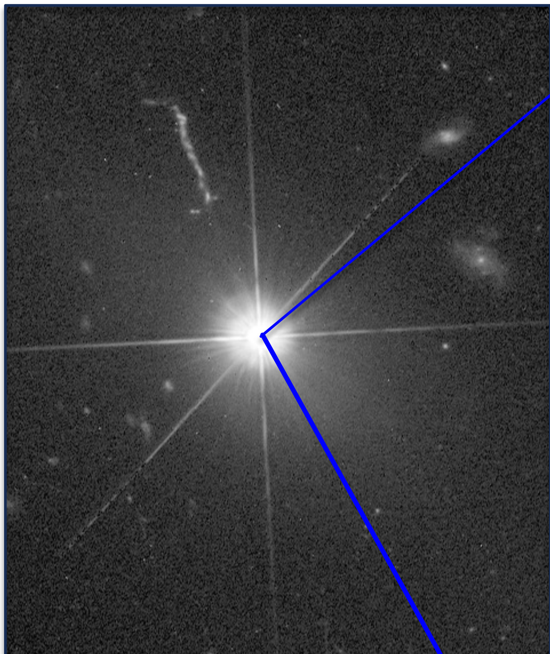
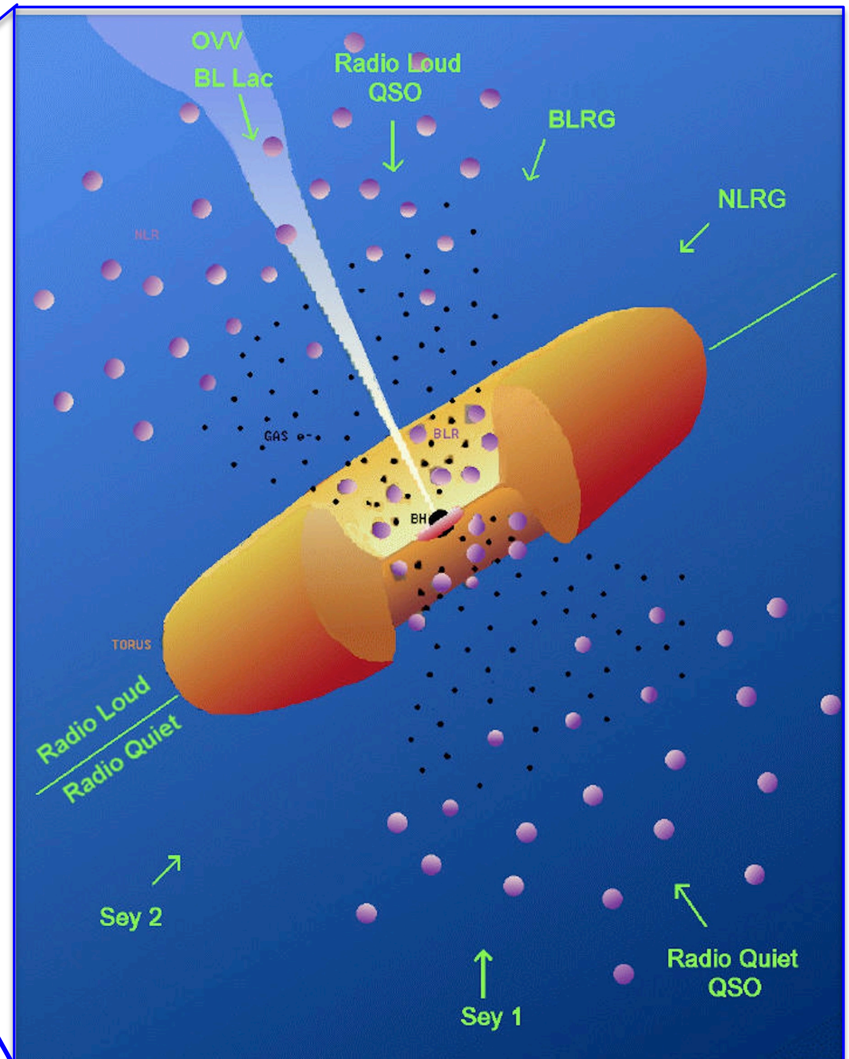
AGN VARIABILITY STUDIES WITH THE NANCY GRACE ROMAN SPACE TELESCOPE

DR. TRIANA ALMEYDA
POSTDOCTORAL RESEARCHER
SOUTH CAROLINA STATE UNIVERSITY

AGN UNIFICATION MODEL



Quasar 3C 273
Credit: NASA and J. Bahcall (IAS)

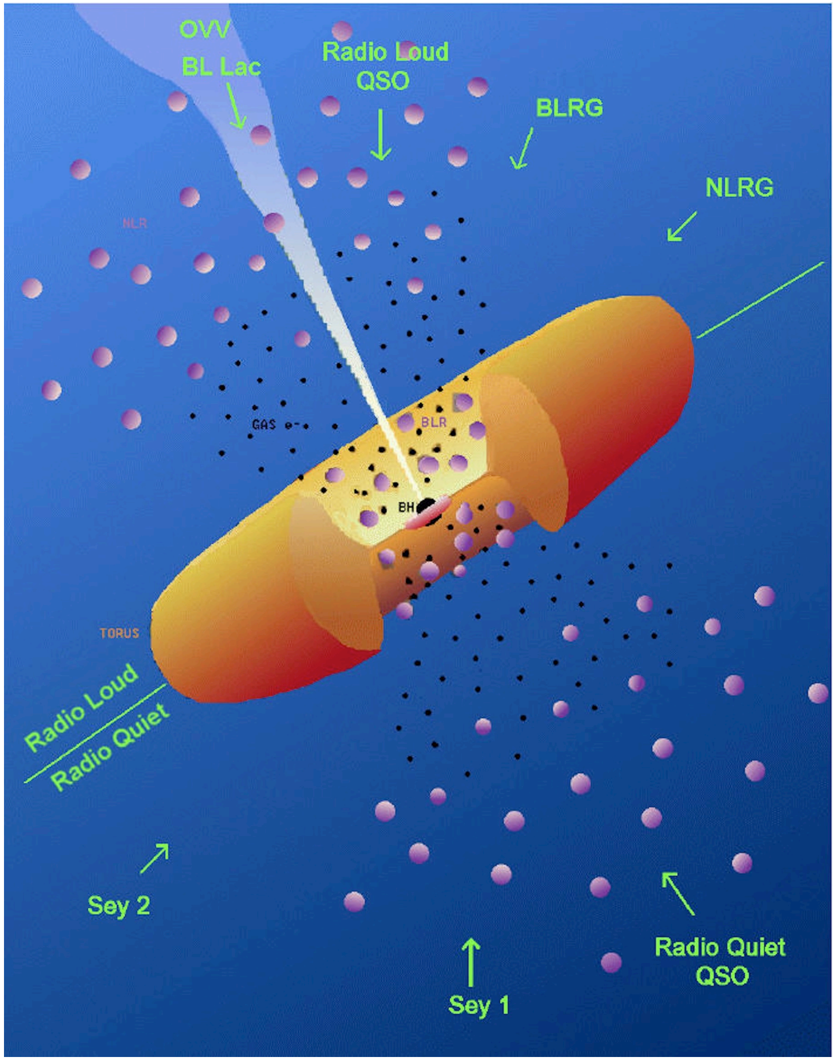


Credit: Urry & Padovani 1995

AGN UNIFICATION MODEL

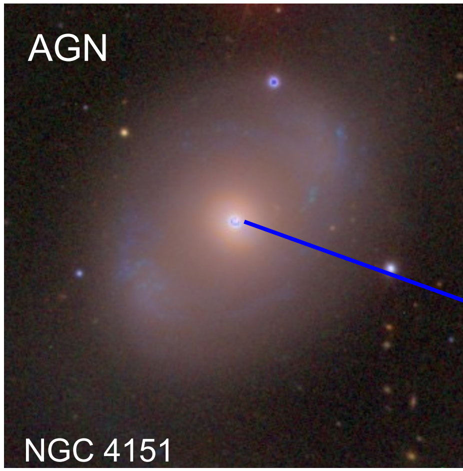
Observational Features

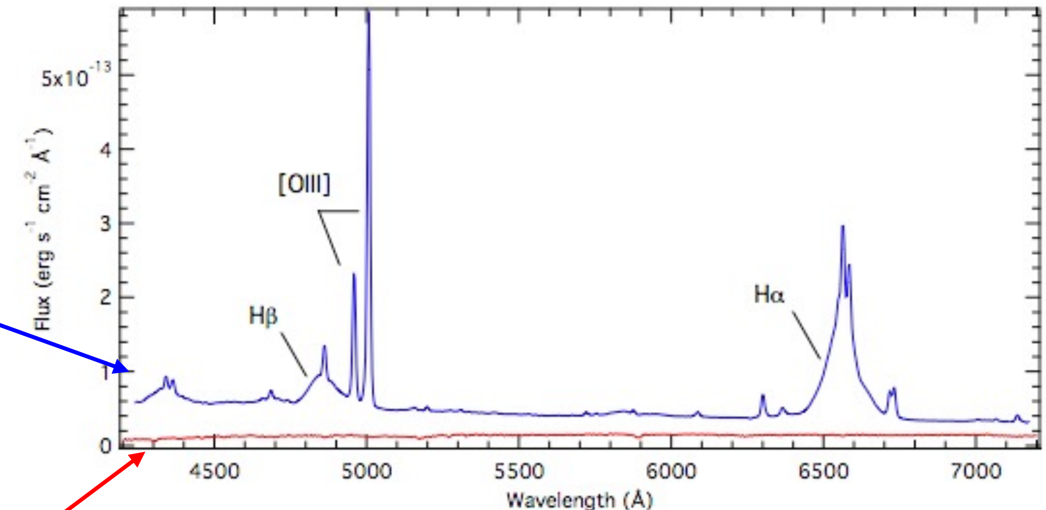
- Broad range of luminosities
- Strong, broad optical/UV emission lines
- Broadband emission (X-ray to radio)
  - IR excess
- Variable

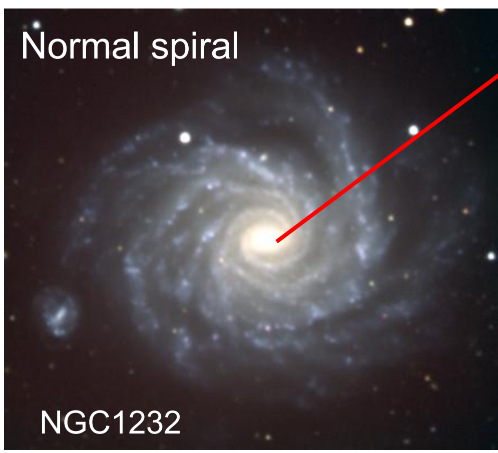


Credit: Urry & Padovani 1995

BROAD AND NARROW EMISSION LINES







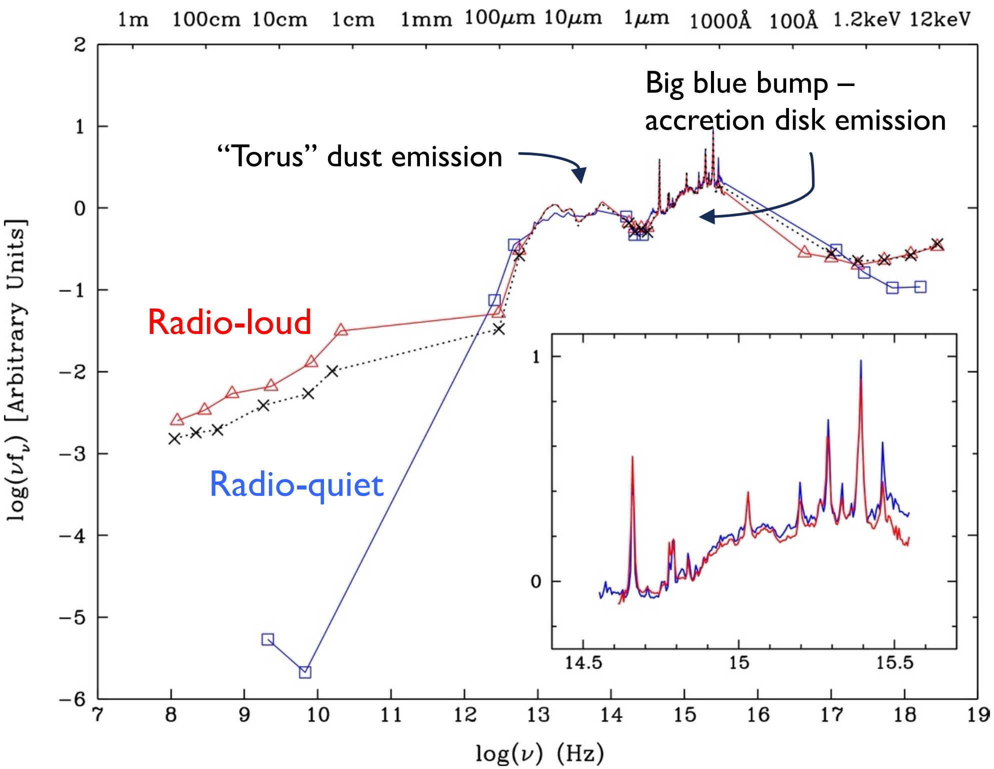
Optical AGN spectra:

- rich emission line spectrum
- wide range of ionization states (O^{+} — Fe^{+9}) line widths ~ 500 km s^{-1}
- permitted lines (Hα, Hβ etc) have broad wings — velocities ~10^4 km s^{-1}

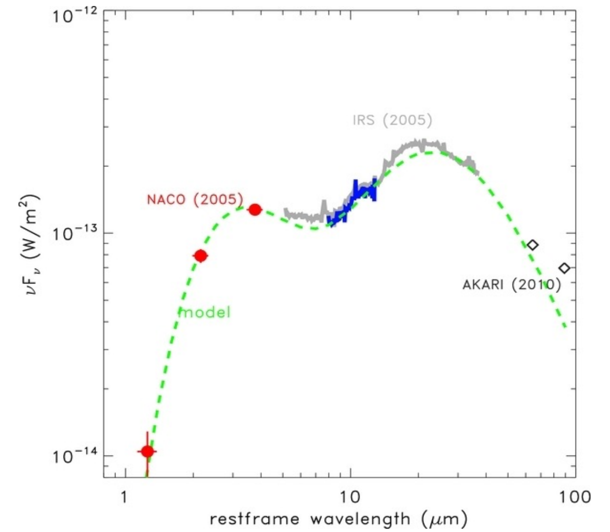
$$M_{BH} \approx \frac{f R_{BLR} \sigma^2}{G}$$

AGN SPECTRAL ENERGY DISTRIBUTION

IR dust emission from torus accounts for significant fraction of AGN bolometric luminosity



Shang et al. 2011: median AGN SED

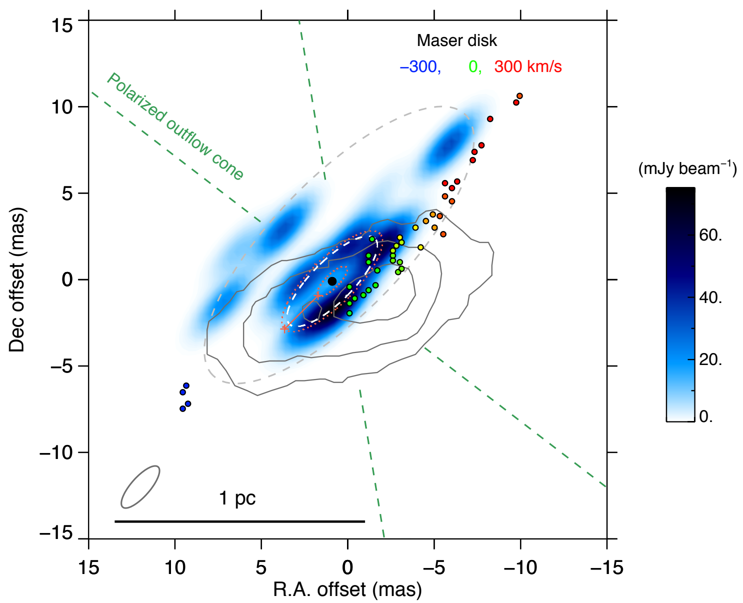


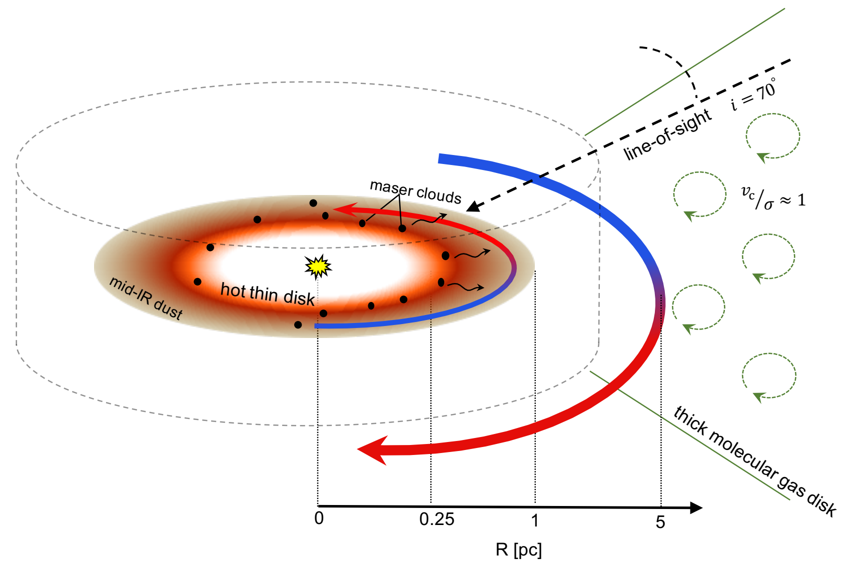
Hönig et al. 2013: IR SED of NGC3783 (+ two component dust RT model)

NIR INTERFEROMETRY – HOT DUST

GRAVITY Collaboration 2020

- Sublimation region resolved in NGC1068



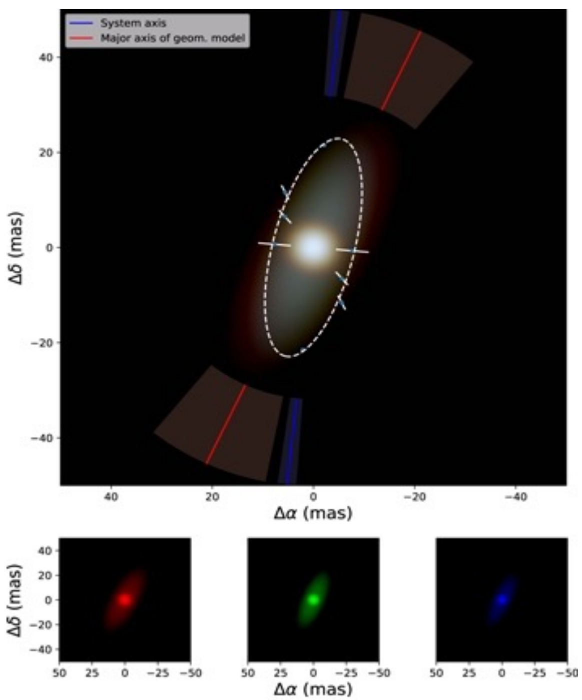


ALMA: Compact (~5 pc) counter-rotating "torus" observed in HCN & HCO^+ (Imanishi et al. 2018)

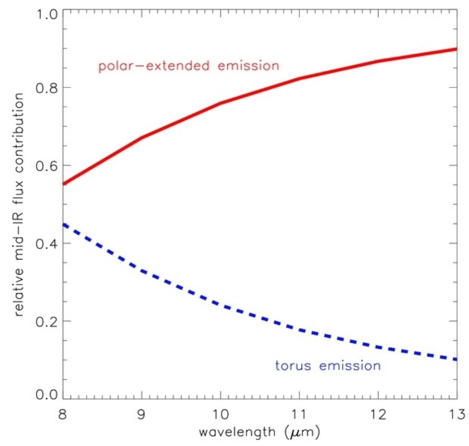
~10 pc bipolar outflow observed in CO (Gallimore et al. 2016)

MIR INTERFEROMETRY (AND PHOTOMETRY) – POLAR DUST

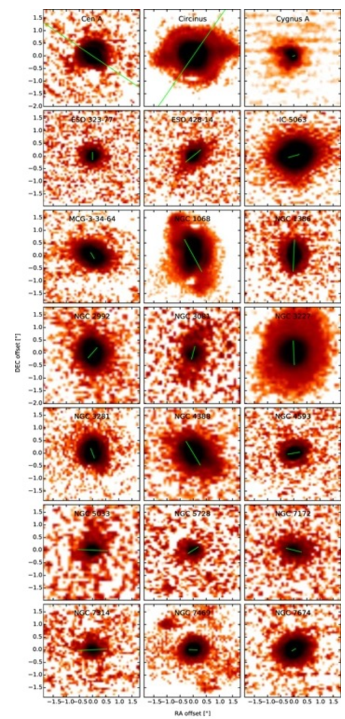
- MIR interferometry shows that in many AGN substantial fraction of MIR flux originates in ~1 pc scale elongated polar structures
- Similar structures common at ~ 100 pc scales



Leftley et al. 2018: geometric model of MIDI interferometry observations of ESO 323-G77



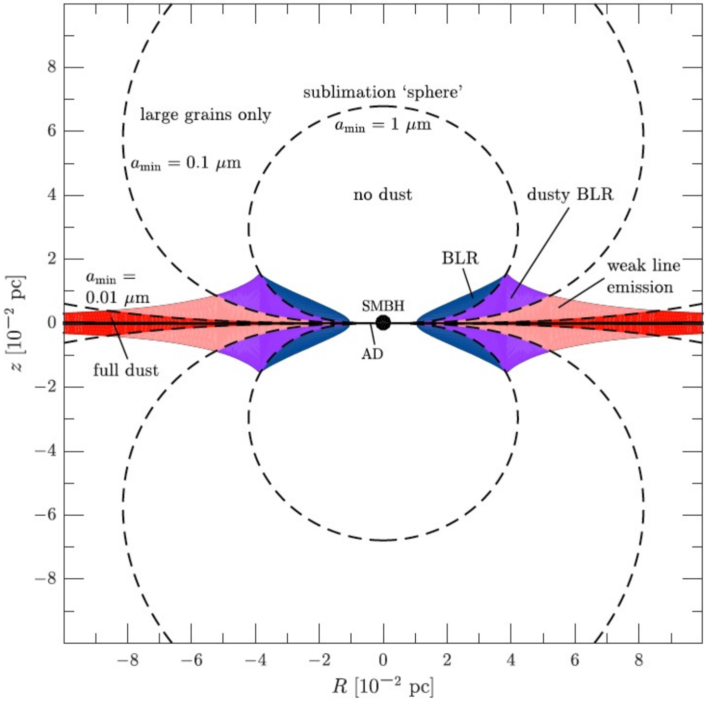
Hönig et al. 2013: relative fluxes of polar and torus components in NGC3783



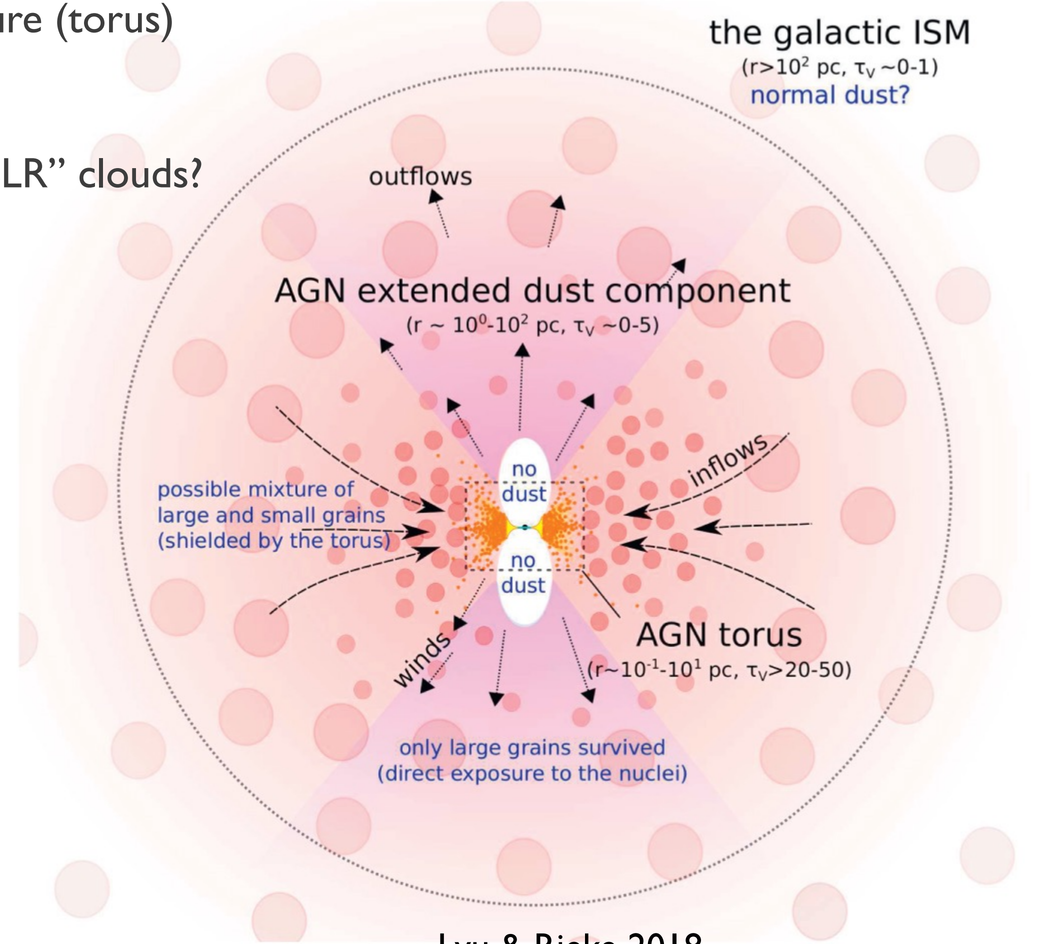
Asmus et al. 2016: single dish MIR images

A MORE COMPLETE PICTURE?

- Multiple components of emission and obscuration
  - Thick disk-like obscuring structure (torus)
  - Dusty bipolar wind
  - Hot dust component – dusty "BLR" clouds?



Baskin & Laor 2018

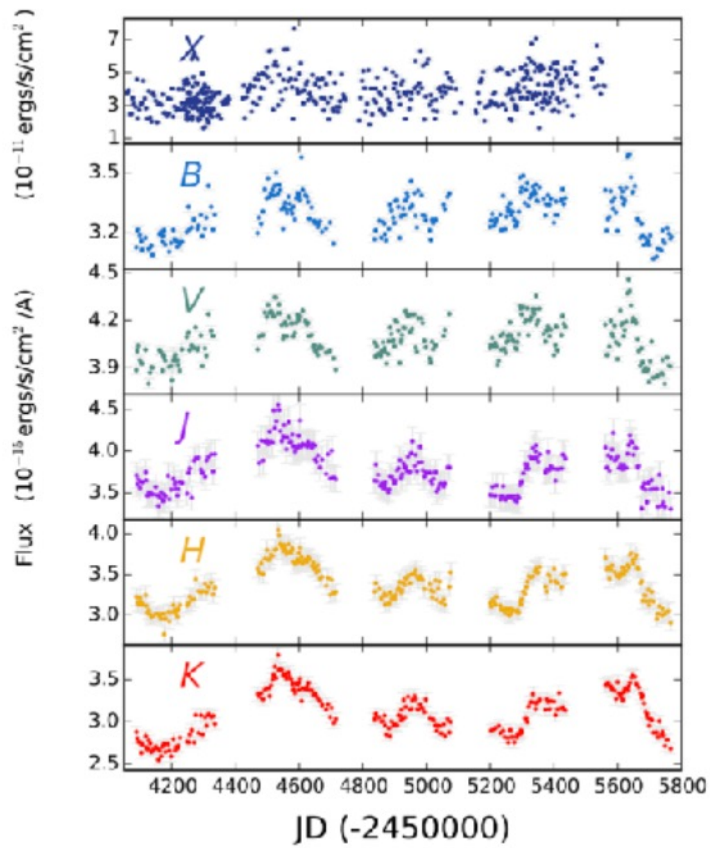


Lyu & Rieke 2018

TIME DOMAIN STUDIES OF AGN

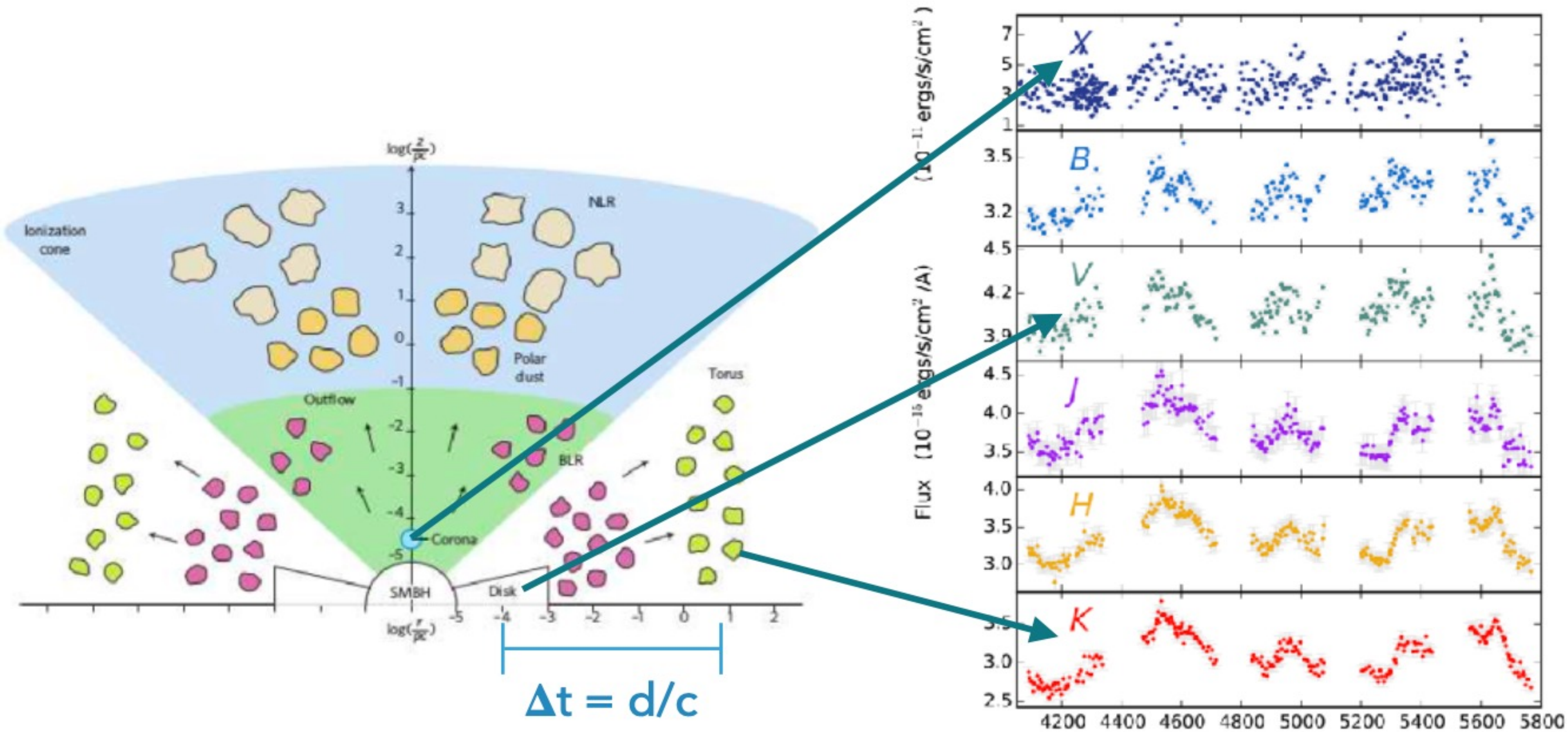
BROAD BAND VARIABILITY

- Characteristic variability timescales range from hours to years,
  - Shorter timescales associated with shorter emission wavelengths
- Observe correlation between the variations at different wavelengths



MCG-6-30-15 from Lira et al. 2015

BROAD BAND VARIABILITY

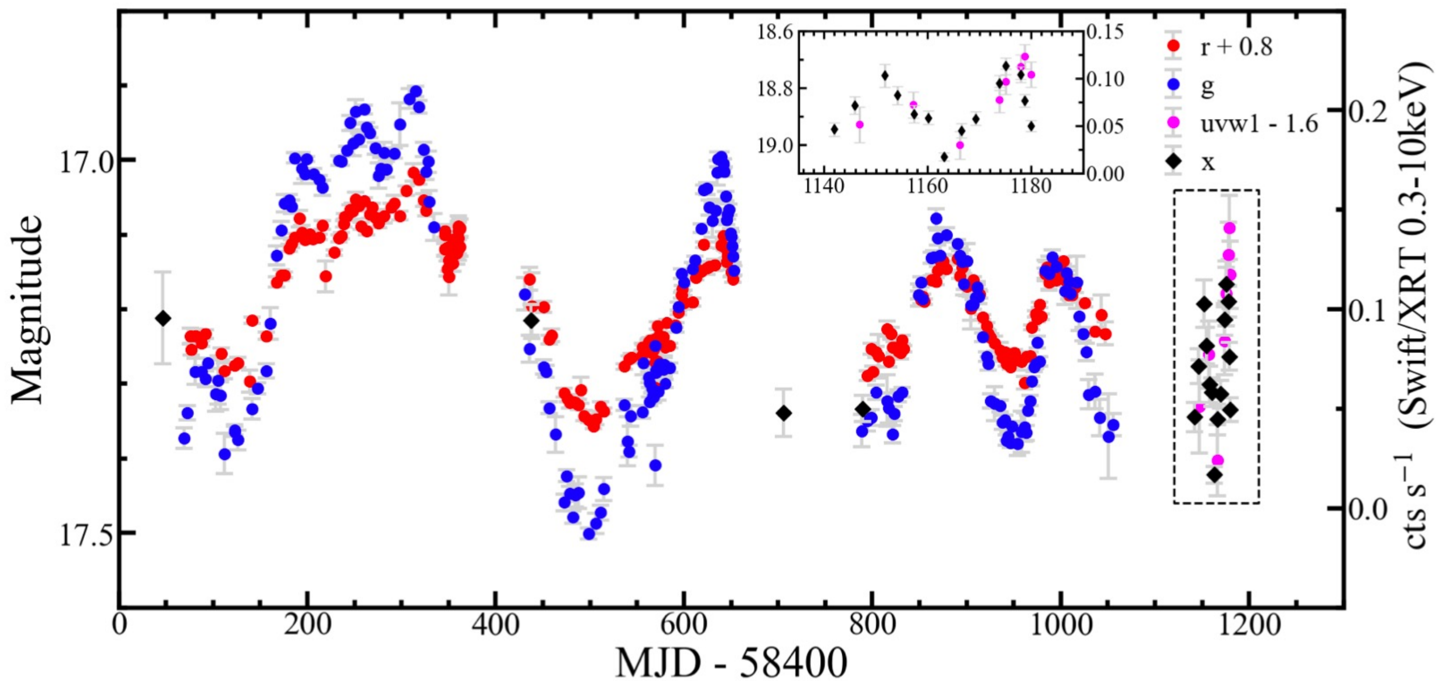


Ramos Almeida & Ricci (2017)

MCG-6-30-15 from Lira et al. 2015

DETECTION OF BINARY SMBH

Optical, UV, and X-ray light curves of SDSSJ1430+2303



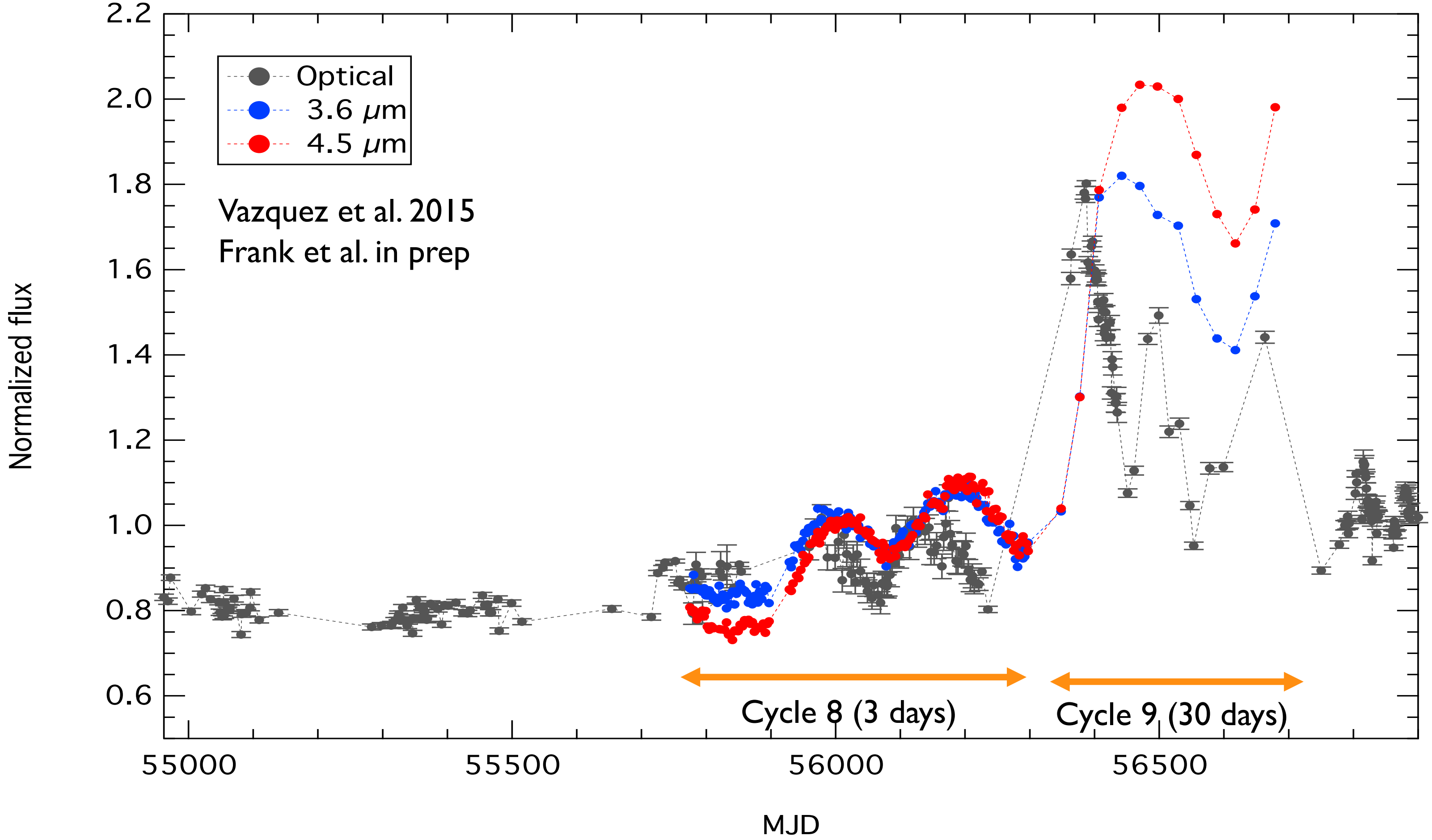
Jiang et al. 2022, arxiv:2201.11633v1

*Other famous candidate for a sub-pc binary SMBH is OJ287 (Komossa+2021)

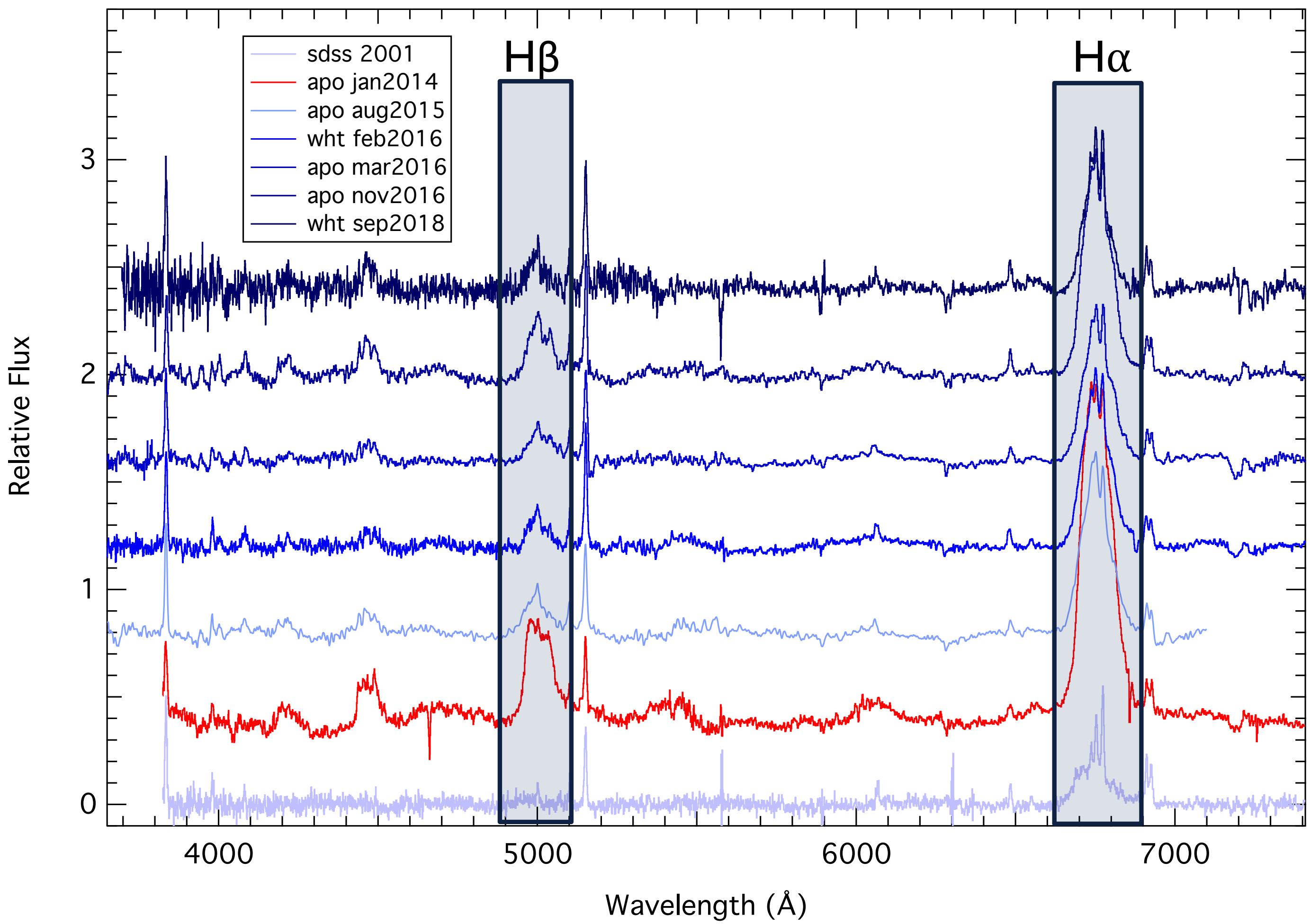
TRANSIENT EVENTS: CHANGING-LOOK AGN

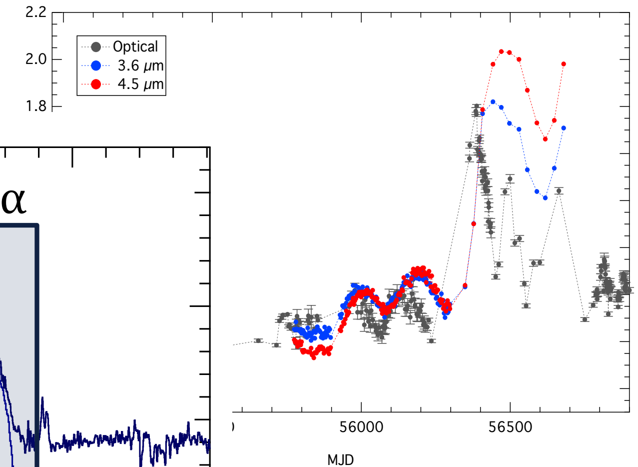
- Spitzer and optical monitoring campaign

(See **Ashley Frank**'s poster for more information)



TRANSIENT EVENTS: CHANGING-LOOK AGN



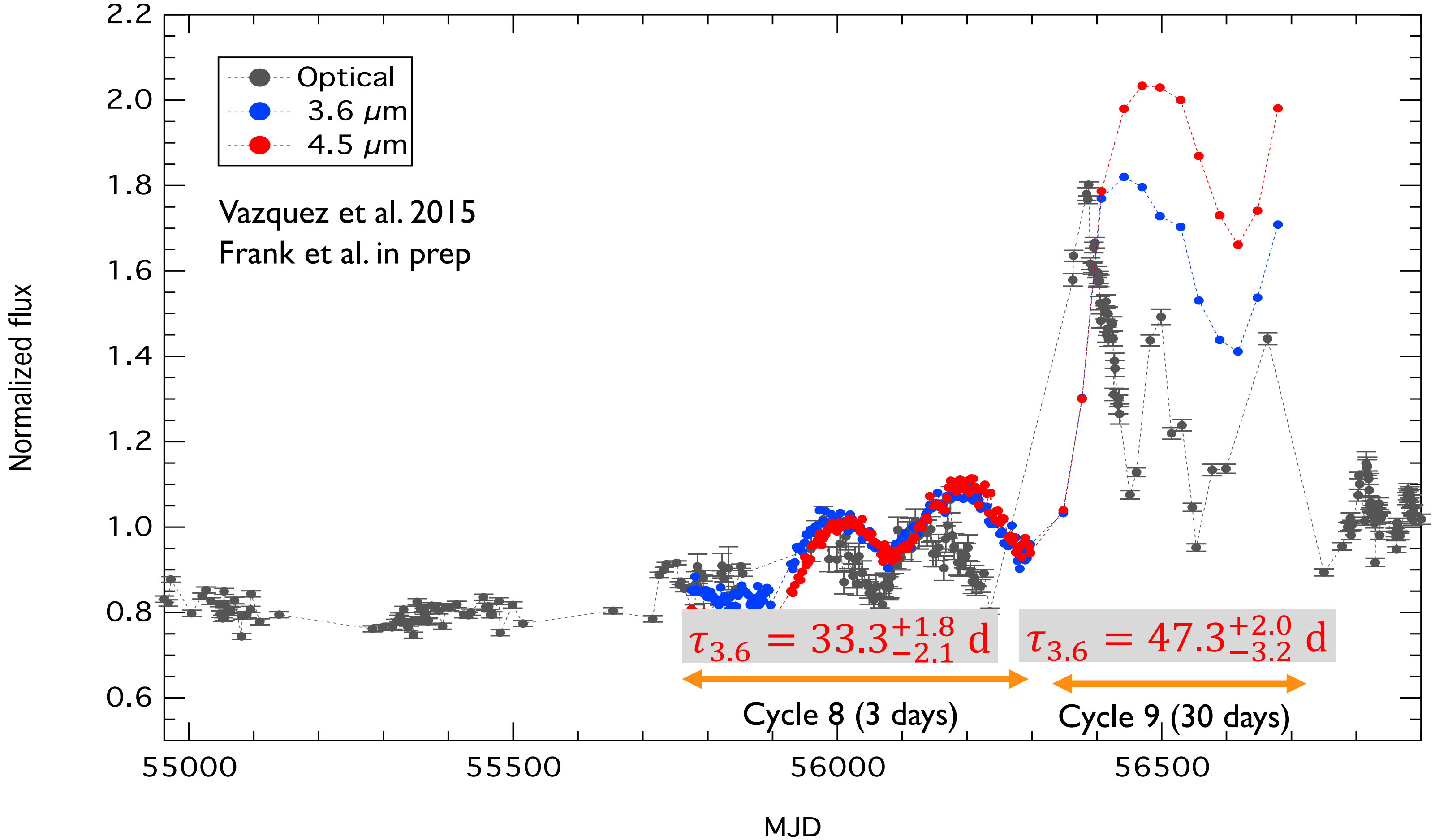


Vazquez et al. 2015
Frank et al. in prep

TRANSIENT EVENTS: CHANGING-LOOK AGN

- Increase in IR– optical lags following flare => $r_{sub} \sim L_V^{1/2}$

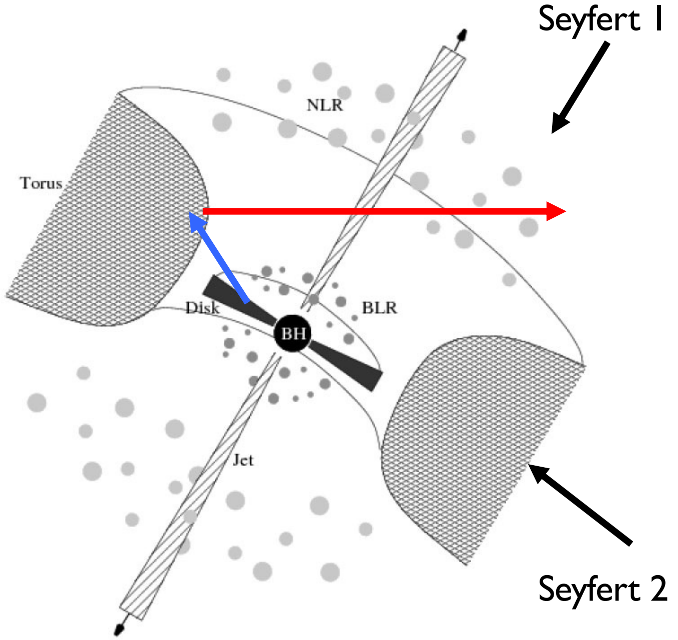
(See **Ashley Frank**'s poster for more information)



AGN DUST REVERBERATION MAPPING

- Reverberation map torus at IR wavelengths
- Response of torus dust emission to UV-optical variations depends on size, geometry, cloud distribution, etc.

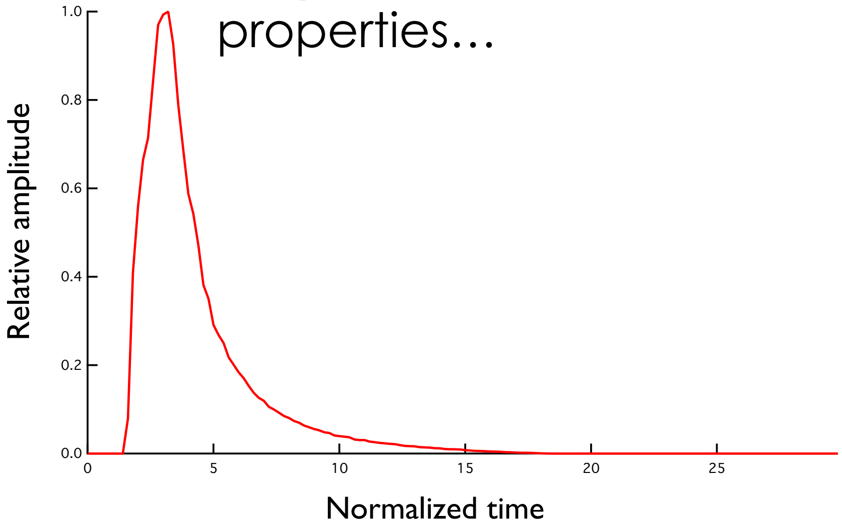
Dust absorbs UV–visible radiation and re-emits in the IR



Credit: Middelberg & Bach 2008

AGN DUST REVERBERATION MAPPING

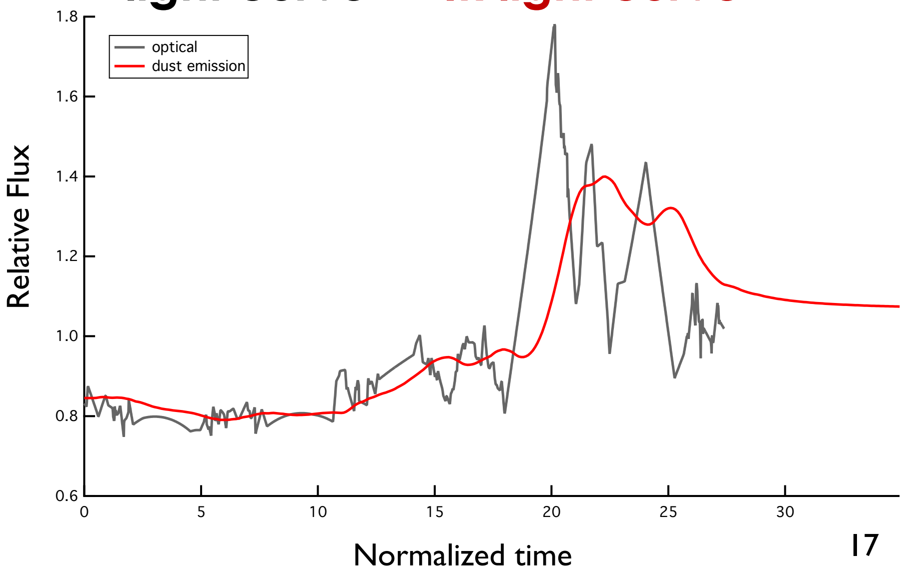
Response function encodes torus properties…



- Cross-correlating optical light curve and IR light curves → lag, t_d
- This measures the effective (emissivity-weighted) radius

$$\tau_d \sim r_d / c$$

…convolution with driving **optical light curve** → **IR light curve**



MODELING AGN DUST EMISSION

Collaborators:

ANDREW ROBINSON

ROBERT NIKUTTA

NADIYA IKONNIKOVA (UNDERGRADUATE STUDENT)

BRYANNE MCDONOUGH (UNDERGRADUATE STUDENT)

SHAELYN SHADWELL ((UNDERGRADUATE STUDENT)

MICHAEL RICHMOND

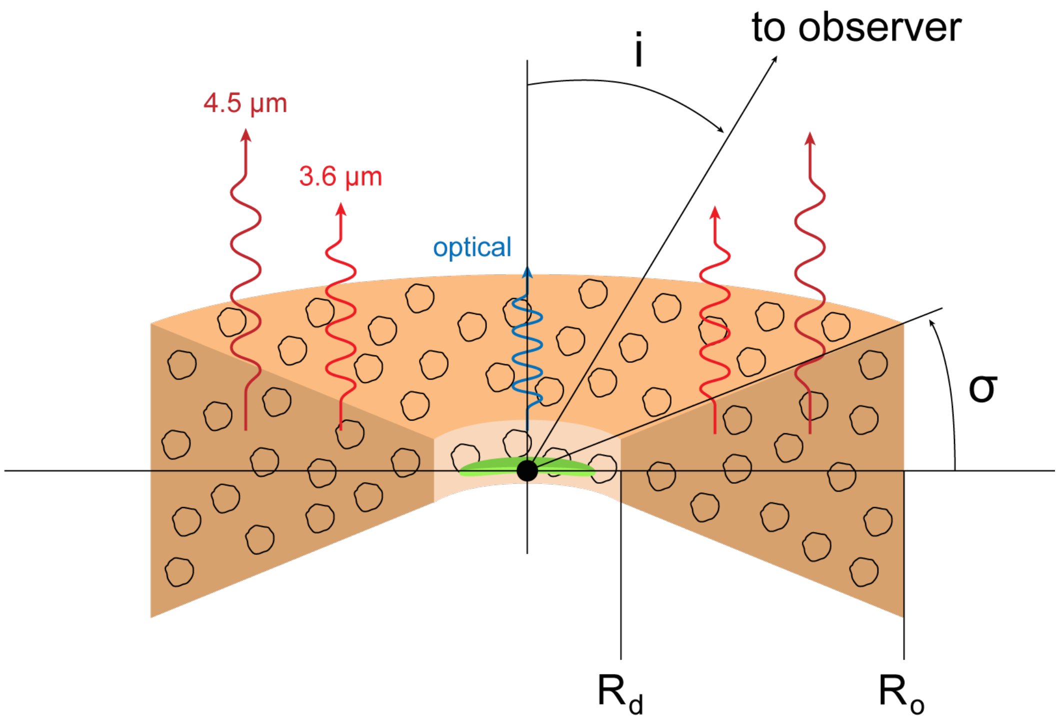
JACK GALLIMORE

SEBASTIAN HÖNIG

Supported by:
NASA/ATP NNX12AC68G
NASA/ADAP NNX16AF42G
NSF/AARG 2009508

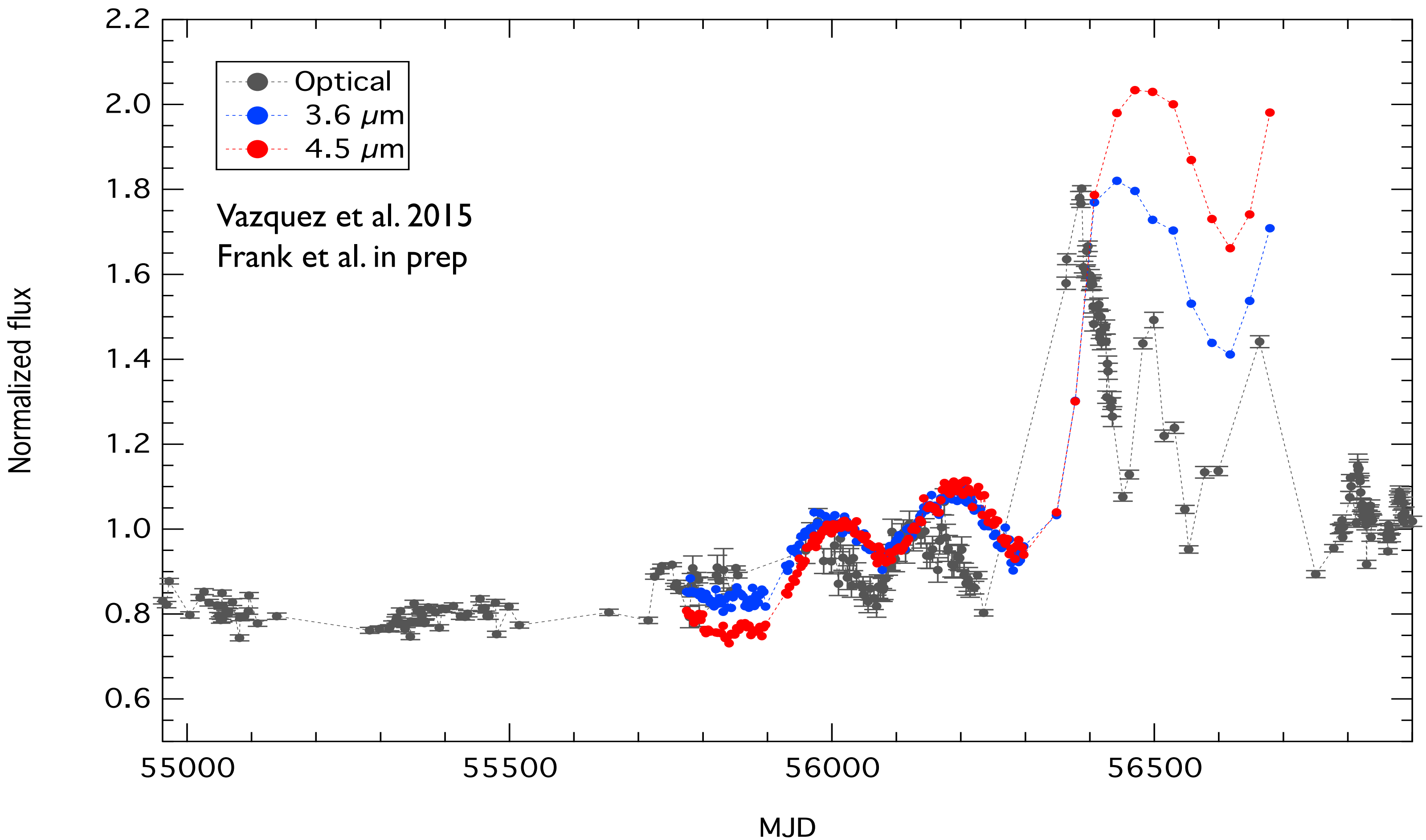
TORUS REVERBERATION MAPPING CODE (TORMAC) FEATURES

- TORMAC compatible with any radiative transfer grid/database
- Simulates multi-wavelength time dependent response of dust emission for any input light curve
- Dust radiative transfer within clouds
- Global opacity effects
- Isotropic or anisotropic illumination by the central source



Nenkova et al. 2008a,b; Almeyda et al. 2017, 2020

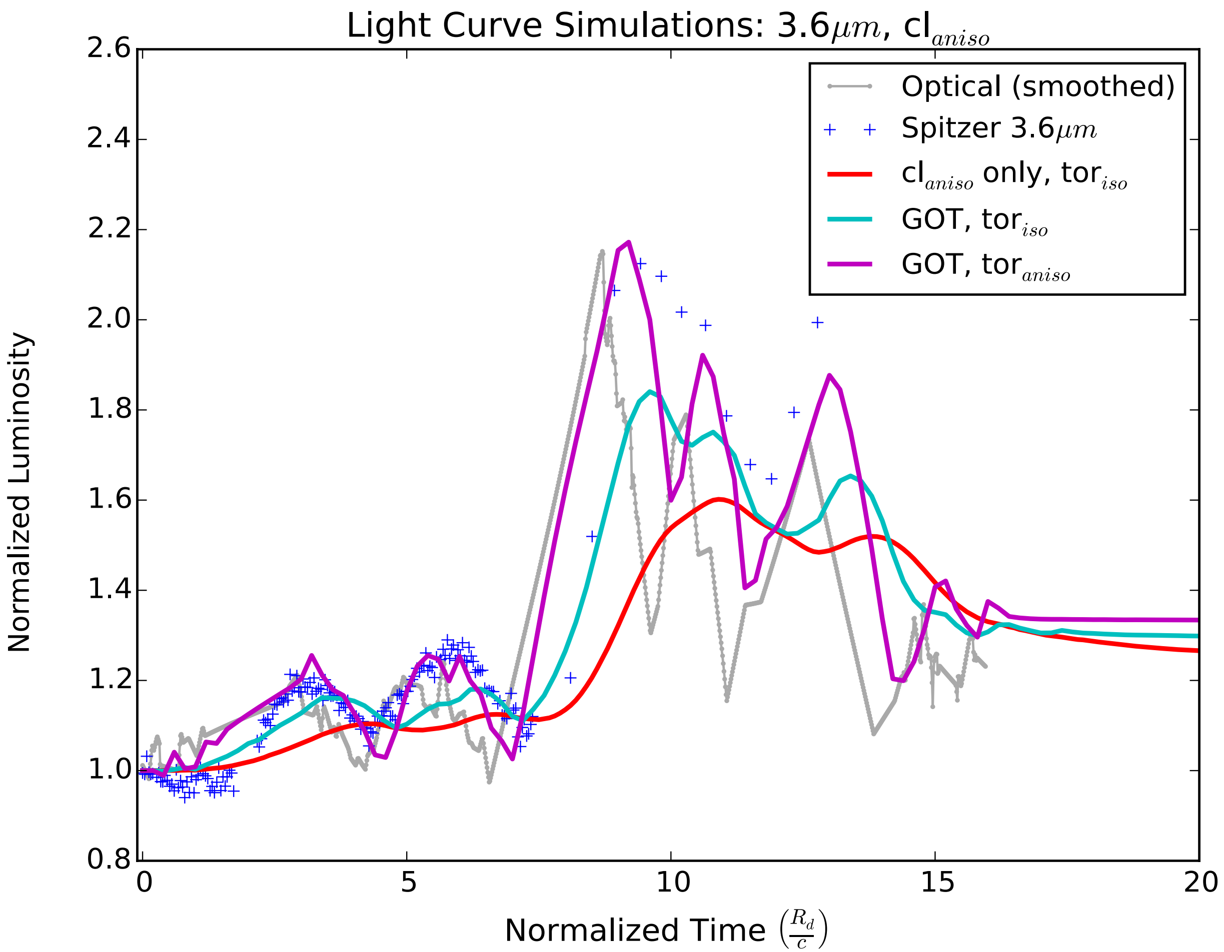
NGC 6418



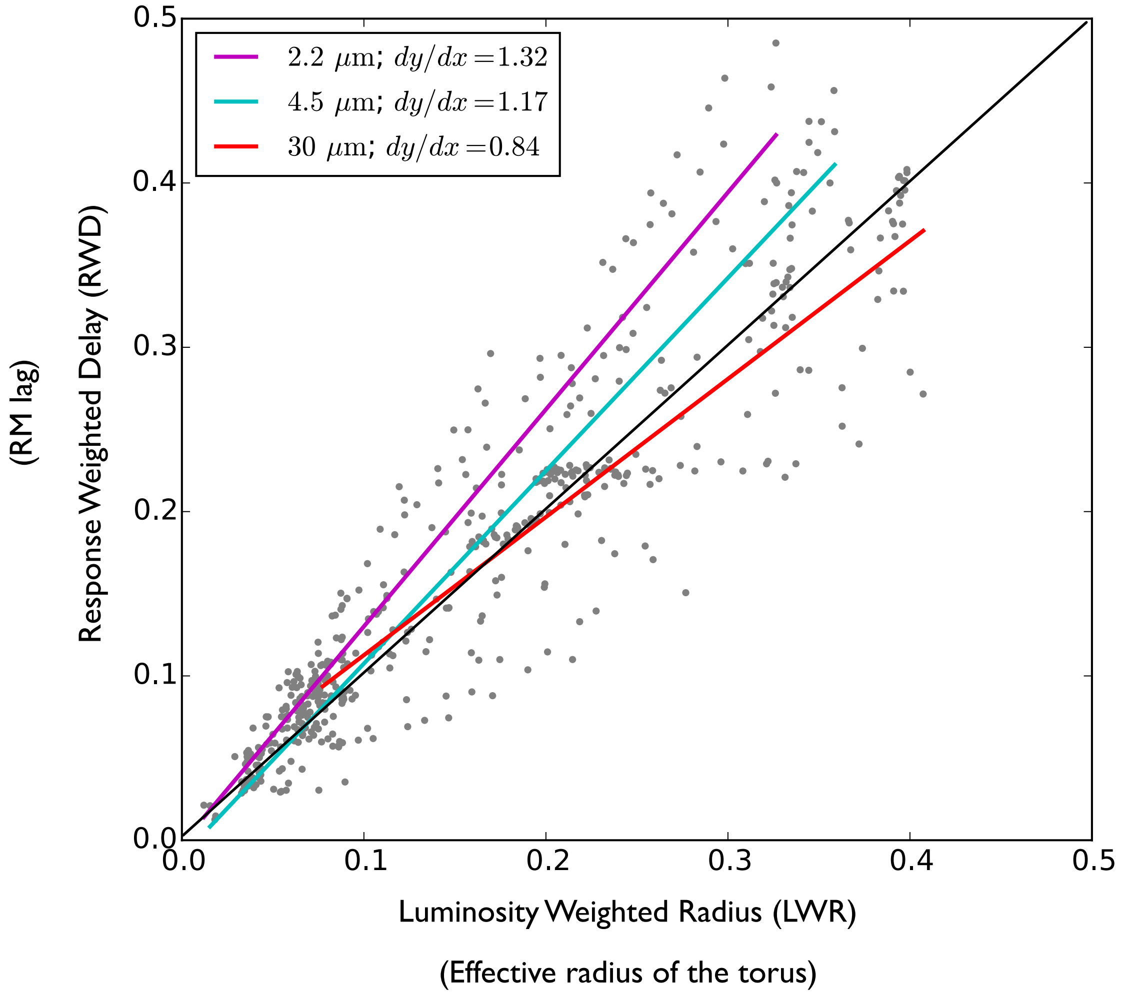
Optical
3.6 μm
4.5 μm
Vazquez et al. 2015
Frank et al. in prep
Normalized flux
MJD
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
55000
55500
56000
56500

NGC 6418: TORMAC MODELS

TORMAC light curve simulations for torus models



RWD VS LWR

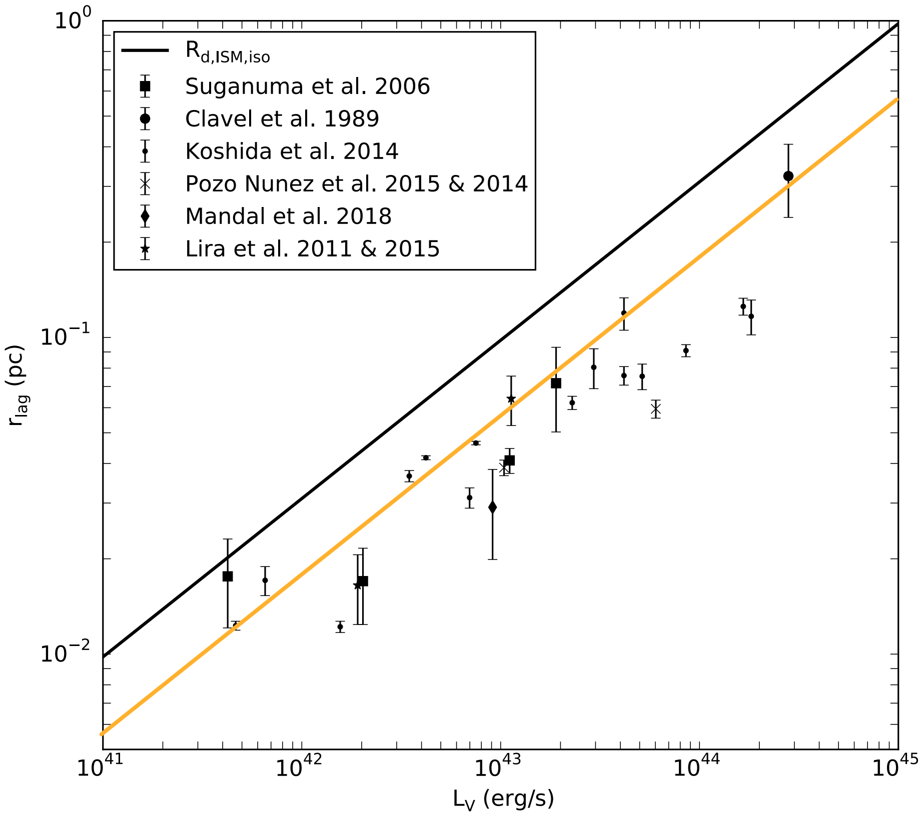


$$\tau = \frac{r}{c}$$

0.4LWR<RWD<1.8LWR

Almeyda et al, 2020

RADIUS-LUMINOSITY RELATIONSHIP



- R-L relationship
  - $\tau \propto \frac{r}{c} \qquad r \propto L^{1/2}$
- Dust Sublimation radius

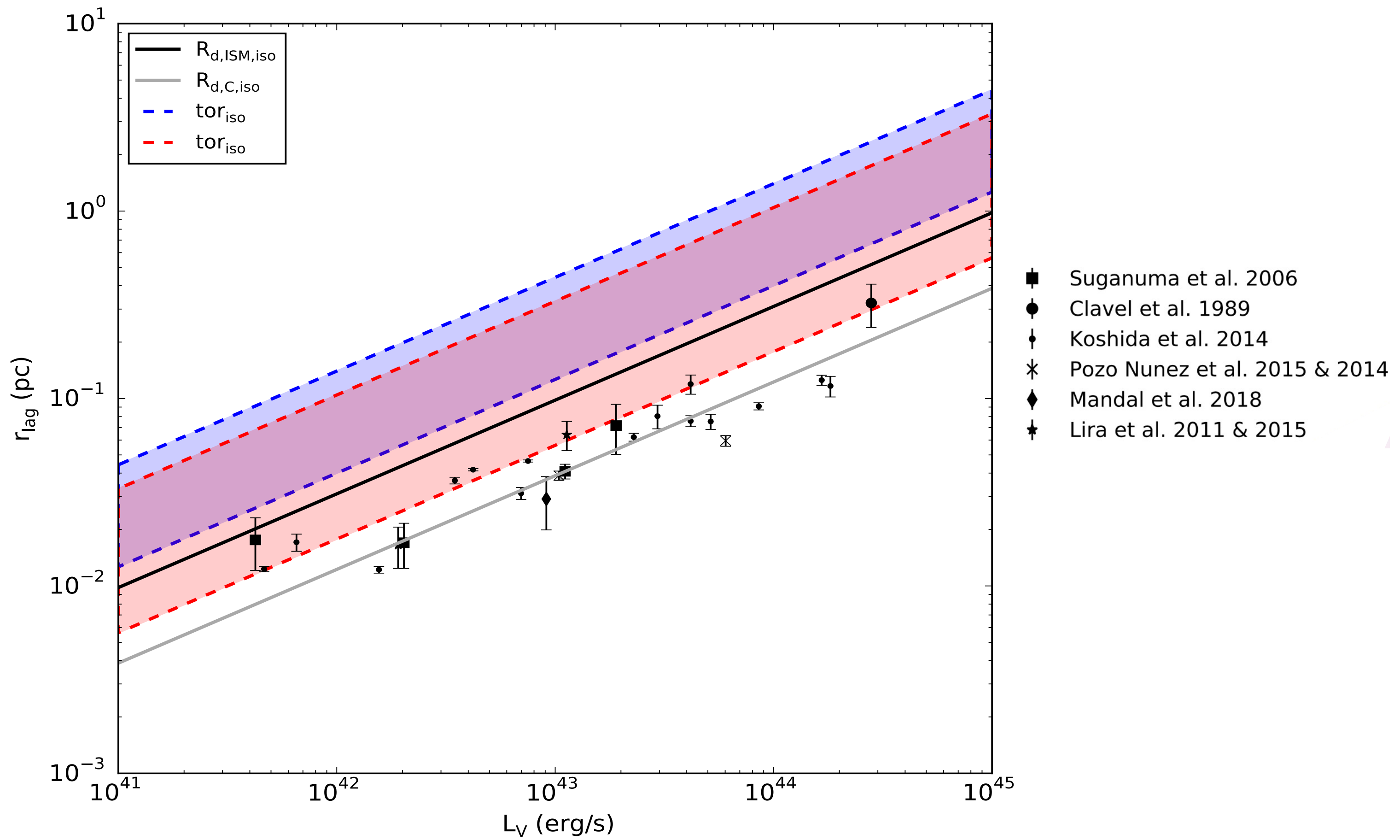
$$R_d \approx 0.4 \left(\frac{L}{10^{45} erg^{-1}} \right)^{0.5} \left(\frac{1500K}{T_{sub}} \right)^{2.6} pc$$

(Nenkova et al. 2008b, Barvainis 1987)

- Observed radii are ~2 time smaller than theoretical dust sublimation radius

(Kishimoto et al. 2007, Vazquez et al. 2015)

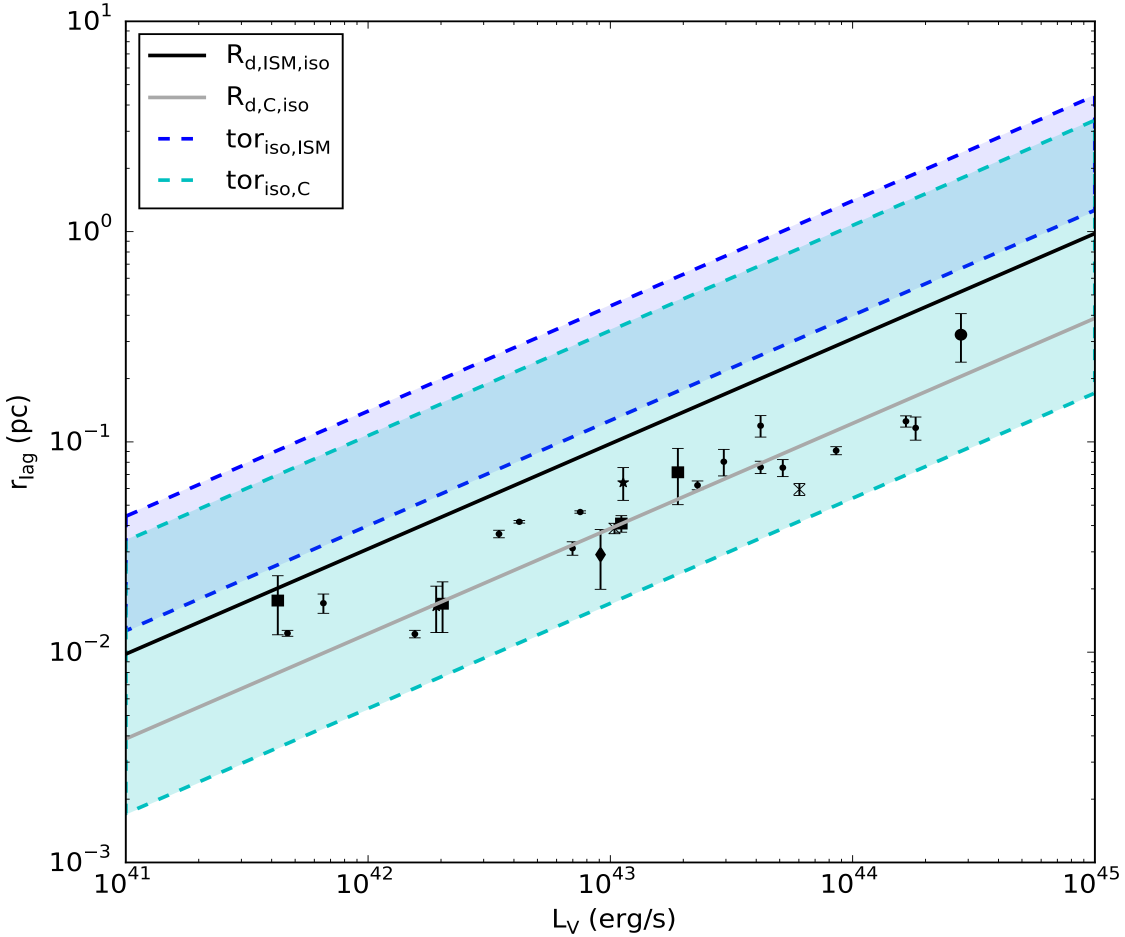
RADIUS-LUMINOSITY RELATIONSHIP



Almeyda et al, 2020

INCLUDING HOT GRAPHITE DUST

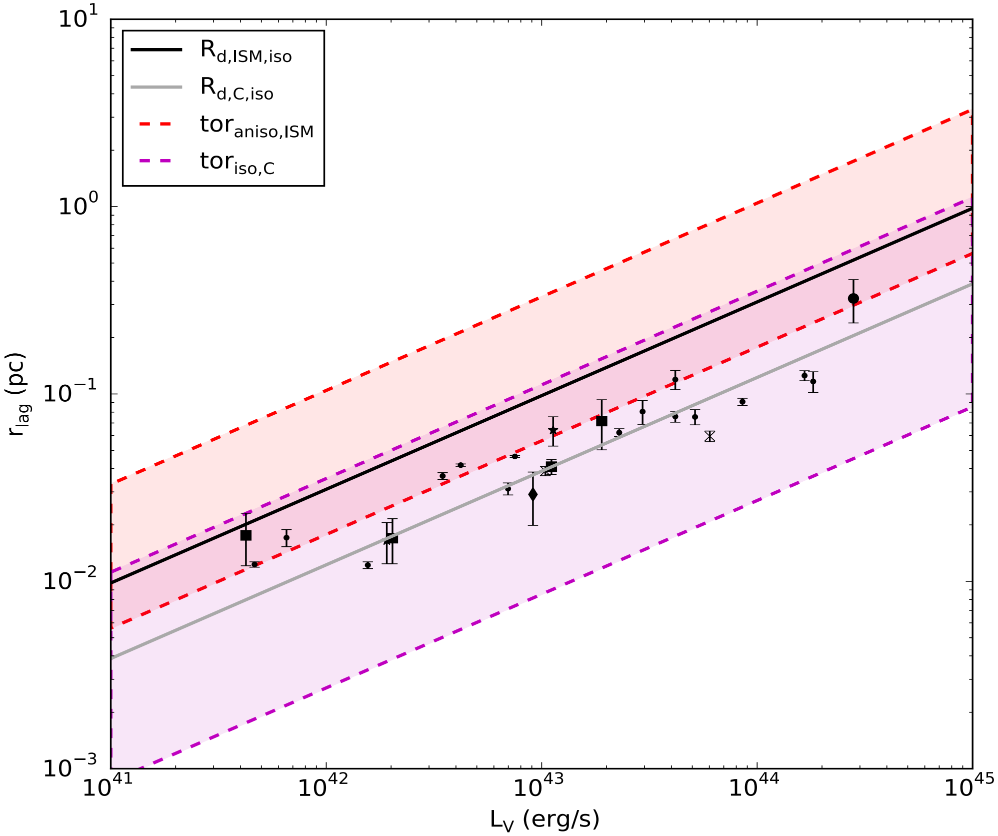
- Gradient in composition of clouds from Carbon-dominated to full ISM composition
  - *http://cat3d.sungrazer.org/



Almeyda et al, in prep

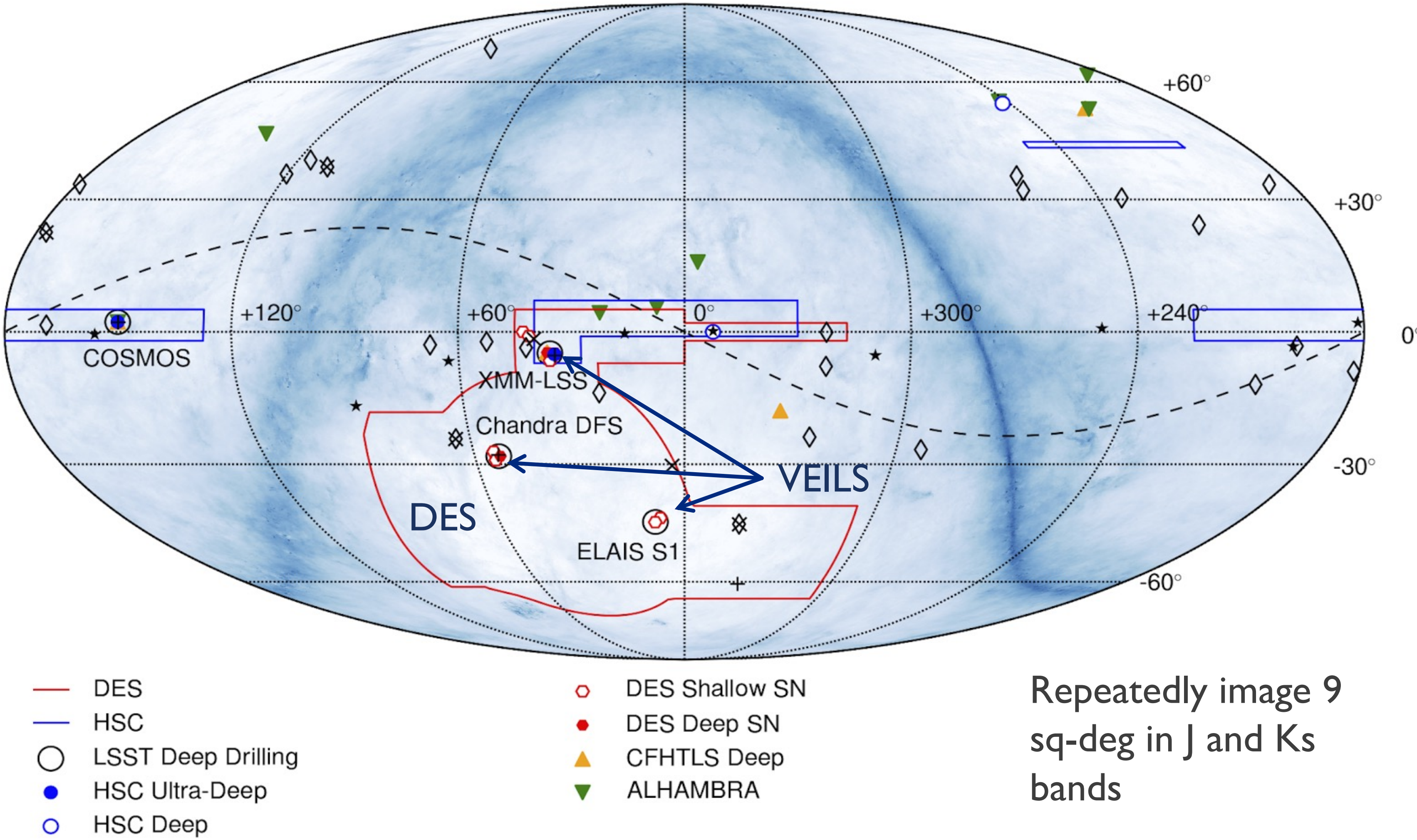
INCLUDING HOT GRAPHITE DUST

- Gradient in composition of clouds from Carbon-dominated to full ISM composition
  - *http://cat3d.sungrazer.org/



Almeyda et al, in prep

VEILS: VISTA EXTRAGALACTIC INFRARED LEGACY SURVEY

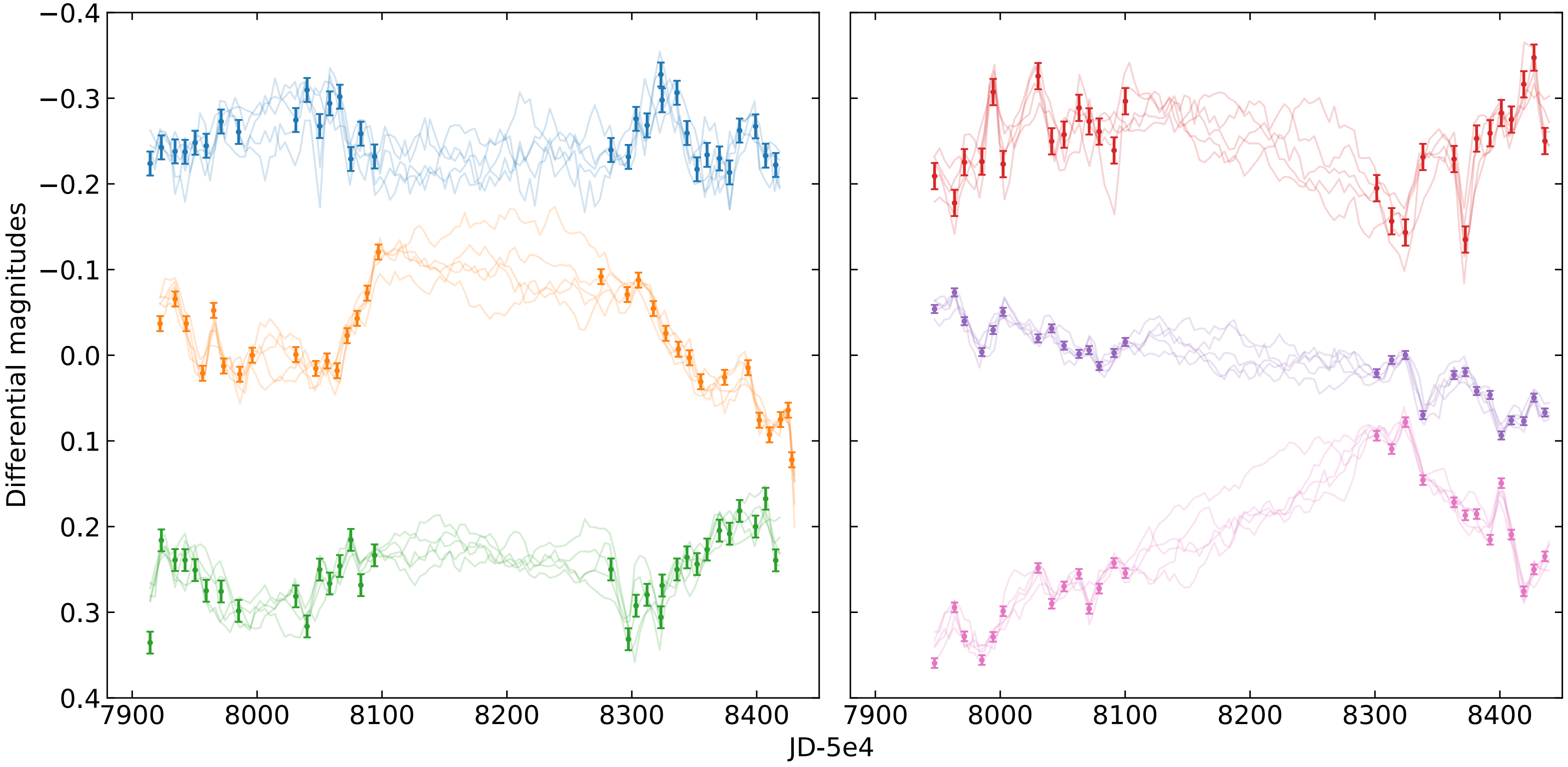


Repeatedly image 9 sq-deg in J and Ks bands

Adapted from presentation by Manda Banerji at UK LSST-AGN Consortium Meeting Oct 2017

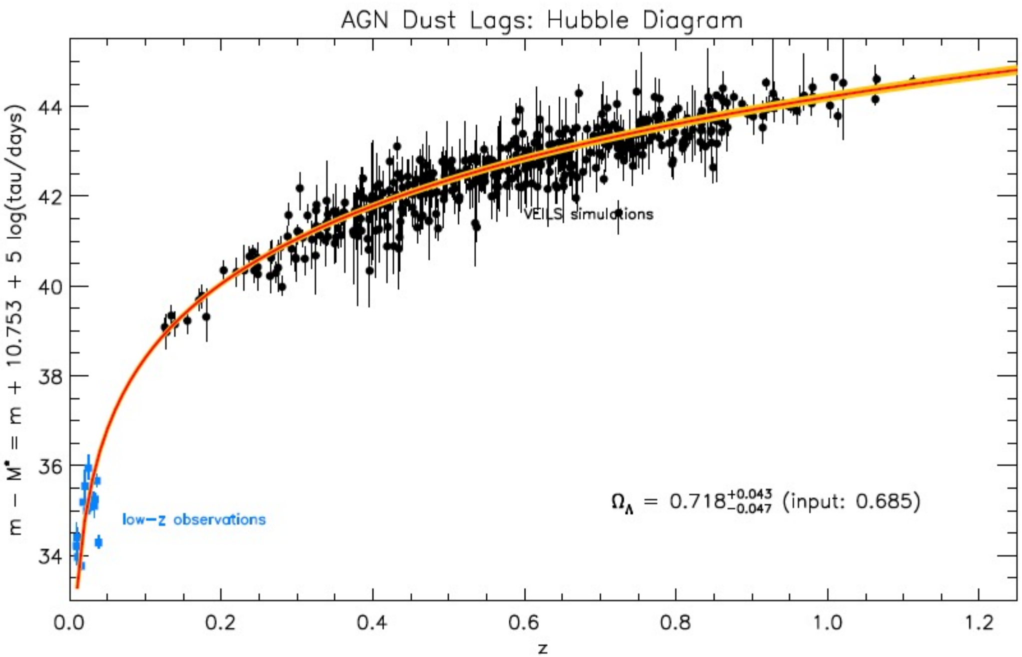
VEILS: CURRENT STATUS AND FUTURE WORK

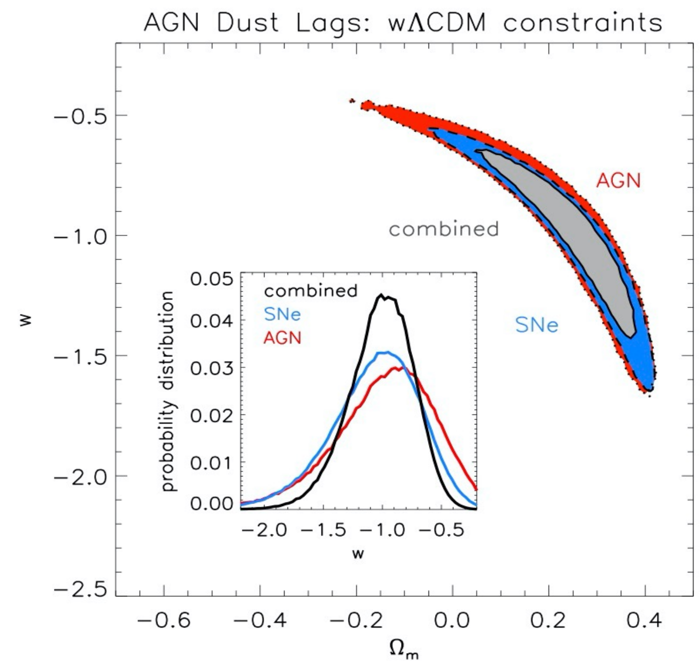
- Extracting light curves
- Perform Cross Correlation Analysis to determine torus radius



COSMOLOGY: AGN AS STANDARD CANDLES

The tight correlation of the optical-NIR time lags with luminosity can be used to define a new standard candle for cosmology





Honig et al, 2017, MNRAS, 464, 2

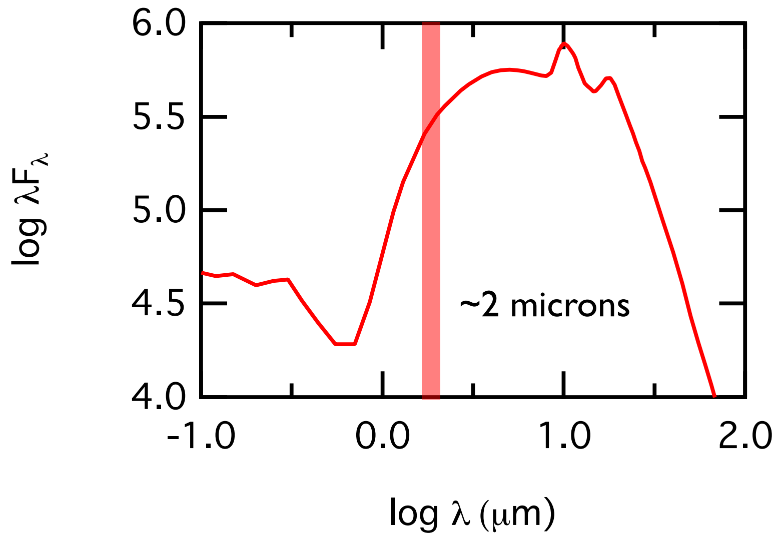
AGN SCIENCE WITH ROMAN

OPEN QUESTIONS ON AGN: TIME DOMAIN

- Accretion disk physics and variability
- The nature of the hot dust component and/or BLR-torus interface
- Causes of large luminosity variations (e.g., Changing Look AGN)
- Populations of binary SMBH and mergers

HOT DUST REVERBERATION MAPPING WITH ROMAN

- Roman can provide multiband light curves – Y, J, H, F/W
- J, H,F/W-bands sample hottest dust ~ 1-2.2 μm in z ~ <1 AGN
  - Probes large graphite grains in sublimation zone, dusty BLR clouds

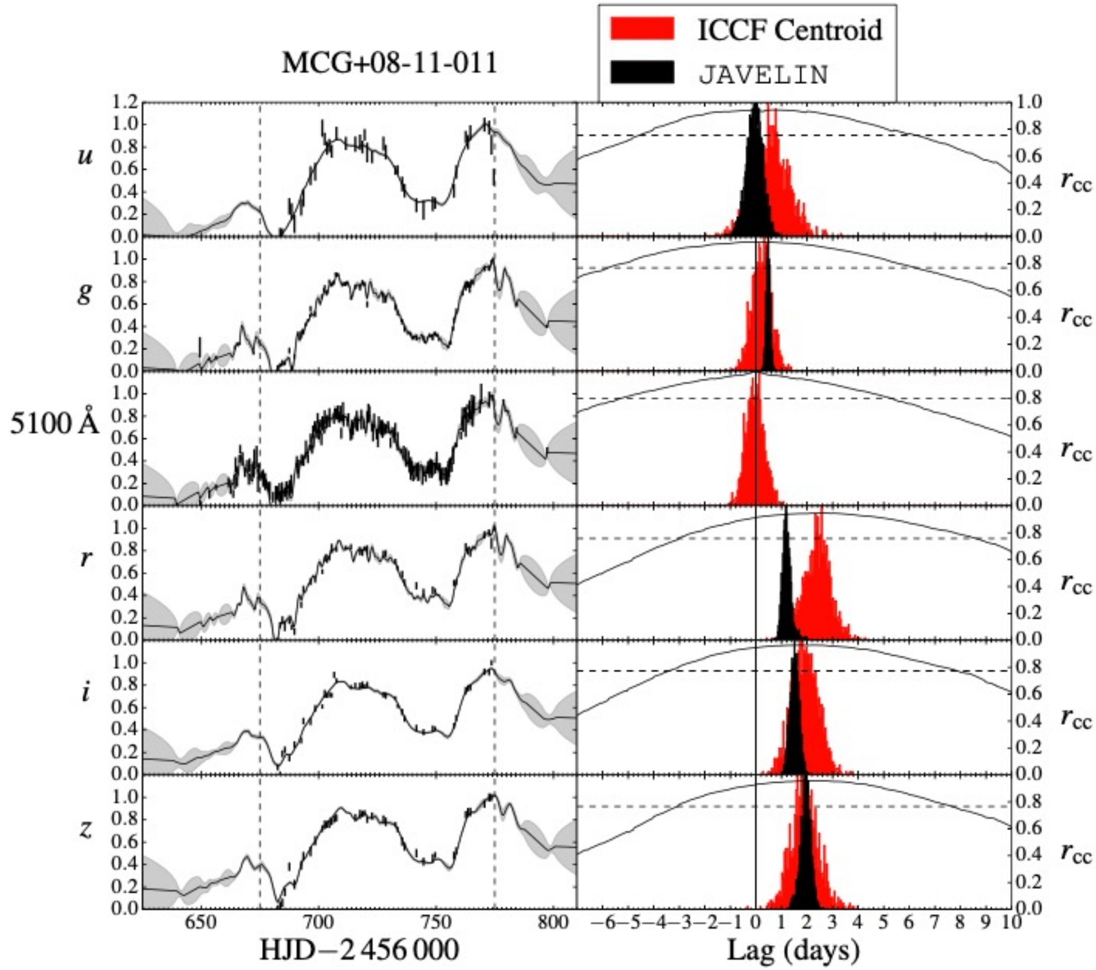


Torus SED model including large graphite grains
Hönig & Kishimoto 2017
http://cat3d.sungrazer.org

Also need to account for accretion disk contribution

AGN CONTINUUM RM

- Roman can provide multiband light curves – Y, J, H, F/W
- Probes temperature structure of the accretion disk



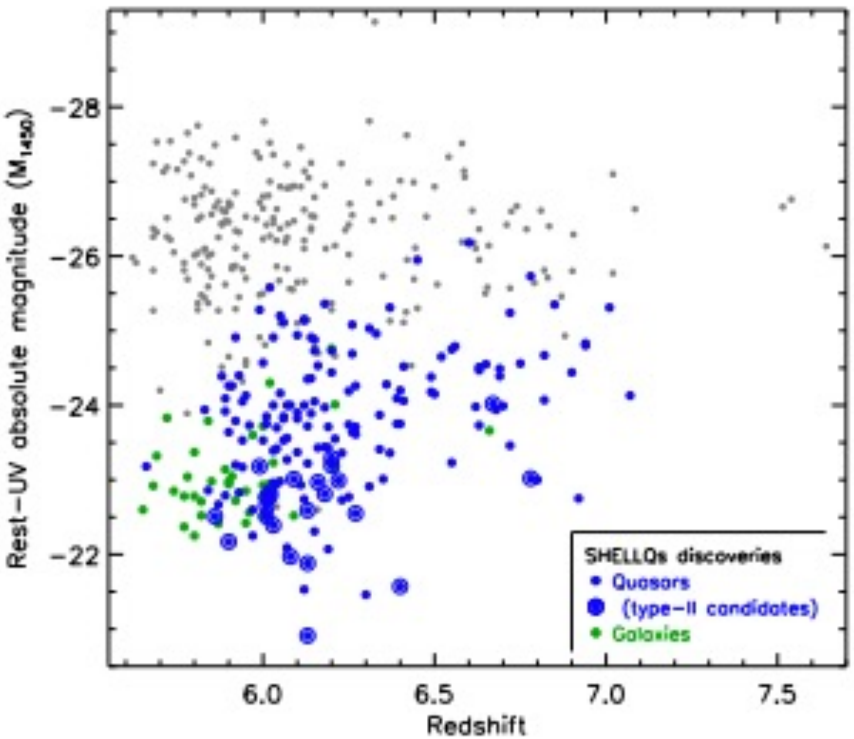
Fausnaugh et al. 2018

OPEN QUESTIONS ON AGN: GENERAL SURVEY SCIENCE

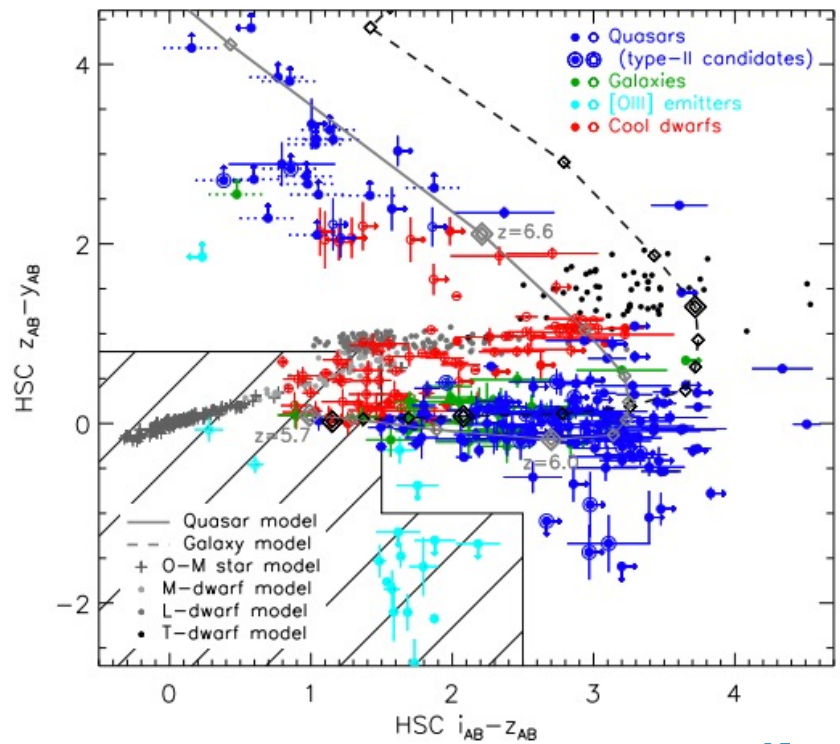
- Understanding the faint end of the AGN/Quasar luminosity function
- Coevolution of SMBHs and their host galaxies through the formation ($z\sim1$-4) and reionization ($z>4$) eras
  - Feedback, star formation
  - Effects of large-scale cosmic environment
- How and when did massive BHs get seeded and how fast did they grow

DISCOVERY/DETECTION OF HIGH-Z AGN

Redshifts and the rest-frame UV absolute magnitudes of high-z objects



Colors of high-z Quasars from HSC



Matsuoka et al. 2021

SYNERGIES WITH OTHER OBSERVATORIES

- Optical
  - Rubin, SDSS-V; 4MOST, MSE
- NIR missions
  - EUCLID, JWST
  - ground-based e.g., Gemini South; ESO/VLT; WINTER; Tokyo Atacama Observatory
- Radio
  - SKA, MeerKAT, ALMA
- X-ray
  - eRosita, Athena

- AD, BLR, and dust reverberation mapping
  - BLR RM (Time Domain Spectroscopy Campaigns; SDSS-V BH Mapper and 4MOST TiDES)
- Expand time baseline and sampling of AGN light curves
- Multi-wavelength follow-up
  - Evolution and modeling of AGN SED
  - probe dusty torus/wind spatial structure, host-galaxy subtraction, radio kinematics and spatial information
- Discovery and synergistic follow up of transients: e.g., CLAGN, TDEs, etc.
  - map changes in the torus and emission lines