F00183-7111:
Are AGNs turned on by mergers?

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F00183-7111: An AGN Dominated ULIRG

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Why this is interesting

- IRAS F00183-7111 is one of the most extreme Ultra Luminous Infrared Galaxies (ULIRGs) known
- ULIRGs are believed to represent a transitional stage towards the formation of dusty quasars (e.g. Armus, Heckman & Miley 1987)
- Understanding the nature of ULIRGs is thus critical to understanding the evolution of galaxies
- Especially when they're relatively close like F00183… ($z = 0.3276$)
- F00183 appears to have been caught just as it's transitioning to quasar-mode (Norris et al. 2012)
- Debates have raged over whether ULIRGs are predominately powered by star-formation (e.g. Genzel et al. 1998) or AGN (e.g. Sanders 1999)
- Let's find out…

ULIRG: What's in a name?

A nose by any other name would still smell… – Reduced Shakespeare Company

- **Ultra** → Very; extremely
- **Luminous** → Full of or shedding light; bright or shining, esp. in the dark
- **Infrared** → Having a wavelength just greater than that of the red end of the visible light spectrum but less than that of microwaves. Infrared radiation has a wavelength from about 800 nm to 1 mm, and is emitted particularly by heated objects
- **Galaxy** → A system of millions or billions of stars, together with gas and dust, held together by gravitational attraction

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ULIRG: What's in a name?

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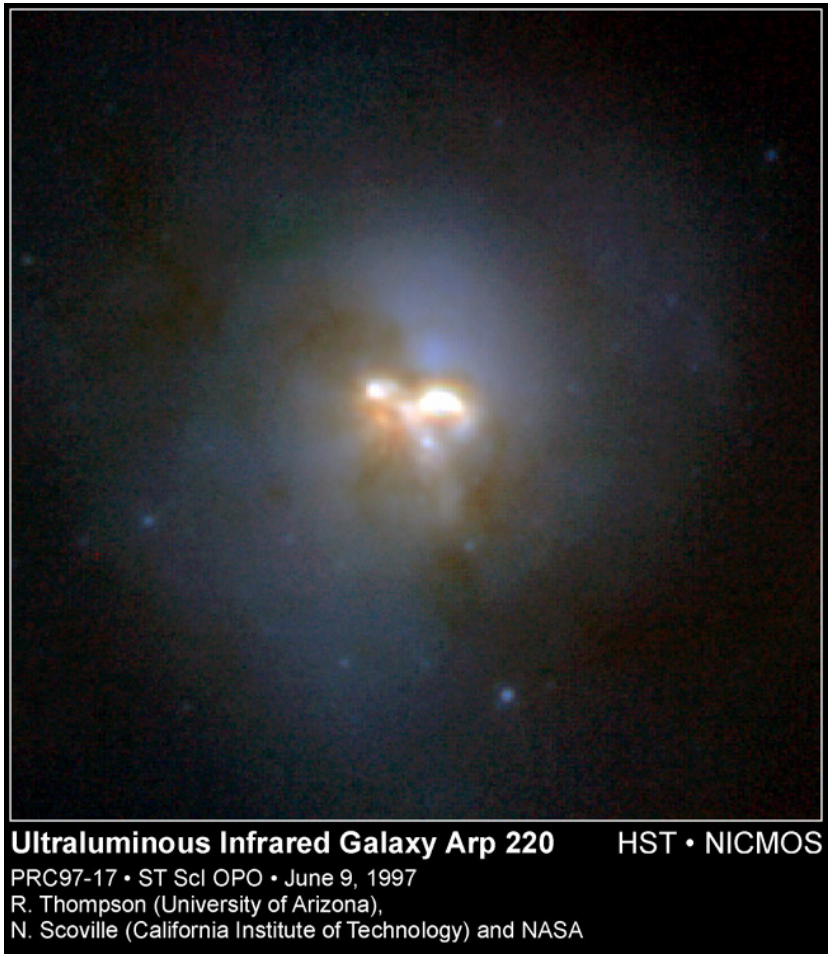
- **A system of millions or billions of stars, together with gas and dust, held together by gravitational attraction** that is **extremely full of or shedding light** that **has a wavelength just greater than that of the red end of the visible light spectrum but less than that of microwaves…**
- IR emission → dusty! – hot dust may be attributed to the UV emission from young hot OB stars, which is being absorbed by the dust and reradiated…
- ULIRGs are galaxies that are extremely star-bursty?

ULIRGs

- Ultra Luminous InfraRed Galaxies
- Extremely Luminous FIR sources (ELFs)
- Classically defined as $L_{IR} > 10^{12} L_{\odot}$
- ULIRGs were first discovered by IRAS almost 30 years ago (Aaronson & Olszewski 1984)
- ULIRGs are believed to be predominately powered by star-formation, but may have a significant contribution by AGN (e.g. Lonsdale 2006)
- Veilleux et al (2009) find that the average AGN contribution to the bolometric luminosity is ~35 – 40%
- The closest ULIRG to us is Arp 220 (z = 0.018)



ULIRGs

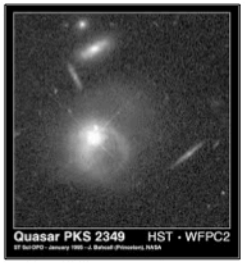
- Current observations suggest that ULIRGs are formed as a result of the merger of two gas-rich spirals (Sanders et al. 1988)
- The merger scenario for ULIRGs triggers “cold-mode” accretion onto the central black hole
- The dusty, gas-rich spiral galaxies feed the black hole resulting in its rapid growth
- This leads to powerful quasar winds that quench star-formation (e.g. Hopkins et al. 2008), which drives the black hole’s fuel away thus starving both the AGN and the star-formation
- The AGN now accretes hot gas inefficiently resulting in “hot-mode” accretion

ULIRGs

Spiral Galaxies

Interaction / Early Stage Merger LIRG

Late Stage Merger ULIRG



Quasar

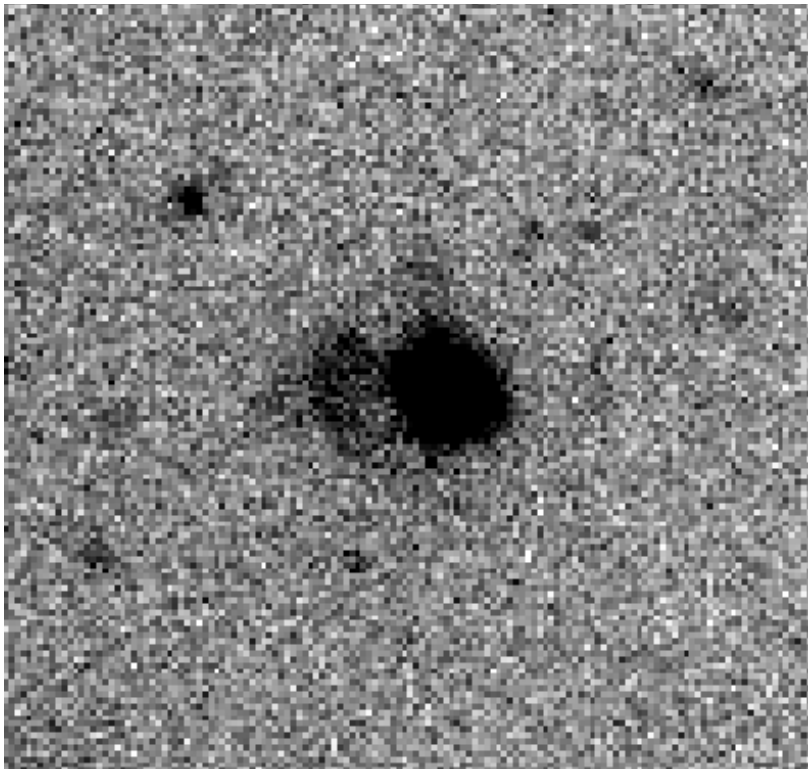
Elliptical Galaxy

Image credit: CANDELS

ULIRGs are believed to be an evolutionary stage of the classic double-lobed radio galaxies we see in the local Universe

IRAS F00183-7111

- F00183 is one of the most luminous sources discovered by IRAS!
- z = 0.3276 (Roy & Norris 1997)
- $S_{70\mu m}$ = 1.5 Jy
- $L_{8\text{-}1000\mu m} = 9 \times 10^{12}\ L_{\odot}$ (Spoon et al. 2009)
- $L_{4.8GHz} = 3 \times 10^{25}$ W/Hz (Roy & Norris 1997)



IRAS F00183-7111

- One of the best ways of distinguishing between star-formation and AGN is the use of VLBI.
- Recently, Norris et al (2012) detected F00183 at 2.3 GHz using the LBA
- The LBA image displays a classical core-jet morphology
- The morphology and spectral index are both consistent with Compact Steep Spectrum (CSS) sources (O'Dea 1998)
- CSS sources are widely thought to represent an early stage of evolution of radio galaxies (e.g. Randall et al. 2011)

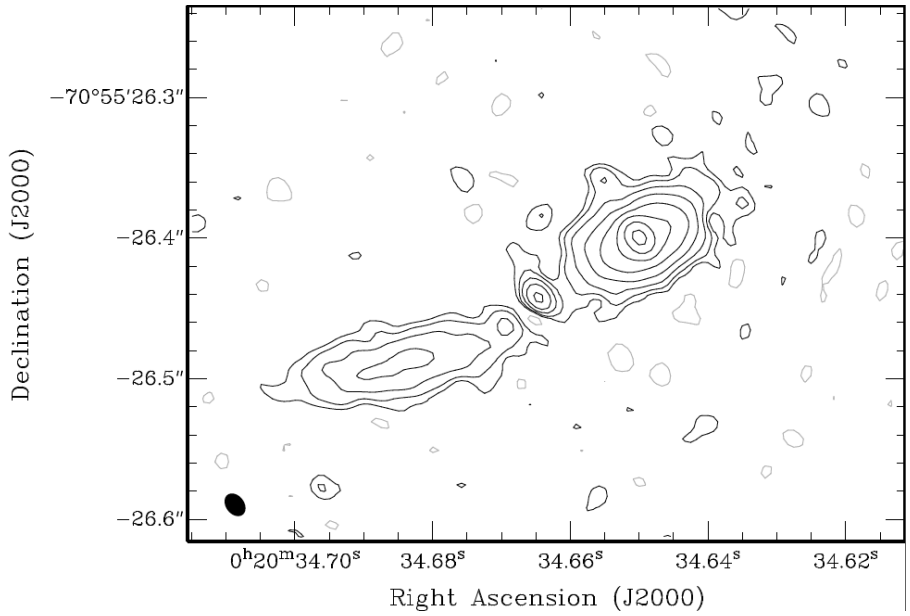


Image: Figure 1 from Norris et al. 2012. Naturally weighted 2.3 GHz LBA image of F00183. The peak flux is 45 mJy/beam and the source has a total integrated flux of 178 mJy.

IRAS F00183-7111

- F00183 is believed to have been caught in the brief transition period between merging starburst and radio-loud "quasar-mode" accretion (Norris et al. 2012)

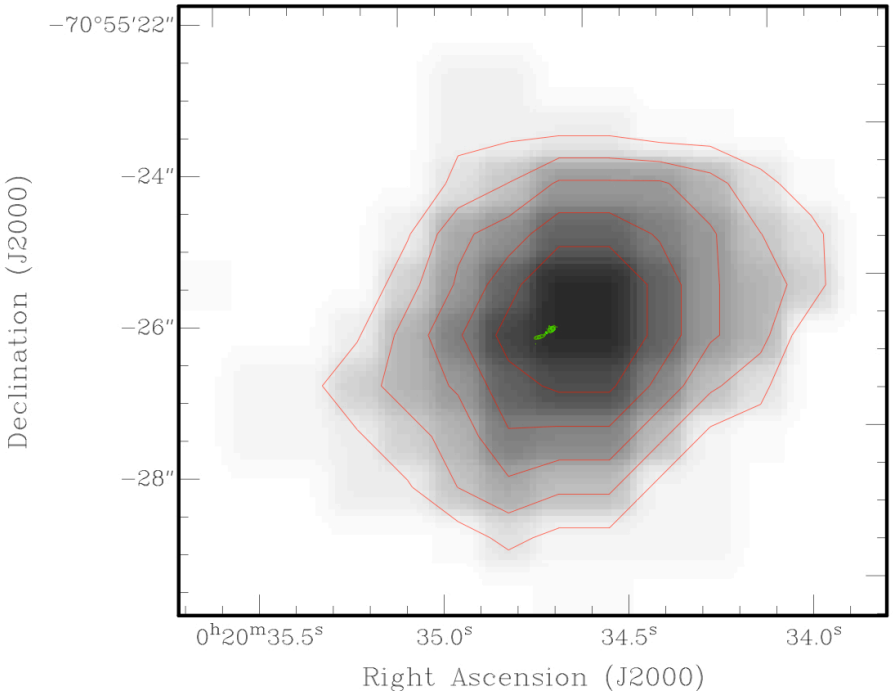


Image: Figure 3 from Norris et al. 2012. UKST R-band image of F00183. The green contours show the location of the LBA detection

CO(1–0)

- Molecular hydrogen (H2) is a key ingredient to forming stars
- However, unless shocked or heated to very high temperatures, H_2 is very difficult to see due to its strongly forbidden rotational transitions
- H_2 may be traced by carbon monoxide (CO), which emits strong rotational transition lines that occur primarily through collisions with H_2.
- CO traces the star-formation and is NOT contaminated by the presence of AGN
- At z = 0.3276, CO(1-0) is redshifted into the 3mm observing band on the Australia Telescope Compact Array.

ATCA

- **A**ustralia **T**elescope **C**ompact **A**rray
- Located in Narrabri, NSW (~6h drive from Sydney)
- 6 x 22m antennas
- 6km maximum baseline
- Operates from 1GHz to 106GHz in 5 discrete bands (~3mm – 30cm)
- In 2009, ATCA was upgraded with the Compact Array Broadband Backend (CABB)
- Operated by the CSIRO Astronomy and Space Science (CASS) division and is part of the Australia Telescope National Facility (ATNF)

CABB

- **C**ompact **A**rray **B**roadband **B**ackend
- Wilson et al. (2011)
- Pre-CABB instantaneous bandwidth: 2 x 128MHz
- CABB instantaneous bandwidth: 2 x 2GHz (full Stokes)
- 16-fold increased in bandwidth! → 4-fold increase in continuum sensitivity

- CABB's increased sensitivity has substantially advanced the science capabilities of the ATCA!

CO(1–0) in F00183

- Measuring the reservoir of molecular gas in F00183 will enable us to estimate the contribution by star-formation of the overall energy budget *without* contamination of AGN
- If all the IR luminosity were due to star-formation we would expect an extremely strong CO(1-0) detection…

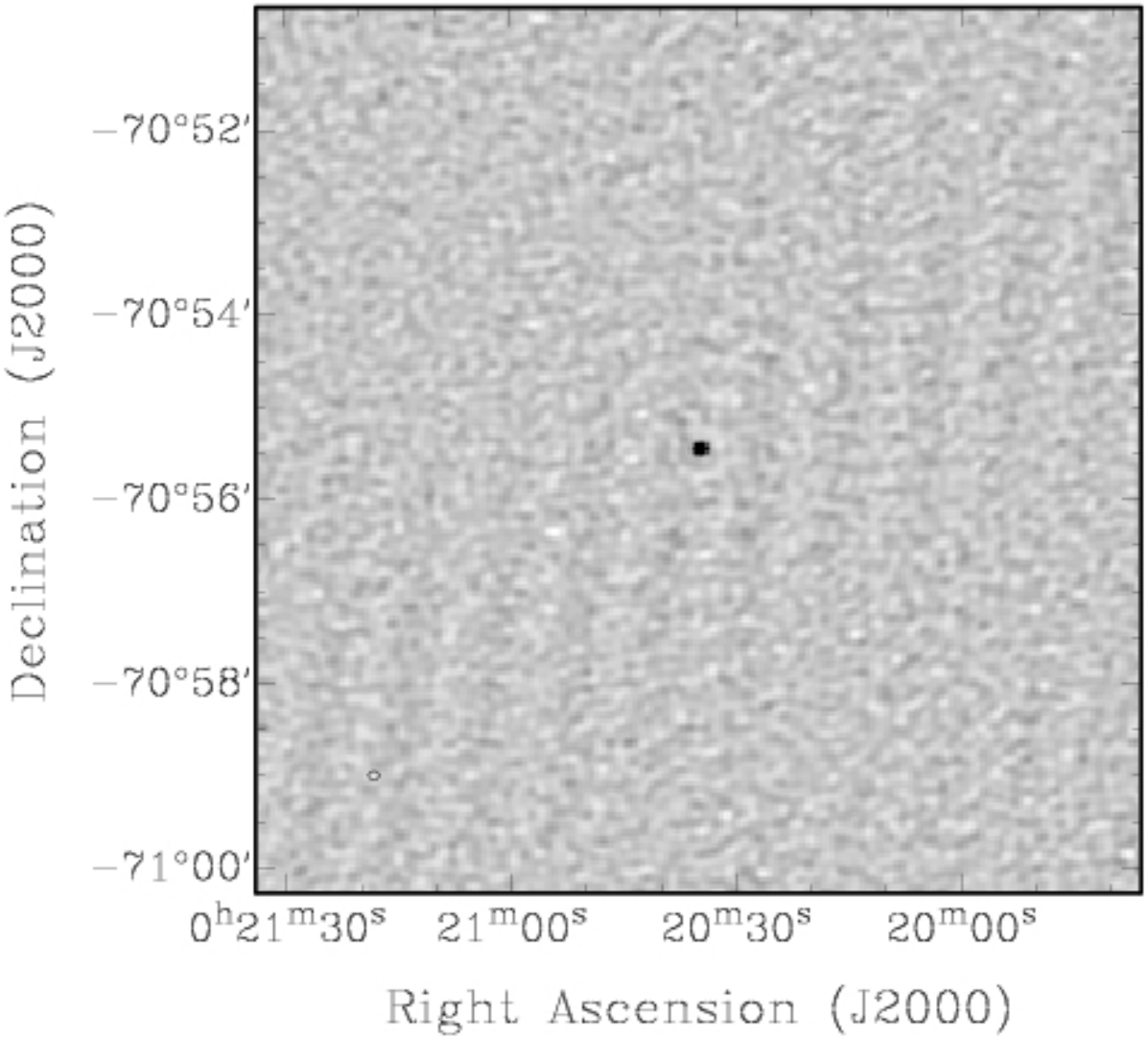
Huge-normous star-formation?

- $L_{8\text{-}1000\mu m} = 9 \times 10^{12}\ L_{\odot}$ (Spoon et al. 2009)
- If powered solely by star-formation this would imply a SFR of ~1600 $M_{\odot}$/year!
- $L_{2\text{-}10keV} \sim 2 \times 10^{44}$ erg/s (Nandra & Iwasawa 2007)
- If powered solely by star-formation this would imply a SFR of >12000 $M_{\odot}$/year!

CO(1–0) in F00183

- 4 x 12h in H75 (PI: Norris)
- October 2011
- 7.4 arcsec spatial res
- 2 x 2 GHz, 1 MHz resolution → ~3.5km/s
- Observing frequency: 115.271/(1+z) = 86.8 GHz
- Effective on source time ~25h

CO(1–0) in F00183



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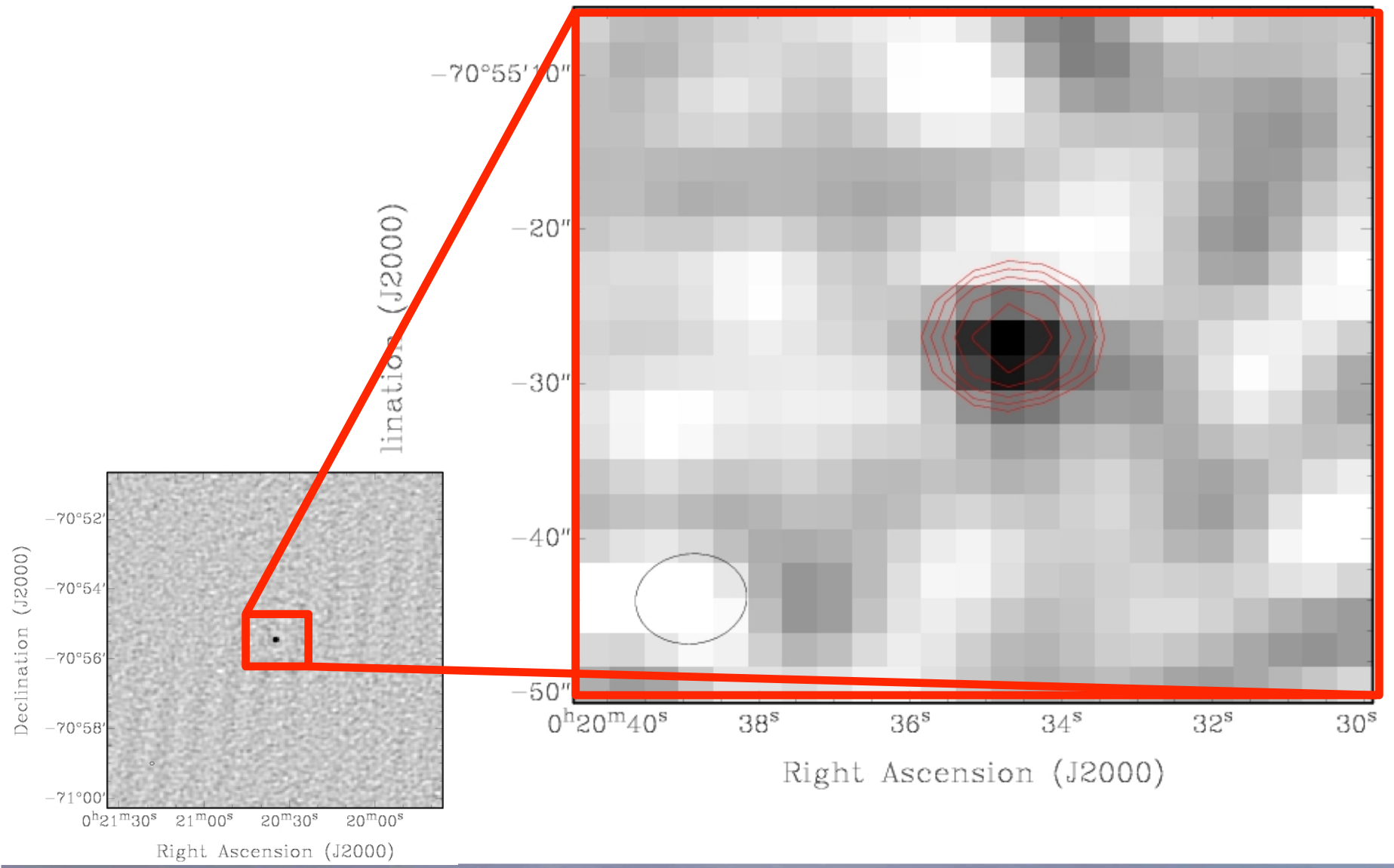

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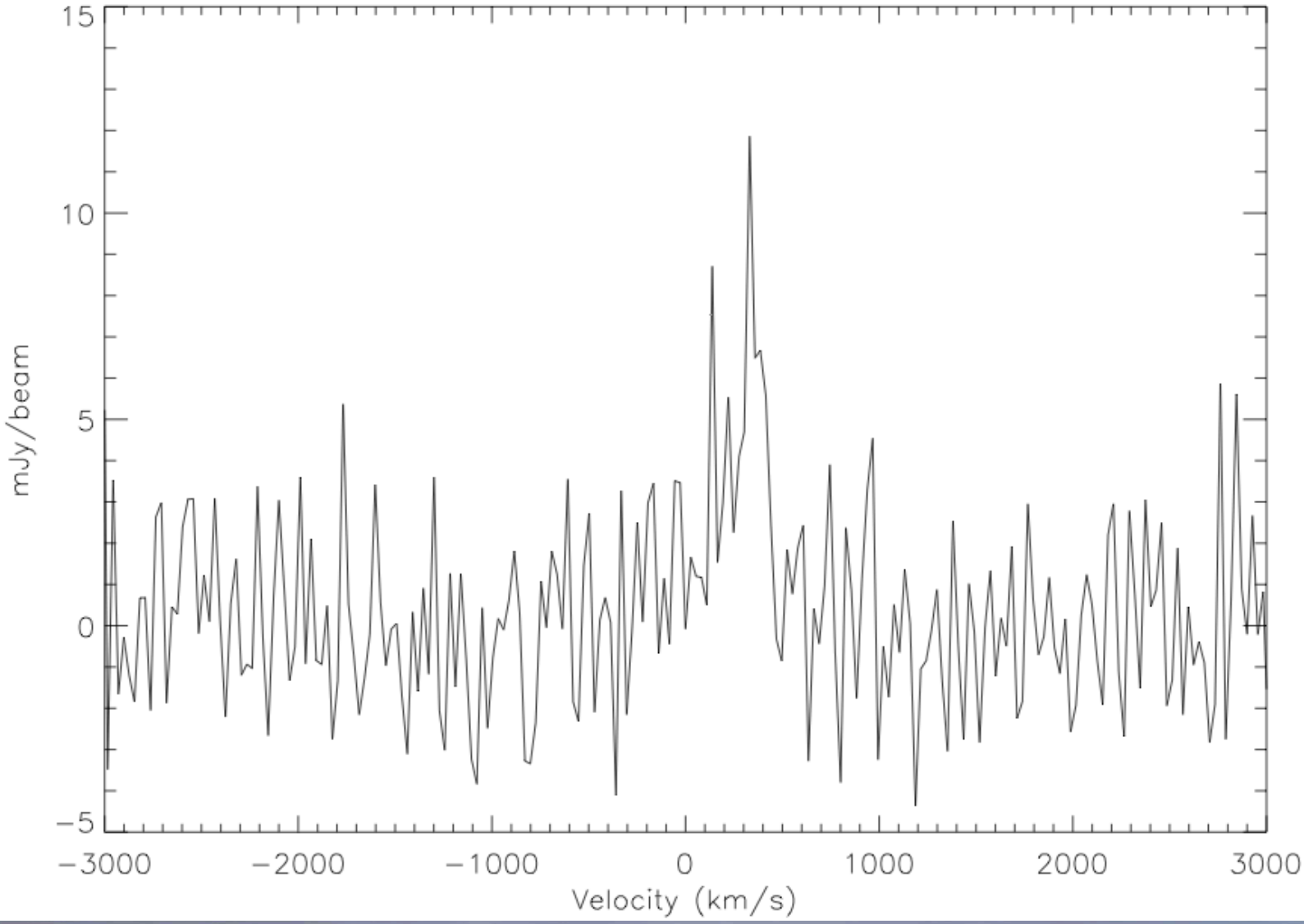

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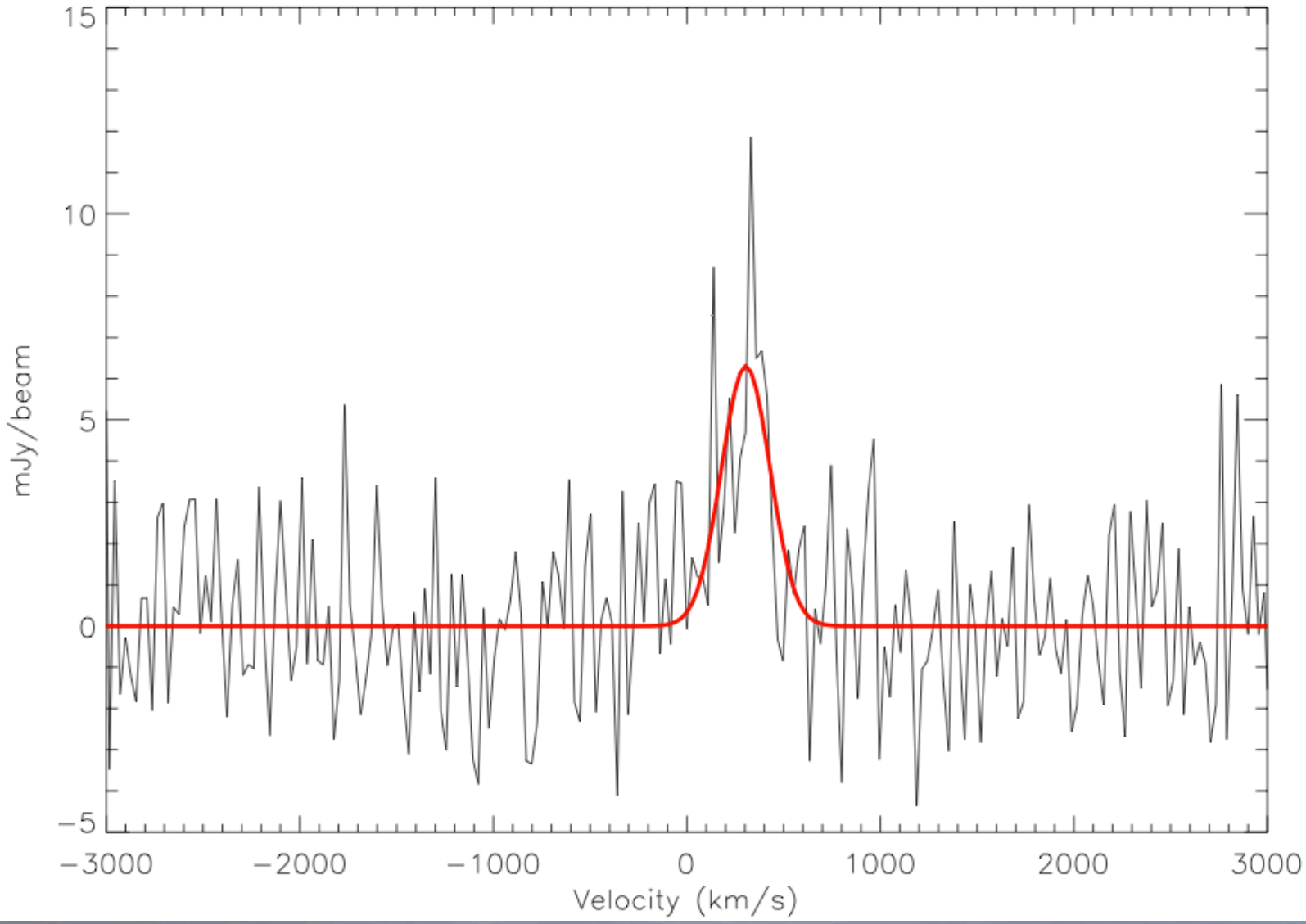

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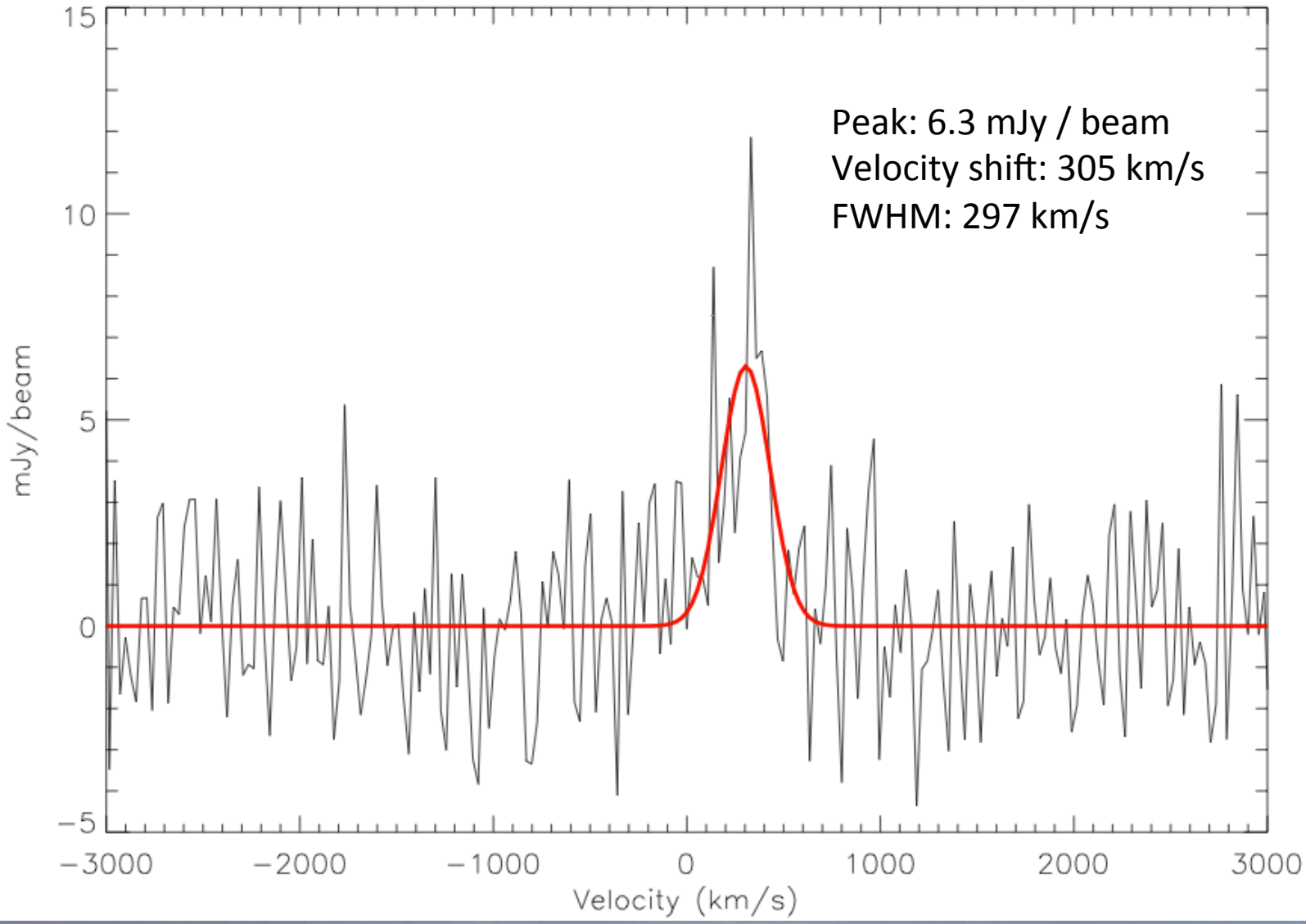
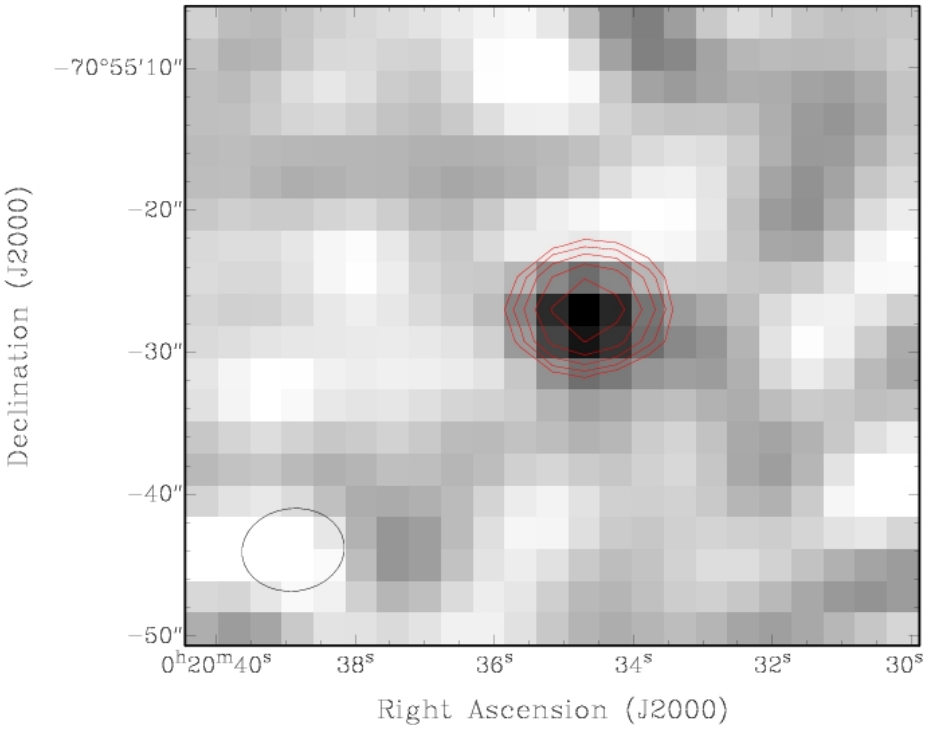


CO(1–0) in F00183

- Spatially unresolved
- $L'_{CO} = 1.25 \times 10^{10}$ K km/s pc^2
- $M_{H2} = 1 \times 10^{10}\ M_\odot$ ($\alpha_X = 0.8\ M_\odot$, Downes & Solomon 1998)
- Implies SFR ~220 $M_\odot$/year (e.g. Carilli & Walter 2013)
- Only 14% of the total power is contributed by star-formation



But there's a whopping great AGN…

- Norris et al. (2012) find a 10^{25} W/Hz AGN core
- Nandra & Iwasawa (2007) calculate that the AGN contributes >80% of the total IR luminosity
- Ranalli et al. (2003) infer the SFR from the soft X-ray luminosity to be 310 $M_{\odot}$/year
- Spoon et al. (2004) find that star-formation contributes only *up to* 30% of the total IR luminosity…

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Consistent-ish SFRs

- Despite the extremely high infrared luminosity, near and mid-IR diagnostics suggest that no more than 30% is due to star-formation
  - <30% of 9 x 10^{12} $L_\odot$ =~<3 x 10^{12} $L_\odot$ → SFR ~<540 $M_\odot$/year
  - Recall that this is an upper limit
- X-ray diagnostics suggest the SFR is ~310 $M_\odot$/year
- The CO luminosity we derive from our ATCA observations suggest the SFR is 220 $M_\odot$/year
- F00183 is still very star-bursty but no longer super insanely so…

What this means and what next?

- F00183 harbours both a powerful AGN and large amounts of star-formation…
- …but not as large as we had thought
- If the evolutionary scenario is believed, this suggests that F00183 is at a late stage in its merger and the star-formation is ramping down as the AGN ramps up
- That is, all evidence is consistent with the AGN in F00183 transitioning between quasar-mode and radio-mode

F00183-7111

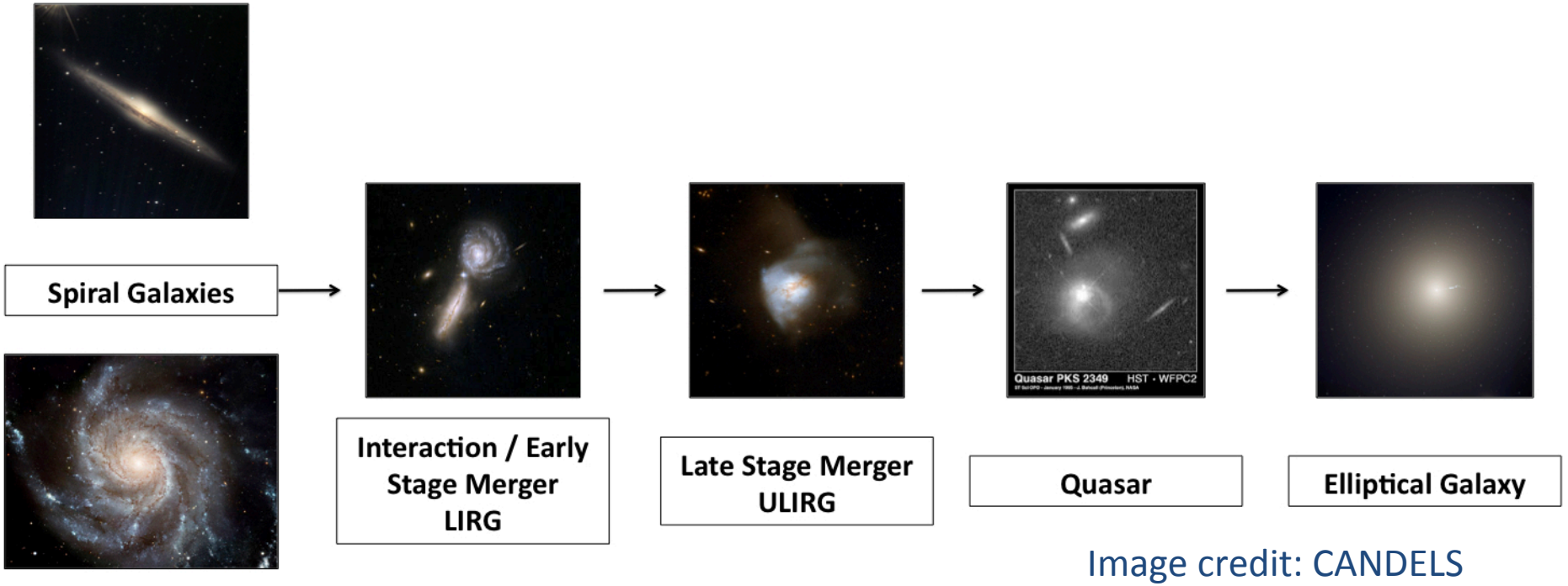

Image credit: CANDELS

F00183 may represent objects that are at the end of their "ULIRG" period…

F00183-7111

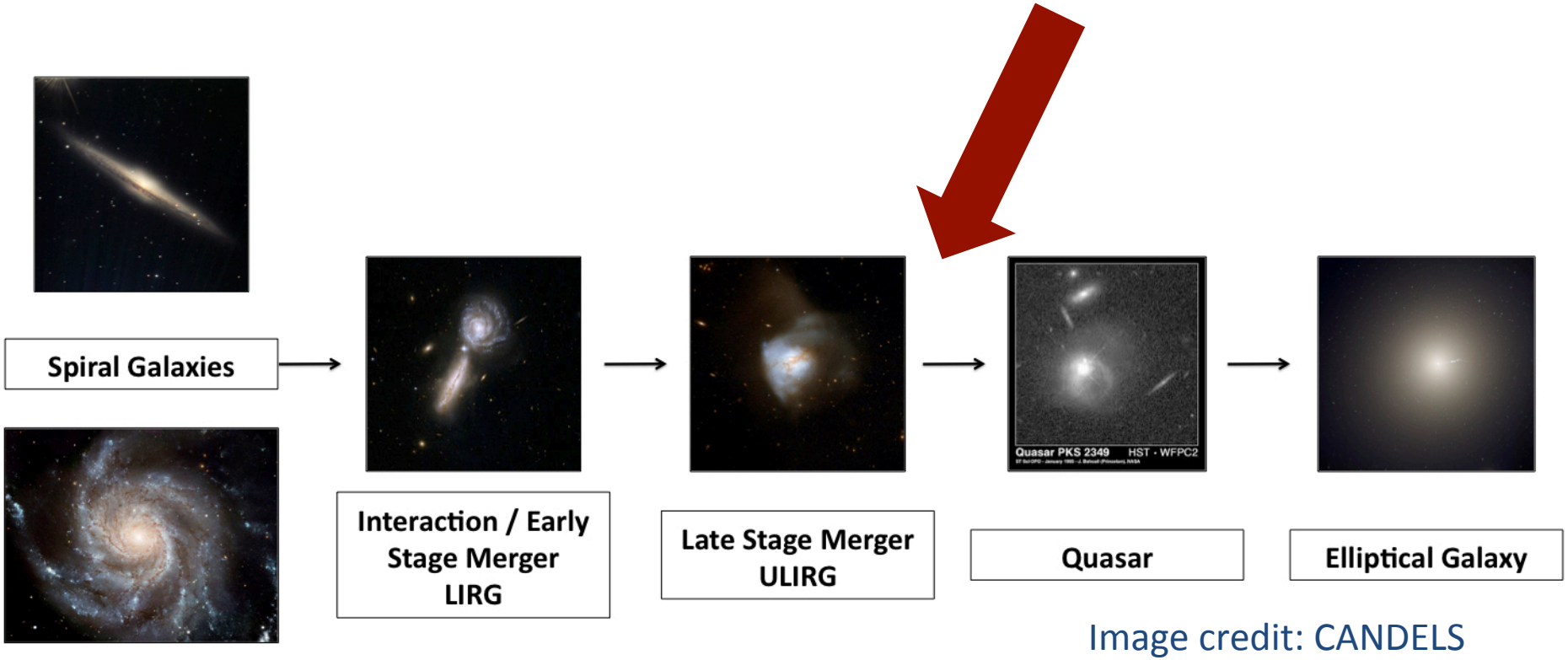

Image credit: CANDELS

F00183 may represent objects that are at the end of their "ULIRG" period…

What this means and what next?

- The majority of ULIRGs studied to date are star-formation dominated
- The contribution to the total energy budget by AGNs discovered in ULIRGs appears to vary greatly
- Lonsdale et al. 1995 find a relation between core radio power and bolometric luminosity for radio-quiet QSOs
- What is the incidence of radio-loud sources in ULIRGs?
- Hypothesis: ULIRGs harbouring radio-loud sources in their cores should have a smaller contribution from star-formation to their total infrared luminosity.

What this means and what next?

- **Hypothesis**: ULIRGs harbouring radio-loud sources in their cores should have a smaller contribution from star-formation to their total infrared luminosity.
- **How can we test this in the radio regime?** CO traces star-formation while (at high enough redshifts) a VLBI continuum detection is almost certainly due to the presence of an AGN. Using these two diagnostics with a sample of ULIRGS should enable us to determine the contribution of each to the total energy budget…

Summary/Conclusions

- We have detected CO(1-0) in F00183 and the CO luminosity we derive suggest the SFR is 220 $M_{\odot}$/year
- This is consistent with IR and X-ray studies of this object
- We find this ULIRG to be AGN dominated and suggest this source is nearing the end of its “ULIRG” phase and thus star-formation may be ramping down
- The relative scarcity of AGN dominated ULIRGs may attest to how short-lived this period may be…