An Evolutionary Timeline for High-Mass Star Formation

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Main Collaborators for this work

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Outline

- High-mass star formation, a primer.
- Interstellar masers as an evolutionary clock?
- The oldest class II methanol maser sources.
- Class I methanol the déjà vu masers?

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High-Mass Stars – Who cares?

A small fraction of stars, but they play a very important role in the evolution and energetics of galaxies.

NGC3603 in Carina
Image: http://hubblesite.org/
News Release Number: STScI-2007-34

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Occupy Wall Street

The Milky Way

Occupy Wall Street has been driven by the disproportionate fraction of wealth controlled by a small number of individuals.

- O Stars make up ~0.00003% of stars in the Milky Way by number.
- O Stars are responsible for ~15% of the energy output of the Milky Way.

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Ignorance isn't always bliss

- Despite their importance in many aspects of astrophysics the formation of high-mass stars remains poorly understood.
- There isn't a single confirmed proto-O star in the Galaxy.
- Observational studies of high-mass star formation focus on associated astrophysical phenomena.

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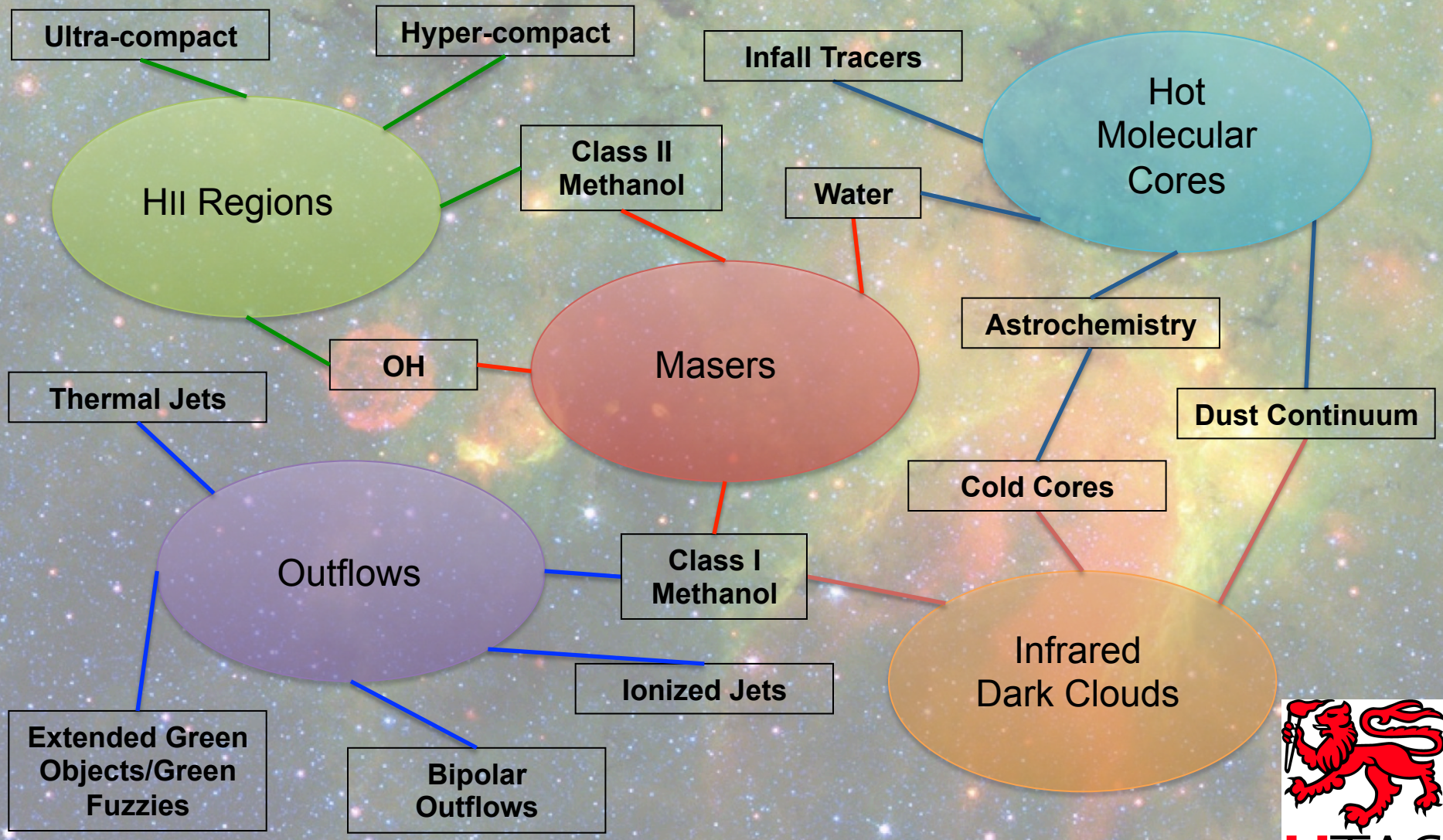
Star Formation – Rogues Gallery



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Bringing Order to Chaos

- Each of these high-mass star formation tracers reveals something about the process.
- What is the relationship between the different tracers and the bigger picture?
- How do the different tracers relate to each other – what is exclusive, what is complementary?
- How might we form a reliable evolutionary timeline for high-mass star formation?

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Star Formation Masers – the current state of play

- Masers have been observed from transitions of OH, H_2O, CH_3OH, SiO, H_2CO, NH_3, …
- There are only a handful of transitions which are both strong and common :
  - OH at 1665/1667 MHz (hundreds)
  - Water at 22 GHz (thousands)
  - Methanol at 6.7, 12.2 GHz (class II) and 44 GHz (class I) (~ 1000 and many hundreds resp.)

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Relationship to other HMSF tracers

- Some masers are associated with UCHII regions (esp. OH and class I methanol).
- Most methanol and water masers are associated with objects which show no centimetre radio continuum emission.
- Most (perhaps all) methanol masers are associated with MIR sources (24 μm), all are associated with millimetre dust continuum emission.
- Many are associated with IRDC and/or EGOs/green fuzzies. Most maser sources are likely at the hot-core, or earlier evolutionary phases.

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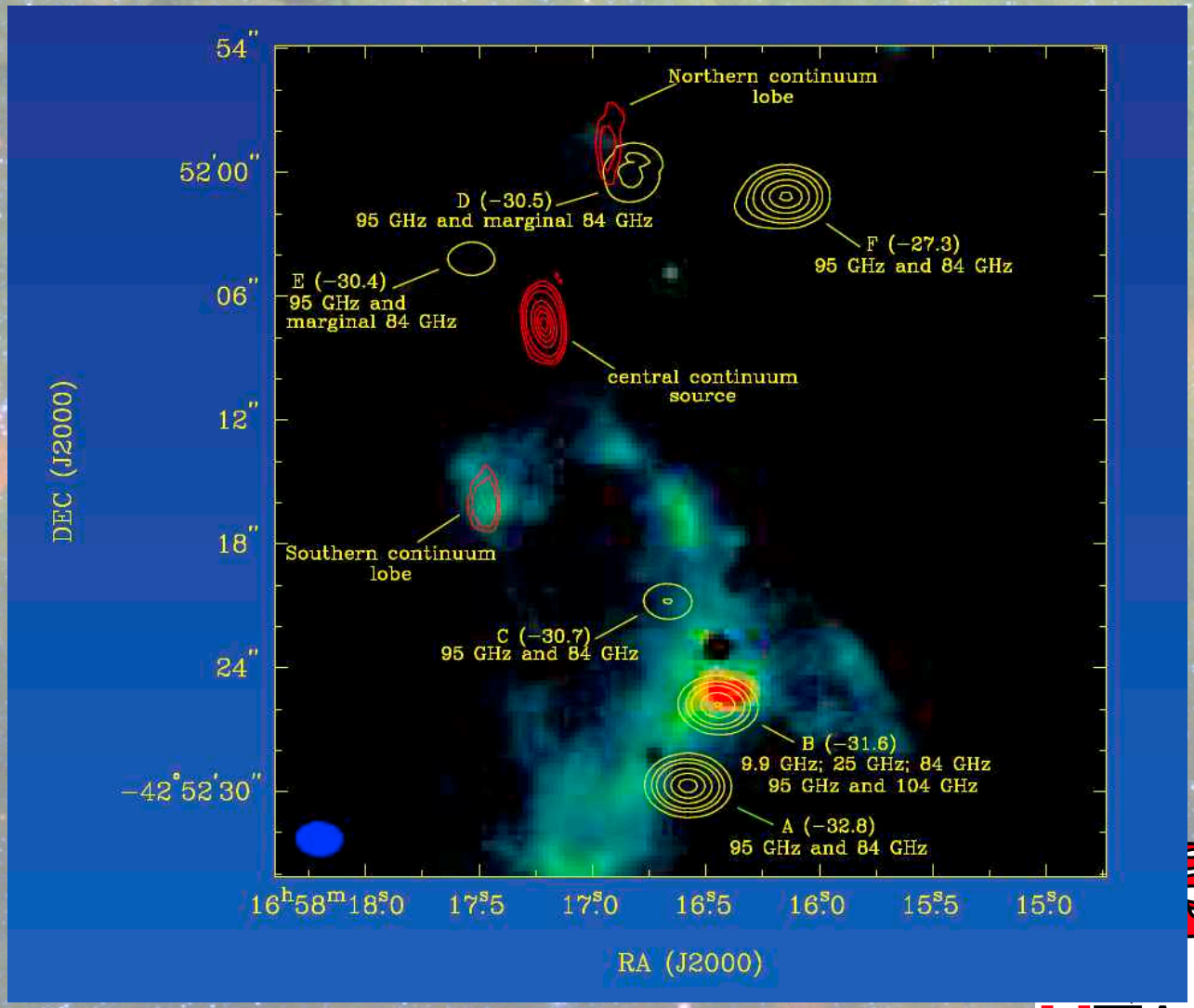
IRAS16547-4247/G343.12-0.06

The location of class I methanol masers (yellow contours) compared to the radio continuum (red contours) and H_2 emission (false colours)

Voronkov et al. (2006)



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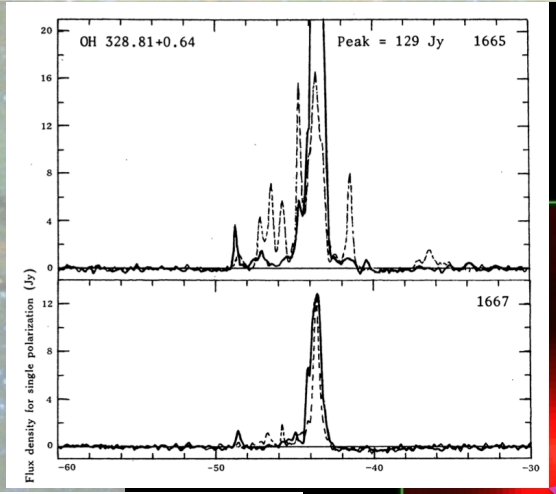
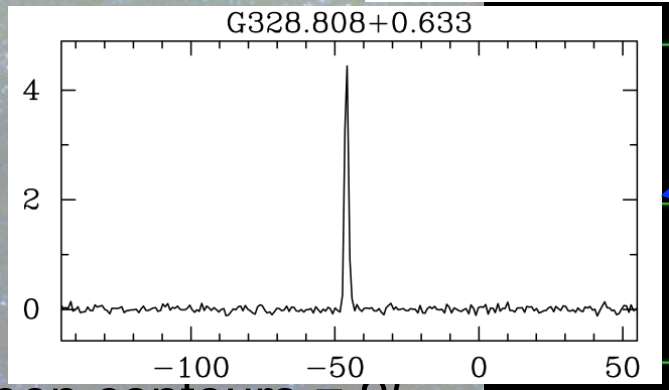
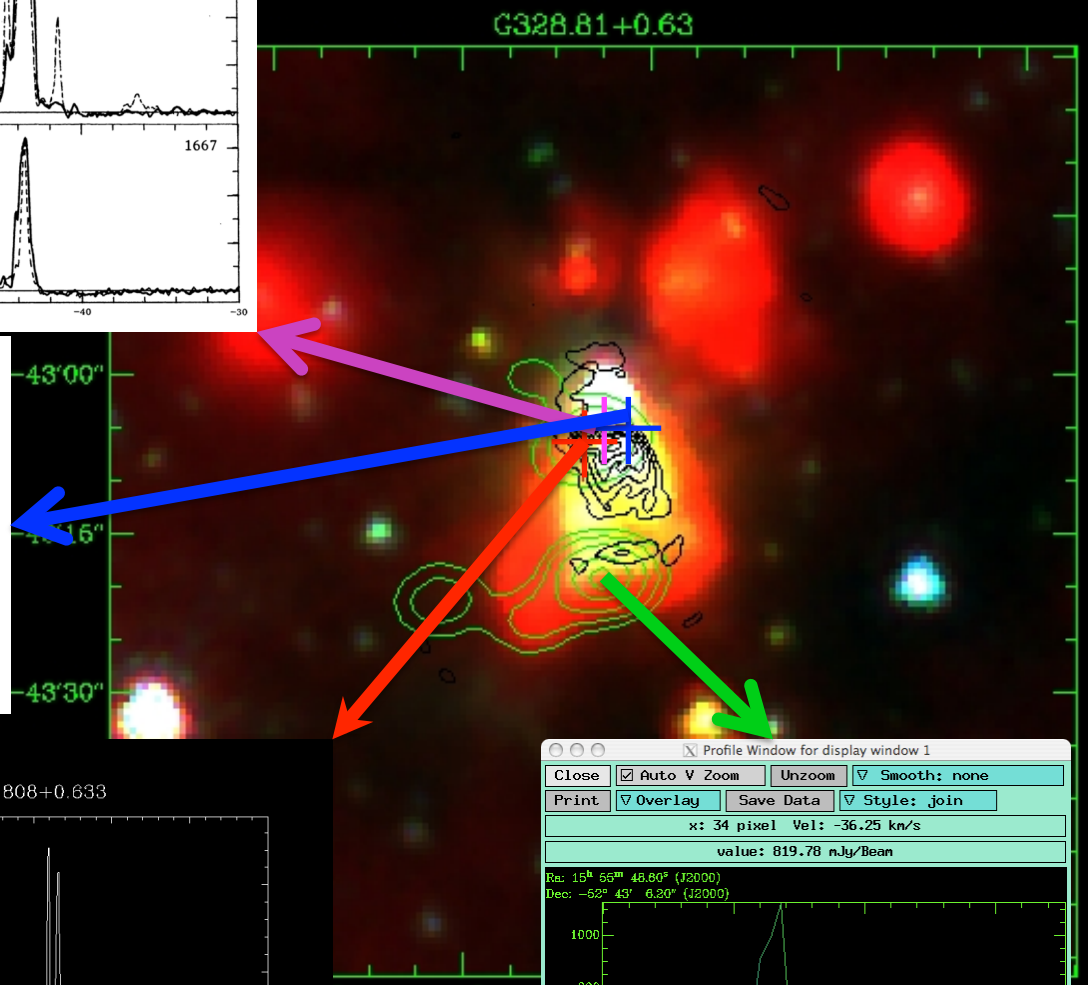
+ = 6.7 GHz methanol masers

+ = OH masers

+ = water masers







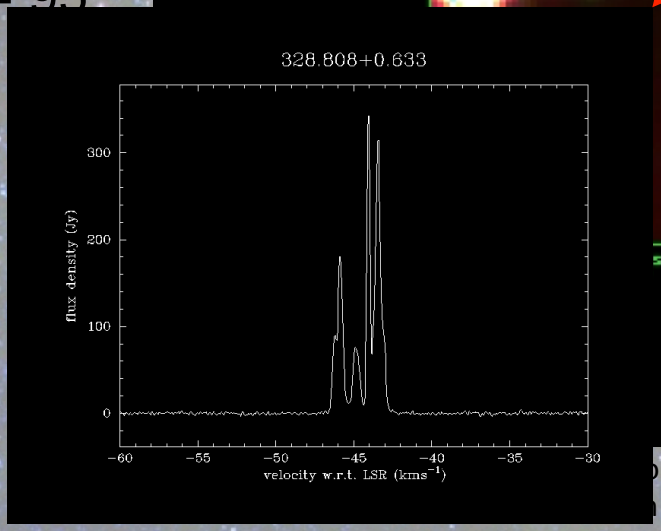
Green contours = 95 GHz methanol

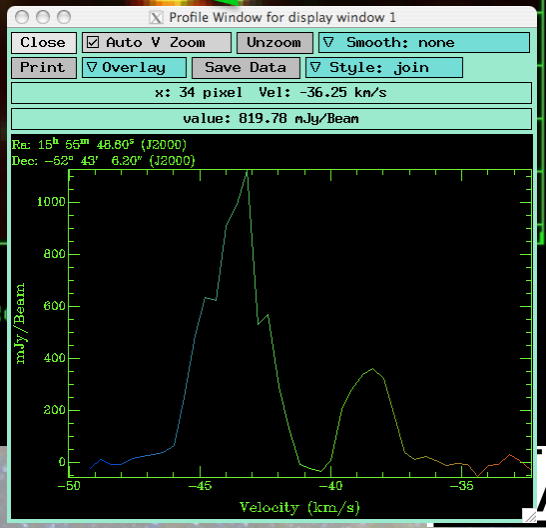
Black contours = 3cm continuum.

Blue = 3.6 μm

Green = 4.5 μm

Red = 8.0 μm





or High-Mass

Anniversary

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Masers and Evolution?

- Any type of maser requires a specific range of physical conditions.
- Those transitions which are strong and common are either – not very fussy, or trace conditions which arise commonly and persist.
- In many HMSF regions more than one type of maser transition is detected, but there are some which only show one species or transition.
- Does the presence/absence of different species trace an evolutionary timeline?

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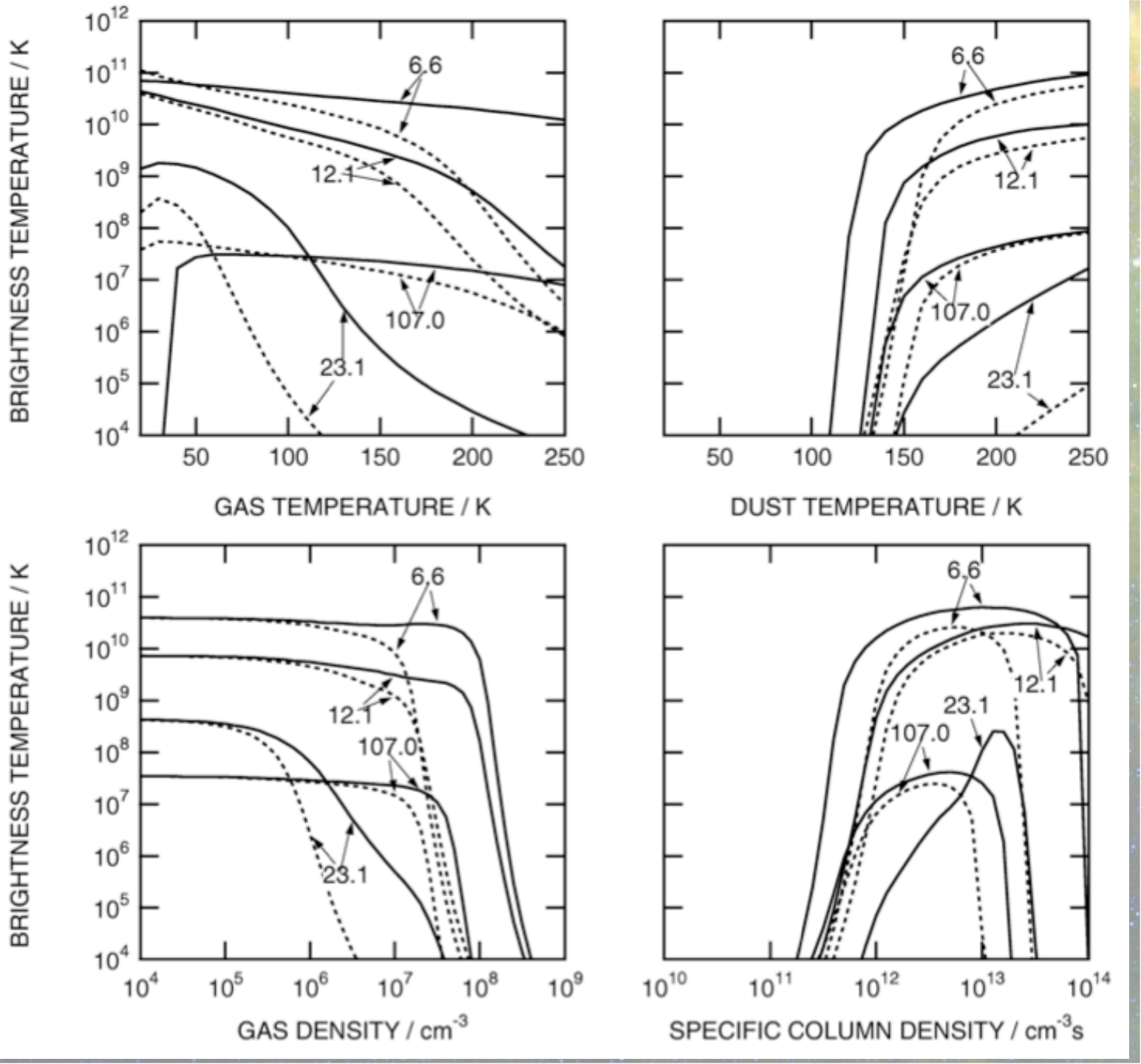
Methanol Maser pumping models

Cragg et al. (2005)



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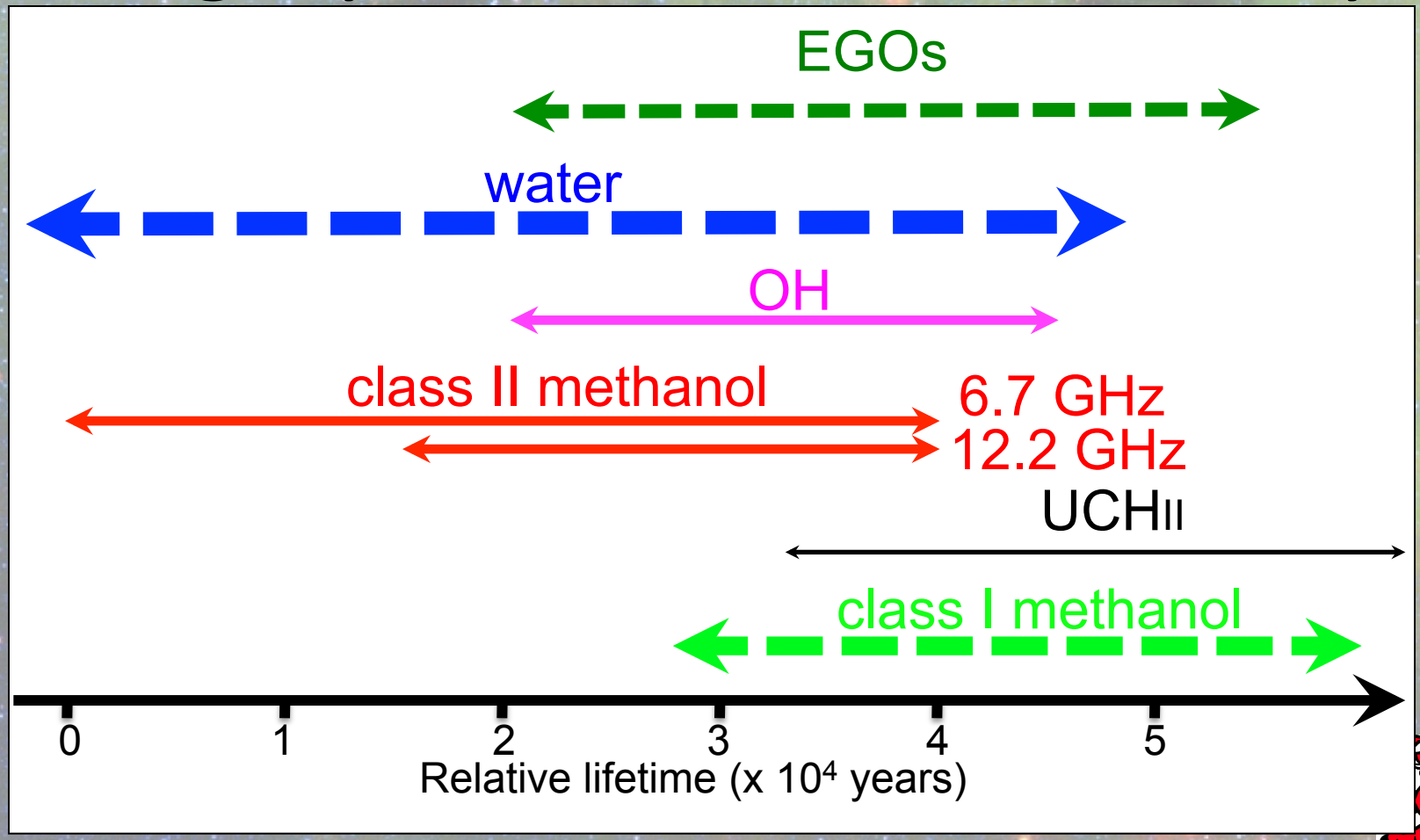
The Maser-based timeline
A Legacy of Parkes Maser Surveys



Based on Breen et al. (2010).

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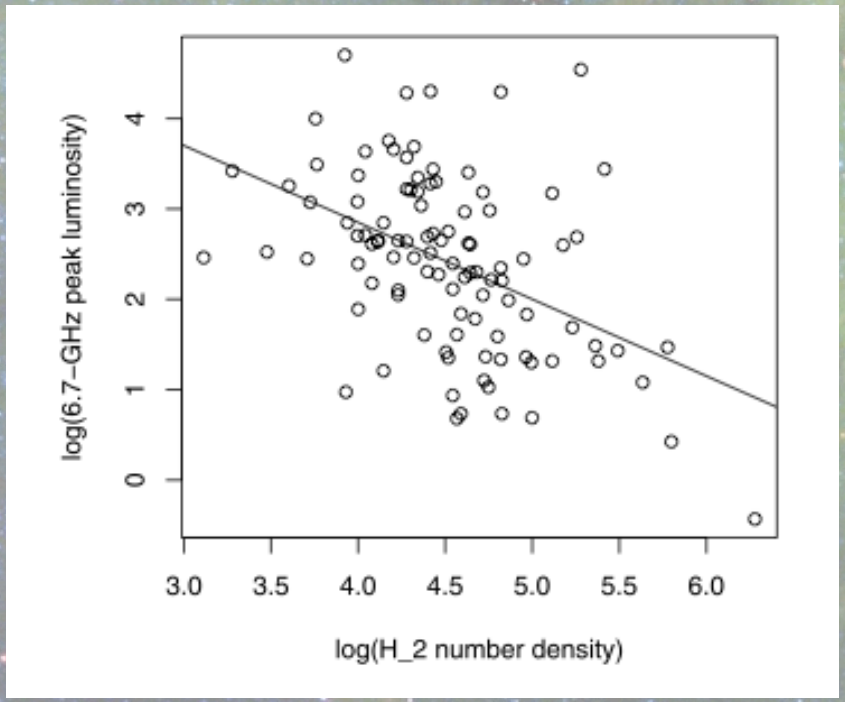
Are Rare Masers Useful?



Breen et al. (2010) demonstrate that the luminosity of 6.7 GHz methanol masers increase with decreasing density (or increasing temperature).

- There are approximately a dozen rare (<30 sources) class II methanol maser transitions (e.g. 23.1 & 107 GHz).
- Rarity suggests either unusual sources, or short-lived phases.
- Pumping models suggest that these rarer masers favour higher dust temperatures and lower densities (likely a later evolutionary phase).

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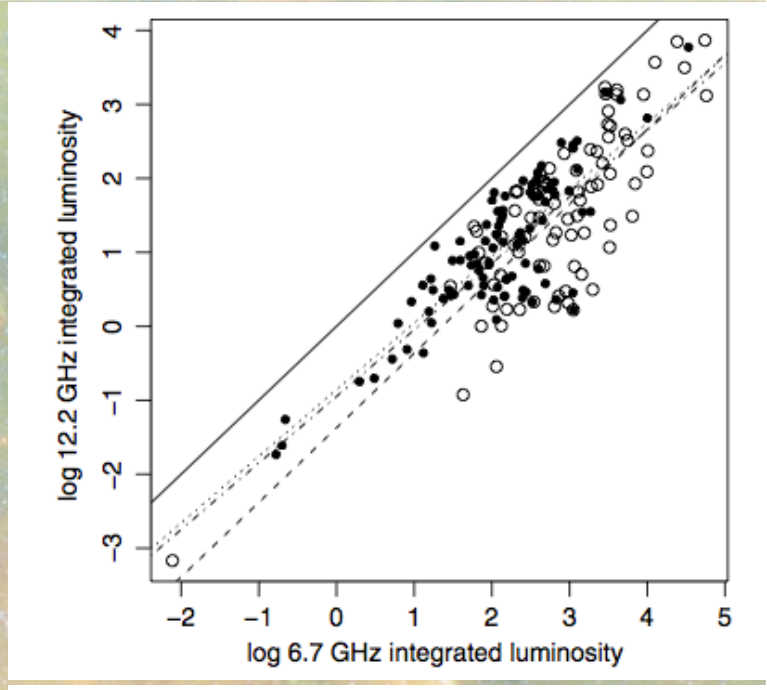
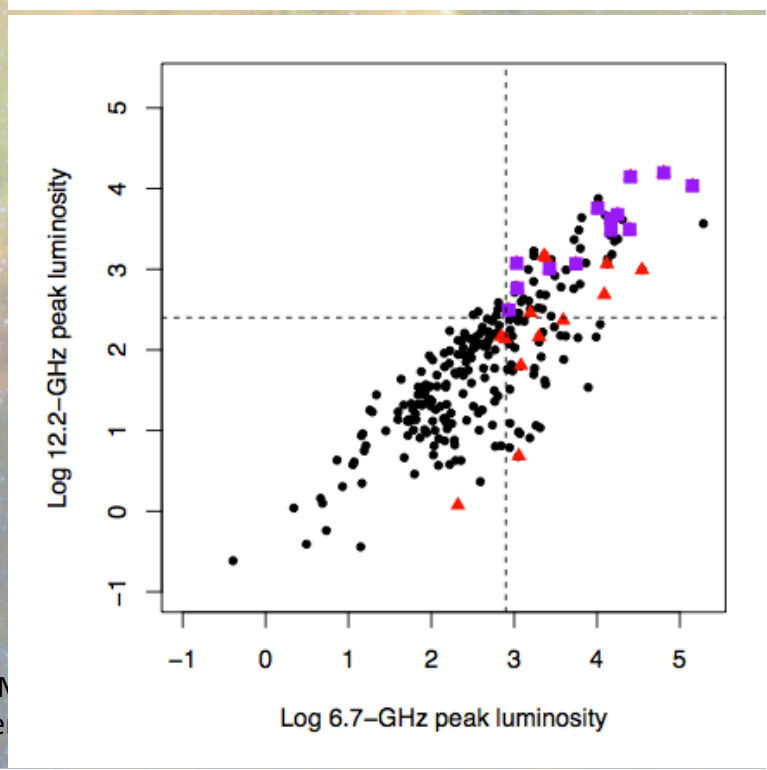
- The 6.7 and 12.2 GHz maser luminosities are correlated, and OH masers are preferentially associated with the most luminous (Breen et al. 2011).
- Recent Mopra Observations have shown that both the 37.7 GHz methanol masers (purple squares) and the 107 GHz methanol masers (purple squares and red triangles) are only observed towards the most luminous 6.7 GHz methanol masers (Ellingsen et al. 2011)





Horsemen of the Apocalypse

- Combining our results with the MMB survey and the estimated 6.7 GHz methanol maser lifetime 25000-45000 (van der Walt 2005), we can estimate the lifetime of the 37.7 and 107 GHz phases.

Horsemen of the Apocalypse by Victor Vasnetov, 1887

107 GHz methanol masers: 2000-7000 years

37.7 GHz methanol masers: 1000-4000 years

In both cases, just prior to the cessation of methanol maser activity

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Class I methanol – a spanner in the works?

- Some class I methanol masers are associated with outflows. For example class I masers are observed towards 55% of EGOs (Chen et al. 2011).
- Some class I methanol masers are associated with OH masers and other tracers of later phases of high-mass star formation (Voronkov et al. 2010).
- Some class I methanol masers are known to be associated with low-mass star formation (Kalenski et al. 2010).
- We really need a sensitive unbiased survey for class I methanol masers to try and sort out

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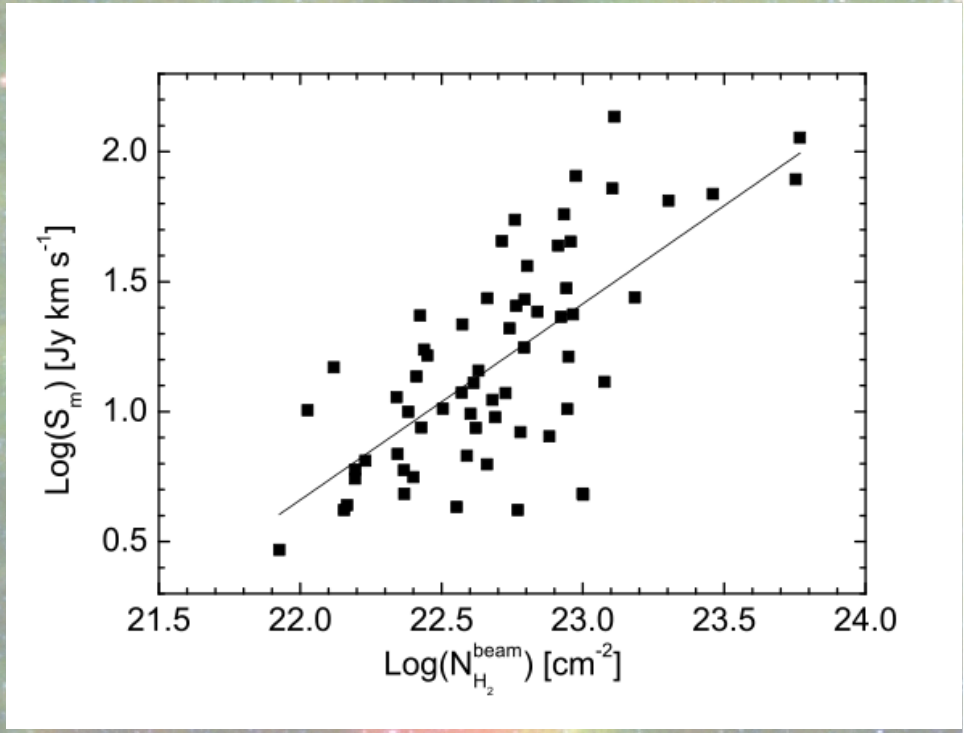
- The integrated flux density of 95 GHz class I methanol masers is correlated with the column density of the associated dust emission (Chen et al. 2012, in prep).
- These observations are consistent with the class I masers being associated with lower mass sources than class II masers, but also with them being associated with younger sources.



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Conclusions

- Interstellar masers do appear to give a generally reliable timeline.
- Some transitions are confined to relatively short evolutionary phases – but are these phases interesting for other reasons?
- Class I methanol and water masers still pose a lot of questions. The most direct way of answering those questions is with unbiased searches (i.e. a 22 GHz multibeam on Parkes)

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