SF-04-0010

Angular Momenta in the Envelope/Disk/Outflow in IRAS 16293-2422 Source A

YITP YUKAWA INSTITUTE FOR THEORETICAL PHYSICS

Yoko Oya

Kyoto University/YITP, yoko.oya@yukawa.kyoto-u.ac.jp

Abstract

Disk formation process in young low-mass protostellar sources is closely related with the outflow launching via the angular momentum of the gas. To tackle with the early phase of the disk formation process, we performed ALMA observations toward IRAS 16293-2422 Source A and delineated the physical structures in the vicinity of its protostar with the aid of 'molecular markers'.

IRAS 16293-2422 Source A is a Class 0 multiple source. The protostars A1 and A2 involved in Source A were spatially resolved in the 1-mm and 3-mm dust continuum emission. The circummultiple structure of Source A and the circumstellar disk of the protostar A1 are traced by the $C^{17}O$ and H_2CS emissions, respectively. We compared their kinematic structures with simple models and evaluated the specific angular momenta of the gas.

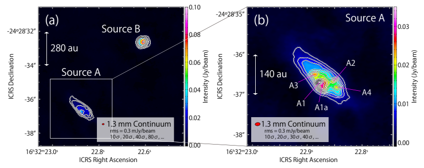
We also delineated the outflow structure in the SO emission. We detected its rotation motion, whose direction is consistent with that of the disk/envelope system. Comparing the specific angular momenta of the outflow and the disk/envelope structures, we found that the outflow can extract the angular momentum of the gas in the circumstellar disk. These results provide us with a novel information on the formation of disk/envelope systems in this complex multiple source.

(Oya et al., 2016, ApJ, 824, 88; Oya & Yamamoto, 2020, ApJ, 904, 185; Oya et al., 2021, ApJ, 921, 21; Oya 2022, Springer Theses; Oya et al., 2022, PASP, 134, 094301)

1. Background

- Disk formation in YSOs
  - Evolution: Infalling envelopes → Rotationally-supported disks
  - Discontinuity in the gas motion
    - Where is the transition zone?
    - Role of the outflow launching?
- Redistribution of the angular momentum
  - Mass accretion onto protostars
  - Substructures within disks?
    - Multiplicity, Planet formation
  - Diversity in planetary systems?
    - Spin orbit angle (Xue et al. 2014)

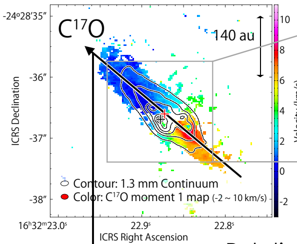
2. IRAS 16293-2422 Source A



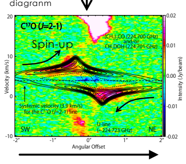
- Class 0 low-mass protostellar source
- Ophiuchus $d \sim 141$ pc (Dzib et al. 2018)
- Binarity: A & B
- Multiplicity within A

3. Kinematic Structures Traced by Different 'Molecular Markers'

Circummultiple Envelope Gas

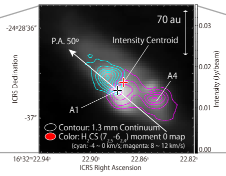


Position-Velocity diagram

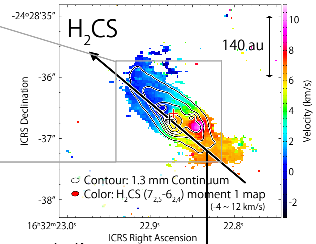


- Rotation + Infall surrounding A
- Envelope model*
  - $M = 1.0\ M_{sun}$
  - $i = 80°a$
  - $R_{in} = 50$ au

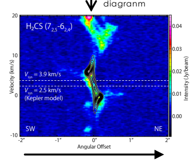
Different Centroid



Circumstellar Keplerian Disk



Position-Velocity diagram



- Keplerian rotation around A1
- Disk model*
  - $M = 0.4\ M_{sun}$
  - $i = 60°$
  - $R_{out} = 30$ au

*Model: FERIA (Oya et al. 2022)

Species	Transition	Freq. (GHz)	E_u (K)	Resolution
OCS	J = 19-18	231.0609934	111	~89 x 70 au
CH_3OH	$11_{0,11}$-$10_{1,10}$; A^{++}	250.5069800	153	~82 x 64 au
$HCOOCH_3$	$19_{9,10}$-$19_{8,11}$; E	232.5972780	166	~88 x 70 au
$C^{17}O$	J = 2-1	224.714385	16	~16 x 11 au
$C^{34}S$	J = 2-1	96.41294950	6.2	~29 x 23 au

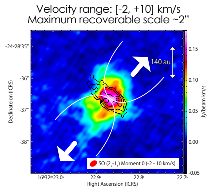
Species	Transition	Freq. (GHz)	E_u (K)	Resolution
H_2CS	$7_{0,7}$-$6_{0,6}$*	240.266872	46	~16 x 11 au
H_2CS	$7_{2,5}$-$6_{2,4}$*	240.549066	99	~16 x 11 au
H_2CS	$7_{2,6}$-$6_{2,5}$*	240.382051	99	~16 x 11 au
H_2CS	$7_{4,4}$-$6_{4,3}$, $7_{4,3}$-$6_{4,2}$	240.33219	257	~16 x 11 au

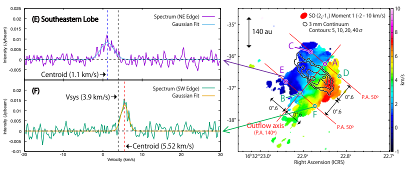
*Both of the disk & envelope are traced by K = 0, 2 transitions.

Outflow

- ~Parallel to the plane of the sky
- Rotation
  NE: blueshifted
  SW: redshifted

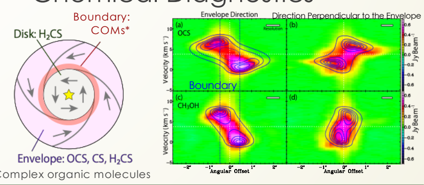
Velocity range: [-2, +10] km/s
Maximum recoverable scale ~2"





Species	Transition	Freq. (GHz)	E_u (K)	Resolution
SO	$J_N = 2_2$-1_1	86.093950	19	~34 x 24 au
OCS	J = 7-6	85.13910320	16	~34 x 27 au

Chemical Diagnostics



*Complex organic molecules

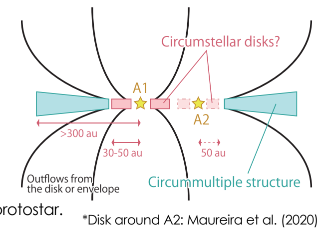
4. Discussion: Angular Momenta in Three Structures

Structure	Specific Angular Momentum (j; 10^{-4} km/s pc)	
	$i = 60°$	$i = 80°$
Circummultiple Envelope	–	12.9–15.8
Circumstellar Disk*	5.0–5.6	–
Outflow (NW, SE)	10.4±0.3, 10.2±0.3	9.1±0.3, 8.9±0.2

(*) At 30-au distance from the protostar A1

- Changes from the envelope to the disk
  - Loss of the specific angular momentum
  - Mis-alignment: centroid, V_{sys}, inclination angle
- j in the outflow > j in the circumstellar disk
  - The outflow can extract the angular momentum (L) from the disk

→ The outflow may help the mass accretion toward the protostar.

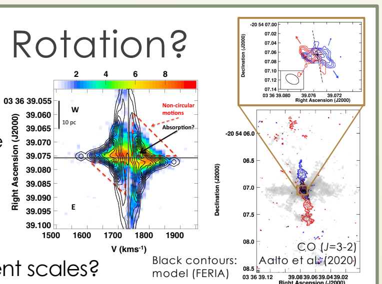


*Disk around A2: Maureira et al. (2020)

5. Analogy of Rotation?

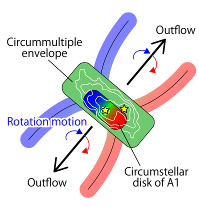
- NGC 1377: AGN
  - Dusty torus around a super massive black hole
- Model: Rotation + Infall
  - $M = 3 \times 10^6\ M_{sun}$
  - $i = 90°$
  - $R_{in} = 1$ pc

→ Similar physics on different scales?



Black contours: model (FERIA)

6. Summary



- Chemical diagnostics for three structures
  - → Specific angular momenta
- What is the driving source of the outflow?
  - Contribution for the angular momentum loss
    1) Envelope → Disk 2) Disk → Protostar

References

Aalto et al., 2020, A&A, 640, A104; Dzib et al., 2018, A&A, 614, A20; Maureira et al., 2020, ApJ, 897, 59; Xue et al., 2014, ApJ, 784, 66

ALMA Observations

ADS/JAO.ALMA#2012.1.00712.S (P.I. J. K. Jørgensen), #2016.1.004557.S, #2017.1.01013.S (P.I. Y. Oya)

pdf of this poster →