The Structure of the Radio Recombination Line (RRL) Maser in MWC349A

by
J.M. Moran*

Harvard Smithsonian Center for Astrophysics

* For the SMA Group: Qizhou Zhang, Deanna Emery, Brian Claus, Linda Watson, Jonathan Weintroub, +JM

For detailed modeling results see poster paper 2 by Alejandro Baez-Rubio

IAU Symposium 136, Astrophysical Masers, Cagliari, Italy, September 7, 2017

MWC 349 A

Mount Wilson Catalog, discovered in 1932, classified as Herbig Be star

Located in Cyg OB2 association
Standard distance ~ 1200 pc

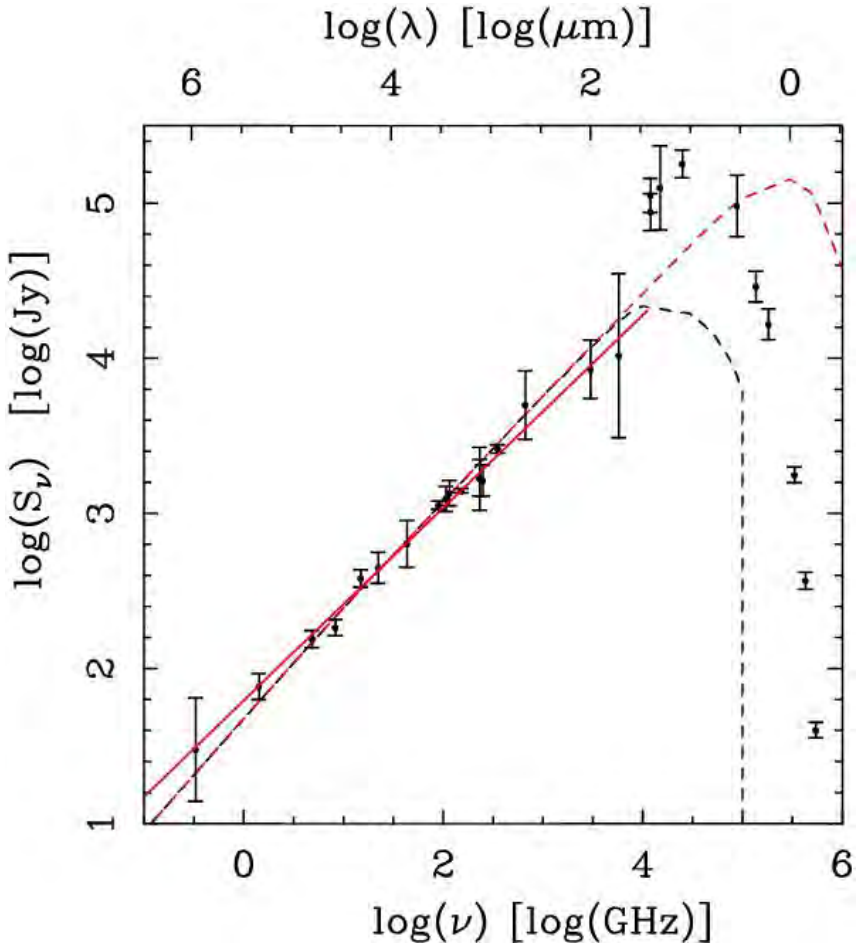
L ~ 30,000 L_{sun}

M ~ 40 M_{sun}

Classic $\nu^{0.6}$ spectrum (outflow)

Photoionized disk

Companion star MWC349B 2.4" away



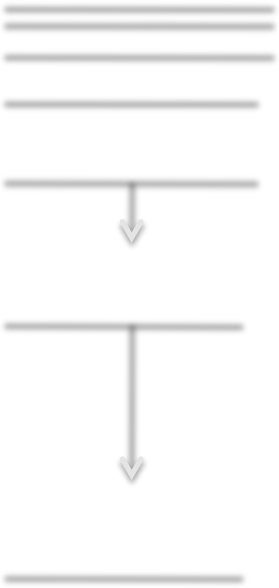
History of the Study of the Angular Structure of the RRLs in MWC349A

1992	OVRO	Planesas et al.,	H30α	Separation of the two major spectral peaks ~ 65 mas (80 AU), M ~ 30 M_{sun}
2008	SMA	Weintroub et al,	H30α	Slope of P-V curve Annulus , R_{30} ~ 25 mas (25 AU)
2011	PdBI	Martin-Pintado et al.,	H30α	Off disk features Wind
2017	SMA	Zhang et al.,	H30α / H26α	Change of Radius with n n_e vs R, M ~ 10 M_{sun}
2017	SMA	Emery	H31α	Confirm change in radius with n
2018	ALMA	Zhang, Moran, Martin-Pintado, Baez-Rubio, Jimenez-Serra	H31α/H26α	Observations approved (details of angular momentum loss "spots" or continuous structure)

Basic Physics of RRL Masers

Ultraviolet ionizations and collisional cascade to n = 1

Hydrogen atom energy levels



$$E \sim \frac{1}{n^2}$$

$$\nu \sim \frac{1}{n^3} \quad n >> 1$$

$H_{31}\alpha$ = 210.5 GHz
$H_{30}\alpha$ = 231.9 GHz
$H_{26}\alpha$ = 353.6 GHz

Correspondence Principal and Larmour Formula

$$P = \frac{2}{3}\frac{e^2}{c^3}a^2 = h\nu A \quad erg\ s^{-1}$$

$$\text{a} = \text{centripetal acceleration} = (2\pi\nu)^2 R, \quad R \sim n^2$$

$$\text{A} = \text{Einstein A coefficient}$$

$$A \sim \frac{1}{n^5}$$

OPPOSITE of A for diatomic molecules where A ~ J^3

N_e low ➔ A controls level populations

H has a natural predisposition to population inversion

This "bottleneck effect" in cascade recognized by Menzel ~1937, applied by Dupree and Goldberg ~ 1969 to explain nonLTE conditions

I Should Have Followed Up on That . . .

PHYSICAL PROCESSES IN GASEOUS NEBULAE

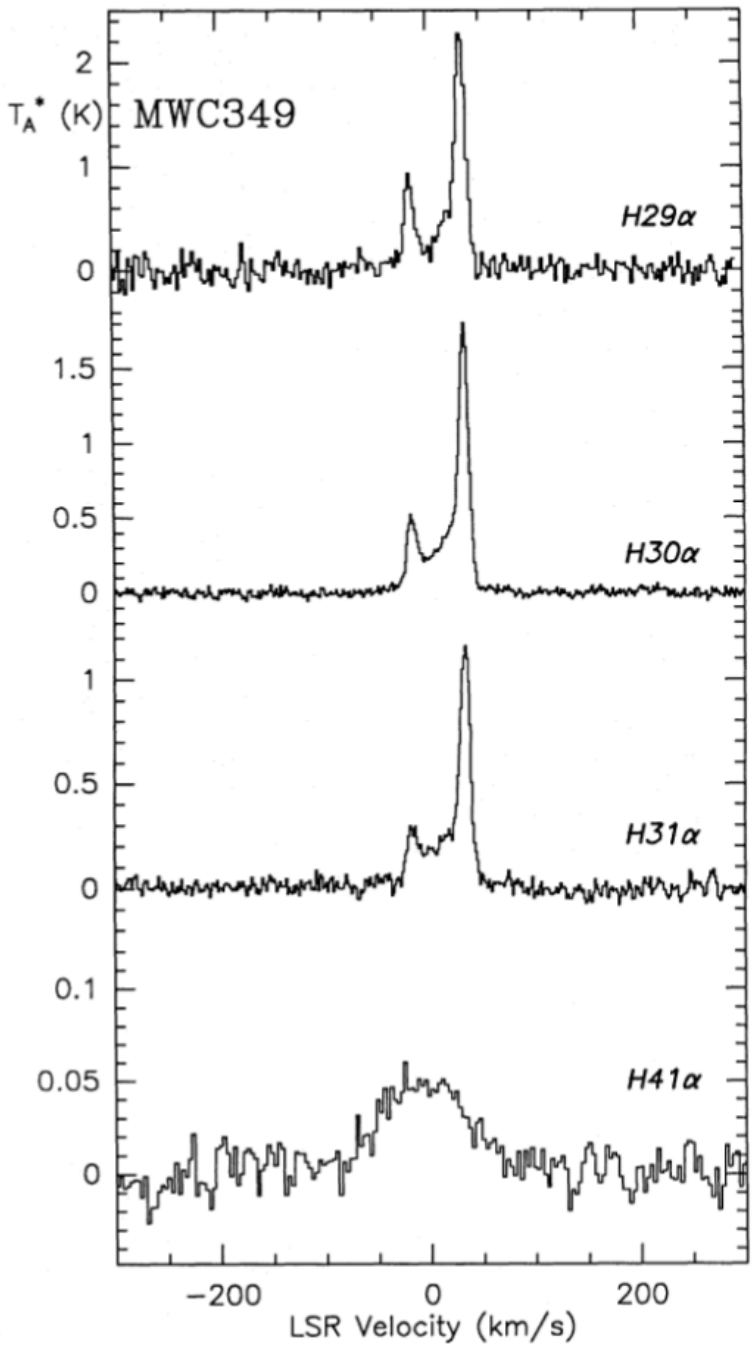
1. ABSORPTION AND EMISSION OF RADIATION

DONALD H. MENZEL

Ap.J. 1937, 85, 330

The total radiation, absorbed in the transition $n'-n$, including the effect of the "stimulated emissions," which must be counted as negative absorptions, is easily found to be . . . .

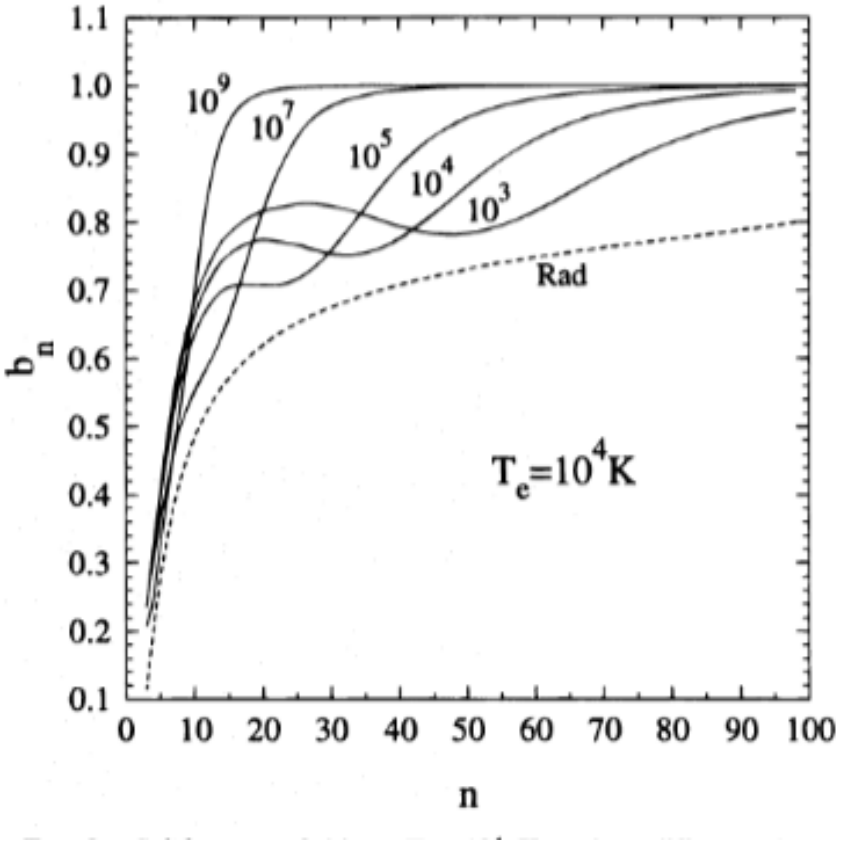
Outside of thermodynamic equilibrium, the condition may conceivably arise when the value of the integral [above] turns out to be negative. The physical significance of such a result is that energy is emitted rather than absorbed. This energy must be distinguished, however, from that arising in random emissions. The process merely puts energy back into the original beam, as if the atmosphere had a negative opacity. This extreme will probably never occur in practice.

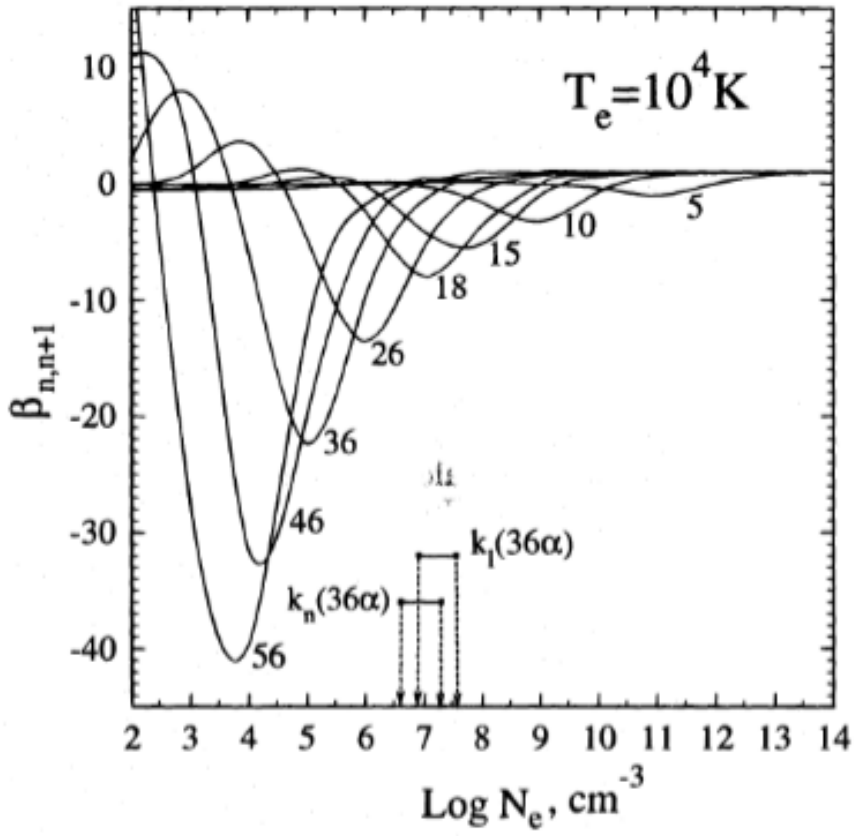


Discovery of the First RRL Maser in MWC349A

by Martin-Pintado, Bachiller, Thum and Walmsley
A&A 215, L13, 1989

Level population departures from LTE



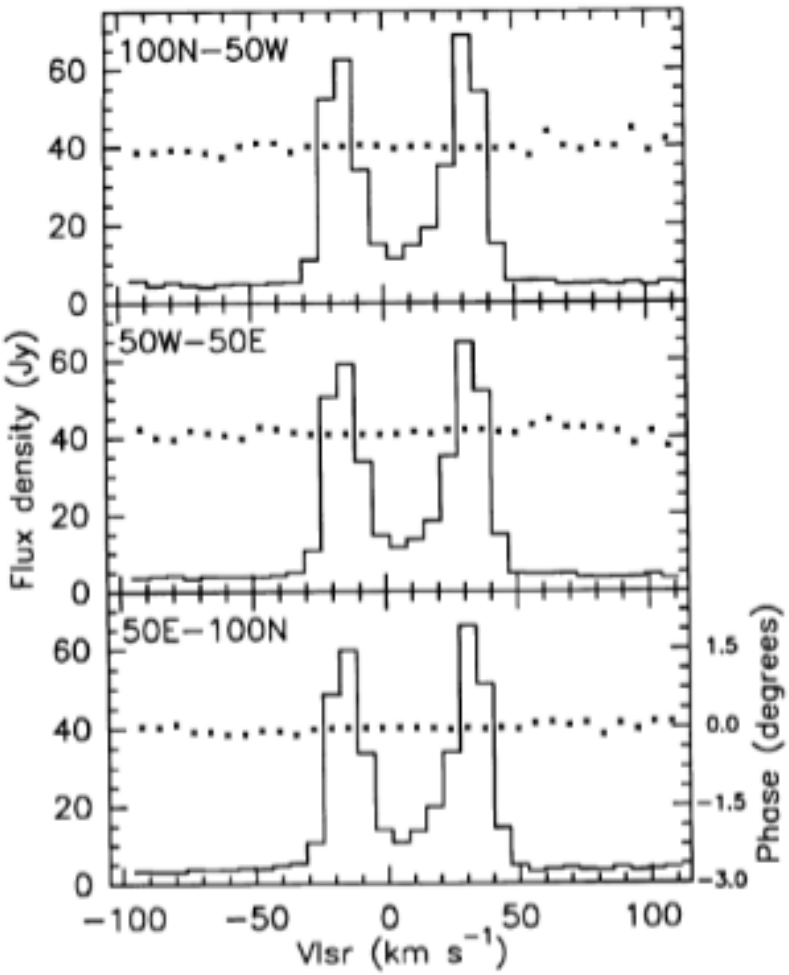


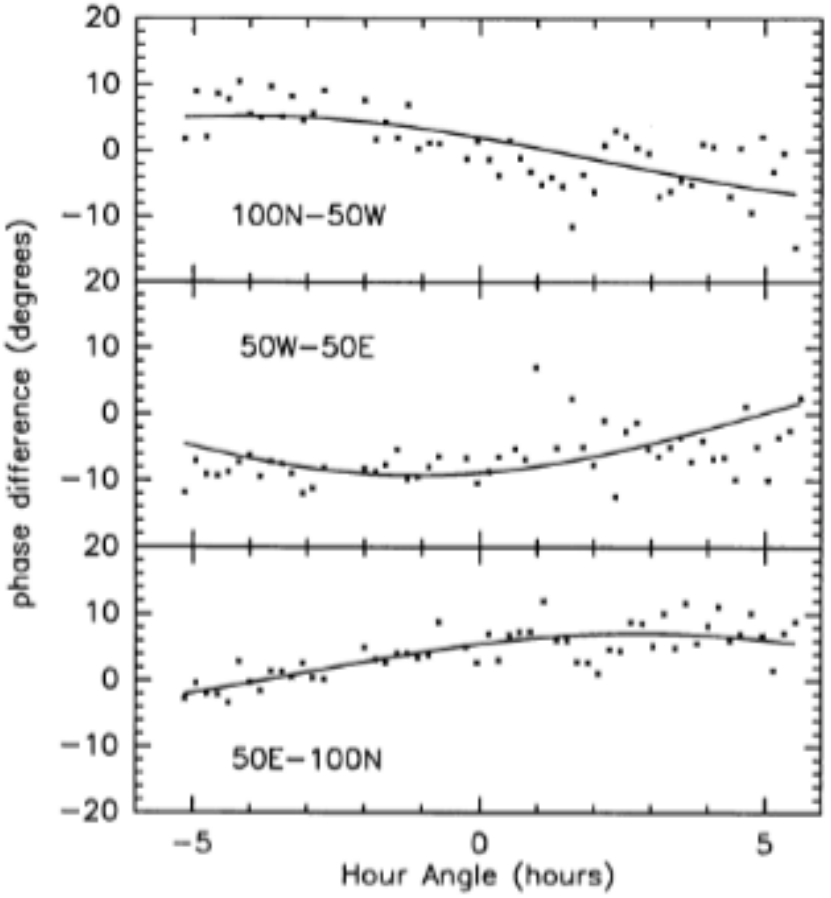
Departure coefficient b_n versus n for various values of electron density, N_e. "Rad" corresponds to zero collisions

$$\beta_n \approx -\frac{kT_e}{h\nu}\frac{\Delta b_n}{b_n} \approx \frac{T_e}{T_x} \sim -db_n/dn$$

From Strelnitski, et al., ApJ (1996) based on calculations of Storey & Hummer, ApJ (1995)

Relative Positions of Maser Peaks in MWC 349A Determined with OVRO Interferometer for H30α

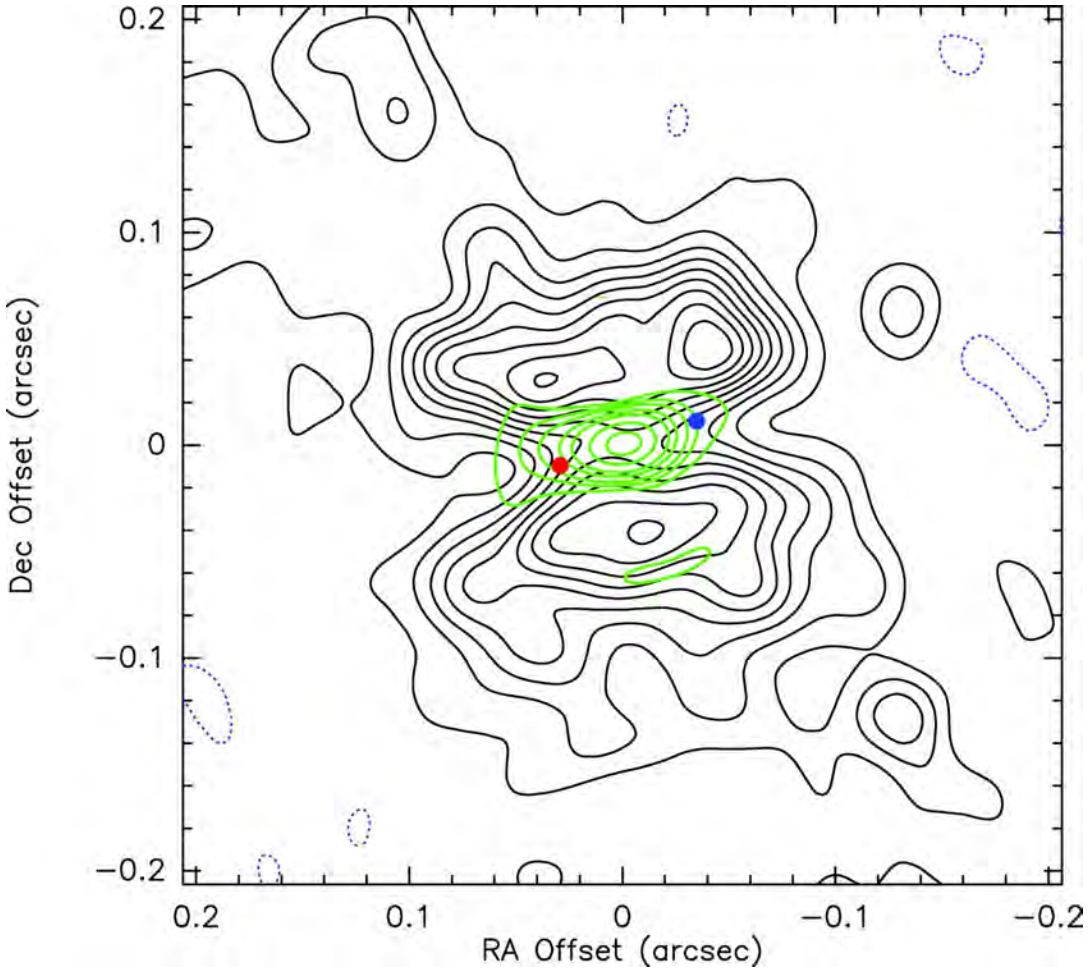




Separation = 65 +/- 5 mas, PA = 107 deg

Planesas, Martin-Pintado, & Serabyn, ApJ 1992

Continuum, IR and H_2O Maser Emission in MWC349A

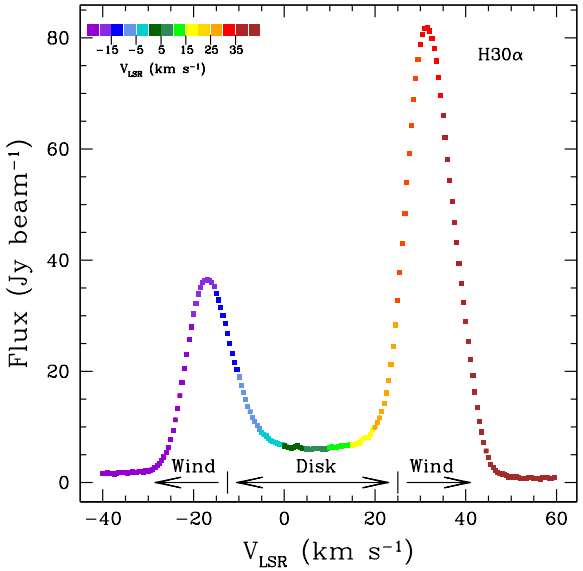


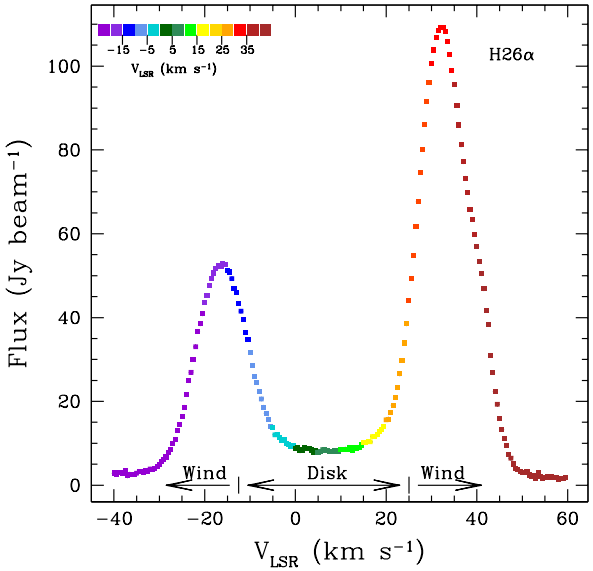
Black contours: 7 mm continuum. Green contours 2.27 micron IR. Red/blue dots H_2O masers

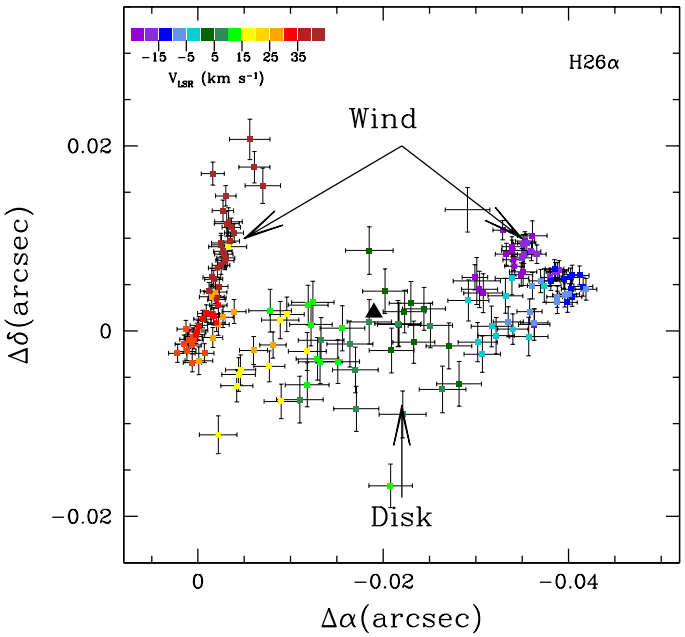
Submillimeter Array (SMA), Mauna Kea, Compact Array

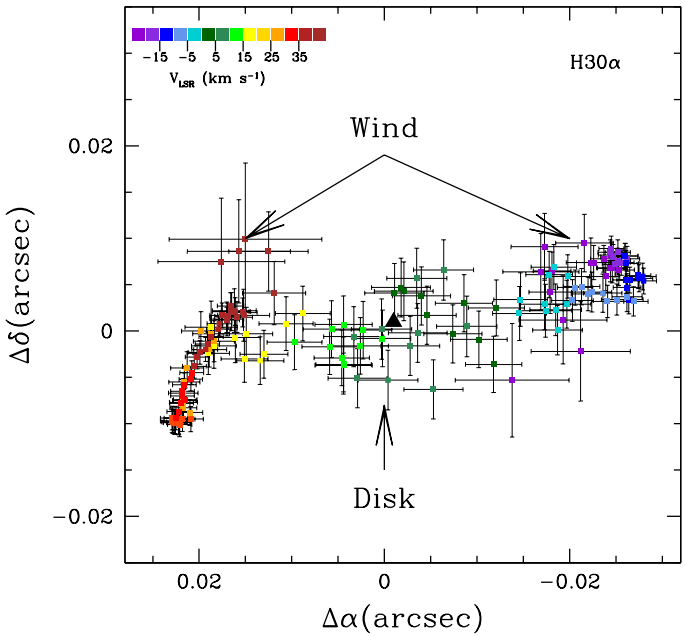


Spectra and Images of H30α and H26α in MWC349A

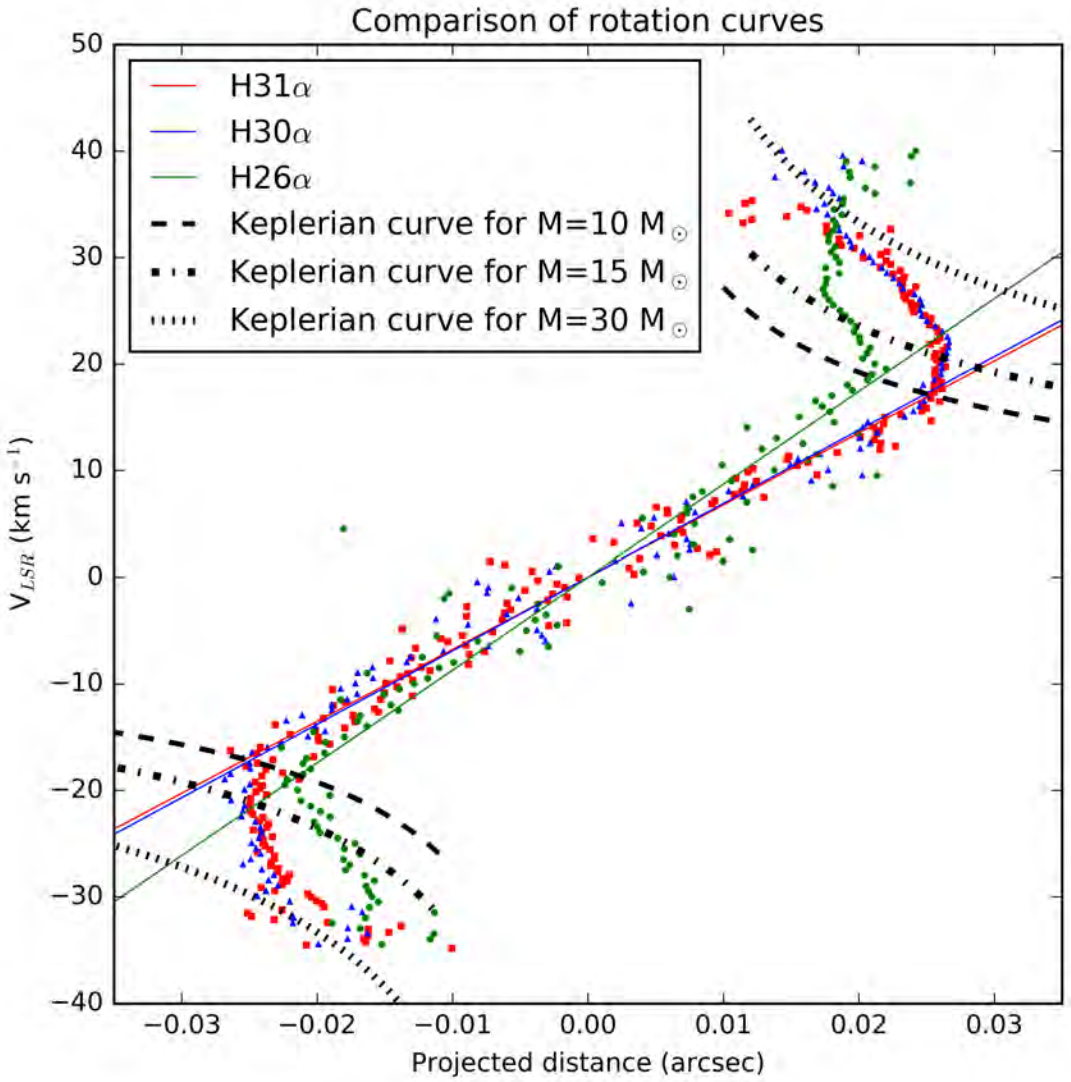




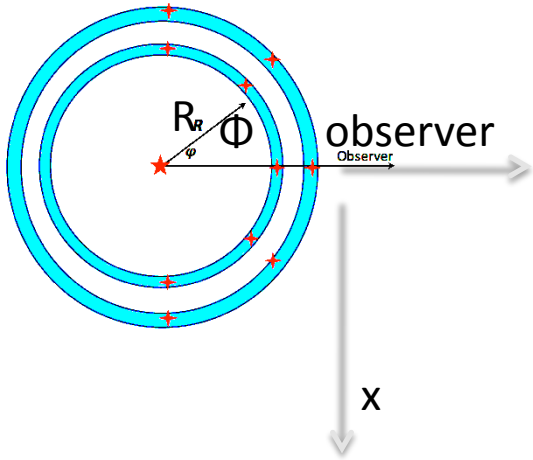




Position-Velocity Diagram for 3 RRL Masers in MWC349



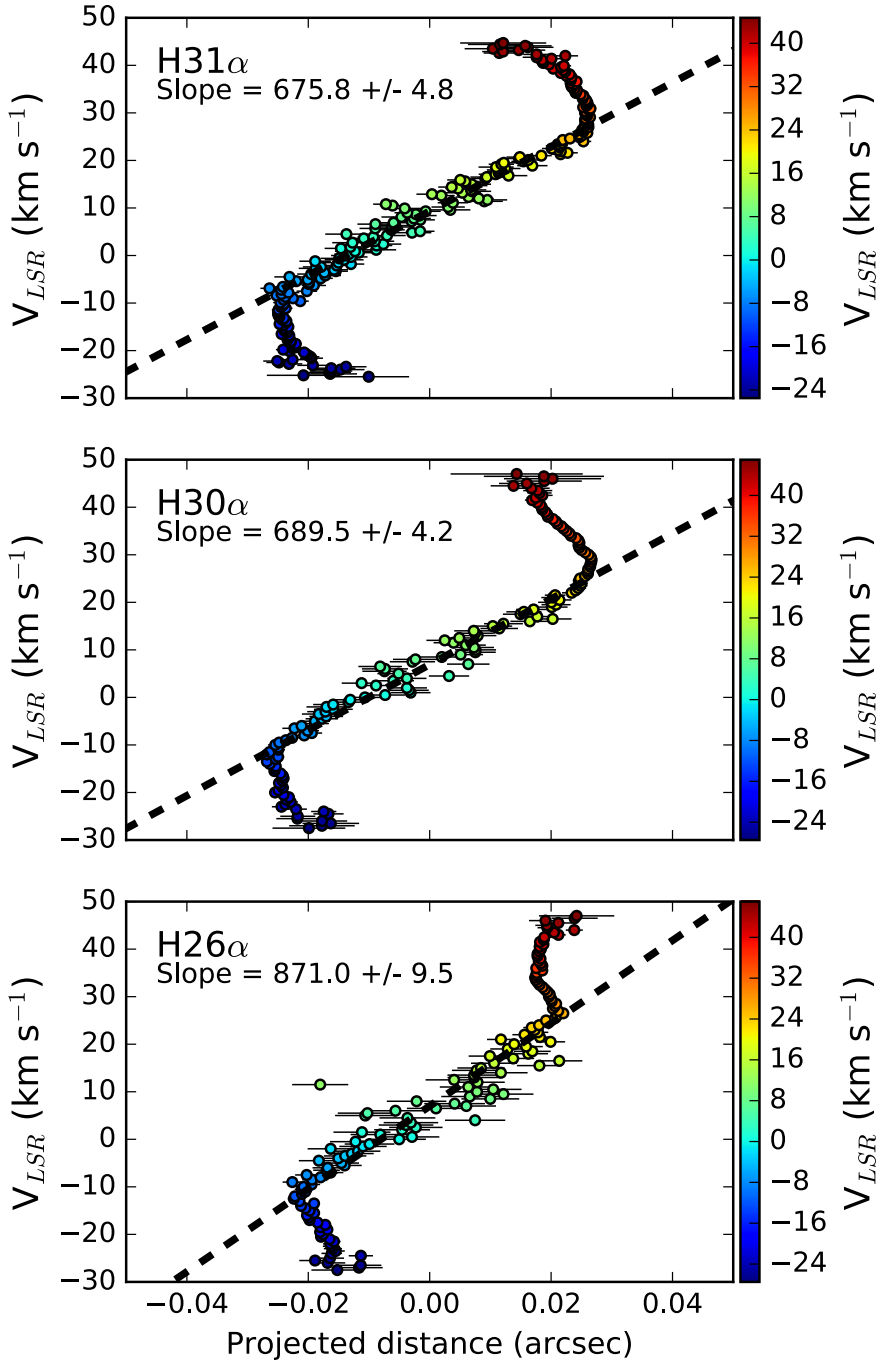
Edge-on rotating disk model



$$v_{los} = v_R \; sin \; \phi = \sqrt{\frac{GM}{R}} \frac{x}{R} = \sqrt{\frac{GM}{R^3}} \; x$$

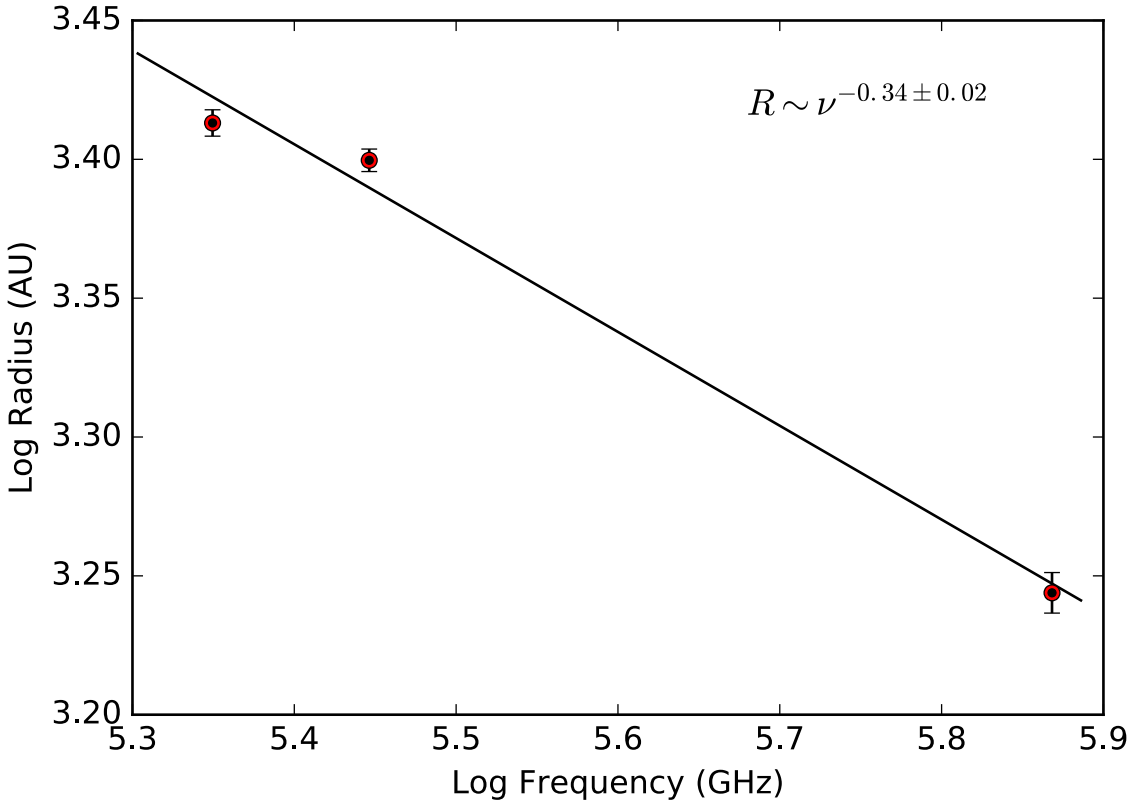
M ~ 10 M_{sun}

Position-Velocity Diagram for three RRLs



Emery, BS thesis, 2017

Radius Versus Frequency of RRL Maser Emission in MWC349A



Emery, BS thesis, 2017

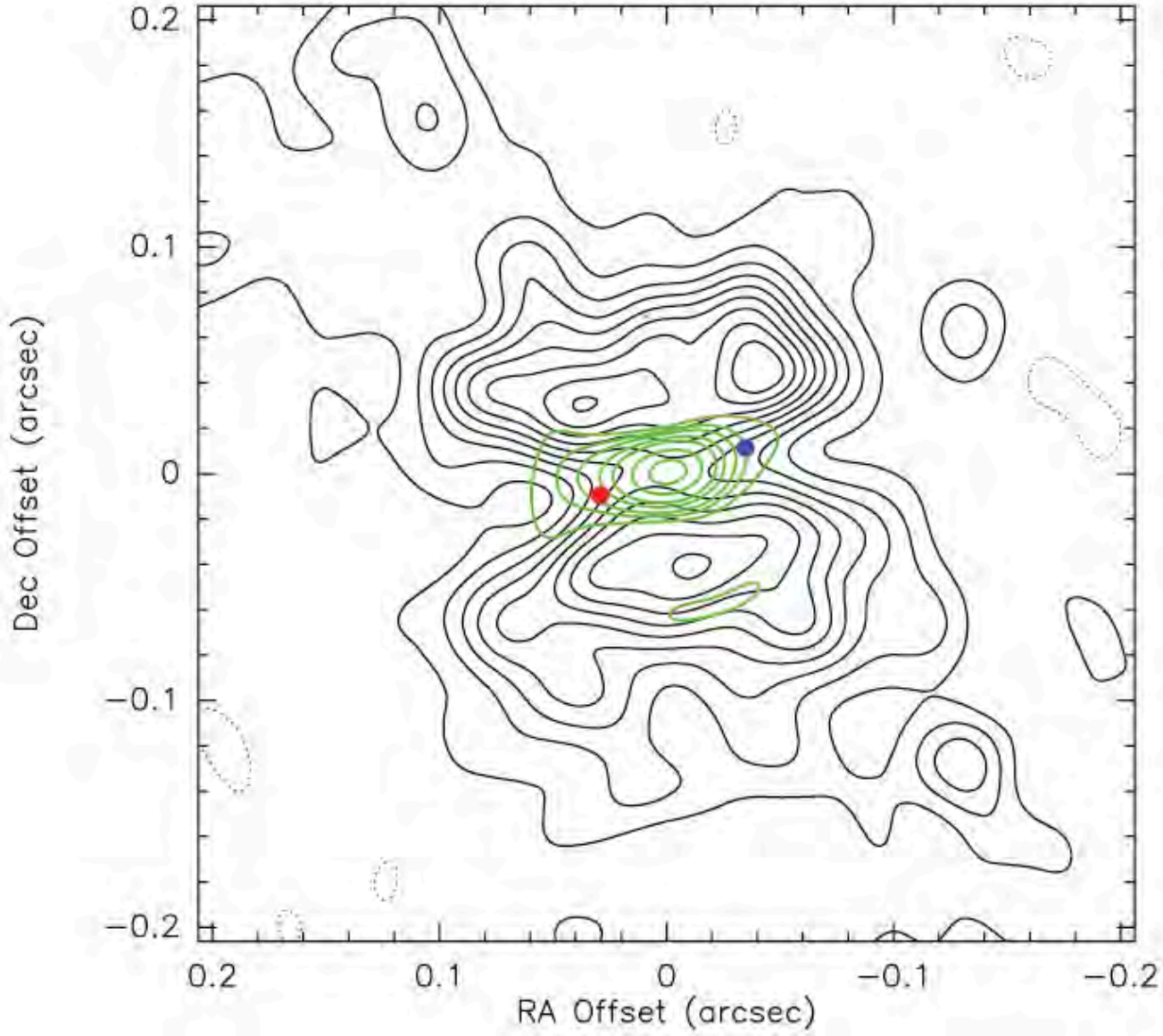
Summary

1. Change in radius with frequency of RRL (smaller radius at higher frequency and lower n)

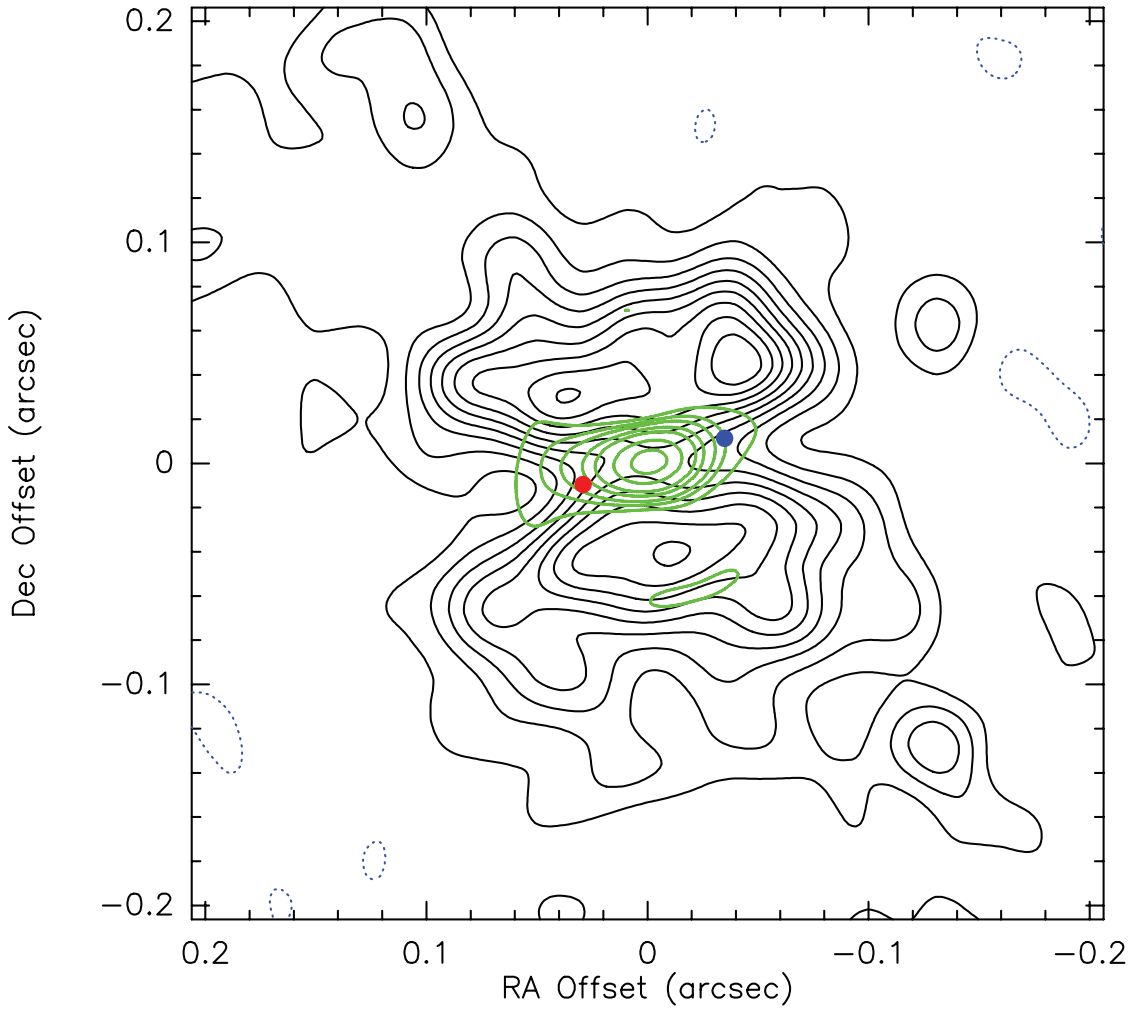
2. Direct evidence of angular momentum transfer from disk

3. $M \sim 10\ M_{sun}$

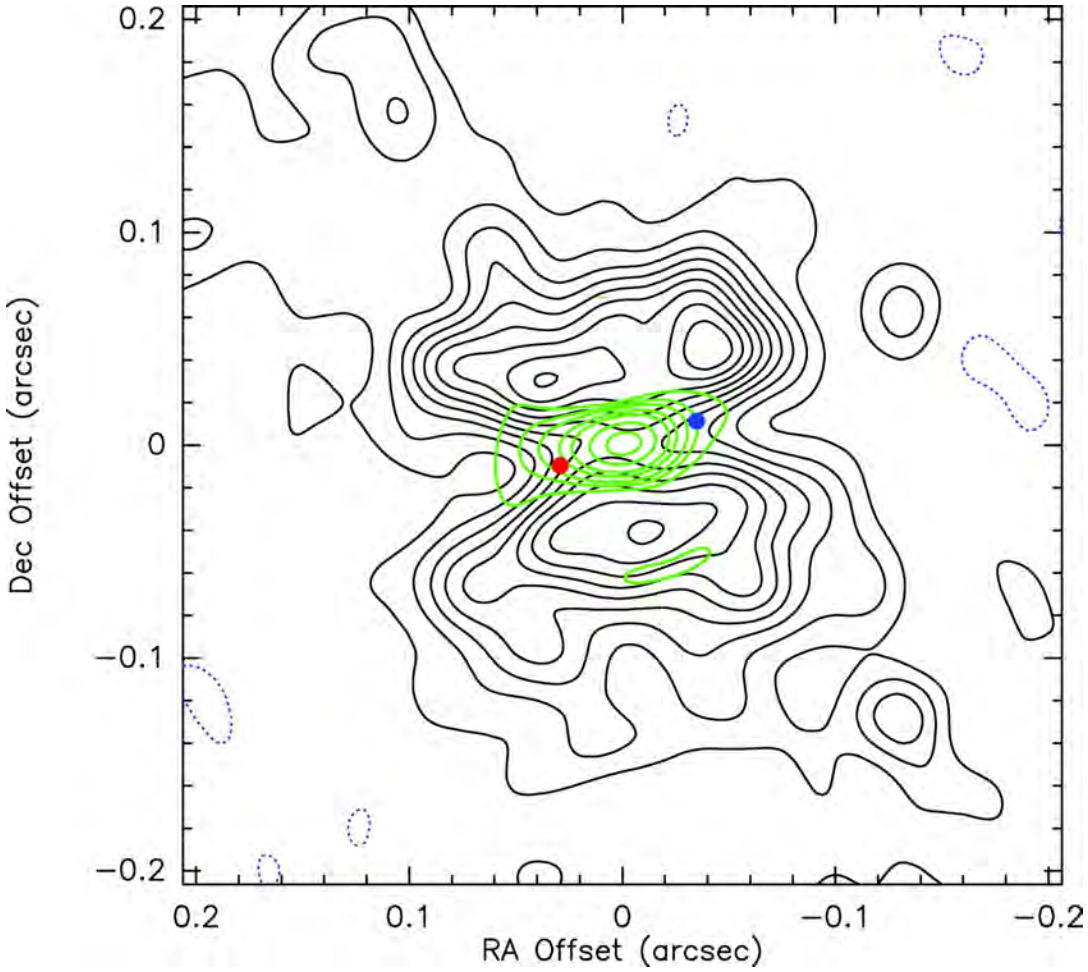
Screen shot of pdf from ADS (89 kbyte)



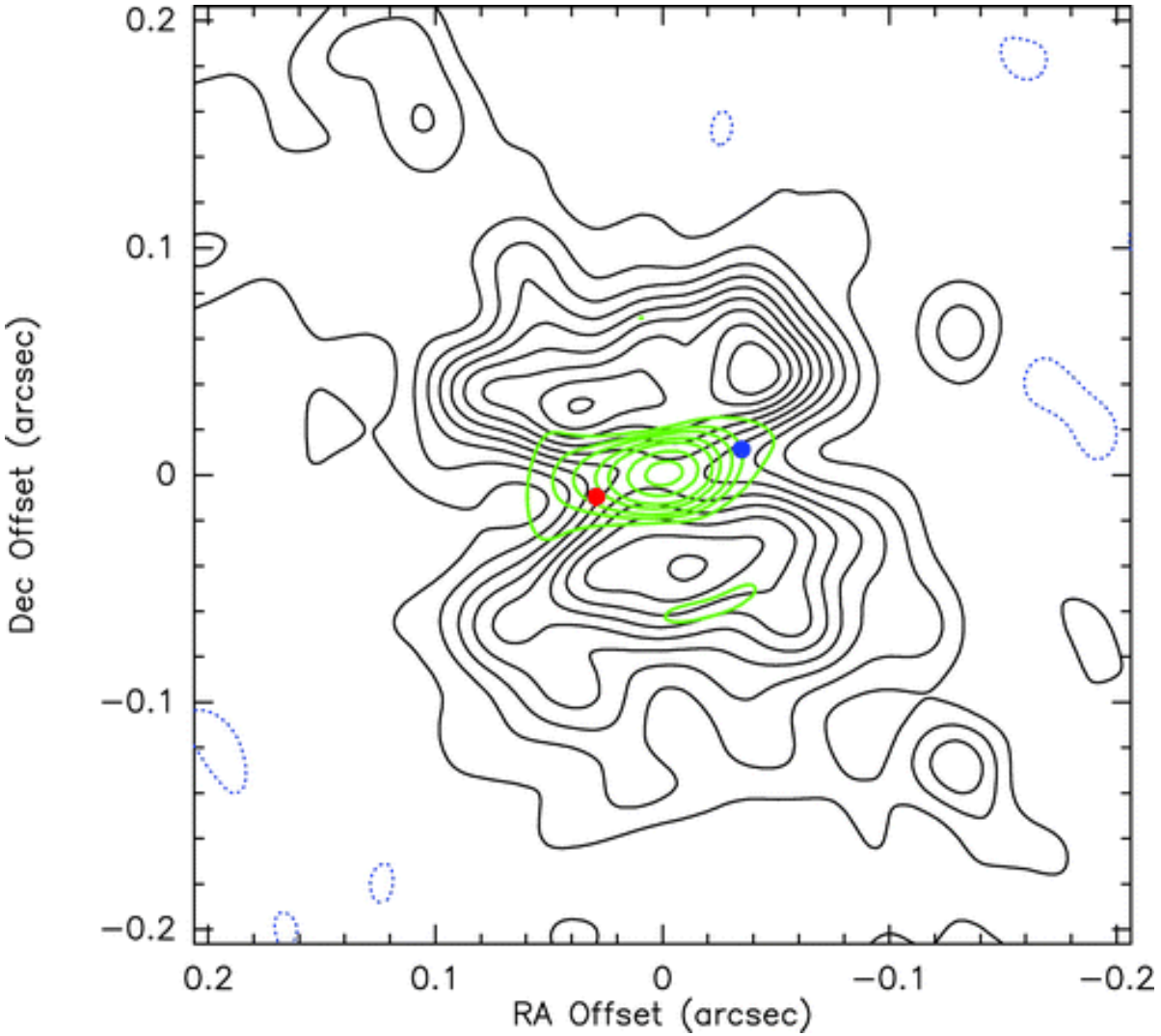
ADS/pdf cropped 106kbyte (full)

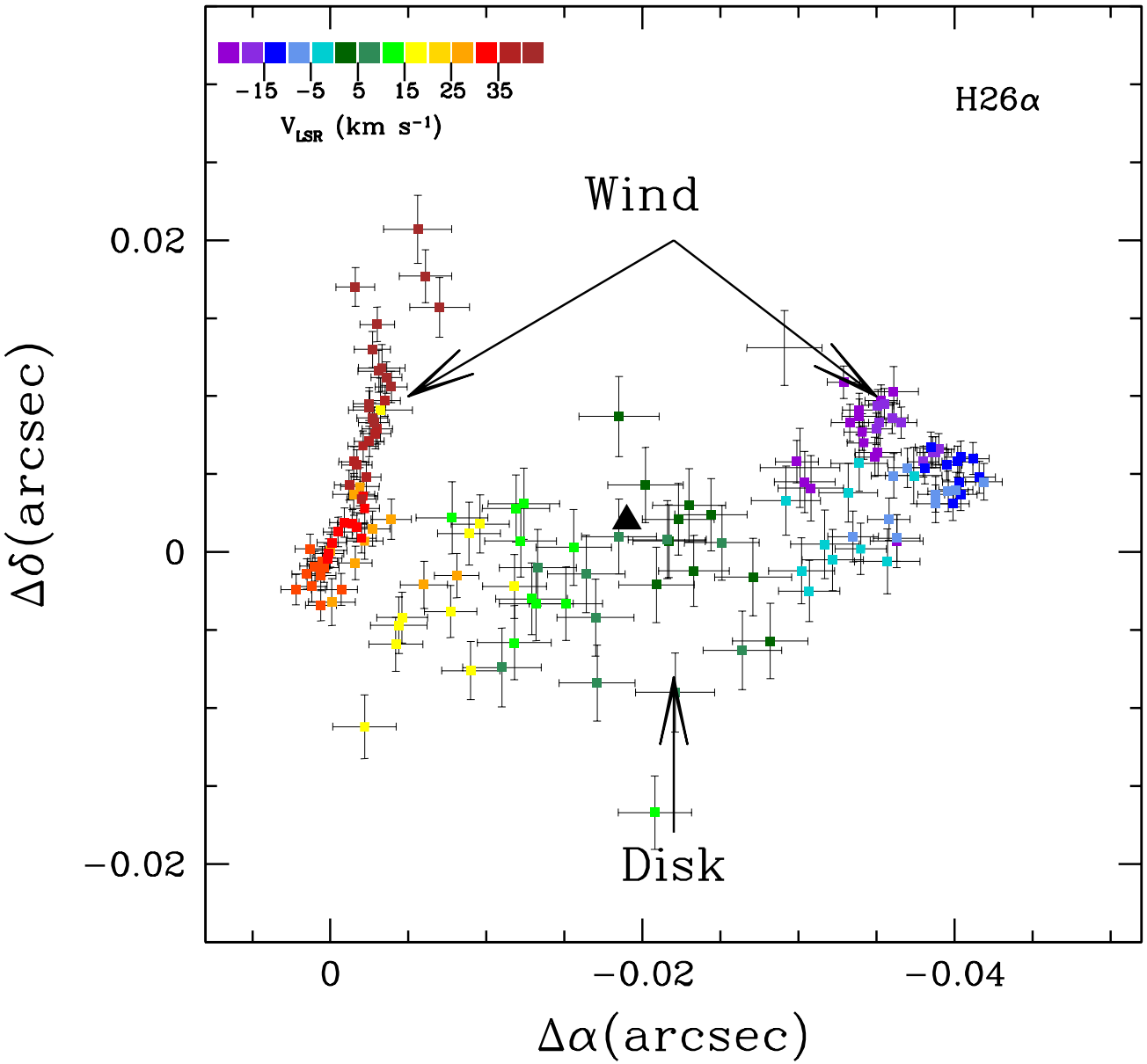


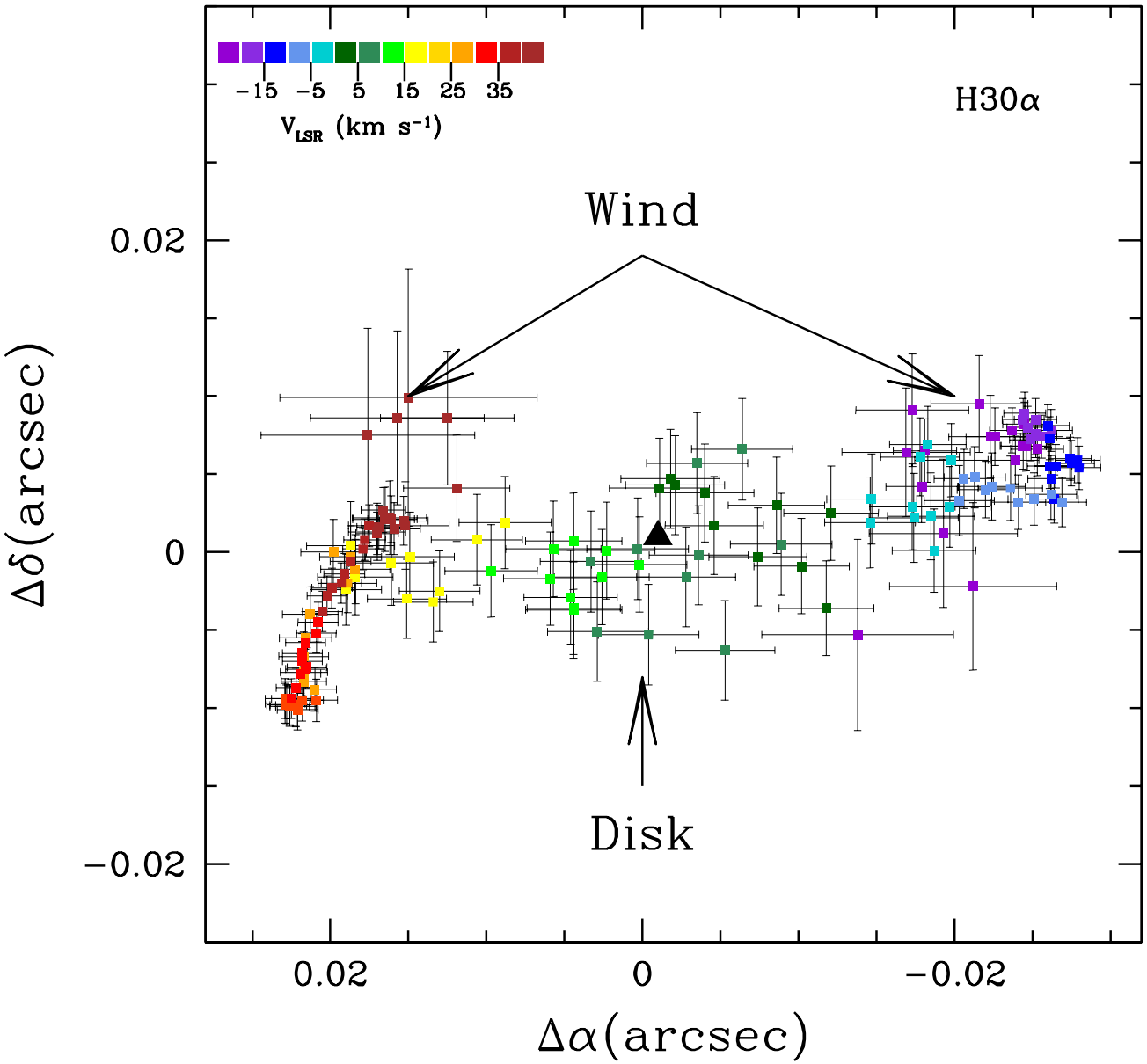
ADS hres jpeg 377 kbyte

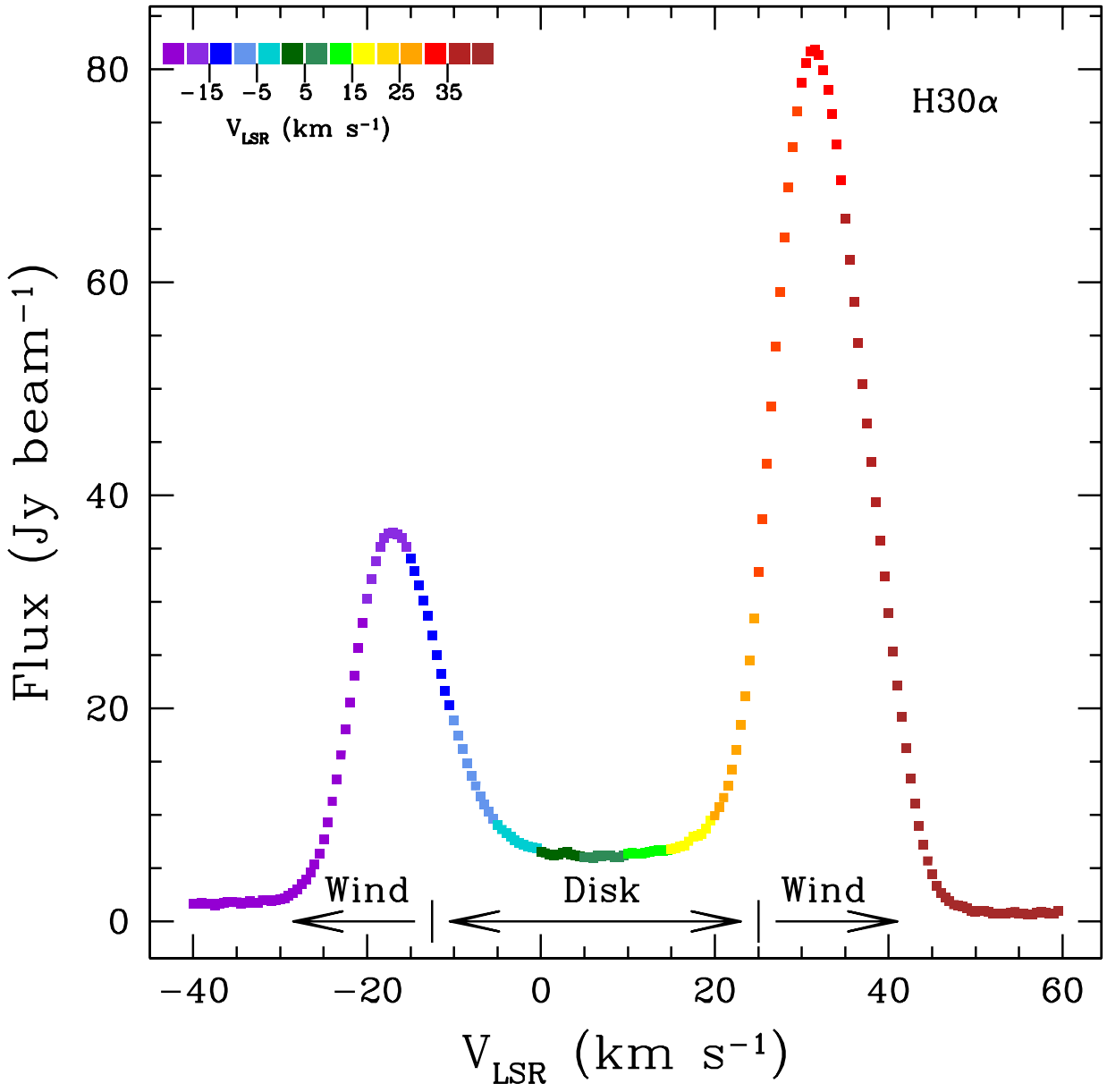


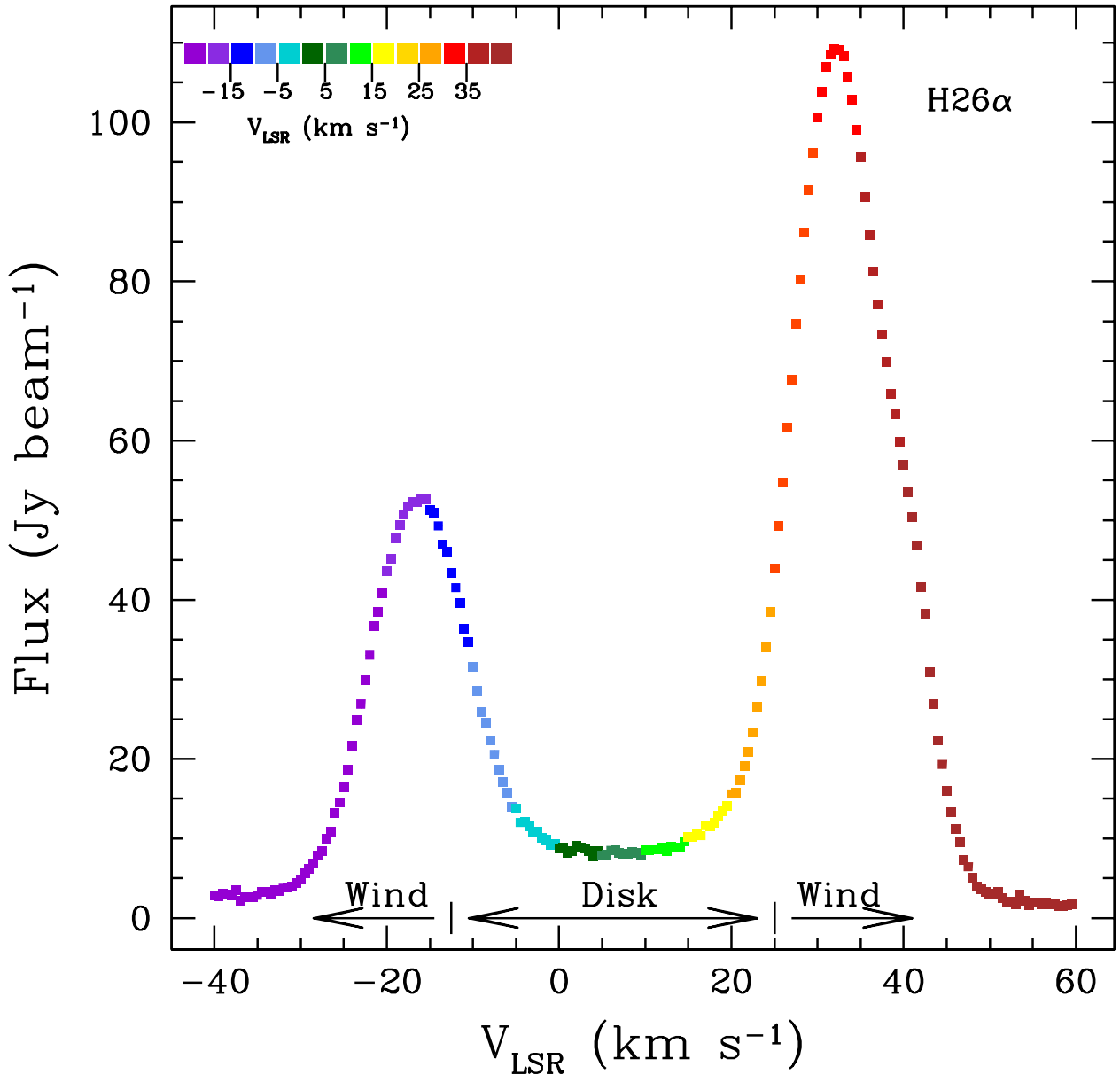
Weintroub ads mres 41 kbyte



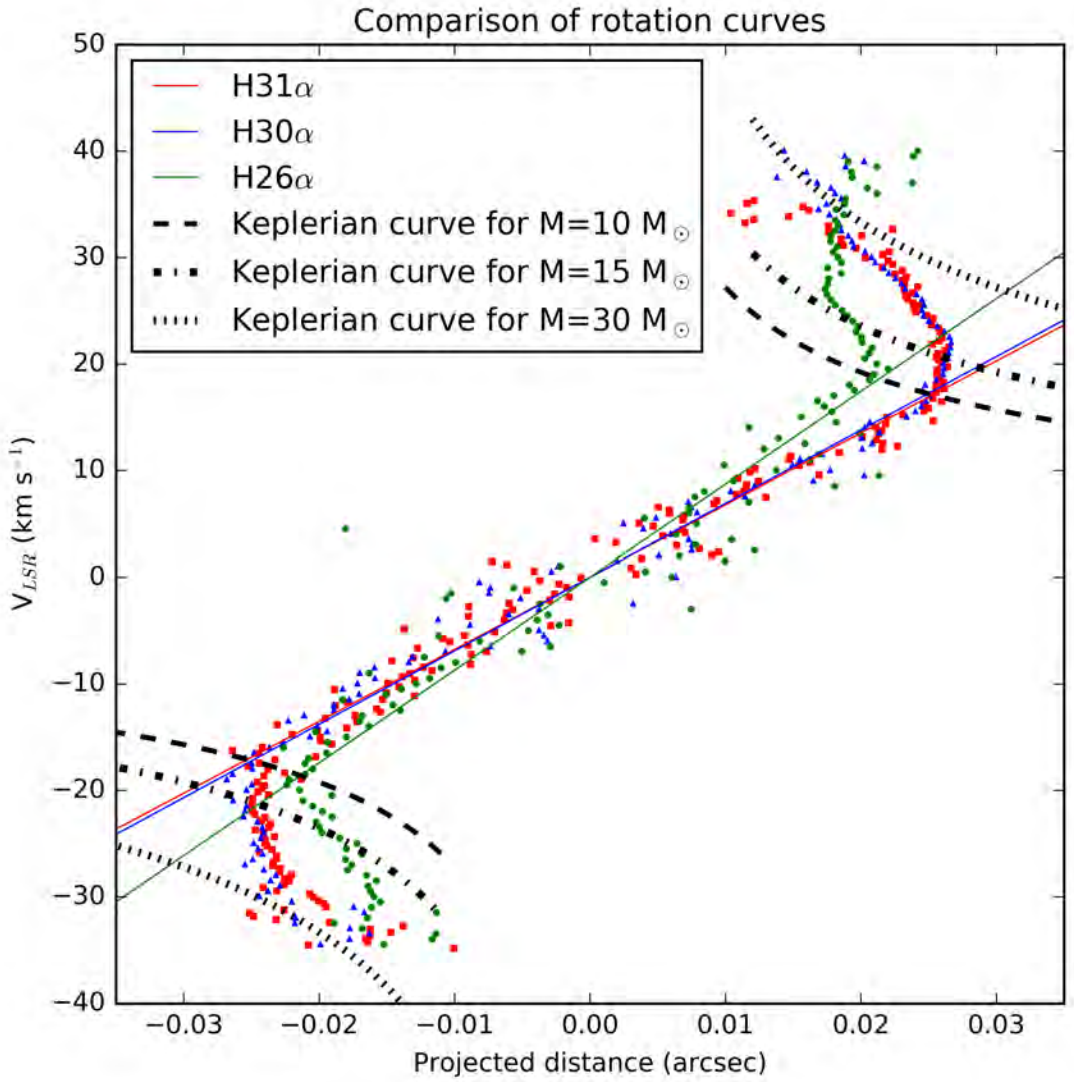

−15 −5 5 15 25 35
V_{LSR} (km s^{-1})
H26α
Wind
Disk
0.02
0
−0.02
0
−0.02
−0.04
Δδ(arcsec)
Δα(arcsec)

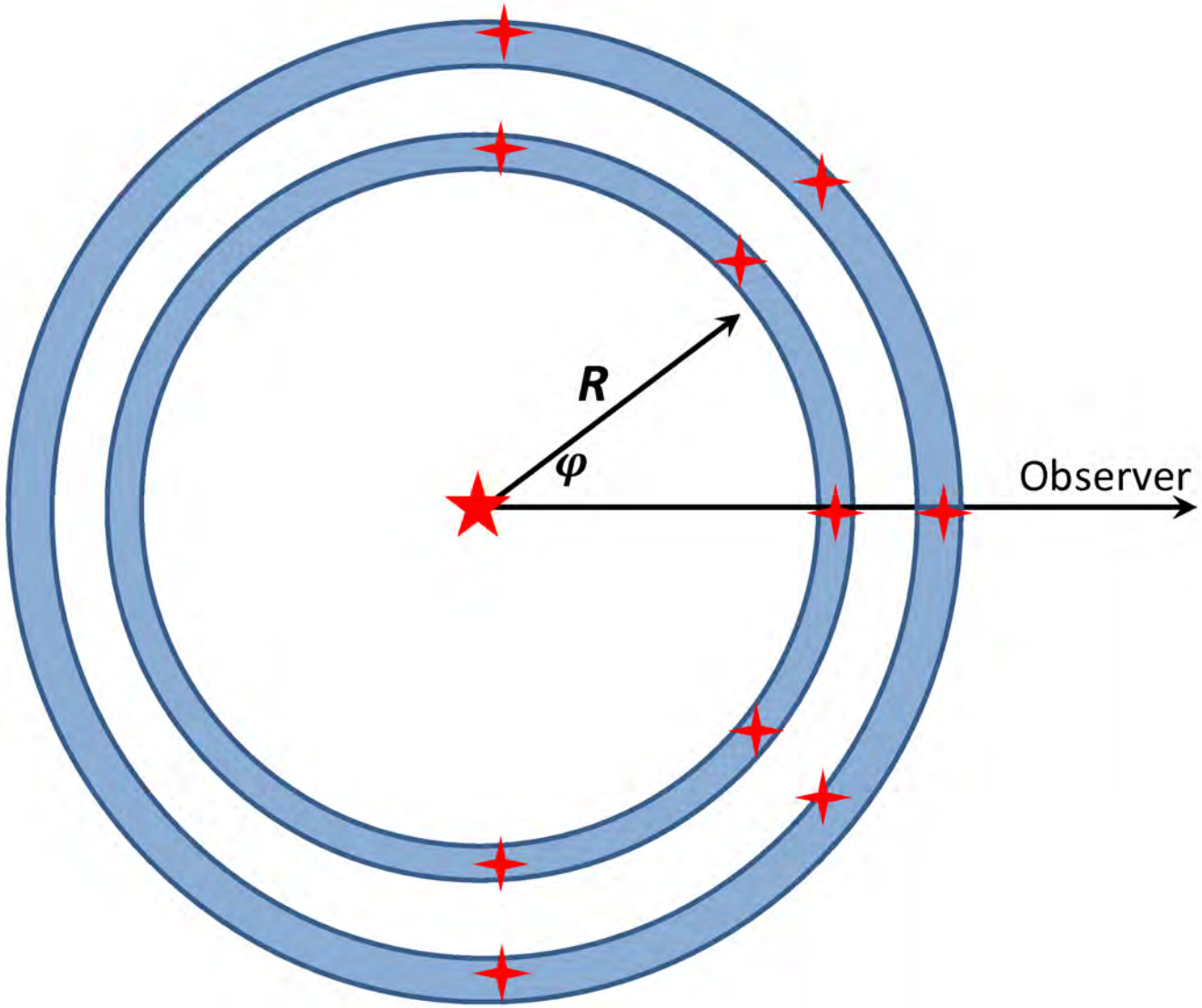

−15 −5 5 15 25 35
V_{LSR} (km s^{-1})
H30α
Wind
Disk
0.02
0
−0.02
Δδ(arcsec)
0.02
0
−0.02
Δα(arcsec)

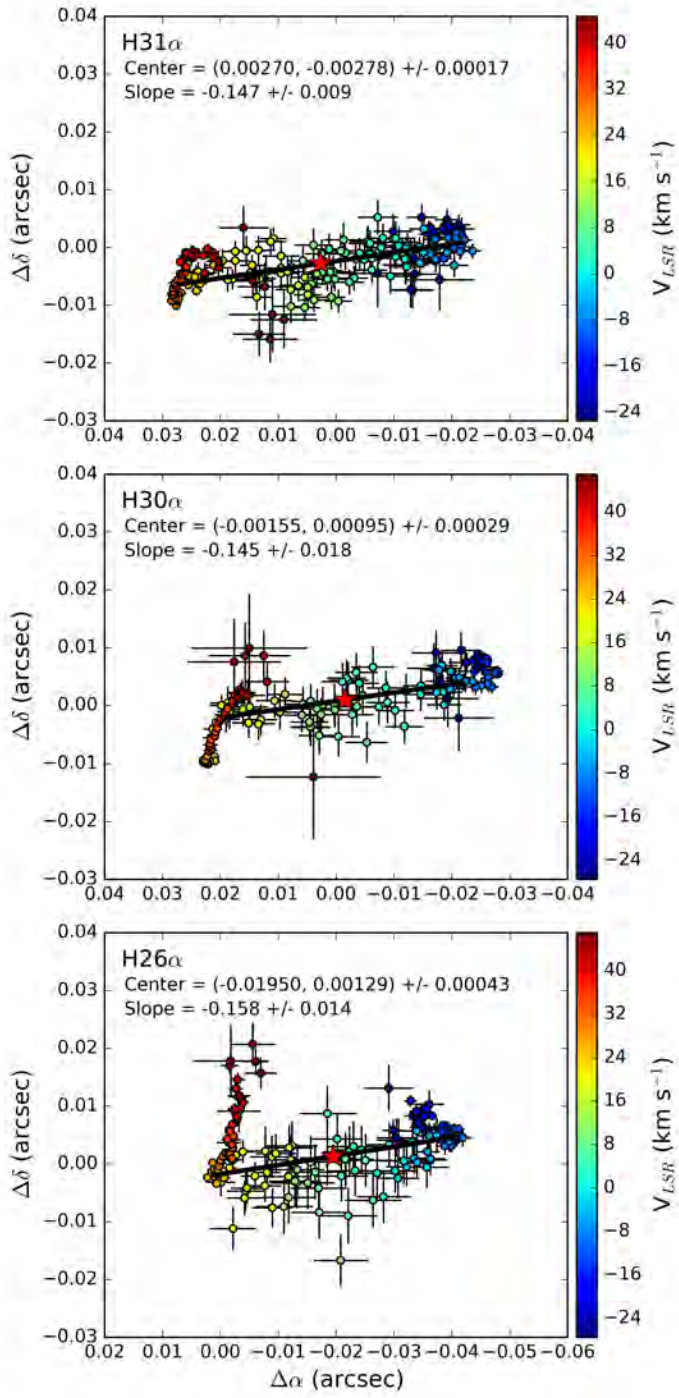

−15 −5 5 15 25 35
V_LSR (km s⁻¹)
H30α
Wind
Disk
Wind
Flux (Jy beam⁻¹)
V_LSR (km s⁻¹)
0
20
40
60
80
−40
−20
0
20
40
60

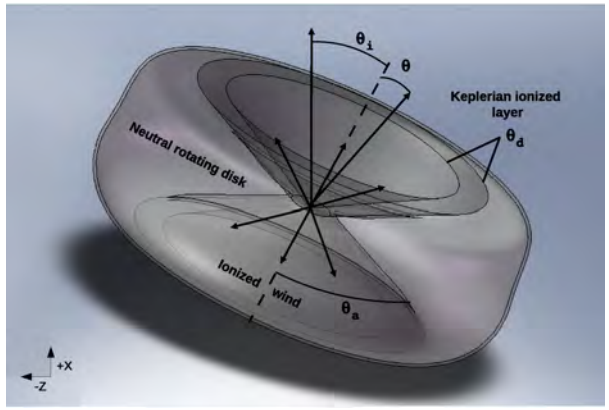

−15 −5 5 15 25 35
V_{LSR} (km s^{-1})
H26α
Flux (Jy beam^{-1})
100
80
60
40
20
0
Wind
Disk
Wind
−40
−20
0
20
40
60
V_{LSR} (km s^{-1})

Position-Velocity Diagram for 3 RRL Masers in MWC349




R
φ
Observer


H31α
Center = (0.00270, -0.00278) +/- 0.00017
Slope = -0.147 +/- 0.009
H30α
Center = (-0.00155, 0.00095) +/- 0.00029
Slope = -0.145 +/- 0.018
H26α
Center = (-0.01950, 0.00129) +/- 0.00043
Slope = -0.158 +/- 0.014
Δδ (arcsec)
Δα (arcsec)
V_LSR (km s^-1)


θi
θ
Keplerian ionized layer
θd
Neutral rotating disk
Ionized wind
θa
+X
-Z

