Multi-wavelength investigations of Star and Cluster Formation in the Rosette Molecular Complex

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Colloquium at NAOC, 7 Sept.2022

Outlines

1. General views of MC and SF
2. Systematic search for Herbig-Haro flows in the Rosette Nebula
3. Clustered star formation in the RMC
4. An extensive survey of H_2 flows and the discovery of the Rosette Eye
5. Herschel view of massive SF in the RMC

Astonishing v.s. Humble

形成类太阳恒星的摇篮
孤立的分子暗云 - Lynds 183

The Circinus Cloud


ESO

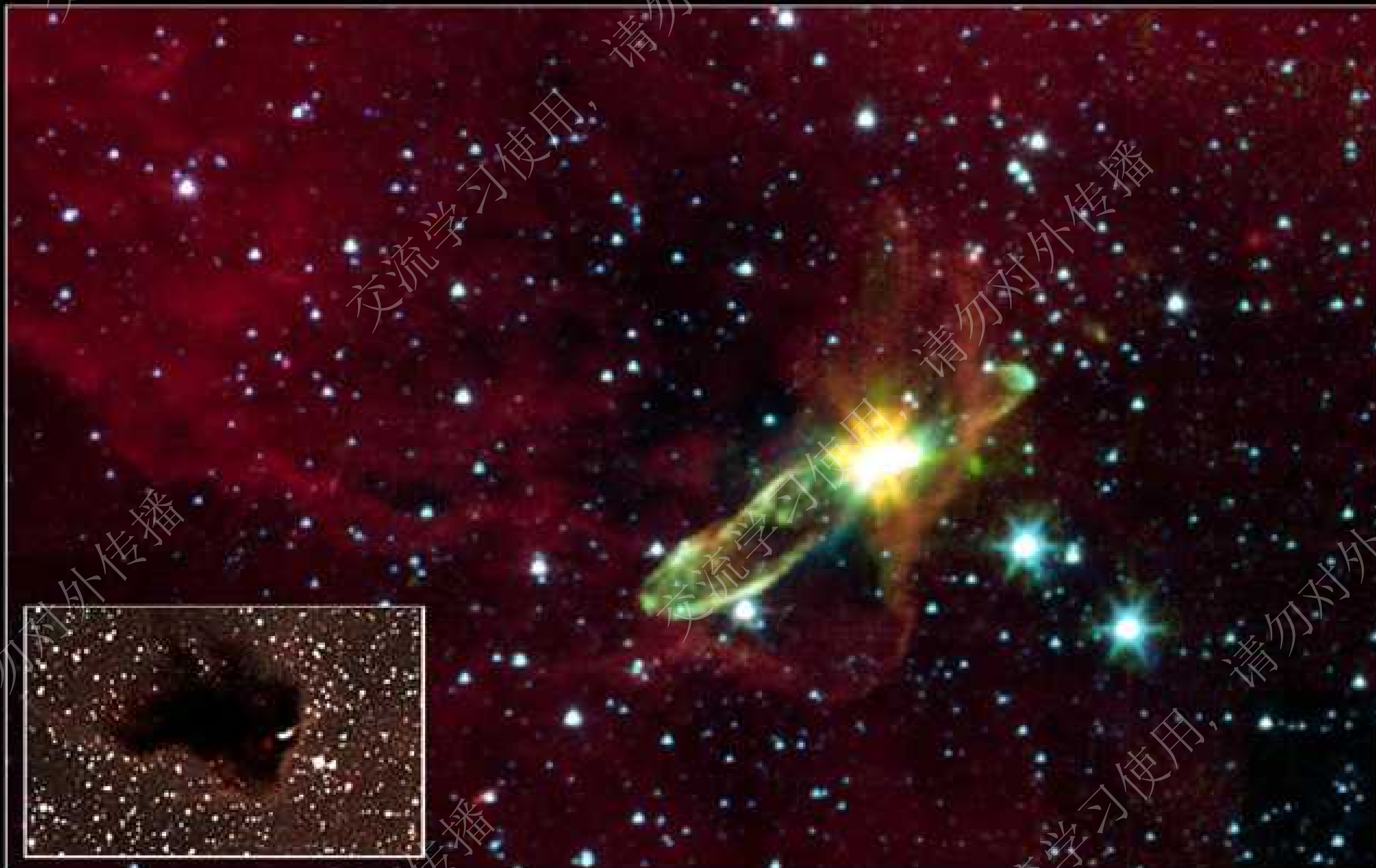
鹰状星云

哈勃太空望远镜拍摄


马头星云

Cone Nebula - 麒麟座锥状星云

Carina Nebula - 船底座星云



Embedded Outflow in HH 46/47

Spitzer Space Telescope • IRAC

Inset: visible light (DSS)

NASA / JPL-Caltech / A. Noriega-Crespo (SSC/Caltech)

ssc2003-06f

恒星与星团形成

- ✓ 恒星诞生于分子云中，观测表明，绝大多数恒星以成团的模式形成。
- ✓ 红外星团代表着星团形成及演化的早期状态。对红外星团的观测研究是恒星形成领域的重要课题。
- ✓ 红外星团（**Infrared clusters**），又称嵌埋星团（**Embedded cluster**），由于嵌埋在冷暗浓厚的气尘物质之中，只能通过红外波段进行研究，因此得名。
- ✓ 随着观测技术的发展、全波段观测项目的顺利展开，让我们有能力瞻仰宇宙的全貌，揭开星团形成及早期演化的面纱！

恒星与星团形成——研究历史和进展

- 1991：首次对红外星团进行系统的观测研究（**Lada et al. 1991**）
- 1993-1999：确定红外星团的标识特征：**IRAS**源、分子外向流、主序前星等
- 2001-2003：利用多波段数据搜寻研究红外星团
- 2003：Porras等人列出73个距太阳1kpc以内的红外星团
  Lada & Lada 列出76个2.5kpc以内的红外星团
  Bica等人总结整理出276个红外星团
- 2004：Carpenter 等人根据已有观测结论总结整理出474个红外星团候选体
- 2005-2008：确定星团的外部激发形成理论: **HII** 区、超新星爆发、分子外向流等都可能激发影响星团的形成(**Hester&Desch 2005, Yasui et al. 2006, Shimajiri et al. 2008**)

恒星与星团形成--研究意义

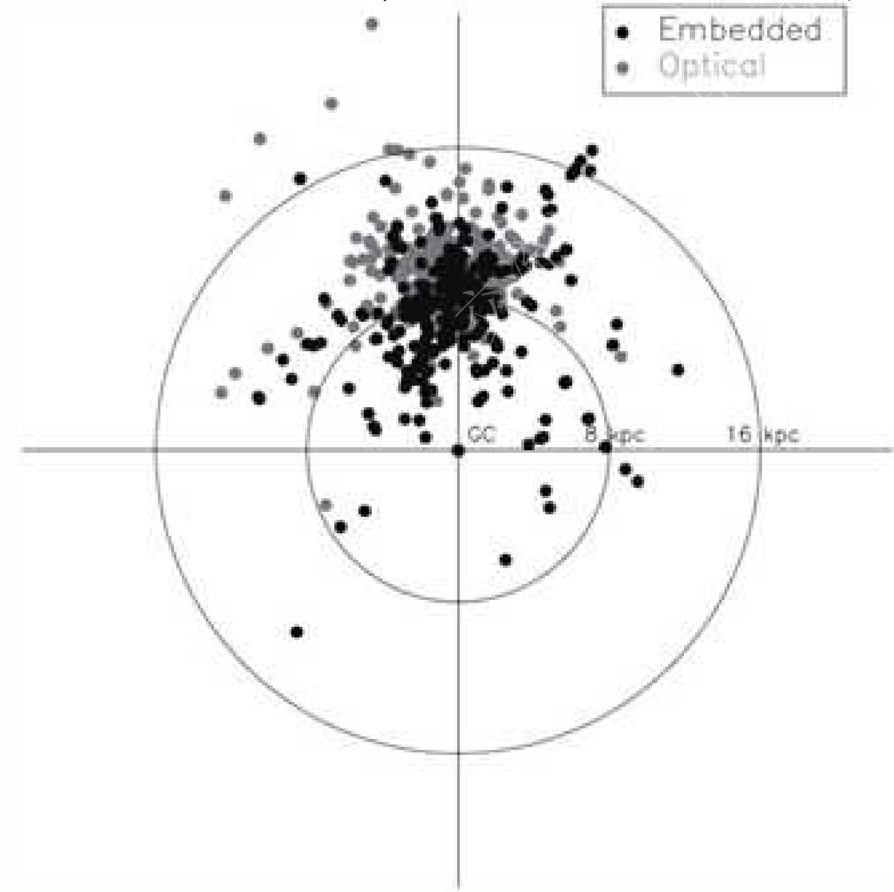


图1.6 已知光学和红外星团在银盘上的位置分布图（Carpenter 2004）。

红外星团可以认为是宇宙中恒星形成的基本单元

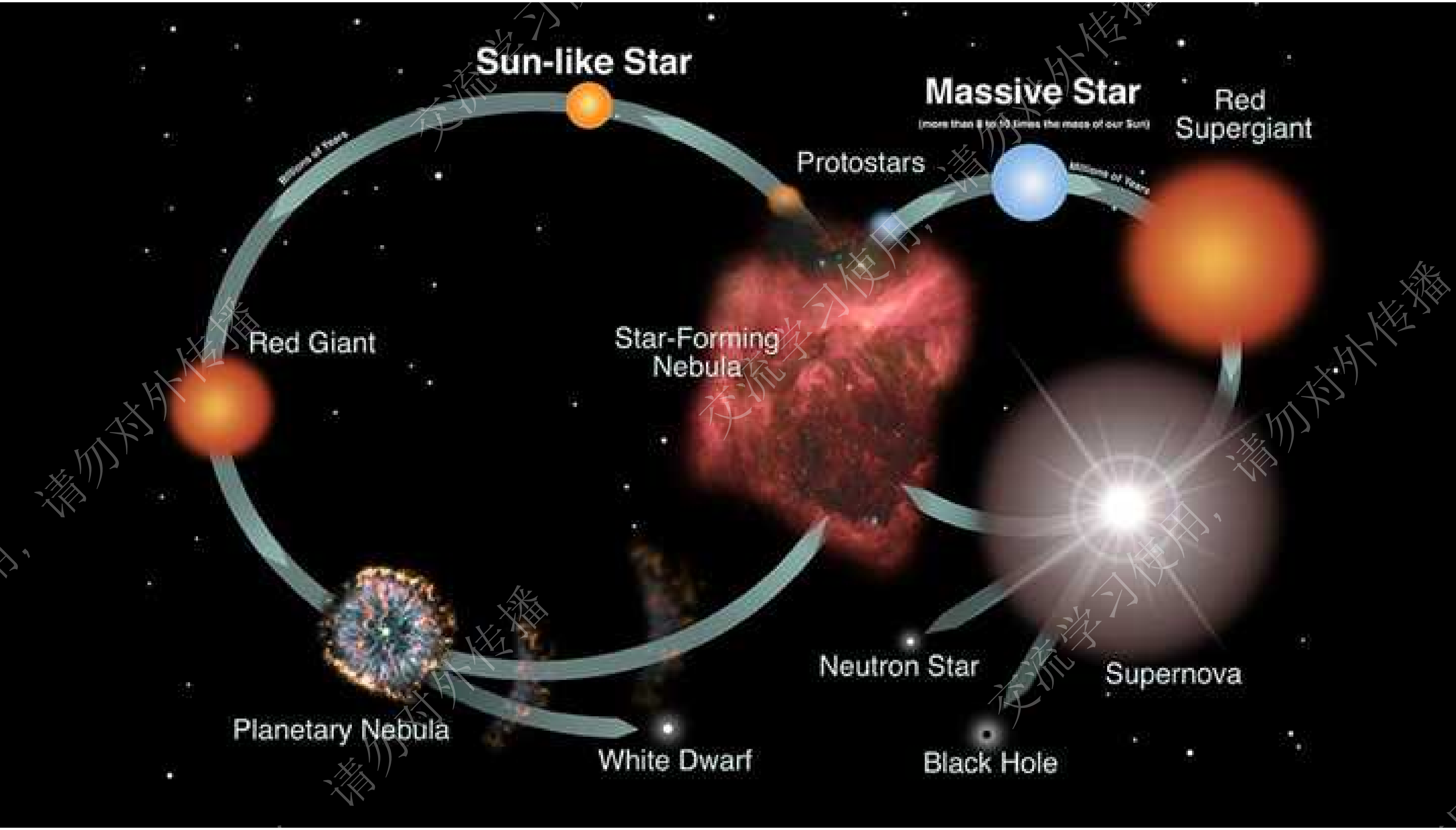
对它们的研究可以很好地揭示天文学中遇到的很多问题

星团的形成和早期演化	恒星与行星系统的初始状态和演化过程

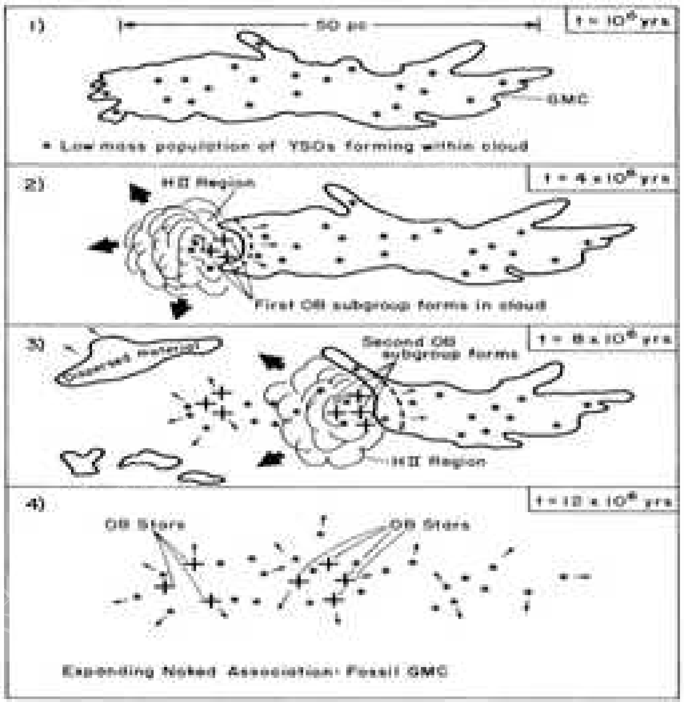
由于银盘上大多数恒星诞生于红外星团之中

星系的基本属性、恒星形成率、恒星的初始质量函数等问题

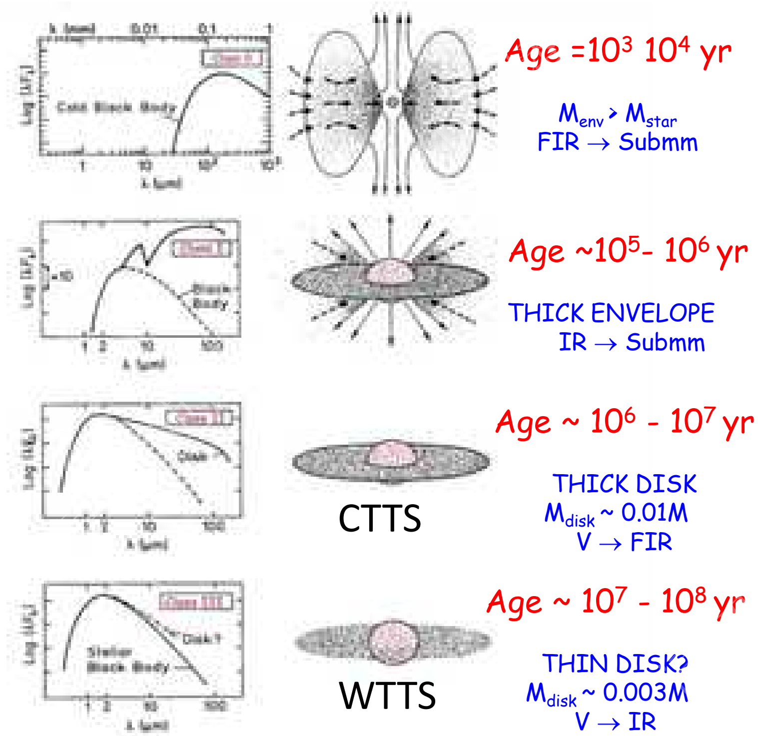
SF and evolution



恒星形成及早期演化



分子云中大质量**OB**星恒星序列形成的图景（**Lada 1987)**

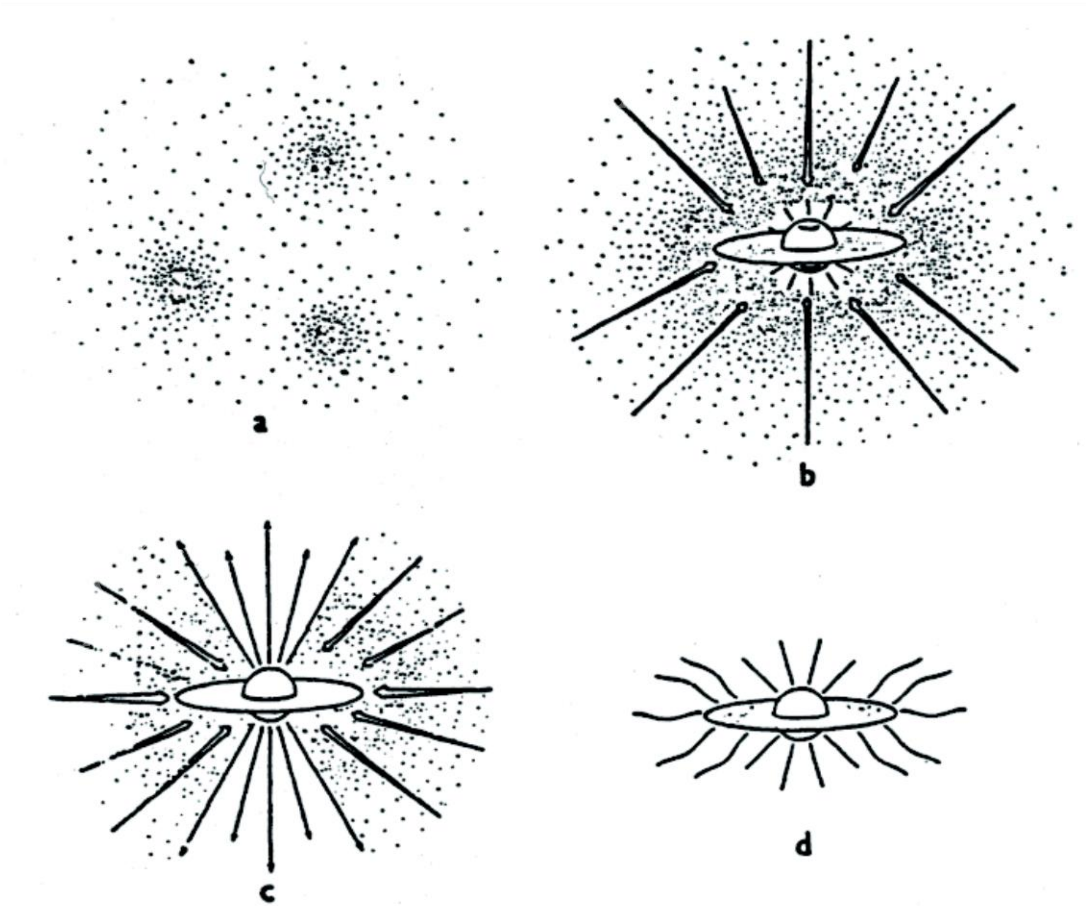


低质量星形成图景
(Lada e Wiking 1984, Andrè et al. 1993)

恒星诞生于分子云中，红外星团代表着星团形成的早期演化阶段，尘埃消光严重，其形成与早期演化研究只能在红外波段进行。

星团形成是当前天体物理学恒星形成研究领域富有挑战性的国际前沿课题。

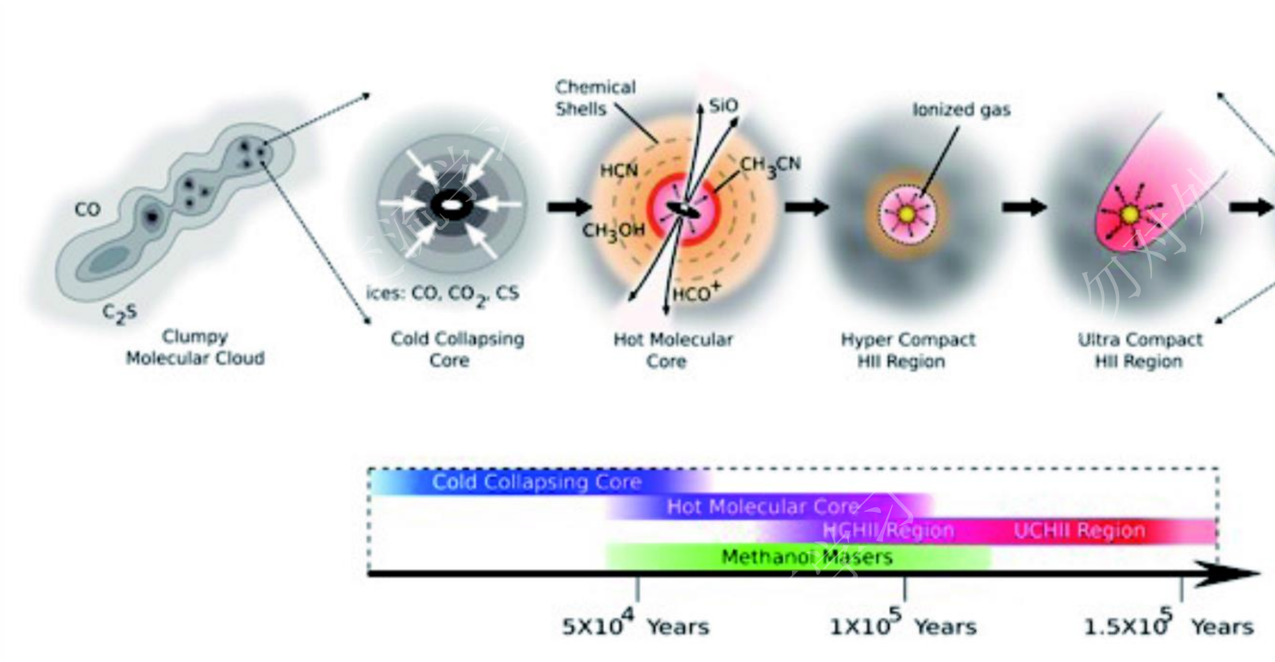
恒星形成——中低质量恒星形成及演化



孤立分子云中低质量恒星形成“标准模型”（Shu et al. 1987）

云核形成阶段
↓
等温塌缩阶段
↓
外向流阶段
↓
主序前星演化阶段

恒星形成---大质量恒星形成及演化



冷暗分子云 → 星前核阶段 → 热核阶段 → 超致密 H II 区 → 极致密 H II 区 → OB 星协和开放的电离氢区

大质量恒星形成演化各阶段特征

恒星形成——年轻恒星的分类

根据质量的分类

- $2\,M_\odot \sim 8\,M_\odot$
  - **Herbig Ae/Be stars**
  - 光谱型早于F0且有巴尔末发射；
  - 光度分类属于III-V型；
  - 具有较强的由星周气尘物质引起的红外色余.

(George Herbig 1960,
Waters & Waelkens 1998)

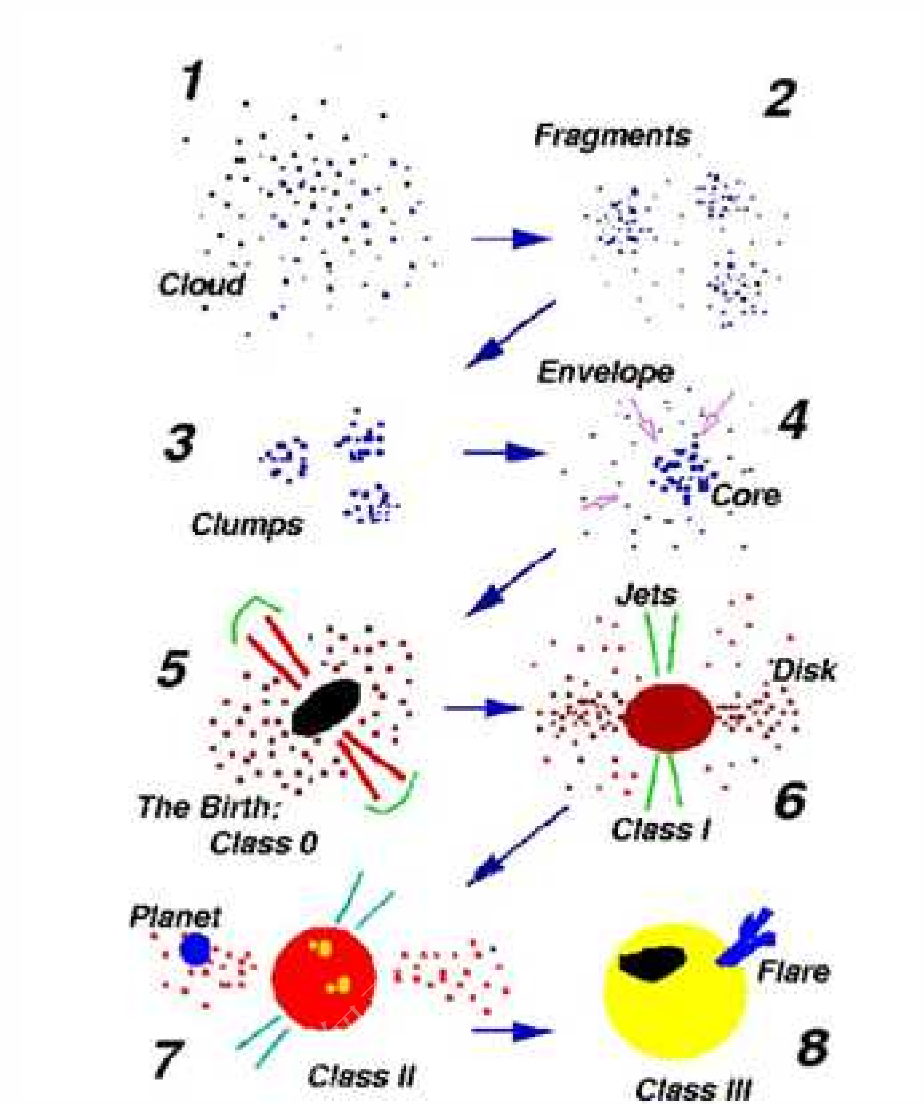
- $< 2\,M_\odot$
  - **T Tauri stars**
  - **Classical T Tauri stars(CTTS)**
  - **Weak-line T Tauri stars(WTTS)**

	CTTS	WTTS
光谱型	EW[Hα]	
K0 – K5	> 3 Å	< 3 Å
K6 – M2.5	> 10 Å	< 10 Å
M3 – M5.5	> 20 Å	< 20 Å
M6 – M7.5	> 40 Å	< 40 Å

(White & Basri 2003)

恒星形成：全阶段

- 根据演化状态的分类



1. Cloud of atoms
2. Fragments
3. Clumps
4. Cores
5. Class 0
6. Class 1
7. Class 2
8. Class 3

Systematic investigations of SF in the RMC

(HH and H_2 flows, clustered SF)

Color-composite from ISSA
25, 60 & 100 μm

Spitzer IRAC obs. of Rosette

Why the Rosette Complex?

- Most stars originate in OB associations (Roberts 1957) and are formed out of GMCs (Blitz 1980)
- 70-90% of stars in nearby GMCs are in embedded clusters (Lada et al. 1991, etc.)

- An isolated massive SFR.

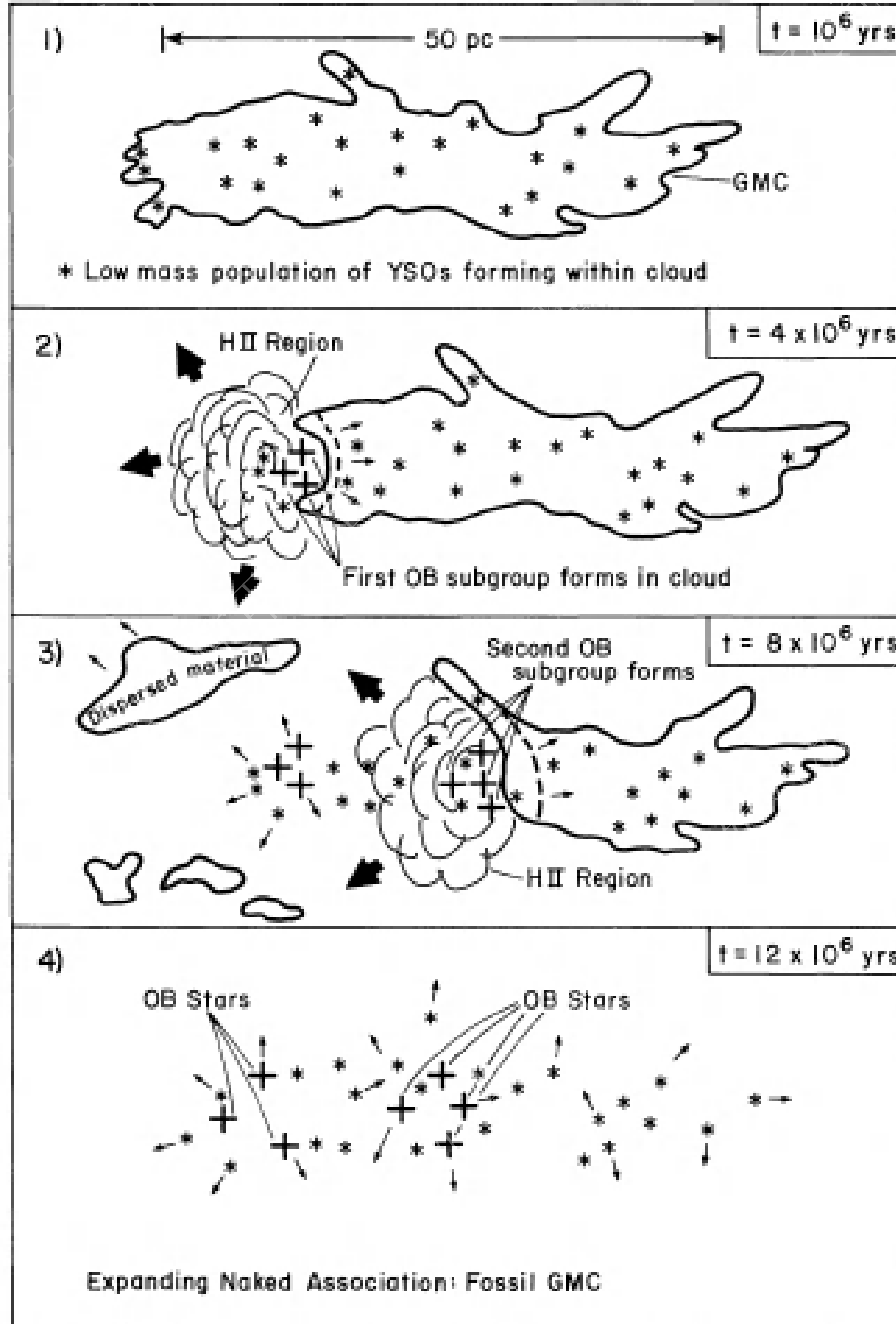
    D~1.39 kpc; M_{gas}~$10^5 M_{\odot}$; Scale ~ 100pc

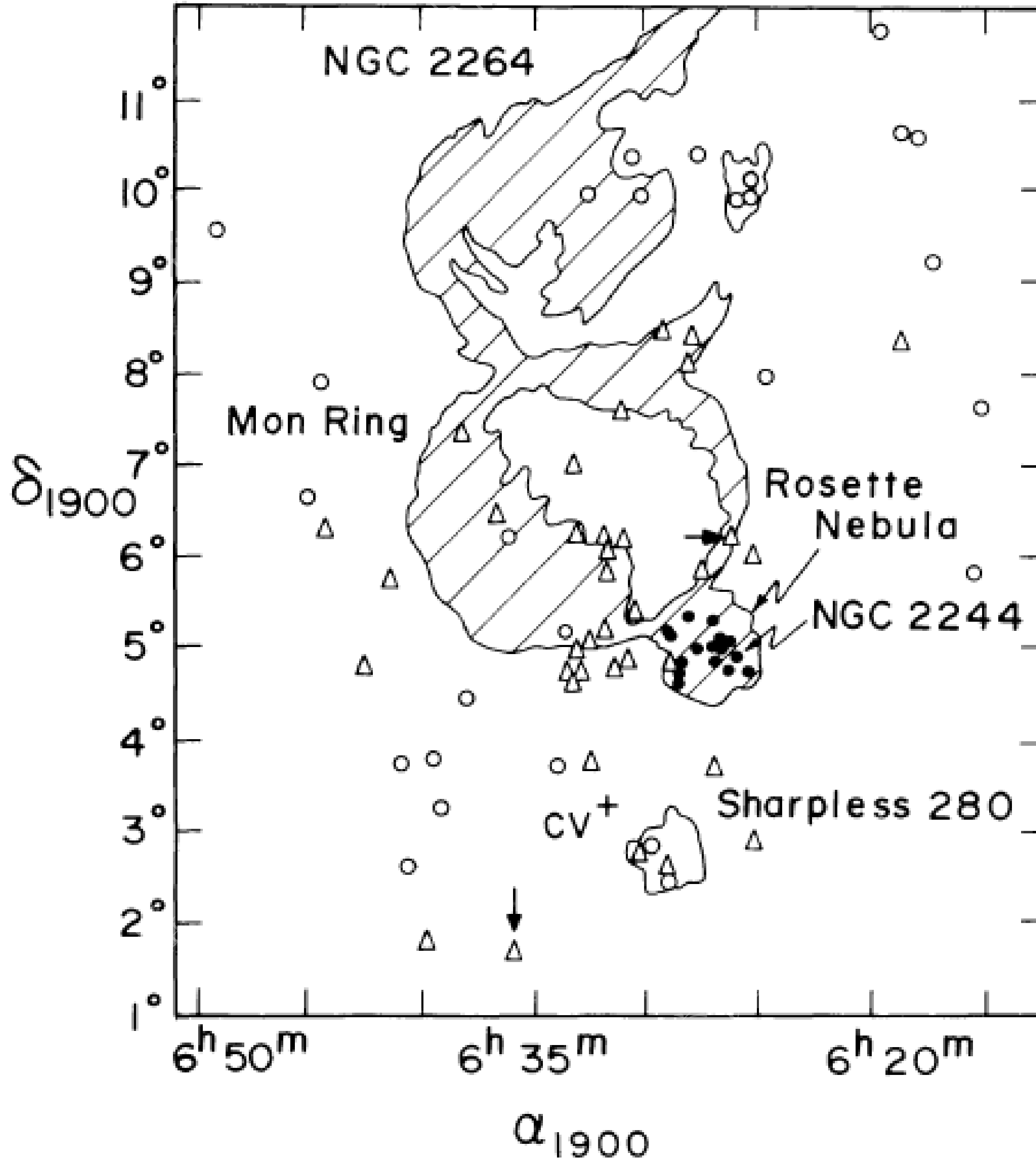
- Region of sequential OB clusters formation

    Mon OB2: 280 pc; ~10 Myrs → 5 Myr → 1.9 Myr

Sequential formation of OB star clusters in GMCs

(Lada 1987)




NGC 2264
Mon Ring
Rosette
Nebula
NGC 2244
Sharpless 280
CV+
11°
10°
9°
8°
7°
6°
5°
4°
3°
2°
1°
δ1900
6h50m
6h35m
6h20m
α1900

(Turner 1976)

Why Rosette?

- **An isolated massive SFR.**

  d~1.39 kpc; M_{gas}~$10^5 M_\odot$; scale ~ 100pc

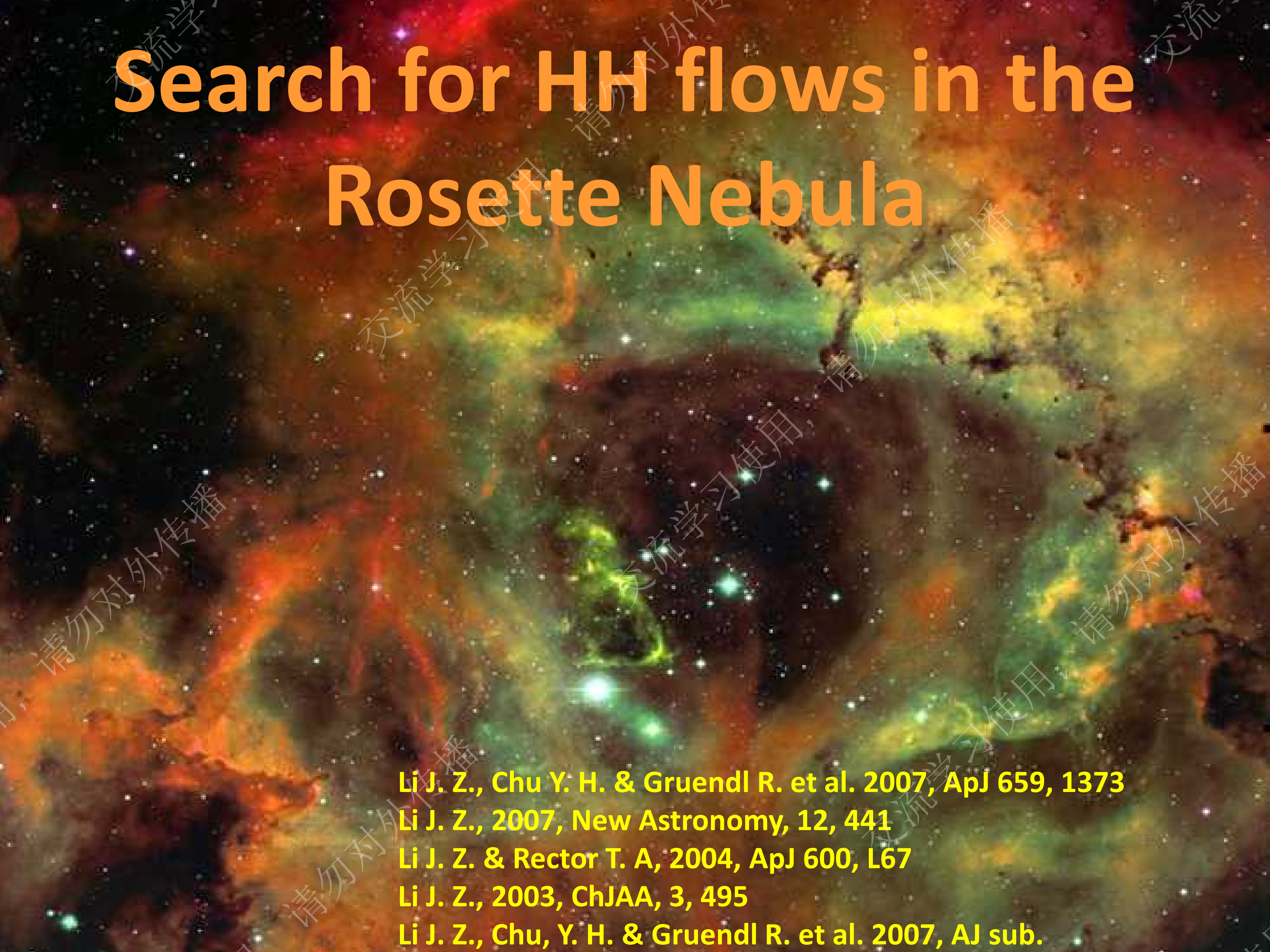
- **Region of sequential OB clusters formation**

  Mon OB2: 280 pc; ~10 Myrs → 5 Myr → 1.9 Myr

- **Among the most active SFRs**
- **The occurrence of OB cluster formation is common in the Galaxy**
- **The solar system could well have been formed in such environments (though in peripheral and comparatively isolated regions).**

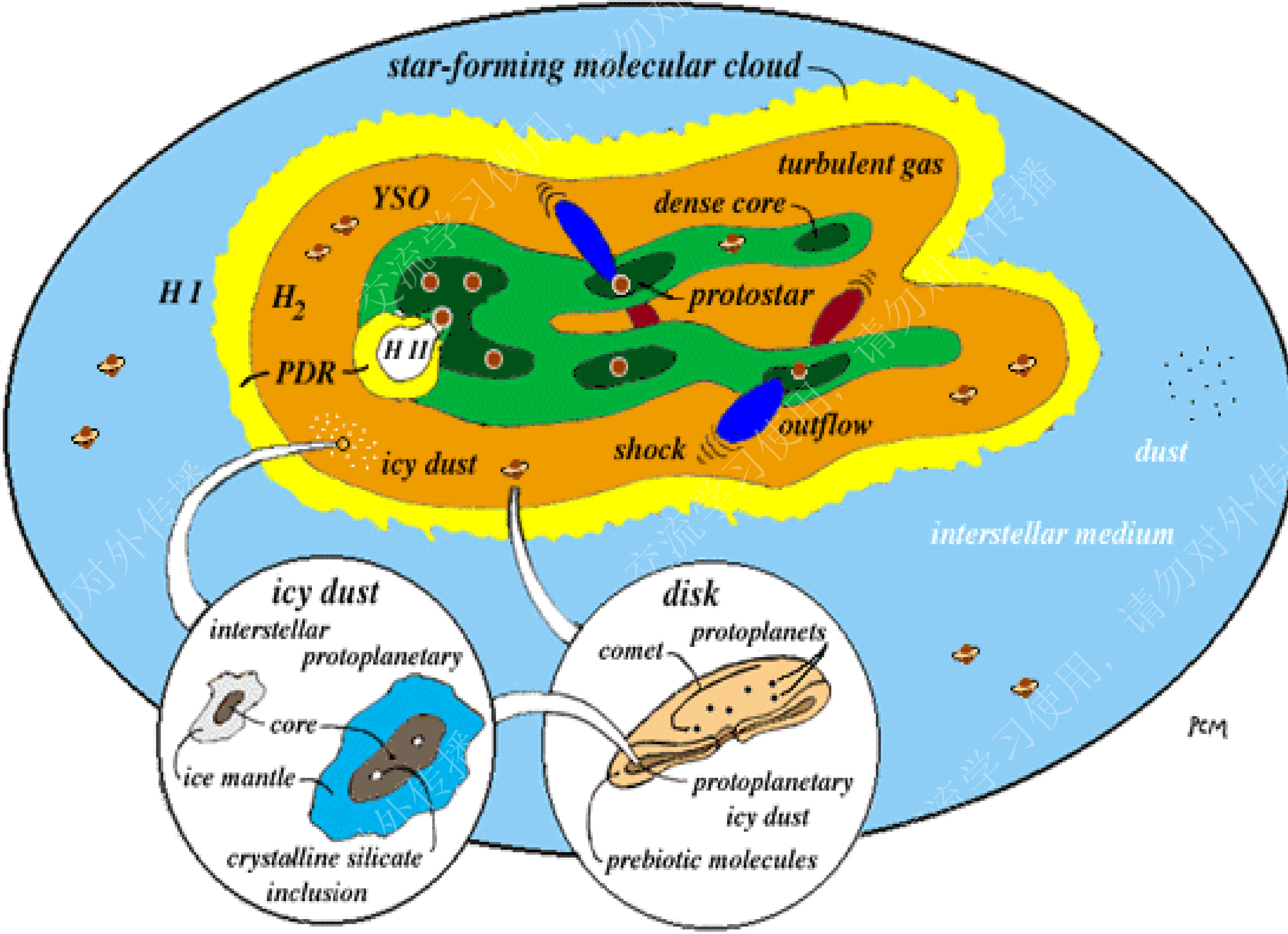
Why Rosette?

- Rosette Nebula: a giant HII region excavated by dozens of OB stars (<B4V)
- Would any HHOs and jets survive the harsh UV ionization and dissipation from massive OB stars at the center of NGC 2244
- Favorable orientation – low extinction

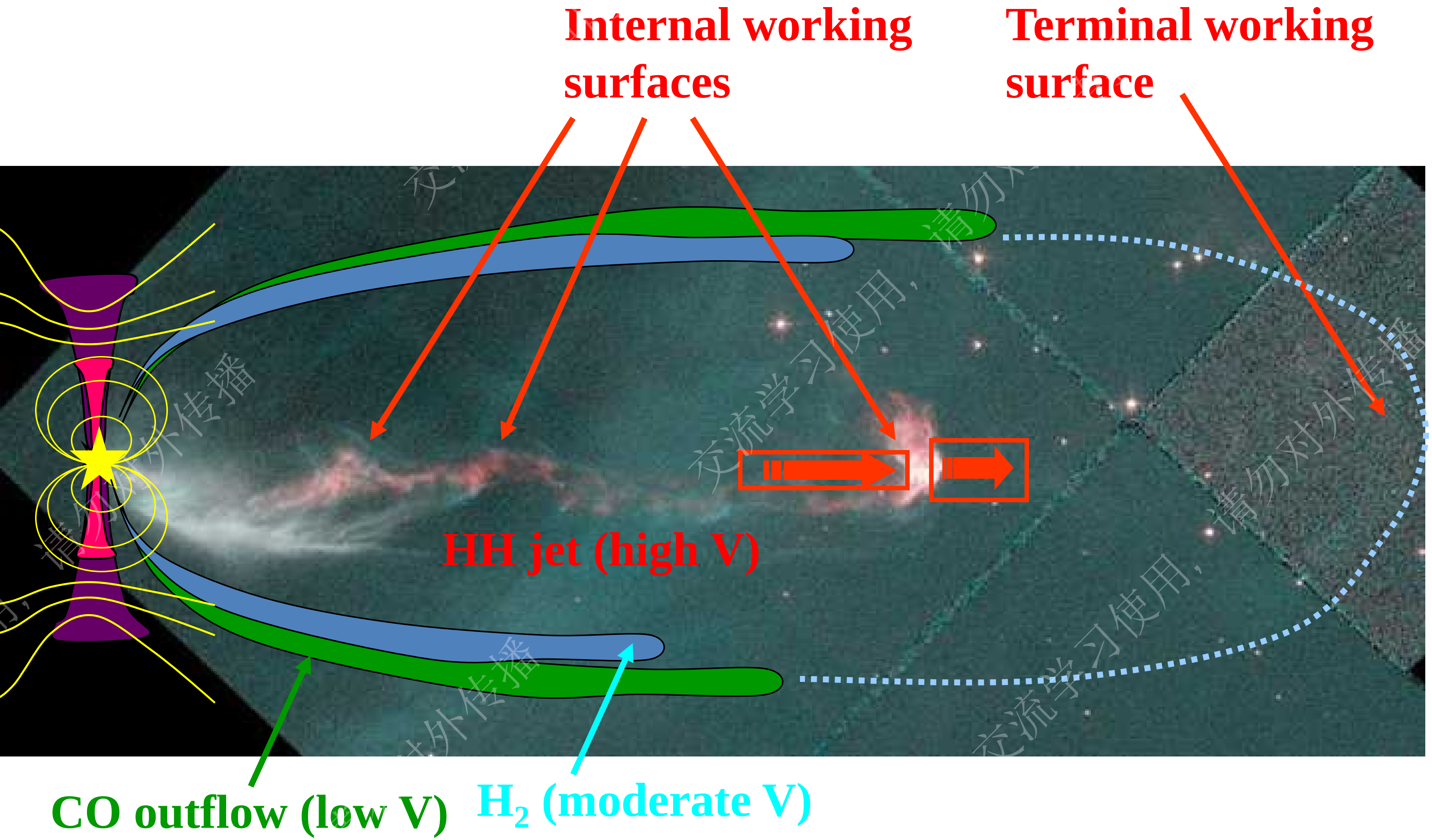


Search for HH flows in the Rosette Nebula

Li J. Z., Chu Y. H. & Gruendl R. et al. 2007, ApJ 659, 1373
Li J. Z., 2007, New Astronomy, 12, 441
Li J. Z. & Rector T. A, 2004, ApJ 600, L67
Li J. Z., 2003, ChJAA, 3, 495
Li J. Z., Chu, Y. H. & Gruendl R. et al. 2007, AJ sub.


star-forming molecular cloud
turbulent gas
dense core
YSO
H I
H_2
protostar
H II
PDR
outflow
shock
icy dust
dust
interstellar medium
icy dust
interstellar
protoplanetary
core
ice mantle
crystalline silicate
inclusion
disk
protoplanets
comet
protoplanetary
icy dust
prebiotic molecules
PCM

Outflows: HH objects, H_2, CO



HH 111

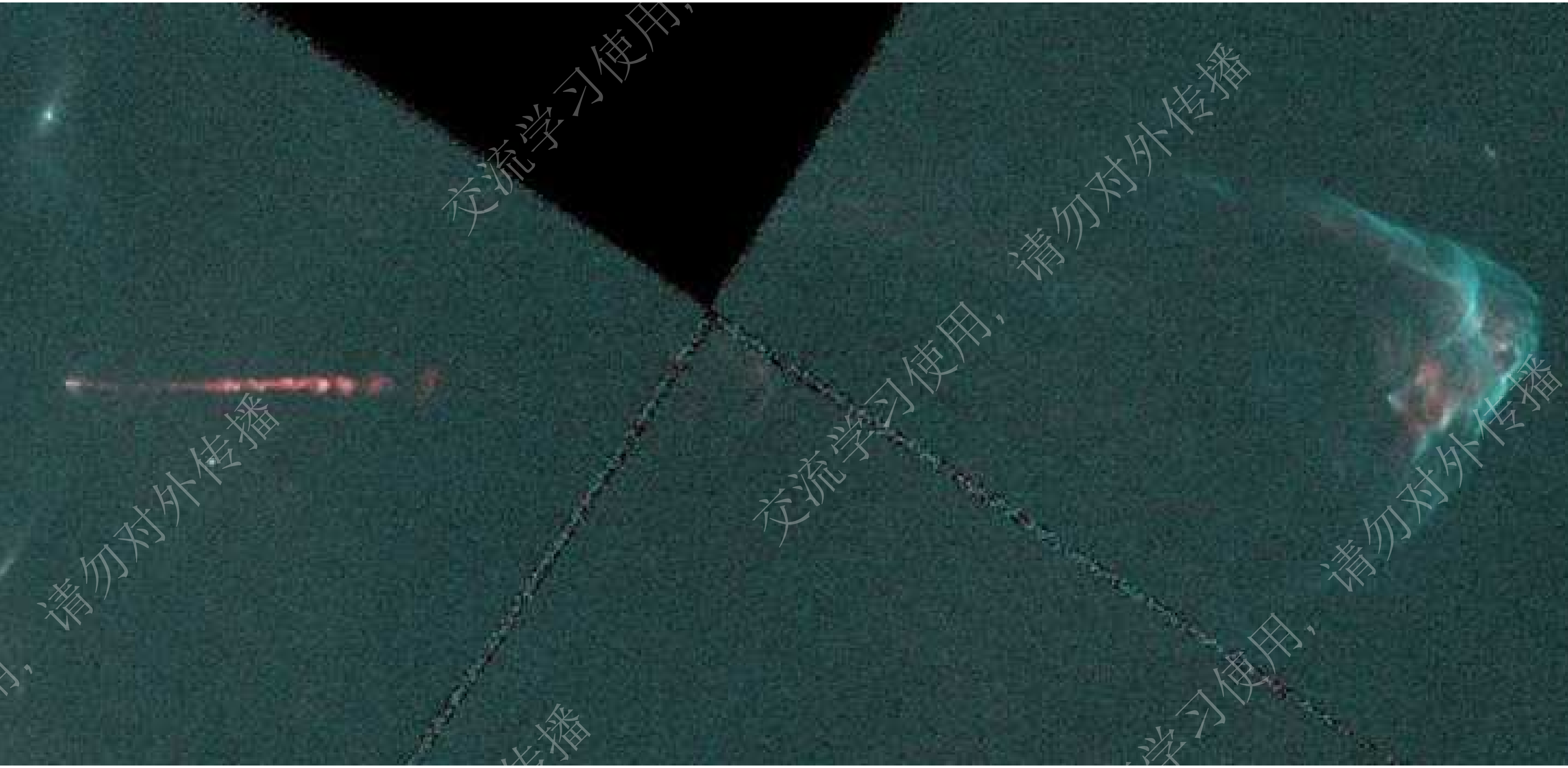
[Fe II] + K

Ha + [SII]

NICMOS

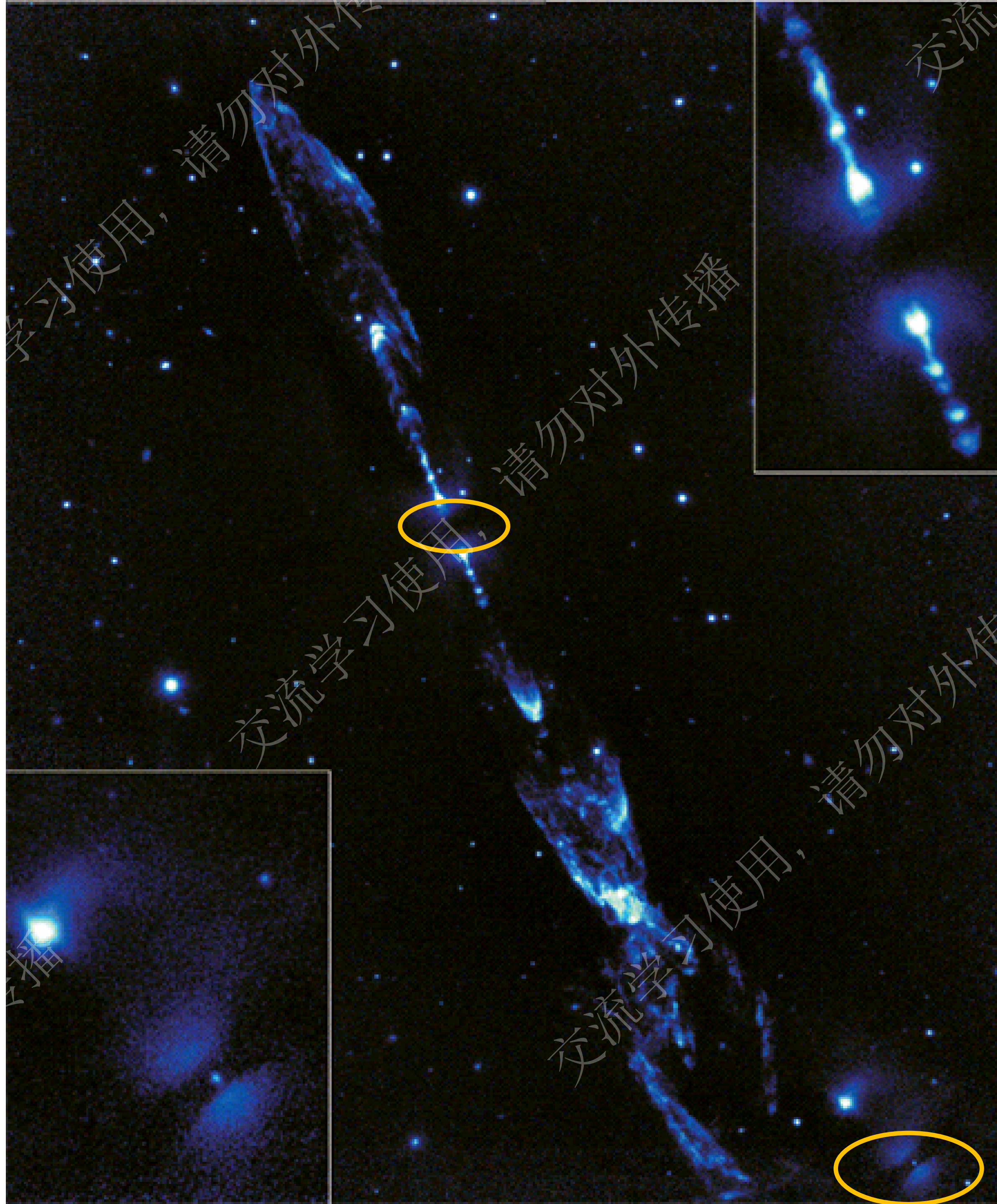
WFPC2

HH 34



HST 1997 - 1994

HH 212

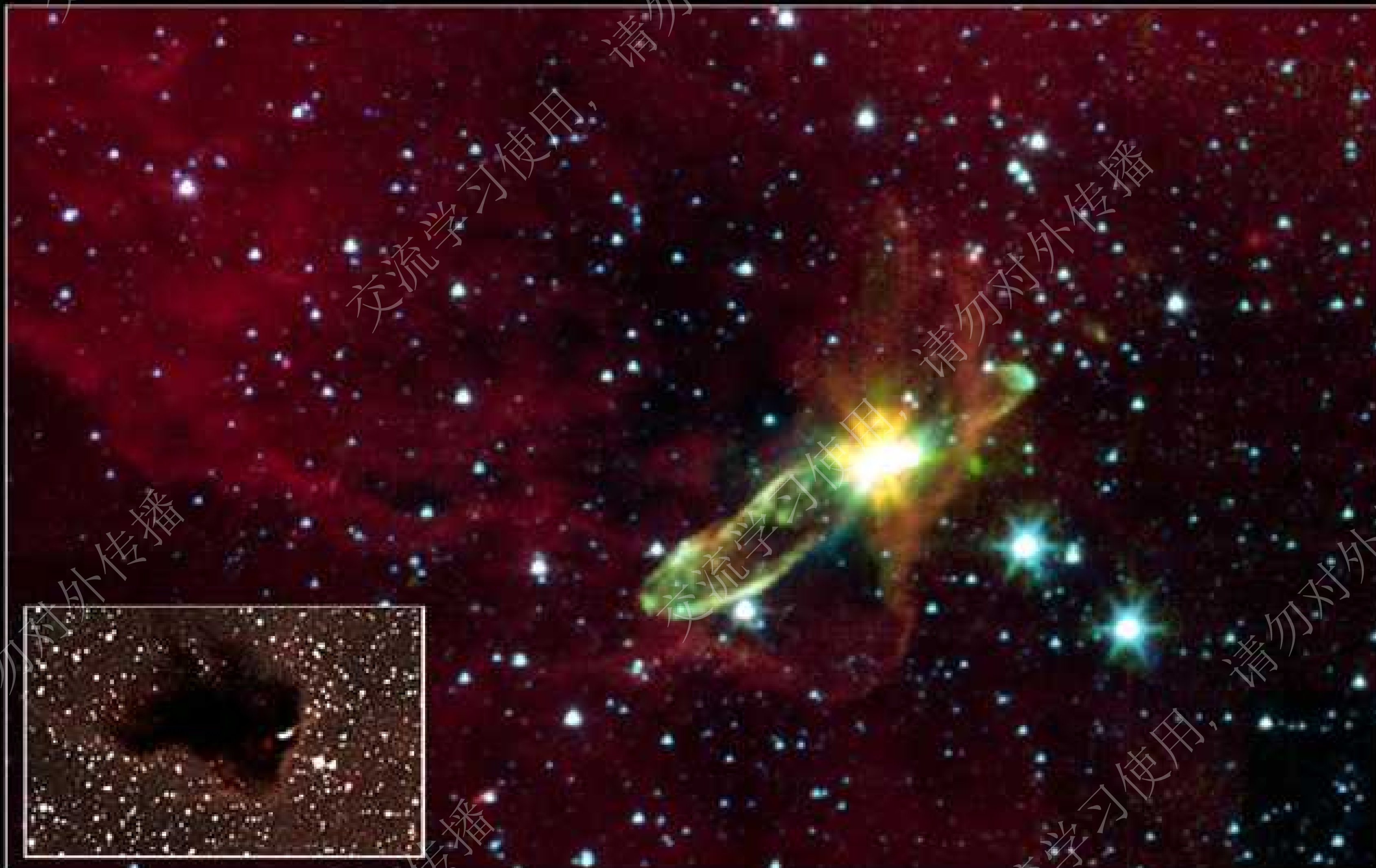


Mark McCaughrean
Hans Zinnecker

HH212-VLT


HH 34 parsec-scale flow
S-shaped symmetry
2.5 pc


NGC 1999
HH 3
New jet
HH 1
HH 2
proplyd



Embedded Outflow in HH 46/47

Spitzer Space Telescope • IRAC

Inset: visible light (DSS)

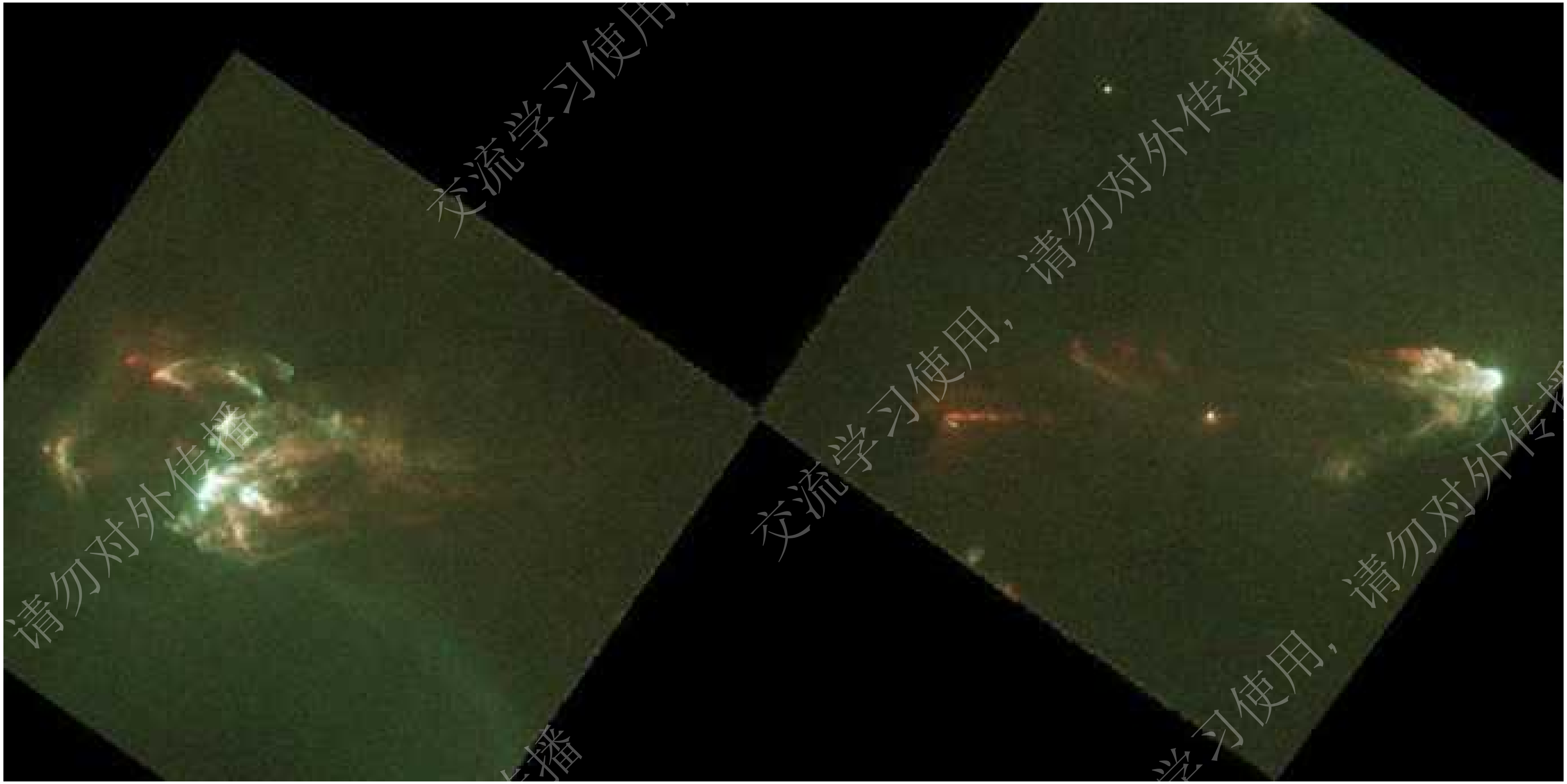
NASA / JPL-Caltech / A. Noriega-Crespo (SSC/Caltech)

ssc2003-06f

NGC 1333 in Perseus: 150 young stars

HH 2

HH 1



HST 1997 - 1994

HH 2 HH 1

HST 1997 - 1994

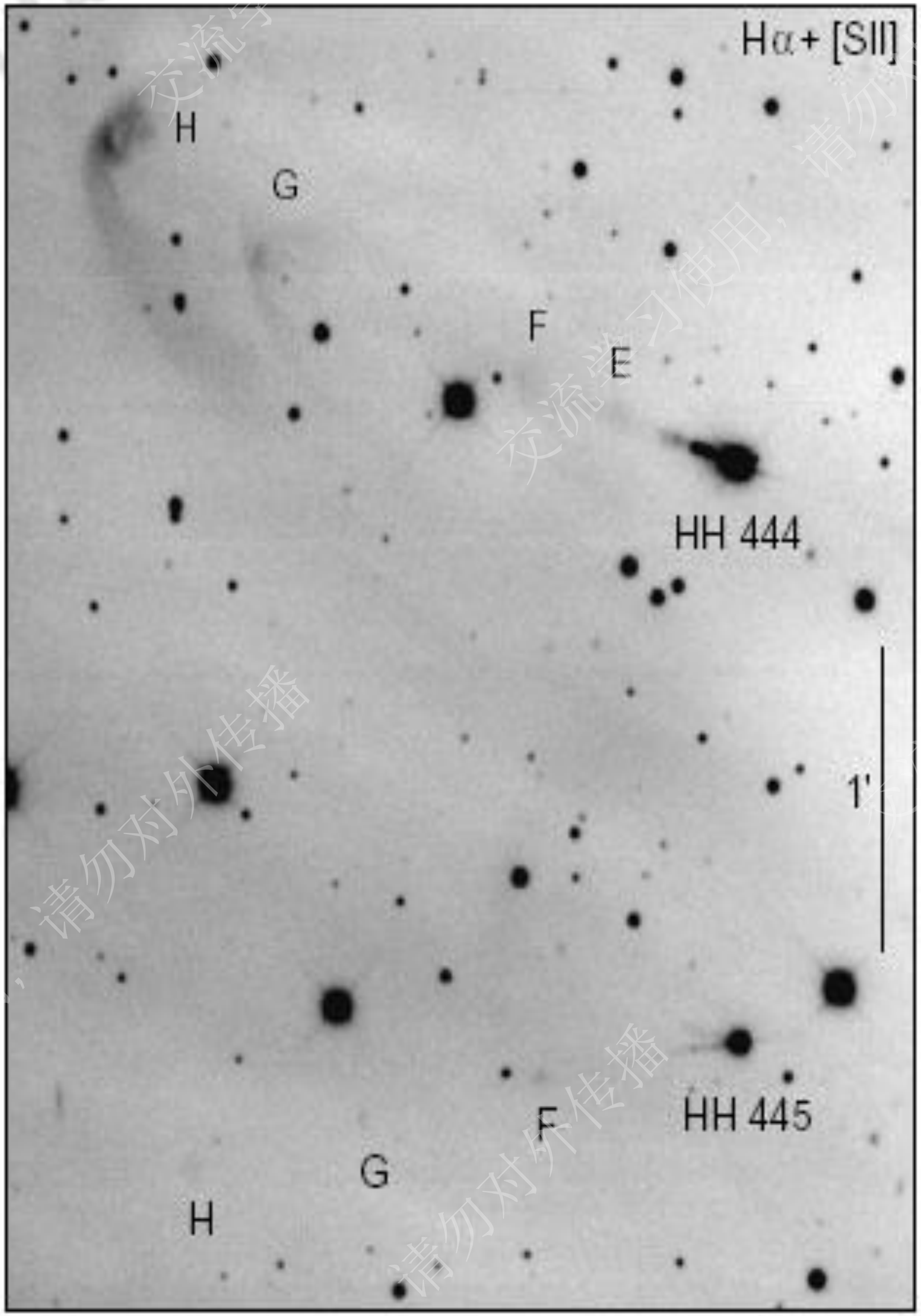
HH 1

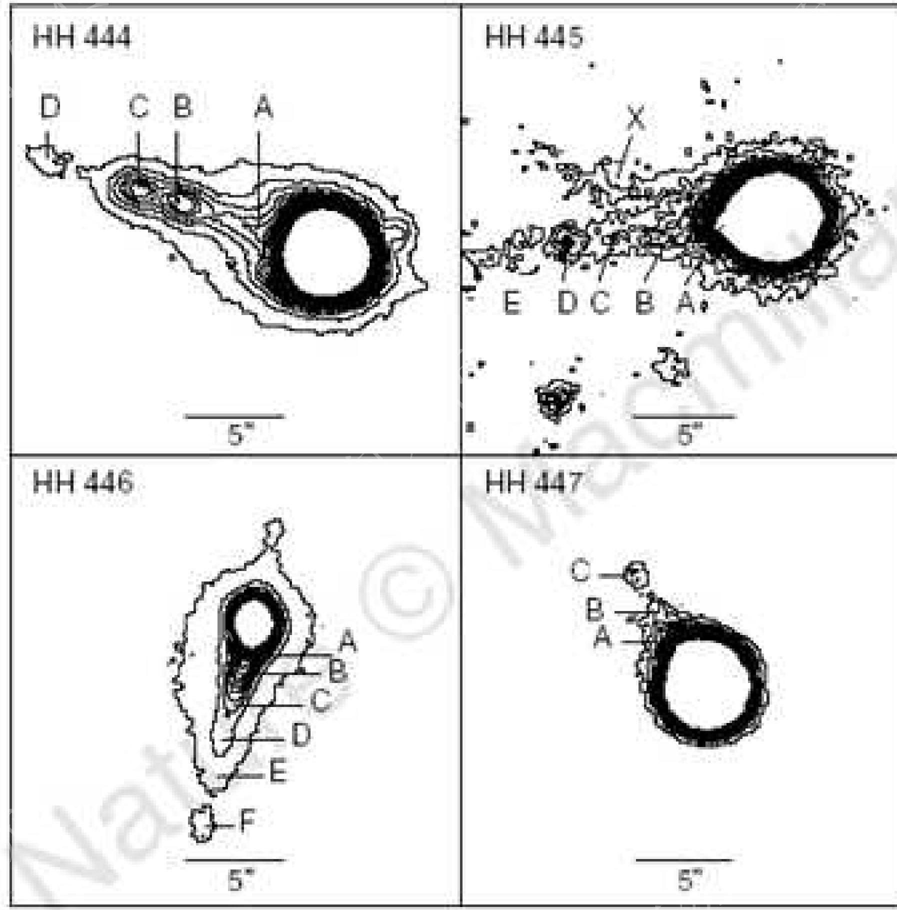
HST 1997 - 1994

HH 1

HST 1997 - 1994

Exciting sources of HH jets used to be embedded in dense molecular cloud cores or extended envelopes of dust and gas, which severely impeded efforts for investigations in the optical regime and makes our view of early stages of star formation remain quite as a puzzle.





Irradiated Jets in Orion

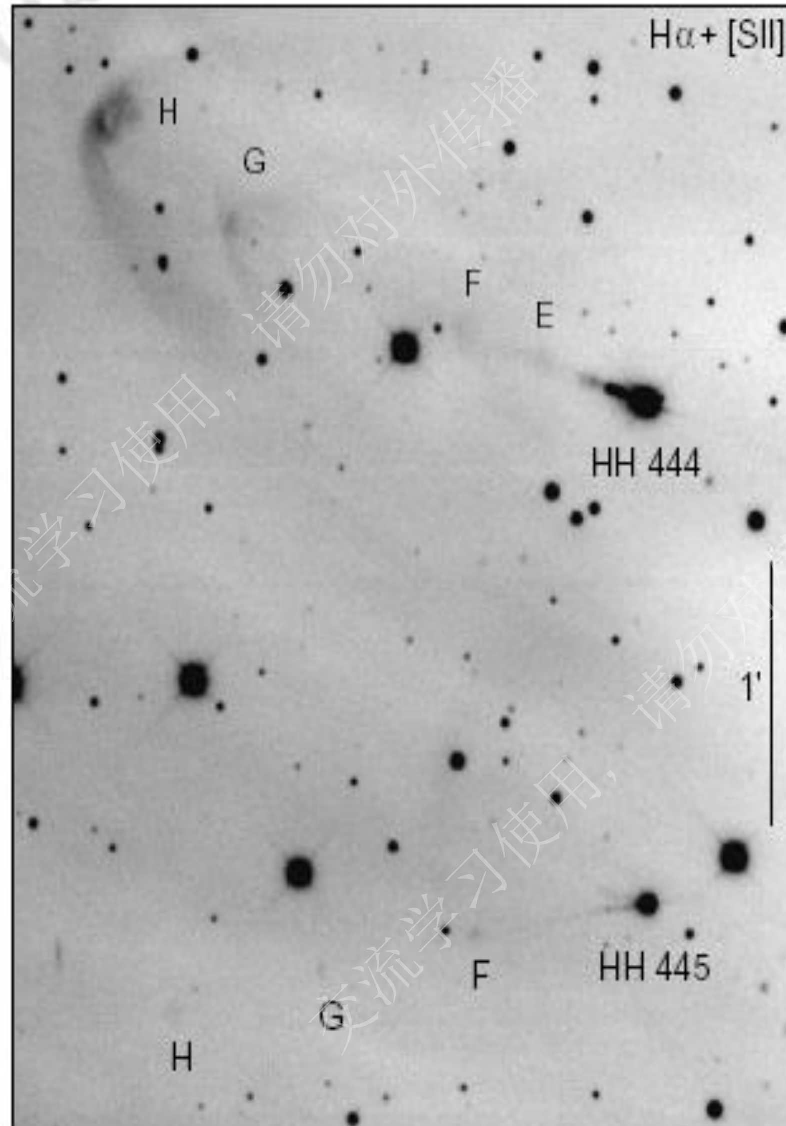
Reipurth, B., et al. 1998, Nature 396, 343)

Properties of externally irradiated Jets

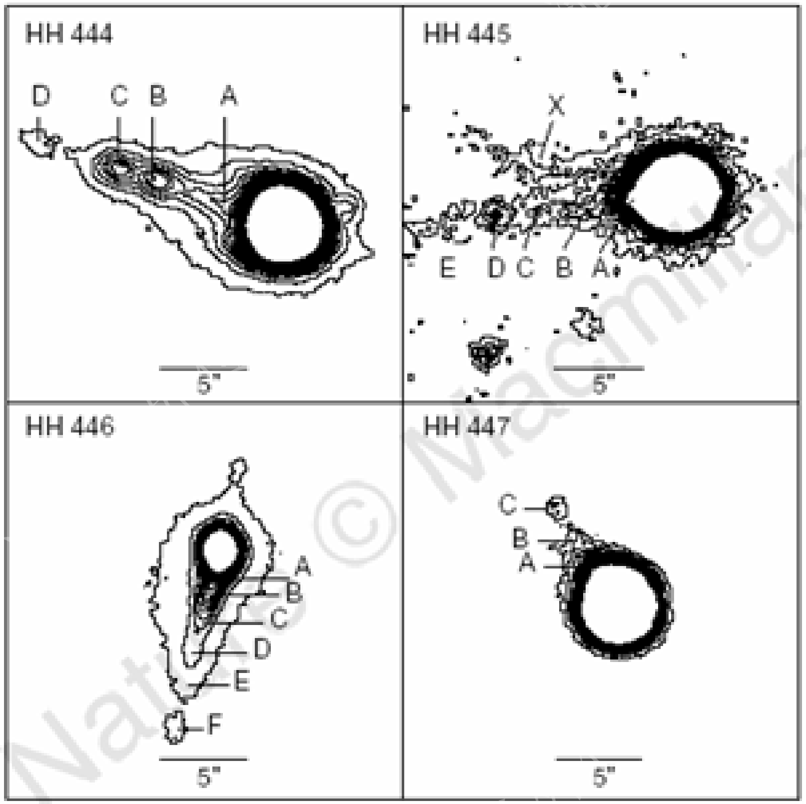
- **Located in the close vicinity of an O9 star in the Orion Nebula**

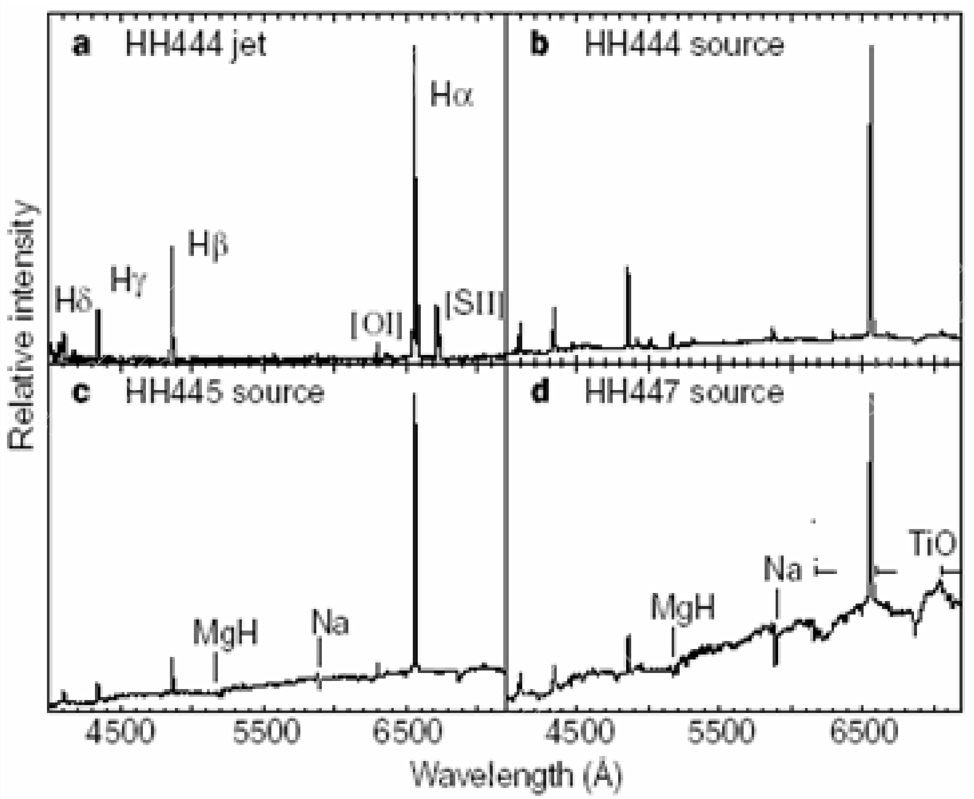
  --- Externally irradiated origin
- **[SII]/Hα ratio decreases rapidly from the base of the jet.**

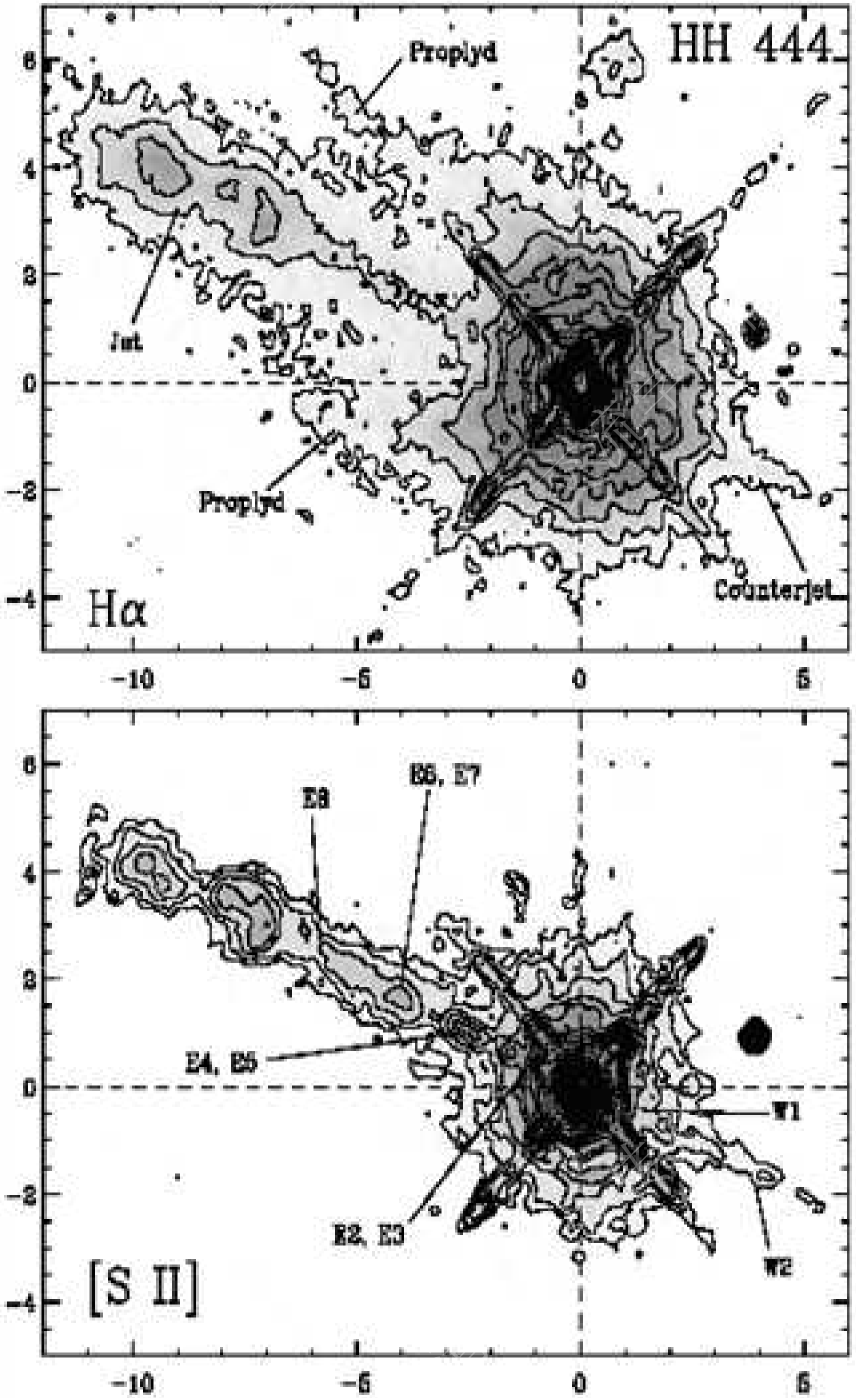
  Shock → Photoionized origin
- **Highly asymmetric or unipolar in morphology → different conditions of jet formation**
- **Low excitation**

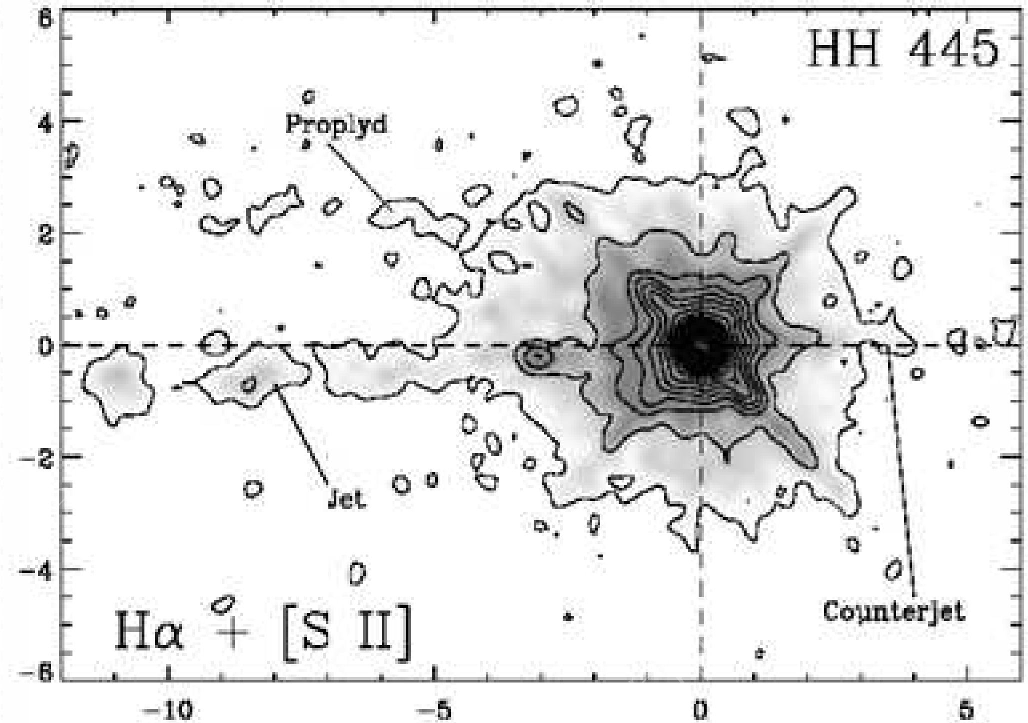


- The jet sources are visible, with spectral characteristics of typical TTS
- None was detected by IRAS, indicating the lack of circumstellar materials/envelopes

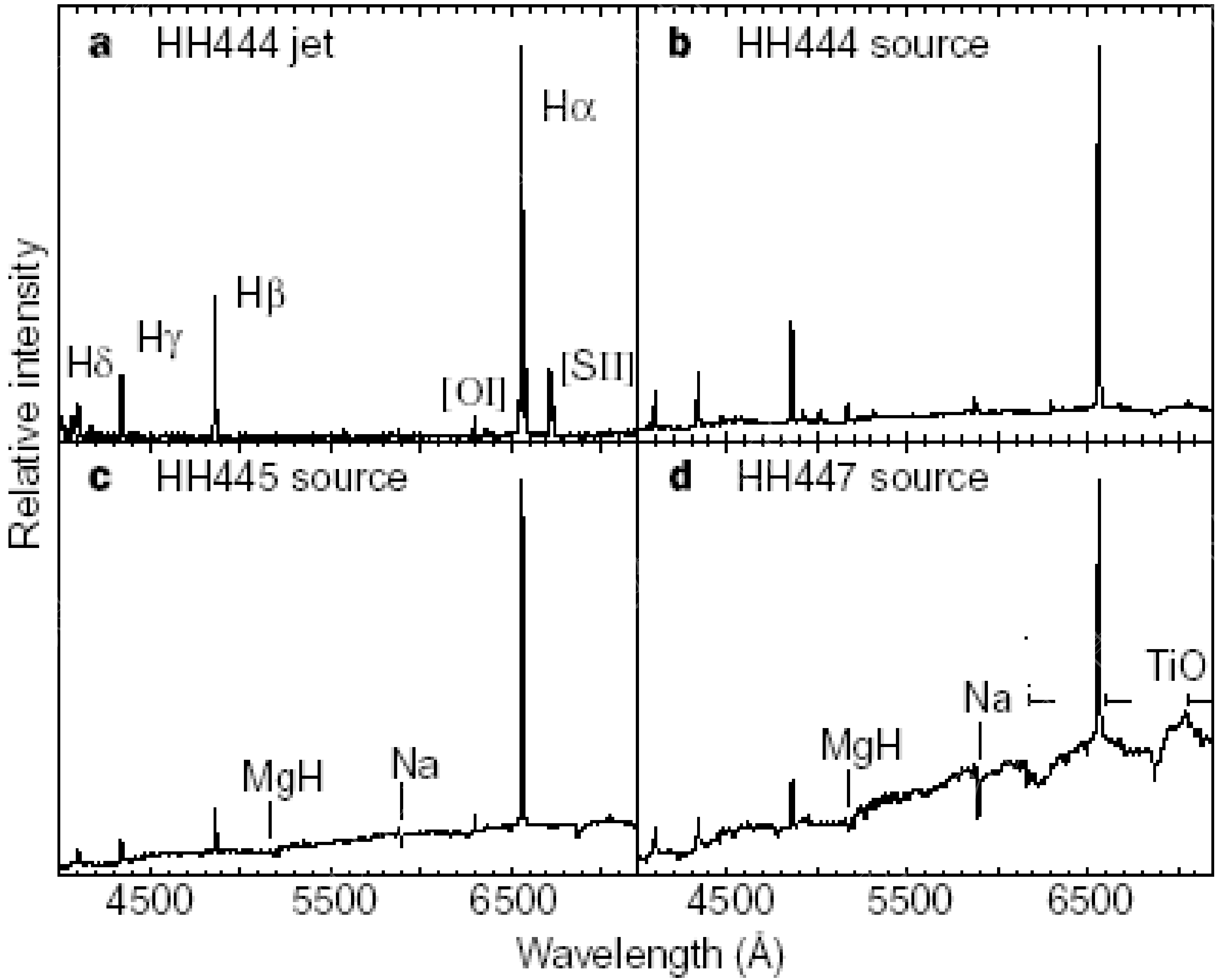






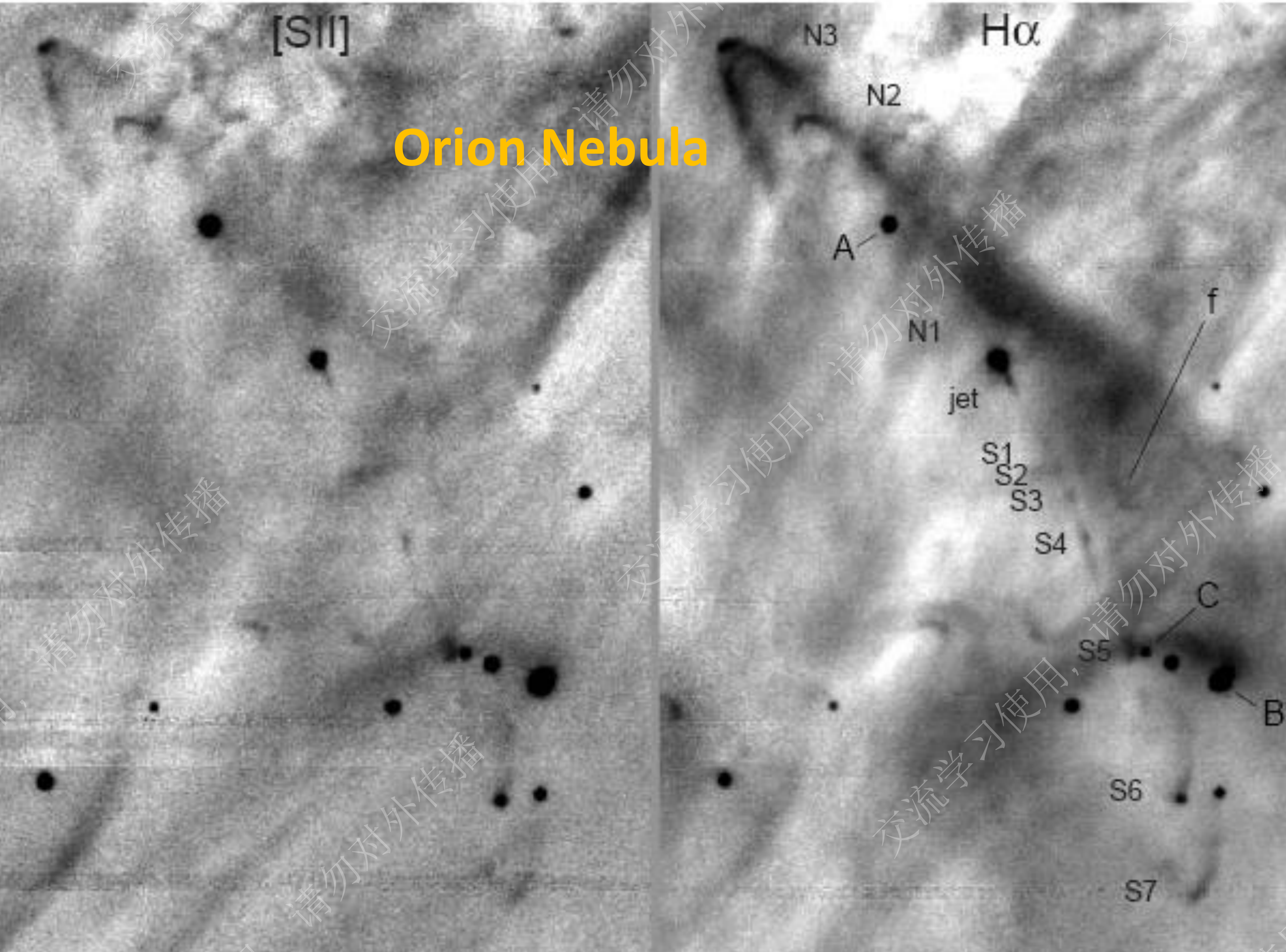


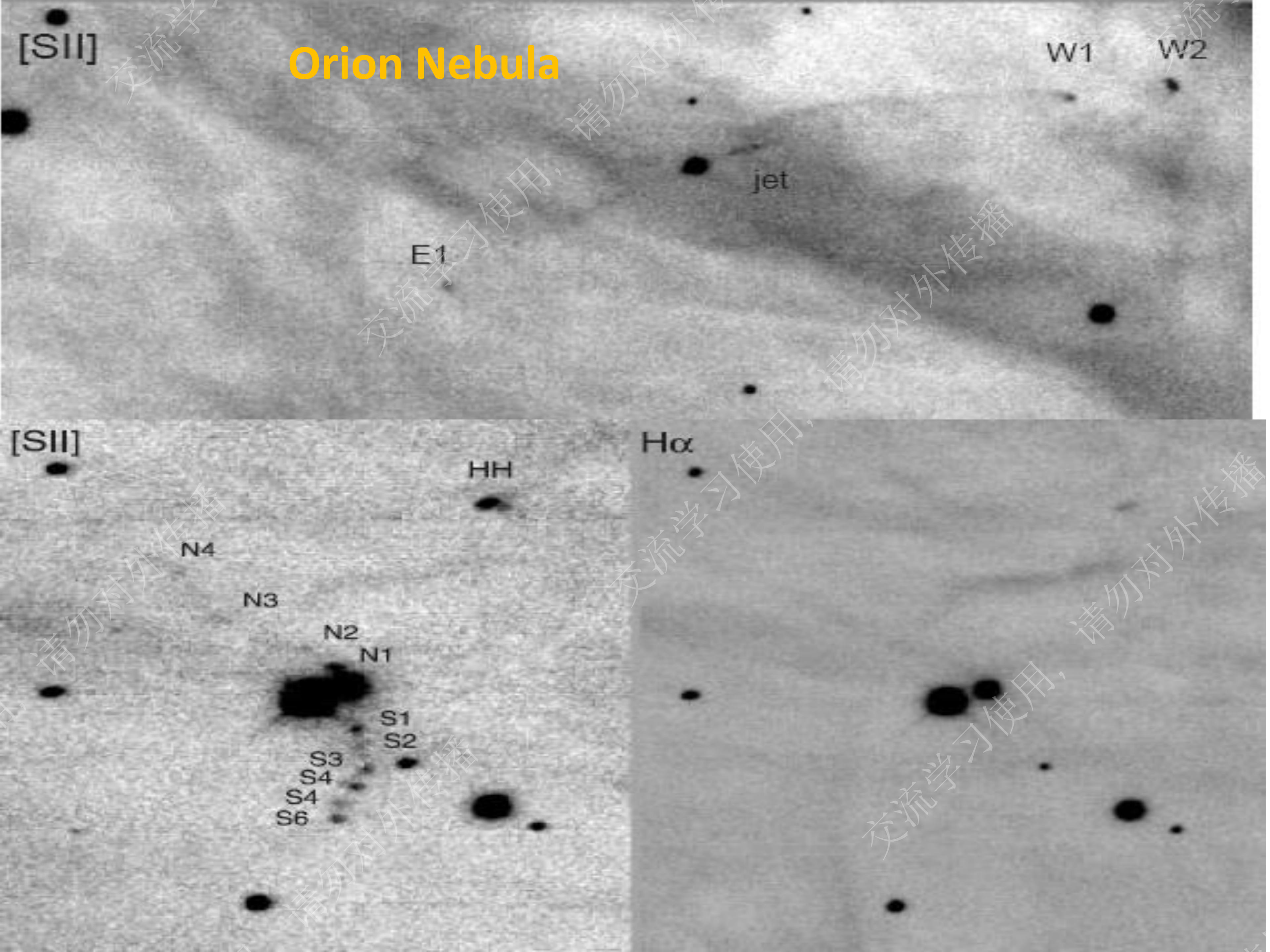
Andrews, S. M. et al. 2004, ApJ 606, 353

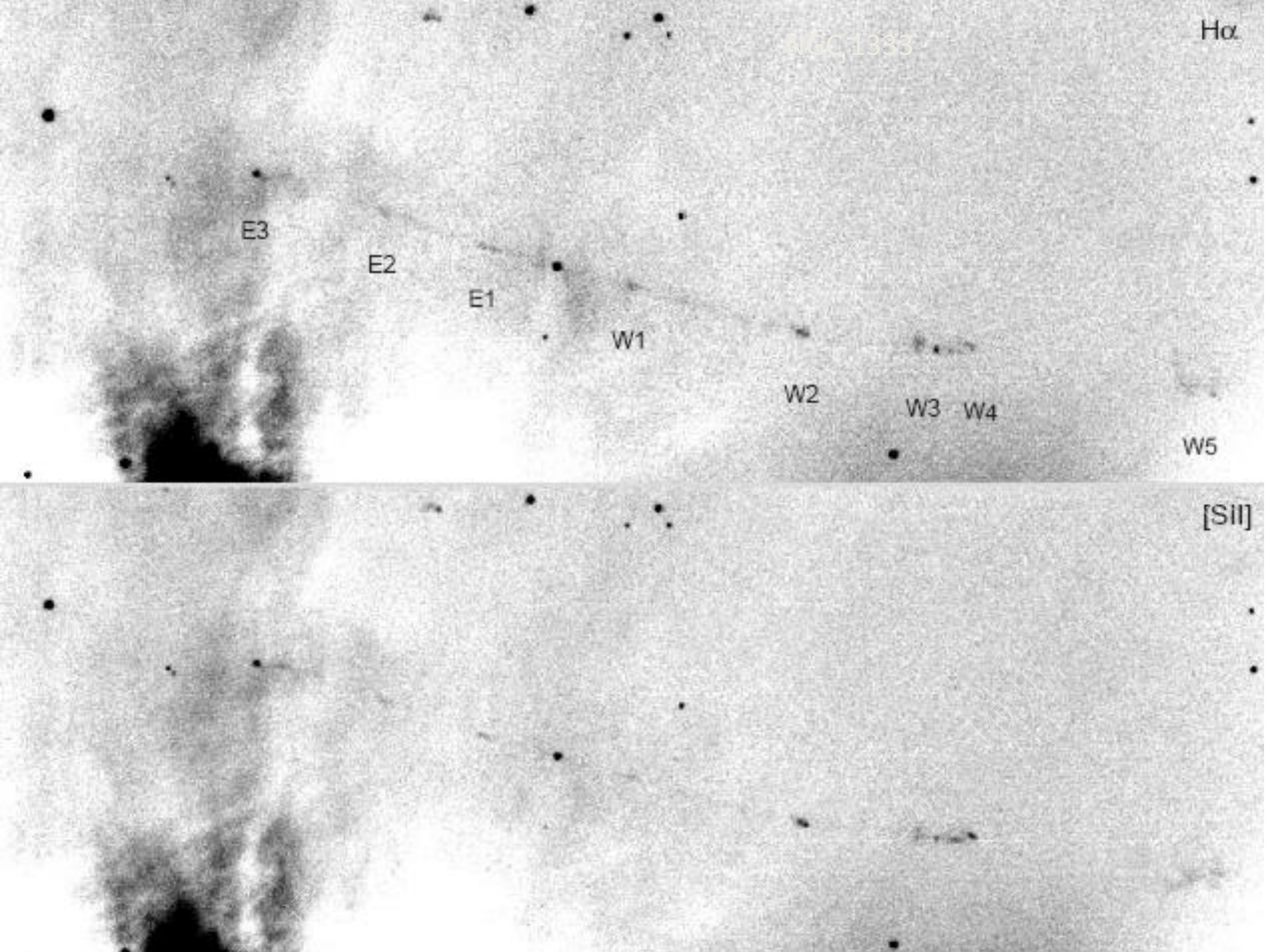


a HH444 jet
Hα
Hβ
Hγ
Hδ
[OI]
[SII]
b HH444 source
c HH445 source
MgH
Na
d HH447 source
TiO
Na
MgH
Relative intensity
4500
5500
6500
Wavelength (Å)

Orion Nebula




Orion Nebula
[SII]
W1
W2
jet
E1
[SII]
HH
N4
N3
N2
N1
S1
S2
S3
S4
S4
S6
Hα


Hα
NGC 1333
E3
E2
E1
W1
W2
W3
W4
W5
[SII]

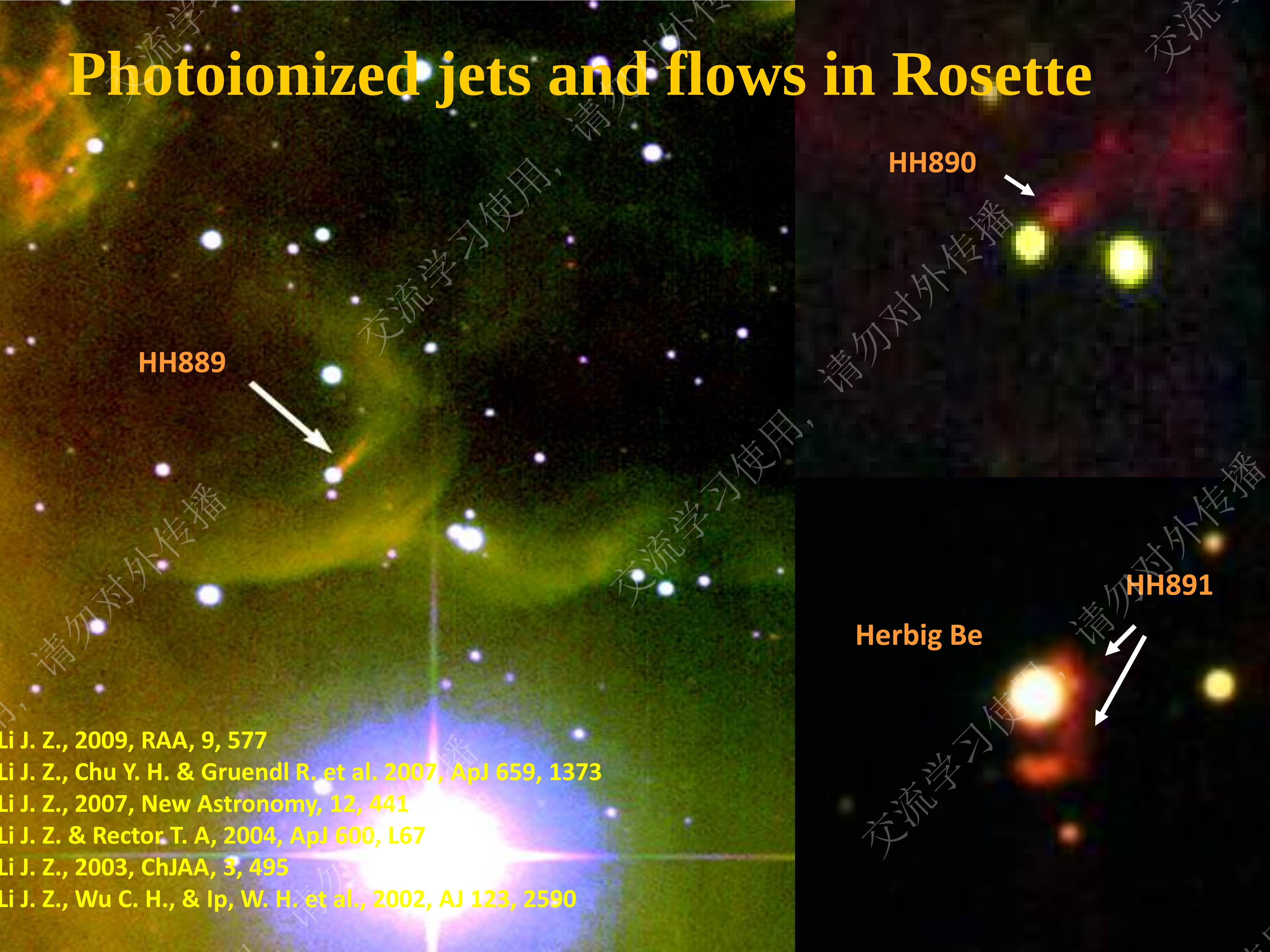
Search for HH flows in the Rosette Nebula

Data Acquisition

- KPNO 0.9m + MOSAIC I camera.
- Hα、[SII]、[OIII] (Travis Rector)
- Credit: You-Hua Chu & IoA of NCU

- NAOC 2.16m, low resolution spectroscopy
- KPNO 4m + MOSAIC camera (John Bally)
- Blanco 4m + SITe2K #6 CCD (Echelle spectroscopy, You-Hua Chu)

Photoionized jets and flows in Rosette



Li J. Z., 2009, RAA, 9, 577
Li J. Z., Chu Y. H. & Gruendl R. et al. 2007, ApJ 659, 1373
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Li J. Z., 2003, ChJAA, 3, 495
Li J. Z., Wu C. H., & Ip, W. H. et al., 2002, AJ 123, 2590

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EMBARGOED FOR IMMEDIATE RELEASE: Thursday, January 22, 2004
RELEASE NO: NOAO 04-03

Fitful Young Star Sputters to Maturity in the Rosette Nebula

Images
With links to a page with larger versions.

The Rosette Nebula

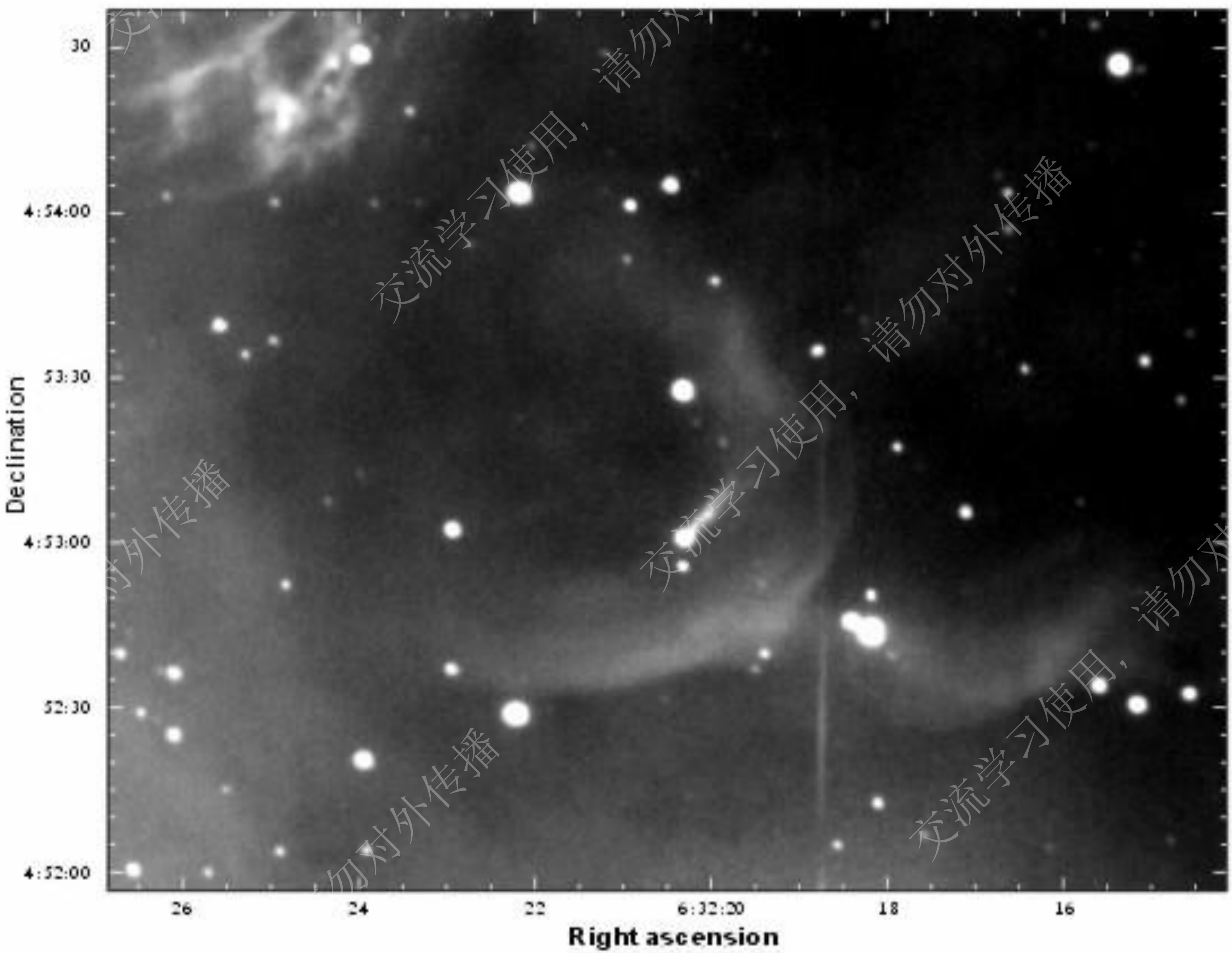
Image Credit: T. Rector/University of Alaska Anchorage, WIYN and

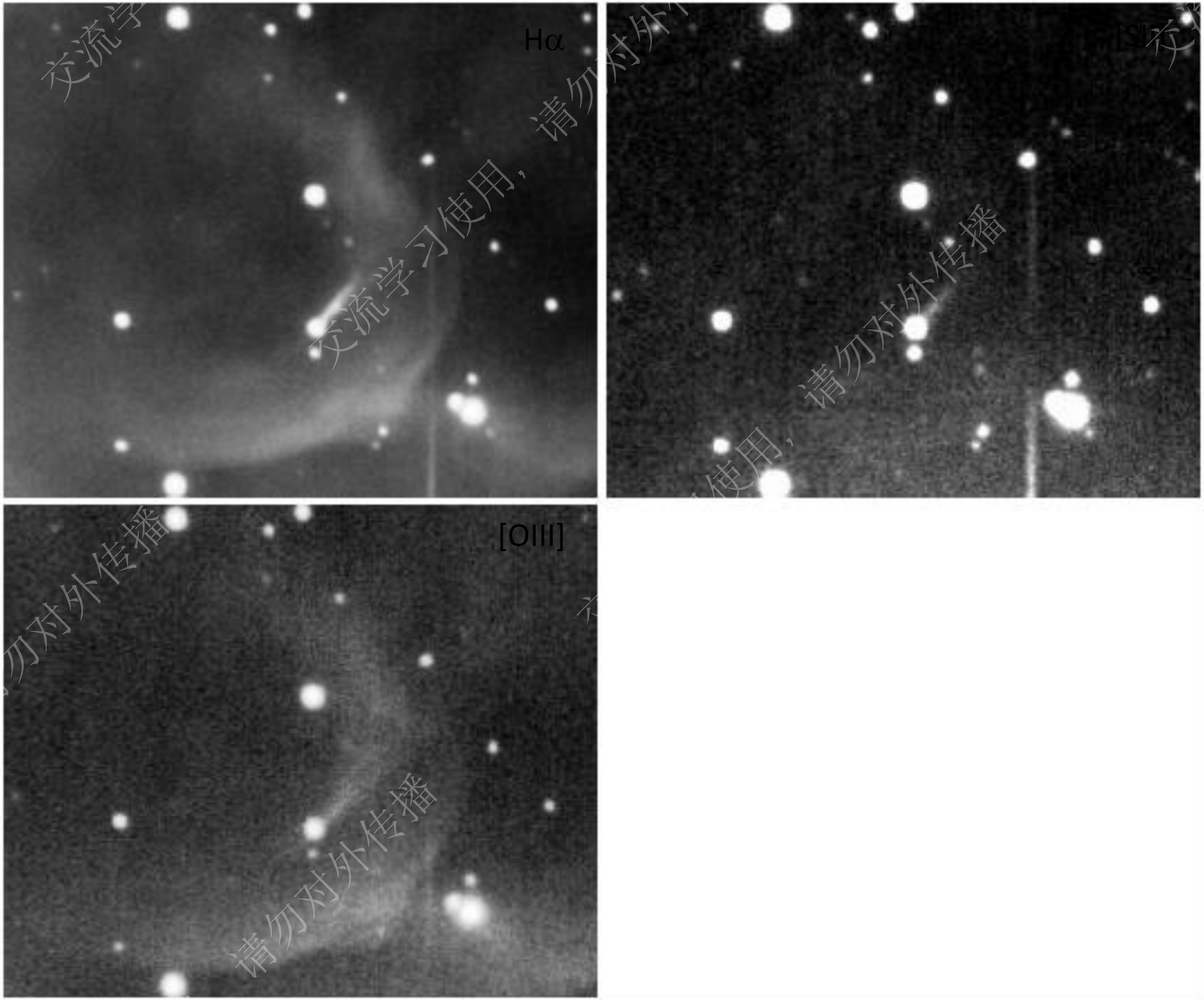
A duo of Chinese and American astronomers have discovered a young star in the fierce environs of the Rosette Nebula that is ejecting a complex jet of material riddled with knots and bow shocks.

Stripped of its normally opaque surroundings by the intense ultraviolet radiation produced by nearby massive stars, this young stellar object is likely one of the last of its generation in this region of space. Its tenuous state of existence exposes the limitations that young stars—and perhaps even sub-stellar objects such as brown dwarfs and large planets—face in attempting to form in such a violent environment.

A close-up image from this study of the young star, and a striking, newly reprocessed wide-field image of the colorful Rosette Nebula, are available above.

"Most young stars are embedded in very dense molecular clouds, which makes our view of the early stages of star formation normally impossible with optical telescopes," says Travis Rector of the University of Alaska Anchorage, co-author of a paper on the young stellar object (YSO) in the

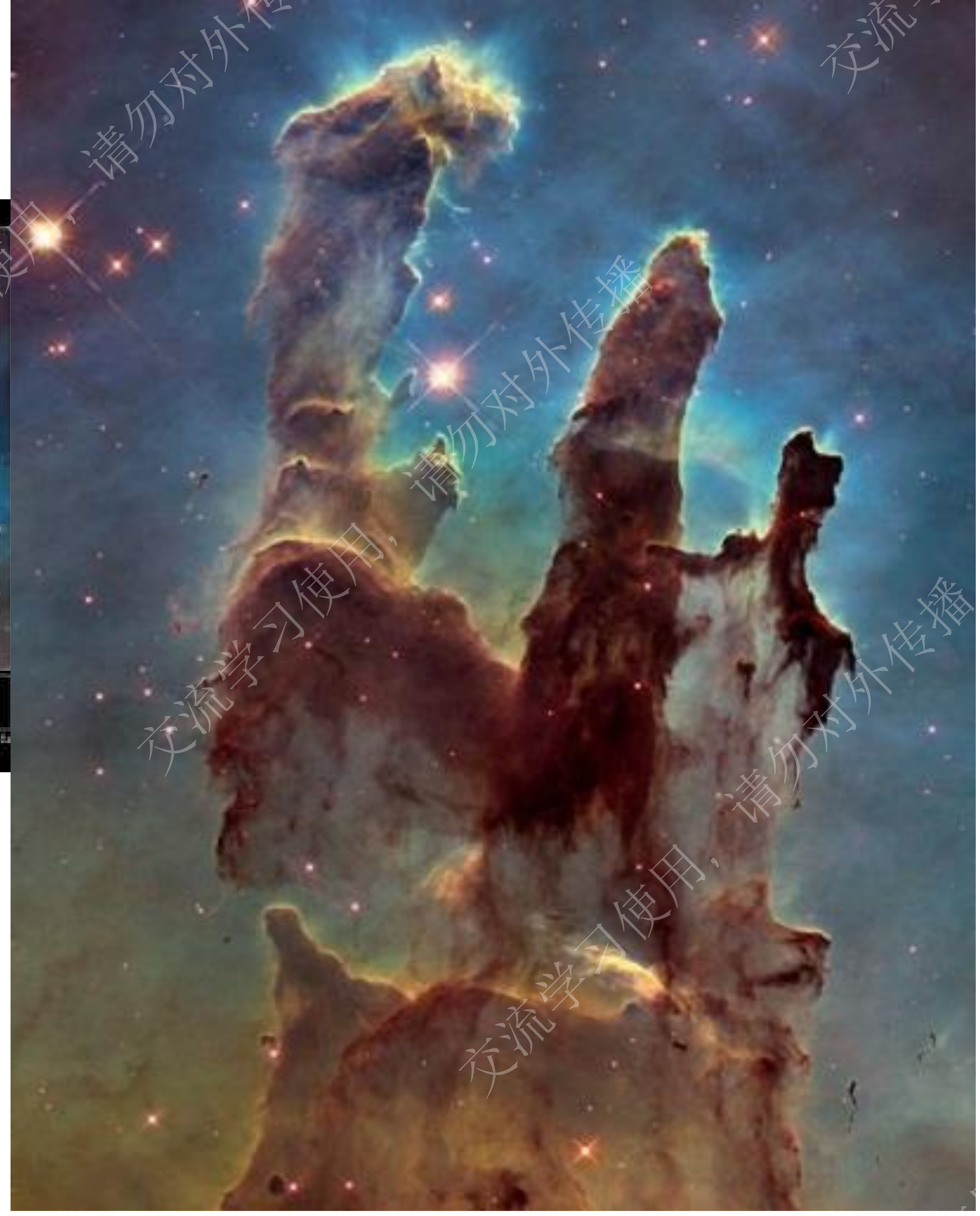

30
4:54:00
53:30
4:53:00
52:30
4:52:00
Declination
26
24
22
6:32:20
18
16
Right ascension


Hα
[SII]
[OIII]

Properties of the jets in Rosette

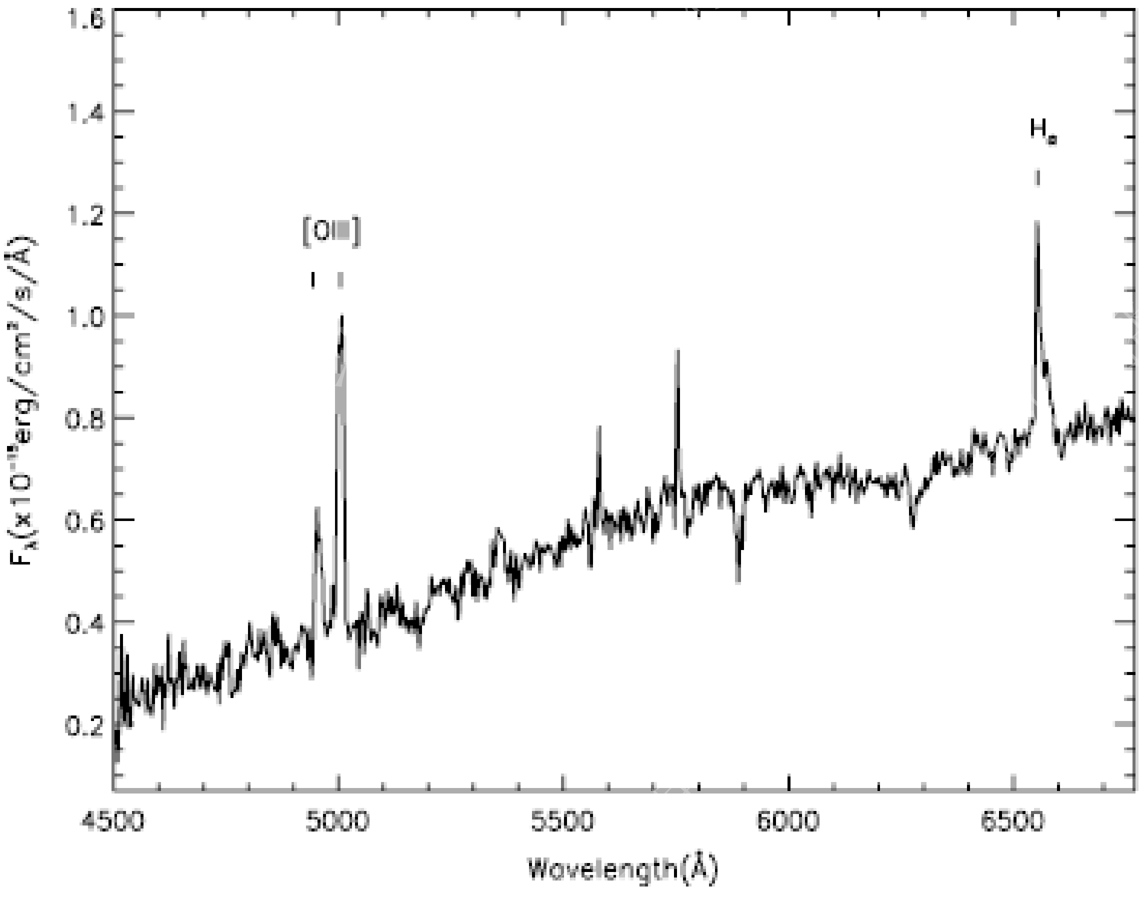
- Bathed in harsh UV radiation of the OB stars that excited the Rosette Neubla
- Visible jet sources with spectral characteristics of Weak-line TTS and Herbig Ae/Be
- None was detected by IRAS, indicating the lack of circumstellar disks/envelopes
- [SII]/Hα ratio decreases rapidly from the base. Shock → Photoionized origin
- Highly asymmetric or unipolar morphology → different conditions of jet formation
- Diffuse [OIII] emission → photoionized origin

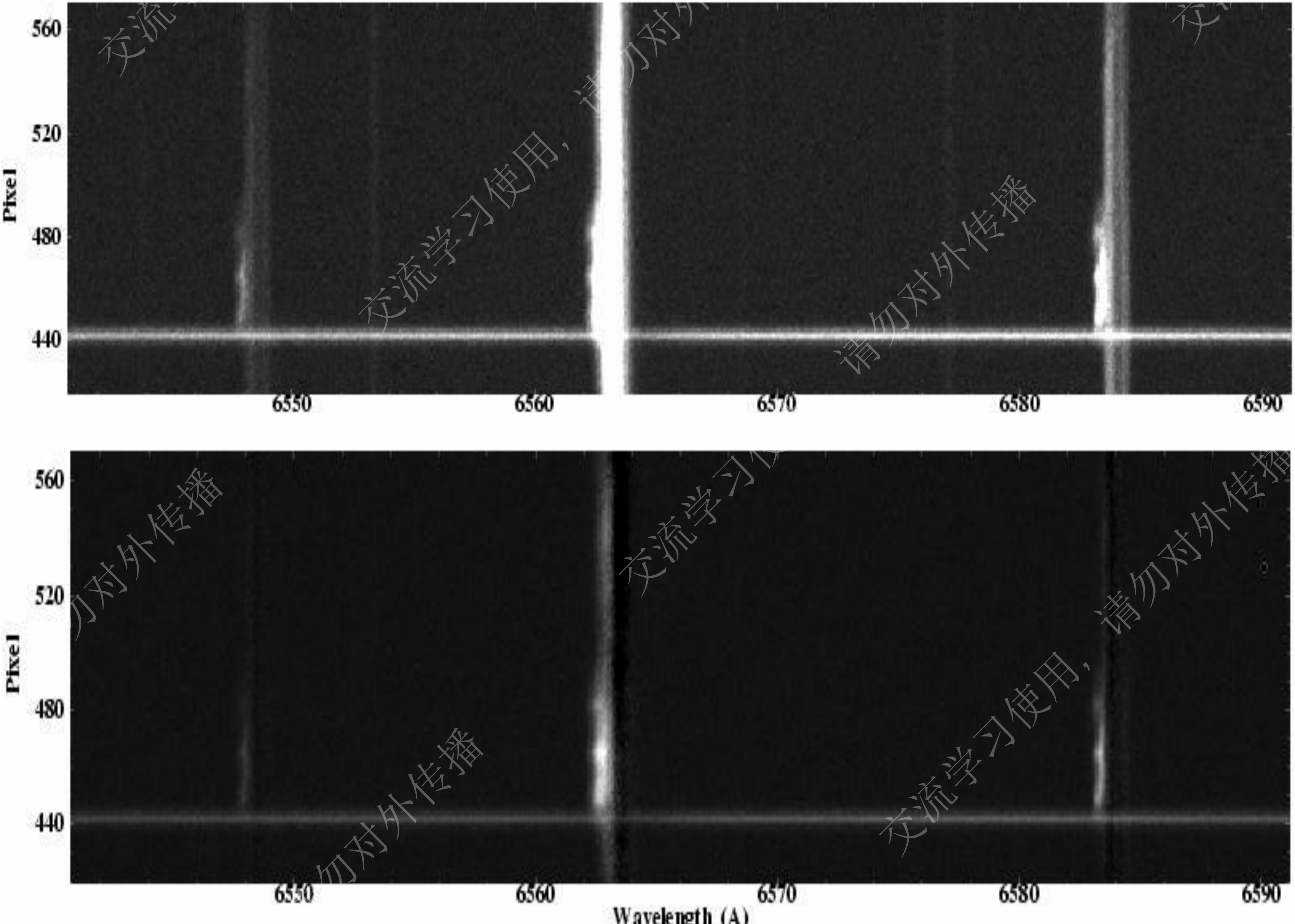

M16 • Eagle Nebula
Hubble Space Telescope • WFPC2 • WFC3/UVIS



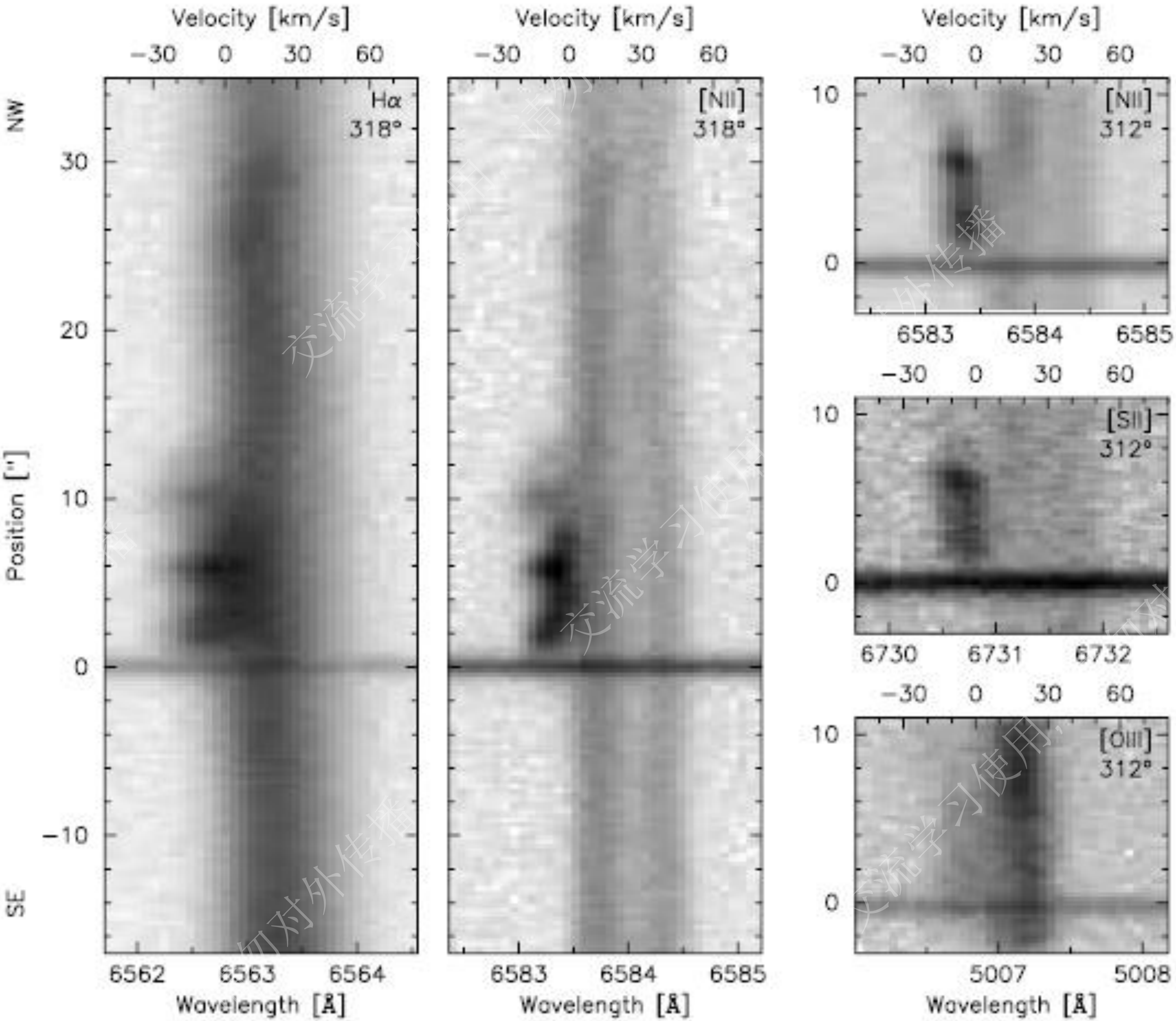
Low-resolution Spectroscopy of HH889

- **High excitation status of the jet systems**





560
520
480
440
Pixel
6550
6560
6570
6580
6590
560
520
480
440
Pixel
6550
6560
6570
6580
6590
Wavelength (A)

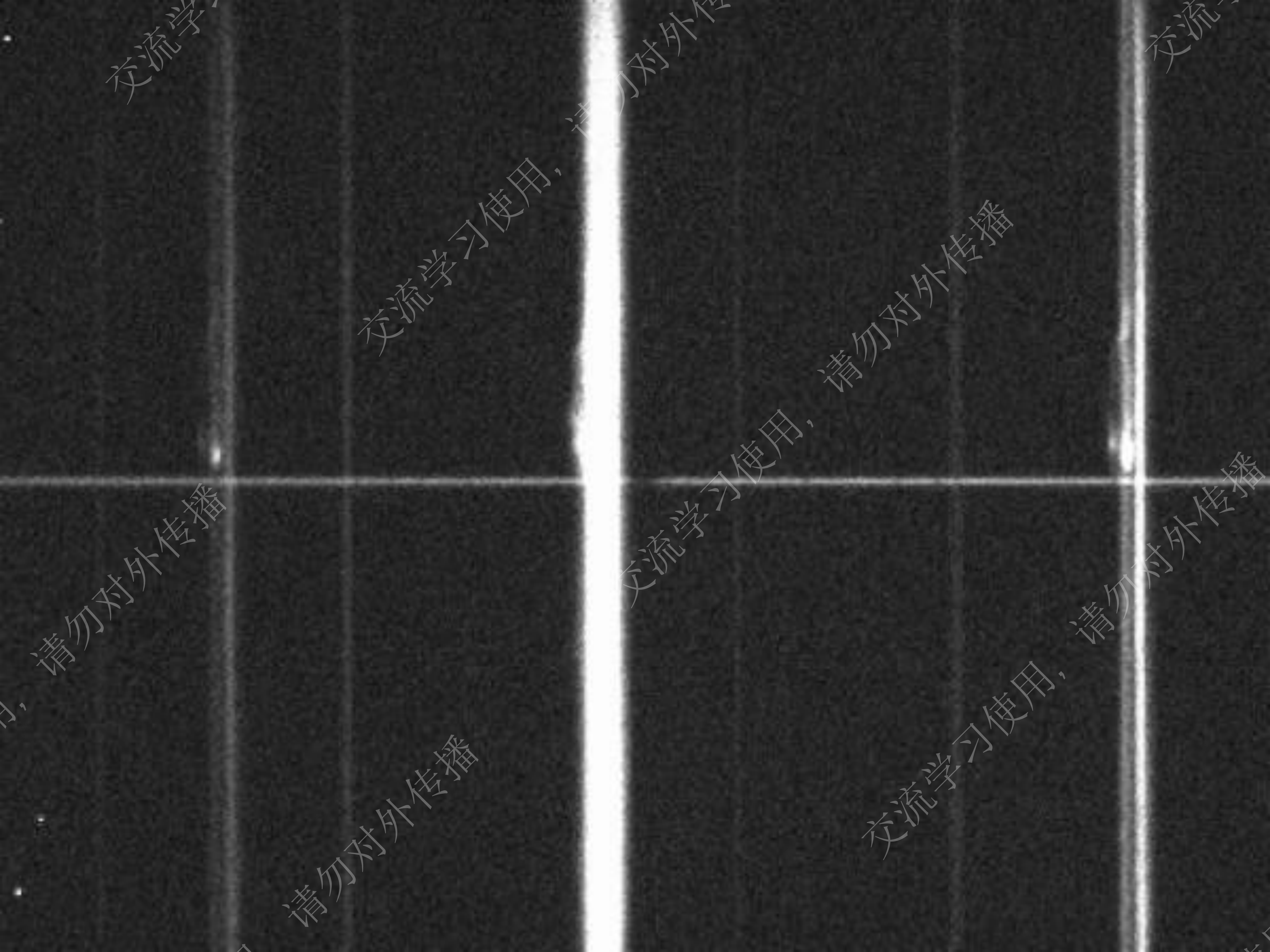


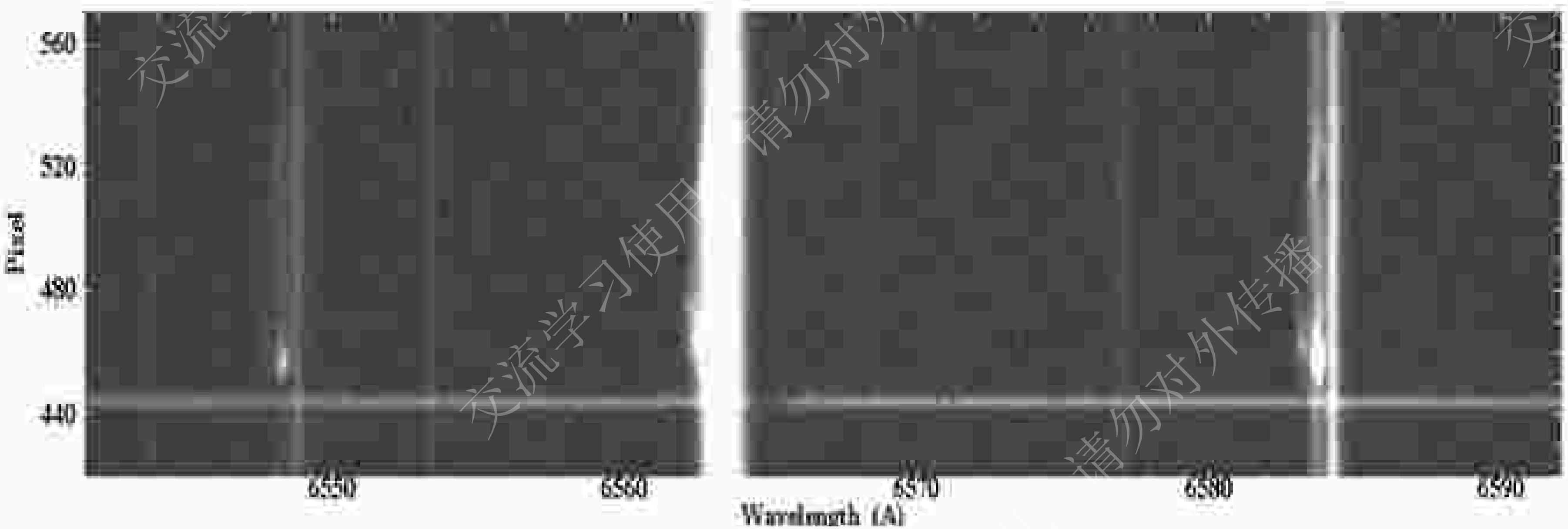
Velocity [km/s]
−30
0
30
60
Hα
318°
[NII]
318°
[NII]
312°
[SII]
312°
[OIII]
312°
NW
SE
Position ["]
30
20
10
0
−10
6562
6563
6564
6583
6584
6585
6730
6731
6732
5007
5008
Wavelength [Å]

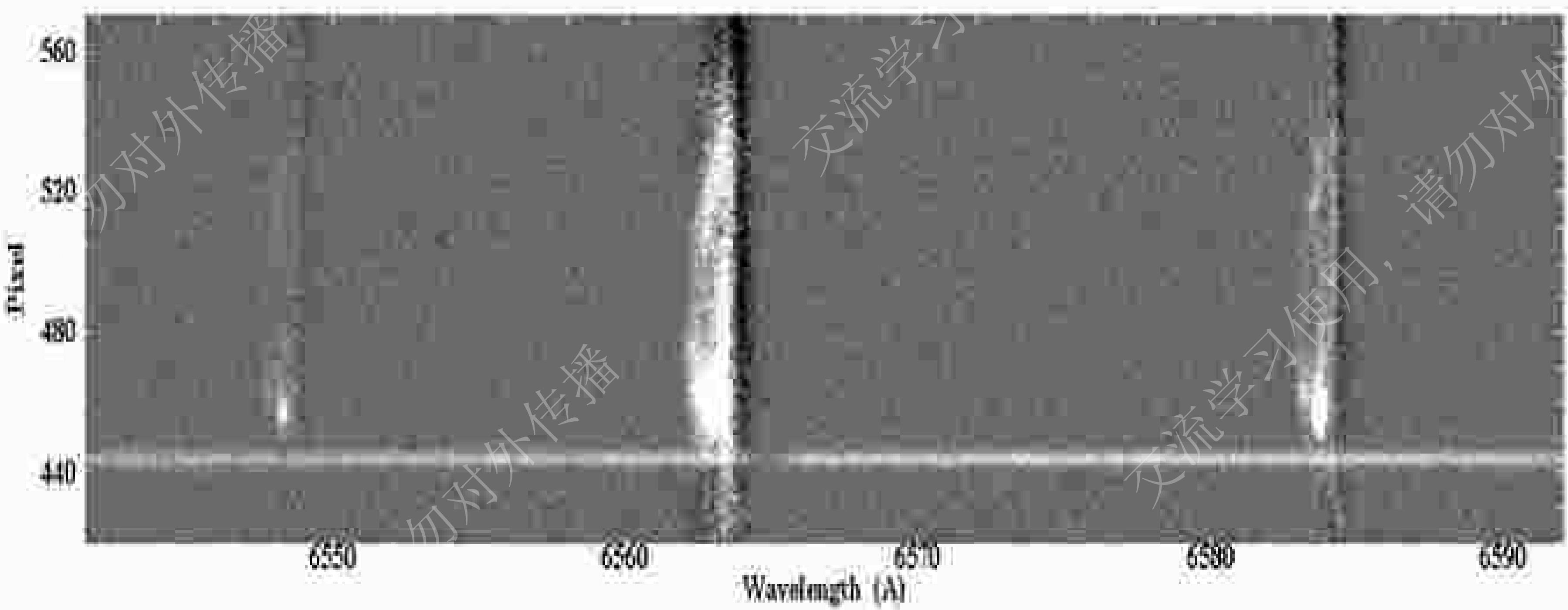
Results of the study

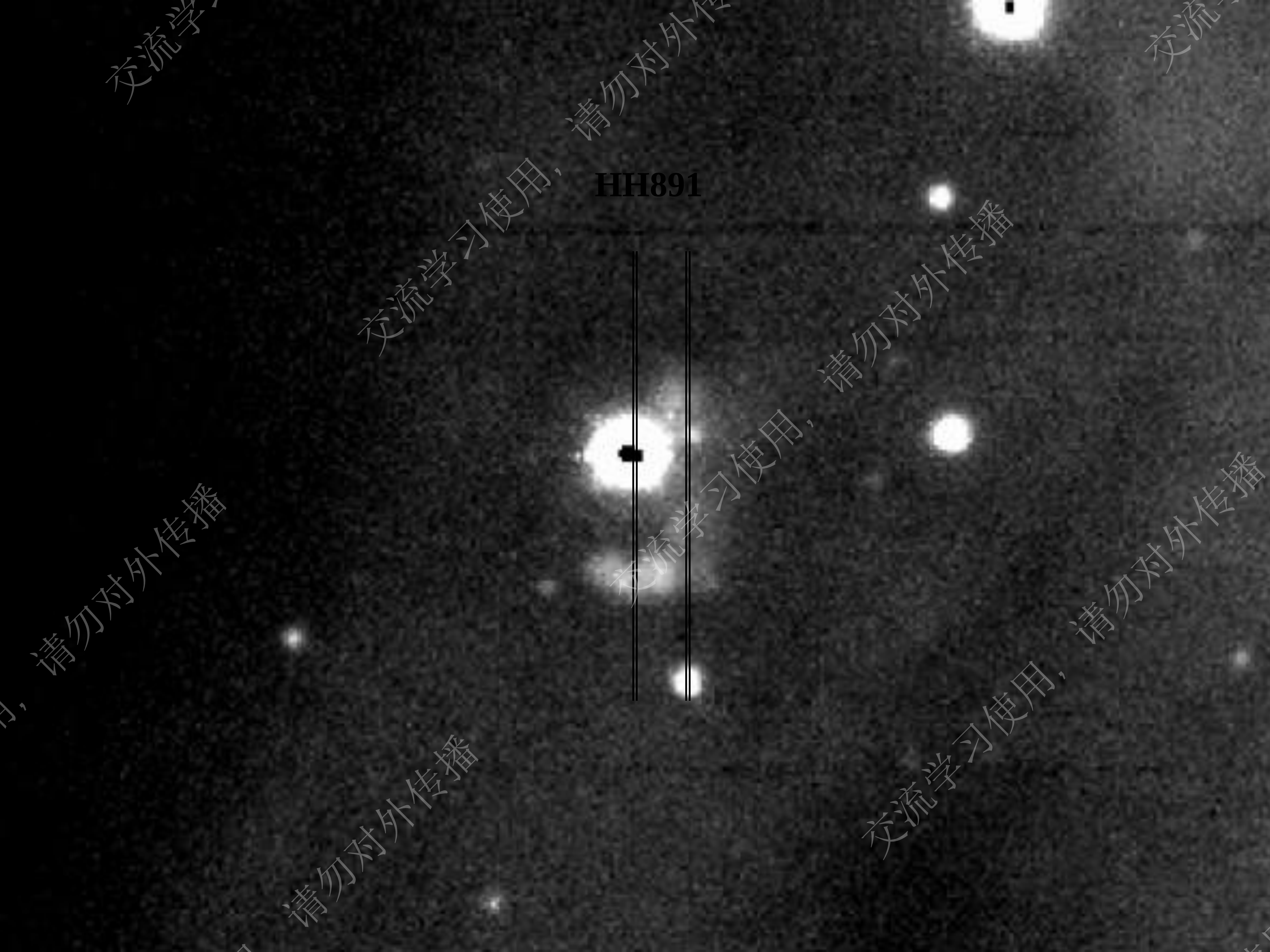
- **Expanding shells of the Rosette Nebula: 13 & 40 km/s → systematic velocity: 27 km/s**
- **Relative velocity of the jet along the line of sight: 57 km/s**
- **n_e in the jet: ~1000 cm^{-3}, HII region: < 100 cm^{-3}**
- **No detection of H_2 1-0 S(1) emission.**
- **Evaporation timescale of the relic disk: 10^3 – 10^4 yr**

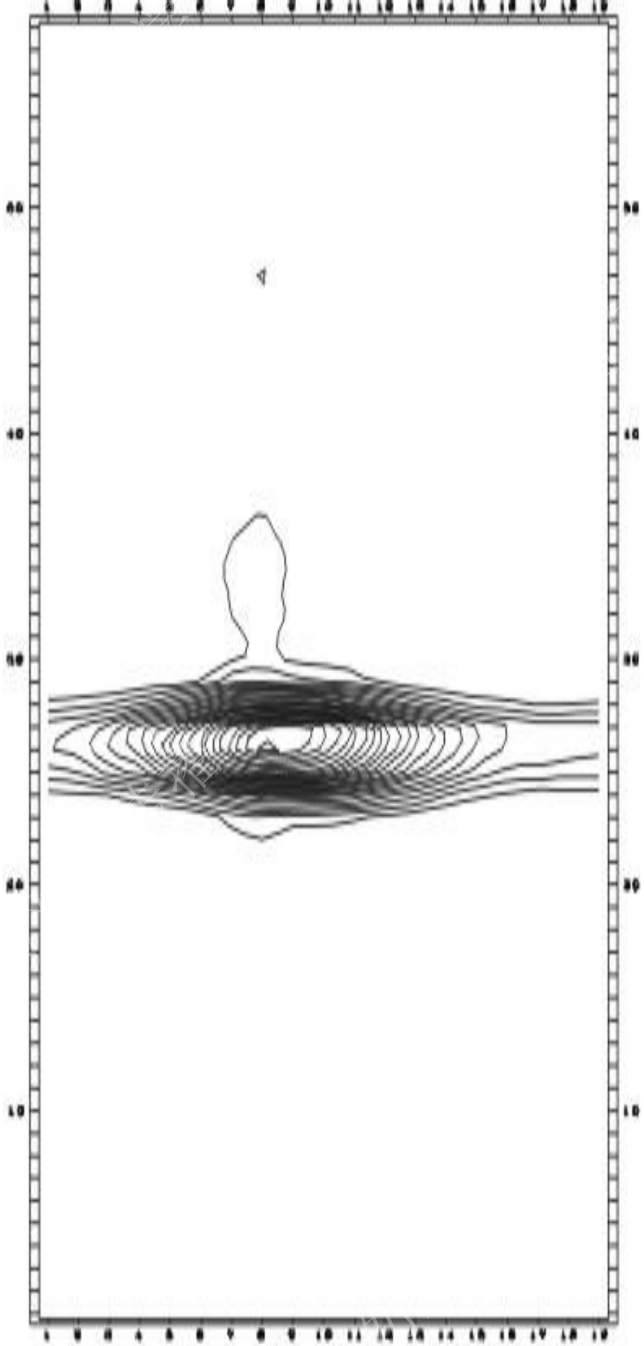
HH890



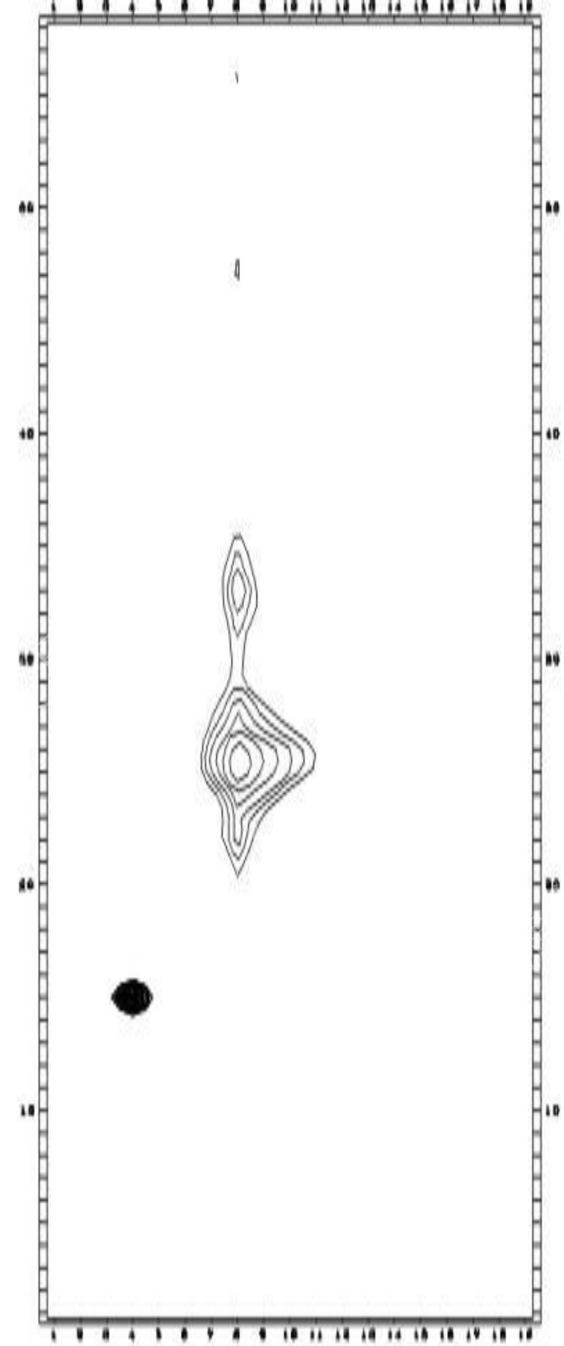

560
520
480
440
Pixel
6550
6560
6570
6580
6590
Wavelength (A)


560
520
480
440
Pixel
6550
6560
6570
6580
6590
Wavelength (A)

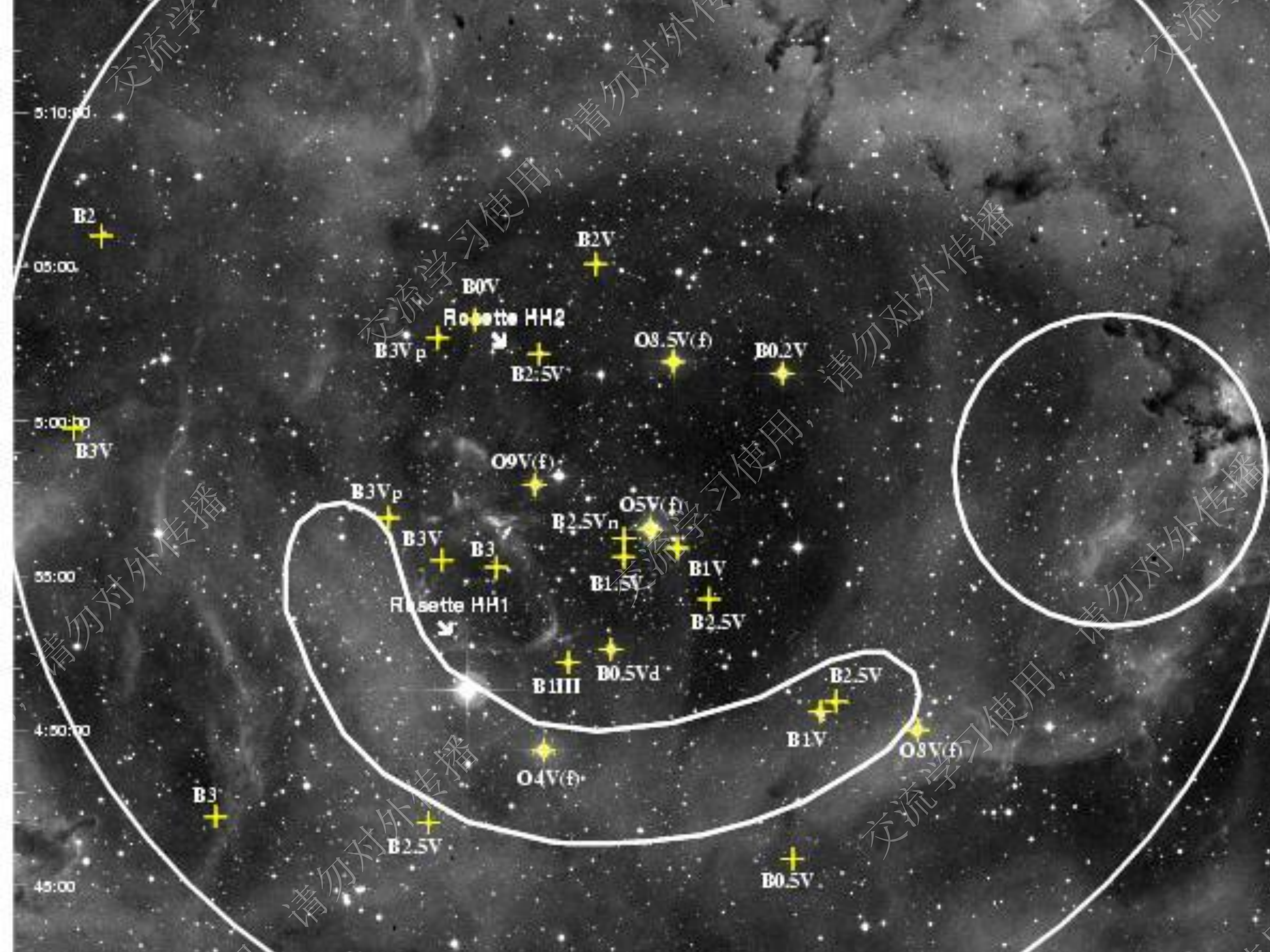

HH891



contoured from 1580. to 7580.. interval = 300.
NOAO/IRAF V2.12.1-EXPORT ljz@Rosette Tue 10:29:58 24-Feb-2004

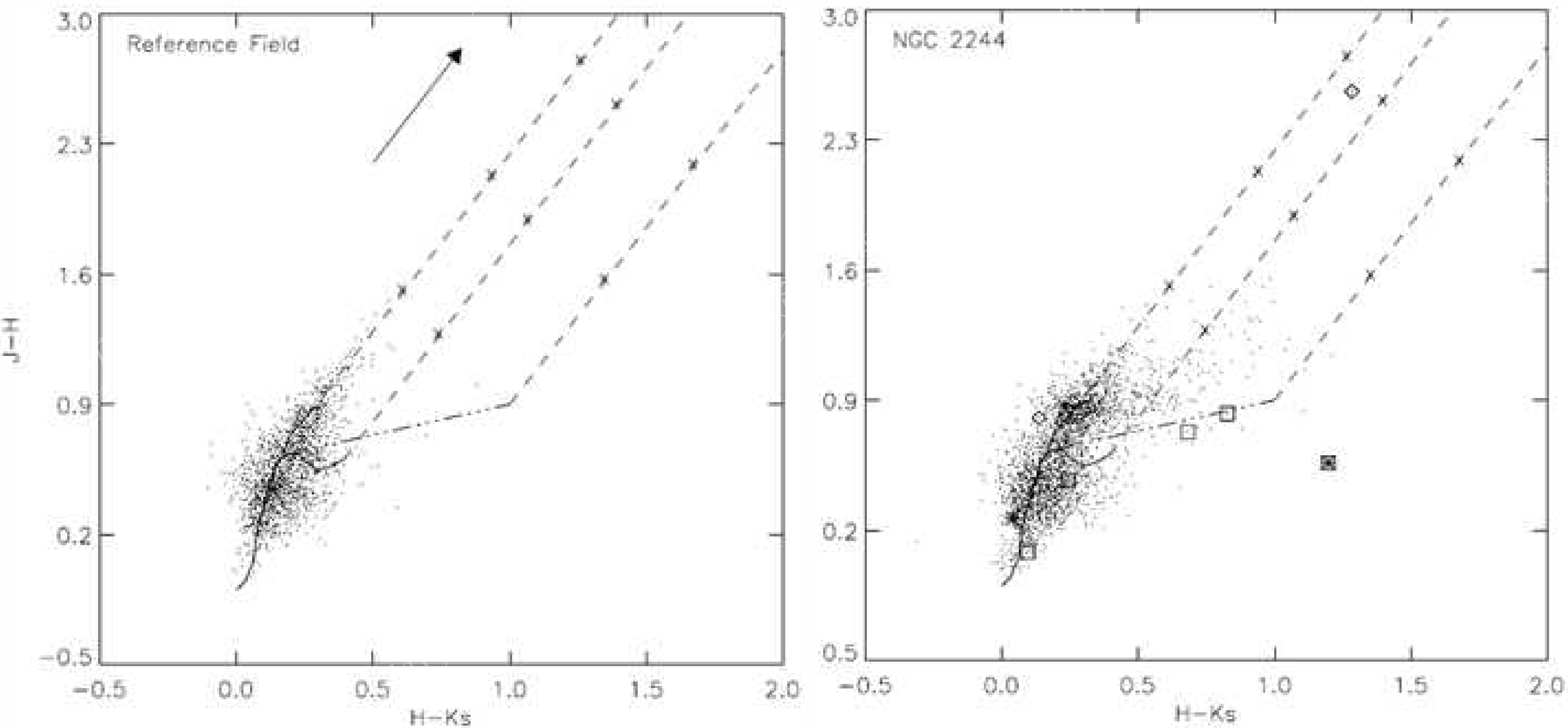


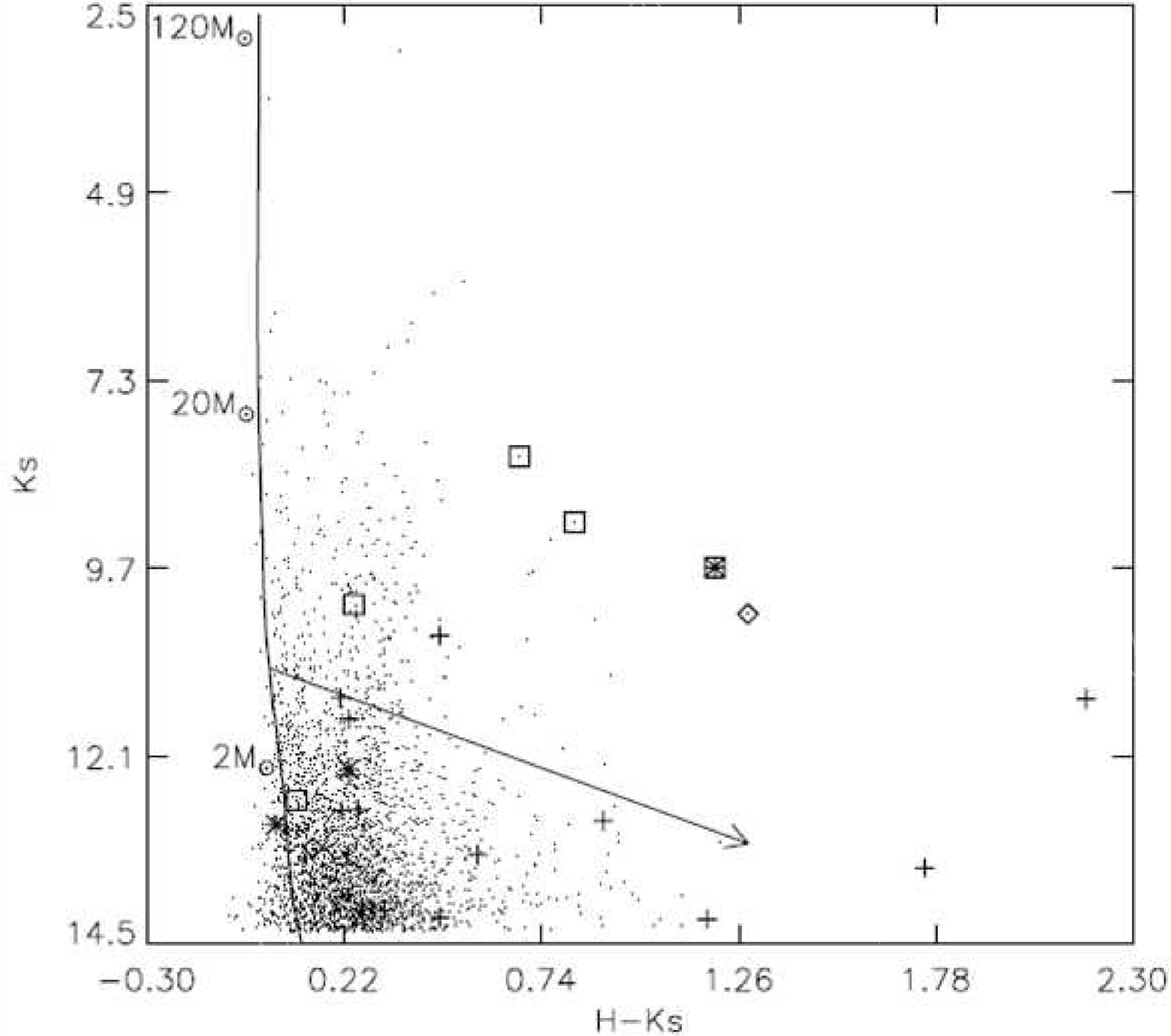
contoured from 1930. to 4430.. interval = 100.
NOAO/IRAF V2.12.1-EXPORT ljz@Rosette Tue 10:04:12 24-Feb-2004



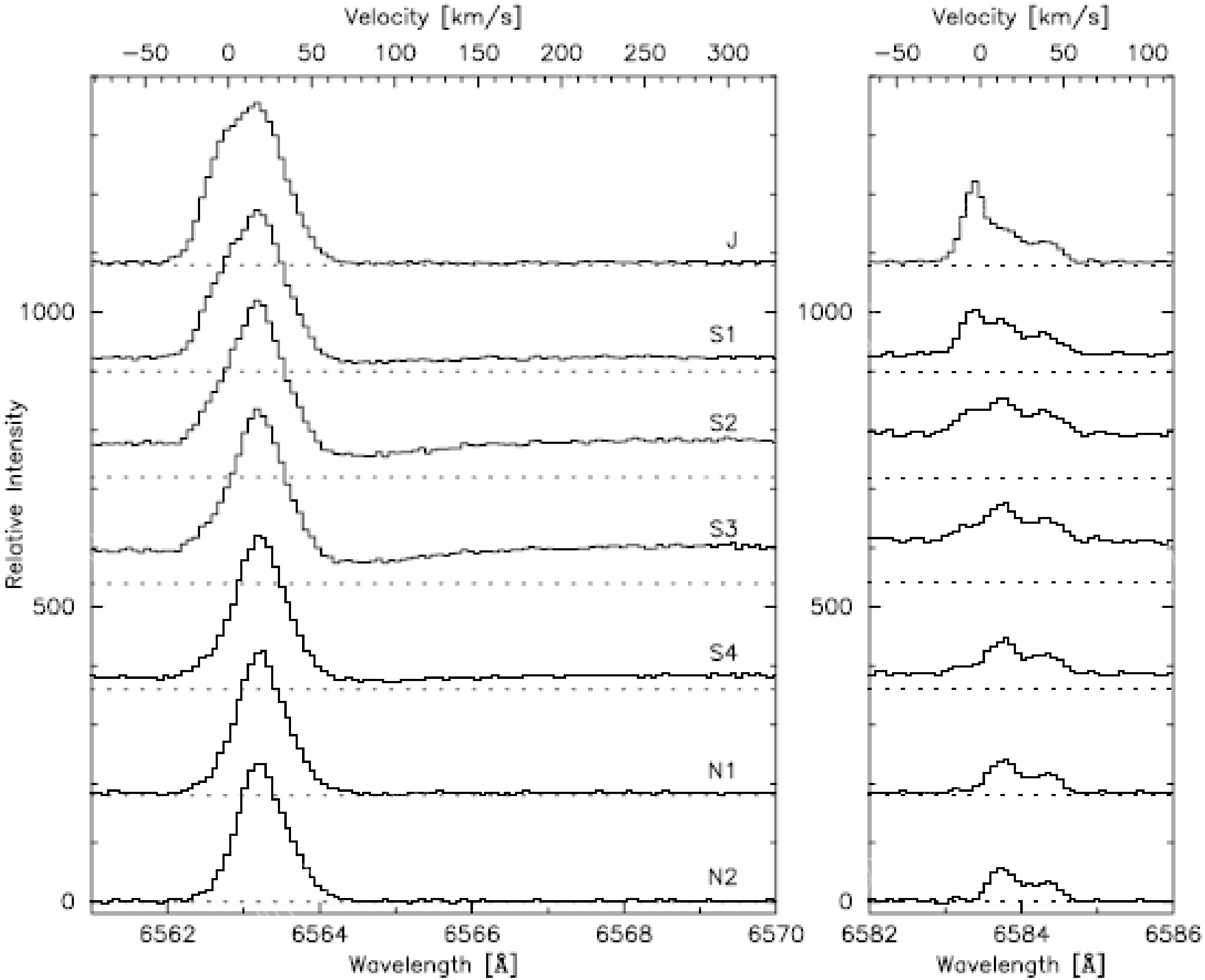
5:10:00
05:00
5:00:00
55:00
4:50:00
45:00
B2
B2V
B0V
Rosette HH2
B3Vp
B2.5V
O8.5V(f)
B0.2V
B3V
O9V(f)
B3Vp
O5V(f)
B2.5Vn
B3V
B3
B1V
B1.5V
Rosette HH1
B2.5V
B1III
B0.5Vd
B2.5V
B1V
O8V(f)
O4V(f)
B3
B2.5V
B0.5V

WTTS spectra, jets + no IR excess!
=> Fast disk dissipation
=> Transient Objects

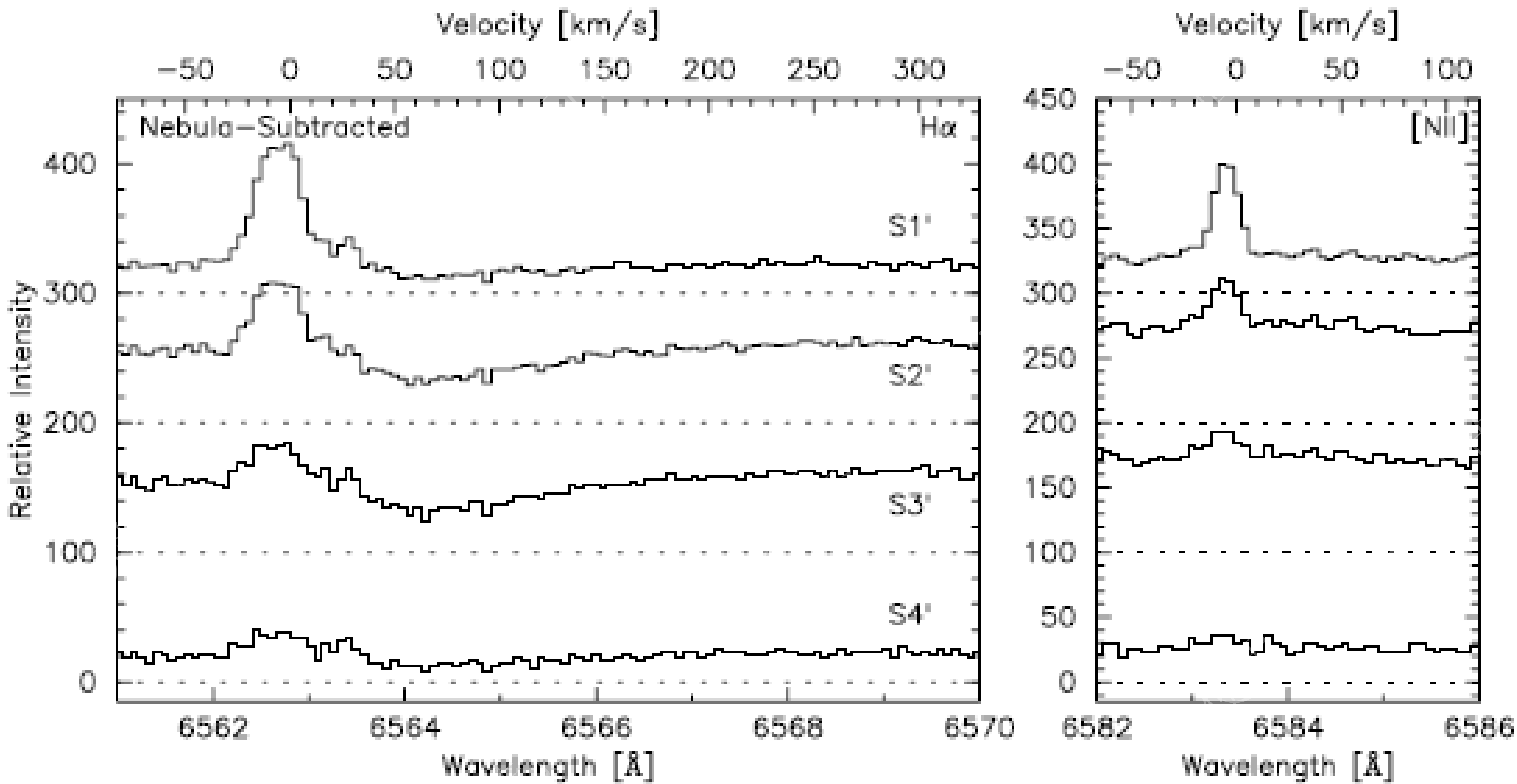




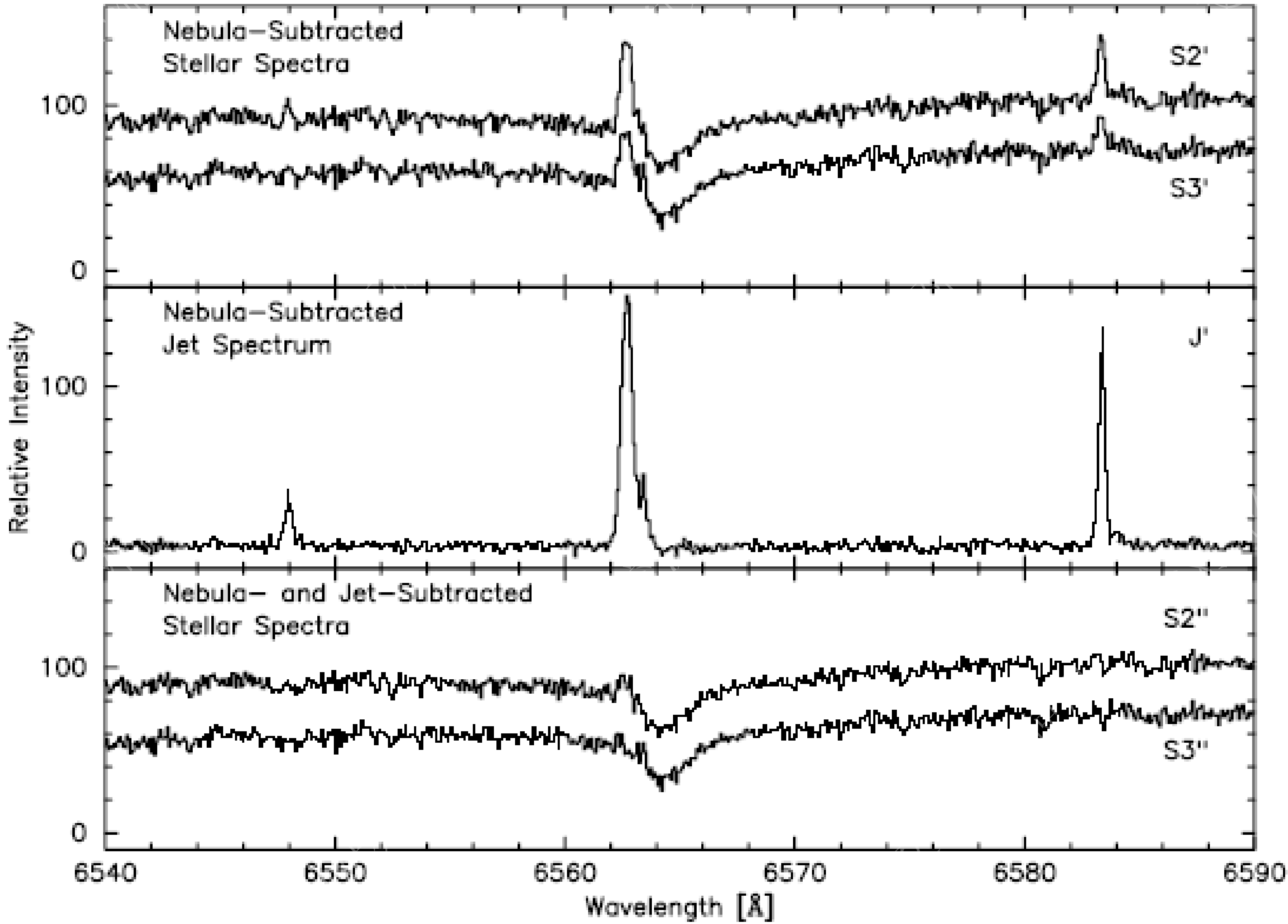
2.5
4.9
7.3
9.7
12.1
14.5
Ks
120M⊙
20M⊙
2M⊙
−0.30
0.22
0.74
1.26
1.78
2.30
H−Ks



Velocity [km/s]
−50
0
50
100
150
200
250
300
Velocity [km/s]
−50
0
50
100
J
S1
S2
S3
S4
N1
N2
Relative Intensity
1000
500
0
6562
6564
6566
6568
6570
Wavelength [Å]
6582
6584
6586
Wavelength [Å]

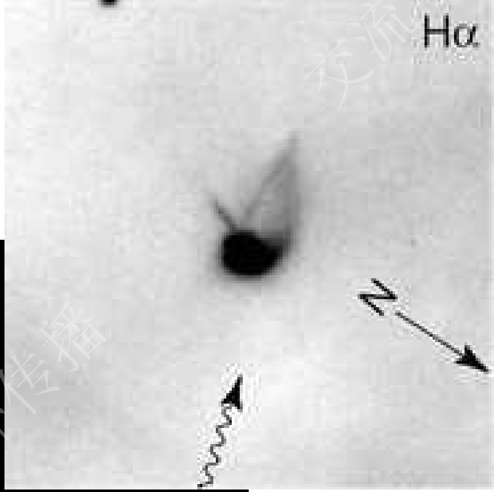


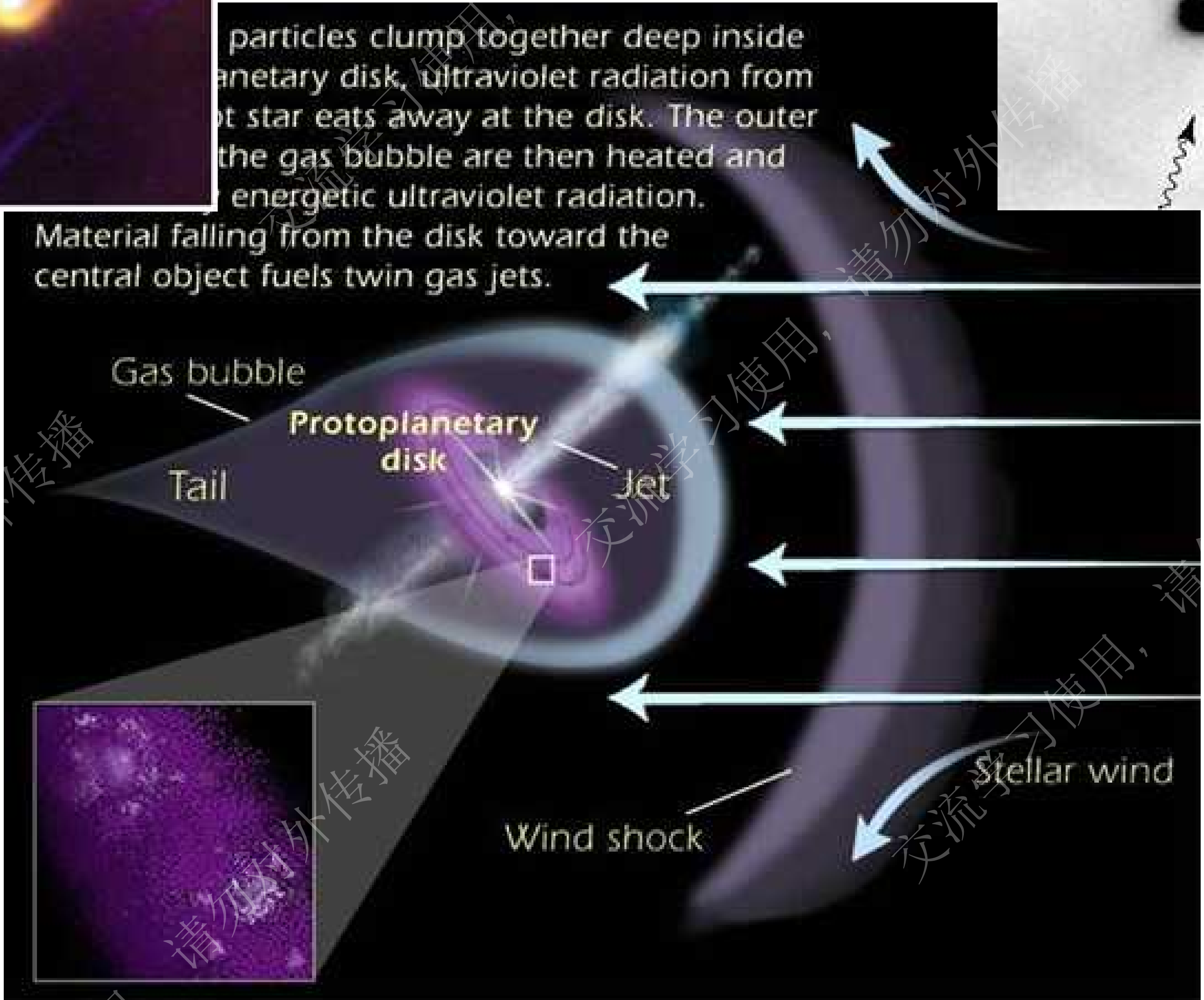
Velocity [km/s]
−50
0
50
100
150
200
250
300
Nebula−Subtracted
Hα
Relative Intensity
400
300
200
100
0
S1'
S2'
S3'
S4'
6562
6564
6566
6568
6570
Wavelength [Å]
Velocity [km/s]
−50
0
50
100
450
400
350
300
250
200
150
100
50
0
[NII]
6582
6584
6586
Wavelength [Å]



Nebula–Subtracted
Stellar Spectra
S2'
S3'
Nebula–Subtracted
Jet Spectrum
J'
Nebula– and Jet–Subtracted
Stellar Spectra
S2''
S3''
Relative Intensity
100
0
6540
6550
6560
6570
6580
6590
Wavelength [Å]

Anatomy of a Proplyd





What can we learn from the discovery of the extreme jet systems?

- **Fast transition status of the exciting sources of the extreme jets between CTTS and WTTS due to fierce external UV dissipation.**
- **As we discovered only monopolar jets bathed in strong UV dissipation of the Rosette Nebula.**
- **This provides clues on how bipolar jets evolved into monopolar or highly asymmetric jets, which is quite a puzzle in our understanding of jet formation and evolution.**

What can we learn from the discovery of the extreme jet systems?

- **The excting sources of the extreme jets has been long <u>starved of material as its accretion disk is being evaporated</u>, leaving a very low-mass star or most likely a failed star.**
- **In some cases, this process will result in an isolated brown dwarf or planetary mass object. This, however, <u>offers an evolutionary solution for the lonely floating objects</u> that have been spotted in the Orion Nebula (Zapatero Osorio, et al. 2000, Science 290, 103) and other nearby hotspots of active SF in the Milky Way.**

A&A 427, 299–306 (2004)
DOI: 10.1051/0004-6361:20041131

Astronomy & Astrophysics

The formation of free-floating brown dwarves and planetary-mass objects by photo-erosion of prestellar cores

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Received 21 April 2004 / Accepted 22 July 2004

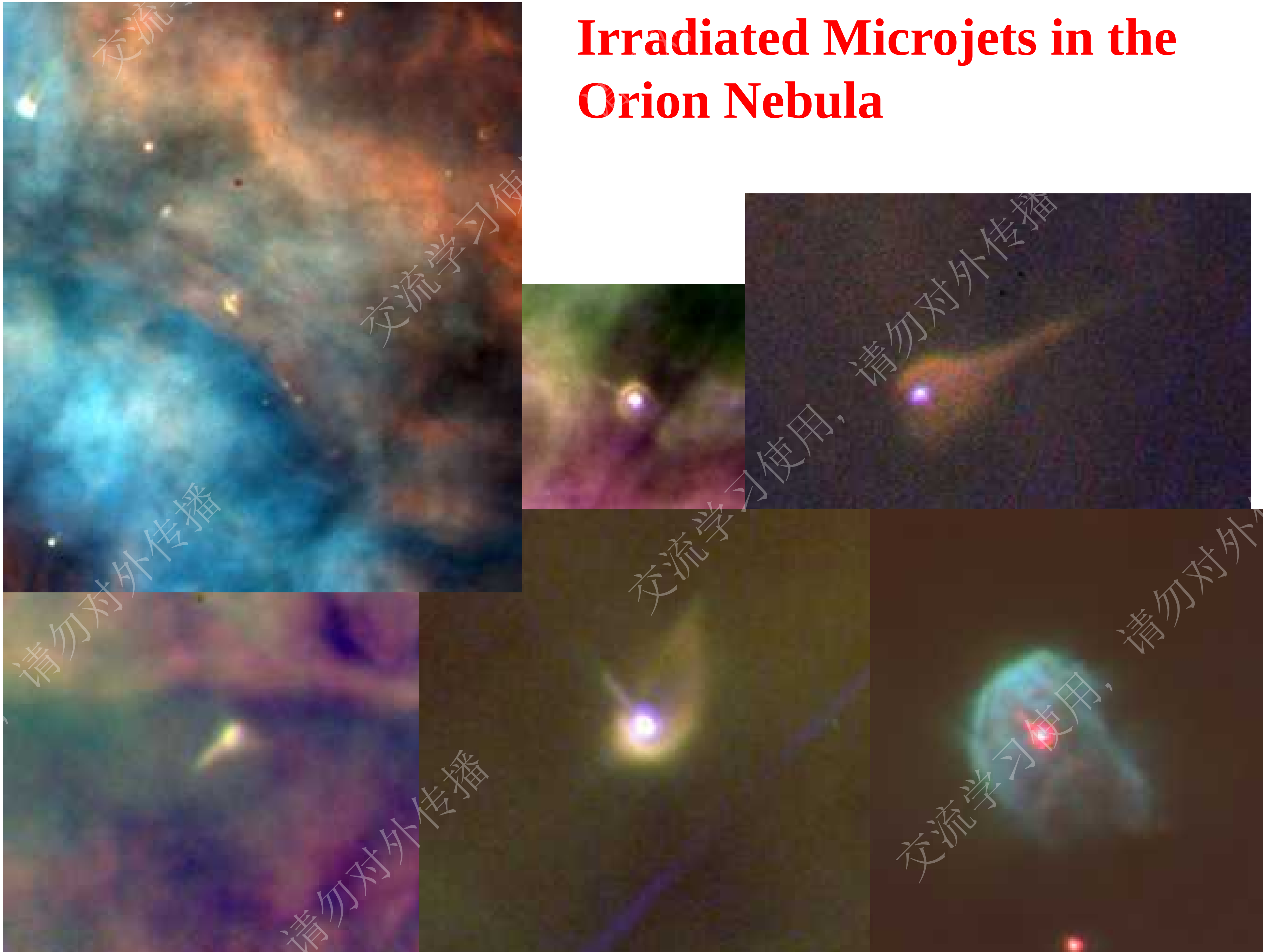
Abstract. We explore the possibility that, in the vicinity of an OB star, a prestellar core which would otherwise have formed an intermediate or low-mass star may form a free-floating brown dwarf or planetary-mass object, because the outer layers of the core are eroded by the ionizing radiation from the OB star before they can accrete onto the protostar at the centre of the core. The masses of objects formed in this way are given approximately by $\sim 0.010\,M_\odot\,(a_{\rm I}/0.3\,{\rm km\,s^{-1}})^6\,(\dot{N}_{\rm Lyc}/10^{50}\,{\rm s^{-1}})^{-1/3}\,(n_0/10^3\,{\rm cm^{-3}})^{-1/3}$, where $a_{\rm I}$ is the isothermal sound speed in the neutral gas of the core, $\dot{N}_{\rm Lyc}$ is the rate of emission of Lyman continuum photons from the OB star (or stars), and n_0 is the number-density of protons in the HII region surrounding the core. We conclude that the formation of low-mass objects by this mechanism should be quite routine, because the mechanism operates over a wide range of conditions ($10^{50}\,{\rm s^{-1}} \lesssim \dot{N}_{\rm Lyc} \lesssim 10^{52}\,{\rm s^{-1}}$, $10\,{\rm cm^{-3}} \lesssim n_0 \lesssim 10^5\,{\rm cm^{-3}}$, $0.2\,{\rm km\,s^{-1}} \lesssim a_{\rm I} \lesssim 0.6\,{\rm km\,s^{-1}}$) and is very effective. However, it is also a rather wasteful way of forming low-mass objects, in the sense that it requires a relatively massive initial core to form a single low-mass object. The effectiveness of photo-erosion also implies that that any intermediate-mass protostars which have formed in the vicinity of a group of OB stars must already have been well on the way to formation before the OB stars switched on their ionizing radiation; otherwise these protostars would have been stripped down to extremely low mass.

Key words. stars: formation – stars: low-mass, brown dwarfs – ISM: HII regions

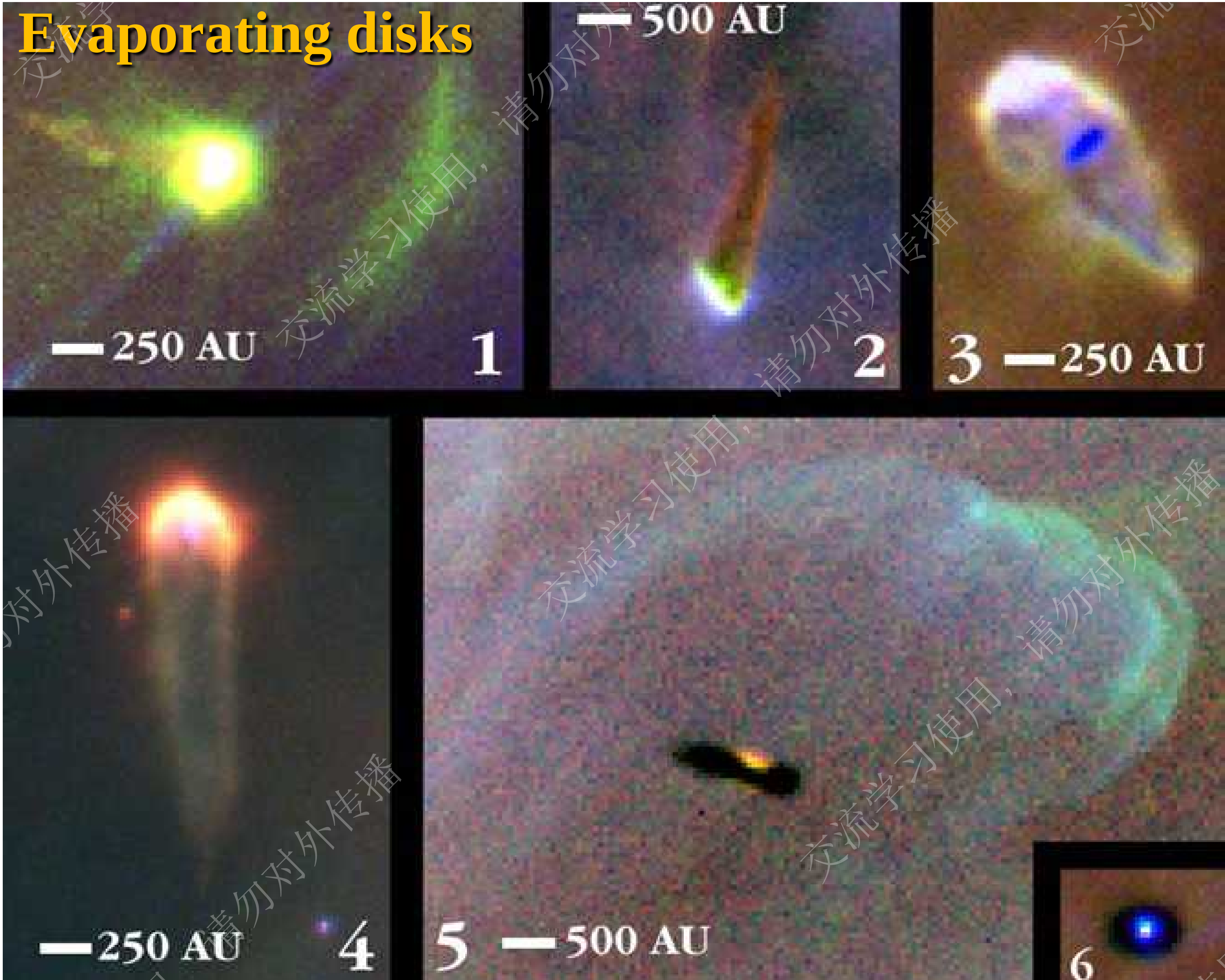
What can we learn from the dsicovery of the extreme jet systems?

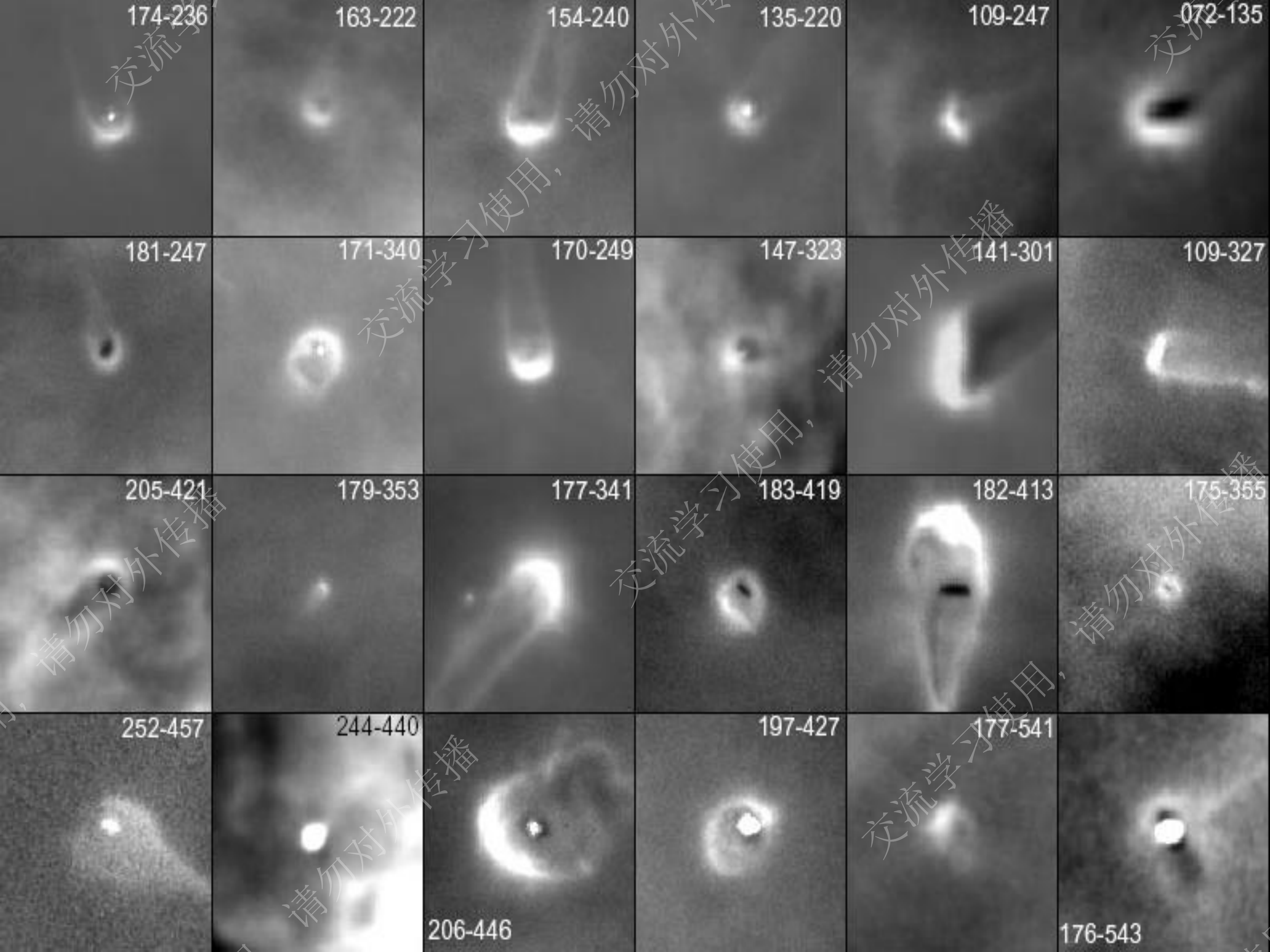
- **The discovery of the extreme jet systems in active high-mass star forming regions indicates explicitly how the incipience of high mass stars inhibits further generations of low mass stars from formation in their immediate vicinity.**
- **On the other hand, it's likely that the formation of the OB stars triggers new generations of massive star formation at a distance of tens of pcs as the HII region propogates.**

Irradiated Microjets in the Orion Nebula



Evaporating disks

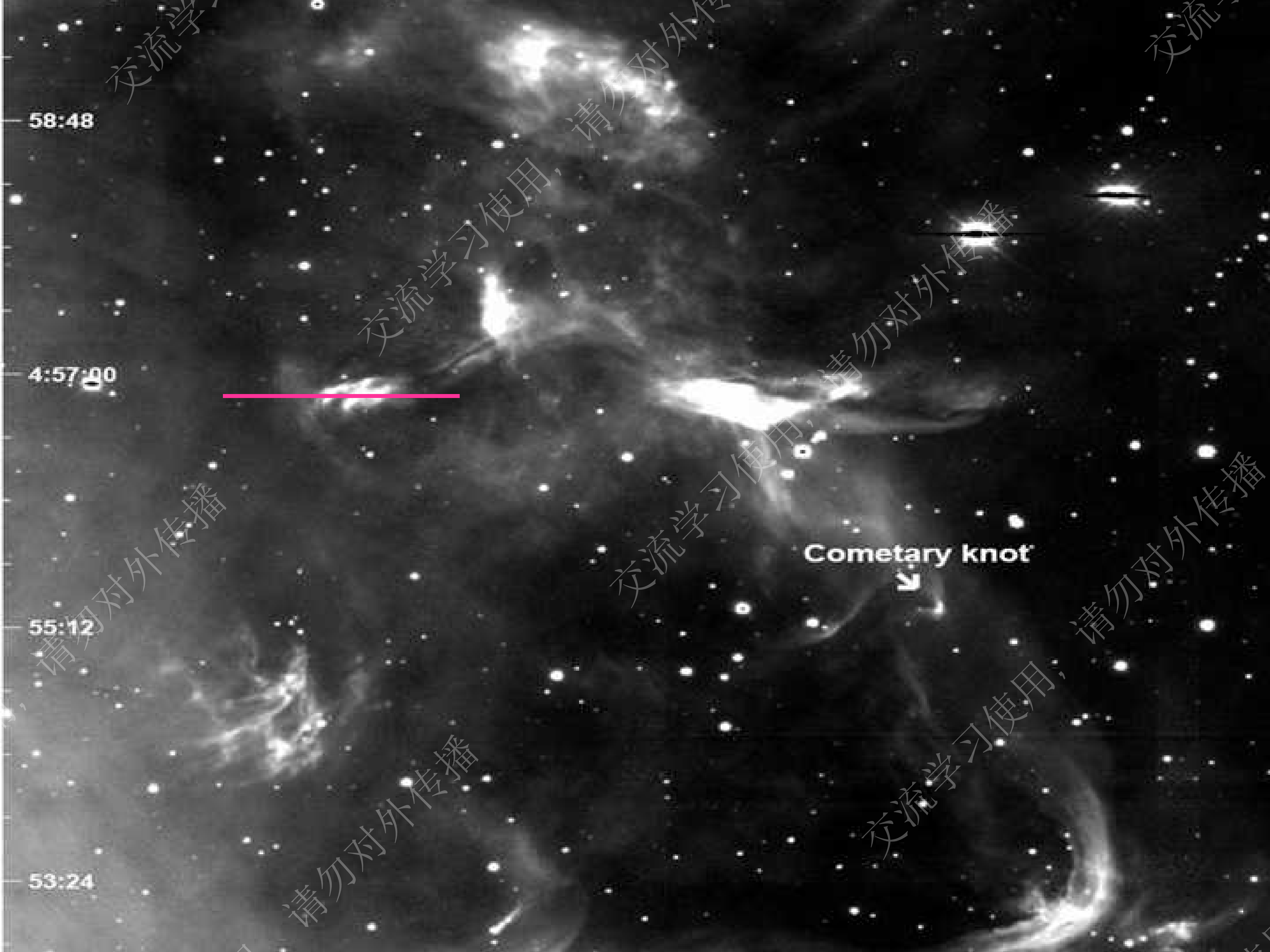



174-236
163-222
154-240
135-220
109-247
072-135
181-247
171-340
170-249
147-323
141-301
109-327
205-421
179-353
177-341
183-419
182-413
175-355
252-457
244-440
206-446
197-427
177-541
176-543

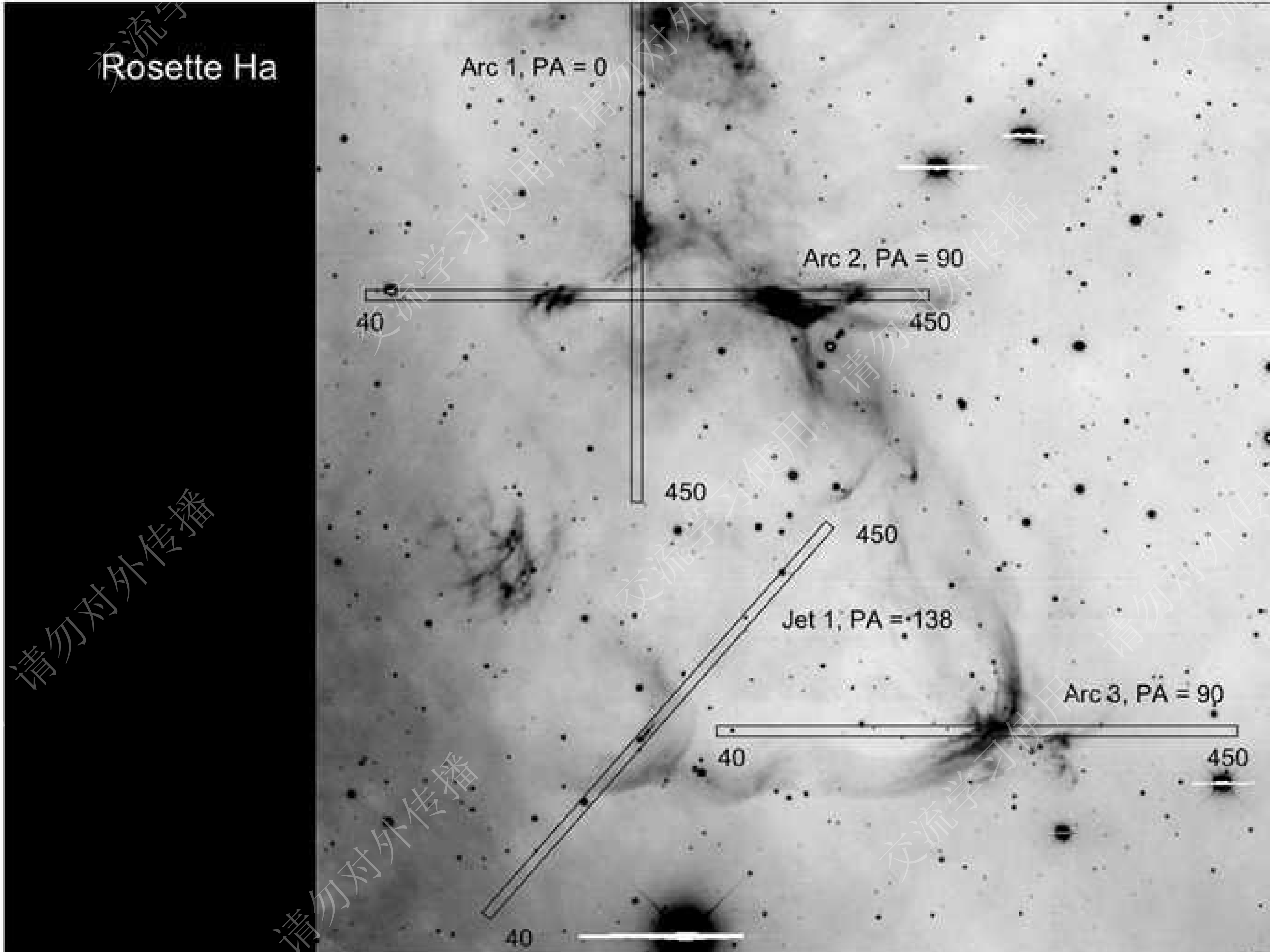
Evaporating disks

M20 irradiated jet
Hester et al.

Could the jets and the large bow shock structures in Rosette share a similar photoionzed origin?


58:48
4:57:00
55:12
53:24
Cometary knot

- Meanburn & Walsh, 1986, MNRAS 220, 745



Rosette Ha
Arc 1, PA = 0
Arc 2, PA = 90
40
450
450
450
Jet 1, PA = 138
Arc 3, PA = 90
40
450
40

Modes of star and cluster formation in the RMC

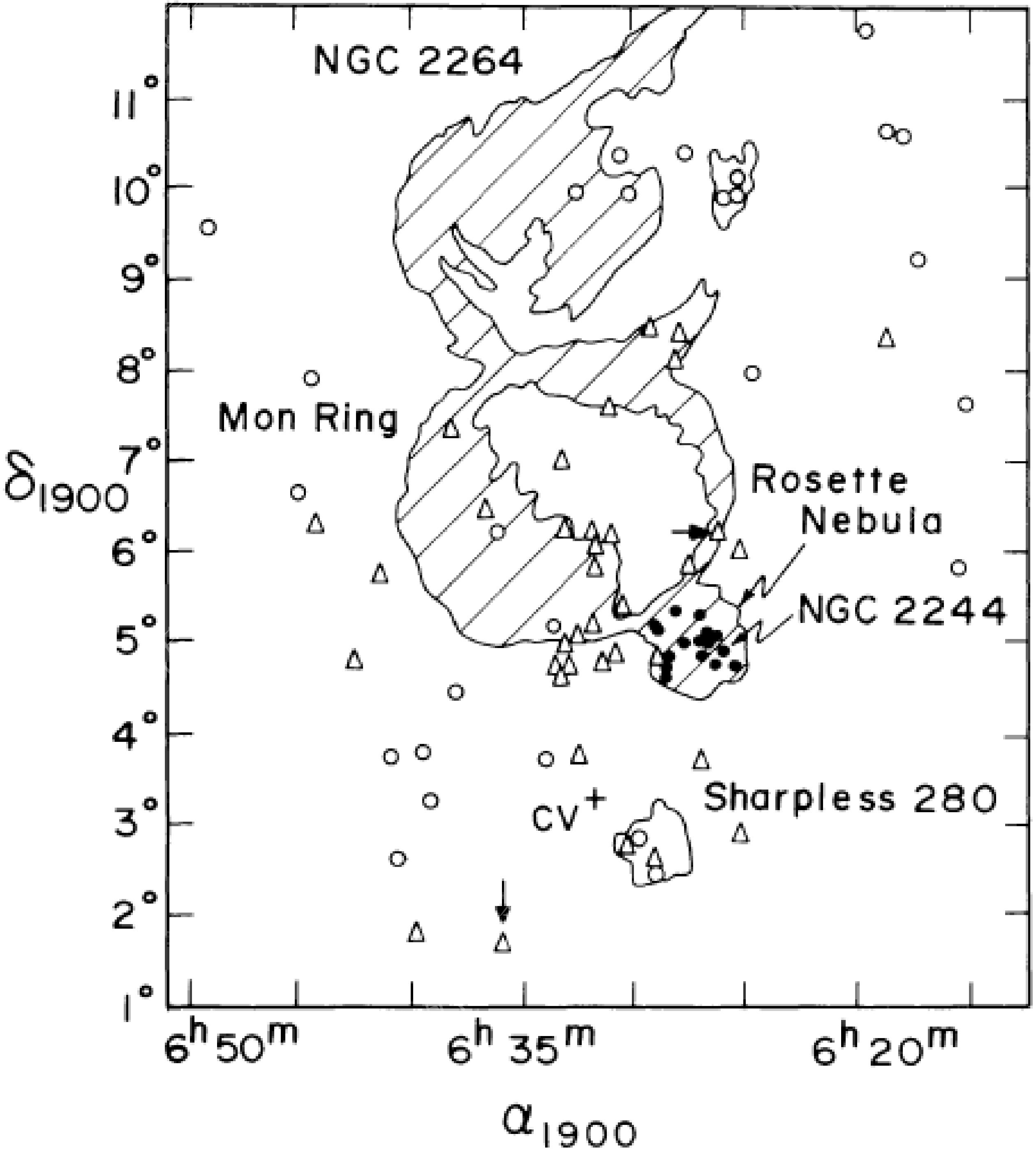
Li J. Z. & Smith M. D. , 2005, ApJ 620, 816

Li J. Z. , 2005, ApJ 625, 242

Li J. Z. & Smith M. D., 2005, AJ 130, 2757

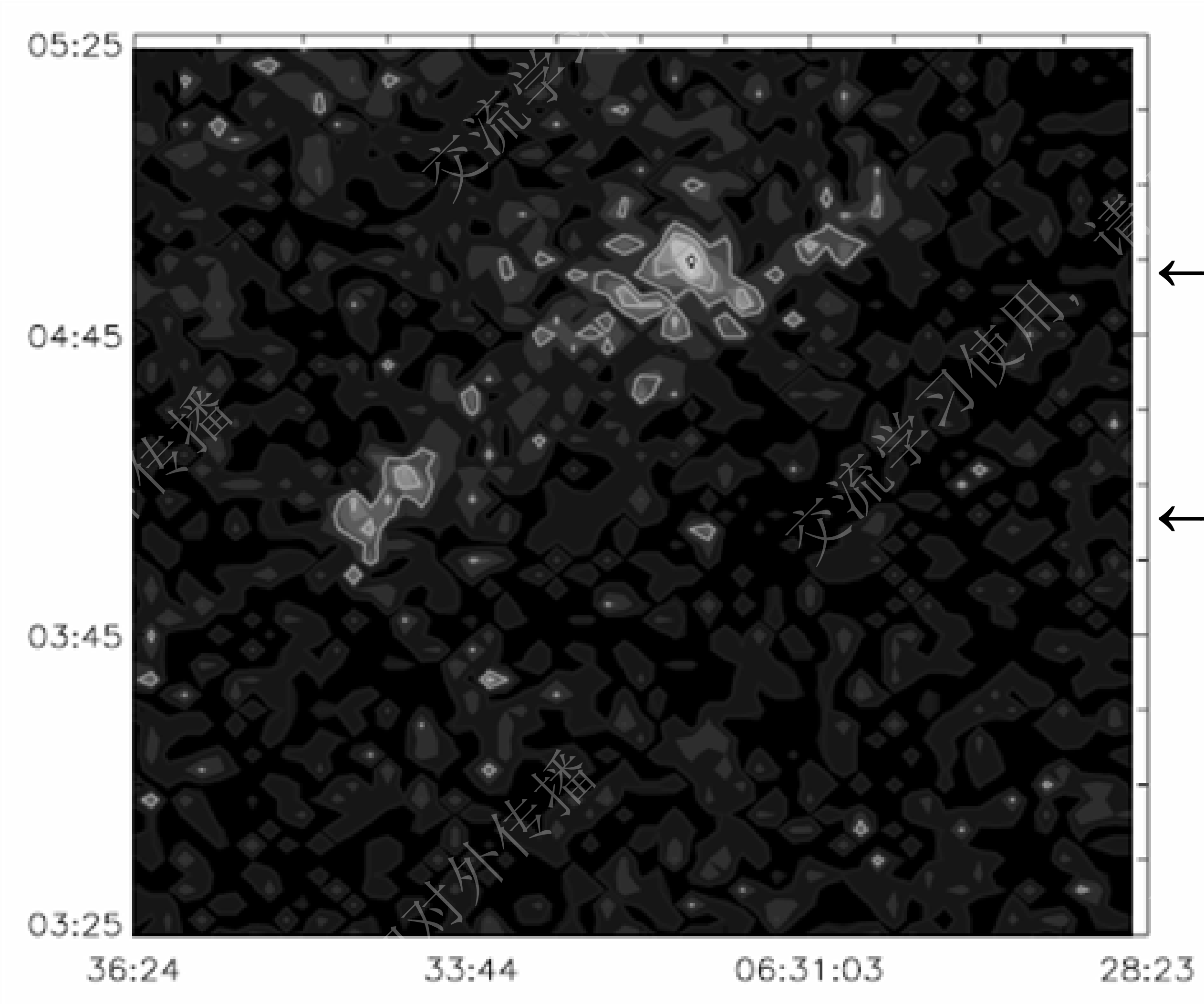
Li J. Z. & Smith M. D., 2005, AJ 130, 721

Li J. Z. & Smith M. D. , 2005, A&A 431, 925


NGC 2264
Mon Ring
Rosette
Nebula
NGC 2244
Sharpless 280
CV+
δ1900
α1900
11°
10°
9°
8°
7°
6°
5°
4°
3°
2°
1°
6h 50m
6h 35m
6h 20m

Turner 1976

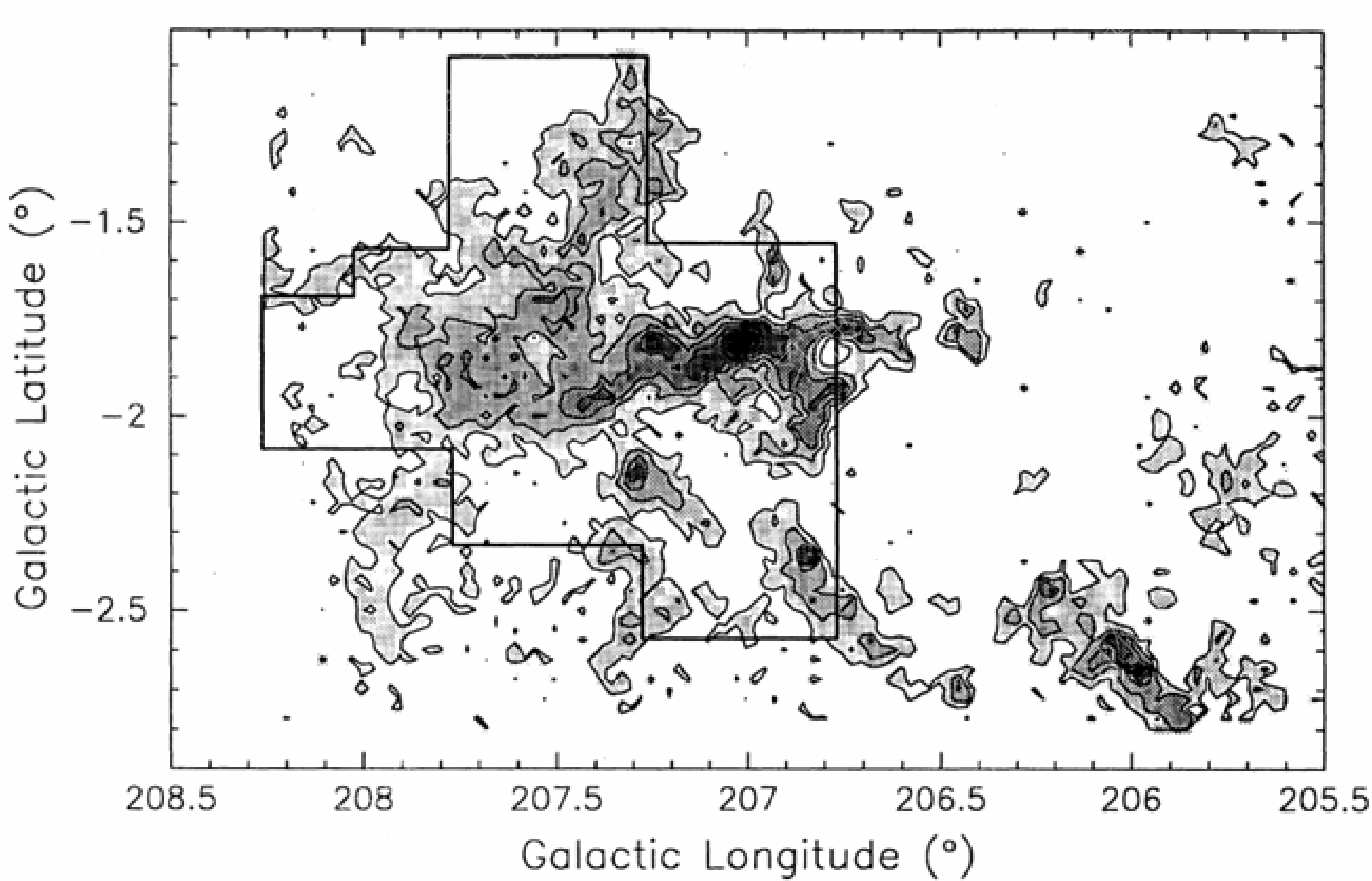
The Formation of New Generation OB clusters in the RMC



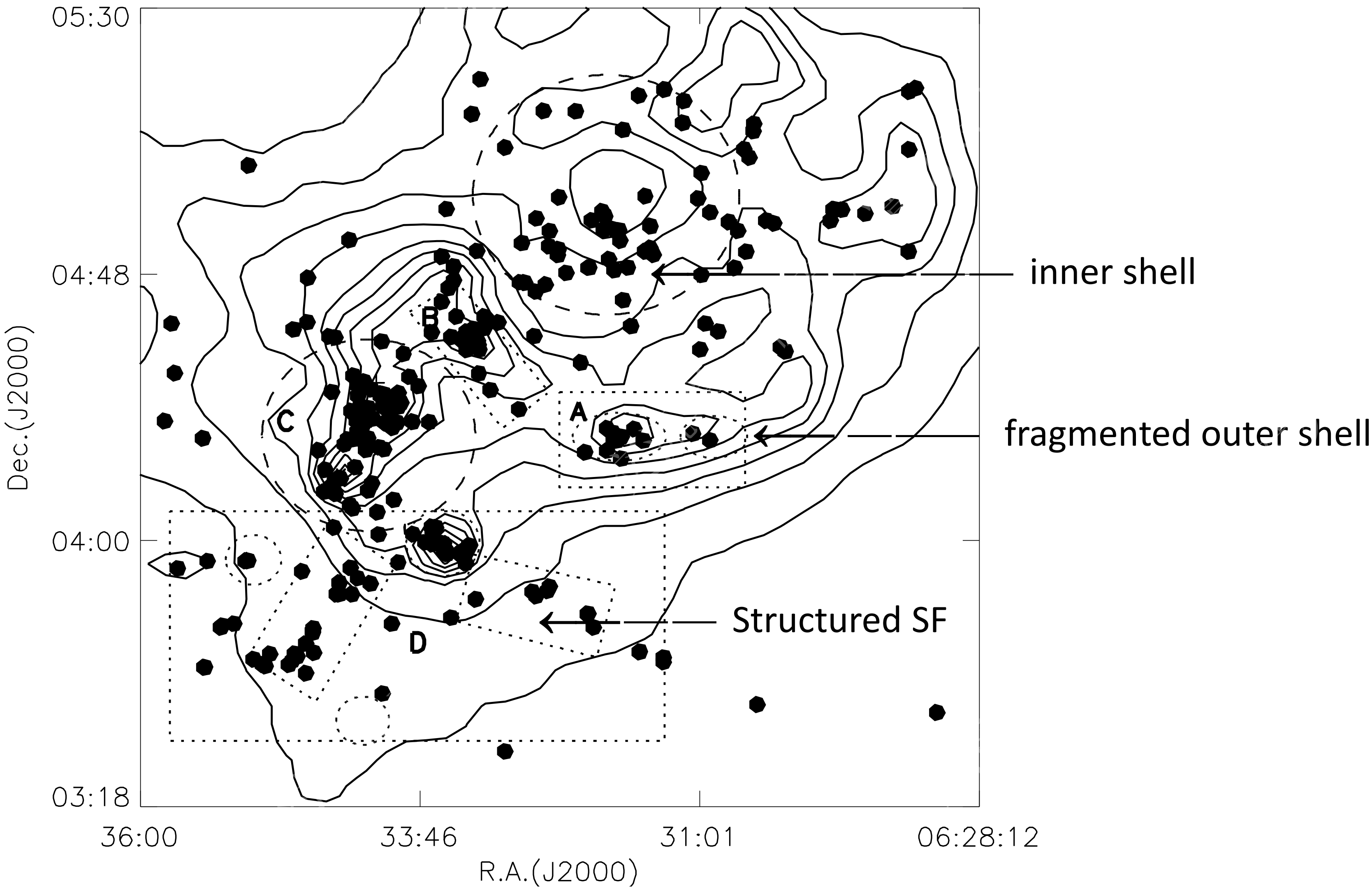
← NGC 2244

← New massive cluster
Tens of pc away

CO Detections of the RMC

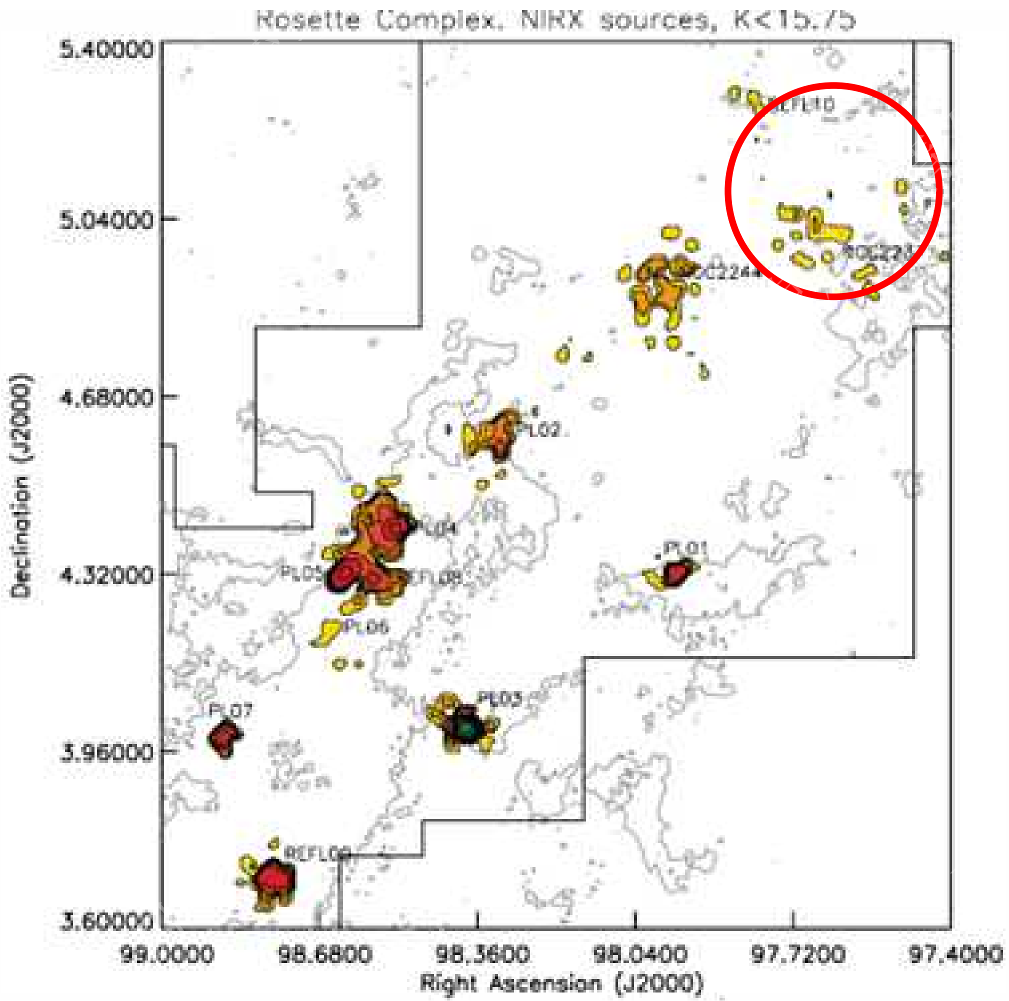


Excessive emission stars with (H-Ks) > 0.7

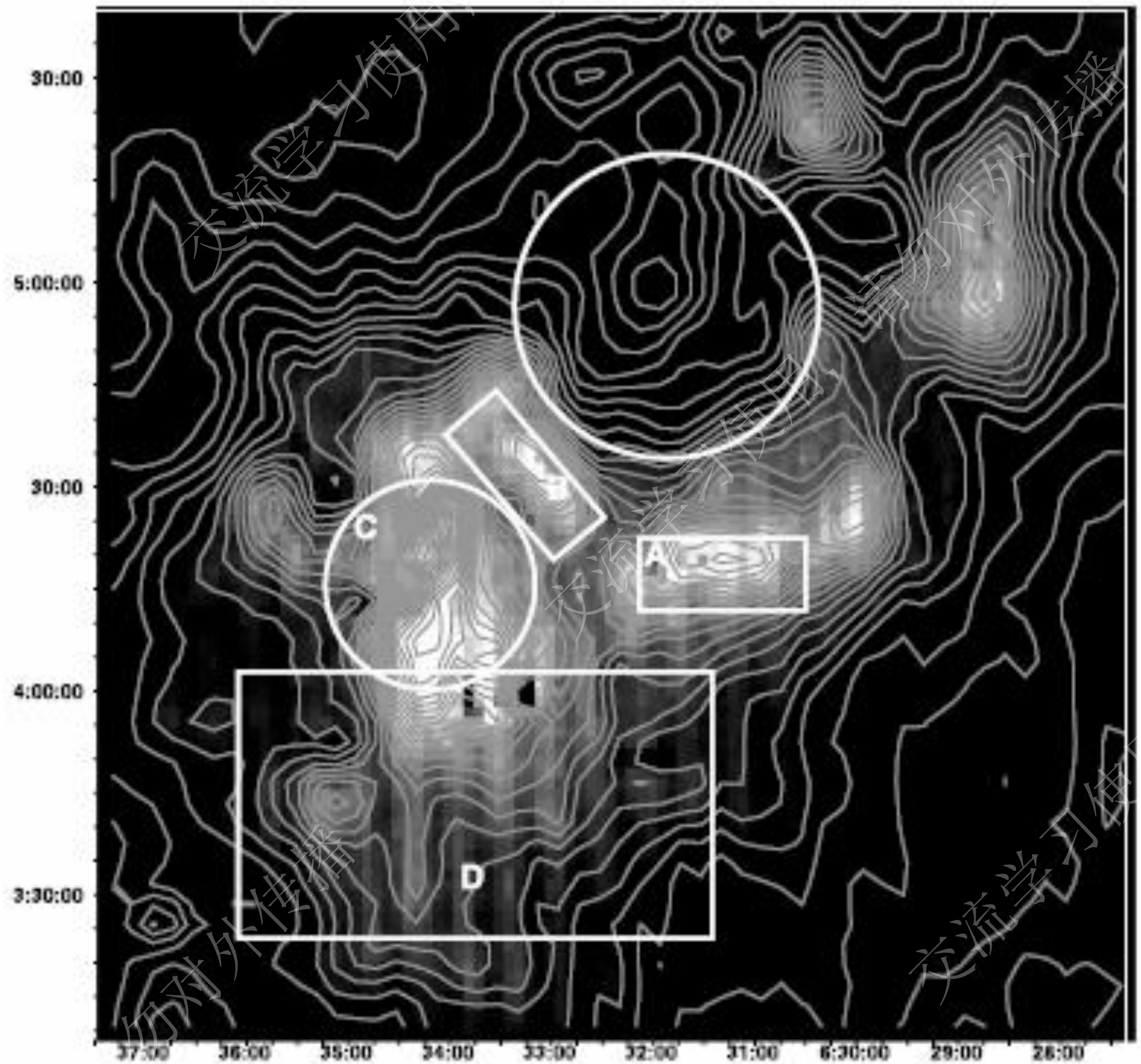


Clustered SF in the RMC

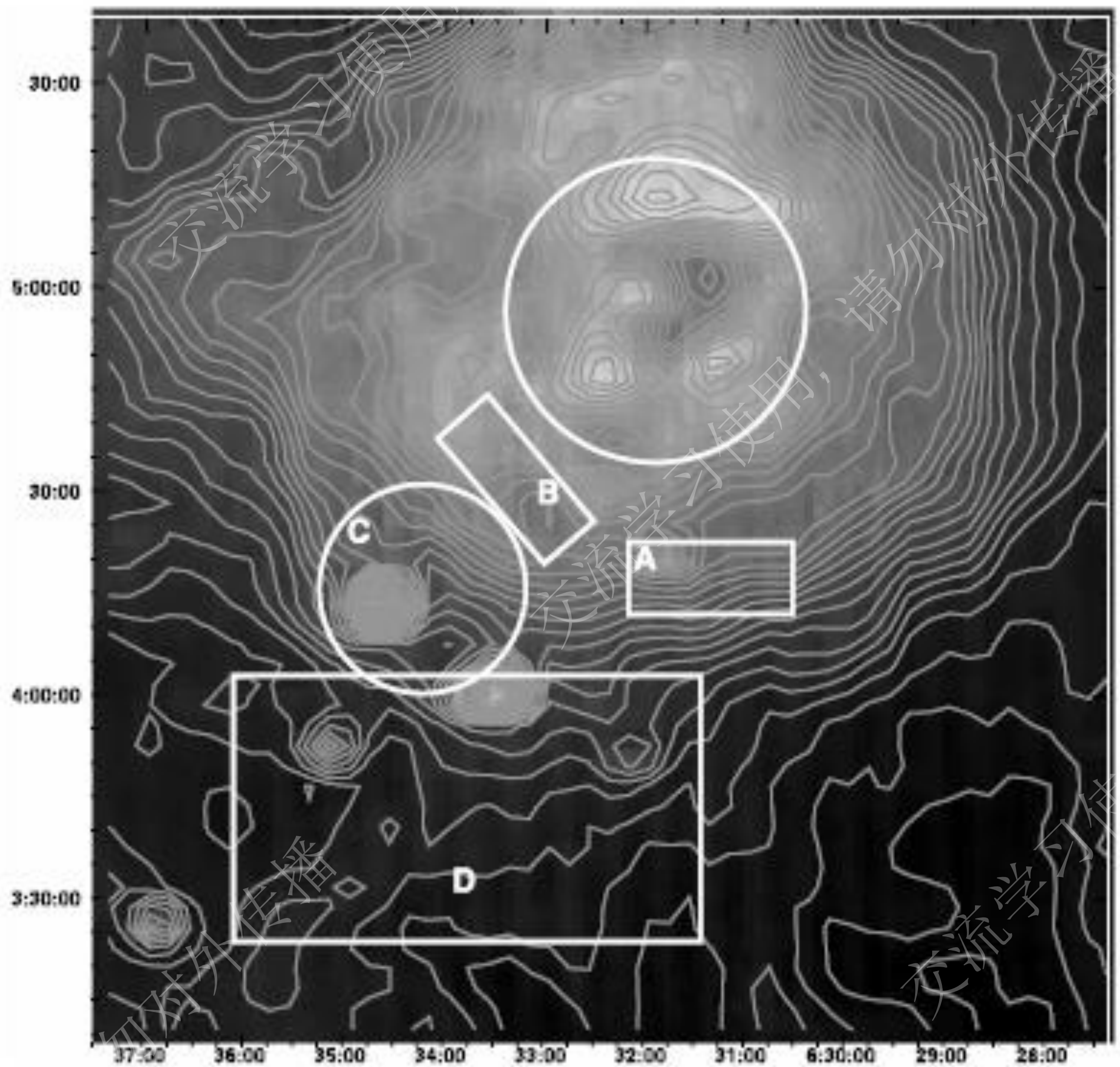
原星团形成模式、机制研究的模板



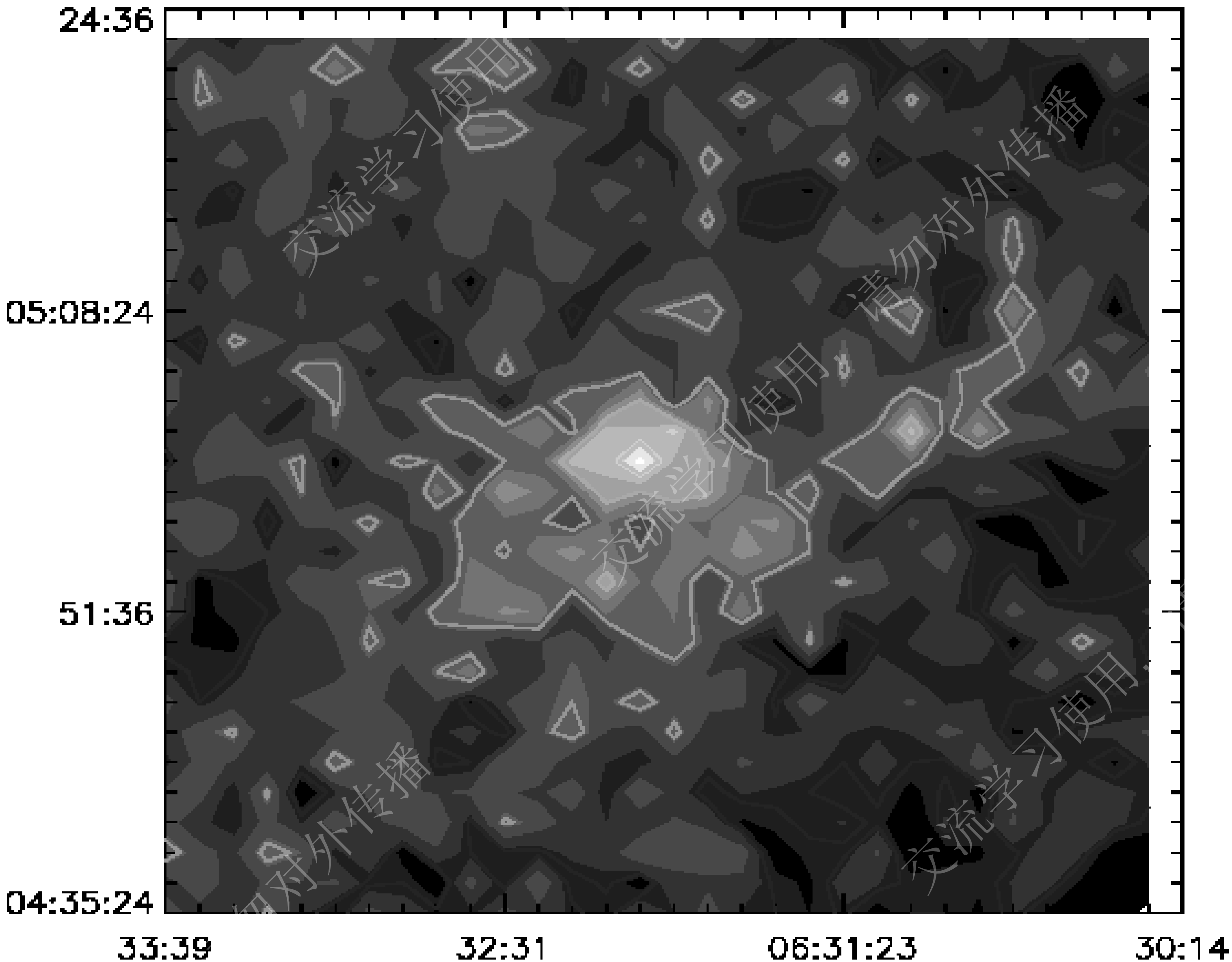
Possible constraints on clustered SF



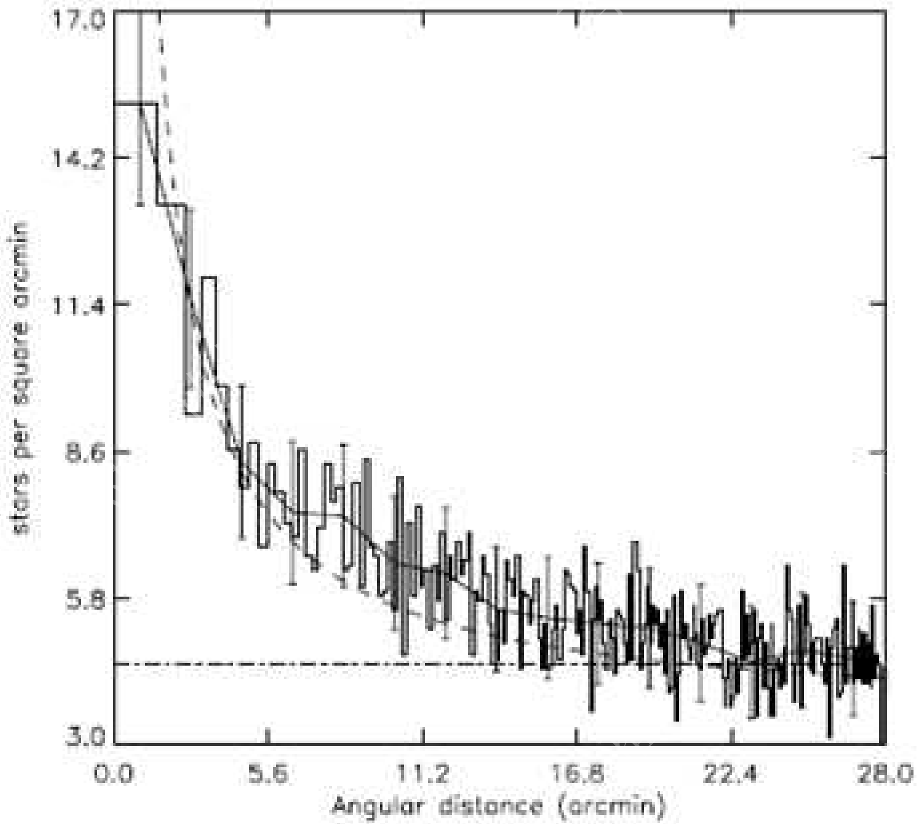
Dust temperature distribution

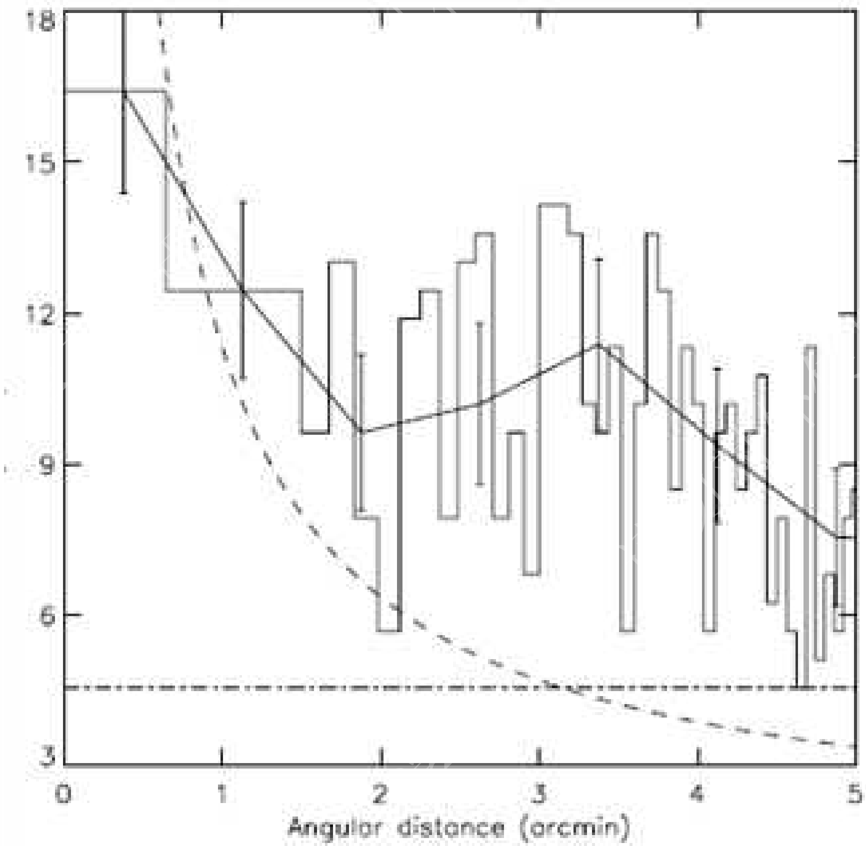


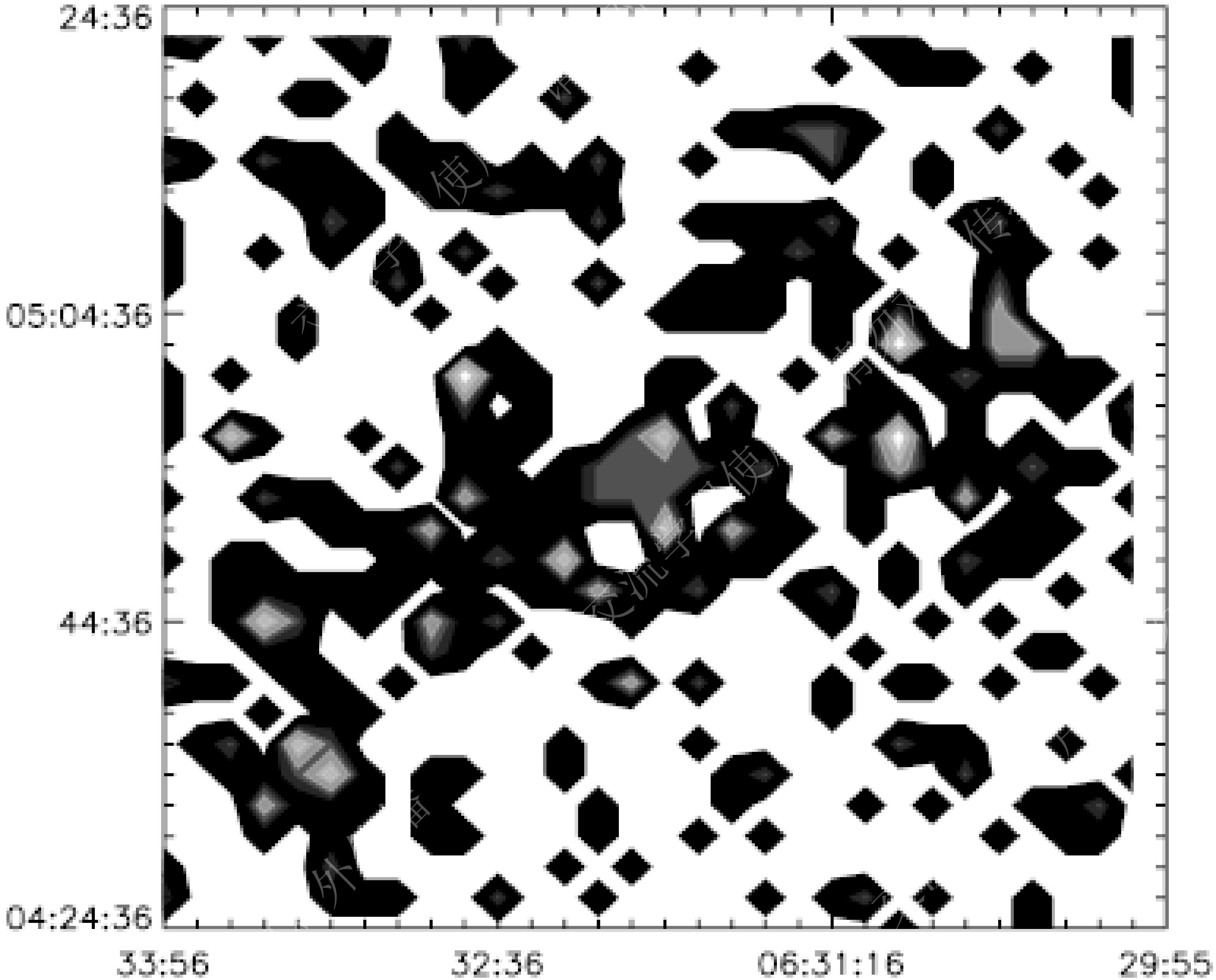
Is NGC 2244 a *twin* cluster ?

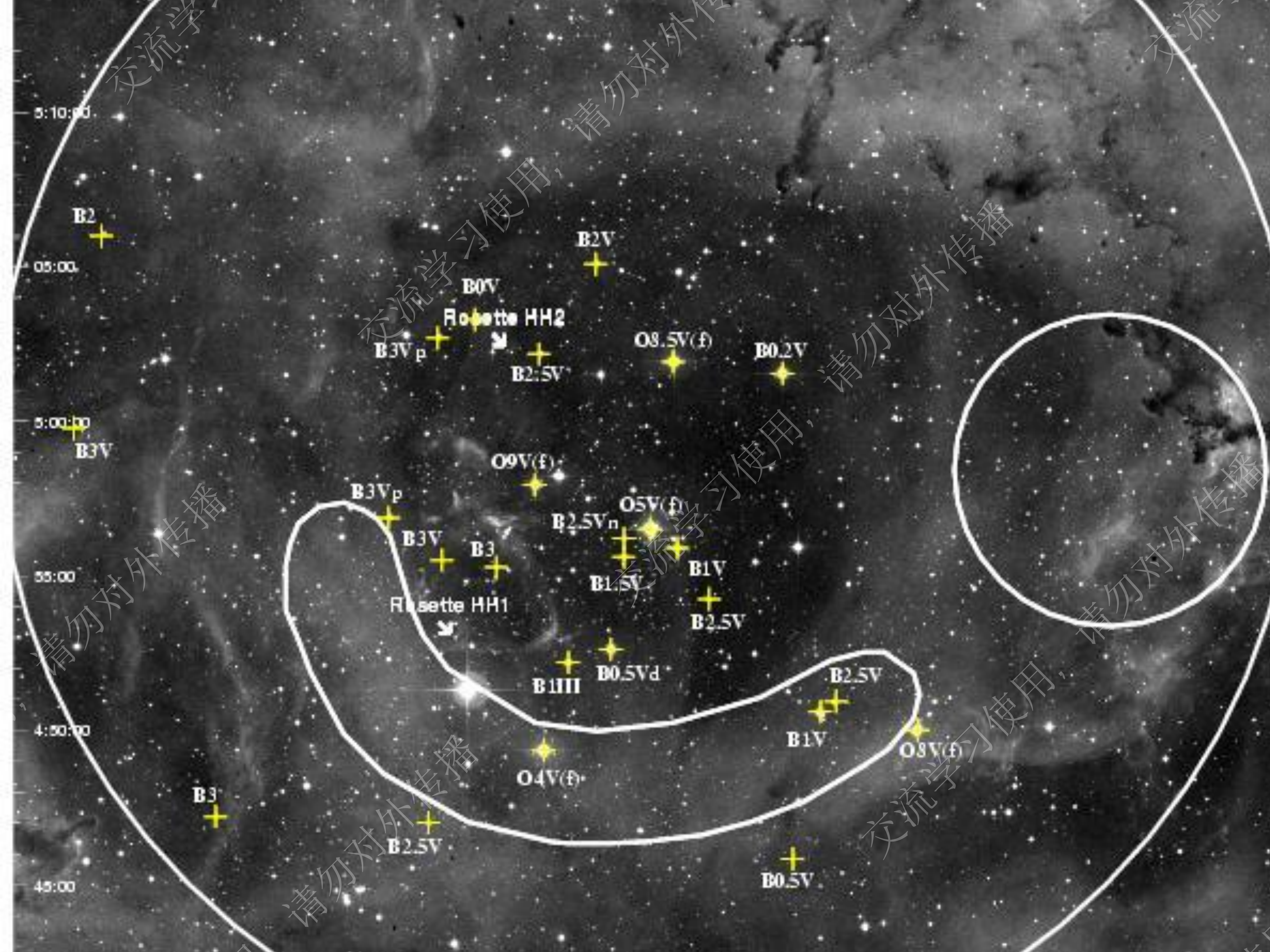


Radial profile of the subclusters

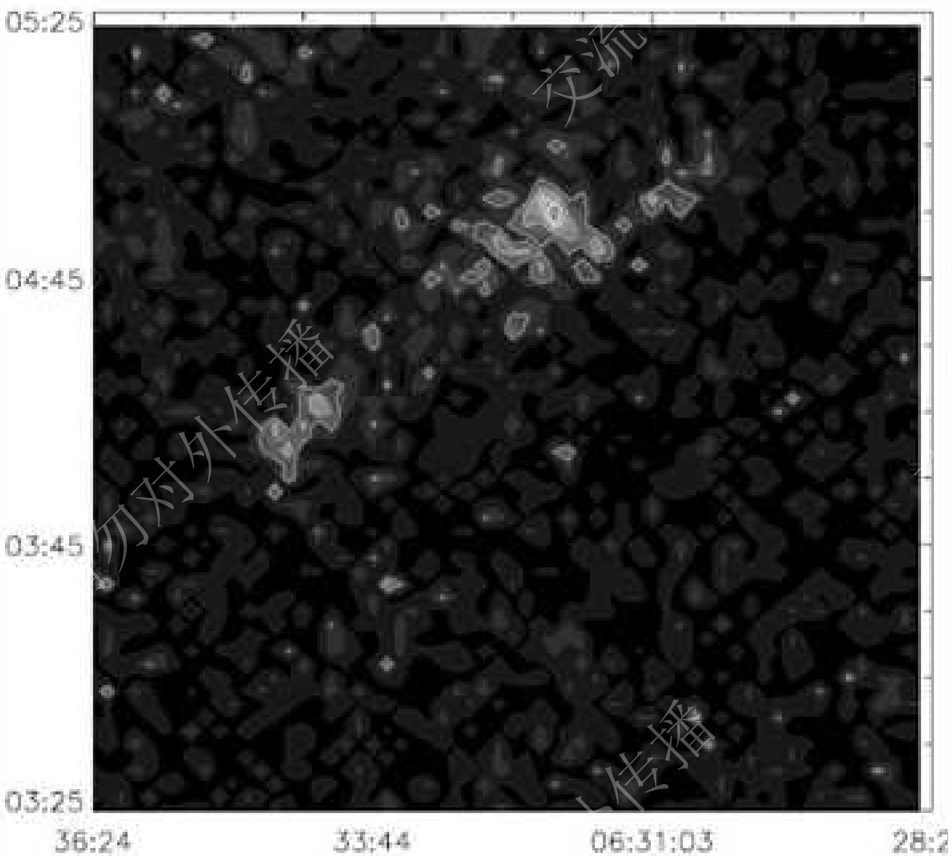


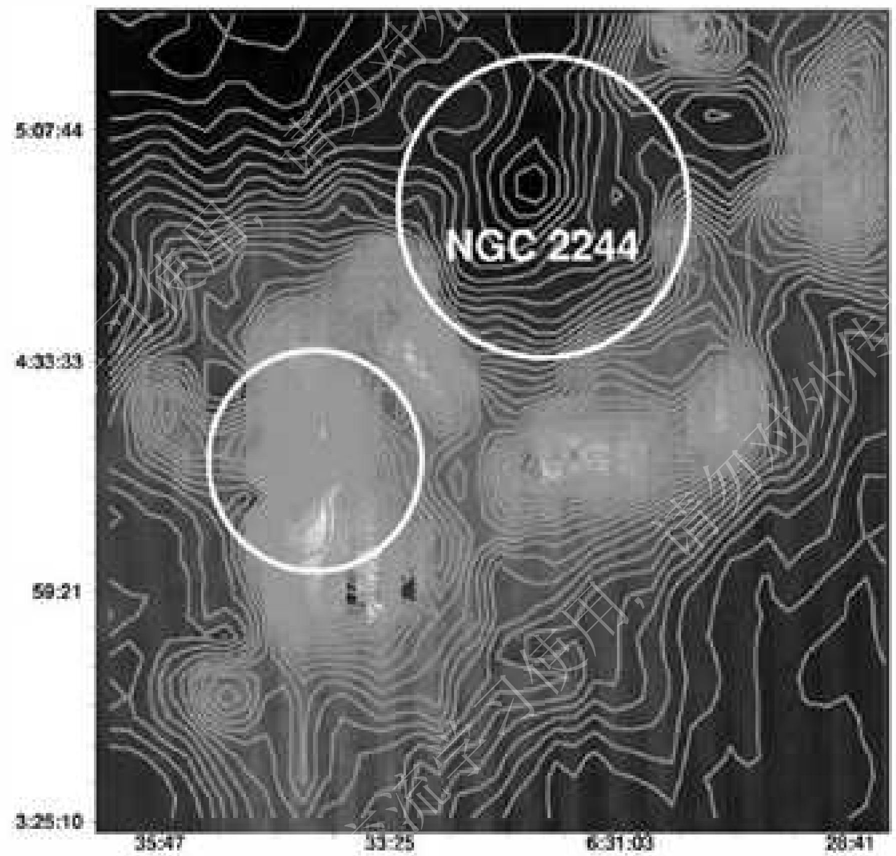



24:36
05:04:36
44:36
04:24:36
33:56
32:36
06:31:16
29:55

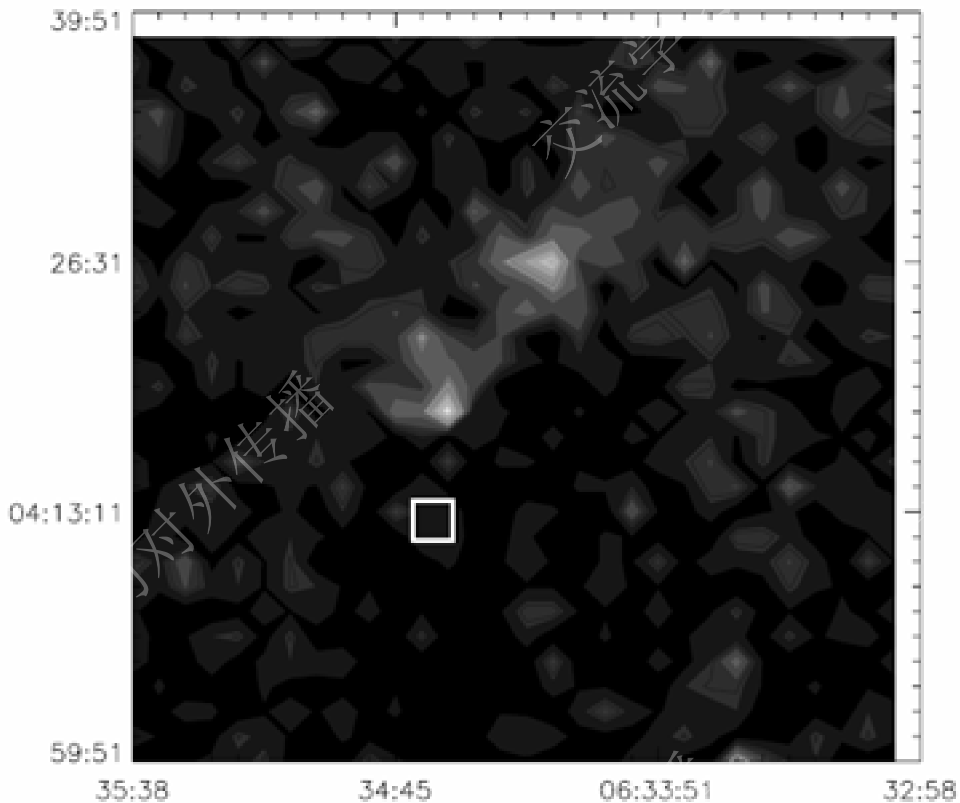

5:10:00
05:00
5:00:00
55:00
4:50:00
45:00
B2
B2V
B0V
Rosette HH2
B3V p
B2.5V
O8.5V(f)
B0.2V
B3V
O9V(f)
B3Vp
O5V(f)
B2.5Vn
B3V
B3
B1V
B1.5V
B2.5V
Rosette HH1
B1III
B0.5Vd
B2.5V
B1V
O8V(f)
O4V(f)
B3
B2.5V
B0.5V

Clustered Star Formation in the Densest Ridge of the RMC

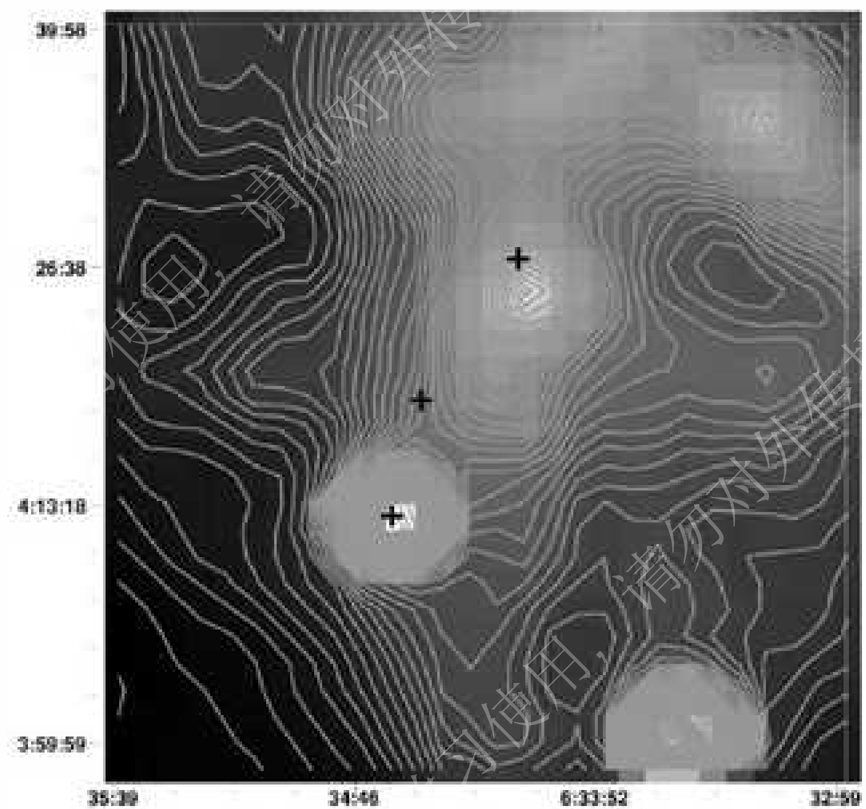




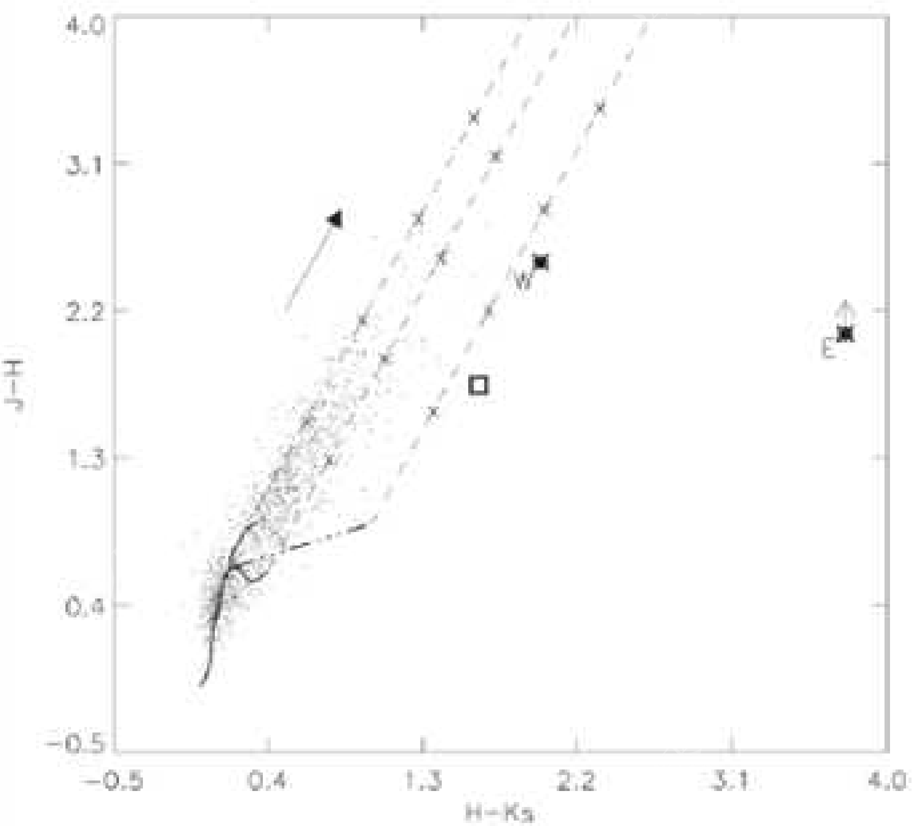
Stellar Density Distribution

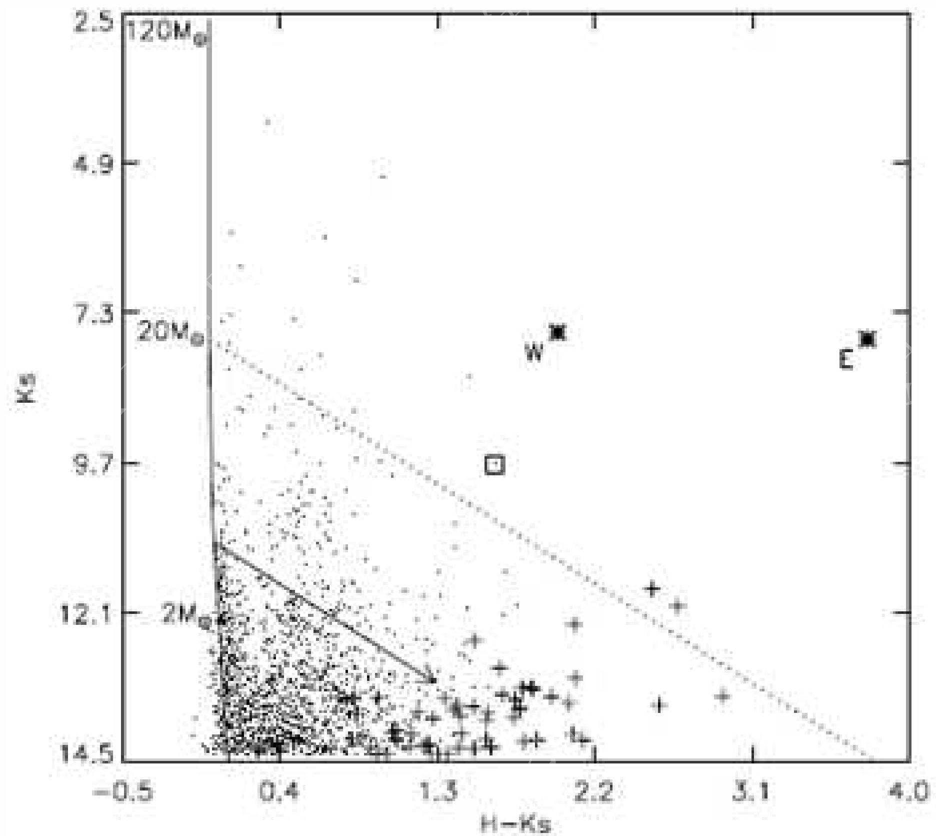


ISSA 100 μm emission

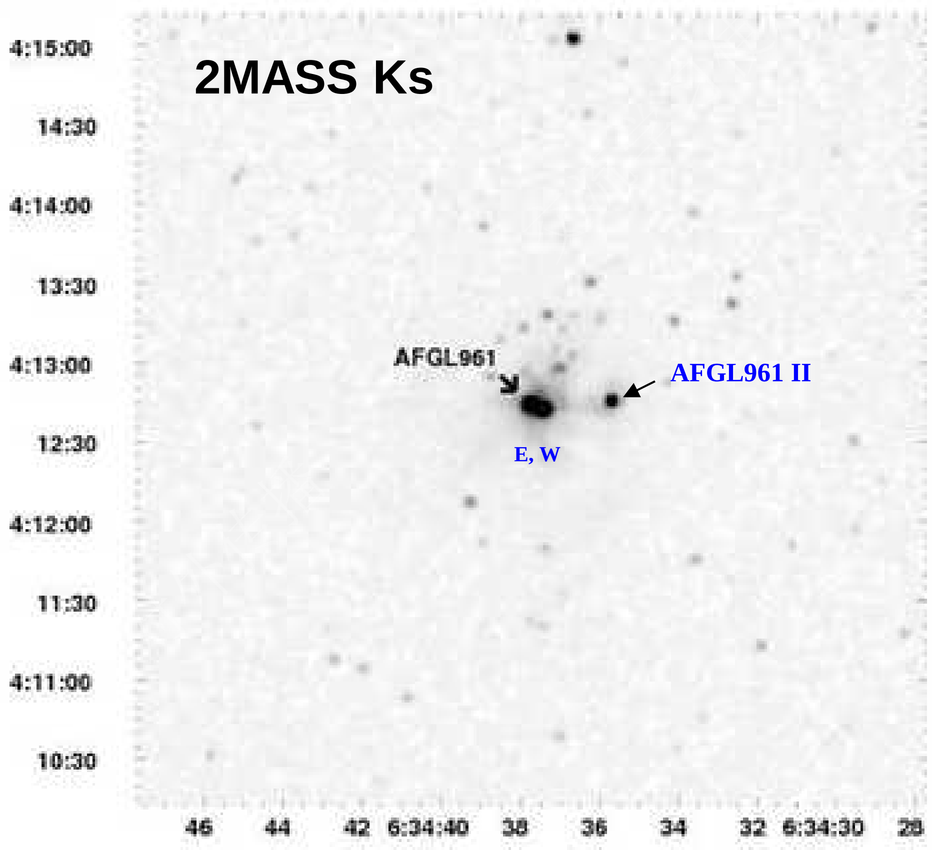


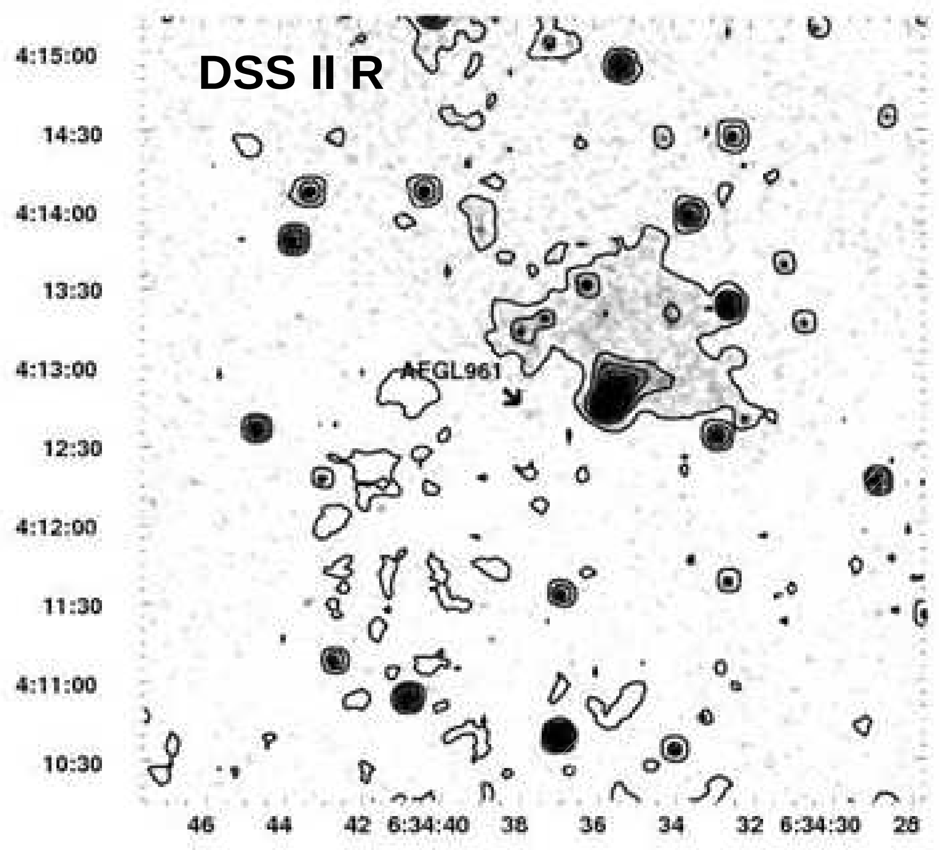
CCD & CMD of the massive proto-clusters in the densest ridge





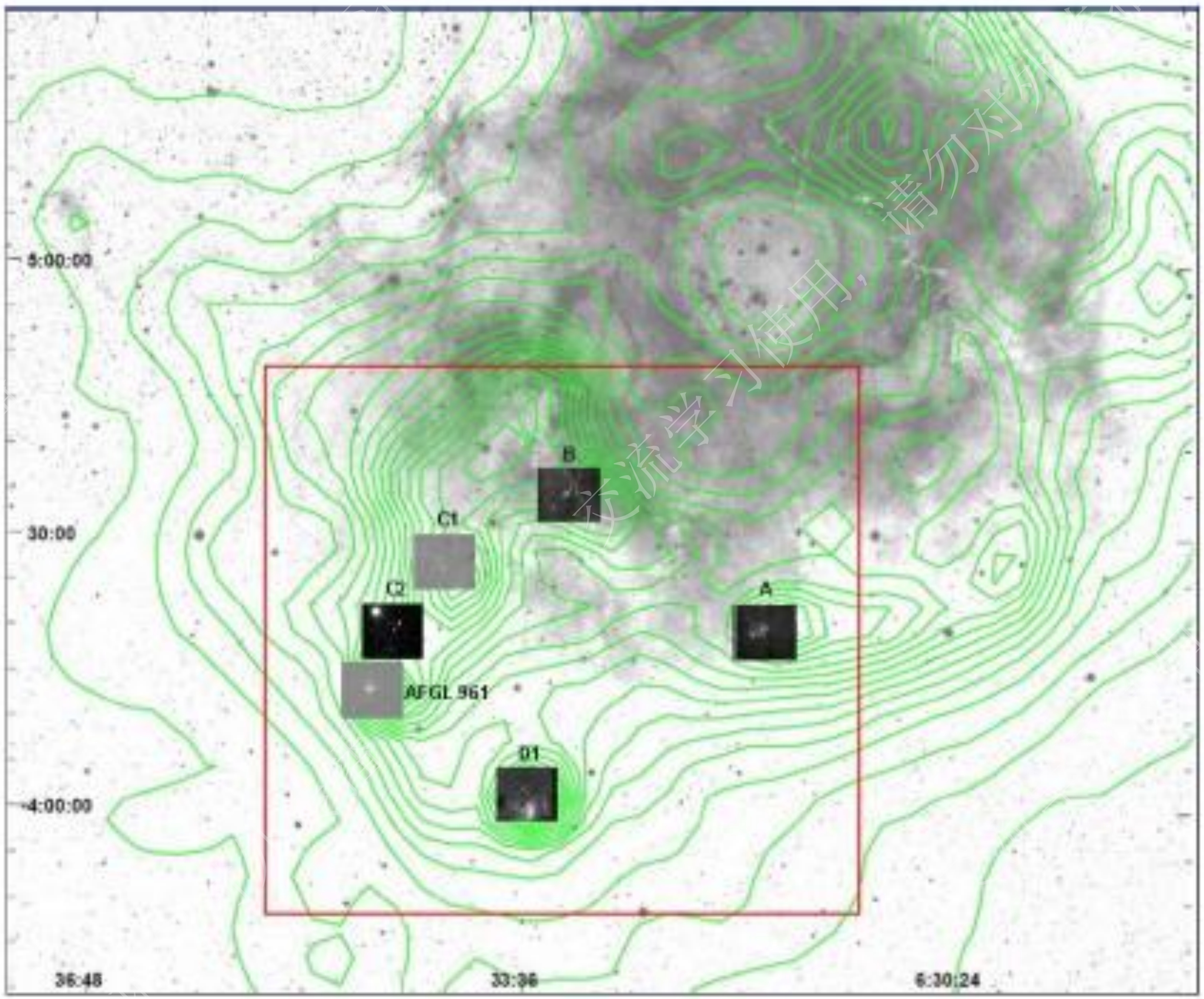
The AFGL 961 System

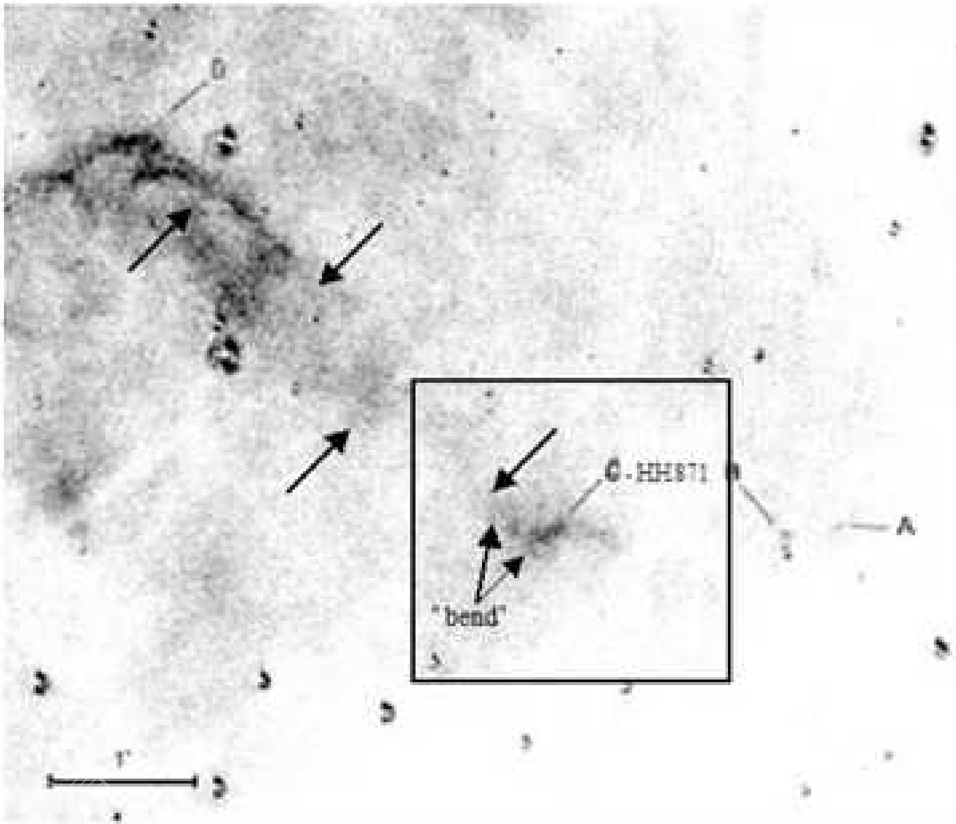




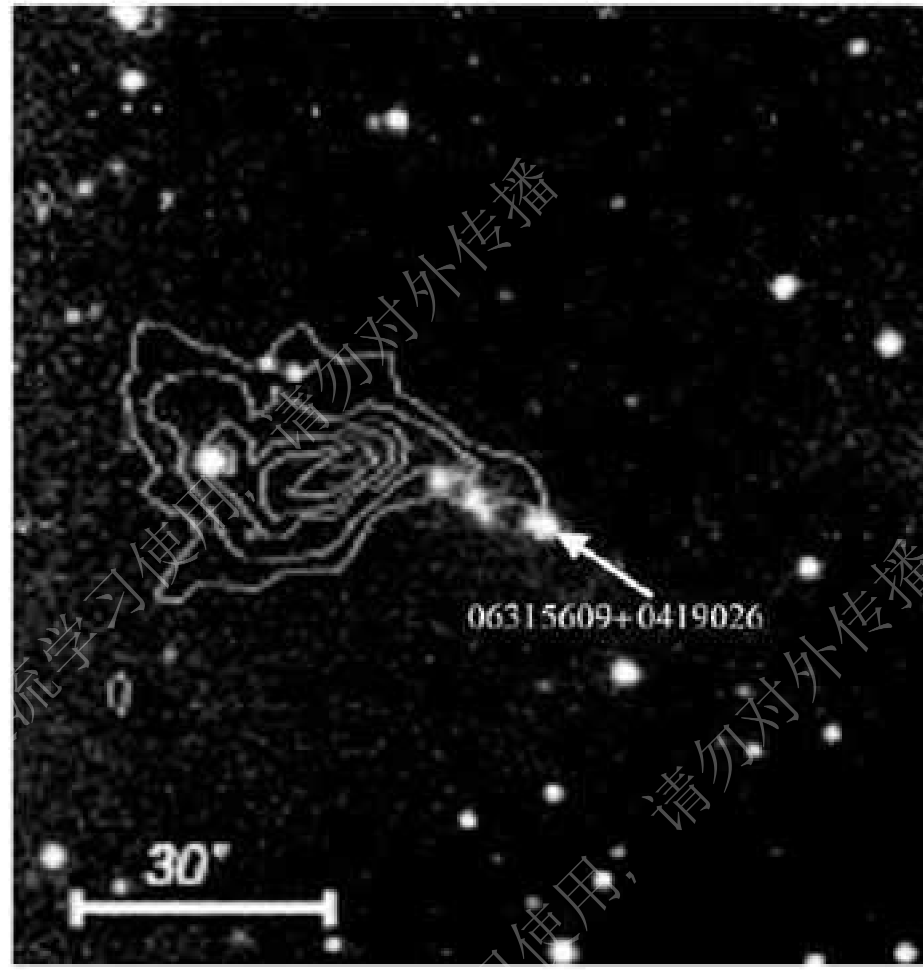
Li & Smith, 2005, AJ 130, 721

An Extensive Search for H2 flows in the RMC





Ybarra & Phelps, 2004, AJ 127, 3444



Phelps & Ybarra, 2005, ApJ 627, 845

Intent of investigations

- Protostellar obejcts are, in most cases, deeply embedded and enshrouded by heavy foreground extinction → early stages of star formation remain notoriously illusive.
- The critical growth period of massive stars lasts only tens of thousands yrs but is usually accompanied by spectacular ejections of gas in opposite directions.
- Molecular outflows – tracer of early stages of stellar evolution

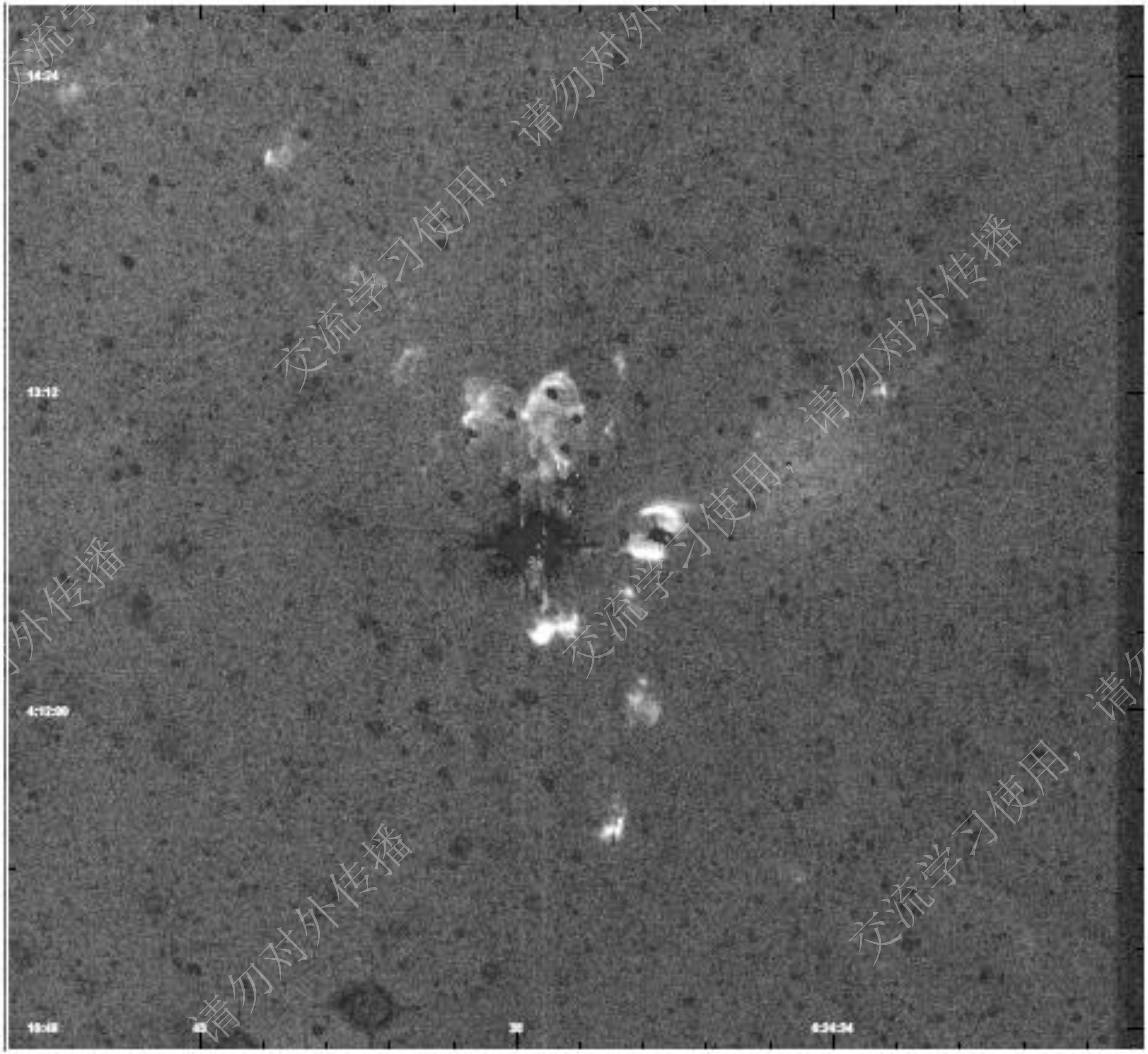
Observations

- **NIR imaging & spectroscopy**
  - NTT + SOFI JHKs & H_2 1-0 S(1) imaging

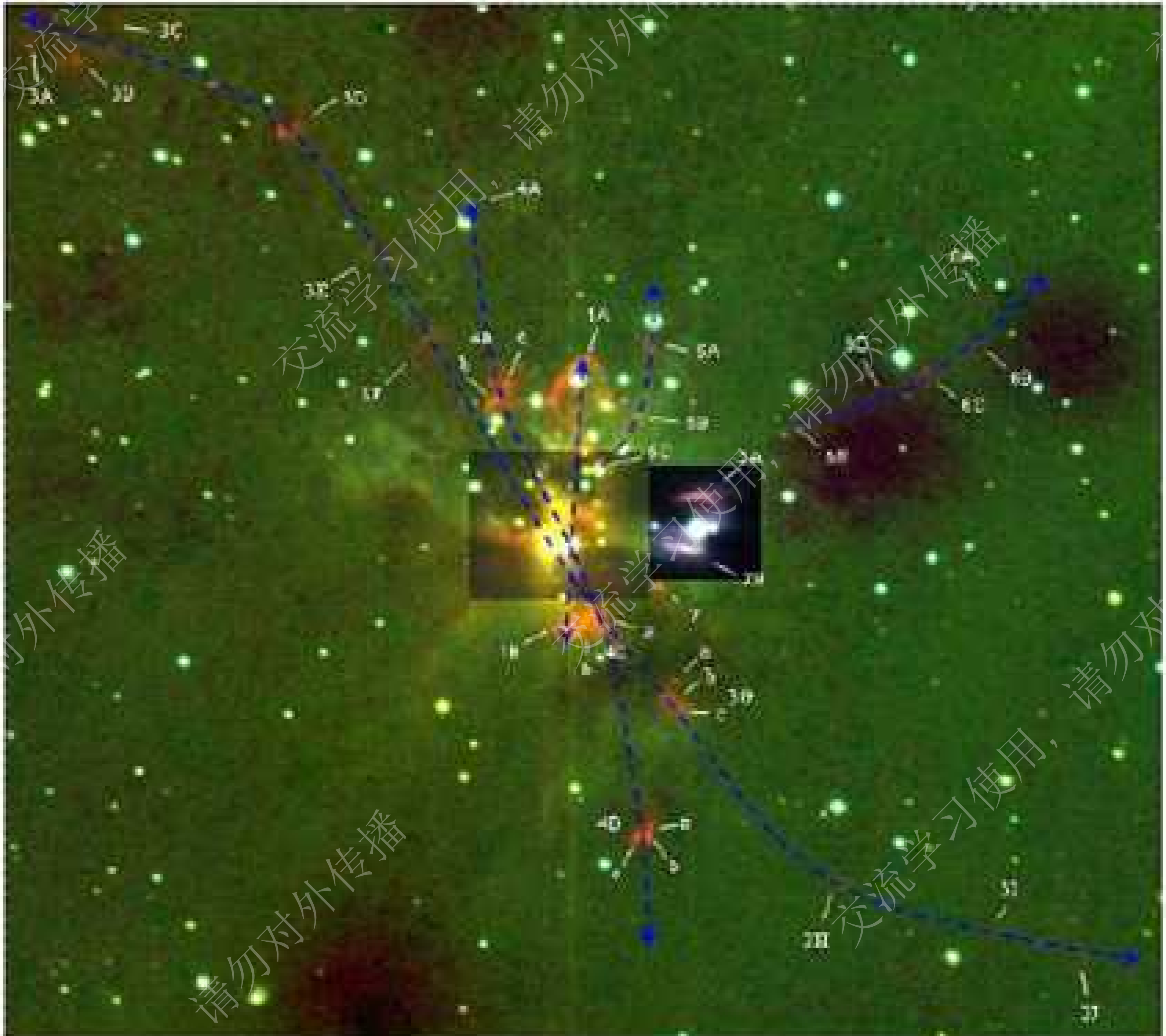
    + medium-res. (R~2200) spectroscopy
  - UKIRT + CGS4 Ks echelle spectroscopy

- **Optical imaging & spectroscopy**
  - KPNO 4m + Mosaic I H**α** & [SII] imaging

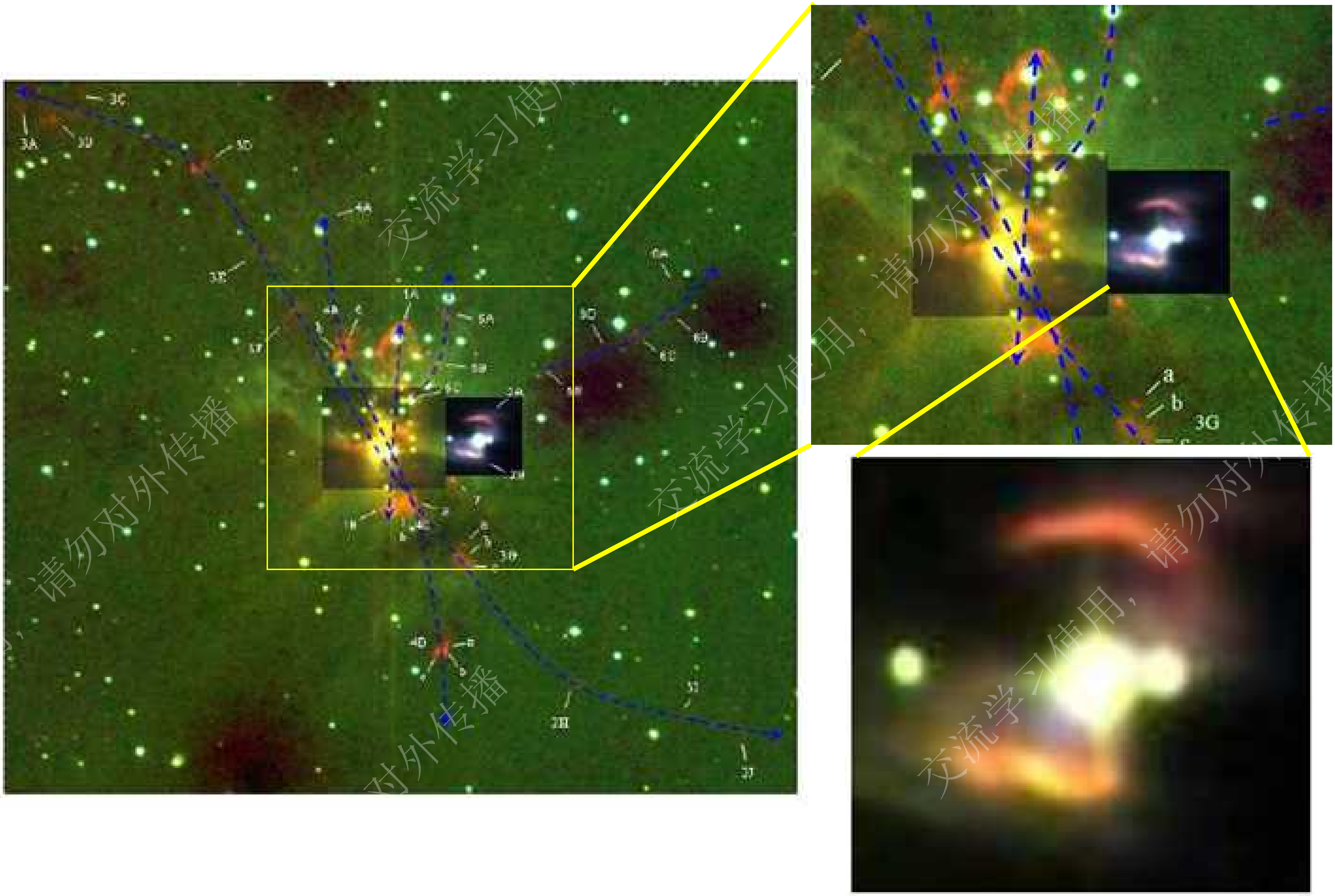
    pixel scale: 0.258” $pixel^{-1}$; seeing: 0.9”
  - NAOC 2.16 m +OMR medium-res. spectro.



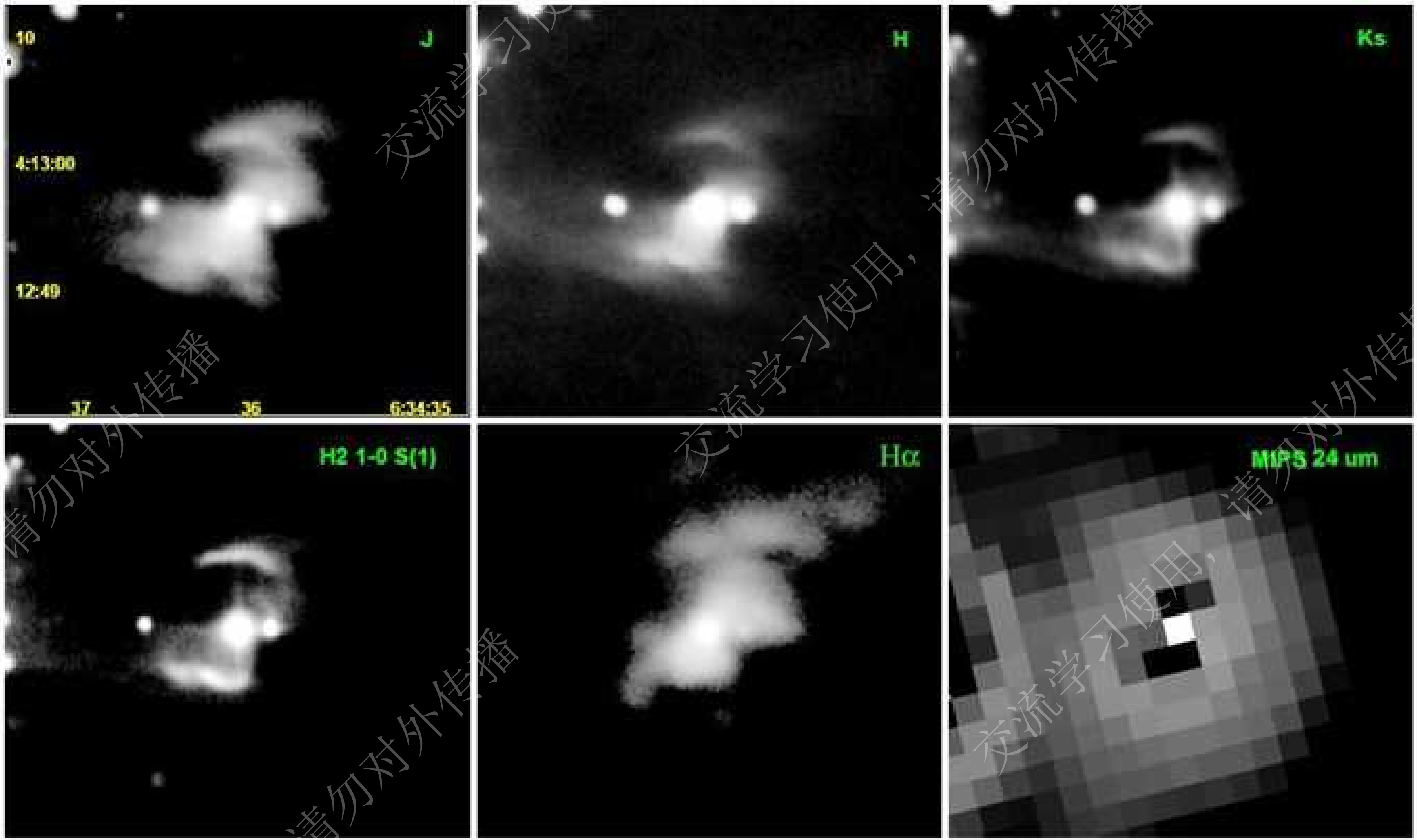
14:24
13:12
4:12:00
10:48
45
30


3C
3A
3D
4A
1A
5A
4D
2B

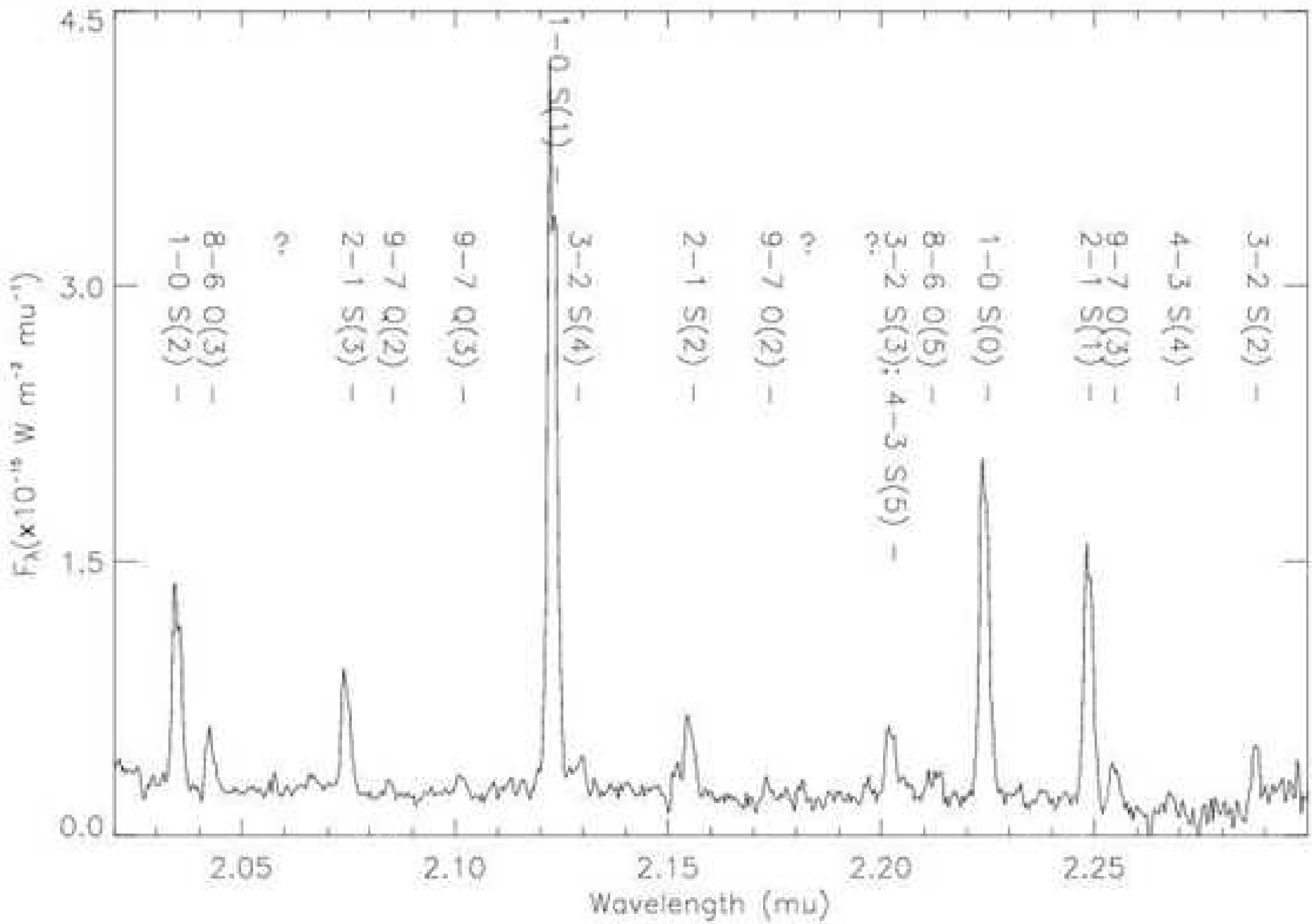
Multi-outflows associated with AFGL 961



Appearance of the Eye at different wavelength



NTT Ks-band spectroscopy



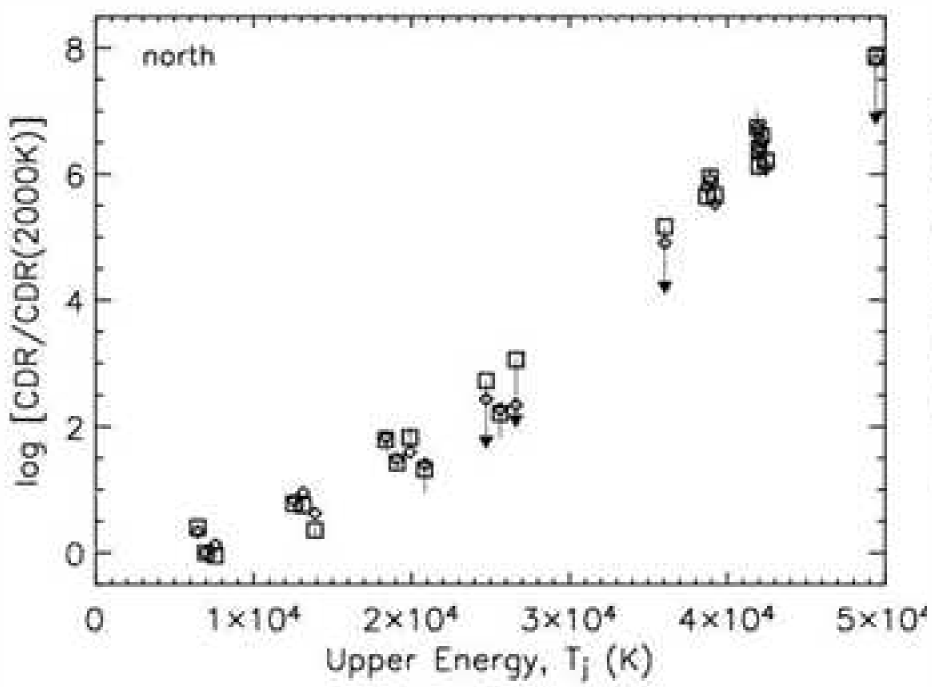
Line fluxes derived from the NTT SOFI data for the north and south rims

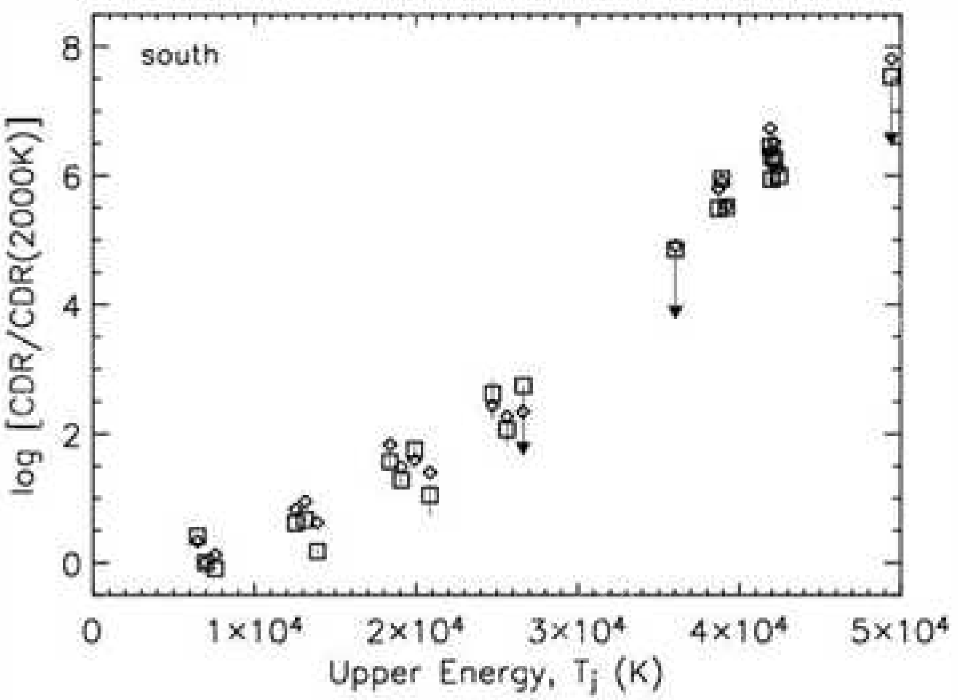
Line	wavelength (μm)	flux South	flux North	Line	wavelength (μm)	flux South	flux North
1 – 0 S(2)	2.033	38.60	20.70	4 – 3 S(6)	2.146	< 2.00	< 2.00
8 – 6 O(3)	2.041	10.30	7.04	2 – 1 S(2)	2.154	18.20	10.82
3 – 2 S(5)	2.065	3.89	3.49	9 – 7 O(2)	2.172	3.36	3.12
12 – 9 O(3)	2.069	< 3.00	< 3.00	3 – 2 S(3)	2.201	16.50	10.80
9 – 7 Q(1)*	2.073			4 – 3 S(5)*	2.201		
2 – 1 S(3)	2.073	20.30	14.80	8 – 6 O(5)	2.210	9.91	6.76
9 – 7 Q(2)	2.084	3.09	3.36	1 – 0 S(0)	2.223	69.40	32.50
9 – 7 Q(3)	2.100	5.59	4.39	2 – 1 S(1)	2.247	43.70	30.40
7 – 5 O(6)	2.108	< 3.5	< 3.5	9 – 7 O(3)	2.253	10.20	6.17
8 – 6 O(4)†	2.121	10.35	5.00	4 – 3 S(4)	2.268	4.95	< 3.00
1 – 0 S(1)†	2.121	127.65	61.60	3 – 2 S(2)	2.286	10.00	8.16
3 – 2 S(4)	2.127	10.30	5.85				

Units of 10^{-19} W m^{-2}. The 1σ flux measurement uncertainty is 2×10^{-19} W m^{-2} and 3.0 $\times$ 10^{-19} W m^{-2} beyond 2.25 μm. The 12-9 O(3) flux upper limit is subject to considerable error due to the location near a strong line.

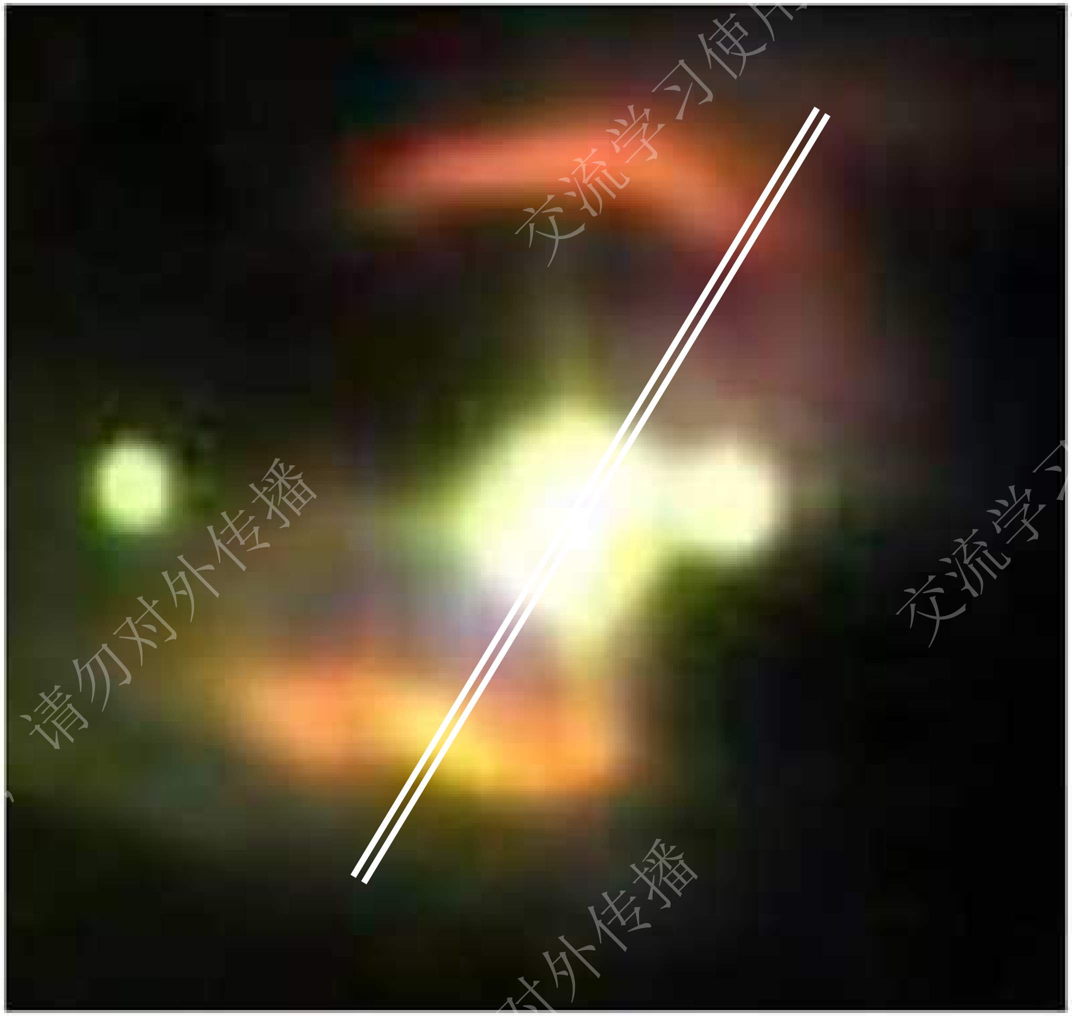
* – Line blended; no decomposition possible. † – relative line fluxes decomposed from echelle data in approximately the same regions.

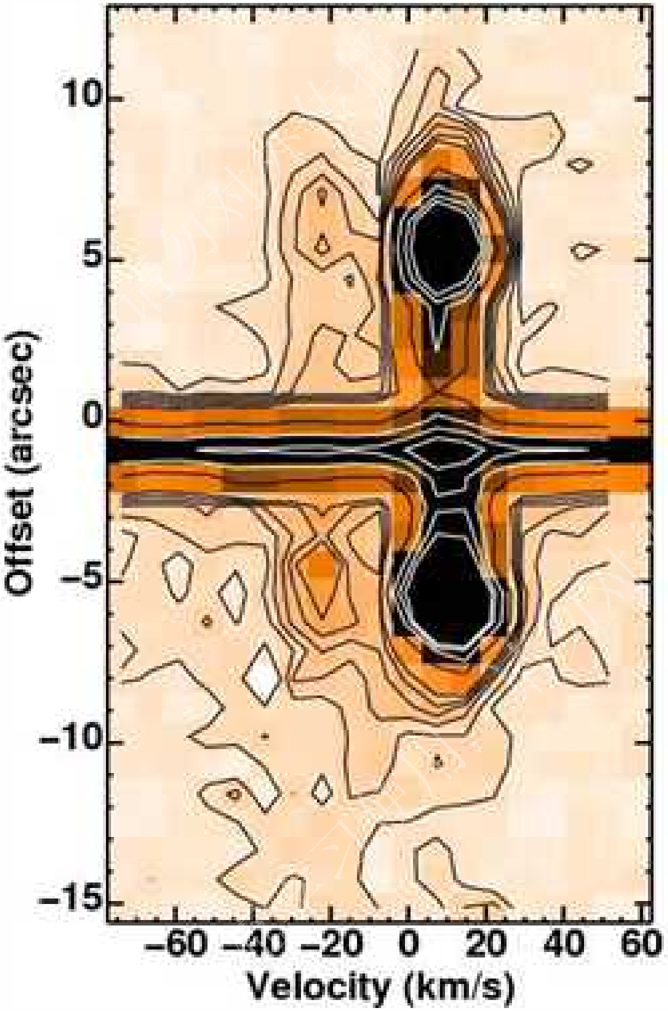
Fluorescence confirmed by simulation based on the observed line ratios





UKIRT echelle spectroscopy



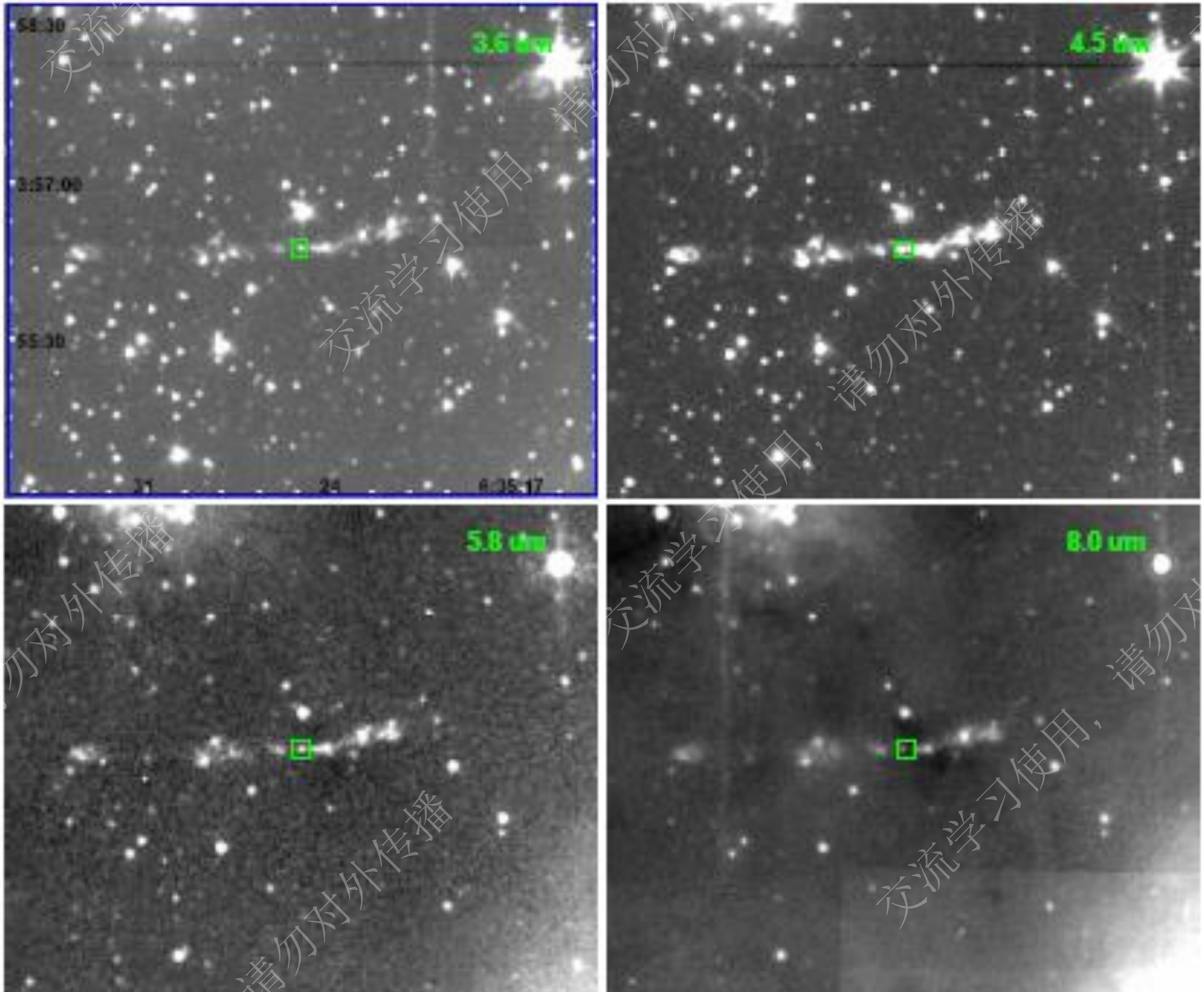


Implications on the discovery the Rosette Eye

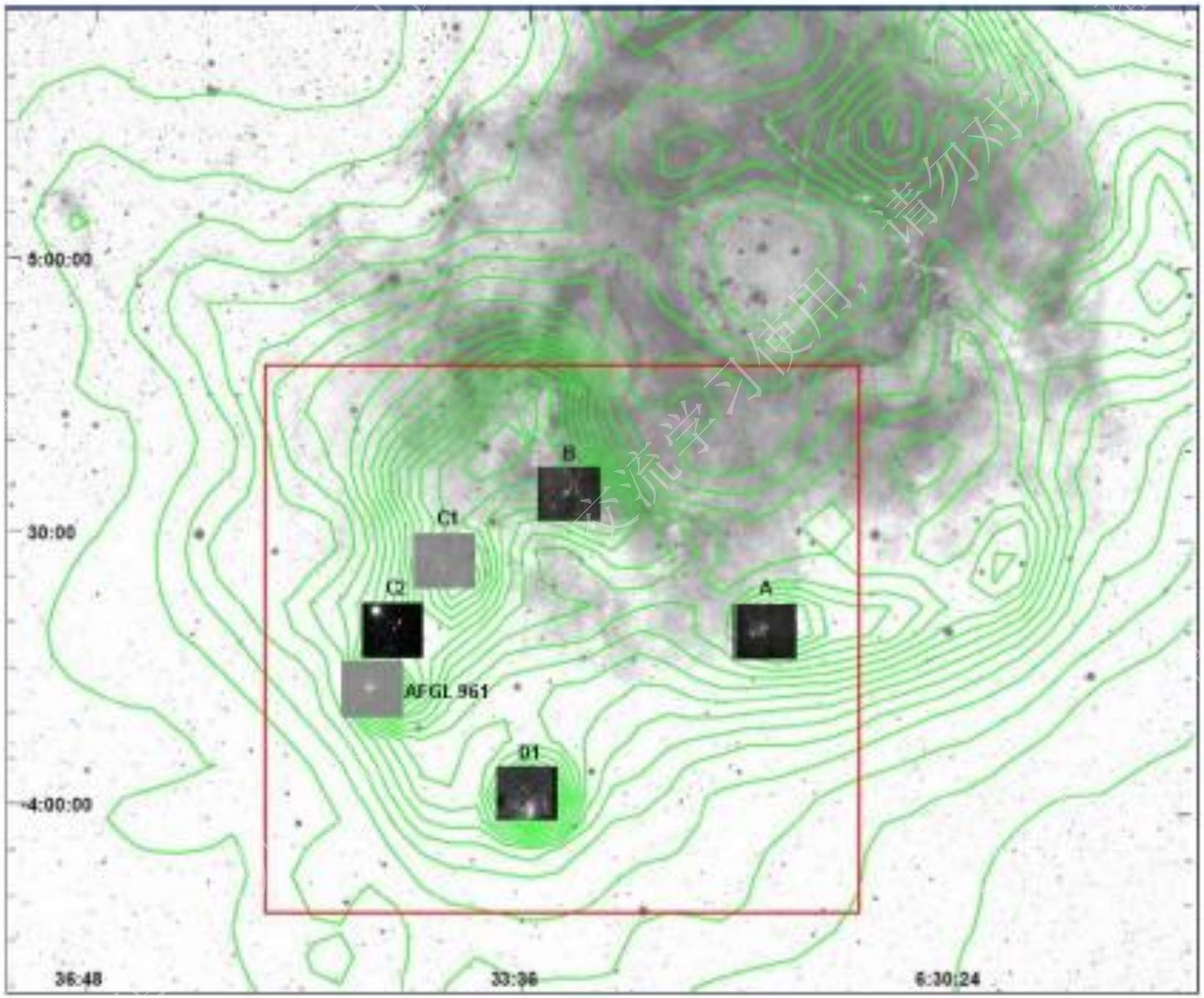
- Young massive stars ($M>10M_{\odot}$) have strong impacts on their surroundings
- Fast evolution and disk dissipation: $<10^5$ yrs
- AFGL961 II, the Rosette Eye →

  a key transition phase in its emergence
- Emerging ionized flows blow out an hourglass shaped nebula
- Caped with static, fluorescent H_2 emission arcs →

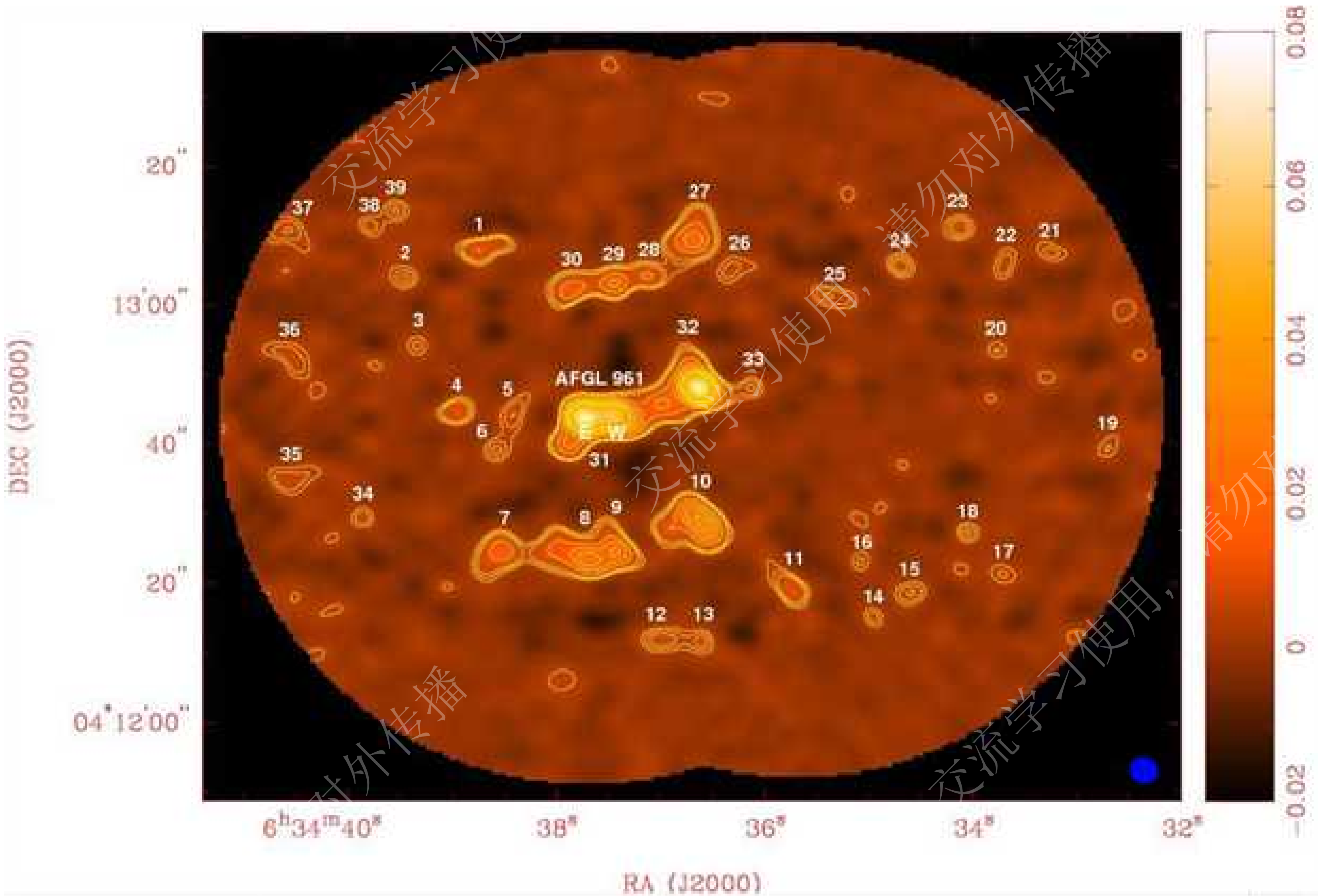
  Onset of UV radiation
- Implications on how massive stars embark on thei formation


3.6 um
4.5 um
5.8 um
8.0 um
58:30
3:57:00
55:30
21
24
6:35:17

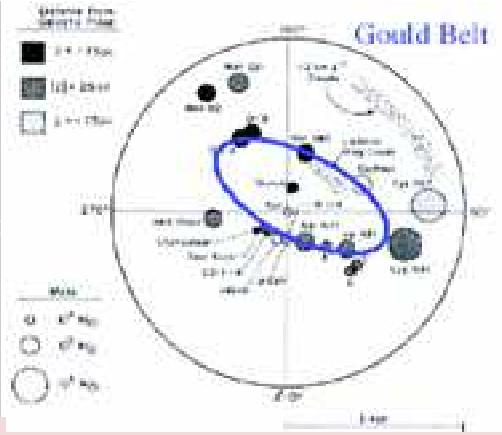
A dearth of H_2 flows in the RMC



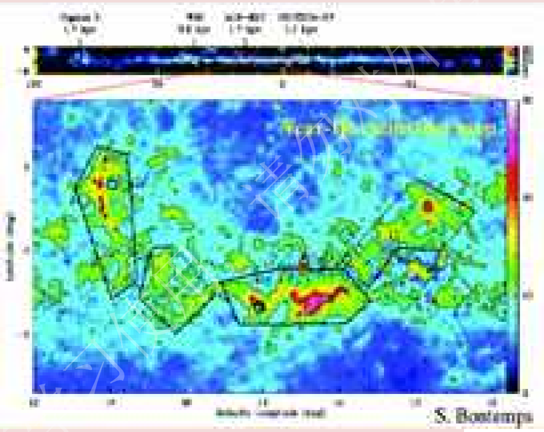
SMA study of AFGL 961



Herschel GT Key Programs on SF

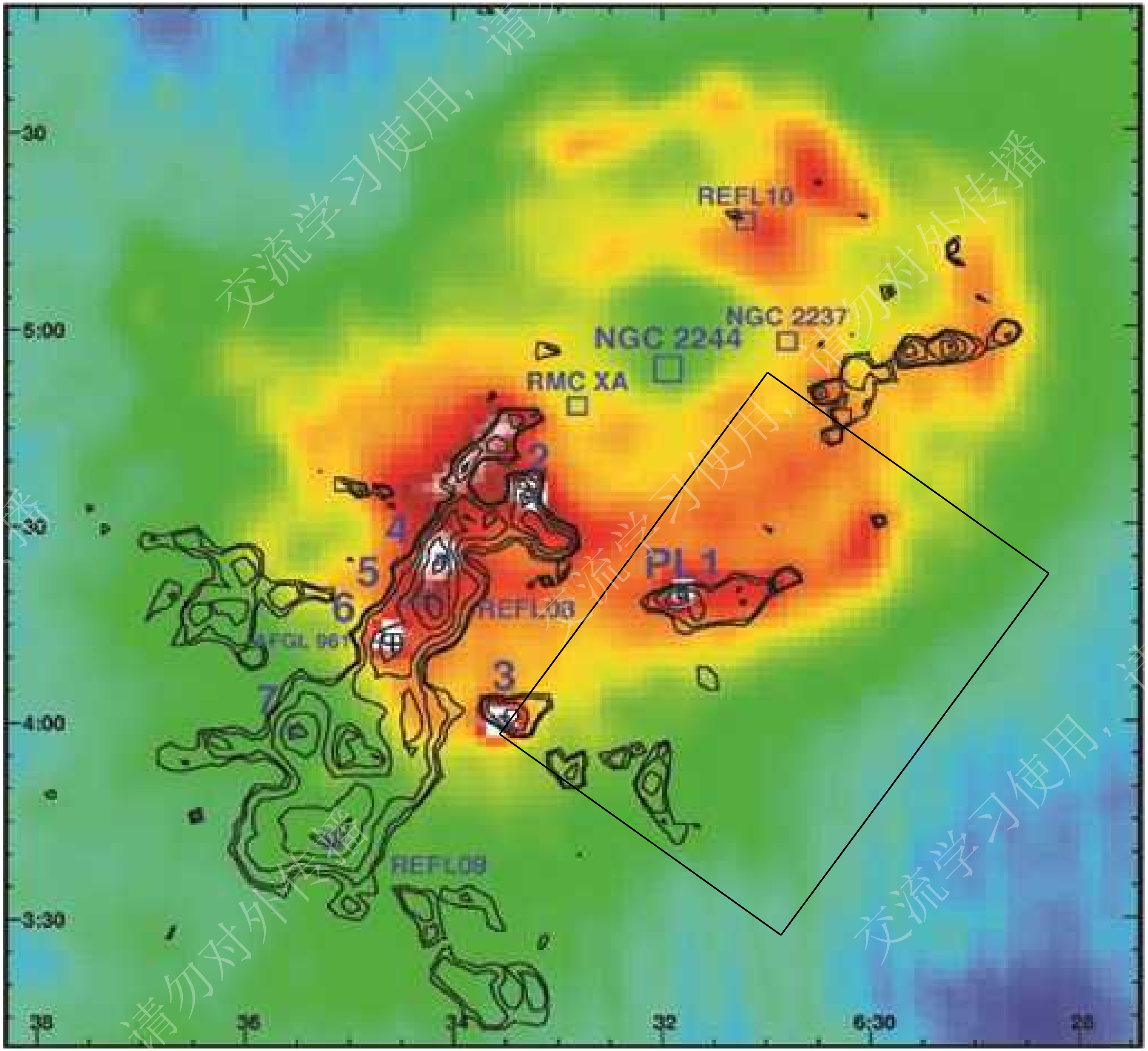


A complete census of prestellar cores and protostars in the Gould Belt regions (< 500 pc) down to a mass limit of 0.01 – 0.1 $M_{\odot}$. All 461 hrs. (Accurate Mass, Luminosity, Temperature, lifetimes)

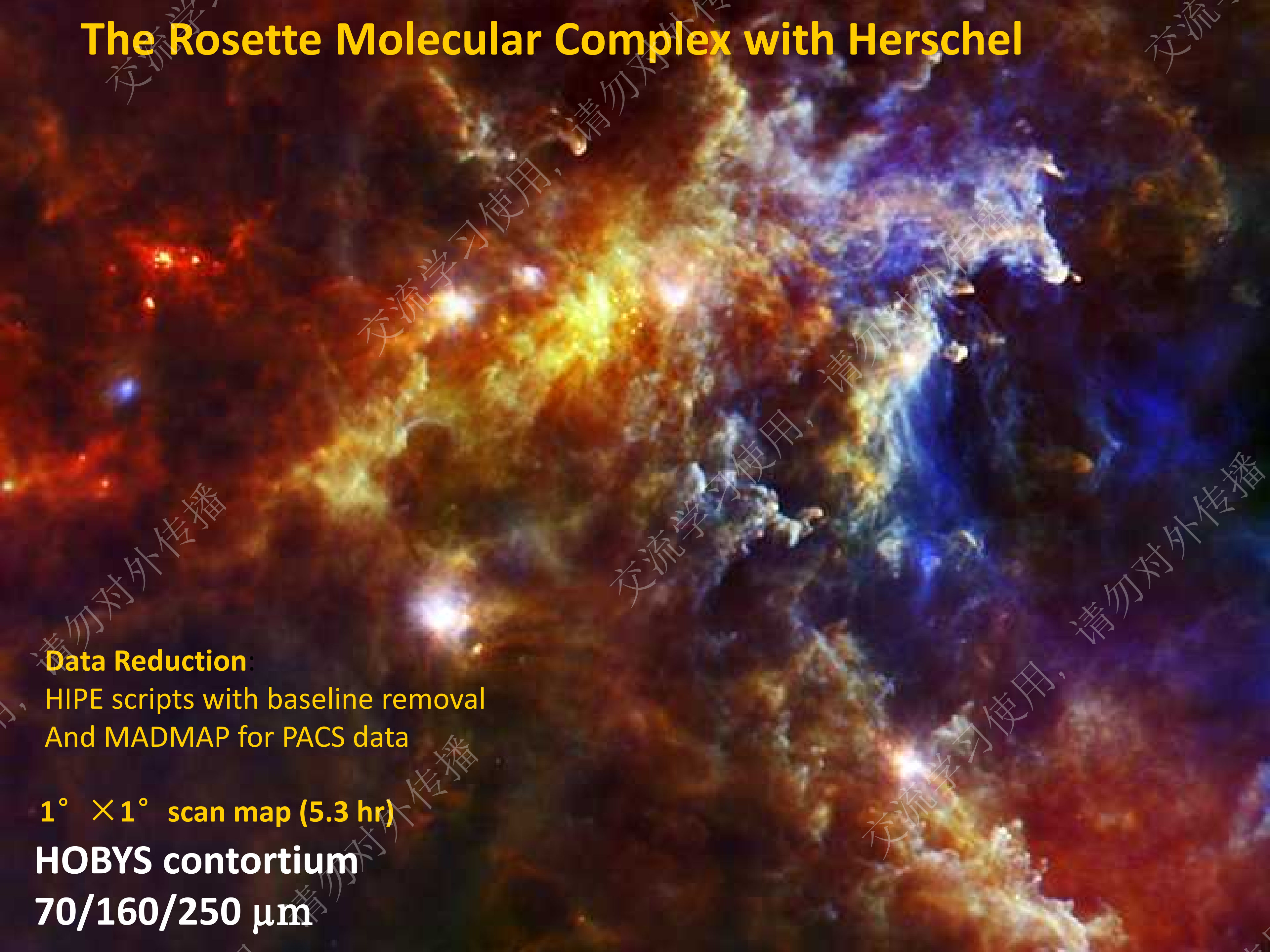


A systematic survey of essentially all massive SF regions within 3 kpc. An unbiased census of OB star precursors at all evolutionary stages. All 125 hrs.

The Herschel SDP fields of HOBYS



The Rosette Molecular Complex with Herschel

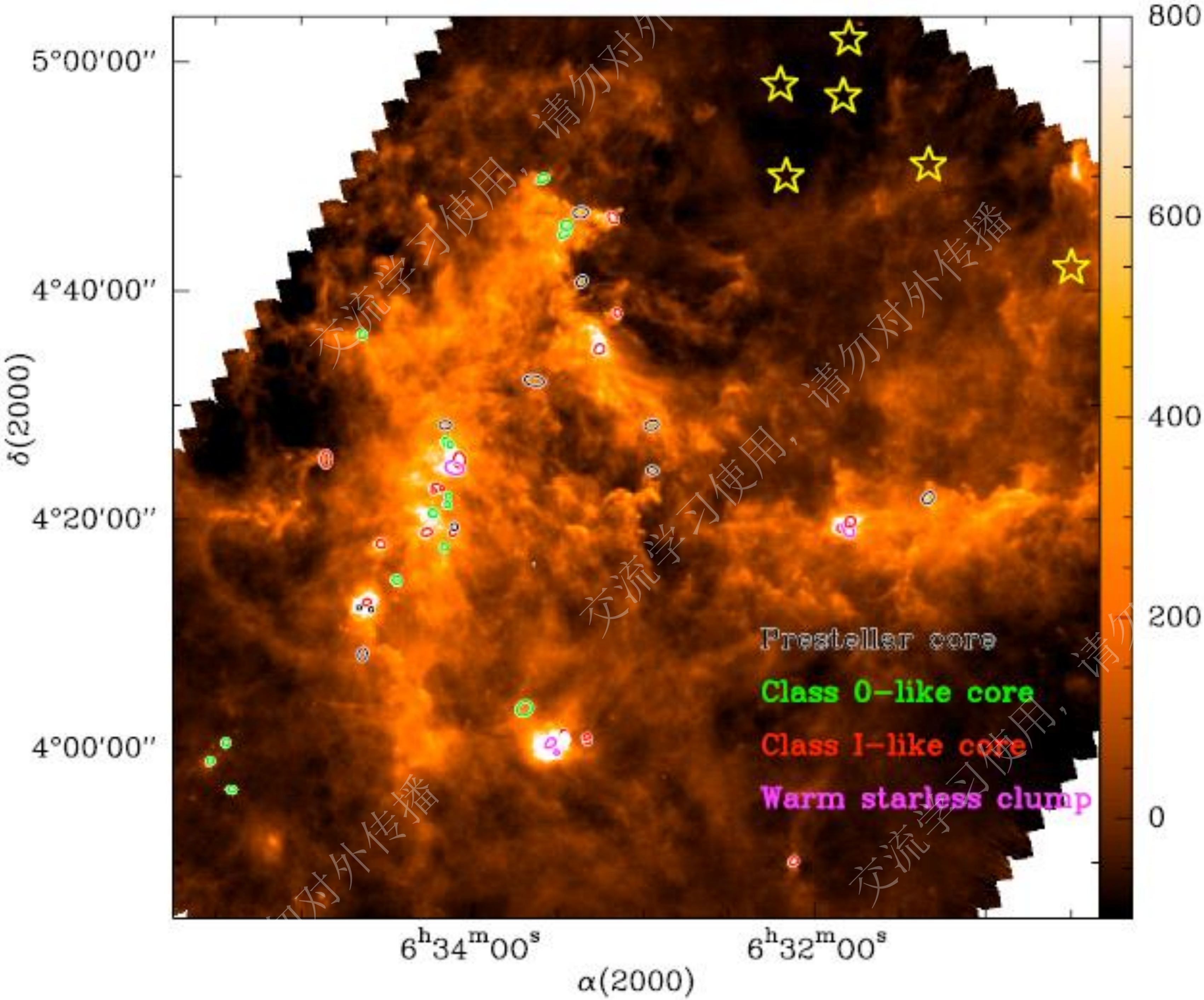


Data Reduction:
HIPE scripts with baseline removal
And MADMAP for PACS data

1° ×1° scan map (5.3 hr)

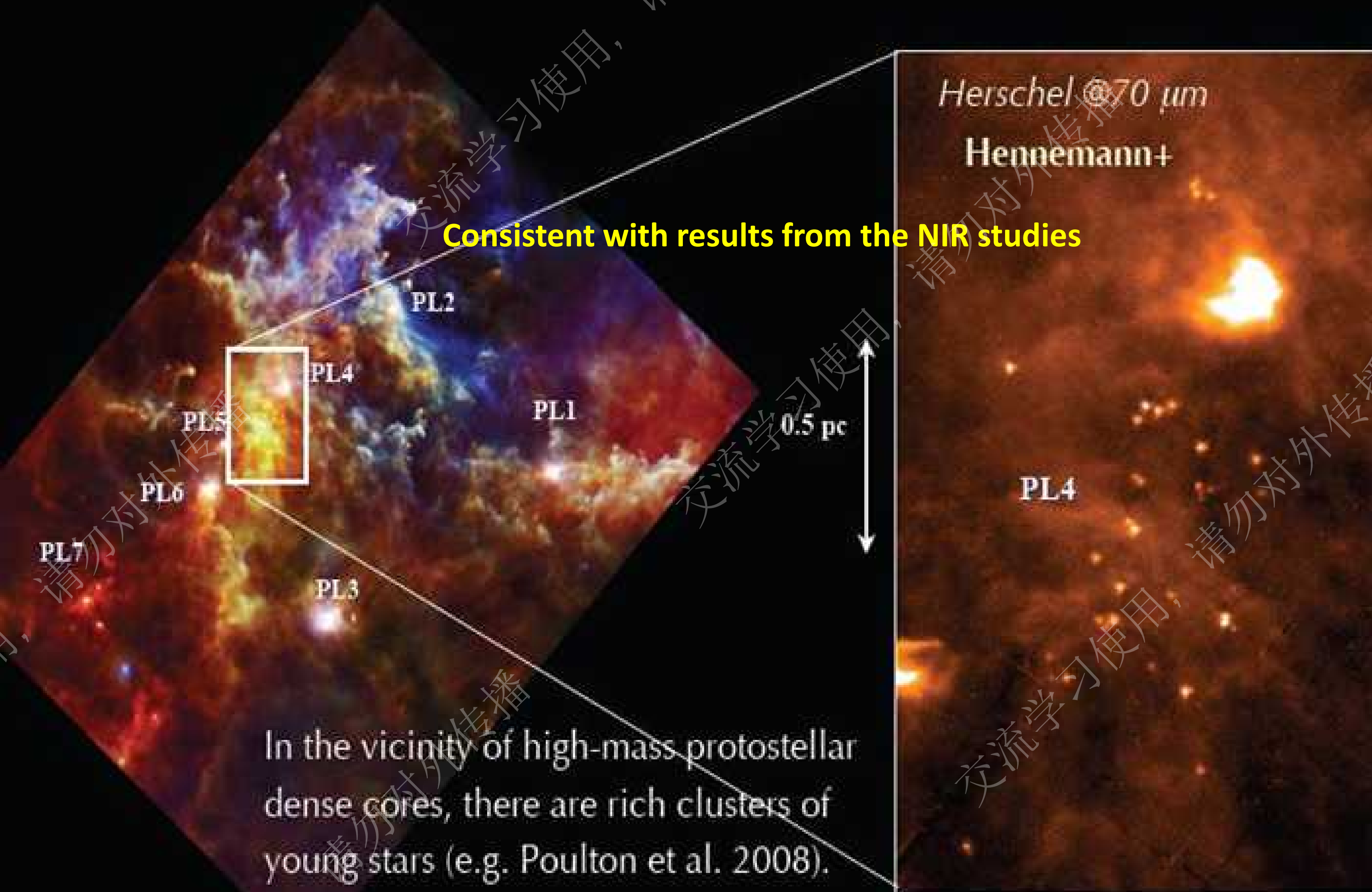
HOBYS contortium

70/160/250 μm



800
600
400
200
0
5°00'00"
4°40'00"
4°20'00"
4°00'00"
δ(2000)
6h34m00s
6h32m00s
α(2000)
Prestellar core
Class 0-like core
Class I-like core
Warm starless clump

Rich clusters of protostars in the Rosette



Consistent with results from the NIR studies

In the vicinity of high-mass protostellar dense cores, there are rich clusters of young stars (e.g. Poulton et al. 2008).


Thanks!