Dynamics of Dense Gas in the Central 2 pc of the Galaxy

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KITP GC Conference

Conference Goals:

Paradoxes of Sgr A*

Question:
Why is Sgr A* so under-luminous?

Why is it variabile?

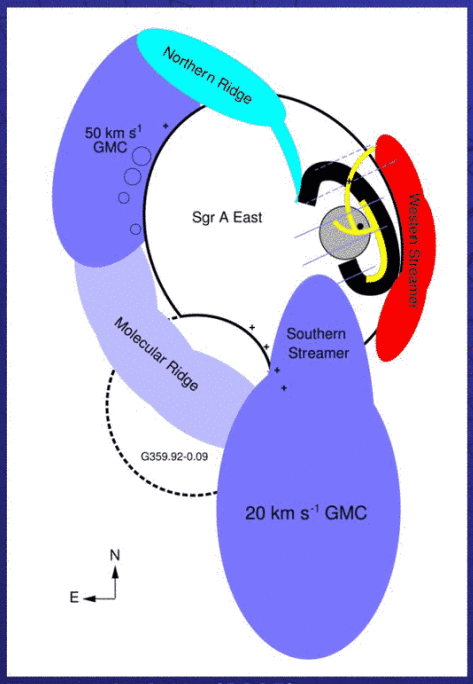
The Paradox of Youth

Question:
Why do we seem to have so many young stars in the central pc?

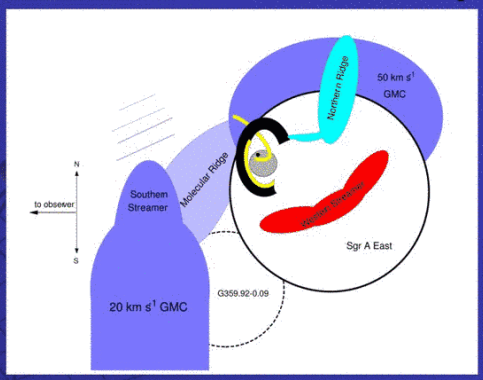
Where and *how* are these stars formed?

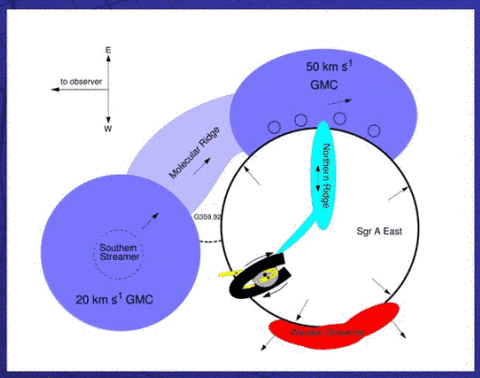
***Molecular gas** is a reservoir from which stars may form or material may accrete! We need to understand the role molecular gas plays in the central parsecs.*

An Introduction to the Central 10 pc

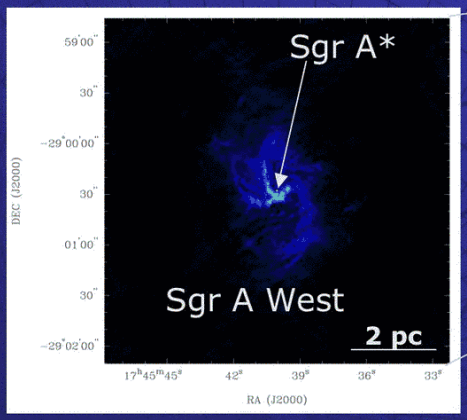


Herrnstein & Ho (2005)

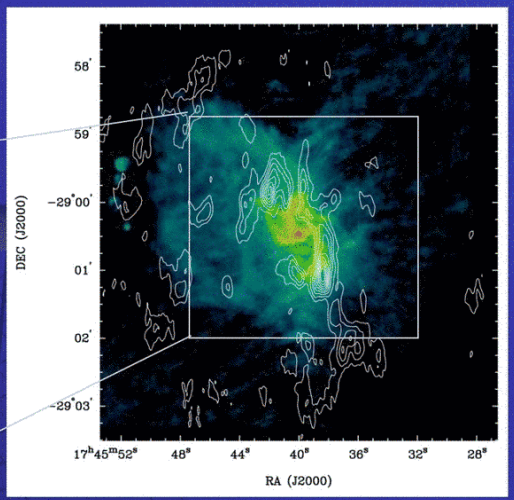




The Circumnuclear Disk



Roberts & Goss (1993)

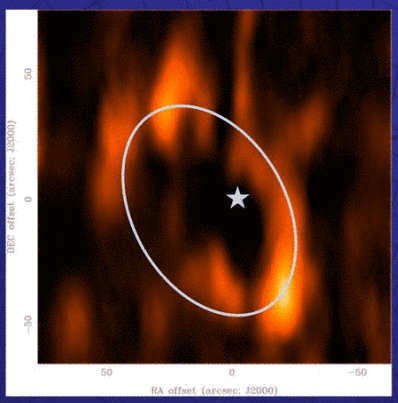


Wright et al. 2001

- Molecular tracers (HCN(1-0) above) show dense, clumpy, ring-like emission
- Counter-clockwise rotation
- Velocity of 110 km/s

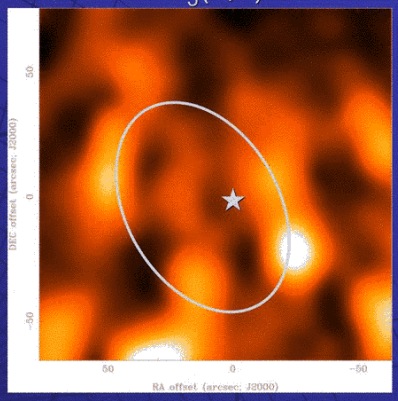
Is there a molecular hole in the central 2 pc?

HCN(1-0)



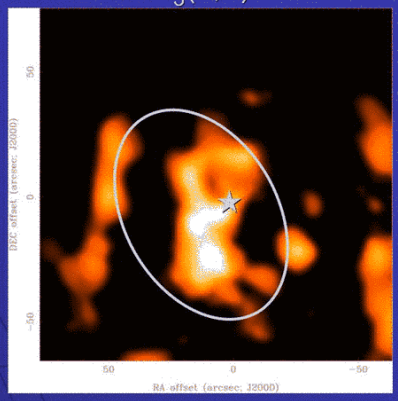
Yes

$NH_3(3,3)$



Yes

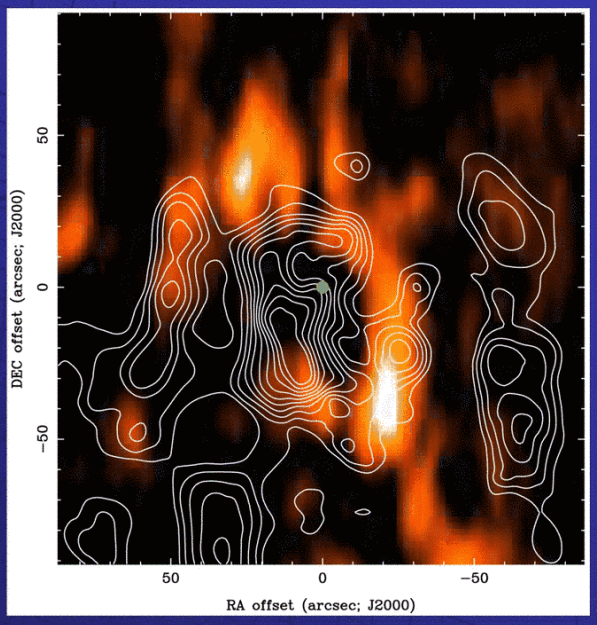
$NH_3(6,6)$



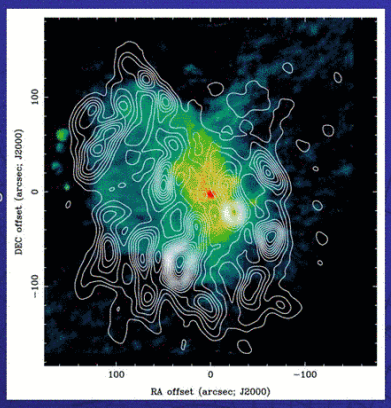
NO!
(at least in projection)

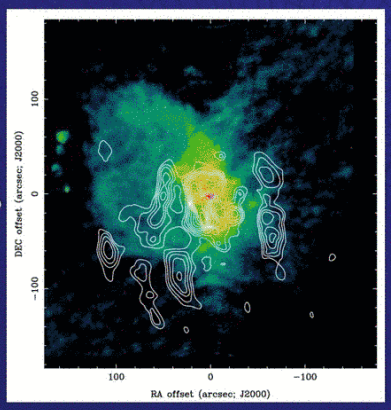
Lack of HCN(1-0) emission outside the CND is due primarily to self-absorption

Molecular Gas <1 pc from Sgr A*

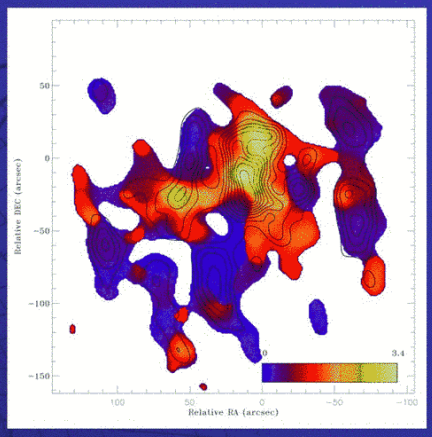


HCN(1-0): colorscale (Wright *et al.* 2001)
NH3(6,6): contours (Herrnstein & Ho 2002)





Lower limit on the (6,6)-to-(3,3) main line ratio



Much of the gas <1 pc from Sgr A has $R_{63} \geq 3$*

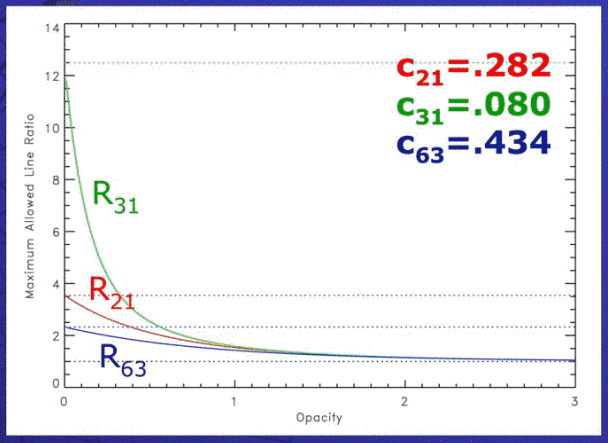
$$T_{R(u,u)\rightarrow(l,l)} = \frac{-\Delta E_{ul}}{\ln\left[\frac{-C_{ul}}{\tau_m(l,l)}\ln\left(1-\frac{\Delta T_A(u,u)_m}{\Delta T_A(l,l)_m}\left(1-e^{-\tau_m(l,l)}\right)\right)\right]}$$

For T_{Rul} to have a solution:

$$R_{ul} \equiv \frac{\Delta T_A(u,u)_m}{\Delta T_A(l,l)_m} < \frac{1-e^{-C_{ul}/\tau_m(l,l)}}{1-e^{-\tau_m(l,l)}}$$

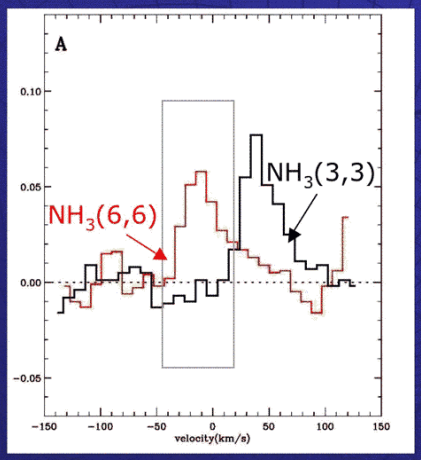
Firm upper limit on R_{ul} of:

$$R_{ul} < 1/C_{ul}$$



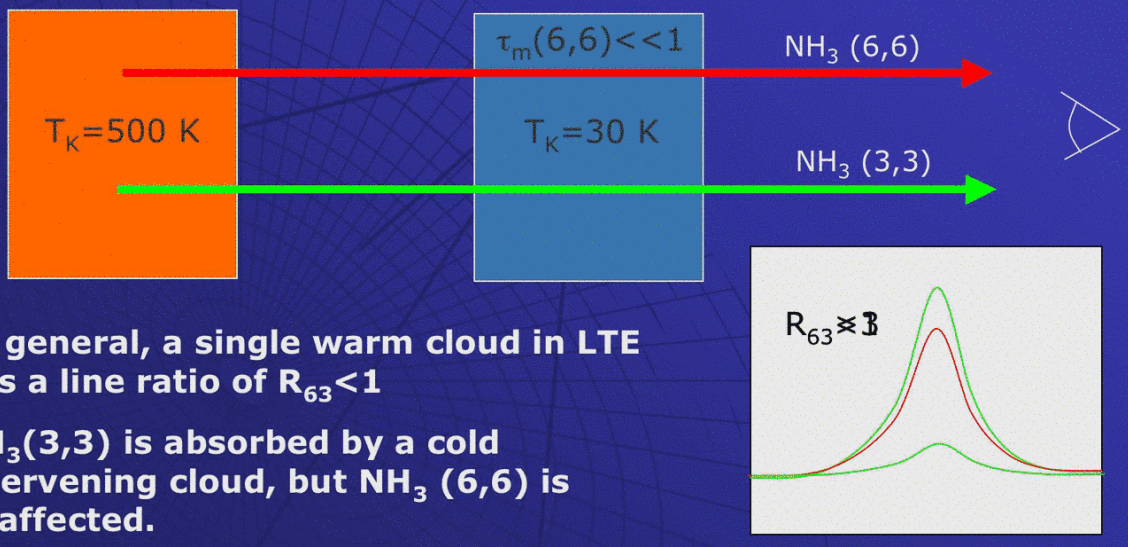
If the gas is in LTE, then R_{63} must be <2.3!

A Clue?



- Those channels with the highest (6,6)-to-(3,3) line ratios tend to be completely devoid of $NH_3(3,3)$.

Possible solution: Absorption of $NH_3(3,3)$ by a cool layer of intervening gas

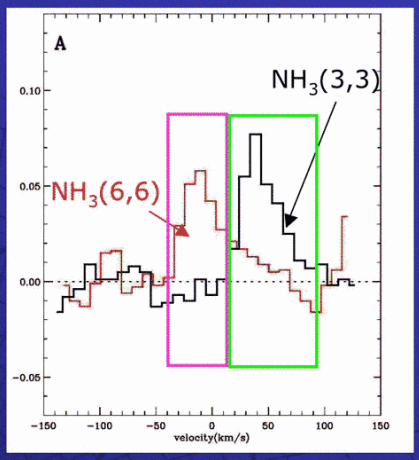


In general, a single warm cloud in LTE has a line ratio of $R_{63}<1$

$NH_3(3,3)$ is absorbed by a cold intervening cloud, but NH_3 (6,6) is unaffected.

The hot cloud must be very dense such that $T_{ex}\approx T_K$

Two Gas Components



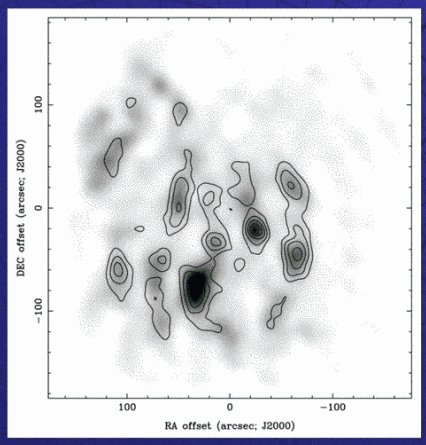
Use $S_\nu(6,6)$-$S_\nu(3,3)$ to define two gas components:

Low-line-ratio (LLR) gas: $S_\nu(6,6)$-$S_\nu(3,3)<0$, $R_{63}<1$

High-line-ratio (HLR) gas: $S_\nu(6,6)$-$S_\nu(3,3)>0$, $R_{63}>1$
probably produced by absorption of $NH_3(3,3)$

Two Gas Components

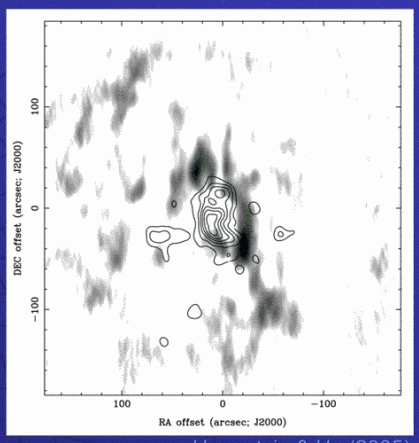
Low-line-ratio (LLR) gas is found throughout the central 10 pc



Herrnstein & Ho (2005)

$NH_3(3,3)$: grey scale
$NH_3(6,6)$ LLR gas: contours

High-line-ratio (HLR) gas is almost entirely confined to the central 2 pc

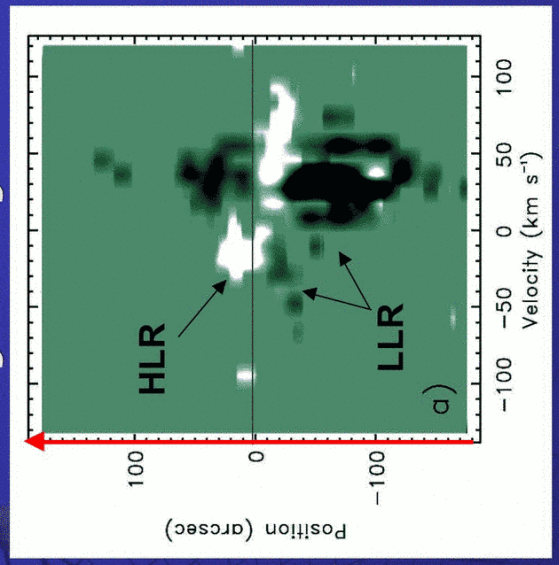


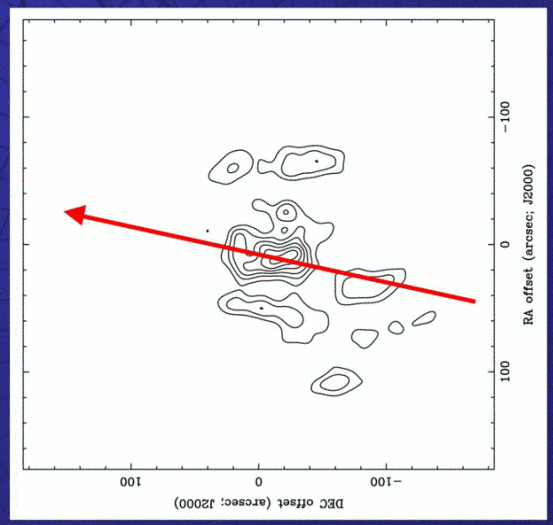
Herrnstein & Ho (2005)

HCN(1-0): grey scale
$NH_3(6,6)$ HLR gas: contours

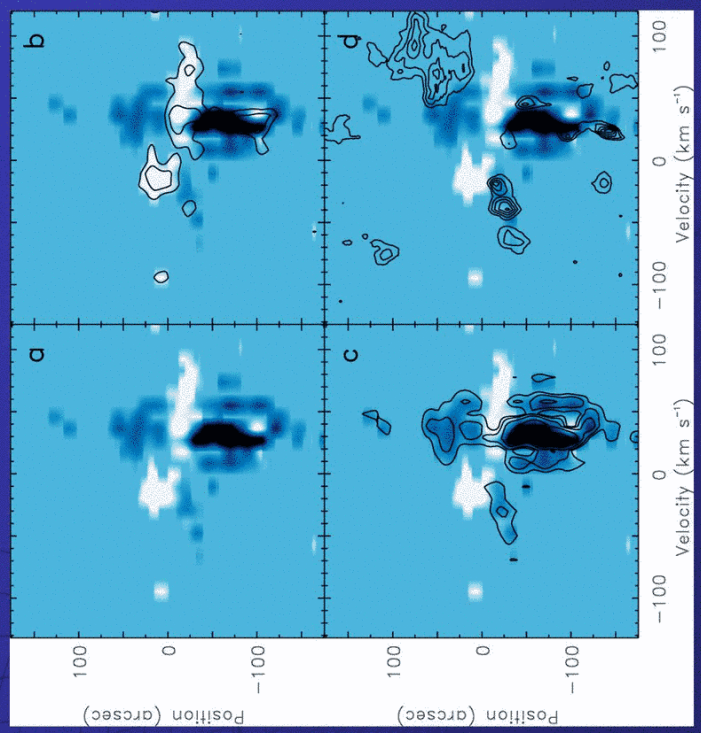
Gas Kinematics near Sgr A*

Dark: LLR gas
Light: HLR gas





Herrnstein & Ho (2005)



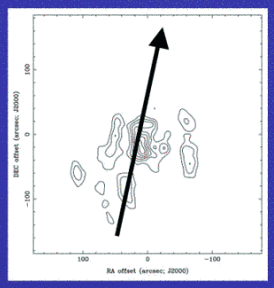
NH_3(6,6) overlaid

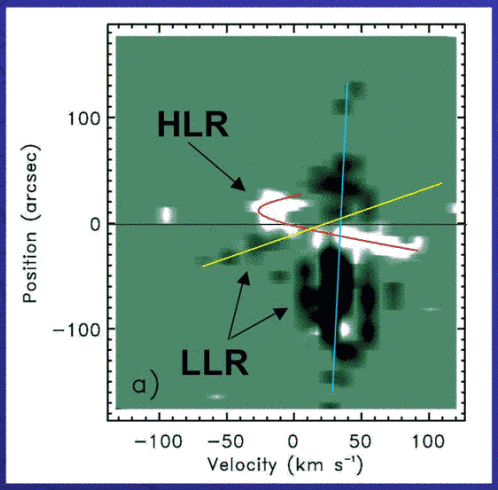
HCN(1-0) overlaid

NH_3(3,3) overlaid

Gas Kinematics near Sgr A*

- CND is seen in LLR gas, though it is not the dominant feature
- 20 km/s GMC extends northwards past GC with almost no velocity gradient… Southern streamer probably a projected cloud along the LOS

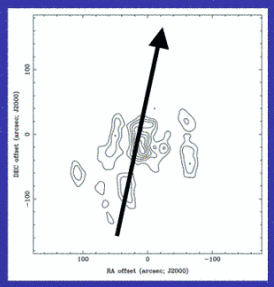


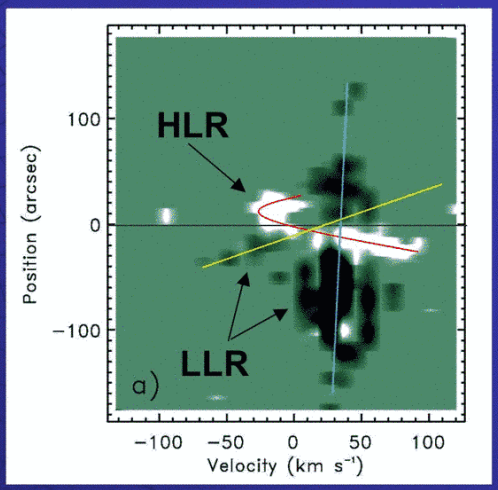


Herrnstein & Ho (2005)

Gas Kinematics near Sgr A*

- HLR gas traces a new component within 30" (~1 pc) of Sgr A*
  - Opposite sense of rotation to the CND
  - Evidence for expansion/contraction
  - Kinematically distinct from both the southern streamer and the CND





Herrnstein & Ho (2005)

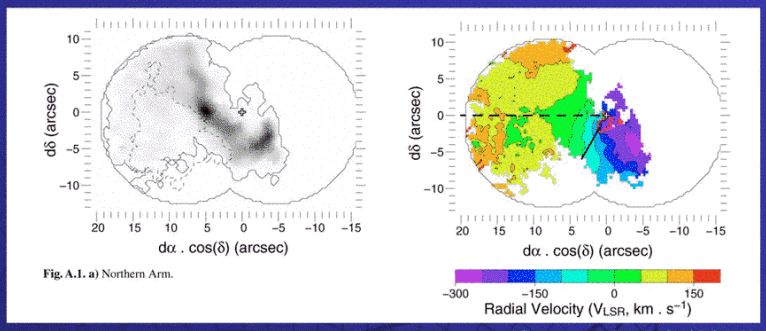
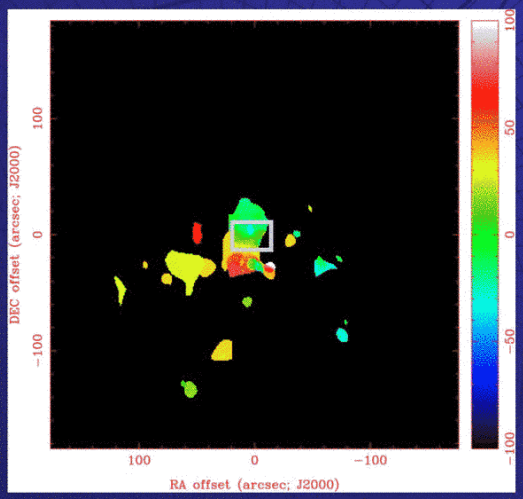


Fig. A.1. a) Northern Arm.

Paumard et al. (2004)



Comparison of Northern Arm and HLR gas kinematics

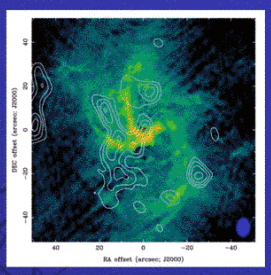
Conclusions

- There is evidence for warm, dense molecular gas < 1pc from Sgr A*
- Observed "unphysical" line ratios result from absorption of (3,3) by a cool layer *in the same cloud*
- The cloud shows evidence for rotation and expansion or contraction and is kinematically distinct from the CND and mini-spiral.

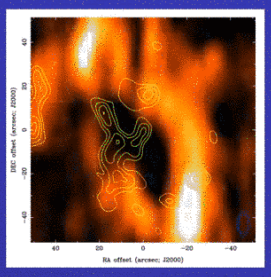
In the Works…

- High-Resolution VLA Images
- VLA-GBT combined data
- Search for high velocity (6,6) *(Jen Donovan, Columbia)*
- *Improved spectral resolution (EVLA)*

6″ Gaussian Taper

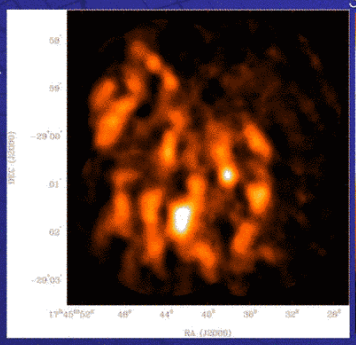


Overlaid on H92α

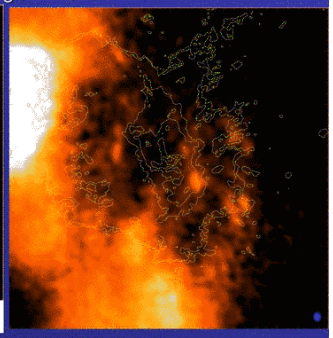


Overlaid on HCN(1-0)

$NH_3(3,3)$



VLA only



VLA+GBT