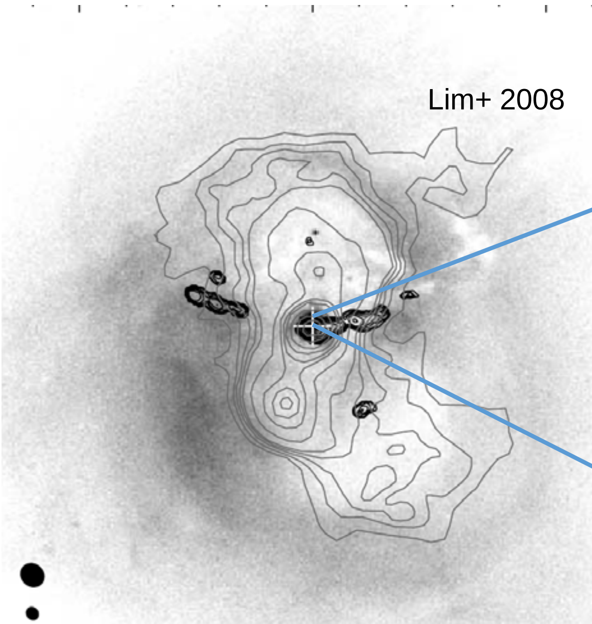
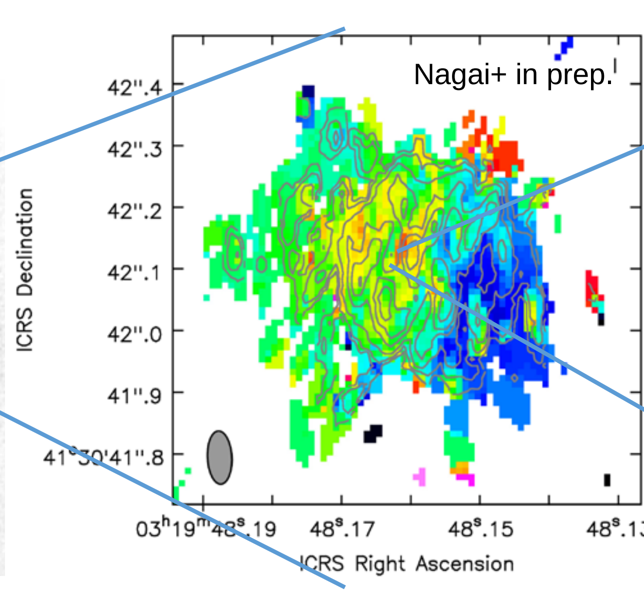
# Inflow and Outflow (Jets) in NGC 1275

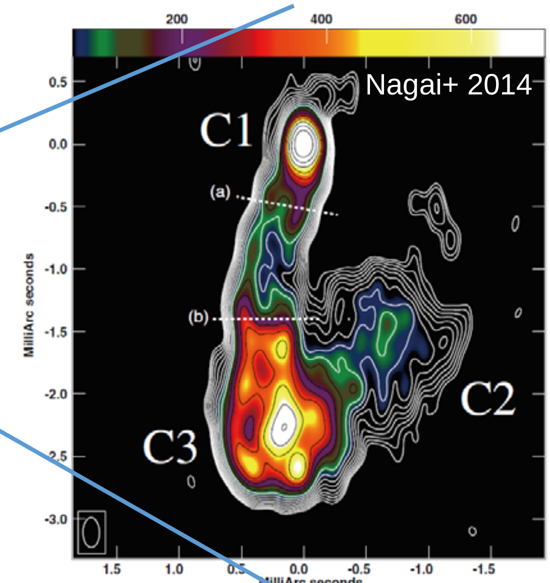
Hiroshi Nagai (NAOJ)




SMA+VLA+Candra




ALMA




VLBI

■ Outlines of this talk

1. Radio-Gamma Connection
2. Accretion Flow Properties
3. ALMA Observations of Cold Gas

# 1. Radio-Gamma Connection

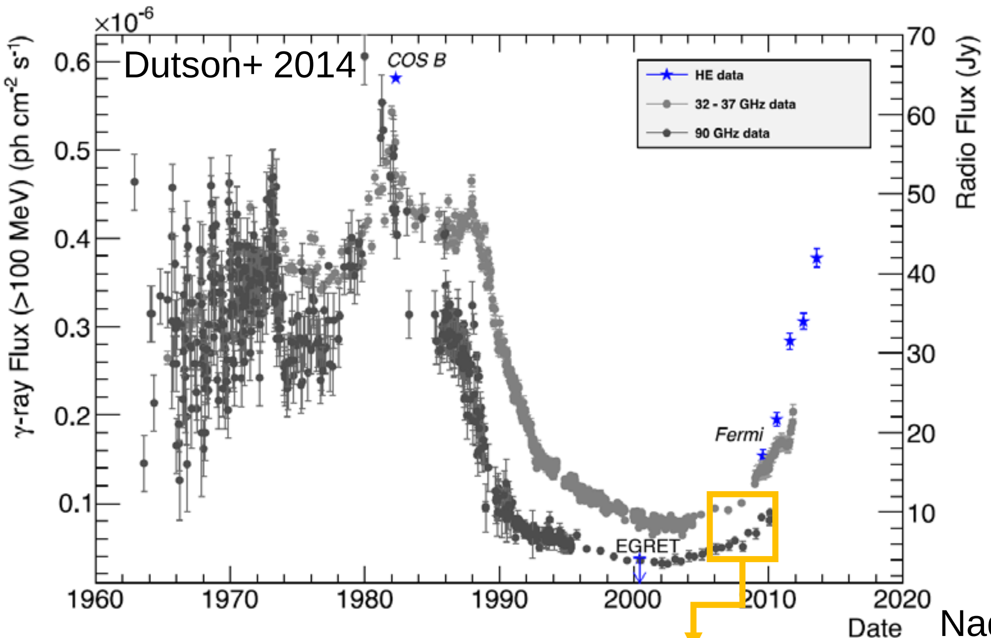
Nagai et al. 2010, PASJ

Nagai et al. 2012, MNRAS

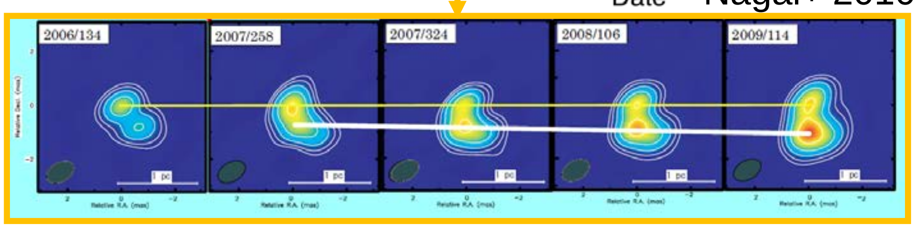
Nagai et al. 2014, ApJ

Fujita & Nagai 2017, MNRAS

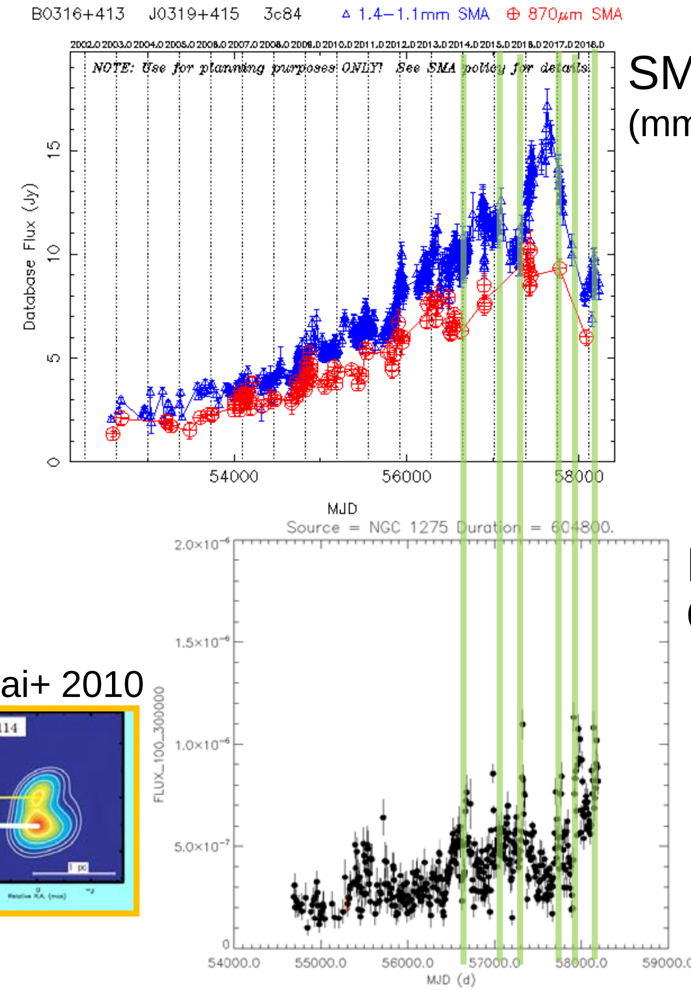
# Radio-Gamma connection?




Nagai+ 2010




SMA
(mm radio)



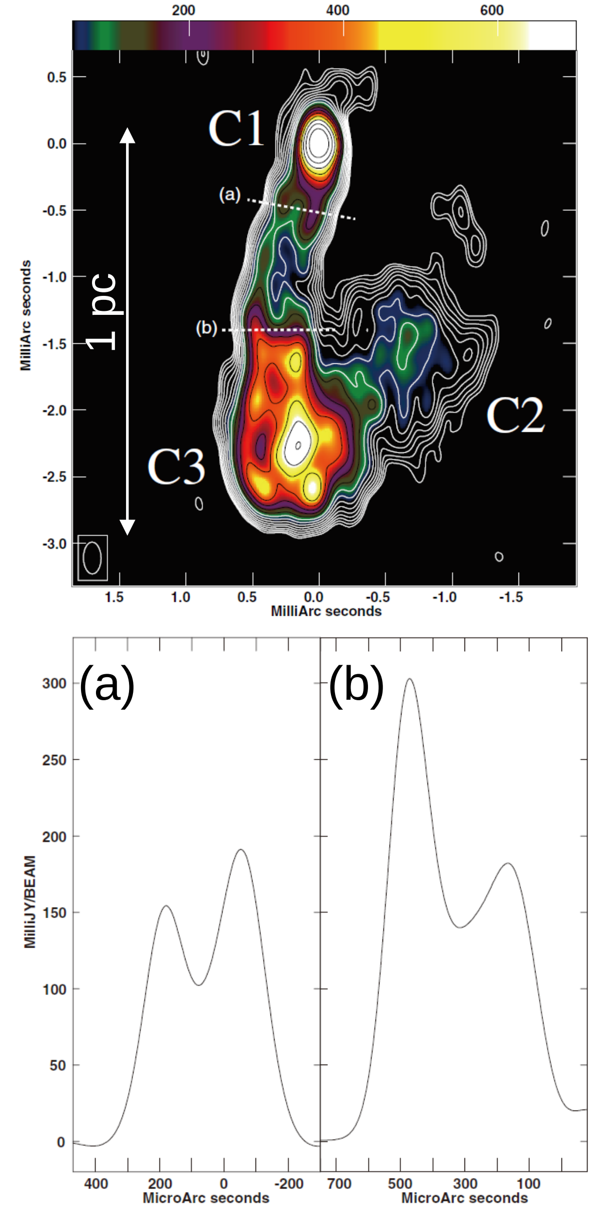

Fermi
(gamma-ray)

- Yes, on the timescale of years
- But, the correlation is not evident on shorter timescales (SMA-Fermi light curve; Nagai+ 12)

# Things to be considered

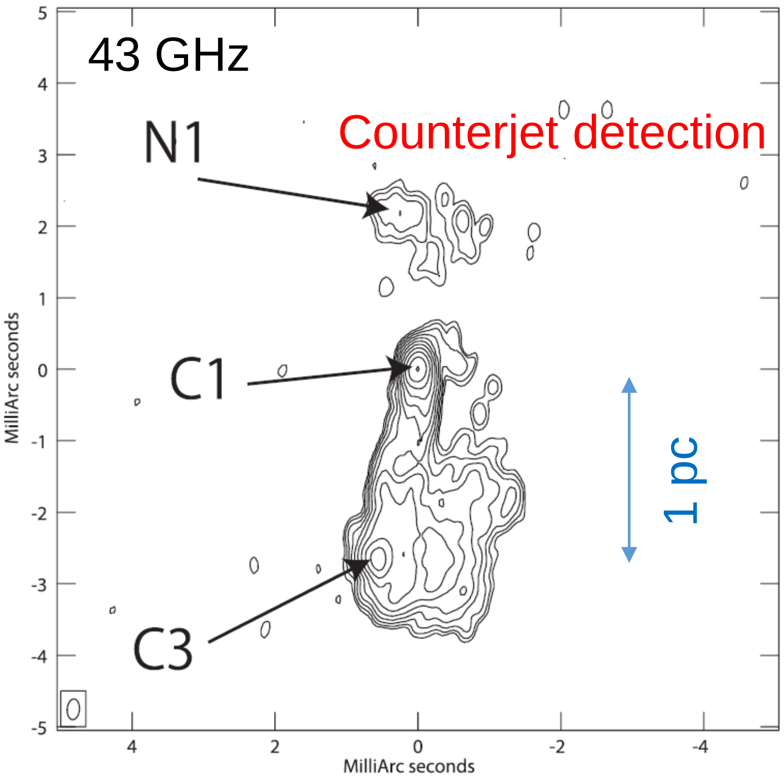
Nagai+ 2014

- Core (C1) + Hotspot/Lobe (C3) + Backflow? (C2)
  - Constitute >80% of total flux
- Integrated flux of C3 is ~2x larger than that of C1 at 22/43GHz, and both C1 and C3 fluxes are variable (Hodgson+ 18).
- C1 can produce HE emissions by SSC, and C1+C2+C3 may also produce HE emissions by upscattering of various surrounding photons (Stawarz+ 08).
- Limb-brightening indicates the spine-layer structure, which works for the amplification of HE emissions (Ghisellini 05; Tavecchio+ 14).

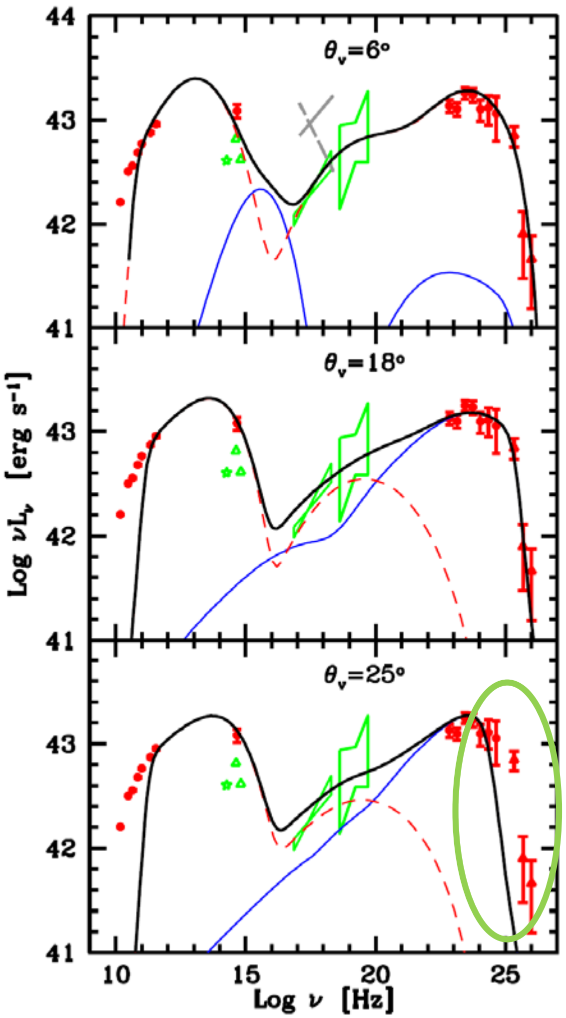


# Misaligned Blazar?

Fujita & Nagai 2017




Tavecchio+ 14




- Jet-length ratio -> viewing angle 65+/-16 deg (Fujita & Nagai 17)
  - Inconsistent with the S-L model with θ=18 deg (Tavecchio+ 14)
- Misaligned blazar models may not work.

# 2. Accretion Flow Properties

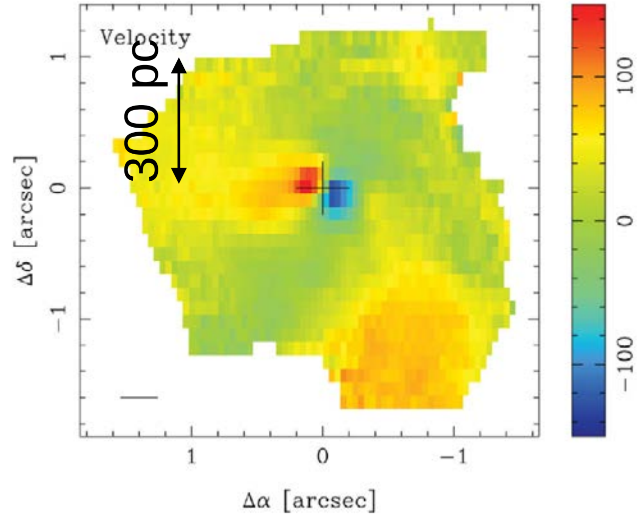
Fujita & Nagai 2017, MNRAS

Nagai et al. 2017, ApJ

Kino et al. submitted to ApJ

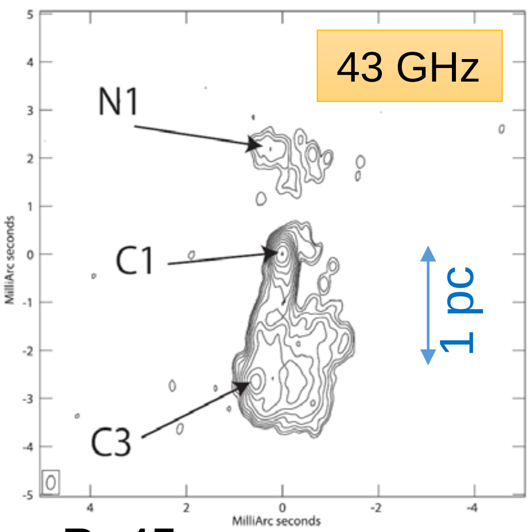
# Recap

- $M_{BH}$=8 x $10^8$ $M_{sun}$ (determined by kinematics of $H_2$ gas, Scharwachter+ 13)
- $L_{bol}$=4 x $10^{44}$ erg/s
  - 0.4% of Eddington Luminosity
  - RIAF should be applicable

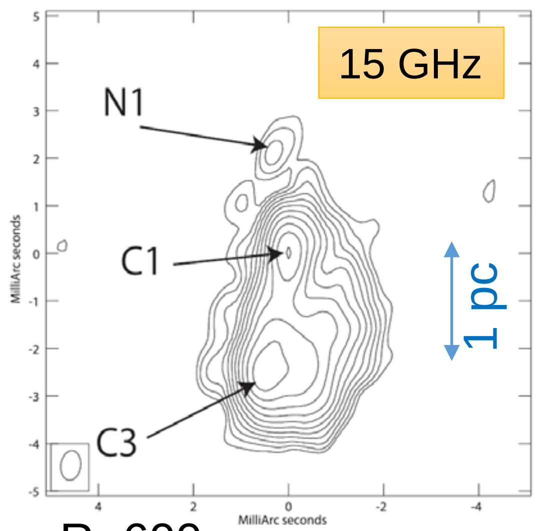


# Jet-Counterjet Asymmetry Caused by Inhomogeneous Disk

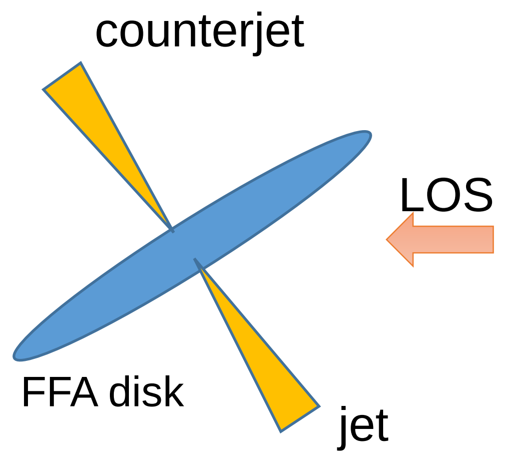
Fujita & Nagai 2017



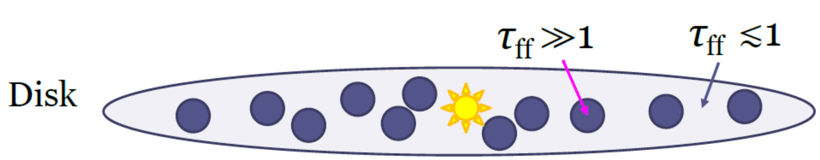

R=45



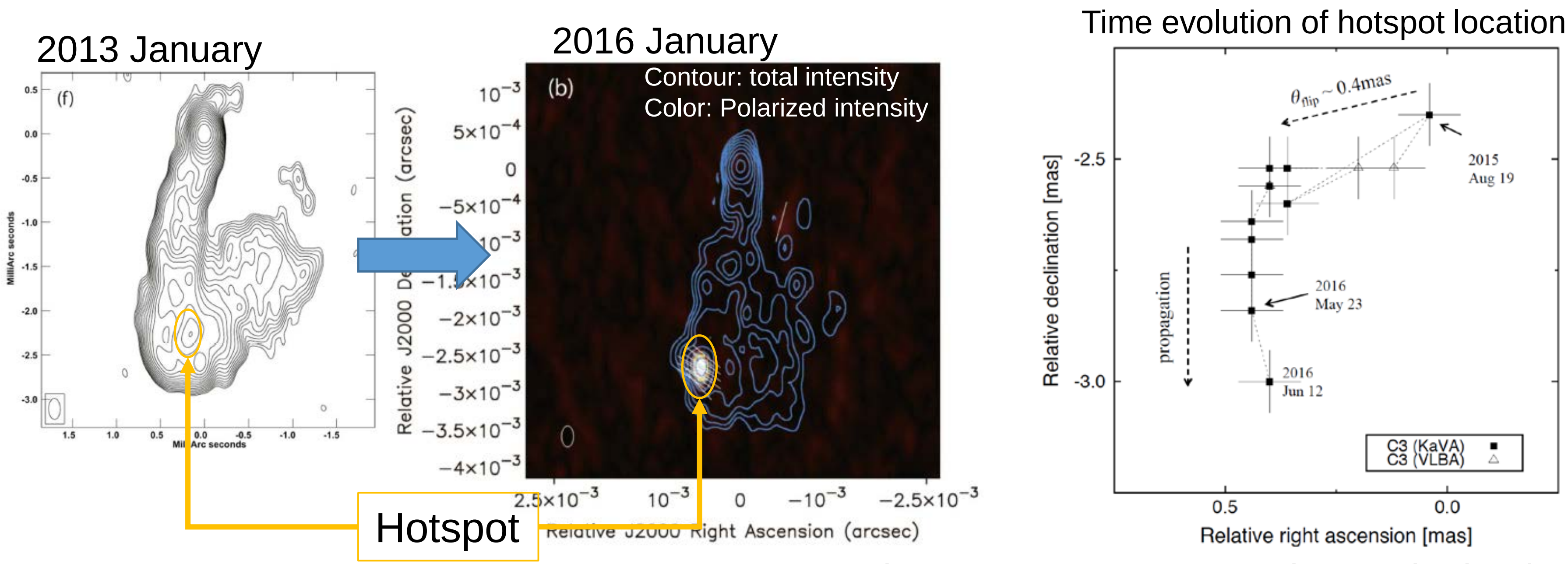

R=600




- Jet-counterjet asymmetry must be caused by FFA (see also Walker+ 2000)
  - $R_{\mathrm{obs}} = R\exp(\tau_{\mathrm{ff}})$
- Optical depth
  - $\tau_{\mathrm{ff}} \propto \nu^{-0.6}$(observation)
  - $\tau_{\mathrm{ff}} \propto \nu^{-2}$(theory for homogeneous medium)
  - The FFA disk may be inhomogeneous



# Jet Interaction with Inhomogeneous Medium




Nagai+ 17

Kino+ submitted

- Detection of hotspot movement with the enhancement of polarized flux
  - Interaction with clumpy/inhomogeneous ambient medium (see also poster by Kino+)
- Measured RM is not consistent with the standard RIAF (Plambeck+ 14; Nagai+ 17)

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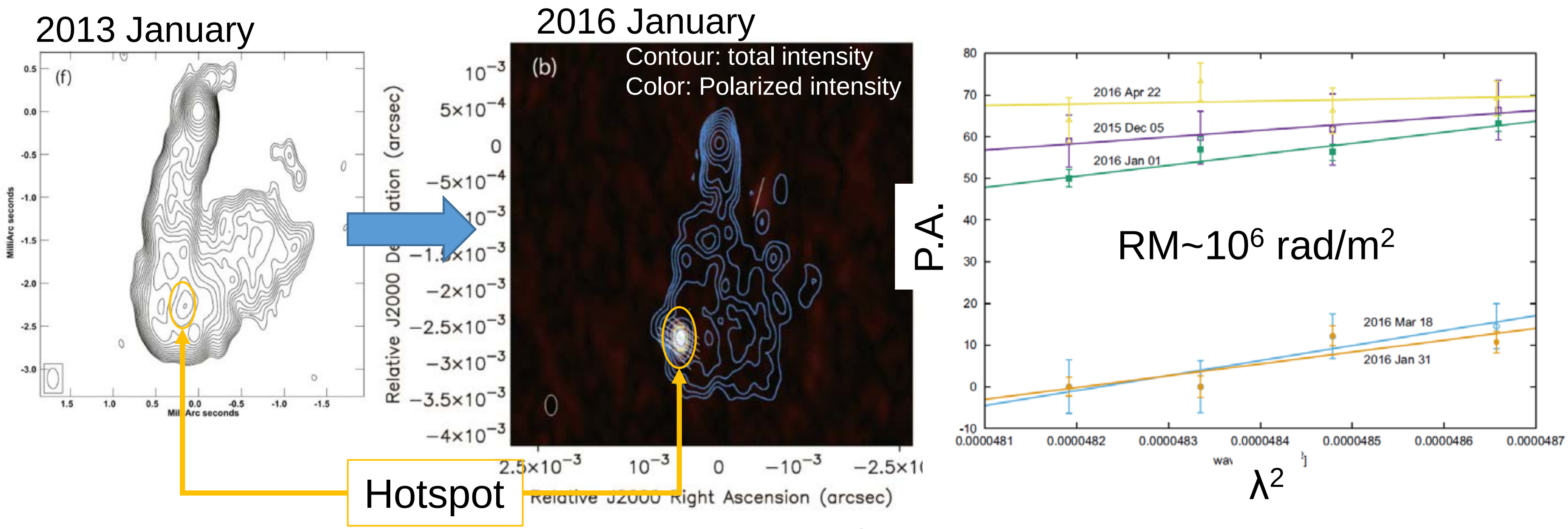


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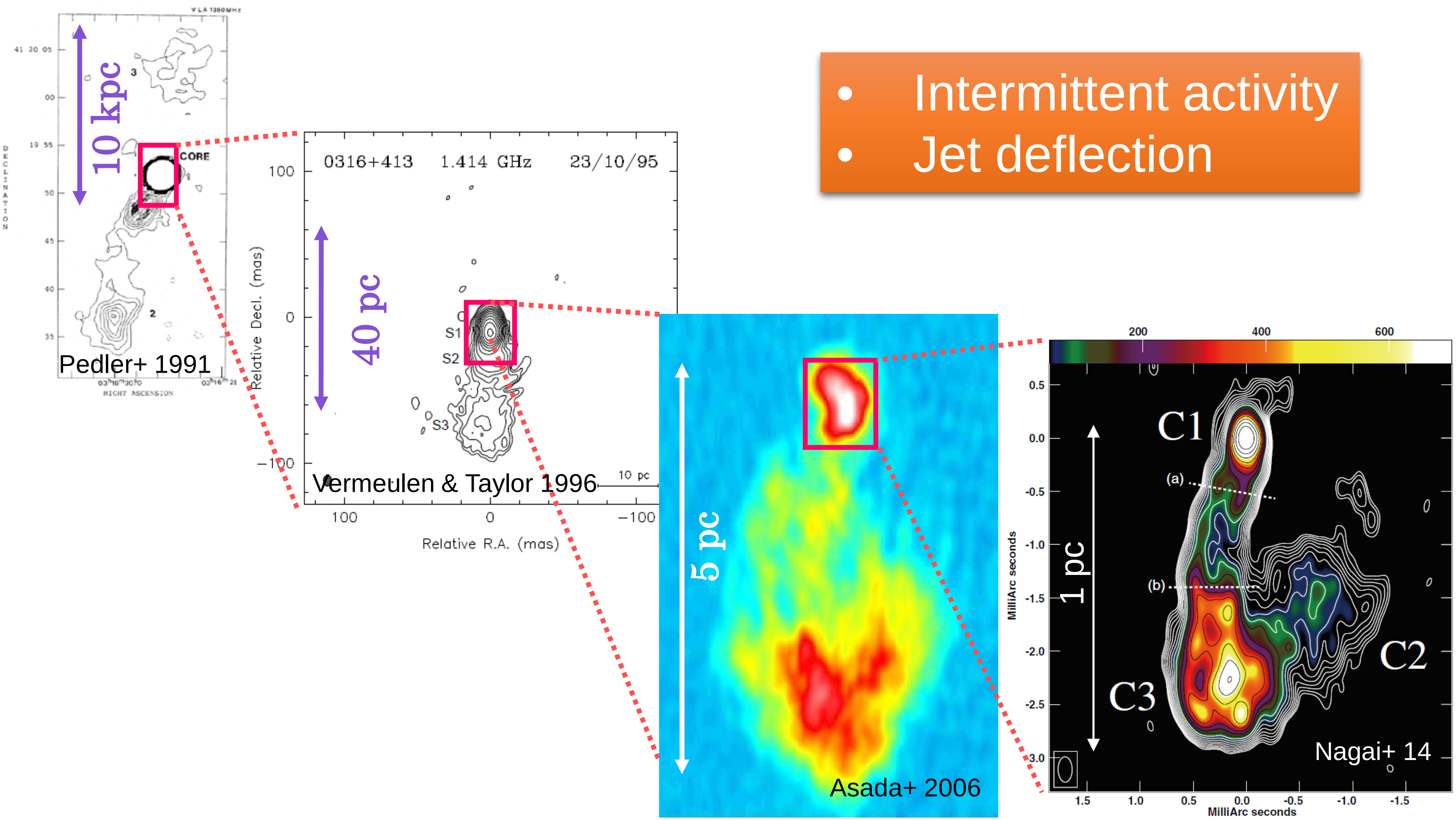
# 3. ALMA Observations of Cold Gas

**Cycle 5 Proposal 2017.1.01257.S**

In collaboration with Keiichi Asada; Yutaka Fujita; Hirofumi Noda; Yasushi Fukazawa; Nozomu Kawakatu; Motoki Kino; Kiyoaki Wajima; Jeremy Lim; William Forman; Jan Vrtilek; Laurence David; Youichi Ohyama

# History of Jet Activities

- Intermittent activity
- Jet deflection



# Chaotic Cold Accretion in BCGs

## Chaotic cold accretion on to black holes

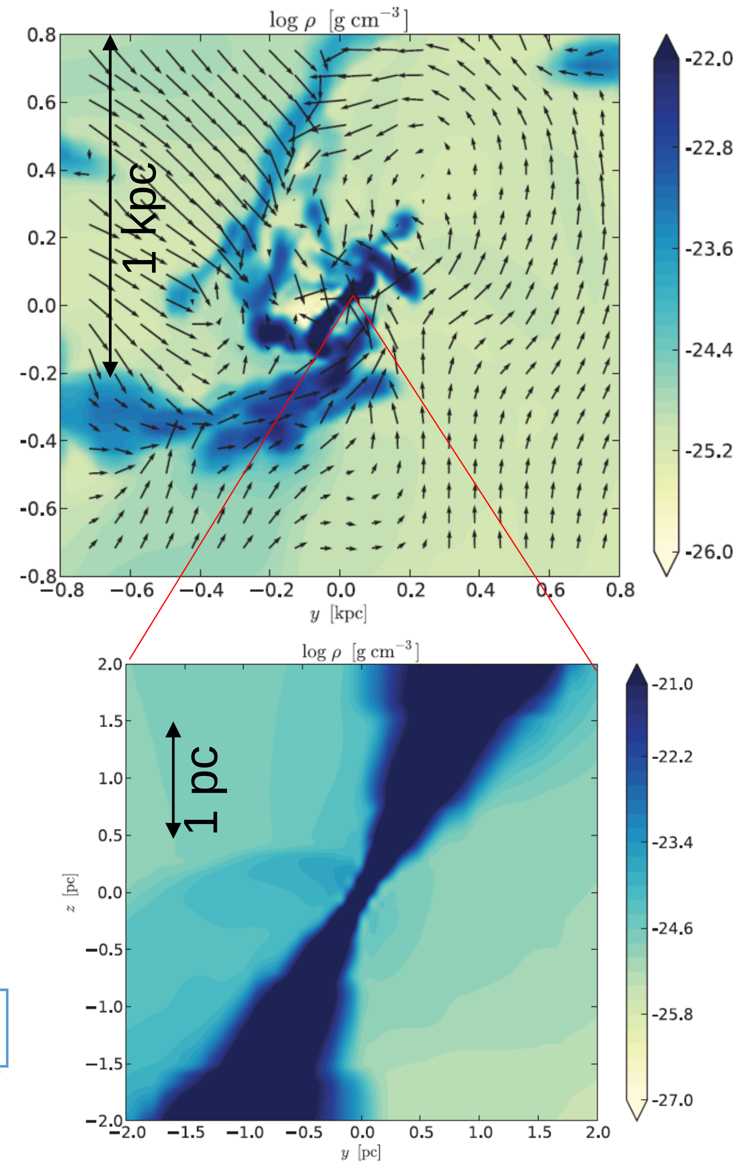
M. Gaspari,[1]★ M. Ruszkowski[2,3] and S. Peng Oh[4]

[1]*Max Planck Institute for Astrophysics, Karl-Schwarzschild-Strasse 1, D-85741 Garching, Germany*
[2]*Department of Astronomy, University of Michigan, 500 Church Street, Ann Arbor, MI 48109, USA*
[3]*The Michigan Center for Theoretical Physics, 3444 Randall Lab, 450 Church Street, Ann Arbor, MI 48109, USA*
[4]*Department of Physics, University of California, Santa Barbara, CA 93106, USA*

Accepted 2013 April 19. Received 2013 April 19; in original form 2013 January 15

**ABSTRACT**

Bondi theory is often assumed to adequately describe the mode of accretion in astrophysical environments. However, the Bondi flow must be adiabatic, spherically symmetric, steady, unperturbed, with constant boundary conditions. Using 3D adaptive mesh refinement simulations, linking the 50 kpc to the sub-parsec (sub-pc) scales over the course of 40 Myr, we systematically relax the classic assumptions in a typical galaxy hosting a supermassive black hole. In the more realistic scenario, where the hot gas is *cooling*, while *heated* and *stirred* on large scales, the accretion rate is boosted up to two orders of magnitude compared with the Bondi prediction. The cause is the non-linear growth of thermal instabilities, leading to the condensation of cold clouds and filaments when $t_{\rm cool}/t_{\rm ff} \lesssim 10$. The clouds decouple from the hot gas, 'raining' on to the centre. Subsonic turbulence of just over 100 km s$^{-1}$ ($\mathcal{M} > 0.2$) induces the formation of thermal instabilities, even in the absence of heating, while in the transonic regime turbulent dissipation inhibits their growth ($t_{\rm turb}/t_{\rm cool} \lesssim 1$). When heating restores global thermodynamic balance, the formation of the multiphase medium is violent, and the mode of accretion is fully *cold* and *chaotic*. The recurrent *collisions* and tidal forces between clouds, filaments and the central clumpy torus promote angular momentum cancellation, hence boosting accretion. On sub-pc scales the clouds are channelled to the very centre via a funnel. In this study, we do not inject a fixed initial angular momentum, though vorticity is later seeded by turbulence. A good approximation to the accretion rate is the cooling rate, which can be used as subgrid model, physically reproducing the boost factor of 100 required by cosmological simulations, while accounting for the frequent fluctuations. Since our modelling is fairly general (turbulence/heating due to AGN feedback, galaxy motions, mergers, stellar evolution), chaotic cold accretion may be common in many systems, such as hot galactic haloes, groups and clusters. In this mode, the black hole can quickly react to the state of the *entire* host galaxy, leading to efficient self-regulated AGN feedback and the symbiotic Magorrian relation. Chaotic accretion can generate high-velocity clouds, likely leading to strong variations in the AGN luminosity, and the deflection or mass-loading of jets. During phases of overheating, the hot mode becomes the single channel of accretion, though strongly suppressed by turbulence. High-resolution data could determine the current mode of accretion: assuming quiescent feedback, the cold mode results in a quasi-flat-temperature core as opposed to the cuspy profile of the hot mode.



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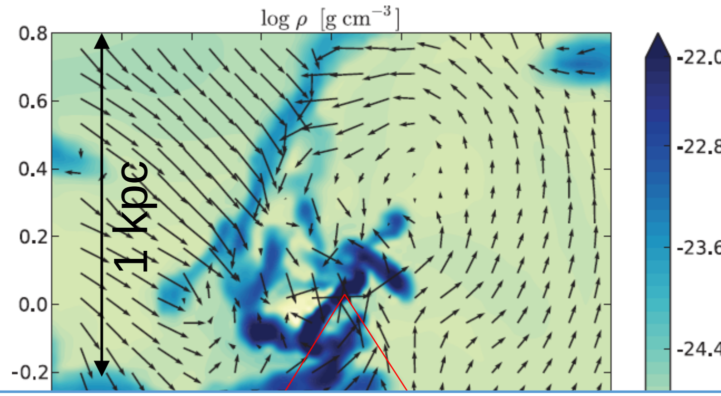


the symbiotic Magorrian relation. Chaotic accretion can generate high-velocity clouds, likely leading to strong variations in the AGN luminosity, and the deflection or mass-loading of jets. During phases of overheating, the hot mode becomes the single channel of accretion, though

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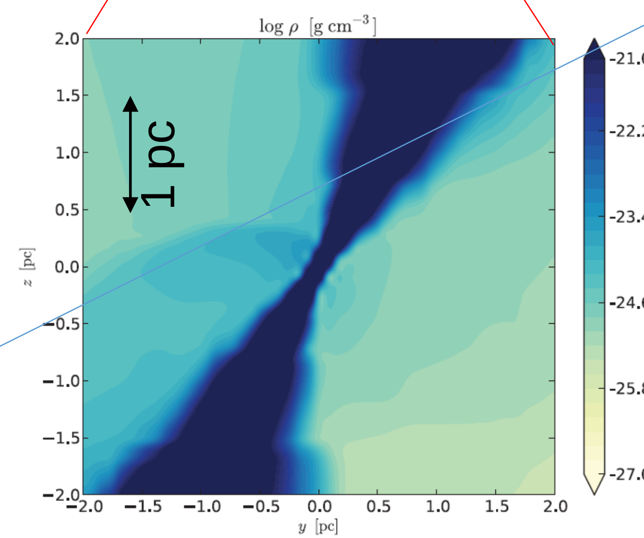
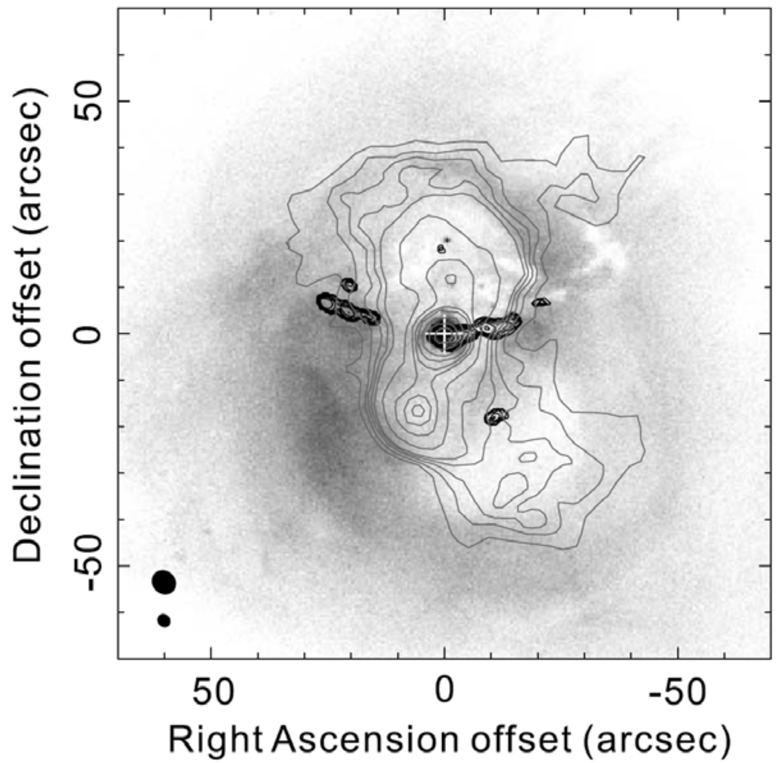
condensation of cold clouds and filaments when $t_{\rm cool}/t_{\rm ff} \lesssim 10$. The clouds decouple from the hot gas, 'raining' on to the centre. Subsonic turbulence of just over 100 km s$^{-1}$ ($M > 0.2$) induces the formation of thermal instabilities, even in the absence of heating, while in the transonic regime turbulent dissipation inhibits their growth ($t_{\rm turb}/t_{\rm cool} \lesssim 1$). When heating restores global thermodynamic balance, the formation of the multiphase medium is violent, and the mode of accretion is fully *cold* and *chaotic*. The recurrent *collisions* and tidal forces between clouds, filaments and the central clumpy torus promote angular momentum cancellation, hence boosting accretion. On sub-pc scales the clouds are channelled to the very centre via a funnel. In this study, we do not inject a fixed initial angular momentum, though vorticity is later seeded by turbulence. A good approximation to the accretion rate is the cooling rate, which can be used as subgrid model, physically reproducing the boost factor of 100 required by cosmological simulations, while accounting for the frequent fluctuations. Since our modelling is fairly general (turbulence/heating due to AGN feedback, galaxy motions, mergers, stellar evolution), chaotic cold accretion may be common in many systems, such as hot galactic haloes, groups and clusters. In this mode, the black hole can quickly react to the state of the *entire* host galaxy, leading to efficient self-regulated AGN feedback and the symbiotic Magorrian relation. Chaotic accretion can generate high-velocity clouds, likely leading to strong variations in the AGN luminosity, and the deflection or mass-loading of jets. During phases of overheating, the hot mode becomes the single channel of accretion, though strongly suppressed by turbulence. High-resolution data could determine the current mode of accretion: assuming quiescent feedback, the cold mode results in a quasi-flat-temperature core as opposed to the cuspy profile of the hot mode.



# Large Amount of Cold Gas

Lim et al. 2008

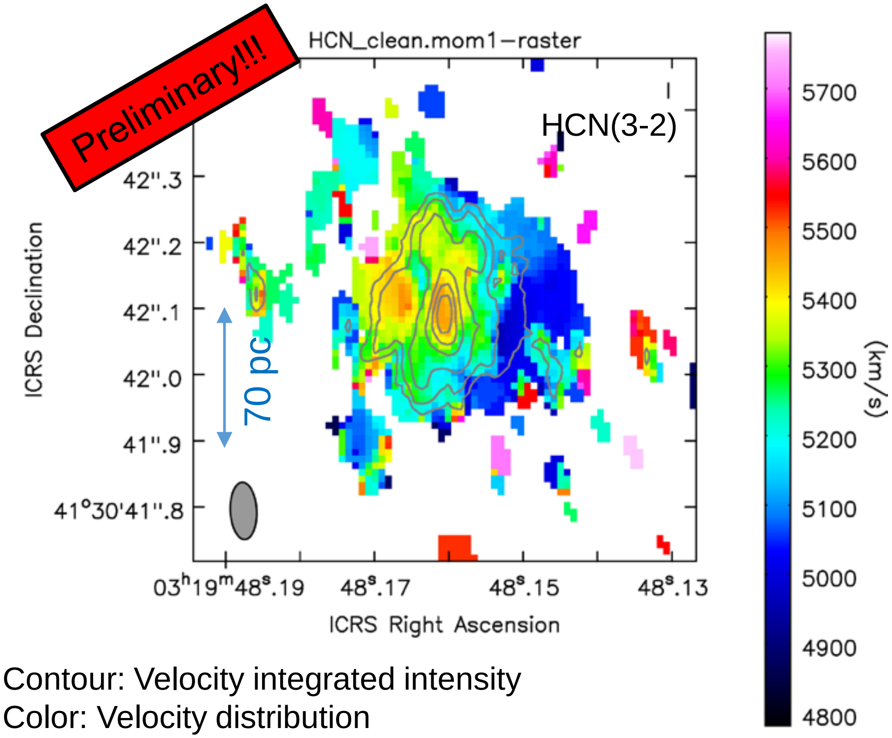


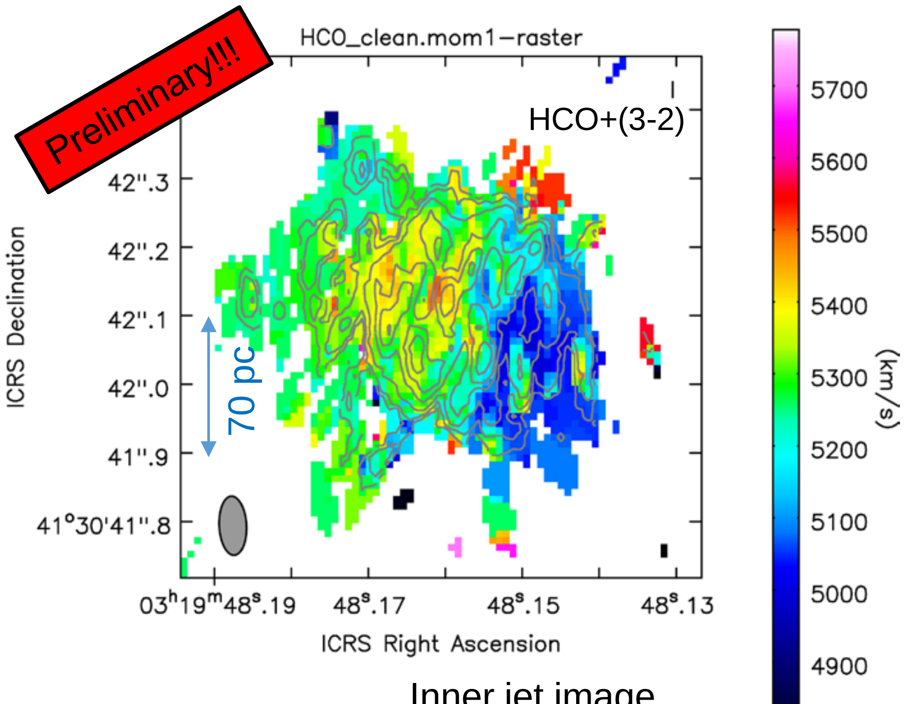

Gray：X-ray
Contour（black）：CO
Contour（gray）：Radio

- CO gas filaments in kpc scale ($10^{10}$ $M_{sun}$)
- Possibly infalling to the center

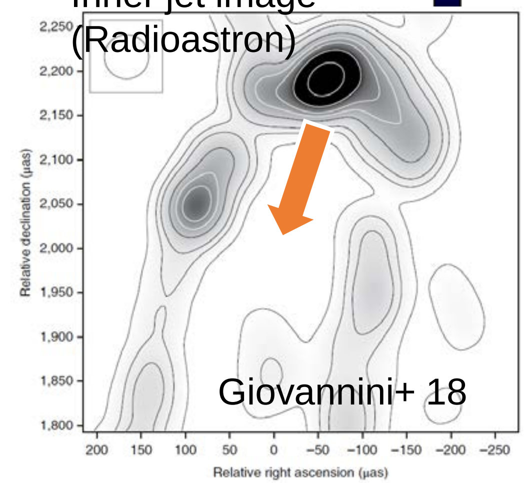

We have ALMA.

# Disk of Cold Molecular Gas



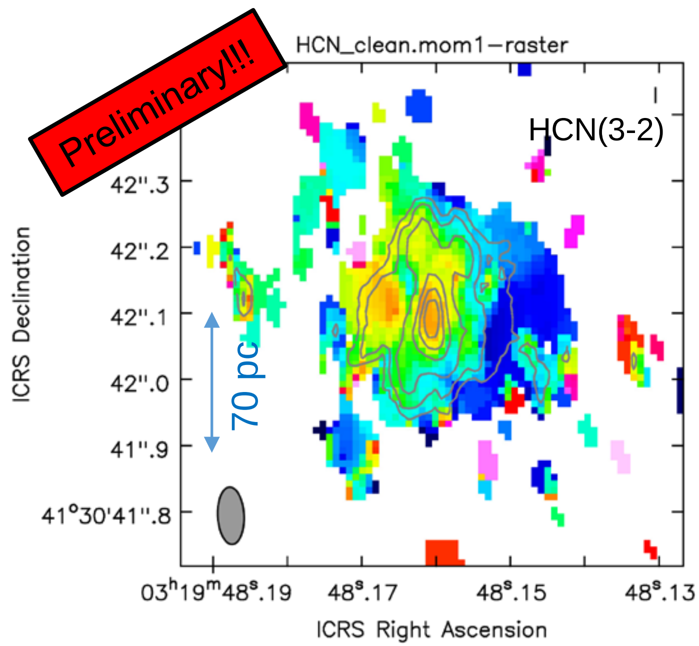



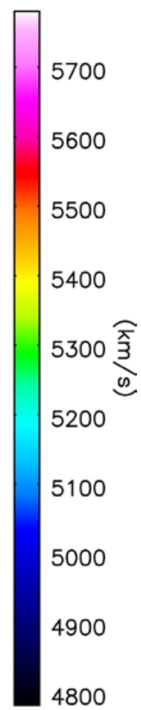

Contour: Velocity integrated intensity
Color: Velocity distribution

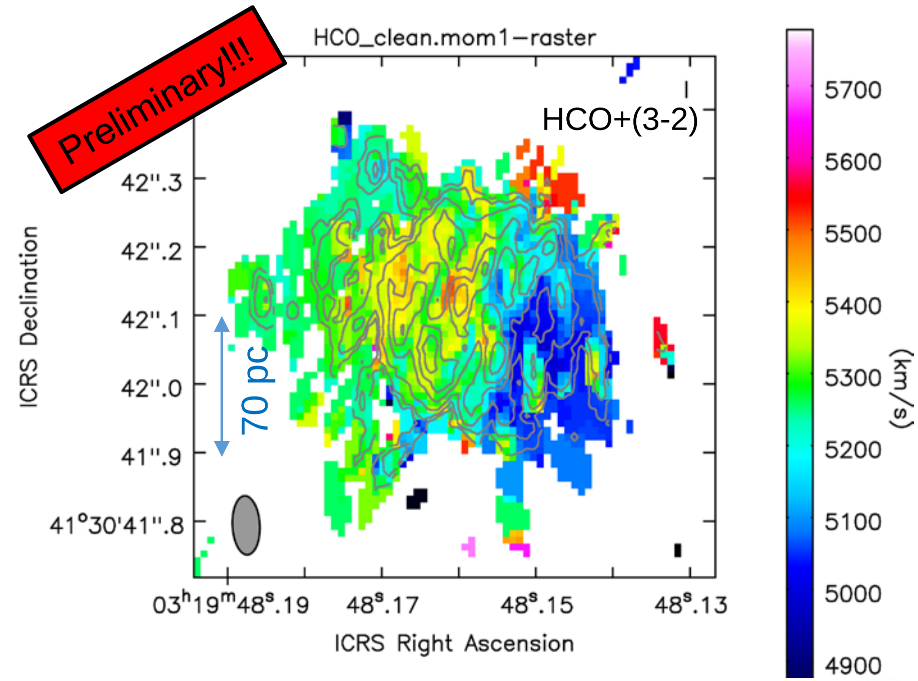



- Detection of the HCN(3-2) and HCO+(3-2) "disk"
  - $\theta_{beam}$=0.086" x 0.024" (30 pc x 14 pc)
- Intensity distribution not smooth
  - Inhomogeneous disk
- Velocity gradient in p.a. ~70 deg, nearly perpendicular to the jet axis in subpc scale

# Disk of Cold Molecular Gas

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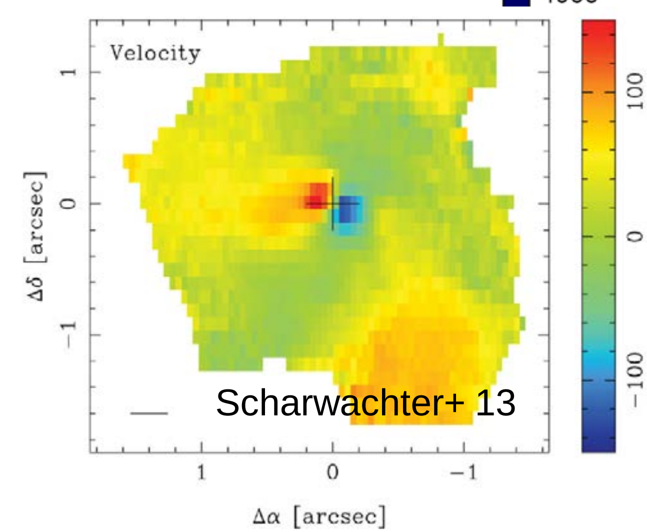
- $v_{sys}$ (=5260km/s) +/- ~200 km/s, roughly consistent with warm $H_2$ gas velocity
- Possible association with the Fe-Kα emitter (Hitomi Collaboration 2018)
- Proposed higher resolution observation for Cy6 to resolve the Bondi radius (8.6 pc)



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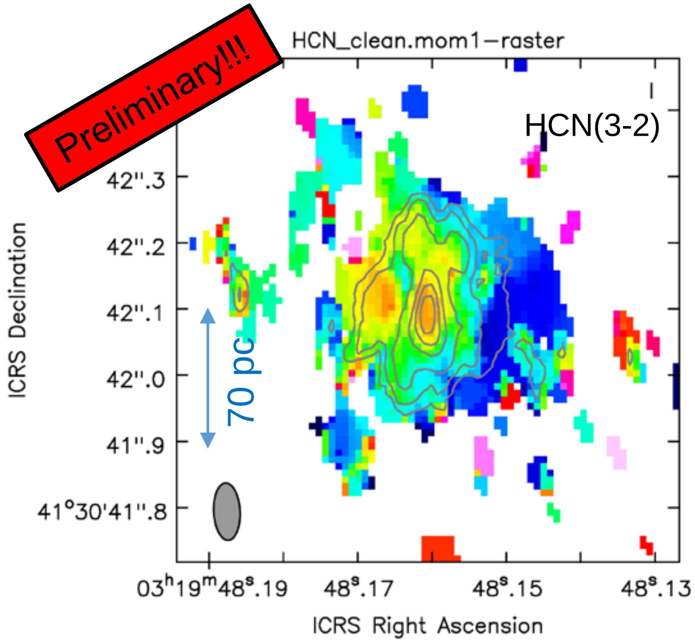


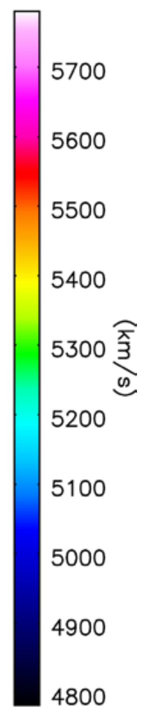


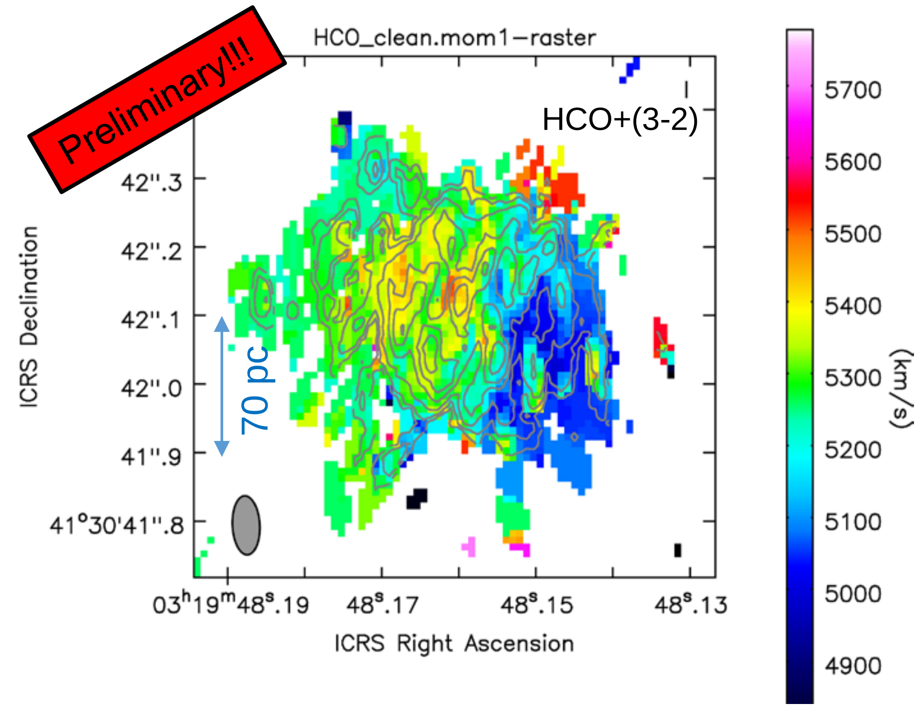


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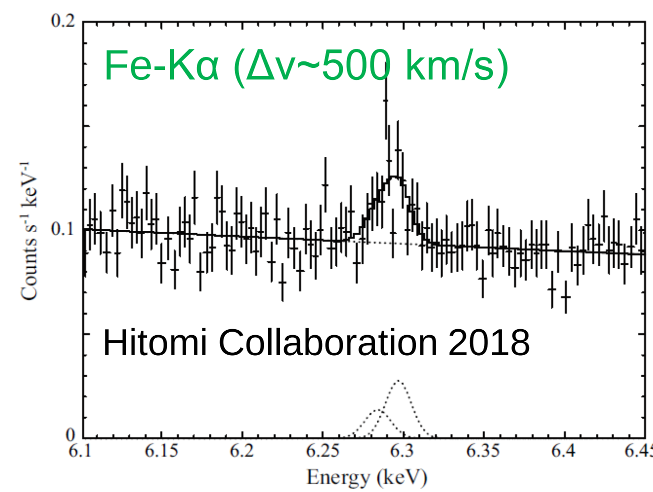
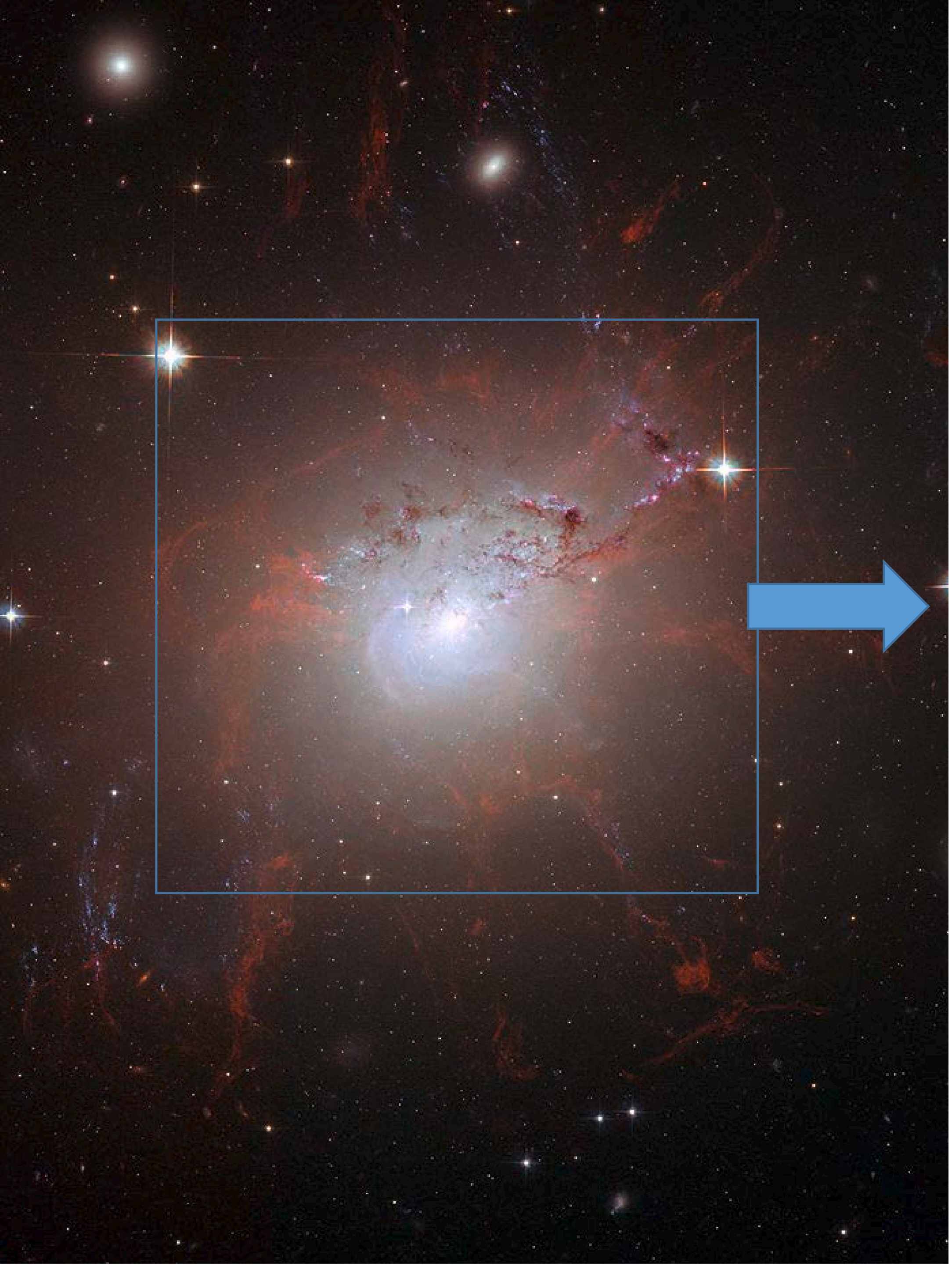


# Take Home Messages

- Radio-Gamma connection, not so simple
  - Jet viewing angle estimated by VLBI observations is not consistent with the misaligned blazar scenario
  - Multiple locations can contribute HE emissions (spine-layer, hotspot/lobe)
- Accretion flow properties
  - Subpc environment is likely inhomogeneous (FFA, hotspot movement, polarization/RM)
  - Not standard RIAF
- ALMA observations of cold molecular gas
  - Revealed the HCN(3-2)/HCO(3-2) disk on tens-pc scale
  - Velocity gradient perpendicular to the subpc jet axis, suggesting disk rotation?
  - Gas distribution is inhomogeneous, as expected by recent numerical simulations



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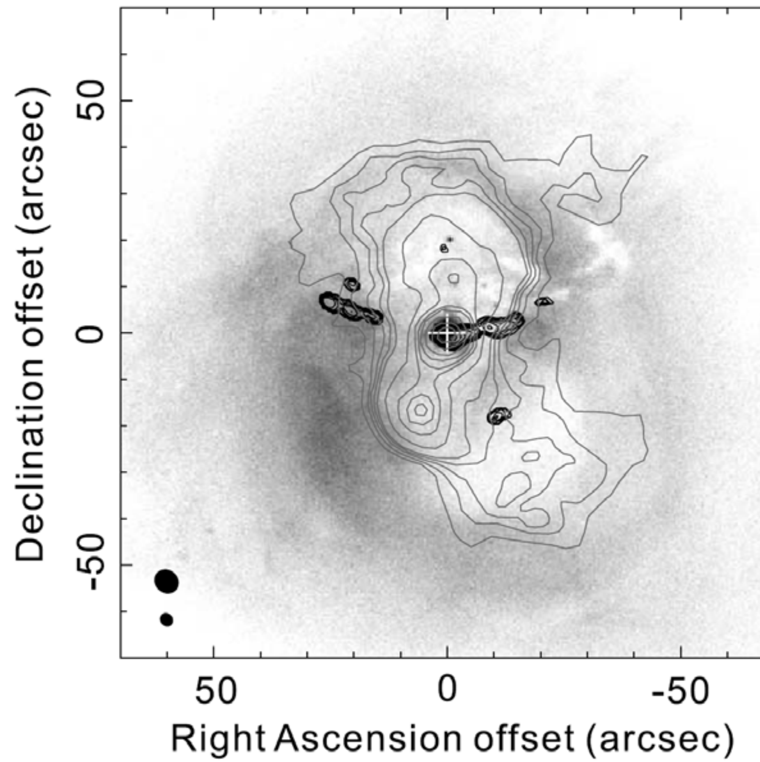


- CO gas filaments in kpc scale ($10^{10}$ $M_{sun}$)
- Possibly infalling to the center
- Partially overlapped with the Hα filaments