The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2246-35

Workshop on Cosmic Rays and Cosmic Neutrinos: Looking at the Neutrino Sky

20 - 24 June 2011

Prospects for the detection of cosmic accelerators with neutrino telescopes

Alexander KAPPES

DESY
Germany

Detecting Cosmic Accelerators with Neutrino Telescopes

and

GRB Results from IceCube

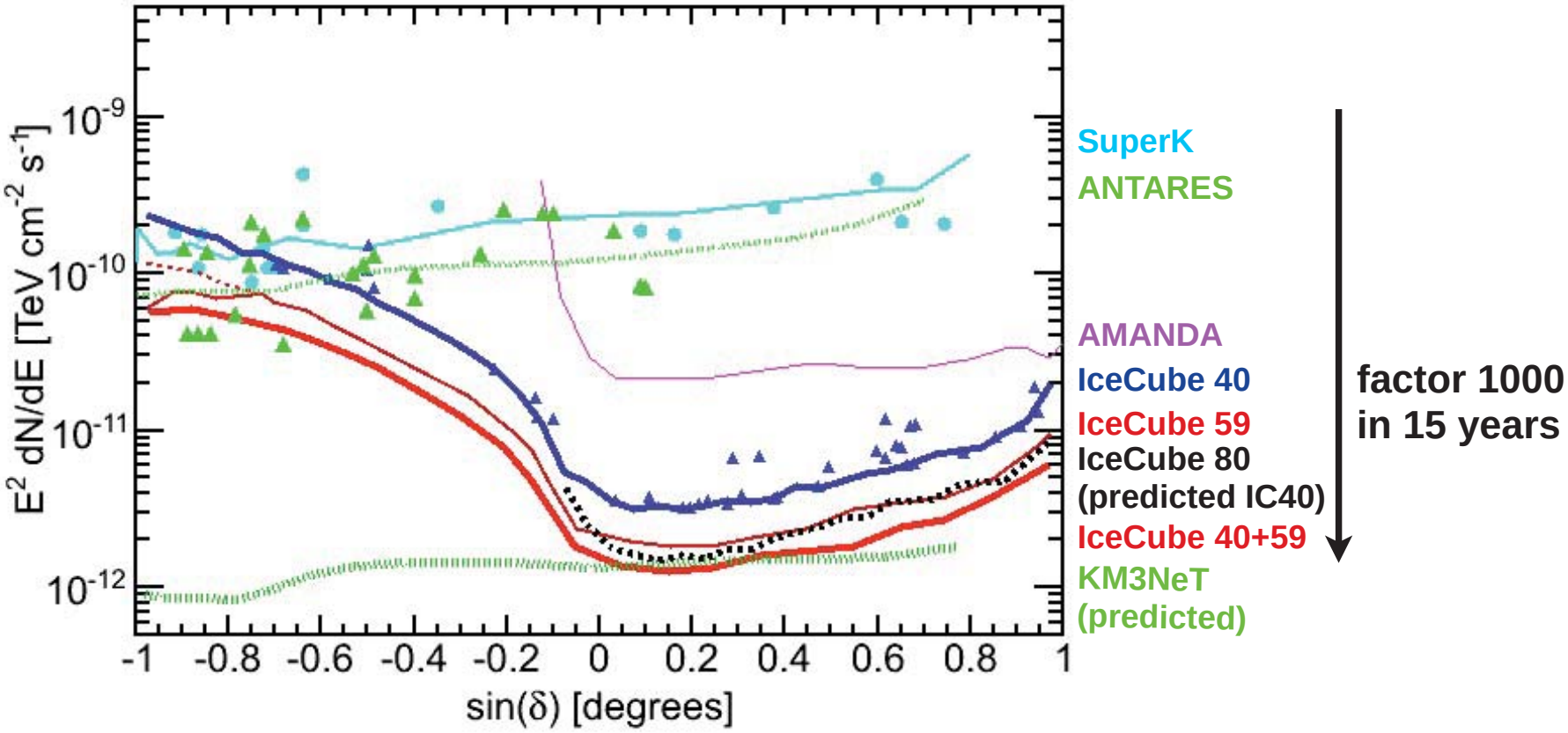
Alexander Kappes
NUSKY 2011
Trieste, June 24, 2011

HUMBOLDT-UNIVERSITÄT ZU BERLIN

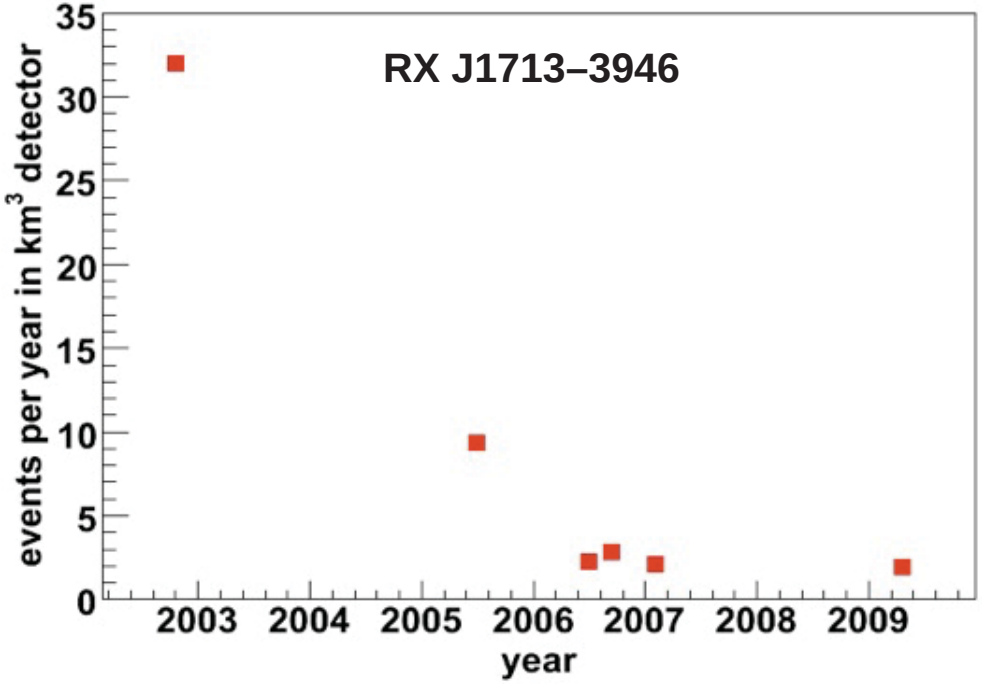
Outline

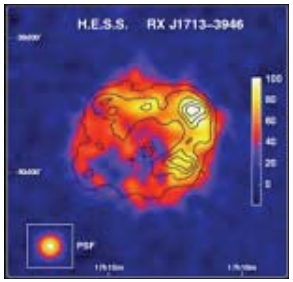
- Some thoughts on the detectability of Galactic sources
- Extragalactic sources
  - Recent IceCube results on GRBs
  - IceCube follow-up programs

Sensitivity development



Development of flux predictions: An example

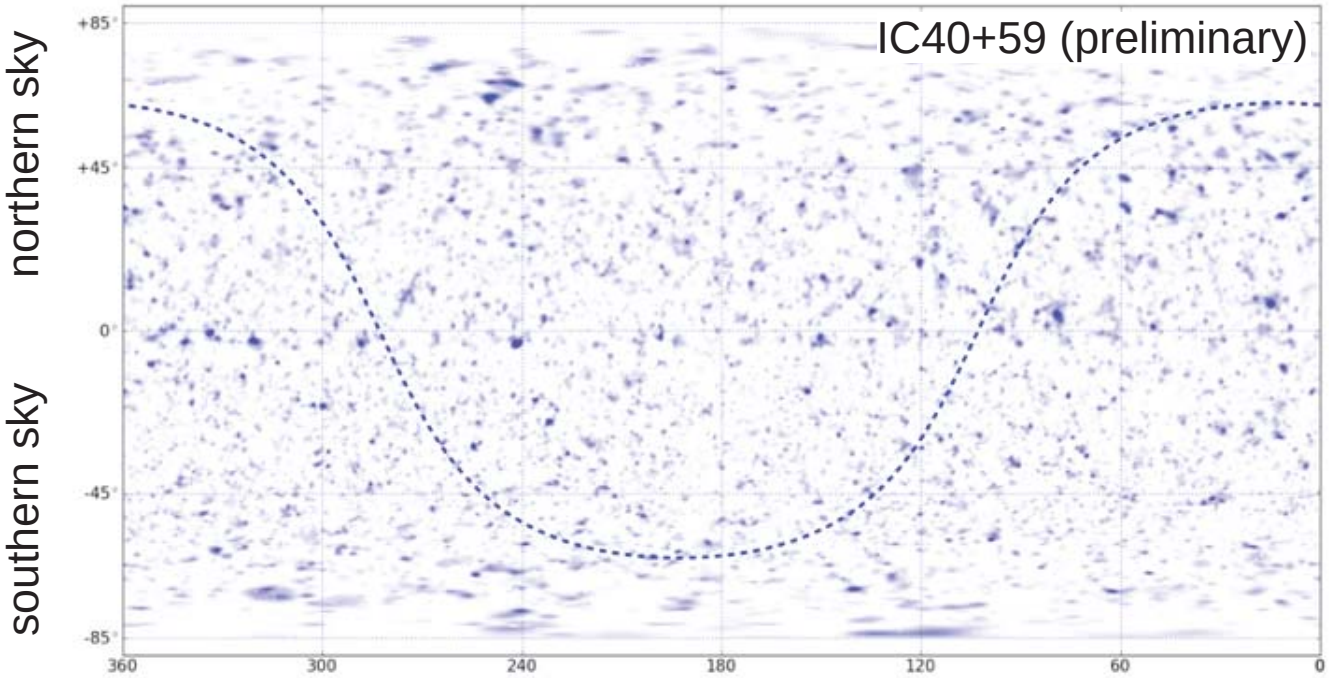




Alvarez-Muniz & Halzen (2002)
Costantini & Vissani (2005)
Distefano (2006)
Kistler & Beacom (2006)
AK et al. (2007)
Morlino et al. (2009)

- Early predictions too optimistic (but correctly calculated!)
  (wrong γ-ray measurements, no ν oscillation, no cut-offs)
- Now expecting (1 km^3, E_ν > 1 TeV): 1 – 3 evt yr^{-1}
  (for pure hadronic acceleration)

Most sensitive look at the (steady) neutrino sky



- Highest fluctuation: p-value = 0.67 after trials; in southern sky
- Data corresponds to almost 1 year IC86
  → if there is a source it takes quite long to become significant
  (improved angular resolution will help)

Trial factors in steady all-sky searches

- Difficult to see a (steady) source in the all sky search
- Trial factor for IC40+59: 3×10^4 ($4\sigma \rightarrow 0.5\sigma$)
  $\rightarrow$ pick the right sources
- What are the right sources?

Galactic sources: Northern hemisphere

- **IceCube source list (IC40+59)**

point-like hyp. preliminary

Source	Type	p-value
TYCHO	SNR	--
Cas A	SNR	--
MGRO J1908+06	SNR	0.38
MGRO J2019+37	SNR	--
IC443	SNR	--
Geminga	Pulsar	--
Crab Nebula	PWN	--
Cyg OB2	UNID	--
Cyg X-1	MQSO	--
Cyg X-3	MQSO	--
LSI 303	MQSO	--
SS433	MQSO	0.48

periodic analyses? (IC40: CygX3 p-value 0.02 pretrial)

"--" = negative fluctuation

IceCube stacked searches (IC40)

extension taken into account

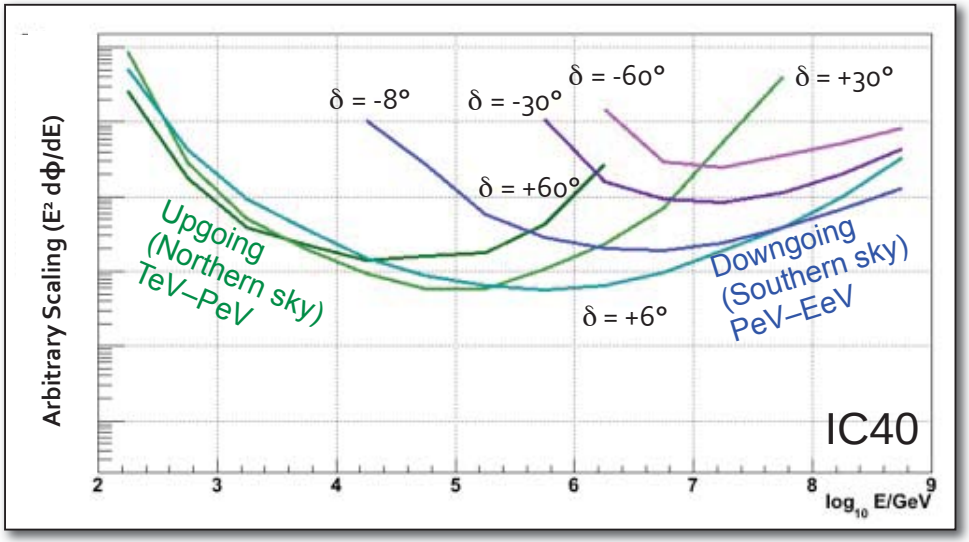
Source	p-value	Remark
Milagro 17 srcs	0.32	
Milagro 6 SNR	0.02	posteriori

unblinding for IC40+59 soon

Up to now, all suspects have good alibis (high p-value) !

Galactic sources: Southern hemisphere

- IceCube sensitive to energies > 1 PeV (not likely Galactic origin)

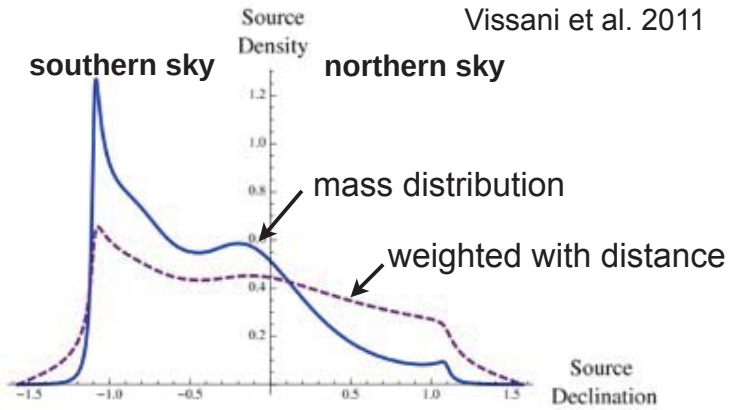


- ANTARES 2007-08:
  - 14 sources (RXJ1713, Vela Junior, Gal.Center, LS5039 . . .)
  - Best p-value: 0.07 (GX339, posttrial)
  - Significant sensitivity improvement expected in next years but discovery unlikely

Galactic sources: Southern hemisphere

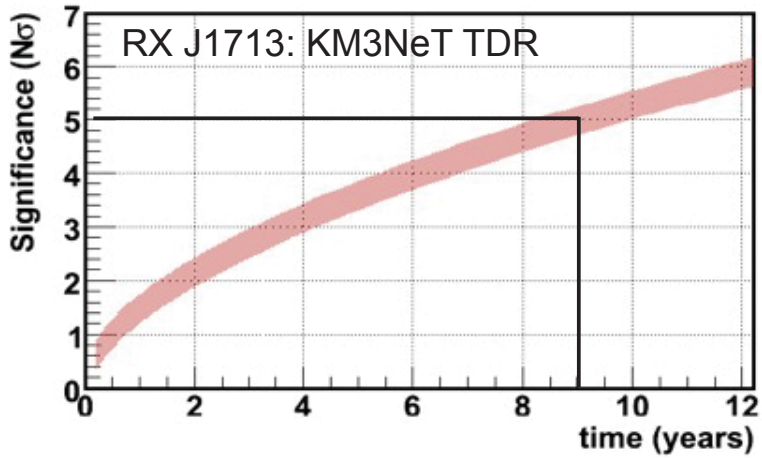
KM3NeT would open new possibilities . . .

Vissani et al. 2011



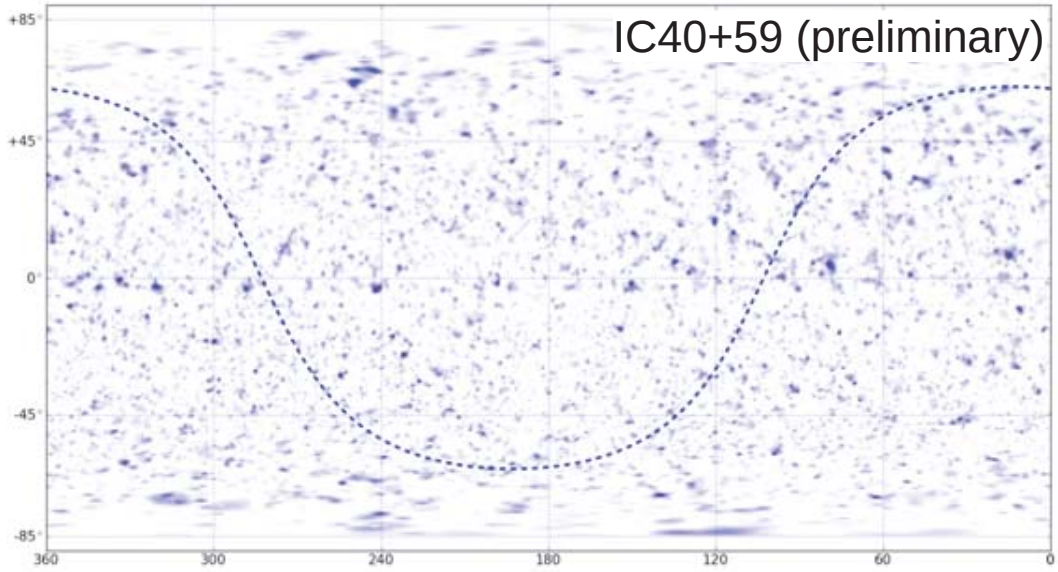
Example RX J1713:

- Neutrino flux from gamma-ray flux (purely hadronic)
- Simulation of extended source (flat disk)
- Full Monte Carlo simulation of detector response (signal and background)
- Detection possible in 5-10 years



Galactic sources

. . . but currently, IceCube is in the driving seat !

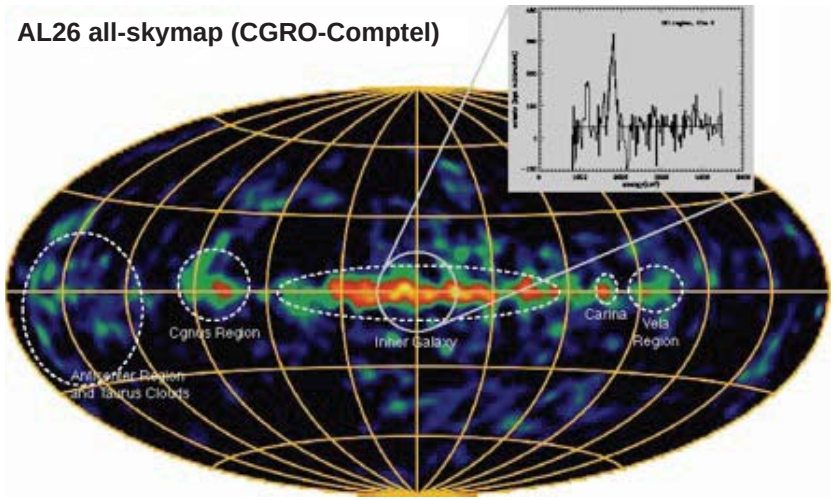


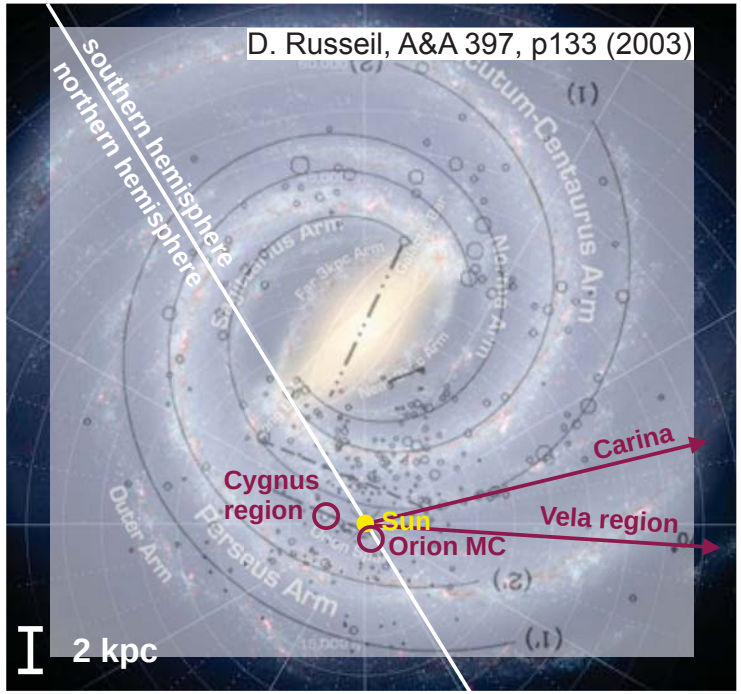
- Are we looking at the wrong sources?
- How large are the potential sources?
- Are the individual fluxes too small?
  → Do we have to use more stacking?
  Which sources?

Galactic sources

- Do we concentrate too much on high-energy gamma-ray sources?
  - IACTs do have problem with extended sources
  - and are most sensitive at lower energies

  } → Milagro, HAWC
- Francis: look at star forming regions!



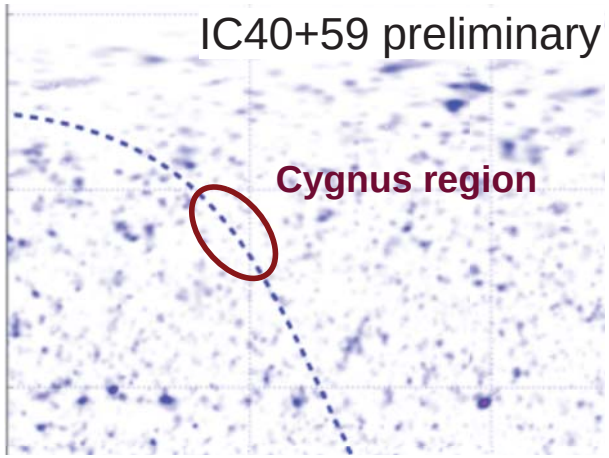


Galactic sources

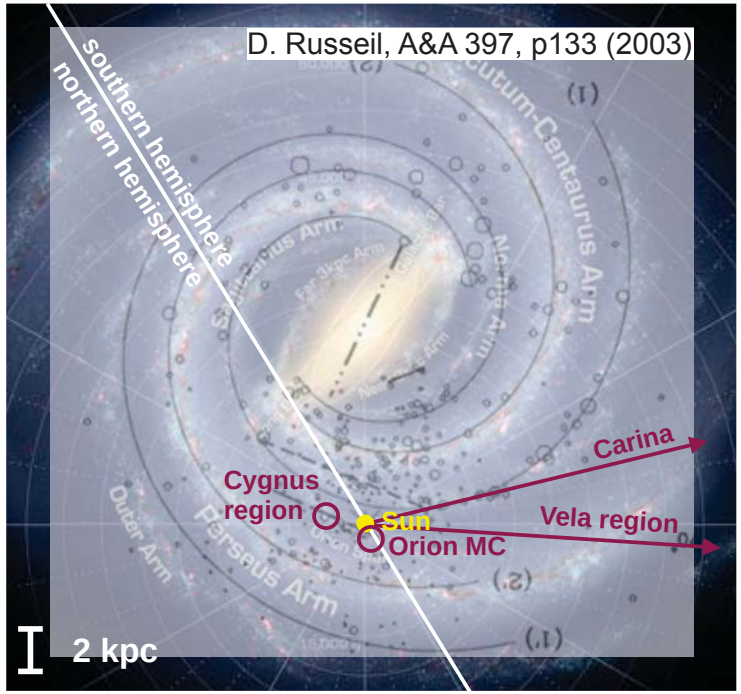
- Do we concentrate too much on high-energy gamma-ray sources?
  - IACTs do have problem with extended sources
  - and are most sensitive at lower energies

  } → Milagro, HAWC
- Francis: look at star forming regions!

AL26 all-skymap (CGRO-Comptel)



→ Cygnus region not very cooperative up to now



Are the Galactic sources still active?

Possible (depressing) alternative scenario?

- Source (e.g. Central black hole) produced cosmic rays 10^7 years ago during “short” period
- Cosmic rays stored in Galactic magnetic field
- Neutrinos have escaped Galaxy a long time ago

  → neutrinos “only” from CR interaction with Molecular clouds uncorrelated with CR sources

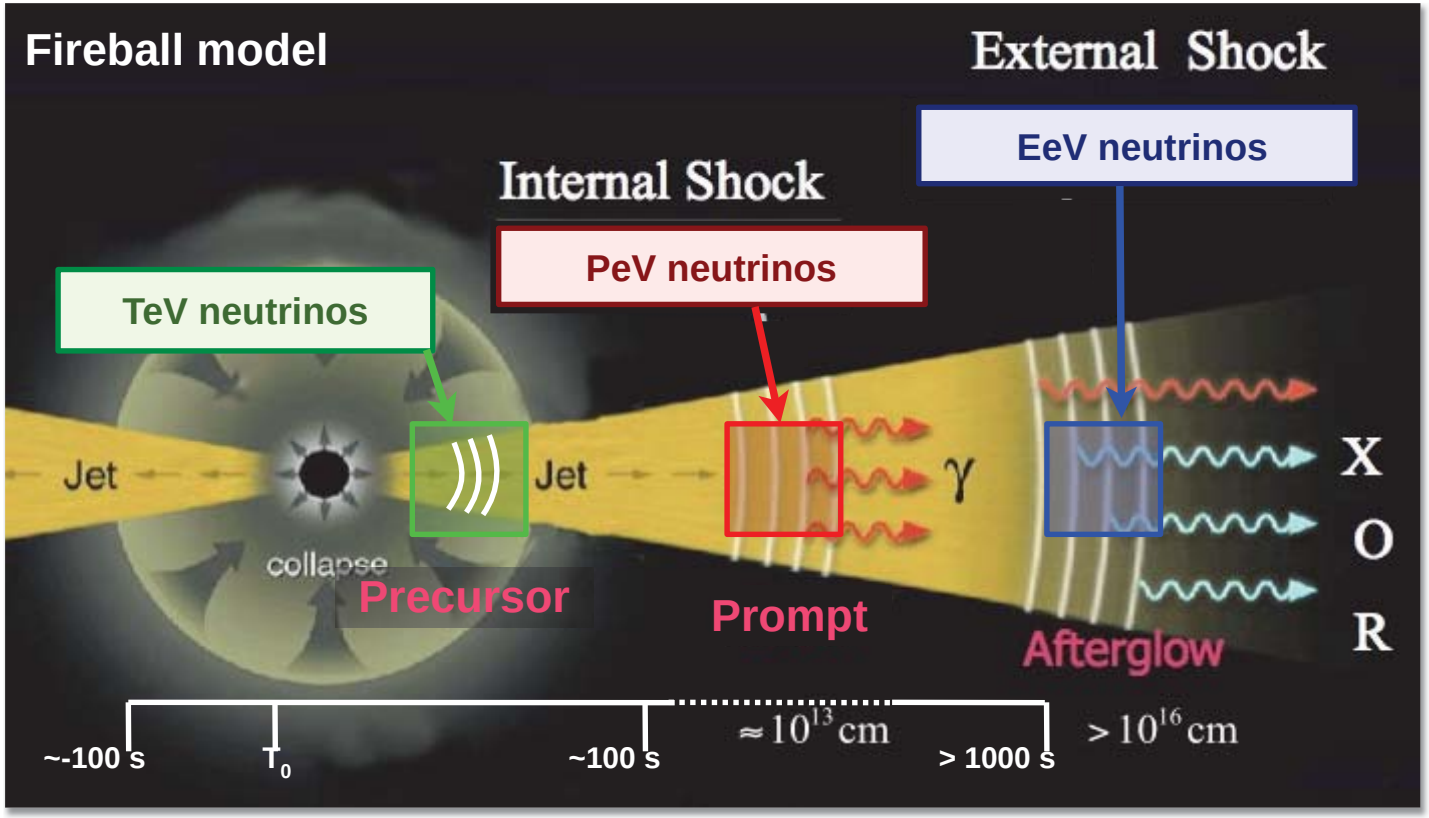
Extragalactic sources

- A lot of potential sources are variable
  → already single large flare might be detectable
- But flux predictions only order of magnitude

- Most extreme “variable” sources:

Gamma-ray bursts

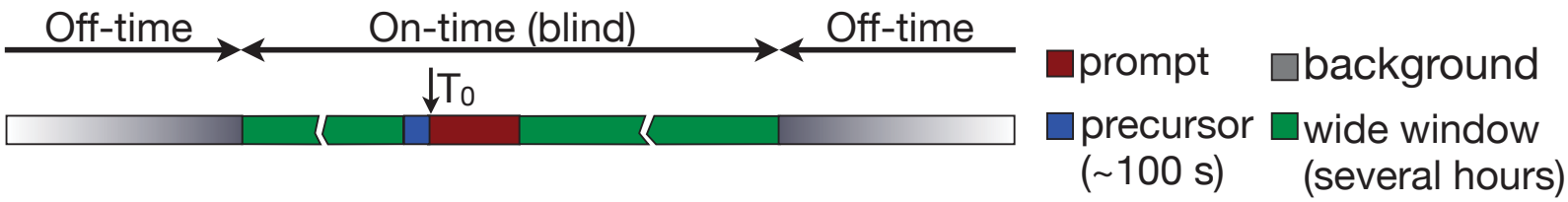
Neutrinos from GRBs



Smoking gun evidence for hadronic acceleration → sources of UHECR

GRBs with IceCube

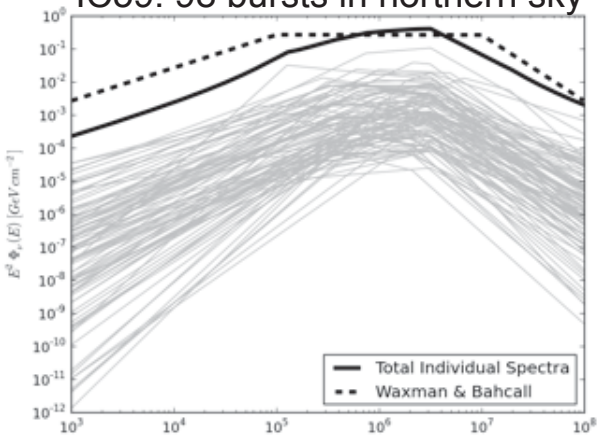
- GCN-satellite triggered searches



very low background → 1 event can be significant !

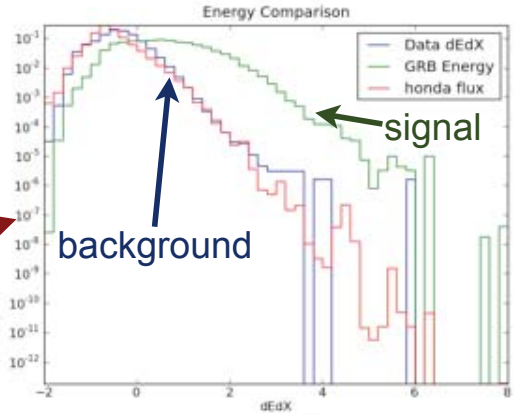
- Individual modeling of neutrino fluxes (fireball model)
- Measured parameters: γ spectrum, (redshift)
- Average parameters: Γ_{jet} (316), t_{var} (10 (1) ms), L_{iso} ($10^{52\,(51)}$ erg), ε_B *(0.1)*, ε_e *(0.1)*, $f_{e/p}$ (0.1)

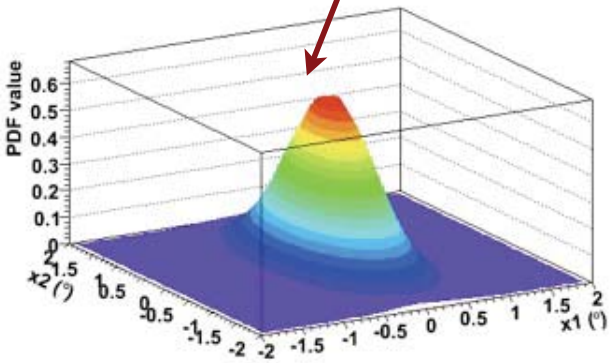
IC59: 98 bursts in northern sky

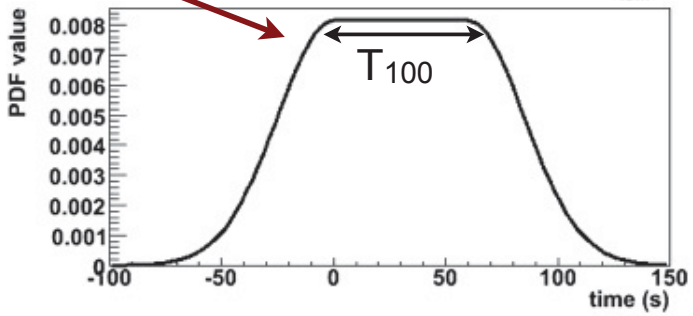


Prompt GRB analyses: Some technical details

- Events after quality cuts (BDT) → Likelihood function
  - $\ln(L) = -n_s - n_b + \sum_i \ln\left(n_s\, S_i(\vec{x}) + n_b\, B_i(\vec{x})\right)$
  - $S_i^{tot}(\vec{x}, t, E) = PDF_i^{space}(\vec{x}) * PDF_i^{time}(t) * PDF_i^{Energy}(E)$







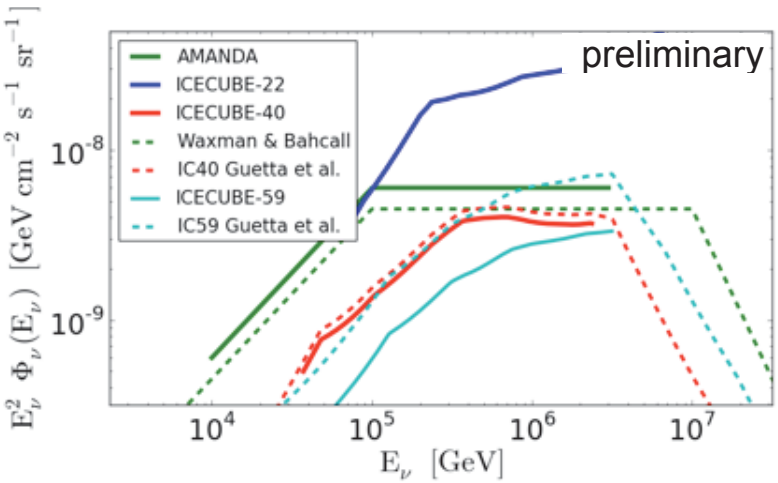
  - Background PDF accordingly (flat time PDF; azimuthal assym. included)

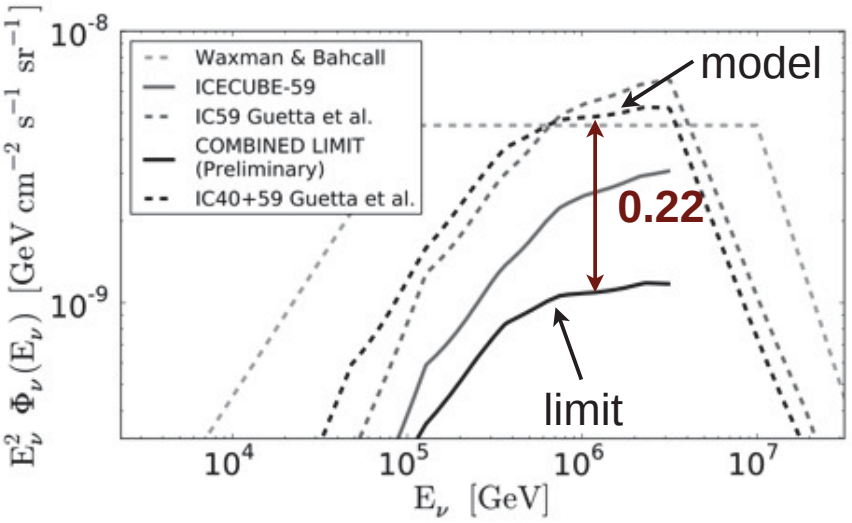
- Final likelihood ratio ($L(n_s)$ / $L(0)$): $\ln(R) = -n_s + \sum_{i=1}^{N} \ln\left(\frac{n_s\, S_i}{n_b\, B_i} + 1\right)$

GRBs: Limits on prompt emission

- 1.9 evts needed for ≥5σ (50% cases)
- IC59: No signal-like events found (expected 5.8)

  → limit (90% CL) factor 2 below model





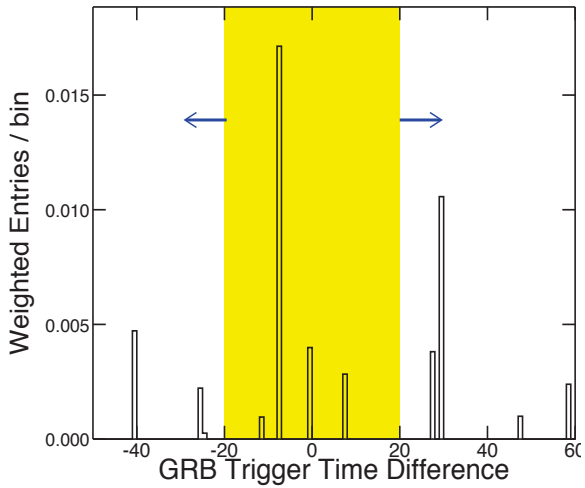
- Combination with upper limits from IC40

  → limit factor 5 below model

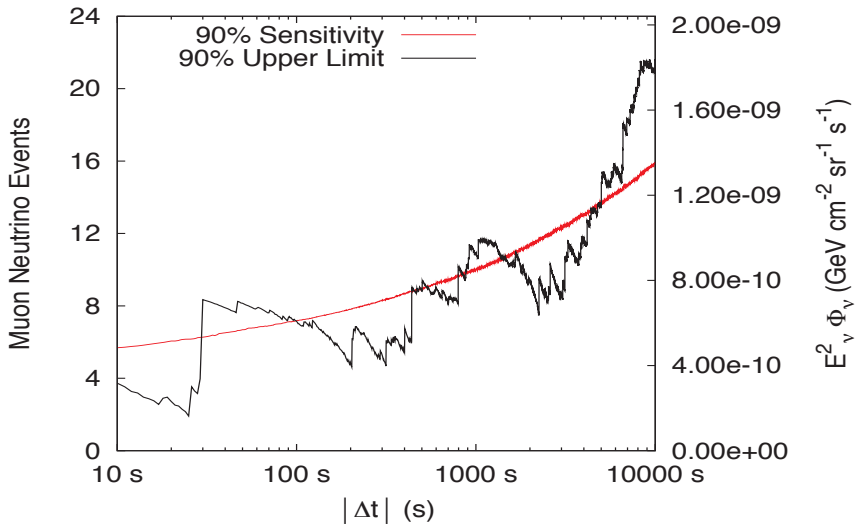
GRBs: Model independent search

Approach for “arbitrary” time scales:

- Start with search in small window and increase it consecutively
- Trial factor taken into account
- IceCube 40+59: No signal found



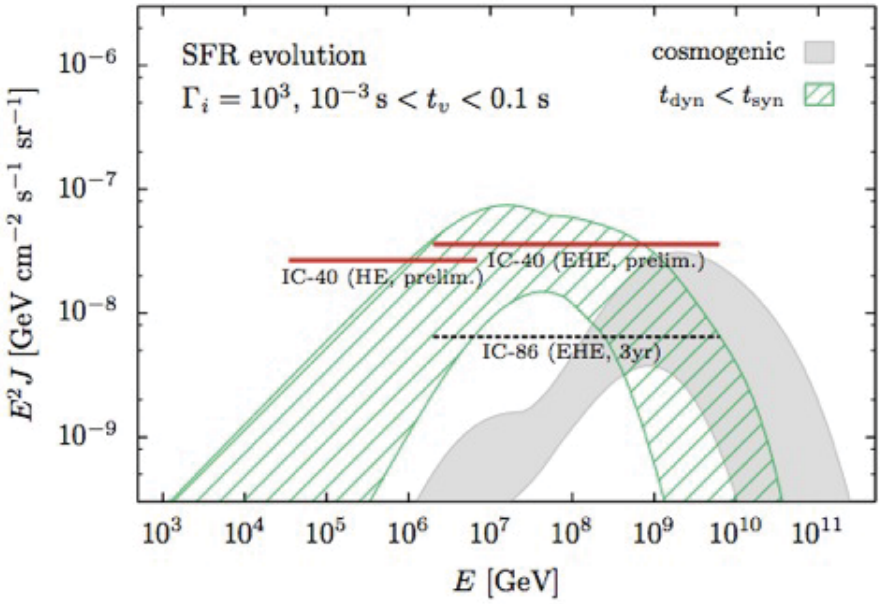
Limits E^{-2} ν_μ (90%CL; IC 40+59, preliminary)



GRBs and UHECRs

- Up to now no hint for neutrinos from GRBs
- Diffuse IC40 limit starts to disfavor GRBs as major sources of UHECR (see M. Ahlers' talk)

Ahlers et al. 2011



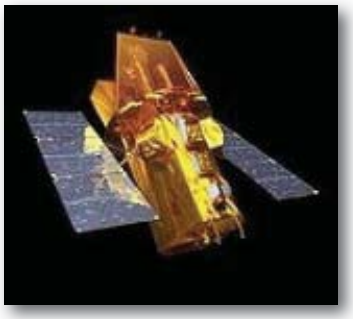
- But GRBs could still be neutrino sources !

Extragalactic sources

- **Other searches:**
  - **AGNs** → IC40+59: best p-value = 0.14 (PKS 1454-354 pretrial)
  - **Starburst galaxies** → IC40 (127 srcs): limit 60×model flux (p-value = 1)
  - **Galaxy clusters** → IC40 (5 clusters): limit 6×model flux (p-value = 0.78)

- **Alternative:** Trigger other instruments
  (IACTs, optical telescopes, X-ray satellites . . .)

MAGIC

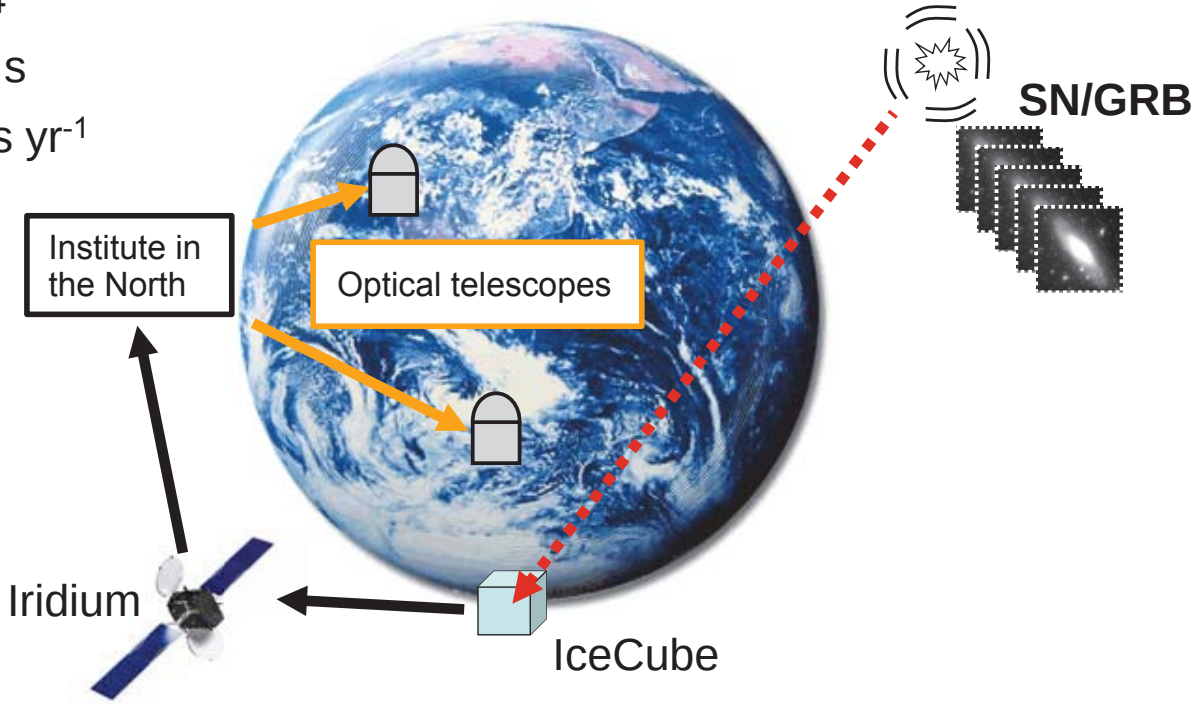


Swift

ROTSE, PTF

Optical follow-up

- IceCube multiplets trigger optical follow-up
  - angular window 4°
  - time window 100 s
  - 20−30 false alerts yr^{-1}



- Delay neutrino detection → start of optical observations: < 5 min (was 6.5−8 hours for <IC79)

ROTSE telescope network

- Fully robotic
- 24 hour (almost) all sky coverage
- Large field of view (1.85°× 1.85°)

McDonald, Texas

TUG, Turkey

H.E.S.S., Namibia

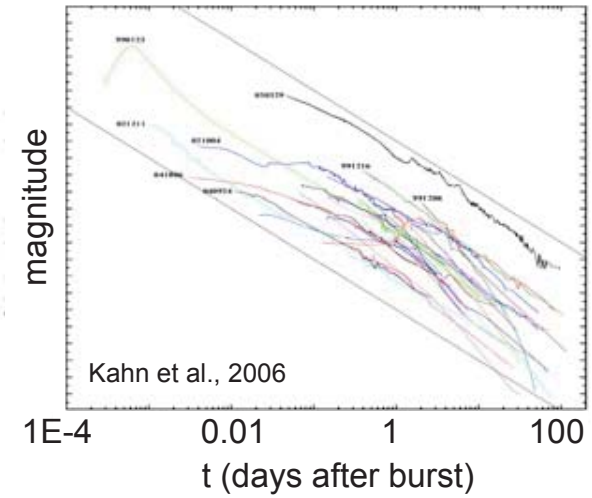
SSO, Australia

Observational program

- **Prompt observation (first night):**

  Search for fast decreasing GRB afterglow

  - 30× 60 s exposures



- **Follow-up observations (24 following nights):**

  Slowly rising supernova light-curve

  - 8× 60 s exposures every night (>12 days: every second night)

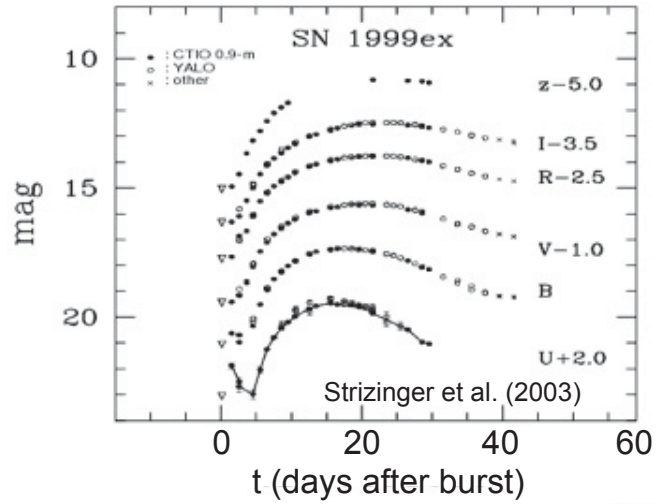
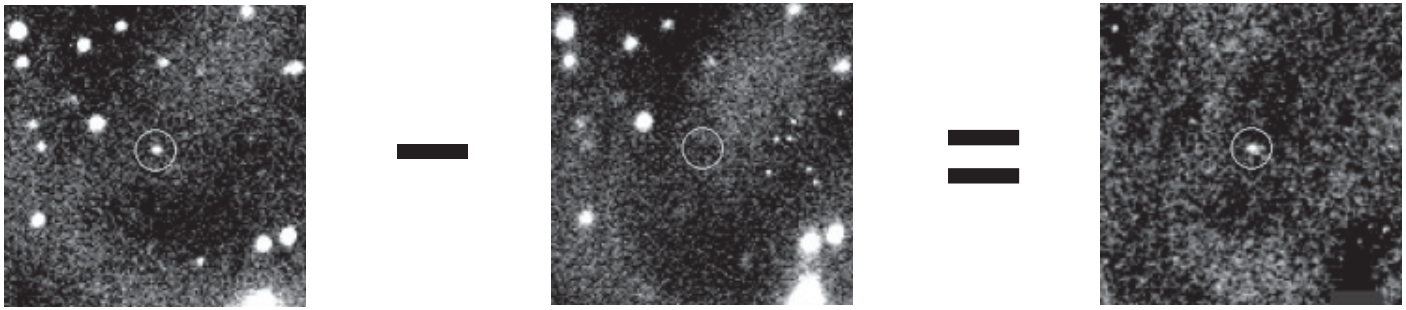


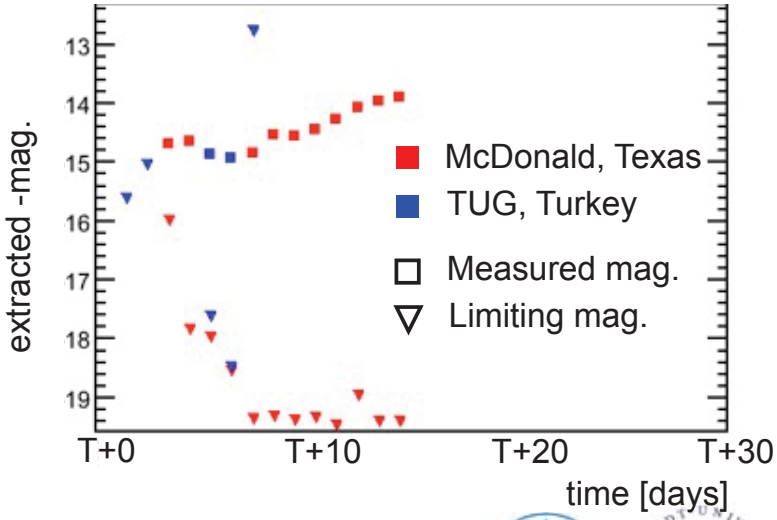
Image processing



„New“ „Reference“ Subtraction

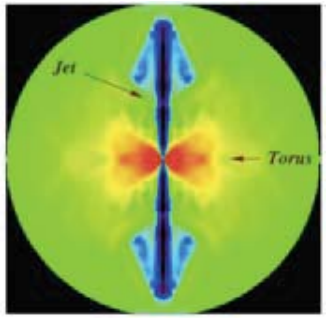
- Automatic candidate selection
- Test of algorithms with simulated SN light-curve
  (SN light-curve model by P. Nugent (SN1999ex))
- System successfully running since end of 2008

Simulated SN light-curve



Optical follow up: Results

- **Data set:** Dec 2008 to Dec 2009; 17 alerts with ROTSE observations → 0 SNe observed (0.04 accidental detections expected)

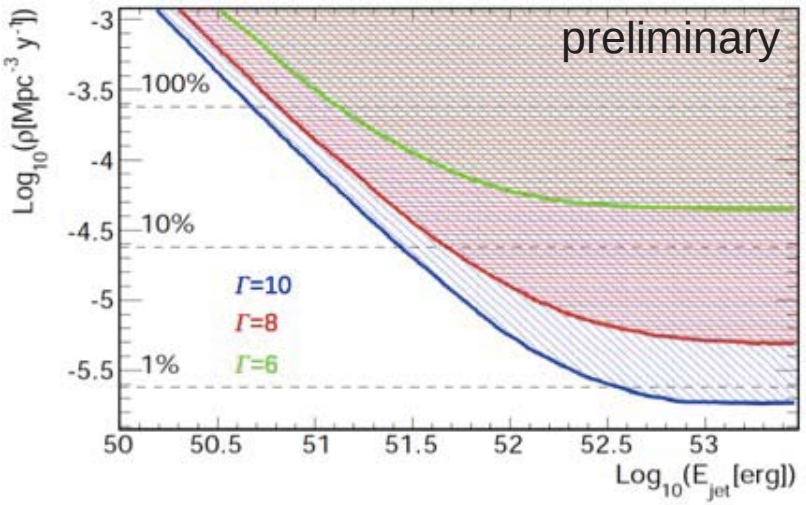


Mac Fadyen 2000

- **Model for neutrino spectrum:**
  "Slow jet" model (Ando, Beacom 2005)

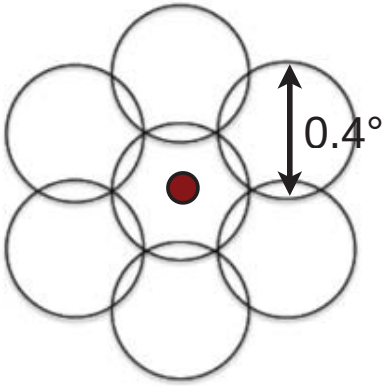
  Parameters:

  - density of SNe with jets ρ
  - jet energy E_{jet}
  - jet boost factor Γ



Swift follow up

- Motivation for X-ray observations:
  GRB afterglow / GRB and SNe shock breakout
- Similar to optical follow up (triggered by multiplets)
- Delay until start of Swift observation: ~5 min
- XRT field of view: 0.4°
  → Tiled observation



- Program running since Feb. 2011

Summary

- **Detectability of (steady) Galactic sources:**
  - all-sky map shows no hint of a signal
    → a signal might take long to emerge
  - source list becomes more and more important
    → look for new tracers of potential neutrino-production sites

- **GRB results from IceCube**
  - Combined IC40+59 limit now factor 5 below fireball predictions
    → IceCube starts to seriously constrain fireball model
  - Follow-up program very promising extension to IceCube
    → first upper limits on “slow jets” in SNe from optical follow up