AGN Cosmology

— a new perspective for VLTI in the E-ELT and LSST era —

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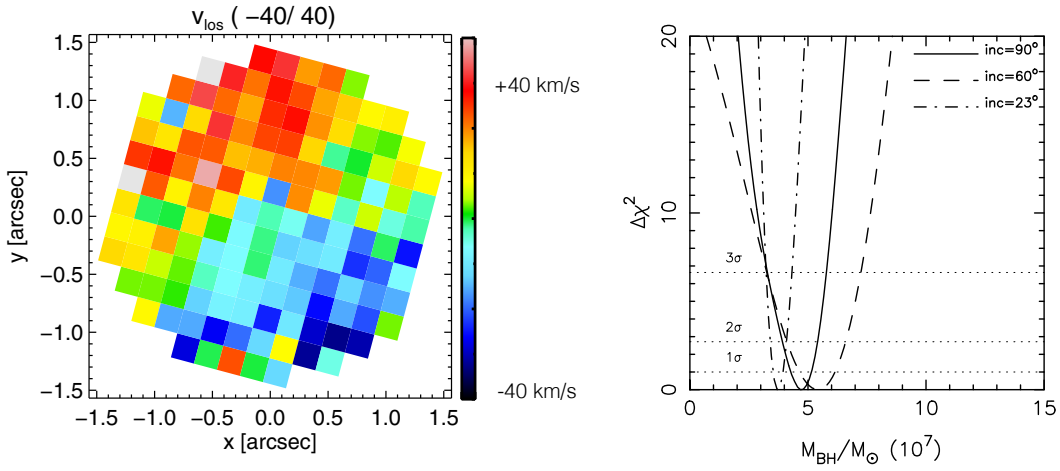
Extragalactic priorities in the 2020s

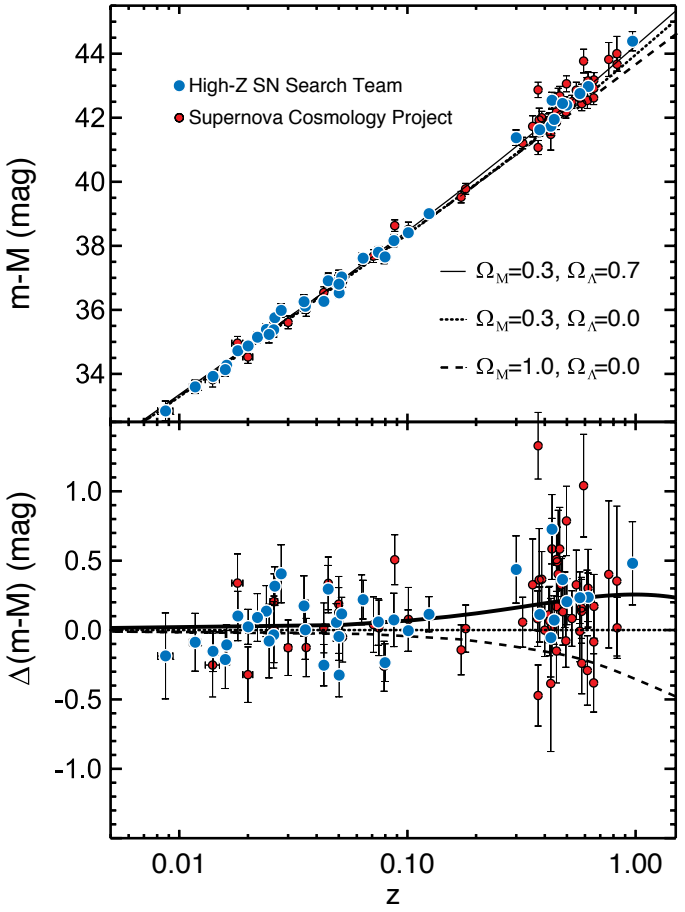
- **Nature of Dark Energy**
  (LSST and E-ELT primary science goals)

- **black holes masses / sphere of influence**
  (E-ELT DRM science case)

- Both cases require **precise distances**
  Hubble diagram; absolute radii



dynamical black hole mass measurement in NGC 4151 (Onken+14)



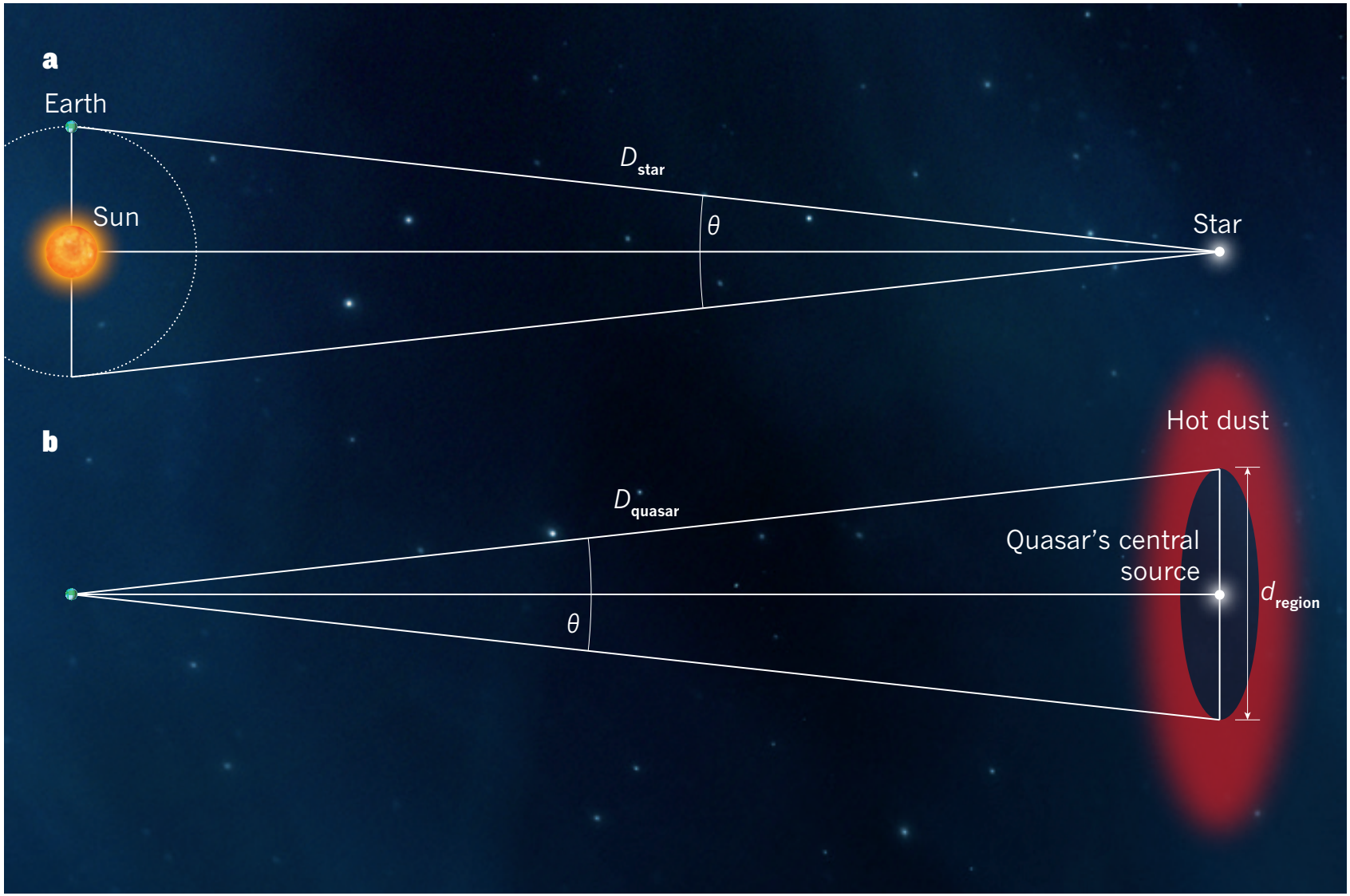
SN Ia Hubble Diagram (Riess+98)

Precise geometric distances to AGN

via “Dust (and Quasar) Parallaxes”

Dust Parallaxes: Idea (1/2)

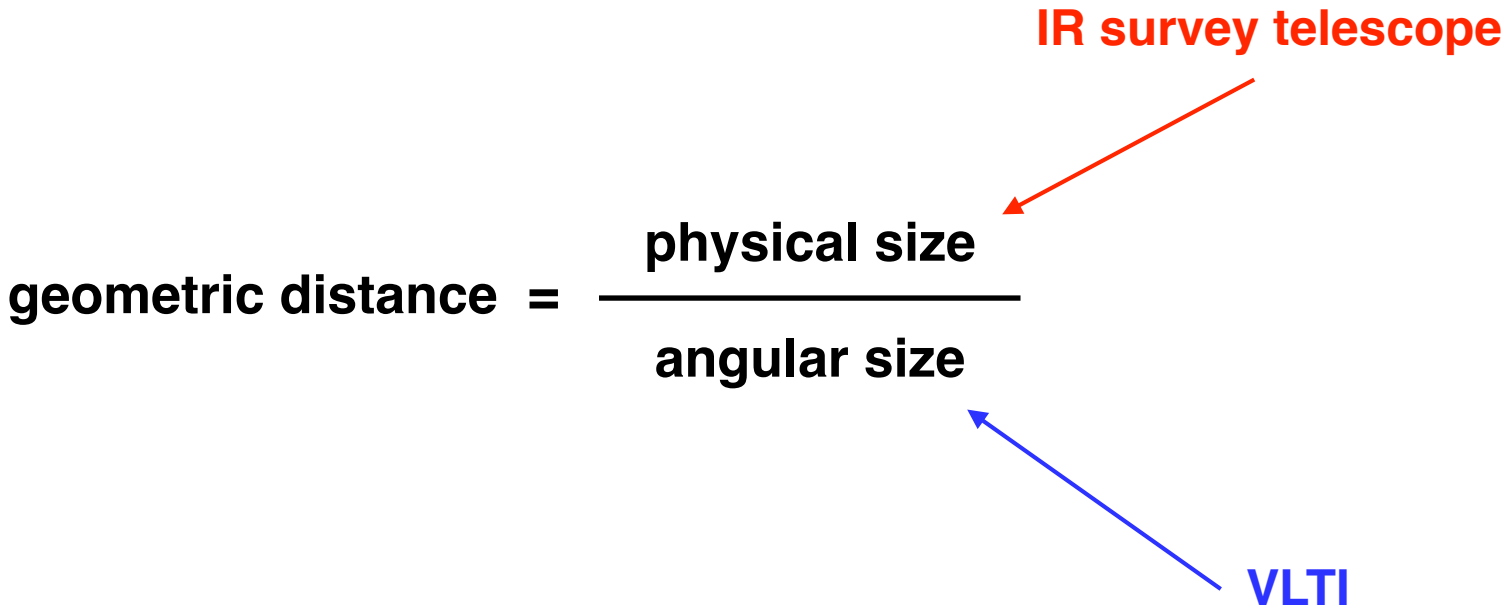
- **Standard Ruler:** Invert the **parallactic triangle**



M. Elvis, Nature News & Views

Dust Parallaxes: Idea (2/2)

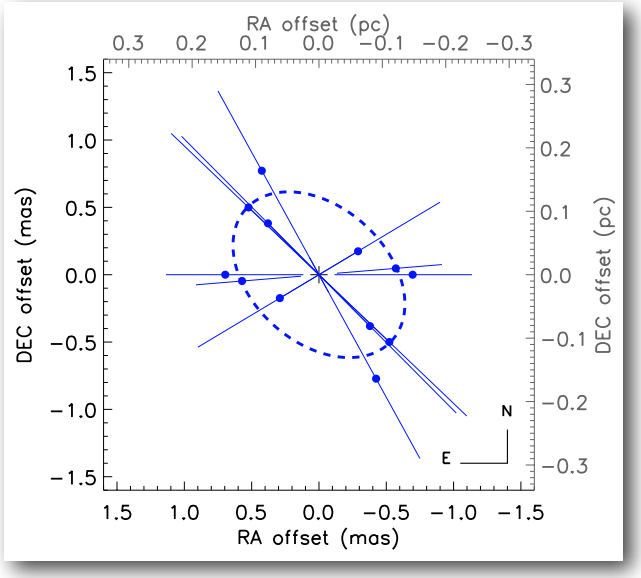
- **Geometric distance:**



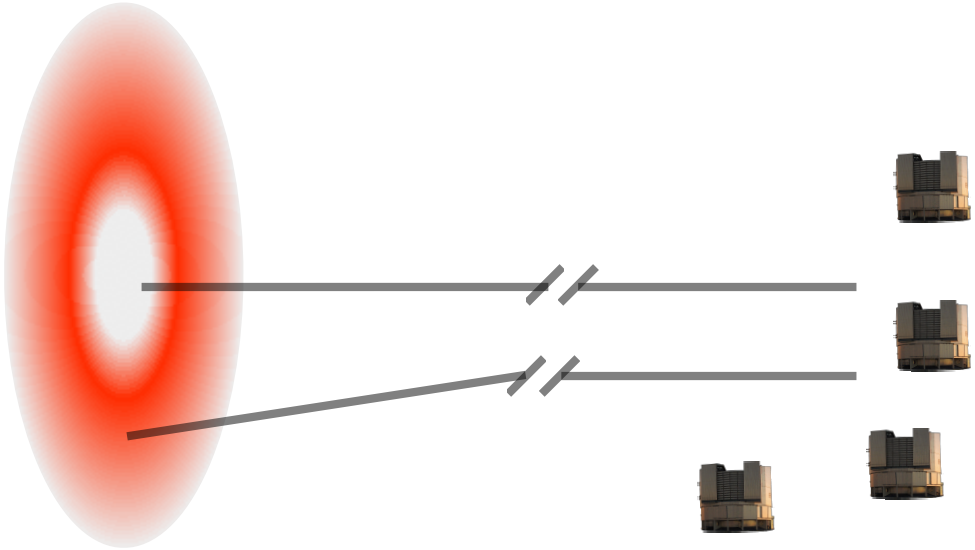
- As reference, one may use:
  - **broad line region** of AGN (Elvis & Karovska 02)
    → difficult for VLTI, but potentially possible (Rakshit+15, Petrov+15)
    → have to work out gas physics (models)
  - the **hot dusty ring** at the inner edge of the torus (Hoenig 2014)
    → successfully shown! (Hoenig+14, *Nature*, 515, 528)

Dust Parallaxes: Angular Size

- (Instrinsic) angular size from **near-IR interferometry**



Weigelt+12, Hoenig+13



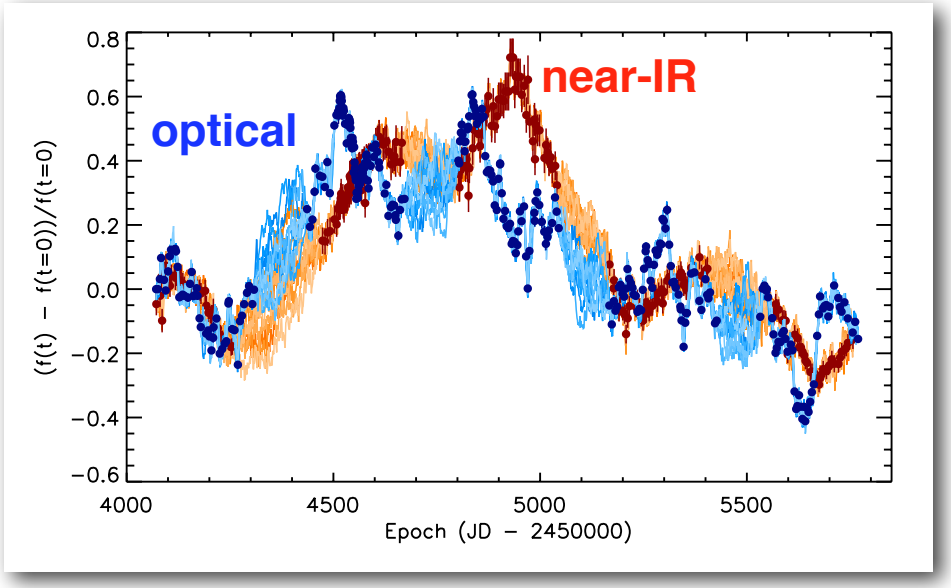
- Important: **De-projection** using geometric constraints from…
  - … well-covered uv-plane
  - … gas dynamics on 10+pc scales → E-ELT, ALMA
  - … (spectro-)polarimety → E-ELT
  - … radio jet

- Dust distribution from **multi-band interferometry**… or **see next slide**

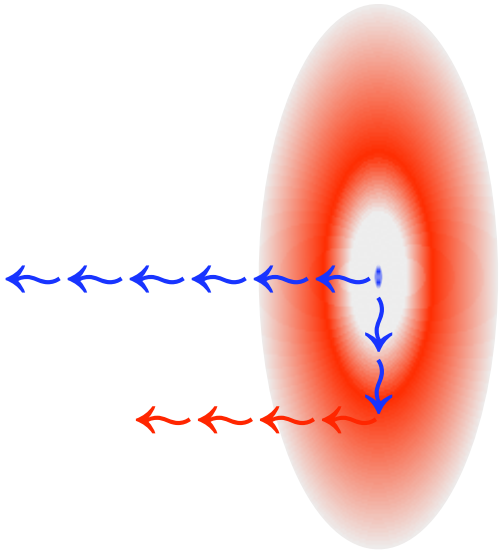
Dust Parallaxes: Physical Size

- (Instrinsic) physical size from **optical/near-IR photometric monitoring**

- Idea: dust reprocesses UV-optical emission → **optical-IR time-lag = physical size**



P. Lira, priv. comm.



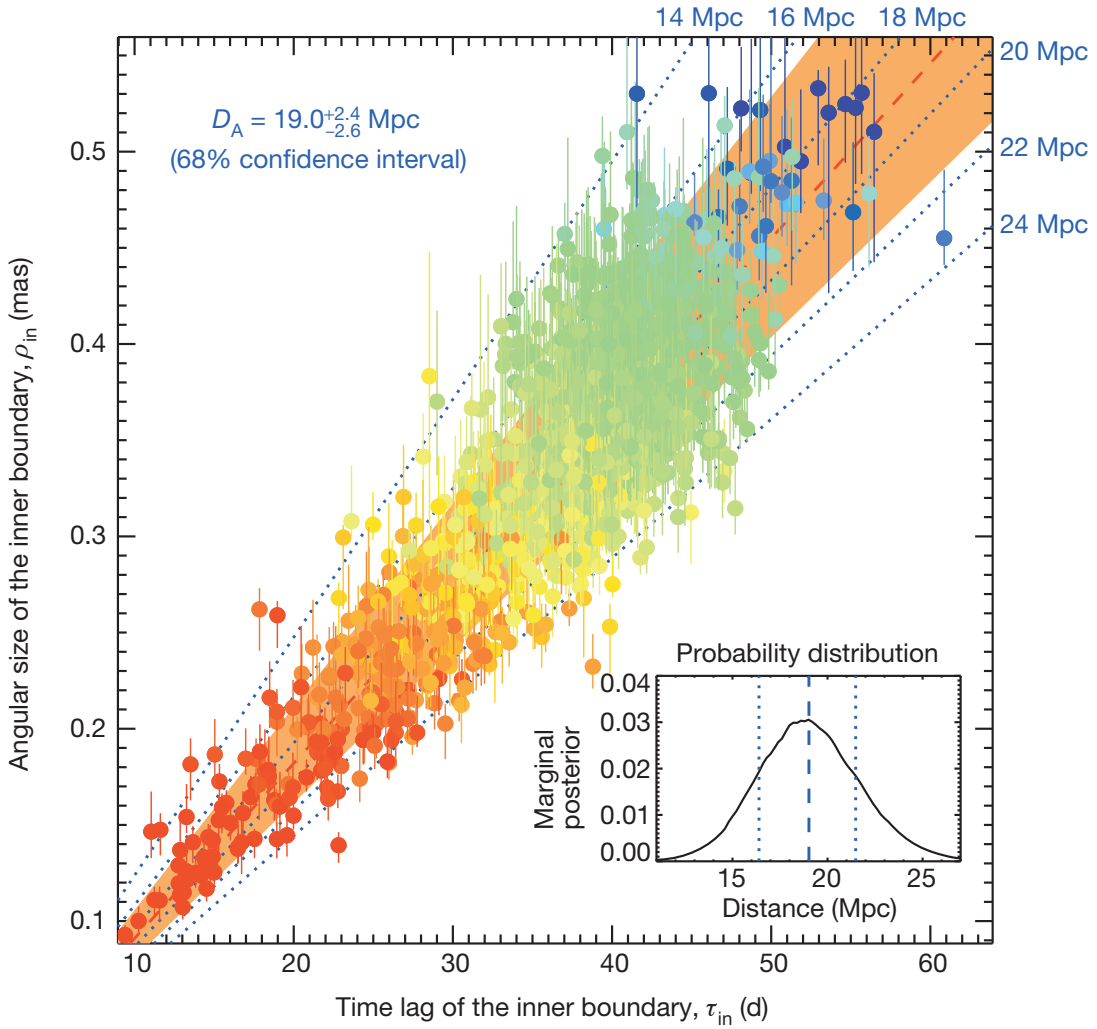
- Dust distribution from **near-IR transfer function**

  → in principle also useable for **inclination** (high cadence, photometric quality)

- NB: In favour of a **near-IR photometric survey telescope**

Dust Parallaxes: Precision

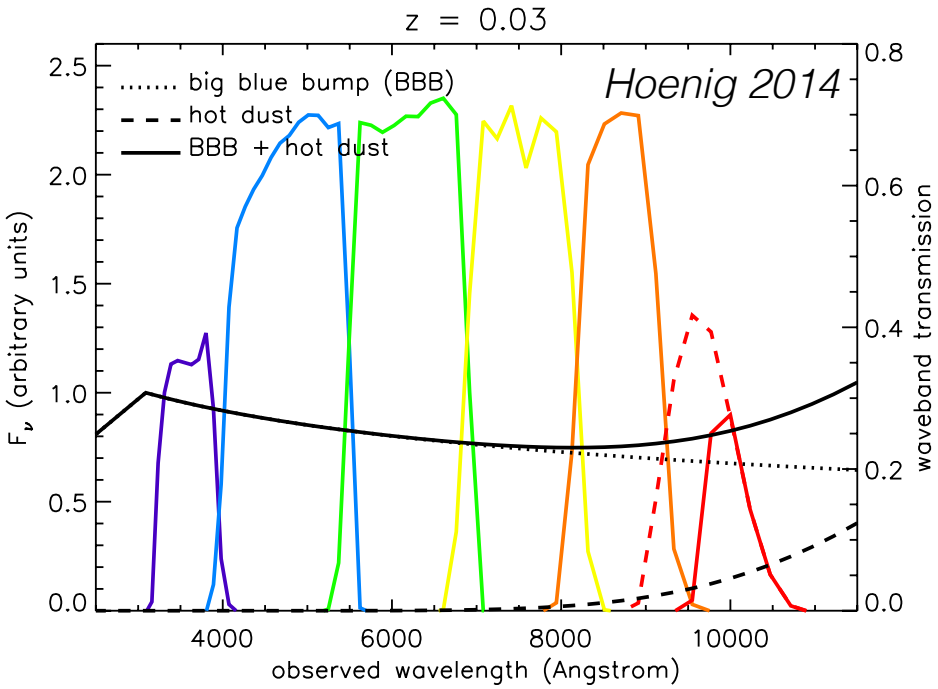
- How well can we do?



- NGC 4151 non-optimised data: **12-13% including all systematics!!!**
- better uv-coverage and photometric monitoring: **<10%**
- **combining constraints** from multiple objects: 3% (11 AGN); 1.5% (44 AGN)

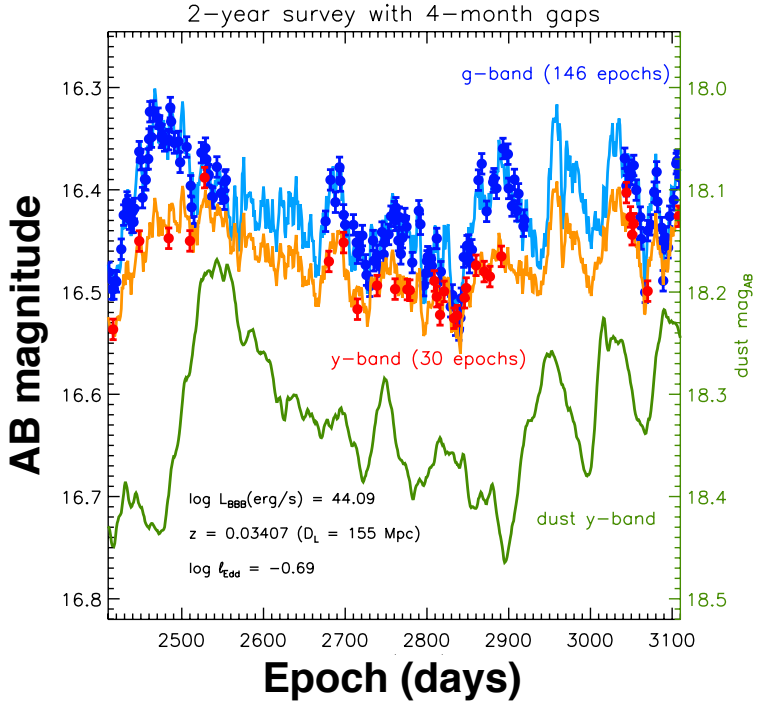
Dust and candles (1/2)

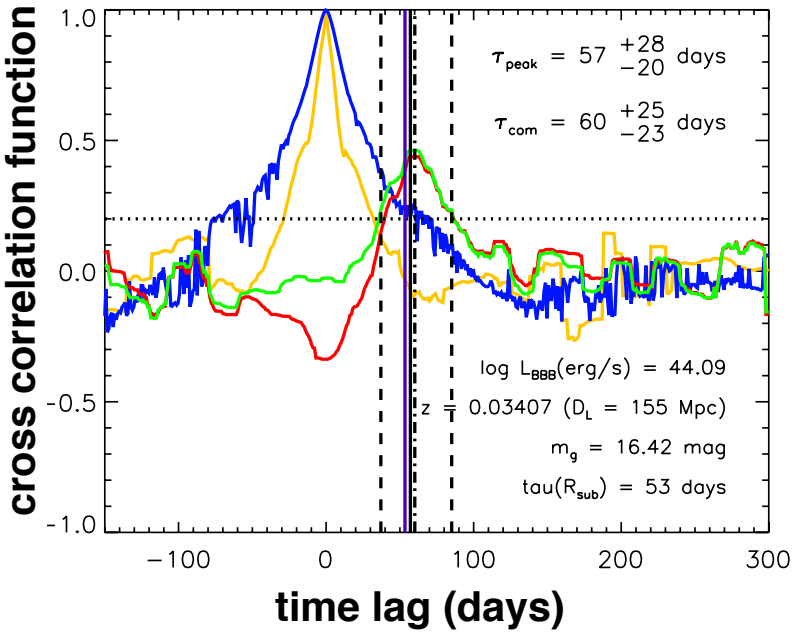
- How to connect to **LSST?**



Relative Contributions of Hot Dust to Wavebands at Different Redshifts

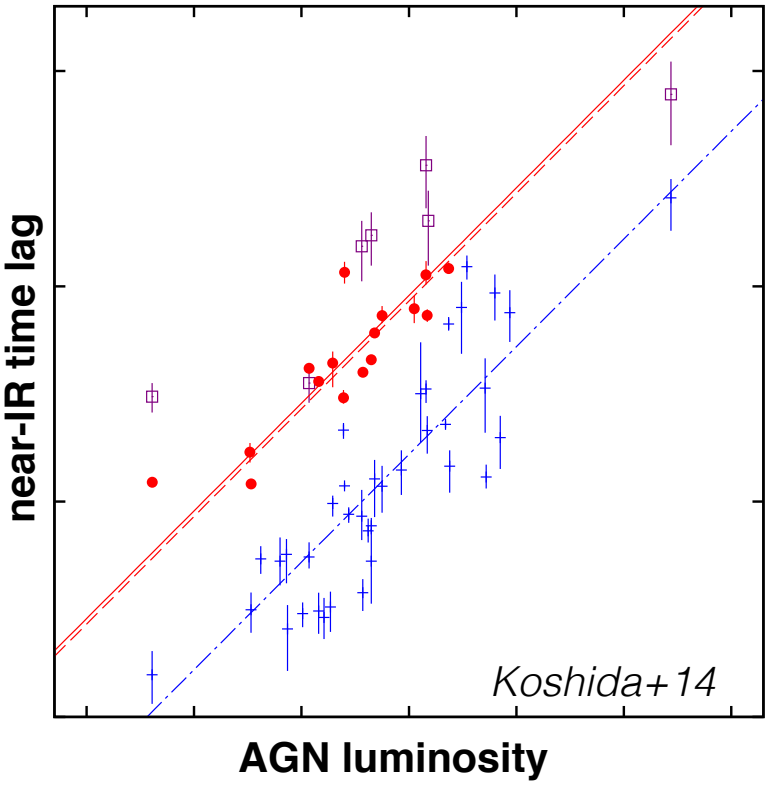
Redshift	$z = 0$	$z = 0.05$	$z = 0.1$	$z = 0.2$	$z = 0.3$
i band	0.019	0.012	0.007	0.003	...
z band	0.073	0.052	0.031	0.014	0.004
y band (*y*3)	0.206	0.158	0.109	0.053	0.020
y band (*y*4)	0.168	0.126	0.085	0.041	0.015

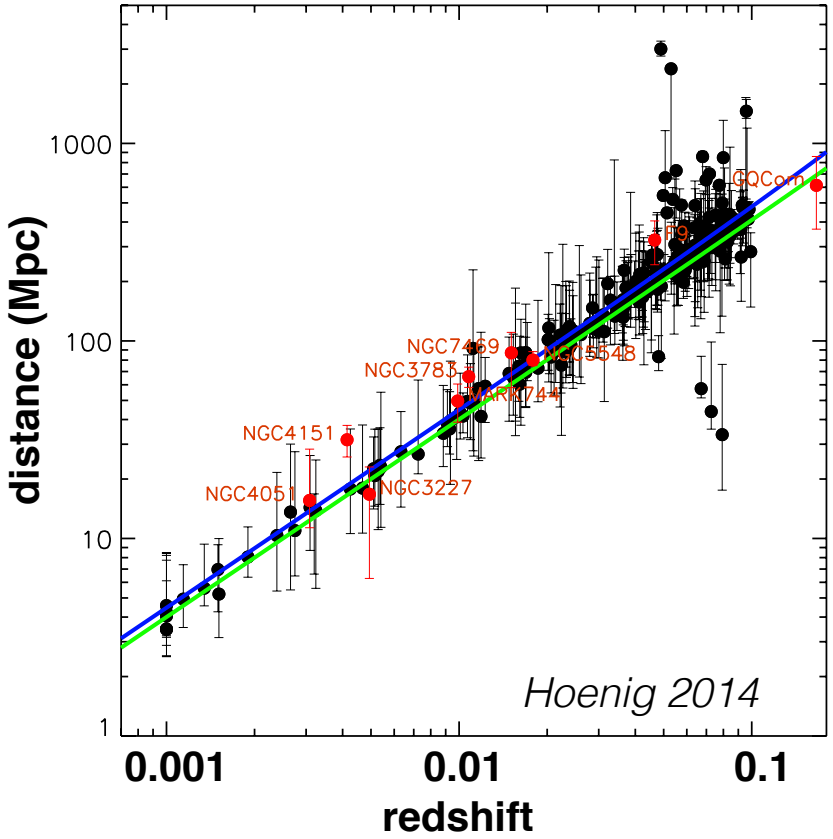




Dust and candles (2/2)

- Dust is also **standard candle**!!! (e.g. Oknyanskij & Horne 01; Yoshi+04,14)



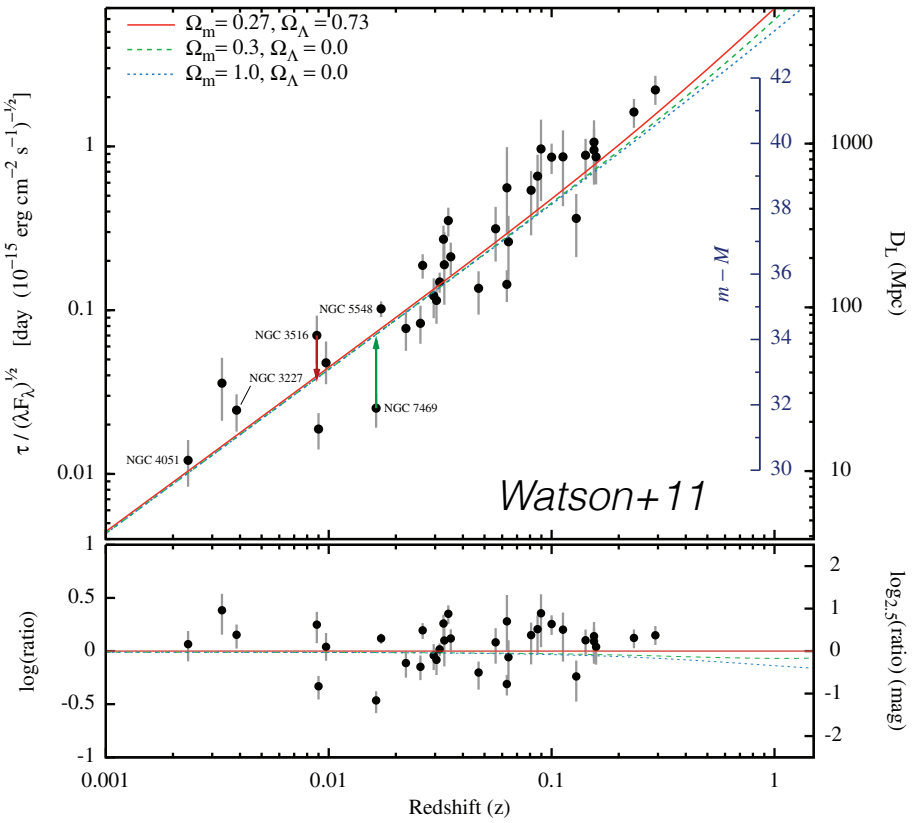


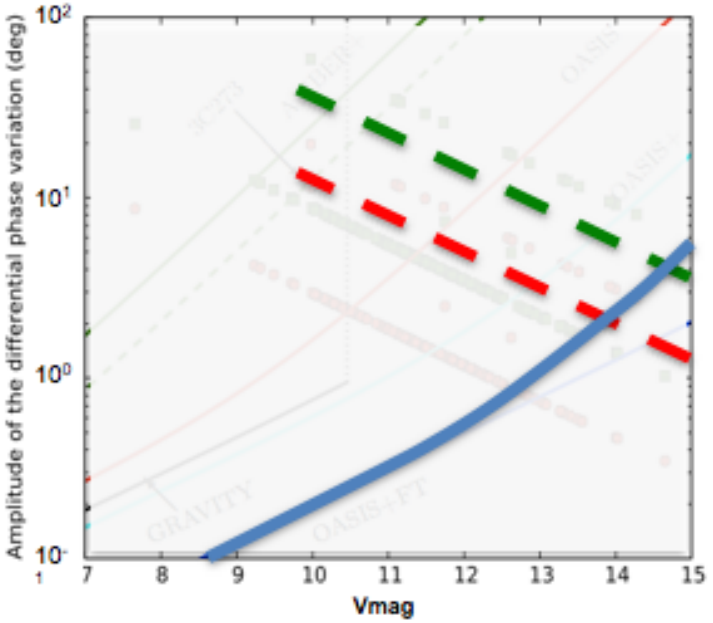
- With **LSST**: $10^{3\text{-}5}$ suitable AGN to z<0.2

- **AGN = Standard candle + standard ruler**

The broad-line region

- Similar combination **possible for BLR**!!! (Elvis & Karovska 01; Watson+11; Haas+11)





Courtesy of Romain Petrov (OCA)

- Again: the **BLR monitoring by LSST** (Chellouche+14)

- alternatively: **spectroscopic survey telescope**

Summary: AGN Cosmology

- VLTI can be used to measure …

  accurate geometric distances to extragalactic objects from 10 Mpc to ~1000 Mpc

- **Useful for:** → **high-precision H_0** in the local universe
  → testing **"universality" of cosmological parameters**
  → establishment of AGN as **independent branch of distance ladder**
  → precise **dynamical black hole mass** measurements
  → constrain peculiar velocities

- Complementary approach to BAO

- Direct connection to **LSST** (dust reverberation mapping), **E-ELT** (black hole masses)

- **Wishlist: (1) sensitivity, (2) simple IR imaging instrument, (3) near-IR survey**
  → not necessarily longer baselines
  → well-performing Fringe Tracker inevitable

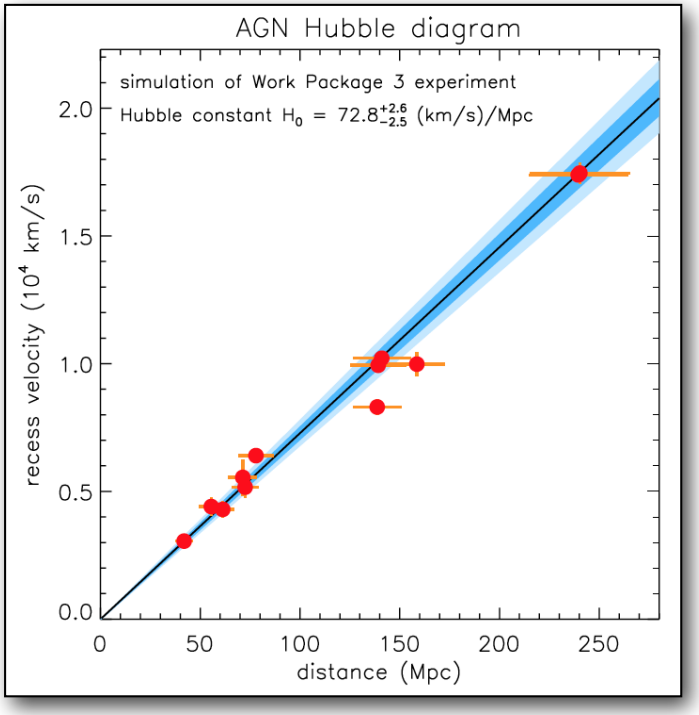
- **(4) add optical** and spectral resolution
  → **VLTI a one-stop shop** of cosmology and BH masses

Summary: AGN Cosmology

"This opens up the prospect of extending AGN size and distance measurements out to the earliest cosmic times, and thus of **measuring cosmological properties at distances far beyond where supernovae can take us.** […]

[W]e may now have to consider whether **some of our resources** should soon be put into **building a next generation of optical interferometers.**"

— Martin Elvis, Harvard CfA, Nature News & Views, 2014



Dust parallax Hubble diagram 2015-2020 based on 1st gen. instruments