Fractionation in GRB host galaxies

Sarolta Zahorecz

MTA CSFK Konkoly Observatory, Budapest

in collaboration with L. Viktor Toth (Eötvös University, Budapest), Christian Henkel (MPIfR, Bonn), Bunyo Hatsukade (NAOJ, Tokyo)

Zsolt Bagoly (Eötvös University), Lajos, G. Balazs (MTA CSFK Konkoly Observatory), Istvan Horvath (National University of Public Service, Budapest), Sandor Pinter (Eötvös University), Istvan I. Racz (Eötvös University)

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Outline

- GRBs & their host galaxies
- cold ISM content, molecular line observations of the hosts
- isotope ratios in extragalaxies
- ^{13}CO observability of the host galaxies

Gamma-Ray Bursts (GRBs)

- the most energetic explosions in the Universe
- types according to average duration of gamma emission:
  - Short (SGRB, <t>~0.3 s) and long (LGRB, <t>~30s)
    - a double neutron star or a neutron star and a black hole binary merges
    - a massive star undergoes core collapse (hypernova)
- LGRBs → trace galaxies with ongoing star formation
- New tool to trace star-formation in the distant universe?
  - GRB detection up to z~8 (GRB 090423)
- Need to establish the link between GRBs and star-forming activity:
  - understand the molecular content of GRB host galaxies

(Woosley & Bloom 2006)

GRB afterglows

- after the initial burst of gamma rays → object still observable at less energetic wavelengths, smoothly varying, lower energy radiation for several days
    - GRB afterglow
- X-ray afterglow – catalogued spectra (e.g. Swift-XRT GRB Catalogue at UKSSDC)
- only 50% optical and radio afterglow
    - Dark burst: not detected in optical
- Detailed study of afterglows, e.g. first molecular gas detection in a GRB host galaxy, GRB 080607 (Prochaska+ 2009)
    - H_2 absorption with Keck spectroscopy

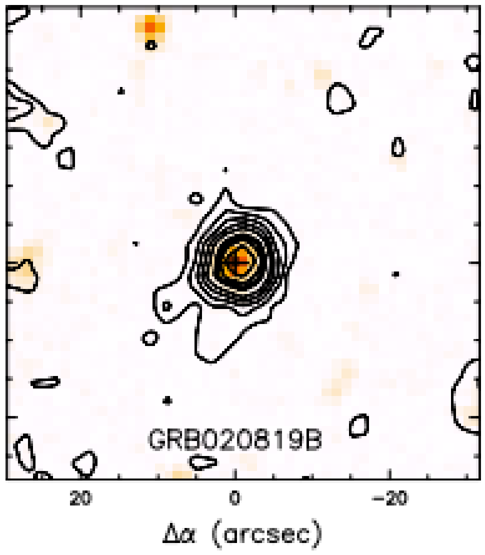
Massive host galaxies of LGRBS - post merger SF?

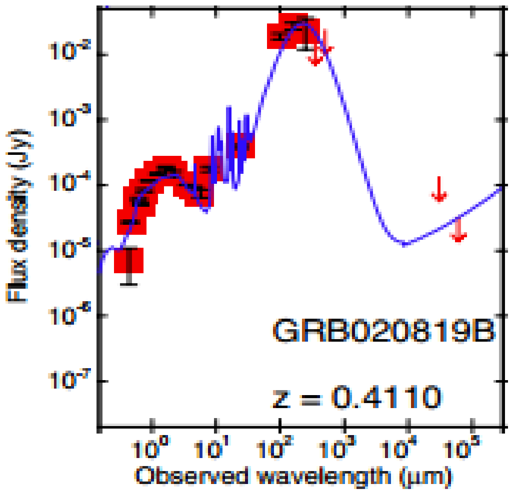
- LGRB hosts: typically metal poor galaxies of intermediate mass (Levesque+ 2010) with high star forming rate (SFR), and low opacity
- few atypical host galaxies with total stellar mass over $10^9 M_\odot$, showing significant star forming rate (SFR) and opacity (Hatsukade+ 2014)
- LGRB model: the progenitor is formed in a low metallicity environment
- a recent infall (cannibalism) could be responsible for the enhanced star formation at the location of the GRB
- the GRB progenitor is one of the massive stars of the expected starburst

--► GRBs may also be used as tracers of wet galaxy mergers (Toth+ 2016)

LGRB host galaxies - observations

- better known in the low-z regime (z <~ 1.5):
  - typically low-mass, young, star-forming blue galaxies with low dust extinction (e.g. Fruchter+ 2006; Savaglio+ 2009)
- Dark GRBs in massive, star-forming galaxies with red colors, high extinction and large star formation rates (e.g. Perley+ 2013).
- Hunt+ 2014, Herschel dust emission study of 17 hosts

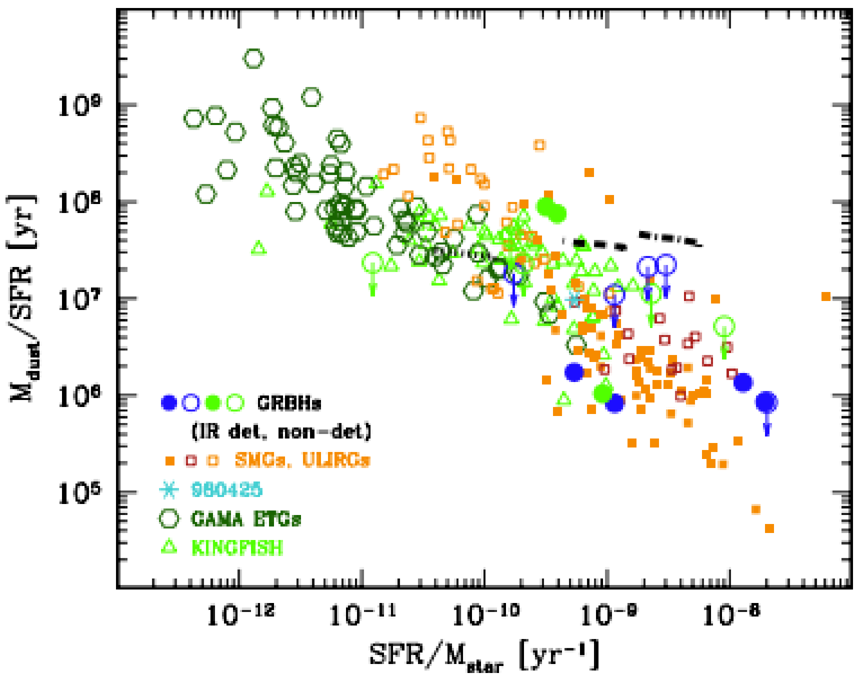




Herschel survey of GRB hosts

- SED fitting with templates: numerical calculations of radiative transfer within a galaxy (a triaxial system with diffuse dust and dense molecular clouds - sites of star formation)

- Z >~0.5:
  - high sSFRs
  - high dust-to-stellar mass ratios
  - similar in terms of M_{star}, SFR, and A_V to other populations
  - M_{dust}/M_{star} ratios and sSFR
    - similar to SMGs and ULIRGs



Hunt+ 2014

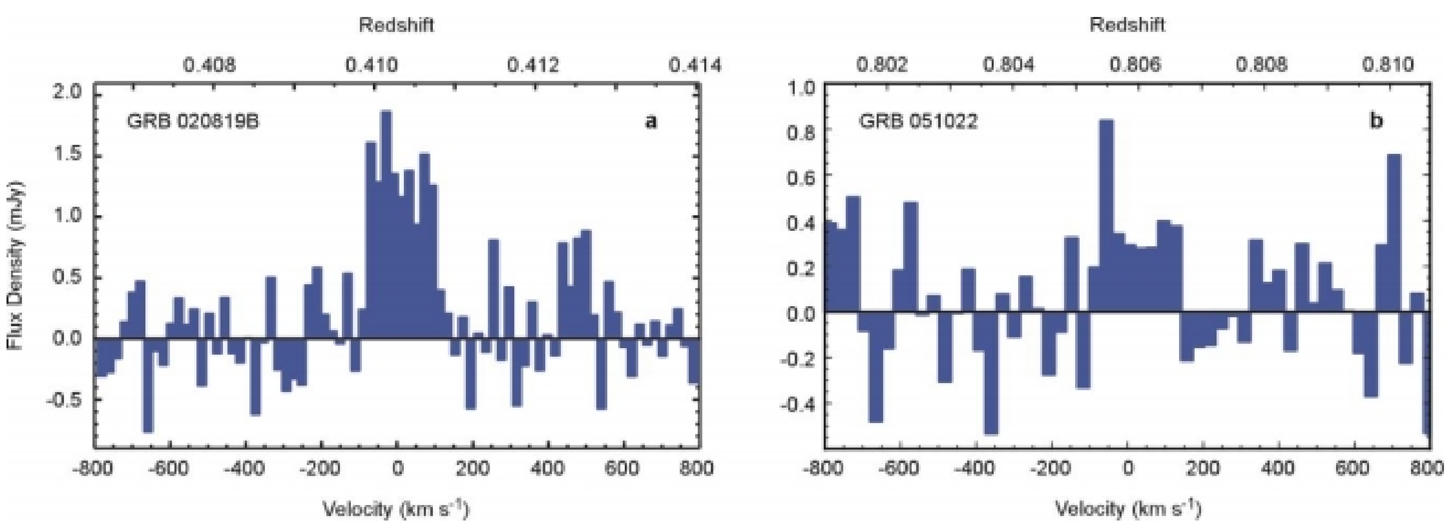
Molecular gas in host galaxies

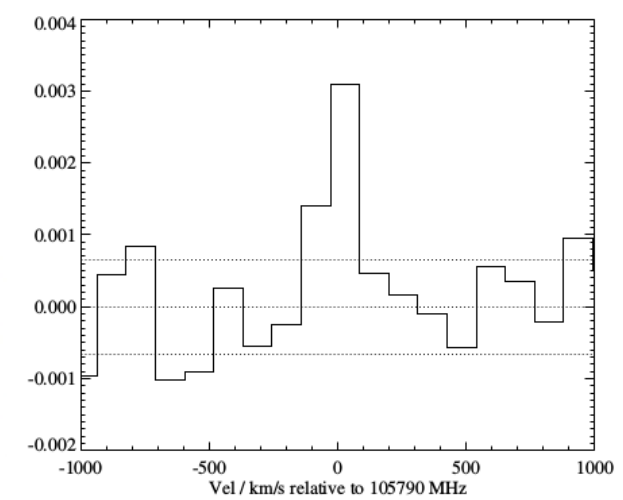
- Long GRB → massive star formation → star forming host galaxies
  - Predicted to be rich in molecular gas (Draine & Hao, 2002)
- Study of GRB afterglows:
  - Absence of absorption signatures → concerns
  - Possible explanations:
    - Unusually low metallicity (Ledoux+ 2009)
- Alternative approach:
  - Direct emission of CO in the far-infrared (Hatsukade+ 2007, 2011, Stanway+ 2011, Endo+ 2007)
  - GRB980425 (z = 0.0085), GRB030329 (z = 0.17), GRB000418 (z = 1.1), GRB090423 (z = 8.2)

Non - detections

CO detection in host galaxies

- ALMA and NOEMA observations
- Hatsukade+ 2014:
  - GRB020819B and GRB051022, z=0.41 and z=0.81
- Stanway+ 2015
  - GRB080517, z=0.09





^{13}C vs. ^{12}C production

- ^{12}C is formed in and ejected from high-mass stars (“primary”)
- ^{13}C is a “secondary” species produced in low-to-intermediate mass stars (Wilson & Rood 1994).
- ^{13}CO is associated with the later stages of star formation → age can play a role in determining the $^{12}CO/^{13}CO$ ratio
- Large $[^{12}C]/[^{13}C]$ variation is expected:

$$20 < [^{12}C]/[^{13}C] < 140 \text{ (Martin+ 2010)}$$

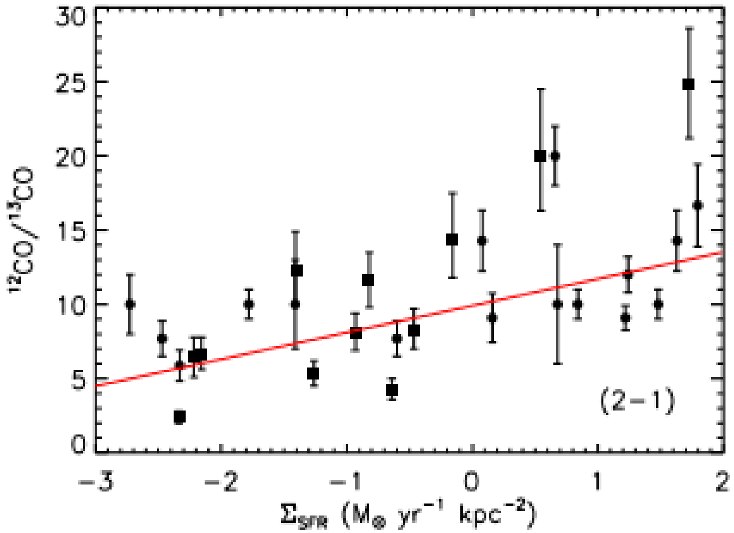
- actual value may reveal SF history

$^{12}CO/^{13}CO$ enhancement

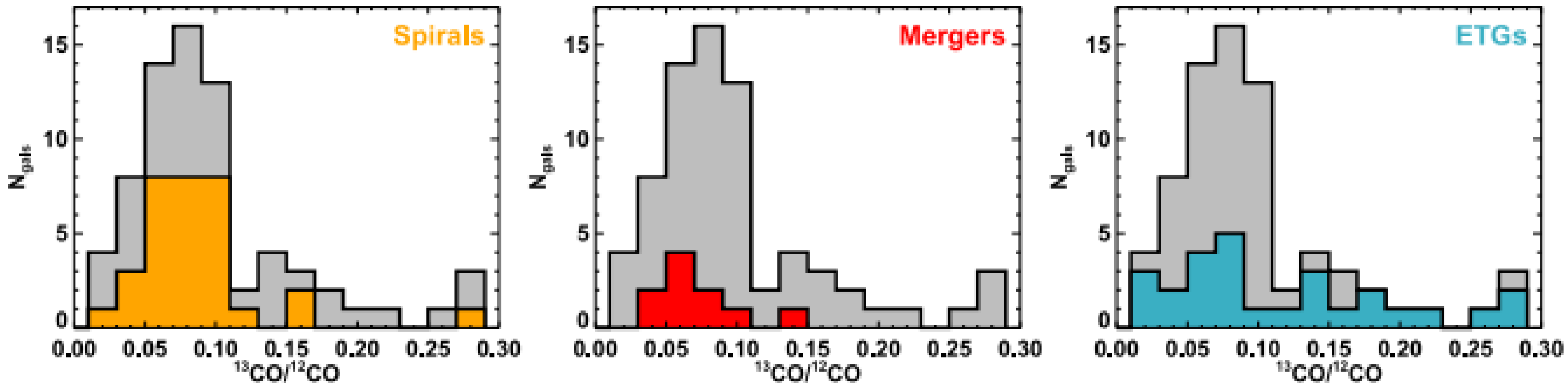
- Higher $^{12}CO/^{13}CO$:
  - systems with many newly forming stars (Henkel+ 2010)
  - in galacies with lower metallicity, i.e. ULIRGs (e.g. Henkel+ 1998; Meier & Turner 2004, Genzel+ 2012)
  - in regions of recent bursts of star formation, particularly of massive stars (Casoli+ 1992)
  - infall of unprocessed gas from the disk into the nuclear region of starbursts
- Lower value for $^{12}CO/^{13}CO$:
  - chemical fractionation (Watson+ 1976)

$^{12}CO/^{13}CO$ measurements

- Davis+ 2014, for nearby galaxies
  - $^{12}CO/^{13}CO$ intensity ratio varies systematically as a function of the star formation rate surface density and gas surface density



- Alatalo et al. 2015, survey of early type galaxies



CO study in GRB hosts

- Published: ^{12}CO observation of 3 hosts, only 1-1 transition

- Next steps:
  - testing several more LRGB host galaxies for CO lines
  - multiple transitions of ^{12}CO

    → excitation conditions
  - ^{13}CO observation

    → star-formation history, infall

Observability of ^{12}CO and ^{13}CO

- ^{12}CO, ^{13}CO lines at different redshifts, observable with ALMA, NOEMA

Name	z	CO (1-0)	CO (2-1)	CO (3-2)	CO (4-3)
GRB080517	0.09	105.75	211.50	317.24	422.97
GRB020819B	0.41	81.75	163.50	245.25	326.98
GRB051022	0.81	63.69	127.37	191.05	254.72

- ^{12}CO transitions at different redshifts, as observed with ALMA, integrated line flux [Jy km/s]:

Name	z	CO (1-0)	CO (2-1)	CO (3-2)	CO (4-3)
GRB080517	0.09	0.39 ± 0.05			
GRB020819B	0.41			0.53 ± 0.04	
GRB051022	0.81				0.19 ± 0.03

^{12}CO and ^{13}CO proposals

- Reported L'_{CO}(1-0) values: 1.5×10^{8} – 4.9×10^{9} K kms^{-1} pc^{-2}
  - ALMA Band 2,3 / NOEMA Band 1 for ^{12}CO transition
  - ^{12}CO peak line intesities S_{peak}~1.5 mJy
    - on-source time with ALMA / NOEMA ~ 1 / 10 hrs

- ^{13}CO ?
  - (1-0) lines are in NOEMA Band 1 / ALMA Band 2,3 for low z
  - expected $S_{peak}(^{13}CO) = 0.1 \pm 0.05\ S_{peak}(^{12}CO) \sim 100$ μJy
  - on-source time with NOEMA: t_{ON} ~ 50-100 hrs?

Conclusion

- Massive host galaxies of LGRBs – post merger SF
- ^{13}CO detection to reveal star formation history
- Interferometry is needed for resolution
- Large project for any available interferometers

Looking for collaborators to detect ^{13}CO in GRB hosts with brightest L'_{CO}