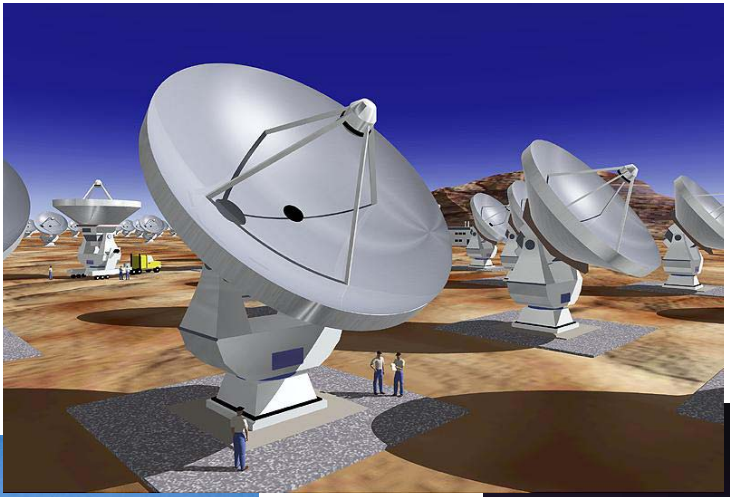
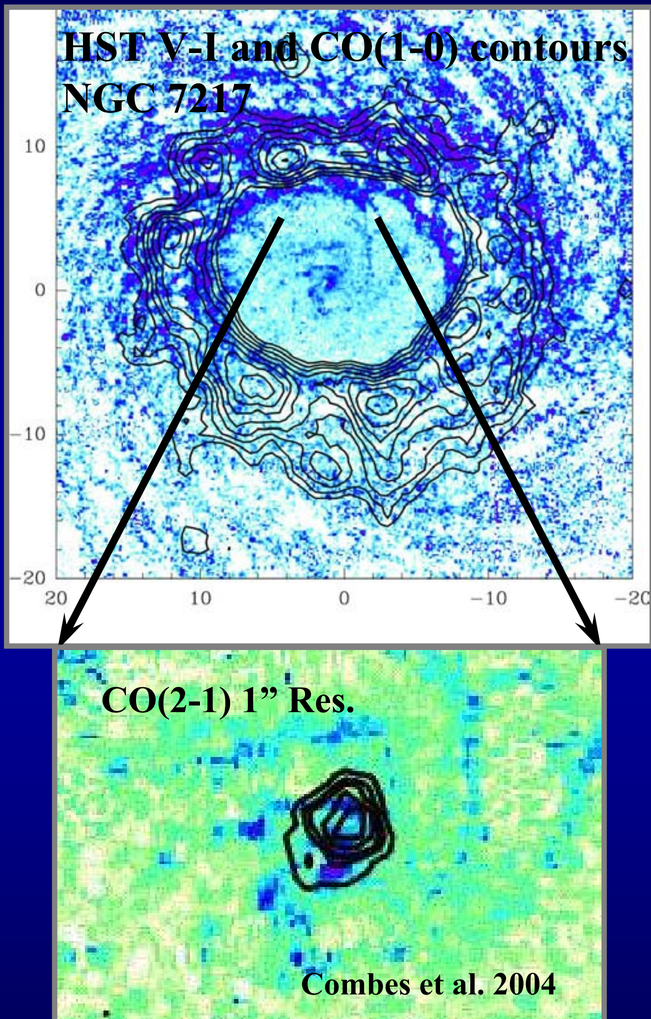
Molecular Gas in Galaxy Nuclei: Inward and Upward Bound

Linda Tacconi, MPE, Garching



Alma Community Day, 24 September 2004

Current State of the Art: Circumnuclear Gas Concentrations at 50- Few 100 pc Scales



~35-40 galaxies with spatial resolutions < 300 pc: Interferometric CO Surveys

BIMA SONG: 44 spirals
Regan et al. 01, Helfer et al. 03; Sheth et al 03

OVRO/Main: 40 CO bright spirals, starbursts, AGN
Sakamoto et al 99; Baker 00;Jogee et al 01, 03

IRAM NUGA: >20 AGN 50-100 pc resolution
Garcia-Burillo et al. 03, Combes et al. 04, Krips et al 2004

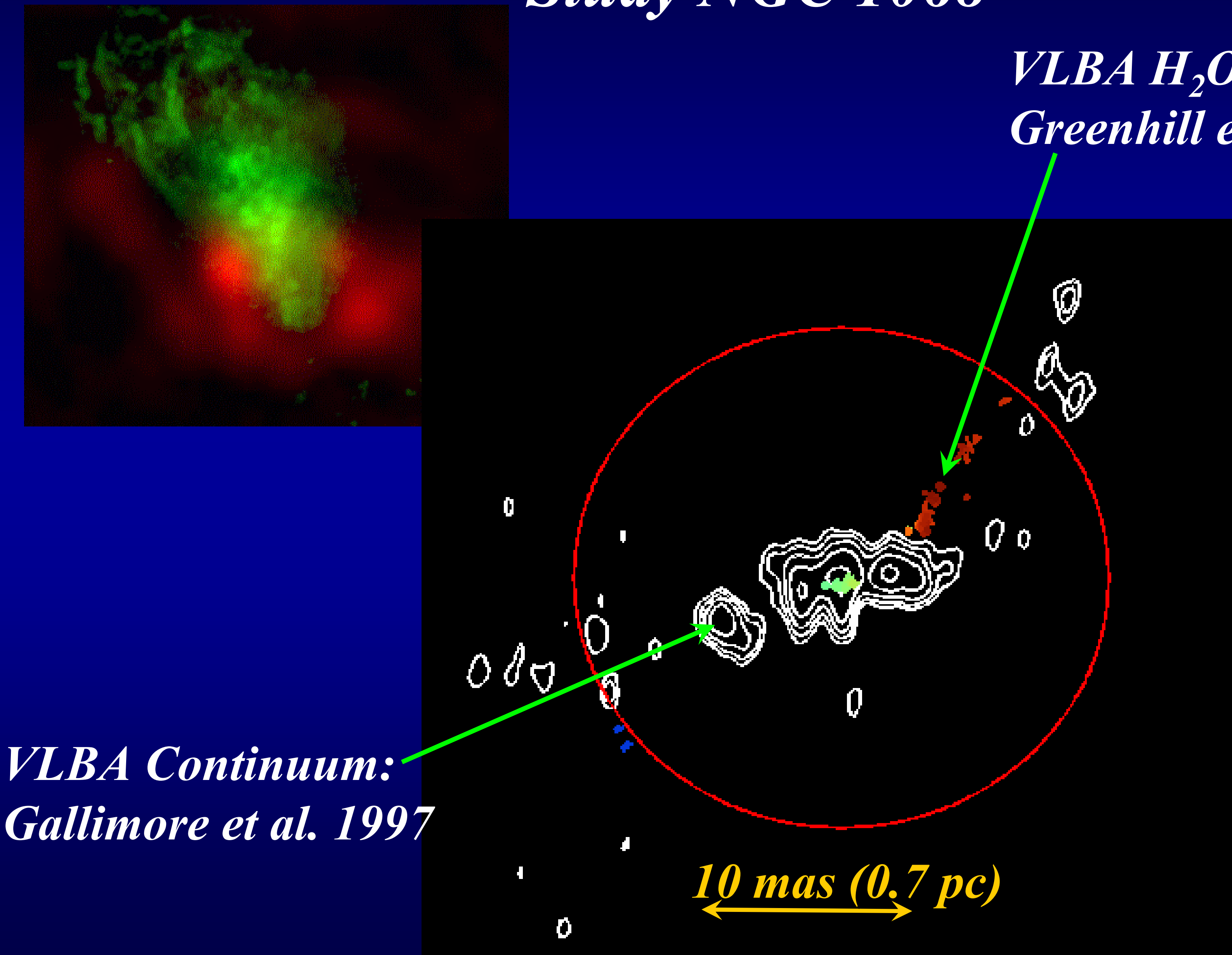
Nobeyama: Dense gas in 20 spirals
Kohno et al, 2001, 2004

CO scale lengths <0.5 kpc in >50% of galaxies: central gas concentrations !

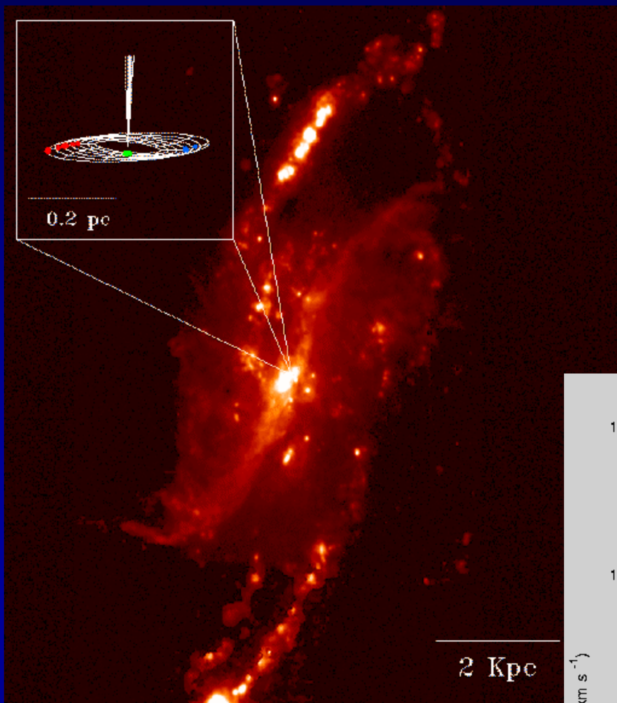
- $M_{gas, 500pc}/M_{gas, tot} \sim 50\%$
- rotating disk/ring structures
- Gas more centrally concentrated in barred galaxies
- Degree of gas concentration not correlated with AGN activity
- $<\Sigma_{gas}> \sim 500\ M_\odot\ pc^{-2}$ independent of AGN activity
- $<M_{gas, 500pc}/M_{dyn, 500pc}>$ ~20% for HII nuclei
  <10% for Liners, Sy

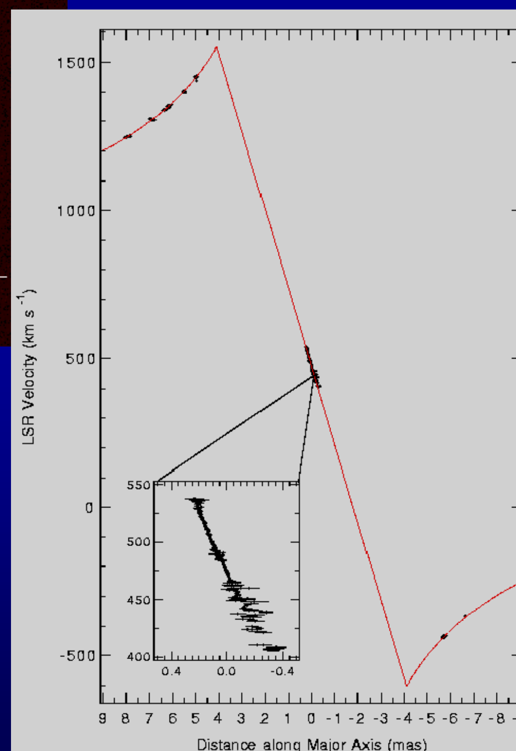
Baker 2000; Combes et al. 2004; Davies, Tacconi & Genzel 2004; Garcia-Burillo et al. 2003; Helfer et al. 2003; Jogee et al 2003; Kohno et al. 2001; Sakamoto et al. 1999; Schinnerer et al. 2000 a,b ; Sheth et al 2003

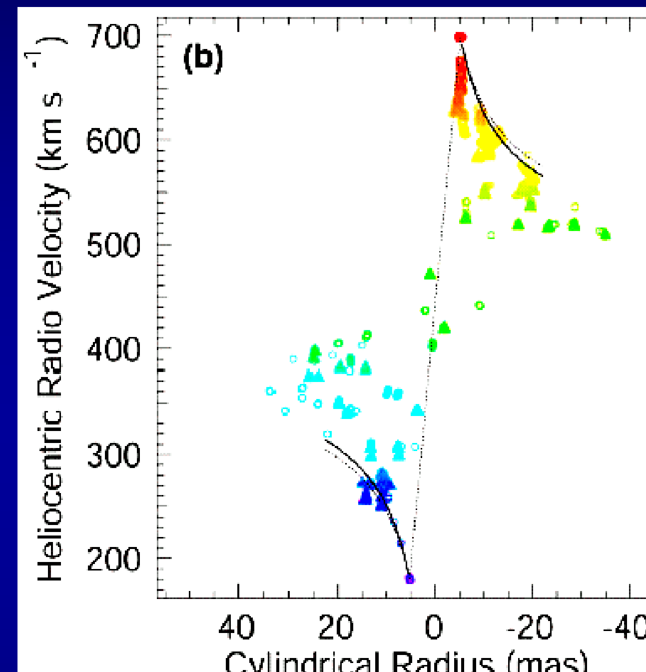
Properties of pc-Scale Gas and Dust: Case Study NGC 1068



Central BH Mass Estimates: H_2O Maser Disks







NGC 4258

$M_\bullet = 3.6x10^7\ M_\odot$

$\rho_\bullet > 10^{12}\ M_\odot pc^{-3}$

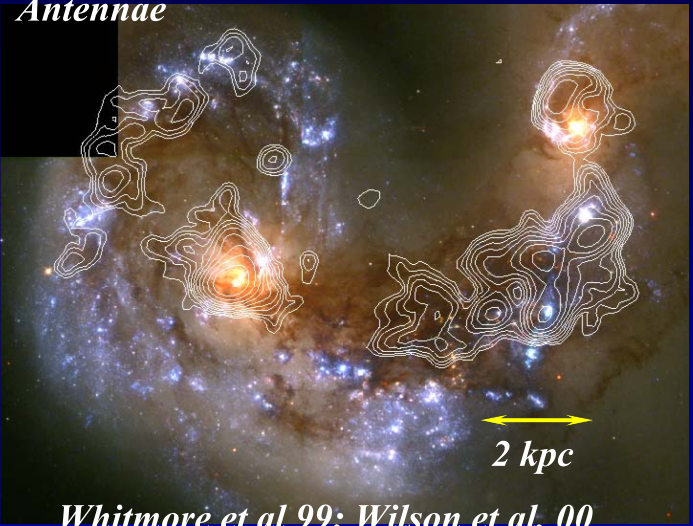
Circinus

$V_{max} = 260$ *km/s @ r=0.11 pc*

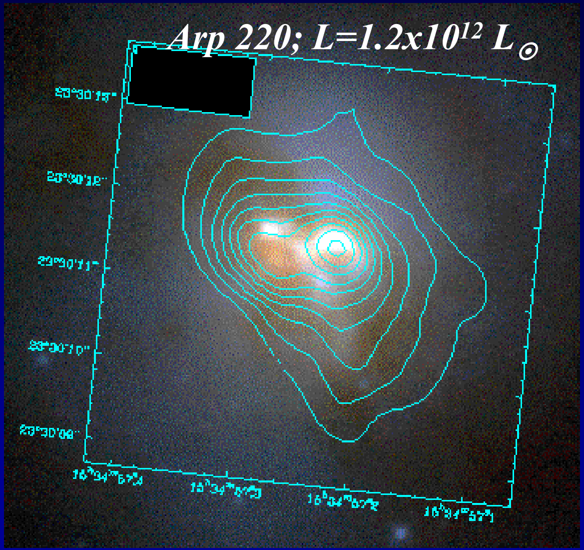
$M_{enc} = 1.7x10^6\ M_\odot$

Miyoshi et al 1995; Herrnstein et al. 1996; Moran et al. 1997; Greenhill et al. 1995, 2003

Properties of Luminous Mergers



Whitmore et al 99; Wilson et al. 00



Scoville et al. 97; Downes &Solomon 98
Sakamoto et al. 99

From the 1 Jy Sample of 118 ULIRGs (Veilleux, Kim & Sanders 02):

- *No ULIRG in earliest merger stages*
- *56% coalesced to single nucleus*
- *fraction of single nucleus systems increases with L:*
  at L>5x10^{12}, 83% single or separations < 2.5 kpc
- *AGN/starburst vs merger state: all Sy1 and most Sy2 nuclei have separations < 5 kpc*

Typical of Arp 220:

M_{gas} ~ few x 10^9 $M_\odot$ within r < 500 pc

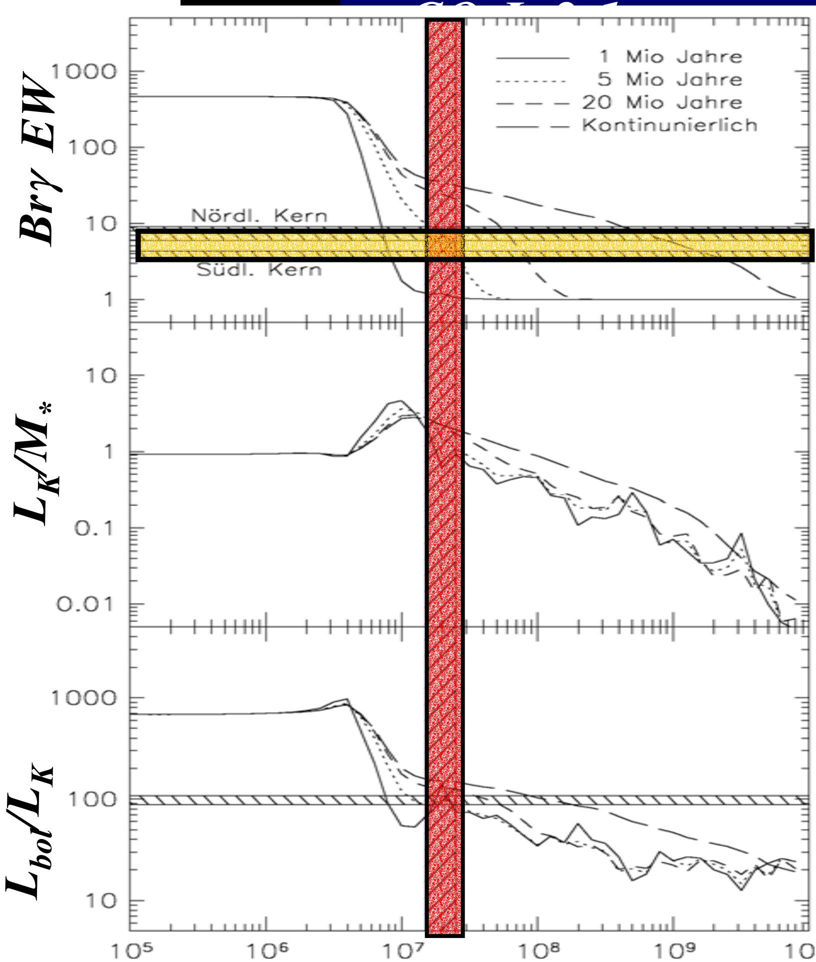
Σ_{gas} ~ 4x10^4 $M_\odot$ pc^{-2}

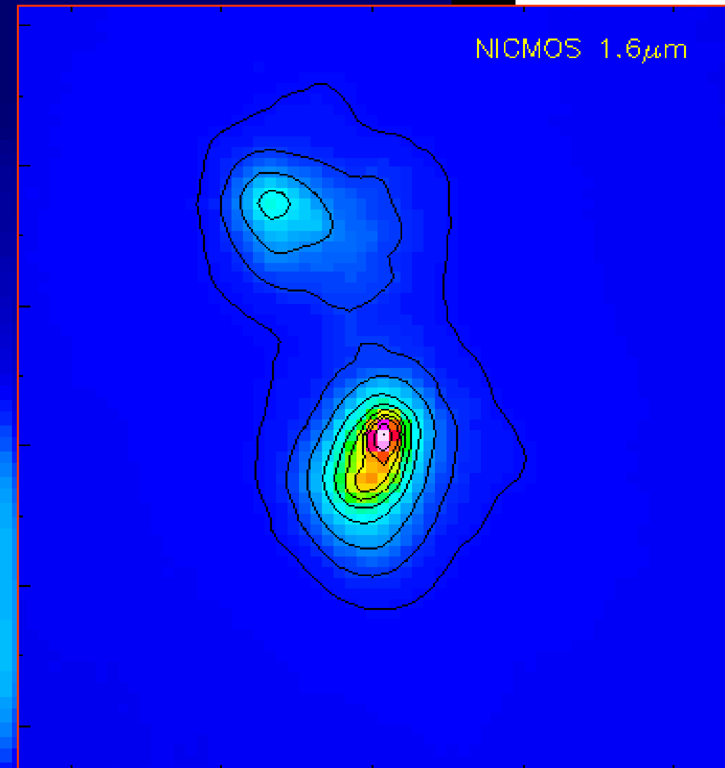
M_{gas}/M_{dyn} ~ 40%

(Downes & Solomon 98; Scoville & Bryant 99)

Case Study: NGC 6240

Genzel et al. 98, 01; Komossa et al. 03; Lutz et al. 03; Scoville et al. 00; Tacconi et al. 99; Tecza et al. 00, 04;

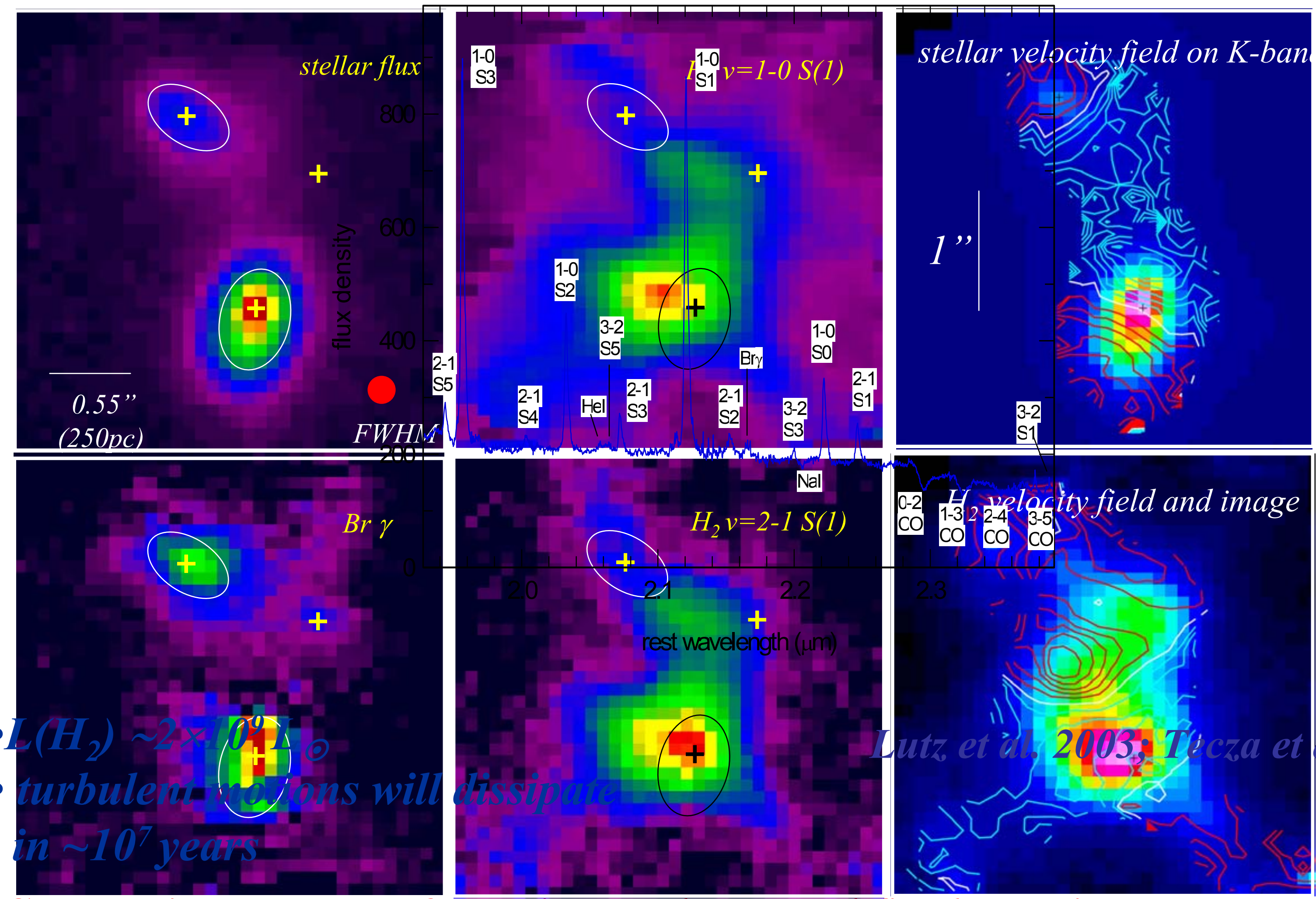




M_{dyn}~5-8×10^9 $M_\odot$

- K-band dominated by supergiants
- Burst age 15-25 Myr
- Burst duration <5 Myr
- Burst ~1/2 L(bol)

NGC 6240: A Large Scale Shock



- *$L(H_2)$ ~$2\times10^9 L_\odot$*
- *turbulent motions will dissipate in ~10^7 years*

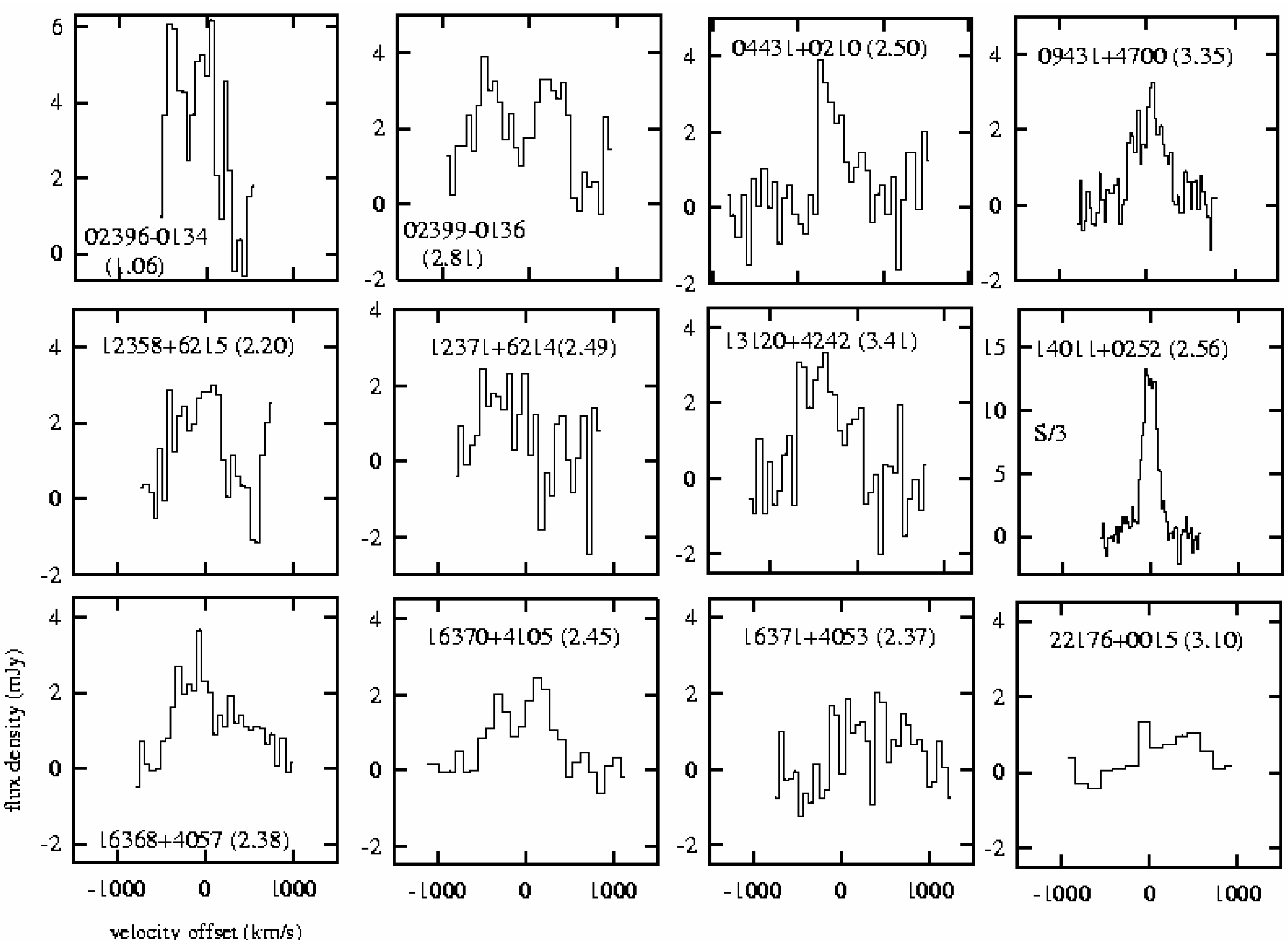
Lutz et al. 2003; Tecza et al. 2004

➡ *Stage prior to onset of massive starburst and final merging*

Eisenhauer et al 2003, ESO Messenger

~0.27” resolution at K-band with SPIFFI GI on VLT

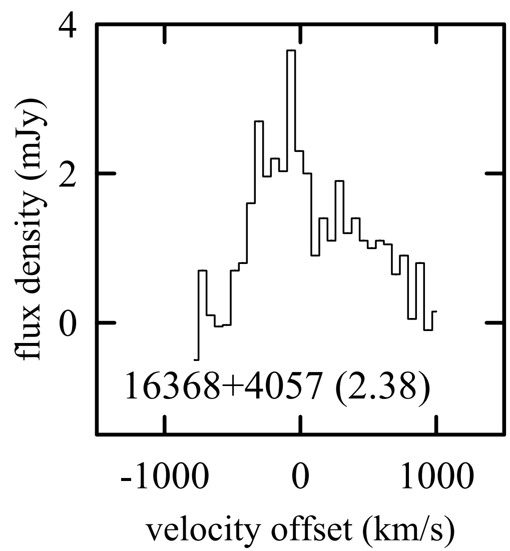
Investigating Maximum Star Formation: PDBI CO Survey of SCUBA sources with optical redshifts

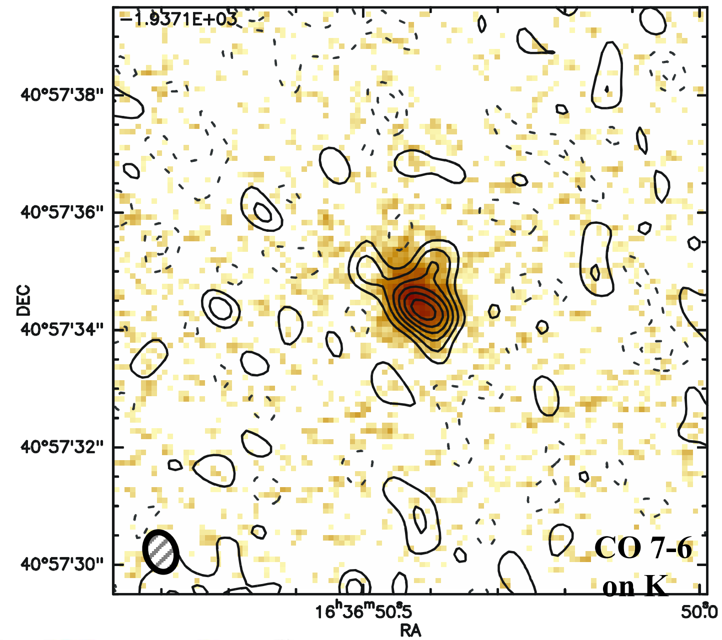


- PdBI program of submm galaxies with reliable Keck redshifts (2-3 tracks each: 20 hours)
- High resolution A/B configuration follow-up to spatially resolve CO dynamics/sizes
- so far 12 detections between z~1 and 3.5, bringing total number of CO confirmed submm galaxies to 14

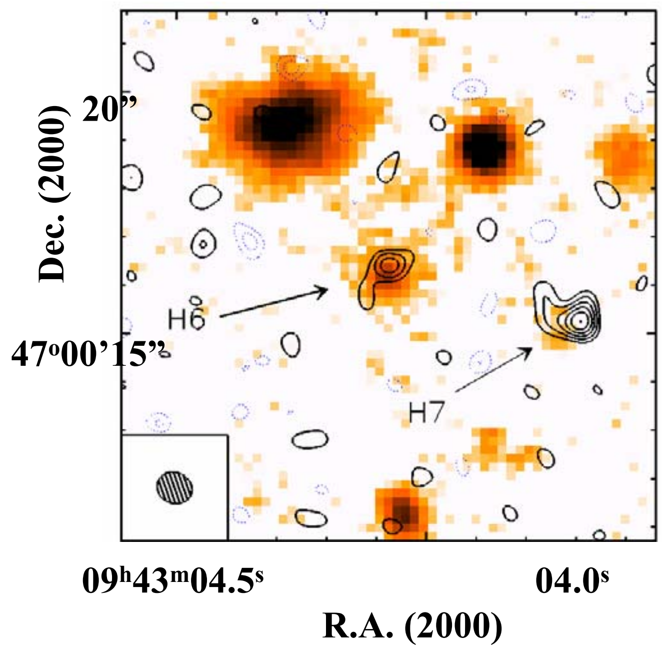
Neri et al. 2003, ApJ 597, L113, Greve et al. 2004, ApJ submitted

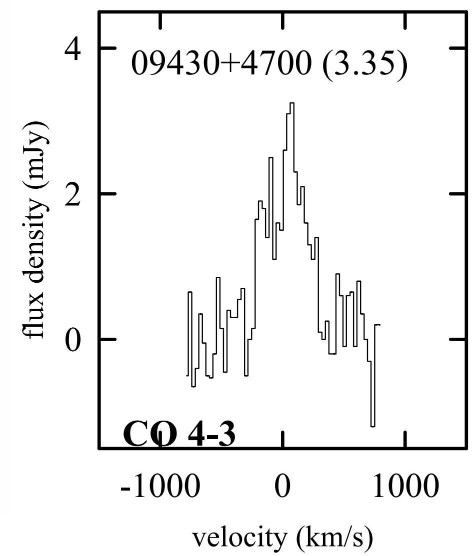
Compact Molecular Gas in z~2.5 Submm Galaxies





Neri et al. 2003, Greve et al. 2004, Tacconi et al. 2004





Submm Galaxies at z~2.5 May Be Today's Massive Ellipticals in Formation….

- **Submm galaxies are compact: $\langle R_{1/2}\rangle \sim 1.6$ kpc for 4 SMGs.**

- **They are massive:**

  $\Delta v \sim 700$-800 km/s, implying circular velocities $\langle V_c \rangle \sim 400$ km/s, and gas velocity dispersions $\sigma_g \sim 100$ km/s.

  This implies $\langle M_{dyn} \rangle = 7 \times 10^{10}\ M_\odot$ within this compact region

- **They are gas rich: $\langle M_{gas} \rangle = 2.4 \times 10^{10}\ M_\odot$, and gas fraction $M_{gas}/M_{dyn} \sim 0.4$**

- **They are rapidly forming stars: SFR~1000 $M_\odot$/yr (from FIR luminosities)**

- **They have matter densities comparable to ellipticals and massive bulges. $\Sigma_{dyn} \sim 7000\ M_\odot/pc^2$**

Maximum Star Formation in Submm Galaxies

Criterion for global gravitational instability

tively

Maximum star formation rate

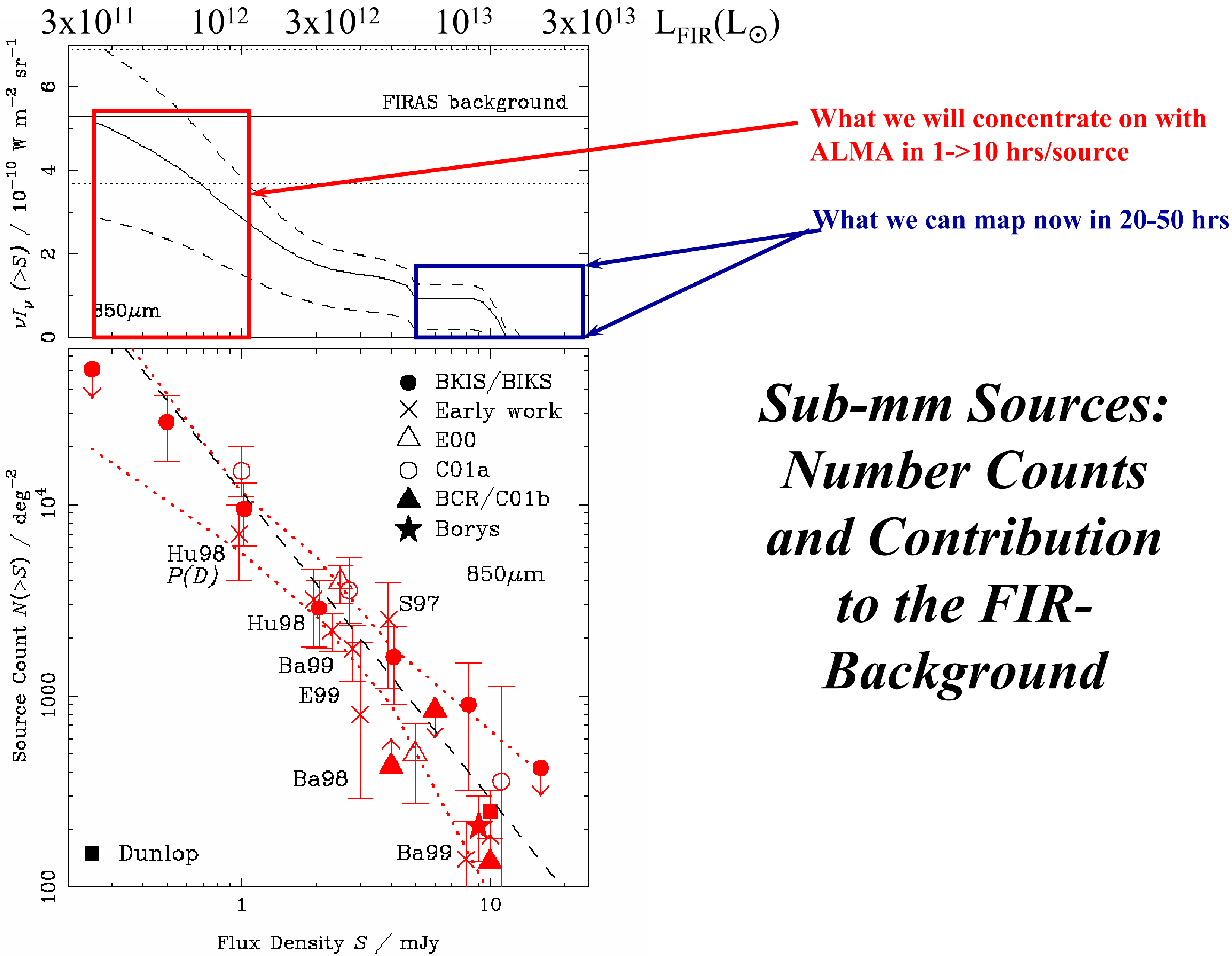
SFR_{max}

$\Sigma_{\mathrm{SFR\ max}}$ $^{1} kpc^{-2}]$ (4)

Criterion for starburst to continue in the presence of negative feedback (SN, rad. pressure, winds)

SF ivalently

σ_{g}



Sub-mm Sources: Number Counts and Contribution to the FIR-Background

Smail et al. 2002

Summary of Some ALMA Possibilities

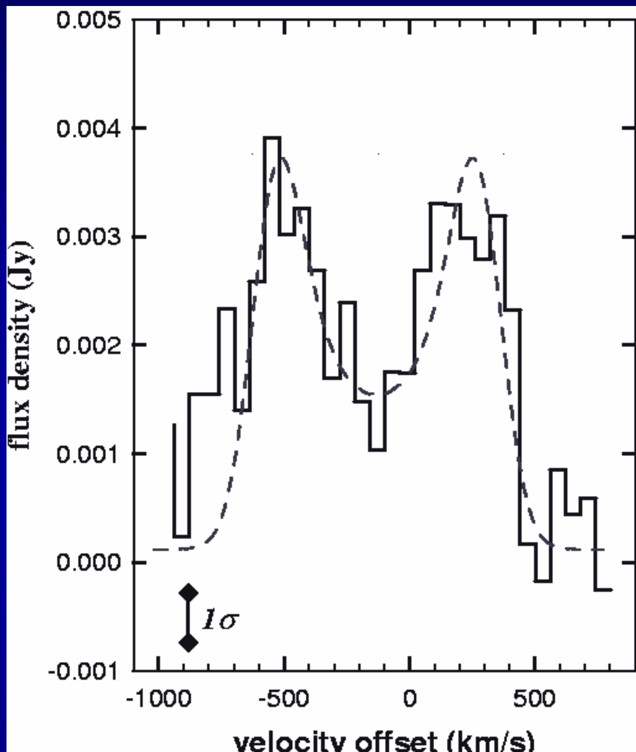
Nearby Nuclei: For galaxy nuclei in the local universe, the key issue will be getting to the highest possible spatial resolution - <1-5 pc scales!

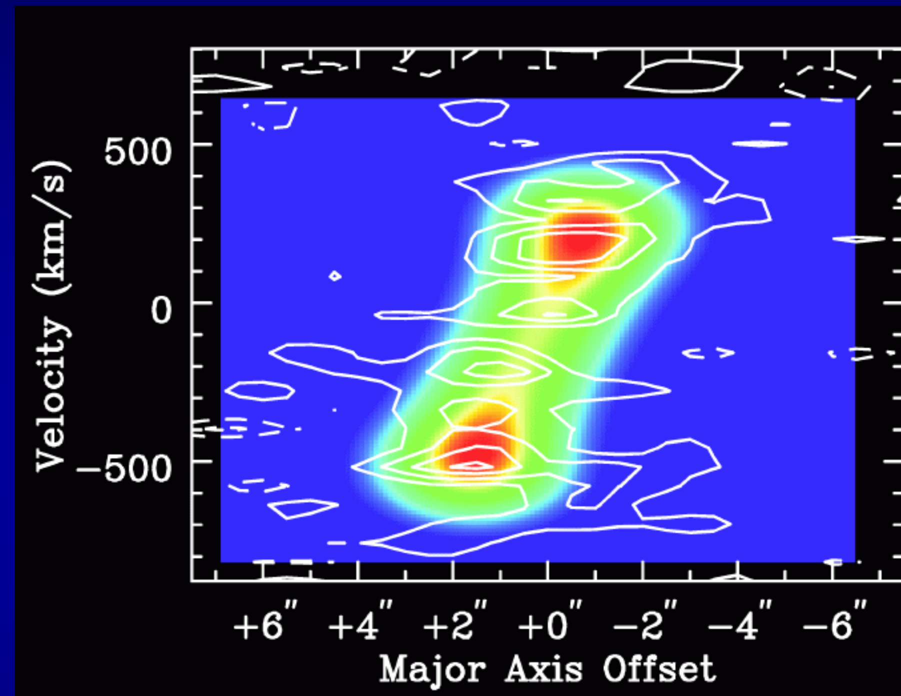
- AGN and Nuclear Starburst Fueling
- Direct detection and properties of AGN "Tori"
- Measuring masses of supermassive black holes

Ultraluminous Nuclei: Investigations of merger induced star formation on 5-10 pc scales. Observing starburst/black hole feeding at rates similar to what is expected in the early Universe.

High Redshift Nuclei: Spatially and spectrally resolved maps of gas and dust, to probe star formation in galaxies making up the peak of the FIR/submm background

Molecular & Dynamical Masses at High z: SMM02399-0136 at z=2.8





$L_{IR} = 1.2x10^{13}\ h_{0.7}^{-2}\ L_{\odot}$

$V_{rot} \geq 420$ km/s $\Rightarrow M_{dyn} \geq 3x10^{11} \sin^{-2}i\ h_{0.7}^{-1}\ M_{\odot}$

$M_{gas} \sim 6x10^{10}\ h_{0.7}^{-2}\ M_{\odot}$

Genzel, et al. 2003

Molecular Gas in Nearby AGN: NUGA

- *Sub-arcsec resolution CO study of 12 AGN hosts (50-100 pc res.) with IRAM interferometer*
- *Sey 1, Sey 2, and LINERs all represented*
- *Combined with HST/ground based optical/NIR imaging*
- *Combined with other CO data: "supersample" of 25-30 objects*

- *Measure high dynamic range gas & velocity distributions in central kpc regions*
- *Investigate gravitational instabilities necessary for fueling AGN*
- *Comparing with numerical simulations of stellar potentals*

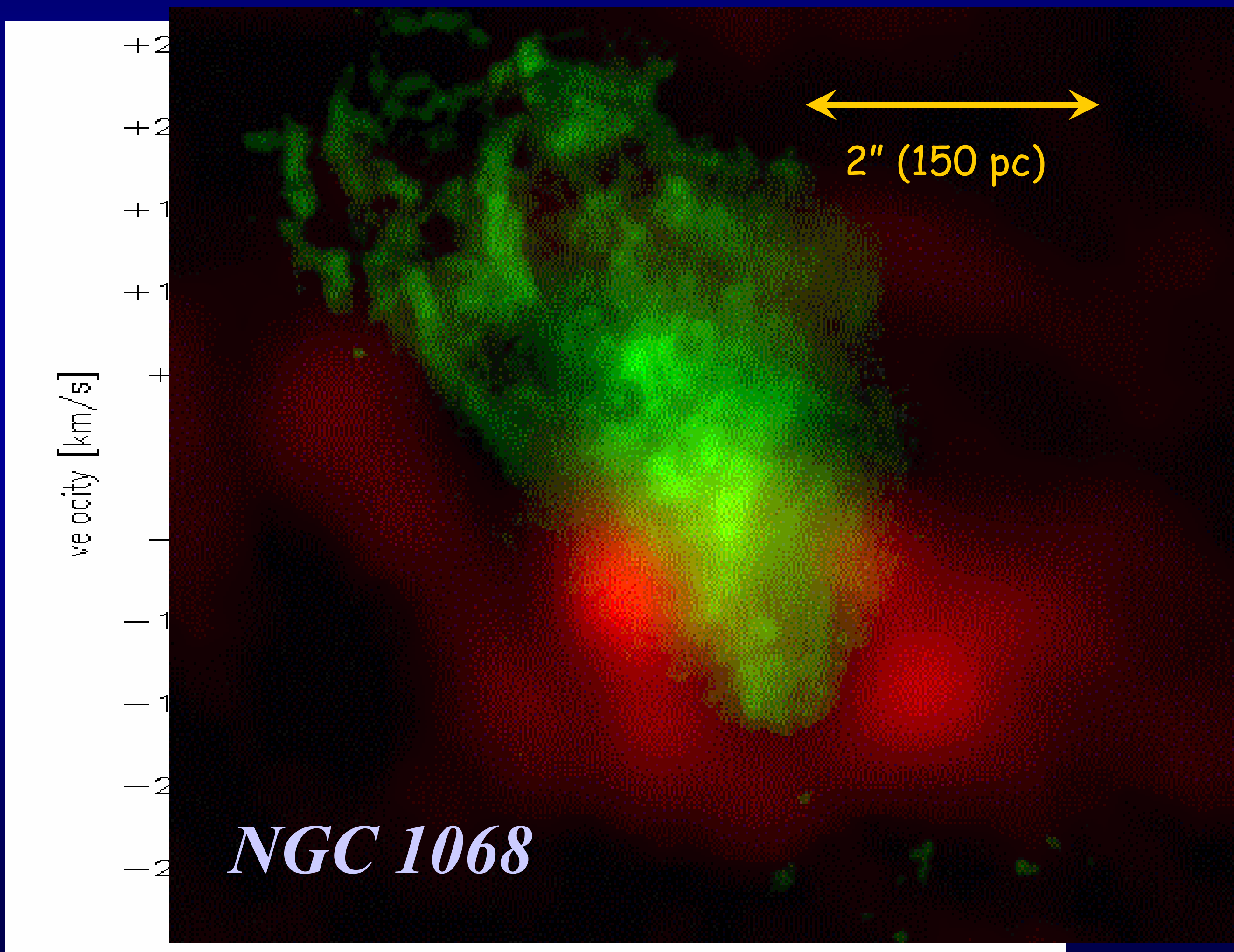
S García-Burillo & F.Combes: plus A. Baker, F. Boone, A.Eckart, P. Englmaier, L.Hunt, S.Leon(3), R. Neri, E.Schinnerer, L. Tacconi

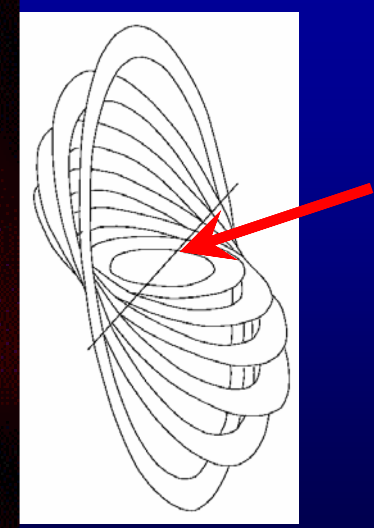
Properties of Tori: Large Scale Effects

CO: Schinnerer et al. 2000, Helfer and Blitz 1995, Baker 2000, Krips et al. in prep

hinnerer et al.
00, Baker 2000

HST: Macchetto et al 1996



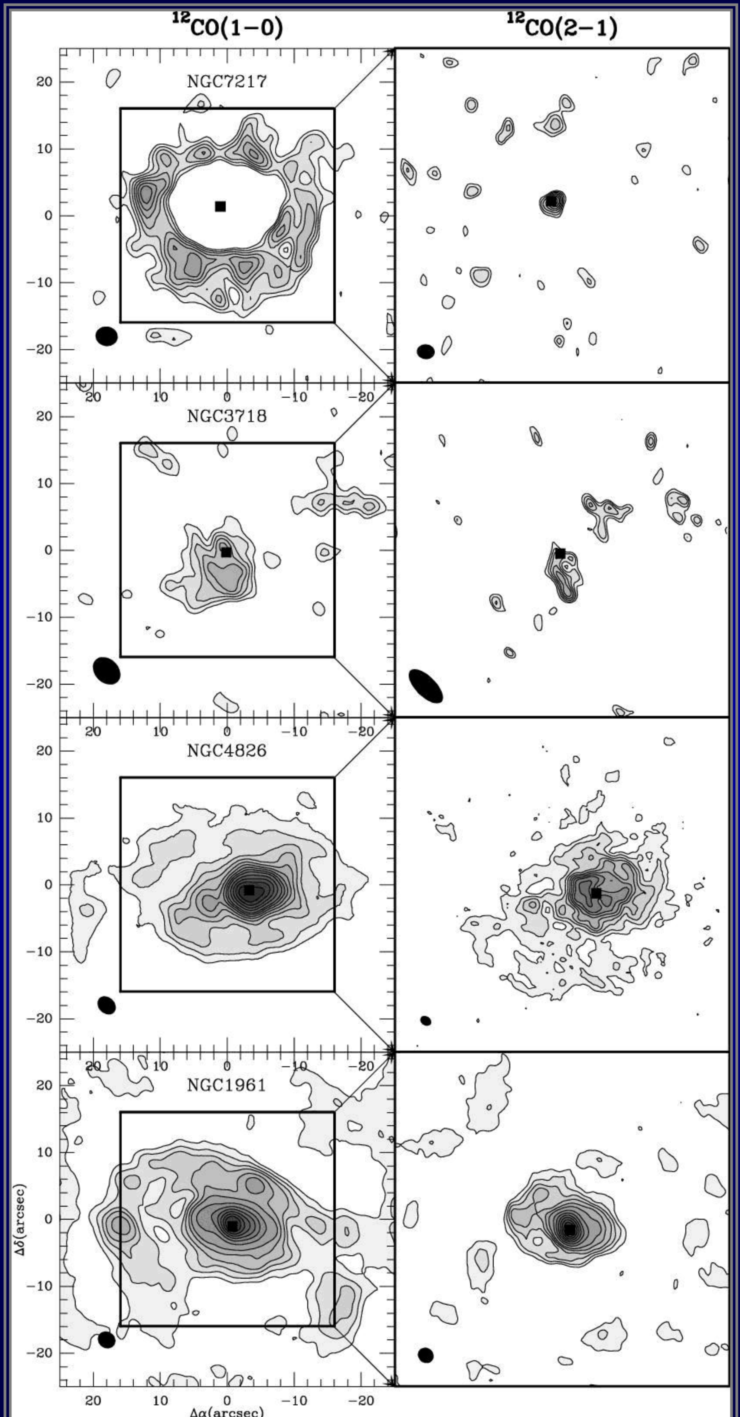


Molecular Gas in Nearby AGN: NUGA

S García-Burillo & F.Combes: plus A. Baker, F. Boone, A.Eckart, P. Englmaier, L.Hunt, S.Leon, R. Neri, E.Schinnerer, L. Tacconi

Variety of structures:

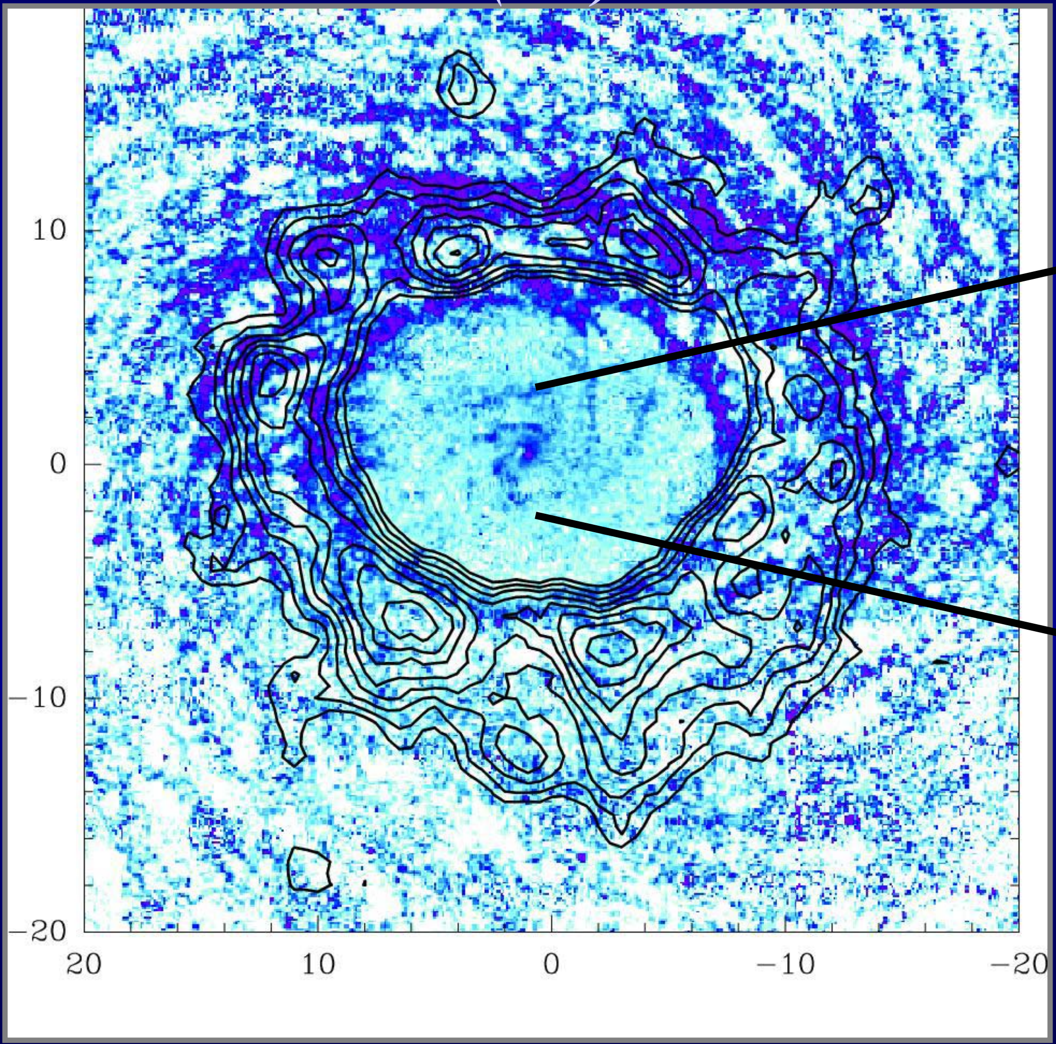
- *unresolved compact sources*
- *rings*
- *lopsided disks*
- *other asymmetric features*



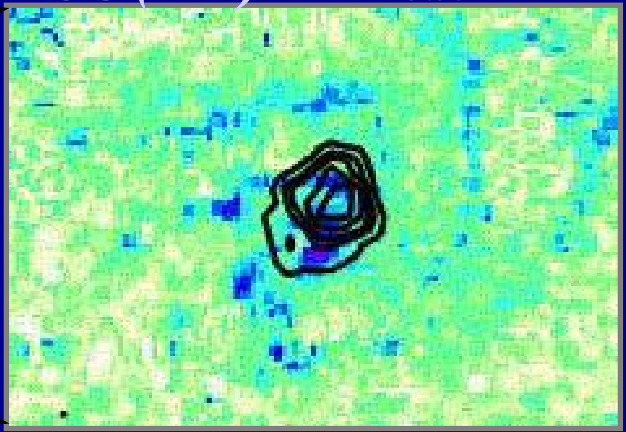
Details in Garcia-Burillo Talk!

NGC 7217: Feeding Star Formation

HST V-I and CO(1-0) contours



CO(2-1) 1” Res.



Combes et al. 2003, in press
IRAM PdBI

Details in Garcia-Burillo Talk!

Masses of SMBHs in Nearby Nuclei

Why ALMA?

- *Obscured central regions*
- *Presence of luminous AGN: AGN/host contrast*
- *spatial resolution*
- *molecular gas in rotating disks*