Rapid Reformation of the Innermost Dust Distribution in the Changing-Look AGN Mrk 590

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(to be submitted)

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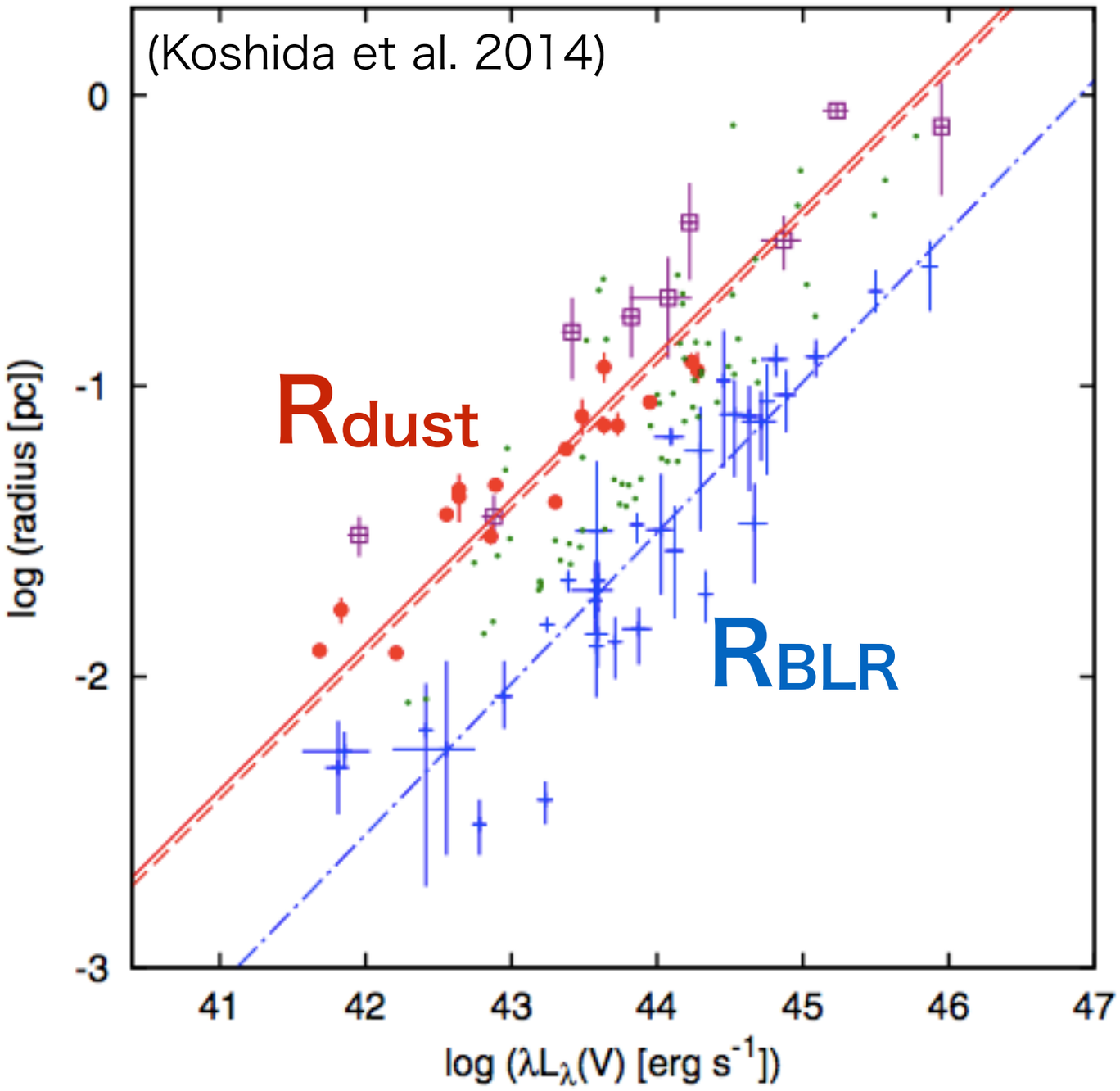
http://www.astro.gsu.edu/AGNmass/

Reverberation Mapping (RM) measurements of $R_{H\beta\ BLR}$ & R_{dust} in local AGNs



AGN optical luminosity

- Hβ Broad Line Region RM
  — **AGN Watch, LAMP2008, …**
  (Peterson+1998, Bentz+2009, …)
- K-band dust innermost radius RM
  — **MAGNUM project**
  (Suganuma+2006, Koshida+2014)

$R_{BLR} \propto L_{opt}^{0.5}$

$R_{dust} \propto L_{opt}^{0.5}$

&

$R_{dust} \sim 4 \times R_{BLR}$

"Dust sublimation-limited R_{dust}"

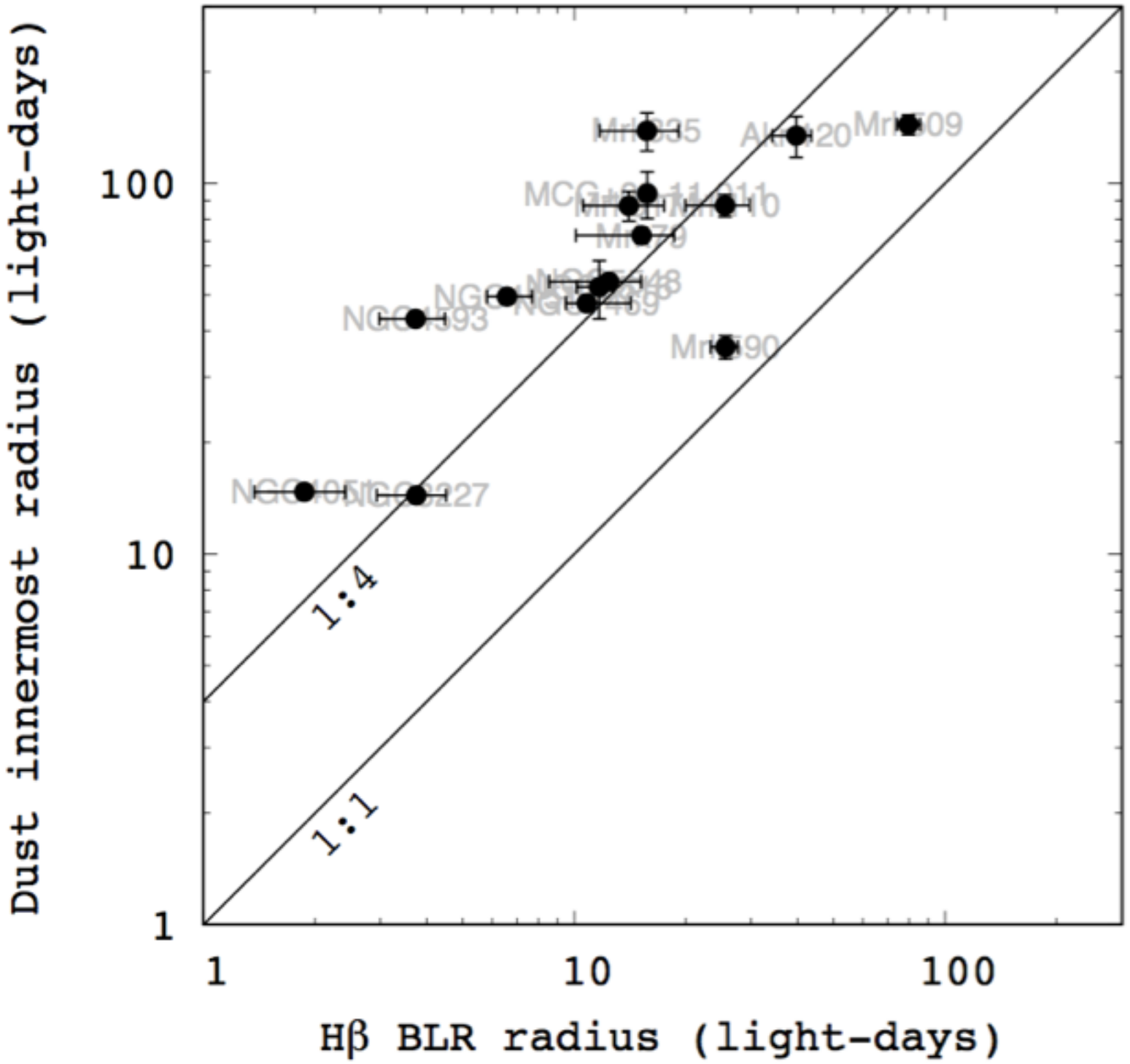
(e.g., Netzer & Laor 1993, Baskin & Laor 2018)

(also J. Dexter's slide)

R_{dust} vs. R_{BLR} in each of the 15 AGNs

(data from Koshida et al. 2014, Bentz 2009, Peterson+2014, Fausnaugh+2017)

R_{dust}



R_{BLR}

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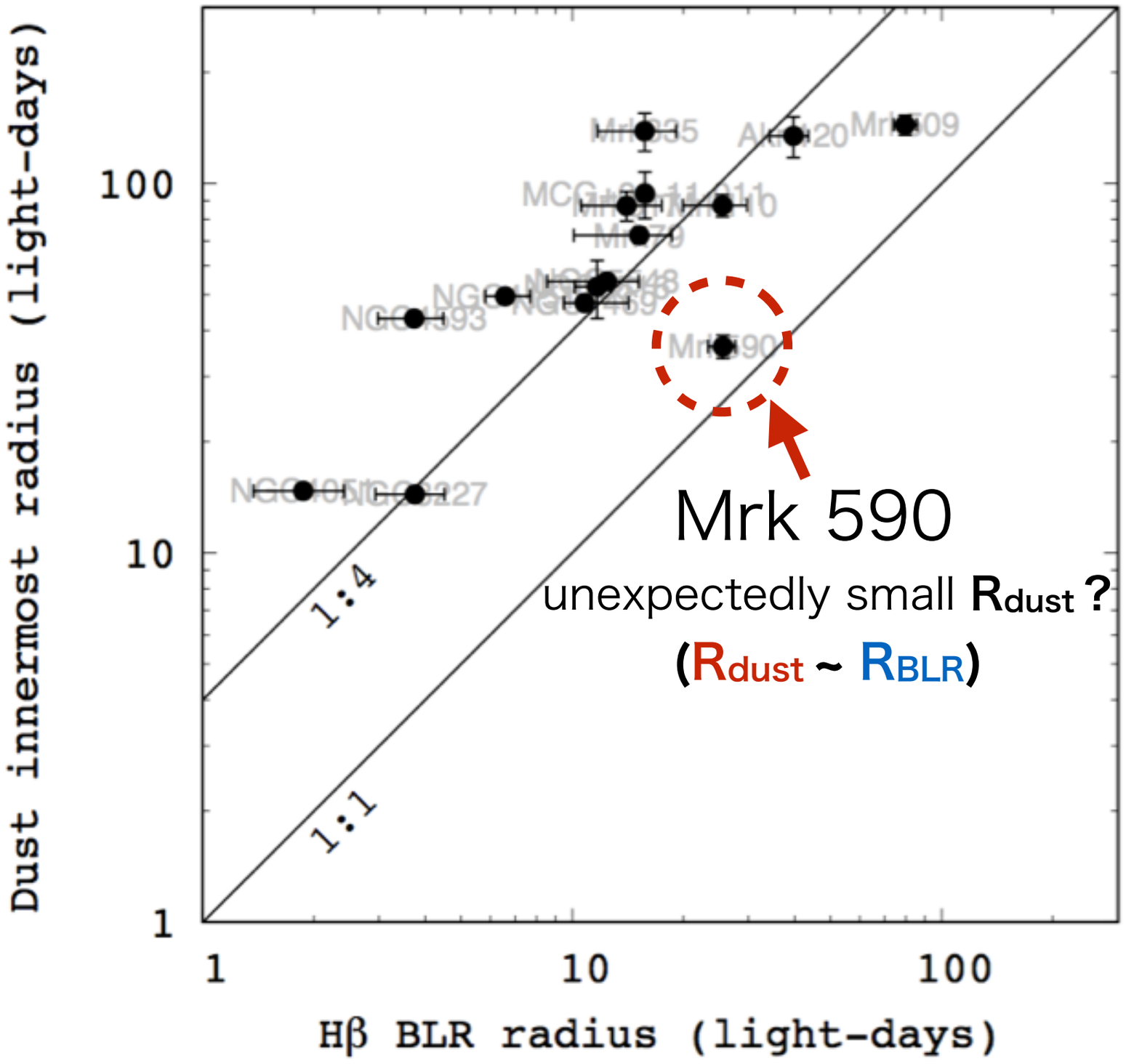
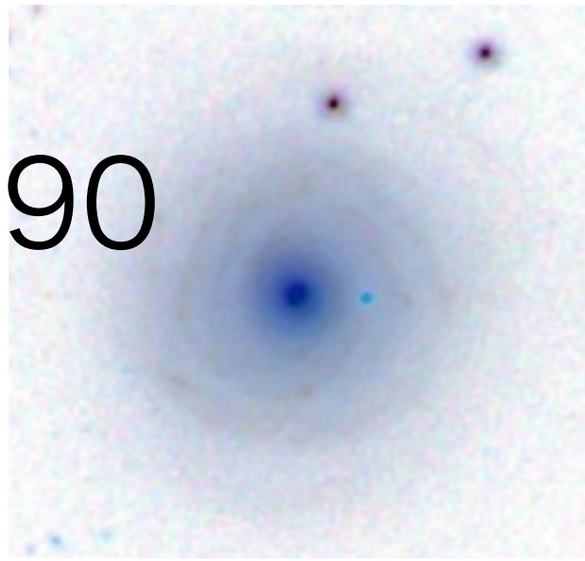


R_{BLR}

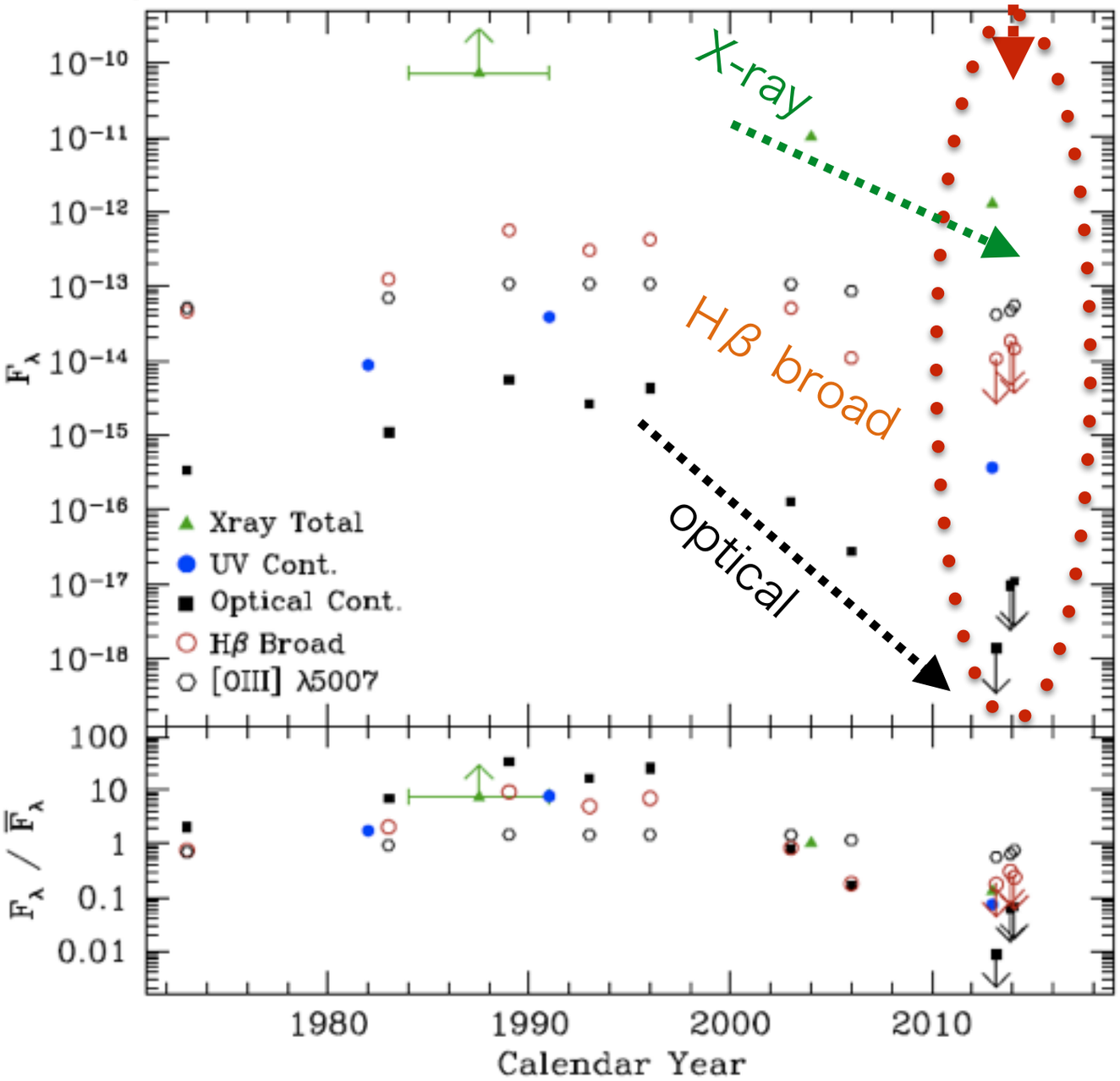
Changing-look AGN Mrk 590



No broad lines in 2013

type 1 —> type 2

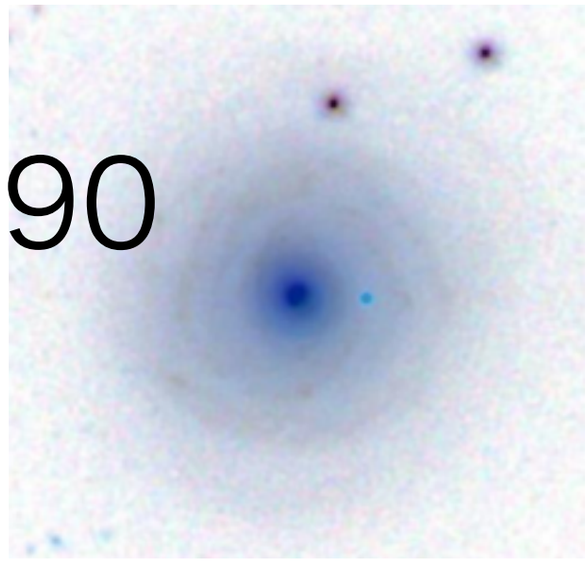
Denney et al. 2014



- Mrk590 **was** a type 1 AGN with $M_{BH} = 4.75 \times 10^7\ M_{sun}$ @ z=0.026
- A factor of 100 change in L_{bol}

type 1 —> **type 2 in 2013**

Changing-look AGN Mrk 590



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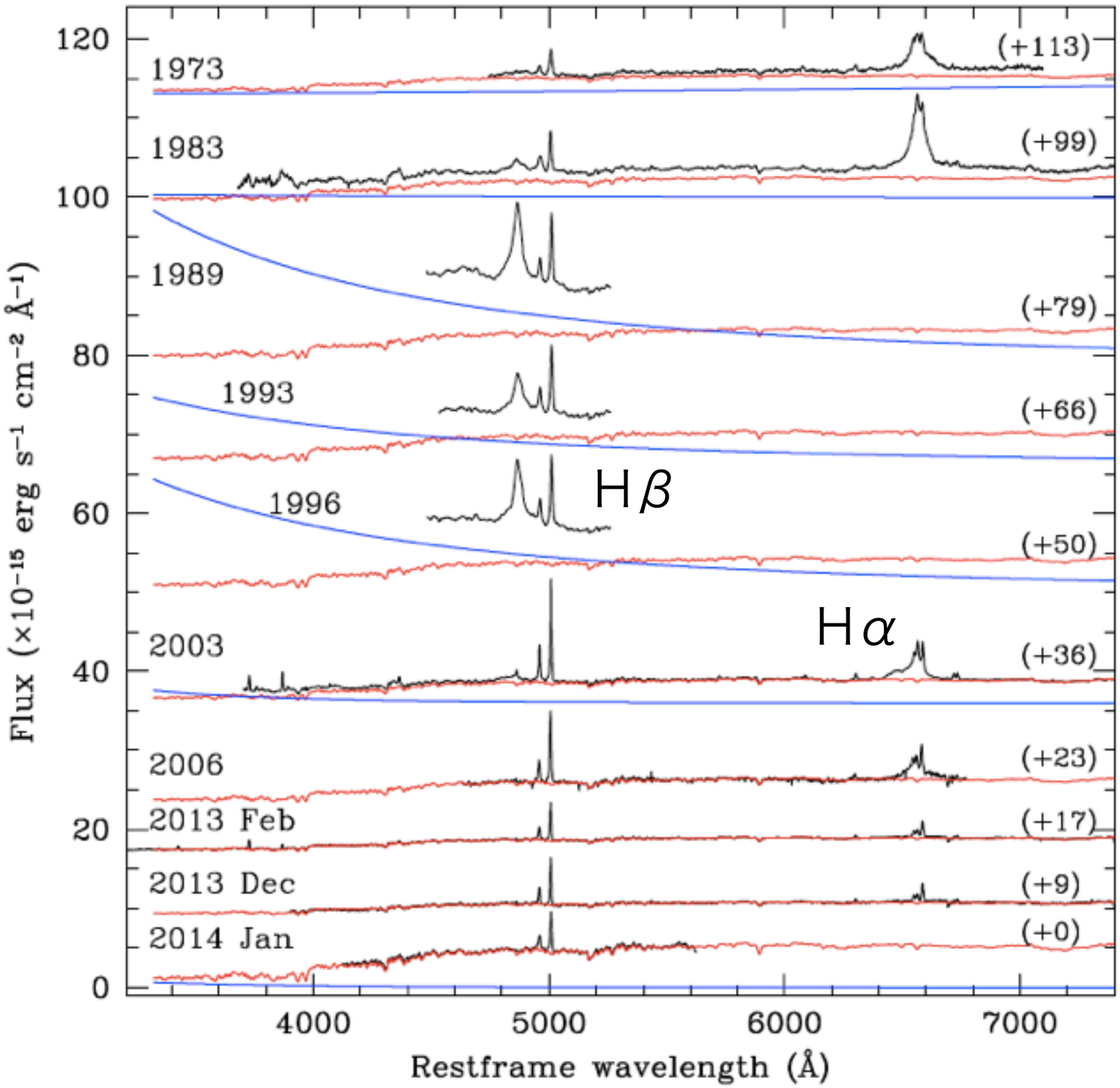
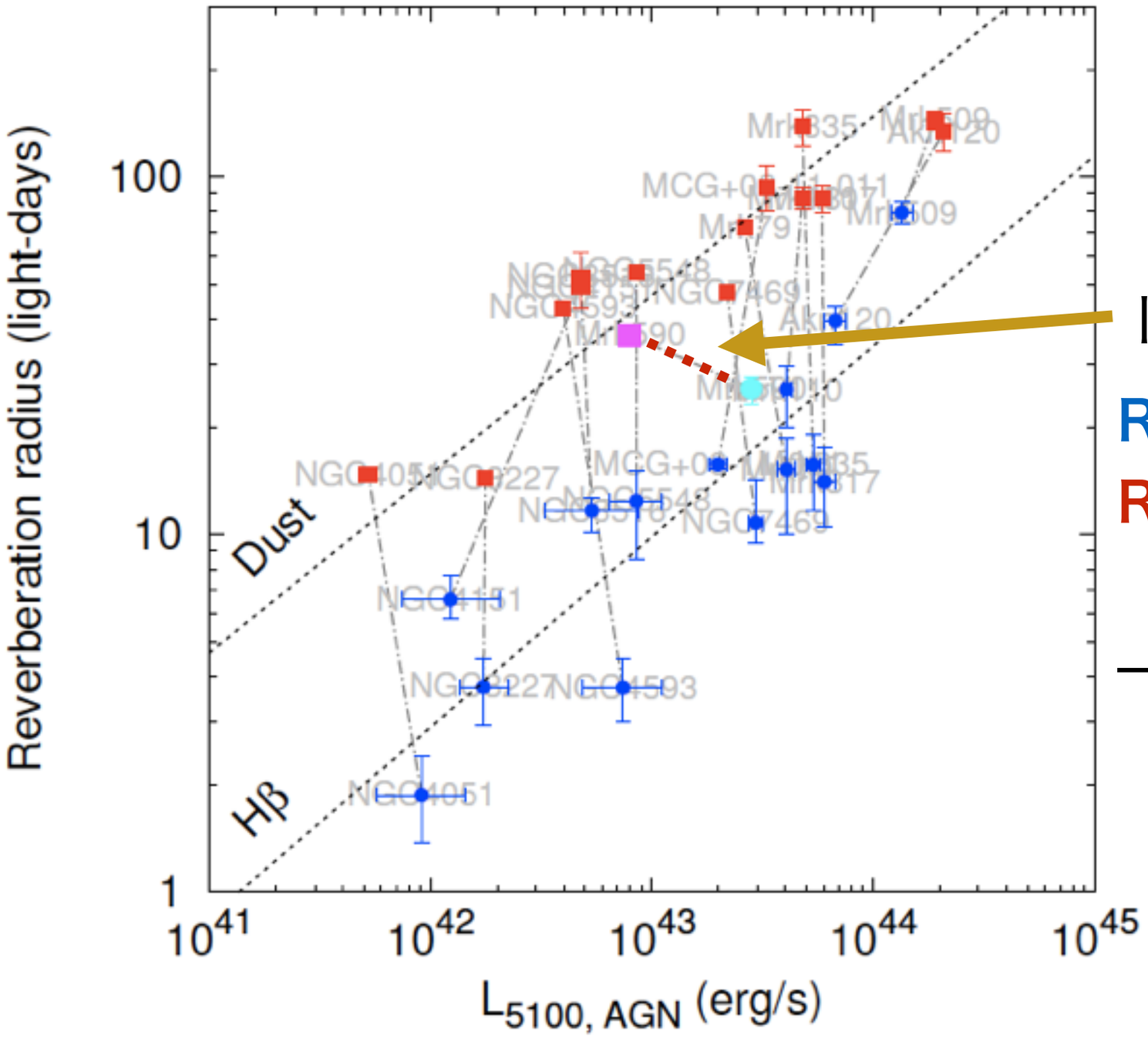


AGN Wacth Hβ RM
in 1990s (bright phase)

MAGNUM Dust RM
in 2000s (faint phase)

Broad lines disappear
in 2010s (very faint phase)
(Denney+2014)

R_{dust} / $R_{H\beta\ BLR}$ vs. luminosity in each of the 15 AGNs



AGN optical luminosity

In Mrk 590,

R_{BLR} measured in bright phase

R_{dust} measured in faint phase

—> R_{dust} ~ R_{BLR} << 4 × R_{BLR}

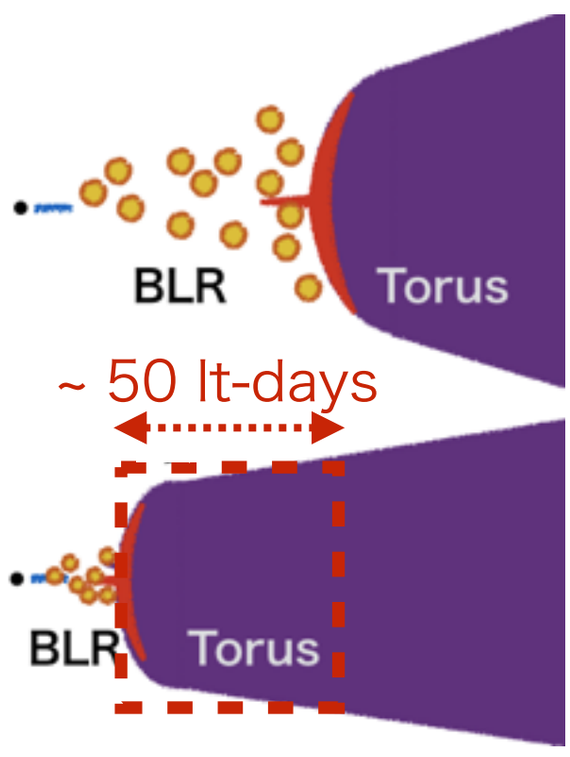
The aim of this work

- The luminosity change between 1990s and 2000s can explain the small R_{dust} measured by MAGNUM

- **Question:** if so, how is the innermost dust distribution replenished ?

  inflow of dust clouds? new dust formation ?

  (e.g. Elvis 2000, Honig's talk)

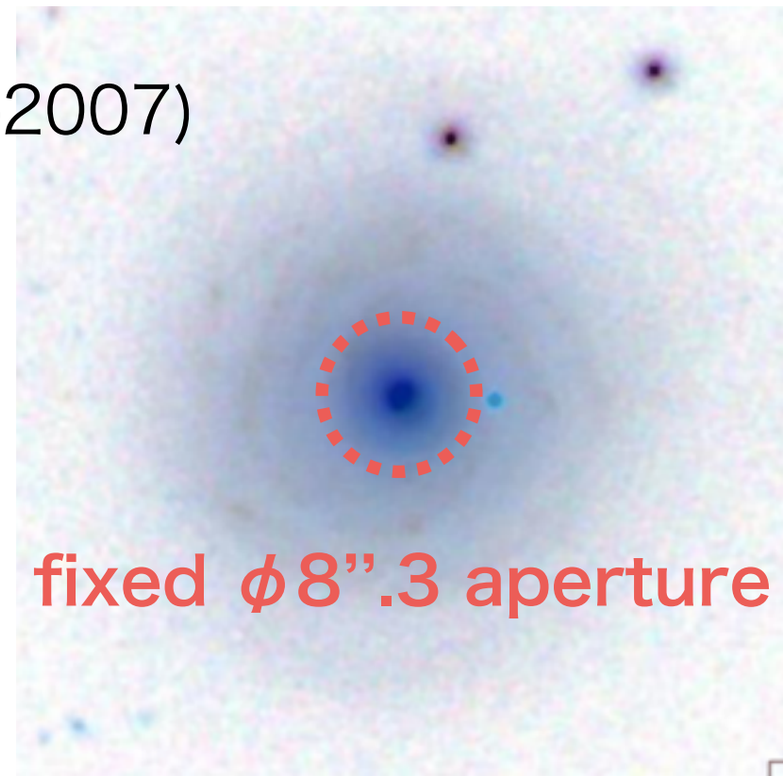


Analysis of historical light curves of Mrk 590
—> constraints on the **dust replenishment time scale & the dust replenishment mechanism**

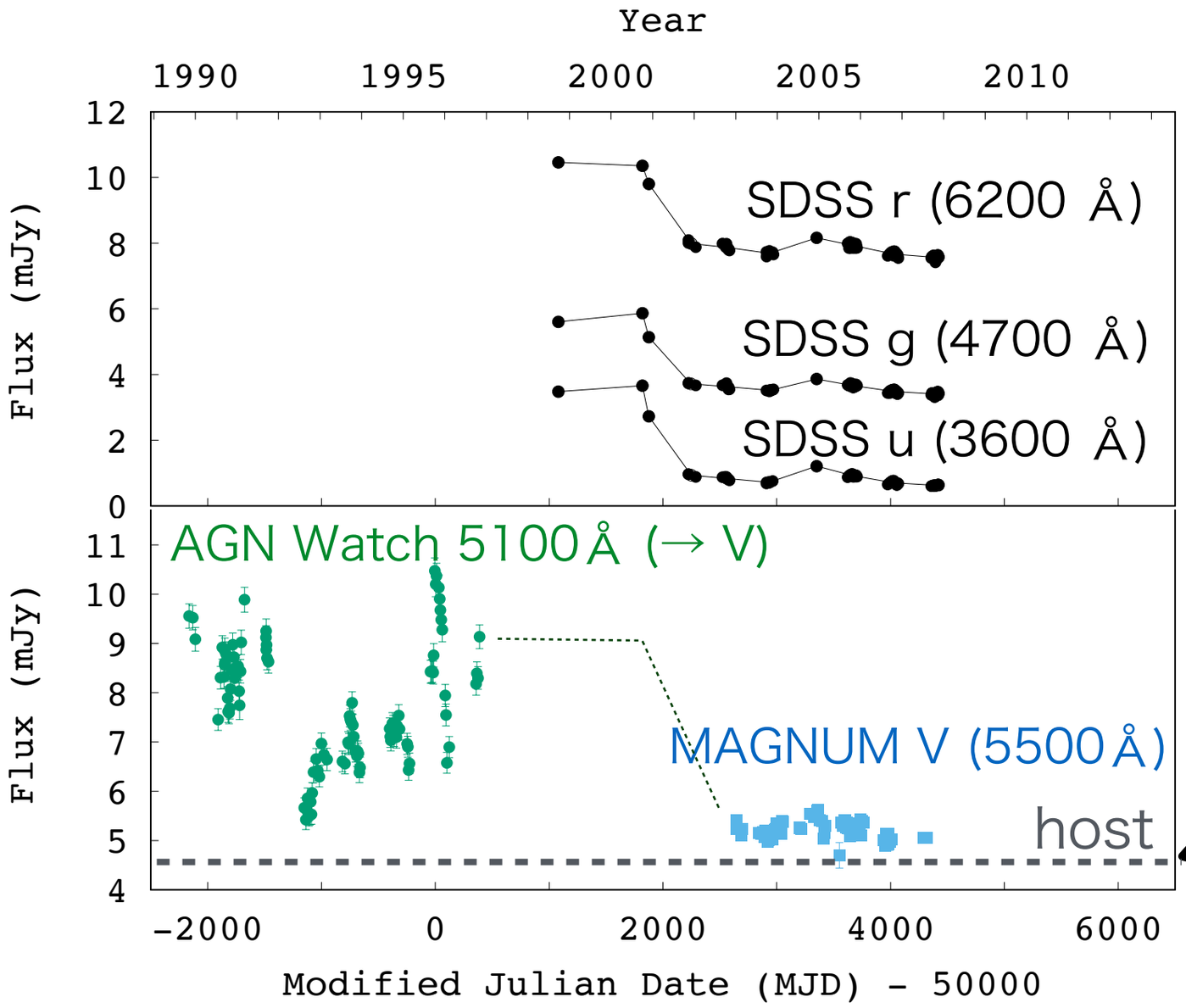
Optical imaging data of Mrk 590

- We compiled optical photometry data of Mrk 590 in 1990s - 2000s (8”.3 aperture photometry is performed, if necessary)
  - **AGN Watch** 5”.0×7”.6 aperture spectroscopic 5100 Å data (1989-1996)
  - **MAGNUM** V-band light curve (2003-2008)
  - SDSS Stripe 82 u, g, r, i, z light curves (1998-2007) (unpublished in the literature)

(…many other optical-NIR data)



Derived optical light curves (u, g, r, V)



- SDSS data fill in the gap between AGN Watch and MAGNUM obs.
- **SDSS data reveal a rapid decline in optical luminosity in 2001-2002**

Host galaxy flux contribution estimated from HST/ACS F550M image (Bentz+2013, Koshida+2014)

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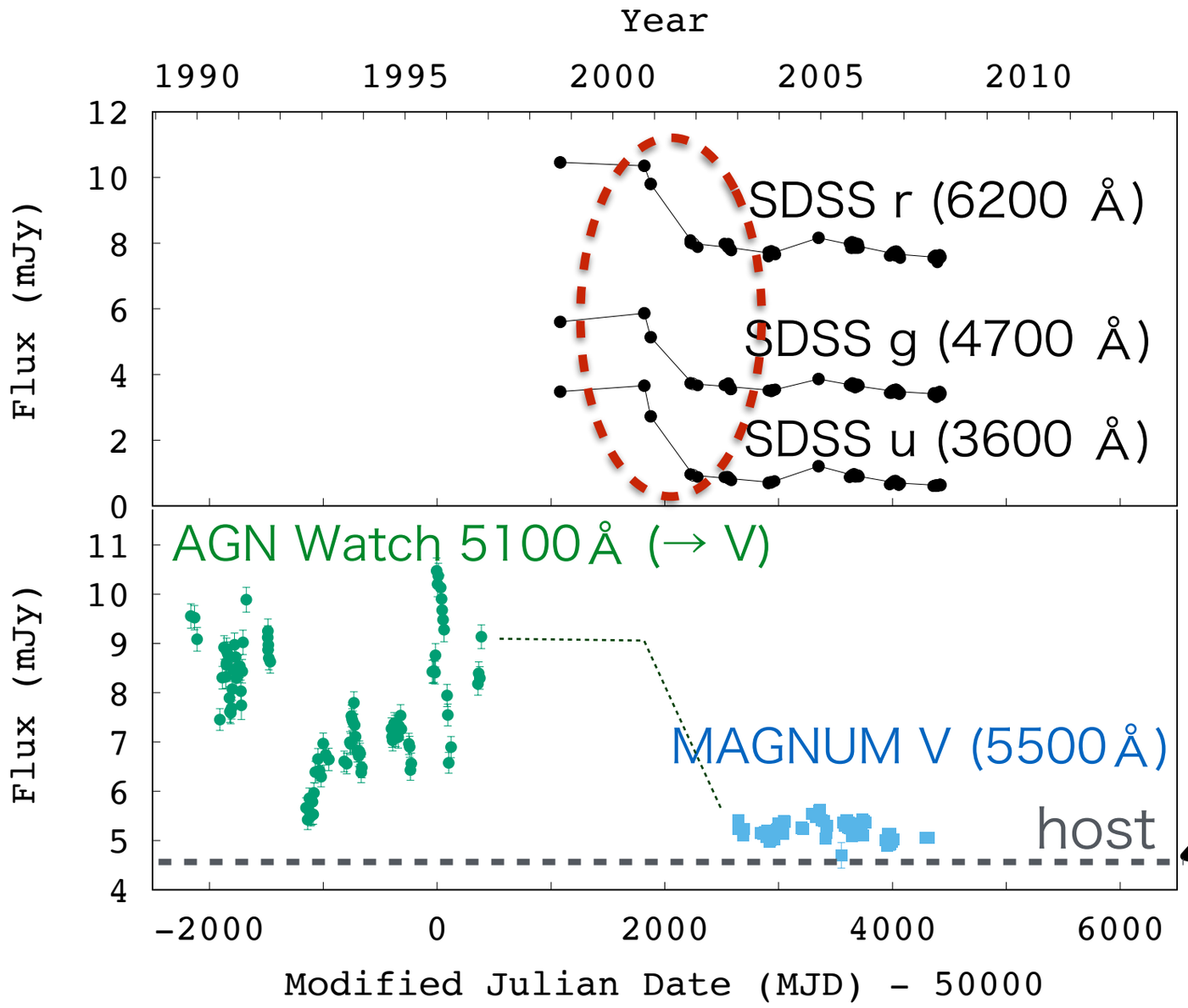

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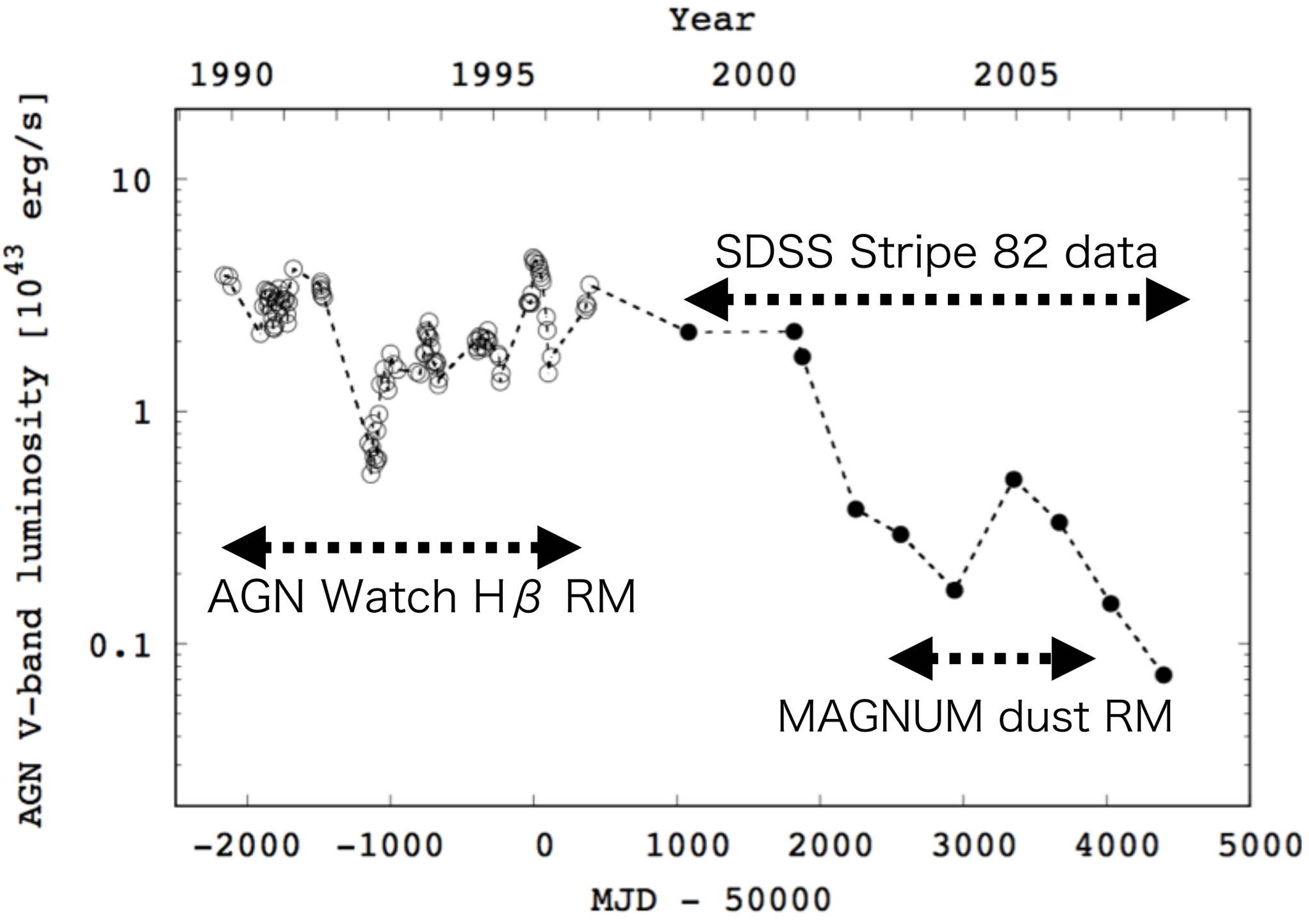
Host galaxy-subtracted V-band AGN luminosity

(combined, interpolated light curve from 1989 to 2007)



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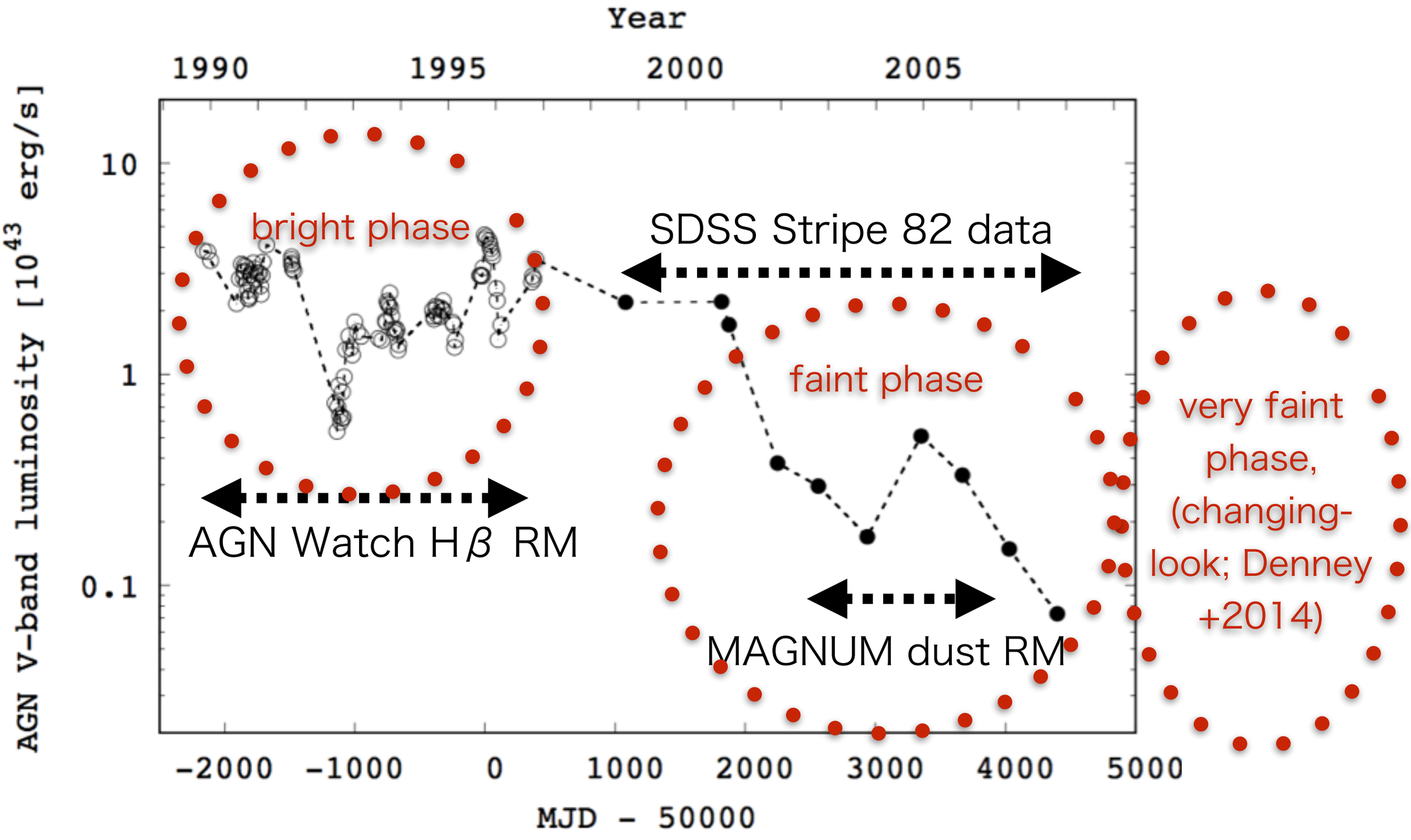

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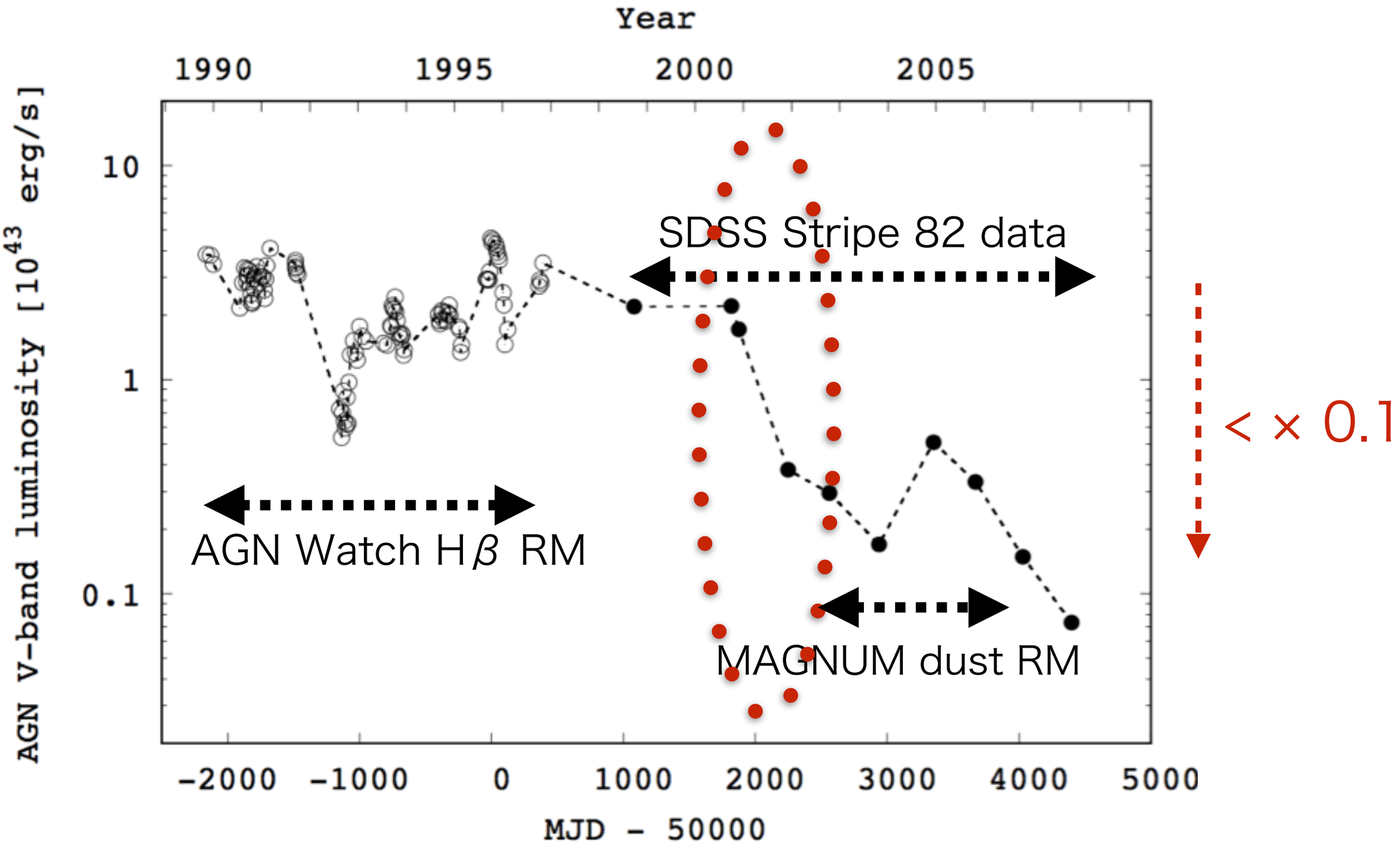


Expected dust radius evolution

empirical R_{dust} - luminosity relation

(Koshida+2014)

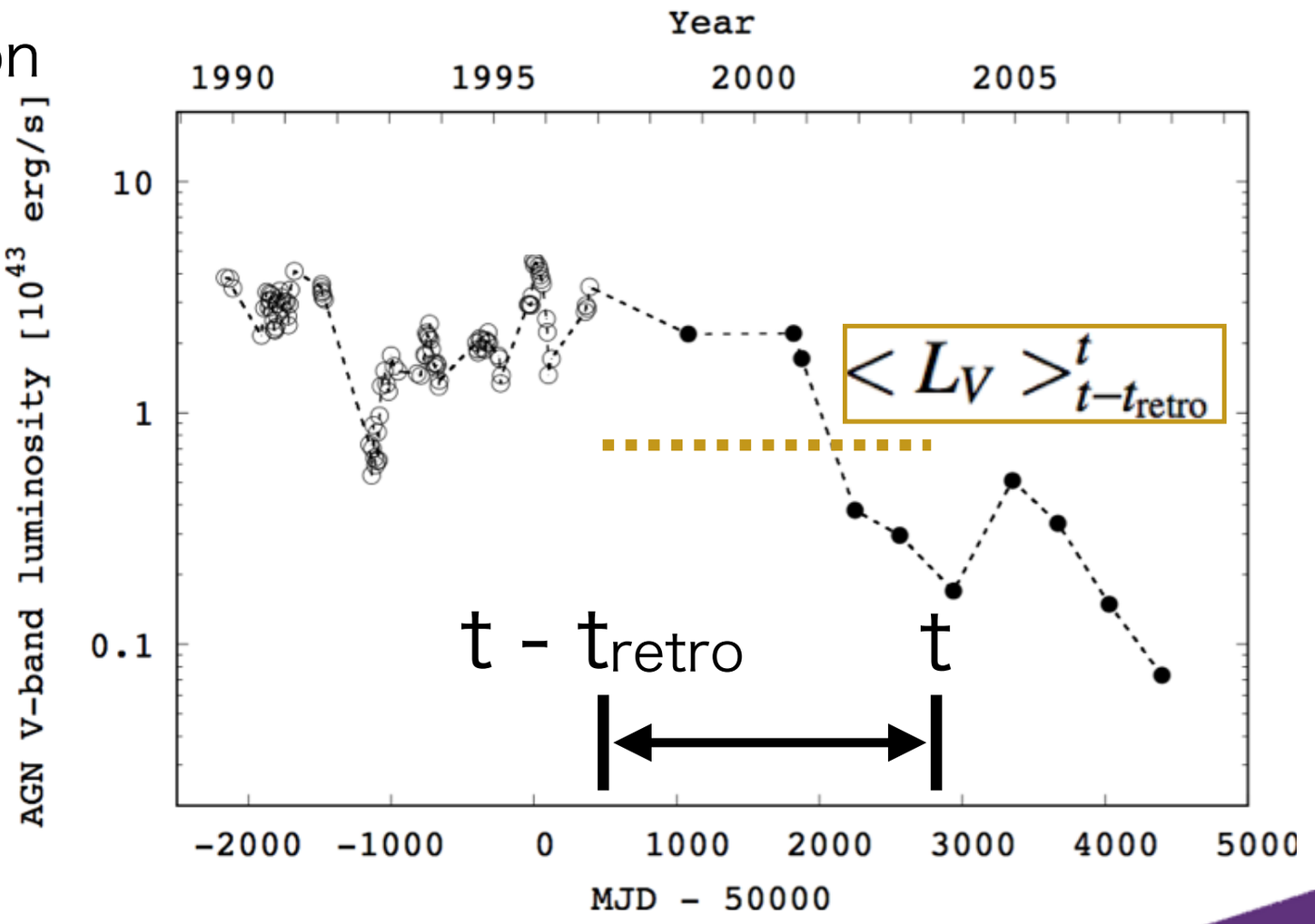
$$\log R_{\rm dust} = -0.89 + 0.5 \log \left(\frac{L_V}{10^{44}\ {\rm erg/s}} \right)$$

"Resto flux" model

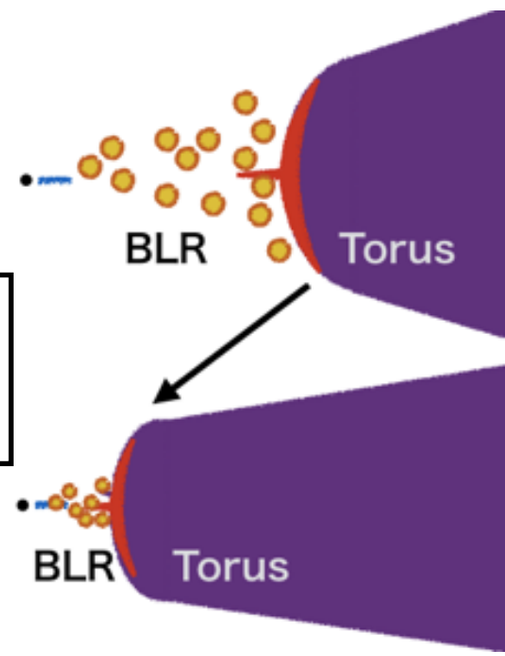
(e.g., Koshida+2009, Kishimoto+2013)

$$\log R_{\rm dust}(t) = -0.89 + 0.5 \log \left(\frac{< L_V >^{t}_{t-t_{\rm retro}}}{10^{44}\ {\rm erg\ s^{-1}}} \right)$$

R_{dust}(t) at a given epoch **t** is set by the average AGN flux ("retro flux") over the past **t_{retro}** years, **from t - t_{retro} to t**



t_{retro} represents time scale of response of **R_{dust} to Lv(t) is**



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Rdust

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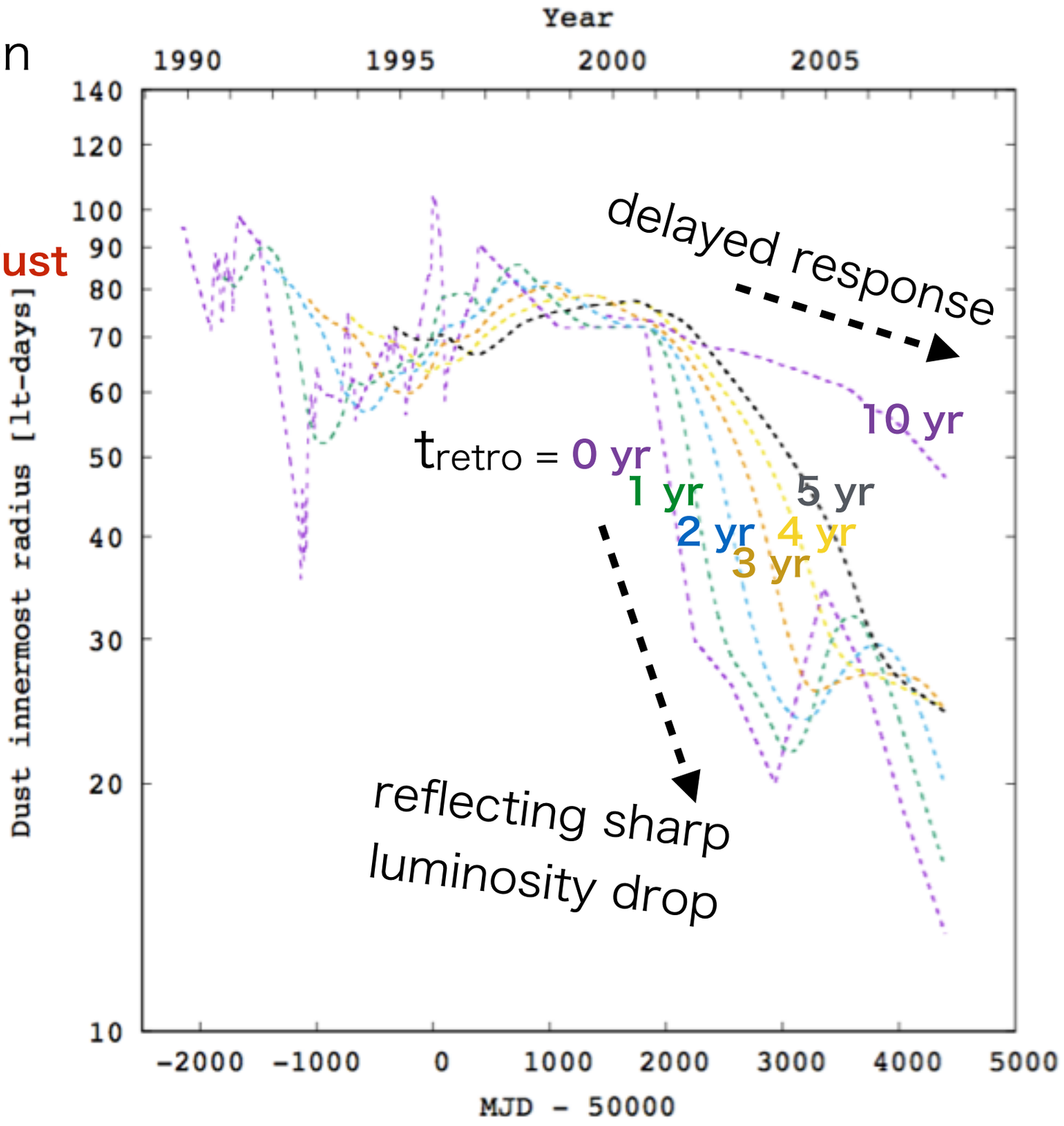

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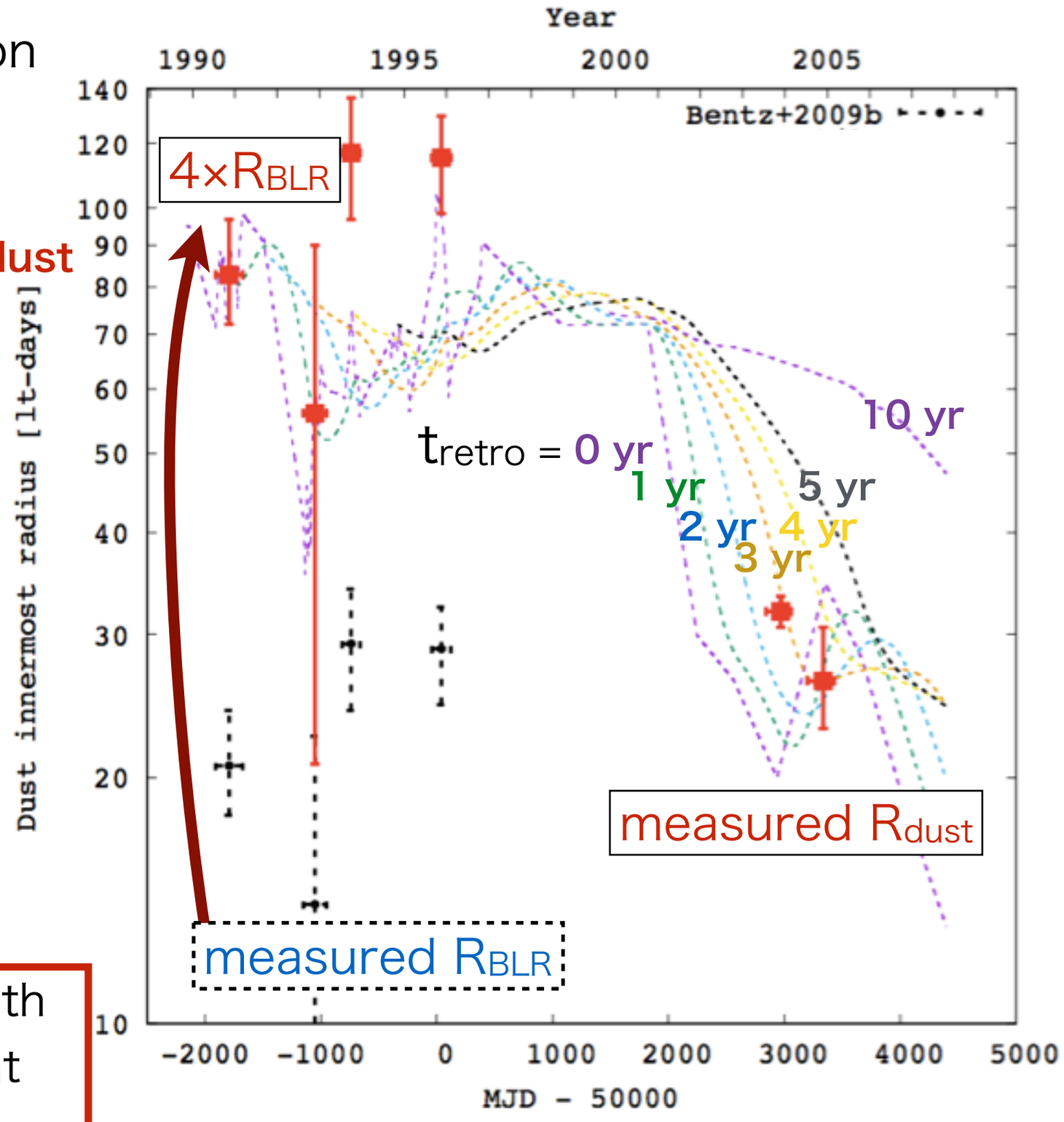
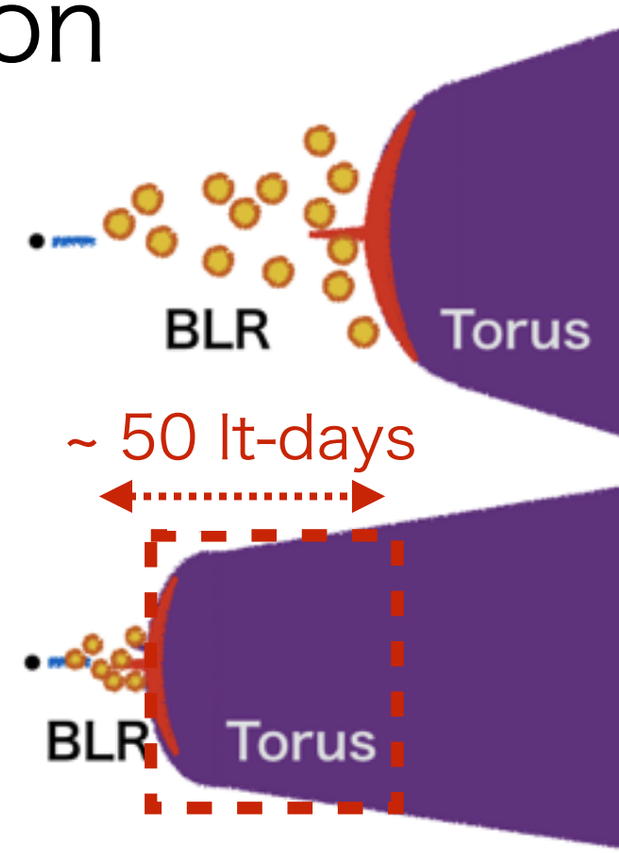
Measured R_{dust} is best described with **2 yr < t_{retro} < 4 yr**, and inconsistent with **t_{retro} > 5 yr**



The rapid reformation time scale of the innermost dust distribution

- The dust replenishment time scale is short: **2 yr < t_{retro} < 4 yr**



- Inflows of dust clouds ? ⋯ impossible
  (too fast, requiring ~50 lt-days/t_{retro} ~10,000 - 20,000 km/s)

- **New dust formation in the BLR gas ⋯ possible**

  - metal line cooling of **BLR gas** (**n ~ 10^{10} cm^{-3}**)
    after the rapid luminosity drop
    —> T_{gas} ~ 10,000 K to 2,000 K on a time scale of **< 20 days**

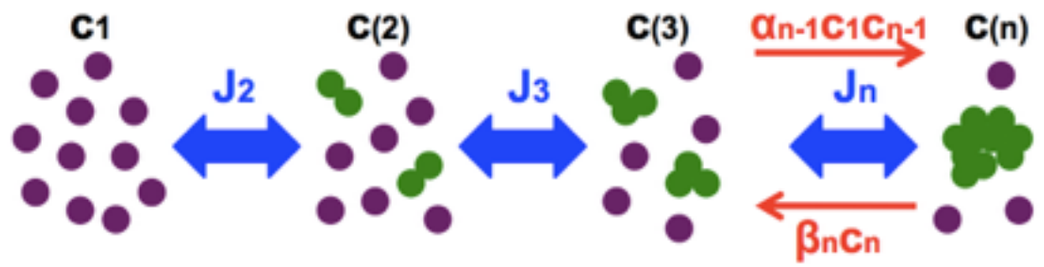
(e.g., Koshida+2009, Ichikawa & Tazaki 2017)

  - Nucleation and subsequent grain growth

graphite C:

$$t_{\rm form} \simeq \frac{4}{3}\pi a^3 \rho_{\rm bulk}\left[4\pi a^2\sqrt{\frac{m_C}{2\pi k_B T}}P_C\right]^{-1},$$

$$\sim 27\ {\rm days}\left(\frac{a}{0.1\ \mu{\rm m}}\right)\left(\frac{T}{1{,}800\ {\rm K}}\right)^{-1/2}\left(\frac{n}{10^{10}\ {\rm cm}^3}\right)^{-1}$$



(T. Nozawa's slide)

Summary & Conclusions

- A **rapid response of the R_{dust}** to the sharp drop in the AGN luminosity between 2001-2002 is required to account for RM results for Mrk 590:

  R_{dust} (faint state in 2000s) **≈ R_{BLR}** (bright state in 1990s)

- The rapid reformation of the innermost dust distribution in Mrk 590 (**2 yr < t_{retro} < 4 yr**) is probably realized by **dust grain formation in radiatively cooled BLR gas clouds** outside of the new dust sublimation surface in the faint phase

  - detailed calculations of dust grain formation process (gas cooling, changes in ionization states, nucleation, …) are needed

(too faint for interferometry?)

backup slide

Receding dust torus in NGC4151

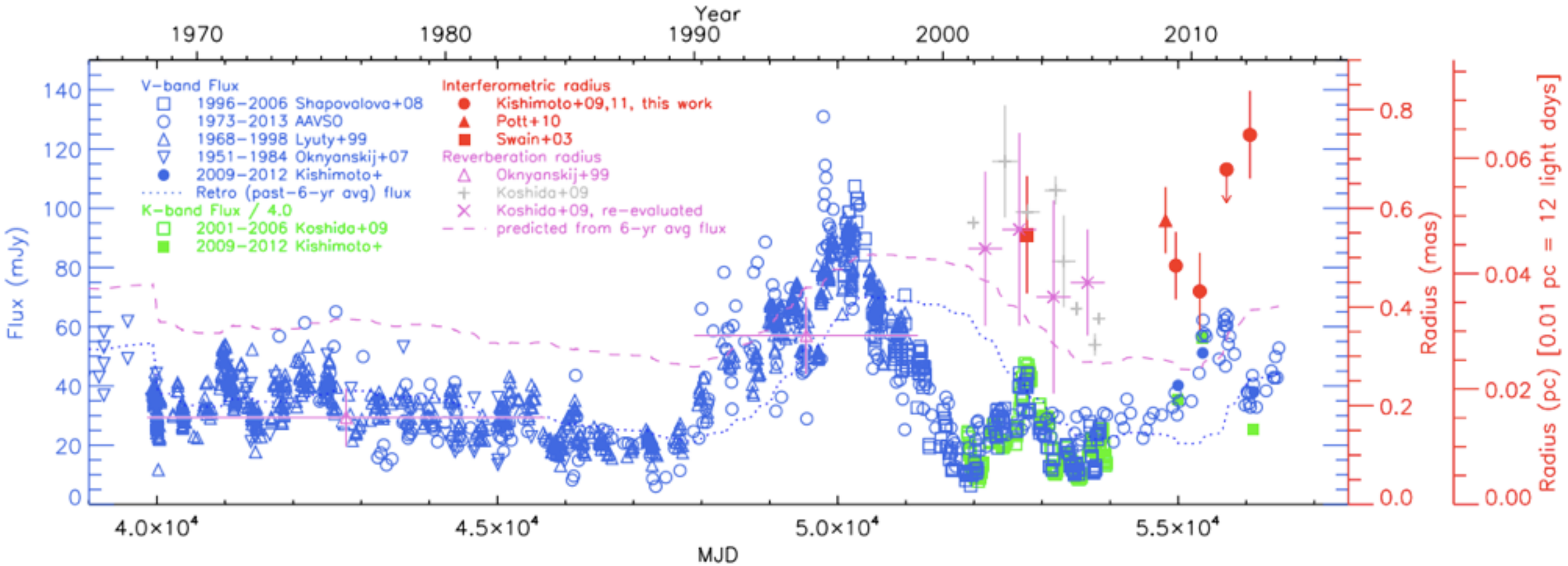


Figure 3. Various measurements of the nuclear flux (scale on left axis) and the inner radius (scales on right axis) for NGC 4151 as a function of time.

t_{retro} ~ 6 yr in NGC4151 (Kishimoto et al. 2013)