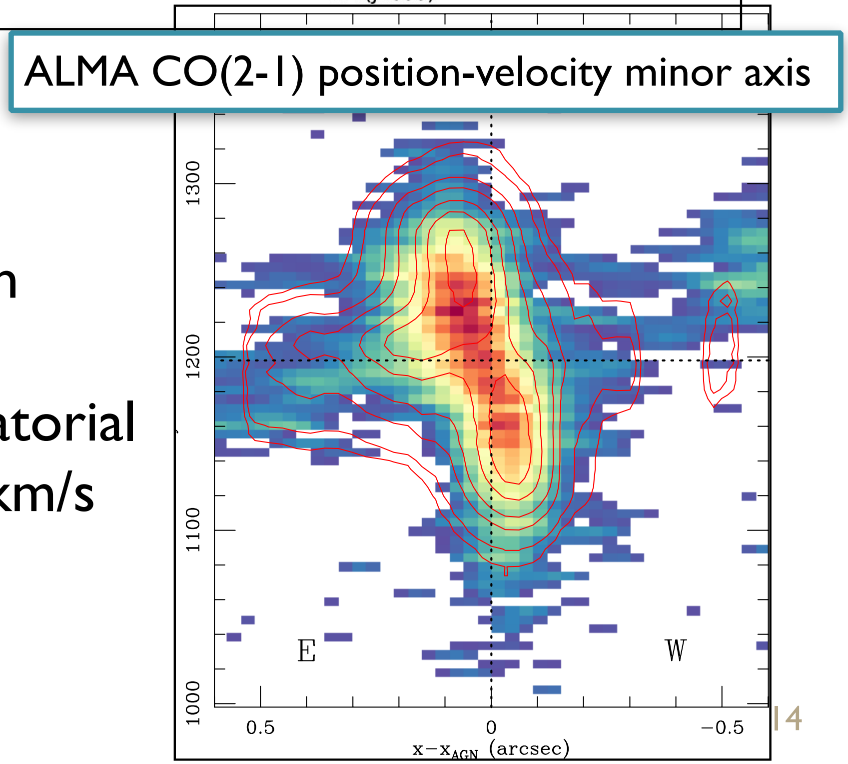




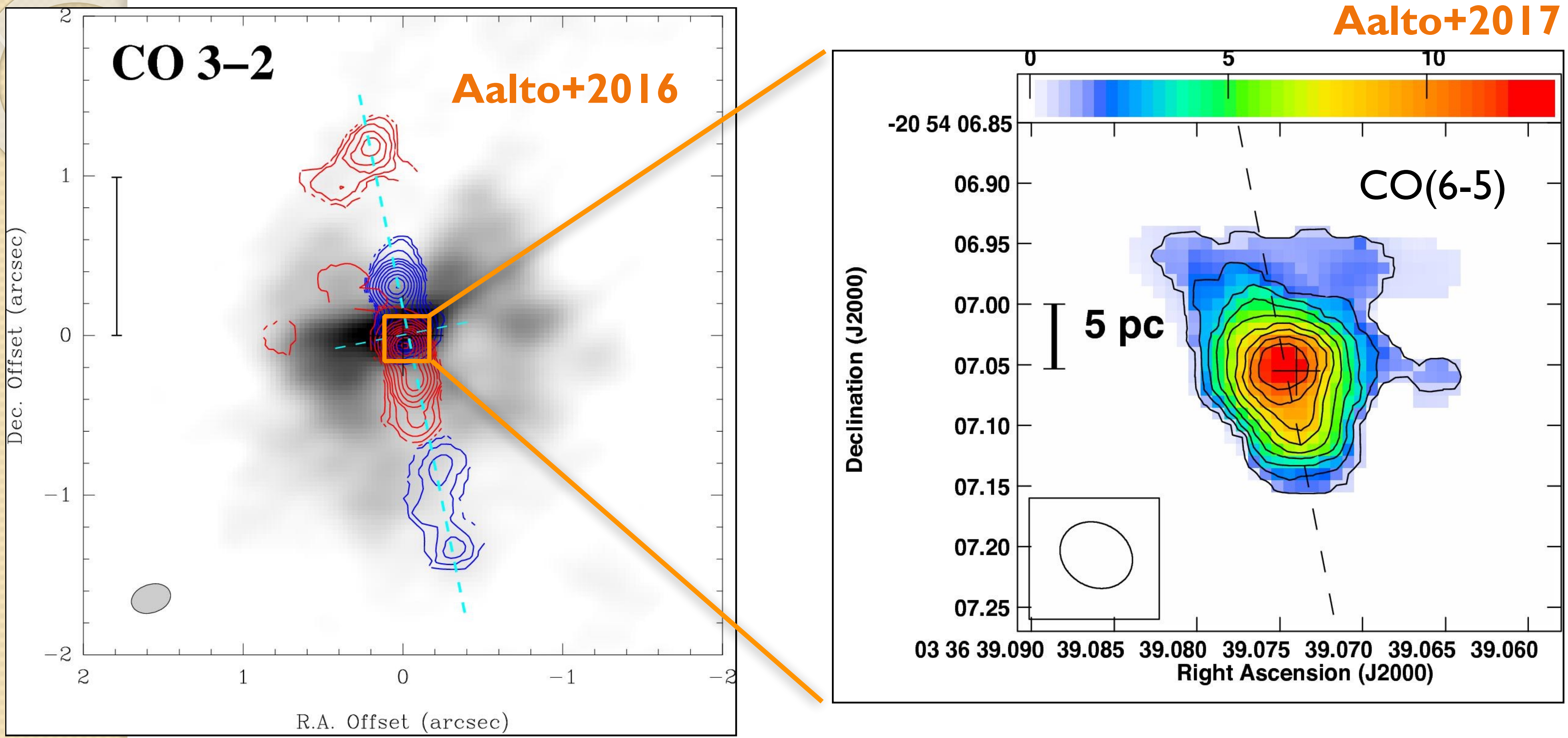


Artist Impression: ESO/M. Kornmesser

Massive torus with M_{GAS}~$10^7 M_\odot$ and outflowing in equatorial plane with v~100km/s

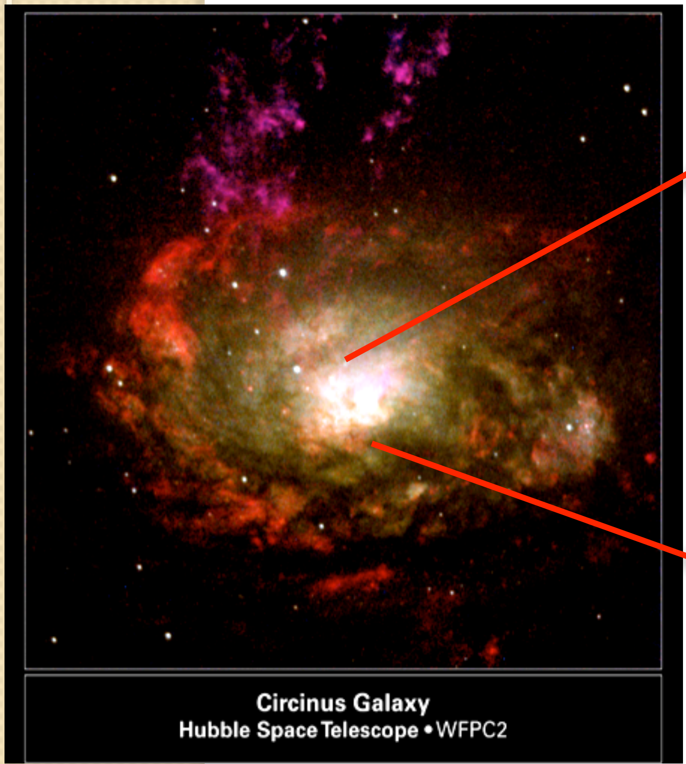


An obscured AGN in NGC1377 revealed by a cold molecular gas jet

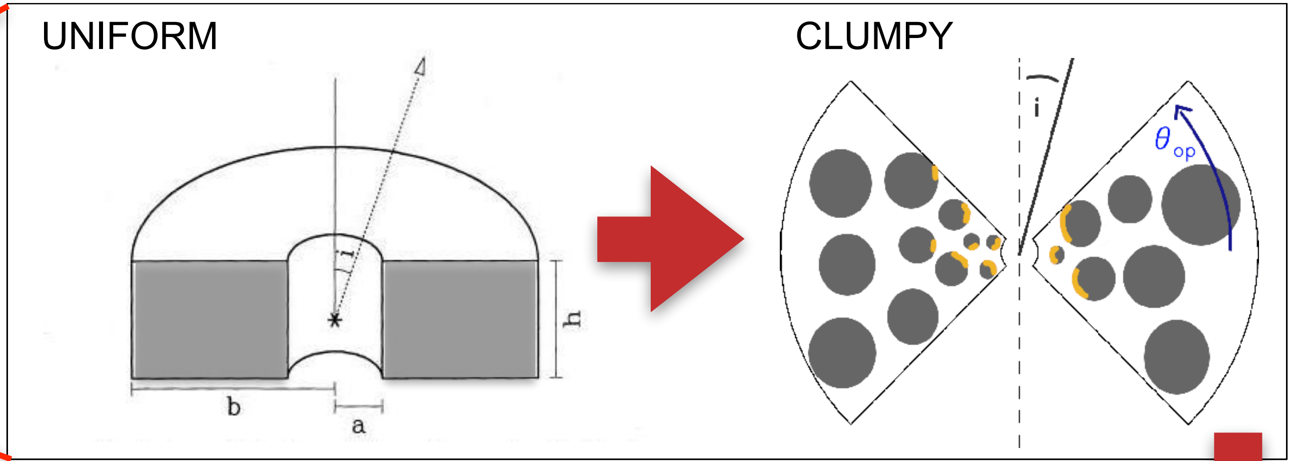


- No evidence of star formation, therefore outflow must be AGN driven
- Outflow rate 9-40 $M_\odot$ /yr
- No continuum dust emission detected at 690GHz (434μm) with ALMA. Could be explained by an unresolved obscured nuclear source 0.2-0.7pc ?

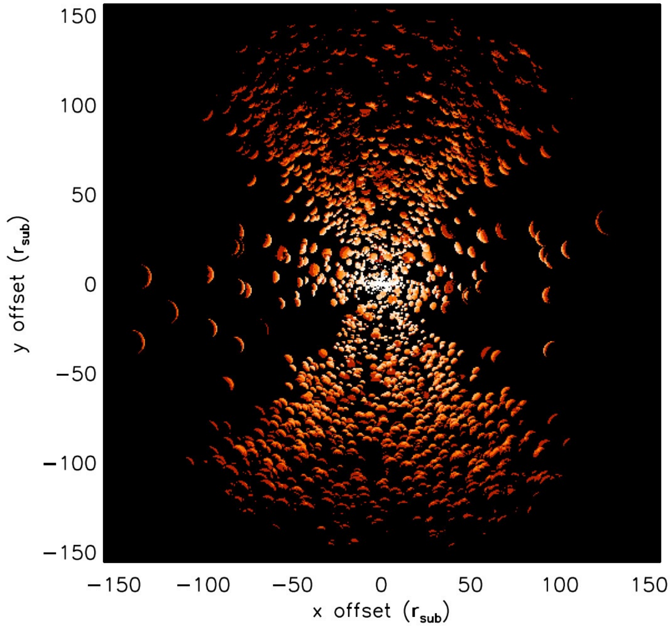
The new paradigm for the obscuring material of AGN



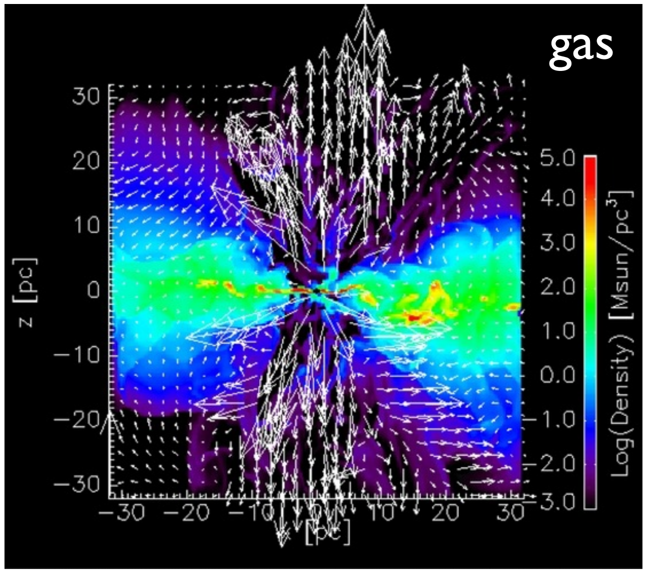
Pier & Krolik 1992   Schartmann+2008

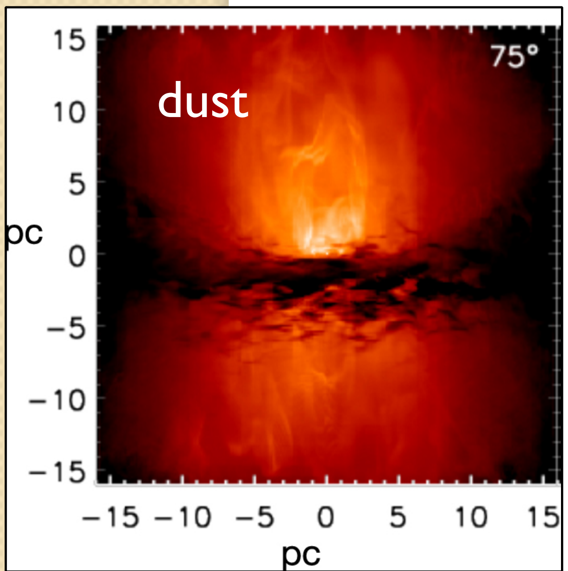


Hönig & Kishimoto 2017



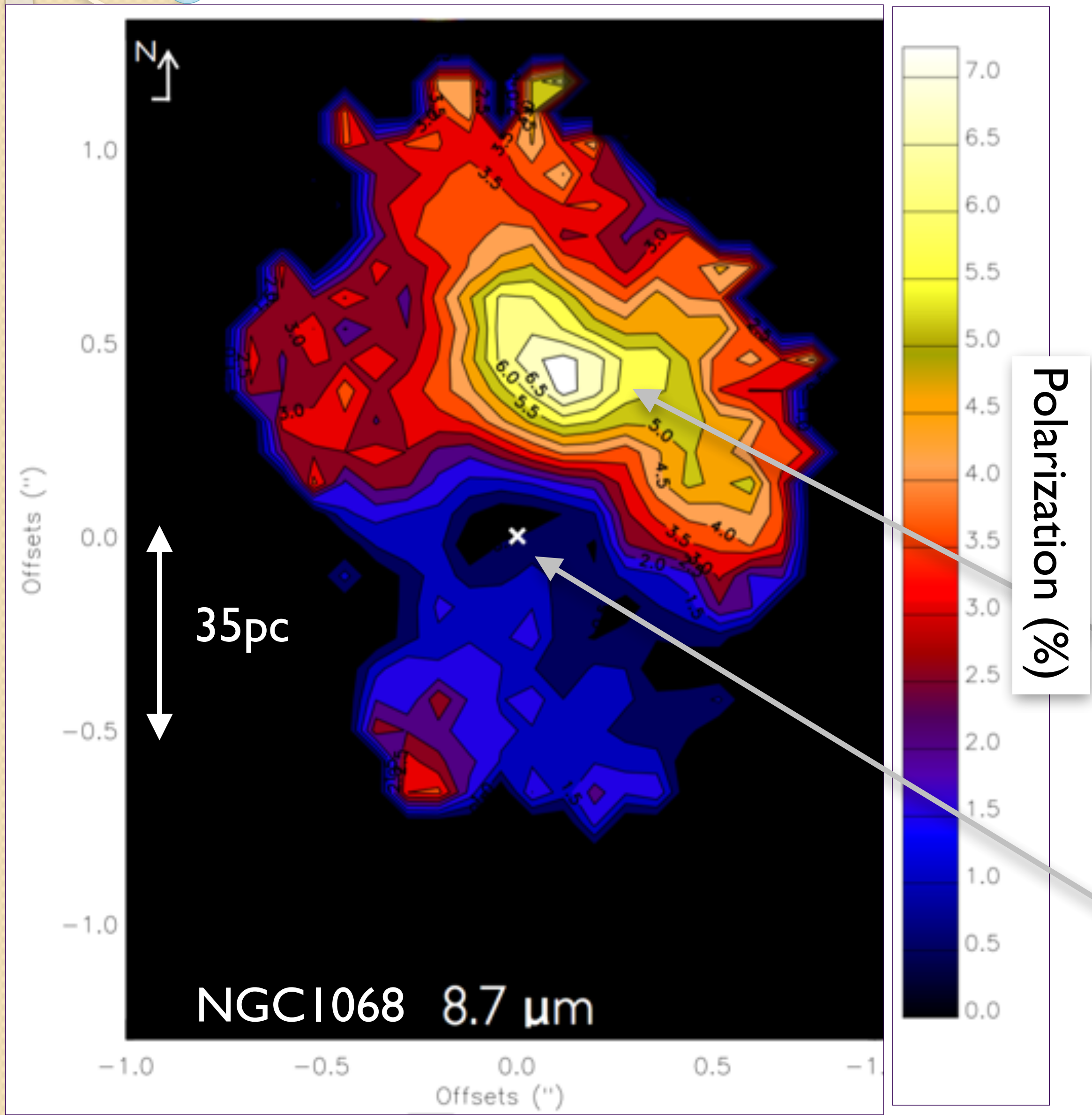
Wada 2012, 2016

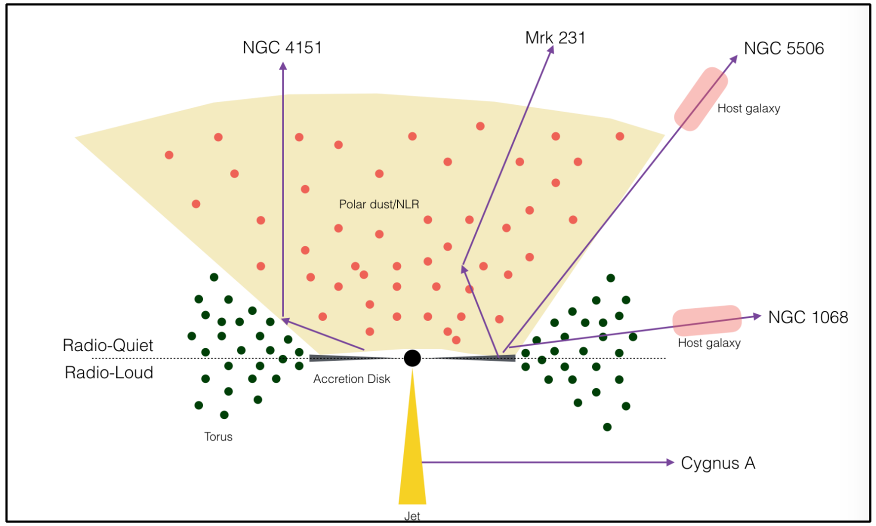




Mid-Infrared Polarimetry of AGN

- López-Rodríguez+2016, 2018b



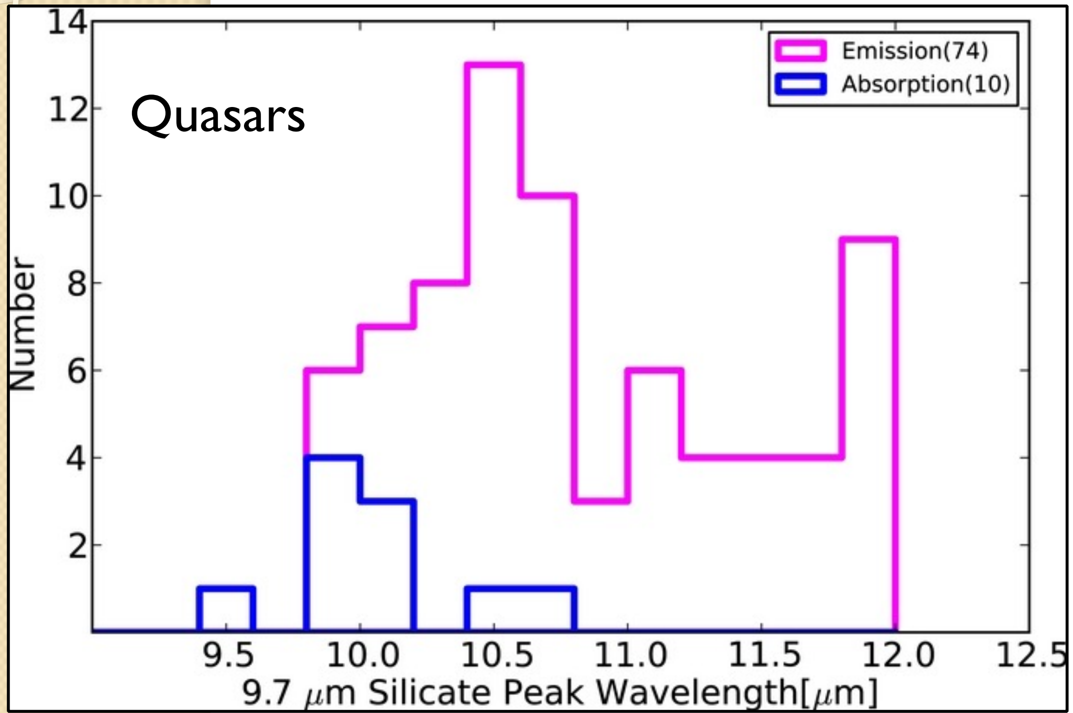


Jet-molecular cloud interaction in northern ionization cone: No silicate feature in polarized light: **dust grains different from those in ISM?**

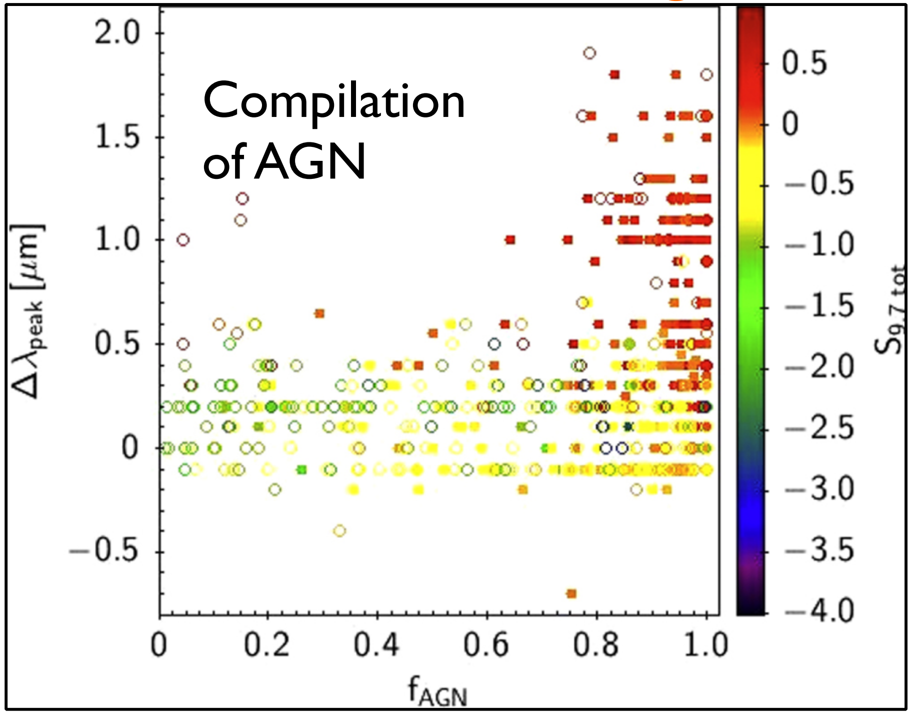
AGN location <0.3% polarization from the torus

Silicate Feature AGN

Shi+2014

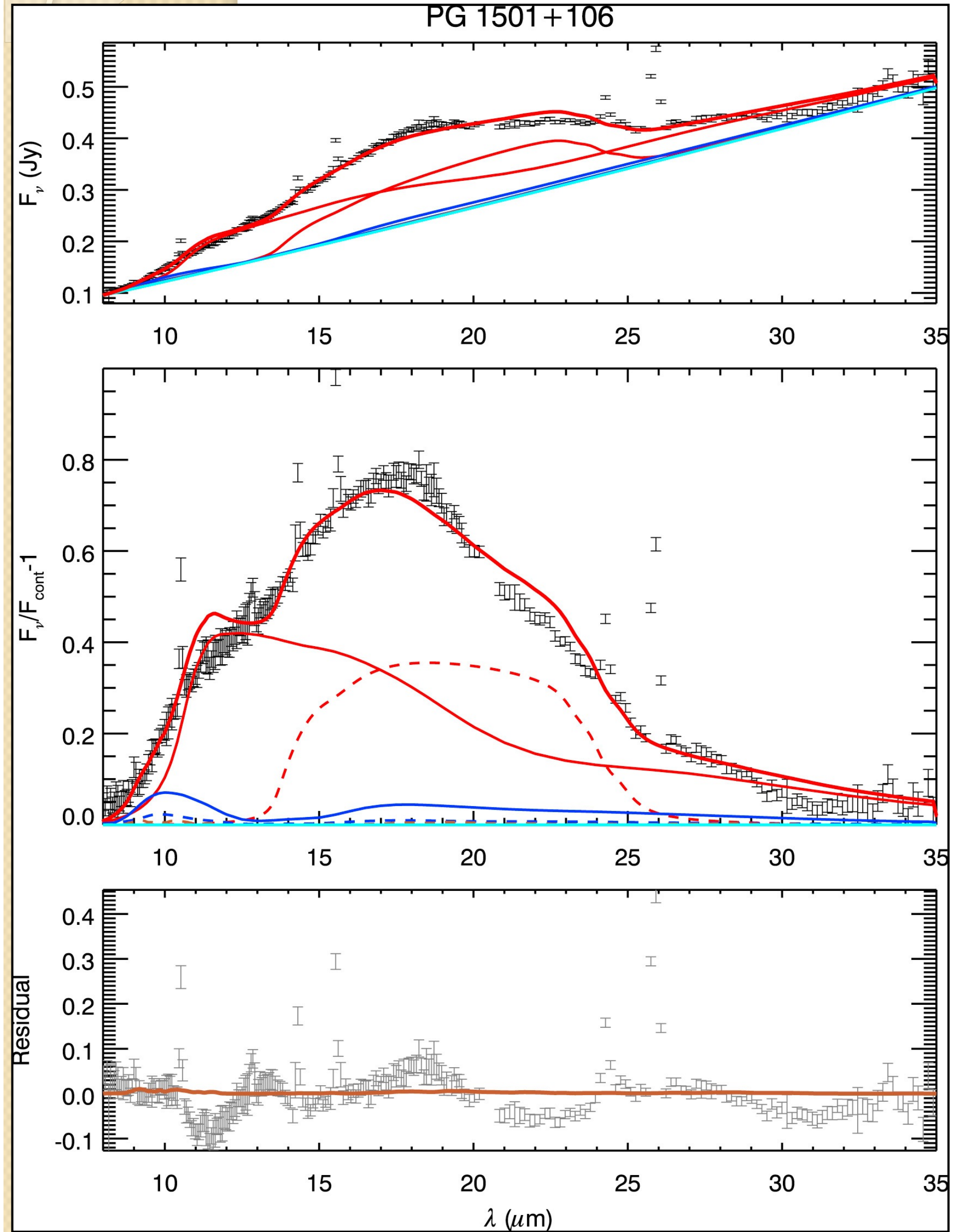


Hatziminaoglou+2015

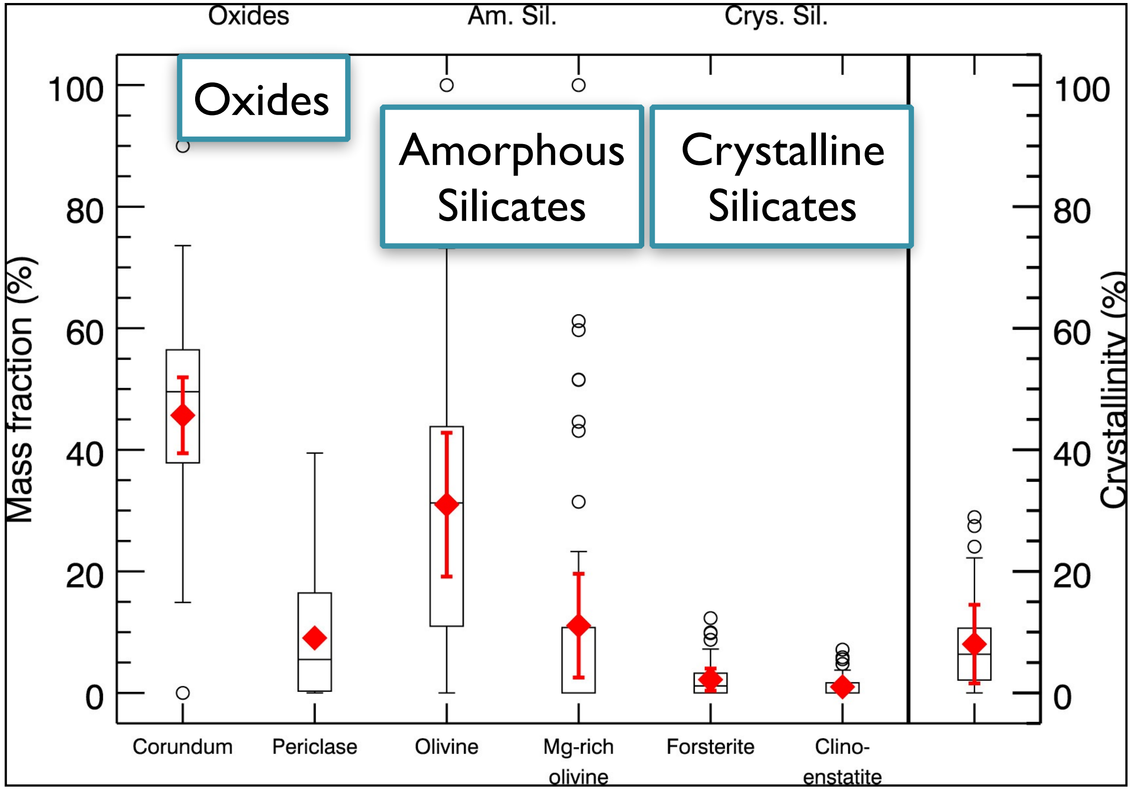


- Porous (large grains) dust: Li+2008, Smith+2010 (M81 dust produced in AGN wind), Siebenmorgen+2015, Xie+2017
- Different dust species: Markwick-Kemper+2007
- Radiative transfer effects: Nikutta+2009
- Modified chemical composition in the presence of a strong radiation field: Smith+2010, Shi+2014

Dust composition in quasars



Example of a QSO fit: corundum: solid red, periclase: dashed red, olivine: solid blue, Mg-rich olivine: dashed blue, PAH: cyan

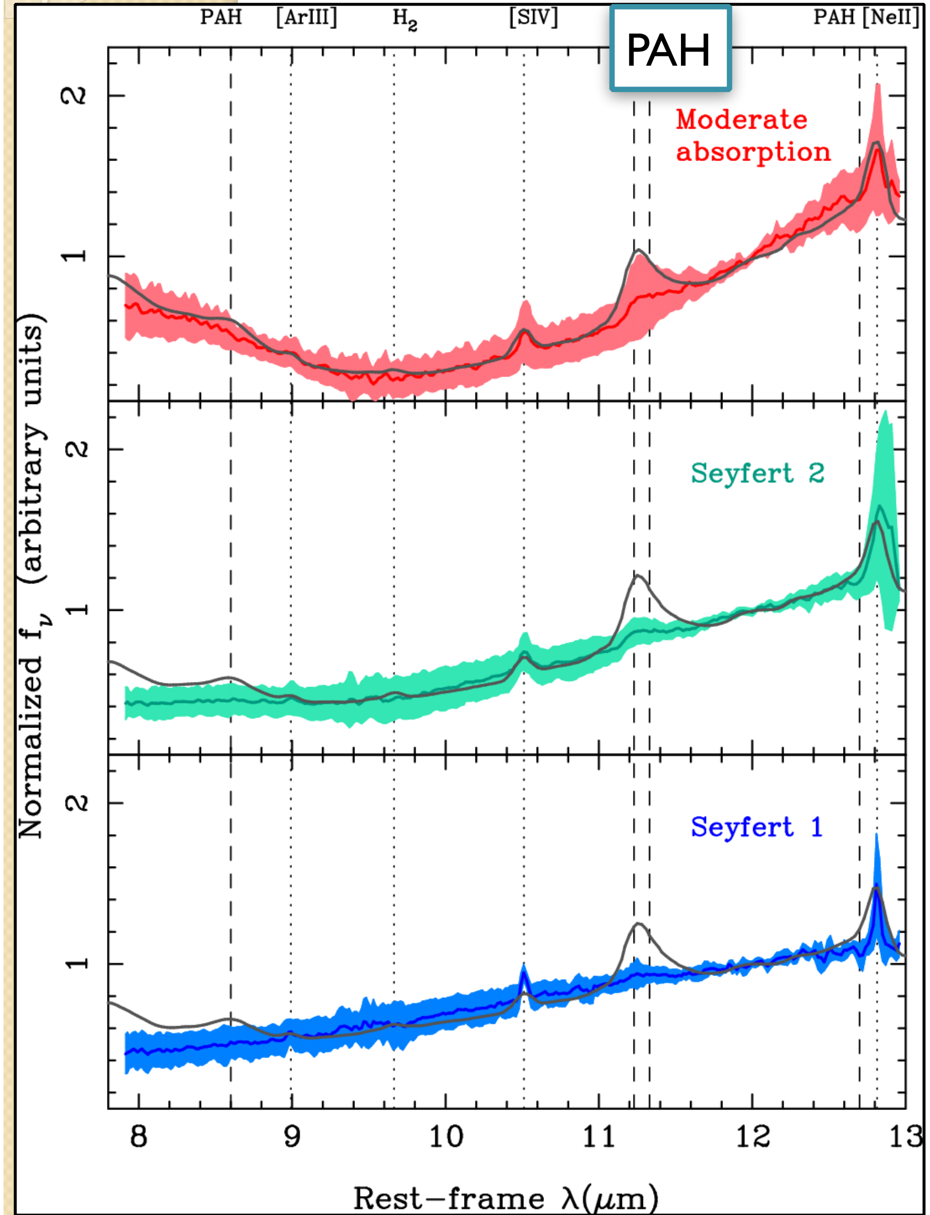


Mass fractions of various dust species for a sample of 53 quasars ≠ dust composition in ISM

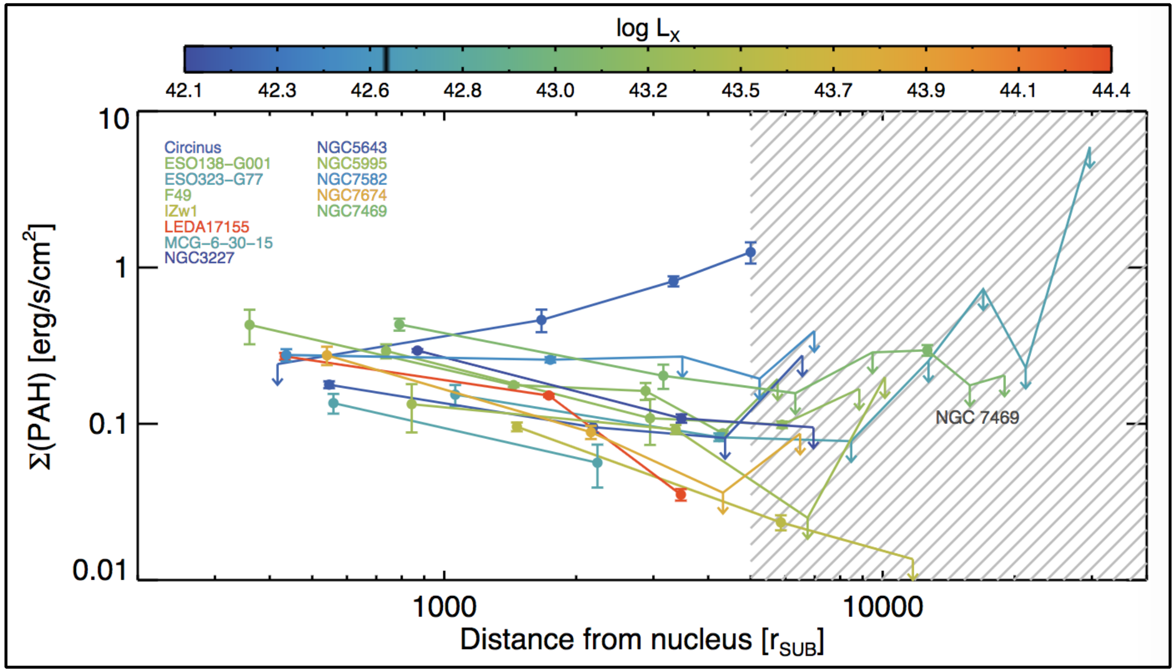
Srinivasan+2017, see also Markwick-Kemper+2007, Xie +2017

Dust produced in quasar winds? Elvis +2002

PAH emission in the nuclear regions of AGN



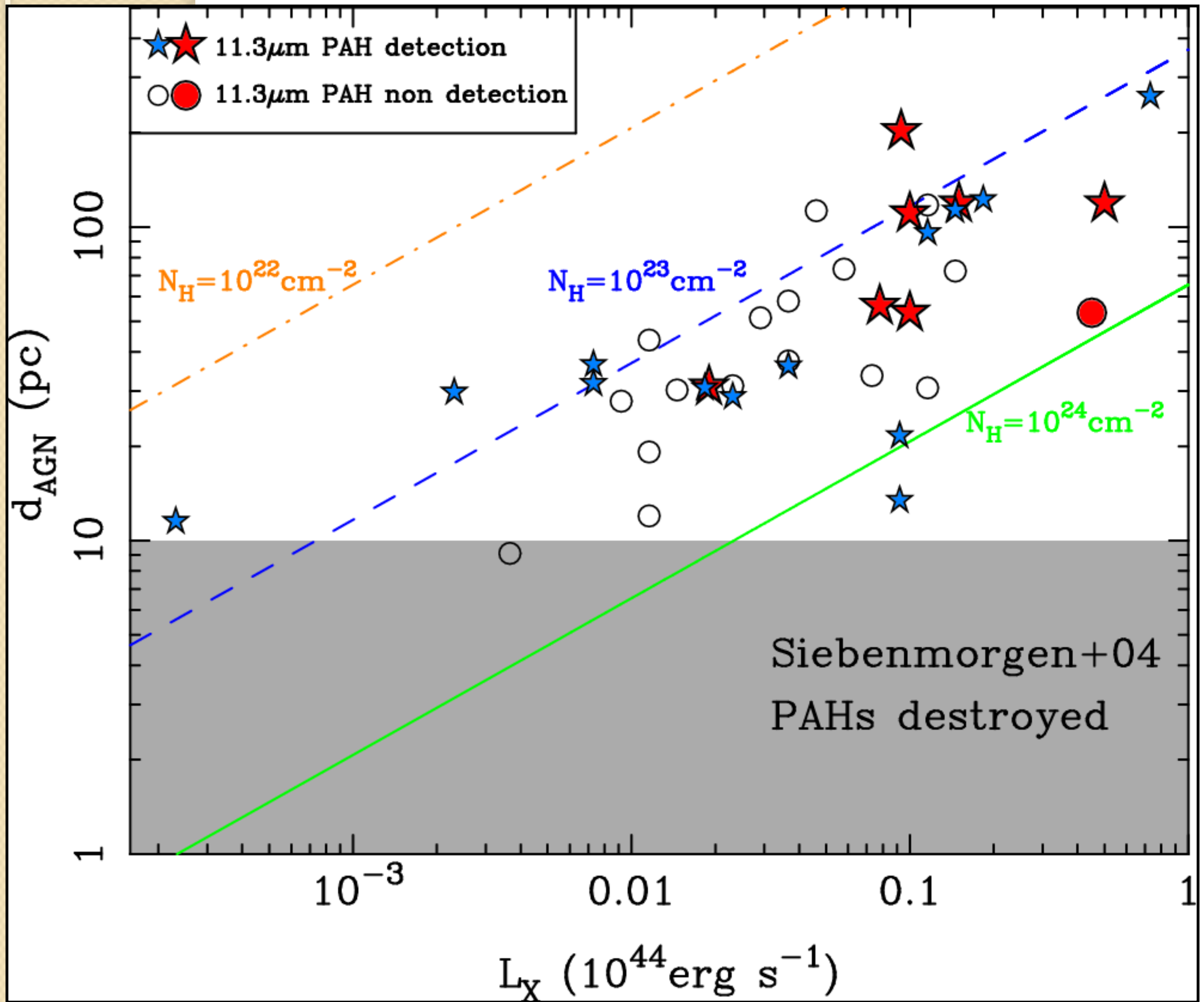
Jensen+2017



PAH emission excitation on scales of tens of parsecs: AGN vs. Nuclear SF?

Alonso-Herrero+2014, also Hönig+2010, González-Martín+2013, Esquej+2014, Ramos Almedia+2014, Ruschel-Dutra+2017, Esparza-Arredondo+2018

Protecting PAHs in the nuclear regions of AGN



Alonso-Herrero+2014

Torus, nuclear gaseous disks, and/or material in host galaxy provide sufficient material to shield the PAH molecules for Seyfert-like luminosities

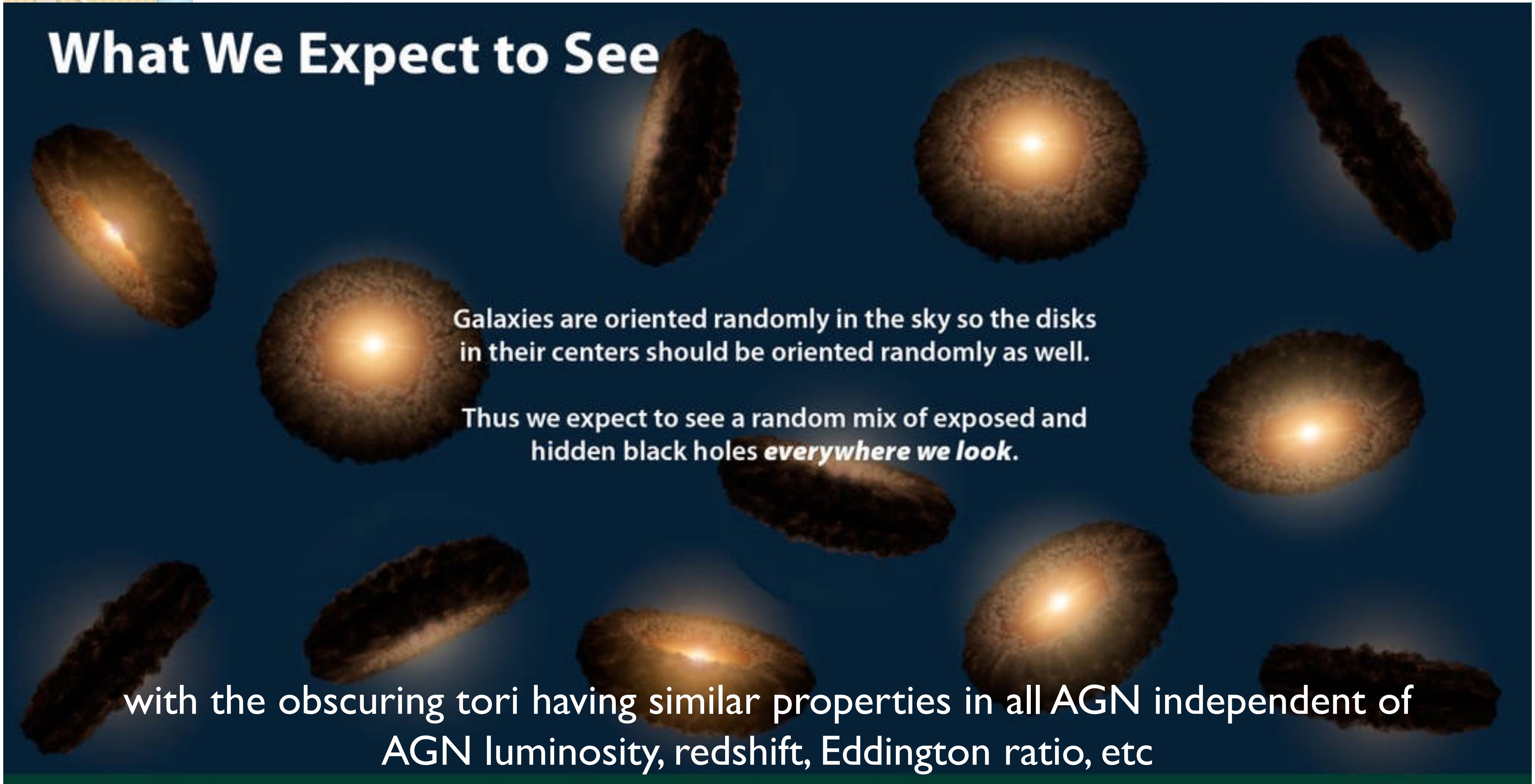
PAHs will survive if rate of reaccretion of carbon onto PAHs higher than evaporation rate due to harsh AGN radiation field

$$\tau \approx 700\,\mathrm{yr} \left(\frac{N_{\mathrm{H}}(\mathrm{tot})}{10^{22}\,\mathrm{cm}^{-2}}\right)^{1.5} \left(\frac{D_{\mathrm{agn}}}{\mathrm{kpc}}\right)^{2} \left(\frac{10^{44}\,\mathrm{erg\,s}^{-1}}{L_{\mathrm{X}}}\right)$$

Voit 1991, 1992, Miles 1994

Simplest version of the AGN Unified Model

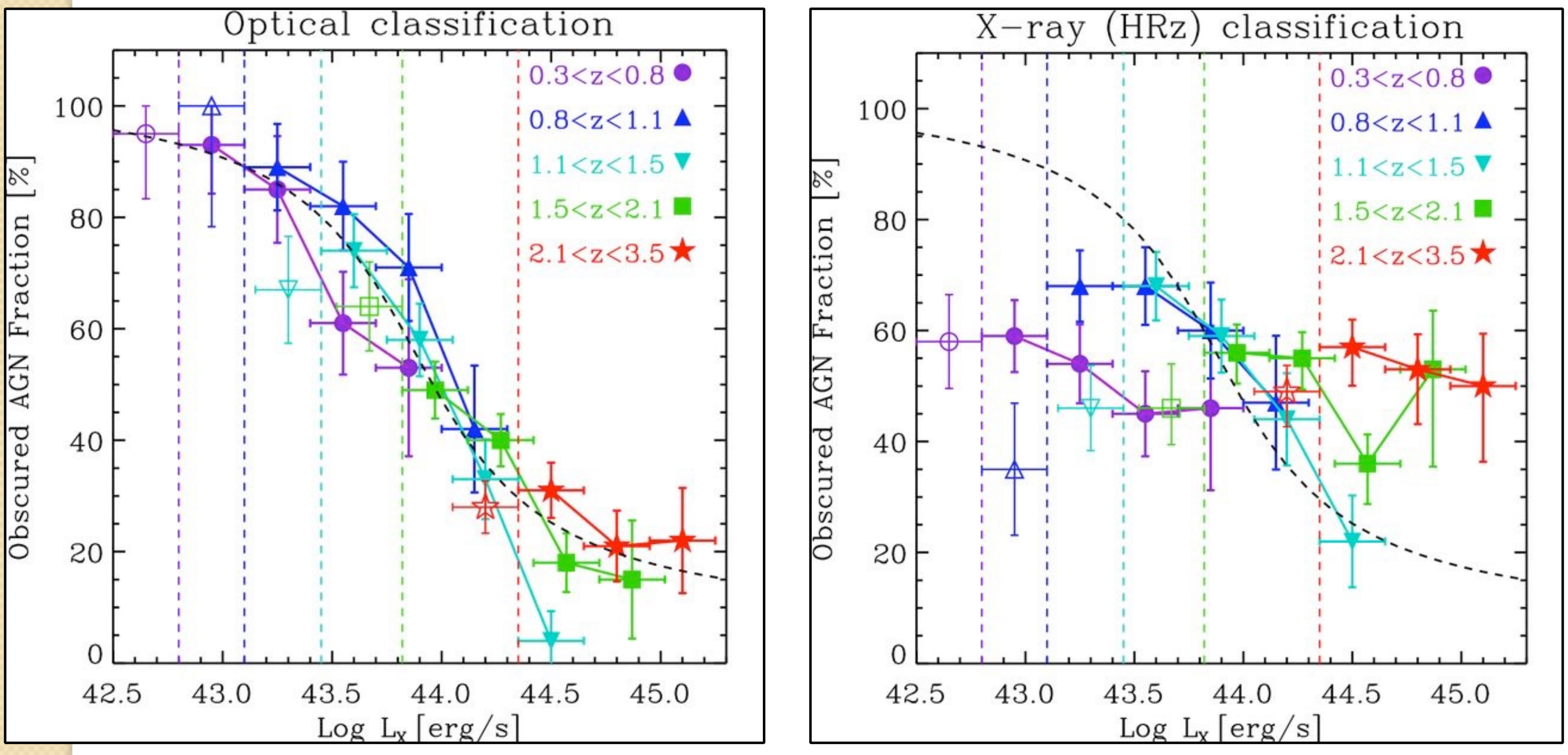
Credit: NASA WISE



The Obscured AGN fraction

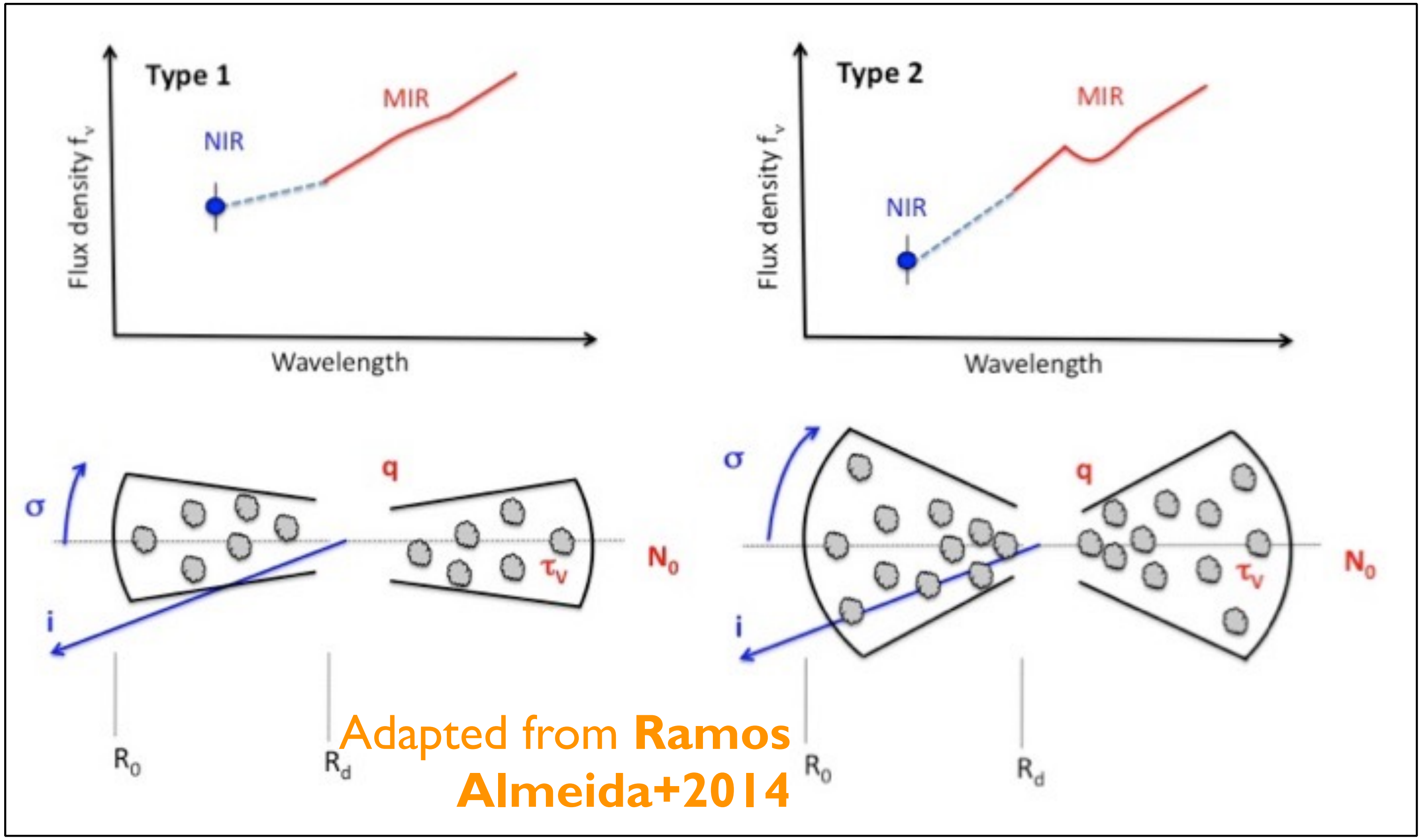
Obscured fraction is usually derived from X-ray column densities (N_H,) and optical class (type 1 broad vs. type 2 narrow lines)

Dependence with AGN luminosity?



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

Modelling the AGN IR unresolved emission



Adapted from **Ramos Almeida+2014**

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

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

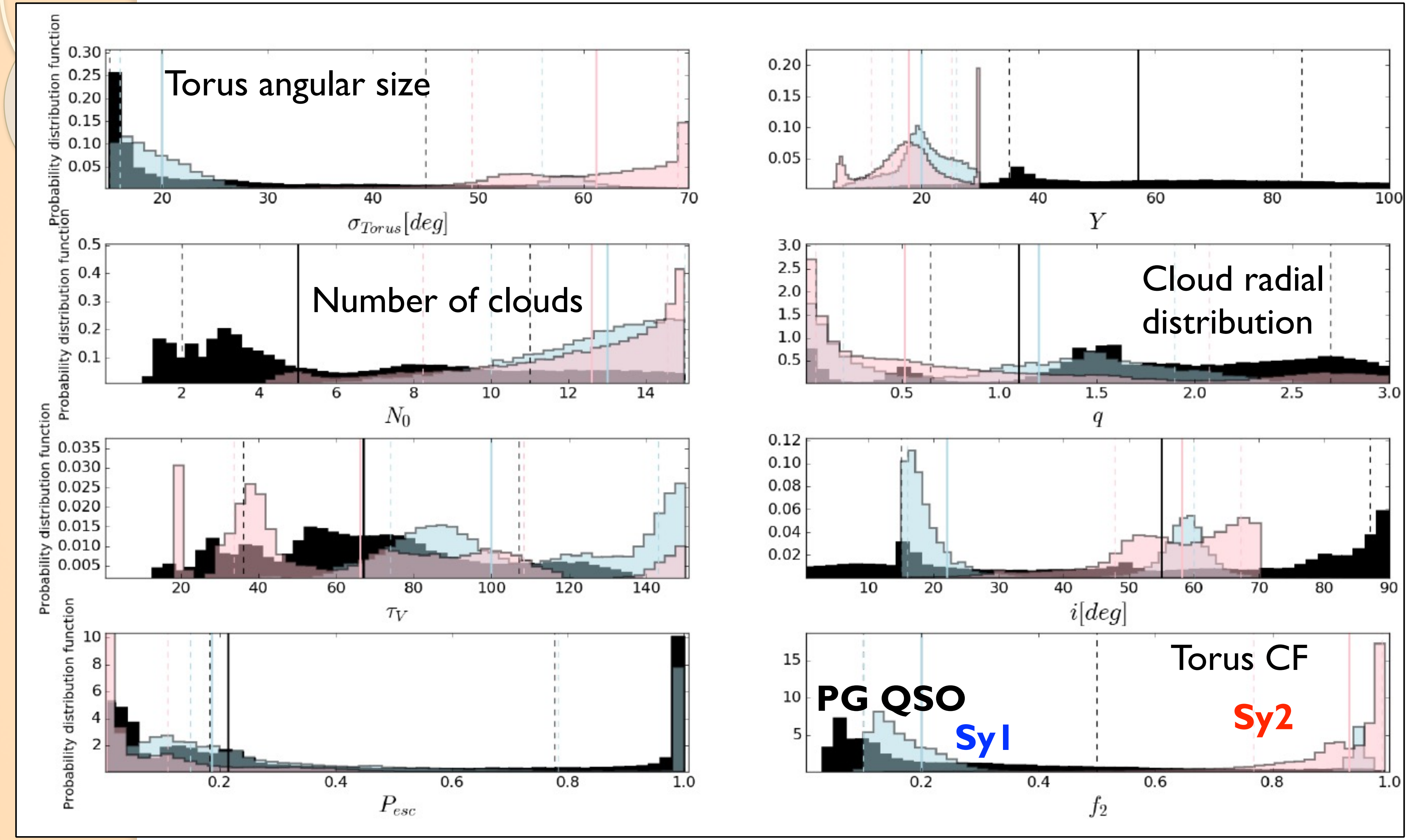
ß=90-i

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

Elitzur 2012

Geometrical covering factor (CF) f_2 is only a function of torus angular width and number of clouds along equatorial direction and defines **the fraction of obscured AGN**

Different torus model parameters for Type 1 and Type 2 AGN



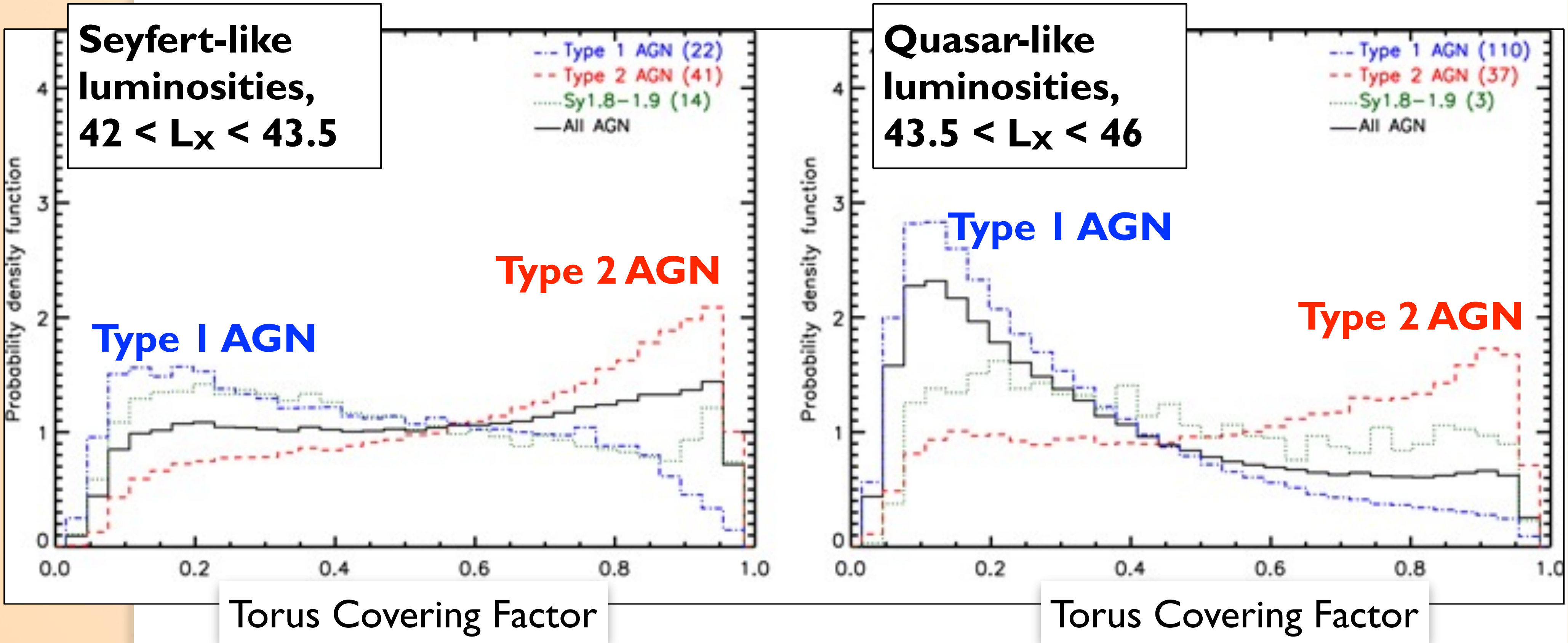
Martínez-Paredes+2017

Also Ramos Almeida+2011, Alonso-Herrero+2011, Mor+2012, Ichikawa+2015

Torus Dust Covering Factors vs Luminosity

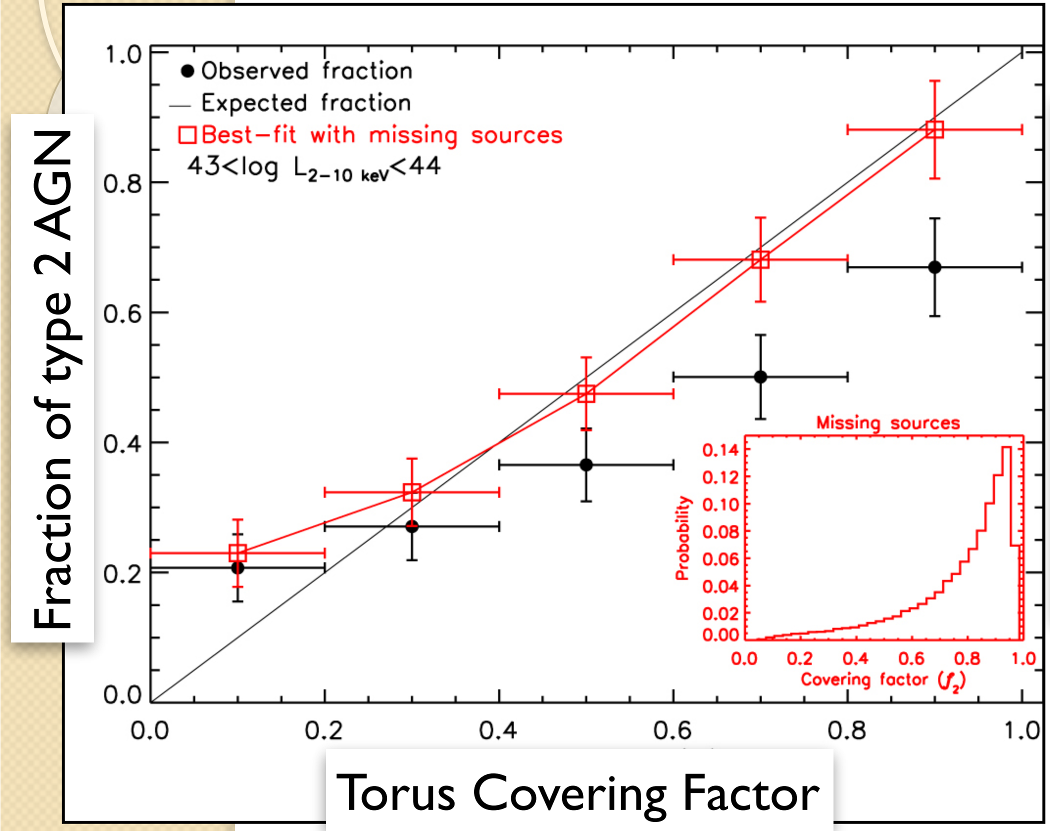
- Complete sample of X-ray selected AGN: 132 type 1 AGN and 78 type 2 AGN at redshifts z~0-1.7

- Small CF values are preferred at high AGN luminosities, as postulated by simple receding torus models

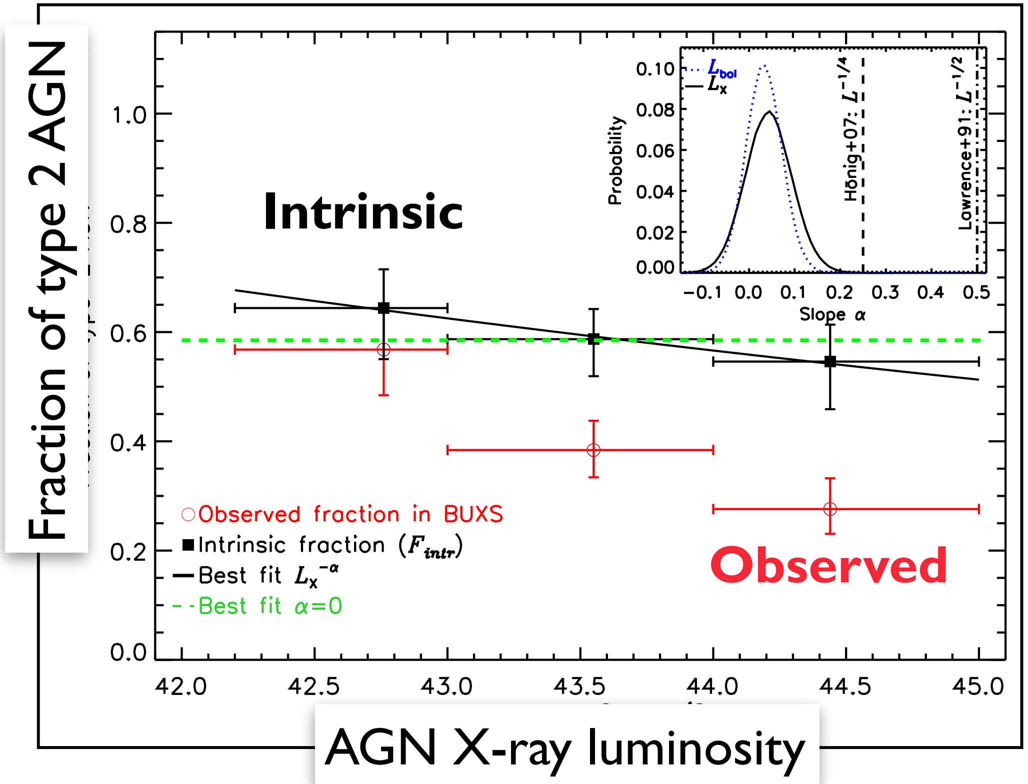


Mateos+2016, see also Mor+2009, 2012, Roseboom+2015

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



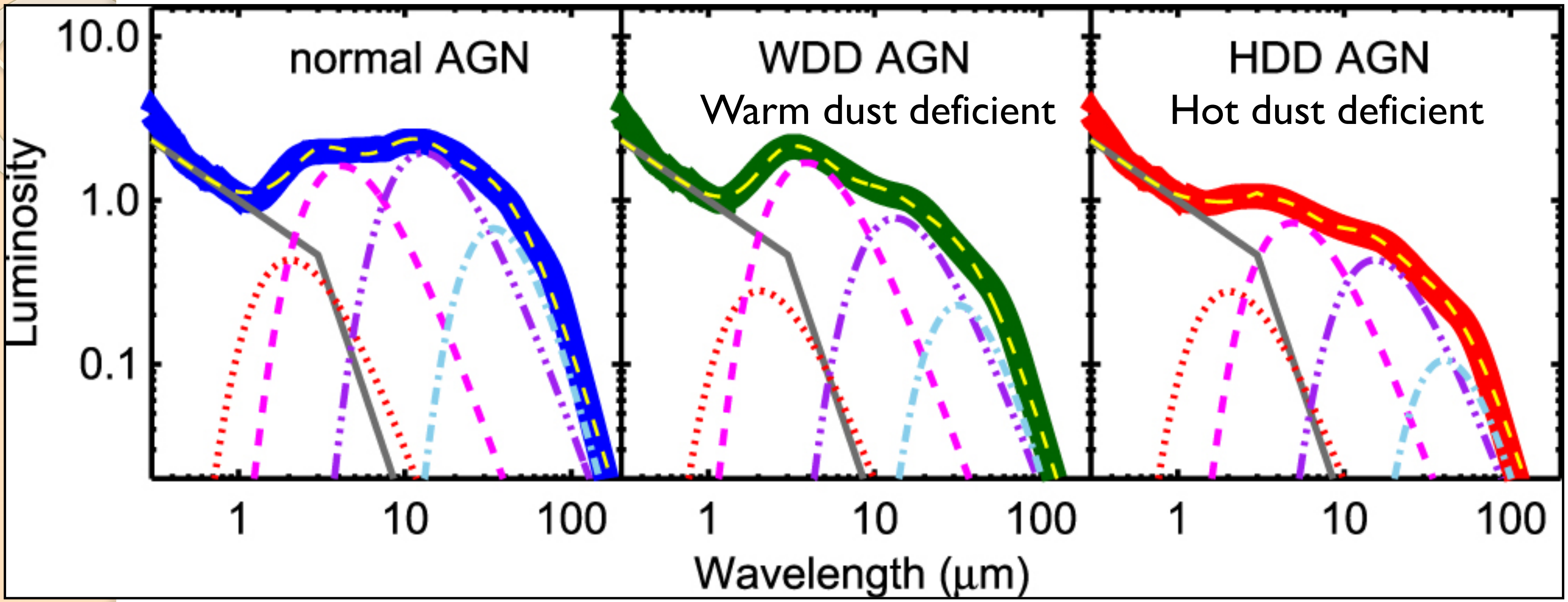
Mateos+2017



- A non-negligible fraction of luminous, heavily obscured (high covering factors) type-2 AGN X-ray detection (at energies < 10keV) are missing:
- Comparison of optical fraction of type 1/type 2 of X-ray selected AGN with the modelled distribution of torus geometrical covering factors

Normal and dust deficient quasars

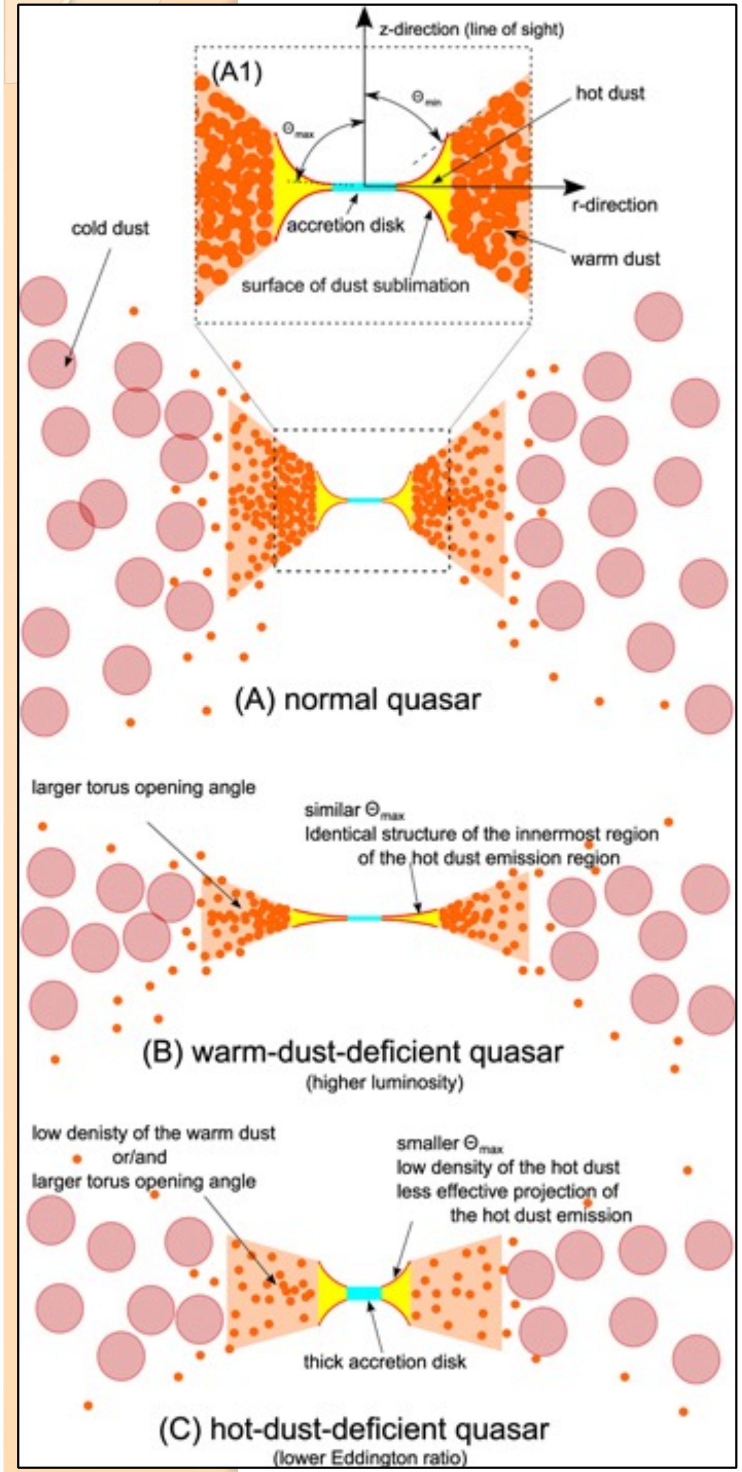
Lyu+2017b



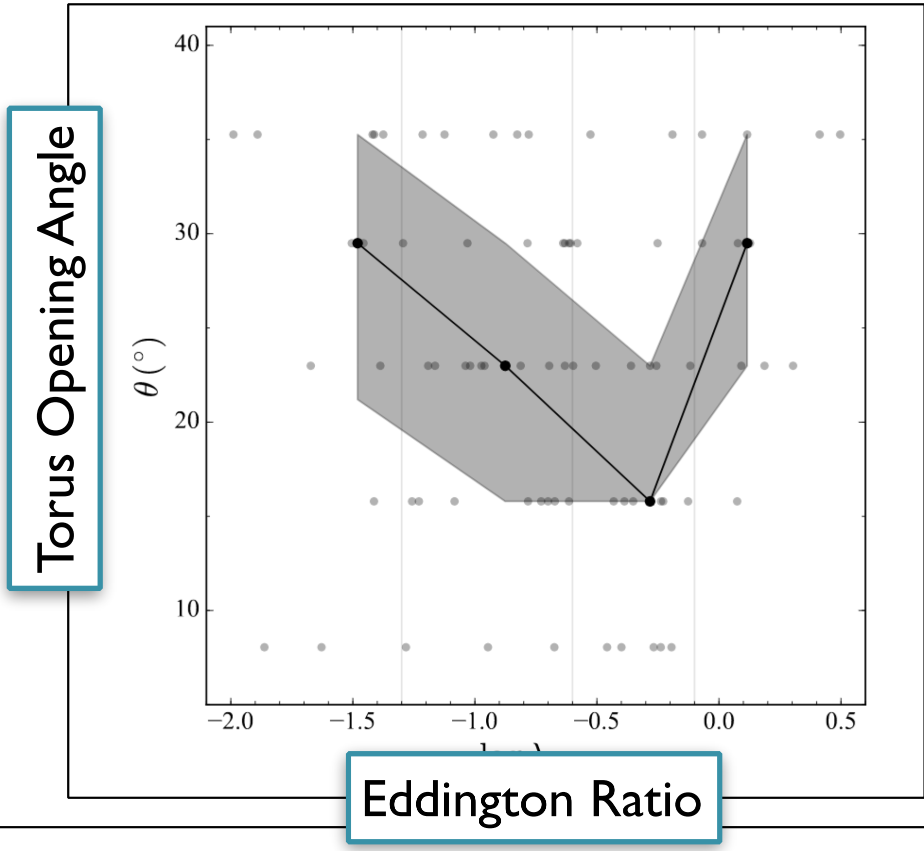
- Warm and hot dust deficient quasars are only 10% of type 1 quasar population
- All quasars have very similar far-infrared SED that are also consistent with those of lower luminosity AGN
- **Similar emitting properties in the outer parts of the AGN-heated dusty structures, i.e., optically thin dust in the far-infrared**

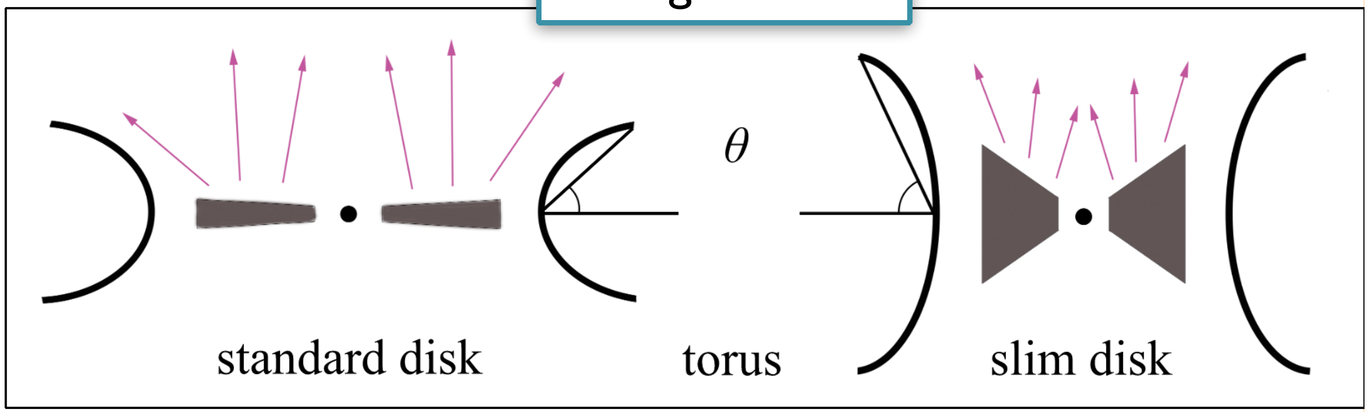
Lyu+2017a

Evolution of the obscuring material (torus) in PG quasars



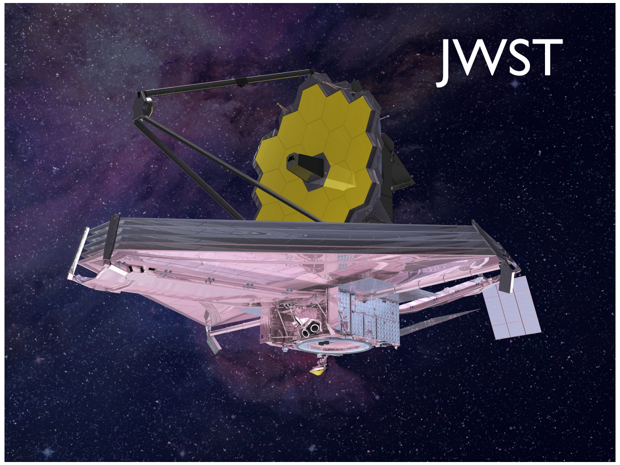
Zhuang+2018





Summary

We are only starting to glimpse the *true nature* of the torus and the properties of the AGN dust



- Images of the torus: detailed geometry of the torus in nearby active galaxies including sizes, polar dust
- Inflows/outflows
- Connection with the host galaxy including positive/negative feedback, nuclear star formation activity

- Dust properties in large AGN samples
- Evolution of torus properties in AGN vs luminosity, redshift, Eddington ratio, etc