Korea Astronomy and Space Science Institute

Cosmological QUOKKAS

Jeffrey A. Hodgson
Korean Research Fellow, KASI
with Benjamin L'Huillier (KASI), Sang-Sung Lee (KASI), Ioannis Liodakis (Stanford), Arman Shafieloo (KASI)

NRF National Research Foundation of Korea
KRF KOREA RESEARCH FELLOWSHIP 해외 우수신진연구자 유치사업
SAMSUNG Samsung Science & Technology Foundation

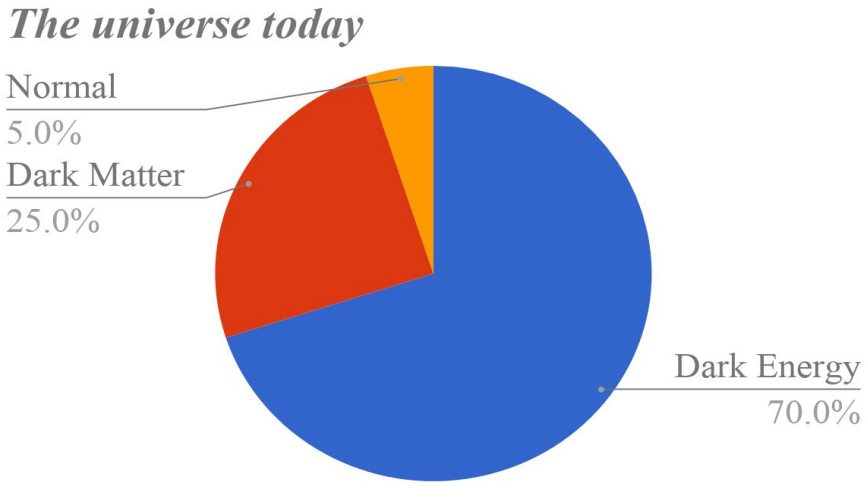
Introduction

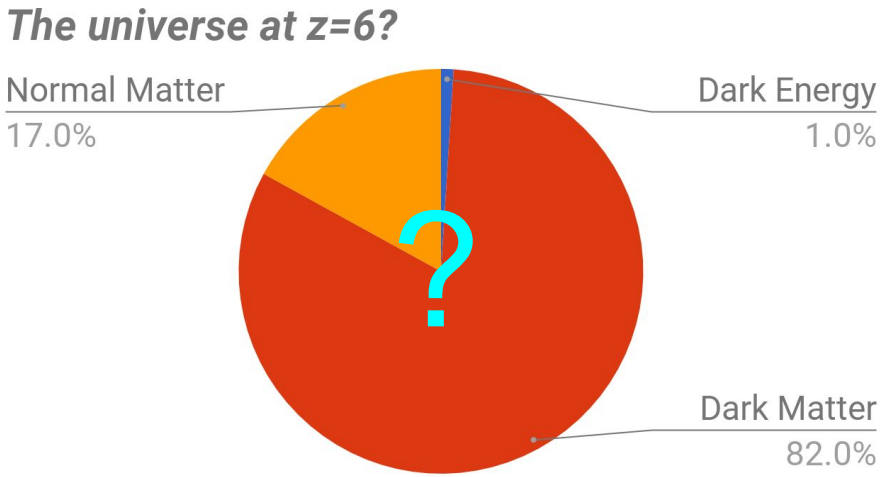
- Introduce the CosQUOKKA(S) project
- Describe our methods
- Preliminary results
- Introduce the QUOKKA array...

Key questions

- **We don't know what ~95% of the Universe is**
- What is the nature of Dark Energy?
- Was there **really** so little Dark Energy in the early universe?
- Does Dark Energy evolve with time?
  - Hints but unproven (Zhao+ 2017, Nature)
  - Deviations at high-z? (Risaliti+ 2018, Nature)

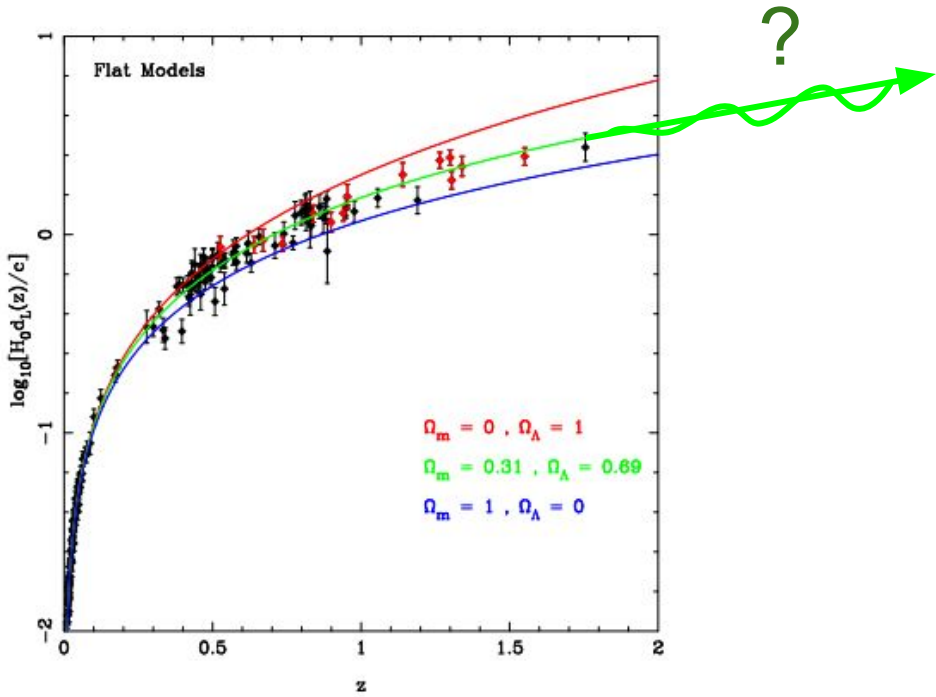
Any variations from the concordance cosmology would be expected to be seen at high-z





Current cutting-edge

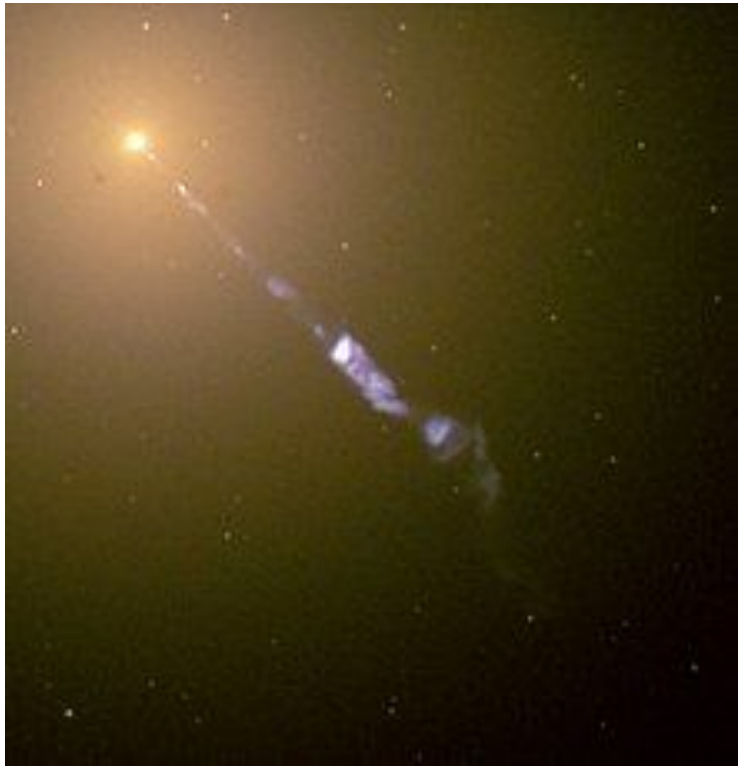
- Type Ia Supernovae (SN Ia)
  - Very bright “standard explosion”
  - Dark Energy discovery (Nobel 2011)
  - Distances up to z~2
- Baryonic Acoustic Oscillations
  - Imprint of early universe physics on large scale galaxy distribution
  - Distances up to z~2.5
- Cosmic Microwave Background
  - Fit cosmological model parameters to the observed CMB power spectrum
  - Model dependent
- **Does the distance-z trend continue as expected past z~2?**



Roy Choudhury & Padmanabhan 2008

Active Galactic Nuclei as standard candles

- AGN are supermassive black-holes (SMBH) at the center of massive galaxies producing jets that move at near the speed of light
- When jet is pointing at us: quasars and blazars
- Most continuously bright objects in the Universe
- Long desired as a standard candle
  - Reverberation mapping
    - Accurate, but difficult and need BH mass
  - Size scales (Gurvits+ 1995)
    - Complicated, has other dependencies
  - Parsec scale structures
    - Not possible (Wilkinson+ 1998)
- Many have proposed, none succeeded
- **Need better methods**



M87 jet, Image: NASA

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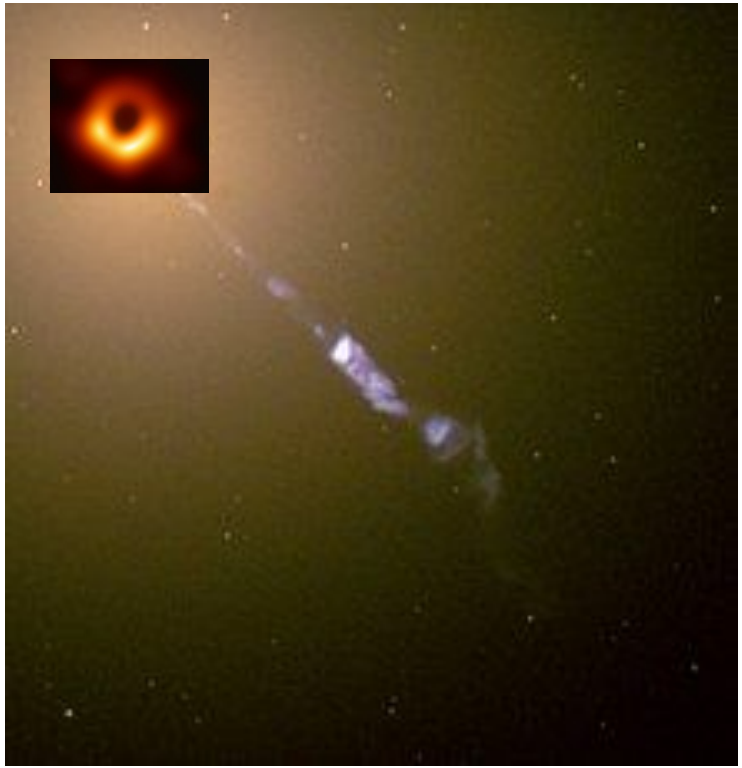

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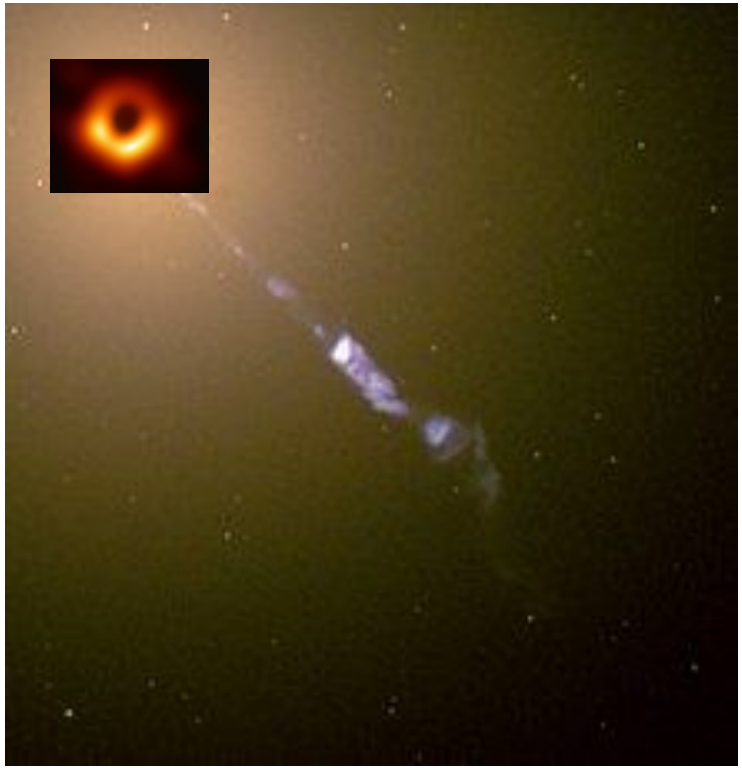
- **Anyone want to know how to make the BH image?**



M87 jet, Image: NASA

Active Galactic Nuclei as standard candles

- New paper out in Nature Astron. a few months ago
- Use UV/X-ray luminosity relationship:
  - $\log(L_X)=\gamma\log(L_{UV})+\beta$
  - But beta parameter needs to be fit with the Type 1as
- Claim a 4-sigma deviation from LCDM at high-z
- They interpret the deviation as due to dynamical Dark Energy
- Is it real? Maybe we can find out...

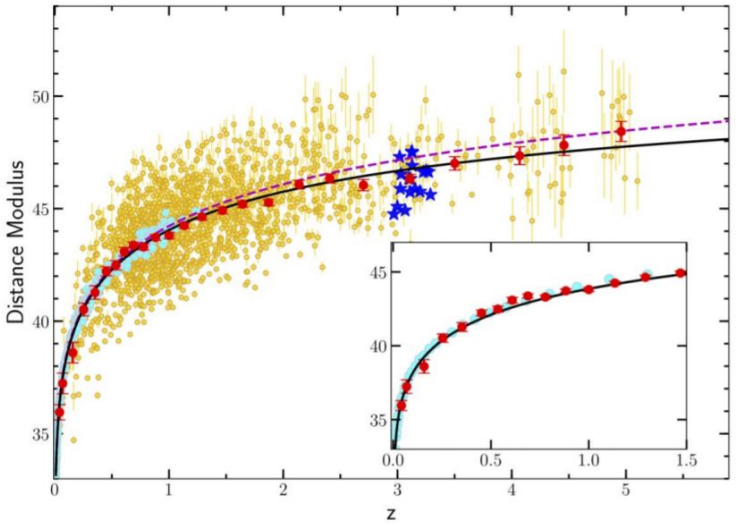


Figure 2: Hubble diagram of supernovae from the JLA survey[2] (cyan points) and quasars (yellow points). Red points represent the mean (and uncertainties on the mean) of the distance modulus in narrow redshift bins for quasars only. These averages are shown just for visualization and, as such, are not considered in the statistical analysis. The new sample of $z>3$ quasars with dedicated XMM-*Newton* observation is shown with blue stars. The inset is a zoom of quasar and supernovae averages in the common redshift range. The dashed magenta line shows a flat ΛCDM model with $\Omega_M=0.31\pm0.05$ fitting the $z<1.4$ data and extrapolated to higher redshifts. The black solid line is the best MCMC fit of the third order expansion of $\log(1+z)$.

Risaliti et. al. 2018

Introducing Cosmological QUOKKAS

- Stands for:

- **Cosmological Quasar Observations on the KVN from Korea to Australia (and Spain)**

- Project that aims to measure distances to the active nuclei of quasars and blazars
- How do we do it?
- Use the variability of AGN to our advantage

How are we doing it?

Causality limited “variability size” $\Theta_{var} \sim c\tau$

Compare against the size directly measured by VLBI Θ_{VLBI}

$$D_L = \frac{c\tau\delta(1+z)}{\theta_{\mathrm{VLBI}}}[\mathrm{Mpc}].$$

Luminosity distance can be found when the Doppler factor is known!

θ - VLBI size [mas]

τ - Variability timescale [dy]

Measuring distances to AGN using archival data

- Arguably better than SNIa*
  - We can constrain Hubble constant *and* Omega_m
  - In principle, can go from very nearby to very far away inc inside the galaxy
- Testing our methods on archival BU 7mm VLBA data
- Methods are “geometric”: so long as we can detect the source, we can (in principle) get the distance
- Case study in 3C 84
- **Very** preliminary results…

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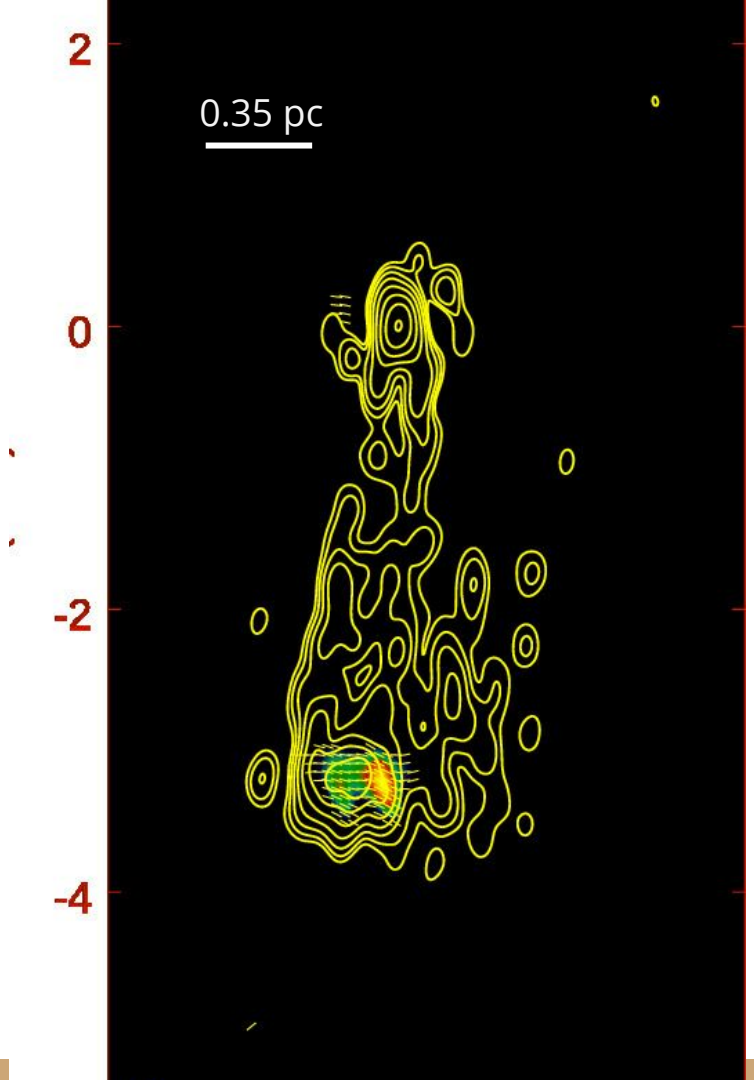
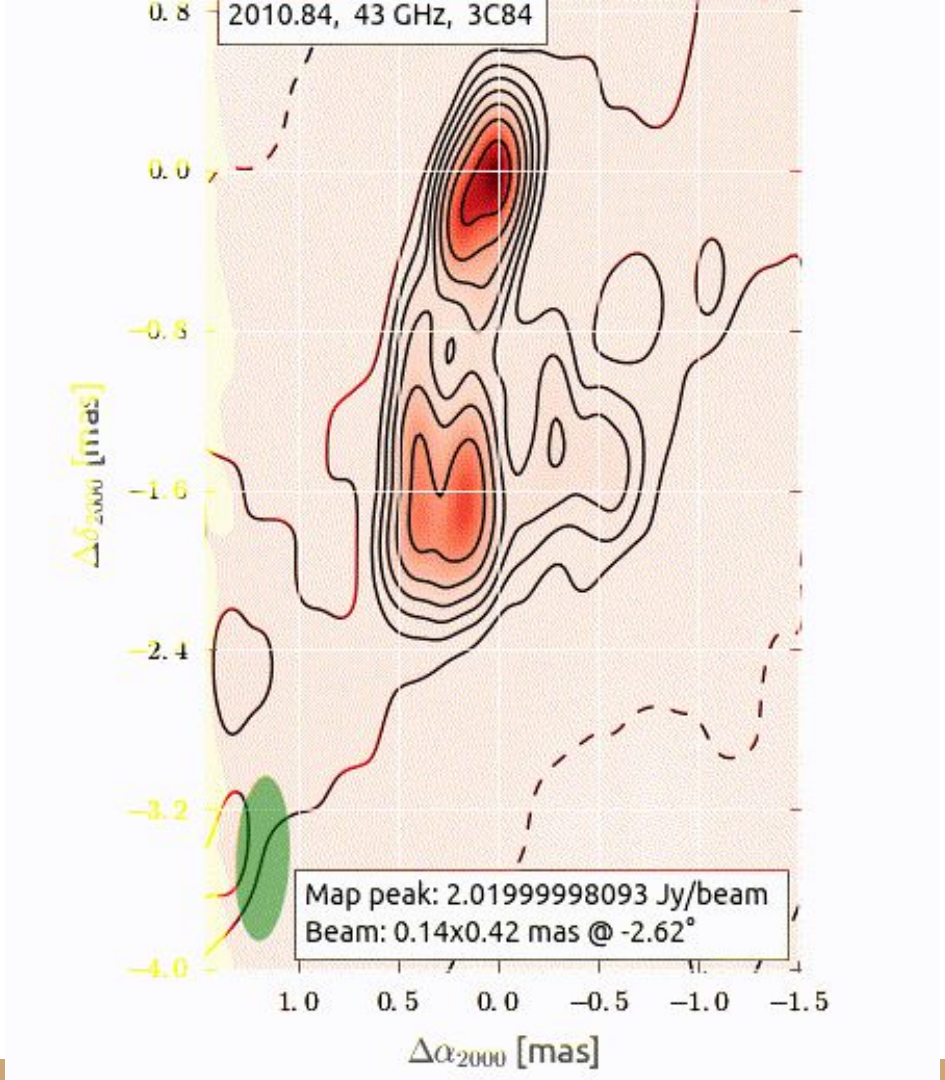
- Case study in 3C 84
- **Very** preliminary results…
- *Disclaimer: Type Ias are awesome

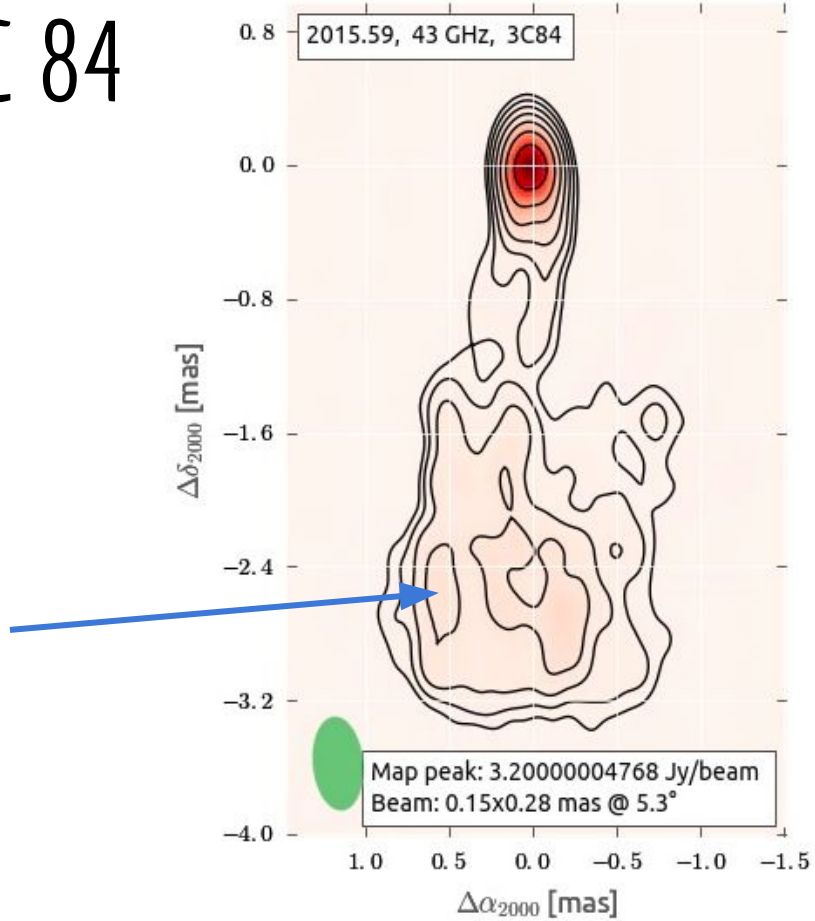
Distance to 3C 84

- z=0.0178
- Often compared with M87
- 3C84: Doppler ~1 is justified
- Big flare with clearly resolved components
- LCDM DL (H0=70,Om=0.3) = 78 Mpc
- SN Ia 64 +/- 6 Mpc (Lennarz et. al. 2012)




2010.84, 43 GHz, 3C84
Map peak: 2.01999998093 Jy/beam
Beam: 0.14x0.42 mas @ -2.62°
0.8
0.0
−0.8
−1.6
−2.4
−3.2
−4.0
1.0
0.5
0.0
−0.5
−1.0
−1.5
$\Delta\alpha_{2000}$ [mas]
$\Delta\delta_{2000}$ [mas]

A flare in 3C 84



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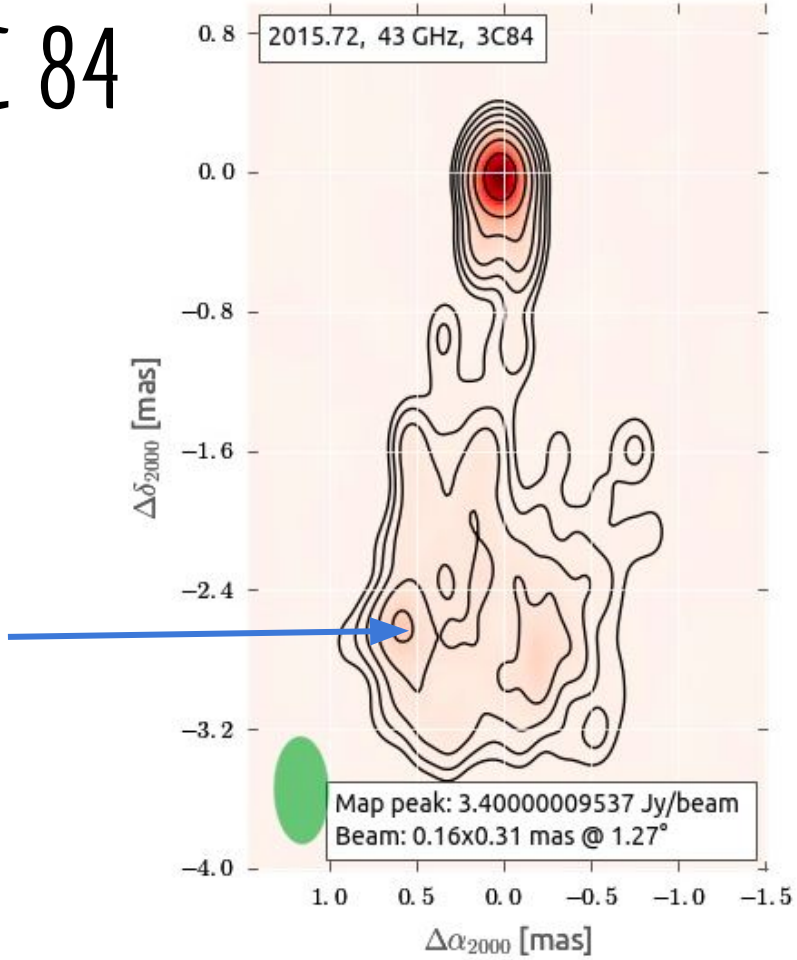

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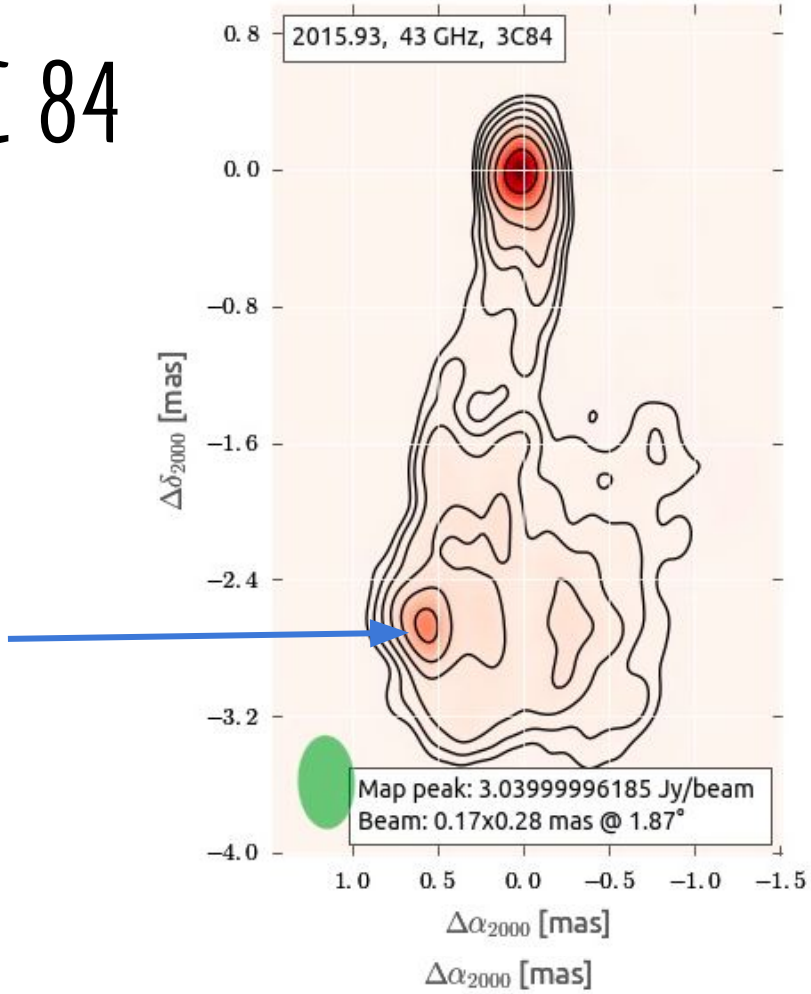

$\Delta\alpha_{2000}$ [mas]

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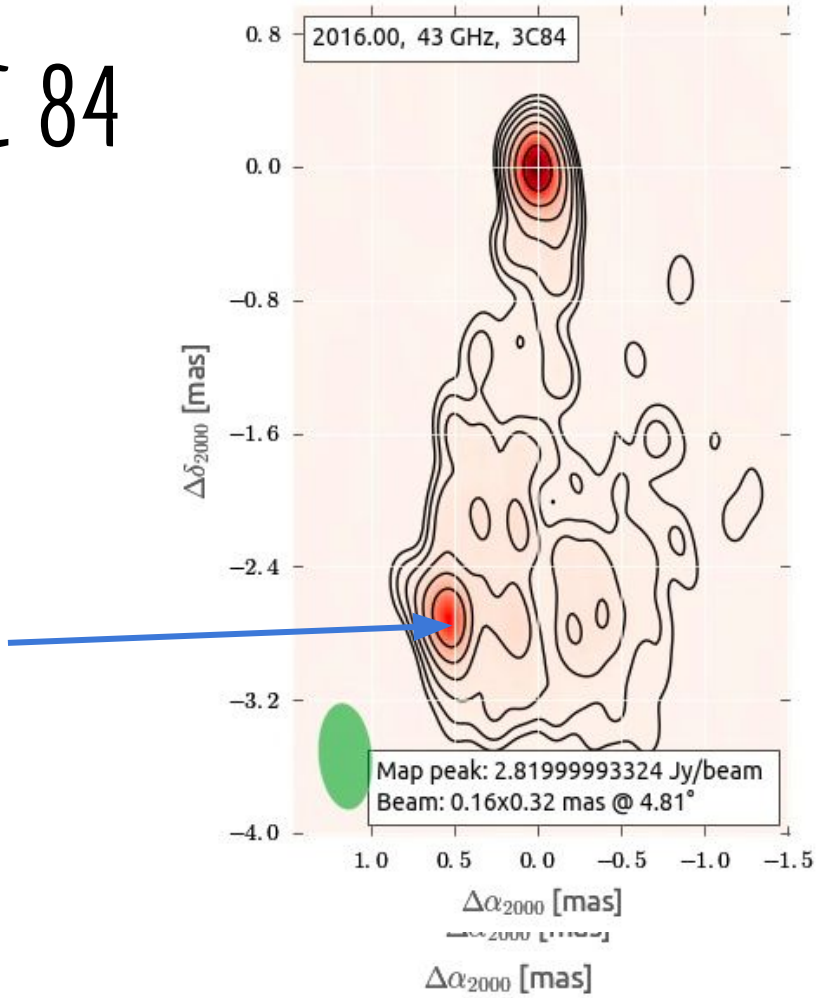

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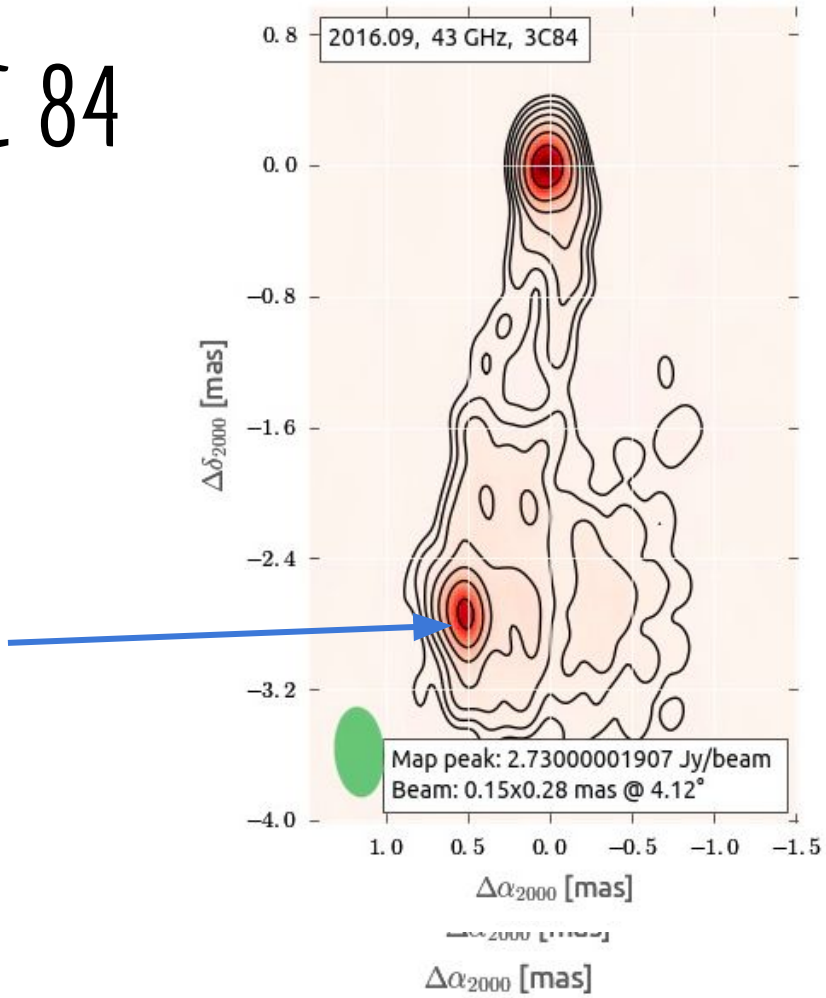

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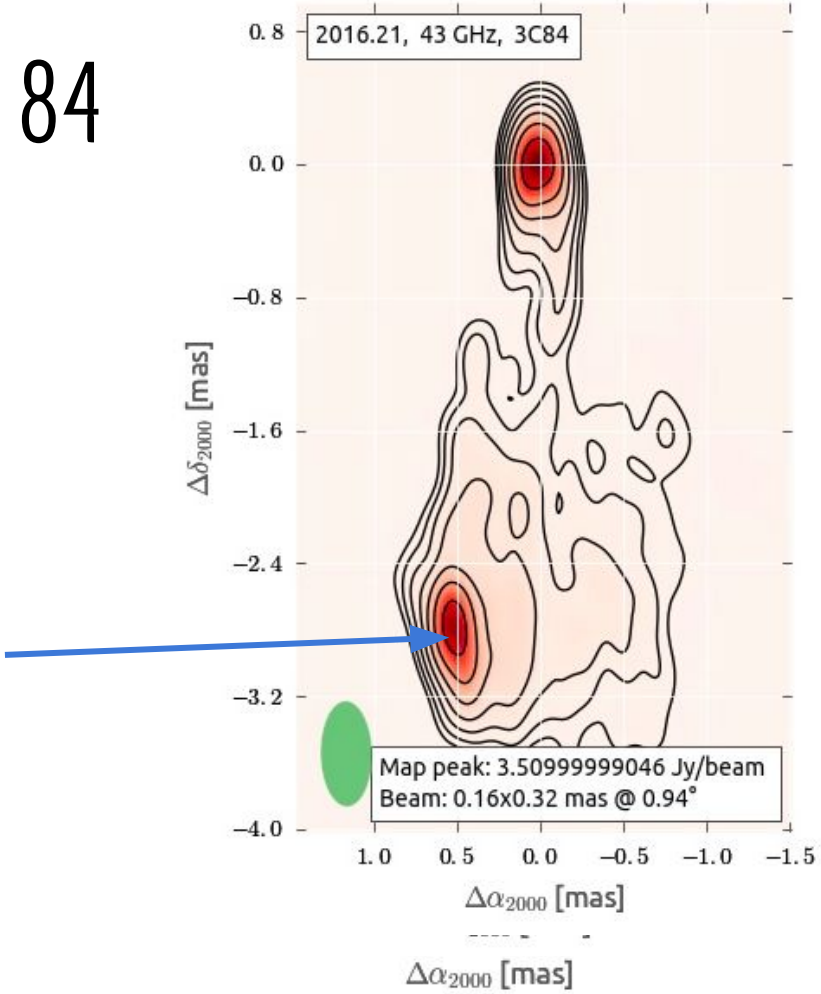

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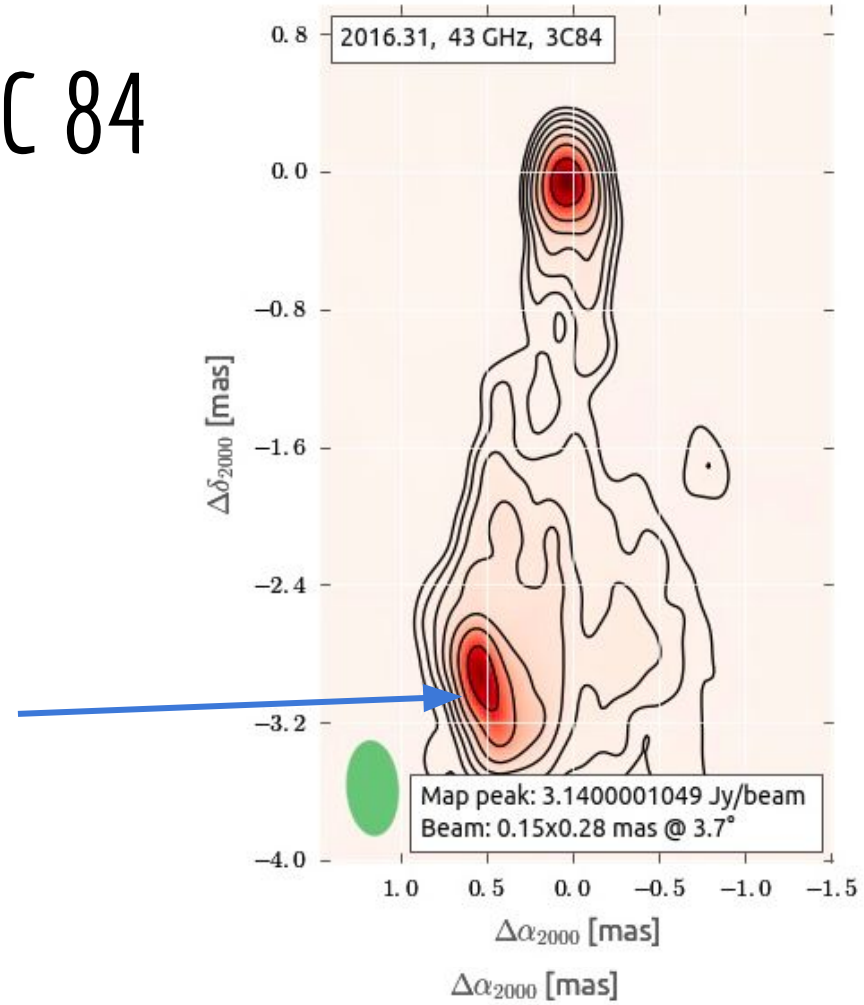

$\Delta\alpha_{2000}$ [mas]

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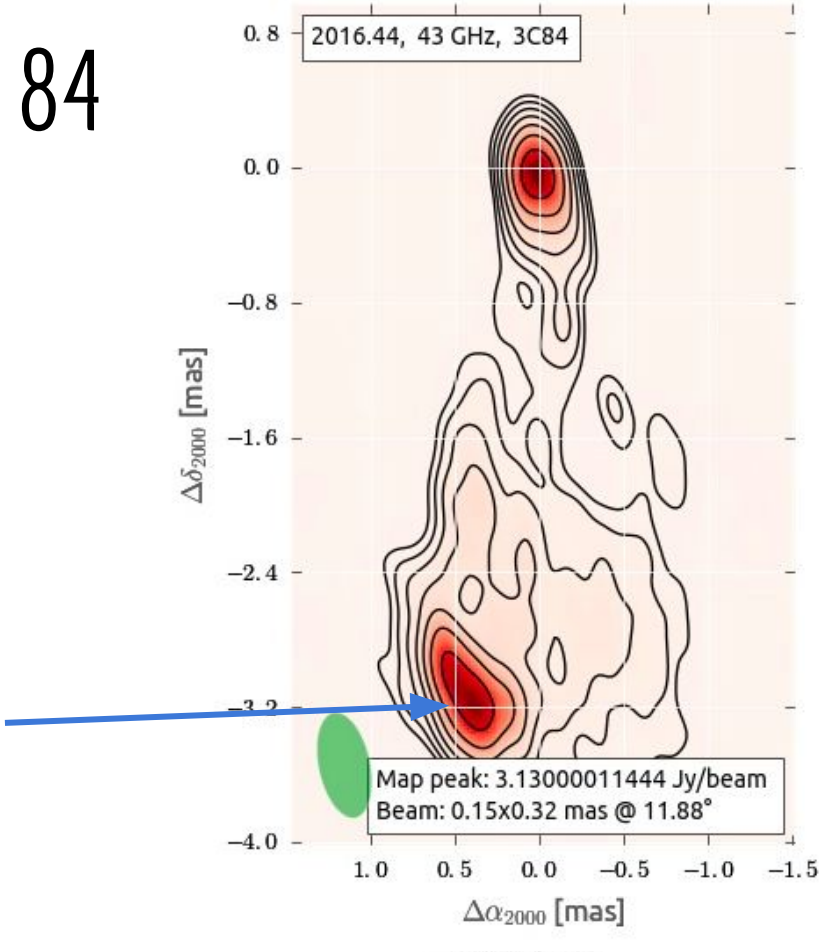

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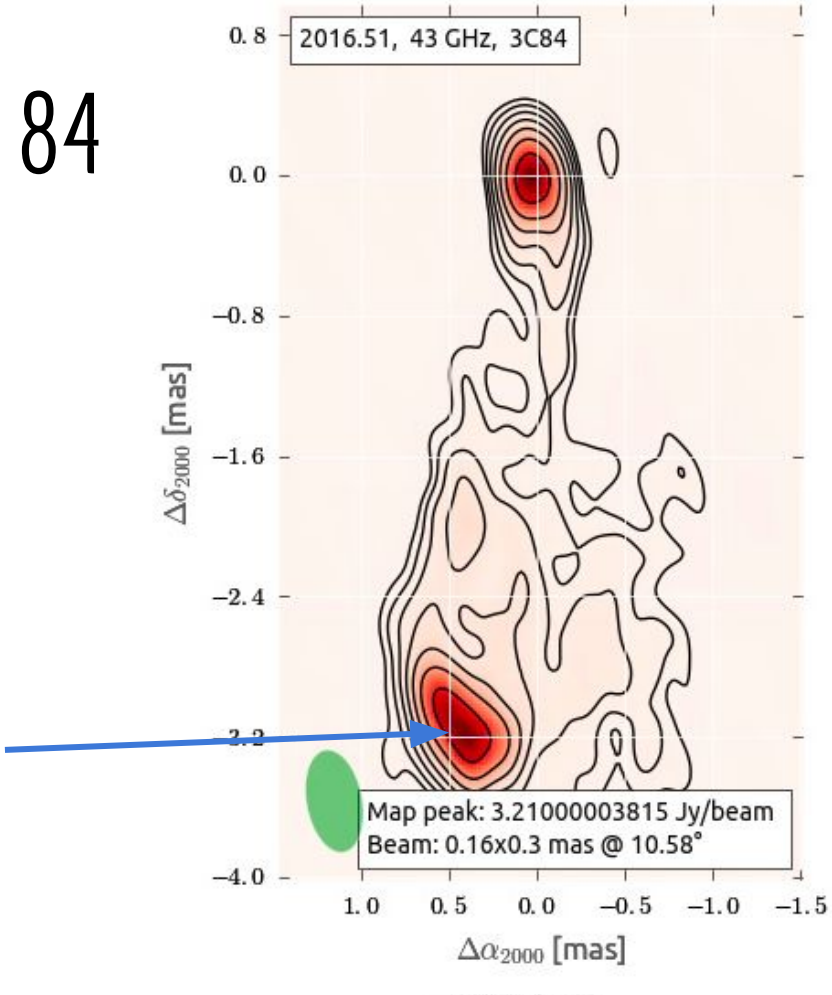

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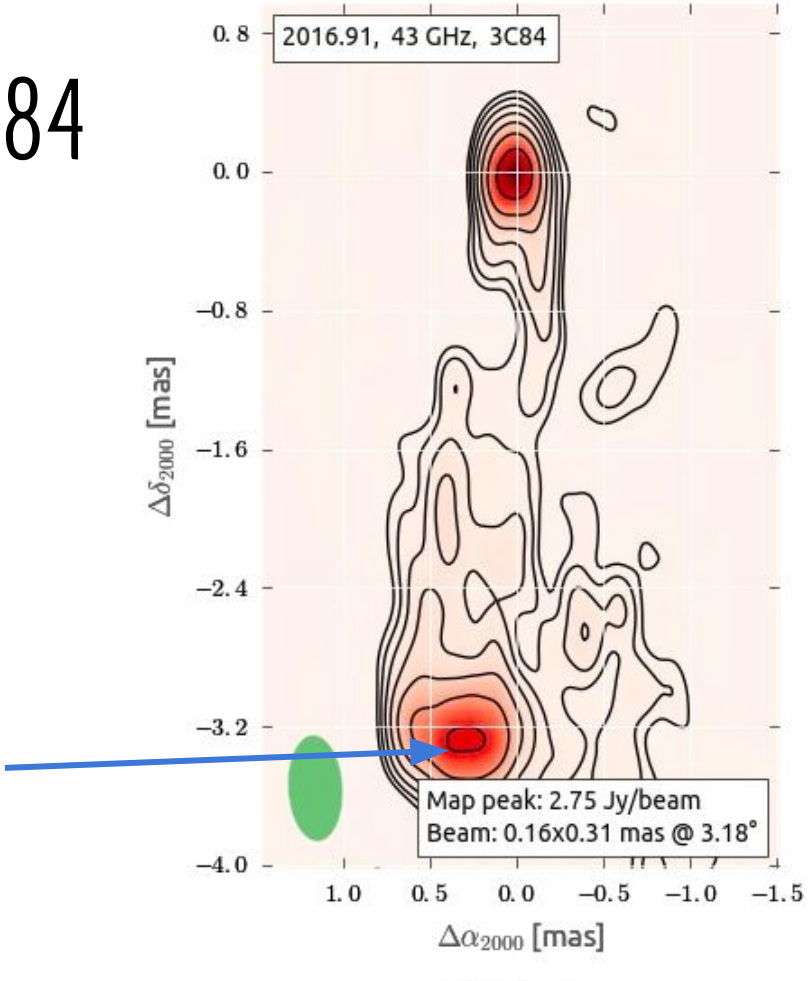

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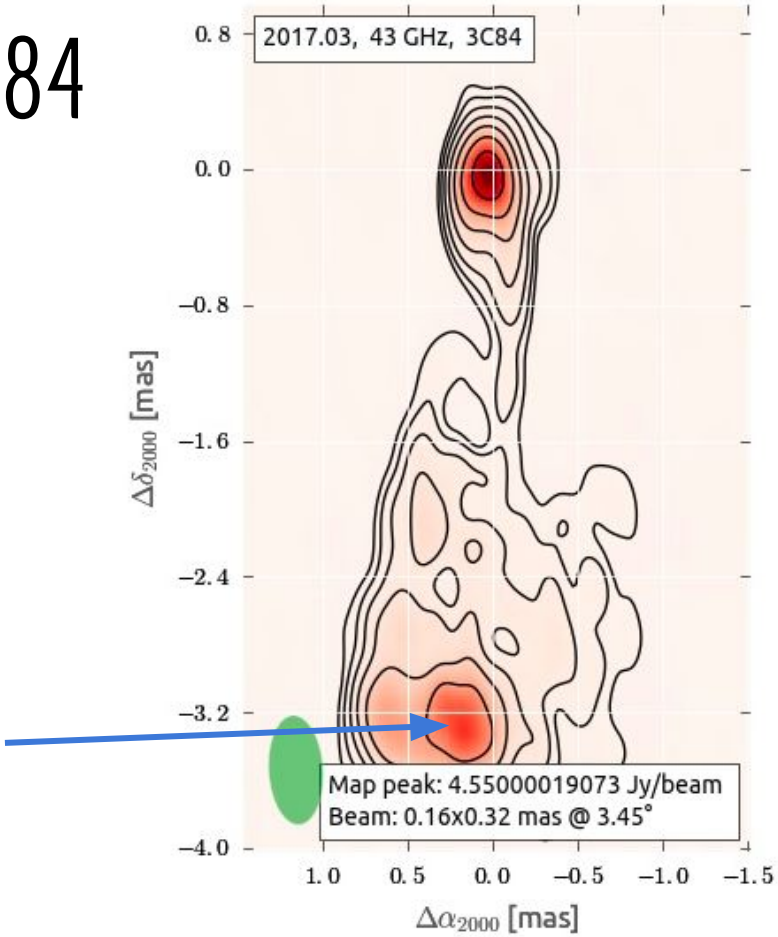
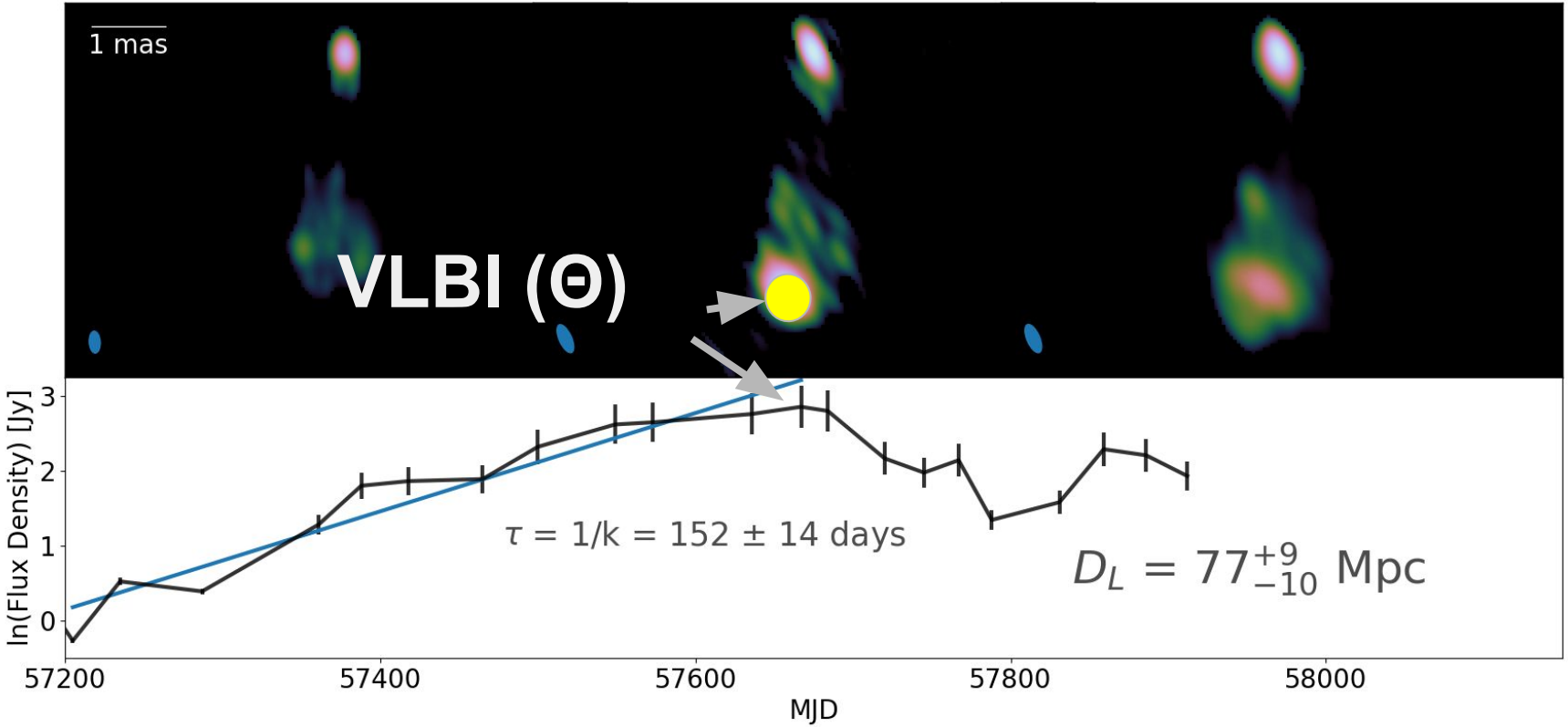
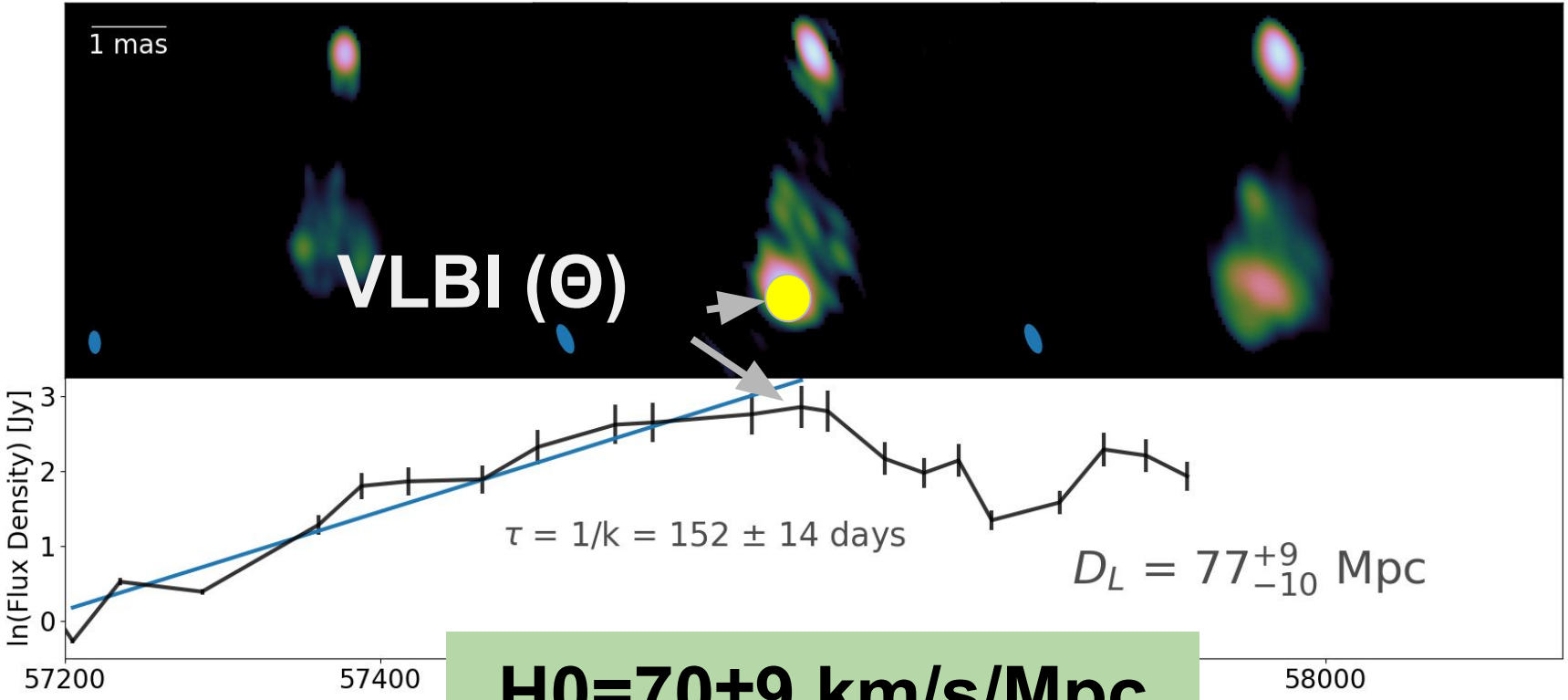




Hodgson+ in prep.



H0=70±9 km/s/Mpc

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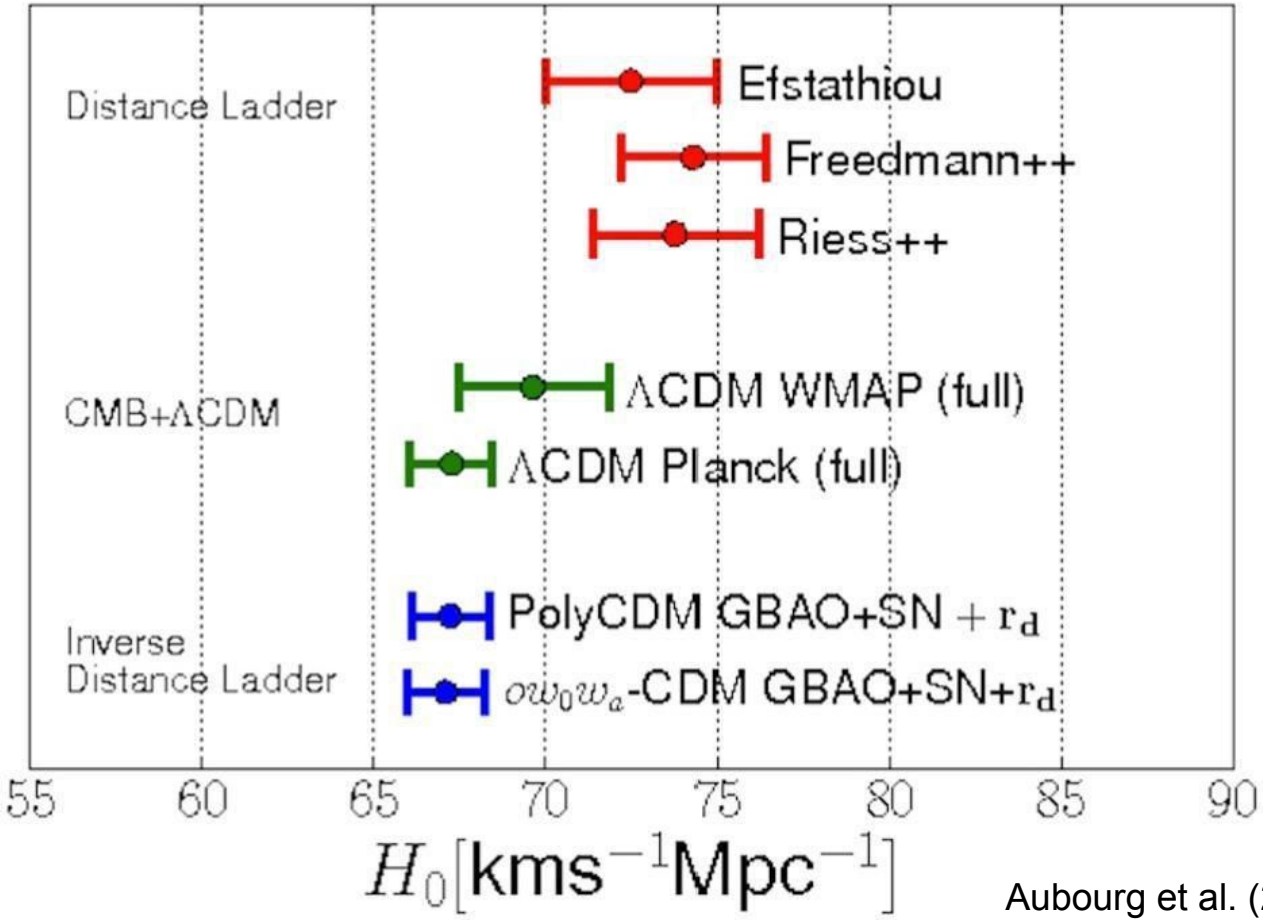
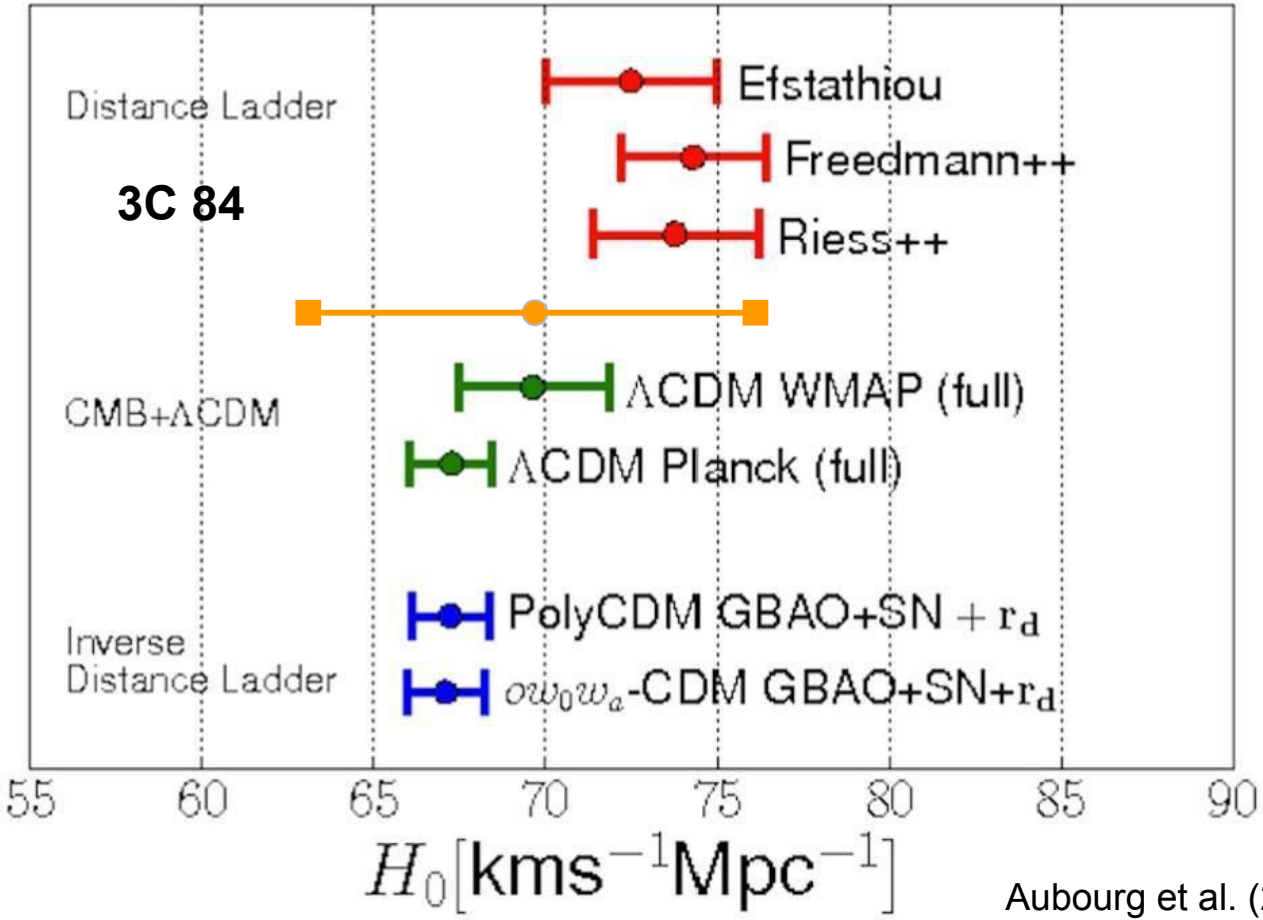


Aubourg et al. (2015)



Aubourg et al. (2015)

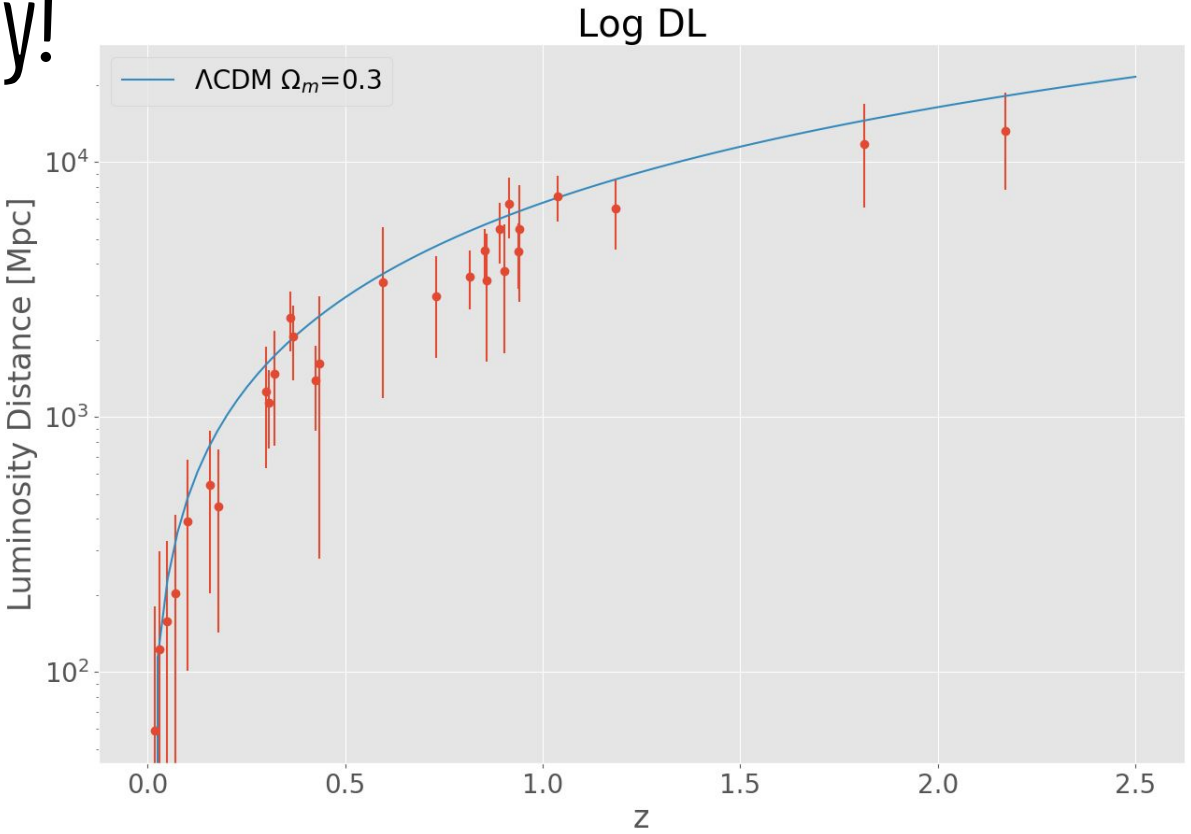
Cool! But...

- Error bars currently still too large
  - Cadence, amp-cal issues...
- Archival data is highly cadence limited
  - Full project requires very high cadence, weekly or better preferrable
- POSITIVE: We can observe multiple flares in the same source and average down the errors (unless systematic)
- Light-travel time argument may not by 100% accurate
  - Can test this on microquasars with parallax measurements
- Can also do blazars...

VERY Preliminary!

- Using BU (Jorstad 17) archival data

- Due to low cadence, seem to be underestimating slightly in some sources



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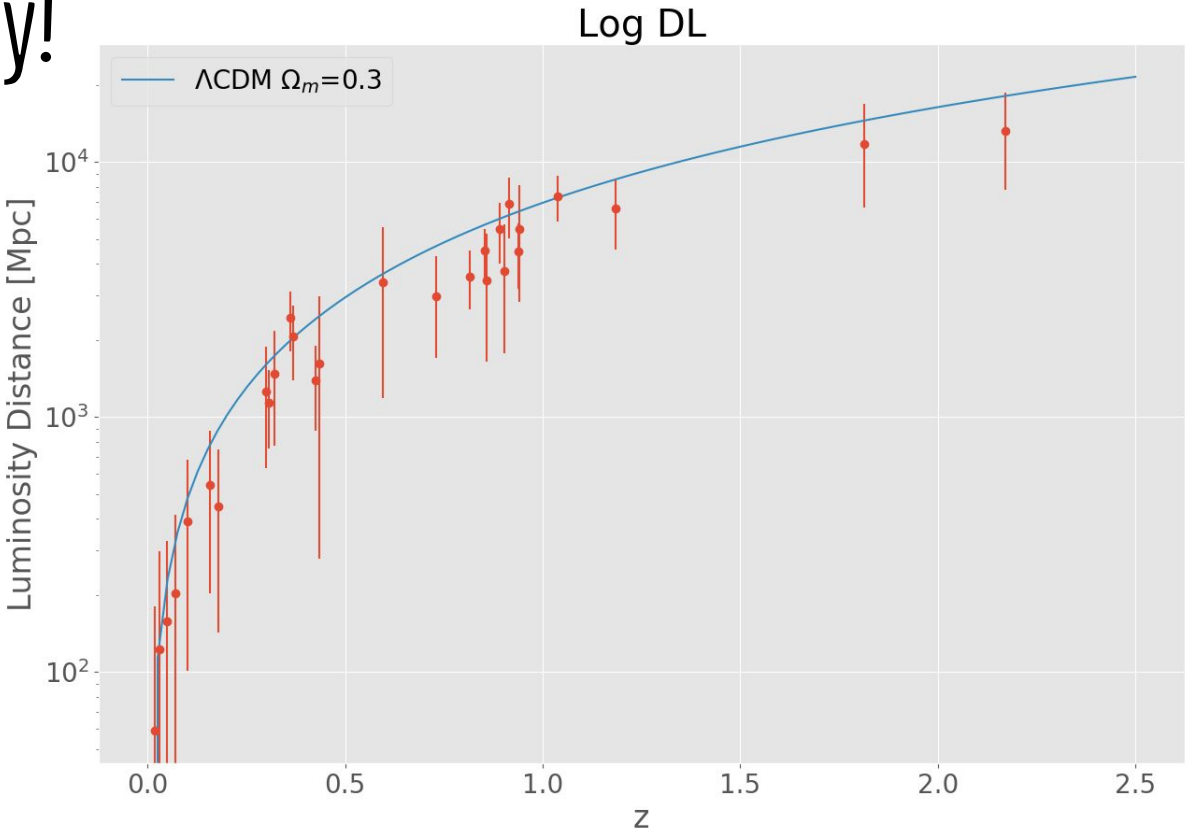
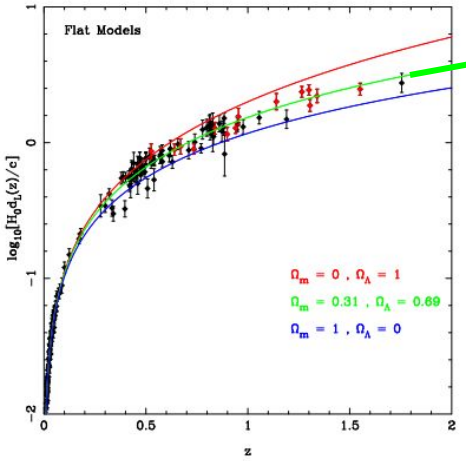
- In order to handle the systematics...



Cosmological QUOKKAS

Quasar observations using the KVN from Korea to Australia and Spain

- Project to measuring the luminosity distance-redshift relationship from 0 > z > 7
- “Standard speedgun”
- Requires high cadence
- Requires high-resolution



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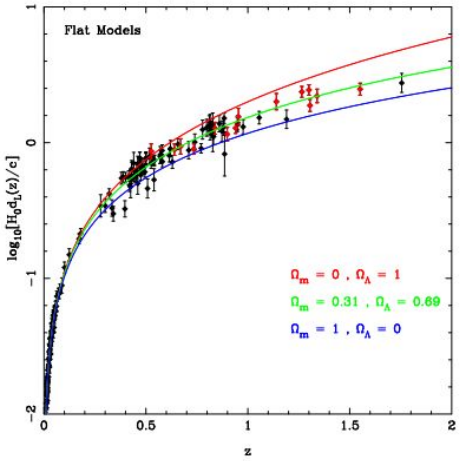

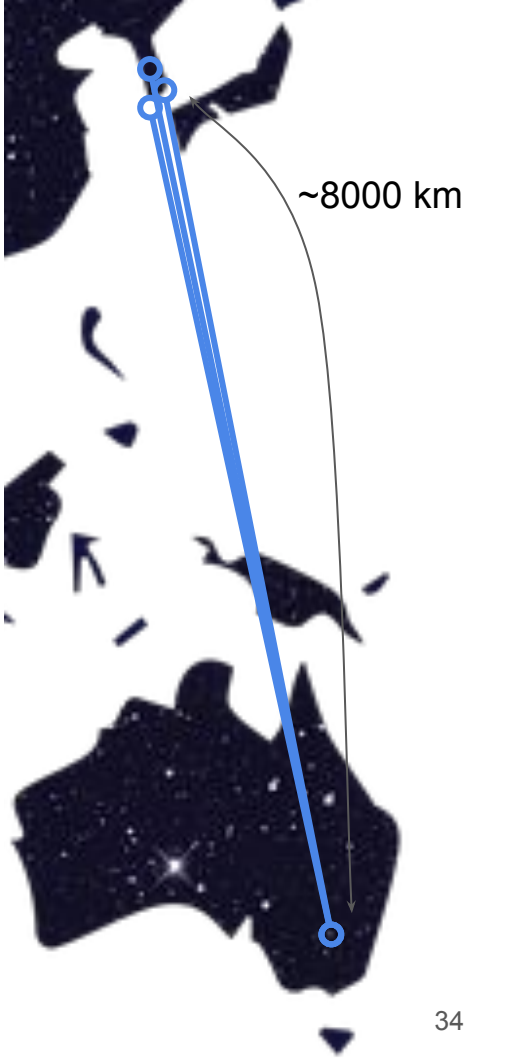

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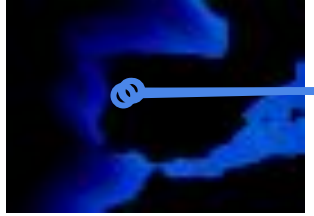

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- A Quokka is a small marsupial on an island off Perth
- Asked Samsung to fund the conversion of Mopra telescope for conversion to KVN-style quasi-optics

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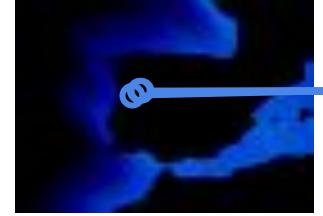

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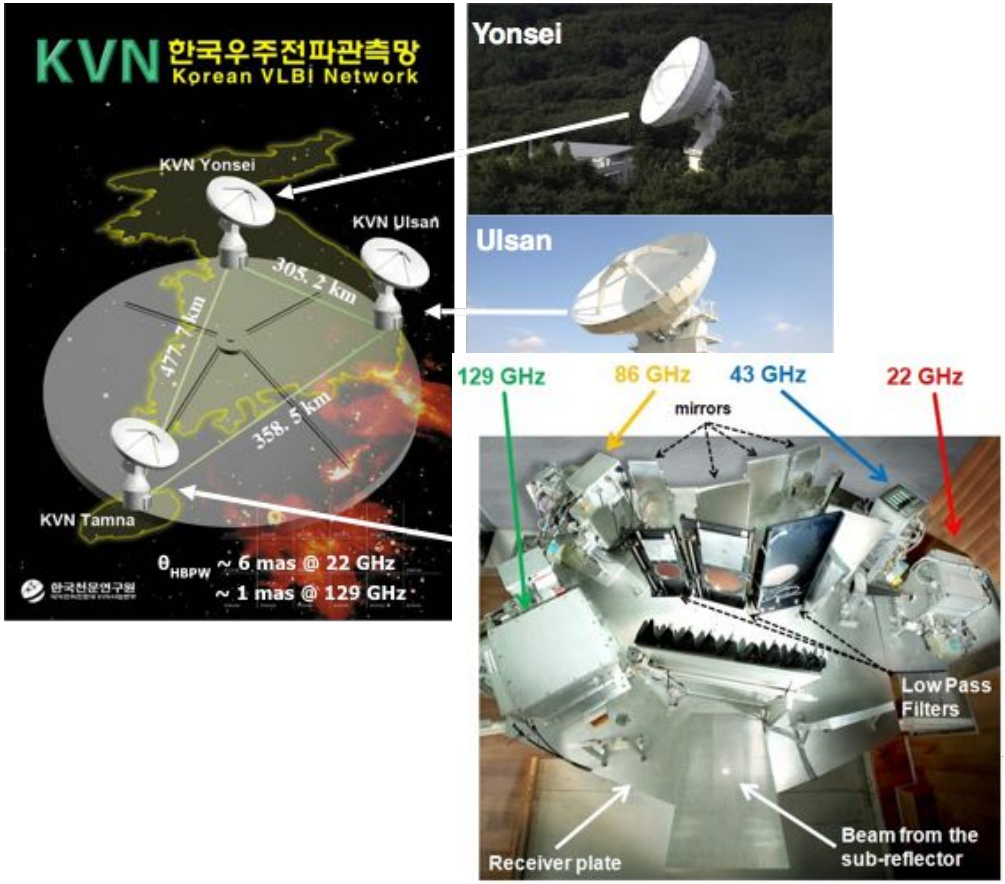
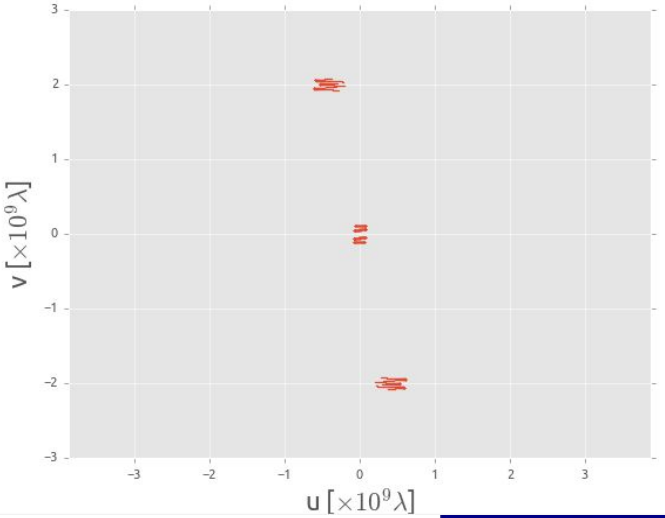
The Korean VLBI Network

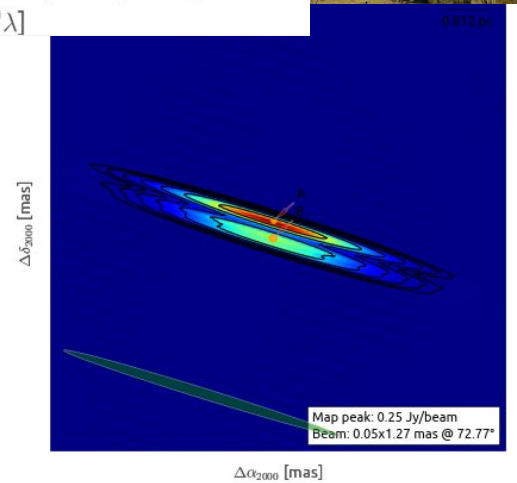
- Three 21m dish located in Seoul, Ulsan, and Jeju island, Korea
- Remotely operated from Daejeon, center of the array
- 22/43/86/129 GHz bands
- Multi-frequency quasi-optics
  - First realization in the world
  - Simultaneous multi-frequency observations
  - Frequency Phase Transfer technique



The QUOKKA(S) Array

- High cadence observations of the high-z sample
- Mopra for low-dec sources
- Yebes for high-dec sources
- Extremely high resolution (~50 uas at 3mm)
- Unique NS baseline
- Mark6 and OCTAD backend ordered, test observations early next year...





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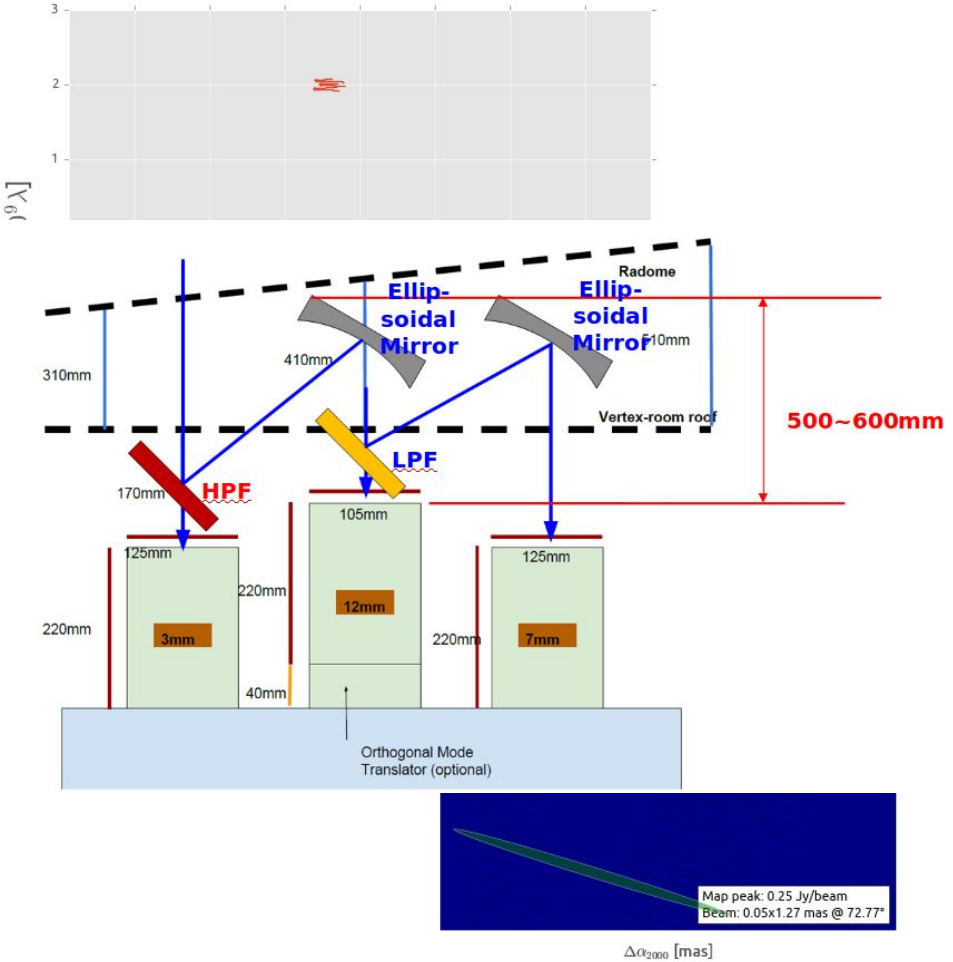

Towards an Asia-Pacific VLBI Network

- Effectively a single-baseline
- Can we do more than just the cosmology project?
- Limited imaging capabilities
- KaVA/EAVN with Mopra?
  - 22/43 single frequency
- Good for mid-dec sources
  - M87
  - Sgr A* (may be resolved out…)
  - Cen A

Towards an Asia-Pacific VLBI Network

- Thailand will make imaging on the array much better
- Very useful mid-spacing
- NS orientation has implications for common visibility/high cadence obs.
- New Zealand?
- South Africa?
- Mauna Kea?
- Multi-frequency a must...

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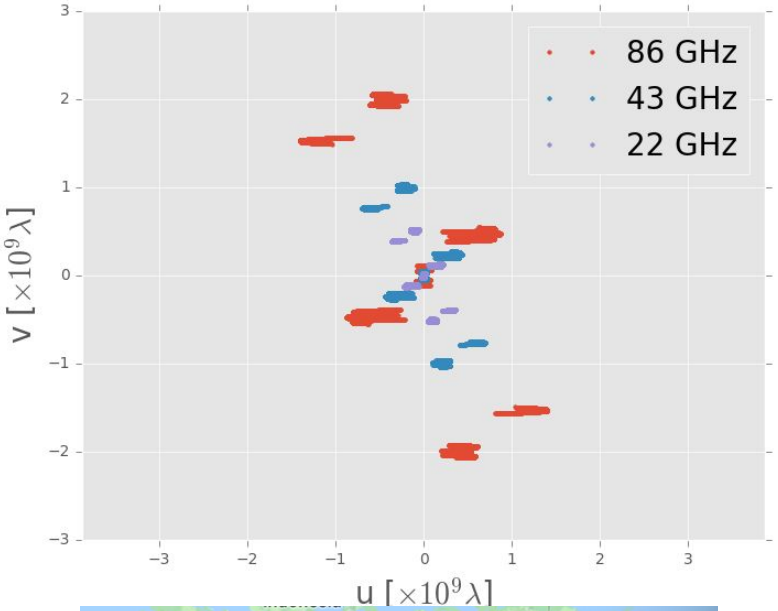

Conclusions

- Derived an accurate distance to 3C 84, demonstrating how AGN can be used as “standard speedguns”
- Very preliminary results showing that AGN appear to be useable for measuring cosmology
- QUOKKAS array coming online soon to begin observations and pursue the project, beginning early observations later this year