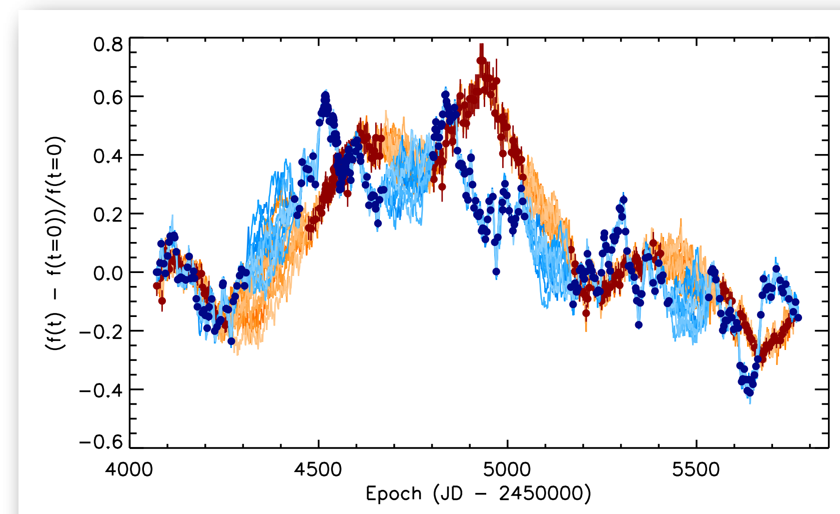
Dust Reverberation Mapping

From Dust Chemistry to AGN Cosmology



Sebastian F. Hoenig

Guilin, 20 September 2019

UNIVERSITY OF Southampton

European Research Council

Science & Technology Facilities Council

Topics

- **I. The setup of the dusty environment**
  What do we expect to see?
  What is our basic picture?

- **II. Dust reverberation mapping: the observer's view**
  How do the data look like?
  What do we learn about the AGN dust distribution?

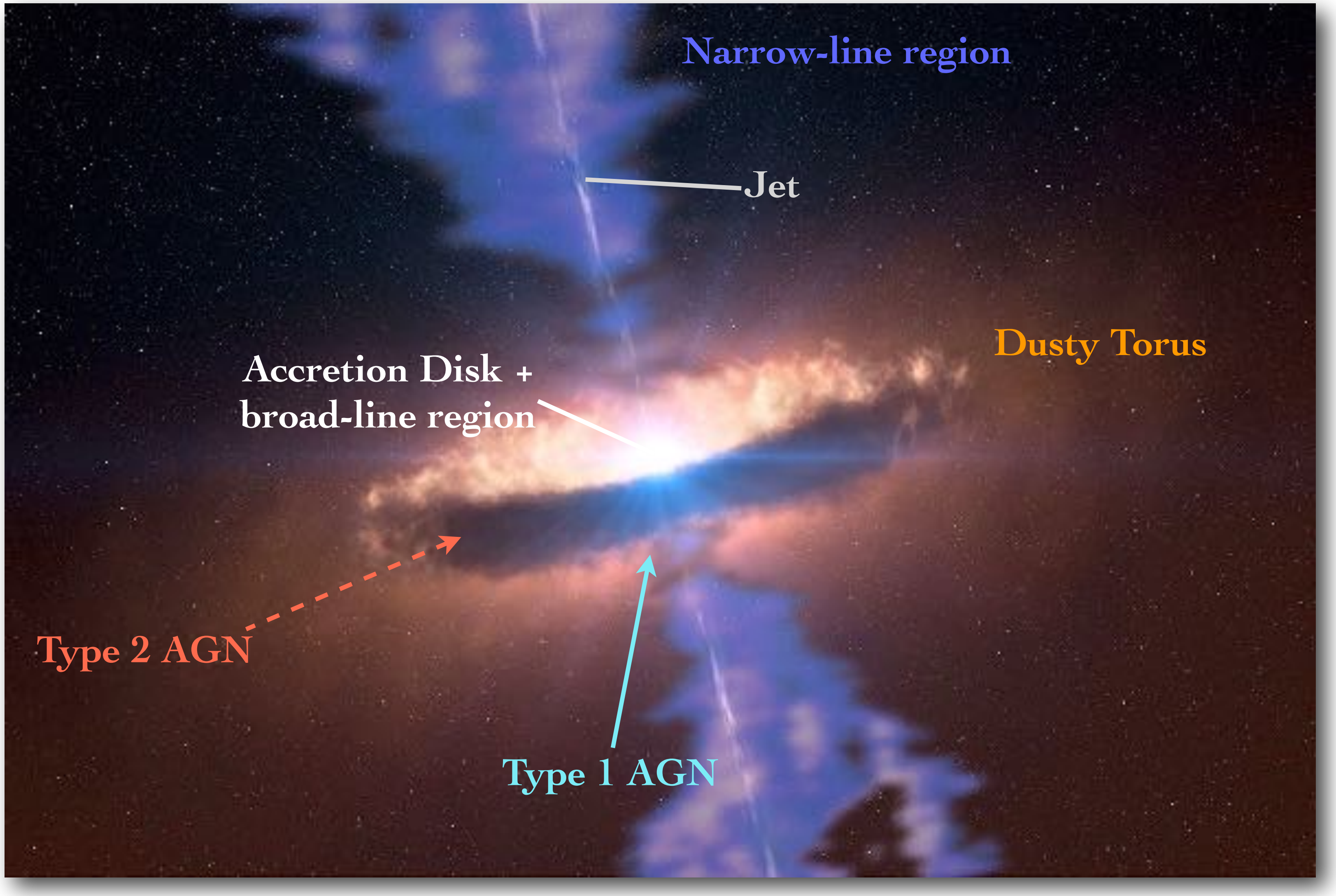
- **III. The theorist's point of view**
  Does it all make sense?

- **IV. VEILS: Cosmology with dust lags**
  How can we use dust reverberation for cosmology?

- **V. Some further thoughts**

I. The setup of the dusty environment

I. The (overly) simple picture



- in the IR we see the **dusty torus**
- cornerstone of **AGN unification**
- Typical scaling: **few pc ~ 10 milliarcseconds**
- dust = **simple radiative physics** (famous last words…)

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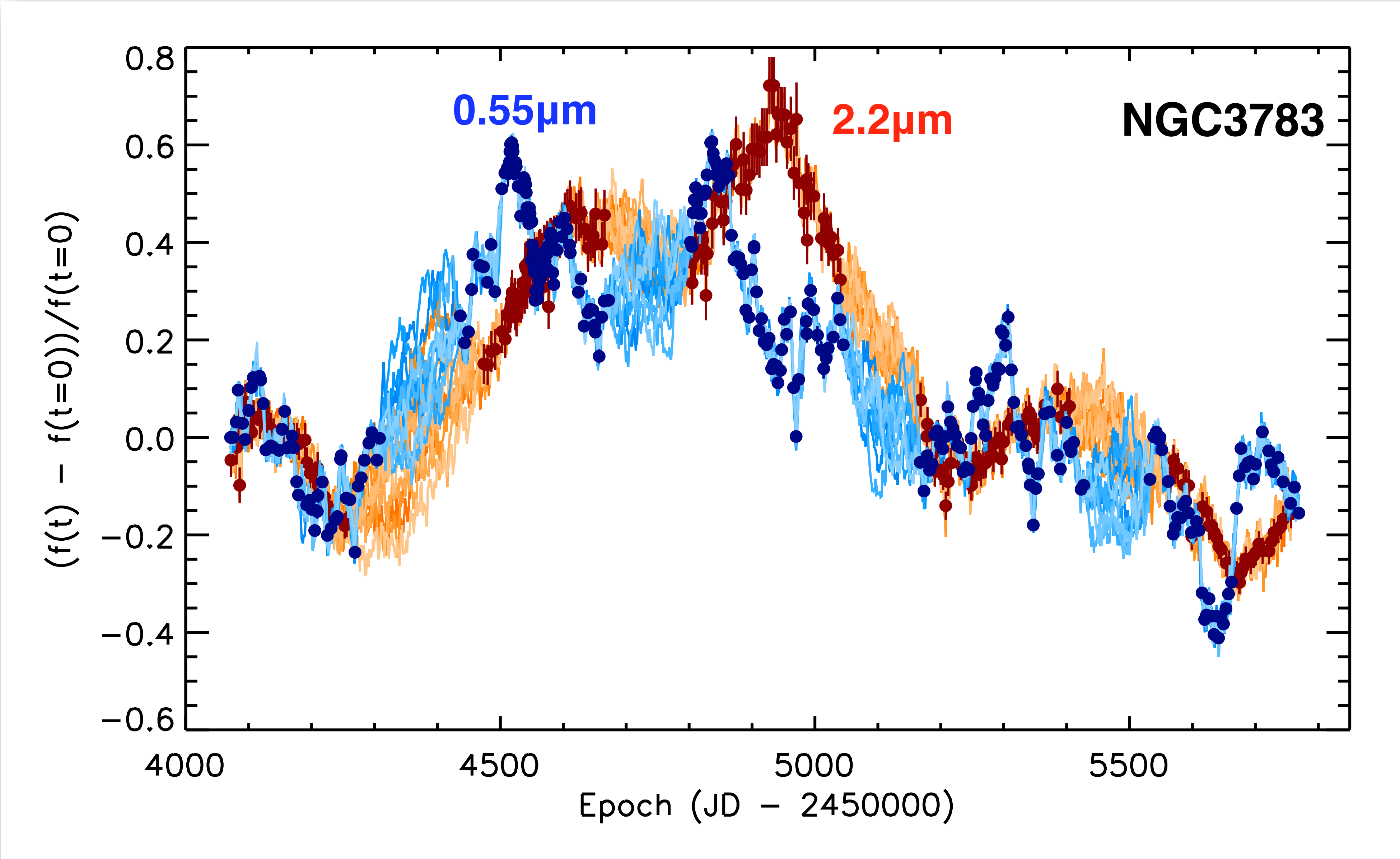

Lira et al. 2011

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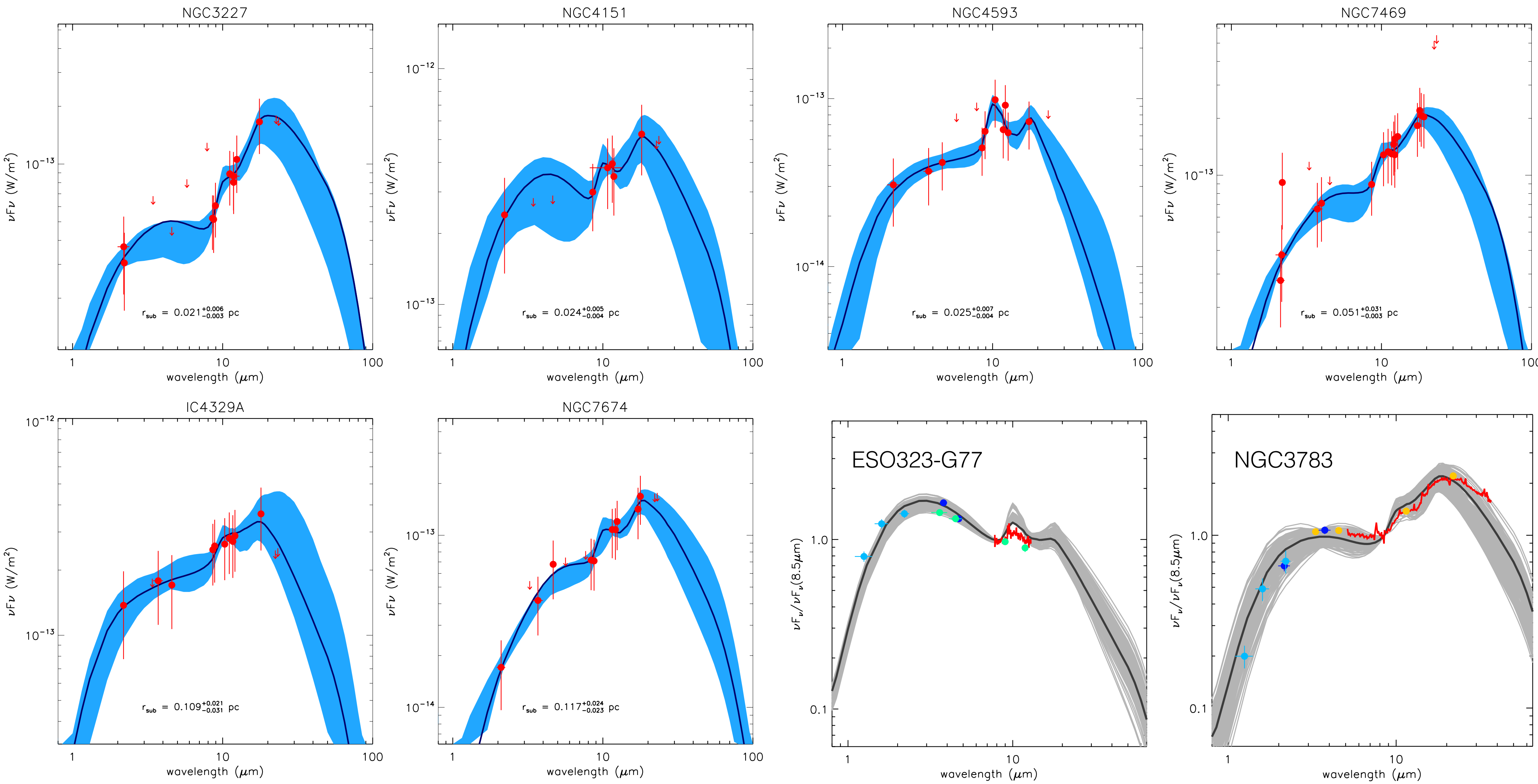

Asmus, Hoenig et al., in prep — Leftley et al. 2018 — Hoenig et al. 2013

- often flatter at 3-5 µm than in the mid-IR, or distinct bump
  → 3-5µm bump
- near-IR covering factor **~20-50%**
- more prominent in **quasars/QSOs**

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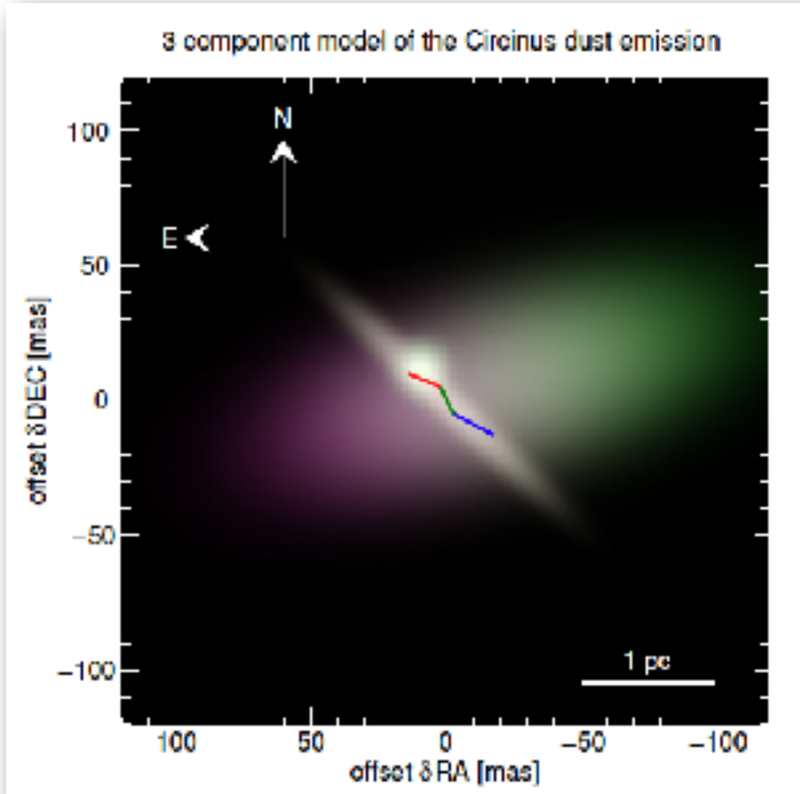
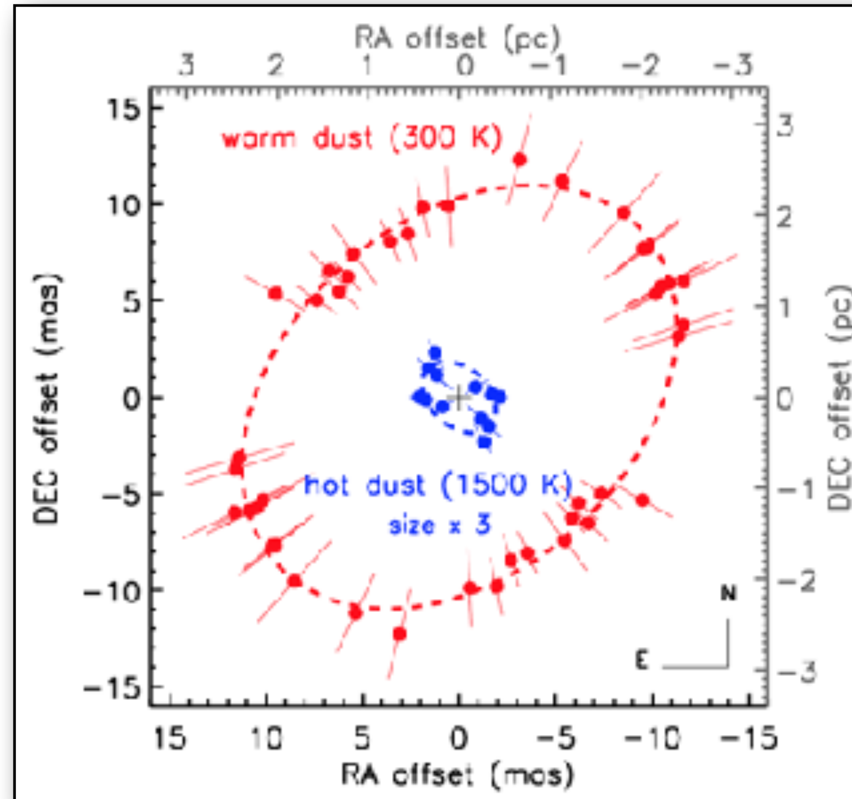
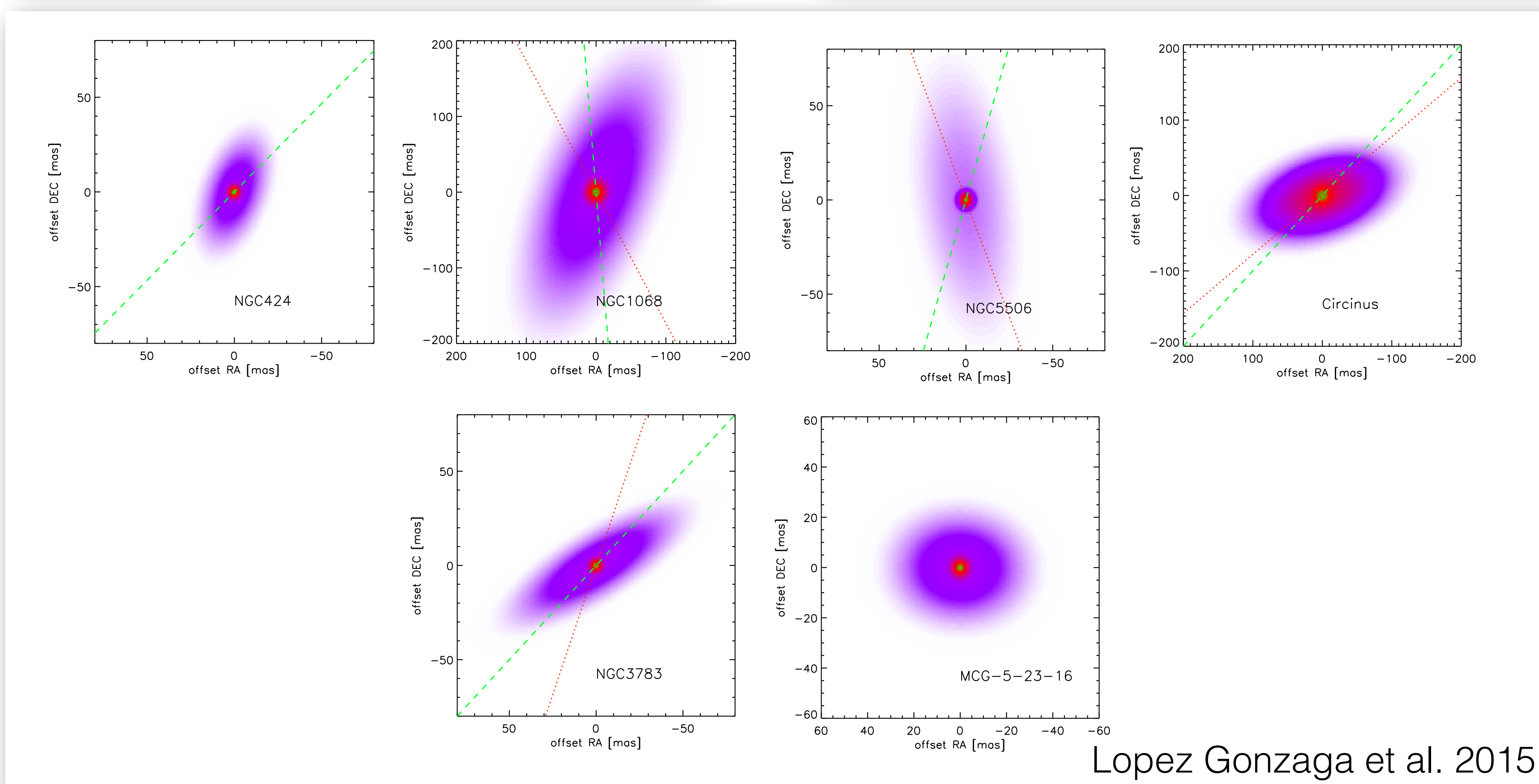


Tristram et al. 2014



Hoenig et al. 2013



Lopez Gonzaga et al. 2015

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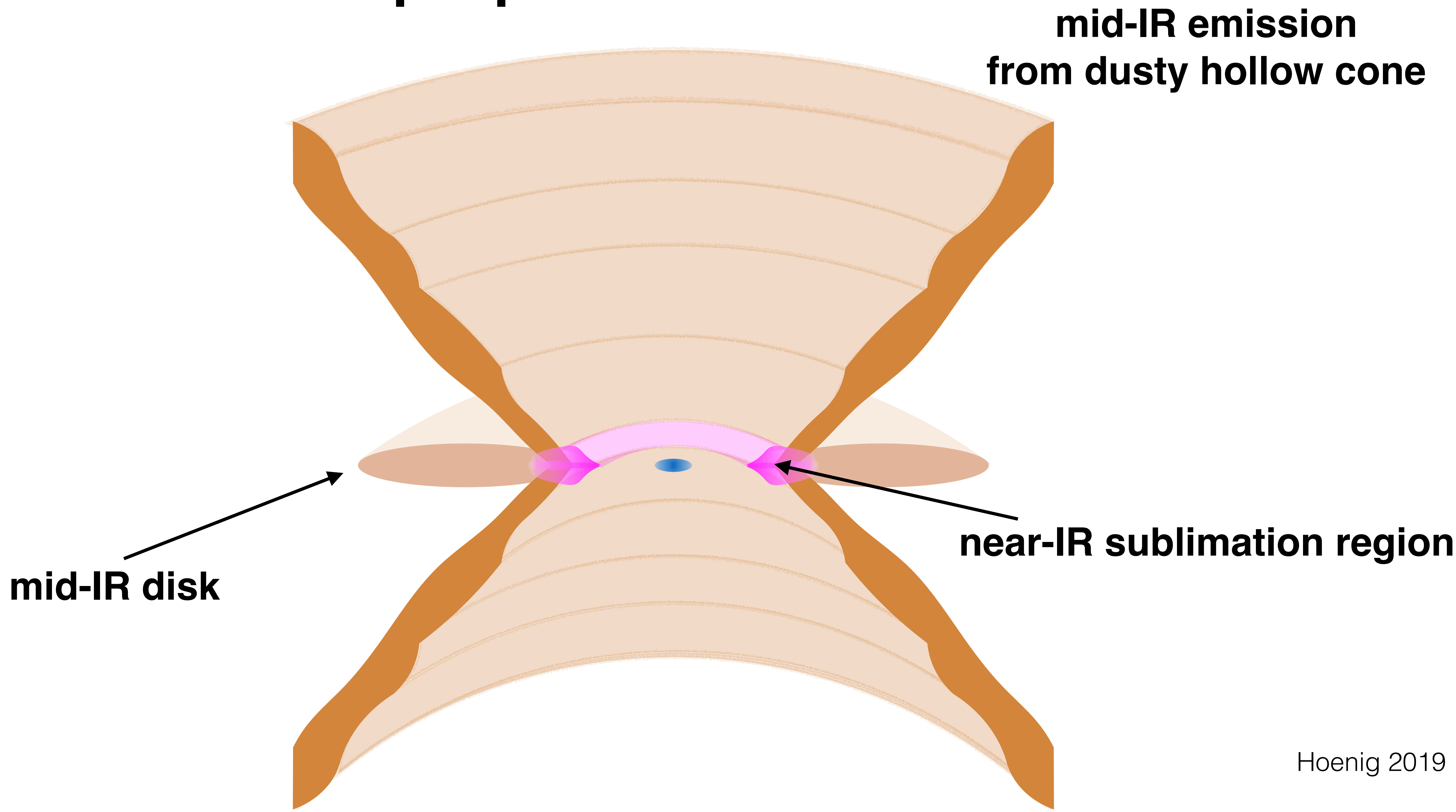

Hoenig 2019

- two dust-emitting components: **disk + wind**
- hot dust emission a combination from both
- BUT IR interferometry suggests **near-IR dominated by disk**
- sublimation zone is the **origin of the dusty winds**

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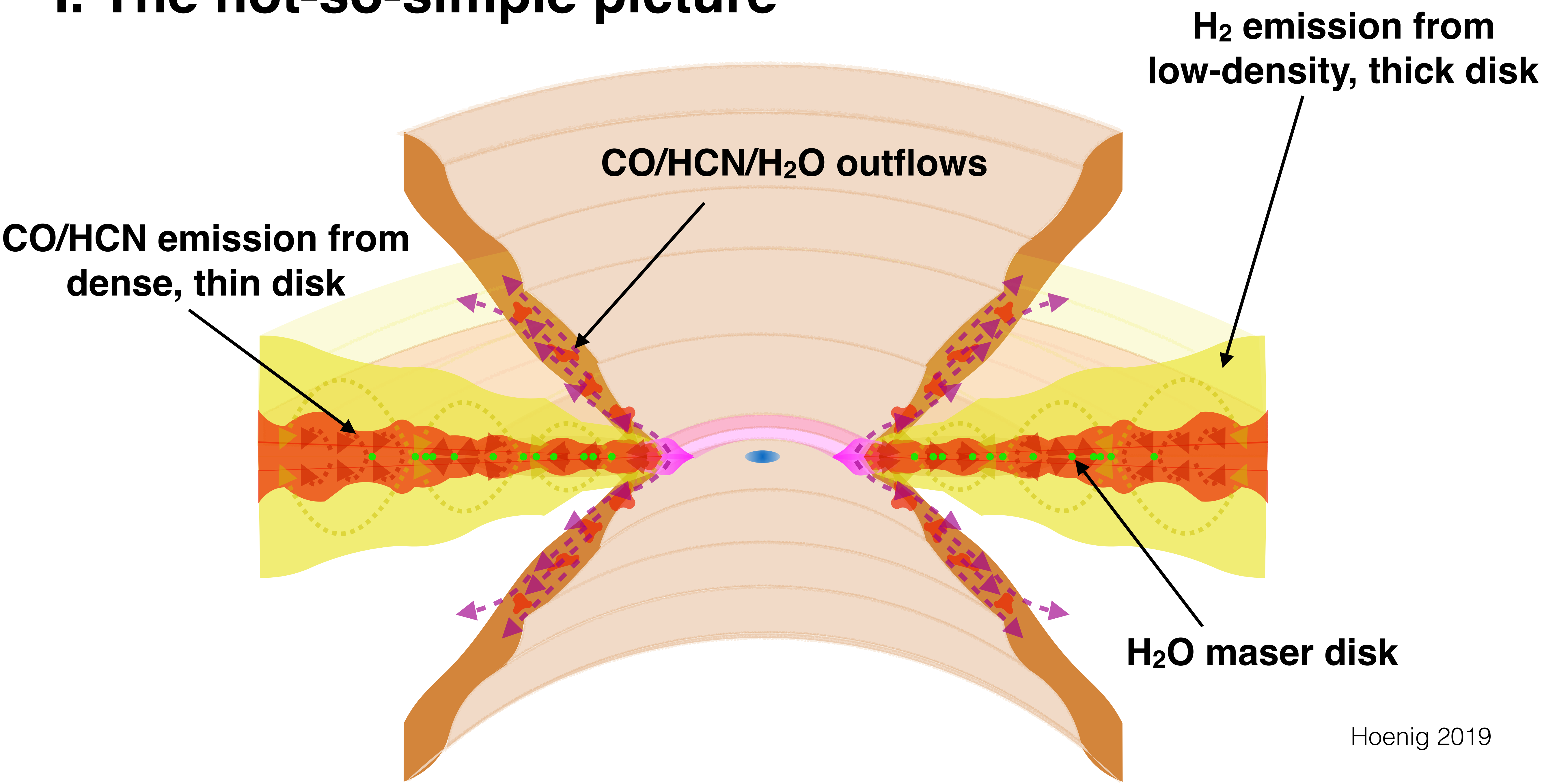

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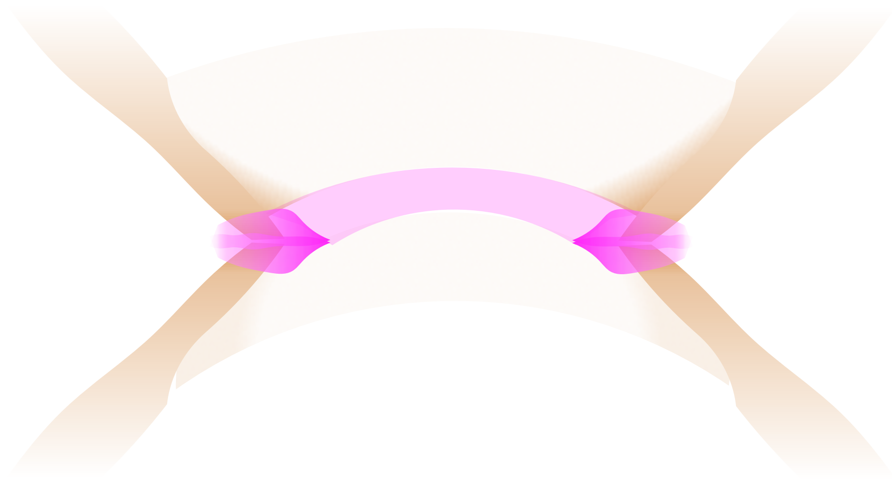

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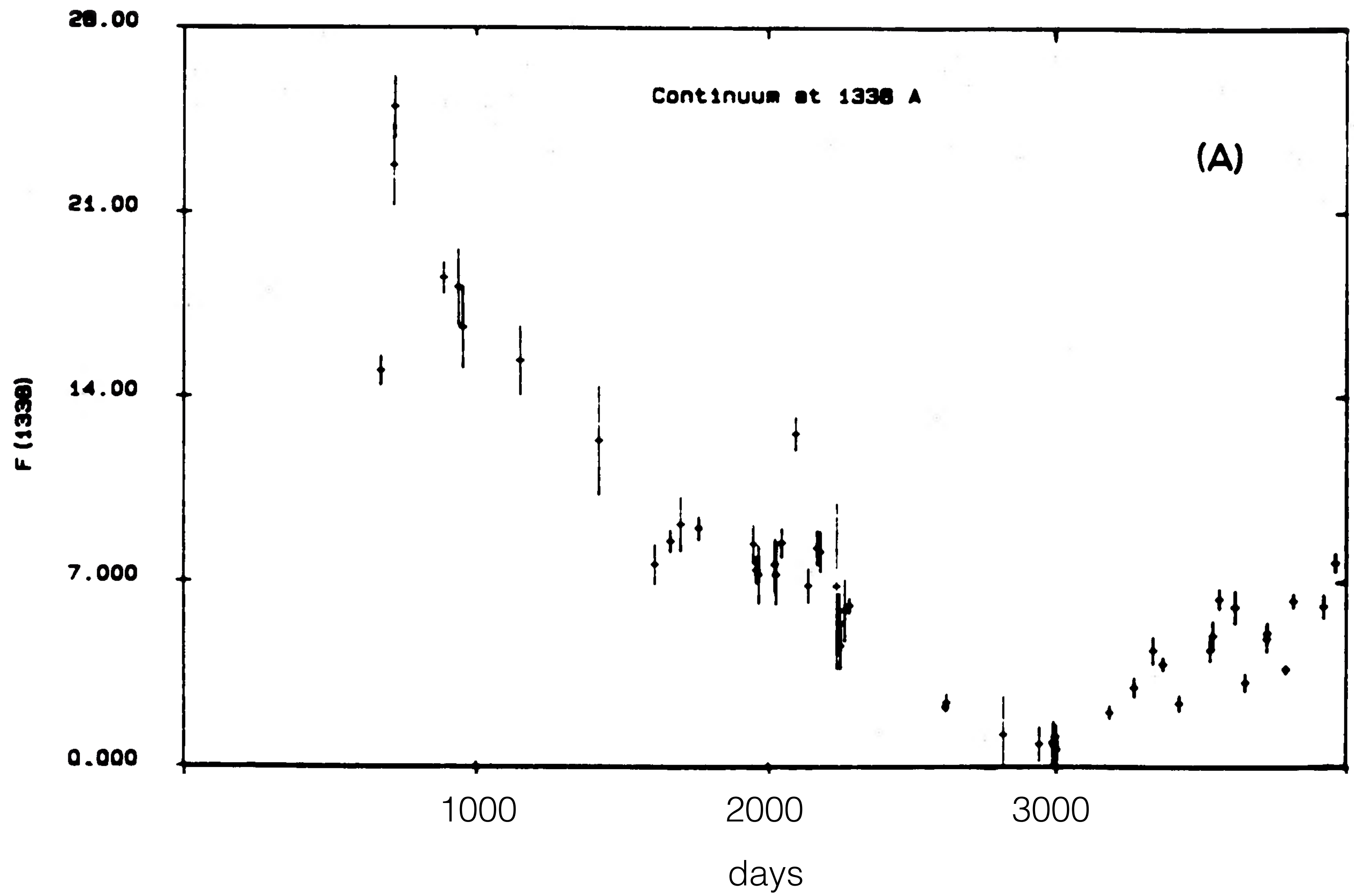
II. Dust reverberation mapping: the observer's view

II. Dust reverberation has a long history

Clavel+89, Glass+92,97a,97b,98,04, Sitko+93, Oknyanskij+99,01,02,14,15, Suganuma+06, Koshia+09,14,17, Lira+11, Hoenig+11,14a,14b,17, Schnülle+13,15, Pozo-Nunez+14,15, Yoshii+14, Vazquez+15, Almeyda+17, …



Clavel et al. 1989

- overall **similar procedures and methods** as with BLR reverberation mapping
- variability r**esponse significantly smeared** in the near-IR
- biasing issues from **host and accretion disk**

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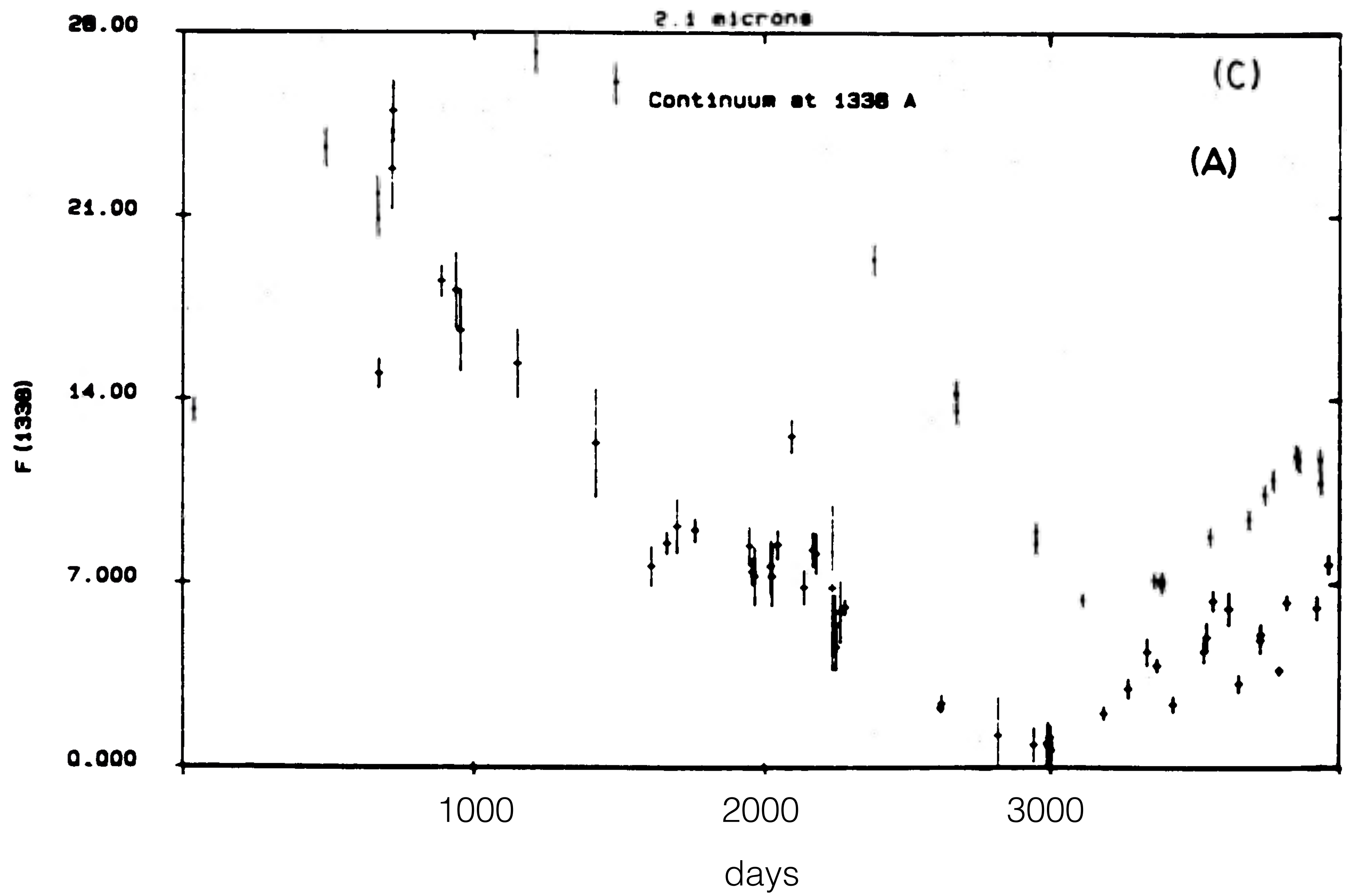

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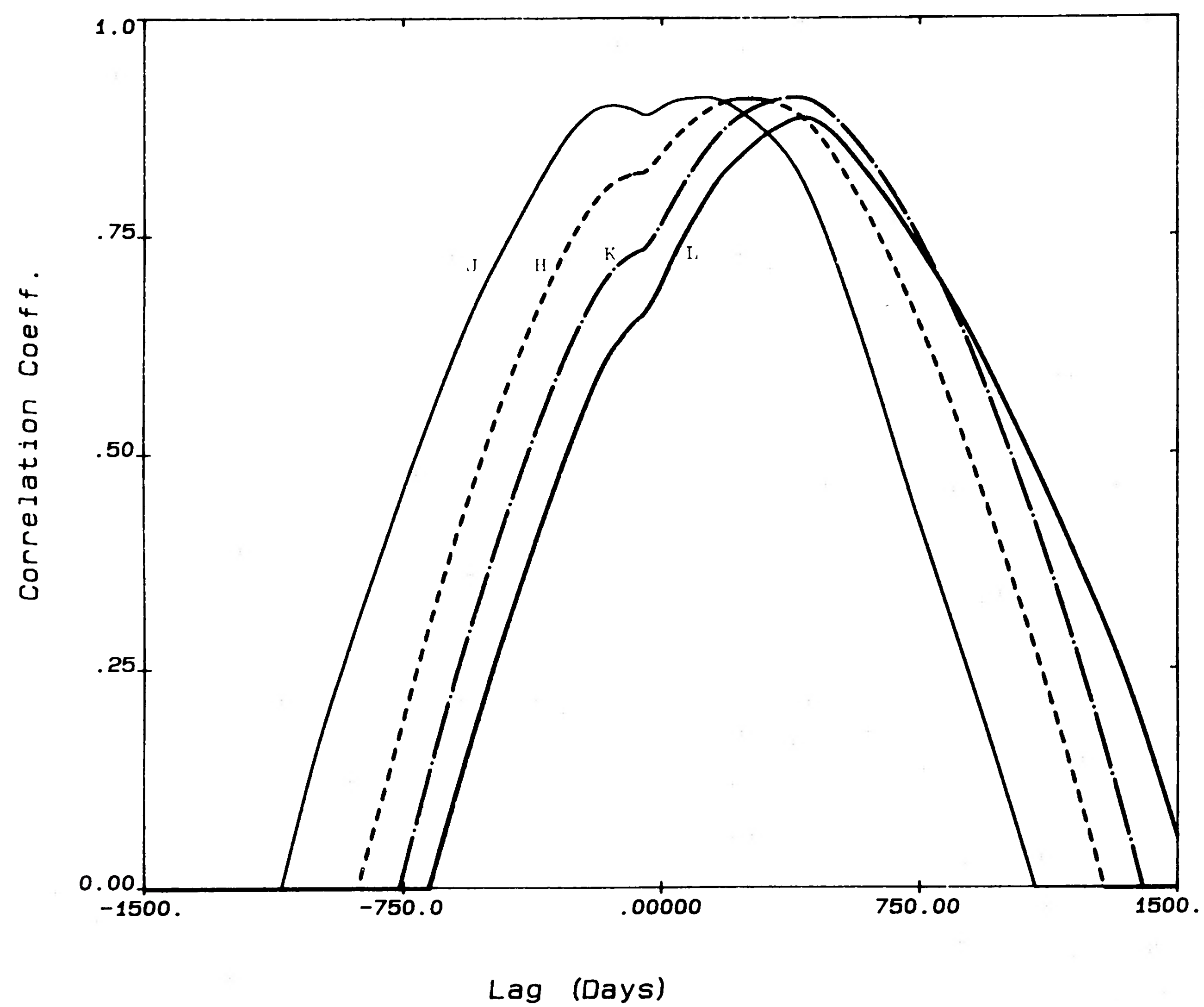

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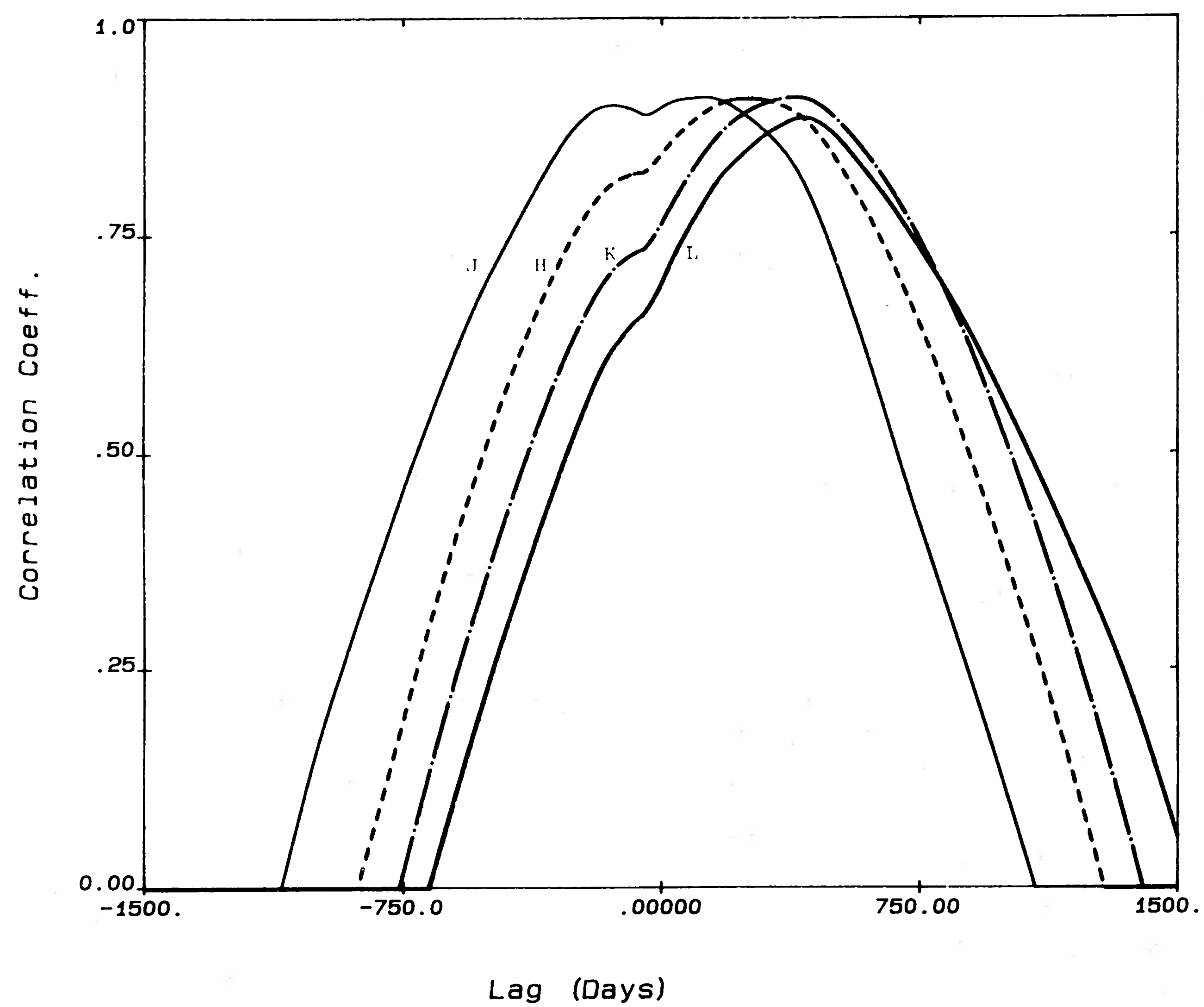

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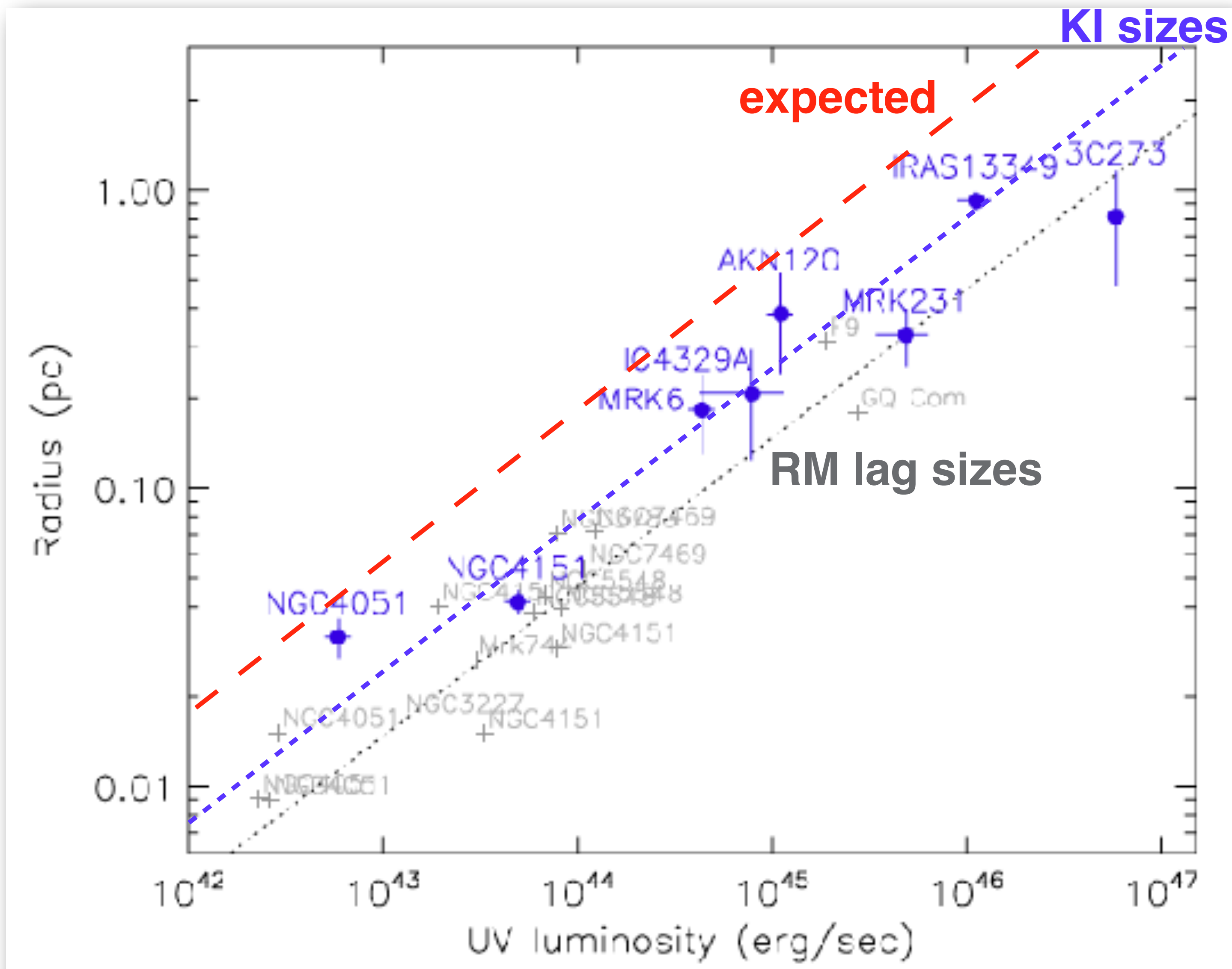
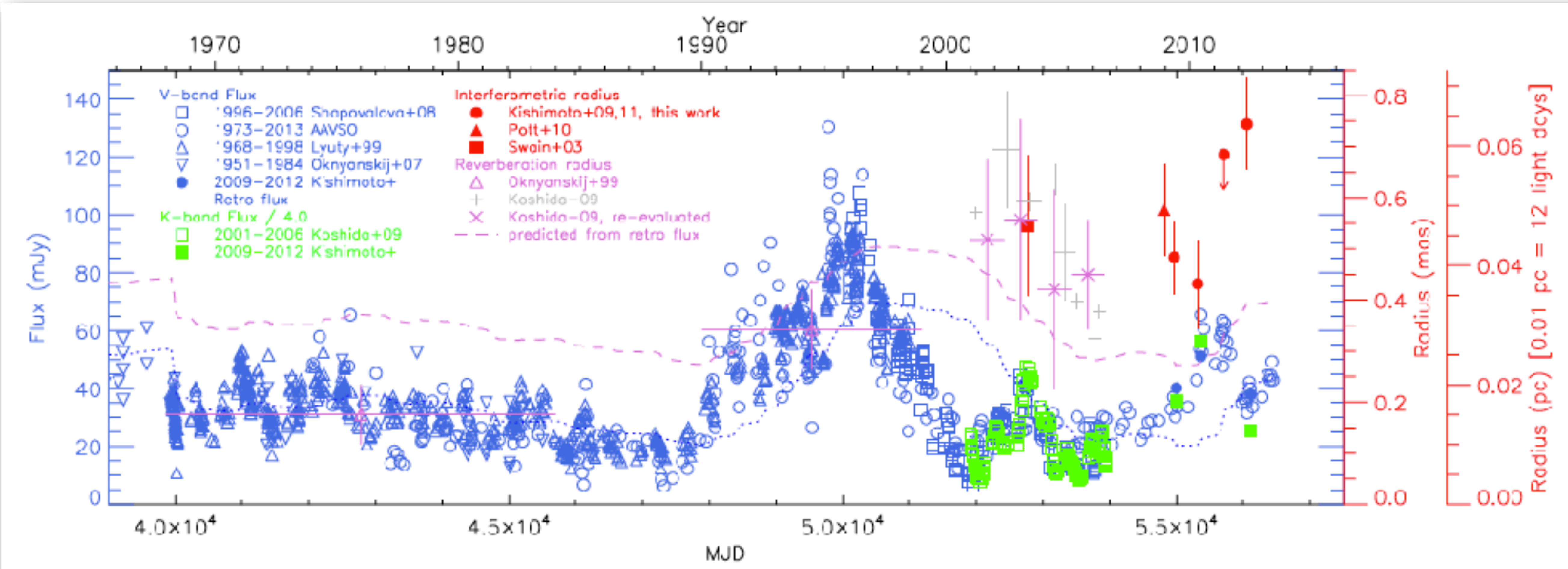
II. The size-luminosity relationship



Kishimoto, Hoenig et al. 2011a

- inner radius of torus **scales with $L^{1/2}$** (as expected from dust)
- brightness and colour **temperatures ~ 1500 K** (as expected from dust)
- absolute sizes are **smaller than expected by factor ~3**
- emissivity + sizes: **large graphite grains**

II. The (non-)varying sublimation radius

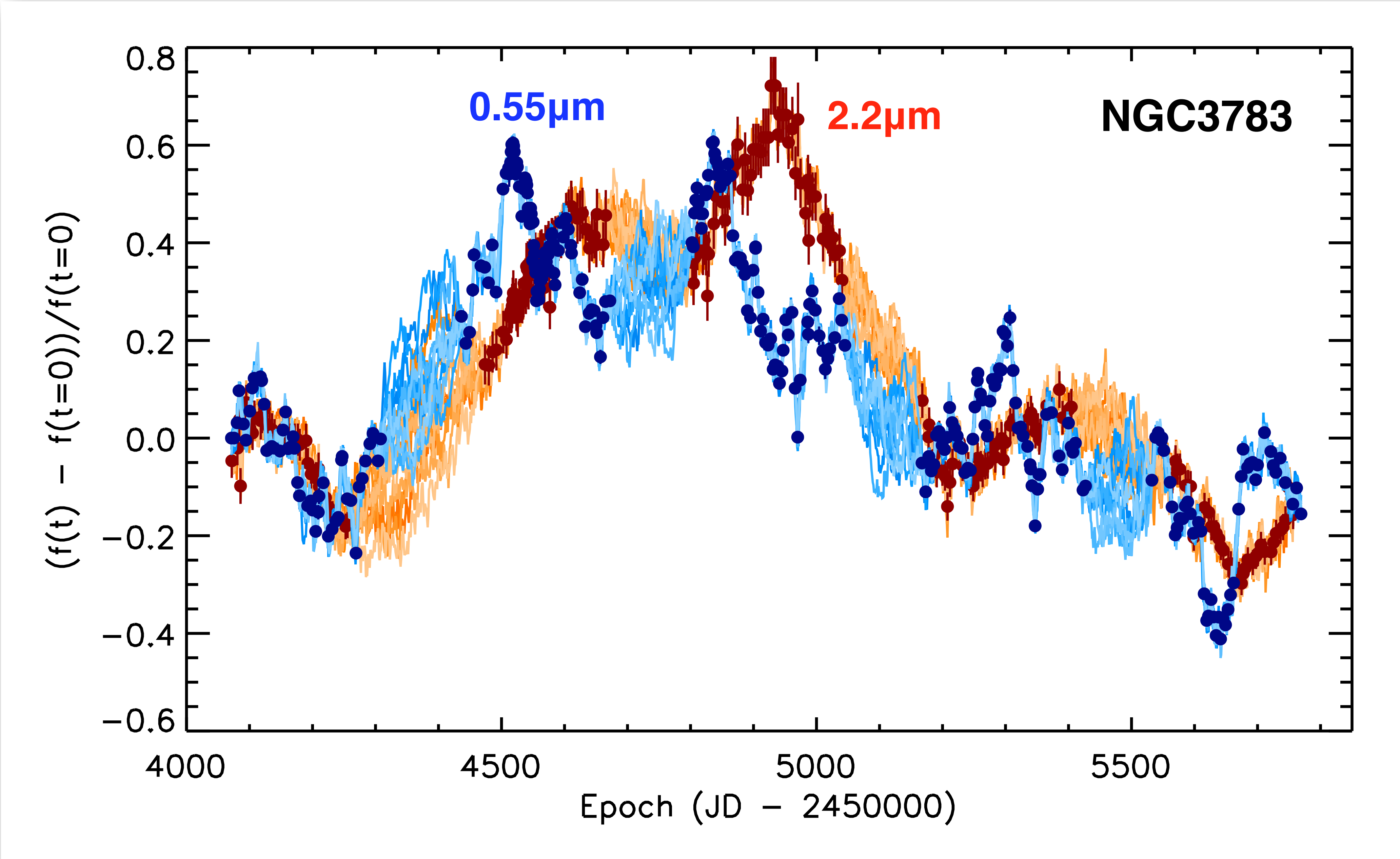


Kishimoto et al. 2013

- sublimation radius changes with **varying AGN luminosity** (Koshida+09, Pott+10, Kishimoto+11a)
- BUT: **~5 year integrated flux**, not instantaneous flux (Kishimoto+13)
- consistent with **“melting snowball” model** (Hoenig & Kishimoto+11)
- gas density **n_H ~10^9 cm^{-3}**, i.e. similar to BLR

III. The theorist’s point of view

III. What we learn from the smearing



Lira et al. 2011

- projected radial distribution causes asymmetric transfer function
  - → **with model: constraints 1D brightness distribution**
  - → **bias towards longer lags**
- inclination only broadens response (to first order)

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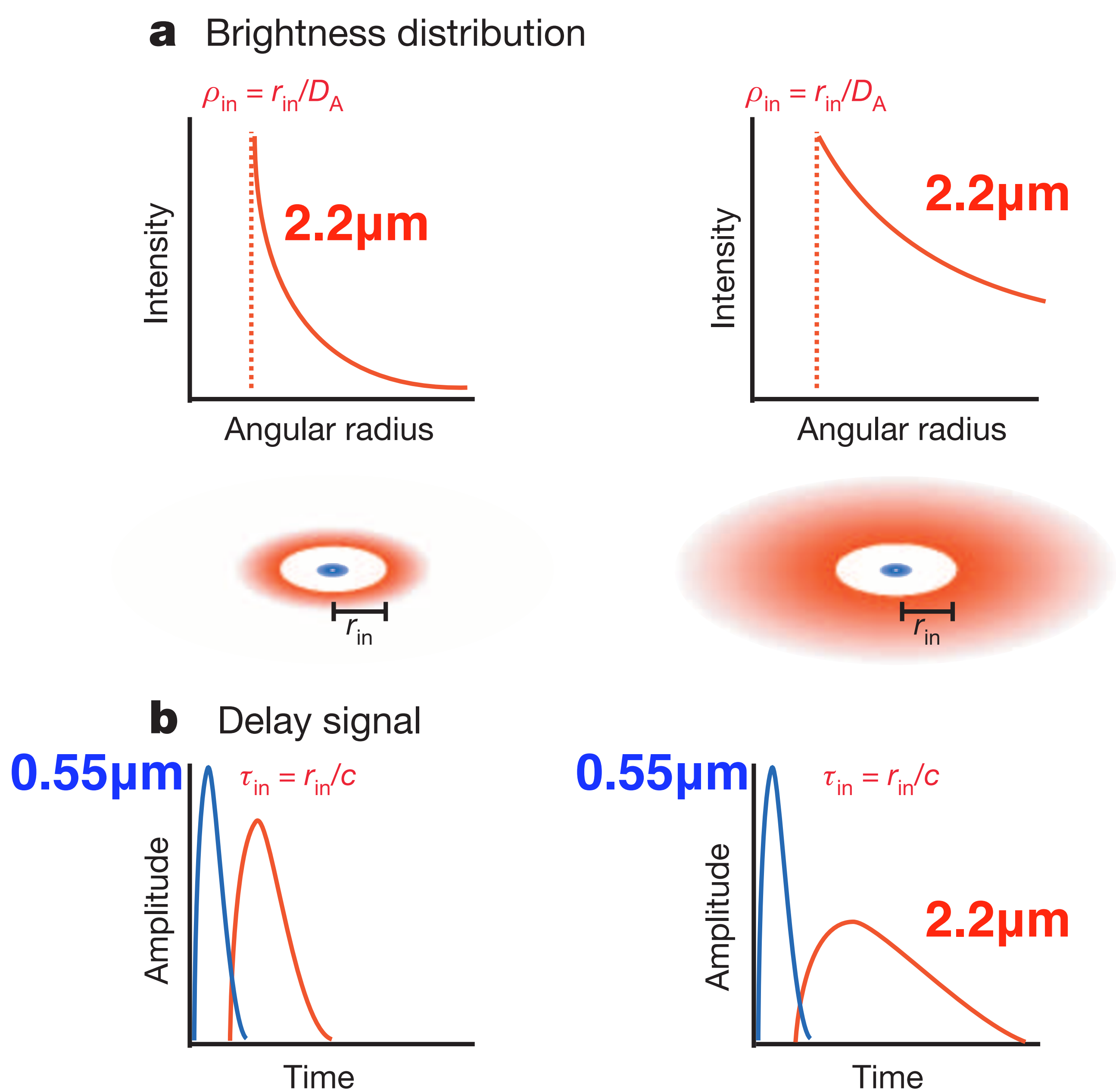

Hoenig et al. 2014

- projected radial distribution causes asymmetric transfer function
  → with model: constraints 1D brightness distribution
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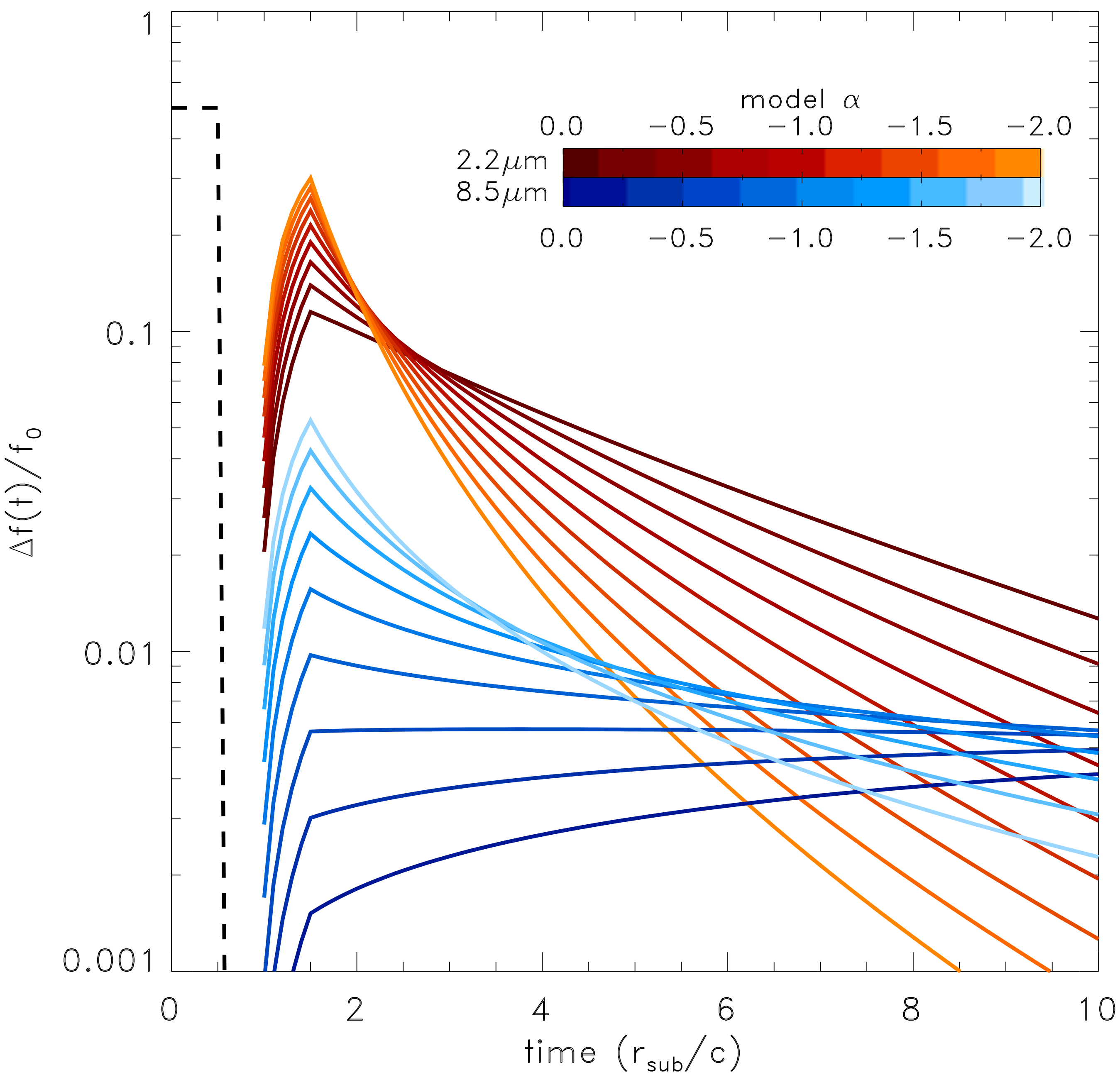
- inclination only broadens response (to first order)

III. Do wavelength-dependent lags trace the T profile?

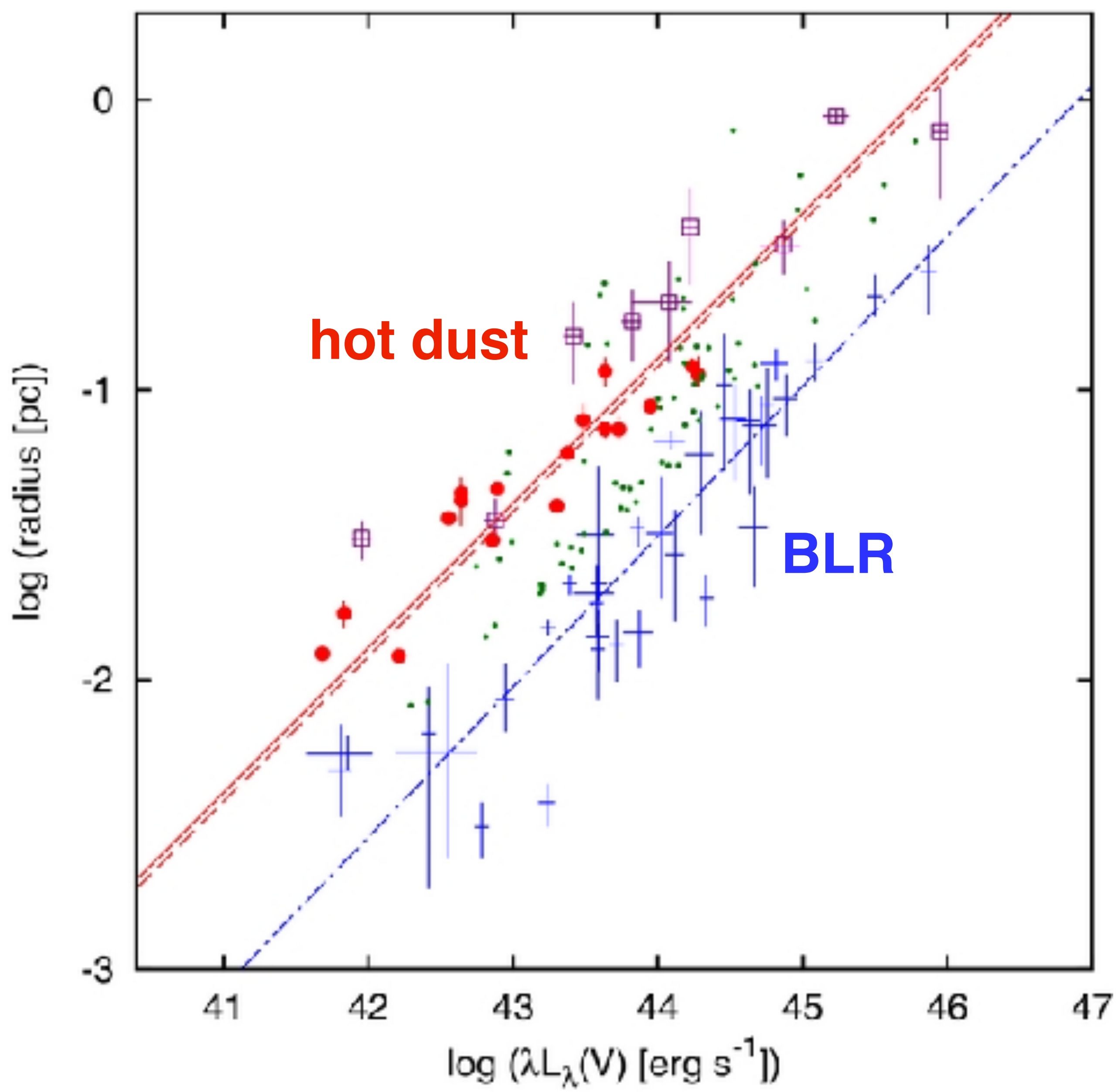


Hoenig & Kishimoto 2011

- response peak not necessarily shifting much with wavelength
  → **Wien tail** of hot dust emission
  → possible in **multi-component dusty environment**
- beware of **accretion disk contamination**!

IV. Cosmology

IV. The size-luminosity relationship



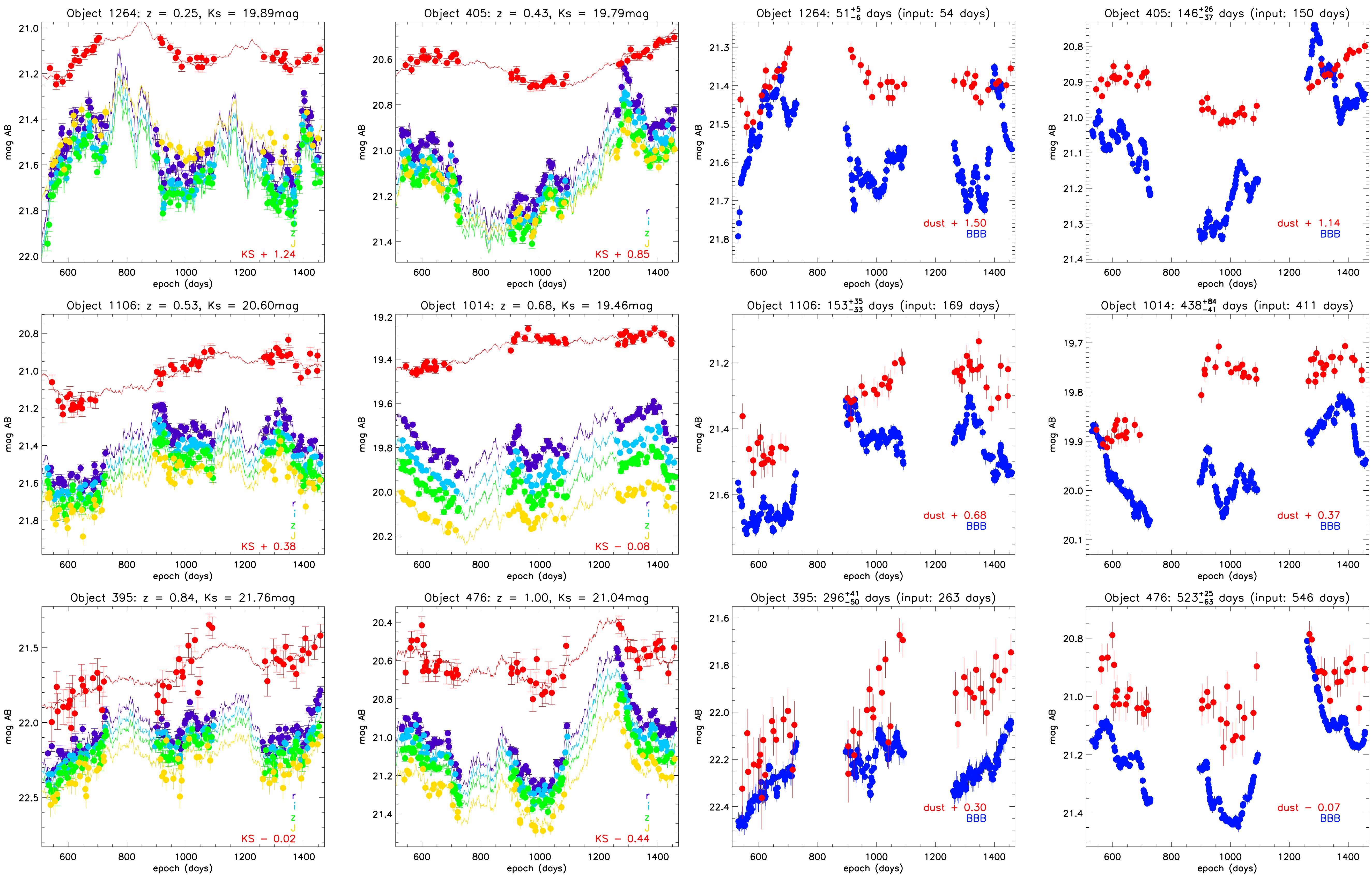
Koshida et al. 2011a

- lag-luminosity relationship makes hot dust emission a **standardisable candle** (Oknijansky & Horne 2001, Yoshii et al. 2004)
- probably **narrower than the BLR relation**
- remember: **"simple physics"**

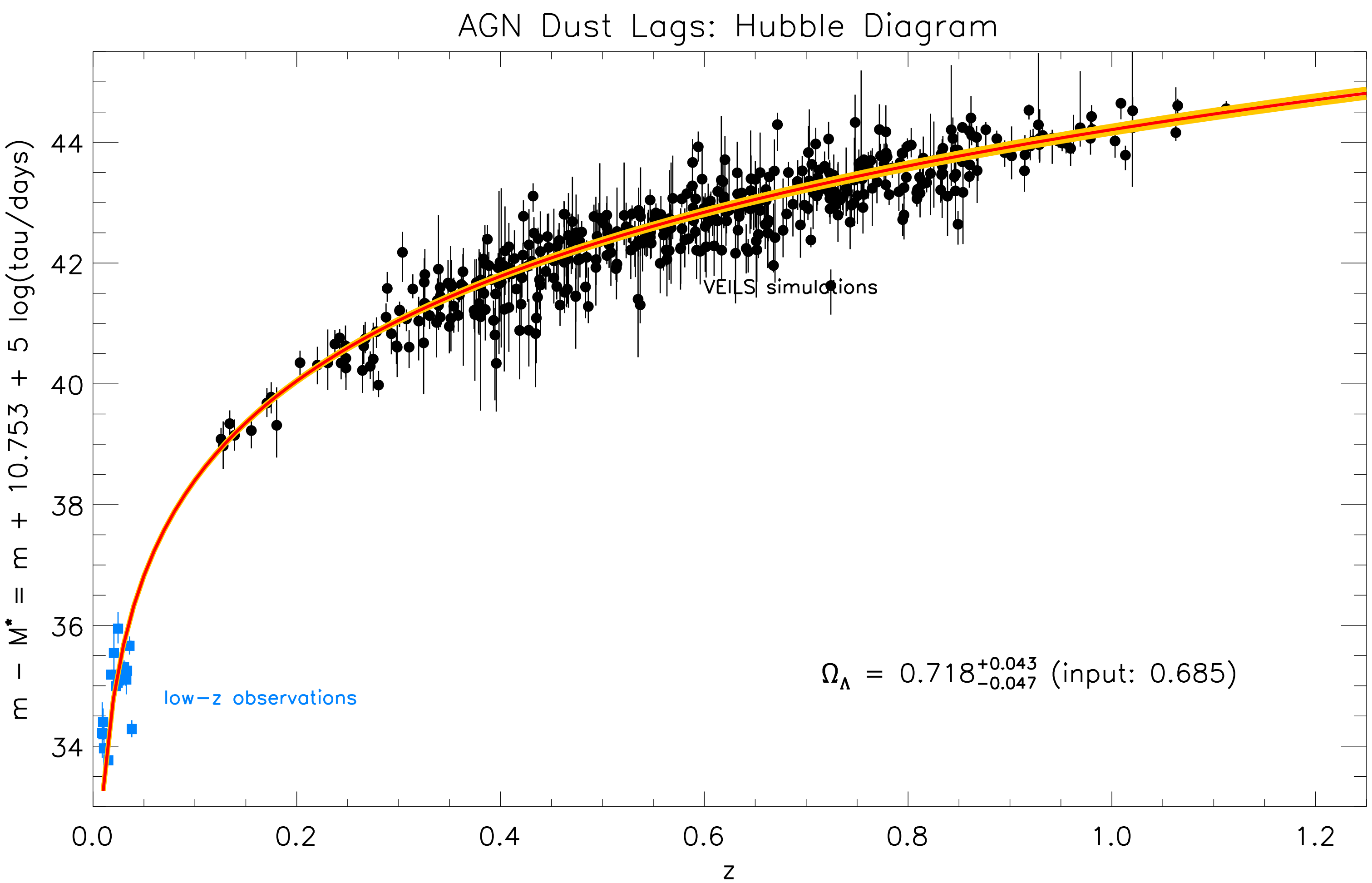
IV. Introduction to VEILS

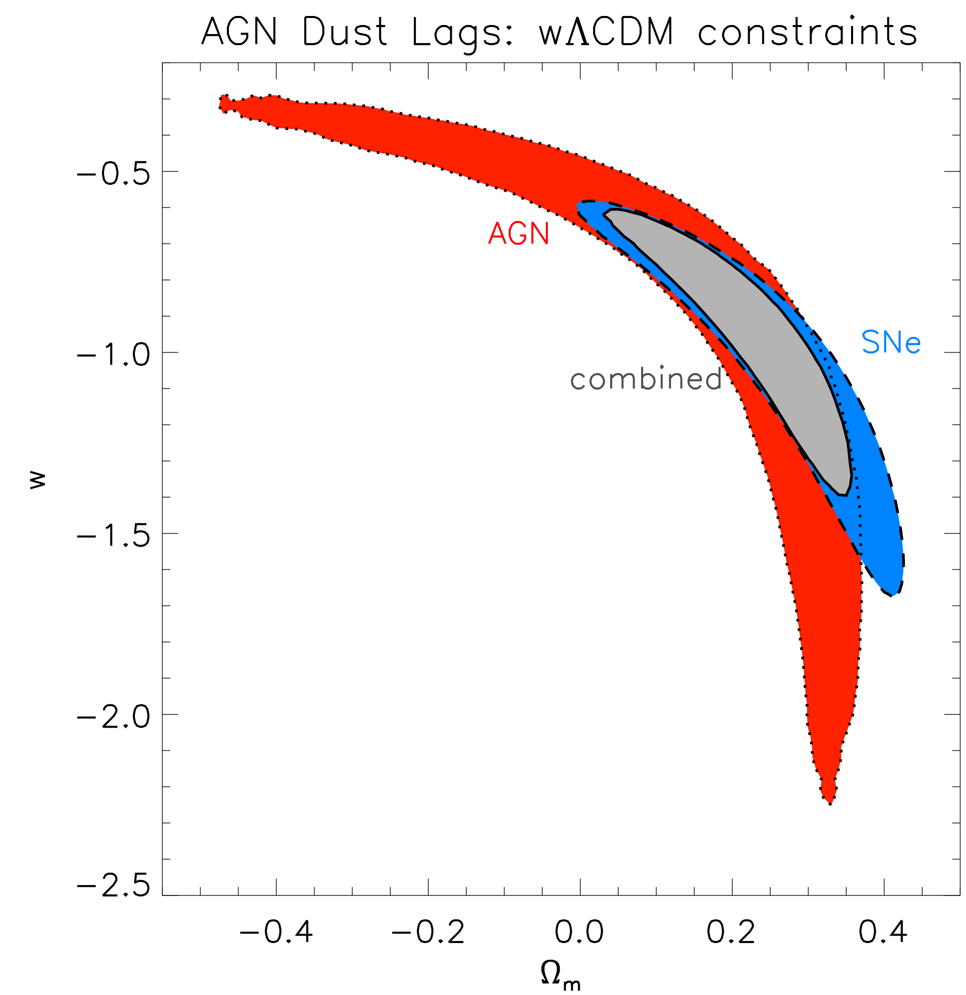
- **Deep infrared survey of extragalactic legacy deep fields**
- **First ever infrared time domain survey on this scale**
- **Static science (= science from co-added data)**
    - Sources of re-ionisation in the universe
    - Massive galaxy assembly at high (z~6-7) redshift
    - Quenching of star formation at mid- to high redshifts
- **Transient science (= variable objects from individual epochs)**
    - Supernovae (SNe) cosmology with type Ia supernovae
    - AGN dust time lags as standard(isable) candles
    - Infrared transients (with no or faint optical counterpart)
- **Combination with Dark Energy Survey (DES) optical data**
- **9 sqrdeg (= two 1.5x1" pointings per field) in deep fields**
    - per epoch depths: **J=23.5 mag, Ks=22.5 mag; 14 day cadence**

IV. VEILS AGN simulations



IV. VEILS SNe+AGN cosmology





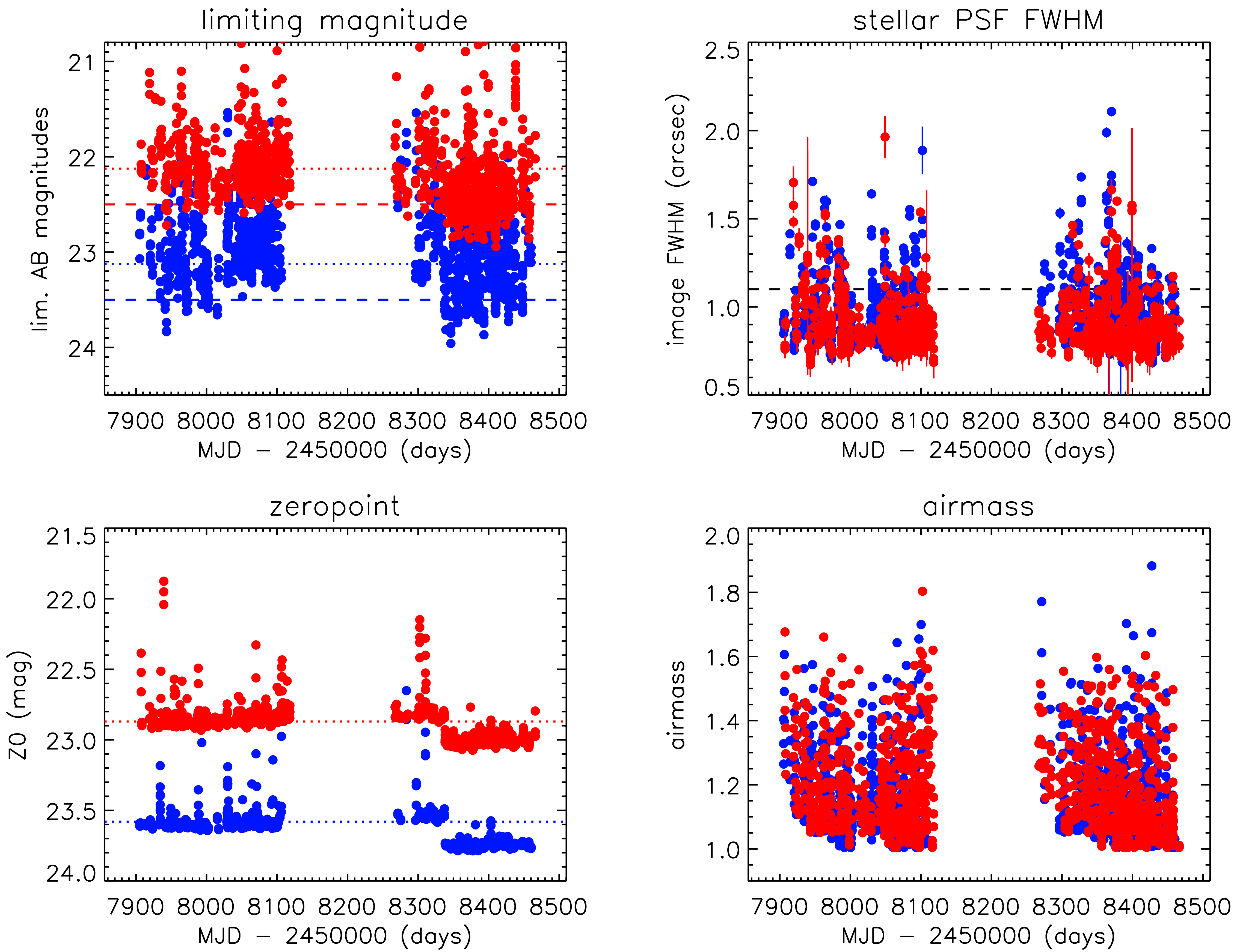
IV. The hard working realtime VEILS data reduction & analysis team

Triana Almeyda
postdoc
VEILS realtime data reduction
AGN light curves

Ella Guise
PhD student
VOILETTE realtime data reduction
AGN light curves


J-band
m(AB) < 23.89 mag
30”

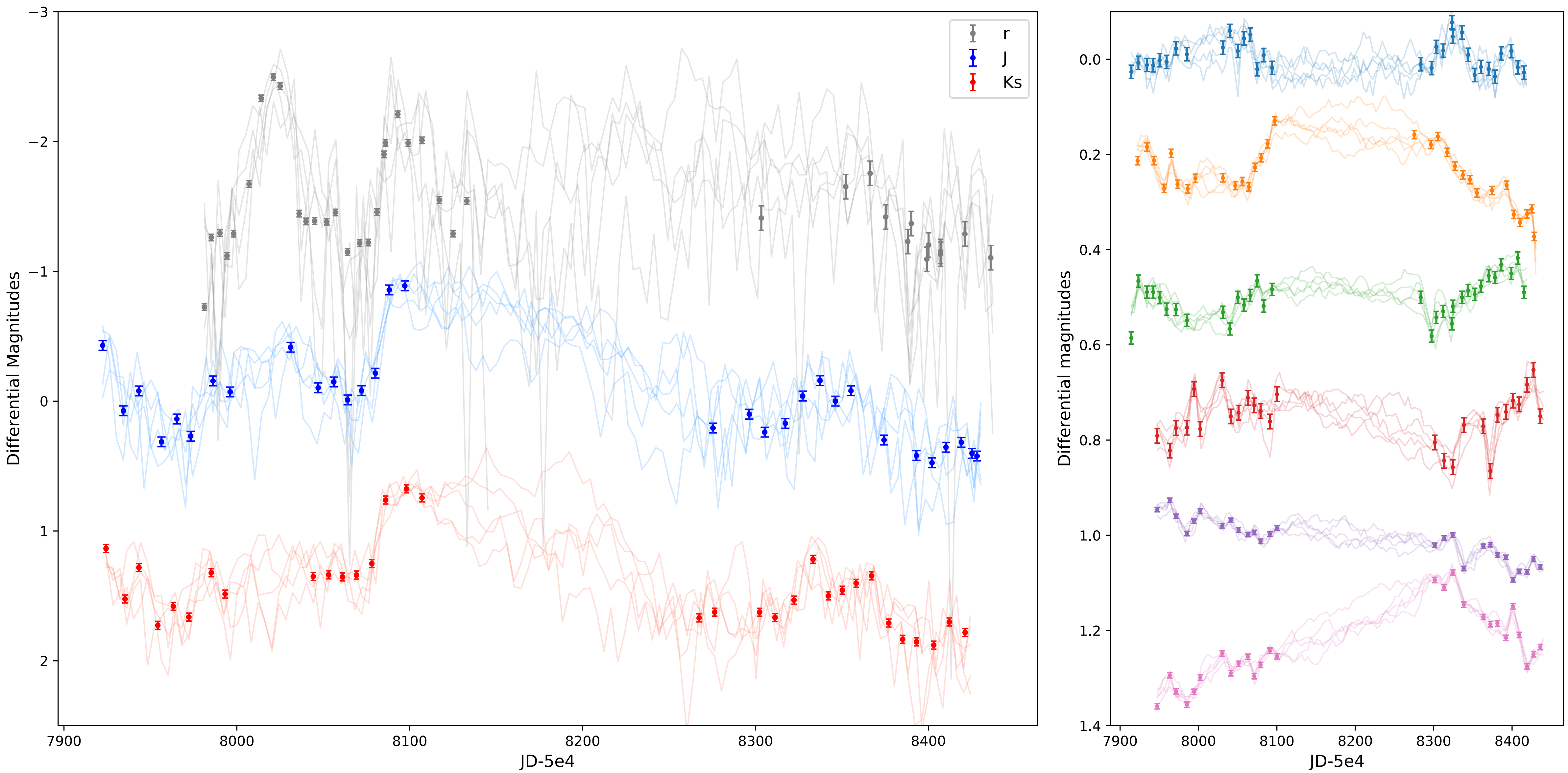
IV. Survey progress: Data quality



IV. Survey progress: Data quality

- **Single-epoch depth**
  - Ks-band: 22.63 mag (-0.25,+0.19); expected: 22.5 mag → ✓
  - J-band: 23.44 mag (-0.35,+0.26); expected: 23.5 mag → (✓)
- **PSF FWHM**
  - Ks-band: 0.92” (-0.07”,+0.12”); expected: 1.1” → ✓
  - J-band: 0.98” (-0.10”,+0.18”); expected: 1.1” → ✓
- **Notes**
  - conditions have been exceptionally bad in 2017 southern summer
  - **~98% of OBs/epochs executed**
  - **VOILETTE issues** in Year 2

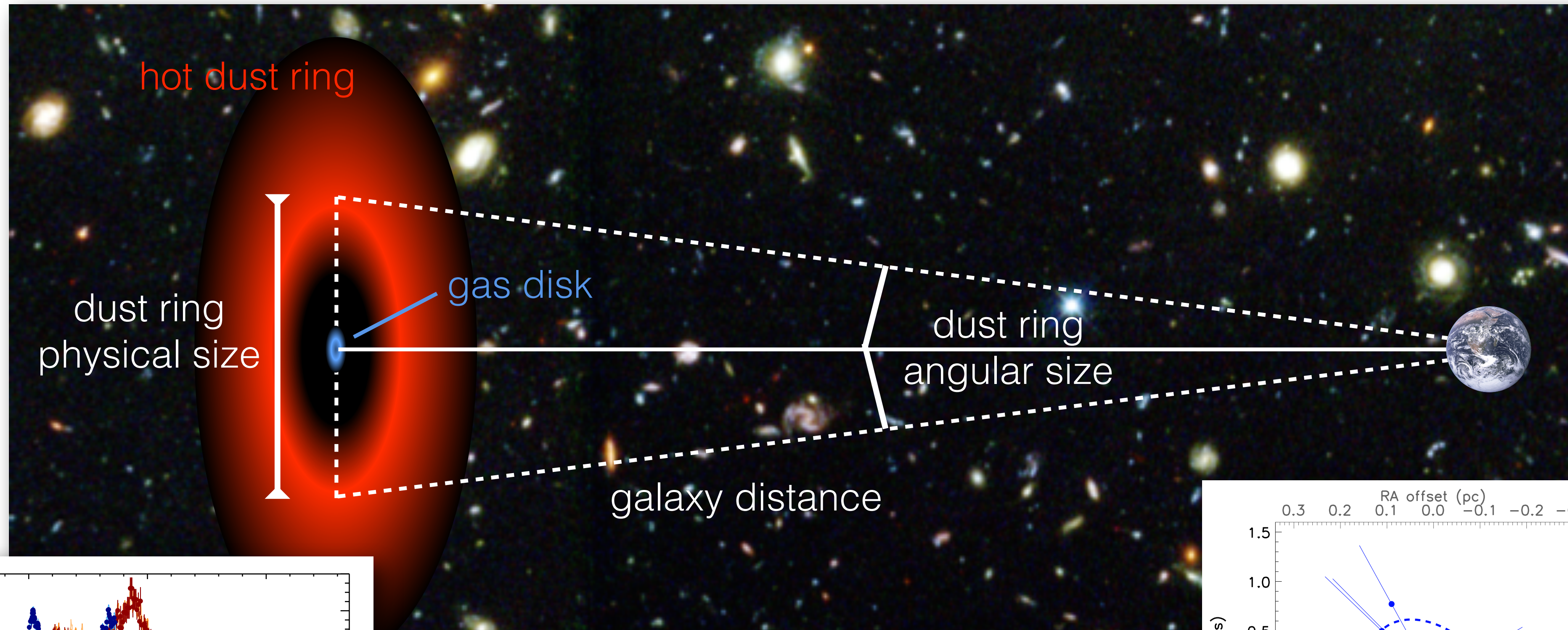
III. Early light curves

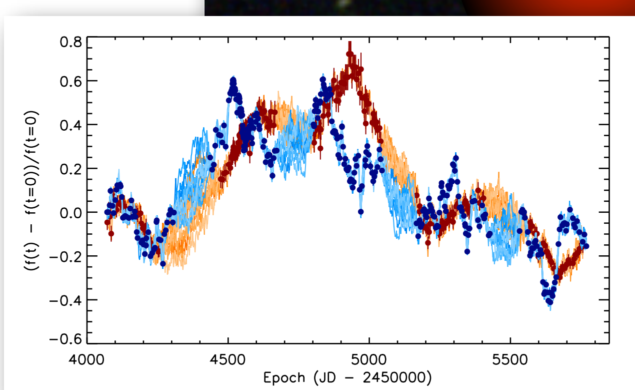


- Based on **OzDES catalogue:** 77 variable AGN identified
  - estimate: **450+/-50 AGN** for 3-year VEILS
- Some variability already usable for reverberation mapping
- Interesting individual sources

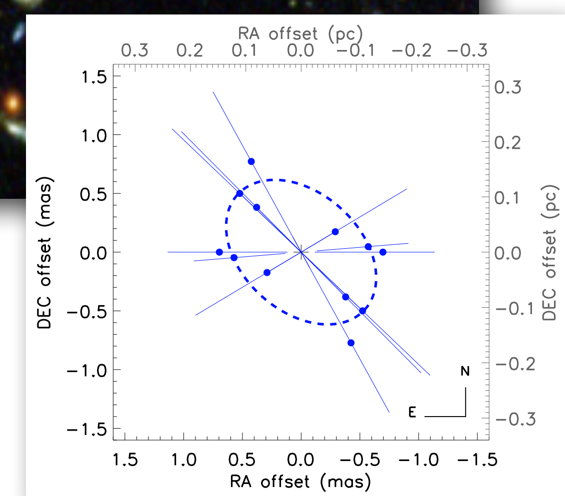
V. Some further thoughts

V. Direct distances to AGN





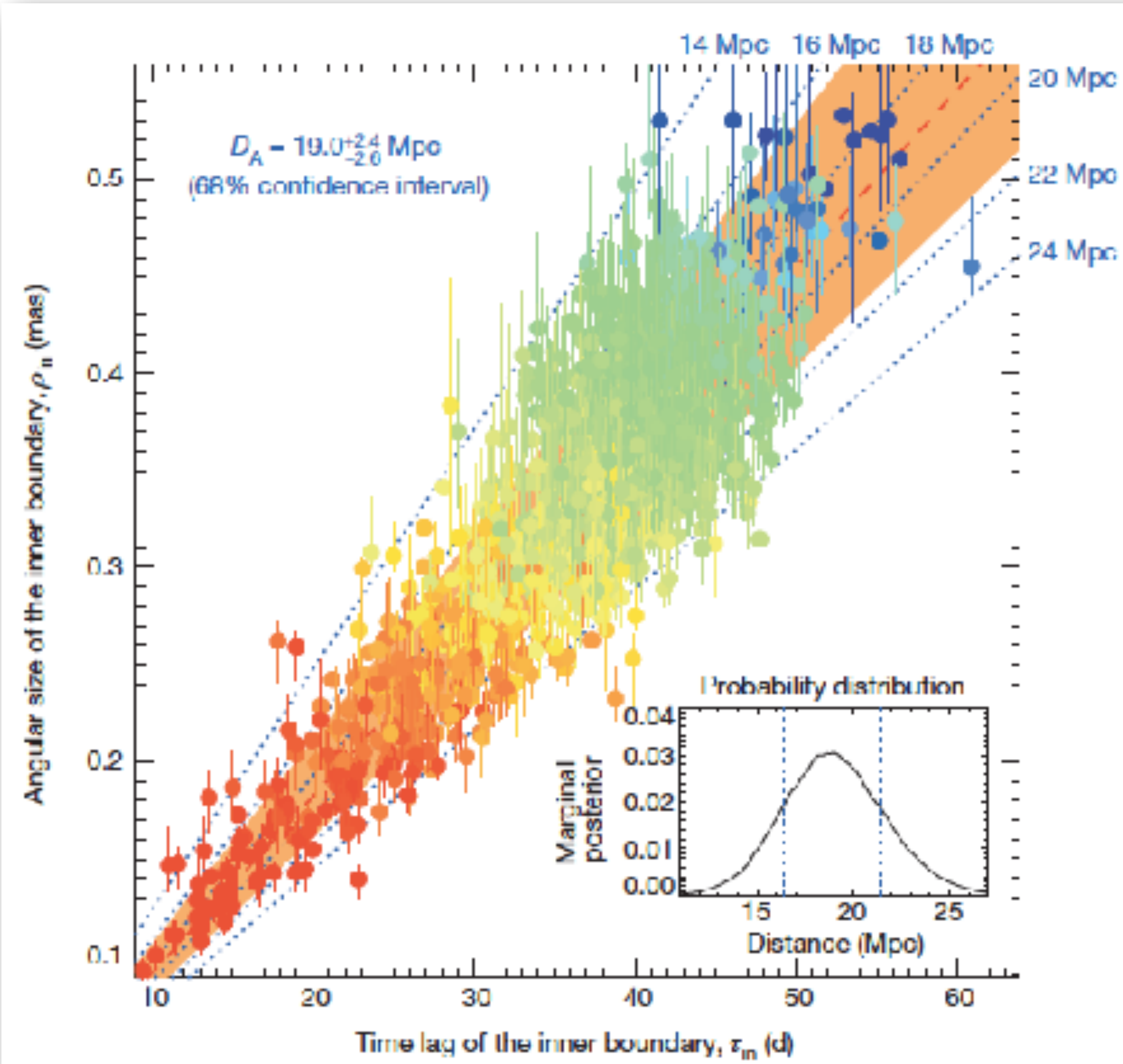
near-infrared reverberation mapping:
absolute size

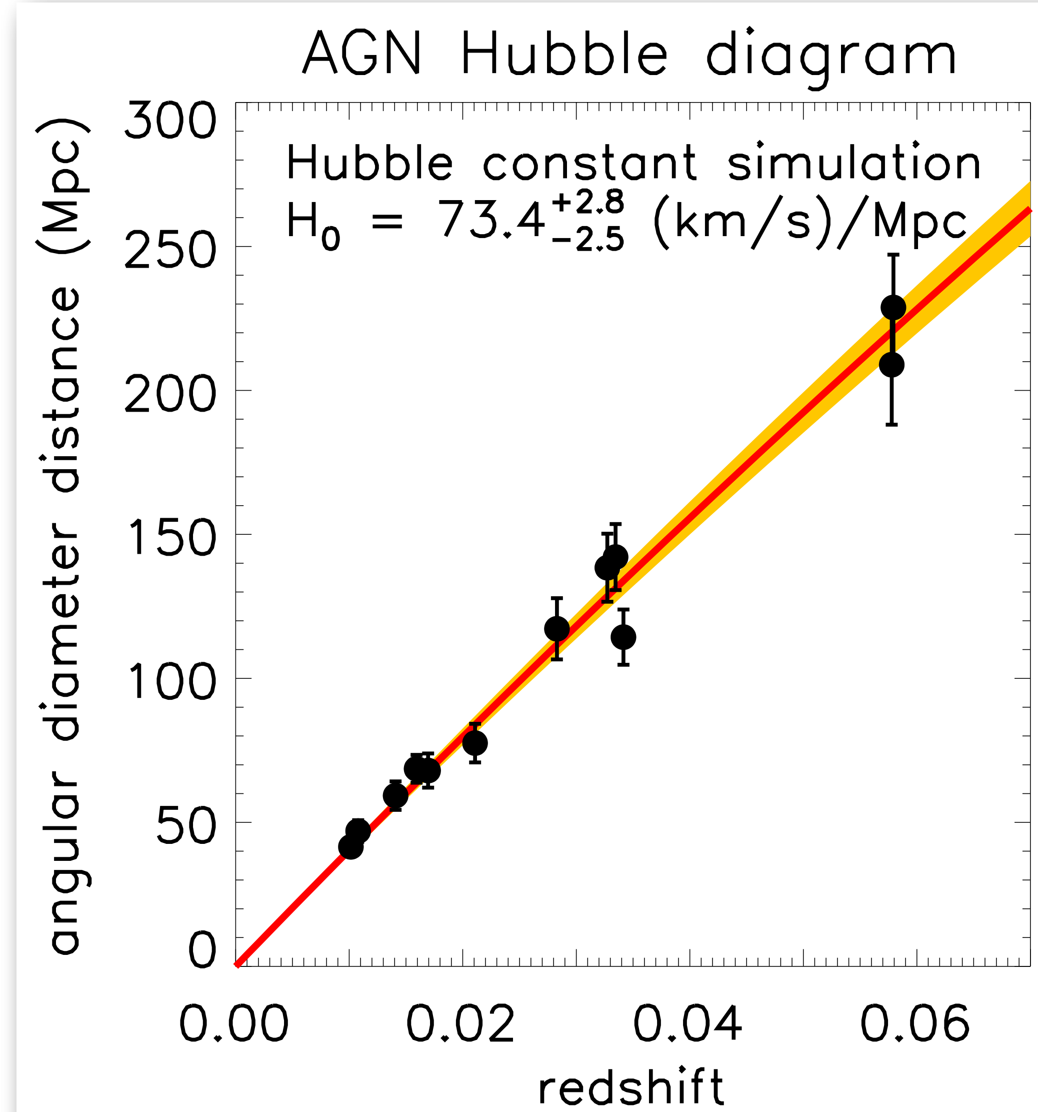


near-infrared interferometry:
angular size

$$\textbf{geometric distance} = \frac{\textbf{absolute size}}{\textbf{angular size}}$$ (±10-13% *including* systematics)

V. Direct distances to AGN





- precision cosmology: measuring **direct distances in the Hubble flow**

Summary

- **What we learned…**
  - dust reverberation probes **dusty, molecular accretion flow and dusty wind launching region**
  - dust emission shows expected **lag-luminosity relation**…
  - …but is dominated by **large graphite grains**
  - lags not necessarily temperature dependent
  - constraints on the **gas density and radial mass distribution**

- **What we will be learning on cosmology soon…**
  - dust lag Hubble diagram
    → **VEILS**
  - direct distances to AGN
    → **GRAVITY + 5-year SMARTS ANDICAM campaign**
    → **Hubble constant**