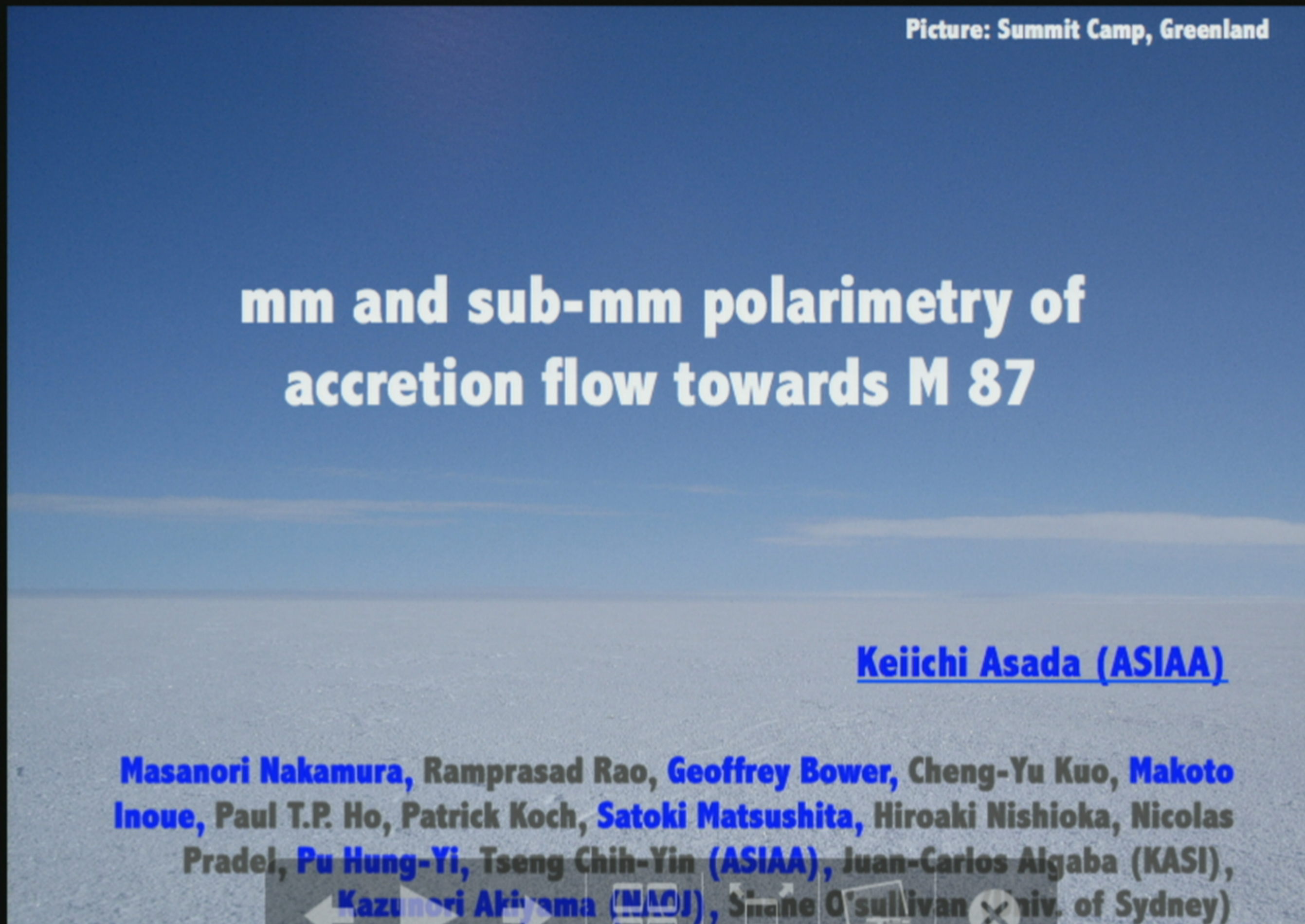
Title: mm and sub-mm polarimetry of accretion flow towards M 87

Date: Nov 11, 2014 12:00 PM

URL: http://pirsa.org/14110079

Abstract: Mass accretion rate on the SMBHs is one of the fundamental parameters used to investigate AGNs. Faraday Rotation Measure (RM) observations at mm/sub-mm wavelengths is one of the powerful methods to derive the mass accretion rate of hot accretion flows towards our galactic center, Sgr A* (e.g., Marrone et al. 2006). Based on this scheme, we conducted an SMA observation to apply this method to M 87, which is one of the primary target for our submm VLBI observations, in February 2013. We succeeded to derive an RM of (2.1 Â± 1.8) Ã— 10^5 rad m^-2, it gives the range of the mass accretion rate (M_dot) between 0 and 9.2 Ã— 10^-4 M_sun yr^-1 at the distance of 21 rs from the SMBH. Our estimated M.is already two orders of magnitude smaller than the M_dot at the outer part of the accretion flow (~10^5 r_s) of 0.1 M_sun yr^-1 determined by X-ray observations (Di Matteo et al. 2003). This significant suppression of the M_dot at the inner region is expected with the radiatively inefficient accretion flow (RIAF) model. With future submm VLBI polarimetry towards jetted sources including M 87, we will derive the profile of accretion flow along the jet. It is very important itself for the study of the accretion process onto the SMBH, but also provide fundamental properties to derive BH parameters from the BH shadow imaging.


Picture: Summit Camp, Greenland
mm and sub-mm polarimetry of accretion flow towards M 87
Keiichi Asada (ASIAA)
Masanori Nakamura, Ramprasad Rao, Geoffrey Bower, Cheng-Yu Kuo, Makoto Inoue, Paul T.P. Ho, Patrick Koch, Satoki Matsushita, Hiroaki Nishioka, Nicolas Pradel, Pu Hung-Yi, Tseng Chih-Yin (ASIAA), Juan-Carlos Algaba (KASI),

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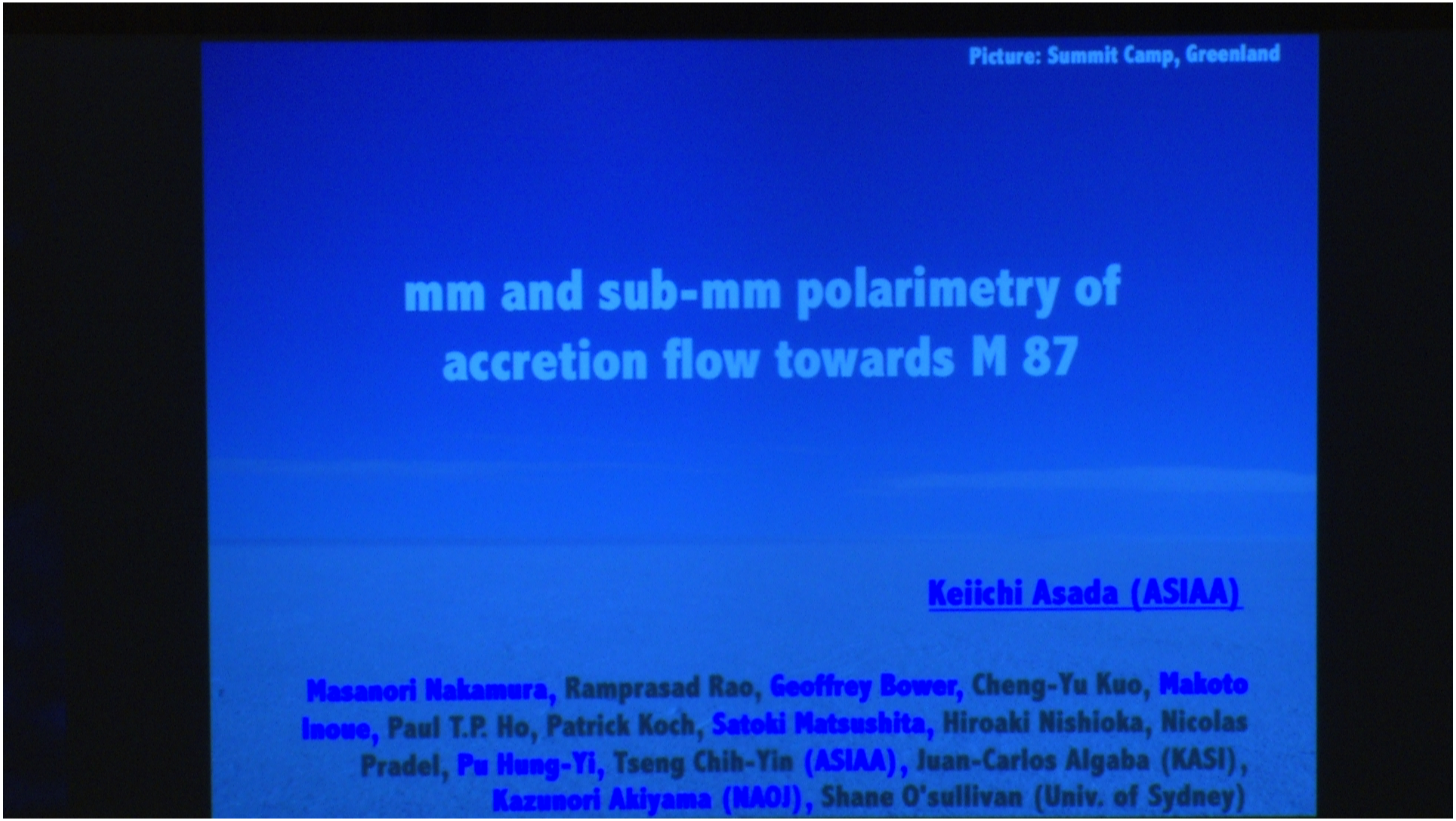
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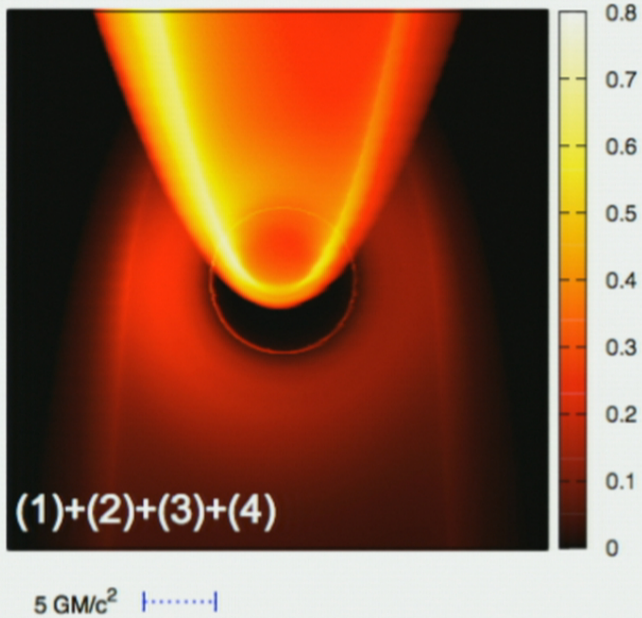
Towards BH shadow imaging

- Structure of the BH shadow can be different depends on the emission properties.

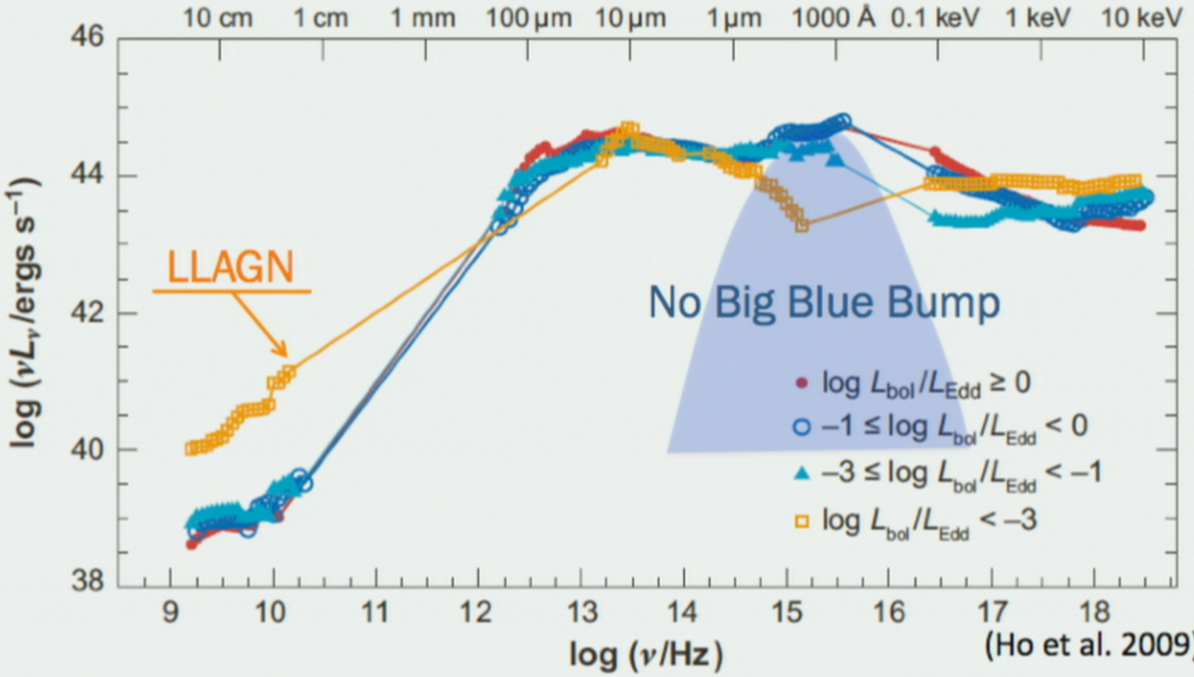
- Jet and accretion flow properties are crucial to subtract physics from future BH shadow imaging.



See: Poster by Pu Hung-Yi as well.

M 87 and its Accretion Flows

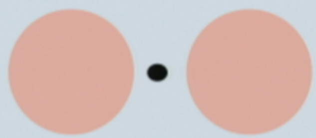
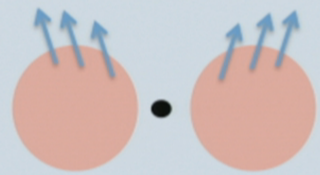
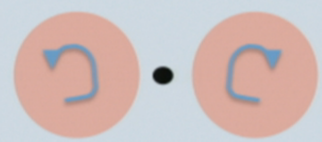
- Low-Luminosity AGNs are subclass of AGN. ($L < 10^{-3} L_{edd}$)
- LLAGNs (Ho et al. 1997) are considered to accommodate RIAF
- M 87 is categorized as LLAGN.



(Ho et al. 2009)

Accretion flow of LLAGNs

Three types of RIAFs:

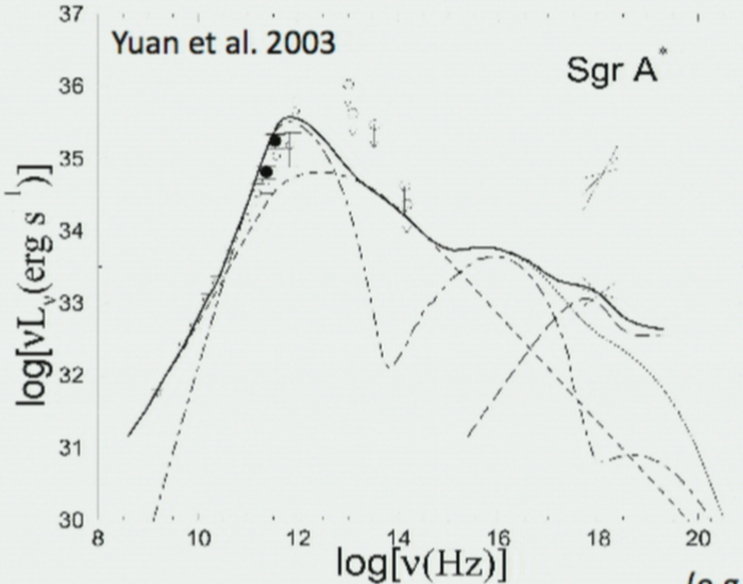
	ADAF (Ichimaru 1977; Narayan & Yi 1995)	**ADIOS** (Blandford & Begelman 1999)	**CDAF** (Igumenshchev & Abramowicz 1999)
Structure			
$\dot{M}$	$\sim (r/r_B)^0$	$\sim (r/r_B)^{0\text{-}1}$	$\sim (r/r_B)^1$

r_B: Bondi radius ($\sim 10^{4\text{-}6}\, r_s$)

- Substantial decrease of the mass accretion rate can be expected for ADIOS and CDAF !!

Mass Accretion Rate is fundamental parameter to consider energy balance between L_{acc} and L_{rad} or L_{jet}.

Probing Accretion Flow with SED fitting



(e.g., Narayan et al. 1995; Manmoto et al. 1997)

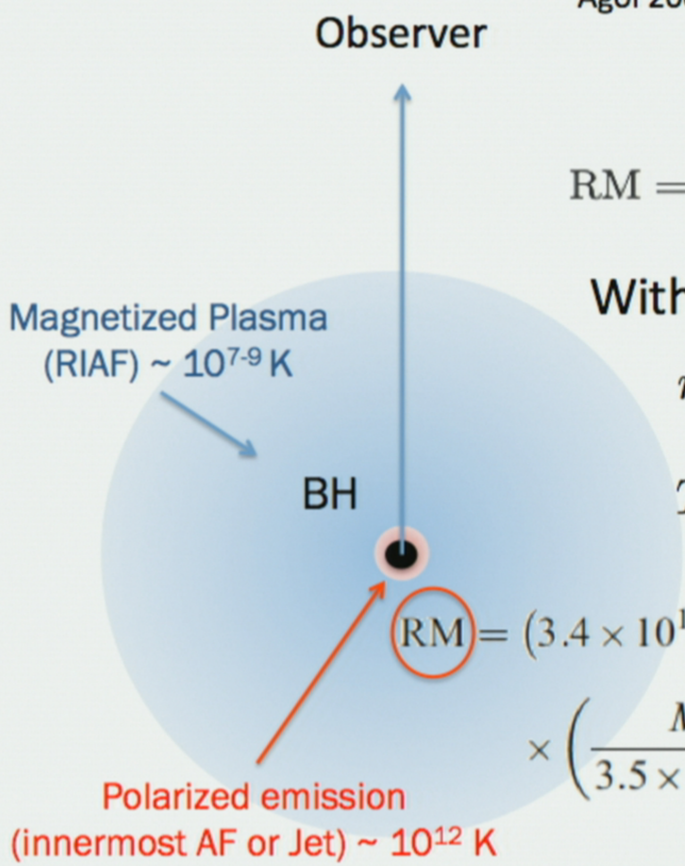
- Very succeeded method for Sgr A*

$$\dot{M} \sim 4 \times 10^{-8}\, M_{\odot}\, yr^{-1}$$

SED can be contaminated/dominated by jet....

Probing Accretion Flow with Faraday Rotation

Agol 2000, Quataert & Gruzinov 2000, Bower et al. 2003, Marrone et al. 2006, Macquart et al. 2006



$$\mathrm{RM} = 8.1 \times 10^5 \int_{LOS} n_e \mathrm{B}_{||} dl$$

With RIAF model:

$$n(r) \sim \left(\frac{r}{r_s}\right)^{-\beta}$$

$$T(r) \sim \left(\frac{r}{r_s}\right)^{-1}$$

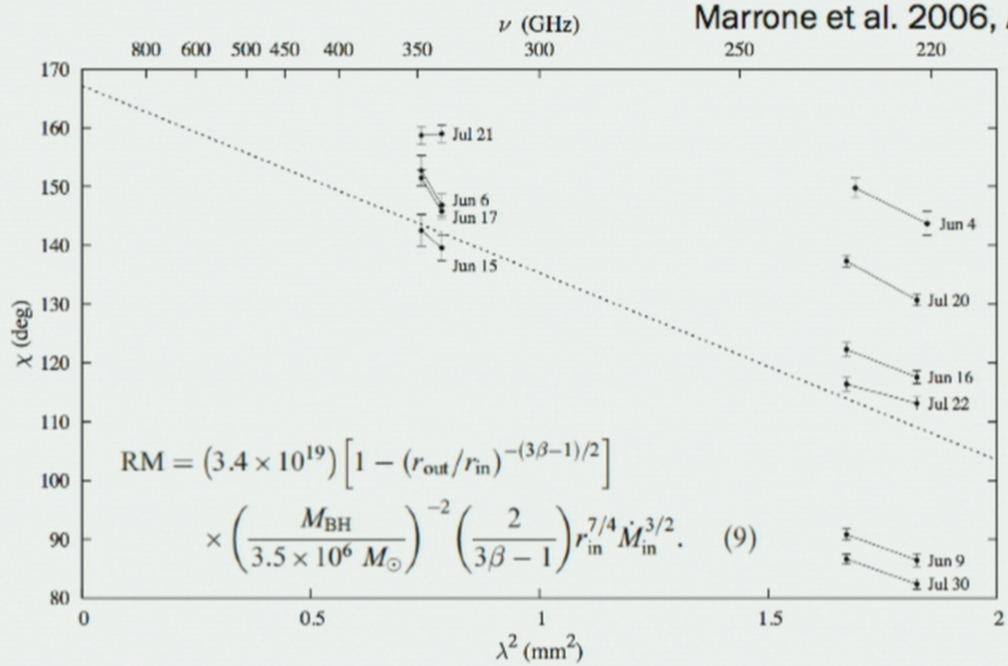
$$\beta = 1/2 \text{ (ADAF)}$$
$$= 3/2 \text{ (CDAF)}$$
$$= 1/2 - 3/2 \text{ (ADIOS)}$$

$$\mathrm{RM} = (3.4 \times 10^{19}) \left[1 - (r_{\rm out}/r_{\rm in})^{-(3\beta-1)/2}\right] \times \left(\frac{M_{\rm BH}}{3.5 \times 10^6 \, M_\odot}\right)^{-2} \left(\frac{2}{3\beta - 1}\right) r_{\rm in}^{7/4} \dot{M}_{\rm in}^{3/2}. \quad (9)$$

Marrone et al. 2006, ApJ, 640, 308

SMA Polarimetry towards Sgr A*

Marrone et al. 2006, ApJ, 640, 308



RM observation with SMA towards Sgr A*

- RM = $(5.6 \pm 0.7) \times 10^5$ rad m^{-2}

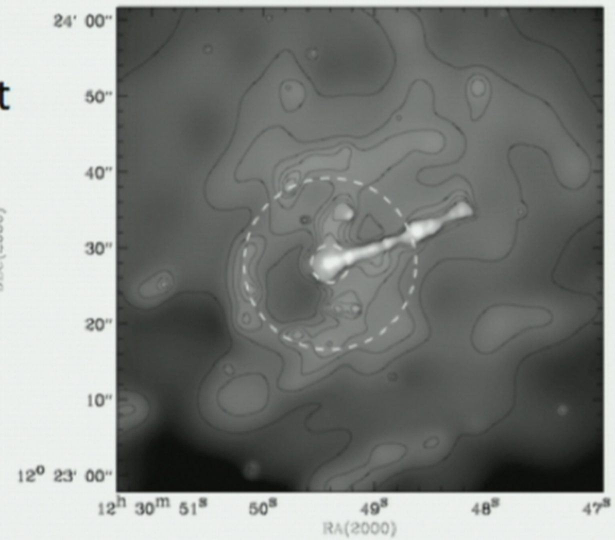
▶ $M = 2 \times 10^{-7} - 2 \times 10^{-9}\ M_\odot\ \mathrm{yr}^{-1}$

M 87

- Apply the same scheme to M 87
  - Primary target for EHT/GLT project
  - $M_{BH} \sim 6.6 \times 10^9 M_\odot$
  - Relativistic Jet exists
  - D = 16.7 Mpc

- With Chandra Observation
  - $r_B \sim 230$ pc ($3 \times 10^5 r_s$)
  - $P_B \sim 7 \times 10^{45}$ erg s^{-1}
  - $M_B \sim 0.12 M_\odot$ yr^{-1}

    Di Matteo et al. 2003, ApJ, 582,133



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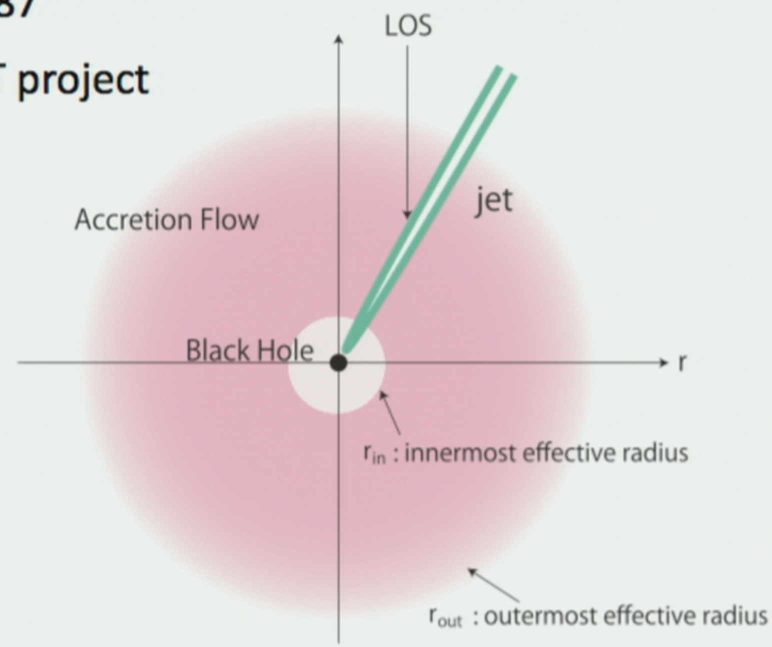


$$\dot{M} = 1.1 \times 10^{-8} \left[1 - (r_{\rm out}/r_{\rm in})^{-(3\beta-1)/2}\right]^{-2/3} \times \left(\frac{M_\bullet}{6.6 \times 10^9 M_\odot}\right)^{4/3} \left(\frac{2}{3\beta - 1}\right)^{-2/3} r_{\rm in}^{7/6} R M^{2/3}$$

Observations

SMA observations:

1st epoch observation:

Date: 2013/Jan/27
Frequency: 218.4, 220.4, 230.3, 232.3

Kuo, KA, et al. 2014 ApJL, 783, 33

2nd epoch observation:

Date: 2014/Jan/9
Frequency: 218.4, 220.4, 230.3, 232.3

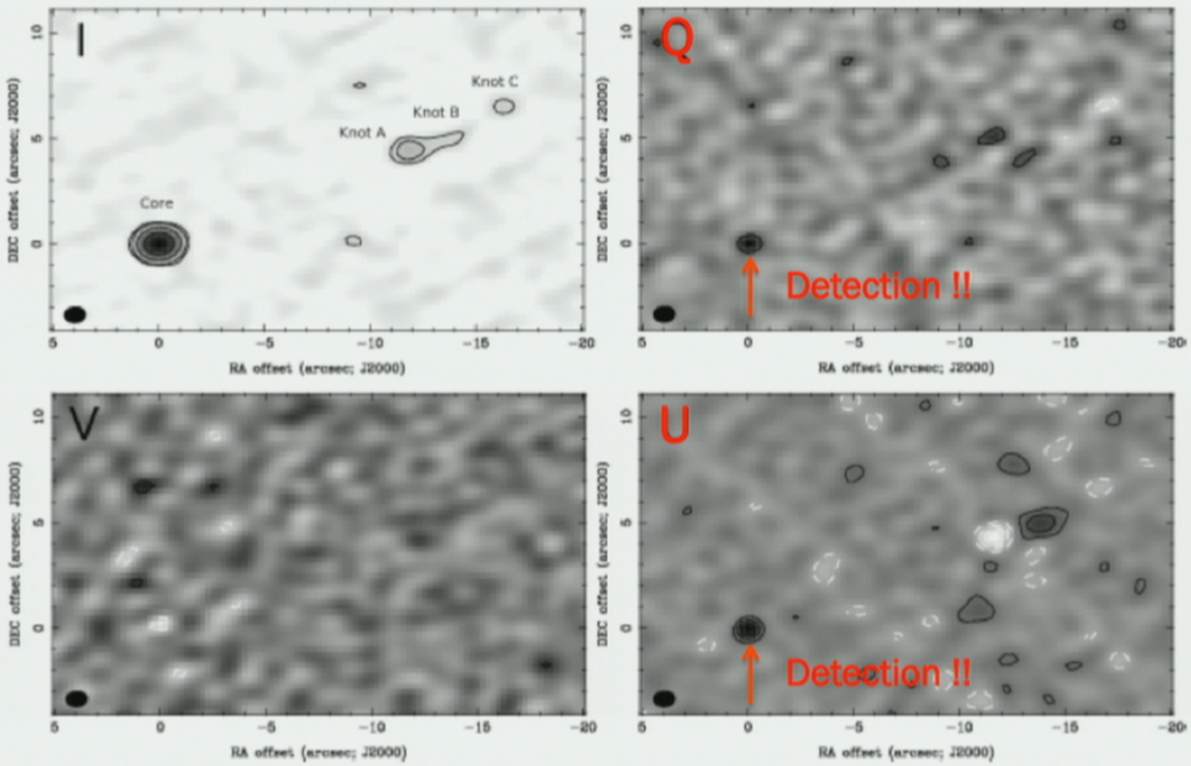
3rd epoch observation:

Date: 2014/Feb/28
Frequency: 214.3, 219.3, 229.3, 234.2

4th epoch observation:

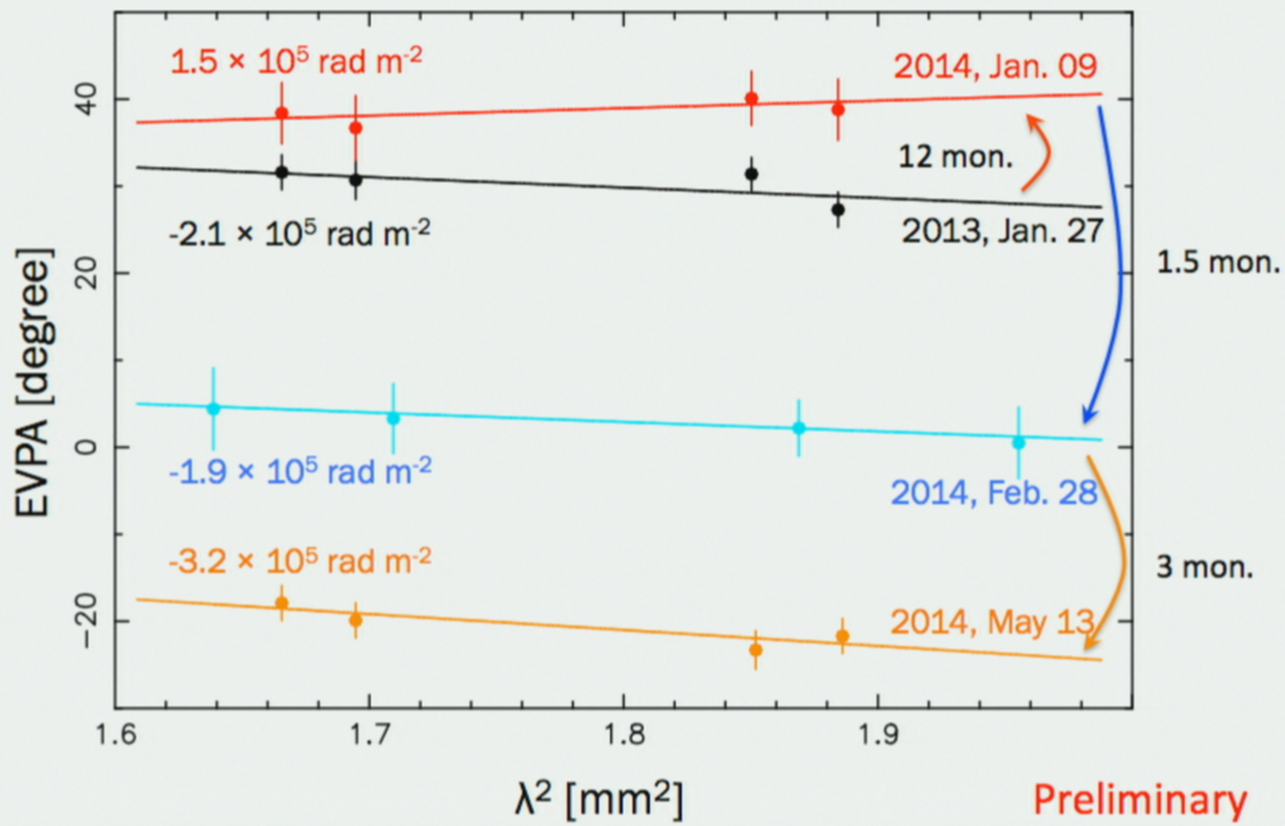
Date: 2014/May/13
Frequency: 218.3, 220.3, 230.3, 232.3 GHz

Stokes Images with SMA



Polarization images at 230 GHz towards M 87 at the first epoch.

RM fitting towards M 87



Mean RM and Mass accretion rate

Assuming no time variation,

<RM> = (-1.8 ± 0.3) × 10^5 rad m^{-2} !!

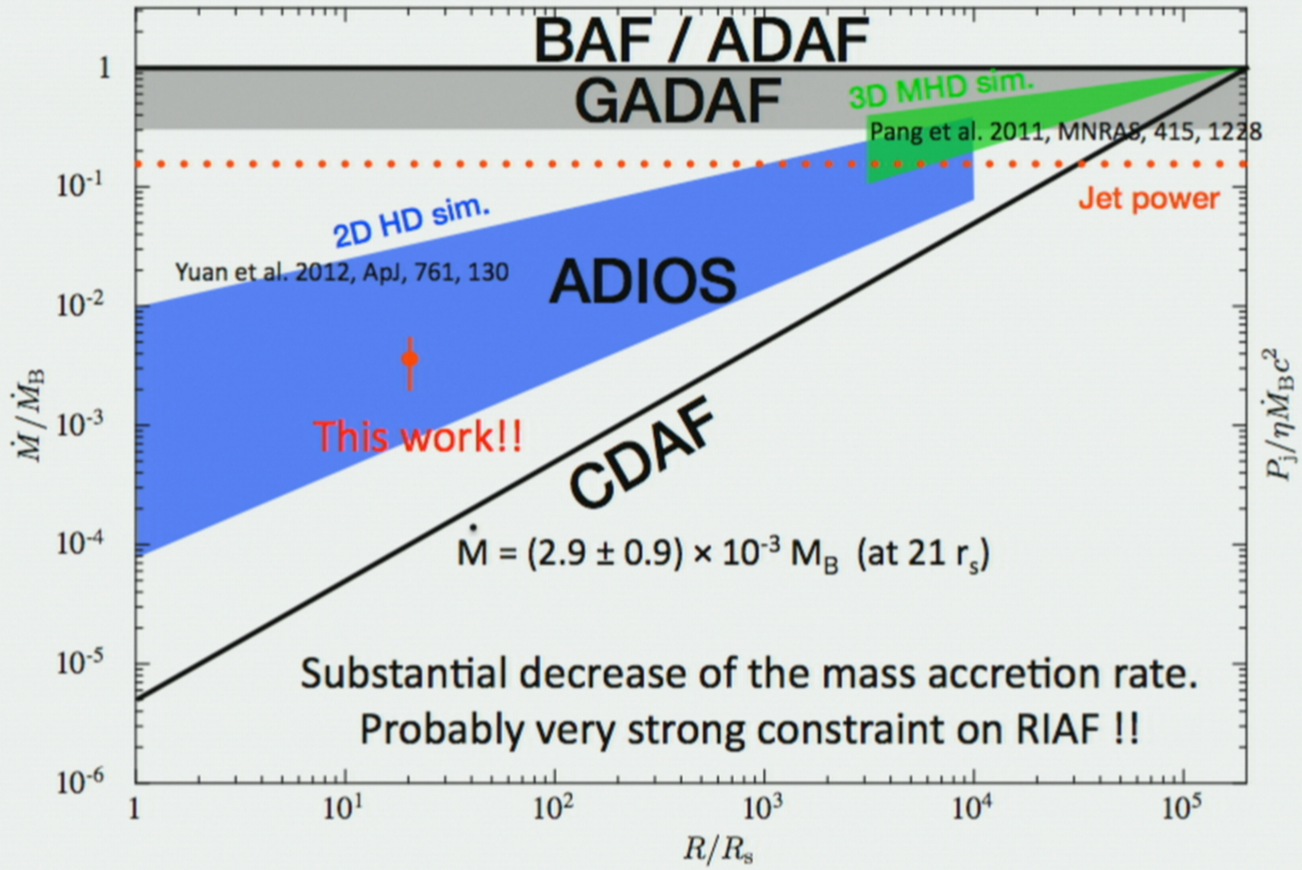
First **"solid detection"** of RM !!

$$\dot{M} = 1.1 \times 10^{-8} \left[1 - (r_{\rm out}/r_{\rm in})^{-(3\beta-1)/2}\right]^{-2/3} \times \left(\frac{M_\bullet}{6.6 \times 10^9 M_\odot}\right)^{4/3} \left(\frac{2}{3\beta - 1}\right)^{-2/3} r_{\rm in}^{7/6} RM^{2/3}$$

$\dot{M}$ = (3.6 ± 1.1) × 10^{-4} $M_\odot$ yr^{-1} (at 21 r_s)

$\dot{M}$ = (2.9 ± 0.9) × 10^{-3} M_B (at 21 r_s)

RM fitting towards M 87



Comparison with Jet Power

Accreting Power : P_{acc} (= $\dot{M}c^2$) ~ 2×10^{43} erg s^{-1}

Table 3
Jet Power from the Published Literature

L_j/erg s^{-1}	Ref.
$\sim 10^{44}$	Bicknell & Begelman (1996)
2×10^{43}	Reynolds et al. (1996)
$\sim 10^{44}$	Owen et al. (2000)
3×10^{42}	Young et al. (2002)
$\sim 10^{44}$	Stawarz et al. (2006)
5×10^{43}	Bromberg & Levinson (2008)

Li+ 2009, ApJ, 699, 513

Even if 10 % of P_{acc} used for jet, it's slightly smaller than L_{jet}

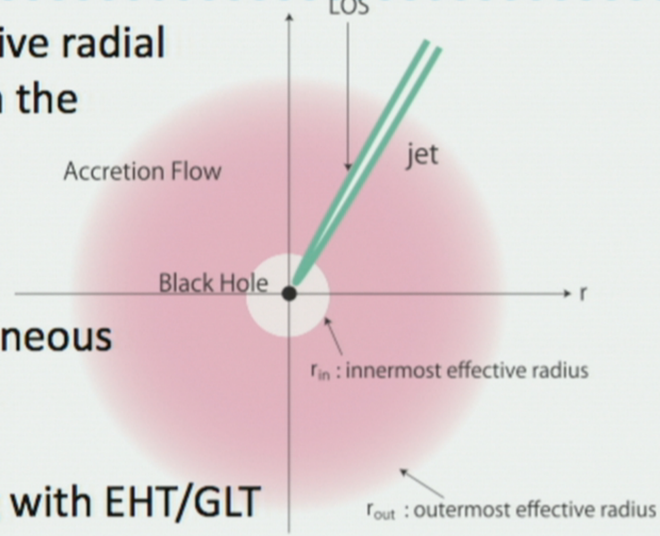
Another possibilities to support jet power:

▶ Jet would be supported by "BH spin" !!

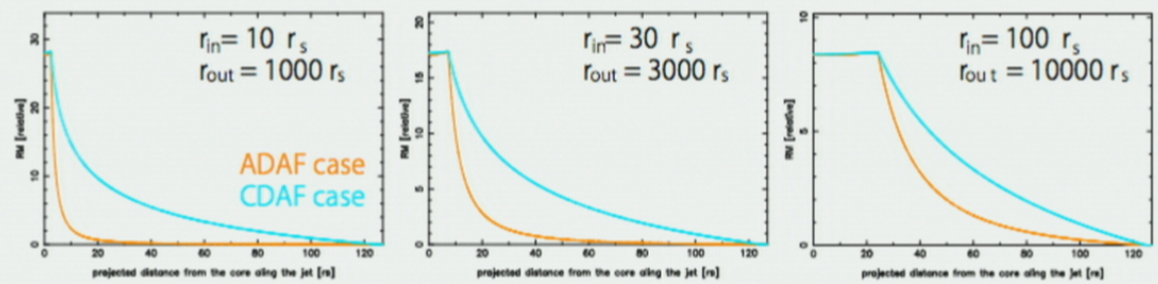
Towards future submm RM observation

- Future submm VLBI RM obs. will derive radial profile of accretion flow together with the direct image of its innermost region.

- Our ALMA proposal at band 3 was approved, together with quasi-simultaneous SMA observation at 230 and 345 GHz.



- Joint analysis of polarimetric imaging with EHT/GLT and spectral polarimetry with ALMA and SMA would be useful.



Summary

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- Multi-frequency SMA polarimetry was conducted to measure RM associated with accretion flow of M 87
- RM was determined
- It gives constraint on the mass accretion rate of $3.6 \pm 1.1 \times 10^{-4}\ M_{\odot}\ yr^{-1}$ at 21 r_s from the BH.
- The mass accretion rate is substantially decreased, in good agreement with MHD/HD simulations.
- Accreting Power may not be enough to support Kinetic Power of Jet.
- ALMA date will come, and future mm/submm polarimetry VLBI is crucial.

Job opportunities at ASIAA

- EACOA Fellowships: Due Nov. 15th
- ASIAA postdoctoral Positions: Due Dec. 15th