Mapping Cometary Comae with the SMA

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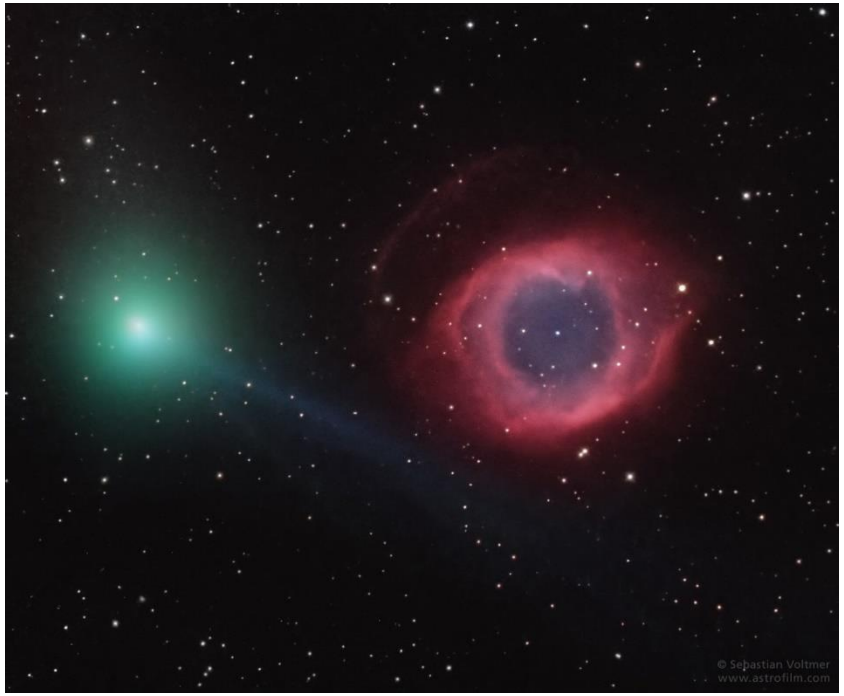
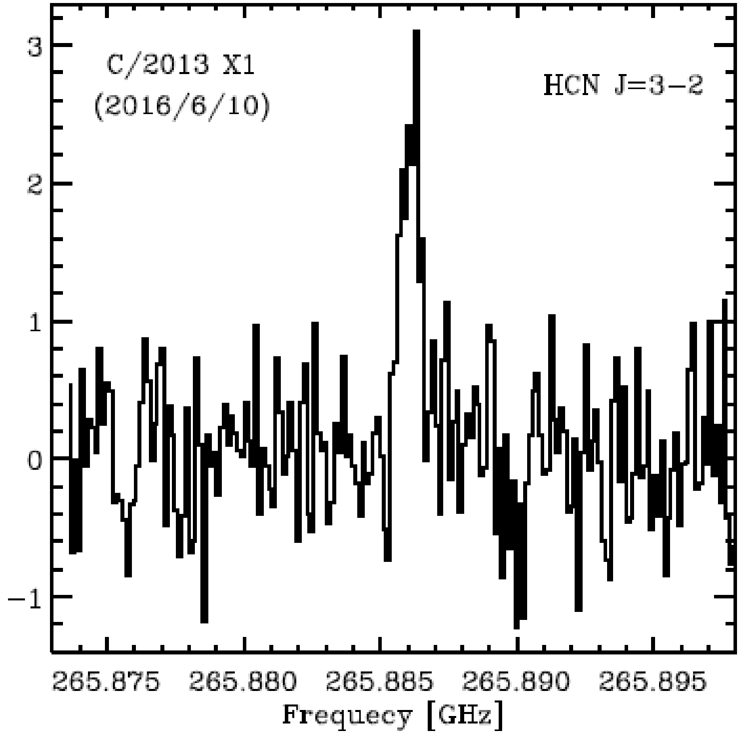
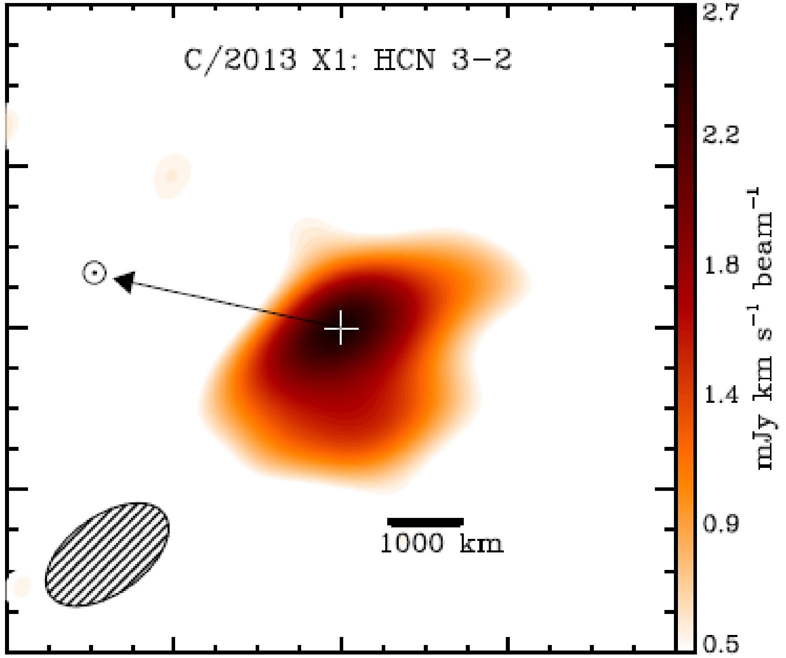
Harvard-Smithsonian CfA





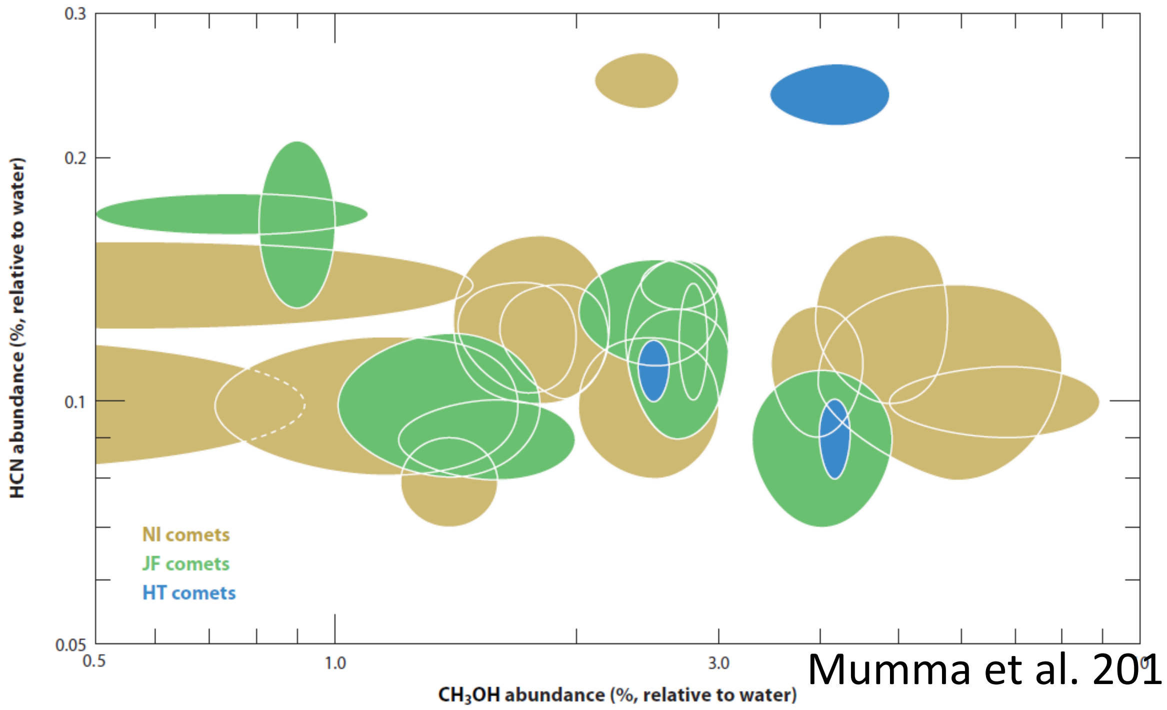


Comets - origin

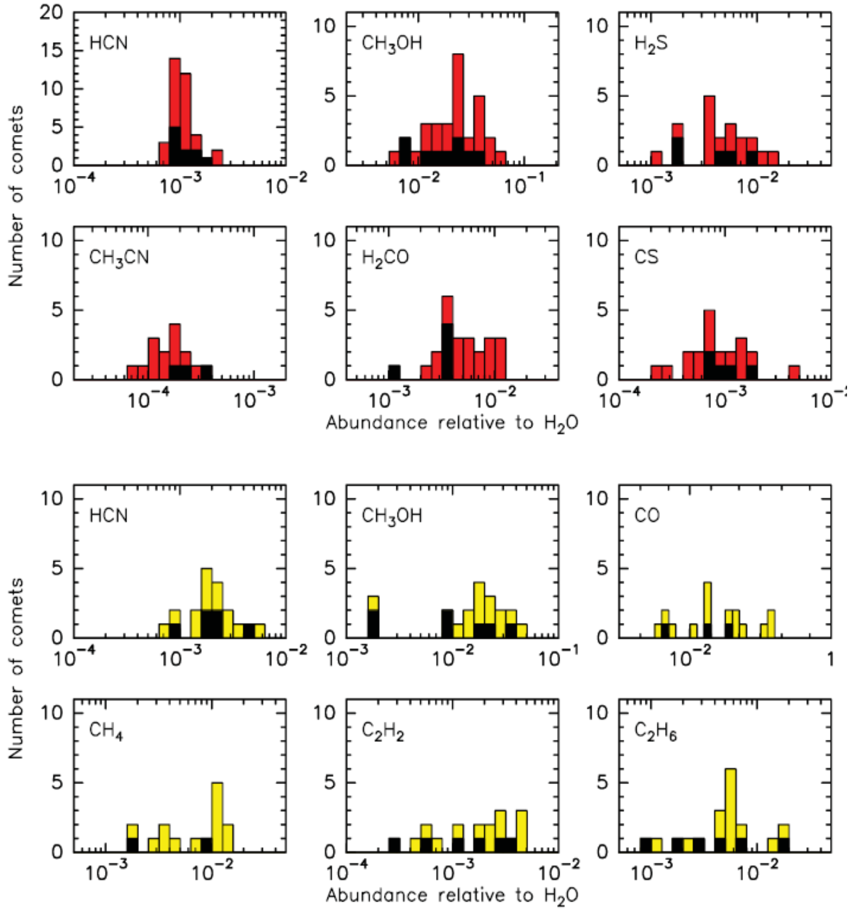
- Main cometary reservoirs
  - the Oort Cloud
  - the Kuiper Belt
- Dynamical classes
  - nearly isotropic (long-period or Halley-type)
  - ecliptic (Centaur-type, Encke-type or Jupiter-family)
- Theory of dynamical transport

Composition difference between families

- HCN as proxy for water, CO varies a lot
- No obvious correlation observed between the hypervolatile and the dynamical class.



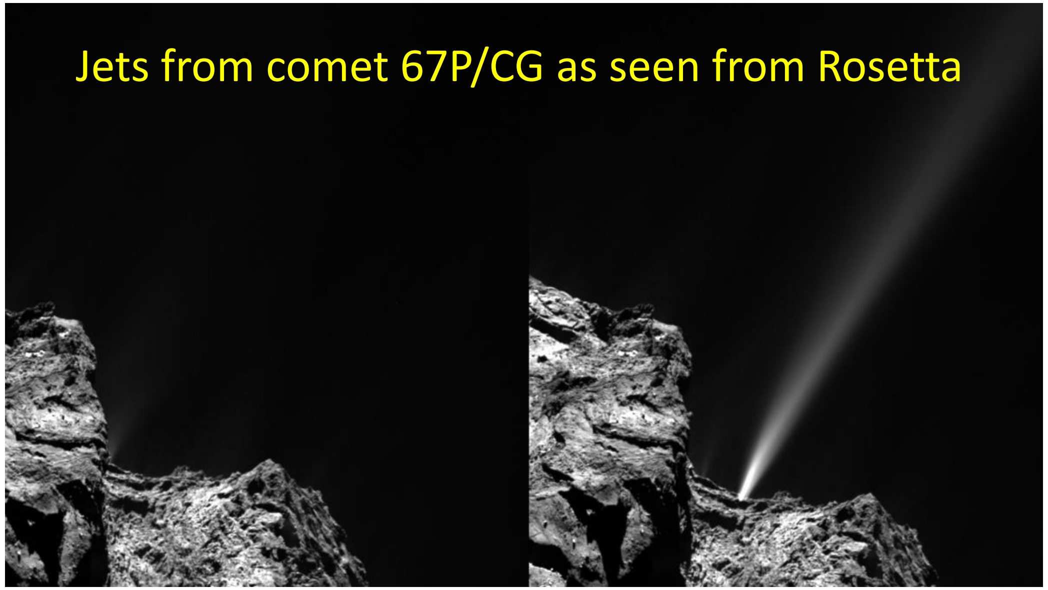
Mumma et al. 2011



Bockelee-Morvan 2011

Key question:
What is the true composition of the nucleus ?

- Coma emission representative of the nucleus composition ?
  - ➢ Inner coma
  - ➢ Parent molecules
- Nucleus homogeneous ?
  - ➢ Jets, outbursts
- Temporal variations ?
  - ➢ Simultaneous multiple-line observation

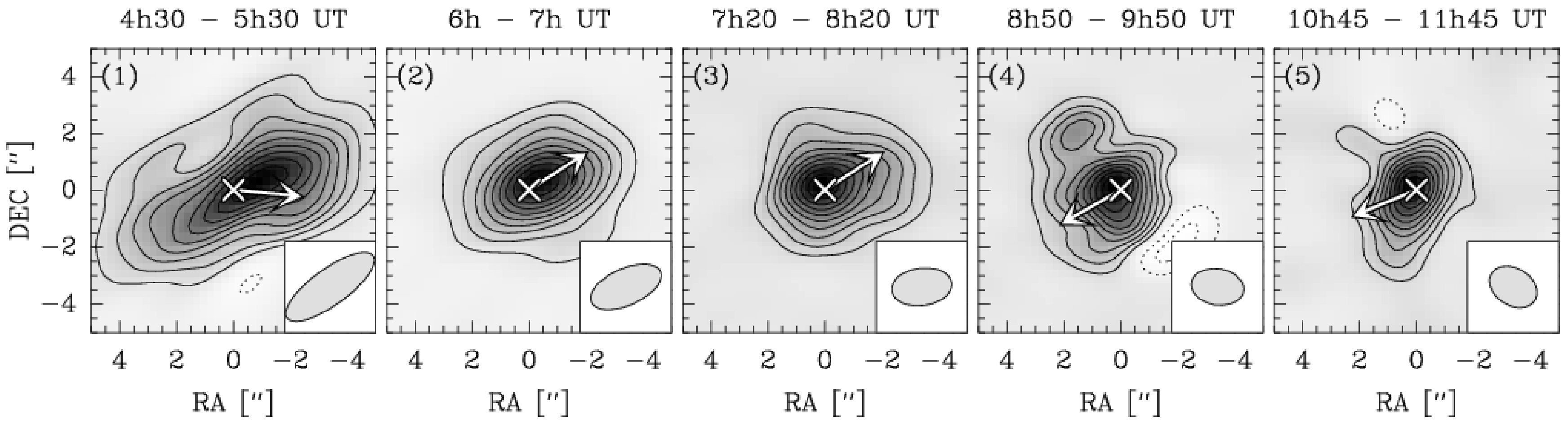


Why mm interferometry

- Millimeter spectroscopy – many rotational lines, which allows for retrieving velocity and temperature information.
- Spatial resolution – which allows for studying the **anisotropy** of gas production near the nucleus surface.
- The tool to examine spatial relations among primary volatiles to test heterogeneity in the coma and nucleus.
- Dust continuum – nucleus thermal emission: size

C/1995 O1 (Hale-Bopp) – Oort Cloud comet

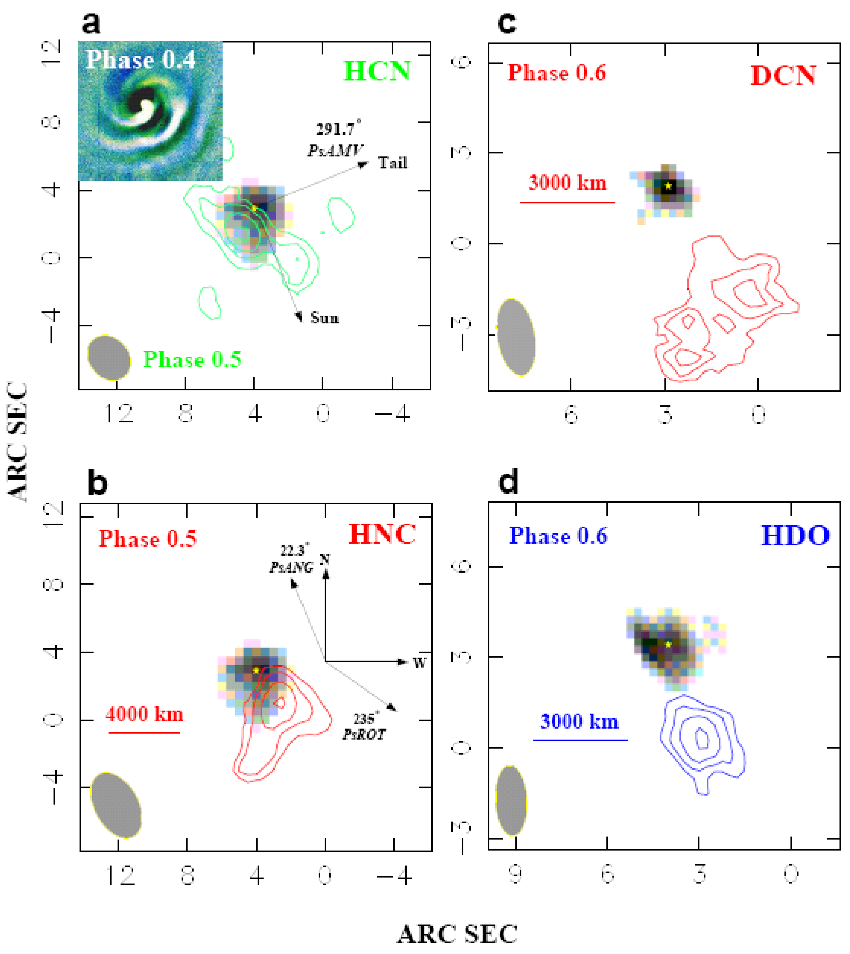
- PdBI: 1-3” angular resolution
  - Wink et al. (1999), Despois (1999), Henry et al. (2002): early works
  - Boissier et al. (2007): CS, H_2S, SO
  - Bockelée-Morvan et al. (2009, 2010): CO 1-0, 2-1, rotating jets
  - Boissier et al. (2011): hydrodynamical coma simulation.

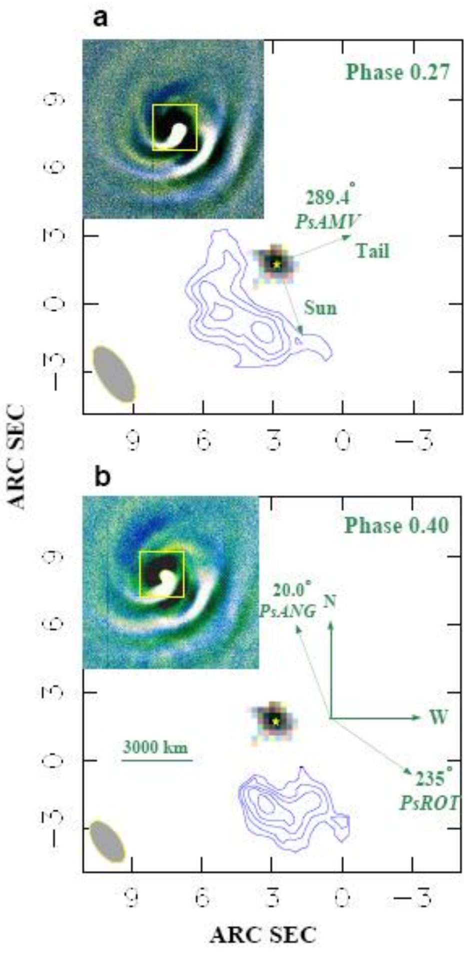


Bockelée-Morvan et al. 2009

C/1995 O1(Hale-Bopp) – Oort Cloud comet

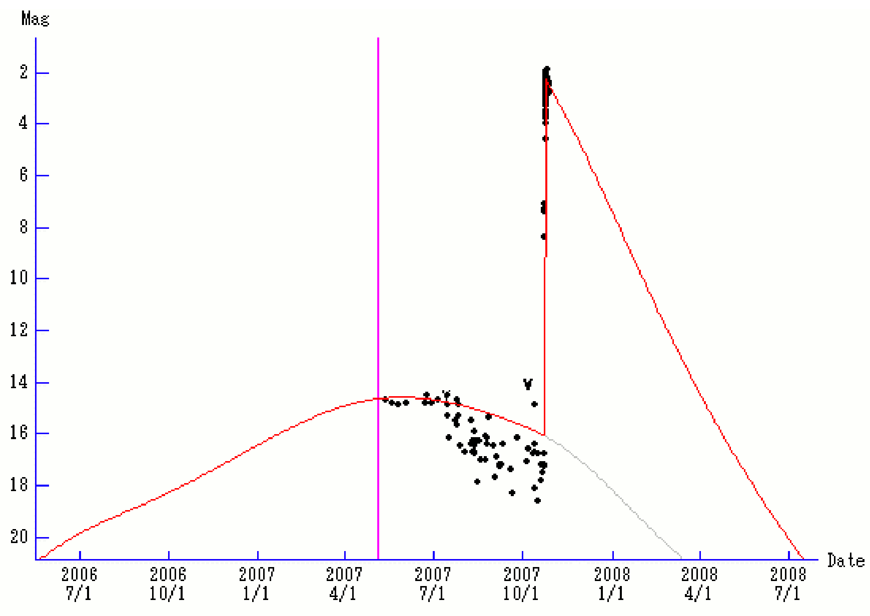
- OVRO: 2-4” angular resolution – Blake, Qi et al. (1999): HCN, DCN, HNC, HDO, arc-like structure offset from the nucleus.
- Fresh material from jets.

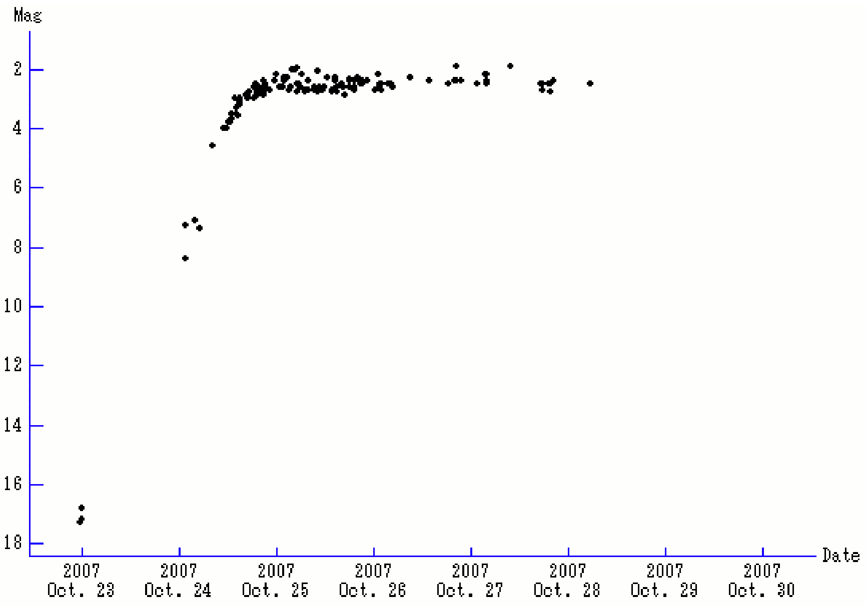




Blake, Qi et al. 1999

Comet 17P/Holmes (Jupiter-Family comet): 2007 Outburst





Importance of outburst

- The scale of the outburst provides the opportunity to measure the chemical abundances in a Jupiter-family comet.
- The nature of the comet nucleus
  - Outburst: sudden event exposes fresh ices from within the nucleus to solar radiation.
  - Material that was once in the interior of the comet nucleus is released during outburst.

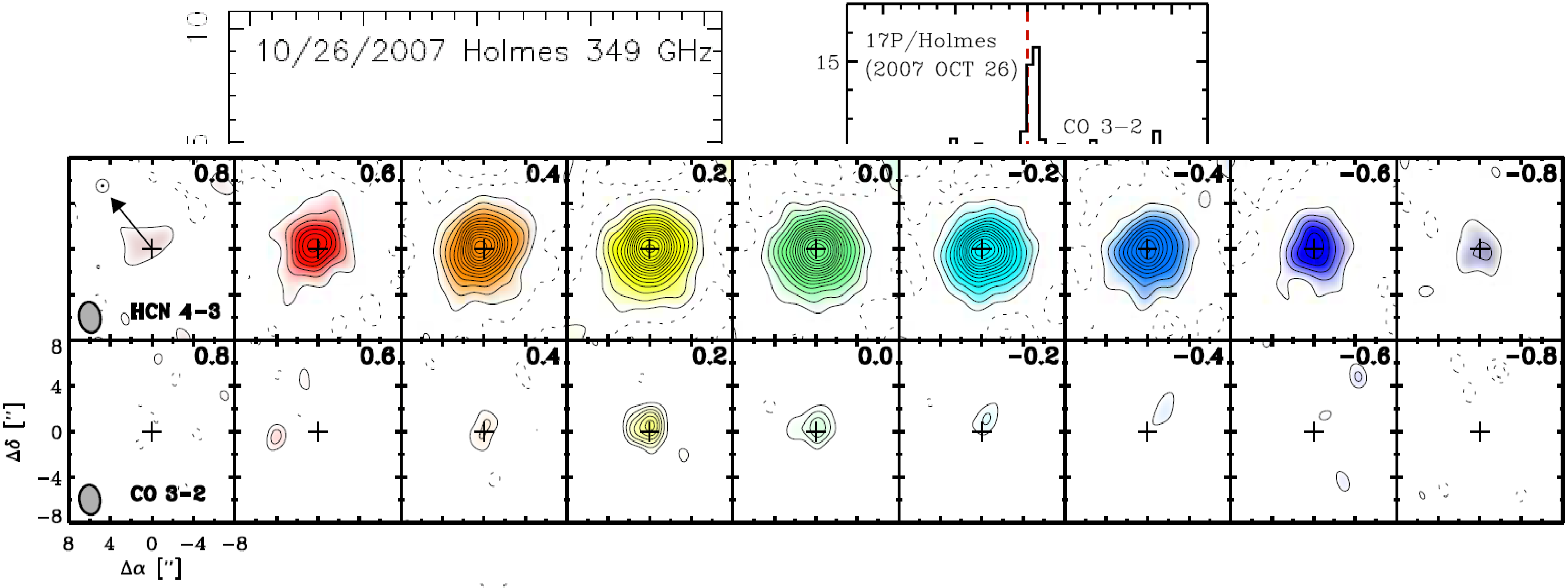
SMA observational parameters

Observational Parameters for Line Observations

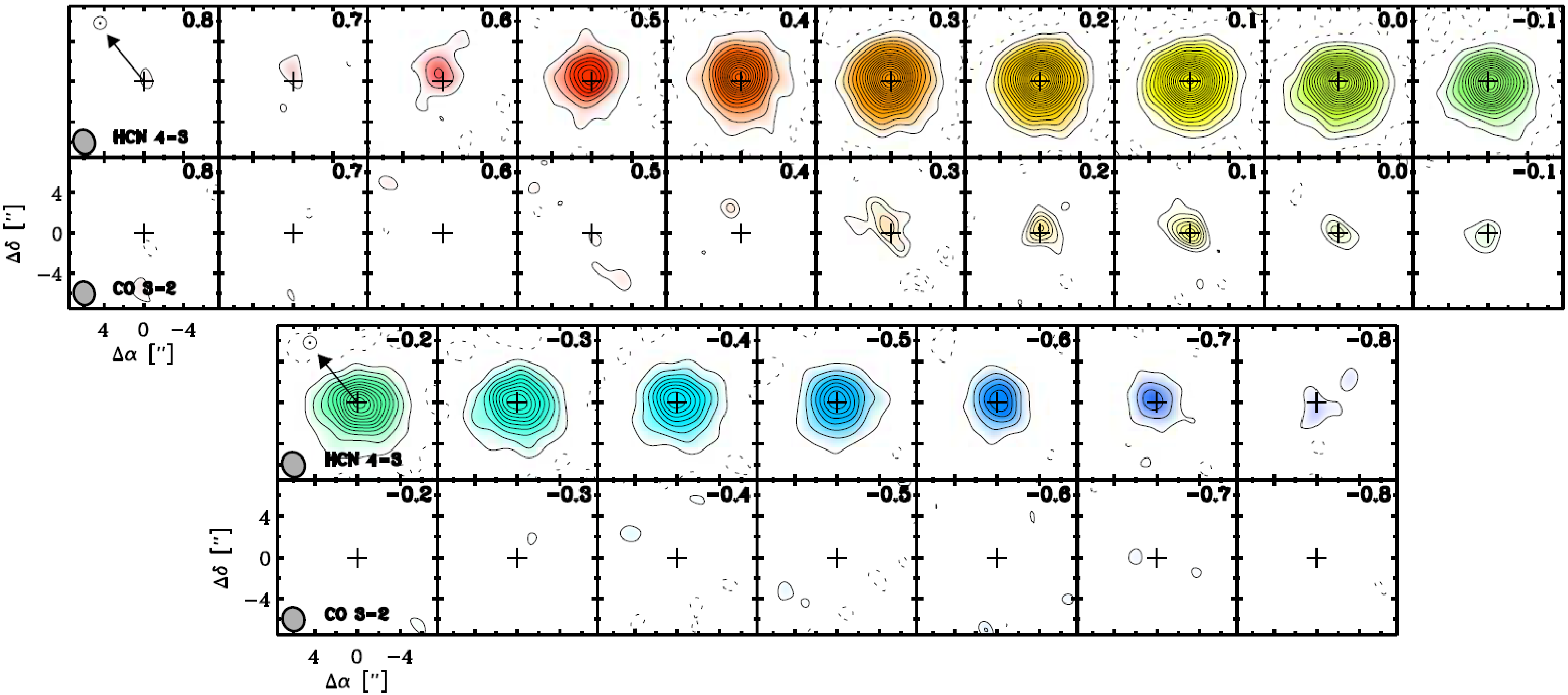
Lines	Rest Frequency (GHz)	Beam (″)	P.A. (°)	Channel Spacing (km s^{-1})	FWHM[a] (km s^{-1})	Int. Intensity[b] (Jy km s^{-1})
UT: 2007 Oct 26.3–26.7						
HCN 4–3	354.505	2.7 × 2.1	12.9	0.17	0.89	52.09[0.22]
$H^{13}CN$ 4–3	345.340	2.6 × 2.0	9.6	0.35	0.92	1.32[0.22]
CO 3–2	345.796	2.6 × 2.0	9.6	0.18	0.42	2.27[0.21]
UT: 2007 Oct 27.3–27.7						
H_2CO $3_{1,2}$–$2_{1,1}$	225.698	3.8 × 3.2	49.6	0.27	0.72	3.03[0.14]
HDO $3_{1,2}$–$2_{2,1}$	225.897	3.8 × 3.2	49.6	0.54	...	[0.14]
DCN 3–2	217.239	4.2 × 3.9	−39.1	0.28	...	[0.14]
H_2S $2_{2,0}$–$2_{1,1}$	216.710	4.2 × 3.9	−39.1	0.56	...	1.36[0.14]
CH_3OH $5_{1,0}$–$4_{2,0}$	216.946	4.2 × 3.9	−39.1	0.56	...	1.34[0.14]
UT: 2007 Oct 28.3–28.7						
HCN 4–3	354.505	2.5 × 2.1	19.4	0.086	0.69	48.79[0.16]
$H^{13}CN$ 4–3	345.340	2.4 × 2.1	14.2	0.35	0.68	1.07[0.16]
CO 3–2	345.796	2.4 × 2.1	14.2	0.088	0.50	1.75[0.15]
CH_3OH $13_{0,0}$–$12_{1,0}$	355.603	2.5 × 2.1	19.4	0.34	...	2.40[0.16]
UT: 2007 Oct 29.3–29.7						
HCN 4–3	354.505	2.4 × 2.1	15.6	0.17	0.65	50.16[0.21]
CS 7–6	342.883	2.4 × 2.2	11.1	0.18	0.46	4.45[0.21]

Qi et al. 2015 hereafter

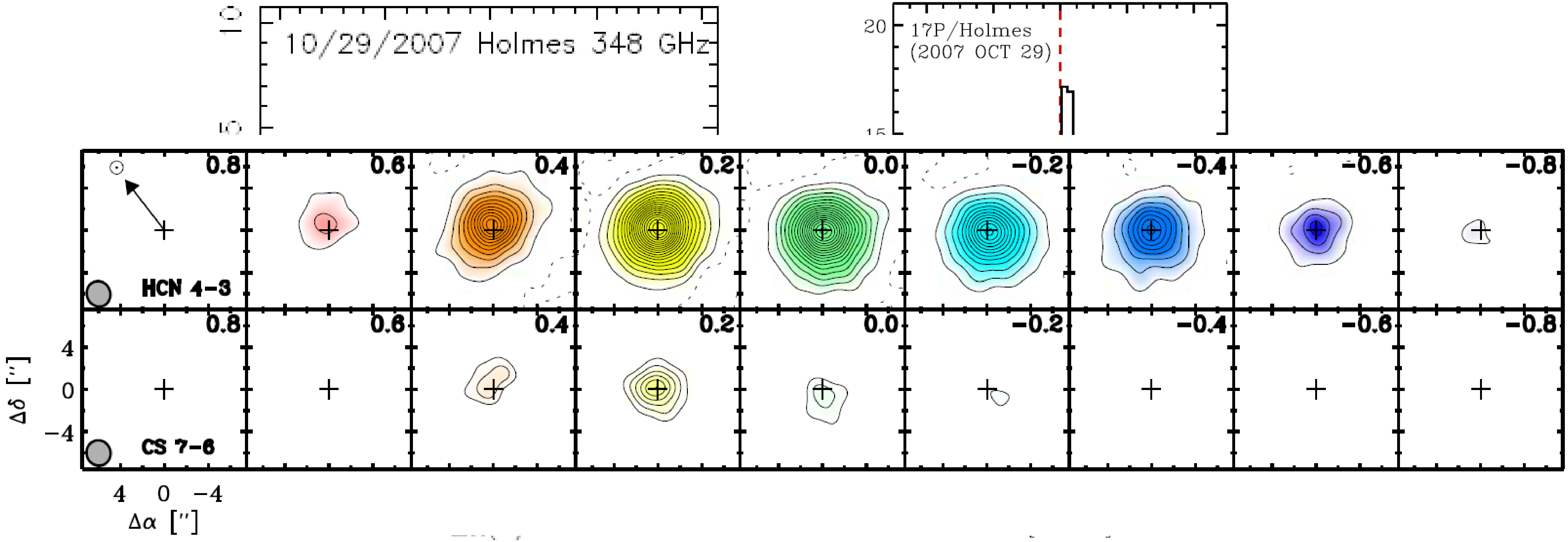
October 26, 2007



October 28, 2007



October 29, 2007



Model description

<u>Symmetric outgassing model</u>

$$n(r) = \frac{Q}{4\pi r^2 v_o} \exp^{-\frac{(r-r_n)}{r_\lambda}},$$

Free parameters: Q, v_o, T_{kin}

Resample

<u>Data</u>

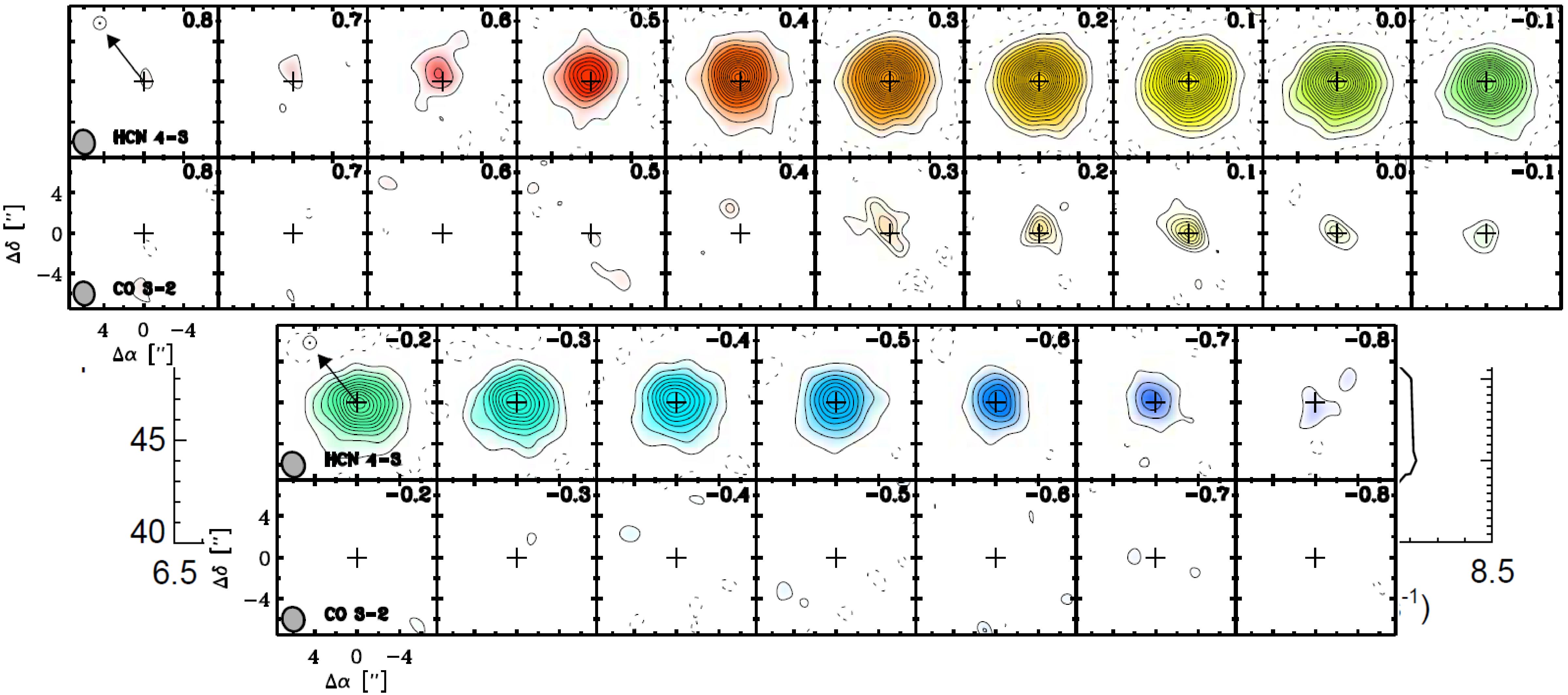
visibilities

$$\chi^2 = \Sigma_n \Sigma_i (Re(mod_{i,n}) - Re(obs_{i,n}))^2 \times W_i + \Sigma_n \Sigma_i (Im(mod_{i,n}) - Im(obs_{i,n}))^2 \times W_i$$

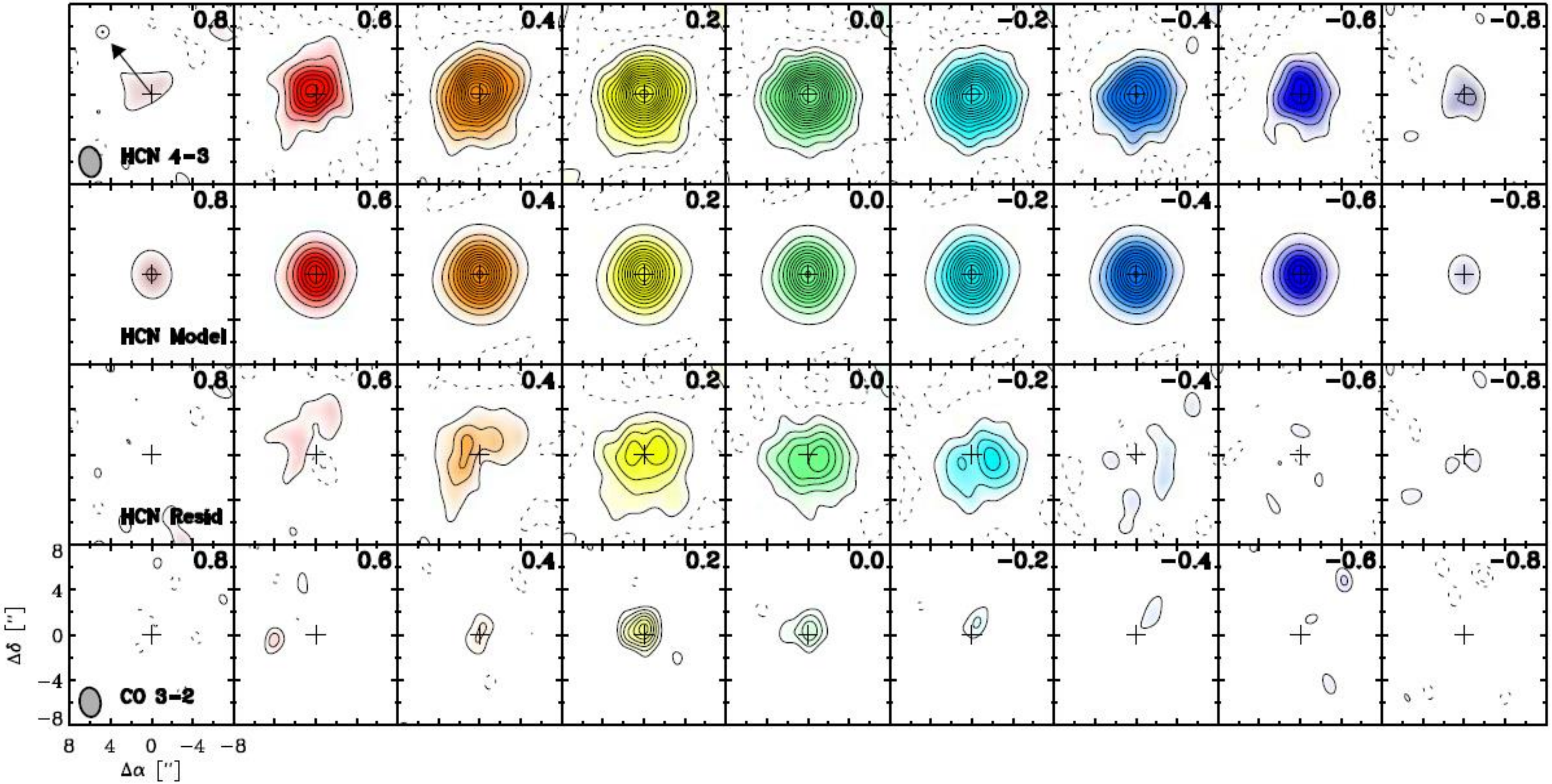
$$W_i = \frac{1}{\sigma_i^2} \quad \text{with} \quad \sigma_i = \frac{\sqrt{2} k T_{sys}}{A_{eff} \eta \sqrt{\tau \Delta \nu}}$$

- Molecular excitation code includes the effects of collisions with water and electrons, as well as pumping by the Solar infrared photons. (See details in Hogerheijde et al. 2009)
- Production rate Q, gas temperature T_{kin} and the expansion velocity v_o can be fit with χ^2 minimization.

χ^2 minimization – determine Q, T, v

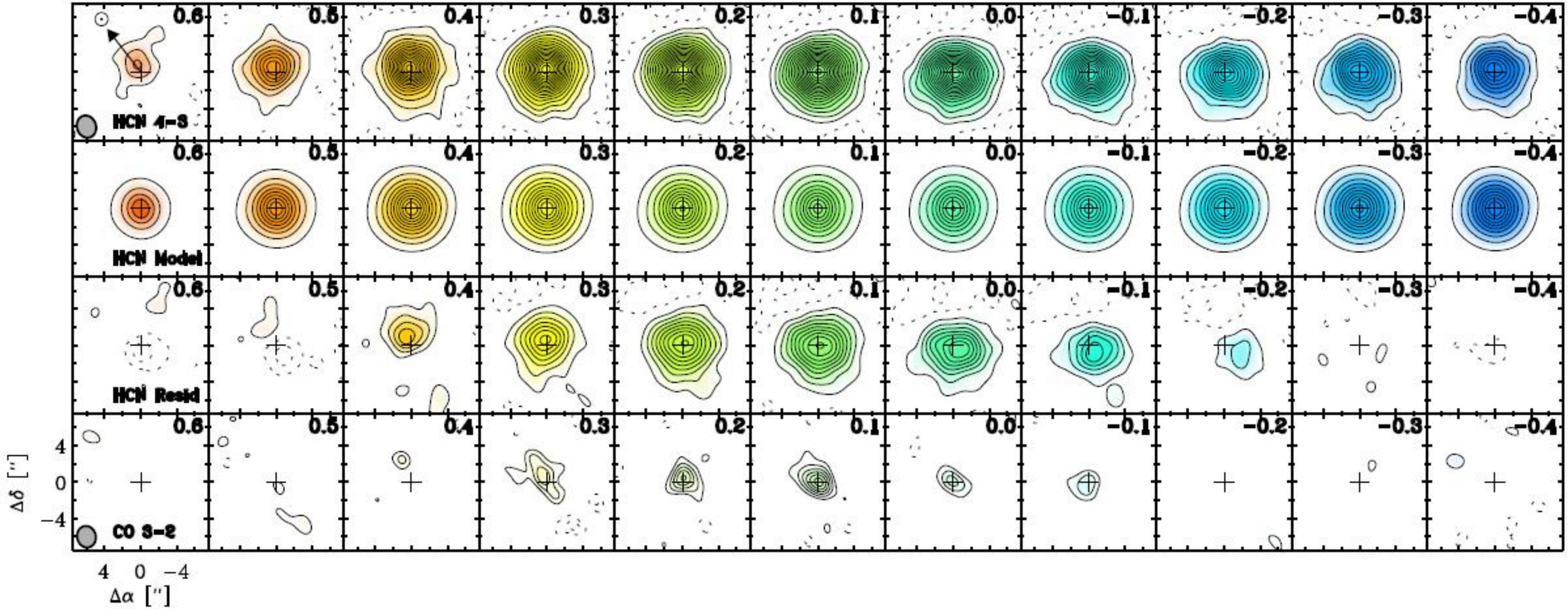


Oct. 26: data vs model



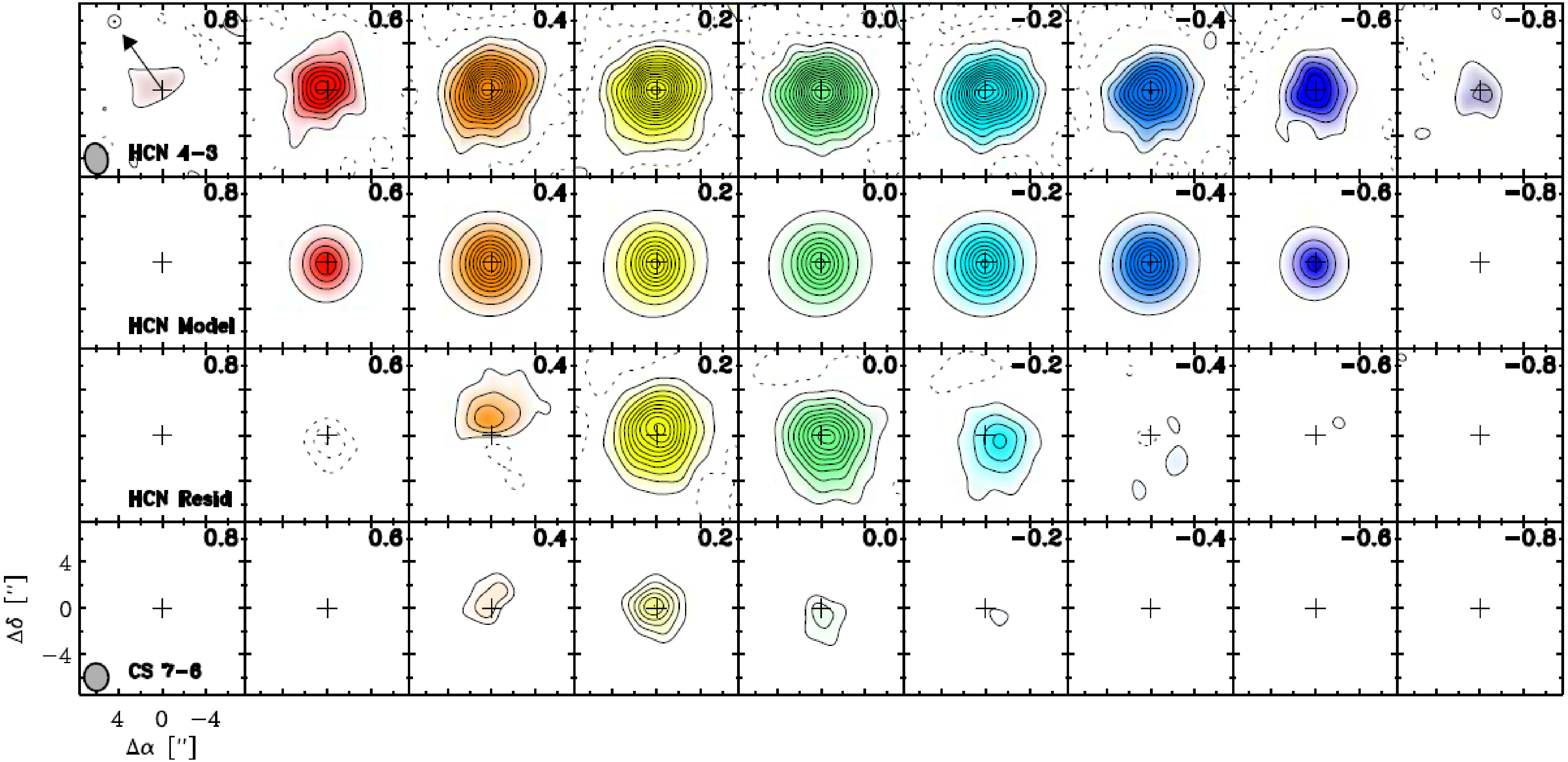
- Fitting results: : Q_{HCN}=1.25×10^{27} s^{-1}, v_{exp}=0.46 km s^{-1} , T=48 K

Oct. 28: data vs model



- Fitting results: : Q_{HCN}=8.0×10^{26} s^{-1}, v_{exp}=0.44 km s^{-1} , T=48 K

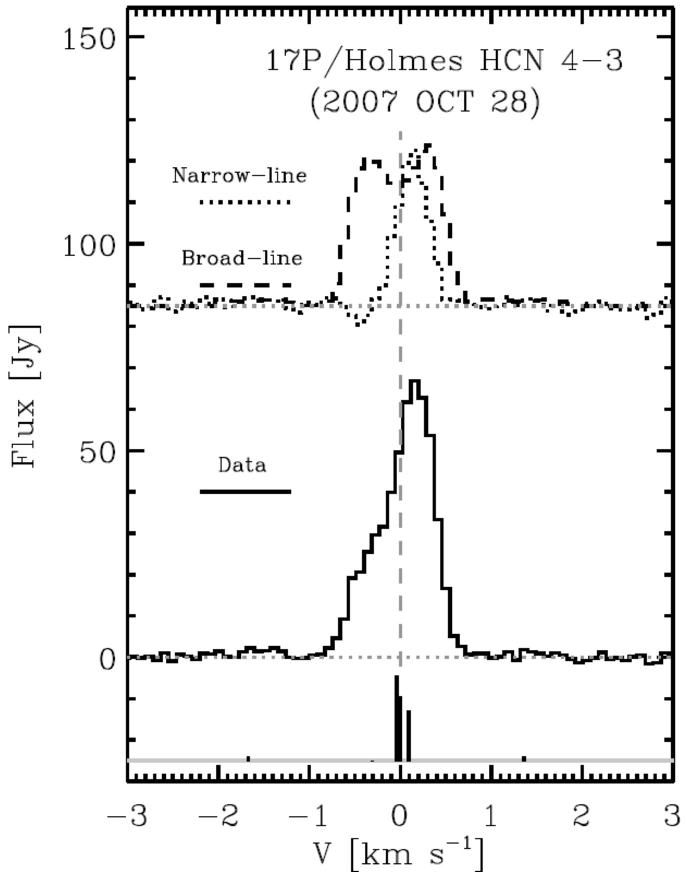
Oct. 29: data vs model



- Fitting results: : Q_{HCN}=6.3×10^{26} s^{-1}, v_{exp}=0.38 km s^{-1} , T=46 K

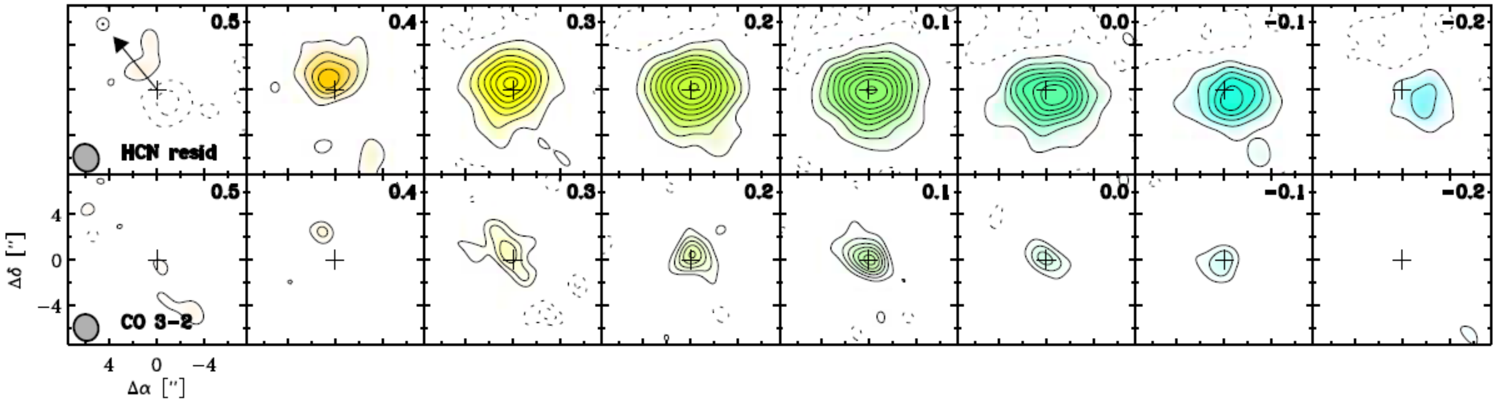
Two components in HCN emission

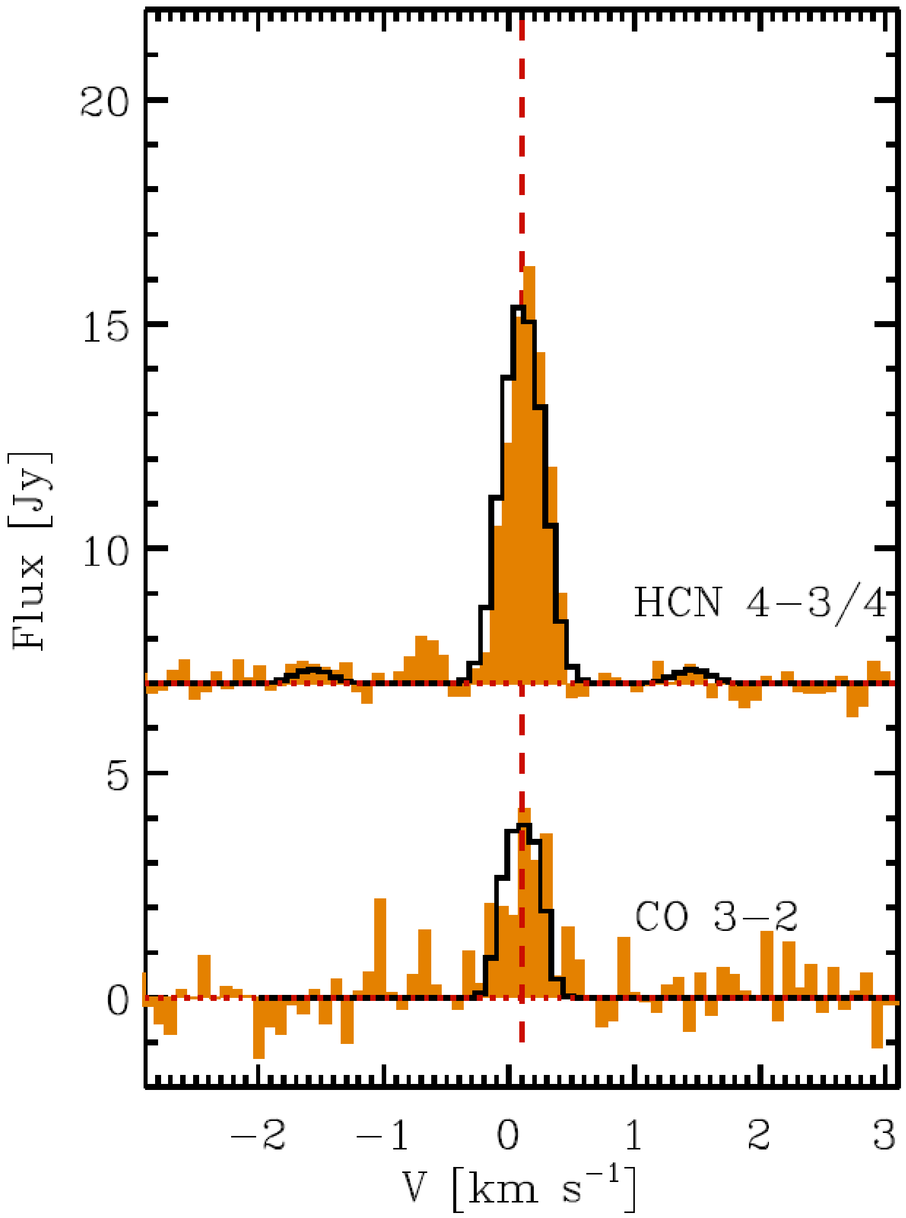
- Symmetric outgassing —
  broad line with FWHM ~ 1 km/s
- Asymmetric outgassing —
  narrow line with FWHM 0.4 km/s ,
  red-shifted 0.1-0.2 km/s



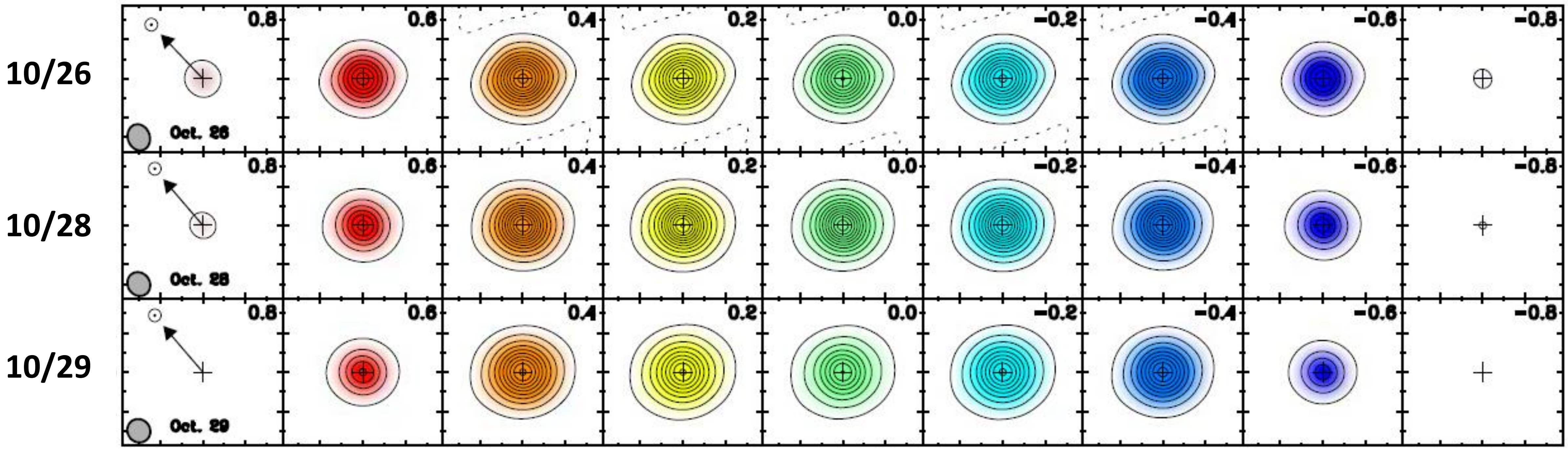
CO/HCN ratios in jet (Oct 28)

- Fitting the residual HCN emission and CO emission, outflow velocity 0.1 km/s
- CO/HCN = 40±5 in the jet component
- CO/HCN < 7 in the symmetric outgassing component (upper limit beyond -0.2 and +0.4 km/s)



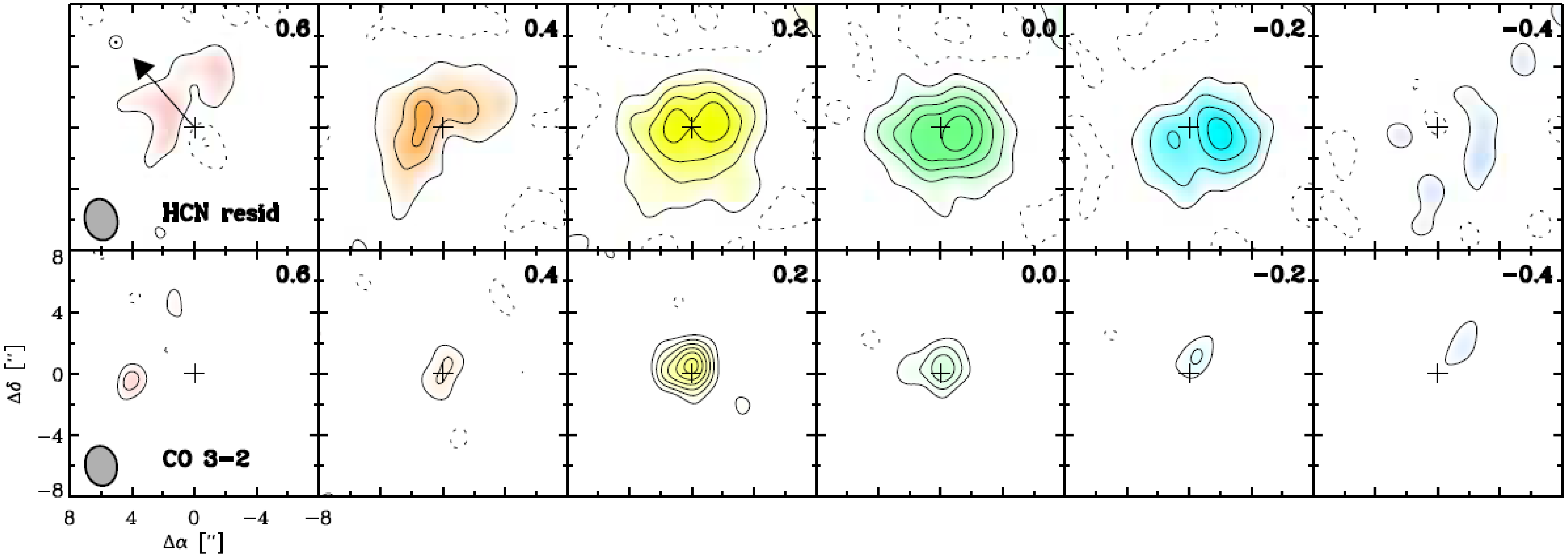


Broad-line component — symmetric outgassing emission peak at nucleus position



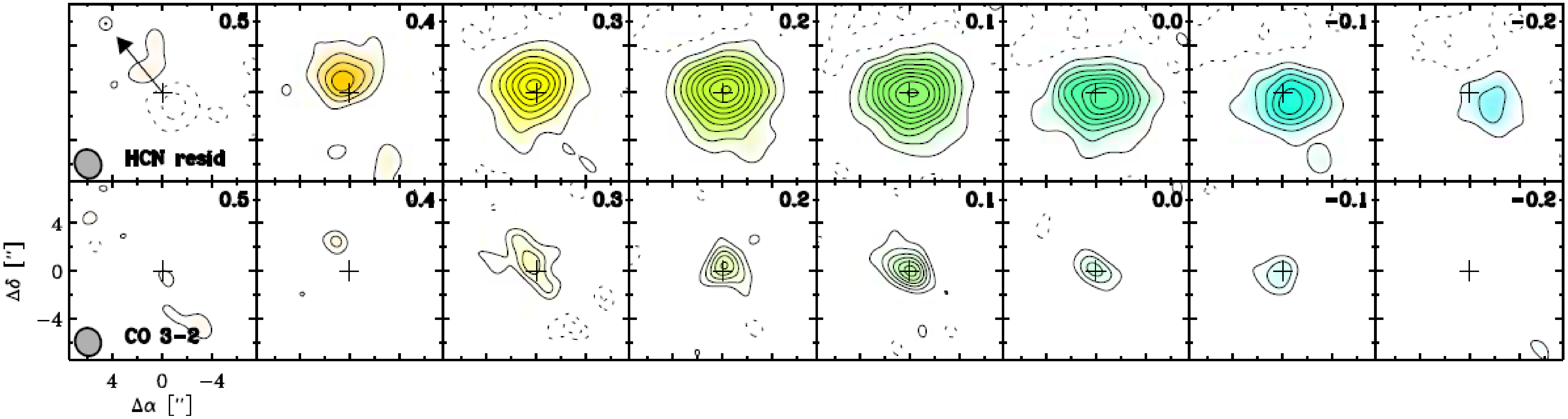
Narrow-line comp.: asymmetric outgassing

10/26



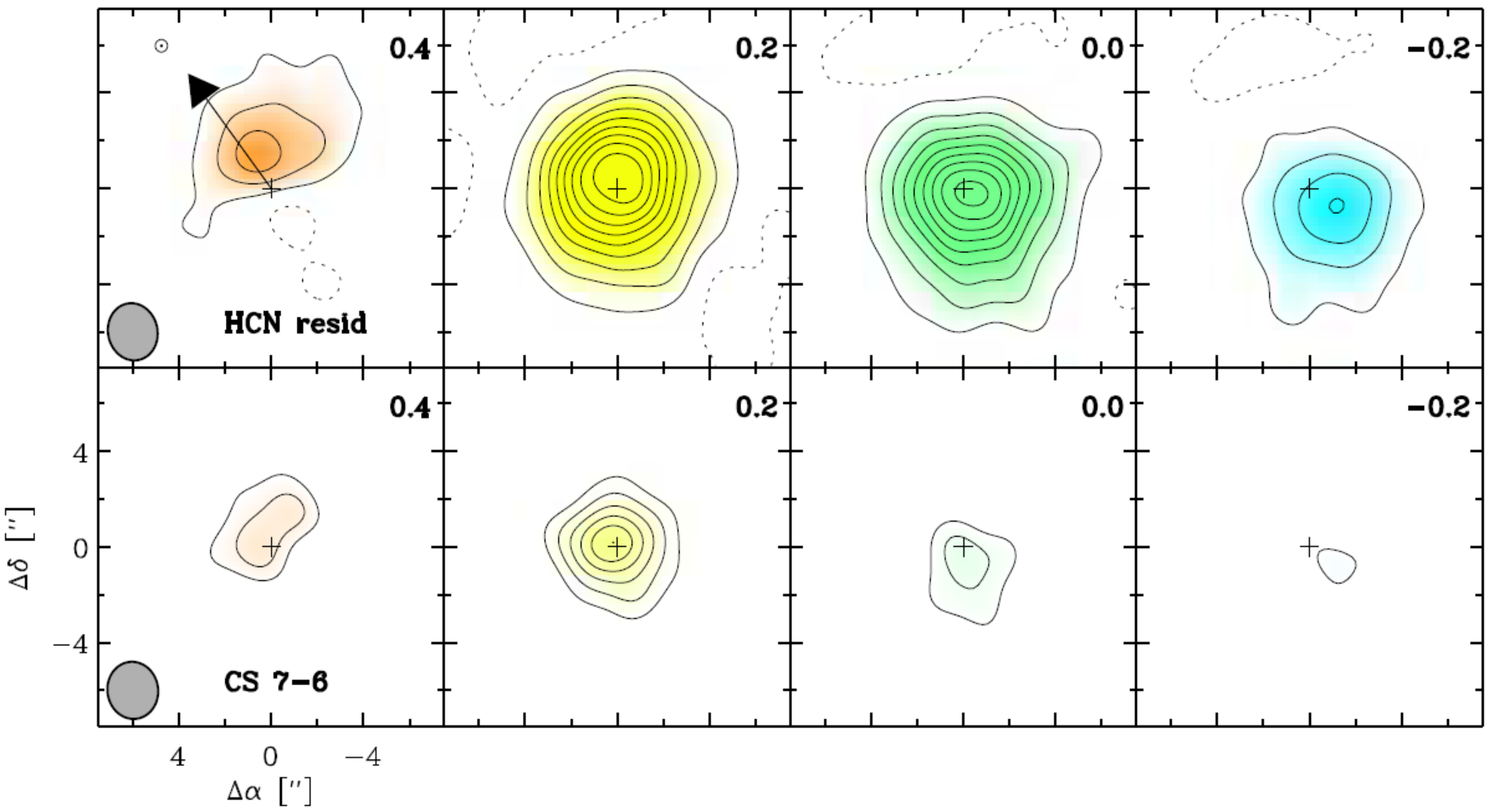
Narrow-line comp.: asymmetric outgassing

10/28



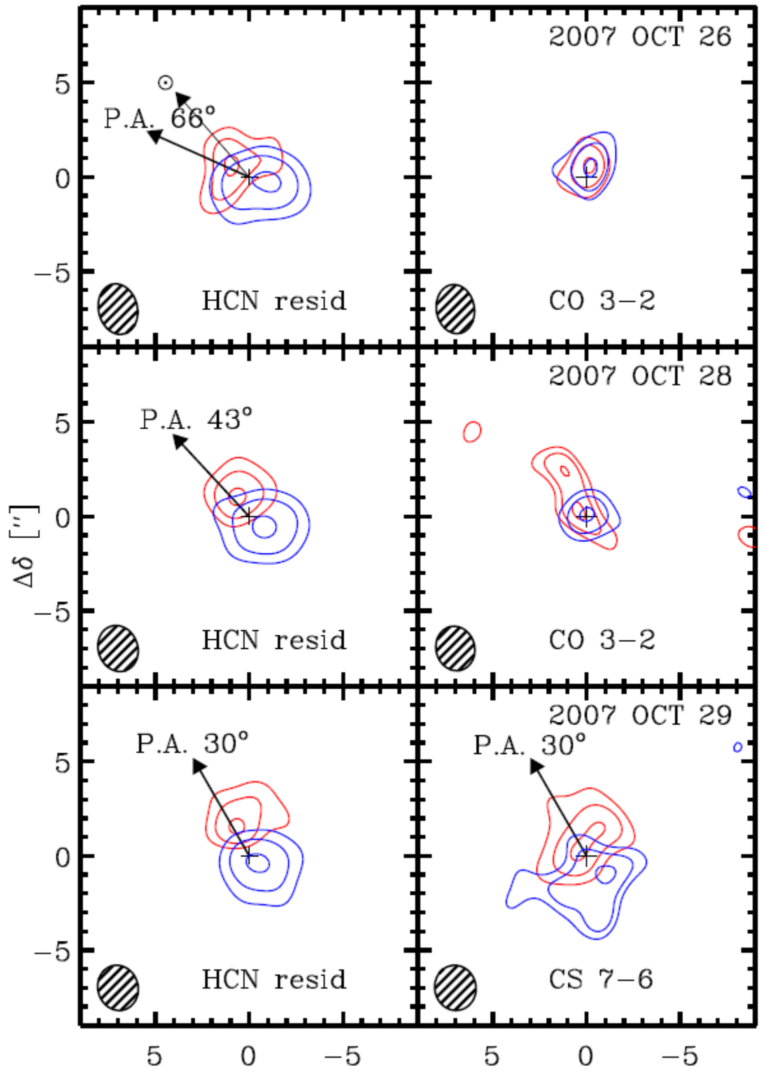
Narrow-line comp.: symmetric outgassing

10/29

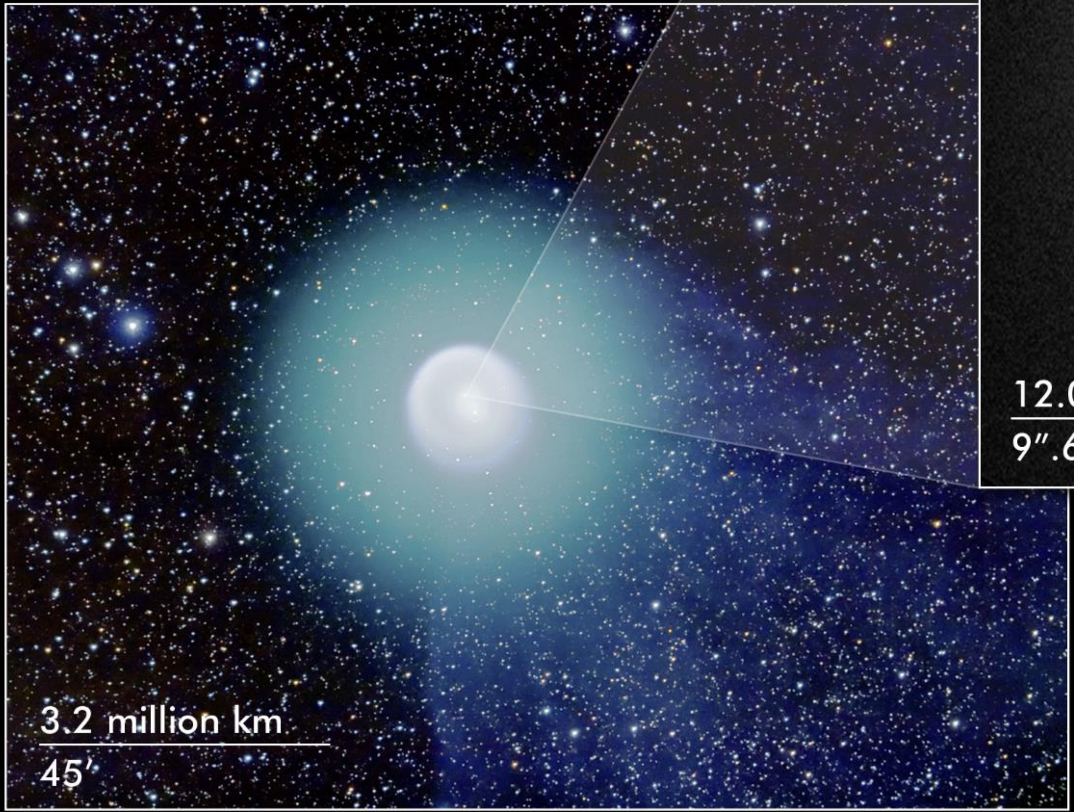


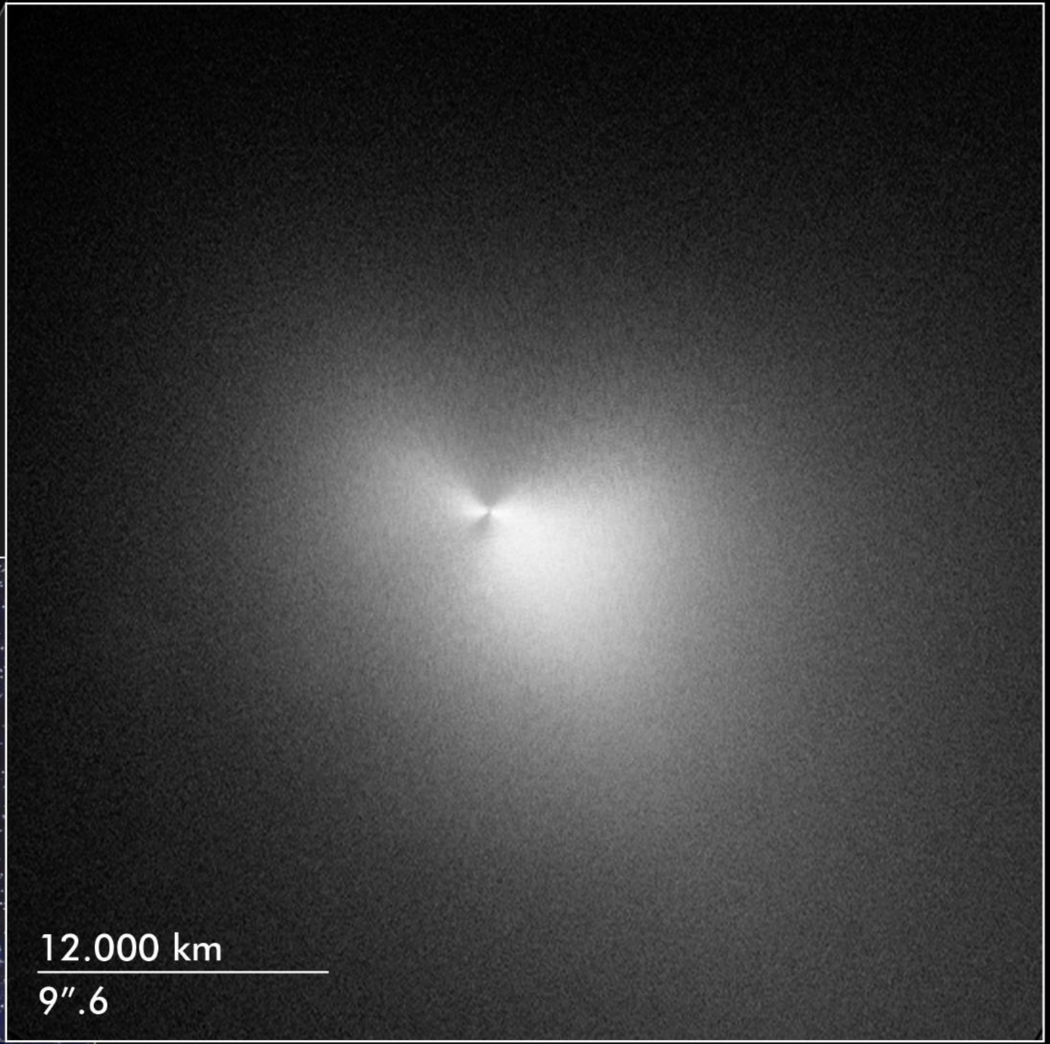
Asymmetric outgassing: jets feature

- Line center red-shifted by 0.1-0.2 km/s
- The peaks of the narrow-line component emission shift with velocity across the nucleus position.
- The P.A. of the red/blue gradient changed from 66º to 30º during the four days of observations.
- The morphologies of the narrow-line component consistent with jets feature.



November 1, 2007
A. Dyer, Alberta, Canada



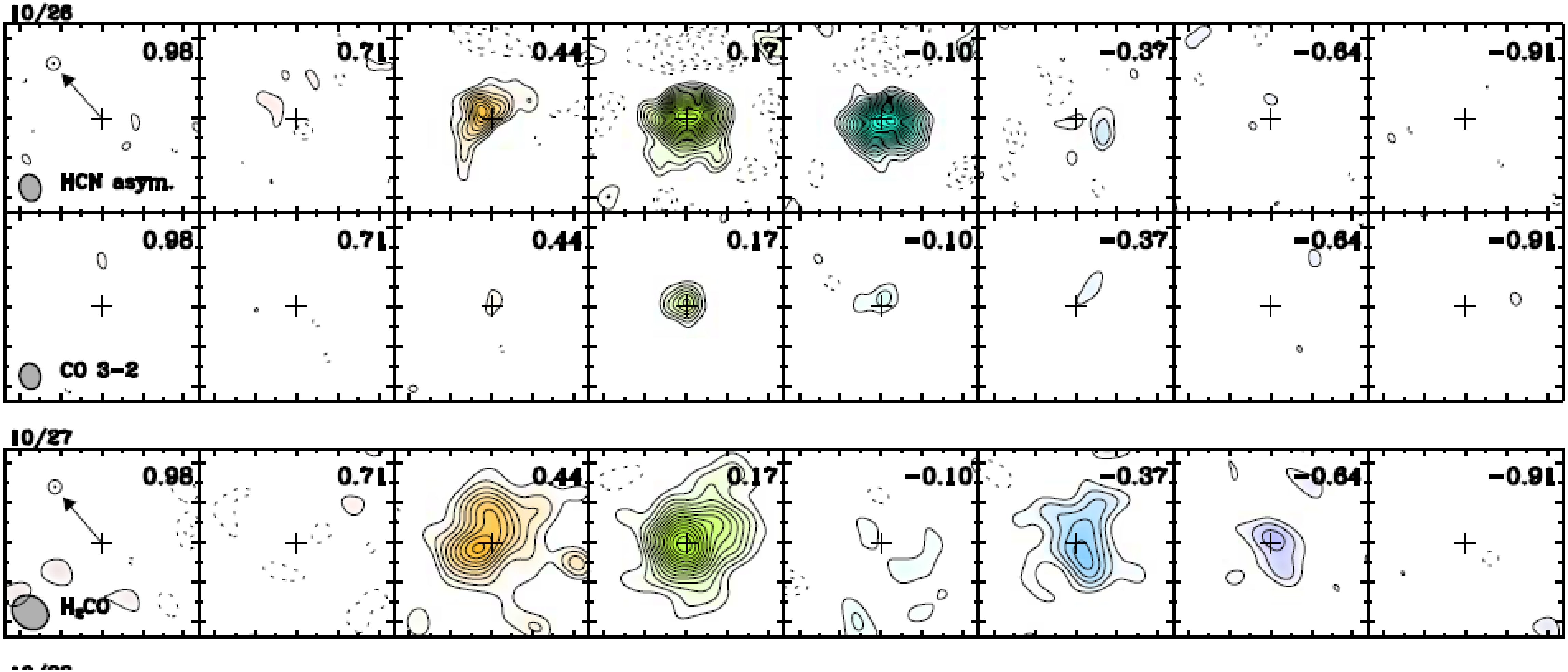


November 4, 2007
HST WFPC2

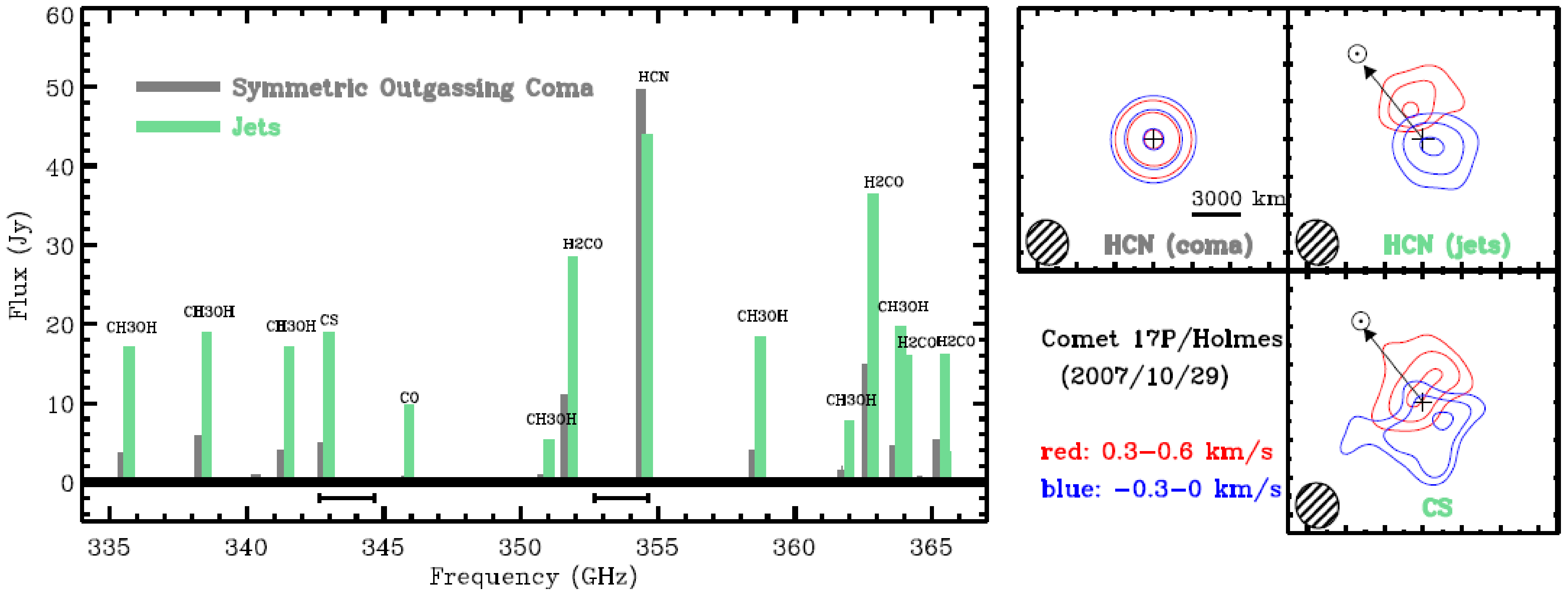
Summary

- We found two components in the near-nucleus outgassing after the outburst of 17P/Holmes.
  - Symmetric feature, broad-line FWHM 1 km/s, peak at nucleus
  - Asymmetric jets feature, emission extending from NE (red-shifted) to SW (blue-shifted), narrow-line FWHM 0.4 km/s
- CO, CS, and H_2CO were more abundant in the narrow-line component.
- On Oct 28, CO/HCN ratio < 7 in the broad-line component, and around 40 in the narrow-line component (jets).
- The higher CO/HCN ratio in the jets component reflects the more pristine volatile composition of nucleus material released in outburst.

H_2CO observation on 10/27
no simultaneous HCN observation



What wSMA can offer: wideband, flexible op



Goal: to probe heterogeneity of cometary nucleus and reveal its true composition

Collaborators: David Jewitt (UCLA), Michiel Hogherheijde (Leiden U.),
Mark Gurwell, David Wilner (CfA)

END